FY13 Cosmic Frontier Experimental Research Program – Lab Review

Fermilab

Background Material
Program Status & Plans

September 16 - 19, 2013

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1. Introduction: Particle Astrophysics at Fermilab

The mission of the High Energy Physics program is to understand how our universe works at its most fundamental level. We do this by discovering the most elementary constituents of matter and energy, exploring the basic nature of space and time itself, and probing the interactions between them.
—Mission Statement, DOE Office of High Energy Physics

Fermilab's main mission is fundamental physics, and the experiments that led to the Standard Model have mainly used the accelerators that are Fermilab's signature technology. However, other kinds of experiments probe physical effects in regimes not accessible with laboratory accelerators, and sometimes reveal new and unexpected physics beyond the standard model. Important new discoveries in recent years have come from many directions: the new Higgs-like scalar particle was found in a collider, but neutrino masses and mixing were discovered using astrophysical sources. Dark matter and dark energy were both found using astronomical measurements.

Fermilab's non-accelerator-based experiments share many science goals and experimental techniques with accelerator-based experiments, but seek new physics in complementary ways. The scope of the program is very broad, and covers literally all physical scales of space, time and mass where new physics might appear. Some new kinds of particles may be too massive or elusive to create in colliders, but may survive in detectable numbers from the early universe, or from natural cosmic accelerators. Some new physics, such as exotic interactions of gravity, cannot be studied in microscopic particle interactions, because they are so weak that they only dominate other forces in large assemblies of mass and volumes of space afforded in cosmic systems. New quantum physics of space and time on the smallest scales may create coherent macroscopic correlations not detectable in localized, microscopic particle interactions. The cosmos provides us with measurable particles or observable effects created in more extreme environments, higher energies and temperatures than can ever be created in a laboratory. These experiments come under the general headings of particle astrophysics, or the Cosmic Frontier.

At the largest scales, we study so-called cosmic "dark energy", the accelerating expansion of universe, manifested in the mean motion and distribution of matter and radiation on the largest scales. It is caused by new physics in the largest, emptiest stretches of the cosmos. Fermilab studies use massive, high precision surveys of matter and light over large volumes of space, and extending back in time over much of cosmic history, to get precise data on the large-scale behavior of matter and gravity.

Strong astrophysical evidence suggests that the dominant mass in the universe is in the form of "dark matter": effectively cold, nearly non-interacting particles. So far, the measured effects of these particles are from gravity, both in collapsed systems such as galaxies, and in linear precursor waves seen in cosmic background radiation. We can now test the hypothesis that these particles are a new form of electrically neutral matter, a relic from the early stages of the big bang. If they are massive particles interacting via known forces, such as Higgs intermediaries, the dark matter of our Galaxy may be detected directly, perhaps soon, in one or more of Fermilab's underground experiments. These experiments may even find evidence for a "dark sector" of particles and forces, as rich as the Standard Model for normal matter.

Nature creates particles with energies well beyond reach of accelerators. The Pierre Auger Observatory, with management from Fermilab, measures the properties of the very highest energy particles from space. The measurements provide new information about particle interactions, as well as the origin, acceleration and propagation of the particles over vast reaches of space.

The relationship of space, time, and gravity with quantum mechanics is a deep mystery in physics that cannot be addressed directly in accelerator experiments. The quantum origin of space-time and locality can be studied in experiments that very precisely measure positions of massive bodies over a macroscopic region of space-time. Fermilab is developing an experiment designed to measure or rule out quantum-geometrical fluctuations with a spectral sensitivity to transverse position given by the Planck time--- an important threshold suggested by gravitation theory.

Fermilab also pioneers promising new detection technologies to create new capabilities for future experiments. These R&D efforts are funded from the generic detector R&D program, but the particle astrophysics budget supports the scientific effort involved. Many of these initiatives have prospered, either at Fermilab or elsewhere, and others hold great promise in the farther future.

Fermilab particle astrophysics experiments are created and operated in collaborations with university researchers, where Fermilab has a particular and unique role. Although they do not use accelerators, the experiments have a scope of technical demands in size, precision, complexity, duration, and cost that call for the capabilities of a laboratory to complement the creative scientific contributions of university PIs. The experiments have clear scientific and technical synergy with each other, and with Fermilab's accelerator program. Areas of technical synergy include particle detection, precision techniques, massive computation, data and simulation technique, experimental systems (vacuum, mechanical, cryogenics, RF engineering, background control, large scale production), project management, and infrastructure for collaboration support and workshops.

The program is guided under the auspices of the Fermilab Center for Particle Astrophysics (FCPA). We set the primary directions of our program to align our major effort with community and agency priorities, as recommended by HEPAP, including P5, PASAG and other planning studies, and with advice from the Fermilab PAC. At the same time, we aim to provide some flexibility, setting aside some effort and support for small initiatives to explore and demonstrate the feasibility (or not) of new directions, a step that was also recommended by PASAG. We also take deliberate steps to retire Fermilab effort on projects, even successful ones, at the appropriate time, to make room for new opportunities. We aim to create an intellectual environment where creativity can prosper, and co-exist with a disciplined, balanced, planned and managed program of long term experiments.

2. Program Summary

This summary of Fermilab's particle astrophysics program effort is organized according to major experimental thrusts: Dark Energy, Dark Matter, High Energy Cosmic Particles, Cosmic Microwave Background, Quantum Space-time, and Research and Development.

Dark Energy, in our experimental program, is a shorthand name that refers to precision physical measurements based on cosmic surveys that probe the nature of matter, space-time, and their interactions on the largest scales. These surveys measure the distribution and motion of matter, and the curvature of space-time, within the precise theoretical framework of general relativity: "Space-time tells matter how to move, and matter tells space-time how to curve". They aim in particular to illuminate the nature of the mysterious force accelerating the cosmic expansion.

Fermilab's contributions to precision cosmology started with the Sloan Digital Sky Survey in 1990. The transformative impacts of SDSS were recognized, along with microwave background measurements, as the 2003 Science Breakthrough of the Year, and the SDSS-based BOSS survey continues to make spectacular breakthroughs today. The largest current enterprise in our program is leading the Dark Energy Survey (DES), which has just started its main survey operations.

Progress over the last three years: Our most important milestone was the successful construction and deployment of the Dark Energy Camera, within budget and on schedule. Now installed on the Blanco 4-meter telescope at Cerro Tololo in Chile, it is one of the most powerful imagers ever created. A successful program of science verification and commissioning on the telescope was completed, and the entire system, including data management systems, has now been tested and demonstrated to be ready for survey operations. Full survey operations start on August 31, 2013. As the widest, deepest survey to date, it is projected to advance the subject significantly over the next five years.

A smaller effort was directed to R&D on spectroscopic surveys complementary to DES imaging. This work originally included two concepts (DESpec and BigBOSS), but has recently been consolidated into one group working on the Dark Energy Spectroscopic Instrument (DESI) project, led by LBNL.

Fermilab has also continued a role in SDSS, and has led the SDSS Supernova survey, one of the largest supernova surveys conducted to date. It uniquely probes the intermediate redshift range with high quality photometry, and has significantly improved control of systematic errors in distance measurements using supernovae.

Plan for the next three years and beyond: The main activity for the next five years will be operations and science with the Dark Energy Survey. Although this will be the bulk of our scientific effort for some years to come, we are gradually shifting effort as DES systems become more secure and operations become more reliable and routine. Some DES scientist effort is shifting now to DESI in its R&D phase; this effort is expected to increase as the project matures and proceeds through the DOE approval process. We plan to contribute to management, fabrication, operations and analysis. DESI is expected to start operations soon after DES finishes. A smaller research effort is also connected with LSST, mostly focused on the Dark Energy Science Collaboration and its computing needs, and connections with DES. There will also be significant connections with our emerging program on the cosmic microwave background (CMB, see below).

Dark Matter: Fermilab leads a multi-modal, direct experimental search for weakly interacting massive particles (WIMPs) left over from the hot early phase of the universe, that may constitute the dark matter seen indirectly from astronomical observations. These experiments, deployed deep underground to shield from cosmic ray backgrounds, seek to detect or constrain recoils of atomic nuclei from extremely rare collisions of Galactic dark matter particles. Current experiments have already ruled out particles with generic Z mediated interactions and are now probing the region of much weaker Higgs interactions. The range of most plausible theoretical models will be explored in the next few years.

The mass and detailed interactions of these particles are not known. Fermilab's program employs a range of target materials and detection technologies to seek a wider range of particle types, prepare to validate any detection in spite of possible spurious backgrounds, and provide better information on particle parameters. Fermilab is the managing lab in four experimental collaborations, three of which have at some time in the past three years obtained the world's-best results for constraints on some class of dark matter particles.

Progress over last three years: A list of achievements include: the upgrade to operating with iZIP cryogenic germanium detectors for SuperCDMS Soudan in Minnesota; operating COUPP 4kg and 60kg bubble chambers at SNOLAB; DAMIC silicon CCD-based system deployed at SNOLAB in Canada; a Darkside argon purification system operating at Fermilab, with Darkside itself preparing for operations in Italy at LNGS. CDMS has achieved some of the best limits on standard WIMPS, and recently identified some possible low-mass WIMP candidate events. DAMIC has produced the best limits for very low WIMP masses, and COUPP the best limits on WIMPs that have spin-dependent interactions with nuclei.

Plan for the next three years and beyond: All four experiments will continue operating their present setups for the next 2-3 years. For the next generation of experiments (G2), DOE and NSF plan for a "downselect" among five candidates, three of which are Fermilab experiments (SuperCDMS SNOLAB, PICO-250L and DarkSide-G2). An elimination of one of these experiments from construction funds will prompt consolidation of lab effort into other advancing projects. A funded proposal will require the lab to step up the level of its commitment, to manage a larger project. Any evidence for WIMPs will motivate follow up with the same, as well as different techniques, to confirm the signal and characterize the particle properties. In the absence of detection, some of the next generation G2 experiments, and certainly many of the G3 experiments, may run up against a nuclear-recoil background from solar, atmospheric or cosmic neutrinos. This limit will strongly curtail the utility of deeper searches and most likely define an end to this kind of search.

High Energy Cosmic Particles: Fermilab has been the lead and managing laboratory for the Pierre Auger Observatory, the world's leading and largest detector of the highest energy cosmic rays, since it started operations in 2008. Auger has detected most of the particles ever measured at the very highest energies, above about 10^{19} eV.

Highlights of progress over the last three years: In its first few years, Auger has confirmed that the energy spectrum shows a long-predicted strong suppression above the energy threshold for the Greisen-Zatsepin-Kuzmin (GZK) effect, has found tentative evidence above 55 EeV that the arrival directions correlate with the matter distribution in the nearby universe, has measured the cosmic ray particle composition from $10^{18} – 3 \times 10^{19}$ eV, and determined the proton-air cross-section at 57 TeV in the center of mass, above the energy range of the largest colliders.

Plans for the next three years: Responding to agency advice, we are in the process this year of transferring Auger management responsibility to Karlsruhe Institute of Technology. Although we will continue to participate in Auger research, in response to budget pressure we will have to gradually downsize scientist effort at Fermilab on Auger.

Cosmic Microwave Background: Although CMB is discussed here separately from dark energy surveys, the two are most powerful when they are joined together. Indeed, the original vision for the Dark Energy Survey's southern-sky footprint was closely and specifically linked to the South Pole Telescope project. Taken together, these techniques not only advance the precision cosmology measurements already discussed, they also probe detailed properties of a new, exotic effective field, the inflation (whose prediction of a spectral slope of fluctuations slightly less than from 1 is now confirmed), and even quantum gravity, via the *B* modes of polarization. The CMB program is on a course to achieve competitive measurements of the neutrino mass hierarchy in the next decade.

Summary of contributions in the last three years: Fermilab previously built important components for the QUIET experiment, an effort endorsed by a specific recommendation of the PASAG report. Following a successful run and analysis of results from that experiment, in response to budget pressure, our effort on CMB has tapered off to almost zero in last two years.

Plans for the next three years and beyond: Fermilab plans to re-enter CMB studies. We will partner with the university community and other HEP labs in the development, construction and operation of high resolution, wide angle, multi-frequency polarization surveys. In the next three years, we plan to participate significantly in the development of the South Pole Telescope "3G" survey. We will also collaborate on design and development towards a future "Stage 4" project. DOE's role in these projects resembles that in DES and LSST: the development and construction of advanced detectors, a massive focal plane, optics, and data systems to achieve a wide field, high precision and survey speed, on a telescope facility funded by NSF or other sources.

Quantum Space-time: It is well known that in spite of its spectacular successes, the standard hybrid of quantum field theory with classical space-time suffers from multiple inconsistencies: at the Planck scale, with itself; on all scales, between classically deterministic space-time events and “spooky” quantum non-locality; and with information bounds from gravitation theory. However, at present, no laboratory experiments address Planck scale physics directly enough to shape theoretical ideas beyond the standard paradigm. Fermilab is conducting a unique experiment that addresses a particular, possible new Planck scale behavior of quantum geometry. The Fermilab Holometer is designed to measure or constrain quantum-geometrical position noise with Planck spectral sensitivity, an important theoretical threshold.

Progress to date: The main apparatus has been constructed, including two separate but adjacent 40-meter, power-recycled interferometers, and a real-time cross-correlating DAQ and analysis system. It has produced operational data at design bandwidth, albeit with test optics, not yet at its design sensitivity. The system is now being commissioned and tested for the first time with final, high-finesse optics in place.

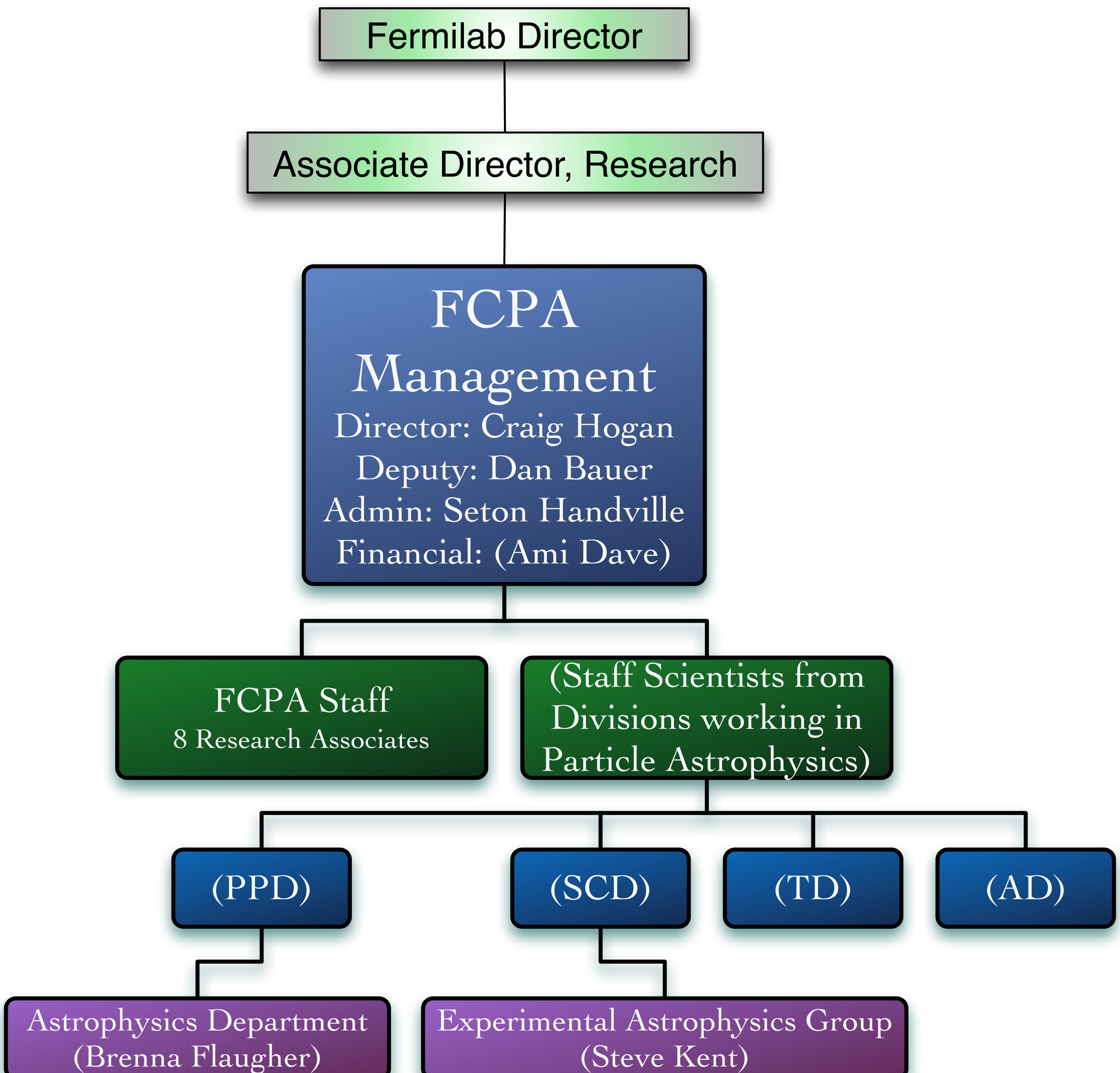
Plan for next three years: The Holometer experiment will be finished when the sensitivity is well below a Planck spectral density for broadband position noise, a threshold that should be achieved in the next two years. The follow up plan depends on results of the experiment. If there is a positive result, it will first be checked with null configurations; if confirmed, a higher signal (that is, greater sensitivity and spectral resolution) can be obtained straightforwardly with longer arms, and the effect can be probed with other geometries. Effectively, this would amount to a direct laboratory measurement of the Planck time, independent of Newton’s gravitational constant. A definitive, sub-Planck null result would define the end of this program.

Research and Development efforts are an important of our program. Some of them, such as low noise CCDs, are offshoots of experiments that lead to new and very different capabilities. Others, such as the SCENE program, involve a foundational, basic calibration of physical effects, in this case, response of noble liquids to nuclear recoil that cuts across many experiments. Still others, such as MKIDs, represent entirely new and potentially transformative technologies that will likely enable new experimental approaches across multiple frontiers.

Future Program Planning is one important function of the Fermilab Center for Particle Astrophysics (FCPA). The Center helps lab management shape the program, and works with divisions to align lab effort with DOE goals and quality science. It also helps “glue” our scientist community into a coherent intellectual whole. Our collective activities support the program in practical ways, such as a shared postdoc program and housing for visitors, as well as enrichment and stimulus by workshop, visitor and seminar programs, informal local gatherings such as journal club discussions and chalk talks, and mini-retreats to allow long term strategic discussions. In the next year, we also plan to have a Center retreat to help organize our future strategic planning, based on input from the HEPAP Community Summer Study and P5 processes.

3. Organization

The Cosmic Frontier program at Fermilab is managed by the Fermilab Center for Particle Astrophysics (FCPA), which reports to the lab Directorate. FCPA has line management responsibility its own management staff and research associates (postdocs) working on experimental particle astrophysics. Staff scientists are "matrixed" into the program, with their line management located in the lab Divisions, mostly particle physics (PPD) and scientific computing (SCD). FCPA has the responsibility to manage the KA23 research budget, in close cooperation with the management of these Divisions, and with the Directorate.



4. Experiments & Projects

Dark Energy

Dark Energy Survey (DES) – Host Lab

- Science goals
  - *Probe Dark Energy and the origin of cosmic acceleration using 4 primary techniques: clusters, gravitational lensing, supernovae, and galaxy clustering*
- What part is HEP-related
  - *DES is optimized and organized to probe Dark Energy, a central theme of the Cosmic Frontier in HEP.*
- Overall organization
  - *FNAL is the host lab and lead for DES operations and DECam maintenance and support. NOAO/CTIO operates the telescope and camera. NCSA is the lead on Data Management, supported by collaboration scientists at FNAL and other institutions. DES Management Committee, with representation from each institution or consortium, manages collaboration affairs. DES Executive Committee manages operational issues.*
- Collaboration
  - *Over 200 people (including students and postdocs) at 4 DOE labs, 1 U.S. national observatory, 7 U.S. universities, and 5 foreign institutions and consortia*
- Agency involvement
  - *DOE, NSF, plus scientist support from foreign agencies.*
- Phase and status of the experiment
  - *DECam Project completed (CD-4) in 2012. Commissioning and Science Verification took place Sept. 2012-Feb. 2013.*
  - *April 2013 held DOE-NSF review of status and operational readiness.*
- Upcoming major milestones (reviews, CD's)
  - *Full science survey starts Aug. 31, 2013 and planned for 5 seasons.*
- Roles and responsibilities, positions, deliverables your lab has
  - *Led construction of and successfully delivered DECam, major roles in installation and commissioning.*
  - *Host the project office (Director, Deputy Director, Operations Systems Scientist), lead the operations of the experiment, and lead the DOE portion of DECam operations and maintenance*
  - *Leadership roles in Data Management (DESDM Project Scientist), calibration (Calibration Scientist), survey strategy (Project Scientist), and analysis computing*
  - *Leadership roles in the science collaboration (co-coordinators of 4 science working groups)*

DES MOU commits Fermilab along with NOAO and NCSA to the scientific success of the project. Fermilab Director or designate serves on and currently chairs the DES Council, to which DES Director reports.

DESI – Project activities

- Science goals
    - *Probe Dark Energy and the origin of cosmic acceleration using measurements baryon acoustic oscillations and red shift space distortions.*
- What part is HEP-related
    - *DESI is designed to probe Dark Energy, a central theme of the Cosmic Frontier in HEP.*
- Overall organization
    - *LBNL is the host lab for the DESI project. Fermilab is contributing by leveraging the experience, investments and infrastructure developed while building, installing and operating DECam.*
- Collaboration
    - *The collaboration is in the process of forming. By-laws have been drafted and Fermilab has submitted a letter of intent.*
- Agency involvement
    - *DOE, NSF, plus scientist support from foreign agencies.*
- Phase and status of the experiment
    - *In preparation for a DOE CD-1 review in Jan. 2014.*
- Upcoming major milestones
    - *Nov. 2013 LBL Director's review, Jan. 2014 DOE CD-1 review.*
- Roles and responsibilities, positions, deliverables of Fermilab
    - *L2 manager in charge of leading the design and construction of the corrector barrel (supports the lenses).*
    - *L2 co-manager for integration and testing.*
    - *Lead CCD packaging and testing.*
    - *Lead development of end-to-end simulations (SPOKES) and software framework.*
    - *Co-lead development of the science and technical requirements. Work with Ohio State University to develop the online software and databases.*

Dark Matter

Chicago Observatory for Underground Particle Physics (COUPP) – Host Lab

- Science goals
  - *Direct detection of WIMP Dark Matter on multiple target nuclei using bubble chambers.*
  - *High sensitivity to both spin-dependent and spin-independent interactions.*
- What part is HEP-related
  - *Detection and understanding of particle dark matter is one of the primary missions of the DOE OHEP program.*
- Overall organization
  - *2 US DOE labs involved (FNAL, PNNL). Experiments installed underground at SNOLAB in Canada.*
- Collaboration
  - *COUPP: 20 scientists and students, 3 labs, 3 universities.*
  - *PICO: New collaboration formed by merger of COUPP and PICASSO. 60 scientists and students at 13 institutions.*
- Agency involvement
  - *DOE, NSF, Canada.*
- Phase and status of the experiment
  - *COUPP-60. Began operations in June 2013. Operating through FY16.*
  - *PICO-2L. Low mass WIMP search beginning October 2013.*
  - *PICO-250L (previously COUPP-500). R&D and design in FY13-FY14.*
- Upcoming major milestones
  - *Obtain continued DOE and NSF G2 Dark Matter funding in late 2013.*
- Roles and responsibilities, positions, deliverables of Fermilab
  - *Fermilab is main center of activity for COUPP*
  - *Remote operations of experiments installed at SNOLAB, covered by MOU*
  - *Project management*
  - *Design and build most detector components.*
  - *Design and build R&D chambers.*
  - *Calibration measurements using Fermilab test beam and underground facilities.*
  - *Data storage and processing.*
  - *Physics analysis coordination.*

DarkSide-50 – (U.S. Host lab)

- Science goal
  - *Direct detection of Dark Matter in Liquid Argon and development for larger detectors.*
- What part is HEP-related?
  - *Detection and understanding of particle dark matter is one of the primary missions of the DOE OHEP program.*
- Overall organization
  - *Host lab is Laboratori Nazionali del Gran Sasso, (LNGS), Italy. Spokesperson is C. Galbiati, Princeton.*
- Collaboration
  - *1 Chinese, 2 French, 6 Italian, 1 Polish, 3 Russian, 15 U.S. groups (12 U.S. Universities and Fermilab) ~ 100 people*
- Agency involvement
  - *DOE, INFN, NSF - DOE supports 3 out of 15 U.S. groups*
- Phase and status of the experiment
  - *DarkSide-50 commissioning with atmospheric argon. Underground argon in late 2013.*
- Upcoming major milestones
  - *DOE and NSF G2 Dark Matter selection in late 2013*
- Roles and responsibilities, positions, deliverables of Fermilab
  - *Coordinator of DOE groups (Fermilab, Princeton, UCLA)*
  - *Responsible with LNGS for TPC Data Acquisition System*
  - *Responsible with UCLA & Princeton for Argon Handling System.*
  - *Responsible for TPC trigger and full detector trigger*
  - *Responsible with Princeton for purification of underground argon*
  - *Responsible for DS-50 schedule management*
  - *Will host U.S. data repository*
  - *Will host U.S. event reconstruction facility*

SupperCDMS – (Host lab)

- Science goals
  - *SuperCDMS is an experiment whose goal is direct detection of Weakly Interacting Massive Particles that are the favored candidate to explain the dark matter that is known to constitute 85% of the matter in the universe.*

- Relationship to HEP
  - *Detection and understanding of particle dark matter is one of the primary missions of the DOE OHEP program.*

- Overall organization
  - *Fermilab is the host laboratory for SuperCDMS. SLAC has a significant role in SuperCDMS SNOLAB, and PNNL has recently joined for that project as well. There are also strong US and Canadian university contributions to the design, fabrication, operation and data analysis of the experiments.*

- Collaboration
  - *The SuperCDMS collaboration is comprised of the 3 national laboratories, 4 DOE-supported university groups (Caltech, Minnesota, Stanford, Texas A&M), 7 NSF-supported university groups (Berkeley, Denver, Florida, MIT, Santa Clara, Southern Methodist and Syracuse), 2 new university groups (Evansville and South Dakota), 2 Canadian groups (Queens and UBC) and one Spanish group (MultiDark, Madrid). The present spokesperson is Prof. Blas Cabrera, Stanford and the chair of the collaboration Board is Prof. Sunil Golwala (Caltech).*

- Agency involvement
  - *SuperCDMS is funded by DOE, NSF and Canada (NSERC and CFI)*

- Phase and status of the experiment
  - *CDMS II is finishing data analysis, SuperCDMS Soudan is operating and actively analyzing data and SuperCDMS SNOLAB is doing R&D and design work, with a fabrication project expected next year.*

- Upcoming major milestones (reviews, CD's)
  - *SuperCDMS Soudan operations were reviewed in fall 2012. SuperCDMS R&D was also reviewed in fall 2012, and selected for G2 R&D funding. It will be reviewed again in late 2013 as part of the G2 dark matter process.*

- Fermilab roles, responsibilities, positions, deliverables
  - *Fermilab is the lead lab for SuperCDMS, and is responsible for project and operations management, cryogenics, shielding and experimental infrastructure. Fermilab also contributes to electronics, data acquisition, software and analysis. The Project and Operations Manager is Dan Bauer (Fermilab), and the Analysis Coordinator is Lauren Hsu (Fermilab).*

Dark Matter in CCDs (DAMIC) - Host Lab

- Science goals
    - *Direct detection of WIMP Dark Matter*
    - *Low threshold experiment with high sensitivity to low mass Dark Matter Particles.*
- What part is HEP-related
    - *Detection and understanding of particle dark matter is one of the primary missions of the DOE OHEP program.*
- Overall organization
    - *1 US DOE lab involved (FNAL), with 5 universities. Experiments installed underground at SNOLAB in Canada.*
- Collaboration
    - *9 scientists and students, 2 labs, 5 universities.*
- Agency involvement
    - *DOE.*
- Phase and status of the experiment
    - *DAMIC began operations at SNOLAB in December 2012*
    - *DAMIC-100 to begin operations at SNOLAB Summer 2014*
- Roles and responsibilities, positions, deliverables your lab has
    - *Current Spokesperson of DAMIC is Juan Estrada from FNAL*
    - *Fermilab is main center of activity for DAMIC*
    - *Remote operations of experiments installed at SNOLAB.*
    - *Design and build most detector components.*
    - *Physics analysis active at FNAL*

High Energy Cosmic Particles

Pierre Auger Observatory – Host Lab

- Science goals
  - *Measure spectrum, composition, origin and interactions of ultra-high energy cosmic rays (UHECR).*
- What part is HEP-related
  - *Probing acceleration mechanisms and propagation of the highest energy particles recorded in nature.*
  - *Studying particle interactions, including measuring cross-sections, at center-of-mass energies an order of magnitude above those achievable at terrestrial accelerators.*
- Overall organization
  - *Scientific management provided by a Collaboration Board, with financial oversight provided by an international Finance Board.*
  - *Project management provided by the Spokesperson and Project Management organization.*
- Collaboration
  - *~450 people in 92 institutions among 19 countries*
- Agency involvement
  - *Observatory oversight by the Finance Board consisting of funding agencies in the collaborating countries including DOE and NSF.*
- Phase and status of the experiment
  - *Science data has been collected since 2004; full observatory operational since 2008; currently 44 journal articles published; additional 20 articles in preparation.*
- Upcoming major milestones
  - *Submission and review of Auger Observatory upgrade proposal.*
  - *Transfer of management functions from Fermilab to Karlsruhe Institute of Technology by December 2013*
- Roles and responsibilities, positions, deliverables of Fermilab
  - *Fermilab hosted the project office from 1995 until August 2013*
  - *Fermilab played a key role in the design, development and production of the surface detectors.*
  - *Analysis effort on cosmic ray composition*
  - *Studies of detector performance*
  - *Planning of detector upgrades*
  - *Effort or partial effort of 4 senior scientists, 2 emeriti, 1 postdoc*

Quantum Space-time

Holometer – Host Lab

- Science goals
    - Probe Planck-suppressed position uncertainty intrinsic to space-time.
- What part is HEP-related
    - Studying the basic nature of space and time, i.e. microphysics at the Planck scale, new quantum geometrical degrees of freedom
- Overall organization
    - 1 lab involved, FNAL, with 4 universities
- Collaboration
    - 14 people, 1 lab, 4 universities
- Agency involvement
    - DOE (Early Career award to Aaron Chou), NSF (support at U. Michigan), NASA (Craig Hogan theory grant at U. Chicago, ended 2009)
- Phase and status of the experiment
    - Commissioning FY13-14.
    - Science studies start early 2014.
- Upcoming major milestones (reviews, CD's)
    - Fermilab technical review in October/November 2013
- Roles and responsibilities, positions, deliverables your lab has
    - Co-spokesperson, Project manager – Aaron Chou
    - Project scientist – Craig Hogan
    - Host the experiment and infrastructure at FNAL
    - Vacuum/mechanical installation and maintenance
    - Co-lead on development of digital data acquisition system
    - Interferometer simulations and optics metrology
    - Development of high photocurrent detectors

Cosmic Microwave Background

South Pole Telescope (SPT 3G) – Project activities

- Next-generation CMB polarization mapping experiment, with DOE contributing the main elements of a new detector system

- ANL is the lead lab

- Fermilab aims to participate in cryostat development, production level detector testing, optics support engineering, and research synergy with DES

QUIET

CMB polarization mapping experiment in which Fermilab was involved. Our roles were:

- Design and Construction of a Rotating Sparse Wiregrid for Polarization Calibration.
- Experimental Operations: shifts in Chile, scripting tools to improve Observations
- Data Analysis

Other Science and detector R&D

- SCENE R&D- (Host Lab): laboratory calibration of noble gas scintillation
- Solid Xenon R&D- (Host Lab) Development of new noble material detector fabrication techniques
- MKIDs- (Host Lab) Development of new detector systems based on energy sensitive cryogenic arrays

Research Activities only

Dark Energy

LSST: Software, science, and enabling project tools on the Open Science Grid (OSG); participation in overall planning via LSST Corporation and AMCL

SDSS: Archive maintenance; analysis related to DES photometry and supernova program

Other

- Fermilab Center for Particle Astrophysics: Cross-cutting science activities, program planning, management

5. Cosmic Frontier Program - Status and Future Plans

The Cosmic Frontier research program at Fermilab is robust and well-aligned with DOE OHEP priorities in dark energy (DES, DESI, LSST), dark matter (SuperCDMS, COUPP, DarkSide, DAMIC), high energy cosmic particles (Pierre Auger) and the fundamental nature of spacetime (Holometer), as well as an active detector R&D program to develop new technologies for particle astrophysics experiments.

In dark energy, we have completed our migration from the successful SDSS II program to the completion of DECAM and the imminent start of the Dark Energy Survey. This will be the focus of the US dark energy program for the next five years, and Fermilab is the lead lab. Farther down the road, we are partners with LBNL on the Dark Energy Spectroscopic Initiative (DESI), for which they are the lead lab and we will contribute our scientific expertise from all of these experiments to LSST, for which SLAC is the lead lab. Approximately half of our scientific manpower is devoted to the dark energy program, and we expect this to remain stable for at least the next three years under all budget scenarios.

Fermilab has long been the leading US national laboratory in dark matter direct detection. We manage projects and operations for three major experiments: SuperCDMS, a cryogenic solid-state experiment currently at the Soudan Underground Laboratory and headed towards SNOLAB in Canada; COUPP, a bubble chamber experiment situated at SNOLAB; and DarkSide, a liquid argon experiment at LNGS (Gran Sasso). We also manage a small CCD-based experiment, DAMIC, at SNOLAB; this is supported partly from a Presidential Early Career (PECASE) award to Juan Estrada. These are complementary technologies, and give us the best chance to find particle dark matter and study its properties, whatever form its interaction with normal matter takes. A bit less than 1/3 of our scientific manpower is currently devoted to the dark matter program, although this is expected to grow somewhat over the next three years in favorable budget scenarios.

Another long-standing experiment led by Fermilab is Pierre Auger, the premier observatory for the highest energy cosmic rays, situated in Argentina. We have led the project and managed the operation of the observatory for many years. Although we are phasing out of those roles in FY14, we would like to maintain our strong scientific involvement with Auger’s continuing studies of the isotropy and composition of these high-energy particles. However, this may not be possible in flat or declining budget scenarios.

We are just finishing the construction of a unique experiment, the Holometer, which is intended to study aspects of spacetime behavior at the Planck scale in the laboratory. This work is supported by an Early Career grant to one of our outstanding young scientists, Aaron Chou. We expect it to produce science over the next two years, with the small amount of manpower then moving to other areas of our program.

Fermilab was involved in cosmic microwave background (CMB) work several years ago, when we joined the QUIET project led by Bruce Winstein (U. Chicago). Although work at Fermilab stopped when the second phase of that experiment did not happen, our scientists have retained a keen scientific and technical interest in this subject. In coordination with U. Chicago, ANL and other national laboratories, and following on from the very successful SPT program, there is now an opportunity to explore together future CMB experiments that utilize our scientific and technical capabilities. We consider this a major future direction for the Fermilab program, and plan to make an opportunistic hire of a young scientist from the current SPT collaboration as soon as budgets allow, in time to contribute significantly to the construction of the next generation experiment (SPT-3G). Additional manpower from the Fermilab scientists interested in CMB would join this scientist in developing our CMB program.

Finally, Fermilab has a leading program in detector R&D, and our young scientists (especially Wilson Fellows) have made excellent use of these resources to develop new initiatives that have become particle astrophysics experiments (e.g. COUPP, DAMIC and Holometer). We believe it is vital to foster this program, and we support these young scientists through the KA230102 research budget.

Due to declining HEP budgets, the Fermilab KA23 research budget has been reduced from its peak in 2011. We have managed this decline through a combination of eliminating some small programs (e.g. QUIET, 21cm) and staff retirements leading to shrinkage in other programs, particularly Auger. However, we cannot continue to deal with declining, or even "flat-flat" budgets, without cutting into our core programs. As shown in the tables below, our strategy in those scenarios is to maintain our strong dark energy and dark matter programs, as well as our small programs developed by young scientists. We would have to further ramp down support for Auger in those scenarios, losing access to some extraordinary and unique science. We also would have trouble managing the diverse dark matter program in the critical next generation (G2) phase and would be very slow to ramp up our involvement with CMB. Scenario C shows how we would like our program to evolve, maintaining our science presence in areas where we are leaders, and establishing a vibrant new program in CMB.

Actual HEP Funding & FTEs (KA230102) in $K

				FTEs
Thrust	**FY11**	**FY12**	**FY13**	**FY13**
Dark Energy	4300	4318	4917	17.6
Dark Matter	2800	2800	2438	8.6
High Energy Cosmic Particles	1500	1200	628	2.0
CMB	400	0	0	0
Other	2570	1764	2147	5.8
TOTAL	11570	10082	10130	34.0

Proposed HEP Funding (KA230102) in $K

	Scenario A			**Scenario B**			**Scenario C**		
Thrust	**FY14**	**FY15**	**FY16**	**FY14**	**FY15**	**FY16**	**FY14**	**FY15**	**FY16**
Dark Energy	5005	5105	5236	4927	5045	5166	5047	5145	5076
Dark Matter	2485	2590	2721	2665	2705	2766	2680	2740	2801
High Energy Cosmic Particles	609	375	165	607	414	205	614	628	643
CMB	0	0	0	220	226	330	240	545	568
Other	1829	1858	1806	1711	1740	1663	2091	1871	1873
TOTAL	9928	9928	9928	10130	10130	10130	10672	10929	10961

Scenarios:

A. FY14 = FY13 – 2%; FY15 = FY14; FY16 = FY15
B. FY14 = FY13; FY15 = FY14; FY16 = FY15
C. FY14 = FY13 + new requests prioritized; same for FY15 and FY16

6. Dark Energy - Status and Future Plans

This review comes at a time of important transition for Fermilab's Dark Energy program. The bulk of our effort centers on the world-leading Dark Energy Survey, which is at this moment starting its five-year operational data-taking period. Although the operational demands will remain considerable for the next five years, we plan a gradual transition of effort to new opportunities, such as the Dark Energy Spectroscopic Instrument (DESI) project, led by Berkeley lab. We are also closely connected to planning activities associated with LSST science, particularly where they overlap with DES. Reports are also included below for previous work on DESpec, BigBOSS, and SDSS.

Dark Energy Survey

Progress Report

Introduction

The Dark Energy Survey (DES) is a project to build, install, and carry out a forefront cosmological survey with the Dark Energy Camera (DECam) and its associated Data Management system at the prime focus of the 4-meter Blanco Telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile. The primary scientific objective of DES is to probe the origin of cosmic acceleration, be it dark energy or a modification of Einstein gravity. In particular, DES will determine the nature of dark energy by making a precise measurement of the dark energy equation of state parameter, *w,* and its evolution over cosmic time. To achieve these goals, DES will operate DECam for 525 nights over 5 years (roughly 30% of the observing time) on the Blanco telescope beginning on Aug. 31, 2013. DES will carry out two, interleaved, multi-band imaging surveys: a wide-area survey of ~300 million galaxies over 5000 square degrees and a time-domain survey over 30 square degrees to discover and measure light curves for several thousand supernovae.

DES will measure the dark energy equation of state parameter through four complementary techniques: (i) the redshift distribution and clustering evolution of galaxy clusters, (ii) weak gravitational lensing on large scales, (iii) the distribution of large scale structure traced by galaxies, including the baryon acoustic oscillation feature, and (iv) Type Ia supernova distances. These four measurements will provide substantially better precision on *w* than current experiments will have achieved when the Survey begins. Having multiple techniques will constrain systematic errors far more robustly than can be done with any single technique. In the language of the Dark Energy Task Force (DETF), these data are forecast to yield an improvement of a factor of 3-5 in the DETF figure of merit relative to DETF Stage II constraints, meeting the goals established for a DETF Stage III experiment.

DOE and NSF charged the Particle Physics Project Prioritization Panel (P5), a HEPAP subpanel, to develop a road map for particle physics and set priorities. DETF and P5 delivered their reports to HEPAP in July 2006: one recommended the start of a Stage III experiment like DES, and the other recommended starting DES construction in FY08. This support was reiterated in the 2008

P5 report. Following an R&D period, construction of DECam began in FY08 and was completed in FY12, on budget and on schedule.

The construction phase of DES comprised three distinct Projects: the camera (DECam), the data processing system (DES Data Management, or DES DM), and upgrades to the Blanco Telescope (CTIO Facilities Improvement Project, CFIP). The DECam Project was funded by the DOE and by substantial in-kind contributions from US universities and foreign consortia, and was hosted by Fermilab. DES DM development and operations are funded primarily by the NSF, with in-kind contributions from DES institutions; DES DM is led by the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign. CFIP was hosted by the National Optical Astronomy Observatory (NOAO), which is managed by the Association of Universities for Research in Astronomy (AURA) for the NSF. NOAO operates the Blanco Telescope through its CTIO Division, headquartered in La Serena, Chile. It now operates and maintains DECam as a facility instrument available to the astronomy community for competitively awarded use on nights when DES is not observing. The DES collaboration, led by Fermilab, plays an active, on-going role in supporting DECam maintenance during the course of DES operations, as described in the *DECam Operations and Maintenance Plan*.

DES has assembled an international collaboration of over 200 scientists (including students and postdocs) whose institutions have provided cash and in-kind resources to the project: Fermilab, University of Illinois at Urbana-Champaign, University of Chicago, NOAO/CTIO, Lawrence Berkeley National Lab/UC Berkeley, Argonne National Lab, Stanford University, SLAC National Lab, UC Santa Cruz, University of Michigan, University of Pennsylvania, Ohio State University, Texas A&M University, DES-United Kingdom consortium, DES-Spain consortium, DES-Brazil consortium, Universitäts-Sternwarte München, and the Eidgenoessische Technische Hochschule Zurich (a new institution admitted in FY 2012). In addition to the DOE, NSF, and the institutions, foreign funding agencies include the UK Science and Technology Facilities Council, the UK Science Research Infrastructure Fund, the Astronomy and Astrophysics program of the Ministry of Science and Innovation of the Spanish Government, the Brazilian Government agency FINEp, the Brazilian Ministry of Science & Technology, the Brazilian state science agency FAPERJ, the Brazilian federal agency CNPq, and the German science foundation's Excellence Cluster "Origin and Structure of the Universe".

The *Memorandum of Understanding for the Dark Energy Survey* (hereafter the DES MOU) describes the complete project (construction through operations) in detail and is the overall governing document for the project. That document is a formal agreement between Fermilab, NCSA, and NOAO.

The DECam Project: Integration and Completion

The DECam Project has built a new 570-megapixel CCD camera (DECam) and delivered it to CTIO in late 2011. The camera was mounted at the prime focus of the Blanco 4m telescope at CTIO in mid-2012. DECam was designed, built, and tested at Fermilab and the collaborating institutions of DES, with the major part of the work and project management (Brenna Flaugher and Wyatt Merritt, Fermilab Scientists, were Project Manager and Deputy Project Manager) occurring at Fermilab. The DECam Project included construction, integration, and delivery of the large mosaic camera, a five-element optical corrector, five filters for DES operations plus three slots for additional filters, and the associated infrastructure for operation in the prime focus cage. The focal plane consists of 62 2048 x 4096 CCD modules (0.263 arc second/pixel) arranged in a hexagon inscribed within the 2.2 degree diameter field of view. The project used the thick, fully depleted CCDs that were developed at the Lawrence Berkeley National Laboratory (LBNL) in order to obtain the best available quantum efficiency at near-infrared wavelengths.

The DECam Project received its CD-1 approval at the beginning of FY08. It received CD-2 and CD-3a approval for long-lead-time procurements in the third quarter of FY08. R&D was largely complete by the end of FY08, with some activities finishing in FY09; total R&D costs were $11.7M. CD-3b approval for full construction was received at the beginning of FY09. The completion of the DECam Project was accomplished within its baselines. The DECam Project was baselined with a CD-4 date of September 2012. All the project deliverables were provided to CTIO by the end of April 2012, completing the technical goals of the project. The CD-4 ESAAB was held on June 4, 2012, four months ahead of schedule and with $1.27 million of cost contingency remaining. The project work was accomplished with no accidents or injuries. Monthly reports on the progress of the project were submitted starting in Aug. 2007 until the completion of the Project, and during this period we successfully completed annual status reviews.

The DECam project successfully demonstrated a new CCD acquisition model, which built on the unique strengths and experience of the national labs (LBNL and Fermilab) with the silicon vertex detectors for the Fermilab and LHC Collider programs. The CCD design and wafer-processing program was developed by LBNL and involved processing steps at a company (DALSA) and at LBNL. Bare silicon die were shipped to Fermilab with testing data for the 2k x 4k devices. At Fermilab we designed and developed CCD packages for 2k x 4k (imaging) and 2k x 2k (guide and focus) devices that could be assembled in house and that meet the strict flatness and performance requirements for the Dark Energy Survey. We also developed a CCD testing facility and developed automated testing programs for CCD characterization. We packaged and tested over 450 devices in various package configurations including R&D. We finished with more than 120 science-grade imaging 2k x 4k CCDs, with enough spares to mitigate the risk of a mishap at CTIO.

During CCD testing, a small number of engineering-grade CCDs showed degradation in their full-well capacity. This was eventually traced to sensitivity of these devices (when powered) to very high light levels, well in excess of those expected under normal DECam operations at the observatory. Fermilab DECam scientists organized a workshop on this issue with leading CCD experts. As a result, photodiodes were installed around the edges of the focal plane that cause the system to shut off if high light levels are detected. We also developed operating protocols with CTIO to reduce the risk of high light levels occurring in the dome.

By the beginning of FY11, construction of the major camera components, including the hexapod, prime focus cage, corrector barrel, filter changer, and shutter, was nearly complete, and the focus was on integration and testing at Fermilab. All of these systems met specifications. In order to verify that the assembled camera met the technical specifications for the Dark Energy Survey and to reduce the time required to commission the instrument on the telescope and to verify and exercise the imager installation procedure, we constructed a "Telescope Simulator" at Fermilab and performed full system testing of all DECam systems except the lenses, prior to shipping to CTIO. The Telescope Simulator was also used to test and successfully demonstrate the new F/8 mirror handling system prior to shipping it to Chile. In late 2010, the CCD imager with a half-populated focal plane with engineering-grade CCDs was installed in the DECam prime focus cage on the Telescope Simulator and operated in the configuration and orientations expected for the telescope, as shown in Fig. 1. In Jan. 2011, several mock observing runs using DECam on the Telescope Simulator (with artificial light sources) were carried out, exercising the data acquisition and controls software system (SISPI) and other aspects of the operational system. These tests also exercised the cooling system and cabling. The Telescope Simulator tests also enabled training of CTIO staff in DECam and f/8 handling procedures prior to installation on the telescope. After the Telescope Simulator tests were completed, the DECam focal plane was fully populated with science-grade CCDs, as shown in Fig. 1, and final pre-shipment tests were carried out. The assembled imager was shipped to Chile in late 2011, when the new clean room for the imager on the mountain was completed and commissioned. Upon arrival at CTIO, the imager was further tested by DECam scientists and technicians with a cool-down followed by mock observing runs in early 2012 similar to those carried out on the Telescope Simulator, demonstrating that the imager was working according to specifications.

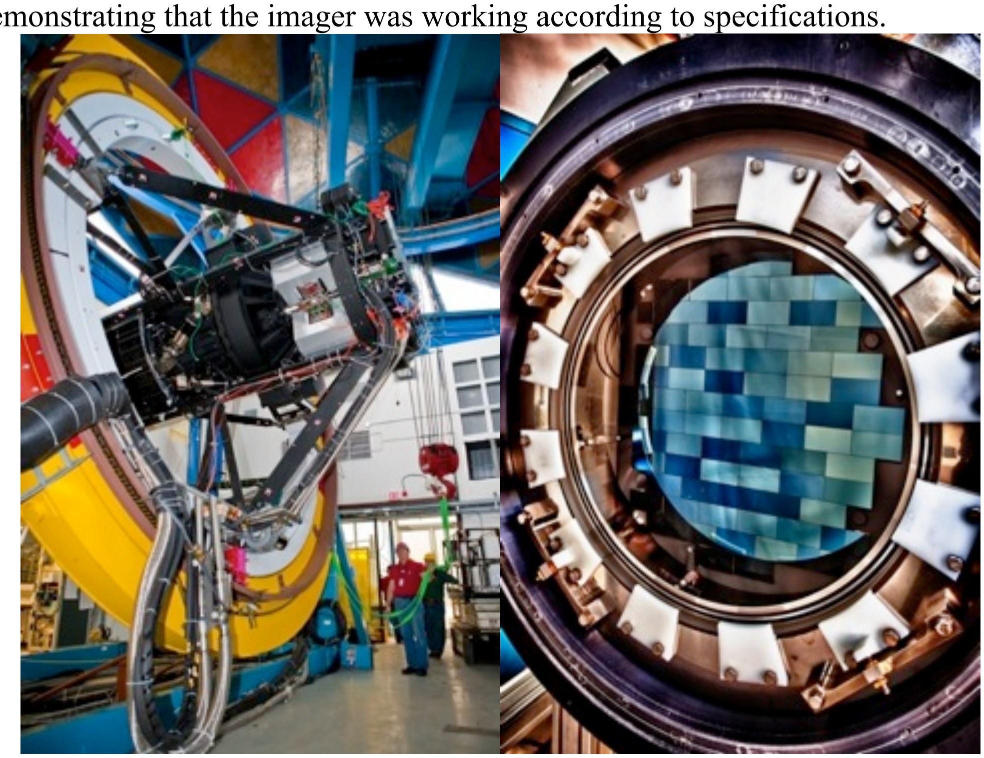


Fig. 1: *Left:* DECam installed in new prime focus cage on the Telescope Simulator at Fermilab in 2011. The inner white ring has the same dimension as the ring at the top end of the Blanco telescope, shown below in Fig. 2. *Right:* completed DECam focal plane with full complement of CCDs, mid-2011, prior to shipping to Chile.

The optical lenses for the camera were very challenging and were under construction for nearly four years; funding for the lenses was provided by DES university funds and the UK funding agency STFC. The completed lenses were delivered from the vendor to the optical sciences lab at University College London (UCL). UCL fit the lenses into cells, installed them in the corrector barrel, and performed optical tests prior to shipping to Chile. We fabricated two barrels to allow corrector assembly at UCL and the camera tests at Fermilab to occur in parallel. The completed barrel with all five lenses installed was shipped from UCL to CTIO in late 2011, and tests on the mountain in early 2012 confirmed that the lens alignment within the barrel remained within specifications. The corrector handling fixtures and procedures came from Fermilab engineering.

Another potential area of schedule concern during construction was the procurement of the 5 large filters from the Japanese vendor, Asahi, which fabricated a new facility (coating chamber) for this purpose. These concerns were amplified when the magnitude 9 Tohoku earthquake and tsunami hit in March 2011, which delayed production due to the lack of consistent power. Remarkably, the vendor was able to resume production within 2-3 months (their facility was just outside the Fukushima evacuation zone) and rapidly produced all 5 DES filters that met or exceeded specifications.

Installation and Commissioning

The Blanco telescope was shut down for DECam installation activities in Feb. 2012. An accident with the Blanco f/8 secondary mirror, unrelated to DECam installation, led to a safety stand-down and review by NOAO, in which Fermilab personnel participated. After the safety situation was resolved, the installation activities resumed. The Blanco primary mirror was removed, scaffolding was erected on the telescope structure, and the old prime focus cage was removed. The new prime focus cage, without the corrector, was installed as a test in April 2012, removed, and the new cage with corrector was installed in early May. During this installation period, additional counterweights were added to the Cassegrain focus cage to maintain telescope balance with the new DECam prime focus cage. Following installation of the prime focus cage, the telescope was dressed with new cooling and electrical cables for the imager. The installation and commissioning activities were led by NOAO, with substantial technical support by DECam technicians, engineers, and scientists from Fermilab and other DES institutions, which was critical for the success of these phases of the project.

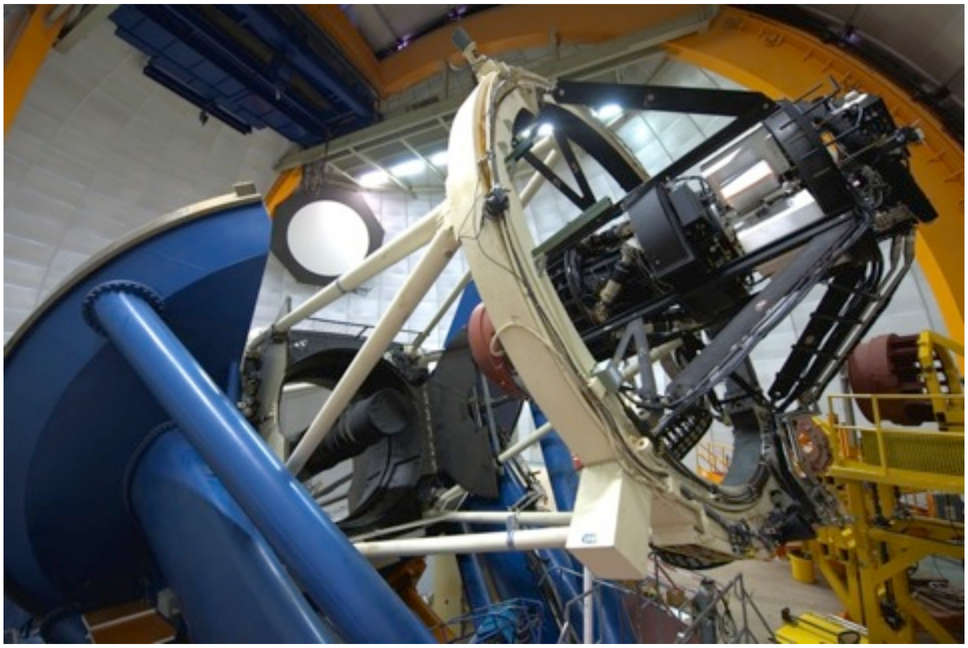


Fig. 2: DECam and new prime focus cage installed on the Blanco telescope; image from Oct. 2012.

The annual DOE review of DES Operations in May 2012 led to large number of recommendations and a request for a “replan” of the project, which was carried out through the summer, vetted by the DES Council, and presented to the agencies in August. This exercise clearly demonstrated the need for additional resources for the DES Data Management project to meet its responsibilities, leading to a supplemental request in Dec. 2012 for NSF funds that was strongly endorsed by the April 2013 DOE-NSF Operational Readiness review. As of this writing (Aug. 2013), this supplement has recently been funded.

The imager was installed in the prime focus cage on the telescope for the first time in Aug. 2012, and DECam commissioning began during that period. Following additional tests, the imager had official first light on the telescope on the night sky on Sept. 12, 2012 (see Fig. 3). The first images showed that the system was working well. Within several nights, images with a point-spread-function (PSF) of 0.8” were obtained, demonstrating good optical performance of the system. Commissioning, also an NOAO-led activity with substantial support from Fermilab and other DES scientists, continued through Oct. 2012. In addition to DECam, the reworked Blanco Telescope Control System was also being commissioned in this period.

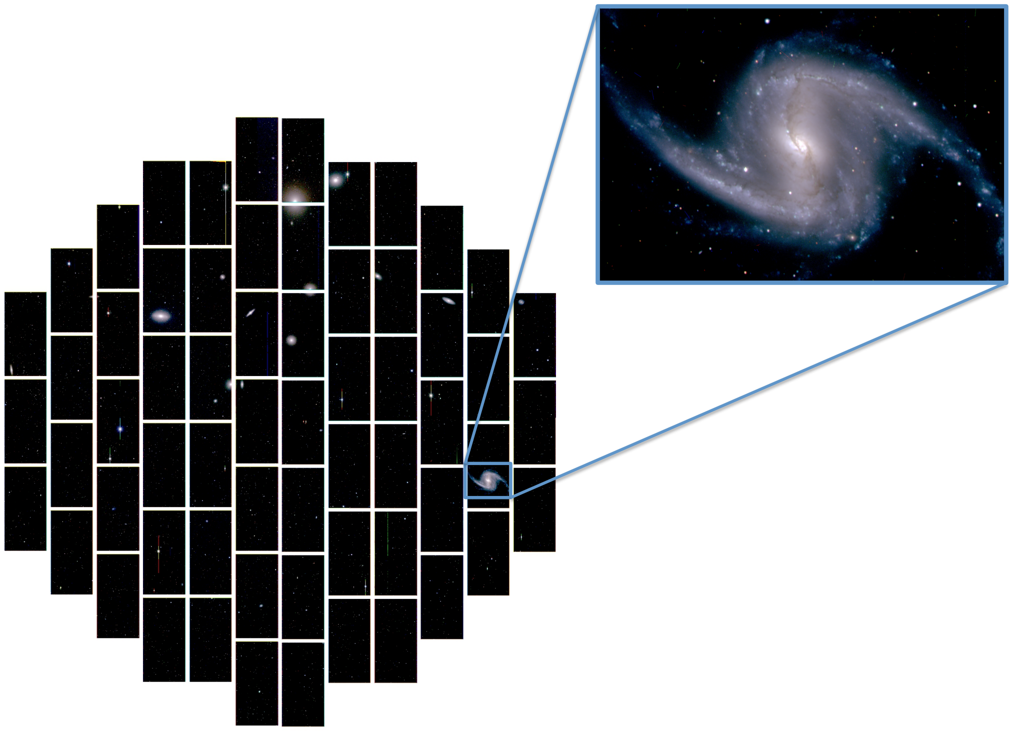


Fig. 3: one of the first on-sky images taken with DECam, showing the nearby Fornax cluster of galaxies and a zoom-in to the galaxy NCG 1365.

Science Verification

Following commissioning, Science Verification (SV) observations were carried out over 3 weeks in Nov. 2012, with time split between DES and community observations. For DES, the purpose of Science Verification was to exercise survey operations and determine whether the system was (capable of) producing survey-quality data with efficiency sufficient to meet the science goals (Science Requirements) of the survey. DES SV nights included operations that mimicked those of the survey itself. During this period, it became evident that telescope guiding, pointing, and tracking required further diagnostic testing and improvement in order to meet survey requirements, and DES Science Verification observations were extended eventually to the end of the nominal DES season in late Feb. 2013. The SV and extended SV observations were extremely useful for diagnosing and improving performance of the telescope and camera and for testing and refining DES operations, including training of observers and of Run Managers. These data have also provided a valuable training set for further development of the DES Data Management system; from early in the extended SV period, the DES DM system was able to keep up with the data flow and produce "first-cut" reduced images and catalogs as well as difference images for supernova discovery on a ~24-hour timescale.

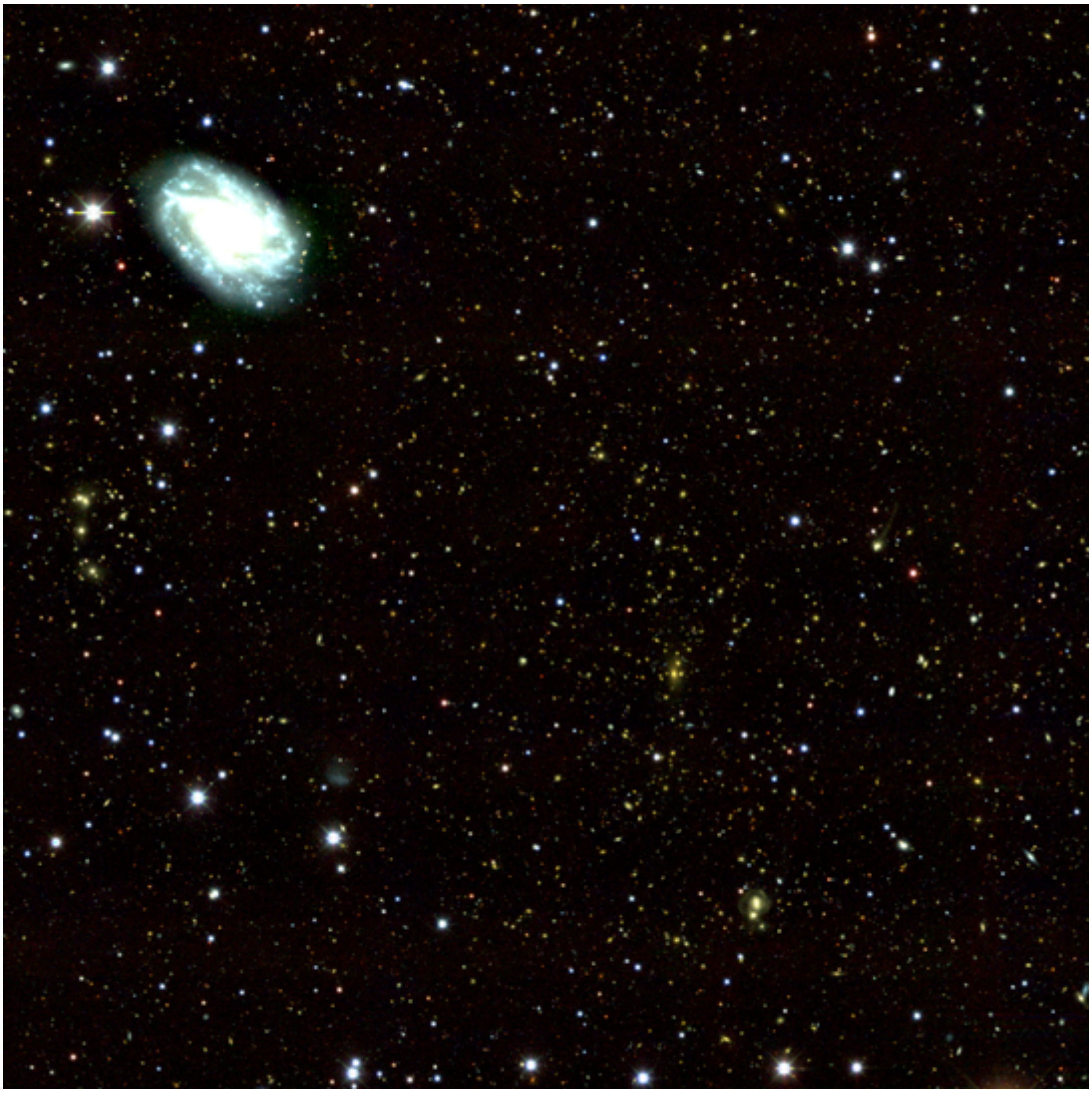


Fig. 4: part of a DECam DES Science Verification image of a cluster of galaxies previously found by the South Pole Telescope at a redshift z=0.35. The center of the cluster is just to the right and below the center of the image; large galaxy in upper left is in the foreground of the cluster.

The SV and extended SV data offer opportunities to DES scientists for early science analysis and checking of dark energy systematic errors by covering a substantial area to nearly the full depth of the survey. During SV and extended SV, over 34,000 exposures were taken, the bulk of them covering two areas of roughly 150 sq. deg., plus several known cluster fields (Fig. 4). In the eastern of these two fields, nearly full-depth imaging (approaching 10 exposures in each filter) was obtained. In addition, the DES Supernova fields were covered at a cadence comparable to that expected for the survey (between 9 and 14 exposures in each SN field); enabling testing of the supernova discovery pipeline and construction of deep template images for image subtraction once the survey starts (see Fig. 5). In the end, a handful of supernovae were confirmed by spectroscopy, and hundreds of photometric SN candidates were also found. Other early science highlights include the discovery of high-redshift clusters (see Fig. 9 below), weak lensing mass maps for several previously known clusters (Fig. 11), construction of cluster catalogs, cross-correlation with South Pole Telescope data and with Vista Hemisphere Survey (VHS) near-infrared data, and discovery of strongly lensed galaxies (arcs). As of this writing, the DES Data Management team has released two versions of the SV catalog (Y1C1 and Y1C2), and a further refined version is underway (SVA1).

During SV and extended SV, DES scientists were able to test and verify a large number of requirements, as described in the *DES Science Verification Report*. During and after this period, a number of improvements were made by CTIO to the telescope performance, in particular, tracking, guiding, and pointing, as reflected in monitoring of community metadata following the end of DES observing in Feb. and in regression tests run as part of monthly engineering runs. These improvements and tests demonstrated that DES is operationally ready to commence survey operations on Aug. 31, 2013, as judged by the outcome of the joint DOE-NSF DES Operational Readiness Review in April 2013. SV analysis also revealed a number of features of the instrument (non-linear response, PSF FWHM that is a function of object brightness, etc.) that were characterized, studied with other CCDs in the lab at Fermilab, and for the most part the signatures of these features are being addressed through software changes to DES DM. Studies by the SV team of the different contributors to Image Quality are continuing, and NOAO is planning on improvements to thermal/environmental control as well as improved dynamic control of the shape of the Blanco primary mirror. Regularly scheduled community observing with DECam commenced in Dec. 2012 and has been continuing; feedback from the astronomy community on DECam performance and capabilities has been extremely positive.

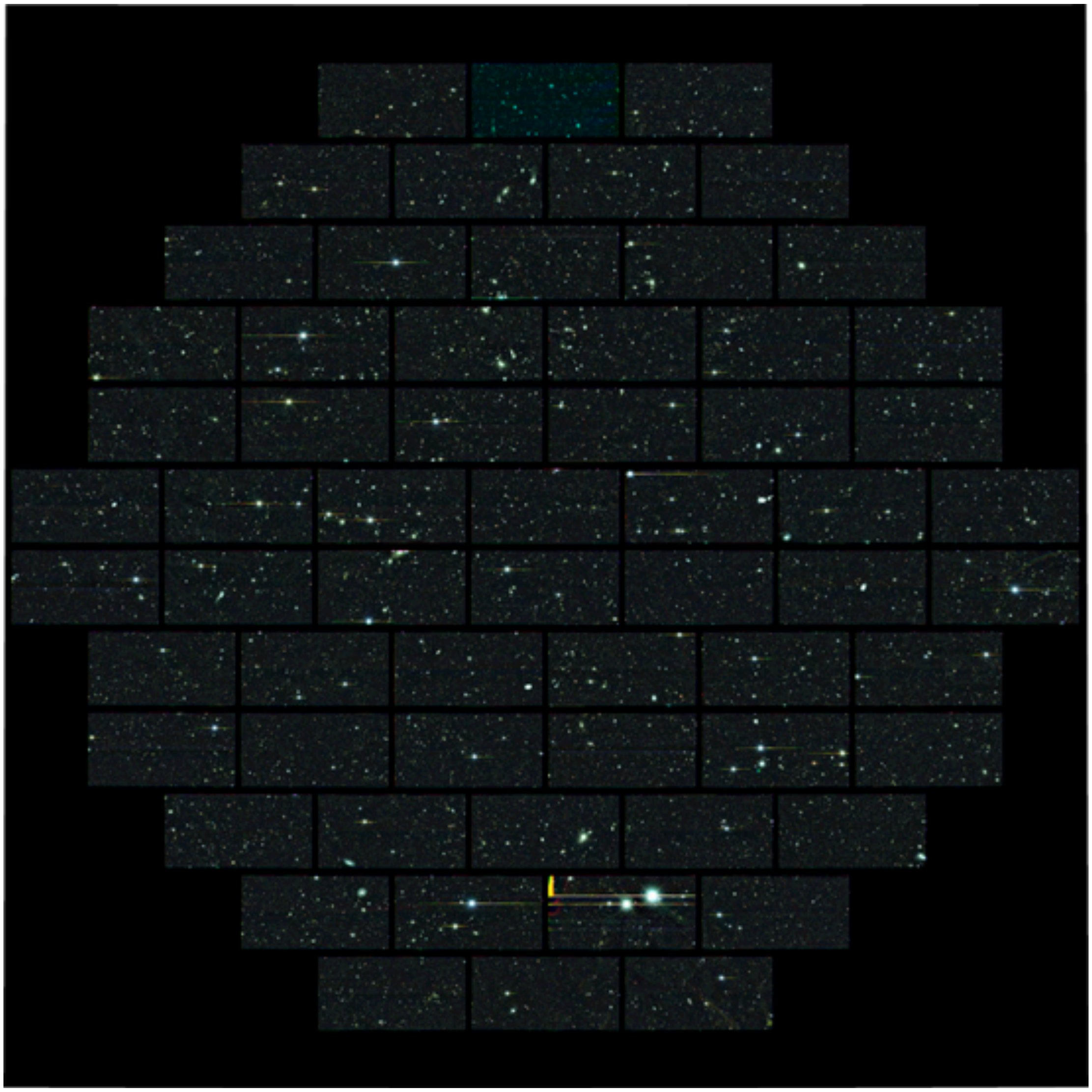


Fig. 5: DECam composite multi-band image of one of the deep DES Supernova fields (X3), taken during DES Science Verification (Nov. 2012-Feb. 2013). This field will be imaged every few nights during the survey in order to discover and measure light curves for high-redshift supernovae. Co-added images of this field taken throughout the survey will also result in a very deep, cumulative exposure.

Data Management and Community Pipeline

The DES deliverable to NOAO is the DECam System, which comprises the DECam instrument and its interfaces as well as the Community Pipeline (CP), which is operated by NOAO Science Data Management to reduce and process community DECam data. The CP is for the most part derived from the DES DM system, but with a number of changes necessary to provide the wider variety of community data, and its development has been led by NCSA. Fermilab computing professionals have contributed to CP code development. As of this writing (Aug. 2013), the CP has been functioning at NOAO for a number of months, with regular code improvements, it has been provisionally accepted by NOAO, and it is expected to shift into maintenance and bug fixing mode over the next couple of months. Continuing improvements in DES DM that would be beneficial for CP will be made available by mutual agreement.

In June 2011, DES submitted a 5-year proposal to NSF Astronomy Division to support DES DM operations, with D. Petravick (NCSA) as PI. The proposal was funded but at an amount substantially below the request. In response, the project made a number of de-scopes and brought in resources from the collaboration where possible (e.g., the addition of the ETH-Zurich group to the collaboration brought in-kind software computer professionals who have contributed directly to DES DM). However in 2012, the project identified a critical shortfall in effort, leading to the Dec. 2012 supplemental request, recently funded by NSF.

In late 2011/early 2012, Fermilab computing professionals and scientists worked with NCSA staff to evaluate the capabilities and design of the DES DM system. They concluded that the system needed to be restructured ("refactored") in order to be operationally viable for the long term. Fermilab and NCSA have collaborated on the DES DM refactoring project, with Fermilab contributing wrapper code for many of the DES DM pipeline components. The refactoring project has passed its major milestones, and the refactored system is expected to be used starting with the co-adds that will be produced during the first observing season that starts at the end of Aug. 2013. This effort builds on the increased role Fermilab has played in DES DM development and operations, with Fermilab scientist B. Yanny serving as DES DM Project Scientist starting in mid-2012.

Survey Strategy and Planning
In FY11, detailed simulations led to optimization of the DES Supernova survey (Bernstein, et al. 2011), settling on a strategy of 2 deep and 8 shallow SN fields. Simulated, realistic light curves and a resulting SN Hubble diagram were generated, leading to forecast dark energy constraints including statistical and systematic errors (Fig. 6).

Building upon the lessons learned during SV, during the latter part of FY13 DES has been reevaluating and refining its survey strategy and wide-area footprint, with the aim of improving efficiency and early science returns. For many years, the default survey strategy has been to cover the entire 5000 sq. deg. footprint twice in each filter (grizY) in each season, building up depth and offsetting pointings (to improve photometric calibration via overlaps) as we go. The disadvantage of this approach is that the photometric calibration across the survey area is expected to have relatively large errors after only a single season (two tilings per bandpass). After extensive consultation with and study by the Science Working Groups, and detailed simulations based on the ObsTac automated scheduling program, we have decided to adopt a strategy in which complementary halves of the DES footprint will be covered four times in each filter during each of the first two seasons. This will produce a moderately deep, wide-area, well-calibrated survey data set after the first season, without compromising the homogeneity of the completed survey. We are also contemplating a small shift in the final wide-area footprint in order to maximize overall data quality, given the observing season, placement of the Galactic plane, etc. Fermilab scientists have led this survey strategy planning effort, in collaboration with DES scientists from other institutions.

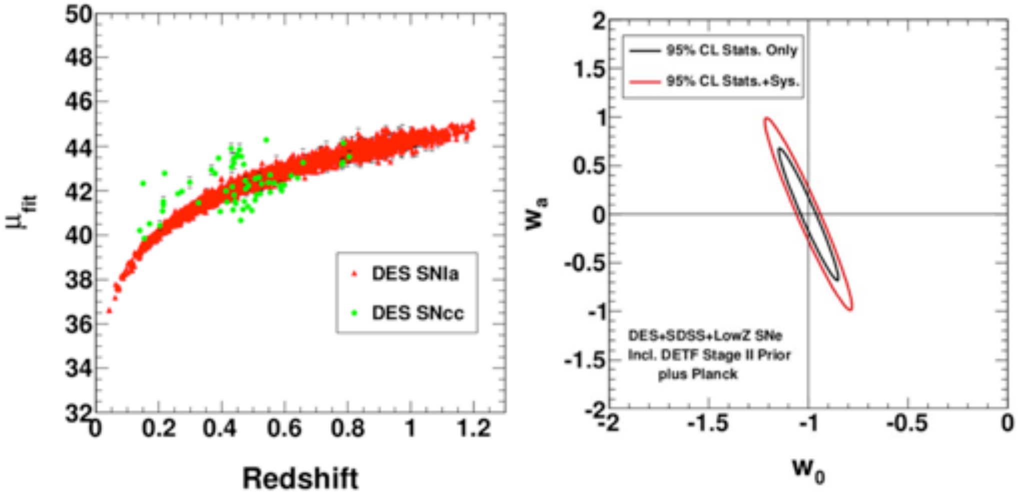


Fig. 6: Forecast DES SN Hubble diagram (left), including contamination from core-collapse (non-Ia) SNe and resulting constraints on Dark Energy equation of state parameters (right), from Bernstein, et al. 2011.

Proposed Research

Introduction

To achieve the goals of probing dark energy and the physical origin of cosmic acceleration, the international DES collaboration will use DECam for 525 nights over 5 years on the Blanco telescope beginning on Aug. 31, 2013 to carry out two interleaved surveys: a wide-area survey of ~300 million galaxies over 5000 square degrees and a time-domain survey over 30 square degrees to discover and measure light curves for several thousand supernovae. Normal survey operations are expected to continue through FY18, with final data reductions and science analysis continuing for at least another two years beyond that. The nominal DES observing season runs from Aug./Sept. to Feb., when the DES footprint area is accessible from CTIO at reasonable airmass. Over the last three years, as construction reached completion, the three Projects (DECam, DES DM, and CFIP) were merged into a coherent effort as we transitioned through integration, installation, commissioning, and science verification (as described above in the Progress Report section), and headed toward normal survey operations and science analysis. With this transition, funding for DES moved from DECam project construction funds to DES operations, which covers all the activities from installation onward.

DES Survey Operations

The Dept. of Energy provides DES Operations and Maintenance funding, administered at Fermilab through the Particle Physics Division and controlled by the DES Operations Systems Scientist (T. Diehl, Fermilab). This person is the project point of contact for DOE resources, manages the DOE operations budget, and helps ensure that resources are allocated optimally across the Operations subsystems. This funding pays for hardware and labor required for camera maintenance, hardware and labor for survey operations, some labor costs for computing services provided by Fermilab, and for travel to the telescope for observations by collaborators from U.S.

institutions. Note that funding for DM and CTIO is separate and not covered under this budget. The DOE costs amounts to approximately $1.8M per annum for each year of operation.

Here we summarize the overall DES Operations and Maintenance budget picture. The budget had carry-over into FY 13 of $2654.7k. We expect funding of $1500k (burdened) per annum to execute the survey, in addition to that carry-over, though in FY'13 we received only $1400k. The expected FY 13 expenditures are projected to be several hundred thousand larger than the $1500k expected yearly funding so this year we will eat into the carry-over. That will happen in each successive year with the carry-over running out sometime close to the end of the survey.

Observing Plan & Strategy - In order to reach the precision and accuracy of a DETF Stage III project, the survey must meet a number of requirements, principally with regard to survey area, depth, number of filters, photometric calibration precision, image quality (principally for weak lensing measurements), and (for the time-domain survey) cadence. There are also efficiency requirements, since the survey has been allocated a finite number of nights (nominally 525) in order to reach its science goals. These requirements are laid out in the *DES Science Requirements document*. These requirements flow down to requirements on the performance of the telescope and instrument and observing systems (particularly image quality and observing efficiency/overheads) and on the data management system.

DES will make an optical-near infrared survey of 5000 square degrees of the South Galactic Cap to approximately 24^{th} magnitude in each of five filters (grizY). The Survey will also include ten fields (2 deep, 8 shallow, 3 sq. deg. each) that will be imaged repeatedly with high cadence in order to obtain multi-band supernova light curves. Simulations indicate that these goals can be achieved with 525 scheduled nights, given the weather conditions that are likely to be encountered at CTIO over a five-year period. Optimizing the survey in terms of the amount and quality of the data collected in a fixed amount of observing time and monitoring progress of the survey toward its goals are tasks undertaken by the DES Project Scientist (J. Annis, Fermilab). Before the beginning of each observing season, a plan for the sequence of observations for the upcoming season will be submitted by the DES Project Director to the CTIO Director.

During operations, photometric conditions are determined by RASICAM, an infrared cloud camera built by SLAC National Laboratory as part of the DECam project for operation at CTIO. A GPS system on the site, procured by U. Chicago and supplied by DES, monitors precipitable water vapor in the atmosphere. During part of the first DES season, a four-filter camera mounted on a small, deployable telescope from Texas A&M will be used to monitor atmospheric transmission in several passbands and measure temporal variations in water vapor, ozone, and other components. We will use those data to evaluate whether a permanent atmospheric monitoring camera should be installed. In addition, the CTIO Differential Image Motion Monitor (DIMM) monitors site seeing and thereby provides information on the expected DECam image quality. If conditions are good (relatively thin clouds and good seeing), the wide-area survey will be undertaken; otherwise the supernova survey fields will be imaged.

The ObsTac (Observation Tactician) program, developed at Fermilab by E. Neilsen, automates the process of deciding the sequence of exposures, based on which fields have already been surveyed in which pass bands, the current local sidereal time, the current atmospheric conditions, moon phase, and the adopted strategy for optimizing the use of the observing time. ObsTac generates a script for automated operations; the role of the observer is to monitor progress, interpret QA information, and react to exceptional cases. All structural elements of ObsTac are ready: it was used successfully and extensively to select observations during DES Science Verification. With the changes and refinements in survey strategy that have been decided upon in July 2013 (see Progress Report section above), ObsTac is undergoing further tweaks and tests in advance of the start of survey operations at the end of Aug. 2013. We will continue to monitor and as necessary improve ObsTac performance during the course of the survey.

DES collaboration members will perform observations according to procedures developed by the DECam team, CTIO, and the Operations Systems Scientist (T. Diehl, Fermilab). The observer schedule will be drawn up and maintained by the Ops Systems Scientist. He maintains a detailed budget and plan for DES operations and DECam maintenance support by Fermilab and is responsible for executing this plan.

It is expected that two DES members will typically participate in each observing night; observers will be drawn from across the collaboration. Observers from each country will require travel support from their respective funding agencies. A detailed observing staffing and training plan has been developed and implemented during DES SV. In addition to the observers, DES will have in place an observing Run Manager, akin to a shift manager in HEP experiments. The Run Manager will be someone with training and experience as an observer, who will ensure that the observers understand and can carry out the observing program and protocols. The Run Manager will serve as liaison to CTIO support staff, with DECam scientists, and with DES Data Management on a daily basis regarding the status of and issues with processing of data from recent nights. It is expected that, at least initially, the Run Manager will have responsibility for filling in the Survey Table, based on DES DM outputs and QA information, that will inform ObsTac as to whether a given field/filter exposure needs to be repeated in a given season. The Run Manager is expected to work primarily in the daytime and to be resident in Chile for more extended periods than the observers, who will typically make weeklong trips.

Data Transport and Processing – DES data from DECam is transmitted from the mountain to NCSA via the NOAO Data Transport System. At NCSA, the DES DM system pipelines process the data, removing instrumental signatures, applying calibrations, co-adding images of the same sky area to produce a deeper image, subtracting SN template images from new SN images, and producing catalogs of detected objects (stars, galaxies, SN candidates, etc.). The images and catalogs will be available to the DES collaboration for analysis through the DES archive.

While NCSA is responsible for the operation of the data processing pipelines and the associated hardware and software infrastructure, many of the DES DM algorithms related to the extraction of image parameters from the data have been developed at other institutions, which will support maintenance of the respective codes in the operations phase. Examples include the Institut d'Astrophysique (image parameters); University of Pennsylvania and associate collaboration members at Brookhaven National Lab (weak lensing); Observatorio Nacional, Brazil (science portal, QA infrastructure), Fermilab (calibration modules, supernova detection, photometric redshifts), University of Chicago (supernova detection, photometric redshifts), and University of Michigan (photometric redshifts).

Data Archiving and Serving - Data archiving and distribution operations will also occur at NCSA. The DM operations plan includes a disaster recovery data archive located at Fermilab. Image data and copies of the Oracle database tables from NCSA are regularly archived into the Fermilab Mass Storage system. The DES operations budget provides funding for the tapes and associated slots in the Fermilab tape robots. The nature of a secondary database archive at Fermilab is currently being re-evaluated. It may be more appropriate to deploy an instance of the analysis portal developed by the DES-Brazil group rather than an exact mirror of the NCSA database. We will be deciding on the appropriate strategy in the next six months.

Science Data Analysis and Analysis Computing - The DESDM system processes the raw images into corrected and co-added images (with instrument artifacts removed) and science-ready catalogs of detected objects. The Science Working Groups carry out analyses of these data products output by the DESDM system and turn them into science results and papers. These analyses require substantial computing resources over and above those used by DESDM for data processing.

Analysis computing for DES has three essential elements: simulations, production of value-added catalogs, and analyses. The Working Groups responsible for carrying out the four Dark Energy analyses (supernovae, clusters, large-scale structure, and weak lensing) have made bottoms-up estimates of their computing needs (CPU hours, number of cores, memory per core, disk and tape space) for each of these three elements.

During the May 2012 review and discussions following the Aug. 2012 planning exercise, the primary issue that arose was the collaboration need for distributed large-scale computing vs. resources available at national centers. Following the recommendations of the 2012 review, DES scientists applied for 5 M CPU hours at NERSC for DES analysis in CY 2013 and were awarded 2.5M CPU hours.

The collaboration is making use of this allocation for analysis of SV data, primarily weak lensing shear pipeline development, galaxy catalog simulations, and likelihood analysis. The simulations group will also request an allocation on XSEDE for the N-body simulations. Using this experience, the collaboration will then formulate an Analysis Computing Plan and associated request for resources as part of DES operations. Use of CPU at NERSC for the weak lensing pipeline development and galaxy catalog simulations will require disk allocations beyond what is typically available to an individual project at NERSC, so we expect at a minimum that this resource request will include disk to be located at NERSC. In addition, other U.S. DES institutions will need small-scale computing resources for local analysis efforts. This on-going planning effort is being led by E. Buckley-Geer, S. Dodelson (Fermilab) and the Analysis Computing Task Force, with input from the Science Working Groups.

Calibration - The DES requirement of 2% photometric precision (1% goal) underlies and is necessary to all of DES science, particularly the Dark Energy goals. The Calibration Systems comprise a number of subsystems, with overall responsibility given to the Calibration Systems Scientist, Douglas Tucker (Fermilab). In addition, the Calibration Systems Steering Group of experts in photometric calibration, chaired by Steve Kent (Fermilab), provides guidance to the Calibration Scientist and to DES project management on the relative priorities of efforts on the various subsystems for achieving the DES calibration requirements. The Calibration Scientist has formulated a *Plan for calibration of early DES data.*

Each night observations will be obtained of standard-star fields at a range of air masses. The tiling scheme to cover the sky will be heavily overlapped, such that an internally consistent relative flux calibration is established across the survey footprint, a calibration that improves with the number of repeat visits to each tile. A new flat-field screen and illumination system, built by Texas A&M, has been installed in the dome and provides spectrophotometric calibration via photodiodes of the total system sensitivity, namely the telescope reflectivity, the corrector transmission, the filter transmission, and the CCD quantum efficiency. A new camera (PreCam), built by Argonne, was used on the Curtis Schmidt telescope at CTIO to establish a network of standard stars, using roughly 100 nights of observing time in late 2010 and early 2011.

Operations and Maintenance of DECam
The DECam instrument is working well and satisfies all DECam Technical Specifications and Requirements with the exception of the mean time between failures of the Liquid Nitrogen pump. A plan is in place to increase the pump lifetime, with the initial steps (placing the pump on an uninterruptable power supply) already taken in July 2013.

As DECam is now a facility instrument operated by CTIO for DES and for the general astronomical community, overall operation and maintenance of DECam are the responsibility of NOAO/CTIO, with support from Fermilab/DES; as described in the *DES MOU* and in the *DECam System Operations and Maintenance Plan.* CTIO is responsible for routine maintenance and for the purchase of spare parts that can be acquired off-the-shelf. For non-routine maintenance, the DECam team based primarily at Fermilab and led by T. Diehl provides necessary support through the 5 years of the DES survey period. These responsibilities have been costed in the Fermilab DES Operations budget document and are included in the budget section of this proposal.

Oversight and Organization
The Associate Director for High Energy Physics in the DOE Office of Science and the Head of the Astronomy Division of the NSF have formed a Joint Oversight Group (JOG) for the DES. The JOG acts as the official contact point between the U.S. agencies and the DES Project Director. JOG meetings are held approximately once per month according to an agenda developed cooperatively between the agency representatives and the DES Project Director.

Reviews of the DES Project have been conducted jointly by the two agencies on a roughly annual basis, most recently in April 2013. Oversight of the DES project is also provided by the laboratory signatories to the *DES MOU* (Fermilab, NOAO, and NCSA) via the DES Council, which is composed of the respective laboratory Directors or their delegates. The DES Director reports to and is appointed by the Council. The Directors conduct periodic reviews organized by the DES Council to assure that the Collaboration is achieving the DES scientific goals, that the operations cost estimates continue to be sound and have sufficient contingency, that the schedule has a high probability of being met, that the funding plan is realistic, and that the teams are capable of executing the Survey.

DES Collaboration Organization

The DES Collaboration consists of senior scientists in the collaborating institutions (designated Members), Associate Members at non-DES institutions, plus students and postdocs of Members and Associate Members. The DES Membership Policy governs the admission of new members (individuals and institutions) as well as their rights and responsibilities. The DES Management Committee (MC) represents the interests of the Collaboration in all phases of the Survey. Each collaborating institution or consortium selects its institutional representative(s) to the MC. The DES Director serves as Chair of the MC and as Spokesperson for the Project. Students and postdocs mentored by collaboration members have access to the data and can participate in the Working Groups.

DES Project Management

The management of DES was restructured as part of the 2012 planning exercise to make it more effective and transparent, to ensure coherence of the project, and to organize it along functional lines; it is described in the *DES Project Organization Chart* and in the *Plan for DES Integration, Commissioning, Science Verification, and Early Operations*. The current Org Chart is shown in Fig. 7. The key organizational principle is division of the project/collaboration into two main phases: Collaboration Affairs, under the Management Committee, and Operations, under the Executive Committee. The Executive Committee comprises the leaders and critical personnel in the Operations subsystems (those named in the boxes on the right hand side of the Org Chart). It meets weekly to track progress and promote communication across the subprojects. The Director and Deputy Director are currently J. Frieman and R. Kron (Fermilab). We also created the new title of DES Operations Systems Scientist in the DES Project/Collaboration Office and T. Diehl (Fermilab) now serves in this role. This person is the project point of contact for DOE resources, manages the DOE operations budget, and helps ensure that resources are allocated optimally across the Operations subsystems. He is responsible for a monthly report on DES operations sent to the DES Director and to the Fermilab Particle Physics Division.

Observing Systems includes a variety of tasks related to data collection, including observing (staffing assigned nights at the Blanco), tracking survey progress and planning future observations, data collection scheduling and training, longer-term survey optimization, and assessment of data quality with respect to requirements. These tasks are coordinated by the DES Project Scientist (J. Annis, Fermilab) and the Operations Systems Scientist (T. Diehl, Fermilab).

DECam Operations Support refers to the coordination of efforts on DECam operations and maintenance between the DECam Instrument Scientist (A. Walker, CTIO) and the DECam team.

DES Data Management (D. Petravick, DES DM PI, NCSA, B. Yanny, DES DM Project Scientist, Fermilab) refers to the nightly processing of data at NCSA, loading the databases, maintaining the primary archive of the data products that serves the DES scientists, supporting data transfers to the secondary archive, and reprocessing as necessary. The secondary archive is at Fermilab and is described earlier.

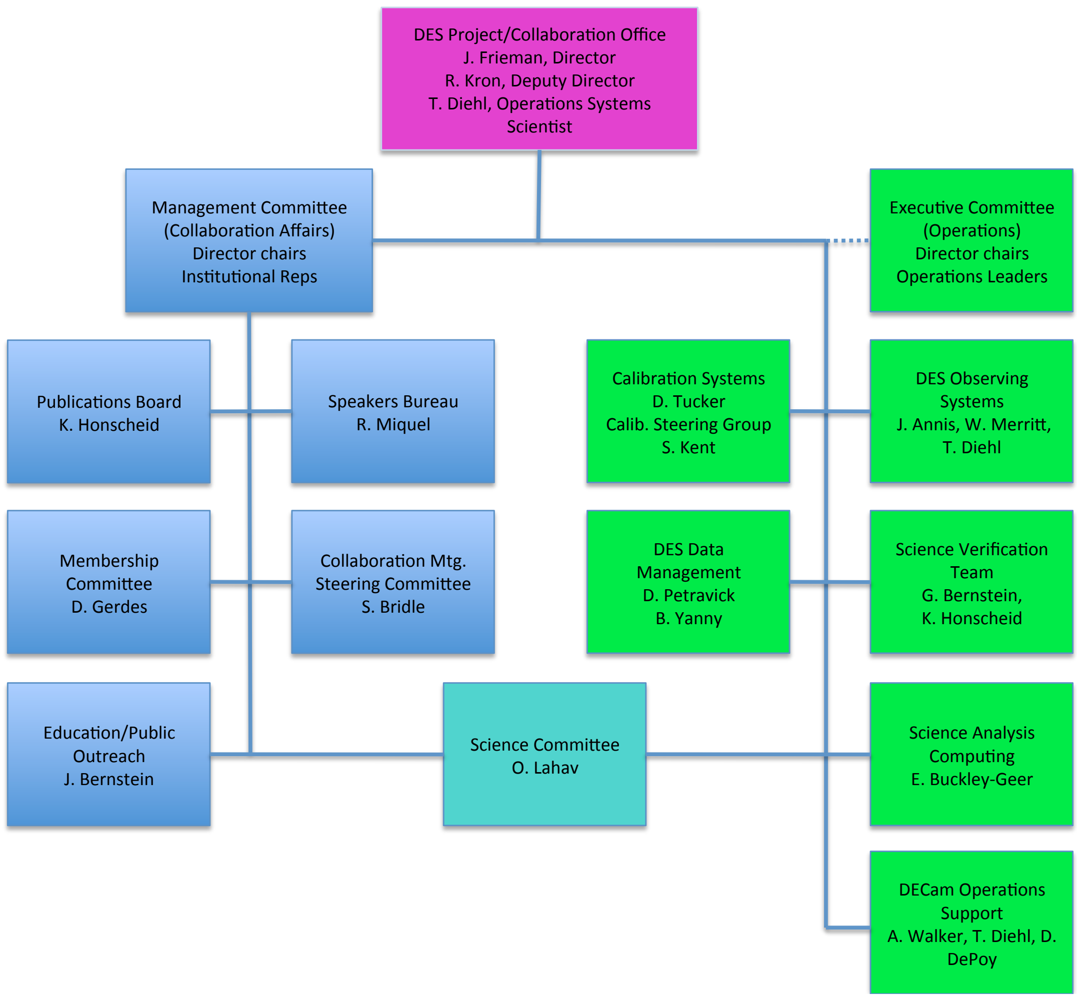


Fig. 7: DES Organization Chart, showing the roles of the Project/Collaboration Office, the Management Committee, and the Executive Committee. Fermilab scientists make up 10 of the Executive Committee members.

The Science Committee, comprising the co-coordinators of the Science Working Groups plus the chair, is appointed by the Management Committee but also plays a key role in DES Operations, so it is shown linked to both sides of the Org Chart. Two recent elements under Collaboration

Affairs are the reconstituted Collaboration Meeting Steering Committee, which shapes the format, cadence, and structure of the collaboration meetings, and Education/Public Outreach, which coordinates and expands the on-going efforts in those endeavors. In E/PO, Fermilab postdocs have taken the lead in implementing and providing content for the weekly DES image blog, darkenergydetectives.org.

Science Organization
Scientific research by the Dark Energy Survey (DES) collaboration is organized by and carried out within the Science Working Groups (SWGs). The SWGs are each led by a pair of co-coordinators. Overall responsibility rests with the Science Committee, which comprises the SWG co-coordinators and a chair (currently O. Lahav, UCL), as shown in Fig. 8. The SWGs and Science Committee operate under the DES Science Committee Charter. They also have specific responsibilities laid out in the DES Publication Policy. In addition to the Dark Energy-focused SWGs, there are others exploring ancillary science that can be carried out with the DES data set. The Theory Group will combine results of the different SWGs into a set of joint constraints on dark energy. The current organizational structure is given in the chart below.

Members of the DES collaboration are free to participate in any of the SWGs, and the membership of each group crosses institutional and international boundaries. Specific Working Group/Science Committee responsibilities include: (i) helping formulate the DES science requirements; (ii) reviewing the technical specifications of the different DES projects and the requirements flow-down; (iii) helping formulate and evaluate survey strategy; (iv) providing simulation support for the DES Data Management system via data ingestion and integrity tests; (v) testing outputs of the DM system via Data Challenges; (vi) acceptance testing outputs of DM and overall data quality during DECam commissioning, SV, and survey operations; (vii) developing and testing science analysis tools that will be run on DM outputs to produce science results; (viii) contributing specific modules to the DM system that are more sensible to have upstream of the DM outputs (including weak lensing shape measurements, photo-z measurement, image differencing for SN discovery, and formulation of an angular mask for large-scale structure and other studies); (ix) developing any additional tools to enhance data access and analysis, as needed.

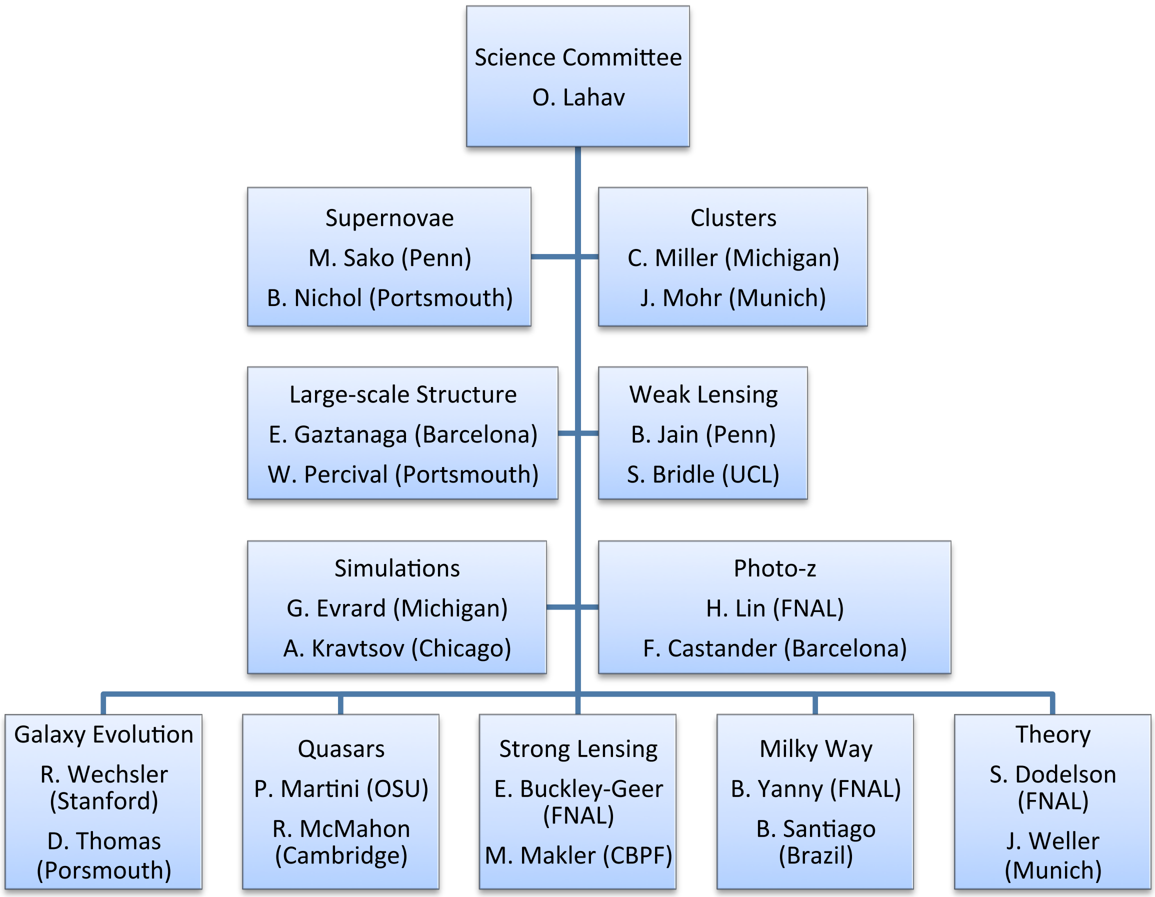


Fig. 8: DES Science Committee and Science Working Groups. Fermilab scientists (Lin, Bridle, Yanny, Dodelson) are co-coordinators of 4 of the Science Working Groups.

Early Science Analyses

As noted above in the Progress Report section, DES collaboration scientists are carrying out a variety of science analyses of the DES Science Verification data taken Nov. 2012-Feb. 2013, and a number of early publications based on the SV data are in progress, with first publications expected to be submitted in the coming months (late 2013 to early 2014). These initial publications will include demonstration of the optical identification of high-redshift clusters (Figs. 9 and 10), measurement of cluster masses and mass distributions via weak lensing (Fig. 11), and the discovery and light curves of type Ia and core collapse supernovae (Fig. 12).

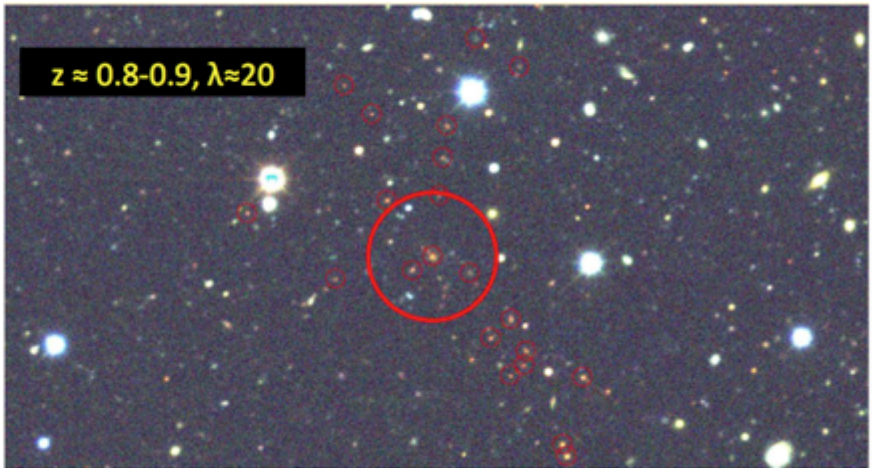


Fig. 9: High-redshift cluster identified in DES Science Verification data based on a search for clustered galaxies with similar (red) colors. Cluster members indicated with small red circles.

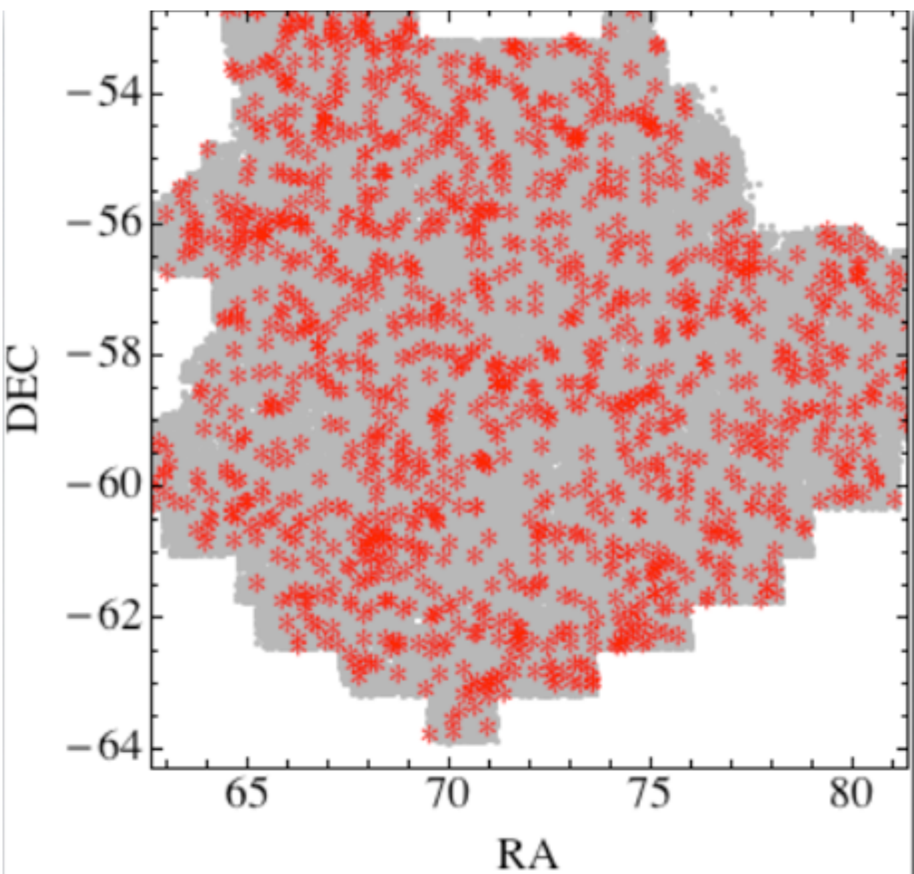


Fig. 10: Preliminary map of massive, high-redshift clusters (red points) of galaxies (grey points) detected in DES SV data using the Voronoi tessellation method, from Fermilab postdoc M. Santos-Soares.

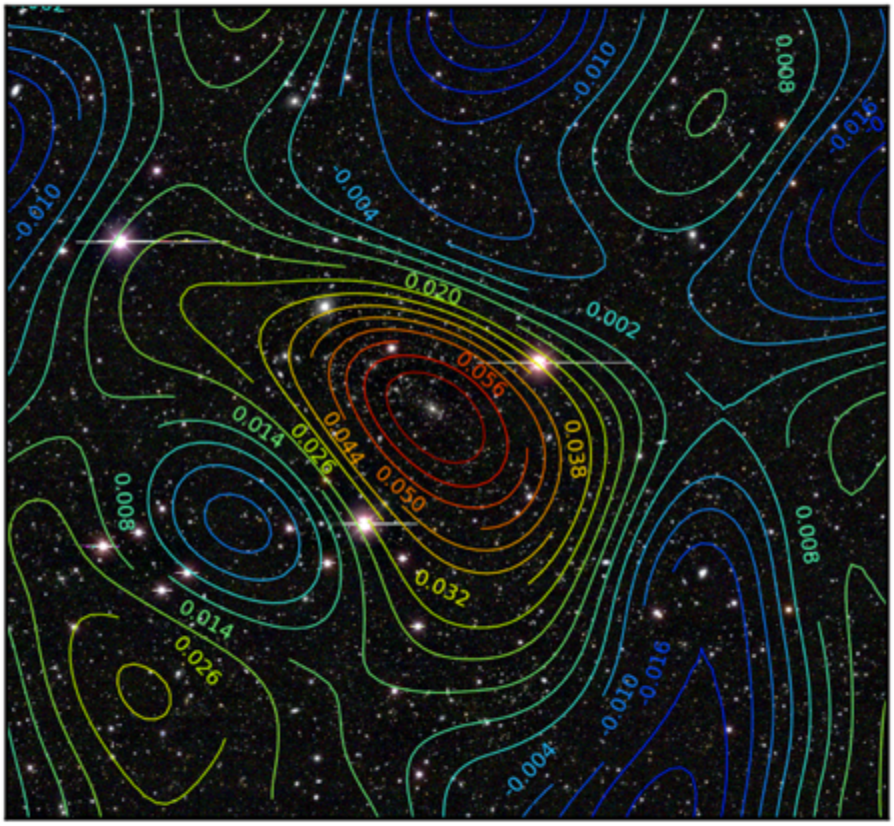


Fig. 11: Preliminary weak lensing mass map of an intermediate-redshift cluster (color contours) superposed on DECam image of the cluster, from DES SV data.

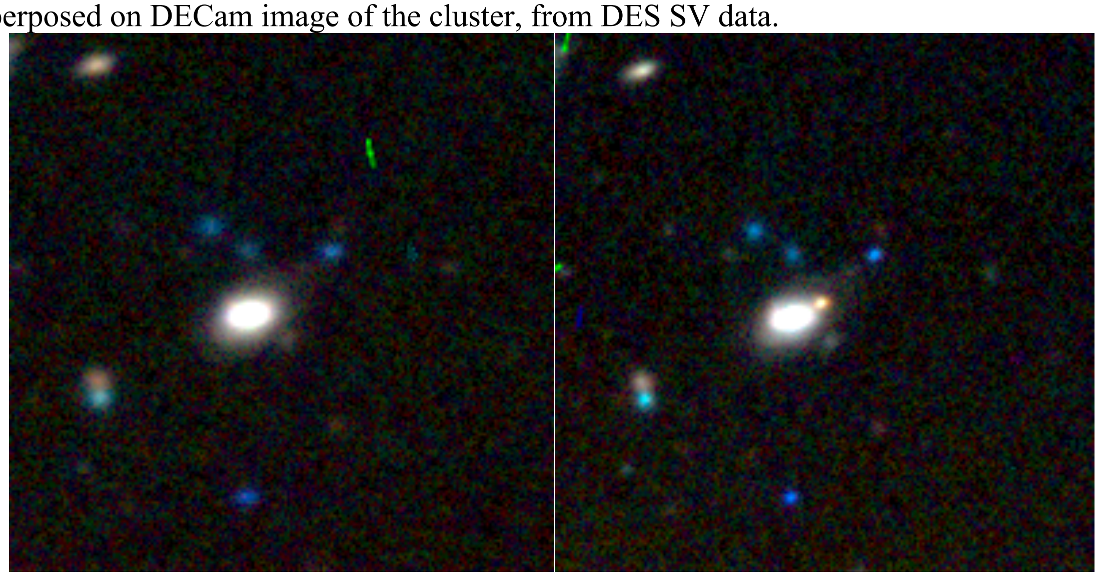


Fig. 12: Before (left) and after (right) images of a type Ia supernova at redshift 0.2 discovered in DES Science Verification data in Dec. 2012.

Fermilab Science and Operations Activities - The Fermilab DES team includes J. Annis, E. Buckley-Geer, T. Diehl, S. Dodelson, J. Estrada, D. Finley, B. Flaugher, J. Frieman, G. Gutierrez, S. Kent, R. Kron, N. Kuropatkin, H. Lin, J. Marriner, K. W. Merritt, E. Neilsen, J. Peoples, V. Scarpine, A. Stebbins, C. Stoughton, D. Tucker, W. Wester, and B. Yanny, postdocs (currently M. Soares-Santos and B. Nord), graduate and undergraduate students from nearby institutions, and is supported by engineers, computing professionals, and technicians.

In addition to the technical labor described above, Fermilab scientists are responsible for DES Project Management (Director, Deputy Director, Operations Systems Scientist) and play leading roles in DES Operations (10 Fermilab scientists on the Executive Committee), including observing systems, survey strategy, calibrations, and analysis computing, and lead the DOE portion of DECam maintenance. Fermilab scientists also contribute centrally to the DES DM project (Project Scientist, pipeline coding, calibration, testing). Fermilab scientists led the construction of DECam, the survey strategy design, and the formulation of scientific and technical requirements.

There is ongoing work at Fermilab in all the dark energy science projects, and Fermilab scientists are co-coordinators of four of the SWGs, as noted above; the Project Director is an ex-officio member of the Science Committee and its former co-chair. The science efforts at Fermilab include development and refinement of photometric redshift techniques (Lin, Frieman, and U. Chicago graduate student Helsby) which underlie all the dark energy probes, study of standard stars for astrometric and photometric calibration (Tucker, Wester), weak and strong gravitational lensing (including identification of strong lensing arcs in SV data, investigation of lensed QSO time delays to constrain dark energy, and detection of galaxy-galaxy weak lensing in SV data, Buckley-Geer, Diehl, Soares-Santos, Dodelson, Annis, Lin, Estrada, Finley, Flaugher, Nord, and a student), cluster identification (Fig. 10, Soares-Santos, Annis, Estrada, Flaugher), a necessary perquisite for cluster counting and dark energy, supernovae (including operations, detection, and photometry, Marriner, Finley, Frieman, Wester, Merritt), cross-correlation of DES data with South Pole Telescope data (to constrain cluster masses and correlate CMB lensing with DES galaxies and clusters, Dodelson, Soares-Santos), theory efforts on combining the different dark energy probes and constraining modified gravity models (Dodelson), detection of dwarf satellites of the Milky Way as a probe of dark matter and structure formation (Yanny and student), and galaxy completeness and star-galaxy separation (Diehl). Given that U. Chicago is the lead institution on the South Pole Telescope (SPT), the Fermilab group also is collaborating with senior scientists, postdocs, and students at U. Chicago on joint analysis of DES and SPT, fostered by UC's Kavli Institute for Cosmological Physics (KICP). In addition, Dodelson is working with computing professionals in Fermilab's Scientific Software Infrastructure group, with analysts at KICP, and with scientists at the U. Manchester to develop a software system for analyzing DES data. This framework will facilitate tracking of runs with different configuration parameters, code testing, and allow for widespread inspection of code used in DES science papers. This work is currently funded by a grant from Computational HEP.

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B. Flaugher, et al., Status of the DECam Project, in SPIE International Symposium on Astronomical Telescopes and Instrumentation, Fermilab-Conf-12-317-AE-E (2012).

I. Sevilla, et al., The Dark Energy Survey, in Proc. Europhysics Conf. on High Energy Physics (2011).

K. Kuehn, et al., PreCam, a Precursor Observational Campaign for Calibration of the Dark Energy Survey, in Pub. Aston. Soc. Pac. 125 (2013) 409, Fermilab-Pub-12-393-AE-CD-PPD.

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M. Antonik, et al., The Impact of Camera Optical Alignments on Weak Lensing Measures for the Dark Energy Survey, arXiv:1206.5320, Fermilab-Pub-12-101-AE, MNRAS, 431, 3291 (2013).

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J.P. Bernstein, et al., Supernova Simulations and Strategies for the Dark Energy Survey, Astrophys. J. 753 (2012) 152 (Fermilab-Pub-11-681-A).

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T. Shaw, et al., System Architecture of the DECam Readout Electronics, Fermilab-Conf-10-175-PPD, in SPIE Astronomical Instrumentation: Ground-based and Airborne Telescopes III (2010).

H. T. Diehl, et al., Testing the Dark Energy Camera on a Telescope Simulator, Proc. SPIE Conf. on Astronomical Instrumentation, Fermilab-Conf-10-179-E (2010).

J. Estrada, et al., Focal Plane Detectors for DECam, Proc. SPIE 77351R (2010).

C. Shapiro, et al., Will Multiple Probes of Dark Energy find Modified Gravity?, PRD 82 (2010) 043520.

Presentations (2010-):

D. Kubik, CCD testing for DECam, presented at TIPP 2011, 2nd International Conference on Technology and Instrumentation in Particle Physics, Fermilab-Conf-11-640-PPD, Dec. 2011

B. Flaugher, DECam, at AAS Special Sessions, Jan. 2011, Jan. 2013.

B. Flaugher, Status of DECam, presentations at SPIE Conferences 2010, 2012.

J. Frieman, Colloquiua on DES at Columbia U., Harvard CfA, Texas A&M, Brown U., U. Chicago (2010-2013).

J. Frieman, DES Overview, at AAS Special Sessions, Jan. 2011, Jan. 2013, Benasque Cosmology Workshop 2012, Cooks Branch Workshop 2012, Aspen Winter Conferences 2010, 2012, UCSC Workshop on the Search for Fundamental Physics, 2013, plus others.

R. Kron, The Dark Energy Camera at the Blanco Telescope, at Conf. honoring P. Salinari, Bavaria, 2010.

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H. Lin, Photometric Redshift Calibration of the DES, at APS DPF meeting, Aug. 2013.

H. Lin, The Dark Energy Survey, Indiana U. Astronomy Colloquium, Mar. 2010.

M. Soares-Santos, DES Science Verification, at APS DPF meeting, Aug. 2013, and DES Cluster Cosmology, at APS DPF meeting, Aug. 2013.
D. Tucker, The Dark Energy Survey, seminar at Southern Connecticut State University, Mar. 2010.

Mid-Scale Dark Energy Spectroscopic Instrument (MS-DESI or DESI)

The great scientific value of a massive, deep spectroscopic survey to complement imaging data was proven by SDSS, and the case is even stronger in the modern context of deeper surveys, precision cosmology, and dark energy. Fermilab led the development of the SDSS system and has worked to develop a similar capability for deep spectroscopy over much larger and deeper volumes, comparable to those probed by DES and later LSST.

There were initially two concepts for a next-generation dark energy spectroscopic instrument: BigBOSS and DESpec. Only within the last year have these efforts merged into a unified project, labeled initially as MS-DESI and now just DESI. Fermilab participated in both of the original concepts, and we report progress based on that work below. However, our proposed research going forward is focused on DESI.

Progress Report

The BigBOSS concept was developed primarily at LBNL. The concept was to rebuild the prime focus cage of the Mayall telescope in Tucson (similar to the way the DECam project rebuilt the prime focus cage and camera for the Blanco telescope in Chile) and install a wide-field spectrometer capable of obtaining redshifts for ~5000 galaxies in a single pointing. Such a capability would make the project a Stage IV Dark Energy experiment. Fermilab participated in the development of the CCD packages, building on the experience and infrastructure developed for CCD packaging for DECam, and in the design and construction of the corrector barrel, again building on the DECam experience. The CCD packaging effort involved reproducing the package station developed by LBNL and then adapting and improving the fixtures and procedures for production quantities. Two prototype packages were successfully produced this past year. Scientific effort was also involved in understanding if there was a gain in the dark energy constraints from overlapping the survey with an optical survey such as DES. All of these efforts transferred naturally to the DESI project.

The Dark Energy Spectrometer (DESpec) was a concept developed primarily at Fermilab around 2010. In the Fermilab manifestation of the concept, the Dark Energy Camera (DECam) on the Blanco Telescope at Cerro Tololo Interamerican Observatory (CTIO) was to be adapted to a wide-field spectrometer capable of obtaining redshifts for 4000 galaxies in a single pointing. Such a capability would upgrade DECam from a Stage III Dark Energy experiment to a Stage IV Dark Energy experiment. Moreover, the spectroscopic capability would uniquely enable measurements of redshift-space distortions, correlating these with weak-lensing mass maps, and thus allow a new test of gravity on large scales. In the DESpec concept, much of the existing DECam hardware would be exploited; new components required included a fiber positioner that takes the place of the DECam imager, and a battery of spectrographs. The evolution of DESpec into DESI means that the Mayall Telescope in the northern hemisphere is used instead of the Blanco Telescope in the southern hemisphere, so the optical components of DECam cannot be repurposed in this way.

During the time DESpec existed as an active concept (as a plan to upgrade DECam on the Blanco), the following Fermilab scientists were especially active: H. T. Diehl, S. Dodelson, B. Flaugher, S. Kent, R. Kron, J. Frieman, H. Lin, J. Annis, C. Hogan, J. Marriner, and postdocs B. Nord and M. Soares-Santos. Accomplishments included identifying the major items requiring R&D, for example the fiber positioner (for which a team at the Australian Astronomical Observatory was recruited); building a Collaboration that included a dozen interested institutions; writing a White Paper (arXiv:1307.8061) that defined the project and demonstrated the science reach for Dark Energy and Modified Gravity; presenting the case to DOE to establish CD-0 in the wake of the "Rocky III" report that recommended that such an instrument be built; and spearheading the development of an end-to-end survey simulation tool, useful for both quantifying the time-to-completion for different survey strategies, and for establishing the effect of different instrument-design trades. This simulation tool (B. Nord) is sufficiently general that it will be used for DESI.

Proposed research

Fermilab has joined with LBNL in the DESI project, and plans to contribute to the construction of the DESI instrument and engage in the scientific analysis of the data expected to be collected with the instrument after it is installed on the Mayall. Fermilab scientists, and their expected contributions to the project and to the science collaboration, are:

- Steve Kent is leading the development of the requirements documents, along with Chris Bebek.
- Gaston Gutierrez is working on corrector barrel design. He will provide guidance to the Fermilab engineer assigned to this project. The engineers would be funded by LBNL MS-DESI project funds.
- Juan Estrada is working on developing the CCD packaging production line for MS-DESI.
- Brenna Flaugher is on the MS-DESI steering committee, the Fermilab institutional representative and will be a Level 2 co-manager of the integration and test WBS section of the project with Bobby Besuner. She is also chairing the MS-DESI spokesman selection committee.
- Liz Buckley-Geer is interested in working with Klaus Honscheid in the development of the online software for MS-DESI. They both worked on this for DES and will use this experience to guide the development for MS-DESI.
- Rich Kron has a joint appointment with U. Chicago (80%) and Fermilab (20%). He expects to spend roughly 50% of his Fermilab time on MS-DESI.
- Scott Dodelson is interested on developing a software framework for analysis, as he is doing for DES and LSST.
- A post-doc, Brian Nord, is working on the SPOKES end-to-end simulations of Multi-object spectroscopy projects. He is already engaged with the MS-DESI simulations

group and working with them to merge the needs of MS-DESI with the SPOKEs framework.

All technical effort and equipment purchased for the project would need to be covered by DOE project funds as distributed by LBNL.

LSST

The LSST survey will have an enormous impact across broad areas of astronomy, astrophysics, and cosmology, and in particular, it will be the largest DOE dark energy experiment during the next decade. The project follows naturally from SDSS and DES, but is far larger and more complex. Recognizing its importance, Fermilab scientists have participated in LSST planning from the beginning; Craig Hogan was a co-founder of LSST Corporation, and now serves as Fermilab's representative there. However, due to its other commitments during LSST's R&D phase, Fermilab will not play a large technical role in DOE's LSST camera construction project, led by SLAC. Nevertheless, Fermilab plans to be an active scientific participant in LSST, and contribute technically in a few key areas.

Most of Fermilab's work on LSST has been in the context of the Dark Energy Science Collaboration (DESC). There are three main thrusts: software, science, and enabling project tools to run on the Open Science Grid (OSG). The first two of these have grown over the past year with the formation of the DESC, while the OSG work has been on-going for the whole 3-year period. After a short term intense focus on DES, a growing number of scientists at Fermilab plan to devote at least some of their time to LSST over the next three years. They will team with groups at Fermilab (Experimental Astrophysics Group, OSG, and Scientific Software Infrastructure) with computing experience on large experiments to deliver products and services to the LSST project and DESC.

Progress report

Erik Gottschalk and Scott Dodelson have served as Conveners of the Software Working Group (WG) within the DESC. The goal of this group, as stated in the DESC white paper, is to develop a software framework that will enable the science WG's to assess the significance of the systematics. The framework needs to be robust enough to handle both the pre-data phase and the phase in which data analysis is the main focus. This is a large undertaking that will require the coordination of many people spread across the national Labs and several universities.

Over the past 12 months, we have begun with a series of first steps, including a dedicated workshop at Fermilab in June 2013 with two representatives from each science WG and computing experts from the Labs. Dodelson has been working with Kowalkowski, Paterno, and Sehrish of the Scientific Software Infrastructure group at Fermilab to polish these use cases and transform them into a series of requirements.

A second software effort is dedicated to exercising tools developed by the LSST Data Management team. The short-term goal is to run these tools on early data from the Dark Energy Survey. To date, the LSST pipeline has been used to calibrate images from the Sloan Digital Sky Survey; the team is now working to apply the pipeline to DES data.

There is synergy between many of the science activities on DES and systematics studies for LSST. One example is the issue of baryonic effects on the weak lensing power spectrum; Dodelson, Gnedin, and postdoc Andrew Hearin have been studying the magnitude of this contamination and different mitigation schemes that can be applied for both DES and LSST, using high-resolution hydrodynamics simulations with different implementations of baryonic effects.

The OSG group at Fermilab has partnered with John Peterson of Purdue to run his photon simulation software on the grid, and facilitated access to new resources. Over the next 3 years, the OSG group at Fermilab plans to fold in the data management tools of the LSST project, enabling them to run on the grid as well.

Proposed research

Fermilab proposes to continue and slowly expand similar thrusts in LSST over the next 3 years: Level 3 Software, DESC science, and enabling project tools to run on the Open Science Grid (OSG). Fermilab scientists and computing professionals will work with the DESC science working groups to produce a software framework for the collaboration and to exercise project tools on surveys such as DES. After continued intense focus on DES in the next year, a growing number of scientists at Fermilab plan to devote at least some of their time to LSST in the following years, contributing to theory, photometric redshifts, weak lensing, and strong lensing. Fermilab will work to make grid computing available to the collaboration.

Publications & Presentations

Publications:

"Accounting for baryons in cosmological constraints from cosmic shear", Andrew R. Zentner, Elisabetta Semboloni, Scott Dodelson, Tim Eifler, Elisabeth Krause, and Andrew P. Hearin, Phys. Rev. D 87, 043509
"Dark energy with gravitational lens time delays", T.Treu, E. Buckley-Geer, D. Finley, et al.arXiv:1306.1272, White paper for Snowmass
"LSST Dark Energy Science Collaboration", arXiv:1211.0310, Fermilab authors: Dodelson, Finley, Frieman, Garzoglio, Gottschalk, Gnedin, Hogan, Kent, Lin, Soares-Santos, Stebbins

Presentations:

Dodelson, "The Current State of Dark Energy," LSST DESC Inaugural Meeting, Philadelphia (2012).
Dodelson, "Dark Energy and Beyond" LSST DESC meeting, SLAC (2013).
Dodelson, "DES Software Framework," LSST DESC meeting, SLAC (2013).
Kowalkowski, "Frameworks for LSST," LSST DESC meeting, SLAC (2013).
Paterno, "CosmoSIS", LSST DESC Software Workshop, Fermilab (2013).

Sloan Digital Sky Survey

Progress report

Fermilab's institutional involvement in SDSS operations ended in 2008, but the lab continues to maintain a publicly accessible archive of all data obtained through that date, and four individual scientists are participants in portions of SDSS III. The archive continues to be used for a wealth of research by the broader community - approximately 100 TB of data are downloaded per year, and in FY11-FY13, over 500 papers in refereed journals were published making use of data from the archive.

Fermilab scientists have been involved in the following three programs:

1) Stripe 82 coadd. This project involved reprocessing and combining repeated imaging scans of about 300 square degrees of sky in order to detect and measure galaxies much fainter than the original SDSS survey. These data resulted in a series of analyses, including construction of a photometric redshift catalog, calibration of the galaxy cluster mass function and detecting cosmic shear, both utilizing the photometric catalog and weak lensing techniques.

2) Detection and modeling of strong lensing system. These systems consist of a distant galaxy whose image is amplified and distorted by a foreground lens. About a dozen systems were studied. These systems are now being proposed as another auxiliary probe of dark energy.

3) Characterization of supernovae. Supernovae are one of the premier classes of objects used to study the accelerated expansion of the universe, which implies the existence of dark energy.

The Sloan Digital Sky Survey Supernova Project covered the redshift range $0.05 < z < 0.4$, an interval that was not covered efficiently by galaxy-targeted low-z surveys nor by deep, but narrow high-z surveys. The SDSS SN search was a magnitude-limited survey, and it was possible to accurately measure the detection efficiency, leading to a precise measurement of the SNIa rate as a function redshift out to $z=0.3$. Previous SN observations had already measured the accelerating expansion of the universe, but the addition of intermediate redshift data placed more stringent constraints on exotic cosmologies as well as improving the uncertainties of the standard cosmological parameters. The existence of the extensive, well calibrated, SDSS galaxy data has enabled studies of SN Hubble residuals and host galaxy properties, including correlations with host galaxy mass, gas-phase metallicity and star-formation rate.

Current research involves collaboration with the Supernova Legacy Survey including a joint calibration (published), a study of light curve training systematics (in preparation), and improved constraints on cosmological parameters (also in preparation). In addition, a full data release of SDSS supernova catalogs, photometry, and spectra is planned. It is expected that these activities will all be completed early in FY2014.

The SDSS archive will continue to be a valuable resource, in particular in support of the Dark Energy Survey (DES) analysis. The "stripe 82" area of the SDSS will be imaged by DES and will serve as a test bed to validate and characterize the accuracy of the DES dataset. DES-detected supernovae will be combined with supernova data from SDSS to provide the best constraints on dark energy. Overlaps between DES and the BOSS survey of SDSS III will be used to aid in calibrating photometric redshifts.

The SDSS SN sample has been used extensively to study the methodology and technique of identifying supernova Type Ia solely from the light curve data. This experience will be applied to the Dark Energy Survey, where spectroscopic observation of the complete sample will be impractical. In addition, the expected excellent relative calibration between SDSS and DES will reduce the calibration uncertainties of present data samples.

<u>SDSS Publications:</u>

2010, ApJS 191, 254 "A GMBCG Galaxy Cluster Catalog of 55,424 Rich Clusters from SDSS DR7", Hao, J. et al.
2010 ApJ 724, 137 "The Sloan Bright Arcs Survey: Discovery of Seven New Strongly Lensed Galaxies from z = 0.66-2.94", Kubo, J. et al.
2011 ApJ 738, 162 "Photometric Type Ia Supernova Candidates from the three-year SDSS-II SN Survey Data", Sako, M. et al.
2011 AJ 141, 90 "The SEGUE Stellar Parameter Pipeline. V. Estimation of Alpha-element Abundance Ratios from Low-resolution SDSS/SEGUE Stellar Spectra", Lee, Y. S. et al.
2012 ApJ 747, 59 "The Sloan Digital Sky Survey Co-add: A Galaxy Photometric Redshift Catalog", Reis, R. et al.
2012 ApJ 748, 128 "The Sloan Digital Sky Survey Co-add: Cross-correlation Weak Lensing and Tomography of Galaxy Clusters", Simet et al.
2012 AJ 144, 17 "A Precision Photometric Comparison between SDSS-II and CSP Type Ia Supernova Data", Mosher, J. et al.
2012, ApJ 755, 61 "The SDSS-II Supernova Survey: Parameterizing the Type Ia Supernova Rate as a Function of Host Galaxy Properties", Smith, M. et al.
2012, ApJ 755, 125 "Type Ia Supernova Properties as a Function of the Distance to the Host Galaxy in the SDSS-II SN Survey", Galbany, L. et al.
2012 ApJ 761, 1 "The Sloan Bright Arcs Survey: Ten Strong Gravitational Lensing Clusters and Evidence of Overconcentration", Wiesner et al.
2012 ApJ 761, 15 "The SDSS Co-add: Cosmic Shear Measurement", H. Lin et al.
2012, Icarus, 218, 571 "Ensemble properties of comets in the Sloan Digital Sky Survey", Solontoi, M. et al
2013, A&A 552, 124 "Improved photometric calibration of the SNLS and the SDSS supernova surveys", Betoule, M. et al.

<u>Additional SDSS-II Supernova Survey Publications:</u>

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2013ApJ...764...48K, Kessler, Richard; Guy, Julien; Marriner, John; Betoule, Marc; Brinkmann, Jon; Cinabro, David; El-Hage, Patrick; Frieman, Joshua A.; Jha, Saurabh; Mosher, Jennifer; Schneider, Donald P., Testing Models of Intrinsic Brightness Variations in Type Ia Supernovae and Their Impact on Measuring Cosmological Parameters
2013ApJ...763...88C, Campbell, Heather; D'Andrea, Chris B.; Nichol, Robert C.; Sako, Masao; Smith, Mathew; Lampeitl, Hubert; Olmstead, Matthew D.; Bassett, Bruce; Biswas, Rahul; Brown, Peter; and 18 coauthors, Cosmology with Photometrically Classified Type Ia Supernovae from the SDSS-II Supernova Survey
2012ApJ...752...79H, Hlozek, Renée; Kunz, Martin; Bassett, Bruce; Smith, Mat; Newling, James; Varughese, Melvin; Kessler, Rick; Bernstein, Joseph P.; Campbell, Heather; Dilday, Ben; and 9 coauthors, Photometric Supernova Cosmology with BEAMS and SDSS-II
2011ApJ...743..172D, D'Andrea, Chris B.; Gupta, Ravi R.; Sako, Masao; Morris, Matt; Nichol, Robert C.; Brown, Peter J.; Campbell, Heather; Olmstead, Matthew D.; Frieman, Joshua A.; Garnavich, Peter; and 6 coauthors, Spectroscopic Properties of Star-forming Host Galaxies and Type Ia Supernova Hubble Residuals in a nearly Unbiased Sample

2011ApJ...741..127G, Gupta, Ravi R.; D'Andrea, Chris B.; Sako, Masao; Conroy, Charlie; Smith, Mathew; Bassett, Bruce; Frieman, Joshua A.; Garnavich, Peter M.; Jha, Saurabh W.; Kessler, Richard; and 4 coauthors, Erratum: "Improved Constraints on Type Ia Supernova Host Galaxy Properties Using Multi-wavelength Photometry and Their Correlations with Supernova Properties" (2011, ApJ, 740, 92)
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2011ApJ...740...92G, Gupta, Ravi R.; D'Andrea, Chris B.; Sako, Masao; Conroy, Charlie; Smith, Mathew; Bassett, Bruce; Frieman, Joshua A.; Garnavich, Peter M.; Jha, Saurabh W.; Kessler, Richard; and 4 coauthors, Improved Constraints on Type Ia Supernova Host Galaxy Properties Using Multi-wavelength Photometry and Their Correlations with Supernova Properties
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2010ApJ...713.1026D, Dilday, Benjamin; Smith, Mathew; Bassett, Bruce; Becker, Andrew; Bender, Ralf; Castander, Francisco; Cinabro, David; Filippenko, Alexei V.; Frieman, Joshua A.; Galbany, Lluís; and 26 coauthors, Measurements of the Rate of Type Ia Supernovae at Redshift lsim0.3 from the Sloan Digital Sky Survey II Supernova Survey
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7. Dark Matter - Status and Future Plans

Astronomical observations of many types, and on many different scales, have confirmed that most of the matter in the universe neither emits nor absorbs light. This cold dark matter would have provided the gravitational scaffolding that caused normal matter to coalesce into the galaxies we see today. In particular, we think our own galaxy is embedded within an enormous cloud of dark matter. As our solar system rotates around the galaxy, it moves through this cloud.

Particle physics theories suggest that dark matter may be composed of Weakly Interacting Massive Particles (WIMPs). Although such WIMPs would rarely interact with normal matter, they could occasionally scatter from an atomic nucleus like billiard balls, leaving a small amount of energy that might be detectable under the right conditions. Experiments around the world are attempting to directly detect WIMPs with many different technologies. Because they have only been detected by gravity, basic properties of these conjectured particles, such their mass and interactions, are unknown. Cosmological theory provides some framework to design experimental search parameters and set expectations, and other experiments (collider and indirect methods via searches for annihilations or decays) provide additional constraints.

The Fermilab program follows the national agenda of deploying direct searches using multiple, and complementary, methods. The Cryogenic Dark Matter Search (CDMS) collaboration has long been a leader in the search for WIMP dark matter, using cryogenic solid-state germanium and silicon detectors. The Chicagoland Observatory for Underground Particle Physics (COUPP) uses bubble chambers with several different target liquids, while the DarkSide collaboration uses a liquid argon time projection chamber. For all three of these experiments, future plans are contingent on the outcome of the G2 competition soon to be launched. Fermilab will support the winners of that competition, if necessary consolidating Fermilab scientist effort to join the experiments that are moving forward. Finally, we also support a small experiment, DAMIC, that uses DECAM silicon CCDs to search especially for low-mass WIMPs.

Cryogenic Dark Matter Search (CDMS II, SuperCDMS Soudan, SuperCDMS SNOLAB)

CDMS has a long history, and a promising future, in the search for WIMP dark matter. The hallmark of the experiment has always been, and continues to be, control of normal matter background interactions at the level that even a few WIMP interactions in the detectors would be recognized as direct detection of dark matter. The CDMS technique uses ultrapure solid-state germanium and silicon detectors, cooled to temperatures very near absolute zero. Particle interactions in the crystalline detectors deposit energy in the form of heat, and in the form of charges that move in an applied electric field. Special sensors detect these signals, which are then amplified and recorded in computers for later study. A comparison of the size and relative timing of these two signals, heat and charge, allow the experimenters to tell whether the particle that interacted in the crystal was a WIMP-- or one of the numerous known particles that come either from radioactive decays or from space in the form of cosmic rays. These background particles must be almost entirely filtered out in order to see a WIMP signal. Layers of shielding materials, and the rock above the underground laboratory that houses the experiment, are used to provide such background suppression.

Detector operation is assessed by frequent exposure to sources of two types of radiation: gamma rays and neutrons. Gamma rays are the principal source of normal matter background in the experiment. Neutrons are the only type of normal matter particles that interact with germanium nuclei in the billiard-ball style that WIMPs would, although neutrons frequently scatter in more than one of our detectors. This calibration data is carefully studied to see how well a WIMP-like signal (produced by neutrons) can be seen over a background (produced by gamma rays). In the standard CDMS analysis, which is the search for WIMPs of mass 10-1000 GeV (with maximal sensitivity around 100 GeV), the event selection is tailored so that no more than one background event would be expected to be visible in the region of the data where WIMPs should appear. The selection criteria are determined in an unbiased way, by looking only at the calibration and sideband data, not at the WIMP signal region itself. More recently, CDMS has explored several methods to explore the low-mass WIMP region, from 1-10 GeV, using techniques to achieve lower energy thresholds at the expense of poorer background discrimination.

CDMS II was the first direct detection experiment that Fermilab joined, in 1997, and the lab has managed the CDMS projects since that time. CDMS II was commissioned in 2002, and operated at the Soudan Underground Laboratory until 2008. The data is still being mined, especially to search for low-mass WIMPS. Meanwhile, SuperCDMS Soudan continues to use the apparatus at Soudan to produce ever-tighter constraints on the cross section for WIMP interactions with normal matter, for a wide range of WIMP masses. While continuing the search at Soudan, the collaboration is proposing a next generation (G2) experiment, SuperCDMS SNOLAB that will provide unprecedented sensitivity to WIMPs.

Progress Report

CDMS II – Reanalysis of data with a focus on light WIMP searches

In the final CDMS II germanium detector data set, taken in 2007-2008, we saw two events with characteristics consistent with those expected from WIMPs. However, it was estimated that there was about a one in four chance to have seen two backgrounds events, so no claim of WIMP discovery was made. Instead, upper limits on WIMP cross sections as a function of WIMP mass were derived and subsequently published in Science [http://arxiv.org/abs/0912.3592].

Since then, analysis of CDMS II data has diversified into a number of interesting follow-ups to the standard WIMP search. The list of efforts that have been active over the past three years includes:

- In 2011, CDMS II published a search for low mass WIMPs [http://arxiv.org/abs/1011.2482]. This was essentially an extension of the standard analysis, but with relaxed selection criteria due to worsening signal-to-noise in the relevant energy region. The result was world-leading at the time and provided much needed crosschecks of observations from several other experiments (e.g. CoGeNT, CRESST and DAMA).

- Following the low mass WIMP result was a search for the dark matter annual modulation. The motion of the Earth around the Sun produces a small variation in the relative Earth velocity with respect to the dark matter halo. This causes the rate of WIMP interaction in a terrestrial detector to vary over the course of a year. Although CDMS did not detect WIMPs in the standard signal region, one can still test for alternative types of dark matter interactions by looking for a modulation in the events that lie outside of this region. The analysis that is underway is in its final stages of completion, and has a preprint available on the arXiv [http://arxiv.org/abs/1203.1309].

- This year, we completed an analysis of the 2007-2008 CDMS II silicon detector data set [http://arxiv.org/abs/1304.4279]. This was done in a very similar manner to that done for germanium. This time, three WIMP candidate events were seen, with a known background estimated to be ~0.5 event. This ~ 3 sigma excess is not quite sufficient to claim evidence for WIMPs, and could still prove to be due to backgrounds that are misunderstood. However, if interpreted as a signal, it corresponds to a WIMP with mass about 8.6 GeV and cross section with nucleons of about 2E-41 cm2. This is in some tension with XENON 10 and XENON 100, although a recent interpretation of that result suggests the tension may not be as severe as indicated in Figure 1 [http://arxiv.org/abs/1306.1790].

- A full reanalysis of the whole germanium data set was undertaken starting in 2010. The full dataset was reprocessed to remove a problematic feature in the data reconstruction. Advanced discrimination algorithms were applied to the reanalysis of the data and the neutron backgrounds have been re-estimated with improved simulations. The analysis was completed last year and is presently being drafted for publication.

- Yet another nearly complete effort is the search for lightly ionizing particles (LIPs). These are hypothetical relativistic particles that are astrophysical in origin. It is assumed they interact only electromagnetically and have a fractional charge. This analysis is also near completion, with a paper draft in place and its anticipated the result will be made public and submitted for refereed publication within the next year.

Figure 1 shows the present-day state of the field at low WIMP masses. The 2010 standard analysis, 2013 silicon analysis and 2011 low mass search are all shown.

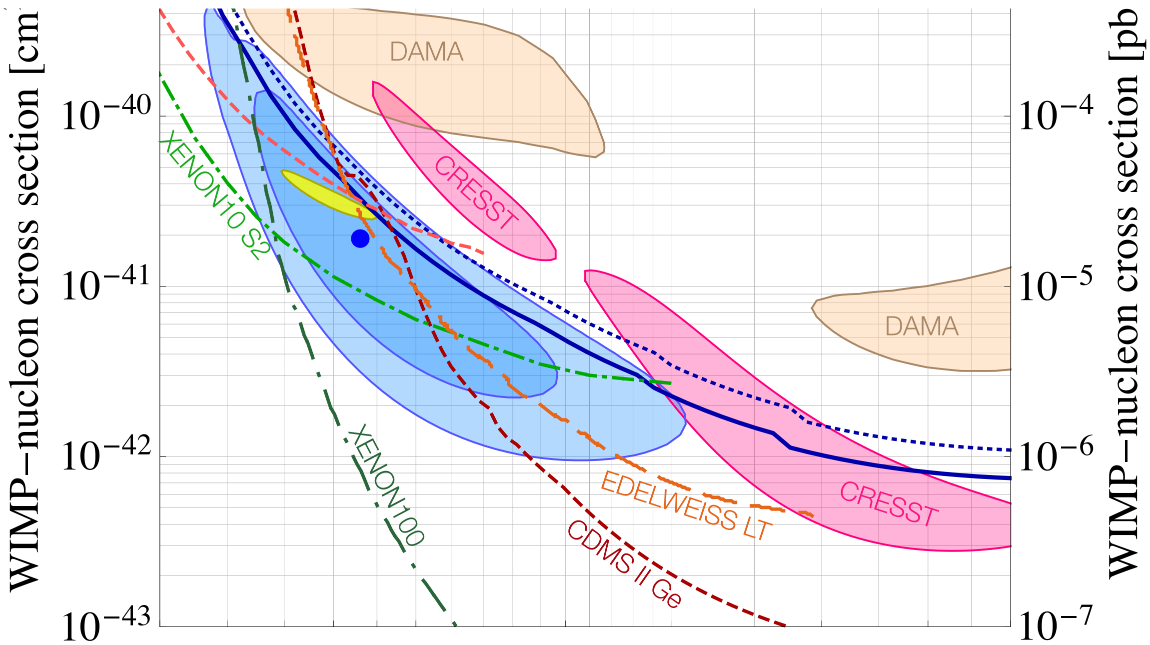

Figure 1 - Upper limits on the WIMP-nucleon spin-independent cross-section versus WIMP mass from the CDMS II silicon data set, along with recent results from other experiments. The blue closed contours indicate a possible interpretation of the three-event excess, compared with the 0.5 event background estimate, as a low-mass WIMP signal.

Fermilab roles in CDMS II

Fermilab physicists played key roles in CDMS II. Dan Bauer was the Project Manager for the joint DOE/NSF CDMS II project, and was also the Operations Manager for the experiment. Two Fermilab research associates, Jeter Hall and Lauren Hsu, were leaders in the CDMS II analysis. Jeter developed data monitoring tools and pioneered the search for low-mass WIMPS. Lauren set up a completely new framework for CDMS reconstruction and analysis. She also played a key role in systematic studies of algorithms for event selection. Lauren has since been promoted to Associate Scientist at Fermilab and Jeter has been hired as a staff scientist at PNNL. Both continue to work on SuperCDMS.

SuperCDMS Soudan – Operations and Analysis

CDMS II sensitivity to WIMPs was limited by surface events, making further running unproductive. SuperCDMS Soudan was proposed as a small project to develop an advanced sensor geometry (iZIP, for Interleaved Z-sensitive Ionization and Phonon detectors) and use it at Soudan to reject the surface event background and improve WIMP sensitivity. Figure 2 shows how the interleaving of ionization and phonon sensors creates an electric field geometry that ensures surface events are registered only on one side of the crystal, whereas events in the bulk of the crystal volume give signals on both sides. SuperCDMS Soudan is an experiment that reuses the experimental infrastructure from CDMS II, but replaces the CDMS II detector payload with 15 of these new iZIP germanium detectors, totaling 9 kg of target mass. The new detector payload was installed in Fall 2011 and commissioned by the end of February 2012. It has been operating continuously since then, at a base temperature of ~50 mK. This unprecedented performance of the cryogenic system at Soudan was obtained by a combination of careful maintenance and installation of an upgraded uninterruptible power system, coupled with an underground diesel generator. Another upgrade was the installation of a cryo-cooler system that captures and reliquefies boil-off helium and nitrogen gases. This has saved considerable money by reducing purchases of expensive liquid helium, as well as improving the experiment live time due to elimination of daily cryogen transfers. Figure 3 shows the accumulated exposure for low-background and calibration source data from the 1.5 years of SuperCDMS Soudan operation, demonstrating the stable performance of the experiment.

Two of the iZIP detectors in SuperCDMS Soudan have thin Si wafers installed near one face, with a low-level of ^{210}Pb radioactivity implanted from Radon gas exposure. This was done to produce a sufficient rate of surface events to measure the discrimination power of the iZIPs "in situ", without limiting the physics reach of these detectors.

We have also tried a new method of operation (CDMSlite) for one of the detectors used in SuperCDMS Soudan. CDMSlite is designed to give a very low energy threshold and thus improved sensitivity to very low mass WIMPs. In this mode, the detector has a much larger charge bias applied across the crystal (69 V) than in normal operation (4V). This boosts the phonon signal considerably due to the phonons released by the drifting electrons and holes, without a significant increase in phonon noise. This has the effect of stretching out the low energy spectrum and gives a measured energy threshold of 170 eVee. However, since the ionization signal is no longer collected, the detector cannot be used to discriminate against electromagnetic backgrounds. Thus, the CDMSlite sensitivity to low-mass WIMPS will be determined by the residual backgrounds on, and nearby, the detector surfaces. Figure 4 shows the energy spectrum obtained thus far from CDMSlite, with sharp germanium activation peaks seen at 1.3 and 10.3 keV. The spectrum below the 1.3 keV activation peak will be used to search for low-mass (~2-10 GeV) WIMP signals.

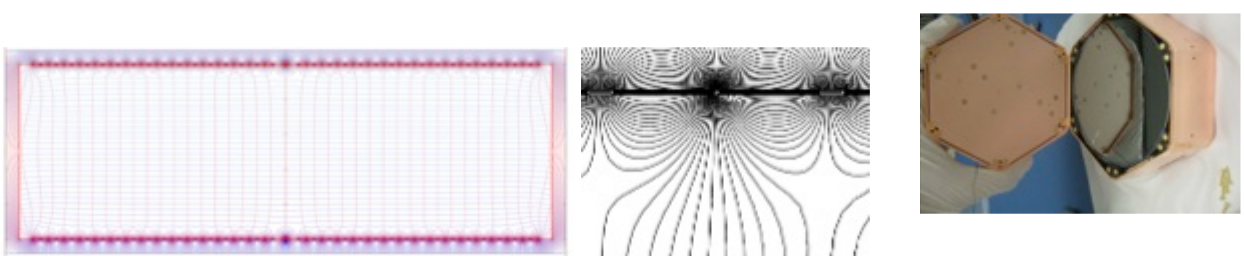

Figure 2 – Interleaved ionization and phonon sensor geometry for the SuperCDMS Soudan iZIP detectors, a schematic of the electric field near the surface and a photograph of one of the detectors.

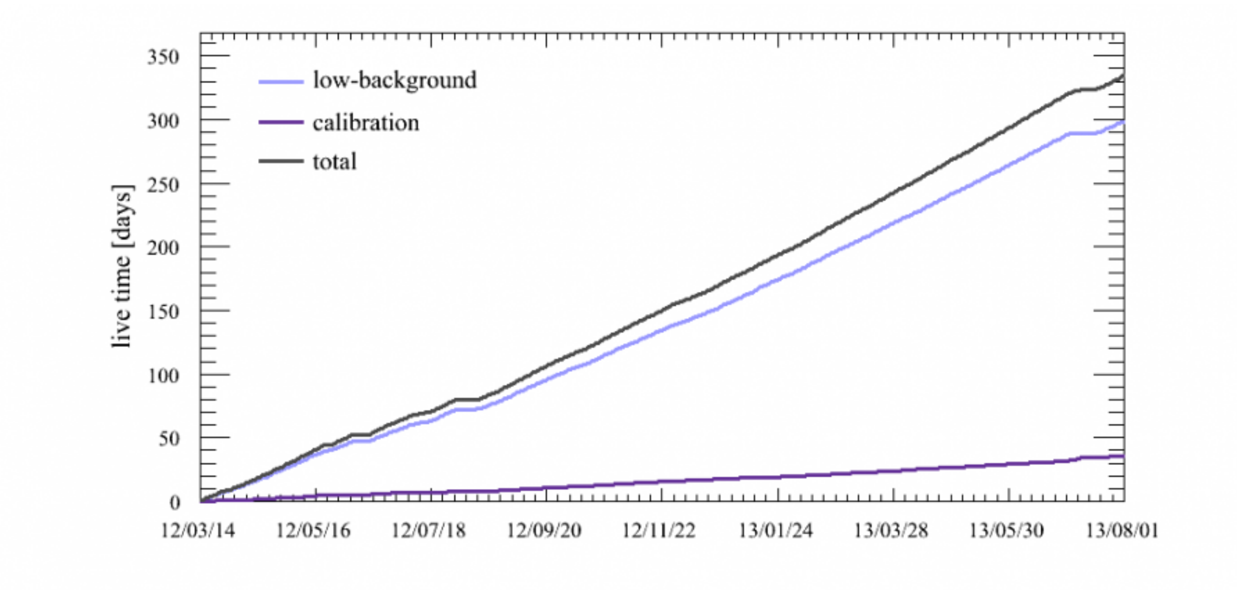

Figure 3 – Live-time for the SuperCDMS Soudan experiment as a function of calendar time, showing the low-background and calibration data integrated over the duration of the experiment.

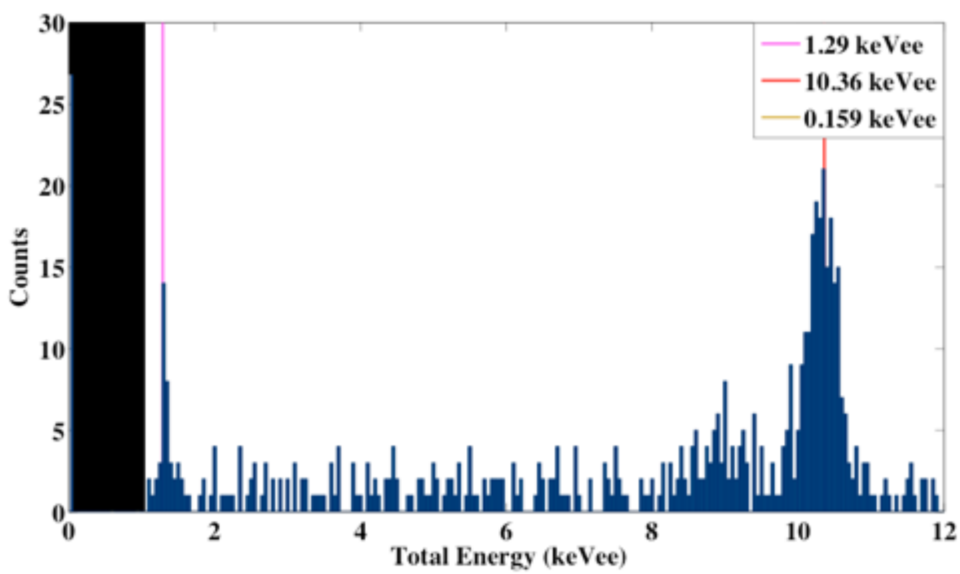

Figure 4 – CDMSlite concept and initial energy spectrum (region below 1 keV is blacked out for ongoing analysis).

Analysis of SuperCDMS data began in 2012. The initial efforts were targeted at determining the surface event discrimination of the new iZIP detectors using the two detectors deployed with ^{210}Pb sources. To date, the analysis has demonstrated a rejection factor of better than 1 in 60,000 at 90% C.L. and is data limited (Fig. 5). This initial technical demonstration has been described in a paper that is available on the arXiv [http://arxiv.org/abs/1305.2405], and is currently under review for publication.

Additionally, the first analysis of iZIP data for WIMPs has also begun. The ongoing analysis work includes the standard high-mass WIMP search with the new iZIP array, a low threshold iZIP search with a 2 keV threshold and an ultra-low threshold search for WIMPs using the CDMSlite configuration described above. The CDMSlite analysis is the closest to completion and its anticipated that the result will be made public in September. Much of the work for the low threshold and standard analyses so far has been towards optimizing the data reconstruction of the new iZIPs. This work is now complete. The ~300 live days of data taken in 2012 and 2013 have been reprocessed with advance reconstruction algorithms and is now being analyzed by a team of students and postdocs.

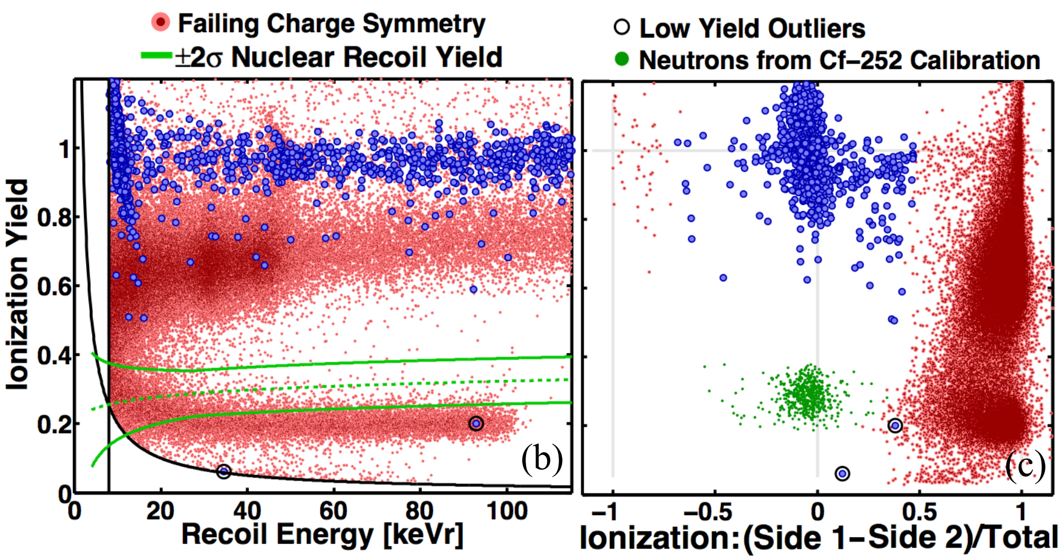

Figure 5 – a) Ionization yield versus recoil energy for an iZIP detector, showing bulk (blue) and surface (red) events, with the nuclear recoil region outlined in green; b) Ionization yield versus ionization partition between the two surfaces of the iZIP, showing bulk electron recoils (blue), surface events (red) and nuclear recoils (green) from a neutron source.

Fermilab roles in SuperCDMS Soudan

Fermilab leads both operations and analysis for SuperCDMS Soudan. Dan Bauer was the Project Manager for fabrication of the experiment and is the Operations Manager. This involves oversight of all technical aspects of the experiment, as well as operations scheduling and financial management. He is also the lead scientist on all cryogenics aspects of the Soudan experiment, working with Fermilab engineers and technicians. Lauren Hsu is the current analysis coordinator for SuperCDMS Soudan, which also includes oversight of the ongoing CDMS II analyses described in the previous section. Ben Loer is a key player in the data quality and analysis teams for the experiment. Don Holmgren authored part of the data acquisition software and set up the computing facility for SuperCDMS Soudan. Ritoban Basu Thakur is a graduate student from the University of Illinois, Urbana, who is resident at Fermilab doing his PhD research on SuperCDMS Soudan, focusing especially on CDMSlite.

SuperCDMS SNOLAB– R&D towards the next generation (G2)

Cryogenics and Mechanical Design

Considerable design work has already been done on the design of the integrated cryogenics and shielding systems. While conceptually similar to the design used for the Soudan experiments, the new facility will employ a cryogen-free dilution refrigerator and make expanded use of cryocoolers to cool the larger detector payload to <50 mK. The layered shielding will employ low-background copper around the detectors, with layers of polyethylene and lead to reduce the flux of neutrons and gamma rays from external radioactivity. Figure 6 shows the current conceptual design.

One of the main reasons to mount this experiment at SNOLAB is that the extreme depth (6800’) reduces the cosmic ray muon flux to negligible levels, so an active muon veto will probably not be needed. However, a neutron background from residual radioactivity within the shielding materials could pose a problem. We are exploring the need, and possible designs, for an active neutron veto as part of the shielding.

Passive and Active Shielding

The basic design of the shielding for the SNOLAB phase of the experiment is derived from the current design employed at Soudan: layers of high density polyethylene (HDPE) surround the copper cans that comprise the detector cryostat to attenuate the ambient flux of neutron and gamma radiation, respectively. Initial estimates of background rates were determined using a straw man design consisting of 0.5” thick copper cans, surrounded by 10 cm of HDPE, 18 cm of lead, and a further 60 cm of HDPE or 100 cm of water. A robust and flexible simulation toolkit based on the GEANT4 Monte Carlo framework was developed, primarily by collaborators at SLAC, in order to quickly simulate background contributions from a variety of sources in different geometries.

Our initial simulations for the straw man passive shielding design, assuming a level of screening comparable to other current dark matter experiments (primarily XENON100 and DEAP), estimated a total rate of around 2 irreducible background counts per ton of germanium per year of exposure, or approximately 0.9 total background events given an assumed 385 kg-yr exposure after all cuts. To achieve the goal of a background-free experiment, the background rate will need to be further reduced by roughly an order of magnitude. One approach to this is to impose tighter restrictions on the levels of radioactive contaminants in detector materials. Measurements from other experiments such as EXO and Majorana indicate that obtaining materials of the required cleanliness is indeed possible; however, the additional cost and time commitment would be considerable.

Another option that we are currently exploring is to replace the HDPE layer directly surrounding the cryostat with an active veto designed to detect radiogenic neutrons, which are responsible for the vast majority of irreducible background events. Our current baseline design assumes a 40 cm thick layer of organic liquid scintillator, most likely linear alkyl benzene (LAB) doped with an element with high neutron capture affinity like boron or gadolinium, contained in modular acrylic tanks. The scintillation light would be concentrated using an array of wavelength-shifting fibers and read out via silicon photomultipliers (SiPMs), which will provide a more compact and lower-background readout option than traditional photomultiplier tubes. Figure 7 shows the simulated neutron detection efficiency for this design as a function of energy threshold (accounting for Birks quenching of heavily-ionizing interactions) for LAB doped with different neutron capture agent concentrations. A separate optical simulation of the fiber+SiPM array estimates a light yield of approximately 0.1-0.2 photoelectrons per keV of energy deposited in the scintillator, indicating that obtaining a threshold low enough to achieve greater than 90% veto efficiency should be possible.

Electronics, Data Acquisition and Triggering
We have nearly completed the design of a new electronics card to replace the CDMS II 9U electronics chain. While originally designed for CDMS test facilities, this new card will also be employed for SuperCDMS SNOLAB. Data acquisition and triggering software being written for test facility use will form the core of the experimental system.

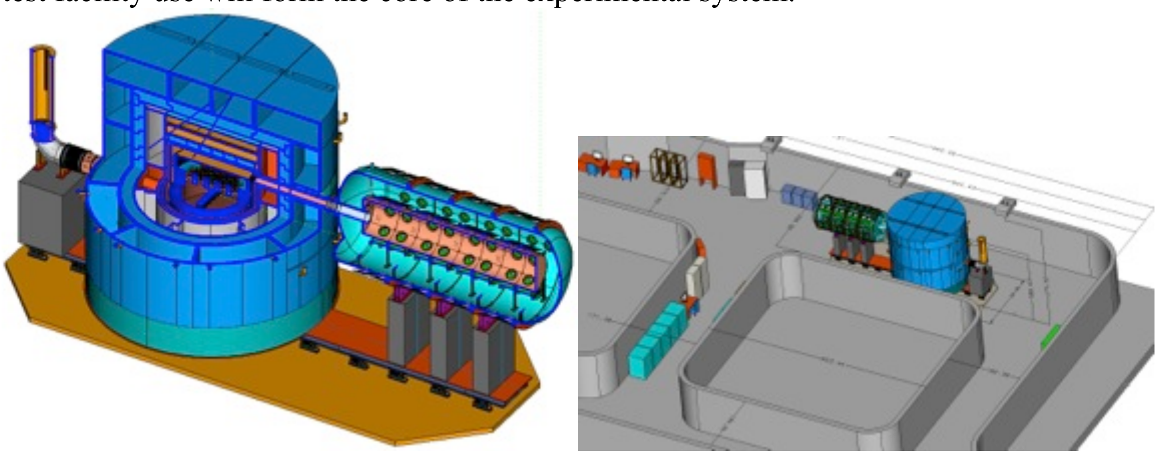

Figure 6 - Cross section of the current cryogenics and shielding design for SuperCDMS SNOLAB, and the proposed layout of the experiment in the ladder lab section of SNOLAB.

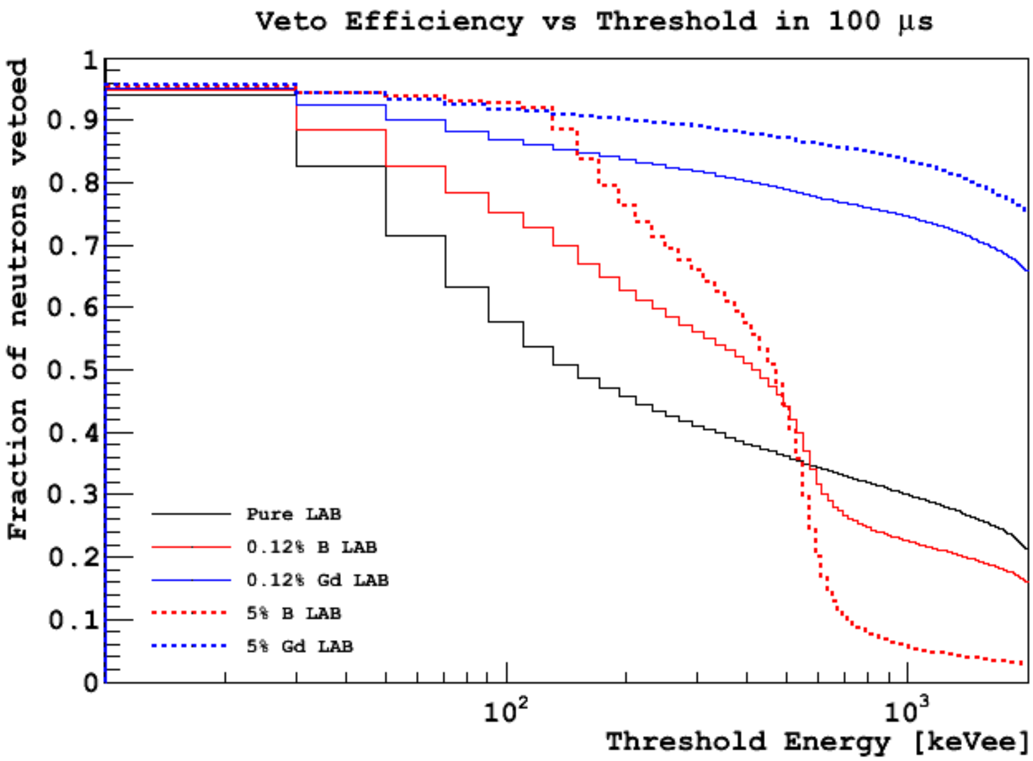

Figure 7 – Simulated neutron veto efficiency for otherwise irreducible background events as a function of electron-equivalent energy threshold, for a linear alkylbenzene-based liquid scintillator with different levels of gadolinium or boron doping fractions.

Fermilab roles in SuperCDMS SNOLAB R&D
Dan Bauer is the leader of the SuperCDMS SNOLAB R&D team. Ben Loer is a working group leader for backgrounds and neutron veto. While he was still at Fermilab, Jeter Hall was the working group leader responsible for warm electronics and data acquisition.

<u>Proposed Research</u>

CDMS II – Final light WIMP search analysis

During the next year, we expect to finish the CDMS II annual modulation search paper, as well as those on Lightly Ionizing Particles and the full reanalysis of the CDMS II germanium data.

Two additional and relatively new efforts have also begun and will continue over the next year. This includes a longer paper describing the 2007-2008 Si analysis, with some additional checks that were not completed at the time of the first publication. Additionally some exploratory analysis of the low threshold dataset is taking place to determine whether certain backgrounds can be subtracted from the signal region (via a likelihood analysis) to increase the sensitivity of the data. If demonstrated to be successful, this will result in an additional publication.

Fermilab roles in CDMS II analysis
Currently, Lauren Hsu is the analysis coordinator. It is anticipated that she will rotate out of this role in the next year. However, she expects to remain active in these CDMS II analysis efforts until they are completed.

SuperCDMS Soudan – Operations and Analysis

The current plan is to operate SuperCDMS Soudan for 1-2 more years, focusing mainly on low-mass WIMP searches. Assuming SuperCDMS SNOLAB is chosen as a G2 project, it is likely that we will cease operation of SuperCDMS Soudan to concentrate effort on fabrication of the new project. However, we expect the Soudan apparatus to be very useful as a testing ground for SuperCDMS SNOLAB detectors and electronics.

The three ongoing analyses described above (standard high-mass WIMP search, low threshold WIMP search and CDMSlite) are anticipated to yield results in the next year. Figure 8 shows projections of the sensitivity expected for the low threshold WIMP searches with SuperCDMS Soudan. The standard analysis is expected to yield sensitivities that are ~4 times better than that of CDMS II. An annual modulation analysis of SuperCDMS Soudan data will also likely be done with the full dataset.

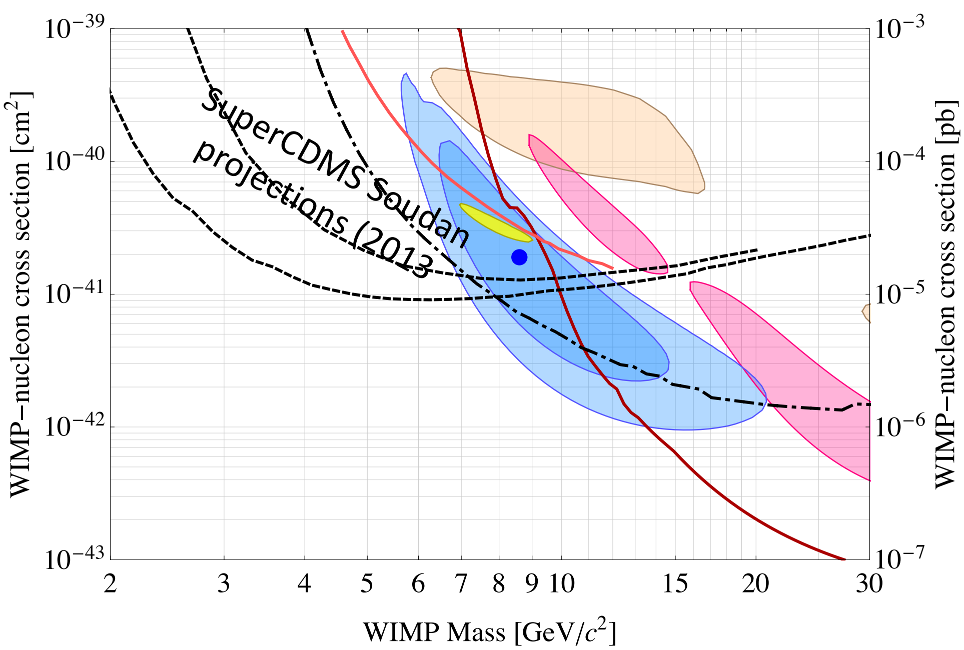

Figure 8 – Projections of sensitivity for SuperCDMS Soudan (dashed and dot-dashed curves), compared with upper limits from CDMS II Ge (red), and interpretations of various data as WIMP signals. Shown are contours from CDMS II Si (blue), CoGeNT (yellow), CRESST (pink) and DAMA (tan).

Fermilab roles in SuperCDMS Soudan
Dan Bauer will continue as Operations Manager for SuperCDMS Soudan. Lauren Hsu and Ben Loer will also continue their roles in data quality monitoring, data processing and physics analysis, and Don Holmgren will continue to support the Soudan data acquisition and computing facility.

SuperCDMS SNOLAB - R&D and G2 Project

We have proposed SuperCDMS SNOLAB as a next generation (G2) dark matter direct detection experiment that would deploy 200 kg of advanced iZIP detectors in a new experimental apparatus at SNOLAB in the Creighton Mine, in Sudbury, Ontario, Canada. SuperCDMS SNOLAB would improve the present sensitivity for dark matter WIMPs by more than two orders of magnitude, and would have extraordinary sensitivity to low-mass WIMPs. The report to HEPAP from the Particle Astrophysics Scientific Assessment Group (PASAG) has recognized the importance of this project in the field and recommended that it proceed under all funding scenarios considered. The recent Snowmass community summer study highlighted the need for a suite of complementary direct detection experiments to give maximal information about any WIMP signals that are found.

Figure 9 shows our current projections for the sensitivity of SuperCDMS SNOLAB, compared with present limits and projections from other dark matter experiments. Note especially the outstanding performance expected from SuperCDMS SNOLAB for low-mass WIMPs. For higher-mass WIMPS, we expect to be competitive despite the smaller exposure, based on the fact that only CDMS technology has been demonstrated to achieve background-free performance.

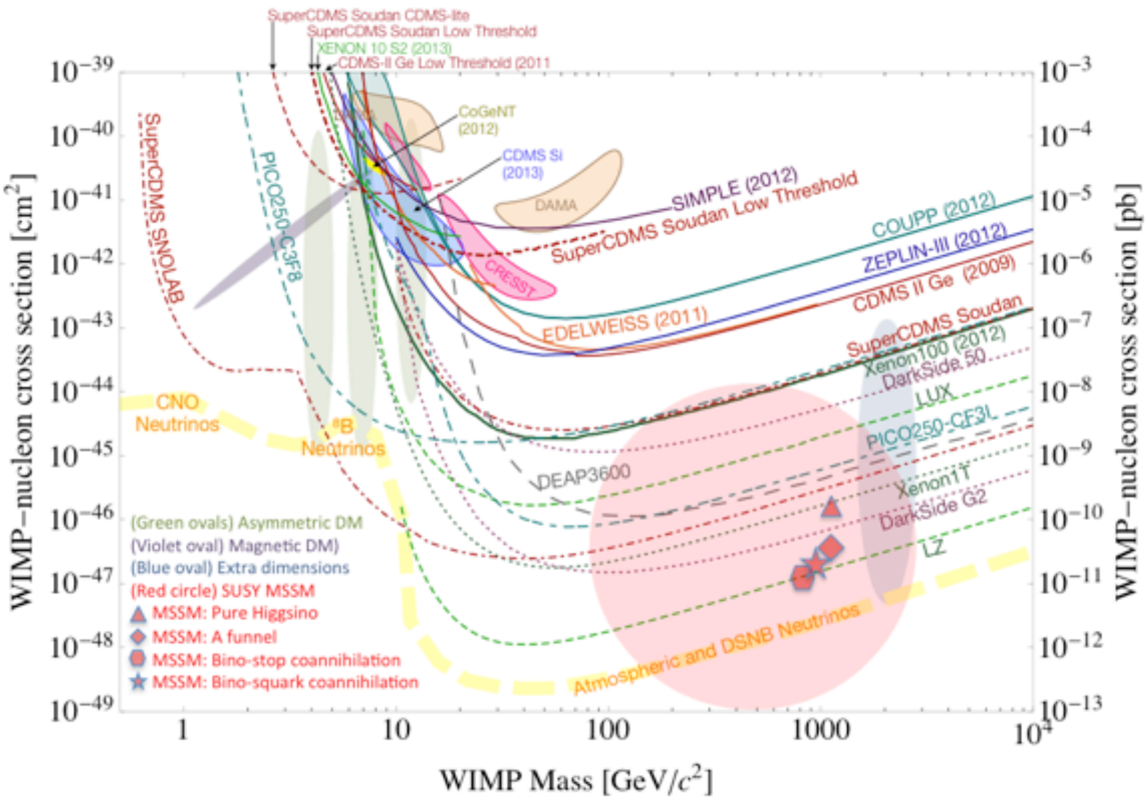

Figure 9 – Projections of sensitivity for SuperCDMS SNOLAB, compared with current upper limits and projections from other US-led experiments.

Cryogenics and Mechanical Design of the Shielding

R&D for the SuperCDMS SNOLAB cryogenics and shielding design is concentrated on three main goals:

1. Achieving the lowest possible base temperature for up to 400 kg of germanium detector payload (the minimum specification is <40 mK). This requires careful design, and measurement, of thermal conductances of all materials, especially thermal joints. A dilution refrigerator with sufficient cooling power must be identified, in consultation with commercial vendors, and the coupling of the refrigerator to the system must be completely specified. The vacuum system requires special attention, to minimize heat loads from the outside world.
2. Reasonable cool down times from room temperature, with manageable stress on the mechanical components. This will require a combination of cryocoolers and liquid cryogen circulation loops at several different thermal levels.
3. A mechanical design of the cryogenics and shielding system that allows access to the detector volume in a reasonable period of time. It must be designed with radiopure

materials and be kept clean during operations. Radioactive source calibration must be designed into the system. Finally, the system must be designed with ease of installation in mind, and this must be verified in a full system test before locating the experiment underground at SNOLAB.

We expect to have a full conceptual mechanical and thermal design by the time of the G2 proposal, currently anticipated December 2012.

Passive and Active Shielding
R&D efforts toward background reduction are divided between simulations and prototyping efforts. GEANT4-based particle propagation simulations are used to estimate the total background rate for different geometries in order refine the shielding design to minimize cost and background rates. Simulations are also used to define specifications for the maximum allowed level of radioactive contaminants for each component of the detector, which are necessary to guide the purchasing and necessary screening levels. Finally, we continue to refine our codes for simulating optical photon propagation in order to more precisely estimate the light yield, and therefore threshold sensitivity, of various active neutron veto designs.

Several prototyping and measurement efforts will take place in the near future. The overall efficiency of an active neutron veto will depend strongly on identifying an acceptable scintillator that is stable over time with high light output. Therefore we are measuring the light output of several different scintillator compounds, custom and commercial, liquid and plastic, with a variety of gadolinium and boron loading methods. We will also study different silicon photomultipliers to determine the best way to bias and read them out. Finally, all of these measurements will be used as “training” datasets to test and refine our optical simulations. Once a suitable scintillator and readout scheme is identified, we plan to produce a full-scale prototype veto module in early 2014.

Electronics, Data Acquisition and Triggering
Design and development of the SNOLAB data acquisition software and electronics will continue through upcoming years as specifications emerge and feedback is received from systems deployed at CDMS test facilities. Fermilab engineers are leading the design of the electronics and firmware of the custom detector readout boards, and expect to produce the first boards capable of reading out all the channels of a SNOLAB iZIP on a single board by fall of 2013. Data acquisition development will focus on optimizing readout and data transfer speed, and designing intelligent triggering and filtering algorithms capable of dealing with the large increase in data rate at SNOLAB. We also continue to develop and refine tools for rapid data quality feedback in order to maximize the fraction of good data collected.

Fermilab roles in SuperCDMS SNOLAB
Fermilab responsibilities for SuperCDMS SNOLAB include project management, cryogenics, active and passive shielding. Fermilab scientists will also participate in other experimental infrastructure at SNOLAB, data acquisition, backgrounds screening and offline software.

SuperCDMS SNOLAB project

Figure 10 shows the expected timeline for the SuperCDMS SNOLAB project, and how it follows on from the experience gained with CDMS II and SuperCDMS Soudan. Assuming the agencies select the project at the end of this calendar year, we expect a rapid progression through the DOE critical design (CD) process, with fabrication beginning in late 2014 and continuing for 2 years. There will be a full “systems test” of the cryogenics and mechanical structures at the surface, before installing the experiment underground at SNOLAB. Operations would commence in 2017 and continue for 4 years.

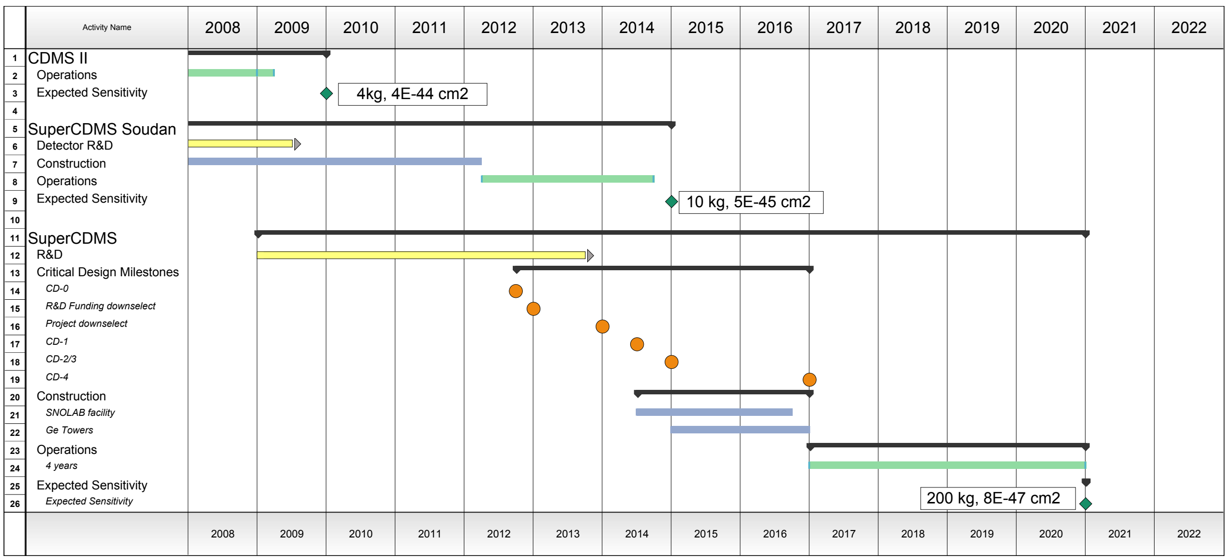

Figure 10 CDMS projects and cross section sensitivity for 100 GeV WIMPs, by calendar year

Publications and Presentations

Publications:

1. Observation of the Dependence of Scintillation from Nuclear Recoils in Liquid Argon on Drift Field, SCENE Collaboration (T. Alexander (Massachusetts U., Amherst & Fermilab) et al.). Jun 24, 2013. FERMILAB-PUB-13-226-E and arXiv:1306.5675 [physics.ins-det]
2. Demonstration of Surface Electron Rejection with Interleaved Germanium Detectors for Dark Matter Search, SuperCDMS collaboration (R. Agnese, et al.). May 10, 2013, 5 pp. arXiv:1305.2405 [physics.ins-det].
3. Dark Matter in the Coming Decade: Complementary Paths to Discovery and Beyond
Daniel Bauer (Fermilab) et al. May 7, 2013. arXiv:1305.1605 [hep-ph]. Submitted to the journal "Physics of the Dark Universe". 3 citations
4. Dark Matter Search Results Using the Silicon Detectors of CDMS II, CDMS Collaboration (R. Agnese (Florida U.) et al.). Apr 15, 2013. 5 pp. FERMILAB-PUB-13-104-AE-E and arXiv:1304.4279 [hep-ex]. Submitted to: Phys.Rev.Lett. 87 citations.
5. Silicon Detector Results from the First Five-Tower Run of CDMS II, CDMS Collaboration (R. Agnese (Florida U.) et al.). Apr 12, 2013. 5 pp. FERMILAB-PUB-13-105-AE-E and arXiv:1304.3706 [astro-ph.CO]. Submitted to: Phys.Rev.D. 13 citations
6. Search for annual modulation in low-energy CDMS-II data, CDMS Collaboration (Z. Ahmed (Caltech) et al.). Mar 2012. 5 pp. FERMILAB-PUB-12-102-AE and arXiv:1203.1309 [astro-ph.CO]. 39 citations.
7. The CDMS II data acquisition system, CDMS-II Collaboration (D.A. Bauer (Fermilab) et al.). 2011. 7 pp. FERMILAB-PUB-11-302-AE. Published in Nucl.Inst.Meth. A638 (2011) 127-133.

8. Combined Limits on WIMPs from the CDMS and EDELWEISS Experiments, CDMS and EDELWEISS Collaborations (Z. Ahmed (Caltech) et al.). May 2011. SLAC-PUB-15044, FERMILAB-PUB-11-342-AE and arXiv:1105.3377 [astro-ph.CO]. Published in Phys.Rev. D84 (2011) 011102. 51 citations
9. Search for inelastic dark matter with the CDMS II experiment, CDMS-II and CDMS Collaborations (Z. Ahmed (Caltech) et al.). Dec 2010. 9 pp. SLAC-PUB-15055, FERMILAB-PUB-11-303-AE and arXiv:1012.5078 [astro-ph.CO]. Published in Phys.Rev. D83 (2011) 112002. 18 citations
10. Results from a Low-Energy Analysis of the CDMS II Germanium Data, CDMS-II Collaboration (Z. Ahmed (Caltech) et al.). Nov 2010. 5 pp. SLAC-PUB-15054, FERMILAB-PUB-10-456-AE-CD-E and arXiv:1011.2482 [astro-ph.CO]. Published in Phys.Rev.Lett. 106 (2011) 131302. 262 citations.
11. A low-threshold analysis of CDMS shallow-site data, CDMS Collaboration (D.S. Akerib (Case Western Reserve U.) et al.). Oct 2010. 18 pp. SLAC-PUB-15053, FERMILAB-PUB-10-455-AE and arXiv:1010.4290 [astro-ph.CO]. Published in Phys.Rev. D82 (2010) 122004. 87 citations.
12. Dark Matter Search Results from the CDMS II Experiment, CDMS-II Collaboration (Z. Ahmed (Caltech) et al.). Dec 2009. 6 pp. FERMILAB-PUB-09-637-AE
DOI: 10.1126/science.1186112 and arXiv:0912.3592 [astro-ph.CO]. Published in Science 327 (2010) 1619-1621. 603 citations.

Presentations:

Dan Bauer
June 2013, Seminar on Dark Matter Direct Detection at Queen's University, Canada
February 2013, Invited plenary talk on Dark Matter Direct Detection at the Lake Louise Winter Institute
February 2010, Seminar on recent CDMS results at the University of Illinois, Urbana

Lauren Hsu
Aug 2013, Aspen Summer Workshop (Dark matter in galaxies, the LHC and direct and indirect searches), Aspen, Colorado - Recent results and future plans for SuperCDMS
May 2013, University of Chicago Physics Department Colloquium, Chicago IL - Si Results from CDMS
May 2013, plenary talk at IceCube Particle Astrophysics, Madison, WI - Overview of Low Mass WIMP Searches
October 2012, Fermilab Colloquium, Batavia, IL - Direct Detection of Dark Matter
July 2012, plenary talk at ICHEP, Melbourne - Direct Detection of Dark Matter
July 2012, parallel talk at ICHEP, Melbourne - Status and Prospects of SuperCDMS
February 2012, astrophysics seminar, Fermilab, Batavia, IL - Status and Prospects of SuperCDMS
Sept. 2011, Shanghai Jiao Tong University, Shanghai - Status and Prospects of SuperCDMS
Sept. 2011, Dark Side of the Universe, Beijing - Status and Prospects of SuperCDMS
May 2011, Pheno, Madison, WI - Low Threshold Results from CDMS II
March 2011, Purdue University Seminar, Lafayette, IN - Status and Prospects of CDMS
March 2011, University of Wisconsin Seminar, Madison, WI - Status and Prospects of CDMS
Feb 2011, University of Michigan Seminar, Ann Arbor, MI - Status and Prospects of CDMS
Jan 2011, Rochester University, Rochester, NY - Status and Prospects of CDMS

Ben Loer
September 2013, "Recent Results and Prospects from CDMS." Weak Interactions and Neutrinos 2013
June 2013,"Dark Matter Search Results Using the Silicon Detectors of CDMS II." University of Chicago Dark Matter HUB seminar
May 2013, "Dark Matter Search Results Using the Silicon Detectors of CDMS II." Argonne National Laboratory HEP Division Seminar
April 2013, "Dark Matter Search Results Using the Silicon Detectors of CDMS II." University of Illinois Medium and High Energy Physics Seminar
July 2012 "The DarkSide WIMP Search Program." 8th Patras Conference on Axions, WIMPs, and WISPs
June 2012, "CDMS and Direct Dark Matter Searches at FNAL." 45th Annual Fermilab Users Meeting

Chicago Observatory for Underground Particle Physics (COUPP/PICO)

COUPP employs bubble chambers to look for WIMP dark matter. This technique has the best available sensitivity to WIMPs interacting by spin-couplings to protons and allows for multiple, exchangeable target liquids. The technology offers perhaps the most economical approach to the study of WIMPs with ton scale or larger target masses and benefits from signals and backgrounds that are very different than those seen in other types of detectors. Rejection against electron recoils from environmental gamma rays is achieved in bubble chambers by tuning the thermodynamic conditions for bubble nucleation. Nuclear recoils can be discriminated from alpha decays in the target liquid by inspection of the acoustic signal produced by the bubbles, which show excess power at high frequencies for alpha events. Nuclear recoils produced by WIMPs can be distinguished from those produced by neutrons on a statistical basis by the absence of multiple site interactions that are characteristic of neutron scattering.

COUPP has traditionally employed CF_3I as the superheated target, exploiting its optimal sensitivity to both spin-dependent and –independent couplings. The most recent published results offer the best sensitivity to spin-dependent WIMP-proton couplings, and lag behind CDMS in spin-independent sensitivity by a factor of a few. COUPP has started to work with C_3F_8 as well, using small test chambers. This alternative compound offers a better sensitivity to low-mass WIMPs, as well as to spin-dependent couplings. Preliminary experimentation with it indicates that at 3 keVnr, the gamma rejection power is 10^{-10}. This low threshold is suitable for the construction of an experiment to search for the ~ 8 GeV WIMP candidate hinted at by recent results [C.E. Aalseth et al. (The COGENT Collaboration, Phys. Rev D 88 (2013) 012002; R. Agnese et al. (The CDMS Collaboration), arXiv:1304.4279; D. Hooper, ArXiv 1201.1303]

In 2013, COUPP announced an intention to merge its future activities with those of the PICASSO collaboration, a competing effort focused on development of superheated droplet detectors. The combination of the two previous collaborations will be called PICO. The PICO collaboration is approximately sixty people strong, with a large contingent of students and postdocs coming from Canadian PICASSO institutions. The PICASSO groups have pioneered the use of acoustic background rejection methods, which are now most effectively exploited by COUPP; an important motivator of this merger of the collaborations is the realization that the homogeneous fluid volumes of COUPP bubble chambers are more suitable for the application of this technique than the droplet-loaded gels used by PICASSO.

Progress Report

(1) COUPP-60 Installation and Commissioning at SNOLAB.

Work towards the SNOLAB deployment of COUPP-60 began in late 2011, with engineering studies of safety issues related to handling CF_3I gas in an underground mine. The installation of the detector underground was a shared responsibility of Fermilab and SNOLAB, with SNOLAB providing significant material and labor, including the external water shielding tank. Fermilab provided the detector itself, the control system, filling system and the muon veto. Safety related installations, including a multi-tier system of emergency gas alarms and supplemental ventilation were a joint responsibility of Fermilab and SNOLAB. In 2012, the detector was removed from the Fermilab NuMI testing site, disassembled, cleaned and a number of improvements were made, including updates to the instrumentation and control system to increase remote monitoring capabilities, a redesign of the optical and illumination system and new low-radioactivity outer pressure vessel. Parts were shipped to SNOLAB beginning in summer 2012, as SNOLAB staff began construction of the water tank. Visiting teams of Fermilab scientists and technicians rebuilt the detector inside the shielding tank over the summer and fall of 2013. A photo of the installation is shown in Figure 1a. An important near-to-last step was the installation of a new generation of low-radioactivity acoustic sensors by the Indiana University group. The detector was filled with 37 kg of CF_3I target liquid in April and the first physics events were recorded in May (Figure 1b) during exposure to a radioactive neutron calibration source.

After a month of testing and calibrations, a dark matter search was begun June 20. 2013, with the detector running at 34 degrees C and 30 psia, corresponding to a 15 keV nuclear recoil threshold. The chamber operated with high live time fraction from the first days of the run, due to a low rate of alpha-induced background events and consequently minimal live time penalty from pressure cycling. An exposure of more than 1000 kg-days has been accumulated to date, already meeting the exposure goal for the first physics run. Initial information on backgrounds and physics sensitivity is planned for release by the end of 2013. The detector is currently being operated by a small group of Fermilab and SNOLAB scientists and postdocs, with almost all operations performed by remote control. Fermilab presence at SNOLAB is at the level of about 0.5 FTE, with an additional 2-3 FTEs devoted to data analysis.

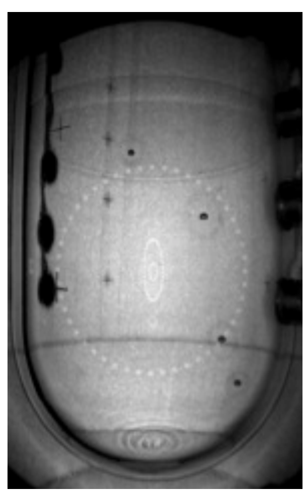

Figure 1a: Installation of COUPP-60 Inner Vessel Underground at SNOLAB and 1b: A neutron calibration event. This four-bubble event was recorded in June during a neutron source exposure. The bubbles are due to multiple elastic scattering of a single neutron.

(2) COUPP-4 Runs at SNOLAB. The COUPP-4kg detector ran at SNOLAB in 2010-2012, producing world-leading limits on spin-dependent WIMP-nucleon interactions.

The detector was installed at SNOLAB in 2010 after runs in Fermilab's shallow NuMI tunnel achieved background levels that were limited by the residual cosmic ray intensity. This detector demonstrated a new acoustic method for rejecting background events from alpha particles (Figure 2). The COUPP-4 detector served as an R&D platform and, as such, demonstrated many new technical features that have been incorporated into COUPP-60 and the designs for future chambers including COUPP-500/PICO-250L. Results from the first SNOLAB run were published in [E. Behnke et al., Phys.Rev. D **86**, 052001 (2012)].

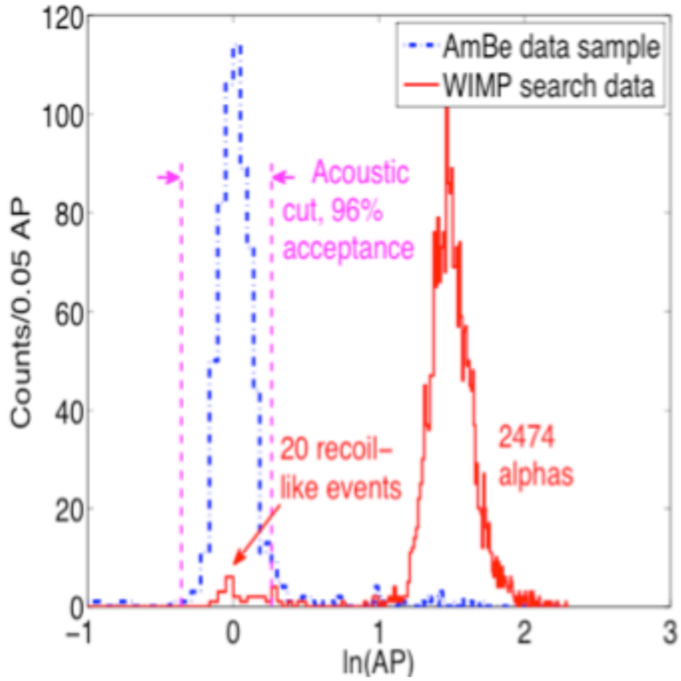

Figure 2: Acoustic discrimination between nuclear recoils and alpha particle backgrounds. The Acoustic Parameter (AP) is a measure of the loudness of the acoustic "plink" resulting from a bubble nucleation. Data from a 553 kg-day WIMP search is shown as a distribution in ln(AP) in red. 20 single nuclear recoil events candidates and 2474 alpha events were observed. The blue histogram shows the identical analysis for data taken in the presence of an AmBe neutron source. We define an acoustic cut of $0.7 < AP < 1.3$ to select nuclear recoils with an acceptance of 95.8% as determined by the AmBe calibration.

(3) Calibration measurements using Fermilab pion test beam

An important part of Fermilab R&D in the last three years was the development of a new calibration method utilizing elastic scattering of pions on a small detector [3]. Calibration of the nuclear recoil response in a bubble chamber is challenging, due to the lack of event-by-event energy information. Bubble chambers are threshold detectors, in which a bubble is nucleated when more than a critical amount of energy is deposited in a small enough volume of liquid. The nucleation efficiency as a function of recoil energy is not easy to measure, since one does not usually have a way to know the recoil energy associated with any individual bubble. Our new method overcomes this problem by tracking pions with a silicon pixel device, precisely measuring the angular deflection of each pion as it scatters on the target. By simultaneously measuring momentum transfer and bubble nucleation, the nucleation efficiency as a function of recoil energy can be mapped without the previously existing ambiguities. In the threshold region, the detector response to pions comes dominantly from the iodine fraction of CF_3I. This is particularly helpful, since sensitivity to WIMPs interacting by spin-independent couplings comes also from iodine. Our initial results (Figure 3) have recently been published [E. Behnke et al. (The COUPP Collaboration), Phys. Rev. D88 (2013) 021101].

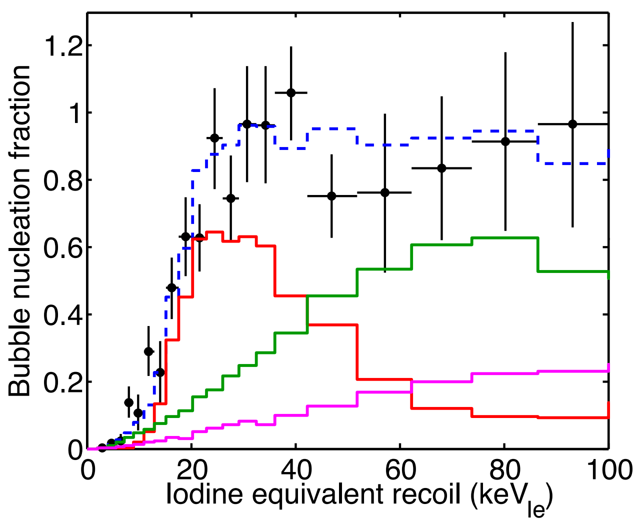

Figure 3: Results from pion elastic scattering calibration experiment in a small CF_3I bubble chamber. Black points with error bars show the fraction of scattering events resulting in bubble nucleation. Colored lines show modeled contributions of iodine (red) carbon (purple) and fluorine (green) nuclear recoils to the fitted detector response (blue). The detector operating condition was 34 degrees C and 30 psia, typical of COUPP-4 and COUPP-60 operation

(4) R&D with Small Test Chambers.

Fermilab has designed and manufactured several small test chambers, which are used across the collaboration for R&D purposes. The 100-ml COUPP-0.1 chamber has been used in the last two years at University of Chicago and Northwestern University for calibration measurements with gamma and neutron sources and is currently being installed in a neutron beam line at University of Montreal for further calibration of the low energy recoil response of C_3F_8. Operation of this chamber at Fermilab in 2012 demonstrated that C_3F_8 could be run at very low thresholds with high gamma rejection power (10^{-10} at 3 keV nuclear recoil energy). The CIRTE chamber (COUPP Iodine Recoil Threshold Response Experiment, 10 ml volume) was used for the pion beam calibrations of CF_3I described above. The acoustic test chamber (2-liter volume), shown in Figure 4, is primarily intended for testing the performance of new acoustic sensor designs. It has also proven to be a valuable test bed for pressure control schemes, instrumentation and software for PICO-2L and PICO-250L.

Figure 4: Acoustic test chamber system at Fermilab. This 2-liter test bed device can be used with a variety of target liquids.

(5) Development of low radioactivity acoustic sensors.

Efficient rejection of alpha particle backgrounds in bubble chambers by the acoustic method discussed above requires acoustic sensors to be mounted close to the active detector volume. We have simulated the production of neutrons by radioactivity in these sensors and found that, due to the proximity to the target liquid, the radiopurity requirements for these devices do not allow the use of off-the-shelf sensor materials. High sensitivity acoustic sensors in this frequency range (10-100 KHz) are manufactured using lead zirconate titanate (PTZ) ceramic materials that typically contain unacceptably high levels of uranium. The University of Chicago group assayed a wide variety of salts used in the production of PZT and found material with extraordinarily low levels of radioactivity, roughly three orders of magnitude lower than in the commercially available PZT. The Virginia Tech group made PZT ceramic from the low activity salts, using optimized adjustments to grain sizes and domain sizes and produced elements which are more sensitive than any commercial PZT. The Indiana University group fabricated and tested complete, working sensors using the PZT material from Virginia Tech and low-radioactivity preamplifiers from Fermilab. Thirteen of these sensors are installed on COUPP-60 at SNOLAB.

(6) Design of PICO-250L

R&D and design work for a ton-scale bubble chamber experiment has been funded by both the NSF and DOE, including most recently by the DOE Generation 2 dark matter program. This project was originally named COUPP-500 but is now called PICO-250L due to the merger of the COUPP and PICASSO collaborations and a decision to design the chamber for 250 liters of either CF3I target liquid (500 kg) or C_3F_8 (400 kg). Fermilab has responsibility for engineering of PICO-250L and began design work in 2012. The scope of work is the completion of R&D, design work and cost estimation for a chamber that could be constructed in FY15-16. The design work is currently about 50% complete, with substantial progress on all the major bubble chambers components and subsystems (Figure 5). The design of the chamber is for the most part a straightforward extension of existing designs for COUPP-60, PICO-2L and the small R&D chambers. The main challenges are in the areas of accurate, high-speed pressure control, due to the relatively large volumes of fluid involved and the specification and procurement of low radioactivity construction materials.

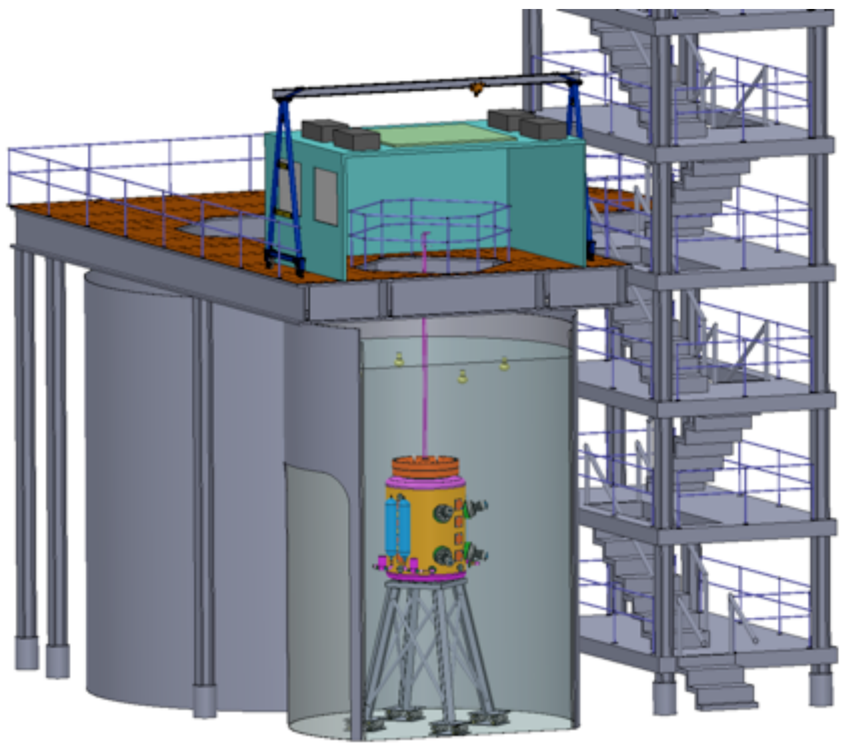

Figure 5. PICO-250 Design. The PICO-250L chamber is shown installed in its water shielding tank.

Proposed Research

(1) Operation of COUPP-60
As discussed above, COUPP-60 was installed at SNOLAB in 2012-2013 and the first physics run began in June. The run plan includes the following phases:

Phase I (June 2013- January 2014 expected)
Initial physics data set of 1000 kg-days, to be recorded with 37 kg of CF_3I. About half of the operating time in this period is expected to be devoted to detector calibration and characterization activities rather than physics data taking. The operational goals are to establish stable running of the detector with a high live time fraction and minimal intervention by operators. The analysis pipeline needs to be set up and tuned. Backgrounds from alpha particles, neutrons and gamma

rays will be studied under a variety of temperature and pressure conditions. Sustained operation of the detector is an important test of the automatic detector protection and safety systems, as this is the period in which equipment failures are most likely to occur.

The physics data set for Phase I will be sufficient to achieve world leading sensitivity to higher mass WIMPs interacting by spin-dependent interactions on fluorine provided that background goals are achieved. For spin-independent interactions (on iodine), zero background sensitivity would result in sensitivity similar to the current results from CDMS, an order of magnitude worse than the best limits from Xenon-100 at 100 GeV.

Background studies are a critical part of the **Phase I** operations. The COUPP-4 experiment achieved low backgrounds from gammas and internal alpha decay, but did have a small residual background from neutrons, tagged via multiple scattering, that were not predicted by background models. In addition, COUPP-4 had a handful of unexplained single-bubble events at low thresholds that had un-WIMP-like time distributions and an anomalous acoustic amplitude distribution. COUPP-60 runs at a variety of temperature and pressure operating points may be needed to study these events if they recur.

Phase II (January 2014 - August 2014 expected)
Intermediate result: 10,000 kg-days after 7 months running with full target volume (75 kg) of CF_3I. This phase will begin after the detector characterization activities of Phase I are complete and backgrounds are demonstrated to be low enough to justify multi-month data collection periods at a single operating point. The target mass of CF_3I will be increased from 37 kg to 75 kg by removing water from the inner vessel and condensing additional CF_3I. Two additional video cameras will be installed in order to photograph the larger target volume and DAQ equipment will be upgraded to process the larger throughput of video data.

With low backgrounds**,** the Phase II exposure is sufficient to exceed the current published sensitivity of XENON-100 for spin-independent interactions.

Phase III (August 2014 – December 2016)
Final result: 50,000 kg-days after three years of full detector operations. The baseline plan is to continue to run with CF_3I for the full three years, at which point neutron backgrounds from construction materials are expected to limit sensitivity. Feedback on actual measured backgrounds will be important input to the design of PICO-250L. Upgrades to the system to improve background or functional capabilities of the detector will be considered as appropriate. An alternative run option, depending on measured backgrounds and the results of PICO-2L (see below) is to convert COUPP-60 to operation with C_3F_8 for part of the three year run.

De-commissioning
Assuming success in the construction of PICO-250L on the planned time scale, COUPP-60 operations will ramp down as PICO-250L ramps up. We currently plan to end operations in FY17.

(2) Searching for Low- Mass WIMPs with PICO-2L

The first experiment proposed by the PICO collaboration is the PICO-2L low threshold C_3F_8 bubble chamber, currently under construction at Fermilab**.** Recent years have seen a great deal of interest in light, O(10 GeV) dark matter particles, as various experiments have seen possible signals in this mass range. Most recently, the CDMS collaboration has reported three WIMP-candidate events consistent with a ~8.6 GeV WIMP mass [R. Agnese et al. (The CDMS Collaboration), arXiv:1304.4279]. To optimize sensitivity to this category of dark matter, a detector would ideally have a light nucleus as a target and a very low energy threshold. A test of a small bubble chamber at Fermilab filled with C_3F_8 has confirmed that a gamma background discrimination of 10^{-10} is achievable at 3 keV. In the spin-independent regime, the combination of threshold and low target mass will explore the low WIMP mass region of parameter space while providing a complement to the more traditional reach of COUPP-60 with CF_3I (Figure 6). In the spin-dependent regime, a 2-liter C_3F_8 detector has the potential to increase the current best direct detection limits by two orders of magnitude. As successful run would also open up the possibility of putting this target liquid into the order-of-magnitude larger COUPP-60 detector after its CF_3I run is concluded.

The PICO-2L detector is the same size as the now decommissioned COUPP-4 and reuses parts of that detector, along with several new items. Groups formerly part of PICASSO have already taken a large role in the construction of PICO-2L and this is expected to increase as the detector is commissioned and begins to take data. The Queens University PICASSO group is providing a new pressure control system based on Fermilab test chamber designs. The detector is scheduled to be installed underground at SNOLAB in September. Due to the relatively high cross sections involved, signal rates on the order of ~ 1 per day are expected for WIMP candidates that can explain the excess CDMS and COGENT events. An important accessory to the operation of this detector underground at SNOLAB is a campaign of low energy recoil calibration measurements that will soon be carried out at the University of Montreal Van De Graaff facility, using the COUPP 100 ml test chamber.

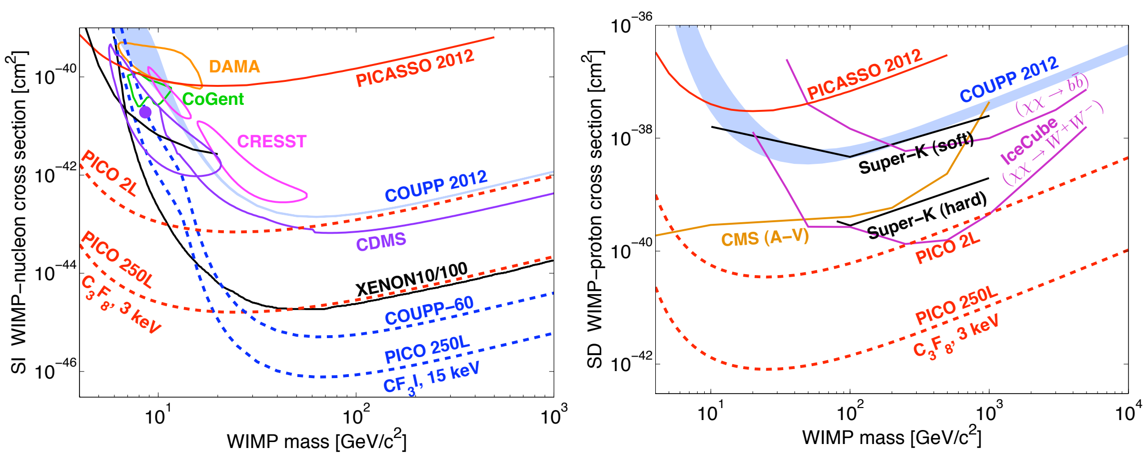

Figure 6: Projected sensitivity for COUPP and PICO projects to spin-independent (left)

and spin-dependent (right) WIMP scattering. The exposures assumed are 100 live days for PICO-2L, one live year for COUPP-60 and one live year for PICO-250LL. The C_3F_8 limits assume the same sharp threshold for nuclear recoils as measured in C_4F_{10}. The shaded green region represents the 90% allowed region from the recent CDMS-II observation of three WIMP-candidate events, a result that would be conclusively tested by a C_3F_8 chamber.

(3) Construction of the PICO-250L detector

We plan to finish PICO-250L design work in FY14 and begin construction as soon as funding allows. The upcoming G2 Dark Matter program review is a critical milestone for Fermilab participation in the future of COUPP/PICO. If PICO-250L is selected for construction as part of the G2 program, we expect that Fermilab will be the engineering, management and data processing center for PICO, with a major role in physics analysis.

The anticipated schedule for the project is shown in Table 1. The first year of DOE funding and the majority of NSF funding are devoted to the design of the experiment. In addition, the NSF groups will order the Outer Vessel and test low radioactivity acoustic sensors. An important milestone for the first year is the selection of a specific location at SNOLAB where the detector will be installed. The schedule for FY14-FY15 will be refined during the first year of design. Currently, we anticipate that the water-shielding tank would be completed at SNOLAB in FY14, while the rest of the detector is assembled at Fermilab. The integration of all detector components at SNOLAB would occur in FY15 and the system would be ready for physics data taking in FY16.

FY2013	Finish mechanical design of all major components First tests of 3rd generation acoustic sensors Select SNOLAB installation location
FY2014	Order outer vessel Prototype hydraulic system; test pressure control at full scale Water tank construction at SNOLAB Inner vessel prototype testing High purity fluid system construction Control system and DAQ testing
FY2015	Construction of final inner vessel Installation of all equipment at SNOLAB
FY2016	Commissioning & early running
FY2017-8	Running

Table 1: Timeline for PICO-250L design and construction

Publications & Presentations

Publications:

"Direct Measurement of the Bubble Nucleation Energy Threshold in a CF_3I Bubble Chamber", E. Behnke et al. (The COUPP Collaboration), Phys. Rev. D88 (2013) 021101.

"First determination of an astrophysical cross section with a bubble chamber: the ^{15}N(alpha,gamma)^{19}F reaction", C. Ugalde, B. DiGiovine, D. Henderson, R.J. Holt, K.E. Rehm, A. Sonnenschein, A. Robinson, R. Raut, G. Rusev, A.P. Tonchev, Phys. Lett. B719 (2013) 74-77.

"First Dark Matter Search Results from a 4-kg CF3I Bubble Chamber Operated in a Deep Underground Site", E. Behnke et al. (The COUPP Collaboration) Phys. Rev. D86 (2012) 052001.

"Improved Limits on Spin-Dependent WIMP- Proton Interactions from a Two Liter CF3I Bubble Chamber", E. Behnke et al. (The COUPP Collaboration), Phys. Rev. Lett. 106 (2011) 021303.

"Improved Spin-Dependent WIMP Limits from a Bubble Chamber", E. Behnke, J.I. Collar, P.S. Cooper, K. Crum, M. Crisler, M. Hu, I. Levine, D. Nakazawa, H. Nguyen, B. Odom, E. Ramberg, J. Rasmussen, N. Riley, A. Sonnenschein, M. Szydagis, R. Tschirhart, Science 319 (2008) 933-936.

Presentations:

"Dark Matter Searches", H. Lippincott, Fermilab Users Meeting, June 2013.

"COUPP Iodine Recoil Threshold Experiment", H. Lippincott, IDM2012, Chicago, IL, July 2012.

"Searching for dark matter with COUPP", H. Lippincott, NDM2012, Nara, Japan, June 2012.

"Searching for dark matter with bubble chambers", H. Lippincott, Naperville Astronomical Association, Public Lecture, October 2011.

" Searching for dark matter with COUPP: First results from SNOLAB", H. Lippincott, TAUP 2011, Munich, Germany, September, 2011.

E. Dahl, Joint Experimental-Theoretical Seminar, Fermi National Accelerator Laboratory, December, 2011.

E. Dahl, Enrico Fermi Institute Colloquium, University of Chicago, January, 2012.

E. Dahl, Physics Colloquium, University of Cincinnati, February, 2012.

"WIMP Measurements", A. Sonnenschein, Instrumentation Frontier Workshop, Argonne National Laboratory, January 10, 2013.

"A Bubble Chamber Revival: Superheated Liquid Detectors for Dark Matter Searches and Other Applications", A. Sonnenschein, APS DNP2012, Newport Beach, October 23, 2012.

"COUPP-60", A. Sonnenschein, International Conference on the Detection of Dark Matter (IDM2012), Chicago, July 26 2012.

"The Fermilab Neutrino Program", University of Michigan, November 2012

Joint Experimental-Theoretical Seminar, Fermi National Accelerator Laboratory, COUPP-4 SNOLAB Result, 12/2/2011

DarkSide

The involvement of Fermilab in a liquid-argon based direct search for Dark Matter originated in 2009 at the suggestion of Andrew Sonnenschein who was aware of both the liquid argon dark matter work at Princeton University and of the basic R & D work in liquid argon technology that was taking place at Fermilab, the latter largely motivated by the prospect of developing large mass neutrino detectors. It was quickly realized that these two physics applications of great interest shared several technical challenges and would be served by similar engineering skills. These challenges include the production of high-purity argon to allow electron drift over distances of meters, the selection of detector materials that will not contaminate the high-purity argon, the application of high-voltage for the drift-field, and the design and implementation of appropriate data-acquisition-systems based in both the Dark Matter and the Neutrino experiment case on waveform digitizers. While the ICARUS program in Europe had demonstrated viable solutions to these issues up to the kiloton scale for Neutrino detectors, there was no U.S. pool of experience in the requisite technologies, a pool which would be needed for any experiments in the U.S., and it was recognized that the U.S. needed to develop its own expertise to advance the field in the U.S. This synergy between the technical challenges of liquid argon for neutrino physics and for dark matter searches, and the commonality of the engineering and technician skill sets required, has prompted and supported the Fermilab involvement in the DarkSide program.

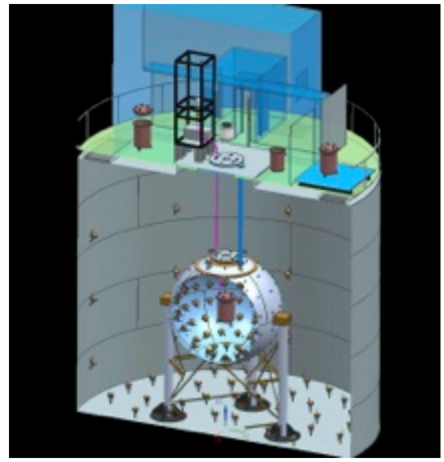

Figure 1: Schematic of the DarkSide-50 Detector. At the core is the LArTPC, then the 4 m scintillator vessel, then the 10 m water tank. At the top the radon-free clean room, in blue.

The discovery of underground argon with very low concentrations of ^{39}Ar has transformed the potential of liquid argon experiments to search for dark matter, allowing both the light-production and ionization drift properties of argon to be exploited in multi-ton detectors. Realizing this potential, the DarkSide collaboration has embarked on a program to enable the construction of just such multi-ton devices. Discussions with management if the Laboratori Nazionali del Gran Sasso (LNGS) in Italy and the Borexino experiment led to the decision to site the program at the LNGS and to use the water-tank of the Borexino Counting Test facility to house the DarkSide detectors of G1 and G2.

Progress report

The work over the past three years has had two major thrusts. One is development of the radon-free clean rooms and construction of water and scintillator based veto systems at the LNGS capable of hosting a multi-ton TPC, and the other is a program for the development of the target TPC, recognizing that while the technology already exists for the veto systems - thanks to the Borexino experience - the development towards a multi-ton LAr TPC needs to follow a staged process. On the first item, the collaboration has fully refurbished the water tank and constructed and instrumented the scintillator-based veto.

On the TPC front, DarkSide-10, the first full-fledged TPC in the program, ran at Princeton and then at LGNS till the end of 2012, serving both as a prototype and a general learning device. DS-10 was used to test the viability of several design features, including the use of ITO coatings as electrodes, the use of acrylic materials (abandoned in favor of fused silica) and the diving bell approach used to contain the gas-phase. Various light-reflectors were tested of which one achieved a record yield of 9 photo-electrons/kev$_{ee}$ [arXiv:1204.6218]. The DS-10 data have also allowed us to develop a data-based model for electron discrimination in the DarkSide detectors, a model that largely confirms our original sensitivity estimates. Assembly of the DarkSide-50 TPC in the radon-free clean rooms at LNGS started in January 2013 and in May 2013, the TPC was deployed for its first run with atmospheric argon inside the scintillator veto vessel. From this deployment we checked the gas-pocket formation in the TPC, and that the remote leveling of the TPC (with rods extending from the interior of the clean room above the water tank) could ensure a uniform thickness gas pocket to better than a millimeter. The complete cryogenic system, including the purification, liquefaction, and circulation system, was exercised. The system performed smoothly through the entire run. Some flexible transfer lines showed an excessive heat-leak due to incorrect installation of the super-insulation resulting in some thermal shorts at the bends; this has been fixed. Despite the reduced recirculation rate, an electron drift lifetime of > 2ms was achieved.

A significant setback has been the performance of some new, lower radioactivity Hamamatsu PMTs, R11065 series 20. While the reduction in background from the new ceramic dynode plate is welcome, the tubes could not hold voltage after a few days in a cryogenic environment. Hamamatsu believes it has identified the cause of the problem, has a proposed remedy, and promises to deliver new tubes soon. For now, however, the experiment plans to deploy with known working tubes from the R11065 and R11065-10 series.

A significant success was the test of the LNGS designed pre-amplifiers installed directly on a few of the PMT bases. These allow the PMTs to operate at lower voltage, improving the signal/noise and increasing the dynamic range. For the second deployment, all the PMT bases will be equipped with these pre-amplifiers.

Purification of Underground Argon

Atmospheric argon has an activity of ~1 Bq/kg from the isotope ^{39}Ar (half-life 250 yrs). At present, the upper limit on the concentration of ^{39}Ar from the CO_2 wells in Colorado that are the source of the DarkSide argon is about 0.5% of atmospheric (arXiv:1204.6011). In late 2009, Fermilab agreed to host the processing plant used to purify the argon from the other gases remaining after a preliminary concentration from ~0.05% to ~4% Ar at the extraction well. The contaminant gases are CO_2 - present in part per million quantities (sufficient to freeze and clog cryogenic lines) -, N_2 (15% to 70%), He (80% to 20%), and CH_4 (up to 0.05%). (The variation is due to small changes in the extraction process.)

The campaign to produce pure argon from the mix has been conducted at Fermilab with major contributions from Princeton with the lead scientist, H. Back, and by Fermilab with scientist S. Pordes, and by Fermilab engineers and technicians. The latter have to date (9/13) been supported on Fermilab Detector R&D and G-2 R&D funds. Once the purification process is fully established, it is anticipated that production for specific experiments will be charged to the experiments. Existing requests are for DarkSide and DEAP with a small amount requested by PNNL.

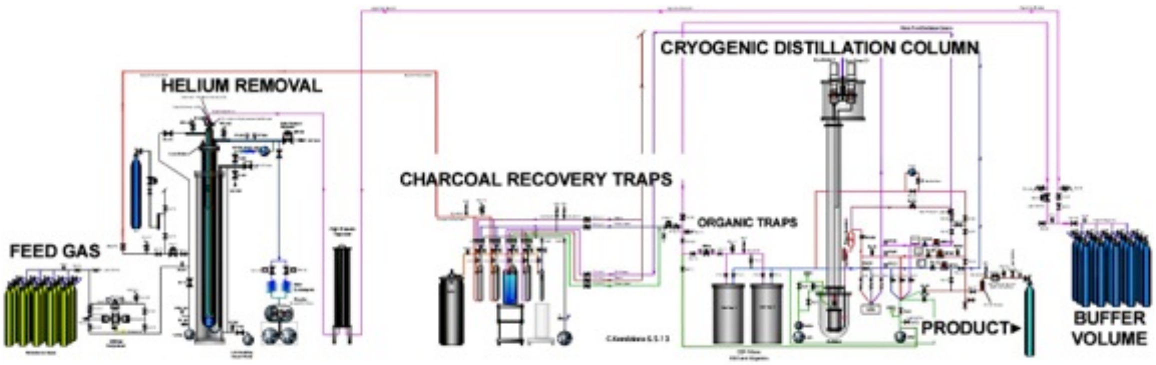

Figure 2: Schematic of the underground argon purification process at Fermilab

Fermilab Contributions

At the request of the DOE, Fermilab became the locus of funding and interactions for the DOE part of the DarkSide program in 2011. Fermilab Scientist Stephen Pordes has been the contact person for proposals and reviews, and in charge of disbursing DOE funds for DarkSide to Fermilab, Princeton (Professor Peter Meyers) and UCLA (Professor Katsushi Arisaka). The construction funding for DarkSide-50 was below $2M, meaning that DarkSide-50 was not a `Project' and Pordes's title has been DOE Co-coordinator. Significant technical and managerial activities specifically on DarkSide-50 started in late calendar 2011 - generic R & D including materials testing and the purification of the underground argon was ongoing and supported by detector R & D funds. A notable official activity of DarkSide-50 in FY11 was the journey to IHEP Beijing by a DarkSide delegation including Pordes and engineer David Montanari where IHEP decided to join the DarkSide collaboration.

DarkSide-50 uses Fermilab resources in cryogenic engineering, in electronics, in data-acquisition and off-line storage and reconstruction, and in organization and management. These resources (except for Pordes and Yoo) are largely paid for by the DarkSide-50 construction and operations funds. In FY12 Fermilab engineers were major collaborators in the design of the system for circulating, purifying, and liquefying the liquid argon, and the U.S. portion of the system was assembled at Fermilab. Fermilab engineer, Montanari, participated in the design of the scintillator vessel and led the safety review process from the experiment side.

In FY13, Fermilab engineers have been responsible for the installation of the argon handling system at LNGS, for the design and implementation of the experiment trigger system, and for a major part of the TPC Data Acquisition system. They have also led the first installation of the

TPC into the neutron veto. Fermilab will host the DarkSide-50 data repository for the U.S. groups and it is planned that the event reconstruction in the U.S. will be done using grid computing at Fermilab. Yoo has been working with the Fermilab Scientific Computing Division to establish a satisfactory rate for transfer of data from LNGS and the setup of the data repository using the Fermilab SAM system.

Proposed Research

The experiment is currently preparing the DarkSide-50 TPC for its second run with atmospheric argon. This run is aimed at measuring the electron rejection (for which the atmospheric argon is the appropriate material). It is expected that the low radioactivity argon will be available by the end of this calendar year and provided the second run goes well, the WIMP search with low radioactivity argon should start towards the end of calendar 2013 or early in 2014.

If the running of DarkSide-50 progresses well, the major support efforts at Fermilab for DarkSide-50 will be for transfer and storage of the data from LNGS, for the reconstruction of the events, and ensuring their easy availability to the U.S. collaborating institutions. It is anticipated that with the arrival of Professor Luca Grandi at the University of Chicago, there will be a strong local analysis effort on the DarkSide-50 data, particularly if DarkSide can attract a post-doc in the Fermilab FCPA. This effort is expected to last two or more years.

DarkSide G-2

Pordes was the final editor of the (successful) DarkSide proposal for G-2 R&D funding from DOE and is working with the spokesperson on the preparation of the proposal to the DOE and the NSF for the G-2 experiment to be submitted later this year (2013). If this is successful, Fermilab is expected to be the host laboratory for an expanded collaboration including SLAC and possibly other DOE institutions.

Dark Matter with CCDs (DAMIC)

CCDs used for astronomical imaging and spectroscopy commonly achieve readout noise levels of 2 e- R.M.S., equivalent to 7.2 eV of ionizing energy in Silicon. Though this allows for a very low detection threshold, these detectors have not been considered for DM search is because of their very low active mass. The microdetector group at Lawrence Berkeley National Laboratory (LBNL) has developed detectors with a depletion region up to 675 μm thick fabricated with high resistivity silicon (~30 kΩ-cm), these sensors have an active mass 10 times larger than conventional CCDs. These devices are the focal plane detectors for Dark Energy Camera (DECam) and other astronomical instruments. The idea of using them in a DM experiment was motivated by the early R&D work with DECam that started in 2010. The two main features that make the thick CCDs good candidates for a direct dark matter search are their thickness, which allows the CCD to have significant mass, and the low electronic readout noise, which permits a very low energy threshold for the ionization signal produced by nuclear recoils.

The DAMIC (Dark Matter in CCDs) experiment is a DM search using CCDs that operate at a threshold of 40 eV. The small team led by the DECam's CCD group at FNAL performed an engineering run to demonstrate the technology in a shallow underground site. The results in this shallow site using a detector with 0.5g of active mass have produced the best limits for DM searches with mass below 4 GeV [Physics Letters B, Volume 711, Issue 3, p. 264- 269 (2012)]. Based on this, the DAMIC Collaboration was formed to perform a competitive DM search using this technology. This collaboration is now conducting an experiment at SNOLAB with an active mass of 10 g.

The DAMIC Collaboration is planning the DAMIC-100 upgrade, to achieve active mass of 100g at SNOLAB. This upgrade has the scientific goal to probe the masses consistent with the recent CDMS, CoGeNT and DAMA hints of DM.

Fermilab has led the development of DAMIC, and because of the very encouraging results an international collaboration has developed around this effort. This collaboration includes institutions in the US, Europe and South-America.

Progress Report

Engineering run at the Fermilab shallow underground site

In the summer of 2010 the prototype DM experiment with CCDs with an active mass of 0.5 g CCD was installed 350' underground in the NuMI near-detector hall at Fermilab. The experiment operated for 11 months starting in June 2010 accumulating a total exposure of 107 g-days. The results obtained in the 2010-2011 constitute the best limit for dark matter particles of masses below 4 GeV.

Developing a formal Collaboration

During 2012 DAMIC developed into a formal Collaboration. There are currently 6 institutions involved in DAMIC: two universities from the US, one National Laboratory and three institutions from abroad. These institutions are Centro Atomico Bariloche, Argentina; Fermi National Accelerator Laboratory, USA; University of Chicago , USA; University of Michigan, USA ; Universidad Nacional de Asuncion, Paraguay; Universidad Nacional Autonoma de Mexico, Mexico; University of Zurich, Switzerland The Collaboration has 9 senior scientists and two postdoctoral researchers. It also has 11 graduate and undergraduate students.

Operations at SNOLAB with 10g active mass

The results from the engineering run at the NuMI near detector hall at FNAL motivated the development of a new prototype experiment on a deeper underground site. SNOLAB was selected as the location for this test.

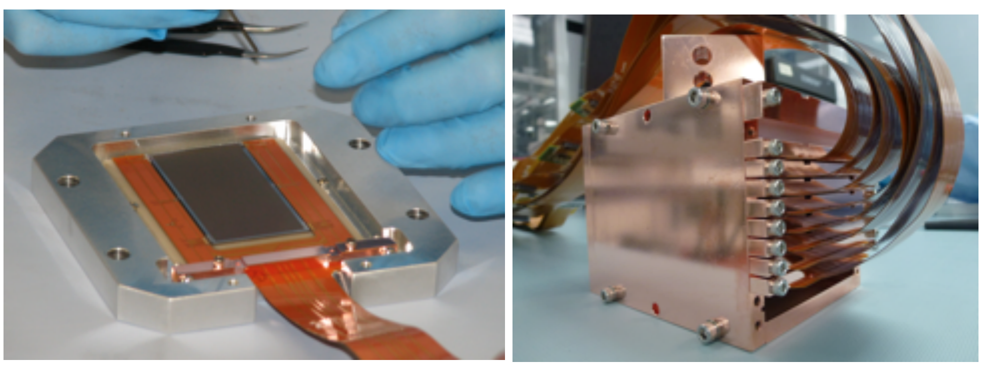

Fig. 1 Left) Low background package developed for the SNOLAB tests, main advantage is the long flex circuit which removes the connectors outside the shield. Right) Stack of 8 CCD detectors ready for installation into the vacuum vessel for operation at SNOLAB.

For the test at SNOLAB a new low background detector package was developed. This package is shown in Fig.1. The new package allows for easily stacking a set of detectors to achieve a larger mass. A stack of 8 detectors inside a copper box is shown in Fig. 1. The installation at SNOLAB took place in November-December 2012. The detectors were installed inside a copper vessel shown in Fig.2, which was kept at -150C for reducing dark current. This vessel was shielded with lead and polyethylene as shown in Fig.2. The completely assembled experiment at SNOLAB is also shown in Fig.2.

The first version of the new package (V1) installed at SNOLAB in December 2012 consisted of a rectangular aluminum nitride (AlN) substrate that provides mechanical support for the CCD and a custom made U-shaped flex cable (fig. 1). During a preliminary run in January 2013 we found that the AlN substrate had traces of ^{238}U. This background was the limiting factor for the detector sensitivity and prevented the identification of other potential contaminations in the materials that are close to the CCD detectors. For this reason we developed a second version of the package (V2) in which the AlN mass was reduced by removing most of the substrate material from the active area of the CCD keeping only an AlN frame. The V2 packages were installed in June 2013 and greatly reduced the effect of the contamination in the AlN as shown in Fig.3. The DAMIC Collaboration expect to produce in Fall 2013 a new DM result based on the data collected with the V2 detectors.

Fig. 2 Left) Copper vessel housing the DAMIC detectors inside a partially assembled lead shield. Middle) fully assembled lead shield at SNOLAB with the base of the polyethylene neutron shield. Right) Fully assembled experiment at SNOLAB, and external Al cover is used to keep a positive pressure of nitrogen inside the shield.

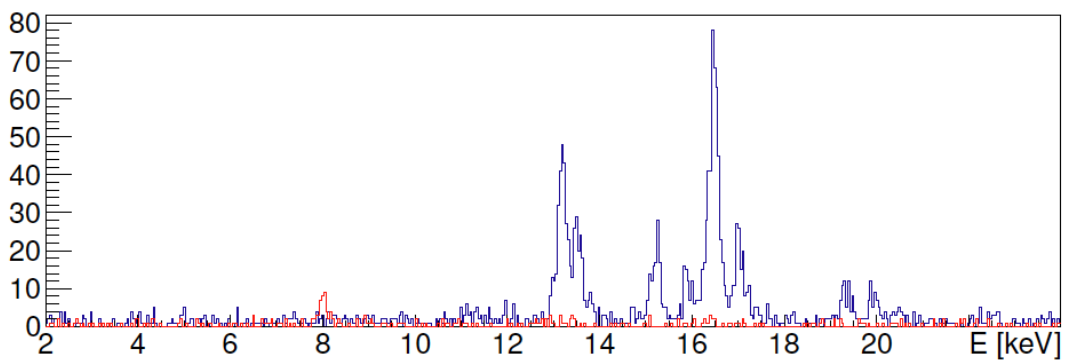

Fig. 3. Hit distribution in the V1 (blue) and V2 (red) DAMIC detectors. The X-ray peaks are associated with the ^{238}U contamination in the AlN (ceramic) board.

Proposed Research

DAMIC-100 upgrade

After the success of the DAMIC operation at SNOLAB, the Collaboration decided to upgrade the experiment to achieve 100g of active mass. This upgrade will consist in replacing the sensors with more massive version produce explicitly for a Dark Matter search. With 18 new sensors an active mass of 100g can be achieved. The upgraded experiment will reuse the cryogenic system and shield already installed at SNOLAB. The collaboration is planning to install the more massive detectors inside the same vacuum vessel during 2014. The schedule for this upgrade is presented in Fig.4. The 90% C.L. cross section limit expected for the upgraded experiment are shown in Fig.5.

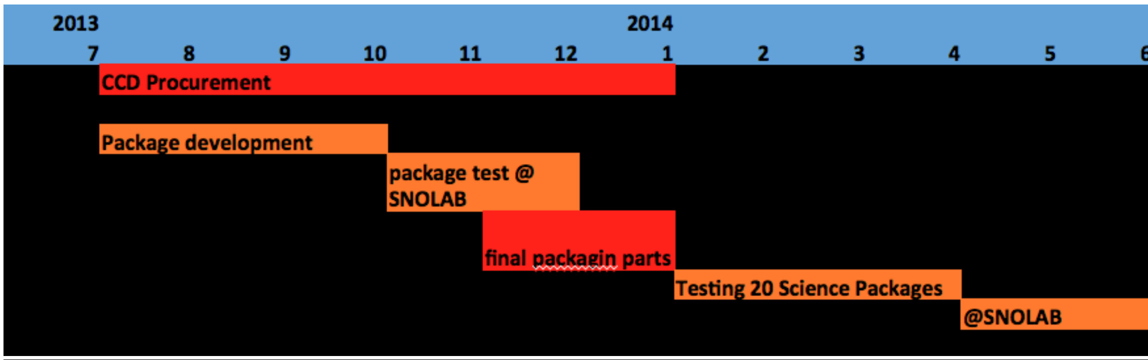

Fig. 4. Schedule for the DAMIC-100 upgrade

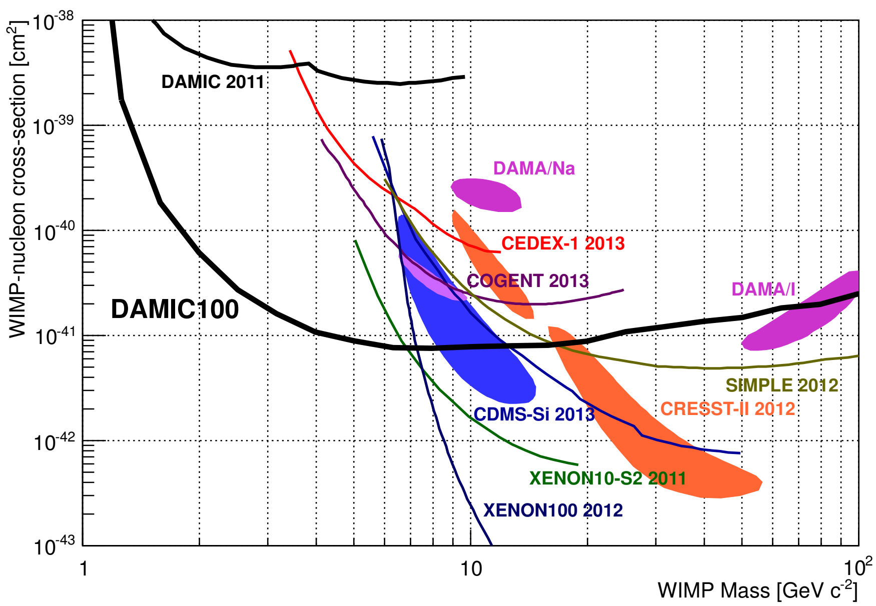

Fig. 4. Expected 90% C.L. cross section limit for DAMIC-100 compared with the DAMIC result published in 2011, and several results from other experiments.

Low energy nuclear recoil calibrations

During 2013-2016 the DAMIC Collaboration expects to produce results for low energy nuclear recoil calibrations in Silicon. Several groups in the collaboration using different techniques are pursuing the calibration effort:

- Fermilab : Scattering experiment using a neutron beam at Notre dame

- University of Chicago & Fermilab: CCD activation at a proton beam
- University of Chicago : Neutron Capture experiment using LAAPD silicon detector
- Centro Atomico Bariloche (Argentina): Neutron Capture experiment using a CCD detector

Publications and Presentations

Publications:

"Direct search for low mass dark matter particles with CCDs", Barreto et al, Physics Letters B, Volume 711, Issue 3, p. 264-269.
"Update of Direct Dark Matter Search using CCDs", N.Harrison and Juan Estrada, American Physical Society, APS April Meeting 2011, April 30-May 3, 2011, abstract #G13.006

Presentations:

"DAMIC experiment", Javier Tiffenberg, SnowDARK, March 22-25, 2013, SnowBird, Utha.
"DAMIC: looking for DM 2km underground", Javier Tiffenberg ,University of Buenos Aires Physics Department Colloquium, April 18, Argentina.
"DAMIC: a novel dark matter experiment", Javier Tiffenberg, 33nd International Cosmic Ray Conference, July 2-9, 2013, Rio de Janeiro, Brazil.
"DAMIC: a novel dark matter experiment. Review", Javier Tiffenberg, Particle Astro Seminar, July 19, 2013, FNAL, Illinois.

8. High Energy Cosmic particles - Status and Future Plans

Pierre Auger Observatory

The Pierre Auger Observatory, located on the Pampa Amarilla in western Argentina, is the world's largest cosmic ray air shower detector. The Observatory has been in full operation since June 2008, taking measurements that have addressed important questions about the spectrum, composition, origin and interactions of the highest energy cosmic ray particles. Auger has confirmed that the energy spectrum shows a strong suppression above the energy threshold for the Greisen-Zatsepin-Kuzmin (GZK) effect, has found tentative evidence above 55 EeV that the arrival directions correlate with the matter distribution in the nearby universe, has measured the cosmic ray particle composition from $10^{18} - 3 \times 10^{19}$ eV and determined the proton-air cross-section at 57 TeV in the center of mass.

The Auger results are having a major impact on the field. The collaboration has published 44 full-author list journal articles. Another five have been submitted for publication and more are in preparation. Auger has also made a significant impact on the training of future scientists, with194 students granted PhDs based on their work in Auger.

Fermilab has played a key leadership role in the organization, design, construction and operation of the Auger Observatory. With the Auger project leadership now transferred from Fermilab to the Karlsruhe Institute of Technology, the Fermilab Auger group will focus on data analysis, characterization of the performance of the detectors and planning for the proposed upgrade. Fermilab commitment to the Auger science will help ensure that maximum science return for the investment by Fermilab, the United States and for the other 18 countries and 92 institutions worldwide that comprise the Auger Collaboration.

Progress report

The following are the main science topics under investigation by the Auger Observatory. The scientific achievements of the Observatory to date and activities of the Fermilab group member are described.

The energy spectrum

Using data taken up to Dec 2012 that contain over $1.7x10^5$ events, the spectral features of the ankle ($5x10^{18}$ eV) and suppression ($4x10^{19}$ eV) have been determined with unprecedented precision [ICRC 2013]. The infill array with a spacing of 750 m extended the energy range down to $3x10^{17}$ eV and allowed the spectral index below the ankle to be measured with high accuracy [ICRC 2013]. Using more precise measurements and better detector reconstructions, the energy scale has also been revised with a shift from +16% (10^{18} eV) to +12% (10^{19} eV) [ICRC 2013]. The systematic uncertainty in the energy scale is now reduced from 22% to 14% [ICRC 2013].

Cross section measurement

Using events with energies between 10^{18} eV - $3x10^{18}$ eV, the proton-air cross section has been measured to be 505 mb by fitting the exponential tail of the Xmax distribution [PRL 2012]. Using Glauber theory and refinements of it, the total (inelastic) proton-proton cross section was deduced to be 133 (90) mb. The mean energy corresponds to 57 TeV, far exceeding the designed LHC energy.

Composition and hadronic interactions

Xmax, the atmospheric depth where the longitudinal development of the air shower reaches the maximum size, is a powerful and widely used observable to extract composition information. Data collected up to Dec 2012 yielded over $2x10^4$ events above $7x10^{17}$ eV. The first two moments of the log-mass (lnA) distribution, which is obtained through the moments of Xmax, has been used to study the evolution of the mass of the cosmic rays with energy [JCAP 02 (2013), ICRC 2013]. The distribution of Xmax has been used in a study by Eun-Joo Ahn and Peter Kasper of Fermilab. The result has been written as a full author collaboration paper that will soon be submitted for publication.

A new method using muons produced along the air shower trajectory, muon production depth (MPD), has been pioneered to study the composition, as the MPD is sensitive to the mass of the cosmic ray [ICRC 2013]. The results from these studies, which require the use of hadronic interaction models, all point to a trend where the composition mass increases with increasing energy. This trend is a surprise because the AGN correlation with UHE arrival directions suggests protons. In order to accommodate a proton-dominated scenario, the hadronic interaction models would need to change. Muon excess observed in the SD showers, suggesting that the number of muons is not well reproduced by shower simulations, is currently being studied [ICRC 2013].

In a separate study led by Eun-Joo Ahn and Peter Kasper, the Xmax distribution is also used to study the proton-air and proton-proton cross section for energies between $7x10^{17}$ eV and $4x10^{19}$ eV, which is expected to help us understand the composition at these energies. The work is intended for a full author collaboration publication. The long-term goal is to address other parameters in hadronic interaction models such as multiplicity and inelasticity.

Anisotropy

Large-scale anisotropy in the arrival direction may signal a transition from Galactic to extra-galactic origin of cosmic rays. Within the systematic uncertainties, no significant deviation from anisotropy in both right ascension and declination has been found for events above 10^{18} eV. In measuring the first harmonic modulation in the right ascension, a smooth transition in phases has been detected below 10^{18} eV [Astropart. Phys. 34 (2011), ApJL 762 (2013)], and to confirm this ~3 sigma observation, a prescription was started in June 2011 for events above 10^{16} eV which is now mid-way completed [ICRC 2013]. For events above $5.5x10^{19}$ eV the correlation with nearby AGNs is above the isotropic expectation, and the largest excess occurs around the radio galaxy Centaurus A [ICRC 2011].

Paul Lebrun has carried out a maximum likelihood analysis of the AGN correlation signal where the systematic uncertainty of the energy scale and detector resolutions was taken into account. The stability of the signal over time has also been studied and a lower bound on the energy resolution and calibration that could affect the correlation has been determined. Cross checks of the propagation errors, implementation of updated Galactic magnetic fields, and new estimation of the significance are in progress.

If there is a significant amount of nuclei at the highest energy, the observed AGN correlation signal is expected to fade away above some critical energy. Paul Lebrun plans to work on quantifying the likelihood of this scenario based on the upcoming full Auger data set.

Neutral primaries

Stringent limits on diffuse photons were set above 10^{18} eV, as well as ruling out many top-down scenarios such as Z-burst and decay of massive particles [ICRC 2011]. There are six photon candidates above 10^{18} eV that are compatible with the photon background expected from nuclear primaries. A directional photon search has also been made [ICRC 2013], which looks for photon-emitting point sources that yielded no candidates. Auger has the best limits on photon fluxes.

Due to its small cross section, neutrino-induced air showers are best searched for using Earth-skimming events and deeply penetrating horizontal events. Exposure obtained during the search period is equivalent to that of 6-years of the complete SD array. No neutrino candidates have been found. Three journal publications [(PRD 84 (2011), ApJL 755 (2012), Adv. HEP (2013)] have reported the neutrino flux limits.

A search for neutron sources within our Galaxy has been made in the form of excess air showers arriving from the direction of the source. Sources emitting high energy gamma rays such as pulsars, x-ray binaries, and magnetars have been considered. No significant excess flux has been found from the targets considered [2012, ICRC 2013].

Proposed research

Air shower simulations using advanced computing power

Billions of particles are generated in a single shower, and a small fraction of the electromagnetic particles can have large energy and mimic a muon-like particle at ground level, contributing to the systematic uncertainty. In order to resolve the muon excess issue with the planned Auger upgrade, reducing the current systematics is vital. An unbiased simulation with no "thinning" will be carried out using multi-core machines (Accelerator Simulation Cluster) or a supercomputer at Argonne National Laboratory. Paul Lebrun plans to modify the current air shower simulation codes (CORSIKA and GEANT) to run simultaneously on a few thousand cores.

Detector studies

Paul Lebrun has investigated systematic uncertainties in the SD angular resolution, energy scale and resolution. In addition to analysis of the monitoring data, detailed studies of the response function of a test Cherenkov Water Detector have been conducted at Malargue in May 2013. Changes in the Tyvek reflectivity or in the water absorption are possible causes of light collection efficiency. Further work is needed to understand the impact of such changes on the energy resolution or on the differential muon- electromagnetic response. Such studies will allow us to improve the AGN correlation analysis and energy spectrum at the highest energies.

Detector R&D
An array of surface detectors and standalone communications stations, the Research and Development Array, RDA, is being commissioned near Lamar, Colorado. The most important goal of the RDA is the development and testing of a communications system based on radio links between surface detector stations rather than from surface detector stations to a few remote towers. This could provide one possible expansion or upgrade path from the present Auger system if that should become necessary. The RDA Surface Detector electronics package is very similar to the electronics being proposed for the Auger upgrade and, as such, the RDA will provide an advanced testing opportunity before the upgrade is undertaken, possibly finding any problems or necessary improvements in a timely way.

Data mirroring
The Fermilab Auger group maintains the North American mirror site for Auger detector data, and serves as the repository for calibration data. This data server is now part of the Fermilab Computing Division pool of dedicated servers for scientific computing.

Upgrade Plans
The primary objective of the upgrade of the Auger Observatory will be to answer the question about the origin of the flux suppression at the highest energies, i.e., to differentiate between energy losses during extragalactic propagation and the maximum energy of particles injected by sources, either galactic or extragalactic. This objective is a natural evolution and major step forward from the original target of the Pierre Auger Observatory to establish the existence of a GZK-like flux suppression. The answer to the origin of the flux suppression will provide fundamental constraints on the astrophysical sources: Are they predominantly extragalactic or galactic? Does a transition between the two occur at some energy? It also will allow much more reliable estimates of neutrino and gamma ray fluxes at ultra-high energy.

The search for a flux contribution of protons up to the highest energies will allow us to do particle physics at these extreme energies not reachable by terrestrial accelerators. We aim to reach a sensitivity to a contribution as small as 10 %. The measurement of the fraction of protons is the decisive ingredient for estimating the physics potential of existing and future cosmic ray, neutrino, and gamma-ray detectors. Prospects for proton astronomy with future detectors such as JEM-EUSO will be determined. The observed anisotropy (AGN correlation) above 55 EeV will be further refined with greater statistics and improved detector resolution.

Determining the mass composition of ultra-high energy cosmic rays is closely related to, and crucially depends on understanding extensive air showers and hadronic interactions. When estimating the number of muons in air showers from Auger data, a discrepancy is currently found between the observed and expected muon numbers. We plan to study of extensive air showers and hadronic multi-particle production. This will include the exploration of fundamental particle physics at energies well beyond those accessible at terrestrial accelerators as well as the derivation of constraints on new physics phenomena, such as Lorentz invariance violation or extra dimensions.

Among the efforts to improve the composition measurement with the current methods, the largest boost in performance is expected to come from an improved discrimination of muons from electrons in the surface detector array.

Several technologies to upgrade a part or the entire surface detector array are now under study and prototyping. These include (1) larger bandwidth of surface detector signals to distinguish sharp, large muon pulses that are superimposed on the smooth electromagnetic signal; (2) install a small PMT to remove non-linearities at the energies > 40 EeV, (3) segmentation of the interiors of surface detectors, to separate penetrating muons from the lower-energy electromagnetic component; (4) placement of external particle detectors (such as RPCs or scintillators) beneath or near the existing Auger detectors. A detailed description of the upgrade finally selected will be given in the upgrade proposal.

The Fermilab Auger group will use its experience in detector development to support the R&D on the upgrade options currently being considered for the proposal, as well as support the CPU intensive shower simulation program, which is critical for the interpretation of this muon excess.

Publications & Presentations

Publications (full author list):

1.) Techniques for Measuring Aerosols using the Central Laser Facility at the Pierre Auger Observatory, JINST, in press (2013).
2.) Bounds on the density of sources of ultra-high energy cosmic rays from the Pierre Auger Observatory, JCAP 1305 (2013) 009
3.) Ultra-High Energy Neutrinos at the Pierre Auger Observatory, Advances in High Energy Physics, 2013 (2013) 708680
4.) The Interpretation of the Depths of Shower Maximum of Extensive Air Showers Measured by the Pierre Auger Observatory, JCAP 02 (2013) 026
5.) Constraints on the origin of cosmic rays above 10^18 eV from large scale anisotropy searches in data of the Pierre Auger observatory, ApJL, 762 (2013) L13
6.) Large scale distribution of arrival directions of cosmic rays detected above 10^18 eV at the Pierre Auger observatory, Astrophysical Journal Supplement, 203 (2012) 34
7.) A Search for Point Sources of EeV Neutrons, ApJ, 760 (2012) 148
8.) Results of a self-triggered prototype system at the Pierre Auger Observatory for radio-detection of air showers induced by cosmic rays, JINST, 7 (2012) P11023
9.) Antennas for the Detection of Radio Emission Pulses from Cosmic-Ray induced Air Showers at the Pierre Auger Observatory, JINST 7 P10011 (2012)
10.) The Rapid Atmospheric Monitoring System of the Pierre Auger Observatory, JINST 7 (2012) P09001

Measurement of the cosmic ray energy spectrum using hybrid events of the Pierre Auger Observatory, M. Settimo for the Pierre Auger Collaboration, Eur. Phys. J. Plus 127 (2012) 87
11.) Measurement of the proton-air cross-section at sqrt(s) = 57 TeV with the Pierre Auger Observatory, Phys. Rev. Lett. 109, 062002 (2012)
12.) Search for point-like sources of ultra-high energy neutrinos at the Pierre Auger Observatory and improved limit on the diffuse flux of tau neutrinos, Astrophysical Journal Letters, 755 (2012) L4
13.) A search for anisotropy in the arrival directions of ultra-high energy cosmic rays recorded at the Pierre Auger Observatory, JCAP 04 (2012) 040
14.) Description of Atmospheric Conditions at the Pierre Auger Observatory using the Global Data Assimilation System (GDAS), Astroparticle Physics, 35 (2012), 591-607
15.) Search for signatures of magnetically-induced alignment in the arrival directions measured by the Pierre Auger Observatory, Astroparticle Physics 35 (2012) 354
16.) Search for ultrahigh energy neutrinos in highly inclined events at the Pierre Auger Observatory, Physical Review D 84, 122005 (2011)
17.) The effect of the geomagnetic field on cosmic ray energy estimates and large scale anisotropy searches on data from the Pierre Auger Observatory, JCAP 11 (2011) 022
18.) The Lateral Trigger Probability function for UHE Cosmic Rays Showers detected by the Pierre Auger Observatory, Astroparticle Physics 35 (2011) 266–276
19.) Anisotropy and chemical composition of ultra-high energy cosmic rays using arrival directions measured by the Pierre Auger Observatory, JCAP06 (2011) 022
20.) Advanced functionality for radio analysis in the Offline software framework of the Pierre Auger Observatory, Nuclear Instruments and Methods in Physics Research A 635 (2011) 92–102
Search for First Harmonic Modulation in the Right Ascension Distribution of Cosmic Rays Detected at the Pierre Auger Observatory, Astropart. Phys. 34 (2011), 627-639
21.) The Pierre Auger Observatory Scaler Mode for the Study of the Modulation of Galactic Cosmic Rays due to Solar Activity, JINST 6, P01003 (2011)
22.) The exposure of the hybrid detector of the Pierre Auger Observatory, Astroparticle Physics 34 (2011) 368–381

Presentations:

ICRC 2013: The Pierre Auger Observatory: Contributions to the 33rd International Cosmic Ray Conference (ICRC 2013), arXiv:1307.5059. Eun-Joo Ahn, Inferences about the mass composition of cosmic rays from data on the depth of maximum at the Auger Observatory, CR-EX MASS1 (690).

June 2013 -46th Annual Fermilab Users Meeting, FNAL, Batavia, USA Eun-Joo Ahn “Recent achievements from the Pierre Auger Observatory”

October 2012 -High Energy Physics lunch seminar, University of Chicago, Chicago, USA Eun-Joo Ahn “Measurement of the proton-air cross section at 57 TeV with the Pierre Auger Observatory”

August 2012 - Joint Experimental-Theoretical Physics Seminar, FNAL, Batavia, USA Eun-Joo Ahn “Measurement of the proton-air cross section at 57 TeV with the Pierre Auger Observatory”

April 2012 - American Physical Society April meeting, Atlanta, USA Eun-Joo Ahn “Determination of hadronic interaction characteristics with the Pierre Auger Observatory”

ICRC 2011:

- The Pierre Auger Observatory I: The Cosmic Ray Energy Spectrum and Related Measurements
- The Pierre Auger Observatory II: Studies of Cosmic Ray Composition and Hadronic Interaction models
- The Pierre Auger Observatory III: Other Astrophysical Observations
- The Pierre Auger Observatory IV: Operation and Monitoring
- The Pierre Auger Observatory V: Enhancements

AIRFLY Collaboration, Precise Measurement of the Absolute Fluorescence Yield, Proceedings for UHECR2010, December 2010, Nagoya, Japan.

9. Cosmic Microwave Background - Status and Future Plans

There has been almost no Fermilab experimental effort on CMB polarization anisotropy in the last two years, since the end of the QUIET experiment. However, the scientific importance of this enterprise has only grown. A persuasive case was made for greater DOE/HEP involvement at the Cosmic Frontier Program review three years ago, and again, with a more mature and detailed set of proposals from a unified experimental community, in the "Snowmass" Community Summer Study process this year. The scientific merit, scale, and the technical challenge of the next-generation experiments all meet the standards of a significant participation by the HEP laboratories. In consultation with the Fermilab PAC, and with project leaders at Argonne National Laboratory and the University of Chicago, Fermilab is making plans to re-start a significant experimental effort in this area, along with other labs.

The high impact science return and added value of Fermilab participation in SPT-3G are clear. Moreover, the Snowmass process has revealed a possible path in the longer term to a more ambitious "stage 4" project, which the HEP labs could claim as an exciting signature achievement in the next decade.

South Pole Telescope CMB Polarization Mapping (SPT-3G)

Proposed research

The cosmic microwave background (CMB) is one of the Cosmic Frontier's most powerful tools for measuring the content and physics governing the universe. The well-understood dynamics of the CMB enable precise calculation of its observable features, which can then be directly connected to fundamental physics. The scientific goals of the CMB research program are directly related to the heart of the HEP mission: to test and constrain the GUT energy scale physics responsible for inflation, to measure the sum of the neutrino masses and the relativistic energy density of neutrinos in the early universe, and to constrain the evolution of the dark energy density and global equation of state.

The next generation of CMB experiments will derive much of their power from more sensitive measurements of the polarization of the CMB and its fine-scale angular power spectrum. CMB detectors are currently photon shot noise (or "background") limited, so the focus of the technological development has been towards fabricating ever-larger arrays of detectors to increase survey speed. The favored technology is superconducting Transition Edge Sensors (TES), which have been deployed with of order 1000 detectors in current Stage-II CMB experiments. Planned Stage-III and Stage-IV experiments will require of order 10,000 and 100,000 detectors, respectively. This scale necessitates a change in the execution of the US ground-based CMB program, with HEP resources and expertise at national labs ideally suited to take a leading role in the micro-fabrication and testing of the superconducting detectors.
For FY14-16, Fermilab will work with Argonne National Lab (ANL) and the University of Chicago to develop CMB detectors for the SPT-3G experiment. Fermilab will provide high-throughput and fast-turnaround detector testing that will be integrated with the existing CMB

detector development program at ANL. This will require the design and integration of a sub-Kelvin cryostat at Fermilab, along with the procurement of its associated refrigeration and readout electronics. In addition, Fermilab will work on the engineering and design of the mechanical support structures for the secondary and tertiary optics for the SPT-3G experiment. To support this work, we plan to hire a scientist from the SPT-3G collaboration, who will work with existing scientists and engineers at Fermilab. By FY15, the CMB community working with the national labs plans to achieve CD-0 status for a Stage-IV CMB (CMB-S4) experiment. The above outline of work will strengthen Fermilab's potential contribution to a future CMB-S4 experiment, while also developing several key technologies required for both the current and next generation of CMB experiments.

QUIET

Progress report

Fermilab was part of the QUIET-I CMB polarization experiment, led by Prof. Bruce Winstein at the University of Chicago. The QUIET Team at Fermilab consisted of: Fritz DeJongh, Scott Dodelson, Donna Kubik, Hogan Nguyen (Head), and Albert Stebbins. Fermilab's major contributions were:

- Design and Construction of a Rotating Sparse Wiregrid for Polarization Calibration.
- Experimental Operations: Shifts in Chile (DeJongh, Kubik, Nguyen). Scripting tools to improve Observations (Nguyen)
- Data Analysis: Data Quality and Bad Weather Checks (Kubik). Paper Editor (Nguyen). CMB Foreground Checks (Kubik, Nguyen), Calibration (Kubik, Nguyen).
- Project Council: Paper Authorship Committee (Nguyen)

We also proposed to assemble and test approximately 1500 W-band detectors and populate them into 3 focal plane cryostats at Fermilab for QUIET-II. NSF turned down the QUIET-II proposal, but we received limited funds to perform R&D to improve detectors for use in QUIET-II. We designed and built low voltage bias boards to control the MMIC HEMT devices. The boards have been adopted for use by C-Bass (a CMB foreground experiment), and by R&D labs at Caltech and KEK.

Publications & Presentations

Publications:

Osamu Tajima, et.al, Novel Calibration System with Sparse Wires for CMB Polarization Receivers, Journal of Low Temperature Physics, http://lss.fnal.gov/archive/2011/conf/fermilab-conf-11-327-ae-e.pdf.
"The Fermilab Large Cold Blackbody Test Stand for CMB R&D", Donna Kubik et al., TIPP 2011 - Technology and Instrumentation in Particle Physics, 2011 Physics Procedia (2012) 1–33. Hogan Nguyen, The QUIET Array for CMB Polarization Measurements, Techniques and Instrumentation for Particle Physics Conference, Chicago, 2011.
"The QUIET Instrument", The QUIET Collaboration, ApJ **768**, 9 (2013).
"First Season QUIET Observations: Measurements of Cosmic Microwave Background Polarization Power Spectra at 43 GHz in the Multipole Range 25 < El < 475", QUIET Collaboration *et al., ApJ* **741** (2012).

“Second Season QUIET Observations: Measurements of the CMB Polarization Spectrum at 95 GHZ”, QUIET Collaboration et al, ApJ **760**, 145 (2012).

Presentations:

Hogan Nguyen, QUIET Q-band Results, Intersection between Nuclear and Particle Physics, Tampa, FL 2012.
Hogan Nguyen, A New Measurement of the CMB Polarization at 90 GHz by the QUIET Experiment, Fermilab Wine and Cheese Seminar, October 26th, 2012.
Hogan Nguyen, “The QUIET Array for CMB Polarization Measurements, Techniques and Instrumentation”, for Particle Physics Conference, Chicago, 2011
Hogan Nguyen, “Fermilab’s Proposed Contribution to QUIET-II”, Presentation to NSF Office, 2011. NSF-Presentation-Nguyen.ppt.
Hogan Nguyen, “Fermilab’s Proposed Contribution to QUIET-II”, Presentation to the PAC 2011. PAC-Presentation-Nguyen.ppt, Fermilab_QUIET_Submission_to_Directorate.doc

10. Quantum Space-time

The relationship between matter and space-time is not adequately addressed by physical theory. In general relativity, a dynamical, classical space-time interacts only with an idealized classical model of matter. In quantum field theory, the quantized field modes propagate on a background, and therefore have a spatial structure, that again is simply assumed to be classical. Many theoretical paradoxes and puzzles associated with this theoretical gap remain unsolved, not the least of which the famous dark energy problem.

There is a strong motivation for any experiment that can shed light on this connection. One such approach is based on measurements of the positions of massive bodies. If there is a Planck scale bound on the information associated with spatial position relationships across macroscopic separations, then there may be no such thing a massive body at rest: there may be universal noise in angular positions, with a spectral density given by the Planck time. This idea has led to the Fermilab Holometer experiment, described here. Mostly an Early Career Award to Aaron Chou funded construction of the Fermilab Holometer. It is now entering a phase of commissioning and performance improvement, and is projected to achieve its goal of Planck spectral sensitivity in the next two years.

<u>Holometer - Status and Future Plans</u>

The Holometer studies Planck-suppressed microphysics that may be intrinsic to theories of quantum gravity. It is currently in the commissioning stage with full science operations to begin in early 2014. Commissioning/operations is funded through FY15 via a 5-year Early Career grant. Follow-up experiments will be planned if a positive signal is detected.

Thought experiments suggest that the Bekenstein-Hawking black hole area-entropy formula can be extended to flat space, away from regions of high space-time curvature. If so, contrary to expectations from counting of quantum field degrees of freedom, the maximum information capacity of any compact volume of space scales “holographically” with the area of its boundary, rather than with the enclosed 3D volume. Moreover, the information density has a finite upper bound and cannot exceed one bit per Planck area, $A_{pl} = 1/M_{pl}^2$. As in any Fourier system with a Nyquist frequency bound, the position of objects cannot be determined to arbitrary precision. A proposed covariant encoding of information on boundaries made of propagating null surfaces may provide a mechanism for the undetectably small fundamental position resolution of a Planck length, $\lambda_{pl}=1/M_{pl}$, to diffractively grow upon propagation over macroscopic distances L. The resulting amplified position uncertainty $\Delta x = \mathrm{sqrt}(\lambda_{pl} L/2\pi)$ is within the reach of contemporary laser interferometers.

The Holometer comprises two neighboring 40m long Michelson interferometers, each operated with 1 kW of 1064 nm laser light, resulting in a shot-noise-limited position resolution of 10^{-18} m/rtHz. The “holographic” uncertainty on the positions of each beamsplitter is predicted to have position noise with a spectral density given by the Planck time. Upon propagation of the fundamentally encoded information over the 40m baseline, the rms displacement is predicted to have a value of order $\Delta x = 10^{-20}$ m/rtHz in a broadband spectrum extending to a few MHz. This amplitude is a factor of 100 below the single interferometer resolution. However, because the intrinsic coordinate uncertainty is a property of the underlying space-time, it is predicted to be highly correlated between the two neighboring beam splitters as long as the beam splitter separation is small compared to the 40m baseline. The complex-valued Fourier spectra obtained from the two interferometers can therefore be cross-correlated and averaged over $(100)^4$ independent FFT samples in order to integrate out the uncorrelated noise component and reach sensitivity to the small correlated fraction. For 100 kHz resolution, only 10 microseconds is required per FFT sample, and so high significance detection of the exotic spectrum can be achieved with only a few hours of data. Various reconfigurations of the apparatus can be used to distinguish between "holographic" noise and correlated technical noise from conventional sources.

The Holometer studies the basic nature of space and time -- part of the HEP mission. It is sensitive to ultra-weak, coherent effects with amplitudes suppressed by large mass scales reaching all the way up to the Planck scale. While the theory being studied is speculative, as is any other model of quantum gravity, the current experiment has low cost and the potential of high impact returns. If a positive signal is seen, then future experiments would provide a window to new physics at high mass scales beyond the sensitivity of any other contemporary technique. Such studies could provide a deeper understanding of the interplay of quantum mechanics and gravity, and shed light on the role of quantum effects in cosmology.

Fermilab scientists working on the Holometer:

- Scientists on Cosmic Frontier research budget: Chris Stoughton, William Wester, Henry Glass; Craig Hogan
- Postdocs: none
- People with other support: Aaron Chou , Craig Hogan (U.Chicago joint appointment)

Leveraged or Overlapping efforts:

- Engineering physicists/Applied Scientists from detector R&D budget: Raymond Tomlin, and James Volk worked on laboratory infrastructure to develop the new laser lab for optical cavity and photodetector R&D.

Project efforts:
The roles of the various Fermilab participants on the Holometer Project are as follows:

- Aaron Chou – co-spokesperson, project management, experimental design, optics specification and procurement, laser launch layout, detector design and fabrication
- Craig Hogan – project scientist
- Henry Glass – optics metrology/validation and interferometer simulation, laser safety
- Chris Stoughton – vacuum system deployment, digital data acquisition system (with Chicago)
- William Wester – analog electronics
- Raymond Tomlin – laser lab infrastructure
- James Volk – mechanical installations

Collaboration:
The Holometer collaboration includes 4 universities, whose roles are as follows:

- University of Chicago -- Stephan Meyer, Craig Hogan + 3 PhD graduate students (1 NSF Fellow, 2 UC supported students) + several undergraduates
  - Deliverables include fiber-optic digital data acquisition system (with FNAL), digital interferometer control system, passive vibration-damping mounts, electronics support, interferometer characterization.
- MIT – Rainer Weiss, Sam Waldman
  - Interferometer design and commissioning efforts.
- University of Michigan – H. Richard Gustafson (NSF-funded)
  - Interferometer commissioning, detector development
- Vanderbilt University – 1 graduate student (NSF Bridge Fellow working at UC)
  - Resident at Chicago and working on detector design and performance tests.

Non-cosmic frontier experimental research scientists or efforts in the KA230102 budget:

- During the construction and commissioning phases of the project, the Holometer budget funds 1 (contract) technician at 100% effort level (paid from Early Career funds) for preparation and validation of UHV vacuum parts and deployment of 160m of vacuum system.

Progress Report

The Holometer is a small experiment, allowing all scientists to take important and unique roles in the development and implementation of the experimental hardware. Fermilab scientists played a large/primary role in the following activities:

FY11:
Prepared experimental hall and endstation hut. An unused beamline in the meson area of Fermilab was refurbished to construct the Holometer lab. To accommodate the perpendicular interferometer arm, a new endstation hut was designed and built outdoors to the east of the beamline to house the vacuum system and associated electronics for sensing and actuating the end mirror vacuum assemblies. Three class 50 clean rooms were built to allow vacuum access to install and align optics. A laser safety interlock system was implemented to require key access to both the main experimental hall and the endstation enclosure.

Procured/deployed 160 m of vacuum systems for two large interferometers. Two separate, optically hermetic vacuum systems are needed to prevent optical crosstalk that would create a background for the exotic noise correlation between the two devices. UHV cleanliness is required to prevent contamination of optical surfaces by residual hydrocarbons that would absorb laser power causing heating and thermal distortion of the optics.
Fourier Transform Infrared Spectroscopy was used to assay the residual hydrocarbon content of delivered vacuum parts. The installation of the 40 m interferometer included survey/metrology of the experimental site and of the pipe flanges to allow for proper alignment. Aluminum baffles

were cut, cleaned, welded, and inserted into each pipe assembly in order to capture the scattered light to prevent it from re-scattering into the measurement beam. The vacuum system was mounted on concrete pillars sunk beneath the frost line. The vacuum system was baked in situ at 150C for several days and vacuum cleanliness was validated using residual gas analysis.

Developed custom piezo-driven mirror mounts. In order to compensate for differential interferometer arm length changes due to seismic motion of the 40 m apparatus, piezo-driven mounts for the end mirrors were designed and fabricated. An epoxy-free design and UHV piezoelectric stacks and wiring were used for low hydrocarbon outgassing. The mechanical resonance of the custom mount assembly was designed to be greater than 1 kHz in order to allow sufficiently large gain in the feedback control system at lower frequencies where the seismic noise amplitude is high.

Procured/validated custom optics. To avoid scattering losses due to mirror surface roughness, custom mirrors were procured with stringent specifications on the polishing quality. The surface roughness figures were verified using Zygo interferometric metrology. To avoid distortions of optics geometry due to thermal absorption of laser power, custom interferometric optical coatings were applied by a specialty ion beam-sputtering vendor using strict tolerances on impurity content. The metrology data were used in interferometer simulations.

FY12:

Completed vacuum system deployment. The final 40 m of the ultra-high-vacuum system enclosing the optical path of the interferometers was installed in the Holometer lab. This vacuum deployment allows the two interferometers to be operated in either nested or back-to-back configurations, thus providing an experimental knob for turning off the holographic noise.

Operated first power-recycled interferometer. On February 14, 2012, the milestone was achieved of operating the first 40 m power- recycled Michelson interferometer. Alignment of the optics inside the pumped- down vacuum system was accomplished using a combination of the picomotors, the PZT actuators, and physically moving the vacuum endstations. The Michelson interferometer was first operated by itself with the power-recycling mirror tilted out of position. By setting a DC lock point on the observed fringe intensity, the PZT end mirror mount was actuated to compensate for seismic disturbances causing differential arm length motion. The power-recycling mirror was then gradually tilted back into alignment, and a radio-frequency opto-electronic feedback loop was engaged to adjust the laser wavelength in response to common arm length “breathing” modes, again due to seismic motion. With both feedback loops engaged, the power in standing waves inside the interferometer built up to about 100 W.

Simultaneously operated two power-recycled interferometers. First light was achieved in the second interferometer in September 2012. The two interferometers allowed for flexibility in the commissioning phase, with one being primarily used for optical power build-up and noise studies and the other being used for development of the digital control system.

FY13:

Designed and implemented digital data acquisition system. The holographic noise signal is broadband with amplitude 100 times below shot noise, and 10 times below the thermal noise of the readout electronics. Separate and independent data acquisition systems for each interferometer have been commissioned. Each use 14-bit, 100 MHz digitizers to acquire the photocurrent data stream. The two systems have independent clocks that are each synchronized to GPS. The digitized time-series data is then sent by fiber-optic link to a central data acquisition computer, thus bringing the two data streams together only after conversion to the digital domain. The multi-core correlator computer is able to compute auto-correlation and cross-correlation power spectra in real time from four independent data streams. Meanwhile, both the real-time spectra and the raw data streams are saved to a local hard disk containing enough capacity to store several hours of continuous data.

The data acquisition system has been tested from end-to-end, using electronic white noise sources, shot noise from photodiodes, as well as injected signals. Uncorrelated random noise averages down with integration time as expected while correlated signal lines remain at full strength in the cross-correlation spectra. The total noise of the data acquisition system, including detectors, is now at holographic noise sensitivity levels.

Began noise hunt with first interferometer data run. First data with two interferometers was taken in April 2013. This was an end-to-end test of all systems, including the seismic stabilization, the digital control system, and the digital data acquisition system with optical link, albeit not yet at full system design power. The dark fringe light from the two interferometers was sent into two photodetectors to produce separate photocurrent data streams. The digitized time-series data were cross-correlated and Fourier analyzed in real-time.

A multitude of narrow and broadband noise was immediately seen, at amplitudes undetectable without the cross-correlation technique. Using various RF noise mitigation techniques, the noise level was sufficiently reduced to provide several windows for clean detection of the holographic signal. Furthermore, a weak phase modulation frequency used in the interferometer control system was seen with high coherence between the two photodetectors, thus proving the ability of the data acquisition system to detect weak correlated signals with negligible timing jitter.

Developed high power photodetectors. To provide photodiodes capable of handling the large photocurrents expected in the interferometers at full 1 kW power, modifications to commercial photodiodes were implemented including swapping in more robust photodiodes, and reworking the amplification chain to allow the sinking of large photocurrents. The initial modified photodetectors were tested, and found to provide suitably flat frequency response across the MHz signal band, though thermal issues and long-term reliability still have to be addressed.

<u>Proposed Research:</u>

Commissioning and operations are fully funded through FY15 via an Early Career grant. The planned schedule is detailed below.

Commissioning phase FY13-14:

- Commission control system for power-recycling at high power. High quality custom optics have recently been installed to enable operation at 1 kW (design) laser power.
- Develop angular sensing and control system to minimize angle noise.
- Measure fringe contrast defect, and mitigate if necessary (by re-baking vacuum system if due to thermal absorption, or by acquiring new optics if geometries not good.)
- Balance the two arm lengths to minimize laser frequency noise.
- Finalize high current photodetector design and fabricate.
- Implement in-vacuo Kerr modulator for in situ sensitivity calibration.

Operations phase FY14-15:

- Perform noise hunt using a series of hour-long chunks of cross-correlation data.
- If found, mitigate low level RF noise/crosstalk imprinted on the optical beams.
- If holographic signal seen, reconfigure interferometers: back-to-back configuration turns it off, changing arm length changes the signal level.

Science deliverables:

- FY14: Paper (signal or limit) on primordial MHz gravitational waves.
- FY14: Paper on technical design of the Holometer apparatus.
- FY15: Paper on holographic noise (signal or exclusion).

If a holographic noise signal is seen, a field work proposal will be developed for the years FY16 and beyond to build a larger apparatus to enable quicker detection of the signal and quicker reconfiguration of the apparatus to investigate the properties of the noise. If not, the present interferometer program at Fermilab is likely to end.

Presentations & Publications

Publications:

Craig Hogan, Interferometers as Probes of Planckian Quantum Geometry, Phys. Rev. D 85, 064007 (2012)
Craig Hogan, Macroscopic Quantum Geometry, arXiv: 1204.5948, to be submitted to PRD
Craig Hogan, Quantum Geometry and Interferometry, arXiv: 1208.3703. In proceedings of the 9th LISA symposium, Proc. Astr. Soc. Pac (2012) (plenary talk)
Community Summer Study White paper, arXiv:1307.4676

Presentations:

Aaron Chou, Holometer talk at Cosmic Frontier Workshop, March 6-8, 2013, SLAC.
Chris Stoughton, Holometer talk at Time and Matter Conference, March 4-8, 2013, Venice, Italy.

11. Other Science and R&D

Many small Fermilab particle astrophysics experiments began as detector R&D developments. This includes COUPP and DAMIC, described in section 7, and the Holometer, described in section 10. The GammeV-CHASE experiments, described below, also started as an R&D effort, then produced a series of world-leading science results, at low marginal cost, by taking advantage of existing Fermilab infrastructure. In all of these cases, outstanding young Fermilab Wilson Fellows led the initial development and the subsequent experiments. In this section, we will describe other such small-scale efforts that may bear similar fruit.

Another now-completed R&D effort studied technology for a new kind of dark energy probe, using intensity mapping of 21cm emission to measure high redshift BAO correlations. The results of that effort have been useful for experiments now under construction elsewhere.

Low noise and threshold experiments with CCDs

In an R&D effort that started with the DECam project, the Fermilab Silicon Detector Facility has developed the capability to package and test CCDs and has acquired extensive expertise in CCD control and readout electronics. R&D efforts have been aimed at understanding the noise limitations of these devices as well as investigating their use in novel applications. The scientists involved in this R&D effort include Juan Estrada, Javier Tiffenberg, DECam CCD team members Tom Diehl and Brenna Flaugher. This effort also involves a large contribution from the Fermilab Scientific Computing Division, lead by Gustavo Cancelo. Graduate students from Mexico and Argentina have been involved in several aspects of this effort.

Progress Report

Current direct dark matter searches have limited sensitivity to low mass particles because most conventional technologies have relatively high threshold (>1 keV) for the observable nuclear recoil energy. The CCD noise reduction techniques used in astronomy enable detection of ionization events in silicon with thresholds as low as 40 eV. Combining the large mass CCDs recently developed for near-IR instrumentation by LBNL (see Fig. 1) with low noise readout techniques; FNAL has developed a new tool for low threshold dark matter searches. A proof of principle test was performed at a shallow underground site at FNAL during 2010-2011 using a CCD with 0.5 g active mass, this produced the world's best limit on dark matter with mass below 4 GeV. These results have prompted interest in the technology by several universities in the US and abroad. The DAMIC experiment currently operating at SNOLAB, discussed elsewhere in this document is a direct as a result of this R&D effort.

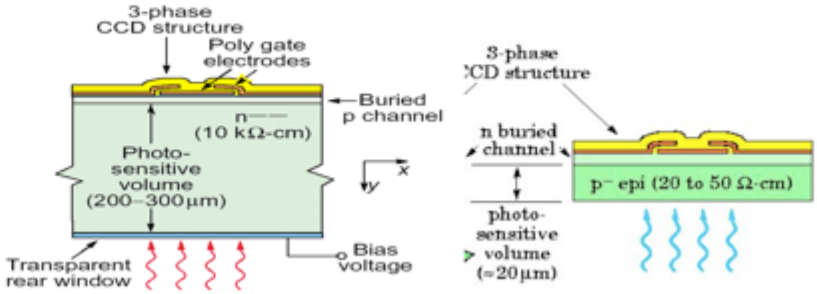

Fig.1. Fully depleted thick CCDs (left) developed for near-IR astronomy by LBNL compared to standard astronomical sensors. These massive sensors make novel low threshold direct Dark Matter and Coherent Neutrino experiments possible.

For monitoring the neutron background in the DM CCD experiment a ^{10}B was deposited on the detector surface. This resulted in a very high position resolution neutron detector that is now being tested as a high-resolution neutron imager. DOE has submitted a patent application for this neutron imaging technology.

Over the last two years Fermilab has developed and tested a filter algorithm that significantly reduces CCD readout noise. The state-of-the-art technology for CCD readout achieves at best 2 to 3 electrons per pixel of noise by using a method called double correlated sampling (DCS). DCS is limited 1/f noise in the output stage of the CCD. The Fermilab technique uses higher speed sampling of the video signal from the CCD's; this allows the low frequency noise across pixel readout boundaries to be estimated and subsequently subtracted. A noise level of 0.5 electrons has been achieved using this method, as shown in Fig.2. For astronomical applications, the decreased readout noise is equivalent to a factor of 4 increase in the area of the telescope mirror. This development will benefit future astronomical observation by increasing the sensitivity of telescopes to faint sources and low photon signal counts, such as high-resolution spectroscopy. In addition to this external solution to CCD noise, Fermilab scientists tested a new CCD design, fabricated by LBNL, which can perform multiple non-destructive measurements using a floating gate output well, thus reducing the noise by square root of the number of measurements. This design, called 'Skipper', resulted in an impressive 0.2 electrons of noise, with 1200 samples. Due to its low readout speed this detector has limited applications to astronomy, but it could be directly applicable for the detection of low energy ionizing radiation in dark matter or for other low count rate experiments.

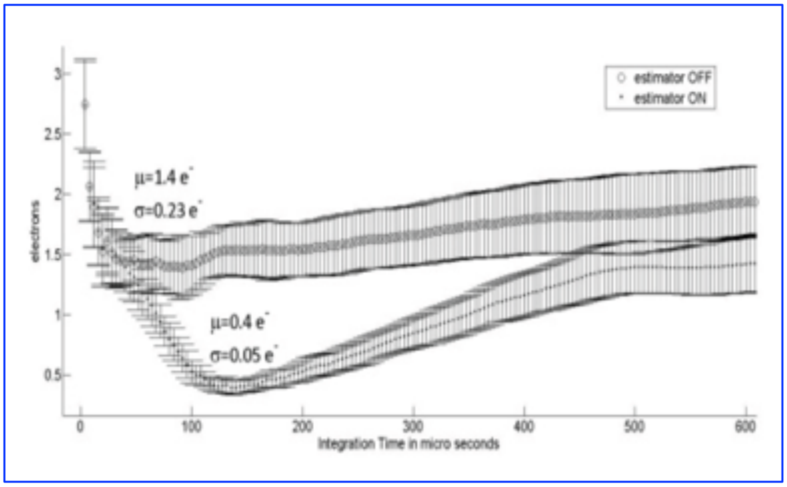

Fig.2. Readout noise for a CCD using standard readout technique (open) and using the digital filter developed at FNAL (closed). A noise reduction better than a factor of 2 is achieved when the filter is used.

Proposed research

A spin-off of this effort Fermilab is also collaborating with a group in Brazil (CBPF) to utilize these low threshold CCDs for the first detection of coherent neutrino-nucleus scattering from a reactor. We expect the installation of the first prototype for this to be installed in a reactor in Brazil during FY14. We expect this to transition from R&D into a formal experiment after the initial tests.

Over the next couple of years we expect to demonstrate the high-resolution neutron imager developed with borated CCDs in a neutron imaging facility. This test will conclude the R&D effort in neutron imaging using scientific CCDs.

The sub-electron readout noise R&D effort is now being supported by a UC/FNAL collaborative research initiative grant received in 2012 and renewed in 2013. The goal is to produce during FY2014 a sub-electron readout noise system that could be conveniently deployed in at astronomical instruments around the world.

Publications and Presentations

- "CONNIE experiment overview", Javier Tiffenberg, Low Threshold Detectors for Detection of Coherent Neutrino Scattering, Dec. 6-7, 2012, Livermore Valley Open Campus, Livermore, California.
- "Scientific CCDs for DM and Neutrino detection", Javier Tiffenberg, InstrumentationFrontier Community Meeting (CPAD), January 9-11, 2013, Argonne National Laboratory, Illinois.
- “Beating the 1/f noise limit on charge coupled devices”, Juan Estrada, High Energy, Optical, and Infrared Detectors for Astronomy V. Proceedings of the SPIE, Volume 8453, article id. 84531E, 7 pp.
- “Sub-electron readout noise in a Skipper CCD fabricated on high resistivity silicon”, F.Moroni et al, Experimental Astronomy, Volume 34, Issue 1, pp.43-64
- “Achieving sub electron noise in CCD systems by means of digital filtering techniques that lower 1/f pixel correlated noise”, G. Cancelo et al, Experimental Astronomy, Volume 34, Issue 1, pp.13-29.
- “Deep sub electron noise readout in CCD systems using digital filtering techniques”, G. Cancelo,

arXiv:1107.0925

- "Plasma effect in silicon charge coupled devices (CCDs)", Estrada et al, Nuclear Instruments and Methods in Physics Research A, Volume 665, p. 90-93 (2011)

Magnetic Kinetic Inductance Devices (MKIDs)

Progress Report

During 2012 Fermilab started an R&D effort in collaboration with U.C. Santa Barbara and Argonne to develop a focal plane for astronomy using Microwave Kinetic Inductance Detectors (MKIDs). An MKID is a superconducting structure that is resonant in the microwave region (~6Ghz). Individual photons with wavelength between 3000nm and 200nm that impinge on an MKID can cause the dissociation of Cooper pairs, resulting in a shift of the resonant frequency that depends on photon energy. MKIDs are fabricated with a number (currently up to 512) of LC resonators, each about 100 microns by 100 microns, connected in parallel to a "feedline." Each resonator is tuned to a different frequency. The array is readout by injecting a "frequency comb" on the feedline, and analyzing the reflected signal.

Fermilab scientists Juan Estrada, Gaston Gutierrez and postdocs Marcelle Soares-Santos, Brian Nord and Javier Tiffenberg are interested in the possibility of using MKIDs as a tool for the study of dark energy. A focal plane camera consisting of MKIDs could collect spectroscopic data in the IR, visible, and UV bands simultaneously over a large field of view while simultaneously producing an image. An MKID camera could be a powerful instrument for wide field low-resolution spectroscopy. The UCSB group is one of the worldwide leaders in the development of MKID technology, and the clear leader in the development of optical and near-IR MKIDs. Fermilab extensive experience in the packaging of cryogenic focal plane devices, RF electronics and sub-kelvin cryogenics is a good match for this effort.

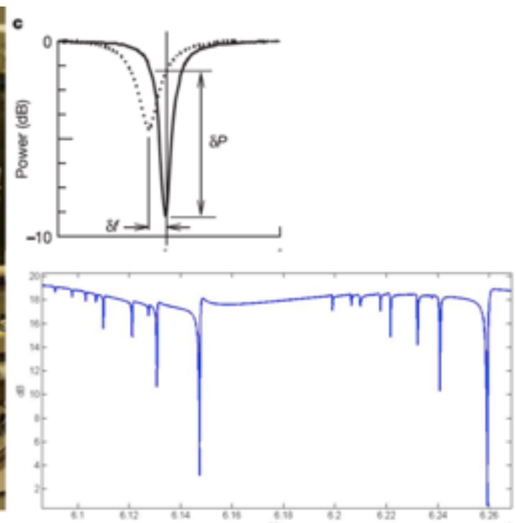

Fig.3. Left) FNAL MKIDs team working on cryogenic laboratory for installation of a MKID sensor. Right-Top) Sketch of frequency change expected for a superconductor resonator in an MKID when hit by a photon. Right-Bottom) 18 superconductor resonators operated at FNAL in summer 2013.

During FY13 the FNAL team has been able to establish a low temperature laboratory capable of operating detectors at 100mK, and has successfully operated superconductor MKIDs produced at ANL. This effort was possible thanks to the support from electronic department in the scientific computing division at Fermilab, lead by Gustavo Cancelo.

Proposed research FY14-FY16

Over the next three years, Fermilab will develop a packaging solution for mounting several MKID arrays, with associated cold electronics and readout cables, on a focal plane, with the goal of building a ~50,000 pixel prototype imager. Fermilab will also work to develop an RF readout system that will have larger bandwidth than the current state of the art. The goal is to increase the number of MKIDs that can be attached to a single feedline (currently 512) by a factor of four. At the back end of the readout system, a 50,000 element MKID imager is expected to produce a data rate of 10 Gbps. Fermilab engineers will also work to develop a cost effective data acquisition system for this throughput. The Director of the SOAR 4m Telescope (Steve Heathcote) has expressed interest in hosting this instrument prototype instrument at the SOAR telescope. This instrument will constitute a step toward the development of large optical astronomical instruments with superconductor detectors.

Scintillation Efficiency of Nuclear Recoils in Noble Elements (SCENE)

Progress Report

The Scintillation Efficiency of Nuclear Recoils in Noble Elements (Scene) project is an R&D effort to measure the light yield from low energy nuclear recoils in liquid argon (LAr) and xenon (LXe) by placing a dedicated time projection chamber (TPC) into a pulsed, low-energy neutron beam obtained at the University of Notre Dame Institute for Structure and Nuclear Astrophysics. The Scene collaboration includes researchers from Fermilab, Princeton, Temple, UCLA, University of Chicago, UMass Amherst, University College London, Naples, and Notre Dame. Fermilab scientists contributing to Scene are Hugh Lippincott, Ben Loer, Stephen Pordes, and Jonghee Yoo.

Noble liquids are promising targets for direct searches of dark matter, with the best existing limits on dark matter interactions coming from the XENON100 experiment. Because the signal in such detectors comes from low energy nuclear recoils, knowledge of the light and ionization yields from such events is crucial for understanding the sensitivity of these searches. Existing data on such events are incomplete in three ways: the energy range of interest for dark matter has not been covered, the electric field dependence of these yields is not fully mapped out, and the data that do exist have significant error bars. The neutron beam is monochromatic, produced by the $^{7}Li(p,n)^{7}Be$ reaction, and we infer the energy deposited in the detector by knowing the energy of the incoming neutron and selecting the recoil neutron angle.

The Scene apparatus contains a TPC built at Princeton, mechanical and cryogenic systems developed at Fermilab and Photomultiplier tubes and a cryocooler provided by INFN, Naples. After a shakedown run in November 2012, two additional weeks of running were taken in May-June of 2013; some of these data appear in a paper posted to the arXiv (http://arxiv.org/abs/1306.5675). This paper presents the first observation of a significant dependence of the signal yield for low energy nuclear recoils in liquid argon on the applied electric field (see Fig. 4). These observations come as a surprise. Until now, sensitivity estimates liquid-argon-TPC based dark matter experiments were based on the assumption that the applied electric field had a minimal effect on the light yield.

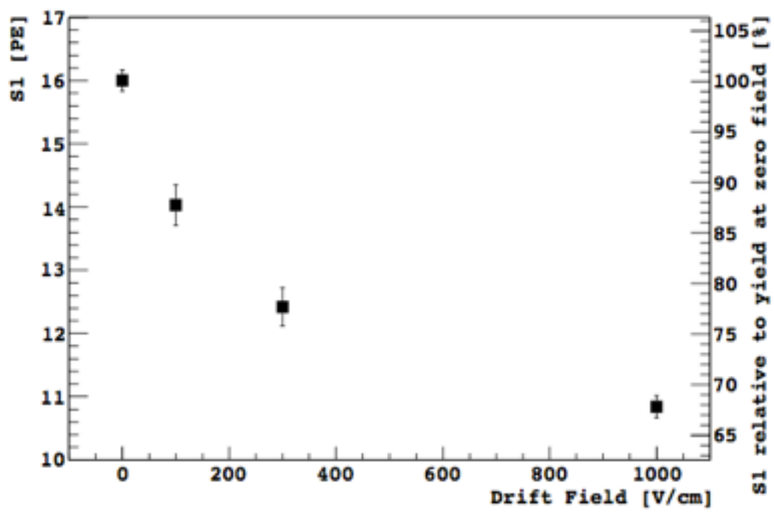

Fig. 4. Light Yield in the Scene detector to 11 keV recoils vs. applied electric field.

These results are also of interest because they raise questions about the published sensitivity of liquid xenon searches. The assumption, based on a single measurement at relatively high recoil energy (56 keV), in the XENON100 limits is that the field effect is small and independent of energy. Scene data show that the field dependence in liquid argon increases with decreasing energy. If the same is true in liquid xenon, then the limits on light dark matter set by the XENON100 experiment would be much weaker, a result of considerable interest given the current controversy surrounding light dark matter.

Proposed research

Over the next year, Scene plans to improve the uncertainty on the light yield from nuclear recoils at zero field (known as L_eff), extend the energy range of L_eff measurements, measure the field dependence over the entire range of interest for DarkSide, and also measure the ionization yield. These measurements will allow for the full specification of the response of DarkSide and other LAr detectors to dark matter. Secondly, a run with a liquid xenon TPC is of obvious importance. Although other groups are also attempting to measure these effects, Scene has already demonstrated that their technique works and plans are underway for another run in the fall with a dedicated LXe TPC.

Axion and Exotic Dark Matter Experiments

Work in this area with renewed interest at Fermilab began in FY06 with the report of a positive signal indicating the presence of an axion-like particle (later non-reproduced) by a laser experiment in Italy. This anomalous result led A. Chou and W. Wester to propose the GammeV experiment that was executed by a 10-member team in FY07-08. A follow-up effort also allowed for first limits of a possible chameleon particle coupling to photons. This then led to the execution of the GammeV-CHASE experiment to look more comprehensively for chameleons (with PI J. Steffen, a Fermilab postdoc) in FY09-10. Results from GammeV and GammeV-CHASE have led to three primary science and four additional peer-reviewed publications. The three primary science papers have over 100 citations.

Publications & Presentations

Publications:
Science results: J.H. Steffen, A. Upadhye, *et al.,* [GammeV-CHASE Collaboration], "Laboratory constraints on chameleon dark energy and power-law fields," Phys. Rev. Lett.,**105**, 261803 (2010); A.S. Chou, *et al.,* [GammeV Collaboration], ``Search for chameleon particles using a photon regeneration technique", Phys. Rev. Lett. , **102**, 030402 (2009) and ``Search for axion-like particles using a variable baseline photon regeneration technique", Phys. Rev. Lett., **100**, 080402 (2008)

Other publications: Updadye, *et al.,* "Designing dark energy afterglow experiments," Phys. Rev. **D86**, 035006 (2012). J.H. Steffen, *et al.,* "On the anomalous afterglow seen in a chameleon afterglow search," Phys. Rev. **D86**, 102003 (2012). A. Upadhye, J.H. Steffen, A. Weltman, "Constraining chameleon field theories using GammeV afterglow experiments," Phys. Rev. **D81**: 015013 (2010); and J. Steffen and A. Upadhye, "The GammeV suite of experimental searches for axion like particles," Mod. Phys. Lett. A. **24**, No. 26, (2009).

Presentations:
FY11: Presentations of GammeV and GammeV-CHASE results at the 7th Patras Workshop on Axions, WIMPs, and WISPs (Patras 2011) and colloquia/seminars at Fermilab, LBNL, UCLA, Northwestern, Washington Univ., and Univ. of Cincinnati. Work on associated publications.
Development of the Resonantly-enhanced Axion Photon Regeneration (REAPR) concept with internal reporting to the Fermilab Center for Particle Astrophysics and presented at the DOE Fundamental Physics at the Intensity Frontier Workshop, Washington D.C.

FY12: Presentations of GammeV, GammeV-CHASE results, and REAPR concepts at Patras 2012 and colloquia/seminars at DESY, Fermilab, Northwestern, CERN, Univ. of Central Florida, Penn. St. , Indiana, Virtual Inst. of Astroparticle Physics, and Univ of Washington.
W. Wester was the chair of the local organizing committee for the 8th Patras Workshop on Axions, WIMPs, and WISPs – held in 2012 in Chicago with Fermilab sponsorship.
Development of the REAPR R&D plan. This work led to unfunded, but well-reviewed proposals under the DOE G2 dark matter R&D solicitation.

FY13: Presentations of GammeV, GammeV-CHASE results, and REAPR concepts at Patras 2013 and a colloquium at Florida St. Univ.
Development of the REAPR R&D plan to lead to a proposal submission.
Discussions with the International Axion Xray Observatory (IAXO) for use of Fermilab low-noise CCDs as a possible detector for a future solar chameleon search (IAXO LOI submitted).

W. Wester served as a convener for Snowmass in the IF-5 New Light Weakly-coupled Particles subgroup with plenary presentations at Argonne and Minneapolis.
Through Snowmass, a new opportunity to use MiniBooNE to search for hidden sector photons has arisen in a test project and will lead to an experimental proposal. This has also lead to a contribution in the Project X Physics book on possible future opportunities for such searches at proton beam dump experiments at Fermilab.

Solid Xenon Detector R&D

Progress report

J. Yoo and collaborators are developing a next generation ultra-low-background and low-energy threshold solid-state noble gas particle detector. The immediate scientific application of these detectors may include dark matter search, solar axion search and neutrinoless double beta decay search.

In the initial phase of the R&D, they have focused on a solid (crystalline) phase xenon detector. The solid phase of xenon inherits most of the advantages of using liquid xenon as a detector target material; transparency, self-shielding, absence of intrinsic background and light yield. The electron drift speed in crystal xenon is expected to be far faster than in the liquid phase. Operation at sub-Kelvin temperature is natural for the solid phase, allowing superconducting sensors to be used to read out photon, ionization, and phonon signals. In addition, solid xenon is advantageous in low-background applications, as the external contamination elements tend to freeze outside of the detector volume. Therefore, the solid phase xenon detector is a strong candidate for next generation low background counting applications.

Two major R&D issues need to be addressed in order to make a solid xenon particle detector: the demonstration of the scalability of crystalline xenon, and the capability to read out signals from solid xenon. The first phase, growing approximately a kilogram of transparent solid phase xenon, was successfully completed in 2009. The second phase, implementing scintillation and ionization signal readout, required upgrade of the system for the xenon purification and DAQ for read out signals. Scintillation light readout from both liquid xenon and solid xenon was demonstrated in 2012. The scintillation light was characterized, and electron drift in liquid and solid phase of xenon was observed, in 2013.

A group of collaborators at the University of Erlangen in Germany made a chamber system for crystallography of solid xenon based on Fermilab's glass chamber design, and measured the crystal structure of the solid noble gas. The group will continue to develop a crystal phase xenon detector, and plans to carry out particle tracking in the solid xenon at Fermilab in the coming year. We plan to publish papers on the instrumentation of the solid xenon R&D system and results of the scintillation readout in 2013, and the electron drift results in early 2014.

21cm intensity mapping R&D

Progress Report

This section briefly reports R&D work on a program that effectively ended at Fermilab about two years ago. Some of that work is now incorporated into a Canadian project including some of our former collaborators, called CHIME.

The goal of 21 cm intensity mapping is to trace the mass density of the universe by measuring radio wave emission from neutral hydrogen. In particular, correlations of line emission in angle and frequency can be used to estimate the scale of the correlation feature introduced by Baryon Acoustic Oscillations (BAO), one of the primary probes of determining cosmological parameters. Unlike the well-established technique of measuring optical spectra, measuring cosmological 21 cm radiation has not been proven to be feasible. It has the potential advantage of providing extremely precise redshift information, but the disadvantage that the signal is buried in an intense spectrum of foreground noise. The distinctive combination of spectral and angular signatures may however allow the cosmological signal to be extracted. A 21 cm intensity mapping experiment is complementary to other HEP efforts to measure cosmological parameters to probe dark energy.

Fermilab people who were involved include:

- *Scientists: John Marriner, Scott Dodelson, David McGinnis, Albert Stebbins, Chris Stoughton, Nick Gnedin*
- *Postdocs: Hee-Jong Seo, Alberto Vallinotto*
- *People with non-KA23 support: Scott Dodelson, Albert Stebbins, Nick Gnedin, Hee-Jong Seo, Alberto Vallinotto (theory)*

Interactions:
The 21 cm intensity effort collaborators included Orsay (France), Saclay (France), Carnegie-Mellon, and Toronto (Canada).

Fermilab has extensive expertise in radio frequency systems because of a wealth of experience with accelerator systems operating in the GHz range. The effort was focused on conceptual design and analysis techniques for a 21 cm radio experiment sensitive to the redshift range of $0.5<z<1.5$. This work resulted in informal notes, presentations to collaborators, and two published papers.

Publications & Presentations:

Seo, Hee-Jong; Dodelson, Scott; Marriner, John; Mcginnis, Dave; Stebbins, Albert; Stoughton, Chris; Vallinotto, Alberto, 2010, A Ground-based 21 cm Baryon Acoustic Oscillation Survey, ApJ, **720**, 1650.

Marin, Felipe A.; Gnedin, Nickolay Y.; Seo, Hee-Jong; Vallinotto, Alberto, 2010, Modeling the Large-scale Bias of Neutral Hydrogen, ApJ, **718**, 972.

12. Lab support and infrastructure

Introduction

Our challenging particle astrophysics experiments could not succeed without Fermilab's extensive technical infrastructure, developed over many years to support the accelerator research program. That infrastructure includes specialized, unique laboratory facilities; access to unusual spaces for experiments, such as well-maintained tunnels and underground experimental halls, not found in other places; and many advanced capabilities of a more general nature, such as computing development and support, vacuum system design and construction, technical safety experts, and project management professionals. Many particle astrophysics projects explore new detection and calibration techniques with the assistance of well-established engineering groups and deploy test detectors in various labs on site at Fermilab, including the test beam facility. The Fermilab non-accelerator program also benefits from support by the detector research (KA15) program and by operational support from other parts of the Fermilab program.

Infrastructure

Fermilab has numerous facilities suitable for assembly, testing and operations of particle astrophysics experiments.

Silicon Detector Facility (SiDet)

This facility, with its many clean rooms, probe stations, microscopes and measuring devices, has been crucial for DECAM testing and assembly. R&D towards QUIET II module assembly and testing is also underway at SiDet. CDMS has used some of the automated optical microscope stations to scan their detectors for fabrication defects and make repairs.

NUMI Underground Laboratory

The COUPP bubble chamber and the DAMIC experiment were developed in this well-supported laboratory space that is situated 300 feet underground. The depth reduces the cosmic ray background for dark matter experiments by two orders of magnitude. This allowed COUPP and DAMIC scientists to explore other background sources, and ways to reject them, while preserving reasonable live times in the bubble chambers.

Proton Assembly Building (PAB)

A state-of-the-art facility for the chemical purification of liquid argon has been constructed in PAB and is being used to qualify candidate detector materials for argon-based dark matter and neutrino detectors. In addition, since the discovery of underground argon depleted in ^{39}Ar in CO_2 wells, a distillation column from Princeton University has been installed at PAB, to separate this argon from its accompanying gases. While the impetus for the column comes from the DarkSide collaboration, it could also be used to remove residual krypton from xenon.

Lab 3

This facility, located in the Fermilab village, has two large class-10000 clean rooms that enable assembly, testing and radioactive screening work in support of the dark matter program, specifically CDMS and COUPP. CDMS has installed a new ultra-low-background alpha counter in this facility, to study materials that will be used in SuperCDMS SNOLAB.

Lab 6

Scintillator prototyping and measurement efforts for SuperCDMS SNOLAB are being carried out using the facilities at Lab 6. Anna Pla-Dalmau and the technicians and students in the scintillator fabrication group have created several early batches of various liquid scintillator cocktails and polymerized plastic scintillators, and have agreed to continue making new samples for at least the near future. Measurements are being conducted using a spare dark box in the Lab 6 dark room, using several radioactive gamma sources and a Cf-252 neutron source. The scintillators are read out using PMTs and SiPMs borrowed from the electronics group and a high voltage power supply and amplifier from the lab electronics pool (PREP).

Support

As important as the Fermilab facilities are the technical personnel that run them, as well as the engineers and designers that help to craft particle astrophysics experiments. The Fermilab computing infrastructure is also vital to our mission. Laboratory personnel also support project management, financial controls and reporting and administrative functions.

Engineering and Technical Groups

Each of the non-accelerator projects takes advantage of experienced engineering and technical groups at Fermilab. These range from the Machine Development group (QUIET), to the Silicon Detector Facility (DECAM, QUIET, CDMS, DAMIC) to the Cryogenic Engineering group (CDMS, COUPP, Solid Xenon and Liquid Argon Distillation). The Mechanical Department within the Particle Physics Division provides engineering, drafting and design support for all of our projects. Similarly, the electronics groups in both Particle Physics and Computing Divisions contribute electronics and data acquisition engineering and design.

Computing

Computing, data storage and software support from the Computing Division are invaluable to all of our particle astrophysics efforts, particularly the large surveys such as SDSS and DES, and in the future, LSST and DESI. CDMS has also benefited greatly from the Fermi grid computing and storage facility.

Project Management and Administrative Personnel

The laboratory has staff that provides help to all of our projects as they navigate the DOE CD review processes.

13. Cosmic Frontier program future planning

Scientific leadership for projects often comes from university physicists, but ambitious large-scale projects also require the resources of a national lab: a rich technical infrastructure, diverse engineering skills, and professional project management. Fermilab has a deeply ingrained cultural tradition as a user facility, supporting physicists at the 86 universities in the Universities Research Association (now a partner with the University of Chicago in the Fermi Research Alliance). It has played an anchor role for large consortia such as Auger, SDSS and DES, and critical leadership and infrastructure roles for CDMS, COUPP, and Darkside, as well as developing new technologies such as liquid argon, solid xenon, holographic interferometry, and MKIDs in collaboration with university groups. Fermilab has helped foster and support new cosmic frontier university research groups, and new connections to international universities.

A particularly important partner for our program is the University of Chicago's Kavli Institute for Cosmological Physics (KICP), together with other academic institutes and departments at the University. Direct support comes from the University in the form of Strategic Collaborative Initiative Grants that have helped to launch several of our experiments, as well as support to university experimental collaborators via KICP. Many of our experiments have faculty collaborators at the University, including DES, DESI, LSST, SDSS, COUPP, DAMIC, Darkside, SPT, Auger, and the Holometer, and many UC grad students do research, including thesis work, on these experiments. Five Fermilab astro theorists have joint or part-time appointments on campus, and plans are underway to similarly expand experimental cross-appointments. Connections with Argonne's HEP cosmic frontier program are similarly being strengthened as part of our new CMB initiative. The Fermi Research Alliance seeks to create similar ties with other regional universities, and on the cosmic frontier this initiative has recently led to a new joint faculty appointment in dark matter at Northwestern University.

Our strategic program choices in large experiments are shaped by the national physics community, through the HEPAP/P5 process, other community panels commissioned by HEPAP such as the *Particle Astrophysics Science Assessment Group* (PASAG), and academy studies such as *New Worlds, New Horizons in Astronomy and Astrophysics*. Within this framework, ideas from university and laboratory collaborators are discussed informally at venues such as Center retreats and workshops. Some emerge as potentially exciting and viable initiatives, with a capable team, and a plausible path to funding and implementation. Every particle astrophysics project at Fermilab is subjected to a staged process of formal review as it matures: internal review, external review, Fermilab PAC review, and Directorate approval before advancing beyond R&D to project status. The final decision about experiment funding is then submitted to external community peer review, either as a proposal, or for larger projects, the DOE CD process or similar review by other lead agencies.

Within that science framework, we adapt to a dynamic budget and planning environment. In addition to launching new initiatives, we also take care to carefully prune the program by descoping efforts where Fermilab is not needed or duplicative, in order to make room for new ones. One important recent adaptation has been to position Fermilab to contribute significantly to future CMB polarization experiments, by allowing attrition in other areas. Another was to help manage a merger of two separate experimental initiatives for deep spectroscopic surveys, to one led by LBNL.

In addition, we maintain close links to Fermilab's Generic Detector R&D program to nurture the new technologies that enable future experiments. A portion of our scientists' research effort is allocated to these developments, and to investigate promising experiments based on them. A recent example of a new technology with potential broad application, but led by Cosmic Frontier scientists, is the MKIDs work described above. New experiments that have grown from R&D at Fermilab include the DAMIC and Holometer experiments. Other Fermilab development work, such as R&D for QUIET and 21cm intensity mapping, has also found its way into ongoing experiments elsewhere.

Fermilab adapts flexibly to science opportunities by maintaining an engaged and interactive intellectual community. At the lab, under the auspices of the Center for Particle Astrophysics, we have programs supporting visitors, seminars, workshops, journal clubs, and other informal interactions. We hold regular Center meetings and occasional mini-retreats for strategic discussions, at times when wide ranging consultation is called for. One important step we plan to take during the next year, endorsed by the PAC, is to hold a strategic planning retreat by all of Fermilab's particle astrophysics scientists. The discussion, culminating in a summary report and plan, will survey the context of a newly reshaped landscape of opportunity, defined by HEPAP's Community Summer Study and P5 processes, by a new Director at Fermilab, by the results of the G2 Dark Matter competition, and of course, as we all fondly hope, by new science discoveries.

14. CV's and Research Summaries

James Annis

Present Position: Scientist II, Fermilab, 1993 – current

Previous Positions: Scientist I, Fermilab, 2002 – 2010, Associate Scientist 1997 2002, Research Associate 1993 – 1997

Ph.D. degree: The University of Hawaii, 1994, Advisor: Professor J. Patrick Henry

Selected recent publications:
Lin et al, "The SDSS-co-add: cosmic shear measurement", *Astrophysical Journal* 761-15

Annis et al, "The SDSS co-add: 275 deg2 of deep SDSS imaging on stripe 82", *Astroph* 1111.6619

Hao et al, "A GMBCG galaxy cluster catalog from SDSSS DR7", *Astrophysical J. Supplement* 654-708

Adelman-McCarthy et al, "The sixth data release of SDSS", *Astrophysical J. Supplement* 175-297

Leadership in the broader community:
NSF Ice Cube annual reviews and midterm review panel member (Don Hartil's panel)

Education and Outreach activities:
Mentor - Fermilab summer science intern program

Mentor – Illinois Math and Science Academy academic year mentor program

James Annis
Research Summary

Current Experiments
Dark Energy Survey (DES) – 100%

Current Roles
DES – with the science committee, design the survey strategy that allows the main survey and supernova survey to each maximize their science given the weather and the telescope
DES – on-site quality assessment and survey progress tools
DES – using pure relative photometric calibration to reach 0.5% precision over the survey area
DES/BOSS/EBOSS – liaison to maximize useful overlap of these surveys
DES – liaison with the scientists of the survey to understand science needs and goals and their relation to the survey requirements and the survey strategy

Recent Accomplishments
Dark Energy Camera commissioned
DES science verification successfully performed
DES survey starting August 31, 2013
Co-author of Weinberg committee that examined the strong benefits that come from overlapping DES, DESI and LSST Surveys

Future Plans
Study dark energy via the use of cluster counts, cluster correlation function, cluster-shear correlation function, and cluster-CMB κ correlation functions to constrain a meaningful halo model. In particular, the use of gravitational lensing at two shells, of the galaxies at $z \sim 0.5$ and the CMB at $z \sim 1000$ is emerging as a powerful cosmological tool.
Perform a tight relative photometric calibration for the survey that enables, among other experiments, a primordial non-gaussianity measurement using matter. Photometric variations across the survey masquerade as apparent violations of statistical isotropy, and large-angle modulations are particularly damaging to cosmological analysis.
Explore the ability of the DES collaboration to increase the sky coverage of the DES experiments and thus the precision on dark energy measurements; explore uses od DECAM for pursuing gravitational wave detection follow-ups as a means to explore strong gravity; and explore the uses DES derived strong lens systems for pursuing cosmological time studies.

Dan Bauer

Present Position: Scientist II, Fermilab, 2002-current
Positions: Research Scientist, UC Santa Barbara, 1984-2002; Research Assistant Professor, University of Pennsylvania, 1981 – 1984; Research Associate, Fermilab, 1979-1981
Ph.D. degree: Michigan State University, 1979, Advisor: Prof. Wendell Chen
Awards: Extraordinary Performance Award (Fermilab), 2011; APS Fellow, 2007
Selected recent publications:
R. Agnese et al., Dark Matter Search Results Using the Silicon Detectors of CDMS II," Accepted for Phys.Rev.Lett. [ArXiv:1304.4279 [hep-ex]].
R. Agnese et al., Silicon Detector Results from the First Five-Tower Run of CDMS II," Accepted for Phys.Rev.D [arXiv:1304.3706 [astro-ph.CO]].
Z. Ahmed et al, Search for annual modulation in low-energy CDMS-II data," arXiv:1203.1309 [astro-ph.CO].
Z. Ahmed et al., Combined Limits on WIMPs from the CDMS and EDELWEISS Experiments," Phys. Rev.
D 84, 011102 (2011) [arXiv:1105.3377 [astro-ph.CO]].
D. A. Bauer et al., The CDMS II data acquisition system," Nucl. Instrum. Meth. A638, 127 (2011).
Selected recent presentations:
Seminar on CDMS results and Dark Matter Direct Detection at Queen's University, Canada, June 26, 2013
Invited plenary overview talk on Dark Matter Direct Detection at the Lake Louise Winter Institute, February 21, 2013
Seminar on recent CDMS results at the University of Illinois, Urbana, February 2010
Public lecture on Dark Matter at Fermilab, November 2008
The Hunt for Dark Matter, opening address at the Symposium on the Hunt for Dark Matter, Fermilab, May 10, 2007
Leadership and management positions at Fermilab:
Deputy Director of the Fermilab Center for Particle Astrophysics (since 2009)
CDMS Project and Operations Manager (since 2002)
Fermilab Operations Manager for Soudan Underground Laboratory (since 2010)
Leadership in the broader community:
Member of the SNOLAB Institute Scientific and Technical Review Board (since 2012)
DOE review panel member for the HAWC project
NSF review panel member for the Xenon 1T project
Working group leader for the Cosmic Frontier CF1 group at Snowmass 2013
Co-organizer and panelist for the Midwest Dark Matter Workshop (April 2012)
Member of the local organizing committee for TIPP 2011 conference in Chicago
Co-organizer of the Cosmic Symposium at Fermilab (March 2011)
Education and Outreach activities:
Supervisor for a Univ. Illinois, Urbana graduate student doing PhD work on CDMS
Active in the Soudan Underground Laboratory outreach program
Coordinate Fermilab Today columns on particle astrophysics efforts at Fermilab

Dan Bauer
Research Summary

Current Experiments
Cryogenic Dark Matter Search (CDMS) – 50%
Fermilab Center for Particle Astrophysics (FCPA) Deputy Director – 50%

Current Roles
Operations Manager for SuperCDMS Soudan
R&D Leader for SuperCDMS SNOLAB
Work with FCPA Director to manage FNAL particle astrophysics scientific program and play a leading role in the broader particle astrophysics community

Recent Accomplishments
CDMS II produced new results from silicon detectors that hint at low-mass WIMPs
Aided in the recovery of the Soudan Underground Laboratory from 2011 shaft fire
Commissioned SuperCDMS Soudan with 9 kg of advanced iZIP Ge detectors
Successfully operated SuperCDMS Soudan for 1.5 years at cryogenic temperatures
Successful proposal for G2 R&D for SuperCDMS SNOLAB; leading design effort

Future Plans
Follow up on CDMS II silicon results with final analyses of CDMS II data (2013)
Produce first SuperCDMS Soudan dark matter physics results (2013)
Continue to operate SuperCDMS Soudan until background-limited
Take SuperCDMS SNOLAB through the G2 down-select to project status
Design and fabricate SuperCDMS SNOLAB

Other Efforts
Fully-supported on the Cosmic Frontier Research program, but active participant in agency and journal review, as well as education and outreach activities.

Steve Brice

Present Position: Scientist II, Fermilab, 2000-current
Previous Positions: Scientist I, Fermilab, 2001-2010
Ph.D. degree: Oxford University, United Kingdom, 1996, Advisor: Prof. David Wark
Selected recent publications:
"A Search for electron neutrino appearance at the Delta m2 = 1eV2 scale", A.A. Aguilar-Arevalo et al. (MiniBooNE Collaboration), Phys.Rev.Lett. 98 (2007) 23180
"Event Excess in the MiniBooNE Search for Muon Neutrino to Electron Neutrino Oscillations", A.A. Aguilar-Arevalo et al. (MiniBooNE Collaboration), Phys.Rev.Lett. 102 (2009) 101802
"First Measurement of the Muon Neutrino Charged Current Quasielastic Double Differential Cross Section", A.A. Aguilar-Arevalo et al. (MiniBooNE Collaboration), Phys.Rev. D81 (2010) 092005
"Measurement of the nu(e) and total B-8 solar neutrino fluxes with the Sudbury Neutrino Observatory phase I data set", B. Aharmim (SNO Collaboration), Phys.Rev. C75 (2007) 045502
"Improved Limits on Spin-Dependent WIMP-Proton Interactions from a Two Liter CF3I Bubble Chamber", E. Behnke et al. (COUPP Collaboration), Phys.Rev.Lett. 106 (2011) 021303
Selected recent presentations:
"The Fermilab Intensity Frontier Program", DOE Labs Intensity Frontier Review, May 2013
"The Intensity Frontier", Particle Accelerators for Science and Innovation Workshop, Rutherford Appleton Lab, UK, April 2013
"The Fermilab Neutrino Program", University of Michigan, November 2012
"The Fermilab Neutrino Program", DOE Science and Technology Review of Fermilab, September 2012
"Current Status of LSND and Reactor Anomalies and Future Prospects for Sterile Neutrino Searches", Invisibles Workshop, Florence, June 2012
Leadership and management positions at Fermilab:
Head, Intensity Frontier Department, Fermilab, 2011 - present
Head, Neutrino Department, Fermilab, 2009- 2012
Co-Spokesperson of MiniBooNE Collaboration, 2007 - 2011
Analysis Coordinator of MiniBooNE Collaboration, 2001 - 2007
Chair, Fermilab Wilson Fellowship Committee, 2010 - present
Leadership in the broader community:
Chair, Fermilab Wilson Fellowship Committee, 2010 - present
Member Review Committee for LBNE Near Detector pre-CD1 Review, 2010
Chair, URA Thesis Award Committee, 2008 - 2010
Reviewer of several DOE grant proposals, 2009 - present
Chair, Organizing Committee for 2009 International Neutrino Summer School, 2009
Member, DOE CD Review Committee of US Daya Bay Project, 2009 - 2011
DOE Comparative Review Panelist, 2011
Education and Outreach activities: Students and Postdocs mentored:
David Schmitz, Columbia University, Eric Dahl, University of Chicago, Hugh Lippincott, Fermilab

Steve Brice
Research Summary

Current Experiments
General Intensity Frontier – 80%
Chicagoland Observatory for Underground Particle Physics – 15%
Neutrinos from STORed Muons – 5%

Current Roles
Head, Intensity Frontier Department
COUPP collaborator
Advocate for nuSTORM

Recent Accomplishments
Forming the new Intensity Frontier Department
Formed and maintained infrastructure for the analysis and online data handling
Formed and maintained infrastructure for the analysis and online data handling
Assisting in getting the nuSTORM idea propagated

Future Plans
Promote the Fermilab program of Intensity Frontier physics
Make the FNAL Intensity Frontier effort coherent
Help steer the expanding COUPP collaboration
Help analyze data from the 60kg device, help the 500kg device secure G2 funding
Assist in getting nuSTORM stage 1 approval from FNAL director

Elizabeth Buckley-Geer

Present Position: Scientist II, Fermilab, 2004-present
Previous Positions: Scientist I, Fermilab, 1997-2004; Associate Scientist, 1992-1997

Ph.D. degree: Queen Mary College, London University, 1986; Advisor: Professor Graham Thompson

Selected recent publications:
"The Serendipitous Observation of a Gravitationally Lensed Galaxy at z = 0.9052 from the Blanco Cosmology Survey: The Elliot Arc", Buckley-Geer, E., et al. 2011, ApJ 742 48
"The Sloan Bright Arcs Survey: Ten Strong Gravitational Lensing Clusters and Evidence of Overconcentration", Weisner, M., et al. 2012, ApJ 761 1
"Discovery of a Very Bright, Strongly Lensed z = 2 Galaxy in the SDSS DR5", Lin, H., et al. 2009, ApJ, 699 1242
"The Sloan Bright Arcs Survey: Six Strongly Lensed Galaxies at z = 0.4-1.4", Kubo, J., et al. 2009, ApJL, 696, L61
"The Sloan Bright Arcs Survey: Four Strongly Lensed Galaxies with Redshift > 2", Diehl, H.T., et al. 2009, ApJ, 707, 686

Selected recent presentations:
Seminar on Strong Lensing Studies with SDSS and BCS, Argonne National Laboratory, March 2010
Poster presentations at AAS meetings in 2009, 2010, 2011
Leadership and management positions at Fermilab:
Fermi National Accelerator Laboratory (FNAL) Experimental Astrophysics Group (2007-present)
Working on the Dark Energy Survey (DES) in a number of roles
Co-leader of the Strong Lensing Science Working Group
Coordinator of the planning for the DES science analysis computing
Deputy Head of the Experimental Astrophysics Group in Scientific Computing Division
Leadership in the broader community:
July 2009 Panelist on the DOE ARRA review
February 2010 reviewer for DOE Site visit of Texas A&M HEP group
December 2011 Reviewed DOE Early Career Proposals for Cosmic Frontier
November 2012 reviewer for DOE Comparative Review of Cosmic Frontier proposals
May 2013 NOAO Users Committee (appointed to a 3 year term)

Elizabeth Buckley-Geer
Research Summary

Current Experiments
Dark Energy Survey 95%
LSST/DESC 5%

Current Roles
Support for DES Survey operations
Co-leader of the DES Strong Lensing Science Working Group
Coordinator of planning for the DES science analysis computing
Dark Energy science with strong gravitational lenses
LSST: Participated in DESC software workshops and discussions

Recent Accomplishments
Successful deployment and ongoing support of DECam online database and related tools
Development of DES analysis computing plan
Publication of "The Serendipitous Observation of a Gravitationally Lensed Galaxy at z = 0.9052 from the Blanco Cosmology Survey: The Elliot Arc", Buckley-Geer, E., et al. 2011, ApJ 742 48

Future Plans
Dark Energy Survey – Dark Energy Science with strong gravitational lenses; survey observations; support of survey operations
DESI – potentially the development of online database pending discussions

Aaron Chou

Present Position: Scientist I, Fermilab, August 2008 - current
Previous Positions: Wilson Fellow, Fermilab, 2008-2012
Ph.D. degree: Stanford University, 2002, Advisor: Martin Breidenbach
Awards: DOE Outstanding Junior Investigator award, 2009' Fermilab-University of Chicago Strategic Collaborative Initiative grant, 2009, 2010; DOE Early Career award, 2011
Selected recent publications:
"Designing dark energy afterglow experiments," A. Upadhye, J.H. Steffen, an A.S. Chou, Phys.Rev. D86, 035006
(2012).
"Laboratory constraints on chameleon dark energy and power law fields," J.H. Steffen, et.al, Phys. Rev. Lett. 105, 261803 (2010)
"Search for chameleon particles using a photon regeneration technique," A.S. Chou, et.al, Phys. Rev. Lett. 102, 030402 (2009)
"Observation of the suppression of the flux of cosmic rays above $4 \cdot 10^{19}$ eV," Pierre Auger Collaboration, Phys. Rev. Lett. 101, 061101 (2008)
"Search for axion-like particles using a variable baseline photon regeneration technique," A.S. Chou, et.al, Phys. Rev. Lett. 100, 080402 (2007
Selected recent presentations:
"Probing the quantum vacuum with lasers," Pre-Snowmass Intensity Frontier Workshop, Argonne National Lab,
April 25, 2013.
"Search for Planck-suppressed Noise in Interferometers," Pre-Snowmass Cosmic Frontier Workshop, SLAC, March 6, 2013.
"The Hunt for Axions," International Conference on the Identification of Dark Matter (IDM2012), Chicago, July 23, 2012.
"Probes of the 10^{-11} GeV^{-1} Photon-Axion Coupling Scale," Axions 2010, Gainesville, Florida, January 15-17, 2010
"Experimental Probes of Axions," (Review talk) , Physics in Collision, Kobe, Japan, August 30-September 2, 2009.

Leadership and management positions at Fermilab:
Co-spokesperson, Project Manager, Holometer (FNAL-E990),
Co-spokespeson, GammeV (FNAL-T1007),
Chair, Fermilab Center for Particle Astrophysics postdoc/fellowship committee,
Member, Fermilab Director's Science Advisory Committee,
Member, Fermilab Intensity Frontier postdoc committee,
Co-editor, Fermilab KA15 program review document, 2012
Leadership in the broader community:
Co-convenor, Snowmass CF-6-C subgroup on Exploring the Basic Nature of Space and Time.
Reviewer for DOE, NSF grants, referee for papers
Education and Outreach activities:
Advisor/thesis committee for U.Chicago graduate students Robert Lanza and Lee McCuller.
Completed Strategic Laboratory Leadership Program sponsored by FNAL Directorate

Aaron Chou
Research Summary

Current Experiments
Holometer, FNAL E-990, 85% (supported by Early Career grant, separate from contract funding)

Current Roles
Co-spokesperson and project manager for FNAL E-990

Recent Accomplishments
Built new safety-interlocked laser lab.
Designed, successfully proposed, and constructed Holometer apparatus -- currently in commissioning phase.

Future Plans
Finish commissioning the optical, electronic control, and data acquisition systems of the Holometer and move into operations phase.
Take science data on 1-2 year time scale, and publish results.
Develop follow-up experiments probing Planckian effects and/or axion physics.

Other Efforts
Fermilab service work (committees, preparation for DOE program reviews), 15%, supported by FNAL overhead

Mike Crisler

Present Position: Scientist II, Fermilab, 1983 - current
Previous Positions: Scientist I, Fermilab, 1992 – 1998, Associate Scientist 1986 – 1992, Wilson Fellow 1983 – 1986
Ph.D. degree: The Ohio State University, 1983, Advisor: Professor T. A. Romanowski

Selected recent publications:
"Direct Measurement of the Bubble-Nucleation Energy Threshold in a CF3I Bubble Chamber", E. Behnke et al., Phys. Rev. D 88, 021101(R) (2013)

"First Dark Matter Search Results from a 4-kg CF3I Bubble Chamber Operated in a Deep Underground Site", E. Behnke et al., Phys. Rev. D 86, 052001 (2012)

"Improved Limits on Spin-Dependent WIMP-Proton Interactions from a Two-Liter CF3I Bubble Chamber", E. Behnke *et al.*, Phys. Rev. Lett. 106, 021303 (2011).

"A Proposal for a Ton Scale Bubble Chamber for Dark Matter Detection", Juan Collar et al., FERMILAB PROPOSAL 1009, Oct 2010.

"Improved Spin-Dependent WIMP Limits from a Bubble Chamber ", By COUPP Collaboration (E. Behnke *et al.*). Science 319:933-936,2008.

Leadership and management positions at Fermilab:
Associate Head, Particle Physics Division, 2004 - 2007

Principal Investigator, COUPP-500 R&D, 2013 - current

Leadership in the broader community:
Member Fermilab Director's Review Panel for MicroBooNe Experiment, 2011 – 2012

Education and Outreach activities:
Served as mentor to Dr. C. Eric Dahl, a Kavli Institute Fellow now Assistant Professor at Northwestern University.

Mike Crisler
Research Summary

Current Experiments
COUPP/PICO Bubble Chamber Dark Matter Search – 100%

Current Roles
Dr. Crisler is currently the Principal Investigator for the G2 funded COUPP-500 R&D program aimed at the design of a 250 liter fast-compression bubble chamber suitable for a dark matter search. The program also includes the design, fabrication, deployment, and operation of an array of specialized small bubble chambers that provide the capability to perform a number of specialized measurements necessary to support the larger design effort. These measurements include nuclear recoil threshold characterization, gamma background rejection, and the characterization of specialized piezo-electric acoustic sensors for alpha background rejection.

Recent Accomplishments
The demonstration of a sharp bubble nucleation threshold from iodine recoils in CF3I. This was accomplished by using reconstructed pion scatters in a test beam as a source of tagged iodine recoils.

The development of a new robust hydraulic control system for bubble chambers.

The demonstration of the stable operation of a C3F8 bubble chamber with a very low nuclear recoil energy threshold, below 2 keV.

The demonstration of 10^{-10} gamma rejection in a C3F8 bubble chamber at a 3 keV nuclear recoil threshold.

The development of a realistic and low cost baseline design for a 250-liter bubble chamber.

Future Plans
Work with the new PICO collaboration to deploy a 2-liter C3F8 bubble chamber at SNOLAB, with results early in 2014.

Contribute the analysis of the COUPP-60 bubble chamber dark matter search, currently operating at SNOLAB

Complete the design, construction and deployment of a new 250 liter C3F8 or C4F10 bubble chamber (PICO-250liter) to be deployed at SNOLAB.

Investigate the possibility of using Xe as a bubble chamber fluid, both as an exercise to validate the Seitz model of bubble nucleation using the Xe scintillation as an additional analysis constraint, and as a possible candidate for a large and competitive G3 dark matter search experiment.

C. Eric Dahl

Present Position: Associate Scientist Joint Appointee, Fermilab, Assistant Professor, Northwestern University 2012 - current
Ph.D. degree: Princeton University, 2009, Advisor: Thomas Shutt
Awards: Kavli Fellowship, Kavli Institute for Cosmological Physics, University of Chicago (2009)
Selected recent publications:
E. Behnke *et al.* "Direct Measurement of the Bubble Nucleation Energy Threshold in a CF_3I Bubble Chamber." Phys. Rev. D 88, 021101(R) (2013)
E. Behnke *et al.* "First dark matter search results from a 4-kg CF_3I bubble chamber operated in a deep underground site." Phys. Rev. D 86, 052001 (2012)
E. Behnke *et al.* "Improved Limits on Spin-Dependent WIMP-Proton Interactions from a Two Liter CF_3I Bubble Chamber." Phys. Rev. Lett. 106, 021303 (2011)
P. Sorensen and C.E. Dahl. "Nuclear recoil energy scale in liquid xenon with application to the direct detection of dark matter." Phys. Rev. D 83, 063501 (2011)
J. Angle *et al.* "First Results from the XENON10 Dark Matter Experiment at the Gran Sasso National Laboratory." Phys. Rev. Lett. 100, 021303 (2008)

Selected recent presentations:
Joint Experimental-Theoretical Seminar, Fermi National Accelerator Laboratory, COUPP-4 SNOLAB Result, 12/2/2011

Enrico Fermi Institute Colloquium, University of Chicago 1/9/2012

Astrophysics Seminar, Stanford University 2/10/2012

Physics Colloquium, University of Cincinnati 2/28/2012

Research Progress Meeting, Lawrence Berkeley National Laboratory 3/5/2012

Leadership and management positions at Fermilab:
Schramm Experimental Fellowship and FCPA Postdoctoral search committees, 2012

Education and Outreach activities:
Advisor to graduate students Miaotianzi Jin, and Daniel Baxter (PhD in progress at Northwestern University)

Postdoctoral advisor to Jianjie Zhang (Northwestern University, starting October 2013)

Mentoring high school student Duk Kyou Lim, Summer 2013, Science Professionals as Resource Knowledge Program (SPARK), Adlai E. Stephenson High School

Coordinated and features in a segment on dark matter focusing the COUPP 4 experiment at SNOLAB on "Daily Planet", Discovery Channel, Canada, Air date: SEP 19, 2012

C. Eric Dahl
Research Summary

Current Experiments
PICO Experiment (recently merged PICASSO & COUPP) – 80%
Chicagoland Observatory for Underground Particle Physics 60 (COUPP-60) – 20%

Current Roles
PI of the Northwestern University COUPP/PICO group

Data Acquisition manager for all current COUPP experiments, PICO-2L and PICO-250L

Major contributor to all COUPP/PICO analysis, design, operations and calibration work

Recent Accomplishments

The COUPP 4 experiment at SNOLAB measured acoustic discrimination of alpha-decay backgrounds to >99.3% and produced the world-leading limit on the spin-dependent WIMP-proton cross section from a direct detection experiment.

The CIRTE experiment at the Fermilab Test Beam Facility measured the bubble-nucleation efficiency for low-energy iodine recoils (spin-independent WIMP signal) in CF_3I.

The COUPP 60 experiment was successfully deployed at SNOLAB, with first bubbles May 1, 2013

Future Plans

Deploying the PICO-2L low-threshold C_3F_8 bubble chamber at SNOLAB to test the dark-matter origin of the CDMS silicon events.

Completing the design, fabrication and deployment the PICO-250L bubble chamber.

Calibrating the gamma sensitivity, nuclear-recoil sensitivity, and alpha-discrimination capability of C_3F_8 and other potential PICO dark matter target fluids.

Other Efforts

I have a joint position at Fermilab and Northwestern University, where I am an assistant professor in the Department of Physics and Astronomy. The Fermilab Cosmic Frontier research program provides 49% of my academic year support and one month of summer support.
My group at Northwestern is also focused on the COUPP/PICO experiments. I am currently advising two Ph.D. students, and a postdoc will be joining the group in October, 2013. I am also mentoring one high school student. All of my group members spend significant time at Fermilab

H. Thomas Diehl

Present Position: Scientist II, 2006 - current
Previous Positions: Scientist I, Fermilab, 2000 – 2006; Associate Scientist 1995 – 2000; Research Associate, 1990 - 1995
Ph.D. degree: Rutgers, the State University of New Jersey, 1990, Advisor: Professor G. Thompson
Awards: Principal Investigator, Department of Energy Award of $435k from Program Titled: "Discovering the Nature of Dark Energy" (LAB0806) December 2007

Selected recent publications:

"PRECam , a Precursor Observational Campaign for Calibration of the Dark Energy Survey", K. Kuehn et al., Publ.Astron.Soc.Pac. 125 (2013) 409-421.

"The Dark Energy Spectrometer (DESpec): A Multi-Fiber Spectroscopic Upgrade of the Dark Energy Camera and Survey for the Blanco Telescope", F. Abdalla et al., arxiv.org/1209.2451.

"The Dark Energy Survey Camera (DECam)", H. Thomas Diehl (for the Dark Energy Survey Collaboration), Proceedings of TIPP 2011 – 2nd International Conference on Technology and Instrumentation in Particle Physics, Physics Procedia 37 (2012) 1332 – 1340.

"Testing the Dark Energy Camera on a Telescope Simulator", H. Thomas Diehl et al., Proceedings of the SPIE Conference on Astronomical Instrumentation, 27 June to 2 July 2010, San Diego, CA, 7735-125 (2010); Fermilab-Conf-10-179-E.

"The Sloan Bright Arcs Survey: Four Strongly Lensed Galaxies with Redshift > 2", H. Thomas Diehl et al., ApJ, **707**: 686-692 (2009).

Leadership and management positions at Fermilab:
Dark Energy Survey Operations Coordinator, 2012 - present

Dark Energy Camera Project Level 2 Project Manager, 2006 - 2012

H. Thomas Diehl
Research Summary

Current Experiments
Dark Energy Survey Collaboration (DES) - 99%
DZero Collaboration - 1%

Current Roles
Operations Coordinator for DES
Organize survey operations, including scheduling, training and equipment checks. Serve as liason to CTIO for camera operations. Maintain integrated schedule and administer operations budget at Fermilab. Lead DES team in operations reviews.

Recent Accomplishments
Most of my Dark Energy Survey (DES) science is in the Large Scale Structure Science Working Group. This working group is responsible for galaxy-galaxy correlation function measurements that provide the galaxy-based baryon acoustic oscillation signature as a function of redshift. The BAO feature originates in the size scale of matter density fluctuations at the time of electron-proton recombination. It appears, for instance, in the 2-point galaxy-galaxy correlation function at size scale about 100 MPc/h^{-1} and is a standard ruler. The evolution of this size scale with redshift provides a handle on dark energy parameters.

Fundamental to this measurement is the accurate identification of galaxies, stars in our own galaxy, and artifacts in the data and the probability of getting them mixed-up. I did “galaxy completeness” (ID efficiency), star-galaxy separation studies versus galaxy magnitude, and magnitude resolution in these fields. These are the best systematic studies on this topic so far from the DES data. This work is also part of the “Science Verification” of the DES data where we show that the survey will identify galaxies up to some specified magnitude and with a specified magnitude resolution that differs for each filter. I continue to perform these systematic studies. This work may be published in a paper about the early DES data.

I also make contributions to the DES Strong Gravitational Lens Working Group. I have personally identified more than 25 excellent candidates for strong lens systems in the data. This is to be published soon.

Future Plans
The Dark Energy Survey will recommence observations on the evening of Aug. 31st. I will continue in my role as Operations Coordinator. I will work on analyses that lead to publications based on DES data.

Other Efforts
An active member of the scientific community, fully-supported on the Cosmic Frontier Research program

Scott Dodelson

Present Position: Scientist III, Fermilab 2011 - current
Previous Positions: Scientist II, Fermilab, 2004 – 2011; Scientist I, 1998 – 2004; Associate Scientist, 1994 – 1998; Research Associate, 1991 – 1994
Ph.D. degree: Columbia University, 1988, Advisor: Gerald Feinberg
Awards: Honorable Mention, Gravity Research Foundation 2011; Fellow, APS 2003
Selected recent publications:
"Probing Gravity at Cosmological Scales by Measurements which Test the Relationship between Gravitational Lensing and Matter Overdensity", P. Zhang, M. Liguori, R. Bean, S. Dodelson, Phys.Rev.Lett. 99 (2007) 141302.
"Galaxy-CMB Cross-Correlation as a Probe of Alternative Models of Gravity", Fabian Schmidt, Michele Liguori, Scott Dodelson, Phys.Rev. D76 (2007) 083518
"Size Bias in Galaxy Surveys", F. Schmidt, E. Rozo, S. Dodelson, L. Hui, E. Sheldon, Phys.Rev.Lett. 103 (2009) 051301
"Will Multiple Probes of Dark Energy find Modified Gravity?" C. Shapiro, S. Dodelson, B. Hoyle, L. Samushia, B. Flaugher, Phys.Rev. D82 (2010) 043520
"The SDSS Coadd: Cosmic Shear Measurement", SDSS Collaboration (H. Lin, S. Dodelson et al.), Astrophys.J. 761 (2012) 15
Selected recent presentations: (from 80 over the past 6 years)
"Particle Physics from Cosmic Surveys," Plenary, Annual Meeting DPF (2013)
"The Cosmic Frontier", Plenary, 11th Conference on Intersections of Particle and Nuclear Physics (2012)
"Gravity on Large Scales", Plenary, Lepton-Photon 2011
"Cosmology", 3 lectures at PASI Summer School (2010)
"Primordial Gravitational Waves," Plenary, AAAS Annual Meeting (2009)
Leadership and management positions at Fermilab:
Co-Founder and Interim Director, Fermilab Center for Particle Astrophysics (2006-8)
Co-Convener, Theory & Combined Probes Working Group, DES (2011-present)
Convener, LSST DESC Software Working Group (2012-present)
Co-Chair, Task Force on DES Scientific Computing (2012)
Leadership in the broader community:
Editor, Physics Letters B (2008-present); Chair, Program Committee, Aspen Center for Physics (2009); Co-Chair, Scientific Committee, TASI (2009); Co-Convener, "Dark Energy and CMB" group, Snowmass CSS (2012-13); Deputy Secretary-Treasurer, Division of Astrophysics, APS (2013-14); DOE HEP Dark Energy Plan Task Force ("Rocky III") (2012); Hans Bethe Award Committee, APS (2012-13); Organizing Committee, International Conference on Neutrino Physics and Astrophysics (2014) and other scientific conferences
Education and Outreach activities:
Supervised PhD students (in last 6 years: Fabian Schmidt, Melanie Simet, Sohyun Park, Eric Baxter, Youngsoo Park, Alessandro Manzotti, Ross Cawthon)
Supervised postdocs (in last 6 years: Peter Adshead, Andrew Hearin, Elise Jennings, Eduardo Rozo, Hee-Jong Seo, Marcelle Soares-Santos, Eric Switzer, Alberto Vallinotto)
Science Year, Astronomy, World Book Encyclopedia (2011-13)

Scott Dodelson
Research Summary

Current Experiments
Dark Energy Survey (DES) – 50%
Large Synoptic Space Telescope (LSST) – 10%
South Pole Telescope (SPT) – 5%
Current Roles
DES: Co-convener, Theory and Combined Probes Working Group and Co-Chair, Task Force on DES Scientific Computing
SPT: Supervising a student on detecting CMB Cluster lensing; leading several cross-correlation projects with DES
LSST: Convener, Software Working Group in Dark Energy Science Collaboration
Recent Accomplishments
Science: I led a team of researchers that published 4 papers on lensing in SDSS; I was co-author on the SPT parameters papers; and I have analyzed data from the Fermi satellite placing constraints on dark matter. In DES, SPT, and LSST, activity has revolved around simulations. On DES and SPT, I am shepherding 4 large science projects, each of which will likely produce several papers: Combining galaxy-galaxy lensing with large scale structure; stacking clusters and luminous red galaxies to observe the Sunyaev-Zel'dovich signal in SPT; stacking clusters to detect the signal of cluster lensing in the CMB; and cross-correlating CMB kappa maps with DES galaxies. We are getting ready to analyze Year 1 data from DES. For both DES and LSST, we are developing methods to account for baryons in weak lensing, having published one paper and preparing at least one more.

Computing: In DES, I am working with computing professionals at Fermilab and the University of Chicago and with scientists at the University of Manchester to build an analysis framework ("CosmoSIS") that will be used by the entire collaboration to analyze DES and future surveys. This is a more robust framework than cosmomc that will enable researchers spread across the globe to contribute modules and build on each other's work. For LSST, I am working with members of each science working group of the Dark Energy Science Collaboration and with computing professionals at the Labs to develop a framework that facilitates use of project tools (such as PhoSim and the Data Management stack) while being geared to the needs of the scientists.
Future Plans
I plan to spend 50% time on DES, but some of this will be relevant to SPT and to DESI. I plan to spend 10-20% time on LSST. Within DES, my plans are to continue contributing to the science by leading the Combined Probes WG, which is likely to become even more relevant as the different probes reach maturity. I plan to continue developing CosmoSIS, initially for DES and then for DESI. Some of my work on DES will likely be with SPT (as it is now), and other parts will inform my research on LSST. I plan to continue developing a software framework for the LSST DESC.

Juan Estrada

Present Position: Scientist II, Fermilab, 2008 - current
Previous Positions: Scientist I, Fermilab, 2008 – 2011; Associate Scientist (Wilson Fellow), 2004 – 2008;
Research Associate, 2002 –2004
Ph.D. degree: University of Rochester, 2002, Advisor: Professor Tom Ferbel
Awards:
Extraordinary Performance Award (Fermilab), 2013
Presidential Early Career Award for Scientist and Engineers 2010
Radiation and Instrumentation Early Career Recognition (IEEE) 2004
Wilson Fellowship 2004 (Fermilab)
Alvin Tollestrup Award for postdoctoral research at Fermi National Accelerator laboratory (2003)
Frederick Lobkowicz Prize at University of Rochester (2002)

Selected recent publications:
The SOAR Gravitational Arc Survey - I: Survey overview and photometric catalogs", Furnaletto et al, Accepted for Publication in MNRAS (2013), arXiv:1210.4136

"Direct Search for Low Mass Dark Matter Particles with CCDs", J. Barreto et al, Physics Letters B, Volume 711, Issue 3, p. 264-269. (2012) arXiv:1105.5191

"Sub-electron readout noise in a Skipper CCD fabricated on high resistivity silicon", G. Moroni et al, Experimental Astronomy, Volume 34, Issue 1, pp.43-64 (2012) , eprint arXiv:1106.1839.

"Achieving sub electron noise in CCD systems by means of digital filtering techniques that lower 1/f pixel correlated noise" C. Cancelo et al, Experimental Astronomy, Volume 34, Issue 1, pp.13-29 (2012) eprint arXiv:1107.0925 (2011)

"Focal plane detectors for Dark Energy Camera (DECam)", J. Estrada et al, Proc. SPIE, Vol. 7735, 77351R (2010).

Leadership and management positions at Fermilab:
Member of Detector R&D advisory committee at Fermilab (since 2012)
Deputy Head of the Detector Development and Operations Department at PPD/FNAL (since 2011)
DAMIC Spokesperson (since 2010
Liaison between the Instrumentation Frontier and Cosmic Frontier for Snowmass 2013.

Education and Outreach activities:
Co-advisor for Ph.D. student at Universidad Nacional del Sur (Argentina) working in DAMIC
Co-advisor for Ph.D. student at Universidad de Buenos Aires (Argentina) working in DAMIC
Supervisor of several undergraduate summer student

Juan Estrada
Research Summary

Current Experiments
Dark Energy Survey (DES) – 35%
Dark Matter in CCDs (DAMIC) – 35%
Detector R&D activities – 30%

Current Roles
Supporting operations and laboratory studies for DECam CCDs
Spokesperson for DAMIC
Leader of the CONNIE R&D effort for installing CCDs in Reactor site in Brazil
Leader of the MKID R&D proposal at FNAL
Advisor to the detector R&D panel at FNAL for the cosmic frontier

Recent Accomplishments
DES started successful operations of the Dark Energy Camera on September 2012.

DAMIC published first results in early 2012 from prototype run. Started operations at Sudbury Neutrino Observatory Laboratory in December, 2012.

R&D effort with Microwave Kinetic Inductance Detectors (MKIDs), superconductor detectors, started at Fermilab in 2012. Currently successfully operating the first devices at the 100mK testing facility at Fermilab.

Future Plans
Continue working on DES support of operations and analysis.

Continue working on DAMIC to produce new results for low mass Dark Matter searches.

Continue the development of instrumentation for astronomy using MKIDs

David Finley

Present Position: Scientist II, Fermilab, 1980 - current
Previous Positions: Scientist I, Fermilab, 1984 – 1990; Associate Scientist, 1981 – 1984
Ph.D. degree: Purdue University, 1978, Advisors: ; Professors Ken Stanfield and Edward I. Shibata

Selected recent publications:

"Search for Electron Neutrino Appearance at the $\Delta m^2 \sim 1$ eV^2 Scale", with A. A. Aguilar-Arevalo et al. (for the MiniBooNE Collaboration), Phys. Rev. Lett. ***98****, 231801 (2007).*

J. P. Bernstein et al., "Supernova Simulations and Strategies for The Dark Energy Survey", July 10 2012, The Astrophysical Journal 753:152.

A. A. Aguilar-Arevalo et al., "Improved Search for nu_bar_mu -> nu_bar_e Oscillations in the MiniBooNE Experiment", Phys. Rev. Lett. 110 161801 (15 April 2013).

T. Treu et al., "Dark energy with gravitational time delays", White Paper submitted to Snowmass 2013 available 6 June 2013 at http://lanl.arxiv.org/abs/1306.1272.

M. Smith et al., "The Effect of Weak Lensing on Distance Estimates from Supernovae" submitted to ApJ July 9 2013 and accepted for publication, available at http://arxiv.org/abs/1307.2566 Selected recent publications:

Leadership and management positions at Fermilab:
Lead Organizer for Fermilab-based liquid argon TPC R&D

Arranged for Shipping and Custodianship of all parts of DECam across international borders within the law and in accord with the DES Interagency MOU

Provided initial versions of the DES Integrated Schedule

Education and Outreach activities:
Took and posted minutes of the DECam Project Management Group meetings (attended by DOE)

Arranged for presentations on science done at Fermilab for elementary school classes

David Finley
Research Summary

Current Experiments
Dark Energy Survey - 80%
Large Synoptic Space Telescope – 10%
MiniBooNE – 10%

Current Roles
DES: Participant in Supernova (SN) Working Group, Scanner for SN; Participant in Quasar Working Group, Participant in Strong Lensing (SL) Working Group.

LSST: Participant in SL group; participant in SpaceWarps.

MiniBooNE: Member of Collaboration

Recent Accomplishments
DES: Evaluation of initial DES data (aka Science Verification) with emphasis on oddities / problems with the camera itself or transients from the sky that confuse SN scanning; second most prolific SN scanner; helped with initial technique to ignore light from bright stars which can confuse SN scanning; found known strong lenses in a DES SN field.

LSST: Began collaboration within the Dark Energy Science Collaboration as a member of the SL group; co-author on Snowmass 2013 white paper "Dark energy with gravitational time delays"; active participant in SpaceWarps to learn how to recognize strong lenses.

MiniBooNE: Read and comment on draft papers

Future Plans
DES: Continue with SN involvement. The involvement with quasars and strong lensing is aimed at understanding how to detect multiple lensed sources, which other instruments will characterize to use time delays to constrain cosmological parameters.

LSST: Help to figure out how to use DES experience to advance the ability of LSST to constrain cosmological parameters (such as the Hubble constant) using time delays from multiple lensed sources. This involves more instruments than just DECam and/or LSST.

MiniBooNE: Continue at same (or increased) level.

Other Efforts
If LSST gets delayed too much, then consider joining DESI

Brenna Flaugher

Present Position: Scientist II, Fermilab, 2005 - current
Previous Positions: Scientist I, Fermilab, 1998 – 2005; Associate Scientist, 1993 – 1998; Research Associate, 1990 – 1993; Research Associate, Rutgers, 1989 – 1990
Ph.D. degree: Rutgers 1989, Advisor: Professor Tom Devlin
Awards: APS Fellow Division of Particle Astrophysics Nov. 2011 "For her important contributions to experimental particle astrophysics, particularly her leadership of and seminal contributions to the design and construction of the Dark Energy Camera
Selected recent publications:
Status of the dark energy survey camera (DECam) project", B. Flaugher et al., Proceedings of the SPIE Conference on Astronomical Instrumentation, 1-6 July 2012, Amsterdam, 8446-35 (2012); Preprint: FERMILAB-CONF-12-317-AE-E
"DECam integration tests on telescope simulator", for the DES Collaboration Proceedings of the 2nd International Conference on Technology and Instrumentation in Particle Physics (TIPP 2011). Physics Procedia. arXiv:1111.4717
"Direct Search for Low Mass Dark Matter Particles with CCDs" J. Barreto, H. Cease, H. T. Diehl, J. Estrada, B. Flaugher, N. Harrison, J. Jones, B. Kilminster, J. Molina, J. Smith, T. Schwarz, A. Sonnenschein; Instrumentation and Methods for Astrophysics (astro-ph.IM); arXiv:1105.5191.
"Status of the dark energy survey camera (DECam) project", B. Flaugher et al., Proceedings of the SPIE Conference on Astronomical Instrumentation, 27 June to 2 July 2010, San Diego, CA, 7735-12 (2010); Fermilab-Conf-10-214-A.
Will Multiple Probes of Dark Energy find Modified Gravity?" C. Shapiro, S. Dodelson, B. Hoyle, L. Samushia, B. Flaugher, accepted by PRD Aug. 2010, arXiv:1004.4810v
Selected recent presentations:
"The dark energy survey camera, DECam" at the DES special session AAS Jan. 2013
Dark energy and Cosmology Lectures to summer students at Fermilab June 2012 and 2013
"Status of the dark energy survey camera (DECam) project", B. Flaugher SPIE Conference on Astronomical Instrumentation, 1-6 July 2012
"DECam" at the DES special session AAS Jan. 2012
"Status of the dark energy survey camera (DECam) project", B. Flaugher SPIE Conference on Astronomical Instrumentation, 27 June to 2 July 2010, San Diego, CA
Leadership and management positions at Fermilab:
Fermilab, 2004 – 2012 Project Manager for the Dark Energy Camera ($35M DOE funds + 7M in-kind contributions; completed on budget and on schedule; CD-0 through CD-4)
Leadership in the broader community:
2009-2010 Member; National Research Council Astro 2010 Decadal Survey Electromagnetic Observations from Space Program Prioritization Panel
Reviewer: LSST DOE/Office of Science Review June 2013; LBNL OHEP program Review June 2013; NSF Advanced Technology Solar Telescope Oct. 2012, Feb. 2013; DOE Cosmic Frontier Experimental Operations Review Sept. 2012; LBNE CD-1 Director's review March 2012; LSST DOE CD-1 Review Nov. 1-3, 2011; LSST Director's Review June 8-10, 2011; WIYN Director's Review of the One Degree Imager (ODI) Project Oct. 2011

Brenna Flaugher
Research Summary

Current Experiments
Mid-Scale Dark Energy Survey Instrument (MS-DESI) – 50%
Dark Energy Survey (DES) 25%
Astrophysics Department Management – 25%

Current Roles
Dark Energy Survey: Committee Chair, Early Career Scientists; Assisting with Operations; Mentor to two postdocs doing DES analysis

MS-DESI: Fermilab Institutional Representative, Member, Steering Committee, Manager for integration on the Mayall.

Recent Accomplishments
I completed the DECam project on budget and on schedule in June 2012

Future Plans
I plan to ramp up to 50% on MSDESI and continue at about 25% on DES.

Other Efforts
Active participant in agency and journal review, as well as education and outreach activities.

Joshua Frieman

Present Position: Scientist III, Fermilab, 1988 - current
Previous Positions: Scientist II, Fermilab, 1996 – 2008; Scientist I, 1992 – 1996; Associate Scientist, 1988 – 1992
Ph.D. degree: University of Chicago, 1985, Advisor: Professor Michael S. Turner
Awards: Performance Recognition Award (Fermilab), 2006; APS Fellow; American Association for the Advancement of Science Fellow; Phi Beta Kappa

Selected recent publications:

J. Frieman, M. Turner, D. Huterer, "Dark Energy and the Accelerating Universe", Ann. Rev. Astron. Astrophys., 46, 385 (2008).
R. Kessler, A. Becker, D. Cinabro, J. Vanderplas, J. Frieman, et al., "First-year SDSS-II Supernova Results: Hubble Diagram and Cosmological Parameters", Astrophys. J. Supp., 185, 32 (2009).
J. Frieman, et al., "The SDSS-II Supernovae Survey", Astron. J., 135, 338 (2008).
J. Bernstein, et al., "Supernova Simulations and Strategies for the Dark Energy Survey", Ap.J., 753, 152 (2012).
H. Campbell, et al., "Cosmology with Photometrically Calibrated Type Ia Supernovae from the SDSS-II Supernova Survey", Ap.J. 763, 88 (2013).

Selected recent presentations:

Colloquium on "The Dark Energy Survey", Columbia University (Sept. 2013), Harvard-Smithsonian Center for Astrophysics (May 2013), Texas A&M (Dec. 2012), Brown University (Nov. 2012), Enrico Fermi Institute (Jan. 2010)
Colloquium and seminars on "Probing Dark Energy: First Results from the SDSS-II Supernova Survey", Carnegie Observatories (Feb. 2008), U. Barcelona (Mar. 2009), U. Chicago (April 2009), Fermilab (Sept. 2009), U. Kentucky (Jan. 2010)
Studies of Dark Energy, APS DPF Plenary, UC Santa Cruz, Aug. 2013
Dark Energy Surveys, Lepton-Photon, SLAC, June 2013, Intl. Conf. on Cosmology and Gravitation, Goa, India, Dec. 2011, Science with a Wide-field Telescope in Space, Pasadena Feb. 2012
The Dark Energy Survey, AAS Jan. 2013 and Jan. 2011, Benasque Cosmology Workshop Aug. 2012, Cooks Branch April 2012, Aspen Winter Conf. Feb. 2012 and Jan. 2010, DOE Workshop on Computing at the Cosmic Frontier, Rockville MD Sept. 2011, The Search for Fundamental Physics, UCSC, Jan. 2013

Leadership and management positions at Fermilab:

Director, Spokesperson, Management Committee Chair of the Dark Energy Survey (since Mar. 2010)
DES Science Committee Co-Chair, 2006-2010
Lead, SDSS-II Supernova Survey, 2004-2009

Leadership in the broader community:

HEPAP Subpanel on Future DOE HEP Facilities, 2013
National Research Council Committee on Astronomy & Astrophysics (CAA), 2012-current
National Research Council Committee on the Assessment of a Plan for US Participation in Euclid, 2012
National Research Council Astronomy & Astrophysics Decadal Survey Committee, 2008-2010
Particle Physics Project Prioritization Panel (P5), 2008-2010
SLAC Science and Technology Review panel, 2012
Astronomy & Astrophysics Advisory Committee (AAAC), 2010-2013
Aspen Center for Physics Vice-President (2013-current), Trustee (2006-2012)
International Advisory Committee, International Institute of Physics, University of Rio Grande del Norte, Natal, Brazil, 2010-2013

Education and Outreach activities:

Supervisor for U. Chicago graduate students C. Cunha (PhD 2008), B. Dilday (PhD 2008), M. Lima (PhD 2008), F. Marin (PhD 2010), J. Helsby (current), A. Zablocki (current), and KICP postdocs R. Reyes (current), K. Bechtol (current)
Board of Directors, Aspen Science Center

Joshua Frieman
Research Summary

Current Experiments
Dark Energy Survey (DES) -90%
Large Synoptic Space Telescope (LSST) - 10%

Current Roles
DES Director, Spokesperson, Chair of Management Committee, Chair of Executive Committee
Report to DES Council
Report to DES DOE-NSF Joint Oversight Group
LSST member of Supernova Science Collaboration and Dark Energy Science Collaboration

Recent Accomplishments
Installation, commissioning, and Science Verification of DES completed successfully
Successful DOE-NSF review of DES April 2013
Project ready for start of survey operations at end of Aug. 2013

Future Plans
Carry out first seasons of DES survey operations and science analysis of Science Verification and early DES data, leading to first dark energy constraints from DES.
Participate in planning of and coordination with LSST and DESI projects.

Other Efforts
Partially supported by the Fermilab Theoretical Astrophysics group. Also teach and carry out research in the Astronomy and Astrophysics Department, and the Kavli Institute for Cosmological Physics at the University of Chicago

Henry Glass

Present Position: Scientist II, Fermilab, 2002-current
Previous Positions: Scientist I, Fermilab, 1996-2002; Associate Scientist, 1990-1996, The Aerospace Corp., 1985-1989, Research Associate, State University of New York at Stony Brook, 1980 - 1985.

Ph.D. degree: State University of New York at Stony Brook, 1985, Advisor: Professor R.L. McCarthy

Selected recent publications:
"The Pierre Auger Observatory: Contributions to the 33rd International Cosmic Ray Conference", (ICRC 2013), arXiv:1307.5059.
"Contrast Defect Due to End Mirror Imperfections, Holometer", Note #1469, 2012.
"Measurement of the energy spectrum of cosmic rays above 10^{18} eV using the Pierre Auger Observatory", Phys. Lett. B685 (2010), 239.
"Correlation of the highest-energy cosmic rays with the positions of nearby active galactic nuclei", Astropart. Phys. 29 (2008) 188.
"Observation of the suppression of the flux of cosmic rays above $4x10^{19}$ eV", Phys. Rev. Lett. 101 (2008) 061101.

Leadership and management positions at Fermilab:
Member, Fermilab Committee for Scientific Appointments (FCSA), 2007-10
Project Manager for Permanent Magnets, Fermilab Technical Division, 1996-99.
Responsible for magnetic field measurements for the Fermilab Main Injector (FMI) accelerator project, including the Recycler program

Leadership in the broader community:
Technical Editor for the Design Study Report for a Staged VLHC; presented at Snowmass Summer Study hadron collider working group, 2001

Education and Outreach activities:
Member of Fermilab Auditorium Committee, 2000-2012; Chair of Auditorium Committee 2004-06
Chair of Public Lecture Sub-Committee, 2006-10.
Teaching Experience - College of DuPage, 2005-2006. Adjunct faculty, Department of Physics. California State University, Dominguez Hills campus, 1987-88; Long Beach campus, 1988-89; Part-Time Lecturer, Department of Physics.

Henry Glass
Research Summary

Current Experiments
Pierre Auger - 25%
Holometer - 25%
Mu2e (Intensity Frontier) - 50%

Current Roles
Auger: I have until very recently been part of the project management office, but this has just transitioned from Fermilab to Karlsruhe Institute of Technology (KIT). That may leave some period where administrative tasks dwindle exponentially. Research tasks will include planning upgrades to carry Auger beyond the 2015 time frame. These upgrades are mainly aimed at enhanced muon detection.

Holometer: My role in this experiment has been to take the lead in developing simulations of the interferometer optics. The simulations include as much detail as possible, including the surface metrology of the mirrors, in order to predict the contrast defect as precisely as possible. I am also the liaison for this experiment to the Laboratory's laser safety committee.

Mu2e: This is a new research area for me that lies outside the Cosmic Frontier. As a member of Fermilab's Technical Division, it is expected that I spend a substantial fraction of my time on Intensity Frontier projects. I have already done a fair amount of project management work for them, including developing a system to manage change control and a web-based system for electronic approvals of requirements documents

Recent Accomplishments
Auger: The last three years have mainly been spent in various project management tasks. An example of such a task was developing database scripts to create author lists in XML format as required by the INSPIRE system. Some research time was available to do statistical analysis of the AGN correlation signal. I was one of the local organizers of the ISVHECRI conference held at Fermilab in July 2010 and edited the proceedings.

Holometer: My main focus has been on laser optics. I have run simulations of the interferometer which has helped us determine which combinations of optical elements would provide the best configuration for the experiment. I also did a conceptual study for an output mode cleaner.

Future Plans
Auger: My involvement will decrease, and may be limited to remaining data analysis issues and upgrade planning.

Holometer: In addition to simulation studies, I expect to be involved in various aspects of commissioning, data taking, and analysis.

Erik Gottschalk

Present Position: Scientist II, Fermilab, 2008 - current
Previous Positions: Scientist-I, Fermilab, 2003 – 2008; Associate Scientist, 1998 – 2003;Visiting Research Assistant Professor, Univ. of Illinois at Urbana-Champaign, 1996 – 1998

Ph.D. degree: Columbia University, 1992, Advisor: Professor Bruce Knapp

Selected recent publications:
Gottschalk, Erik E., A prototype for JDEM science data processing, J.Phys.Conf.Ser., 331, 072016, 2011.

Taylor, Lucas and Gottschalk, Erik E., CMS centres worldwide: A new collaborative infrastructure, J.Phys.Conf.Ser., 219, 082005, 2010.

Gottschalk, Erik E., Collaborating at a distance: operations centres, tools, and trends, J.Phys.Conf.Ser., 219, 012001, 2010.

Bayatian, G.L., et al., CMS technical design report, volume II: Physics performance, J.Phys.G, G34, 995-1579, 2007.

Christian, D.C., et al., Search for exotic baryons in 800-GeV pp ---> p Xi+- pi+- X, Phys.Rev.Lett., 95, 152001, 2005.

Leadership and management positions at Fermilab:
Deputy Head of Particle Physics Division (PPD)

Deputy Head of PPD/EPP, Experimental Physics Projects Department in PPD

Technical Point of Contact for the Large Synoptic Survey Telescope (LSST)

Project Director for MC-1 Building

Project Director for the Liquid Argon Test Facility (LArTF)

Project Director for the Experiment Operations Center (XOC)

Leader of the LHC@FNAL Remote Operations Center (ROC) to establish the Fermilab LHC and CMS operations center, which served as a precursor for CMS Centres Worldwide

Erik Gottschalk
Research Summary

Current Experiments
Compact Muon Solenoid (CMS) – 20%

Fermilab Particle Physics Division (PPD) Deputy Division Head – 80%

Current Roles
Interim Deputy Project Manager for the LHC CMS Detector Upgrade Project

Deputy Division Head for the Fermilab Particle Physics Division

Recent Accomplishments
Acted as Interim Deputy Project Manager for the LHC CMS Detector Upgrade Project. Worked with the Interim Project Manager to establish a Project Office and Project Team to prepare for reviews that are necessary to obtain funding for the CMS Upgrade Project. The Project received CD-0 in September of 2012, had a successful Director's Independent Design Review in May 2013, is preparing for a Director's CD-1 Readiness Review in July 2013, and preparing for a DOE CD-1 Review in August 2013. Responsibilities of the Interim Deputy Project Manager include developing a Work Breakdown Structure, developing a Resource Loaded Schedule, establishing cost accounts, developing documents for CD-1 Director's and DOE reviews, building a team of L2 Managers, managing the team, providing guidance to L2 Managers to prepare for reviews, making presentations to DOE and NSF and Fermilab Management, and preparing for the transition from the Interim Project Manager to the actual Project Manager

Future Plans
Complete the transition to the new Project Manager for the CMS Upgrade (2013)

Gaston Gutierrez

Present Position: Scientist II, Fermilab, 1983 - current
Previous Positions: Scientist I, Fermilab, 1994 – 2001; Associate Scientist 1988 – 1994; Research Associate
1985 – 1988;Guest Scientist, 1983 – 1985

Ph.D. degree: University of La Plata , Argentina, 1983, Advisor: Professor Angel Plastino.
Awards: Fellow, the American Physical Society (APS), 2009; APS Edward Bouchet award, 2008.

Selected recent publications:
"The impact of camera optical alignment on weak lensing measurements for the Dark Energy Survey", MNRAS, 431 (2013) 3291.

"Search for violation of Lorentz Invariance in top quark production and decay", Phys. Rev. Lett. 108 (2012) 261603.

"Direct measurement of the mass difference between top and antitop quarks",

Phys. Rev. D 84 (2011) 052005.

"Precise measurement of the top-quark mass from lepton+jets events at D0",

Phys. Rev. D 84 (2011) 032004.

"Direct measurement of the mass difference between top and antitop quarks",

Phys. Rev. Lett. 103 (2009) 132001.

Selected recent presentations:
"Instrumentation needs in Dark Energy", IFCM, Argonne, January 2013.

"Recent results on top quark physics at the Tevatron", LC11, Trento, Italy, September 2011.

"Top, Higgs and searches at the Tevatron", lecture for summer students, FNAL, June 2009.

"The Physics at the Fermilab Tevatron Collider", Invited talk at NSBP/NSHP, Nashville, February 2009.

Leadership and management positions at Fermilab:
Assistant Head of DDO, January 2012 – current; Associate Head of D0 Department, 2006 - 2012; Co-leader of the "Physics Support Group" of the D0 experiment, 2006 -2012.

Education and Outreach activities:
Taught an Instrumentation School at the "Universidad de Buenos Aires" in Argentina; a nine week graduate level course during October to November , 2011; I also taught at the EDIT2012 and EDIT2013 Instrumentation Schools; Until recently I supervised 4-5 D0 postdocs; Over the past few years I have supervised several high school and physics under graduate students.

Gaston Gutierrez
Research Summary

Current Experiments
Mid-Scale Dark energy Spectroscopic Instrument (MS-DESI) -50%
Dark Energy Survey -5%
Microwave Kinetic Inductance Detectors (MKID)s R&D - 10%

Current Roles
L2 manager for the "Barrel Mechanical" in MS-DESI
Setting up for data analysis in DES
Helping initiate the MKIDs program at Fermilab.

Recent Accomplishments
Finishing the design of the MS-DESI barrel and telescope top end

Future Plans
I plan to continue working on MS-DESI, DES and MKIDs R&D

Craig J. Hogan

Present Position: Scientist III, Fermilab, 2008 - current
Previous Positions: Professor, Department of Astronomy and Astrophysics, Enrico Fermi Institute, and Kavli Institute for Cosmological Physics, University of Chicago (2008-); Vice Provost for Research, 2002-2005; Professor, Astronomy and Physics Departments, 1993-2008; Divisional Dean of Natural Sciences, 2001-2002; Chair, Astronomy Department, 1995-2001; Associate Professor, Astronomy and Physics Departments, University of Washington, 1990-1993
Ph.D. degree: University of Cambridge, United Kingdom, 1980, Advisor: Martin Rees
Awards:
Fellow, American Academy of Arts & Sciences (2009)
Fellow, American Physical Society (2009)
Gruber Cosmology Prize (co-recipient, as member of High Z Supernova Team, for discovery of Dark Energy) (2007)
Alexander von Humboldt Research Award (1999-2008)
Discovery of the Year, *Science* magazine (1998) (for team's co-discovery of Dark Energy)
Selected recent publications:
Indeterminacy of Holographic Quantum Geometry, Craig J. Hogan, Phys. Rev. D 78, 087501, (2008)
Holographic Geometry and Noise in Matrix Theory, Craig J. Hogan, Mark G. Jackson, Phys. Rev. D 79, 124009 (2009)
Interferometers as Probes of Planckian Quantum Geometry, Craig J. Hogan, Phys. Rev. D 85, 064007 (2012)
Macroscopic Quantum Geometry, Craig J. Hogan, arXiv: 1204.5948.
Quantum Geometry and Interferometry, Craig Hogan, arXiv: 1208.3703. To appear in proceedings of the 9th LISA symposium, Proc. Astr. Soc. Pac (2012).
Selected recent presentations:
Aspen Center for Physics 50th anniversary lecture (2012)
Aspen Ideas Festival (2013)
IEEE Aerospace Conference (2013)
Plenary speaker, LISA symposium (2012)
Texas conference on Relativistic Astrophysics (2009
Leadership and management positions at Fermilab:
Director, Fermilab Center for Particle Astrophysics
Leadership in the broader community:
Member, Aura Management Council for LSST; Member, LSST Corporation Board
Member, Scientific Advisory Board, KITP
Member, SLAC SPC
Member, LISA International Science Team
Chair, NASA Astrophysics Subcommittee
Canadian Institute for Advanced Research Chair, Five Year Review Panel, Cosmology and Gravity Program
Austrian Academy of Science, Vienna: Institute for High Energy Physics, Director's Search committee member
National Optical Astronomy Observatories: System Roadmap Committee
Member, Fermilab Director Search Committee

Craig J. Hogan
Research Summary

Current Experiments
Hogan's main research effort is associated with the Fermilab Holometer experiment and related theory, including connections with and implications for other areas such as the dark energy problem.

Current Roles
Hogan is Project Scientist for the Holometer. The studies include connections to the theories that motivate the experiment, phenomenological calculations of signal properties, conceptual design of experimental strategy and procedures (such as design of null test tests), advocacy, publication planning, writing and talks.

Recent Accomplishments
This year he found a new covariant formulation and interpretation of non-commutative geometry that describes a quantum-geometrical theory of a massive body at rest, ignoring all standard quantum degrees of freedom. The theory is intermediate between, and complementary to, quantum field theory and classical relativity. It provides a rigorous connection of the information content of position states with quantum geometrical angular uncertainty, relating the amplitude of geometrical fluctuations directly to the Planck time. (http://arxiv.org/abs/1204.5948).

Future Plans
Connect the results of Holometer experiment with Planck scale quantum geometry theory, including non-commutative geometry and emergent gravity, and with theories of dark energy. Improve the logical connection with standard field theory, starting with quantization of paraxial modes.

Other Efforts
Hogan's main effort on KA23 is his role as Director for the Fermilab Center for Particle Astrophysics, a half time position. The other half of his time is funded by his faculty appointment in the University of Chicago Department of Astronomy and Astrophysics.

Lauren Hsu

Present Position: Associate Scientist, Fermilab, 2012 - current
Previous Positions: Research Associate, Fermilab, 2007 -2012; Postdoctoral Fellow, Nuclear Science Division
Lawrence Berkeley National Laboratory, 2006 – 2007; E.O. Lawrence Postdoctoral Fellow, Lawrence Berkeley
National Laboratory, 2004 - 2006
Ph.D. degree: Cornell University, 2004, Advisor: Professor Ritchie Patterson

Awards: Fermilab Reward and Recognition, Center for Particle Astrophysics, 2011; _ Fermilab Exceptional Performance Recognition Award (EPRA), 2010

Selected recent publications:
"Snowmass CF1 white paper (WIMP Dark Matter Direct Detection)", in final editing
"Demonstration of Surface Electron Rejection with Interleaved Germanium Detectors for Dark Matter Search", R. Agnese et al., submitted to PRL for publication in 2013.
"Dark Matter Search Results Using the Silicon Detectors of CDMS II", R. Agnese et al, submitted to PRL for publication in 2013.
"Silicon Detector Results from the First Five-Tower Run of CDMS II", R. Agnese et al., PRD 2013.
"A Search for the Dark Matter Annual Modulation in South Pole Ice", R. Cherwinka et al, Astroparticle Physics 2012.

Selected recent presentations:
University of Chicago Physics Department Colloquium, Chicago IL, May, 2013
Plenary talk at IceCube Particle Astrophysics, Madison, WI, May 2013
Fermilab Colloquium, Batavia, IL, October 2012
Plenary talk at ICHEP, Melbourne, July 2012

Leadership and management positions at Fermilab:
SuperCDMS analysis coordinator, 2012- current

Lauren Hsu
Research Summary

Current Experiments
SuperCDMS - 100%, not transitioning between experiments

Current Roles
SuperCDMS analysis coordinator (for both ongoing CDMS II and SuperCDMS)

Data reconstruction, calibration and software expert/developer for SuperCDMS

SuperCDMS data quality system expert/developer

Recent Accomplishments
Coordinating first searches for low mass WIMPs with iZIPs (impending results), 2012- present

Coordinated first underground demonstrations of surface event rejection with iZIPs (paper under review), submitted to DOE and NSF as part of G2 R&D proposals, 2012

Coordinated release of two major CDMS II results (WIMP searches with Silicon), 2013

Designed, developed and delivered the SuperCDMS data quality system, 2011-2012

Developed initial sensitivity estimates for a large array of NaI crystals to the annual modulation effect from dark matter interactions, wrote and edited paper describing concept for experiment (concept paper published in 2012)

Future Plans
Expect to be transitioning out of role of SuperCDMS analysis coordinator this coming year. Will continue to be involved with analysis of SuperCDMS Soudan data and reconstruction efforts for foreseeable future.

Developing early career proposal for direct detection of dark matter, expecting to remain on SuperCDMS at least 50% of the time.

Anticipating funding of 200-kg SuperCDMS proposal. If provided, will take a lead role in construction of SNOLAB experiment.

Other Efforts
Research Associate Hiring Committee, Fermilab Center for Particle Astrophysics 2012 - current

Steve Kent

Present Position: Scientist II, Fermilab, 1999 - current
Ph.D. degree: California Institute of Technology, 1980, Advisor: Professor W.L. W. Sargent
Awards: American Physical Society Fellow, 2011; Presidential Young Investigator, 1985-1990; A. P. Sloan Fellow 1985-1989; Fannie and John Hertz Fellow 1974-1979

Selected recent publications:
Abazajian, K. N. + 203 authors 2009, *The Seventh Data Release of the Sloan Digital Sky Survey*, ApJS, 182, 543.
Kent, S., Kaiser, M. E. + 34 authors 2009, *Photometric Calibrations for 21st Century Science*, Astro2010: The Astronomy and Astrophysics Decadal Survey, Science White Papers, no. 155.
Scarpine, N. E., Kent, S. M., Deustua, S. E., Sholl, M. J., Mufson, S. L., Ott, M. M., Wiesner, M. P., & Baptista, B. J. 2010, *The ring of fire: an internal illumination system for detector sensitivity and filter bandpass characterization*, Proc. SPIE, 7731, 108.
Kent, S. + 11 coauthors 2012, *Dark Energy Spectrometer - A Proposed Multi-Fiber Instrument for the Blanco 4 Meter Telescope*, AAS Meeting #219, 422.09.
Deustua, S., Kent, S. & Smith, J. A. 2013 *Absolute Calibration of Astronomical Flux Standards,* in **Planets, Stars and Stellar Systems**, ed. Oswalt, Terry D. & Bond, Howard E., ISBN 978-94-007 (Springer: Dordrecht), p. 375.

Selected recent presentations:
Invited talk at Calibrations Conference, Fermilab, 2012
Colloquium, Indiana University, 2008
Invited talk at NVO meeting, Madrid, 2008

Leadership and management positions at Fermilab:
Head, Experimental Astrophysics Group 1999-present
SDSS, Head, Survey Planning 2000-2008
Deputy Project Scientist, DOE project office, JDEM 2010-2011
DES, Coordinator Focus/Alignment Systems 2011-2013

Leadership in the broader community:
Reviewer, NSF MRI program 2009
Reviewer, LAMOST software 2010
Conference organizer, “Calibrations and Standardization ...” 2012
Reviewer, NASA ADAP program 2013

Steve Kent
Research Summary

Current Experiments
Dark Energy Survey (DES) - 75%
Dark Energy Spectroscopic Instrument (DESI) - 20%
Large Synoptic Survey Telescope (LSST) - 5%

Current Roles
DES: My most important role is being involved in the impact of optics and opto-mechical systems on data quality. I also work on a multitude of issues involving survey strategy and calibration, which involve both simulations and data analysis. I also take shifts down in Chile during observing. I am the maintainer of one of the observing programs used by observers.
DESI: This project supersedes the Dark Energy Spectrograph project. My current role is owning the requirements document in preparation for a CD1 review
LSST: I have been working with the Dark Energy Science Consortium on defining requirements for computing analysis.

Recent Accomplishments
Joint Dark Energy Mission (JDEM) - While this project was active, I served as a deputy project scientist to the DOE project office at LBNL and was heavily involved in simulations for the slit-less spectroscopy component of the mission. I also worked on building a prototype of a calibration illumination system.
Dark Energy Survey: My most important role was serving as Focus/Alignment Systems coordinator, serving to coordinate two different alignment monitoring systems being constructed for use in DECam. I also coordinated with telescope activities in Chile. Finally, I participated in the early commissioning of DECam.
DESpec: This project was a proposed upgrade to DECam, converting it to a multi-fiber spectrograph to obtain high accuracy redshifts for objects detected by DES. My main activity was evaluating the performance of various optical designs and their impact on science requirements. Recently this effort was merged with BigBOSS to create the Dark Energy Spectroscopic Instrument.

Future Plans
I expect to continue working on DES, DESI, and LSST. DES begins operations, so I expect to continue helping with observing and evaluating the performance of DECam based on data quality. DESI will enter the construction phase, and I expect to continue work on the impact of instrument performance on science requirements. For LSST there is a goal of installing and testing some of the project software.

Richard Kron

Present Position: Scientist III, Fermilab, 1990 - current
Previous Positions:
Ph.D. degree: University of California, Berkeley, 1978, Advisor Professor Ivan R. King
Awards: Robert J. Trumpler Award (Astronomical Society of the Pacific), 1981; Newton Lacy Pierce Prize (American Astronomical Society), 1985; Quantrell Teaching Award (University of Chicago), 1995

Selected recent publications:
H. Aihara and 179 co-authors "The Eighth Data Release of the Sloan Digital Sky Survey: First Data from SDSS-III" 2011 ApJS 193, 29
J.A. Frieman and 100 co-authors "The Sloan Digital Sky Survey-II Supernova Survey: Technical Summary" 2008 AJ 135, 338 - 347
D.P. Schneider and 47 coauthors "The Sloan Digital Sky Survey Quasar Catalog. V. Seventh Data Release" 2010 AJ 139, 2360 – 2373
Cosmological constraints for the clustering of the Sloan Digital Sky Survey DR7 luminous red galaxies 2010 MNRAS, 404, 60 Reid, Beth A. and 29 coauthors
Cluster and cluster galaxy evolution history from IR to X-ray observations of the young cluster RXJ1257.2+4738 at z = 0.866 2009 A&A, 503, 399 Ulmer, M.P. and 10 coauthors

Selected recent presentations:
"The Dark Energy Camera at the Blanco Telescope," presentation at a conference honoring Piero Salinari, November 1-3, 2010, Kloster Seeon, Bavaria.
Fermilab Chalk Talk, November 15, 2012, "Adaptive Optics for the Giant Magellan Telescope"
Presentation to the University of Chicago Computation Institute, November 30, 2011, "The Dark Energy Survey"
Presentation at a workshop on Ultra High-Energy Cosmic Rays, Golden, CO May 6, 2008, "Extragalactic Surveys"

Leadership and management positions at Fermilab:
Deputy Director, Dark Energy Survey, March 2010 –
Director, Sloan Digital Sky Survey July 2003 – December 2008
Chair, Dark Energy Spectrometer Steering Committee
Member, Dark Energy Spectroscopic Instrument Steering Committee

Leadership in the broader community:
Chair, Scientific Advisory Committee of the Giant Magellan Telescope
Chair, Scientific Organizing Committee for "Cosmology in the Era of Extremely Large Telescopes"
First Annual GMT Community Science Meeting

Richard Kron
Research Summary

Current Experiments
Dark Energy Survey (DES) – 50%
Dark Energy Spectroscopic Instrument (DESI) – 25%
The remaining 25% is spent on research projects not related to DOE funding

Current Roles
Kron is currently Deputy Director for the Dark Energy Survey, and is a member of the Steering Committee for the Dark Energy Spectroscopic Instrument. He serves on the DES Executive Committee and the Management Committee (representing the University of Chicago), and serves on a number of ad hoc committees (for example, the Survey Strategy Task Force).

Recent Accomplishments
Kron drafted the Project Operations Plan for the Dark Energy Survey and has chaired four reviews of Brazil Science Portal. He edited the White Paper (arXiv:1307.8061) for the Dark Energy Spectrometer that was completed in September 2012. He contributed to the Bylaws document for DESI, focusing especially on the process for recruiting institutional partners.

Future Plans
The DES will start collecting data (officially) on August 31 2013 and Kron expects to be fully involved with all aspects of the project: taking shifts at the telescope, working on assessing data quality, and generally helping to see that the processed data are of high quality and assessable to the DES Collaboration in an effective and timely way. He expects to become more involved in the Science Working Groups from this point forward.

Kron's future role in DESI is not clear at this point, but it will likely be related to Fermilab's involvement since the University of Chicago may choose not to join as a partner. It is possible that Kron can contribute to the definition of the bright-time use of the Mayall Telescope by bringing to bear his connections with the broader astronomy community.

Other Efforts
Kron is a Professor at the University of Chicago and has ongoing teaching responsibilities there, as well as other professional commitments related to his academic appointment. The research programs he is undertaking that do not involve significant Fermilab personnel or other resources include the Giant Magellan Telescope and the Magellan Telescope. Kron is supported on DOE funds for 20% of his salary and by the University of Chicago for 80% of his salary.

Paul LeBrun

Present Position: Scientist II, Fermilab, 1982- current
Previous Positions: Scientist I, Fermilab, 1986 – 1982, Accelerator Physics Center
Ph.D. degree: University Catholique de Louvain, Belgium, 1978, Advisor: Professor Lazlo Grenach

Selected recent publications:
"Simulation of the Electron Flux into the Main Injector Electron Cloud Retarding Field Analyzer Using Vorpal", ***Paul L.G. Lebrun, James F. Amundson, Panagiotis G. Spentzouris, Seth A. Veitzer*** and ***Peter Stoltz*** Pp 1-5 [DOI: 10.2174/1876534301306010001] (Published Date: 30 April, 2013)
"Interpretation of the Depths of Maximum of Extensive Air Showers Measured by the Pierre Auger Observatory", ***JCAP*** 02 (2013) 026; arXiv:1301.6637
"Constraints on the origin of cosmic rays above 10^{18} eV from large scale anisotropy searches in data of the Pierre Auger Observatory", ***ApJL*** 762 (2013) L13; arXiv:1212.3083
"A Search for Point Sources of EeV Neutrons", ***ApJ.*** 760 (2012) 148; arXiv:1211.4901
"Large scale distribution of arrival directions of cosmic rays detected above 10^18 eV at the Pierre Auger Observatory", ***Ap. J. Suppl.*** 203 (2012) 34; arXiv:1210.3736

Leadership and management positions at Fermilab:
Chairman of the Fermilab Colloquium Committee for the past two years

Paul LeBrun
Research Summary

Current Experiments
Pierre Auger - 50%
Various Intensity Frontier - 50%

Current Roles
Pierre Auger Collaboration, active in the Surface Detector data reconstruction and analysis
Performing numerous analysis related to the energy resolution of the Surface Detector
Strong participation in the investigation of Surface Detector aging and related systematic uncertainties
Maintain and update the "master copy" of the non-event database (calibration, weather, etc.)
Participate to Fluorescence Detector data taking – 2012

Recent Accomplishments
Ultra High Energy rays above the GZK do correlate with the AGNs. The change in the apparent rate of correlation that occurred in 2007 to 2009 is on the verge of being understood: the combined effects of a loss of light collection efficiency in the Cerenkov Detector along with non-linearities in the response of the PMT and electronics could lead to a degradation of the energy resolution, leading to a smearing of the anisotropy, should this anisotropy depend strongly on energy
.

Future Plans
Document the above thesis more fully and re-compute the AGN signal significance level, taking into account a conservative estimate of the energy resolution. This, with new Galactic Magnetic Map, and allowing for heavy nuclei at the very highest energies.

Update this recent survey with the most recent data

Other Efforts
LBNE: - Active in the Beam Simulation group

Senior developer of GEANT4 based simulation tools Accelerator Code development - rewriting ESME in C++, ESME is a simulation computer code that simulates the longitudinal motion of particles in a synchrotron. Our ultimate goal is to merge it with Synergia.

As needed - debugging and documenting the Synergia code, developed by the members of the Accelerator Simulation group in the Scientific Computing Division.

Huan Lin

Present Position: Scientist II, Fermilab, 2013 - current
Previous Positions: Scientist I, Fermilab, 2006-2013, Associate Scientist, 2001-2006; Hubble Fellow, Steward Observatory, University of Arizona, 1998 – 2001

Ph.D. degree: Harvard University, 1995, Advisor; Professor Robert Kushner

Selected recent publications:
Lin, H., Dodelson, S., Seo, H.-J., Soares-Santos, M., et al. 2012, "The SDSS Co-add: Cosmic Shear Measurement," ApJ , 761, 15.
Wiesner, M. P., Lin, H., et al. 2012, "The Sloan Bright Arcs Survey: Ten Strong Gravitational Lensing Clusters and Evidence of Overconcentration," ApJ , 761, 1.
Buckley-Geer, E. J., Lin, H., et al. 2011, "The Serendipitous Observation of a Gravitationally Lensed Galaxy at z = 0.9057 from the Blanco Cosmology Survey: The Elliot Arc," ApJ , 742, 48.
Lin, H., Buckley-Geer, E., et al. 2009, "Discovery of a Very Bright, Strongly Lensed z = 2 Galaxies the SDSS DR5,"
ApJ , 699, 1242.
Oyaizu, H., Lima, M., Cunha, C. E., Lin, H., Frieman, J. A., & Sheldon, E. S. 2008, "A Galaxy Photometric Redshift Catalog for the Sloan Digital Sky Survey Data Release 6," ApJ , 674, 768.

Selected recent presentations:
"Photometric Redshift Calibration of the Dark Energy Survey, at APS DPF Meeting, UC Santa Cruz, August 2013
"Gravitational Lensing and Cosmic Shear with the SDSS Coadd," January 2012
Joint Experimental-Theoretical Seminar, Fermilab
"The Dark Energy Survey," Dept. of Astronomy Colloquium, Indiana University Bloomington, March 2010

Leadership and management positions at Fermilab:
Co-coordinator, Dark Energy Survey Photometric Redshift Working Group

Co-Level 2 Manager, WBS 1.7 Survey Planning and Simulations, Dark Energy Camera project

Huan Lin
Research Summary

Current Experiments
Dark Energy Survey (DES) - 85%
Dark Energy Spectroscopic Instrument (DESI) - 10%
Large Synoptic Survey Telescope (LSST) - 5%

Current Roles
Co-coordinator, DES Photometric Redshift Working Group
DES image simulations
Member of DES Strong Lensing, Weak Lensing, and Clusters Working Groups
Member, DES Publications Board
Member, LSST Dark Energy Science Collaboration

Recent Accomplishments
Actively participated in DES science verification, including observations at the telescope, measurement and calibration of photometric redshifts, and characterization of CCD non-linearities.
As co-coordinator of DES Photometric Redshift Working Group, led efforts to compare photometric redshift codes on DES simulations and on real DES science verification data.
Oversaw production of DES image simulations for annual DES Data Management (DESDM) Data Challenges 5, 6, and 7 (2010-2012).
First author of weak lensing cosmic shear paper, and co-author of 3 other papers, utilizing Sloan Digital Sky Survey (SDSS) Stripe 82 coadd data.
Co-author in series of papers describing discovery of 19 strong lensing systems in the SDSS and 1 in the Blanco Cosmology Survey (BCS).

Future Plans
Continue as co-coordinator of DES Photometric Redshift Working Group, and oversee DES photometric redshift measurement and calibration, plus related spectroscopic follow-up activities.
Continue to oversee DES image simulations as needed by DESDM and science working groups.
Continue work on DES weak lensing and cluster science, including galaxy-galaxy lensing, cluster mass calibration, and cosmology constraints.
Continue work on DES strong lensing, including arc searches and cosmology with lensed quasar time delays.
Work on photometric redshift activities for LSST.
Become engaged in activities for the DESI project, potentially in areas of target selection and photometric redshifts.

Paul Mantsch

Present Position: Scientist III, Fermilab 1973 - current
Previous Positions: Scientist II, Fermilab, 1981 – 2008, Scientist I 1973 – 1981; Research Associate Deutsches
Electronen- Synchrontron (DESY), Hamburg, 1970-1972
Ph.D. degree: University of Illinois, 1970, Advisor: James H. Smith
Awards: Fellow, American Physical Society

Selected recent publications:
"Bounds on the density of sources of ultra-high energy cosmic rays from the Pierre Auger Observatory", JCAP 1305 (2013) 009
"Ultra-High Energy Neutrinos at the Pierre Auger Observatory", Advances in High Energy Physics, 2013 (2013) 708680
"Constraints on the origin of cosmic rays above 10^18 eV from large scale anisotropy searches in data of the Pierre Auger Observatory", ApJL, 762 (2013) L13
"Large scale distribution of arrival directions of cosmic rays detected above 10^18 eV at the Pierre Auger Observatory," Astrophysical Journal Supplement, 203 (2012) 34
"Measurement of the proton-air cross-section at sqrt(s) = 57 TeV with the Pierre Auger Observatory", Phys. Rev. Lett. 109, 062002 (2012)

Selected recent presentations:
IUPAP General Assembly, Tsukuba, Japan 15 OCT 2008
IFAE - Barcelona 27 JUNE 2011

Leadership and management positions at Fermilab:
Deputy Head, Research Services Department, Research Division, Fermilab, 1975 – 1978
Head, Research Services Department, Research Division, Fermilab, 1978-1979
Deputy Head, Technical Support Section, Fermilab, 1980-1984
Head, Technical Support Section, Fermilab, 1984-1992
Subsystem manager , SSC - SDC detector calorimetry, 1992-1993
Subsystem manager, photo-detector for the LBNE 200Kton water Cerenkov detector, 2009-2012.
1995-present Project Manager – Pierre Auger Project

Leadership in the broader community:
US ATLAS Project Advisory Panel.
ICE CUBE Project Advisory Panel.
Square Kilometer Array (SKA) Audit Committee (as chair).
KM3Net Science and Technology Advisory Committee
CTA Science and Technology Advisory Committee

Paul Mantsch
Research Summary

Current Experiments
Pierre Auger Project - 50%
Nova - 10%

Current Roles
Leader – Auger group at Fermilab
Auger Collaboration Country Representative

Recent Accomplishments
I held the position Project Manager of the Project Auger Project since 1995. The transfer of the Auger project office to the Karlsruhe Institute of Technology will be complete by 31 December 2013.
The Auger array has been successfully operating at greater than 99% efficiency while the fluorescence detectors also continue to operate with high efficiency. With recent enhancements to the detectors we have been able to extend the energy threshold from 10^18 eV down to 10^17 eV to study the "knee" of the energy spectrum where the sources transition from a galactic to an extra-galactic origin and where the cm energy overlaps that of the LHC.
The data taken with the Pierre Auger Observatory have led to major breakthroughs in the field of ultra-high energy cosmic rays. The Auger collaboration has published 43 full author list papers. Thirty-two oral and poster papers were presented at the June 2013 International High Energy Physics Conference in Rio de Janeiro. The Collaboration will soon publish a paper spearheaded by the Auger group at Fermilab. It will contain a major re-interpretation of the perceived GZK suppression at high energy. A total of 194 PhDs have been awarded based on Auger data. There are a hundred more students in the pipeline.
Future Plans
Analysis - I plan to take an increasing role in the analysis and interpretation of the Auger data. I have been one of the leaders in a continuing effort to monitor the performance of the surface array detectors as their response changes with time. These measurements will have a direct impact on the determination and control of systematic uncertainties in the data.
Upgrade planning – Auger is involved now in designing an upgrade to the Auger detectors to make them more sensitive to the muon component of the showers. The understanding to the shower muon component is the key to understanding both the composition of the primaries and hadronic interactions at high energies. I have been helping the groups developing the upgrade options to understand their technical problems. In particular I have been working with our Torino colleagues to build a prototype muon detector that will be placed under the existing water Cerenkov surface detector for muon identification. I have also been investigating the use of SiPMs for making these muon detectors cost less while being more robust and efficient.
Other Efforts
I was asked by the directorate in December 2012 to assist the Nova management in stabilizing the financial situation.

John Marriner

Present Position: Scientist II, Fermilab, 1978 - current
Ph.D. degree: University of California, 1978, Advisor: Professor M.L. Stevenson
Awards: Fellow, American Physical Society

Selected recent publications:
Seo, Hee-Jong, *et al*., A ground-based 21cm Baryon acoustic oscillation survey arXiv:0910.5007 to be published in ApJ.
Lampeitl, Hubert; *et al.*, The Effect of Host Galaxies on Type Ia Supernovae in the SDSS-II Supernova Survey arXiv1005.4687 (2010) to be published in ApJ.
Dilday, Benjamin, *et al.*, Measurements of the Rate of Type Ia Supernovae at Redshift ~0.3 from the Sloan
Digital Sky Survey II Supernova Survey, ApJ **713** (2010), 1026.
Kessler, Richard, *et al.*, First-Year Sloan Digital Sky Survey-II Supernova Results: Hubble Diagram and
Cosmological Parameters, ApJS **185** (2009), 32.
Gollwitzer, K. and Marriner, J. "The Antiproton Sources," published in Handbook of Accelerator Physics
and Engineering, Alex Chao, ed.

Leadership and management positions at Fermilab:
Convener for SDSS SN group and Joint Lightcurve Analysis group (SDSS+SNLS).
Co-Leader of DES SN group.

Leadership in the broader community:
TJNAF S&T Review (2009)

Education and Outreach activities:
Advised students in the NSF REU (research experience for undergraduates) summer program

John Marriner
Research Summary

Current Experiments
Dark Energy Survey – 100%

Current Roles
I am working primarily on the DES SN survey. I am interested primarily in using SN as standard candles to determine cosmological parameters.

In addition, I am working on finishing the SDSS SN survey including the full data release of all the SDSS SN data

I have the primary responsibility for the DES SN pipeline

Recent Accomplishments
The DES SN pipeline was used successfully during the 2012-2013 science verification run.

I am co-author of about 15 papers based on SDSS SN data.

I am co-author of about 10 papers on other topics, mostly studies for possible future experiments.

Future Plans
I plan to work on DES SN data processing and analysis. I expect that the work on SDSS will be completed soon.

K. Wyatt Merritt

Present Position: Scientist II, Fermilab, 1999-current
Previous Positions: Scientist I, Fermilab, 1993-1999; Associate Scientist, 1986-1993; Research Associate,
1982-1986; Research Associate, University of Chicago, 1980-1982
Ph.D. degree: California Institute of Technology, 1980, Advisor: Prof. Frank J. Sciulli
Awards: Employee Performance Award (Fermilab), 2002

Selected recent publications:
SEARCHES FOR NEW PHYSICS AT THE TEVATRON. K.Wyatt Merritt (Fermilab). FERMILAB-CONF-97-012, Aug 1996. 16pp. Talk given at 1996 Annual Divisional Meeting (DPF 96) of the Division of Particles and Fields of the American Physical Society, Minneapolis, MN,10-15 Aug 1996. In *Minneapolis 1996, Particles and fields, vol. 1* 113-128. e-Print Archive: hep-ex/9701009
DEDICATED OO EXPERTISE APPLIED TO RUN II SOFTWARE PROJECTS. D. Amidei, E. Buckley-Geer, M. Diesburg, N. Hadley, M. Kasemann, W. Merritt, R. Pordes, M. Shapiro, D. Skow, V. White, S. Wolbers Published In *Padua 2000, Computing in high energy and nuclear physics* 45-47

Selected recent presentations:
D0'S EXPERIENCE WITH OBJECT ORIENTED PROGRAMMING. By W. Merritt, J.F. Bartlett, L. Michelotti, L. Paterno (Fermilab), D. Adams (Rice U.), J. Bantly (Brown U.), D. Chakraborty, K. Streets (SUNY, Stony Brook), B.J. May (Northwestern U.), M. Paterno (Rochester U.). Apr 1997. 4pp. Talk given at Computing in High-energy Physics (CHEP 97), Berlin, Germany, 7-11 Apr 1997.
OBJECT ORIENTATION and Other New Experiences at the Tevatron for the Run II Experiments. Plenary talk given at *Padua 2000, Computing in high energy and nuclear physics*

Leadership and management positions at Fermilab:
Convener, DØ New Phenomena Group – 1994 – 1996

Co-Leader, DØ Run II Computing and Software – 1995 – 2001

Department Head, DØ Computing and Analysis Department, 2000 – 2003

Co-Leader, SAM Data Management Project, 2001 – 2005

Deputy Project Manager for the DECam Project, Safety Coordinator for the DECam Project, 2006 - 2011

Deputy Project Manager for the Muon g-2 Project, 2012 – present

Safety Coordinator for the Muon g-2 Project, 2012 – present

Leadership in the broader community:
Member, Ice Cube Science Advisory Committee, 2005 – 2013
Member, Review Team for Argonne Leadership Computing Facility, 2009 & 2010

Education and Outreach activities:
Ask-a-Scientist work at Fermilab: Talk, 2010; Served as volunteer in 2011 & 2013

K. Wyatt Merritt
Research Summary

Current Experiments
Dark Energy Survey (DES) – 50%
Muon g-2 Project – 50%

Current Roles
Deputy Project Manager for Muon g-2
Data Management Requirements Coordinator for DES
Member, DES Executive Committee

Recent Accomplishments
DECam Project and Science Verification period successfully completed and camera is ready to begin the Dark Energy Survey
Successfully concluded Independent Design Review and Director's CD-1 Readiness Review for Muon g-2 Project
Organized safety reviews for Muon g-2 magnet ring transport from Brookhaven to Fermilab
Served on a number of recent internal lab review panels for DOE 413 projects and committees working on the lab EVMS
Served on search committees for PPD Associate Scientist and Scientific Computing Head
Chaired incident response committee for DESDM data loss incident

Future Plans
Help Muon g-2 Project achieve DOE critical decisions and begin construction
Continue to work on DES data management issues
Begin analysis work in DES Supernova Working Group

Other Efforts
Participate in outreach efforts at Fermilab

Hogan Nguyen

Present Position: Scientist II, Fermilab, 2007 current
Previous Positions: Scientist-I, Fermilab, 2002-2007; Wilson Fellow, 1998-2002; Research Associate, 1992-1997
Ph.D. degree: University of Chicago, 1992, Advisor: Professor Frank Merritt

Selected recent publications:
Measuring Im(λ_t) using K_S-K_L Interference, H. Nguyen, Proceedings of 4^{th} Work Shop on Physics with a High Intensity Proton Source, 2009.

The QUIET Instrument, The QUIET Collaboration, ApJ **768**, 9 (2013).

First Season QUIET Observations: Measurements of Cosmic Microwave Background Polarization Power Spectra at 43 GHz in the Multipole Range 25 < El < 475, QUIET Collaboration *et al., ApJ* **741** (2012).

Second Season QUIET Observations: Measurements of the CMB Polarization Spectrum at 95 GHZ, QUIET Collaboration et. al, ApJ **760**, 145 (2012).

Selected recent presentations:
BNL Physics Colloquium on E989: the Fermilab Project to Measure the Muon Anomalous Magnetic Moment, May 2013.

Fermilab Wine and Cheese Seminar on the QUIET measurement of the CMB Polarization in the W-band, October 2012.

HEP Seminar at University of Minnesota on E989: the Fermilab Project to Measure the Muon Anomalous Magnetic Moment, June 2012.

Intersection between Nuclear and Particle Physics Conference, Tampa, FL: QUIET Q-band Results, May 2012
Tipp Conference, Chicago. The QUIET array for CMB Polarization Measurements, June 2012.

Leadership and management positions at Fermilab:
Level 2 manager for Fermilab E989 project to measure the Muon g-2 (Anomalous Magnetic Moment). Lead scientist for the Muon Storage Ring., 2002 - present

Head of Technical Centers Department, Particle Physics Division, Fermilab, 2005 - 2010

Head of the Fermilab group for the QUIET CMB Polarization Experiment. The Fermilab group built the rotating wiregrid for polarization calibration, and a 20K black body temperature calibrator, 2007- 2011

Member of Fermilab Wilson Fellowship Selections Committee, 2006 - 2009

Hogan Nguyen
Research Summary

Current Experiments
Until 2011, I led the Fermilab group on the QUIET-II proposal. The proposal was to assemble and test about 1000 HEMT-based pseudo correllators, and install them into the focal plane at Fermilab. The proposal was turned down by the NSF in 2011 due to limited funds.

Current Roles
Due to commitment to other projects in the Intensity Frontier Department, I currently have no significant role within the Fermilab Particle Astrophysics Center projects.

Recent Accomplishments
I had an active role in the 3 publications of the QUIET-I experiment. I was one of 3 final editors for the QUIET Instrument paper.

In October 2012, I presented the Fermilab Wine and Cheese Seminar on the QUIET-I polarization Cosmic Microwave Background (CMB) map in the W-band.

The W-band result has the lowest reported systematic error in the measurement of r, the parameter describing primordial gravitational wave.

Future Plans
I would like to play an active role to reestablish an experimental CMB group at Fermilab. Some possibilities include joining the SPT-3G proposal, and helping to develop a 4th Generation Proposal.

These efforts aim to establish the neutrino mass scale through CMB B-mode lensing, and also study gravitational waves occurring during inflation.

Other Efforts
I am the Level 2 manager for the E989 project at Fermilab to measure the Muon Anomalous Magnetic Moment (Muon g-2) to better than 0.1 ppm accuracy. E989 will take data in 2017. My primary responsibility (nearly full time) is the 50' diameter Muon Storage Ring. My effort is totally supported by the Intensity Frontier Department and the E989 project.

I was actively involved in the transportation of the 50' diameter superconducting coils from BNL to Fermilab. The coils cannot be disassembled into smaller pieces, due to stringent science requirements. I led the transportation feasibility study, and performed the initial engineering estimates on the forces expected to be seen by the coils during transportation.

The transportation also involved shipping barge via the Atlantic East Coast and the river system in the Midwest. I performed the ocean wave motion statistical analysis to guarantee the safe coil transport. The transportation was successfully accomplished in August 2013.

Stephen Pordes

Present Position: Scientist II, Fermilab 1980 - current
Previous Positions: Scientist I, Fermilab, 1985 – 1990, Associate Scientist, 1980 – 1985; Research Associate,
1980 - 1985
Ph.D. degree: Harvard University, 1976, Advisor; Professor Richard Wilson
Awards: Fellow, American Physical Society, 2011; Fermilab EPRA, 2003
Selected recent publications:
A system to test the effects of materials on the electron drift lifetime in liquid argon and observations on the effect of water. R. Andrews et al. Nucl.Instrum.Meth. A608:251-258,2009

First Commissioning of a Cryogenic Distillation Column for Low Radioactivity Underground Argon. H.O. Back et al., arXiv 1204.6061

Light Yield in DarkSide-10: a Prototype Two-phase Liquid Argon TPC for Dark Matter Searches DarkSide Collaboration, arXiv:1204.6218, 2012

Observation of the Dependence of Scintillation from Nuclear Recoils in Liquid Argon on Drift Field, Scene Collaboration, arXiv:1307.7335, 2013

Synchrotron radiation based beam diagnostics at the Fermilab Tevatron

R. Thurman-Keup, et al., arXiv:1109.3505, Journal-ref: 2011 JINST 6 T09003

Selected recent presentations:
LAr R and D at Fermilab", Stephen Pordes, DOE Review, Washington DC, July 2012

Purification of LAr - work at Fermilab, Stephen Pordes, Chicago (TIPP Meeting), July 2011

Fermilab Institutional Review - LAr , Stephen Pordes, Fermilab, July 2011

Purification in noble liquids, Stephen Pordes, Argonne National Lab, January 2013

The materials Test System, Stephen Pordes, Liquid Argon Workshop, Fermilab, March 2013

Leadership and management positions at Fermilab:
Leader of LArTPC R&D effort at Fermilab - established facilities for material testing, electronics development, and purification without evacuation (LAPD), 2005 - 2011

Member and Chair of Fermilab Lederman Fellowship committee, 2007 - 2012

Member of Fermilab Committee on Scientific Appointments, 2012 - present

Member of Fermilab R & D oversight committee with Argon portfolio, 2010 – present

Leadership in the broader community:
Reviewer for JINST
Reviewer for DOE of SBIR proposals

Stephen Pordes
Research Summary

Current Experiments
Dark Matter Direct Search: DarkSide - 70%
LAr R&D: Scene (Measurement of light yield from nuclear recoils in LAr using a low energy monochromatic pulsed neutron beam) - 15%
Neutrinos: MicroBooNE (consultant on purity and HV issues) 15%

Current Roles
DarkSide - collaborator, DOE coordinator and management of Fermilab resources, consultant to spokesperson
Scene - senior Fermilab collaborator, management of Fermilab resources, co-author of first paper

Recent Accomplishments
DarkSide - encouraged integration of university and Fermilab efforts, encouraged development of overall collaboration, wrote DOE part of proposal for DOE G2 R&D award.

Future Plans
Establish large-scale operation of underground argon purification.
Establish smooth operation of Fermilab computing responsibilities to DarkSide-50 in particular Data Acquisition and offline data infrastructure for storage and reconstruction
Work with colleagues newly arrived at U. Chicago on analysis of DarkSide-50 and if possible a post-doc in the Fermilab FCPA.
Depending on G-2 selection outcome, pursue DarkSide G-2 with full vigor in areas of data-acquisition and electronics in collaboration with SLAC and BNL

Eric Ramberg

Present Position: Scientist II, Fermilab, 1990 - current
Previous Positions: Scientist I, Fermilab, 2000 - 2006; Associate Scientist, 1995 – 2000; Research Associate,
1990 - 1995
Ph.D. degree: University of Maryland, 1990, Advisor: Professor George Snow

Selected recent publications:
"The Next Generation of Photo-Detectors for Particle Astrophysics." R.G. Wagner, et al, Astro2010 Technology Development White Paper

"Improved Spin-Dependent WIMP Limits from a Bubble Chamber, COUPP Collaboration Science 319:933-936, 2008. [ArXiv: 0804.2886]

"Search for Weakly Interacting Massive Particles with the First Five-Tower Data from the Cryogenic Dark Matter: Search at the Soudan Underground Laboratory" , CDMS Collaboration (Z. Ahmed *et al.*). Phys.Rev.Lett.102:011301, 2009.

"Improved measurement of the K+ ---> pi+ nu anti-nu branching ratio",. E949 Collaboration (V.V. Anisimovsky et al), Phys. Rev. Lett.93:031801, 2004.
"Measurements of direct CP violation, CPT symmetry, and other parameters in the neutral kaon system", KTeV Collaboration", A. Alavi-Harati et al, Phys.Rev.D67:012005, 2003,

Leadership and management positions at Fermilab:
Assistant head of Particle Physics Division, in charge of generic detector research at Fermilab. Responsibilities include managing the budget, arranging for research collaborations, and supporting Fermilab's test beam Facilities, where groups from around the world bring state-of-the-art particle detectors for testing in particle beams.
Installation manager for COUPP (Chicagoland Observatory for Underground Particle Physics). This bubble chamber dark matter detector requires installation in various underground locations.

Education and Outreach activities:
Co-manager of two Fermilab outreach programs – Saturday Morning Physics for high school students, and Internship for Physics Majors.
Co-founder of Fermilab Sustainable Energy Club

Eric Ramberg
Research Summary

Current Experiments
Fermilab's Generic Particle Detector Research Manager - 60%
Chicagoland Observatory for Underground Particle Physics (COUPP) - 10%
PET-TOF brain imaging project - 10%
Neutron-Antineutron Oscillation Experiment - 5%
Coherent Elastic Neutrino Nucleus Scattering (CENNS) - 5%
Neutrino Decay experiment with Superconducting Tunnel Junction detector - 10%

Current Roles
Manager for detector research at Fermilab
Manager for cosmic ray veto and underground site preparation in COUPP

Recent Accomplishments
Completed preparation of SNOLAB underground laboratory area for COUPP-60 installation
Initiated research (along with U.Chicago) on a compact Time-of-Flight capable PET brain imager
Coordinated runs of STJ neutrino decay detectors in cryogenic Vertical Test Structure at Fermilab
Helped manage meeting with Beijing colleagues of IHEP and U. Chicago-Beijing
Worked with post-doc from N. Carolina State University to design neutron-antineutron detector

Future Plans
Will continue to manage detector research at Fermilab
Continue involvement with the following experiments:

- neutron-antineutron oscillation
- neutrino decay
- COUPP-60
- CENNS

Other Efforts
Managed effort to build a demonstration tracking solar array using two types of solar panels
Co-managed Saturday Morning Physics program
Co-managed two undergraduate summer Internship programs
Vice-President of Fermilab Sustainable Energy Club

Victor Scarpine

Present Position: Applications Physicist II, Fermilab Accelerator Division, 2002-current
Previous Positions: Research Fellow, University of Michigan, 1995-1996; Research Associate, Texas A&M University,
1992-1994
Ph.D. degree: University of Illinois, 1992, Advisor: Professor Lee Holloway

Selected recent publications:
V. Scarpine et al., “The Ring of Fire: an Internal Illumination System for Detector Sensitivity and Filter Bandpass Characterization,” SPIE Conference on Space Telescopes and Instrumentation, 2010, San Diego, California.
J. Hao et al,. “Measuring the Flatness of Focal Plane for Very Large Mozaic CCD Camera,” Proc.SPIE Int. Soc. Opt. Eng. 7735:77353U, 2010 [arXiv:1010.6072 [astro-ph.IM]].
J. Peterson et al., “21 cm Intensity Mapping,” White Paper for the Astro2010 Astronomy Decadal Review, [arXiv:0902.3091 [astro-ph.CO]].
J. Estrada et al., “A Systematic Search for High Surface Brightness Giant Arcs in a Sloan Digital Sky Survey Cluster Sample," Astrophys.J.660:1176-1185, 2007

Selected recent presentations:
“Novel Beam Diagnostics on PXIE,” Invited talk at Proton Accelerators for Science and Innovation 2nd Annual Meeting, April 2013, Rutherford, England
“Instrumentation Developments and Beam Studies for the Fermilab Proton Improvement Plan Linac Upgrade and New RFQ Front-End,” Invited talk at 2012 High Brightness Workshop, Beijing, China

Victor Scarpine
Research Summary

Current Experiments
Accelerator Division work – 70%
Dark Matter in CCDs (DAMIC) – 20%
Dark Energy Survey (DES) – 10%

Current Roles
Working on low-energy response of silicon to neutrons for DAMIC
Member of the DES collaboration
Primary duties are with the Fermilab Accelerator Division. Small fraction of time allowed for particle astrophysics research

Recent Accomplishments (Particle Astrophysics)
Coordinated engineering run of low-energy response of silicon to neutrons at Notre Dame accelerator in 2013
Previous work for DES on the characterization of the DECam CCDs quantum efficiency measurements

Future Plans Particle Astrophysics)
Continue work on low-energy response of silicon to neutrons for DAMIC. Coordinate additional experiments at Notre Dame.
Participate in dark energy science as part of the DES SN working group

Andrew Sonnenschein

Present Position: Scientist I, Fermilab, 2005 - current
Previous Positions: Wilson Fellow, Fermilab, 2005-2009; Center Fellow, Kavli Institute for Cosmological Physics
and Enrico Fermi Institute, University of Chicago, 2002-2005; Research Associate, Princeton University, 1999-2002
Ph.D. degree: University of California, Santa Barbara, 1999, Advisor: Professor David Caldwell.

Selected recent publications:
"Direct Measurement of the Bubble Nucleation Energy Threshold in a CF3I Bubble Chamber", E. Behnke et al. (The COUPP Collaboration), Phys. Rev. D88 (2013) 021101.

"First determination of an astrophysical cross section with a bubble chamber: the 15N(alpha, gamma)19F reaction", C. Ugalde, B. DiGiovine, D. Henderson, R.J. Holt, K.E. Rehm, A.Sonnenschein, A. Robinson, R. Raut, G. Rusev, A.P. Tonchev, Phys. Lett. B719 (2013) 74-77.

"First Dark Matter Search Results from a 4-kg CF3I Bubble Chamber Operated in a Deep Underground Site, E. Behnke et al. (The COUPP Collaboration), Phys. Rev. D86 (2012) 052001.

"Direct Search for Low Mass Dark Matter Particles with CCDs", J. Barreto et al. (The DAMIC Collaboration), Phys. Lett. B711 (2012) 264-269.

E. Behnke et al. (The COUPP Collaboration), "Improved Limits on Spin-Dependent WIMP-Proton Interactions from a Two Liter CF3I Bubble Chamber", Phys.Rev.Lett.106:021303, 2011.

E. Behnke, J.I. Collar, P.S. Cooper, K. Crum, M. Crisler, M. Hu, I. Levine, D. Nakazawa, H. Nguyen, B. Odom, E. Ramberg, J. Rasmussen, N. Riley, A. Sonnenschein, M. Szydagis, R. Tschirhart, "Improved Spin-Dependent WIMP Limits from a Bubble Chamber", Science 319:933-936, 2008.

C. Arpsella et al. (The Borexino Collaboration), "Direct Measurement of the Be-7 Solar Neutrino Flux with 192 Days of Borexino Data", Phys. Rev. Lett. 101:091302, 2008.

Selected recent presentations:

"WIMP Measurements", Instrumentation Frontier Workshop, Argonne National Laboratory, Jan 10, 2013.

"A Bubble Chamber Revival: Superheated Liquid Detectors for Dark Matter Searches and Other Applications", Invited Talk at APS DNP2012, Newport Beach, Oct 23, 2012.

"COUPP-60", International Conference on the Detection of Dark Matter (IDM2012), Chicago, July 26 2012.

Leadership and management positions at Fermilab:

COUPP-60 Project Manager, 2007-current.

Andrew Sonnenschein
Research Summary

Current Experiments
Chicagoland Observatory for underground Particle Physics (COUPP) - 100%

Current Roles
COUPP-60 Project Manager and DOE PI, Currently in charge of COUPP-60 operations at Sudbury Neutrino Observatory Laboratory (SNOLAB)

Recent Accomplishments
We completed the installation of the COUPP-60 bubble chamber at SNOLAB in April, with physics running beginning in June. The experiment has recorded over 1000-kg-days of data to-date

Future Plans
We expect to operate COUPP-60 through FY'16 while building PICO-LITE, PICO-250 and performing calibration measurements to better understand the low energy recoil response of bubble chambers. My focus for the next year will be on understanding the large amount of data being produced by COUPP-60. I will continue to supervise detector operations.

Other Efforts
Fully-supported on the Cosmic Frontier Research program. I have been active in the Snowmass community planning process, serve on the Fermilab astrophysics seminar committee and am a referee for Physical Review Letters

Christopher Stoughton

Present Position: Scientist II, Fermilab, 1990 - current
Previous Positions: Applied Scientist I, Fermilab, 1995-2002; Associate Scientist, 1990 – 1995, Research Associate, 1987-1990

Ph.D. degree: Columbia University, 1986; Advisor: Professor Wonyong Lee

Selected recent publications:
Quantum Geometry and the Fermilab Holometer, Proceedings of the Time and Matter 2013 Conference in Venice, Italy
Exceptional Optical Emission Observed with ARCONS for Early Crab Giant Pulses, with M.J. Strader et al., in preparation
Direct Detection of SDSS J0926+3642 Orbital Expansion with ARCONS, with P. Szypryt et al., in preparation
ARCONS: A 2024 Pixel Optical through Near-IR Cryogenic Imaging Spetrophotometer, with B.A. Mazin et al, PASP accepted
Lossy compression of weak lensing data, with R. Ali Vanderveld et al., PASP 123 (2011) 996-1003

Selected recent presentations:
Quantum Geometry and the Fermilab Holometer, Time and Matter 2013 Conference, Venice, Italy

Education and Outreach activities:
Mentor, Fermilab/University of Chicago Quarknet program
Presenter at Fermilab's Physics Slam
Cosmology Lecturer at Saturday Morning Physics

Christopher Stoughton
Research Summary

Current Experiments
Holographic Interferometer - 50%
Microwave Kinetic Inductance Detectors (MKID) / Array Camera for Optical to Near-IR Spectrophotometry (ARCONS) -50%

Current Roles
Oversee mechanical construction and vacuum work for the Holographic Interferometer
Computing Coordination for the Fermilab Holographic Interferometer
Software engineering and construction for MKID analysis

Recent Accomplishments
The Holographic Interferometer vacuum system is constructed and operating within specifications.
The Holographic Interferometer data acquisition system and level III trigger computing is operational
MKIDs analysis is producing papers and successful observing proposals for continuing work

Future Plans
Finish the Fermilab Holographic Interferometer. Follow-up experiments as necessary
Continue observing and analysis with ARCONS
Implement working MKIDs detectors at Fermilab

Other Efforts
Continue education and outreach activities

Douglas L. Tucker

Present Position: Applications Physicist 2, Fermilab, 2007 – current

Previous Positions: Applications Physicist 1, Fermilab, 1996-2007; Postdoctoral Researcher, Astrophysikalisches Institut Potsdam, Germany, 1994-1996

Ph.D. degree: Yale University, 1994, Advisor: Professor Augustus Oemler, Jr.

Selected recent publications:
Tucker, D. L., Annis, J. T., Lin, H., et al. 2007, "The Photometric Calibration of the Dark Energy Survey," in *The Future of Photometric, Spectrophotometric, and Polarimetric Standardization,"* ASP Conf. Series, Vol. 364, 187
Allam, S.S., Tucker, D.L., Lin, H., et al. 2007, "The 8 O'Clock Arc: A Serendipitous Discovery of a Strongly Lensed Lyman Break Galaxy in the SDSS DR4 Imaging Data," *The Astrophysical Journal (Letters)*, 662, L51
Abazajian, K. N., Adelman-McCarthy, J. K., Agueros, M. A., et al. 2009, "The Seventh Data Release of the Sloan Digital Sky Survey, "*The Astrophysical Journal (Supplement),* 182, 543
Desai, S., Armstrong, R., Mohr, J. J., et al. 2012, "The Blanco Cosmology Survey: Data Acquisition, Processing, Calibration, Quality Diagnostics, and Data Release," *The Astrophysical Journal,* 757, 83
Kuehn, K., Kuhlmann, S., Allam, S., et al. 2013, "PreCam: a Precursor Observational Campaign for Calibration of the Dark Energy Survey," *Publications of the Astronomical Society of the Pacific,* 125, 409

Selected recent presentations:
"The Dark Energy Survey and the Dark Energy Camera," Seminar at Indiana University, Oct. 2008
"The Dark Energy Survey," Seminar talk at Southern Connecticut State University, March 2010

Leadership and management positions at Fermilab:
Calibrations Scientist for the Dark Energy Survey (DES), 2007-current

Leadership in the broader community:
Co-Chair of the LOC and member of SOC for the workshop, "Calibration & Standardization of Large Surveys & Missions in Astronomy & Astrophysics, held at Fermilab, April 16-19, 2012

Education and Outreach activities:
Chair of the Organizing Committee for the Fall 2007 Sloan Digital Sky Survey (SDSS) Collaboration Meeting, held at Fermilab, November 1-4, 2007

Mentor to a variety of high school and undergraduate interns on research projects associated with the SDSS and the DES

Douglas L. Tucker
Research Summary

Current Experiments
Dark Energy Survey (DES): 95%
Large Synoptic Survey Telescope (LSST): 5%

Current Roles
On DES, I am the Calibrations Scientist and am active in the DES Strong Lensing and DES Milky Way Structure Science Working Groups.

On LSST, I do not yet have a defined role, but I am looking into helping with LSST calibrations

Recent Accomplishments
Since September 2010, I have been an author on 12 refereed journal articles (mostly on gravitational lenses in the Sloan Digital Sky Survey [SDSS], on results from the Blanco Cosmology Survey [BCS], and on DES preparations), 1 article submitted to a refereed journal (on an SDSS gravitational lens), 9 conference proceedings papers or conference abstracts (mostly on DES), and 1 Astronomer's Telegram (on the first set of DES-discovered supernovae), for a total of 23 scientific publications.

In 2010-2012, I oversaw the observing runs and the subsequent data processing & analysis of the PreCam Survey, a 100-night project to establish calibration stars in a grid spanning the DES footprint.

I was co-chair of the LOC and member of the SOC of an international meeting on the topic, "Calibration & Standardization of Large Surveys & Missions in Astronomy & Astrophysics," held at Fermilab, April 16-19, 2012.

In my role as DES Calibrations Scientist, I oversaw the DES calibrations effort.

Future Plans
I plan to continue to provide leadership for the DES calibrations effort.

I plan to continue to develop and maintain the photometric calibration software for DES.

I plan to continue my participation in research in the DES Strong Lensing and DES Milky Way Structure Science Working Groups.

I plan to become more involved in the calibrations effort for LSST

William Wester

Present Position: Scientist II, Fermilab, 1994 - current
Previous Positions: Scientist I, Fermilab 2003 - 2009, Associate Scientist, 1998—2003; Research Associate, 1994--1998 Research Associate, Lawrence Berkeley National Laboratory
Ph.D. degree: University of California at Berkeley, 1989, Advisor; Professor Marjorie Shapiro
Selected recent publications:
J. L. Marshall, *et al.*, ``The Spectrophotometric Calibration System for the Dark Energy Survey Camera," Publications of the Astronomical Society of the Pacific, in preparation
J.H. Steffen, A. Upadhye, *et al.,* [GammeV-CHASE Collaboration], "Laboratory constraints on chameleon dark energy and power-law fields," Phys. Rev. Lett.,**105**, 261803 (2010); A.S. Chou, *et al.,* [GammeV Collaboration], ``Search for chameleon particles using a photon regeneration technique", Phys. Rev. Lett. , 102, 030402 (2009) and ``Search for axion-like particles using a variable baseline photon regeneration technique", Phys. Rev. Lett., 100, 080402 (2008)
T. Aaltonen, *et al.,* [CDF Collaboration], ``Measurement of the $B_c$ meson lifetime in the Decay $B_c$ -> J/y p," Phys. Rev. D87, 011101 (2013) and ``Observation of the decay B_c -> J/y p and Measurement of the B_c Mass," Phys. Rev. Lett.,100, 182002 (2008)

Selected recent presentations:
Colloquium: "New Light Weakly-Coupled Particles: Axion-Like Particles," Snowmass on the Mississippi (CSS 2013), Minneapolis, July 31 2013.
Colloquium: "New Light Weakly Coupled Particles," Intensity Frontier Workshop, Argonne National Lab, Apr. 27, 2013.
Contributed Talk, "Dark Energy Survey and WISPs," 9^{th} Patras Workshop on Axions, WIMPs, and WISPs, Mainz, Germany, June 24, 2013.
Presentation of GammeV results at ICHEP 2012
Parallel Talk, "B_c and Suppressed B_s Decays at CDF," Division of Particles and Fields 2011, Aug. 2011

Leadership and management positions at Fermilab:
2009-- Lederman Fellowship Postdoctoral Search Committee (Chair, 2012--), 2009 - current
Member, Users' Executive Committee (elected) 2009 - 2011
Group Leader of the FNAL ASIC Testing Group, supervisor of engineers and technicians, 1998 - 2009

Leadership in the broader community:
Peer reviewer of various DOE and NSF grants and scientific and technical papers
Subgroup Convener, New Light Weakly-Coupled Particles, IF-5, HEP Snowmass Process 2012
Co-spokesperson, GammeV Collaboration with project management responsibilities, 2006 - current
Education and Outreach activities:
Fermilab Ask-A-Scientist program and other presentations to visitors at Fermilab.
Public lectures including "Connections between Inner and Outer Space," Adler Planetarium, Chicago (Nov 2011)
"The Big Bang and Modern Cosmology," Community Group (Feb 2012

William Wester
Research Summary

Current Experiments
Dark Energy Survey - 80%
Axions and WISPs - 10%
Laboratory Management and Committees - 10%
Collider Detector at Fermilab - <5% concluding efforts as an internal analysis reviewer)

Current Roles
DES Supernova Science Group: Collaborator toward the final goal of extracting dark energy parameters from DES collected supernova. My focus is on calibration issues and single epoch analysis to make a catalog of variable objects that might impact the supernova search.
DES Calibrations Group**:** Support of the Dark Energy Survey efforts to achieve calibration requirements. Primary responsibility is the analysis of the DECal calibration data to produce system response curves. Also, I lead an effort to collect and analysis white dwarf spectra for photometry.
Axions and WISPs**:** The GammeV experiments are completed and published (over 100 citations). Continued participation in the world-wide efforts towards axion and WISP particle searches.
Recent Accomplishments
Dark Energy Survey (Supernova Science Group)**:** Presentations at various internal/collaboration meetings on analysis of Science Verification data. Produced preliminary database catalog. Operational support as an observer at CTIO and as a hand scanner of candidates.
Dark Energy Survey (Calibrations Group**):** Analyzed DECal data and distributed system response curves. Awarded (as Co-I) observing time at Apache Point Observatory 3.5m telescope and have collected about three dozen spectra of white dwarf candidates for calibration purposes. I have made numerous presentations at internal/collaboration meetings on calibrations and instrumental signatures.
Axions and WISPs**:** Leadership by organizing an international workshop (Chicago 2012) and by being a sub-group convener as part of the Snowmass process on New Light Weakly-Coupled Particles.
Collider Detector**:** Leader of an analysis that measured the lifetime of the Bc meson. I helped guide a student through his thesis analysis and the submission of the final (now published) paper
Future Plans
DES: Supernova Science Group and Calibrations Group**:** Continued work as the first year science operations of DES begins. Besides DES, look for opportunities such as with LSST where DES work is relevant. Besides the primary measurements of dark energy parameters, I will help extract other dark energy and dark matter measurements from the rich data set.
Axions and WISPs**:** REAPR is a proposed laser project following GammeV that hopefully will be funded for continued R&D and as a possible future experiment. MiniBooNE has a test run and possible future experiment to search for hidden sector photons where I expect to participate at a low effort. Other ideas and opportunities might arise for low cost experiments with high discovery potential

Brian Yanny

Present Position: Scientist II, Fermilab, 1994 - current
Previous Positions: Scientist I, Fermilab, 2001 – 2006, Associate Scientist, 1996-2001, Term Applications Physicist, 1994-1996, Research Member, Institute for Advanced Study, Princeton, 1993-1994; Institute for Advanced Study, Princeton, Hubble Fellow, 1990-1993; Research Associate, University of Chicago, 1989-1990
Ph.D. degree: University of Chicago, 1989, Advisor; Professor Donald G. York

Selected recent publications:
Widrow, L.M., Gardner, S., Yanny, B., Dodelson, S., Chen, H-Y. "Galactoseismology: Discovery of Vertical Waves in the Galactic Disk" 2012 ApJ 750, 41
Ahn, C.P. et al. "The Ninth Data Release of the Sloan Digital Sky Survey: First Spectroscopic Data from the SDSS-III Baryon Oscillation Spectroscopic Survey" 2012 ApJS 203, 21
Newberg, Heidi Jo; Willett, Benjamin A.; Yanny, Brian; Xu, Yan "An orbit fit for the Orphan Stream" 2010 ApJ 711, 32
Yanny, B., Newberg, H. J., Johnson, J. A., Lee, Y. S., et al. "Tracing Sagittarius Structure with SDSS and SEGUE Imaging and Spectroscopy" 2009 ApJ 700, 1282
Yanny, B., Rockosi, C., Newberg, H., Knapp, G., et al. for the SDSS-II SEGUE collaboration, "SEGUE: A Spectroscopic Survey of 240,000 stars with g=14-20", 2009 AJ 137, 4377

Leadership and management positions at Fermilab:
Dark Energy Survey Data Management Project Scientist 2012-present
Dark Energy Survey Data Coordinator 2010-2012
SEGUE survey co-leader 2008

Leadership in the broader community:
DOE review panel member
NSF review panel member
APOGEE review panel member
LSST review panel member

Brian Yanny
Research Summary

Current Experiments
Dark Energy Survey (DES) - 85%
Sloan Digital Sky Survey / SEGUE-II -10%
LSST - 5%

Current Roles
Dark Energy Survey (DES) - Data Management Project Scientist, role is high currently as experiment begins data taking phase. Duties are to verify and help improve where necessary the quality of science put out by the DES processing production software system. Quality is defined in DES science requirements document.
Sloan Digital Sky Survey – SEGUE-II - Advising on SDSS data releases and in particular involved in documenting existing released spectroscopic data set (DR9).
LSST - Role will increase once DES role is lessened. Serving on review of LSST data systems and comparing LSST software system to DES and SDSS software systems
Recent Accomplishments
Oversaw release of processed on sky-data from DECam to DES collaboration for science analysis after 2 years+ of organizing simulated data challenge campaigns.
Publication of original result studying the distribution of stars above and below the plane of the Milky Way and measuring the effect of dark matter on this distribution. Follow-up work continues.
Obtaining a fit to a halo stellar stream which constrained the total amount of dark matter present in the halo of the Milky Way out to 60 kpc from the Galactic center

Future Plans
My primary focus for the next several years will be DES work: a) in service to the software production quality and b) in science effort to study the distribution and extent of dark matter in and around the Milky Way as well as the cosmic distribution and nature of dark energy.
SDSS involvement will wind down as SDSS-III transitions to SDSS-IV in 2014.
LSST activity will ramp up as experience gained during DES is scaled up and applied to the much larger LSST project

Jong-Hee Yoo

Present Position: Associate Scientist, Fermilab, 2010 - current
Previous Positions: Robert R. Wilson Fellow, Fermilab, 2004 - 2010
Ph.D. degree: Seoul National University, 2004, Advisor: Professor Soo-Bong Kim

Awards: Exceptional Performance Recognition Award, Fermilab, 2009; New Scientist Fellowship, Korea Science and Engineering Foundation, 2004

Selected recent publications:
"Observation of the Dependence of Scintillation from Nuclear Recoils in Liquid Argon". arXiv:1306.5675 (2013)

"Dark Matter Search Results from the CDMS II Experiment", Science, v327 1619 (2010)

"Search for Axions with CDMS detectors", PRL. 103, 141802 (2009)

"A Search for WIMPs with the First Five-Tower Data from CDMS", PRL 102, 011301 (2008)

Kaluza-Klein Dark Matter: Direct Detection vis-a-vis LHC, PRD78, 056002 (2008)

Selected recent presentations:
Nuint12, Rio de Janeiro, Brazil (invited talk) – Coherent scattering of neutrinos, 2012
UCLA DM2012, Marina del Ray, USA – Solid Xenon R&D and CENNS (two talks), 2012
DPF2011, Brown University, USA (invited plenary talk) – Dark Matter Searches, 2011
Axion2010, University of Florida, USA (invited plenary talk) – Search for Axions, 2010
XXIX PIC2009, Kobe, Japan (invited plenary talk) – Reviews on Dark Matter Search, 2009

Leadership and management positions at Fermilab:
Group leader of CDMS axion search analysis, 2007-2009

Organized workshop on Neutrino Coherent Scattering, Fermilab, 2012

Co-convener of the Neutrino Interactions Section in the Project-X workshop, Fermilab, 2012

Leadership in the broader community:
PRL, PRD, PLB, NIM, JCAP, APJ and DOE SBIR-STTR program, 2004

Education and Outreach activities:
2004-present Mentoring Fermilab SULI, QuarkNet students Kathleen Grabowski(2012), Vidya Anjur (2011), Evan Wise (2011), Raymond Co (2010) and more.

Jong-Hee Yoo
Research Summary

Current Experiments

I am involved in liquid argon-based dark matter experiment (Darkside-50, LNGS, Italy). As of September 2013, the approximate fraction of my timeshare to this project is 30%. I am also working on a solid xenon-based detector R&D. My timeshare to this R&D is about 30%.

Current Roles

I am leading the Darkside-50 offline data analysis system setup at Fermilab. I am leading the solid xenon detector R&D.

Recent Accomplishments

Darkside-50 detector is currently commissioning and will be fully operational within 2013. We have recently achieved 40MB/s data transfer rate from LNGS (Italy) to Fermilab, which is sufficient to manage the Darkside-50 data production rate. We are currently working on software package development for the data analysis.

Solid Xenon detector R&D made great progress. The system is stably operating with full automatic control of xenon transfer, temperature and pressure. We measured both scintillation and ionization signals in solid phase of xenon. We are currently carrying out refined measurements

Future Plans

I plan to ramp up my effort to 70% on Darkside-50 experiment as the experiment will begin soon. Analysis of the Darkside data will be my major focus in the next few years.

The initial R&D phase of the Solid Xenon detector development will be completed in 2013 or early 2014. The details of the solid xenon system instrumentation and the results will be published in early 2014.

Other Efforts

My other effort is developing an experiment of measuring Coherent Elastic Neutrino Nucleus Scattering (CENNS) using by-product neutrinos from the Fermilab Booster Neutrino Beam at the far-off-axis. The project successfully measured neutron backgrounds in the neutrino target building, which is crucial to understand the experimental sensitivity. We plan to write a full proposal in 2013. This effort is supported by Detector R&D group and Intensity Frontier Department.