Fermilab Presentation Agenda at DOE Review of Detector R&D - July 24, 2012

Overview:	Erik Ramberg	(25’)
ASIC Development:	Gregory Deptuch	(20’)
Silicon Tracking R&D:	Ron Lipton	(30')
Data Acquisition:	Alan Prosser	(30’)
Break		(15')
Liquid Argon R&D:	Stephen Pordes	(35')
Astrophysics Detectors	Juan Estrada	(25’)
Intensity Frontier Detectors	Bob Tschirhart	(25’)
Future plans and Community Support	Erik Gottschalk	(20')

Fermilab

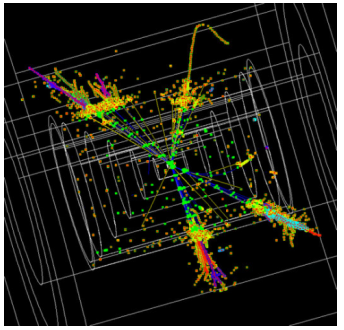
Overview of Fermilab Detector Research and Development

24 July, 2012

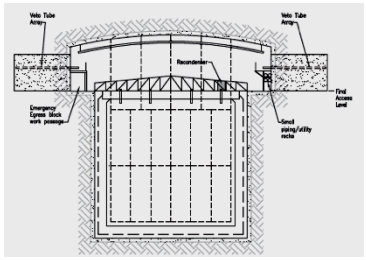
Erik Ramberg
Fermilab

Challenges in the Frontiers of Detector R&D

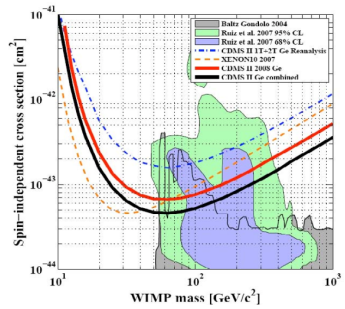
- Energy Frontier:
  - Vertex sensors will have to withstand a total fluence of 10^{16} particles/cm^2
  - At full luminosity, several hundred overlaid events per 25 nsec crossing will make current triggers untenable
  - For future colliders, jet resolution of 3% requires hadronic energy resolutions of better than 30%/sqrt(E)



- Intensity Frontier:
  - The next generation of neutrino detectors will require high-performance, low cost multi-kton liquid Argon TPC's
  - Rare decays and interactions of gigaHz beams will require the lowest masses achievable
  - Ultra-fast timing (~10 psec) photodetectors, trackers and calorimetry will become the norm



- Cosmic Frontier:
  - Dark matter detectors will need background levels of 1 nuclear recoil per ton per year
  - Spectrophotometry of large sky surveys will need new methods to efficiently measure red-shifts in coincidence with position.



Fermilab has a series of portfolios of detector research projects that are designed to meet these challenges

Fermilab Detector R&D Organization

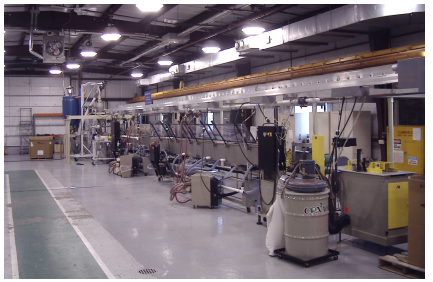
- In response to the 2009 review by DOE, Fermilab updated its organization of detector research by creating an advisory group to oversee R&D
- The **"Detector Advisory Group"** consists of:
  - Technical Point of Contact (Erik Ramberg)
  - Tracking and Triggering representative (Ron Lipton)
  - Calorimetry and photodetection representative (Adam Para)
  - Liquid Argon R&D representative (Stephen Pordes)
  - Astrophysics detectors representative (Juan Estrada)
  - Intensity Frontier representative (Bob Tschirhart)
  - Head, Particle Physics Division (PPD) (Mike Lindgren) (ex-officio)
  - Assoc. head for Engineering (PPD) (Peter Wilson) (ex-officio)
  - Head, Experimental Particle Physics (PPD) (Dave Christian) (ex-officio)
  - Scientific Computing (Panagiotis Spentzouris) (ex-officio)
- New members:
  - Ulrich Heintz (Brown University)
  - Luciano Ristori (INFN/Fermilab)
- The group meets twice a month and monitors and reports on the activities in each of their portfolios.
- Members give advice on the future of the program and participate in reviews of projects in each portfolio
- TPOC informs the Division Heads and Associate Director on Particle Physics of plans arising out of group discussions and reviews.
- After expert review and consultation with DOE, Division Heads and Associate Director then decide on approval of projects

Detector Research and Development Deliverables

PORTFOLIO	DELIVERABLES	DESCRIPTION	THRUST
Tracking & Triggering *(R. Lipton)*	ASIC R&D	Collaborative development of 3D ASICs	Core & Infrastructure
	ASIC Support	Software tools for ASIC design and development	Core & Infrastructure
	Vertex Sensors	Multi-project integrated sensor/readout R&D	Sensors & Electronics
	Tracking Mechanical	Low mass mechanical support and cooling designs	Sensors & Electronics
Calorimetry & Photodetection *(A. Para)*	Fast Calorimetry	Fast calorimetry for Intensity Frontier community	Detector Systems
	Hadron Calorimetry	Dual readout techniques, SiPM testing, simulation, QIE10	Sensors & Electronics
	Scintillator R&D	Scintillator/WLS co-extrusion and testing	Sensors & Electronics
	psec Time-of-Flight	Collaborative LAPPD phototube program at ANL	Sensors & Electronics
	Simulations	Simulation of backgrounds in a muon collider	DAQ & Computing
Liquid Argon *(S. Pordes)*	Materials Test Stand	Testing contamination potential of materials for LAr TPC	Core & Infrastructure
	20-Ton Demonstrator	Large scale LAr purification test system	Detector Systems
	Low Background Ar	Production of low-background Ar for Dark Matter community	Detector Systems
	Cold Electronics	Collaborative cold electronics development w/ BNL & MSU	Detector Systems
	Light yield at low E	Small chamber to test light yield in LAr	Detector Systems
Astrophysics Detectors *(J. Estrada)*	Laser Interferometry	High finesse laser laboratory	Detector Systems
	Bubble Chamber	Acoustic rejection of α background / testing in pion beam	Detector Systems
	Solid Xenon	New type of dark matter / axion / $\beta\beta$ detector	Detector Systems
	CCD R&D	Low noise readout/dark matter/neutron imaging	DAQ & Computing
	MKID	Multiplexed array for spectrophotometry	DAQ & Computing
DAQ *(S. Kwan)*	Sensor DAQ	Radiation hardness testing of new sensors	DAQ & Computing
	µTCA and ATCA	Evaluation of new data-flow architecture	DAQ & Computing
	Optical DAQ	Collaborative development of multi-Gbit data links	DAQ & Computing
Facilities & Community Support *(E. Ramberg)*	Facilities / Contingency	Facility maintenance & repairs / management reserve	Core & Infrastructure
	Detector Tools	Upgrade of R&D tools	Core & Infrastructure
	Test Beam Equipment	Pixel telescope support for test beam	Core & Infrastructure
	Workshops / Schools	Conferences, workshops and schools for HEP community	Core & Infrastructure
	MCenter Upgrades	Preparation of Mcenter area for use as LAr test beam	Core & Infrastructure

Fermilab Assets for Detector Research

- Detector R&D program at Fermilab is enabled by our institutional strengths:
  - Presence of research facilities such as:
    - Test beam facility
    - Silicon Detector facility
    - Liquid argon test facility
    - NICADD scintillator extrusion facility
    - CCD characterization facility
    - Thin-Film Facility
    - High power laser laboratory
  - Experienced, well established engineering groups, such as
    - ASIC development
    - Cryogenics
    - Data Acquisition
- We encourage a high degree of collaboration with the university community and other national labs, and we will continue to advertise the capabilities in detector support that Fermilab can deliver

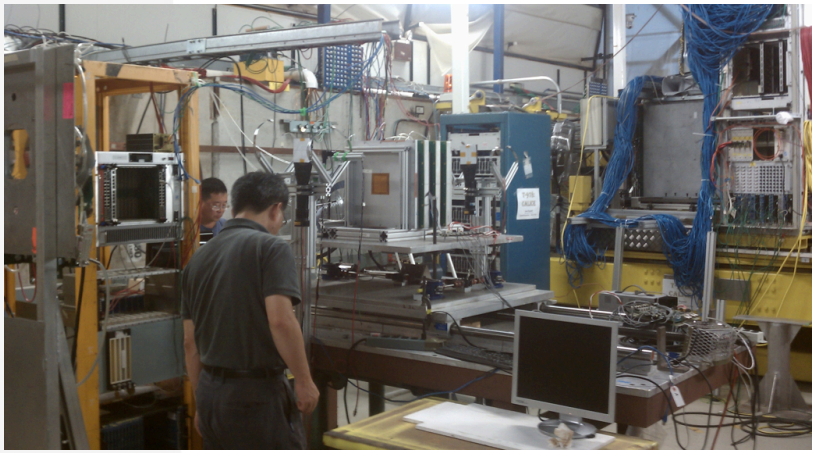


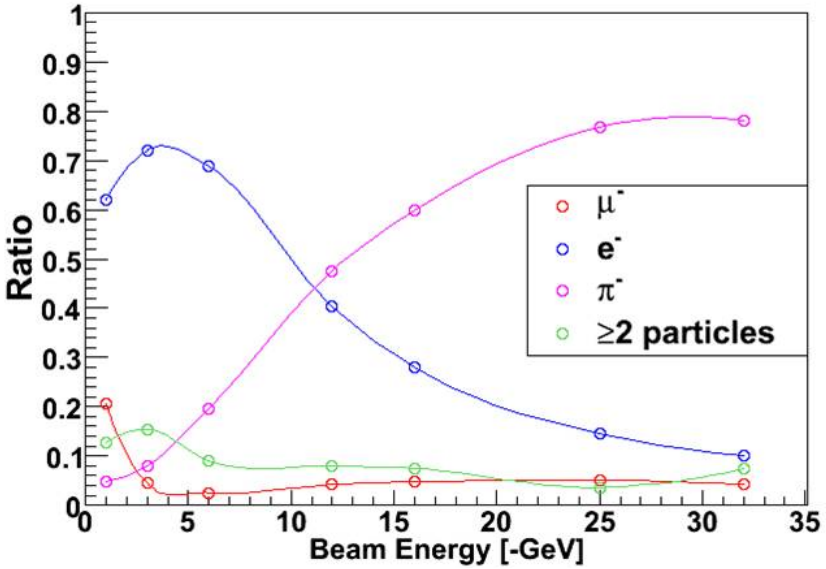
Scintillator extrusion at Lab 5

Clean rooms and metrology at SiDet

CALICE at the test beam

Fermilab Test Beam Facility-
An important detector tool for the HEP Community





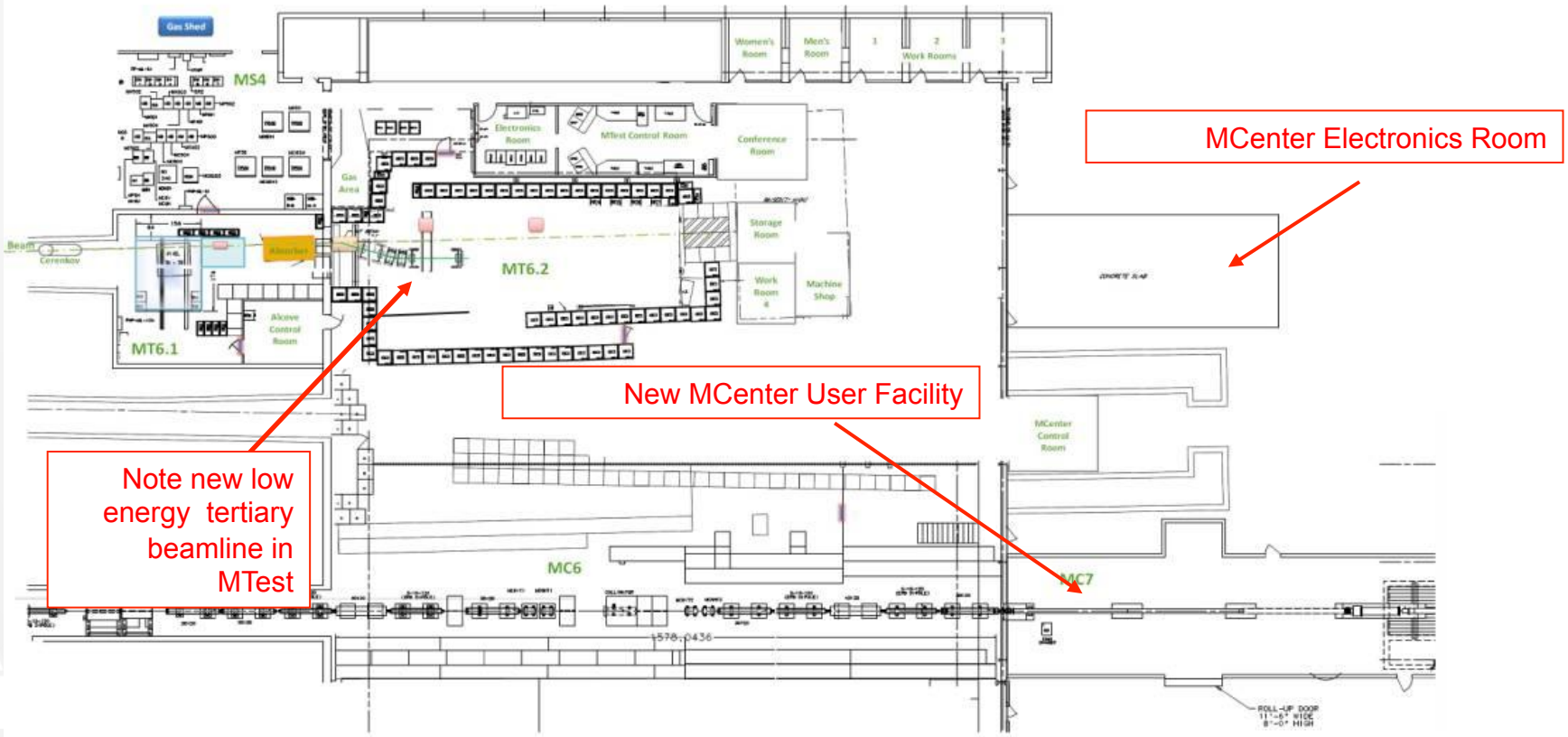
User amenities include:

- 3 Motion Tables
- Tagged cable plant for signals and HV
- Gas delivery infrastructure
- Beam instrumentation including:
  - tracking,
  - time-of-flight,
  - calorimetry
  - differential Cerenkov

Tunable secondary beams for varied detector research. Beam composition (see above) and energy spread (1-3%) are a function of energy.

The 120 GeV proton beam has 7 mm spatial spread, 100 microrad divergence, with rates tunable from 100 Hz to 100,000 Hz.

2nd Test Beam –
A Needed Addition to our Accelerator Complex



The Evolution of Detector Projects

The detector research program is always evolving. Projects turn into experiments; new projects are initiated; some projects get cancelled. Here are a few examples:

- COUPP:
  - Initiated at U. Chicago and became test beam experiment T945 in the NUMI underground laboratory.
  - Using KA15 funds over several years it became a viable technique for dark matter, including a confirmation of acoustic rejection.
  - It transitioned into a full experiment (E961) and is being funded by DOE astrophysics.
  - This technology was exported to Argonne for use in nuclear cross-section measurements
  - Measurements of bubble formation thresholds and efficiency are ongoing using KA15 funds.

- CCD's:
  - CCD characterization facility was built using DES funds
  - Noise reduction techniques and facility maintenance carried on under KA15 support
  - Proposal to use CCD's for dark matter and low-E neutrino investigations was approved for KA15 funds
  - Progress was recently reviewed by Advisory Group based committee, whose recommendations included transitioning to project funds
  - The low noise and multiplexing resources in the CCD group is proposed to transition to MKID development for sky survey spectrophotometry, and this proposal was approved by committee

Response to the 2009 DOE Review

In 2009, the DOE reviewed the national program in detector research.
These are the recommendations for Fermilab and how we've addressed them:

1) *"Develop a coherent detector R&D management plan with a clear vision of the Fermilab role in the national and intemational HEP community."*

   Response: we've established an active advisory panel for detector research, which meets regularly and reports on activity within several major 'portfolios'. These portfolios of work are aimed at the highest priorities of the nation in HEP.

2) "*Generic detector R&D projects should be internally reviewed on a regular basis."*

   Response: the Detector Advisory Group manages regular reviews of detector R&D projects. In the last 3 years there have been 5 such reviews initiated by the advisory group, several with outside members. These reviews, and other instances of oversight, have resulted in significant changes in direction in the program, with some projects cancelled.

3) "*As the only U.S. purely HEP laboratory, Fermilab should be taking leadership in organizing workshops in new detector technology to attract expertise from the other DOE labs, the university community. and non-HEP sources."*

   Response: the summary talk (E. Gottschallk) will outline the extensive series of organizational meetings, workshops, conference sponsorships and schools on detector research that Fermilab has led or cosponsored in the last 3 years.

High Luminosity Tracking, Triggering and DAQ

(talks by G. Deptuch, R. Lipton, A. Prosser)

Comprehensive Approach to Silicon Tracking, Triggering and DAQ R&D

Creating a tracking and trigger system that can withstand the projected HL-LHC luminosities is arguably the most important detector challenge in the field of High Energy Physics.

There must be a comprehensive approach:

Sensor — Testing radiation hardness in new sensors (3D columnar + Diamond)

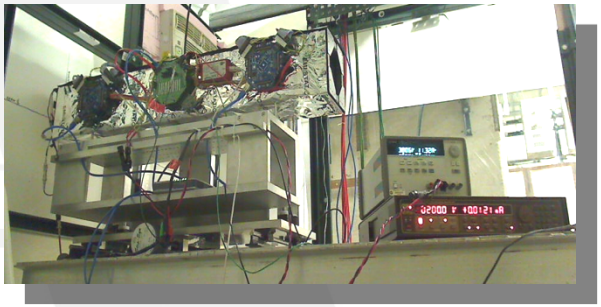
↘

Front End — New 3D ASIC developments to give integrated track segment information

15 US universities
19 foreign institutions
5 laboratories
8 industrial partners

↘

L1 Trigger — Track trigger using 3D techniques



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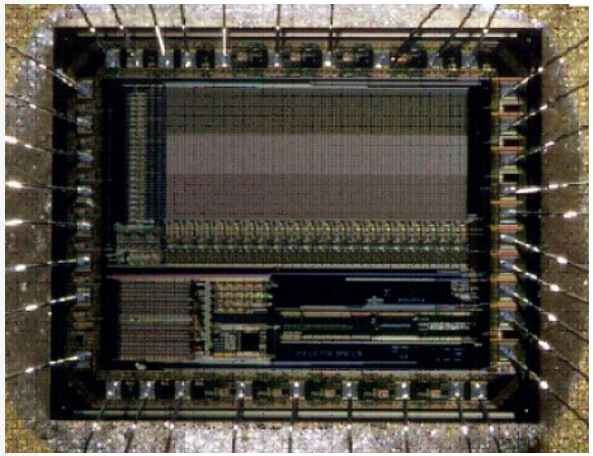
Data Transmission — Multi-wavelength optical DAQ

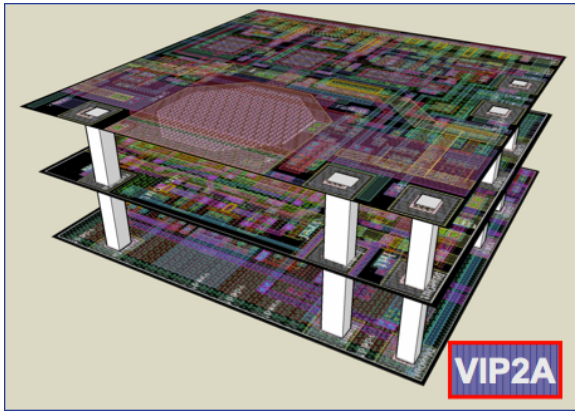
↘

Track Fitting — GPU's and Associative Memory

3-Dimensional ASIC program



Conventional Monolithic
Active Pixel Sensor



3 tier 3D stack for FNAL ILC vertex chip, fabricated by MIT-LL

Moving information to the edges of a detector will eventually become untenable. We must thoroughly explore the option of transmitting information vertically.

Fermilab has led the formation of a large international consortium (http://3dic.fnal.gov) addressing this technology. This group of 17 members from 6 countries shared a multi-project run in 2009 and are now testing structures coming from a new run.

A very important development has occurred in that the tools and techniques learned from this process have been adopted by the major silicon fabrication brokers: MOSIS, CMP and CMC.

Liquid Argon Detectors

(talk by S. Pordes)

The Liquid Argon Program

The development of low-cost, low background and highly efficient liquid argon TPC's are a national priority for both neutrino physics and dark matter physics.

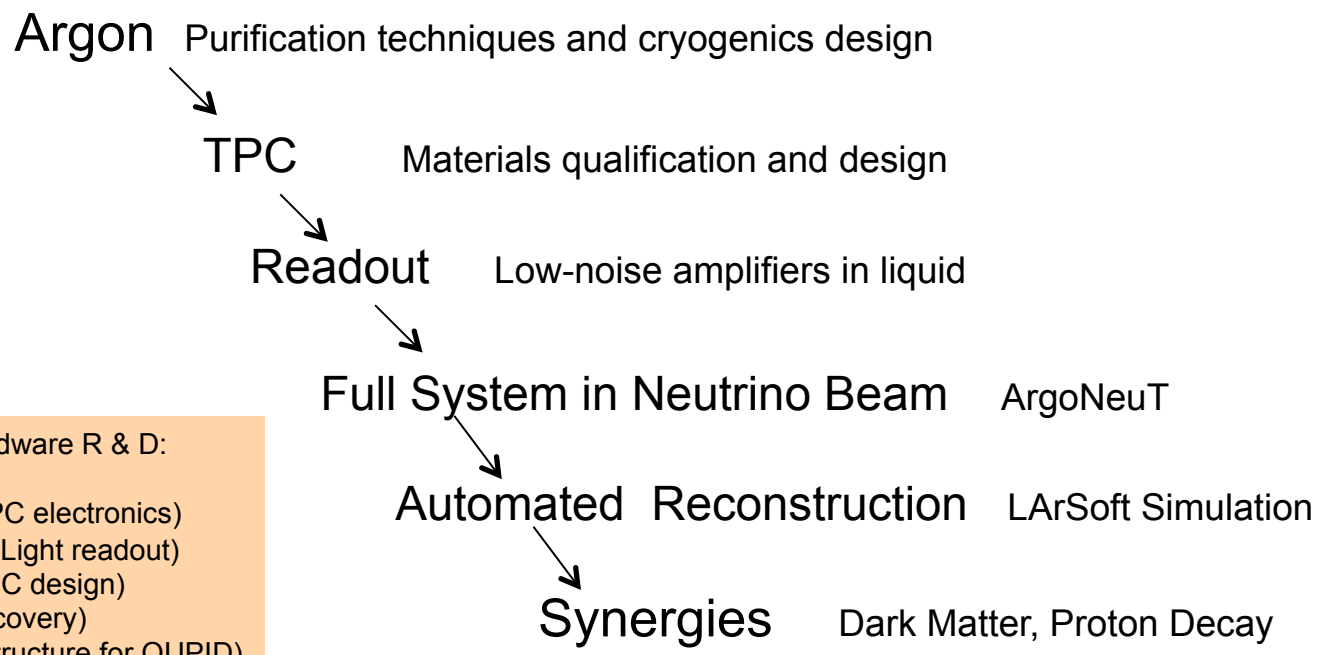
- Fermilab has learned techniques from the international community and from our own test beam efforts (ArgoNEUT). The R&D is now paving the way for implementing truly large detectors (20-30 kton) with industrial techniques

ArgoNeut TPC field cage and installation in NUMI underground lab.

Liquid Argon materials and electronics test stands

Integrated Approach to Liquid Argon R&D

The development of entire liquid argon systems means that new techniques in materials, electronics, or simulation can be addressed immediately:



Institutions collaborating in hardware R & D:
- Yale - Syracuse (ArgoNeuT)
- Michigan State University (TPC electronics)
- M.I.T and Indiana University (Light readout)
- BNL (TPC electronics and TPC design)
- Princeton (depleted Argon recovery)
- UCLA (development of infrastructure for QUPID)
- Indiana University (LAPD)

Future Calorimetry and Photodetection

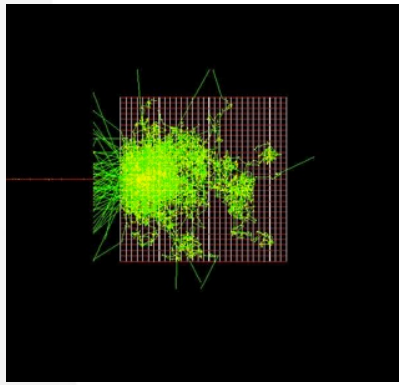
Collaborative approach to calorimetry and photodetection:

- Conceptual Studies – simulation of total absorption hadron calorimeter
- Development of new materials – extruded scintillators, new crystals
- Testing and characterization – optical properties, light yields
- Development of new photosensors – LAPPD, SiPM
- Readout Techniques – QIE10, LAPPD, SiPM (TB4 multichannel readout)
- Test Beam Studies – T1004 (crystals), T1015 (heavy glass), GSI heavy ions
- Large Integrated Systems – CALICE, digital HCAL

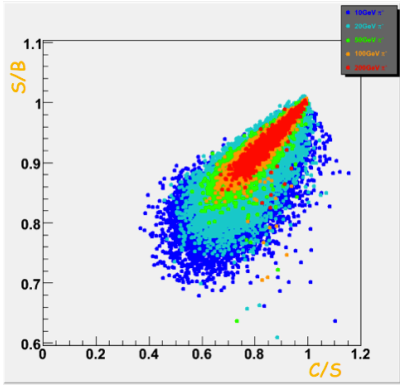
Collaborating institutions:
- ANL (DHCAL, LAPPD)
- Caltech/SICCAS (crystals development)
- LAL Orsay (SiPM characterization)
- University of Iowa (test beam studies)
- University of Udine (scintillating glasses, test beam)
- University of Lecce (test beam)
- University of Cyprus (test beam, materials testing)
- NIU (extruded scintillator)
- U. Cyprus (SiPM charcterization)
- STM; IRST-FBK; Voxtel (SiPM development)
- CERN , Saclay, Milano, GSI (saturation studies)

TAHCAL Calorimetry Research

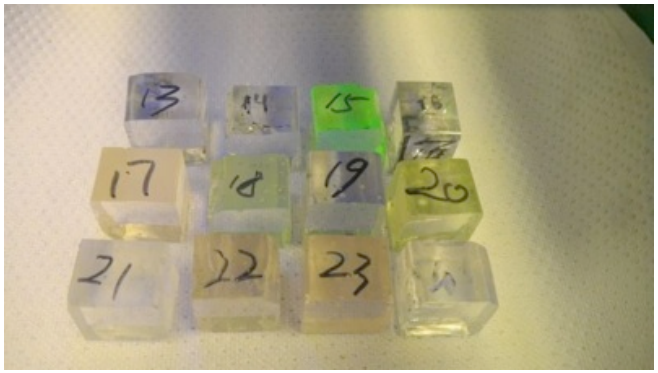
- TAHCAL = 'Total Absorption Hadron Calorimetry'
  - Simulation shows that a homogenous crystal calorimeter with SiPM dual readout could achieve 10%/sqrt(E) resolution using corrections for the binding energy losses:



Purely active calorimeter with 10x10x10 cm^3 units



Reading fast Cerenkov and slow scintillation yields nuclear loss corrections



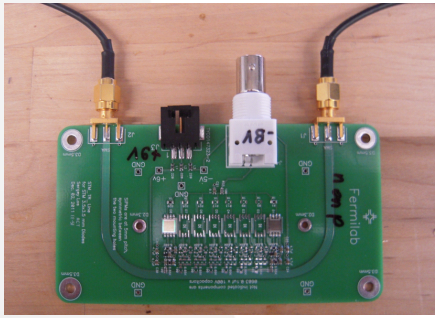
Crystals of doped PbF2 from SICCAS crystal company

FNAL / CalTech / Argonne collaboration received a CDRD grant for this detector R&D

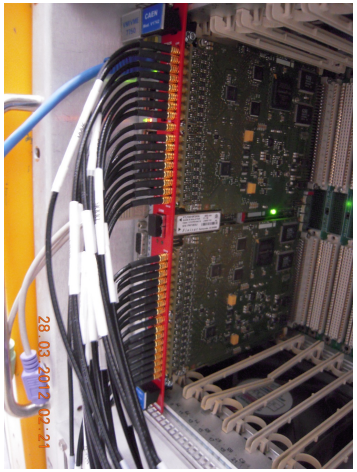
- We are searching for appropriate cost-effective material for this technique (doped PbF2? Heavy glasses? Scintillating ceramics??)
- Working with vendors to improve characterizations of SiPM devices
- Continue test beam studies, including low energy ion beams at GSI, Darmstadt
- Contrast GEANT4 and MCNPX simulations of showering process

SiPM's for Time-of-Flight and Calorimetry

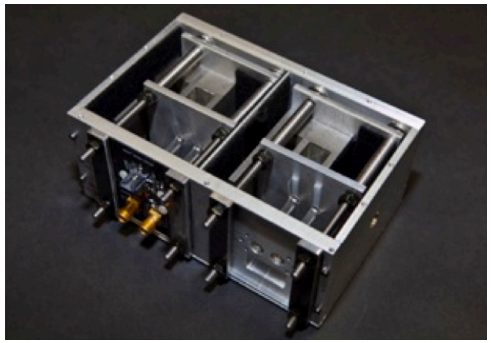
- Silicon PhotoMultipliers are multi-pixel avalanche photodiodes. Pixel sizes on the order of 50 microns and avalanche regions at the micron level.
- Theoretically, they could be one of the fastest particle detectors for HEP (<16 psec proven at FNAL).
- Fermilab has been studying their potential for TOF and calorimetry for several years. Designs developed at FNAL to be used in FP420 forward tracking at CMS.
- DAQ techniques supported by KA15 are being used in Proton Computed Tomography with NIU
- Recently we received a U.Chicago 'seed' grant to apply these techniques to PET-TOF.



Transmission line readout suitable for reading 8 separate SiPM's



CAEN 1742 module digitizes at 5 Gs/s. Good for timing and energy measurement



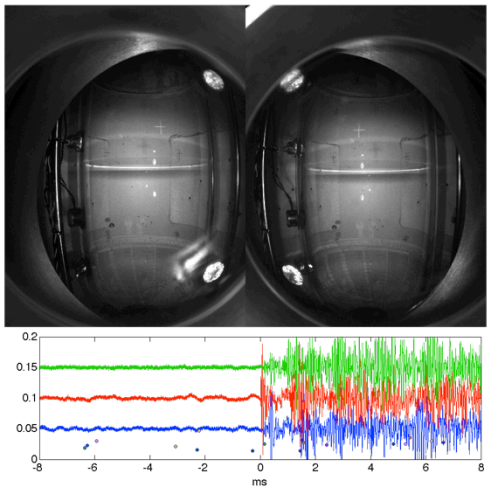
Example of one geometry of quartz bars and SiPMs for CMS forward region

Astrophysics Detectors for Dark Matter/Dark Energy

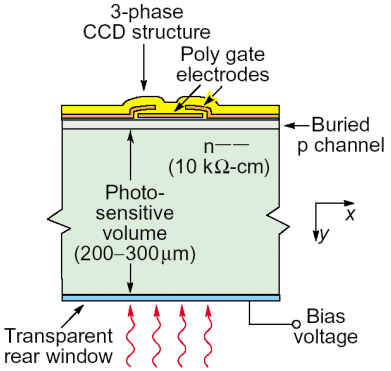
(talk by J. Estrada)

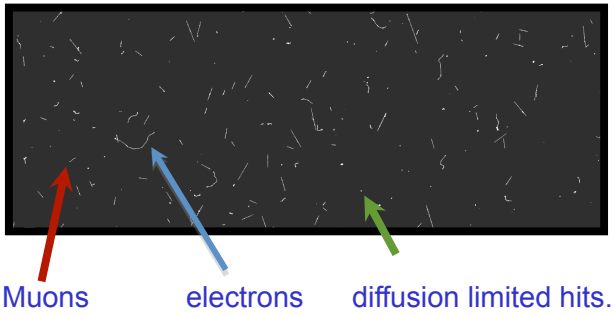
Innovative Techniques in Dark Matter Detector R&D

Distillation column to produce 39Ar depleted Argon for dark matter community, such as Dark-Side



Support bubble chamber calibration R&D, such as threshold measurements and acoustic particle i.d. This technology now resides at ANL for stellar nuclear cross section measurements





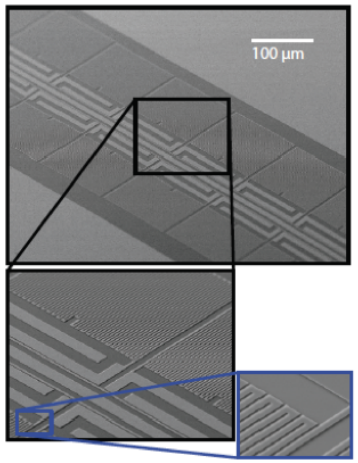
Use DECAM thick CCD sensors for low-mass dark matter search (DAMIC)

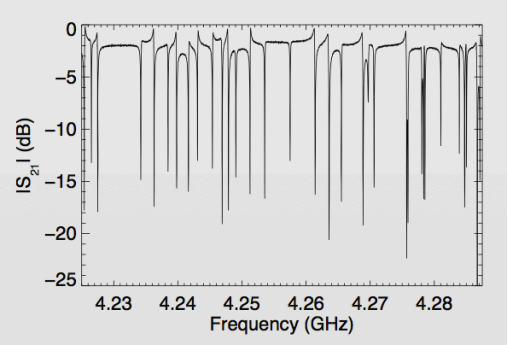
(Not shown: solid Xenon, Chameleon detector)

MKIDs : Proposing a new detector research effort at Fermilab

- MKID = “Microwave Kinetic Induction Detectors”
- Unlike CCD’s, MKID arrays can give a photon-by-photon energy and timing measurement, as well as position.
- The capability of these detectors is well matched to our future astrophysics needs, namely spectrophotometry for large area sky surveys
- Fermilab’s resources are an excellent match to what is needed for optical MKID research: experience in low level RF, high speed digitization and multiplexing.

A recent review called by the Detector Advisory Group recommended transitioning CCD research into project funds and proceeding with a highly multiplexed MKID project. This is now being reviewed by PPD and CD Division management.

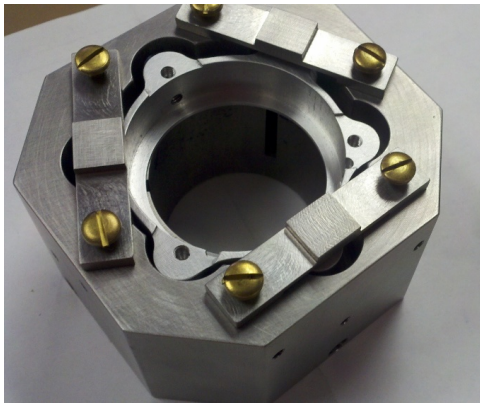




Resonances from each array element are not necessarily uniform or predictable

A High Power Laser Lab

- Developed in an empty beamline (MEast) to support space-time and dark matter axion research
- Contains a 2 watt laser with cavity finesse of 1000, and thus 2 kW of stored power in a baseline of 40 meters
- Developed PZT controlled cavity mirrors instead of typical spring suspension, to reduce lower frequency (<1 kHz) noise



Applications for control of high intensity optical beams:

1) Optical beam dump searches for axions, hidden-sector photons

2) Precision interferometric position measurements (Holometer)

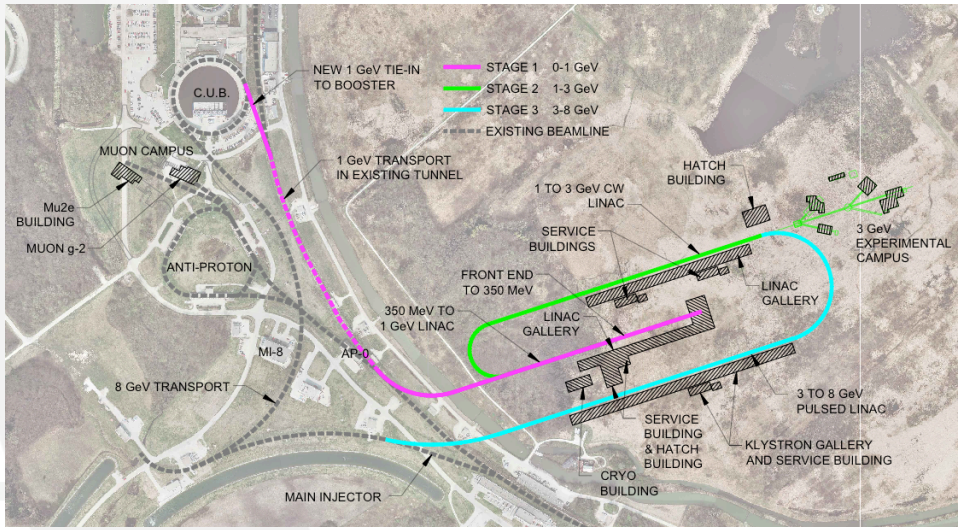
3) Precision interferometric angular motion measurements (5th force searches)

Intensity Frontier Detector R&D

(talk by B. Tschirhart)

Planning for the High Intensity Frontier

- Project X will provide a staged approach to a new high intensity frontier of particle physics, supporting neutrino, kaon, muon and nuclear programs.
- Detector technology must advance to meet these program's requirements.



The Project X Physics Study last month was a workshop to identify the theory motivation and detector requirements for the Project X era.

Detectors for High Intensity are matched well with our current program

Detector challenges studied at PXPS (with conveners):

High rate Precision Photon Calorimetry:
David Hitlin (Caltech), Milind Diwan (BNL)

Very Low-Mass High-Rate Charged Particle Tracking:
Ron Lipton (FNAL), Jack Ritchie (U. of Texas, Austin)

Time-of-Flight System Performance below 10 psec:
Mike Albrow (FNAL), Bob Wagner (ANL)

High Precision Measurements of Neutrino Interactions:
Kevin McFarland (Rochester U.), Jonghee Yoo (FNAL), Rex Tayloe (U. of Indiana)

Large Area Cost Effective (LACE) Detector Technologies:
Mayly Sanchez (Iowa State U.), Yury Kamyshkov (U. of Tennessee)

These map well onto our current and planned program. R&D projects will very likely be established based on these summaries

Summary

- Fermilab has based its detector R&D organization on a "Detector Advisory Group", consisting of representatives of the major detector efforts.
- R&D efforts have been centered on several major portfolios, linked to the highest priorities of HEP:
  - High luminosity tracking and triggering
  - Liquid argon detectors for neutrino and dark matter experiments
  - High speed calorimetry and photodetection
  - Astrophysics dark matter/dark energy
- Fermilab's resources and collaborations are crucial in detector research and testing
- Developing detectors to meet the challenges of the Intensity Frontier will be a new emphasis for the lab, and is highly leveraged by the work we are already doing.

Our web site has links to our detector organization and facilities, as well as links to the EDIT school and our detector retreat:

http://detectors.fnal.gov

Useful Email:

FNAL detector point-of-contact:

ramberg@fnal.gov

Detector Advisory Committee:

detector-advisory@fnal.gov

Detector R&D mail list (94 members):

detectors@fnal.gov

Test beam users (116 members):

test_beam@fnal.gov

Fermilab Presentation Agenda at DOE Review of Detector R&D - July 24, 2012

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Data Acquisition:	Alan Prosser	(30’)
Break		(15')
Liquid Argon R&D:	Stephen Pordes	(35')
Astrophysics Detectors	Juan Estrada	(25’)
Intensity Frontier Detectors	Bob Tschirhart	(25’)
Future plans and Community Support	Erik Gottschalk	(20')