

# Cosmic Frontier Experiments

Craig Hogan  
Fermilab Institutional Review  
June 6-9, 2011

# Cosmic Frontier Research at Fermilab

- Core Program
  - Historical context
  - Main Thrusts:
    - Dark Energy
    - Dark Matter
    - High Energy Particles
- Future
  - Extensions of core program
  - New initiatives: spacetime, axion-like particles

# History of Particle Astrophysics at Fermilab

Theoretical Astrophysics Group (1983)

Sloan Digital Sky Survey (1990)

Pierre Auger Observatory (1994)

Cryogenic Dark Matter Search (1997)

Dark Energy Survey (2003)

Chicagoland Observatory for Underground Particle Physics (2004)

Laser experiments (2008)

# Fermilab Center for Particle Astrophysics

Established in 2007 by DOE/FRA contract

To unify and lead a program aligned with DOE goals,  
science opportunities, university research

Builds on science talent of Fermilab

Mostly particle physicists

Wilson Fellows (Sonnenschein, Chou, Estrada, Yoo)

Presidential Early Career Award (Estrada)

DOE Outstanding Junior Investigator, Early Career  
Awards (Chou)

# Sloan Digital Sky Survey at Fermilab

World's first digital survey of the universe

Highest-impact observatory of the decade

Foundation of precision cosmology (with CMB etc.)

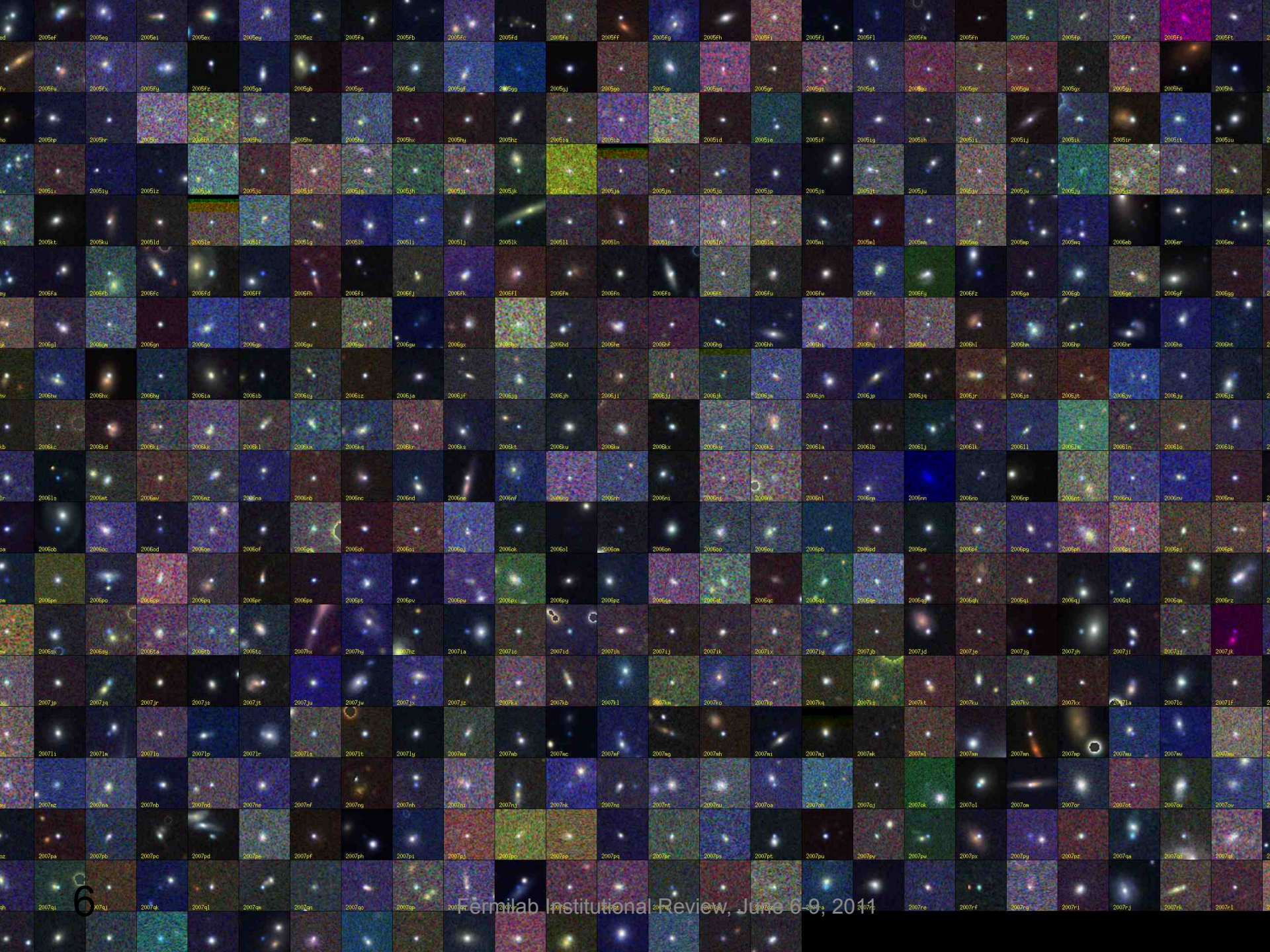
Many discoveries including BAO, ISW effects

Fermilab: anchor institution for technical infrastructure, operations, computing

Directors from FNAL: J. Peoples, R. Kron

Science ongoing: SDSS Supernova Survey, galaxy clusters

Scientists in transition to Dark Energy Survey



# Core program: anchor laboratory for world-leading experiments

## Dark Energy

Dark Energy Survey (DES)

## Dark Matter

Cryogenic Dark Matter Search (SuperCDMS)

Chicago and Observatory for Underground Particle Physics (COUPP)

## Ultra high energy cosmic rays

Pierre Auger Observatory (PAO)

# Dark Energy Survey

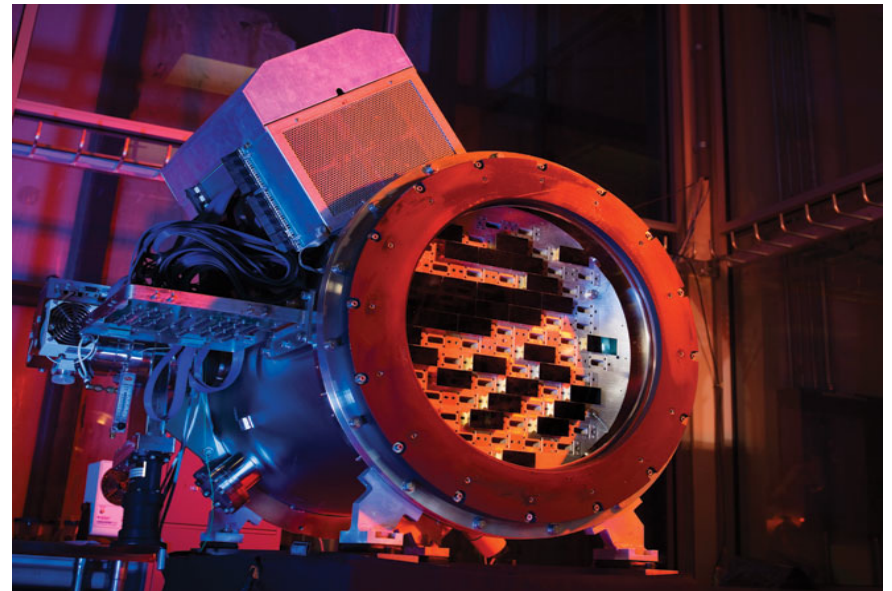
Next big step in cosmic surveys after SDSS

Wide and deep (~Hubble distance)

Led by Fermilab scientists

Survey starts in 2012, then runs 5 years

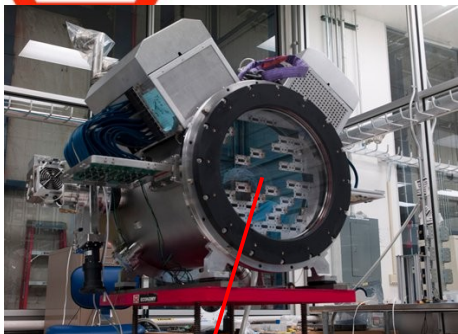
*DECam under construction at Fermilab*







# DECam System



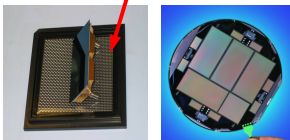
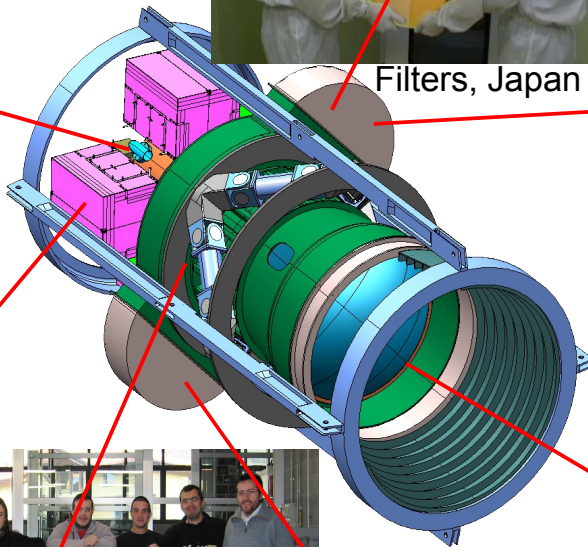
Imager, **FNAL**



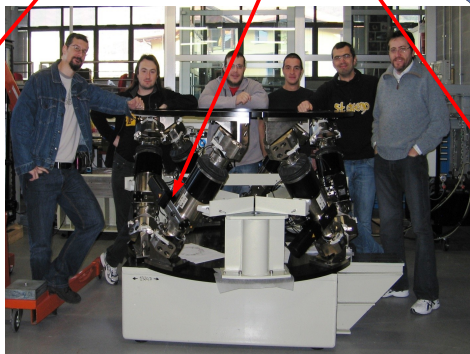
Filters, Japan



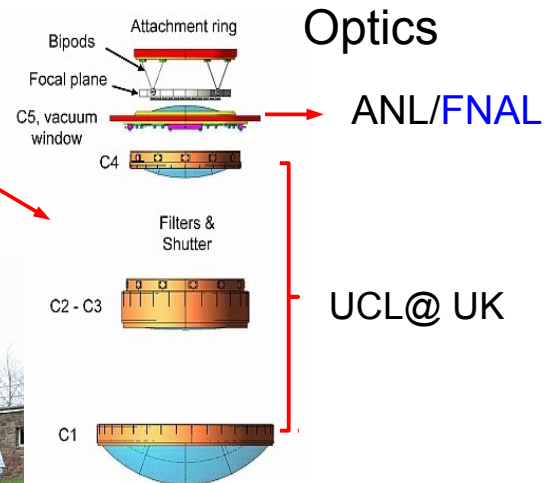
Filter changer, Univ. of Michigan



CCDs, wafer from LBNL, packaged at **FNAL**



Hexapod, Italy

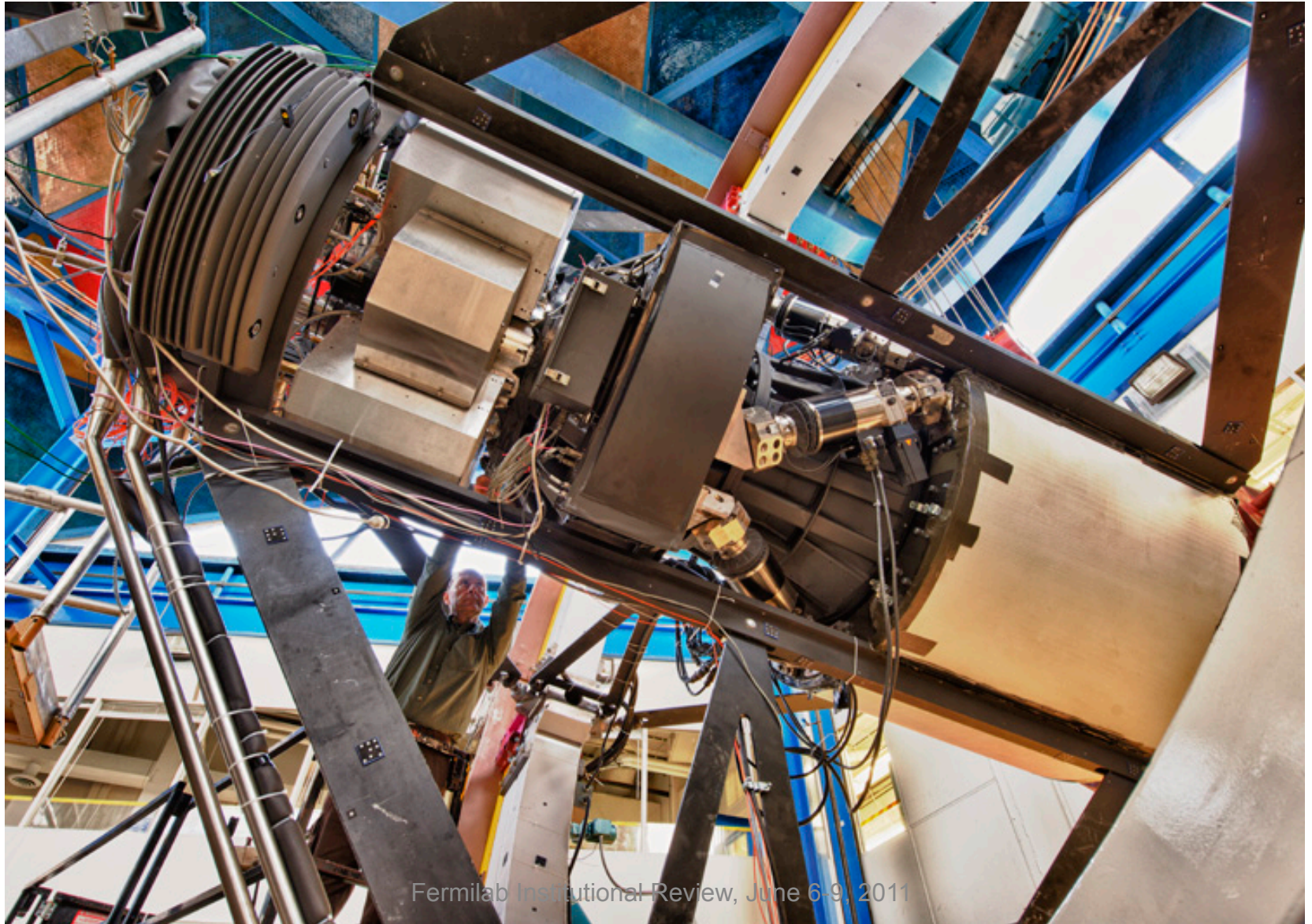


Shutter, Germany



Electronics, Spain and **FNAL**

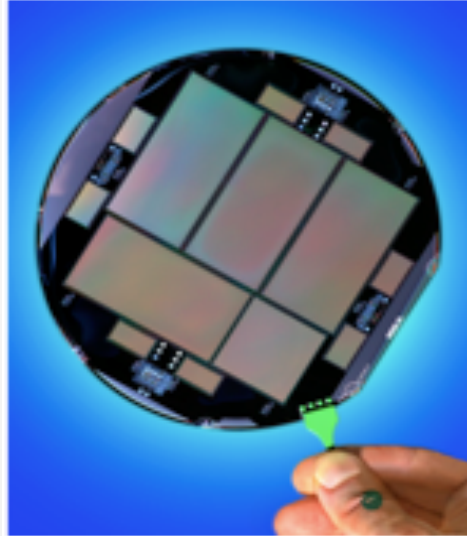
# DECam at SiDet



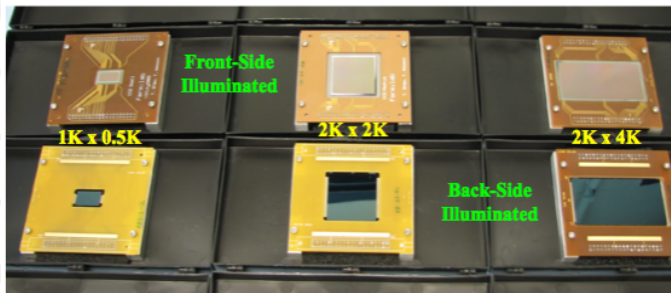
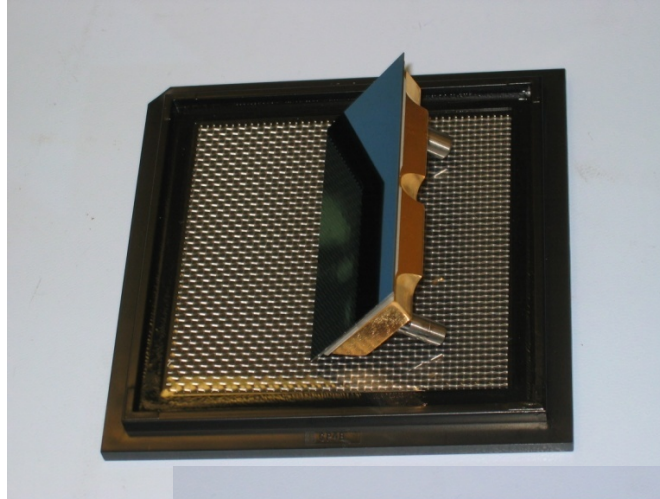


# Fermilab's silicon detector technology

## DECam wafer

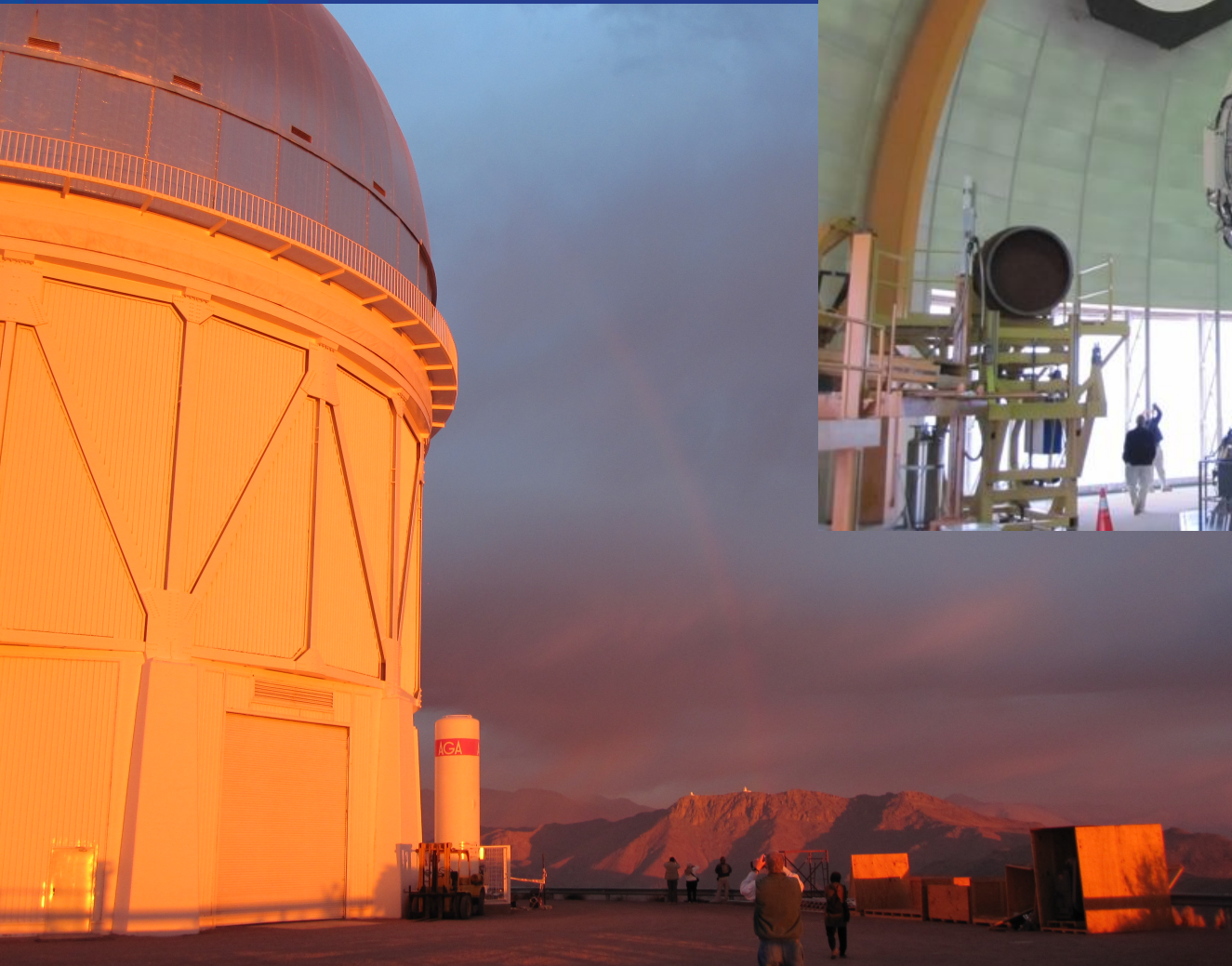


## DECam detector developed with LBNL



*Fermilab's expertise in building silicon trackers has transferred to the design and fabrication of these CCDs*

*DECam's destination: 4 meter Blanco telescope at Cerro Tololo InterAmerican Observatory*

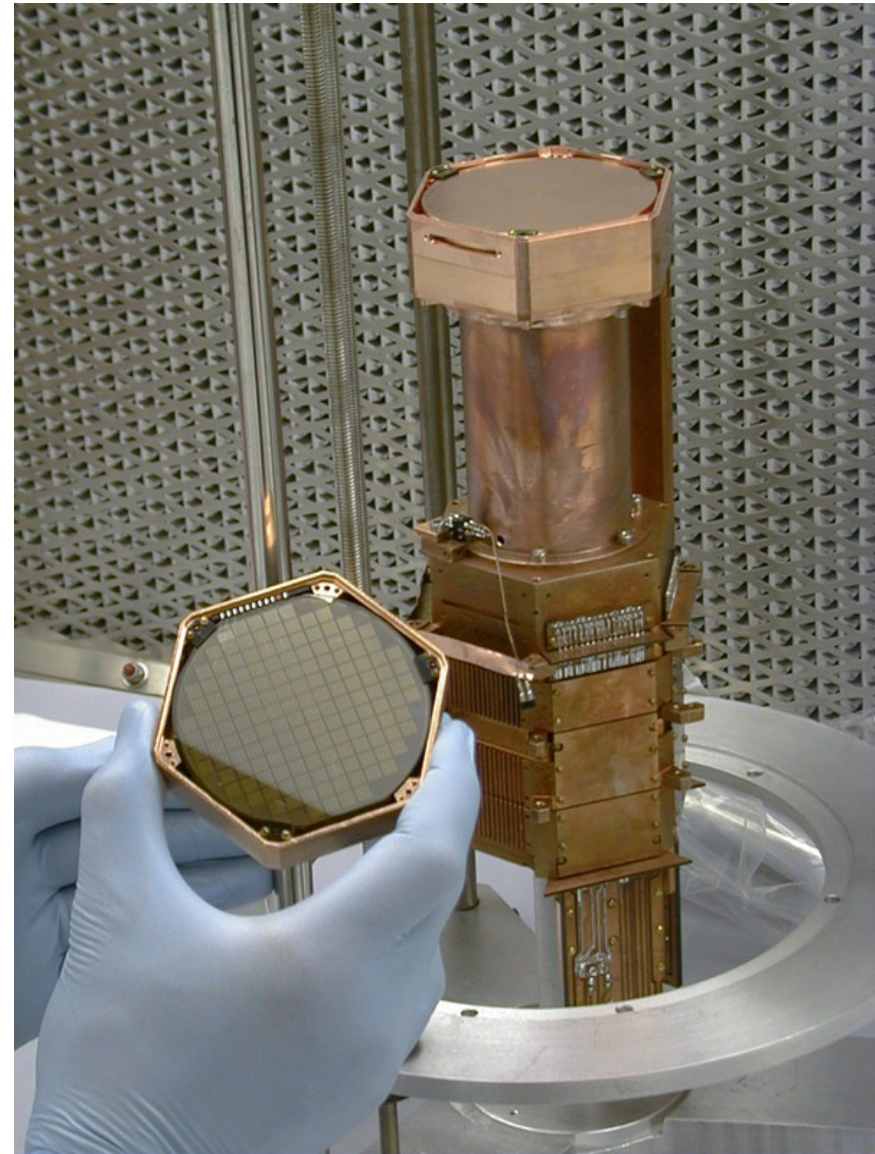


# Dark Matter with Cryogenic Crystals: CDMS

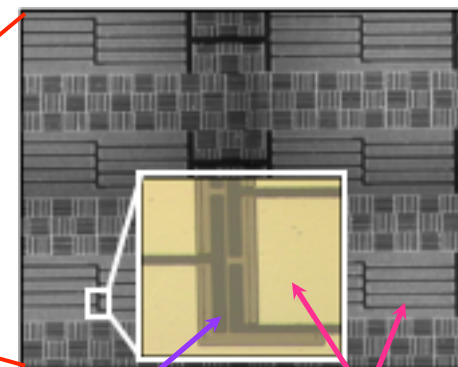
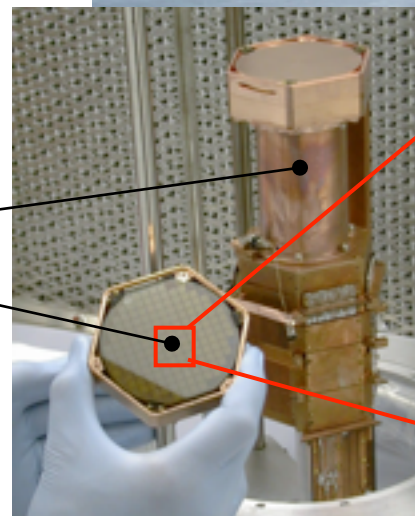
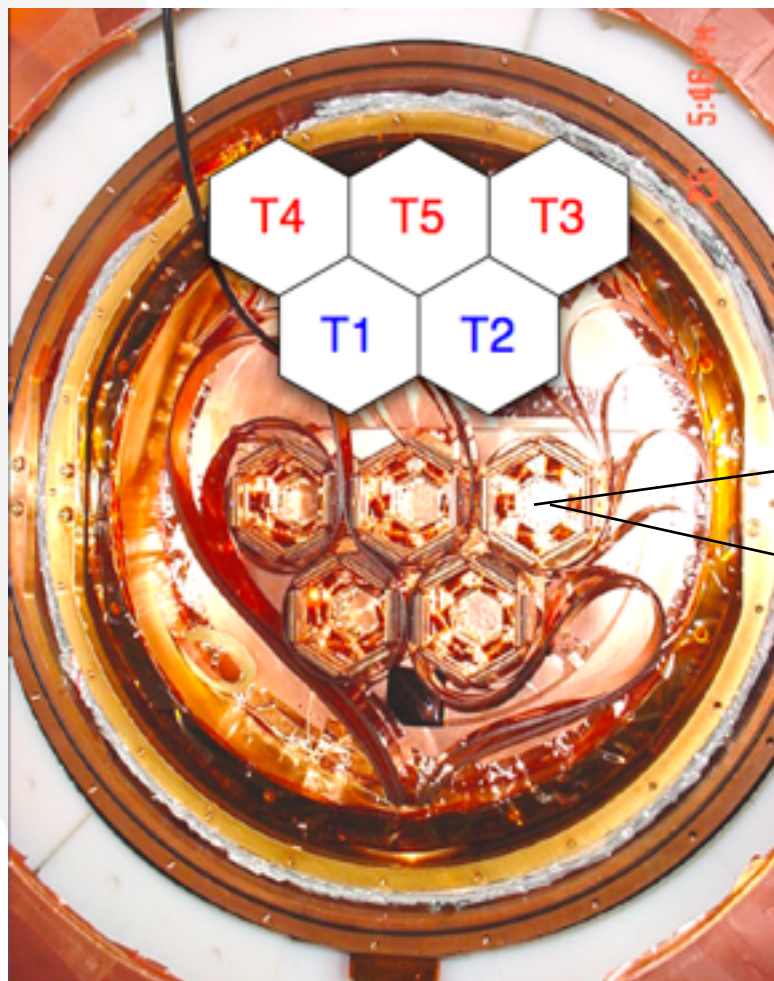
Search for rare collisions of Galactic halo WIMP dark matter particles with nuclei

State of the art in direct detection and background rejection

This year: 15kg at Soudan with better detectors, background rejection



# CDMS-II at Soudan



1  $\mu$  tungsten

380  $\mu$  x 60  $\mu$   
aluminum fins

*Z-sensitive Ionization and Phonon detectors*

# SuperCDMS: Technology Breakthrough

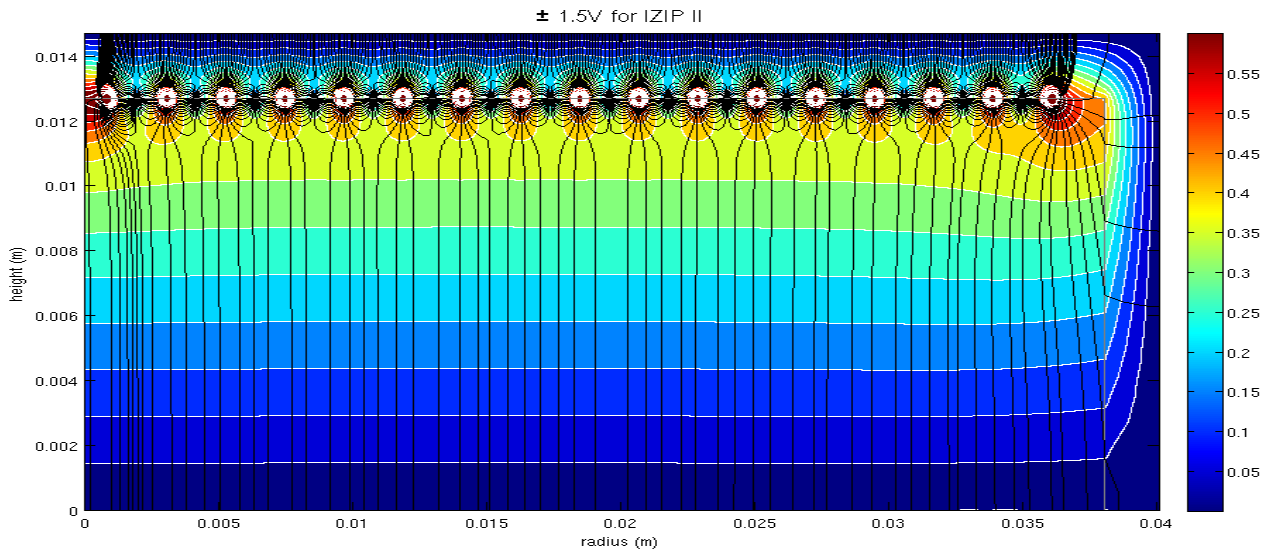
New symmetric detectors (iZIP) improve background rejection by more than an order of magnitude

Ton scale CDMS style experiment now feasible

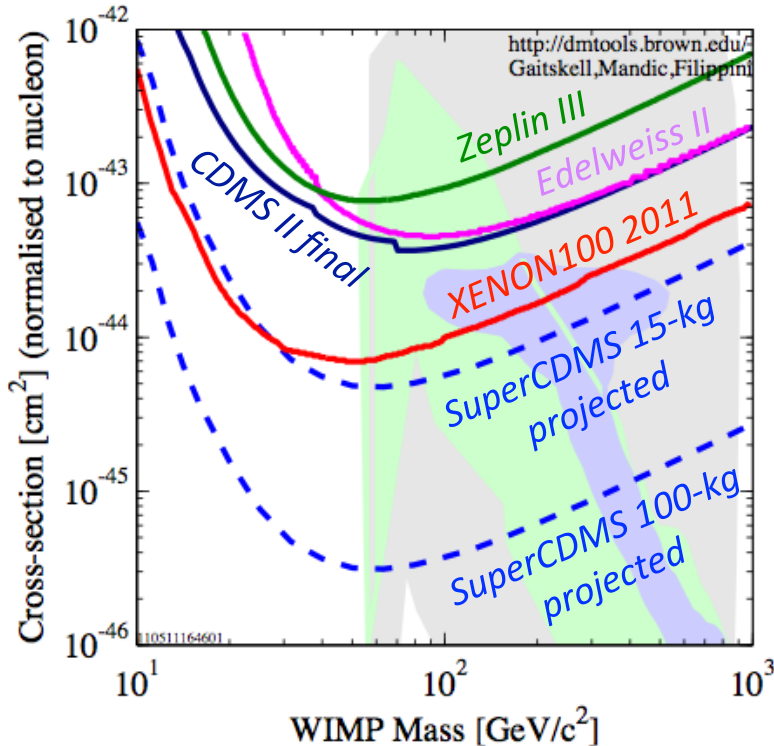
iZIP now installed at Soudan facility

Science run begins this summer

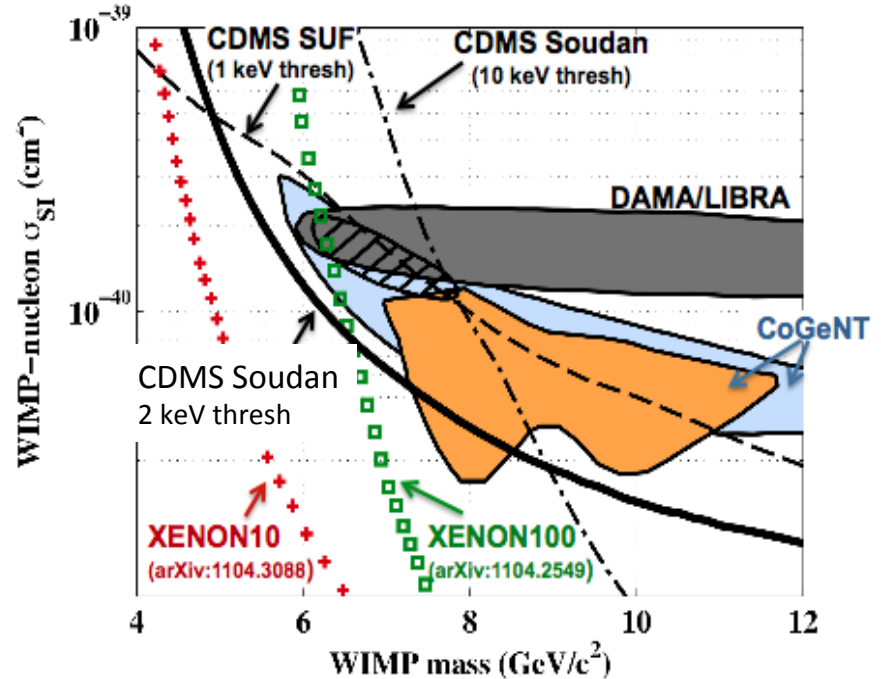
Major funding needed for SuperCDMS at SNOLab



# Current state of WIMP direct detection



*Spin-Independent scattering  
above 10  $\text{GeV}/c^2$  WIMP masses*



*Spin-Independent scattering  
below 10  $\text{GeV}/c^2$  WIMP masses*



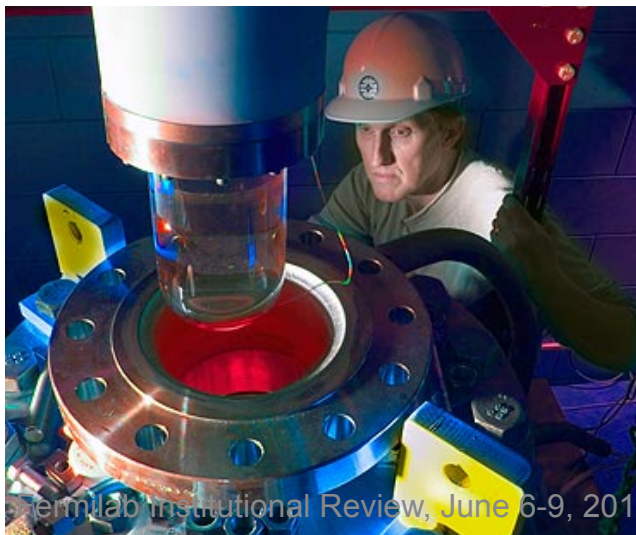
# Dark Matter with Bubble Chambers: COUPP

Old technique applied with stunning early success

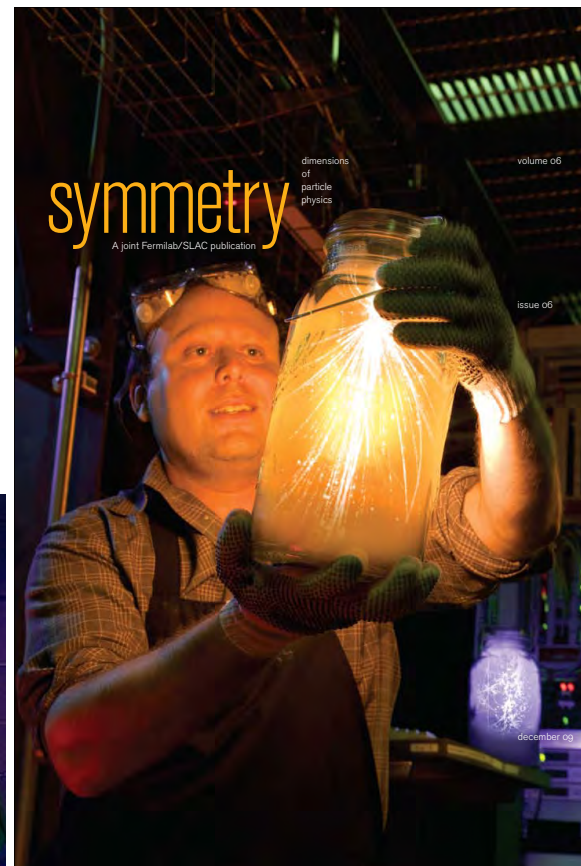
High-purity 4kg and 60kg chambers, new acoustic rejection

Now: 4kg at SNOLab, 60kg at FNAL

Future: 60kg to SNOLab, then 500 kg

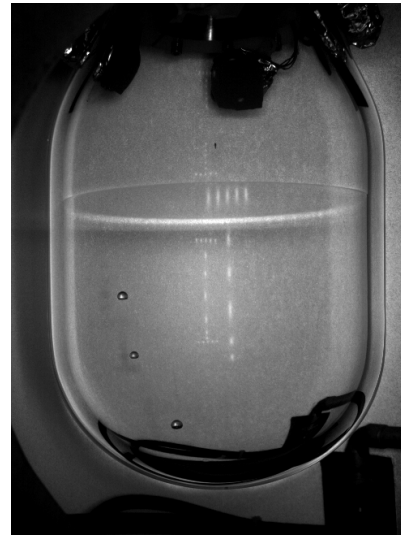
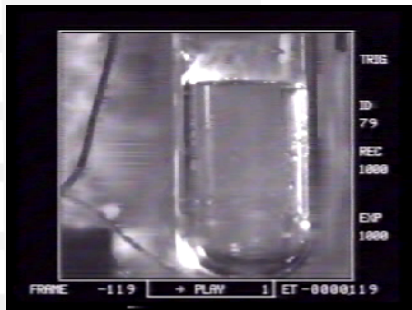


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# COUPP Bubble Chamber Program

smaller chambers lead R&D for larger chambers

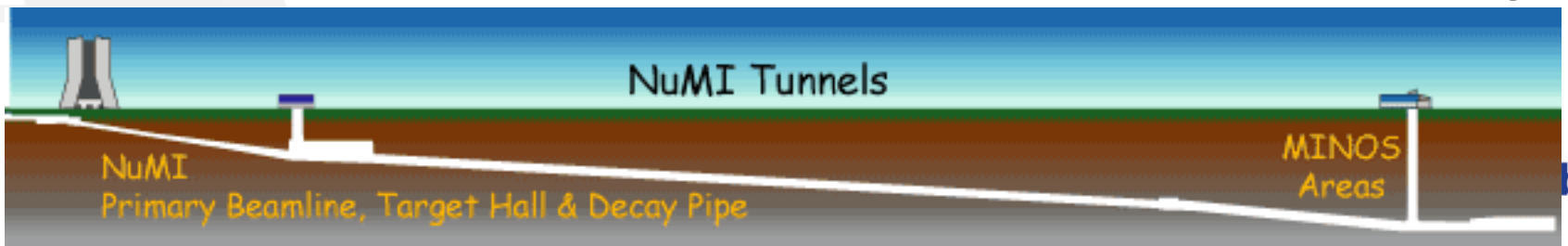


Test tube  
(U Chicago)

COUPP 2kg

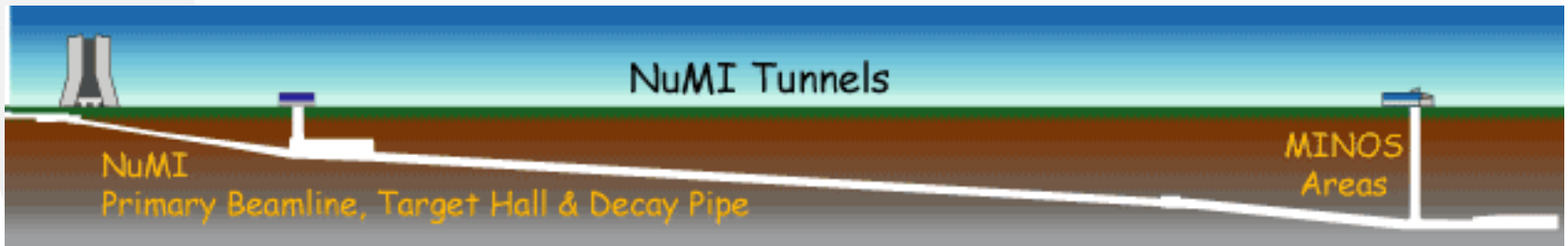
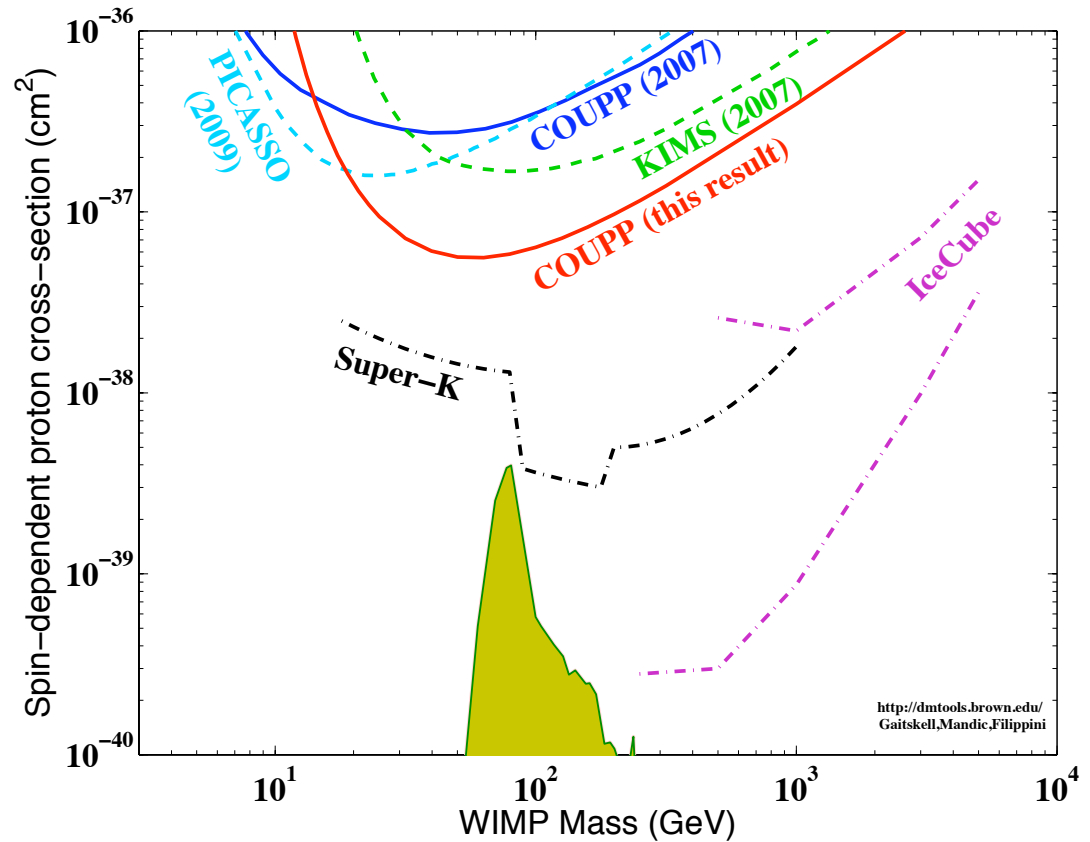
COUPP 4kg

COUPP 60kg



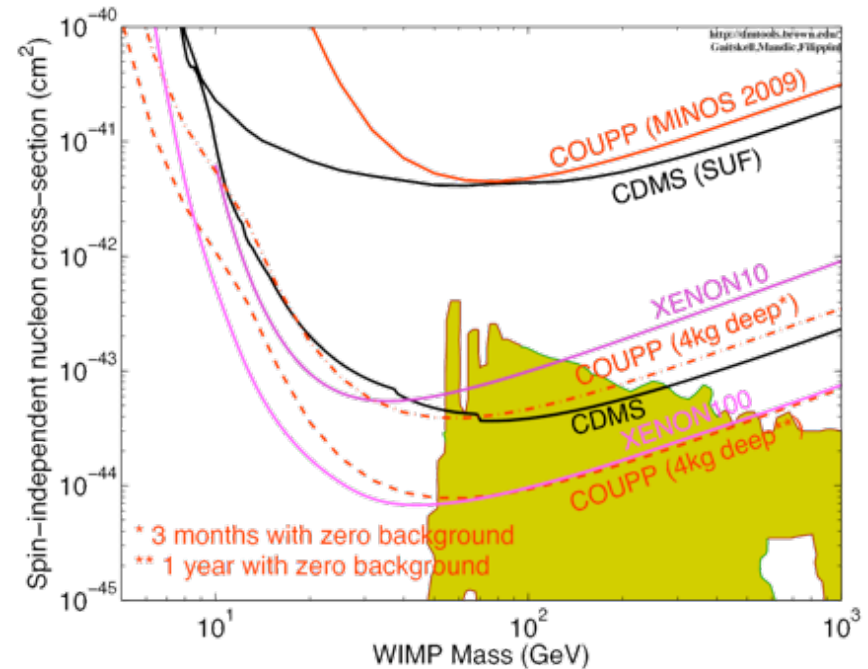
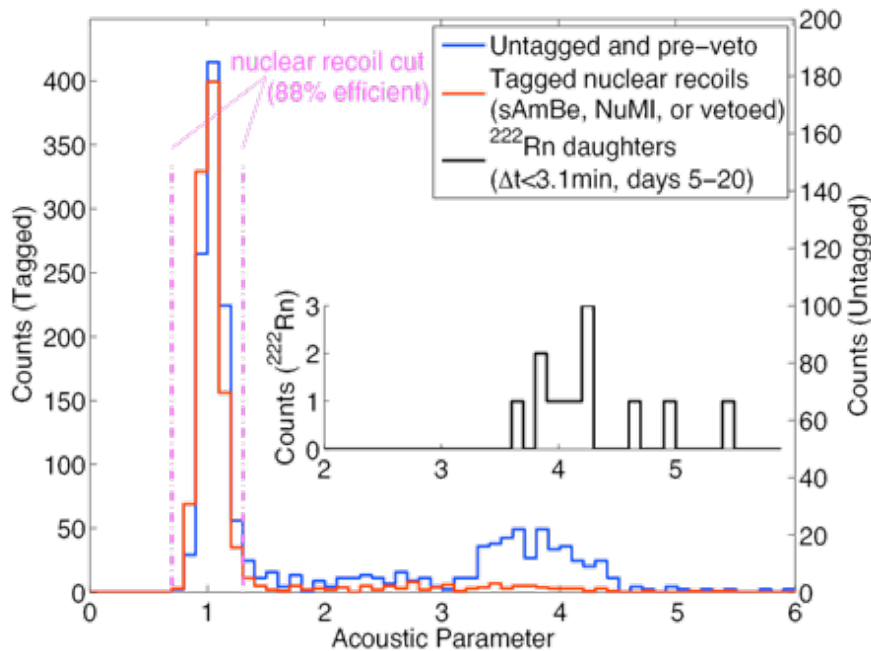
# Best direct limits on spin-dependent WIMPs

- Blue line – Science 319:933-936 (2008)
- Red line – latest result (2010)
- Latest results limited by cosmic radiation in the NUMI tunnel, 350 foot depth



# COUPP acoustic background rejection technique

- Demonstration of acoustic rejection against alphas, a previously limiting background
- Paper published in January, 2011 - PRL, 106, 021303

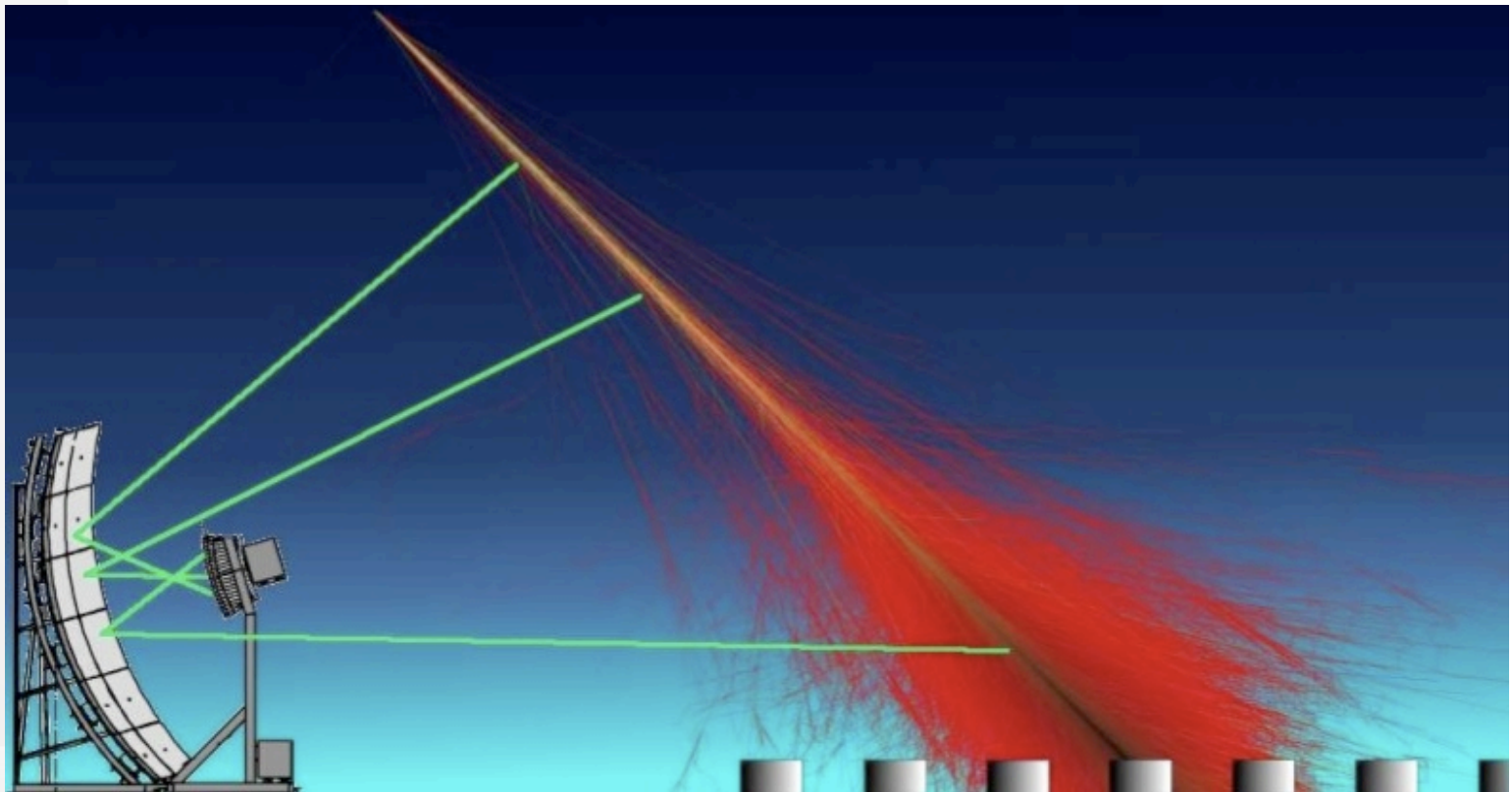


*COUPP-4 is now running at SNOLab with these sensors*

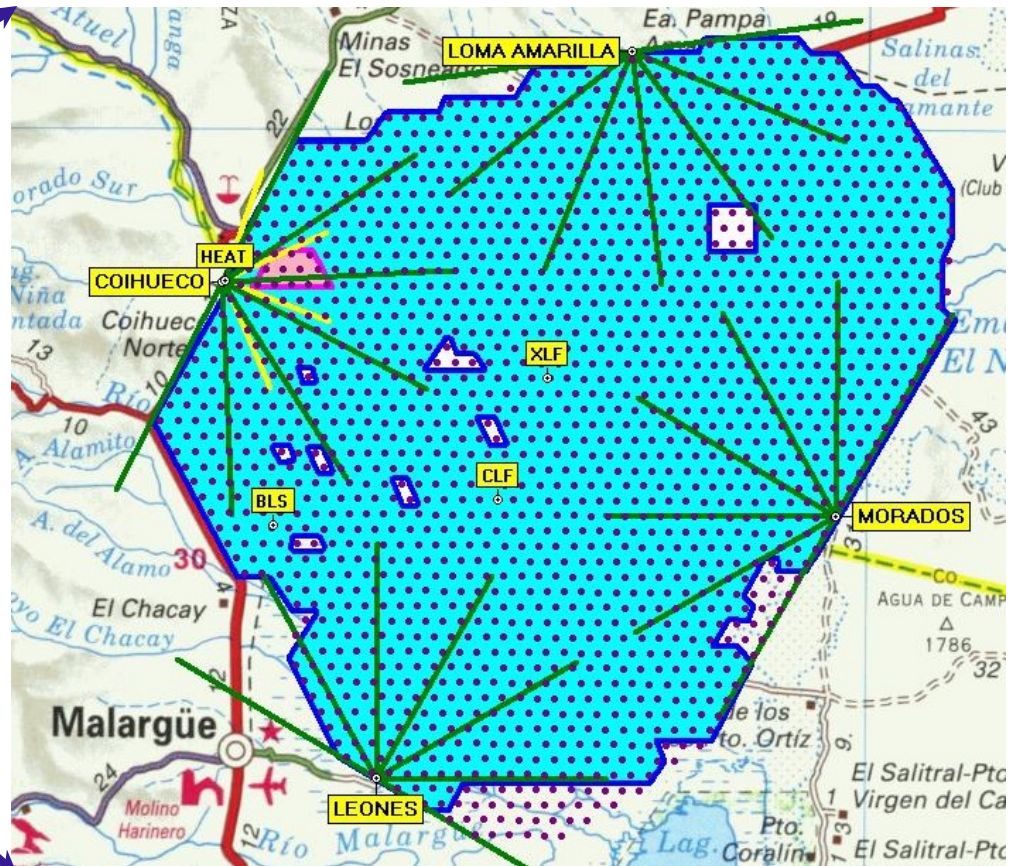
# Pierre Auger Observatory

World's leading observatory for highest energy particles

Discoveries: high energy spectral cutoff from CMB interactions, anisotropy from sources, new composition puzzle

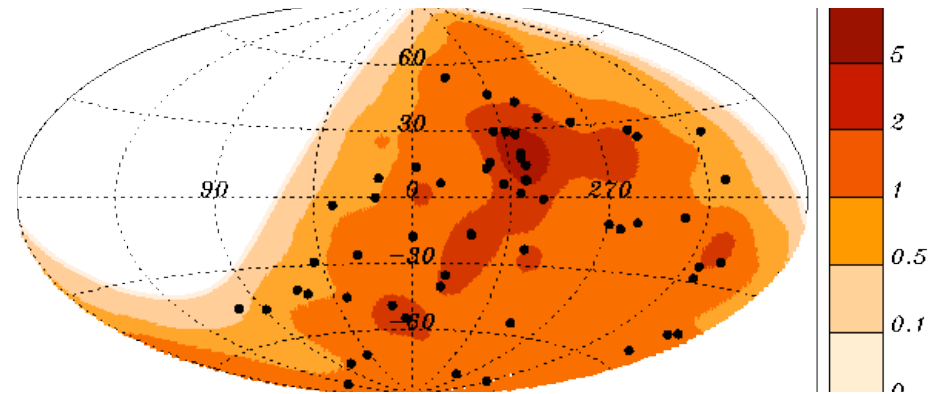
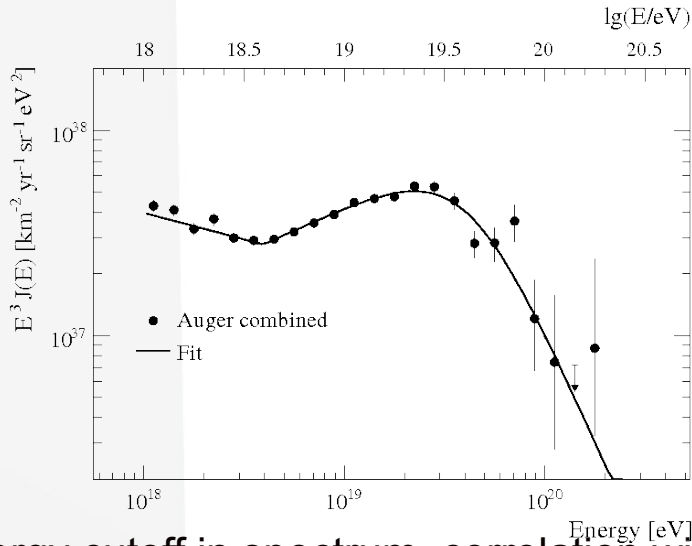


# Pierre Auger Observatory Site

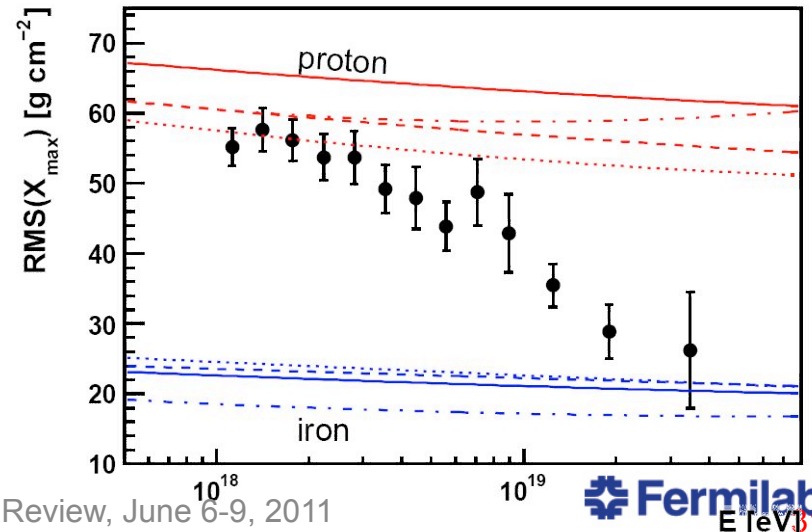
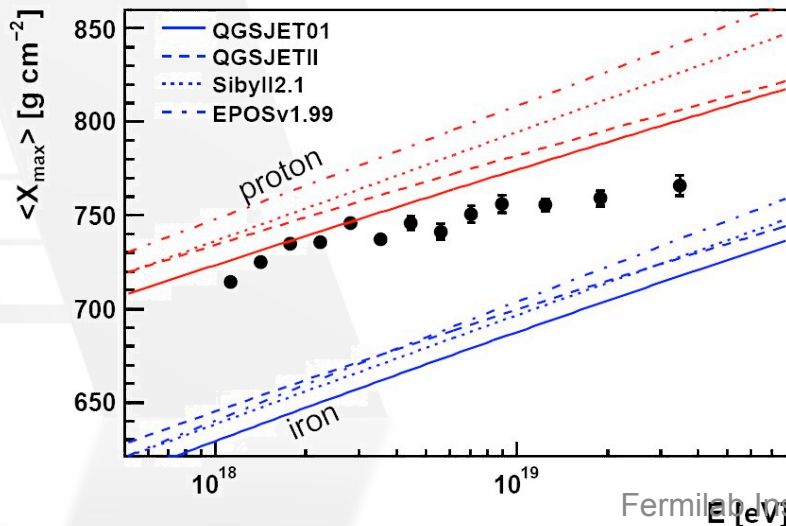


## Pierre Auger Collaboration

# Auger results and puzzles



Energy cutoff in spectrum, correlation with local AGN suggest extragalactic sources and proton composition. Shower penetration depth and fluctuations suggest either violation of unitarity or iron composition.



# FCPA Scientific Effort – FY2011

26 Scientist FTE (from ~41 'heads') and 9 postdocs





# Program Planning

## Align with DOE/HEP

Choices based on science opportunities, community priorities, lab capabilities

Priorities from HEPAP/P5/PASAG/Astro2010

## KA13 Program Review (Sept. 2010)

Overall program well reviewed

Response to budget shortfall:

21cm BAO: retire FNAL involvement

QUIET-II: further involvement contingent on NSF

PAO: scale back FTE staffing

# HEPAP Particle Astrophysics Scientific Assessment Group (2009): Concise summary

“Dark matter and dark energy remain extremely high priorities.”

“Dark energy funding, which receives the largest budget portion, should not significantly compromise U.S. leadership in dark matter, where a discovery could be imminent.”

“Dark energy and dark matter funding together should not completely zero out other important activities in the particle astrophysics program.”

# PASAG/HEPAP recommendations (2009)

“In all budget scenarios, the Xenon100 upgrade, the LUX350 detector, an effort on DAr, funding for the MiniCLEAN detector, the additional towers in SuperCDMS Soudan, the COUPP 500 construction, the 100-kg SuperCDMS- SNOLAB experiment and the phase II upgrade to ADMX are supported.”

***Fermilab aims to establish a leading “WIMPstitute”***

“PASAG recommends that QUIET II be supported at the proposed scope under all budget scenarios.”

***Fermilab will participate in QUIET-II if it is funded by NSF***

“Auger North addresses questions of great interest... Given its relative science priority for HEP and the funding constraints, PASAG recommends significant HEP support for the construction of Auger North in budget Scenarios C and D.”

***Fermilab is concentrating on Pierre Auger South***

# Future Program

On-going experiments: Dark Energy (DES), Dark Matter (CDMS, COUPP), High Energy Particles (PAO)

***Remain the core program for the next ~5 years***

Future projects within core thrusts:

Planning and R&D for Dark Energy after DES

***Fermilab will participate in LSST, R&D on spectroscopic surveys***

Next Generation Dark Matter: add Liquid Argon (Darkside)

***Explore multiple modalities for direct WIMP detection***

Small exploratory initiatives:

Cosmic Microwave Background Polarization (QUIET-II)

***Contingent on NSF funding***

Planck scale spacetime measurement (Holometer)

Axion-Like Particles (REAPR)

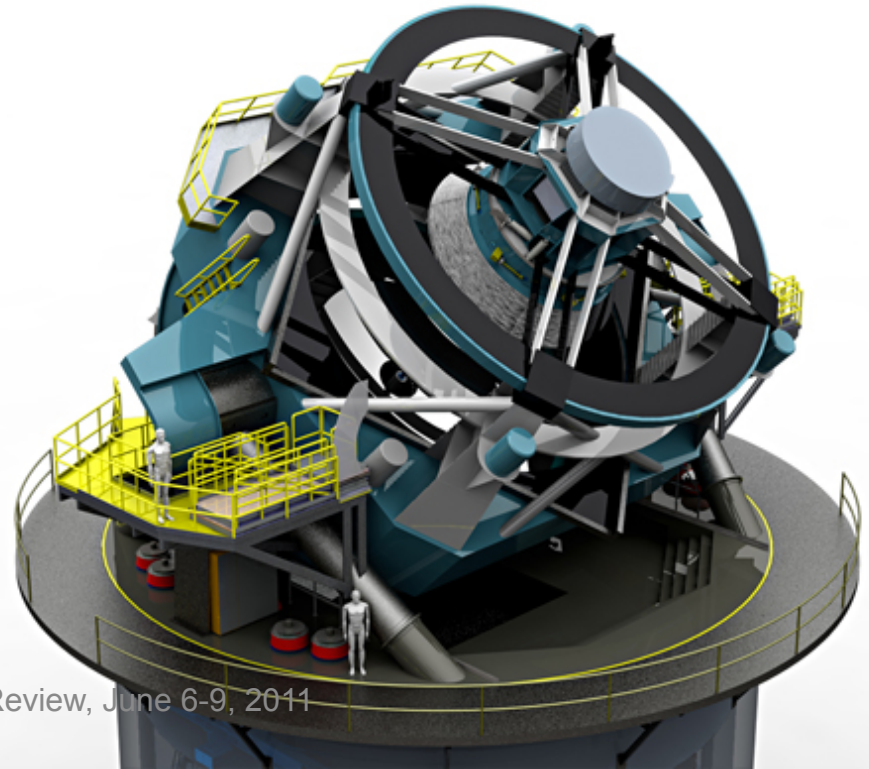
***Low-cost but potentially transformative experiments***

# Dark Energy after DES: Large Synoptic Survey Telescope

*Possible Fermilab roles in calibration, data access,  
database architecture, analysis, camera*

*Fermilab now a member of LSST Corporation (2011)*

*Build on SDSS & DES experience, CMS capabilities,  
NCSA partnership*



# Precision Cosmology at Fermilab: a 40 year experimental campaign

## SDSS (1990- 2010)

Advent of precision cosmology; many first measurements/ breakthroughs (ISW, BAO, SNe...)

## DES (2011-2018)

Extends reach of wide imaging to the Hubble length for the first time; factor of ~5 improvement in Dark Energy parameter measurement

## LSST (2018-2030)

Deeper, wider, longer; close to physical limits  
Faces major funding decisions in the next year

# Astro 2010: LSST on top for DOE

“The top rank of LSST is a result of its capacity to address so many of the identified science goals and its advanced state of technical readiness.”

“DOE is a minor partner in the two largest projects that the survey committee has recommended—LSST and WFIRST—and it is likely that the phasing will involve choices by NSF and NASA, respectively. Other considerations being equal, **the recommended priority order is to collaborate first on LSST because DOE will have a larger fractional participation in that project, and its technical contribution is thought to be relatively more critical.**”

*LSST is the top priority for DOE*

*WFIRST is the top priority for NASA*

DOE no longer a partner agency in funding the mission

*Medium-scale program also recommended, at lower priority for DOE*

# Future Dark Energy: multiplex spectroscopy

## Big Boss

Collaboration led by LBNL

FNAL contributes to telescope interface

## Dark Energy Camera Spectrograph (DESPEC)

Upgrade to DECam after DES completion (2018): add new multi-fiber focal plane and spectrographs

Southern hemisphere followup to DES, LSST

Conceptual design and costing underway

*Both greatly extend the Dark Energy sensitivity of photometric surveys*

*Both medium scale, not yet funded, pre-CD-0*



# Future Dark Matter

SuperCDMS: 100 kg at SNOLab

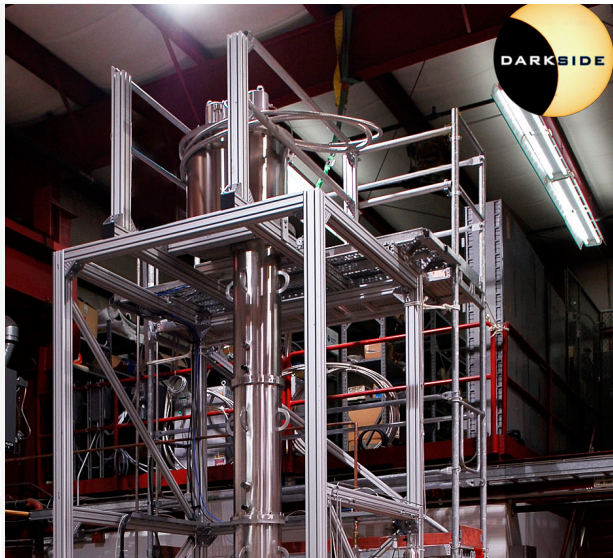
Aim for MIE in FY13

COUPP: 60kg, then 500kg to SNOLab

Darkside: Liquid argon; 50kg in Borexino tank, Gran Sasso

Far future: ton-scale, but not in all techniques

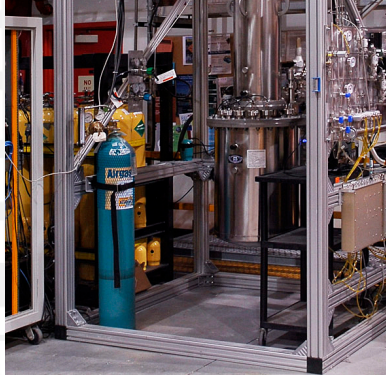
***Fermilab is prepared to advance HEP's program to the next level in any of these technologies***



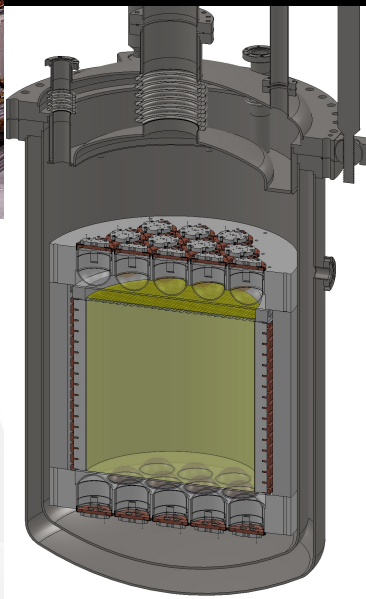
# Darkside at Fermilab

noble liquid distillation column at Fermilab

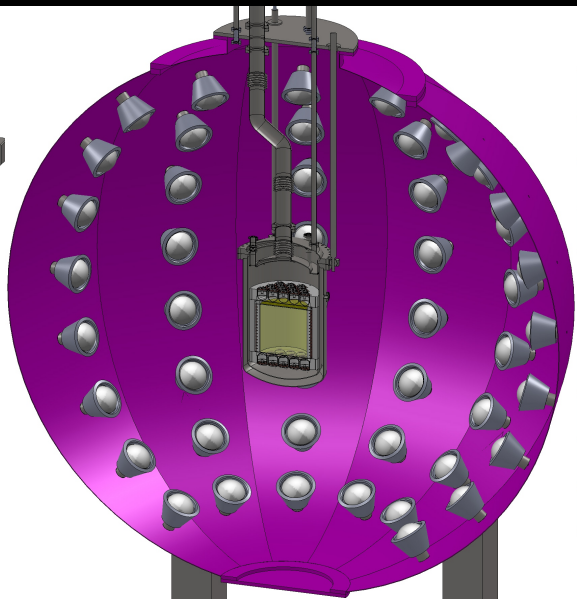
Synergy with LAr neutrino program (LBNE, MicroBoone, ArgoNeut)



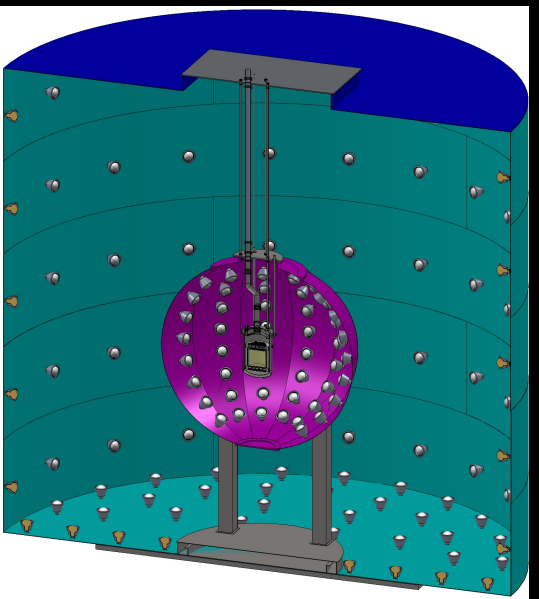
DarkSide 50 at LNGS



DS-50 with QUPIDs



in Scintillator Veto

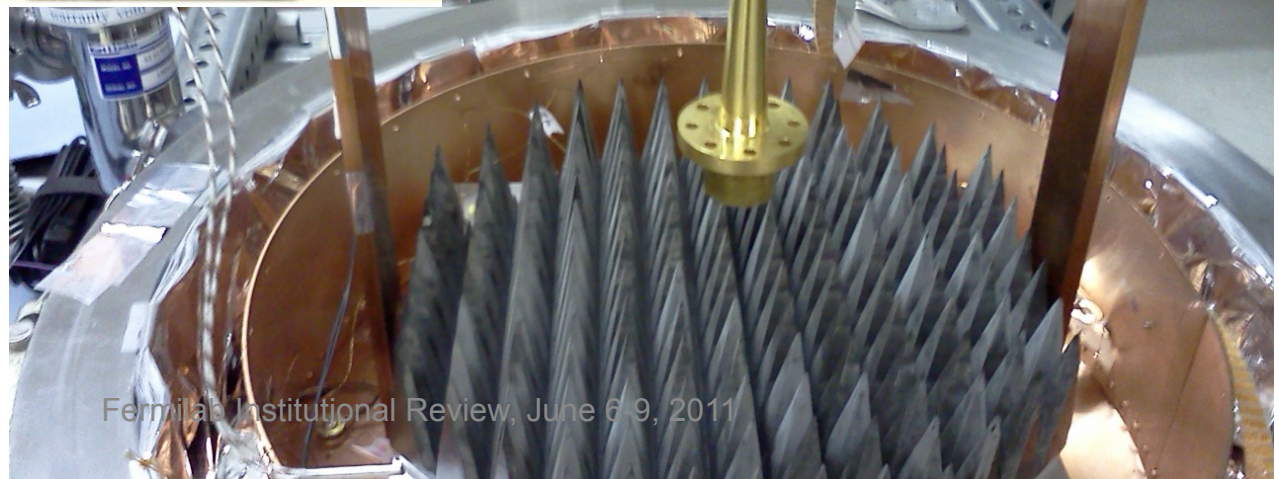
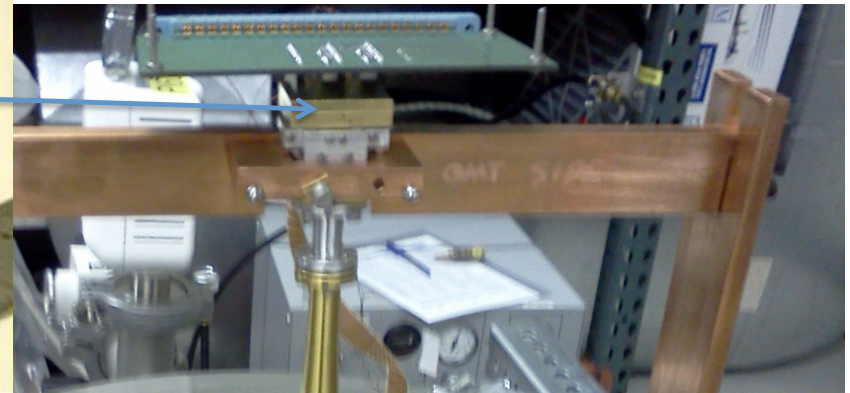
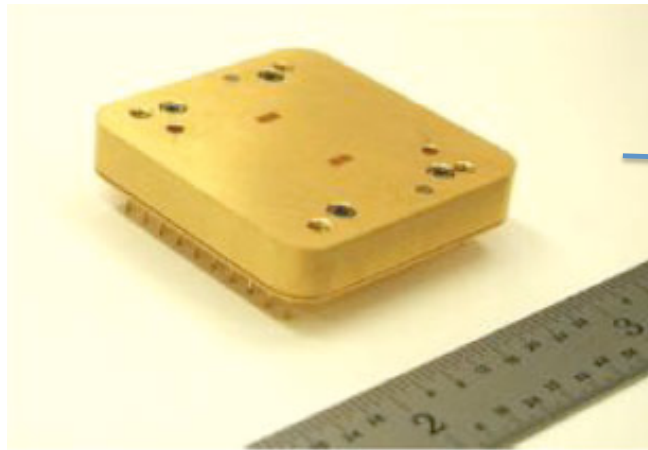


in Borexino Water Tank

# Quiet-II: HEMT-based CMB polarization experiment, probe of inflaton physics

*Future Fermilab effort contingent on NSF funding*

**QUIET 1 Module in Cryostat at Lab 3**



# Laboratory probes beyond the Terascale

Non-accelerator laboratory experiments can address new fundamental physics (matter, energy, space and time), far beyond the TeV scale

Fermilab program uses laser cavities and interferometers

Responsive to high-level PASAG criteria:

*Addresses fundamental physics  
compelling result*

*discovery space, possible important surprises*

*DOE lab leadership and critical role*

*small projects, high science per dollar*

Recent boost: Early Career Award to Aaron Chou

# Axion-like particle searches: GammeV

Mediate interactions of light with magnetic fields

Published limits at the state of the art

This year: CHASE, trapped chameleon afterglow

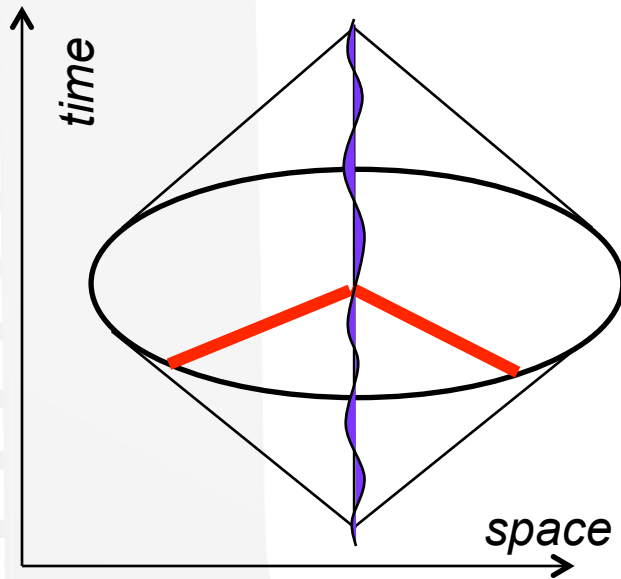
Future: laser cavities in Tevatron magnets

Reach to  $\sim 10^{11}$  GeV scale in the lab

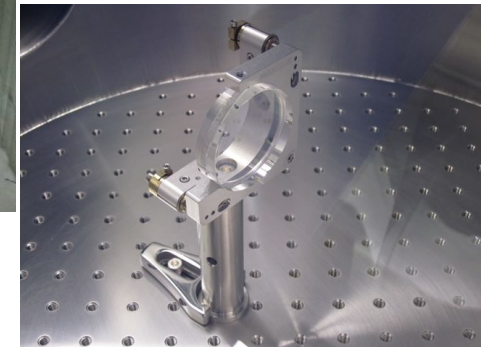
Requires development of high Q optical cavity technology



# Holometer: Planck scale physics in the laboratory



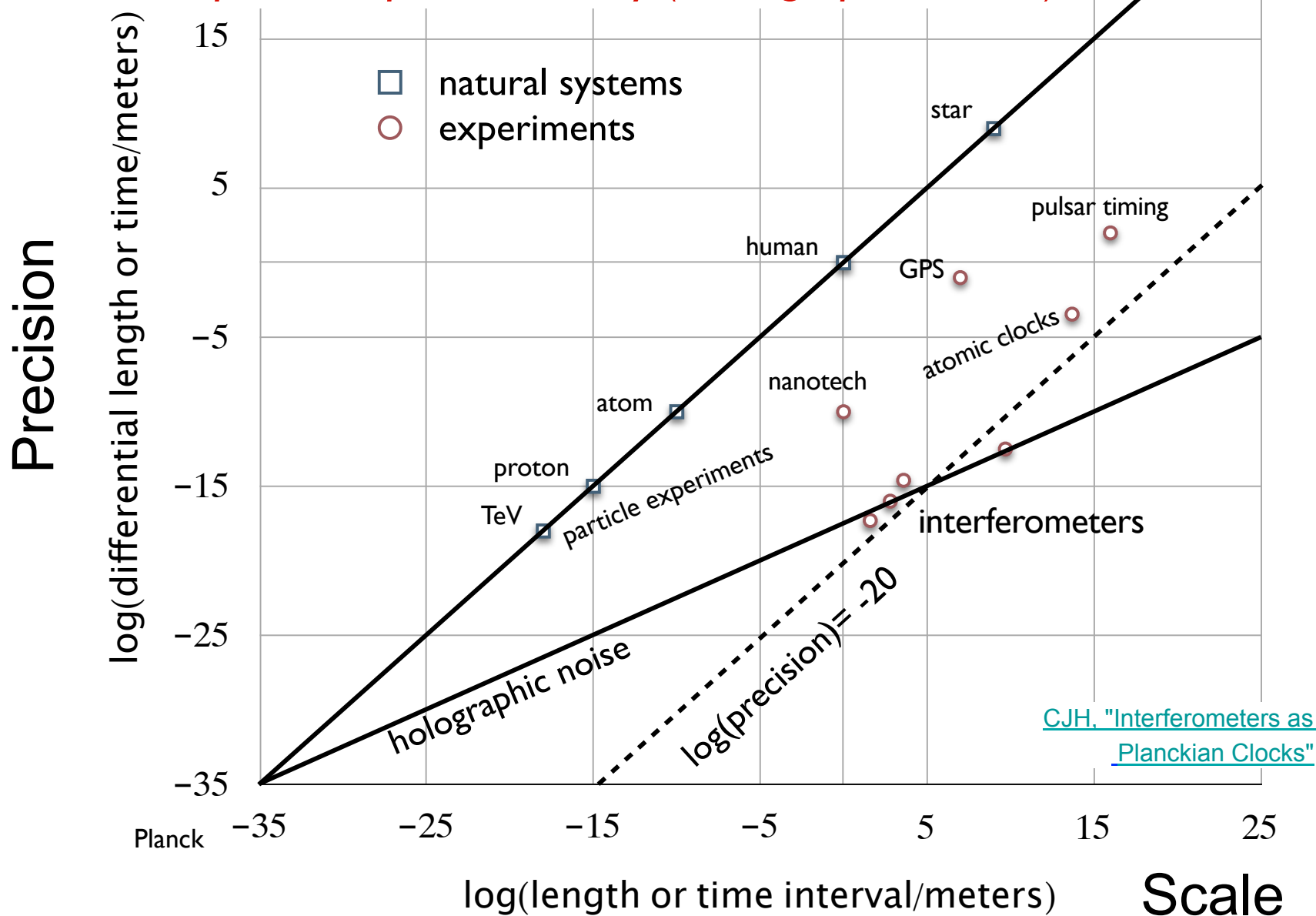
*Holometer R&D cavity in Fermilab  
MP8 beamline*



*Fermilab Holometer will attain Planckian sensitivity to  
transverse position noise with Michelson interferometers*

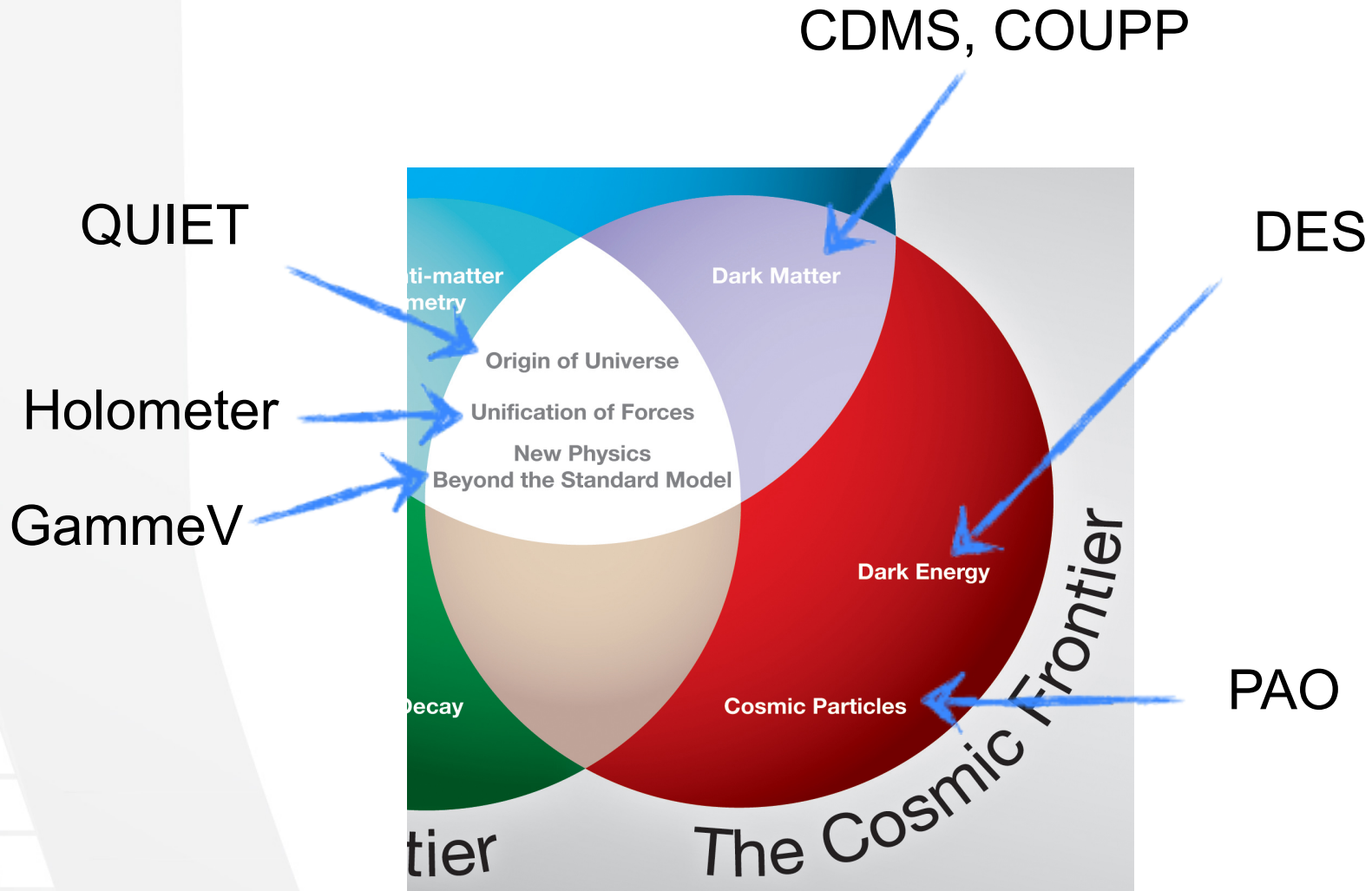
*Probes quantum spacetime geometry*

*Interferometers can achieve Planckian sensitivity in transverse position spectral density (“holographic noise”)*



[CJH, "Interferometers as Planckian Clocks"](#)

# Fermilab Cosmic Frontier Experiments





# Summary: Future Cosmic Frontier Experiments

- Core program extensions
  - Dark Energy: DES then LSST
  - R&D on spectroscopic surveys
  - Dark Matter: Direct WIMP Detection aligned with national program
  - Cosmic Particles: Auger South extensions
- New experiments
  - Laser interferometers and cavities probe quantum spacetime and new axion-like particles
  - Other technologies in R&D