FERMILAB-SLIDES-08-004-A

Fermilab: the Cosmic Frontier

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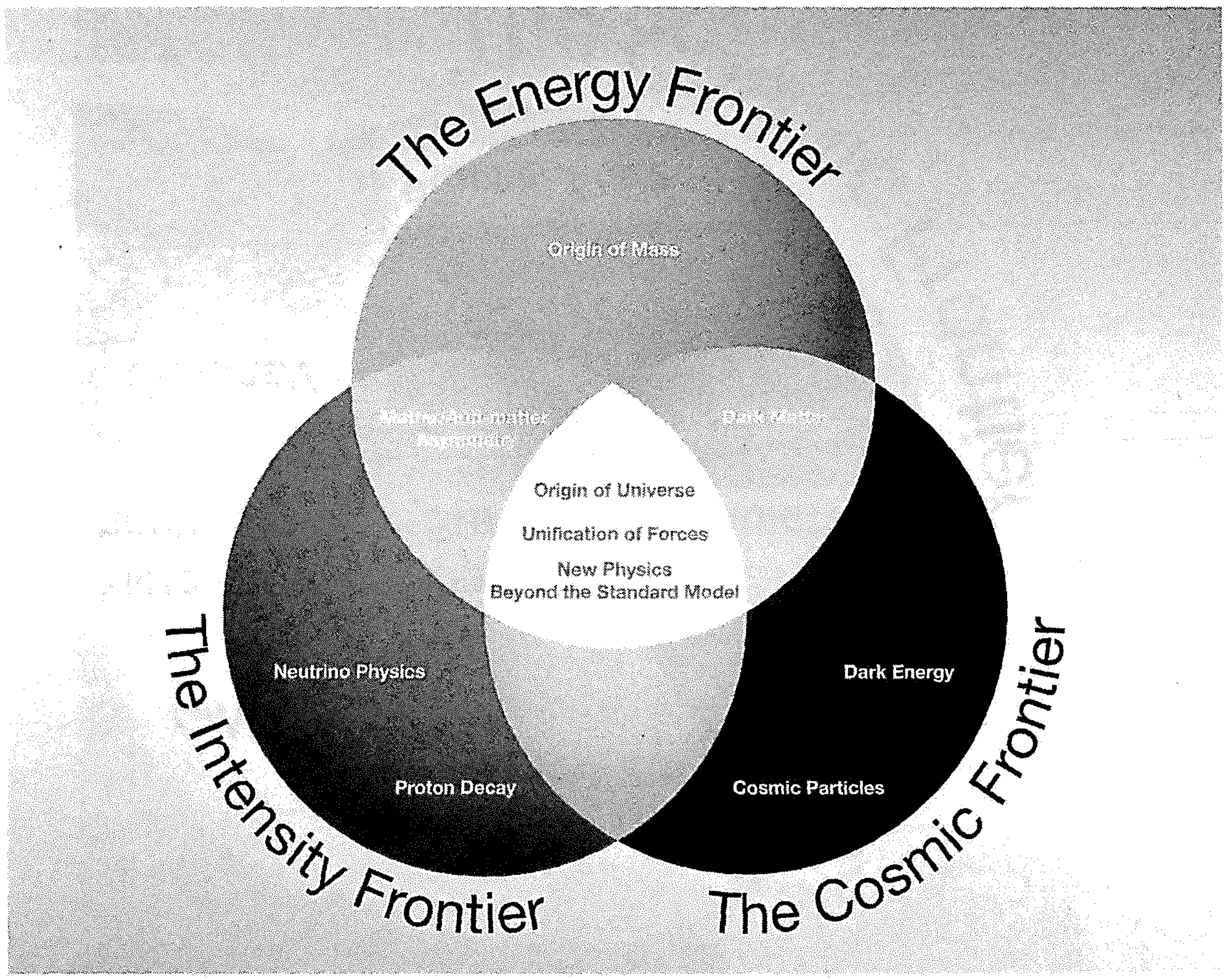
PAC

November 4, 2008

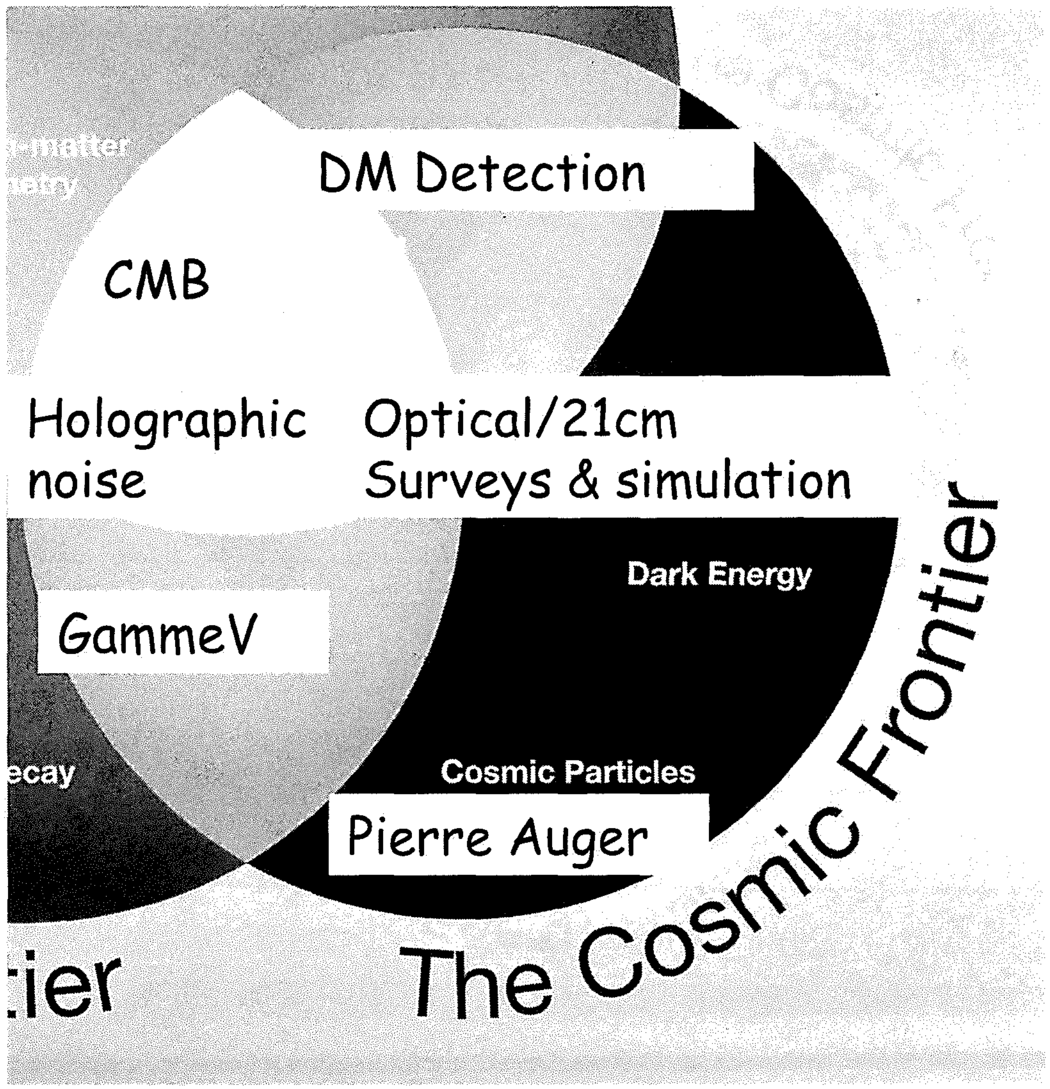
DOE Strategic Vision

- "Explore the fundamental interactions of Energy, Matter, Time, and Space"
- "Understand the unification of fundamental particles and forces and the mysterious forms of unseen energy and matter that dominate the universe, search for possible new dimensions of space, and investigate the nature of time itself."

2008: P5 adds the Cosmic Frontier

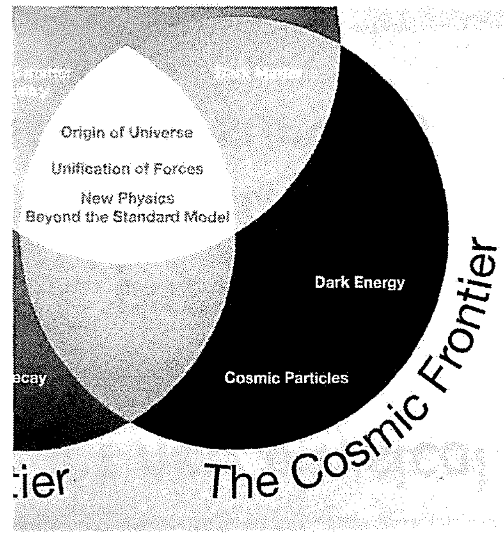


The Cosmic Frontier at Fermilab



Fermilab Center for Particle Astrophysics

- Science:
  - Particles from space
  - Dark matter
  - Dark energy
  - Cosmic Structure
  - Inflation
  - Unification
  - Quantum geometry



- Cross-cutting organization
  - About 70 scientists, including visitors and postdocs
    - includes many part timers (~35 FTEs)
    - Similar number of engineering and technical staff
  - Two half-floors of Wilson Hall
  - experimental groups: (SDSS), DES, JDEM, Auger, CDMS, COUPP, GammeV, +new groups under construction
  - Theory group
  - Staff appointments almost all in PPD, CD

Fermilab Astrophyics Theory Group

- Where astrophysics started at FNAL
- Emphasis on phenomenological theory
- Still at the heart of conceptualizing, designing, simulating, analyzing experiments
- Ties to particle theory: integrating the Cosmic Frontier into fundamental theory
- Synthetic breadth is critical: import new physical ideas, gravitational frontier
- Danger of going subcritical (~3 FTE postdocs)
- Computational Cosmology Initiative: includes simulation, analysis, science support of surveys

Computational Cosmology Initiative

- Hardware, software, sysadmin support for comprehensive simulation program
- Cross cutting support for DES, LSST, JDEM science
- Initial deployment achieved in past year
- We plan a long term sustained effort
- Proposed expansion to multi-lab initiative (w/SLAC, LBL)
- Future expansion by ~ factor of 10

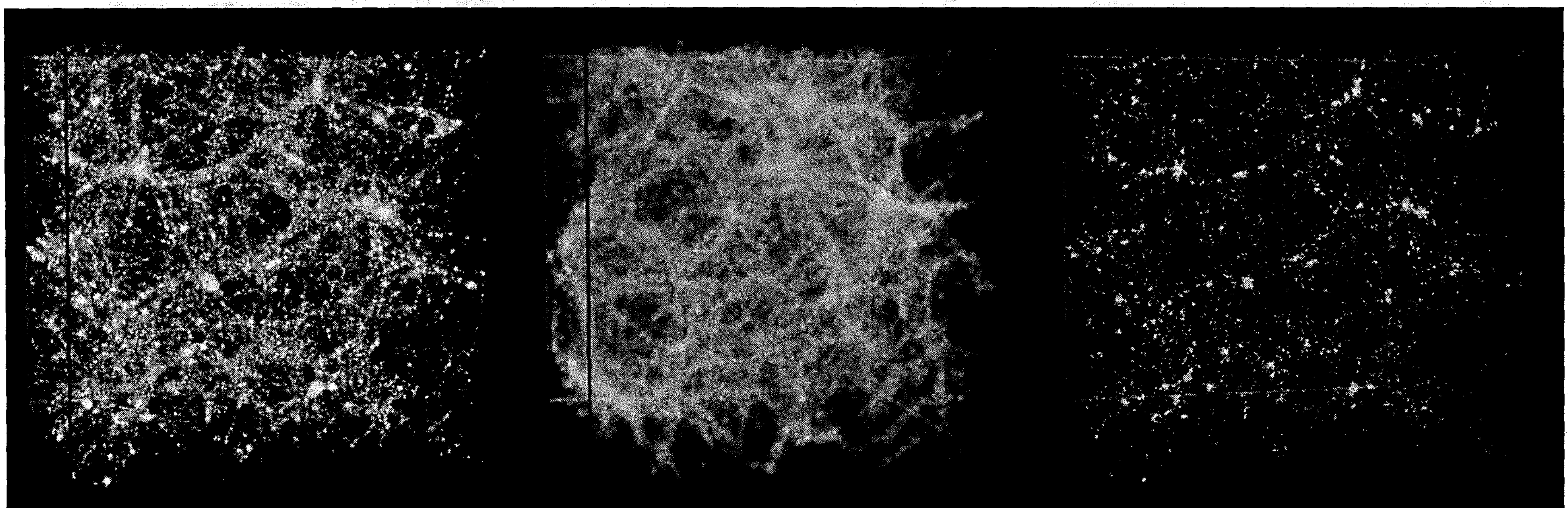
Computational Cosmology: status

Personnel:
- Dodelson, Stebbins, Gnedin, Computing Division

Collaborators:
- Kravtsov (UofC), Zentner (Pitt), Rudd (IAS), Ricotti (IAS), Zemp (UMich), Levine (CITA)
- Next stage: T. Abel (KIPAC,SLAC), M. White (UCB,LBL)

Hardware at FNAL (October 2008):
- 130 nodes/1040 cores/16+ GB per node. (~1 Megawatt)
- About 90% online at any given time.
- ~50 users (together with KICP + external collaborators).

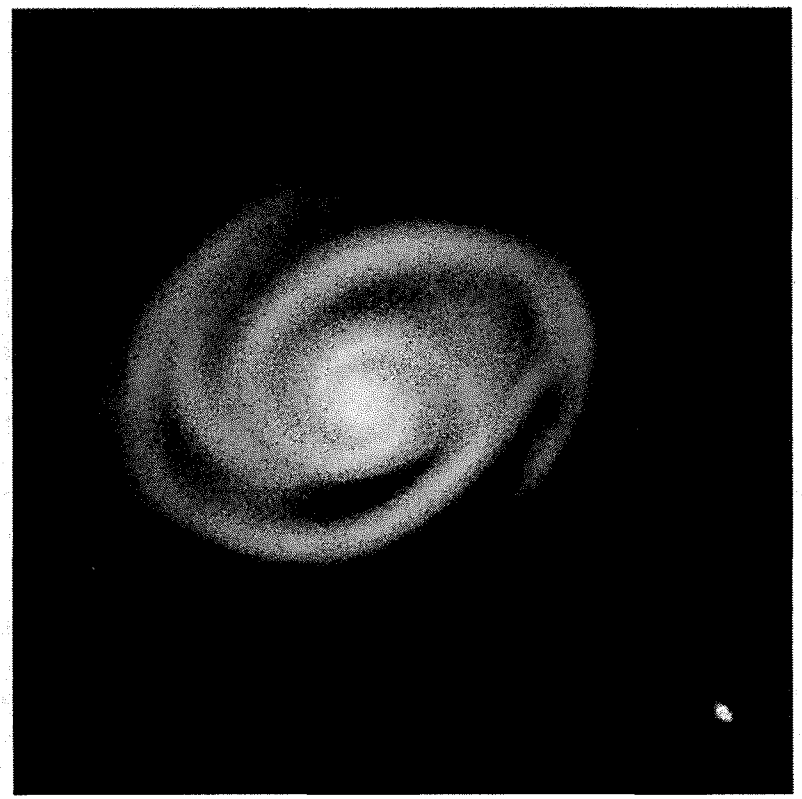
Large Scale Simulations

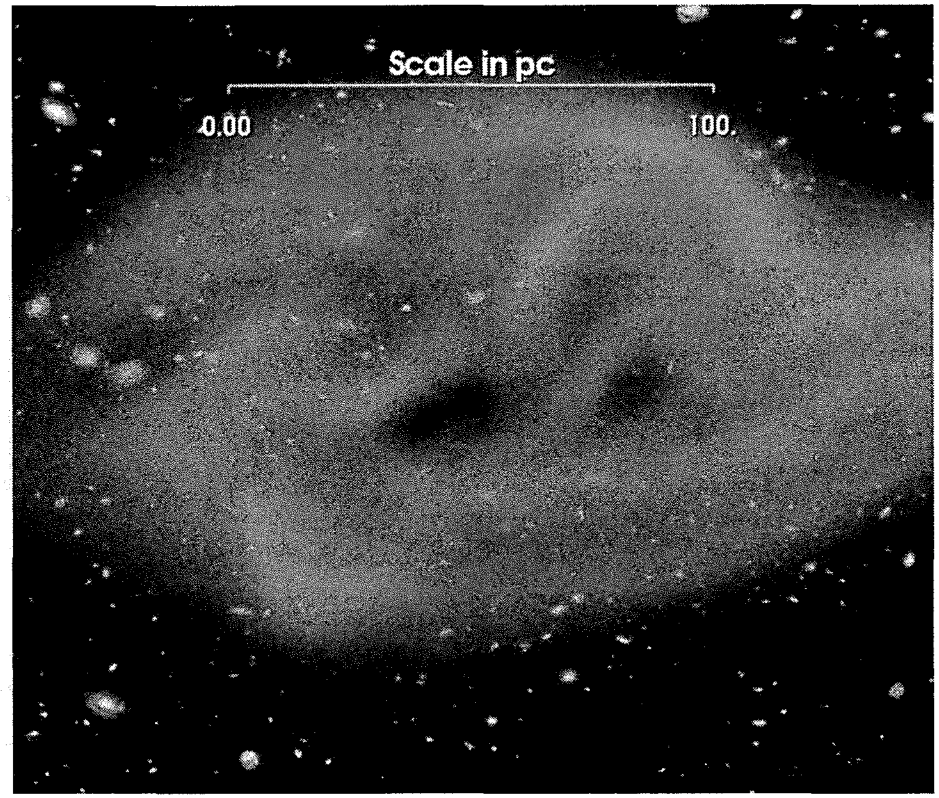


Dark matter Gas Galaxies

Modeling baryonic effects on large scales is important for unbiased calibration of weak lensing signal from future Dark Energy experiments.

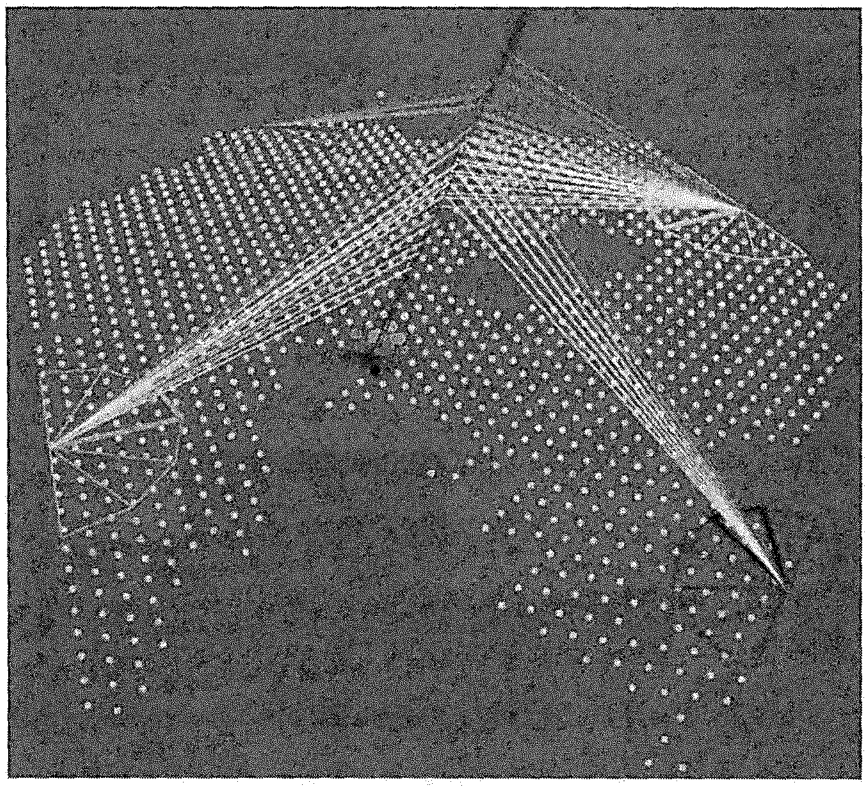
Galaxy, Black Hole Formation





Understanding galaxy and black hole formation is the primary goal of modern Astrophysics, and is also important for calibrating Dark Energy experiments.

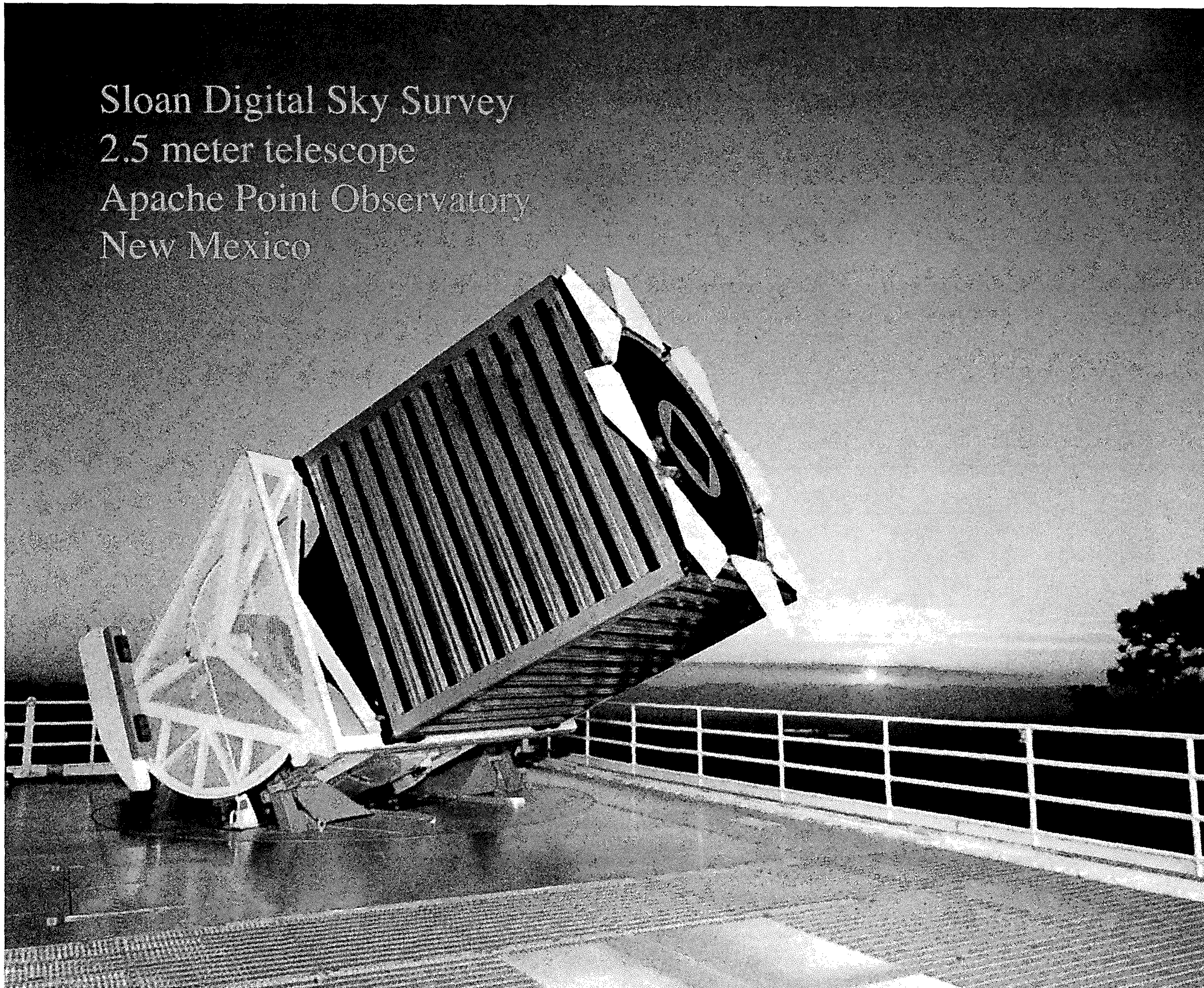
Cosmic Ray Shower Simulations

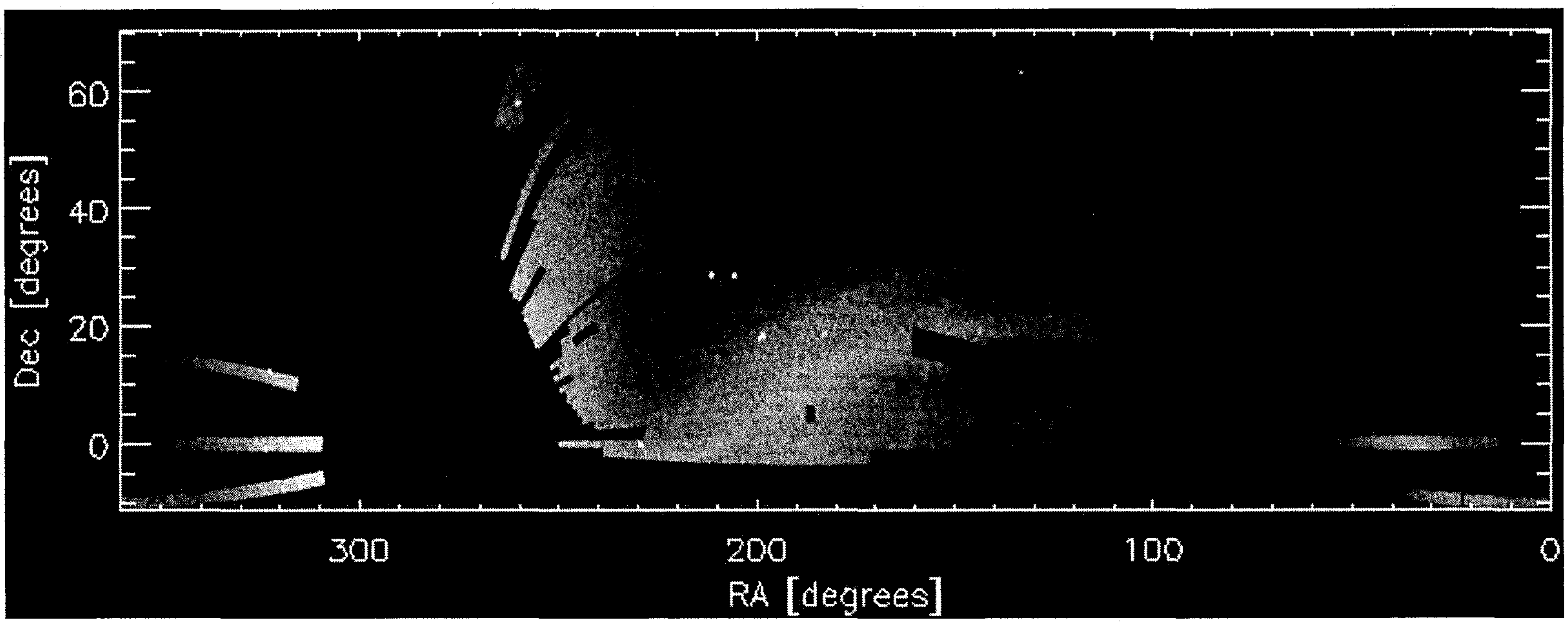


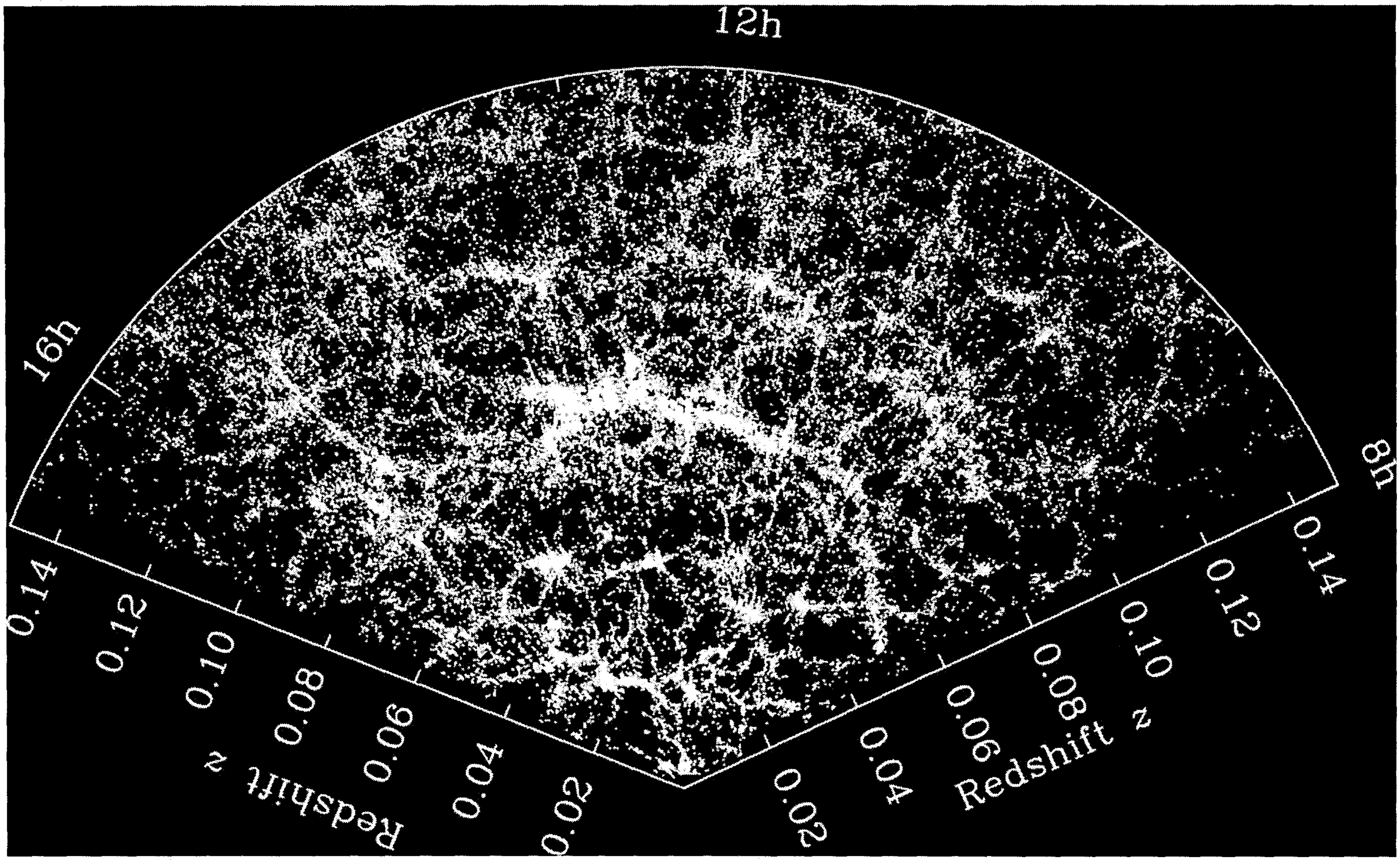
Modeling atmospheric showers caused by cosmic rays is an important part of interpreting data from Pierre Auger Observatory.

Optical/IR surveys

- SDSS, DES, LSST, JDEM are a single enterprise
- Shared science, techniques
- Complementary capabilities
- Cumulative technological advancement
- Culture of synergy where possible: simulations, analysis software, prototyping, detectors


Sloan Digital Sky Survey
2.5 meter telescope
Apache Point Observatory
New Mexico


60
40
20
0
Dec [degrees]
300
200
100
0
RA [degrees]


12h
16h
8h
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Redshift z
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z

SDSS Physics

- Homogeneous catalog of 1/4 of sky in five spectral bands.
- High resolution spectra of > 1 M galaxies.
- Cosmological parameter determination, galaxy clustering properties, baryon acoustic oscillations, weak lensing, strong lensing, high-redshift quasars, etc.
- Supernova search (SDSS-II)
- All data released to community at regular intervals
- >2000 refereed papers, >70,000 citations (09/08)

Top rated observatory in citation impact 2006-2007
(ahead of Hubble, WMAP, Keck, ESO...)

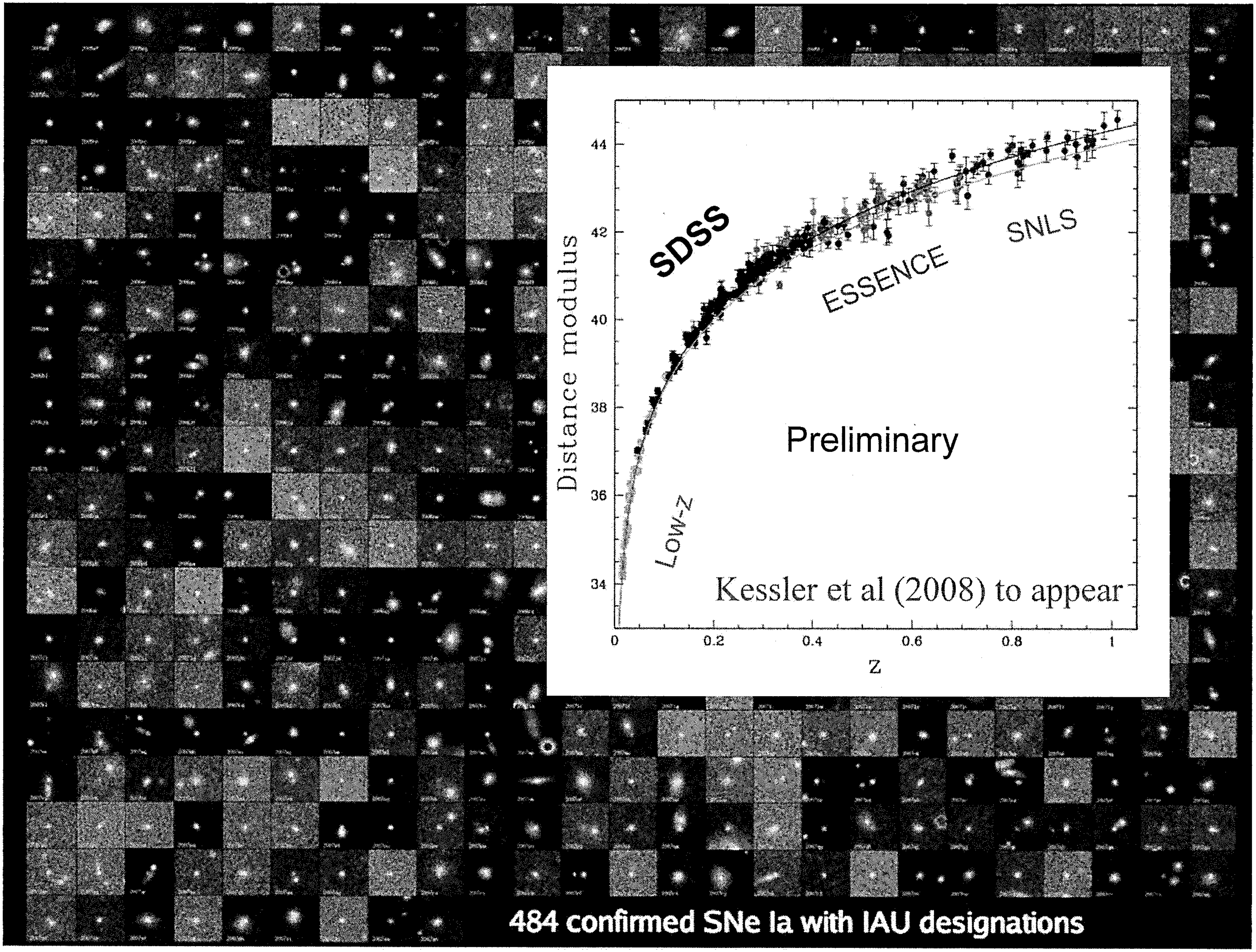
SDSS-II: the end of SDSS at FNAL

collaborators: 25 institutions involved in SDSS-II, roughly 200 scientists

recent highlights: Type Ia SN distance-redshift relation at intermediate redshifts; structure in phase space of orbits of halo stars; identification of strong gravitational lensing by Luminous Red Galaxies

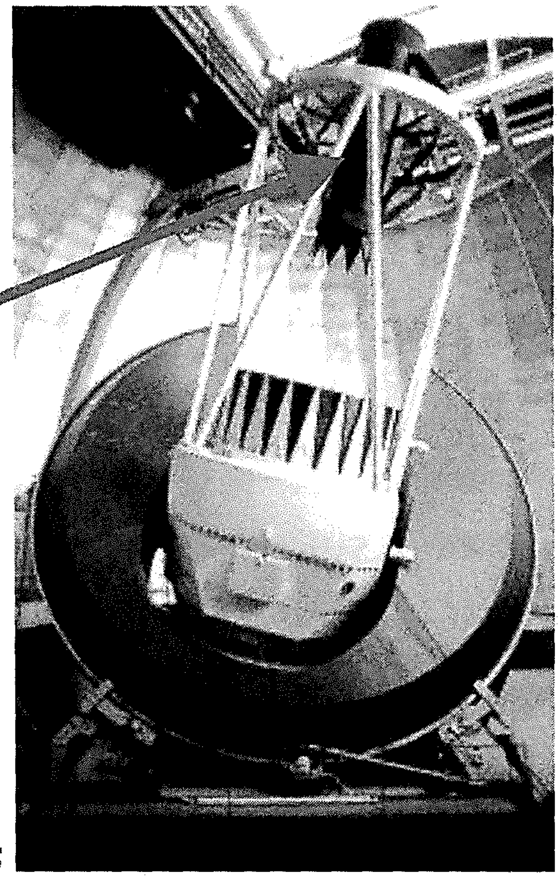
current status: SDSS-II stopped taking data last July. Final data release October 31, 2008.

prospects: Four FNAL scientists have access to data from SDSS-III (but without formal Fermilab participation in SDSS-III). Spectroscopy in SDSS complements imaging in DES.


SDSS
ESSENCE
SNLS
Low-z
Preliminary
Kessler et al (2008) to appear
Distance modulus
z
484 confirmed SNe Ia with IAU designations

Dark Energy Survey (DES)

- Project:
  - Perform a 5000 sq. deg. survey of the southern galactic cap (overlap w SPT)
  - Measure DE w with 4 complementary techniques: Clusters, Weak Lensing, BAO, SNIa
- New Equipment:
  - Fermilab lead: Replace the PF cage with a new 2.2 FOV, 520 Mega pixel optical CCD camera
  - UIUC lead: Data Management, public archive
- Survey
  - 5 year survey: 2010-2015
  - 105 nights/yr when S.Gal.Cap is visible (Sept-Feb)



Use the Blanco 4M Telescope at the Cerro-Tololo Inter-american Observatory (CTIO)

DES approved for construction (CD-3b): 10/08

Differences Between SDSS and DES

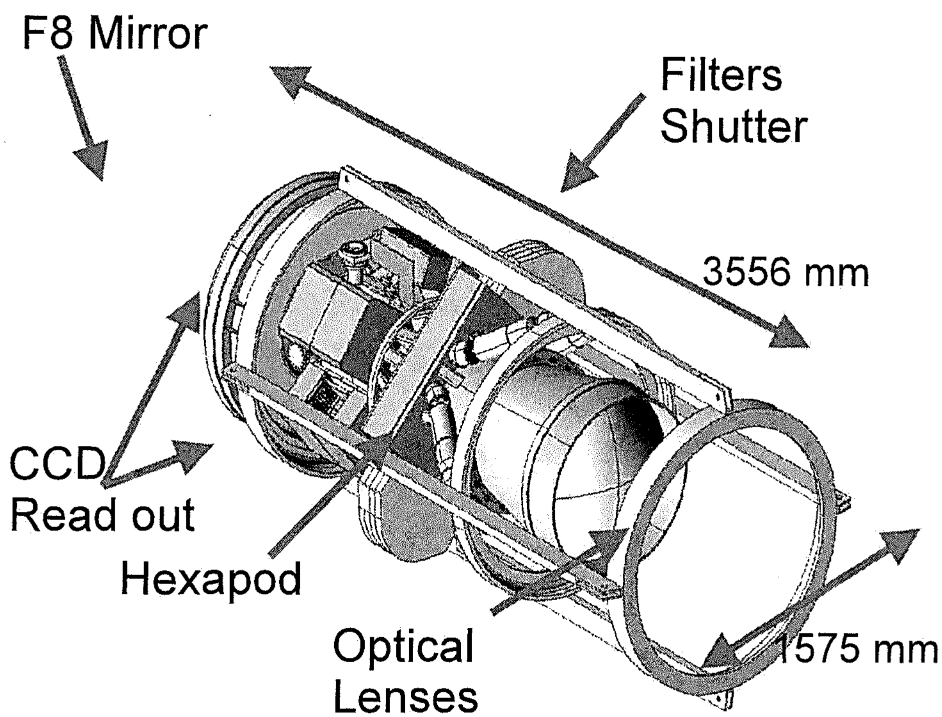
- Bigger telescope (4 m vs 2.5 m)
- Better site (darker, better seeing)
- Better CCDs, with more pixels, >90% efficiency @ 1000 μm
- No spectroscopy, which used a lot of observing time.

Can cover a similar area of sky, but to much greater depth reaching z ~ 1.2 for galaxies instead of z~ 0.3

•Covers southern sky, where it can see the clusters found by the South Pole Telescope (SPT) using SZ effect

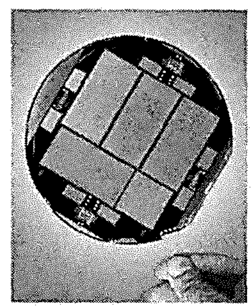
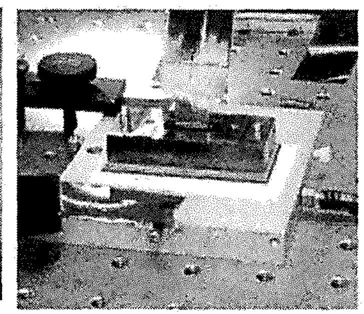
The DES Instrument: DECam

DECam will be larger than any existing CCD camera

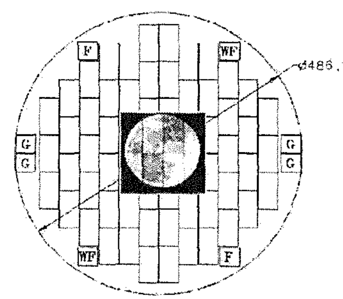


UK provides optical elements
Spain provides production electronics

Fermilab Role:
DECam project management
CCD packaging
CCD readout (lead)
CCD Focal plane and vessel
Optical Corrector barrel
Cage and hexapod/alignment

62 2kx4k Image CCDs: 520 MPix
8 2kx2k Guide, focus, alignment

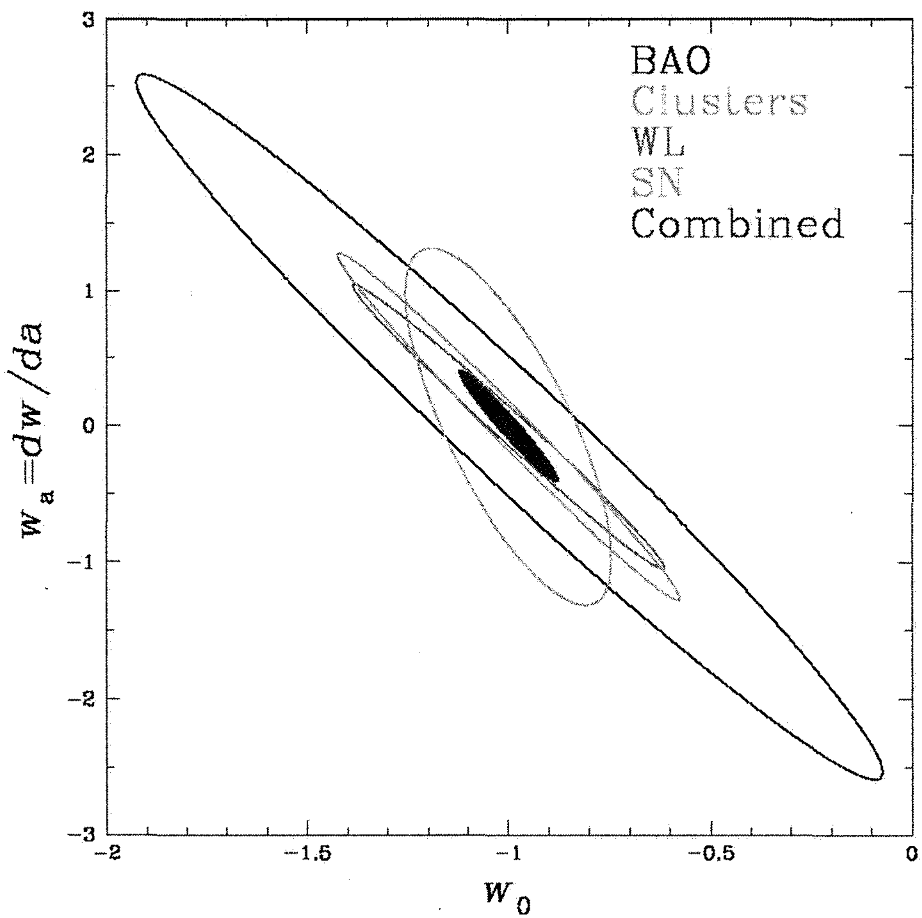


DES Constraints on Dark Energy Parameters

$w = p/\rho$ $w(z) = w_0 + w_a(1-a)$ **68% CL**

- **Four individual measurements of w at 5-10% statistical precision assuming constant w.**
  - **Cluster counts vs. redshift for SPT clusters**
  - **Weak lensing of large scale structure**
  - **Baryon acoustic oscillations**
  - **Supernovae as standard candles**

- **Combined power allows investigation into evolution of w**



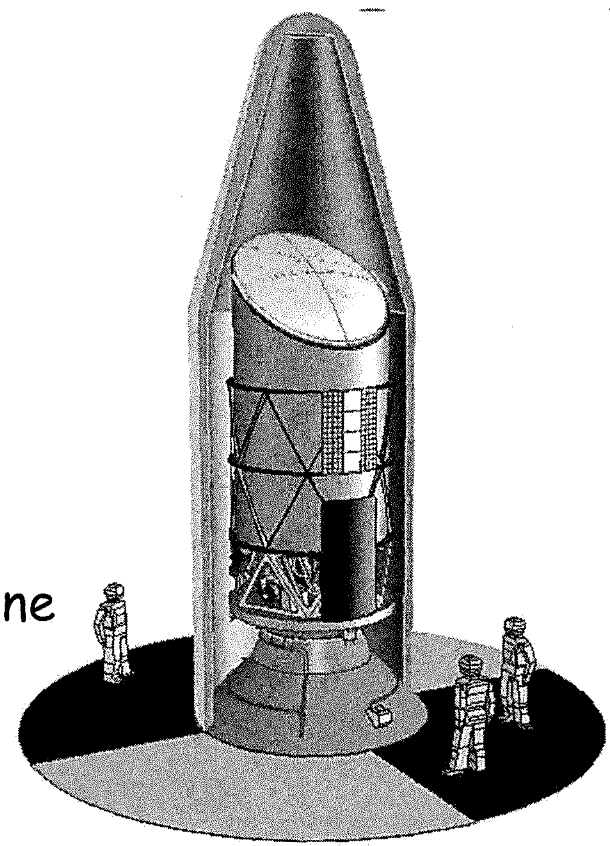
JDEM: Joint Dark Energy Mission

- DOE/ NASA joint venture

  Strategic mission now in preconceptual design

  First priority in NASA Physics of the Cosmos

- Wide- field space telescope
- Visible and infrared imaging and spectrophotometry to z~1.7
- Supernovae, Weak Lensing, Baryon Acoustic Oscillations
- Synergy with DES: Simulations, analysis pipeline development and testing, wavelength complementarity



JDEM is really happening

- NASA/DOE release of Programmatic Information (9/12/08)
  - NASA: lead agency; Goddard/NASA project office
  - DOE: significant contribution (~ 200M)
  - LBL/DOE project office
  - Agencies build instrumentation, participate in science operations
  - PI-led science investigations w/ agency-built instruments (AO 12/08, selection spring/summer 09)
  - "medium-class" mission w/ launch mid 2010's
  - 3+ methods: SNe, Weak Lensing, Baryon Acoustic Oscillations
- JDEM Science Coordination Group (10/08-12/08) N. Gehrels
  - Determine top-level science requirements & instrument capabilities
  - Evaluate initial Yardstick Mission developed by JDEM PO
  - Provide input to JDEM PO in formulating Reference Mission that will be basis for the AO
  - Report to NASA before release of JDEM AO

JDEM at Fermilab

FNAL Contributions and Opportunities

CCDs

Data Management & Software: Science Operations

Flash Memory

Calibration

Simulations

Science

FNAL Effort

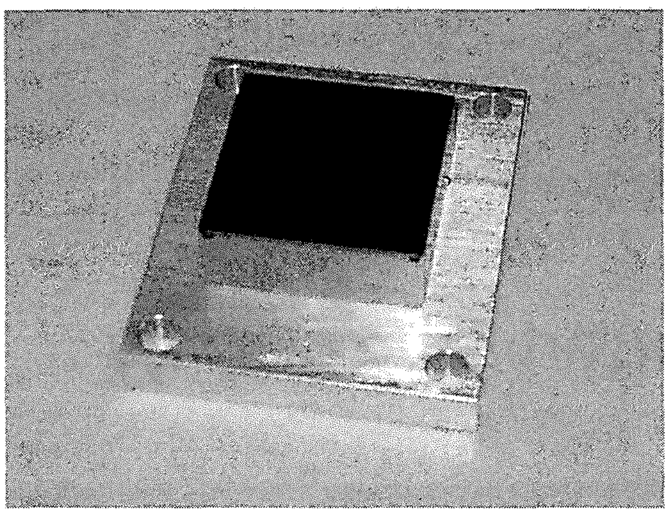
19 Scientists, 11 compute professionals (Science Operations)

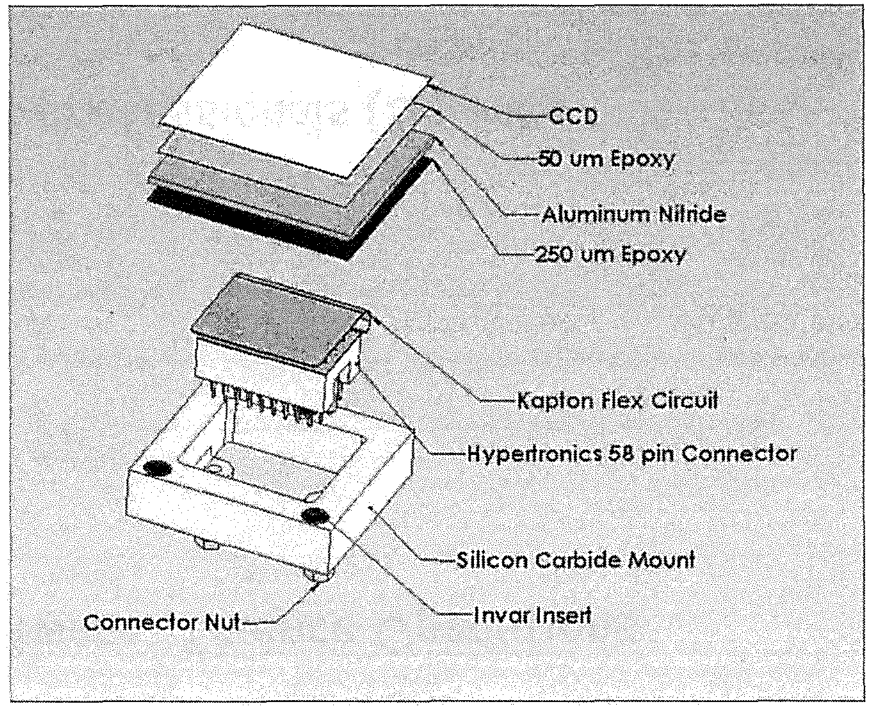
15 engineers, compute professionals, eng. physicists (CCDs)

(*not* FTEs)

Packaging JDEM CCDs

- Ongoing R&D
- Prototype 4-side -buttable package developed at Yale

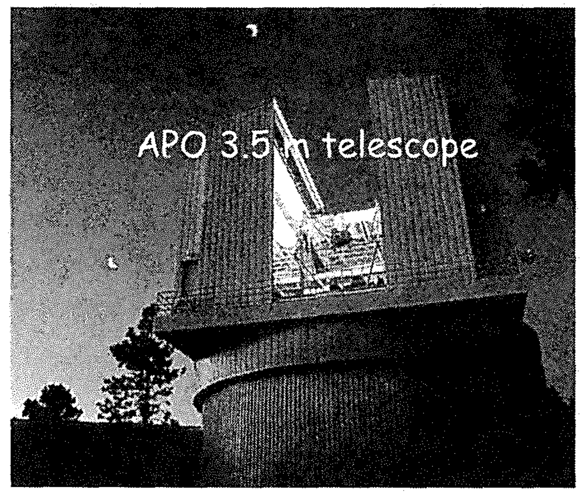




JDEM Calibration

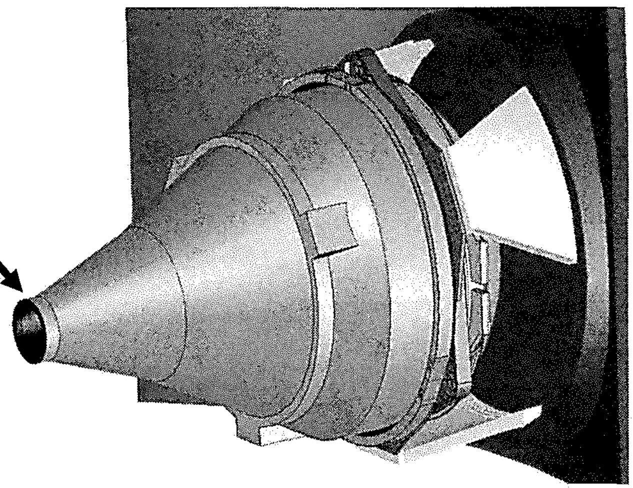
•measure the brightness of SNe Ia to 2%.
•measure the shapes of objects to 0.01%.

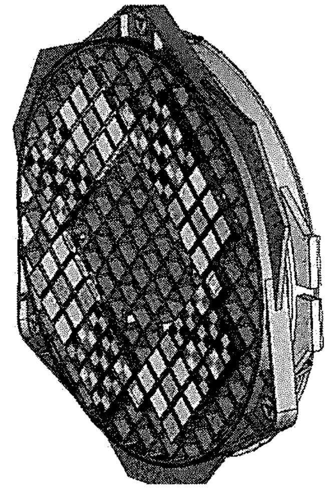
- Work with calib. working group
  - Develop calib. plan
  - Define onboard hardware
- Standard Star Selection
  - Target selection from SDSS, then follow-up with other telescopes.
- Requirements analysis
  - Flowdown from top level req.
- Calibration Planning
  - Calibration pipeline



Illumination System R&D

Ring of Fire

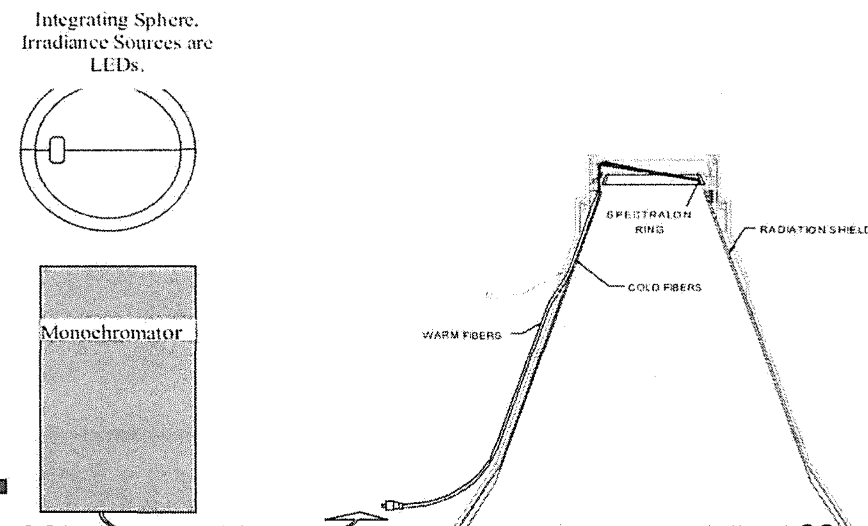




Goals:

1. Construct prototype of R.O.F. and illumination system
2. Test flatfielding uniformity
3. Test filter calibration

Joint with SSL, IU, STScI

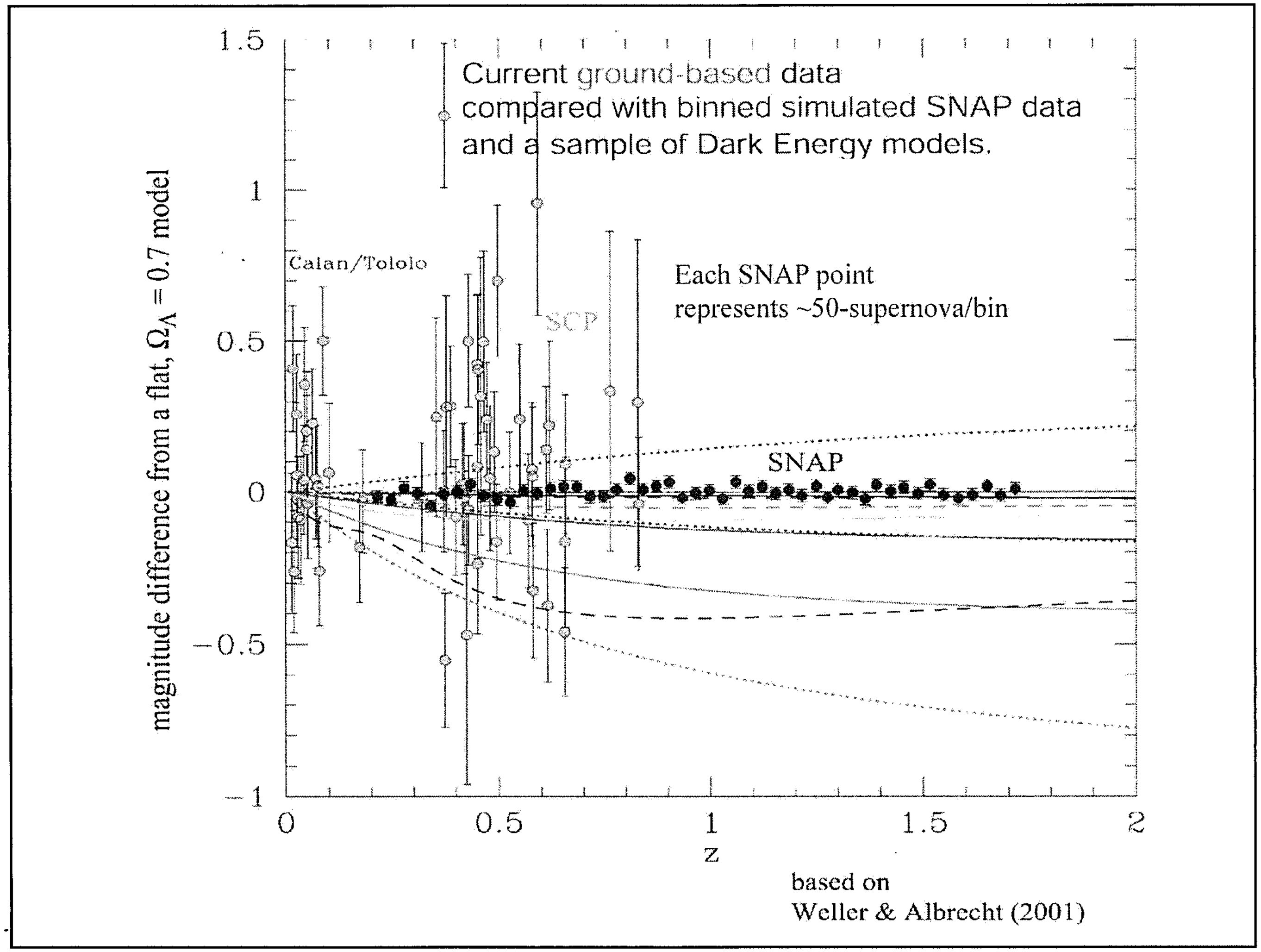


Data Management & Software

- Concept for FNAL participation
  - Software development
  - Science Operations Center
- Size of effort
  - Long-term average of 35-40 FTEs over entire collaboration for all of above activities; half of effort at FNAL?
  - For comparison, SDSS data management at Fermilab was ~18 FTE at peak

(see following talk by Erik Gottschalk)

JDEM Sensitivity

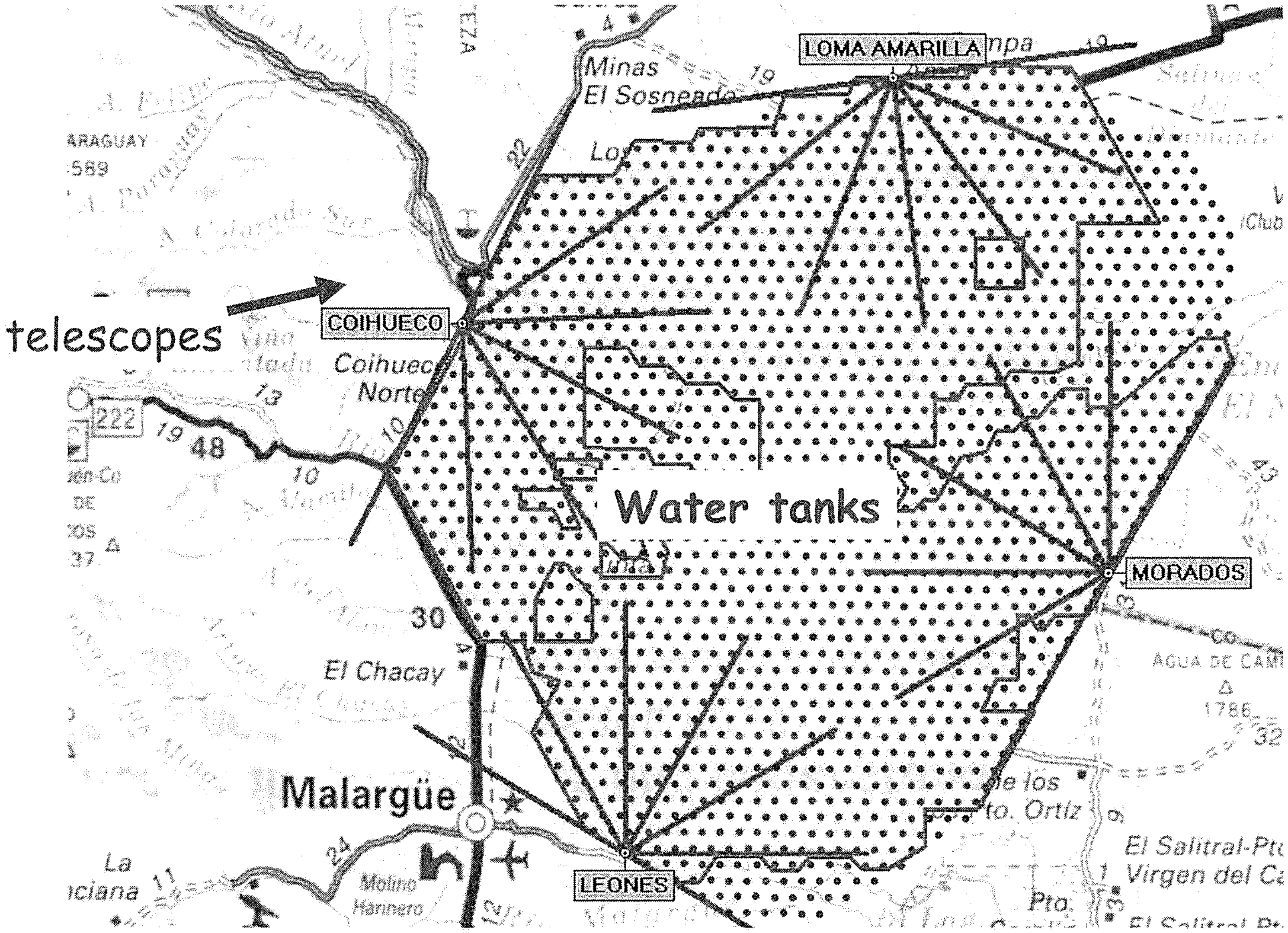


Pierre Auger Observatory

- Science goal: To discover and understand the source(s) of the highest energy cosmic rays
  - Discover and characterize sources over whole sky
  - Measure energy spectrum
  - Determine composition

- Recent results include 8 publications (*Science, Phys. Rev. Letters, Astroparticle Physics*):
  - spectrum demonstrates GZK suppression
  - anisotropy of events where $E > 5.7 \times 10^{19}$ eV, extragalactic origin
  - upper limits on γ and ν_τ

Pierre Auger Observatory layout

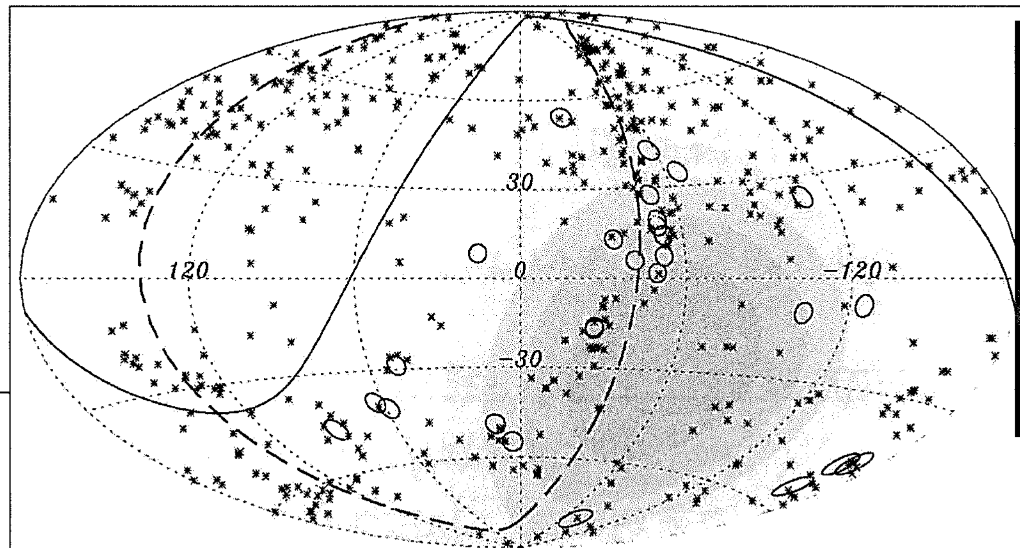


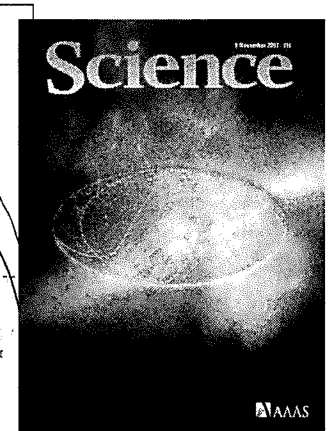
Pierre Auger Observatory Who's Who

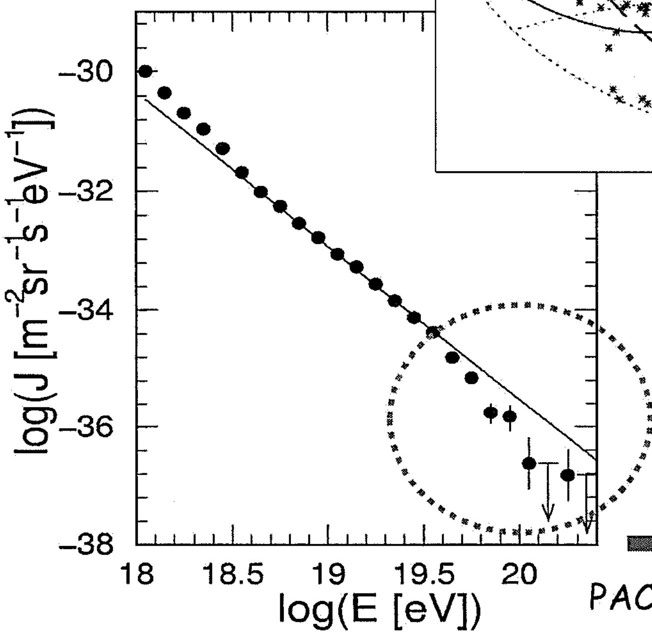
- Key personnel:
  - Spokesperson: Giorgio Matthiae (Rome)
  - Co-Spokesperson: Paul Sommers (Penn State)
  - Collaboration Board Chair: Danilo Zavrtanik (Nova Gorica)
  - Project Manager: Paul Mantsch (FNAL)
  - Deputy Project Mgr, Auger South: Ingo Allekotte (Bariloche)
  - Deputy Project Mgr, Auger North: John Harton (Colorado State)
  - Project Engineer: Marc Kaducak (FNAL)
  - Cost & Schedule: Hank Glass (FNAL)
- Pierre Auger Collaboration:
  - 17 countries, ~400 collaborators (incl. 11 from FNAL)

Results - Anisotropy & Spectrum

- Anisotropy ruled out at the 99%evel
- Correlation with nearby objects - AGN?
  - $E > 5.7 \cdot 10^{19}$ eV distance < 71 Mpc







The cosmic ray spectrum as measured by Auger

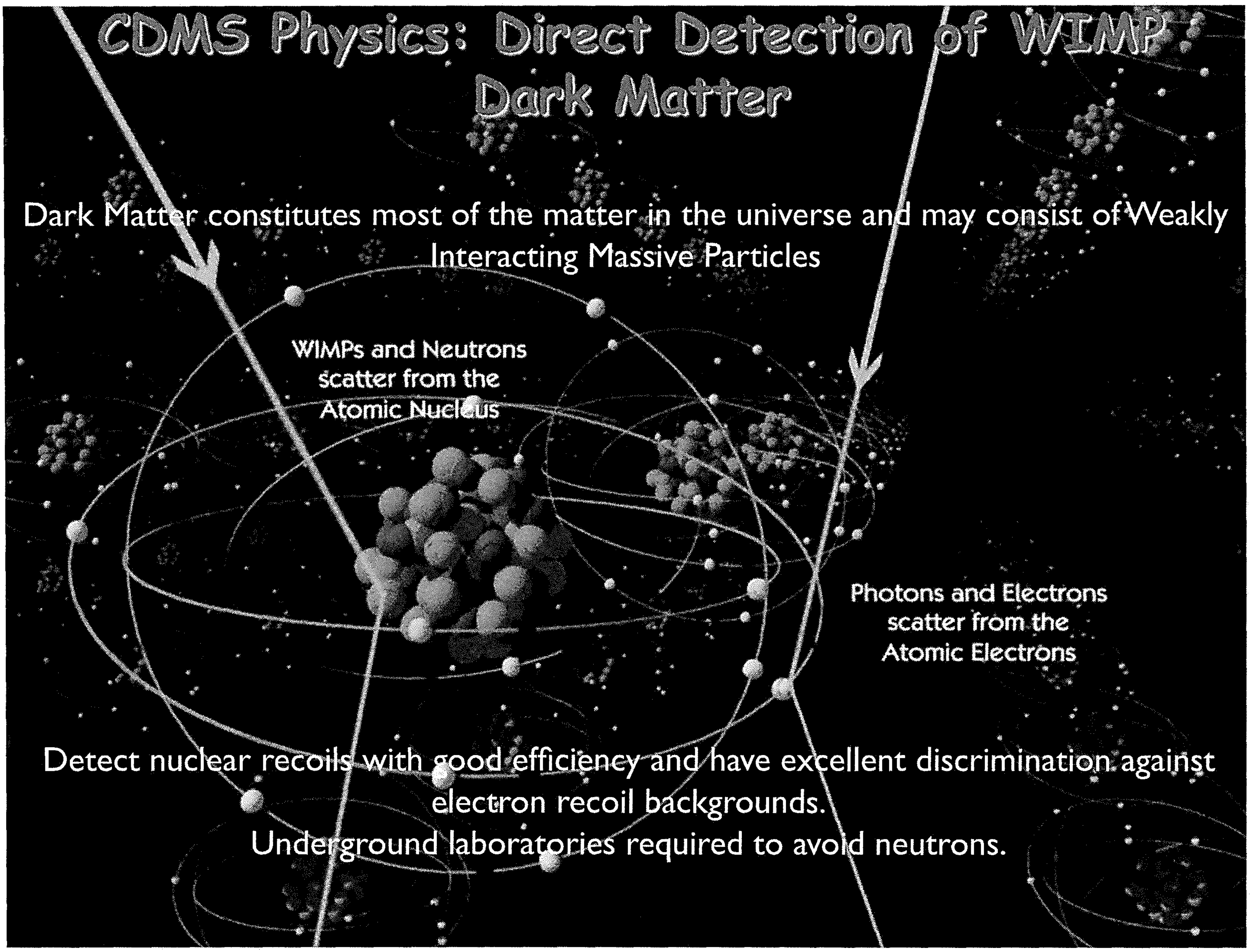
- unambiguous fall-off of very high end is consistent with the GZK effect

Current Status & Prospects

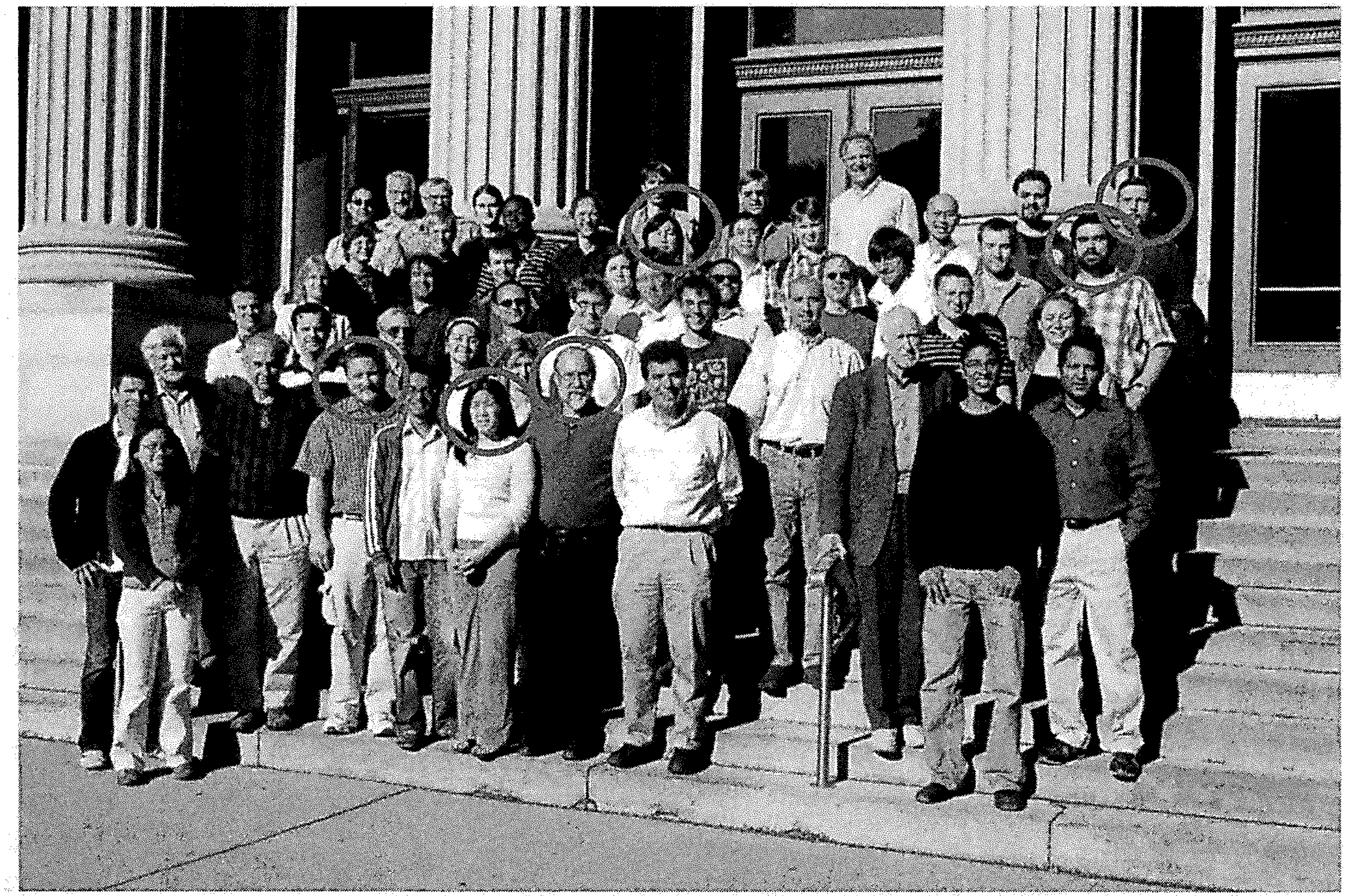
- All 24 fluorescence telescopes and over 1600 surface detector stations have been in stable taking data operation. The baseline Observatory is now in place in the South.
- Design Report for Auger North is being prepared. Northern site (Colorado) will have ~7x aperture of South.
  - Identify sources in the northern sky.
  - Characterize these sources with high statistics (energy spectra).
  - Understand the particle acceleration mechanism in extreme conditions.
  - Map magnetic fields
  - Study interactions beyond LHC energies.

Dark Matter Direct Detection

- FCPA is a leading US center of dark matter direct detection
- Multiple technologies now exploring deeply into WIMP territory
- A variety of collaboration modes on different projects: FNAL lead, FNAL participation, FNAL site
- Synergy with other lab projects: intensity frontier, underground science


CDMS Physics: Direct Detection of WIMP
Dark Matter
Dark Matter constitutes most of the matter in the universe and may consist of Weakly Interacting Massive Particles
WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons
Detect nuclear recoils with good efficiency and have excellent discrimination against electron recoil backgrounds.
Underground laboratories required to avoid neutrons.

CDMS Collaboration



CDMS Institutions

DOE Laboratory
- Fermilab
- NIST

DOE University
- CalTech
- Florida
- Minnesota
- MIT
- Stanford
- UC Santa Barbara

NSF
- Case Western
- Colorado (Denver)
- Santa Clara
- UC Berkeley
- Syracuse

Canada
- Queens

Fermilab Personnel: Dan Bauer (Project Manager), Fritz DeJongh, Erik Ramberg, Jonghee Yoo, Jeter Hall, Lauren Hsu, Sten Hansen, Rich Schmitt

Active Background Rejection

Detectors with excellent event-by-event background rejection

Use charge/phonon AND phonon timing
Measured background rejection:
99.9998% for γ's, 99.79% for β's
Clean nuclear recoil selection with ~ 50% efficiency

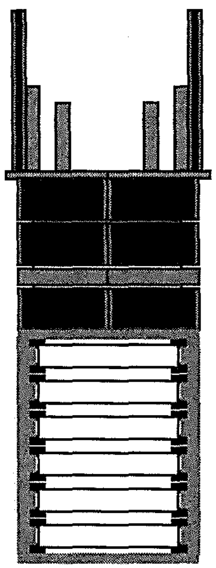
Tower of 6 ZIPs

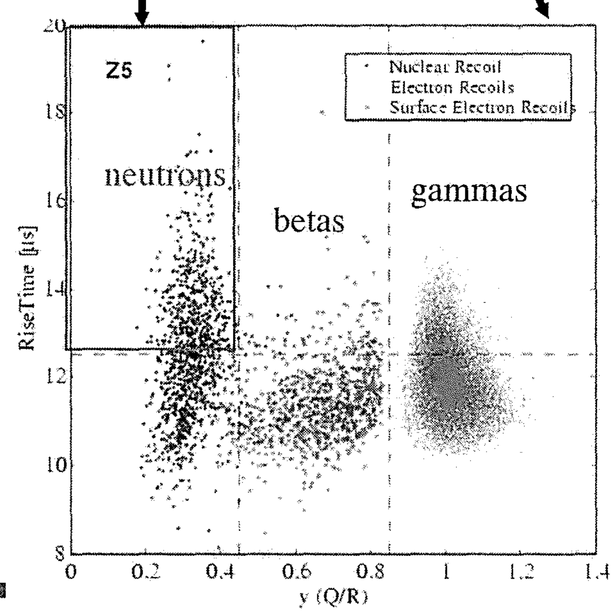
Tower 1

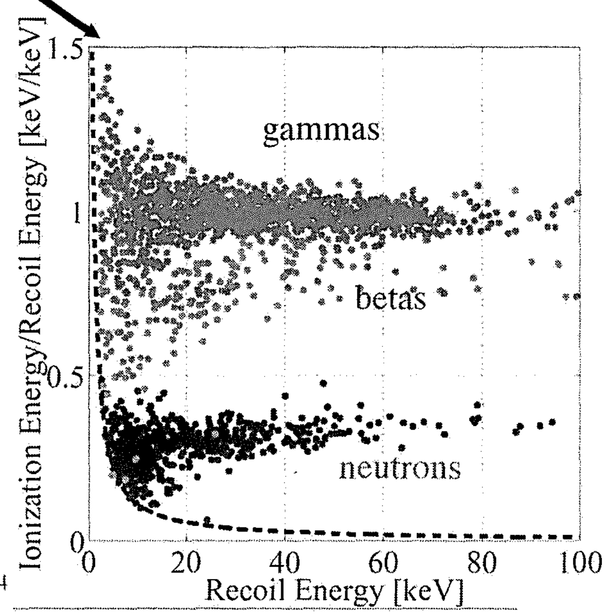
4 Ge

Tower 2

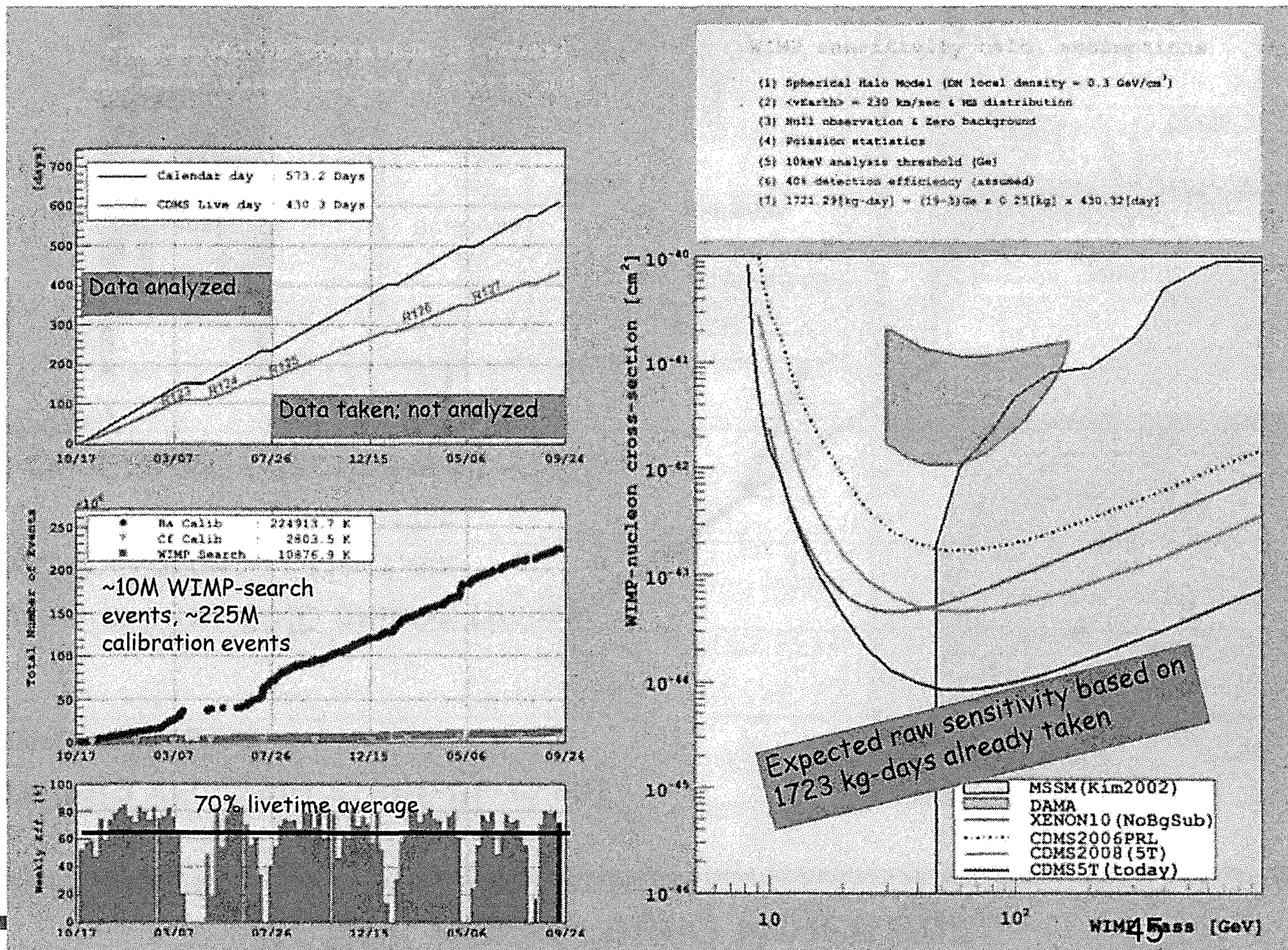
2 Ge



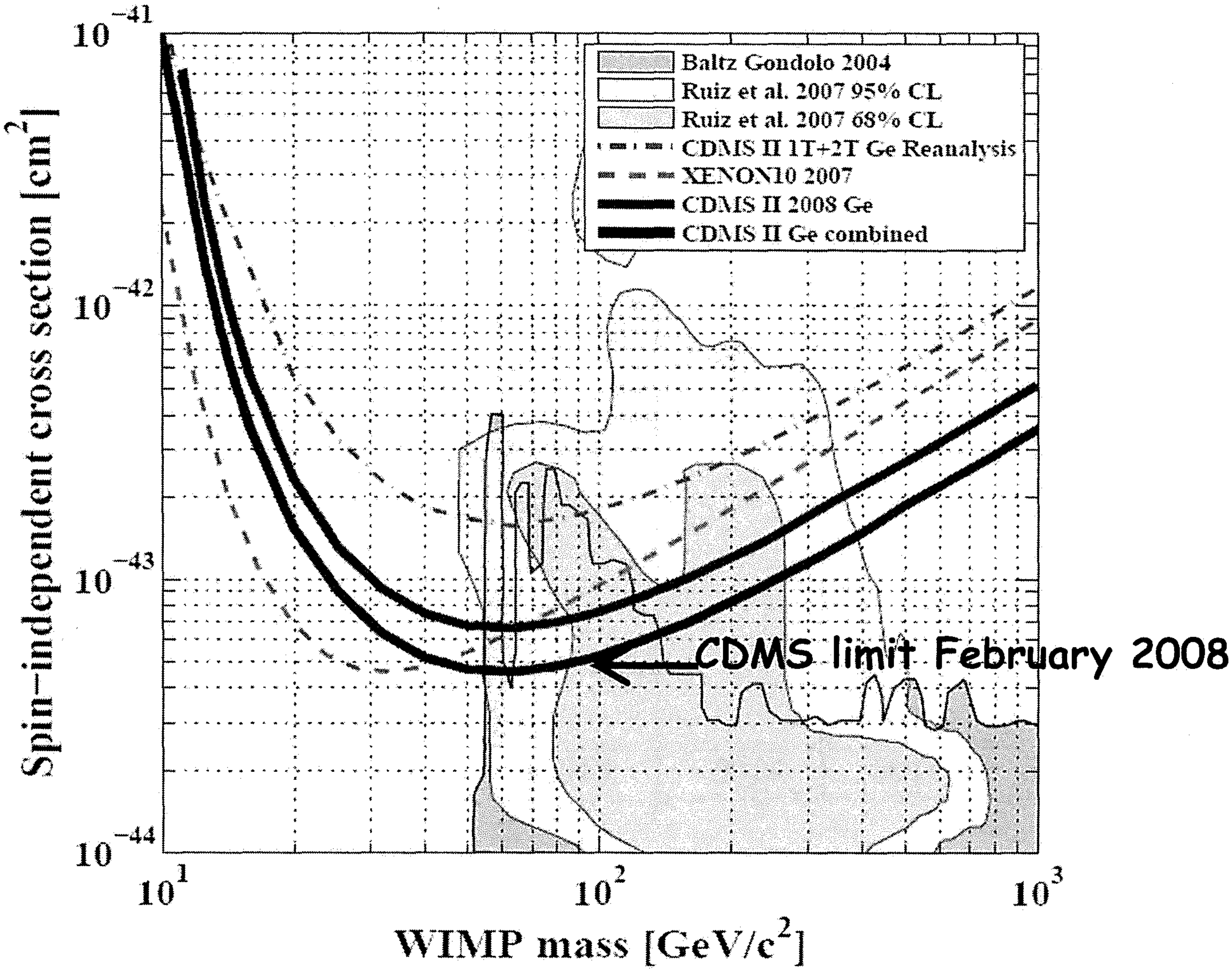




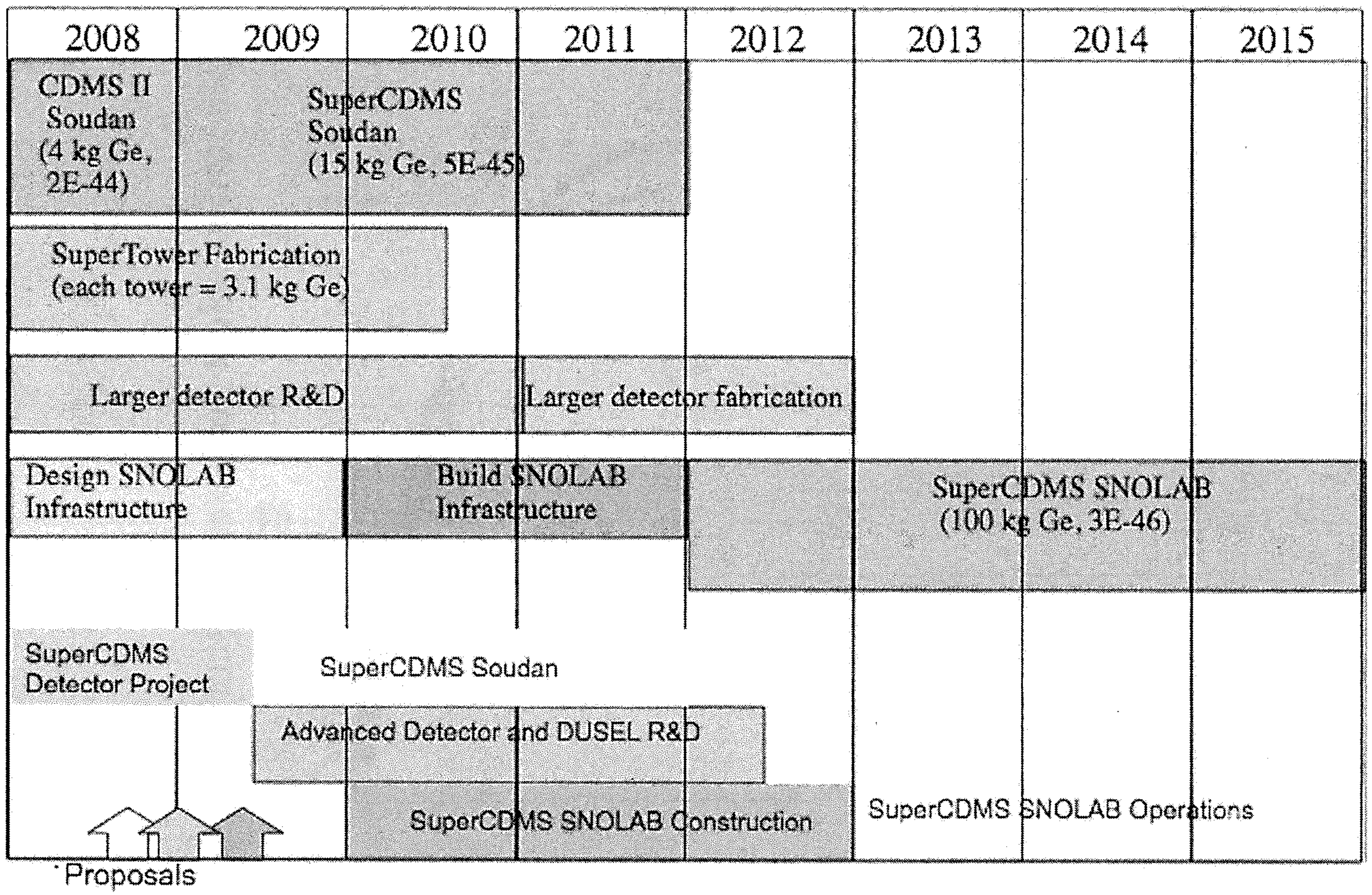
CDMS II Running Well at Soudan!



CDMS has best limits for MSSM



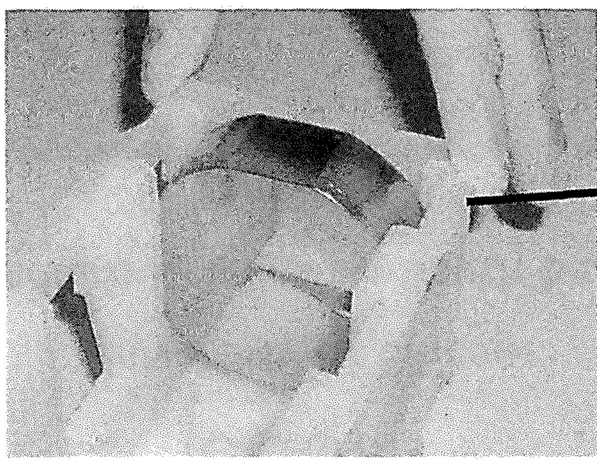
SuperCDMS

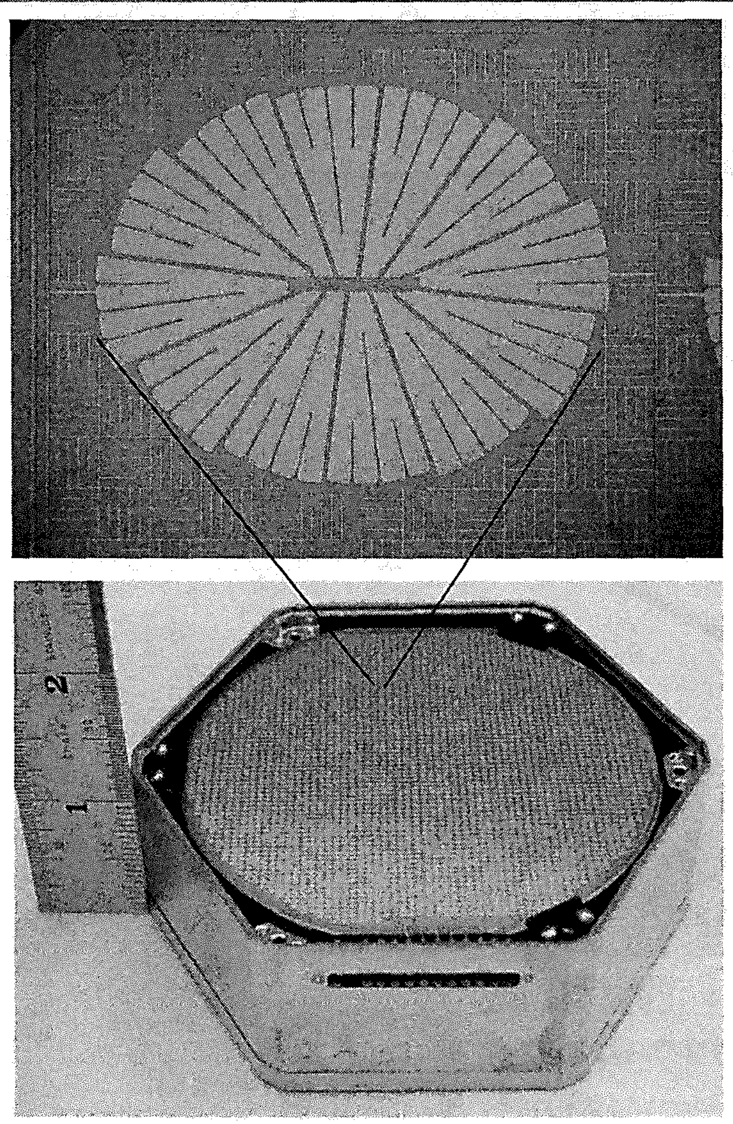

2008
2009
2010
2011
2012
2013
2014
2015
CDMS II Soudan (4 kg Ge, 2E-44)
SuperCDMS Soudan (15 kg Ge, 5E-45)
SuperTower Fabrication (each tower = 3.1 kg Ge)
Larger detector R&D
Larger detector fabrication
Design SNOLAB Infrastructure
Build SNOLAB Infrastructure
SuperCDMS SNOLAB (100 kg Ge, 3E-46)
SuperCDMS Detector Project
SuperCDMS Soudan
Advanced Detector and DUSEL R&D
SuperCDMS SNOLAB Construction
SuperCDMS SNOLAB Operations
Proposals

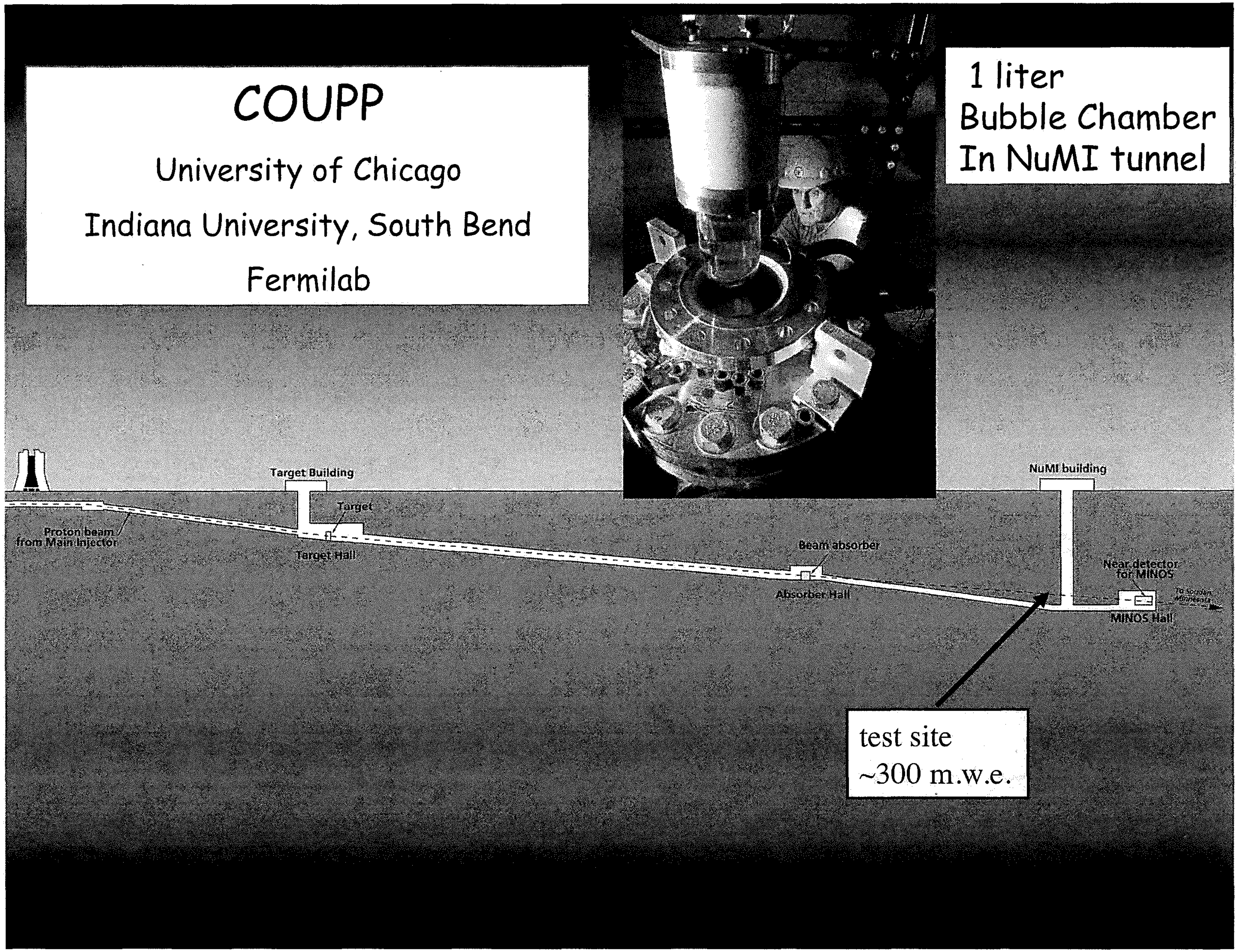
SuperCDMS Detectors

CDMS-II ZIPs:
3" dia x 1 cm => 0.25 kg of Ge

SuperCDMS ZIPs:
3" dia x 1" => 0.64 kg of Ge

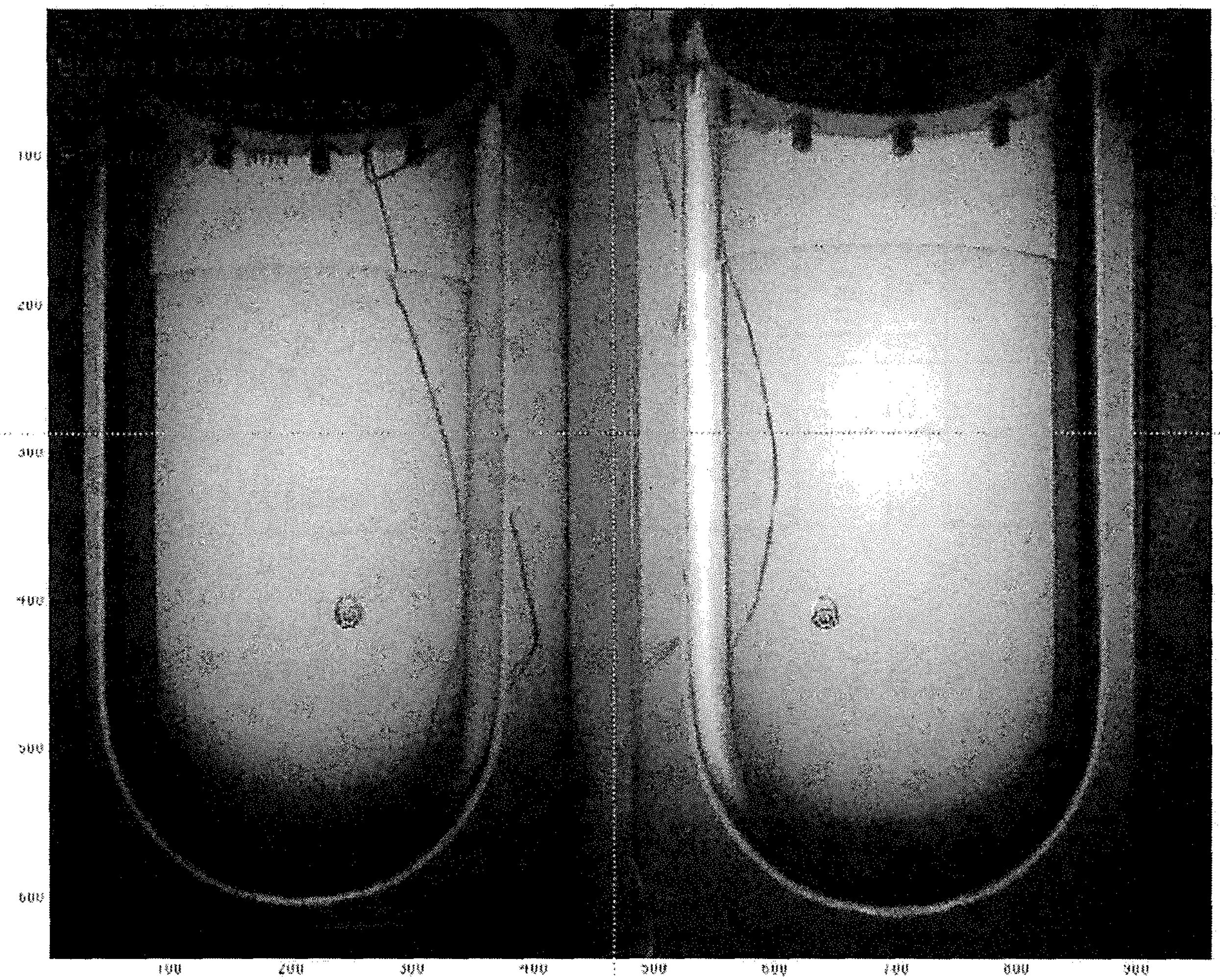





COUPP
University of Chicago
Indiana University, South Bend
Fermilab
1 liter
Bubble Chamber
In NuMI tunnel
Target Building
Target
Proton beam
from Main Injector
Target Hall
Beam absorber
Absorber Hall
NuMI building
Near detector
for MINOS
MINOS Hall
test site
~300 m.w.e.

A Typical COUPP Event

Two views of same bubble (cameras offset by 90°):



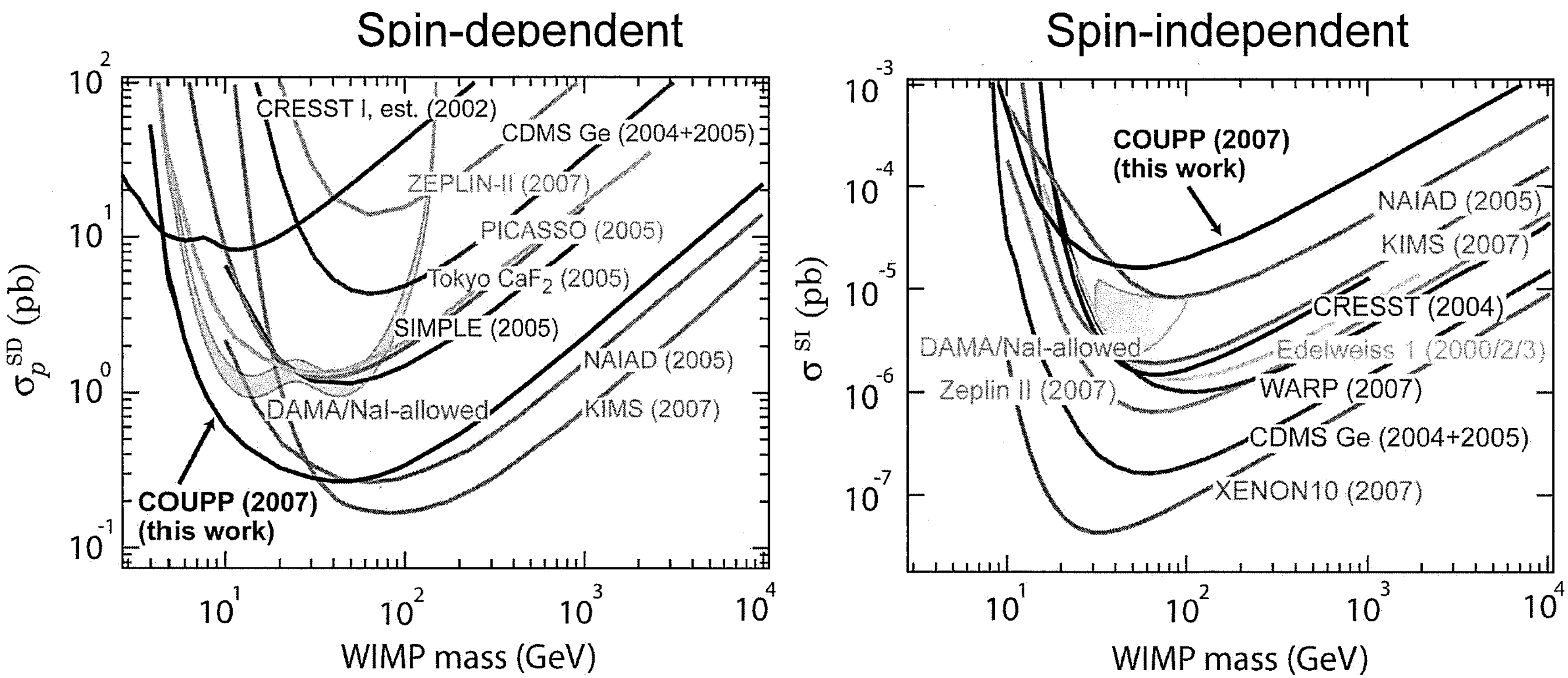
A WIMP interaction would produce a single bubble only.

Appearance of a bubble causes the chamber to be triggered by image processing software.

Bubble positions are measured in three dimensions from stereo camera views

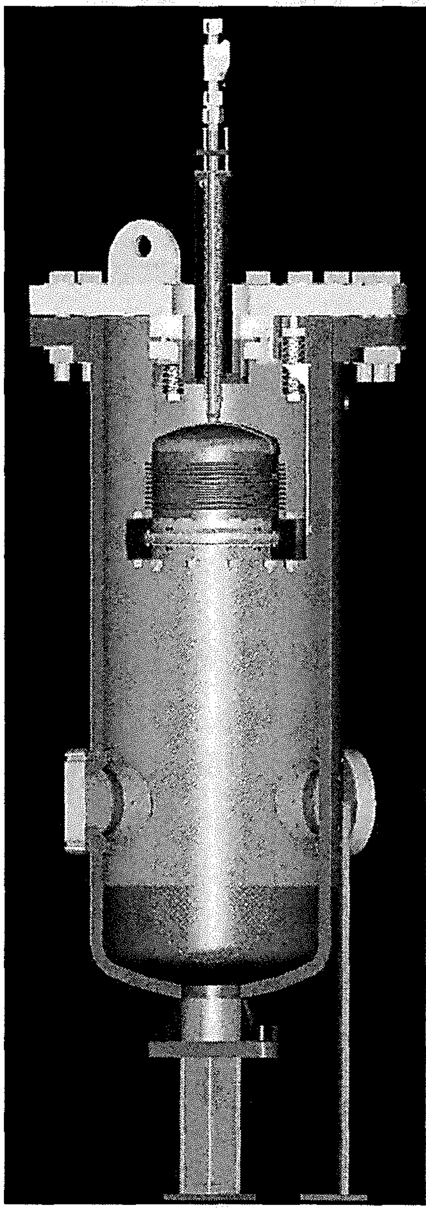
COUPP: First Results

- competitive sensitivity for spin-dependent scattering, despite high radon background
- Now published, *Science, 319: 933-936 (2008).*

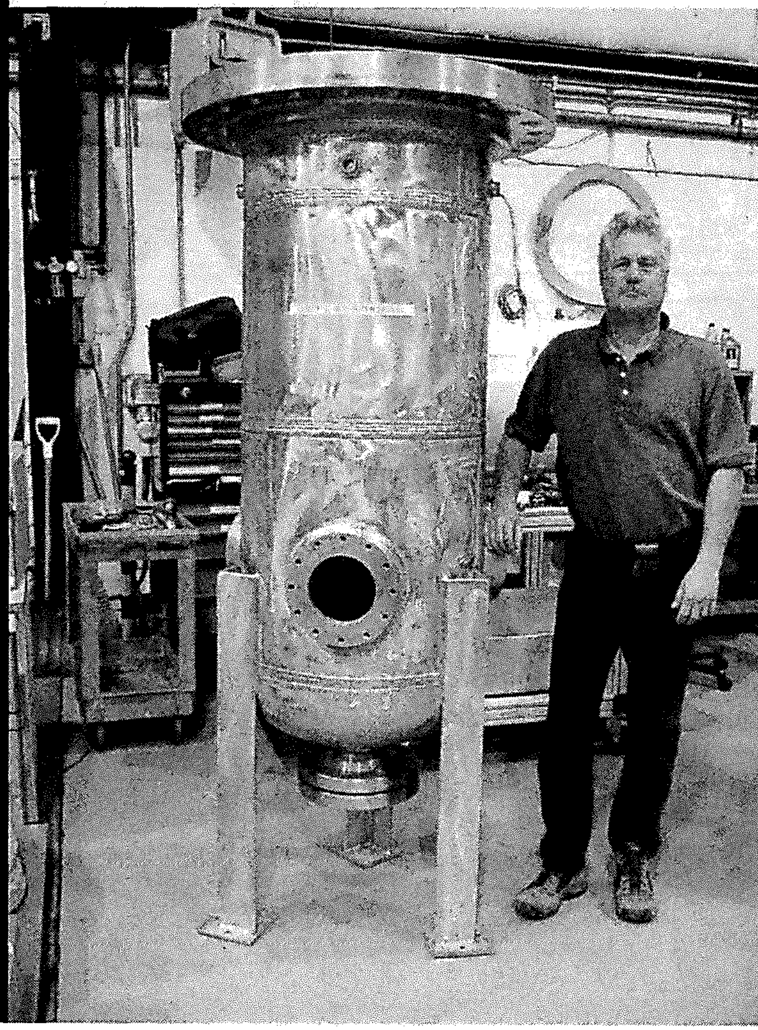


60-Kg Bubble Chamber

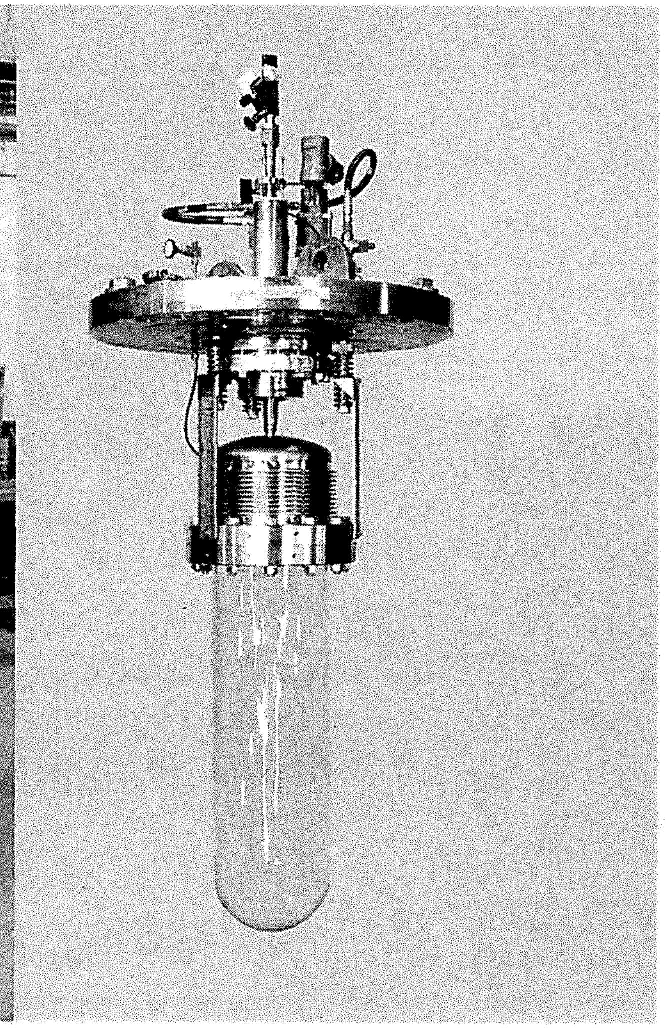
Drawing



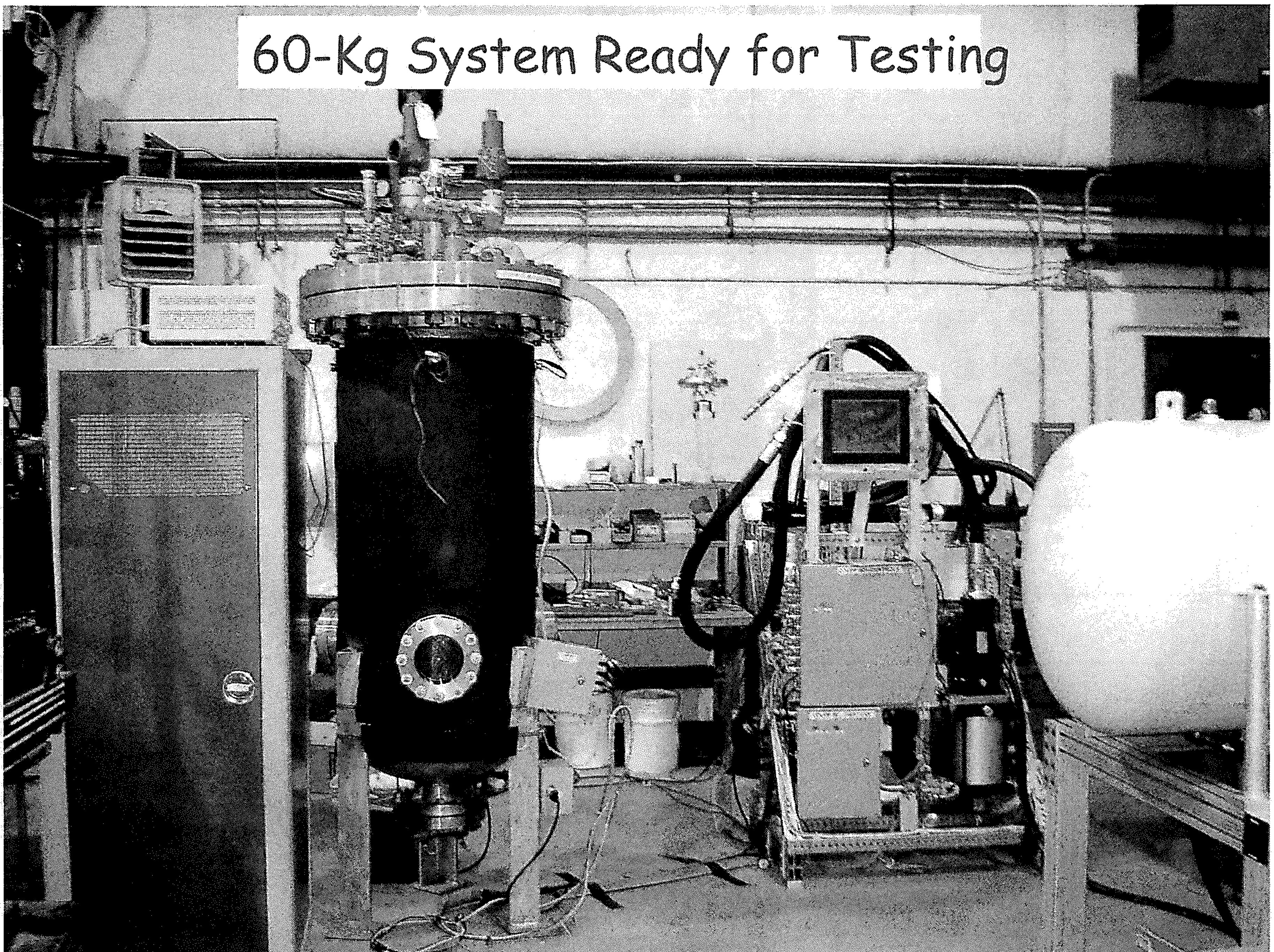
Outer Vessel



Inner Vessel

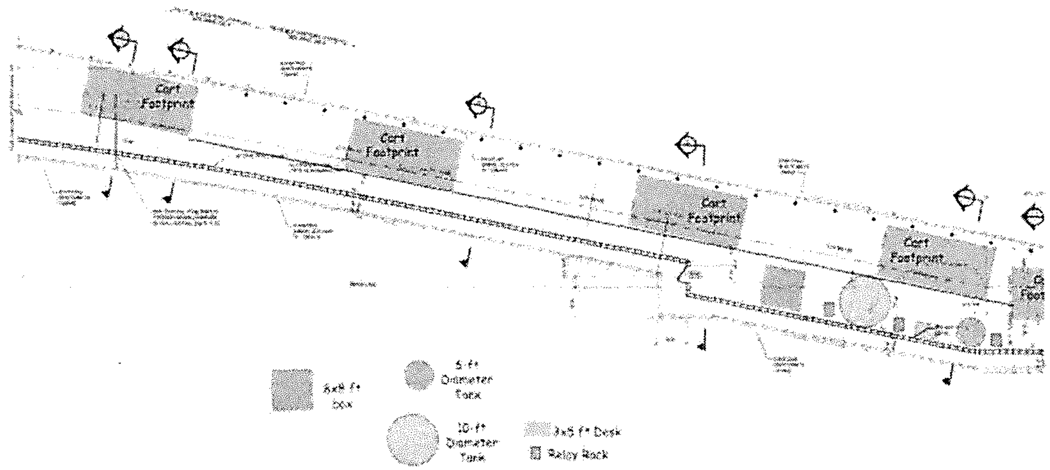


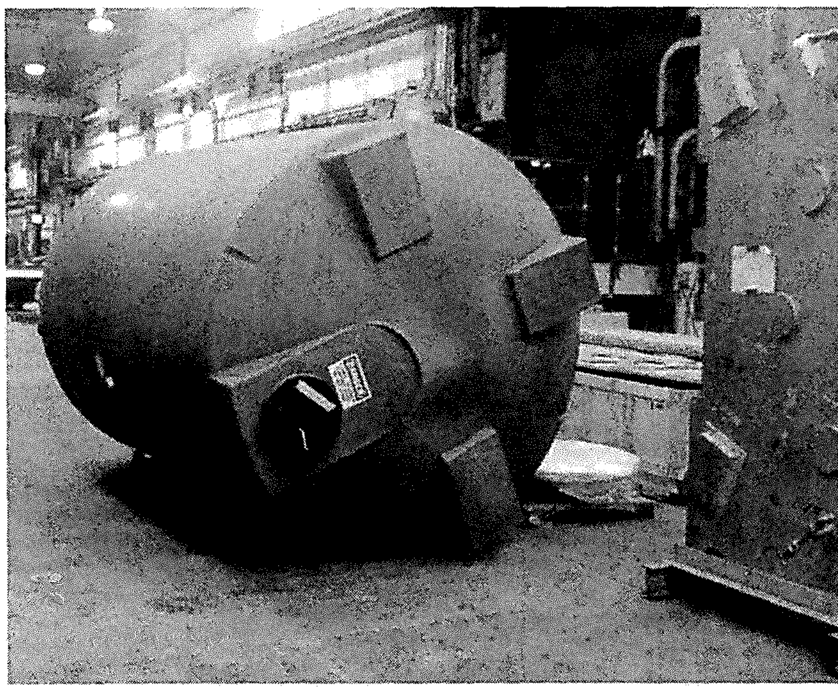
60-Kg System Ready for Testing

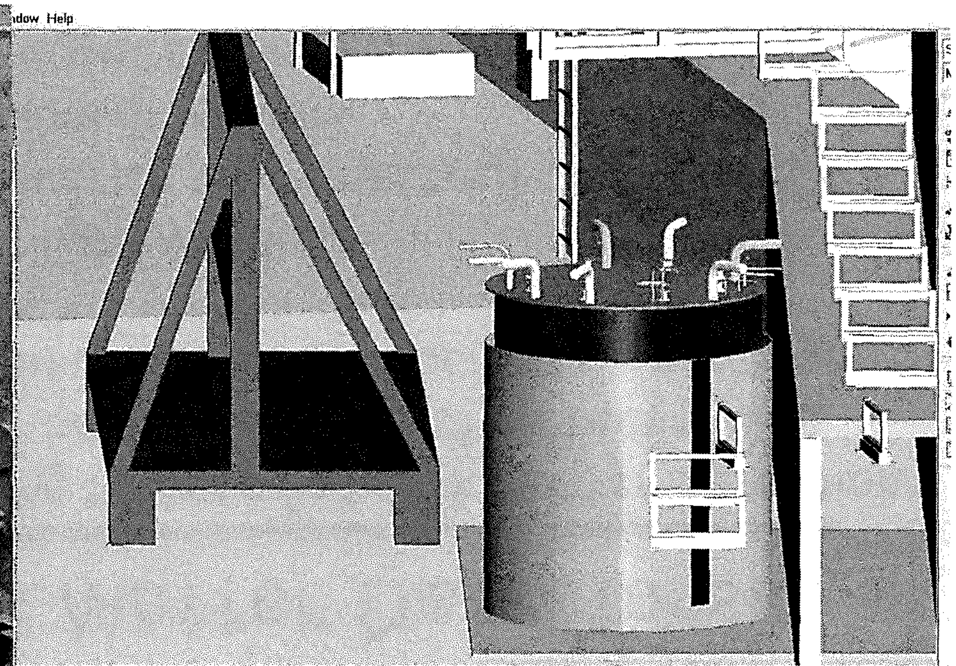


Water Tank for Neutron Shielding and Muon Veto

- 10' diameter water tank
- Tag cosmic muons with Cerenkov light
  12 x 8" PMTs (Auger surplus)
- Installation this spring in NuMI tunnel







Liquid Argon Dark Matter Detectors

Liquid argon is one of most promising targets for dark matter detection:

- Most powerful combination of background rejection techniques
  - Scintillation pulse shape differences for nuclear vs. electron recoils
  - Differences in charge and light yields
  - Precise 3D event reconstruction from electron drift in TPCs
- Low cost compared to germanium or xenon
- Easy scalability to multi-ton target volumes

There are some problems that need to be addressed by R&D:

- High energy thresholds due to problems detecting scintillation light:
  - Low quantum efficiency of phototubes at low temperatures
  - Short wavelength (128 nm) needs to be shifted up.
  - These problems seem to be coming under control as PMTs and light-collection geometries are optimized.
- Internal contamination by Ar-39 isotope
  - May be absent in argon from underground (non-atmospheric) sources.

Liquid Argon Dark Matter R&D

Fermilab scientists: Brice, Chou, Pordes, Sonnenschein

Collaborators: About 20 physicists and students from Augustana College, Black Hills State University, MIT, Princeton, Temple, University of Houston, University of Massachusetts, Notre Dame

Current activities

- Construction of ion chamber for measurement of Ar-39 contamination of underground argon sources.
- Work with Princeton on small prototype chamber to demonstrate improved light detection.

Future:

- Proposals, including NSF S4, Fermilab, DOE university
- Design of a large detector for DUSEL
  - 1- 10 ton range under study
- Intermediate-scale prototypes and physics devices (to be defined)
- DUSEL detector construction beginning ~2012
- Fermilab likely would have large role in mechanical, cryogenic engineering, construction

Fermilab Liquid Argon R&D for Neutrinos

- The lab has a significant and growing investment in liquid argon technology for the long-baseline neutrino program.

- Much of the technology can be reused or is similar to what is required for dark matter detection.

Prototype single-phase TPC

FCPA Retreat, Nov 2007

- OBSERVATIONAL COSMOLOGY /DARK ENERGY
  - DES
  - SDSS
  - SNAP
  - LSST
  - PRIME

21 CM Radio Astronomy
  - Intensity Mapping project
  - Square Kilometer Array

CMB Polarization
  - QUIET
  - CMBpol

DARK MATTER DIRECT DETECTION
  - CDMS
  - COUPP
  - Argon/ Xenon Dark Matter, DUSEL
  - Axion searches
    - ADMX
    - higher mass

COSMIC RAYS
  - AUGER
  - AUGER NORTH
  - GAMMA RAYS
    - GLAST (guest observer)
    - AIR CERENKOV TELESCOPES
      - AGIS
      - DELTA

Questions:

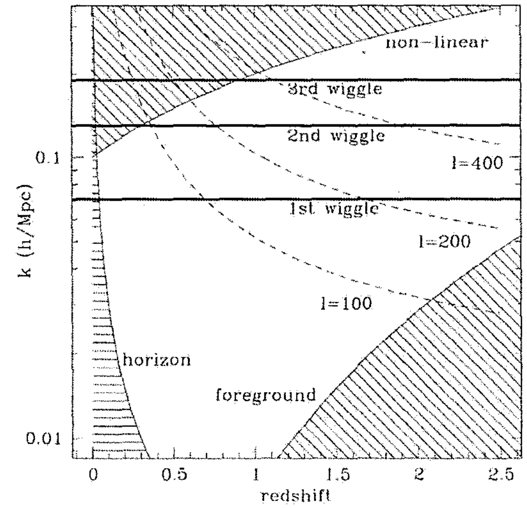
- Is the science important?
- Is it consistent with our mission?
- Can the science be funded by DOE?
- Will it leverage FNAL's resources?
- Who among us will participate?
- What are the time pressures?

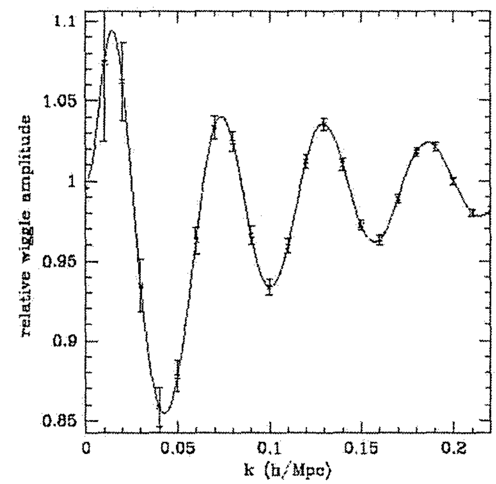
New experiments, R&D

- Dark matter technology: liquid argon, solid xenon
- Dark Energy with cylindrical telescope survey: 21 cm baryon acoustic oscillation
- CMB polarization
- Coherent-cavity GammeV
- Planck scale physics: Holographic noise
- Not all sustainable!

21 cm Survey using a Cylindrical Radio Telescope

- Goal: measure Baryon Acoustic Oscillation correlation peak in the redshift range 0.5<z<1.5.
- Method: Wide field survey of neutral hydrogen 21 cm emission.
- Potentially powerful method to measure BAO and cosmological parameters.
- Complementary to optical surveys being mounted or planned.
- ~Weekly meetings led by J. Marriner

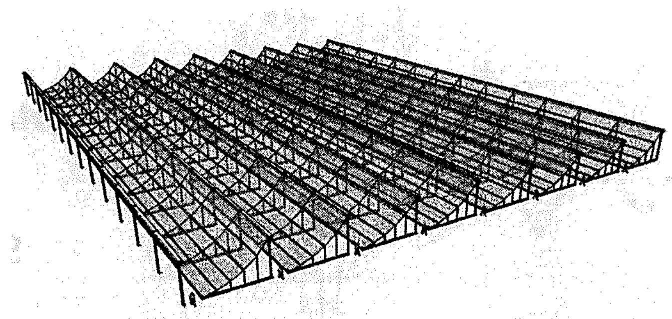


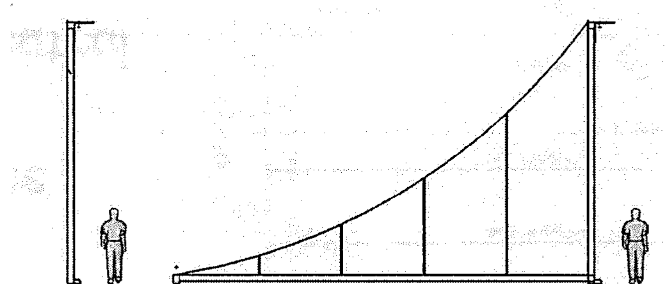


Chang, et al., 2008

21cm BAO: FNAL Activities

- Participating in a proposal (spokesman Peterson, CMU) to build a telescope in Morocco.
- Activities at FNAL
  - Antenna design
  - Site characterization
  - System simulations & mock analysis
  - Engineering tests at existing facilities





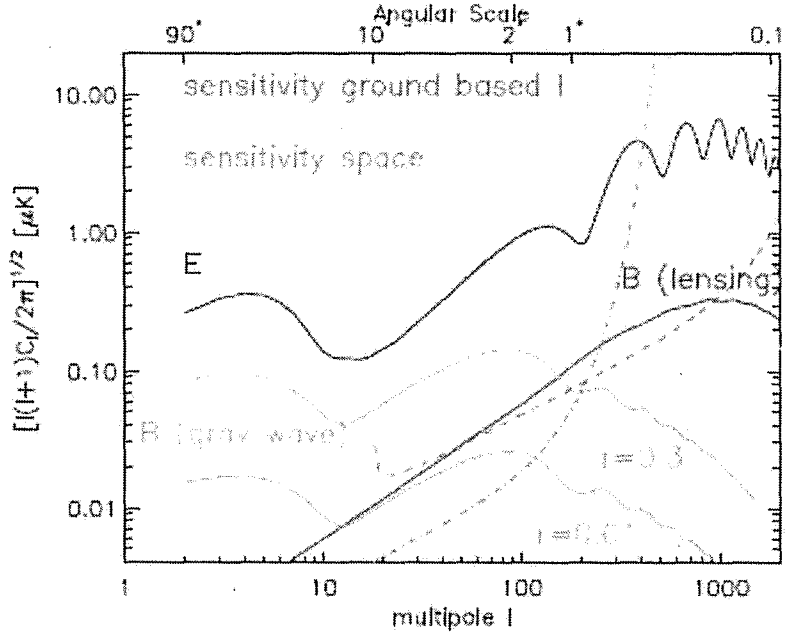
CMB Polarization R & D at Fermilab

Goals

Understand and evaluate the science goals of CMB polarization experiments.

Evaluate upcoming experiments and prospects for Fermilab participation.

Build calibration tools and perform studies for Phase 1 of the QUIET experiment. Explore possible major roles for Phase 2.



Possible experimental sensitivity
D. Samtleben *et al* astro-ph/0803.0834

Collaborators

Fritz DeJongh FCPA - Fermilab
Hogan Nguyen PPD - Fermilab
Bruce Winstein KICP (UC) and QUIET Group

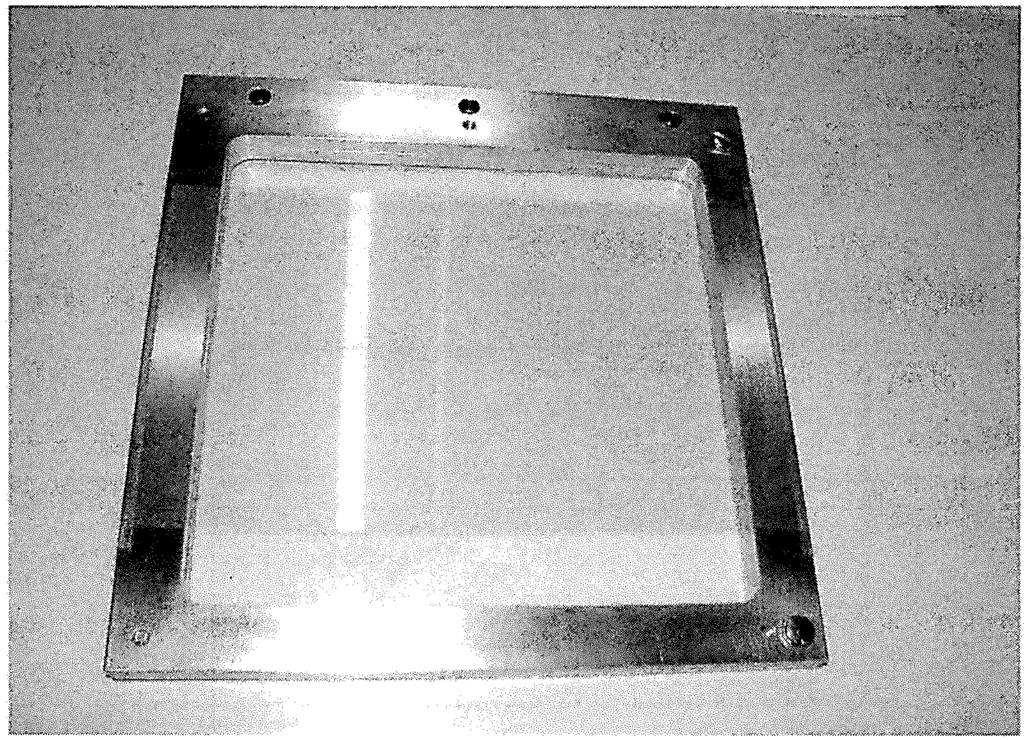
Calibration Tools for QUIET Phase-1

Fabrication Tasks

Polarizer and Modulator

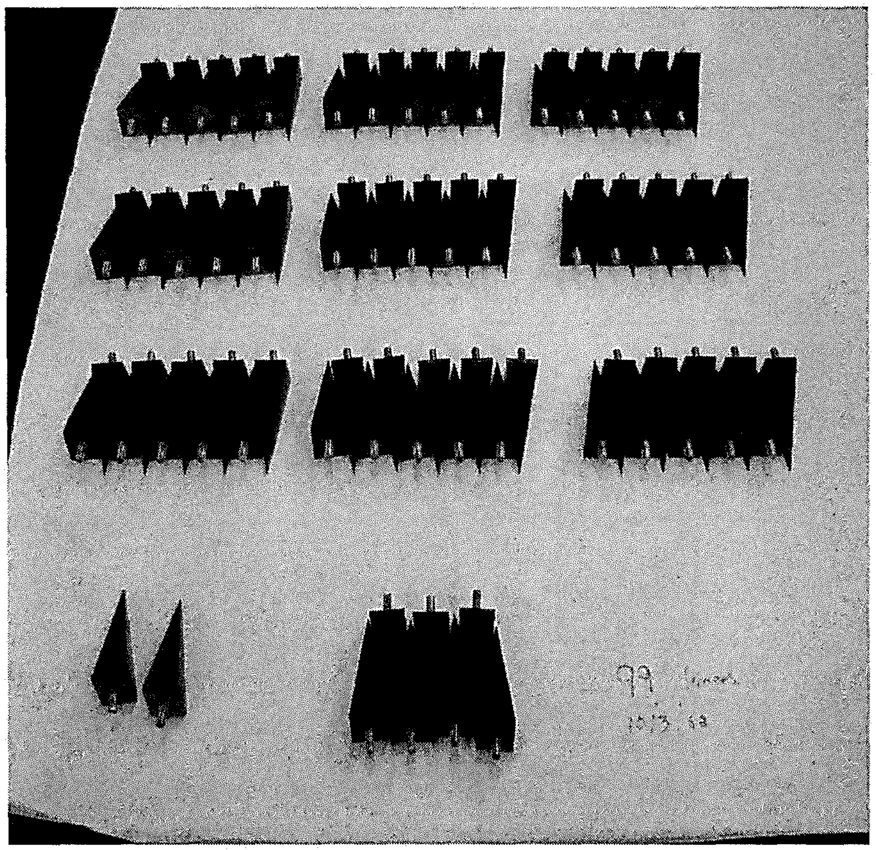
20 Kelvin Black Body Source to study QUIET polarization analyzer modules.

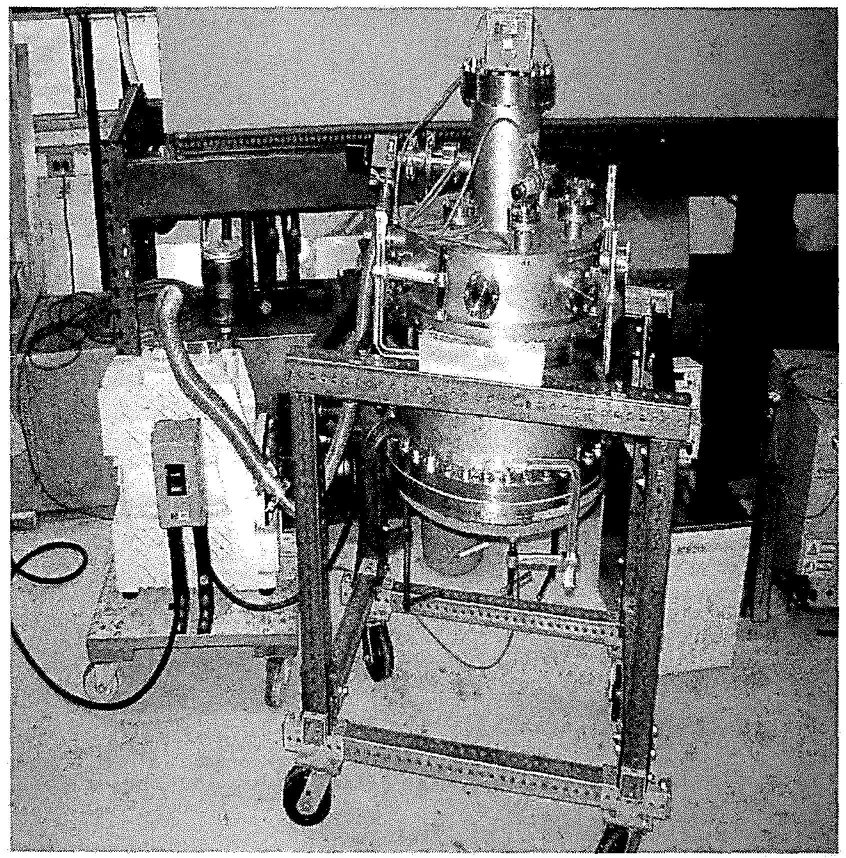
Setup microwave detection lab for general R & D



9" wire grid polarizer fabricated by Fermilab PPD for 40-100 GHz operation

20 Kelvin Black Body Source

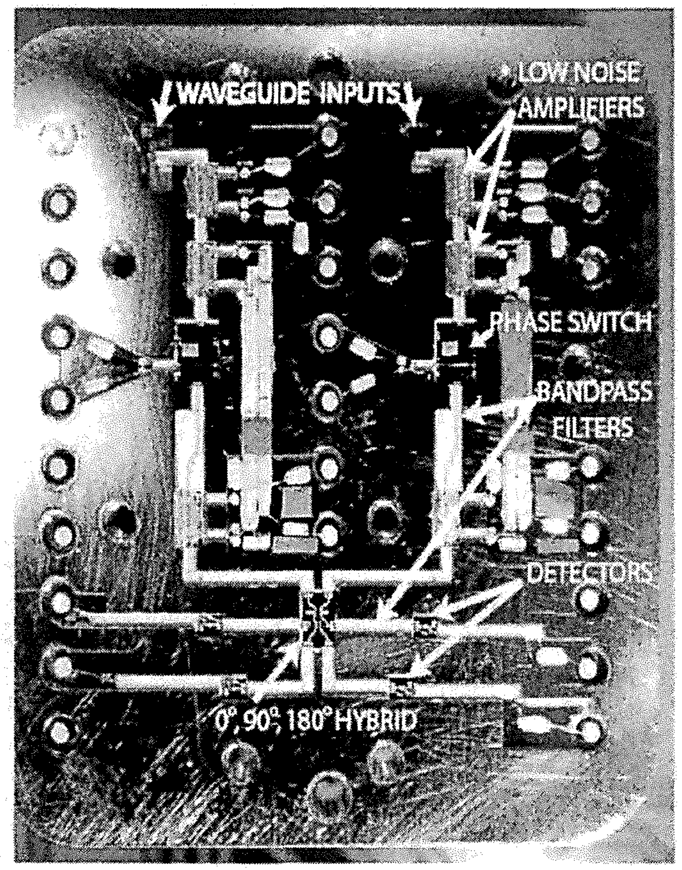




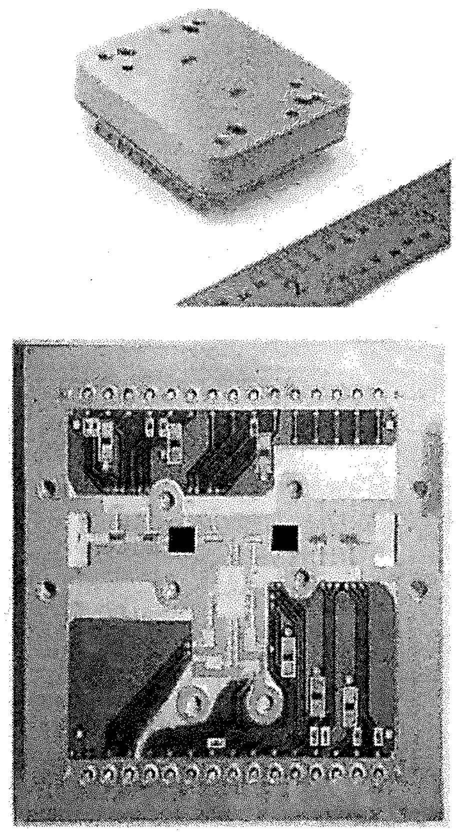
Black body is an array of pyramid-shaped microwave absorbers

Vacuum tank and cryocooler for black body cooling and associated thermal control

Possible Fermilab Involvement in QUIET Phase 2



90 GHz module



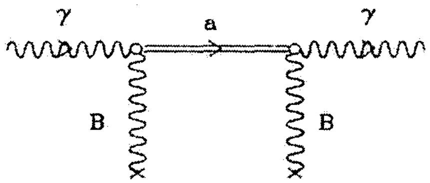
40 GHz module

Fabrication assembly of and testing of polarization analyzer modules

1000 modules proposed for QUIET Phase 2

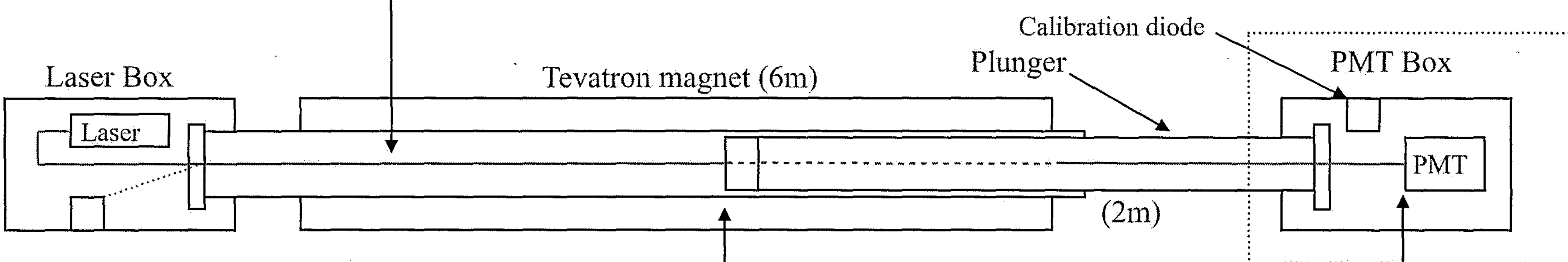
In line with our microassembly experience of silicon detectors for CDF, D0, CMS, and DES.

Shining light through a wall



$$P_{\gamma\to\phi} = \frac{4B^2\omega^2}{M^2(\Delta m^2)^2}\sin^2\left(\frac{\Delta m^2 L}{4\omega}\right)$$

Laser photons coherently scatter on a 5T magnetic field to produce new low-mass particles: axions, chameleons, etc., possibly related to the milli-eV dark energy scale.



Laser pulses are blocked, axions go through

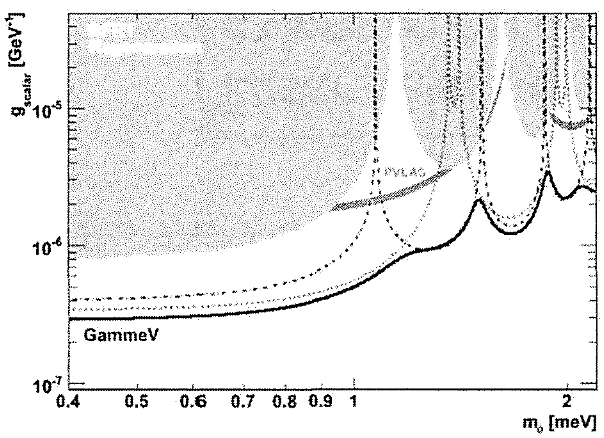
Axions re-scatter on B field, regenerate single photons to be detected via coincidence counting with a PMT.

GammeV

PRL 100, 080402 (2008) PHYSICAL REVIEW LETTERS week ending 29 FEBRUARY 2008

Search for Axionlike Particles Using a Variable-Baseline Photon-Regeneration Technique

A. S. Chou,[1,2] W. Wester,[1] A. Baumbaugh,[1] H. R. Gustafson,[3] Y. Irizarry-Valle,[1] P. O. Mazur,[1] J. H. Steffen,[1] R. Tomlin,[1] X. Yang,[1] and J. Yoo[1]
[1]*Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510, USA*
[2]*Center for Cosmology and Particle Physics, New York University, 4 Washington Place, New York, New York 10003, USA*
[3]*Department of Physics, University of Michigan, 450 Church Street, Ann Arbor, Michigan 48109, USA*
(Received 24 December 2007; published 25 February 2008)



Rules out anomalous PVLAS signal.
Limits also set on U(1) paraphotons.

A search for chameleon particles using a photon regeneration technique

A. S. Chou[1], W. Wester[2], A. Baumbaugh[2], H. R. Gustafson[3], Y. Irizarry-Valle[2], P. O. Mazur[2], J. H. Steffen[2], R. Tomlin[2], A. Upadhye[4], A. Weltman[5,6], X. Yang[2], and J. Yoo[2]
[1]*Center for Cosmology and Particle Physics, New York University, 4 Washington Place, New York, NY 10003*
[2]*Fermi National Accelerator Laboratory, PO Box 500, Batavia, IL 60510*
[3]*Department of Physics, University of Michigan, 450 Church St, Ann Arbor, MI 48109*
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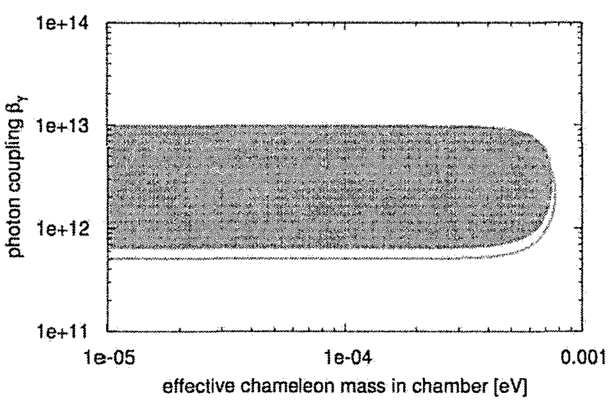
[5]*Department of Applied Mathematics and Theoretical Physics, Cambridge CB2 0WA, United Kingdom*
[6]*Cosmology and Gravity Group, University of Cape Town, Rondebosch, Private Bag, 7700 South Africa*
(Dated: June 15, 2008)



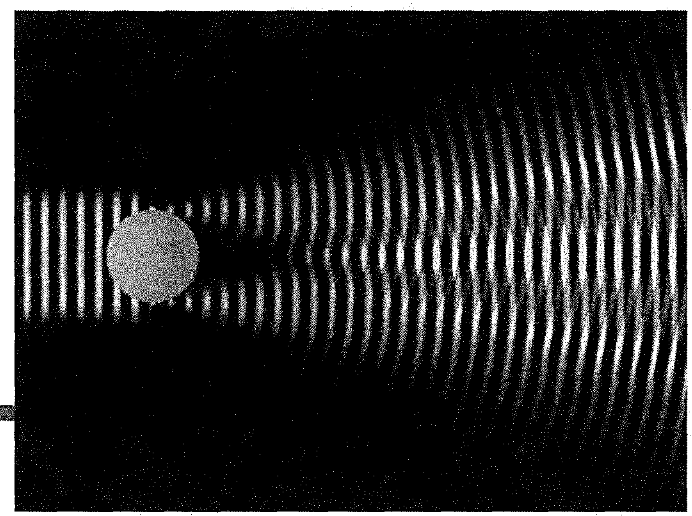
Submitted to Phys.Rev.Letters, first-ever laser search for chameleons

Upgrades to both measurements are being planned:
1) Improved chameleon search using improved vacuum
2) Resonant axion-photon conversion using locked Fabry-Perot cavities.

A new cosmic frontier: holographic noise

- Quantum physics of empty space may be studied directly using interferometers
- Not gravitational waves, but same technology
- Wavefunction of spacetime: limit of holographic theories with Planck UV cutoff (e.g., M theory)
- Large Transverse uncertainty predicted
- New phenomenon: "Holographic Noise", prediction with no parameters
- "Planck diffraction limit"

$$D = \sqrt{\lambda L}$$



Holographic quantum geometry in Matrix Theory

- Transverse position matrices *X*, compact radius *R*
- Hamiltonian of Banks, Fischler, Shenker, Susskind:

$$H = R\ \mathrm{tr}\ \left\{ \frac{\Pi_i \Pi_i}{2} + \frac{1}{4}[X_i, X_j]^2 + \theta^T \gamma_i [\theta, X_i] \right\}$$

- ~wave/diffusion equation for transverse position *x*

$$\partial\psi/\partial t = (iR/2)(\partial/\partial x)^2\ \psi$$

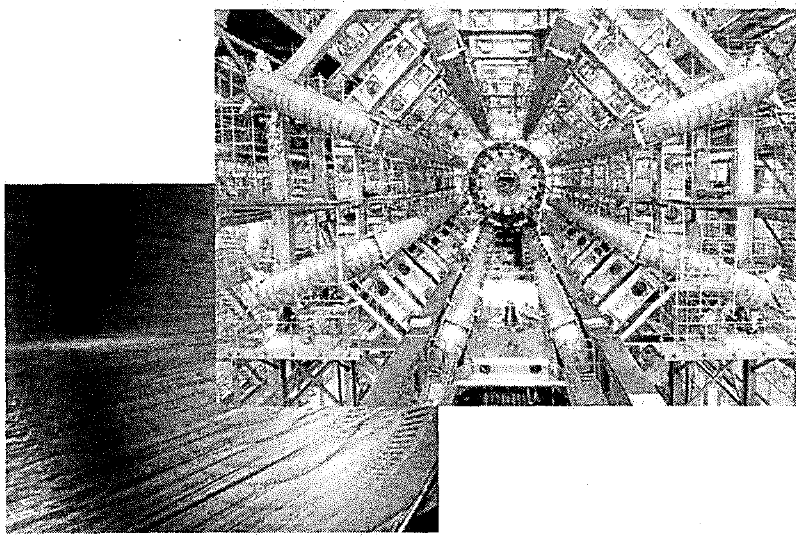
- Transverse random walk: Planck length per Planck time
- Stationary eigenstates

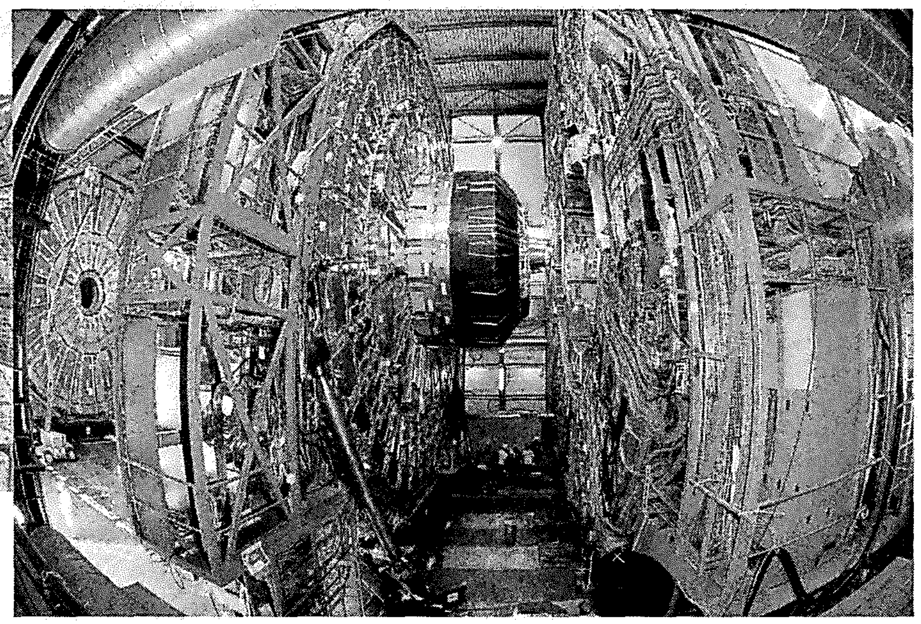
$$\psi \propto \exp[-x(2\omega/R)^{1/2}]$$

CJH & M. Jackson

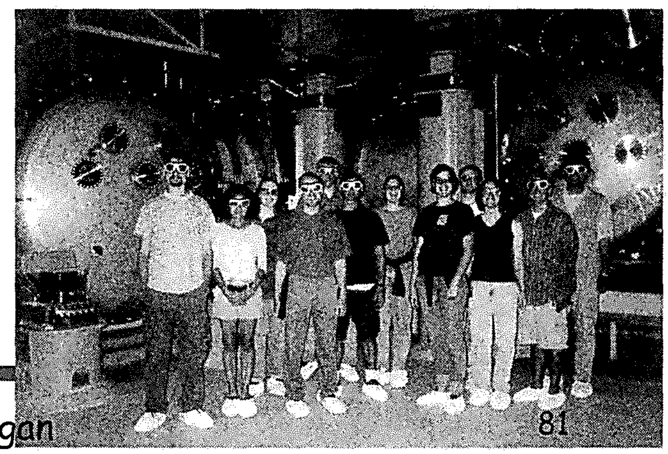
Best microscopes: the "Distance Frontier"

CERN/FNAL: $TeV^{-1} \sim 10^{-18}$ m

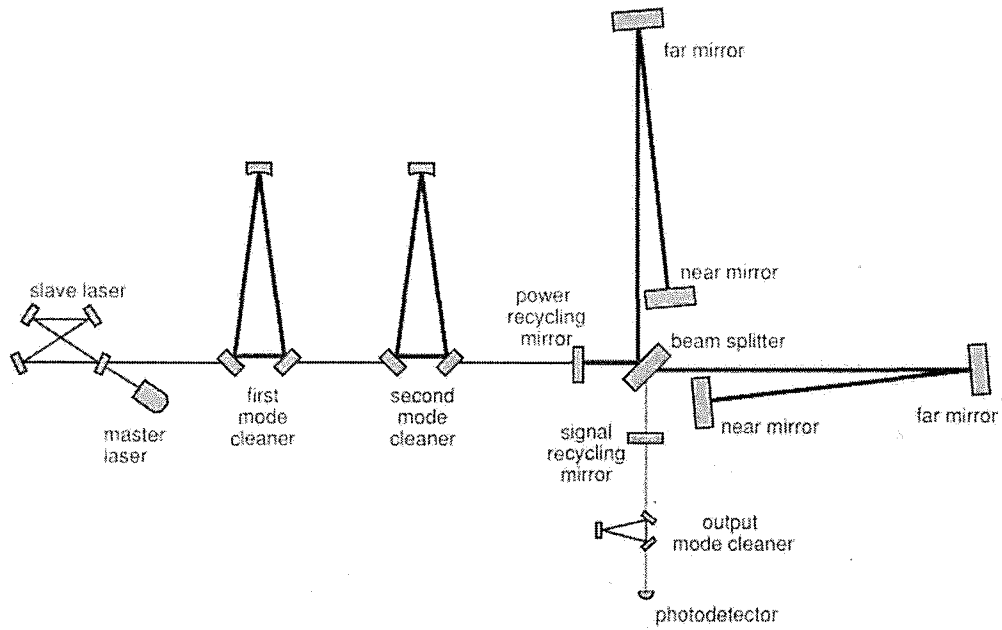


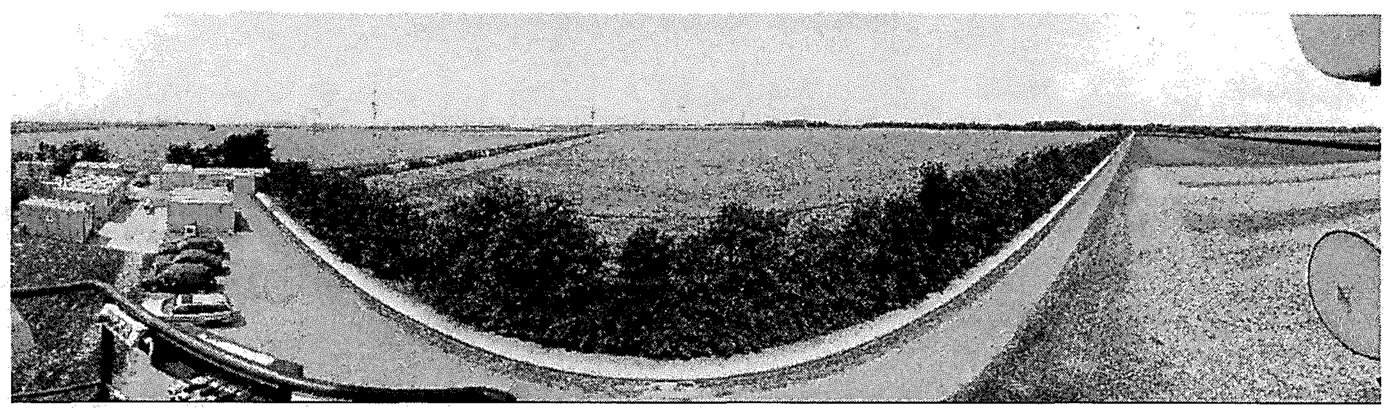


LIGO/GEO600: $\sim 10^{-19}$ m, coherent over $\sim 10^{3}$ m baseline

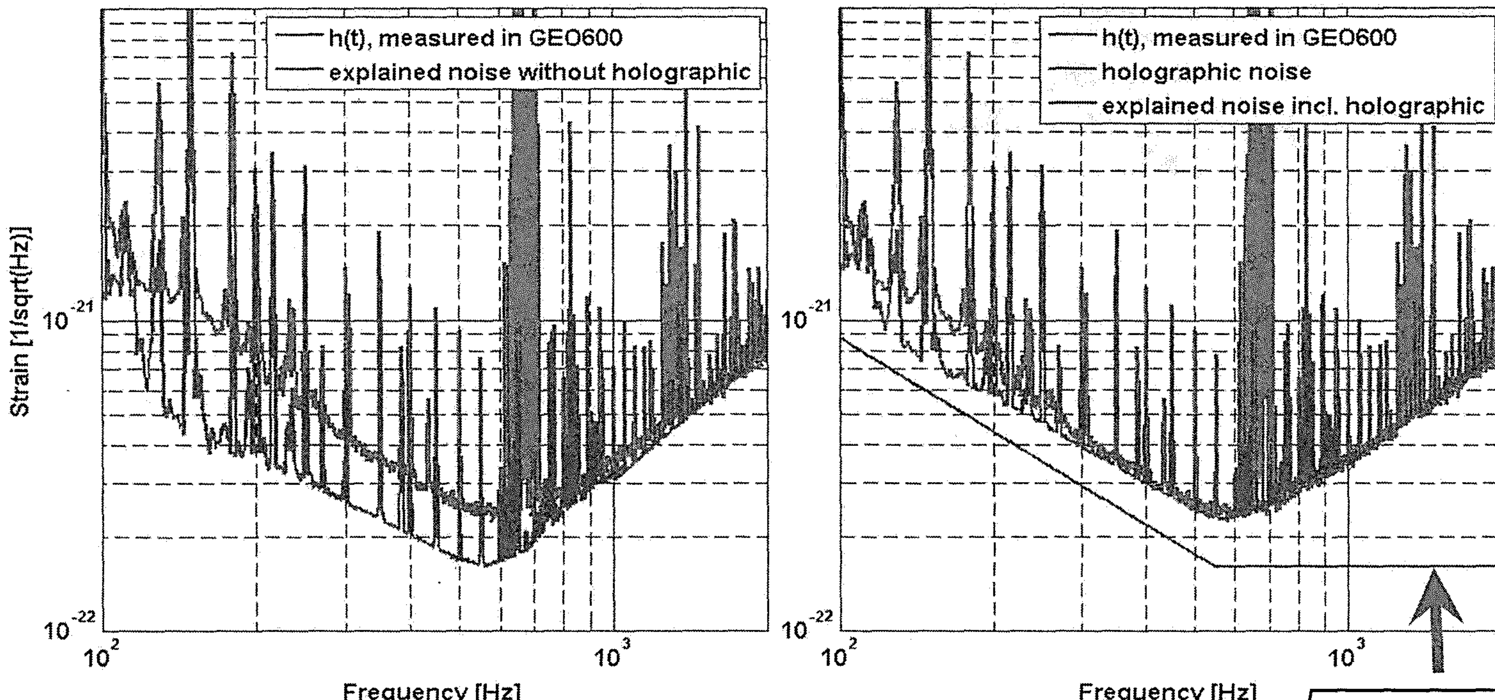


GEO-600 (Hannover): best displacement sensitivity





"Mystery Noise" in GEO600



$$\sqrt{t_{Planck}/2}$$

zero-parameter prediction for holographic noise in GEO600 (equivalent GW strain)

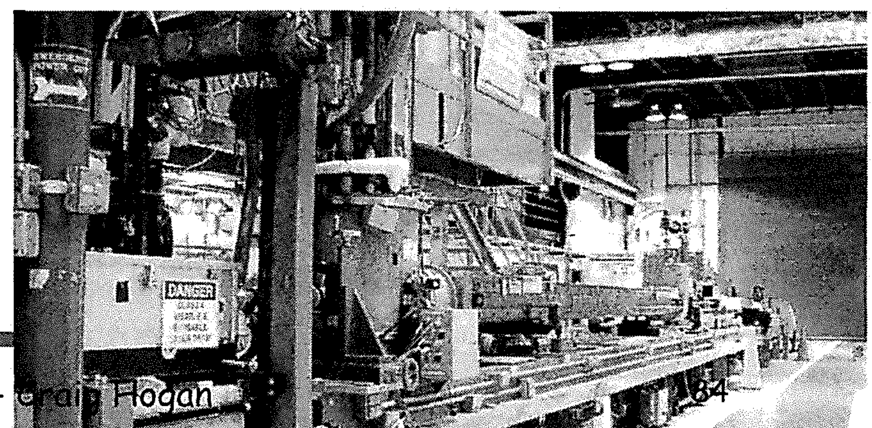
Data: S. Hild (GEO600)

Prediction: CJH, arXiv:0806.0665 (Phys Rev D.78.087501)

Total noise: not fitted

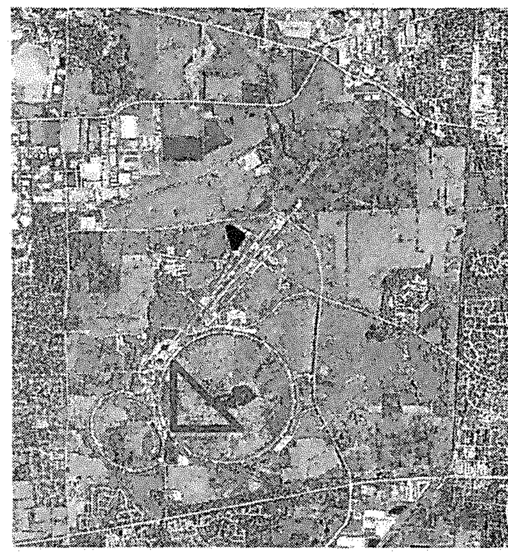
Holographic quantum geometry experiments: beyond GW detectors

- Spectrum: f ~100 to 1000 Hz with existing apparatus
- f ~ MHz possible with similar technique, high power
- Easier suspension, isolation
- Correlated holographic noise in adjacent paths even at high *f* (LHO 2km with 4km? New setup?)
- Optimal designs different from GW studies
- Shared technology with GammeV upgrade: cavities, lasers, detectors
- Currently in preconceptual development



A future experiment at FNAL?

~ 1 km arms
~100cm tubes
~100 kHz
~1kw cavity
or
~100m
~10cm
~1MHz
~100kW

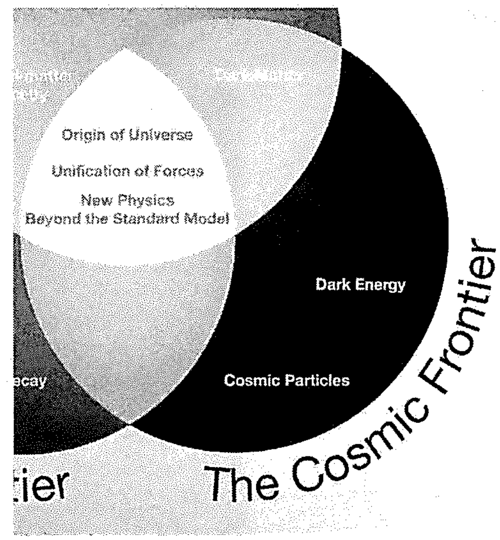


for holographic noise to be detectable above laser photon shot noise

- Direct, precise measurement of the fundamental interval of time
- Holographic gravity~ Dark Energy physics

Where we are

- exciting science results in last year:
    - Auger discovery of anisotropy in highest energy cosmic rays
    - New dark matter limits from CDMS and COUPP
    - Many SDSS-I,II results: Supernovae, lensing, BAO...
    - GammeV search for axion-like particles
    - Prediction of holographic noise
- Engineering/ construction underway:
    - DES camera
    - COUPP 60 kg
    - SuperCDMS
    - Auger North engineering array
    - Computational Cosmology facility
    - GammeV upgrade
- Early stage concept/ R&D:
    - 21 cm BAO measurement
    - Argon dark matter
    - CMB polarization
    - Holographic noise



Where we are going

- This year: full speed ahead on approved projects (biggest: DECam construction)
- Proposed expansion in computational cosmology
- General future directions far ahead are known: Dark Matter, Dark Energy, Unification
- Many new directions in concept/R&D phase
- Prioritization ahead
- New senior experimental staff may be needed to take leadership roles
- Important direction setters: Wilson fellows

PAC: Comments invited on Future Directions

- How can Fermilab best advance the Cosmic Frontier?
- What is the right balance between leadership, partnership, and service?
- What is the right balance between inner space and outer space?
- What is the right size for Computational Cosmology?
- Advice about new experimental directions:
  - Cosmic Microwave Background Polarization
  - New dark matter detection technologies
  - 21 Cm Cosmology
  - GammeV upgrade
  - Holographic noise