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# Fermilab Center for Particle Astrophysics

Andrew Sonnenschein  
FRA Visiting Committee  
April 26, 2008

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# Outline

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- Center for Particle Astrophysics

- Who we are
- Committees
- Postdocs
- Visitors
- Seminars and Conferences
- New director
- Web Page

- Experiments

- SDSS
- DES
- SNAP
- AUGER
- CDMS
- COUPP
- GammeV

## Future

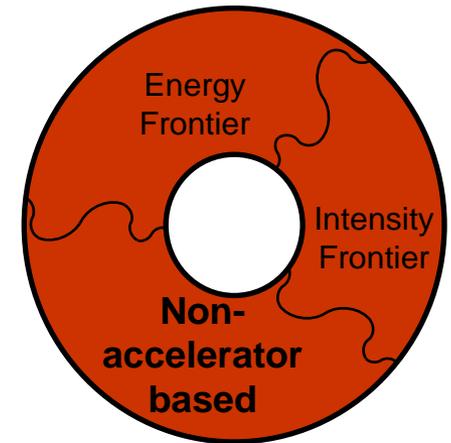
- Strategic planning retreat  
Fall 2007
- R&D proposals
  - 21 cm Cosmology
  - Liquid Argon Dark Matter
  - CMB Polarization

## Conclusion



# Center for Particle Astrophysics

- We study areas of overlap between particle physics and astrophysics:
  - Particles from space  
(Some of them are photons)
  - Dark matter
  - Dark energy
  - Neutrino mass
  - Seeds of primordial structure, inflation
- Organization
  - Acting director: Scott Dodelson
  - About 70 scientists in 2008, including visitors and postdocs
    - Inclusive list, includes many part timers (~35 FTEs?)
    - Similar number of engineering and technical staff
  - Two half-floors of Wilson Hall
  - Six experimental groups
  - Theory group (Albert Stebbin's talk)





## Committees

Futures <b>Monthly meetings to chart future</b>	Bauer, Diehl, <b>Dodelson</b> , Frieman, Flaugher, Kent, Mantsch, Peoples, Sonnenschein
Experimental Postdoc Hiring	Annis, Bauer, Diehl, Flaugher, Mantsch, <b>Merritt</b> , Newman-Holmes, Sonnenschein
Office Space	<b>Bauer</b> , Diehl, Glass, Merritt, Sonnenschein, Stebbins, Stoughton
Visitors	Annis, Glass, <b>Tucker</b> , Stebbins
Ad-Hoc Reviews/Task Forces <b>Computing, GammeV, 8 O'clock Arc Follow-up, SNAP Plan, AGIS participation</b>	Amundson, Annis, Bauer, Carcagno, Diehl, Dodelson, Frieman, Flaugher, Gnedin, Holmgren, Hooper, Lin, Liu, Kowalkowski, Kronfeld, Marriner, McGinnis, Newman-Holmes, Nguyen, Peoples, Petravick, Wilson
Web Page	<b>Kubo</b> , Glass, Jackson, Steffen



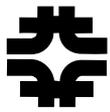
# Postdocs

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- Postdocs:
  - CDMS: Jeter Hall, Jonghee-Yoo, Lauren Hsu (~1/2 time)
  - COUPP: Lauren Hsu (~1/2 time )
  - SDSS: Jeff Kubo, Gajus Miknaitis, Jason Steffen (Brinson Fellow)
  - Auger: Eun Joo Ahn, Fred Kuehn
  - Theory: Emiliano Sefusatti, Pascquale Serpico, Chris Vale, Hee-Jong Seo, Mark Jackson, Kathryn Zurek (Schramm Fellow)

RED= Departing, Green= Arriving

- Departing postdocs are not all being replaced due to budget problem. Theory group going from 5 to 2.
- Now have hiring process separate from rest of lab for both theory and experiment.
  - Our own ads in Physics Today.
  - Fixed application deadline in fall to match with rest of astro field.
    - Dramatic increase in quality and quantity of applicants.
    - Intense competition with other institutions for top choices.



# Visitors 2007-2008

22 short term

8 long term

Goals:

- Help with existing projects where we lack expertise.
- Foster new collaborations.
- Strengthen connections to university groups.

## LONG TERM (>4 weeks)

Name	Institution	Host Group	Host
Blasi, Pascuale	Arcetri/ Florence, Italy	Theory/Auger	Frieman
Depoy, Darren	Ohio State University	DES	Flaugher
Deustua, Susana	AAS, Washington	SNAP	Kent
Jones, John	high school	DES	Estrada
Lahav, Ofer	University College, London, UK	DES	Frieman
Ribeiro, Andre	LATO/DCET/UESC, Brazil	Theory	Dodelson
Soares-Santos, Marcelle	LATO/DCET/UESC, Brazil	Theory	Dodelson
Valkenberg, Wessel	LAPTH, France	Theory	Stebbins

## SHORT TERM (<4 weeks)

Name	Institution	Host Group	Host
Brinchmann, Jarle	Portugal	SDSS	Tucker
Butner, Melissa	Austin Peay State University	SDSS	Tucker
Gustafson, Dick	LIGO	Gammev	Wester/ Chou
Hamilton, James	U Wisconsin, Platteville	COUPP	Sonnenschein
Horesh, Assaf	Tel Aviv	SDSS	Tucker
Jaffe, Andrew	Imperial College	Theory	Stebbins
Lutz, Deiter	MPE- Garching	SDSS	Tucker
Makler, Martin	CBPF	DES	Estrada
McElrath, Bob	UC Davis	Theory	Hooper
Pocar, Andrea	Stanford	CDMS/COUPP	Sonnenschein
Powell, Brian	SUNY Buffalo	Theory	Stebbins
Schramm	Occidental	Theory	Hooper
Shapiro, Chaz	U. Chicago	Theory	Dodelson
Smith, J. Allyn	Austin Peay State University	SDSS	Tucker
Taylor, Andrew	Max Planck	Theory	Hooper
Timbie, Peter	Wisconsin, Madison		Dodelson
Wayth, Randall	Harvard University	SDSS	Tucker
Wu, Proty	National Taiwan Univesity	Theory	Stebbins
Zhange, Pengie		Theory	
Zlosnik, Tom		Theory	
Zurek, Kathryn	Wisconsin, Madison	Theory	Hooper



# Weekly Events

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- Particle Astrophysics Seminars
    - Every monday plus occasional others.  
55 seminars in 2007
    - 80% external speakers
    - Slightly reduced schedule this year due to budget.
  - Cluster Working Group.
    - Weekly meeting of optical astronomers
  - "Munch" Journal Club
    - Moderated discussion of recent astroph postings.
    - Typically about 20 people, theory and experiment
  - Thursday Chalk Talk
    - A 20 minute informal talk by a local person.
    - Coffee and cookies.
-



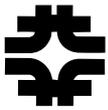
# Conferences

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- We are hosting about 3 workshops and conferences a year.
- Some of them fairly large  
E.g. 164 participants at Hunt for Dark Matter

- Good lab infrastructure for this:
  - Lots of meeting rooms
  - Fermilab Conference Office
  - Fermilab Visual Media Services

- \* 05/15/08 - 05/17/08 SNAP Collaboration Meeting
  - \* 06/23/08 - 06/26/08 CMBPol Mission Concept Study: Theory and Foreground Workshop
  - \* 08/15/08 - 08/18/08 SDSS Symposium
  - \* 11/01/07 SDSS II Collaboration Meeting
  - \* 06/14/07 Searching for Strong Lenses in Large Imaging Surveys
  - \* 05/10/07 The Hunt for Dark Matter
  - \* 05/25/06 External Correlations of the Cosmic Microwave Background and Cosmology
  - \* 05/24/06 Fermilab Atro Theory Group Reunion
  - \* 07/13/05 TeV Particle Astrophysics
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## New Director: Craig Hogan

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- Craig Hogan appointed director, will start this summer.
- Joint appointment with University of Chicago.

### BIO

Cambridge, Ph.D., 1980

Fermi Fellow at U. Chicago

U. Arizona faculty

U. Washington

Astronomy chair

Dean of Natural Sciences

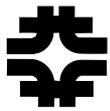
Vice Provost for Research

High-z Supernova Search Team

LISA

LSST





# New Web Page (<http://astro.fnal.gov>)



## CENTER FOR PARTICLE ASTROPHYSICS

[About the Center](#) | [Projects](#) | [People](#) | [Events](#) | [Contact Us](#)



Welcome to the Fermilab Center for Particle Astrophysics.

### News & Events

**Craig Hogan set to join the FCPA this summer**  
See the recent [Fermi Today](#) article.

**CDMS Emulates the Music of John Cage**  
and regains the lead in the race to discover SUSY dark matter  
More details [here](#) and [here](#).

**Chalk Talk: Robyn Levine**  
Thursday, April 17, 4:00pm, Dark Side

**Particle Astrophysics Seminar: Gabriella Sciolla, MIT**

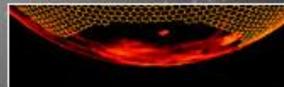
### Current Projects



**Chicagoland Observatory for Underground Particle Physics (COUPP)**  
[Learn More](#)



**Cryogenic Dark Matter Search (CDMS)**  
[Learn More](#)



**Dark Energy Survey (DES)**  
[Learn More](#)



**GammeV**  
[Learn More](#)



**Pierre Auger Observatory**  
[Learn More](#)



**Sloan Digital Sky Survey (SDSS)**  
[Learn More](#)



**SuperNova / Acceleration Probe (SNAP)**  
[Learn More](#)



**Theoretical Astrophysics**  
[Learn More](#)

### Present and Recent Visitors

**Andre Ribeiro** (Univ. Estadual de Santa Cruz)  
**Damiano Caprioli** (Scuola Normale Superiore, Pisa)  
**Rikman Raj** (University of Cambridge)

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

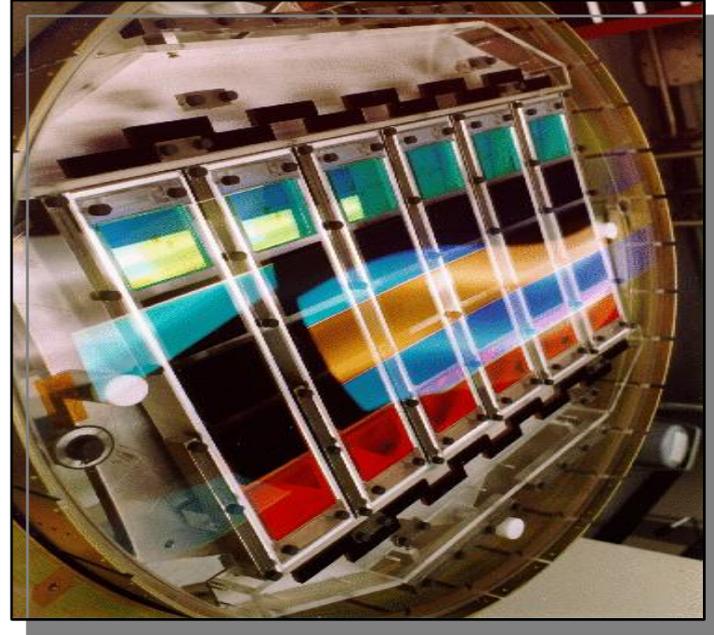




# Sloan Digital Sky Survey

## Collaboration: ~150 scientists from

Am. Museum Nat. History  
Astrophysical Inst. Potsdam  
U. Basel  
Cambridge U.  
Case Western Reserve  
U. Chicago  
Drexel U.  
Fermilab  
Institute for Adv. Studies  
Japanese Participation Grp  
Johns Hopkins U.  
JINA  
Kavli Institute for Part. Astro.  
Korean Scientist Group  
LAMOST (China)  
Los Alamos Nat. Lab  
Max Planck Inst. Astron.  
Max Planck Inst. Astrophy.  
New Mexico State U.  
Ohio State U.  
U. Pittsburgh  
U. Portsmouth  
Princeton U.  
US Naval Obs.  
U. Washington



## SDSS Focal Plane

120 megapixels (30 CCDs)

5 bandpass filters

+ fiber-coupled spectrograph

1.5 degree field of view



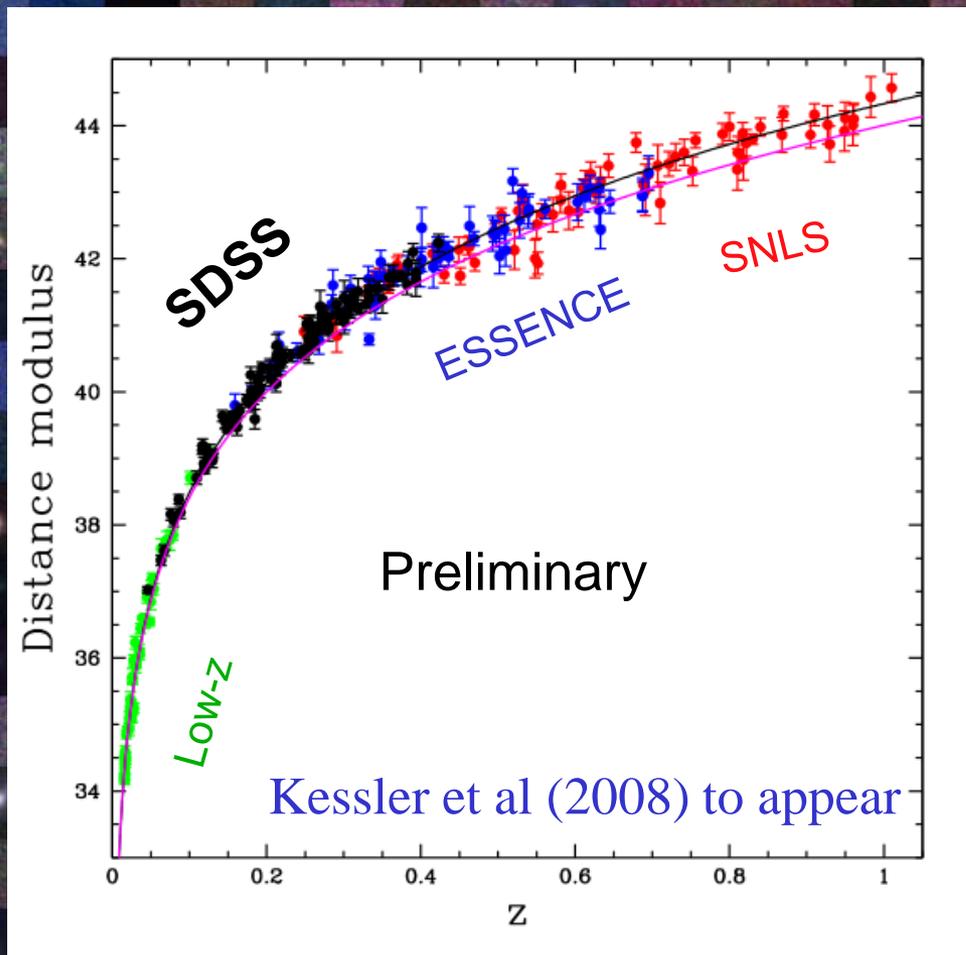
# SDSS Physics

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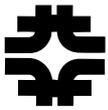
- Homogeneous catalog of 1/4 of sky in five spectral bands.
- High resolution spectra of  $> 1$  M galaxies.
- Cosmological parameter determination, galaxy clustering properties, baryon acoustic oscillations, weak lensing, strong lensing, high-redshift quasars, etc.
- Supernova search (SDSS-II)
- **All data is released to community at regular intervals**
- $>1600$  refereed papers,  $>50,000$  citations

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

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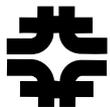
484 confirmed SNe Ia with IAU designations



# Fermilab In SDSS-II

- 14 Fermilab scientists
  - ~4 FTE scientists + 3 postdocs
  - Kent co-leader of Legacy
  - Yanny co-leader of Segue
  - Frieman co-leader of Supernove
- Engineering and technical contributions
  - 10 FTE
  - Data management
    - Archiving
    - Distribution
    - Analysis pipelines
  - Operations
    - about 1/3 of total manpower
  - DAQ
  - Plug plates

These activities will not continue with SDSS-III, as effort focuses towards Dark Energy Survey.



# Dark Energy Survey (DES)

## Proposal:

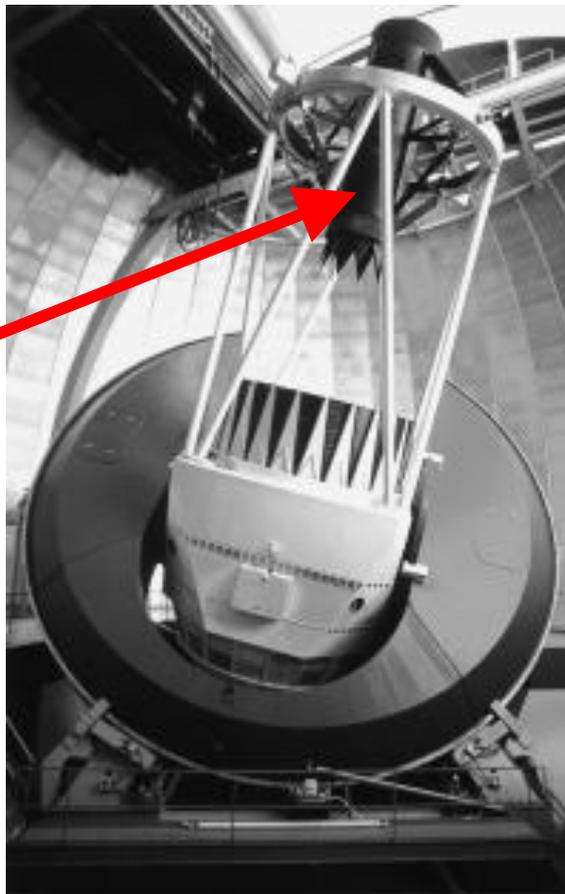
- ∅ Perform a 5000 sq. deg. survey of the southern galactic cap (overlap w SPT)
- ∅ measure  $w$  with 4 complementary techniques: Clusters, Weak Lensing, BAO, SNIa

## 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)



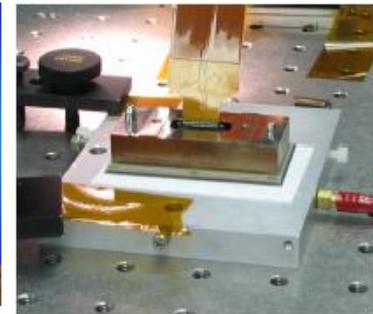
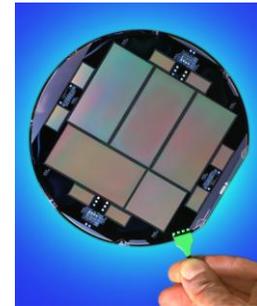
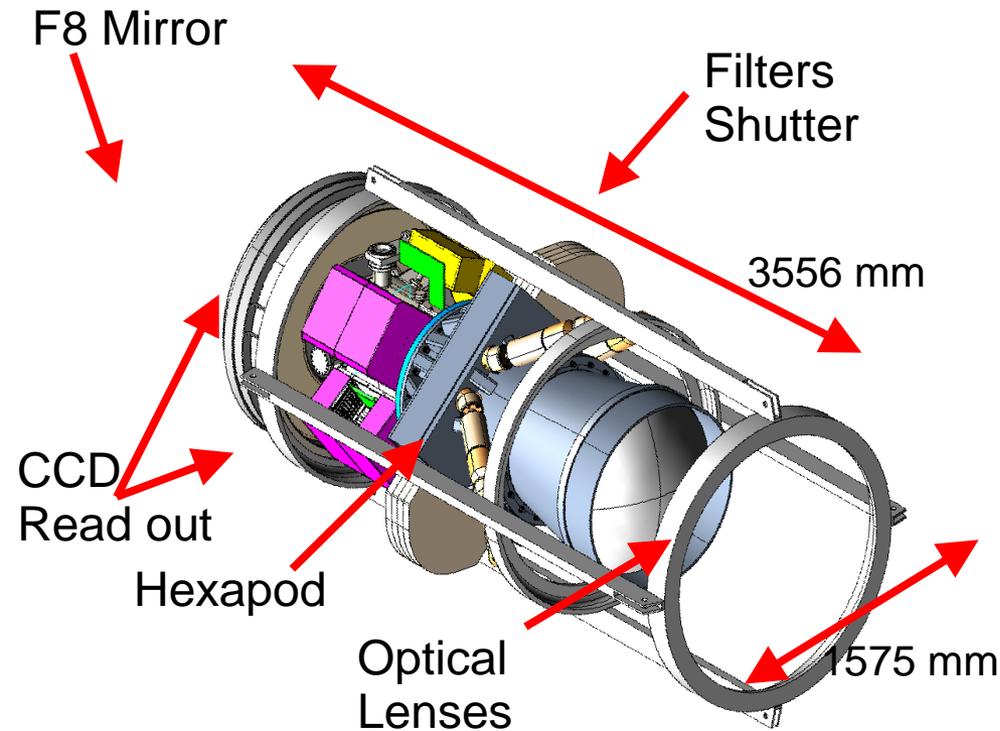
Use the Blanco 4M Telescope at the Cerro-Tololo Inter-American Observatory (CTIO)



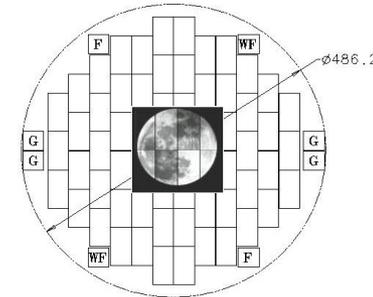
# The DES Instrument: DECam

DECam will be larger than any existing CCD camera

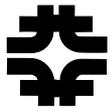
Fermilab Role:  
DECam project management  
CCD packaging  
CCD readout (lead)  
CCD Focal plane and vessel  
Optical Corrector barrel  
Cage and hexapod/alignment



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



UK will provide optical elements  
Spain will provide production electronics



## Differences Between SDSS and DES

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- Bigger telescope (4 m vs 2.5 m)
- Better CCDs, with more pixels and  $>90$  QE at  $1000 \mu\text{m}$
- No spectroscopy, which used a lot of observing time.



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

Four times more galaxies than SDSS

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

The SPT catalog will be complete out to a well-defined limiting cluster mass

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# DES Constraints on Dark Energy Parameters

$$w = p/\rho$$

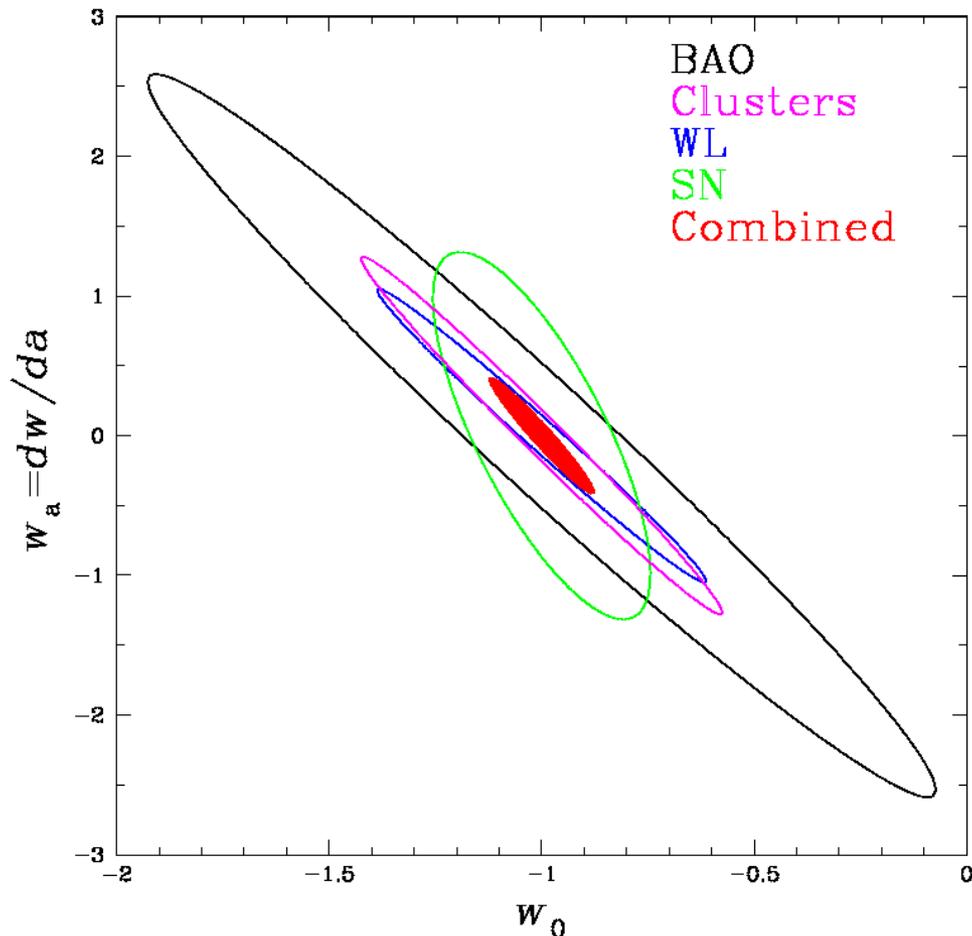
$$w(z) = w_0 + w_a(1-a)$$

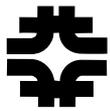
68% CL

• 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  $w$





# SNAP: Supernova Acceleration Probe

- Candidate for DOE/ NASA JDEM dark energy mission.

Announcement of opportunity expected this year.

First priority in Beyond Einstein (NRC)

- Wide- field space telescope.
- Visible and infrared imaging will reach to  $z=1.7$

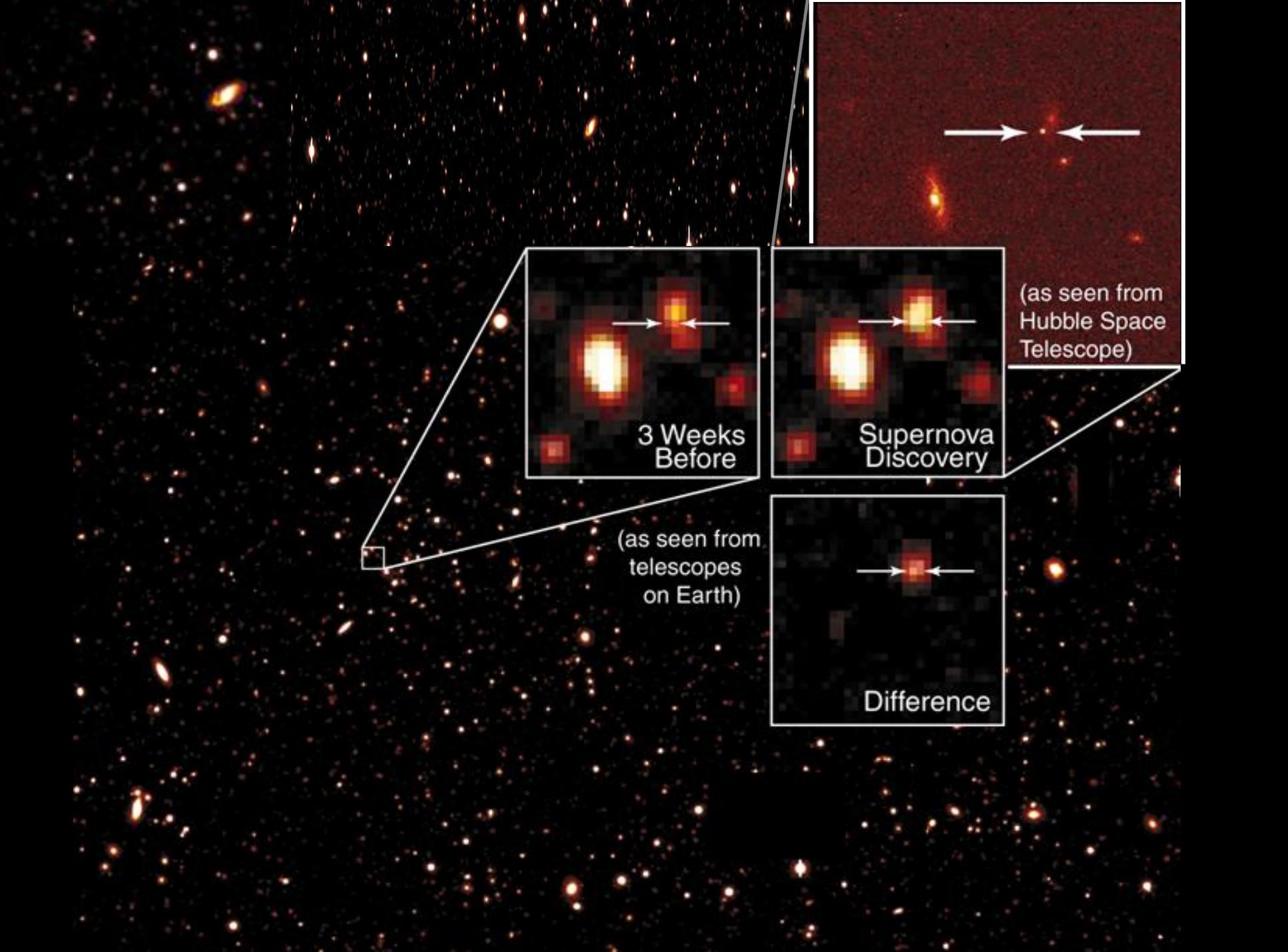
Deep depletion CCDs to  $1 \mu\text{m}$ , 6 filters

HgCdTe devices to  $1.7 \mu\text{m}$ , 3 filters

Spectrograph

- Supernova survey will revisit 15 square degrees every three days.
- Weak lensing survey: 1000 square degrees  
9000 x Hubble Deep Field with similar resolution





(as seen from Hubble Space Telescope)

3 Weeks Before

Supernova Discovery

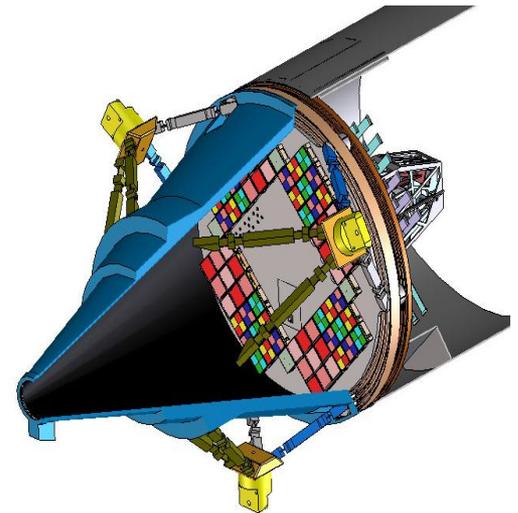
(as seen from telescopes on Earth)

Difference



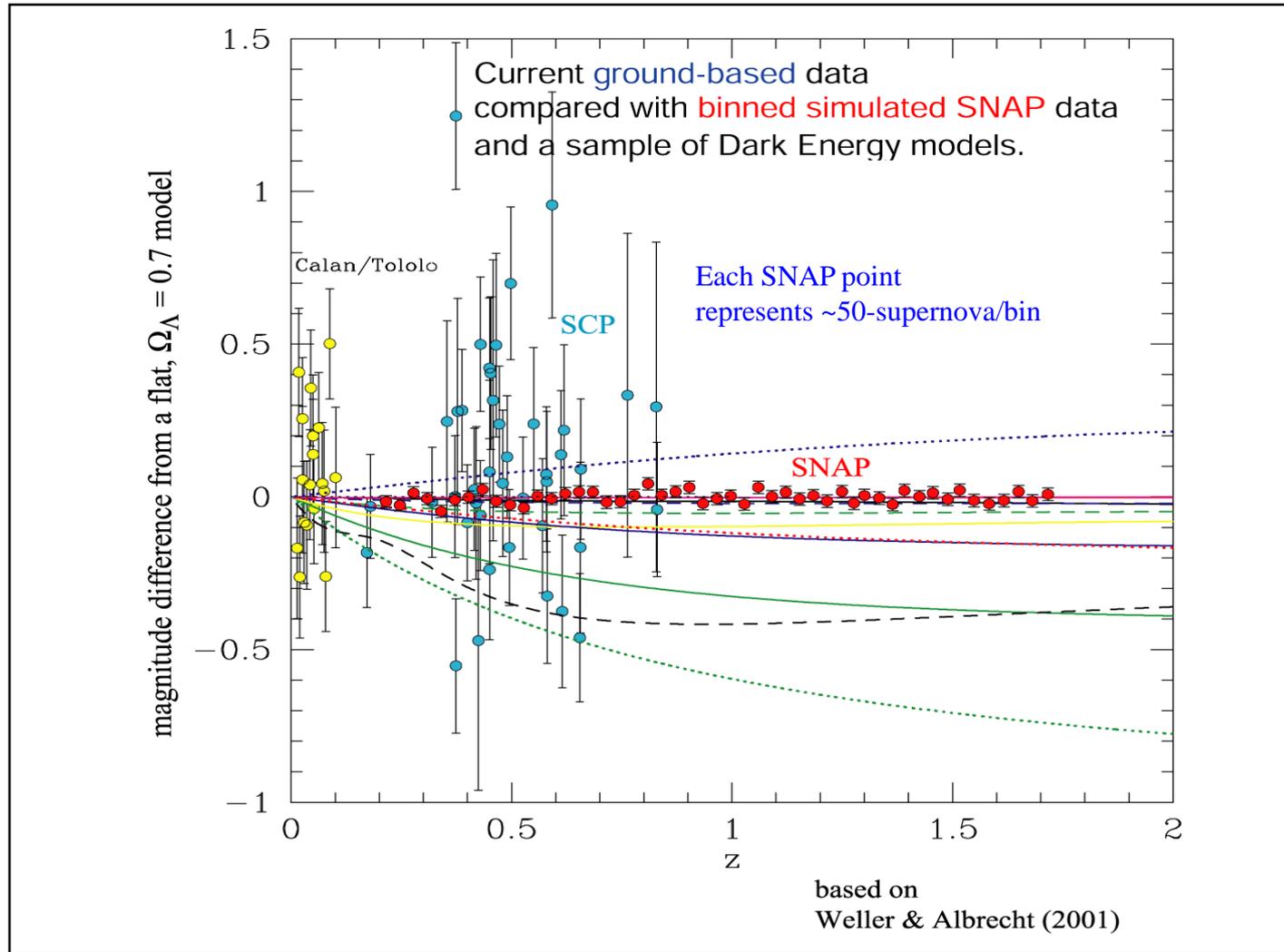
# Fermilab In SNAP

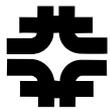
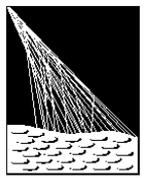
- 17 Fermilab scientists
  - ~3 FTEs in 2008, but participation would grow if approved.
  - Simulations, survey planning
- Engineering and technical contributions
  - ~5 FTE engineers and technicians
  - CCD and Front End Electronics packaging and testing
    - Fermilab Silicon Detector facility
    - Similar to DES camera work
  - Focal plane assembly (?)
  - Data management electronics (SLICE)
    - mass memory
  - Calibration
  - Data management
    - Store and serve data, analysis pipelines
    - As we do now for SDSS





# SNAP Sensitivity





# The Auger Collaboration

PIERRE  
AUGER  
OBSERVATORY

67 institutions

369 collaborators

Argentina

Netherlands

Australia

Poland

Bolivia\*

Portugal

Brazil

Slovenia

Czech Republic

Spain

France

United Kingdom

Germany

USA

Italy

Vietnam\*

Mexico

Project goal is to solve the high energy cosmic ray mystery:

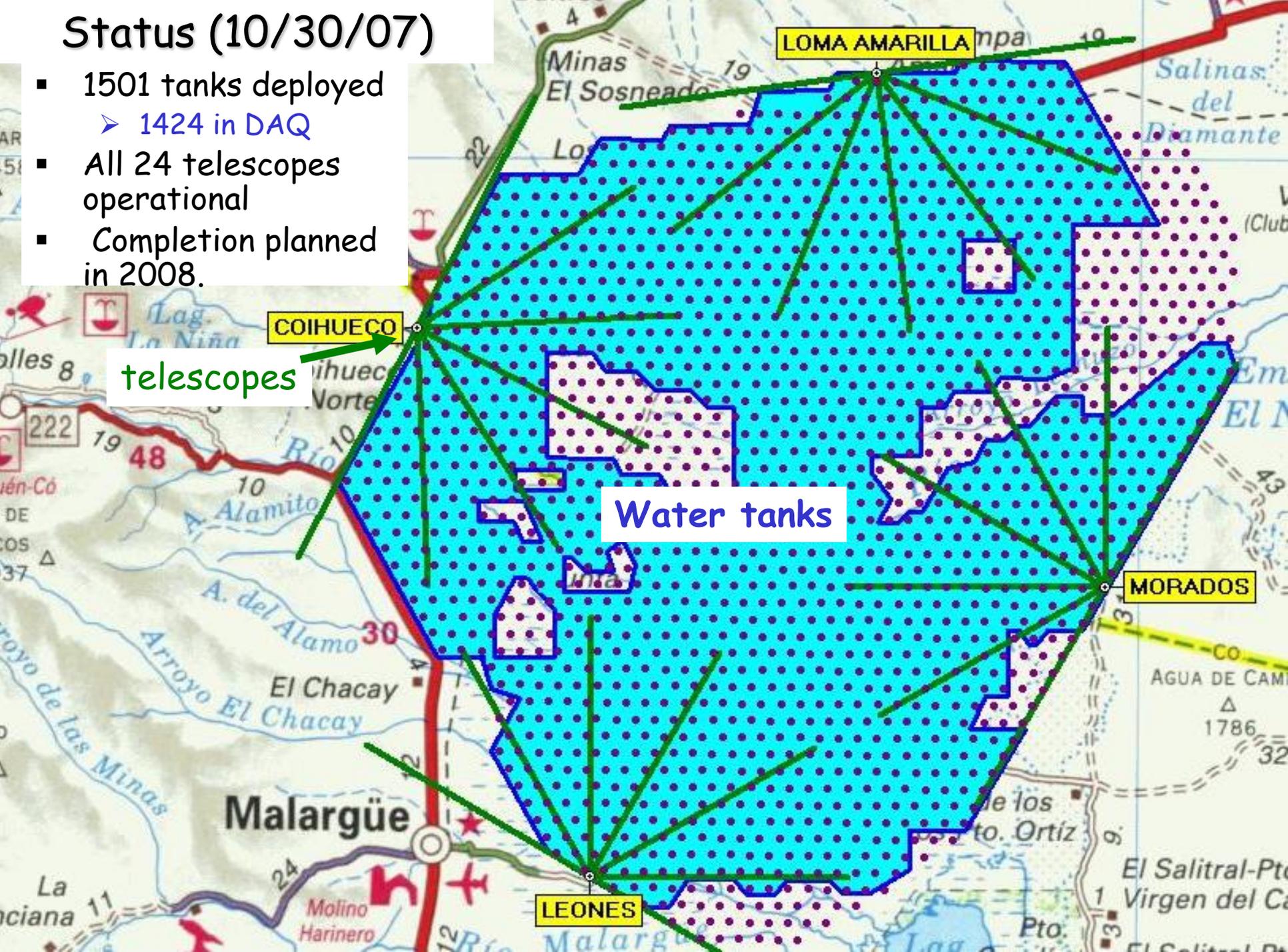
"Simply stated, we don't know what they are, where they came from, or how they got here from there."

*(Science, 9 Nov., 2007)*



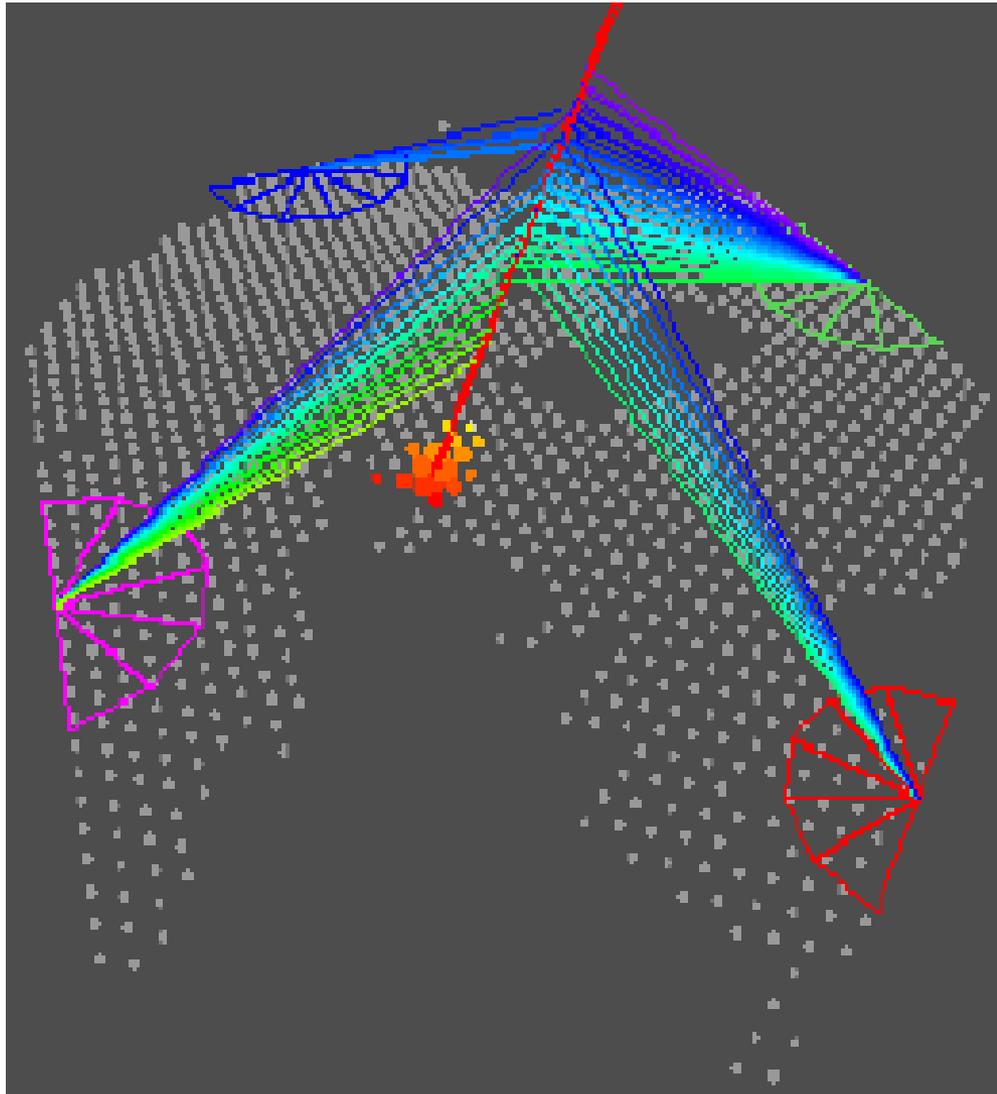
# Status (10/30/07)

- 1501 tanks deployed
  - 1424 in DAQ
- All 24 telescopes operational
- Completion planned in 2008.

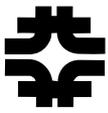




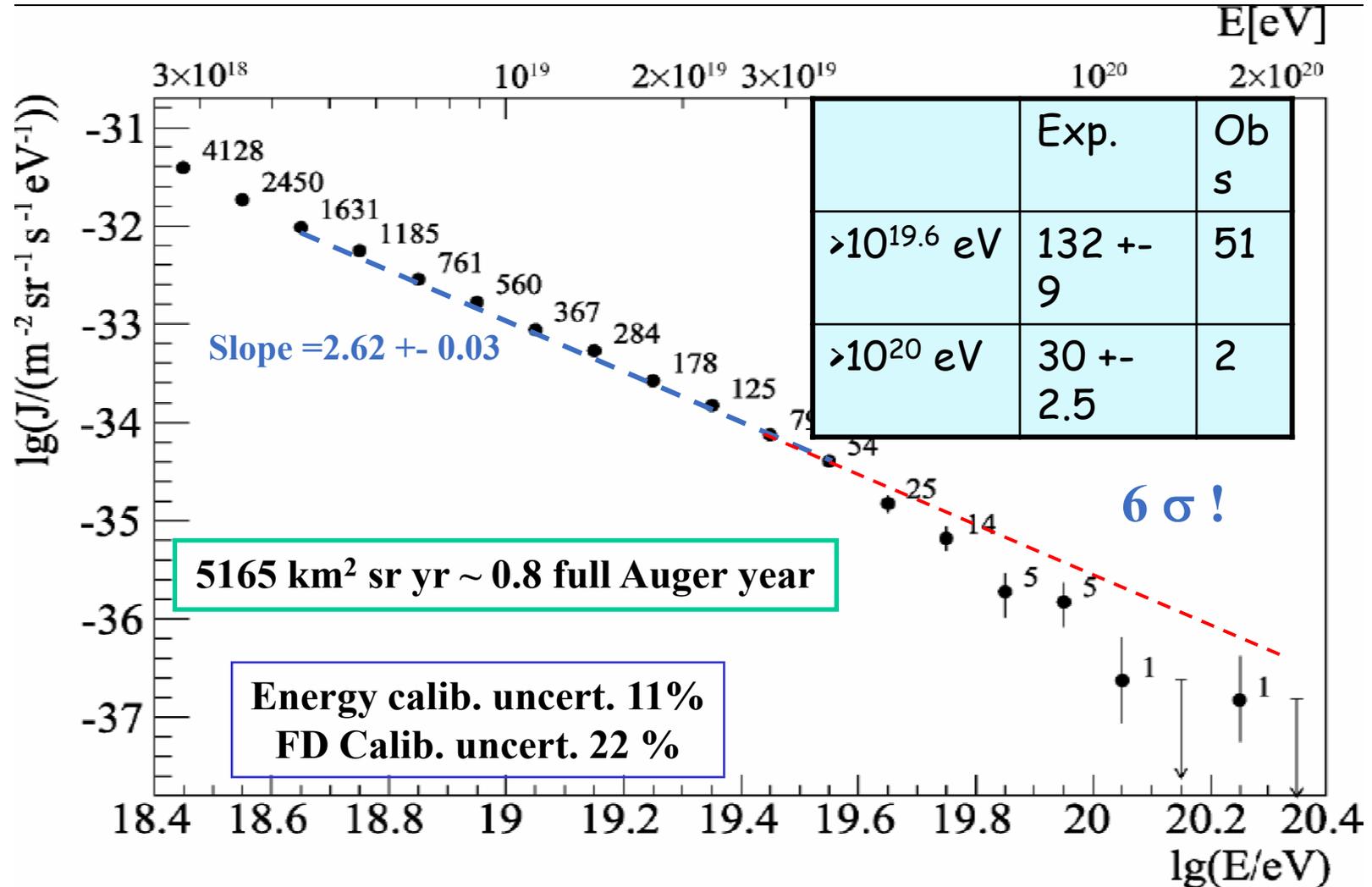
# A Hybrid Event



- Taken May 20 2007
- Seen in all four fluorescence telescopes.
- 18 tanks hit.
- Reconstructed Energy  $\sim 10$  EeV

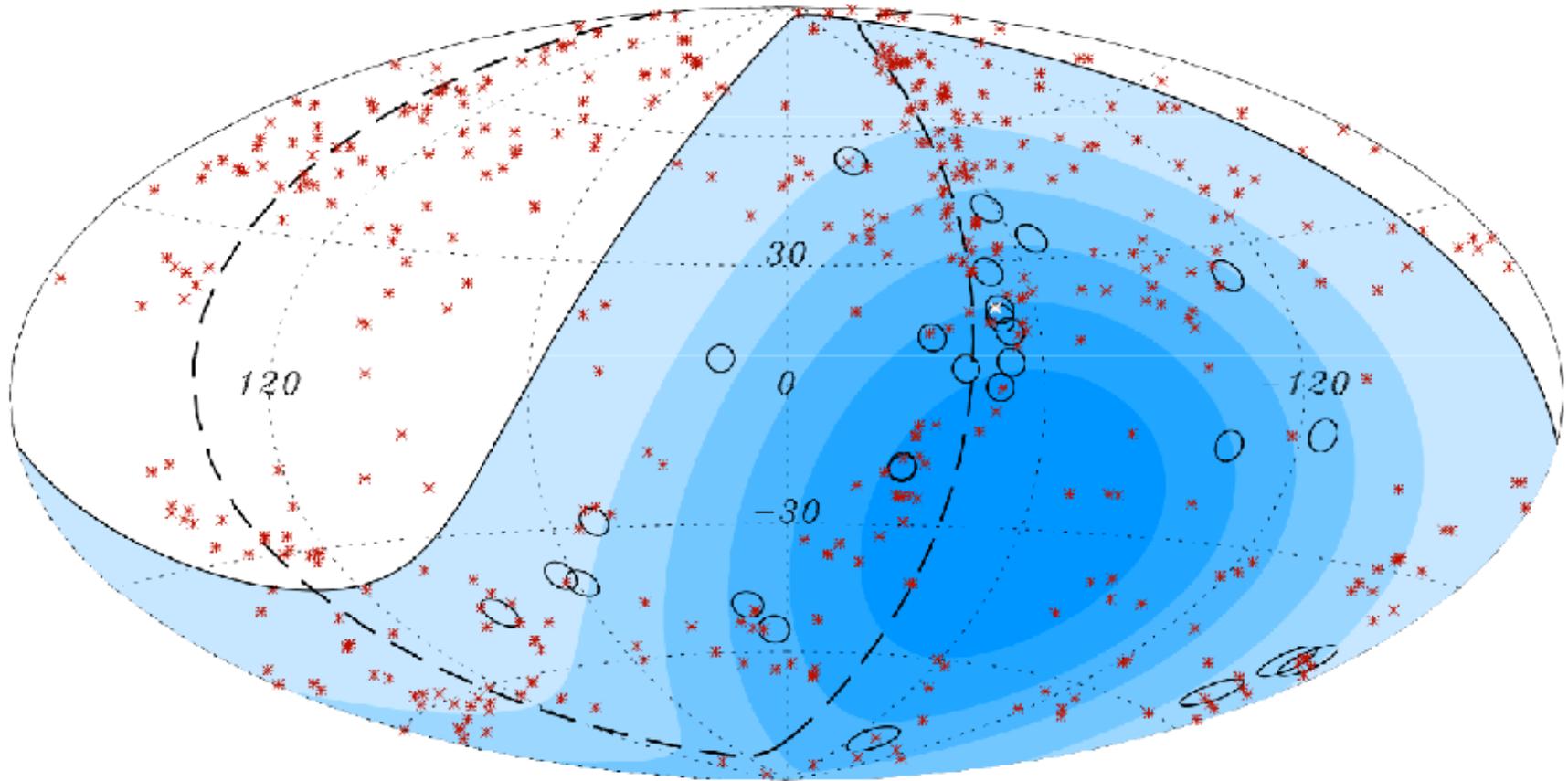


# Energy Spectrum from SD, $\theta < 60^\circ$





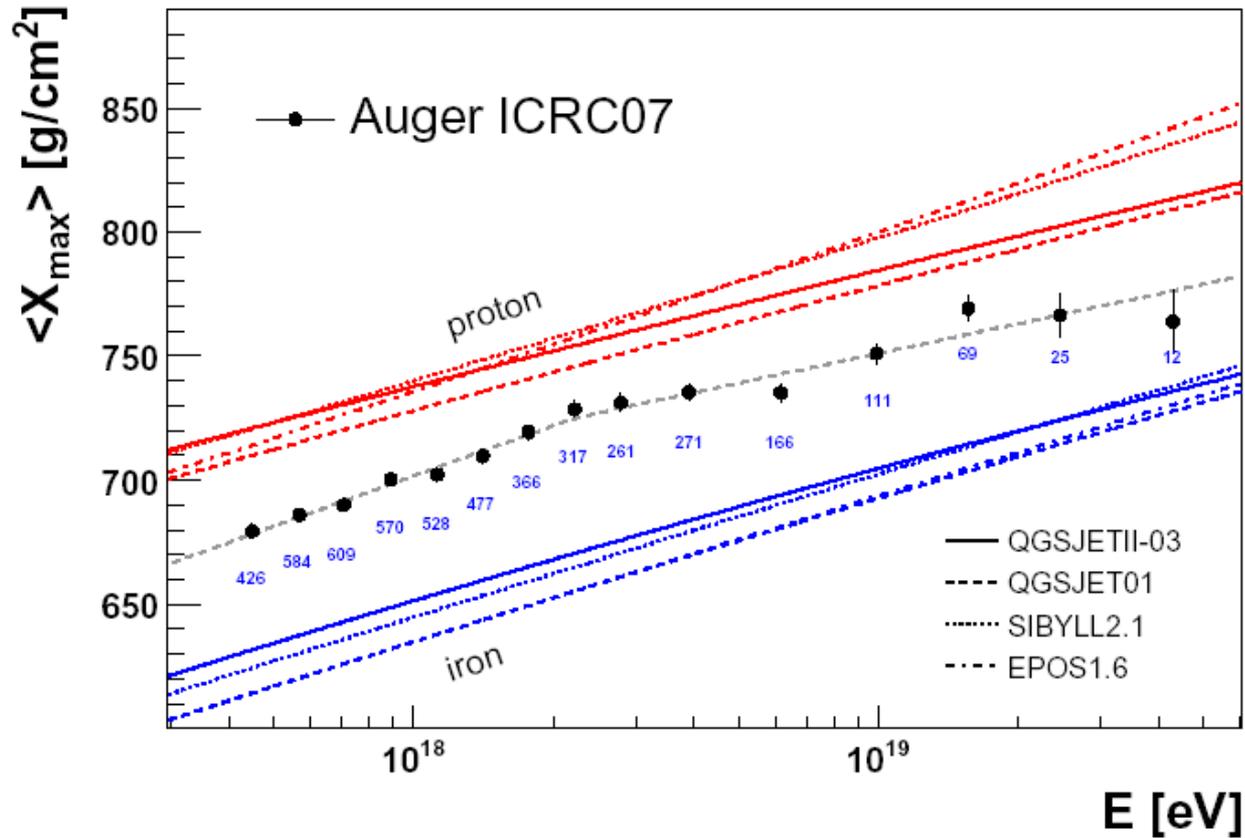
# Sky Map (Galactic coordinates)



3.1° circles: UHECR directions. Red asterisks: AGN within 75 Mpc.  
Blue: equal-exposure regions. Dashed Line: superGalactic plane.  
Solid Line: edge of Auger acceptance.



# Composition



**Suggests (unexpected) mixed composition at high energy  
OR problem with the interaction models.**



# Fermilab Responsibilities

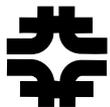
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- Paul Mantsch is the Auger Project Manager.
  - Management is crucial for a project of this complexity and scale.
  - Fermilab staff is contributing to internal Auger reviews
- Expertise in mechanical engineering
- Provide some computing resources ( Databases, data repository)
- Analysis of data
  - Composition
  - Anisotropy study (AGN, Galactic Center, Galactic Plane..)



## Auger North R&D

- The Auger collaboration proposed to survey the entire sky. (The best sources might not be visible from a Southern location)
- A site, Eastern Colorado, has been selected.
- In light of recent Auger result, re-design of the detector is wise:
  - Towards higher energy, where the AGN correlation is seen.
  - Larger exposure
    - -> larger distance between tanks
- R&D is needed:
  - Climate: Colder, water will freeze during the winter.
  - Communication: No tower, only tank to tank and tank to commercially available communication center (fibers) .
  - Improvement in electronics, opportunity to go to lower consumption.
- Engineering array (21 tanks) to be installed this summer.



# CDMS Collaboration



DOE Laboratory  
Fermilab  
LBNL

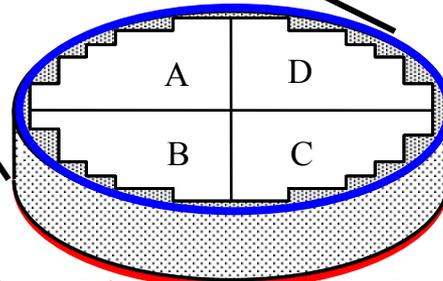
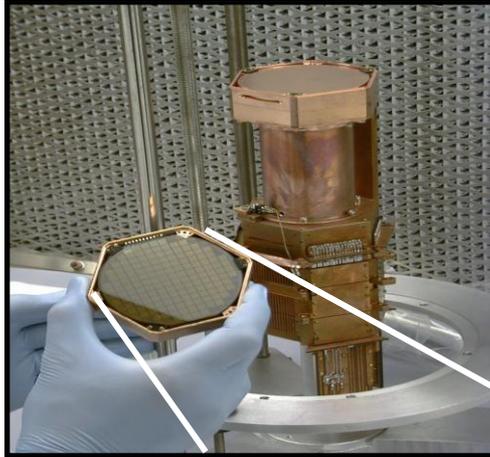
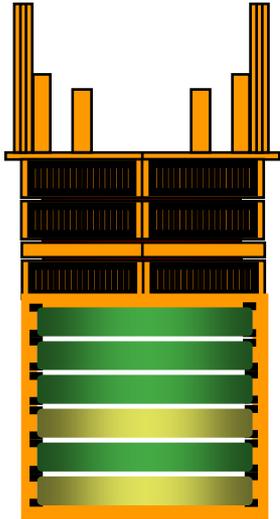
DOE University  
Brown  
CalTech  
Florida  
Minnesota  
MIT  
Stanford  
UC Santa Barbara

NSF  
Case Western Reserve  
Colorado (Denver)  
Santa Clara  
UC Berkeley

Canada  
Queens



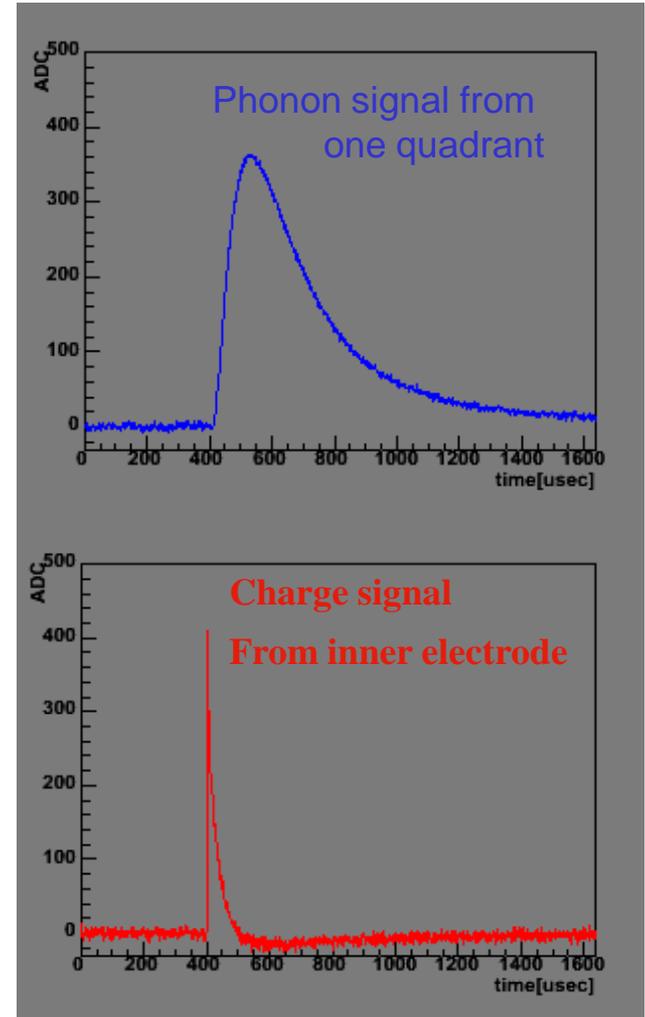
# CDMS-II Detectors

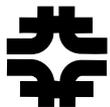


Direct detection of WIMP signal  
Nuclei recoil by elastic scattering  
Read both **phonon** signal (4 channels) and **ionization** signal  
(inner and outer electrode)

1cm thick, 7.8 cm diameter

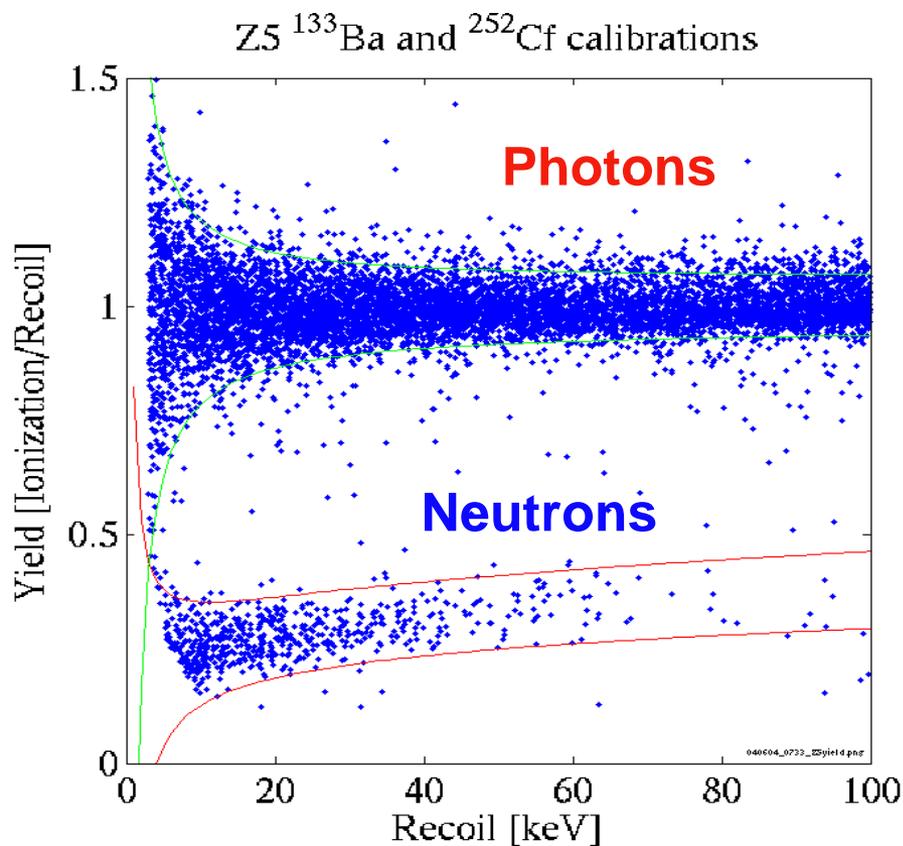
250g Germanium, 100g Silicon

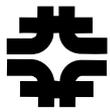




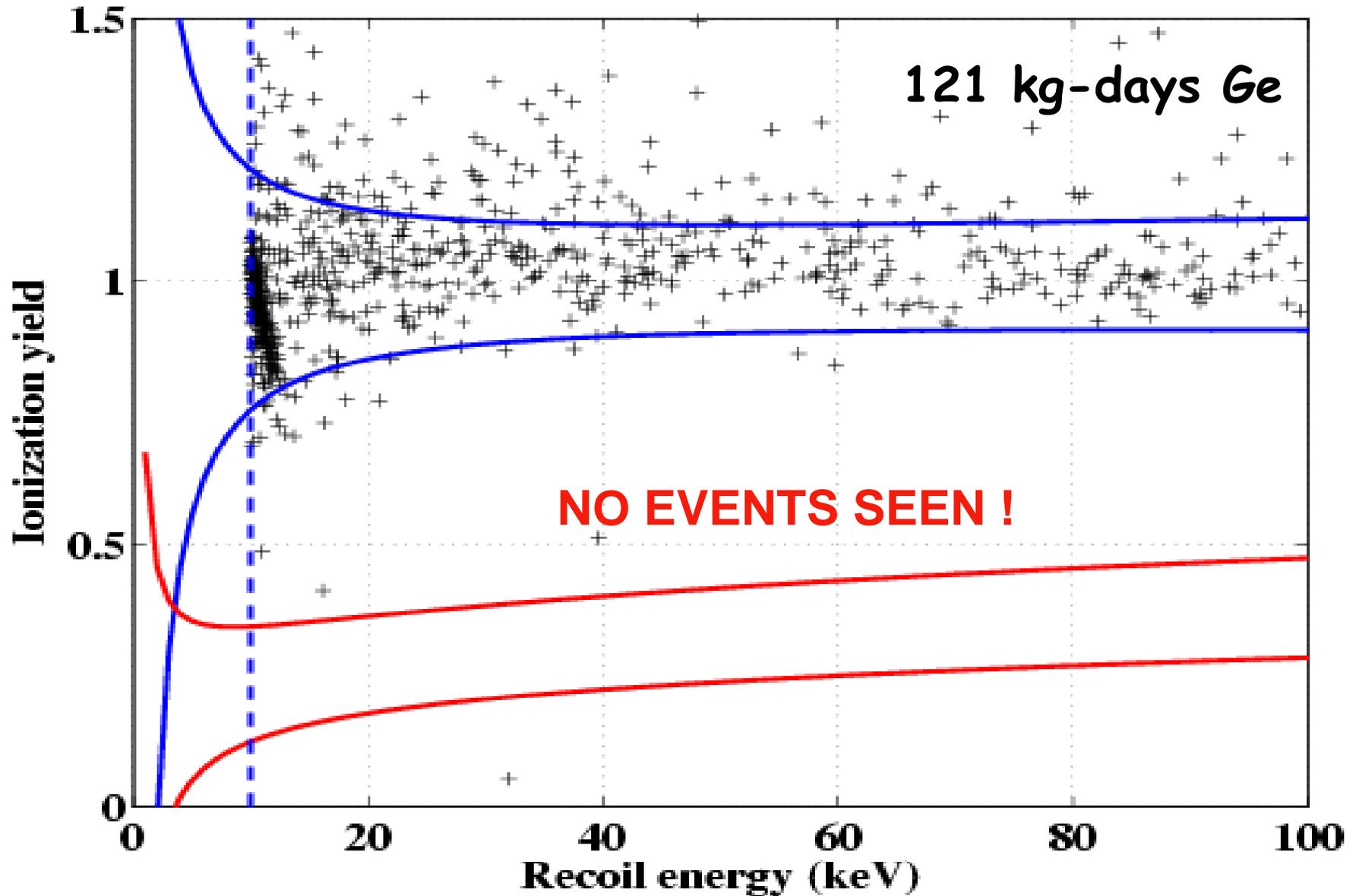
# CDMS Background Discrimination: gammas

$$\text{Yield} = E(\text{ionization}) / E(\text{recoil})$$



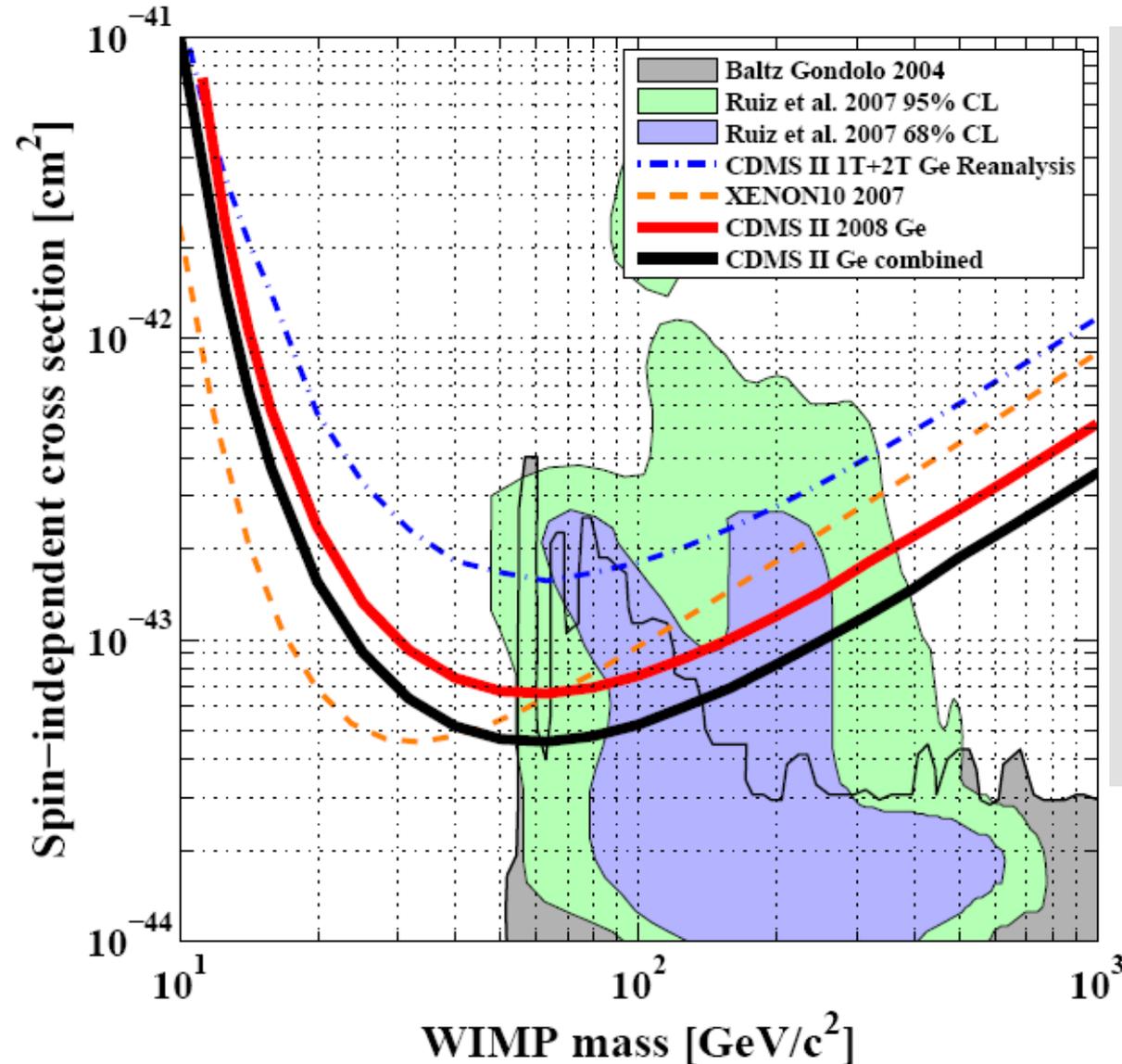


# New CDMS-II Results (Feb. 2008)





# New CDMS-II Results (Feb. 2008)



**Total Livetime (15 Ge detector)**

**397.8 kg-day**

**Effective Exposure (after cuts)**

**121.3 kg-day**

**Zero-Background !**

**Null-Observation !**

**This Results (@60GeV)**

**$\sigma = 6.6 \times 10^{-44} \text{cm}^2$  (90%CL)**

**CDMS Combined (@60GeV)**

**$\sigma = \square 4.6 \times 10^{-44} \text{cm}^2$  (90%CL)**



## Proposed Extension: SuperCDMS 25 kg

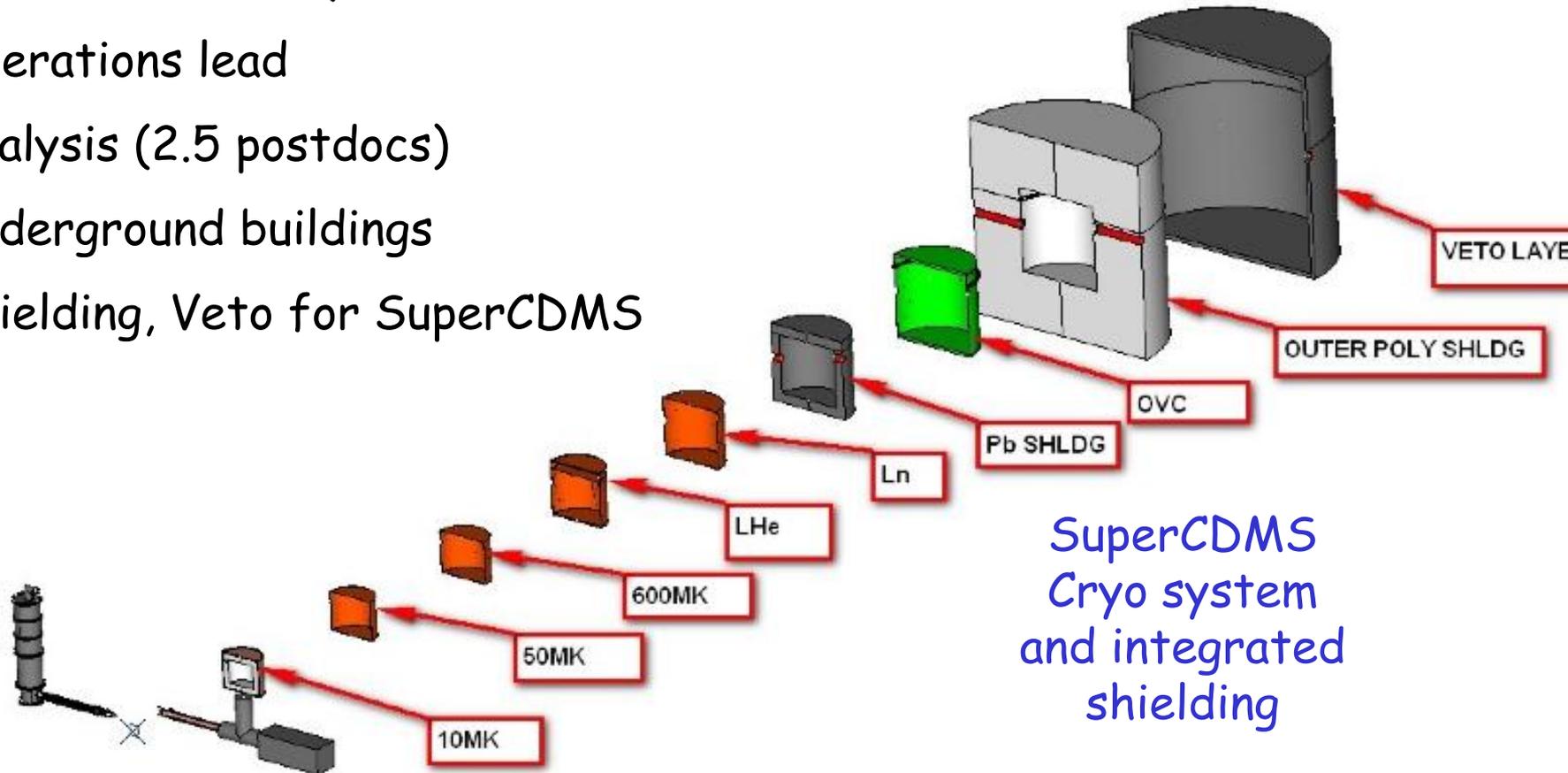
- Proposed 25-kg experiment based on updated 42 x 600-g Ge ZIPs
  - 120x beyond current limits
  - 15x beyond CDMS-II goal
  - Next step towards ton-scale goal
- Detector fabrication and characterization underway
  - Detectors have 3x fiducial volume of CDMS-II design.
  - Cost per  $\text{m}^3$  kg reduced to  $\sim 1/3$ .
- New cryosystem.
- New electronics.
- Deeper site (SNOLab)





# Fermilab Responsibilities CDMS & SuperCDMS

- Project management (Dan Bauer)
- Cryosystem
- Electronics/ DAQ
- Operations lead
- Analysis (2.5 postdocs)
- Underground buildings
- Shielding, Veto for SuperCDMS





## SuperCDMS Status

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- The SuperCDMS project has CDO approval and Stage-I approval from the Fermilab director and PAC.
  - NSF and DOE have funded 2 "SuperTowers" (SuperCDMS detector arrays) for deployment at Soudan.
  - No decision yet to fund long lead time items for SNOlab deployment (e.g. cryosystem, shielding) or remaining 5 detector towers. Intent is to make this decision in 2009.
  - Meanwhile, collaboration continues to run 5 CDMS-II towers in Soudan, while working on the SuperTowers.
-

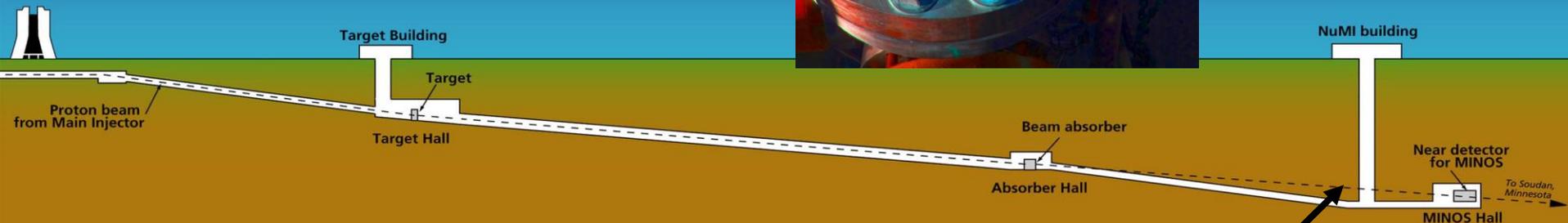
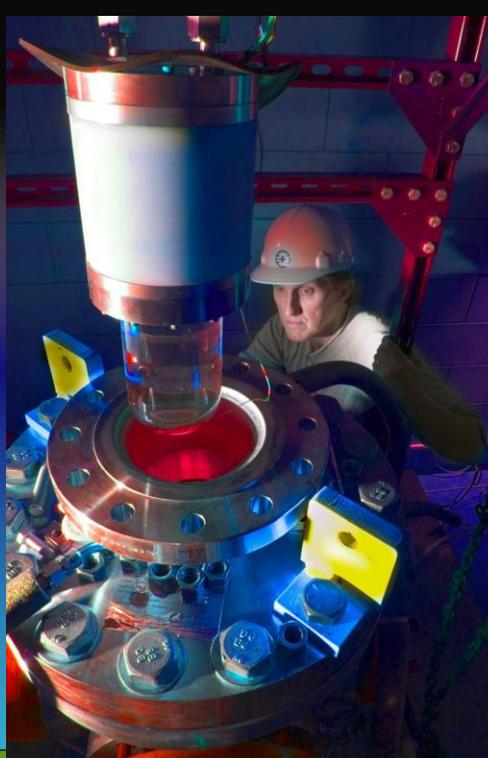
# COUPP

University of Chicago

Indiana University, South Bend

Fermilab

1 liter  
Bubble Chamber  
In NuMI tunnel

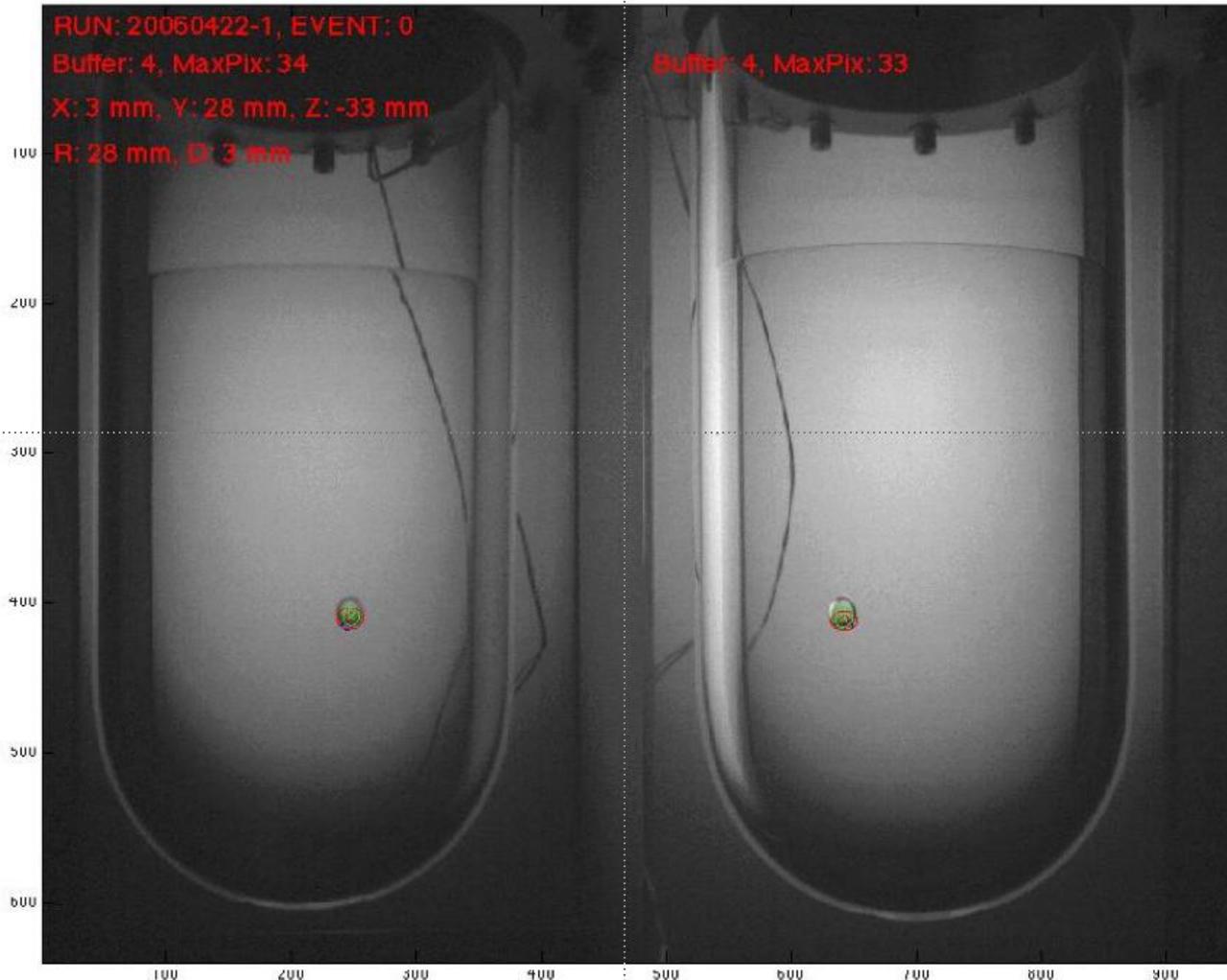


test site  
~300 m.w.e.



# 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.

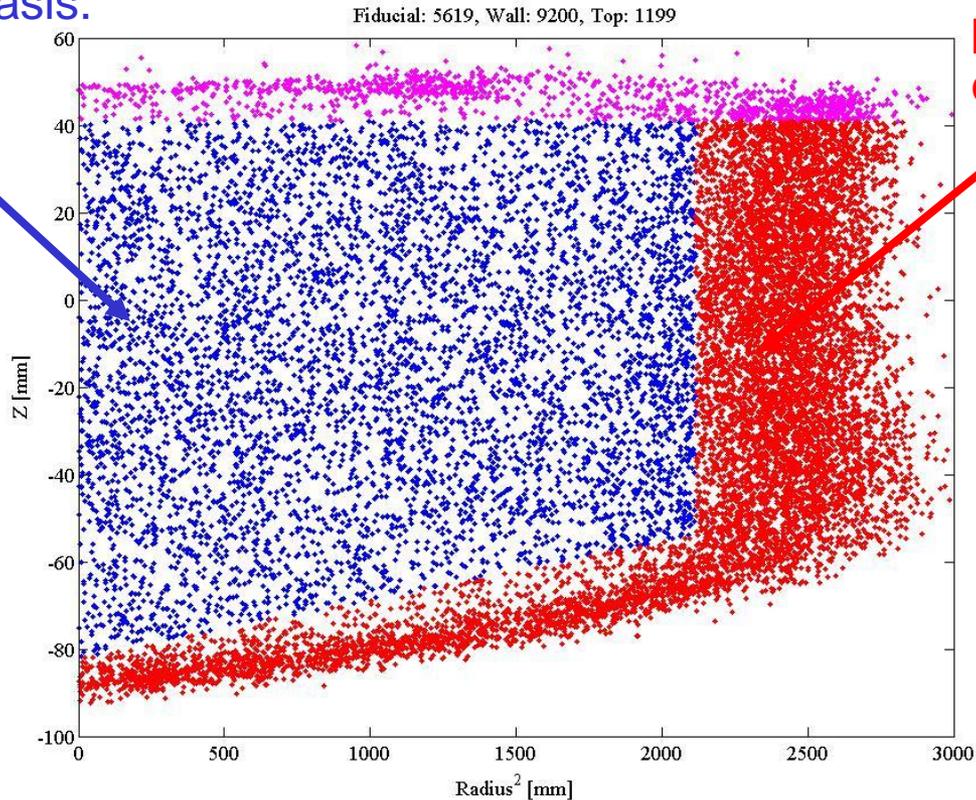
Bubble positions are measured in three dimensions from stereo camera views



# COUPP Alpha Backgrounds

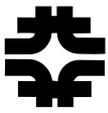
Bulk events from dissolved alpha emitters: indistinguishable from WIMP interactions on an event-by-event basis.

~ 20- 100 events/day



Wall Events: not a background, but they **reduce our live time** due to the need to compress afterwards, prohibitive for larger chambers.

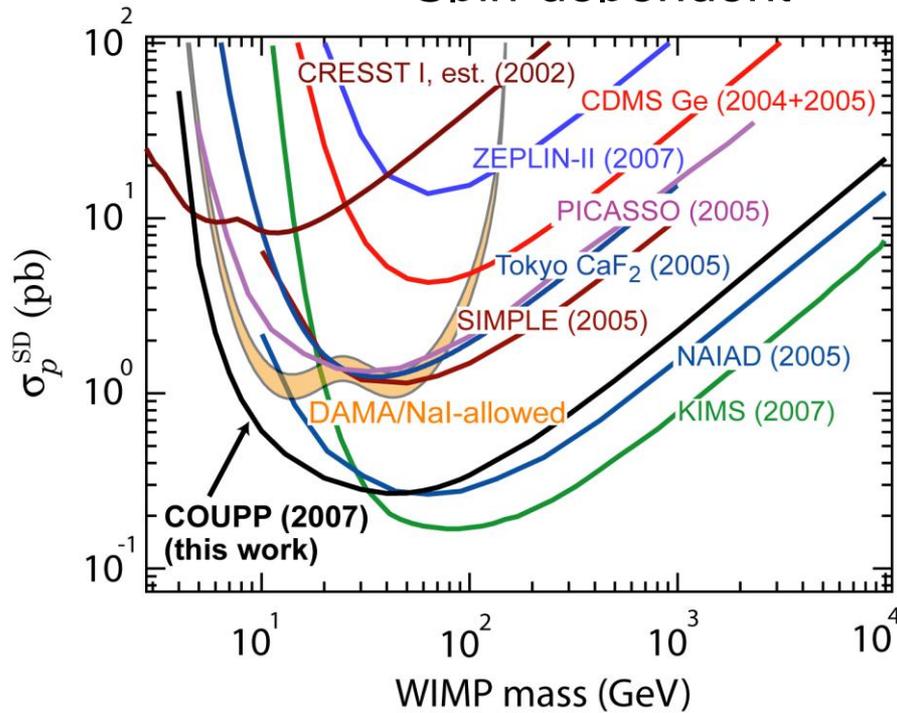
~ 300/day



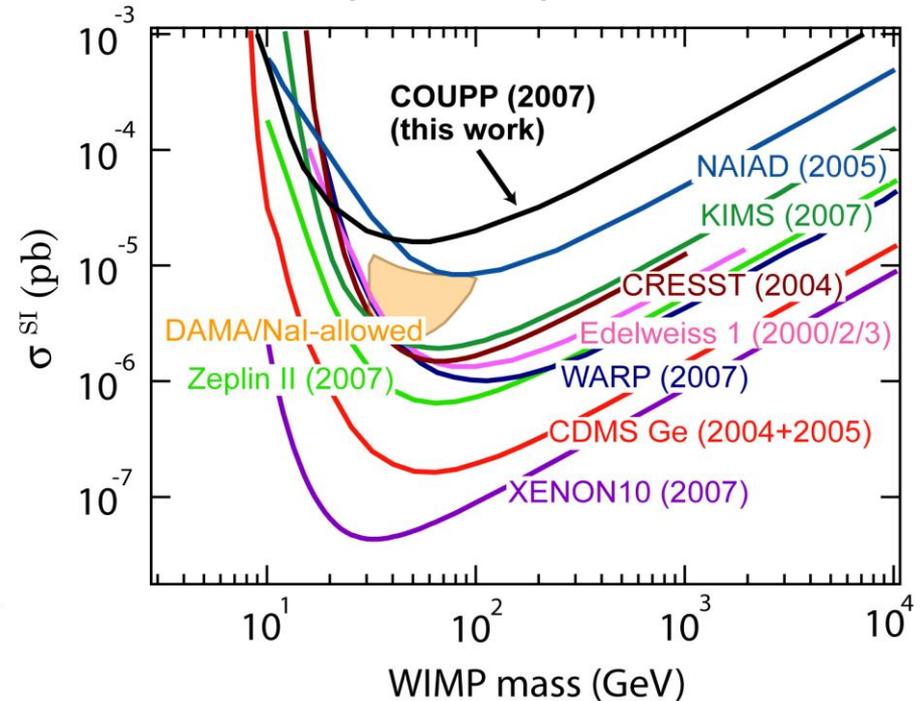
# COUPP: First Results

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

### Spin-dependent



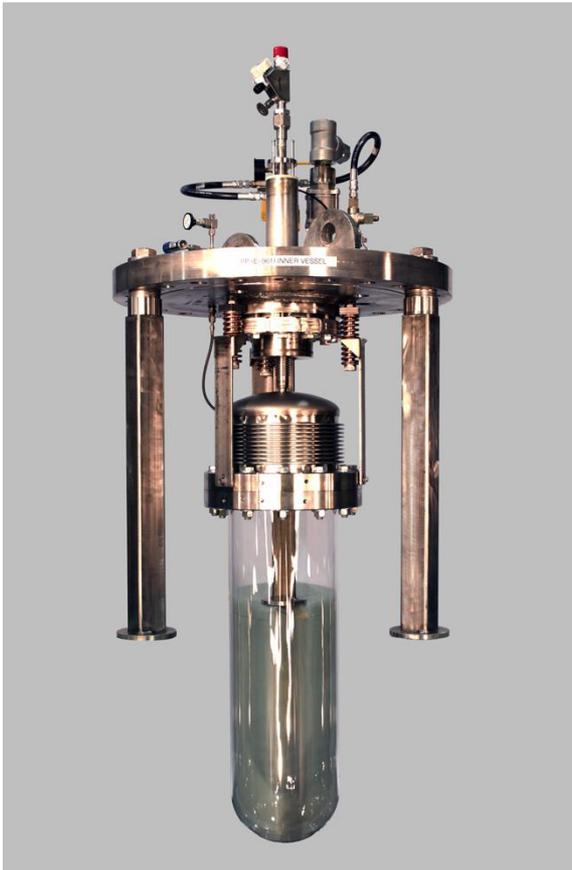
### Spin-independent

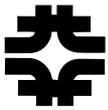




# COUPP 30 Liter Chamber

- Designed and built at Fermilab.
- Will run at NuMI in Fall.





## COUPP Status

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- Improved 1 liter (2 kg) device continues running at NuMI
    - Significant improvement in sensitivity, due to smaller alpha backgrounds.
    - Starting to see limitations of shallow NuMI site, where many events are cosmic-ray induced.
  - Larger devices will be commissioned soon.
    - Running first at shallow local sites seems prudent.
      - Will unexpected backgrounds or operational problems appear?
    - Soudan underground lab is next easiest option due to existing infrastructure, personnel for Minos and CDMS.
      - We want to be ready to move there when background studies indicate that it is necessary.
  - Lab management has encouraged us to think about 1 ton.
-



# The Future

- From FRA proposal:

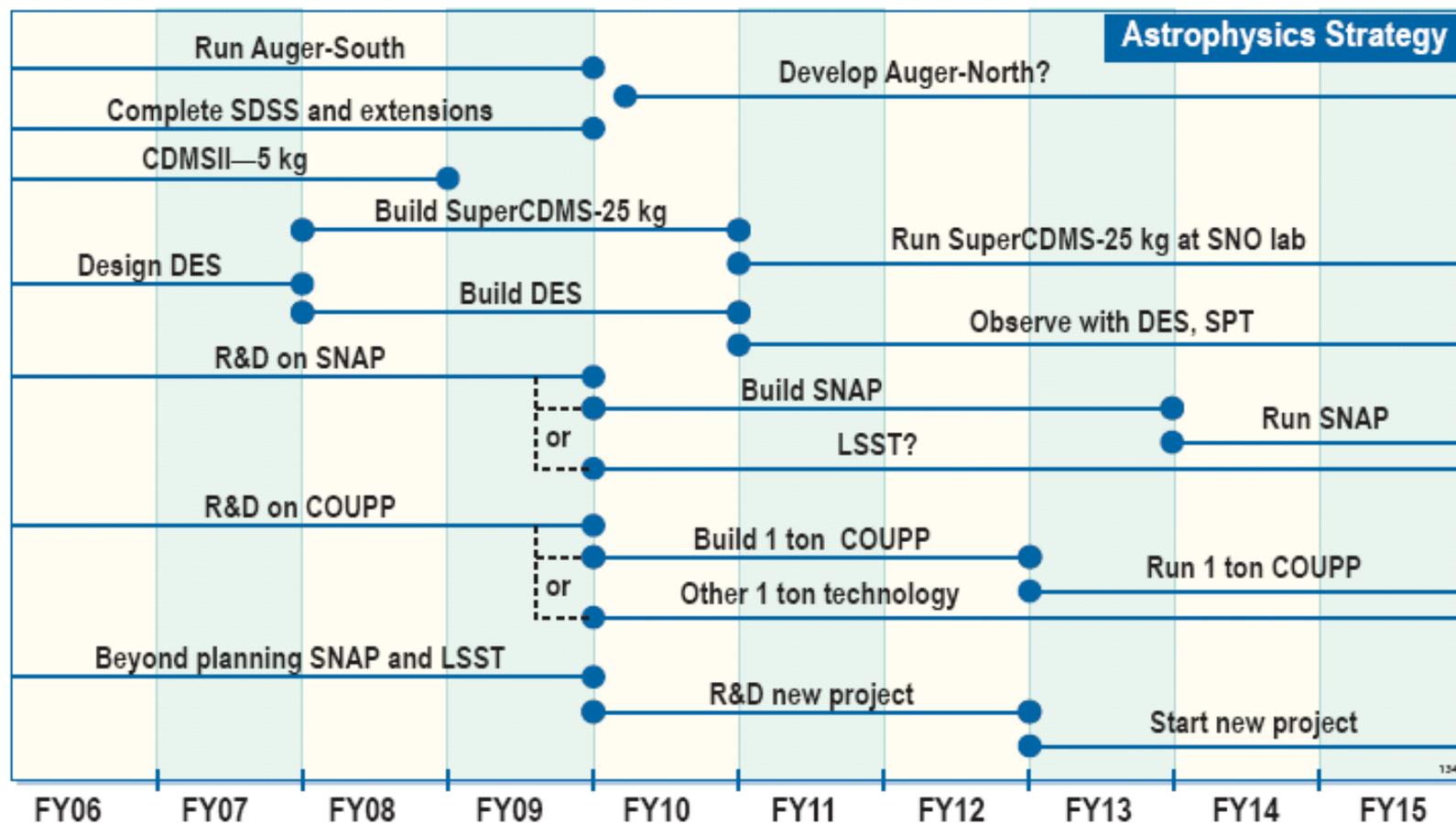


Figure 3.a-8. FRA's Timeline for the Exploration of the Astrophysics Strategy.



# Particle Astrophysics Planning Retreat

- George Williams College, Geneva, WI, Nov. 7-8, 2007.
- About 50 people attended.
- Goals
  - Educate ourselves about the science.
  - Understand how FNAL can contribute.
  - Initiate collaborations
  - Understand time pressures, competition.

Wed., Nov. 7:

-----  
9:00-9:45 Goals of the Retreat  
9:45-10:15 Coffee break  
10:15-11:15 UHECR: Beyond Auger South  
11:15-11:45 Gravity waves: beyond LIGO  
11:45-12:15 Discussion  
12:15-1:30 Lunch  
1:30-2:30 Computational Astrophysics  
2:30-3:30 21 cm observations  
3:30-4:00 Break  
4:00-5:00 CMB  
5:00-6:00 Direct dark matter detection

Thurs., Nov. 8

-----  
9:00-10:00 Optical cosmology  
10:00-10:30 Near-infrared observations  
10:30-11:00 Break  
11:00-12:00 Indirect Dark matter detection  
12:00-12:30 Discussion  
12:30-2:00 Lunch  
2:00-2:30 Underground  
laboratory/experiments  
2:30-3:00 Discussion  
3:00-4:00 Recap/lessons/next steps



# Possibilities We Discussed

## ▪ 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 interesting?
- 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?



# Forward Motion

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- We wrote a report summarizing possibilities in each science area.
  - No serious attempt to prioritize yet (awaiting new director), but some small R&D efforts have started:
    - Cosmic Microwave Background
      - Collaboration with U. Chicago on QUIET (1 scientist)
      - NASA grant to host CMBpol workshops
    - 21 Cm Cosmology
      - R&D on baryon acoustic oscillation measurement at  $z=0.5 - 2$
      - Weekly meetings of RF electronics experts and theorists.
      - Applied for grant from DOE (dark energy solicitation)
    - Liquid argon dark matter
      - Applied for DOE DUSEL R&D grant to study argon purity.
      - SUSEL (Homestake) LOI with Princeton and Temple U.
    - Cosmological Computing (Albert Stebbins talk)
-



# Conclusion

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- Some exciting new 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, grav. lensing, BAO...
    - GammeV search for axion-like particles.
  - Engineering/ construction is proceeding:
    - DES camera
    - COUPP 60 kg
    - SuperCDMS
    - Auger North engineering array
  - Early stage R&D:
    - 21 cm BAO measurement
    - Argon dark matter
    - CMB polarization
    - Cosmological computing
-