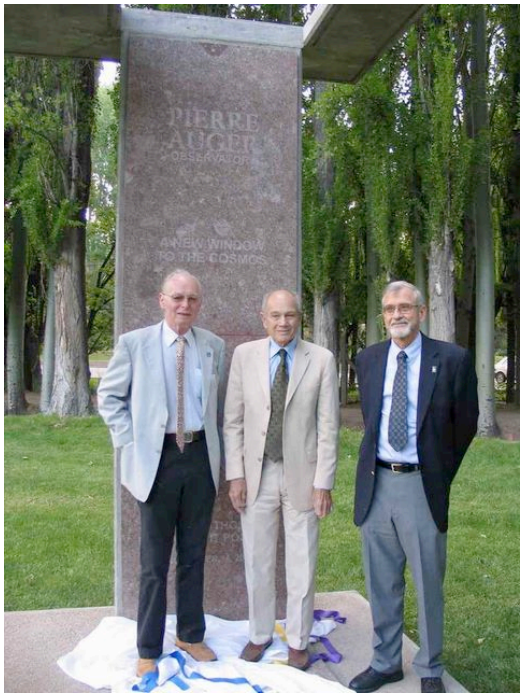
Ongoing FCPA experiments

Aaron S. Chou
Wilson Fellow, FNAL
Fermilab PAC meeting, March 6, 2009

- Auger
- GammeV
- CDMS
- COUPP

Completion of the Pierre Auger Observatory, the world's largest cosmic ray detector (1600 water Cherenkov detectors covering 3000 km^2) Inauguration Nov. 14-15, 2008



17 Countries
67 Institutions
>400 Collaborators

Fermilab Role

- Paul Mantsch is project manager.
- Two postdocs

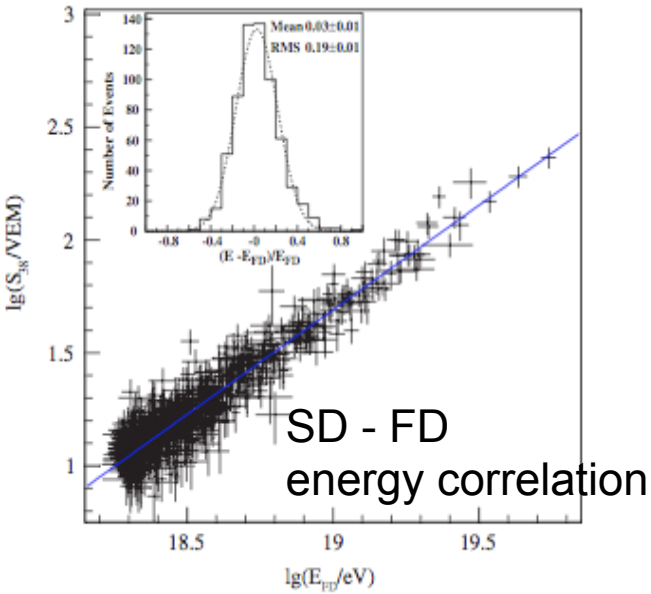
  Eun-Joo Ahn

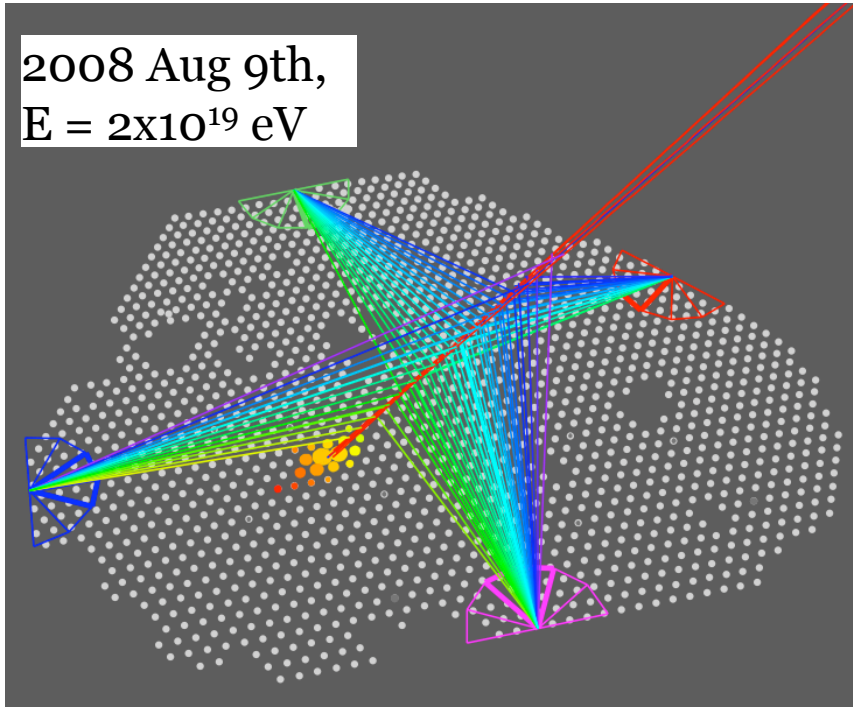
  Fred Kuhn
- Sabbatical visitor (Albuquerque)
- 5 scientists (~4 FTEs)
- Wilson Fellow (Aaron Chou)

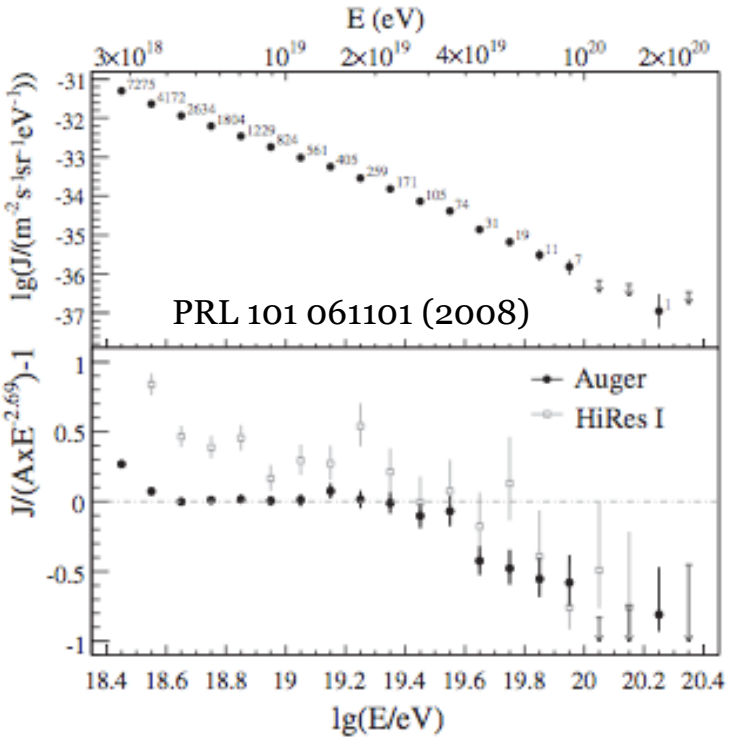
Responsibilities:

- Project Management
- Data Analysis
- Surface Detector Design & Construction
- Data Mirror
- Planning for Auger North

Hybrid detector

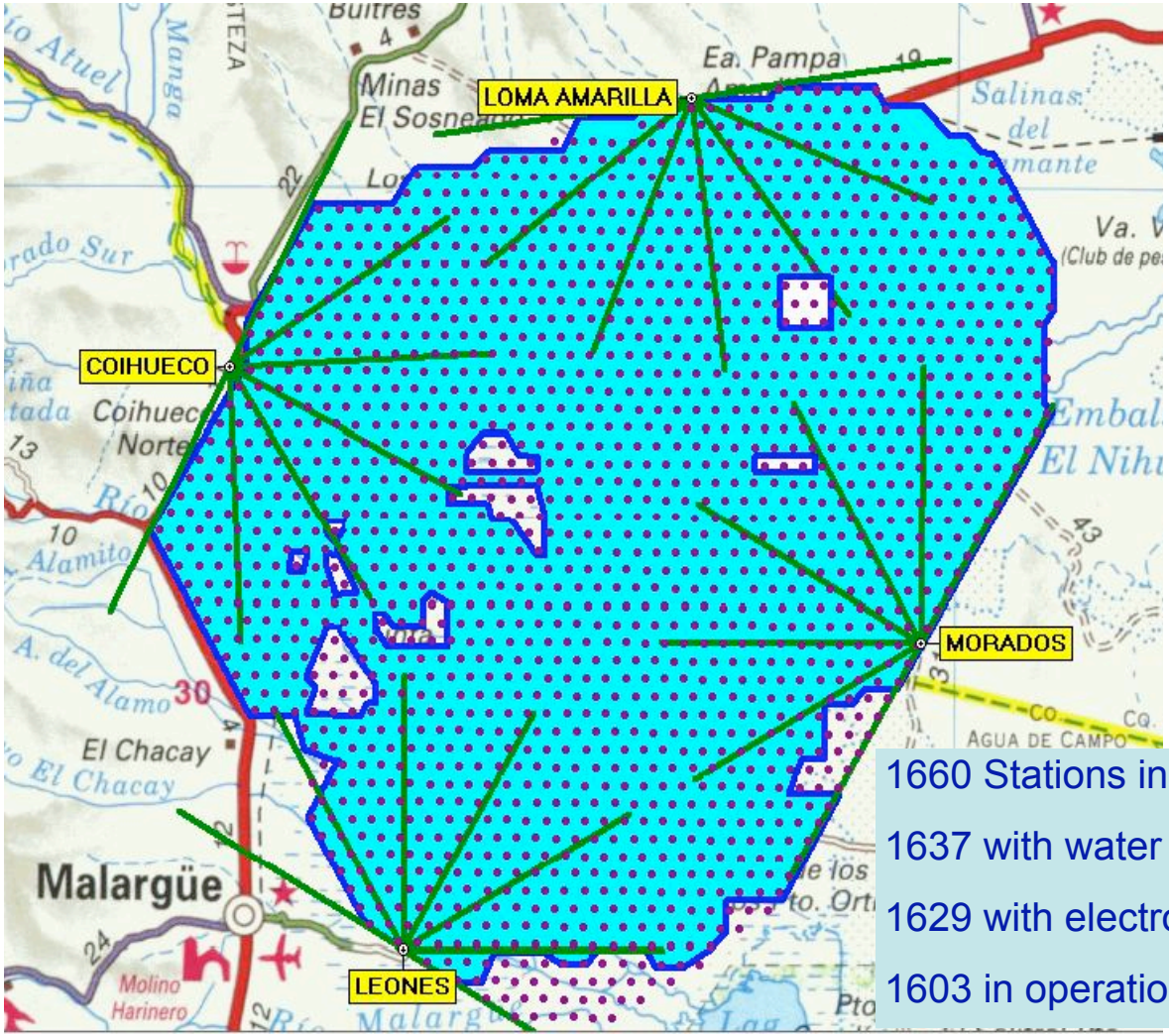






The calibrated energy spectrum clearly shows a GZK-like spectral feature.

Detector layout



1660 Stations in the Field

1637 with water

1629 with electronics

1603 in operation

Exposure as of Dec 2008: ~13000 km² sr yr = 2 full Auger-years.
Data Rate: Surface detector ~1600/day, Golden Hybrid ~50/night
Livetime: Surface detector ~97%, Fluorescence detector ~15%.

PAO Science

Pierre Auger Observatory
studying the universe's highest energy particles

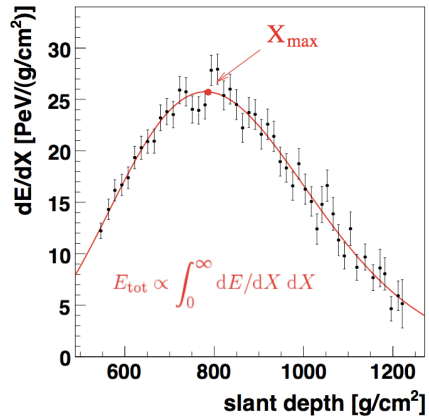
- UHECR spectrum
  - GZK effect
  - Physics of the ankle
- UHECR Composition
  - Proton, Iron, Neutrino, Photon, Exotics
  - FD/Hybrid/SD
- Magnetic fields
  - Multiplets
  - Smooth Vs Stochastic
- Search for Anisotropy
  - Associating sources classes
  - Intrinsic anisotropies
  - Point Sources
- Atmospheric effects on performance
- Technical publications
  - Characterizing detector performance

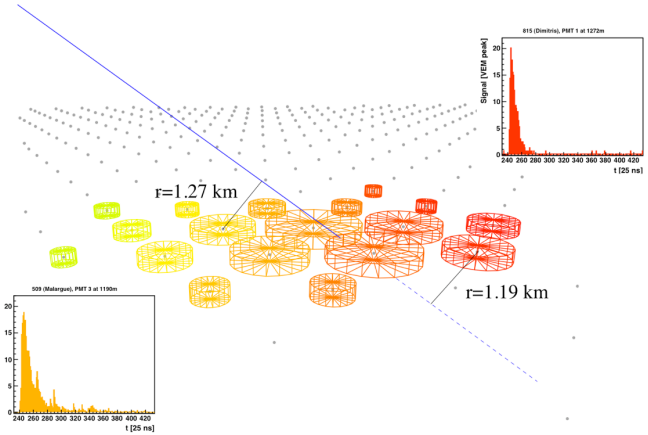
- **310 publications**
- **1100 internal notes**

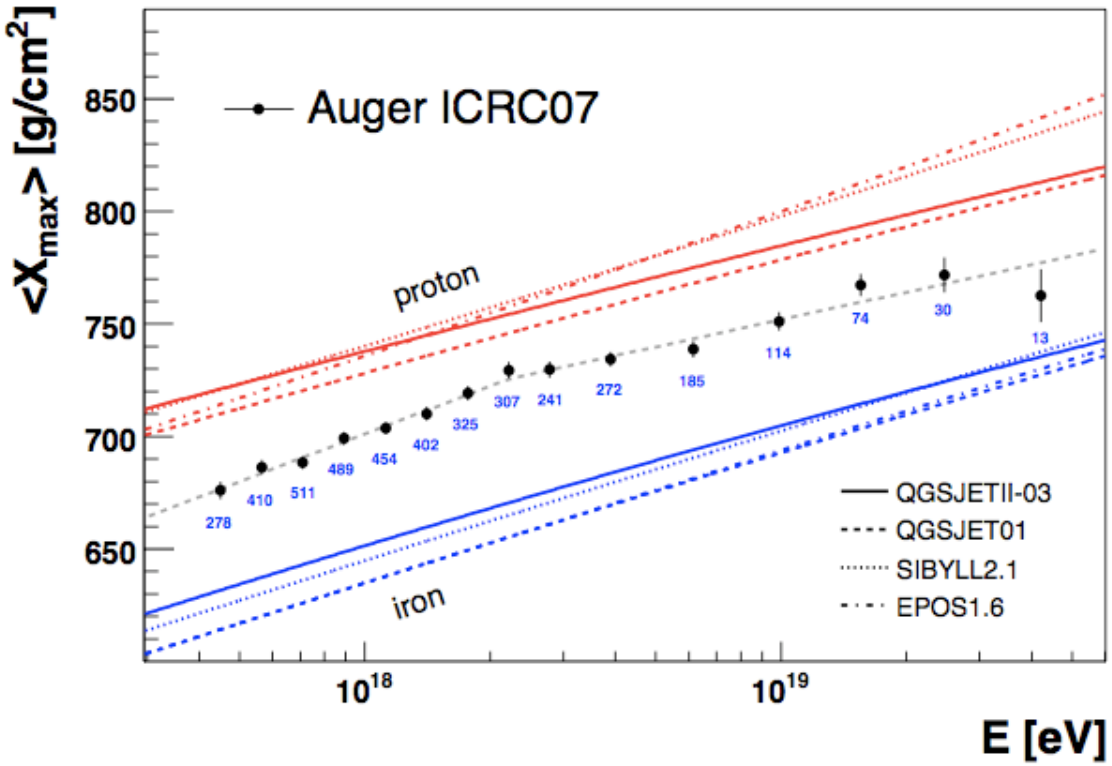
Auger Composition

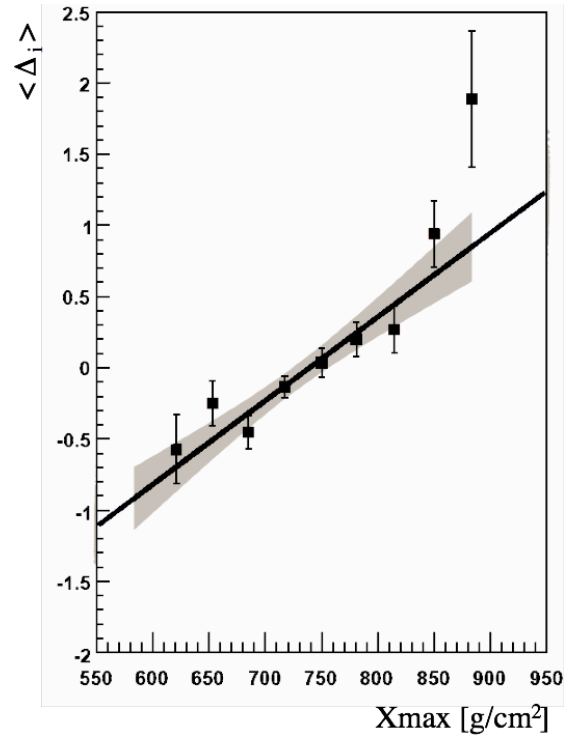
Two methods:

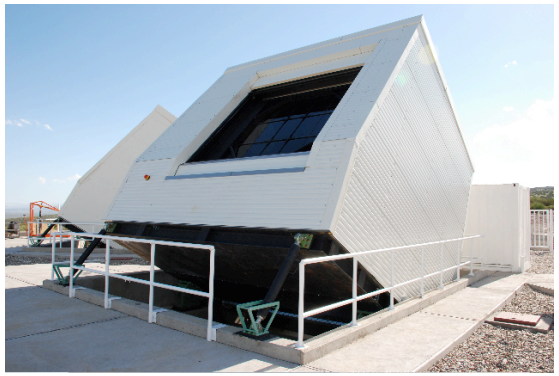
1. FD Xmax
2. SD risetime





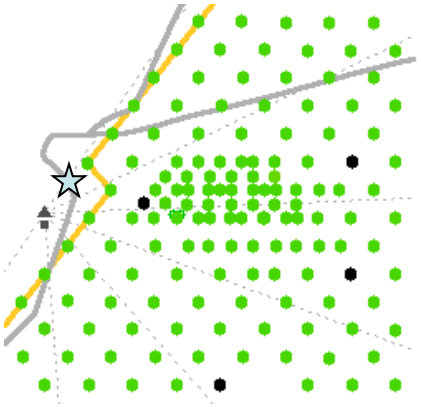






HEAT

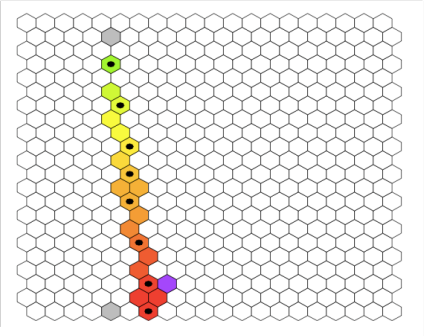
High Elevation Auger Telescope

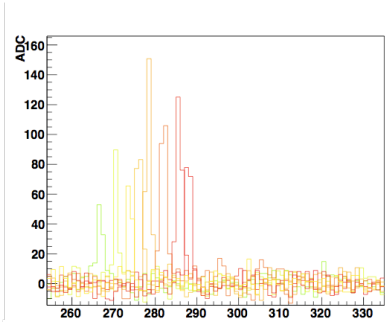


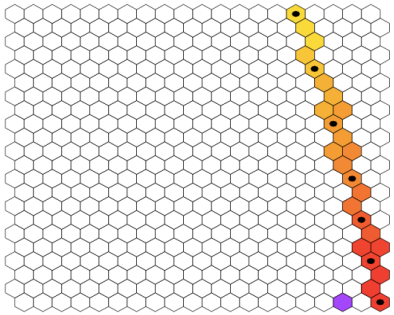
Overlooks small infill array

- Located on western Coihueco site
- First light: Jan 30, 2009
- 3 telescopes view 30° - 60°
- Can see lower energy (~10^{17} eV) cosmic ray showers which develop higher in the sky.

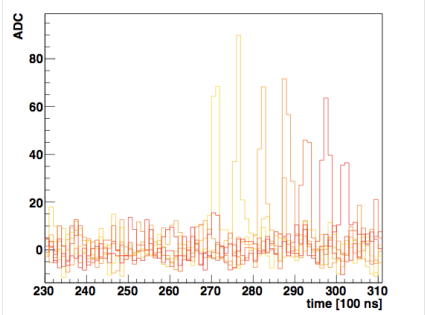
HEAT data





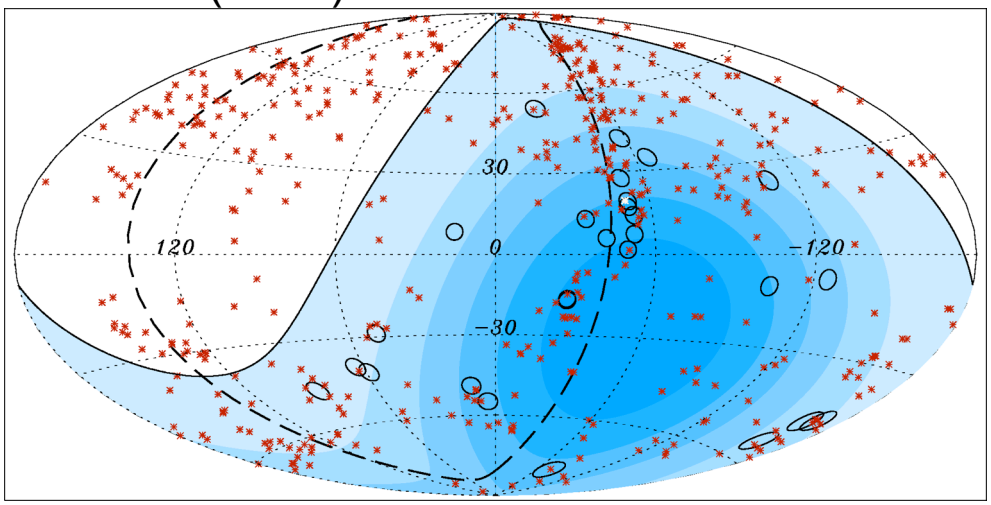


Coihueco data

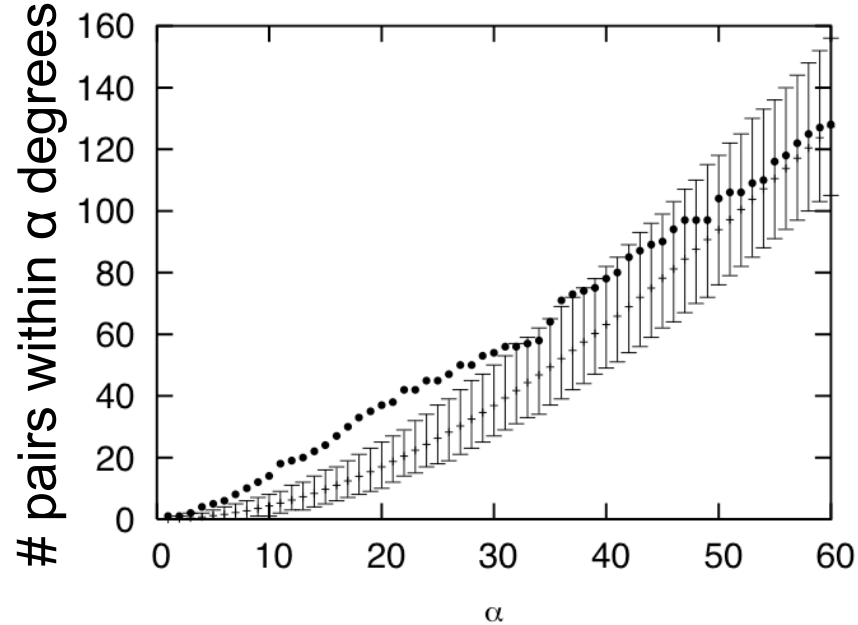


Anisotropy

Science (2007)



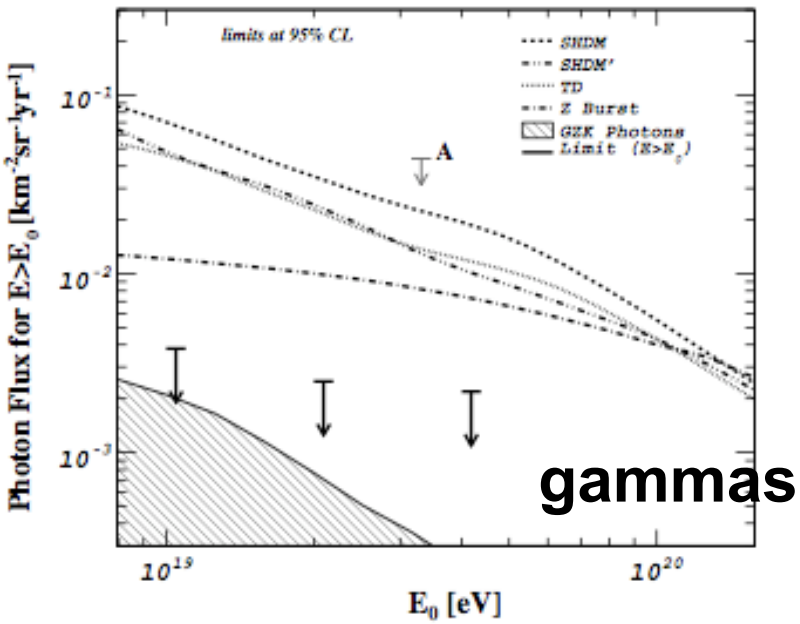
Correlation with nearby AGN.
Current event rate above 60 EeV
~1.5 per month

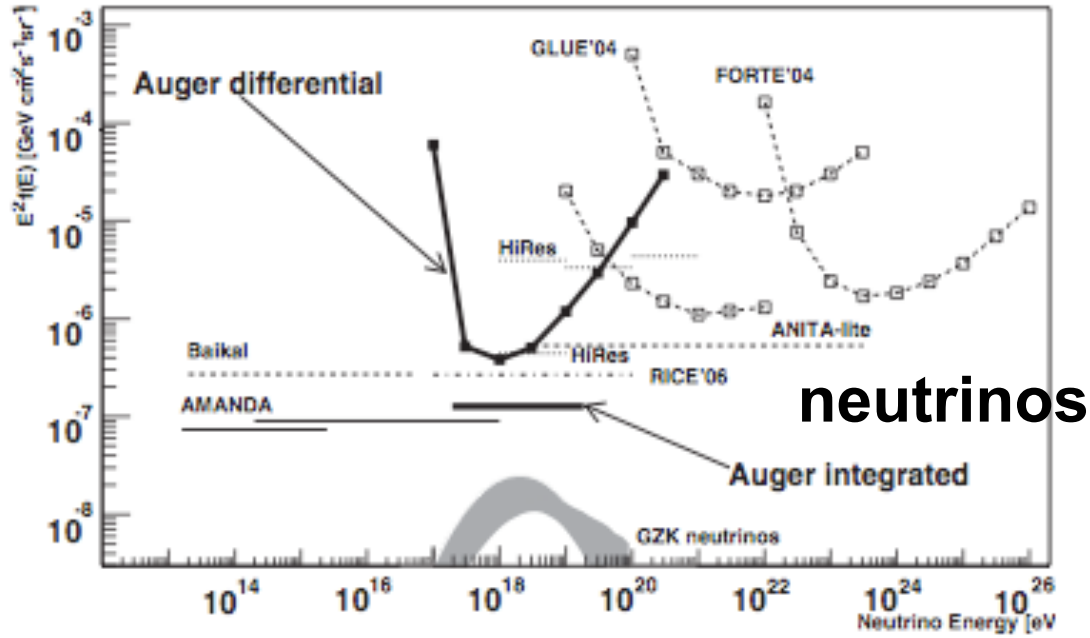


- Cumulative auto-correlation
- 27 highest E events

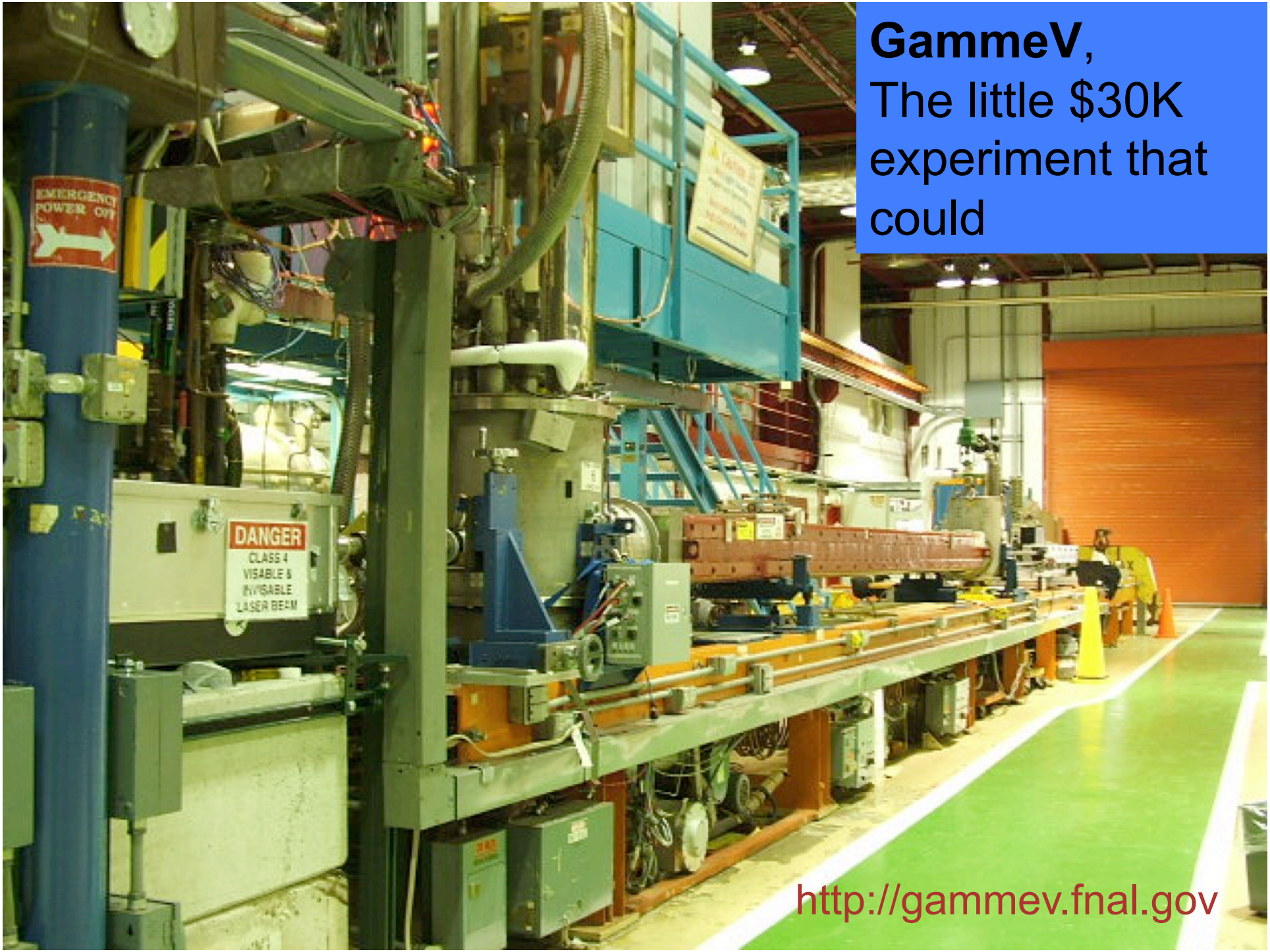
- Correlation with only nearby objects is evidence for a GZK horizon.
- Sources are extragalactic, and appear to be distributed along the large scale structure of matter.
- Multiplets suggest potential for **cosmic ray astronomy**, and measurements of the **galactic magnetic field**.

Eventual sensitivity to GZK daughters





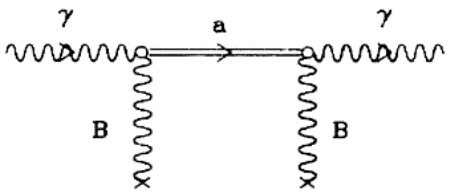
- Photons:
  - Photon candidates are identified via long risetime (deep showers).
  - Limits ‘top-down’ scenarios
    - Super Heavy dark matter annihilation/decay, topological defects, etc.
- Neutrino
  - Signal: horizontal electromagnetic-rich showers from nearby decay of Tau produced by in CC interactions of earth-skimming ν_τ. So far, background-free!
    - Over the lifetime of the observatory, we expect to either see the cosmogenic neutrinos, or improve the bound by an order of magnitude



GammeV,
The little $30K experiment that could

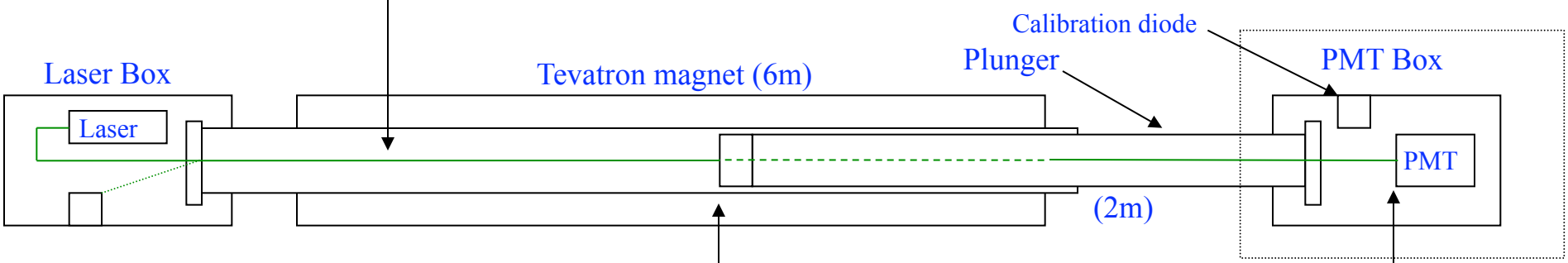
http://gammev.fnal.gov

Light shining 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.

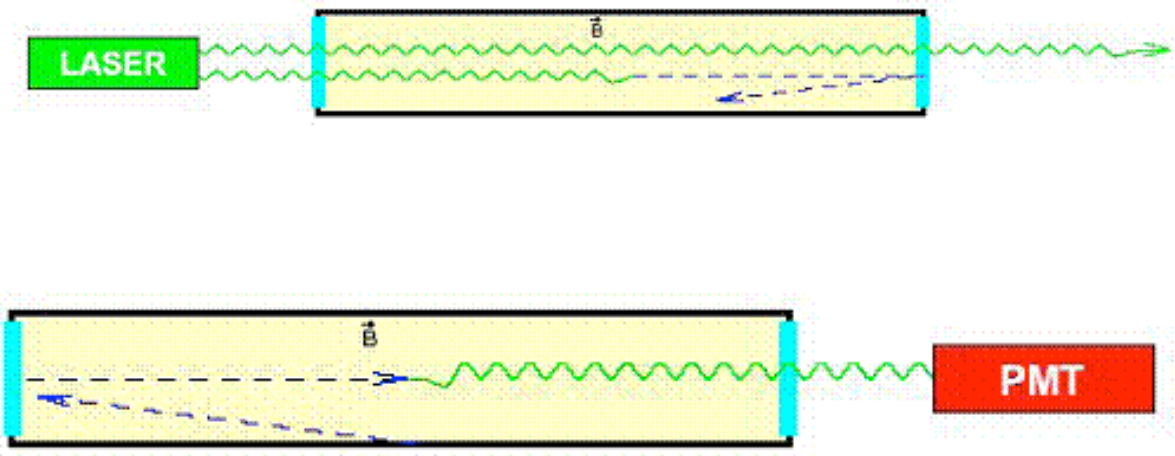


Laser pulses are blocked, axions go through

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

Particles trapped in a jar

Chameleon particles (related to quintessence, dark energy, f(R) gravity) are created via magnetically-induced oscillations. If they have strong matter effects, they will reflect from the exit window of the vacuum chamber while unconverted photons escape.



After turning off the laser, we look for an exponentially decaying afterglow as the trapped gas of chameleons convert back into photons.

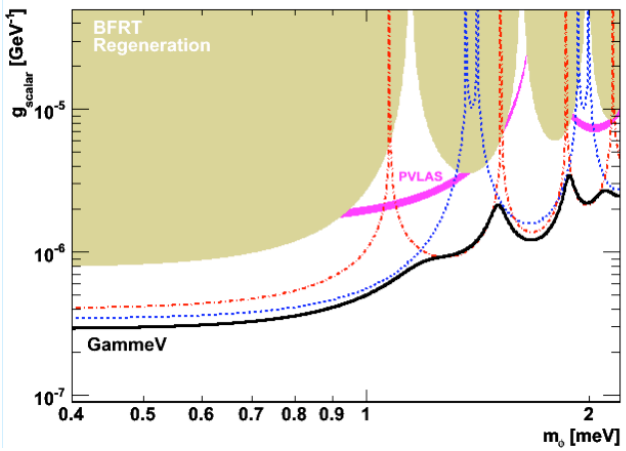
GammeV

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 photon-paraphoton coupling.

PRL **102,** 030402 (2009) PHYSICAL REVIEW LETTERS week ending 23 JANUARY 2009

Search for Chameleon Particles Using a Photon-Regeneration Technique

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[1]*Center for Cosmology and Particle Physics, New York University, 4 Washington Place, New York, New York 10003, USA*
[2]*Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510, USA*
[3]*Department of Physics, University of Michigan, 450 Church Street, Ann Arbor, Michigan 48109, USA*
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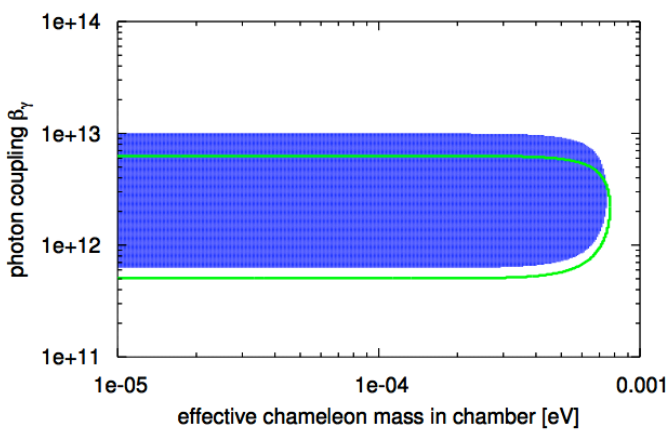
[6]*Cosmology and Gravity Group, University of Cape Town, Rondebosch, Private Bag, 7700 South Africa*
(Received 1 August 2008; published 22 January 2009)



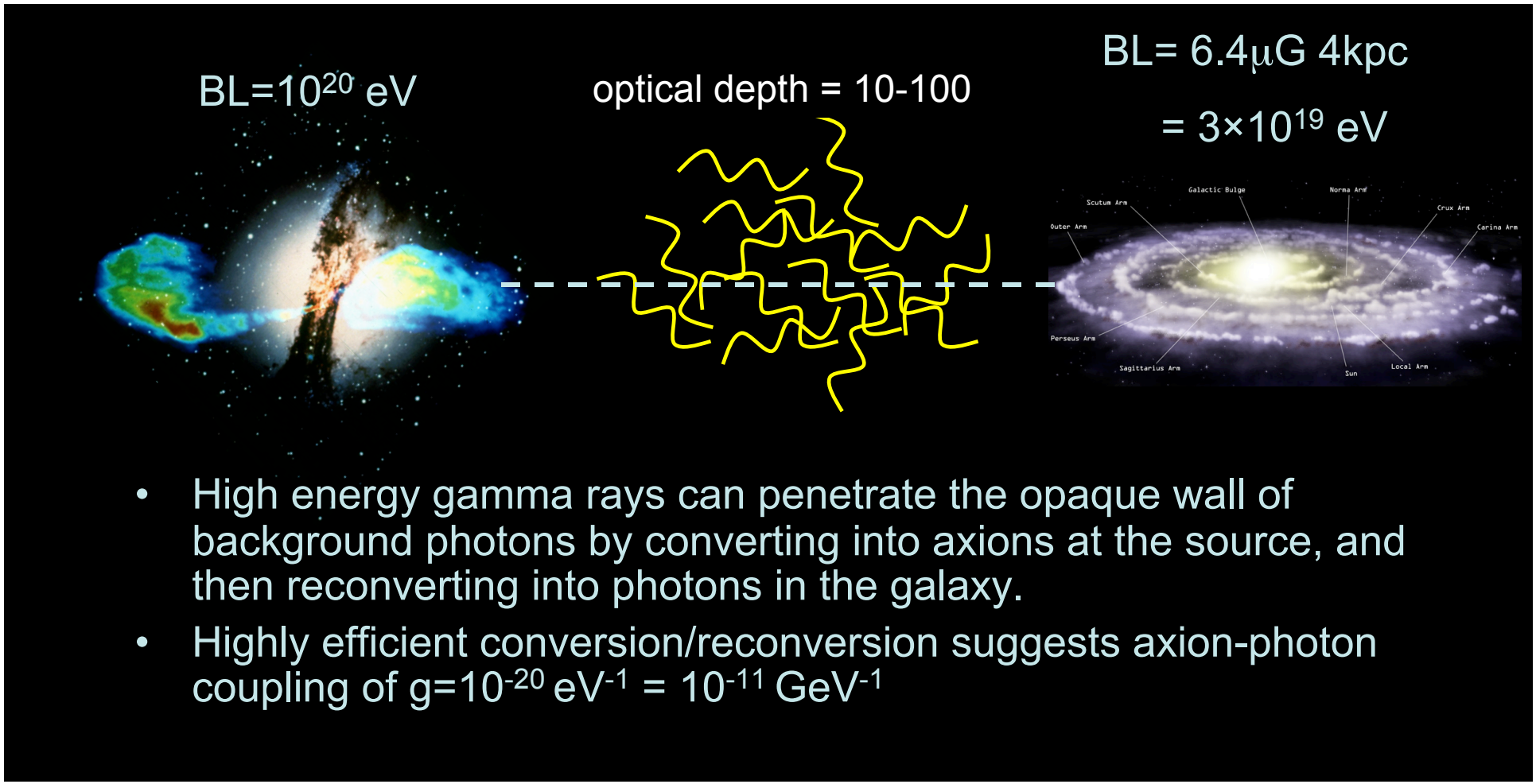
First-ever laser search for chameleons.
Upgrade with improved vacuum is planned.

Laser-based experiments are part of the intensity frontier, probing fundamental coupling scales of up to 10^{11} GeV. Accelerator laboratories with large magnets are uniquely well-suited for these experiments.

Light shining through the universe

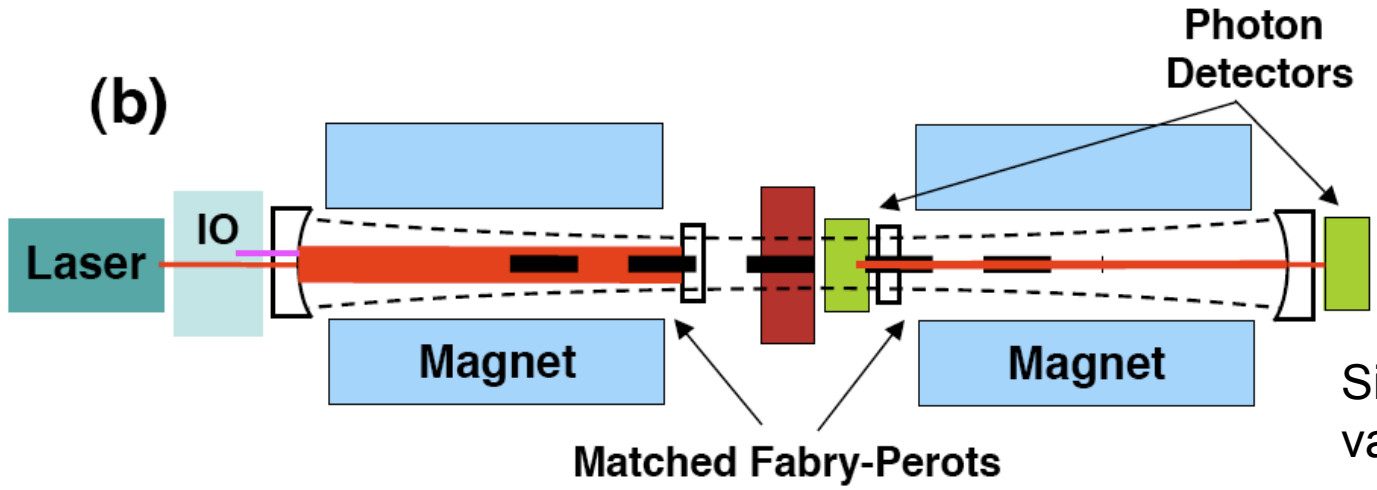
▪Simet, Hooper, Serpico (2008): axions explain anomalous transparency of soft photon background to TeV gamma rays measured by HESS, etc.

▪Fairbairn, Rashba, Troitsky (2009): same for 10^{19} eV cosmic ray photons seen in the HiRes cosmic ray ←→ BL Lac correlation



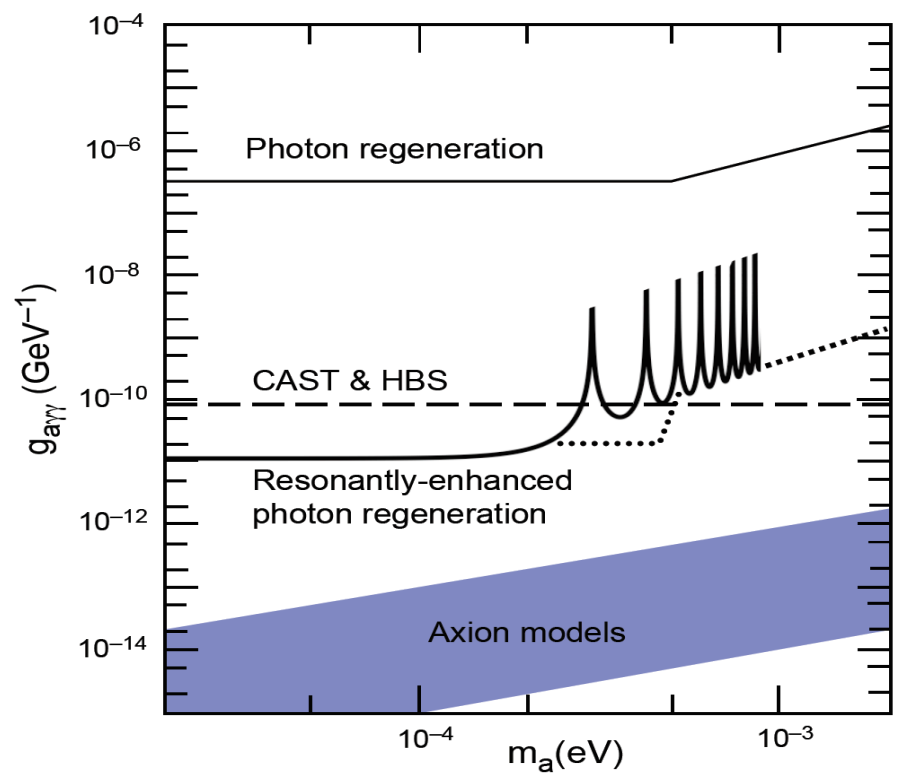
- High energy gamma rays can penetrate the opaque wall of background photons by converting into axions at the source, and then reconverting into photons in the galaxy.
- Highly efficient conversion/reconversion suggests axion-photon coupling of $g=10^{-20}$ eV^{-1} = 10^{-11} GeV^{-1}

Planned Resonant Regeneration Experiment



Sikivie, Tanner, van Bibber, 2007

- Use an optical cavity to prepare the axion beam in a well-defined state, and resonantly reconvert in a matched cavity.
- Using a string of Tevatron dipoles, reach $g \sim 10^{-11}$ GeV^{-1} in several months of running
- Halo dark matter axions also produce frequency sidebands (Melissinos, 2008)



CDMS Collaboration

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

CDMS Institutions

DOE Laboratory

- **Fermilab**
- **NIST**

DOE University

- **CalTech**
- **Florida**
- **Minnesota**
- **MIT**
- **Stanford**
- **UC Santa Barbara**

NSF

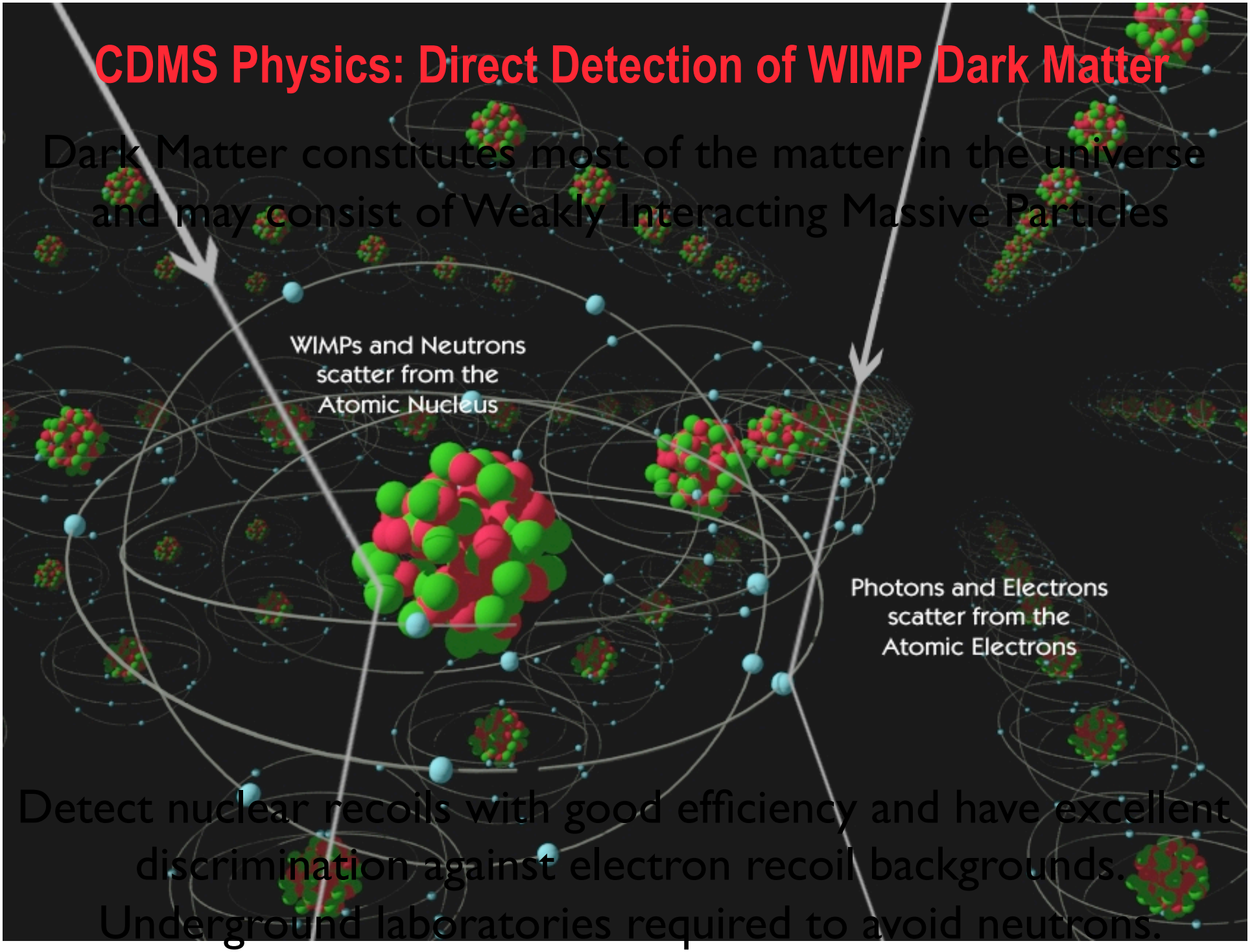
- **Case Western**
- **Colorado (Denver)**
- **Santa Clara**
- **UC Berkeley**
- **Syracuse**

Canada

- **Queens**

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



Detect nuclear recoils with good efficiency and have excellent discrimination against electron recoil backgrounds.
Underground laboratories required to avoid neutrons.

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

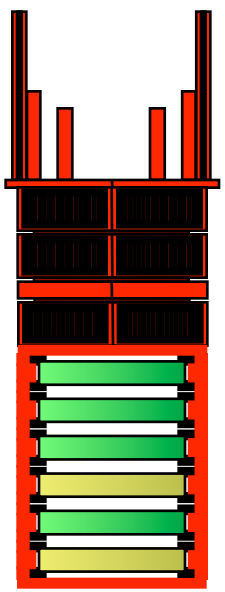
4 Ge

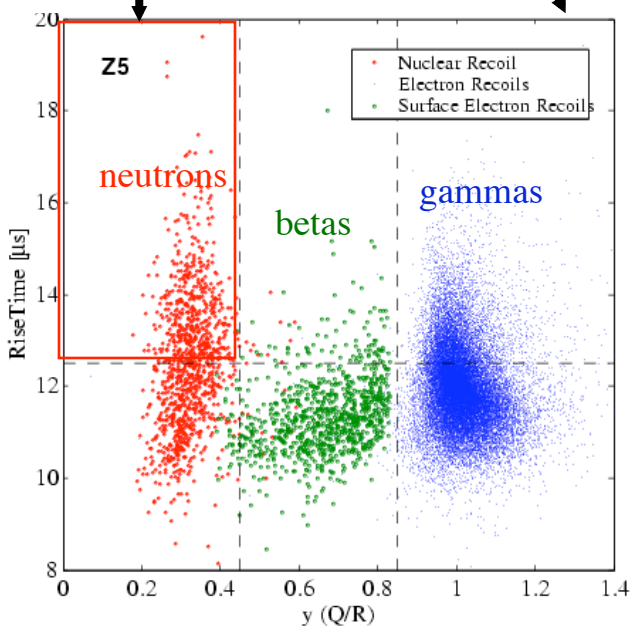
2 Si

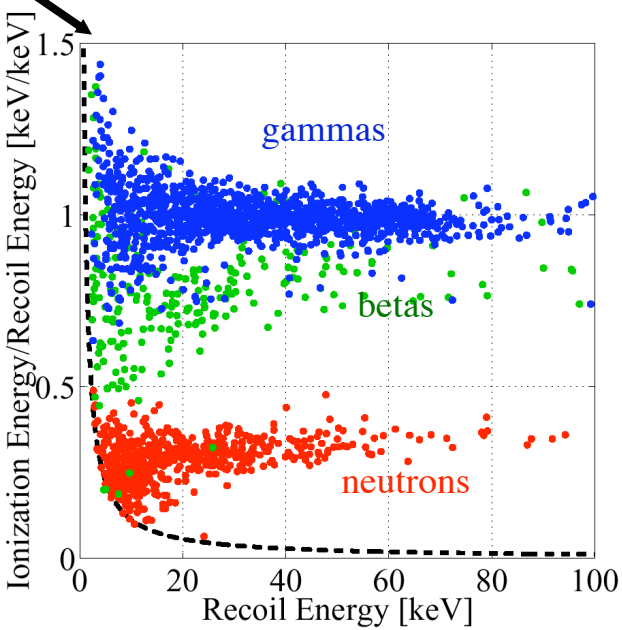
Tower 2

2 Ge

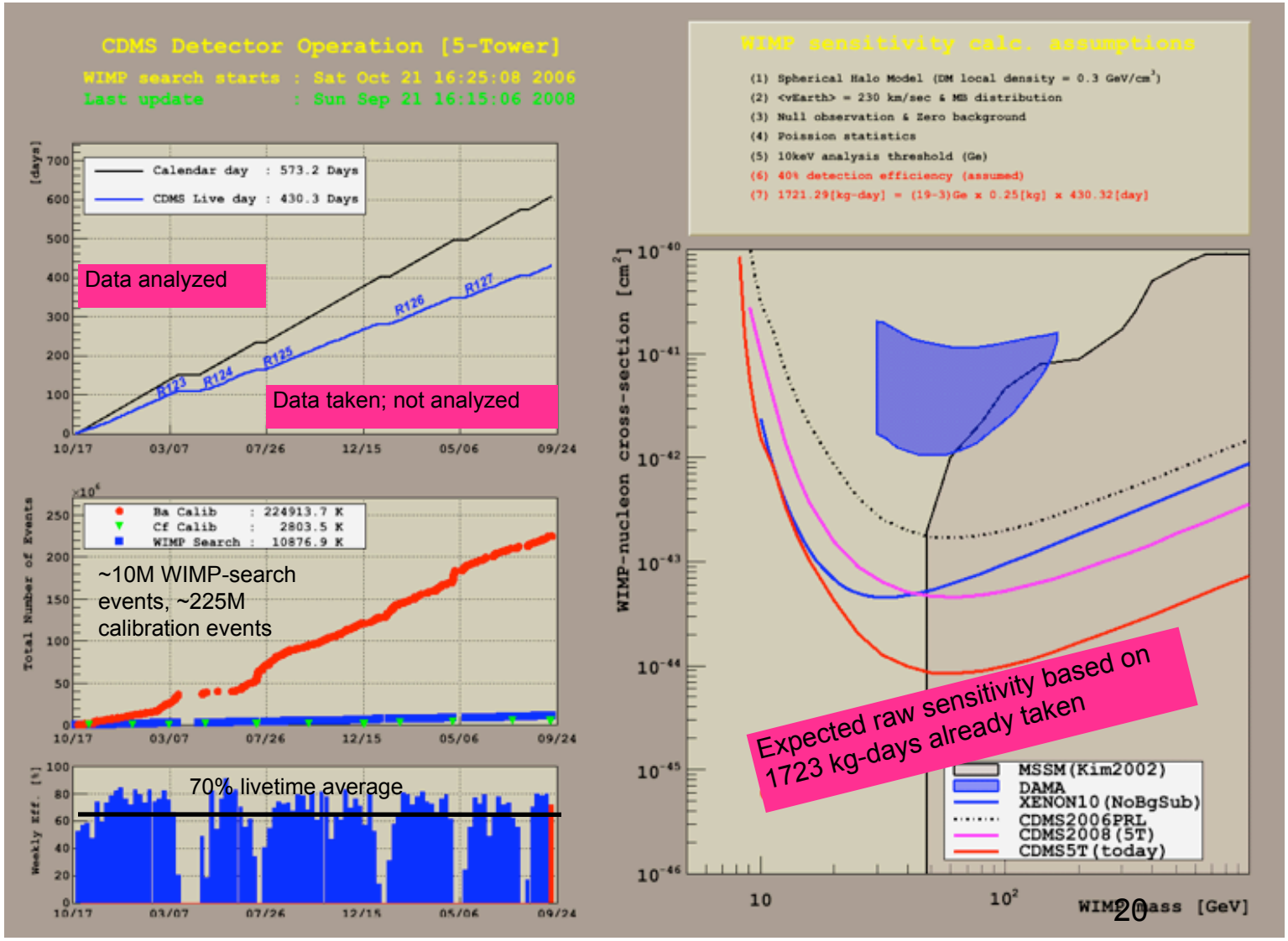
4 Si



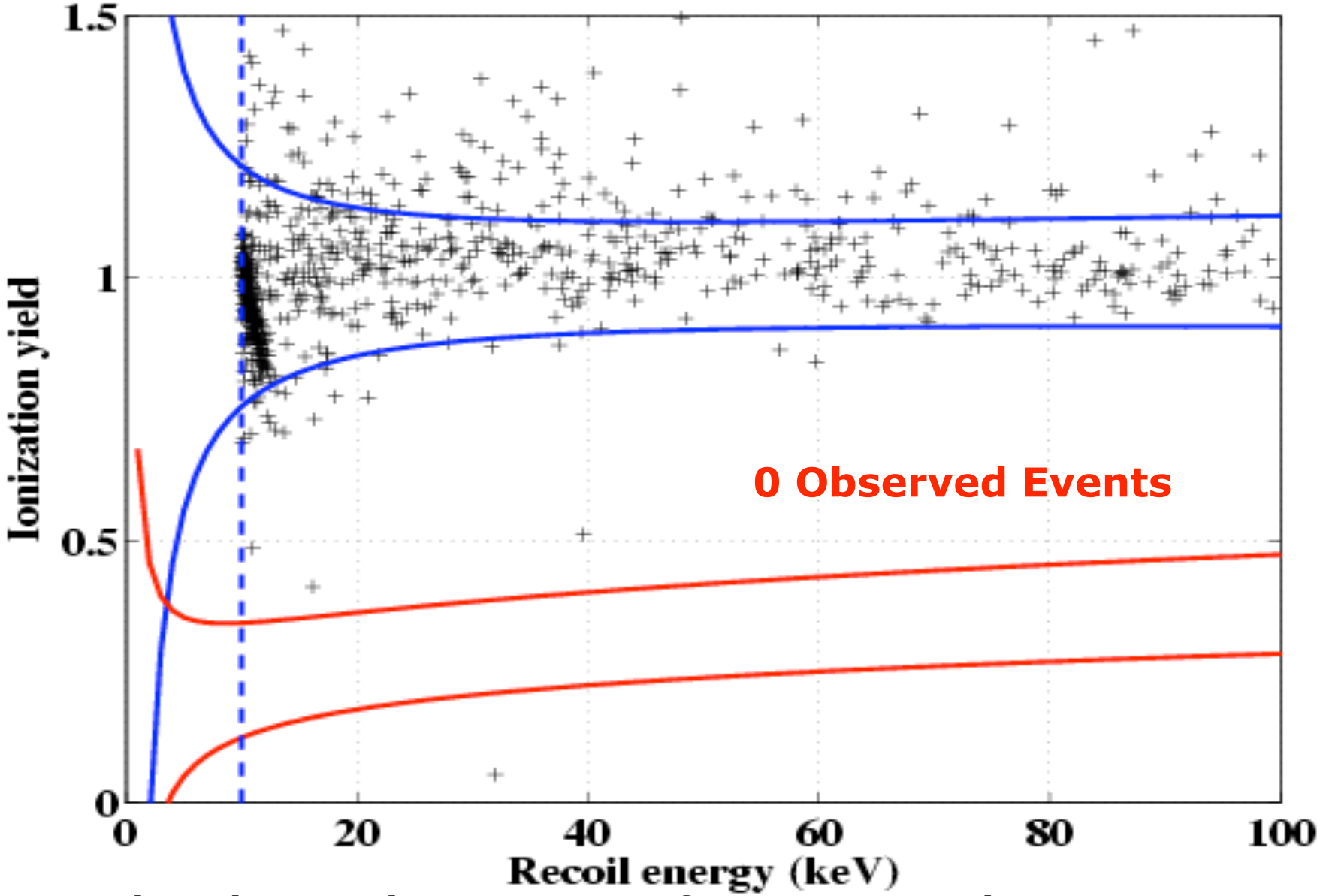




CDMS II Running Well at Soudan!

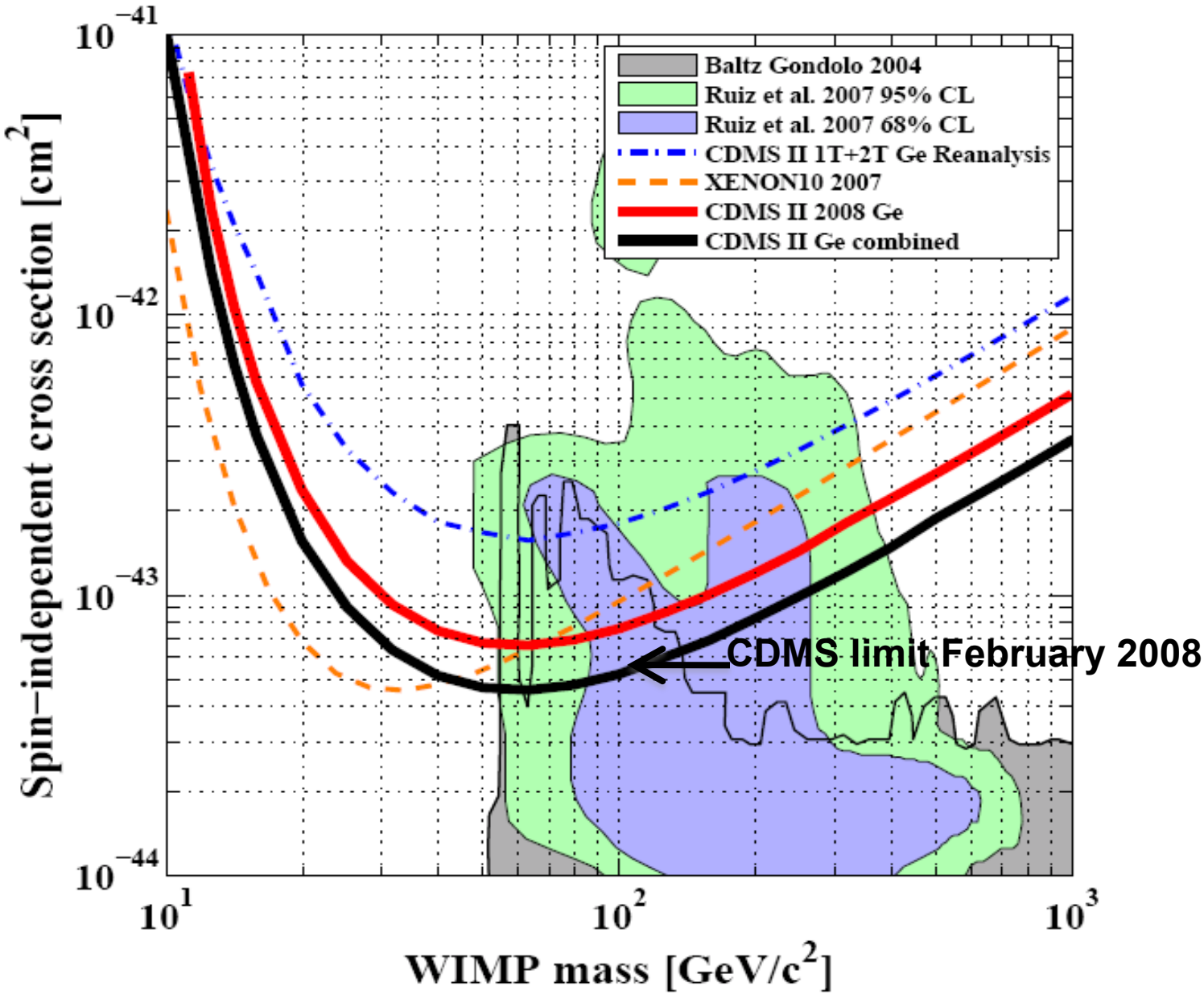


Background rejection is key!



Expected Background: 0.6 ± 0.5 surface events and < 0.2 neutrons

CDMS has best limits for MSSM



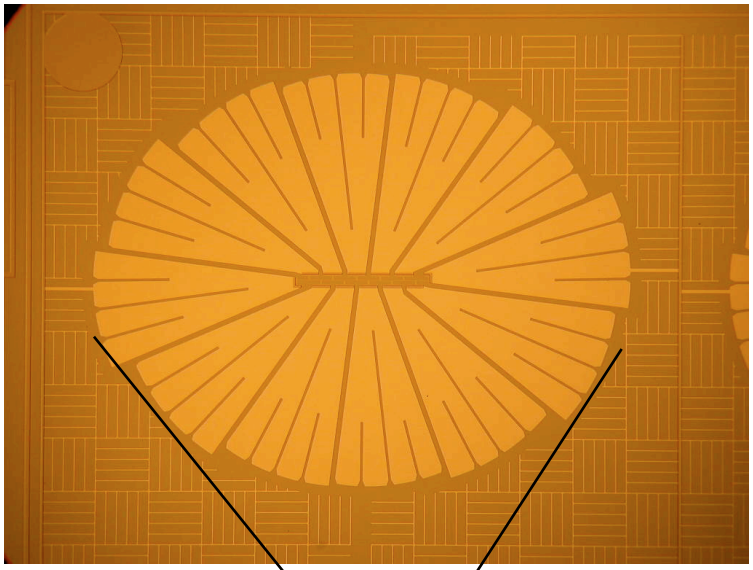
SuperCDMS Detectors

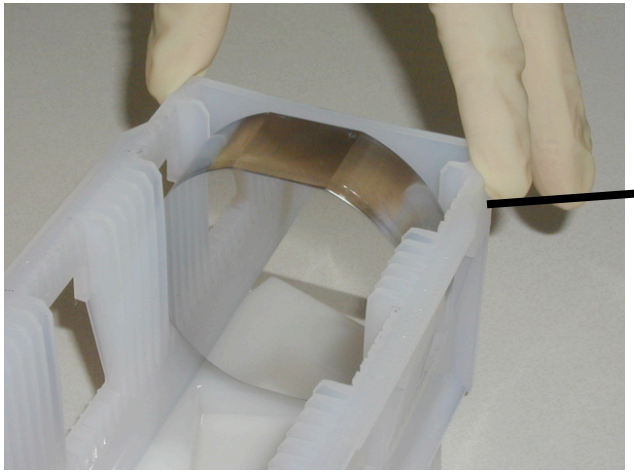
CDMS-II ZIPs:
3" dia x 1 cm => 0.25 kg of Ge

Existing ZIPs

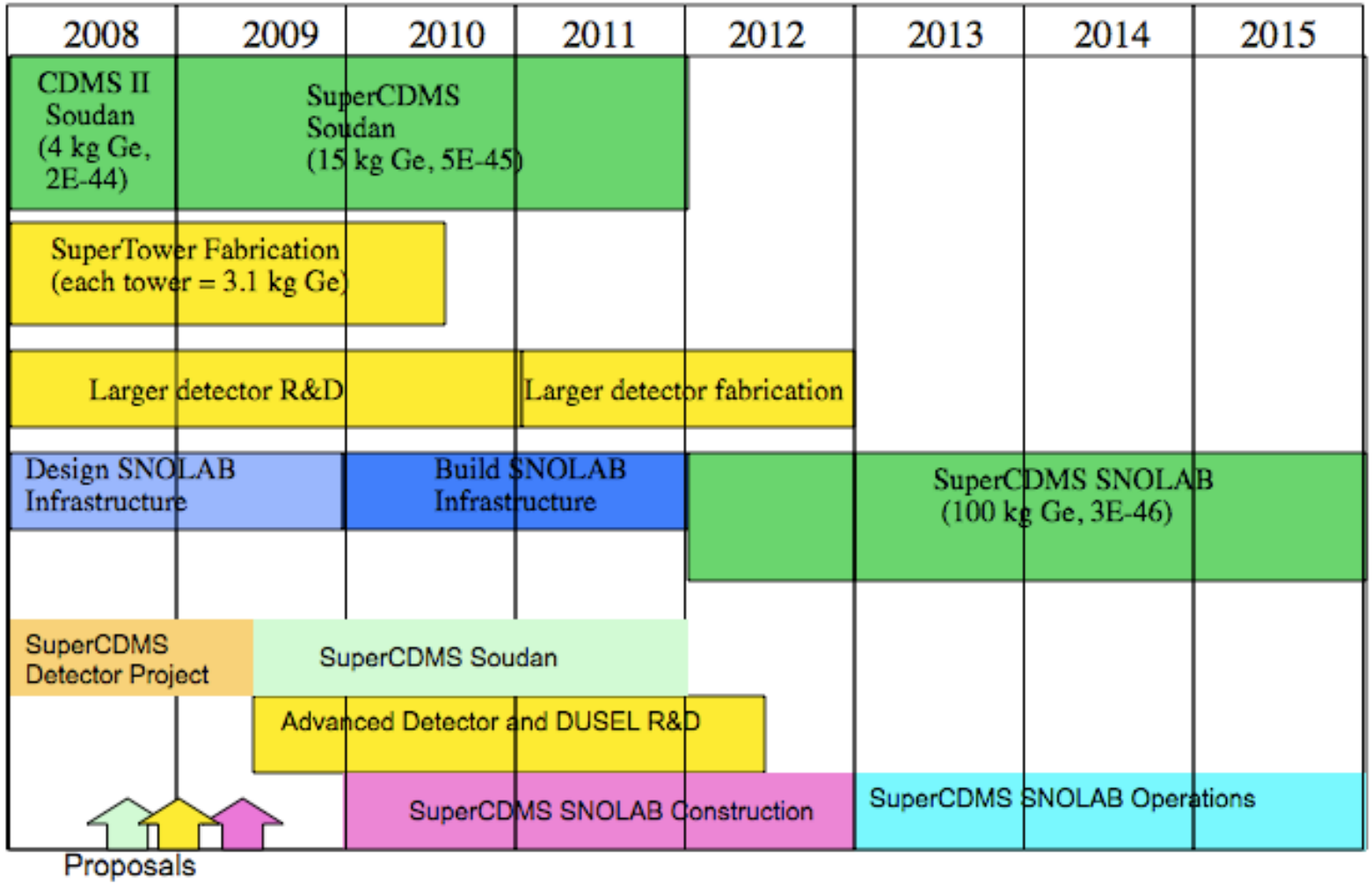
SuperCDMS ZIPs:
3" dia x 1" => 0.64 kg of Ge

ZIPs for SuperCDMS

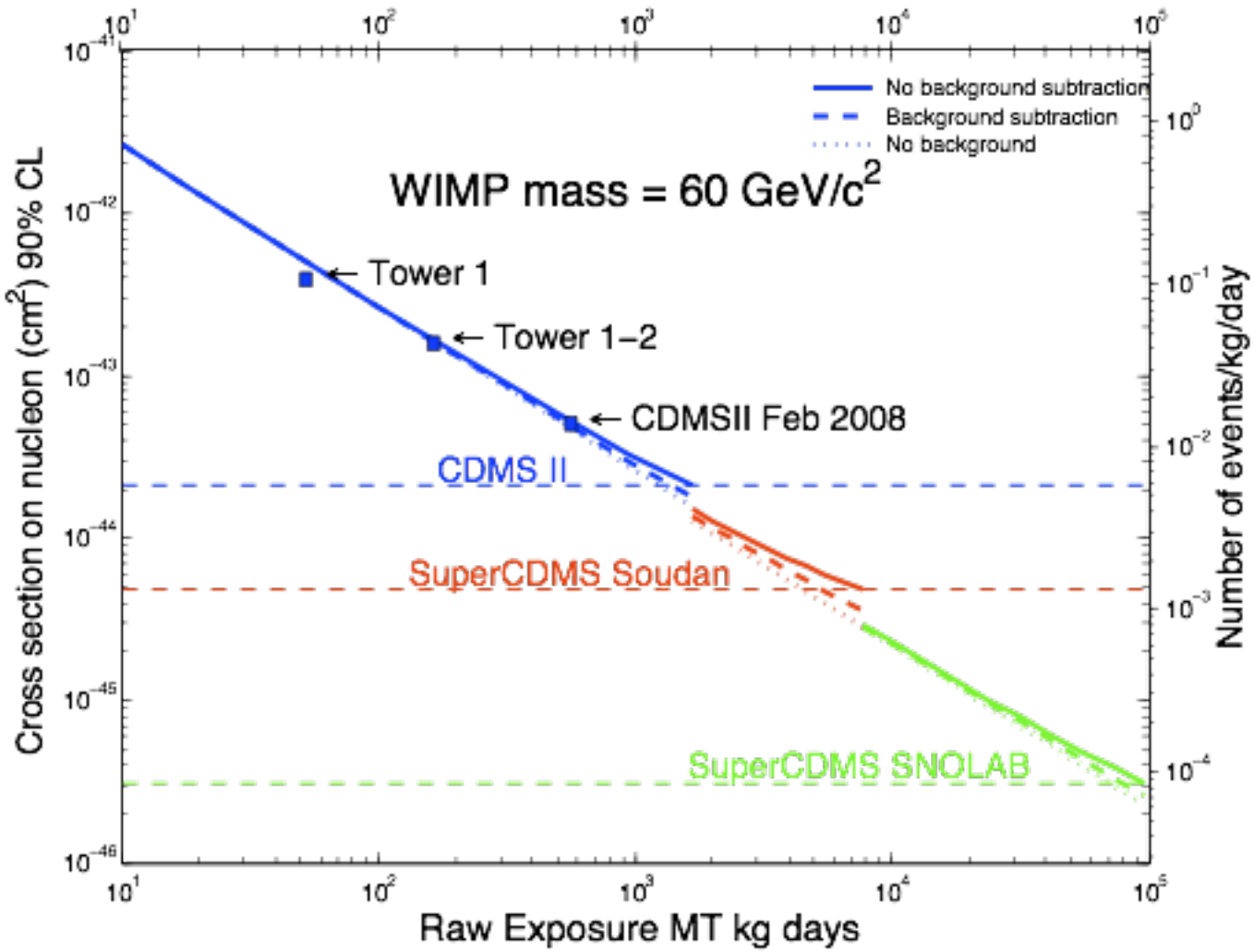




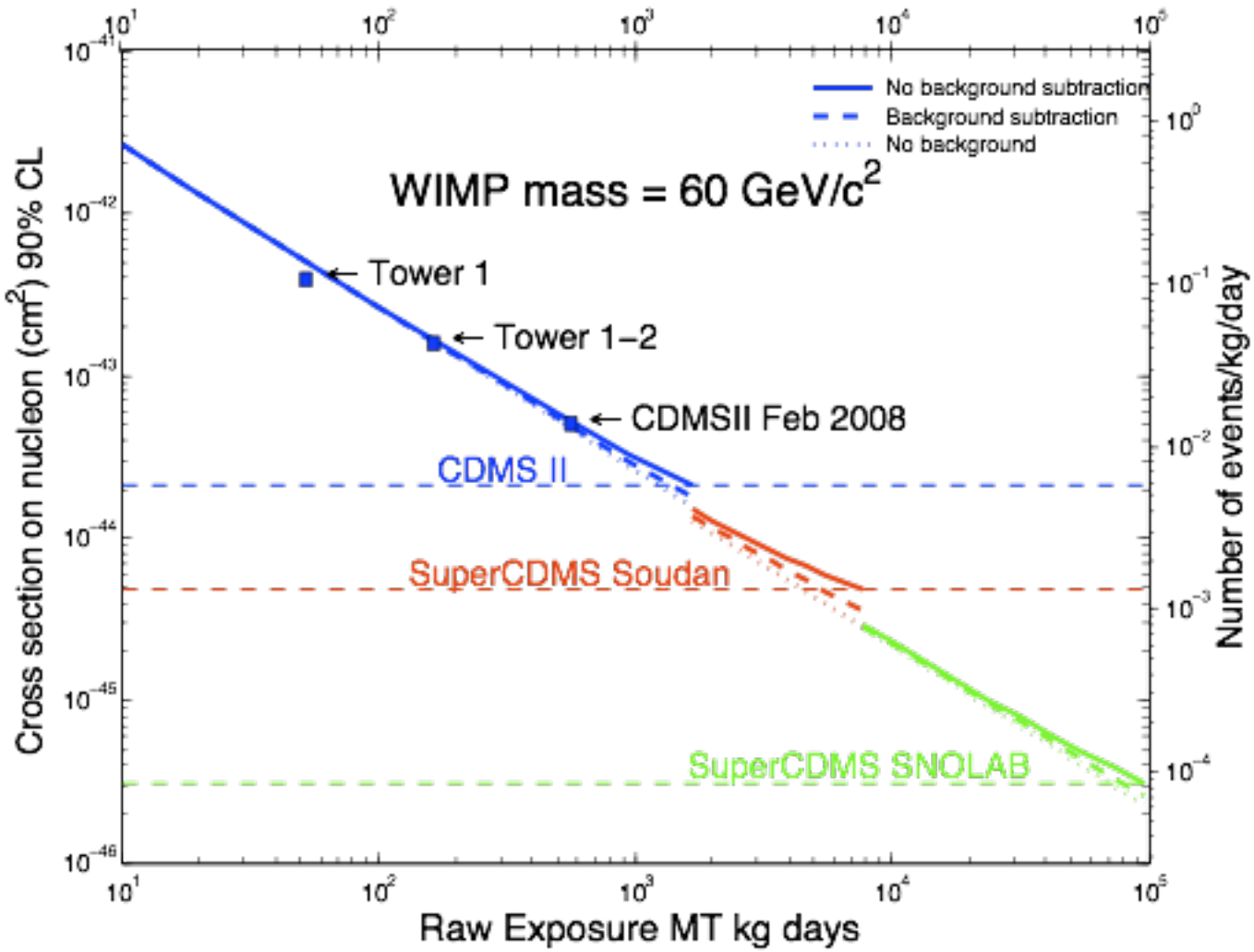
SuperCDMS


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

Zero Background Vital for WIMP Discovery!



Zero Background Vital for WIMP Discovery!

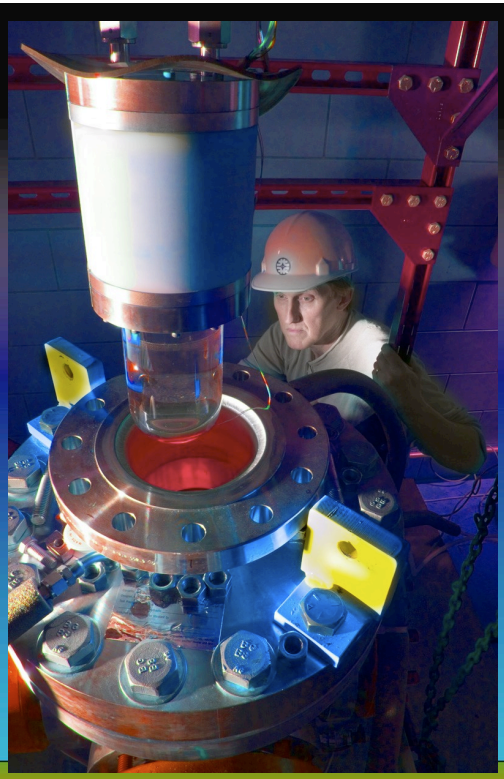


COUPP

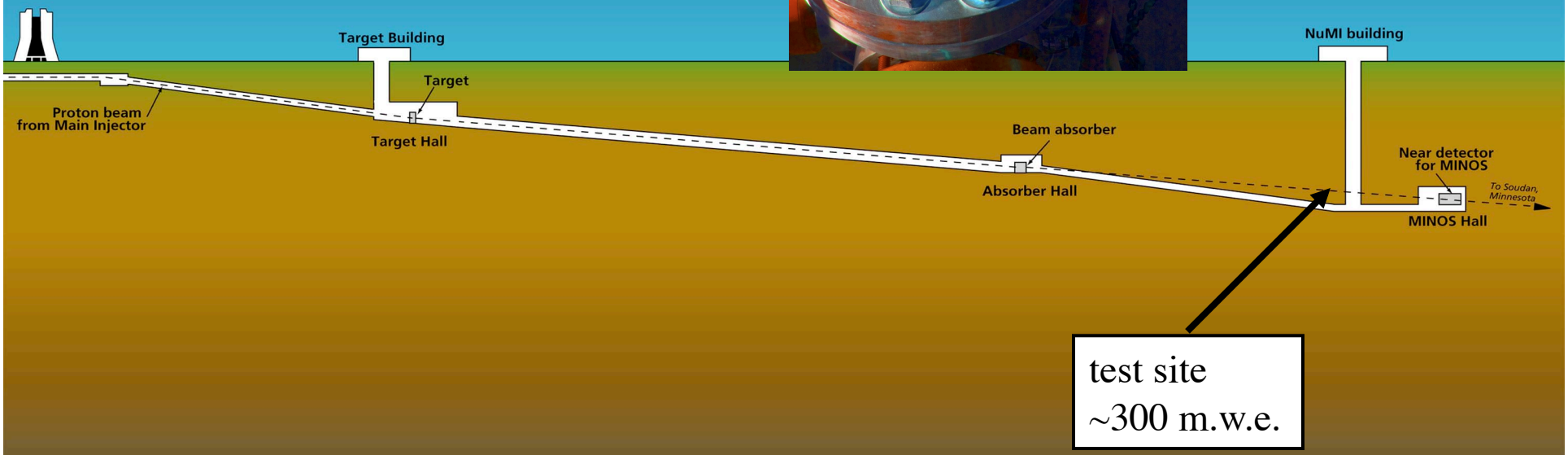
University of Chicago

Indiana University, South Bend

Fermilab (6 staff scientists)



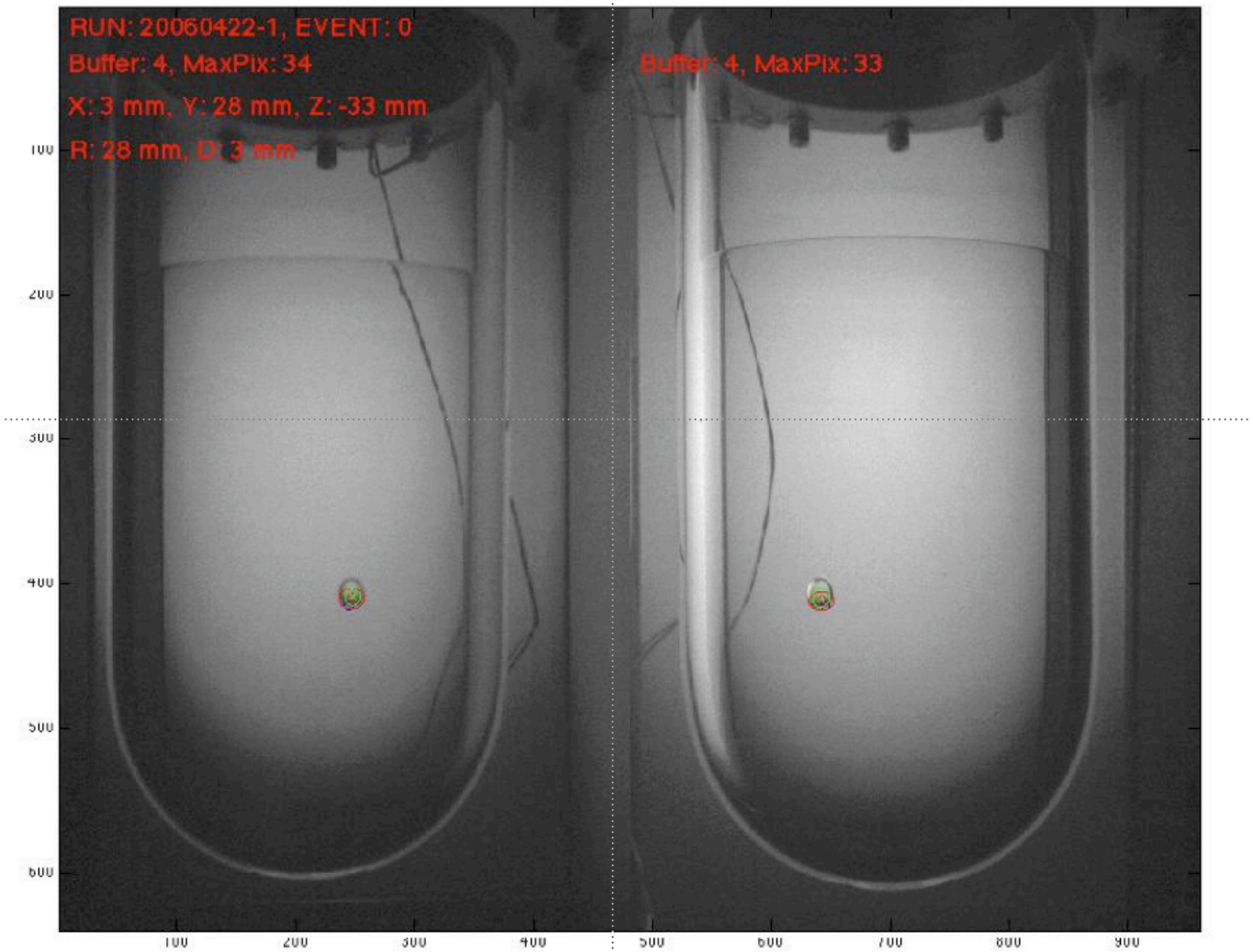
1 liter (2 kg)
Bubble Chamber
In NuMI tunnel



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 (no tracks or multiples)

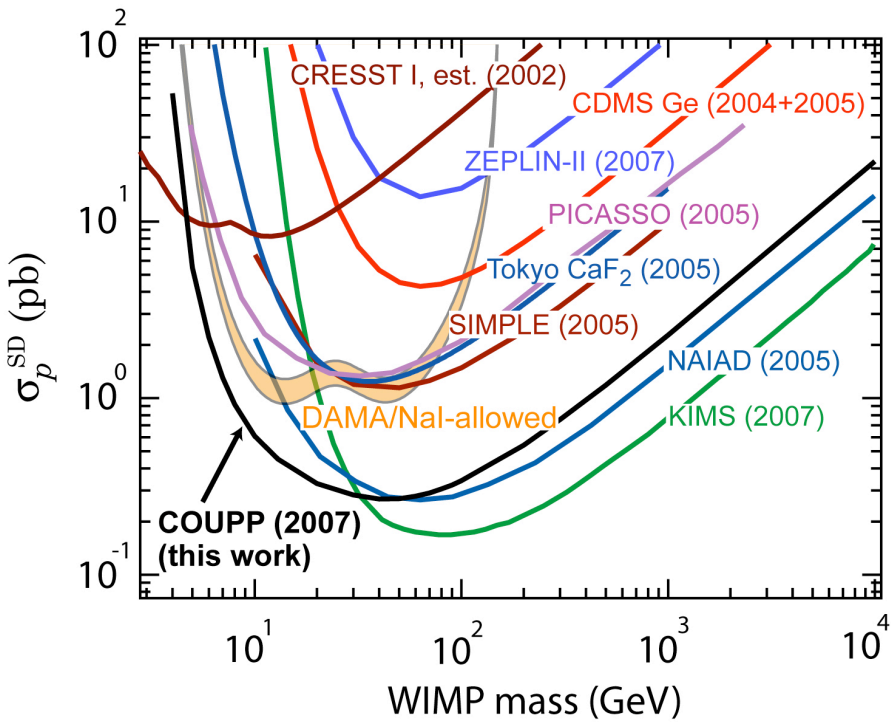
Appearance of a bubble causes the chamber to be triggered by image processing software.

Bubble positions are measured in three dimensions from stereo camera views

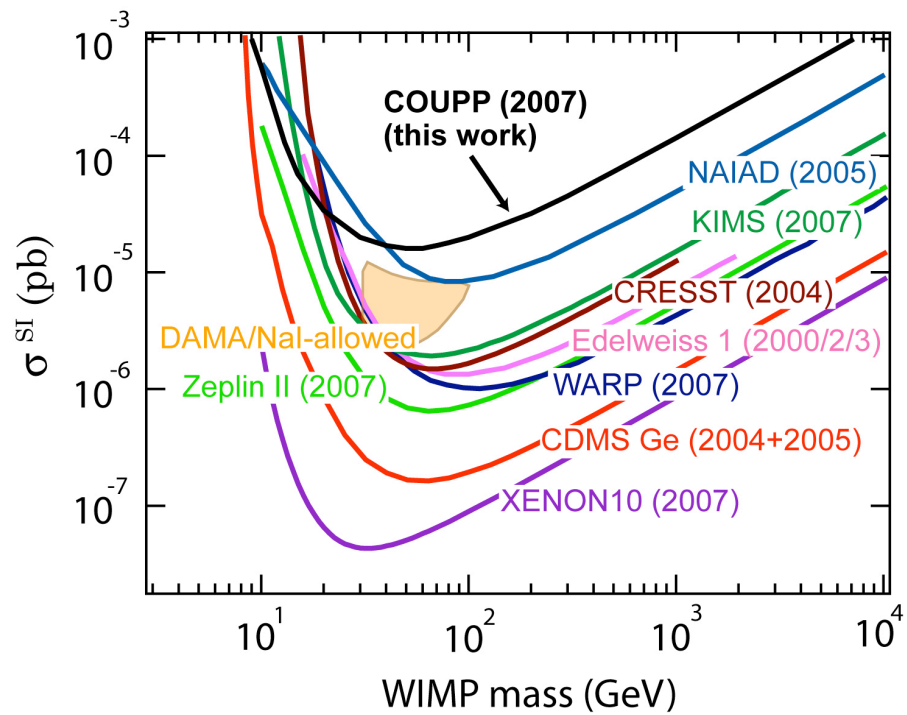
COUPP: First Published Results

- We have competitive sensitivity for spin-dependent scattering, despite high radon background in 200-2007 runs of 2-kg chamber.

Spin-dependent



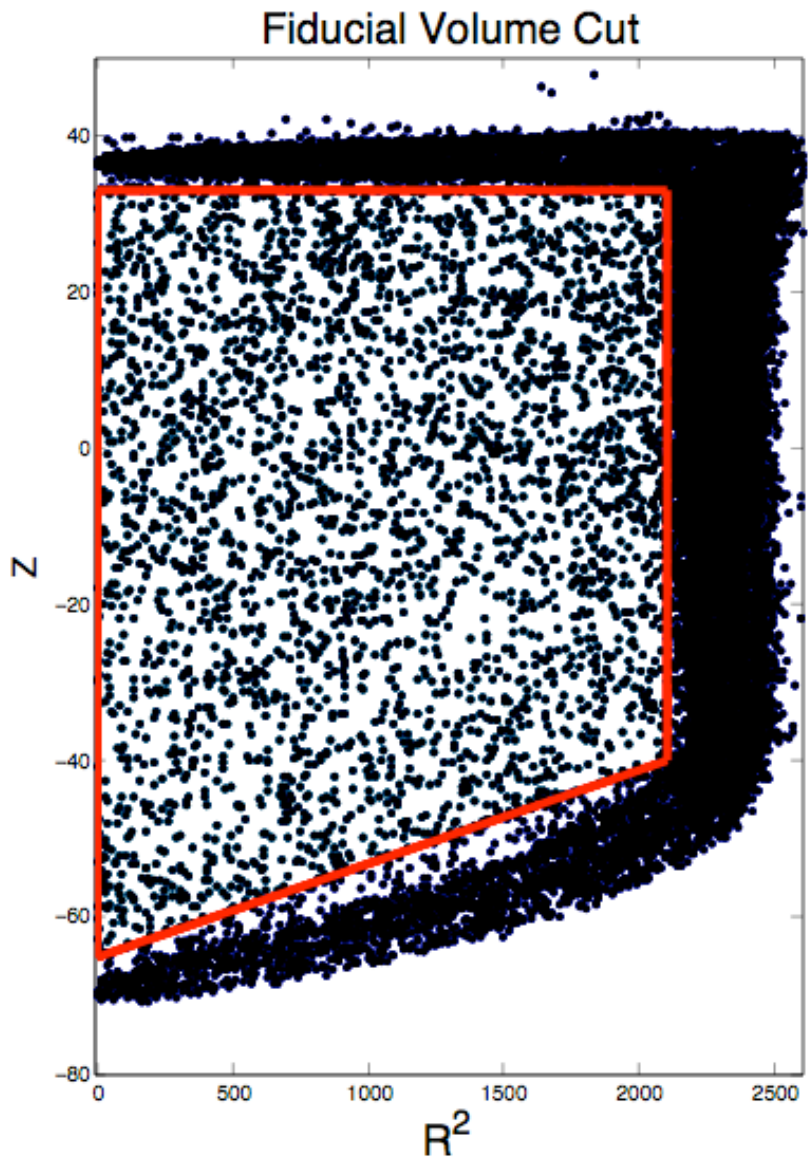
Spin-independent

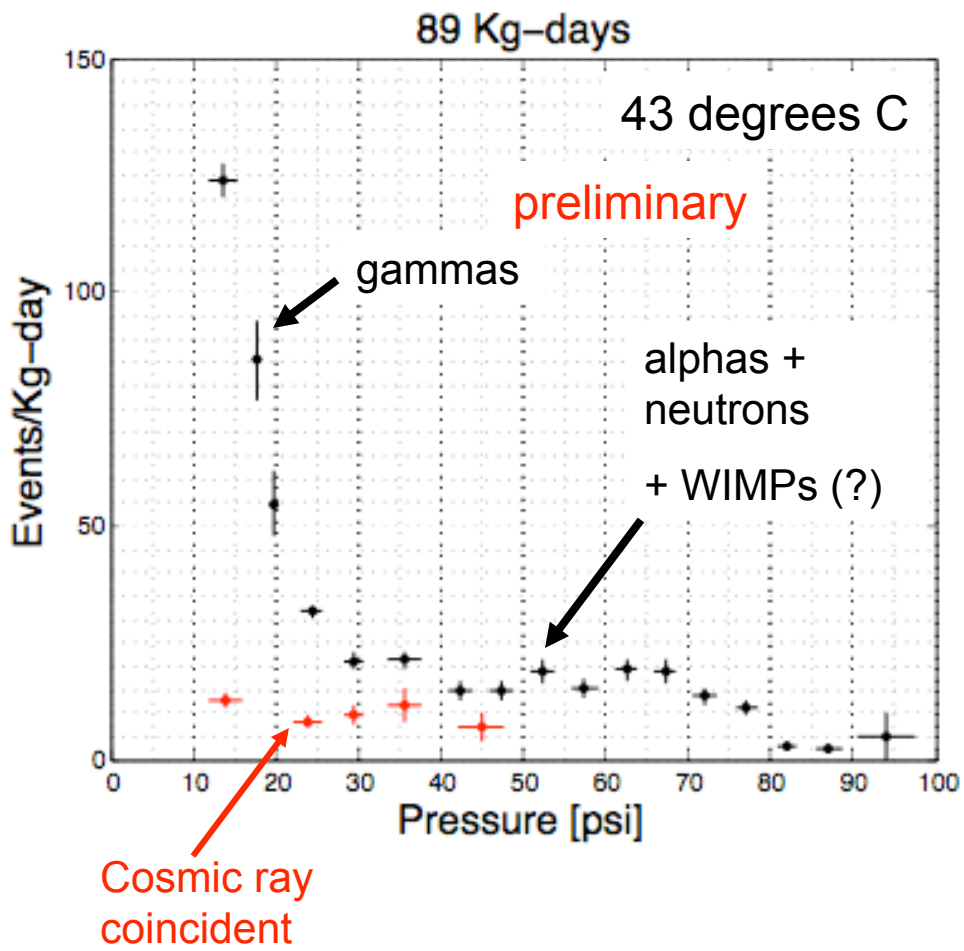


Science, 319: 933-936 (2008).

2008 Run of 2-kg chamber

- Wall events unaffected (quartz impurities)
- **Radon greatly reduced**
- **We begin to see backgrounds from cosmic-ray coincident neutrons**





Next Step: 60-Kg Chamber

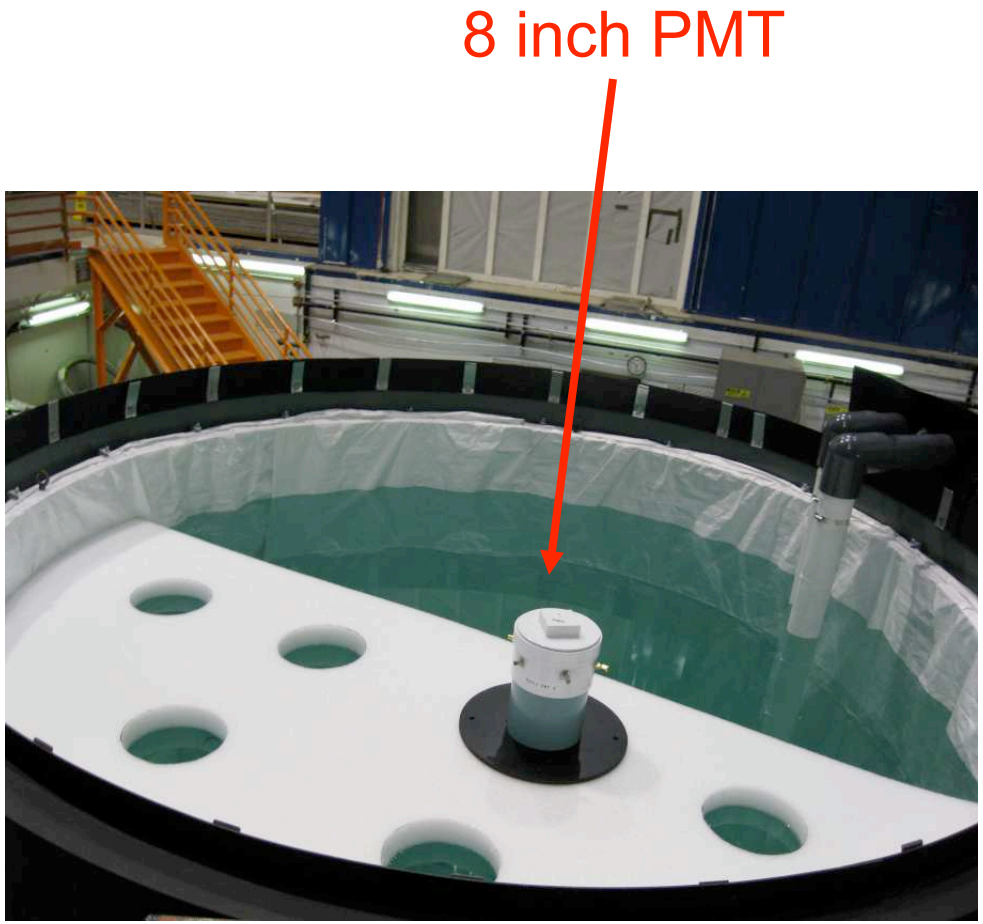
Outer Vessel

Inner Vessel Prototype

60-Kg System Ready for Testing

Water Shield Testing- March, 2009

- Water tank will provide temperature control, neutron shielding and cosmic ray tags via Cerenkov light.



COUPP Status

- 60-kg chamber above-ground construction and commissioning:
  - Prototype inner vessel and hydraulic controls have been tested.
  - Final, high-purity inner vessel nearing completion.
  - Illumination and video system nearing completion.
  - Water tank and Cerenkov veto testing started this week.
  - Largest remaining piece: high purity water and CF3I handling system
    - Critical for achieving low backgrounds from internal radioactivity

    e.g. 10^{-14} g/g Uranium in CF3I => 1 event/100 kg-day from alpha decay

- Running at NuMI Site expected to begin this summer.

- Deep underground site selection
  - SNOLAB or Soudan?
  - If NuMI run demonstrates good radiopurity, will want to move deeper after short run.

- Larger chambers
  - We expect to propose a ~500 kg chamber when 60-kg is running.
  - DUSEL could have array of 500-kg modules

FCPA experiments are producing world-leading physics results!

- Auger
  - first detection of small-scale anisotropy in cosmic rays
  - detailed probe of the origin of cosmic rays, and and interactions at high energy

- GammeV
  - World's best laboratory limits on axion-photon coupling, paraphotons
  - Pioneering experiment for laboratory tests of dark energy

- CDMS
  - World's best limit on spin-independent WIMP-nucleon cross-sections
  - Only direct DM detection experiment with demonstrated background-free operation.

- COUPP
  - World's best limit on spin-dependent WIMP-nucleon cross-sections
  - 100% suppression of electron recoil background! Good progress with alpha background.