Pierre Auger Observatory

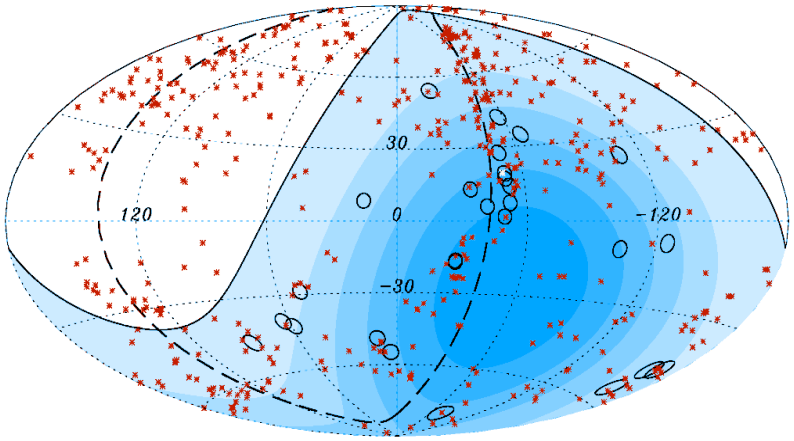
450 scientists from 18 countries
17 peer-reviewed full collaboration publications

FCPA Retreat 2010

PAO @ FNAL
Eun-Joo Ahn, Aaron Chou, Henry Glass, Carlos Hojvat, Peter Kasper, Frederick Kuehn, Paul Lebrun, Paul Mantsch, Peter Mazur

Pierre Auger Observatory — Science Mission

- Fermilab's mission is to study the fundamental properties of matter and energy
- The PAO studies the nature of the highest energy matter particles in the universe
  - The only experiment able to probe matter in this regime
    - Determining the properties of particle interactions at greater than a hundred TeV center of mass energy (~10-30 times the LHC energy)
    - Produced the only evidence related to the nature of potential sources via anisotropy — correlation with local large scale matter distribution
  - First sky map at energies ≥10 Joules

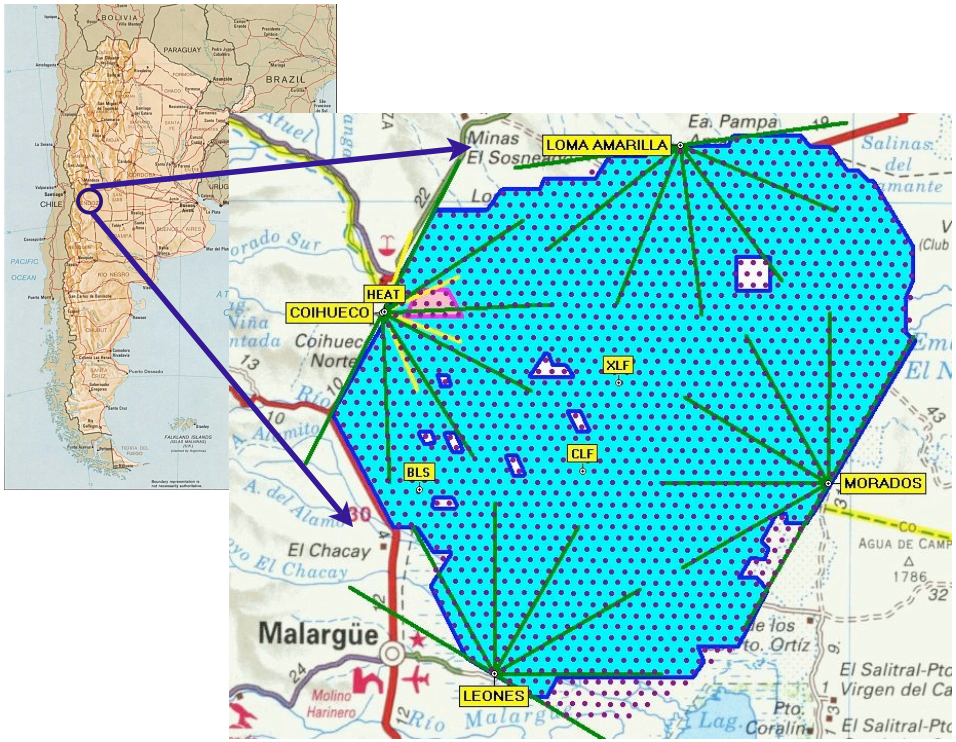


The mission of OHEP is to understand how our universe works at its most fundamental level

http://www.er.doe.gov/hep/mission/index.shtml

Pierre Auger Observatory — Leading the Field

- The PAO is the largest cosmic ray experiment (> 10^{18} eV)
- Size matters — low rate of events at the highest energies
- Combines two established detection techniques
  - Fluorescence telescopes provide energy calibration and shower properties
  - Surface array provides statistics
  - Detector upgrades/enhancements proceeding



Surface Array (3000 km2)

•1642 surface detector tank assemblies deployed

•1619 surface detector stations with water

•1587 surface detector stations have electronics

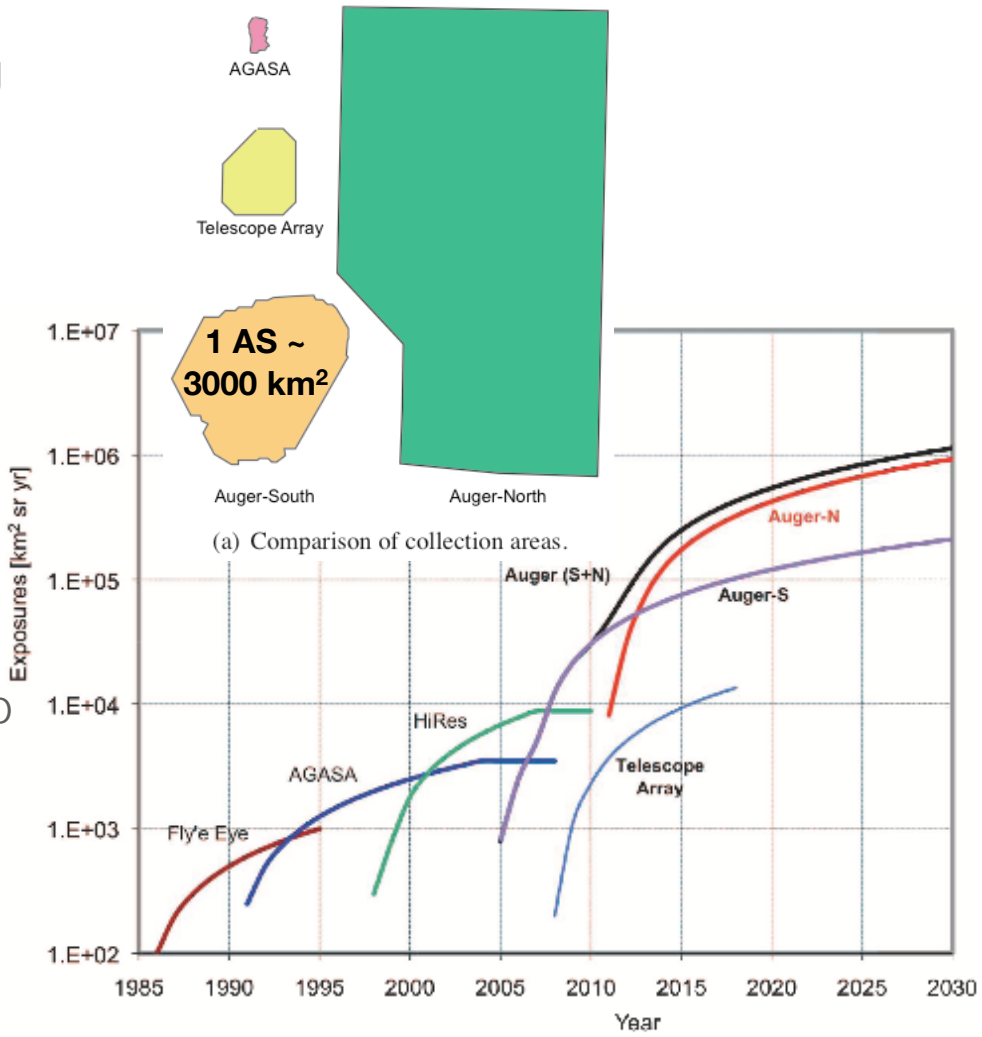
Fluorescence Detectors

•24 telescopes (6 at each site)

•+3 telescopes for HEAT

Pierre Auger Observatory — Leading the Field

- Northern site science case has strong international support
  - See "Important Notes: Auger North" — slide 21 PASAG report, S. Ritz, 23/10/09
  - "We recommend that European groups play a significant role ... and ... make a significant contribution to the design and construction of a Northern Auger Observatory" — ASPERA roadmap Phase I, July 2008
- See, e.g., Angela Olinto's talk from last retreat for details of science case

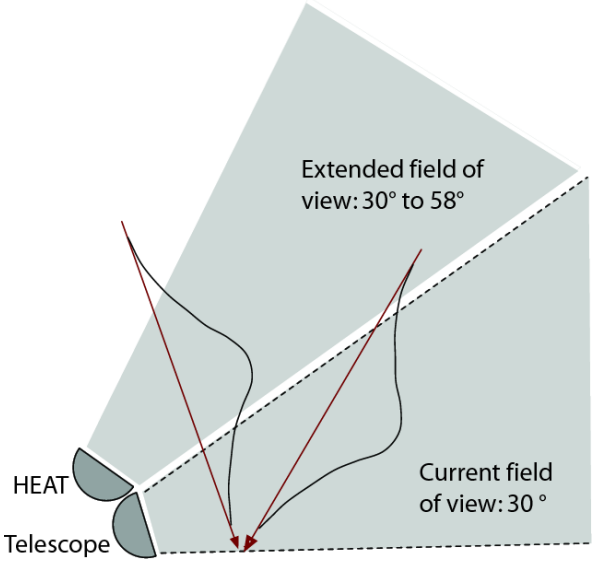


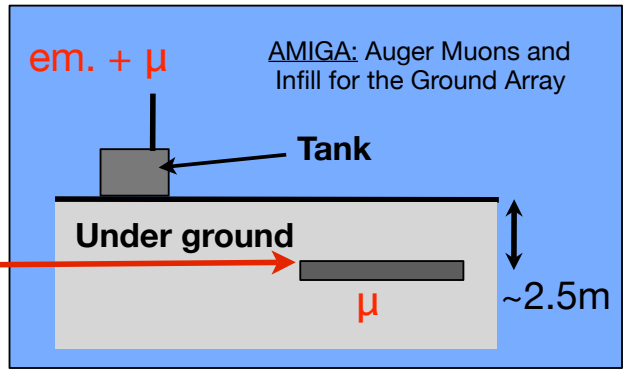
(a) Comparison of collection areas.

(b) Exposures as a function of time.

Pierre Auger Observatory — Enhancements

- Upgrades further widen the gap between the PAO and other experiments
  - High Elevation Auger Telescope (HEAT) & AMIGA (Infill Array) extend energy range down in energy to 10^{17} eV
  - Coherent radio emission, and molecular bremsstrahlung provide R&D for new, independent detection techniques calibrated to known methods
  - Lightning detection system expands physics potential

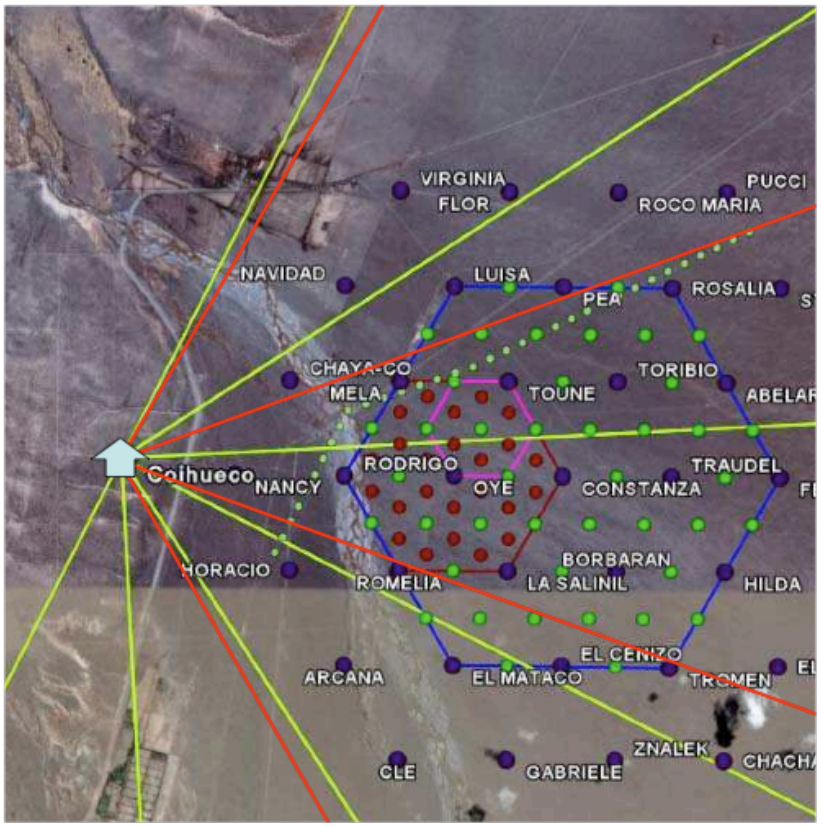




Scintillators from FNAL

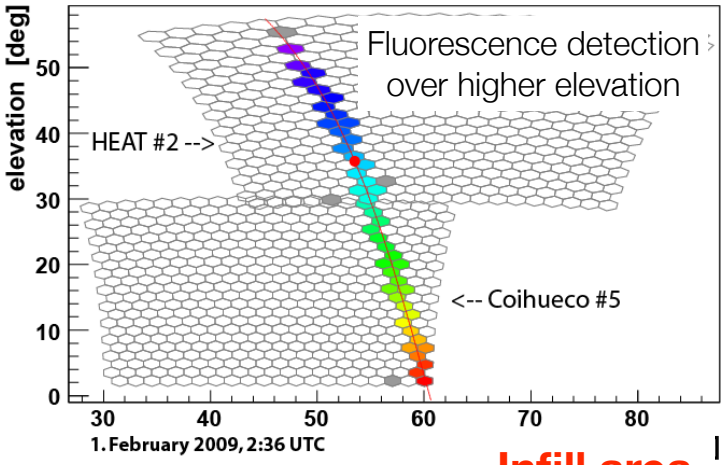
Pierre Auger Observatory — Enhancements

- Upgrades further widen the gap between the PAO and other experiments
  - Auger Muon and Infill for the Ground Array — AMIGA
  - FNAL supporting AMIGA by providing scintillators and manpower — still under construction
  - Muon to electron ratio important for composition measurement — independent of fluorescence measurements

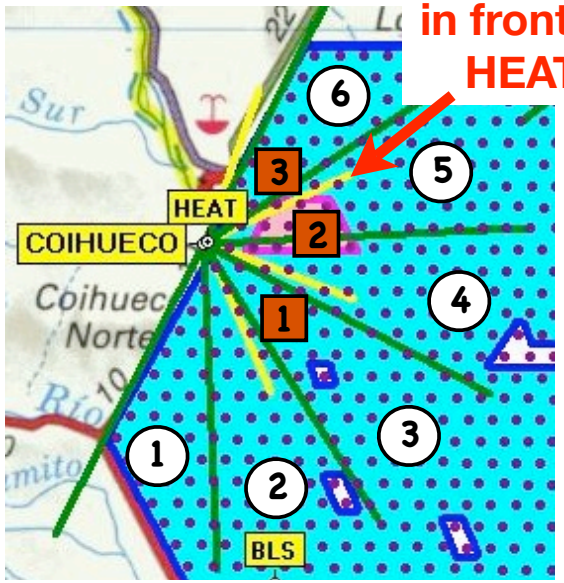


Pierre Auger Observatory — Enhancements

- Upgrades further widen the gap between the PAO and other experiments
  - HEAT — 3 new fluorescence telescopes at same location of Coihueco, both looking over AMIGA
  - Measurement from 10^{17} eV to $>10^{20}$ eV
  - 'Low' energy spectrum with 750 meter Infill surface array is already systematics limited
  - 433 meter Infill will start being installed this year, pushing the energy range even further down
  - Fluorescence Telescope — Surface Detector energy cross calibration at lower energies given by HEAT+Infill
  - Results at next ICRC



Infill area in front of HEAT



Pierre Auger Observatory — Science Results

- *Measurement of the energy spectrum of cosmic rays above 10^{18} eV using the Pierre Auger Observatory*, Phys. Lett. B **685** (2010) 239-246
  - First 'hybrid' (fluorescence+ground) and updated surface detector spectrum
- *Measurement of the depth of maximum of extensive air showers above 10^{18} eV*, Phys. Rev. Lett. **104** (2010) 091101
  - Shows a significant difference in shower properties from proton-only model expectation
- *Limit on the diffuse flux of ultrahigh energy tau neutrinos with the surface detector of the Pierre Auger Observatory*, Phys. Rev. D **79**, 102001 (2009)
  - Best experimental limit on neutrino flux at EeV energies
- *Upper limit on the cosmic-ray photon fraction at EeV energies from the Pierre Auger Observatory*, Astro. Part. Phys. **31** (2009) 399-406
  - First experimental limits on photons at energies at 10 EeV

Pierre Auger Observatory — Science Results 2010

- *Measurement of the energy spectrum of cosmic rays above 10^{18} eV using the Pierre Auger Observatory*, Phys. Lett. B **685** (2010) 239-246
  - Cutoff seen at >20σ
  - Overall energy scale systematic is 22%

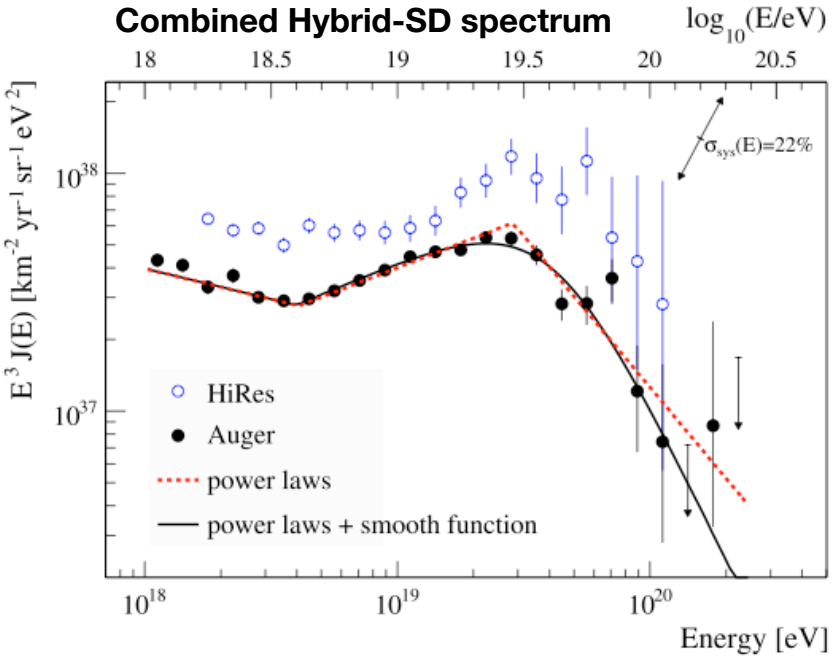


Table 1
Fitted parameters and their statistical uncertainties characterising the combined energy spectrum.

Parameter	Power laws	Power laws + smooth function
$\gamma_1 (E < E_{\text{ankle}})$	3.26 ± 0.04	3.26 ± 0.04
$\log_{10}(E_{\text{ankle}}/\text{eV})$	18.61 ± 0.01	18.60 ± 0.01
$\gamma_2 (E > E_{\text{ankle}})$	2.59 ± 0.02	2.55 ± 0.04
$\log_{10}(E_{\text{break}}/\text{eV})$	19.46 ± 0.03	
$\gamma_3 (E > E_{\text{break}})$	4.3 ± 0.2	
$\log_{10}(E_{1/2}/\text{eV})$		19.61 ± 0.03
$\log_{10}(W_c/\text{eV})$		0.16 ± 0.03
χ^2/ndof	38.5/16	29.1/16

Smoothing function $\propto \dfrac{E^{-\gamma_2}}{1 + \exp\left(\frac{\log_{10} E - \log_{10} E_{1/2}}{\log_{10} W_c}\right)}$

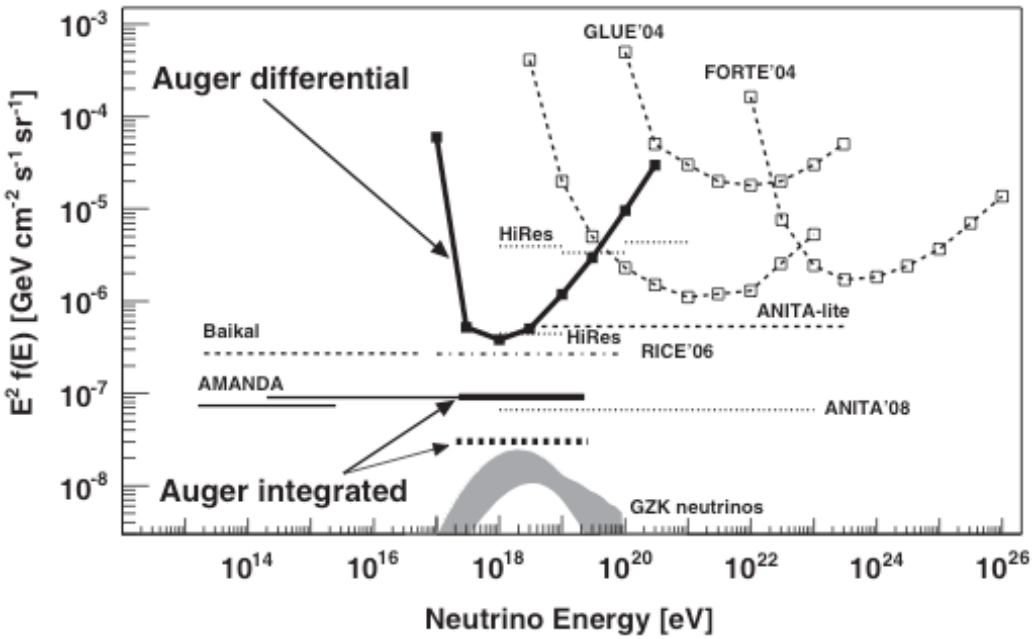
Pierre Auger Observatory — Science Results 2010

- *Measurement of the depth of maximum of extensive air showers above 10^{18} eV*, Phys. Rev. Lett. **104** (2010) 091101
  - New (high statistics) result showing for the first time a significant change from proton only model expectation
  - See Eun-Joo Ahn's accompanying talk, and upcoming 'Wine and Cheese' seminar for details

Pierre Auger Observatory — Science Results 2009

- *Limit on the diffuse flux of ultrahigh energy tau neutrinos with the surface detector of the Pierre Auger Observatory*, Phys. Rev. D **79**, 102001 (2009)
- Neutrinos can be associated with sources of cosmic rays, the GZK effect, and exotic particle decays
- Search is for τ neutrinos — oscillations over cosmological distances give flavour ratio 1:1:1
  - Skimming or upwards going events
  - None seen — upper limits given

90% confidence level
upper limit on neutrino flux

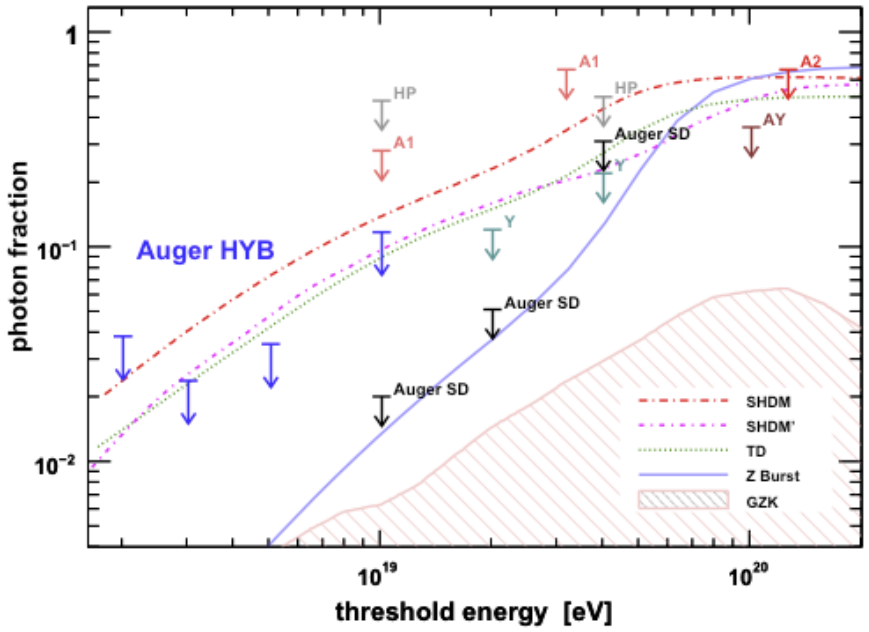


Systematics in exposure varies the limit
Integrated limit assumes - flux ∝ E^{-2}
Differential ∝ E/Exposure

Pierre Auger Observatory — Science Results 2009

- *Upper limit on the cosmic-ray photon fraction at EeV energies from the Pierre Auger Observatory*, Astro. Part. Phys. **31** (2009) 399-406
- Photons produced by GZK, photo-disintegration, and “top-down” models
- Hybrid, and surface detector only limits
- All photon candidates can be explained as background (proton/iron events)
  - Photon and neutrino fractions with GZK model can distinguish proton vs. iron independently from shower maximum

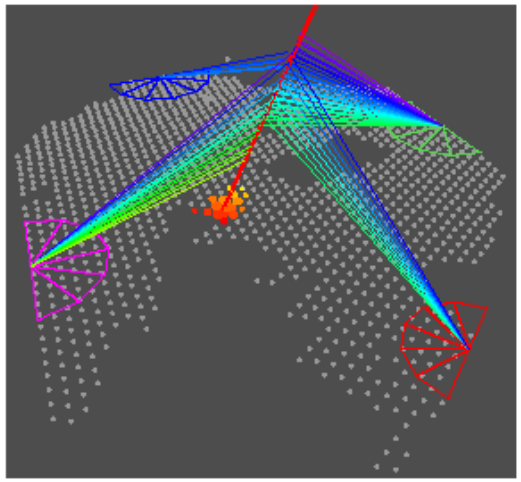
95% confidence level
upper limits on photon flux



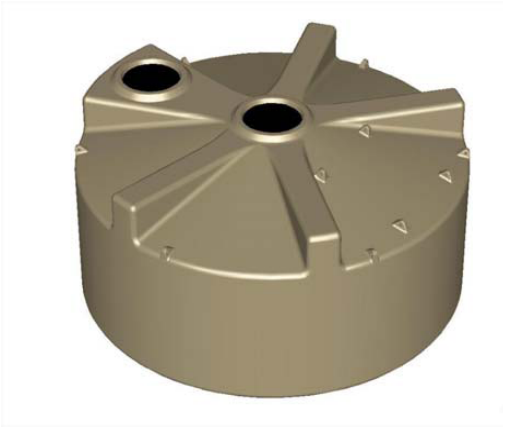
Pierre Auger Observatory — Roles @ FNAL

- Fermilab makes significant science, management, and technical contributions
  - Science: Leading efforts in analyses on composition and anisotropy
  - Management: FNAL is the home of the Auger project management
  - Technical: Surface detector design, Central Data Acquisition System (AN)

Auger South Tank
3 PMTs



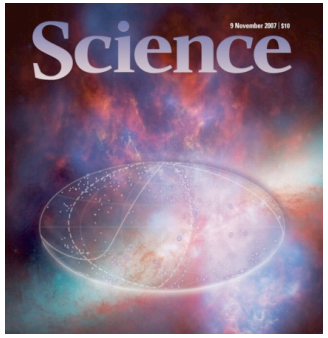
Auger South
Hybrid Event - CDAS



Auger North Tank
1 PMT
Insulated

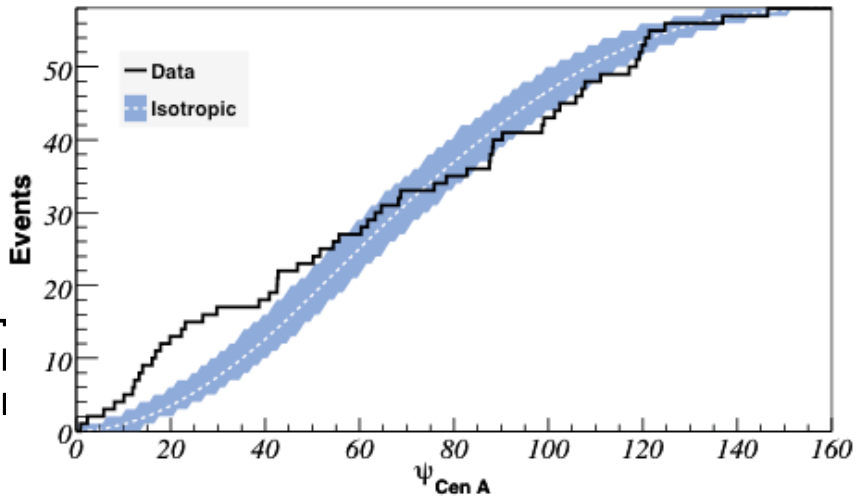
Pierre Auger Observatory — Science @ FNAL

- Fermilab Analysis
  - Anisotropy — intrinsic and catalogue based
  - Composition — cross sections, hadronic interaction modeling
  - Combined anisotropy/composition
  - Exotic searches
  - Search for multiplets
  - 10 Auger internal (“GAP”) notes



Update in progress

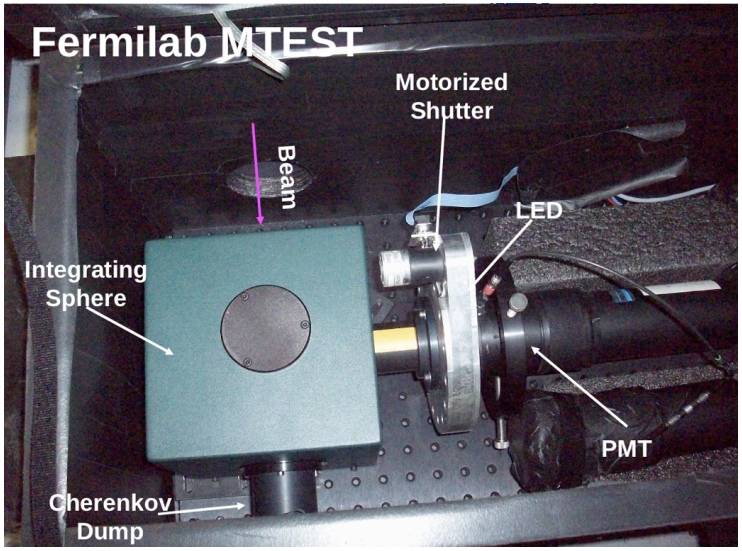
Cumulative number of event >55 EeV within an angle Ψ of Centaurus A

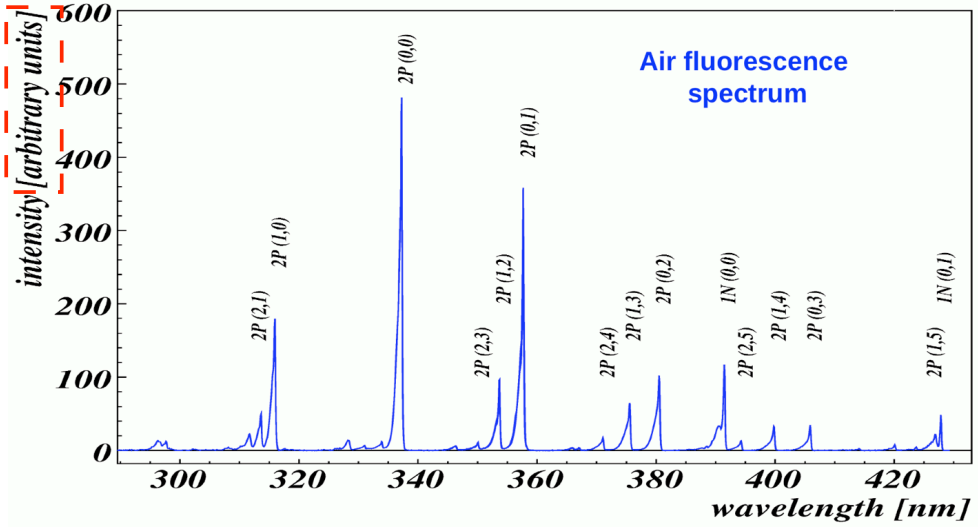


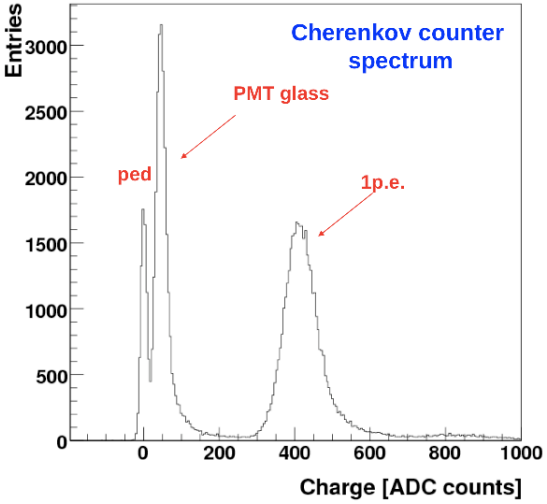
A Faraway Quasar in the Direction of the Highest Energy Auger Event Albuquerque & Chou 2010

Pierre Auger Observatory — Science @ FNAL

- AirFly — Air Fluorescence Yield experiment used for Auger energy calibration
  - Science goal — to determine the absolute yield of photons
  - Meson-Test facility integral to success







Pierre Auger Observatory — Management @ FNAL

- FNAL is the home of the Auger project management
  - Fermilab plays a critical role in maintaining the existence of the PAO via management — also does everything from cost & scheduling, to MOUs determining support level and resources from member institutions
  - Fermilab has brought modern management techniques (including include cost and schedule tracking, elements of systems engineering and quality assurance, and ES&H programs) to the field, impacting both current science and future generations of physicists

Pierre Auger Observatory — Technical @ FNAL

- Fermilab designed essentially all mechanical aspects and developed the production technologies for the surface detectors
  - Auger South tank design
  - Solar power system
  - Tank power control board electronics for advanced solar power controls
  - Auger North tanks and related insulation
  - Computing division support — data storage and non-event database at FNAL

Pierre Auger Observatory — Community

- A unique feature of the PAO is its broad, truly international character in that the project is not dominated by any country, region or institution
- Fermilab involvement was integral to creating a cohesive structure
  - Collaborators from 18 countries with backgrounds in cosmic ray physics, high energy physics, nuclear physics, astronomy, from large and small experiments — a mixture of national and scientific cultures
- Outreach — Auger specific (e.g., school presentations, publicly available data sets for student use, visitor center, dance parties (www.cosmicsensation.nl), parades, hot air balloon launches, etc.), Quarknet, Lederman Center programs
- Hosting ISVHECRI 2010 conference (June 2010); US Auger meeting (May 2010)

Fermilab Bringing Science Education to You!

QuarkNet

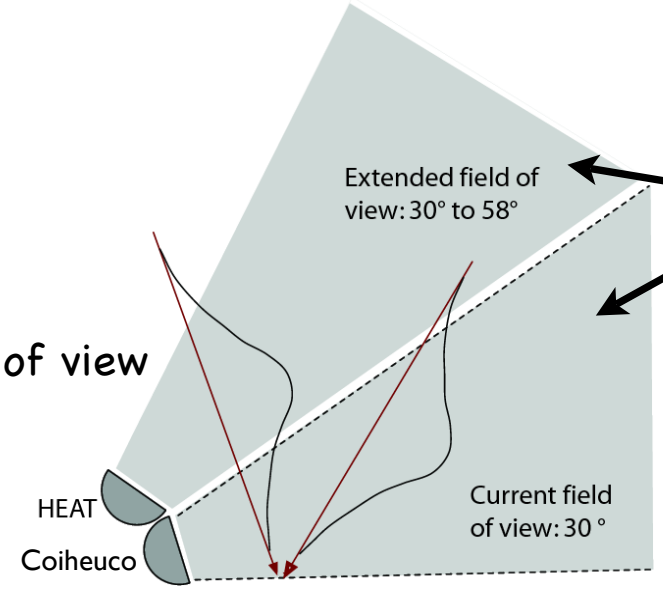
Pierre Auger Observatory — Future

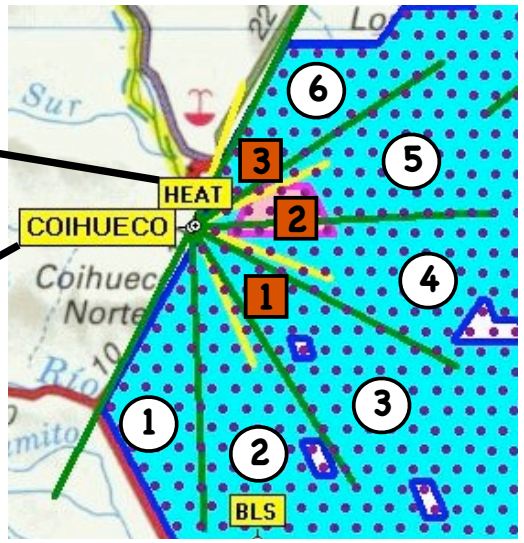
- FNAL currently plays a leading role on the Auger North RDA — proof of principle for very large arrays; platform for R&D for and beyond Auger North
- Continued data analysis will shed light on the goals of understanding the sources, composition, particle interaction properties fulfilling the OHEP mission
- Fermilab has management, engineering, computing, and analysis skills combined with experience building and running Auger South which positions us for success in future cosmic ray experiments

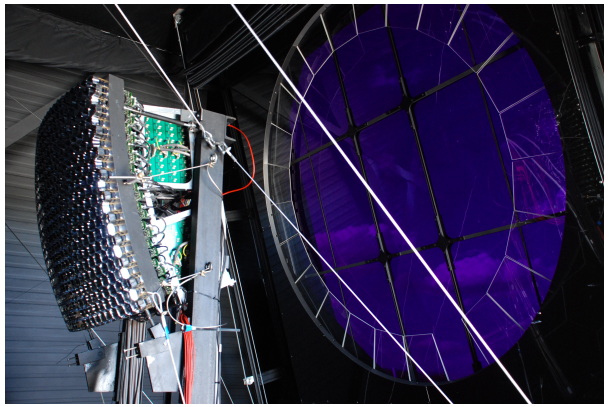
backup

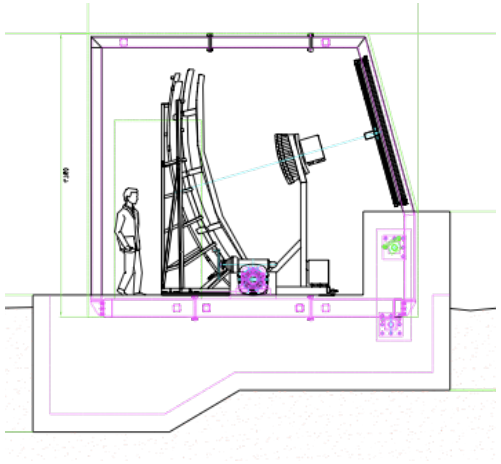
1. HEAT

- 3 tiltable telescopes
- Overlaps with Coiheuco FD
- 30°-58° elevation, extend field of view
- Energy ~ 10^{17} eV

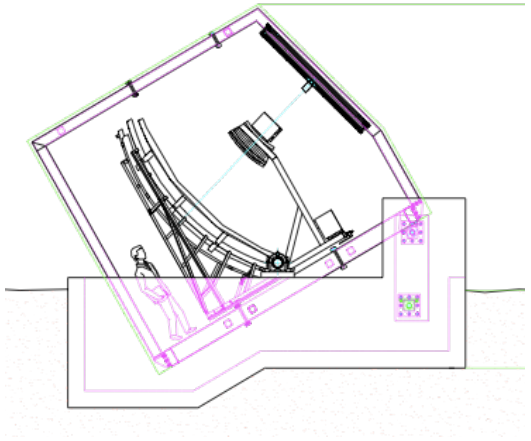








Calibration & maintenance position

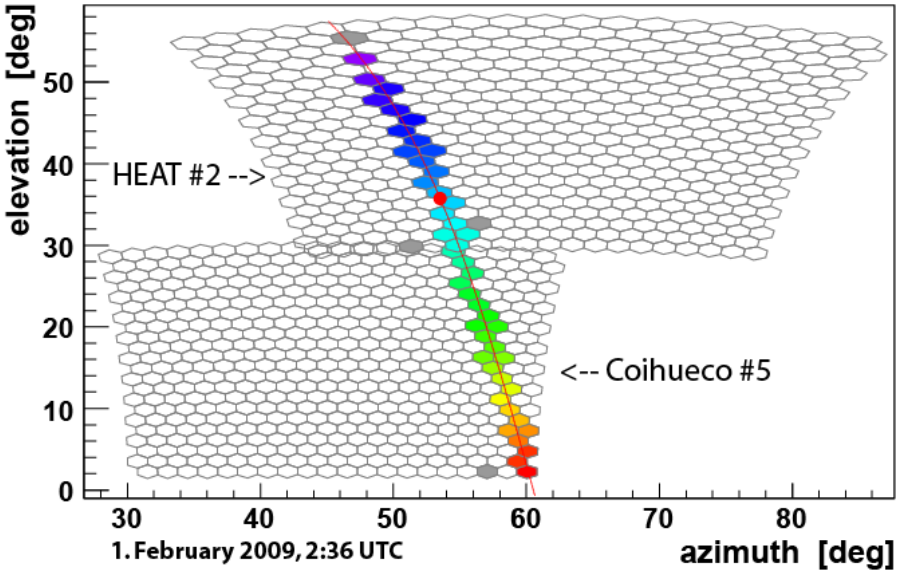


Data taking position

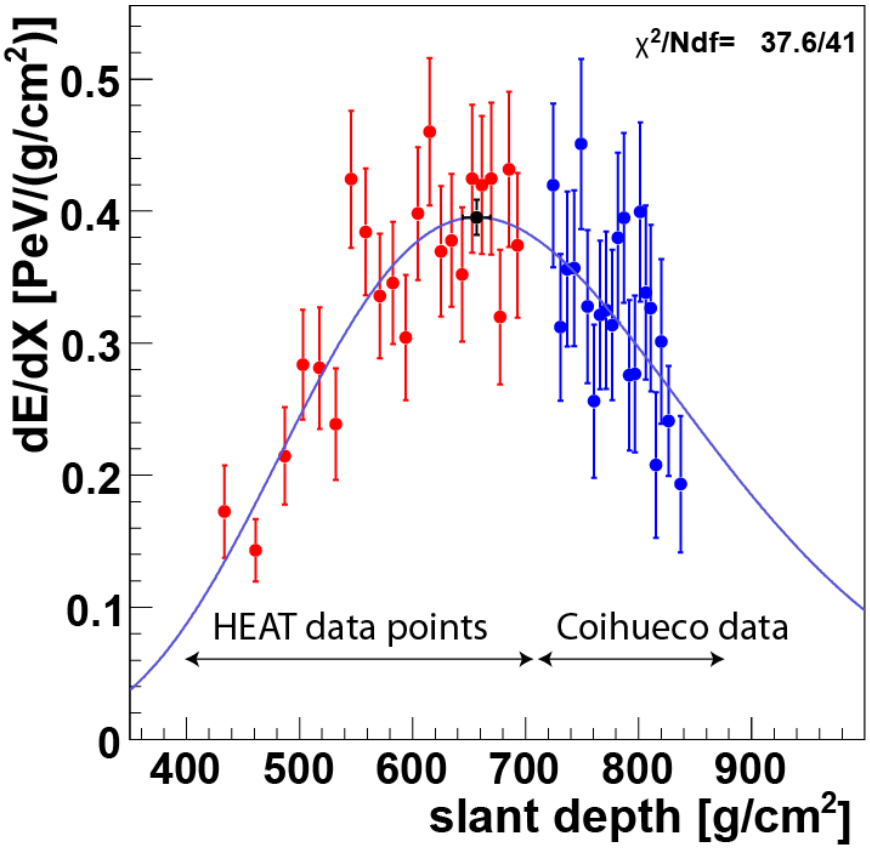
Can observe in both tilt and down positions

First high quality hybrid event with HEAT

Camera view with timing



Shower profile

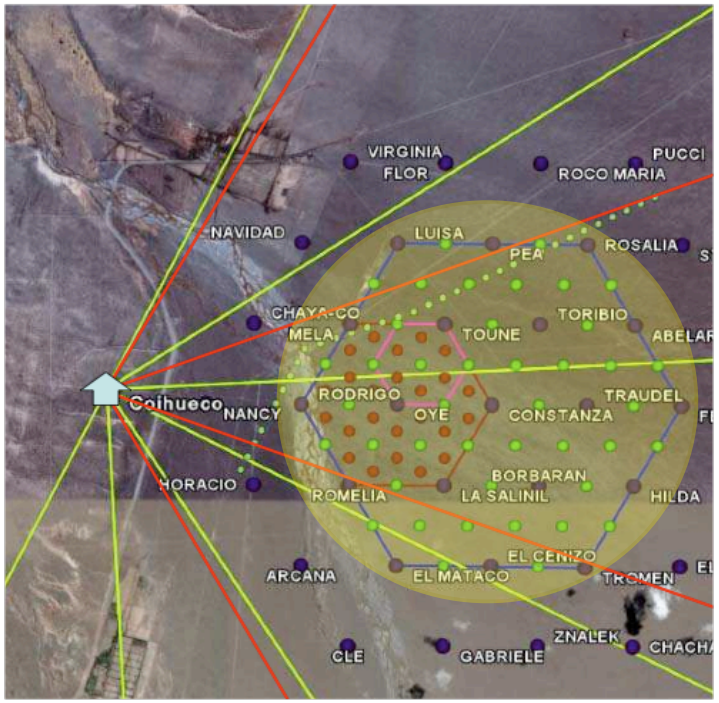


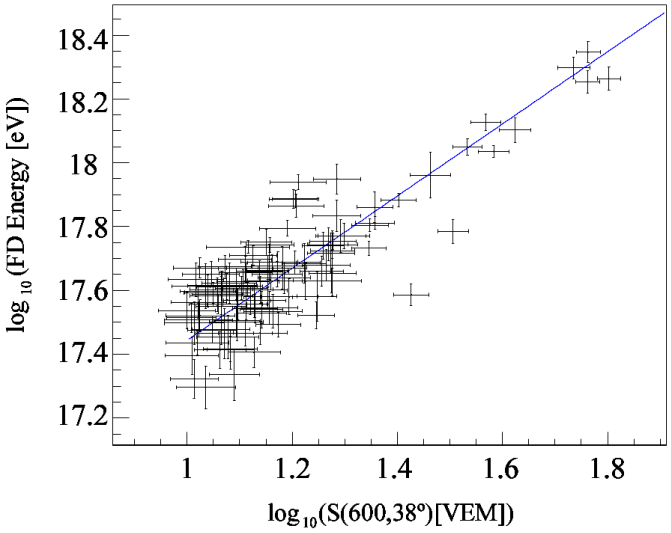
- Shower triggered in both telescopes independently
- Timing well matched
- Reconstruction of X_{max} requires combined data

E = (2.0 ± 0.2)·10^{17}eV
X_{max} = (657 ± 12) g/cm²
Distance: 2.8 km to FD

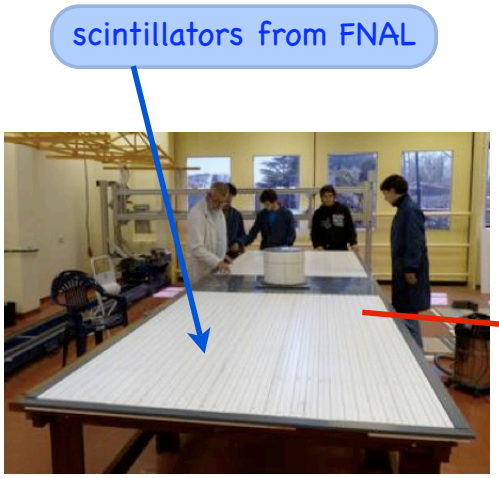
2. AMIGA (Auger Muons and Infill for the Ground Array)

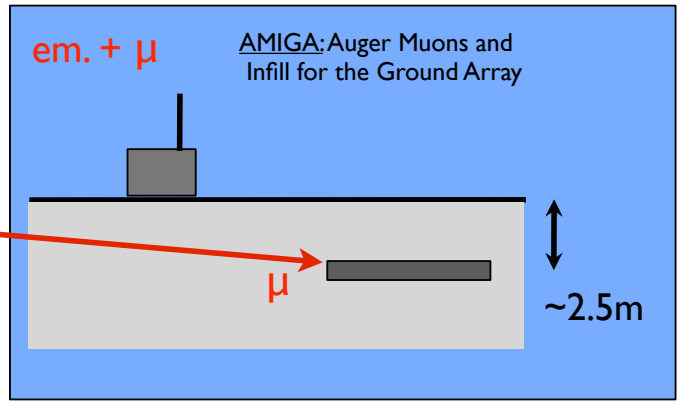
- 750m triangular grid
  - 61 water Cherenkov tanks +
  - 30 m^2 Minos-type scintillators underground
- Infill energy spectrum analysis in progress
- First muon detector buried in Nov 2009
- Deployment and analysis in progress





(more expected with HEAT)





3. AERA (Auger Engineering Radio Array)

- Coherent radiation from shower cascade
- 30-80 MHz
- Measure energy and composition
- Cost-effective, 100% duty-cycle
- Currently installing 24 stations over an area of 20 km^2

(prototypes)

These technologies are still in development and we do not yet know if we can build a successful experiment with them

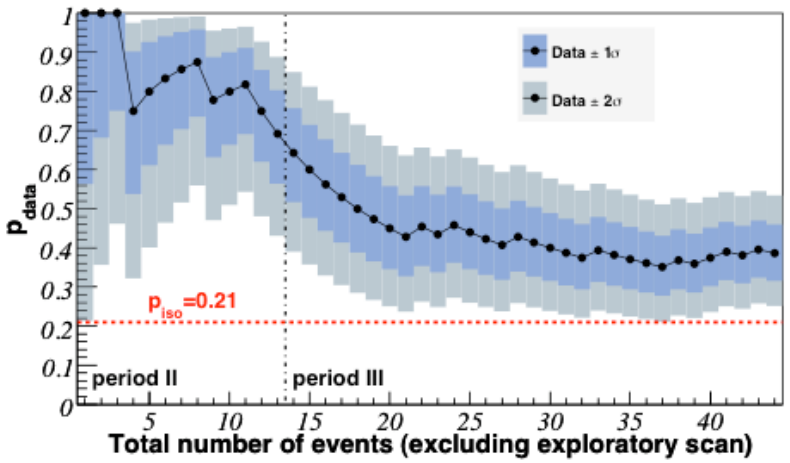
4. R&D on microwave detection

- Molecular bremsstrahlung by electrons in air shower with surrounding medium
- ~ 4 GHz
- Study ongoing at Ohio State Uni. and Uni. Chicago

Pierre Auger Observatory — Science @ FNAL

- Anisotropy studies @ FNAL
  - Plot only shows Poisson errors — no systematics
  - Improving analysis techniques used in catalogue based search
    - More advanced analysis methods
    - Incorporating and understanding the effects of systematics
  - Catalogue based correlation update publication in progress

Fraction of data correlating with VCV as a function of event number



Update in progress