Title: New Results from the Pierre Auger Observatory

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URL: http://pirsa.org/08060156

Abstract: The Pierre Auger Observatory in Malargue, Argentina, is the world\'s largest detector for the study of the origin of ultrahigh energy cosmic rays. The experiment stretches over 3000 km^2 and measures cosmic rays with energies above 10^18 eV using two complementary detector types: an array of 1600 particle detectors on the ground, and 4 fluorescence detectors overlooking the ground array from the periphery. The Observatory is now nearing completion, but scientific data taking started at the beginning of 2004. The analysis of the data shows first indications that the arrival direction distribution of the highest energy cosmic rays is not isotropic, but might be associated with the positions of nearby extragalactic objects. In this talk, I will review recent results from the first few years of data taking.

# New Results from the Pierre Auger Observatory


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***University of Wisconsin-Madison***

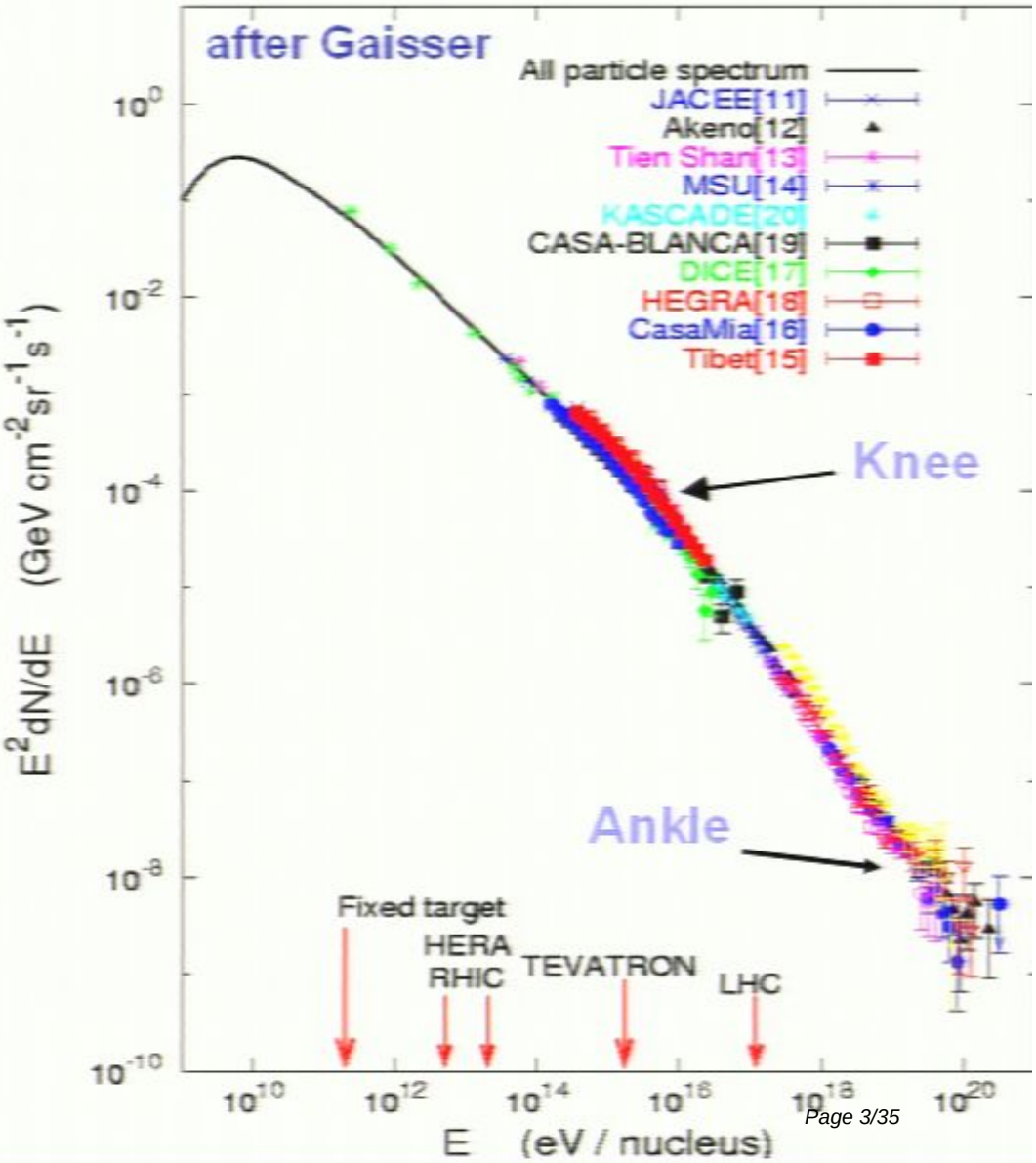
**PASCOS '08**

**Waterloo, June 5, 2008**

THE UNIVERSITY of WISCONSIN MADISON

# Why Study UHECRs?

- Measured spectrum extends to $E > 10^{20}$ eV - the highest particle energies observed in the Universe.
- Where and how are cosmic rays accelerated to these energies?
- Origin at energies above GeV is unknown - no astrophysical object has ever been definitively identified as an accelerator of high energy nucleons.
- The high energy end of the spectrum probes physics at energies still out of reach of any man-made accelerator - search for new physics...



# Why Study UHECRs?

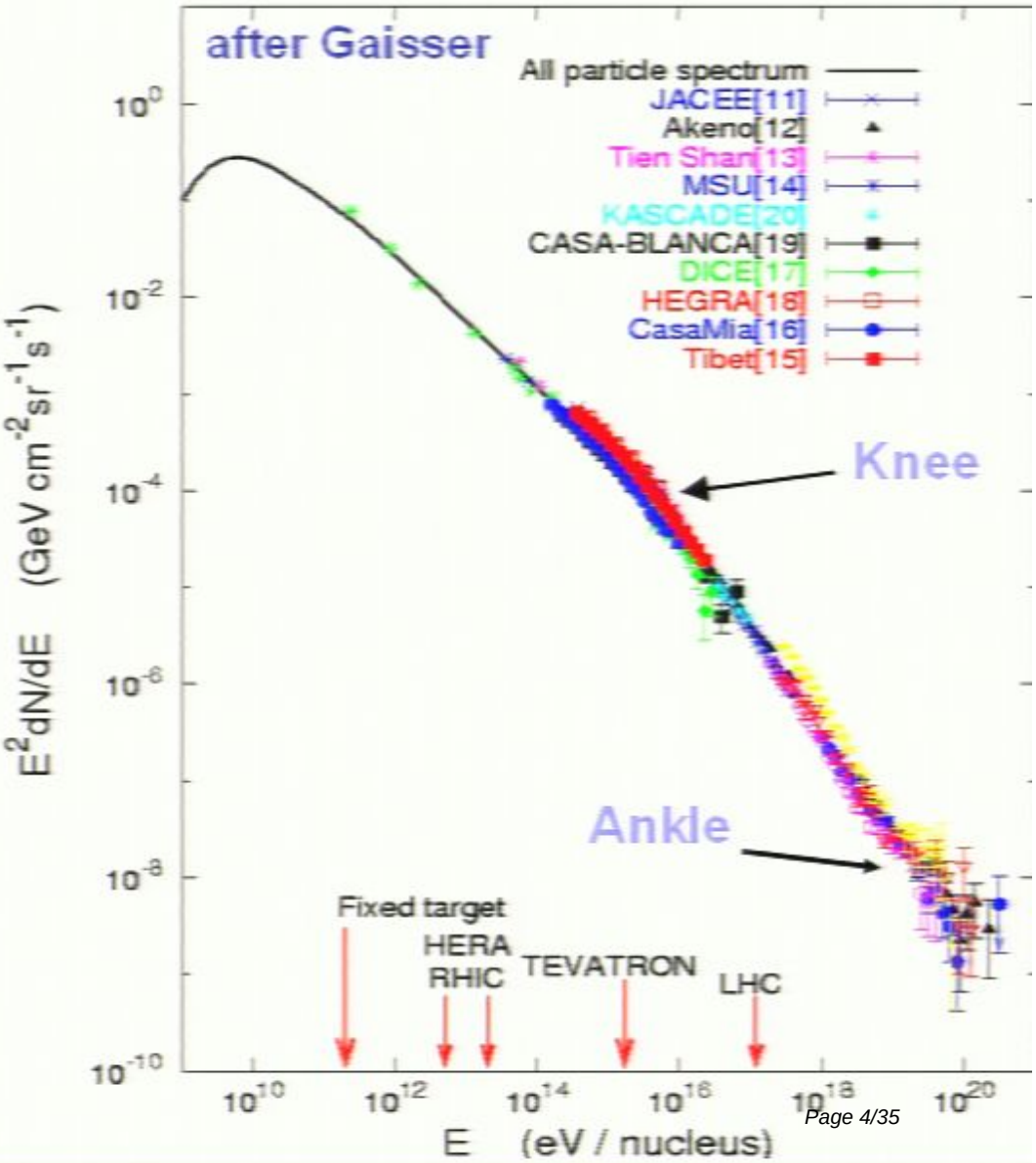
- Accessible to experiment:
  - Energy spectrum.
  - Chemical composition.
  - Arrival directions.
- *Astronomy* with charged particles?

*Problems*

- Protons and nuclei are *charged* and therefore subject to deflection in Galactic and intergalactic magnetic fields (of unknown strength)!

$$R \cong 1\,\mathrm{kpc}\left[\frac{E_{EeV}}{B_{\mu G}}\right]\frac{1}{Z}$$

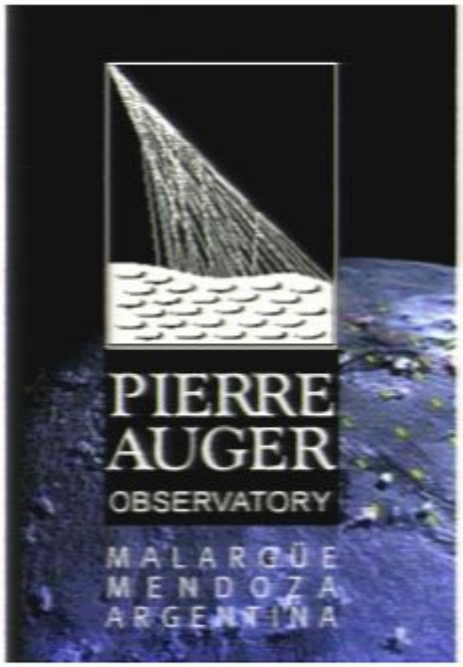
- Rate is 1 per km$^2$ per century…



# Pierre Auger Observatory

*International effort involving more than 350 scientists at 72 institutions in 18 countries:*

- **Argentina, Australia, Bolivia, Brazil, Czech Republic, France, Germany, Italy, Mexico, Netherlands, Poland, Slovenia, Spain, United Kingdom, USA, Vietnam**



# Auger Observatory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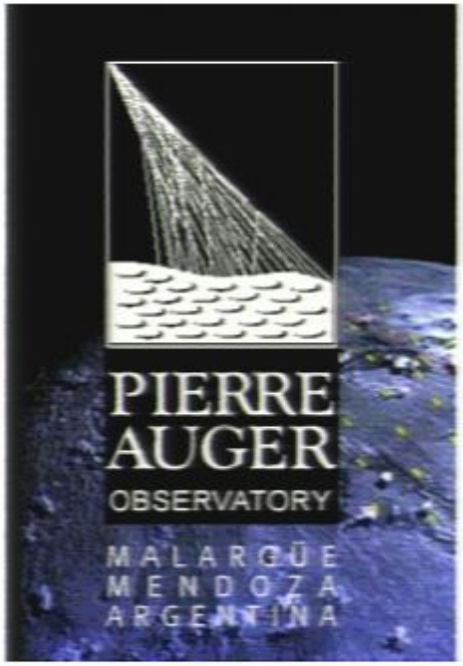
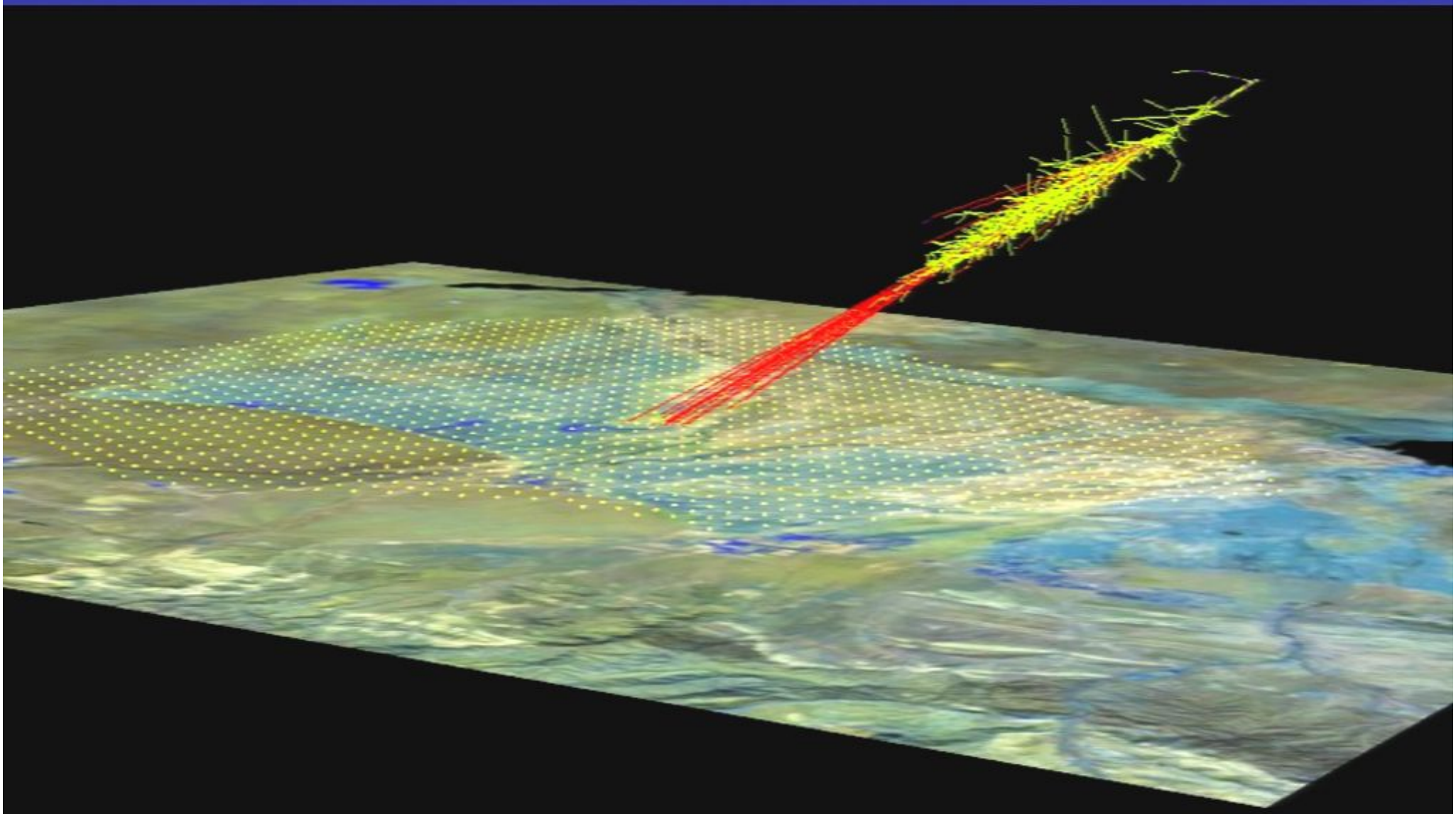


# Detection Techniques



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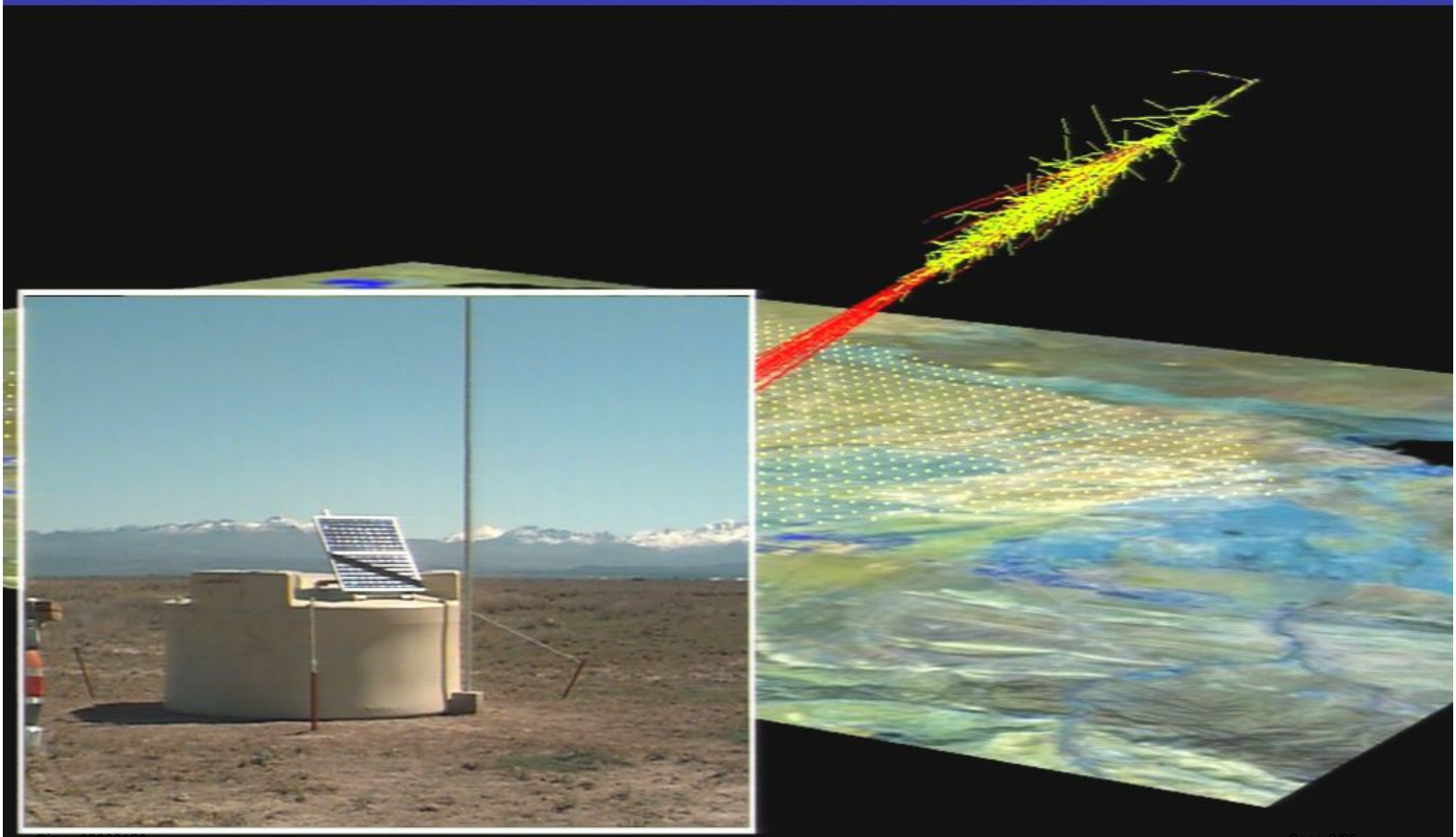

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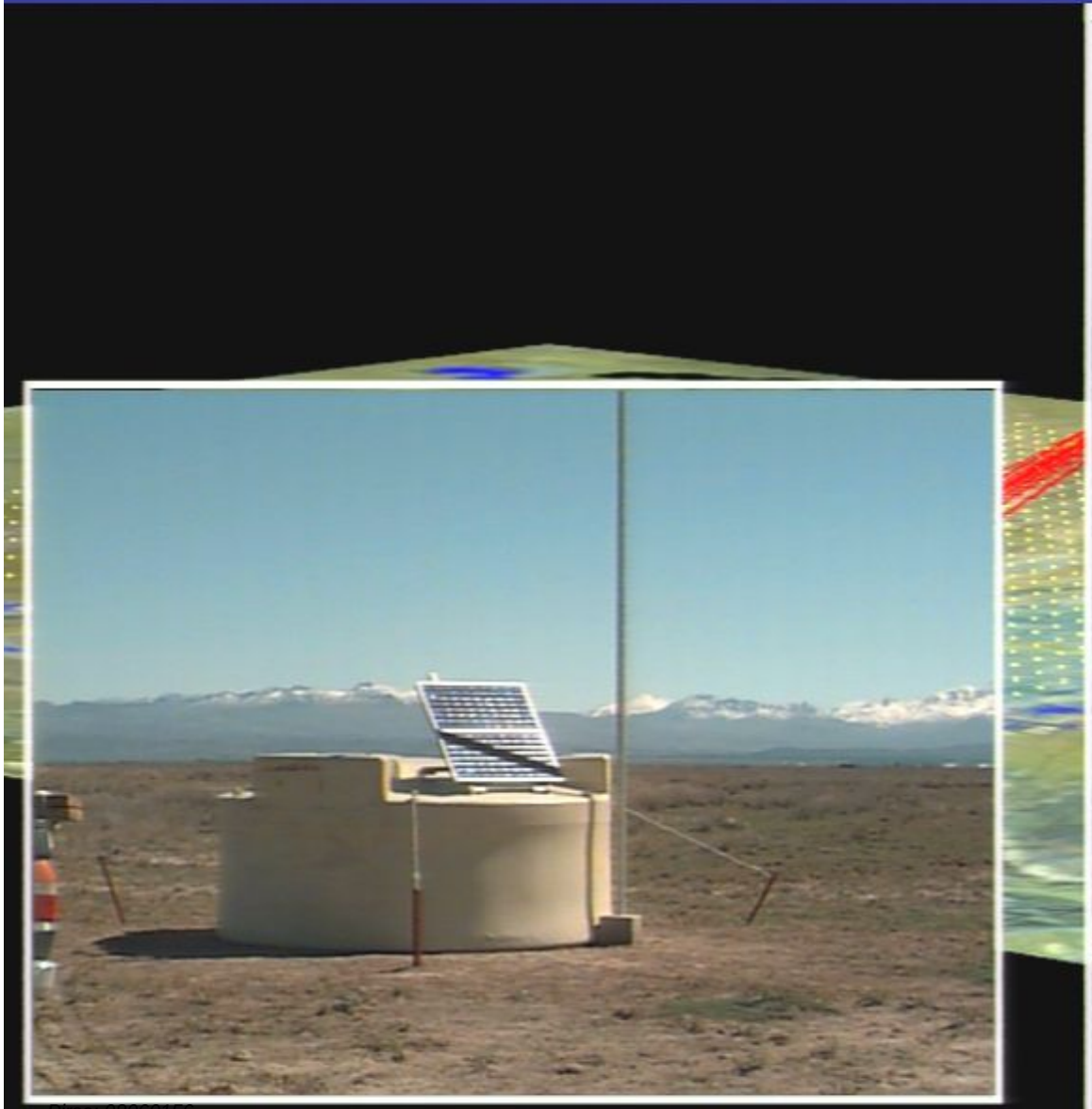
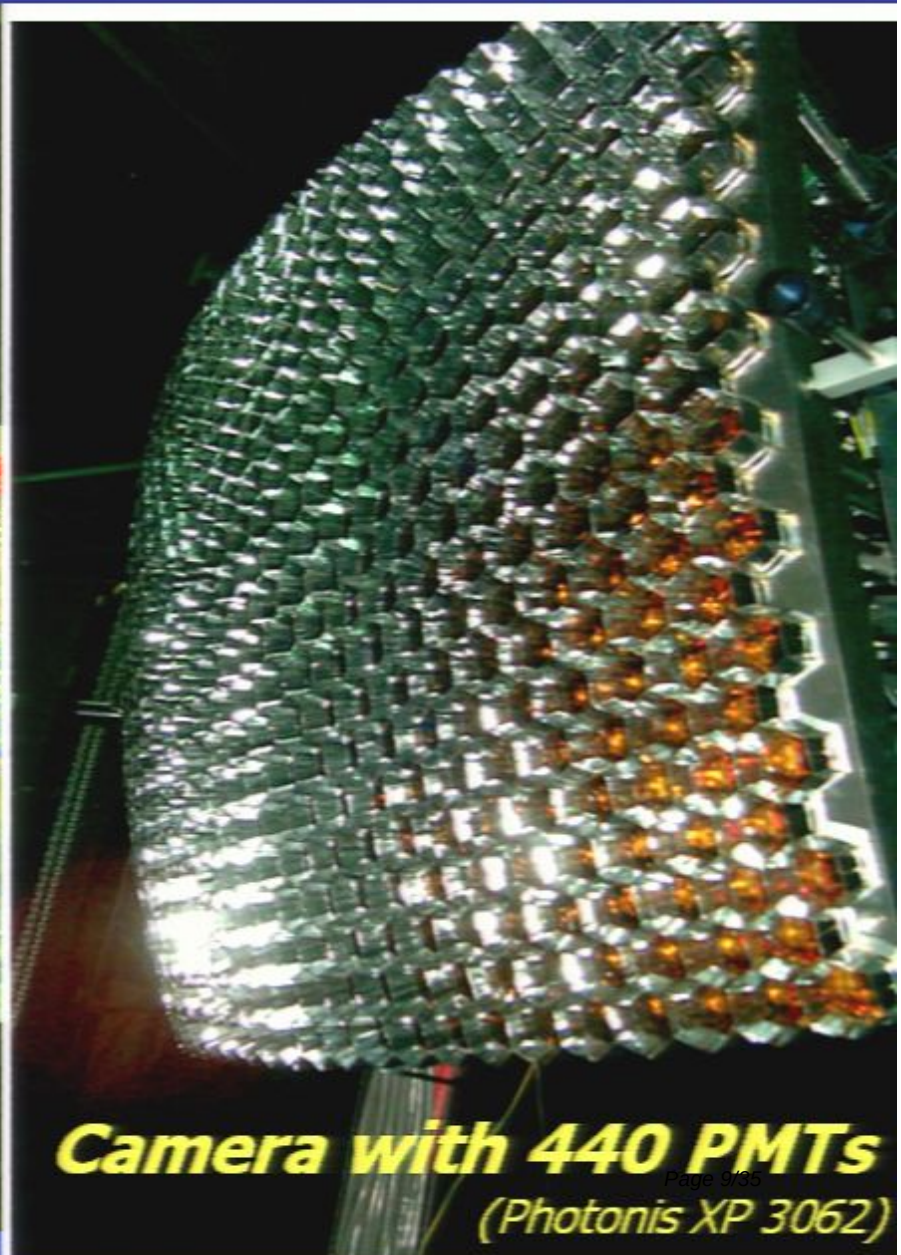




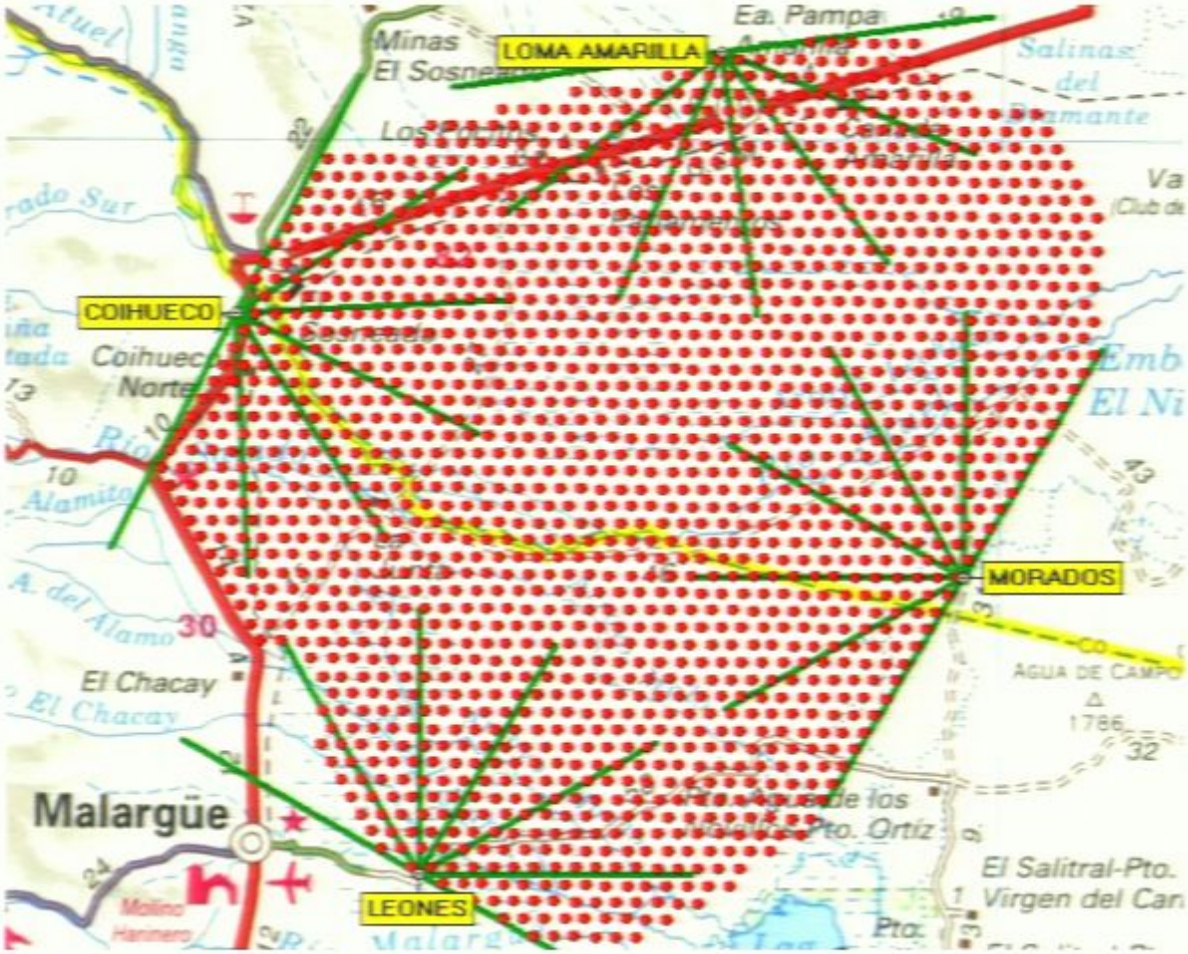
**Camera with 440 PMTs**
*(Photonis XP 3062)*

# Pierre Auger Observatory

*Hybrid Detector*

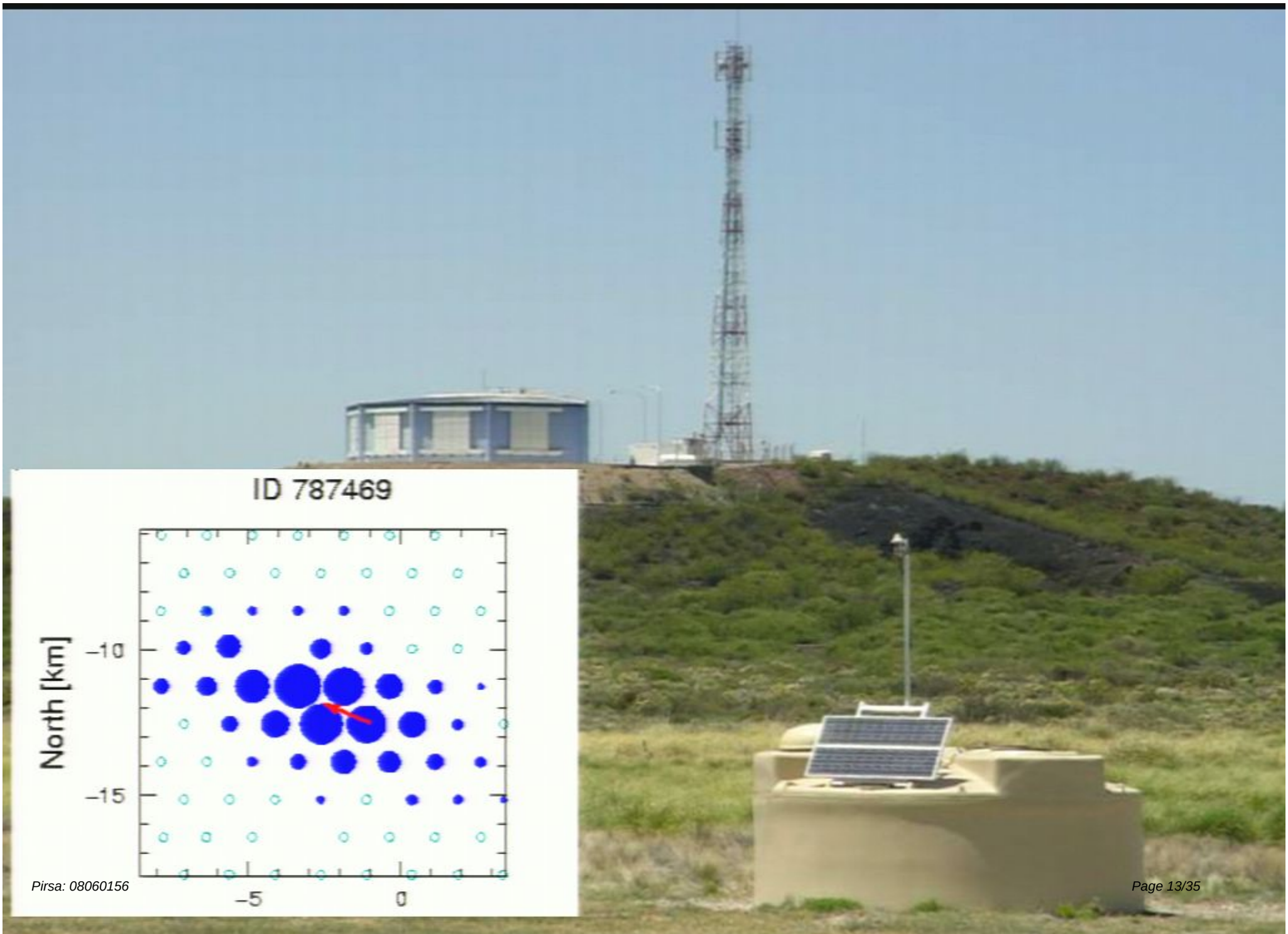
- Auger combines a surface detector array (SD) and fluorescence detectors (FD).
- 1600 surface detector stations with 1500 m distance.
- 4 fluorescence sites overlooking the surface detector array from the periphery.

- 3000 km$^2$ area.
- 1 Auger year = 30 AGASA years (SD).




http://www.auger.org


Surface Detector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North [km]
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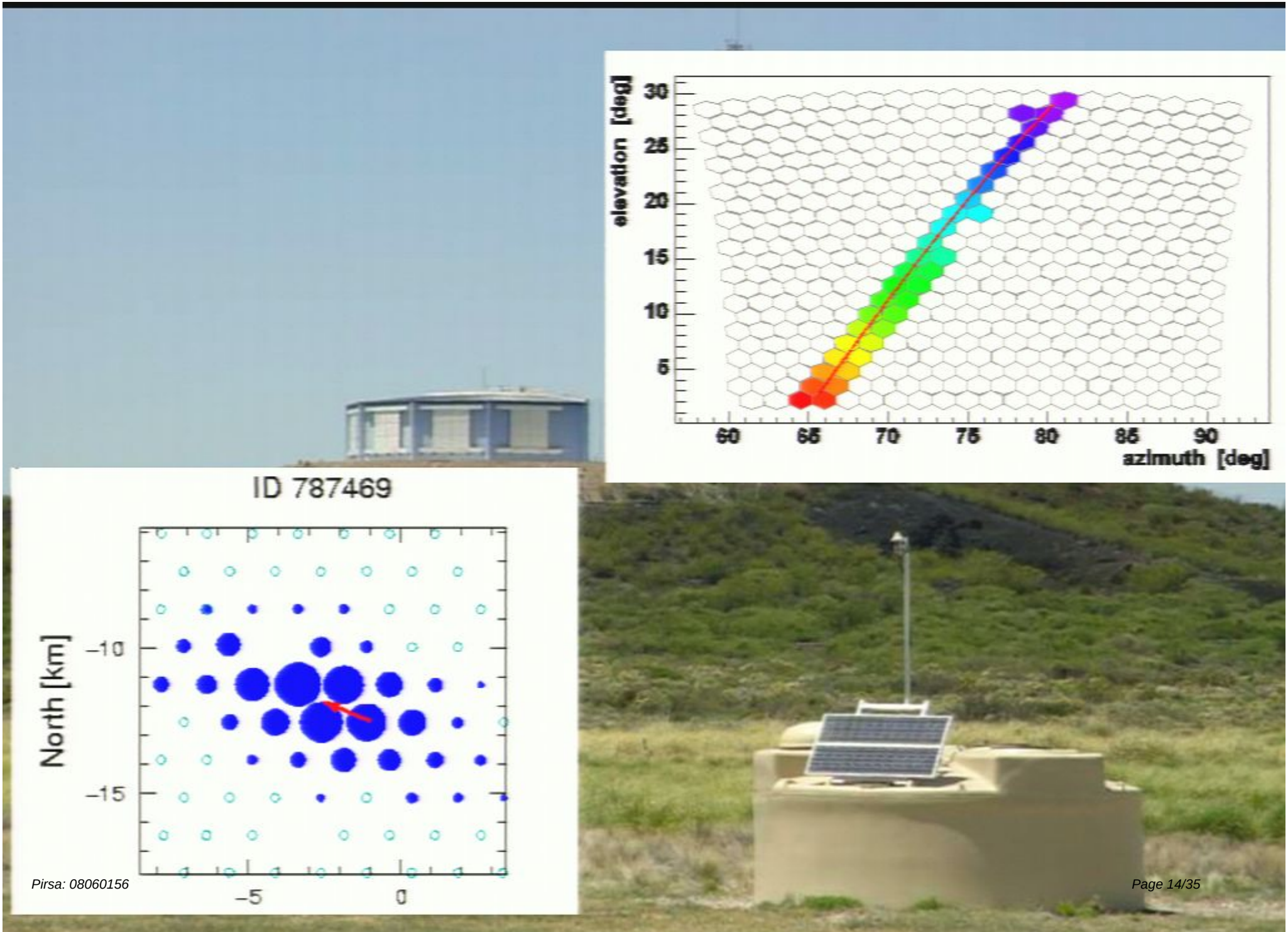
elevation [deg]
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azimuth [deg]
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North [km]
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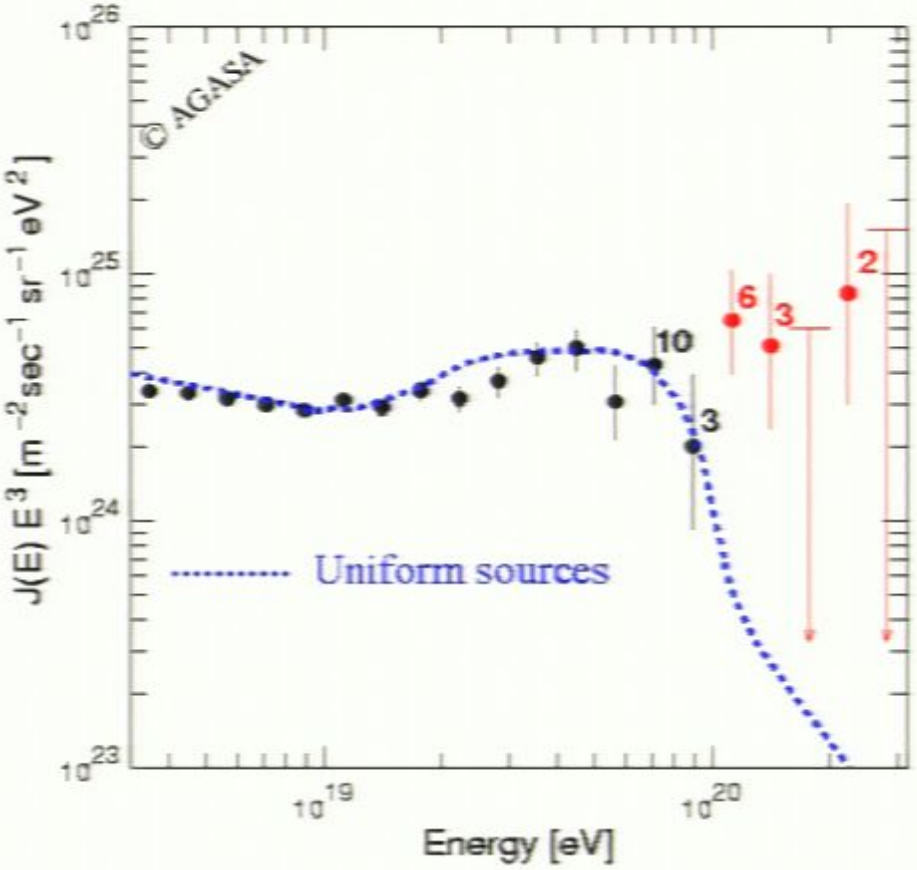
# Energy Spectrum

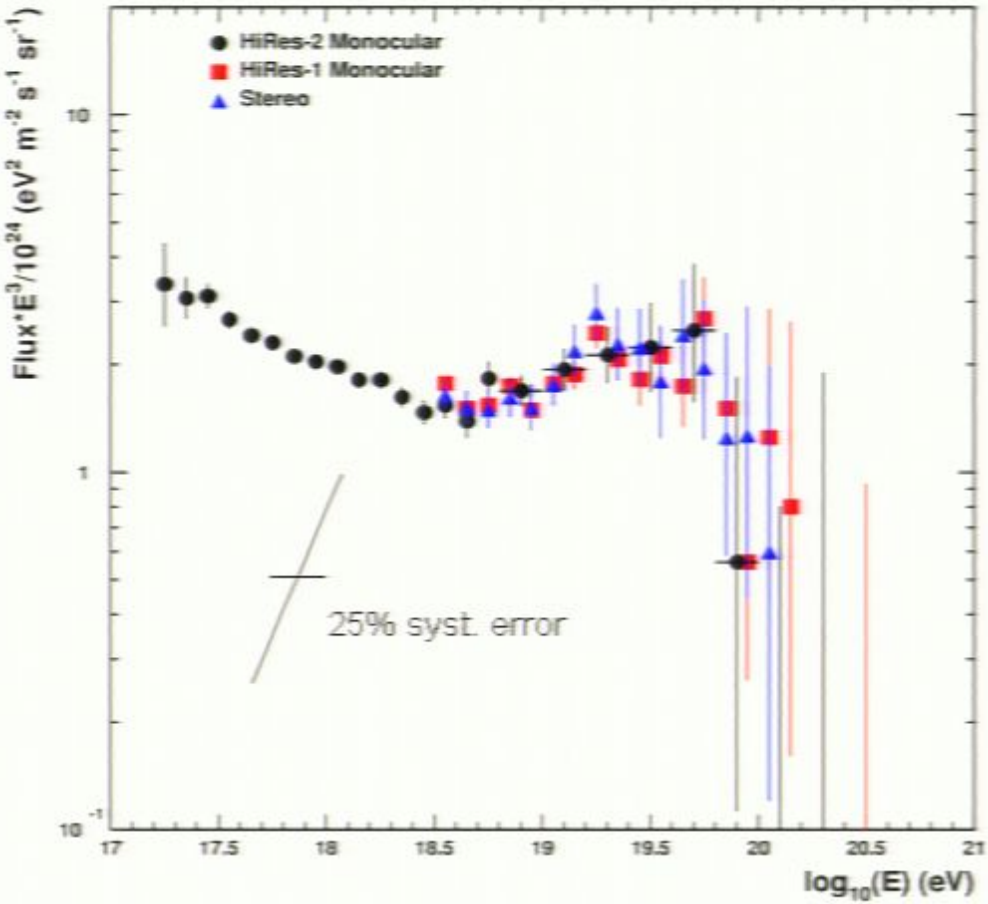
Chemical Composition

Arrival Directions

# GZK Suppression?




M. Takeda et al., PRL 81 (1998) 1163

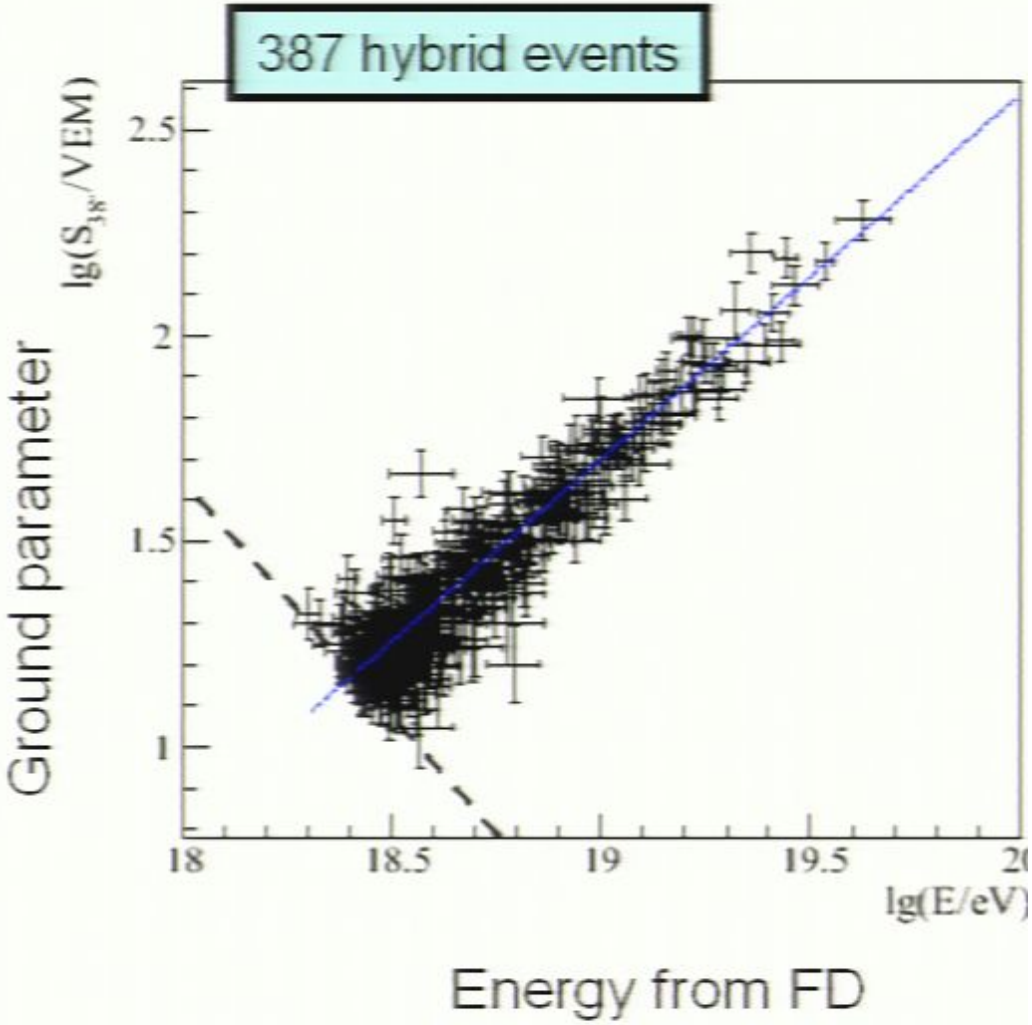



HiRes Collab., PRL, in press (2007)

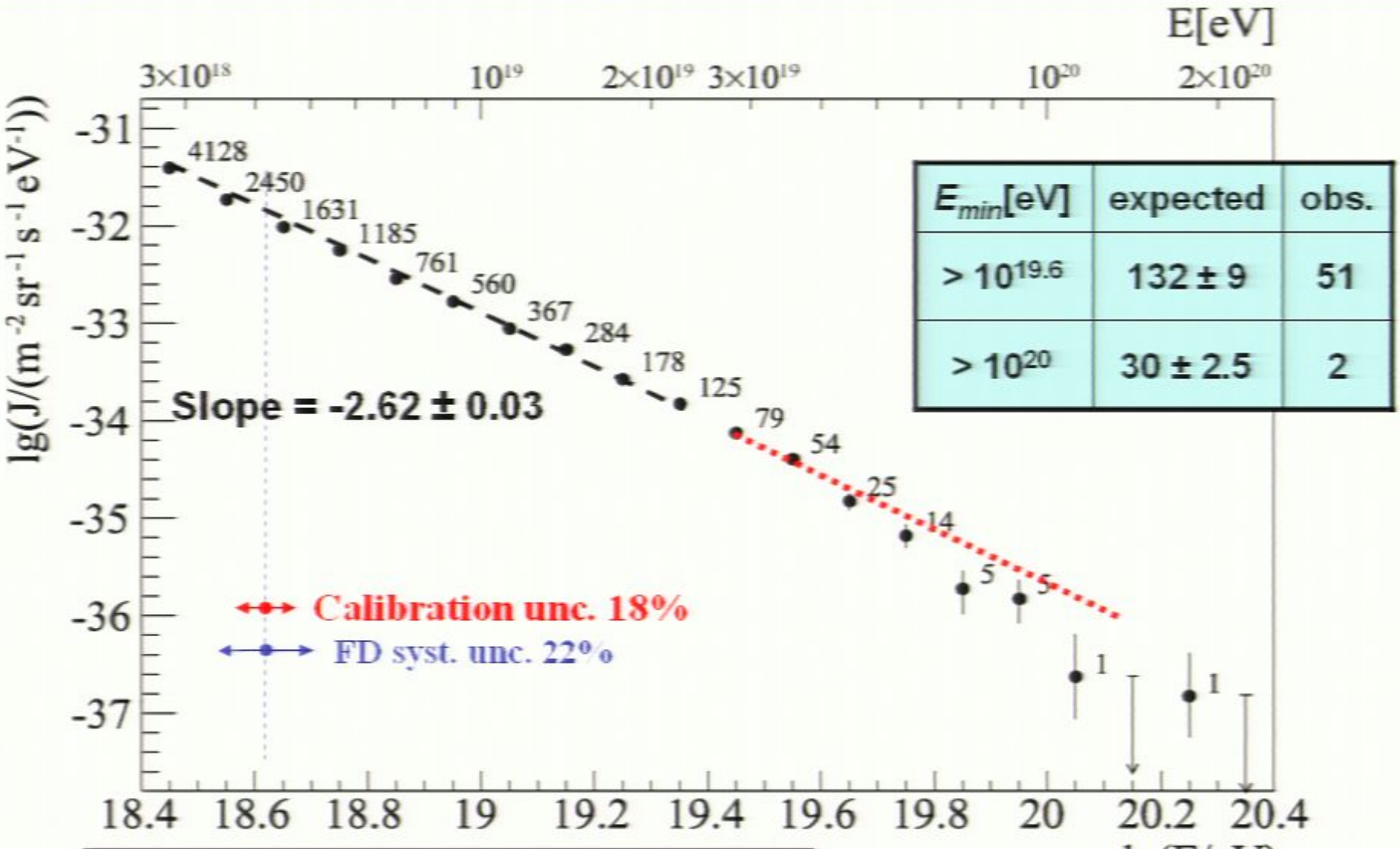
# Auger Energy Spectrum

***Hybrid Advantage***

- **Fluorescence detector gives nearly calorimetric energy measurement (with 10% duty cycle).**
- **Energy scale is determined from the FD data.**
- ***Hybrid data*** **used to calibrate the energy measurement of the surface detector array.**



# Energy Spectrum SD < 60°

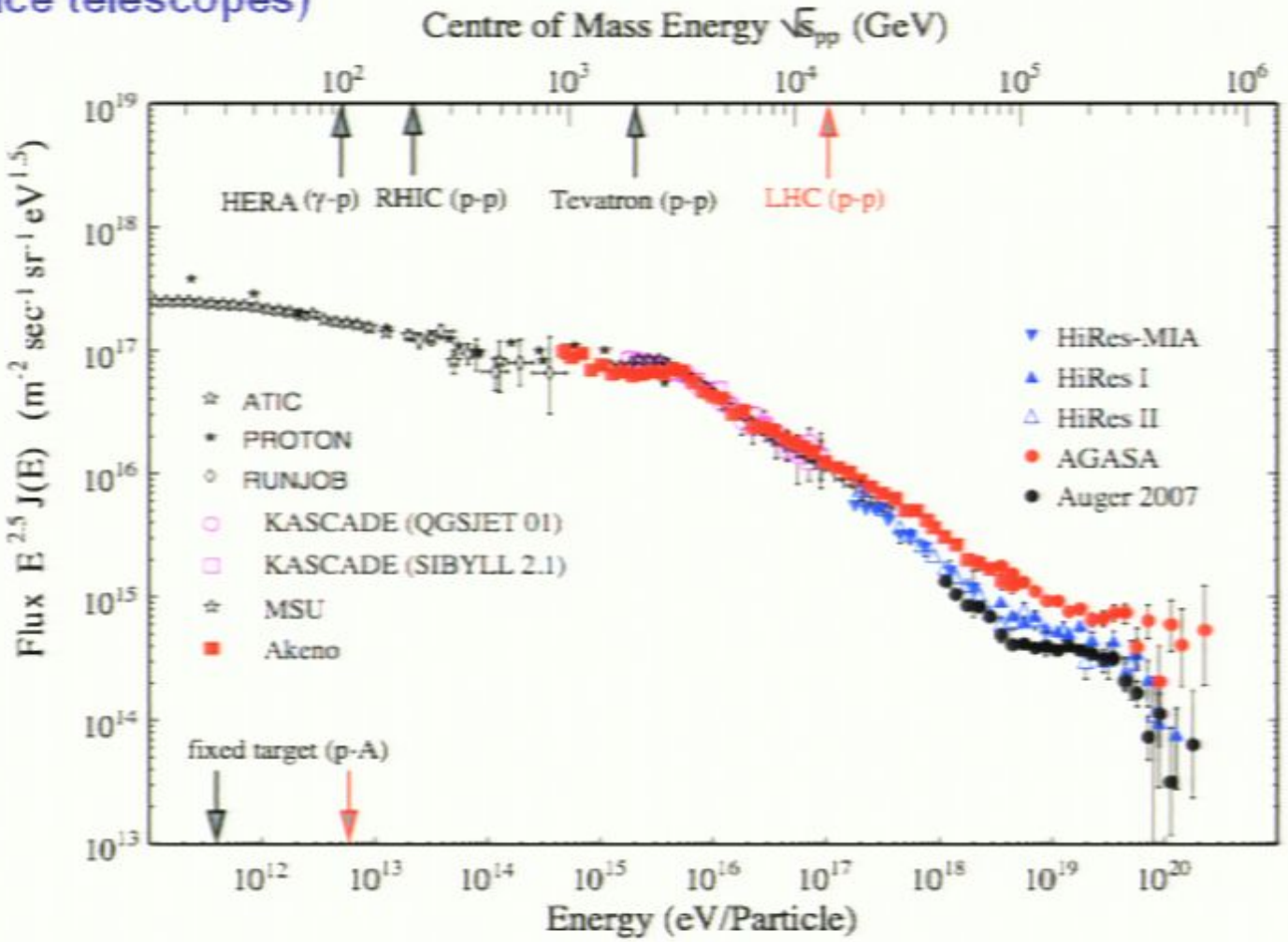



| $E_{min}$[eV] | expected | obs. |
|---|---|---|
| > $10^{19.6}$ | 132 ± 9 | 51 |
| > $10^{20}$ | 30 ± 2.5 | 2 |

**5165 km² sr yr ~ 0.8 full Auger year**

# Comparison

AGASA (surface array)
HiRes (fluorescence telescopes)
Auger (hybrid)



Energy Spectrum

# Chemical Composition

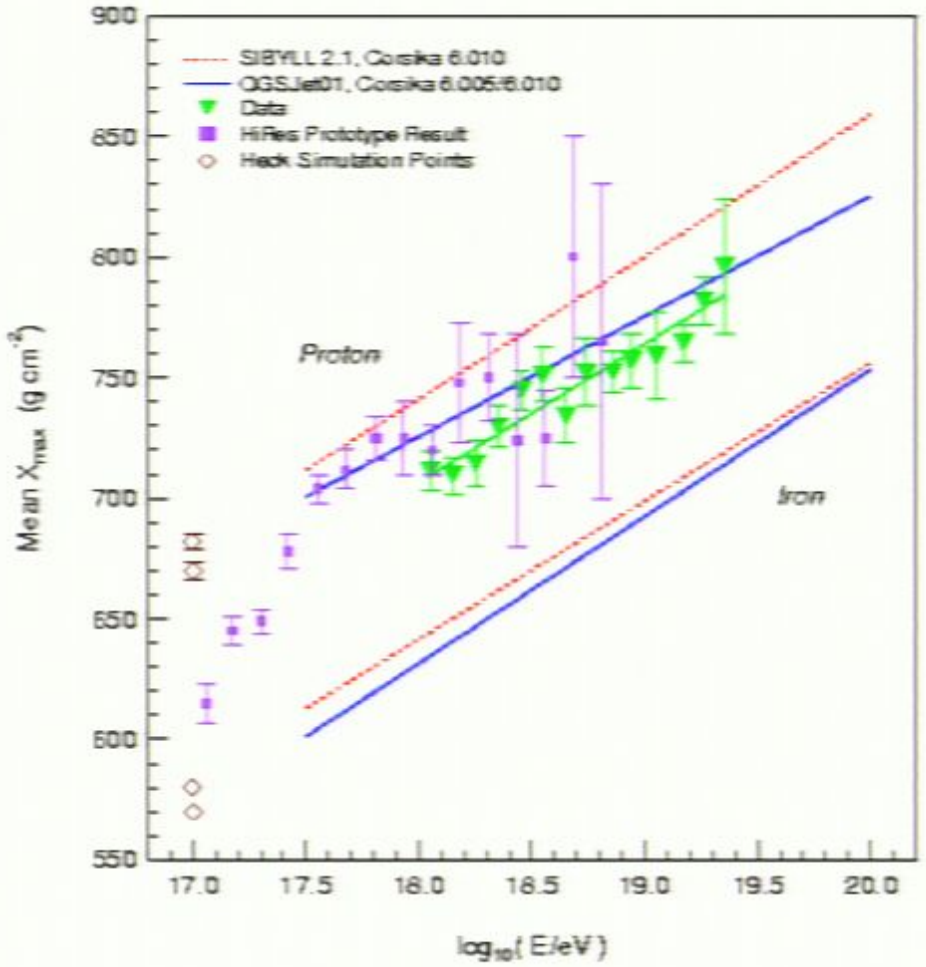
Arrival Directions

# Chemical Composition

- *Elongation rate* (mean shower maximum vs. energy) indicates the dominant chemical component, but we have to compare to simulations to interpret the data (strong model dependence!).

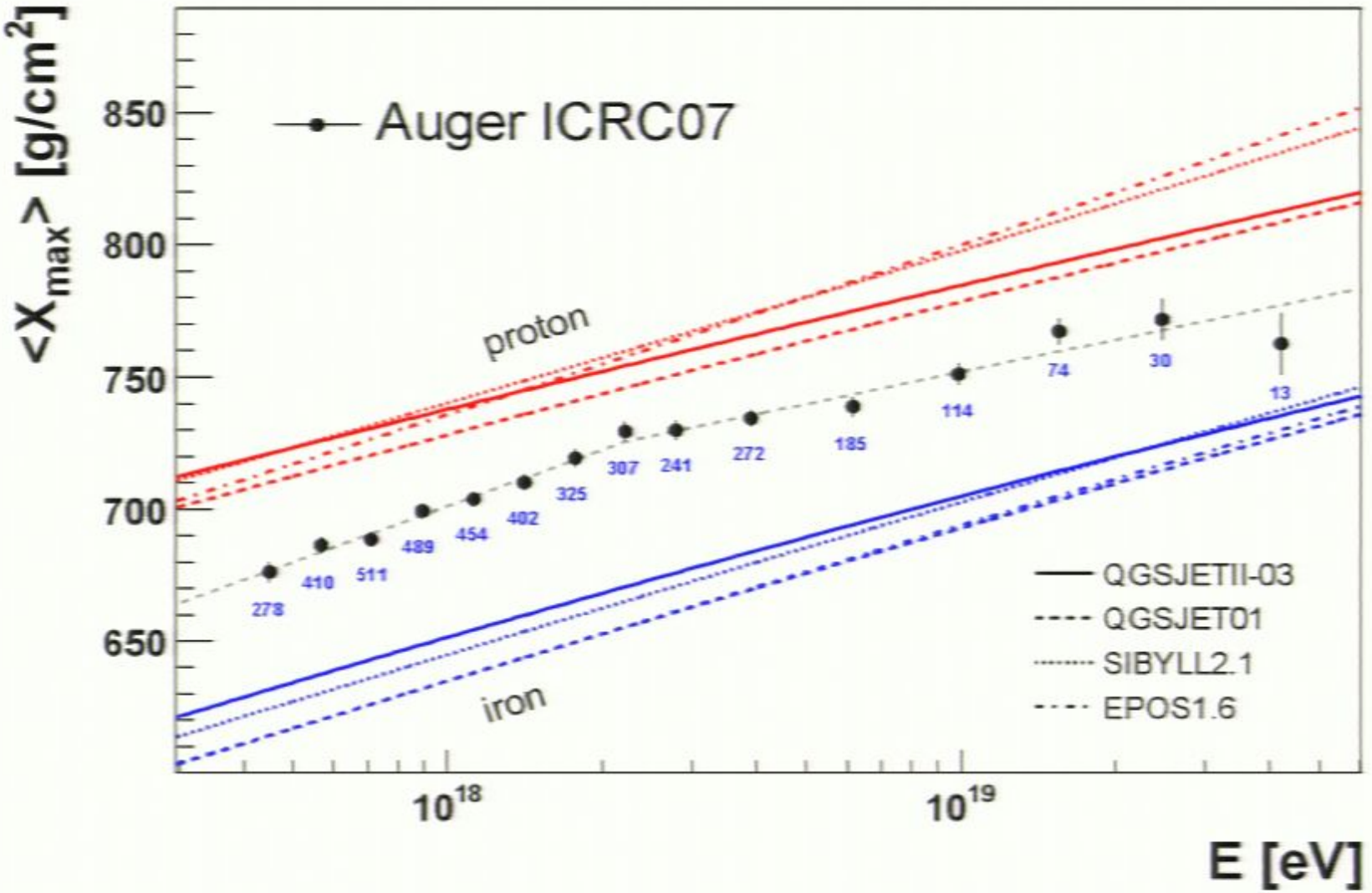
*HiRes Results*

- Transition from "heavy" to "light" between $10^{17}$ eV and $10^{18}$ eV.
- HiRes stereo measurement of elongation rate and mean shower maximum favors light composition above $10^{18}$ eV (80% "proton," 20% "iron").

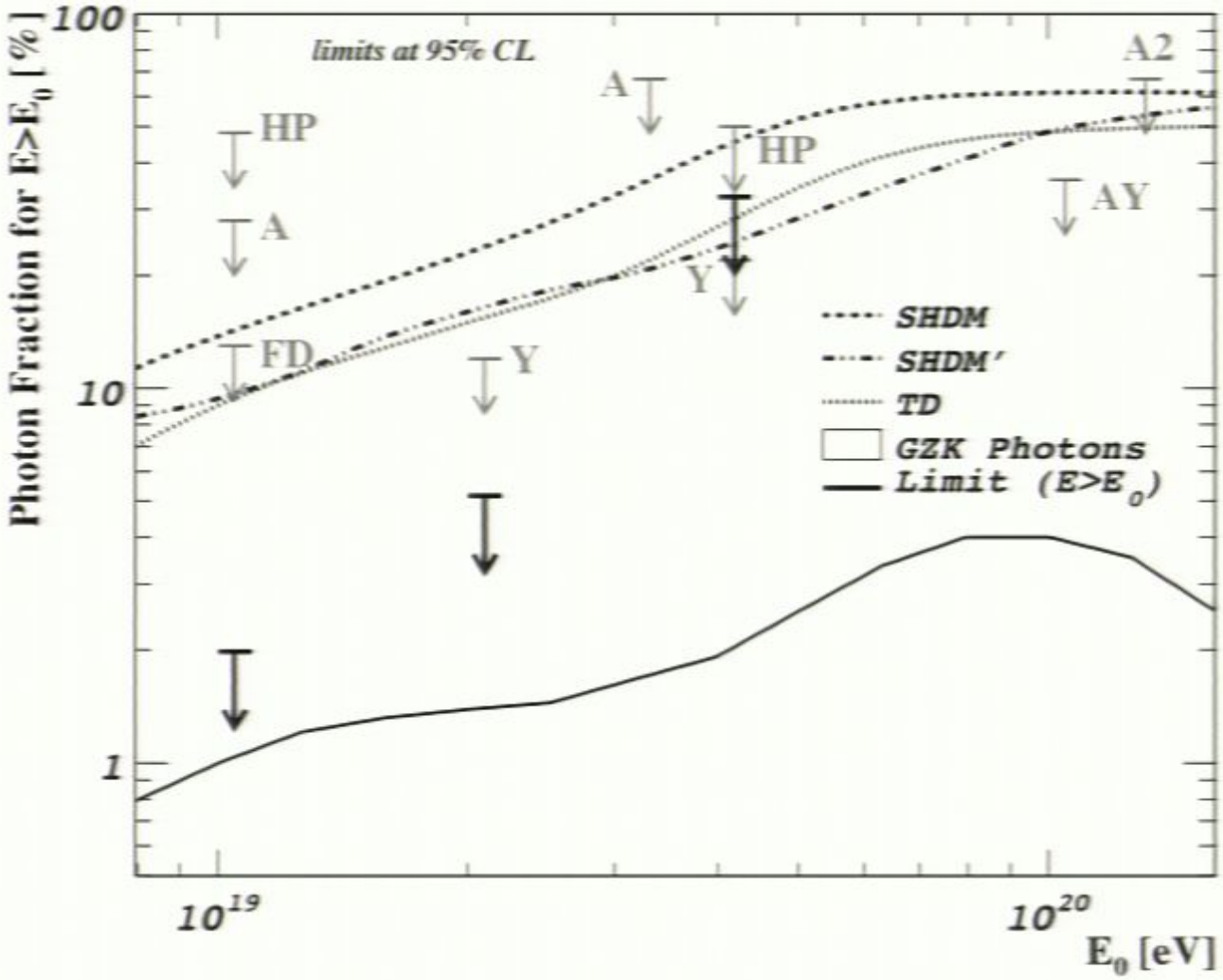



HiRes Collaboration, Astrophys. J. 622 (2005) 910

# Auger Chemical Composition



# Photon Limit




Auger Collaboration, Astroparticle Phys. 29 (2008) 243 (arXiv:0712.1147)

Energy Spectrum

Chemical Composition

# Arrival Directions

# Cosmic Ray Astronomy

*Question*

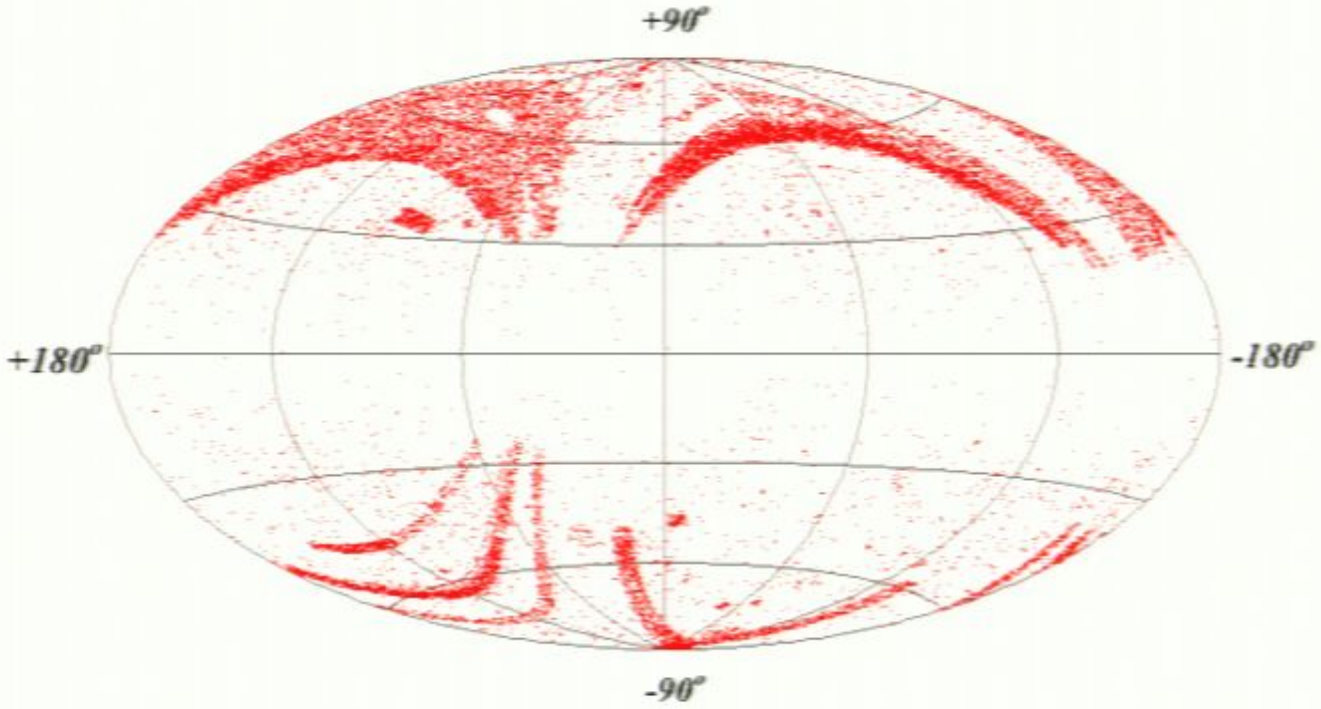
- The existence of the GZK suppression suggests that sources of the highest energy cosmic rays are at large distances (= extragalactic).
- Is it possible to observe the closest sources (sources within the GZK "horizon") *directly*?

- Searches for point sources with previous experiments have been unsuccessful.
  - Magnetic field might scramble arrival directions even for the closest sources.
  - The number of sources might be large and sources might generally be weak.

- From past experience, the signal is expected to be weak, and first evidence for sources might come from a *statistical analysis* rather than from a direct source search. Possible examples are:
  - Searches for clustering of cosmic ray arrival directions.
  - Searches for correlations with known astrophysical source classes (AGN, BL Lacs, ...)

# AGN Catalog

- 12th Catalog of Quasars and Active Nuclei by Veron-Cetty and Veron (Astron. & Astrophys. 455 (2006) 773).
  - 85,221 quasars.
  - 1,122 BL Lacs.
  - 21,737 active galaxies (694 with distance $D < 100$ Mpc).



# Analysis Method

*Two-step analysis*

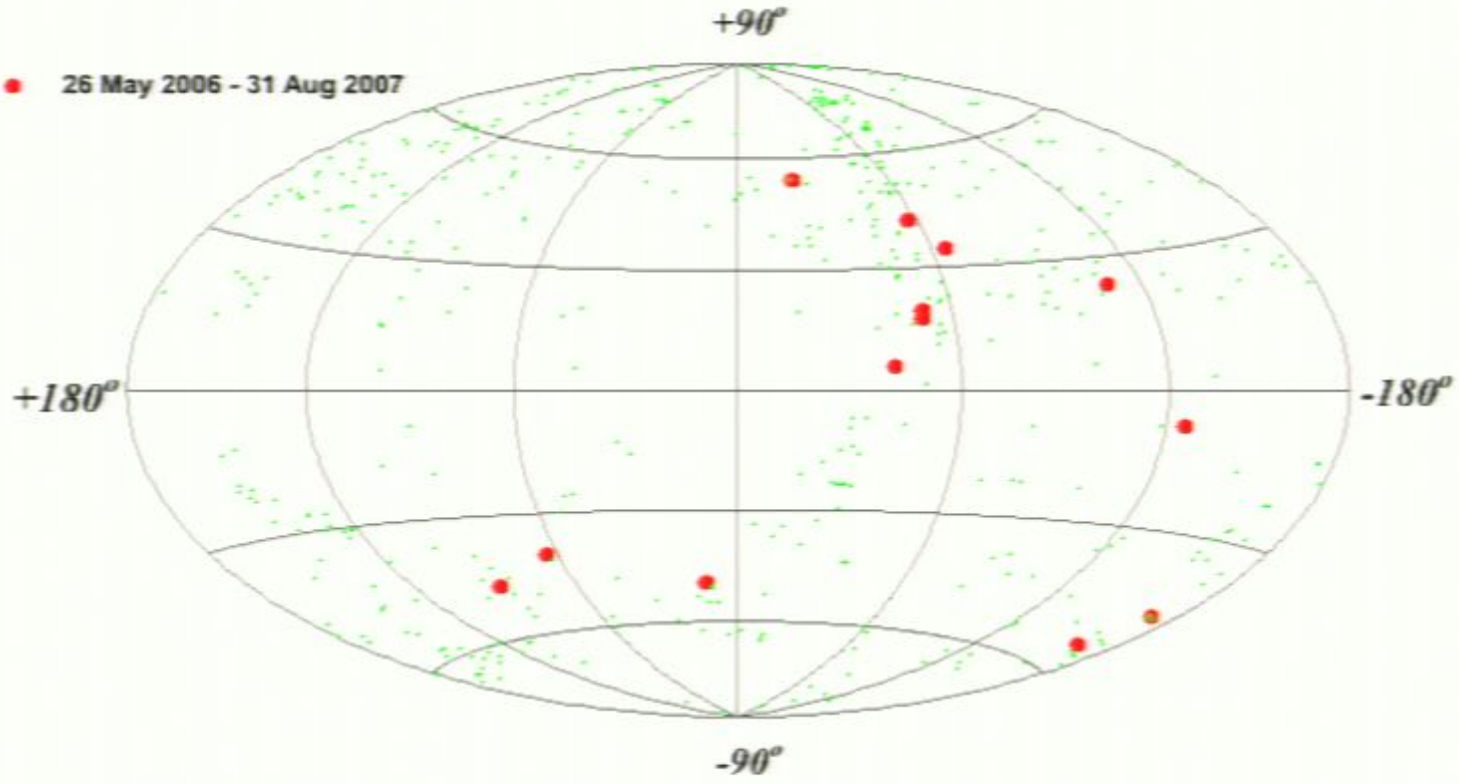
- *Exploratory search* to determine the optimal parameter set that maximizes the correlation
  - $z_{max} = 0.018$ ($D_{max} = 75$ Mpc)
  - $E_{th} = 56$ EeV
  - $\Psi = 3.1°$ ($p = 0.21$)
- *Test of the correlation* with independent data to determine the chance probability of the correlation using the parameter set determined in the exploratory scan

| | # events $E > 57$ EeV | # correlated with AGN | # expected for isotropy |
|---|---|---|---|
| Exploratory set<br>1 Jan 04 – 26 May 06 | 15 | 12 | 3.2 |
| Independent set<br>26 May 06 – 31 Aug 07 | 13 | 8 | 2.7 |

- Chance probability in independent set : 1%

# Result of Test

- Skymap of 472 AGN with $z < 0.018$ (green dots) and Auger events $E > 56$ EeV for exploratory scan (black) and independent set (red).



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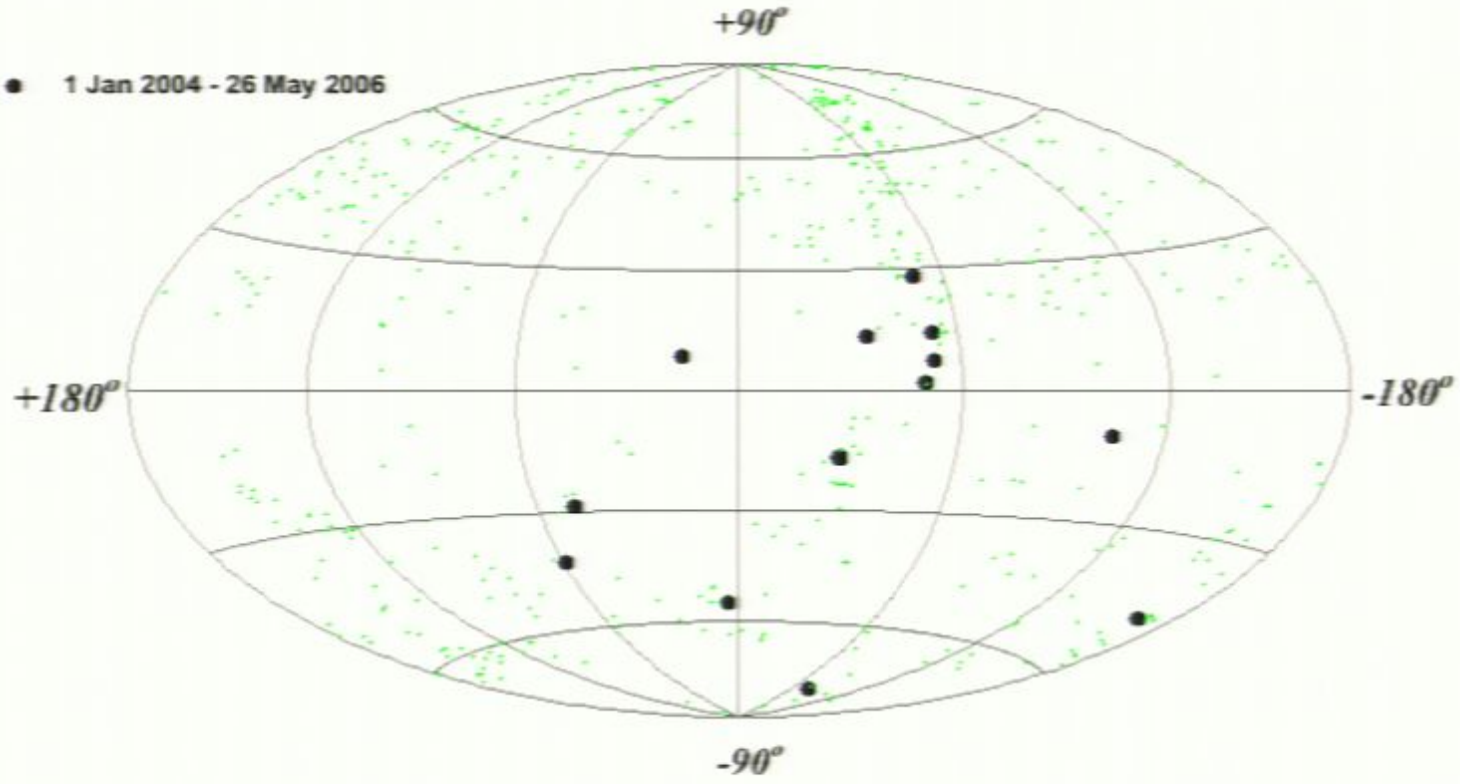

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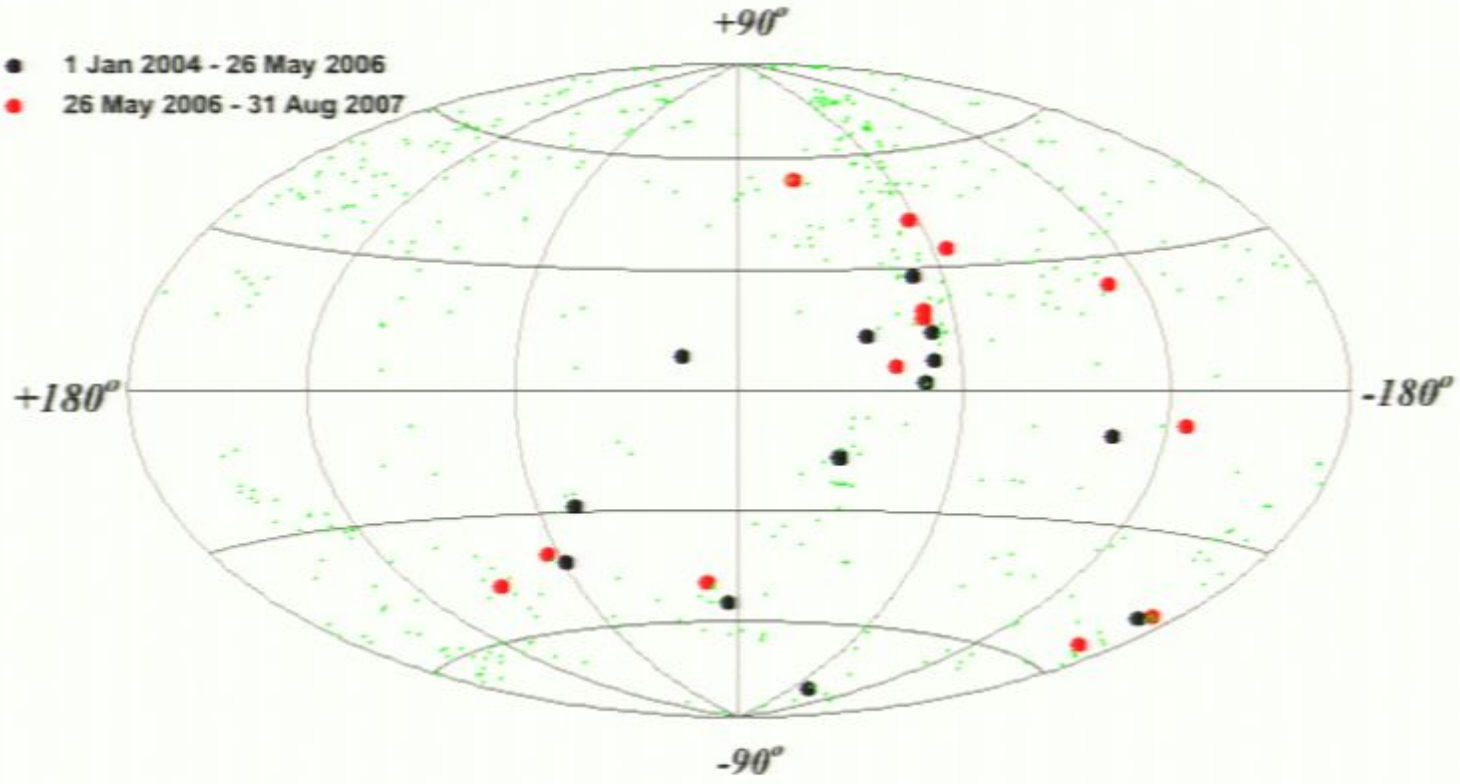

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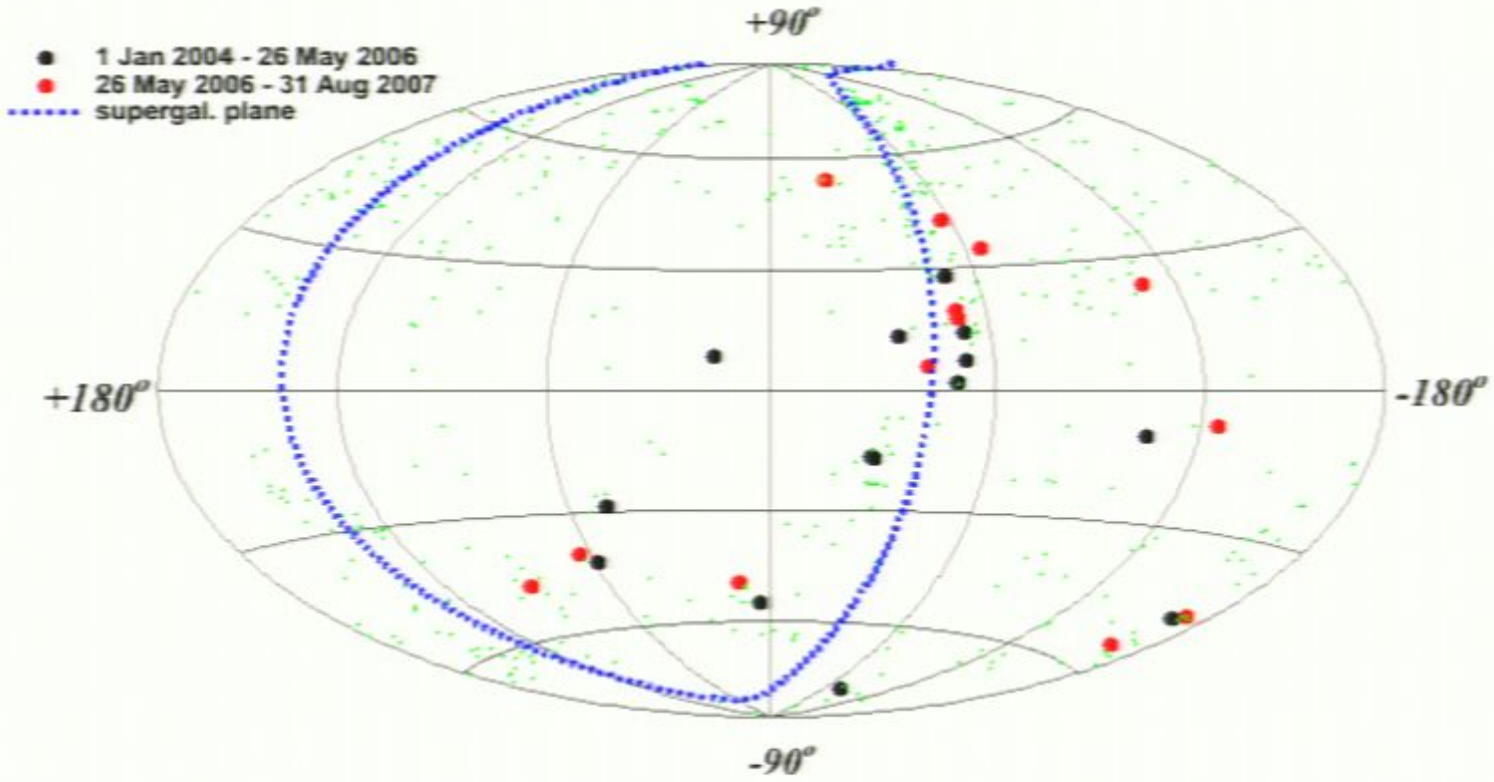
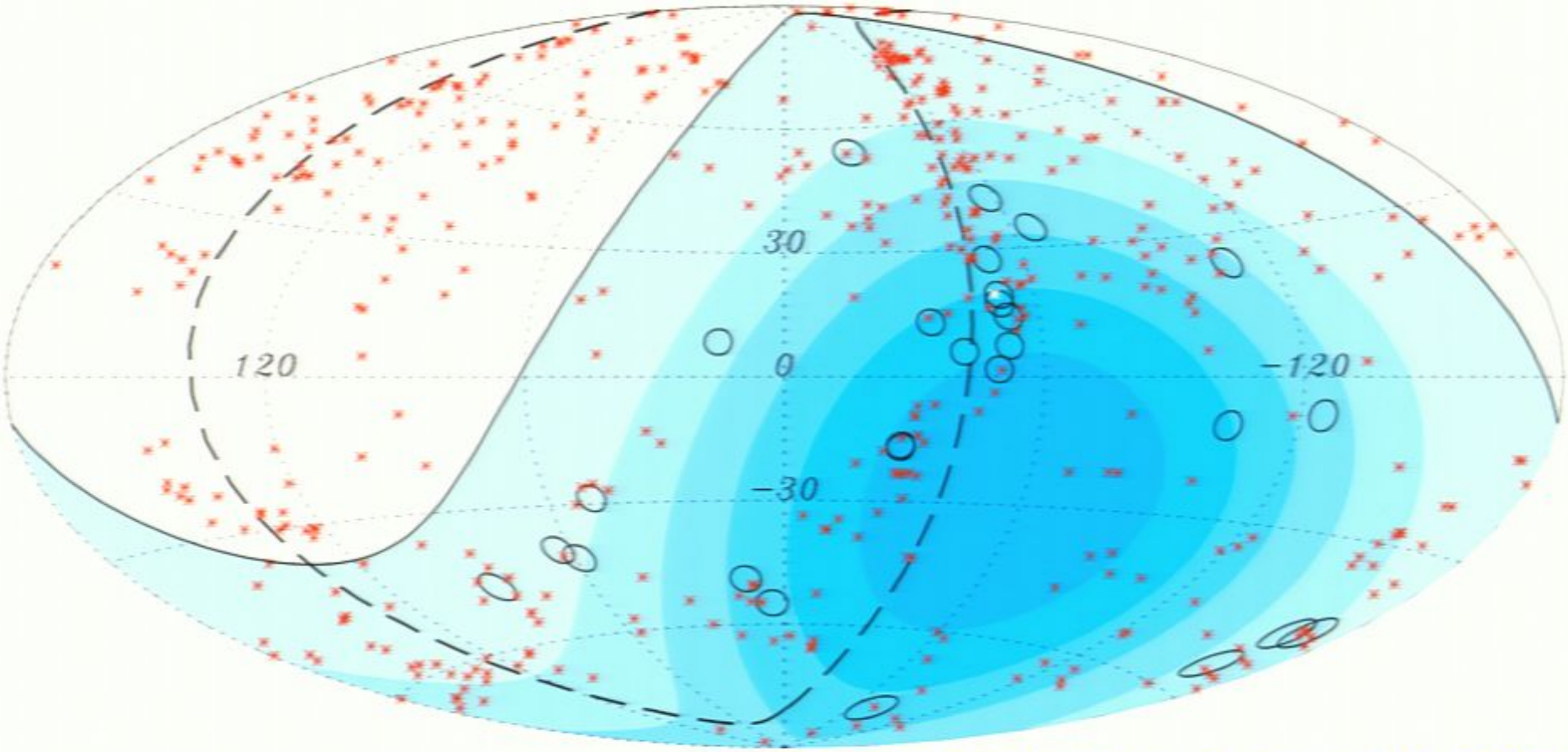


# Skymap

- 472 AGN with $z < 0.018$ (red crosses), 27 cosmic ray arrival directions with 3.1° circle, color indicates relative exposure, position of CenA (white cross).




Auger Collaboration, Science 318 (2007) 938

# Discussion

*Are AGN the real sources or are they tracers?*

- Distribution of matter in the local Universe is strongly non-uniform, and AGN correlate with these non-uniformities - is the Auger correlation signal unambiguously associated with AGN?
- Several tests with different catalogs (Abell clusters, X ray surveys) do not show correlations.
- With the small data set, it is not possible to extract distinctive properties of the AGN that are correlated with AGN.
- Two events are less than 3° away from Centaurus A, one of the nearest active galaxies to Earth (3.4 Mpc), but *no event* from Virgo supercluster (15 Mpc).
- 15 of the remaining events have Seyfert galaxies as the closest AGN.

*New Data*

- Events taken after 31 August 2007 show no significant correlation with AGN or anisotropy.

# Summary

*Energy Spectrum*

- Auger and HiRes observe a steepening of the spectrum at around 60 EeV consistent with the GZK suppression (Auger in a mostly mass- and model-independent analysis).
  - Differences in fluorescence/surface array energy determination and the energy offset between HiRes and Auger need to be studied.
  - Air fluorescence yield parameters need to be updated (upcoming results from various experiments).

*Mass Composition*

- Open question with important ramifications (energy spectrum, anisotropy,…).
  - Some clarification through new simulation code (EPOS) and cross- sections from HEP…
  - What is the composition at the highest energy?

# Summary

*Where are the Sources?*

- First indication that AGN within the GZK horizon are the origin of cosmic rays at the highest energies.
  - Results are further evidence for the existence for the GZK suppression at ~60 EeV.
  - Results support the hypothesis that the majority of cosmic rays in this energy range are protons from nearby extragalactic sources.
- Open questions:
  - The sources: AGN, or sources with a similar spatial distribution?
  - What is the acceleration mechanism? Need to unambiguously identify individual sources…
  - Magnetic fields?

*Outlook*

- The Pierre Auger Observatory is only now nearing completion.
- Exposure is now 9000 $km^2$ sr $yr^{-1}$ and will double in a bit more than a year.