The Pierre Auger Project (E881)

A new cosmic ray observatory to study

The Highest Energy Cosmic Rays

$>10^{19}$ eV

Energy Spectrum - Direction - Composition

Southern Observatory in Mendoza, Argentina

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Construction

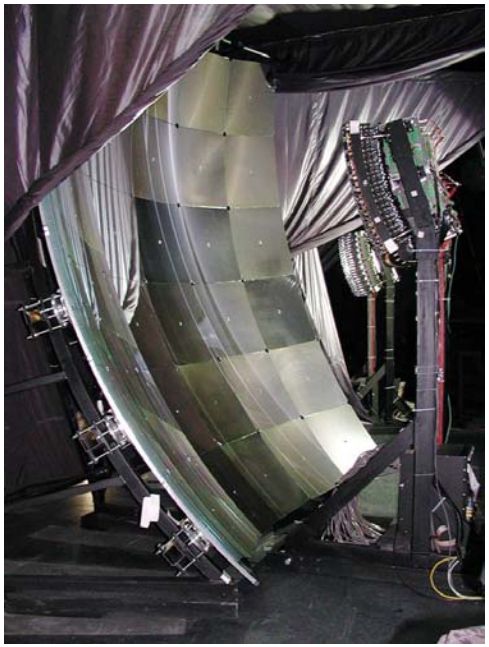
Commissioning

Data taking since 2004

First Results in 2005

Surface detector station

1600 total



Fluorescence telescope

24 total

The Auger Collaboration

PIERRE AUGER OBSERVATORY

Participating Countries - 63 Institutions, ~269 Scientists

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

**Associate countries*
***New countries*

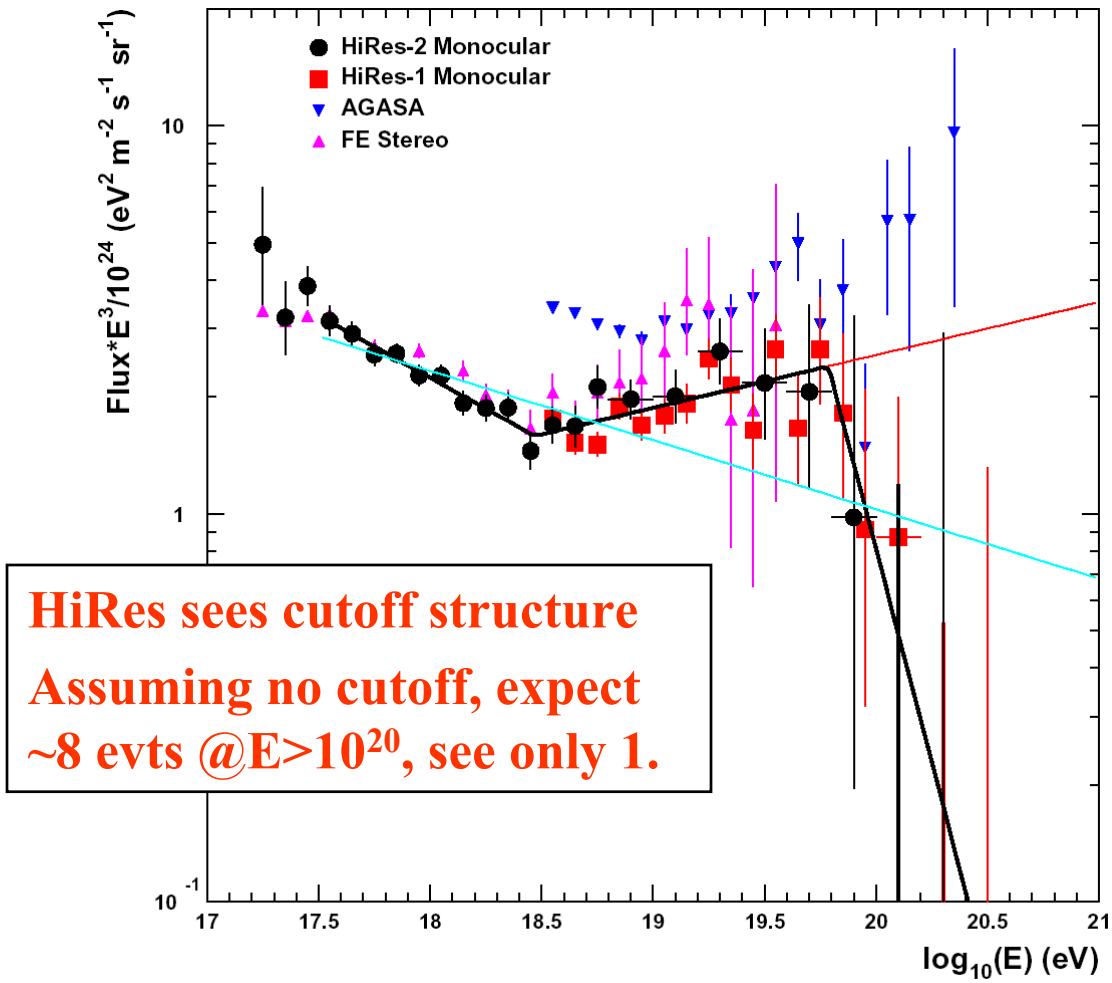
Participating US institutions – 60 Scientists

UCLA
Case Western
Chicago
Colorado
Colorado State
Columbia
Fermilab (and ANL)
Louisiana State
Michigan Tech
Minnesota
Nebraska
New Mexico
Northeastern
Ohio State
Utah

Support

DOE, NSF – Funding agencies in 15 other countries. US support about 25%.

The GZK Feature

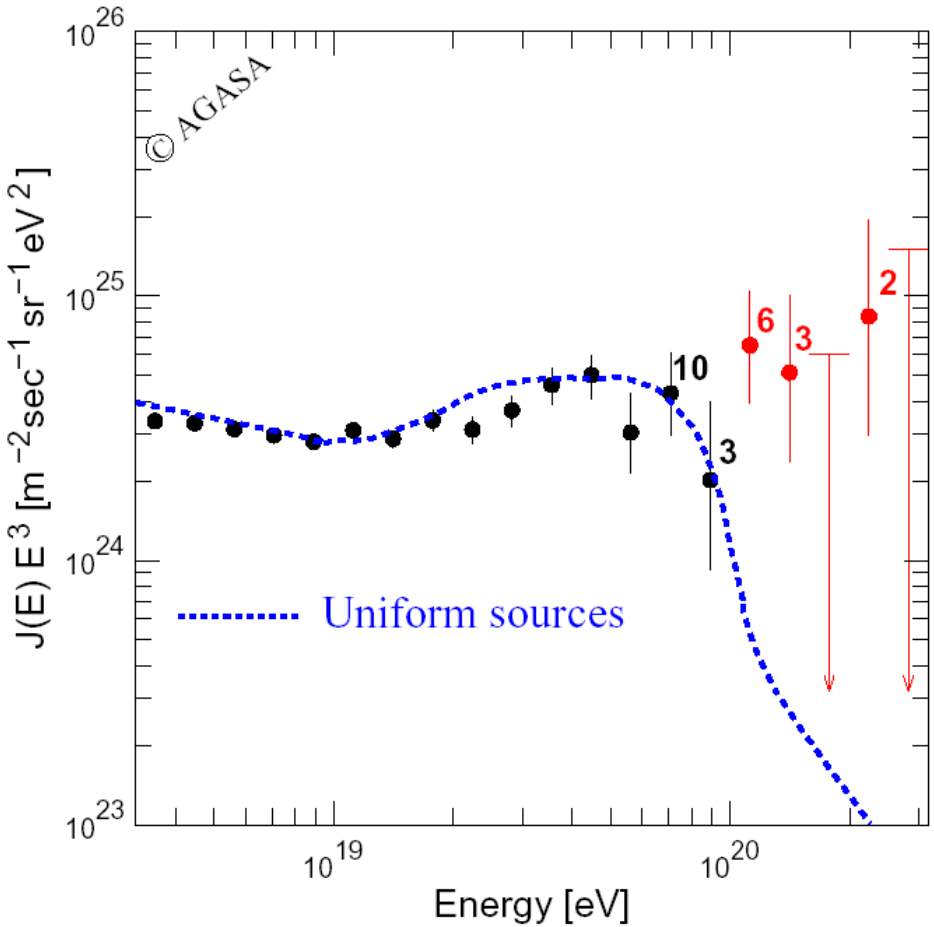


HiRes sees cutoff structure

Assuming no cutoff, expect ~8 evts @E>10^{20}, see only 1.

Protons with E>5*10^{19}eV are expected to lose energy rapidly in resonant collisions with the CMB.

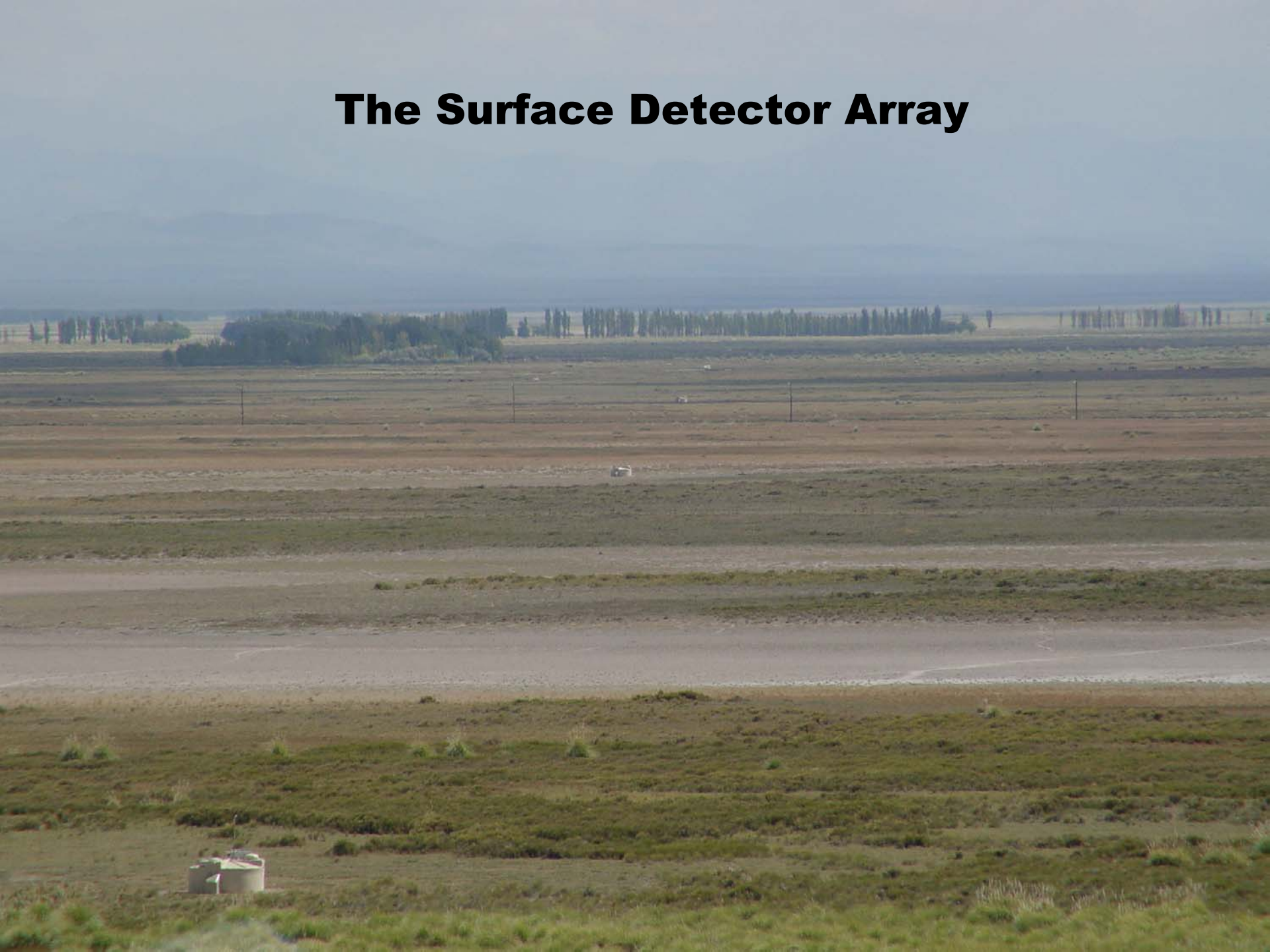
What GZK Feature? AGASA sees 11 evts!



Also, other events seen by many other experiments

What are the super-GZK E~10^{20} eV events???
Hadrons from local sources? Photons from local relic decay?
Hadrons from distant sources, implying Lorentz violation?
Strongly interacting neutrinos? Exotic particles?

The Surface Detector Array



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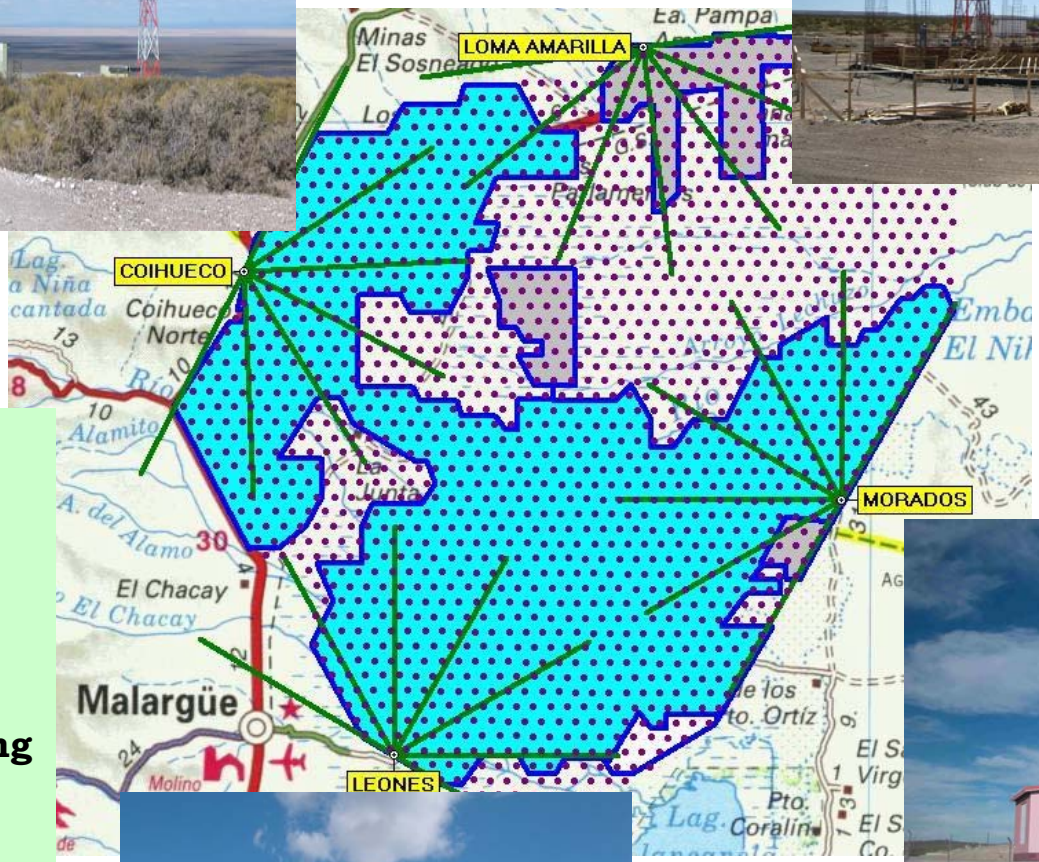


Auger Construction Status

- **1135 surface detector stations deployed, 932 sending data (blue).**
- **Three fluorescence buildings complete each with 6 telescopes – the fourth under construction.**

Accomplishments

- **Auger South Observatory now ~75% complete**
- **First physics results – Summer 2005 - Highlight talk + 38 papers – ICRC (August 05)**
  - **First Surface Detector energy spectrum measurement**
  - **UHE Photon Limit**
  - **Observations of the Galactic Center**

Recent PhDs

- **Brasil:** Ricardo Sato Universidade Estadual de Campinas June 2005
- **Czech Republic:** Michal Prouza Institute of Physics, ASCR March 2006
- **France:** Gilles Maurin APC Université de Paris 7 September 2005
  Eric Armengaud APC: Université de Paris 7 May 2006
- **Germany:** Bianca Keilhauer Karlsruhe University December 2003
  Tilo Waldenmaier Karlsruhe University February 2006
- **Italy:** Domenico D'Urso University of Catania December 2005
- **Mexico:** Juan-Carlos Arteaga Cinvestav July 2005
  Eduardo Moreno BUAP July 2005
- **Spain:** Pedro Facal University of Santiago June 2005
- **United Kingdom:** David Newton University of Leeds, UK December 2005
- **USA:** Tohru Ohnuki UCLA, USA July 2005
  David Barnhill UCLA, USA October 2005
  Alexei Dorofeev Michigan Tech, USA May 2005

Fermilab Participation

- **Fermilab Participation**
  - **Scientists – 5 full time + 2 Part time + 1 postdoc**
  - **+ 1 Brinson Pre-doctoral Fellow**
  - **Staff – 2 full time**
  - **Activities**
    - **Project Management**
    - **Construction**
    - **Commissioning**
    - **Data analysis (FNAL + UChicago)**
  - **Group size – approximately constant; may grow slightly as Auger North evolves.**
- **Funding**

  ~$250K M&S/yr – mostly travel and project office support

The FNAL-UChicago group is heavily involved in all science topics

PIERRE AUGER OBSERVATORY

- **The 2005 SD energy spectrum analysis was led by our group:**
  - **aperture/exposure,**
  - **surface detector calibration,**
  - **hybrid energy calibration,**
  - **Fluorescence detector test beam,**
  - **simulations**

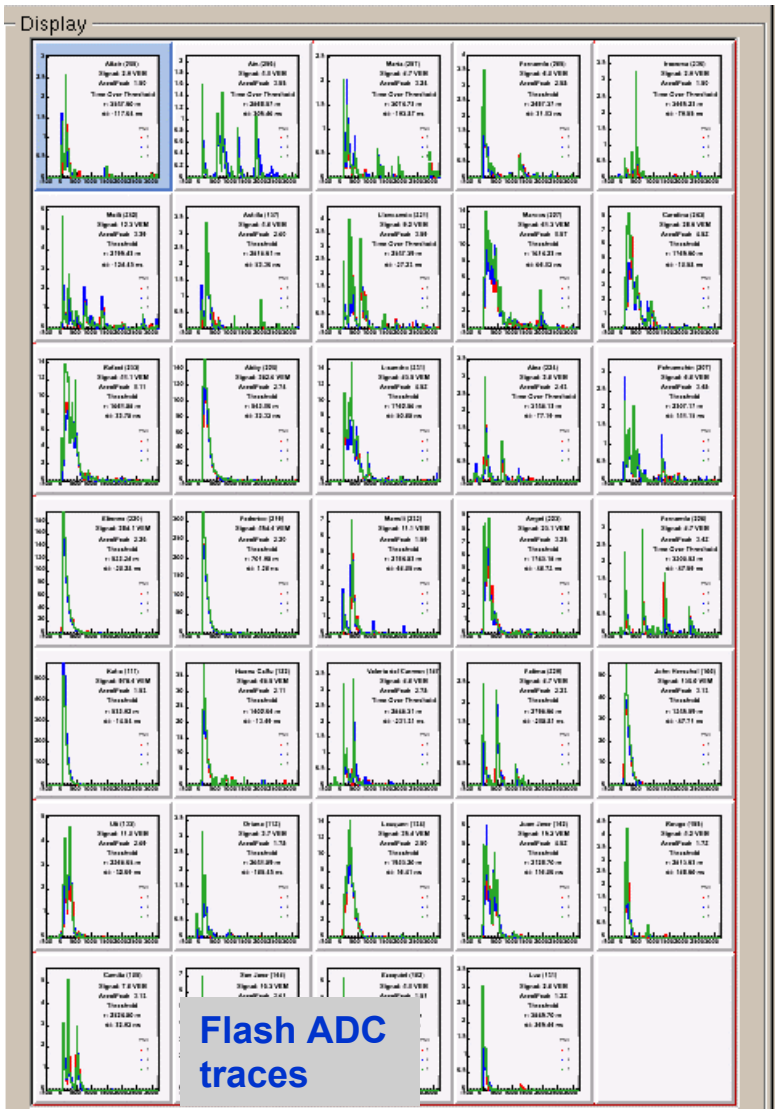
- **2005 Galactic center results- energy systematics**

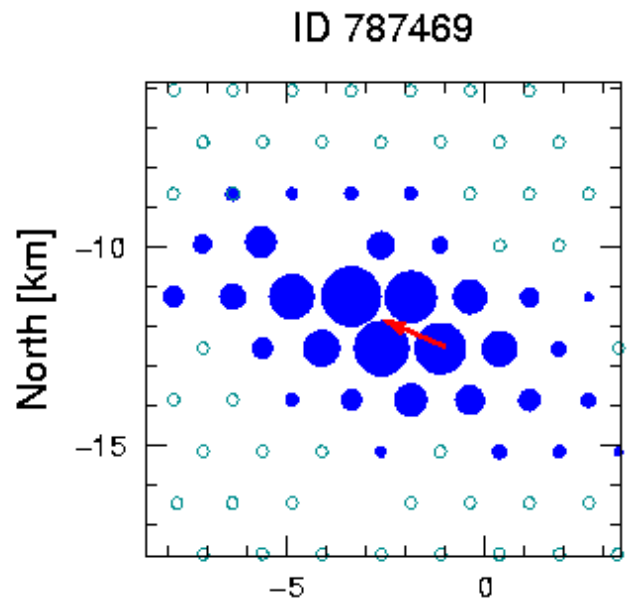
- **Composition studies**
  - **Elongation rate → composition change vs. energy**
  - **Shower front structure**
  - **Theoretical computations of cosmogenic flux**
  - **Searches for exotics**

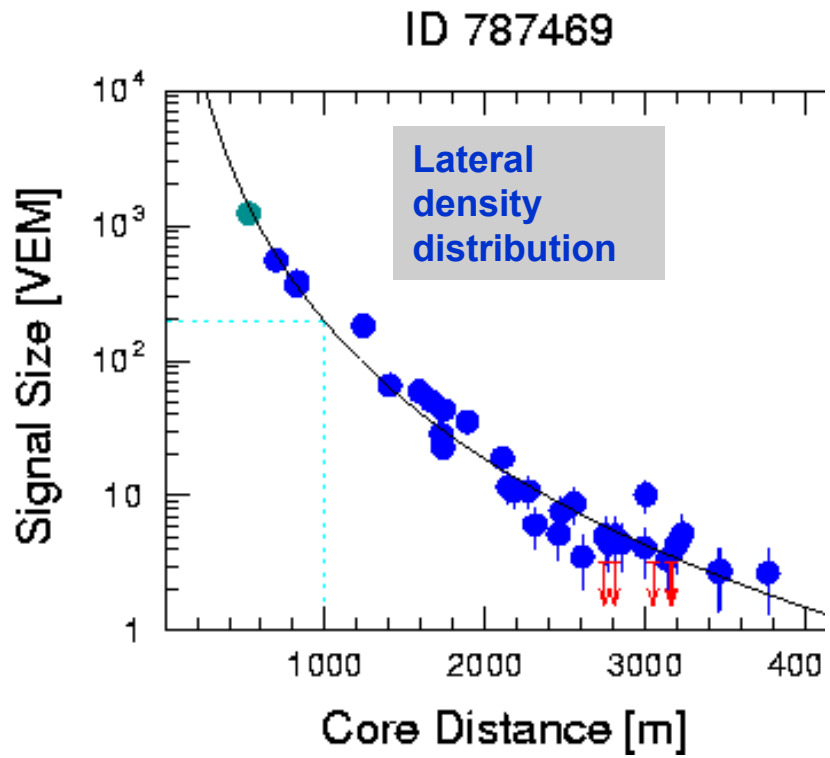
A "Typical" SD Event

An inclined event - 787469

Zenith angle ~ 60°, Energy ~ 86 EeV

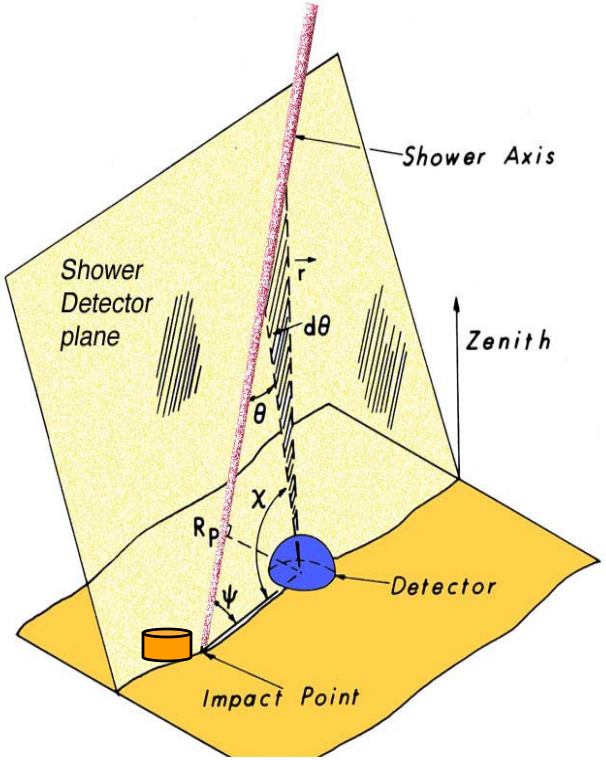




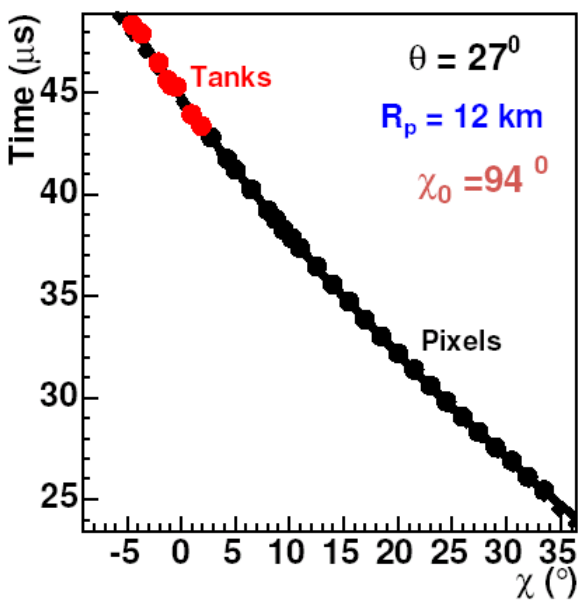


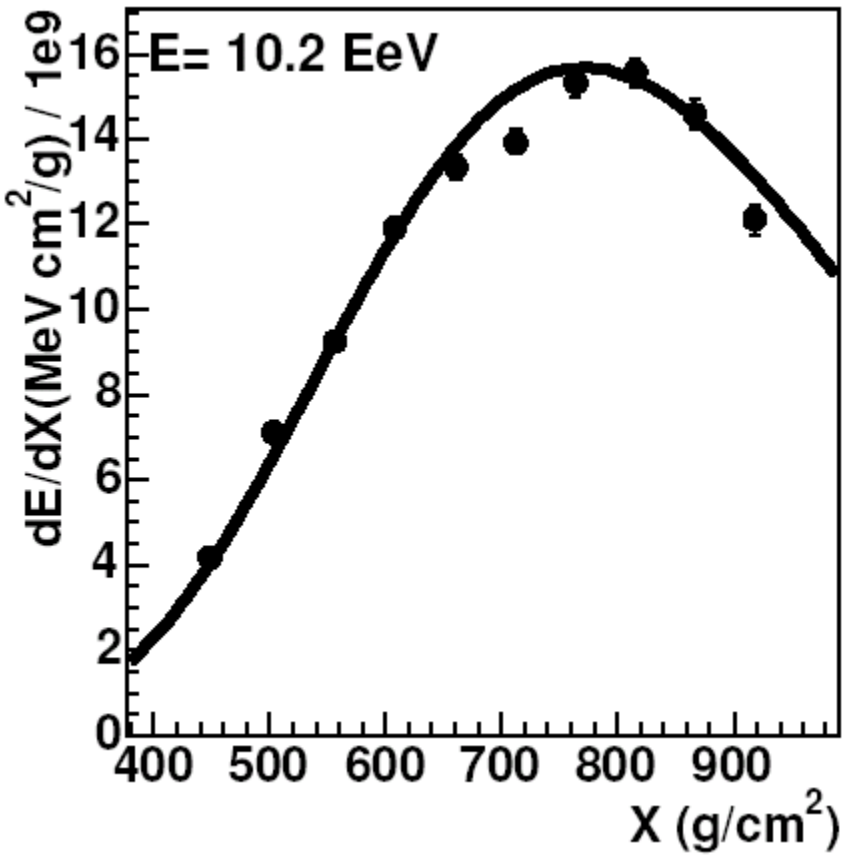
Hybrid Event (FD view)

A hybrid event – 1021302
Zenith angle ~ 30°, Energy ~ 10 EeV

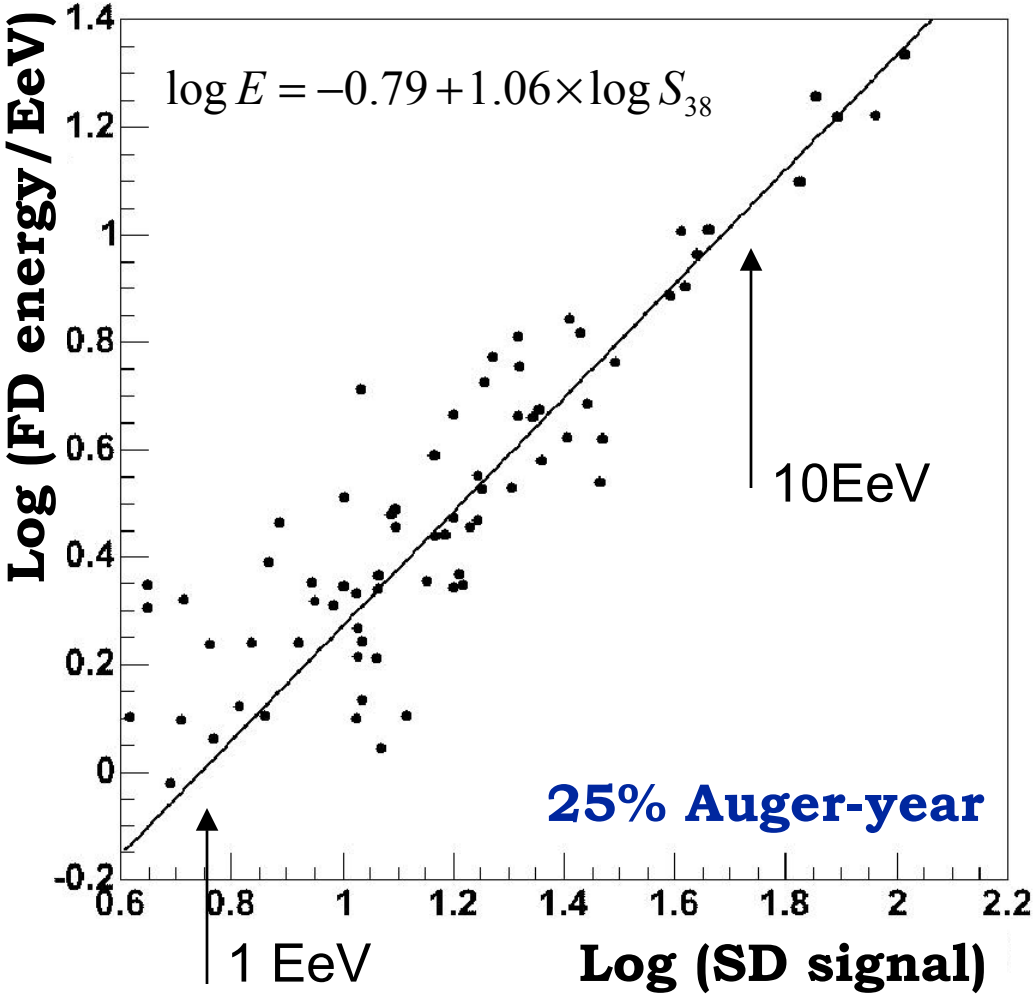


Reconstructed geometry + observed light-vs-angle gives dE/dX profile.





Obtain the SD signal→Energy Correlation with Fluorescence energies from hybrid events

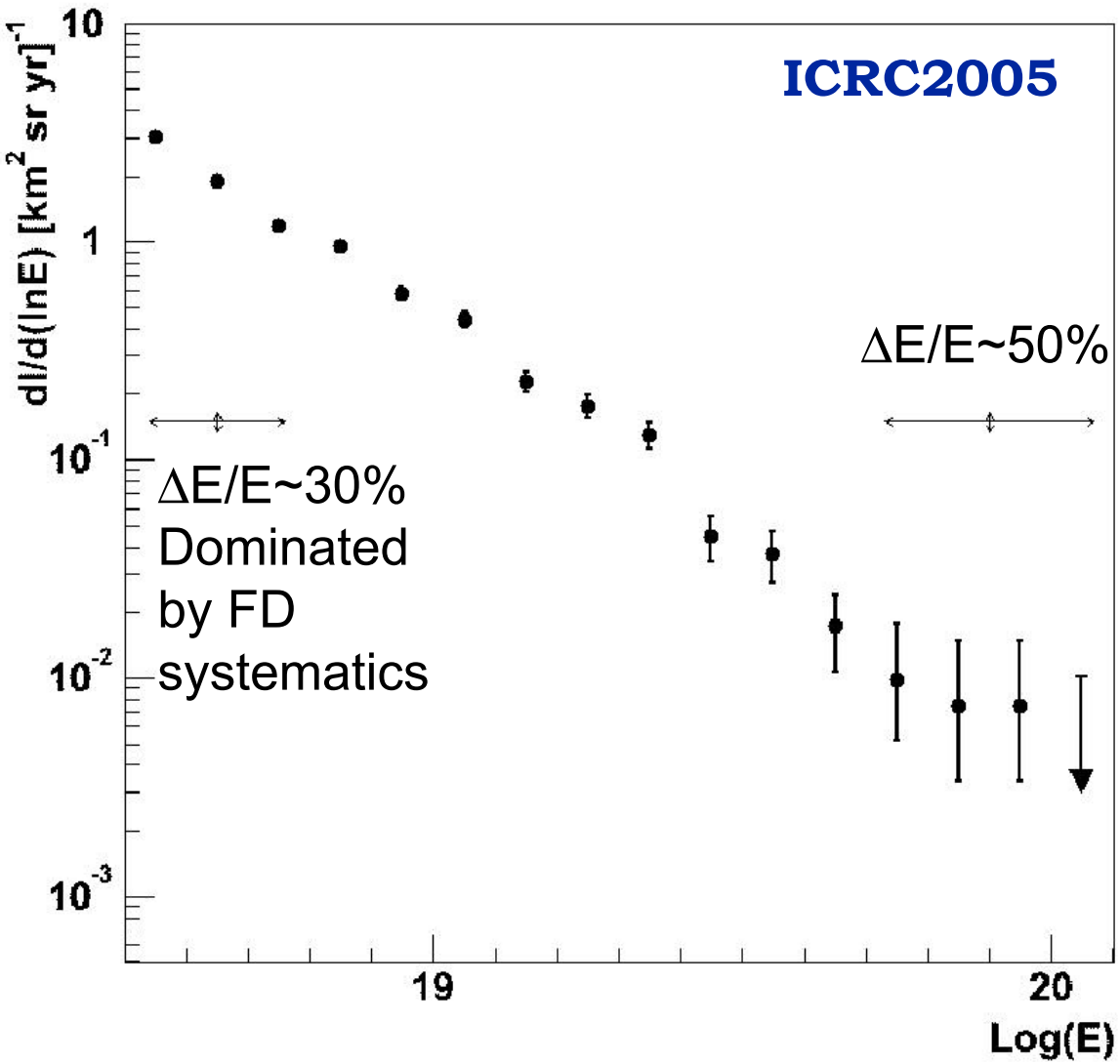


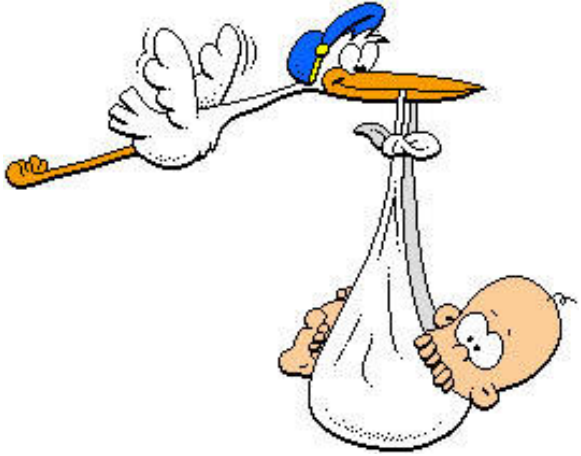
- Strict event selection:
  - tracklength >350g/cm^2
  - Cherenkov contamination<10%
- Obtain converter:

$$E/EeV = 0.16 \times \left(\frac{S(1000)/VEM}{CIC(\theta)} \right)^{1.06}$$

- **Note: systematic error grows when extrapolating this rule to 100 EeV!**
  - **Need ~2-3 years more hybrid data to calibrate at high energies**

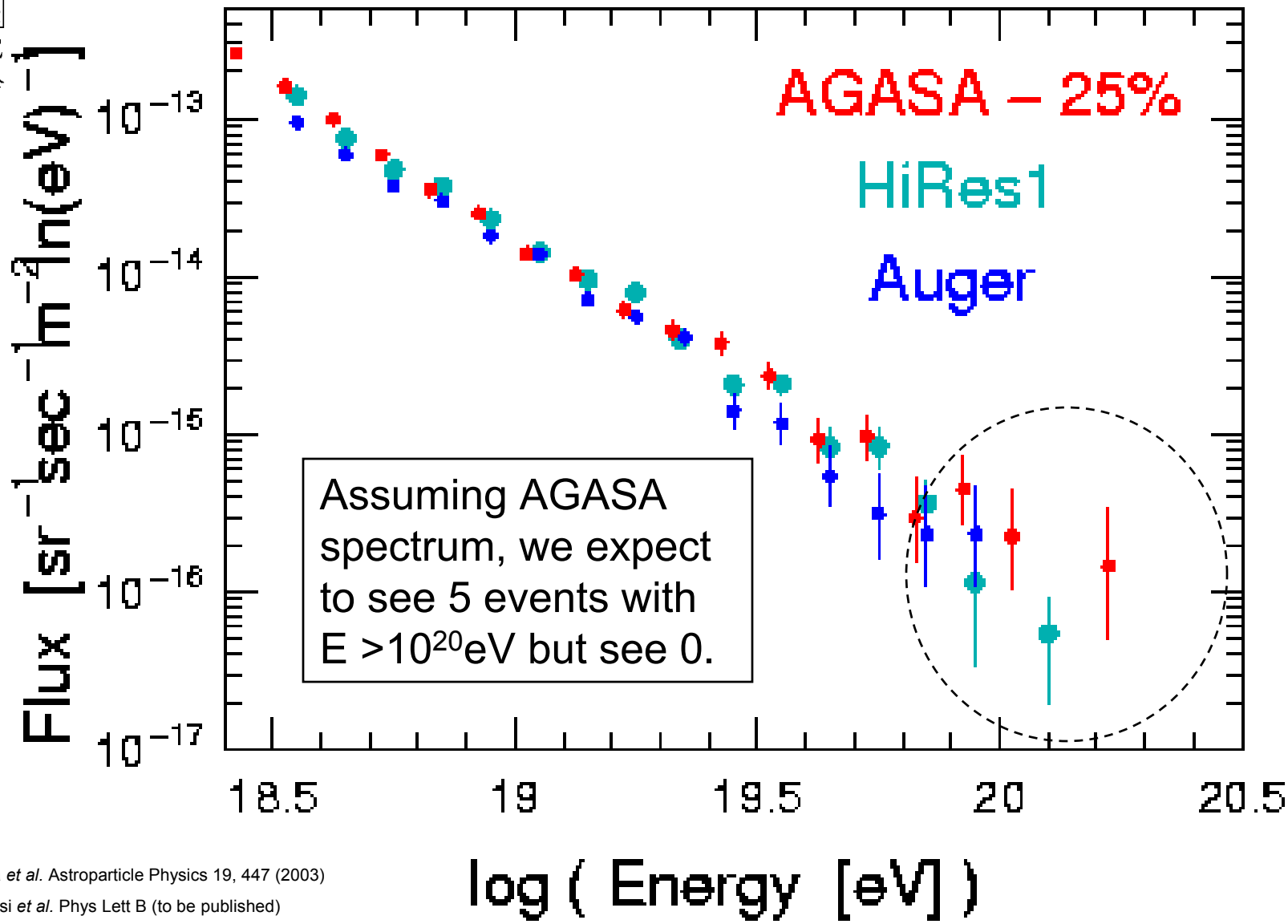
The Auger Southern Sky Energy Spectrum (SD data)





- dN/d(lnE) = E*dN/dE
- Errors on points are Statistical only
- Systematic errors are estimated at two energy regions
  - Energy measurement (horizontal)
  - Exposure determination (vertical)

Comparison with HiRes1 Mono, AGASA (E-25%)

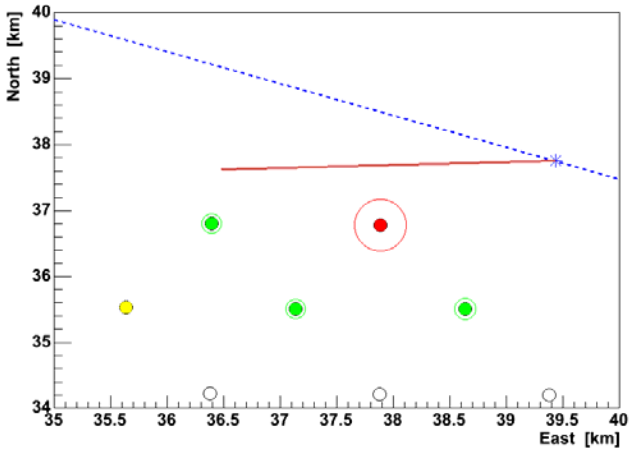


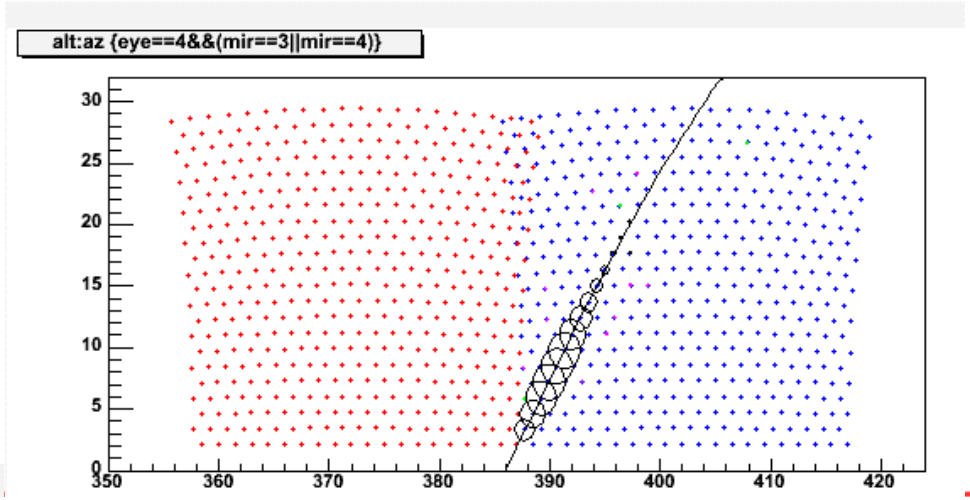
1) M. Takeda *et al.* Astroparticle Physics 19, 447 (2003)

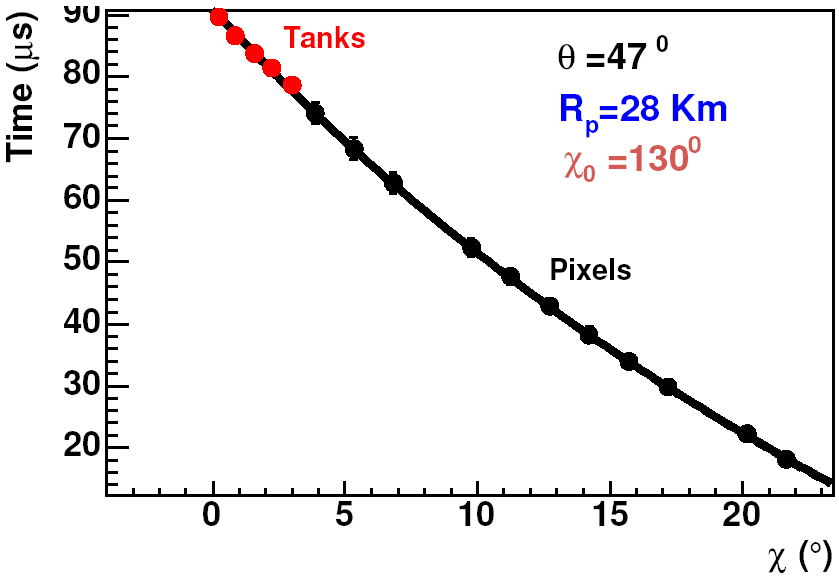
2) R.U. Abbasi *et al.* Phys Lett B (to be published)

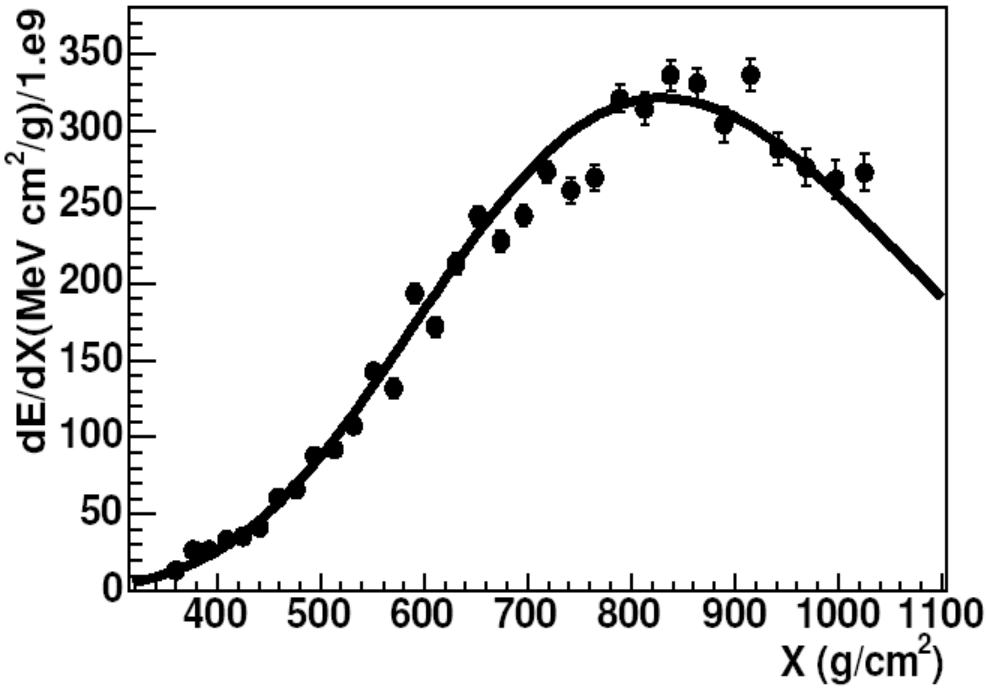
Our Highest Energy Event E_{FD}~2 10^{20}eV

Landed just outside the array, so not used in SD spectrum!

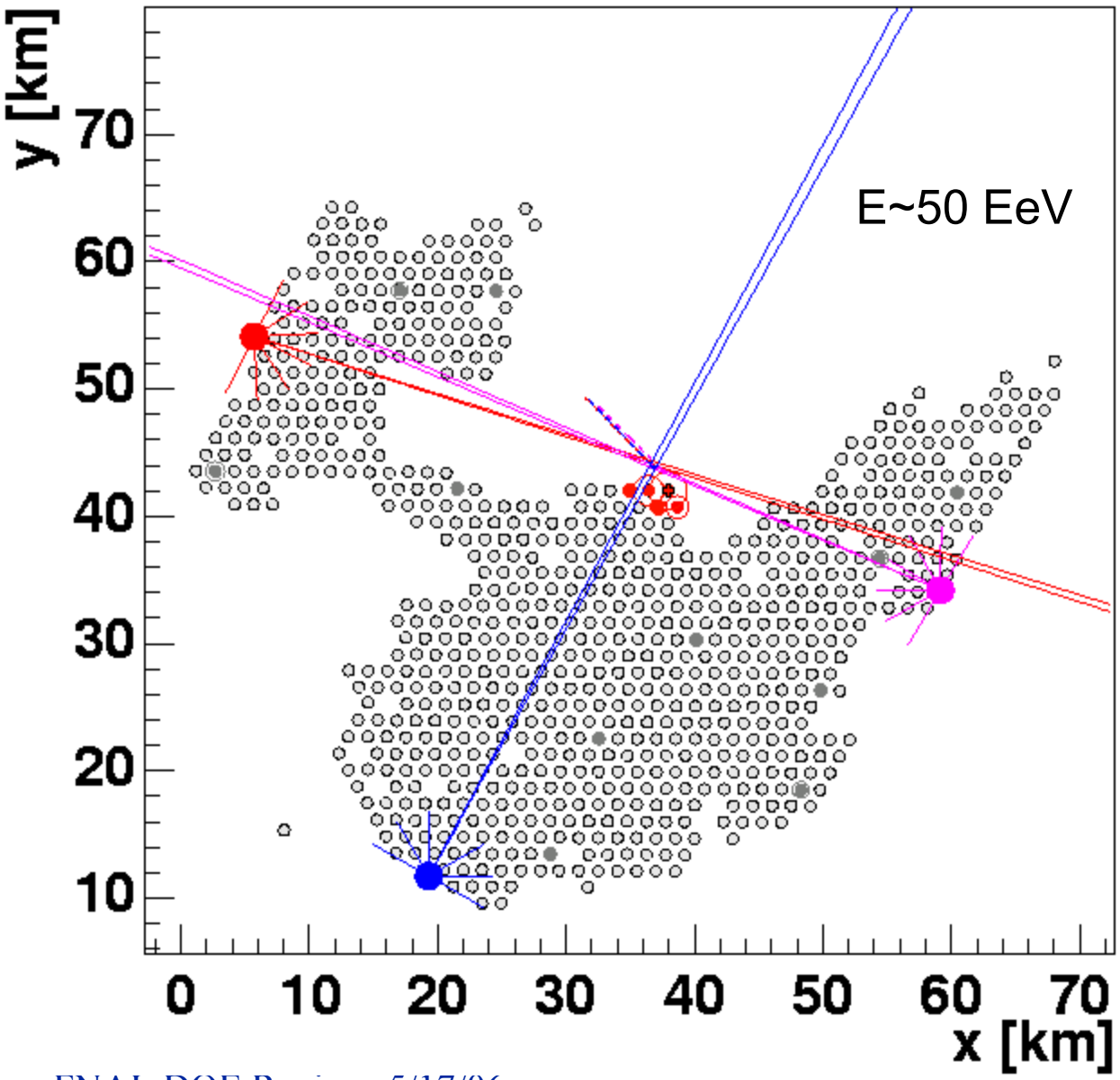




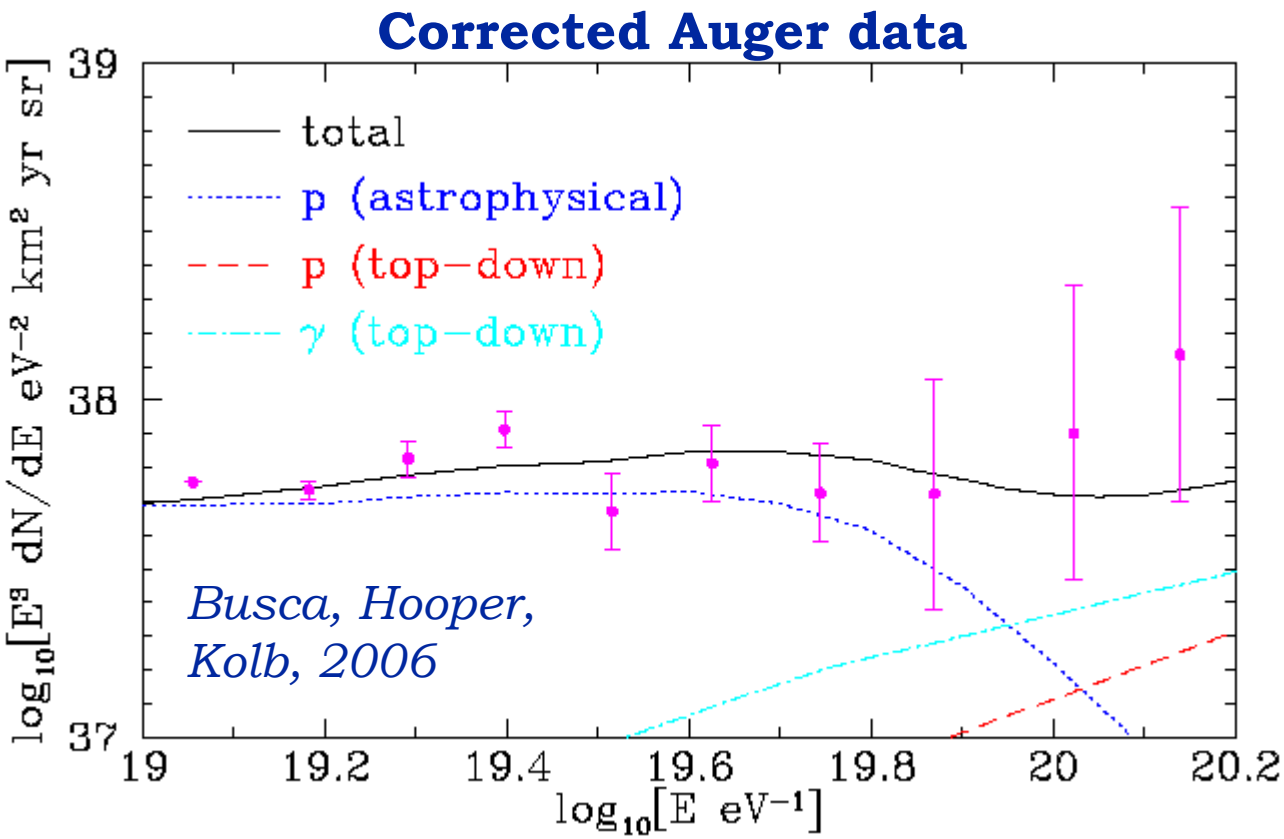




Only one of many frustrating events....



Top-down models generically predict UHE photons which are seen as deeply-penetrating muon-depleted air showers.

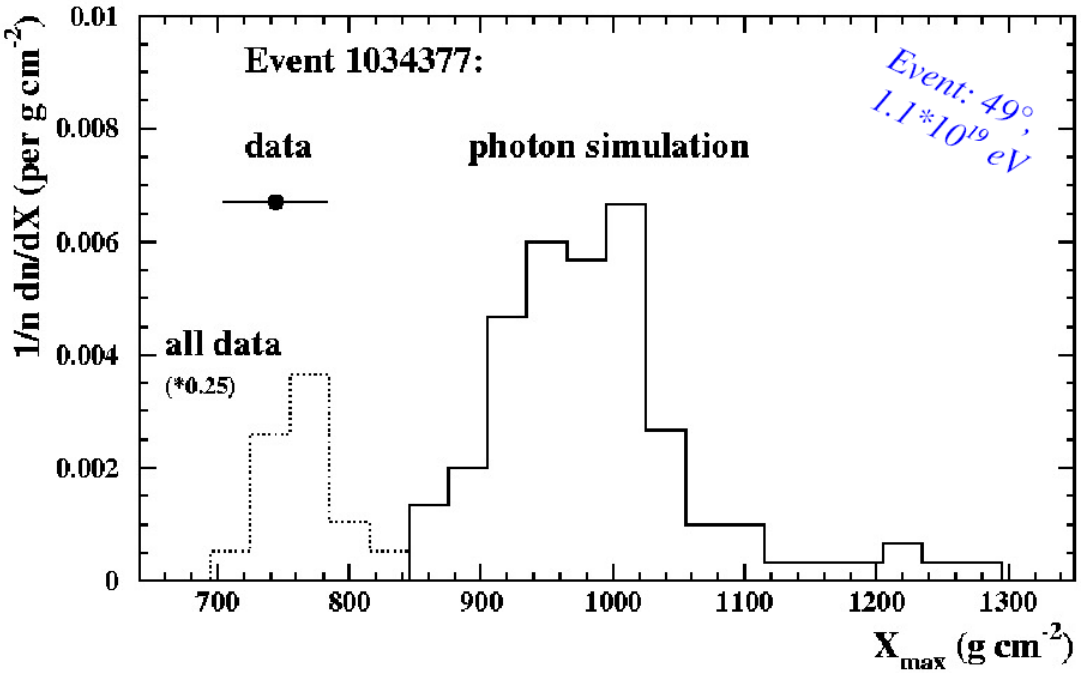


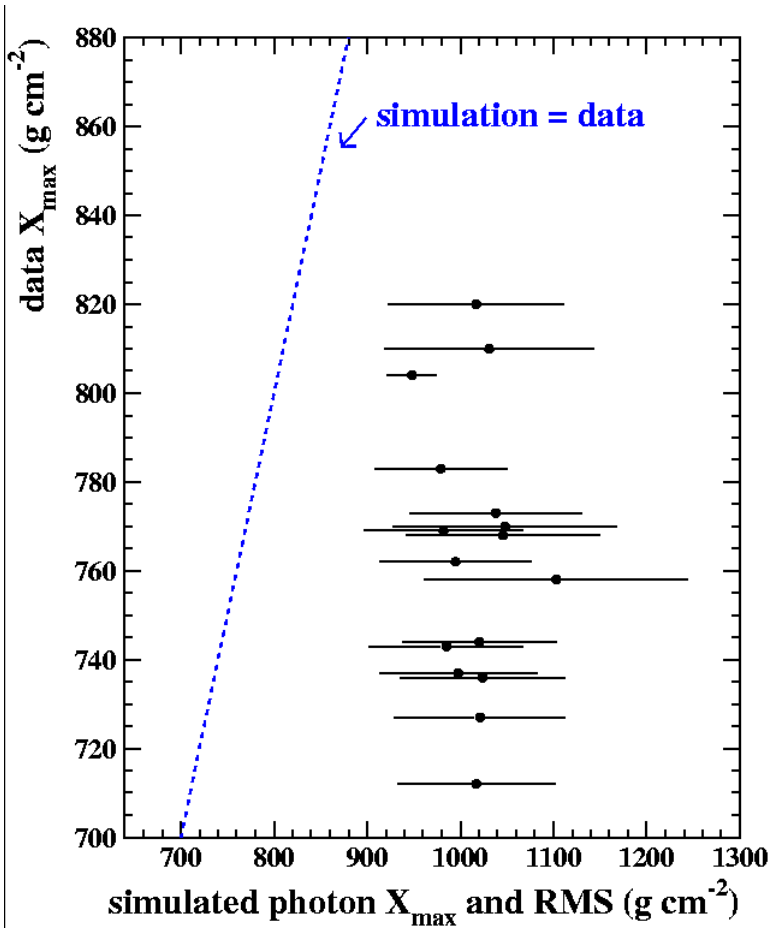
If the superGZK cosmic rays are photons, Auger SD underestimates the energies of these events by a factor of 2!

AGASA energies are okay, but HiRes1 Mono rejects these events(?)

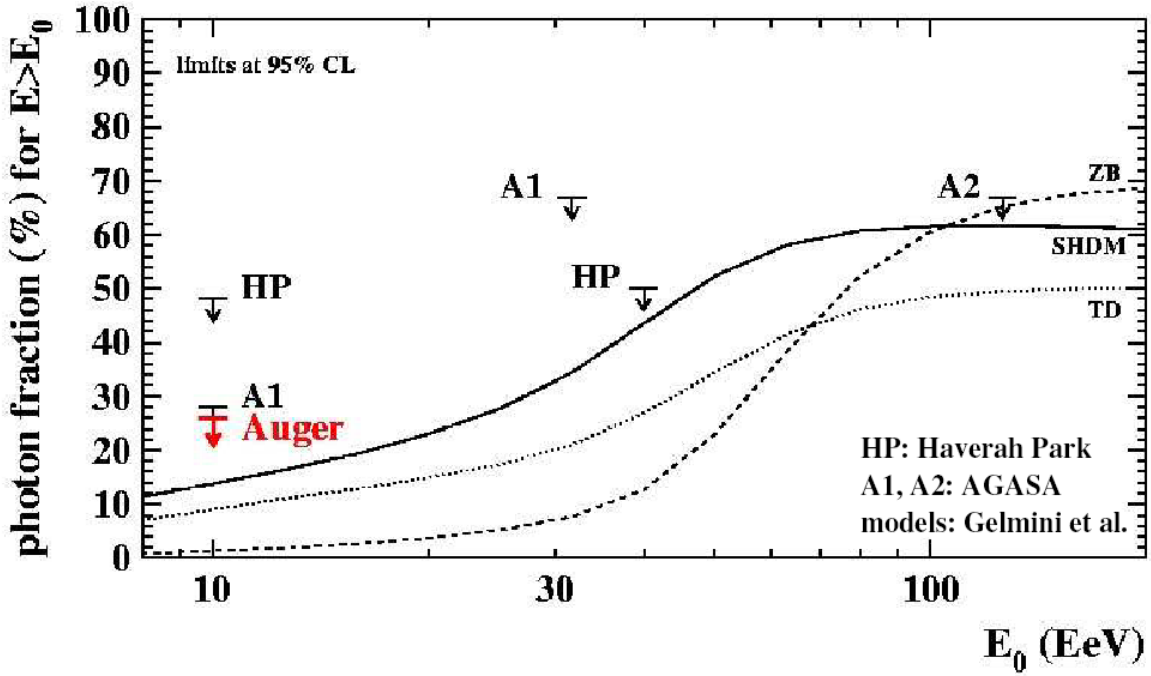
Photons penetrate more deeply into the atmosphere than hadronic showers

Perform simulations for each measured hybrid geometry





Photon Fraction Limit Result from Auger Hybrid data



A1,2 = AGASA
HP = Haverah Park

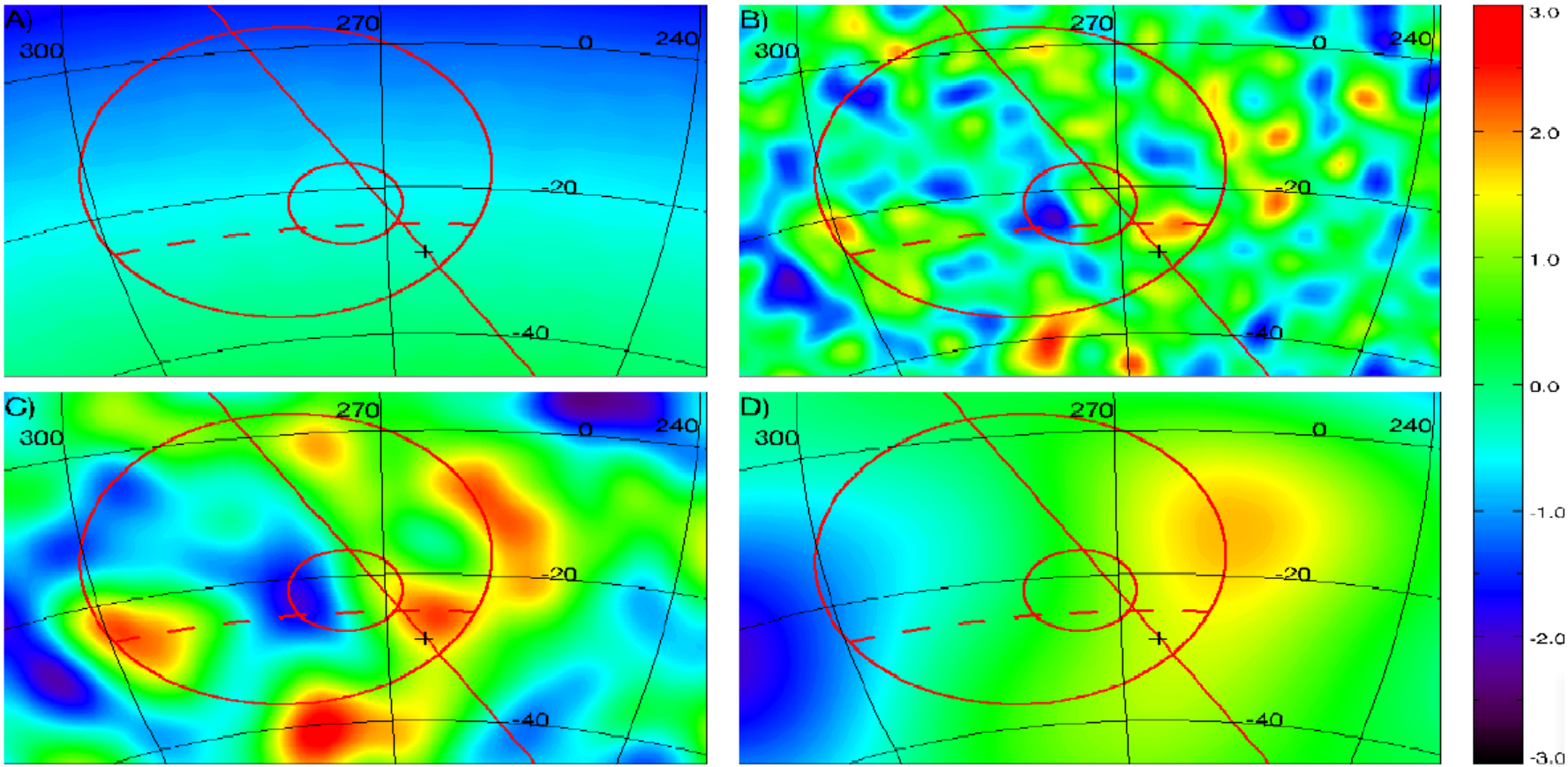
Data not corrected for energy scale

- **Photon Fraction <26% at 95%CL for the integrated flux of cosmic rays with E > 10 EeV.**
- **More to come soon at higher energies!**

Auger SD: No excess from the galactic center

Coverage map by shuffling event UTC times

Events smoothed with true resolution, Energy = 0.8-3.2 EeV



Smoothed at SUGAR scale, SUGAR energy window

Smoothed at AGASA scale, AGASA energy window

Summary and Future Plans

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- With only 25% of a full Auger-year exposure, we have already defined our empirical spectrum analysis strategy and produced our first "model-independent" surface detector spectrum
  - **There is no evidence of non-Gaussian energy resolution tails**
  - **The energy converter is based on the average "hadronic" composition of cosmic rays at lower energies**
    - **Need 10x more hybrid events to study composition ~ 3 years**
    - **Need dedicated searches for exotic non-hadronic cosmic rays.**

- **GC, Photon limit: New results soon.**

- Also to do:
  - Investigate changes of mass composition with energy.
  - Explore feasibility of CR astronomy with 2x sensitivity
    - Clustering, BL Lac correlations (HiRes sees 3 evts from Mrk501), GRB correlations…
  - Look for UHE neutrinos in earth-skimming events
  - Finish constructing the observatory!