Telescope Array Results

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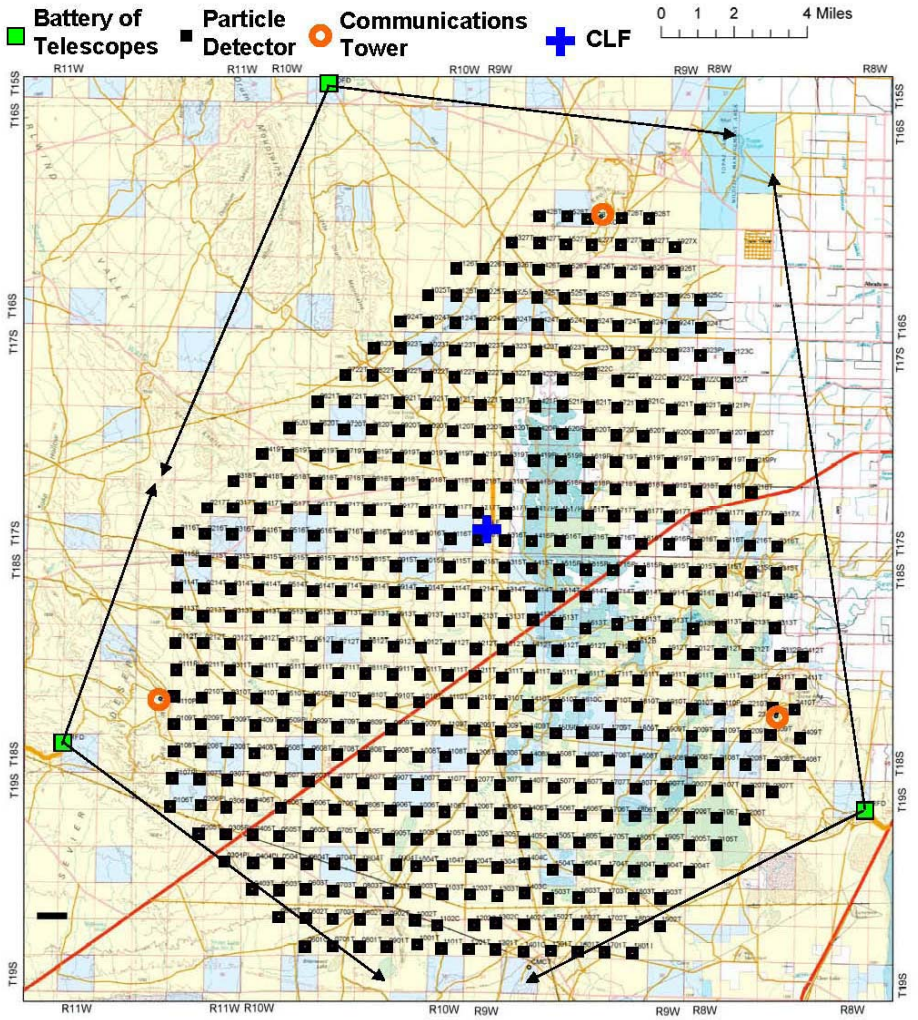
Outline

I. Introduction to TA
II. TA Results
III. The Future

TA is a Hybrid Experiment

- TA is in Millard Co., Utah, 2 hours drive from SLC.
- SD: 507 scintillation counters, 1.2 km spacing, scintillator area= 3 sq. m., two layers.
- FD: 3 sites, each covers 120° az., 3°-31° elev.
- ~4.7 years of data have been collected.



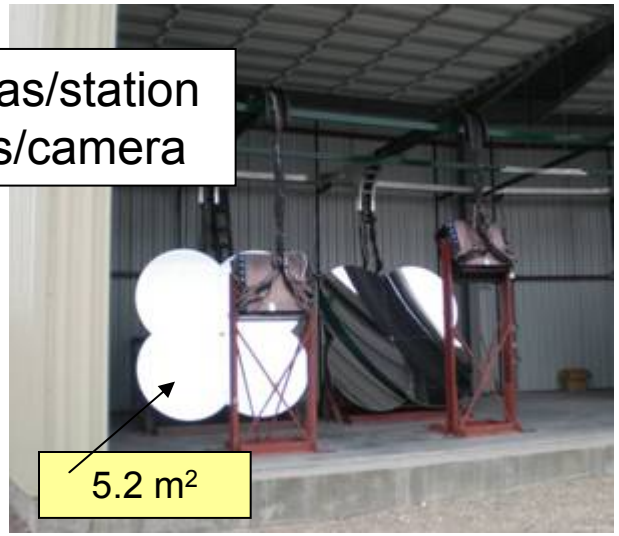
TA Fluorescence Detectors

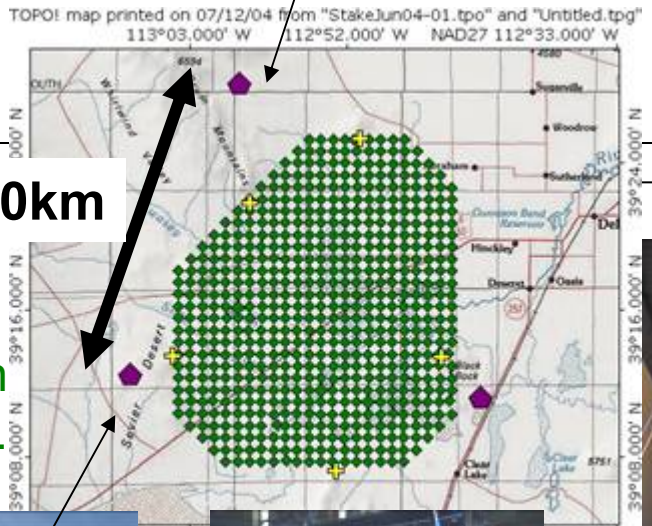
Refurbished from HiRes

Observation started Dec. 2007

Middle Drum

14 cameras/station
256 PMTs/camera





~30km

Observation started Nov. 2007

Long Ridge

~1 m²

New FDs

TA Surface Detectors

- Powered by solar cells; radio readout.
- Self-calibration using single muons.
- In operation since March, 2008.

TA Results: UHECR Spectrum Expectations

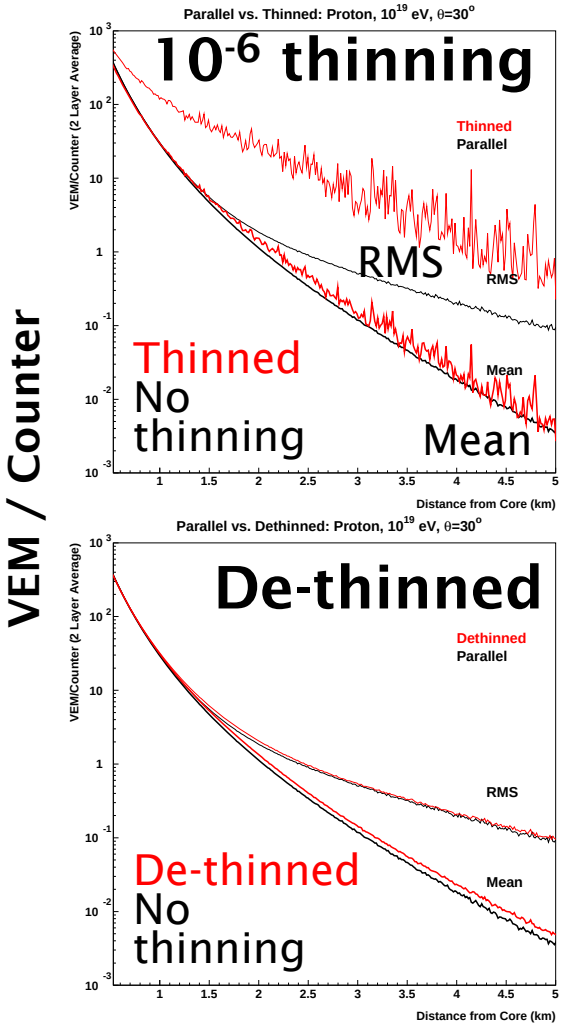
- If protons, expect to see:
  - GZK cutoff at 5-6 x 10^{19} eV ($\gamma+p \rightarrow \pi+p$)
  - "ankle" at 5 x 10^{18} eV ($\gamma+p \rightarrow e^+e^-+p$)

- If heavy nuclei, expect to see:
  - Cutoff due to spallation at 4 x 10^{19} eV,
  - Spallation does not cause an "ankle"

TA Spectrum
(Measured by the Surface Detector)

- 4 years of data, 13738 events.
- We use a new analysis method.
  - Calculate acceptance by Monte Carlo technique.
  - We use HEP methods for this purpose:
    - Complete simulation, using measured spectrum and composition, calibration, trigger, etc.
    - Test with data/MC comparison plots.

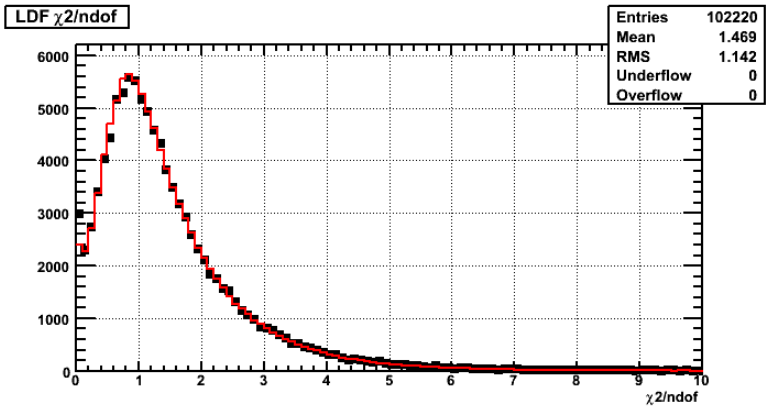
How to Use Corsika Events

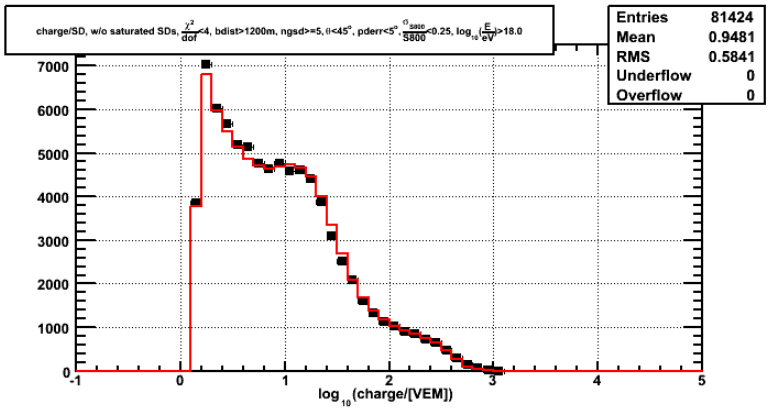


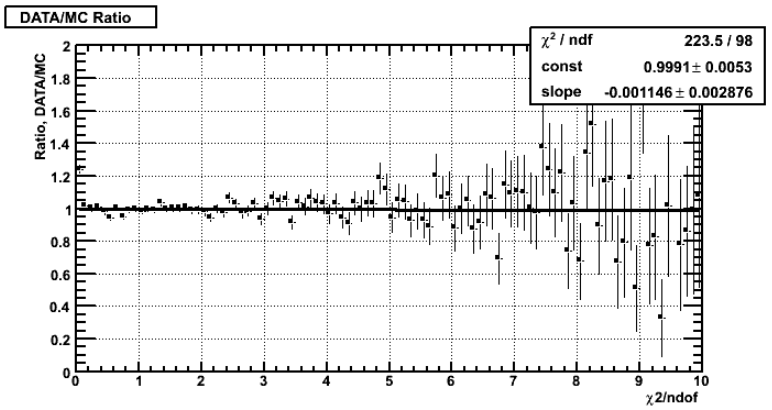
- **Thinning** is an approximation technique where particles are removed from a shower simulation, and other particles, nearby in phase space, are kept but given weights.

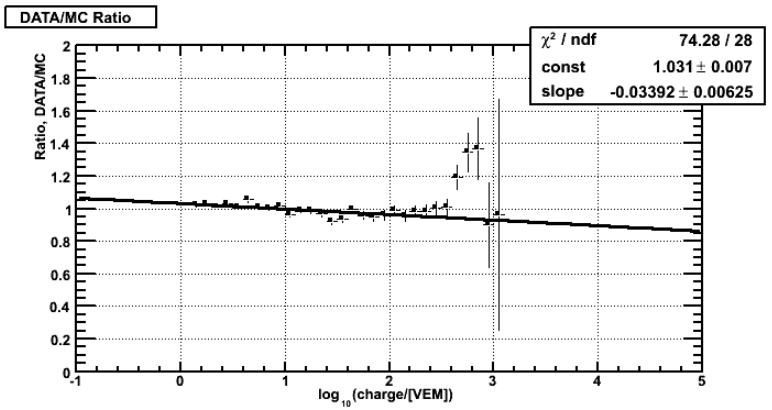
- Use 10^{-6} – thinned CORSIKA QGSJET-II proton showers that are de-thinned: Corsika output particles with weight *w* are replaced with a swarm of *w* particles. **Dethinning** is tuned to give same result as Corsika showers thrown with no thinning.

Data/MC Comparisons





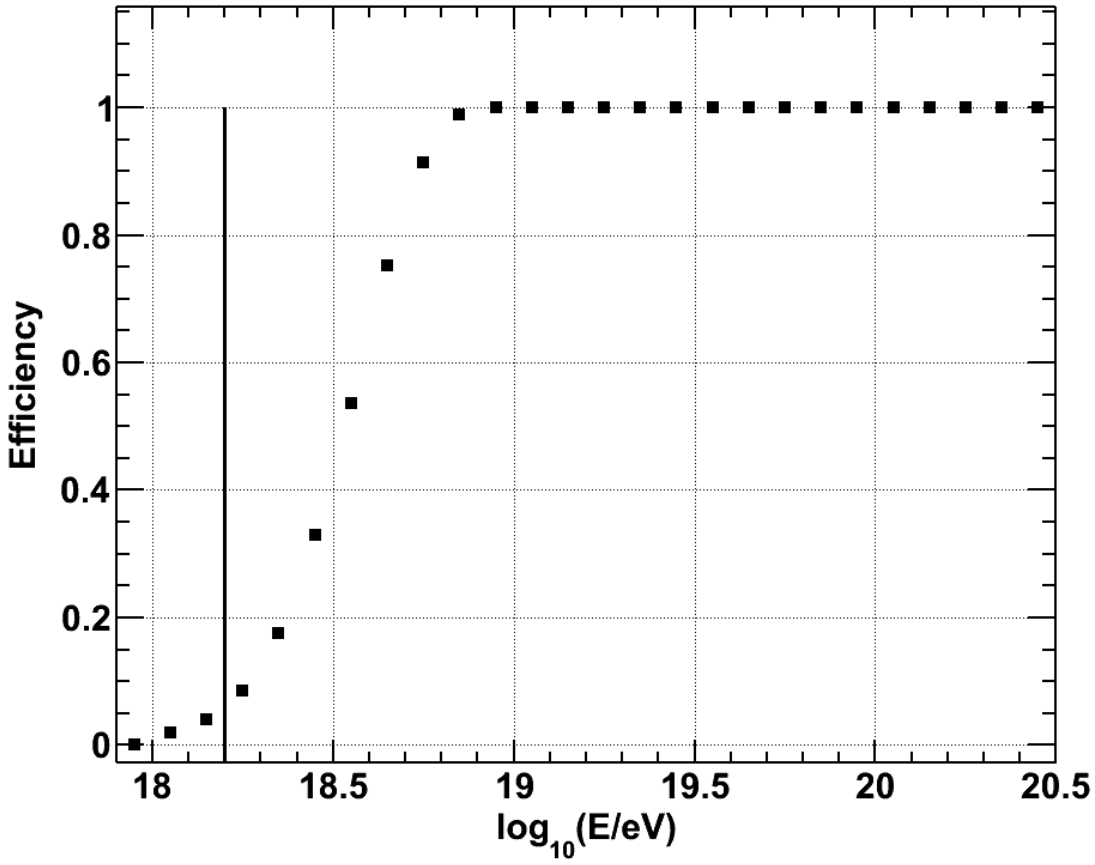




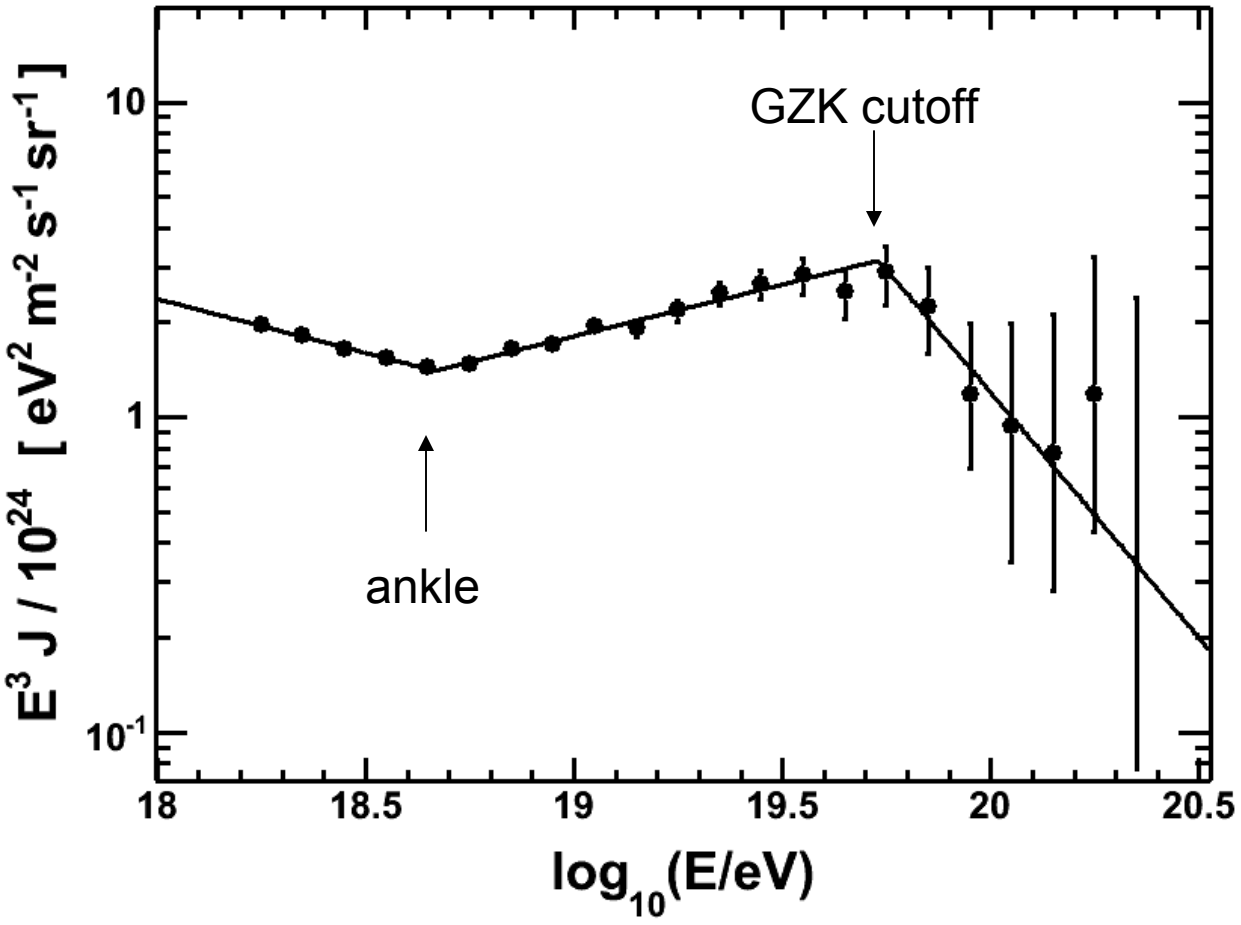
LDF χ^2/dof

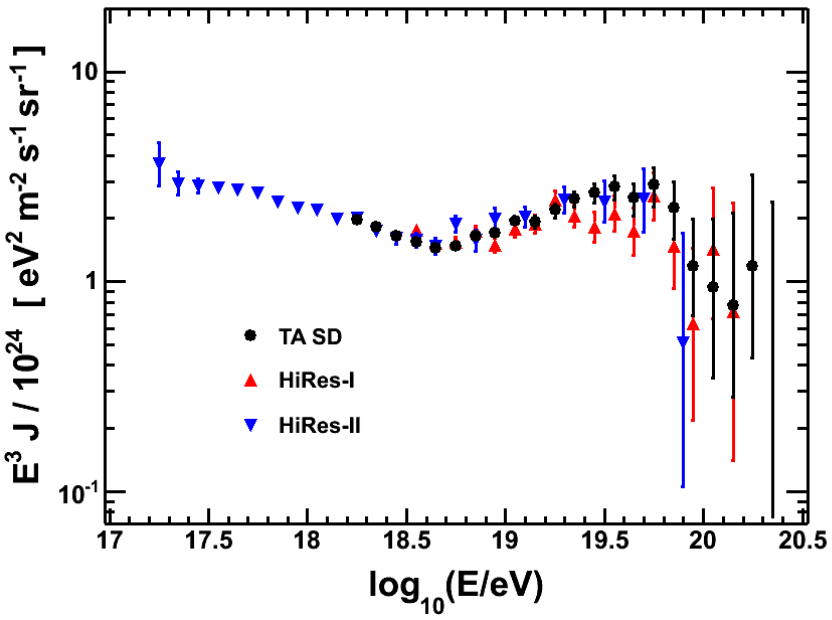
Counter pulse height

Acceptance



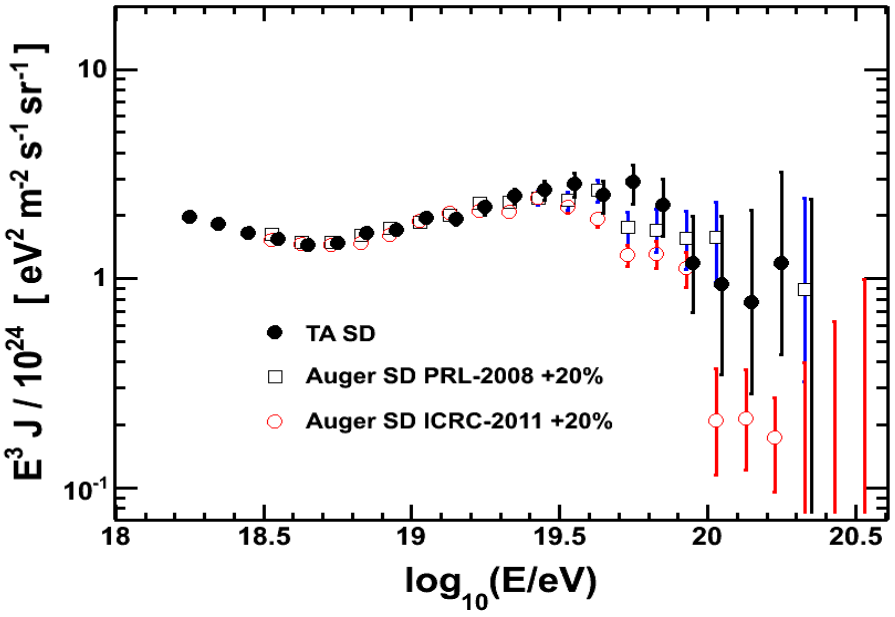
Spectrum Result



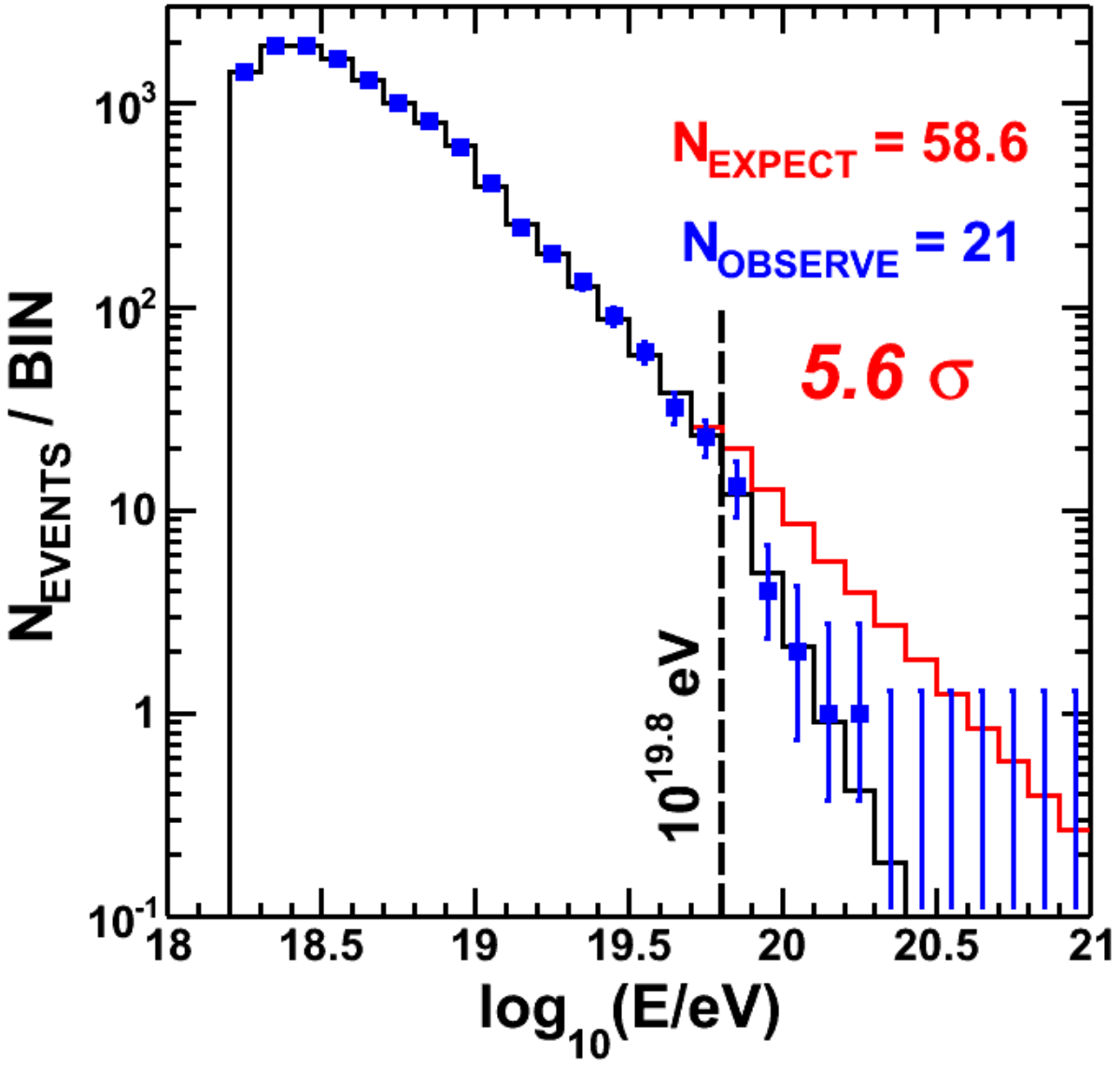


TA + HiRes

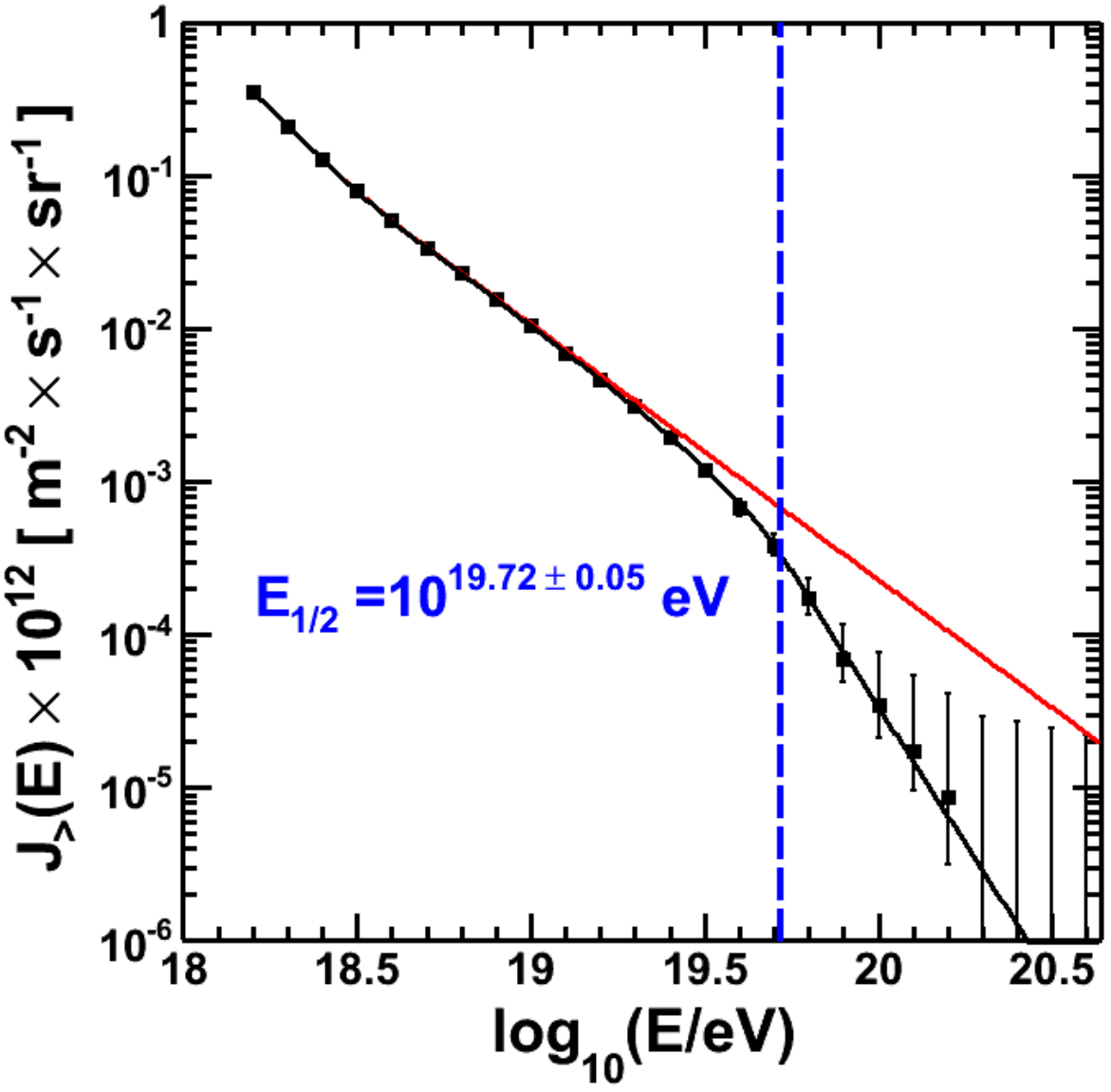
TA + Auger



Significance of the Suppression

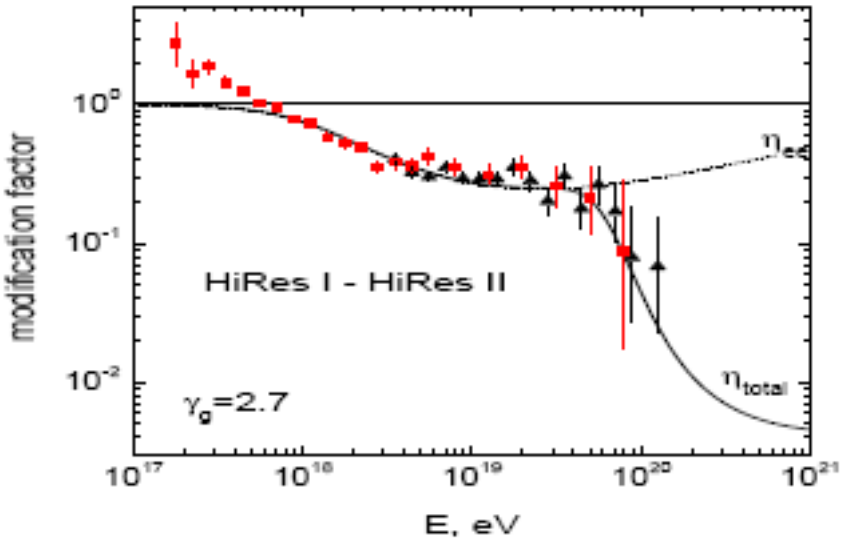


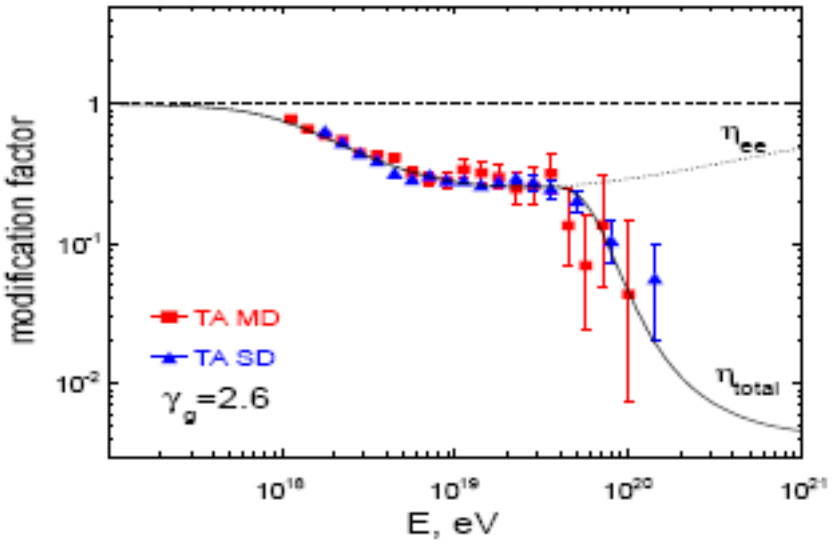
Berezinsky: $E_{1/2} = 10^{19.72}$ eV



Comparison with Theoretical Model

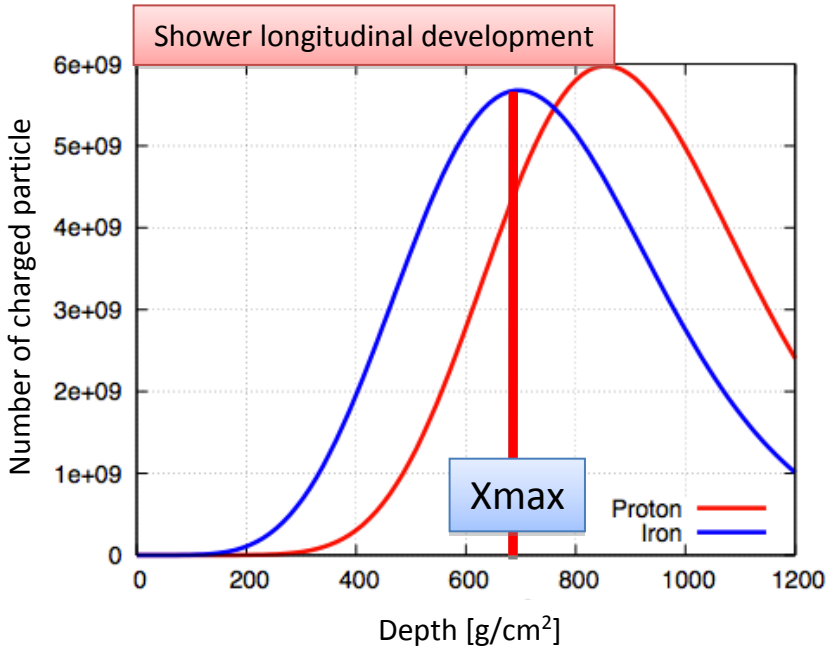
- Assume proton composition, constant density of sources, calculate the “modification factor” due to propagation; compare with HiRes and TA data.

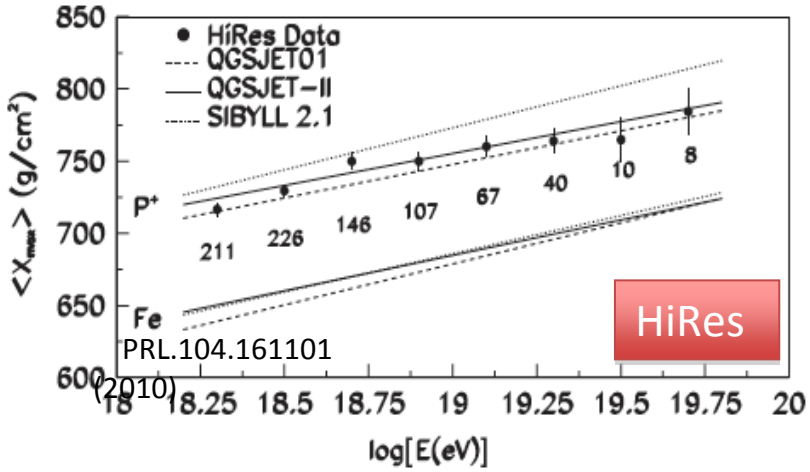




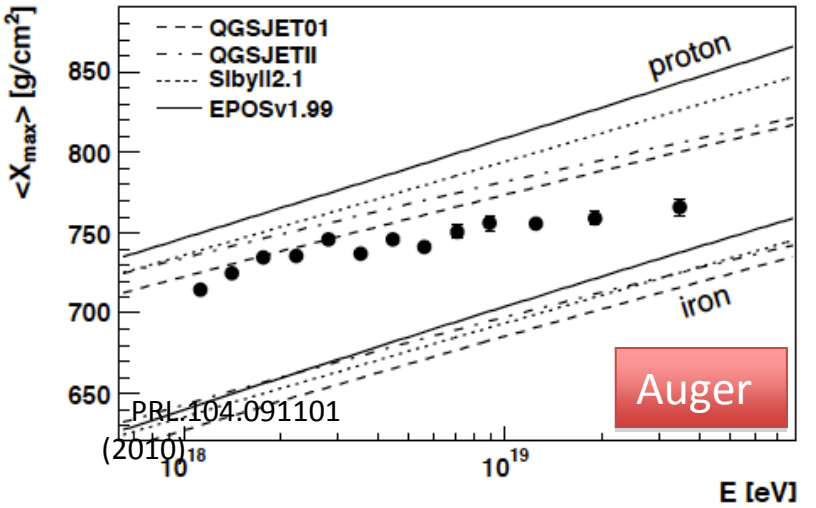
Composition from Xmax

- Shower longitudinal development depends on primary particle type.
- FD observes shower development directly.
- Xmax is the most efficient parameter for determining primary particle type.



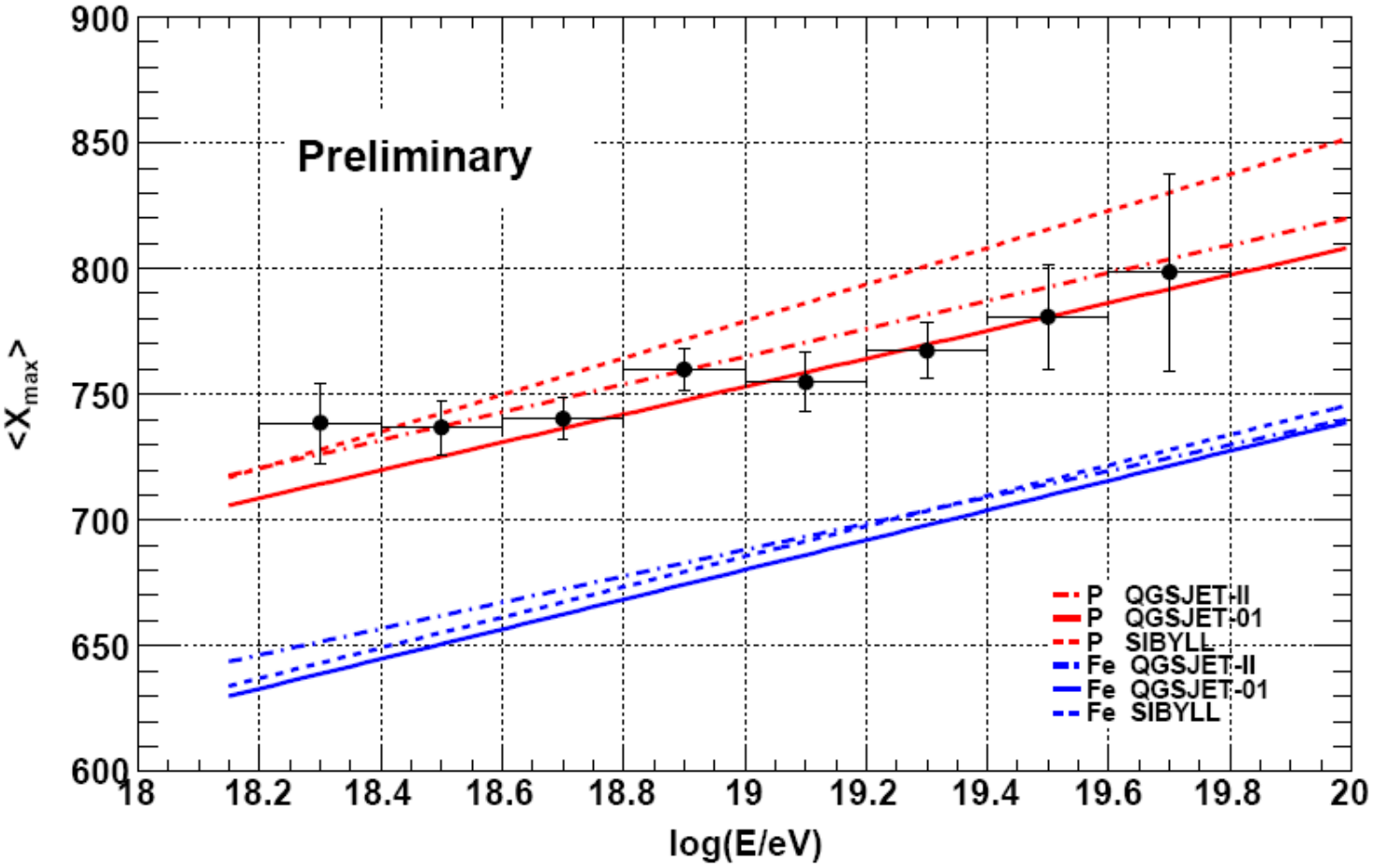


PRL.104.161101 (2010)



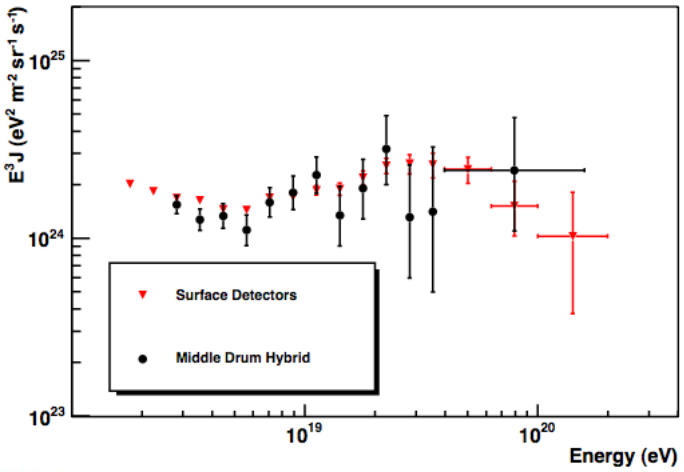
PRL.104.091101 (2010)

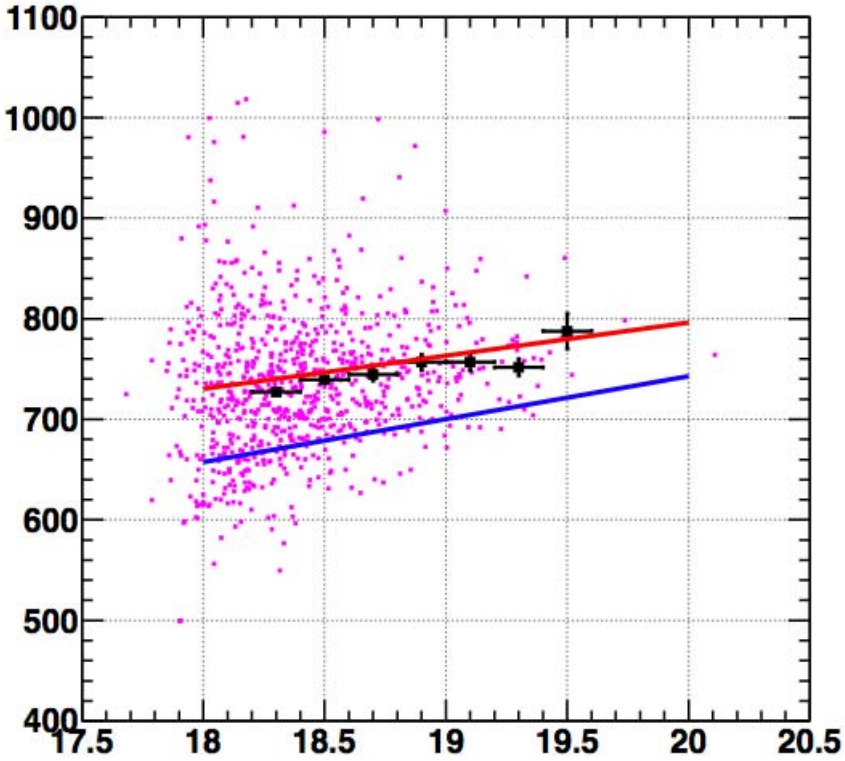
TA Stereo: Energy vs <Xmax>



First TA Hybrid Results

- Preliminary hybrid results (SD + Middle Drum FD):
  - Spectrum
  - <Xmax>
- Hybrid and stereo give consistent <Xmax> results



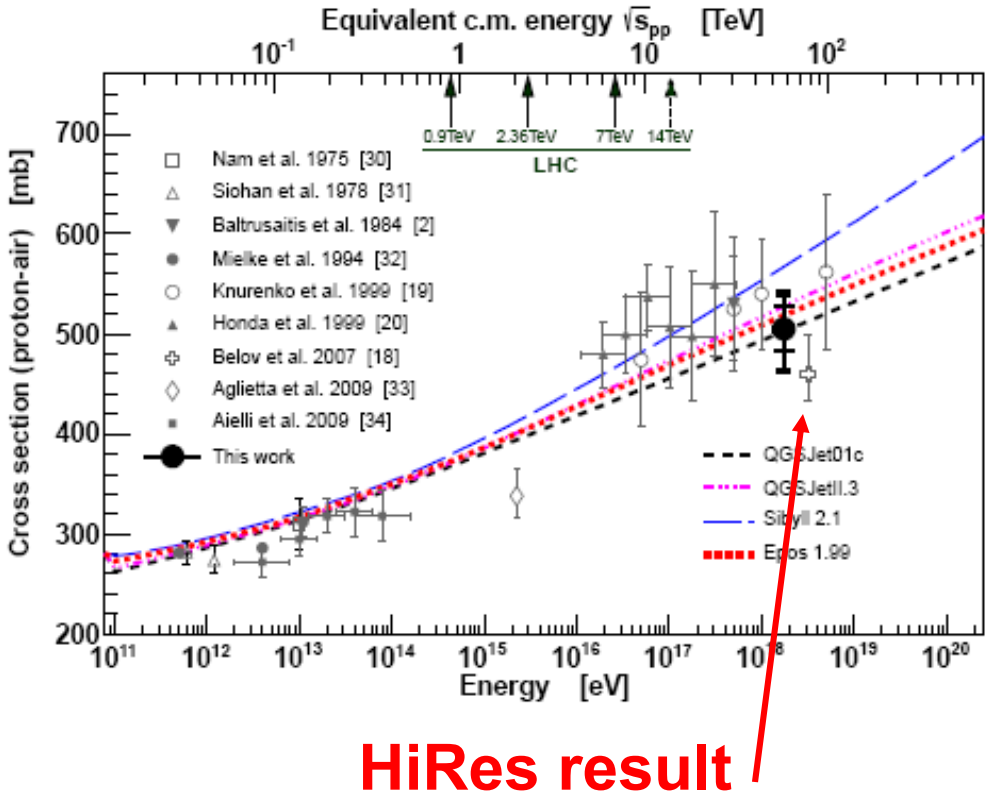


Proton–Air Total Cross Section

- Figure from Auger paper on the p-air total cross section.
- **HiRes data point indicated.**

➔**Good agreement.**

- TA result not yet ready.



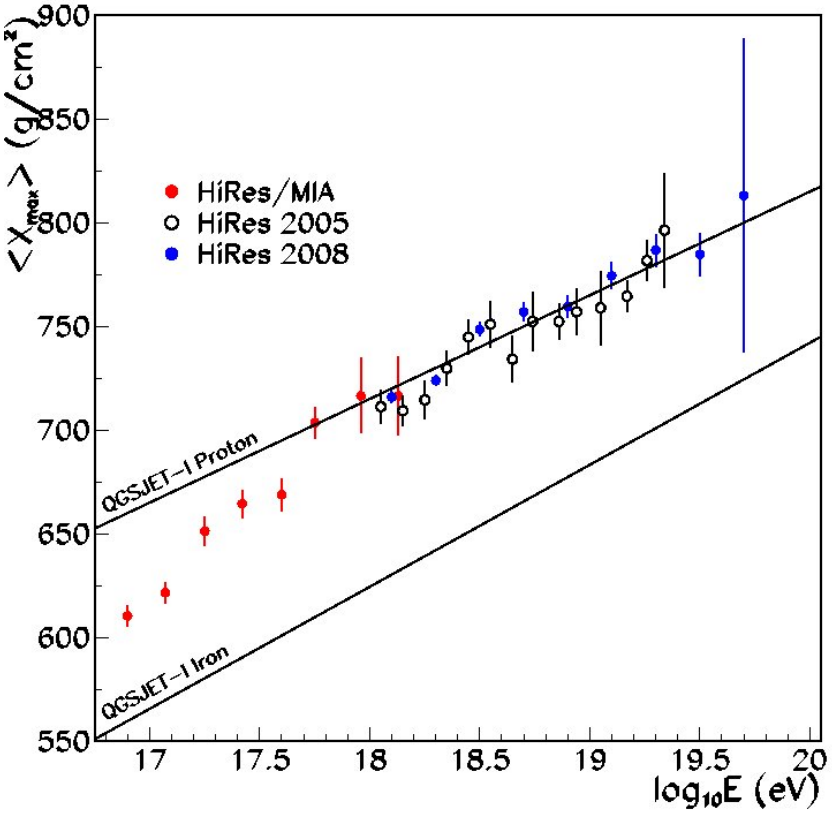
HiRes result

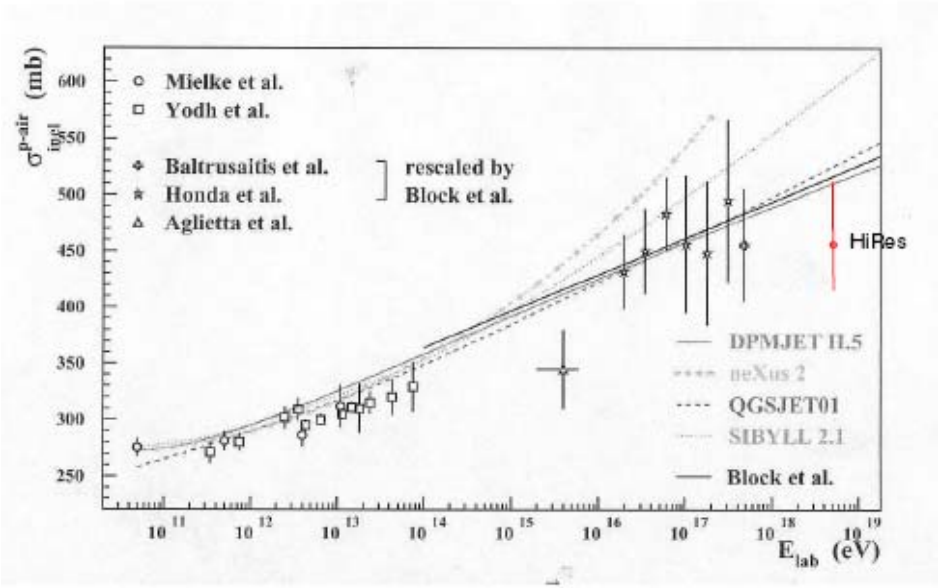
TA Low Energy Extension (TALE)

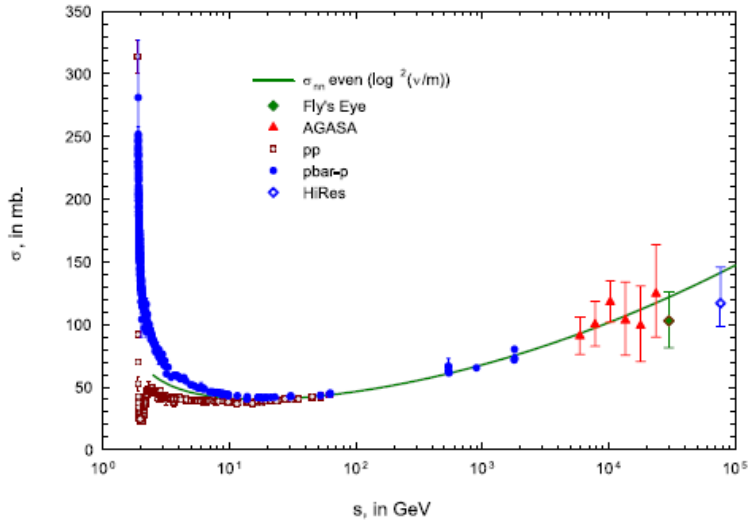
- A lot of physics was skipped in the push to observe the GZK cutoff. ➔ Study the 10^{16} and 10^{17} eV decades with a hybrid detector.
- **Cosmic Ray Astrophysics topics:**
  - End of the rigidity-dependent cutoff that starts with the knee ($3x10^{15}$ - $8x10^{16}$ eV).
  - The second knee
  - The galactic-extragalactic transition
- **Concentrate at LHC energy, $1x10^{17}$ eV**

Physics at ≥1x10^{17} eV

- Study cosmic ray showers exactly at the LHC energy.
  - Cross sections will be measured; no extrapolations will be necessary. Models will be more accurate.
  - 1x10^{17} eV is just above the iron knee; will see galactic iron.
  - E_c for the galactic magnetic field is slightly higher (~3x10^{17} eV); some protons can enter the galaxy.
  - Composition is likely to be a mixture of iron and protons; choose protons using the high-Xmax tail. Measure σ(p-air).
- Extend σ(p-air) measurements to 3x10^{18} eV (composition in 10^{18} eV decade is protonic)

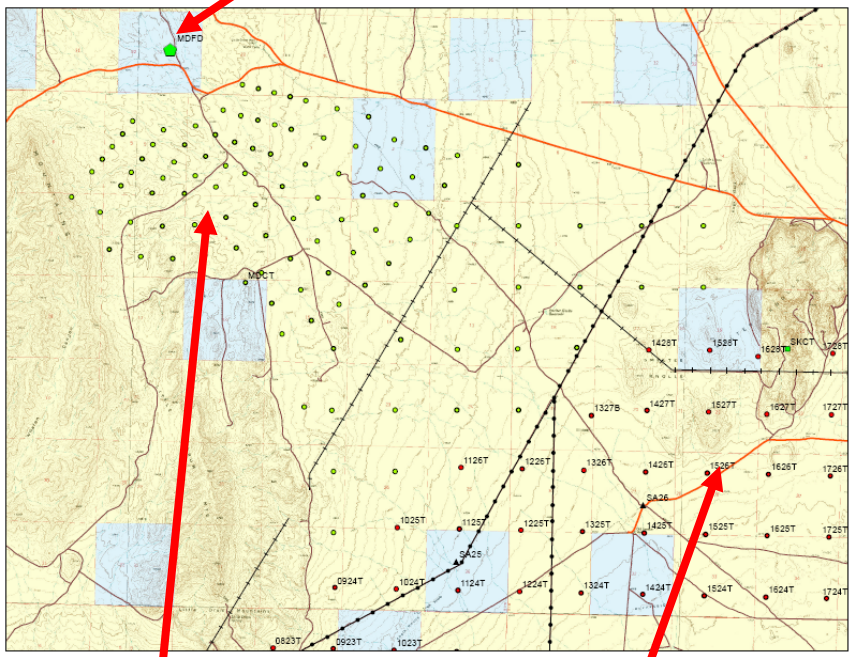


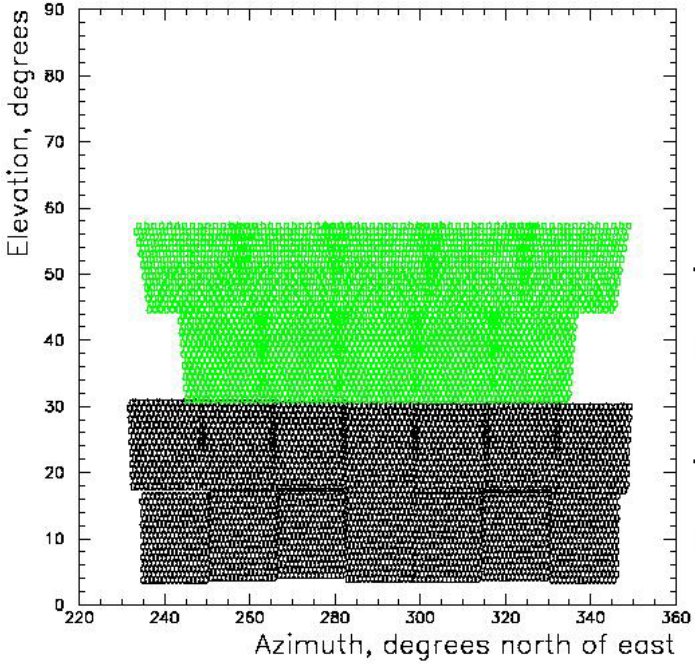




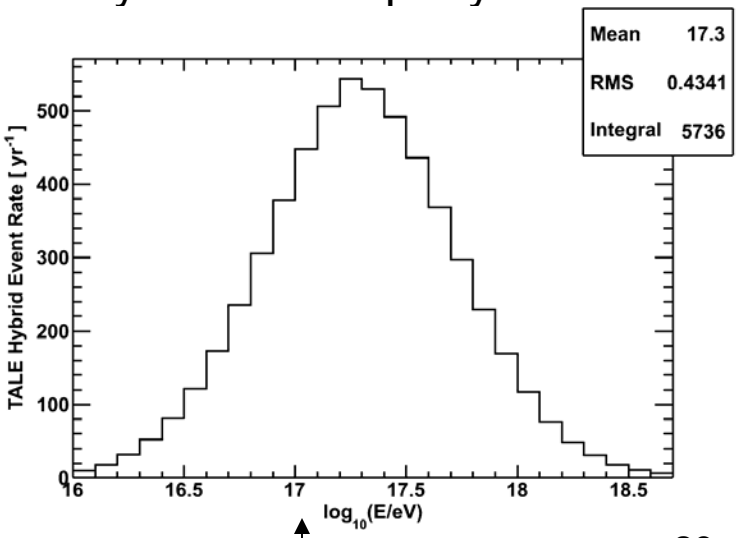
Model by Marty Block

TALE Detectors are being deployed.



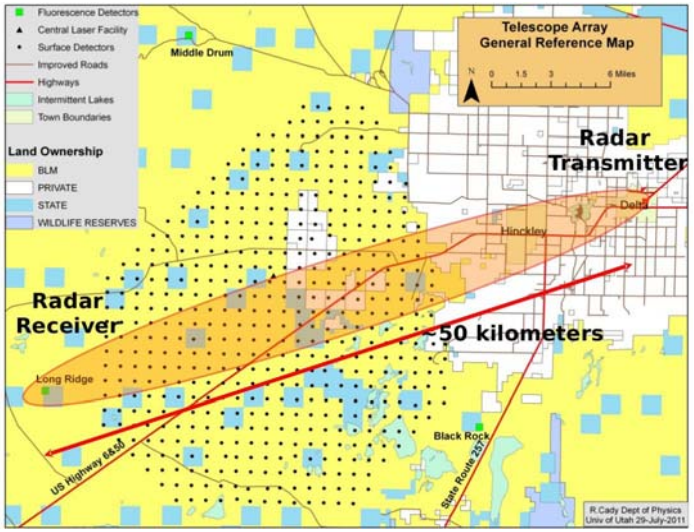


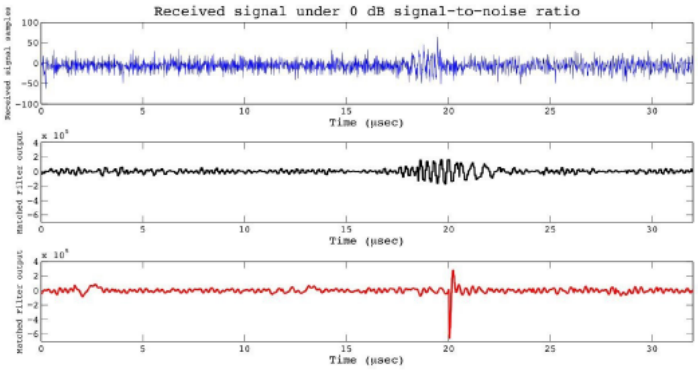
TALE hybrid events per year



R&D on Radar Detection of Cosmic Ray Showers

- Rates at the highest energies are too low ➔ need bigger experiments.
- Bistatic radar detection:
  - Remote sensing
  - Inexpensive
  - 100% duty cycle



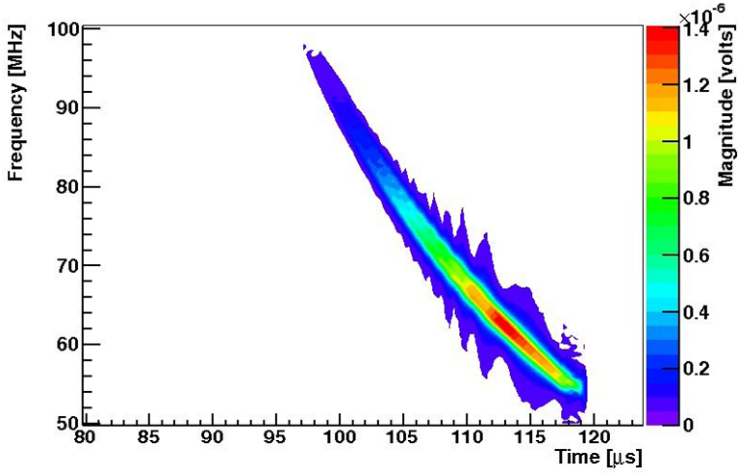


Input 3.5 MHz/microsec "chirp"

1 MHz/microsec filter output

3.5 MHz/microsec filter output

Chirp detection by matched filters



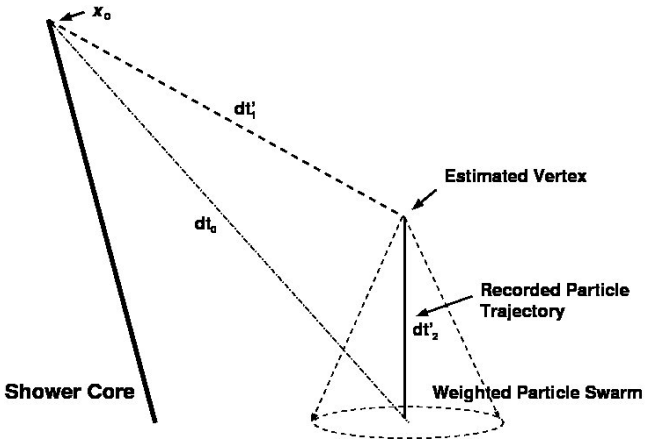
"chirp"

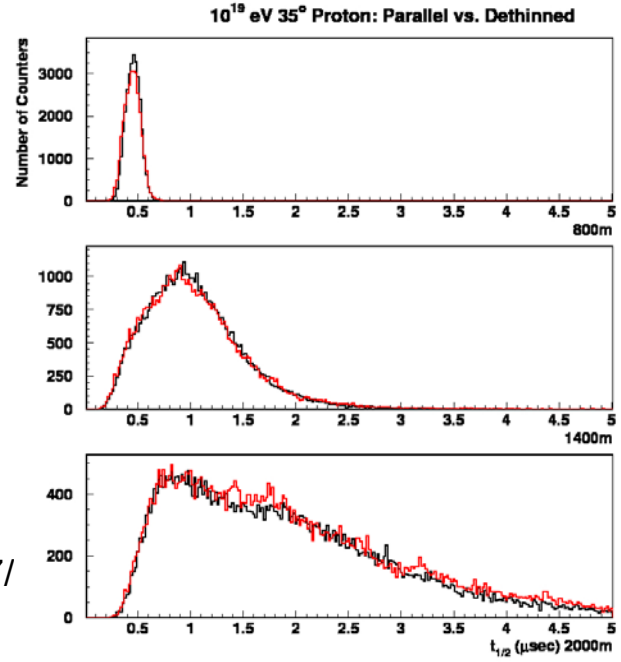
Summary

- TA is the largest UHECR experiment in the northern hemisphere.
- We have excellent control of systematics.
- Composition above 1 EeV is light.
- TALE is turning on.
- Radar R&D project (J. Belz tomorrow)
- Further upgrades are planned.

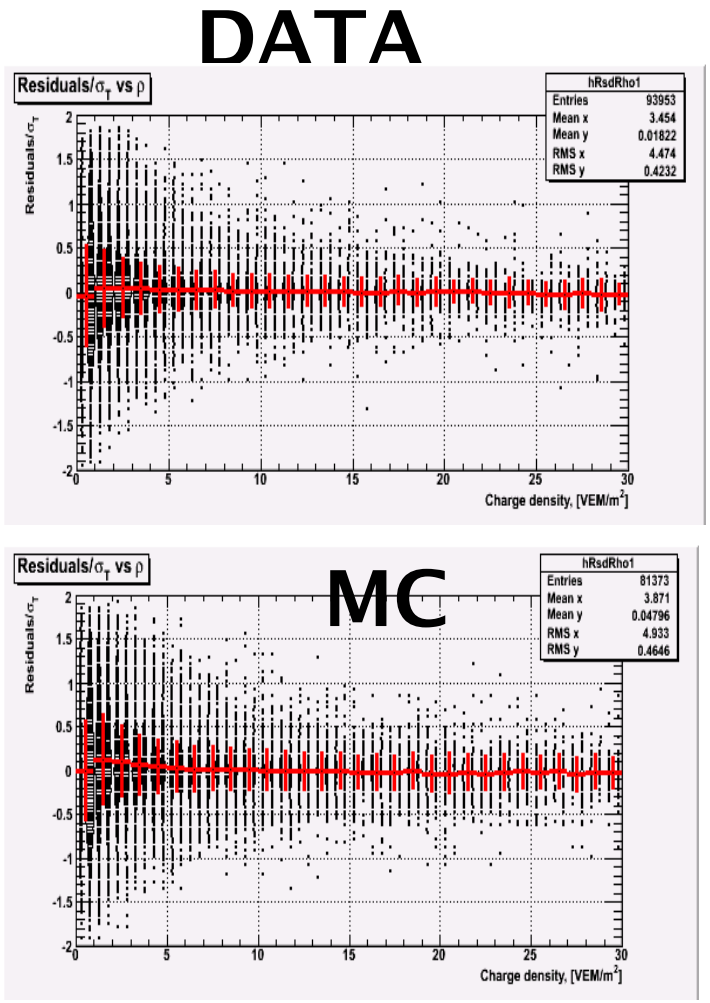
Dethinning Technique

- Change each Corsika “output particle” of weight *w* to *w* particles; distribute in space and time.
- Time distribution agrees with unthinned Corsika showers.



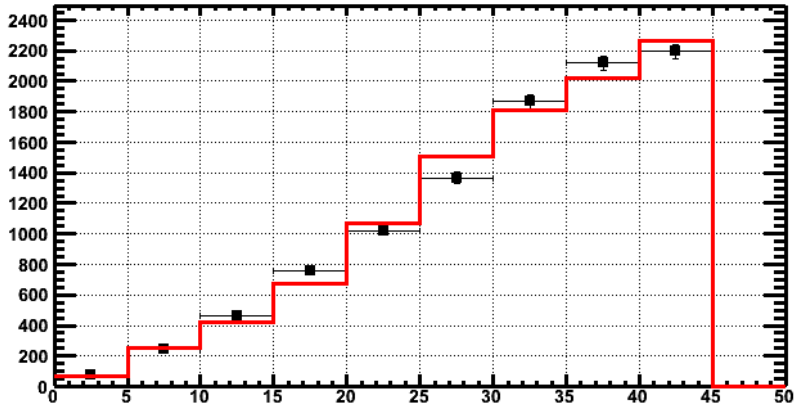


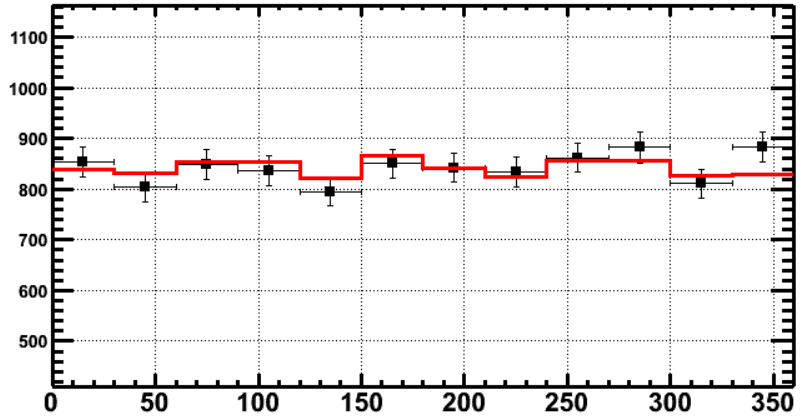
Fitting results

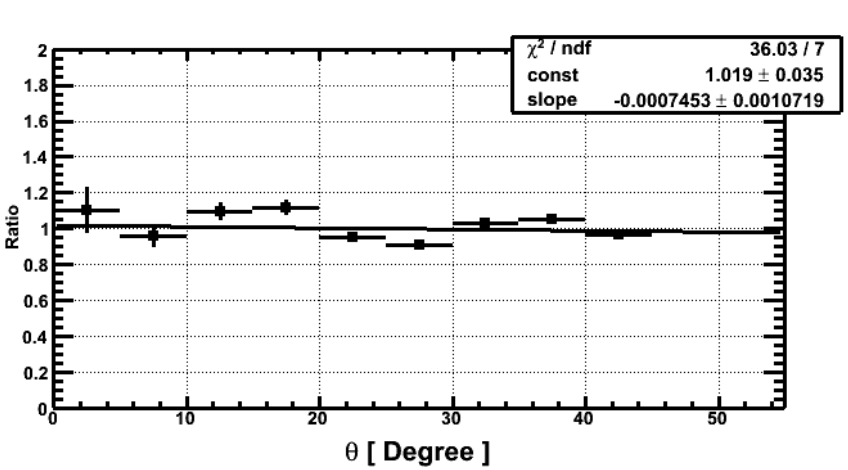


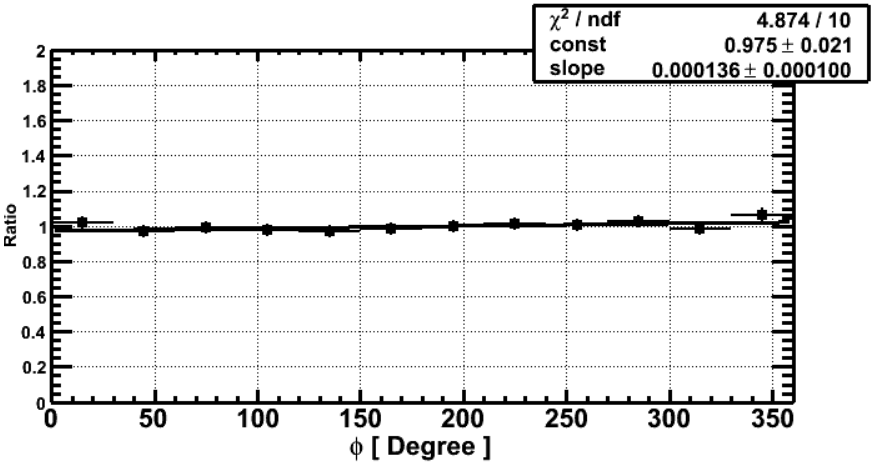
- Fitting procedures are derived solely from the data
- Same analysis is applied to MC
- Fit results are compared between data and MC
- MC fits the same way as the data.
- Consistency for both time fits and LDF fits.
- Corsika/QGSJet-II and data have same lateral distributions!

Data/MC Comparisons





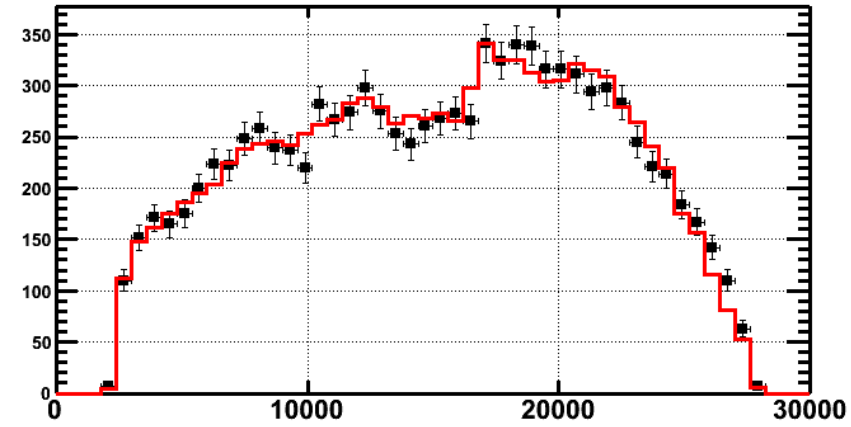


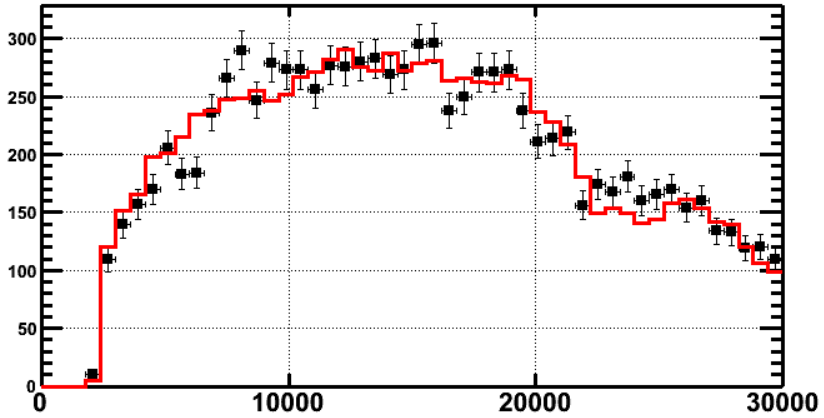


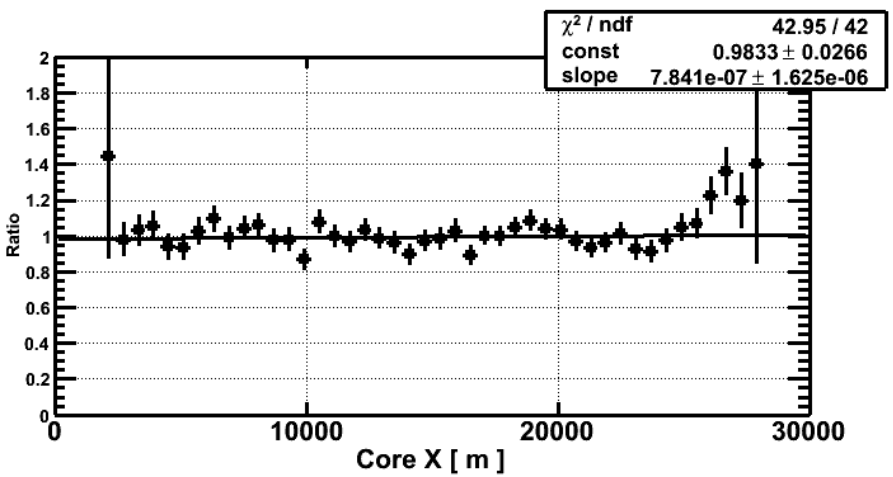
Zenith angle

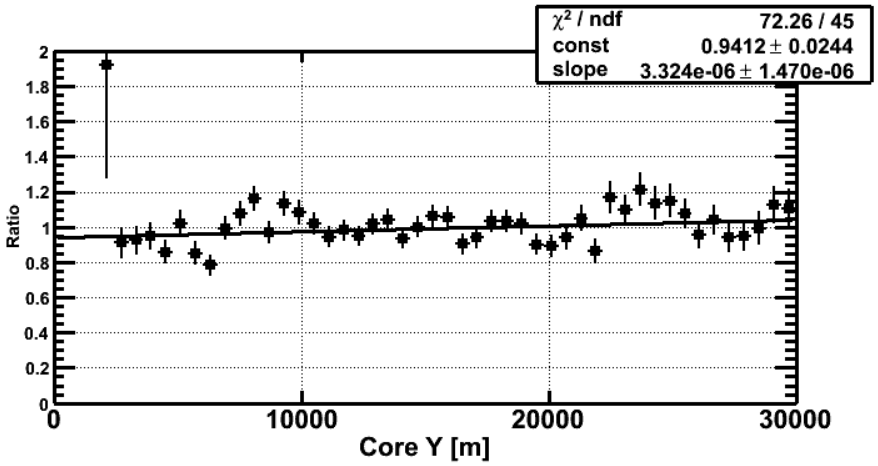
Azimuth angle

Data/MC Comparisons









Core Position (E-W)

Core Position (N-S)