# Results from the Telescope Array Experiment

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ICHEP-2010

# Telescope Array Collaboration

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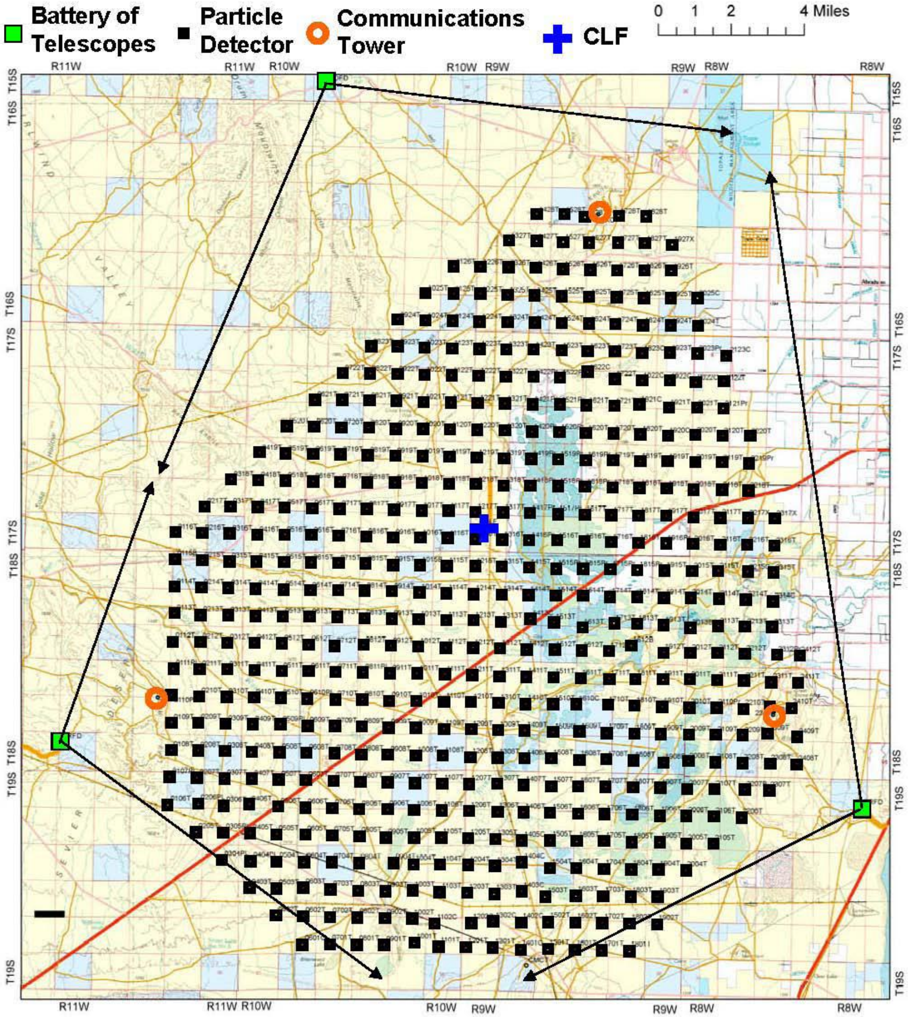
# Outline

- Introduction
- TA Results:
  - FD mono spectrum
  - SD mono spectrum
  - Stereo composition result
  - Search for AGN correlations
- Conclusions

# 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.
- 2.5 yr (FD) and 2 yr (SD) of data have been collected.



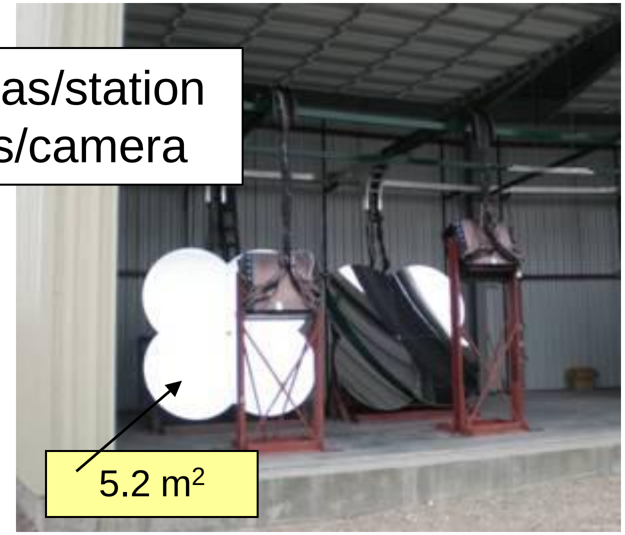
# TA Fluorescence Detectors

**Refurbished from HiRes**

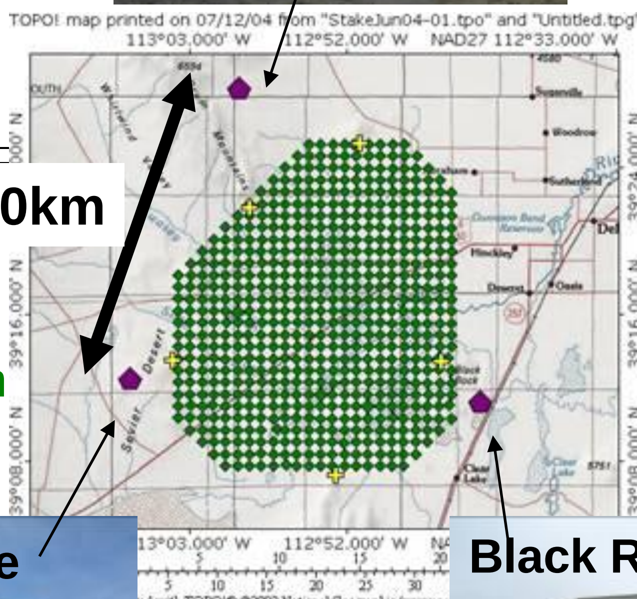
Observation started Dec. 2007

**Middle Drum**

14 cameras/station
256 PMTs/camera

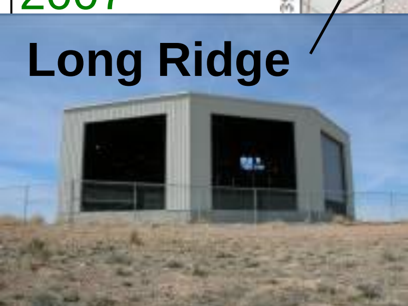



**~30km**




Observation started Nov. 2007

**Long Ridge**



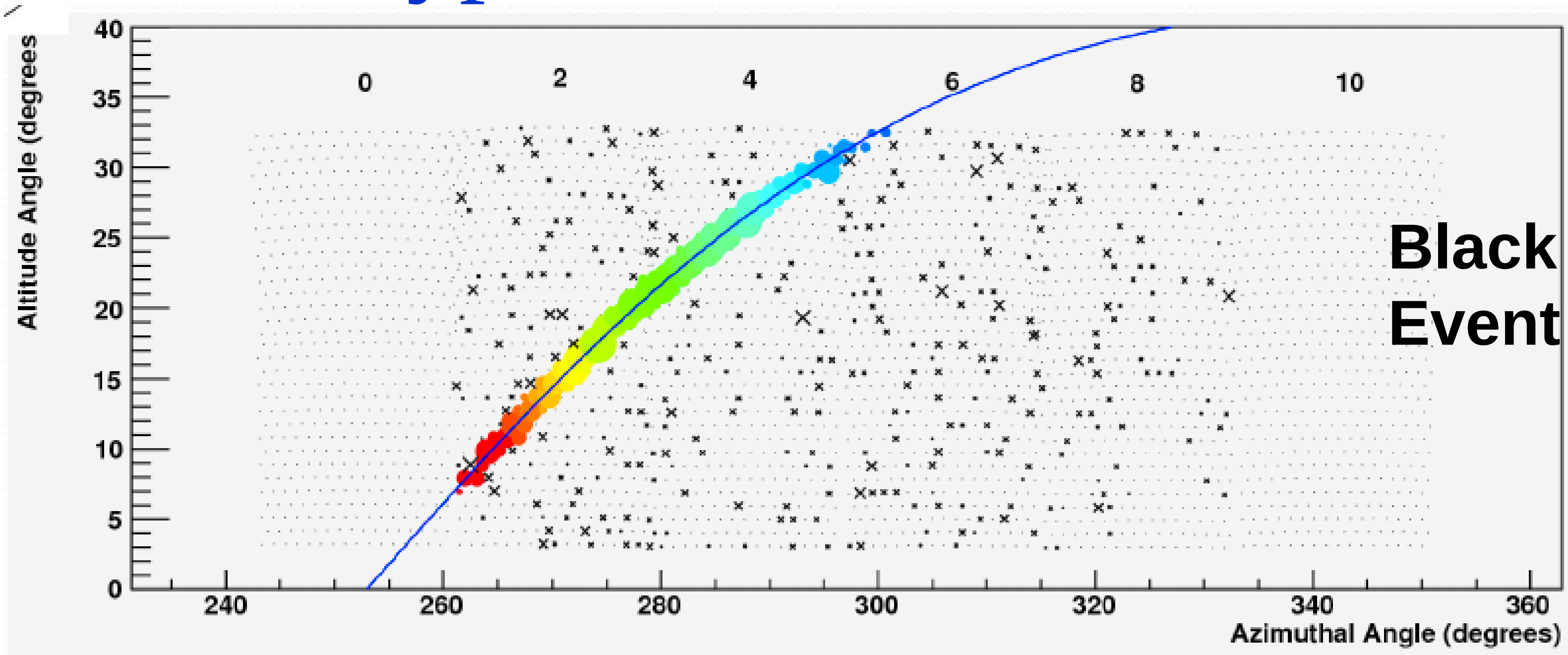
Observation started Jun. 2007

**Black Rock Mesa**

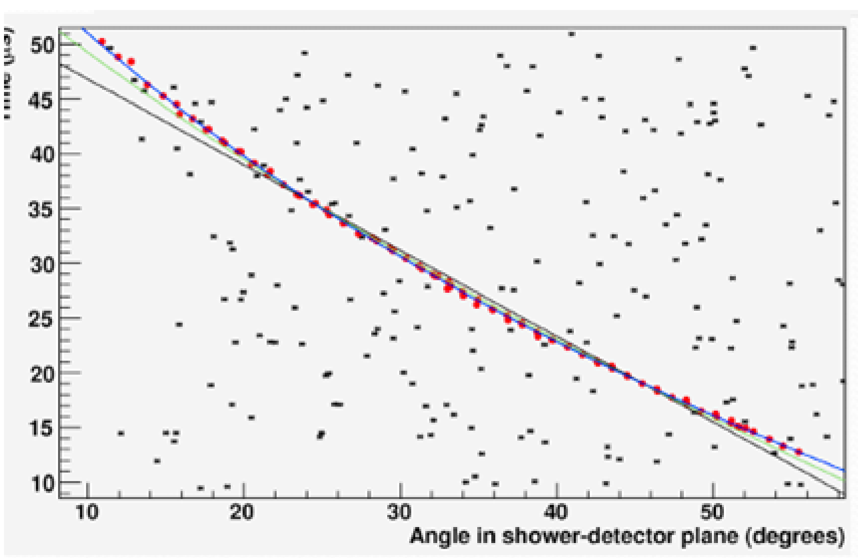
**New FDs**

256 PMTs/camera
HAMAMATSU R9508
FOV~15x18deg
12 cameras/station

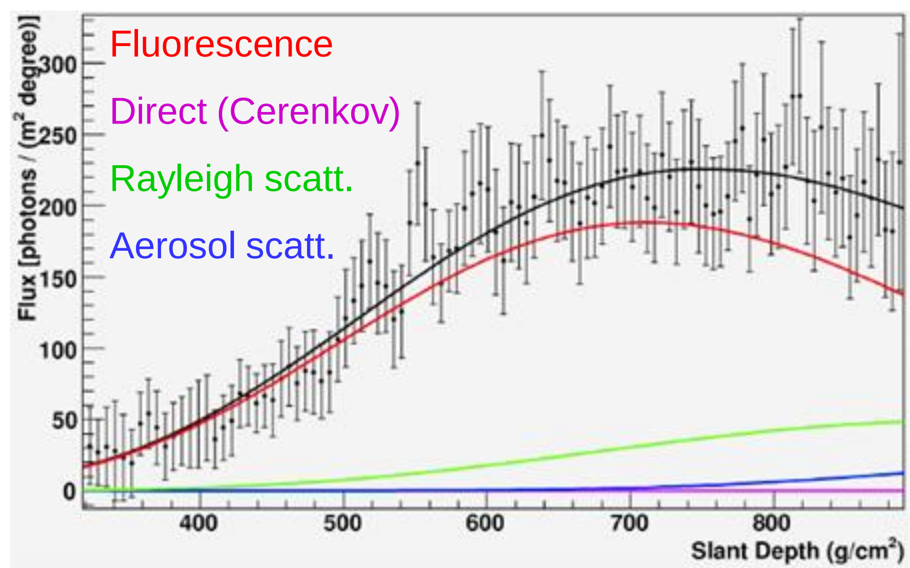

# Typical Fluorescence Event




**Black Rock Event Display**




**Monocular timing fit**



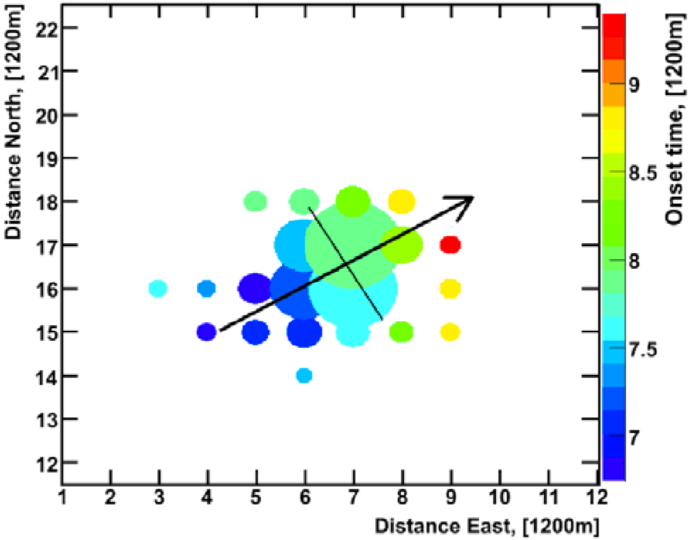

**Reconstructed Shower Profile**

# TA Surface Detector

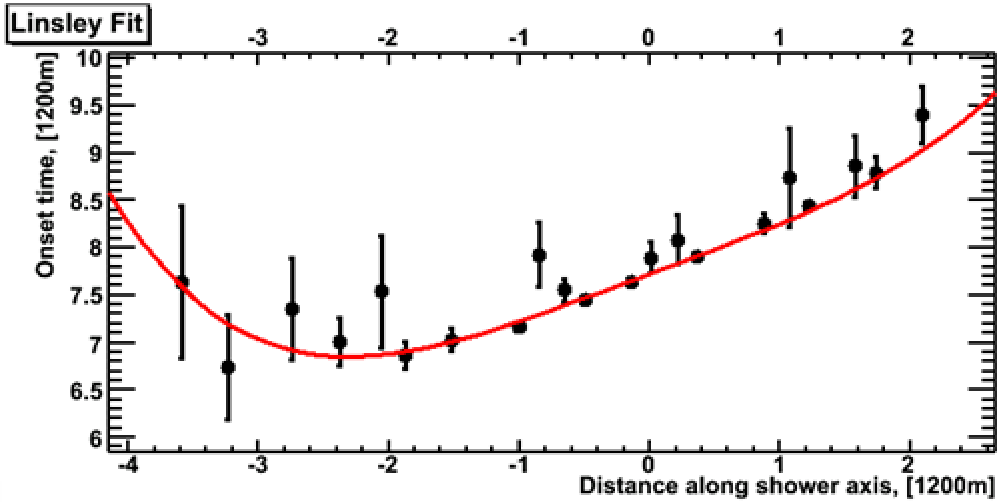
- Powered by solar cells; radio readout.
- Self-calibration using single muons.
- In operation since March, 2008.

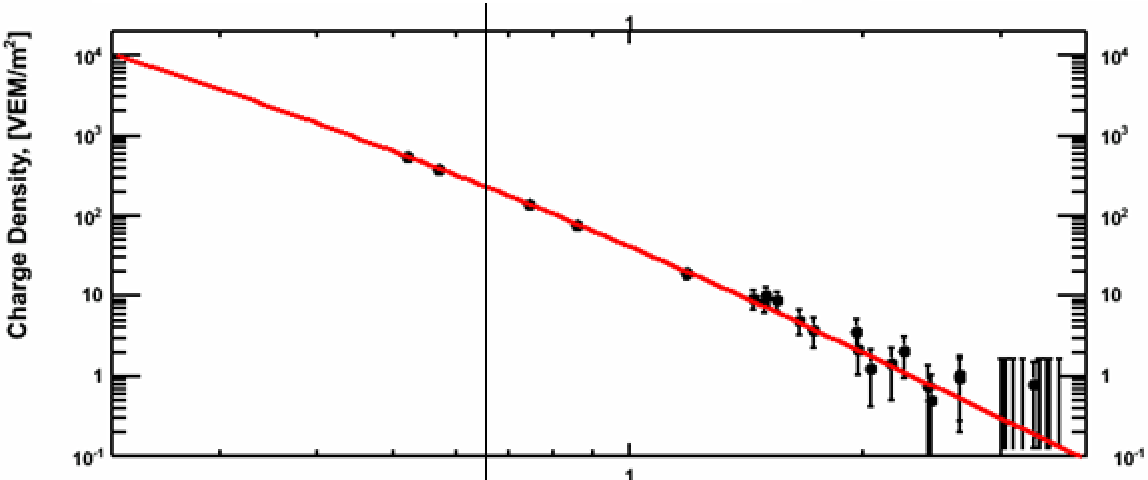
# Typical surface detector event

**2008/Jun/25 - 19:45:52.588670 UTC**




**Geometry Fit (modified Linsley)**




**Lateral Density Distribution Fit**

***r* = 800m**

Fit with AGASA LDF

$$\rho(r) \propto \left(\frac{r}{R_M}\right)^{-1.2} \left(1+\frac{r}{R_M}\right)^{-(\eta-1.2)} \left\{1+\left(\frac{r}{1000}\right)^2\right\}^{-0.6}$$

$$\eta = (3.97 \pm 0.13) - (1.79 \pm 0.62)\,(\sec\theta - 1)$$

- S(800): Primary Energy
- Zenith attenuation by MC (not by CIC).

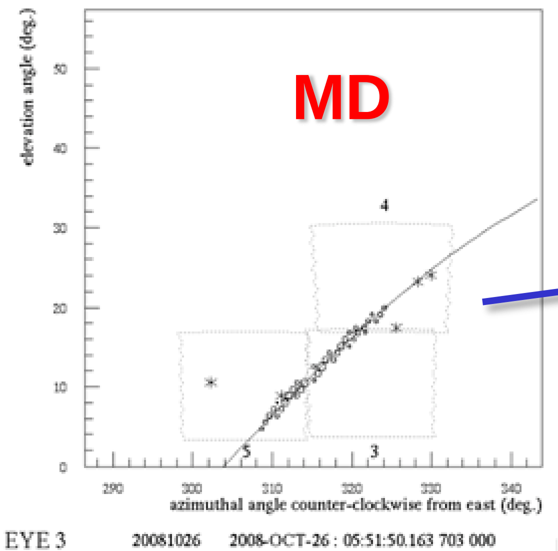
# Stereo and Hybrid Observation

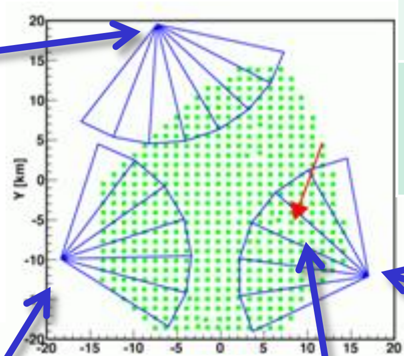
- Many events are seen by several detectors.
  - FD mono has ~5  resolution in $\psi$.
  - Add SD information (hybrid reconstruction) → ~0.5 resolution.
  - Stereo FD resolution ~0.5
- Need stereo or hybrid for composition analysis.

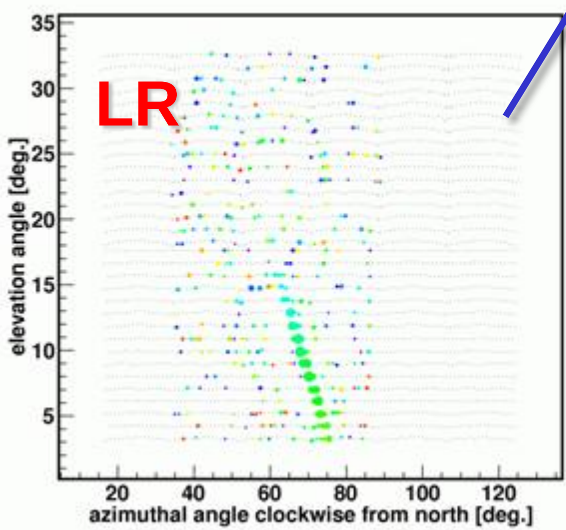
- Independent operation so far.
- Hybrid trigger will be instituted this summer.

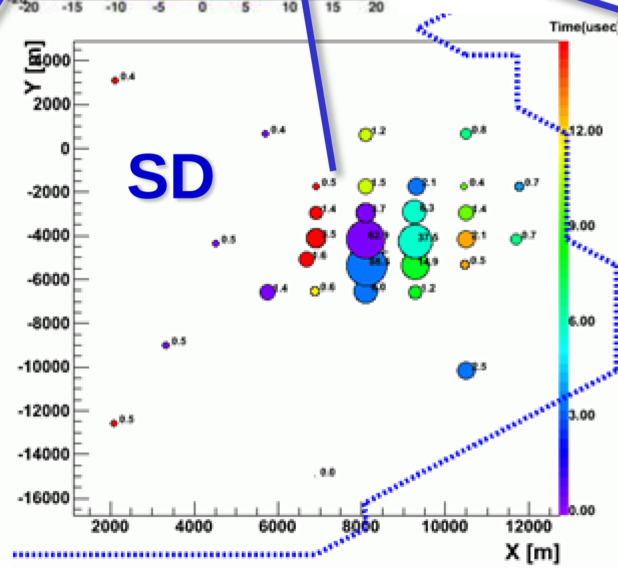
# Triple FD Event (2008-10-26)

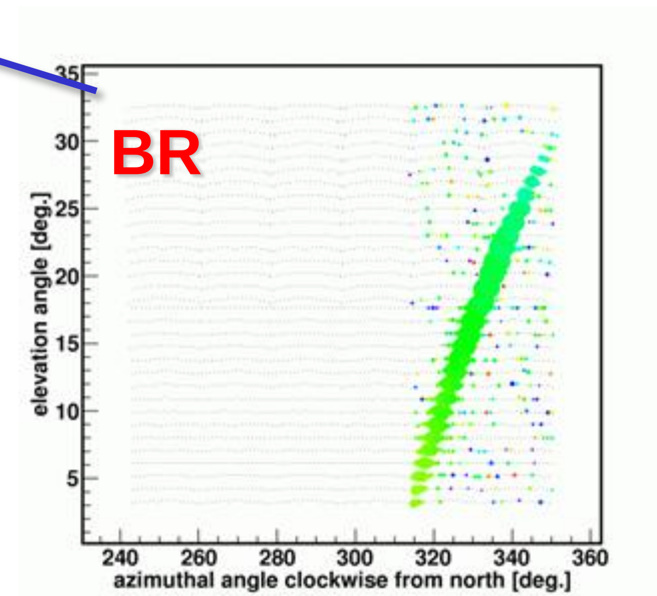
| | $\theta$[deg] | $\phi$ [deg] | X[km] | Y[km] |
|---|---|---|---|---|
| MD mono | 51.43 | 73.76 | 7.83 | -3.10 |
| BR mono | 51.50 | 77.09 | 7.67 | -4.14 |
| Stereo BR&LR | 50.21 | 71.30 | 8.55 | -4.88 |



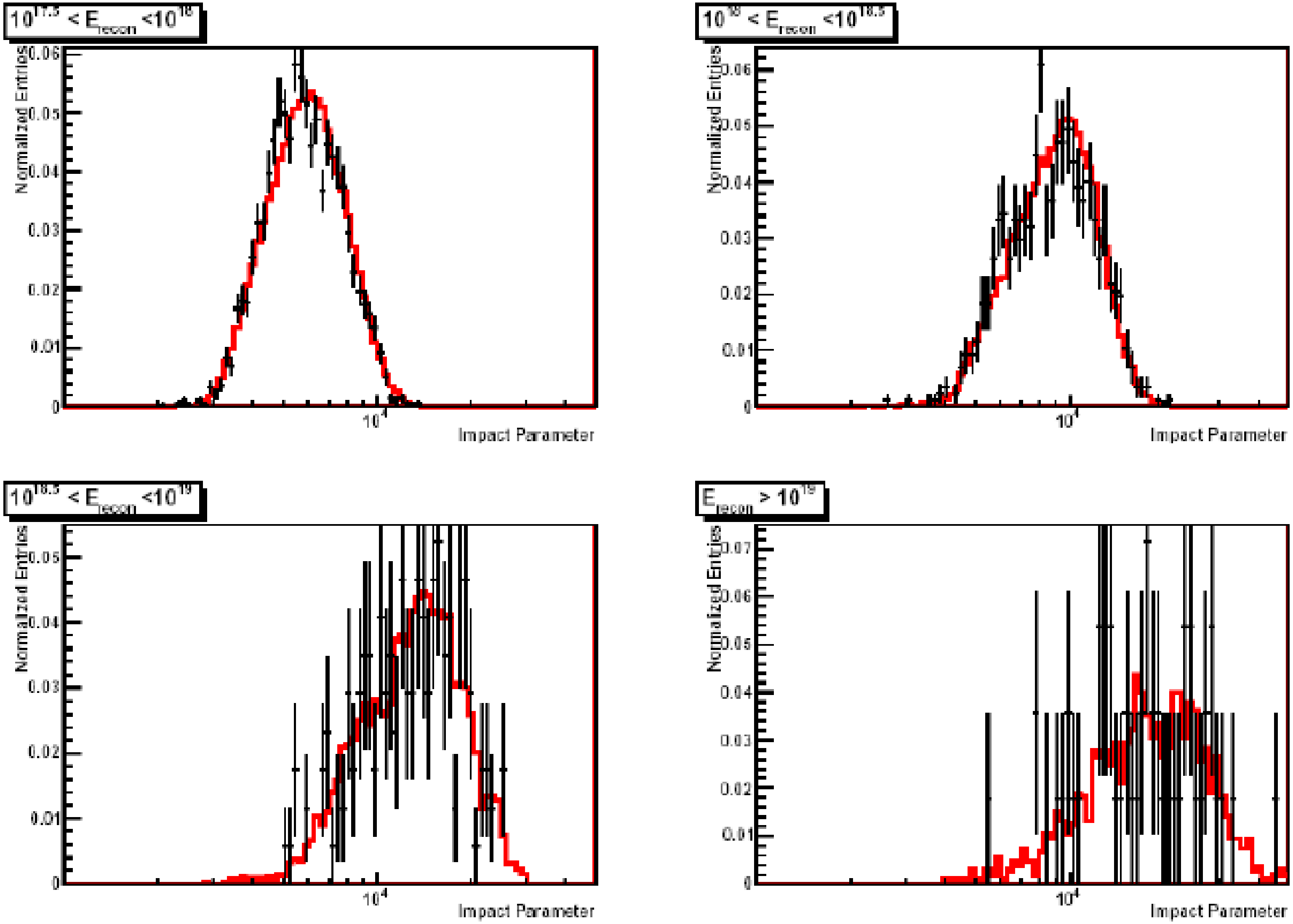
# Fluorescence Detector (FD) Monocular Spectrum

- For FD (mono, hybrid, stereo) measurements, the aperture depends significantly on energy. ➔ Must calculate it by Monte Carlo technique.
- This is an important part of UHECR technique, and must be done accurately.
- We use HEP methods for this purpose.

# MC Method

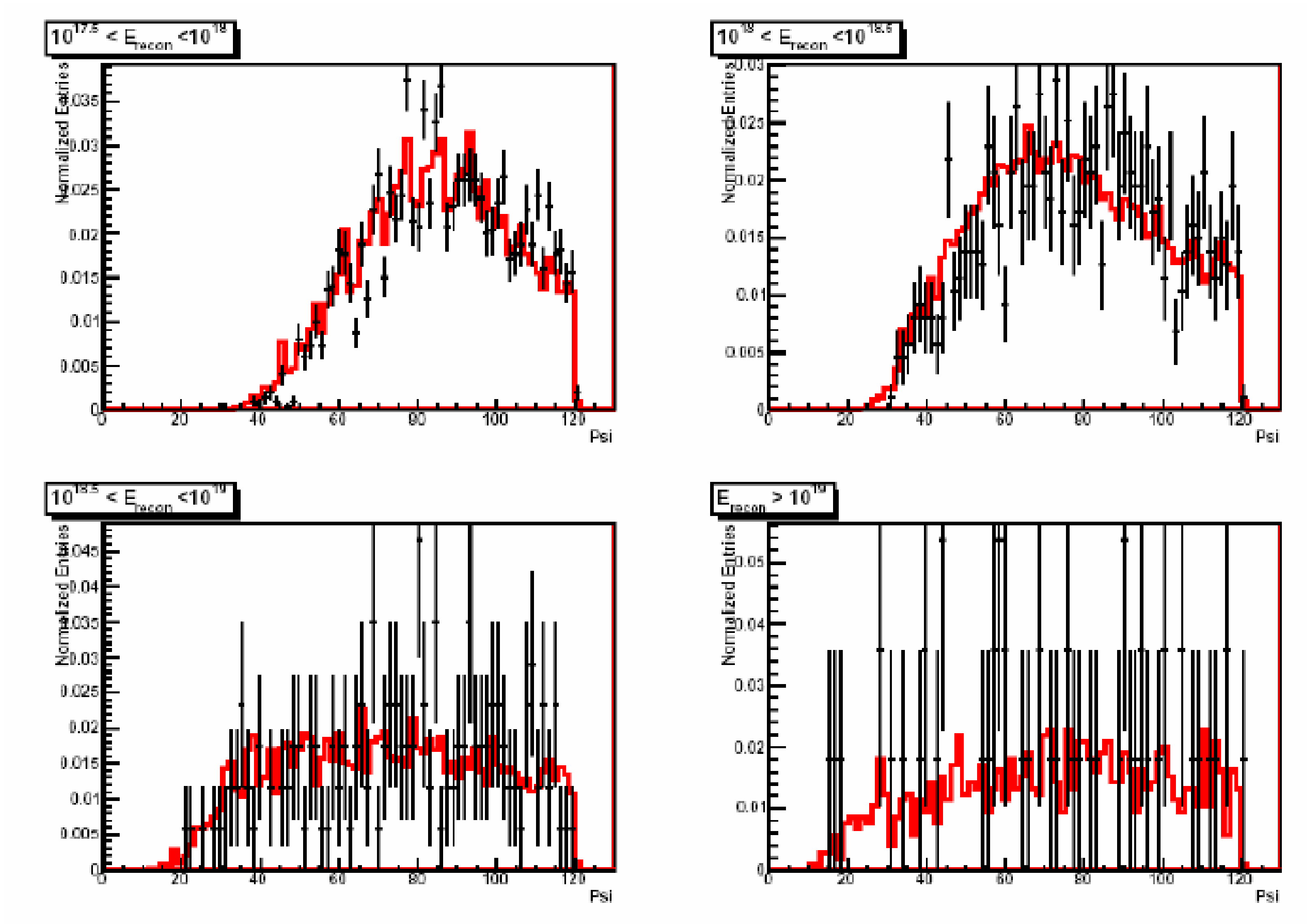
- Simulate the data exactly as it exists.
  - Start with previously measured spectrum and composition.
  - Use Corsika/QGSJet events.
  - Throw with isotropic distribution.
  - Include atmospheric scattering.
  - Simulate trigger, front-end electronics, DAQ.
- Write out the MC events in same format as data.
- Analyze the MC with the same programs used for data.
- Test with data/MC comparison plots.
- This method works.

# Rp (km)

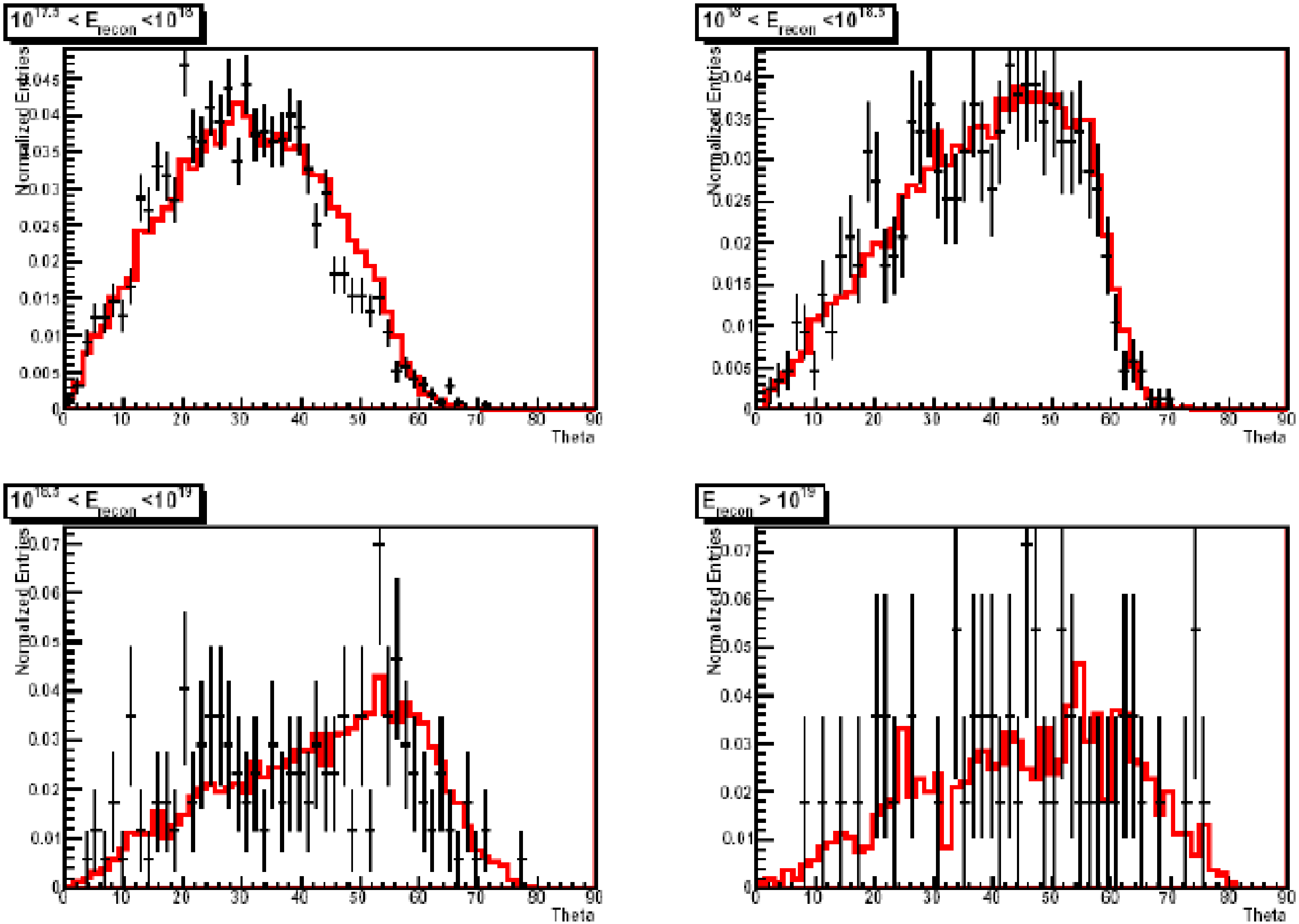


$10^{17.5} < E_{recon} < 10^{18}$
$10^{18} < E_{recon} < 10^{18.5}$
$10^{18.5} < E_{recon} < 10^{19}$
$E_{recon} > 10^{19}$
Normalized Entries
Impact Parameter
$10^4$

# Psi angle (deg)



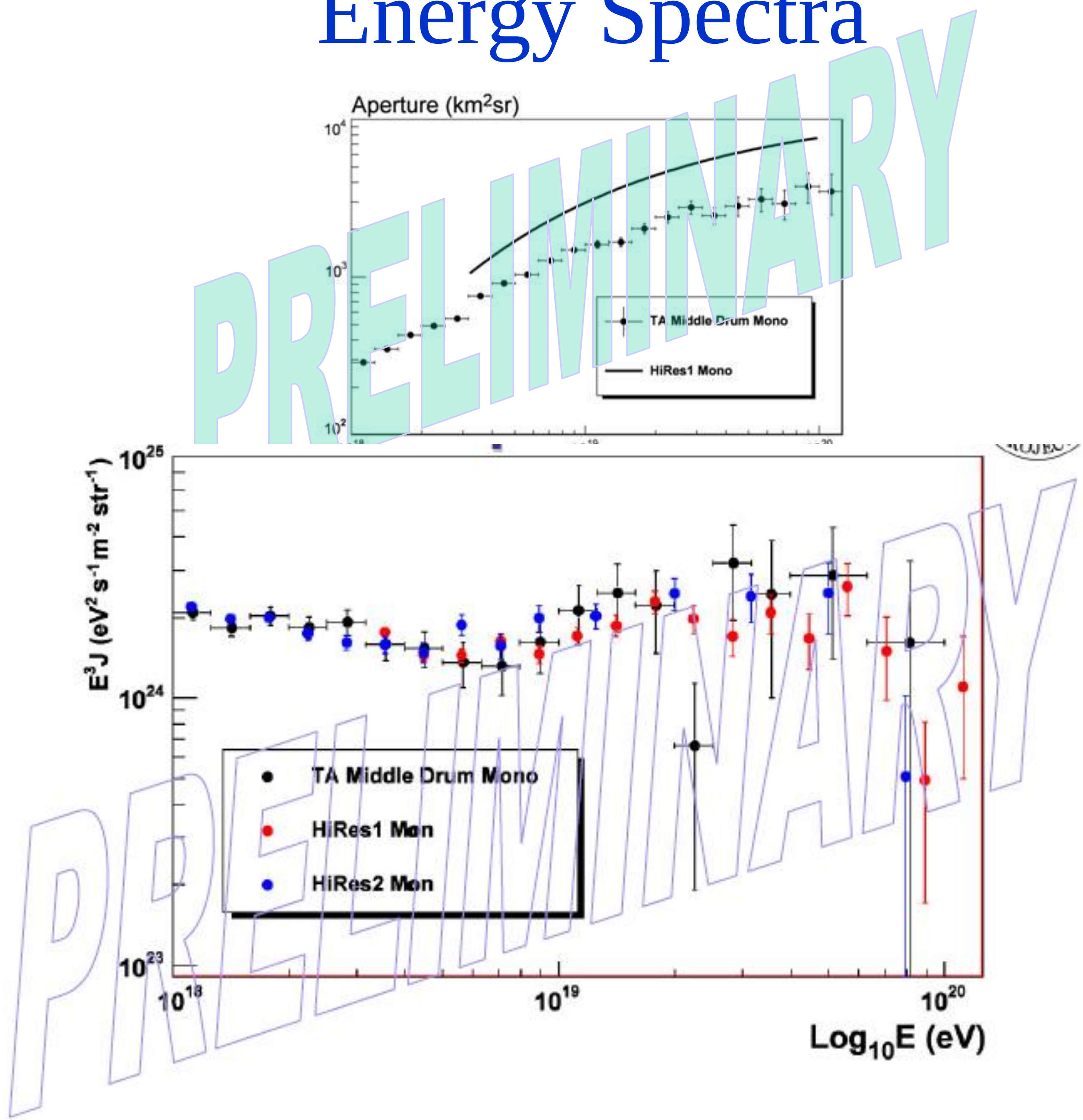
# Zenith angle (deg)



# Energy Spectra

**Monocular Energy Spectrum from Middle Drum (MD) Detector**

- 14 refurbish HiRes-1 telescopes
- TAMD mono processing is identical to HiRes-1 monocular data analysis
  - Same program set, event selection, cuts
  - Using the same "average" atmospheric model (aerosol VAOD=0.04)
- Differences
  - telescope location and
  - pointing directions
  - Thresholds (~20% lower
  - than HiRes-1)
- **Preliminary MD spectrum in good agreement with HiRes.**



# Surface Detector (SD) Monocular Spectrum

- Must cut out SD events with bad resolution. ➔ Must calculate aperture by Monte Carlo technique.
- We use the same techniques for the SD that we use for FD.

# List of Cuts

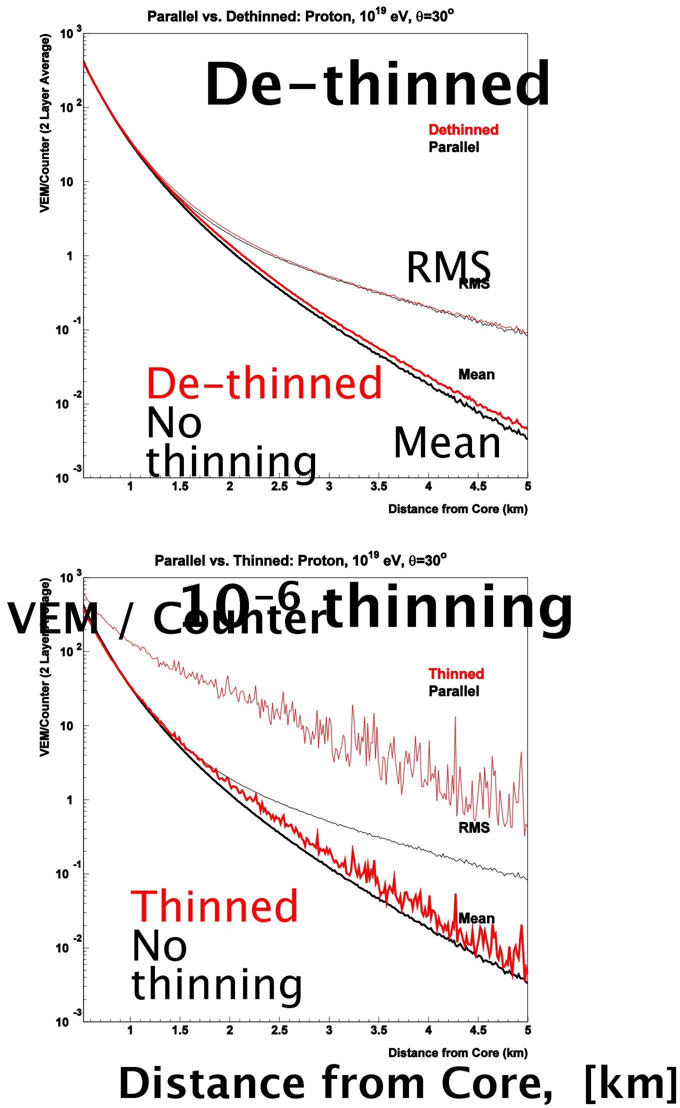
- chi2/ndof cut: 4.0
- Border Cut > 1200m
- Zenith Angle Cut, 45 degrees
- Pointing direction resolution: 5 degrees
- Fractional S800 uncertainty: 0.25

- **1.75 years, 6264 events.**

# SD Monte Carlo

- Simulate the data exactly as it exists.
  - Start with previously measured spectrum and composition.
  - **Use Corsika/QGSJet events.**
  - Throw with isotropic distribution.
  - Simulate trigger, front-end electronics, DAQ.
- Write out the MC events in same format as data.
- Analyze the MC with the same programs used for data.
- Test with data/MC comparison plots.

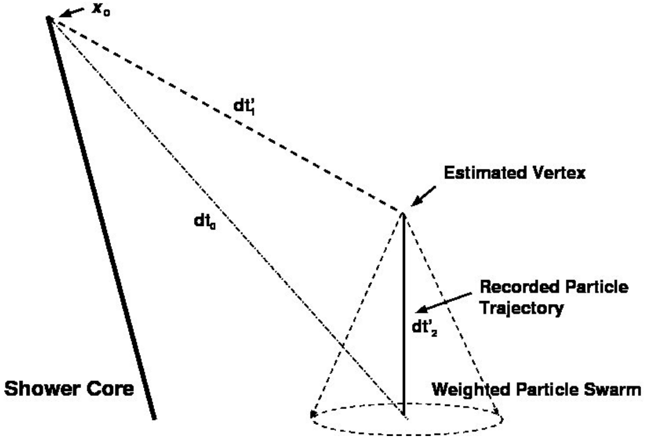
# How to Use Corsika Events

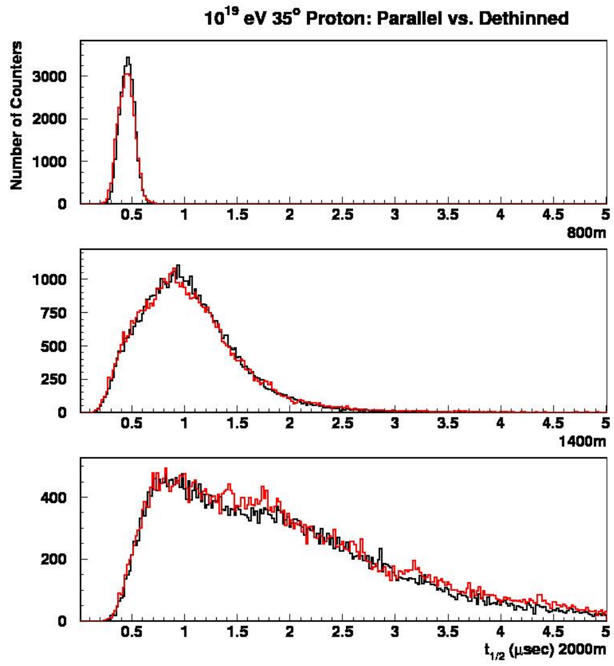



- Use $10^{-6}$ – thinned CORSIKA QGSJET-II proton showers that are de-thinned in order to restore information in the tail of the shower.
- De-thinning procedure is validated by comparing results with un-thinned CORSIKA showers, obtained by running CORSIKA in parallel
- We fully simulate the SD response, including actual FADC traces

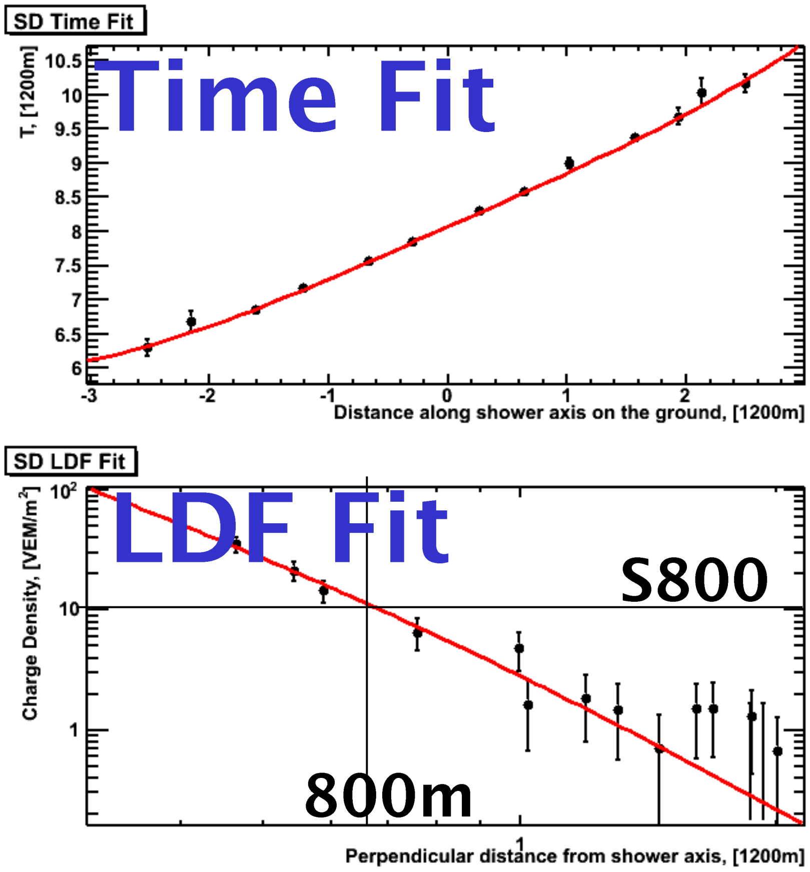
# Dethinning Technique

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



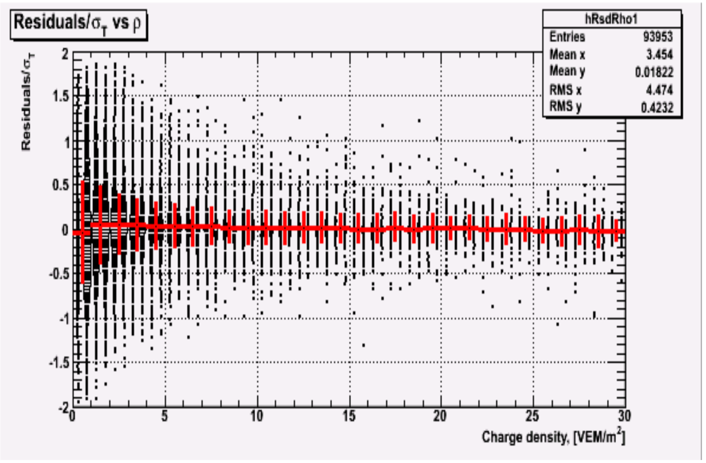
# SD Event Reconstruction




- Two fits:
  - Time fit to determine event geometry (modified Linsley function).
  - Lateral distribution fit (LDF) to determine signal size 800m from the shower axis, S800 (AGASA fitting function).
- **Fitting procedure and formulas are adjusted using only the data.**

# Fitting results

**DATA**



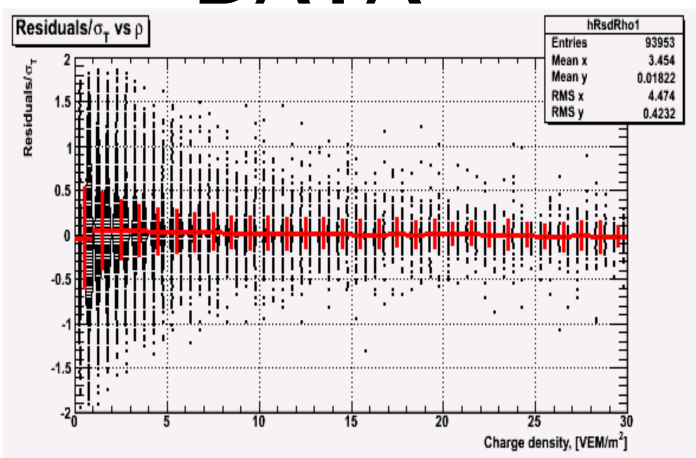

**Time fit residual, over sigma**

**Counter signal, [VEM/m²]**

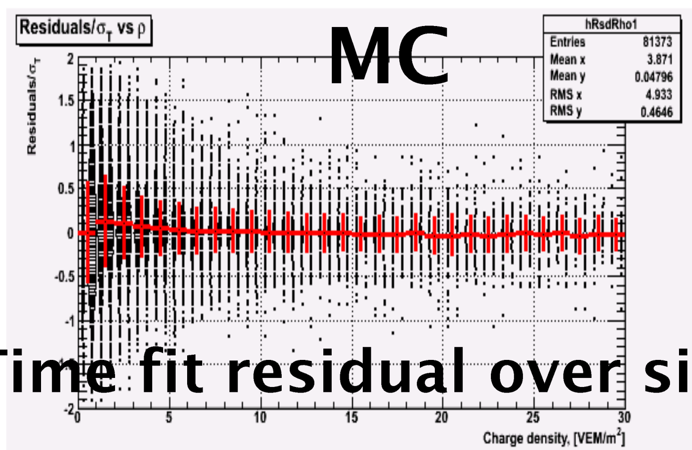
- Fitting procedures are derived solely from the data

# Fitting results

DATA




MC

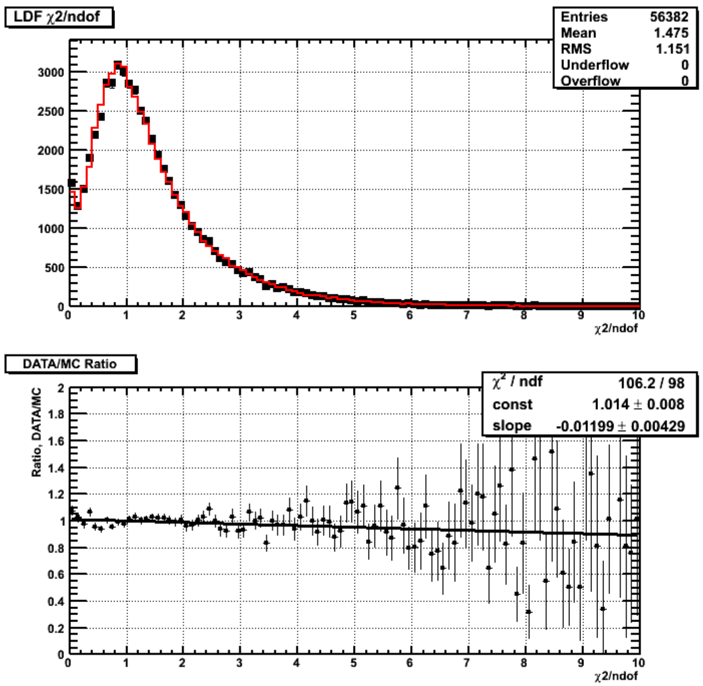



Time fit residual over sigma

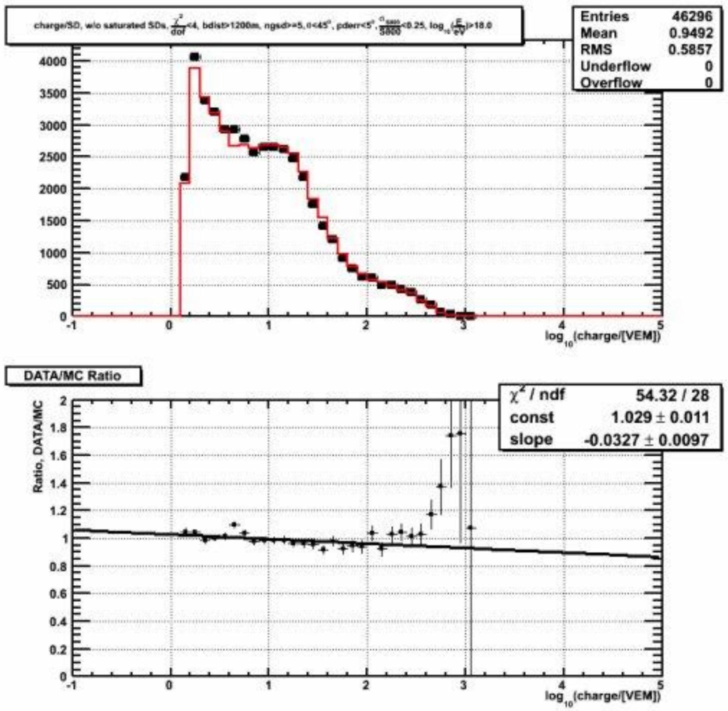
Counter signal, [VEM/m²]

- 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

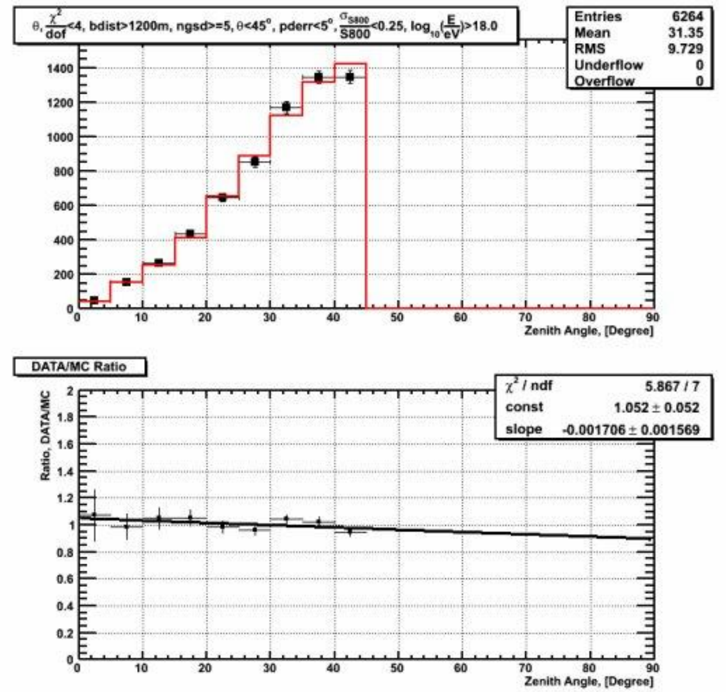



LDF fit $\chi^2$/dof

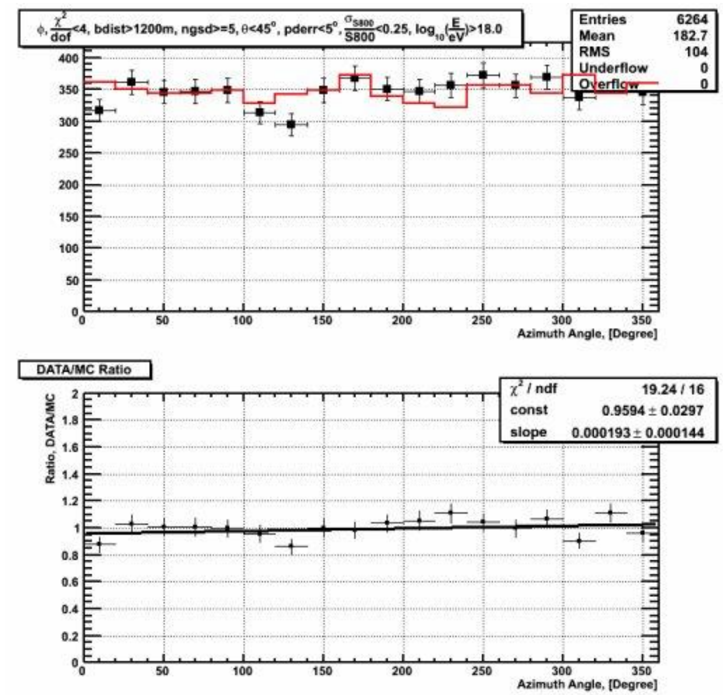



VEM / event

# DATA/MC Event Direction

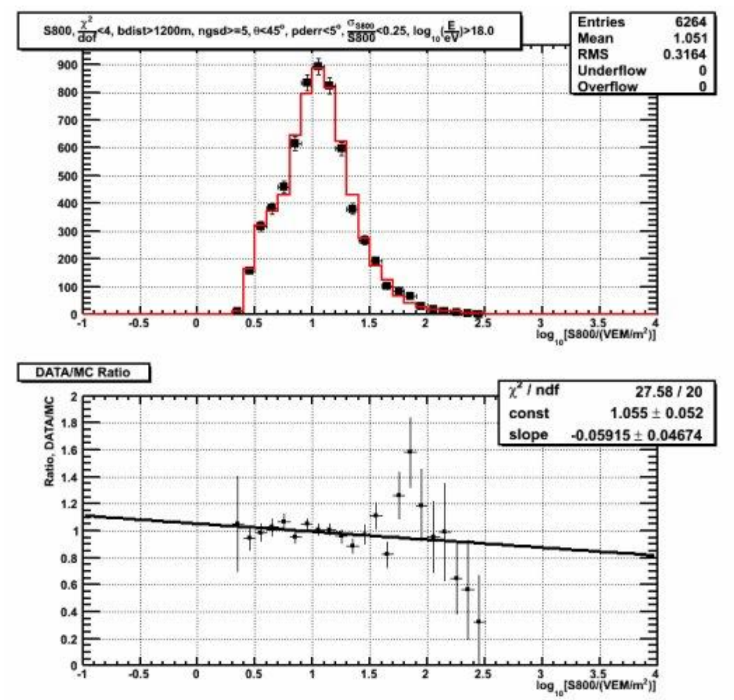



Zenith angle

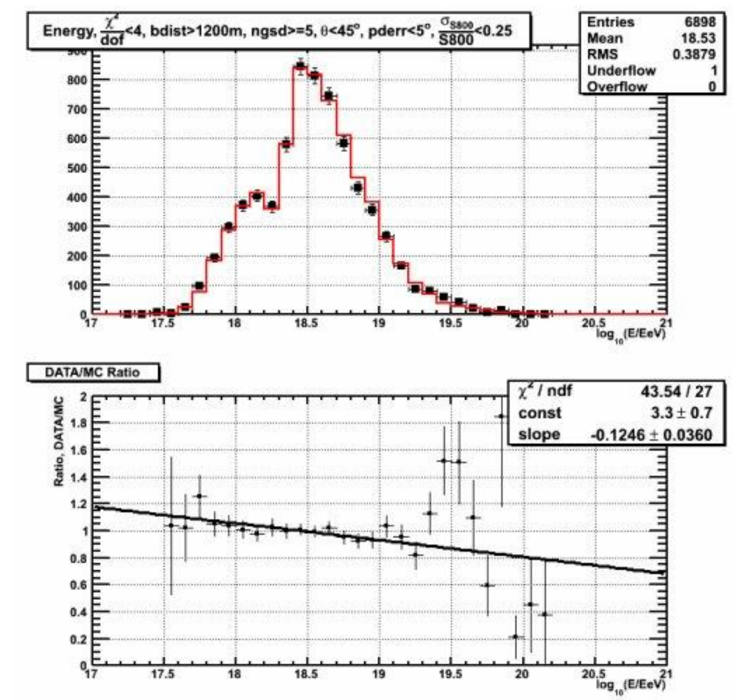



Azimuthal angle

# DATA/MC: S800, Energy

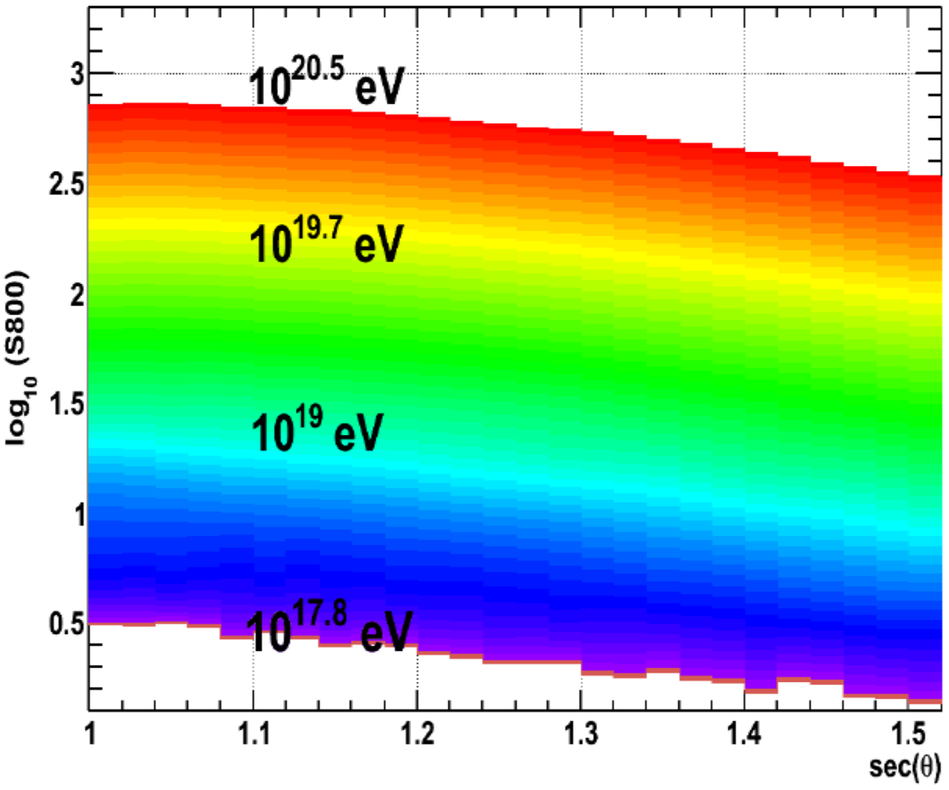



**S800**



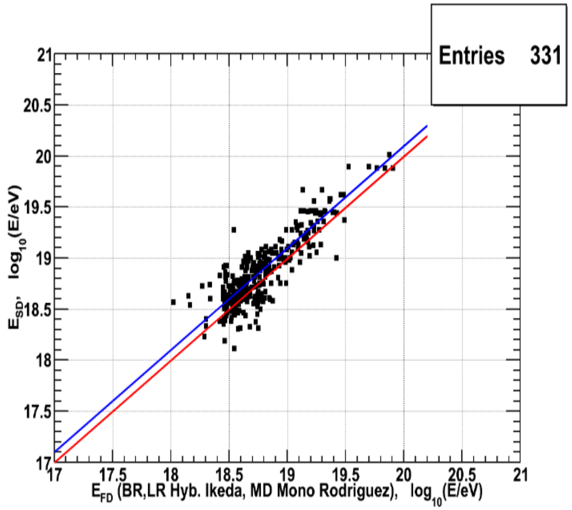

**Energy**

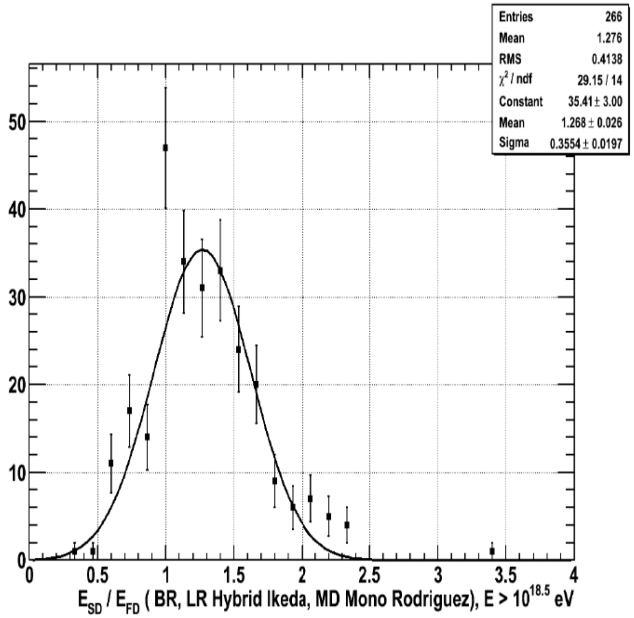
# First Estimate of Energy




- Energy table is constructed from the MC
- First estimation of the event energy is done by interpolating between S800 vs sec(θ) lines

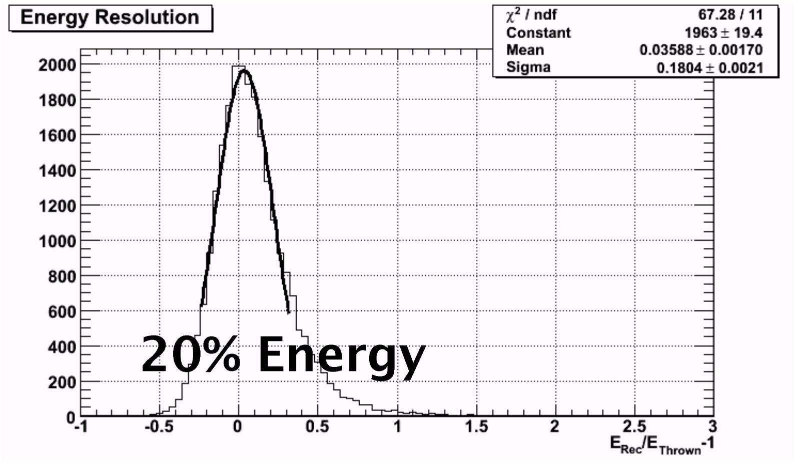
# Energy Scale

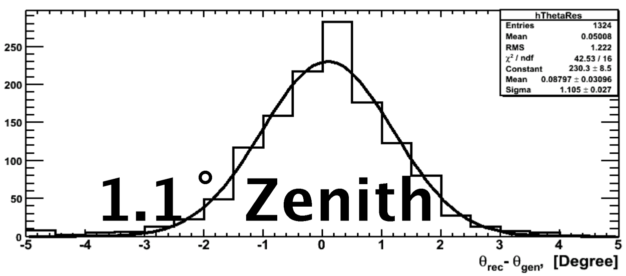


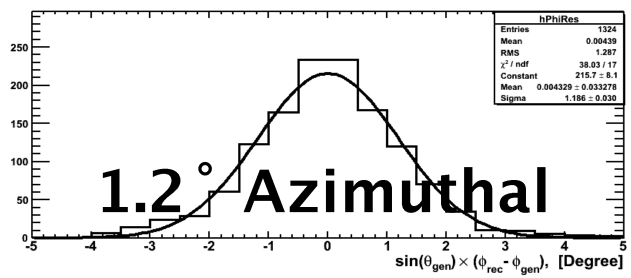




- Energy scale is determined more accurately by FD than by CORSIKA QGSJET-II
- Set SD energy scale to FD energy scale using well-reconstructed events seen by both detectors:
- 27% renormalization.

# TA SD Resolution

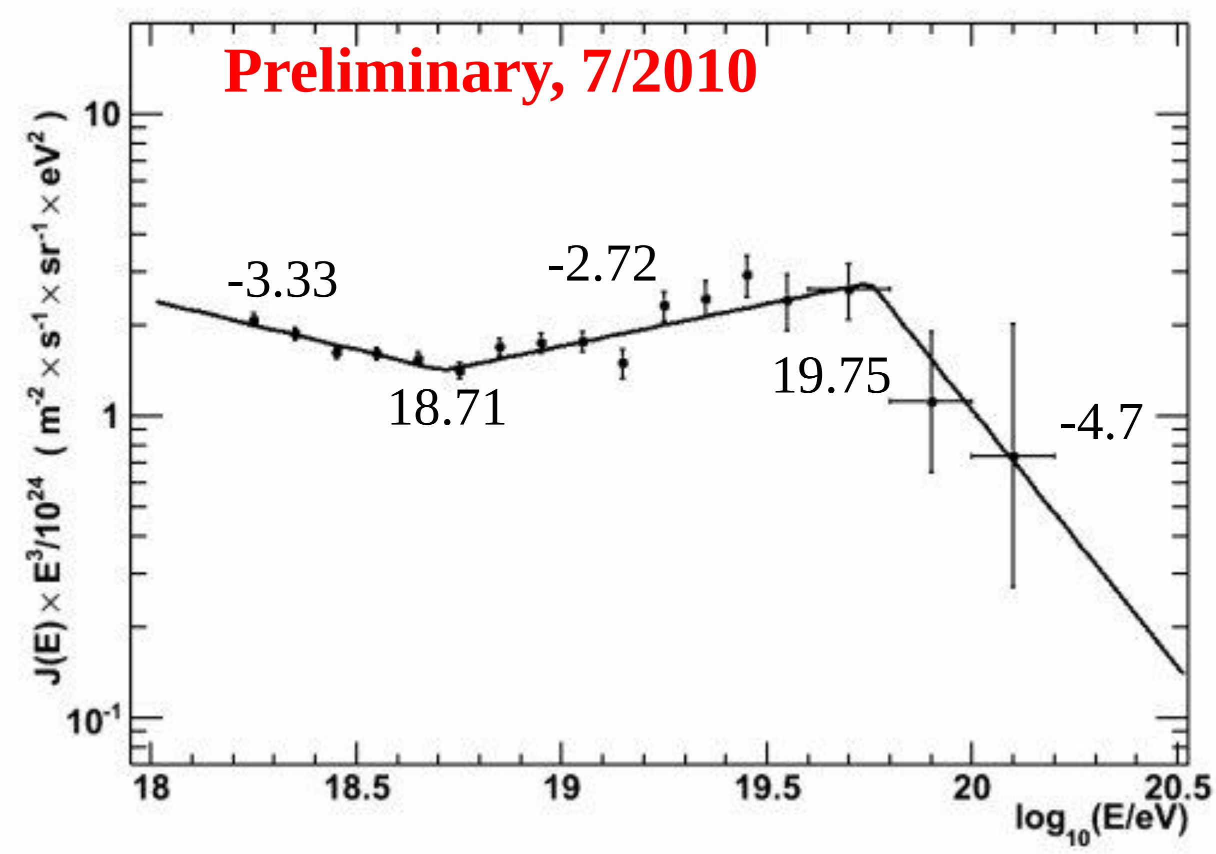


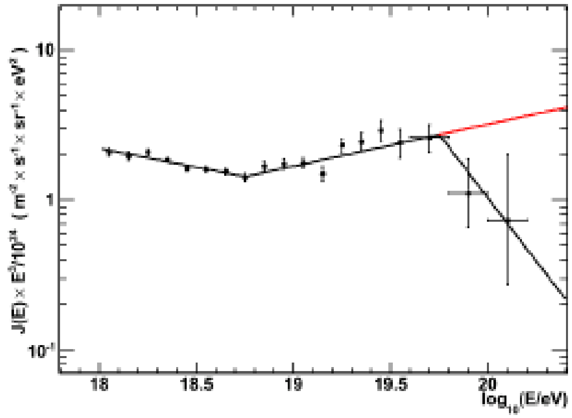



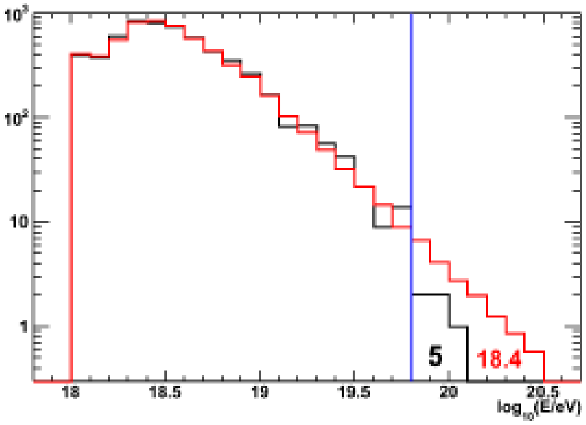

- To achieve good resolution one applies quality cuts
- Correct aperture is calculated from MC which:
  - Agrees with the data
  - Analyzed in the same way as the data, including the quality cuts

# TA SD Spectrum



# Significance of the Suppression



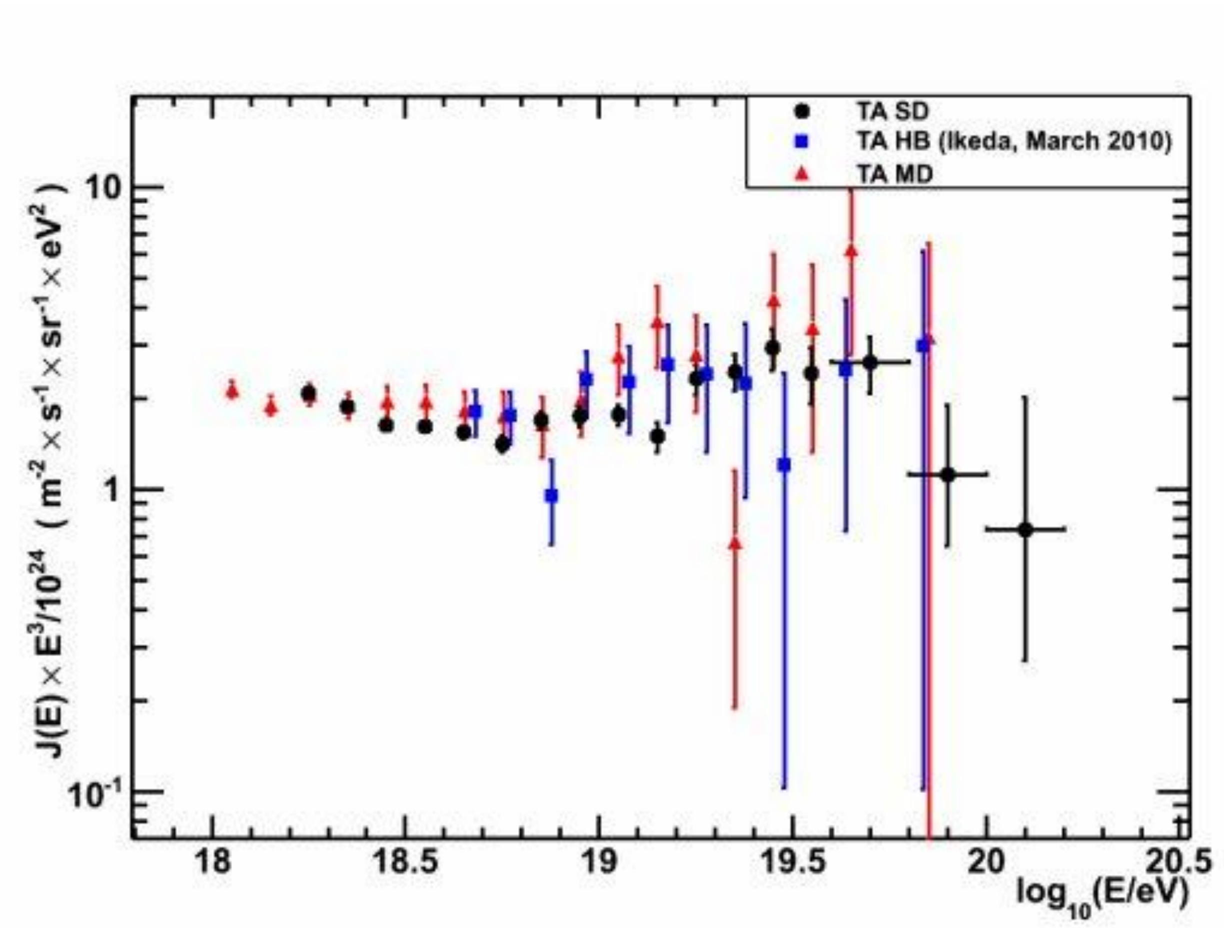




- Assume no GZK cutoff and extend the broken power law fit beyond the break
- Apply this extended flux formula to the actual TASD exposure, find the number of expected events and compare it to the number of events observed in $\log_{10}E$ bins after $10^{19.8}$eV bin:
  - $N_{EXPECT} = 18.4$
  - $N_{OBSERVE} = 5$

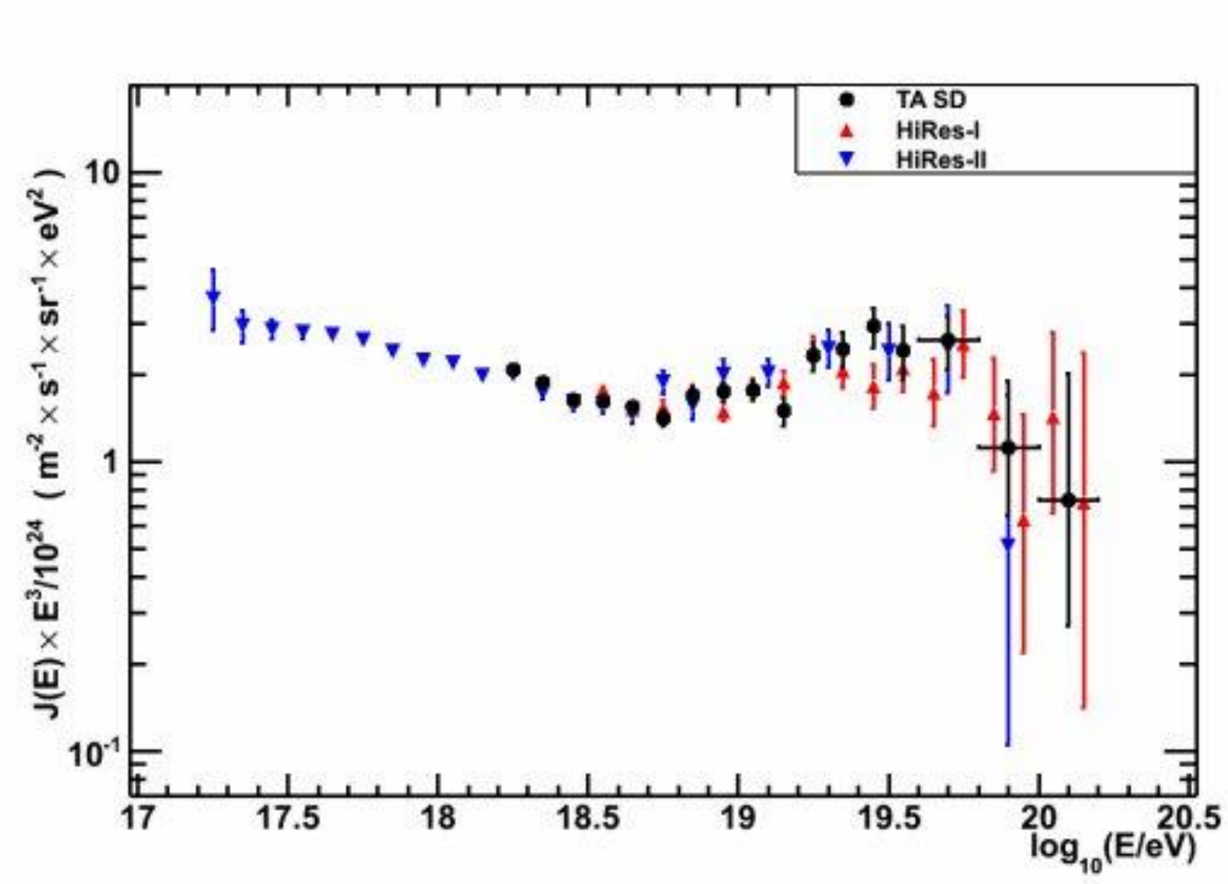
$$\text{PROB}=\sum_{i=0}^{5} Poisson(\mu = 18.4; i) = 2.41 \times 10^{-4}$$

(3.5σ)

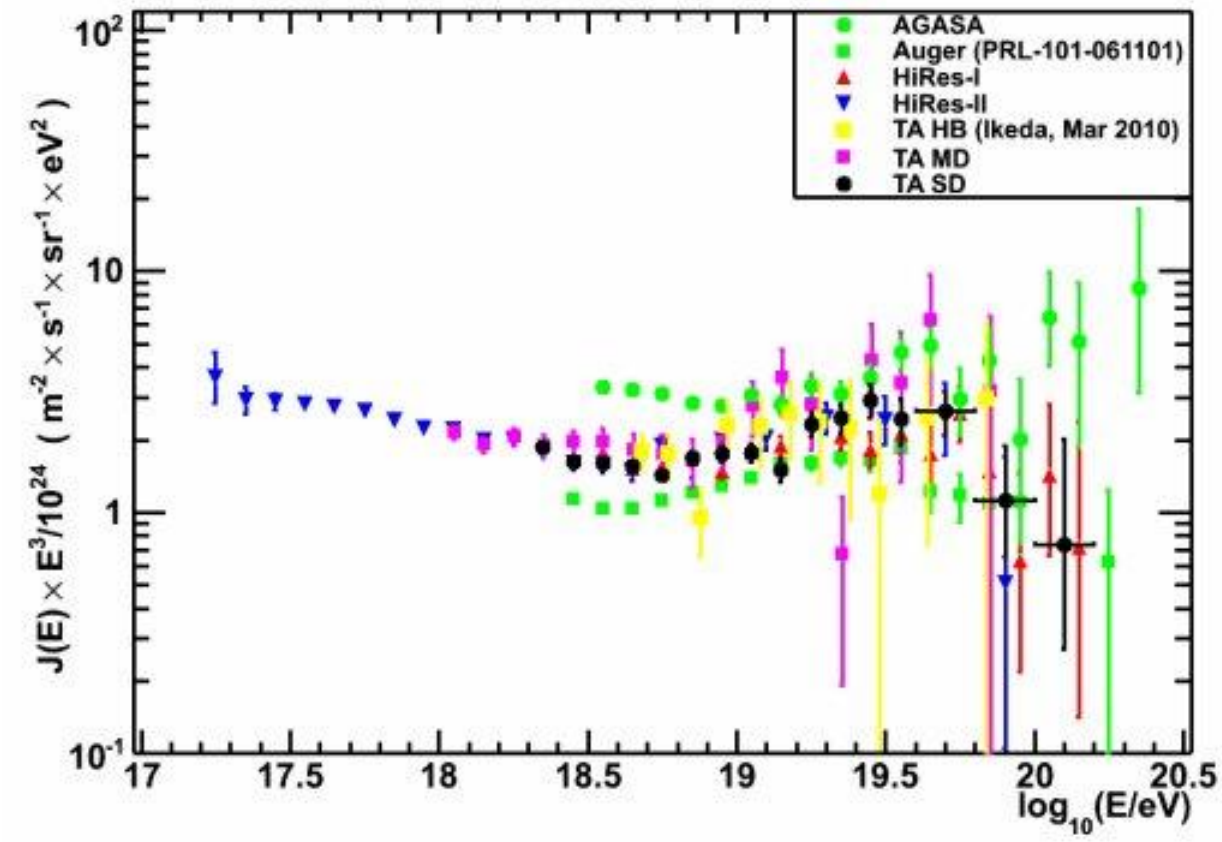
# TA SD, Middle Drum Monocular, and TA Hybrid Spectra



# TA SD and HiRes Spectra



# AGASA, Auger, HiRes, TA Spectra



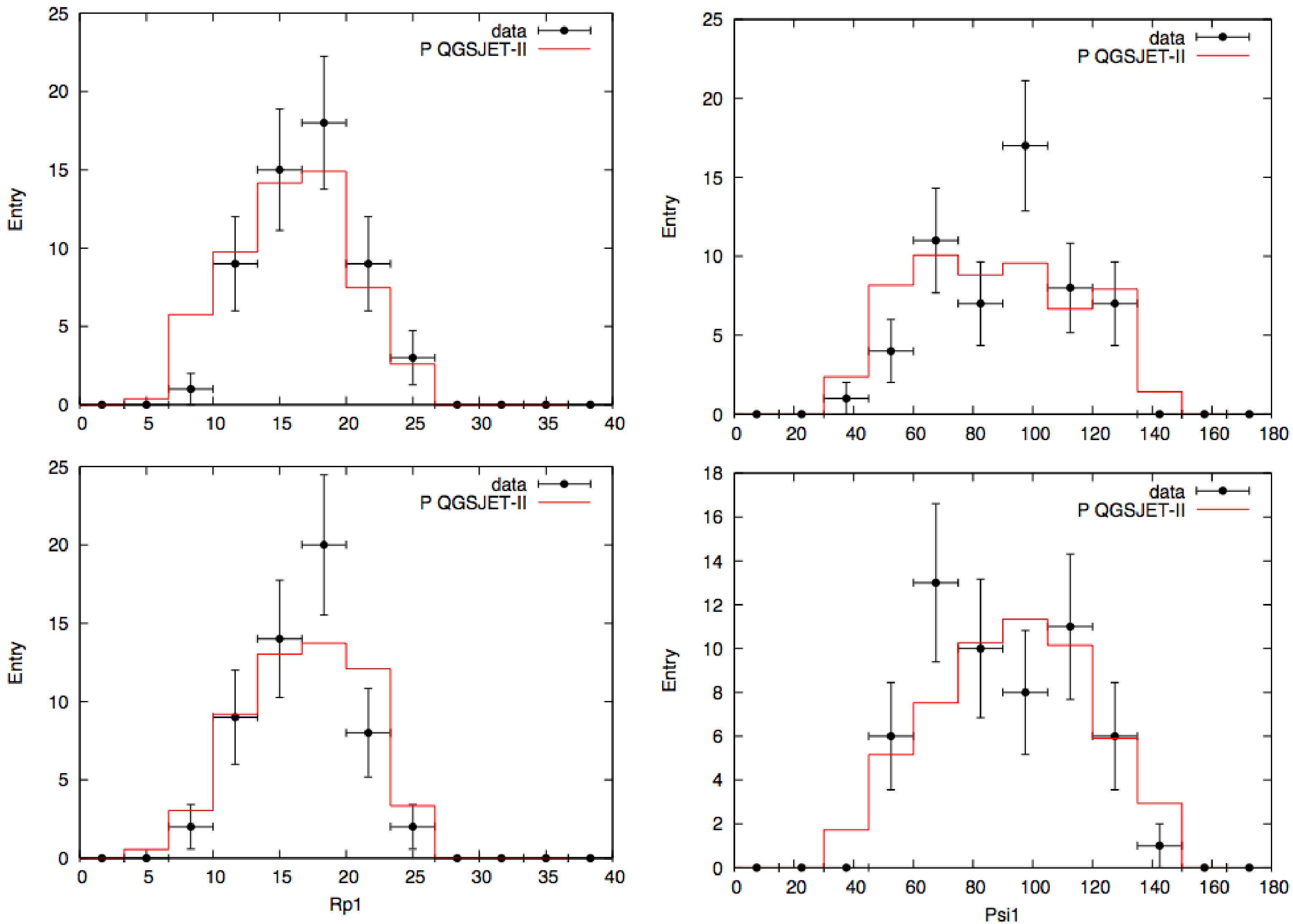
# FD Stereo Composition

- Measure $x_{max}$ for Black Rock/Long Ridge FD stereo events
- Create simulated event set
- Apply exactly the same procedure as with the data

# Data/MC Comparisons

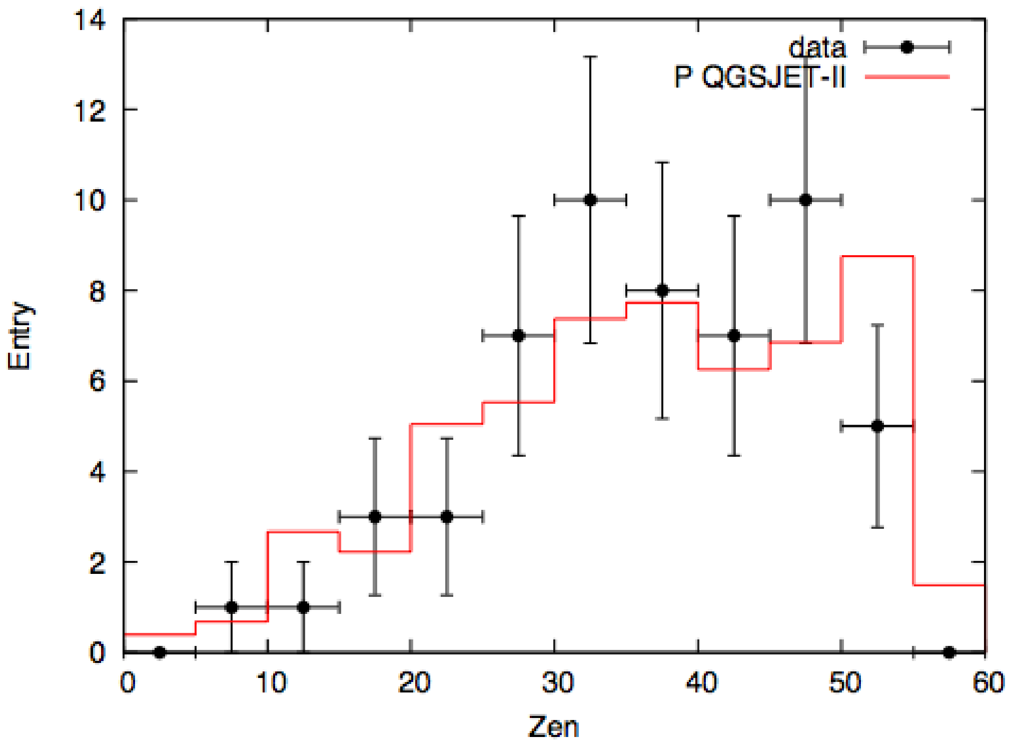
**Black Rock**

**Long Ridge**




$R_p$ $\psi$

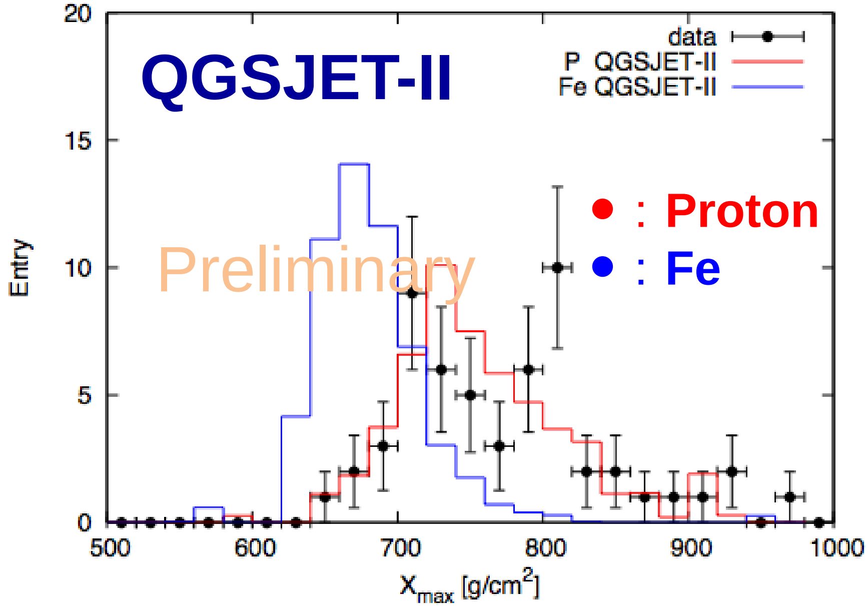
# Data/MC Comparisons (cont.)

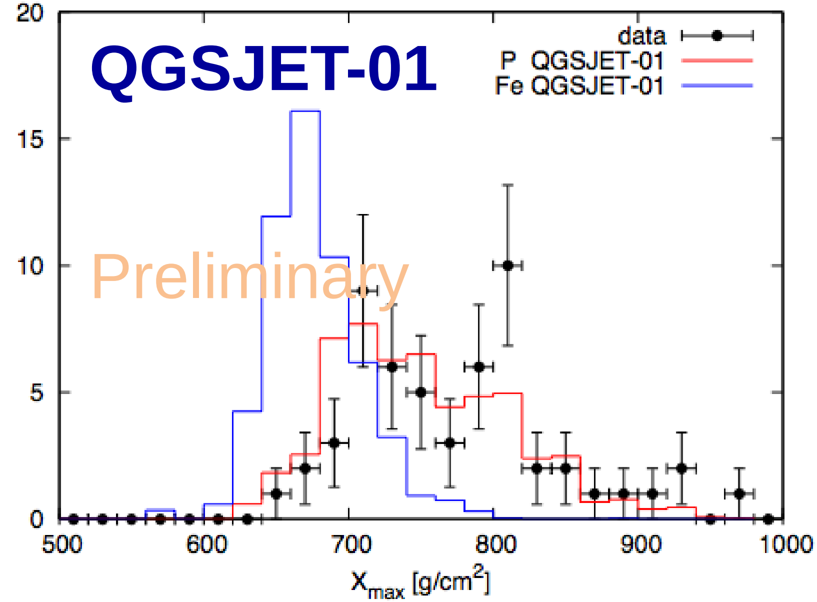


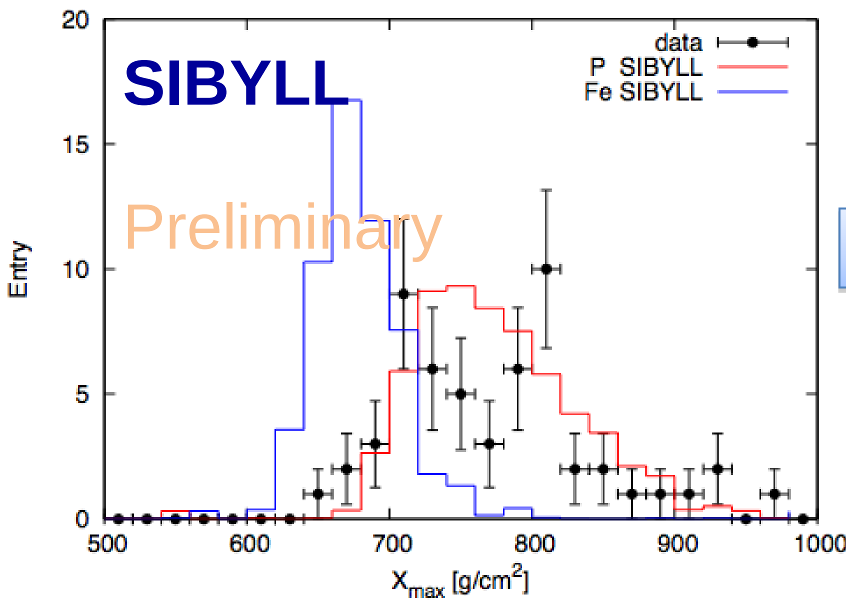

**Zenith Angle**

- Data and MC show excellent agreement geometric agreement
- What about $x_{max}$?

# $x_{max}$ Data/MC comparison



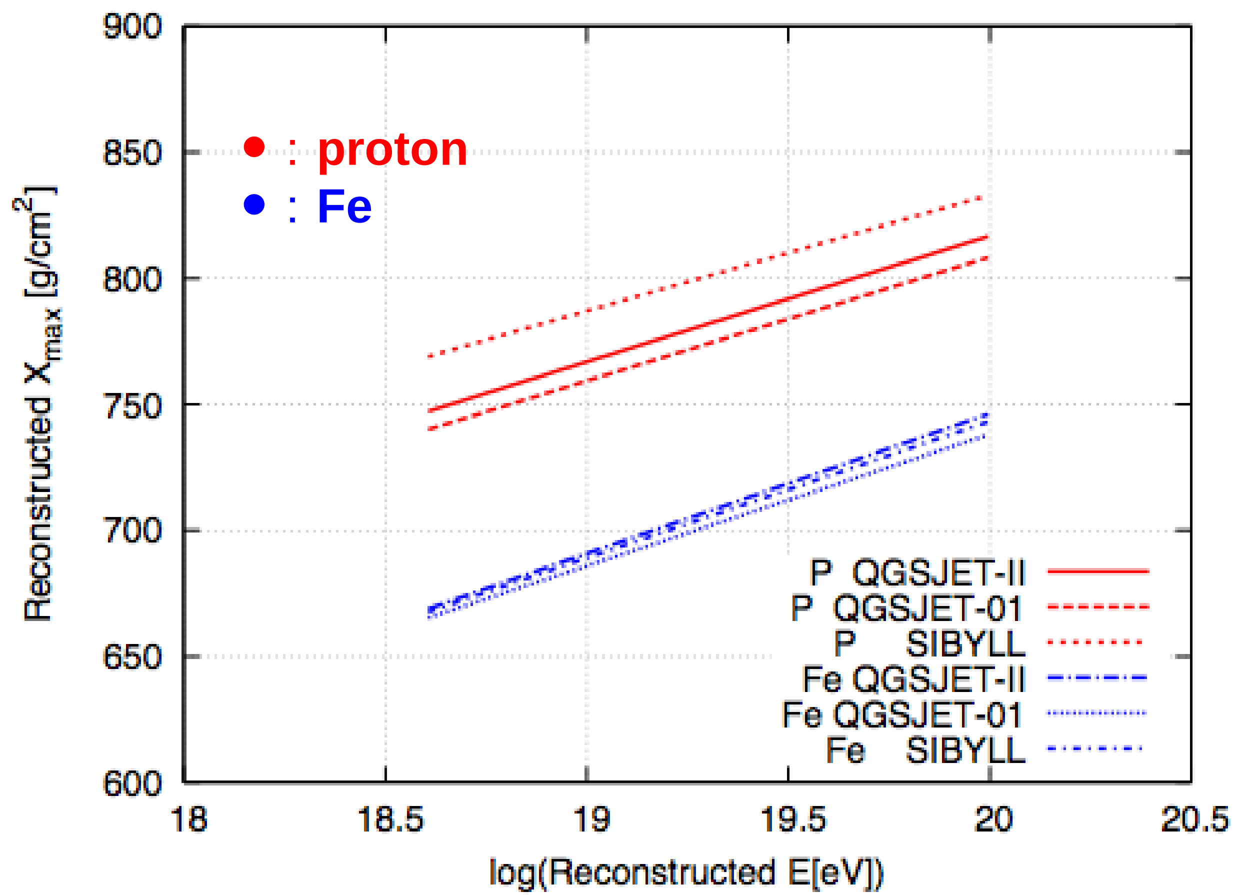



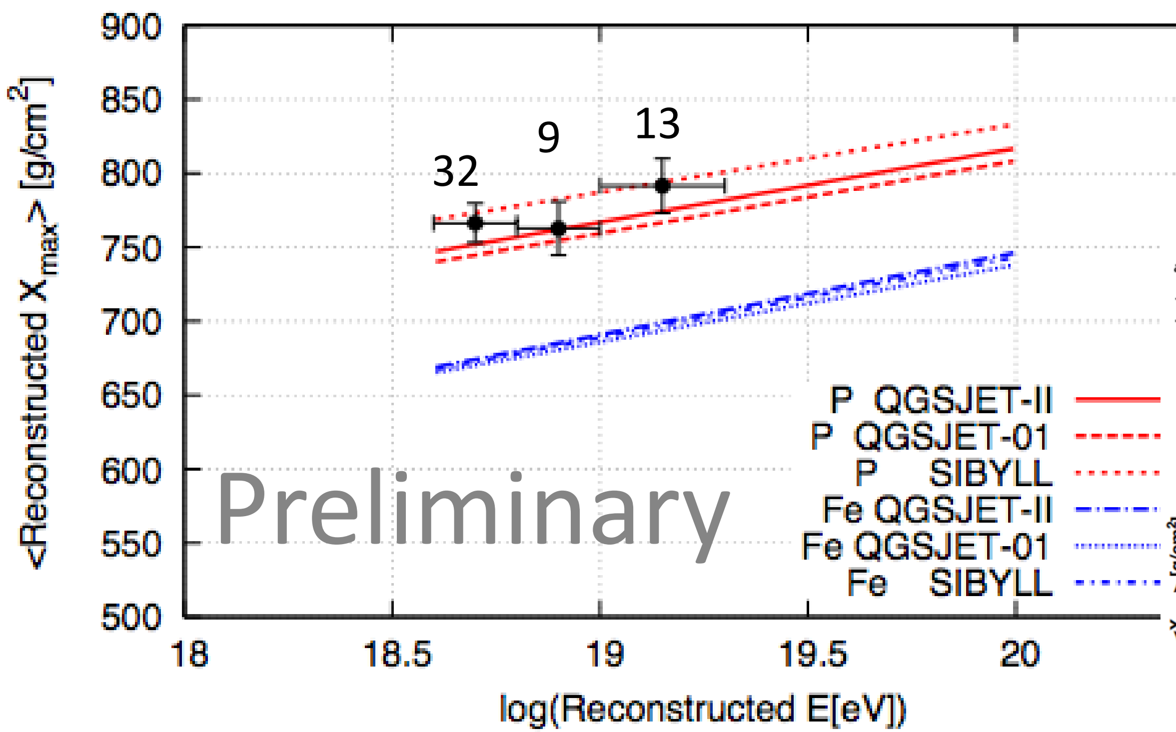

| $\chi^2$ /dof | QGSJET- II | QGSJET-01 | SIBYL L |
|---|---|---|---|
| P | 1.44 | 1.046 | 1.63 |
| Fe | 55.54 | 56.67 | 85.71 |

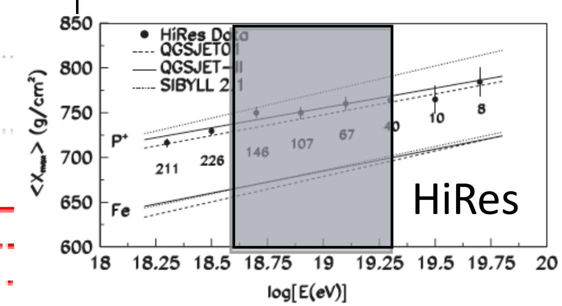
# $x_{max}$ vs. Energy

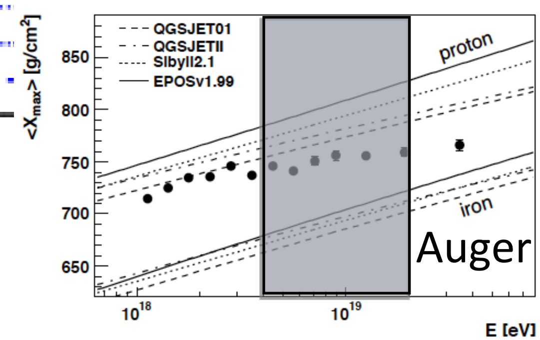
- Use MC treated identically to the data to establish energy dependence



# TA-FD stereo : Mass Composition



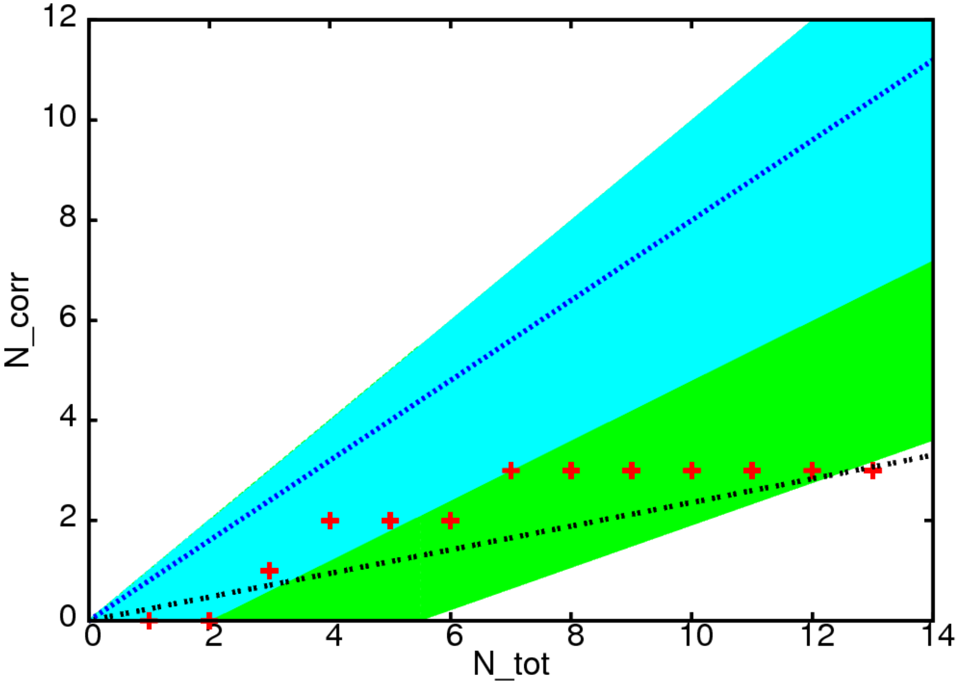



# Search for AGN Correlations

- Auger found correlations with AGN's with (57 EeV, 3.1 ,0.018). 14 events scanned + 13 event test sample appeared in Science article; 2.9σ.
- Later Auger data (42, 12, 8.8) show no significant correlations.
- HiRes data (13, 2, 3) show no significant correlations.
- TA data (13 events) has 3 correlated events, 3.0 expected by chance.

➔ **No Effect.**



# Conclusions

- The Telescope Array (TA) Experiment is collecting data in the northern hemisphere.
- TA is a LARGE experiment which has excellent control of systematic uncertainties.
- SD mono, FD mono, stereo, hybrid, hybrid-stereo analyses are all ongoing.
- Important TA spectrum, composition, and anisotropy results are being presented. With more to come.
- TA is a discovery experiment.