Analysis Techniques Used for Telescope Array Surface Detector Data

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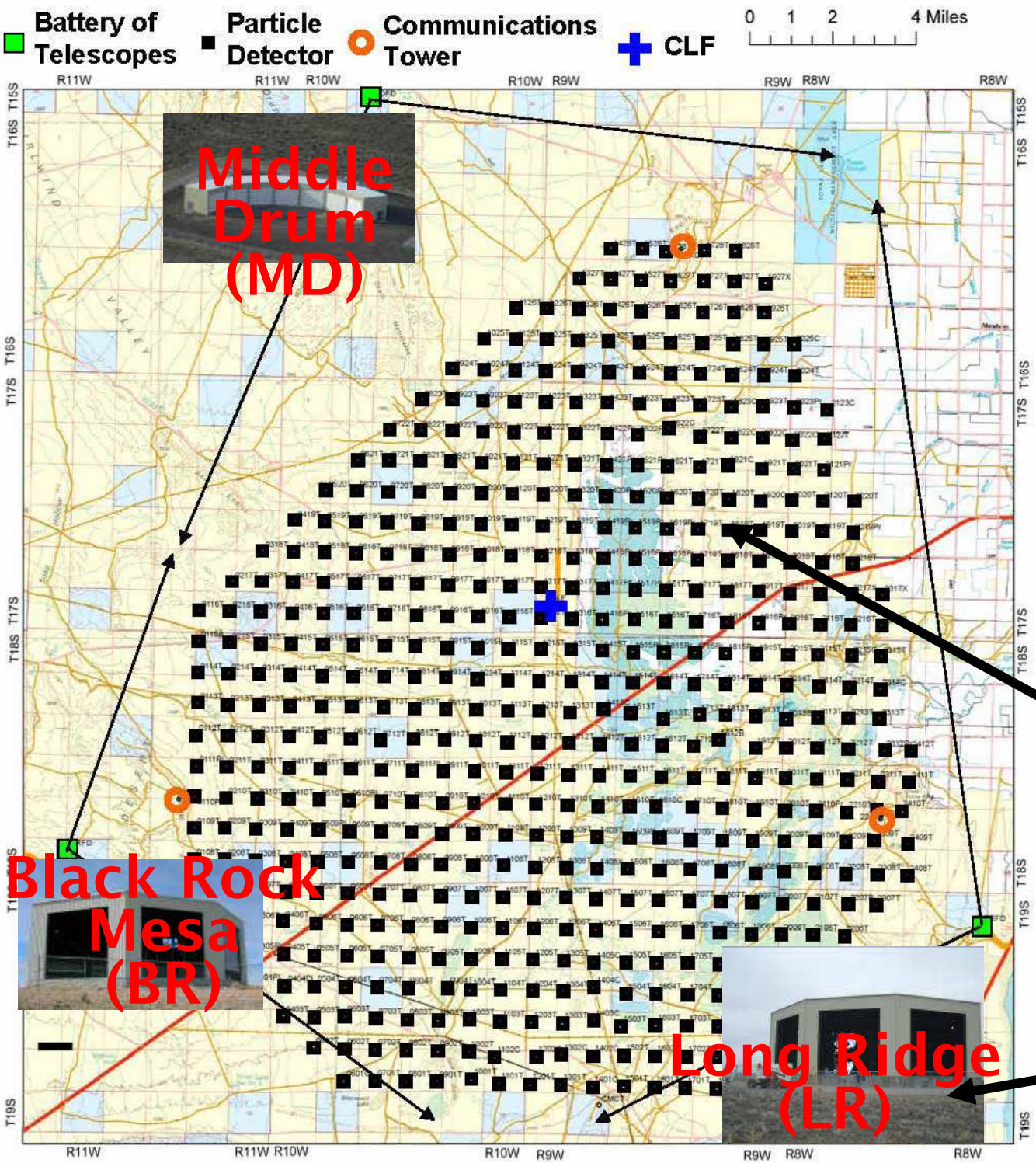
Outline

- Telescope Array Detector
- Telescope Array Surface Detector (TA SD) Event Reconstruction
- TA SD Monte-Carlo
- TA SD DATA/MC Comparison
- Preliminary Results
- Conclusions

Telescope Array

Hybrid detector

Millard County, UT
39.3° N , 112.9° W,
Alt. 1400m



507 plastic scintillator counters, 1.2km apart, cover 680km² area

3 FD detectors: BR,LR,SK

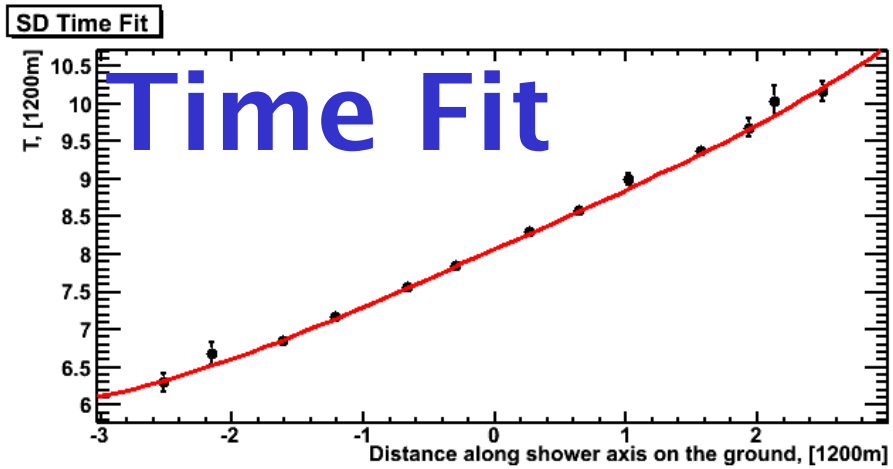
TA Surface Detector

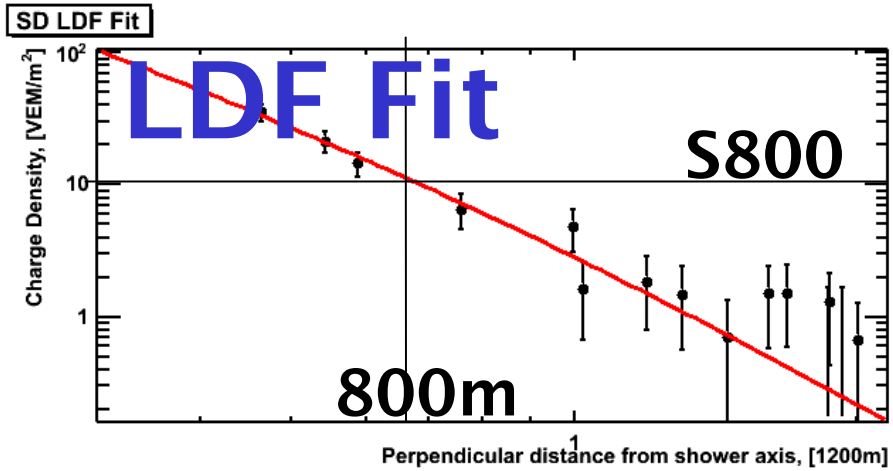
- Powered by solar cells; radio readout.
- Self-calibration using single muons.
- In operation since March, 2008.

Introduction

- Basic TA SD event reconstruction is done in a Monte-Carlo - independent way:
  - As a starting point, we use results of the AGASA experiment (LDF, shower front timing)
  - Reconstruction procedures and formulas are adjusted to fit TA SD data by applying self-consistency tests to the results of fitting
  - This is sufficient for reconstructing event geometry, as well as lateral distribution profile
- We then use carefully tested MC set, which shares all the characteristics of the real data to estimate the event energy and calculate the aperture.

SD Event Reconstruction

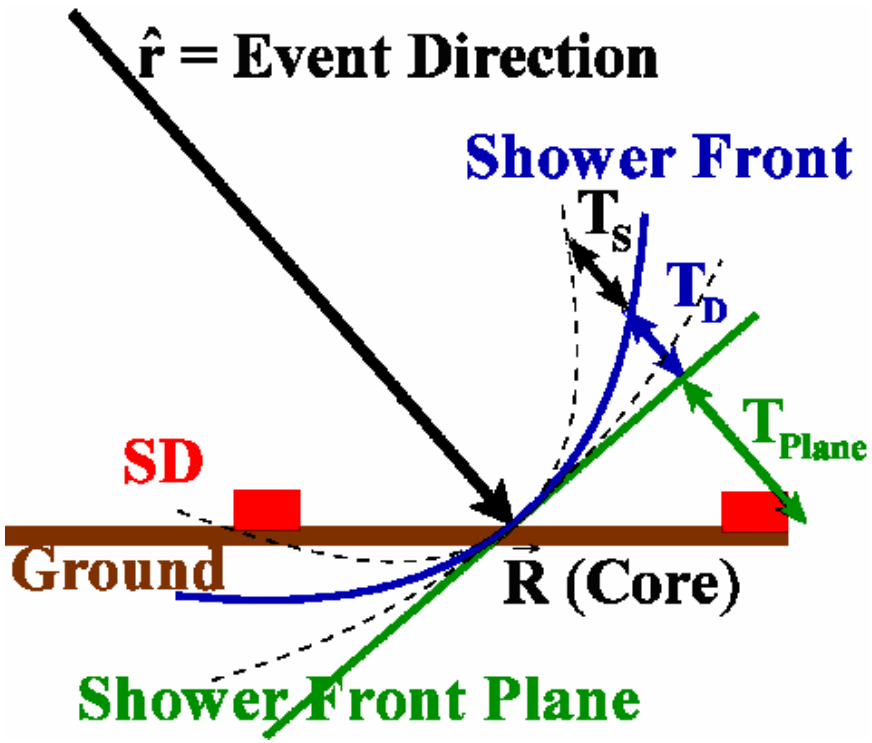




Use AGASA LDF

- Two fits:
  - Time fit to determine event geometry
  - Lateral distribution fit (LDF) to determine S800 (signal size 800m from the shower axis)
- Fitting procedure and formulas are adjusted using only the real data
- Use Monte-Carlo to obtain the first estimate of the energy from event geometry and signal size 800m away from the shower axis

SD Fitting Procedure



- **S800 is found by fitting the lateral profile to AGASA LDF function**

- **Event direction is found by minimizing:**

$$\chi^2 = \sum_{i=1}^{\text{nSDs}} \frac{\left(t_i - T_0 - T_{\text{Plane}} - T_{\text{D}}\right)^2}{T_{\text{S}}^{\,2}} + \frac{\left(\vec{\mathbf{R}} - \vec{\mathbf{R}}_{\text{COG}}\right)^2}{(180\text{m})^2}$$

T_0 - Time of the core hitting ground

T_{Plane} - Time of the shower front plane

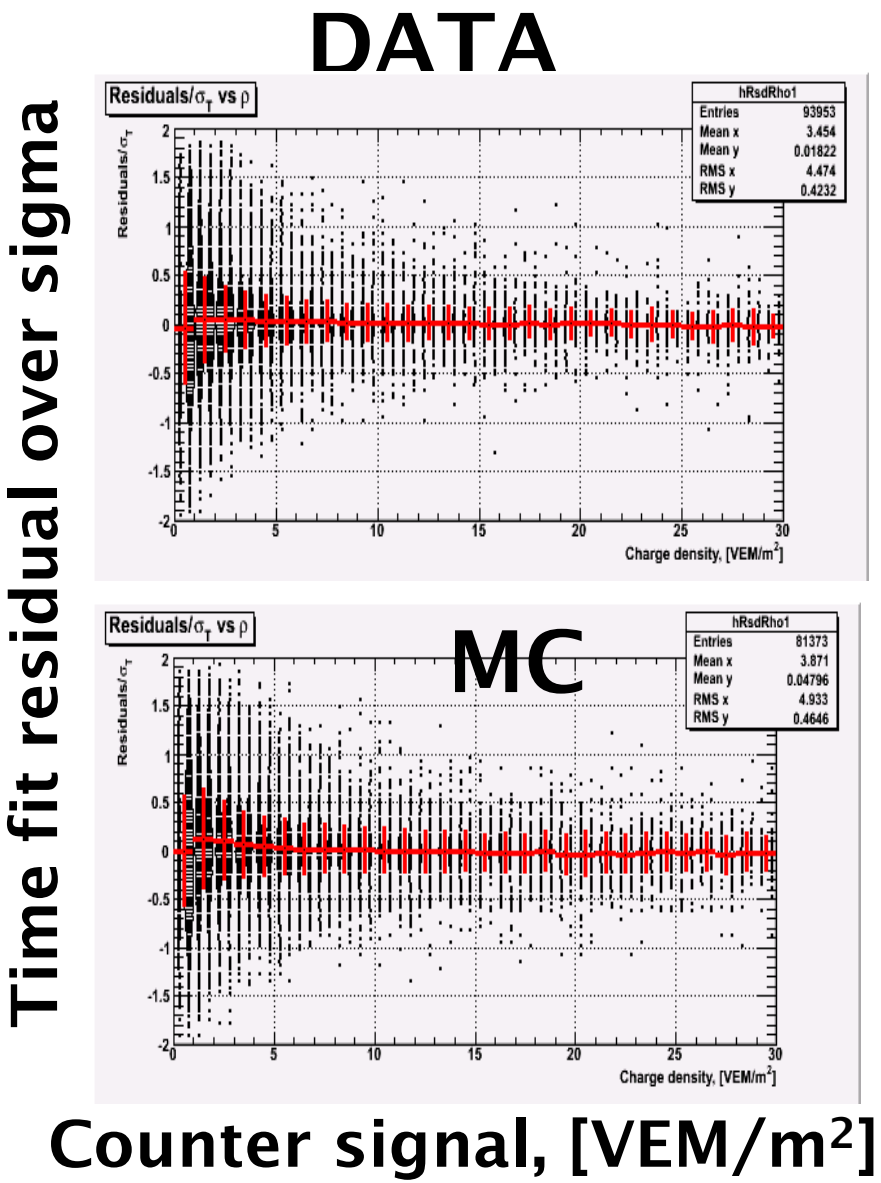
T_{D} - Time delay (Modified Linsley)

T_{S} - Fluctuation of time delay (Modified Linsley)

$\vec{\mathbf{R}}$ - (Fitted) core position

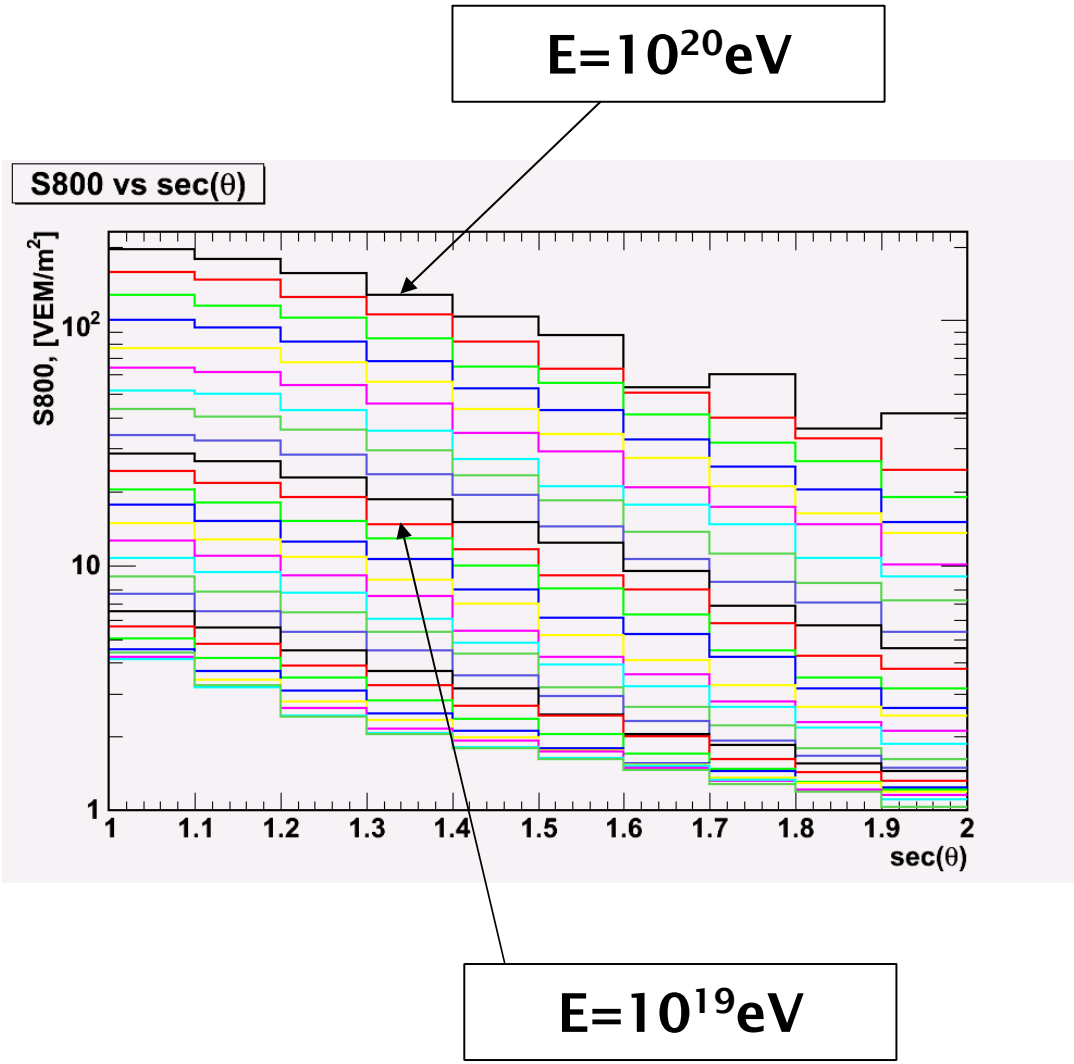
$\vec{\mathbf{R}}_{\text{COG}}$ - Core position found from the center of gravity of charge

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.

First Energy Estimation



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

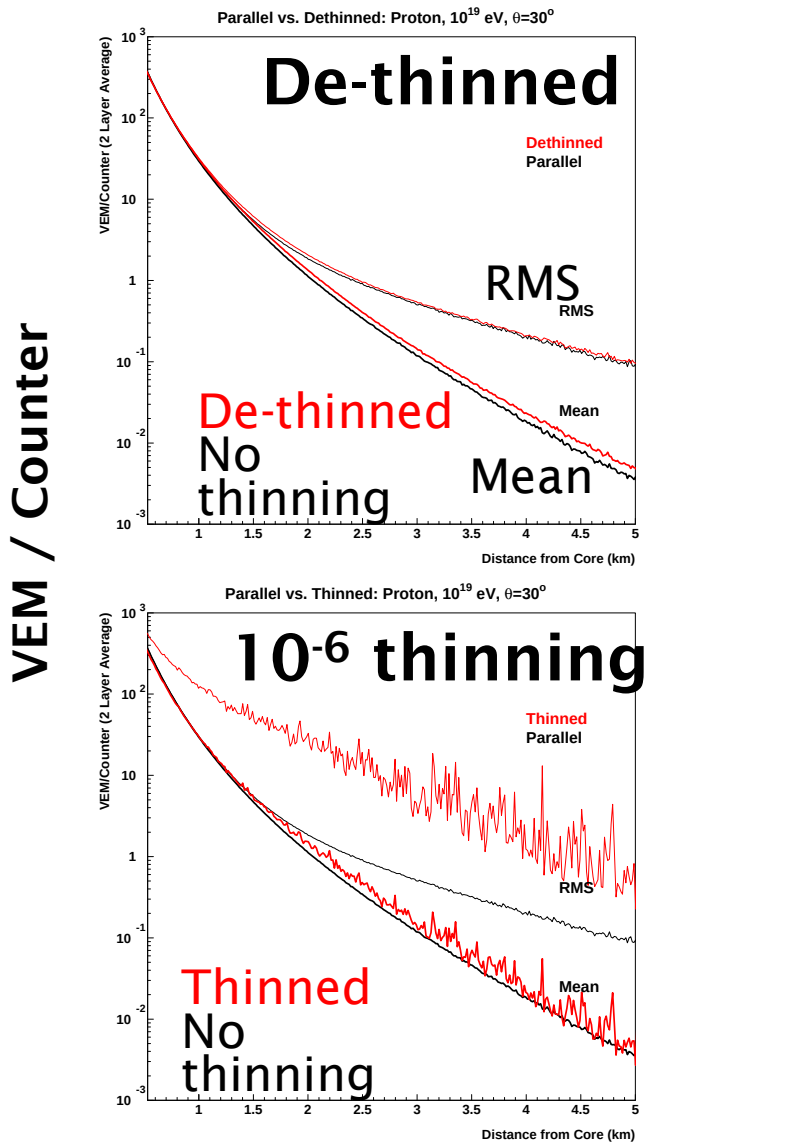
Next Step

- Must cut out events with bad resolution
- ➔ Must calculate aperture by Monte Carlo technique.
- TA uses same analysis techniques based on DATA/MC comparisons that were first introduced to UHECR physics by HiRes experiment.

SD Monte-Carlo: Methodology

- Simulate an event set which has all known characteristics of the real data:
  - Energy distribution is continuous and follows power laws measured by HiRes:
    - $E^{-3.25}$, $E < 10^{18.65}$ eV
    - $E^{-2.81}$, $E > 10^{18.65}$ eV
  - Angular distribution is continuous and isotropic in the local sky, in a way appropriate for the ground arrays (sin 2θ)
  - Use the composition measured by HiRes
- Record the MC in the same format as the data
- Run the same reconstruction programs on MC as on the data
- Validate the SD MC by comparing the distributions of its reconstructed variables with the real data.

Simulating SD Events

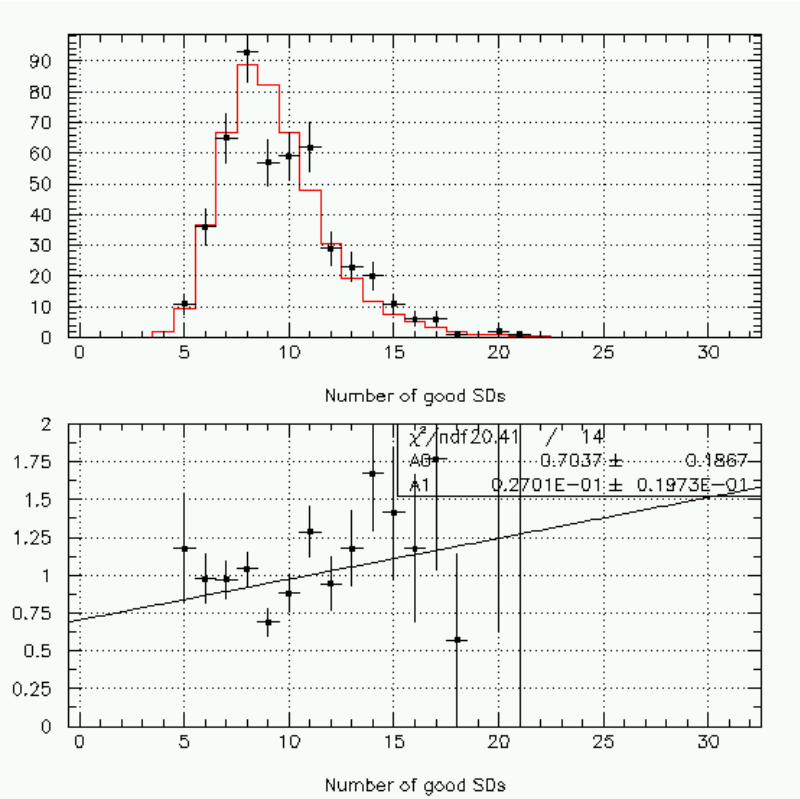


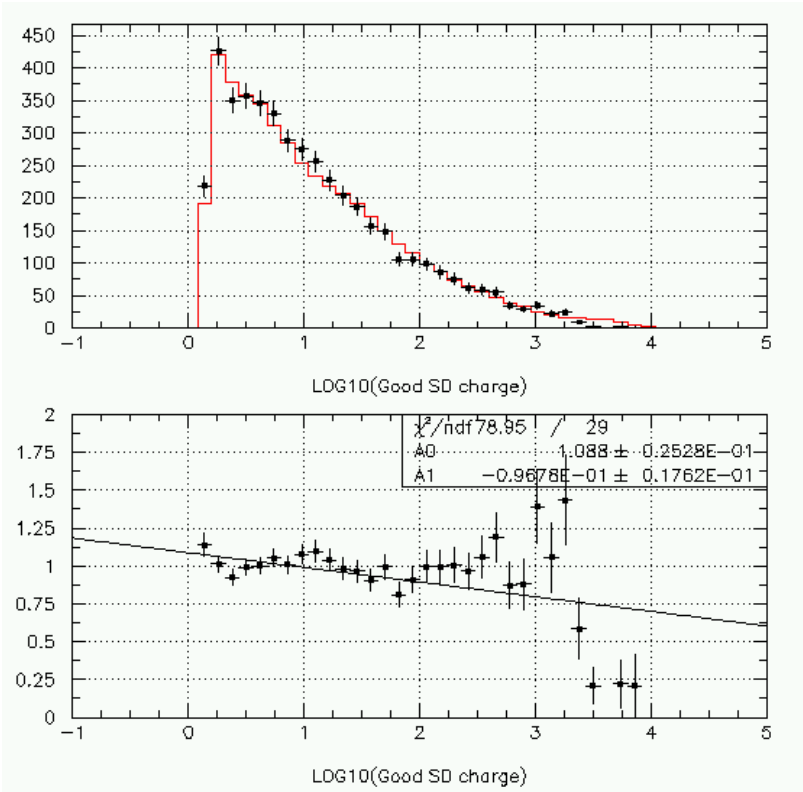
- Use 10^{-6} – thinned CORSIKA QGSJET-II proton showers that are de-thinned in order to restore information at the shower tail needed by the ground array.
  - De-thinning procedure is validated by comparing results with un-thinned CORSIKA showers, obtained by running CORSIKA in parallel
- We fully simulate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

Data/MC Comparison

- Run reconstruction program on data and MC in the same way
- Histogram a common observable for data and MC
- Normalize MC histogram to the real data
  - Data and MC histograms have same integral
- Form the ratio of the two histograms

DATA/MC: SD Information

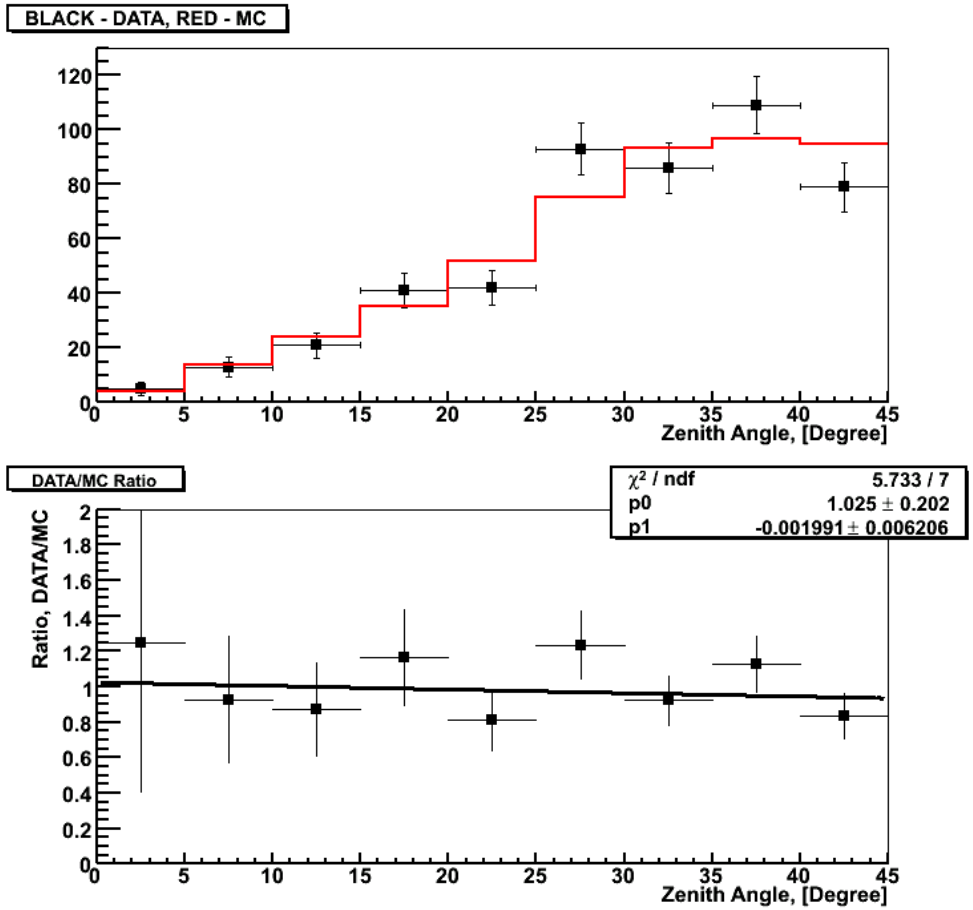


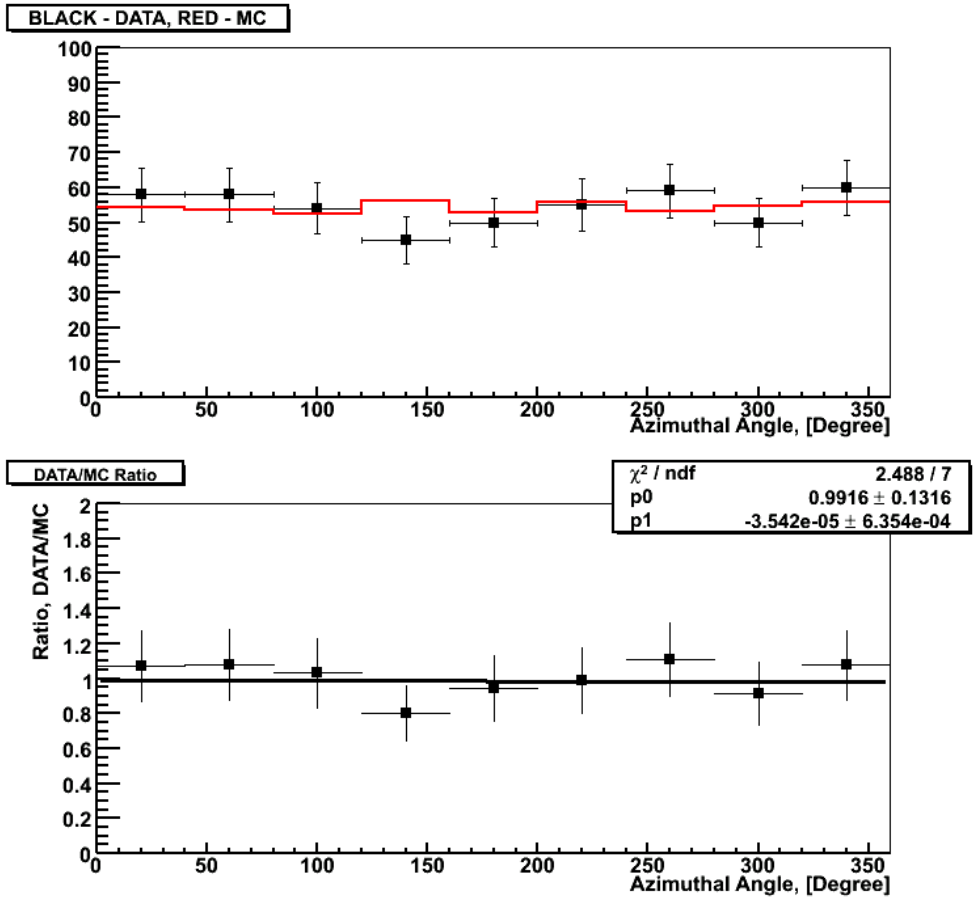


Number of good SDs / event

VEM / SD

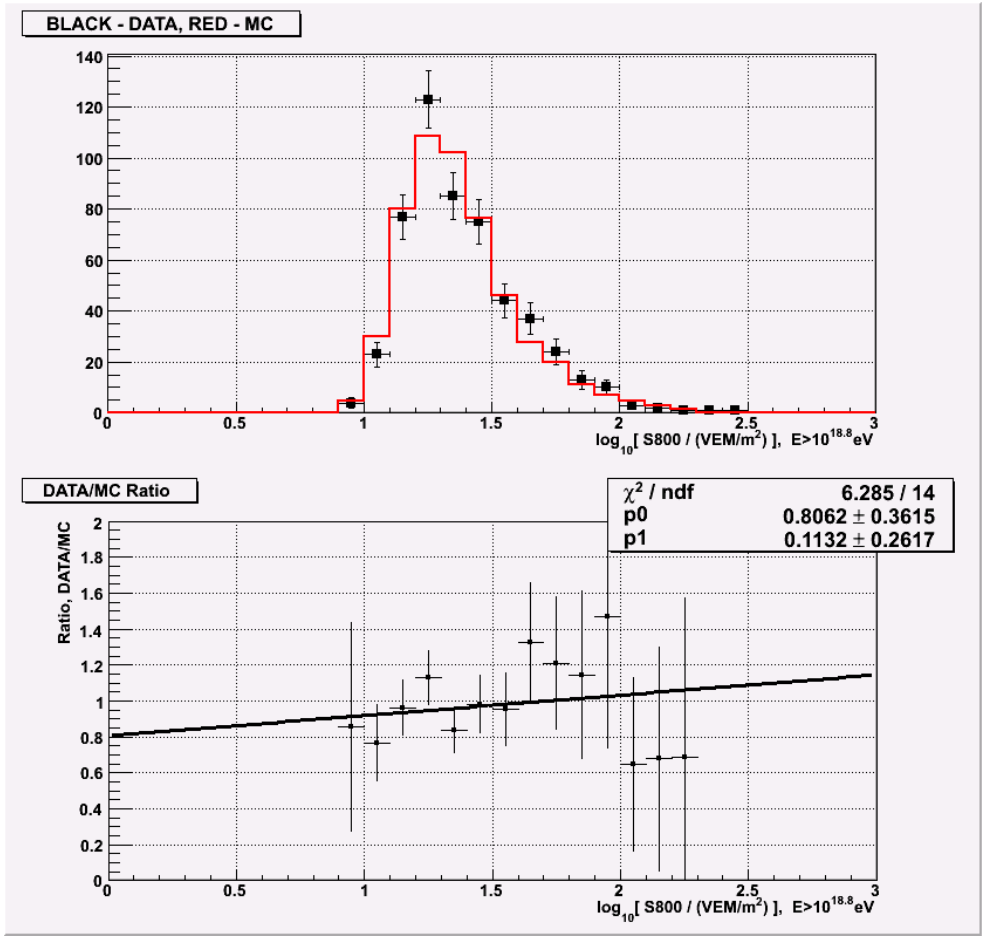
DATA/MC Event Direction

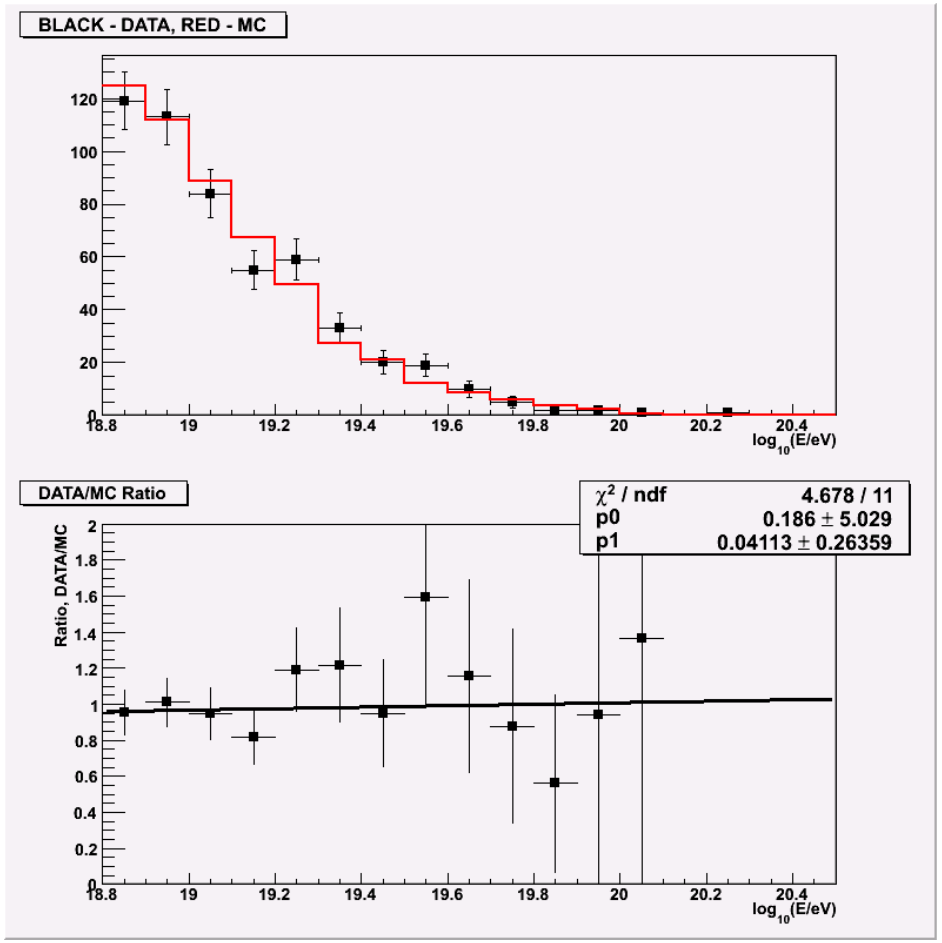




Zenith angle **Azimuthal angle**

DATA/MC: S800, Energy

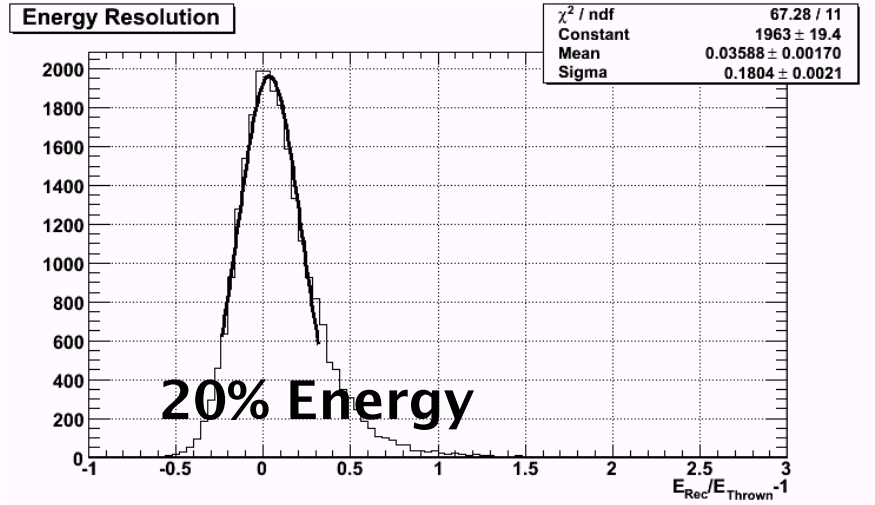


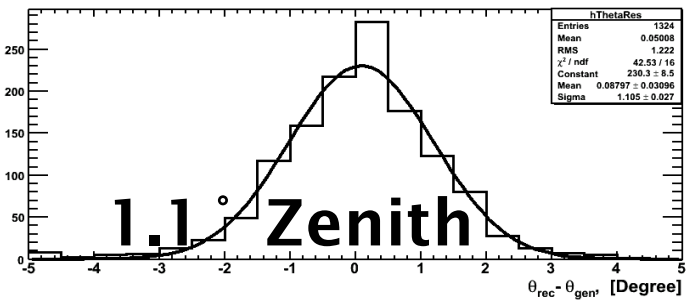


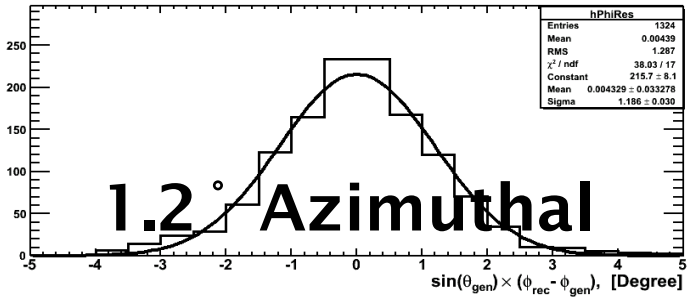
S800

Energy

TA SD Resolution

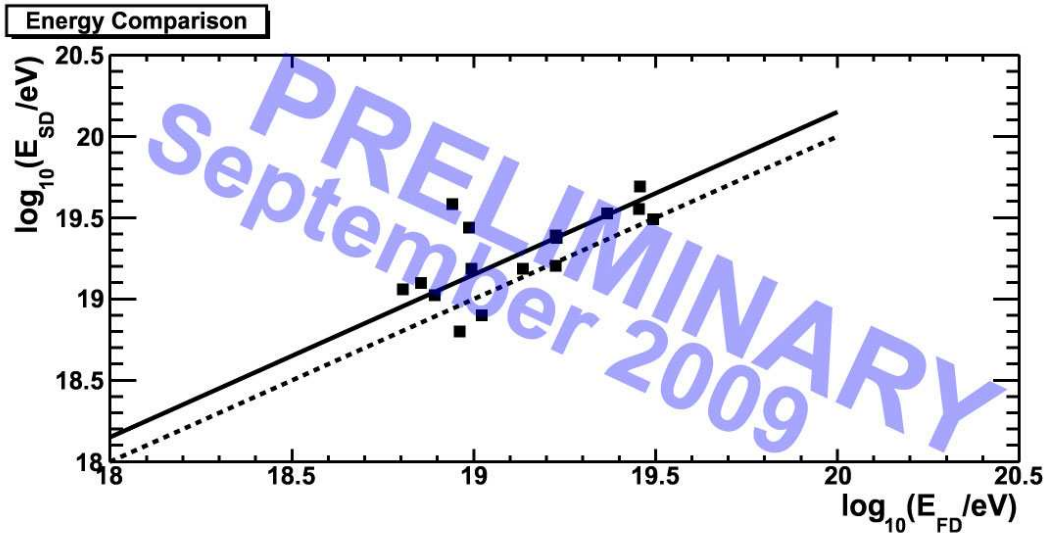


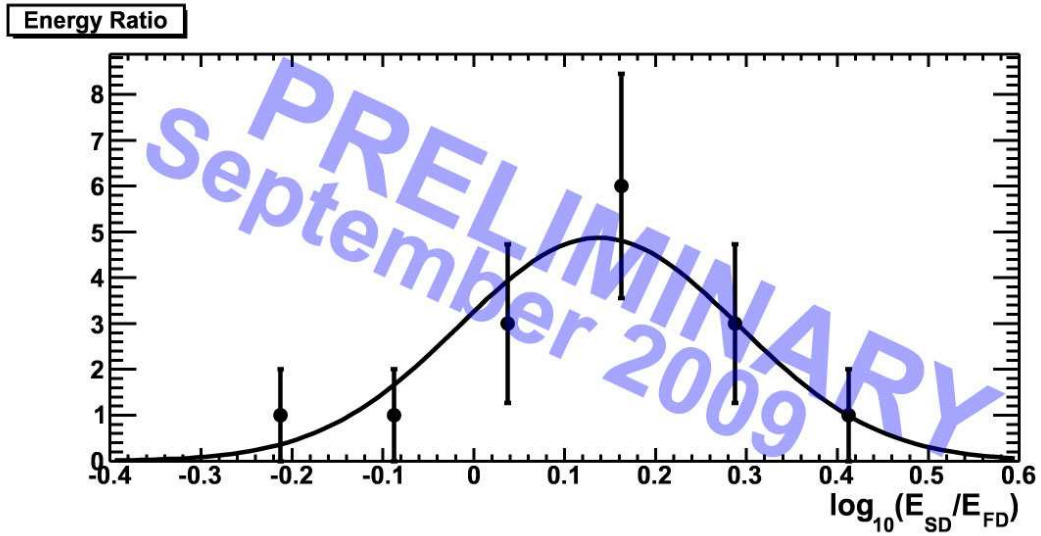




- To achieve good resolution one applies quality cuts
- Correct aperture is calculated from MC which:
  - Agrees with the data
  - Analyzed in the same way as the data, including the quality cuts

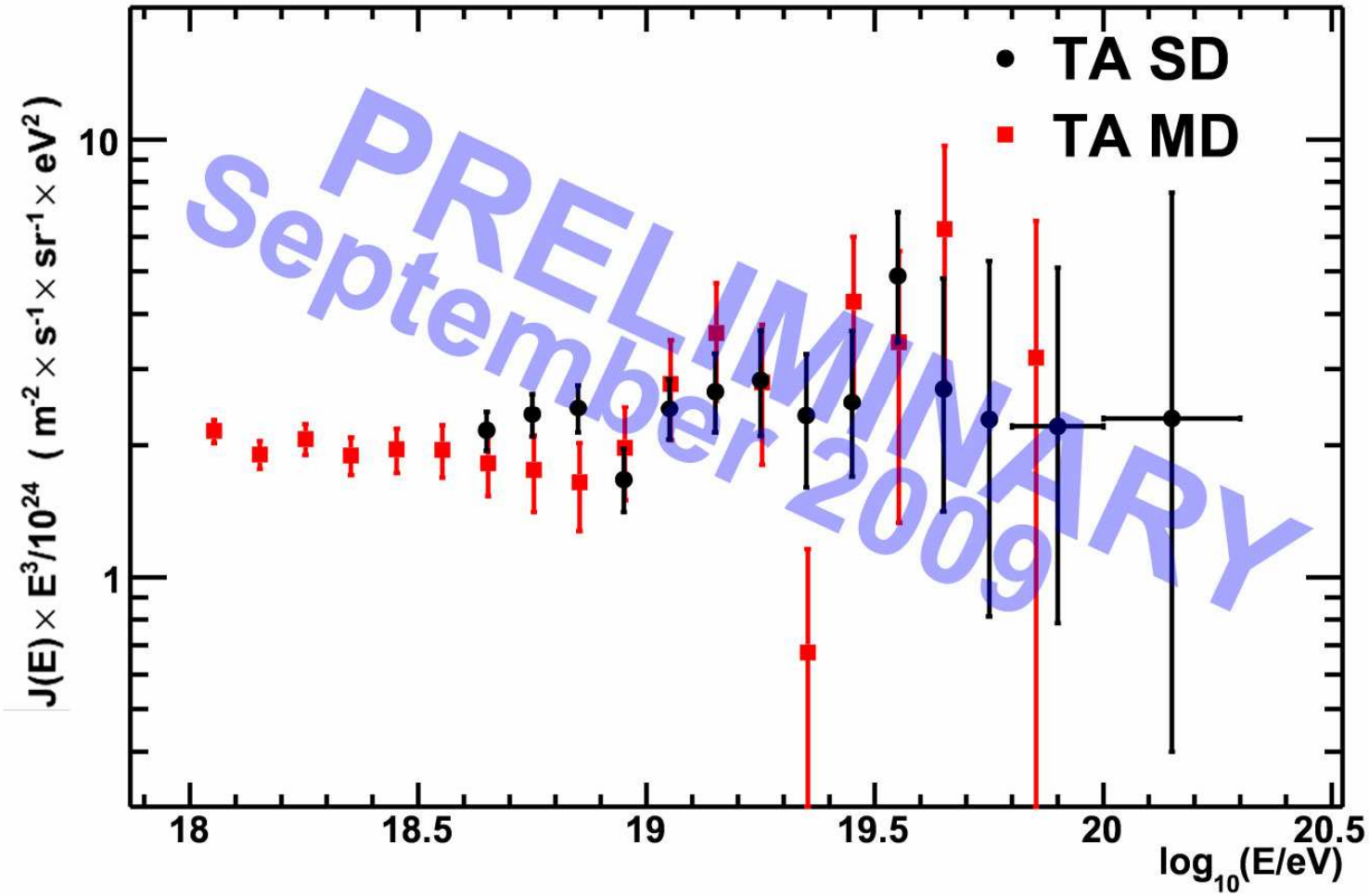
Energy Scale





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

Energy Spectrum



- **TA SD and FD results agree**

Conclusion

- Calculated SD energy spectrum using new techniques
- Geometry and LDF reconstruction are based solely on characteristics of the data
- Generated MC set with all characteristics of the real data
- Verified the validity of our MC by comparing with the data
- Tied SD energy scale to FD
- TA SD and FD energy spectra are in agreement

Thank You

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MEXT

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