TELESCOPE ARRAY: RECENT RESULTS, FUTURE PLANS

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Cosmic Ray Anisotropy Workshop
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TA Experiment

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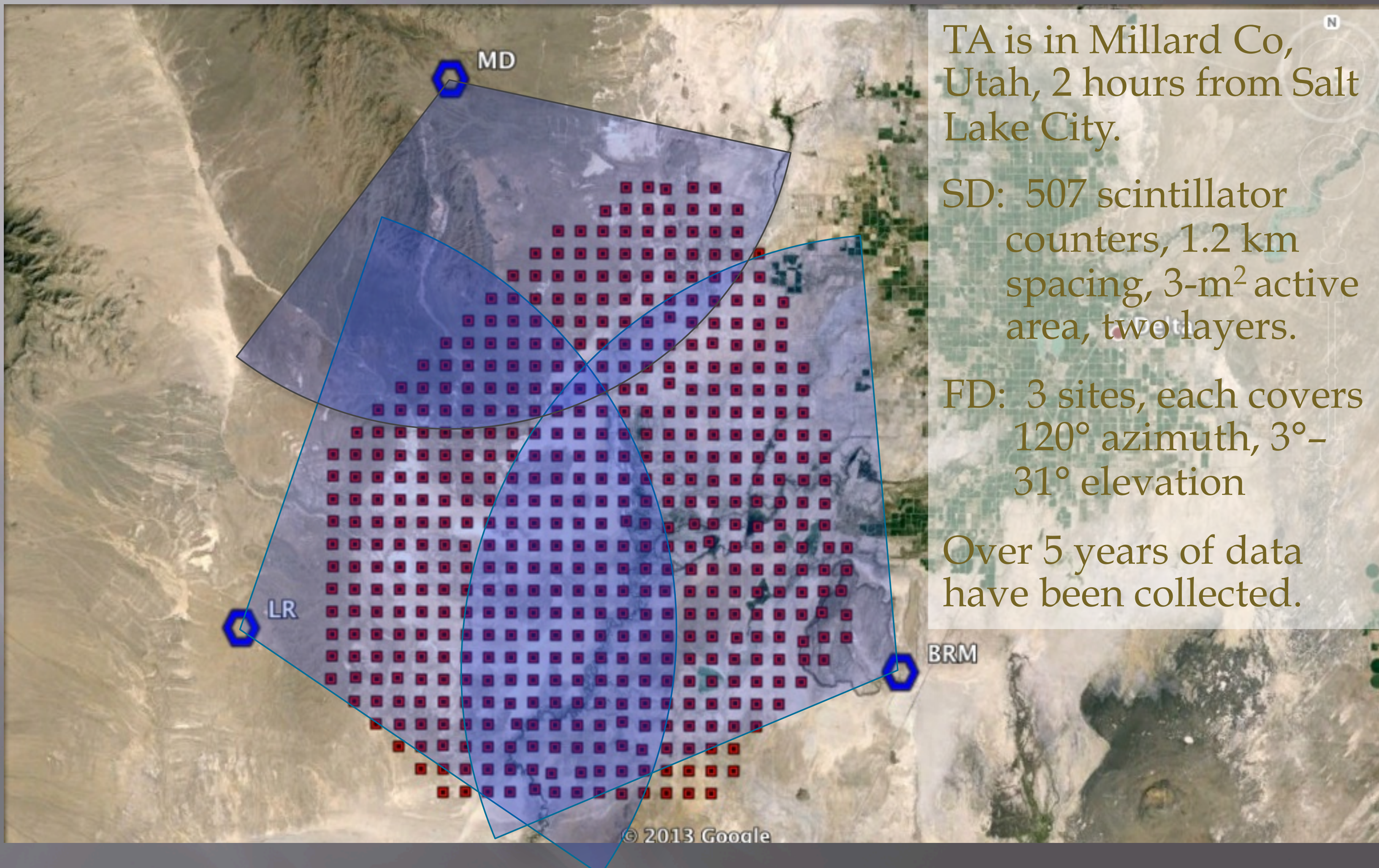
U.S., Japan, Korea, Russia, Belgium

TA Experiment



TA is in Millard Co, Utah, 2 hours from Salt Lake City.

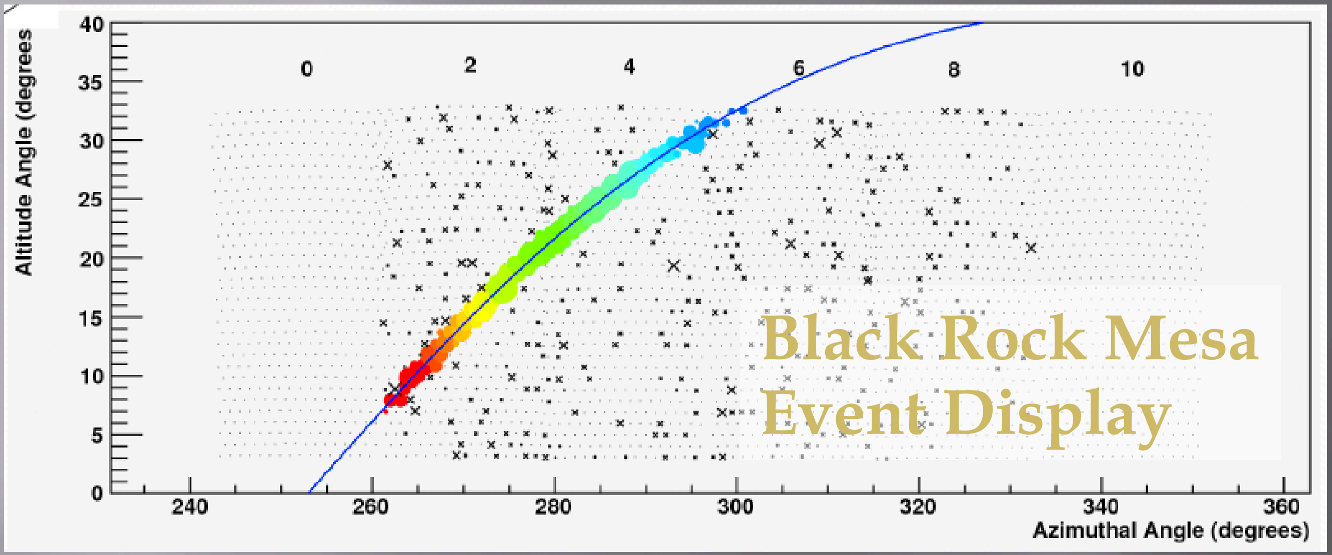
SD: 507 scintillator counters, 1.2 km spacing, 3-m^2 active area, two layers.

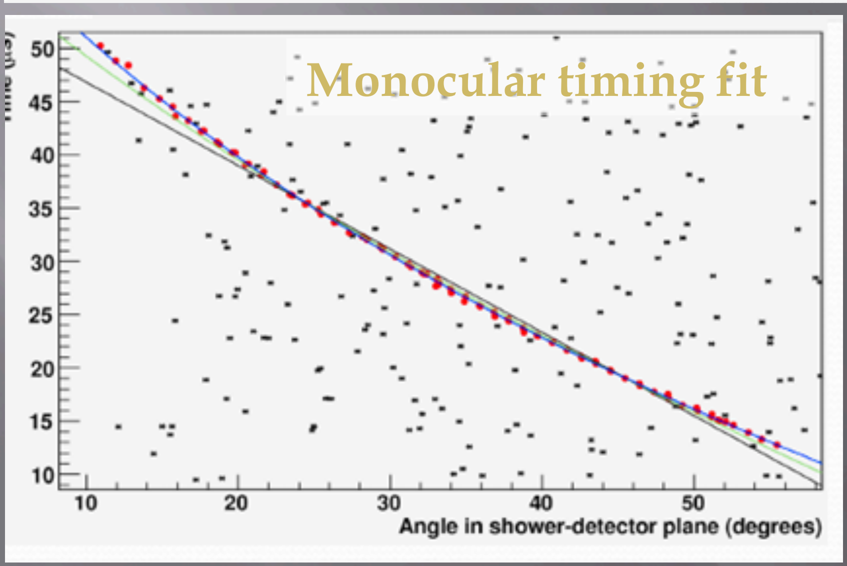
FD: 3 sites, each covers 120° azimuth, 3°–31° elevation

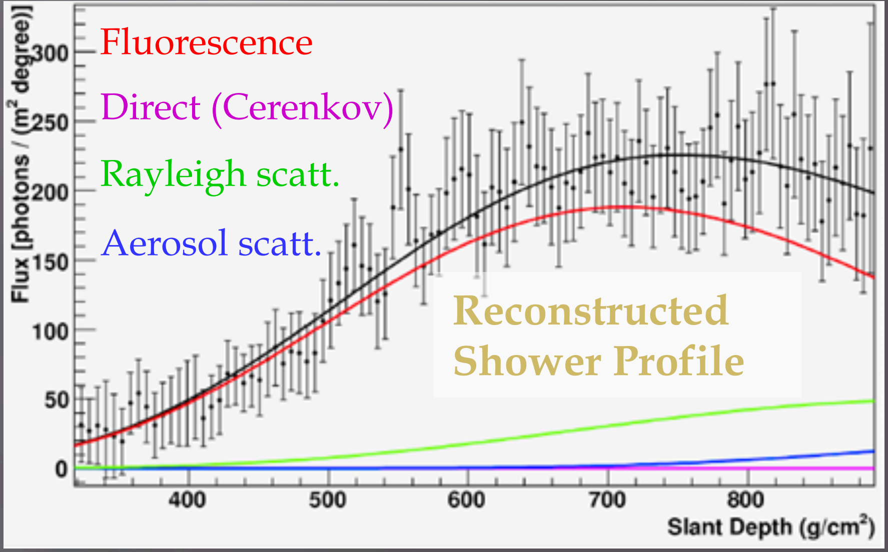
Over 5 years of data have been collected.

TA Experiment

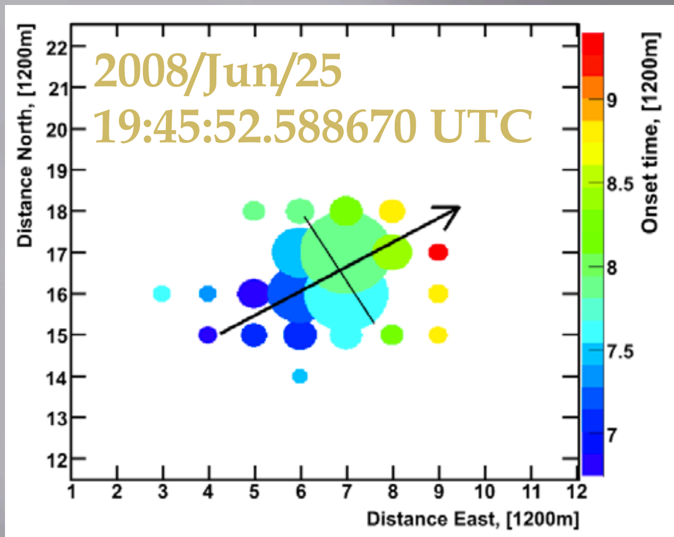
Typical Fluorescence Event

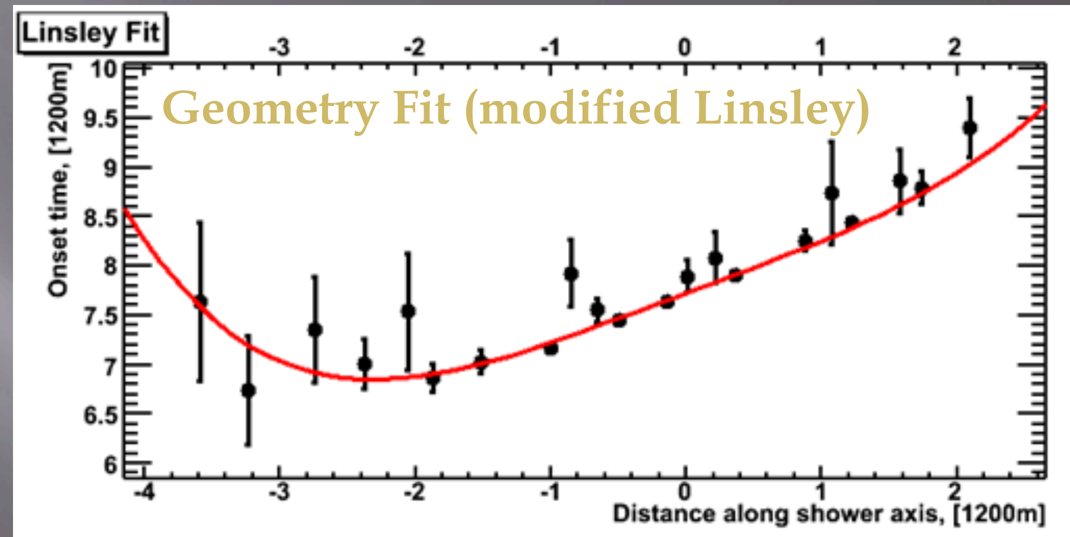


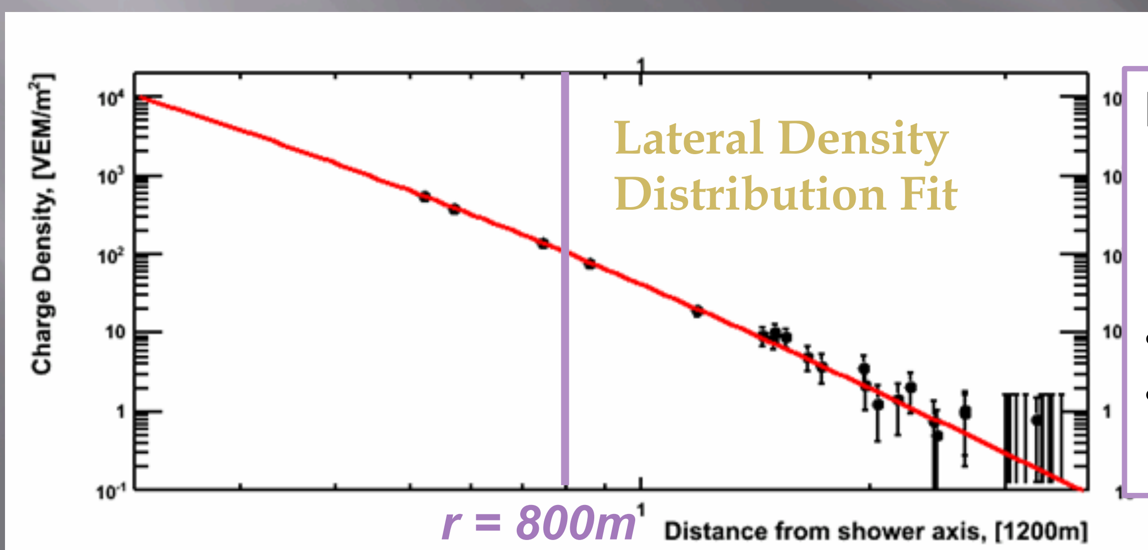




Typical SD Event







Fit with AGASA LDF

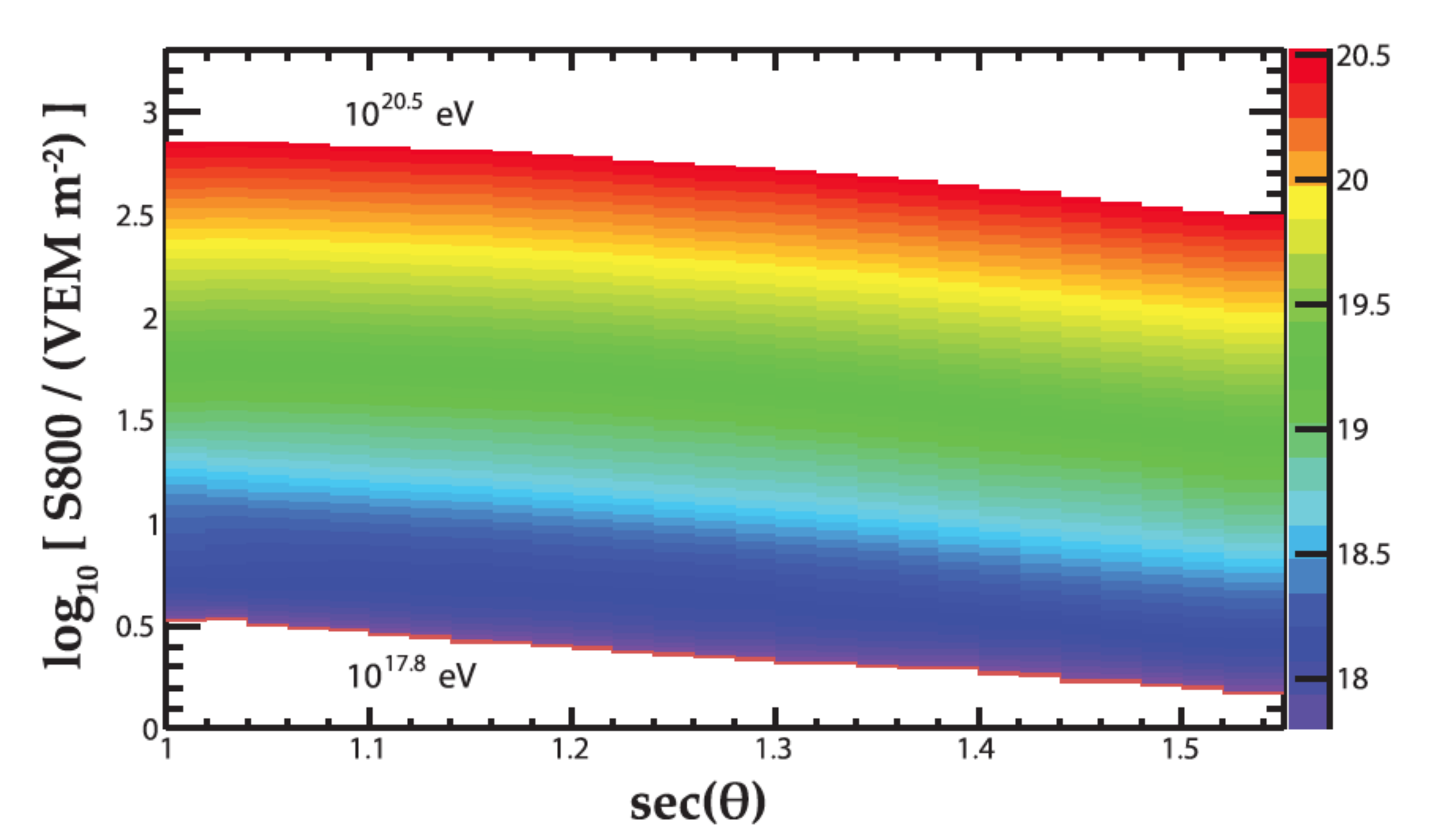
$$\rho(r) \propto \left(\frac{r}{R_M}\right)^{-1.2}\left(1+\frac{r}{R_M}\right)^{-(\eta-1.2)}\left\{1+\left(\frac{r}{1000}\right)^2\right\}^{-0.6}$$

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

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

First Energy Estimate

- For each energy find make $\log_{10}$S800-vs-sec(θ) curve from MC
- Estimation energy by looking up, interpolating between $\log_{10}$S800-vs-sec(θ) curves



Stereo and Hybrid Observation

- Many events are seen by several detectors.
  - FD mono has ~5° angular resolution.
  - Add SD information (*hybrid* reconstruction) get ~0.5° resolution.
  - Stereo FD resolution ~0.5°
- Need stereo or hybrid for composition analysis.

- Independent SD and FD operation until 2010.
- Hybrid trigger is in operation now.

Large Scale Structure

- The only real *a priori* expectation for anisotropy is that it should be associated with the matter distribution in the Universe
- Method
  - Calculate a flux from the actual distribution of galaxies (2MASS XSCz): 110 000 galaxies from 5 Mpc to 250 Mpc
  - Take flux from beyond 250 Mpc as uniform
  - Assume proton primaries
  - Account for all interactions and redshift losses
  - Apply Gaussian smearing in arrival direction, with the angular size treated as a free parameter. This mimics magnetic field deflections and angular resolution.
  - Compare prediction to data by the flux sampling test

Correlation with Large Scale Structure

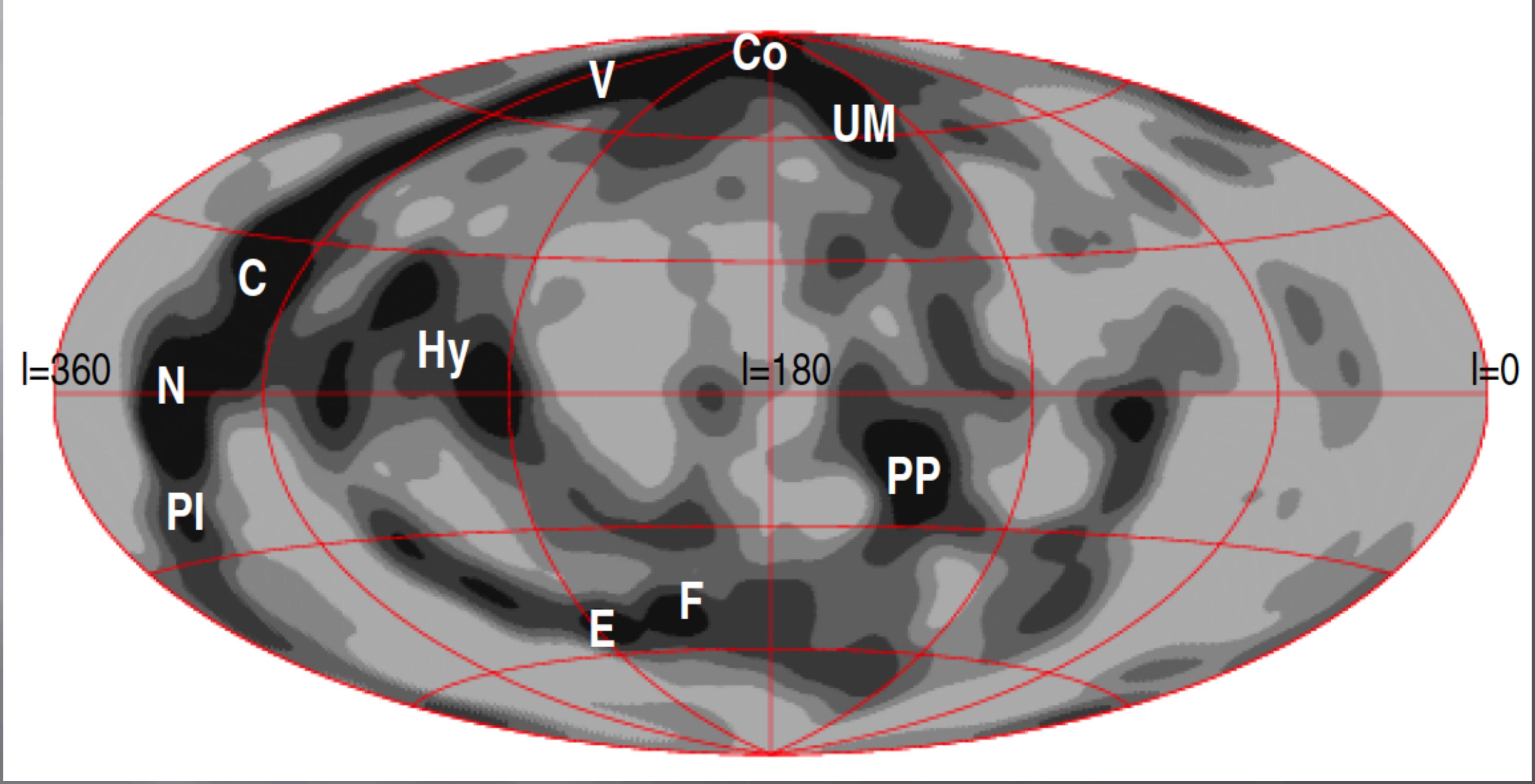
- There is only one *a priori* expectation for anisotropy at the highest energies: *UHECRs should be associated with distribution of visible matter in the Universe*

Correlation with Large Scale Structure

- Use 2MASS & XSCz surveys to provide sources of UHECRs: 110,000 galaxies, from 5 Mpc to 250 Mpc (assume uniform beyond 250 Mpc)
- Assume proton primaries and apply interactions and redshift losses
- Smear arrival direction by a variable angle to mimic deflections and resolution
- Make map of fluxes (including detector exposure)
- Compare prediction to data by the flux-sampling test (K-S test of the sampled fluxes between data and MC samples)

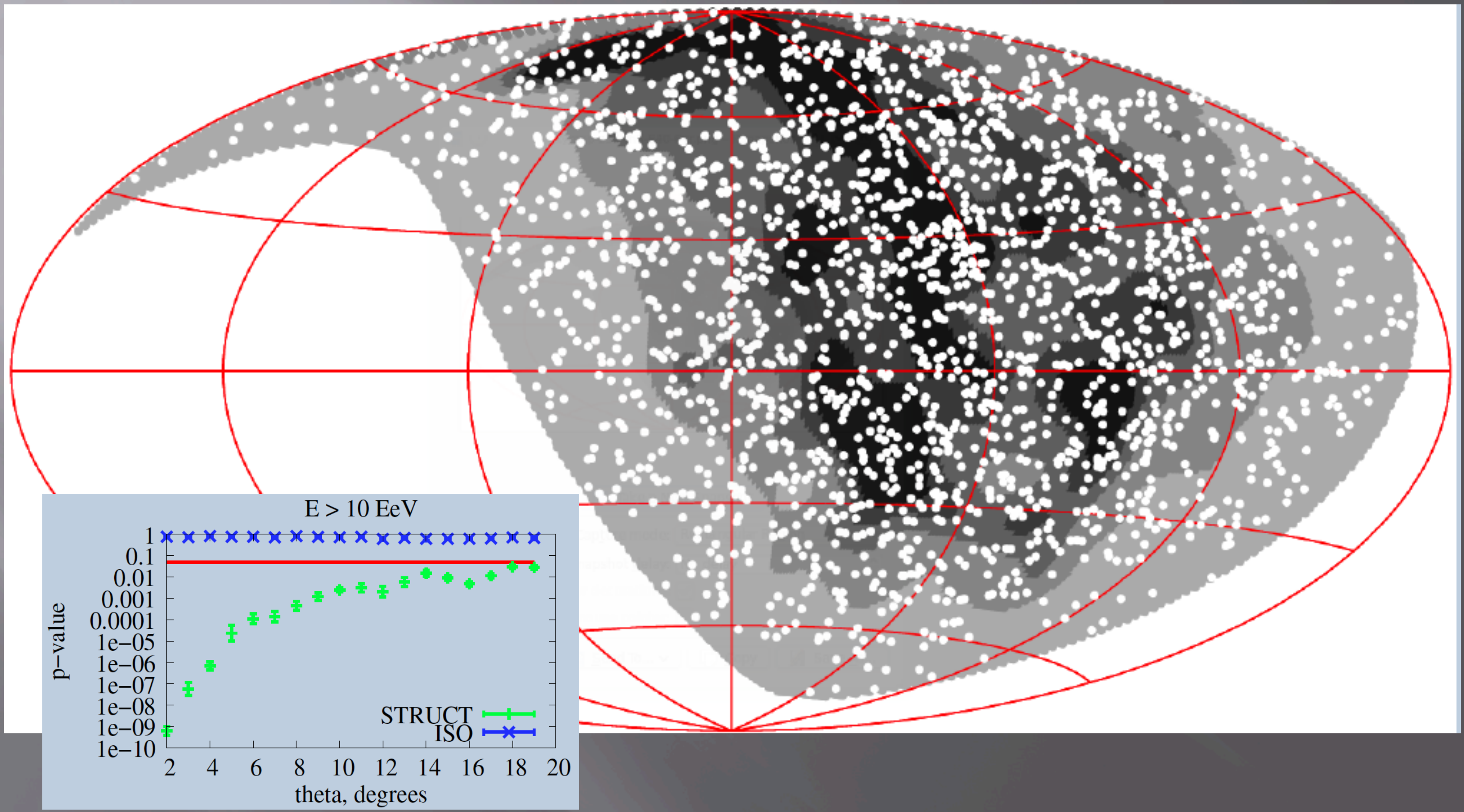
Correlation with Large Scale Structure

Flux map with 6° smearing and no detector sensitivity



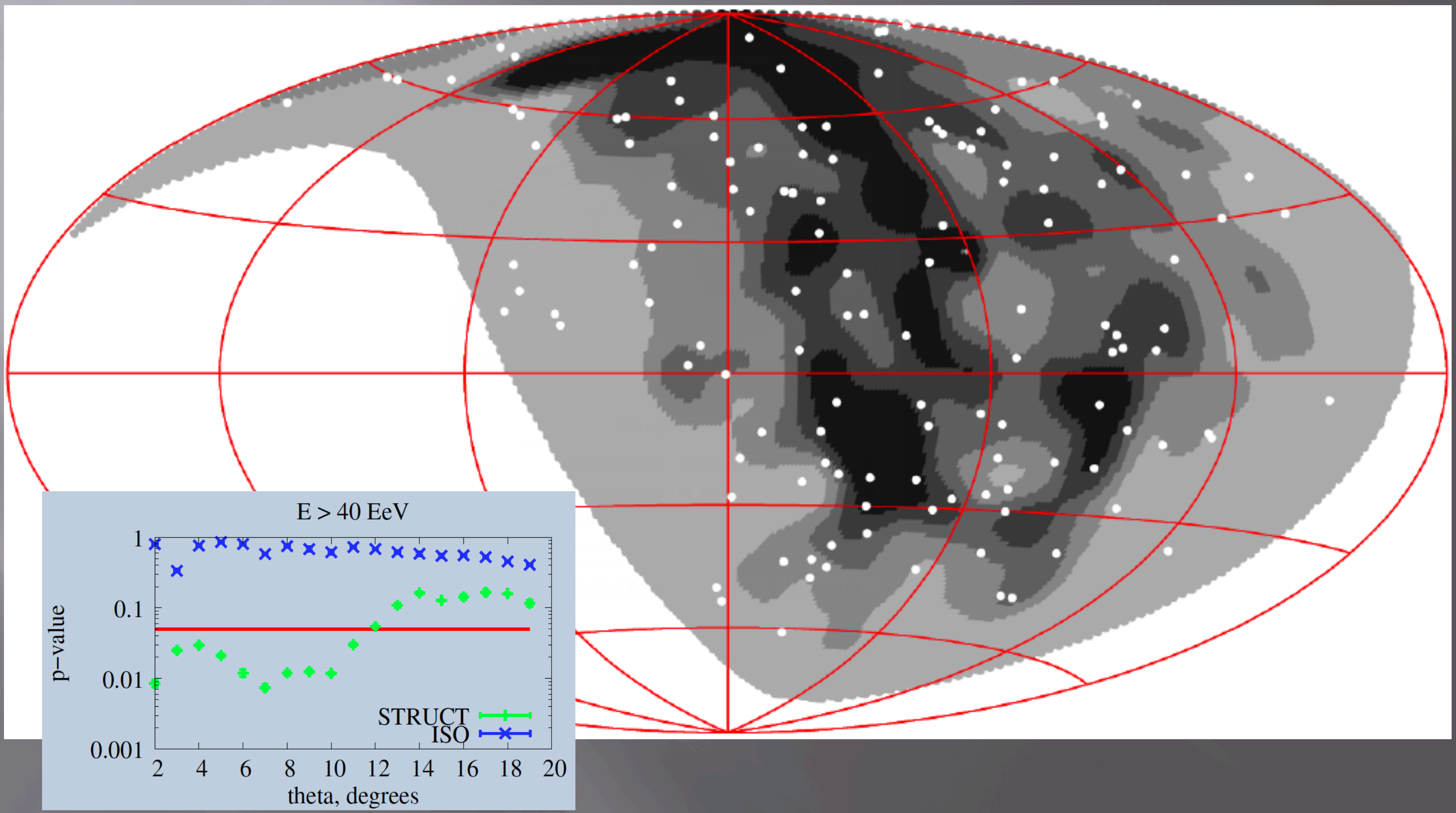
Correlation with Large Scale Structure

Events with $E > 10$ EeV



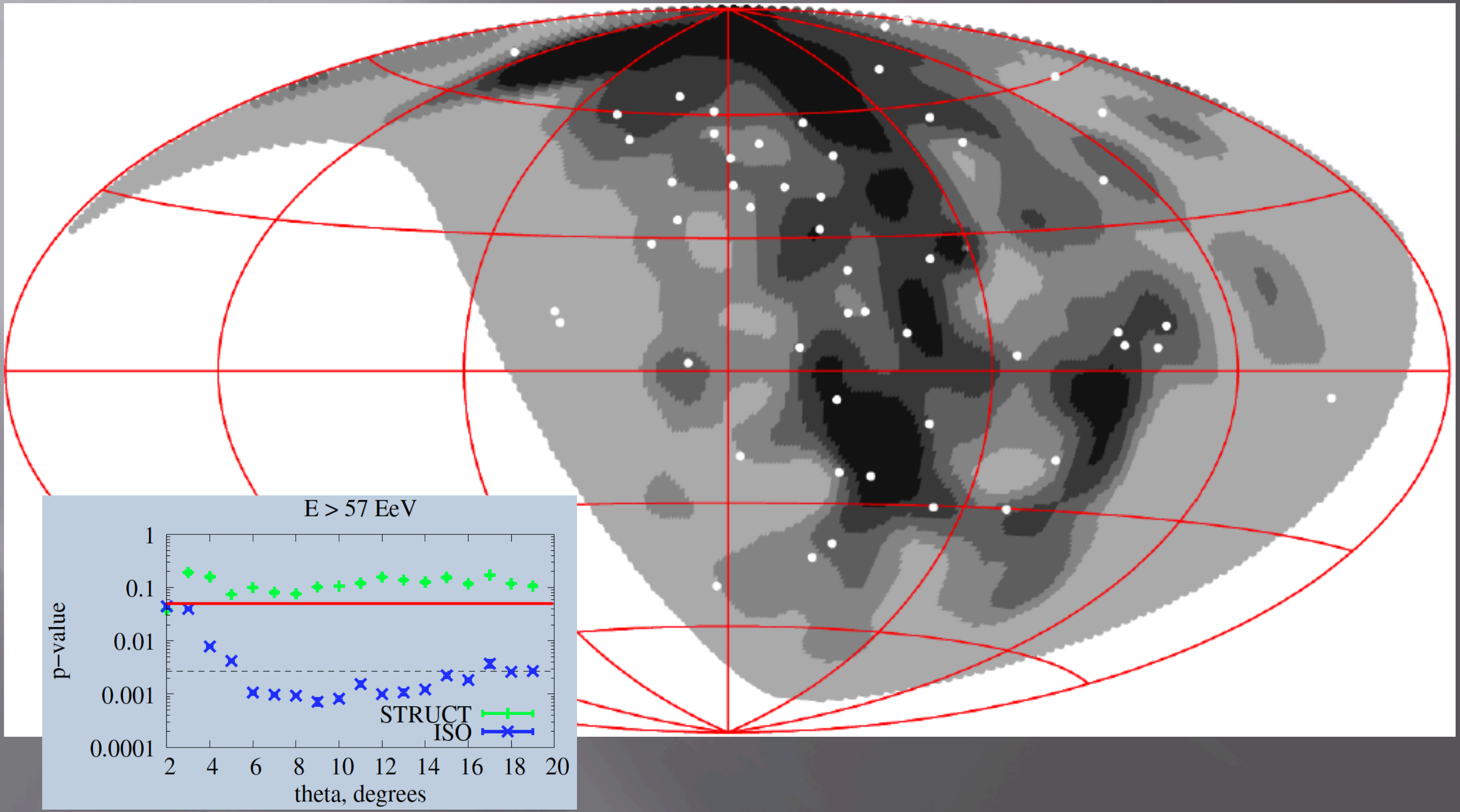
Correlation with Large Scale Structure

Events with $E > 40$ EeV



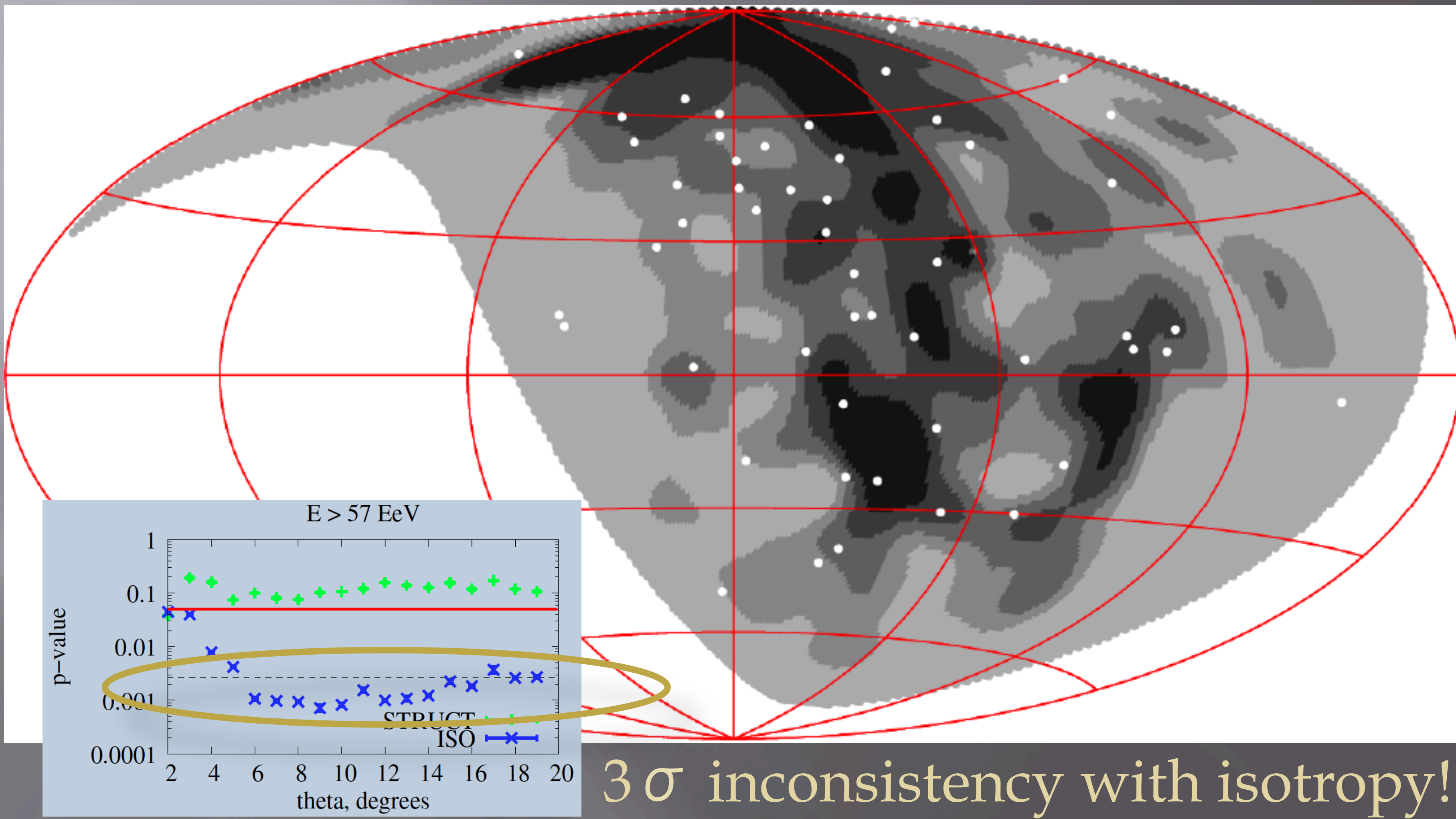
Correlation with Large Scale Structure

Events with $E > 47$ EeV



Correlation with Large Scale Structure

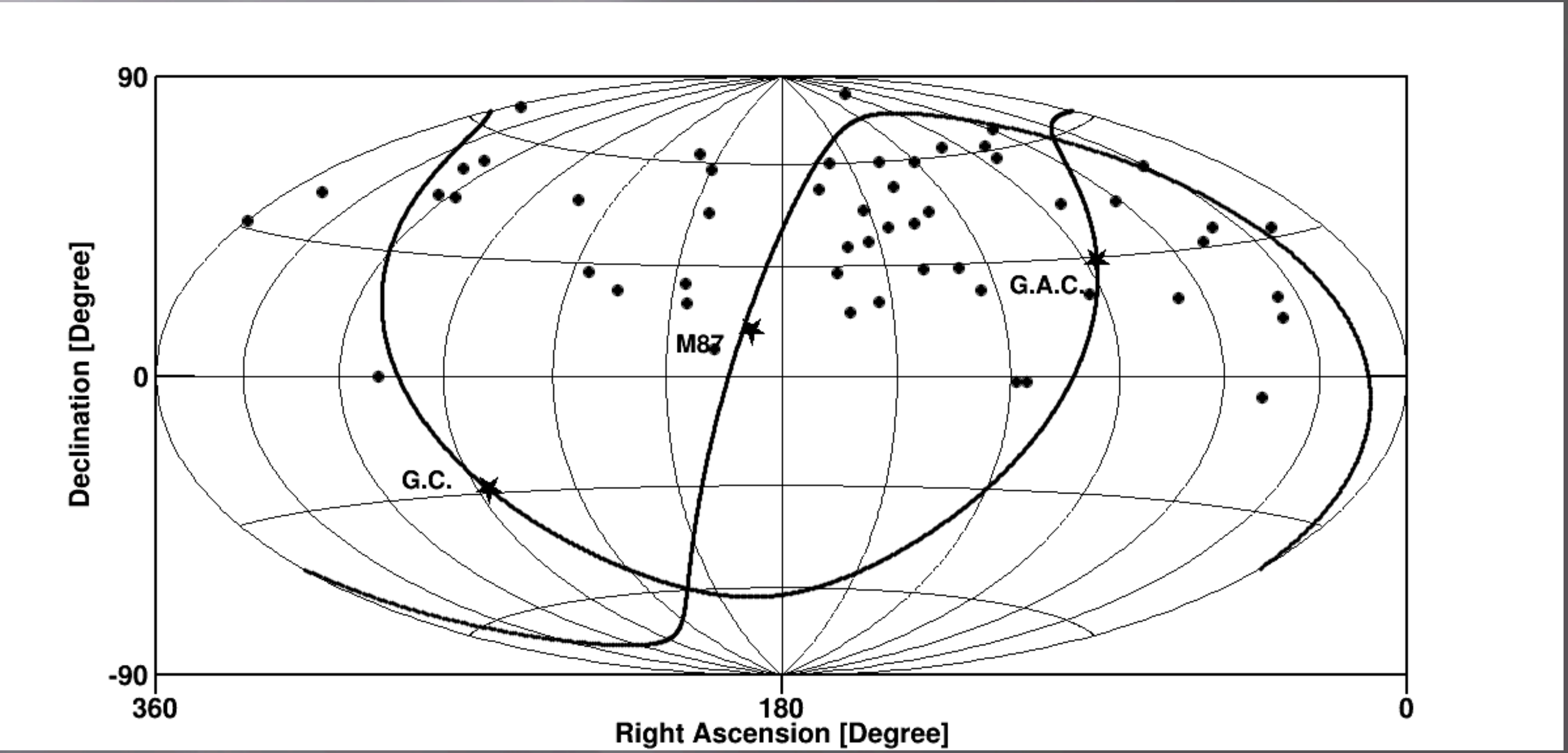
Events with E > 47 EeV



3 σ inconsistency with isotropy!

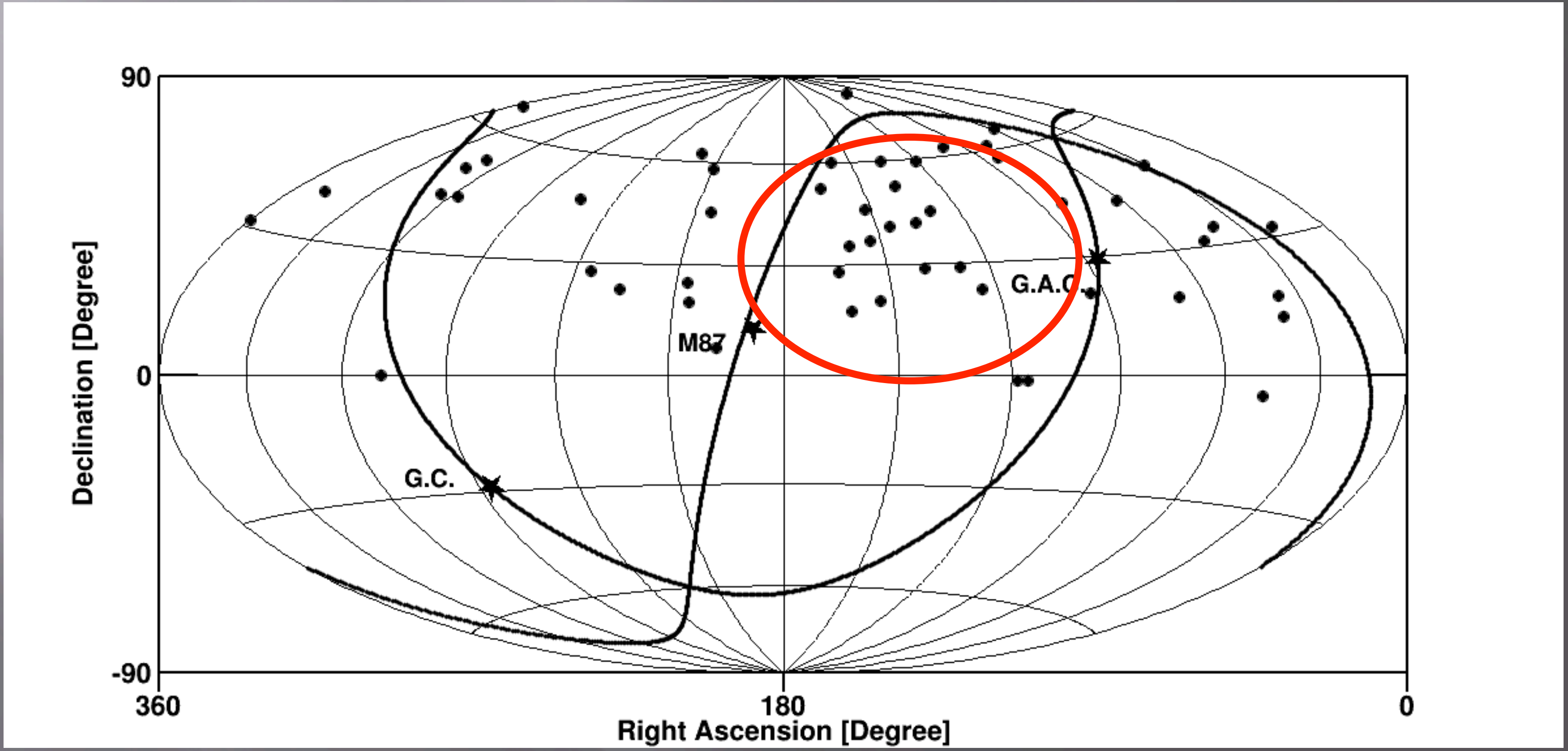
TA "Hotspot"

- By eye, one might say there's a spot in the E > 57 EeV sample



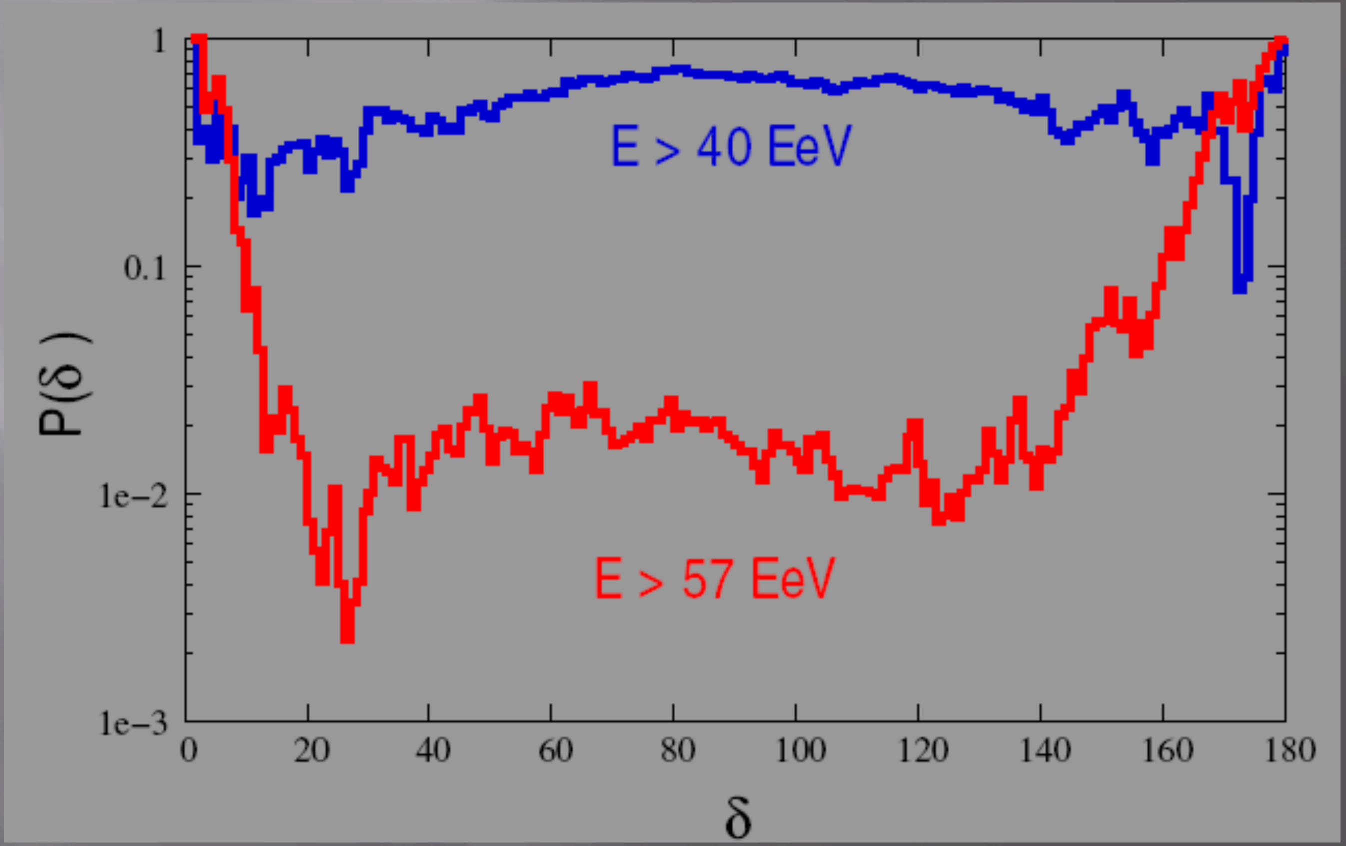
TA "Hotspot"

- By eye, one might say there's a spot in the $E > 57$ EeV sample
- Real or apophenia?



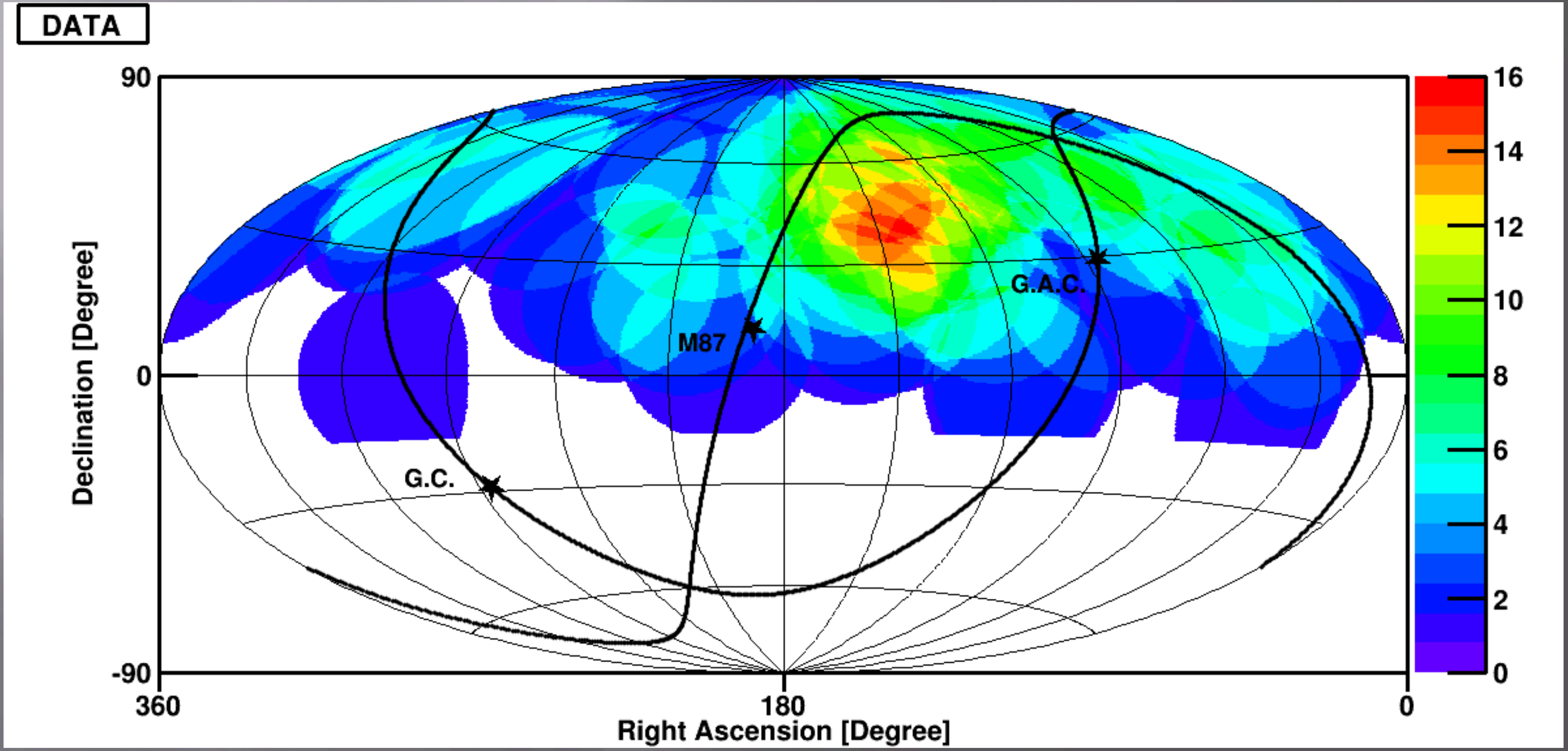
Autocorrelation

- 3σ (pre-trial) minimum at ~25°; largely comes from hotspot.

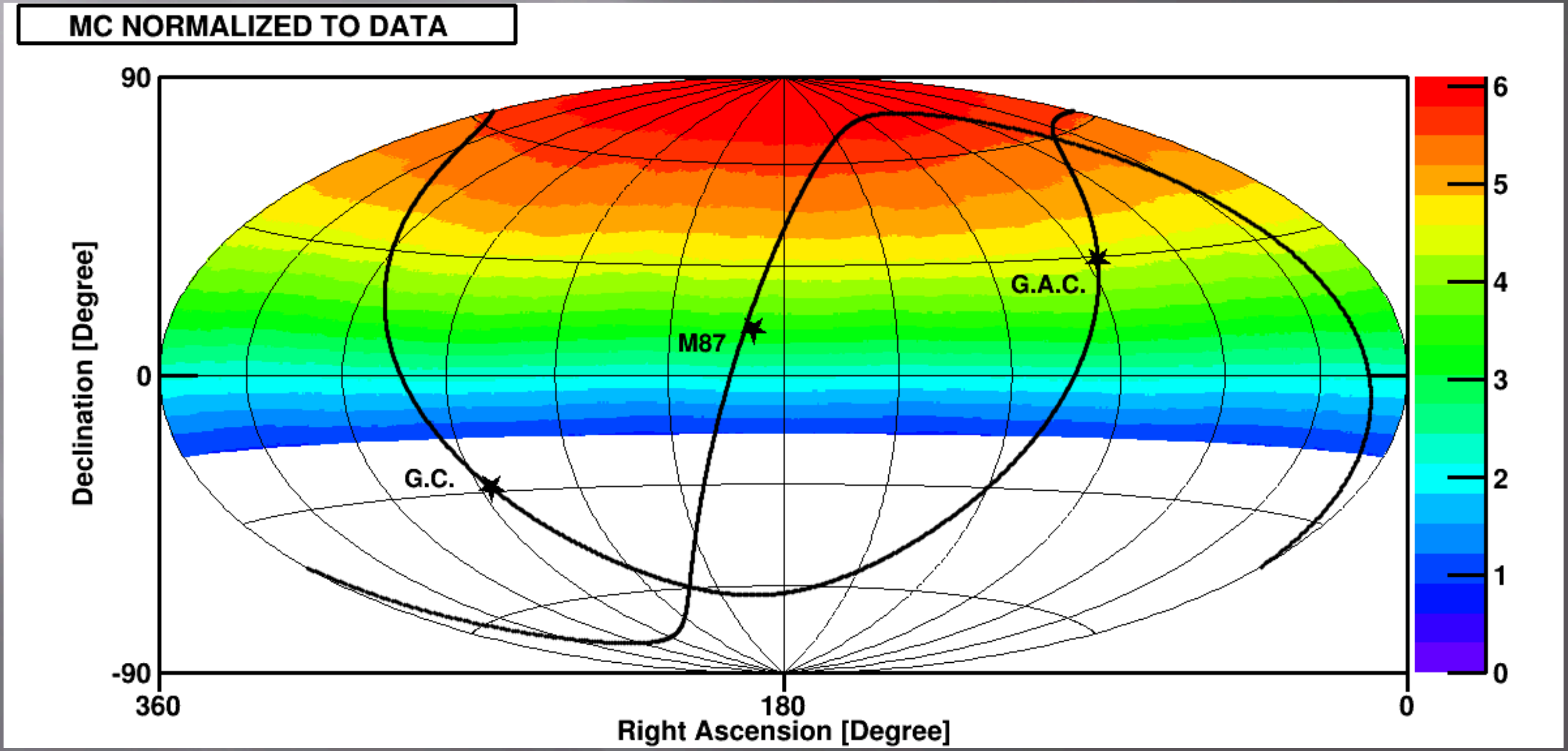


Hotspot with oversampling

- Oversample in 25˚ circles (25˚ from autocorrelation)

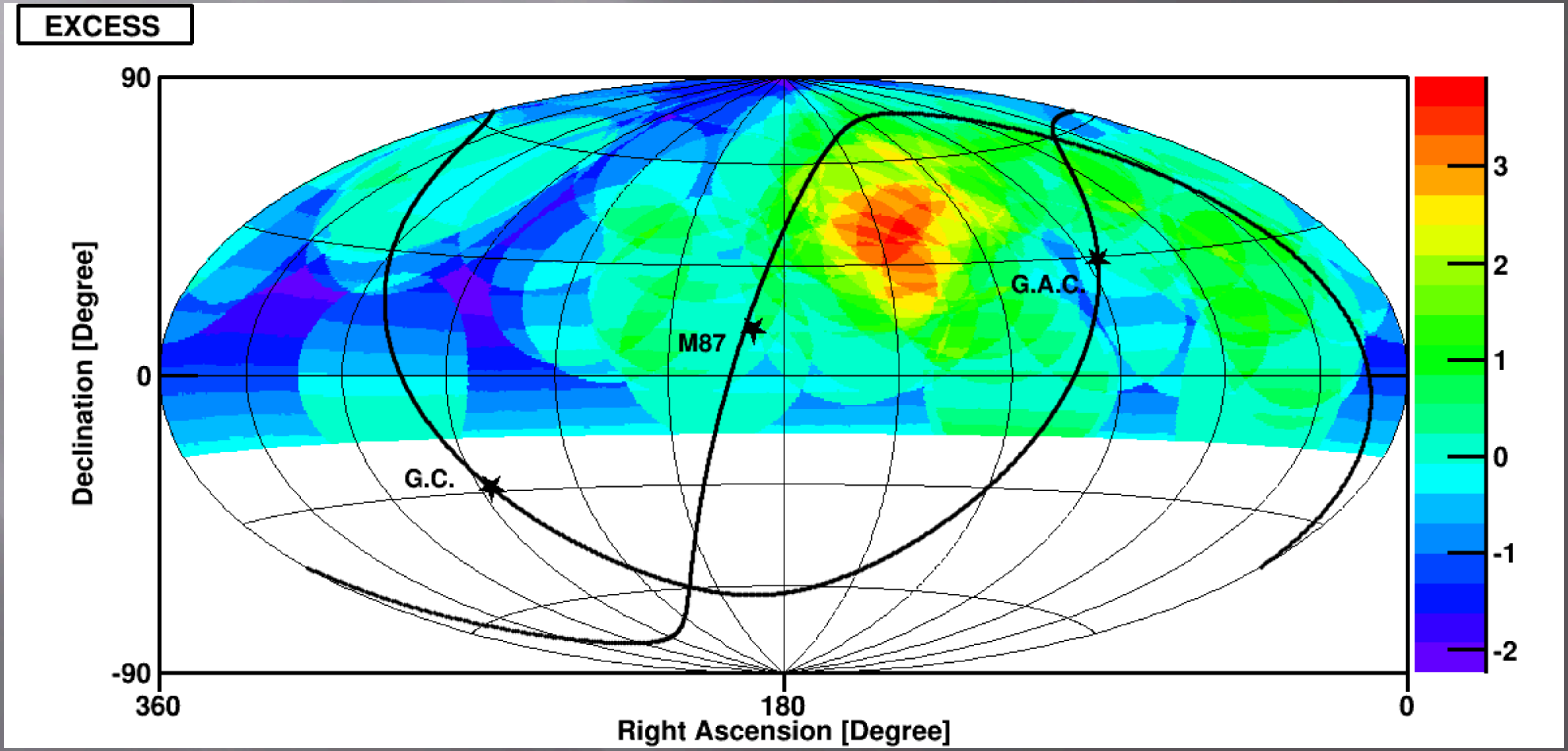


Expectation



Hotspot significance

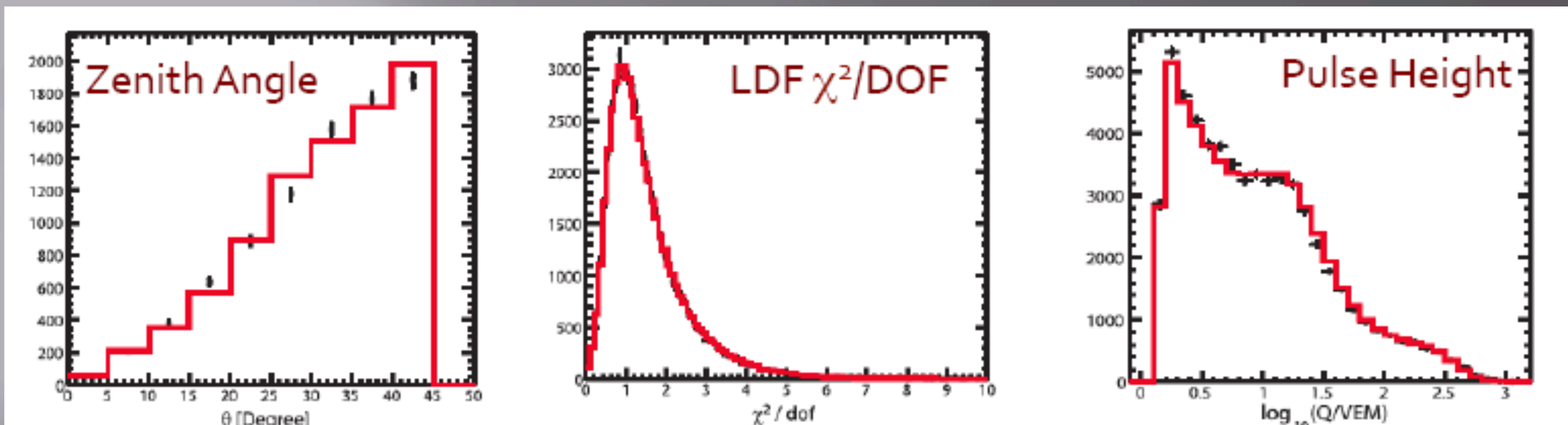
- A priori KS test gives 3 σ significance
- Sky map gives 3.9 σ significance
- Isotropic samples give chance probability of 0.012 (2.3 σ)

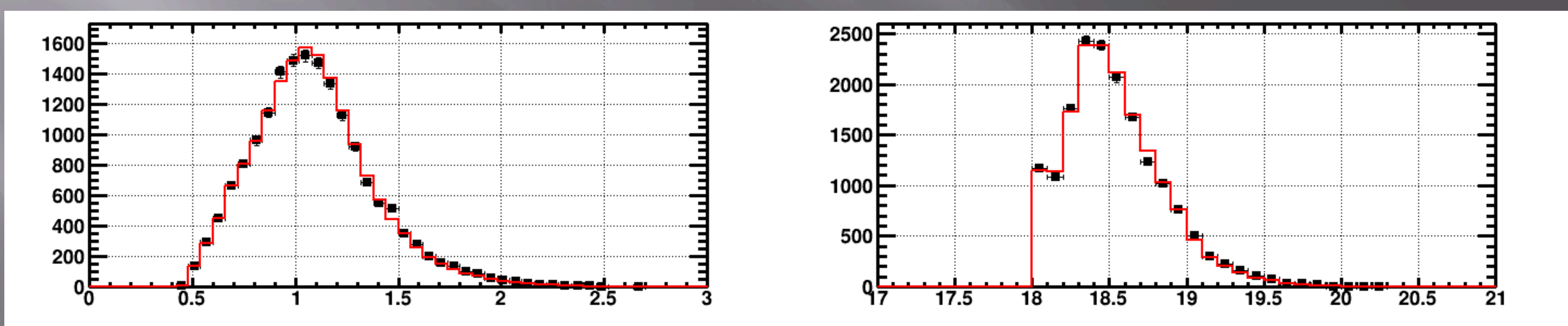


SD Spectrum

- 5 years of data
- 14787 events
- New analysis method
  - Cut out SD events which have poor resolution
    - Have to calculate aperture by MC
  - Can extend measurement below the energy plateau
  - Use HEP methods of Data/MC comparisons in calculating acceptance (aperture)
- Aperture calculation
  - Generate using measured spectrum and composition
  - Treat simulated data *exactly* the same as real data: same format, same analysis chain, same cuts
- Verify aperture calculation via Data/MC comparisons

Data/MC Comparisons

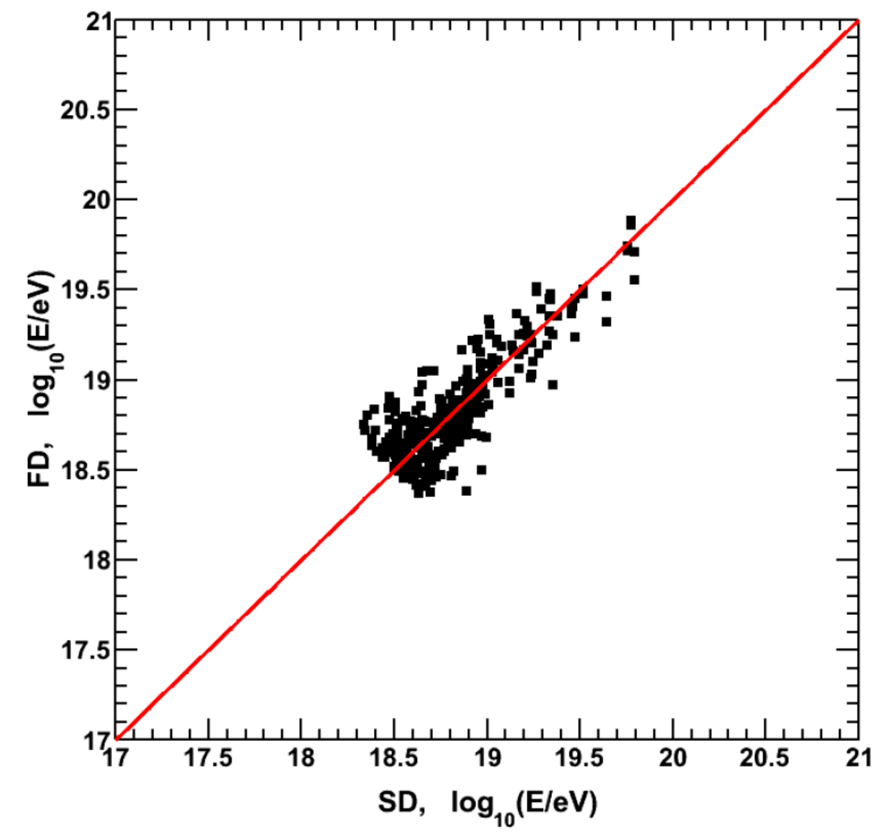




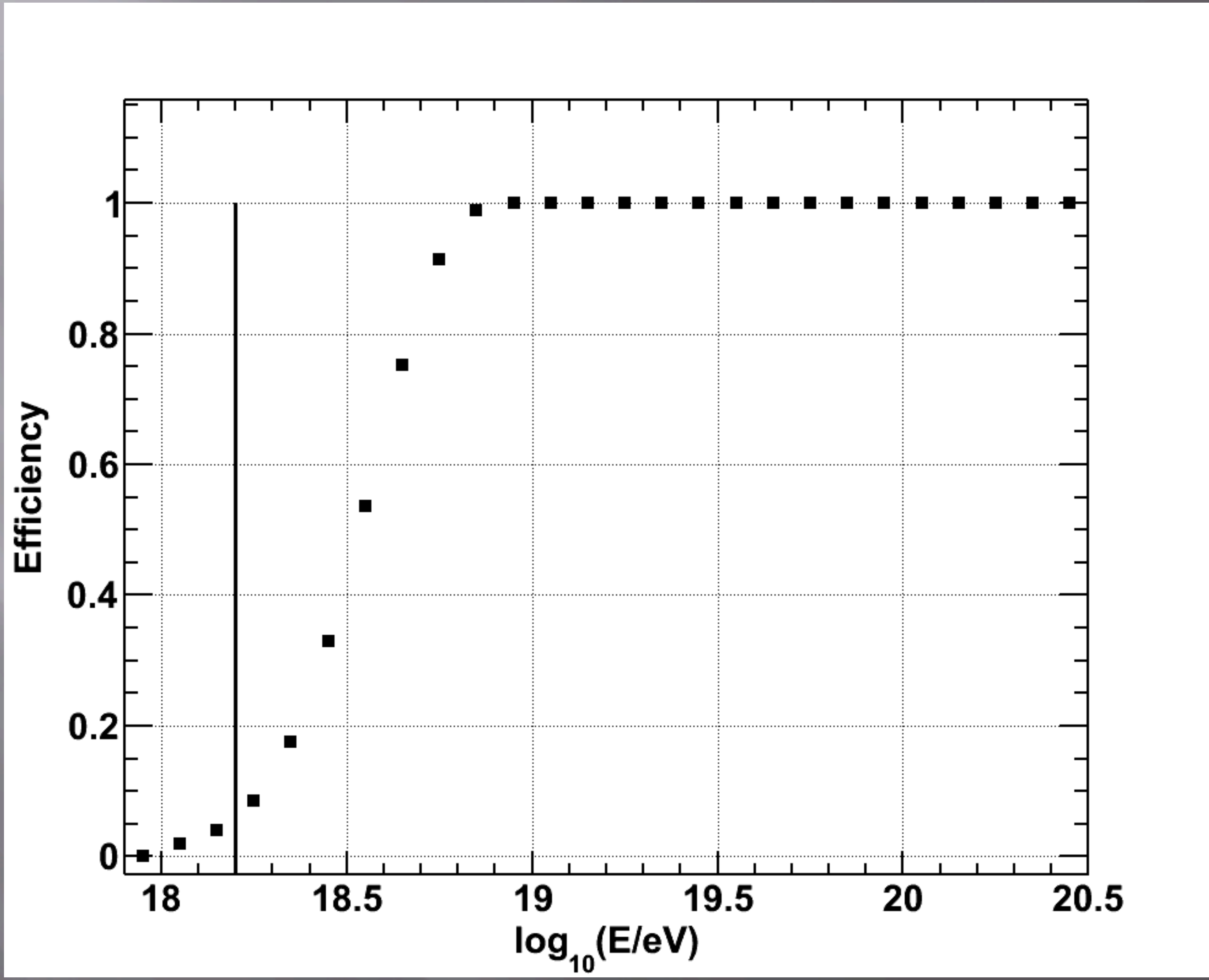
$\log_{10}$ S800 $\log_{10}$ E/eV

Energy Scale

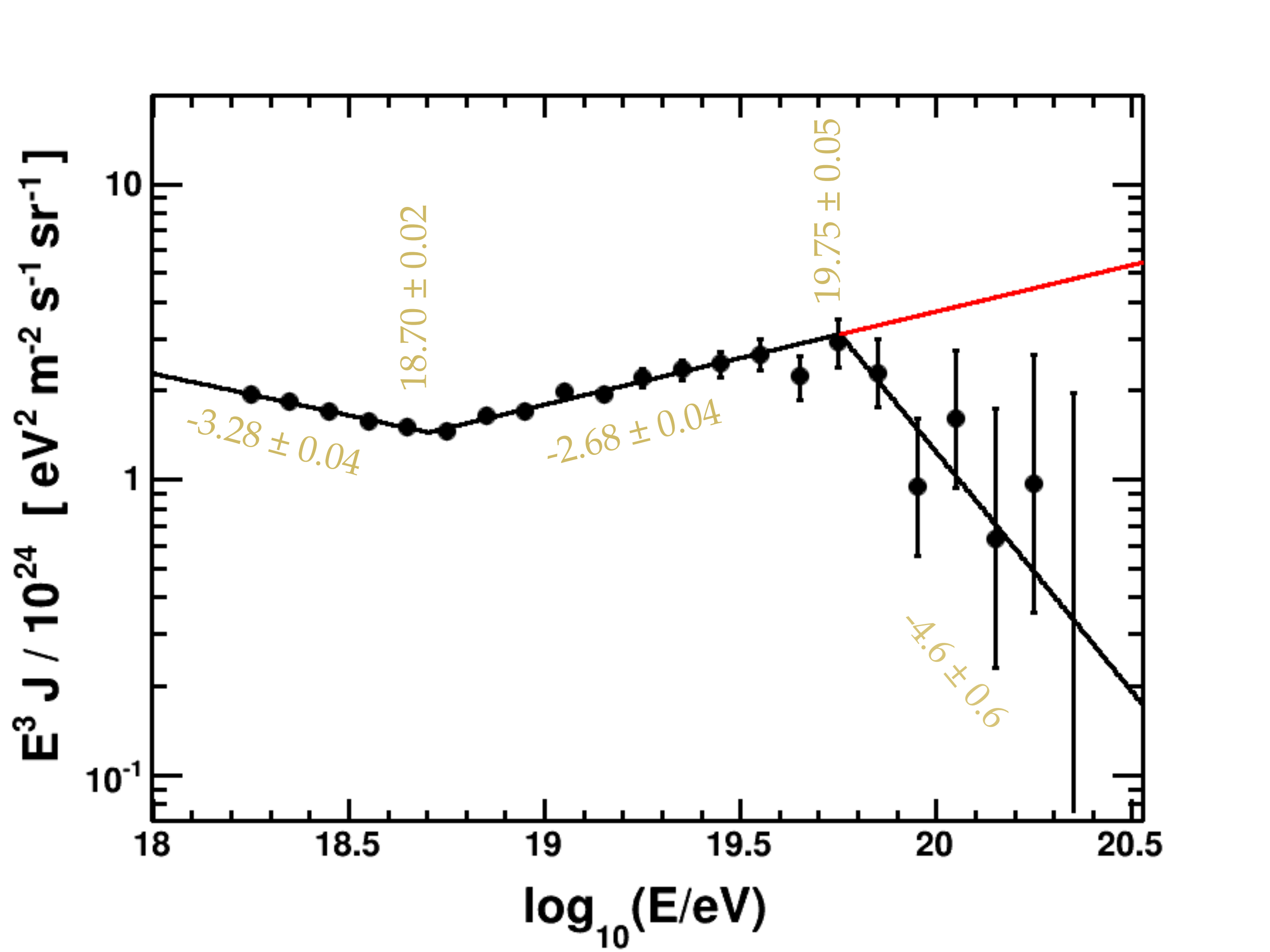
- SD and FD energy estimations disagree
- FD estimate possesses less model-dependence
- Set SD energy scale to FD energy scale using well-reconstructed events from all 3 FD detectors
- **27% renormalization.**
- 21% systematic uncertainty in FD energy scale



SD Acceptance

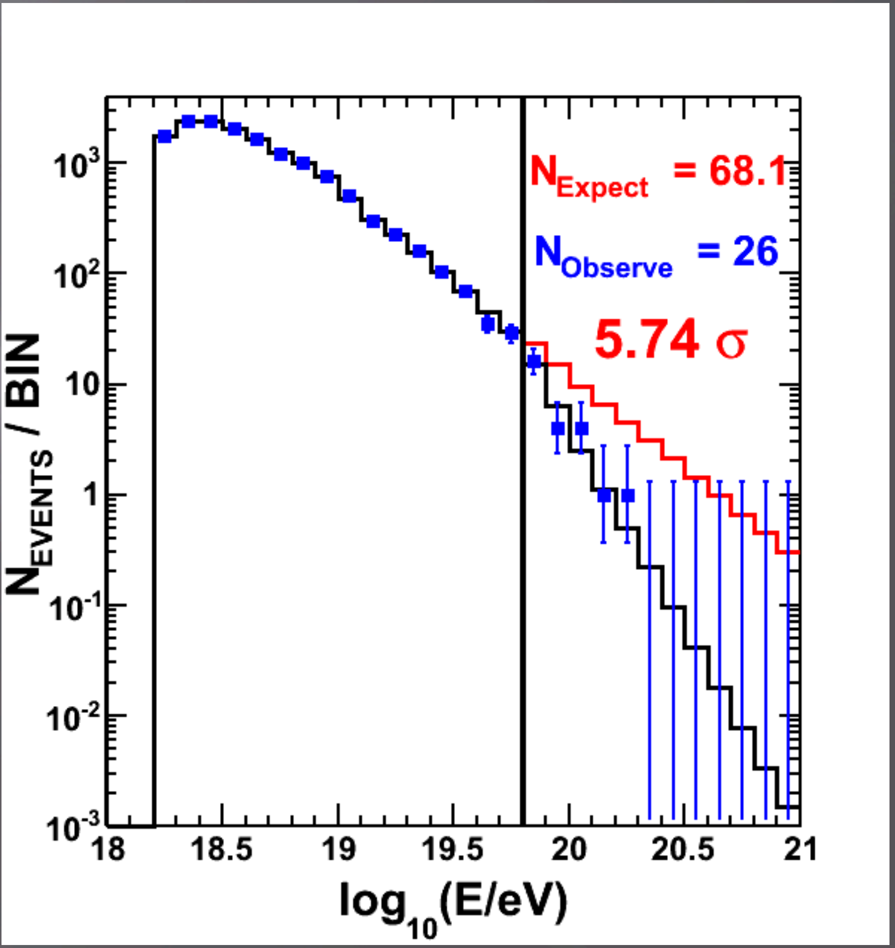


SD Spectrum with Broken PL Fit

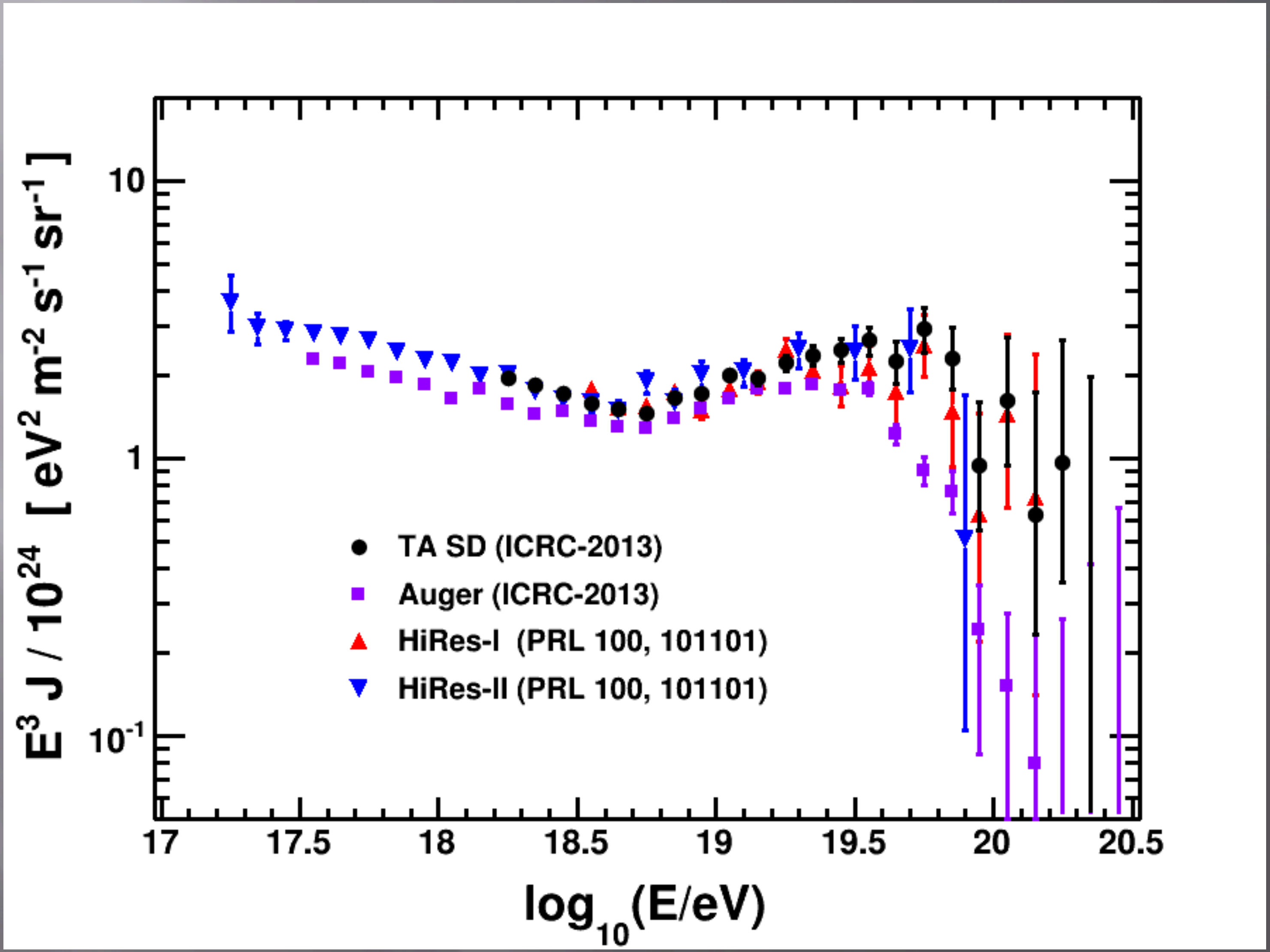


GZK Significance

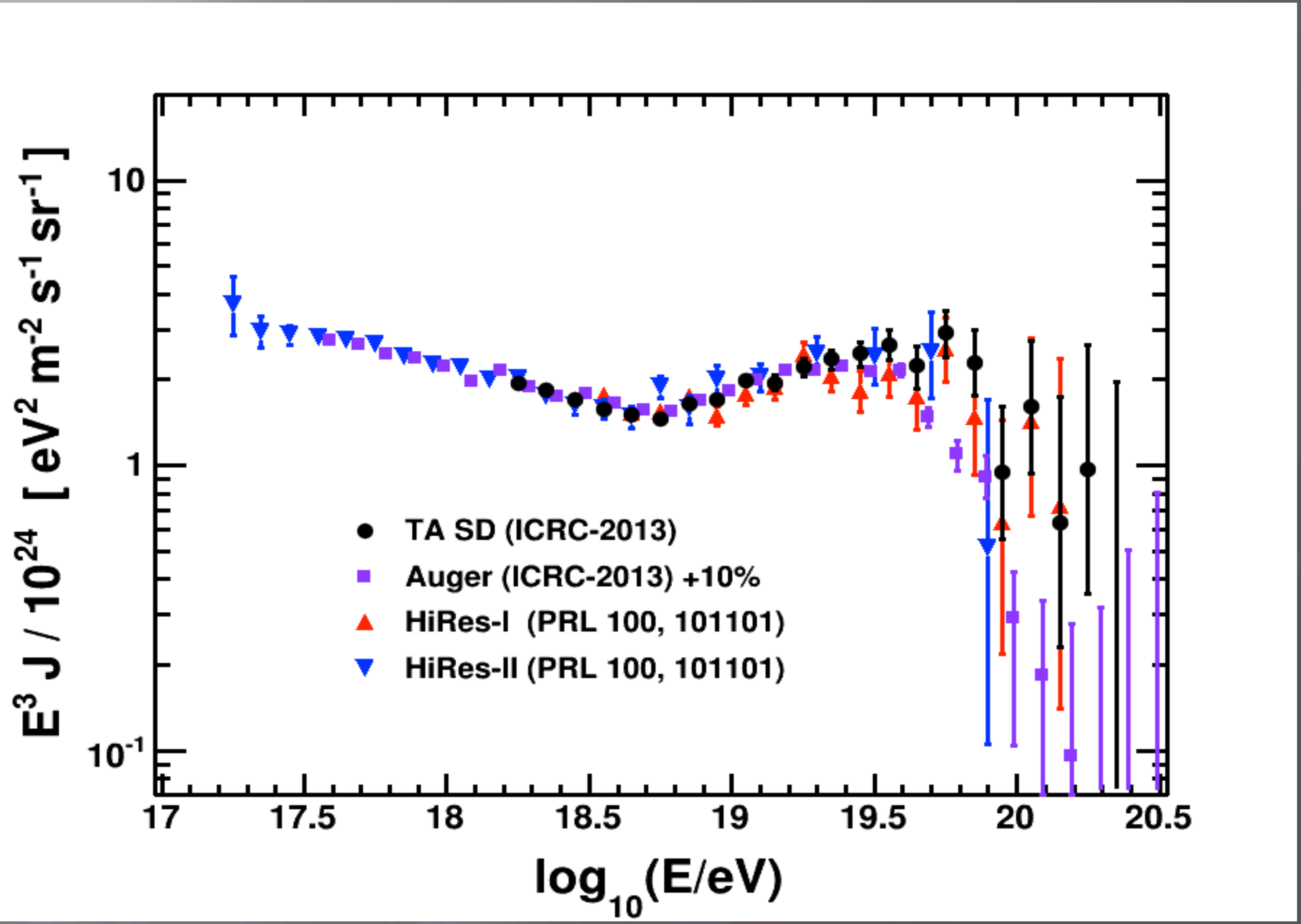
- What's the statistical significance of the HE break (GZK cut-off)?
- Calculate the number expected with no break and compare to the number seen
- Expect 68.1, observe 26, 5.74 σ significance



TA-SD with HiRes & Auger



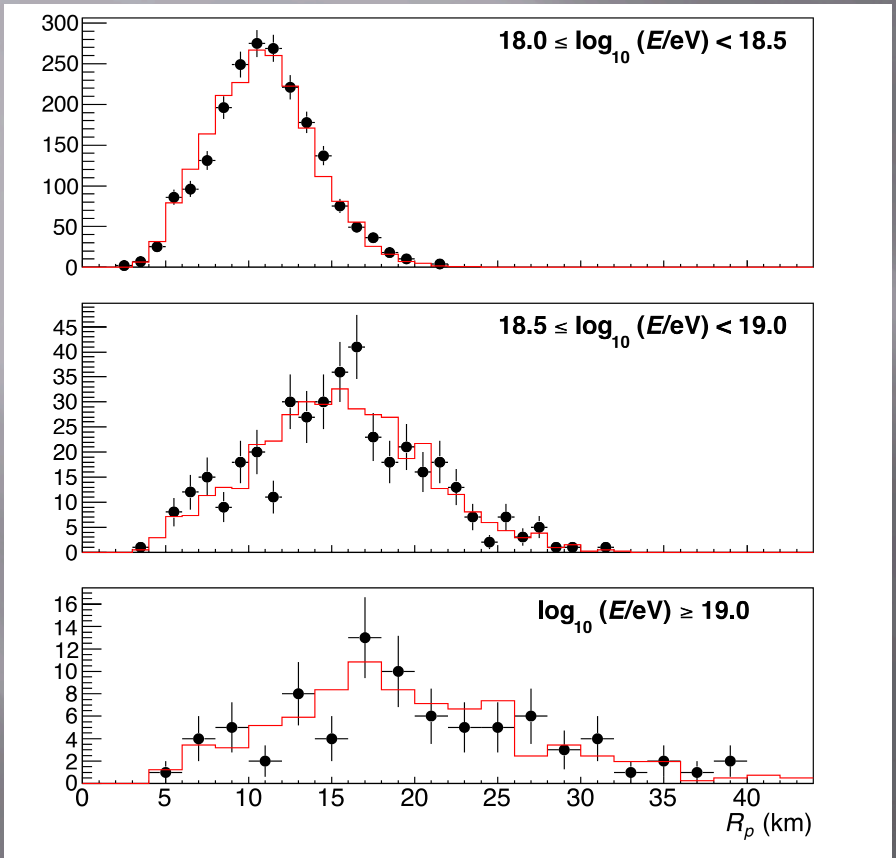
TA-SD with HiRes & Auger

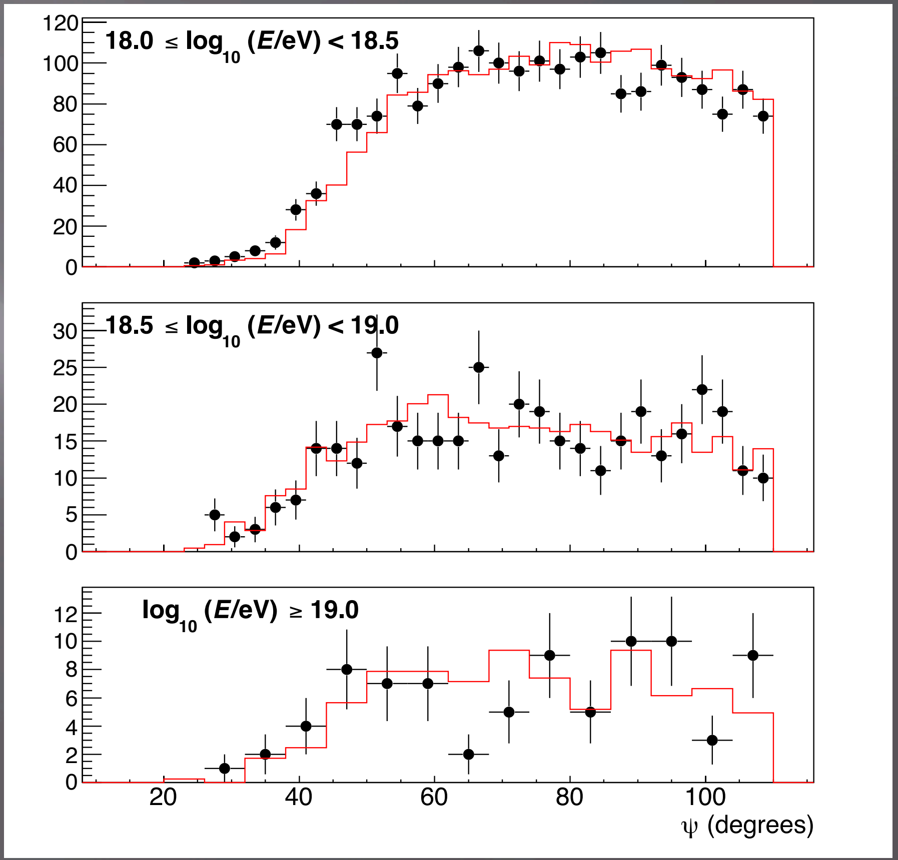


Monocular FD Spectrum

- All FD spectrum measurements (monocular, stereo, hybrid) depend on a changing aperture. The aperture grows with energy.
- This changing aperture *must* be calculated by MC simulation.
- Again we rely on full analysis of simulated data in the same format as actual data, and comparisons of distributions between data and MC, to verify this calculation.

Monocular Data/MC

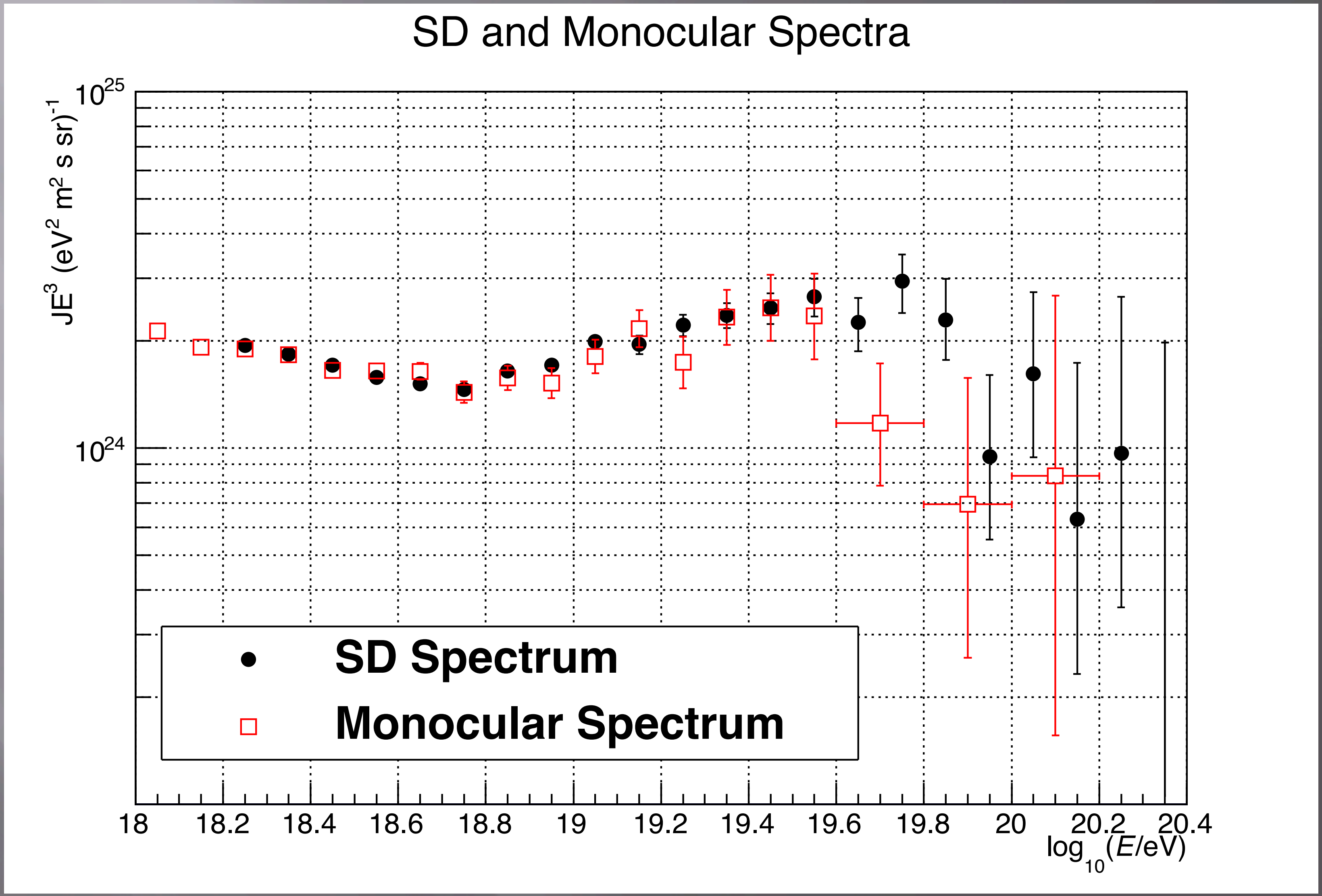




R_p

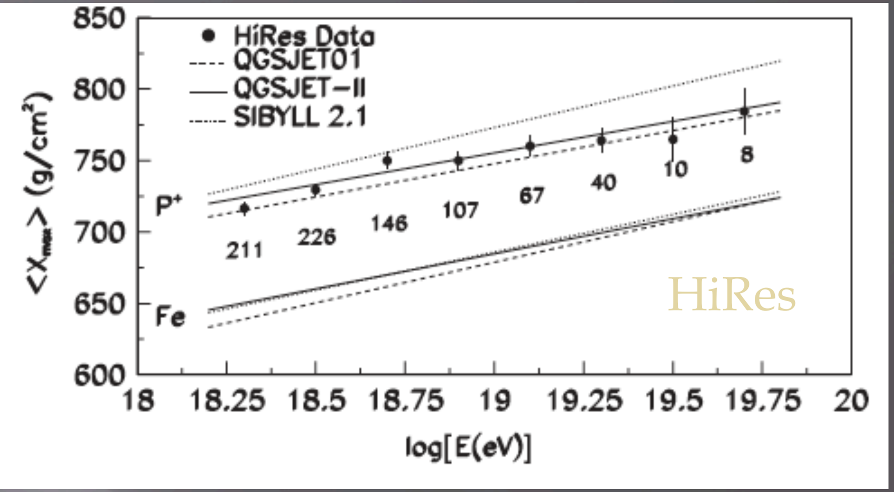
Zenith angle

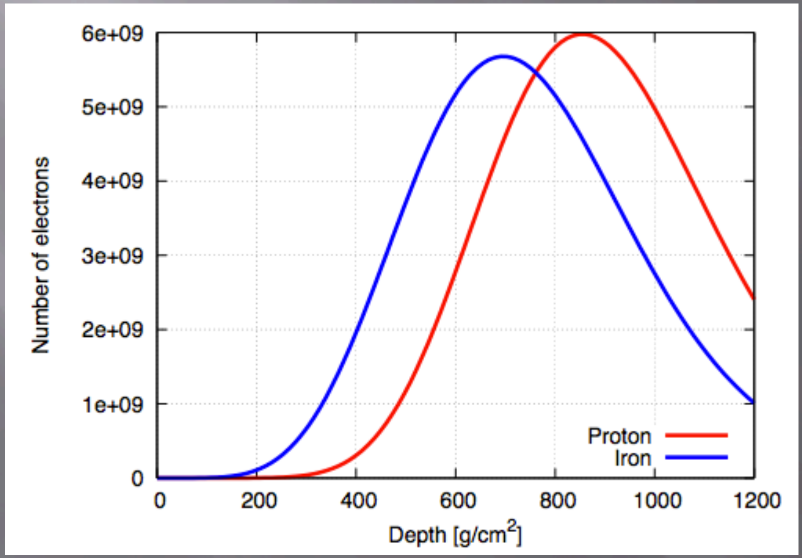
SD & FD Comparisons

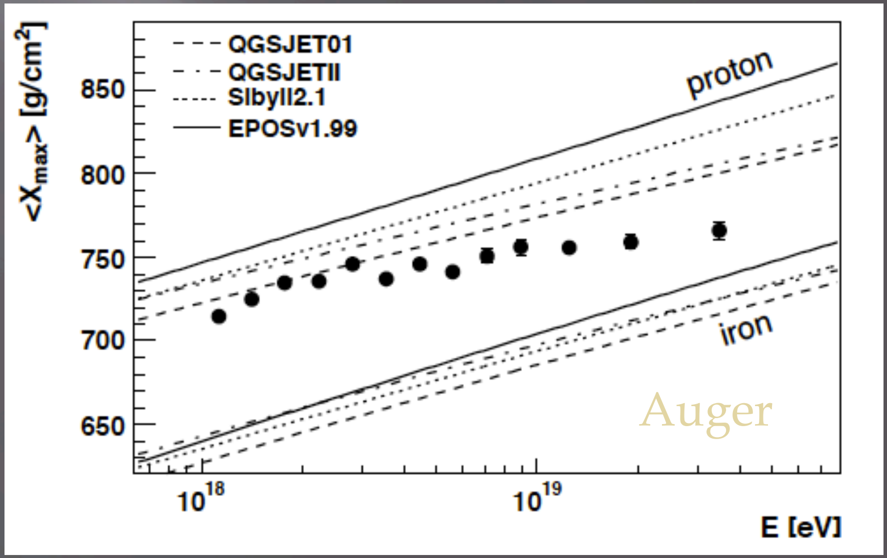


Composition from X_{max}

- Shower longitudinal development depends on primary particle type
- FD observes shower development directly
- X_{max} is the most efficient shower parameter for determining primary particle type

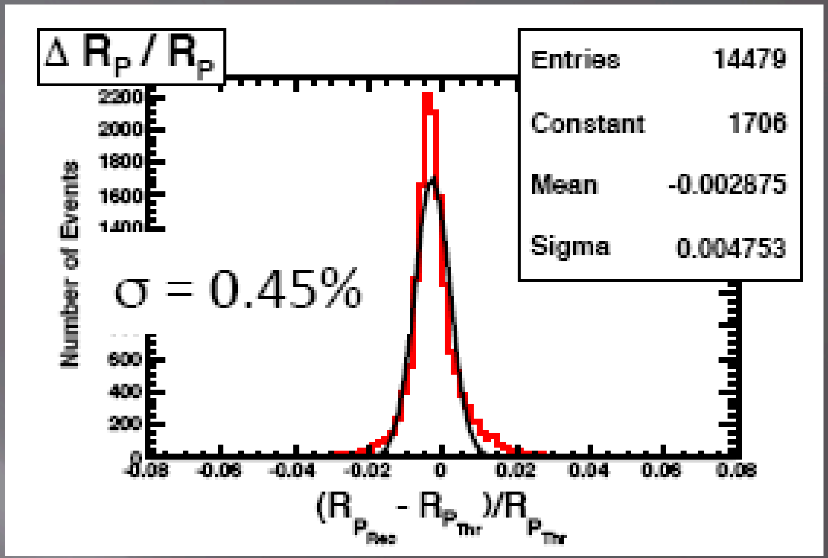


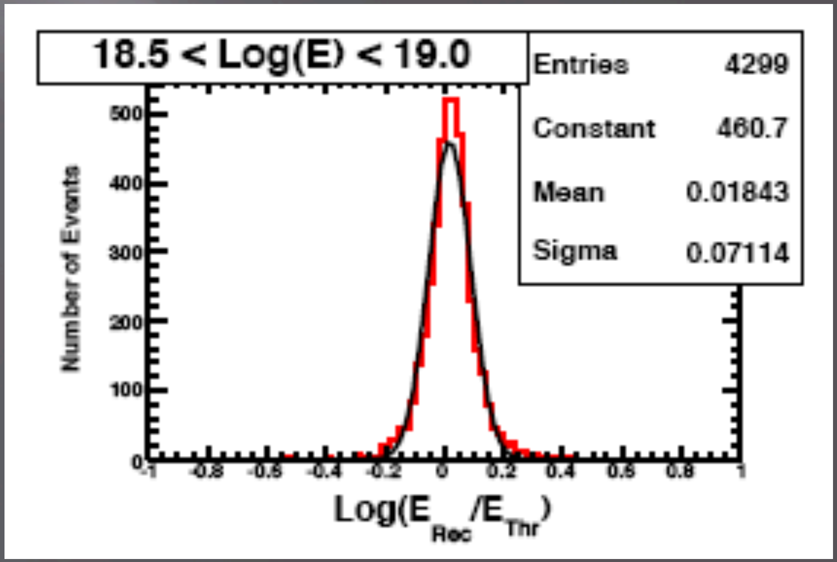




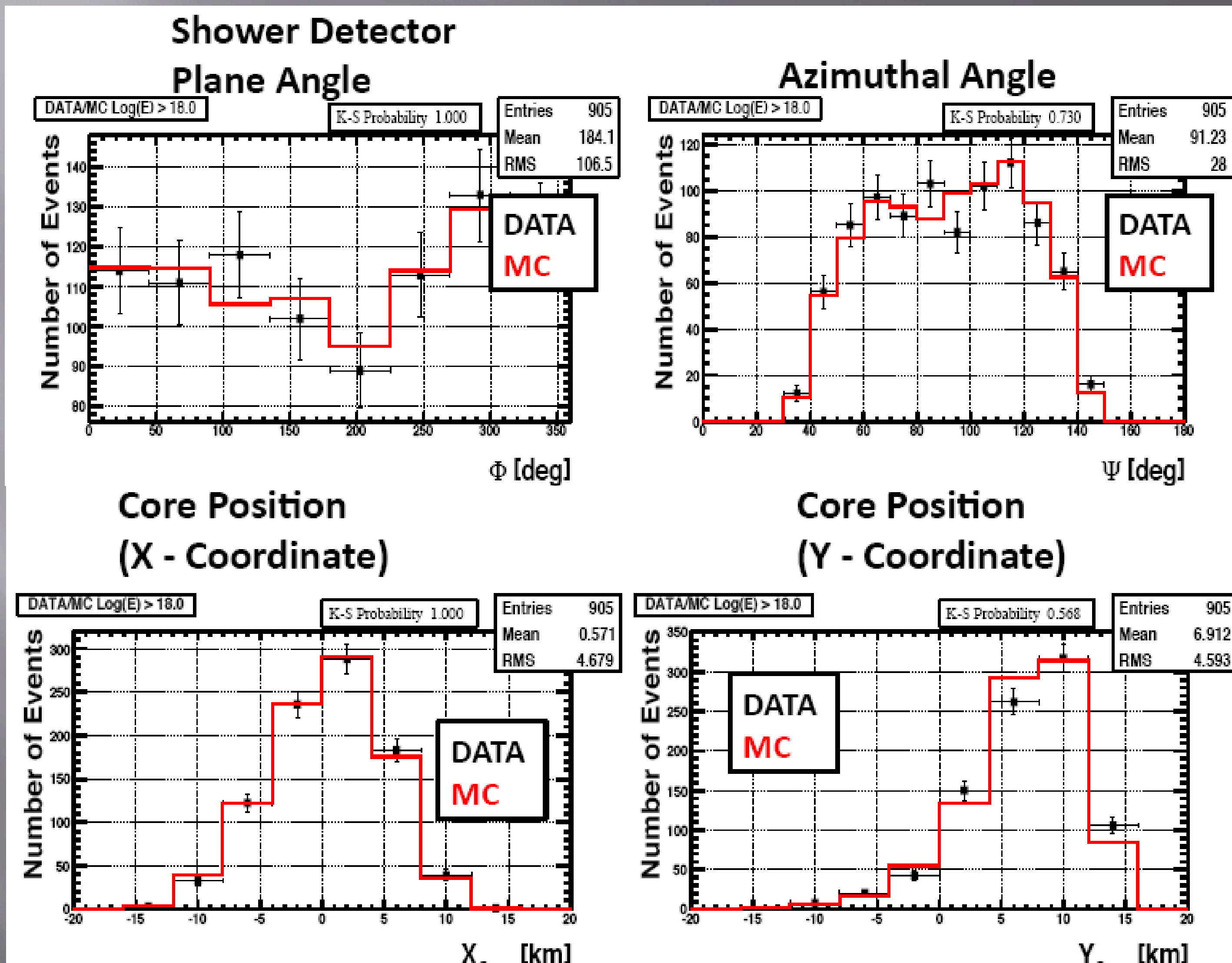
TA MD Hybrid Composition

- Measure X_{max} for events seen in hybrid mode by Middle Drum FD and SD.
- The resolution is excellent
- Create simulated event set; apply exactly the same procedure as with the data: **acceptance bias is the same in both.**

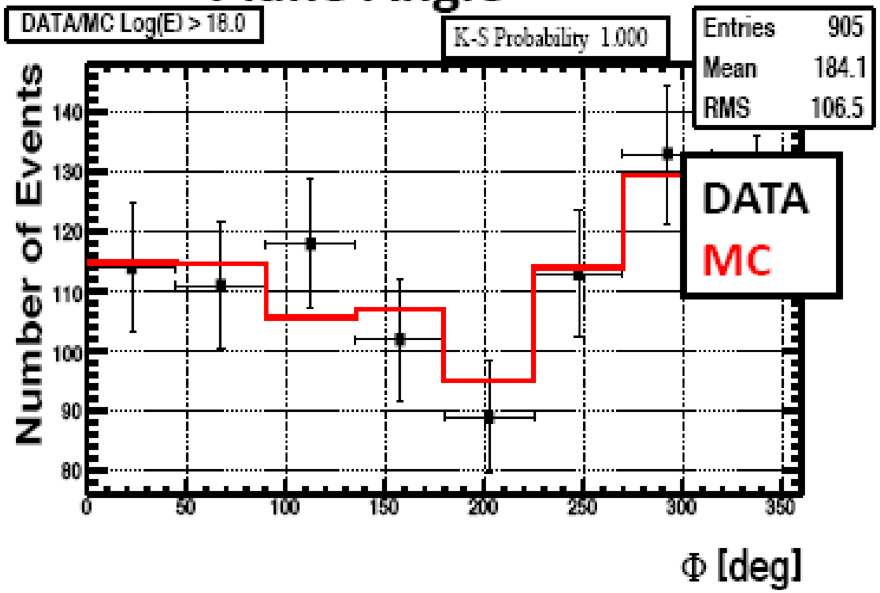




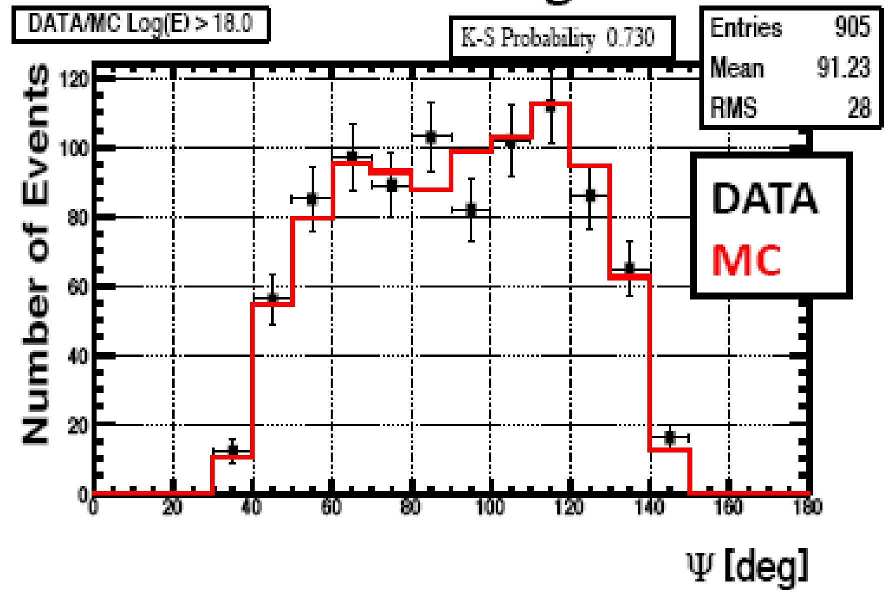
Hybrid Data/MC Comparisons



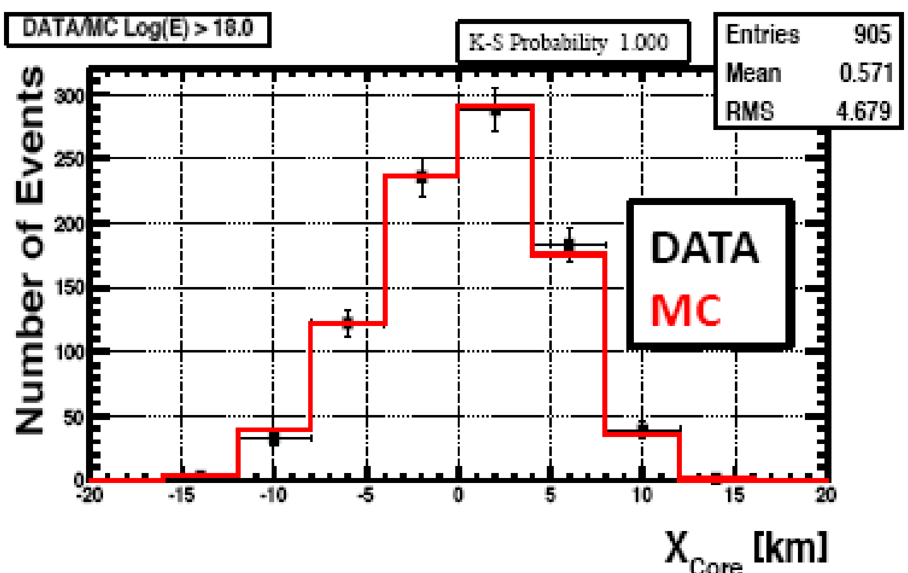
Shower Detector Plane Angle



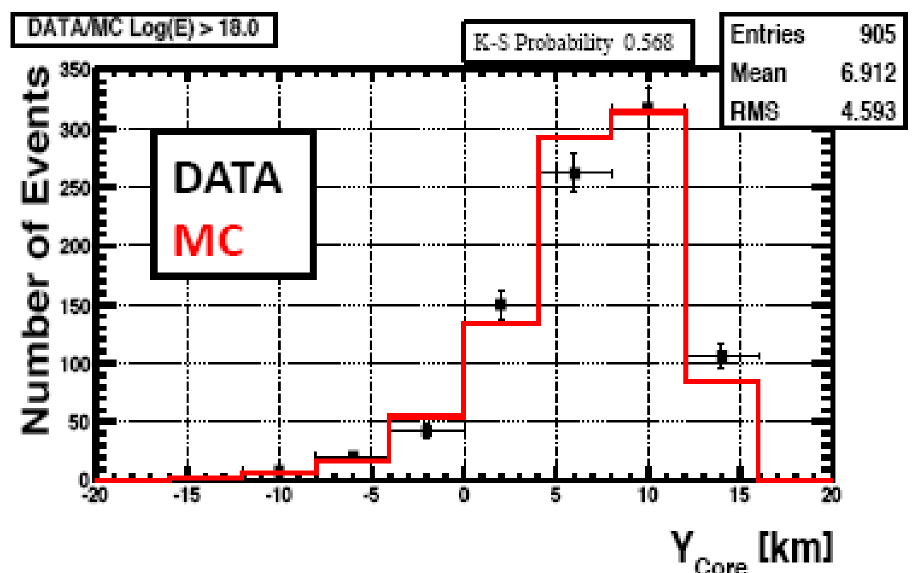
Azimuthal Angle



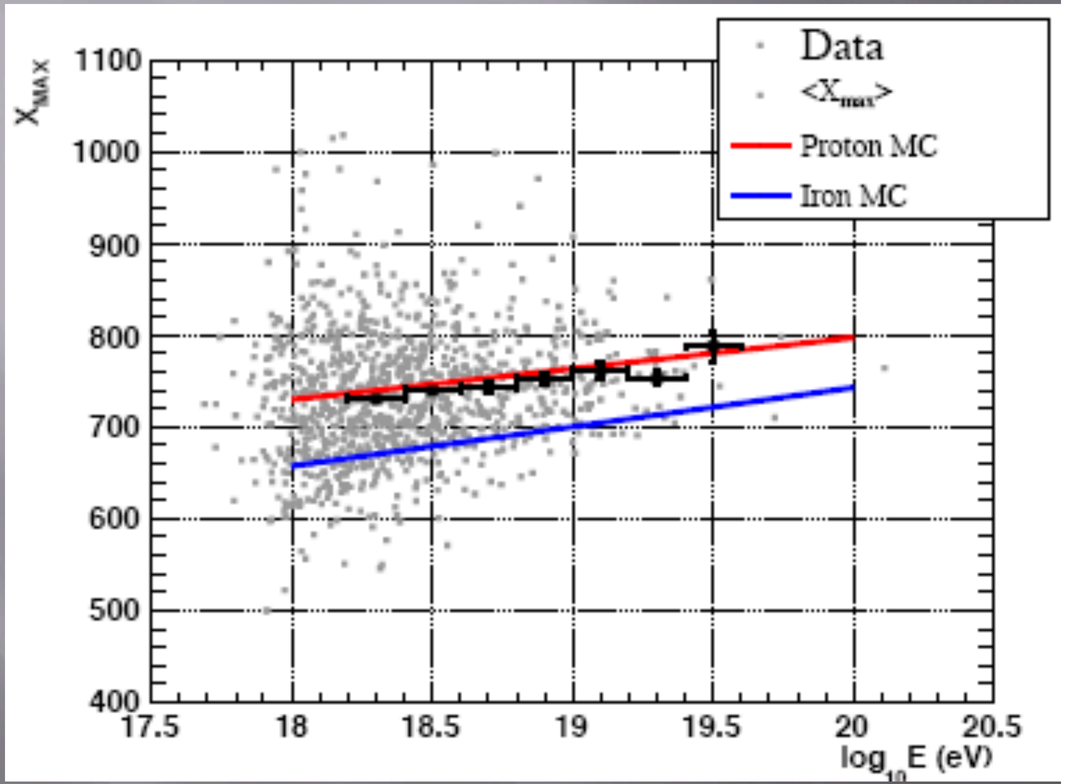
Core Position (X - Coordinate)

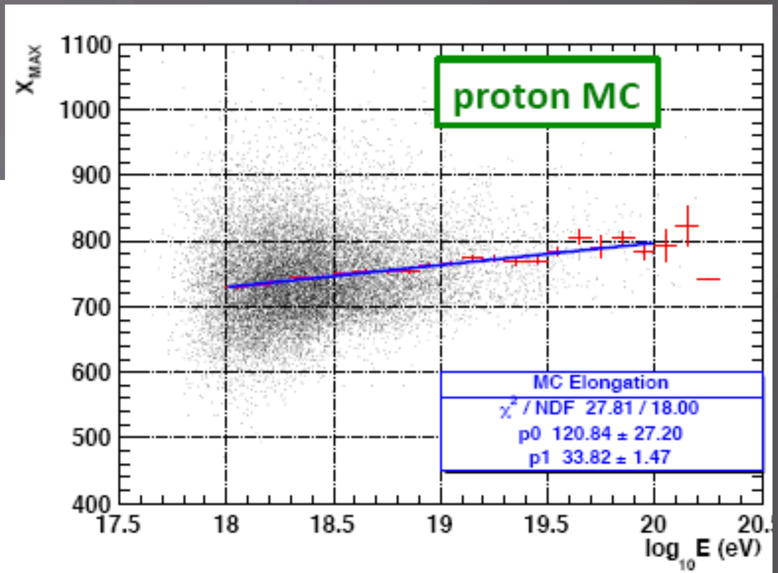


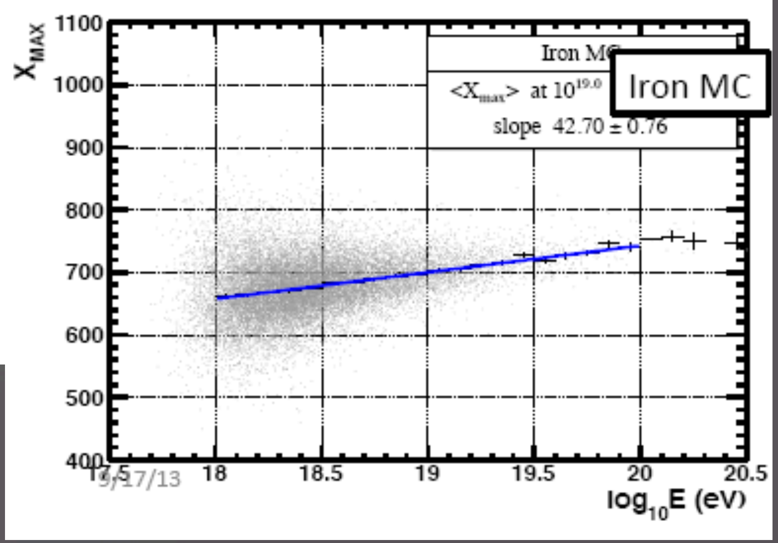
Core Position (Y - Coordinate)



Mean X_{max} Measuremnt

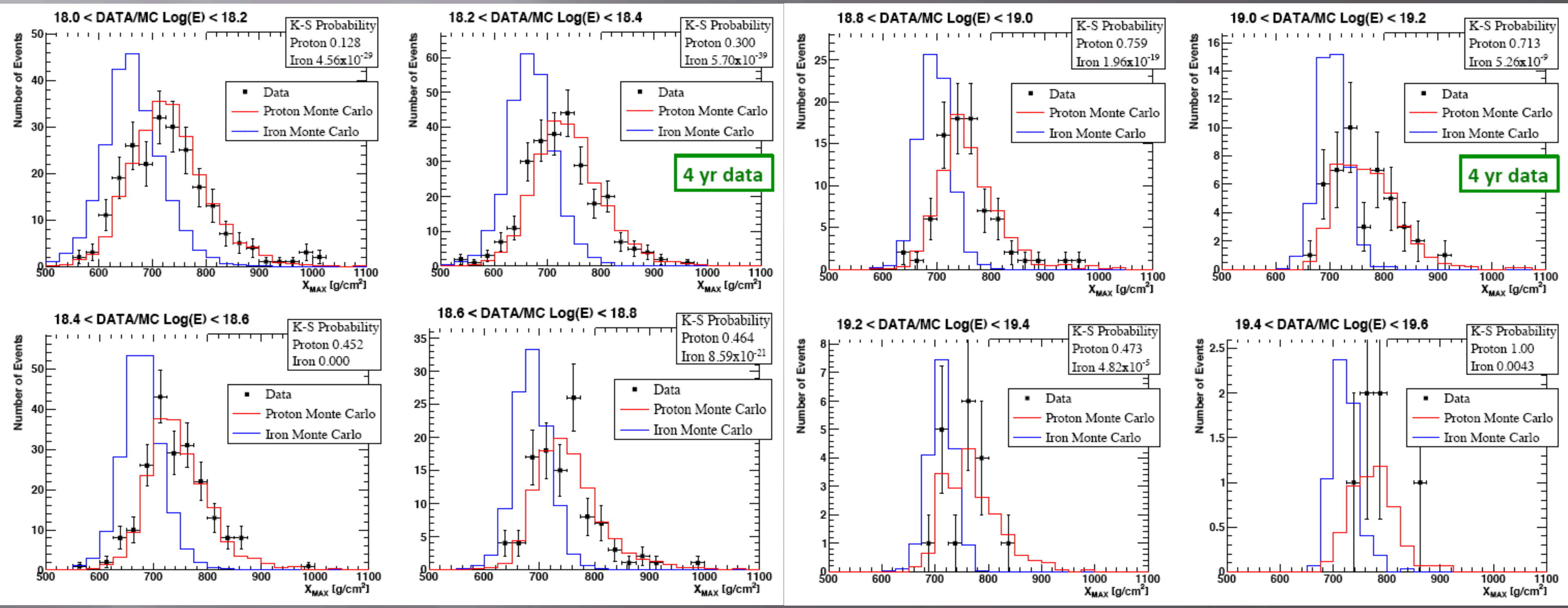






TA data look like protons in QGSJet-II

X_{max} by Energy



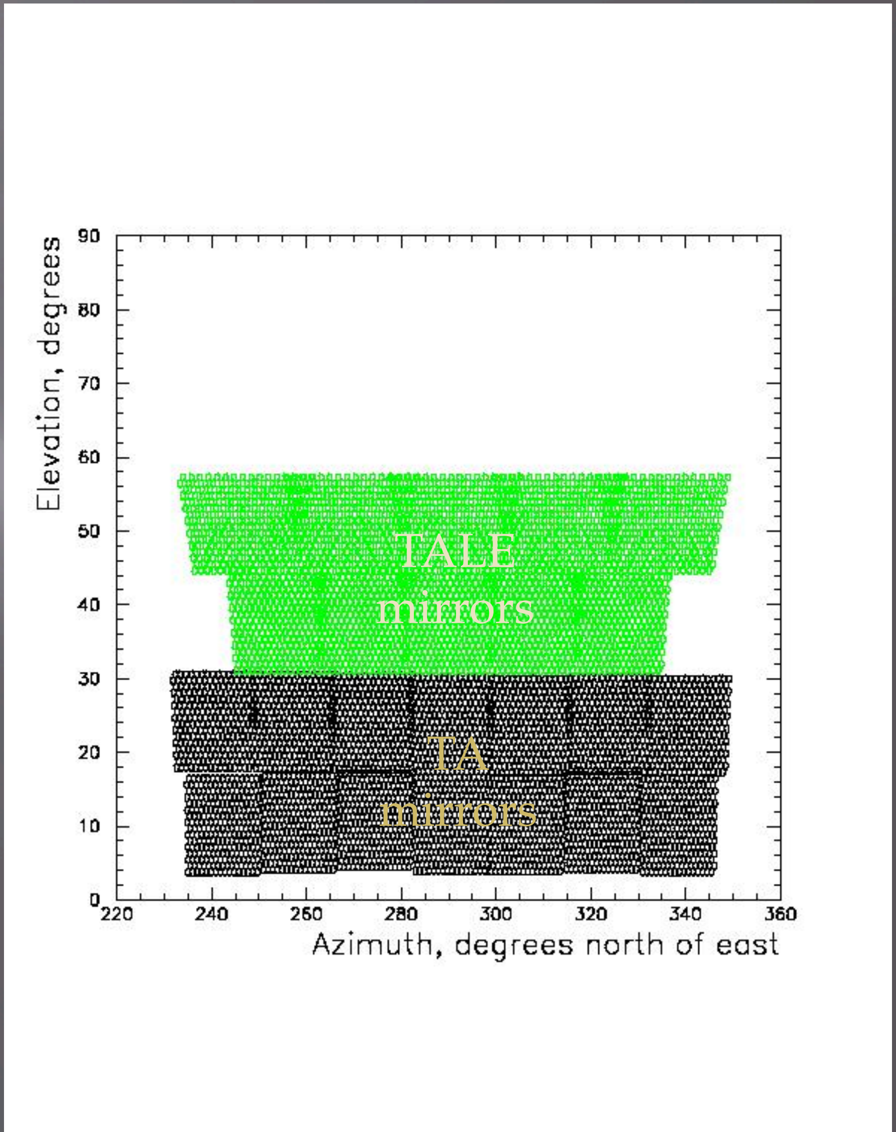
TA data look like protons in QGSJet-II, at all energies!

Future Plans: Low Energy

- A lot of physics was skipped in the push to observe the GZK cutoff.
  - End of the rigidity-dependent cutoff that starts with the knee (at $3\text{x}10^{15}$ eV).
  - The second knee
  - The galactic-extragalactic transition
- Study the 10^{16} and 10^{17} eV decades with hybrid detectors.
- Need to observe from 3×10^{15} eV to 3×10^{20} eV all in one experiment. That is TA, TALE and NICHE.

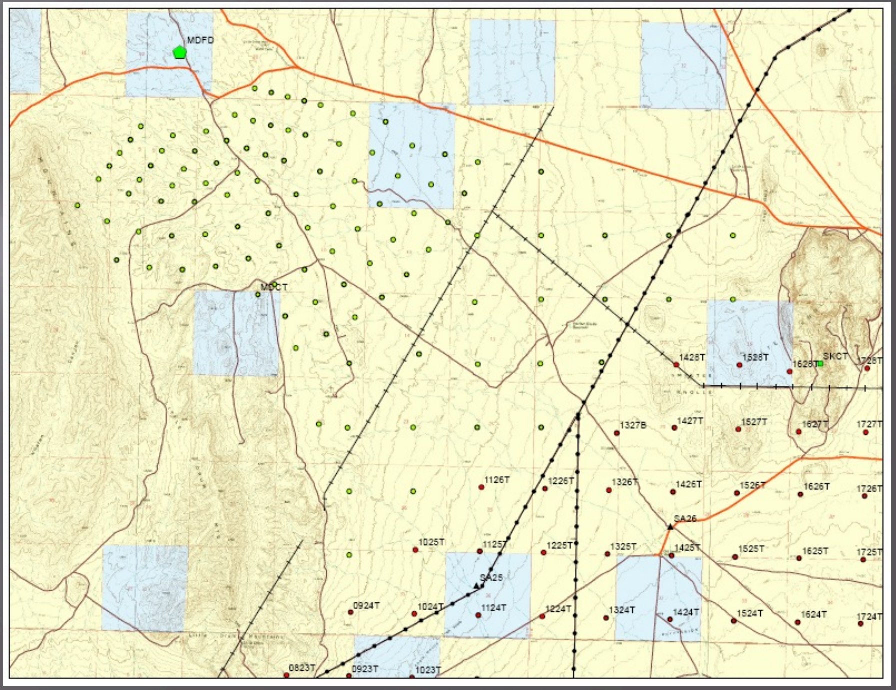
TALE

- Add 10 telescopes at the Middle Drum site, looking from 31°-59° in elevation.
  - Operate in conjunction with the TA Middle Drum FD.
- High elevation allows measurement of close-by showers



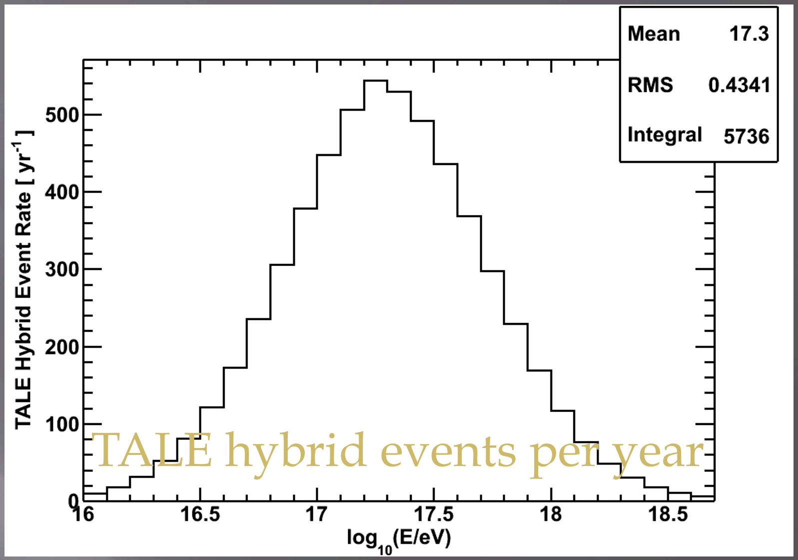
TALE

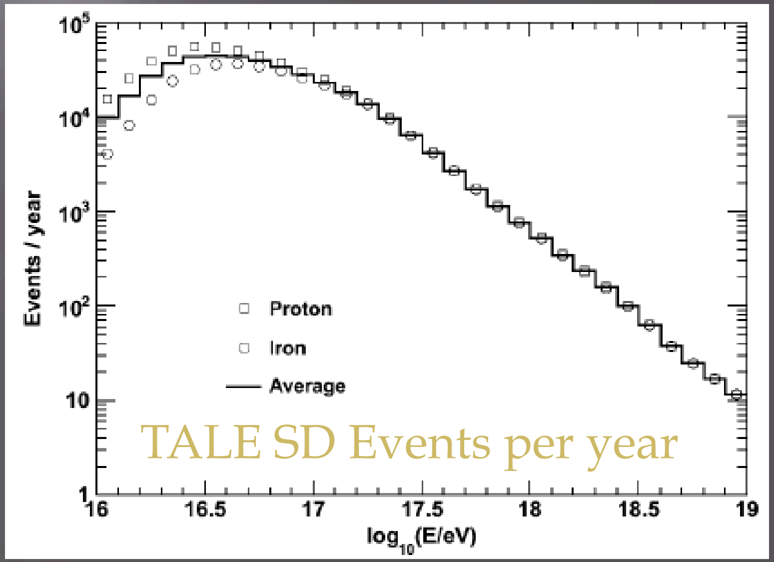
- Add infill array (400m and 600m spacing) for hybrid observation.
- Hybrid provides accurate geometric reconstruction for composition measurements



TALE

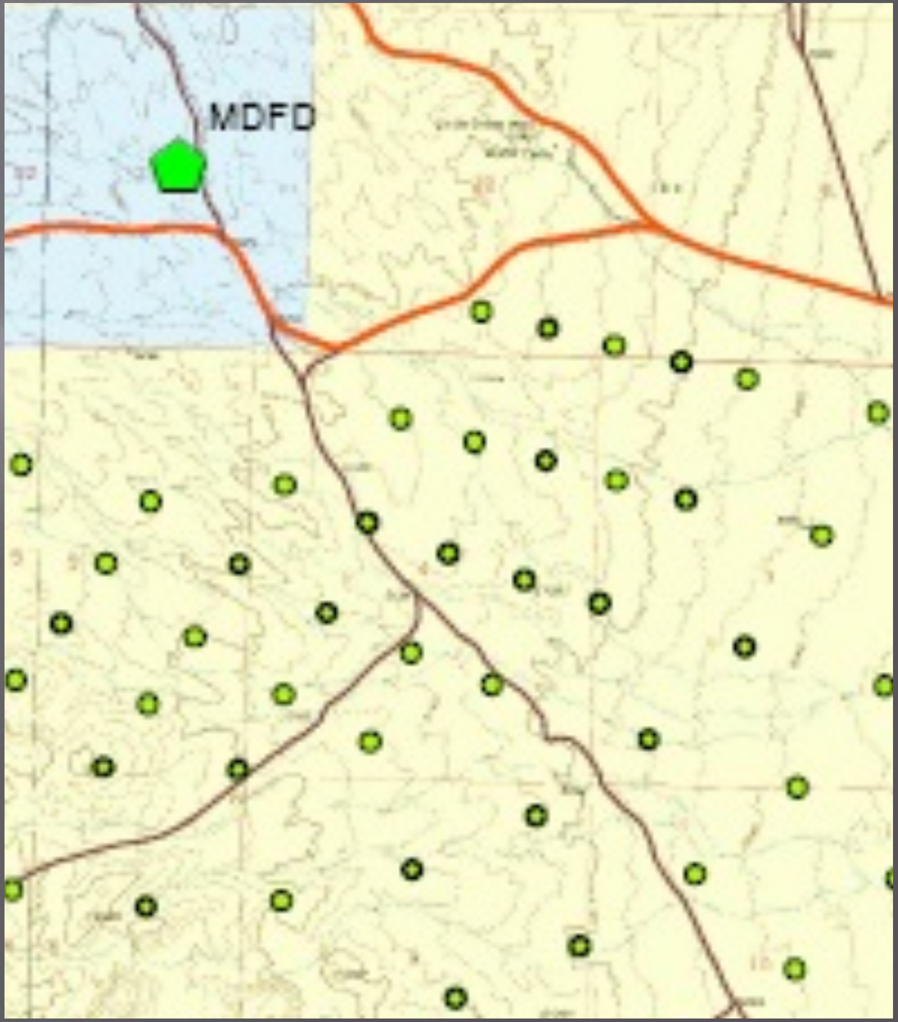
- TALE hybrid will cover energies down to $10^{16.5}$ eV
- TALE will be able to confirm the observation of the Iron knee seen by Kascade-GRANDE and measure the heavy-to-light composition change expected in the 10^{17} eV decade.



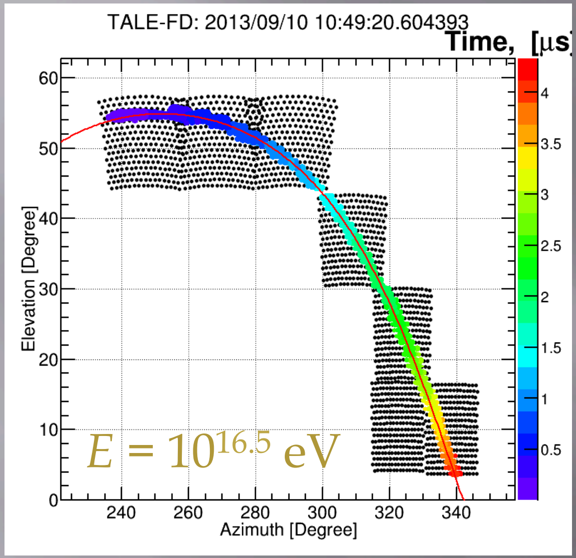


NICHE

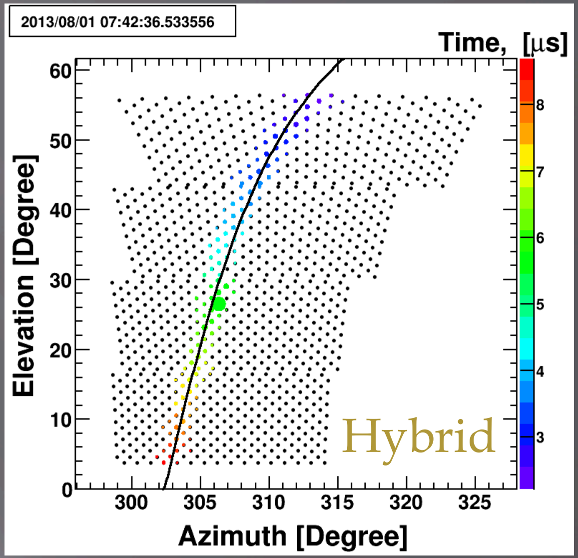
- To go lower in energy than TALE, need to use Cherenkov light
- Aim to build a Non-Imaging CHErenkov array (NICHE) within the field-of-view of the TALE FD.



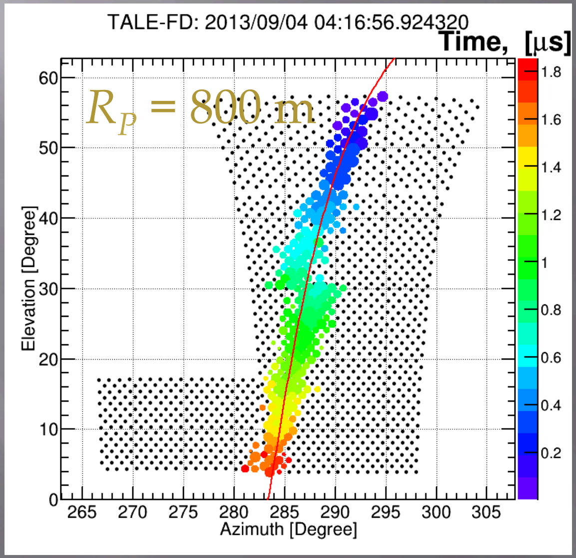
TALE Events



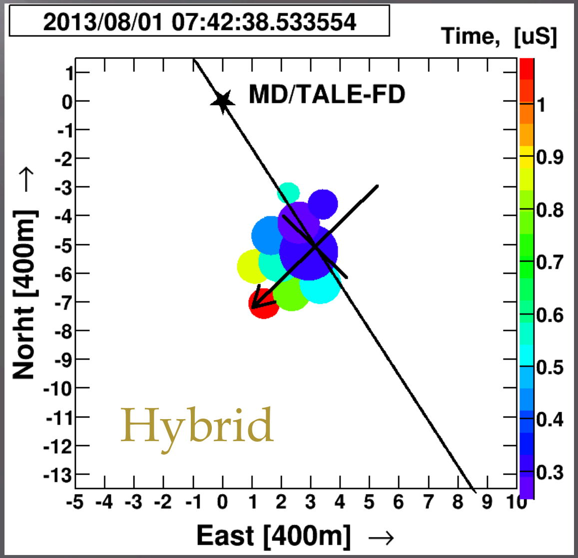
TALE-FD: 2013/09/10 10:49:20.604393
Time, [μs]
Elevation [Degree]
Azimuth [Degree]
E = 10^16.5 eV



2013/08/01 07:42:36.533556
Time, [μs]
Elevation [Degree]
Azimuth [Degree]
Hybrid



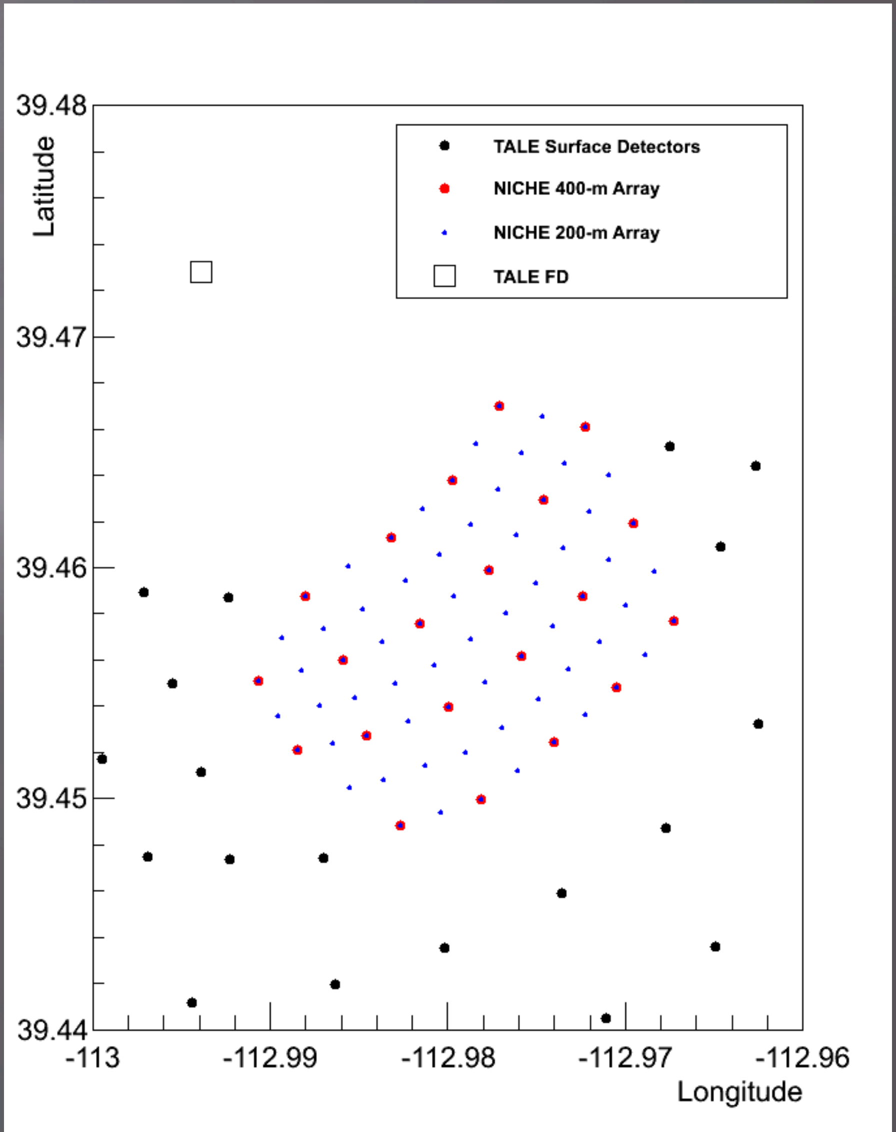
TALE-FD: 2013/09/04 04:16:56.924320
Time, [μs]
Elevation [Degree]
Azimuth [Degree]
R_P = 800 m



2013/08/01 07:42:38.533554
Time, [uS]
MD/TALE-FD
Norht [400m] →
East [400m] →
Hybrid

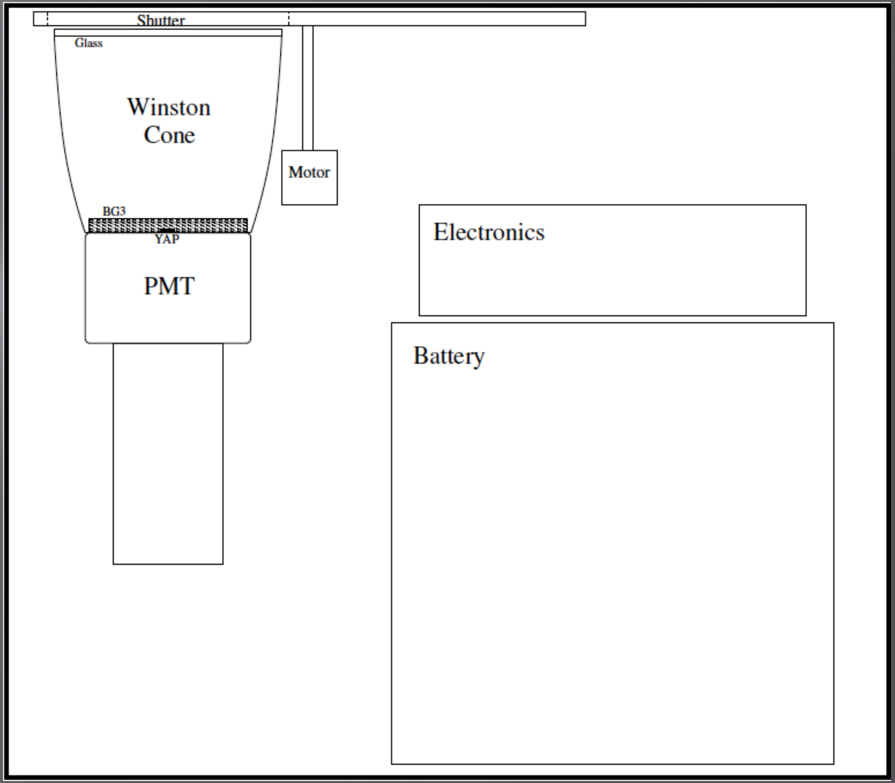
NICHE

- To go lower in energy than TALE, need to use Cherenkov light
- Aim to build a Non-Imaging CHErenkov array (NICHE) within the field-of-view of the TALE FD.



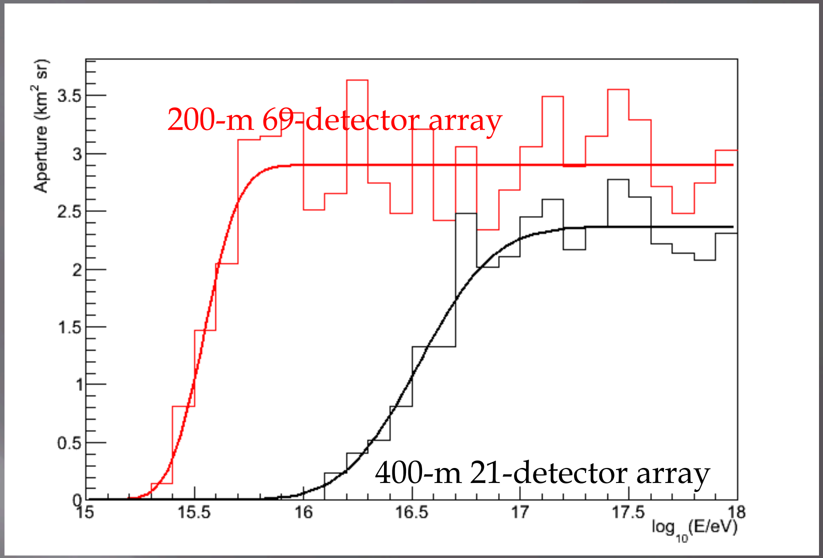
NICHE

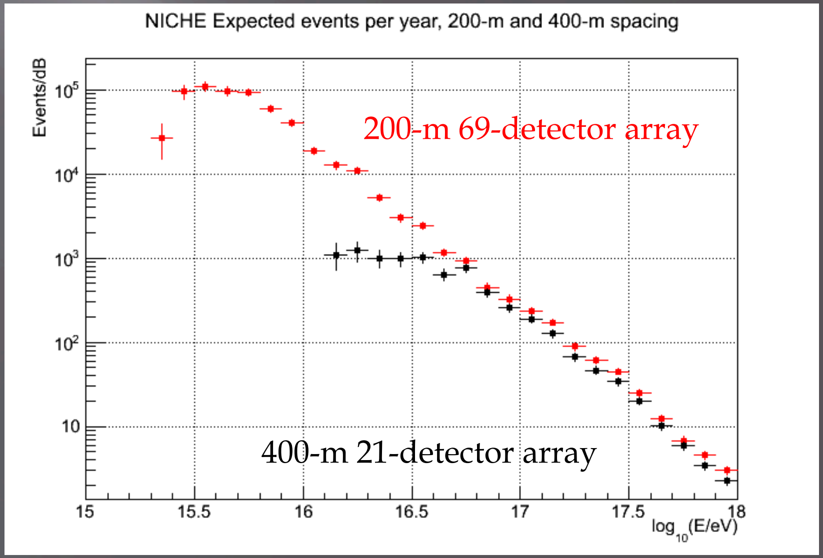
- To go lower in energy than TALE, need to use Cherenkov light
- Aim to build a Non-Imaging CHErenkov array (NICHE) within the field-of-view of the TALE FD.
- Use light, easy-to-deploy counters
- Rely on timing width for composition



NICHE

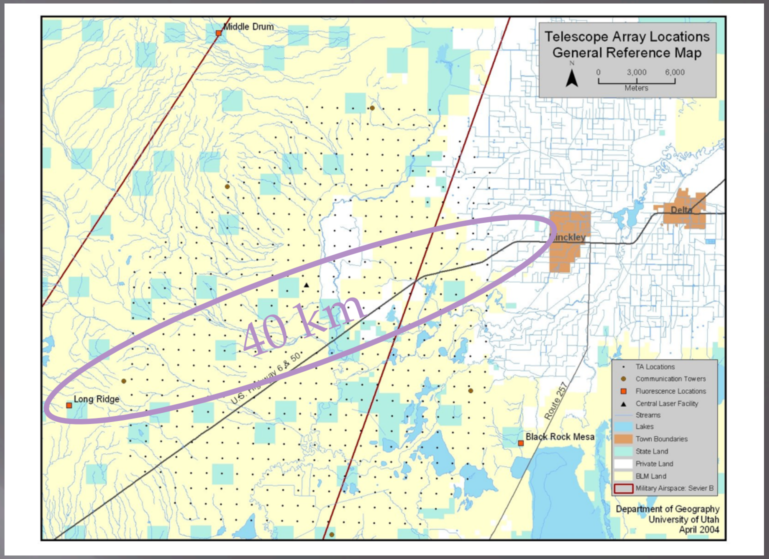
- Can easily measure below 10^{16} eV with fairly wide spacing
  - Can go below Knee with smaller spacing
- Expect overlap of at least a decade in energy with TALE
  - Cross calibration of energy and X_{max} measurements

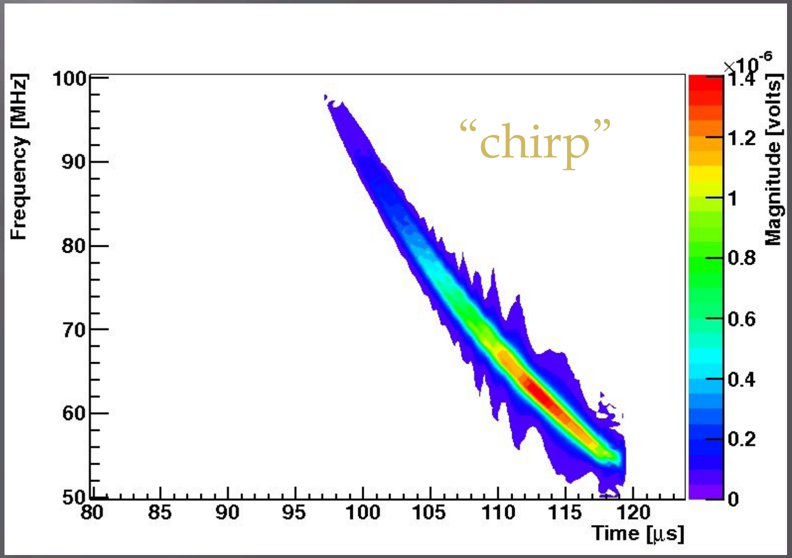




TARA

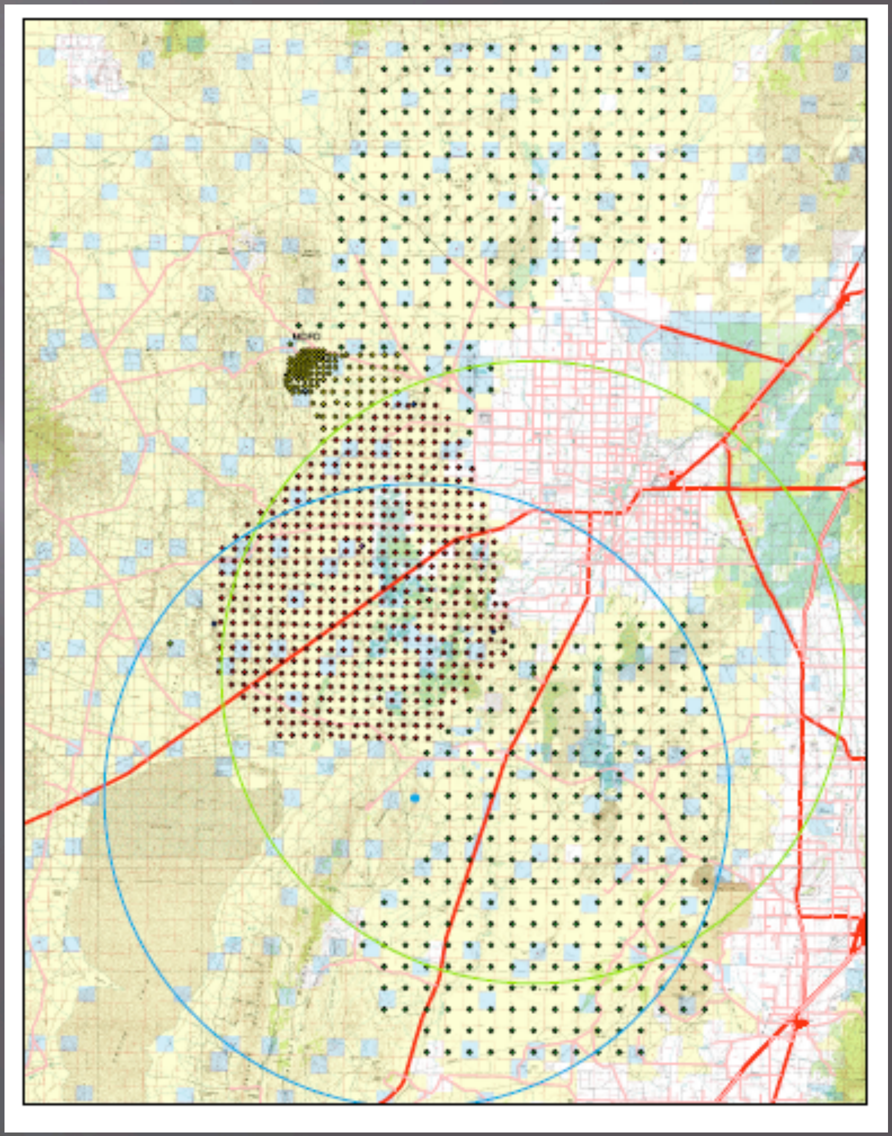
- Rates at the highest energies are too low
  - Need bigger experiments.
- Bistatic radar detection:
  - Remote sensing
  - Inexpensive
  - 100% duty cycle





TAx4

- **Fourfold increase in size of TA.**
  - Add 500 SD counters (plenty of room to N and SE), 2.08 km spacing.
  - Add one SD site, 14 telescopes
- Get 20 TA-years by 2019: Definitive answer to LSS and hotspot questions.
- Proposals to be submitted this fall:
  - SD = Japan
  - FD = U.S.



Conclusion

- The Telescope Array (TA) Experiment is collecting data in the northern hemisphere.
- TA is a LARGE experiment which has *excellent* control of *systematic uncertainties*.
- Important TA spectrum, composition, and anisotropy results are being presented.
- New projects are starting.
- TA is a *discovery* experiment.