Anisoptropy in Cosmic Ray Arrival Directions Observed by the Telescope Array

Benjamin Stokes

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Telescope Array Collaboration

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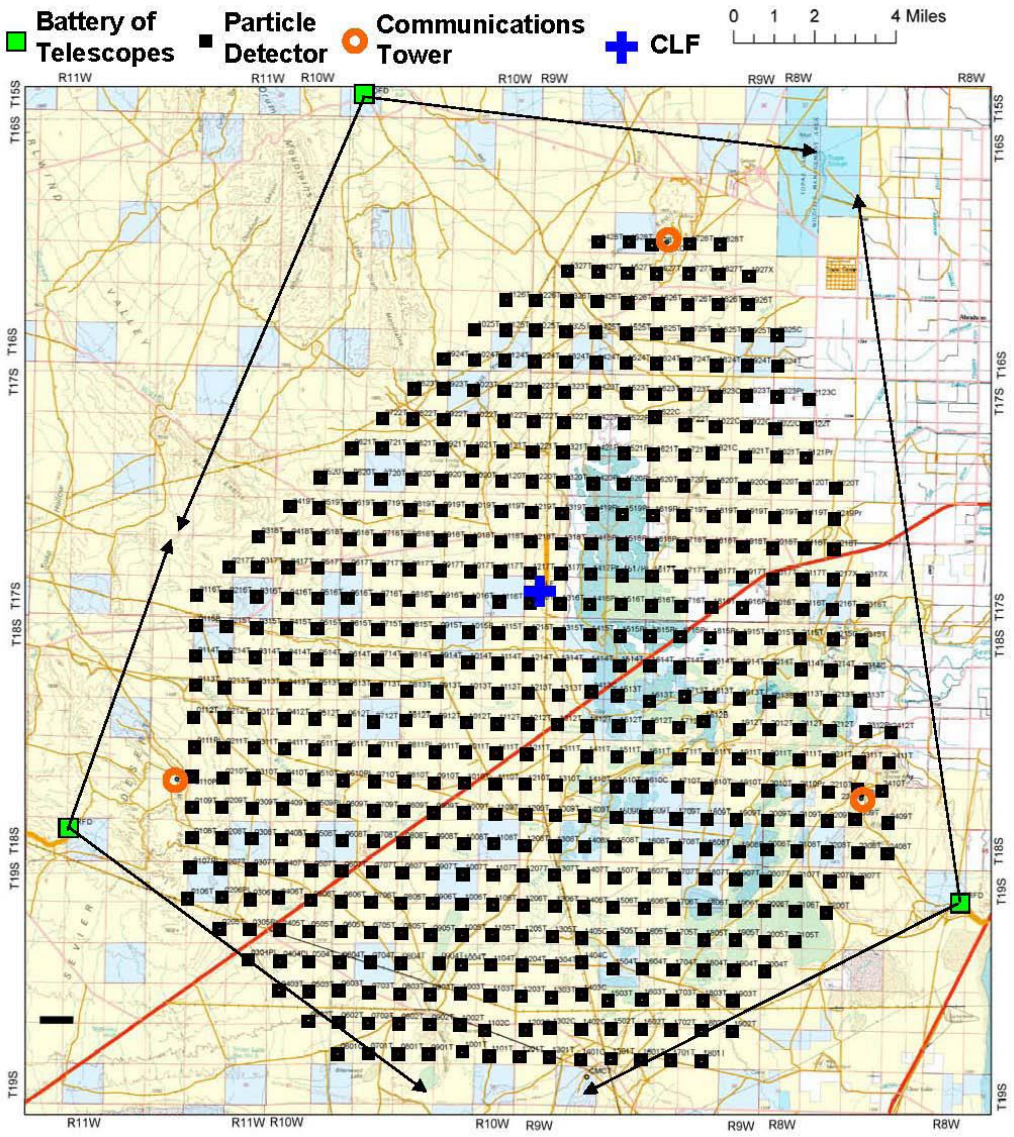
Japan, US, Korea, Russia, Belgium

~120 researchers

Telescope Array Configuration

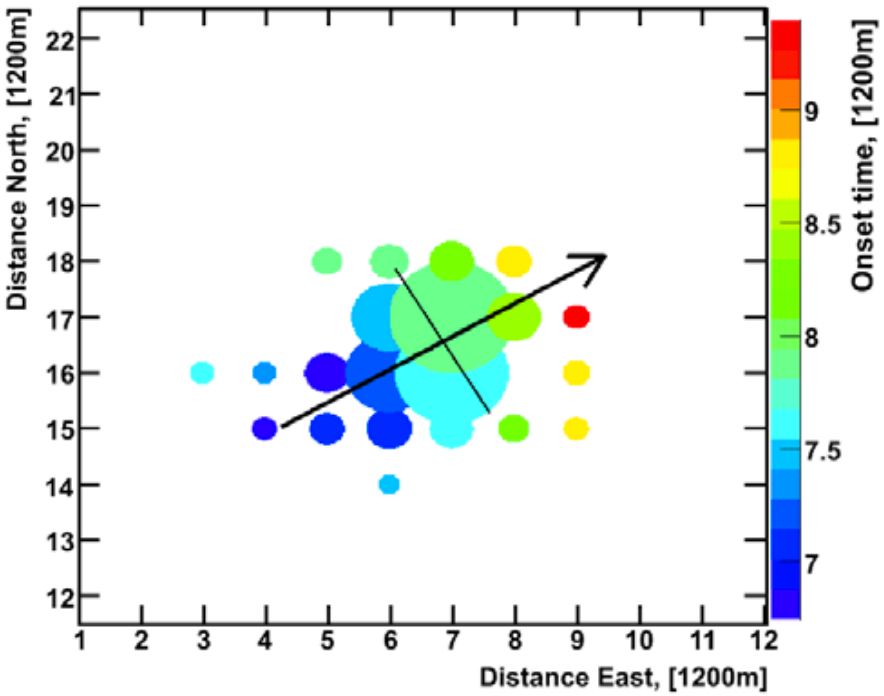


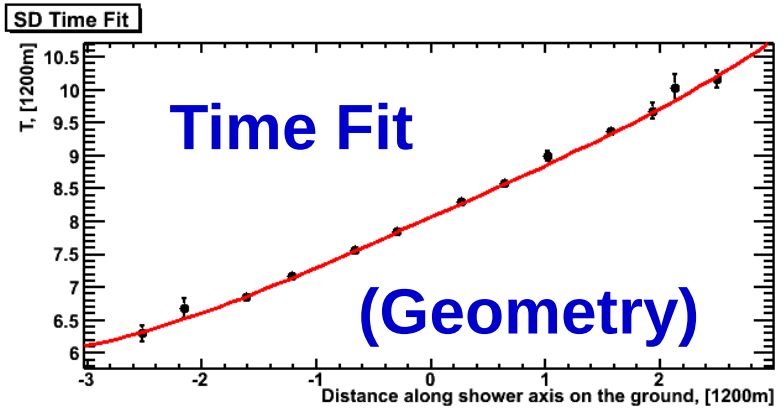
- Located 200 km SW of Salt Lake City
- 507 surface units on 1.2 km rectangular grid
- Total area: 680 km^2
- SD augmented by 3 air fluorescence stations
- SD commissioned in May 2008

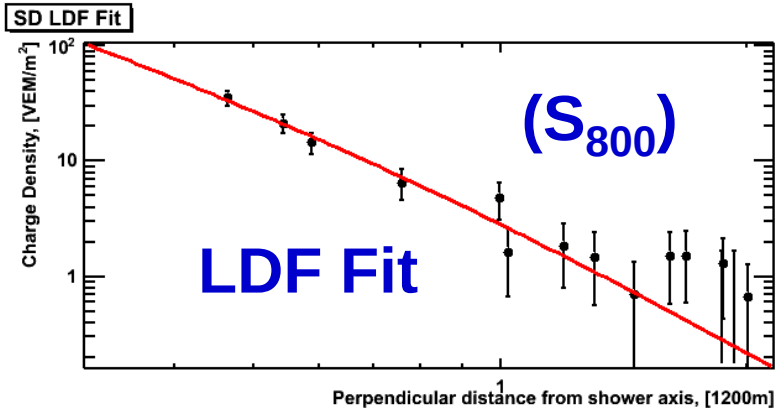
TA Surface Detector

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

Typical Event: Surface Detector







Each counter self-calibrates every 10 min

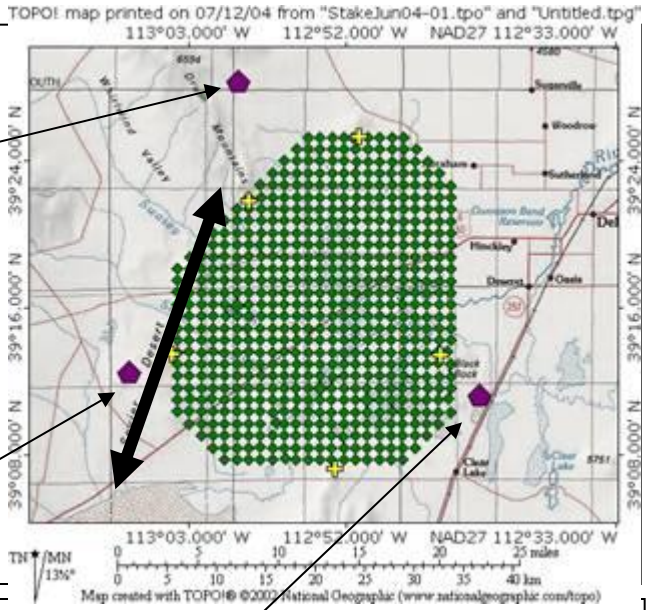
TA Fluorescence Detectors

Refurbished from HiRes

Observation started Dec. 2007

Middle Drum

14 cameras/station
256 PMTs/camera



~30km

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

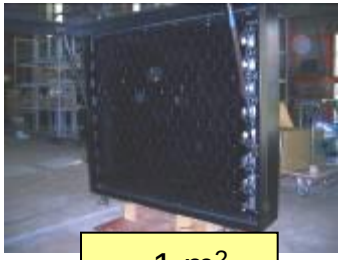
New FDs

Observation started Nov. 2007

Long Ridge

Observation started Jun. 2007

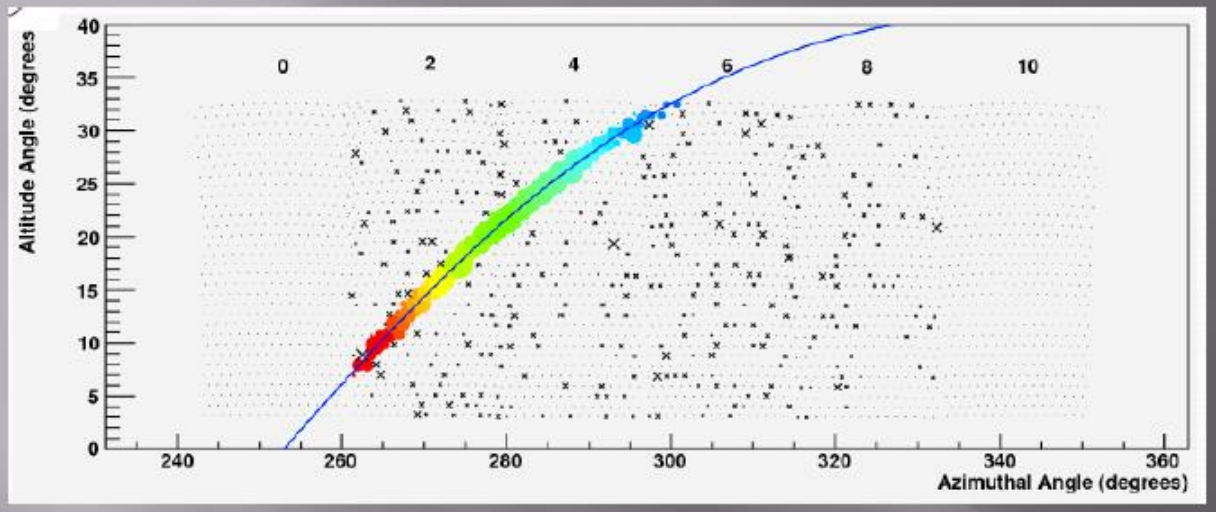
Black Rock Mesa

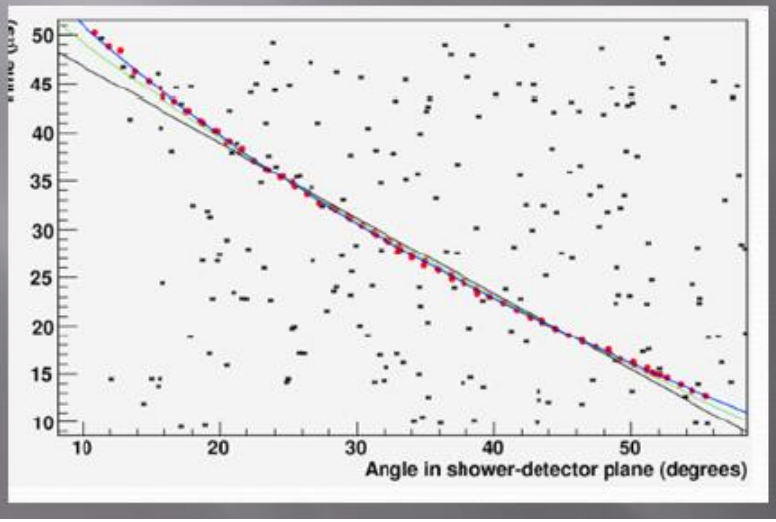


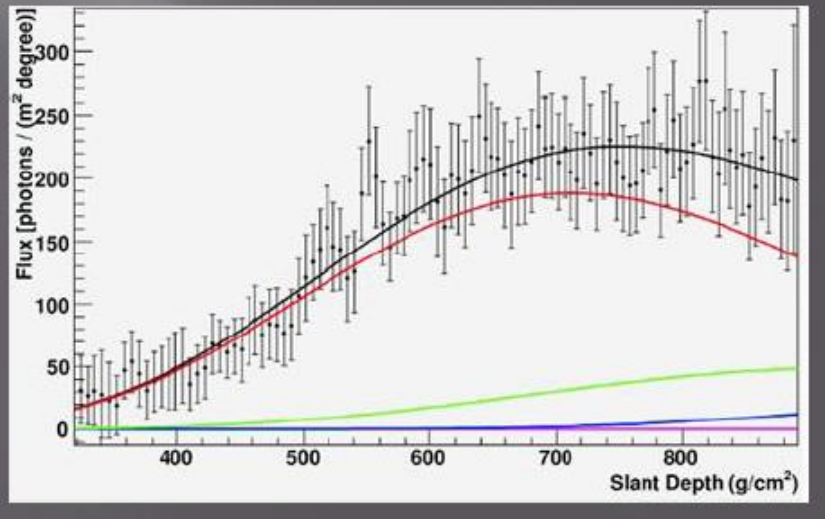
~1 m²

6.8 m²

Typical Event: Fluorescence Detector



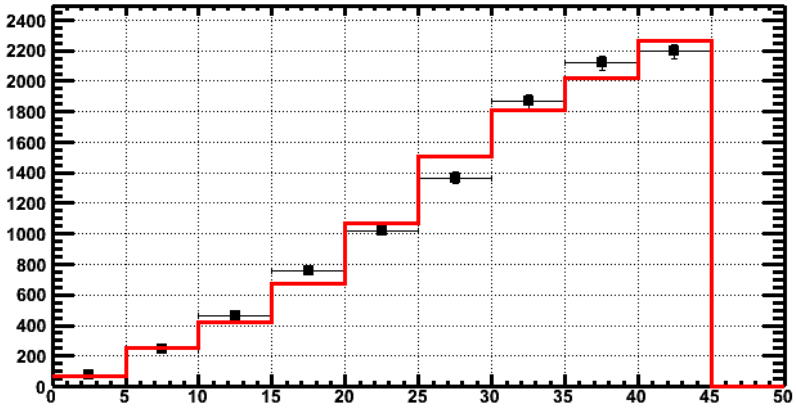


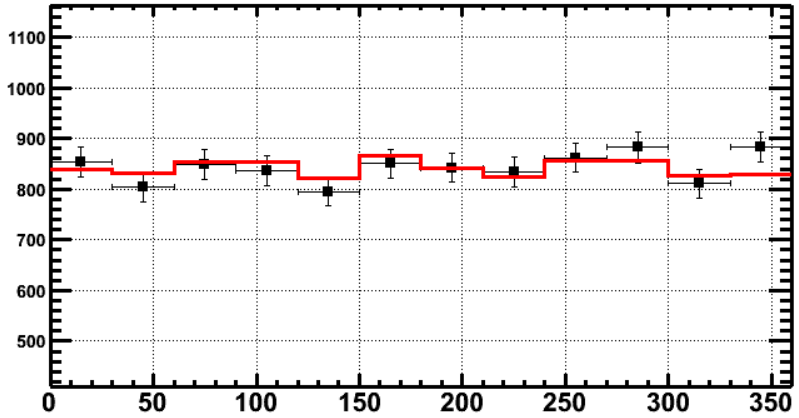


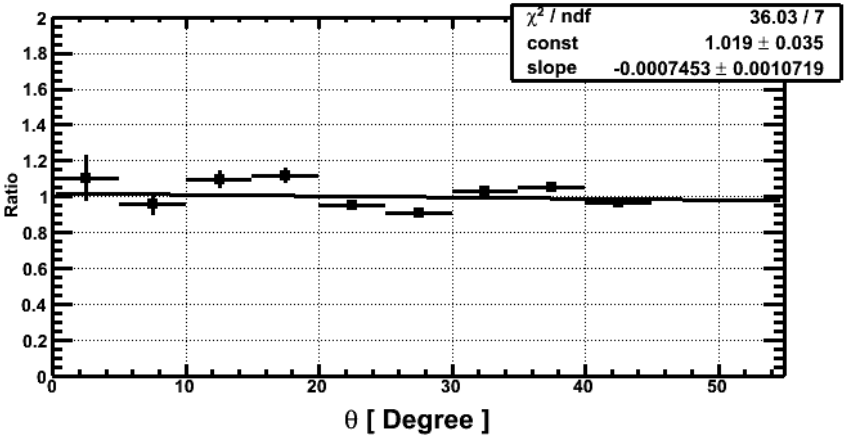
A Careful Analysis Method

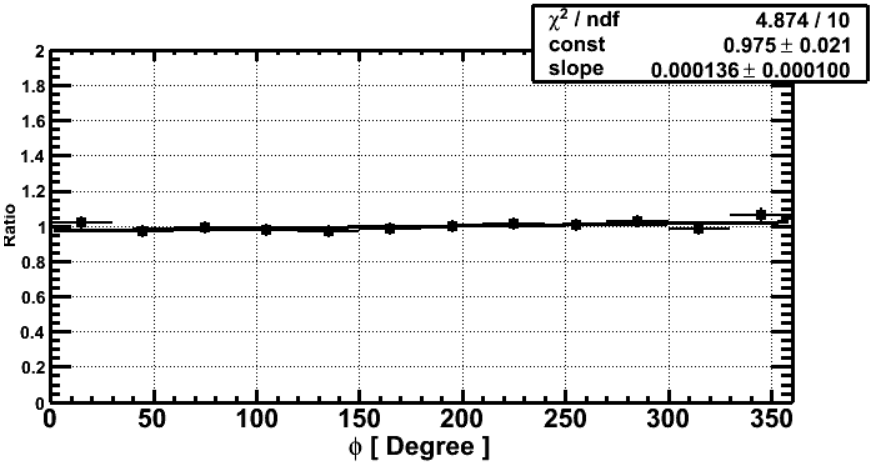
- **No CIC approach, but rather full Monte Carlo**
  - Simulate the data the same way it is observed by writing out the MC events in same format as data.
  - Fits tuned to data using functional form observed by previous experiment (i.e. AGASA) to ensure model independence.
  - Analyze the MC with the same programs used for data.
  - Confirm with data/MC comparison plots.

SD Analysis:
Geometric Data/MC Comparisons





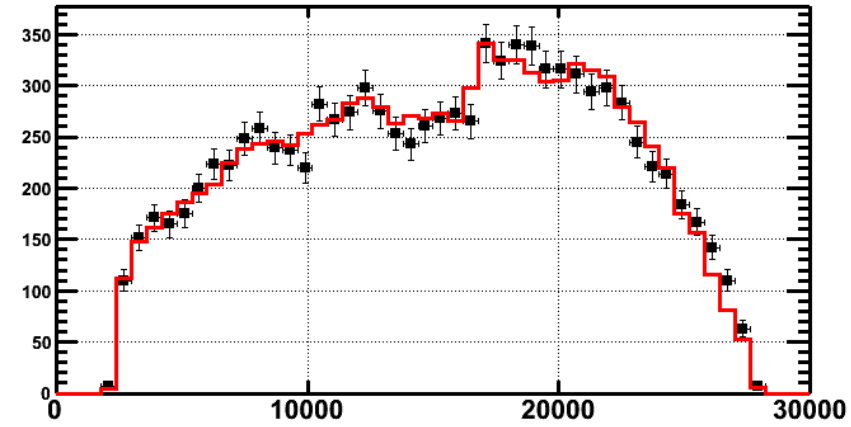




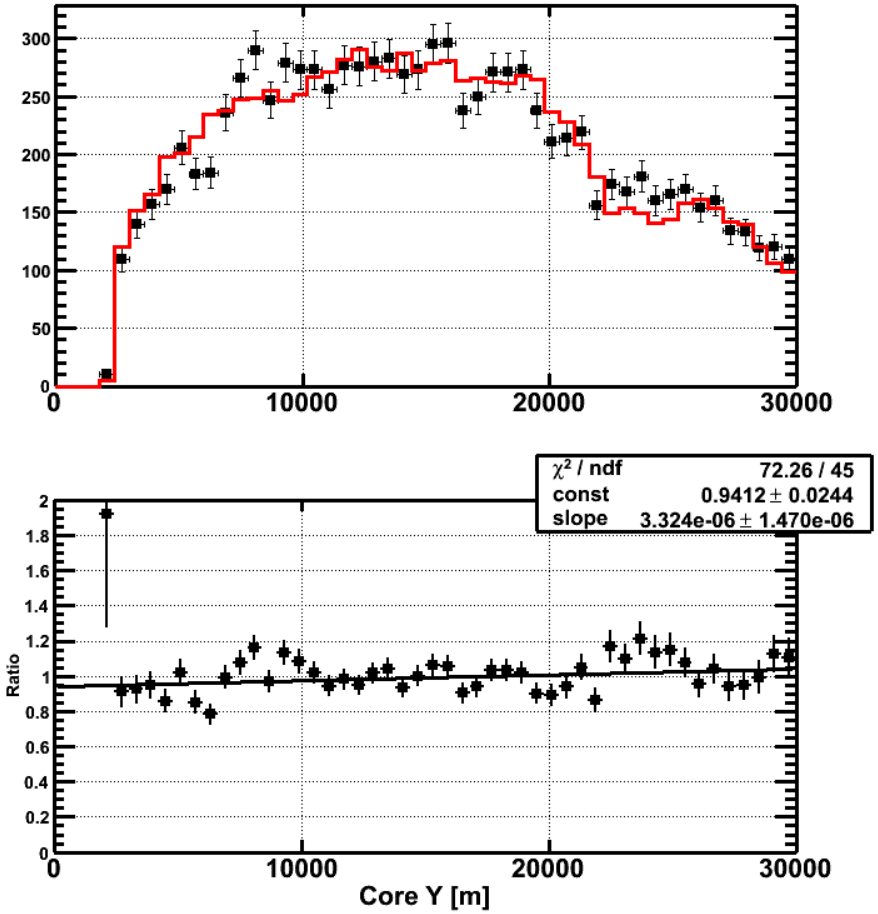
Zenith angle

Azimuth angle

SD Analysis: Geometric Data/MC Comparisons

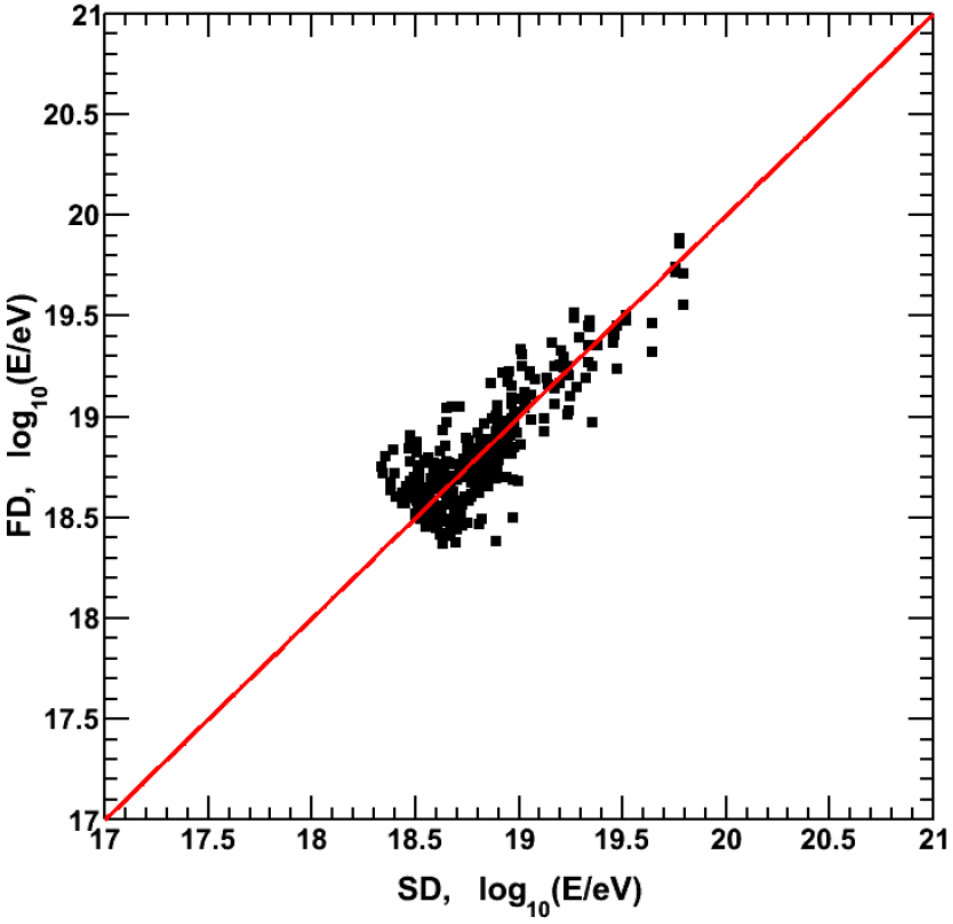


Core Position (E-W)



Core Position (N-S)

SD Analysis: Energy Scale



- SD and FD energy estimation 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 w/QGSJET-II-03 protons**

Anisotropy Studies

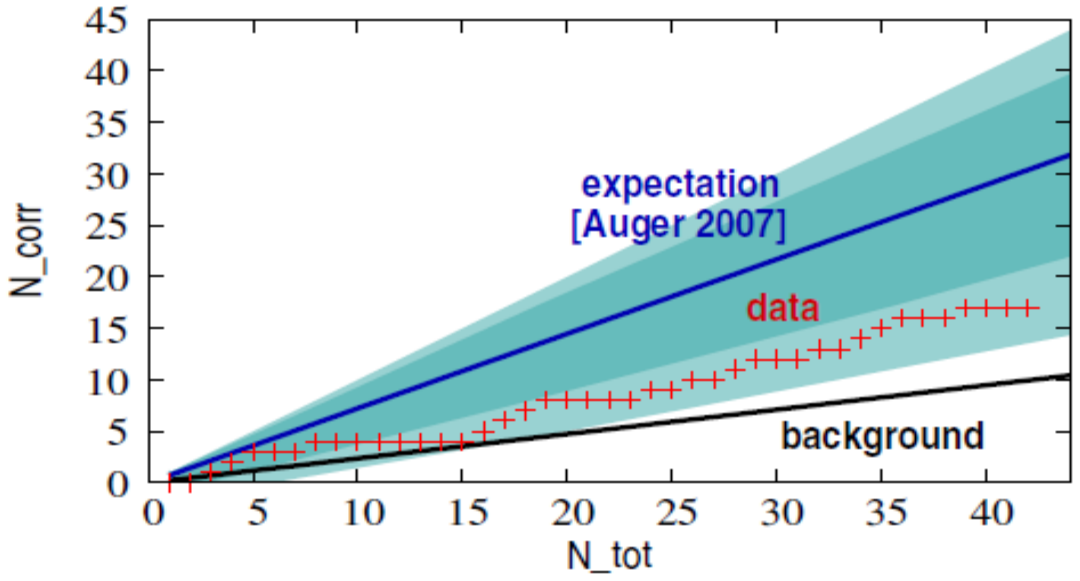
- Correlation with AGNs (as per Auger)
- Autocorrelation (as per AGASA)
- Correlation with Large Scale Structure
- “Hotspot” Search

Anisotropy Data Set

- 8 May 2008—13 May 2013 (5 years)
- <55º zenith angle
- **2130** events above 10 EeV
- **132** events above 40 EeV
- **52** events above 57 EeV

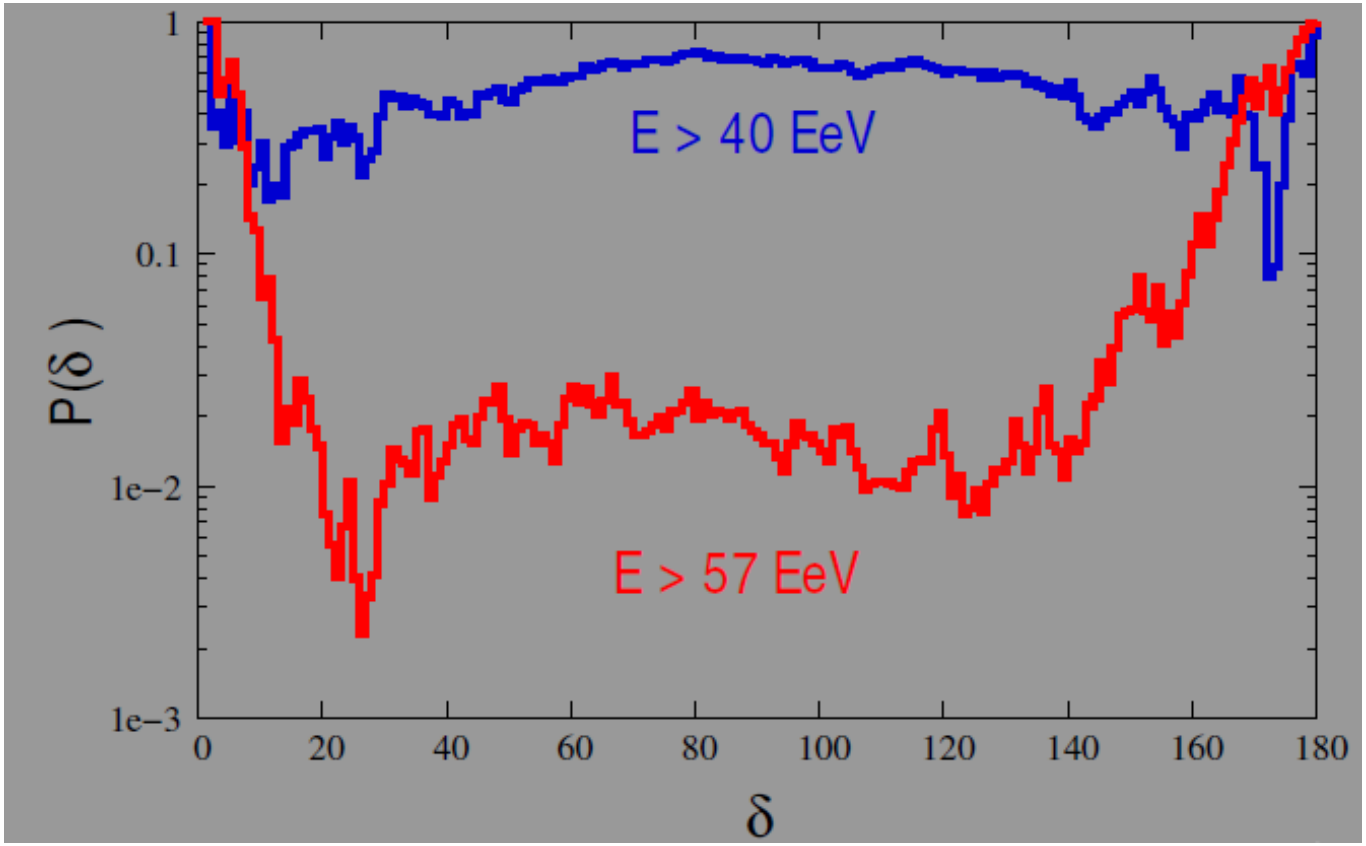
Cosmic Ray Origins
Search for AGN Correlations

- Parameters from the Auger 2007 publication:
  - Veron-Cetty & Veron catalog 2006
  - Redshift 0 < z < 0:018 465 AGN
  - Angular separation < 3.1º
- **17/42** events **p=0.017**



Autocorrelation

- No evidence of small scale clustering (as per AGASA)
- Departure from isotropy of **3σ** at ~20º



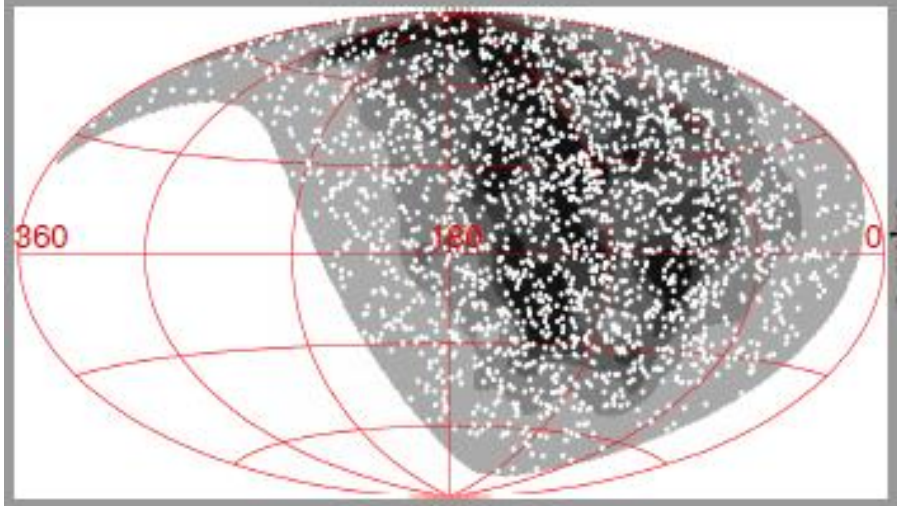
Correlation with LSS

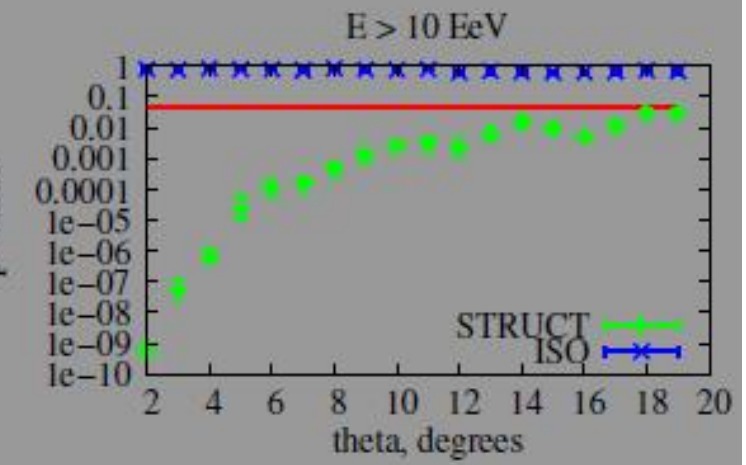
Motivation:

- TA composition consistent with protons
- Protons @10^{20} eV only expected to have 2-5º deflection at GZK distances
- Hence arrival directions at the highest energies should correlate with LSS
- Only free parameter: deflection angle

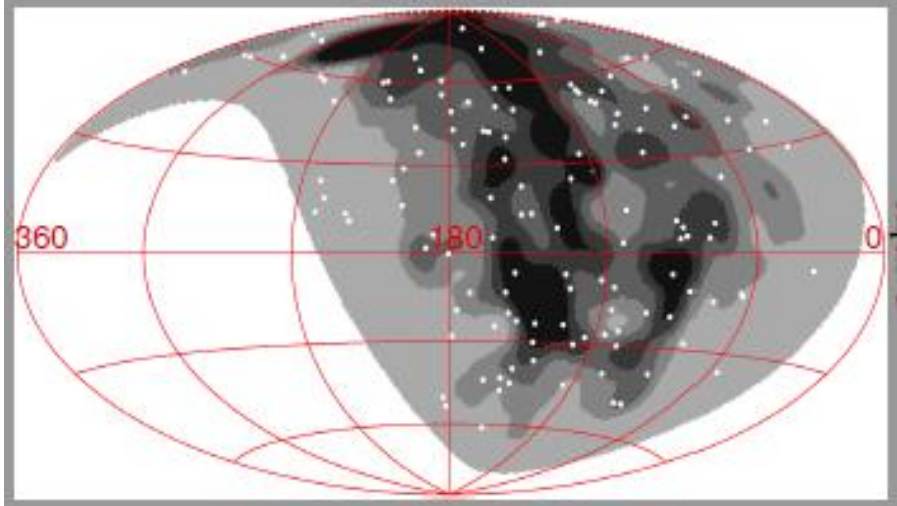
Correlation with LSS

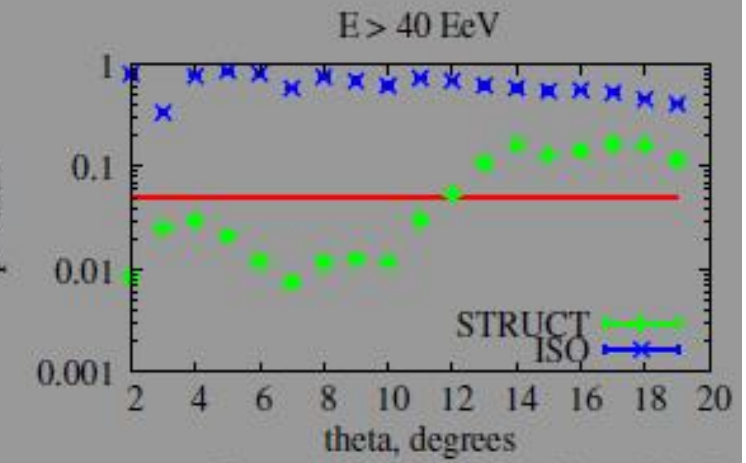
$E > 10$ EeV





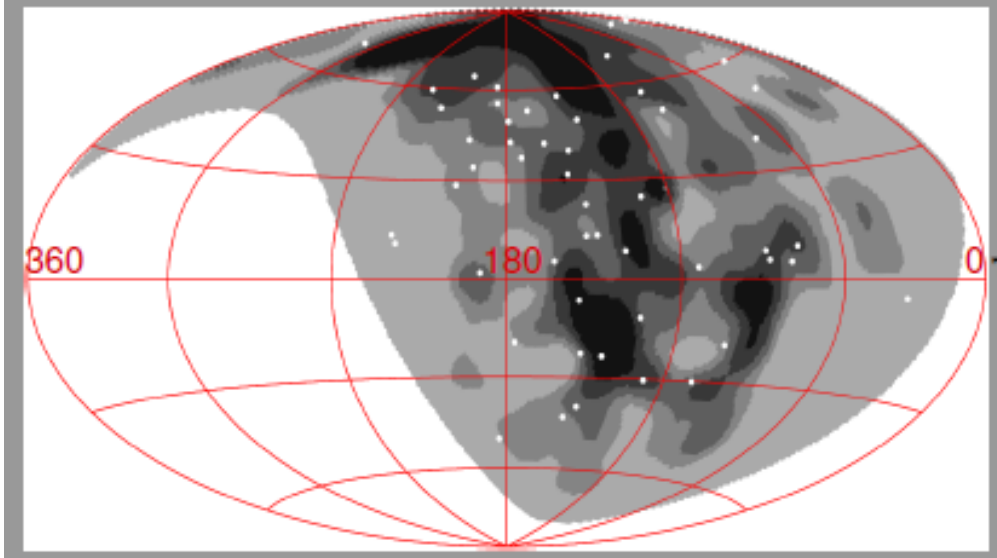
$E > 40$ EeV

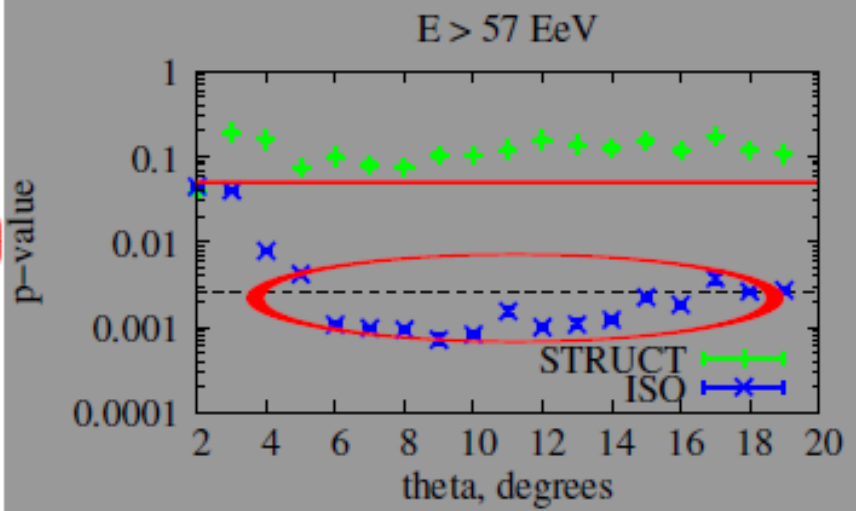




Correlation with LSS

$E > 57$ EeV



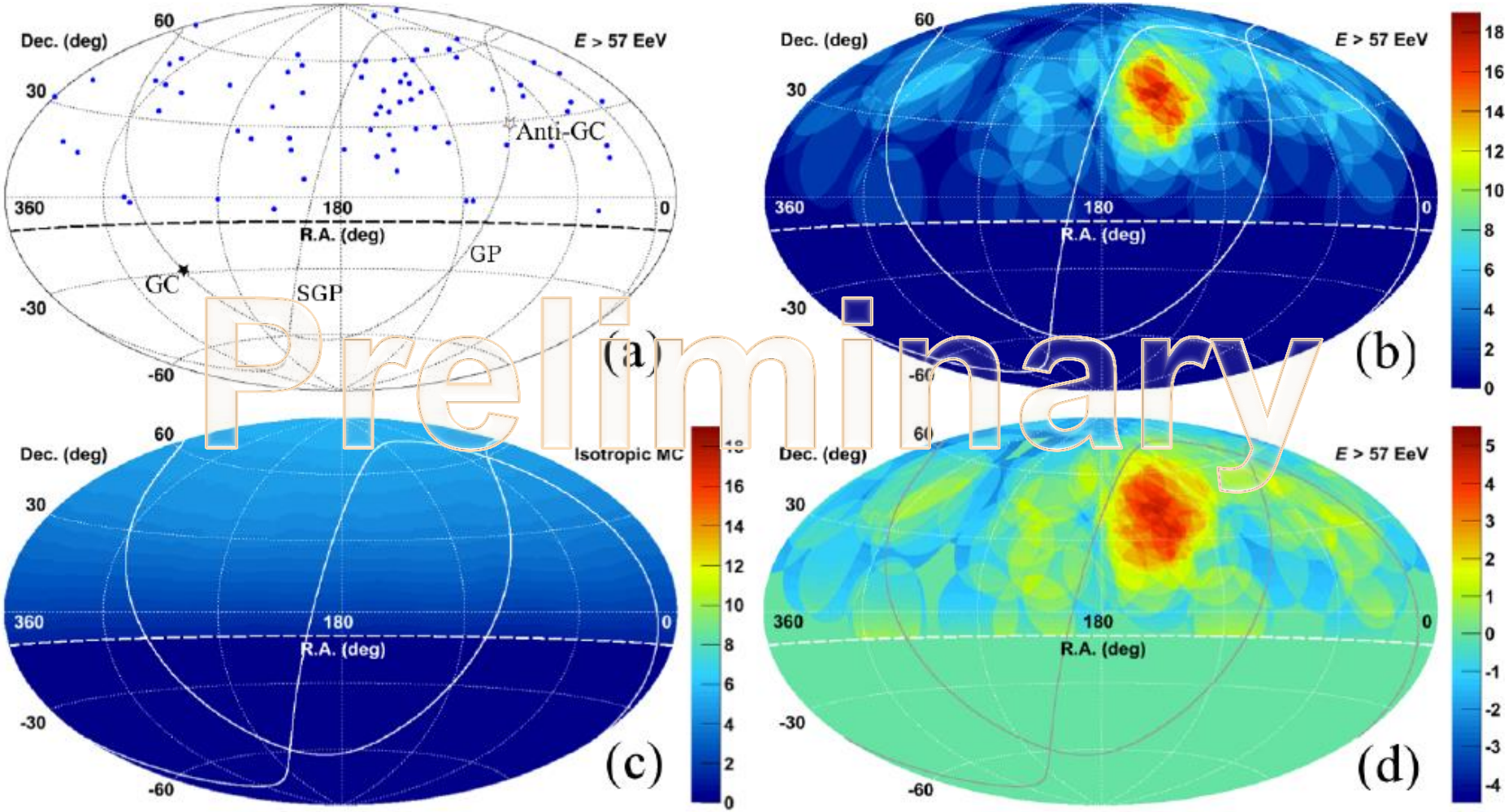


- High energy $E > 57$ EeV data are not compatible with isotropy at $\sim 3\sigma$ (pre-trial)

Needed: More Statistics

- Telescope Arrary event set optimized for energy spectrum studies
- Looser cuts are acceptable for anisotropy studies
- **52** events >57 EeV → **72** events >57 EeV

The TA Hotspot

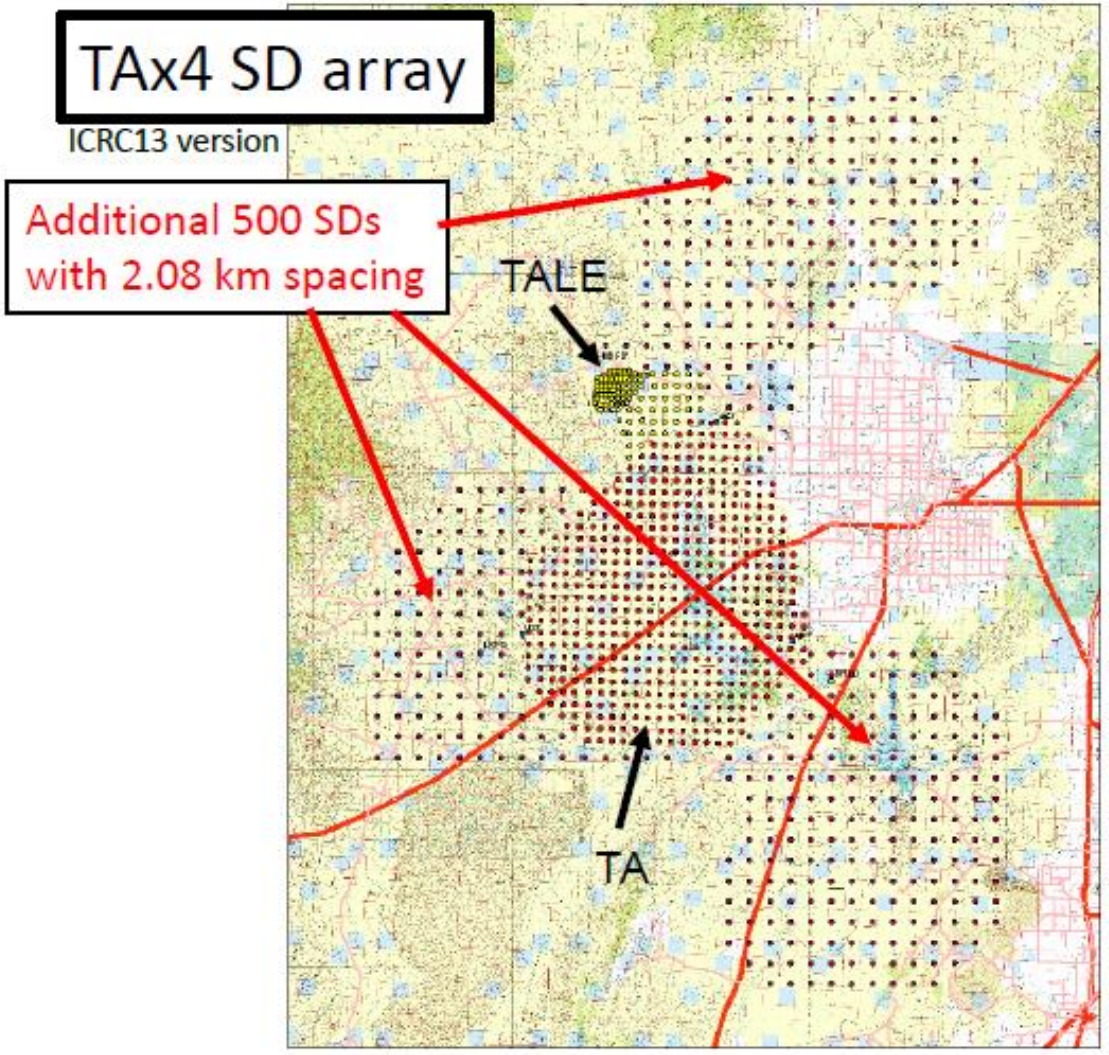


Hotspot Description

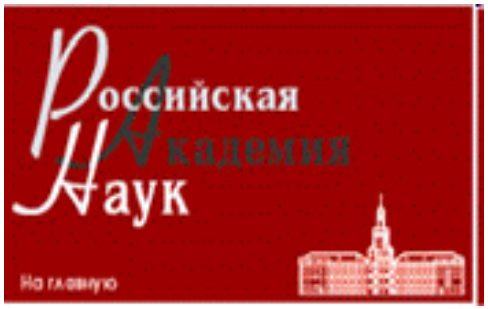
- 20º oversampling
  - No scanning
- Maximum: 19 events/4.5 expected 5.1σ
- Chance of a 5.1σ maximum **anywhere** in a isotropic set: 3.6σ

If we're going to study this hotspot, we need a lot more data…

- TAx4
  - **500** additional SD's with 2.08 km spacing
  - One additional FD composed of recycled HiRes-II components



Conclusions

- TA possesses the largest aperture for UHECRs in the Northern Hemisphere.
- Several different analyses point to anisotropy above at energies above 57 EeV
- More data needed

Acknowledgments