



Results from the Telescope Array Experiment

Yoshiki TSUNESADA



*Tokyo Institute of Technology
for the Telescope Array Collaboration*

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Contents

• TA Detectors



• TA Observation

• TA Results





- Spectra: FD-mono, FD-hybrid, SD
- Xmax: Shower longitudinal development
- Anisotropies: LSS/AGN correlations, clusterings

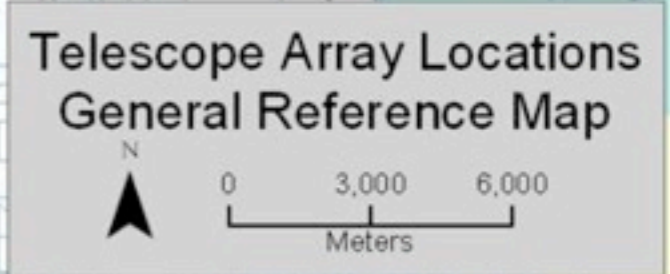
TA: A Hybrid Experiment

Surface detector array (SD)

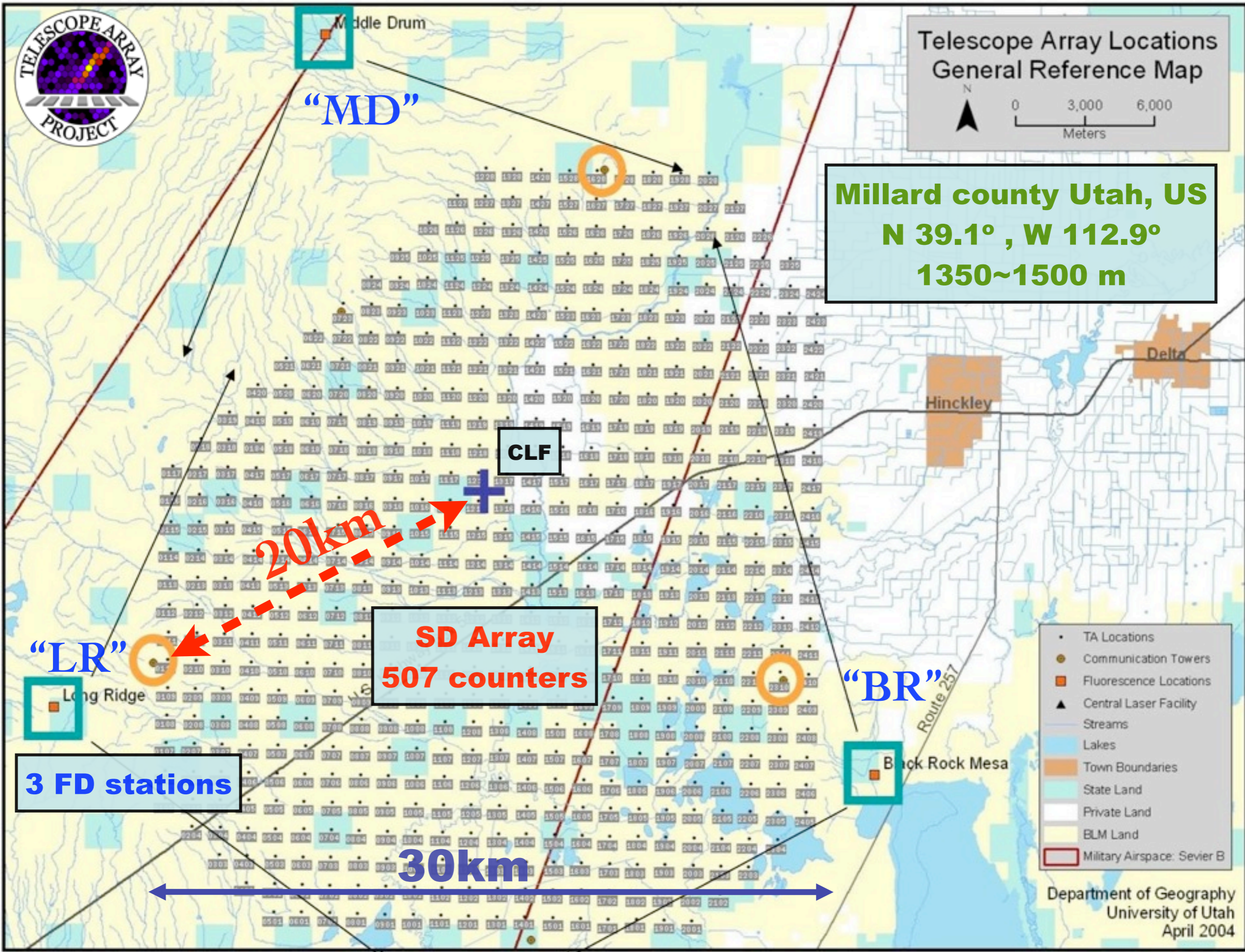
-  507 scintillation counters
-  1.2km grid in $\sim 700\text{m}^2$

Fluorescence detectors (FD)

-  3 stations: “BRM”, “LR” and “MD”
-  12 (BRM&LR) and 14 (MD) telescopes
 -  14 MD telescopes: HiRes-I detectors
-  36deg x 120deg FOV



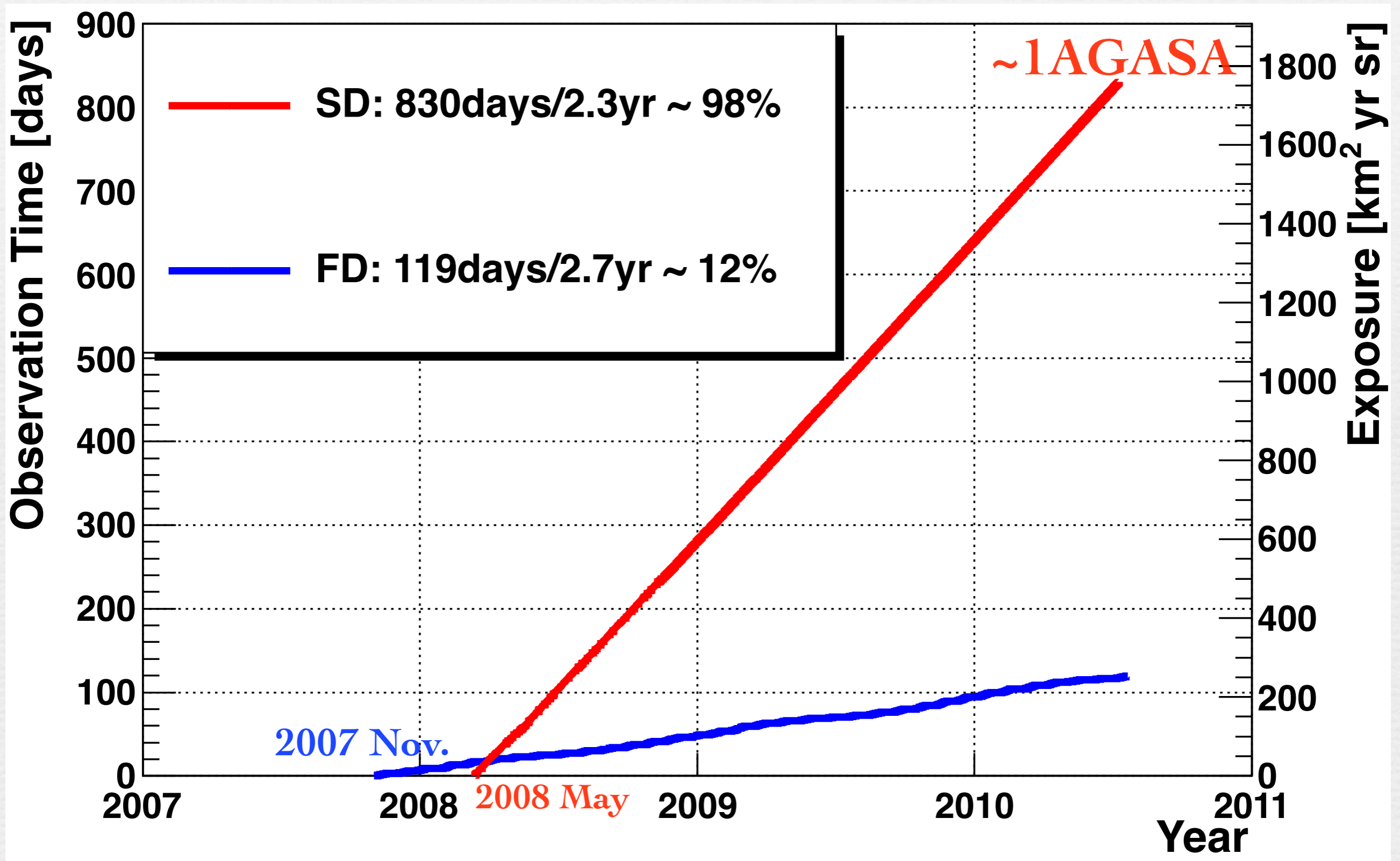
Millard county Utah, US
N 39.1° , W 112.9°
1350~1500 m



- TA Locations
- Communication Towers
- Fluorescence Locations
- ▲ Central Laser Facility
- Streams
- Lakes
- Town Boundaries
- State Land
- Private Land
- BLM Land
- Military Airspace: Sevier B

Department of Geography
University of Utah
April 2004

TA Observation/Exposure



TA Results

Energy Spectra

- FD Mono : from MD HiRes-I detectors D. Rodriguez (U. Utah)
- FD *Hybrid* : well-determined FD events D. Ikeda (ICRR, U. Tokyo)
- SD : ~1AGASA exposure D. Ivanov (Rutgers U./U. Utah)

Mass Composition: “Xmax” analysis Y. Tameda (ICRR, U. Tokyo/ TokyoTech)

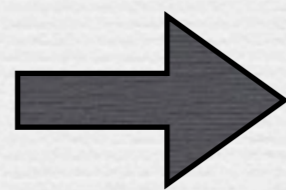
Photon Limit G. Rubtsov (INR, Russian Ac. Sci.)

Anisotropy

- LSS correlation E. Kido (ICRR, U. Tokyo) , P. Tinyakov
- AGN correlation I. Tkachev (INR, Russian Ac. Sci.)
- Autocorrelation (event clustering) T. Okuda (Osaka City U.)

TA Analysis: Principle

- Several data analyses ongoing
 - SD, FD-mono, FD-stereo, FD-hybrid
 - Multiple codes exist for each: cross-check
- MC-Data comparison:
 - Use previously measured spectrum and composition
 - Generate MC events, including detector & trigger simulation
 - Apply the same reconstruction program for MC/Data



**Understanding our detectors
and reconstruction procedures**

FD Mono Spectrum

from the 14 HiRes-I telescopes at the “MD” station

• Use the HiRes-I identical analysis procedures

- Same program, event selection and cuts
- Same “average” atmospheric model
- Same FLY model: Kakimoto et al. (1996) + FLASH (2008)

• The differences:

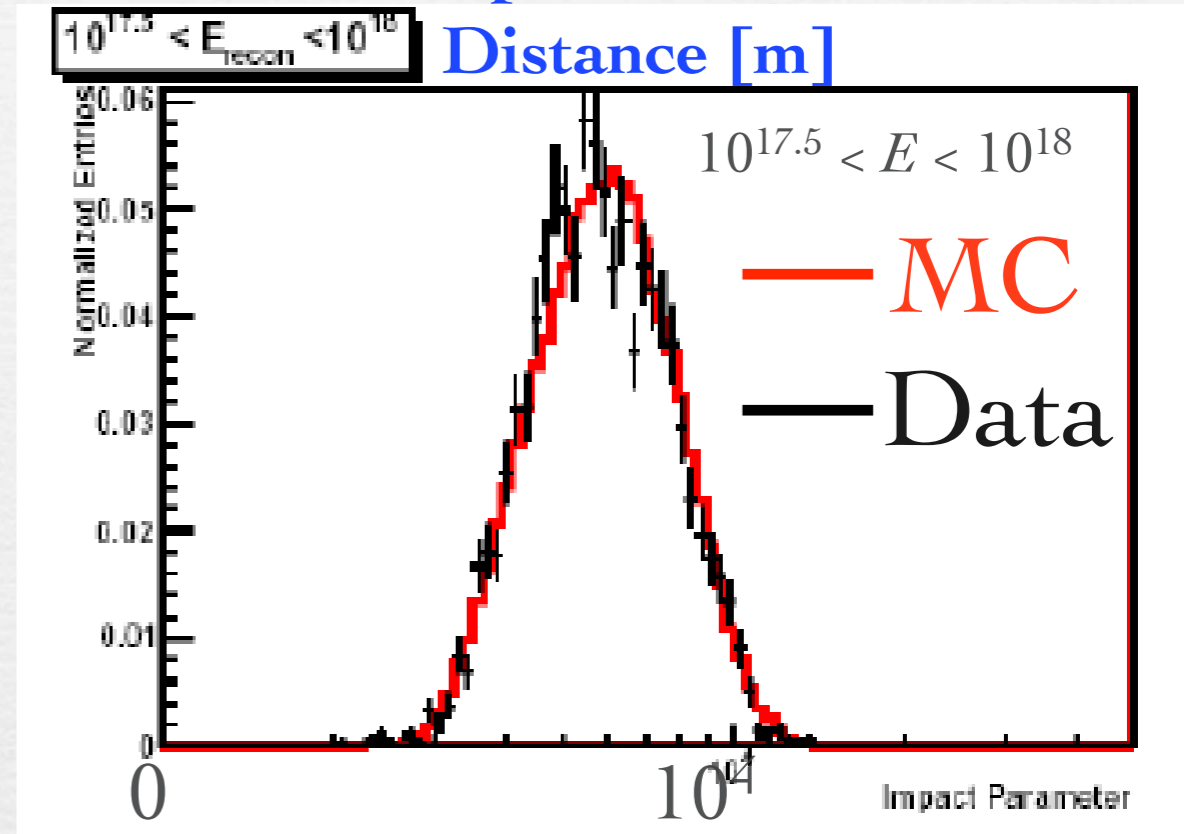
- The telescope location and pointing directions
- Energy threshold (~20% lower than HiRes-1)

• Data: 2007 Dec ~ 2008 Dec (~1 year)

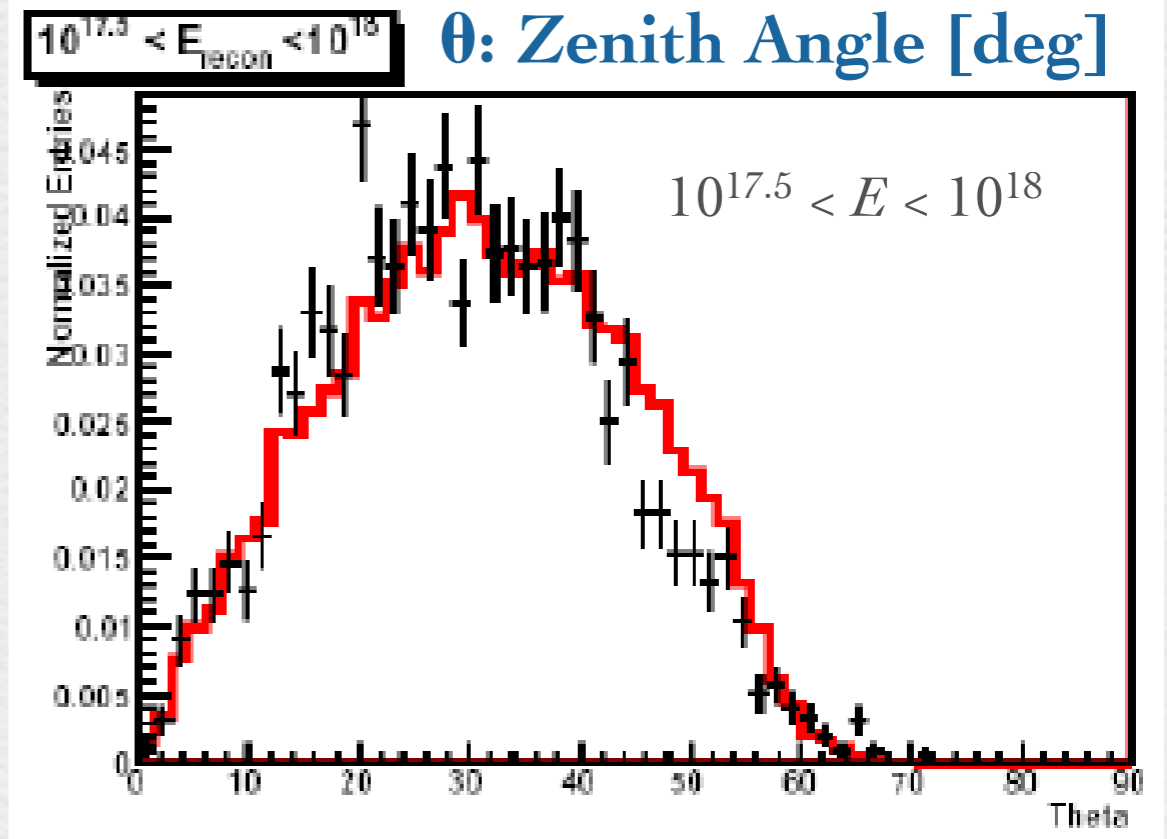
FD-MD: Data/MC Comparison

- Use previously measured spectrum and composition
- Generate MC events, including detector & trigger simulation
- Apply the same reconstruction program for MC/Data

Rp: Shower-Detector
Distance [m]

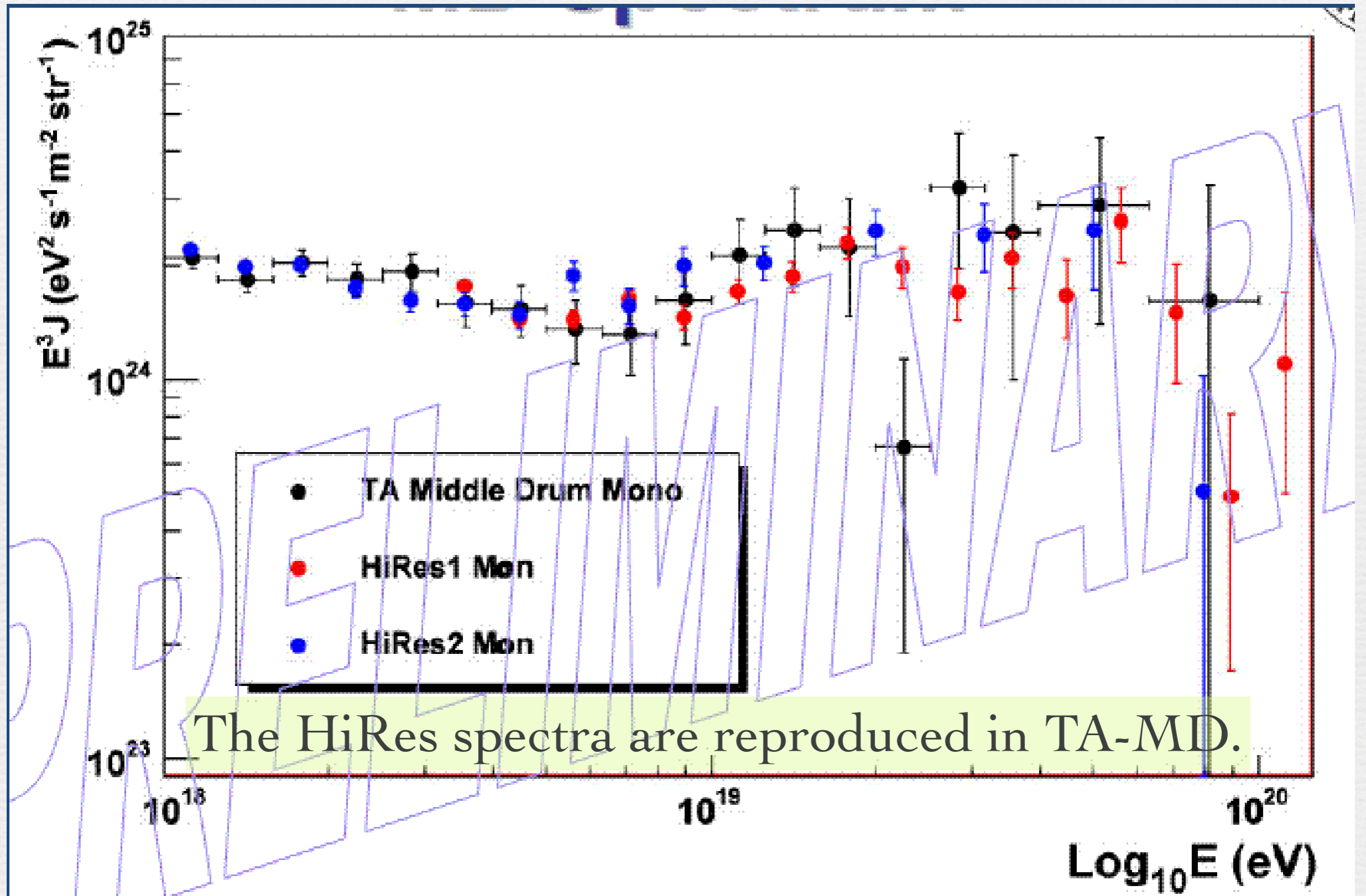


θ : Zenith Angle [deg]



FD Mono Spectrum

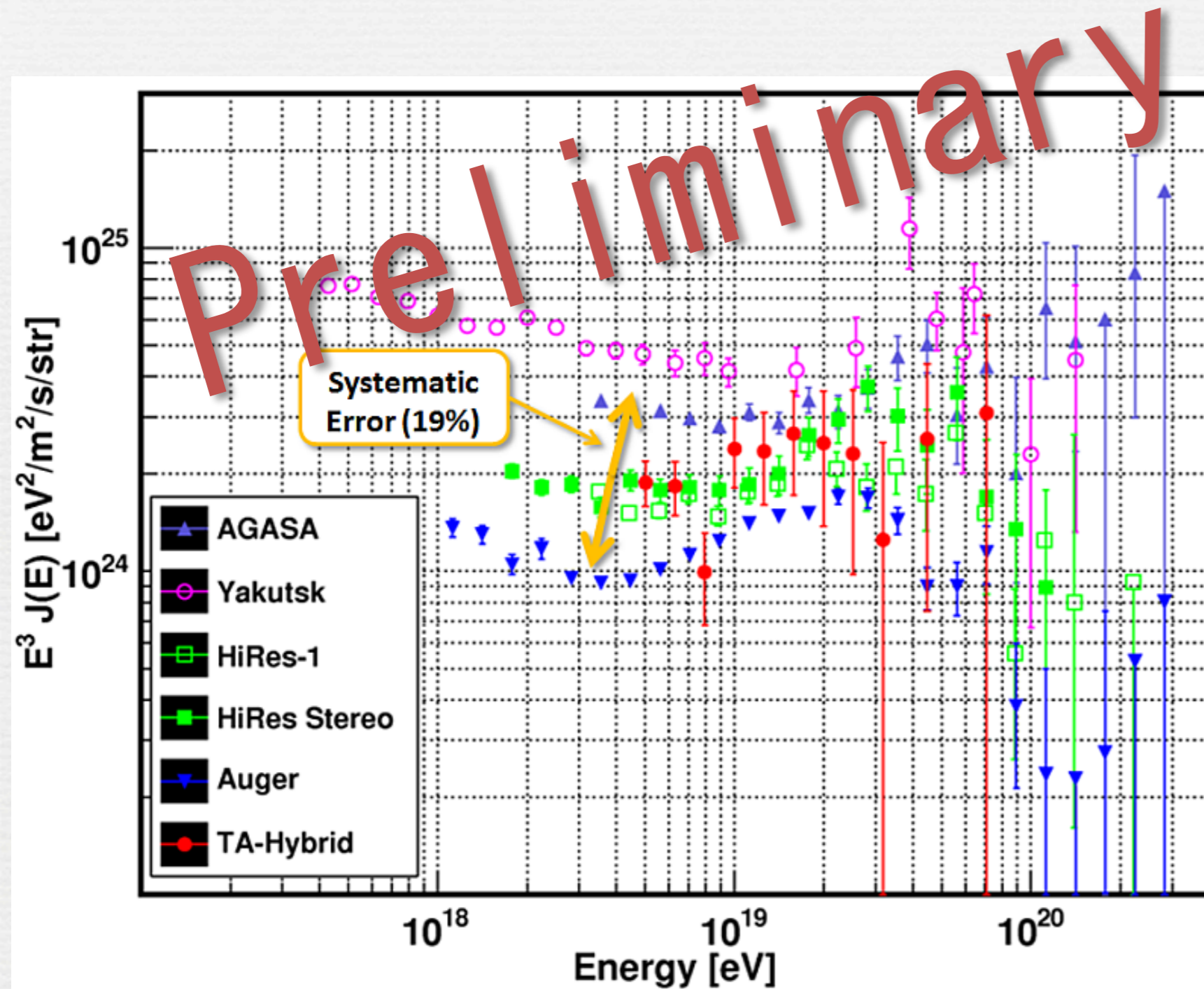
from the 14 HiRes-I telescopes at the "MD" station



Spectrum from FD *Hybrid* Analysis

- Using FD/SD individually triggered events
- Using both data for geometry reconstruction
- Using (only) FD data for longitudinal develop fit
 - “*Hybrid*”: Well-determined-geometry FD events
 - Energy scale: FD
 - FLY: Kakimoto et al. (1996) + FLASH (HiRes, TA-MD)
- Hybrid* Aperture: (SD aperture) X (FD relative detection efficiency)
- Data: 2008May ~ 2009Sep, 1978 events

Spectrum from FD *Hybrid* Analysis



Systematic errors

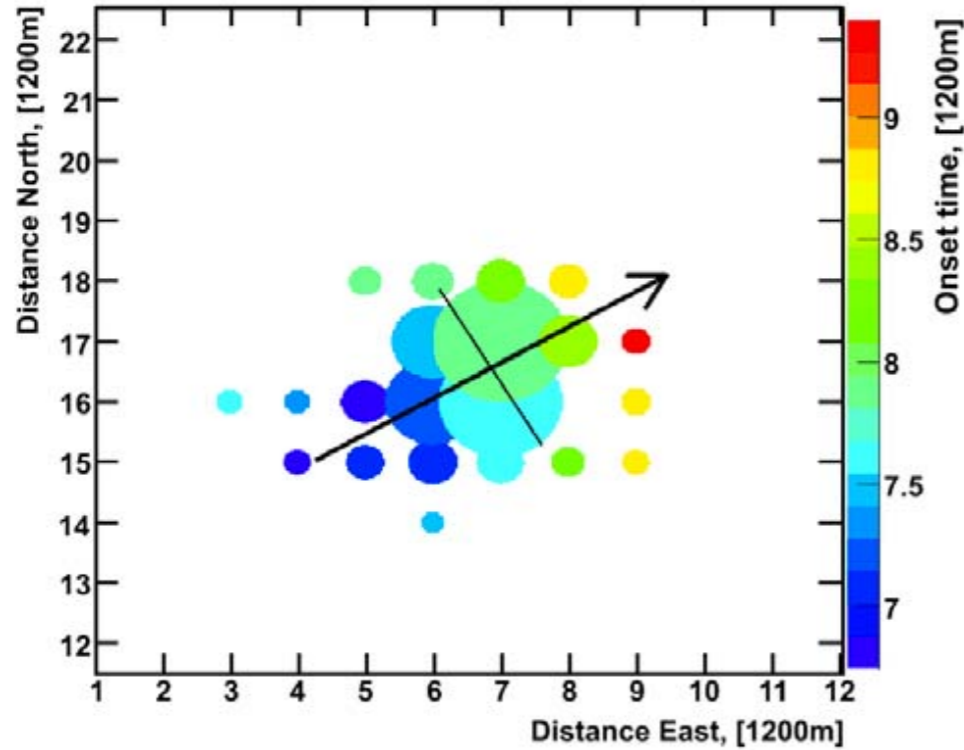
Item	Systematic error
Fluorescence yield	12%
Detector	10%
Atmosphere	11%
Primary particle mass	5%
MC correction	3% (--->1%)
Total	19%

SD Analysis

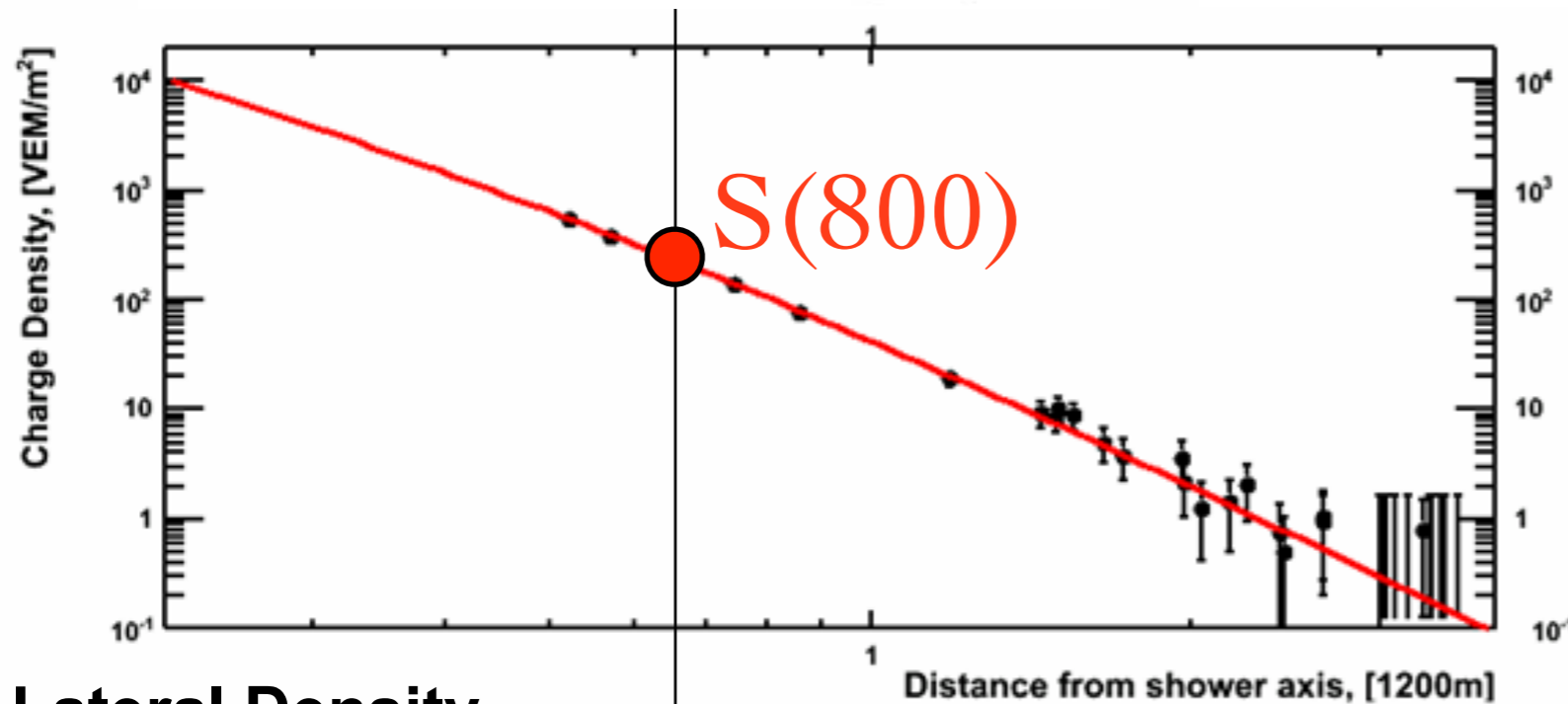
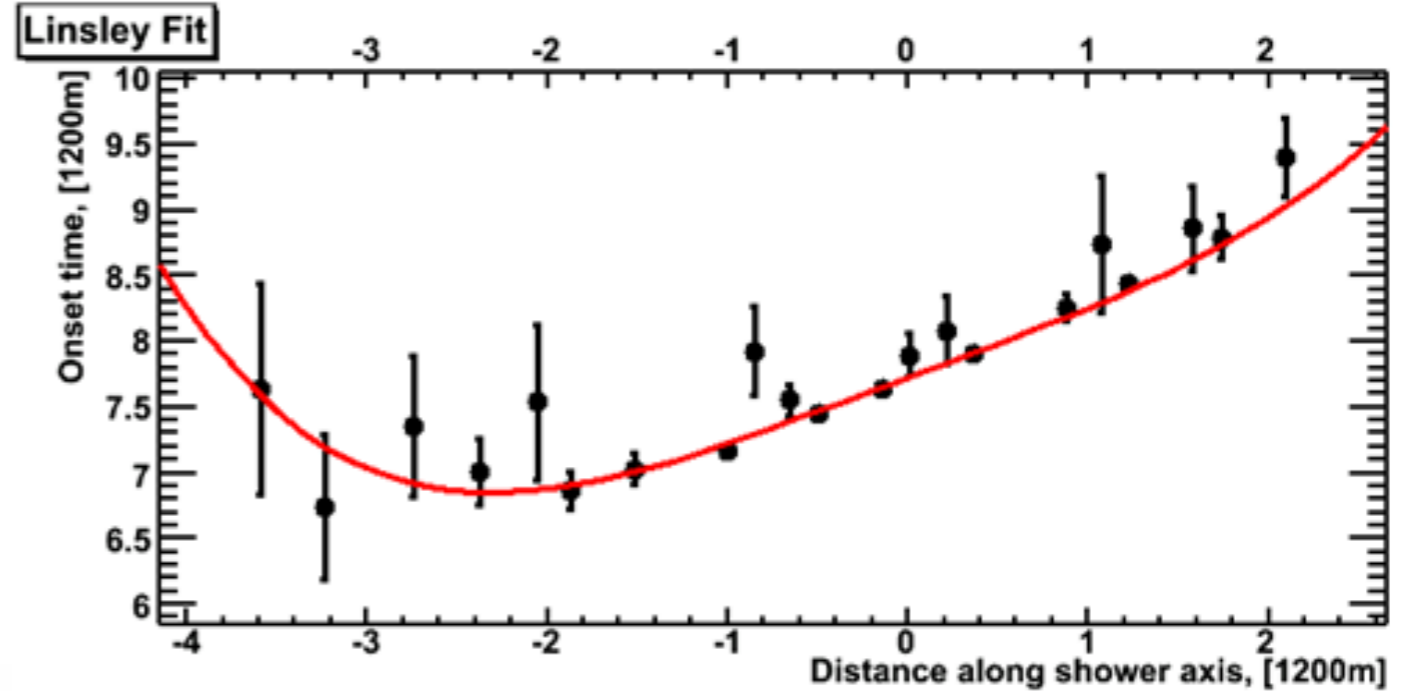
- Reconstruction method (fitting functions) : from previous air shower array experiments (AGASA), and adjusted to fit TA SD data
- Data: 2008May - 2009Feb
 - ~1.75 years,
 - 1500 [km² yr sr] ~ 1 AGASA exposure
- Data Cuts:
 - $\theta < 45^\circ$
 - Border cut: $> 1.2\text{km}$
 - etc.
- 6264 events

Typical SD Event

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



Geometry Fit (modified Linsley)



Lateral Density
Distribution Fit

$r = 800m$

Fit with AGASA LDF

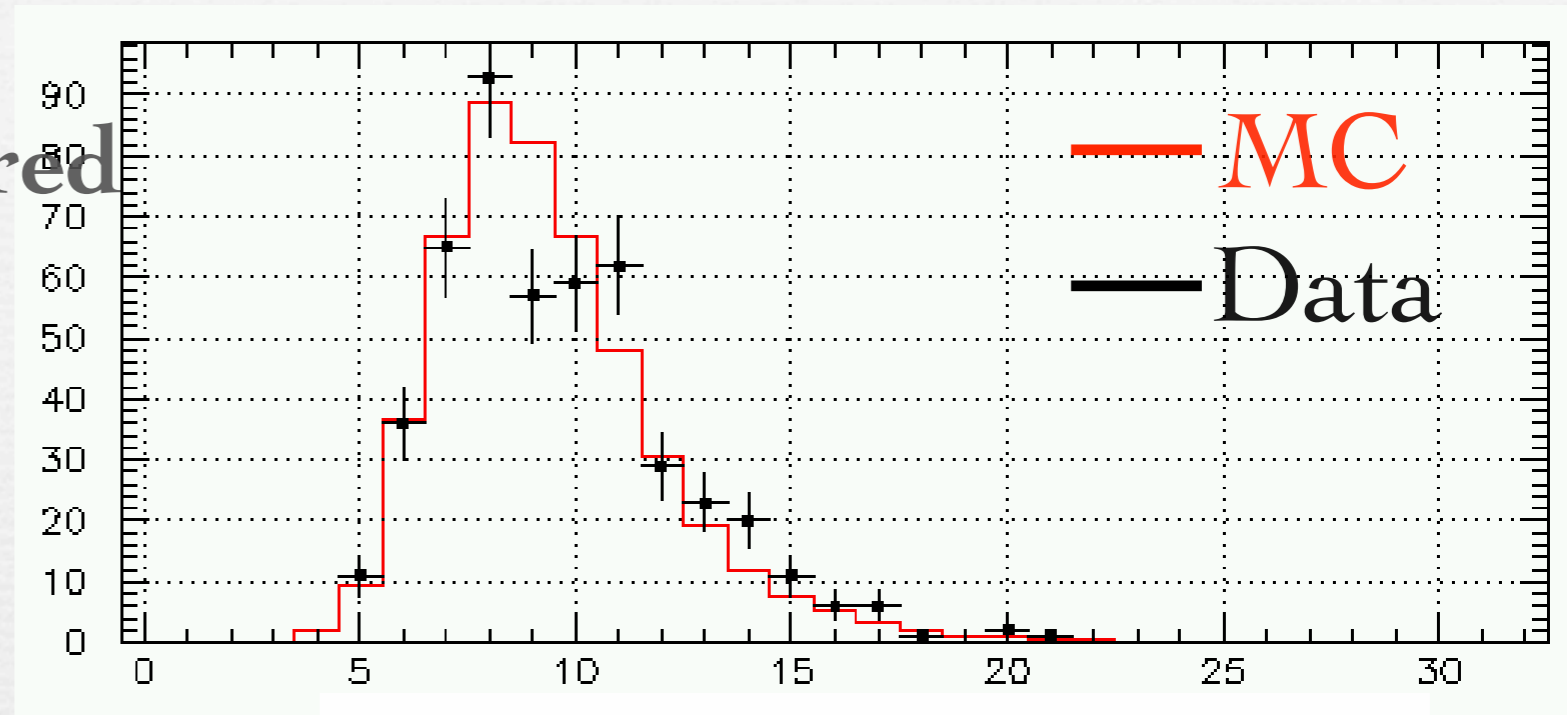
$$\rho(r) \propto \left(\frac{r}{R_M}\right)^{-1.2} \left(1 + \frac{r}{R_M}\right)^{-(\eta-1.2)} \left\{1 + \left(\frac{r}{1000}\right)^2\right\}^{-0.6}$$

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

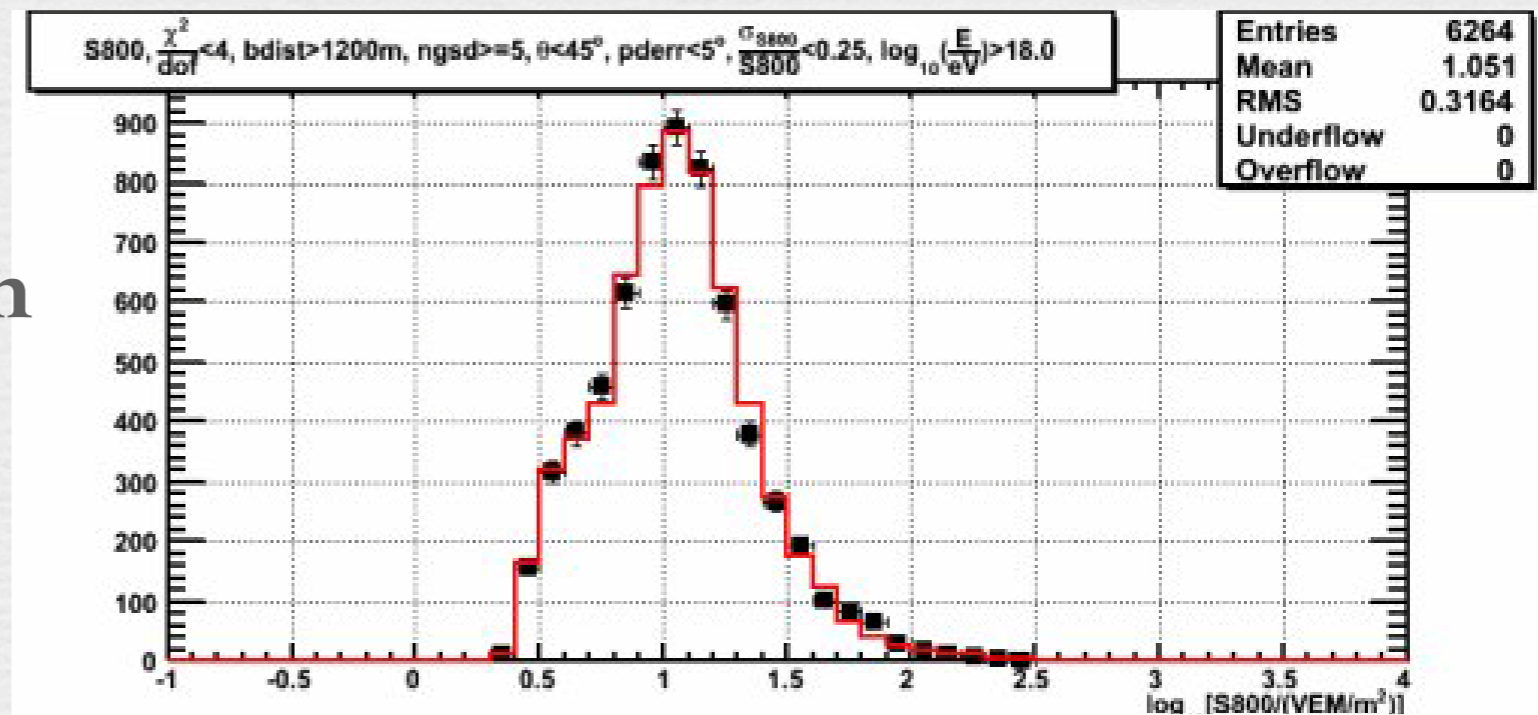
- S(800): Primary Energy
- Zenith attenuation by MC (not by CIC).

SD: Data/MC Comparison

- Use previously measured spectrum and composition
- Generate MC events, including detector & trigger simulation
- Apply the same reconstruction program for MC/Data



Number of “good” SDs

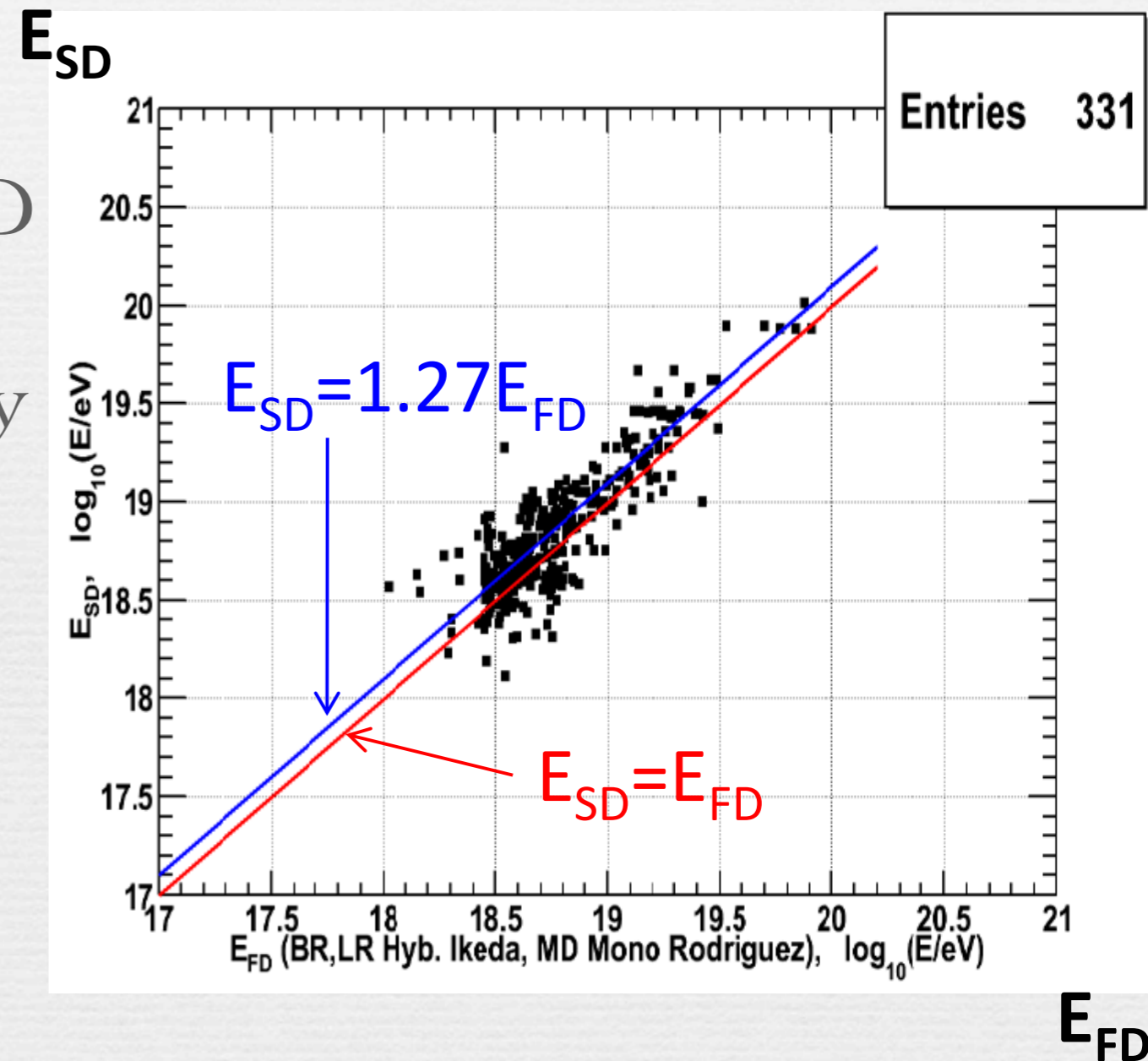


S(800): Energy estimator

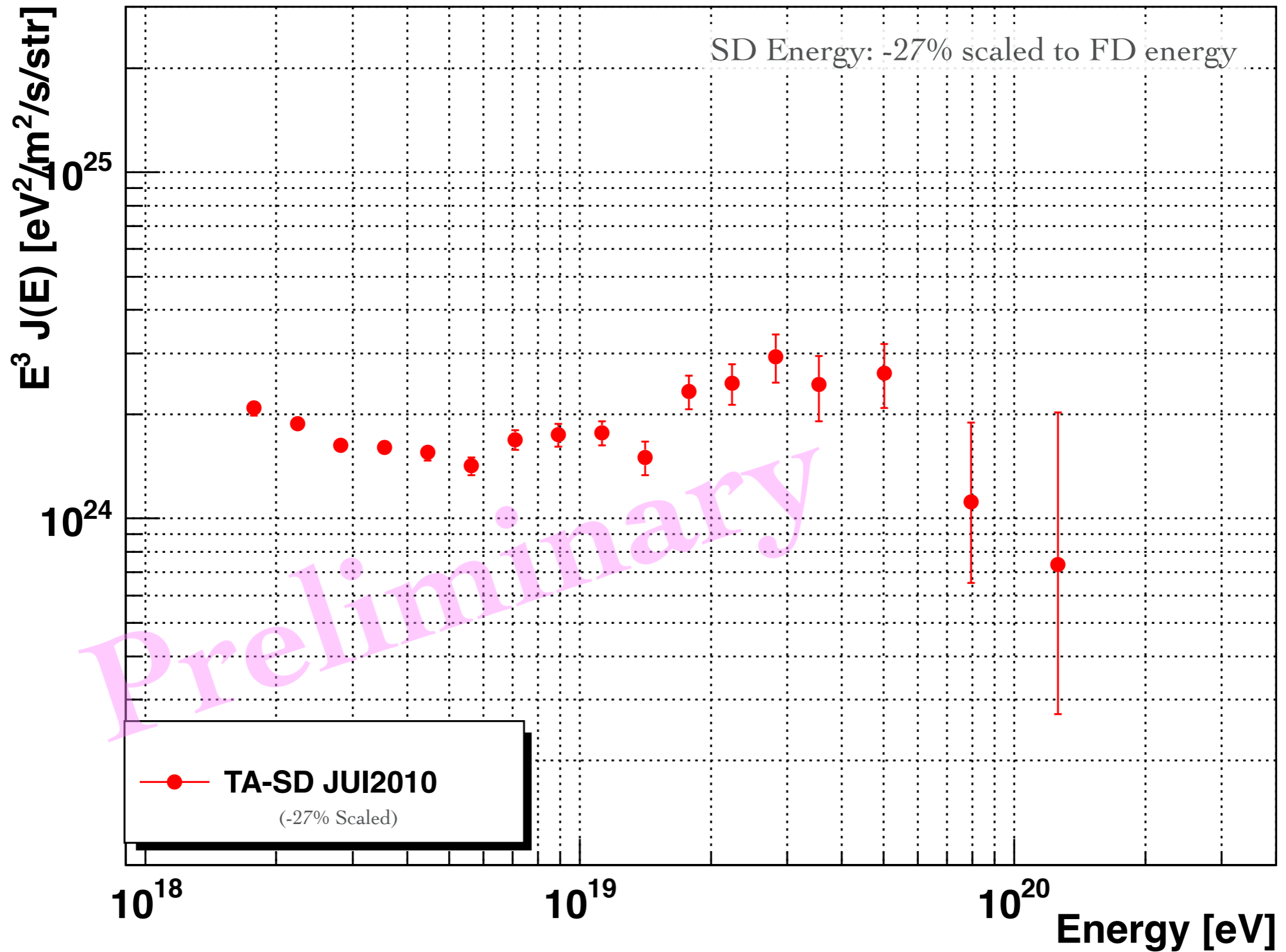
Y.Tsunesada @ 7AFWS, Coimbra, Portugal 2010/Sep/22

TA Energy Scale

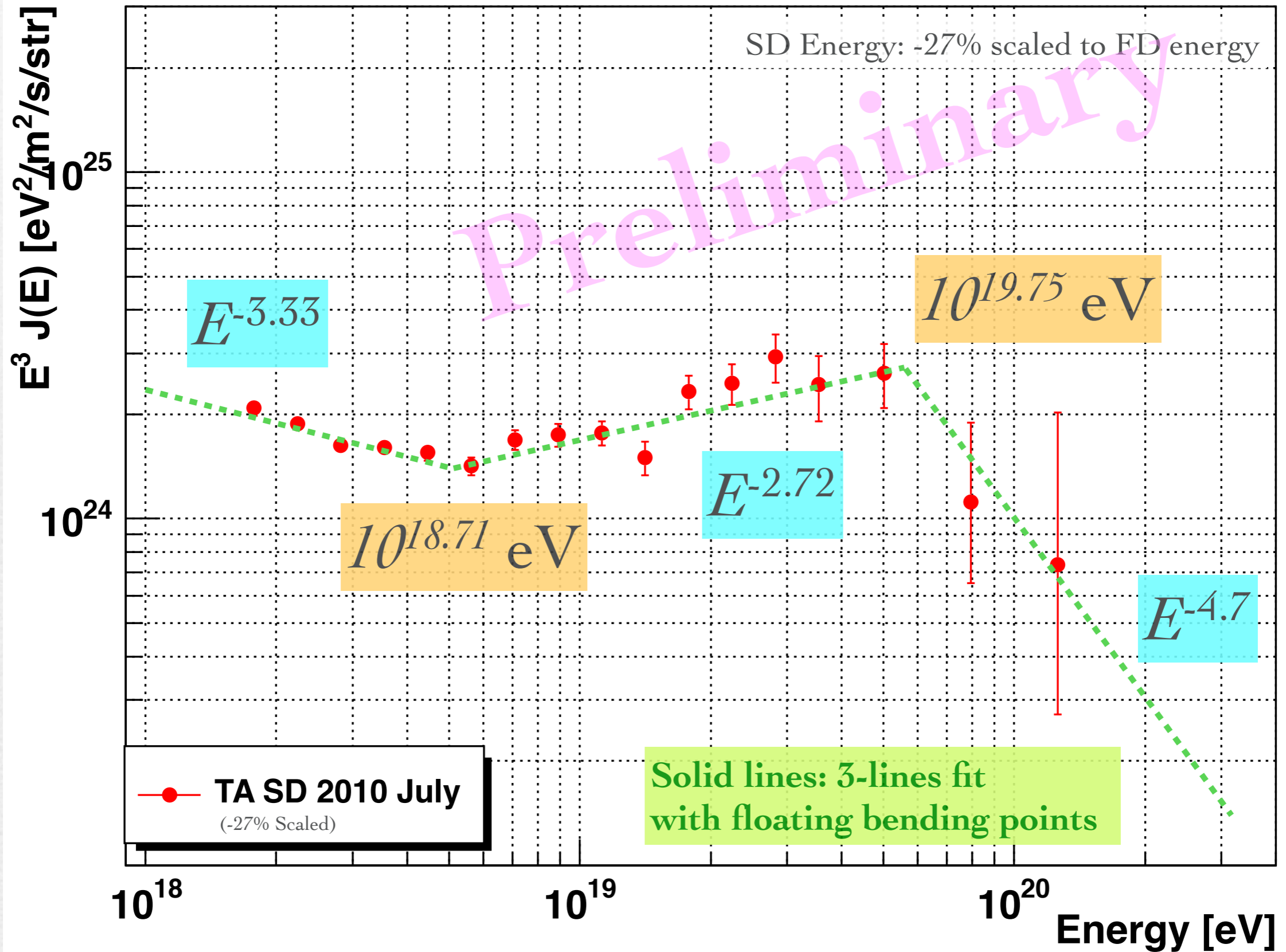
- Determined more accurately by FD, than by shower MC
- Set SD energy scale to the FD energy scale using well-determined events detected by both detectors
- SD energy scale: -27% normalization to fit the FD energy
- Systematic error: 19% (from the hybrid analysis)



TA-SD Spectrum



TA-SD Spectrum



Supression??

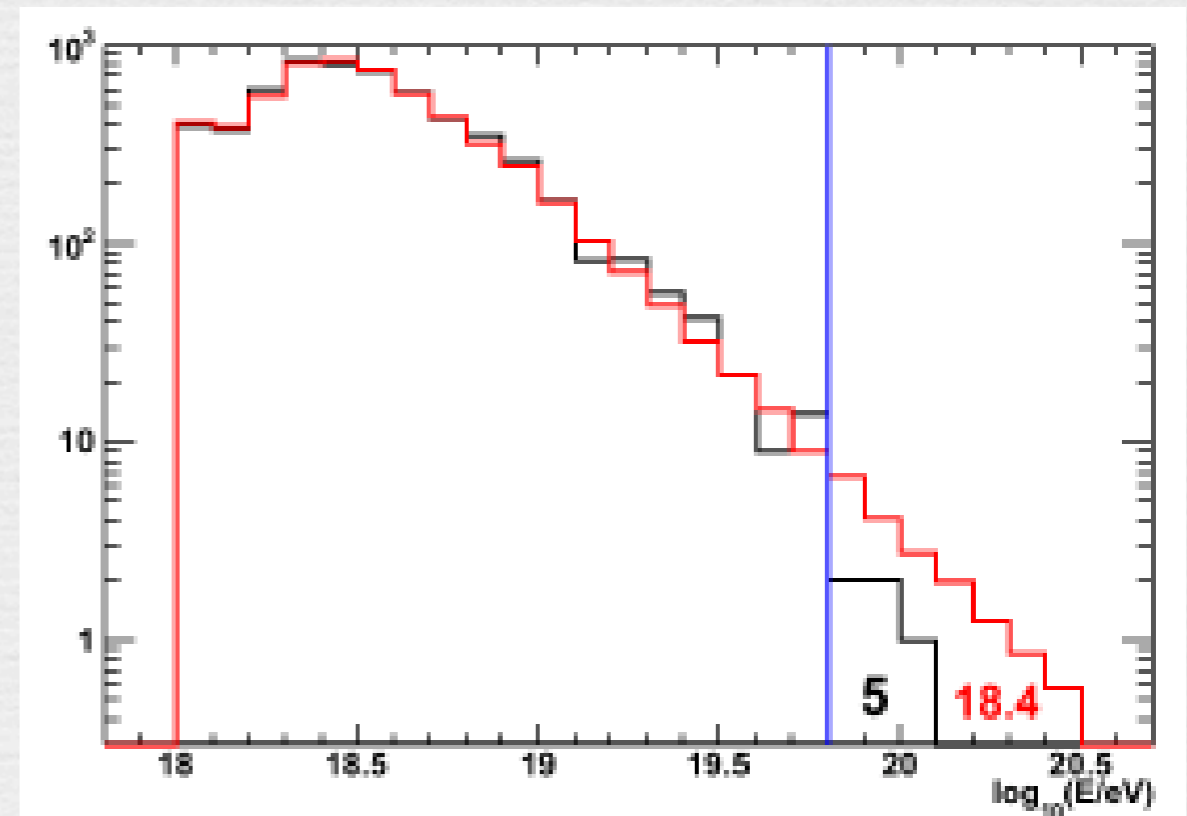
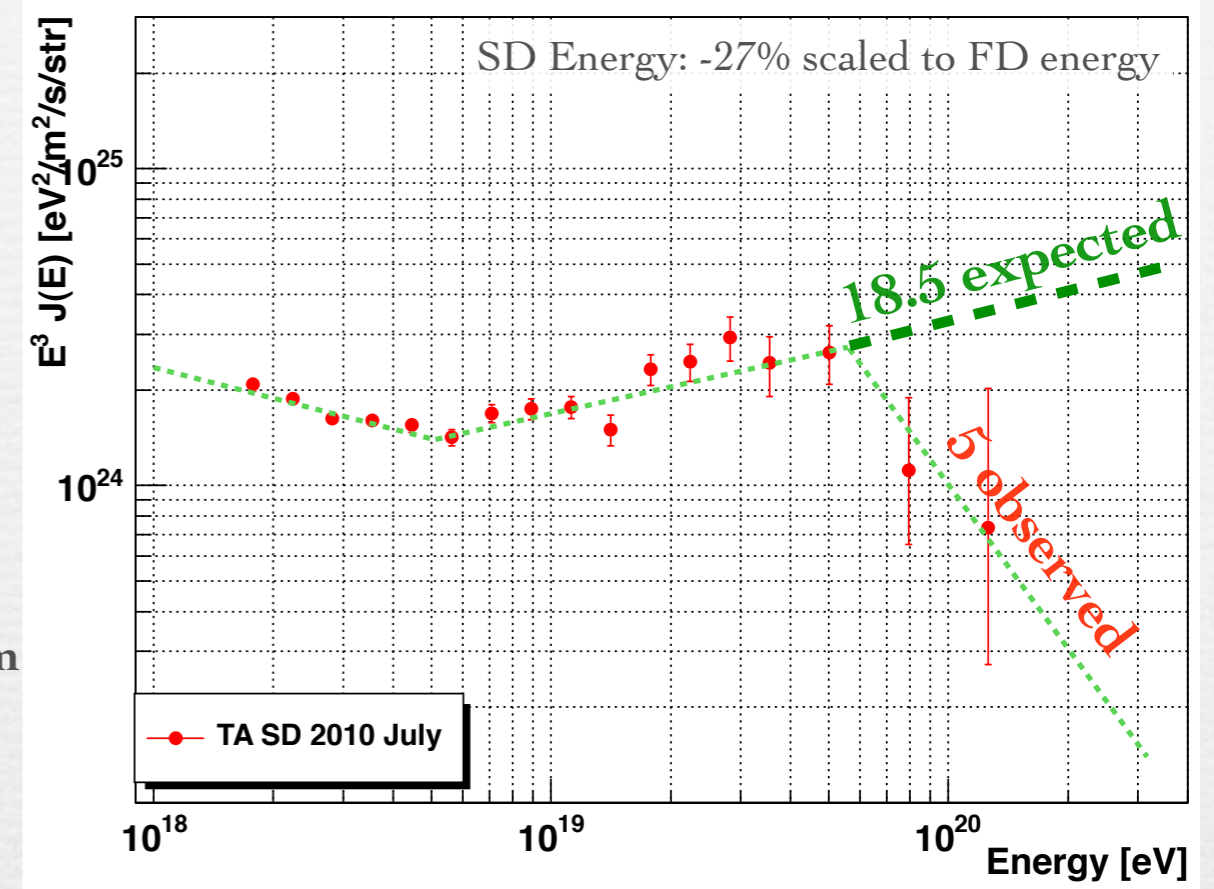
Assuming no cut-off and extend beyond the break

Number of events:

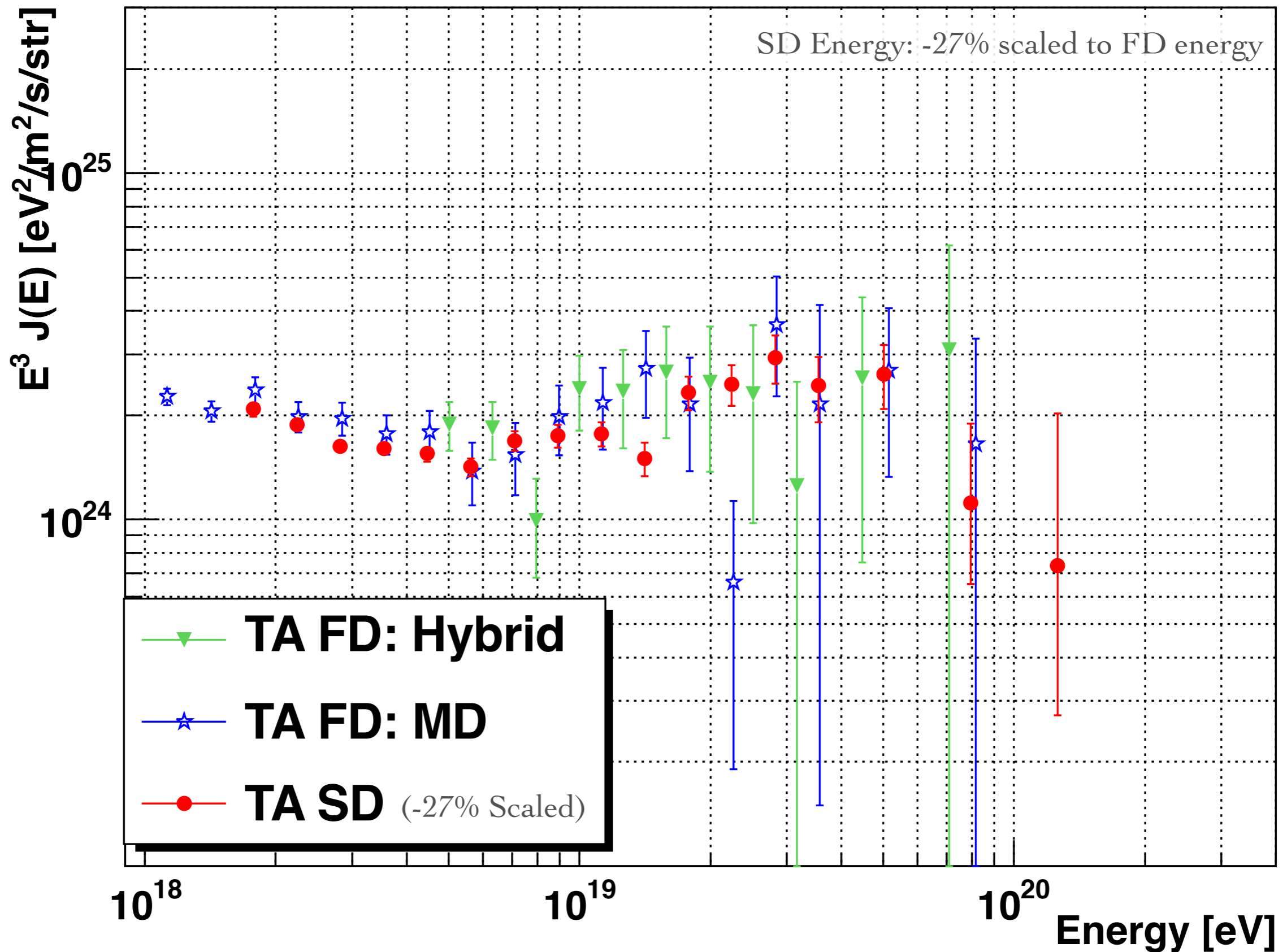
N_{exp}: 18.5 from an extended spectrum & TA exposure

N_{obs}: 5

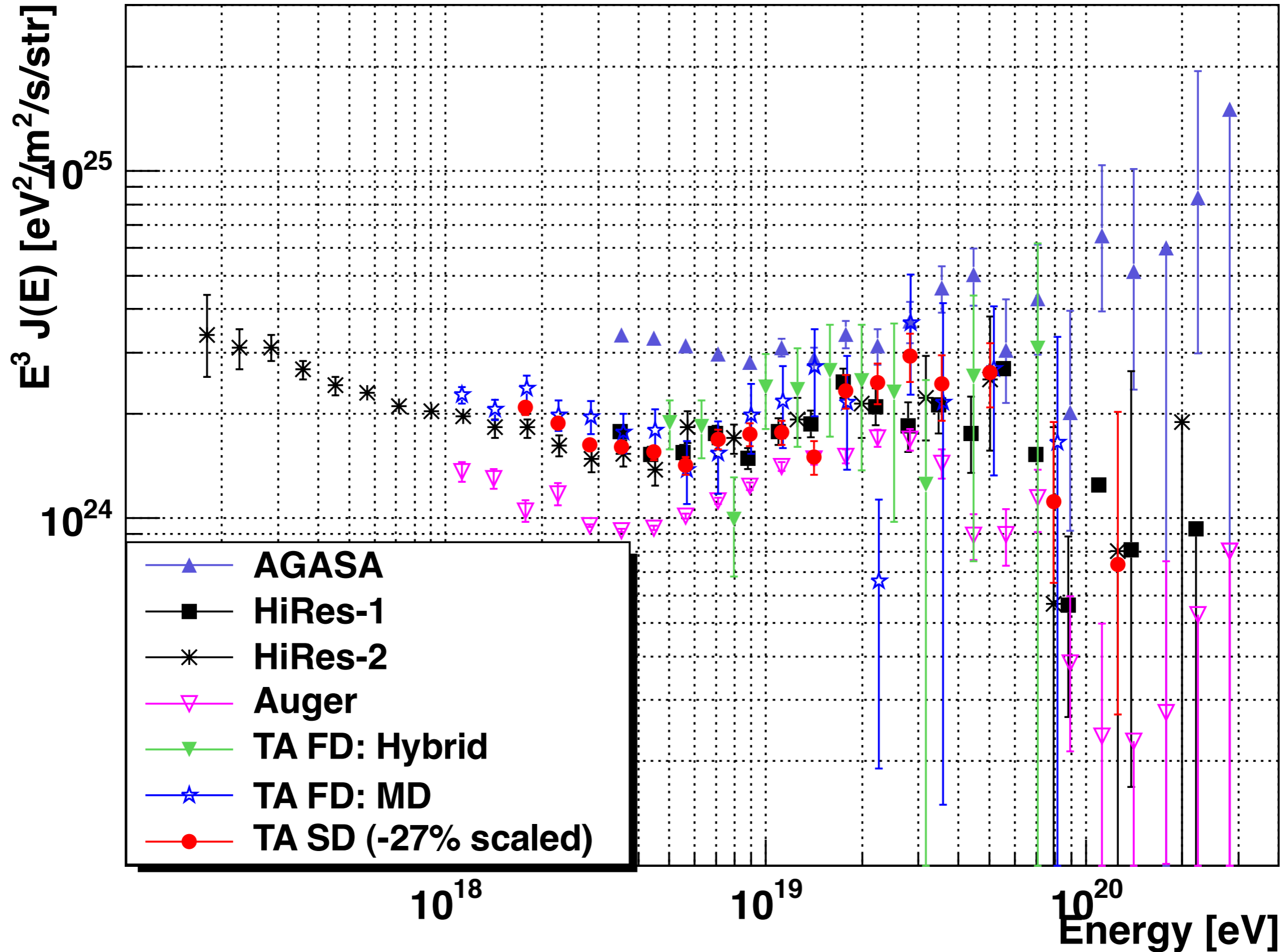
$$\begin{aligned} \text{Prob.} &= \sum_{n=0}^5 \text{Poisson}(n; \mu = 18.5) \\ &= 2.41 \times 10^{-4} \quad (-3.5\sigma) \end{aligned}$$



TA Energy Spectra

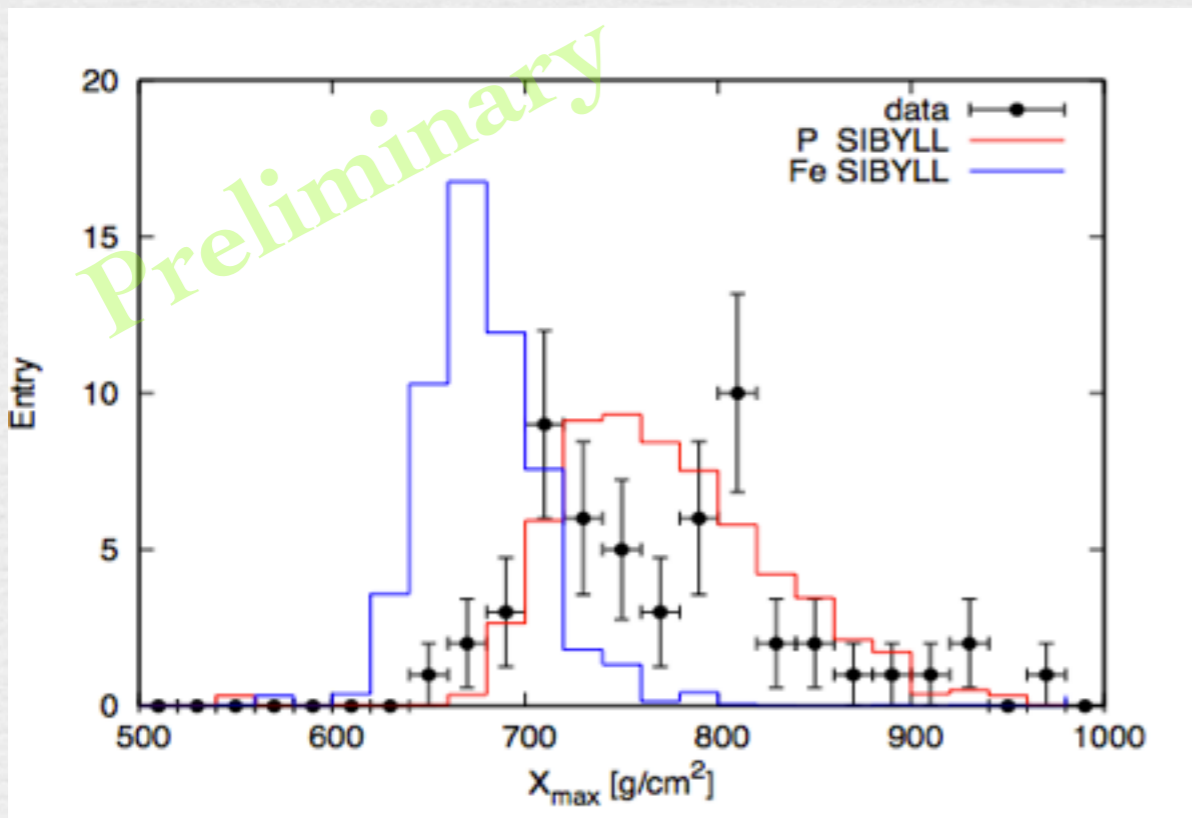
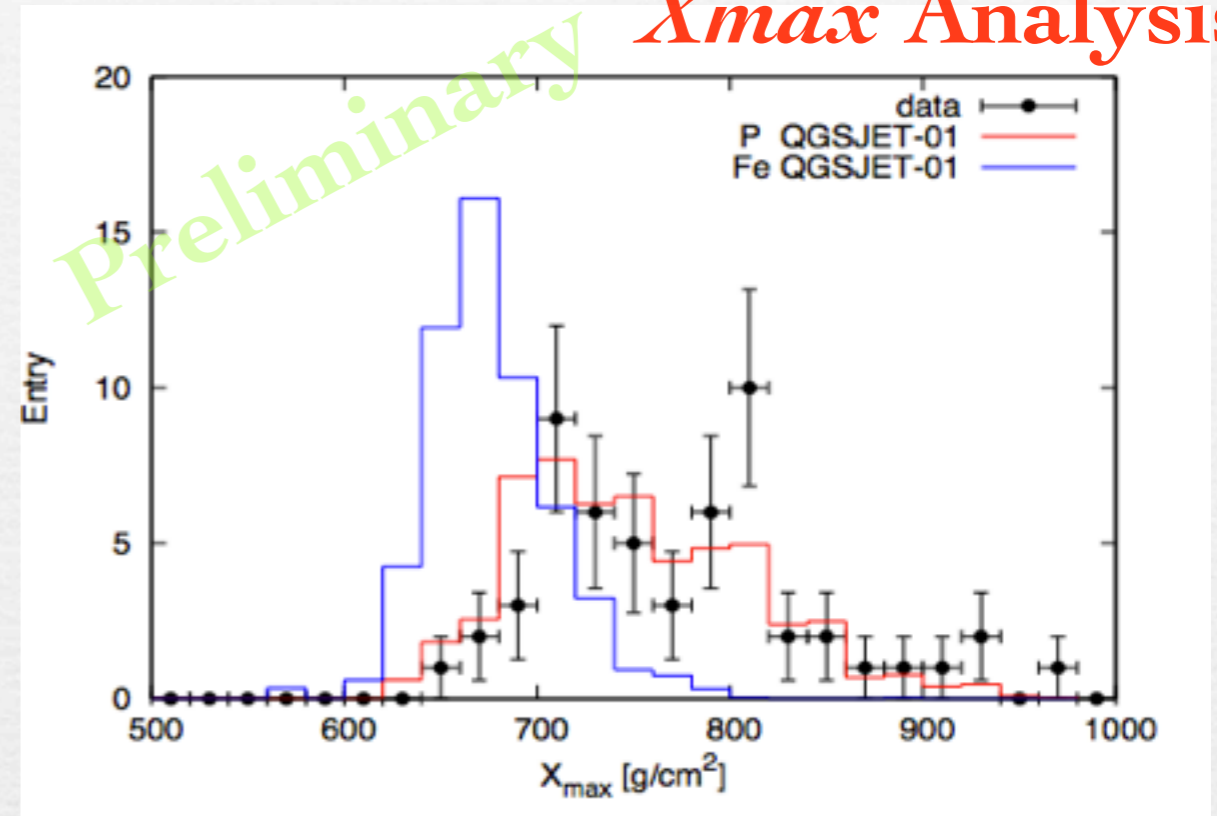
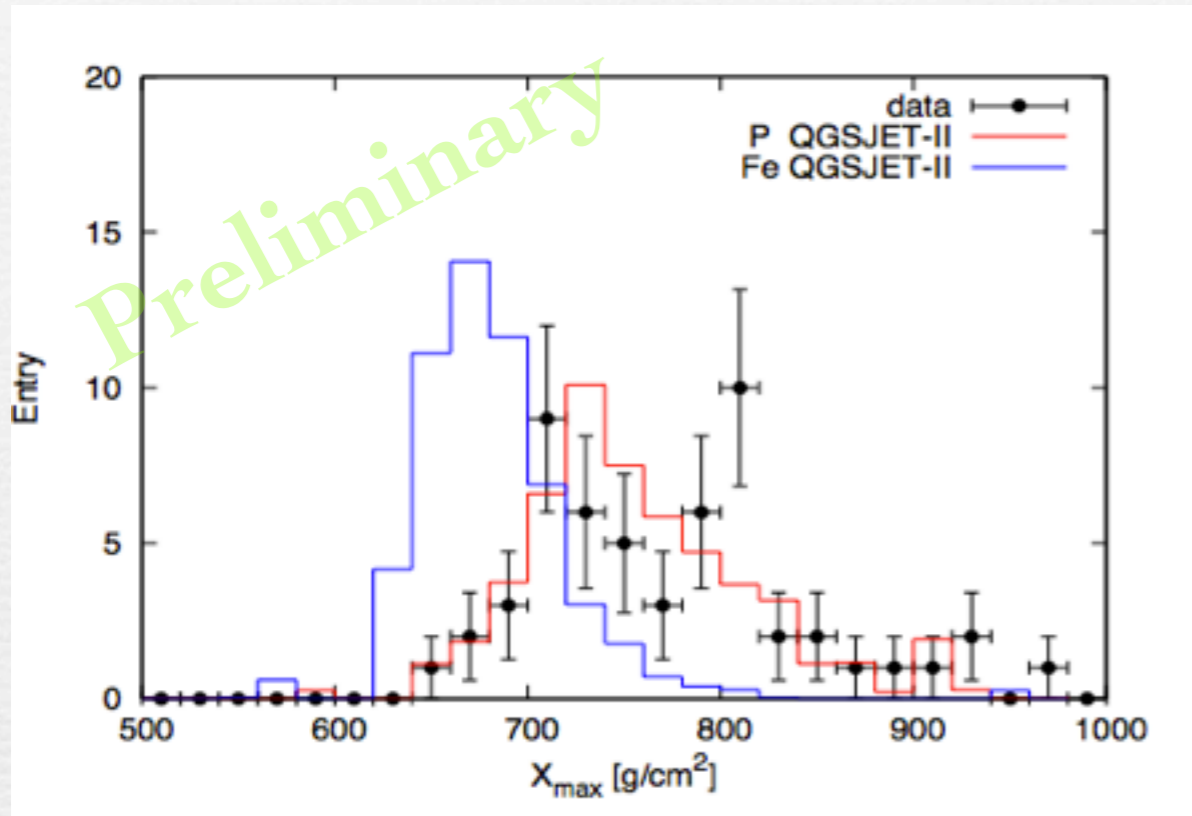


UHECR Spectra: Comparison



Toward UHECR Mass Composition

X_{max} Analysis



— Proton: CORSIKA+FD MC+Trg.

— Iron: CORSIKA+FD MC+Trg.

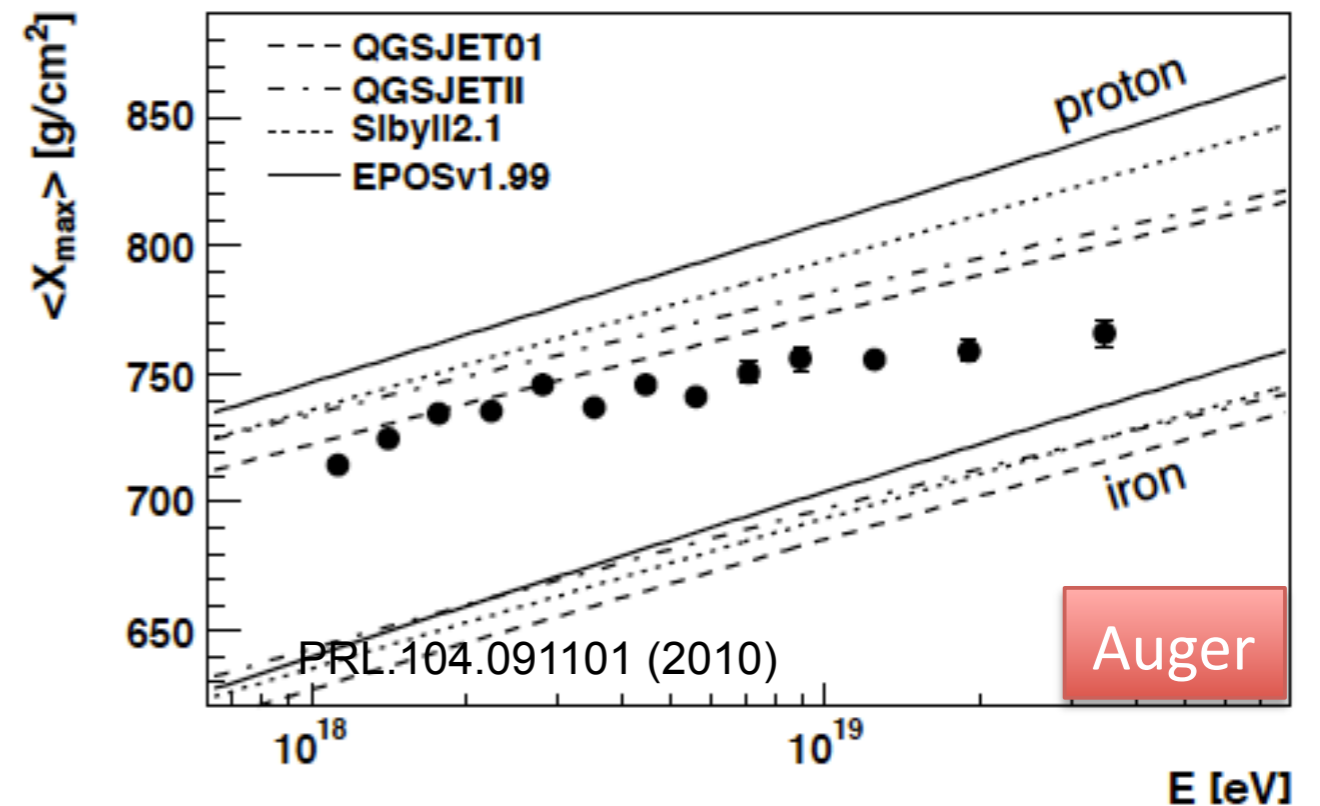
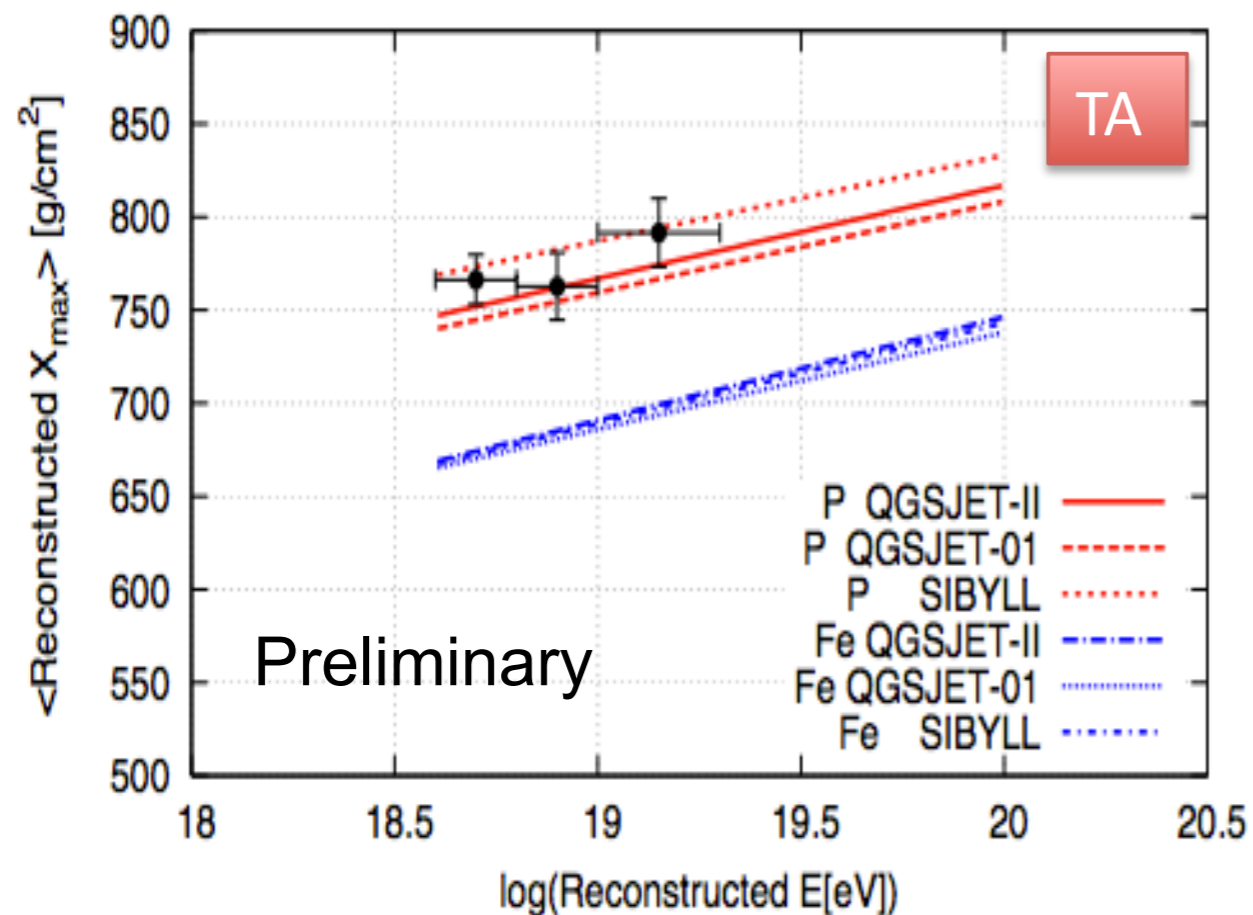
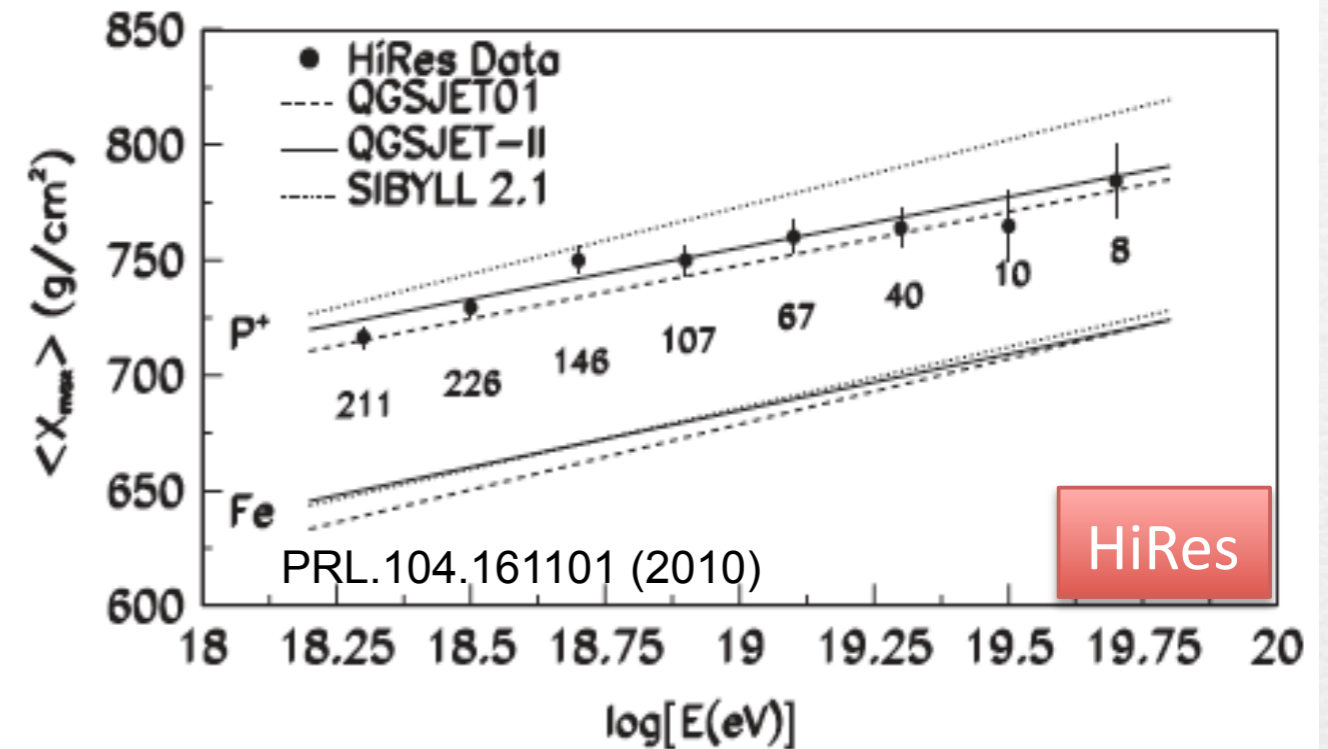
● TA-FD Stereo Data

chi ² /dof	QGSJET-II	QGSJET-1	SIBYLL
Proton	1.44	1.05	1.63
Iron	55.54	56.67	85.71

Toward UHECR Mass Composition

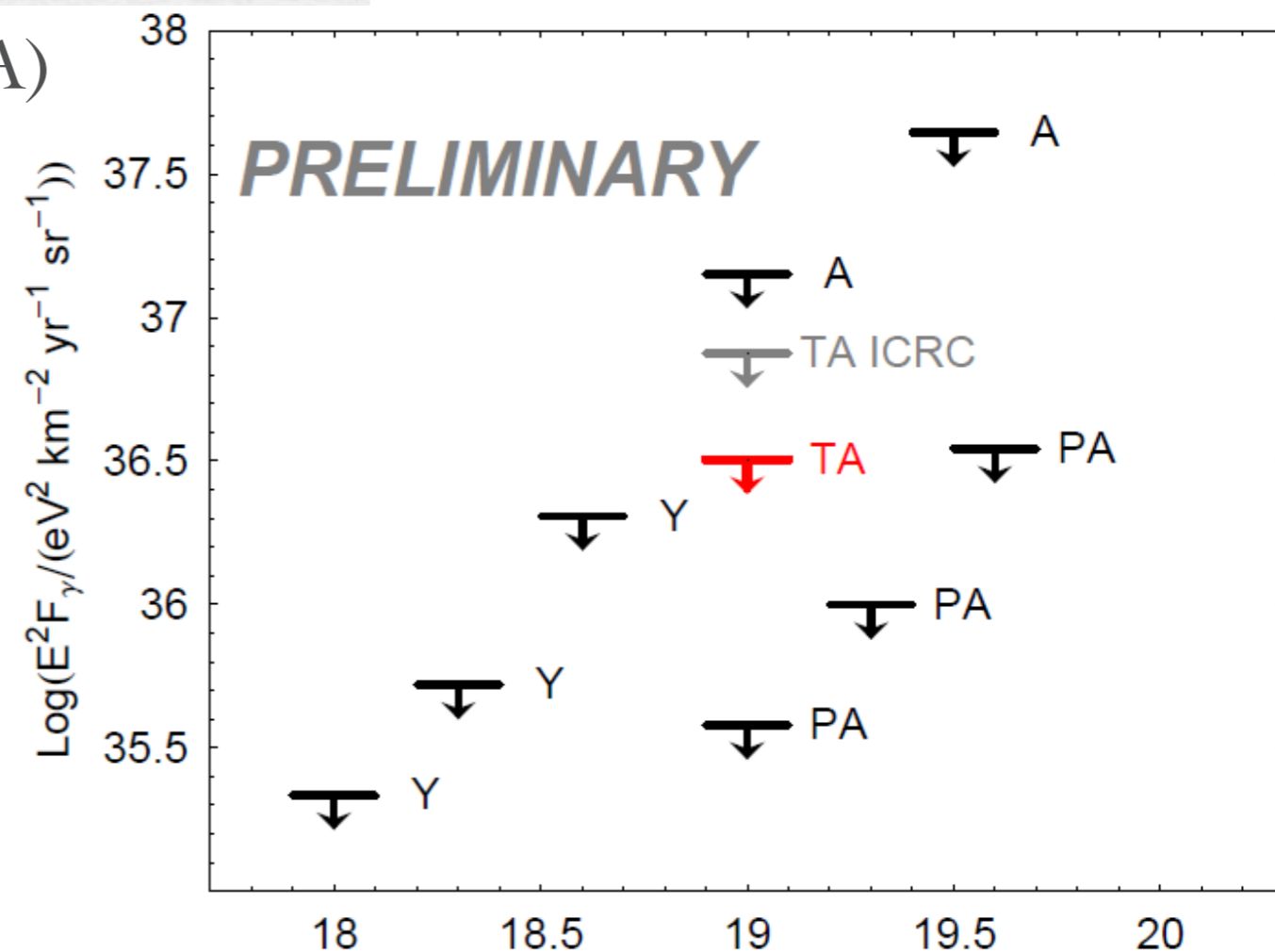
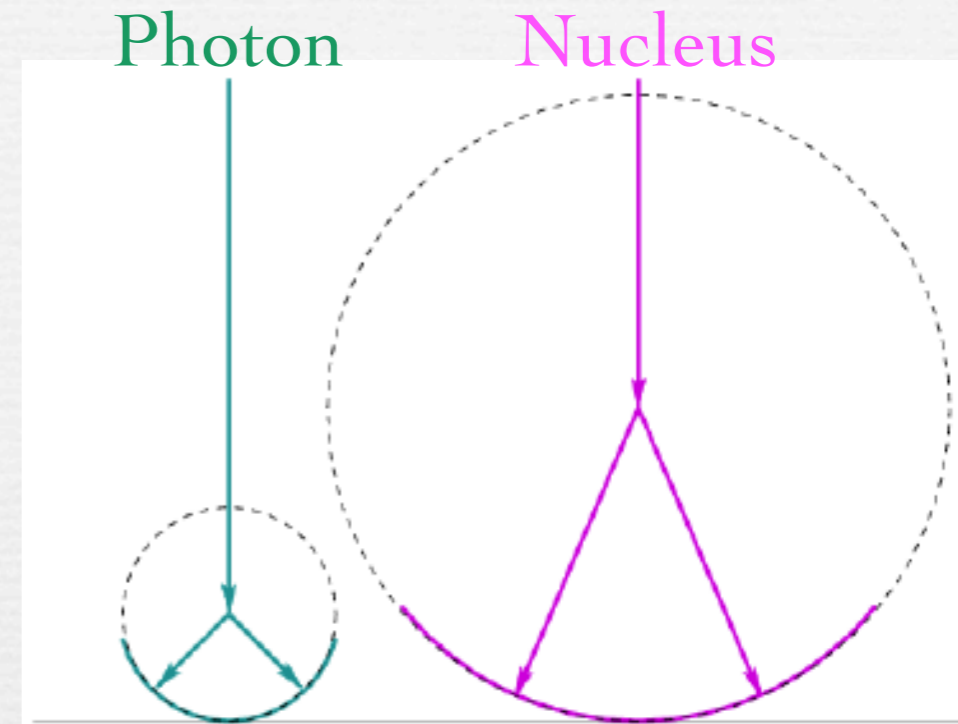
X_{max} Analysis

Energy - Average $\langle X_{max} \rangle$



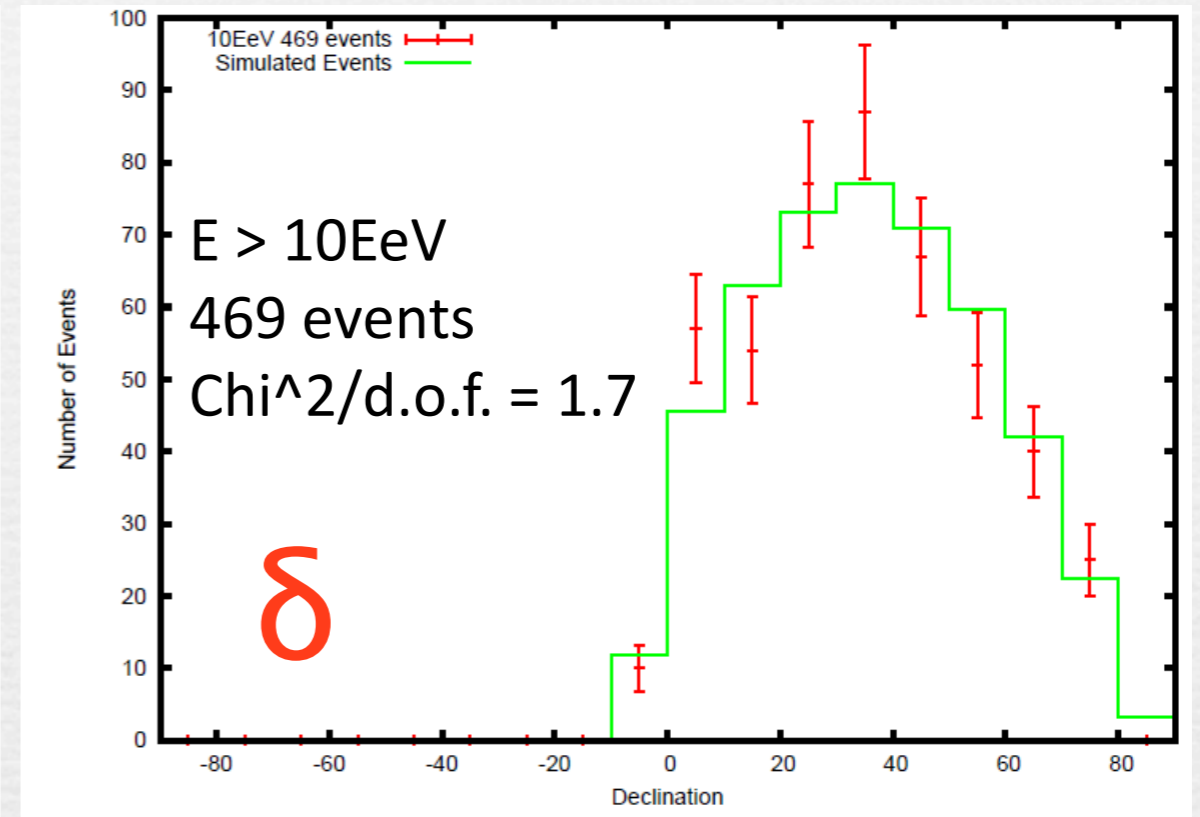
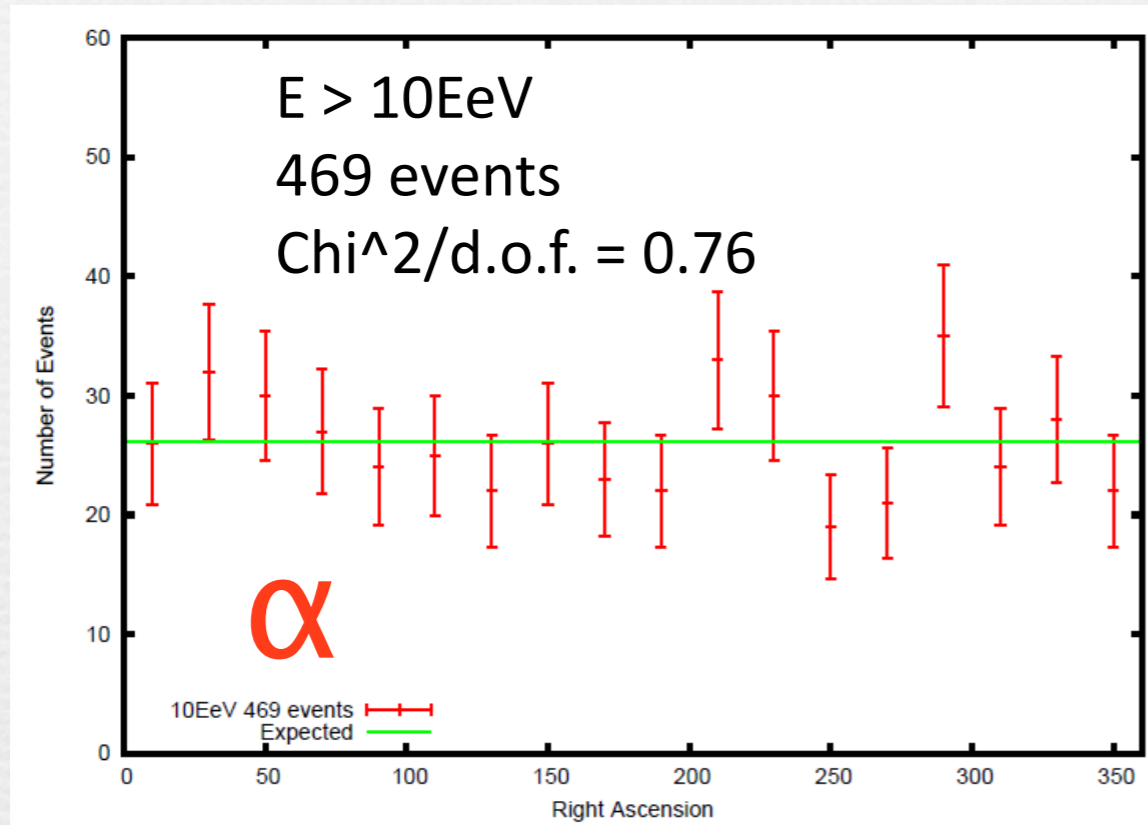
UHE Photon Limit from SD Events

- Photon Showers
 - Deeply penetrated
 - Large curvature at the shower front
- Event selection:
 - $E > 10^{19} \text{ eV}$
 - $45^\circ < \theta < 60^\circ$
 - Proton/Photon discrimination by MC studies
 - (1 event remain)
- Exposure: $158 \text{ [km}^2 \text{ yr sr]} (\sim 0.1 \text{ AGASA})$
- Flux limit:
 - $F < 3.3 \times 10^{-2} \text{ [km}^{-2} \text{ yr}^{-1} \text{ sr}^{-1}] (95\% \text{ CL})$



SD Events: Search for Anisotropies

- Distribution in the Equatorial coordinates:



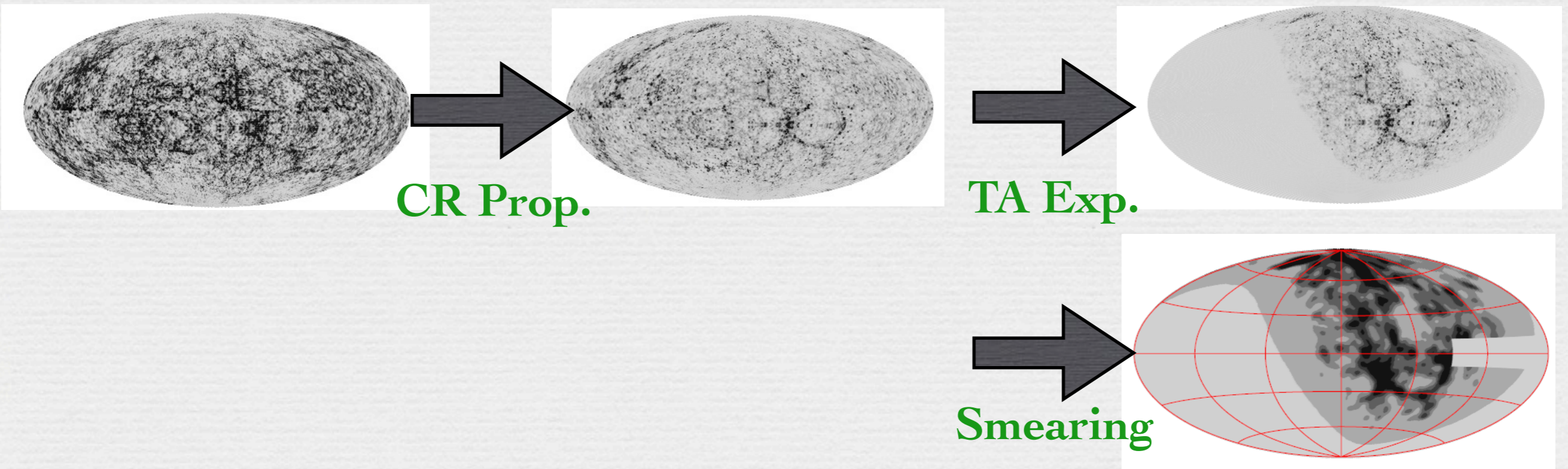
- Search for correlations:

- LSS
- AGNs
- Auto-correlation

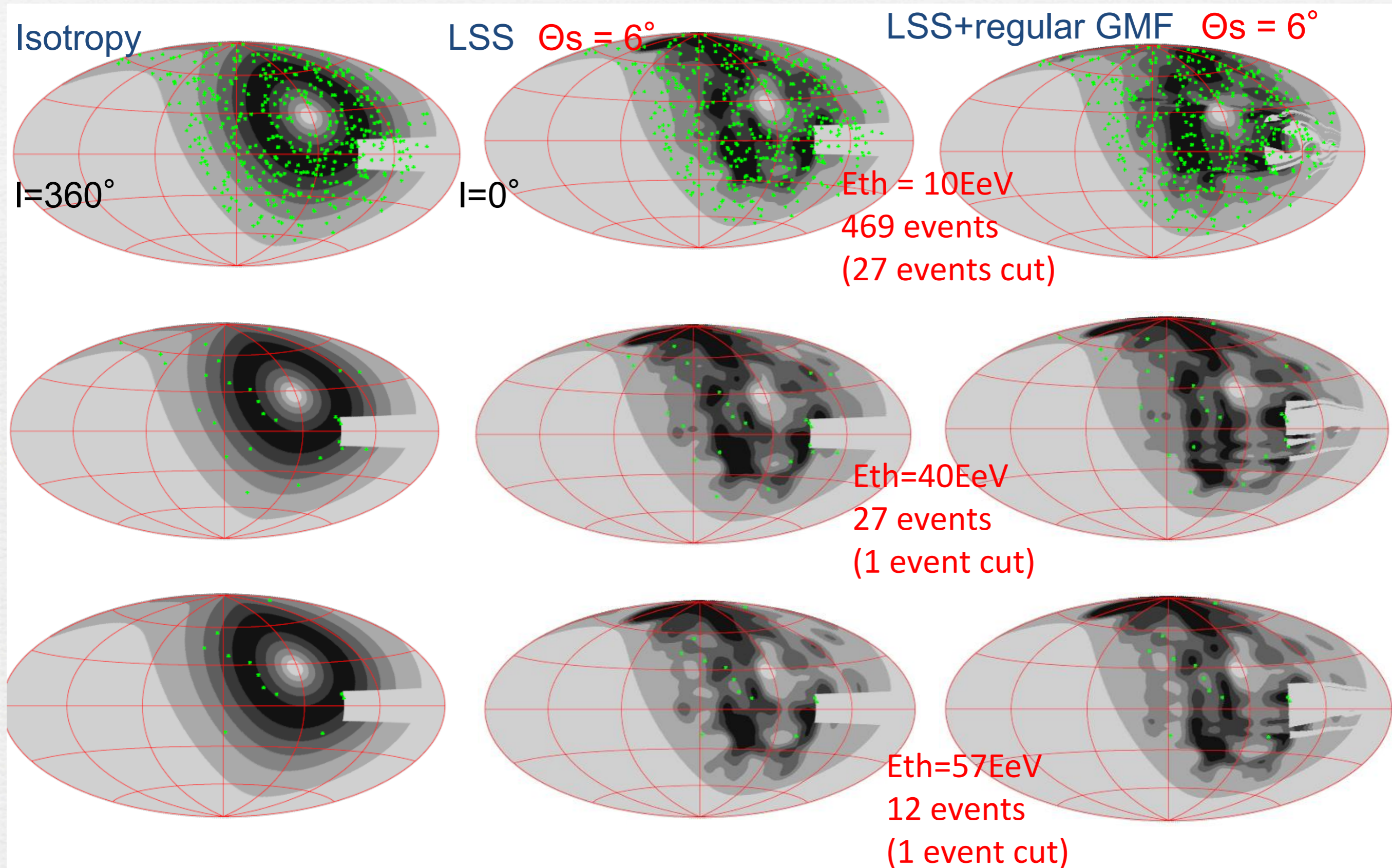
- Angular resolutions:
 - 1.5° @ 10EeV
 - 1° @ 40EeV
- SD energies : Scaled to the FD energies

Simulating UHECR Map from LSS

- Galaxy catalogue: 2Mass Extended Sources (XSCz)
 - $m < 12.5$, $5 \text{ Mpc} < D < 250 \text{ Mpc}$
- Propagation: interaction with CMB photons, 4π dilution
 - Assume same CR luminosity
 - Injection: proton, $E^{-2.2}$
- TA exposure
- *Smearing* effect by intervening magnetic field (Galactic/ex-galactic) --- free parameter

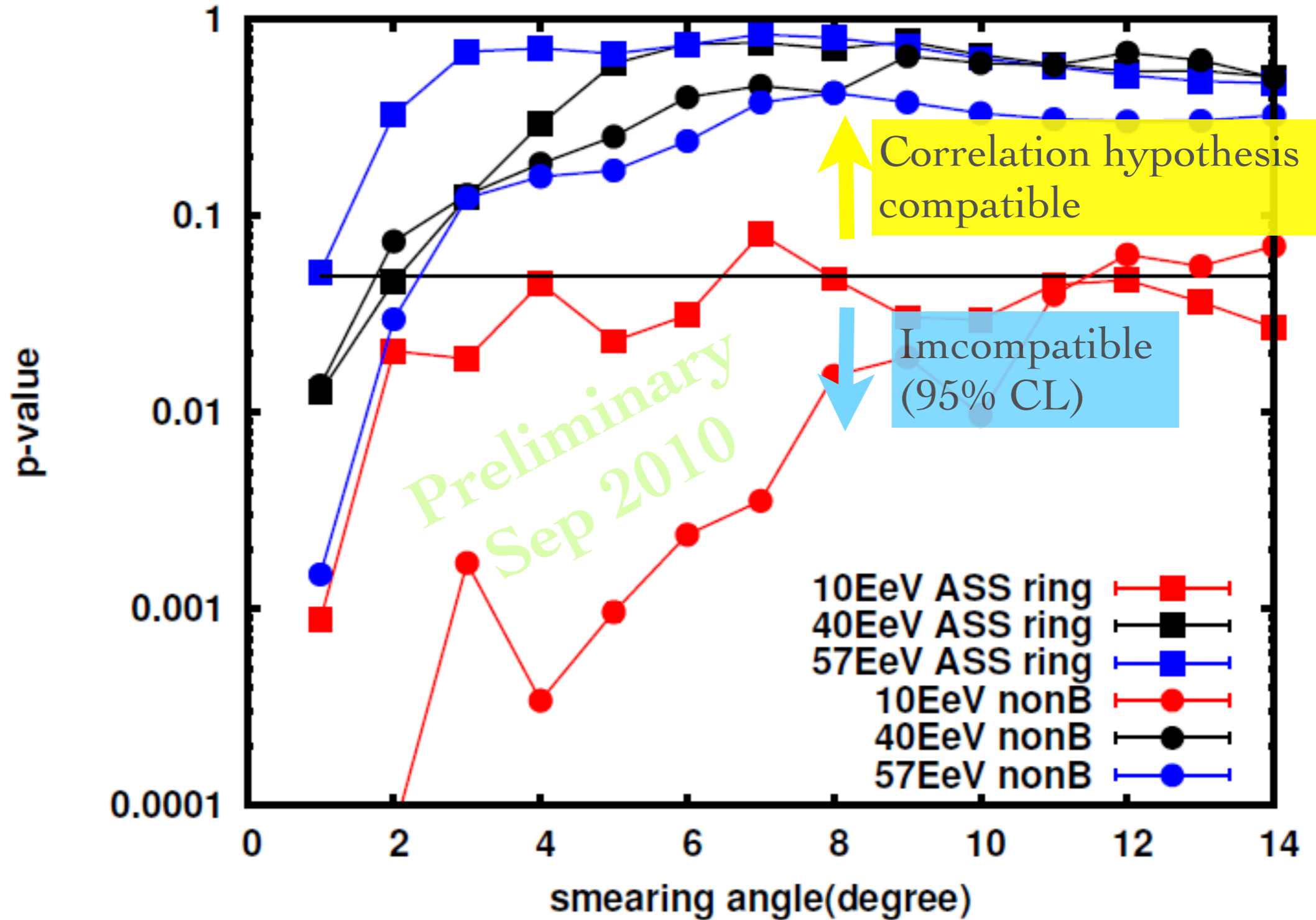


SD Events: LSS Correlation?



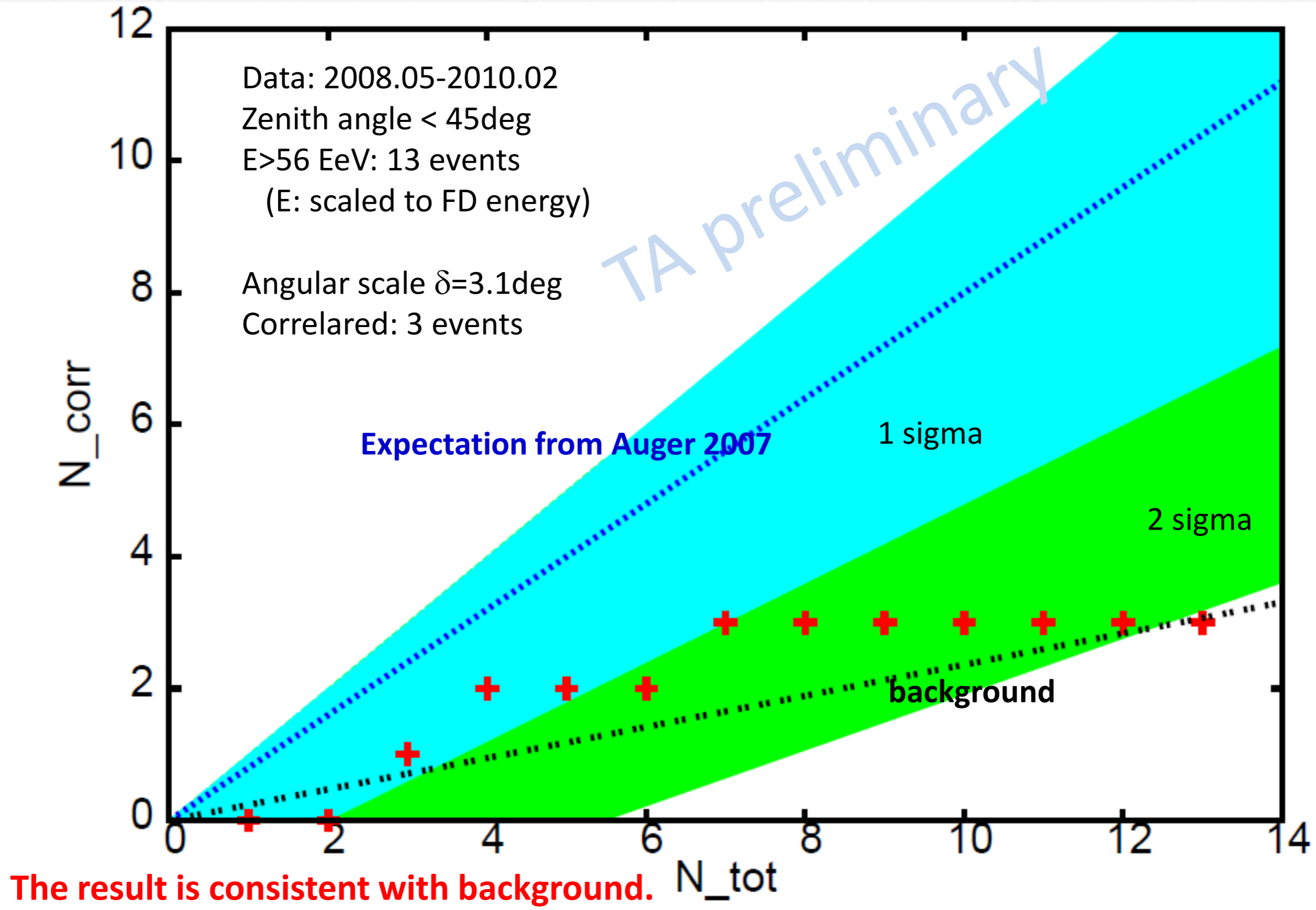
LSS Correlation Hypothesis: Compatibilities

KS-Test:

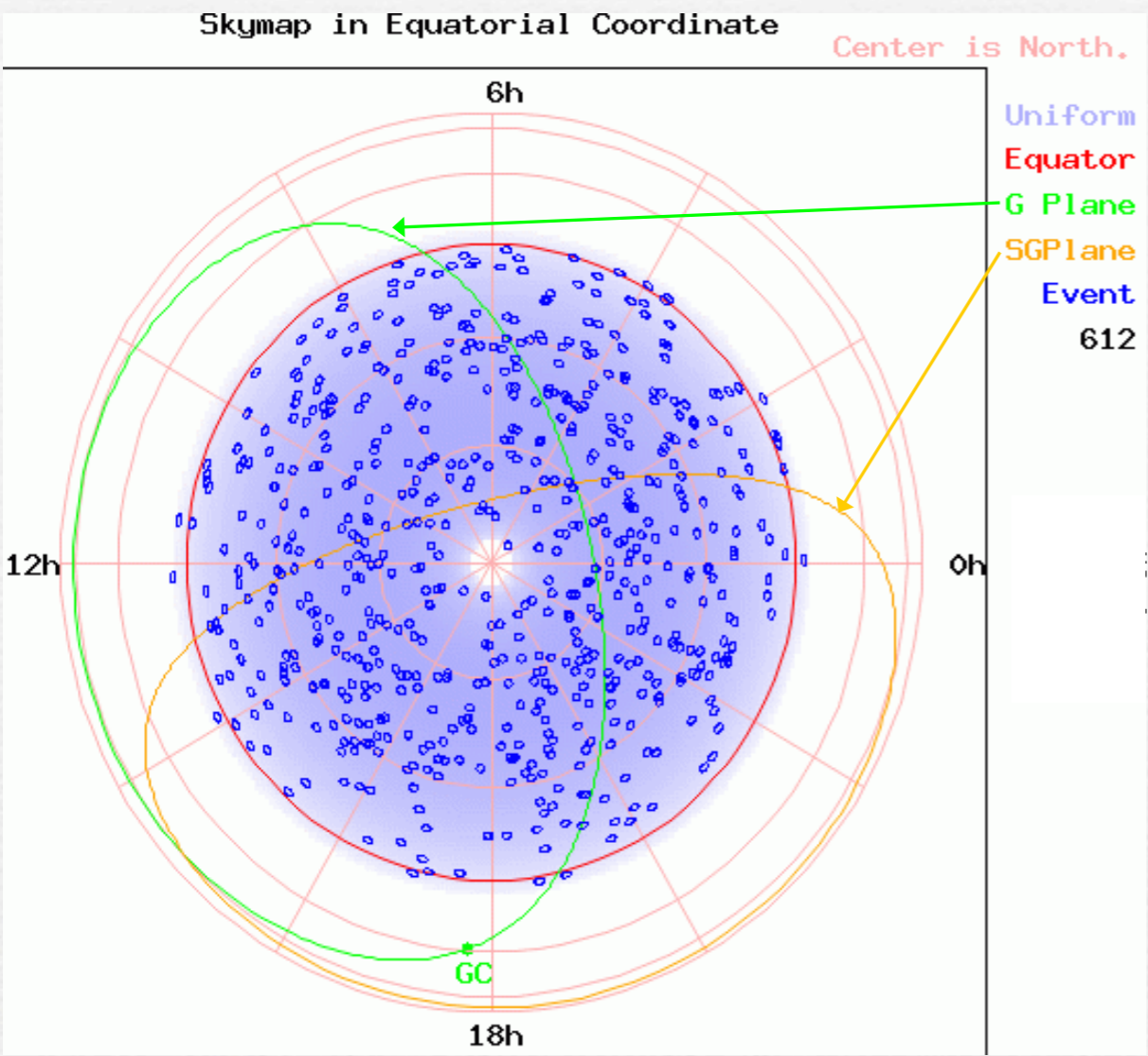


- Incompatible with the LSS correlation hyp. for small smearing angles
 - (Less significant the rather larger p-values for larger smearing angles)

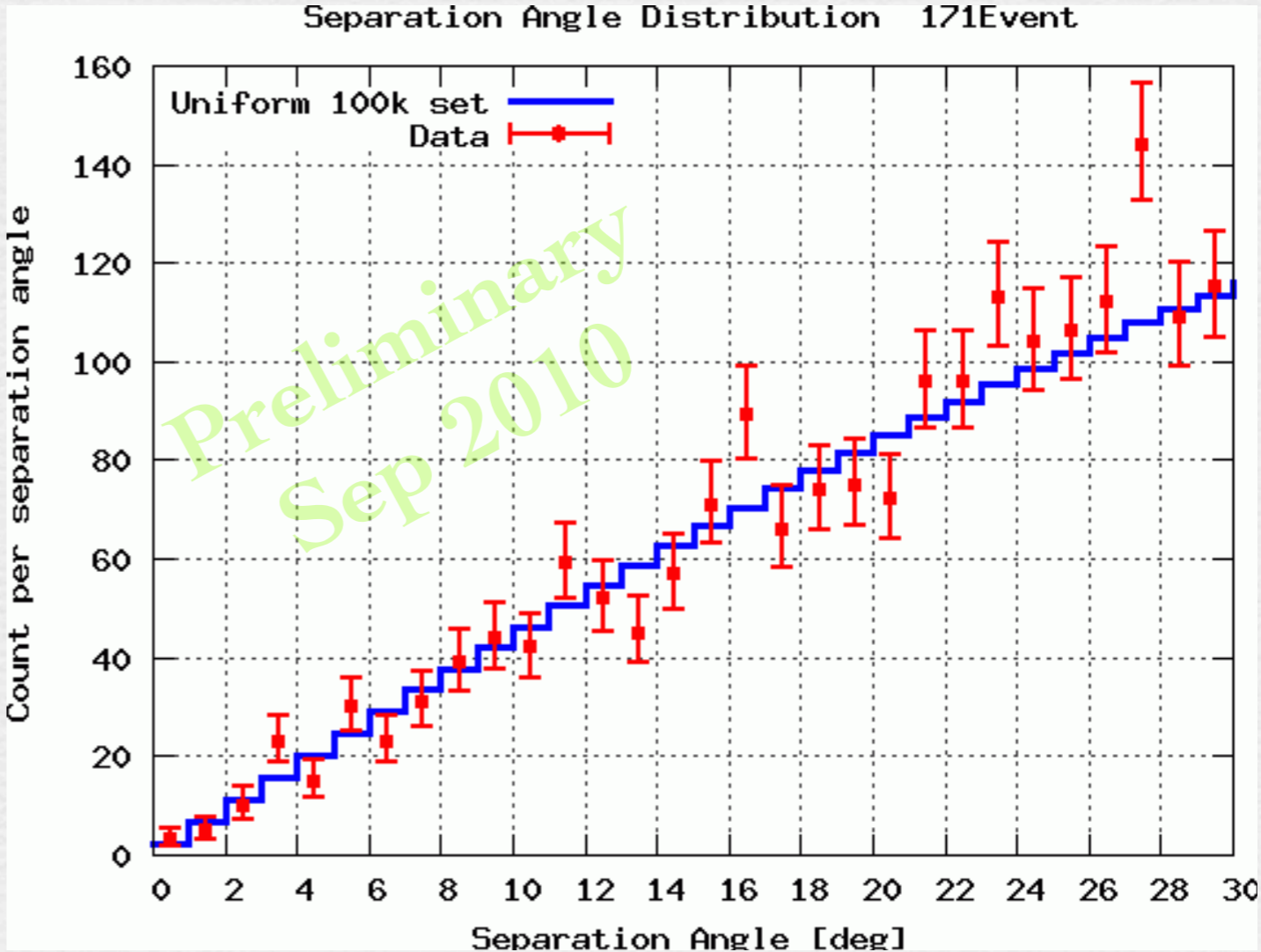
SD Events: AGN Correlation?



SD Events: Search for Clustering



- The number of event pairs in given separation angles is consistent with the expectation from the uniform distribution.



Conclusions

📍 Rapid progress in TA:

- Observation/Exposure
- Analyses

📍 TA *preliminary* results:

- Spectra: FD-mono, FD-hybrid, SD
 - Consistent with the HiRes results
 - SD spectrum: a suppression $> E^{19.75}$ eV (-3.5σ)
 - ❖ (“suppression”: just a statistical meaning, not astrophysical)
 - ❖ (SD energy: -27% scaled to the FD energy)
- Xmax: Consistent with a proton dominant composition
- Anisotropies:
 - No apparent correlation with known sources
 - No significant event clusterings found

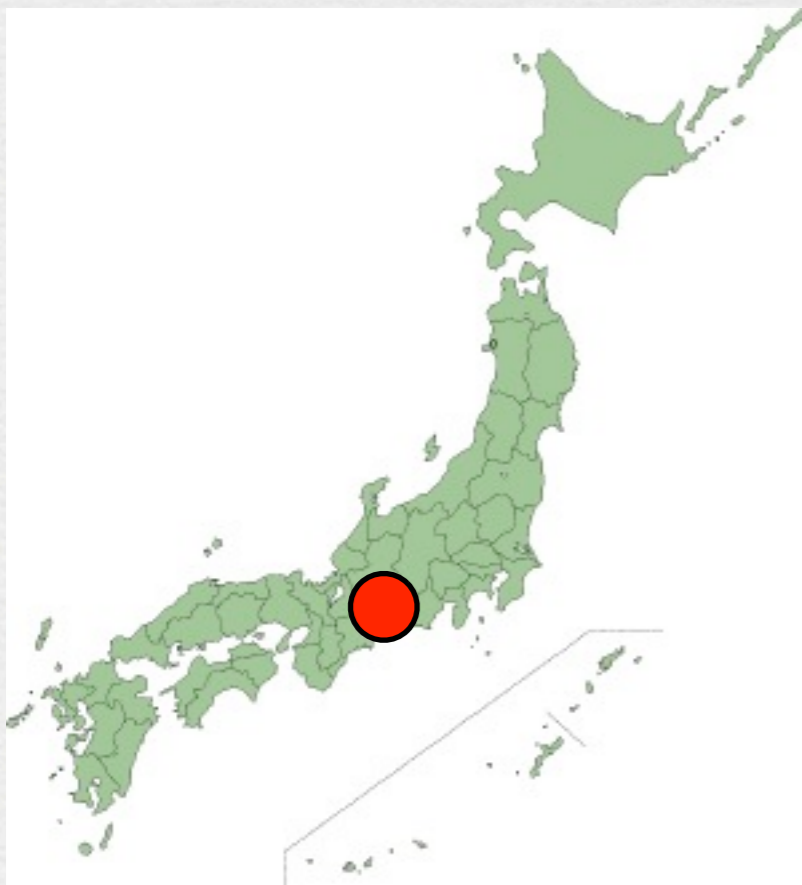
📍 More come...

Announcement: Symposium Invitation

The Symposium on “the Recent Progress of Ultra-High Energy Cosmic Ray Observation”

10-12 December, 2010

Nagoya Congress Center, Nagoya, Aichi, Japan



Y.Tsunesada @ 7AFWS, Coimbra, Portugal 2010/Sep/22