TA Recent Results and Prospects

ISVHECRI-2014

CERN, Geneva

2014/08/19

Masaki Fukushima for Pierre Sokolsky

and the TA Collaboration

Telescope Array Collaboration

~120 collaborators in 5 countries
Japan, USA, Korea, Russia, Belgium

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TA detector in Utah

39.3°N, 112.9°W
~1400 m a.s.l.

3 com. towers

Middle Drum (MD)

~30 km

CLF

ELS

Long Ridge (LR)

Surface Detector (SD)

507 plastic scintillator SDs

1.2 km spacing

700 km²

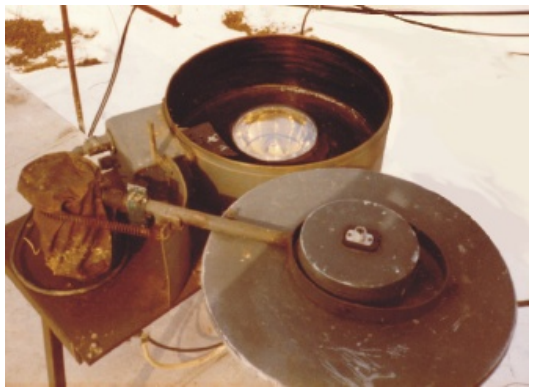
Fluorescence Detector(FD

3 stations

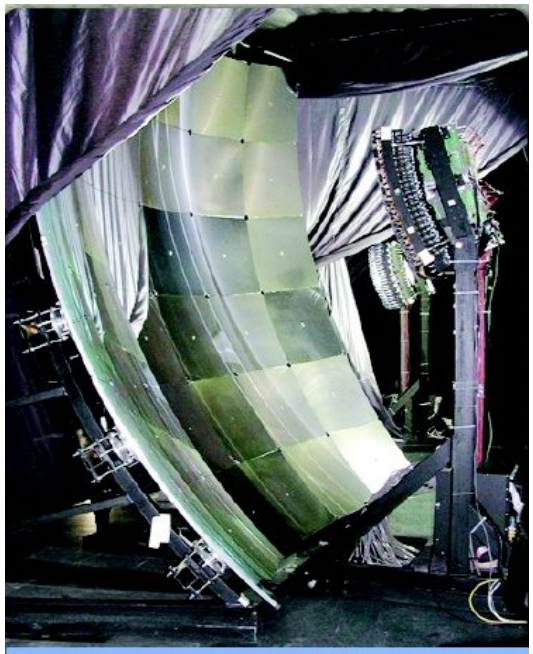
38 telescopes

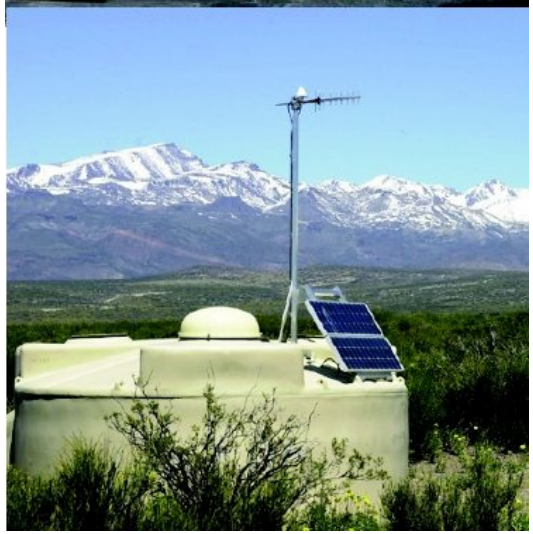
Эксперименты по КЛСВЭ ($E \gtrsim 10^{18}$ эВ)

Yakutsk array

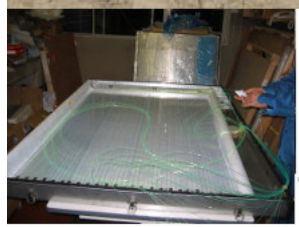


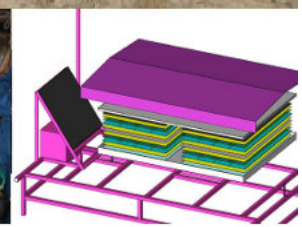
Pierre Auger





Telescope Array





UHE Cosmic Ray Spectrum

SD Data (6 Yrs: 20080511-20140511, 5400 km^2 str yr)

Broken Power Law Fit

γ_1 = -3.298 +/- 0.029

γ_2 = -2.673 +/- 0.028

Log(E_GZK/eV) = 19.74 +/- 0.038

γ_3 = -4.539 +/- 0.441

Significance of GZK Effect:

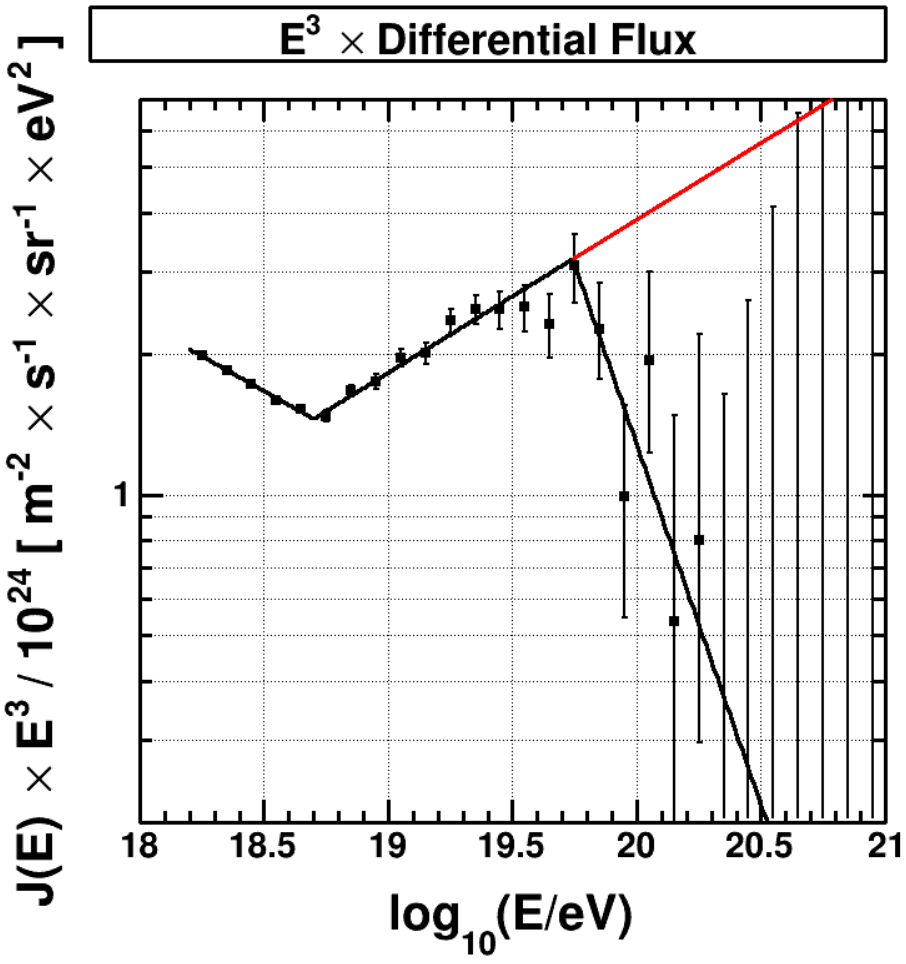
Integrate log10(E/eV) = 19.8 to 21.0

N_{exp} = 85.9 N_{obs} = 32

GZK $_{Chance\ Prob}$ = 2.248e-11 = 6.59σ

Berezinsky $E_{1/2}$:

Log(E/eV) = 19.73 +/- 0.042

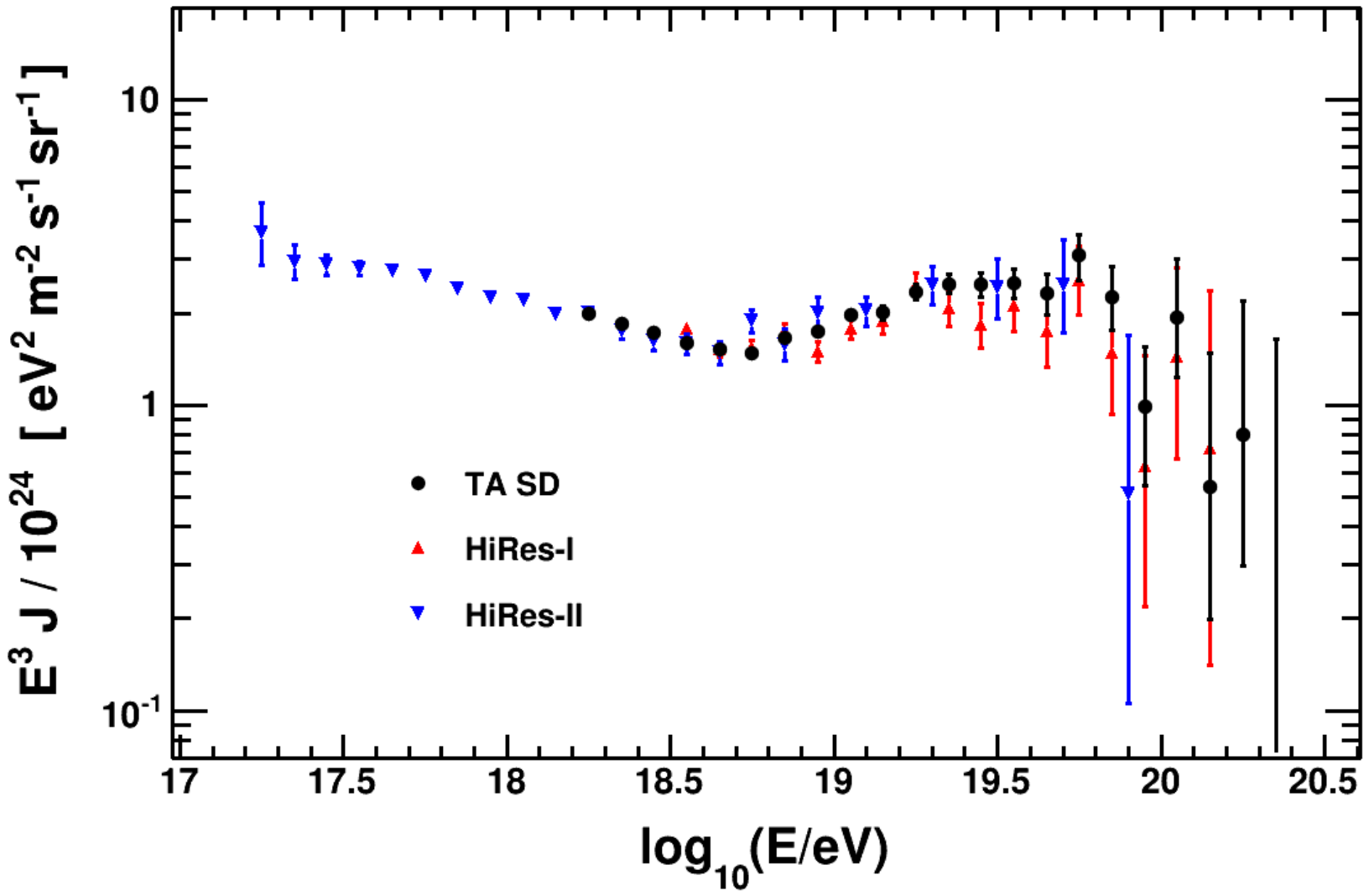


Break significance = 6.59σ

CR Spectrum

SD Data (6 Yrs: 20080511-20140511)

Comparison with HiRes-I and HiRes-2



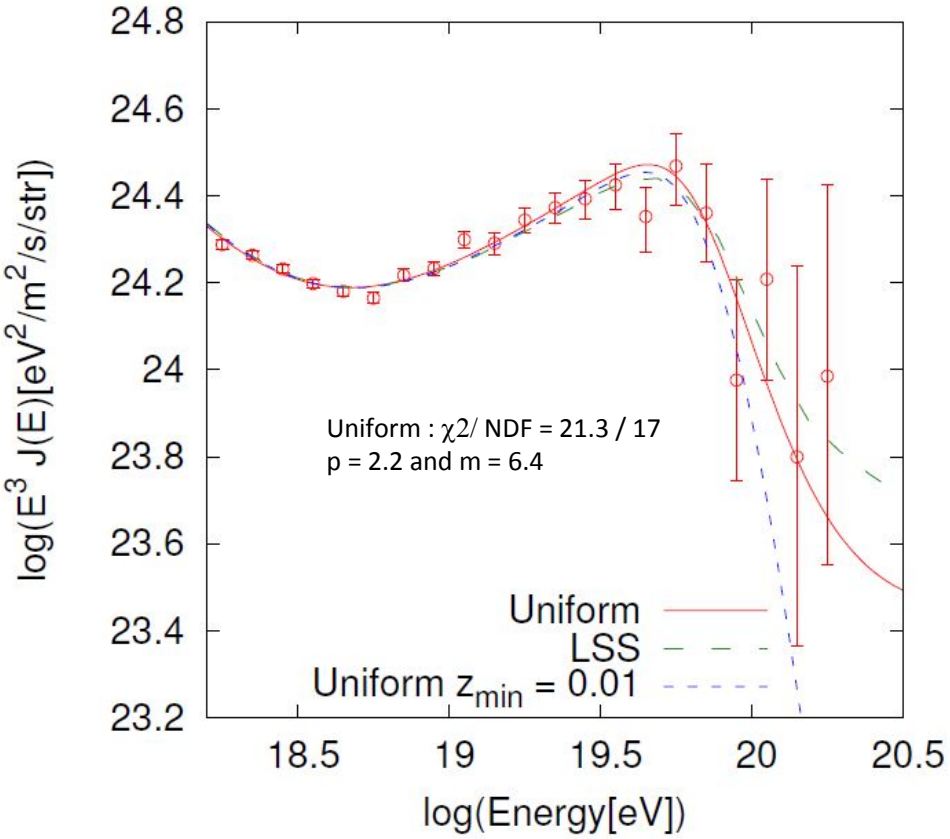
Fitting TA Spectrum with extra-Galactic Proton

Energy Loss with
- CMB
- Infra-Red

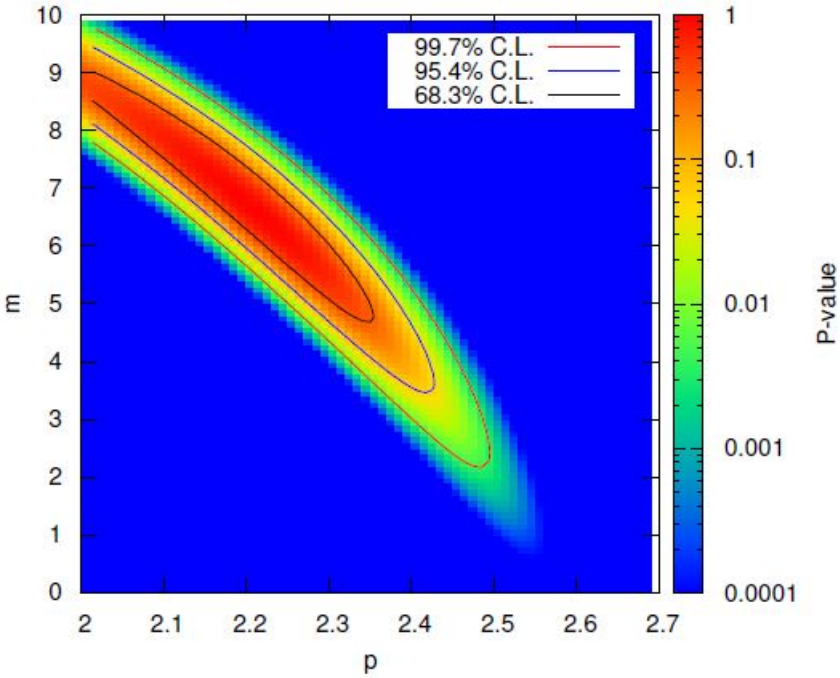
using CRPropa 2.0 checked with transport eq.
(Kalachev+Kido, arXiv:1406.0735)

Source Distribution
- Uniform
- LSS (~2MASS XSCz) up to 250 Mpc
- No magnetic field

4-parameter fit
- Injection spectrum : E^{-p} $E_{max} = 10^{21}$ eV
- Evolution : $(1+z)^m$
- Flux normalization
- Energy scale



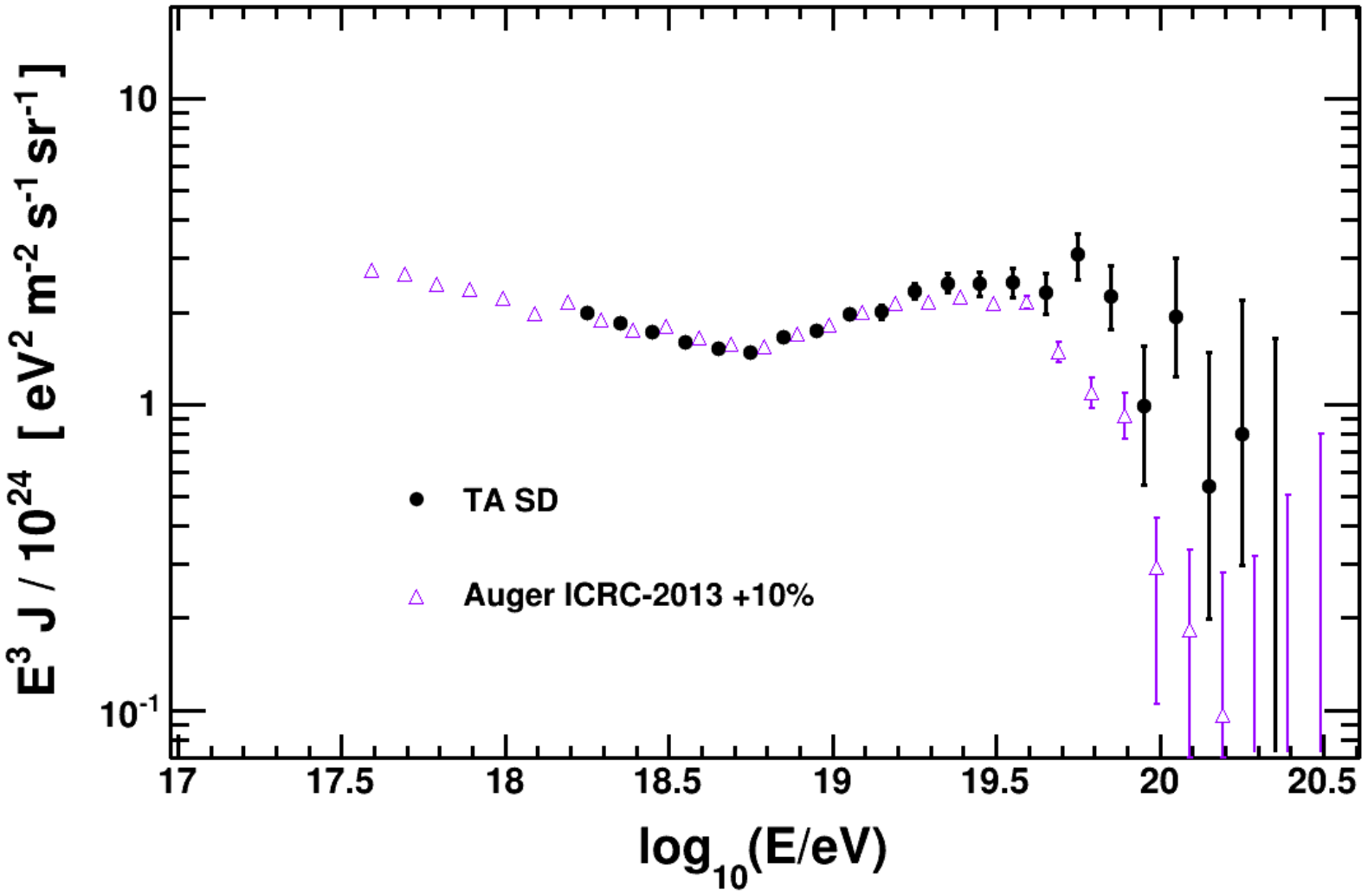
Preliminary



CR Spectrum

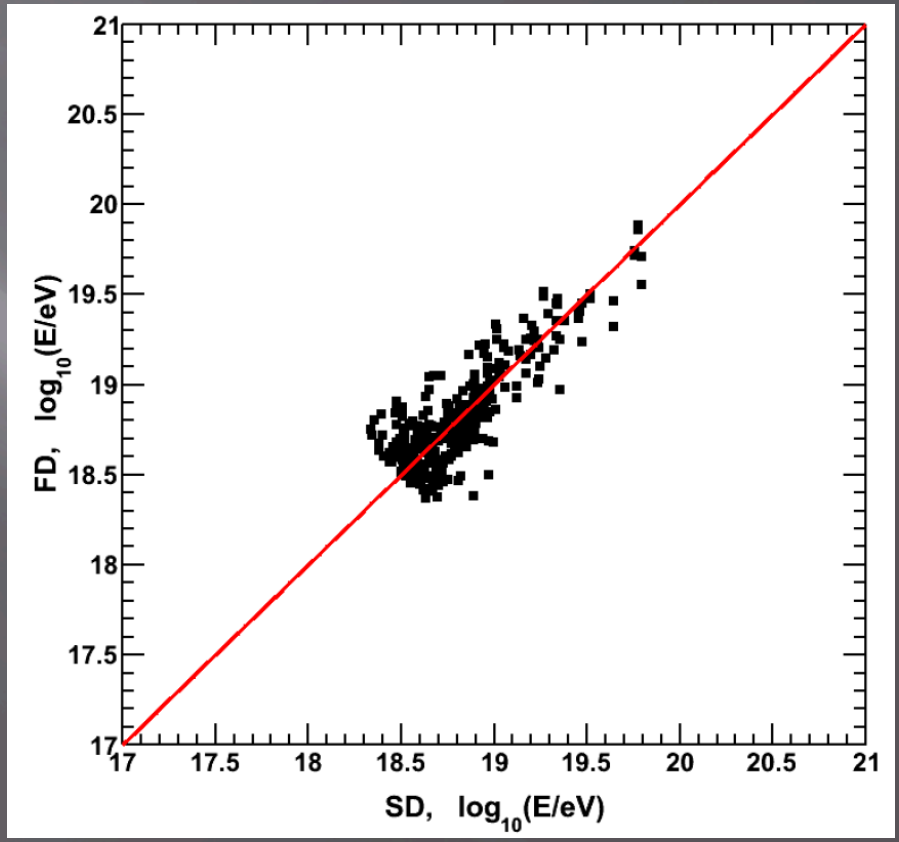
SD Data (6 Yrs: 20080511-20140511)

Comparison with Auger: ICRC 2013 + 10%



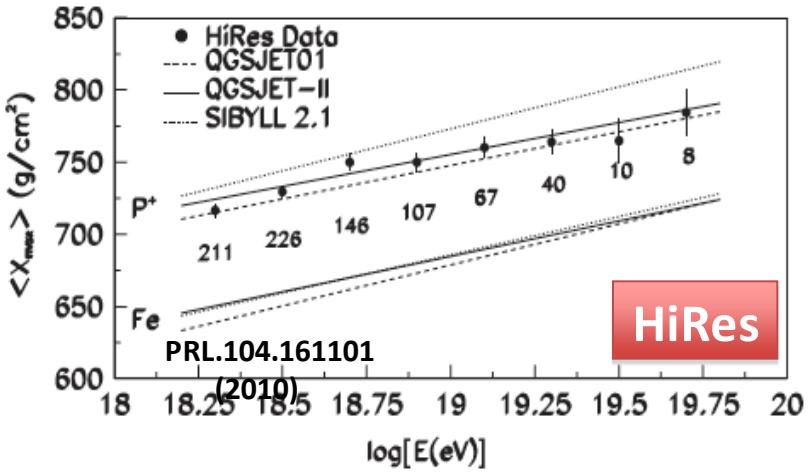
Energy Scale

- 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

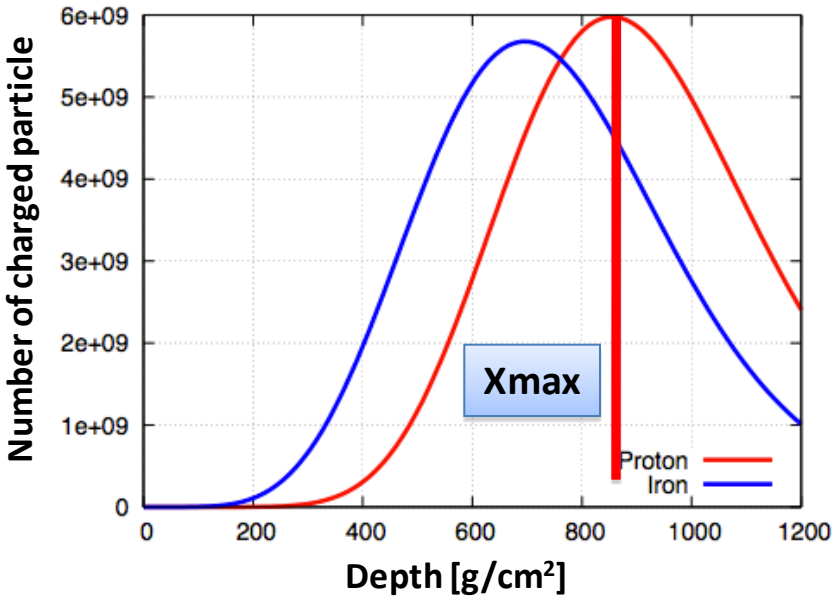


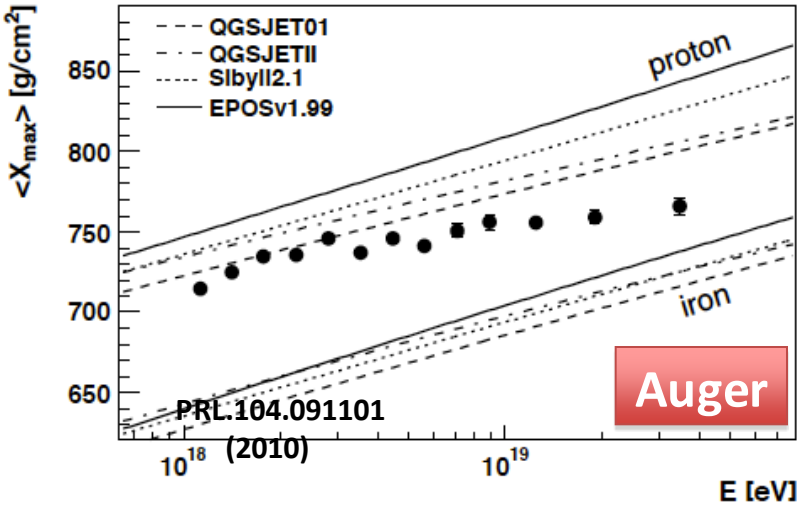
Xmax Technique

- Shower longitudinal development depends on primary particle type.
- FD observes shower development directly.
- Xmax is the most efficient parameter for determining primary particle type.



Shower longitudinal development





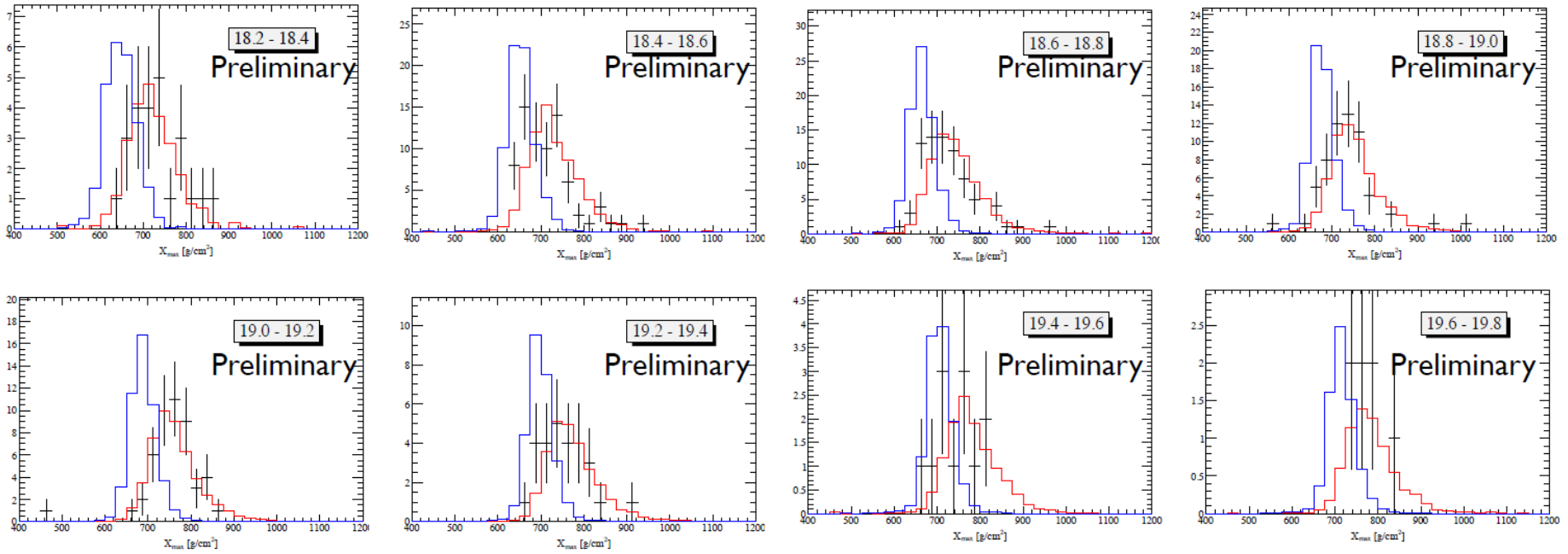
FD Stereo Xmax

Blue: Iron (QGSJET-II-03)

Red: Proton (QGSJET-II-03)

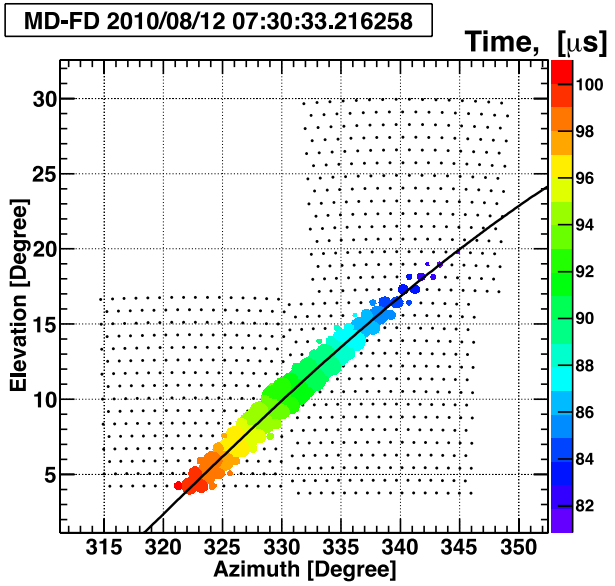
Black: Data

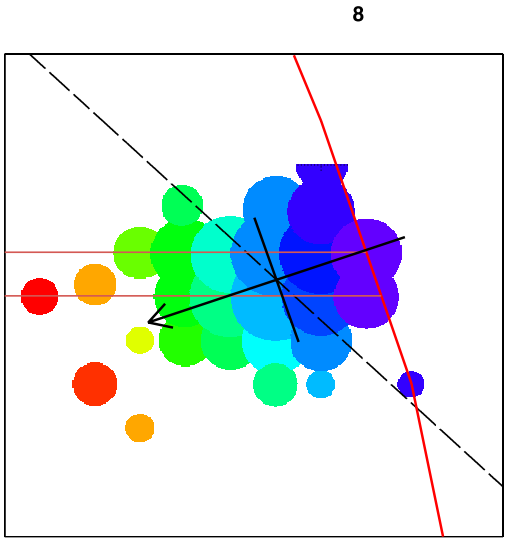
Y.Tameda
ICRC2013

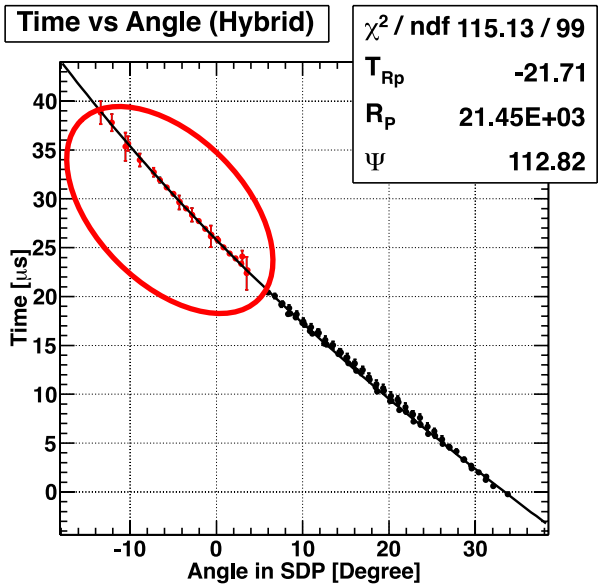


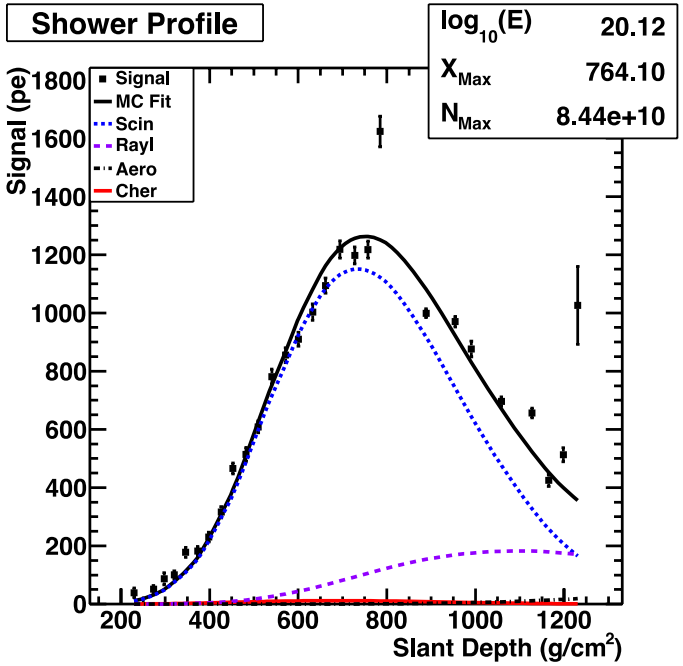
The TA data (stereo) is consistent with QGSJET-II-03 proton prediction.

High Energy Hybrid Event







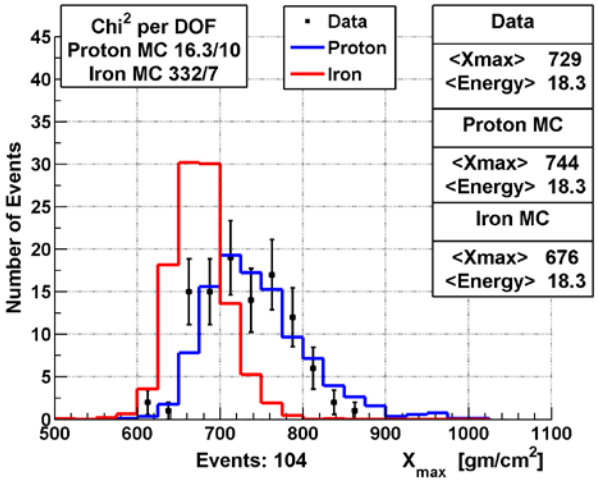


Energy: 1.282 10^{20} eV

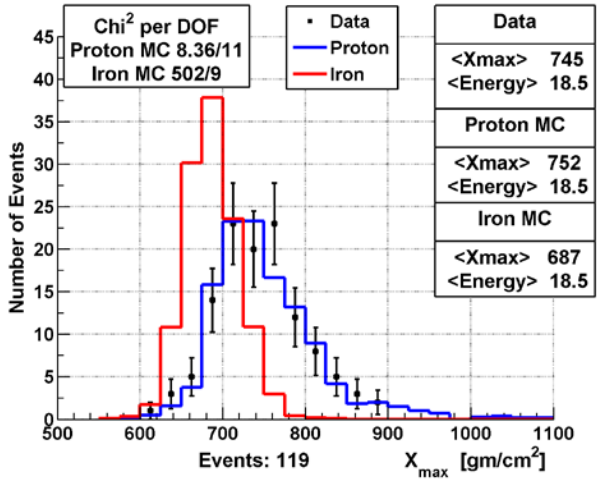
Zenith Angle: 55.7°

Surface array constrains geometry fit via extra timing & core information

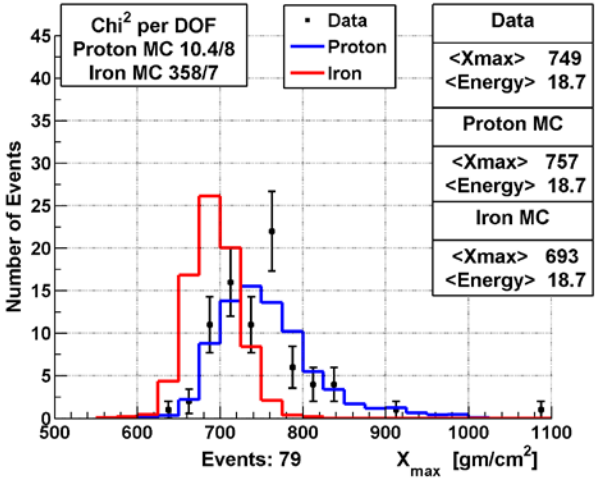
Xmax in Energy Slices
Comparison to p/Fe MC



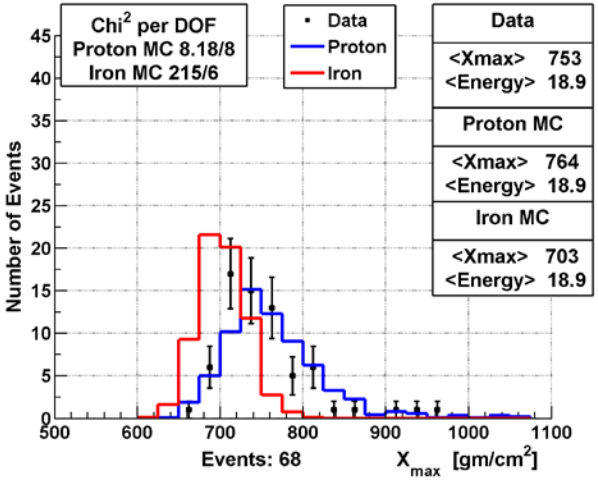
18.2 < Log10(E/eV) < 18.4



18.4 < Log10(E/eV) < 18.6

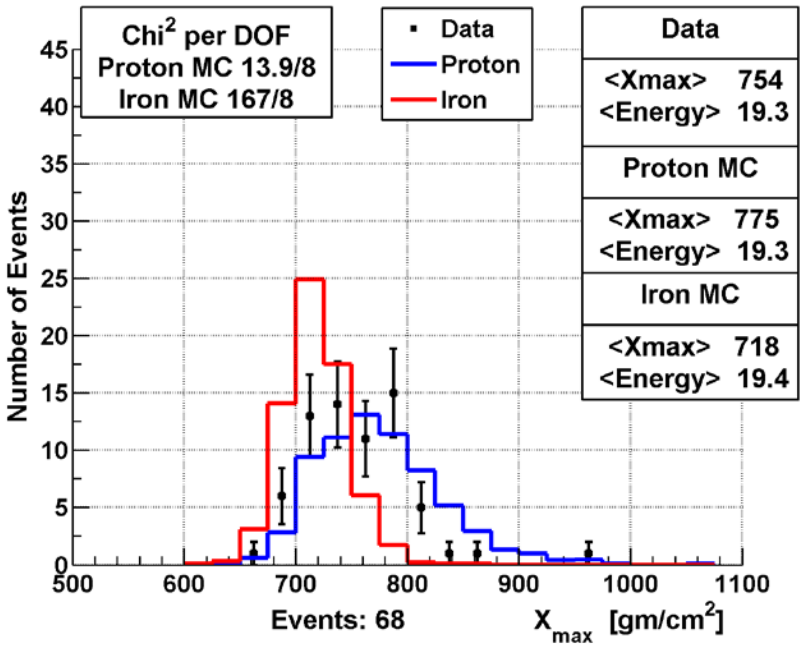


18.6 < Log10(E/eV) < 18.8

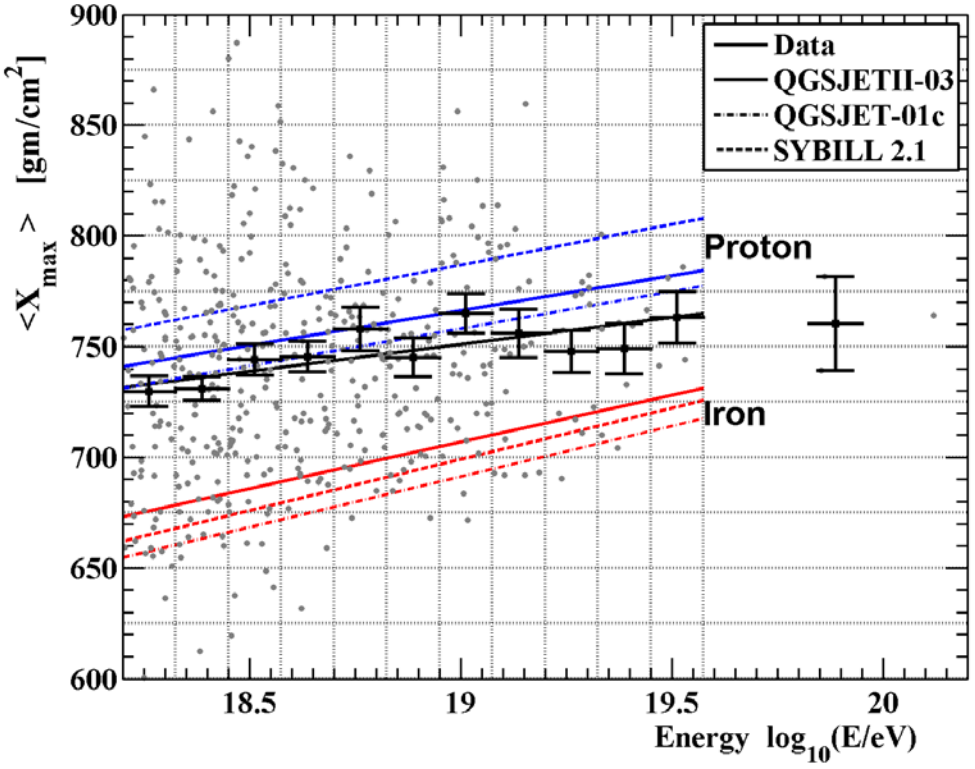


18.8 < Log10(E/eV) < 19.0

Xmax in Energy Slices
Comparison to p/Fe MC

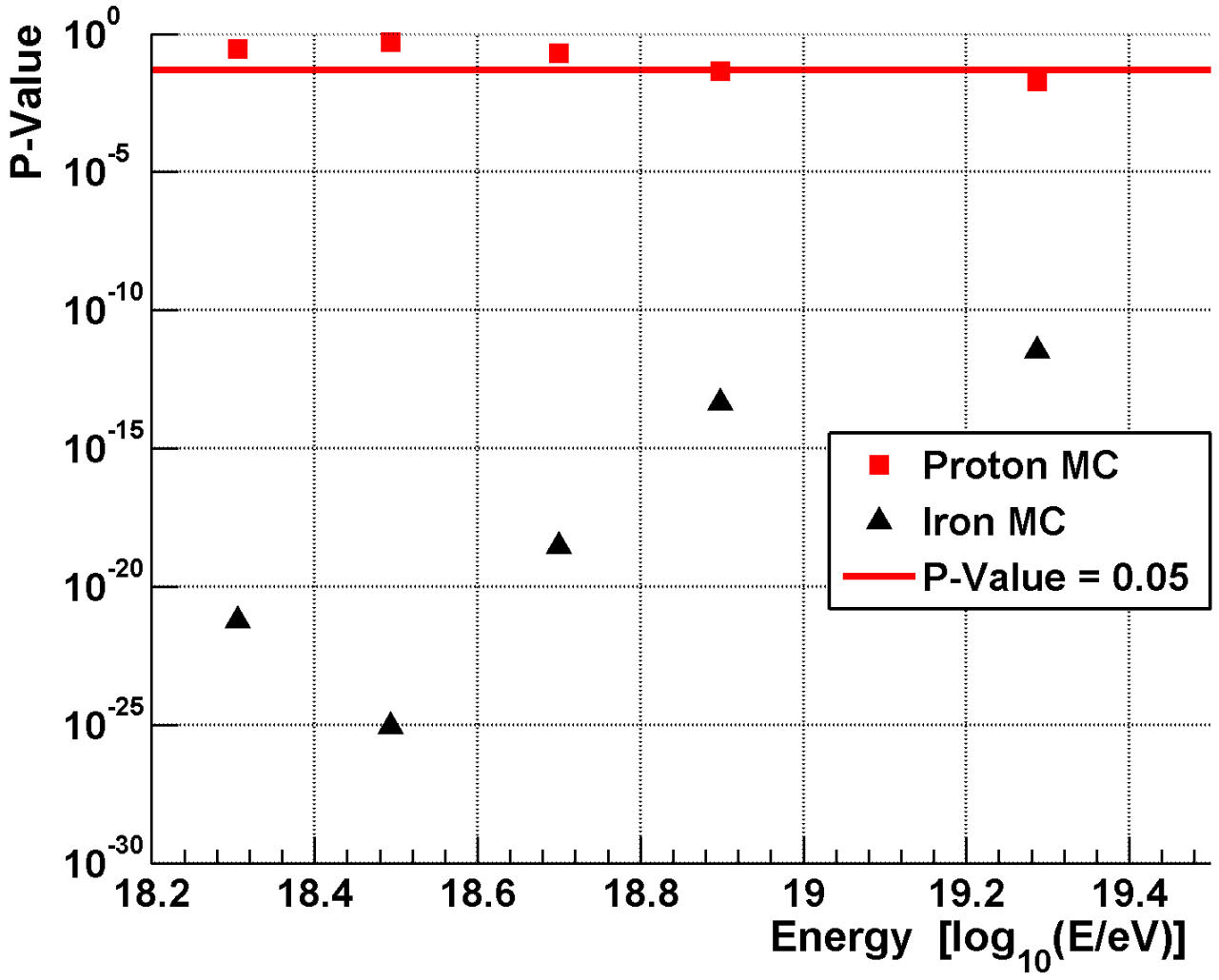


Log10(E/eV) > 19.0



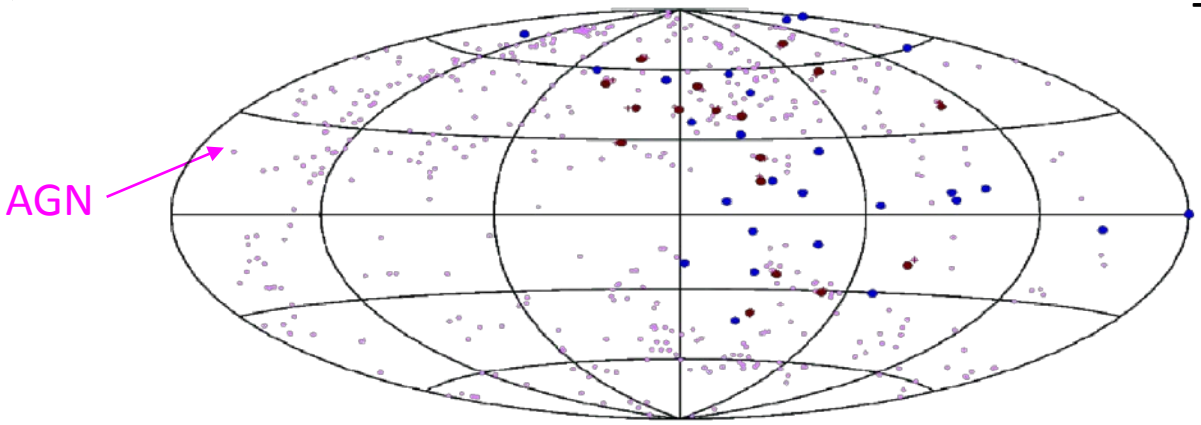
Results are consistent with proton at all energies and inconsistent with iron.

KS Test


P-Value
10^{0}
10^{-5}
10^{-10}
10^{-15}
10^{-20}
10^{-25}
10^{-30}
18.2
18.4
18.6
18.8
19
19.2
19.4
Energy [$\log_{10}$(E/eV)]
Proton MC
Iron MC
P-Value = 0.05

Correlation with AGNs

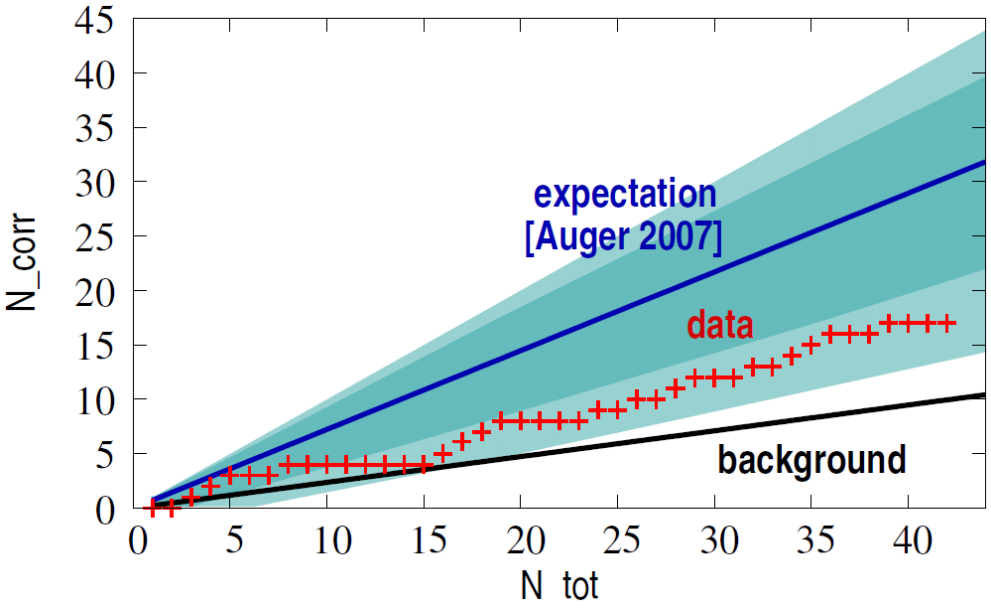
P. Tiynakov
ICRC2013



TA events:
- correlated
- not correlated

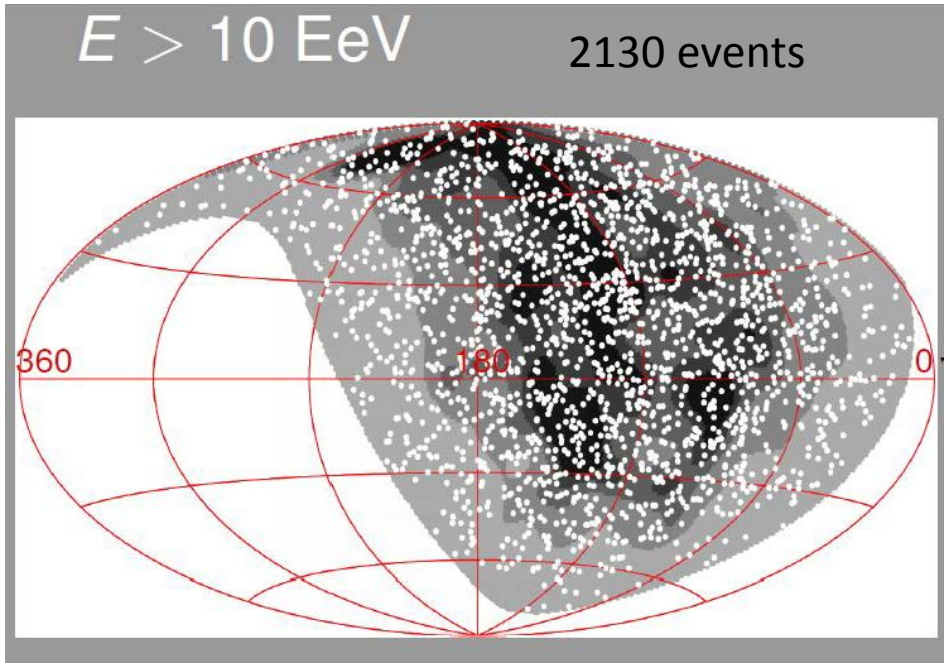
- 42 UHECR events
  (>57EeV, θ<45°, 5 years)
- 472 AGNs from VCV catalog
- Separation angle : 3.1°

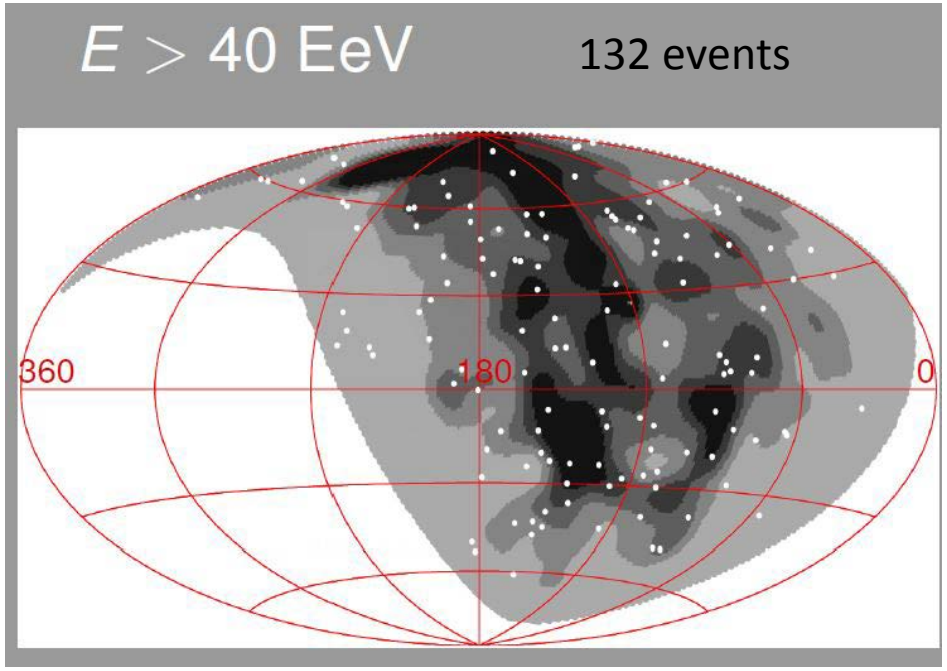
- 17 events correlate out of 42
  → Chance probability p=1.4%

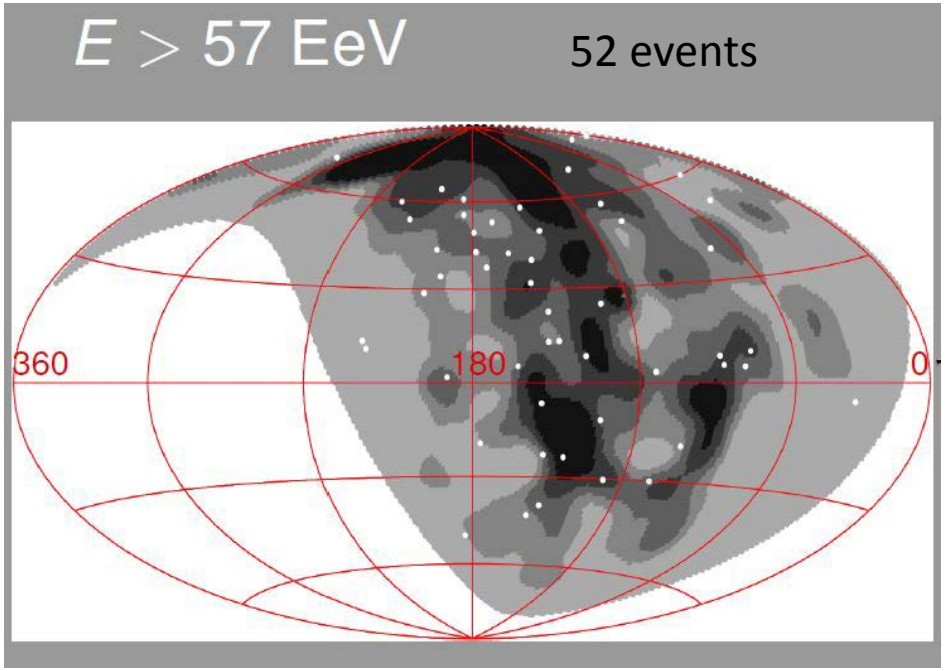


P. Tinyakov, ICRC2013

TA Skyplots







Correlation with LSS

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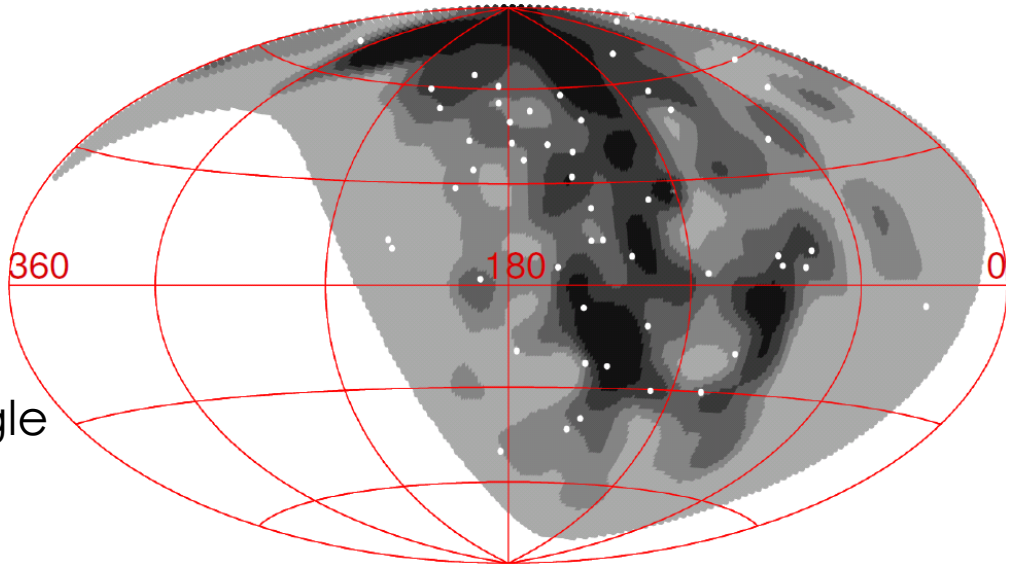
ICRC2013

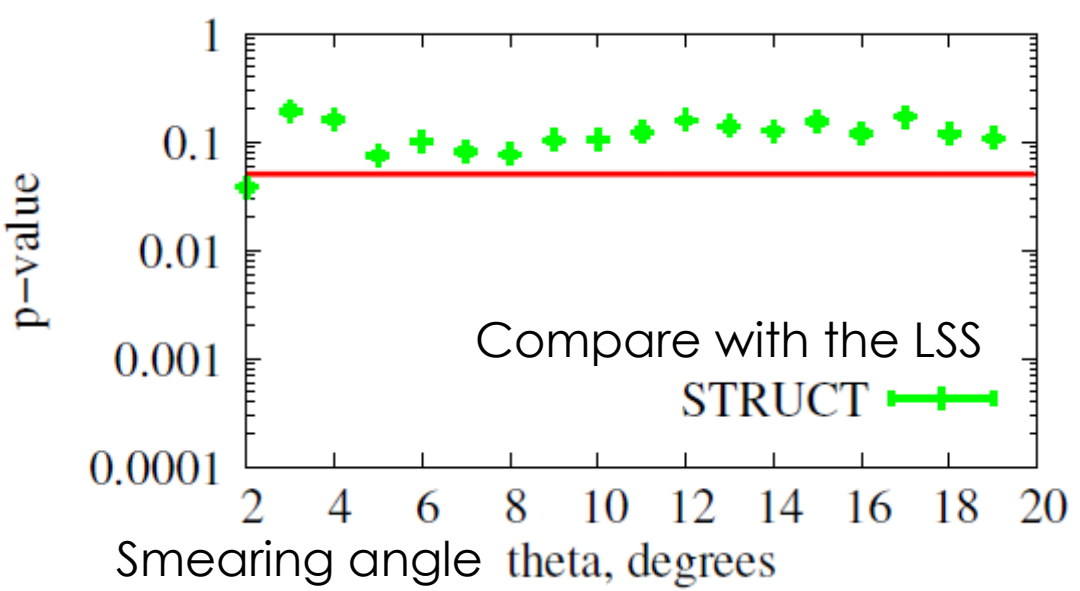
- Large-Scale Structure model
  2MASS Galaxy catalog (XSCz)
  Protons form sources

- Grey Pattern: Model with
  TA exposure at 6° smearing angle
- White points: >57 EeV TA data



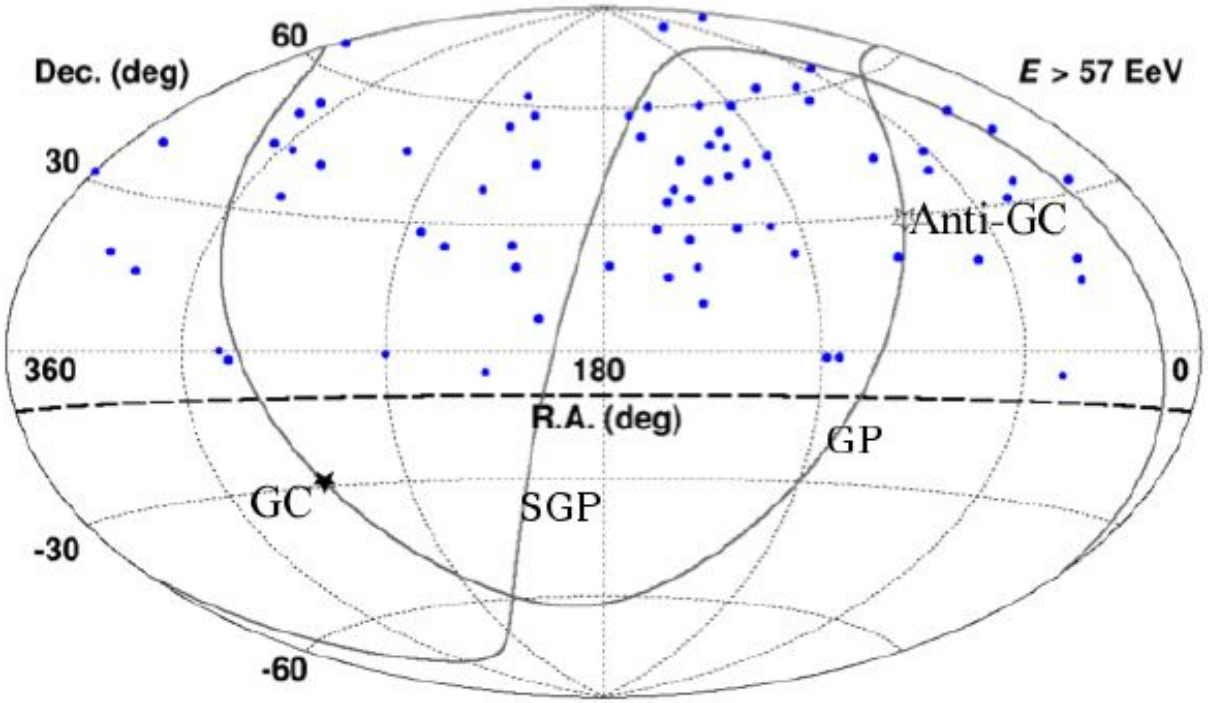
- Our data is consistent with the LSS model ~10%
  In all smearing angles.

- Consistency with isotropy at 6° smearing angle
  Is ~0.1% level.



Hotspot

arXiv:1404.5890

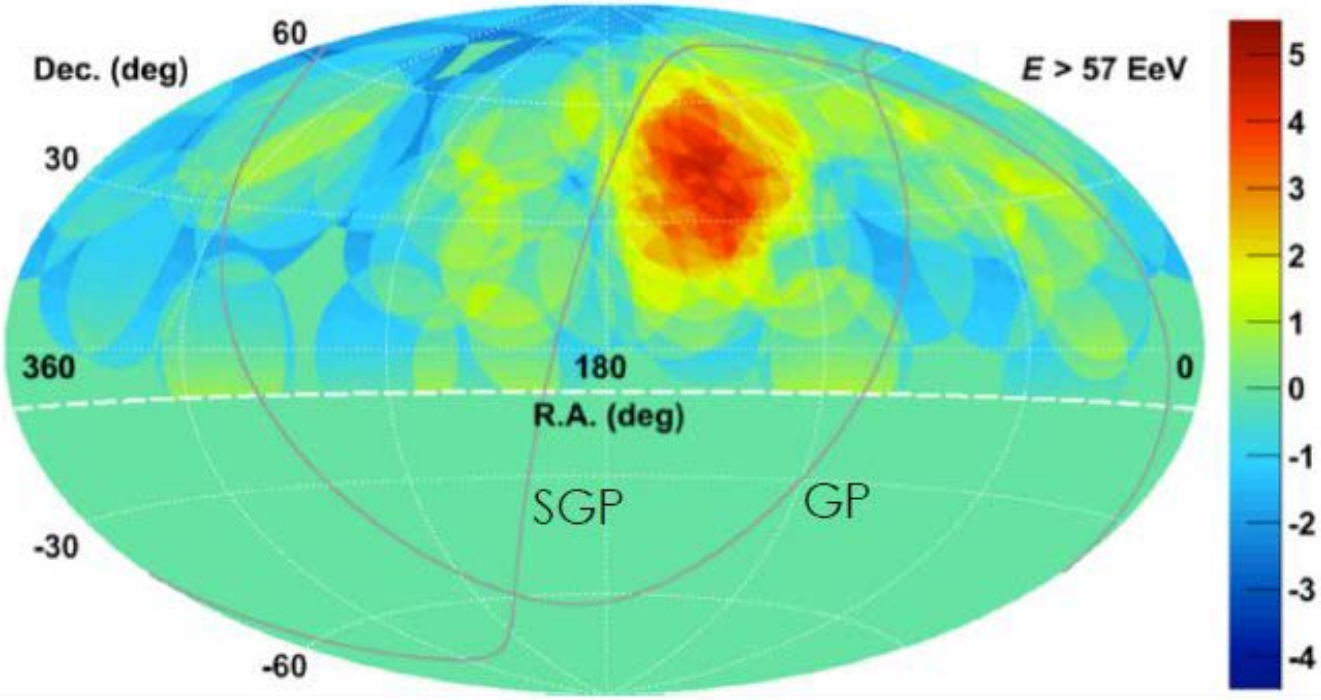


- Loose cut data: 72 events >57EeV, θ<55°, No boundary cut
- E resol. and Angular resol. do not change very much

For more detailed, see arXiv:1404.5890
Event list (>57EeV) has been published.

Hotspot

arXiv:1404.5890

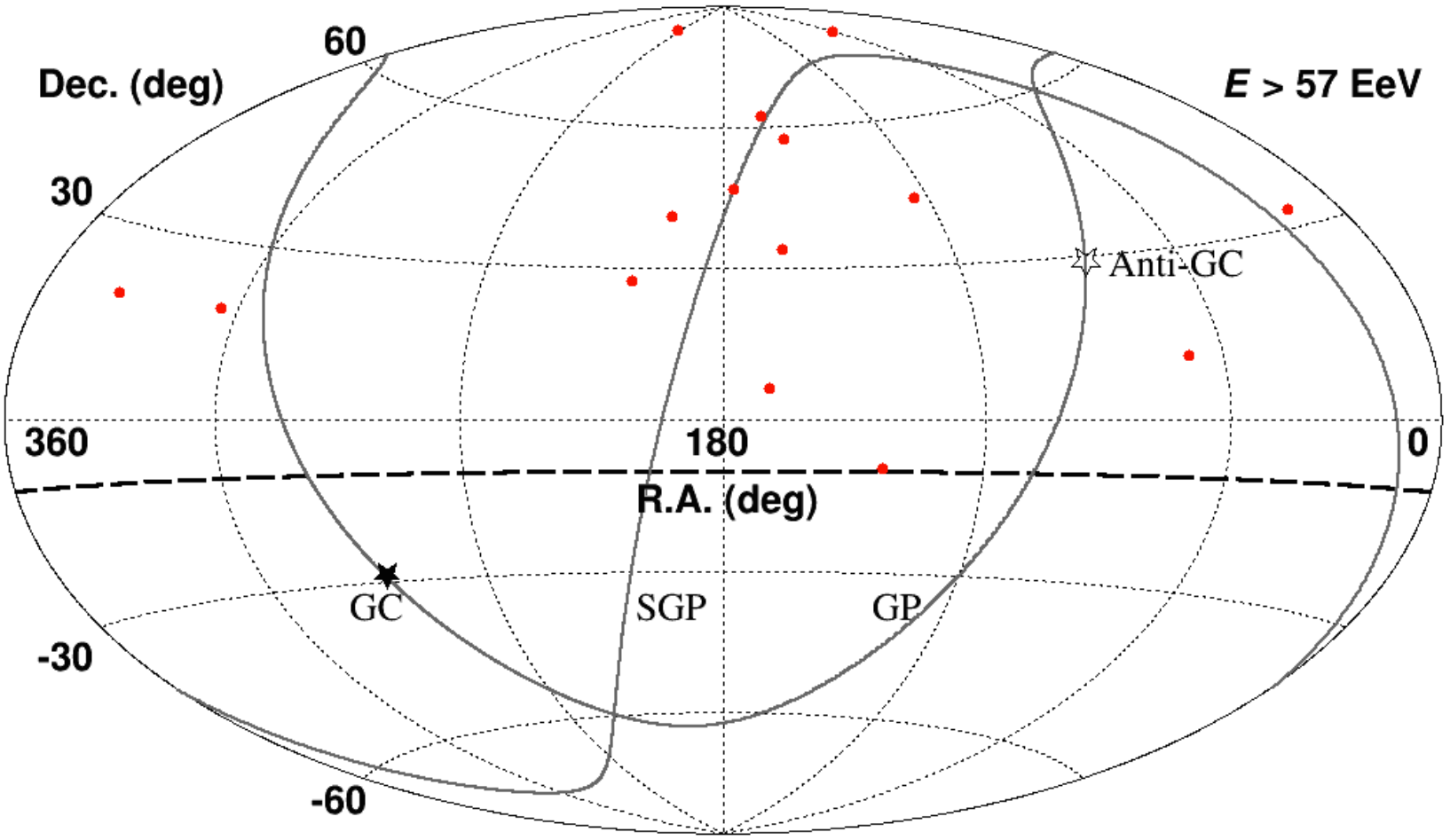


- Loose cut data: 72 events >57EeV, θ<55°, No boundary cut
- Angular resolution does not change very much
- Oversampling with 20°-radius circle

- Hotspot center R.A.=146.7°, Dec. = 43.2° (max. 5.1σ)
- Chance probability from Isotropic sky : 3.7×10^{-4} (3.4 σ)

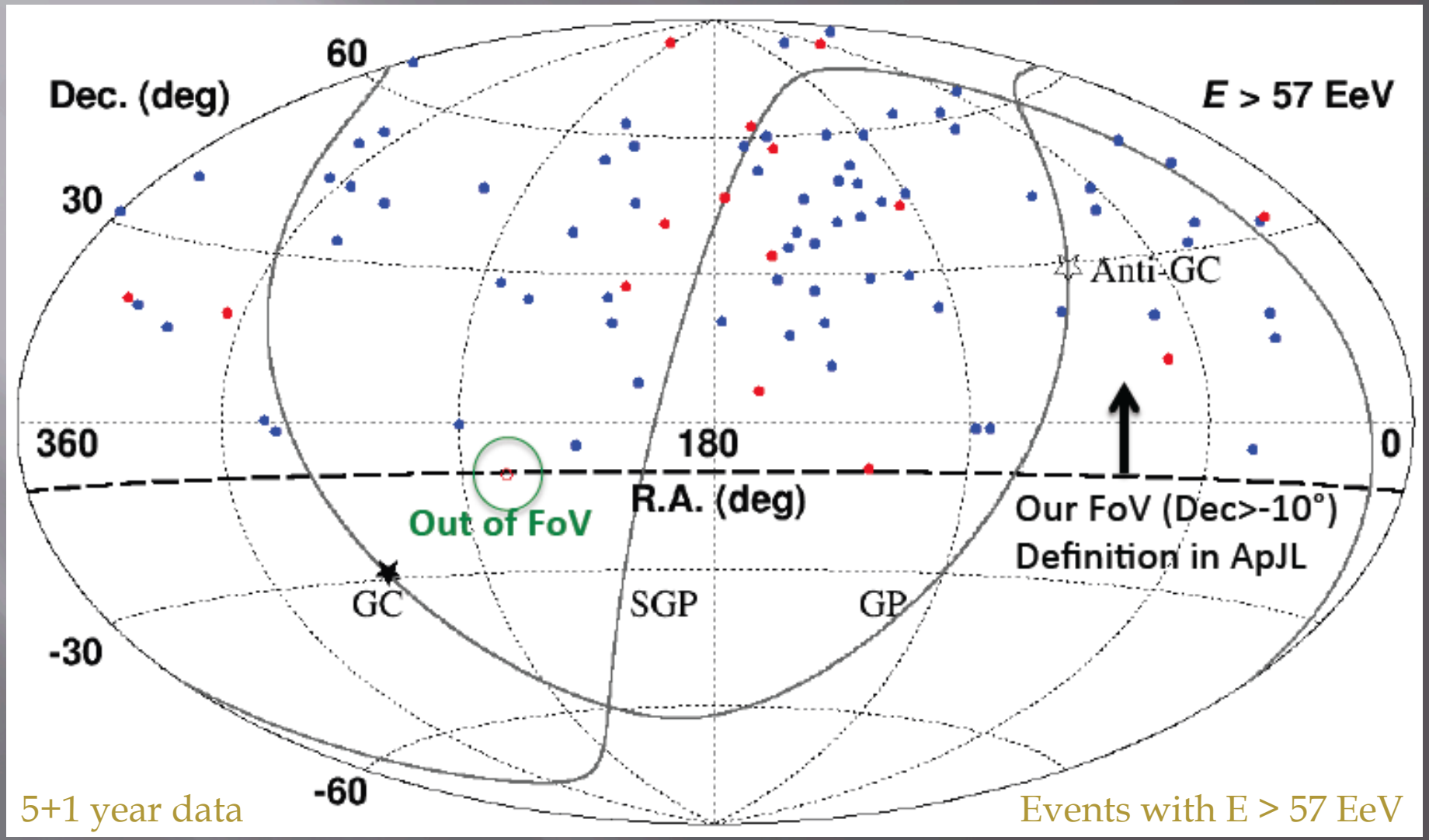
i.e. 5.1σ enhancement anywhere in TA's FoV & any size r=15, 20,… 35°.

Event Distribution New 1 year



New 1-year data : 15 events

The TA Hotspot, Update



5+1 year data

Events with E > 57 EeV

The TA Hotspot, Update

- 72 events (5 years) + 15 events (6th year) total with $E > 57$ EeV
- 19 events (5 years) + 4 events (6th year) in hotspot
- 5.1σ Li-Ma significance goes to 5.55σ
- 3.4σ (with sampling penalty) goes to 4.0σ
- For 6th year only, 4/15 events in previous hotspot: 7% probability

- The hotspot is getting hotter!

TAx4 Proposal

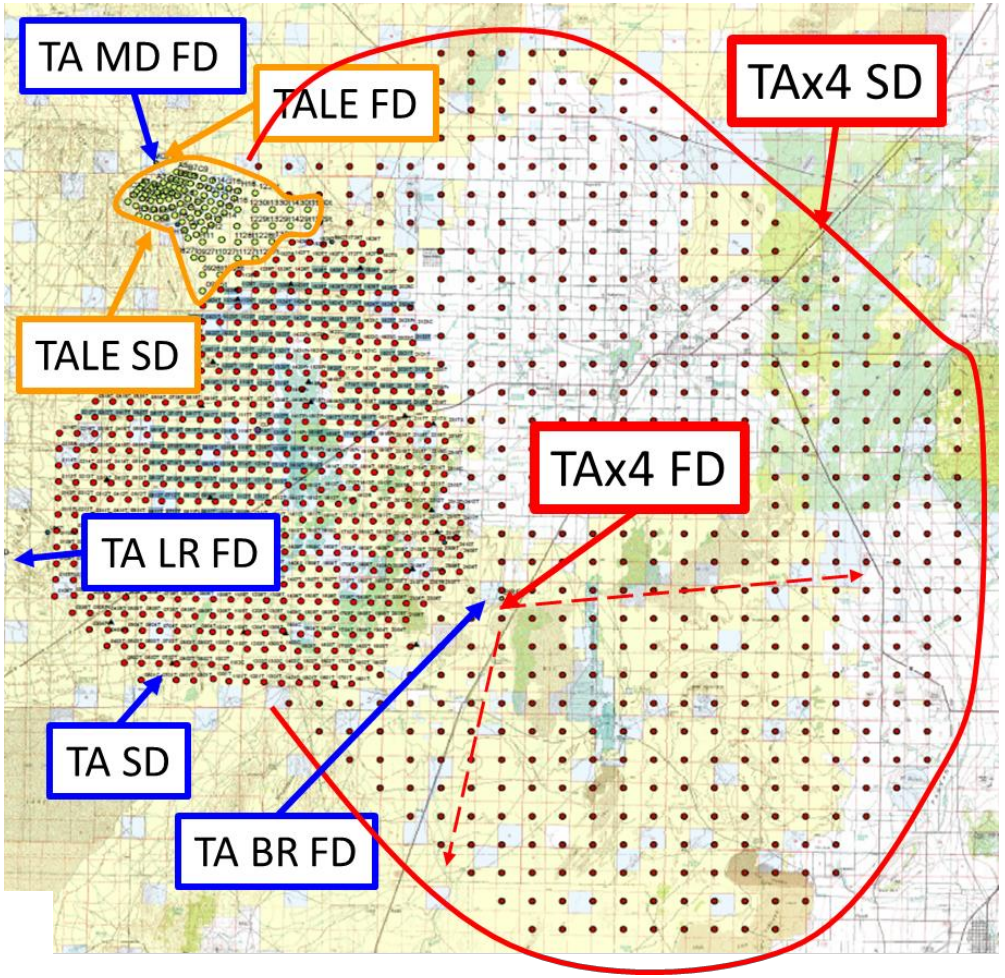
✧ Now there is hint of anisotropy at 3σ level for northern sky.

❖ Plan to expand TA by 4 times (3,000km^2)

1. Add 500 scint. counters with 2.1 km spacing
2. 10 refurbished HiRes tels

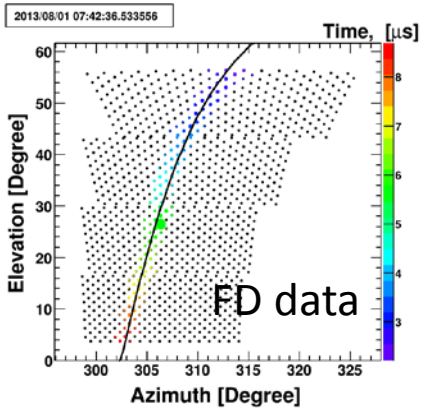
❖ Science (3-year observation)

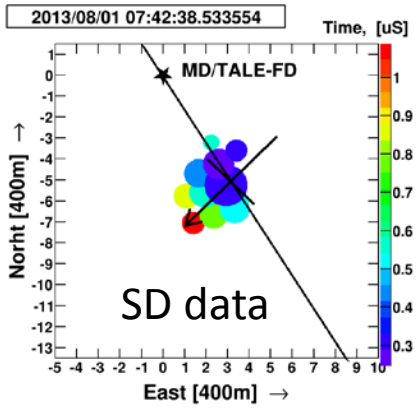
1. Study of anisotropy
   → Expect 5σ
2. Xmax at highest energy region
3. UHE photon & neutrino search

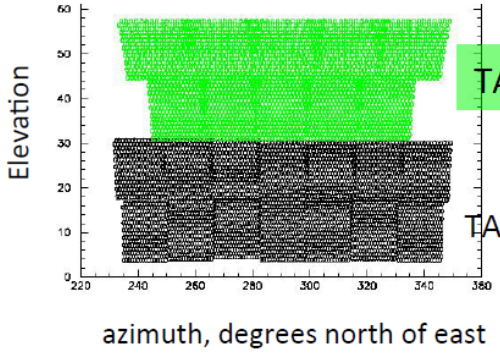


TALE (TA Low-E Extension)

- Target range $10^{16.5}$-10^{19}eV
  - Second Knee
  - Change of mass composition
  - LHC center of mass E
- TALE is operating partly now





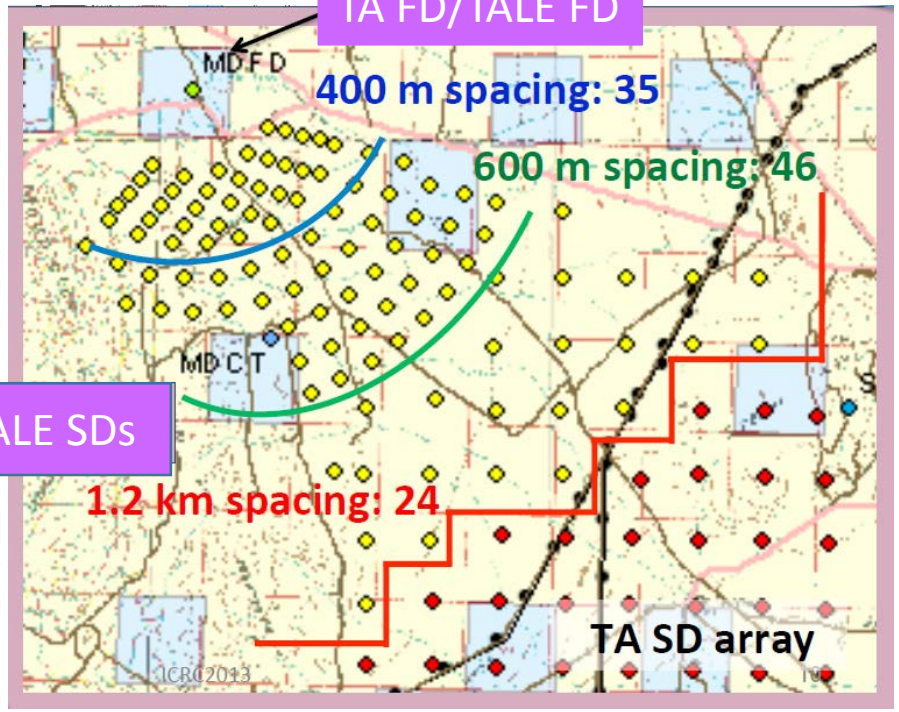


TALE mirrors

TA Middle Drum

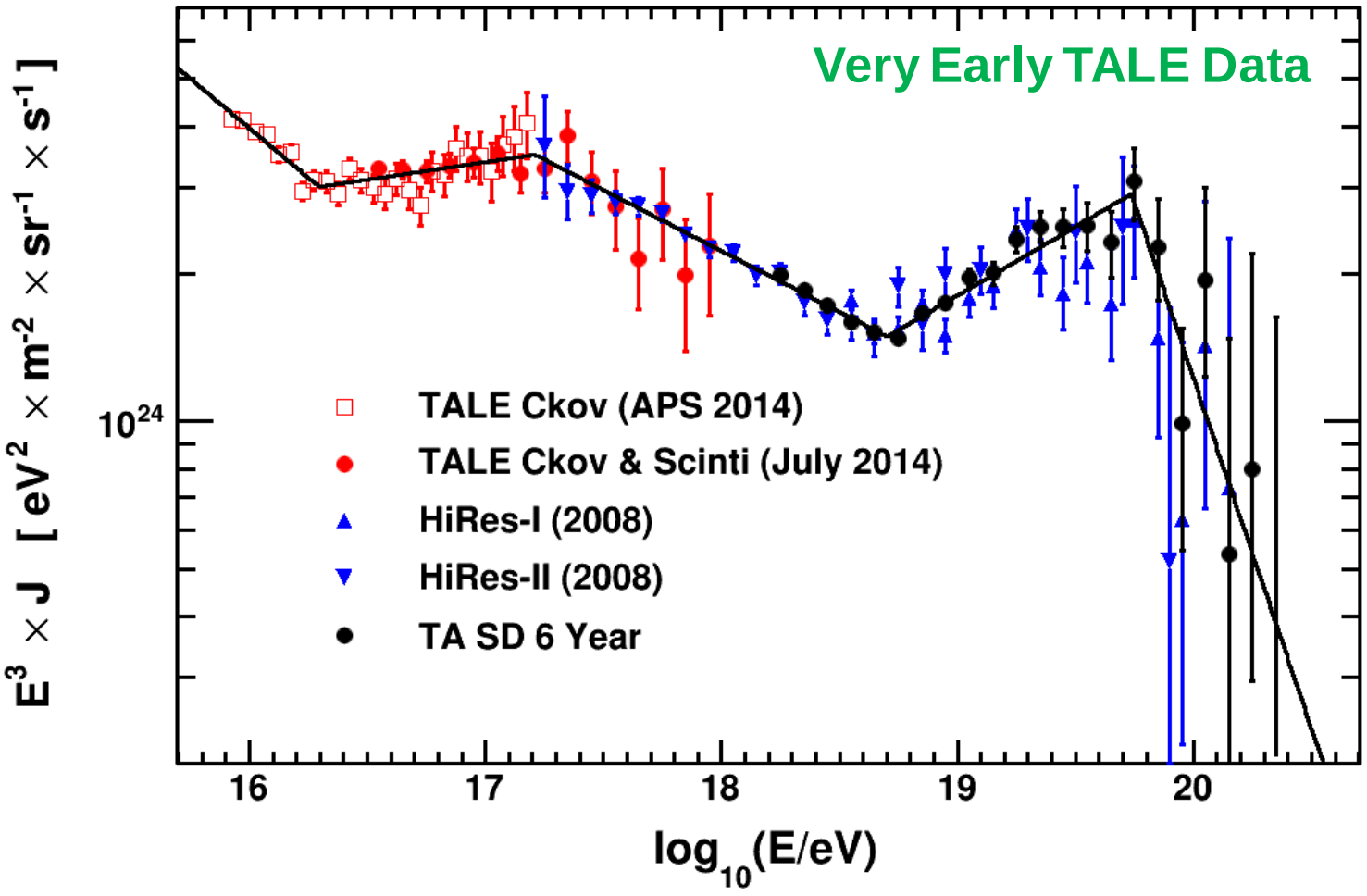
TA FD/TALE FD

101 TALE SDs

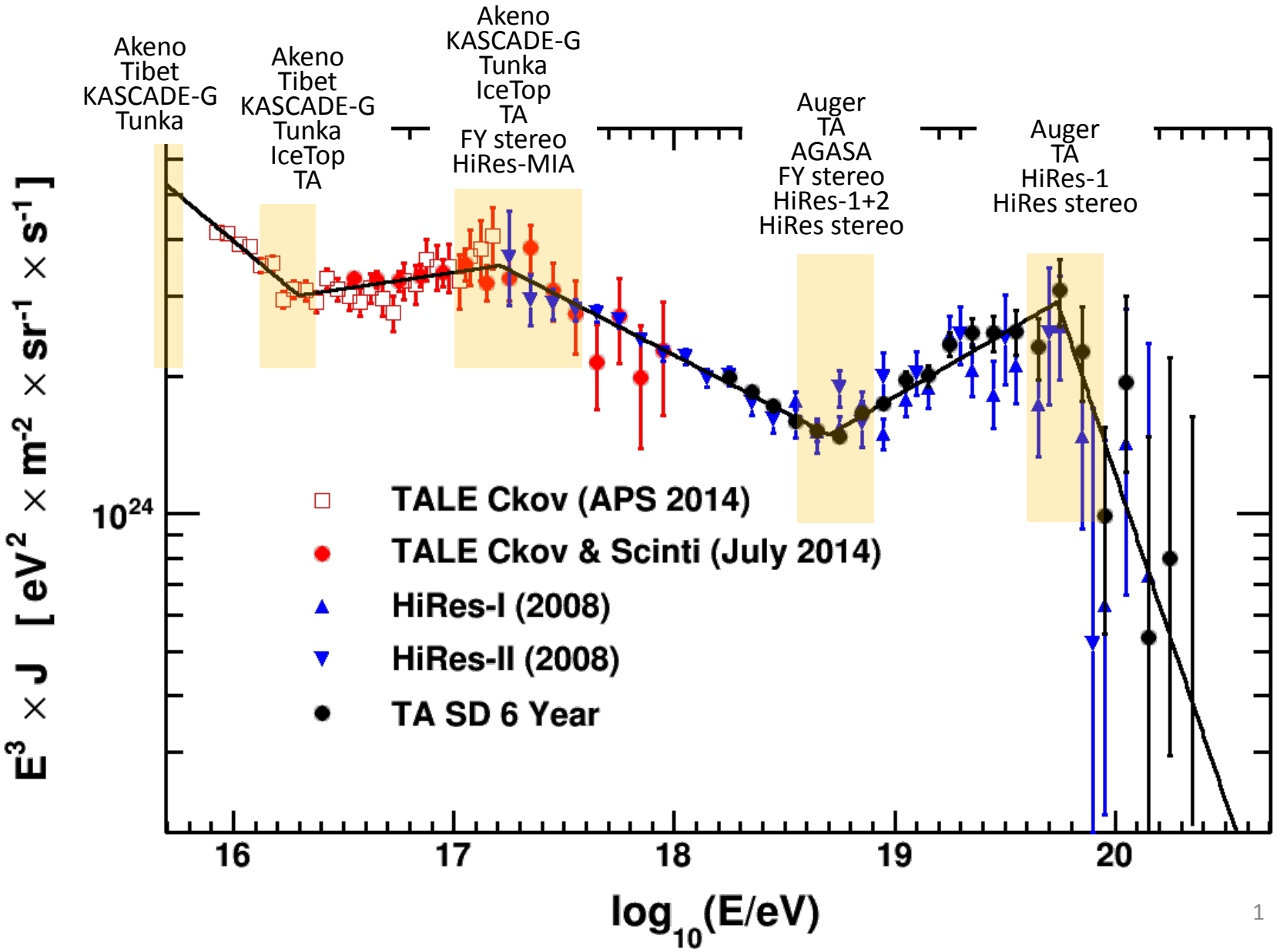


CR Spectrum

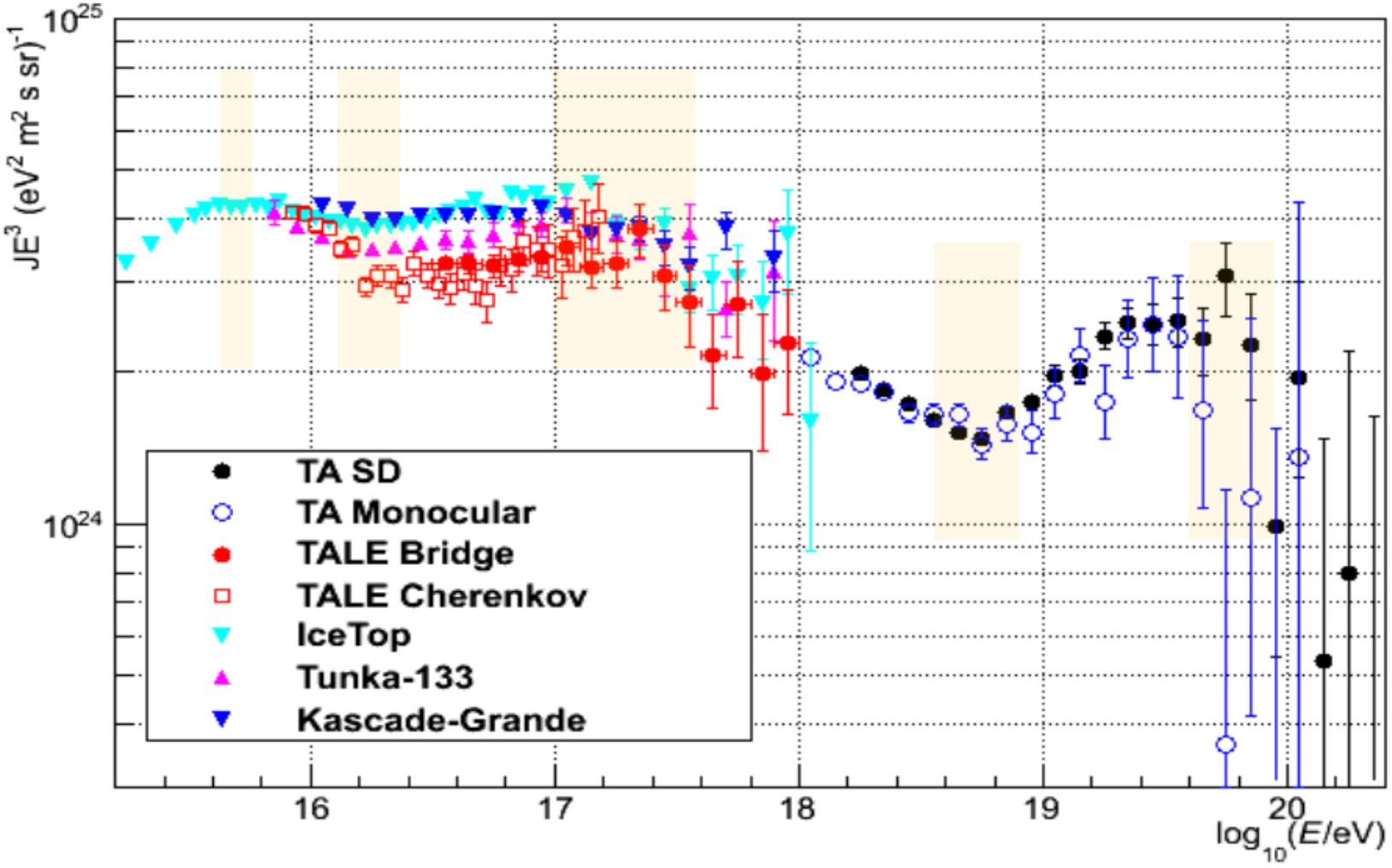
SD Data (6 Yrs: 20080511-20140511)
+ high elevation TALE telescopes (no MD so far)
and events with large Cerenkov contribution



SPECTRUM: from Knee to Cutoff



SPECTRUM: from Knee to Cutoff

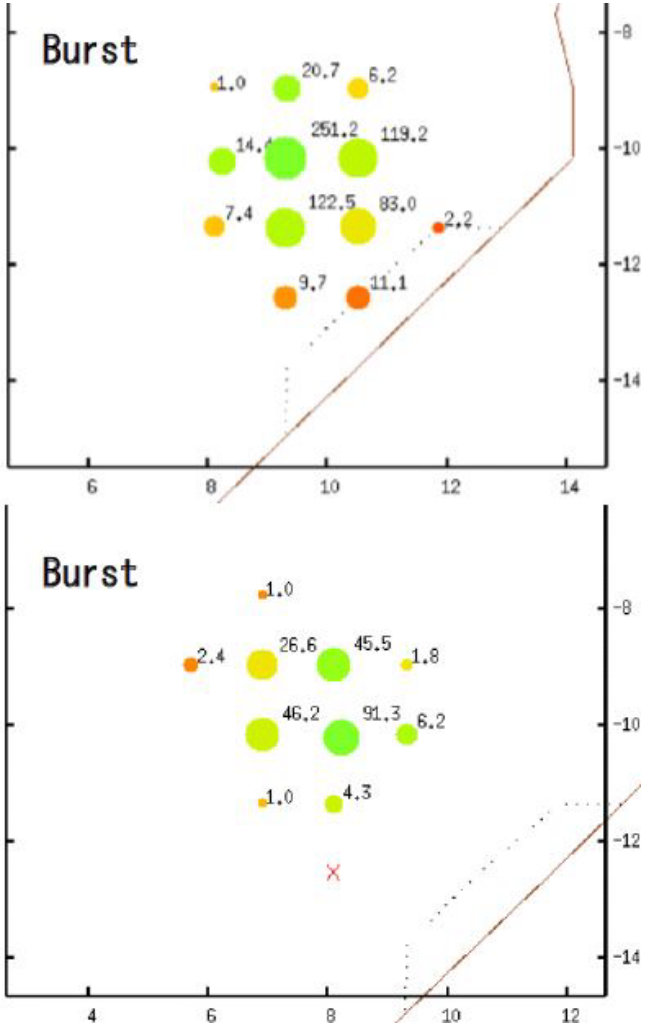


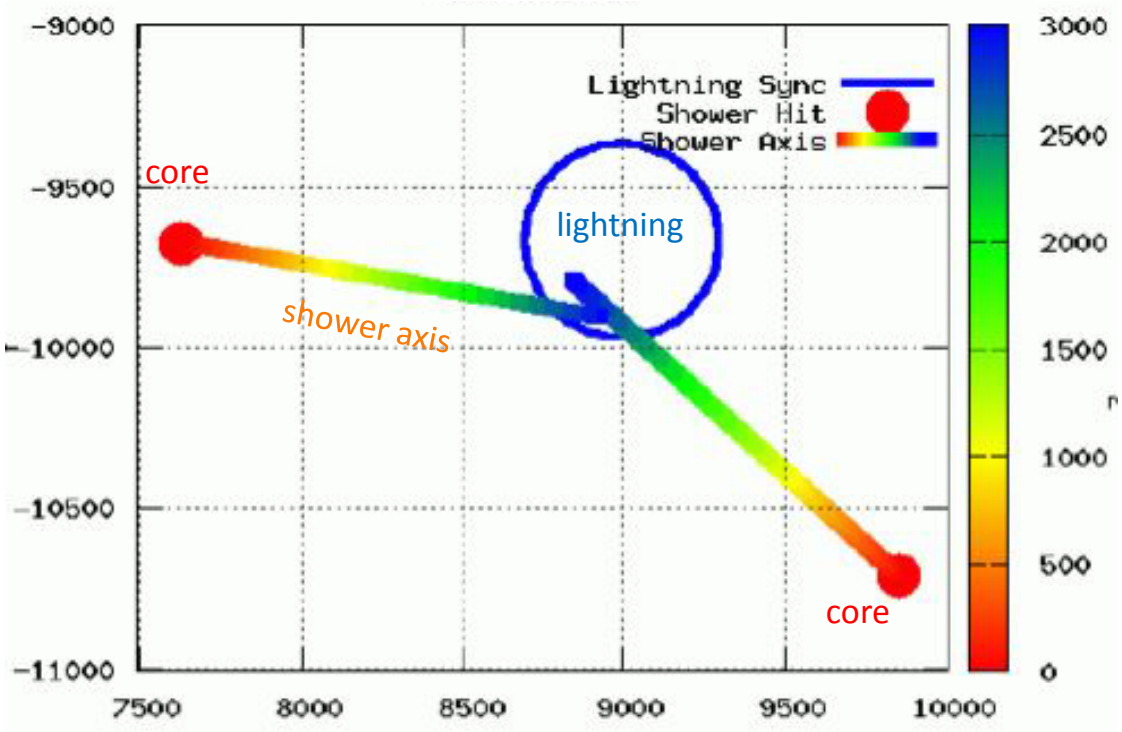
Conclusion

- TA sees evidence for anisotropy in the Northern Hemisphere
- TA has observed the GZK Cutoff and extended the spectrum energy down to 10^{16} eV with 4 spectral features
- TA observes a proton-like composition

Burst of Particle Showers associated with Lightning

- Burst == 3 particle showers within 1ms.
- 5 Bursts in 5 years
- ~10^{-4} burst from randoms (of CR-EAS).

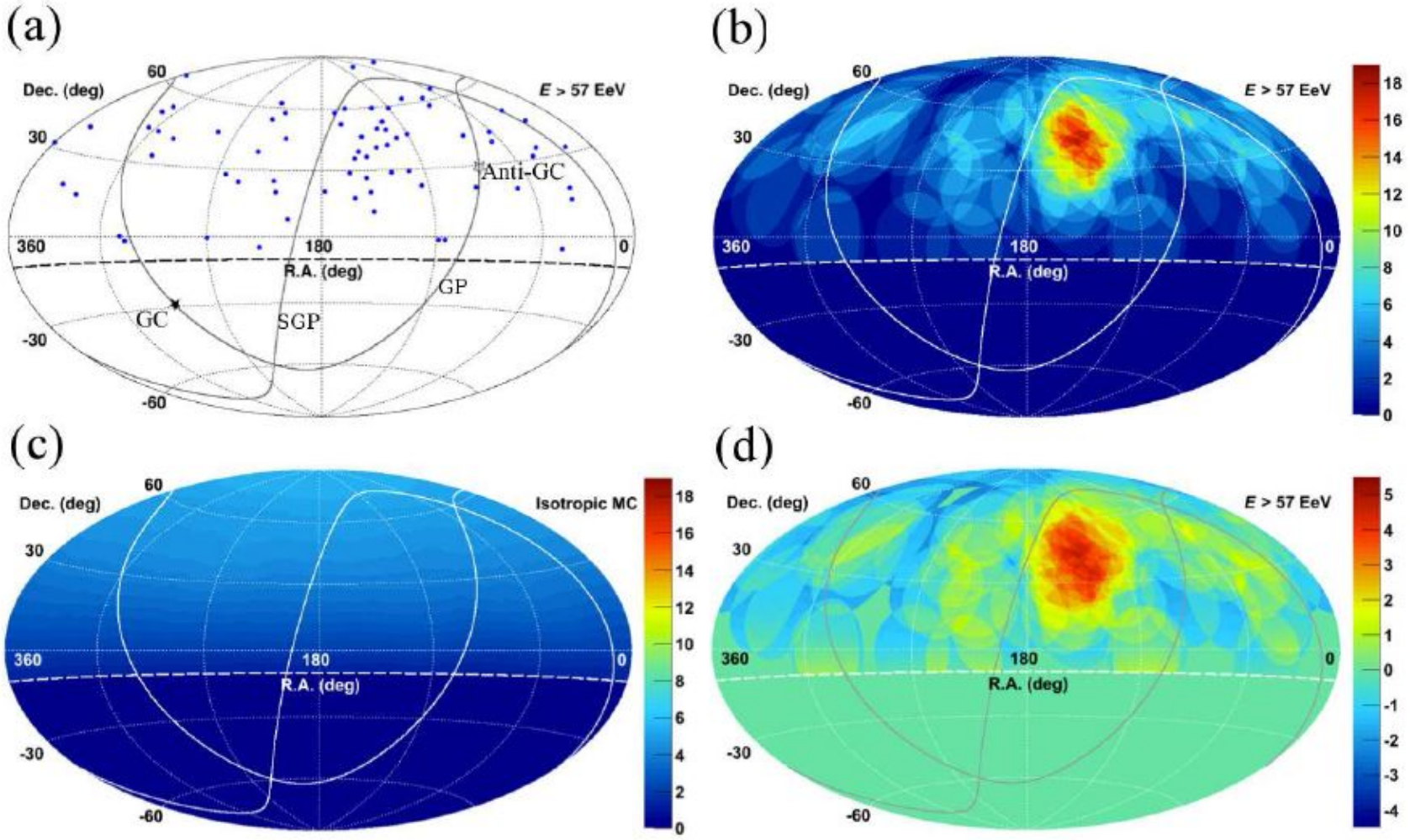




- Core locations ~2km apart.
- Common "origin" ~3km above Ground. (highly curved shower front r~3km)
- Lightning found within 1ms (NLDN-db)
- Lightning location ~ core location

T. Okuda
CosPA 2013

Thank You, and see you all
@UHECR2014 in Springdale, Utah
for Oct.12th-15th.
Thanks are also for Douglas Bergman, Kazumasa Kawata,
John N. Matthews, Grisha Rubtsov, Pierre Sokolsky,
Peter Tinyakov and the TA colleagues for preparing
this presentation quickly.



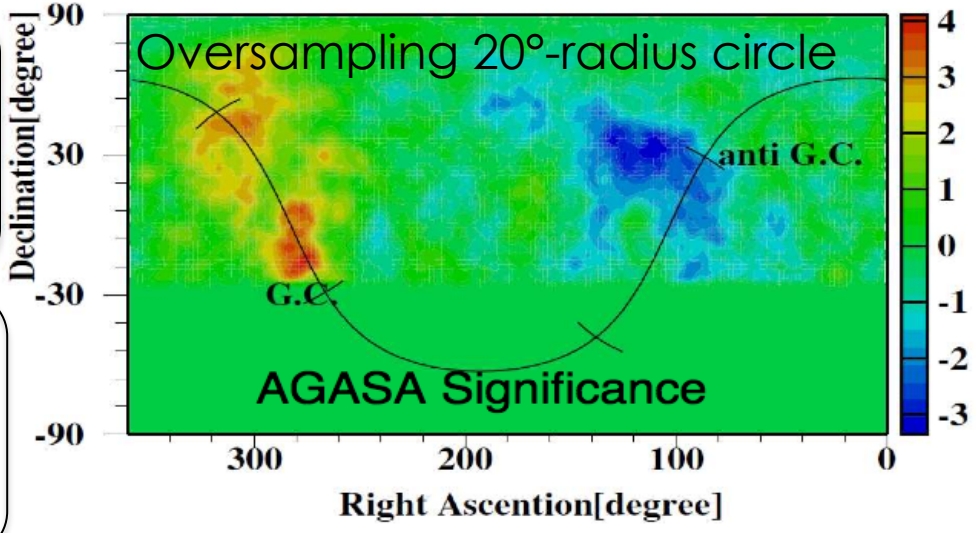
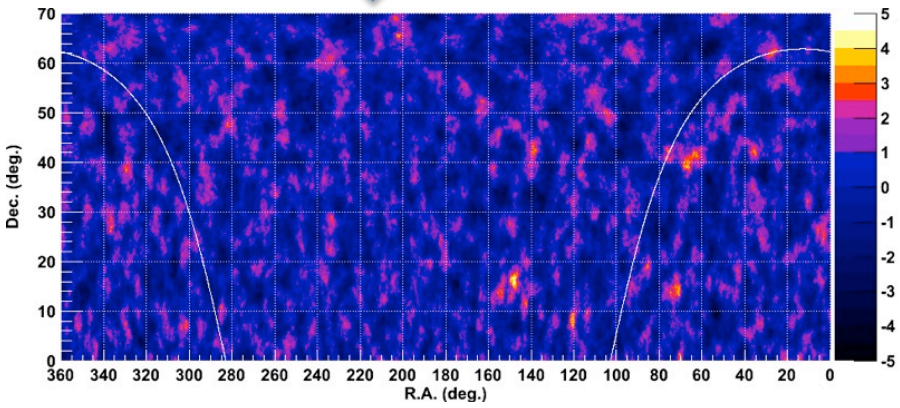
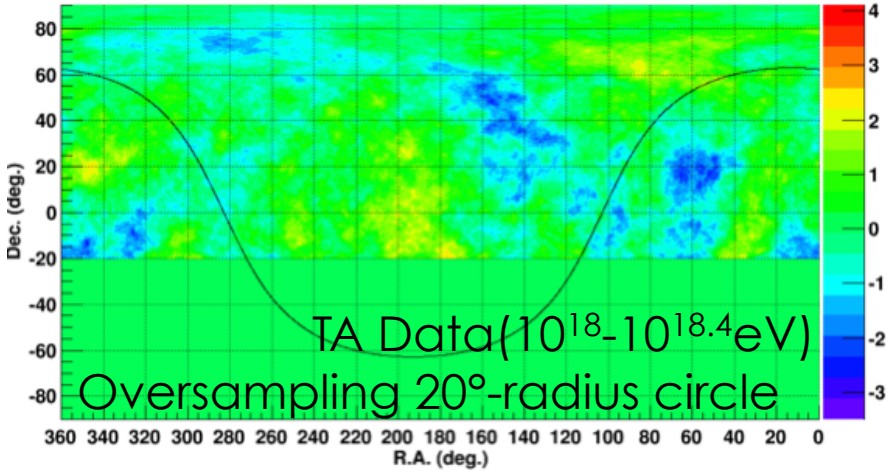
arXiv: 1404.5890

Anisotropy at 10^{18}eV

K.Kawata
ICRC2013

- Large-scale anisotropy search
  - verify AGASA anisotropy
  - Statistics TA =1.6 x AGASA
  → No strong anisotropy

- Point-like source search
  - Neutral particle from our Galaxy
  → No significant excess
  Stringent upper limit in north sky



TA Data>1EeV