

Telescope Array Experiment : Recent Results and Future Plans

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For the Telescope Array Collaboration



Outline

- Telescope Array experiment
- Energy Spectrum
- Mass Composition (X_{\max})
- Anisotropy
- Future/Ongoing Projects



Telescope Array Collaboration

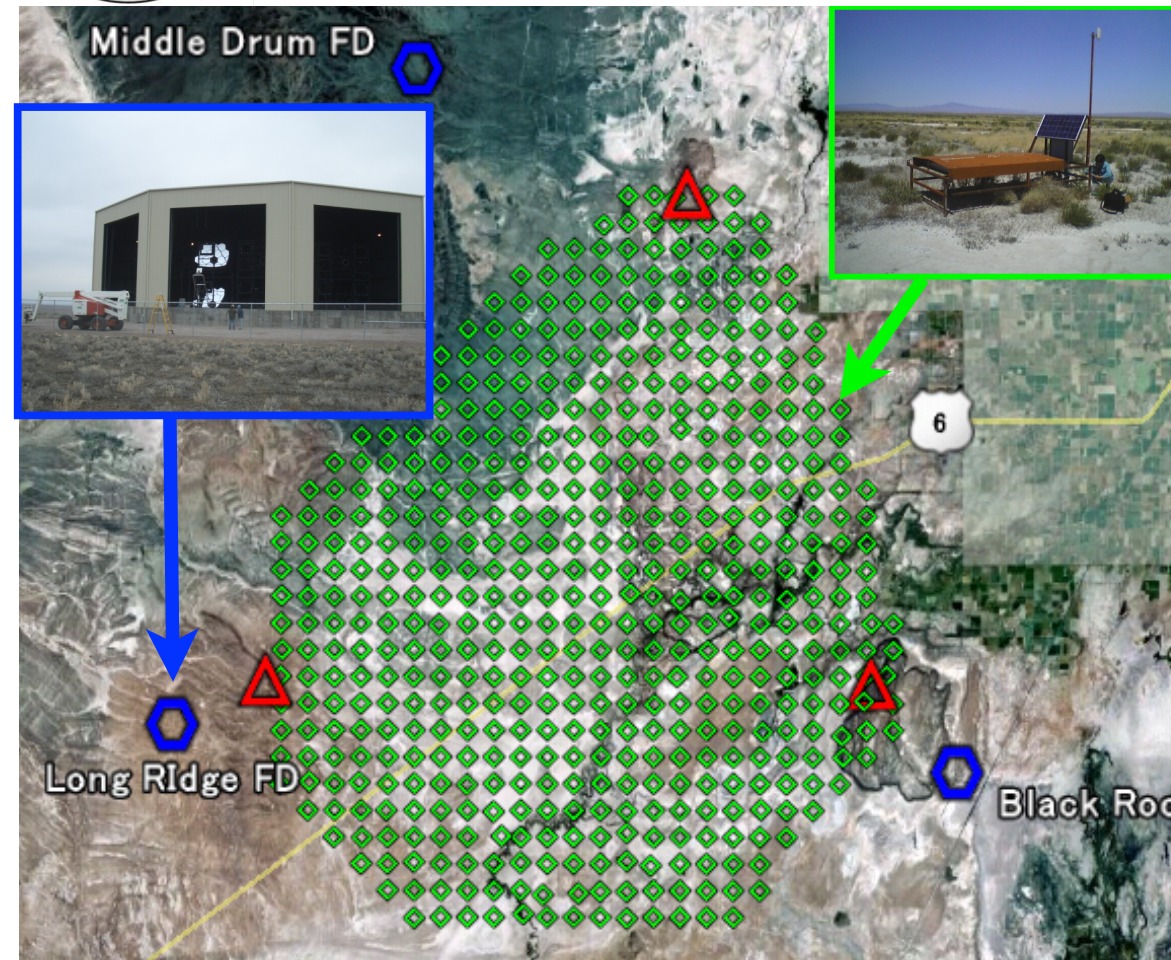
R.U. Abbasi¹, M. Abe¹³, T. Abu-Zayyad¹, M. Allen¹, R. Anderson¹, R. Azuma², E. Barcikowski¹, J.W. Belz¹, D.R. Bergman¹, S.A. Blake¹, R. Cady¹, M.J. Chae³, B.G. Cheon⁴, J. Chiba⁵, M. Chikawa⁶, W.R. Cho⁷, T. Fujii⁸, M. Fukushima^{8,9}, T. Goto¹⁰, W. Hanlon¹, Y. Hayashi¹⁰, N. Hayashida¹¹, K. Hibino¹¹, K. Honda¹², D. Ikeda⁸, N. Inoue¹³, T. Ishii¹², R. Ishimori², H. Ito¹⁴, D. Ivanov¹, C.C.H. Jui¹, K. Kadota¹⁶, F. Kakimoto², O. Kalashev¹⁷, K. Kasahara¹⁸, H. Kawai¹⁹, S. Kawakami¹⁰, S. Kawana¹³, K. Kawata⁸, E. Kido⁸, H.B. Kim⁴, J.H. Kim¹, J.H. Kim²⁵, S. Kitamura², Y. Kitamura², V. Kuzmin¹⁷, Y.J. Kwon⁷, J. Lan¹, S.I. Lim³, J.P. Lundquist¹, K. Machida¹², K. Martens⁹, T. Matsuda²⁰, T. Matsuyama¹⁰, J.N. Matthews¹, M. Minamino¹⁰, K. Mukai¹², I. Myers¹, K. Nagasawa¹³, S. Nagataki¹⁴, T. Nakamura²¹, T. Nonaka⁸, A. Nozato⁶, S. Ogio¹⁰, J. Ogura², M. Ohnishi⁸, H. Ohoka⁸, K. Oki⁸, T. Okuda²², M. Ono¹⁴, A. Oshima¹⁰, S. Ozawa¹⁸, I.H. Park²³, M.S. Pshirkov²⁴, D.C. Rodriguez¹, G. Rubtsov¹⁷, D. Ryu²⁵, H. Sagawa⁸, N. Sakurai¹⁰, A.L. Sampson¹, L.M. Scott¹⁵, P.D. Shah¹, F. Shibata¹², T. Shibata⁸, H. Shimodaira⁸, B.K. Shin⁴, J.D. Smith¹, P. Sokolsky¹, R.W. Springer¹, B.T. Stokes¹, S.R. Stratton^{1,15}, T.A. Stroman¹, T. Suzawa¹³, M. Takamura⁵, M. Takeda⁸, R. Takeishi⁸, A. Taketa²⁶, M. Takita⁸, Y. Tameda¹¹, H. Tanaka¹⁰, K. Tanaka²⁷, M. Tanaka²⁰, S.B. Thomas¹, G.B. Thomson¹, P. Tinyakov^{17,24}, I. Tkachev¹⁷, H. Tokuno², T. Tomida²⁸, S. Troitsky¹⁷, Y. Tsunesada², K. Tsutsumi², Y. Uchihori²⁹, S. Udo¹¹, F. Urban²⁴, G. Vasiloff¹, T. Wong¹, R. Yamane¹⁰, H. Yamaoka²⁰, K. Yamazaki¹⁰, J. Yang³, K. Yashiro⁵, Y. Yoneda¹⁰, S. Yoshida¹⁹, H. Yoshii³⁰, R. Zollinger¹, Z. Zundel¹

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5 Tokyo University of Science 6 Kinki University 7 Yonsei University 8 ICRR, University of Tokyo
9 IPMU, the University of Tokyo 10 Osaka City University 11 Kanagawa University 12 University of Yamanashi
13 Saitama University 14 Astrophysical Big Bang Laboratory RIKEN, Wako 15 Rutgers University
16 Tokyo City University 17 INR of the Russian Academy of Sciences 18 Waseda University
19 Chiba University 20 KEK 21 Kochi University 22 Ritsumeikan University 23 Sungkyunkwan University
24 Universite de Libre de Bruxelles 25 Ulsan National Institute of Science and Technology
26 ERI, University of Tokyo 27 Hiroshima City University 28 Advanced Science Institute, RIKEN
29 National Institute of Radiological Science 30 Ehime University



Telescope Array (TA)



- Utah, USA
 - 39.3°N , 112.9°W
 - 1400m asl.
- Surface Detector (SD)
 - 3m^2 Scintillation det.
 - 507 detectors
 - 1.2km spacing
 - Effective area 700km^2

High duty cycle, high statistics
→ Anisotropy, spectral shape

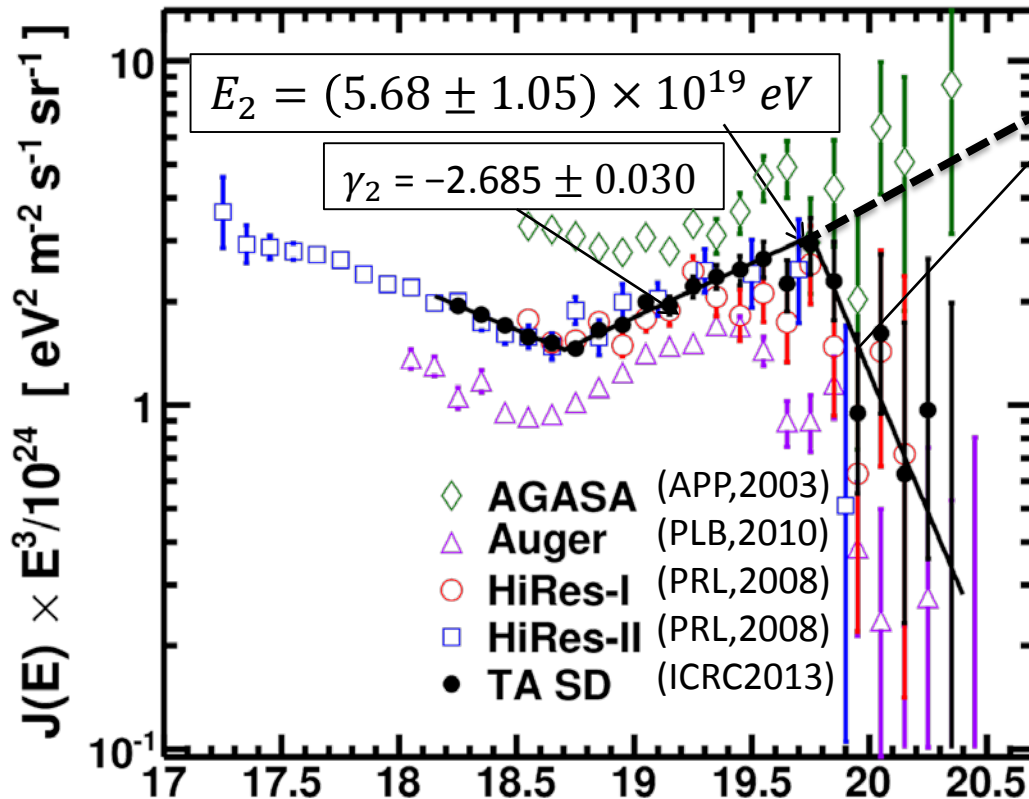
- Fluorescence Det. (FD)
 - 3 stations
 - 12 telescopes/station

Mass compoition from X_{max}
Energy calorimetrically

The TA is the largest aperture hybrid cosmic ray detectors in the northern hemisphere.



Energy Spectrum (5 years)



Suppression consistent with the GZK cutoff

Suppression ($>10^{19.8} \text{ eV}$):
 N (continue) = 68.1
 N (observed) = 26

Continuous spectrum is excluded at **5.74σ**

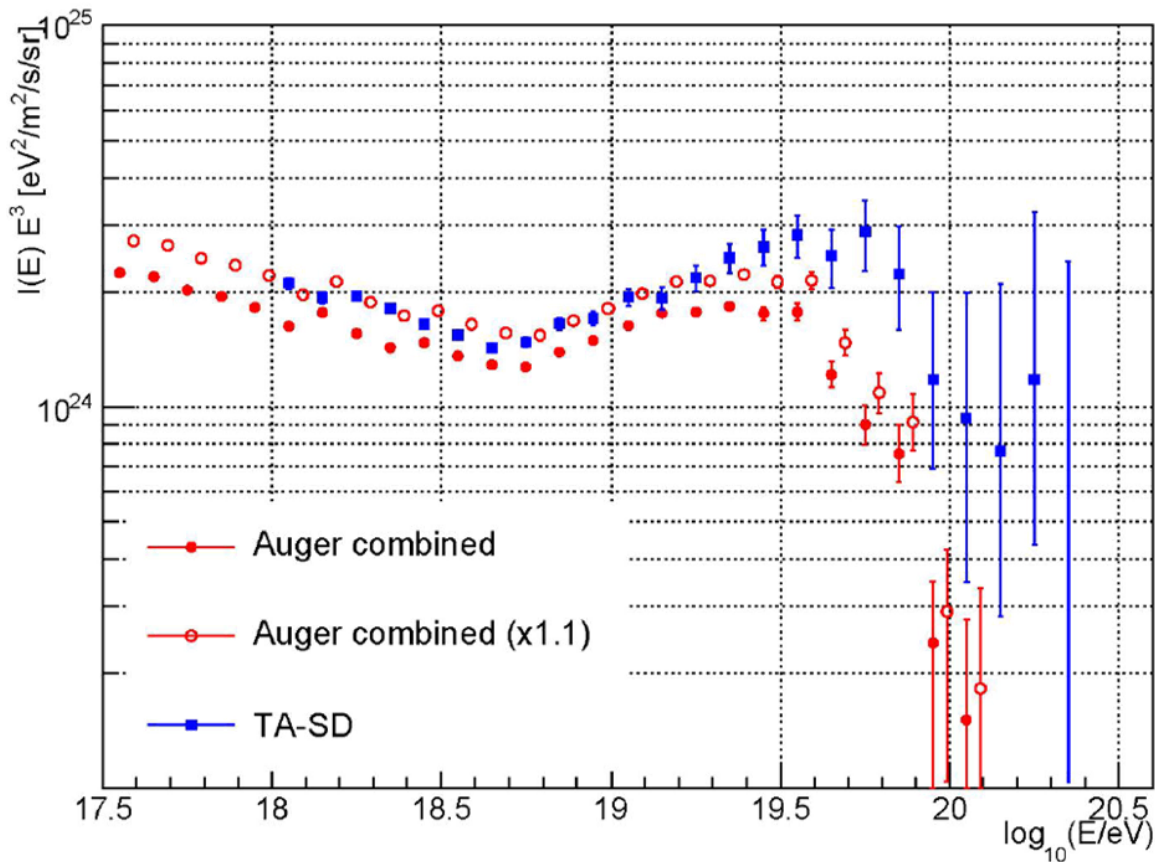
$$E_{SD} = \frac{1}{\left\langle \frac{E'_{SD}}{E_{FD}} \right\rangle_{hyb}} E'_{SD} = \frac{1}{1.27} E'_{SD}$$

SD energy is scaled to FD energy



TA vs Auger Spectrum

Rapporteur talk by Y. Tsunesada at ICRC2013



❖ TA and Auger agree well around dip
If E-scale shifted by 10%.

❖ $E_{1/2}$: TA suppression
at higher energy

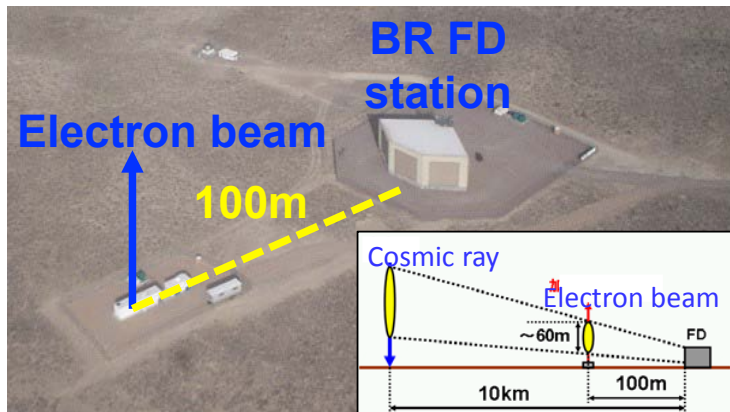
Systematic Error of Energy Scale: Auger 14%, TA 21%



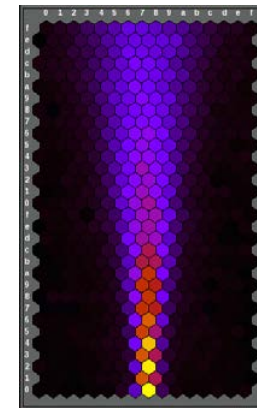
Electron Light Source (ELS)

preliminary

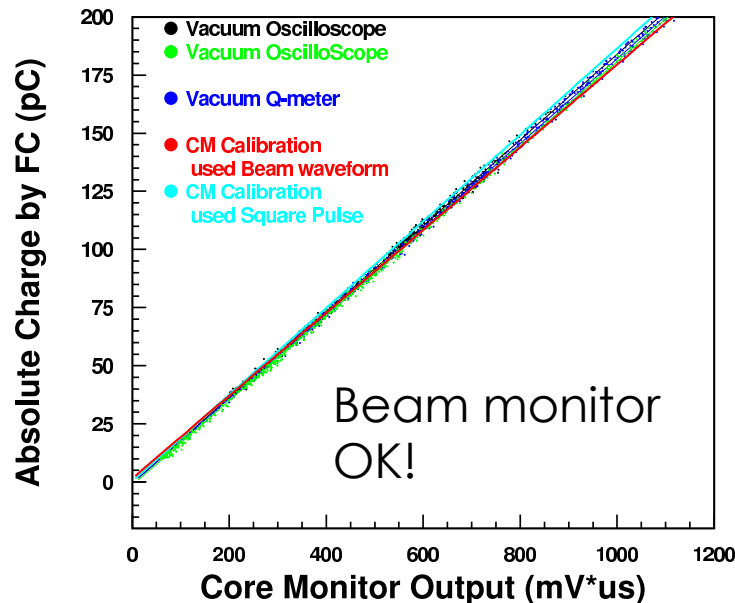
T. Shibata
ICRC2013



- 40-MeV, 10^9 electrons (typical)
- End-to-end FD energy calibration



An image of data
Measured with FD



- ❖ Beam monitors have been calibrated. (Faraday Cap, Core monitor)
- ❖ MC simulation has been developed.
- ❖ Test fluorescence yield models
 - TA model(Kakimoto modifiend+Flash) :
Data/MC = 1.18 ± 0.01 (stat) ± 0.18 (syst)
 - Common Model (based on AirFly)
Data/MC = 0.96 ± 0.01 (stat) ± 0.15 (syst)

We expect that we can calibrate true energy scale of the FD with the ELS in near future. 7



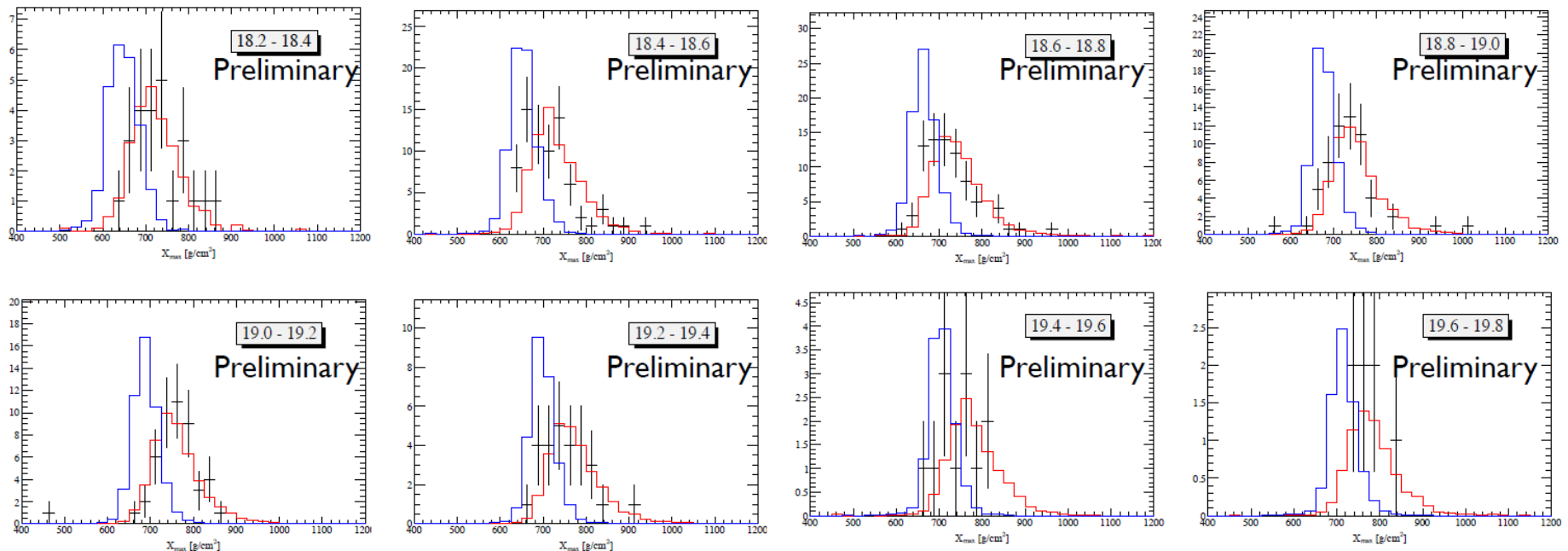
FD Stereo Xmax

Blue: Iron (QGSJET-II-03)

Red: Proton (QGSJET-II-03)

Black: Data

Y. Tameda
ICRC2013



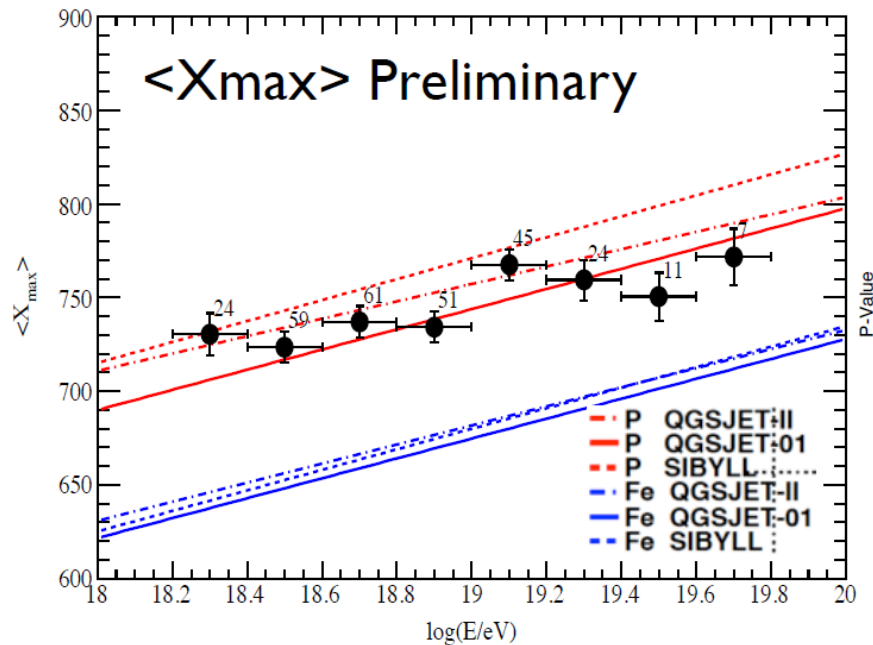
The TA data (stereo) is consistent with
QGSJET-II-03 proton prediction.



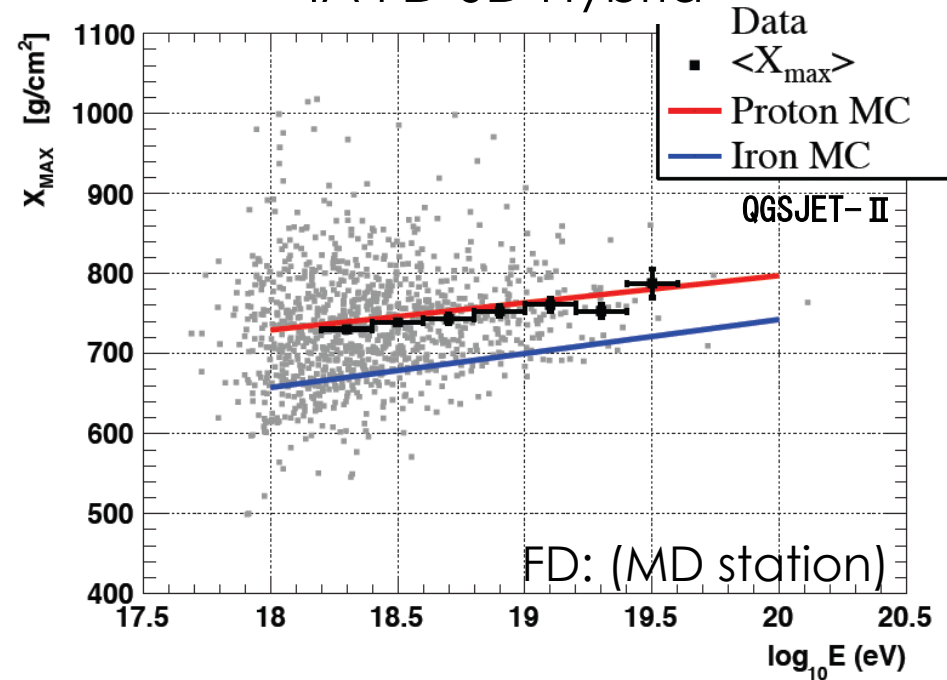
Averaged Xmax

M. Allen
ICRC2013

TA FD Stereo



TA FD-SD Hybrid



Consistent with QGSJET-II-03 **proton** prediction ($E > 10^{18.2}$ eV)
Need more data for $E > 10^{19.4}$ eV

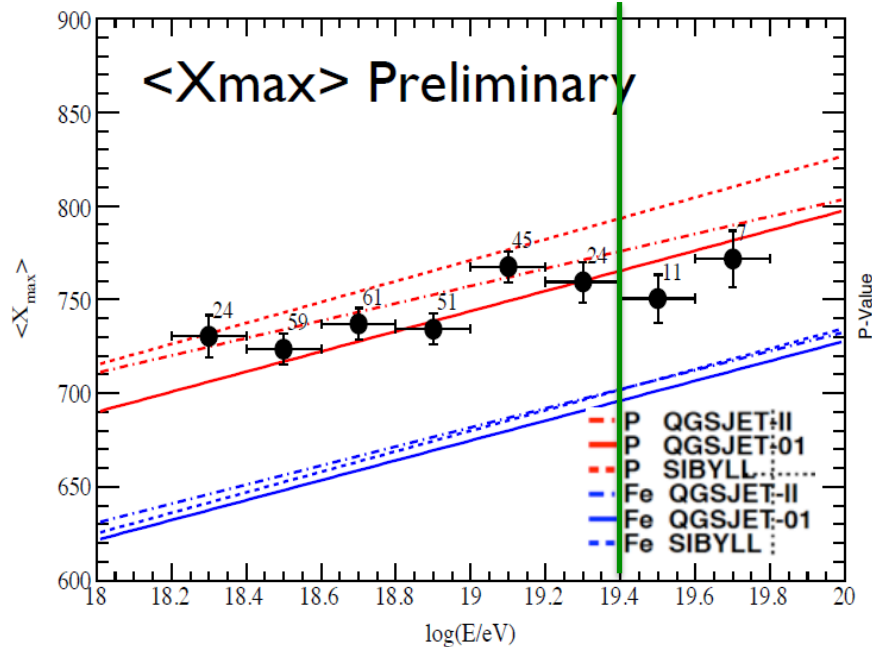
Similar result is obtained for FD-SD hybrid Xmax



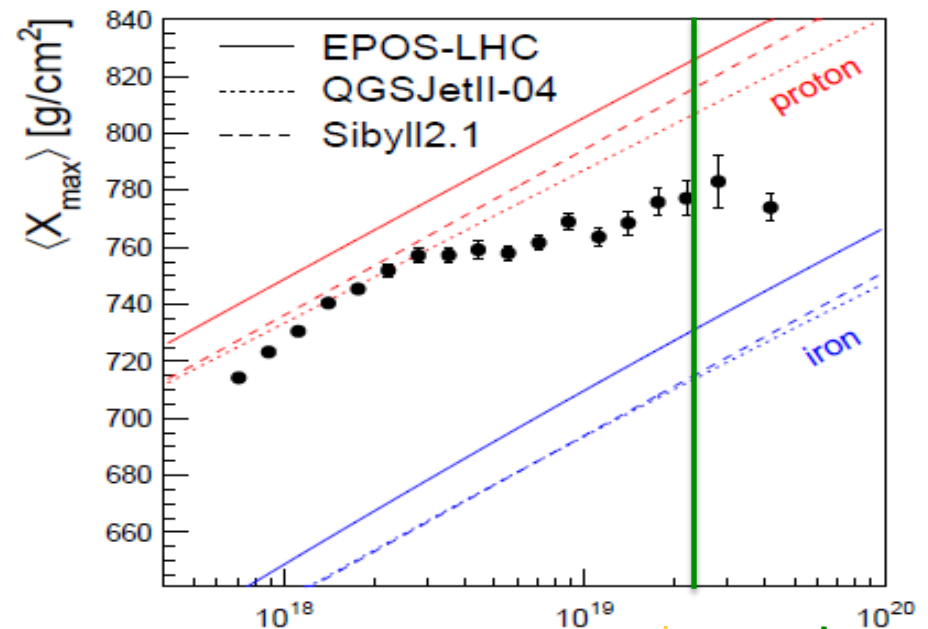
Averaged X_{\max}

E.J. Ahn
ICRC2013

TA FD Stereo



Auger FD



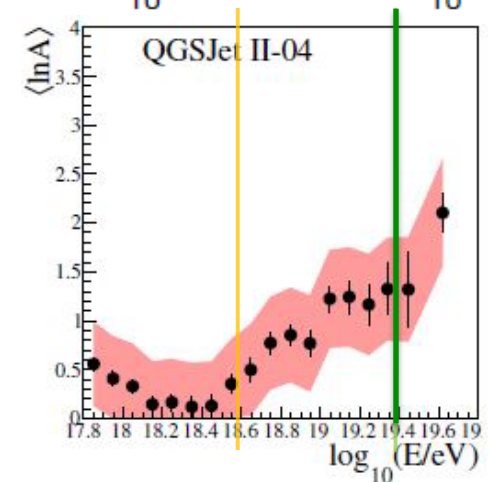
Mass Composition $< 10^{19.4}\text{eV}$

TA with QGSJET-II-03

→ Consistent with Proton

Auger with QGSJET-II-04

→ Suggest a transition from Proton to Helium





Anisotropy Studies

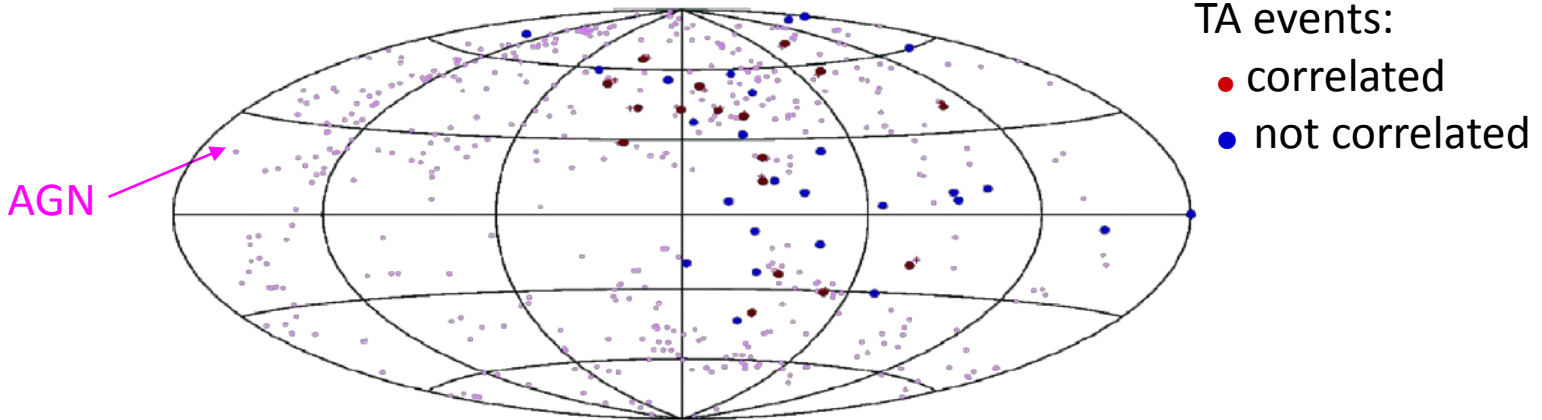
Updated result based on 5-year dataset

- Correlation with AGN $>57\text{EeV}$
- Correlation with LSS $>57\text{EeV}$
- Anisotropy around 1EeV
- Hotspot $>57\text{EeV}$

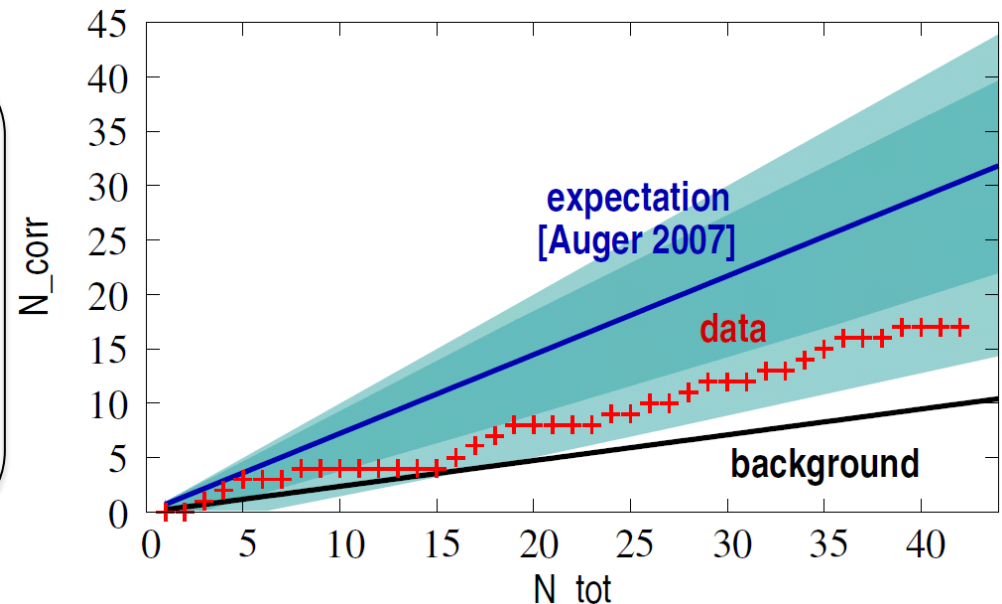


Correlation with AGNs

P. Tiynakov
ICRC2013



- ❖ 42 UHECR events
($>57\text{EeV}$, $\theta < 45^\circ$, 5 years)
- ❖ 472 AGNs from VCV catalog
- ❖ Separation angle : 3.1°
- ❖ 17 events correlate out of 42
→ Chance probability $p=1.4\%$

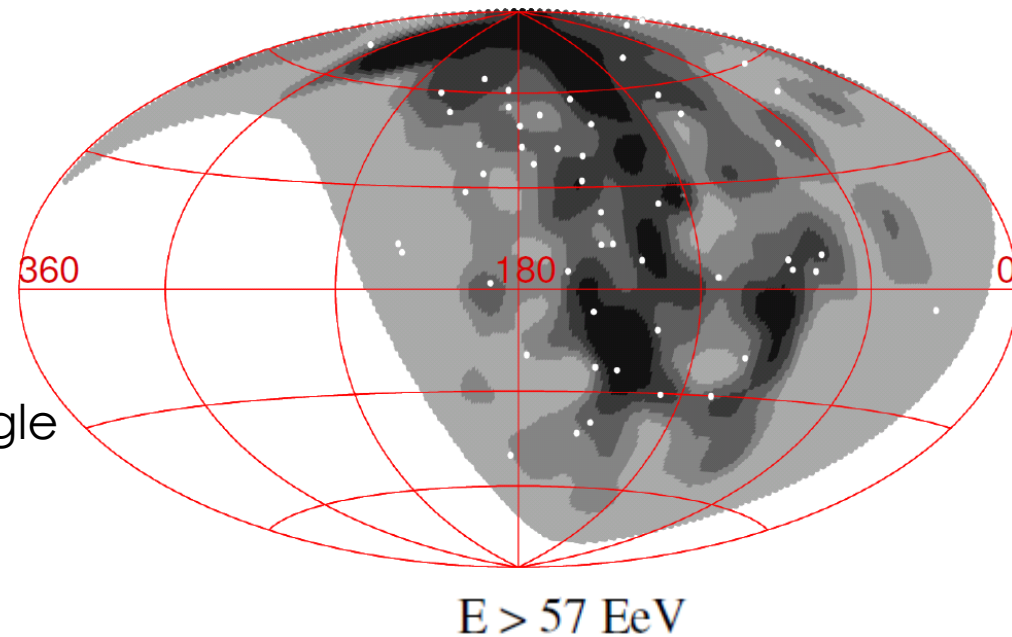




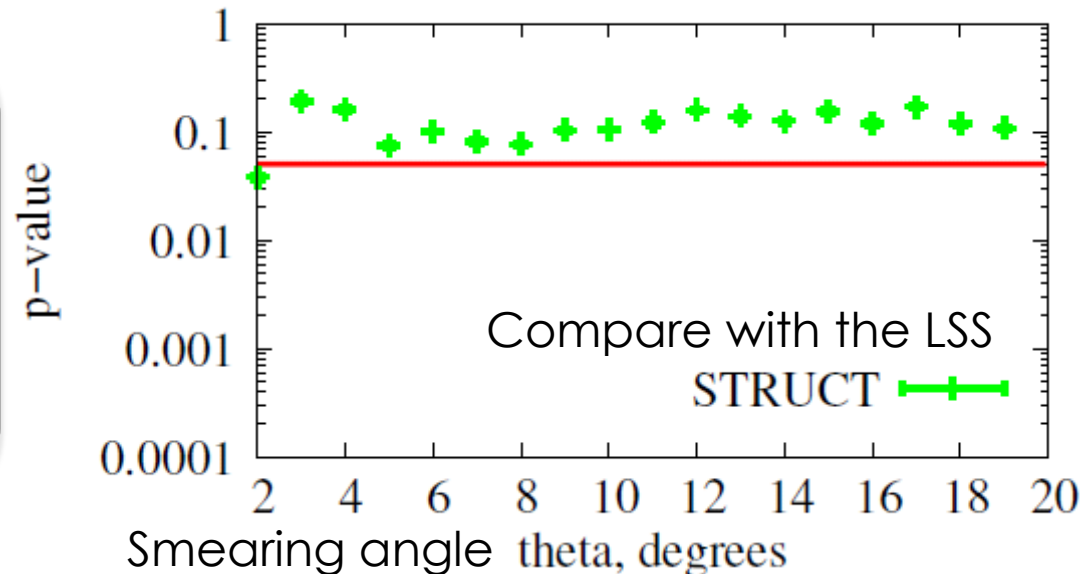
Correlation with LSS

P. Tiynakov
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 $\sim 10\%$ In all smearing angles.
- ❖ Consistency with isotropy at 6° smearing angle is $\sim 0.1\%$ level.





Anisotropy at 10^{18}eV

K.Kawata
ICRC2013

Loose cut data \rightarrow statistics $\times 10$ @EeV, Resolution $\sim 3^\circ$

❖ Large-scale anisotropy search

- verify AGASA anisotropy
- Statistics $TA = 1.6 \times AGASA$



\rightarrow No strong anisotropy

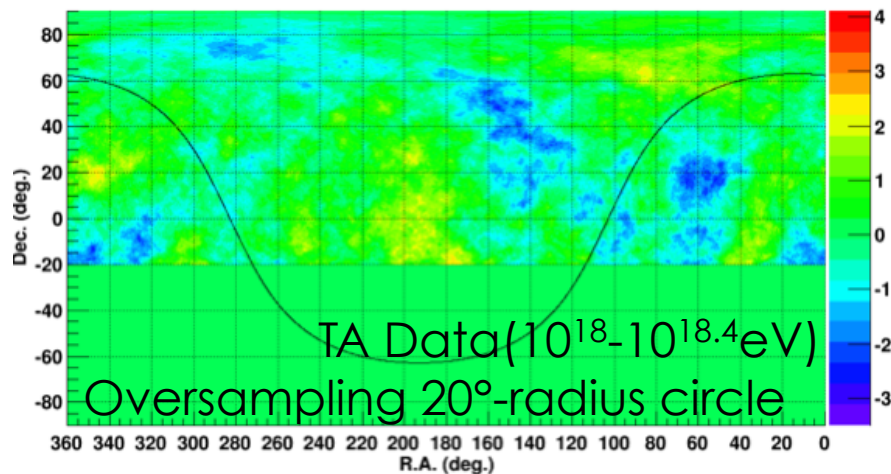
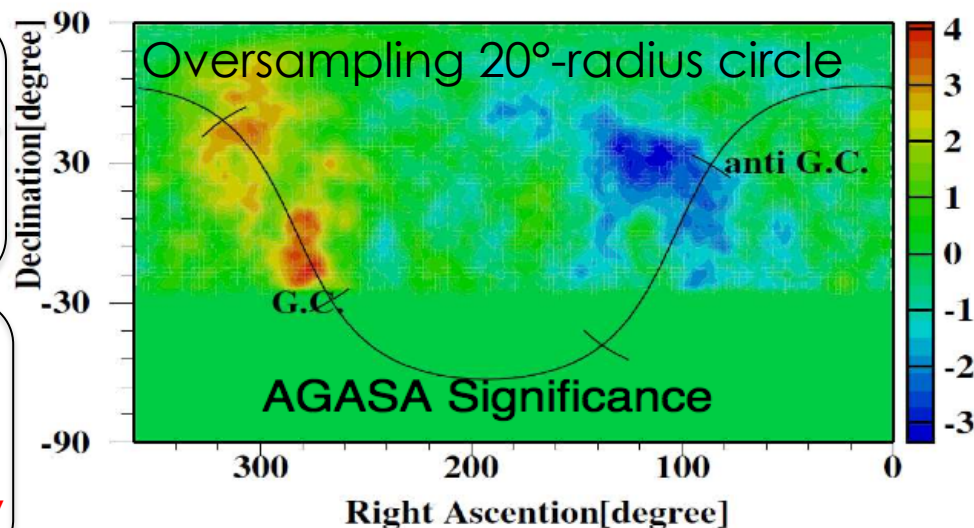
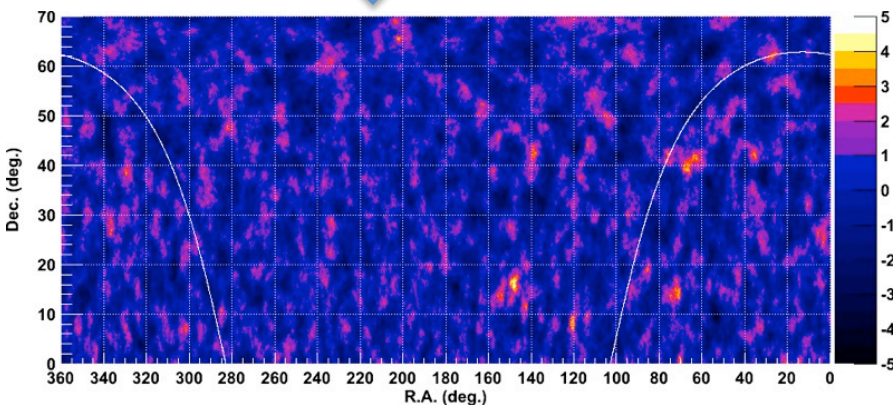
❖ Point-like source search

- Neutral particle from our Galaxy
- \rightarrow No significant excess

Stringent upper limit in north sky



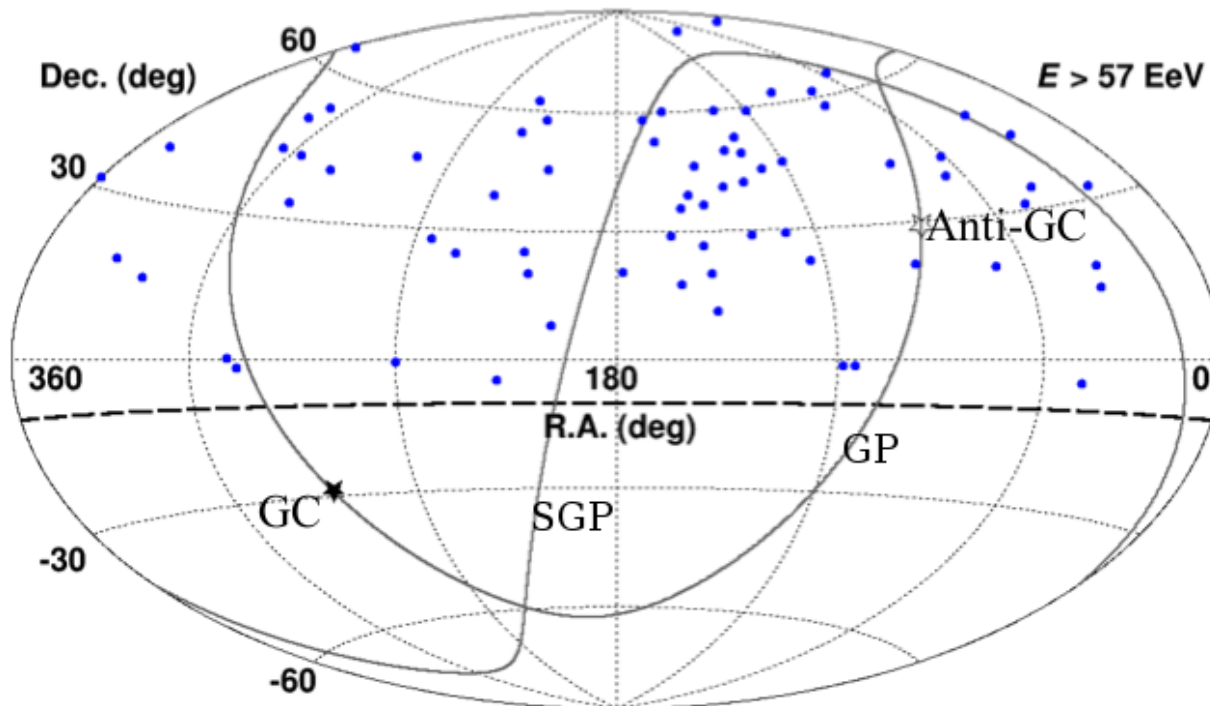
TA Data $> 1\text{EeV}$





Hotspot

arXiv:1404.5890



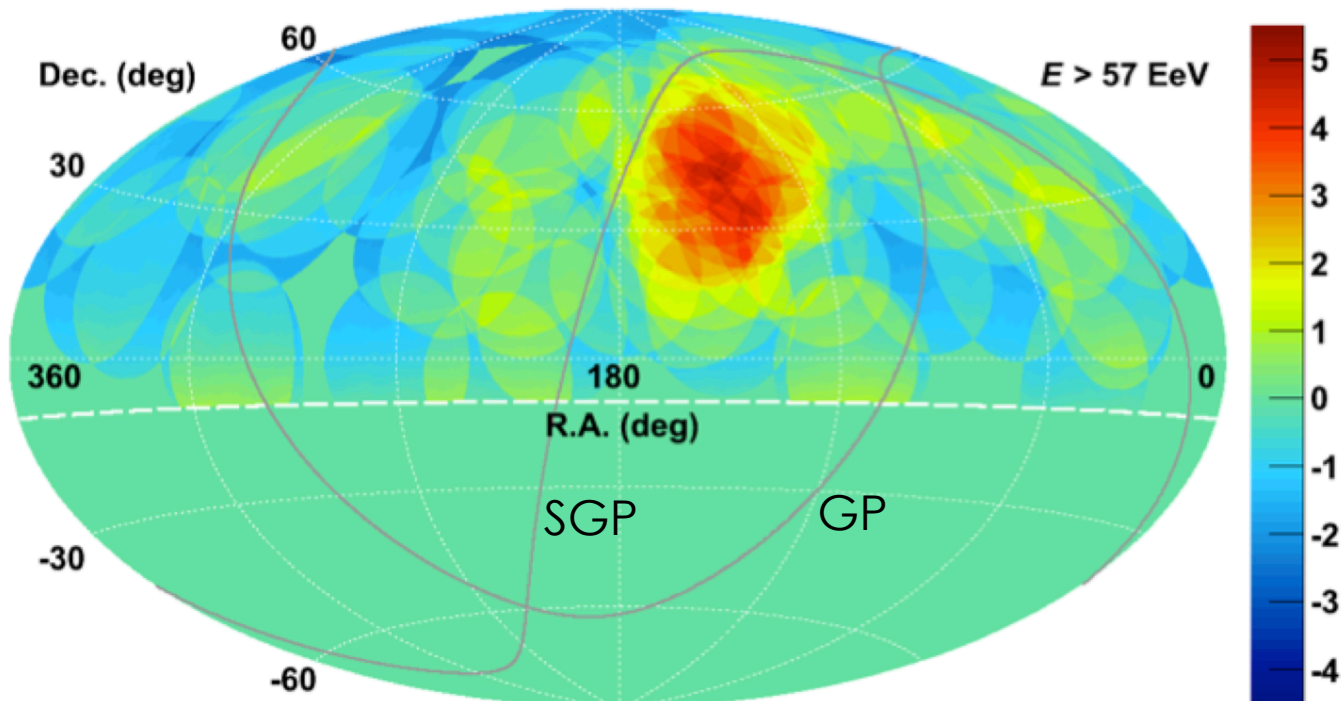
- ❖ Loose cut data: 72 events $>57\text{EeV}$, $\theta < 55^\circ$, No boundary cut
- ❖ E resol. and Angular resol. do not change very much

For more detailed, see arXiv:1404.5890
Event list ($>57\text{EeV}$) has been published.



Hotspot

arXiv:1404.5890



- ❖ Loose cut data: 72 events $> 57 \text{ EeV}$, $\theta < 55^\circ$, No boundary cut
- ❖ Angular resolution does not change very much
- ❖ Oversampling with 20° -radius circle
- ❖ Hotspot center R.A.=146.7, Dec.=42.6 (Maximum 5.1σ)
- ❖ Chance Probability from isotropic sky : 1.4×10^{-4} (3.6σ)

For more detailed, see arXiv:1404.5890
Event list ($> 57 \text{ EeV}$) has been published.



Future Plans

- TAx4 (Proposal)
 - TA 4 times extension
- TALE (Operating partly)
 - TA Low-energy Extension
- Other related projects



TAx4 Proposal

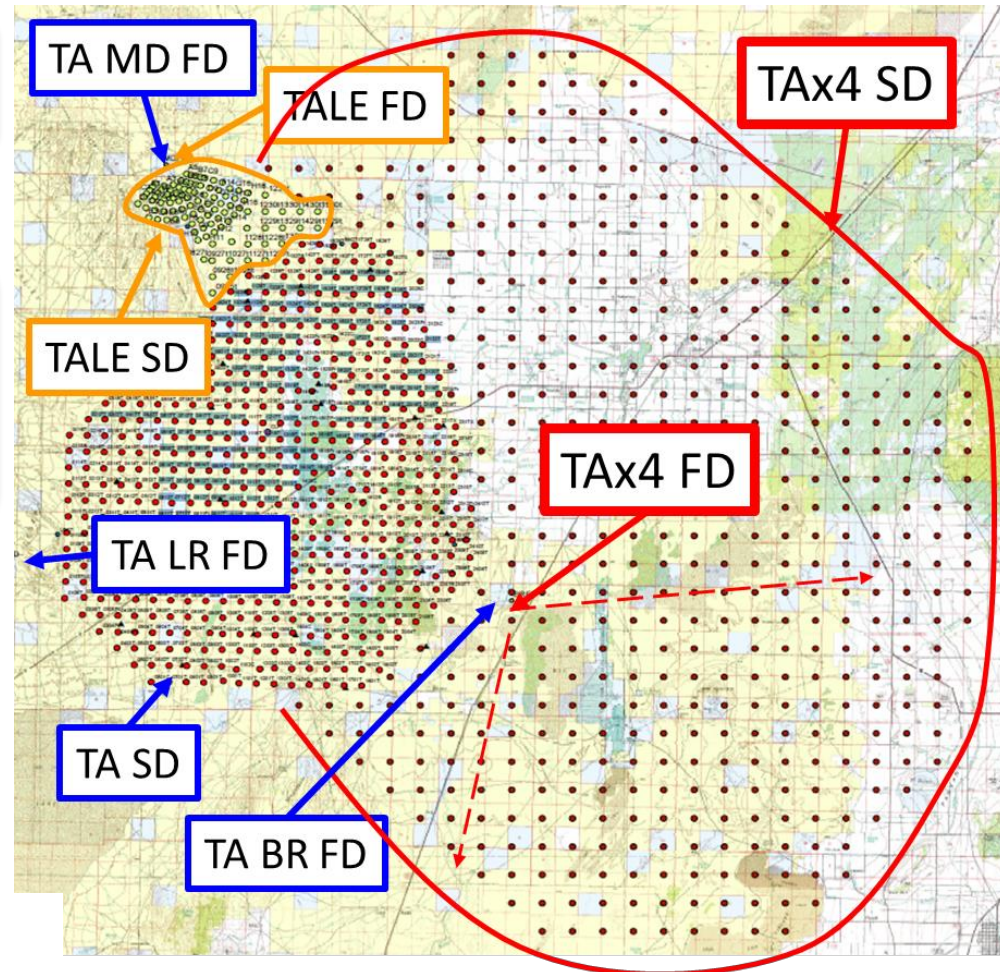
✧ Now there is hint of anisotropy at 3σ level for northern sky.

❖ Plan to expand TA by 4 times (3,000km²)

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

❖ Science (3-year observation)

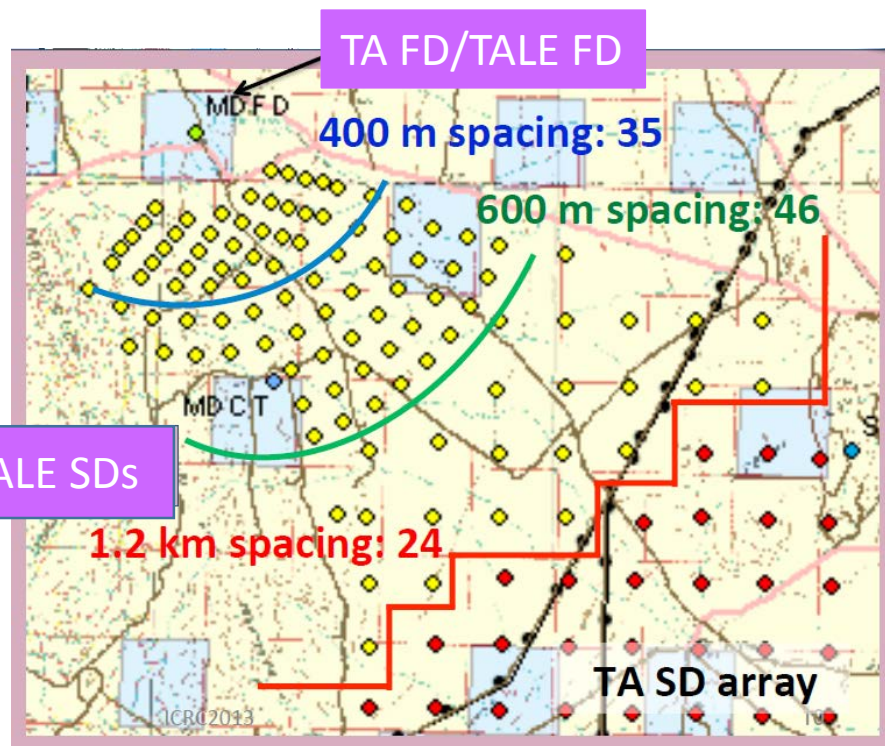
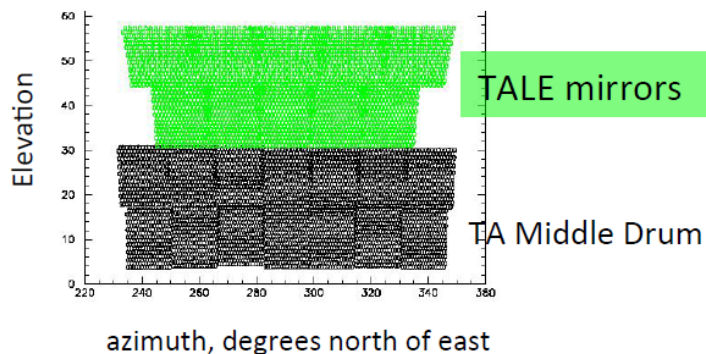
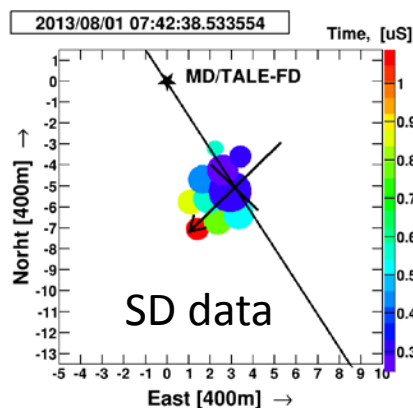
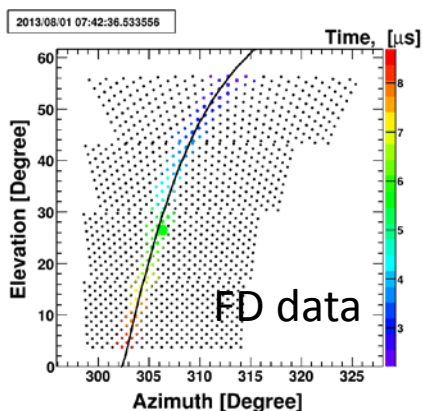
1. Anisotropy study
→ Expect $>5\sigma$
2. Xmax at highest energy region
3. UHE photon & neutrino search

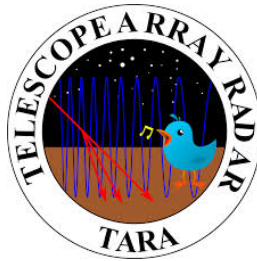




TALE (TA Low-E Extension)

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





Other Ongoing/Future Projects

- TARA (TA Radar)
- TA Muon Detectors
(varied Scinti., Lead plate, water tanks)
- NICHE (Non-Imaging CHerenkov)
- TA-EUSO (Test JEM-EUSO system at TA site)
- TALMA (TA Lightning Mapping Array)
(Recently, we found shower-like bursts with lightning)
- TA-Augur Joint Analysis (Anisotropy study)
- TA-Augur Cross Calibration
(Calibrated light source on the Octocopter)
- ...





Summary

- Recent results for 5 years
 - E Spectrum : significance of **suppression** consistent with GZK cutoff ($5.7\sigma > 10^{19.8}\text{eV}$)
 - Composition : consistent with **proton**
 - Anisotropy : **Hotspot** (3.6σ)
- TA Extension Plans
 - **TAx4** : TA aperture x4 (Proposal)
 - **TALE** : low-energy extension down to $10^{16.5}\text{eV}$ (10 FDs and part of SDs are operating)
- Other associated experiments
 - Ongoing / Future plans, High activities