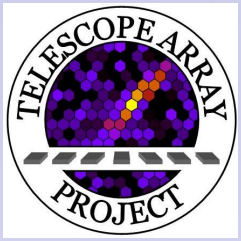
TELESCOPE ARRAY: LATEST RESULTS

P. Tinyakov[1,2]
for the Telescope Array Collaboration

[1]Université Libre de Bruxelles, Bruxelles, Belgium

[2]Institute for Nuclear Research, Moscow, Russia



Outline

Telescope Array detector

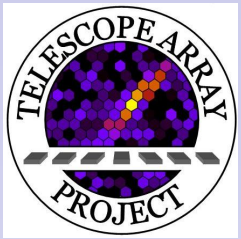
Spectrum

Composition

Anisotropies

Photon limit

Summary



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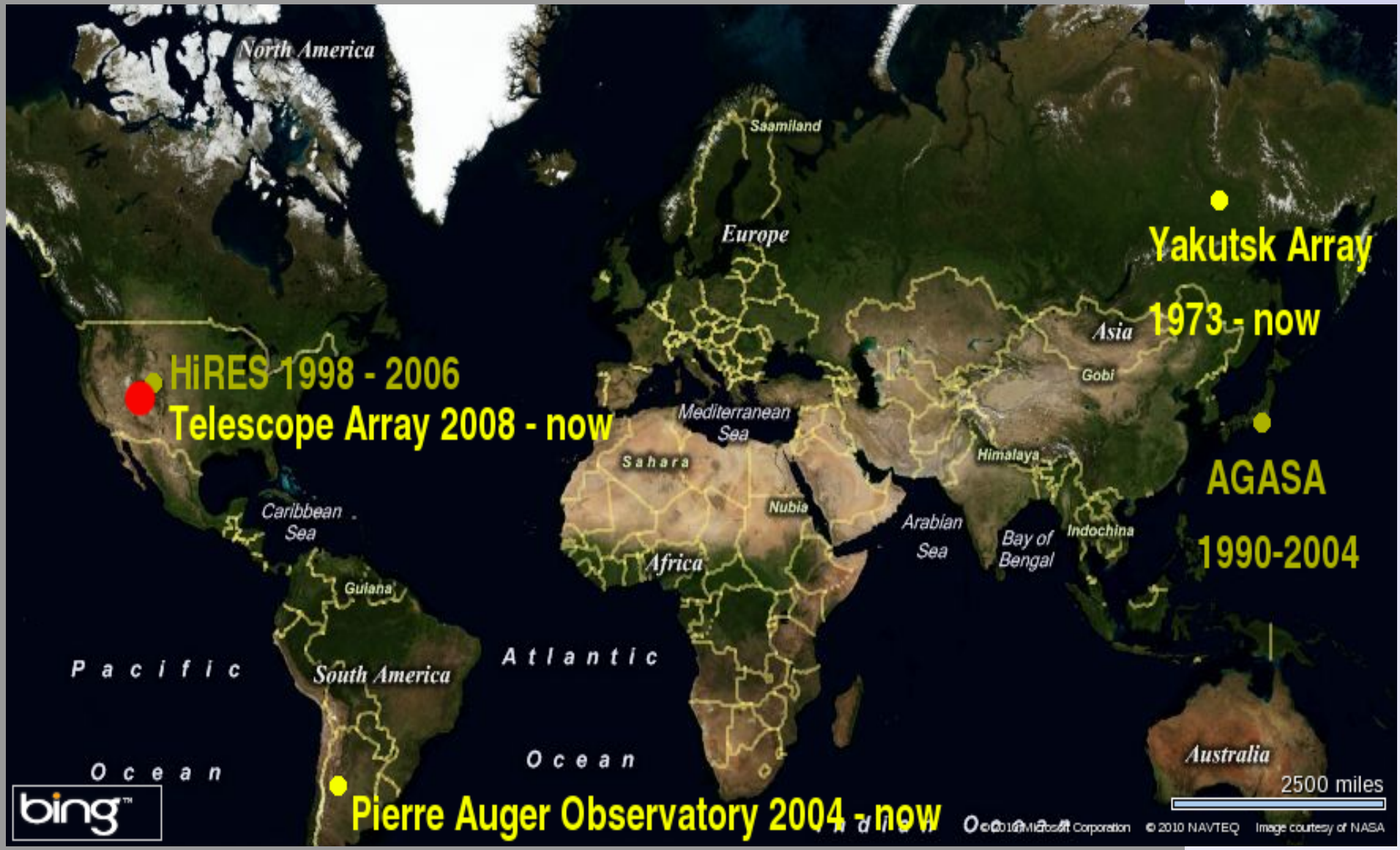
Latest UHECR experiments

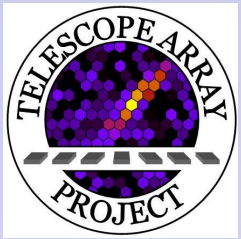


TELESCOPE ARRAY COLLABORATION

T. Abu-Zayyad[1], R. Aida[2], M. Allen[1], R. Anderson[1], R. Azuma[3], E. Barcikowski[1], J. W. Belz[1], D. R. Bergman[1], S. A. Blake[1], R. Cady[1], B. G. Cheon[4], J. Chiba[5], M. Chikawa[6], E. J. Cho[4], W. R. Cho[7], H. Fujii[8], T. Fujii[9], T. Fukuda[3], M. Fukushima[10,11], W. Hanlon[1], K. Hayashi[3], Y. Hayashi[9], N. Hayashida[10], K. Hibino[12], K. Hiyama[10], K. Honda[2], T. Iguchi[3], D. Ikeda[10], K. Ikuta[2], N. Inoue[13], T. Ishii[2], R. Ishimori[3], D. Ivanov[1,14], S. Iwamoto[2], C. C. H. Jui[1], K. Kadota[15], F. Kakimoto[3], O. Kalashev[16], T. Kanbe[2], K. Kasahara[17], H. Kawai[18], S. Kawakami[9], S. Kawana[13], E. Kido[10], H. B. Kim[4], H. K. Kim[7], J. H. Kim[1], J. H. Kim[4], K. Kitamoto[6], S. Kitamura[3], Y. Kitamura[3], K. Kobayashi[5], Y. Kobayashi[3], Y. Kondo[10], K. Kuramoto[9], V. Kuzmin[16], Y. J. Kwon[7], J. Lan[1], S. I. Lim[19], S. Machida[3], K. Martens[11], T. Matsuda[8], T. Matsuura[3], T. Matsuyama[9], J. N. Matthews[1], M. Minamino[9], K. Miyata[5], Y. Murano[3], I. Myers[1], K. Nagasawa[13], S. Nagataki[20], T. Nakamura[21], S. W. Nam[19], T. Nonaka[10], S. Ogio[9], M. Ohnishi[10], H. Ohoka[10], K. Oki[10], D. Oku[2], T. Okuda[22], A. Oshima[9], S. Ozawa[17], I. H. Park[19], M. S. Pshirkov[23], D. C. Rodriguez[1], S. Y. Roh[24], G. Rubtsov[16], D. Ryu[24], H. Sagawa[10], N. Sakurai[9], A. L. Sampson[1], L. M. Scott[14], P. D. Shah[1], F. Shibata[2], T. Shibata[10], H. Shimodaira[10], B. K. Shin[4], J. I. Shin[7], T. Shirahama[13], J. D. Smith[1], P. Sokolsky[1], B. T. Stokes[1], S. R. Stratton[1,14], T. Stroman[1], S. Suzuki[8], Y. Takahashi[10], M. Takeda[10], A. Taketa[25], M. Takita[10], Y. Tameda[10], H. Tanaka[9], K. Tanaka[26], M. Tanaka[9], S. B. Thomas[1], G. B. Thomson[1], P. Tinyakov[16,23], I. Tkachev[16], H. Tokuno[3], T. Tomida[27], S. Troitsky[16], Y. Tsunesada[3], K. Tsutsumi[3], Y. Tsuyuguchi[2], Y. Uchihori[28], S. Udo[12], H. Ukai[2], G. Vasiloff[1], Y. Wada[13], T. Wong[1], M. Wood[1], Y. Yamakawa[10], R. Yamane[9], H. Yamaoka[8], K. Yamazaki[9], J. Yang[19], Y. Yoneda[9], S. Yoshida[18], H. Yoshii[29], X. Zhou[6], R. Zollinger[1], and Z. Zundel[1]

- $\sim$ 140 collaborators from 29 Institutions in Belgium, Japan, Korea, Russia, USA

TELESCOPE ARRAY DETECTOR



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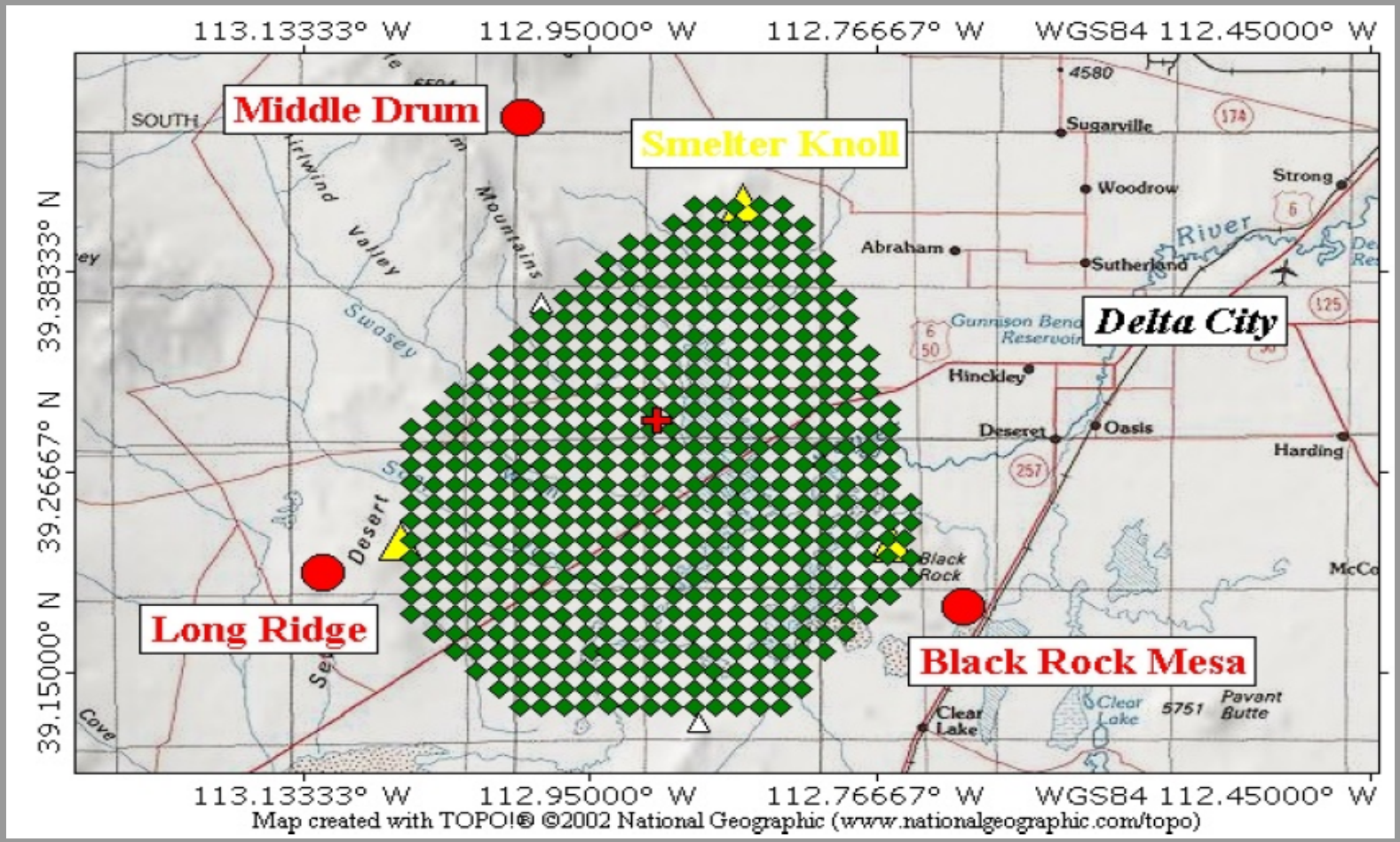
TELESCOPE ARRAY HYBRID DETECTOR



- 507 scintillator detectors covering 680 km^2
- 3 fluorescence sites, 38 telescopes
- Surface detector fully operational from March 2008
- SD relative size: TA $\sim 9 \times$ AGASA $\sim$ PAO/4

TA surface detectors

- Deployed with the spacing $\sim$ 1.2 km
- Powered by solar panels. Connected by radio.

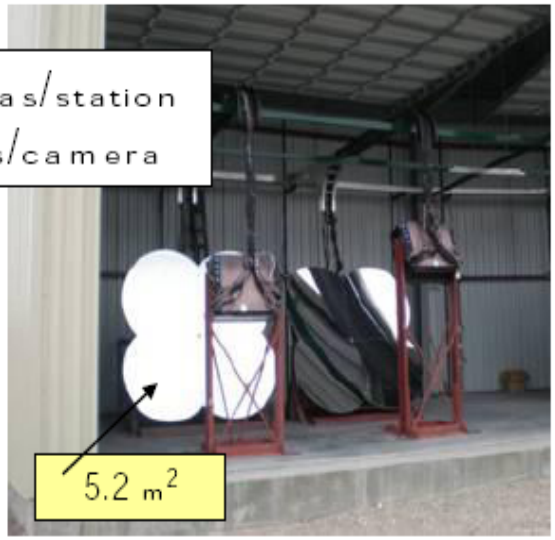
TA Fluorescence Detectors

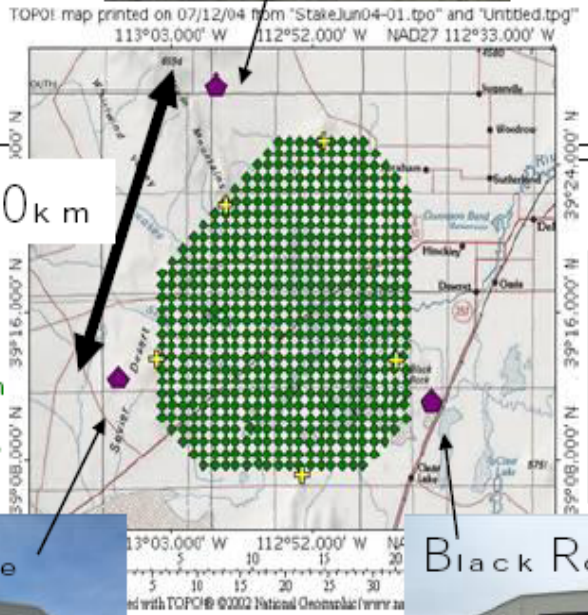
Refurbished from HiRes

Observation started Dec. 2007

Middle Drum

14 cameras/station
256 PMTs/camera





~30km

Observation started Nov. 2007

New FDs

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

Long Ridge

Black Rock Mesa

Observation started Jun. 2007

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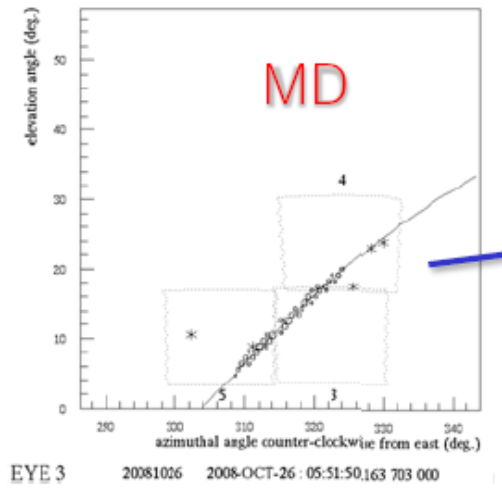
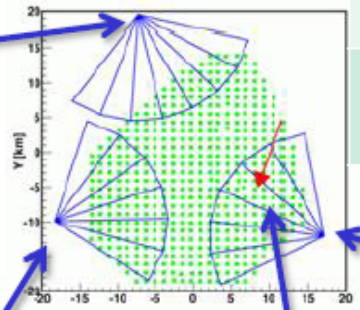
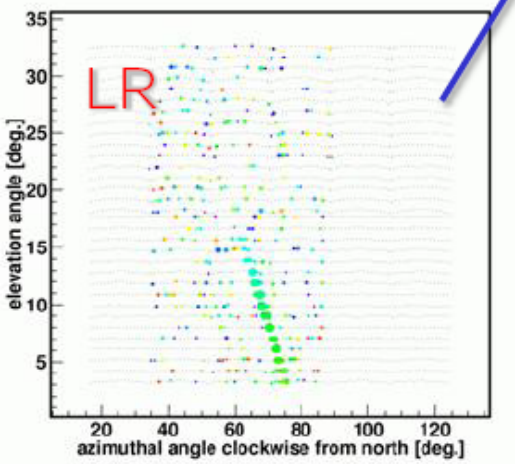
Hybrid event example

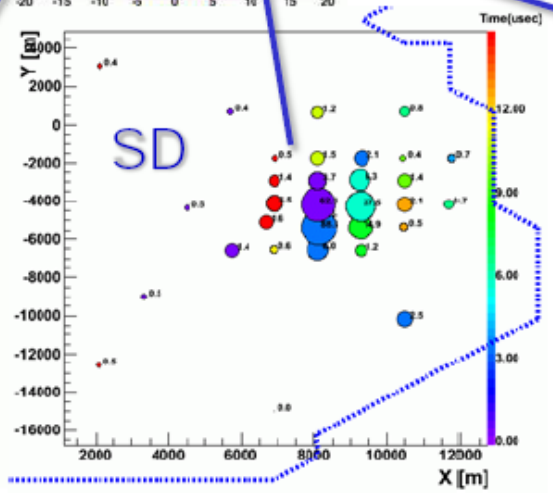
Triple FD Event (2008-10-26)

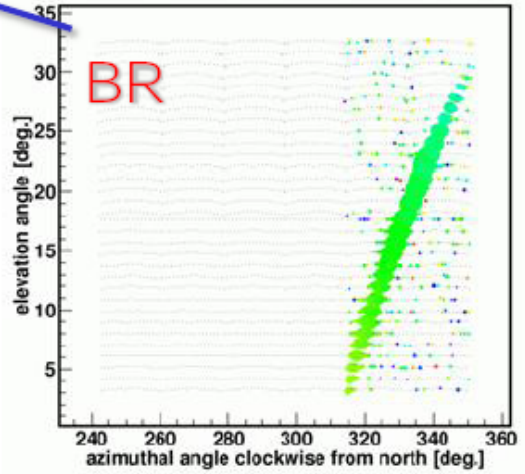
	θ[deg]	ϕ[deg]	X[km]	Y[km]
MD mono	51.43	73.76	7.83	-3.10
BR mono	51.50	77.09	7.67	-4.14
Stereo BR&LR	50.21	71.30	8.55	-4.88











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SPECTRUM

TA spectrum

TA measures spectrum by several techniques:

- Fluorescence detector (FD-mono) – at three stations independently + in stereo mode (FD-stereo)
- Surface detector (SD) – largest statistics
- Hybrid (SD+FD) – used for calibration
- All spectra agree after rescaling of SD energies down by 1.27

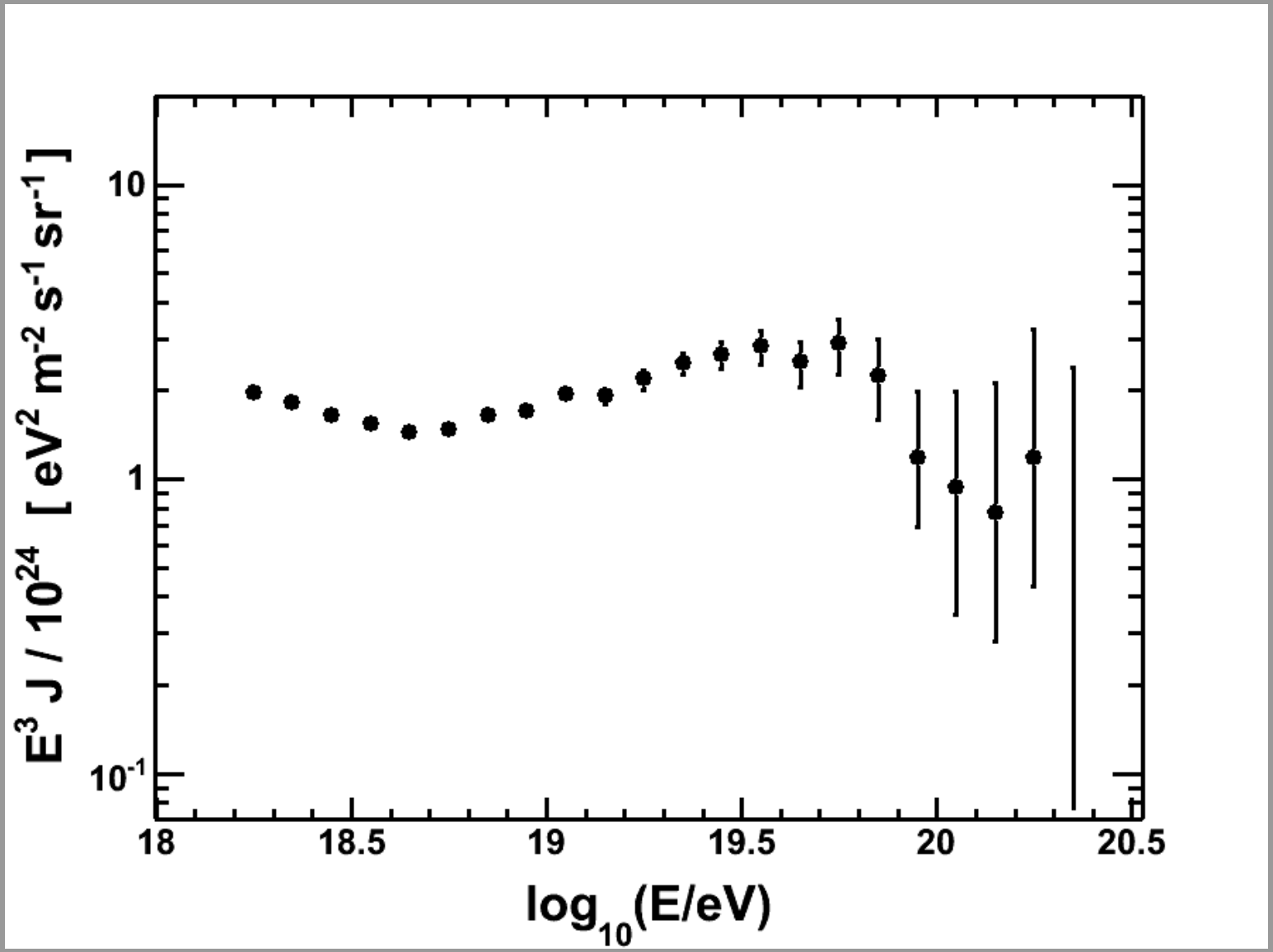
Surface detector spectrum

Data set [ApJ'2013]:

- Geometrical cuts:
  - $\theta < 45^\circ$
  - core inside the array, distance to border > 1200 m
- Cuts on reconstruction quality:
  - number of detectors hit ≥ 4
  - $\chi^2/d.o.f < 4.0$
  - pointing direction resolution $< 5^\circ$
  - fractional S_{800} uncertainty < 0.25

- May 2008 $\rightarrow$ May 2012 = 13100 events above $10^{18.2}$ EeV
  aperture 920 km^2 sr
  exposure 3690 km^2 sr yr

SD spectrum



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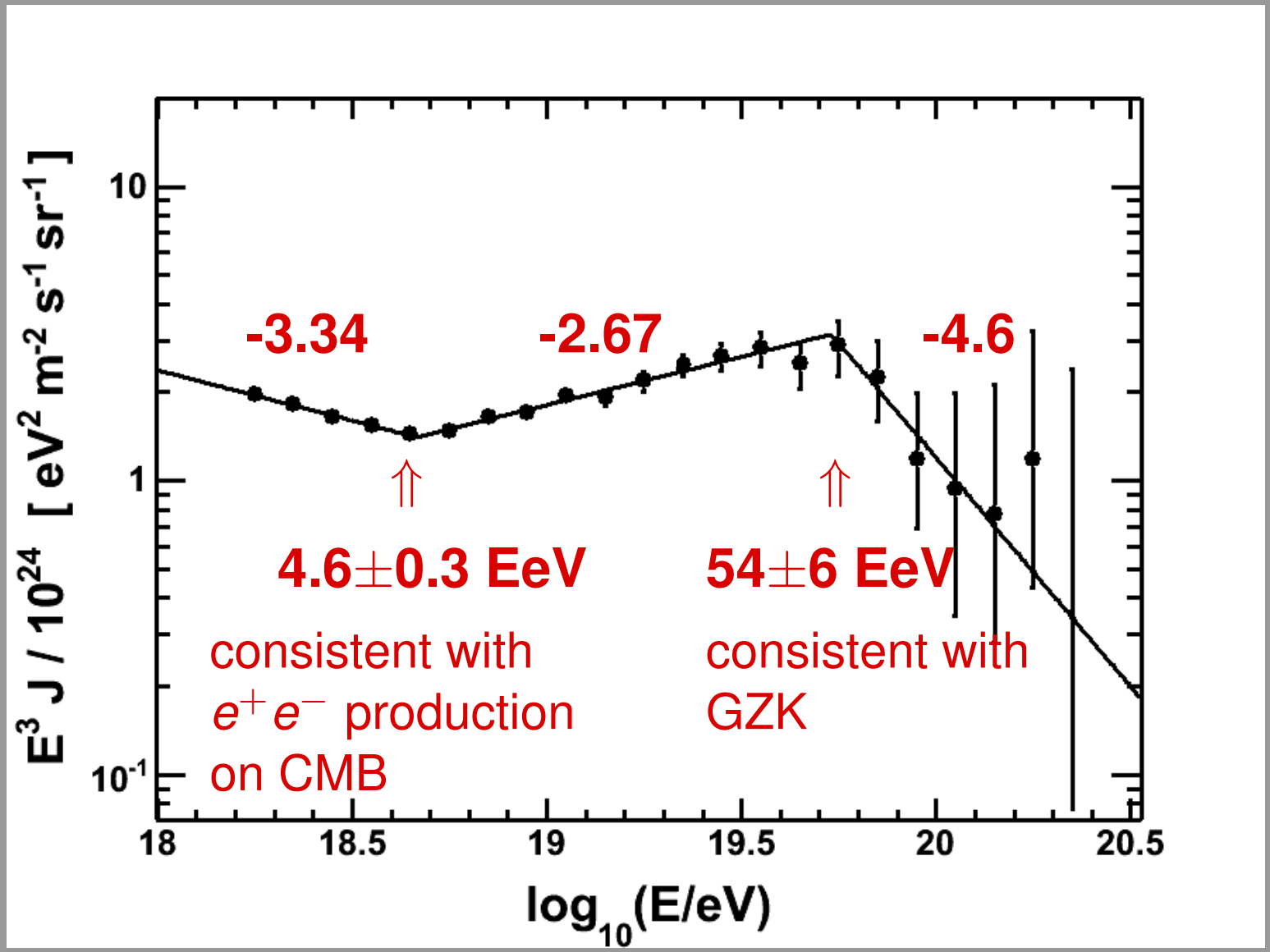
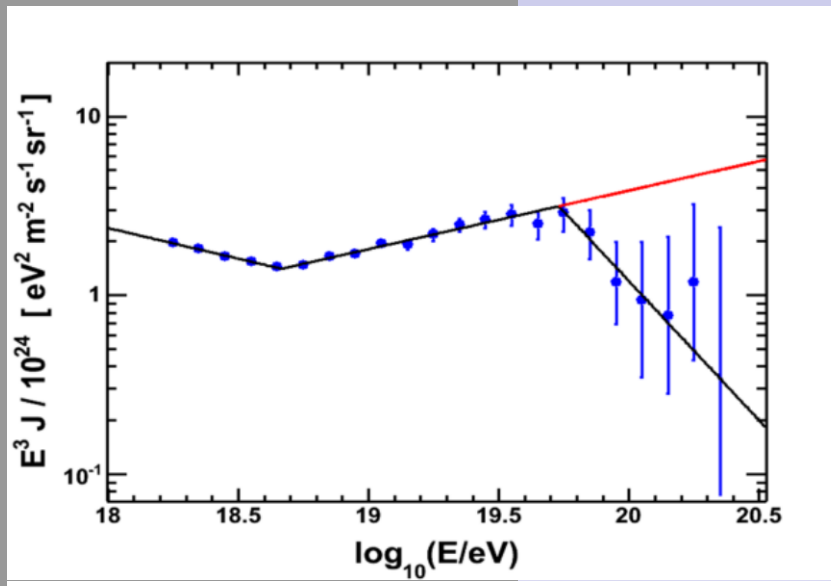
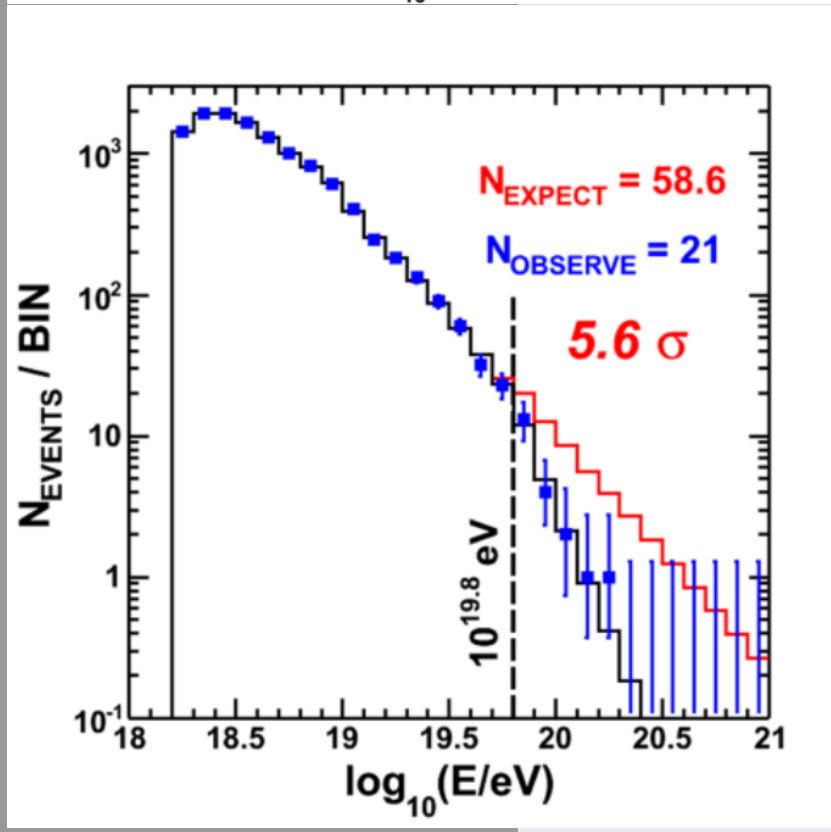
SD spectrum: fit with broken power law



Significance of suppression

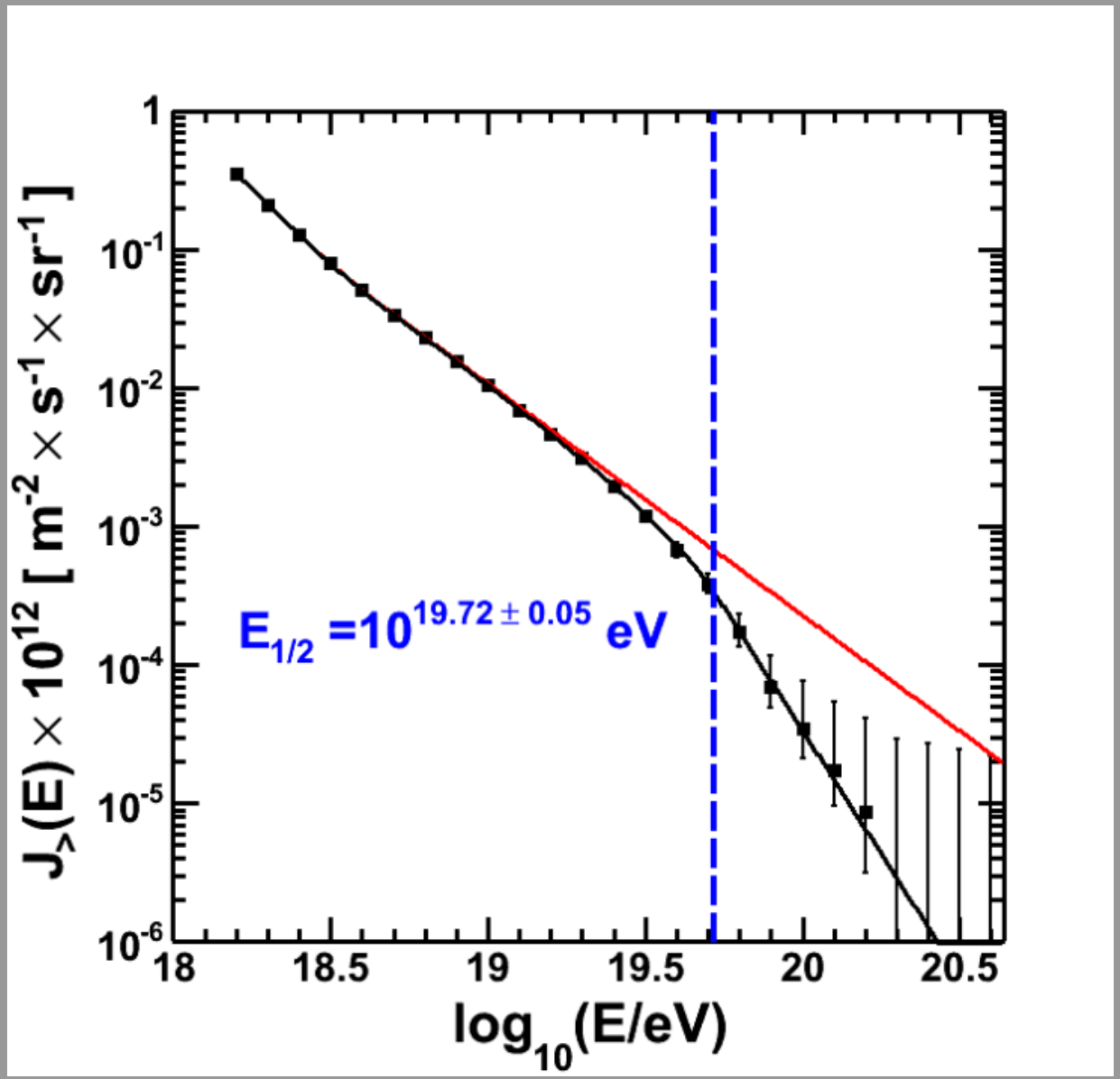
- Assume no suppression and extend the power law beyond the break
- Number of events above $E = 10^{19.8}$ eV:
  - expected: 58.6
  - observed: 21
- $\Longrightarrow$ Significance of the cutoff is 5.6σ



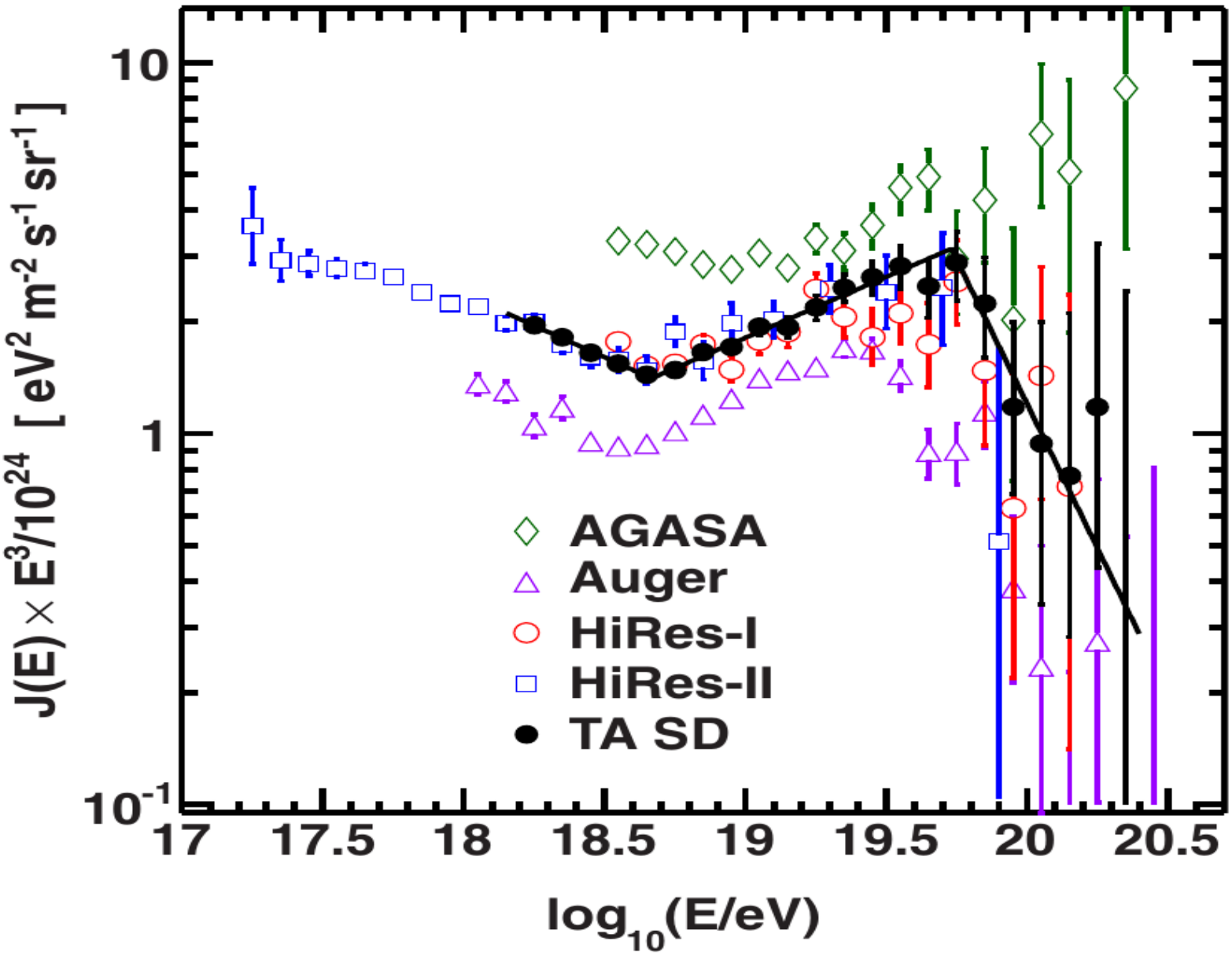


Predicted for protons: $E_{1/2} = 10^{19.72}$ eV

[Berezinsky'2006]



SD spectrum vs. other experiments



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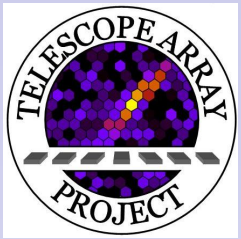
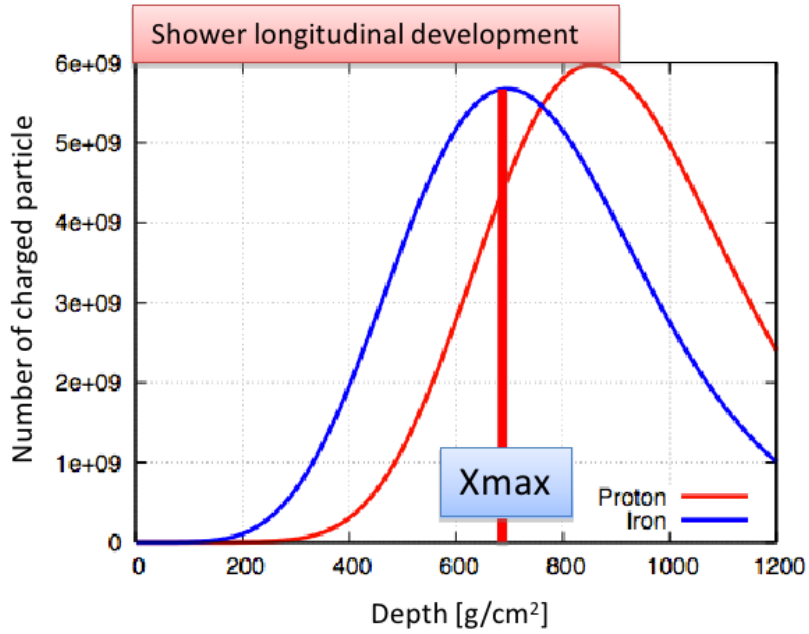
COMPOSITION

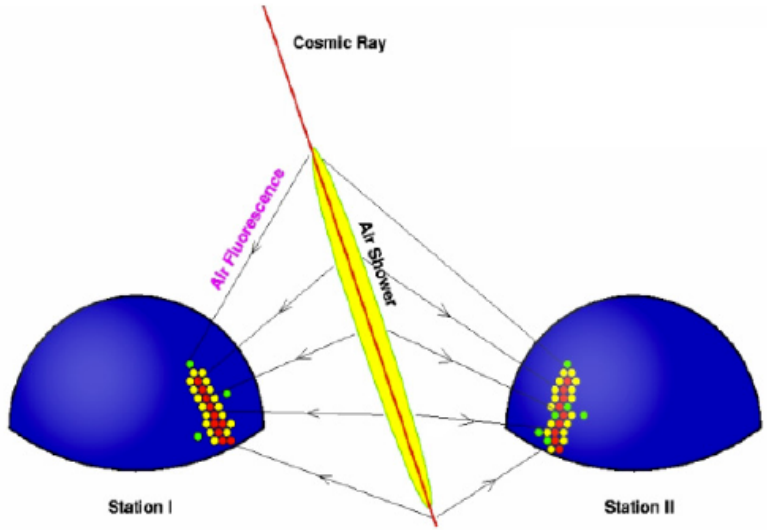


TA composition measurement

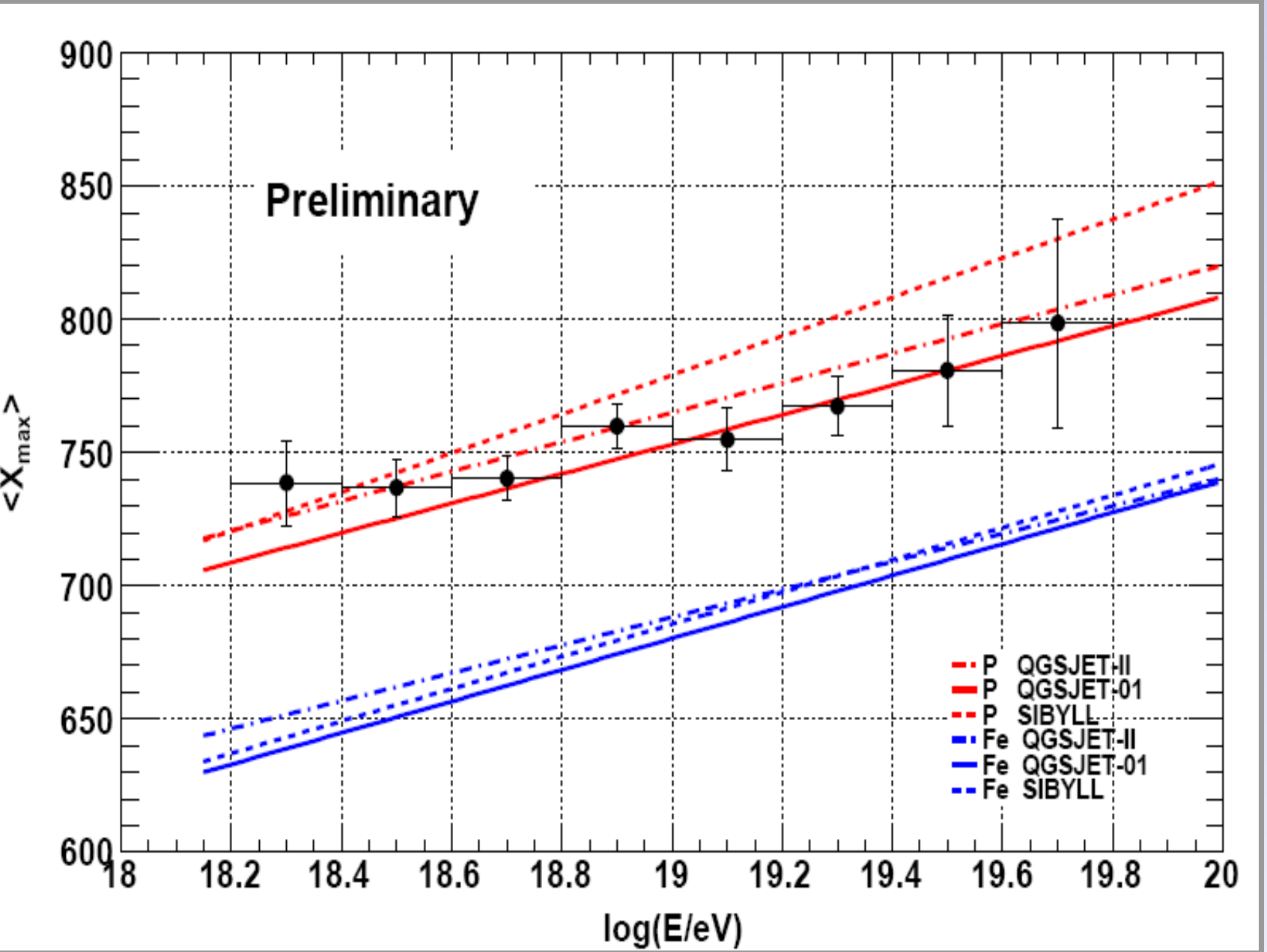
- Observable sensitive to composition: shower depth $X_{\max}$
  $\Longrightarrow$ FD data only
- Difficult measurement:
  - large fluctuations
  - limited statistics
  - biases in event selection
- TA strategy:
  - full MC simulation of the data analysis chain (including event selection)
  - prediction for different compositions
  - comparison to data



FD stereo analysis



Mean X_{max} as a function of energy



TELESCOPE ARRAY: LATEST RESULTS

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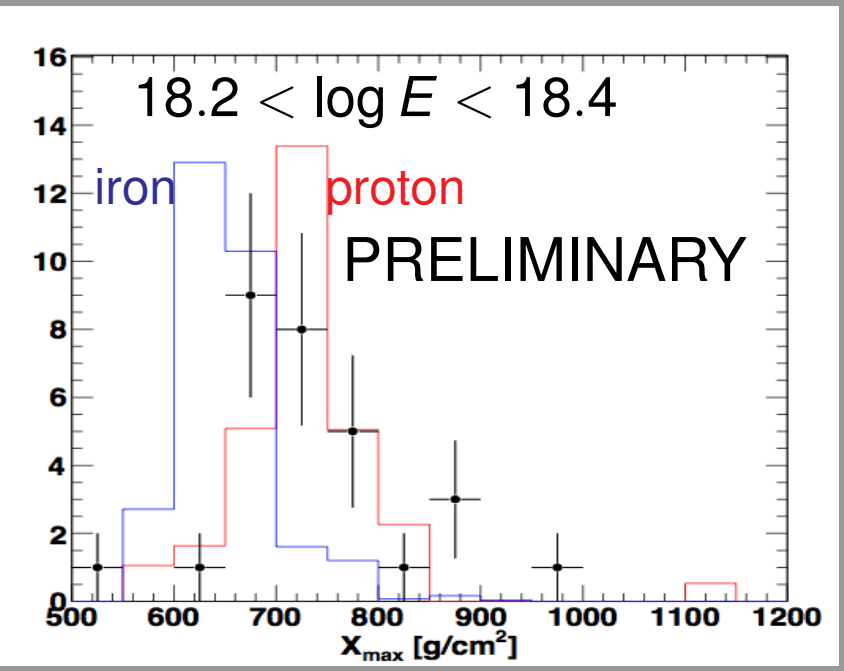
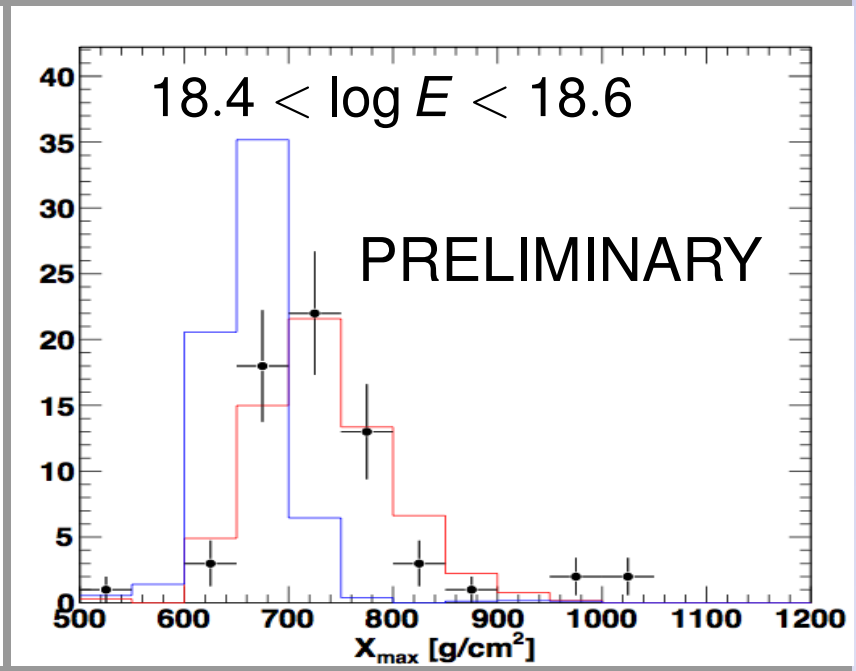
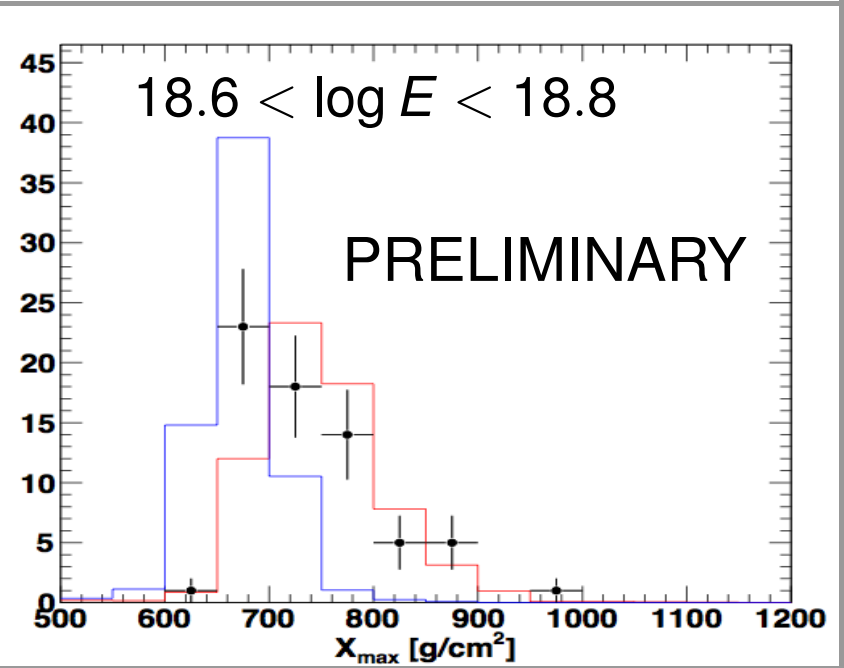
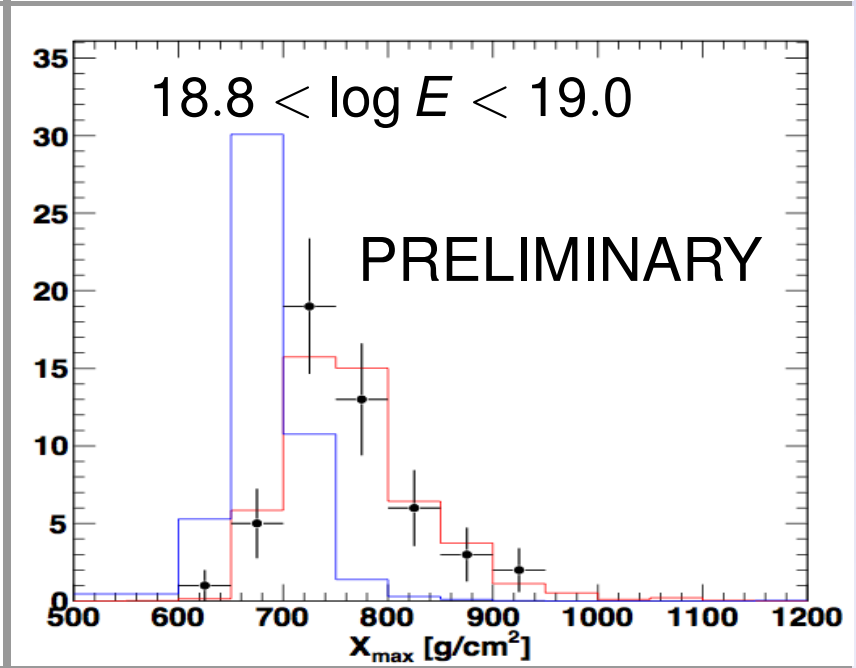
Distributions of X_{max} in energy bins









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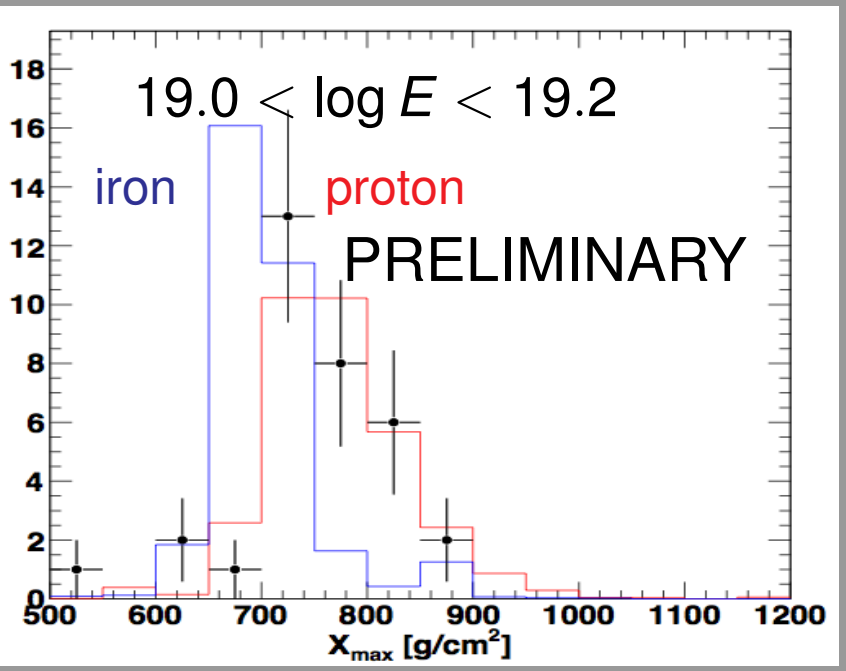

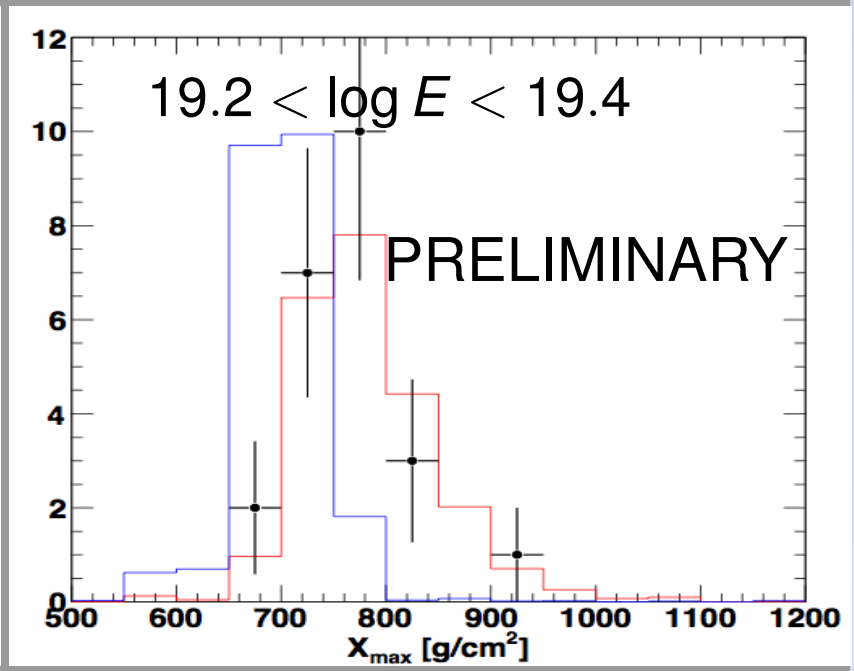

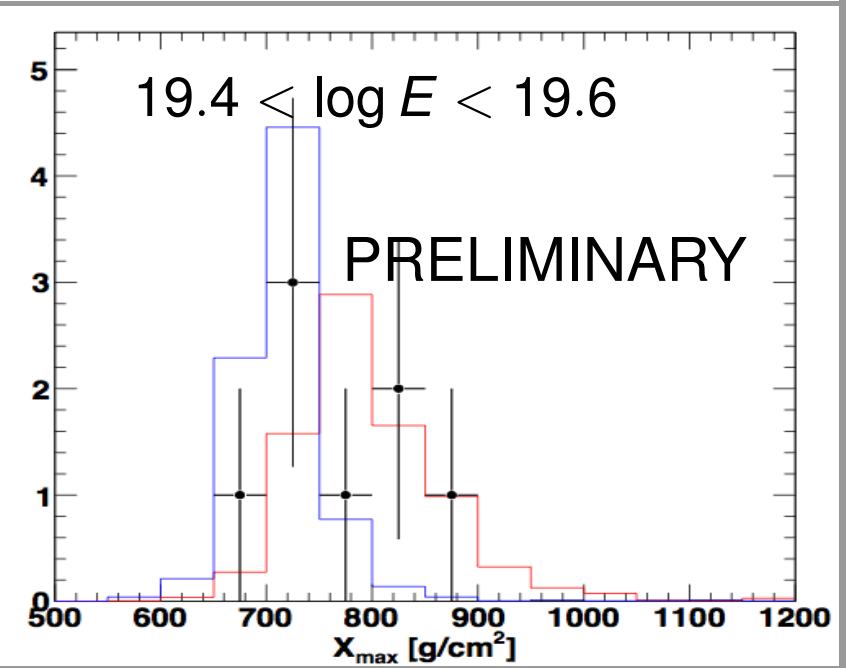

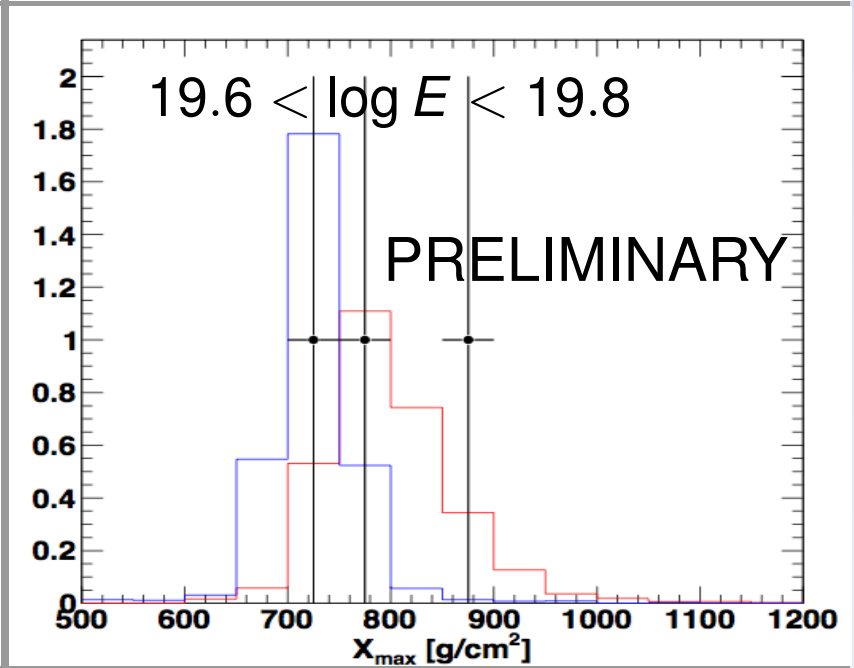

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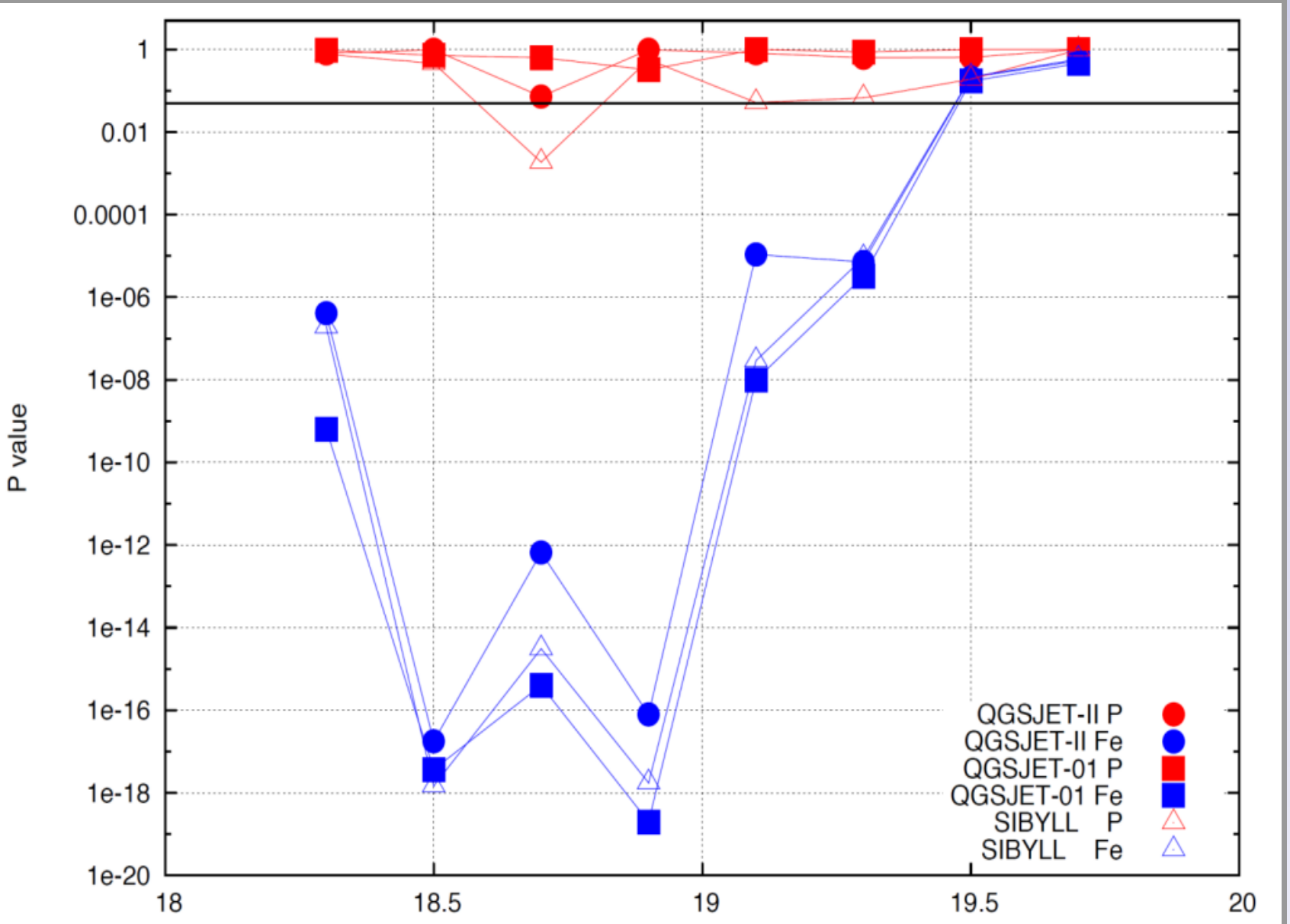
Comparison of X_{max} distributions by the KS test



ANISOTROPIES

Dedicated anisotropy data set

- SD events
- covers the period 08.05.12 — 12.07.18 ($\sim$ 50 months)
- zenith angle up to 55°
- loose cuts
- total exposure $\sim$ 5200 km^2 yr sr
- 1807 above 10 EeV
- 114 above 40 EeV
- 42 above 57 EeV

STRATEGY

- Consider 3 energy thresholds of 10, 40 & 57 EeV
- Tests:
  - test against uniform distribution in right ascension and declination in equatorial and supergalactic coordinates
  - autocorrelation function
  - correlation with AGN ($E > 57$ EeV)
  - correlation with LSS

RESULTS:

- No deviation from isotropy at $E > 10$ EeV and $E > 40$ EeV
- Marginal deviation at $E > 57$ EeV

STRATEGY

- Consider 3 energy thresholds of 10, 40 & 57 EeV
- Tests:
  - test against uniform distribution in right ascension and declination in equatorial and supergalactic coordinates
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  - correlation with LSS

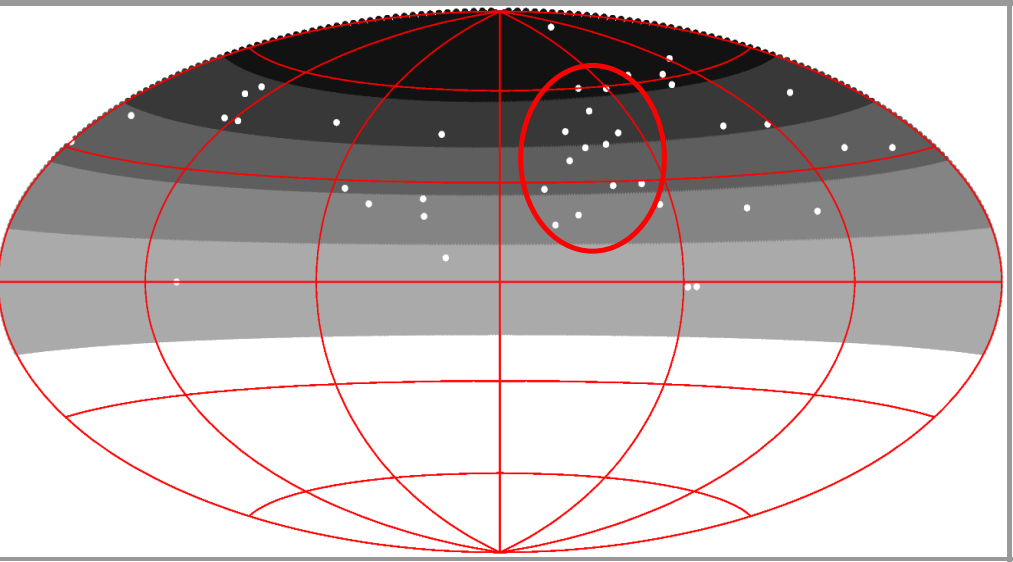
RESULTS:

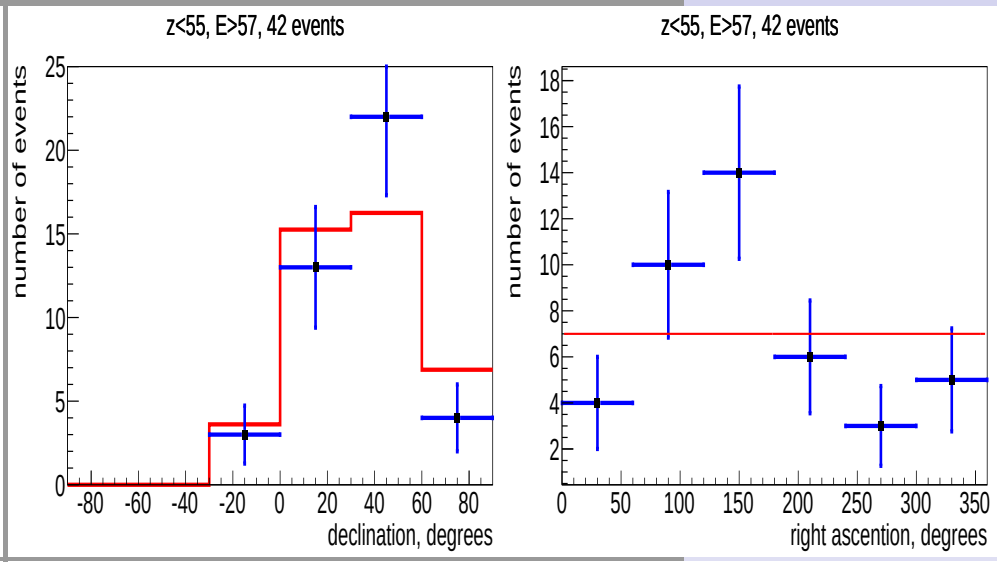
- No deviation from isotropy at $E > 10$ EeV and $E > 40$ EeV
- Marginal deviation at $E > 57$ EeV

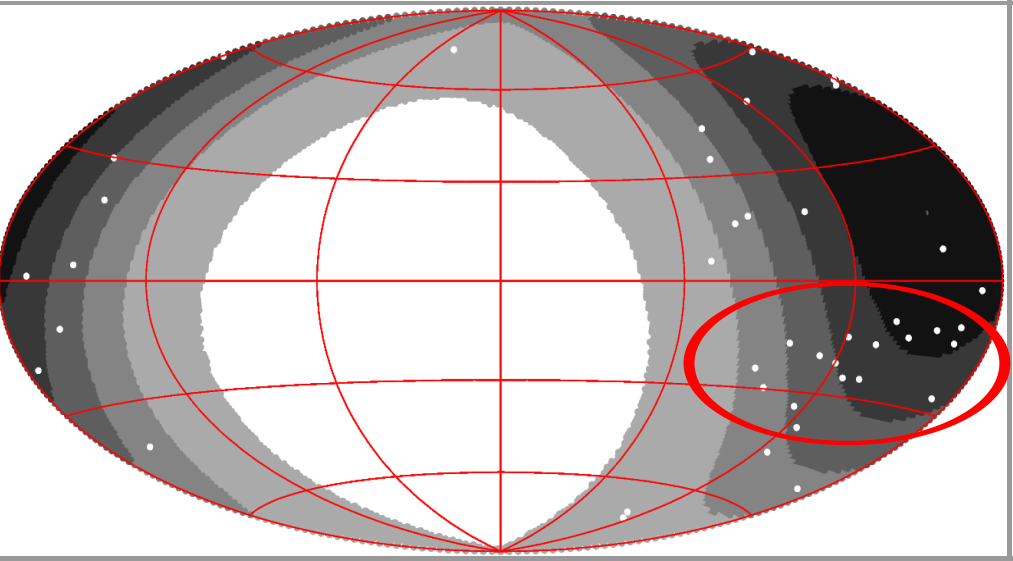
$E > 57$ EeV: KS test with isotropic distribution

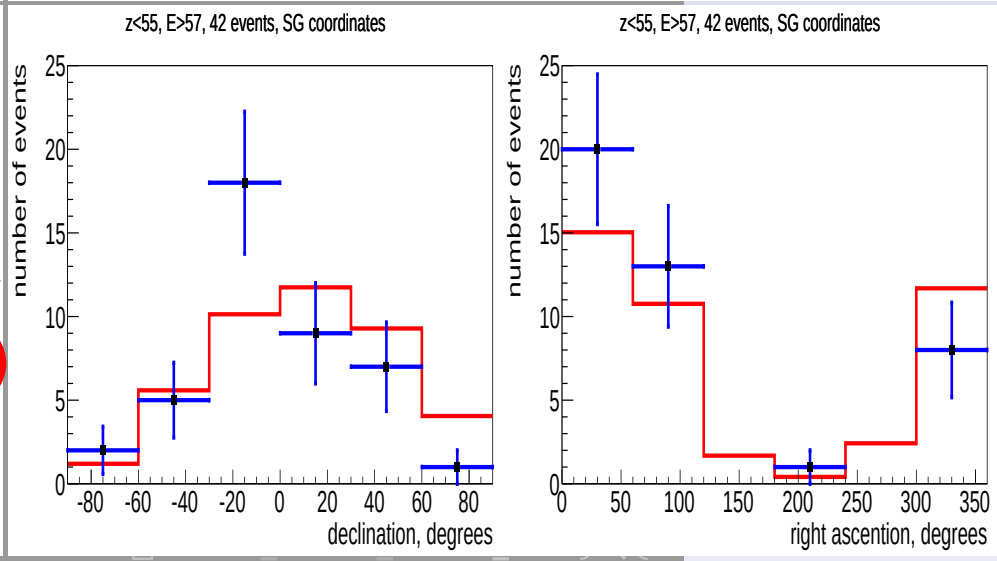
Coords	right ascension	declination
Equatorial:	0.04	0.13
Supergalactic:	0.04	0.006

TELESCOPE ARRAY:



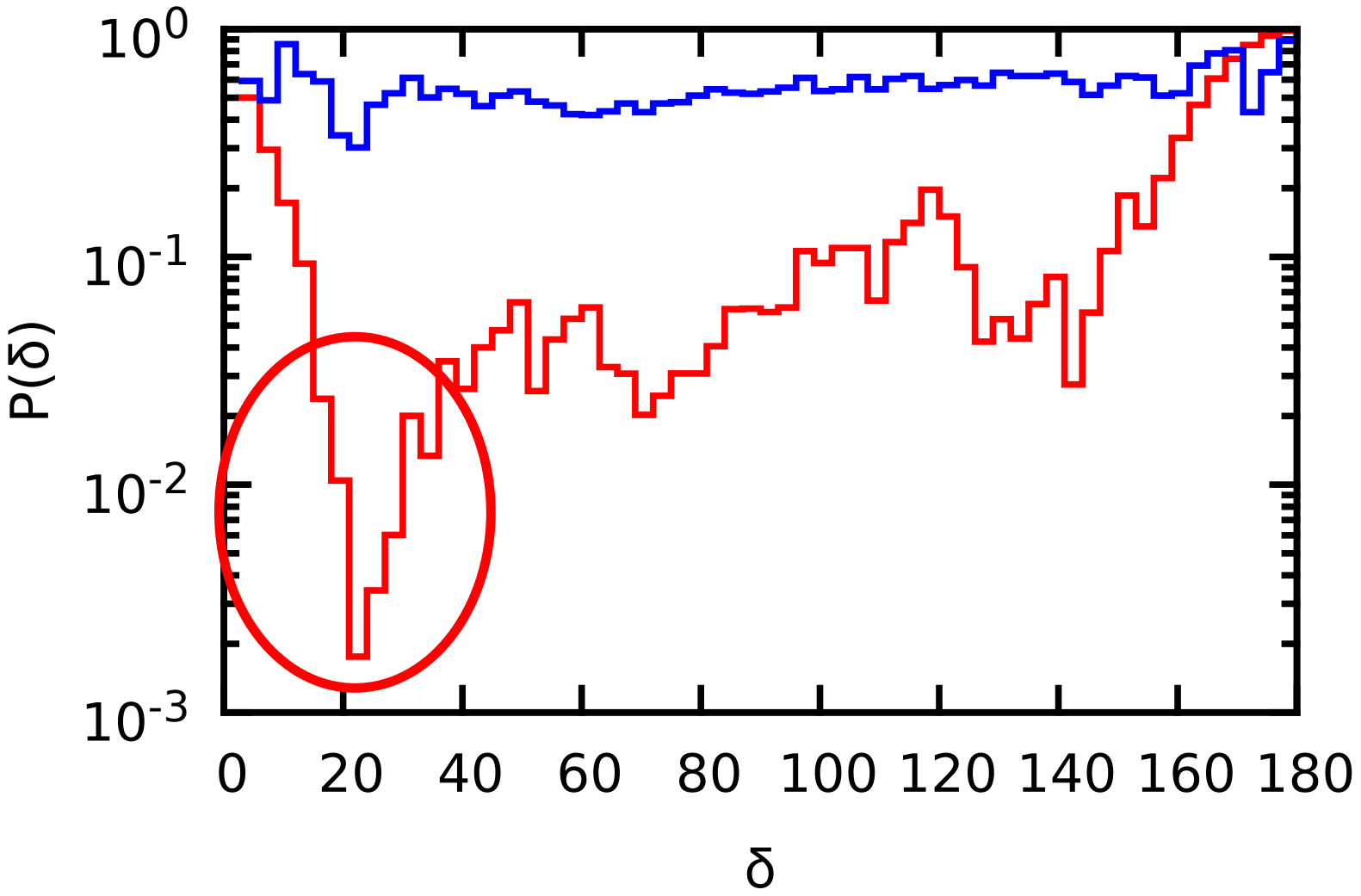






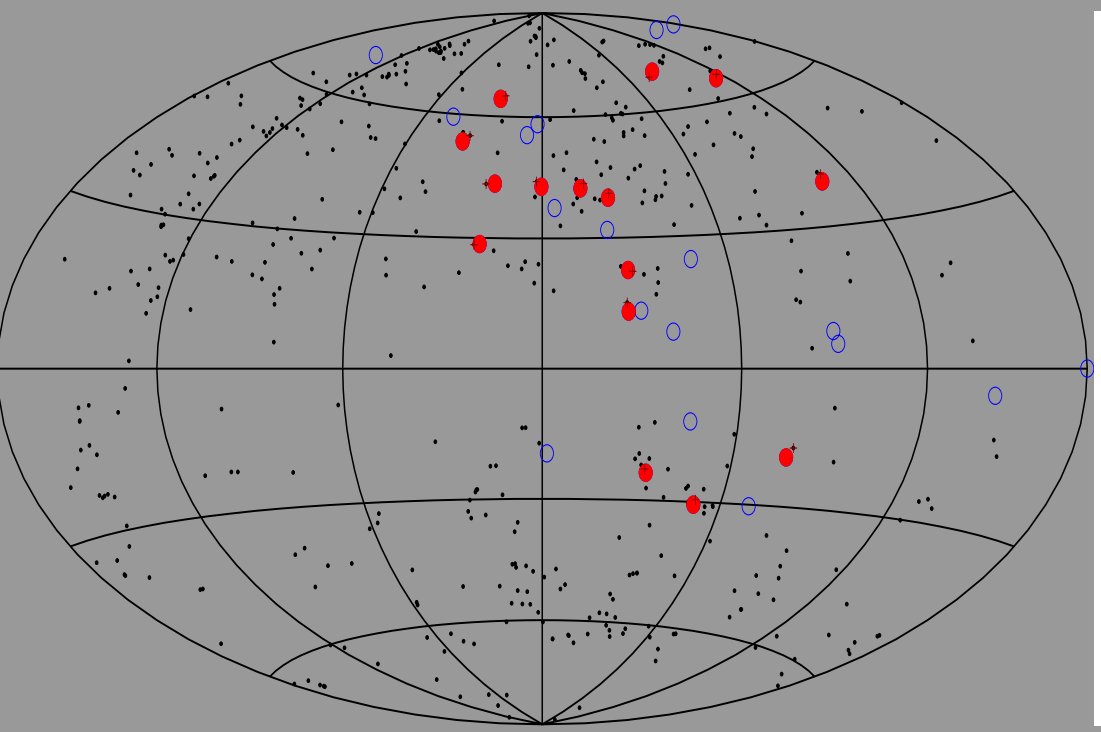
AUTOCORRELATION FUNCTION

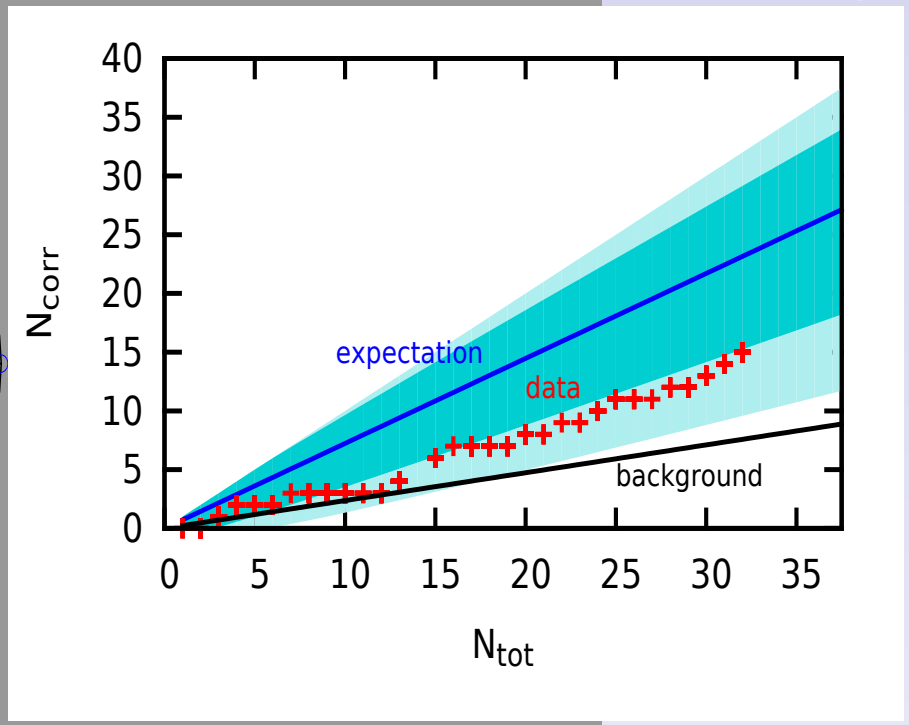
Blue: $E > 40$ EeV Red: $E > 57$ EeV



Correlations with AGN

- 472 AGN from 2006 Veron catalog with $z < 0.018$
- separation angle 3.1°
- $E > 57$ EeV , ZA $< 45°$, tight cuts ($N = 32$)





15 correlate, 7.7 expected, *p*-value 0.004.

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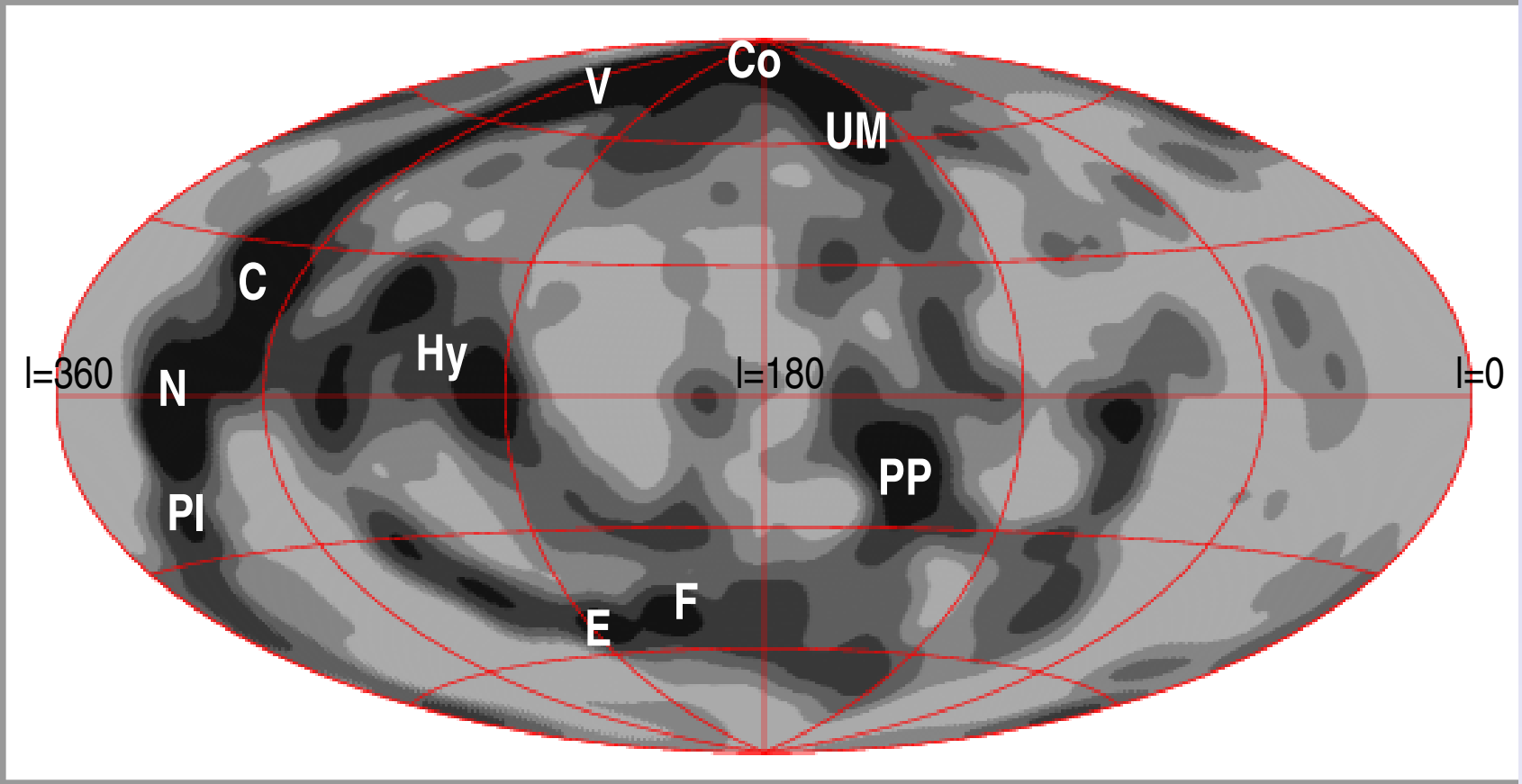
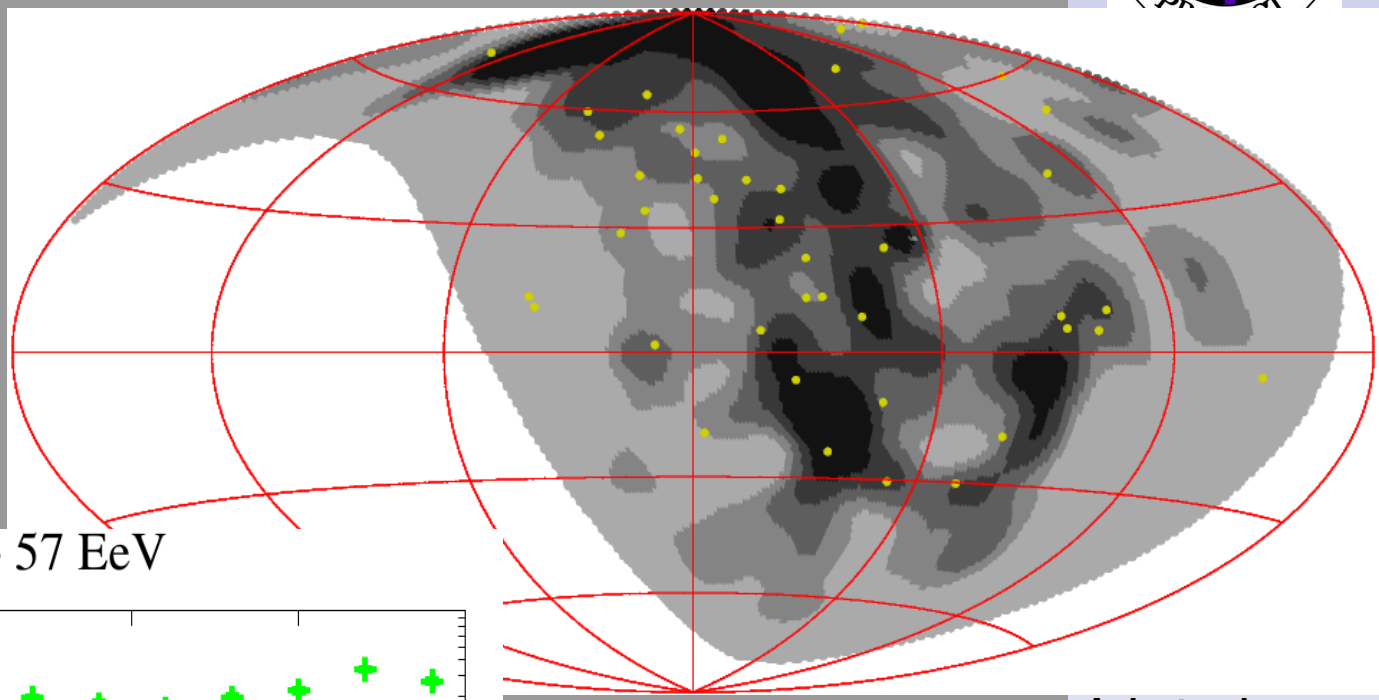
CORRELATIONS WITH LSS

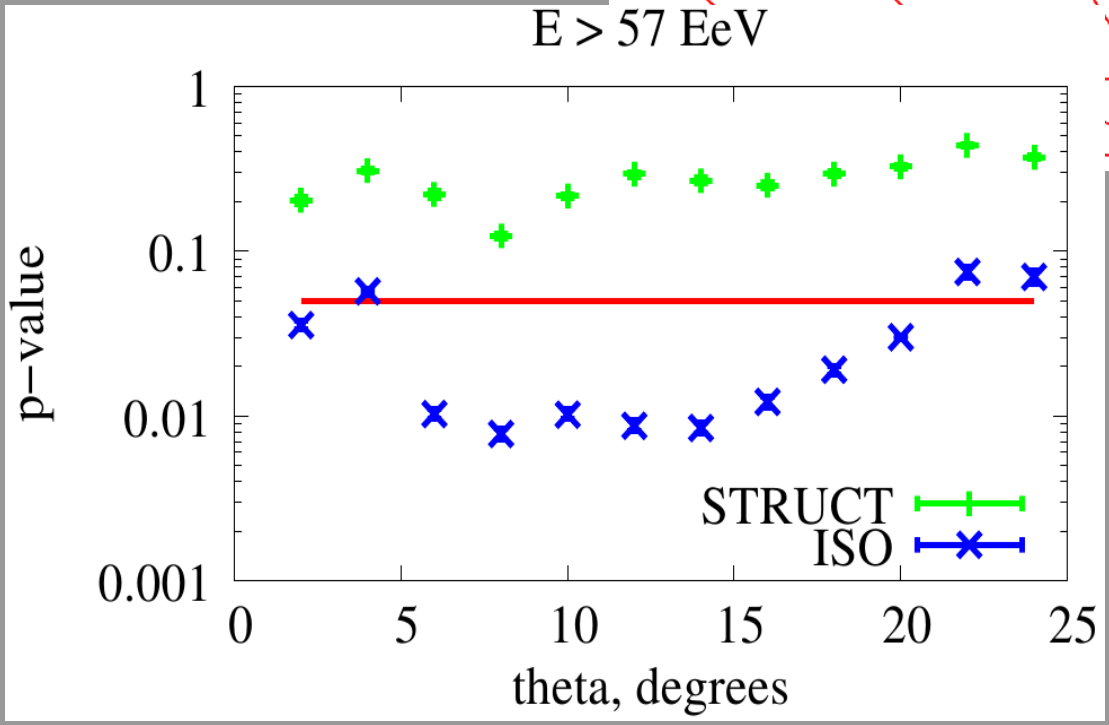
At highest energies, anisotropic flux is expected for protons



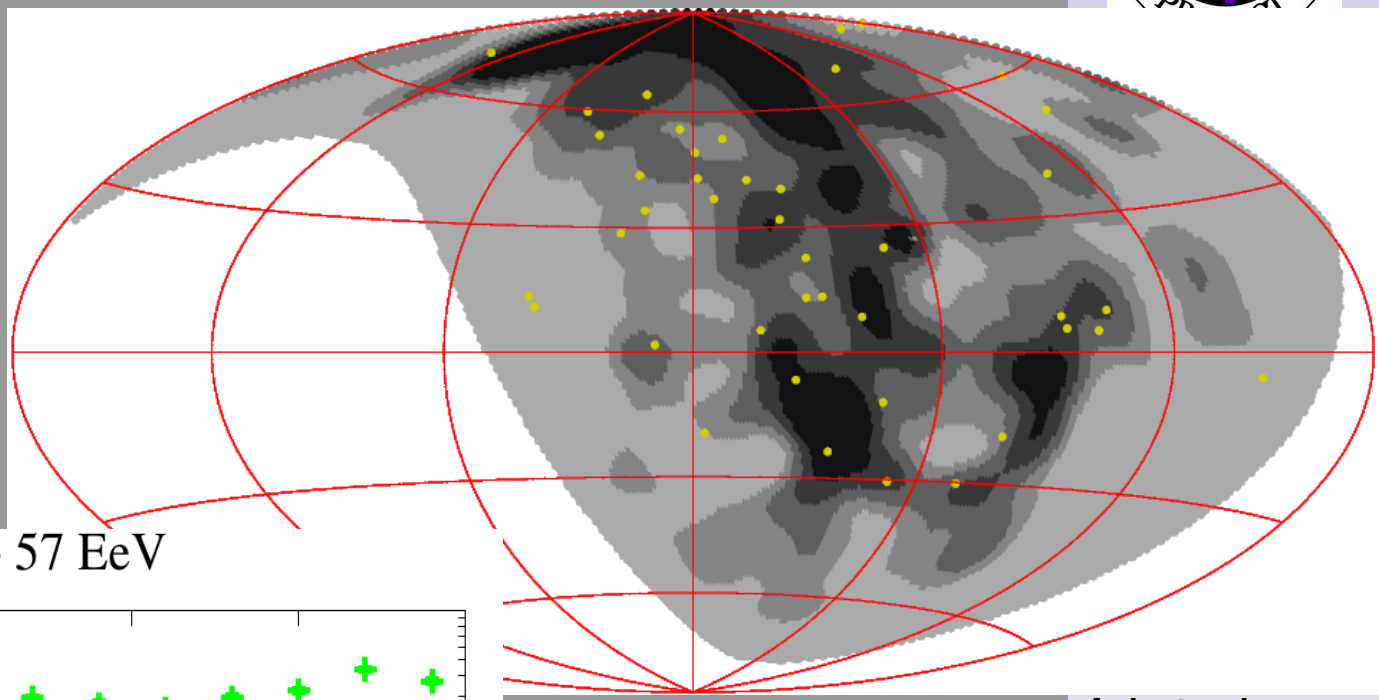
C: Centaurus supercluster (60 Mpc); Co: Coma cluster (90 Mpc); E: Eridanus cluster (30 Mpc); F: Fornax cluster (20 Mpc); Hy: Hydra supercluster (50 Mpc); N: Norma supercluster (65 Mpc); PI: Pavo-Indus supercluster (70 Mpc); PP: Perseus-Pisces supercluster (70 Mpc); Ursa Major North group (20 Mpc) South group (20 Mpc); V: Virgo cluster (20 Mpc).

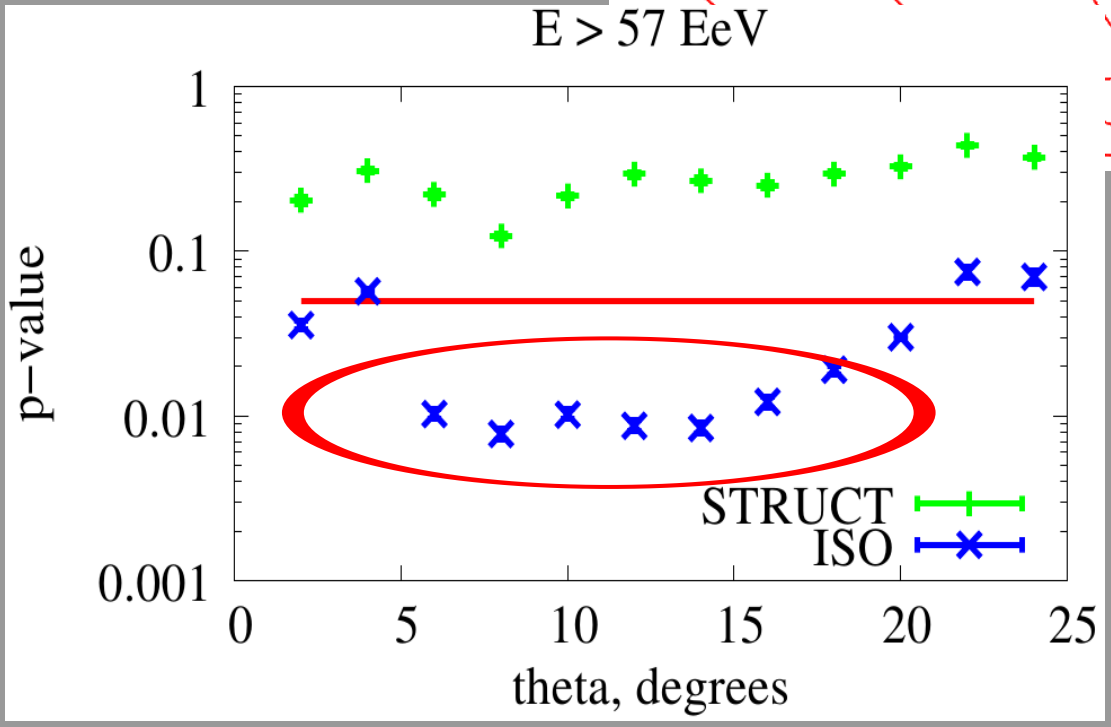
COMPARISON WITH DATA



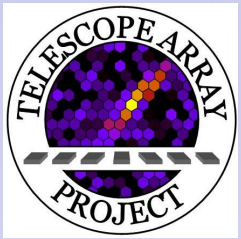


COMPARISON WITH DATA



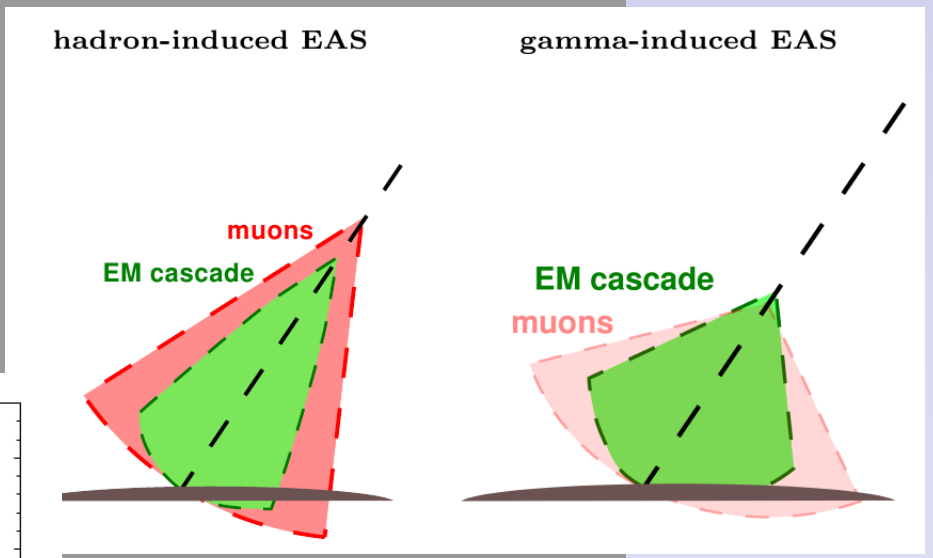


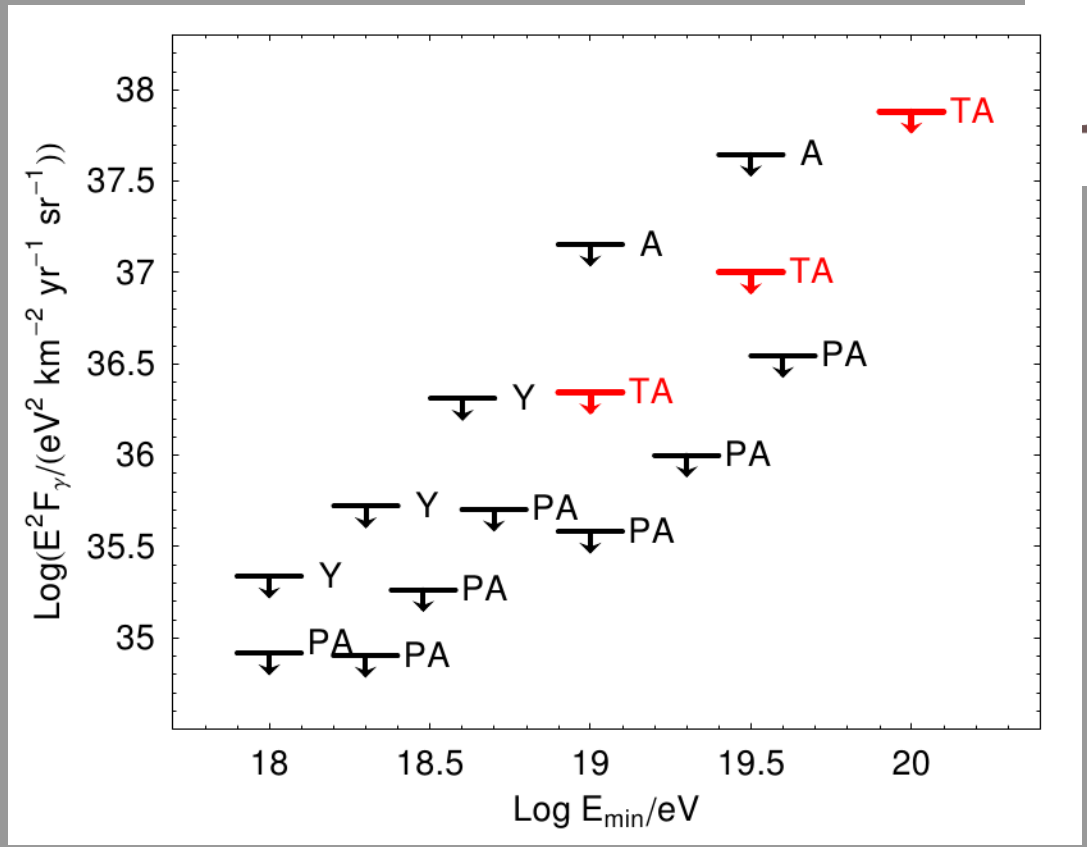
PHOTON LIMIT



Photon flux limits

- Observable: front curvature
  - photon showers are deeply penetrating
  - larger front curvature
- Event selection:
  - zenith angle $45° < \theta < 60°$
  - exposure $= 1286$ km^2 yr sr

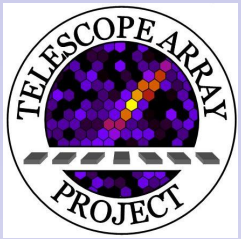




[arXiv:1304.5614]

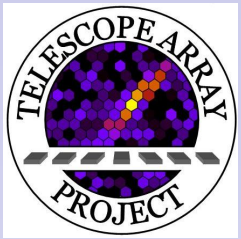
SUMMARY

- Spectrum: ankle and suppression at high energies
  - Agrees with HiRes
  - Ankle and GZK suppression energy are consistent with protons
- Composition: consistent with protons
- Anisotropy:
  - no deviations from isotropy at low energies
  - a marginal deviation from isotropy at $E > 57$ EeV
  - consistent with LSS model + protons
- Photon limit: no photons detected

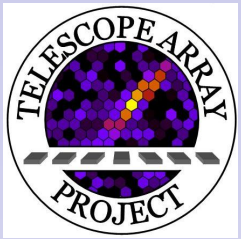


OUTLOOK

- TALE (= TA low-energy extension) has seen the first light
- Calibration project with JEM-EUSO goes on
- WGs with Auger
  - composition WG: trying to pin down the origin of the difference
  - anisotropy WG: multipole analysis is on the way (first presentation at ICRC)

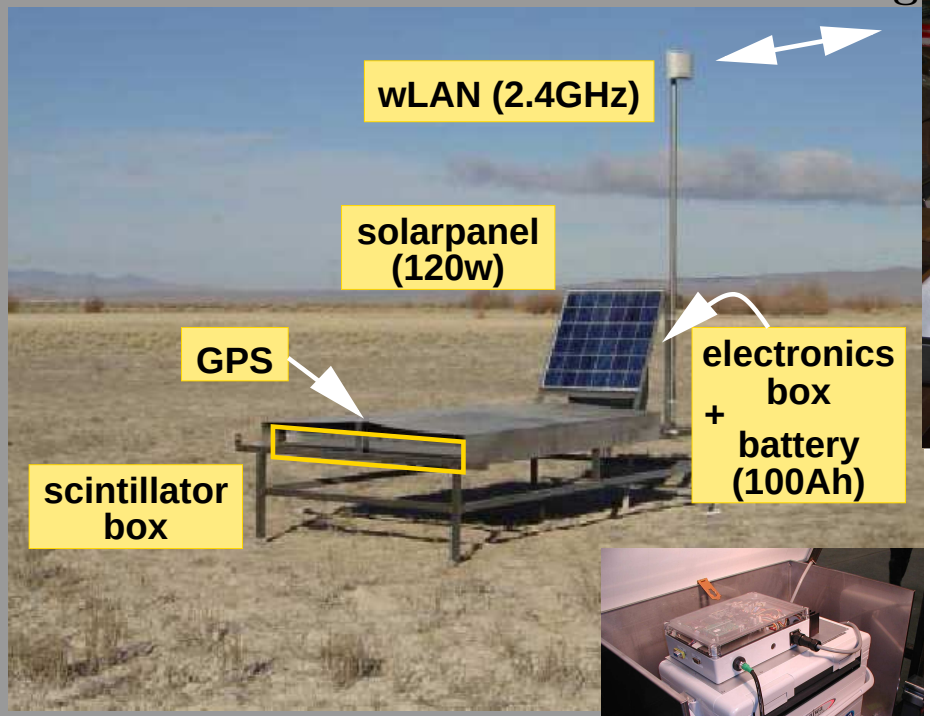


BACKUP SLIDES

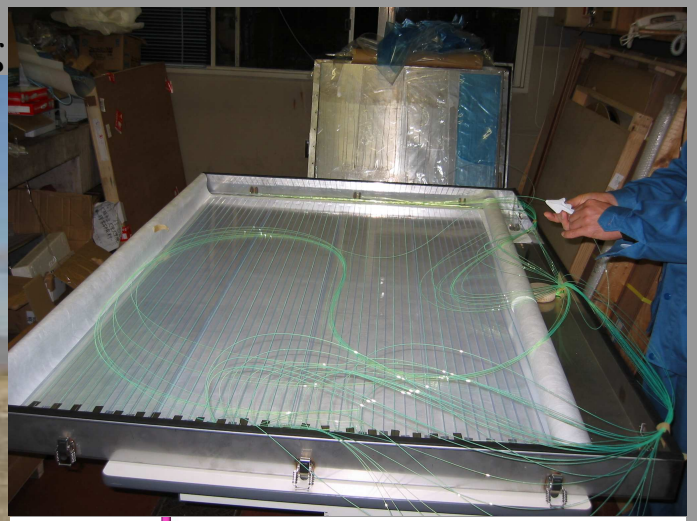


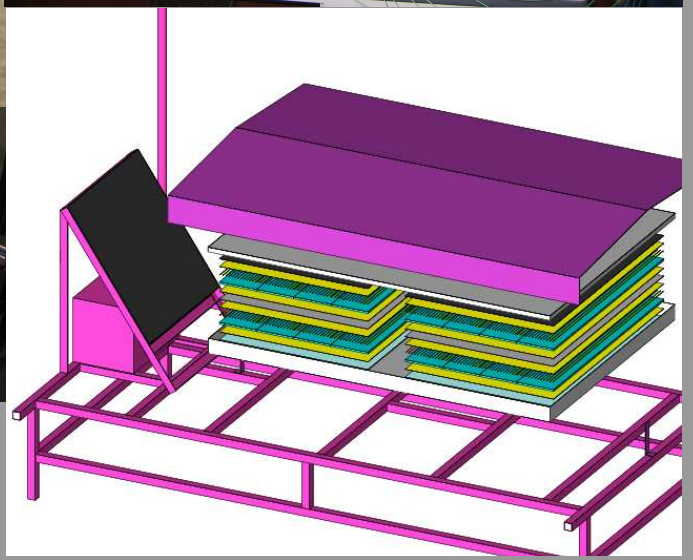
TA surface detector in detail

< Surface Detector >



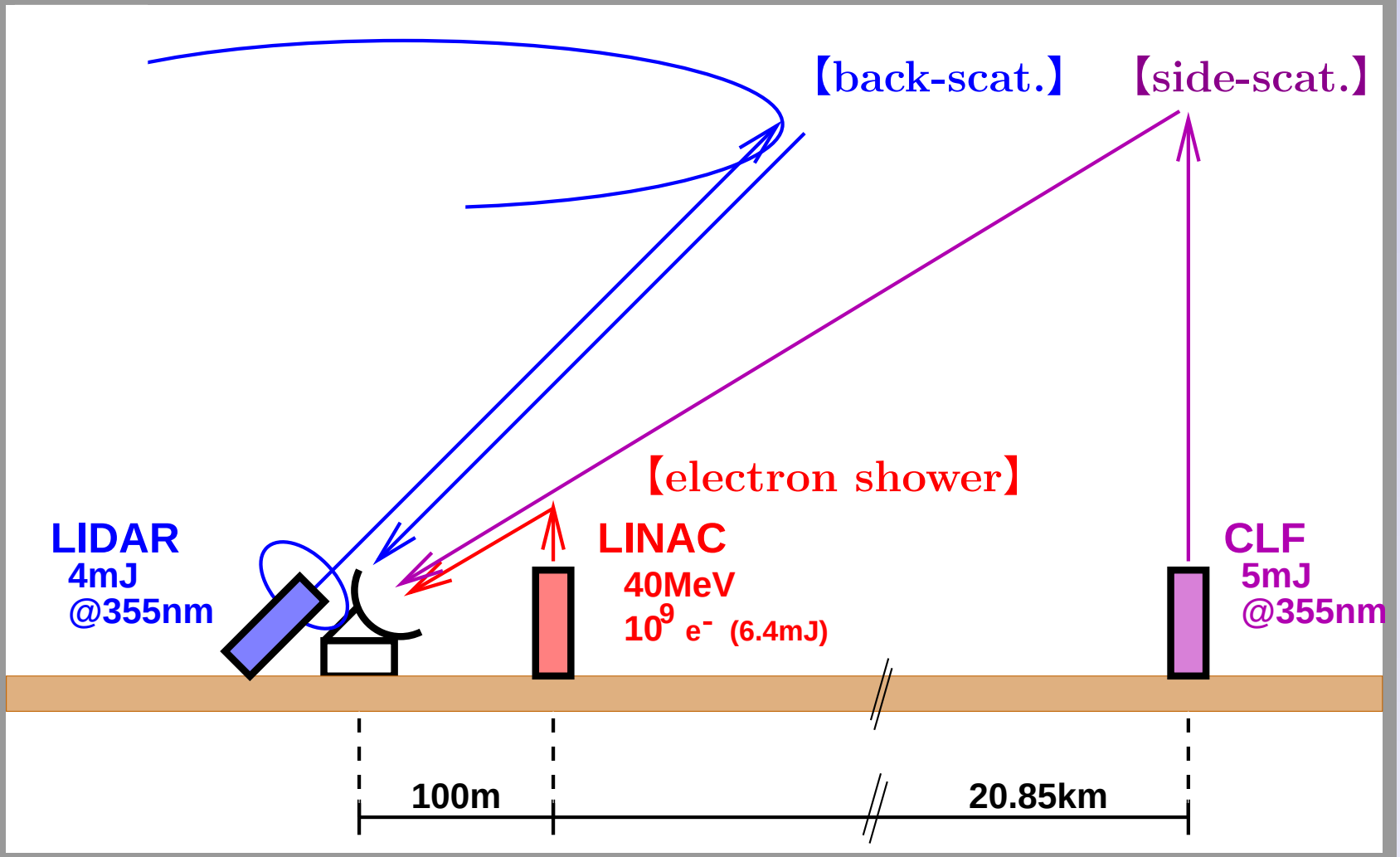
- WLSF: 1.0mmϕ (2cm separation)
- PMTs: ET 9123SA $\times$ 2
- 3m^2 (12mm $\times$ 2 layers)



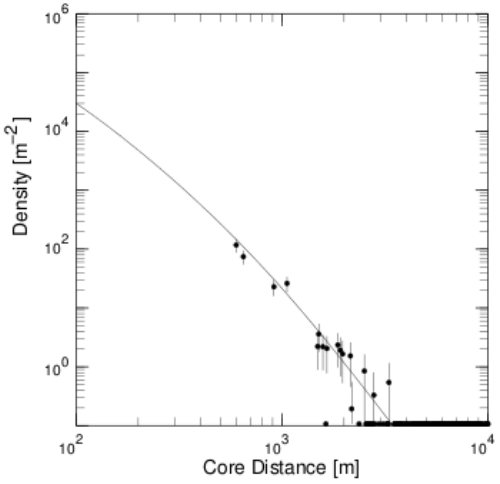


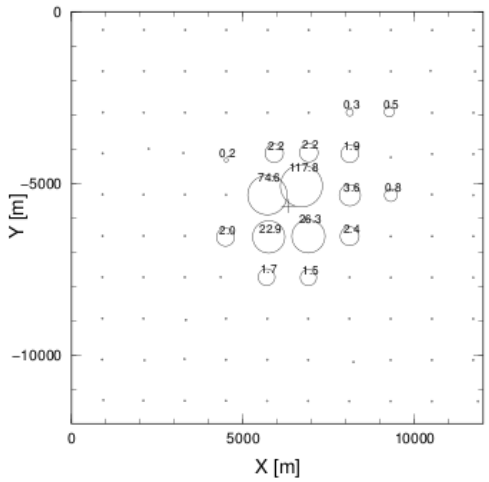
atmosphere monitoring

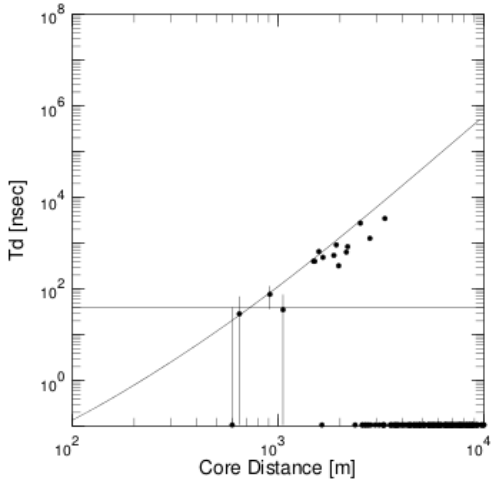
< Atmospheric Monitor (LIDAR, CLF) & LINAC >



SD event example

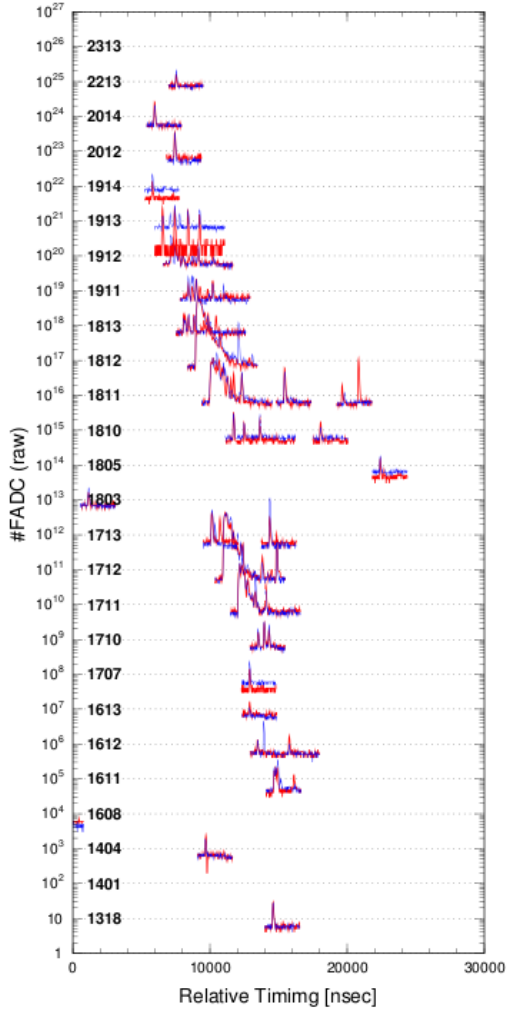






RUN(50141) EVENT(2182)

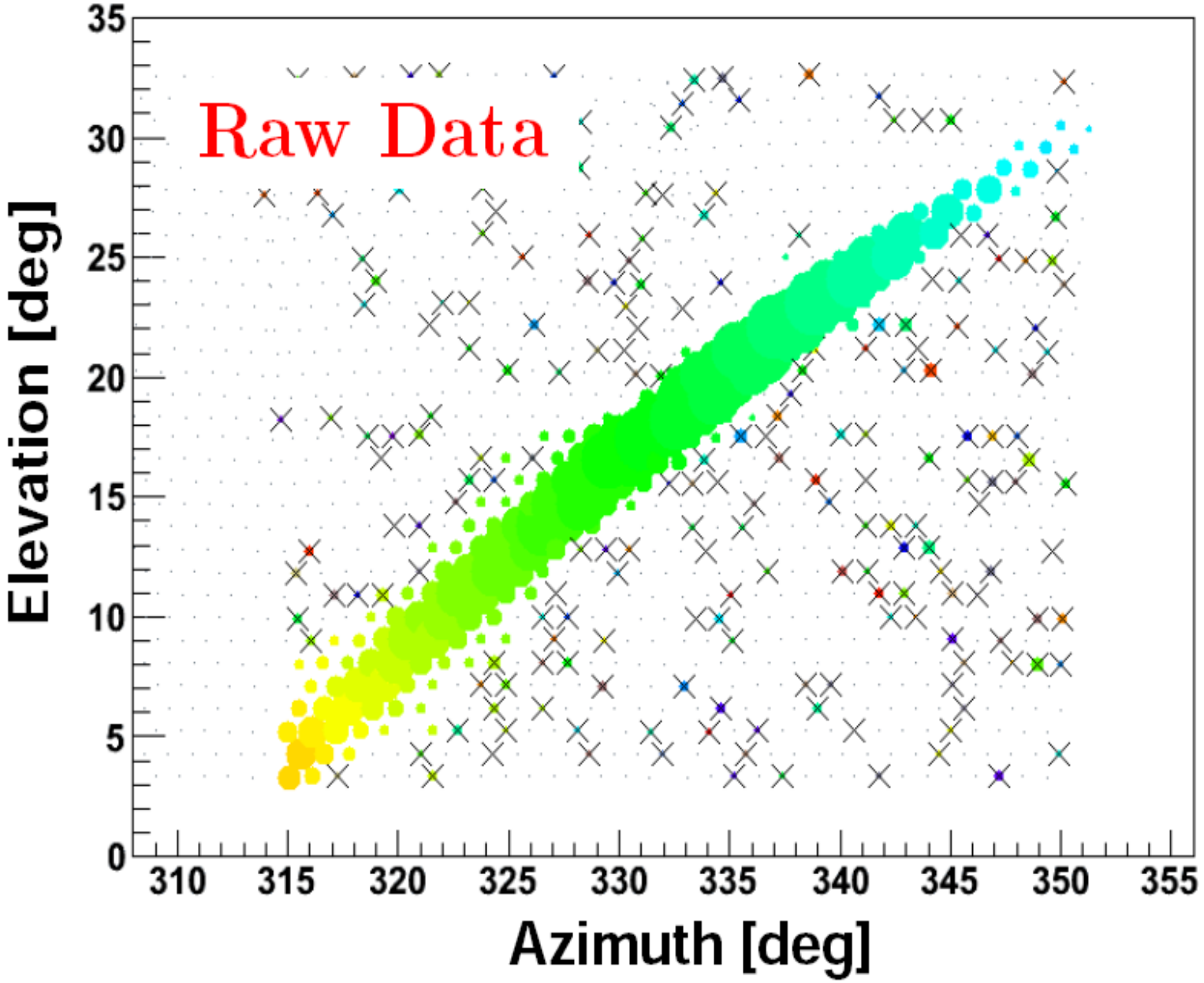
DATE(080531) TIME(050737)



TELESCOPE ARRAY: LATEST RESULTS

P. Tinyakov for the Telescope Array Collaboration

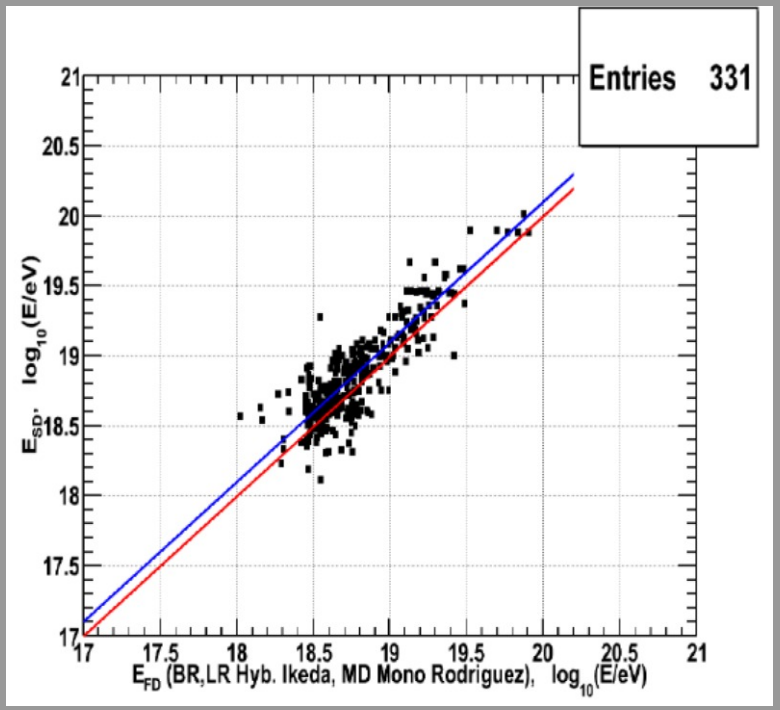
FD event example

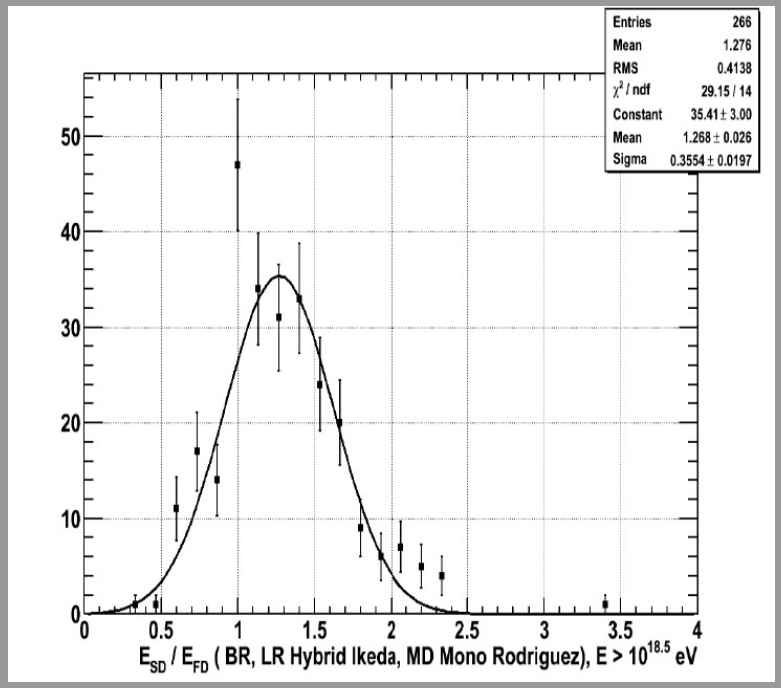


TELESCOPE ARRAY: LATEST RESULTS

P. Tinyakov
for the Telescope Array Collaboration

Energy scale

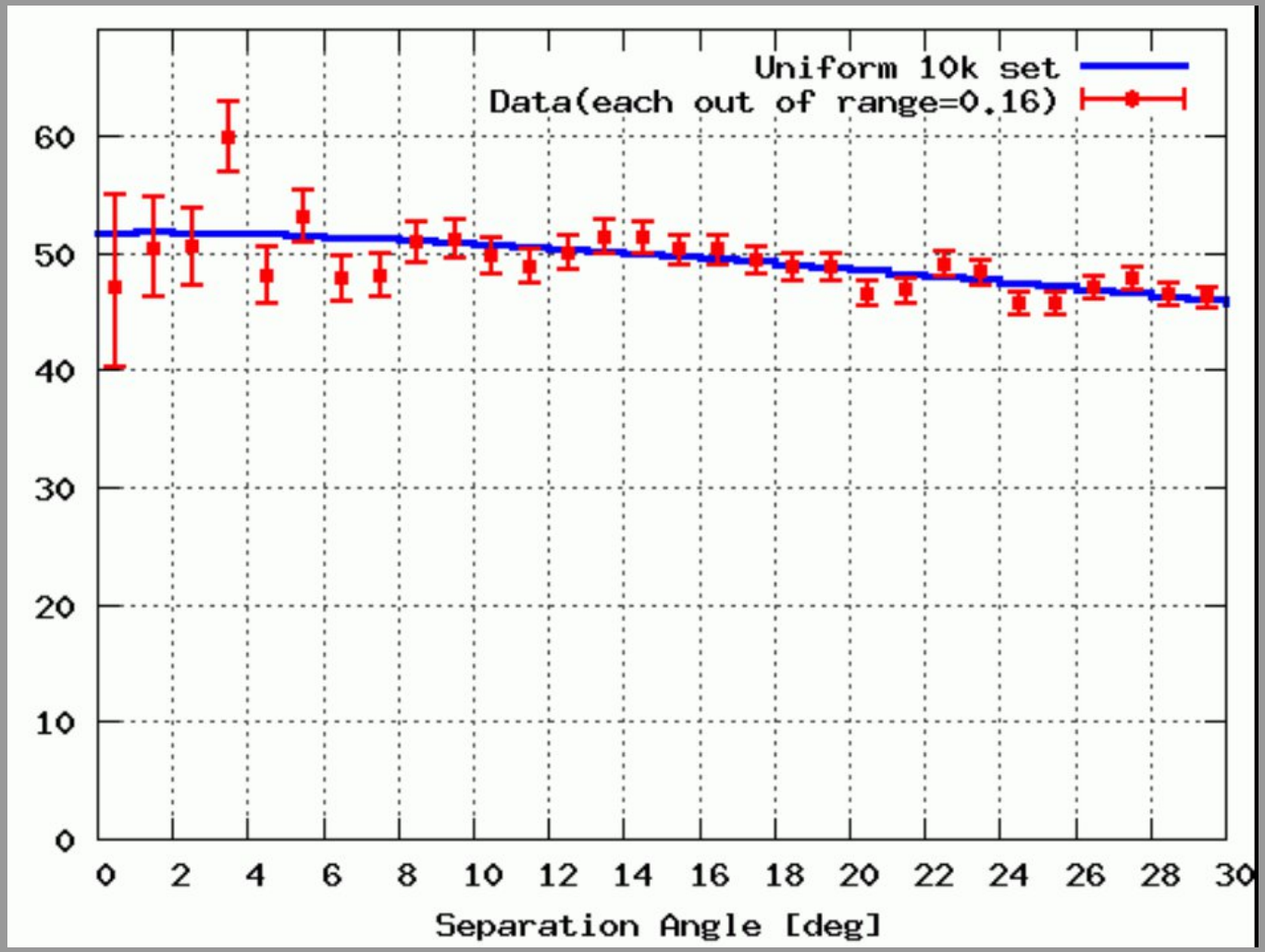




- SD energy: CORSIKA QGSJET-II full MC
- FD energy: MD mono, BRM, LR hybrid
- Result: $E = E_{SD}/1.27$

Search for clustering at small scales

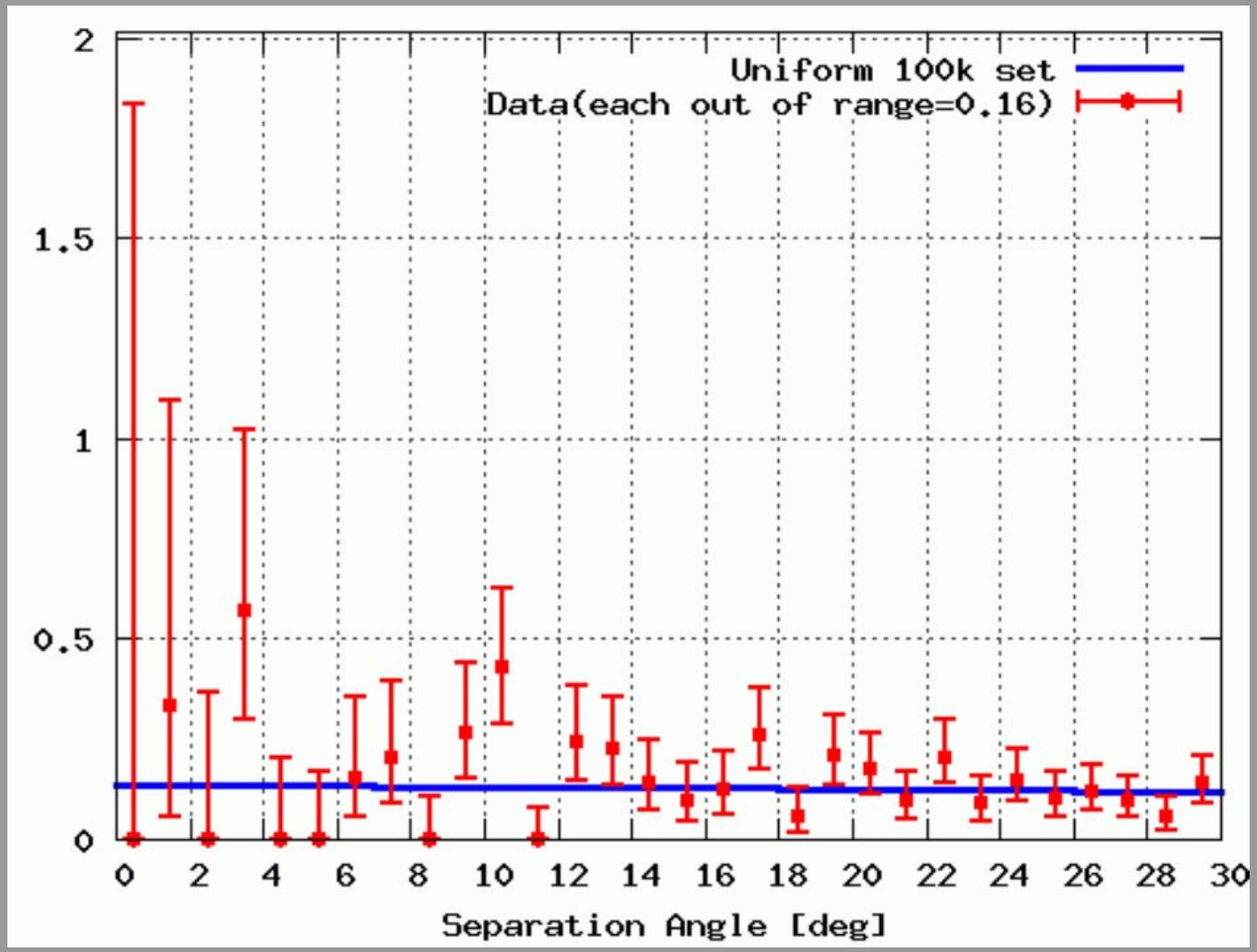
$E > 10$ EeV



$\Longrightarrow$ no excess over background

Search for clustering at small scales

$E > 40$ EeV



$\Longrightarrow$ no excess over background