Results from the Telescope Array Experiment

for the Telescope Array Collaboration

Charlie Jui, University of Utah, Jun 19

Portopalo di Capo Passero, Sicilia,Italia.

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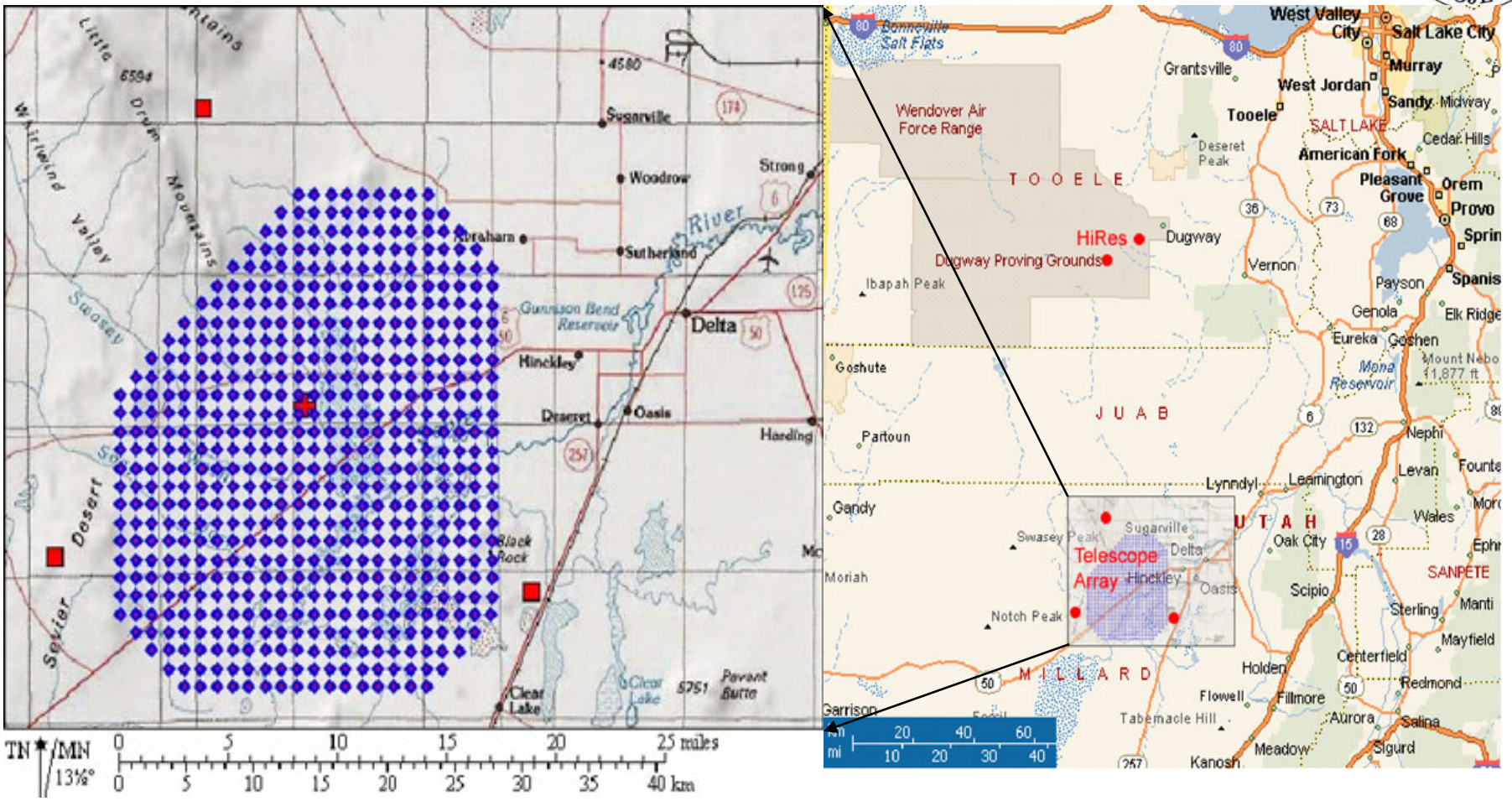
Telescope Array

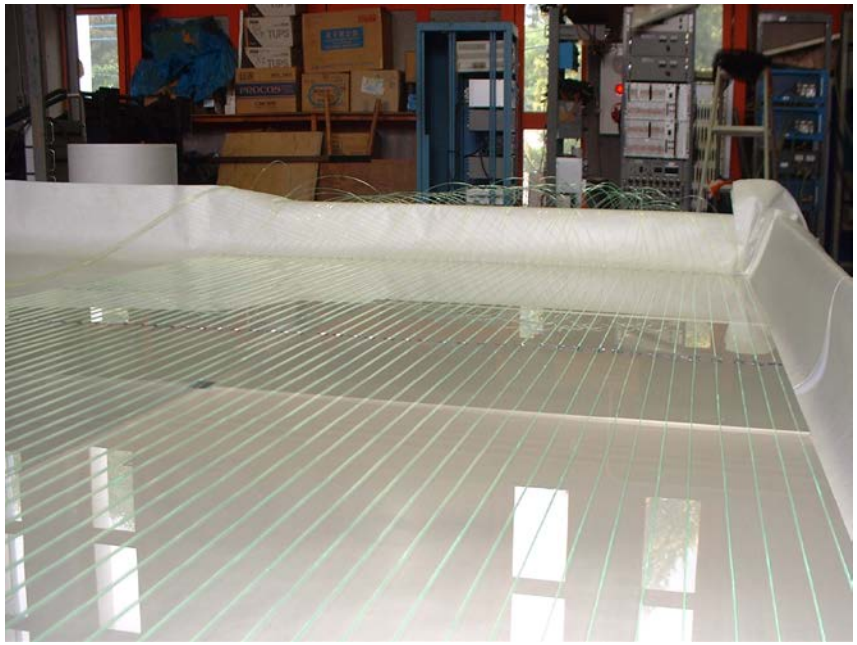


507 scintillation counters surface detector (SD): Area: ~700 km^2.

3 fluorescence detector (FD) stations

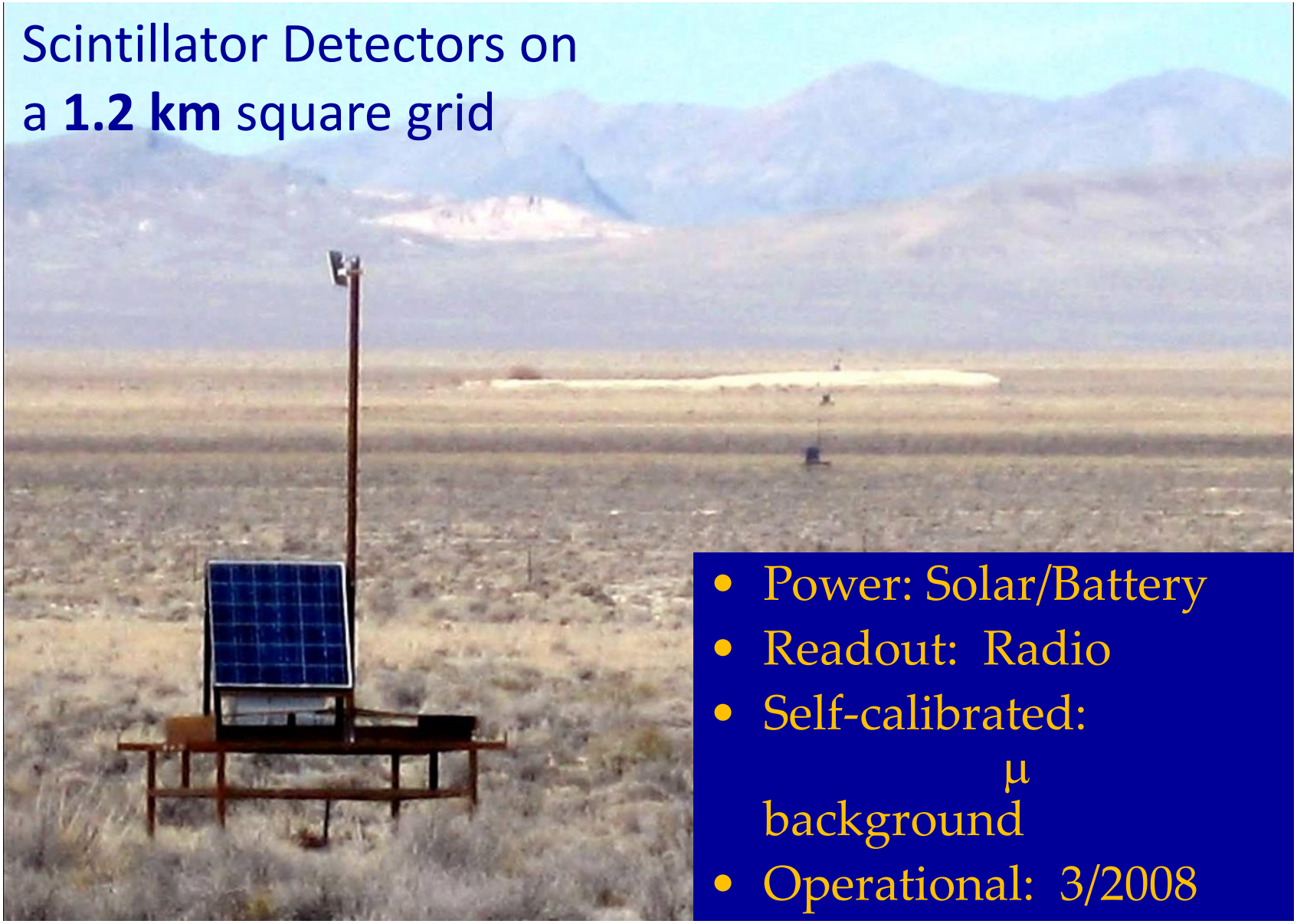
In operation since 2008

Scintillation Counters



Pre-assembled in Japan, Final Assby/testing in Delta: **2 layers**, **1.25 cm** scintillator, **3m^2** area

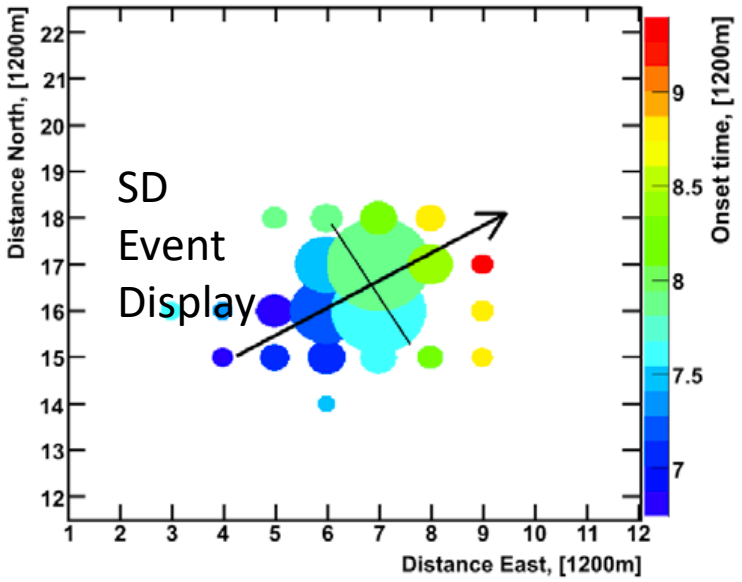
Scintillator Detectors on a **1.2 km** square grid

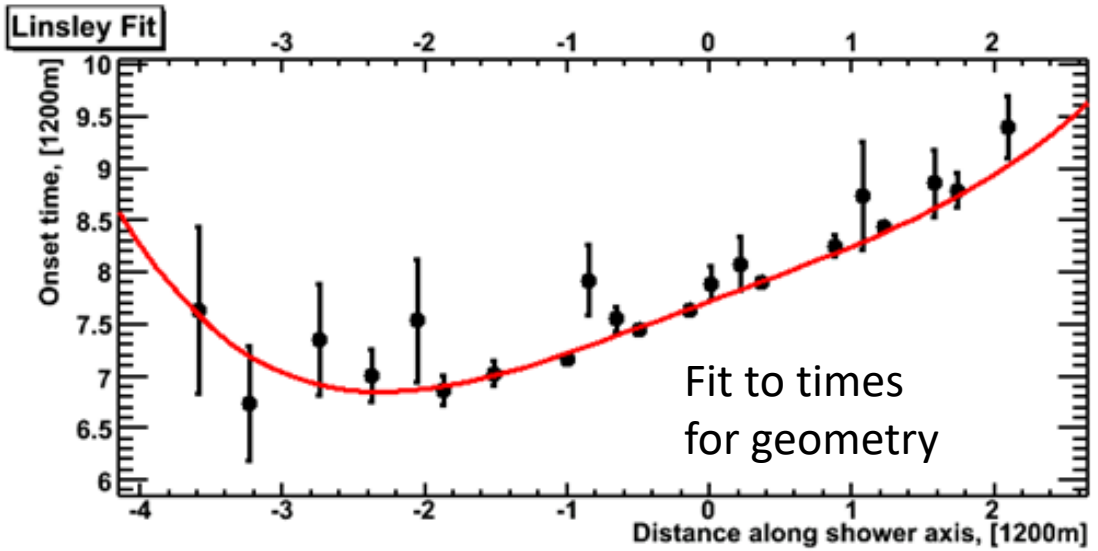


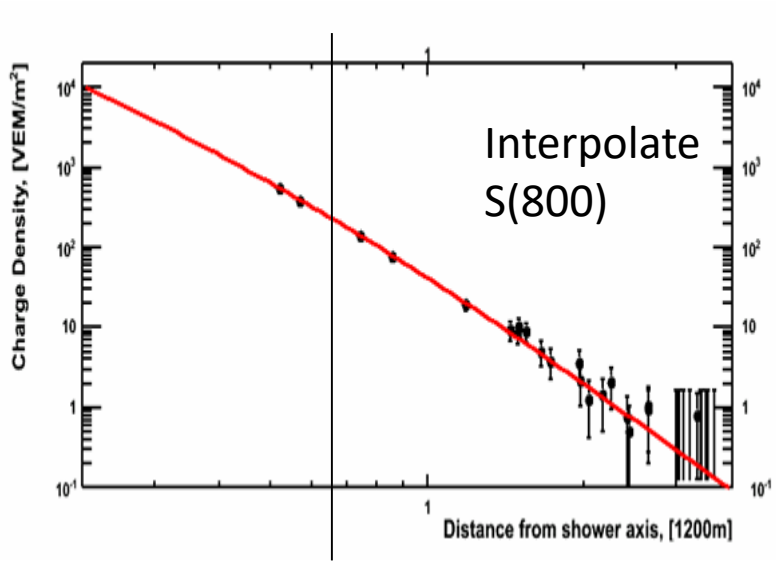
- Power: Solar/Battery
- Readout: Radio
- Self-calibrated: μ background
- Operational: 3/2008

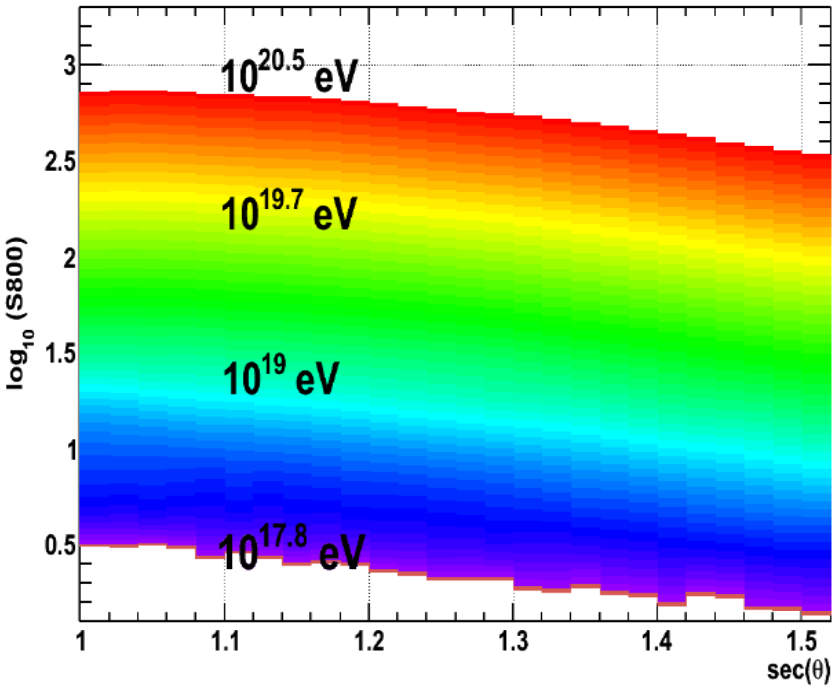
Energy Spectrum Results

Analysis of SD Events





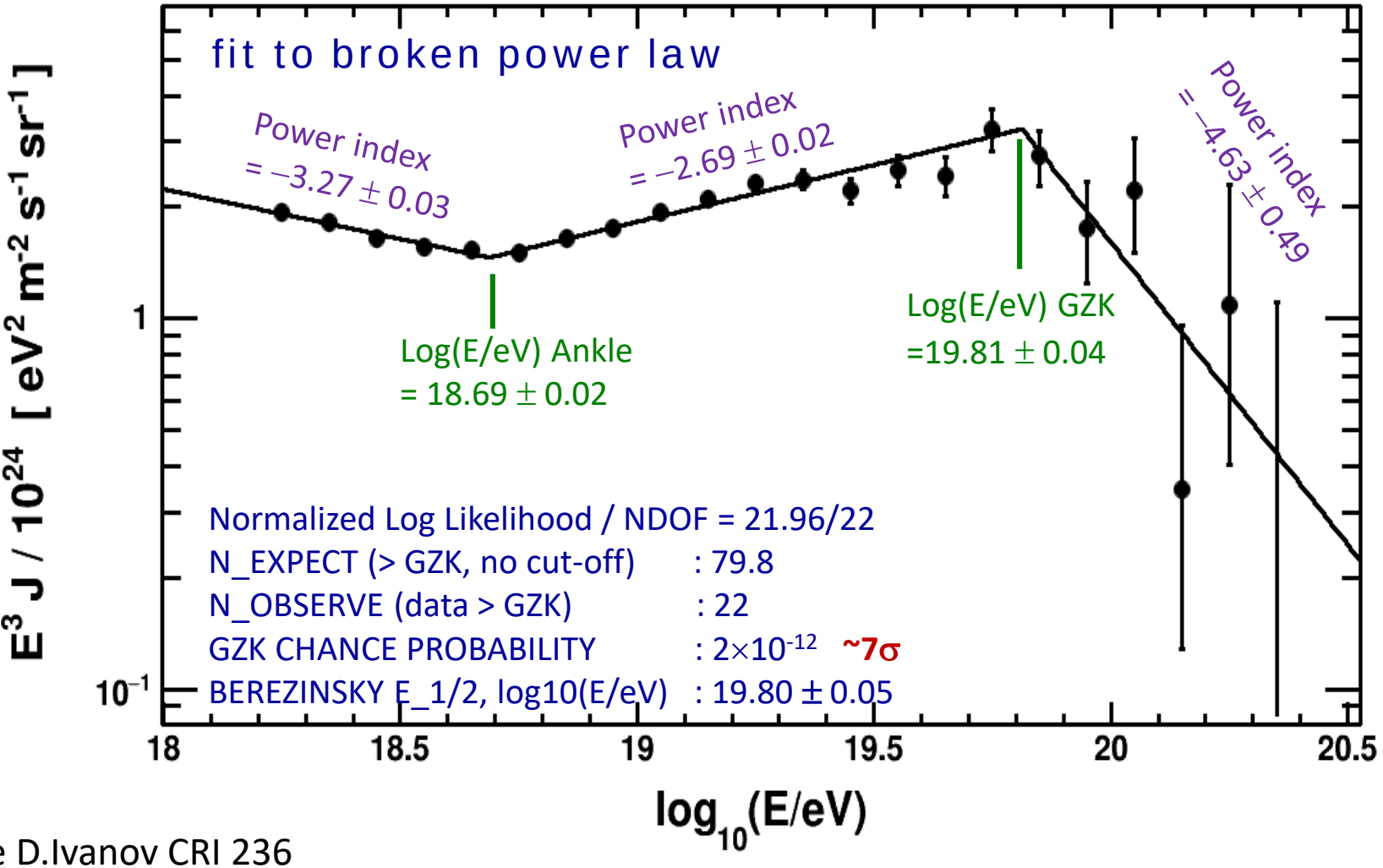




Read off
Energy from
MC Table

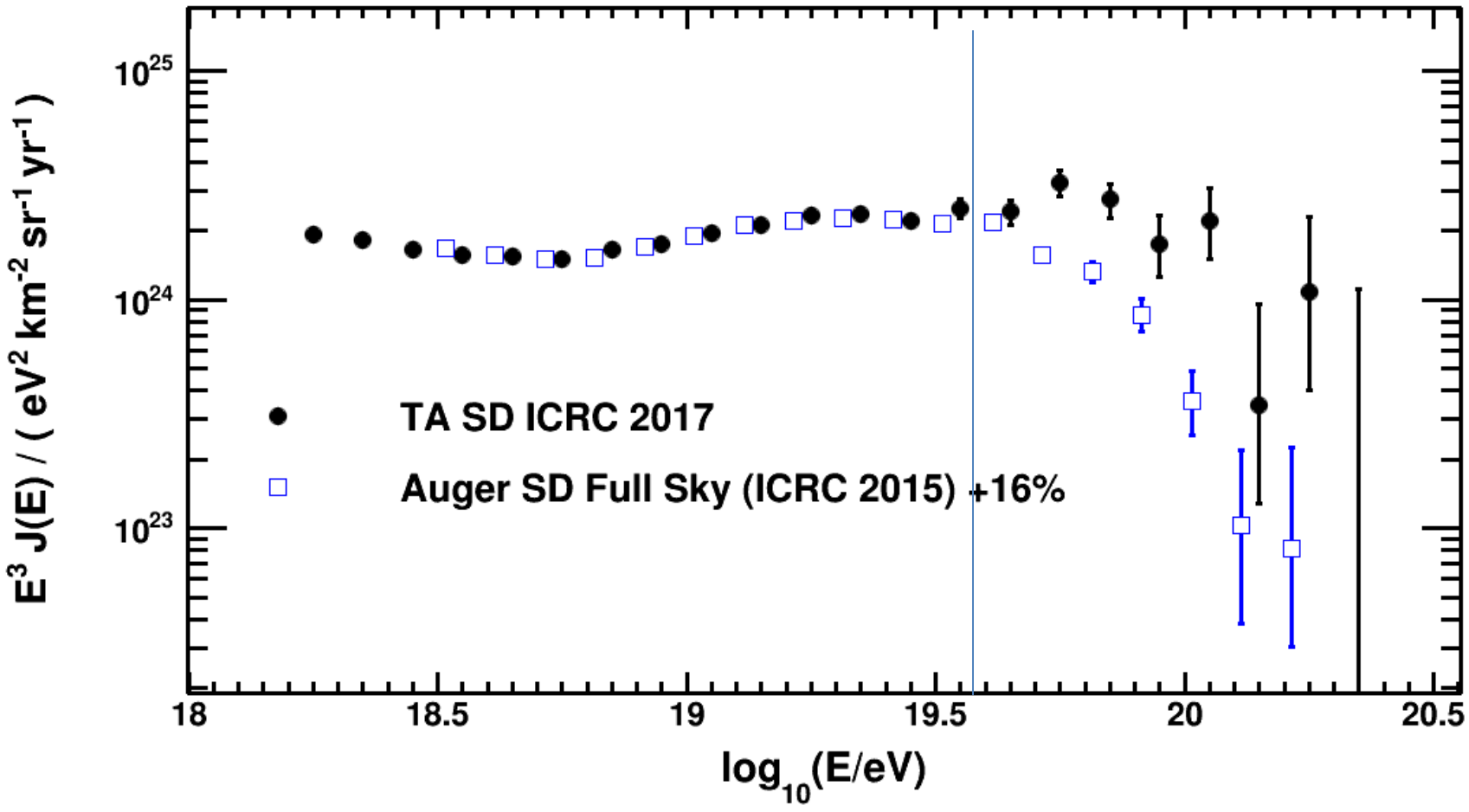
 r = 800m

TA SD Spectrum (9 yrs data)

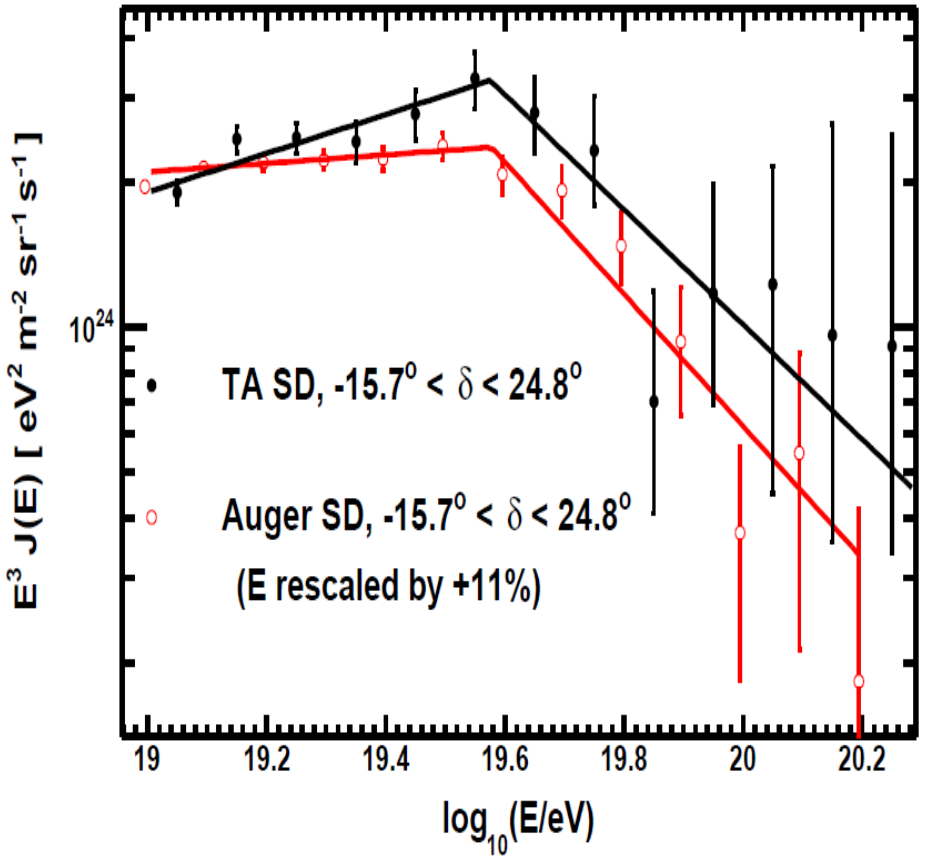


See D.Ivanov CRI 236

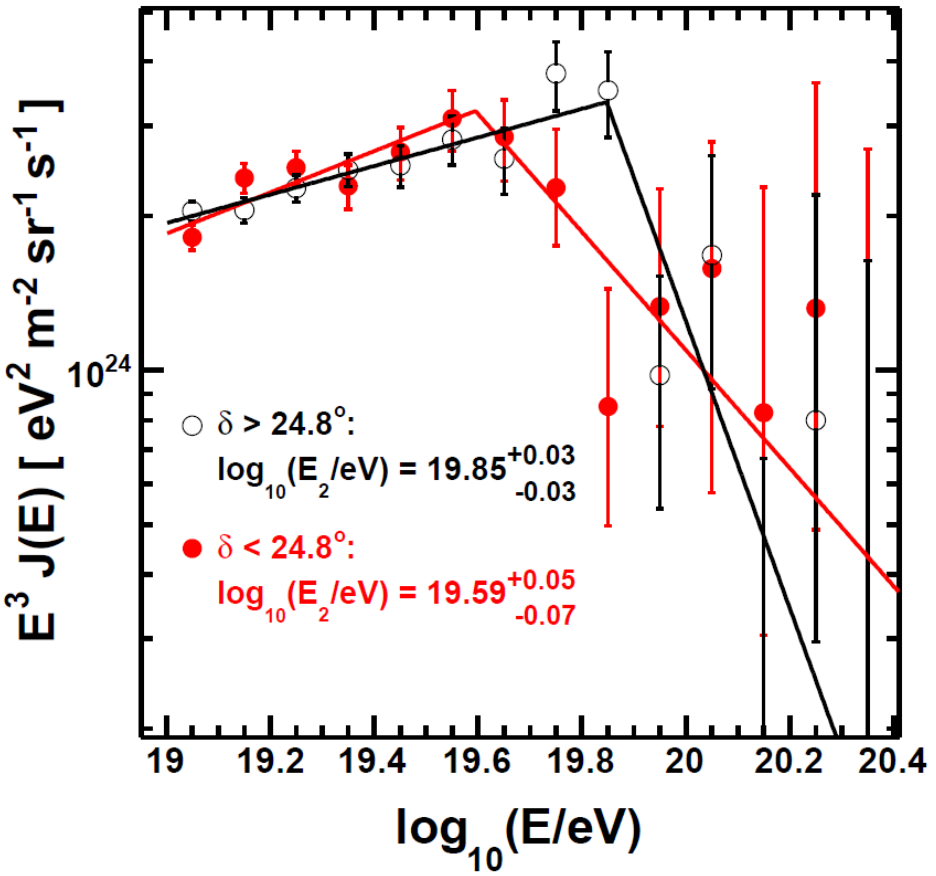
Telescope Array & Pierre Auger (+16%) Spectra



Declination Dependence of TA Spectrum



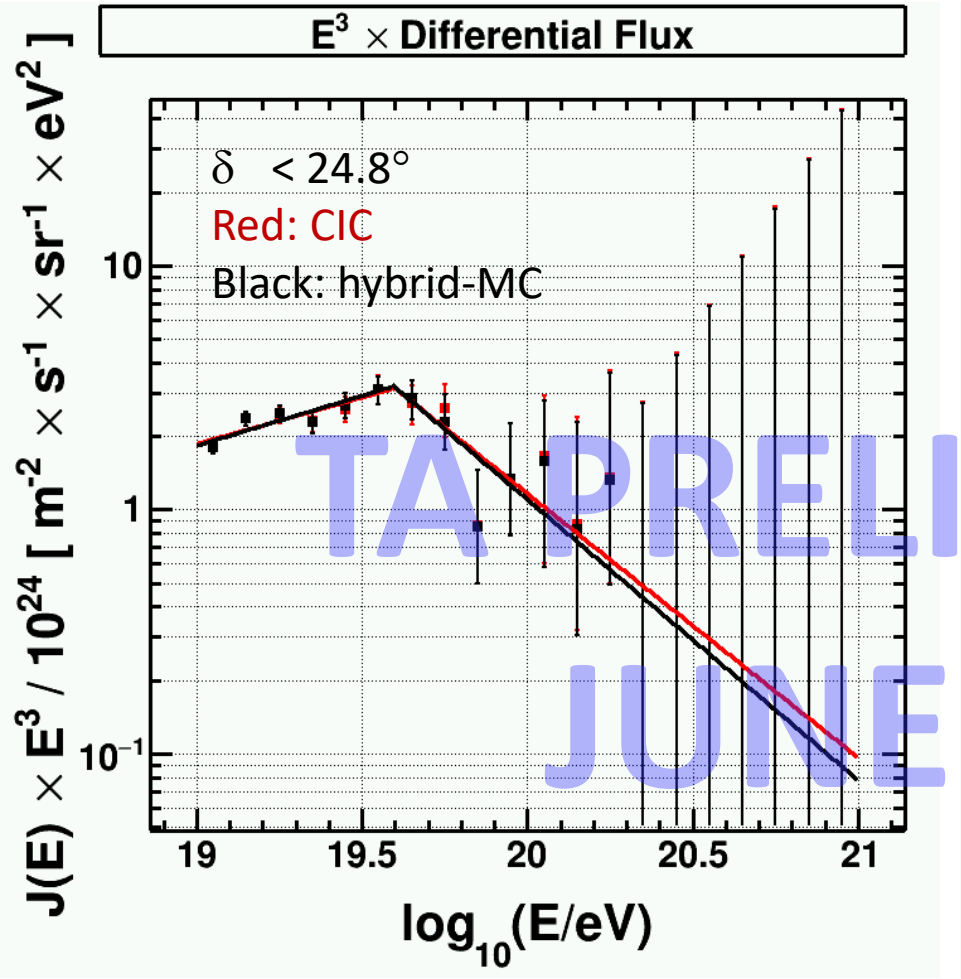
Energy spectra of TA and Auger in the common declination band. The locations of the high energy breaks agree to within 1σ

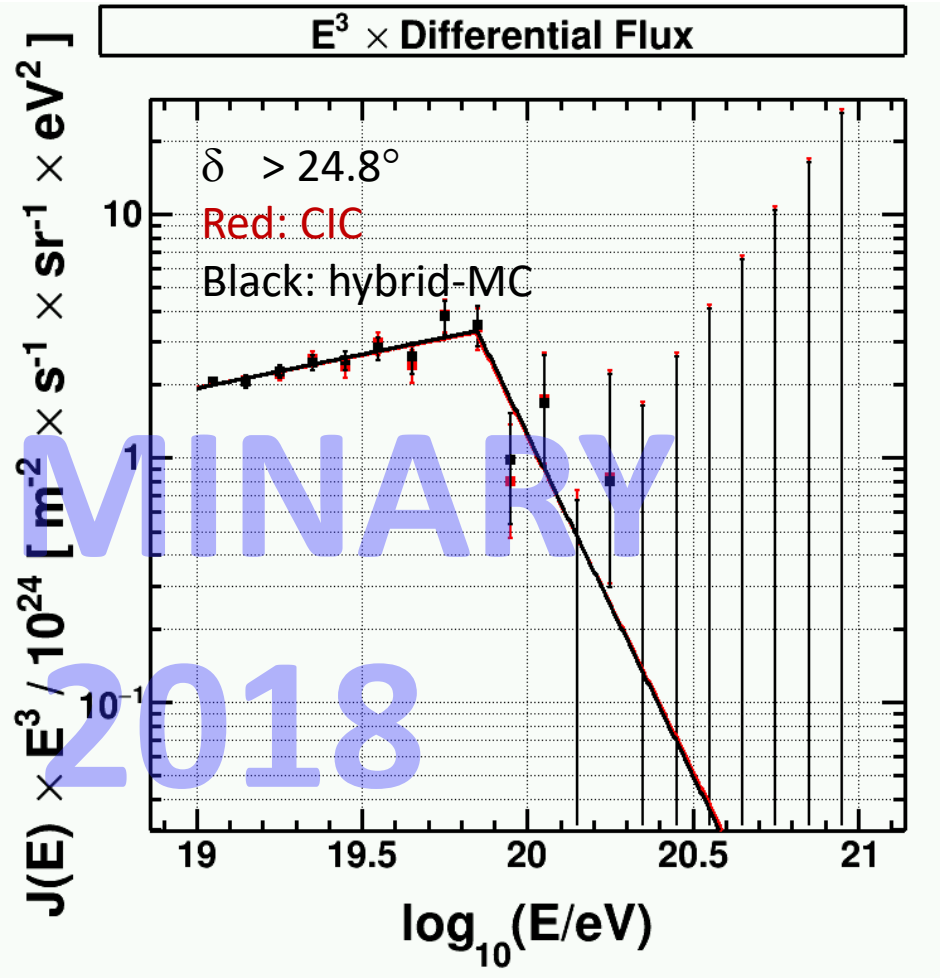


Energy spectra of TA above and below δ=24.8° The locations of the breaks disagree at ~4σ level

Global Significance ~ 3.2 σ

Constant Intensity Cut Check





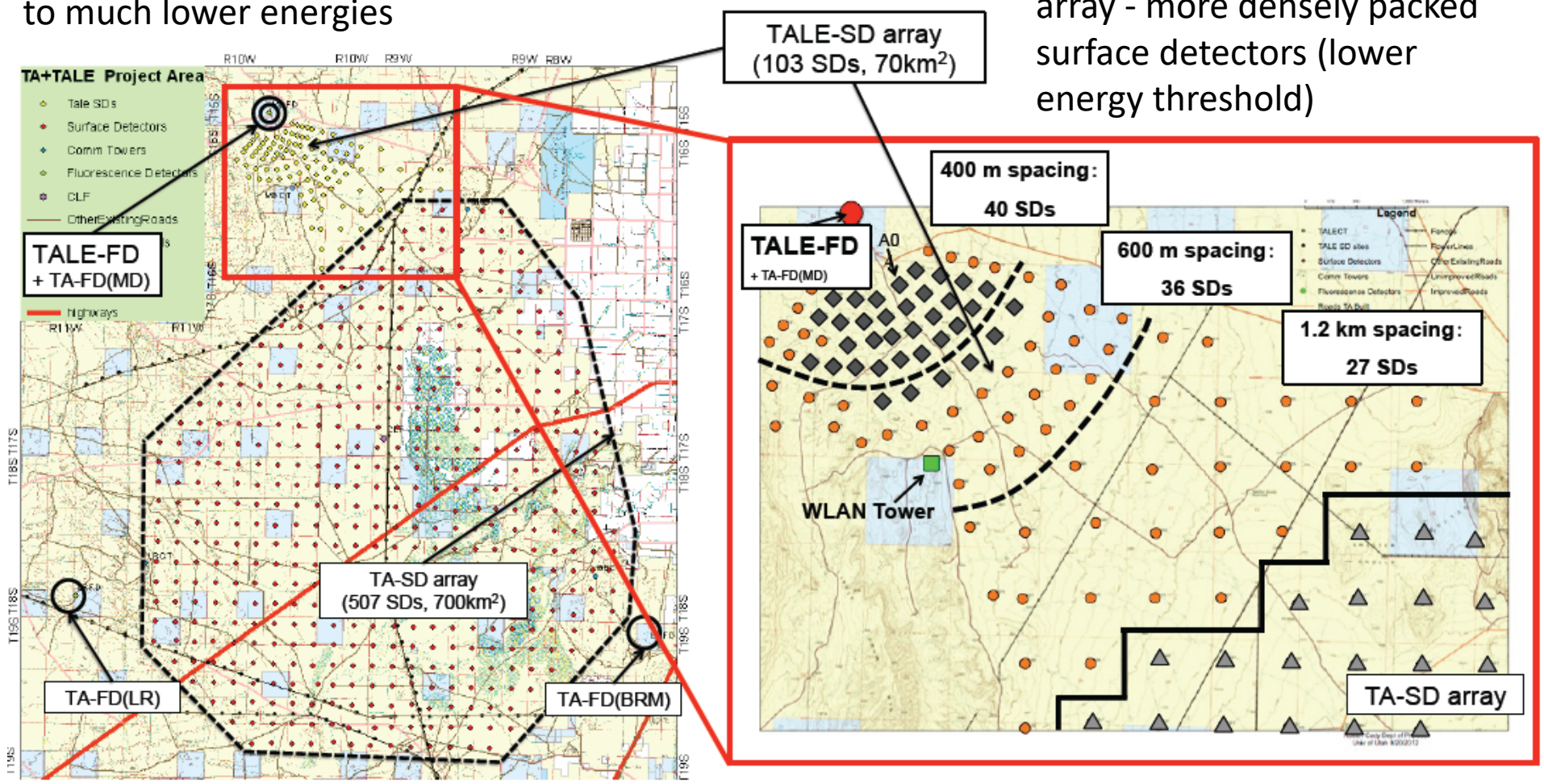
High/low declination persist in spectrum constructed using Constant-Intensity-Cut energy estimation

TA Low Energy Extension (TALE)

Galactic to Extra-Galactic Transition

10 new telescopes to look higher in the sky (31-59^{o}) to see shower development to much lower energies

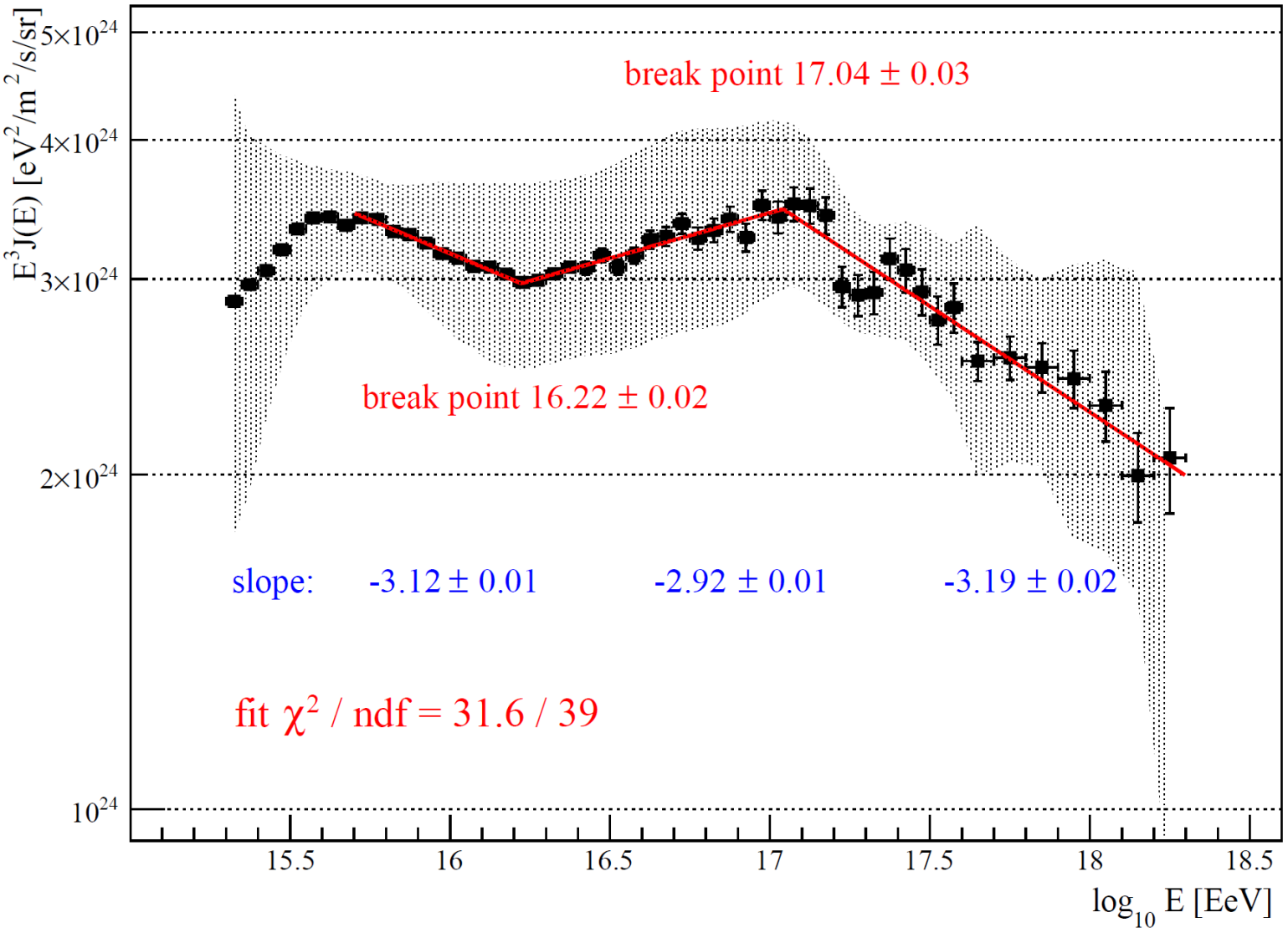
Graded infill surface detector array - more densely packed surface detectors (lower energy threshold)



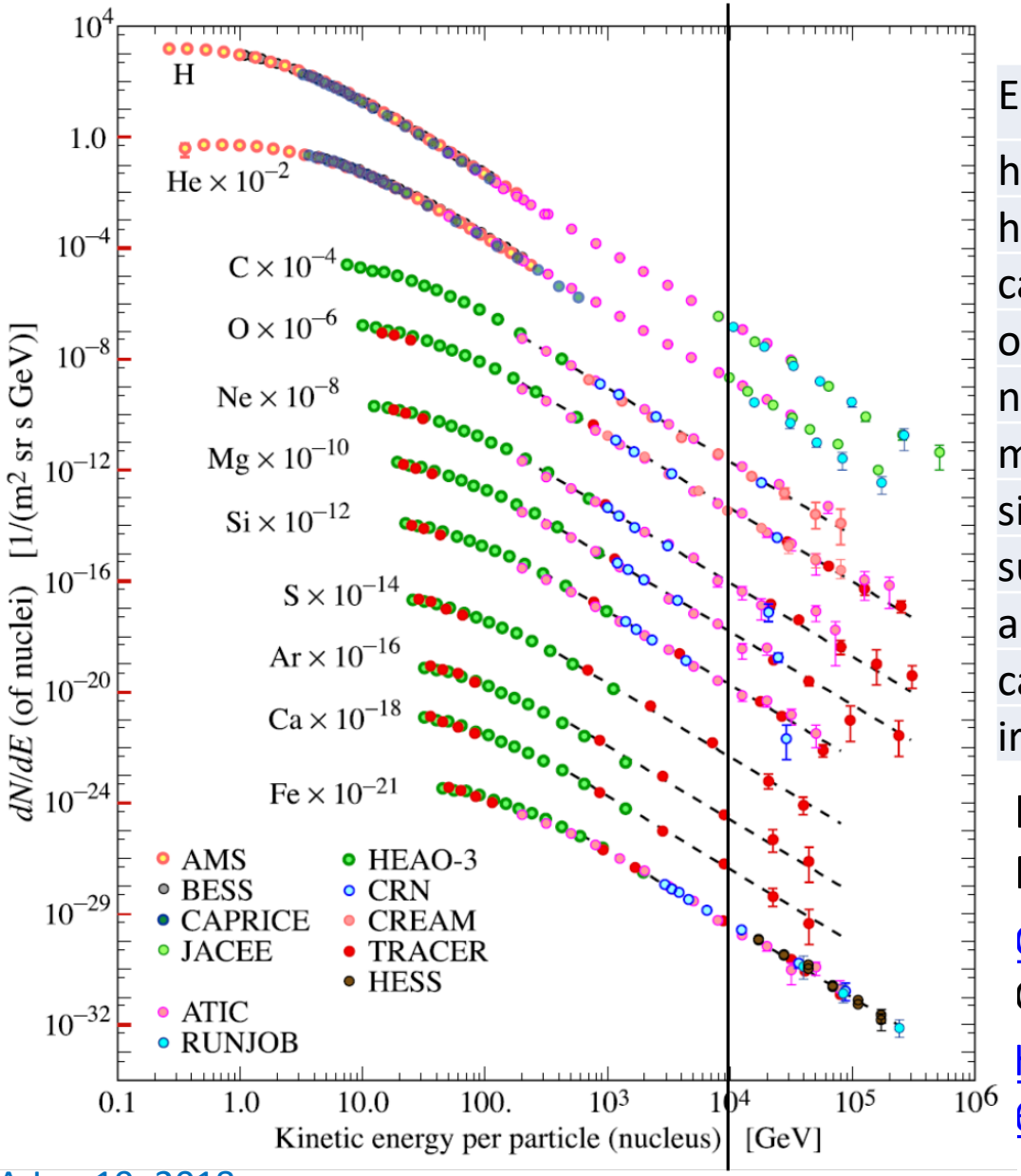
All 10 Telescopes installed and in operation since fall 2013

Test array of 16 scintillation surface detectors in operation

TALE FD Spectrum



Interpretation of TALE Spectrum



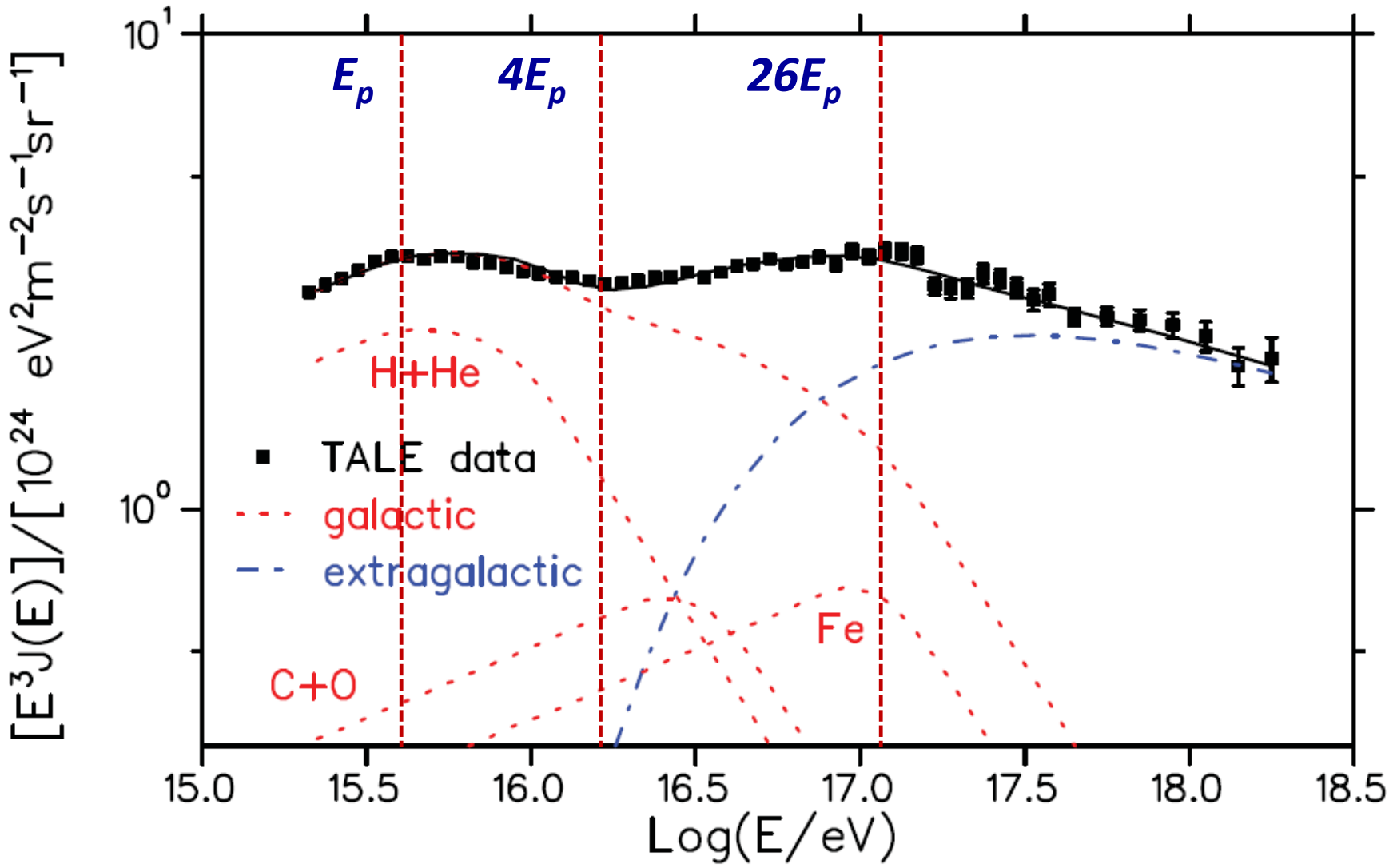
Element	Z	fraction at 10^{13} eV
hydrogen	1	0.3019
helium	2	0.4104
carbon	6	0.0388
oxygen	8	0.0745
neon	10	0.0153
magnesium	12	0.0293
silicon	14	0.0308
sulfur	16	0.0082
argon	18	0.0043
calcium	20	0.0070
iron	16	0.0800

Interpolated flux at 10^{13} eV from Figure 29.1 Particle Data Book

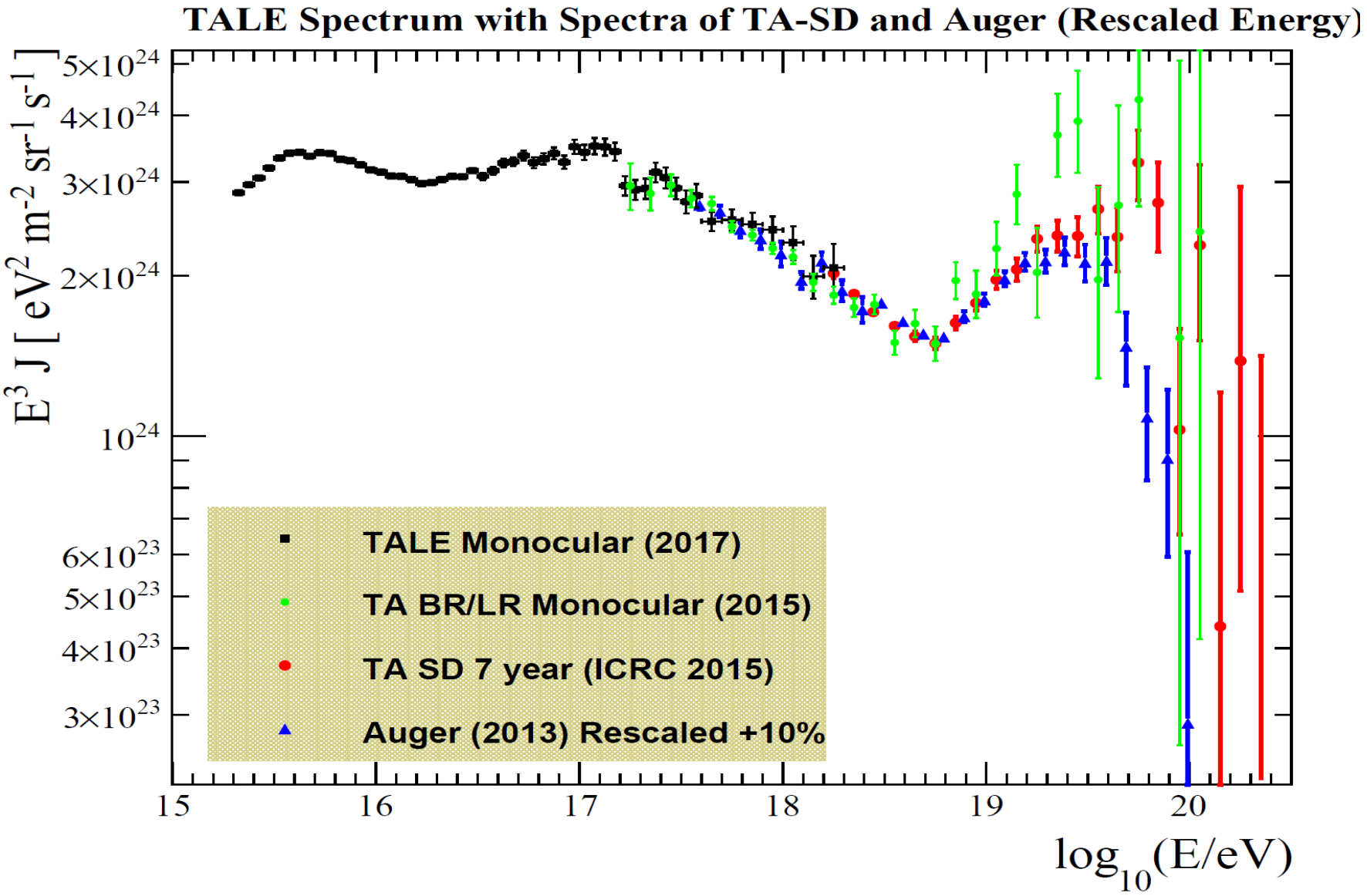
C. Patrignani *et al.* (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016).

http://pdg.lbl.gov/2016/reviews/rpp2016-rev-cosmic-rays.pdf

Spectrum


E_p
$4E_p$
$26E_p$
H+He
TALE data
galactic
extragalactic
Fe
C+O
10^1
10^0
$[E^3J(E)]/[10^{24}\ eV^2m^{-2}s^{-1}sr^{-1}]$
15.0
15.5
16.0
16.5
17.0
17.5
18.0
18.5
Log(E/eV)

TALE Spectrum: 5 orders of magnitude



Composition Results

TA Fluorescence Detectors

Refurbished from HiRes-I

Observations since ~10/2007

Middle Drum

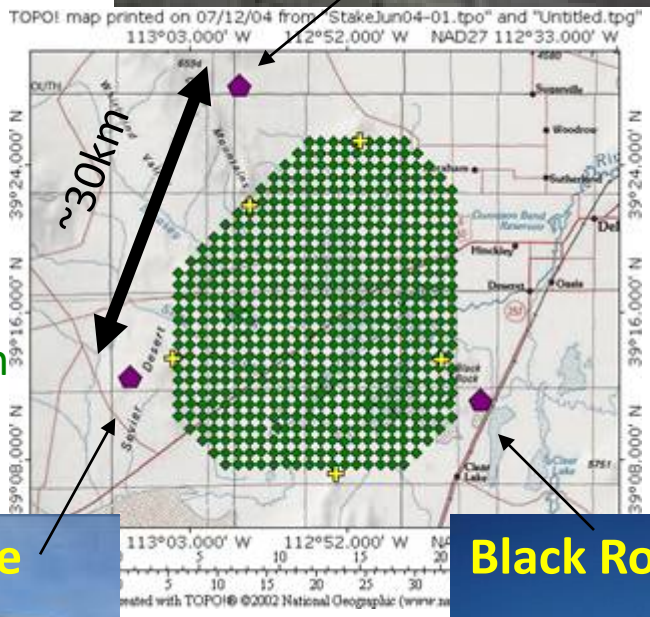
14 telescopes@station
256 PMTs/camera

5.2 m^2

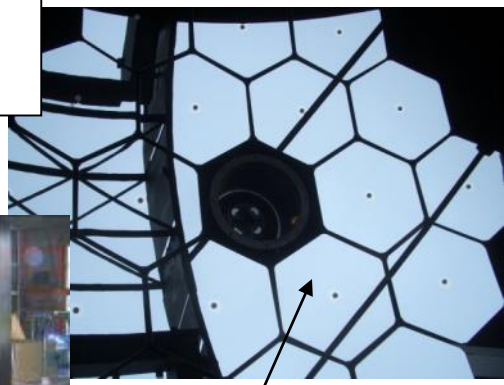
1° pixels

New FDs

Observation since ~11/2007



12 telescopes/station
256 PMTs/camera
Hamamatsu R9508
FOV~15x18deg



6.8 m^2

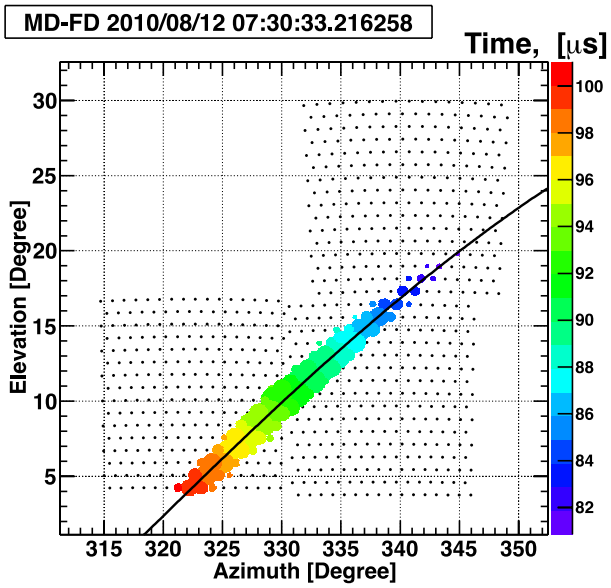
Long Ridge

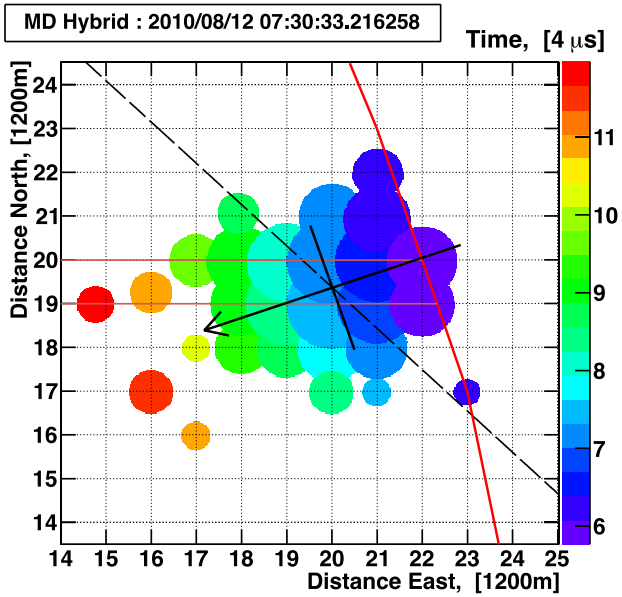
Observation since ~6/2007

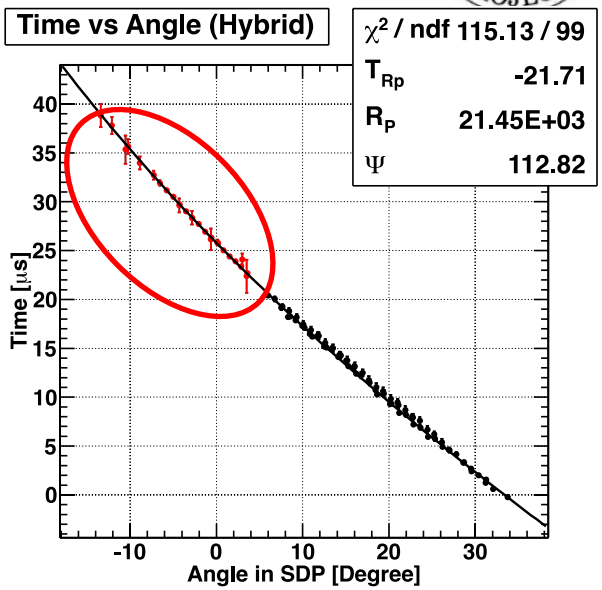
Black Rock Mesa

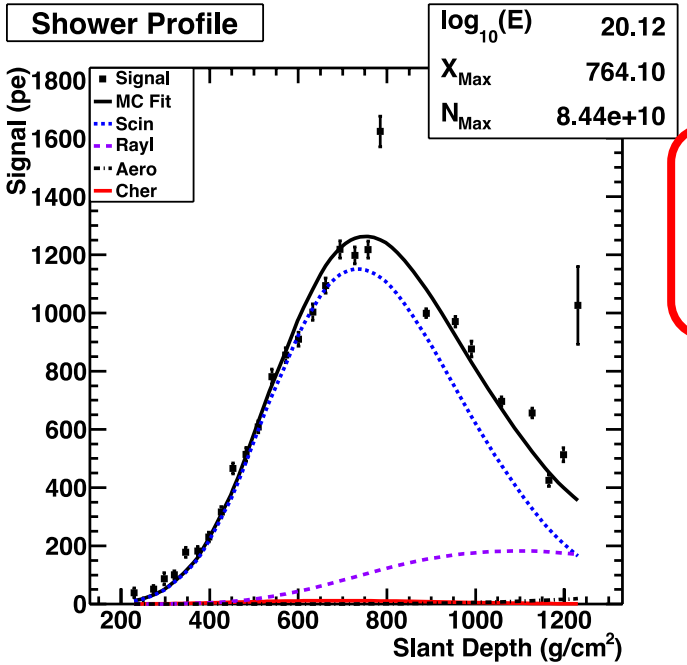
~1 m^2

High Energy Hybrid Event









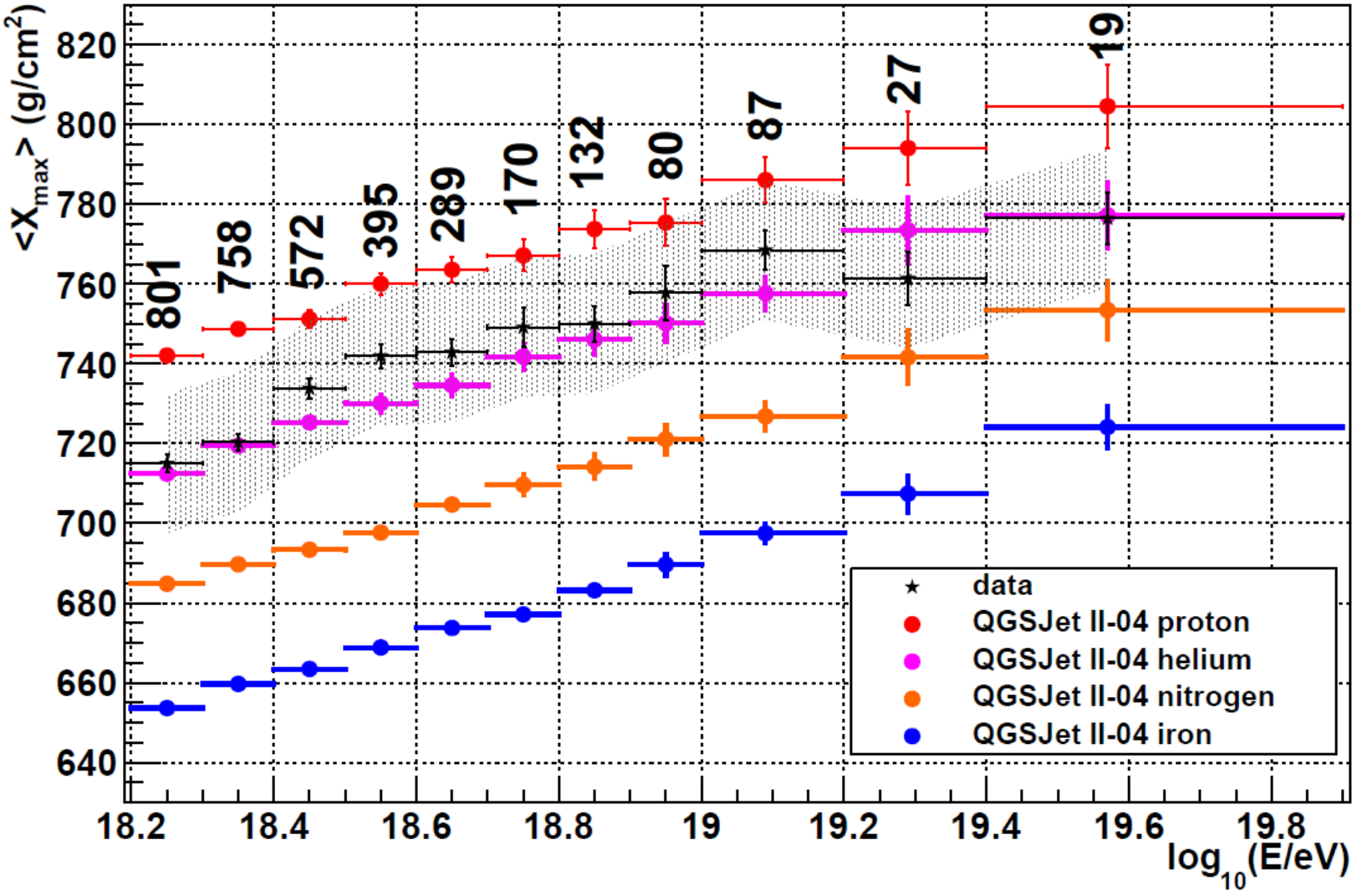
Energy: 1.3 × 10^{20} eV

Zenith Angle: 55.7°

Surface array constrains geometry fit via extra timing & core information

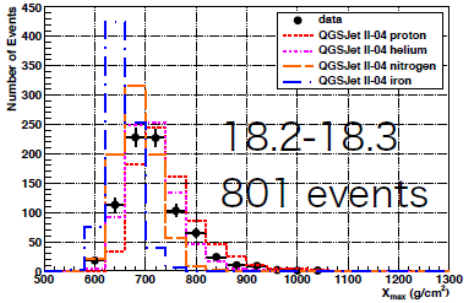
<Xmax> vs logE

Ap. J., 858, 76(2018)
arXiv: 1801.09784

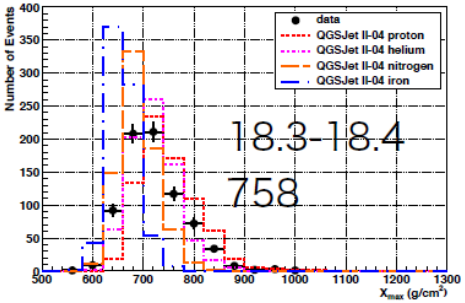


Xmax Distributions

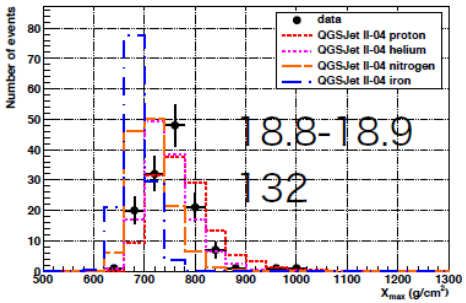
Ap. J., 858, 76(2018)
arXiv: 1801.09784



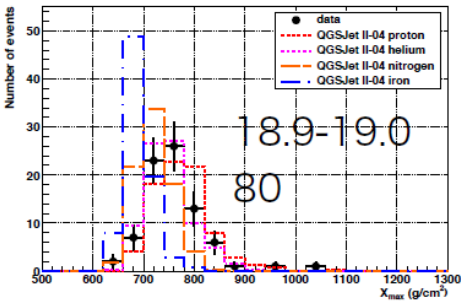
(a) $18.2 \leq \log_{10}(E/\mathrm{eV}) < 18.3$



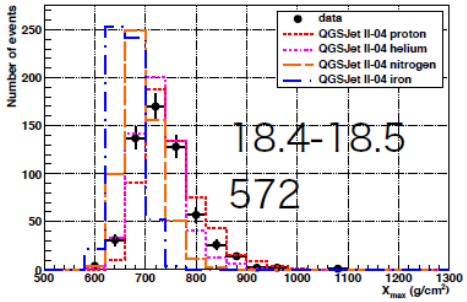
(b) $18.3 \leq \log_{10}(E/\mathrm{eV}) < 18.4$



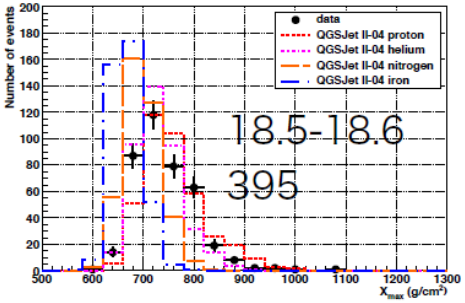
(a) $18.8 \leq \log_{10}(E/\mathrm{eV}) < 18.9$



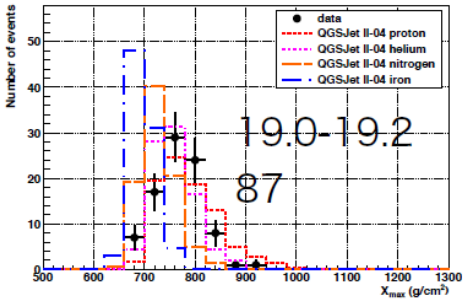
(b) $18.9 \leq \log_{10}(E/\mathrm{eV}) < 19.0$



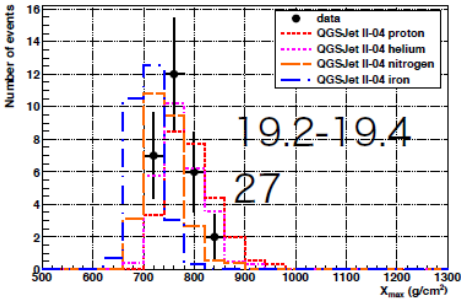
(c) $18.4 \leq \log_{10}(E/\mathrm{eV}) < 18.5$



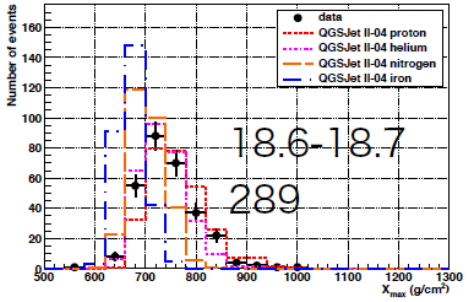
(d) $18.5 \leq \log_{10}(E/\mathrm{eV}) < 18.6$



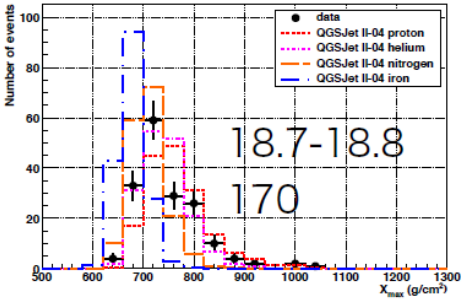
(c) $19.0 \leq \log_{10}(E/\mathrm{eV}) < 19.2$



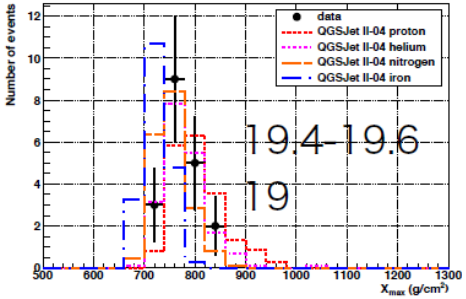
(d) $19.2 \leq \log_{10}(E/\mathrm{eV}) < 19.4$



(e) $18.6 \leq \log_{10}(E/\mathrm{eV}) < 18.7$



(f) $18.7 \leq \log_{10}(E/\mathrm{eV}) < 18.8$



(e) $19.4 \leq \log_{10}(E/\mathrm{eV}) < 19.9$

Comparison to MC

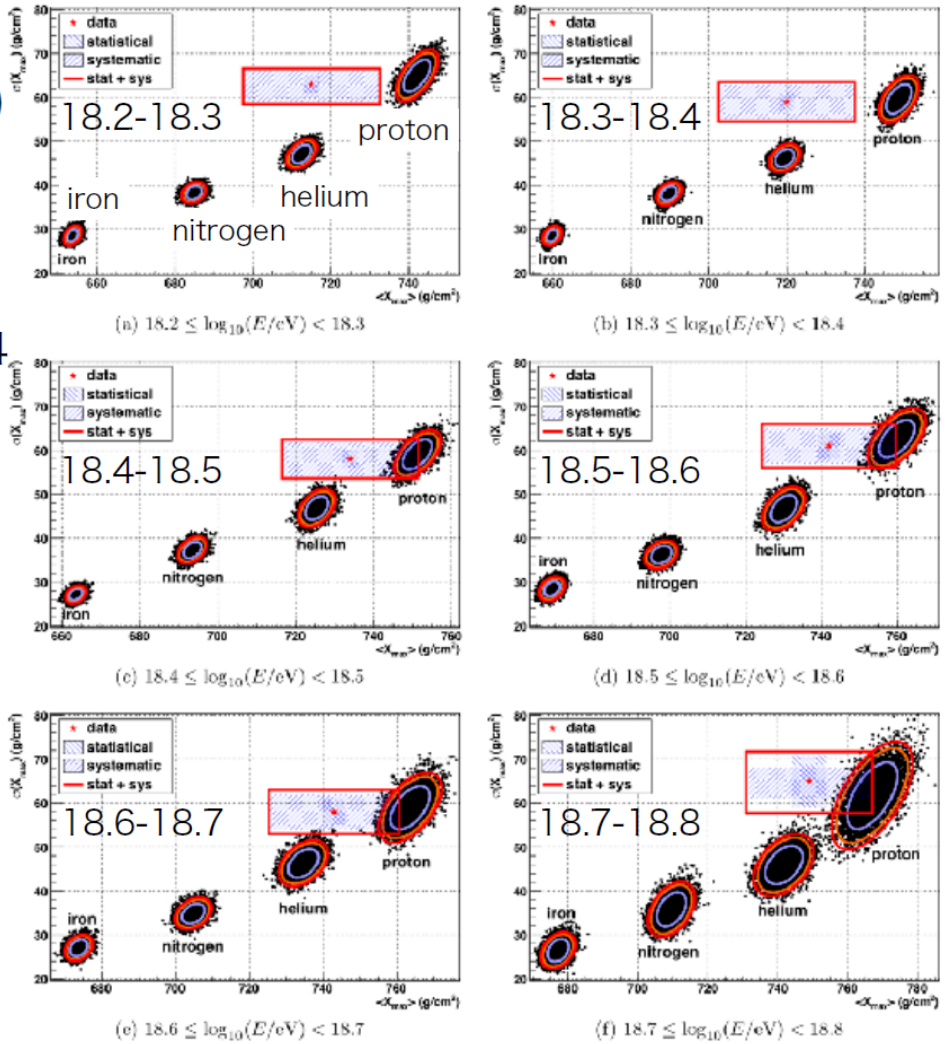
Ap. J., 858, 76(2018)
arXiv: 1801.09784

Compare Data and MC using both <X_{max}> and width of distribution(σ_{Xmax})

- Data : rectangles
- MC: contours

  Repeating 5,000 sets of MCs (Each set = the same # of events, 4 primary types)

In lower energies, log E < 18.8, allowing 10-20g/cm^2 shifts, Data points looks like "proton".



(a) $18.2 \leq \log_{10}(E/\mathrm{eV}) < 18.3$ (b) $18.3 \leq \log_{10}(E/\mathrm{eV}) < 18.4$

(c) $18.4 \leq \log_{10}(E/\mathrm{eV}) < 18.5$ (d) $18.5 \leq \log_{10}(E/\mathrm{eV}) < 18.6$

(e) $18.6 \leq \log_{10}(E/\mathrm{eV}) < 18.7$ (f) $18.7 \leq \log_{10}(E/\mathrm{eV}) < 18.8$

Systematic uncertaiinty

<Xmax> : 17.4g/cm^2

σ_{Xmax} : 21.2g/cm^2

Comparison to MC

Ap. J., 858, 76(2018)
arXiv: 1801.09784

Compare Data and MC using both <Xmax> and σ_{Xmax}

- Data : rectangles
- MC: contours

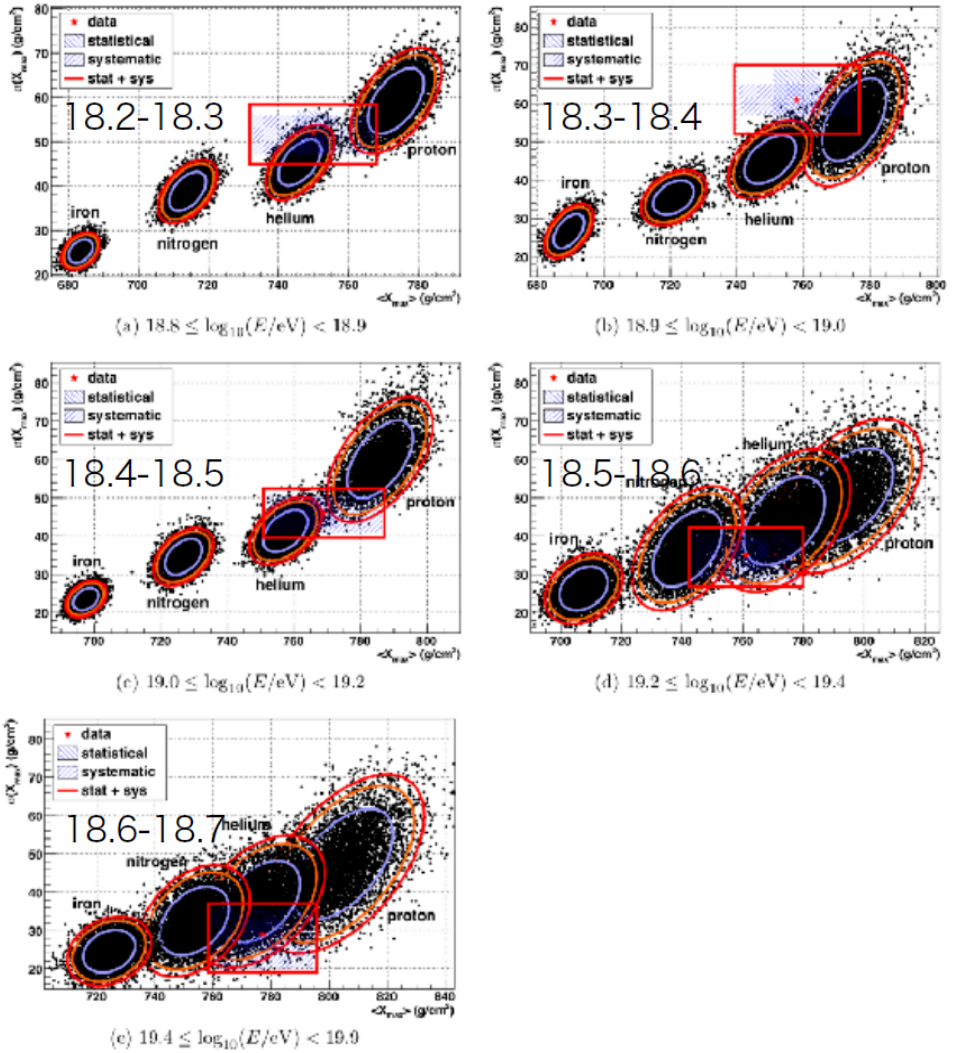
  Repeating 5,000 sets of MCs (Each set = the same # of events, 4 primary types)

In higher energies, log E > 18.8, data points looks like heavier primary than "proton", and there are significant overlaps between contours of different primaries because of small statistics.

Systematic uncertaiinty

<Xmax> : 17.4g/cm^2

σ_{Xmax} : 21.2g/cm^2



(a) $18.8 \leq \log_{10}(E/\mathrm{eV}) < 18.9$ (b) $18.9 \leq \log_{10}(E/\mathrm{eV}) < 19.0$

(c) $19.0 \leq \log_{10}(E/\mathrm{eV}) < 19.2$ (d) $19.2 \leq \log_{10}(E/\mathrm{eV}) < 19.4$

(e) $19.4 \leq \log_{10}(E/\mathrm{eV}) < 19.9$

Shape of Xmax Distribution

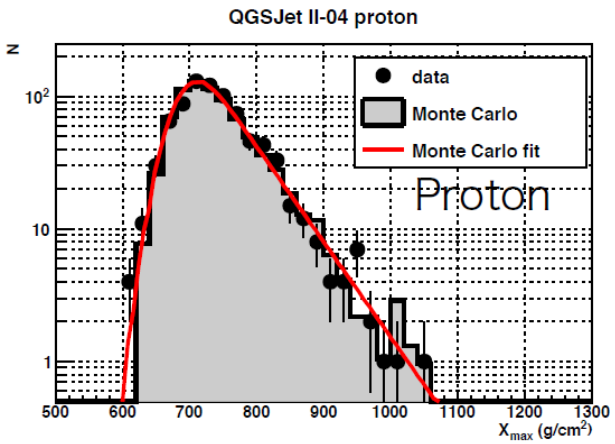
Compare shape of X_{max} distributions of Data and MC allowing Xmax shift

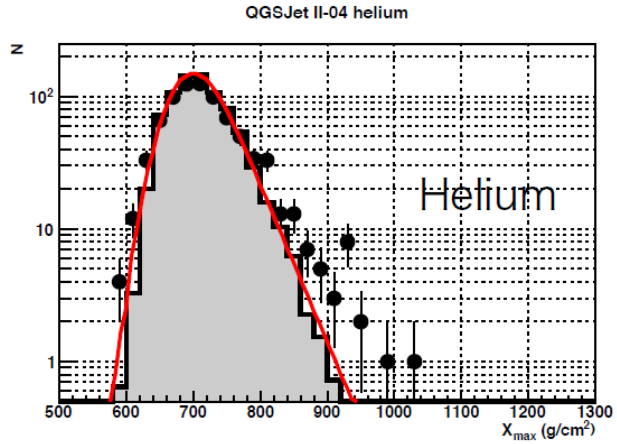
Ap. J., 858, 76(2018)
arXiv: 1801.09784

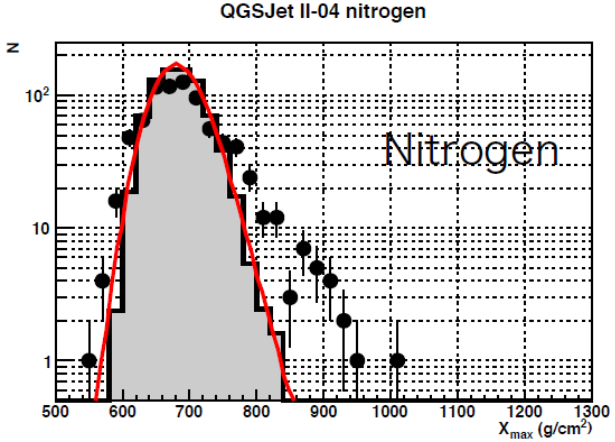
18.2 < log(E/eV) < 18.3

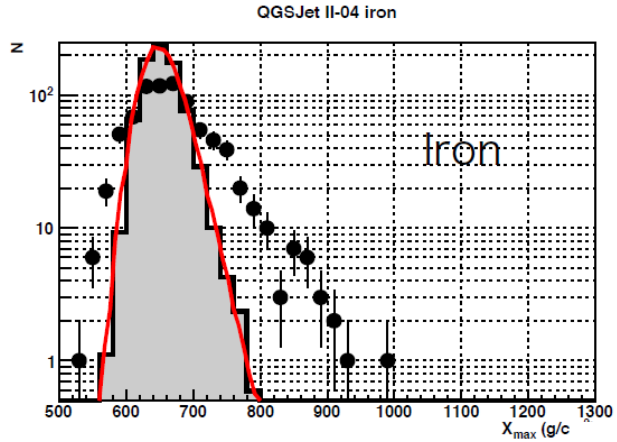
Xmax shift
proton : +29g/cm^2
He : +7g/cm^2
N : -21g/cm^2
Fe : -43g/cm^2

Systematic uncertaiinty
<Xmax> : 17.4g/cm^2

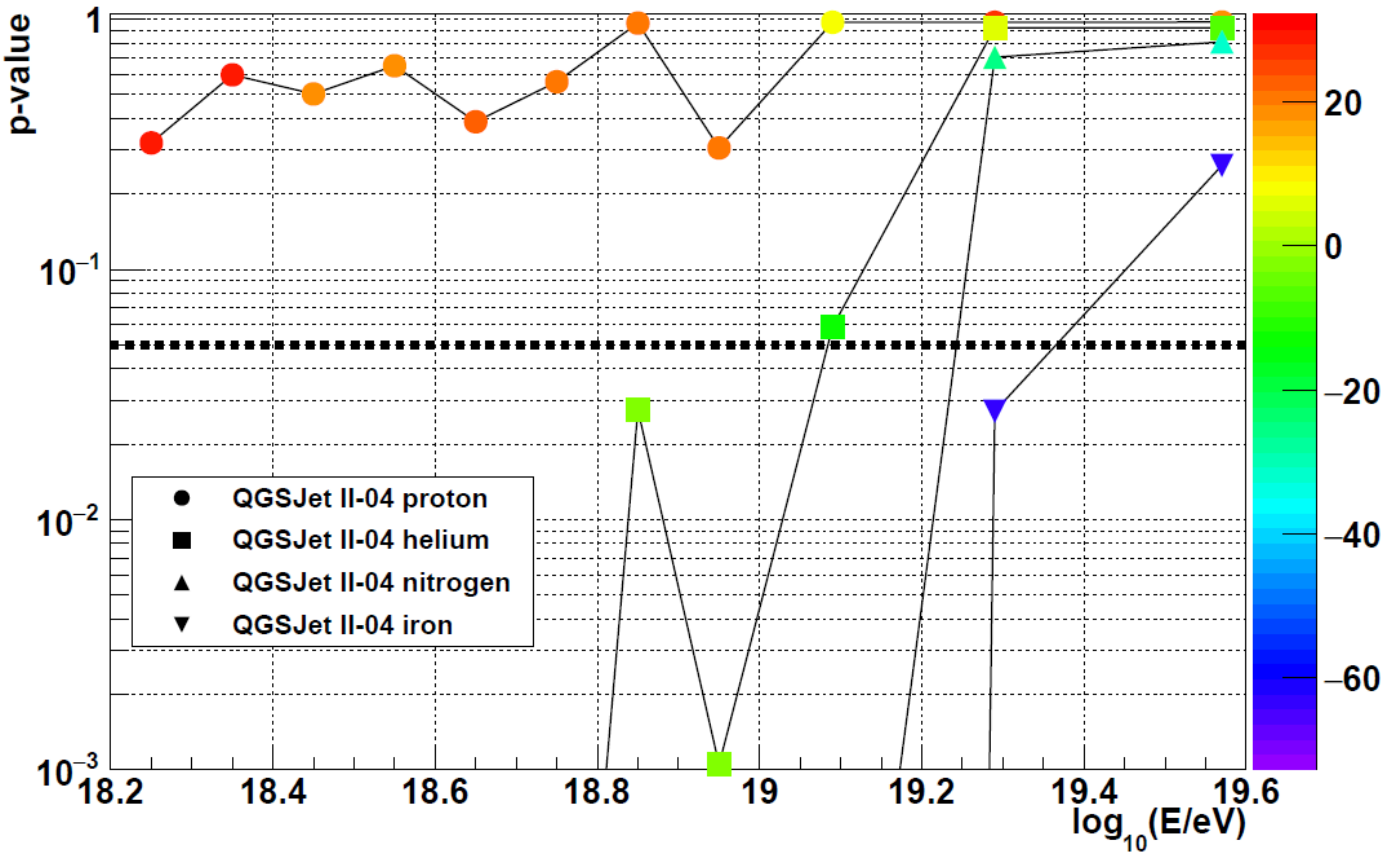








Shape analysis



Ap. J., 858, 76(2018)
arXiv: 1801.09784

Color indicates the amount of shift in Xmax applied to data for best fit to MC (in g/cm^2)

$E<10^{19.0}$eV

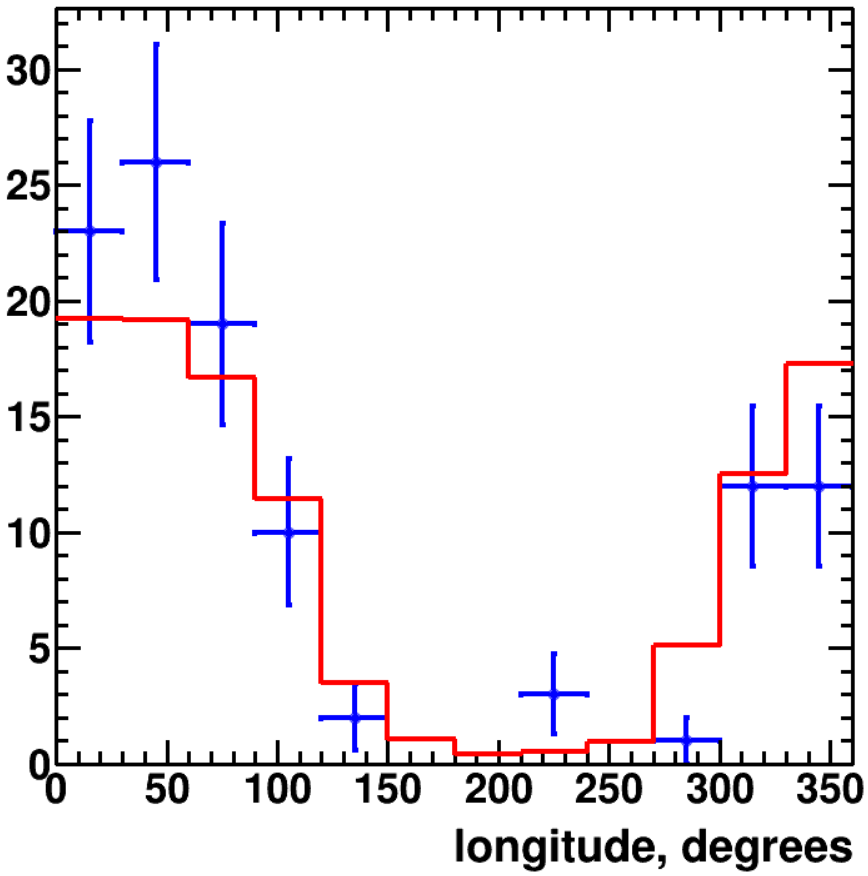
- max. log$L$ derived p rejects (at 95% C.L.) all species except H

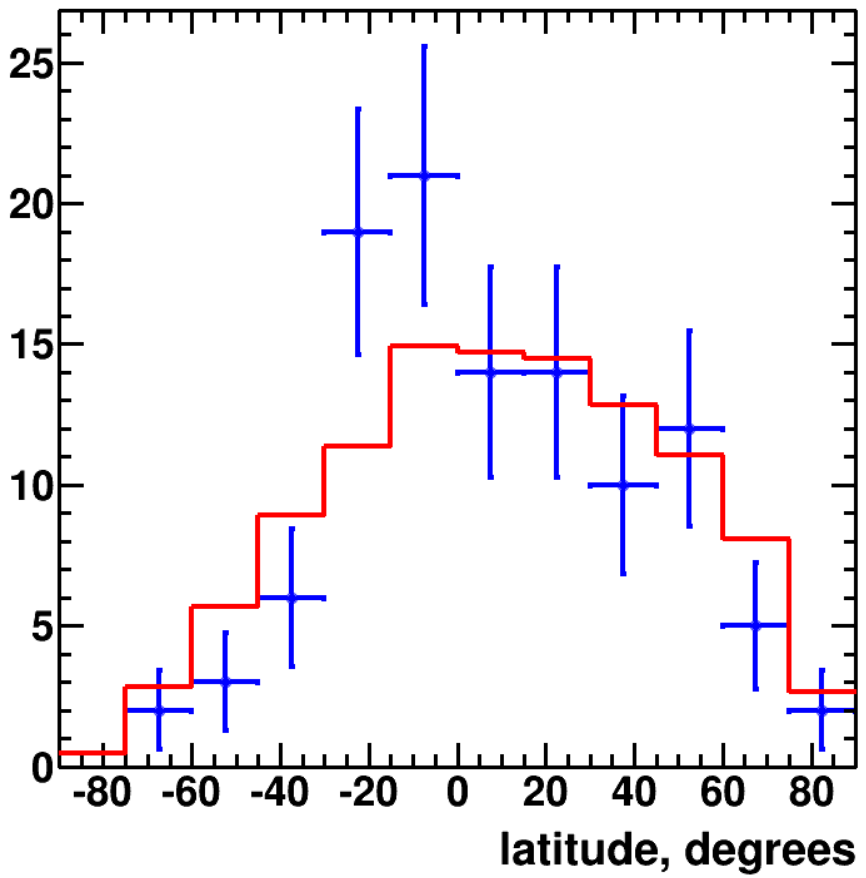
$E>10^{19.2}$eV

- max. log$L$ derived p FAILS to reject (at 95% C.L.) any species

Anisotropy Results

Supergalactic Coordinates

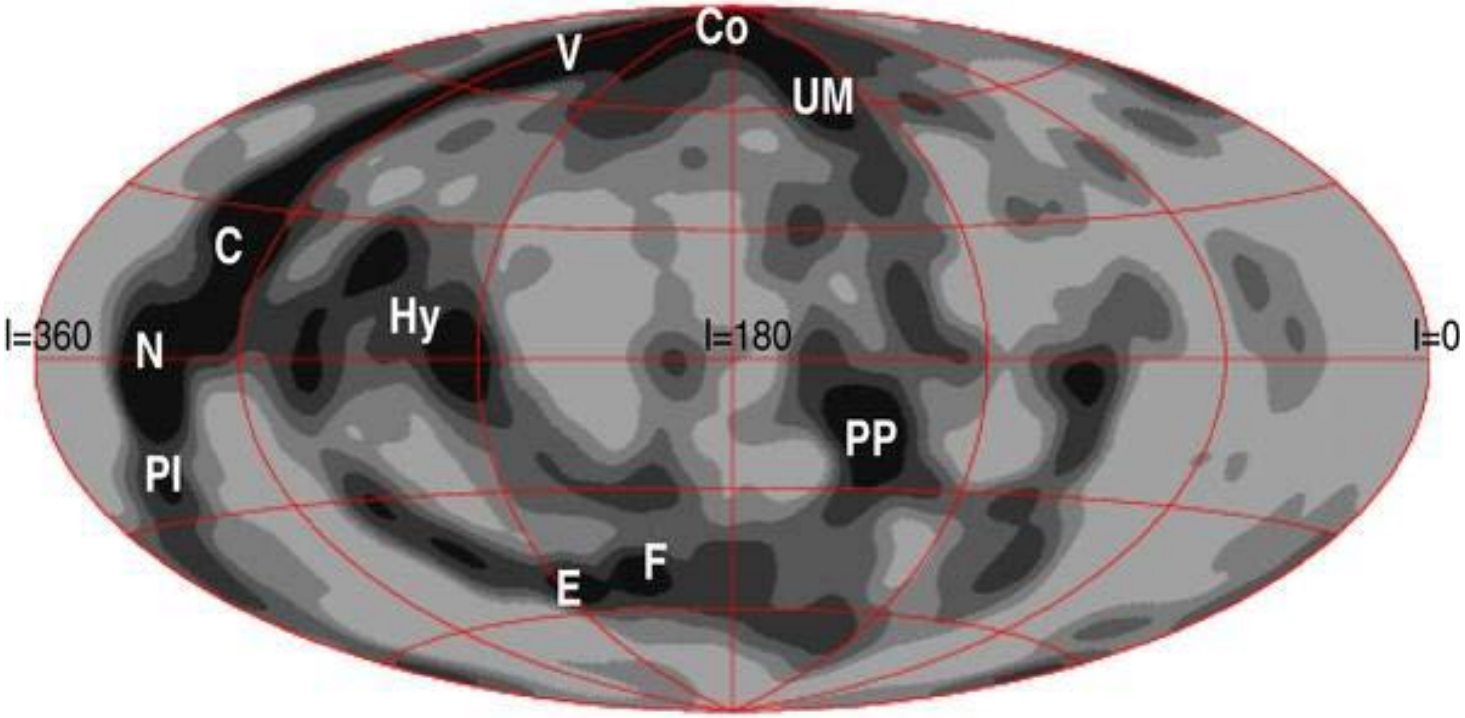




Kolmogorov-Smirnov p-value = 0.01 for SG latitude, E>57 EeV

other thresholds/coordinates = isotropic

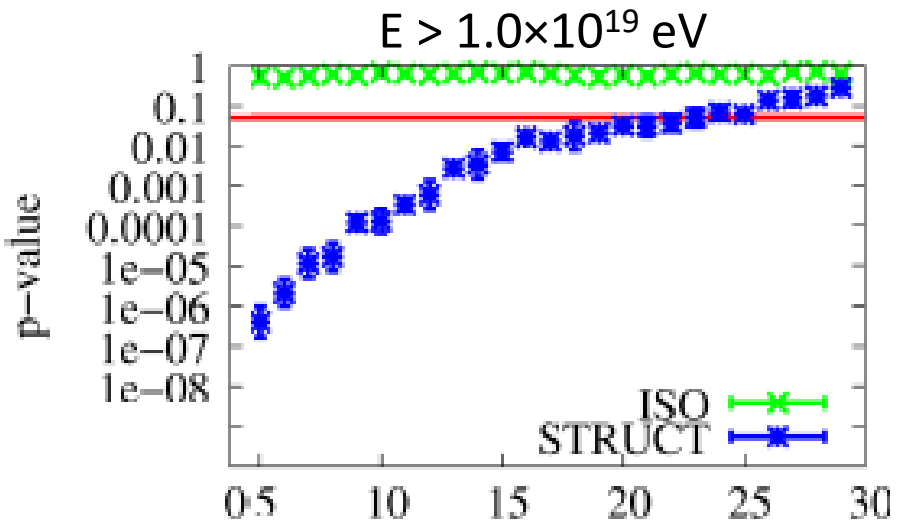
Large-Scale Structure

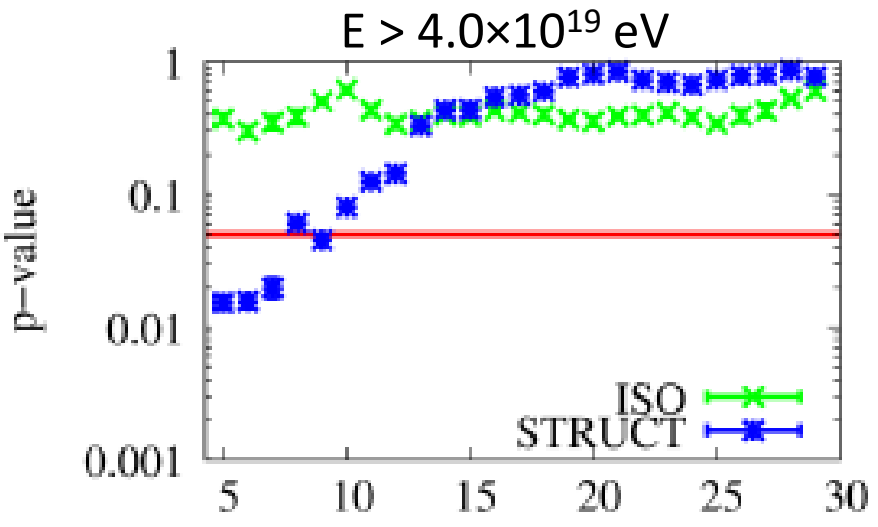


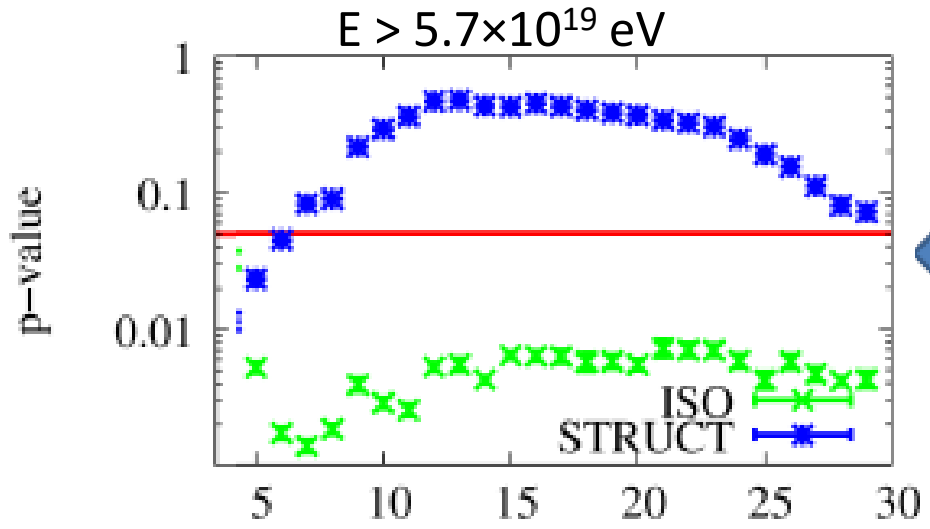
C: Centaurus SCl (60 Mpc); Co: Coma Cl (90 Mpc); E: Eridanus Cl (30 Mpc); F: Fornax Cl (20 Mpc); Hy: Hydra SCl (50 Mpc); N: Norma SCl (65 Mpc); PI: Pavo-Indus SCl (70 Mpc); PP: Perseus-Pisces SCl (70 Mpc); UM: Ursa Major Cl (20 Mpc); and V: Virgo Cl (20 Mpc).

- **Sky map of expected flux at $E > 57$ EeV (Galactic coordinates)**;
- smearing angle is 6°.

Large-Scale Structure

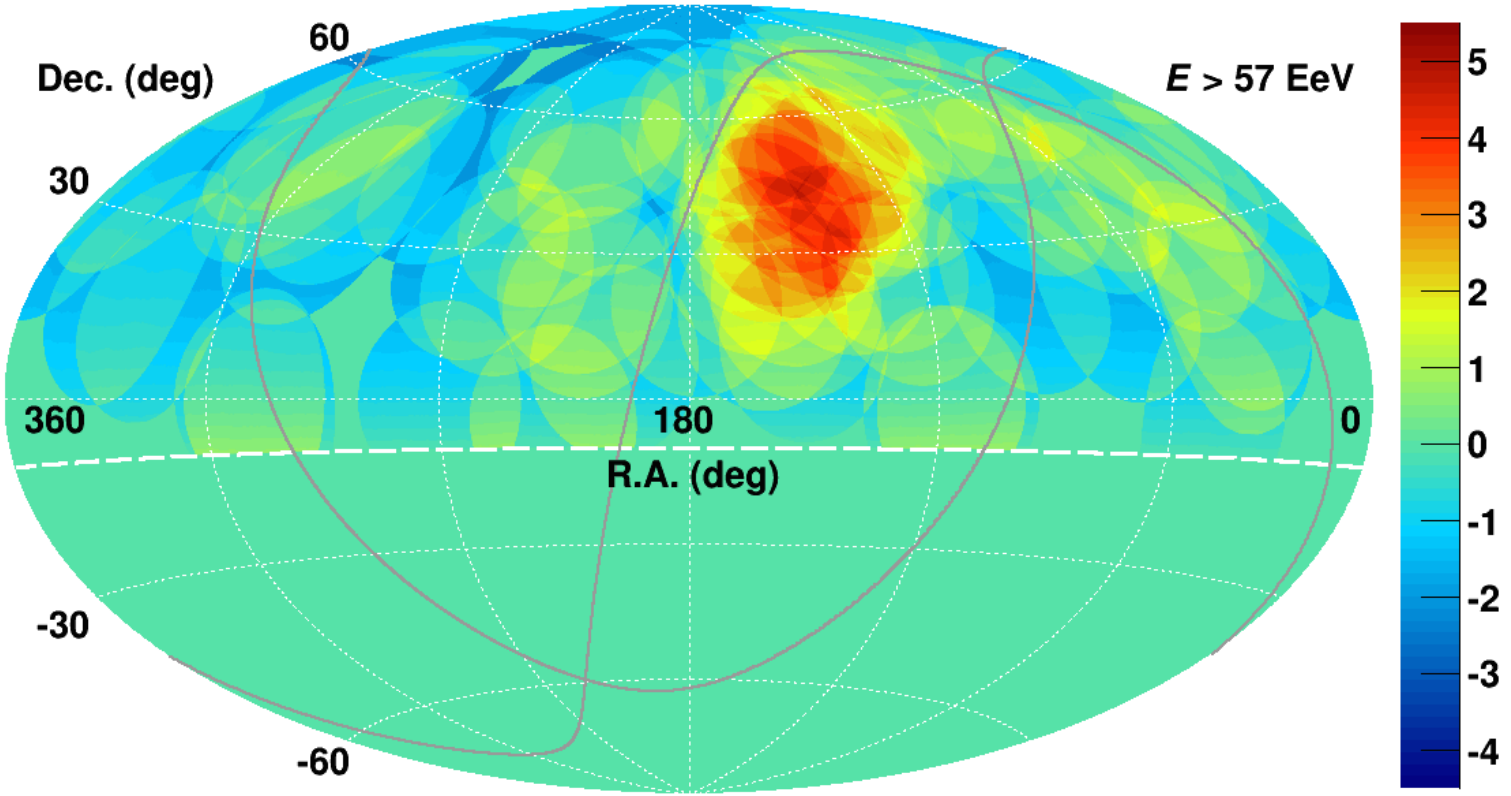






E>5.7×10^19 eV
Consistent with LSS
Inconsistent with isotropy

Hot Spot (2014)



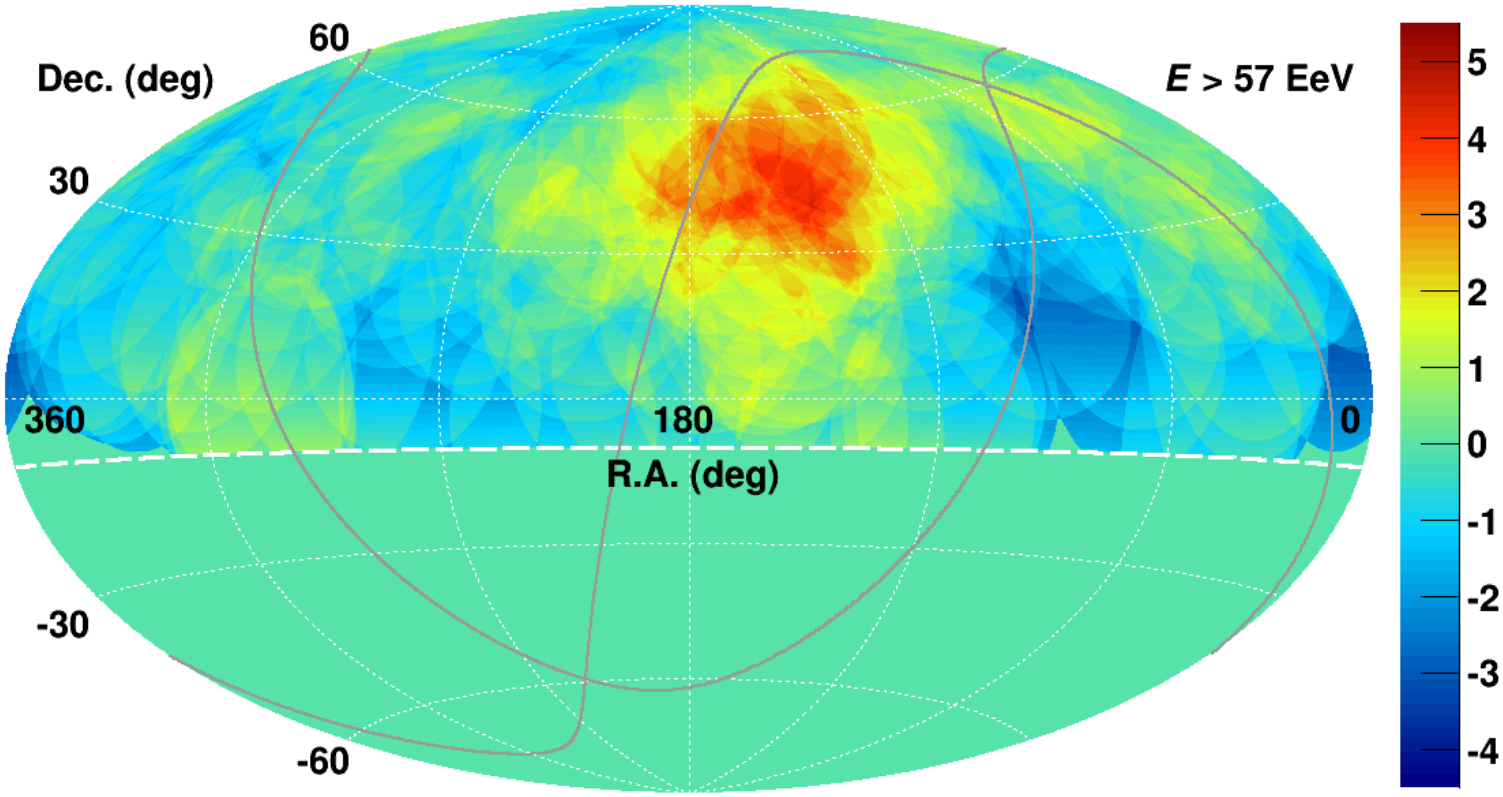
Total events: 72
Observed: 19
Expected : 4.5

Best circle center: RA=146.7°, Dec=+43.2°
Best circle radius: 20°
Local significance : 5 σ
Global significance : 3 σ

Hot Spot (2017)

E>57 EeV - Years 1-9 excess map

TA preliminary



Total events: 143

Observed: 34

Expected : 13.5

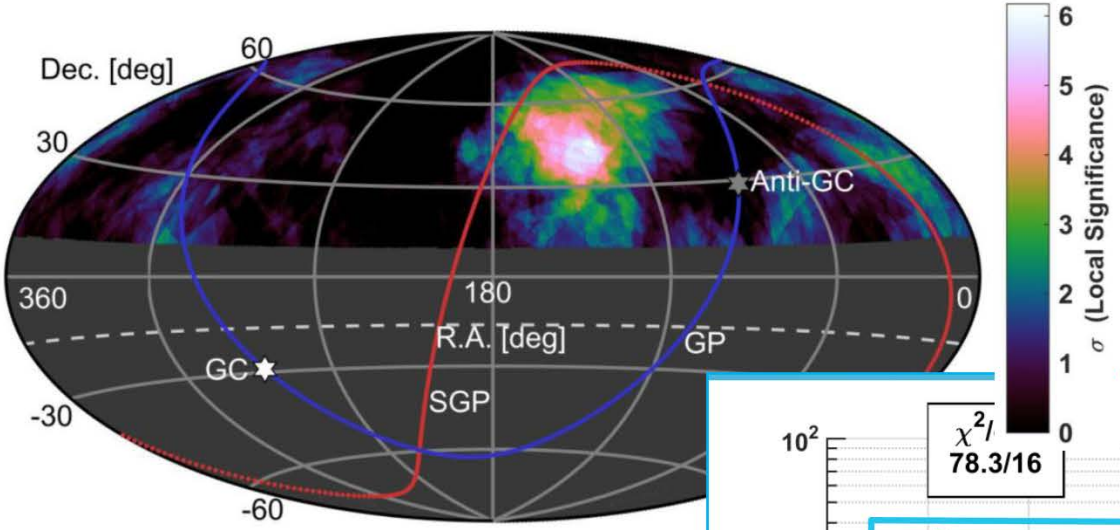
Best circle center: RA=144.3°, Dec=+40.3°

Best circle radius: 25°

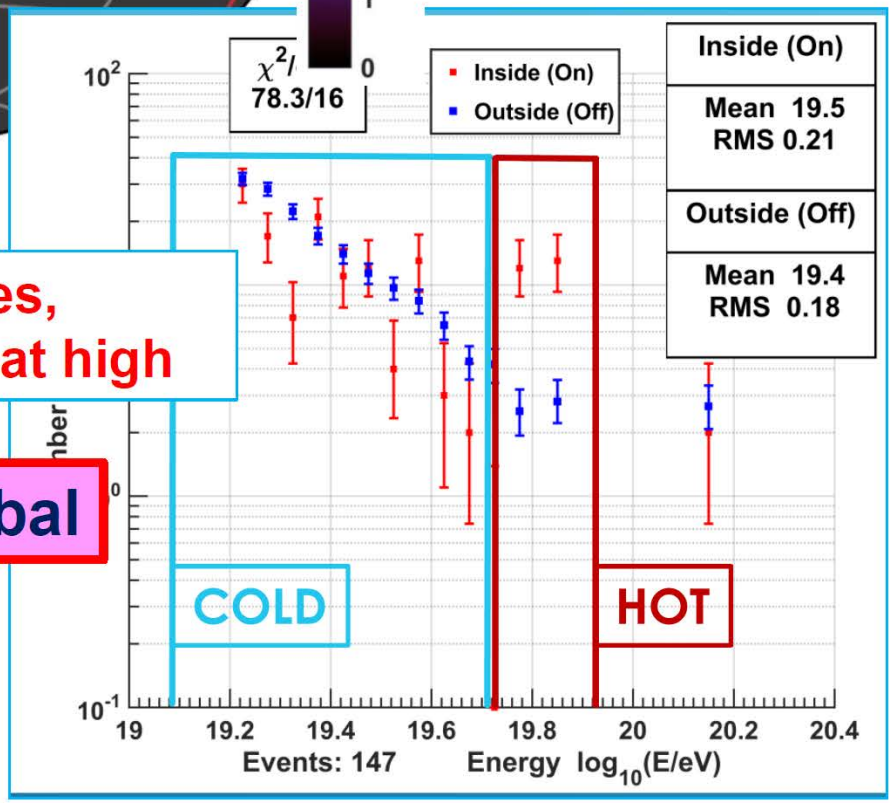
Local significance : 5 σ

Global significance : 3 σ

Cold Spot



$E \geq 10^{19.2}$ eV

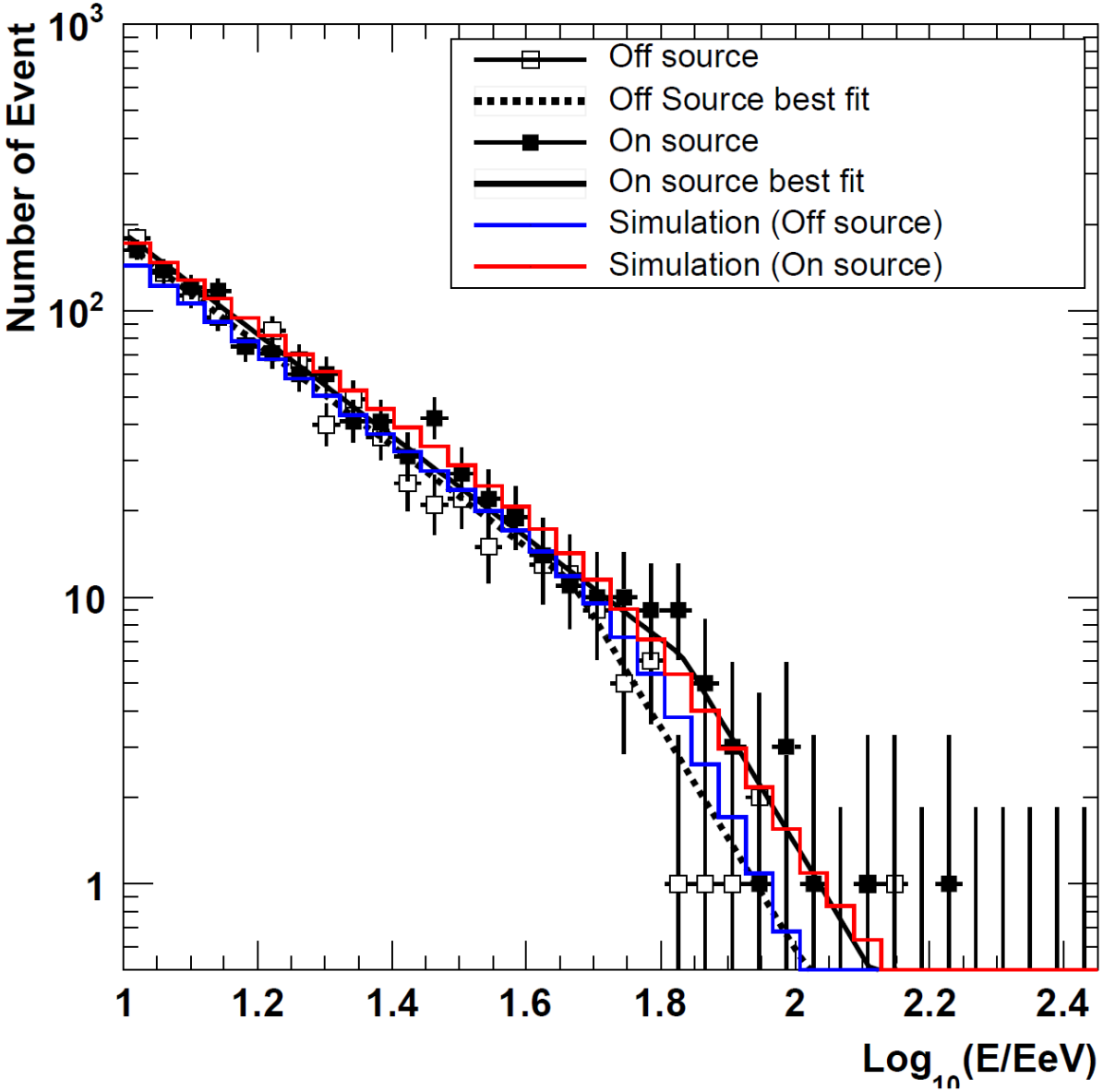


"cold spot" at lower energies, same place as the hot spot at high

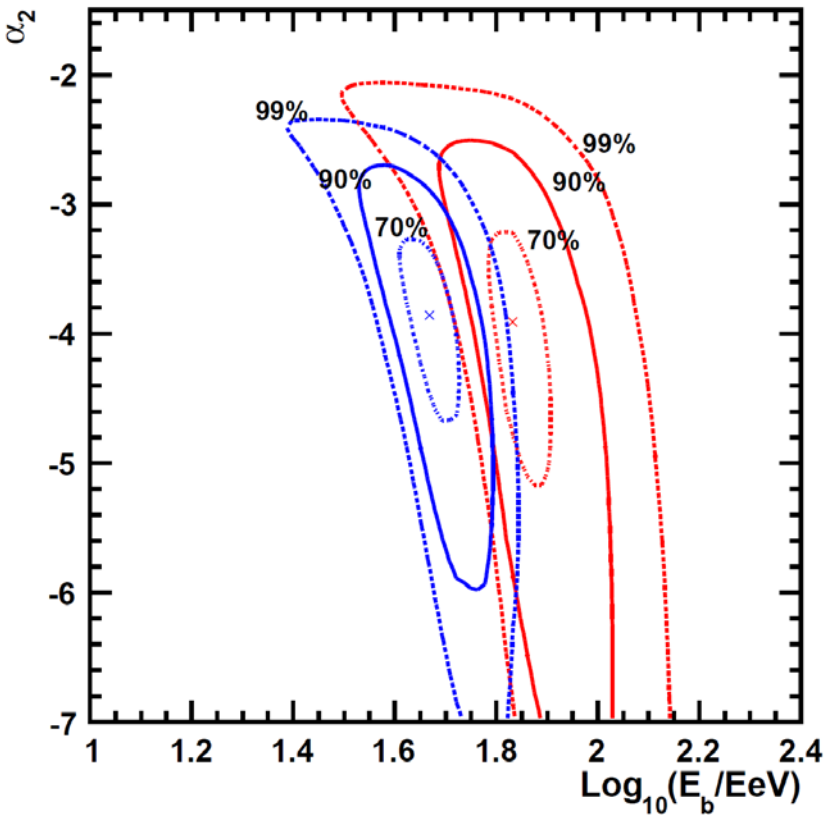
3.7σ global

Lundquist talk CRI 231

Enhancement along SGP



- Source: Within 30° of the Supergalatic Plane (SGP)
- Simulation: using the large-scale structure model shown previously, assuming proton primaries



Difference between on-source and Off-source

Each spectrum fit to broken power law with:

(1) Power Law Index of no. of events vs logE before break: α_1

(2) Break point energy = $E_{b:}$

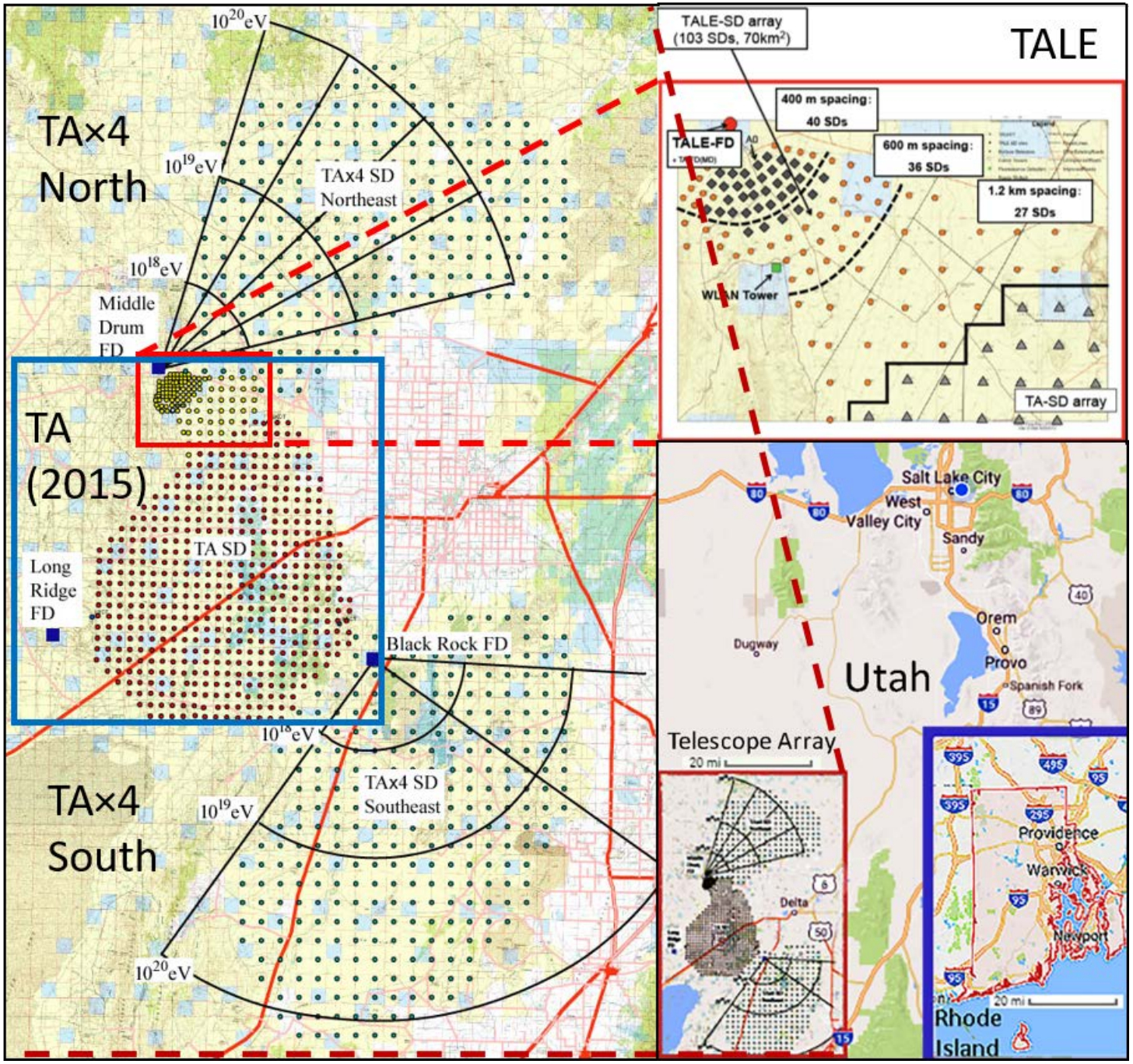
(3) Power Law Index of no. of events vs logE before break: α_1

arXiv:1707.04967v3 [astro-ph.HE] 11 Aug 2017, submitted to PRL

Region	C_o	α_1	$\log_{10}(E_b/EeV)$	α_2
All	$2.14^{+0.34}_{-0.30} \times 10^{+4}$	$-1.775^{+0.053}_{-0.053}$	$1.778^{+0.040}_{-0.068}$	$-3.91^{+0.64}_{-0.66}$
On source	$(1.1128 \times 10^{+4})$	(-1.775)	$1.832^{+0.069}_{-0.041}$	$-3.91^{+0.70}_{-1.30}$
Off source	$(1.0286 \times 10^{+4})$	(-1.775)	$1.668^{+0.052}_{-0.053}$	$-3.86^{+0.58}_{-0.82}$

TABLE I. Parameters of the best fit broken power law in the SGP case.

Global Chance Probability/Significance:
$p = 6.2 \times 10^{-4}$ (3.2σ)



TAx4 under construction:

End