Recent results from the Telescope Array experiment

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< The Telescope Array (TA) Collaboration

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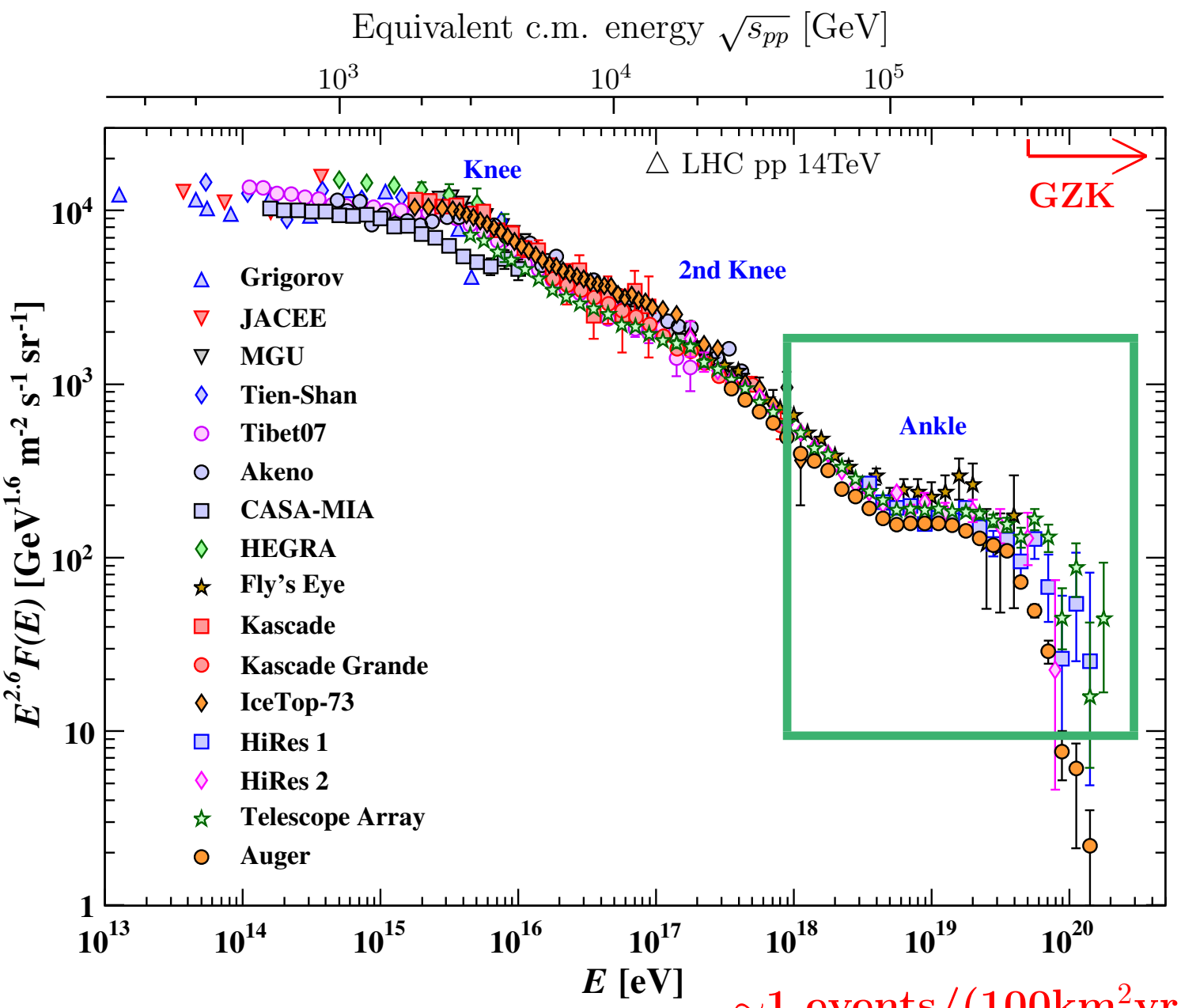
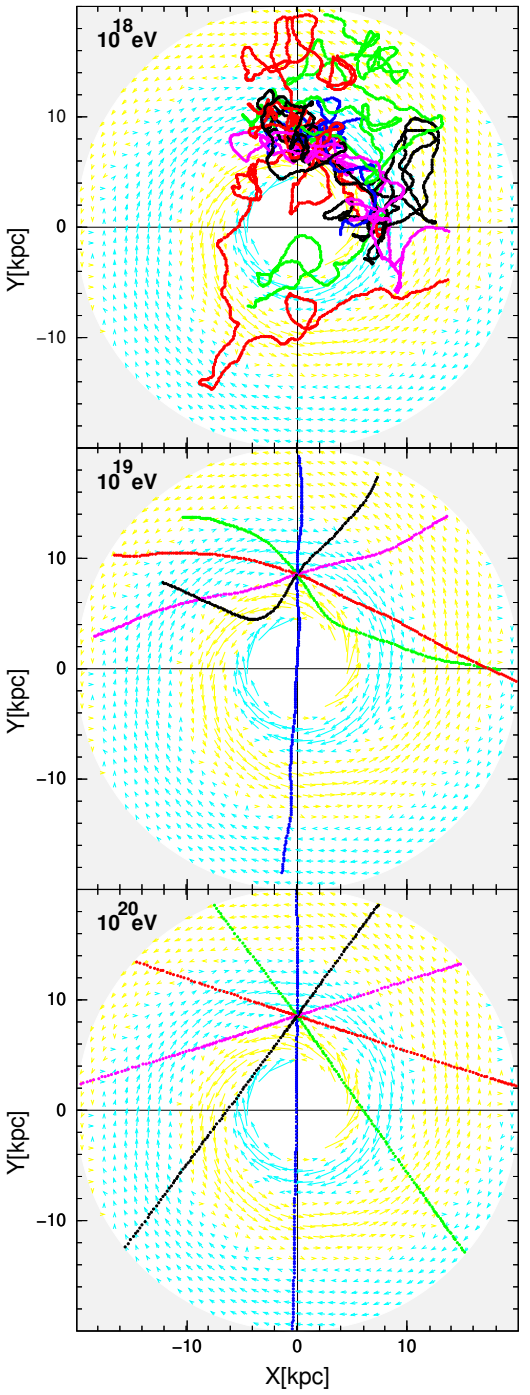
(126, 30)

< Ultra High Energy Cosmic Rays >

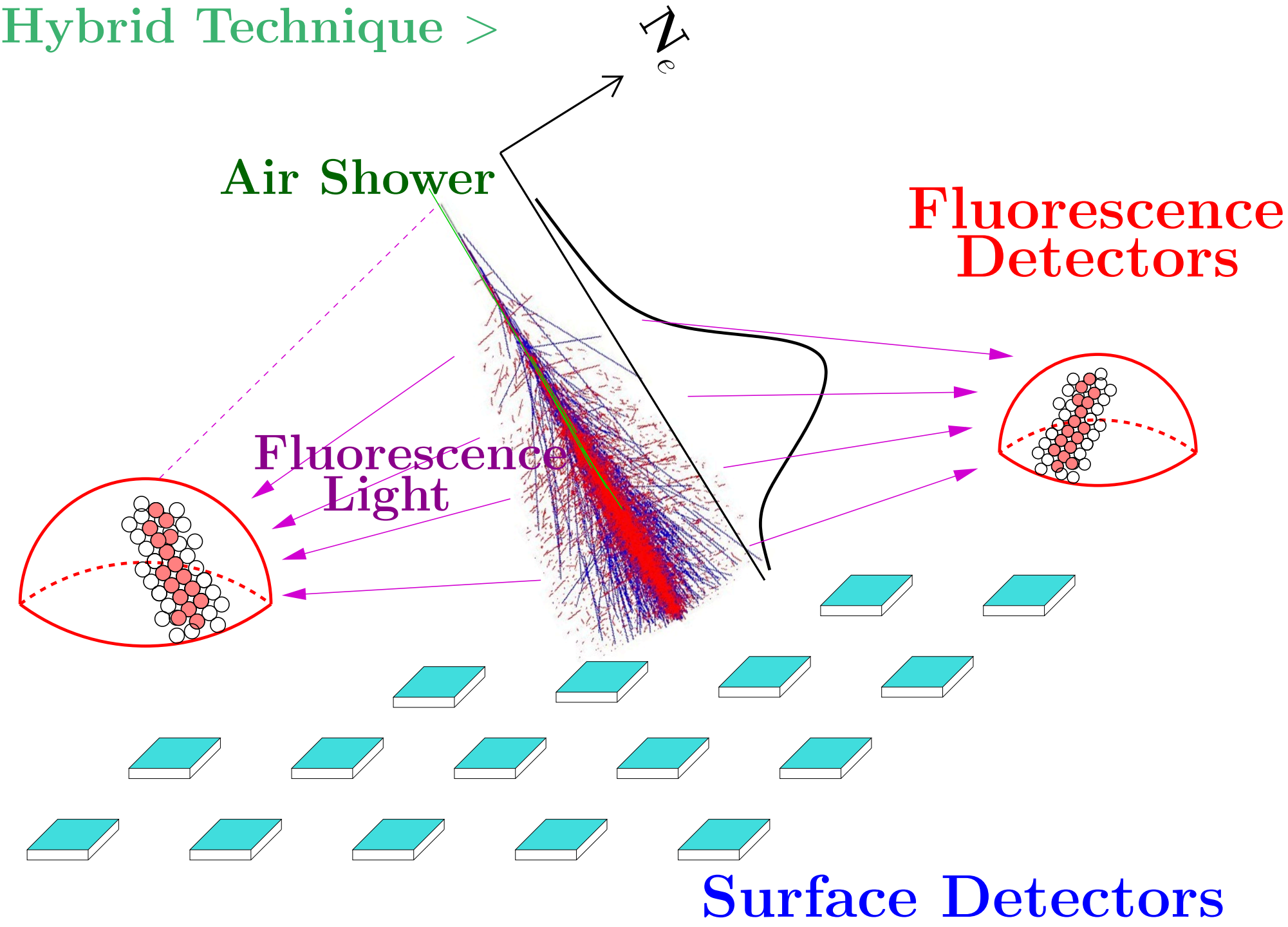




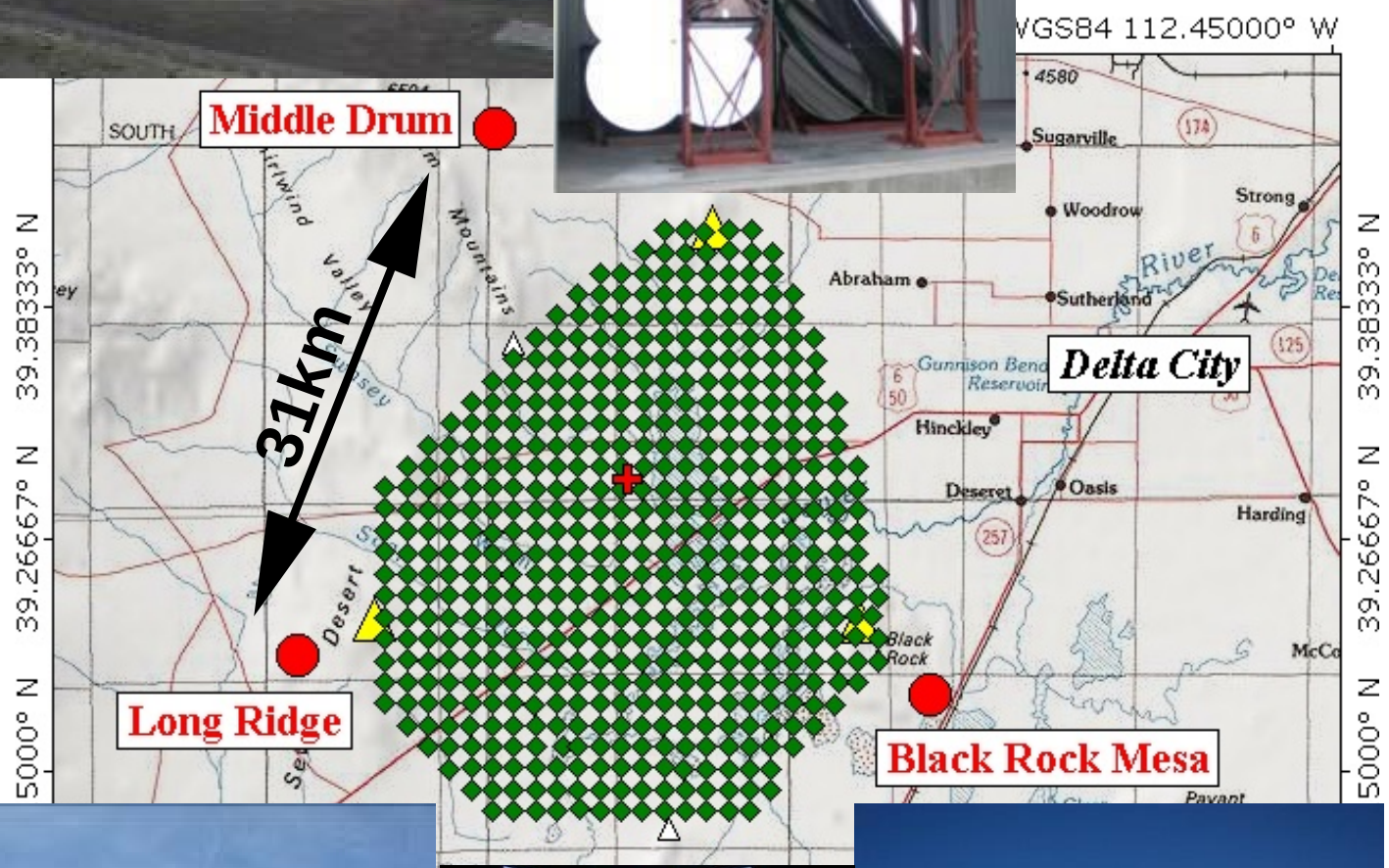
~1 events/(100km^{2}yr)
@ 10^{20}eV

PDG2016

< Hybrid Technique >



< Telescope Array Experiment >



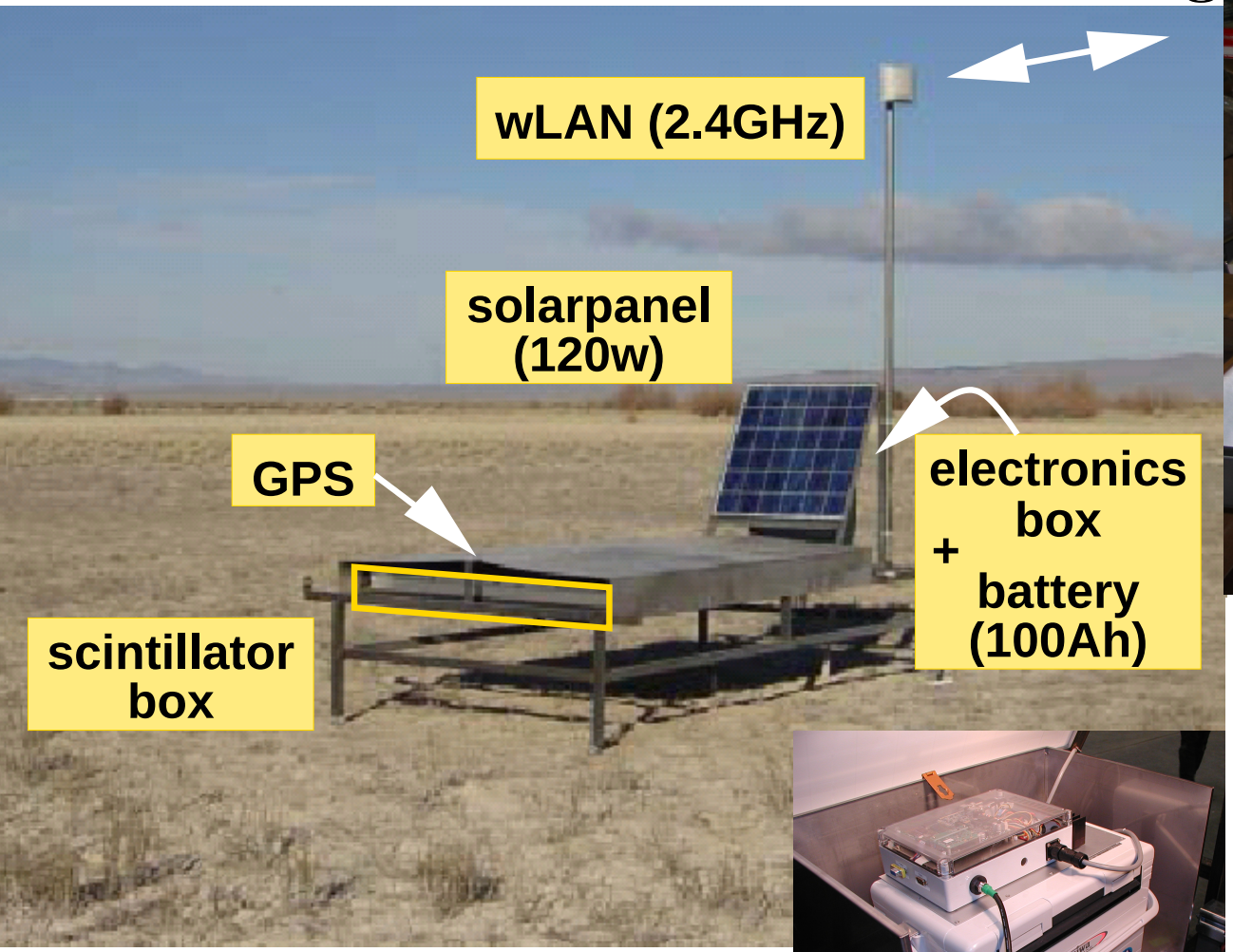
- **MD FD**
  14 telescopes
  - $5.2m^2$
  - 256 PMTs
  - 1° pixel

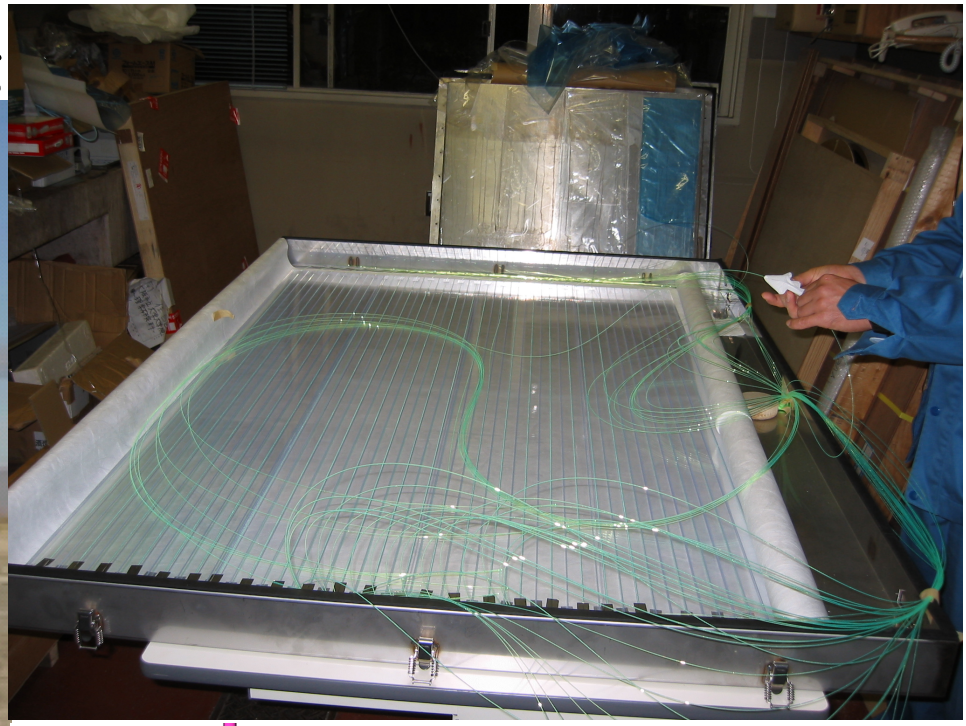
- **SD array**
  507 detectors
  - 1.2km grid
  - $3.0m^2$
  - wireless comm
  - solar panel

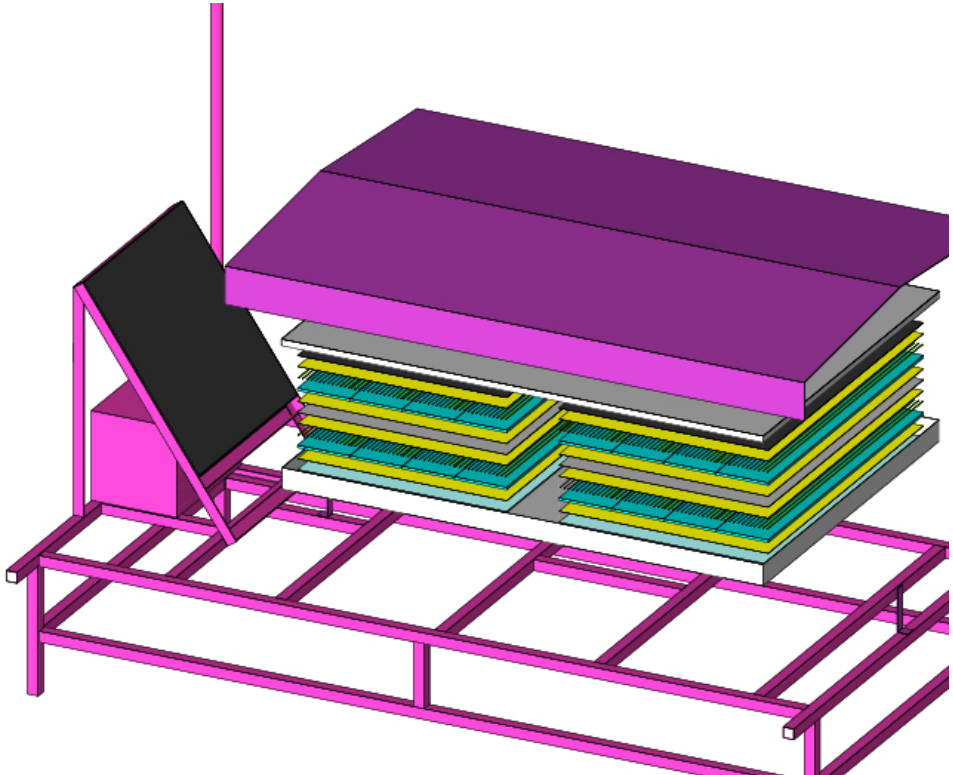
- **BRM / LR FD**
  12 telescopes
  - $6.8m^2$
  - 256 PMTs
  - 1° pixel

< Surface Detector >

~200kg

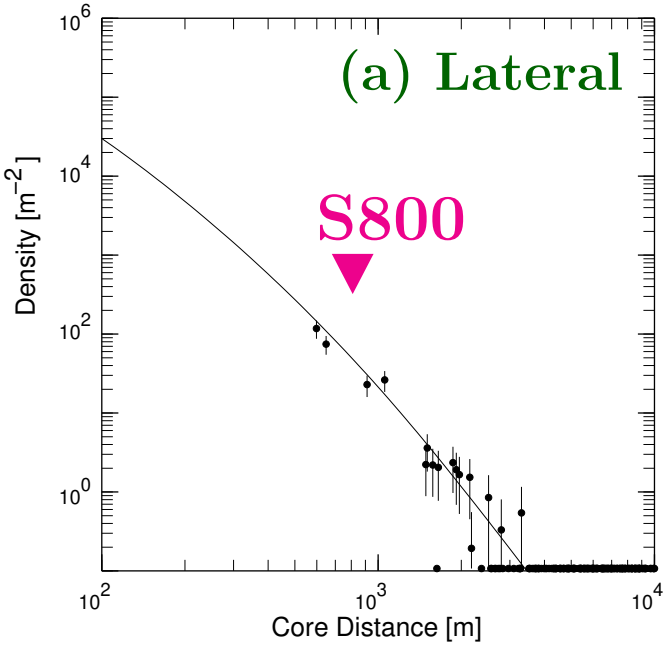


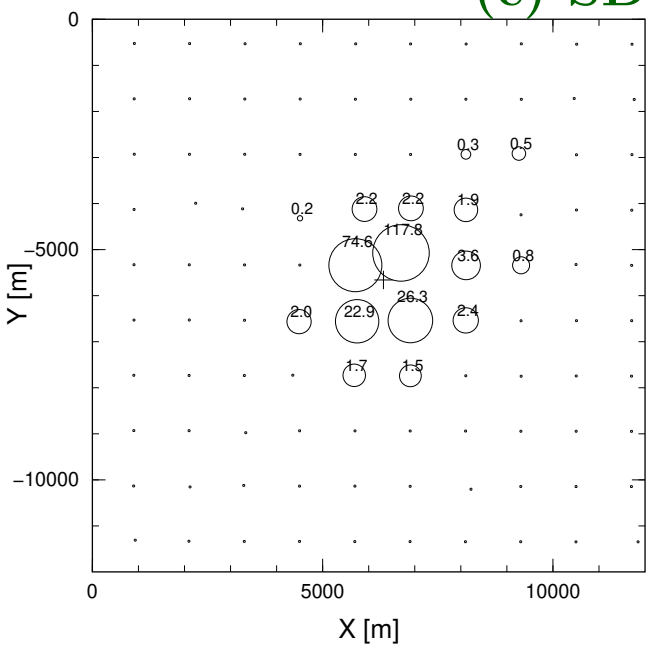


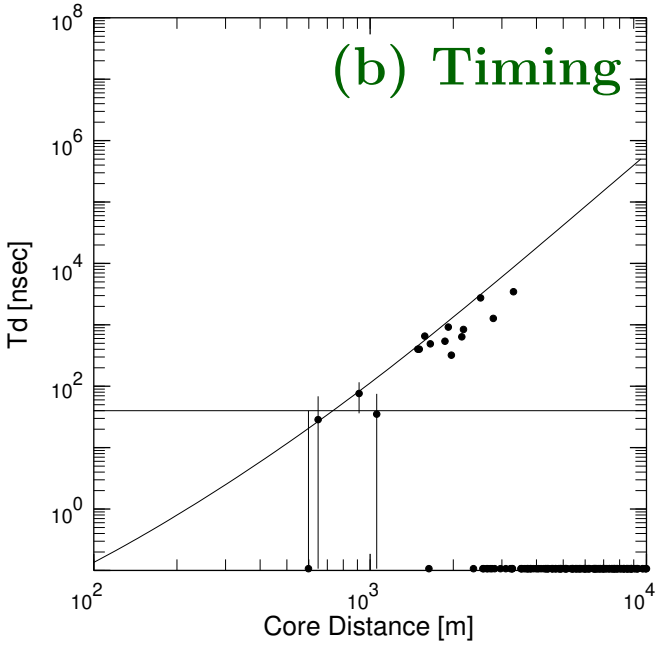


- WLSF: 1.0mmϕ (2cm separation)
- PMTs: ET 9123SA $\times$ 2
- 3m^2 (12mm $\times$ 2 layers)

< SD Event Example >



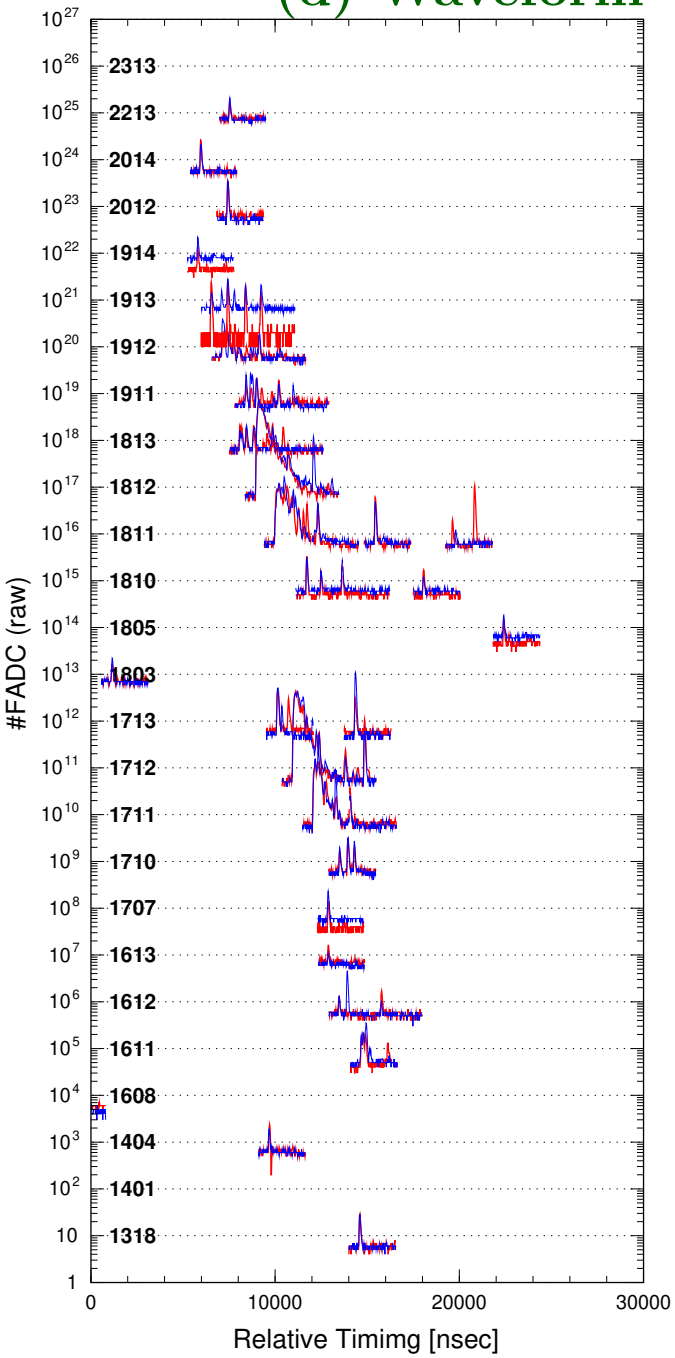




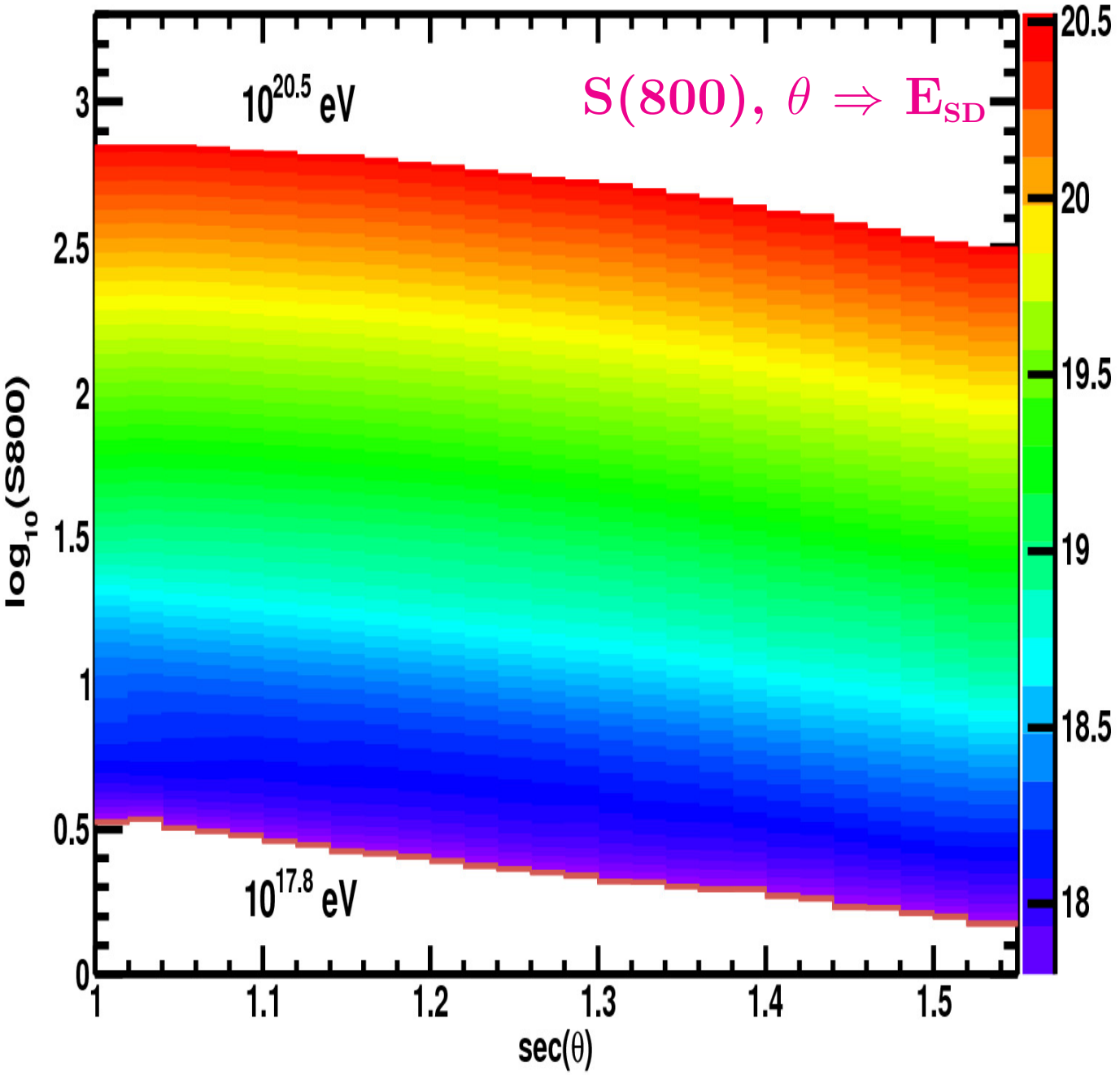
RUN(50141) **EVENT(2182)**

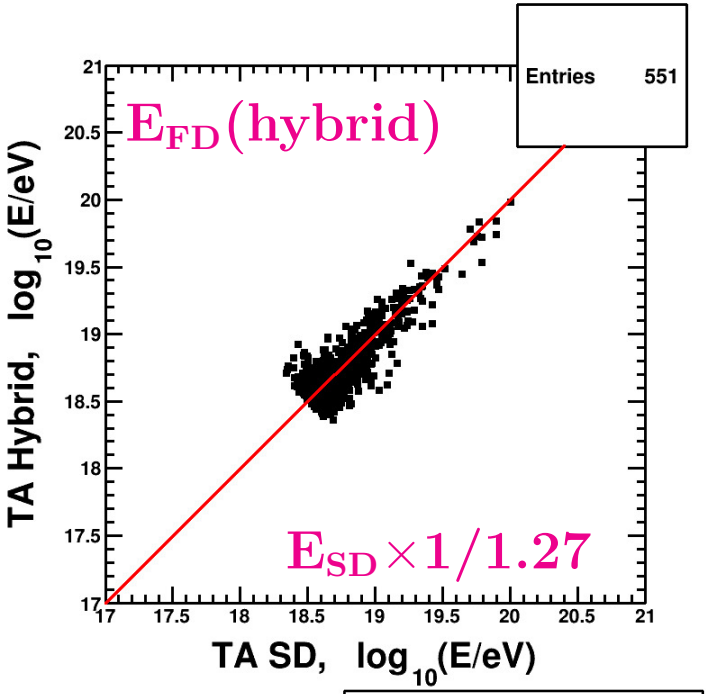
DATE(080531) **TIME(050737)**

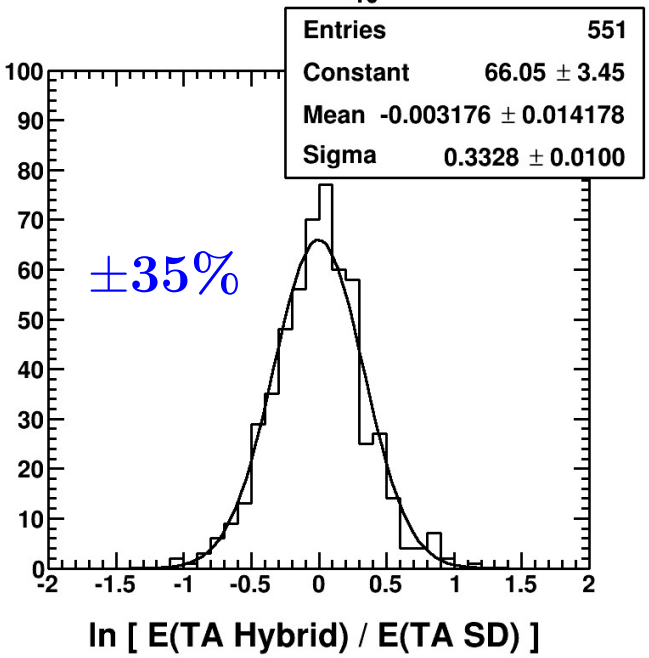
(θ, ϕ)



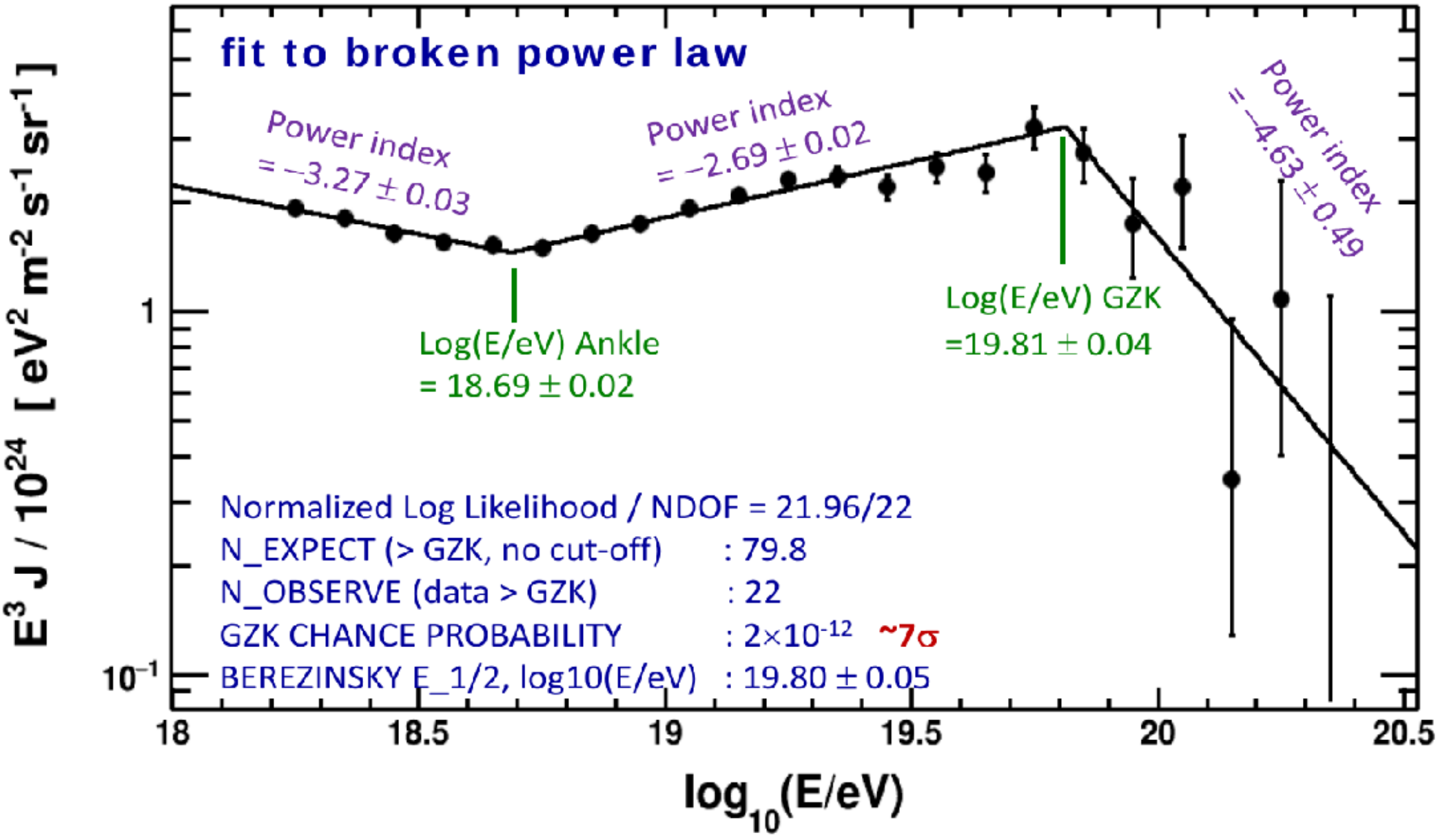
< TA Energy Estimation >





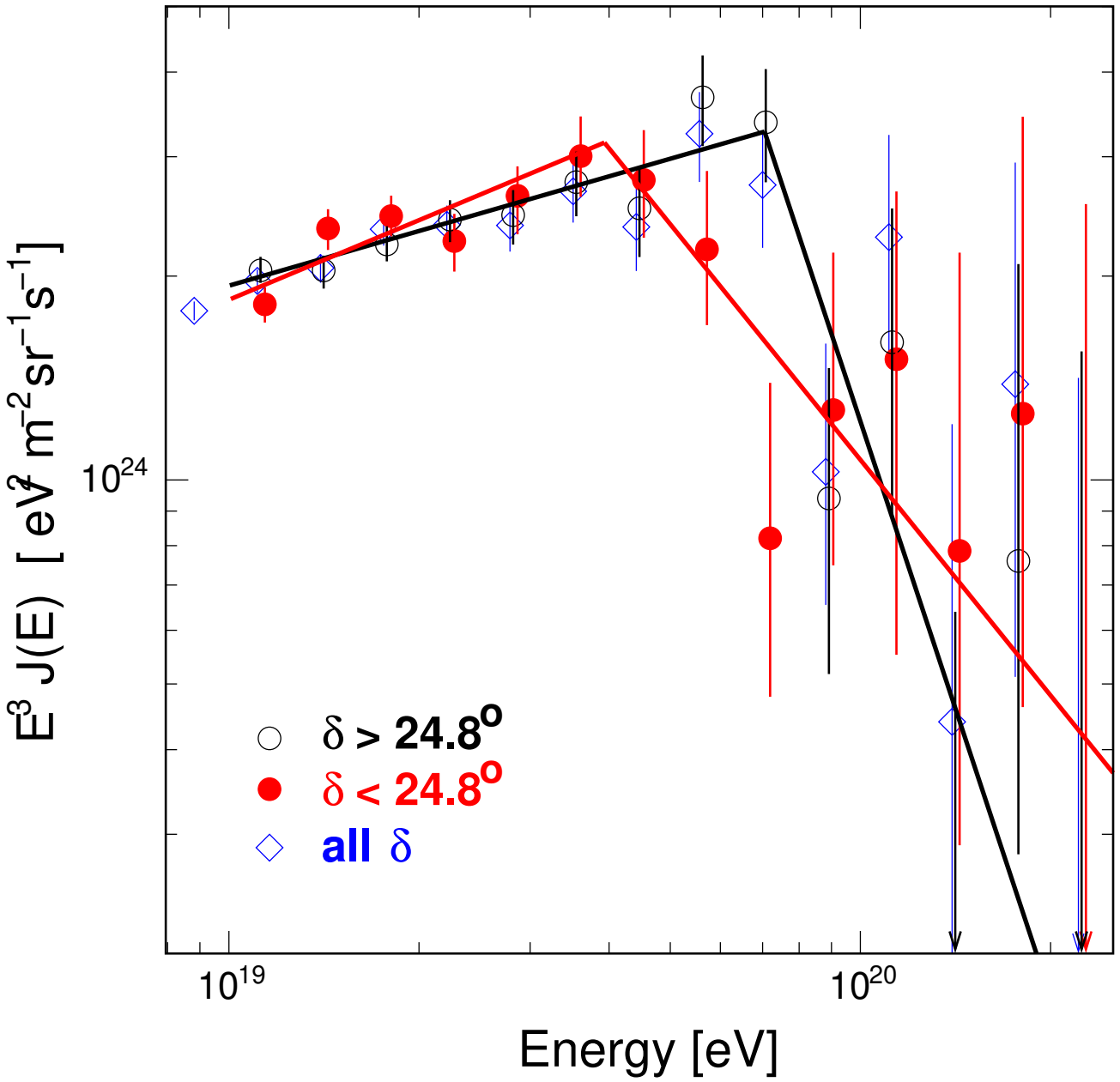


< Energy Spectrum (TA-SD: 9yrs) >



ICRC2017 CRI172

< Declination Dependence >



E_2[eV]: Cutoff Energy

◇ **all δ**

$\log(E_2[\mathrm{eV}]) = 19.78^{\pm 0.06}$

• $\delta > 24.8^\circ$ **(North)**

$\log(E_2[\mathrm{eV}]) = 19.85^{\pm 0.03}$

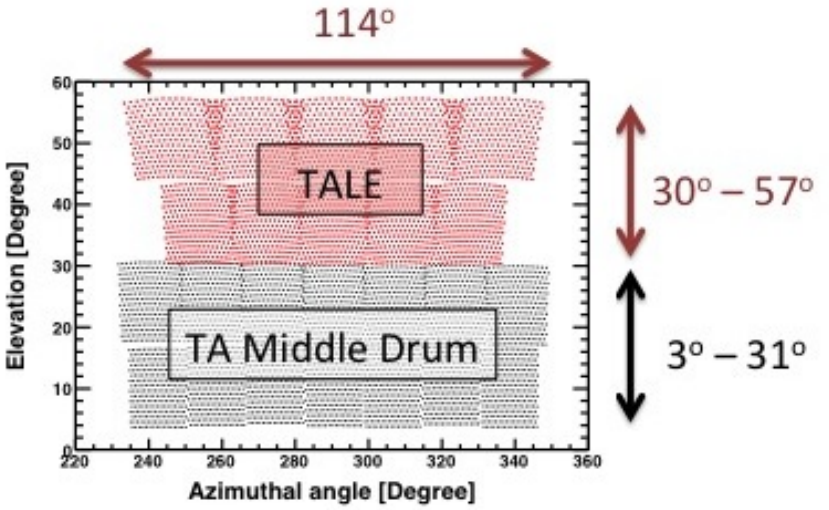
⇕ **3.5σ difference**

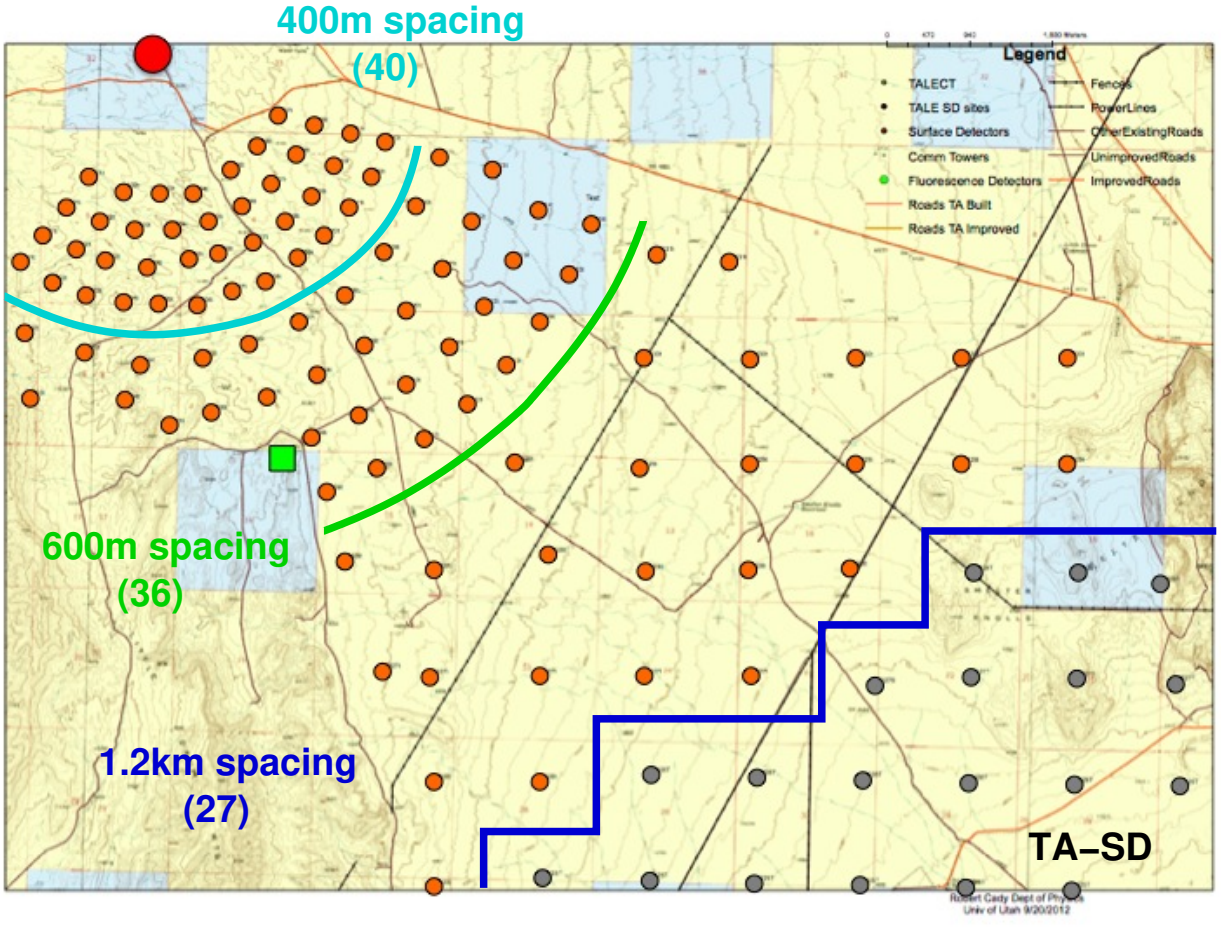
◦ $\delta < 24.8^\circ$ **(South)**

$\log(E_2[\mathrm{eV}]) = 19.59^{+0.05}_{-0.07}$

arXiv:0181.07820

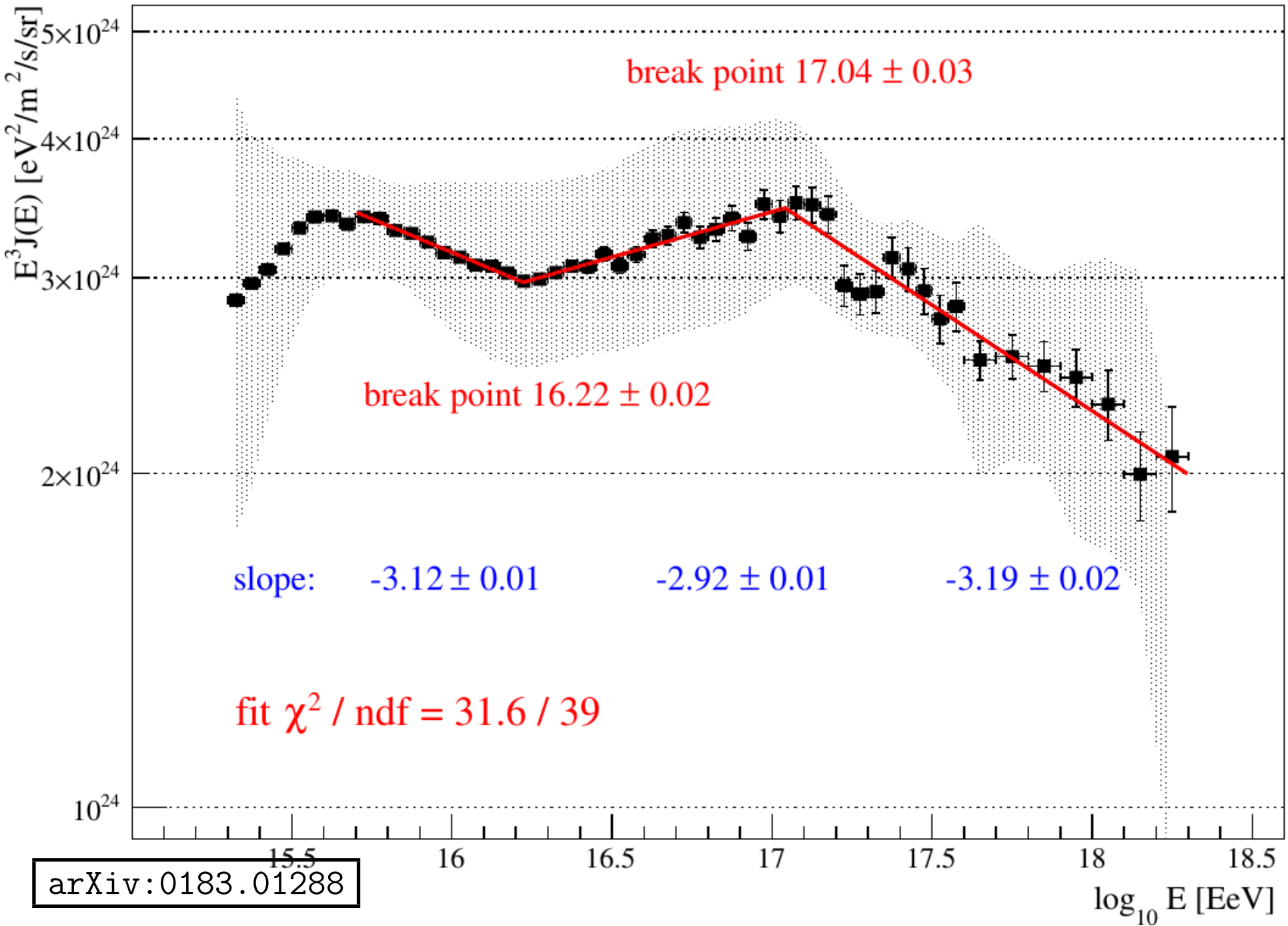
< TALE (TA Low-energy Extension) >





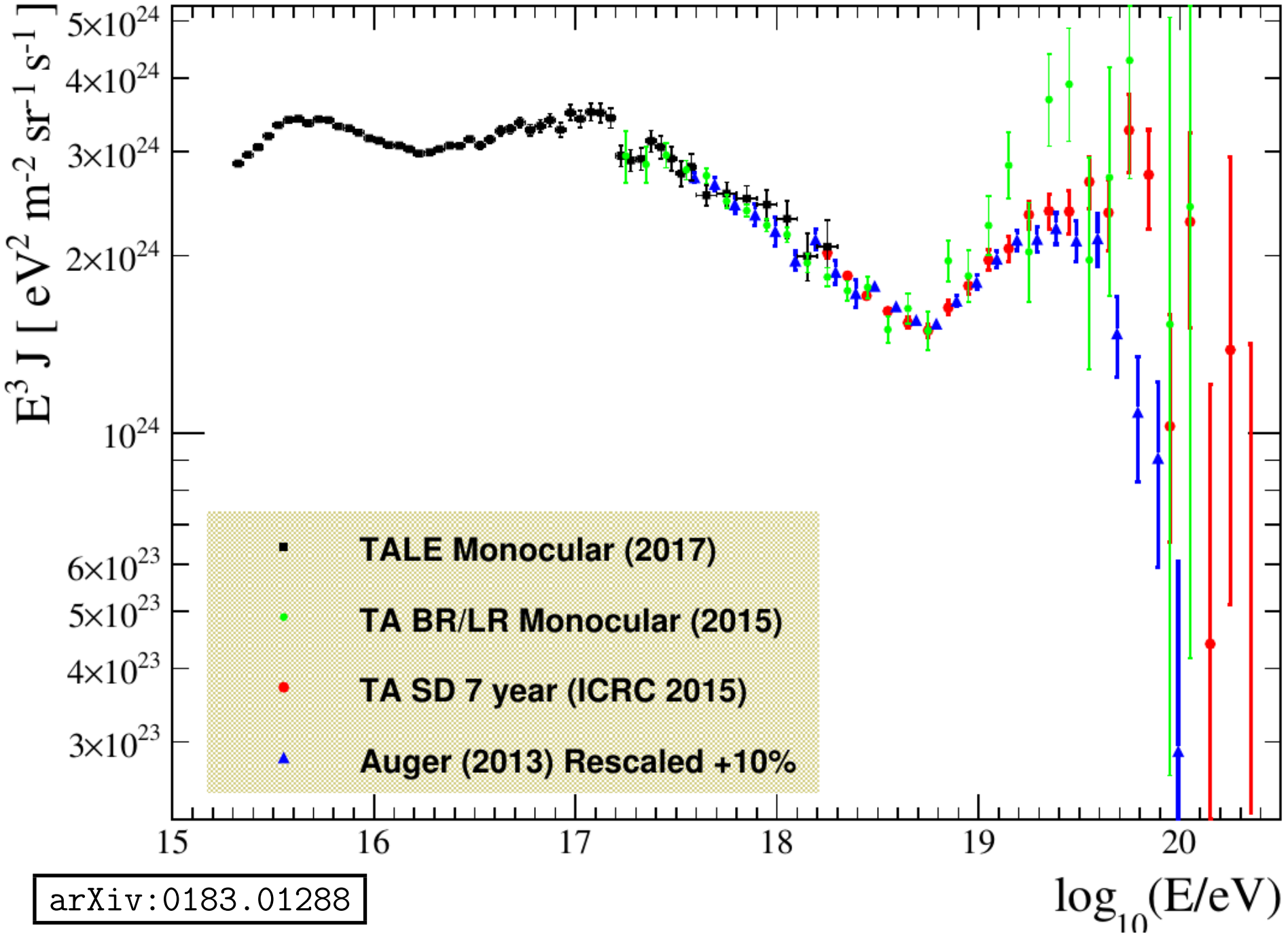
- Hybrid = FD + SD
- 10^{16}eV–$10^{18.5}$eV

< Energy Spectrum (TALE-FD: 2yrs) >



arXiv:0183.01288

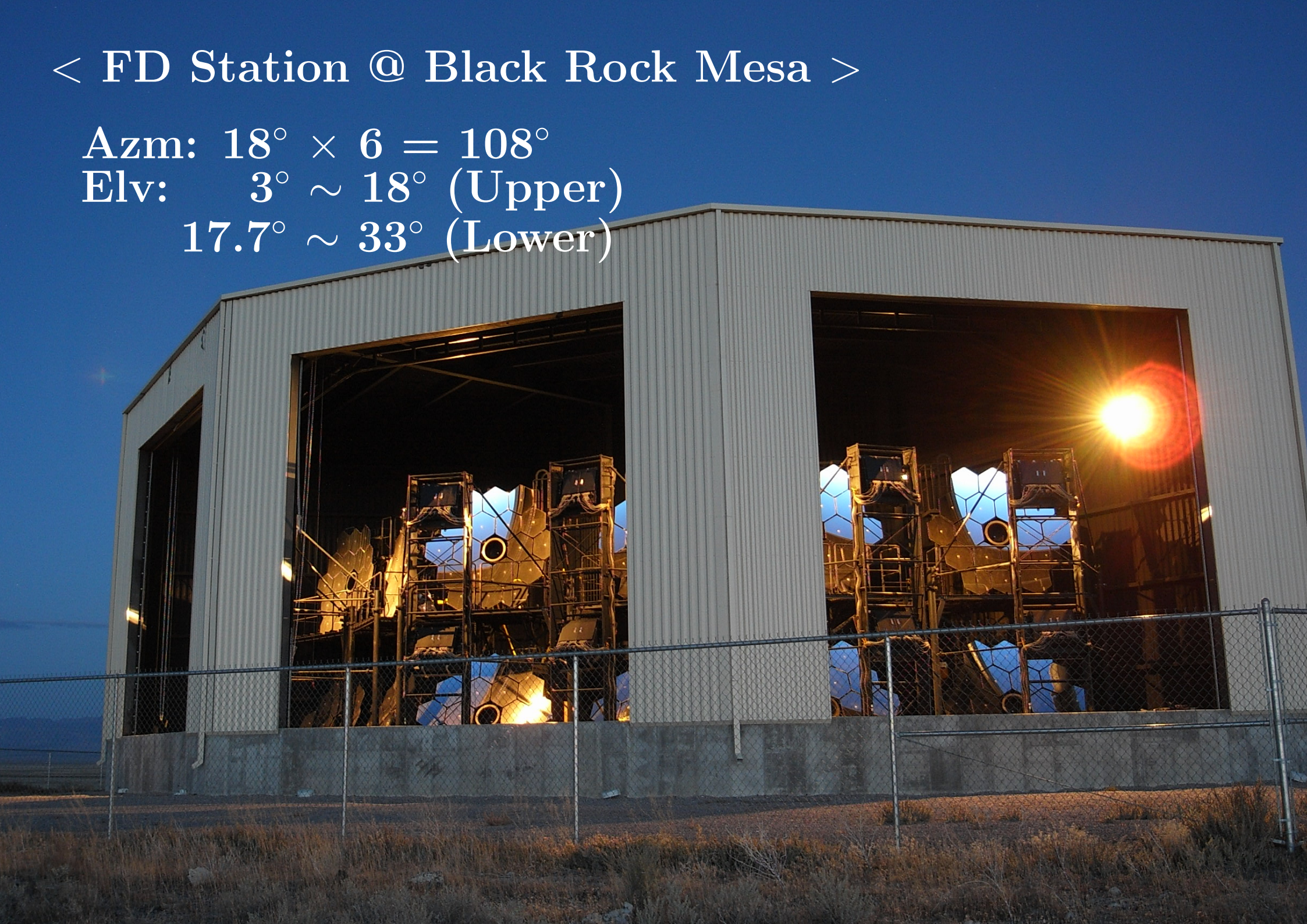
< Energy Spectrum (TA-SD, TA-FD, TALE-FD) >



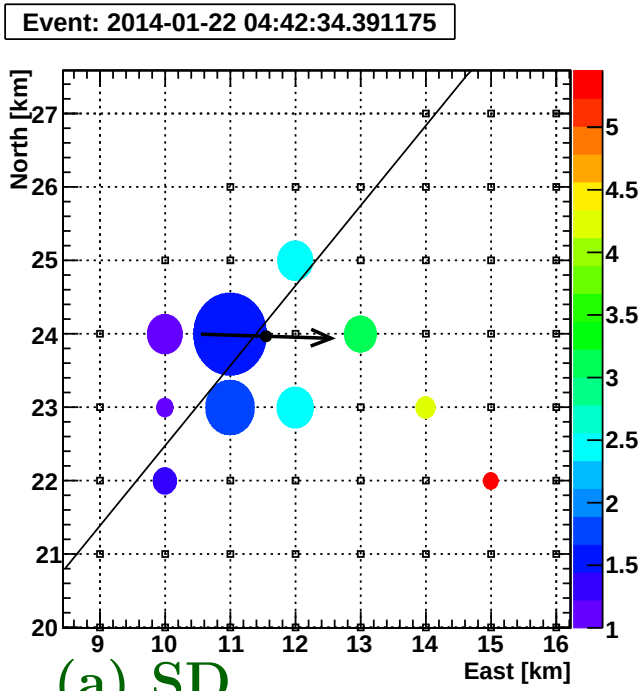
arXiv:0183.01288

< FD Station @ Black Rock Mesa >

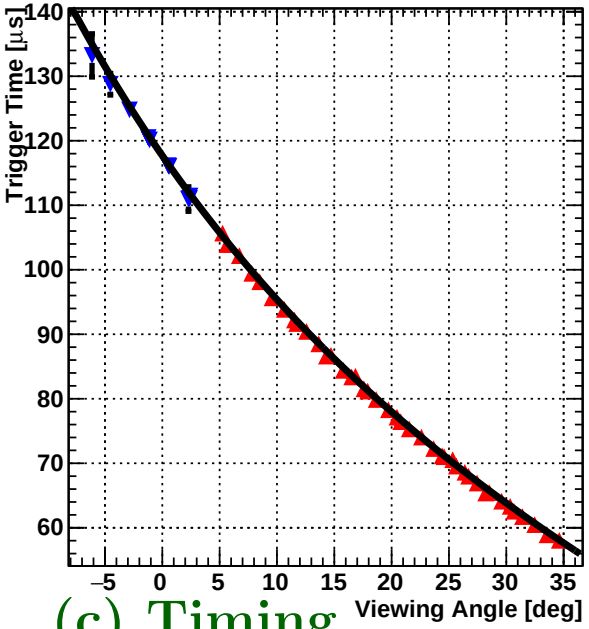
Azm: $18^\circ \times 6 = 108^\circ$
Elv: $3^\circ \sim 18^\circ$ (Upper)
$17.7^\circ \sim 33^\circ$ (Lower)



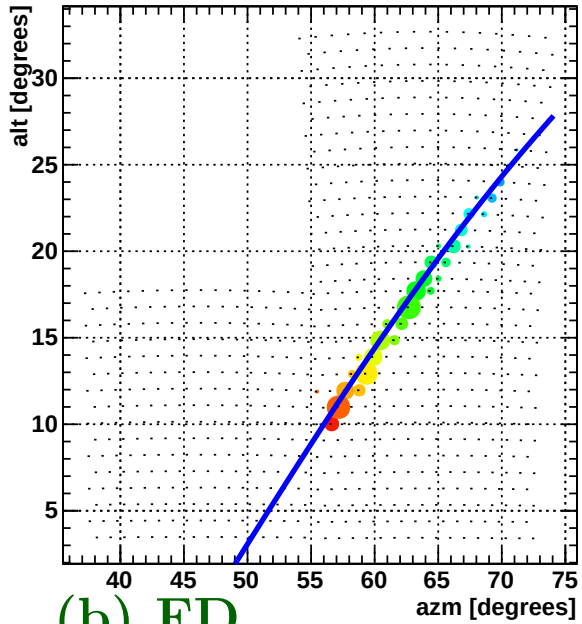
< FD (hybrid) Event Example >



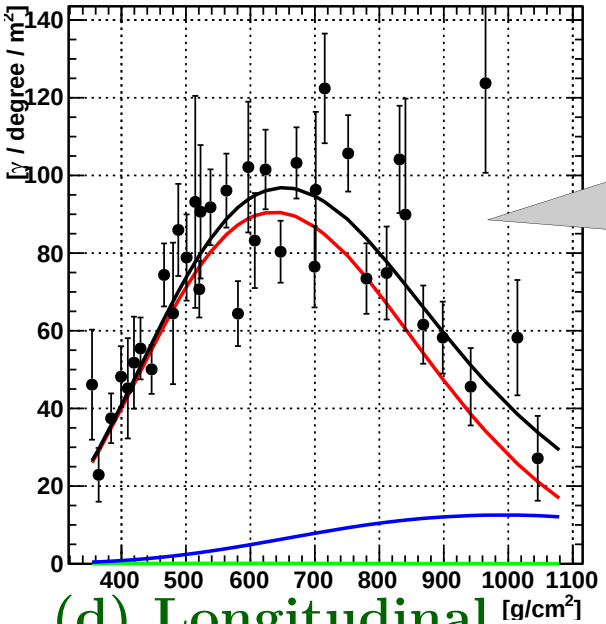
(a) SD



(c) Timing



(b) FD

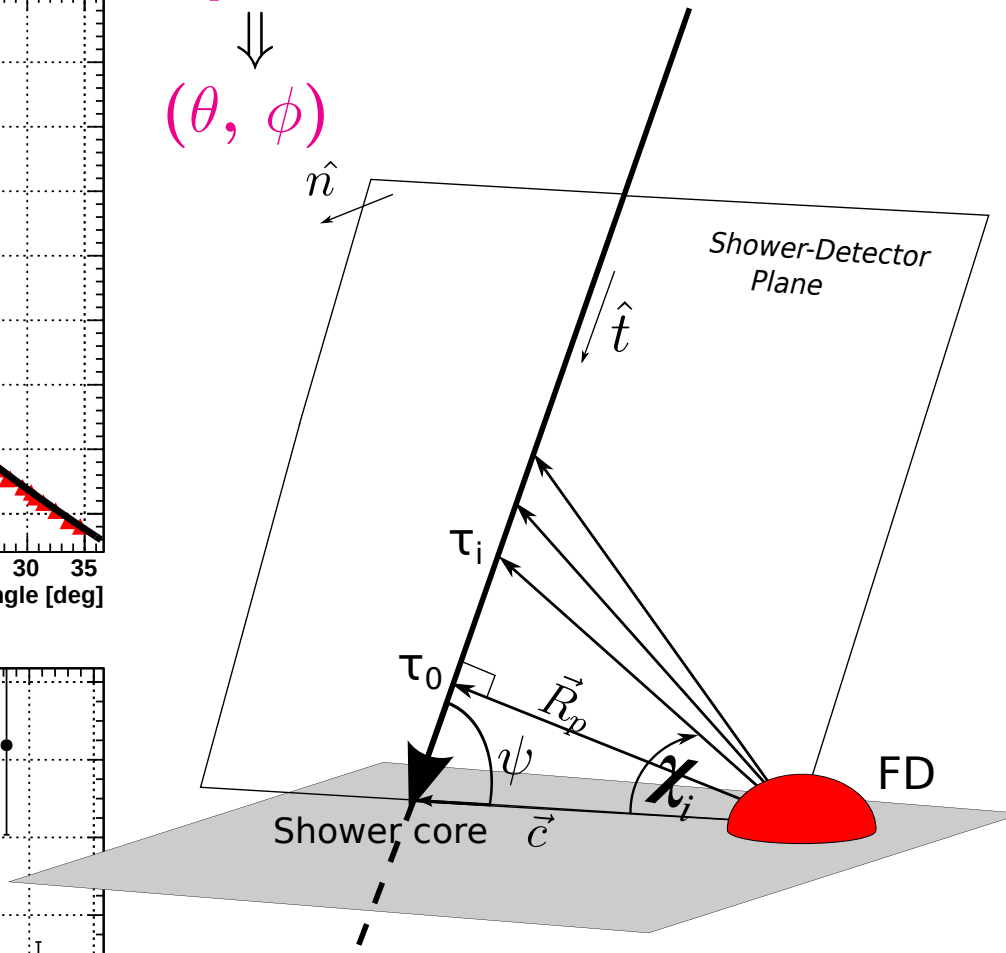


(d) Longitudinal

$(\mathbf{R}_p, \psi)$

$\Downarrow$

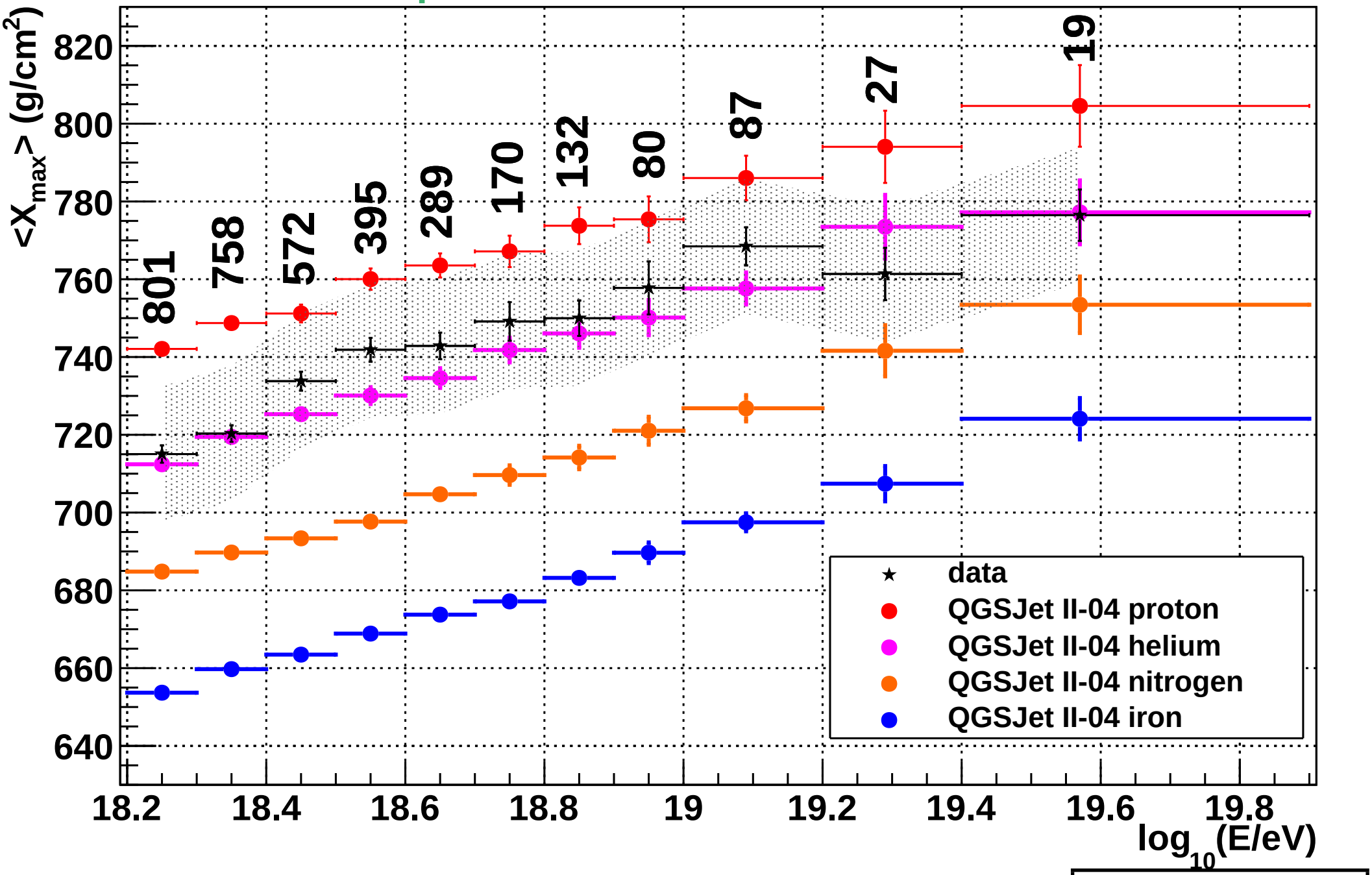
(θ, ϕ)



(E, Xmax)

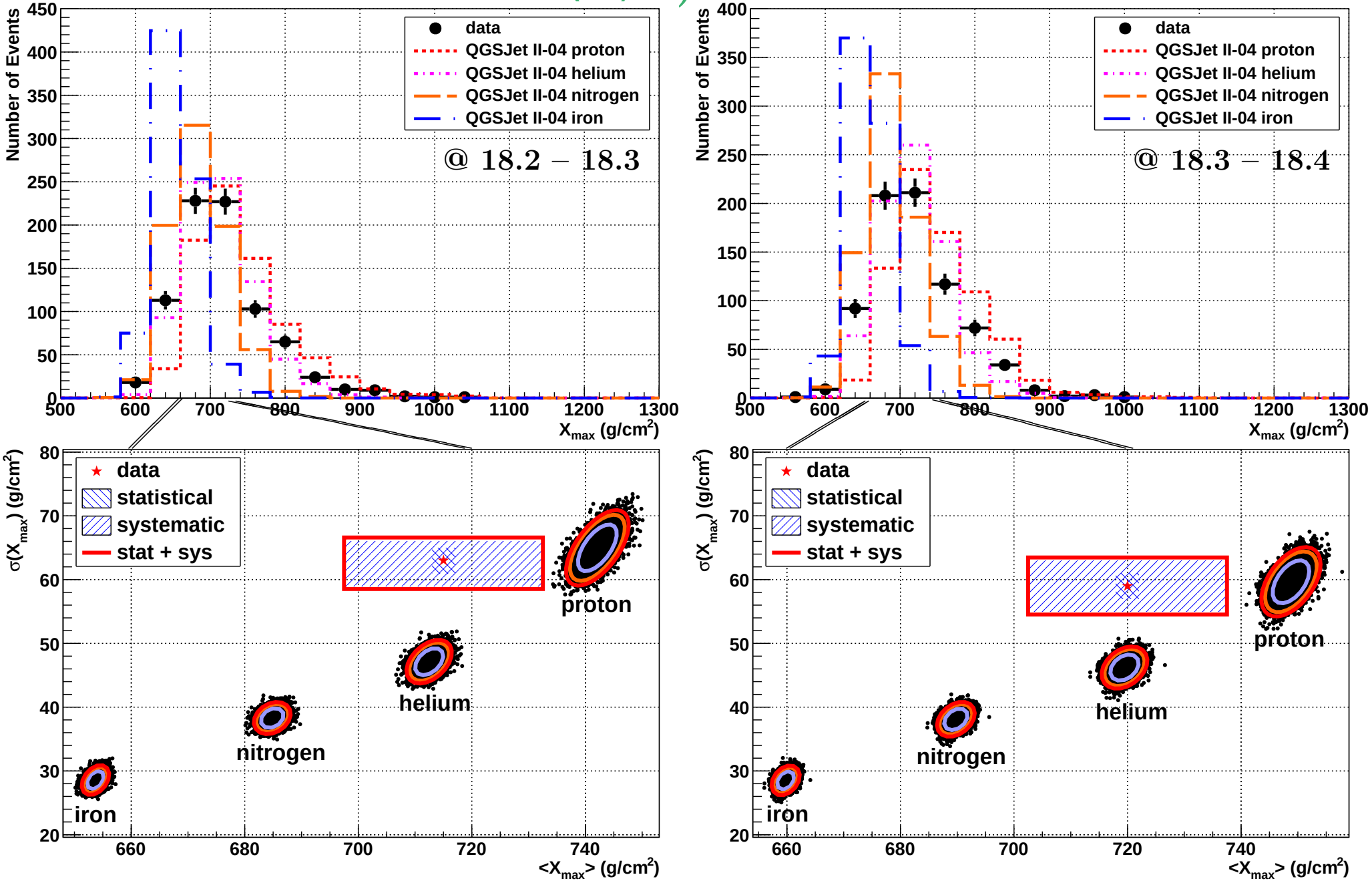
ApJ 858(2018)76

< Mean Xmax -plot >



ApJ 858(2018)76

< Xmax distribution (1/6) >



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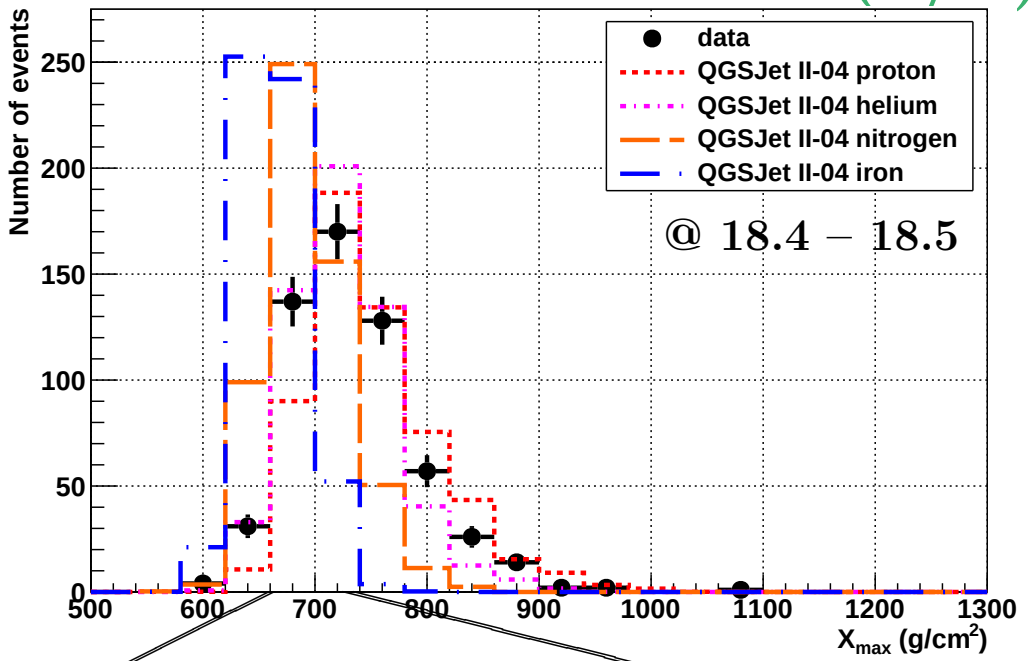
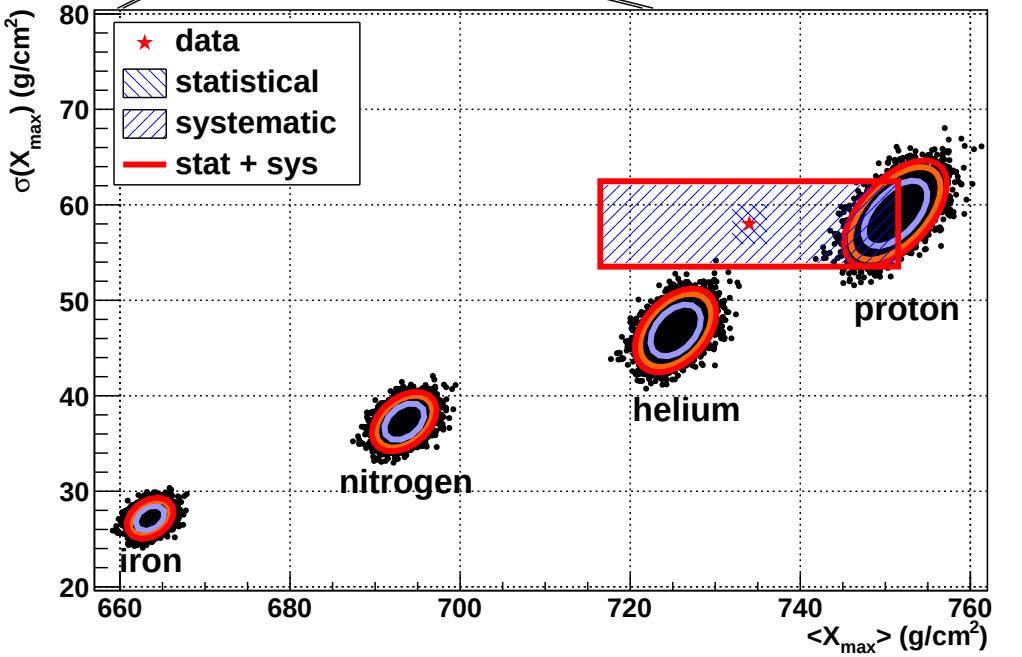
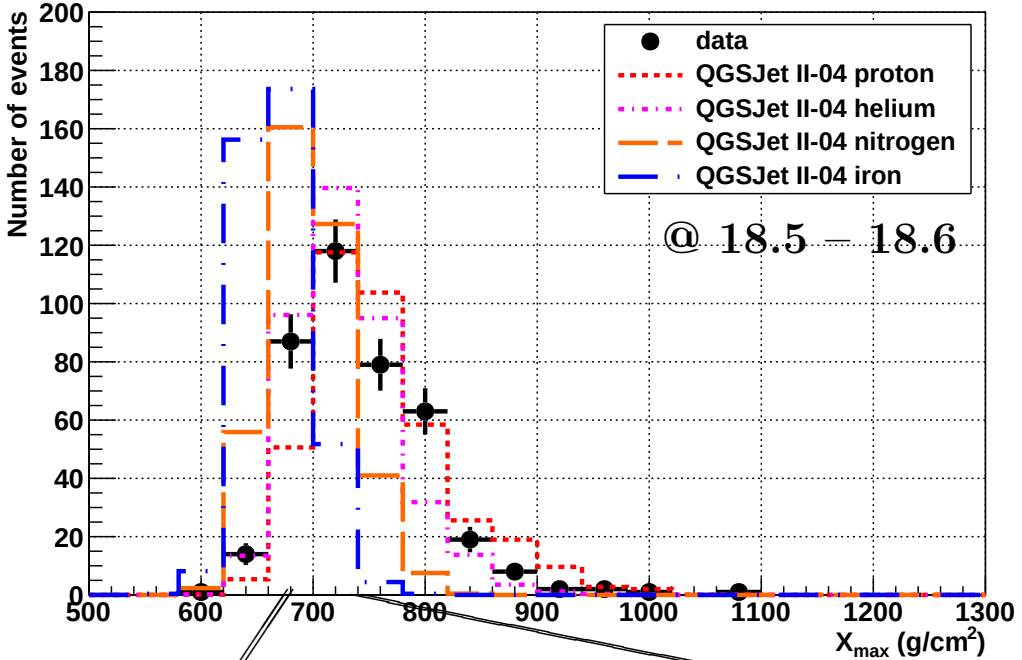
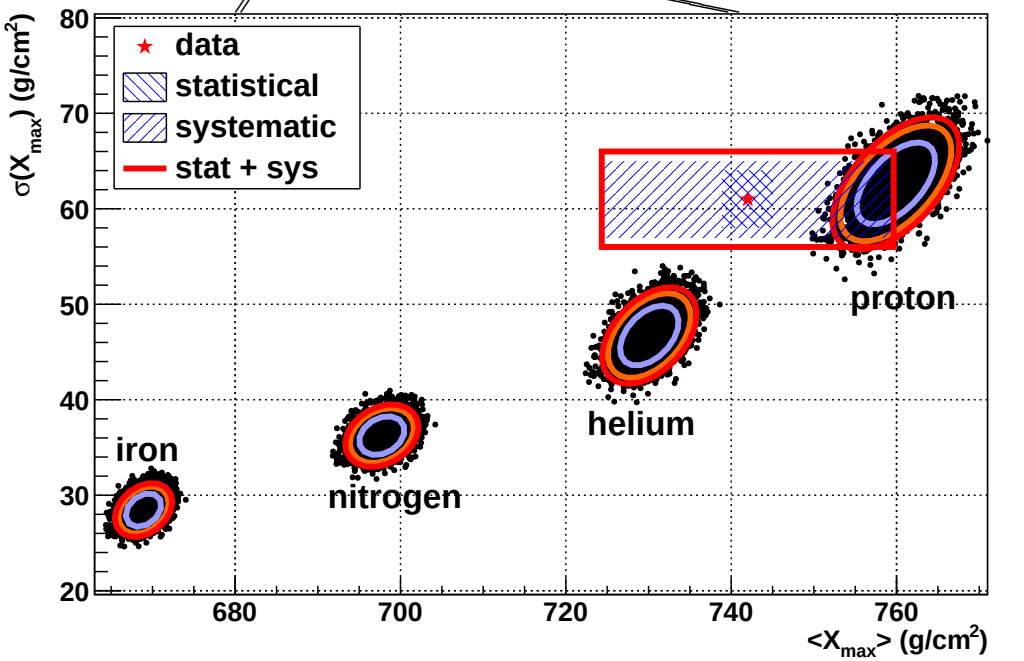
< Xmax distribution (2/6) >









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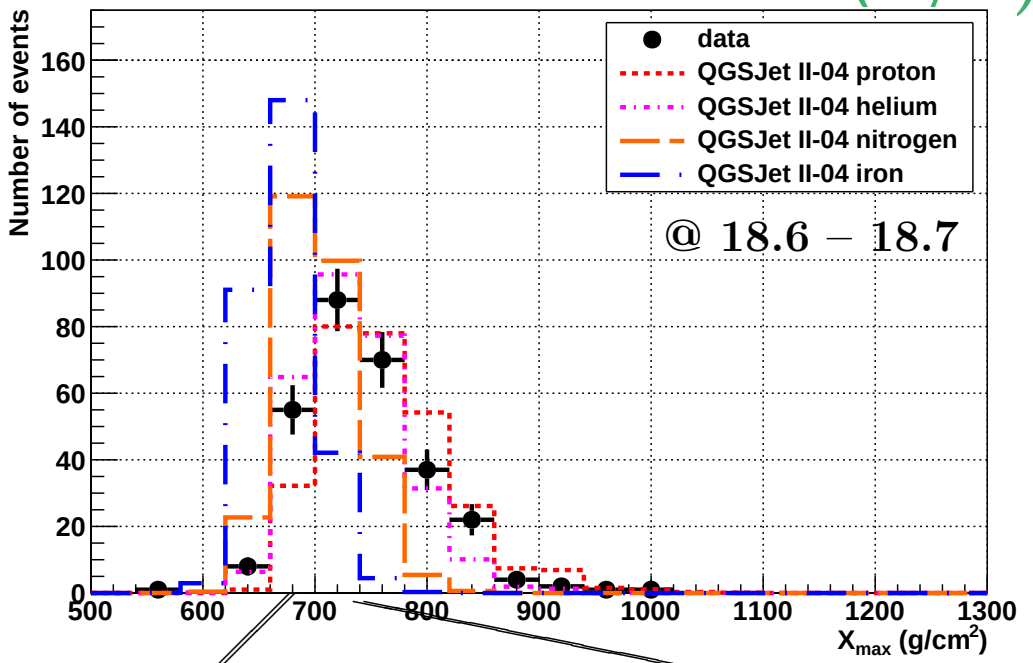

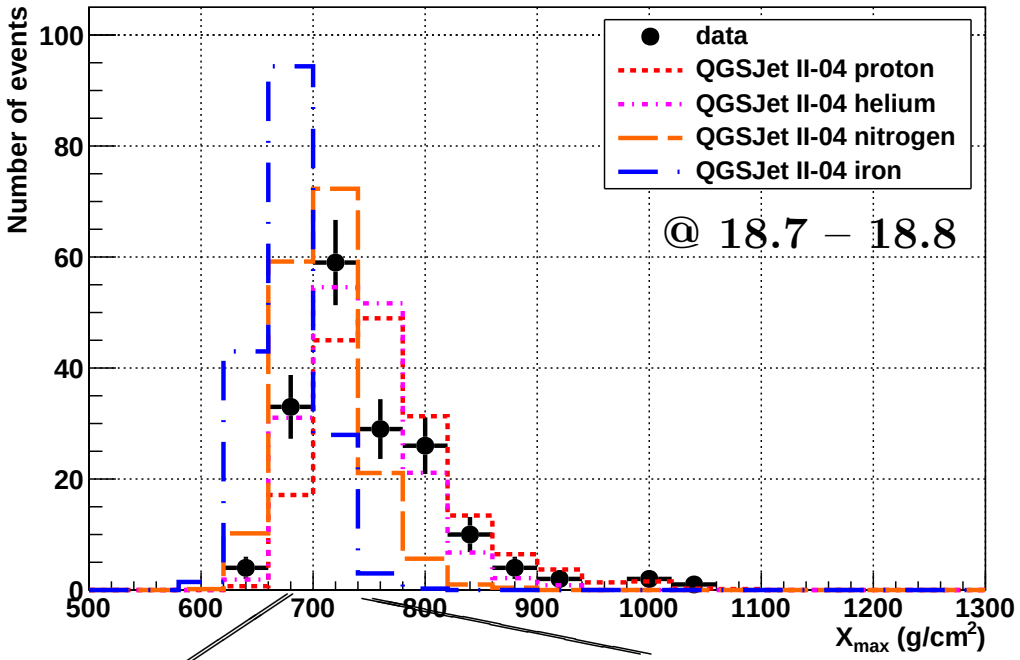

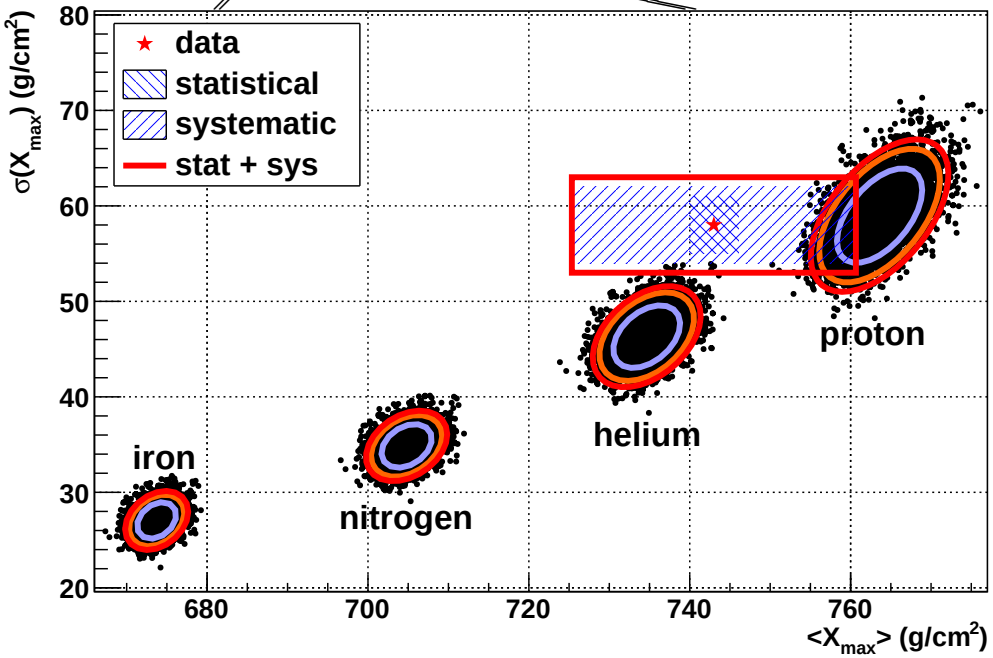

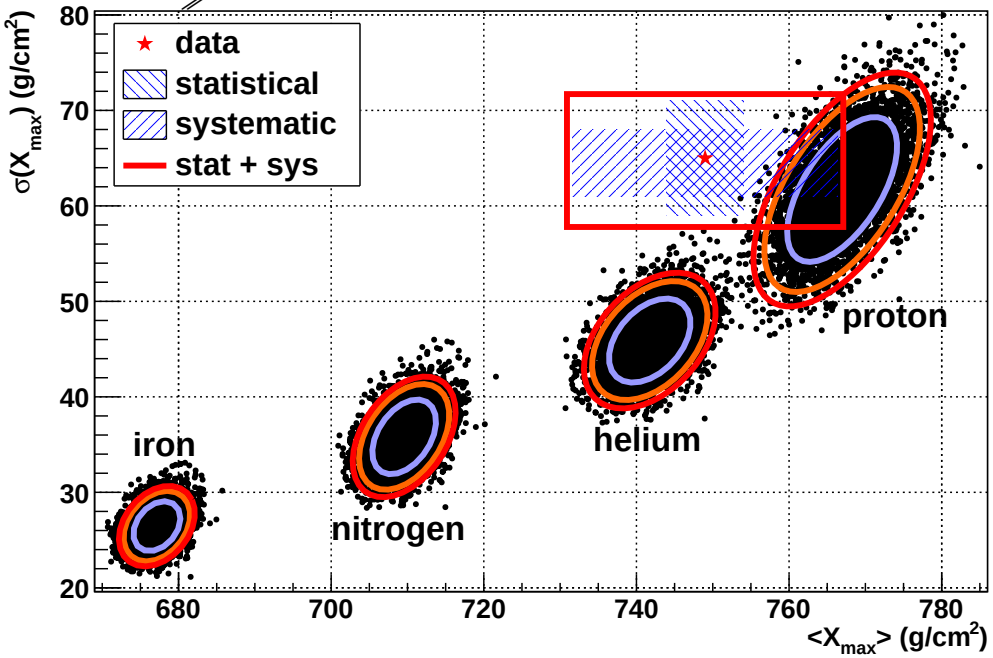

ApJ 858(2018)76

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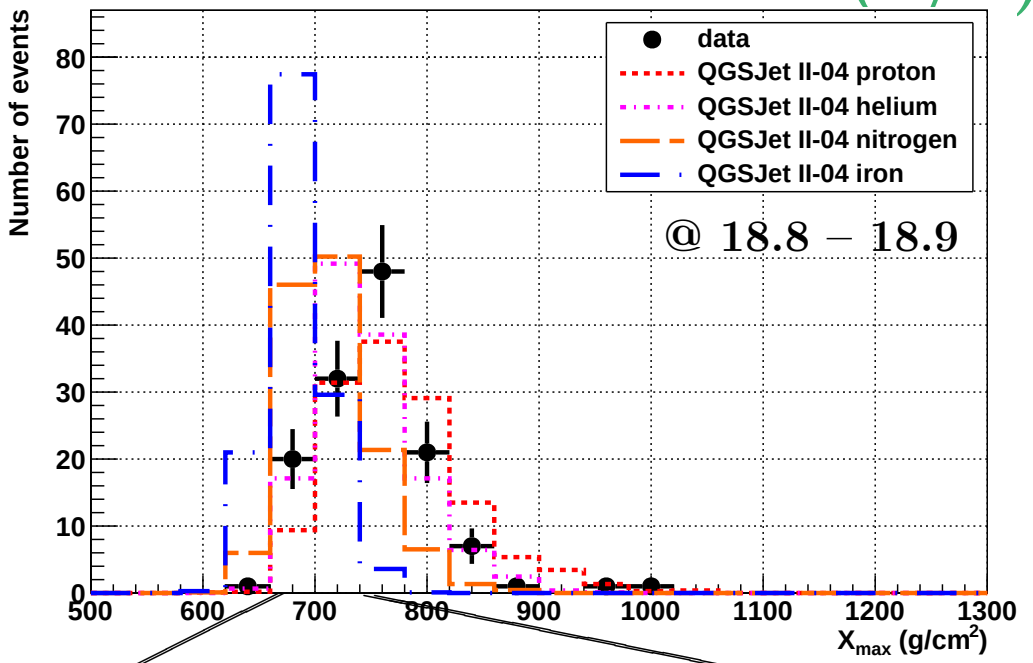

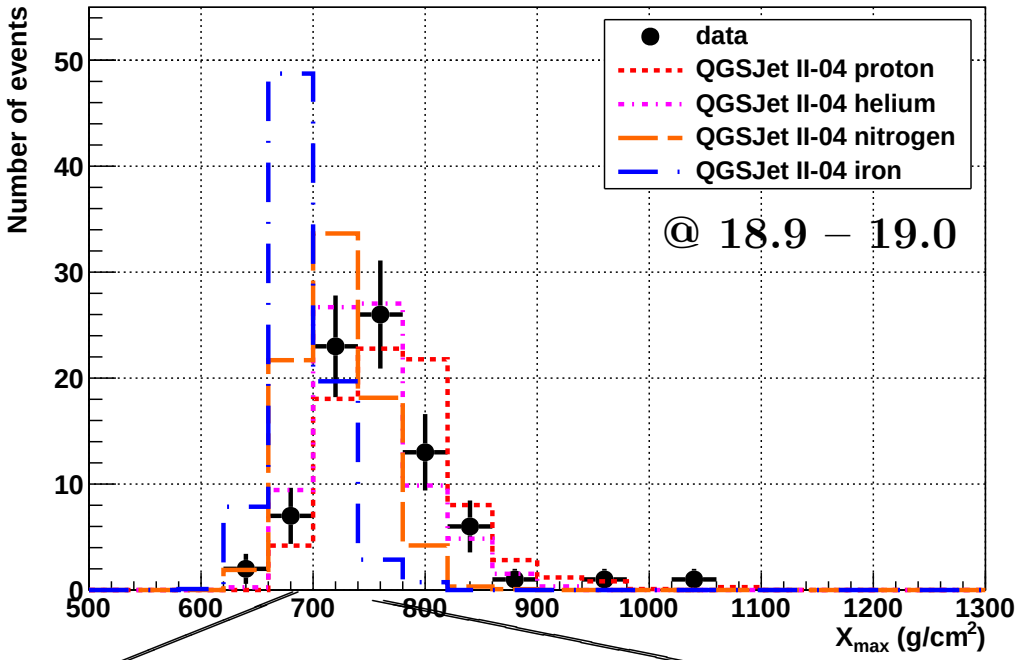

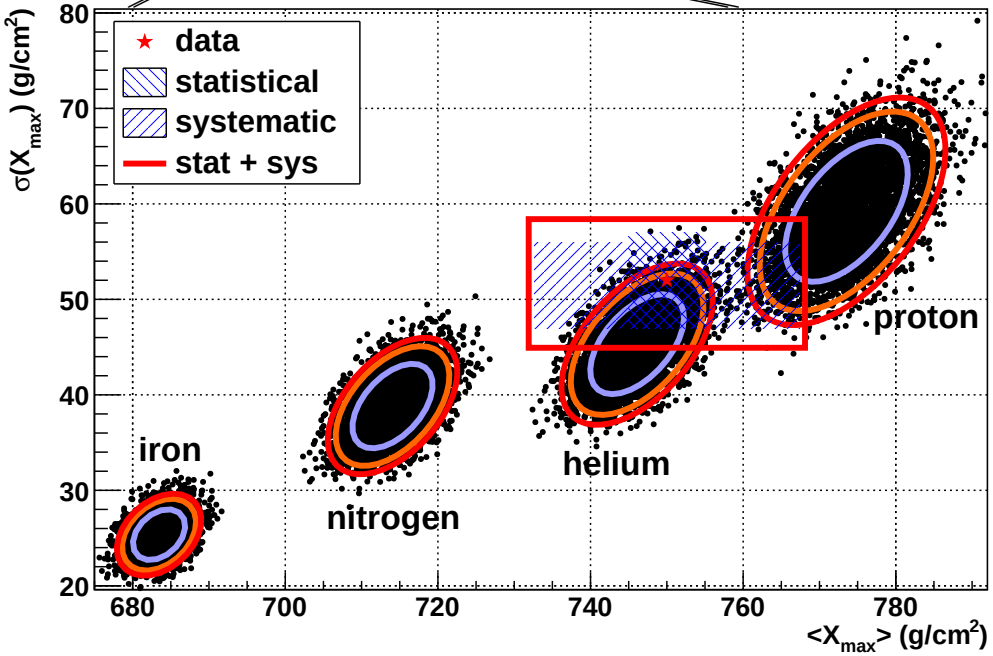

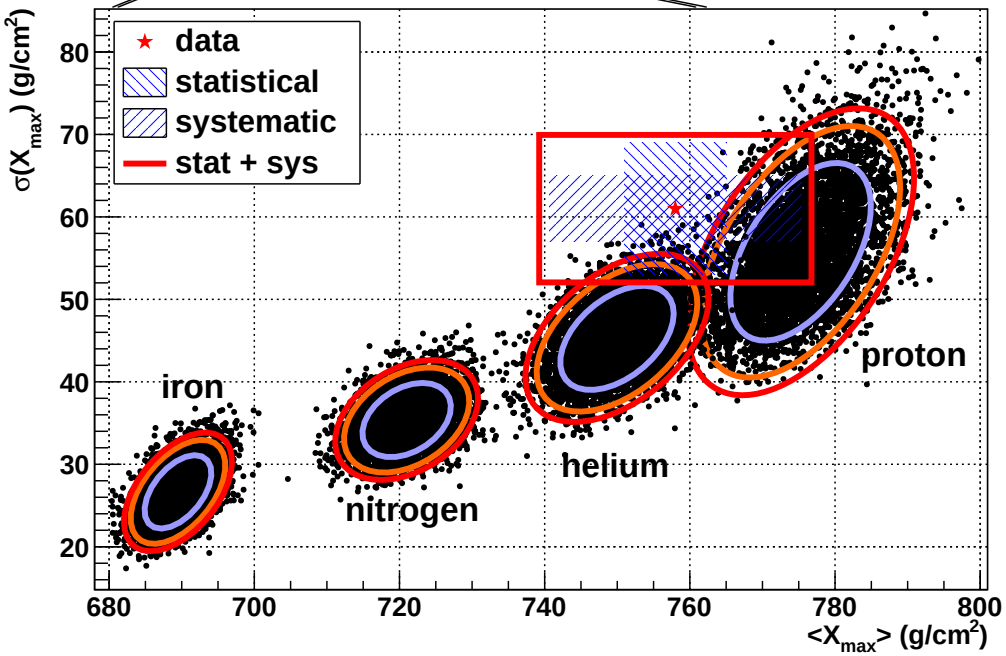

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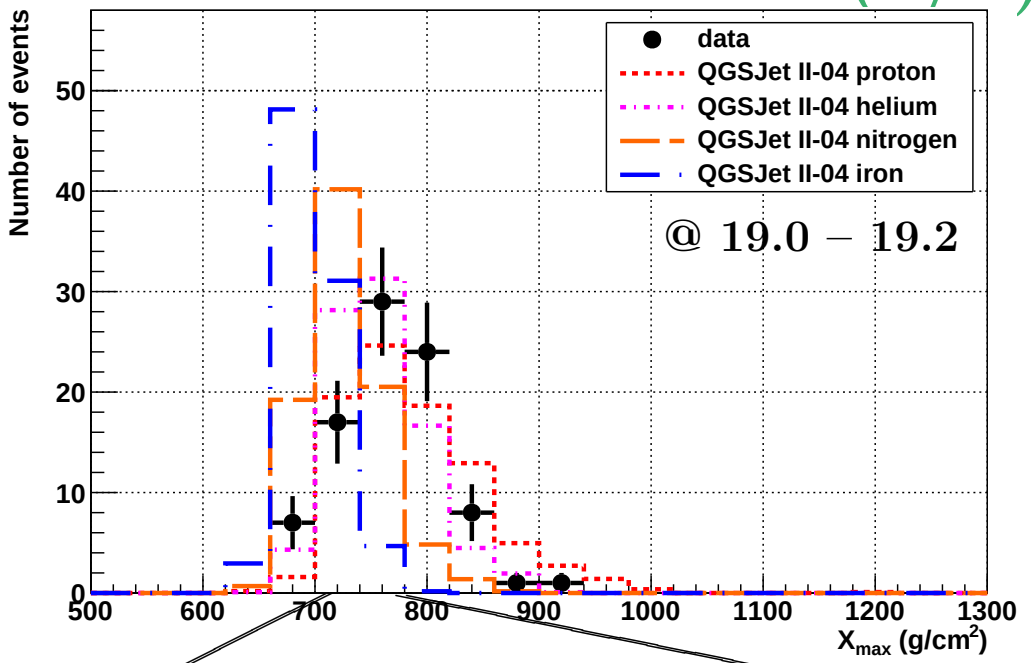
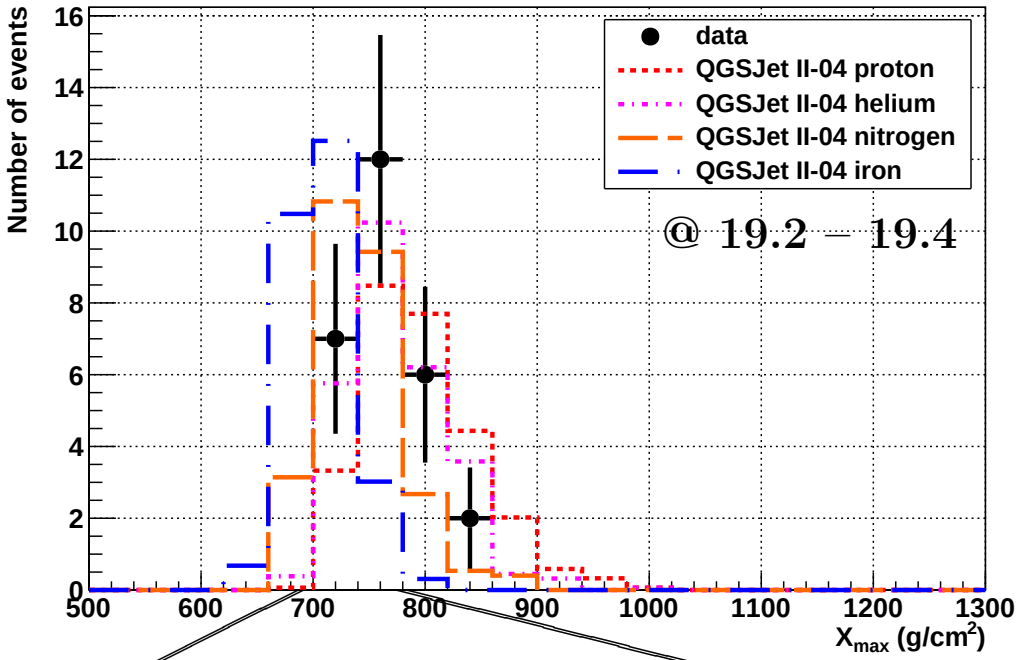
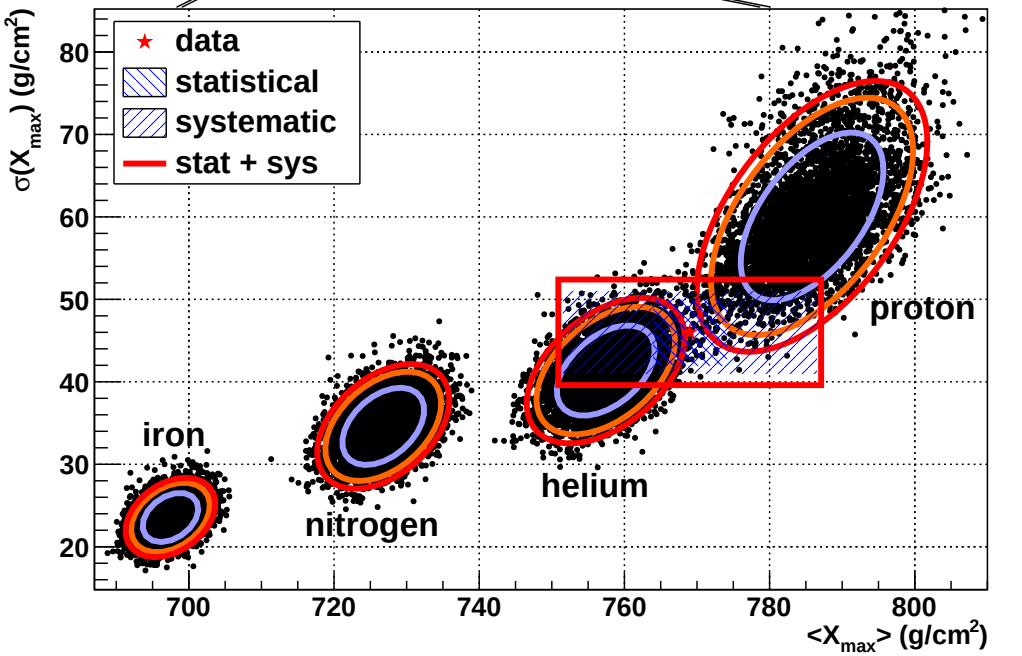
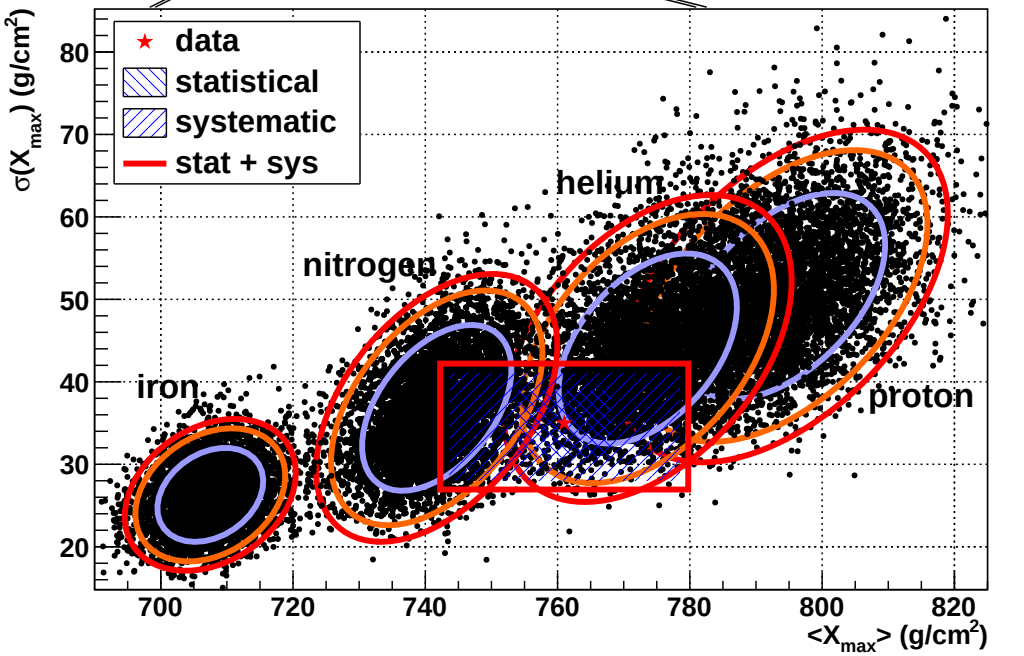


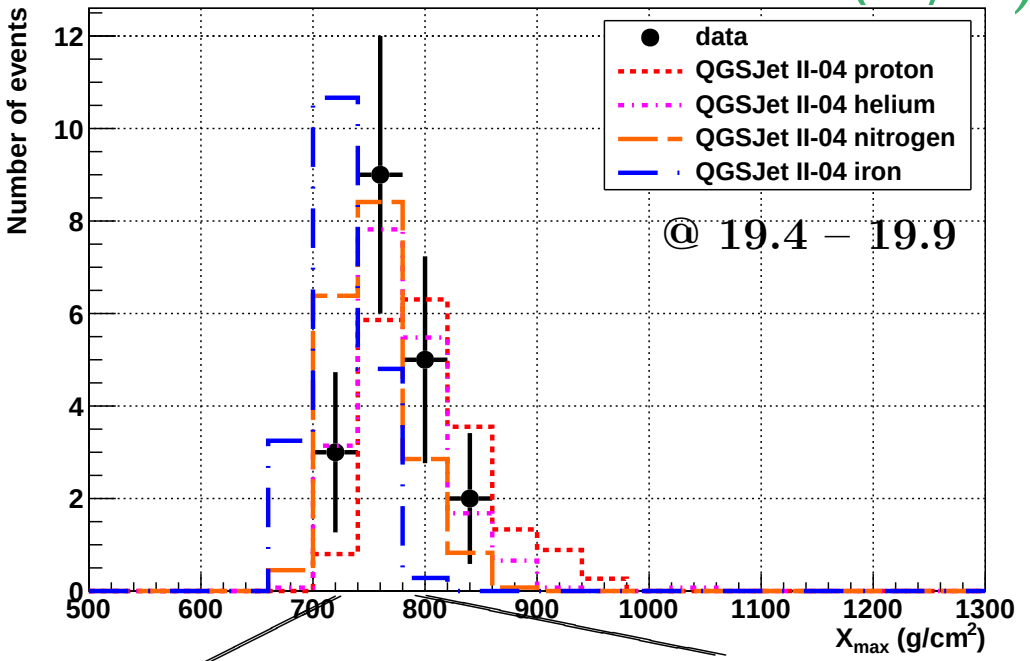


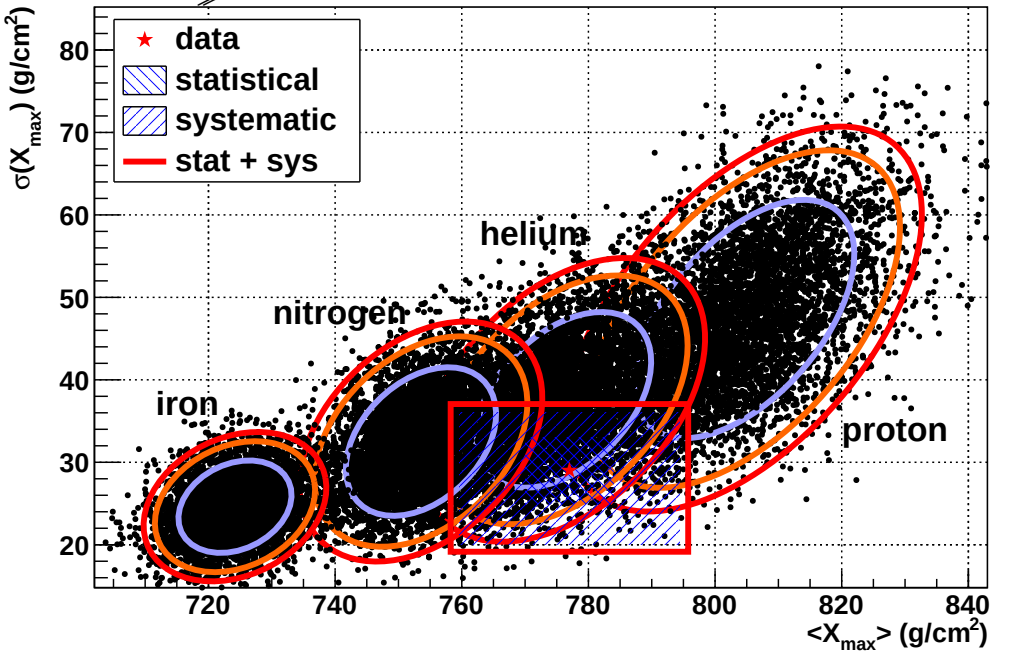




ApJ 858(2018)76

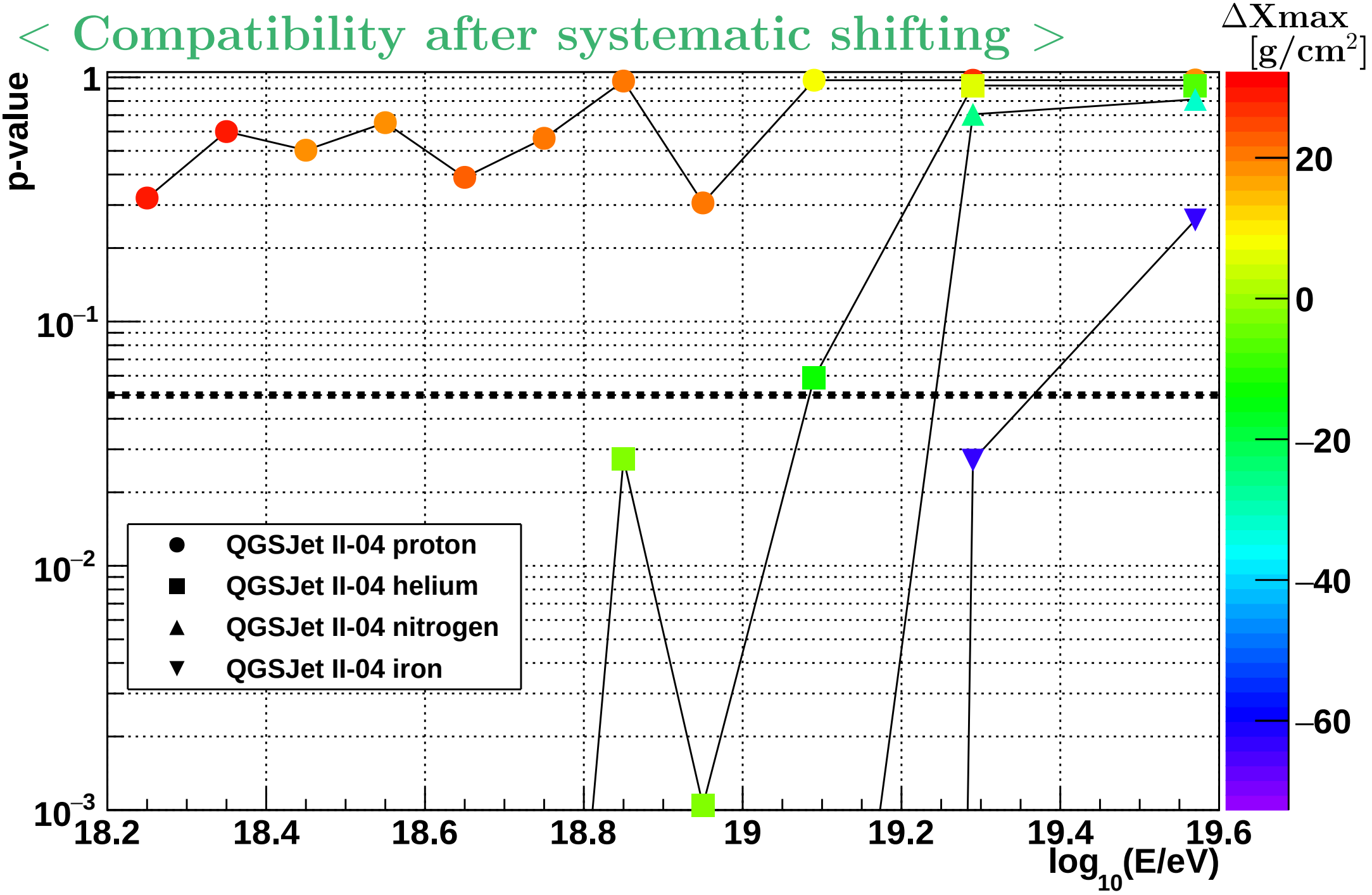
< Xmax distribution (6/6) >





ApJ 858(2018)76

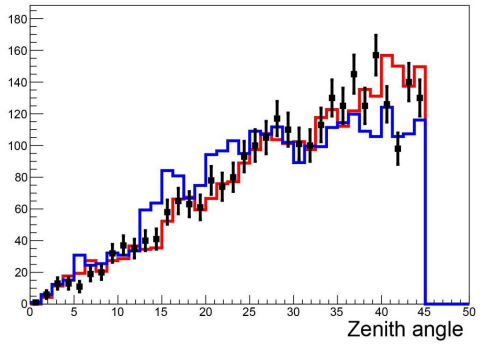
< Compatibility after systematic shifting >

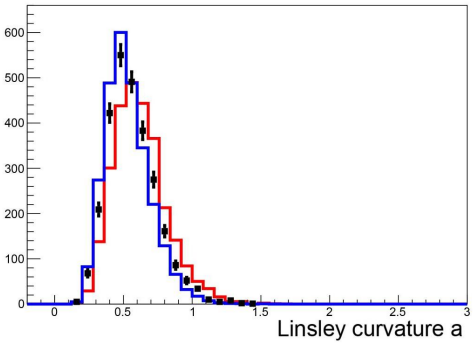


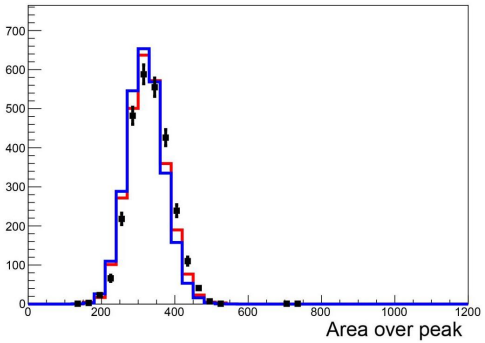
ApJ 858(2018)76

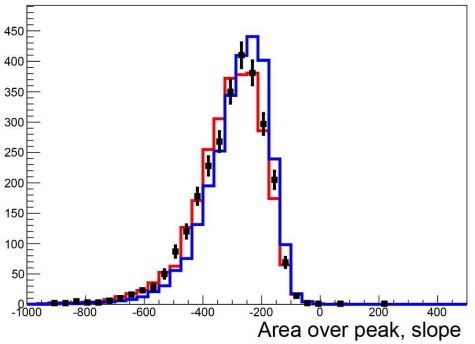
< SD Composition (BDT parameters) >

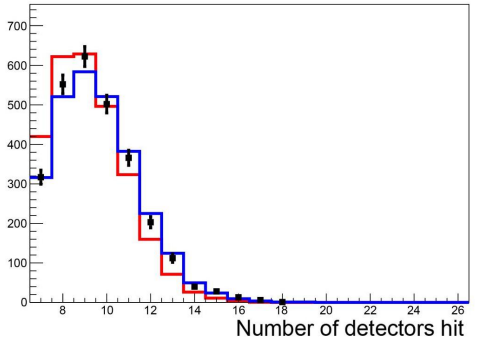
$\mathbf{E = 10^{18.8-19.0}eV}$

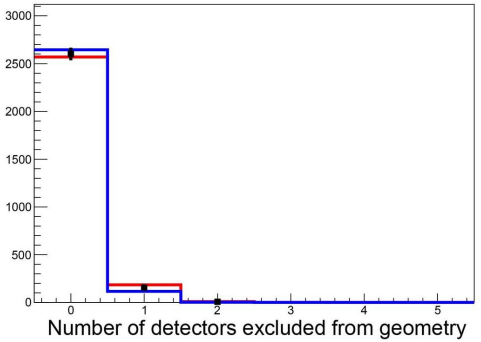


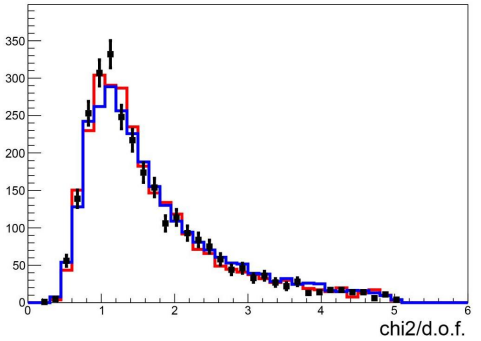


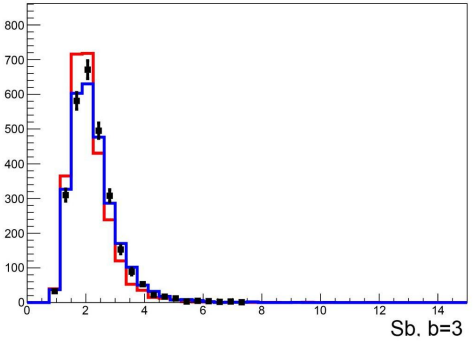


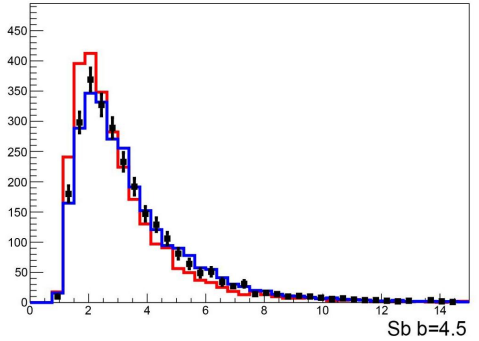


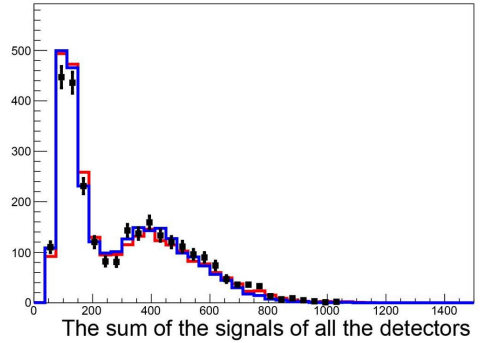


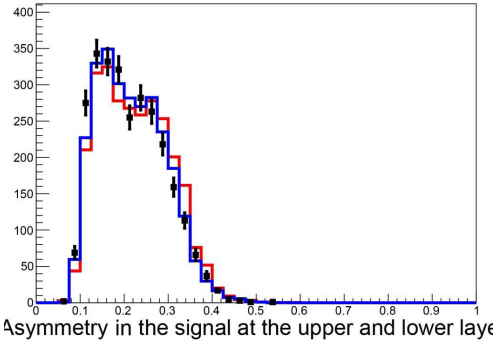


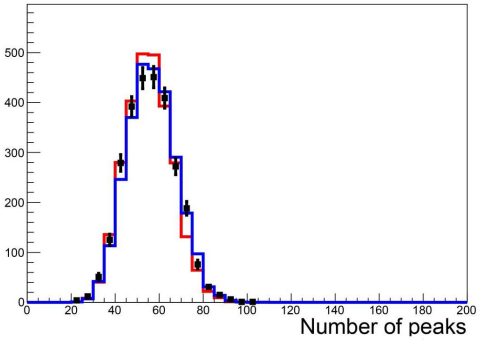


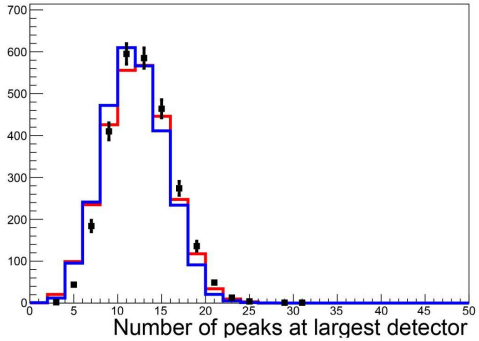


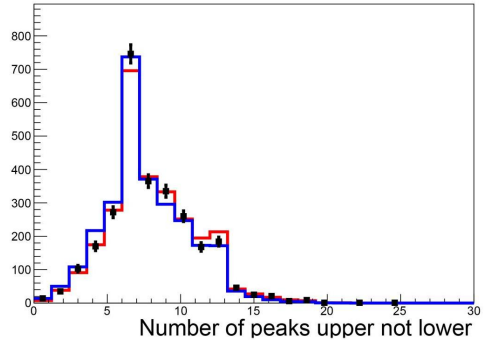


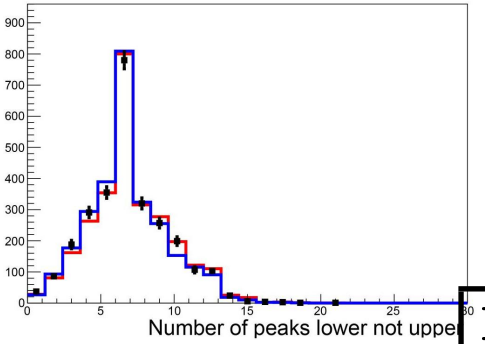












– **proton**

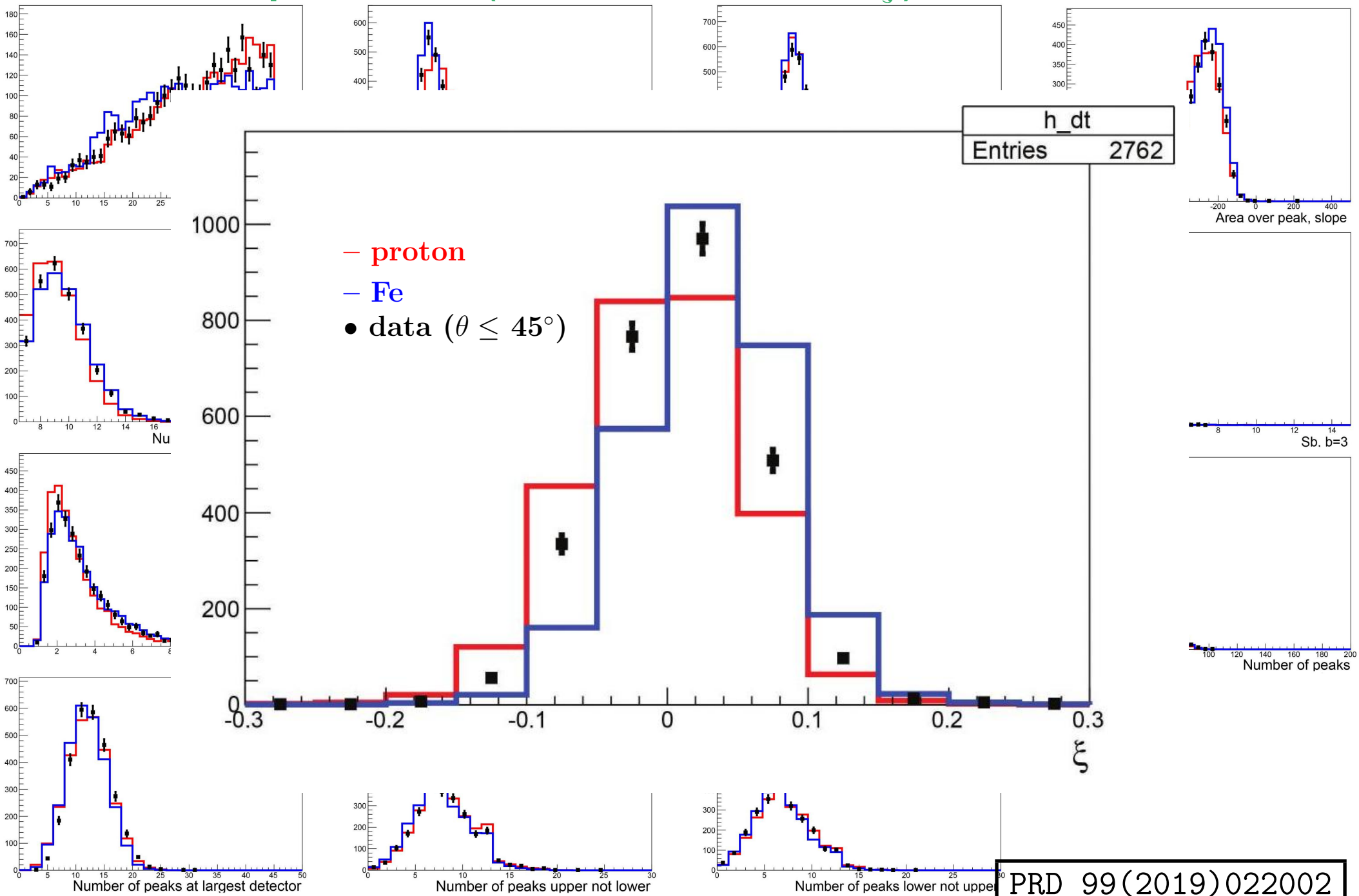
– **Fe**

• **data** ($\theta \leq 45°$)

PRD 99(2019)022002

< SD Composition (BDT classifier ξ) >

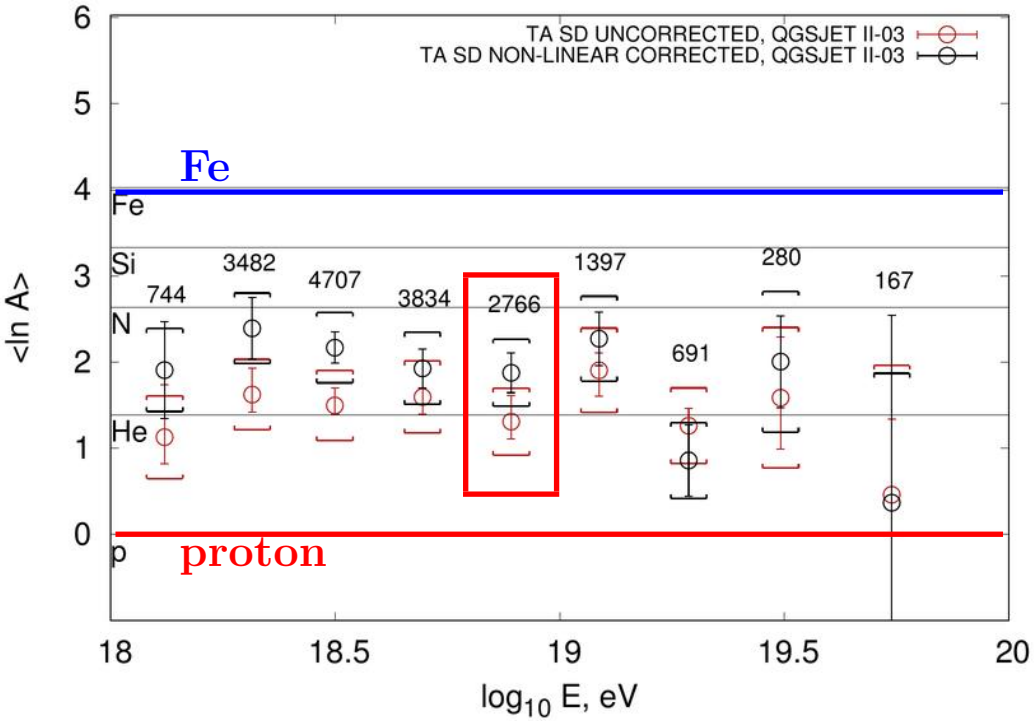
$\mathbf{E = 10^{18.8-19.0} eV}$



PRD 99(2019)022002

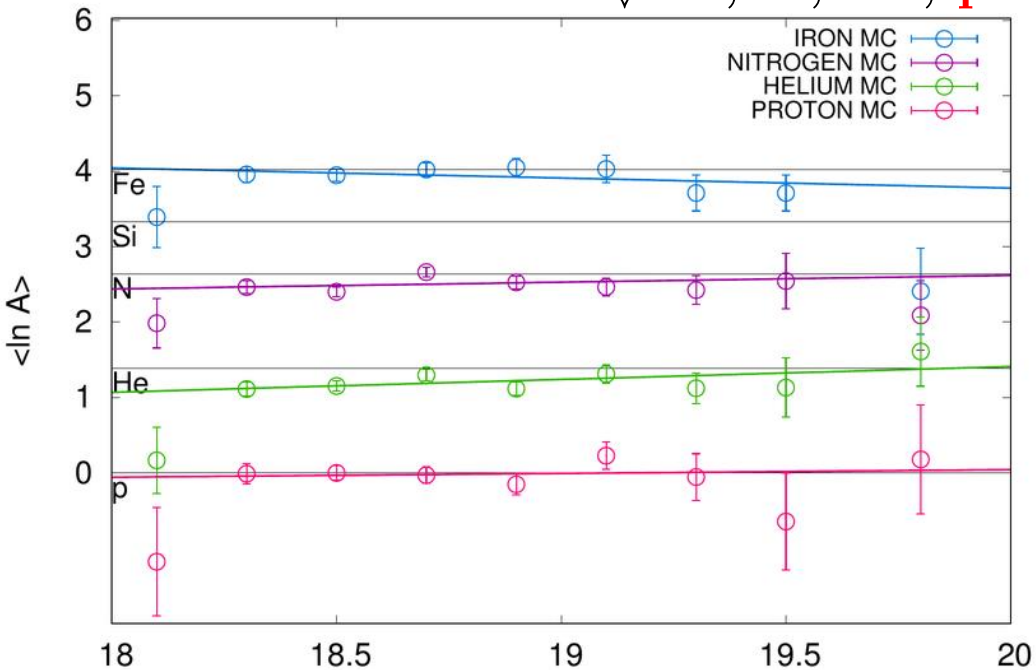
< SD Composition (BDT) >

- $< \ln A >= 2.0 \pm 0.1(\text{stat.}) \pm 0.44(\text{syst.})$
- No significant energy dependence
- Heavier than proton

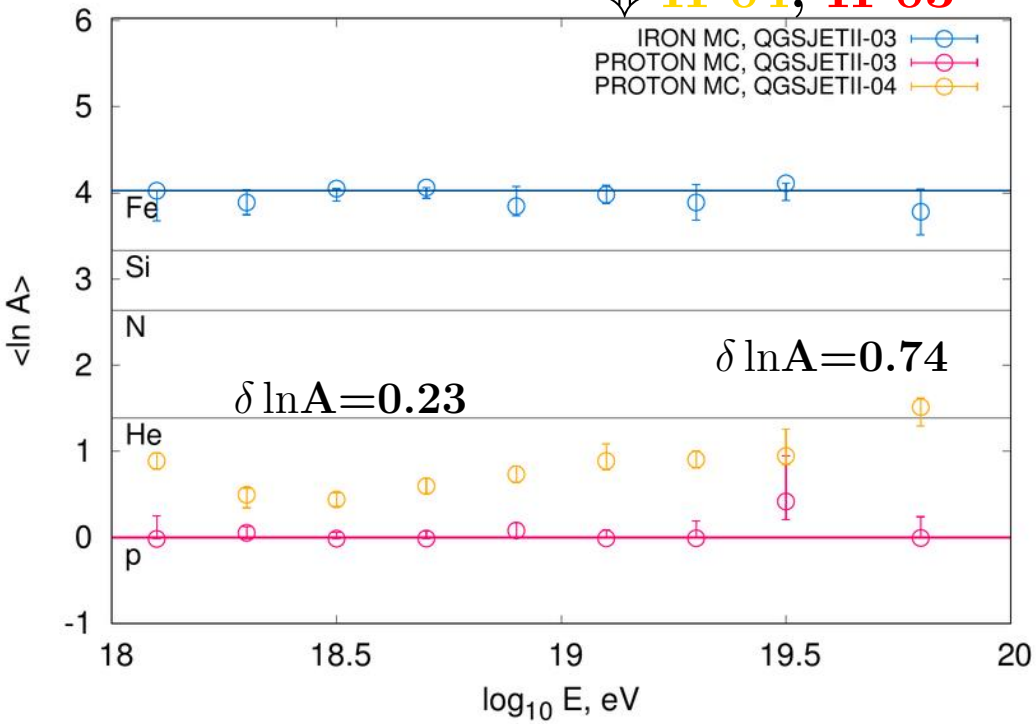


⇑ bias correction

⇓ Fe, N, He, p



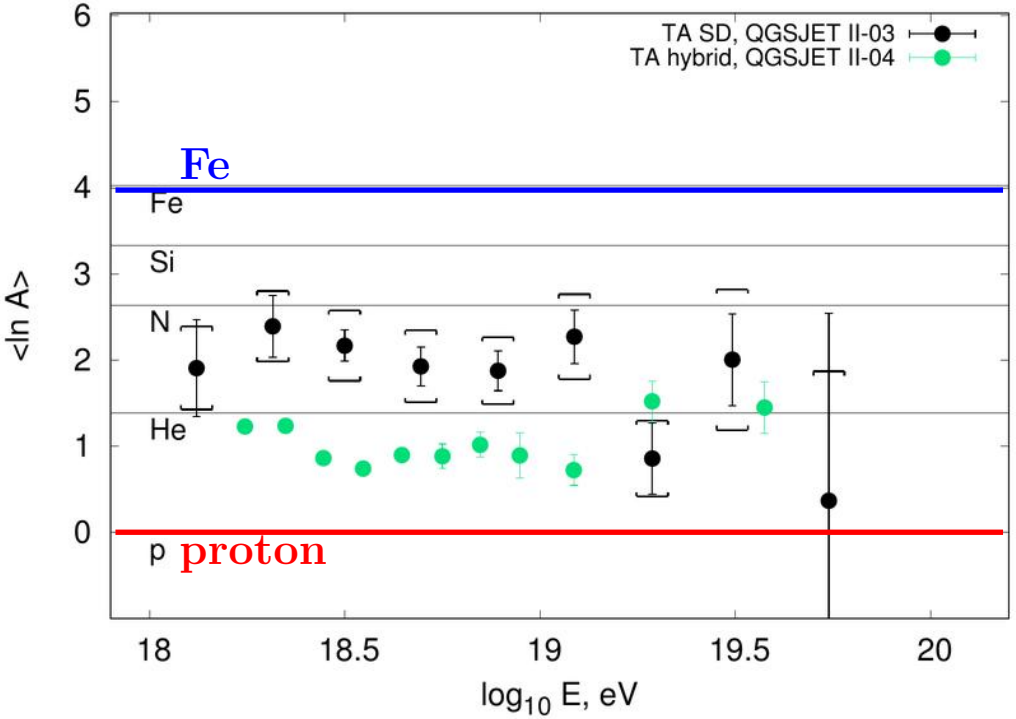
⇓ II-04, II-03



PRD 99(2019)022002

< SD Composition (BDT) >

- $< \ln A >= 2.0 \pm 0.1(\text{stat.}) \pm 0.44(\text{syst.})$
- No significant energy dependence
- Heavier than proton

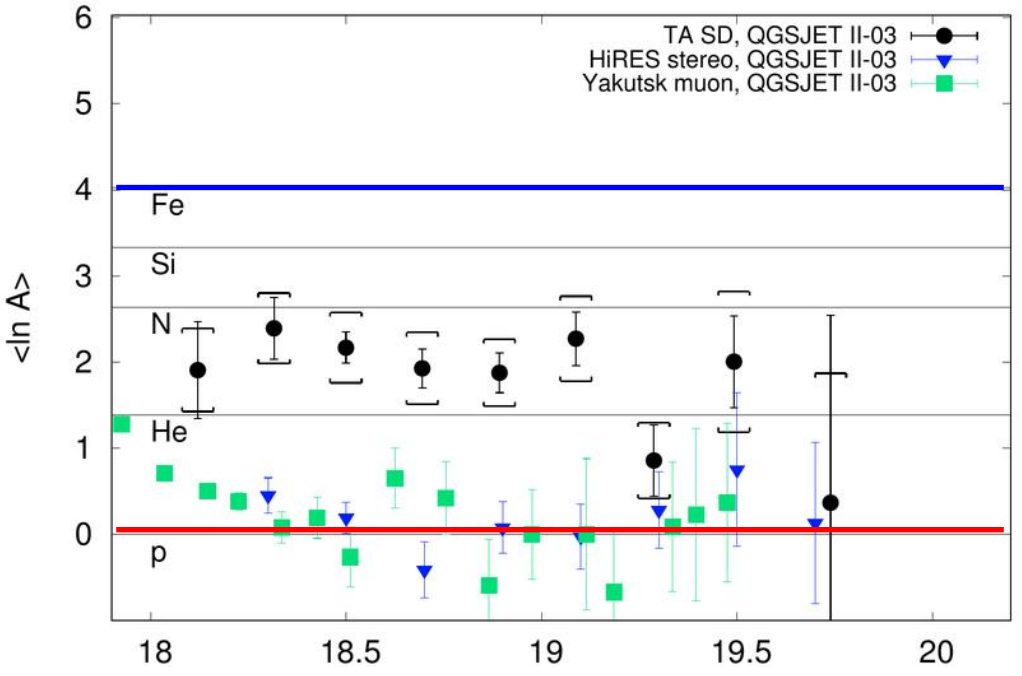


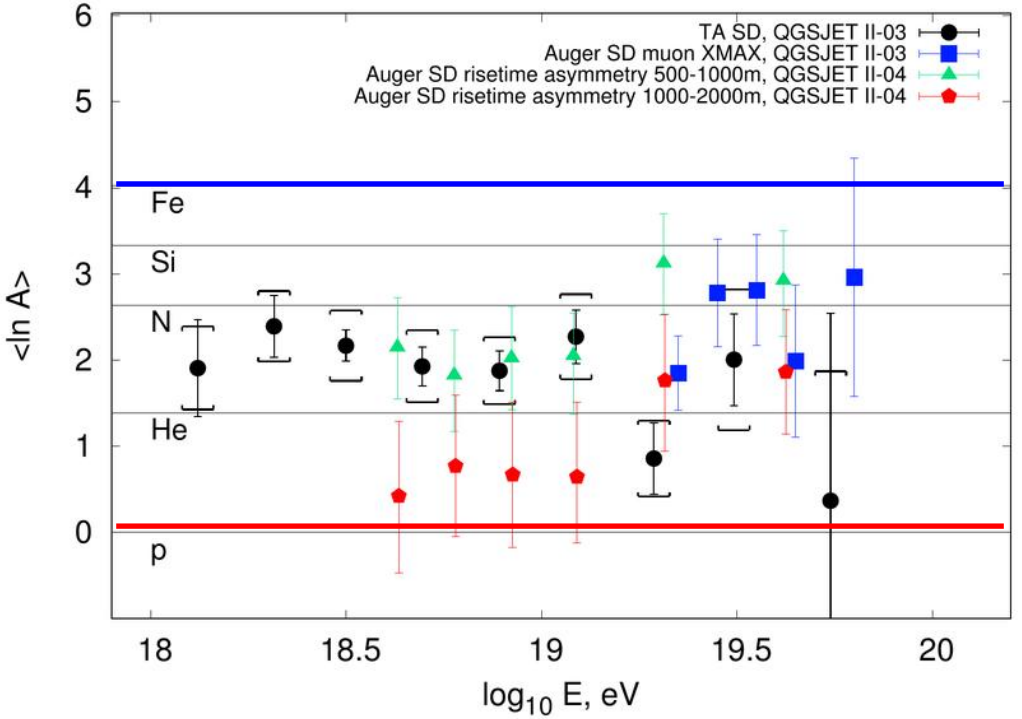
↑ TA hybrid

↗ HiRes(stereo)

Yakutsk μ

→ Auger SD

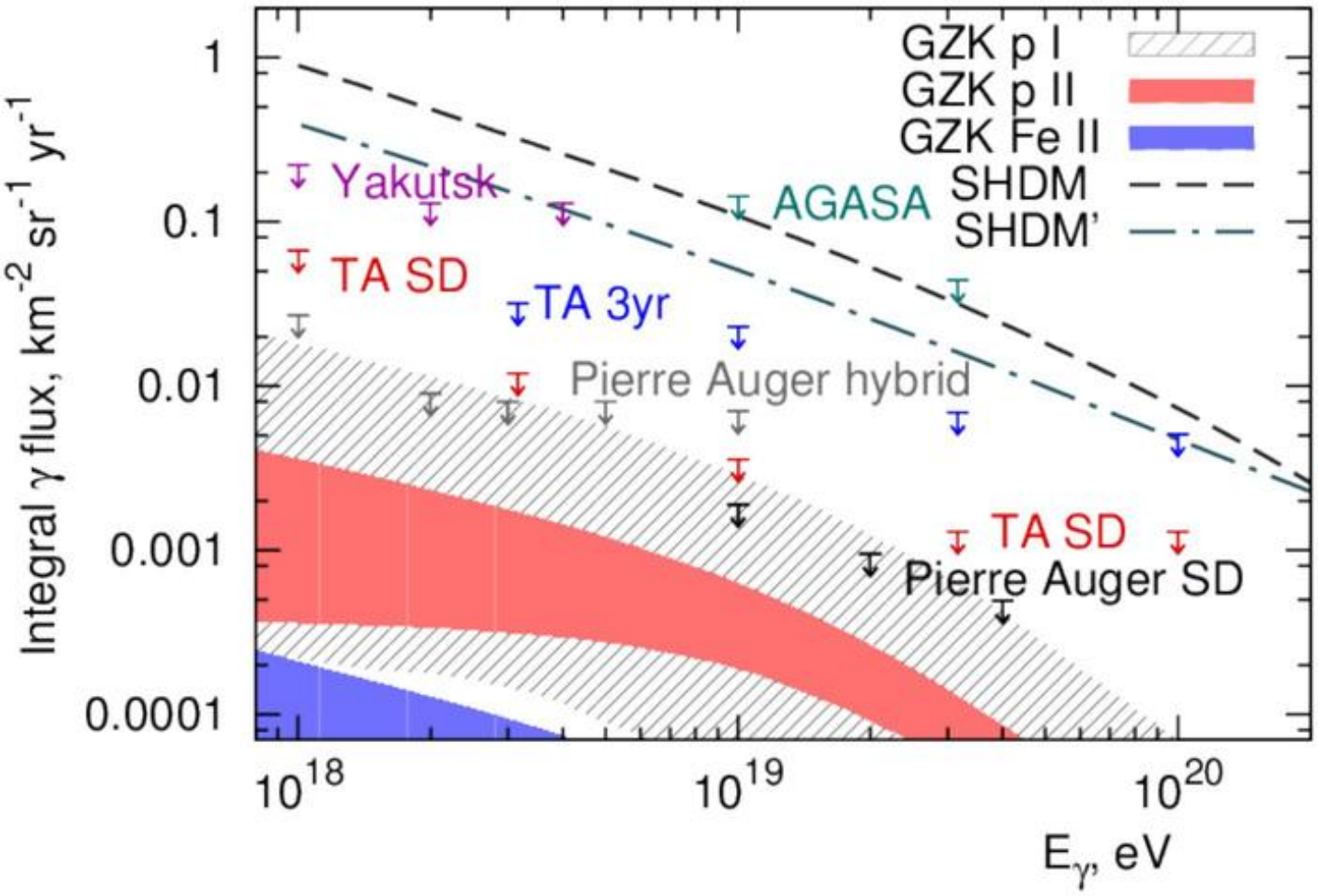




PRD 99(2019)022002

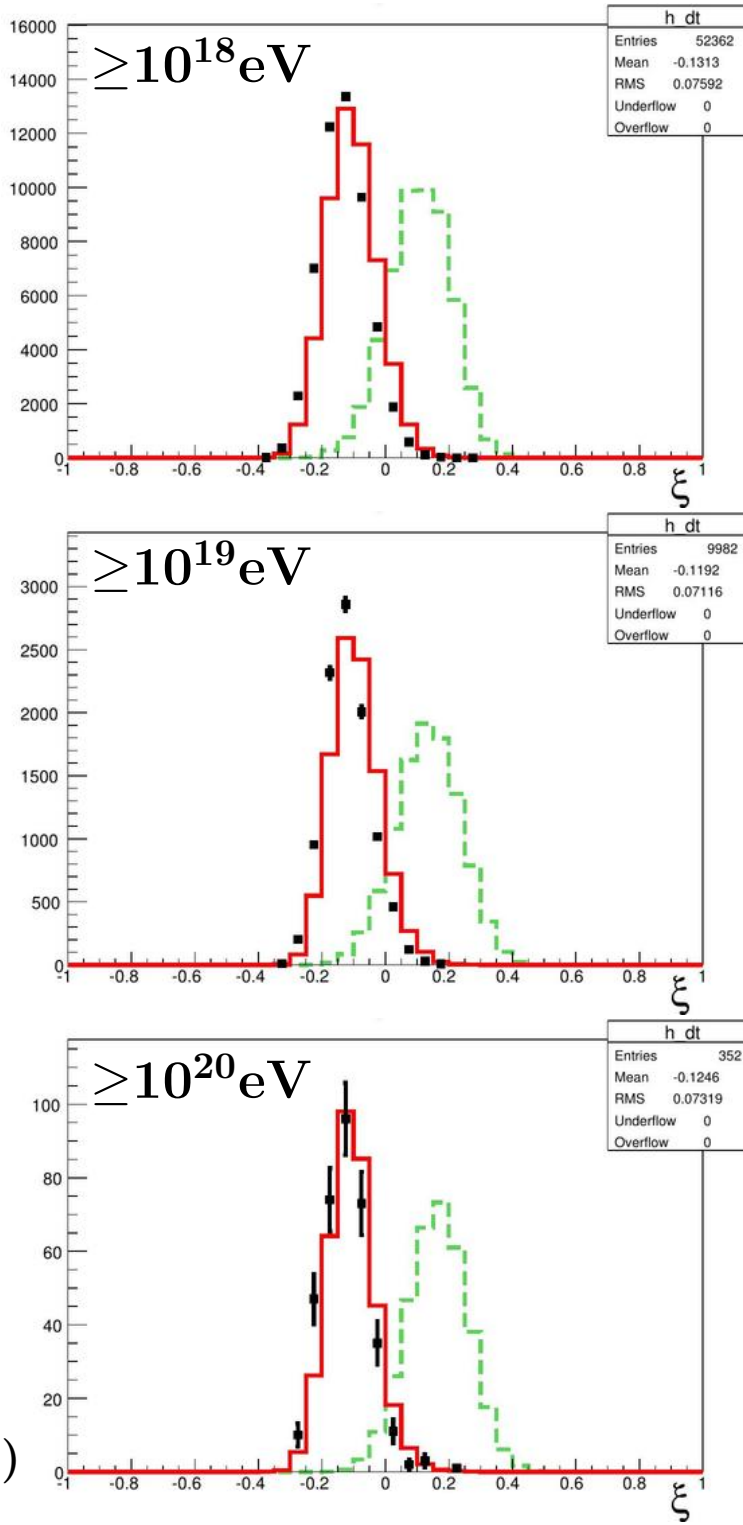
< SD Diffuse Photon Flux Limit >

- another BDT application



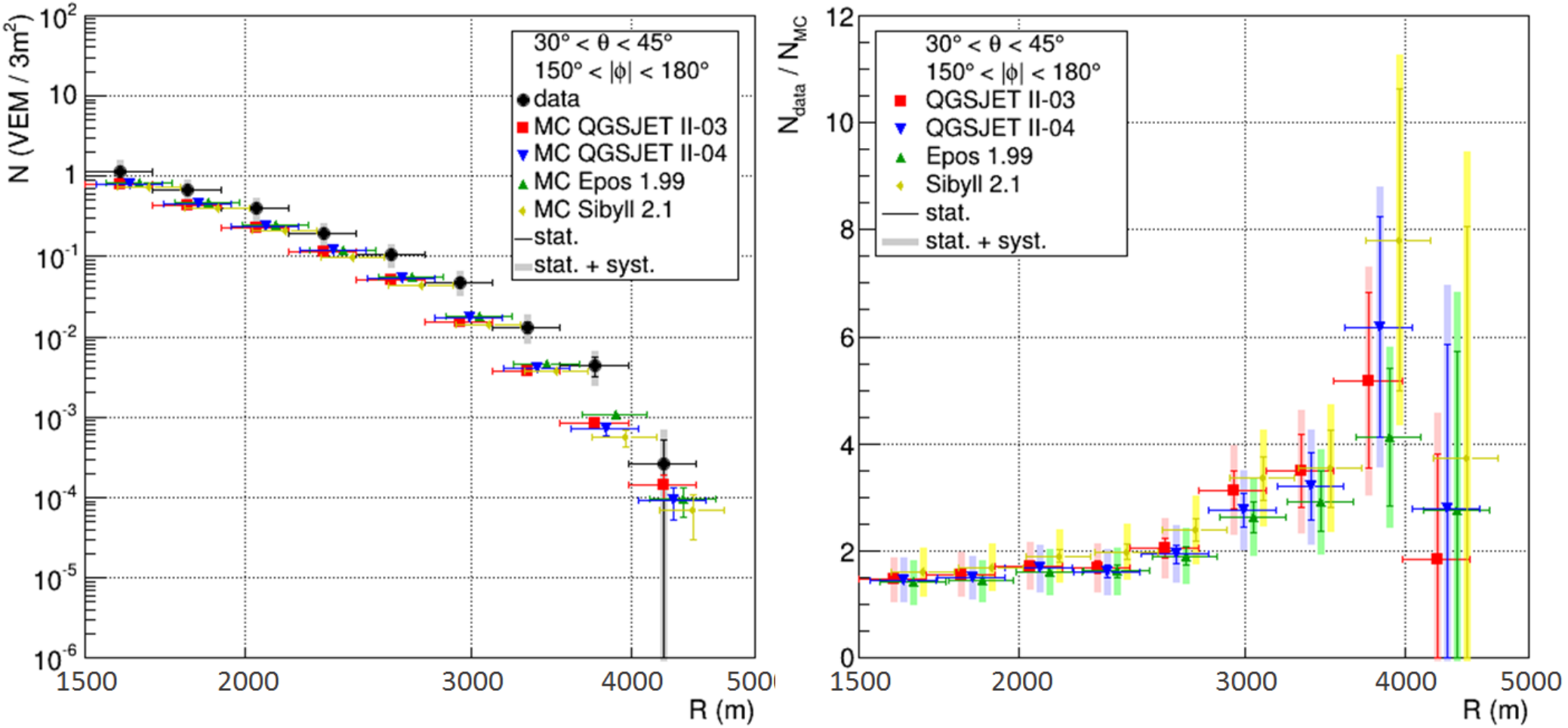
- found 2 photon candidates, but it's compatible with BG.

arXiv:1811:03920



– proton
– photon
• data ($\theta \leq 60°$)

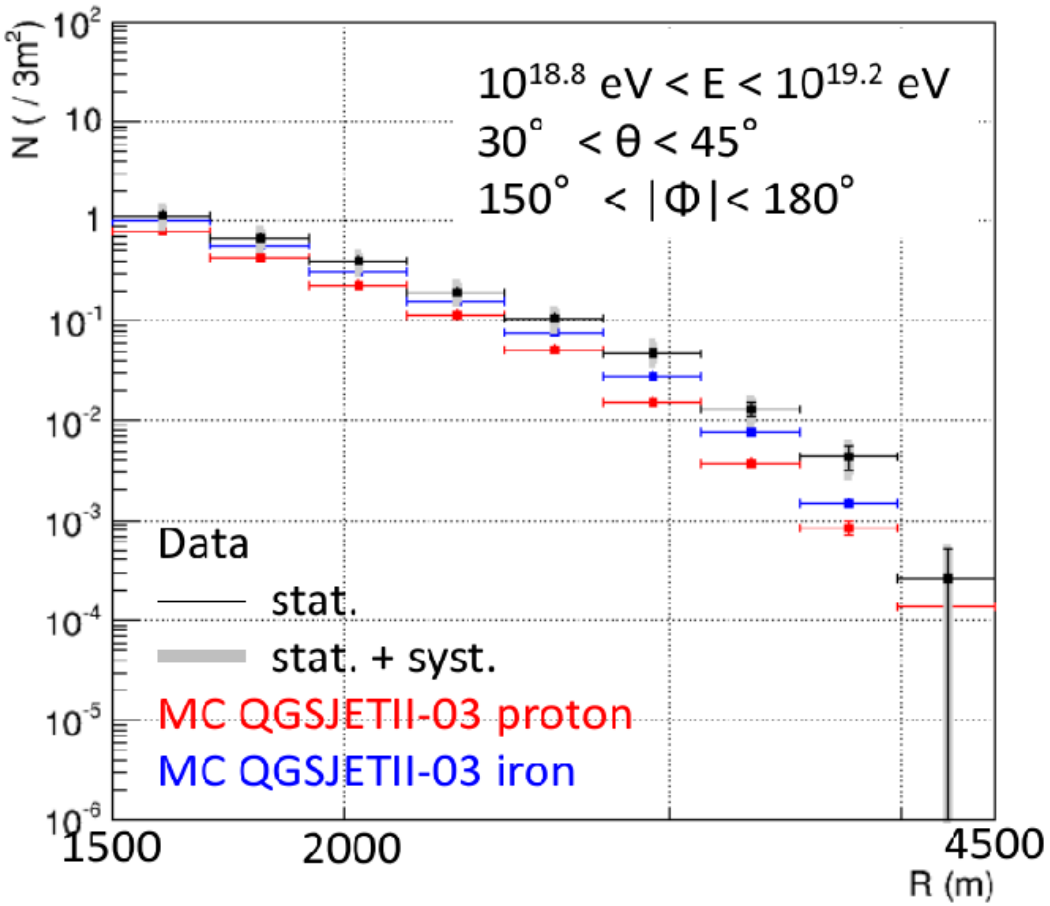
< Muon Excess in MC Comparison >

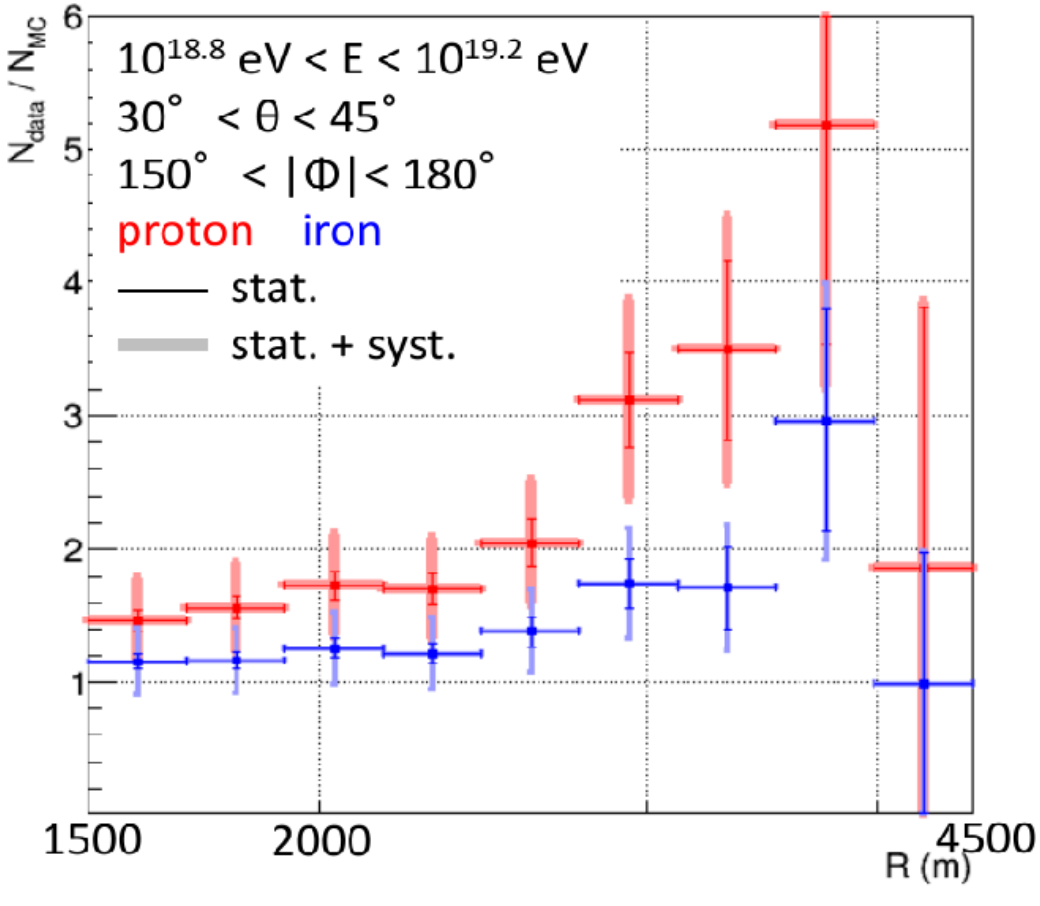


- Lateral distribution with various hadronic models;
  QGSJET II-03 , QGSJET II-04 , EPOS 1.99 , Sibyll 2.1
- Data is larger than MC for all considered models.

PRD 98(2018)022002

< Muon Excess in p/Fe Comparison >

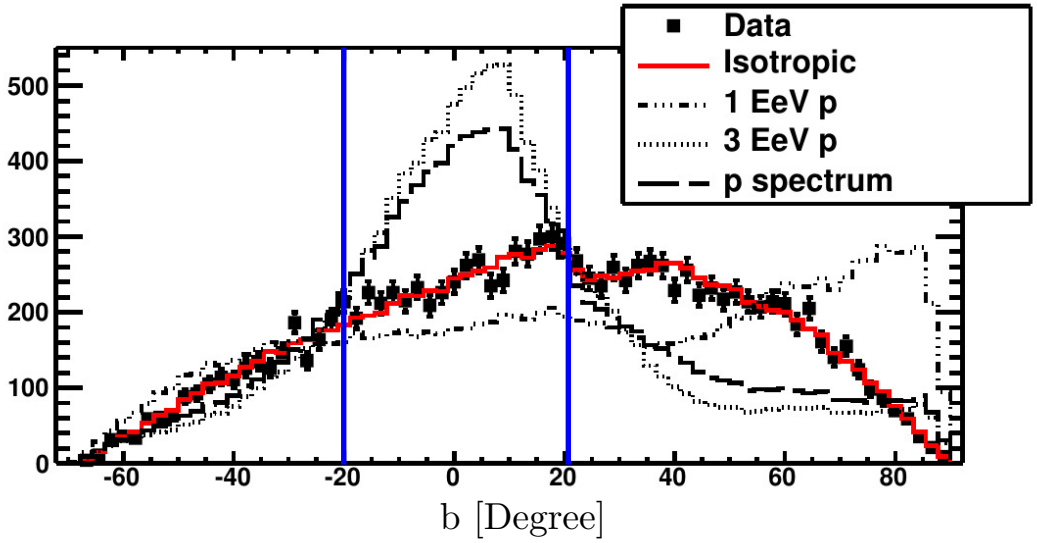




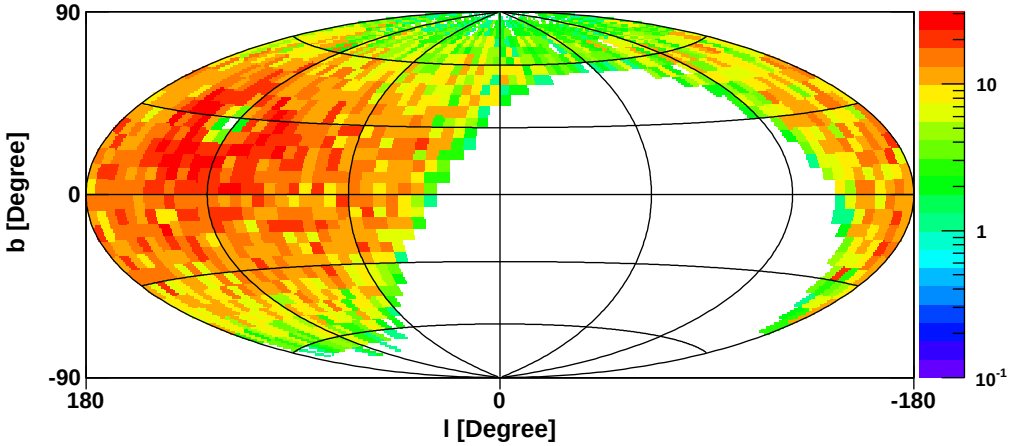
R (m)	Data/MC proton	Data/MC iron
[1910, 2160]	1.72±0.10(stat.)±0.40(syst.)	1.26±0.07(stat.)±0.29(syst.)
[2760, 3120]	3.14±0.36(stat.)±0.72(syst.)	1.74±0.19(stat.)±0.40(syst.)

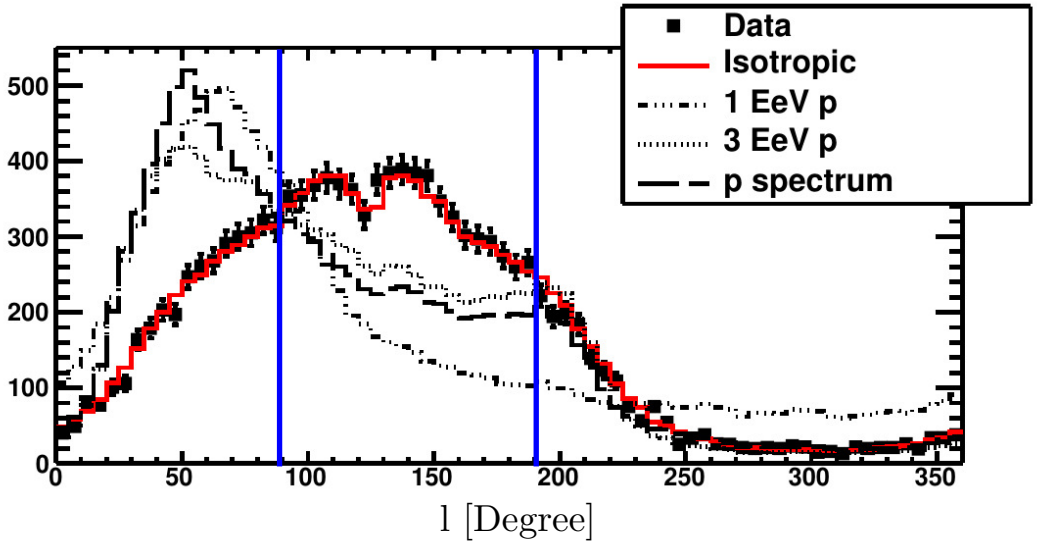
PRD 98(2018)022002

< Anisotropy around 1EeV @ TA >

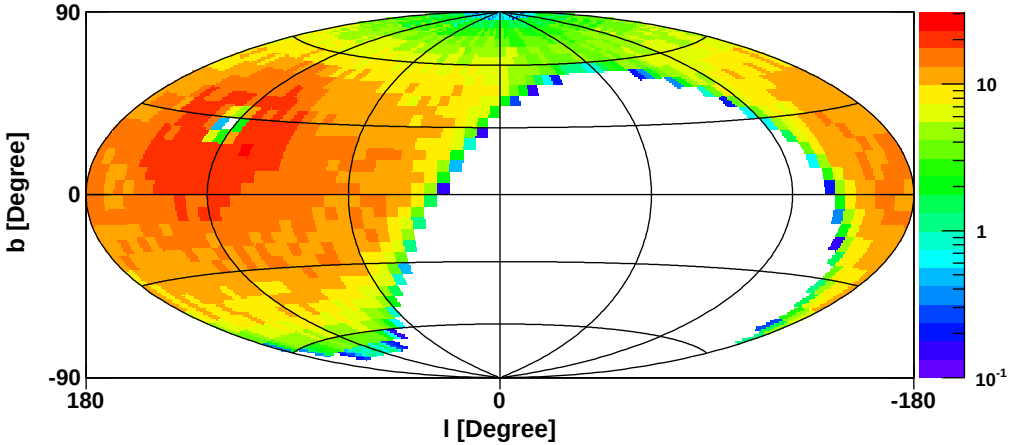


- Data @ $10^{18.0}$eV–$10^{18.5}$eV





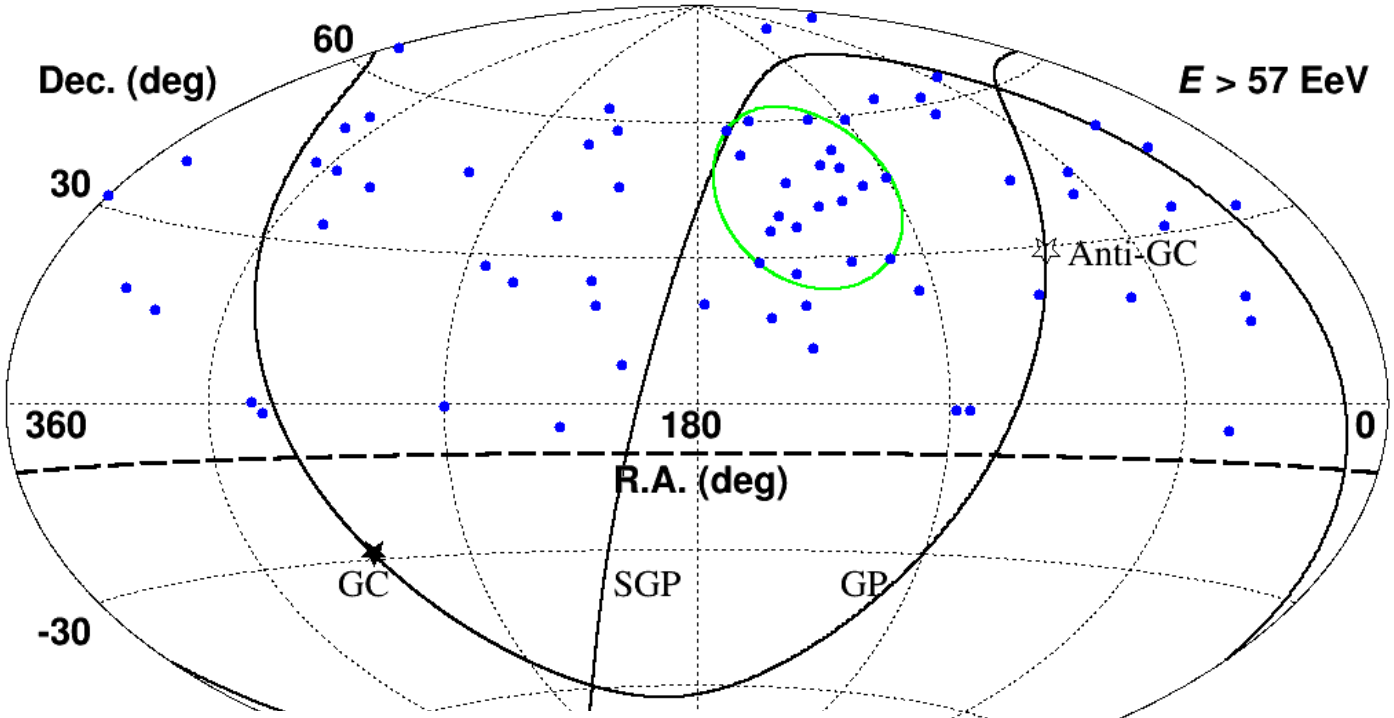
- MC w/ 0.9% Galactic Protons



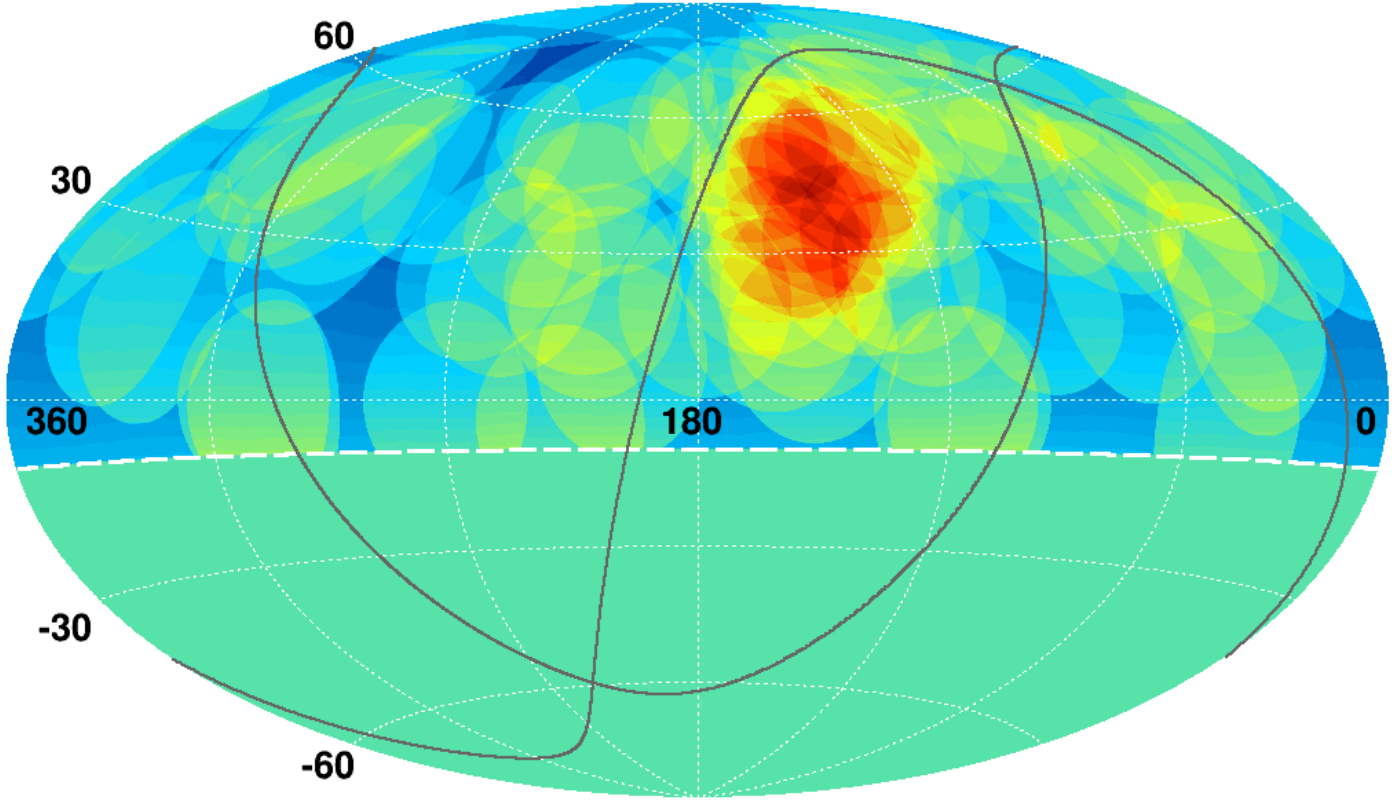
AstroPartPhys 86(2017)21

PSRs 0.3% in l, 1.3% in b

< Hot Spot >



- 5yrs data in ApJL
  5.1σ (Nobs=19/Nexp=4.49)



- $E \geq 57$ EeV
- $\theta \leq 20^\circ$

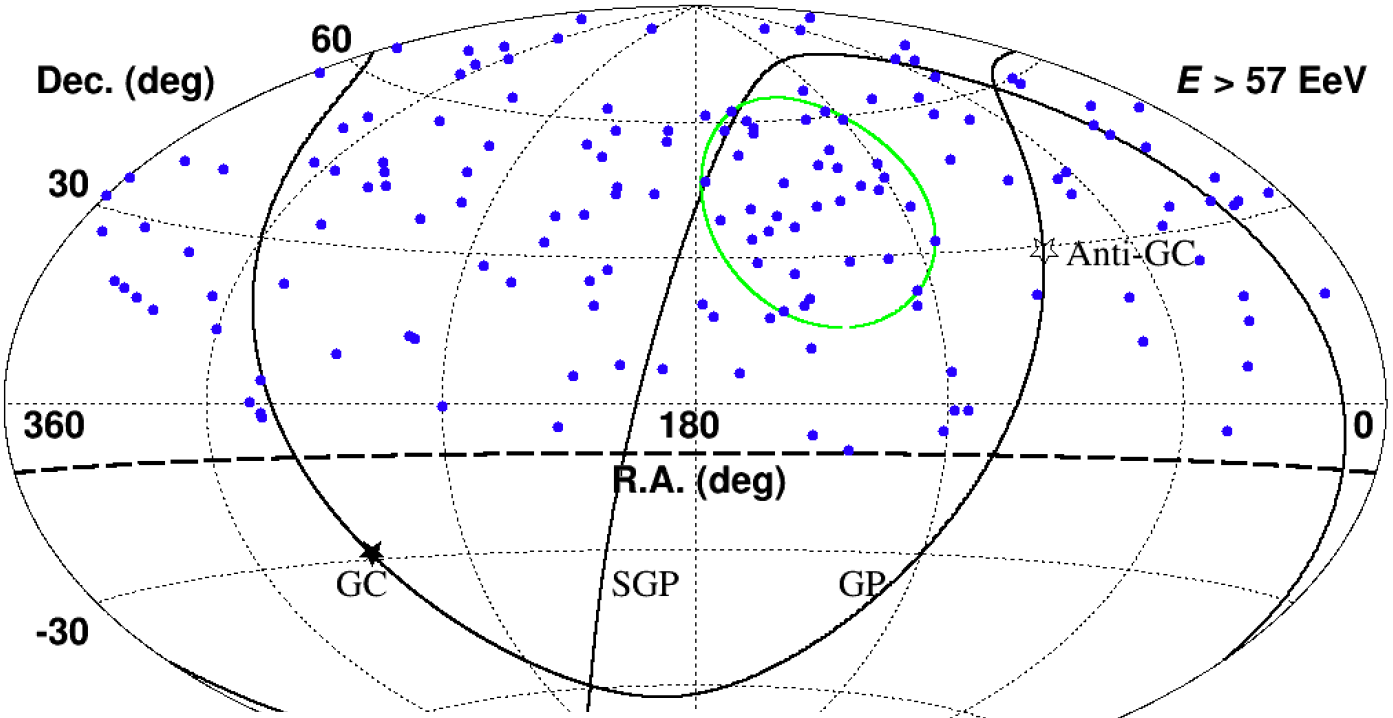
ApJL 780(2014)L21

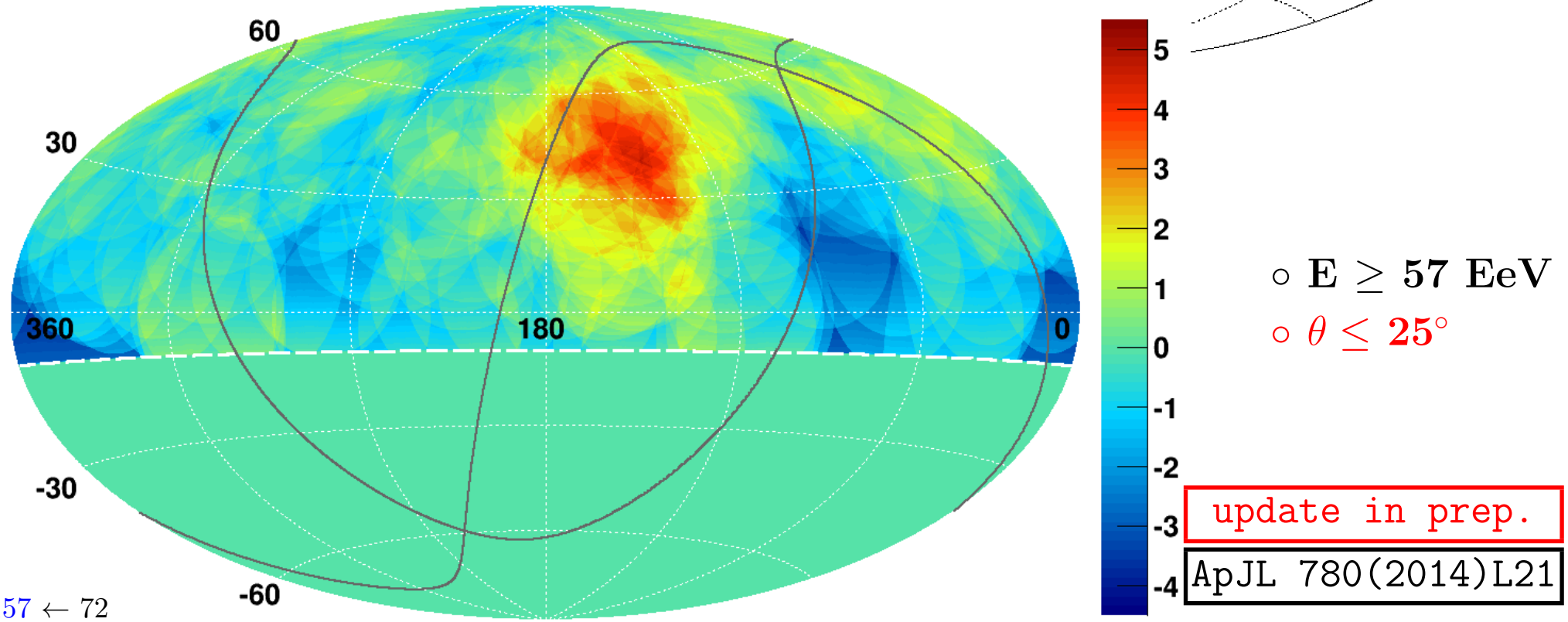
< Hot Spot >

- 10yrs data
  $\sim 3\sigma$ (Nobs=36/Nexp=12.6)

$\Uparrow$

- 5yrs data in ApJL
  5.1σ (Nobs=19/Nexp=4.49)





- E $\geq$ 57 EeV
- $\theta \leq 25^\circ$

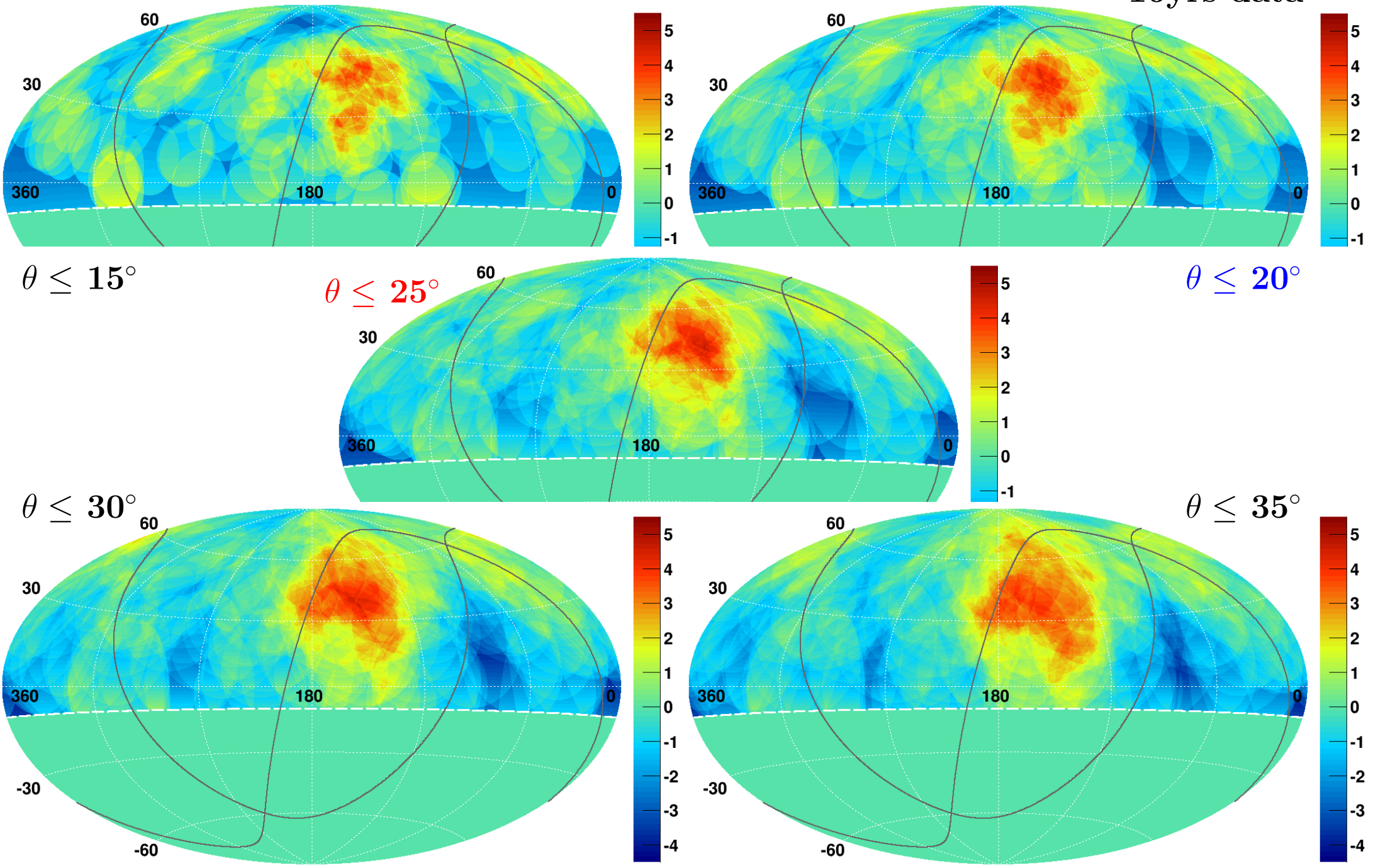
update in prep.

ApJL 780(2014)L21

Ntot=157 ← 72

< Hot Spot (Over-Sampling Scales) >

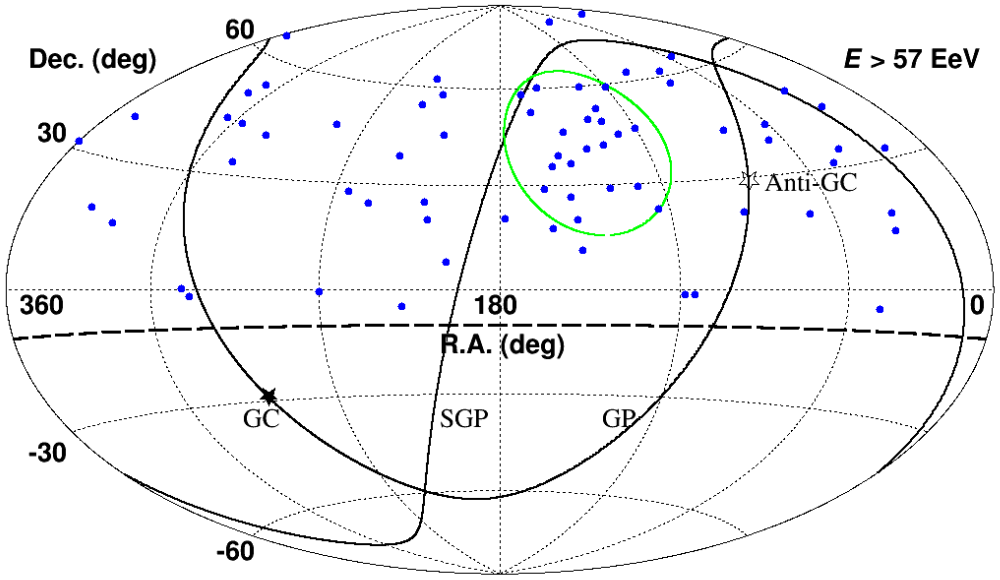
- $E \geq 57$ EeV
- 10yrs data

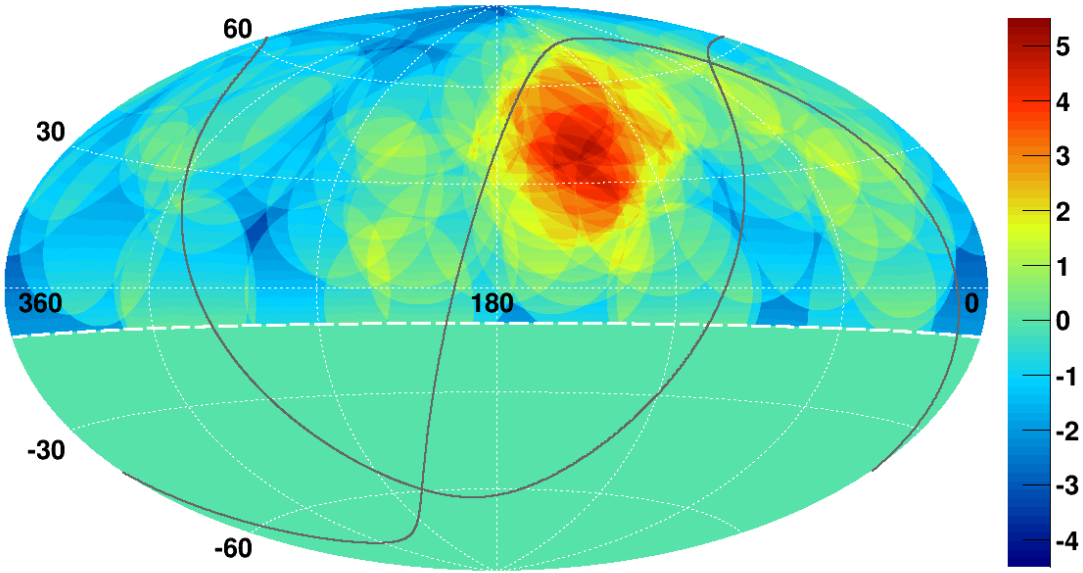


< Hot Spot (Independent 5yrs) >

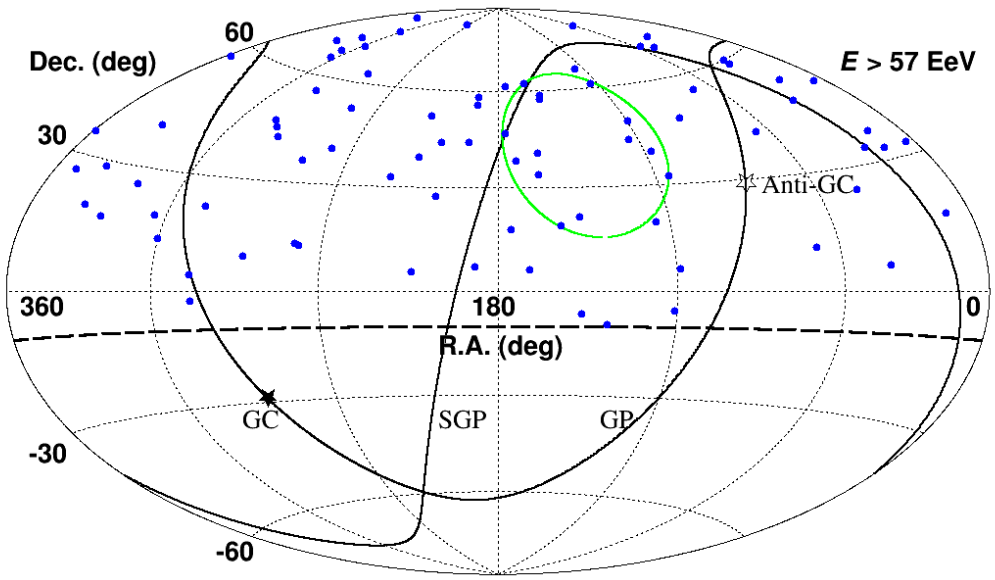
- $E \geq 57$ EeV
- $\theta \leq 25^\circ$

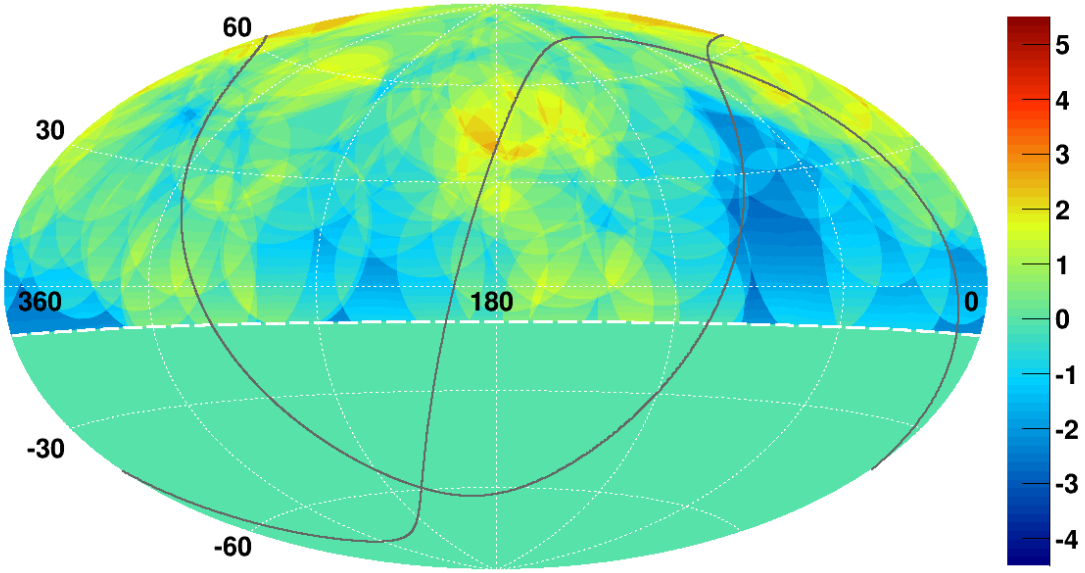
- 1st 5yrs (72 events)





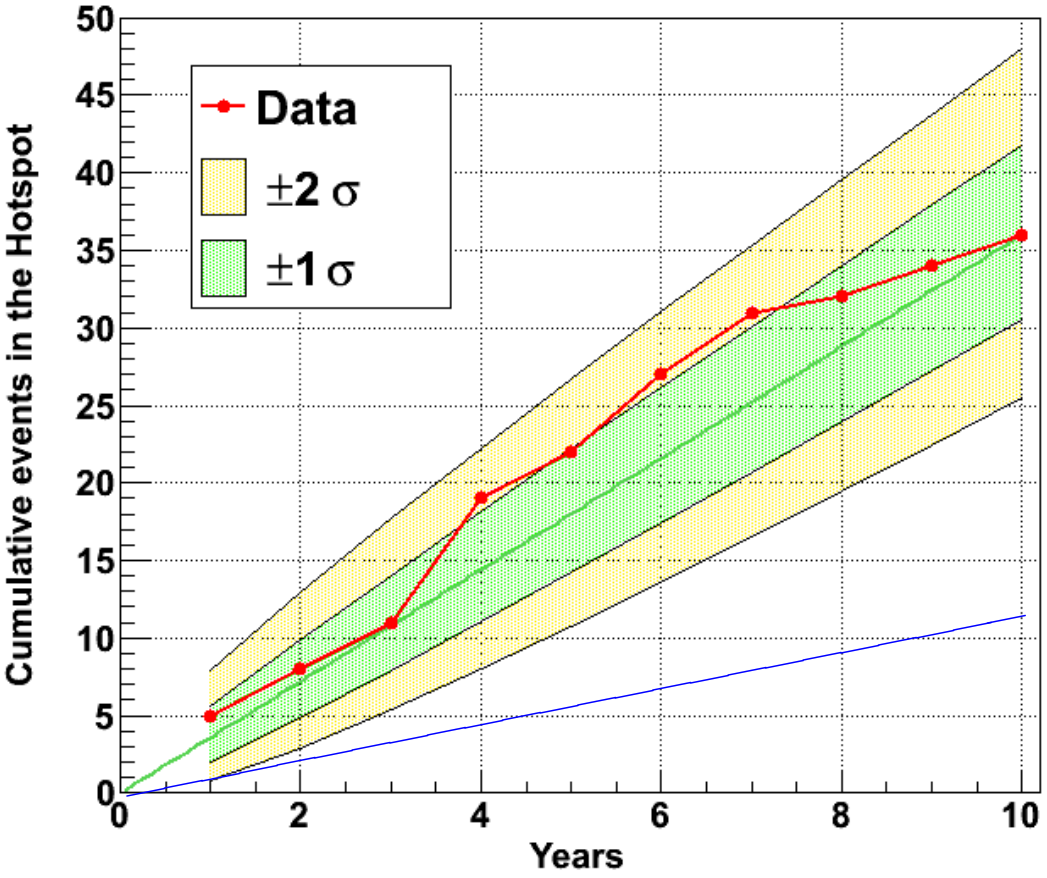
- 2nd 5yrs (85 events)





< Hot Spot (Temporal Development) >

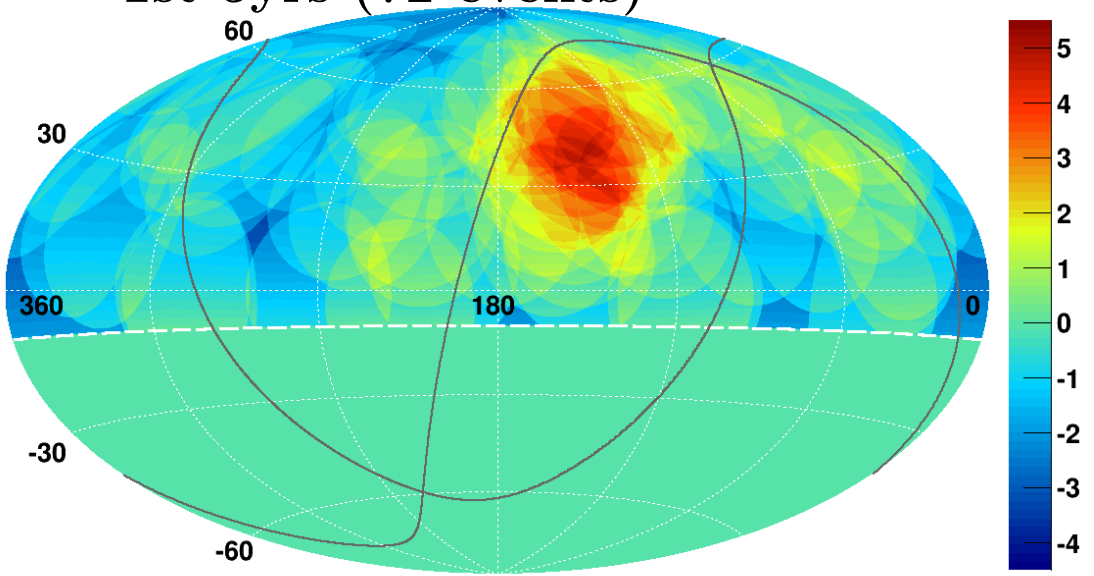
- 10yrs hotspot position
- $\theta \leq 25^\circ$



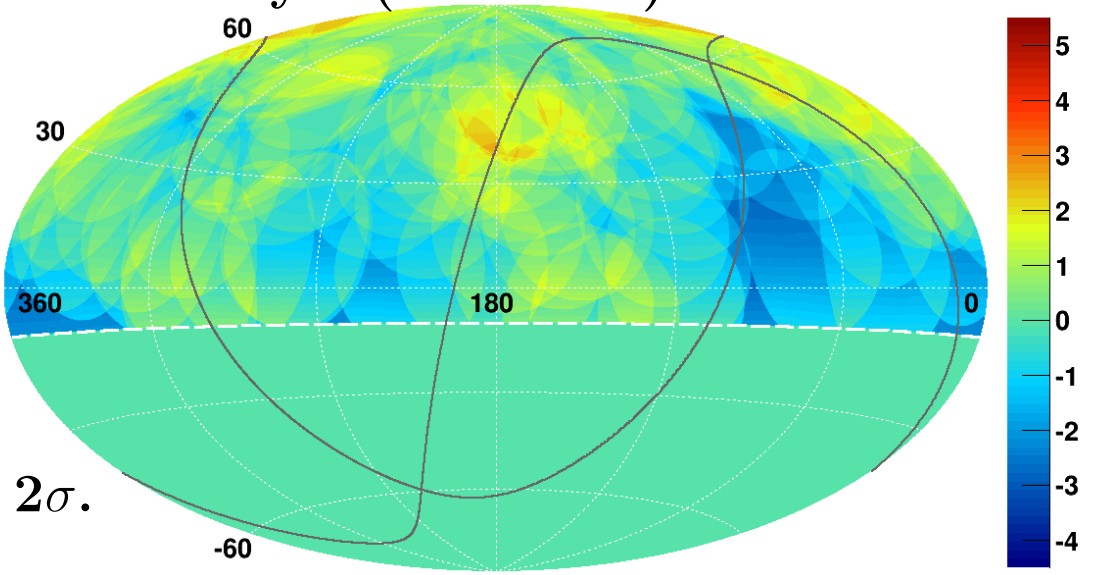
⇓

Consistent with linear increase within 2σ.

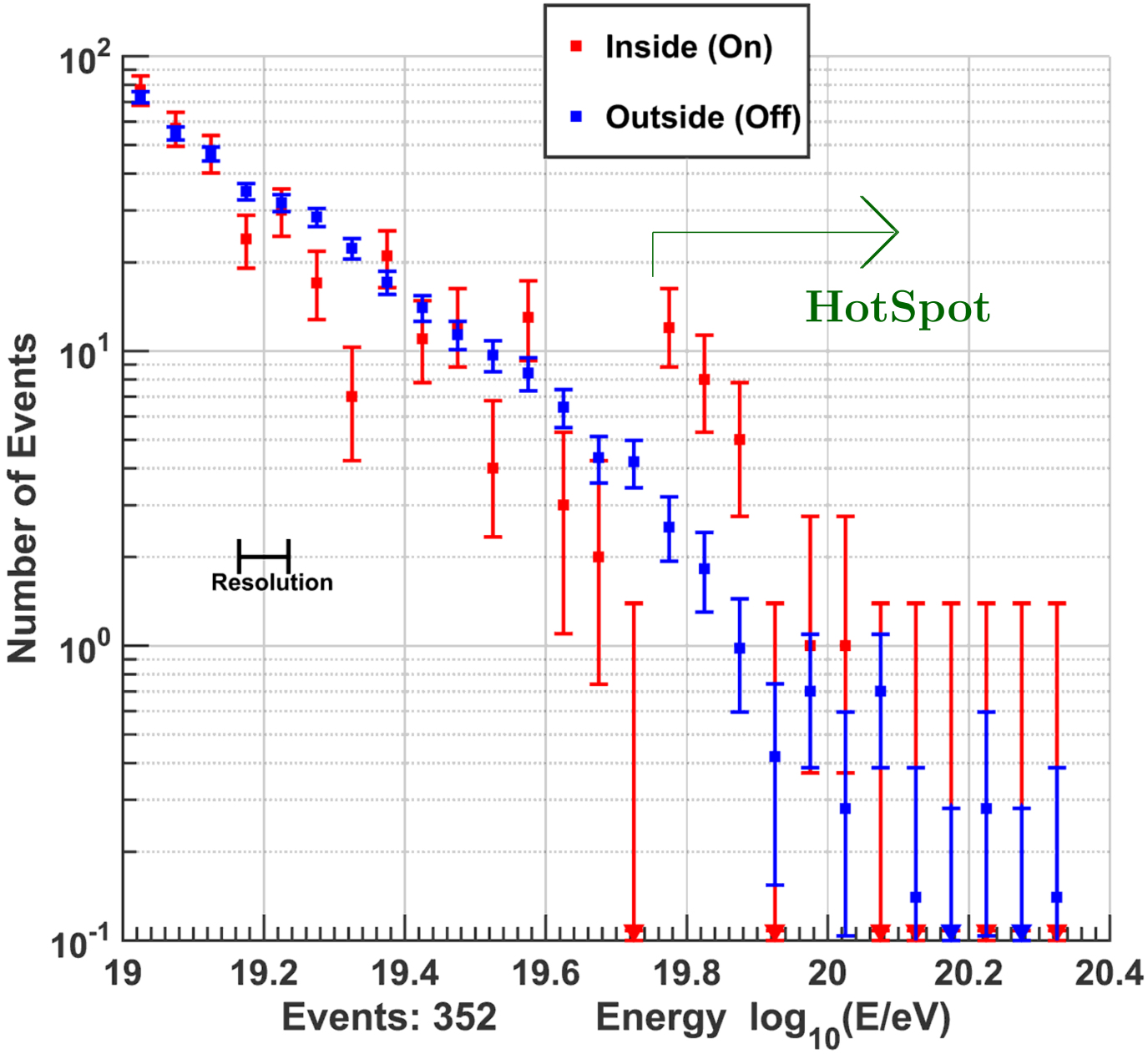
- 1st 5yrs (72 events)



- 2nd 5yrs (85 events)



< Hot / Cold Spot (Energy Distribution) >



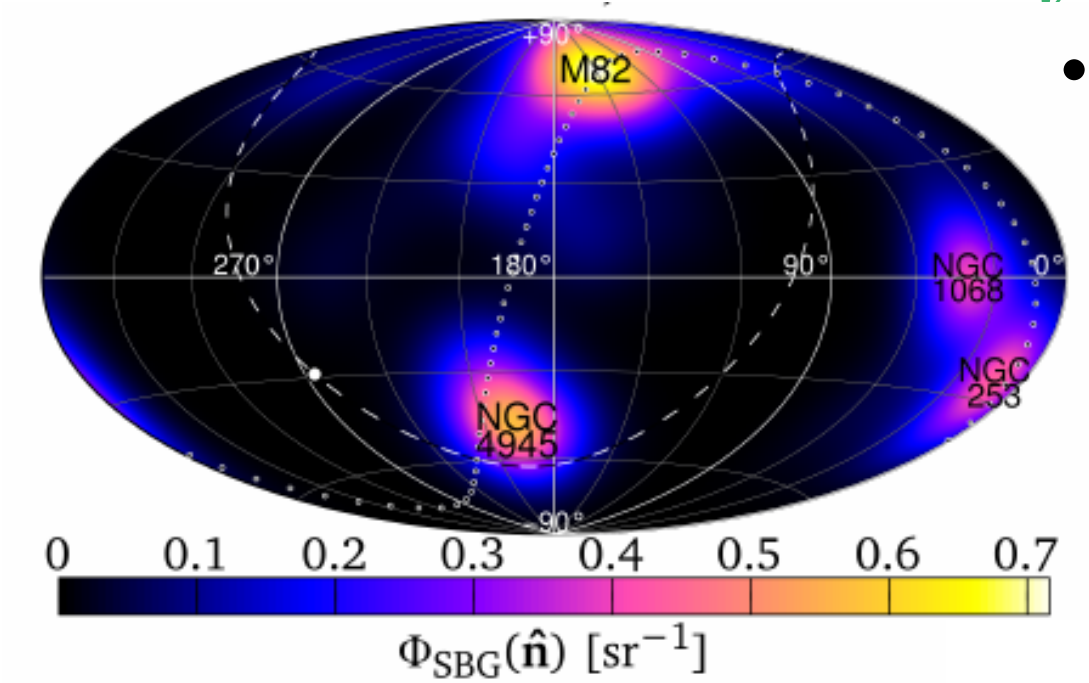
@ $(9^h16^m, 45^\circ)$

- Inside ($\theta \leq 28.43^\circ$)
- Outside ($\theta > 28.43^\circ$)
- 7yrs data

ApJ 862(2018)91

6.17σ(local) $\rightarrow$ 3.74σ(global)

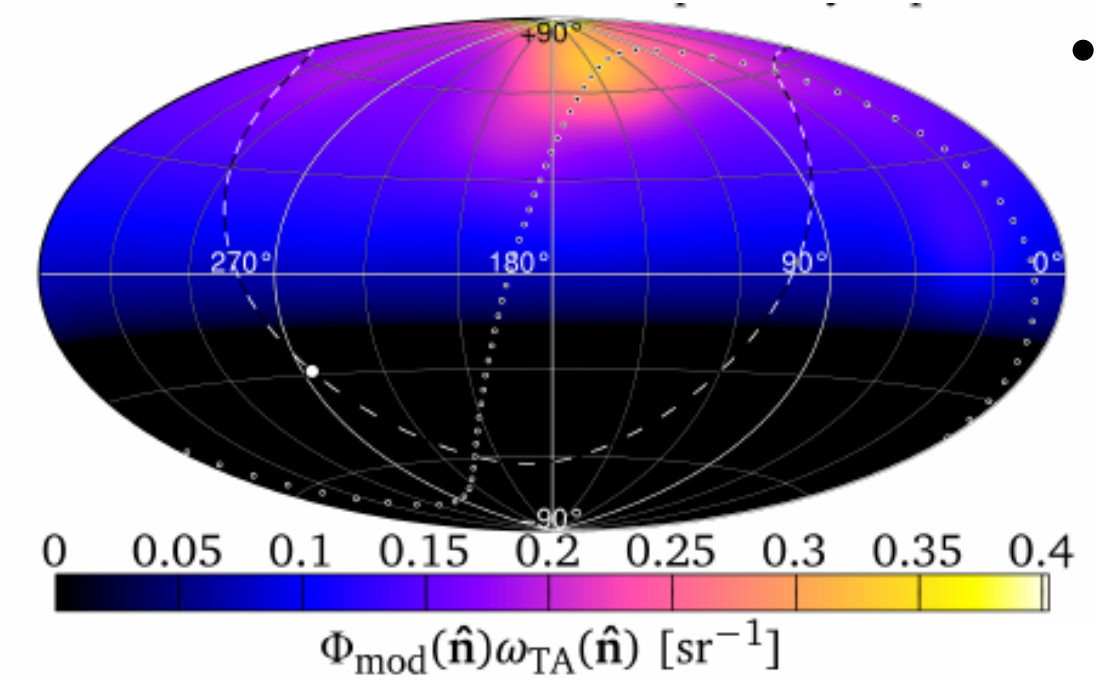
< Flux Pattern from Nearby Starburst Galaxies >



- **SBG model flux w/ $\theta = 12.9^\circ$**

$$\Phi_{mod} = f_{SBG}\,\Phi_{SBG} + (1 - f_{SBG})\Phi_{ISO}$$

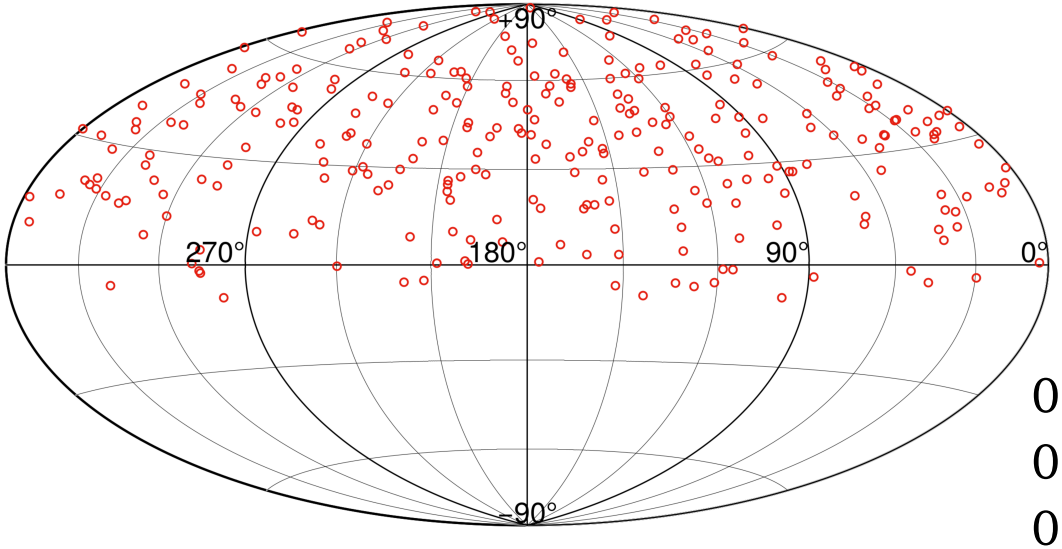
  - f_{SBG}: **SBG fraction (top: $f_{SBG} = 0$)**
  - Φ_{ISO}: **Isotropic flux**
  - Φ_{SBG}: **weighted sum of von Mises-Fisher distributions ($\sim$ spherical 2D Gaussian)**
  - θ: **RMS deviation ($\sim$ smearing)**



- **SBG model flux w/ TA exposure**
  - $\theta = 12.9^\circ$
  - $f_{SBG} = 9.7\%$
  - **Energy $\geq$ 43EeV $= 39\text{EeV}\times 1.1$**

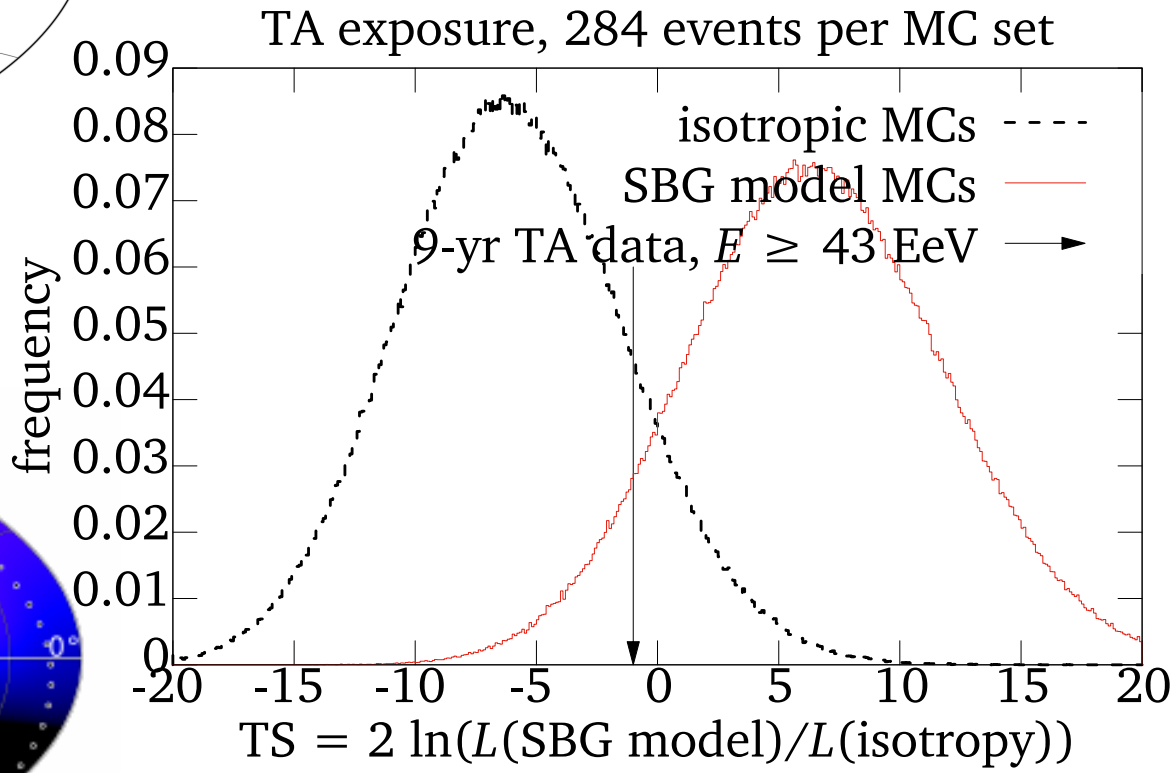
ApJL 867(2018)L27

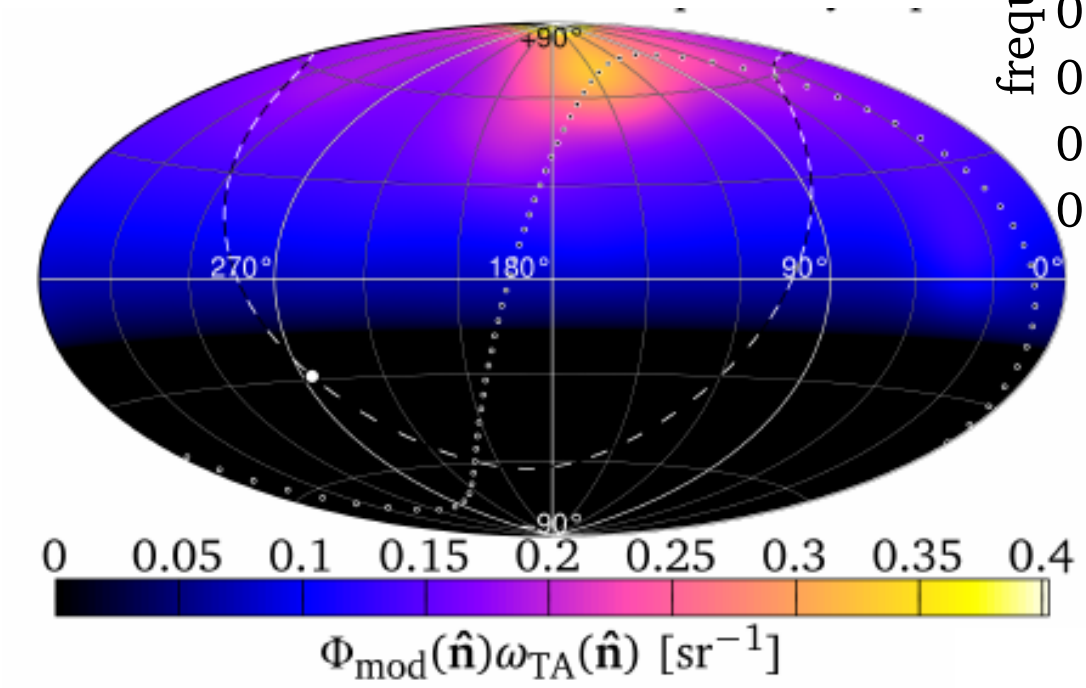
< Flux Pattern from Nearby Starburst Galaxies >



isotropic model **SBG model**

$+1.1\sigma$ -1.4σ





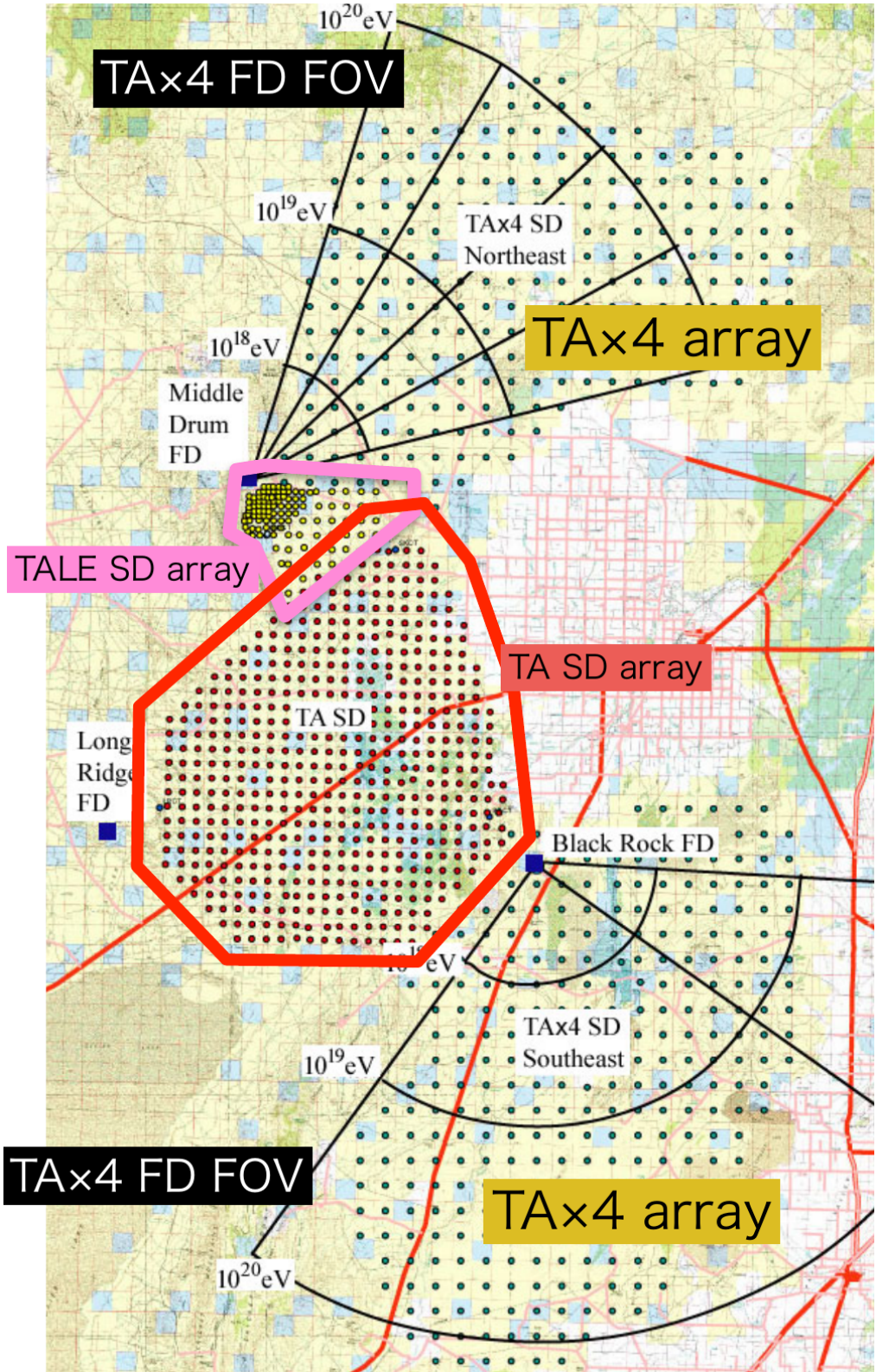
ApJL 867(2018)L27

< TAx4 Experiment >

- **2 FD stations**
  - refurbished 12 HiRes-II telescopes
  - approved by US NSF 2016
  - first light at the northern station
  - Site construction is underway at the southern station.

- **$\sim$3000km^2 SD array (Quadruple area)**
  - approved by Japanese government 2015
  - 500 scintillator SDs (plan)
  - 2.08km spacing
  - 3yrs construction
  - Deployment is on going.

- **by 2020,**
  - Get 19 TA-equiv years of SD data
  - Get 16.3 (current) TA years of hybrid data



< TAx4-FDs >

- North station @ MD
  - 4 telescopes
  - has operated since 2018

- South station @ BRM
  - 6/8 telescopes
  - under construction

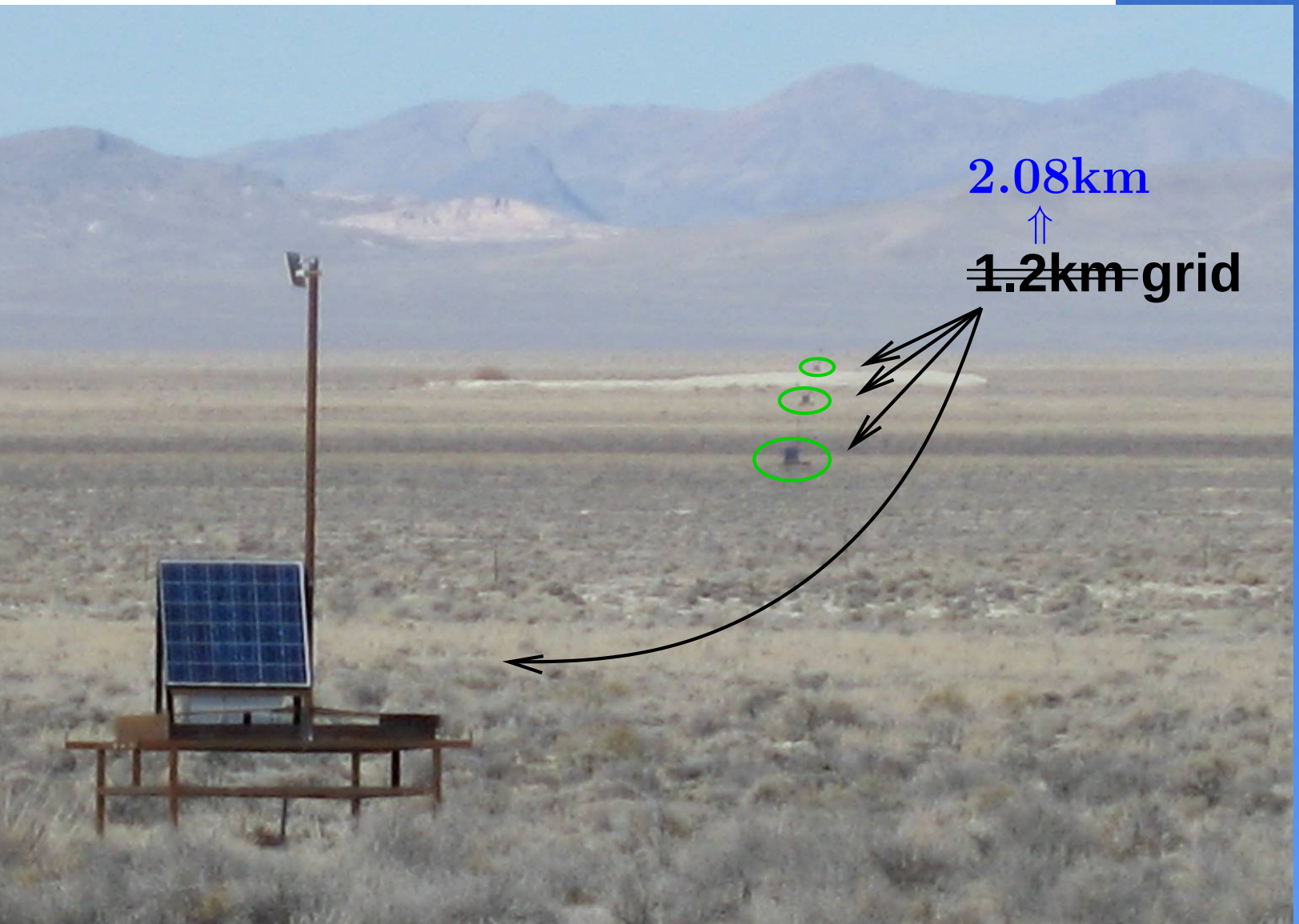
< TAx4-SD Assembly @ Delta >

- prepared 205 SDs in JP + 30 SDs in KR., and then transported to Delta.
- assembled all SDs in Delta in this winter.

< TAx4-SD Deployment >

- US Gov't. shutdown delays our schedule.
- We will fly in this week !

(pictures: original TA-SDs)



< Summary >

- **Telescope Array is UHECR observatory in the northern hemisphere.**
  - **Hybrid = Fluorescence Detectors + 700 km^2 Surface Detector array**
- **TA hybrid Xmax measurements**
  - **Below $10^{18.8}$eV, allowing 10-20g/cm^2 shifts, data points looks like "proton".**
  - **Above $10^{18.8}$eV, data points looks like heavier primary than "proton",**
  - **There are significant overlaps between plots of different primaries because of small statistics.**
- **Energy spectrum from 9 year observations by TA SD array**
  - **Auger-TA discrepancy above $10^{19.4}$eV**
  - **Indication of the declination dependence**
- **TA Low-energy Extension (TALE) FD have measured energy spectrum.**
  - **TA and TALE covered $10^{15.3}$eV to 10^{20}eV and observed spectral features.**
- **We have reported a Hot Spot in the direction of Ursa Major. It now appears larger(extended) than we originally thought.**
- **We need much more data at high energy end. – TAx4 comes soon.**
- **Full TALE SD is now on-line !**
  - **Hybrid measurement has extended the energy reach below $\sim 10^{16}$eV.**