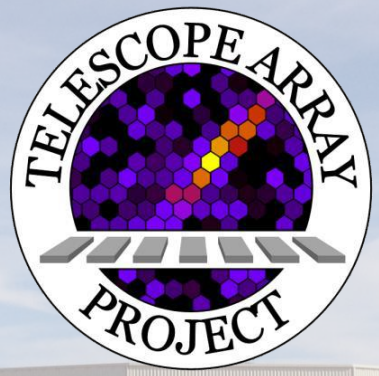
Recent Results from the Telescope Array Experiment



Heungsu Shin (ICRR, University of Tokyo)
For the Telescope Array Collaboration
20th Lomonosov Conference on Elementary Particle Physics

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Telescope Array Experiment

Collaboration

- 160 Members, 35 Institutes, 7 countries

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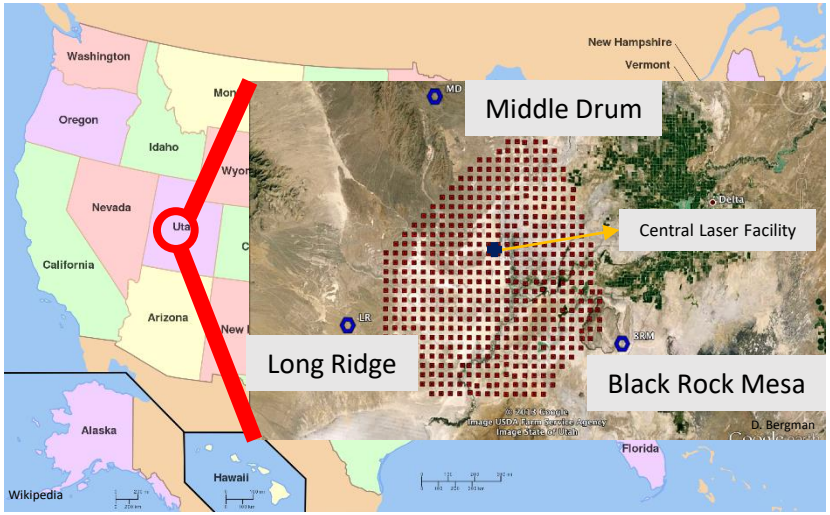
Telescope Array Experiment

The Largest UHECR Observatory on the Northern Hemisphere

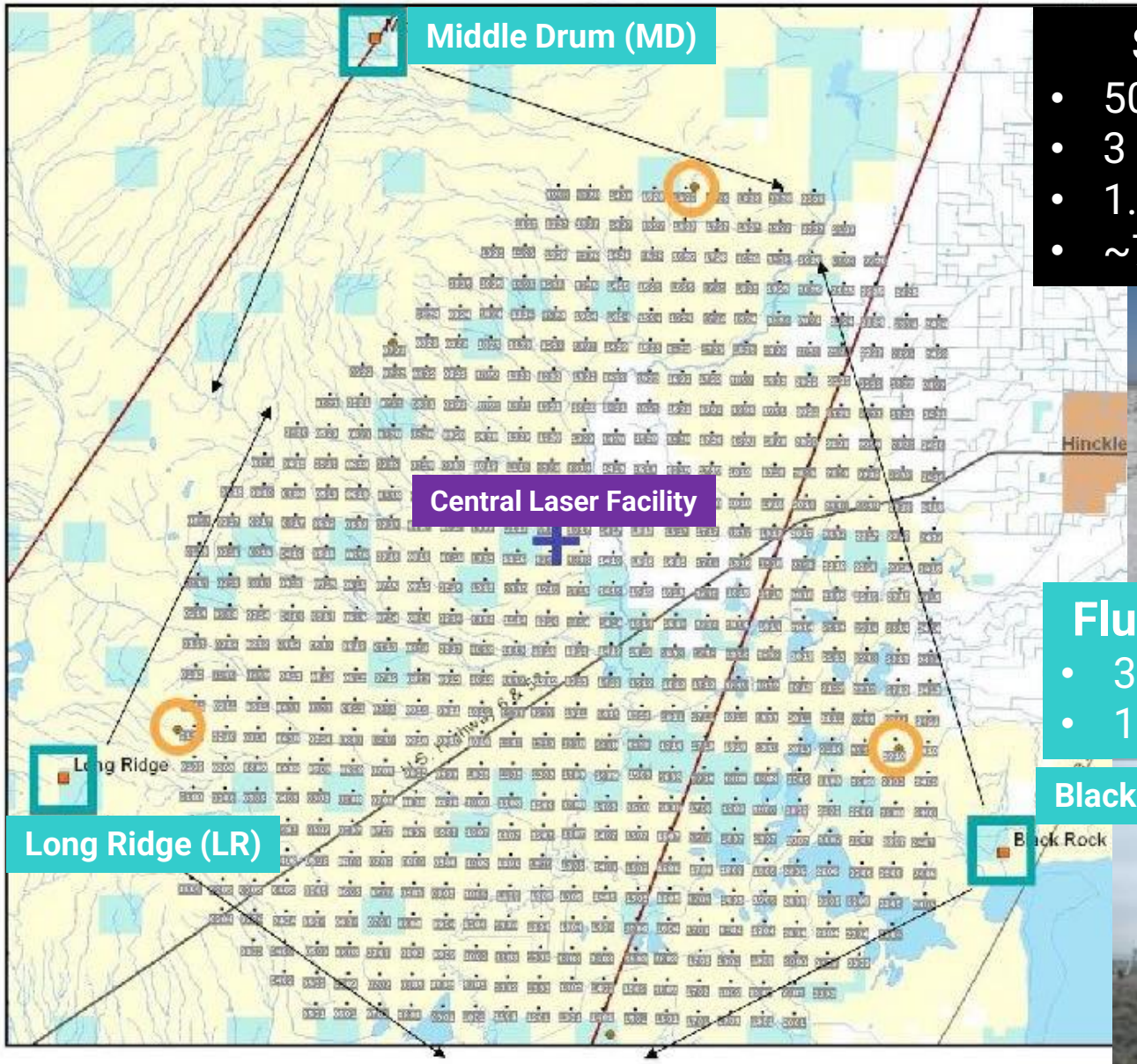
- Millard county, Utah, USA



Science Goals

- Origin and properties of ultra-high-energy cosmic rays
- High energy hadronic interactions
- Multi-messenger studies with photons, neutrino, DM
- Interdisciplinary studies with Thunderstorms, TGF, Meteoroids

Telescope Array Experiment



Surface Detectors

- 507 scintillation detectors
- 3 m^2 detection area
- 1.2 km spacing
- ~700 km^2 coverage

Fluorescence Detectors

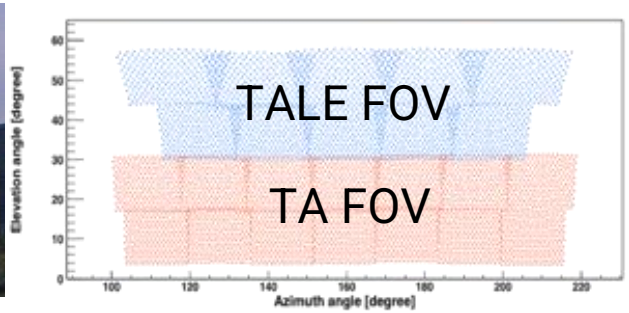
- 3 stations (BRM, LR, MD)
- 12 - 14 telescopes

Black Rock Mesa (BRM)

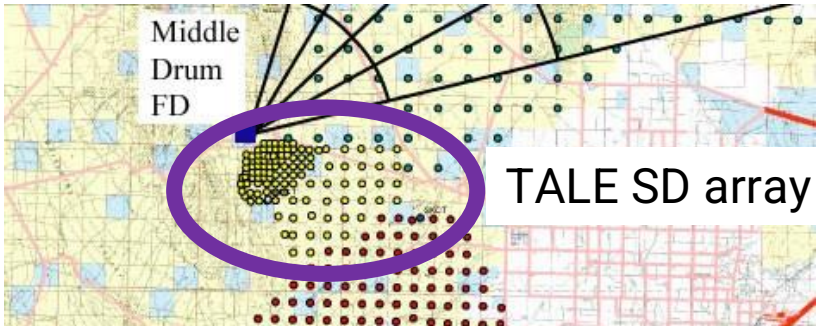
TALE (Low Energy Extension)

Higher elevation FD & Densely deployed SD for lower energy

- TALE FD located at MD station (10 telescopes)
  Elevation 30° - 57°



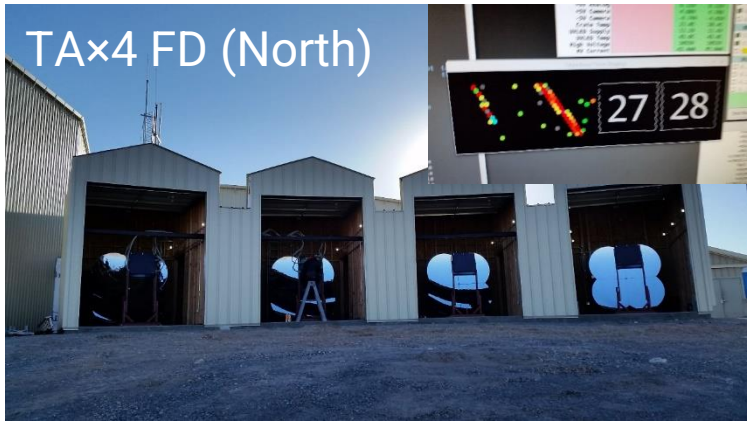
- TALE SD array
  104 Scintillation detectors (Design identical to TASD)
  Various spacing up to 400 m

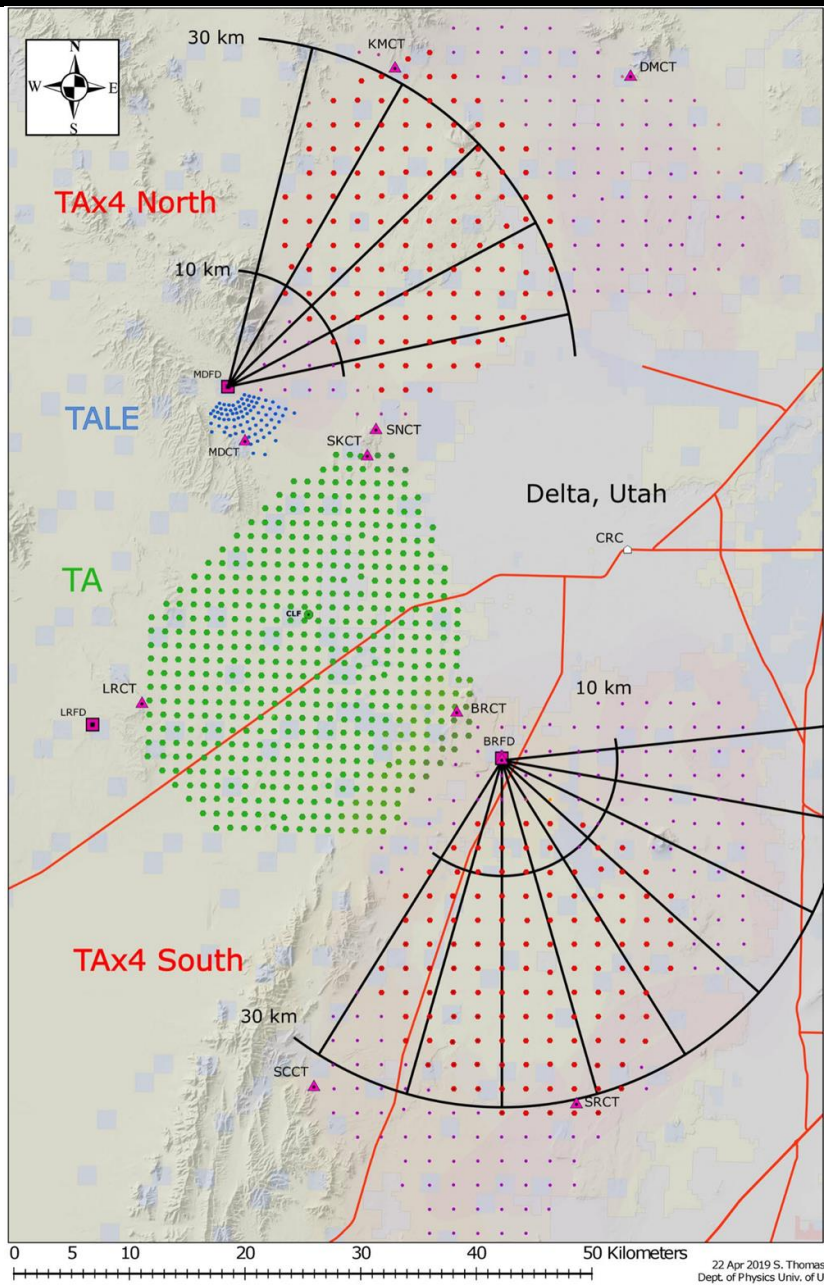


TA×4

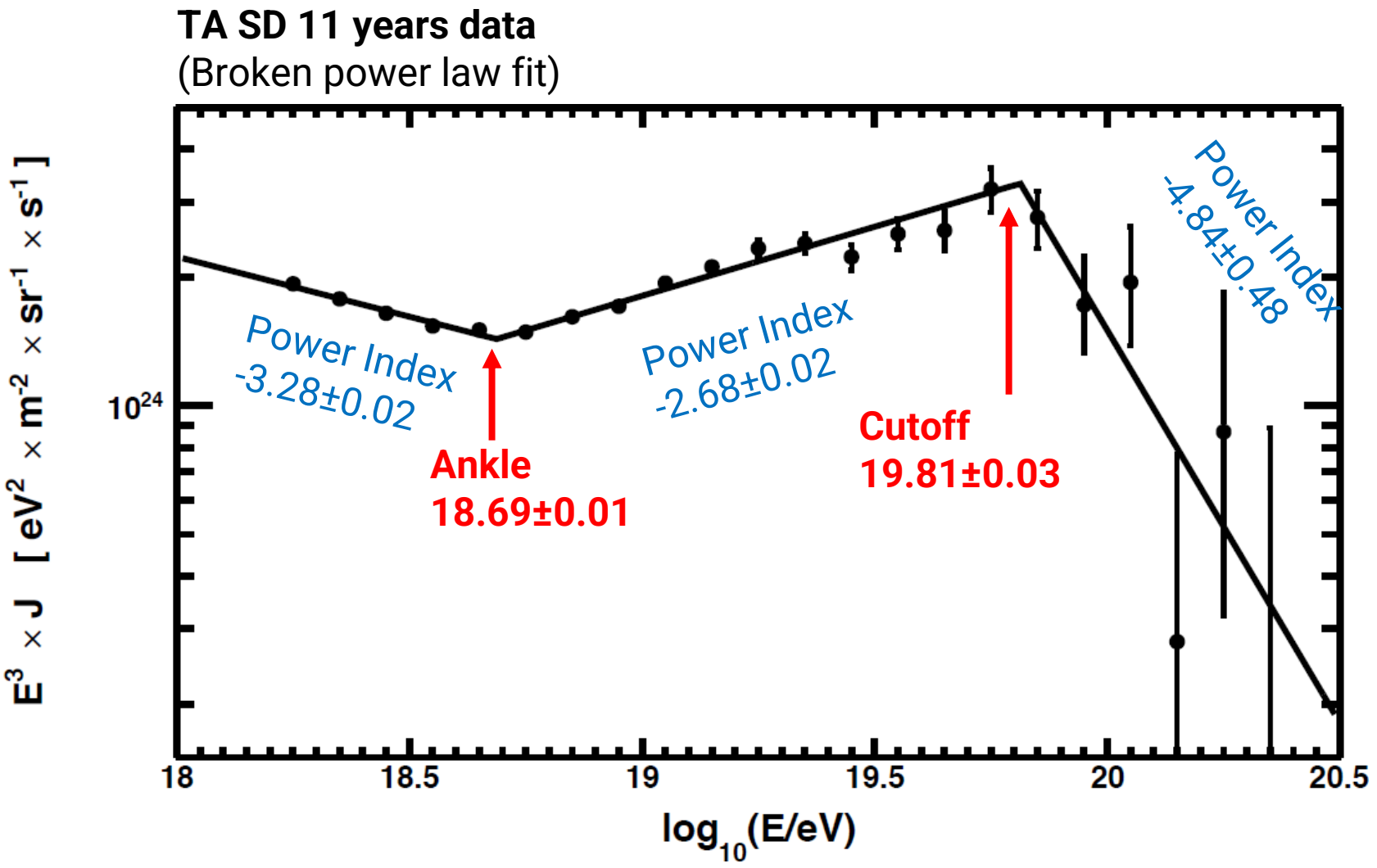
The most recent upgrade of TA
4-fold increase in size of TA SD array

- Up to ~3,000 km^2
- 2 additional FD stations for Hybrid
- Observation started since 2019

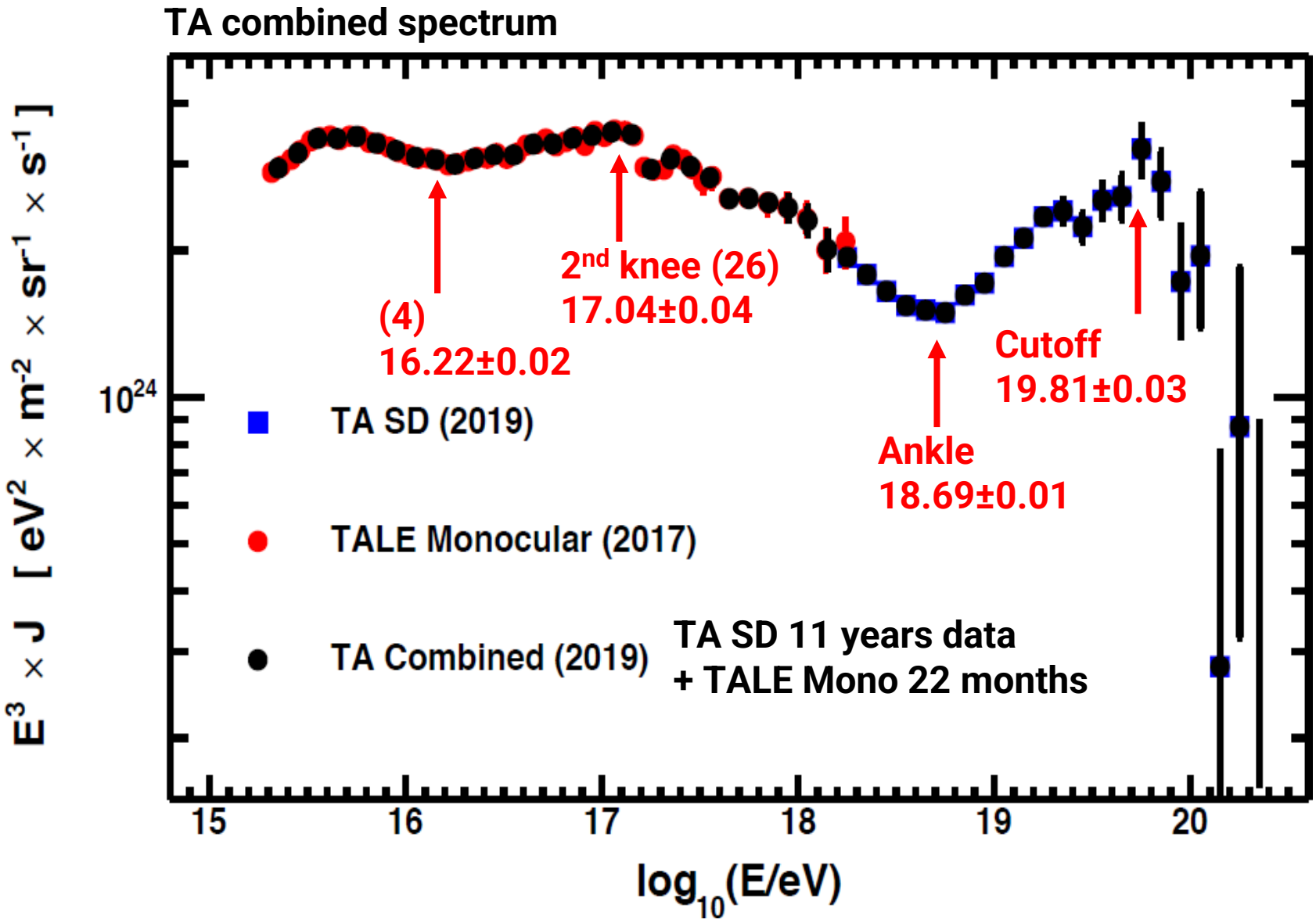




Spectrum


TA SD 11 years data
(Broken power law fit)
$E^3 \times J$ [$eV^2 \times m^{-2} \times sr^{-1} \times s^{-1}$]
10^{24}
Power Index
-3.28±0.02
Ankle
18.69±0.01
Power Index
-2.68±0.02
Cutoff
19.81±0.03
Power Index
-4.84±0.48
18
18.5
19
19.5
20
20.5
$\log_{10}(E/eV)$

Spectrum

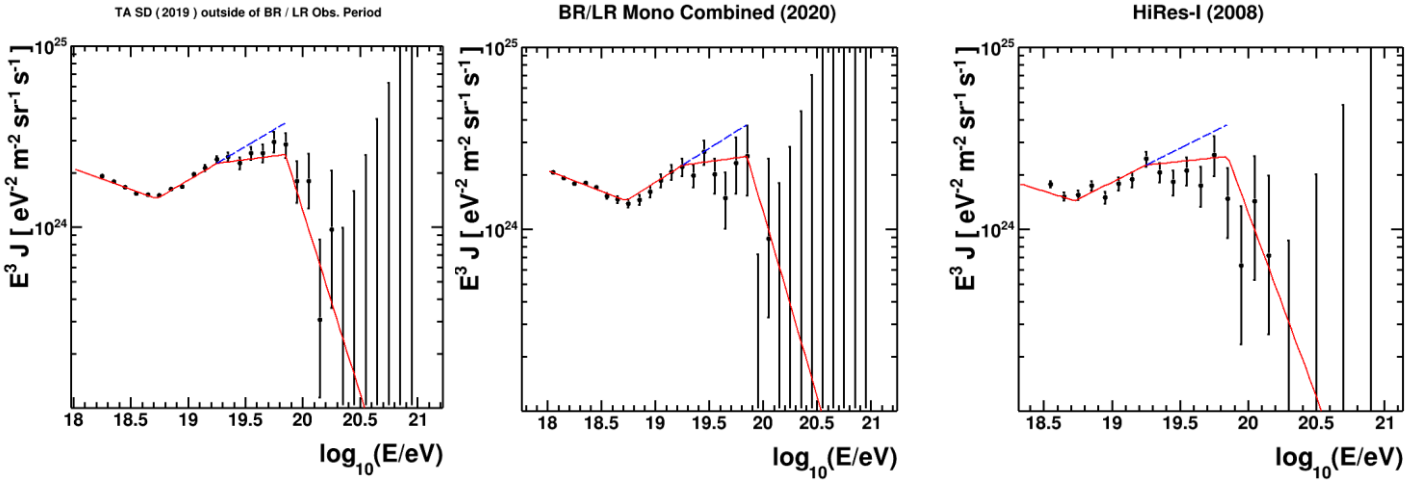

TA combined spectrum
$E^3 \times J$ [$eV^2 \times m^{-2} \times sr^{-1} \times s^{-1}$]
10^{24}
(4)
16.22±0.02
2nd knee (26)
17.04±0.04
Ankle
18.69±0.01
Cutoff
19.81±0.03
TA SD (2019)
TALE Monocular (2017)
TA Combined (2019)
TA SD 11 years data
+ TALE Mono 22 months
15
16
17
18
19
20
$\log_{10}(E/eV)$

Spectrum

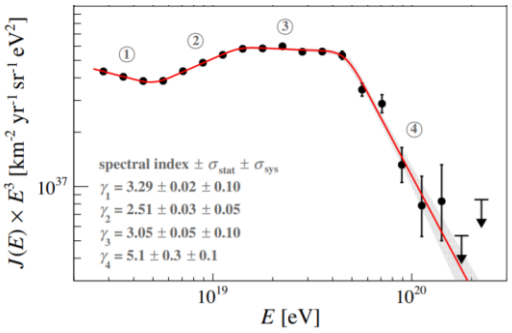
Instep feature

- Pierre Auger reported a spectrum hardening in 10^{19}eV - $10^{19.5}$eV
- Combining TASD, TAFD, Hires data, we observe the Instep feature in the Northern hemisphere at $10^{19.25\pm0.03}$eV with 5.3σ significance

TA result



PAO result



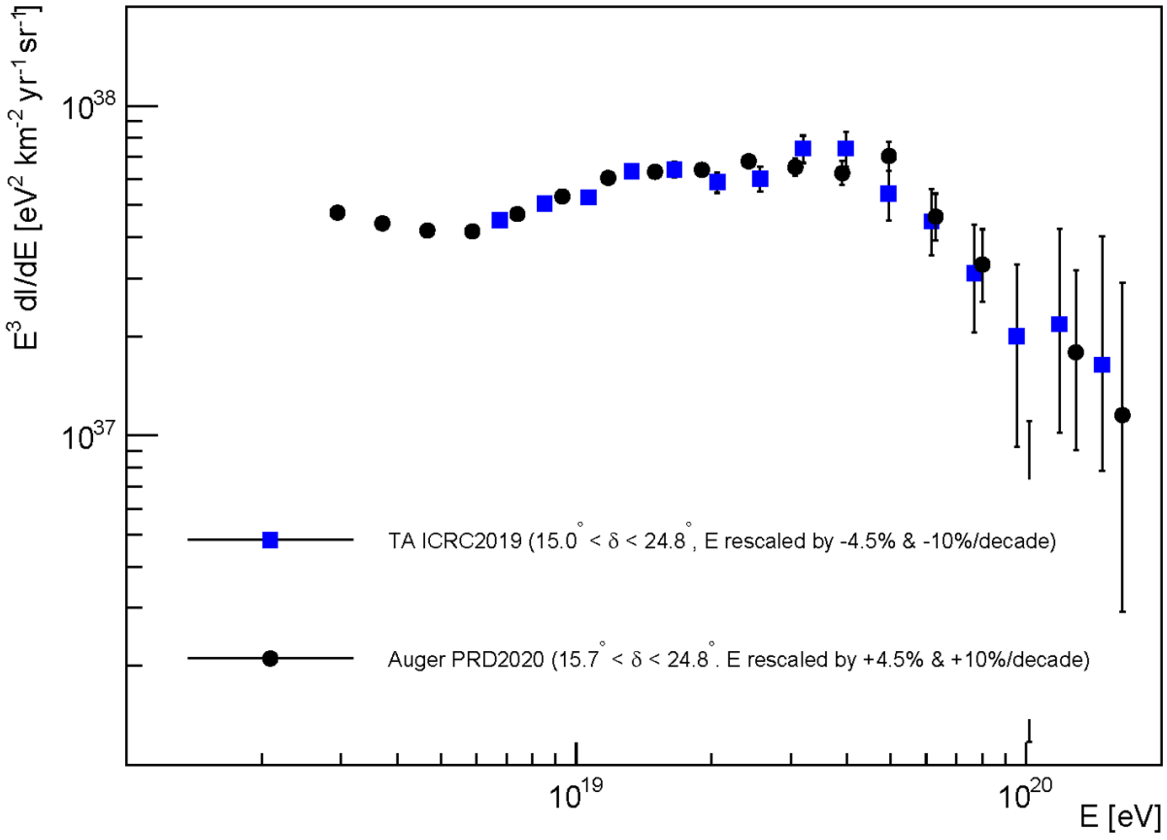
Parameters Comparison

Parameter	Auger	TA
γ_1	3.29 ± 0.02	3.23 ± 0.01
γ_2	2.51 ± 0.03	2.63 ± 0.02
γ_3	3.05 ± 0.05	2.92 ± 0.06
γ_4	5.1 ± 0.3	5.0 ± 0.4
$E_{\rm ankle}$/EeV	5.0 ± 0.1	5.4 ± 0.1
$E_{\rm instep}$/EeV	13 ± 1	18 ± 1
$E_{\rm cut}$/EeV	46 ± 3	71 ± 3

Spectrum

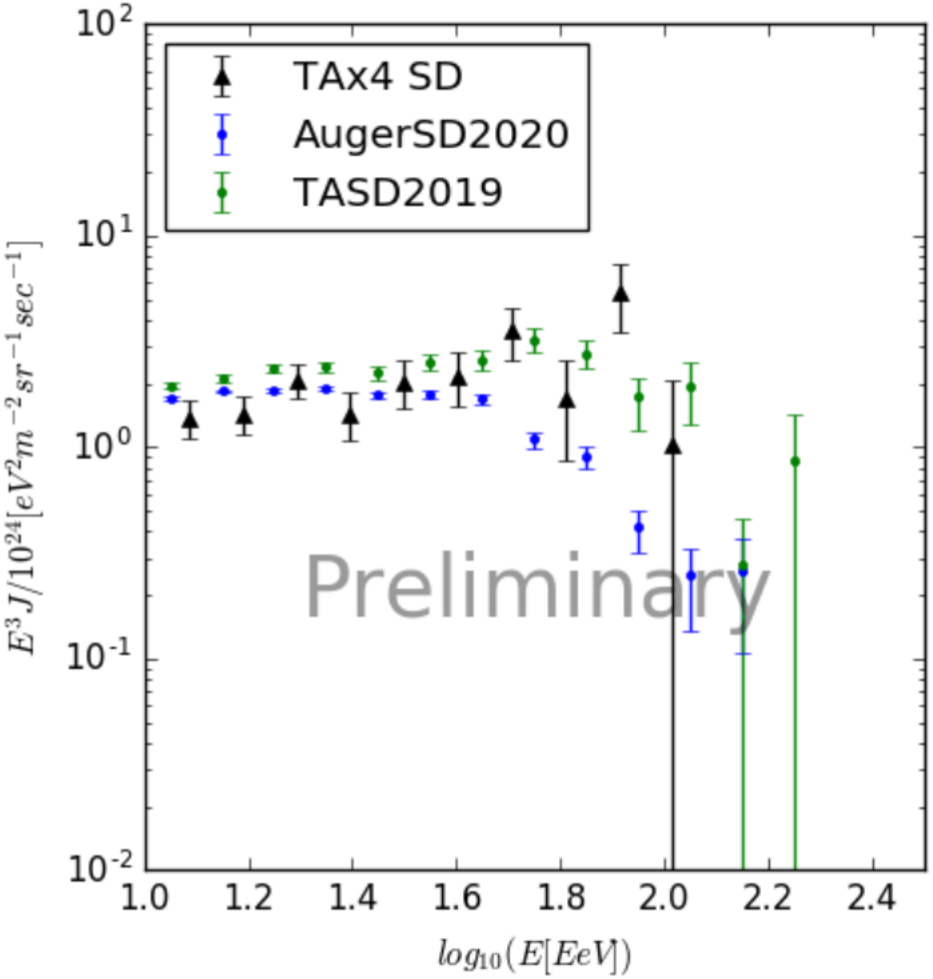
TA + PAO Joint spectrum working group result

- Absolute energy scale difference of 9 %
- Energy dependent shift ±10 % per decade

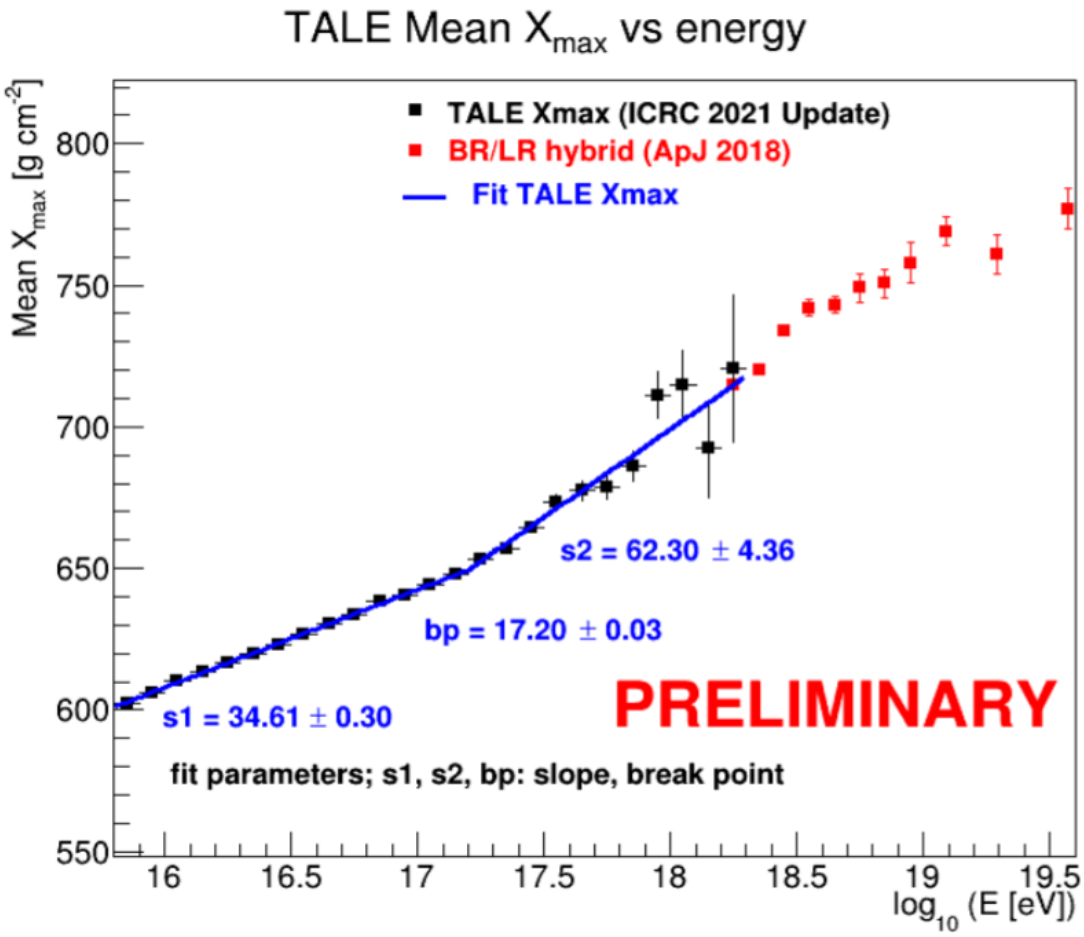


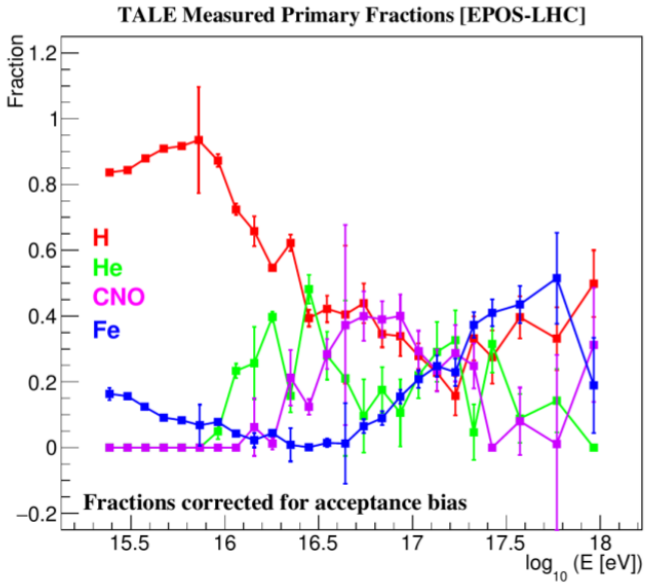
Spectrum

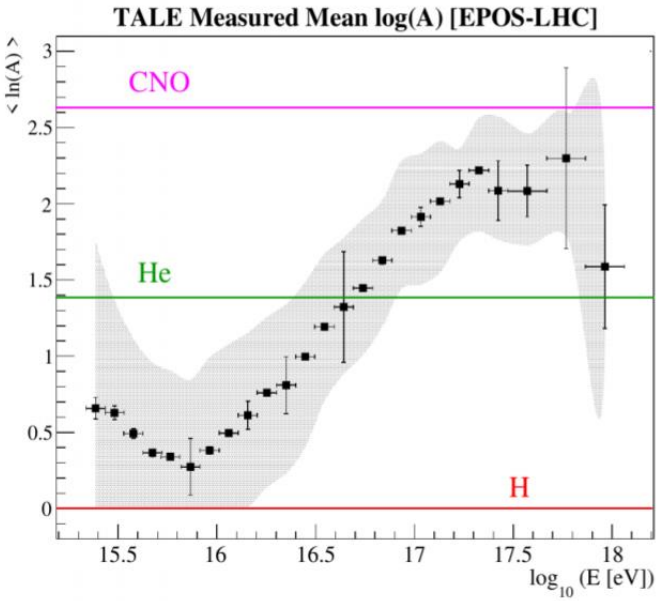
Preliminary TA×4 SD spectrum



TALE monocular Xmax

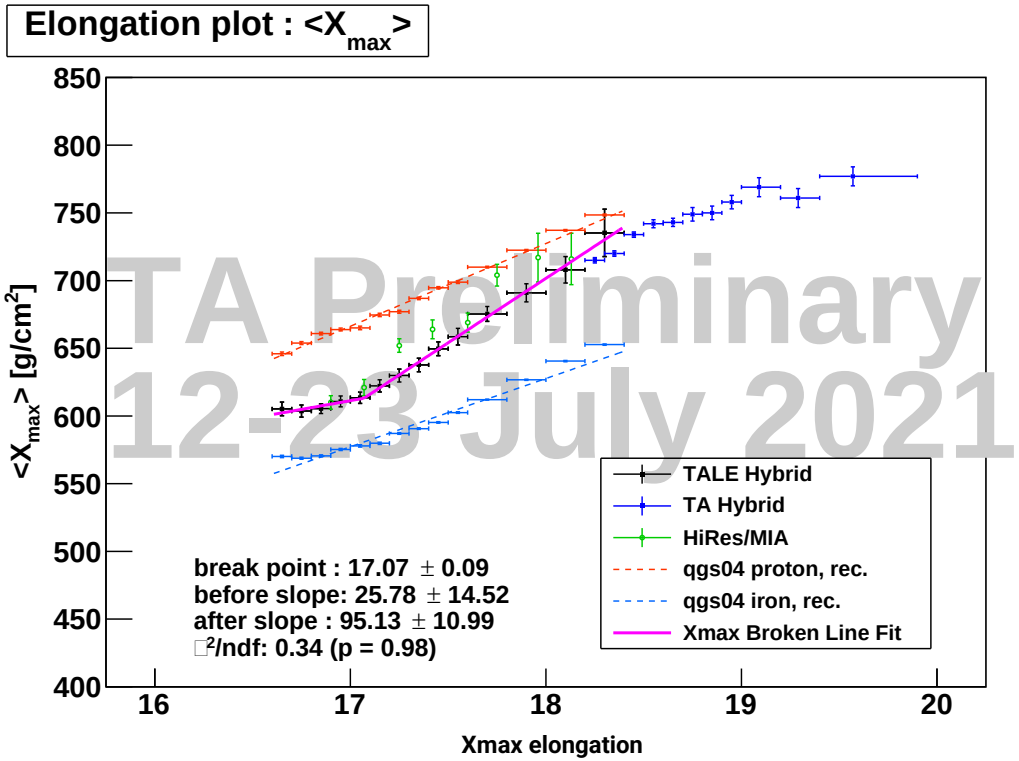




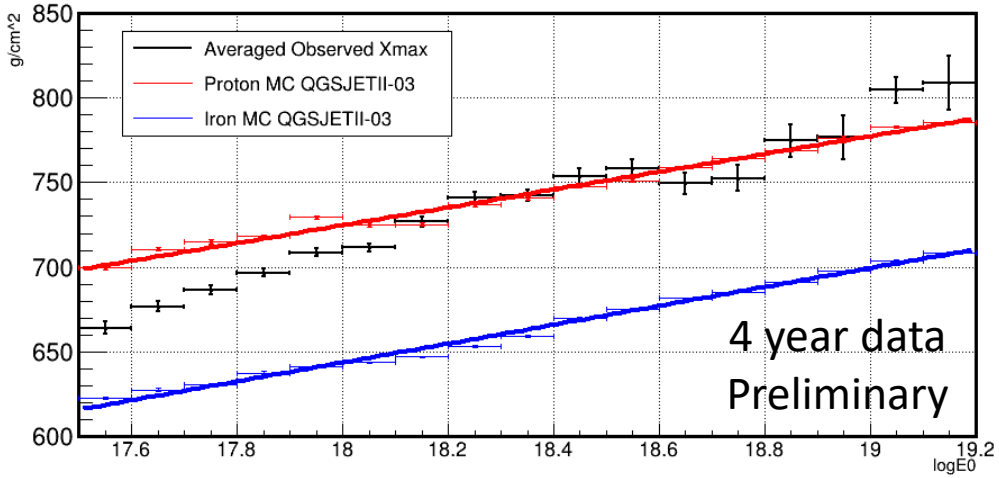


TALE & TA Hybrid trigger Xmax

TALE Hybrid



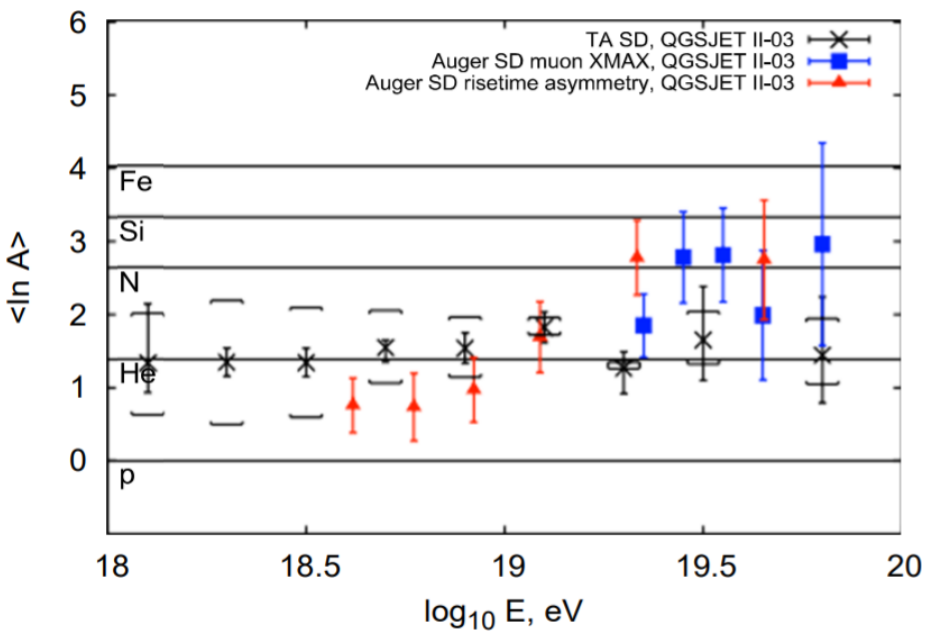
TA Hybrid trigger

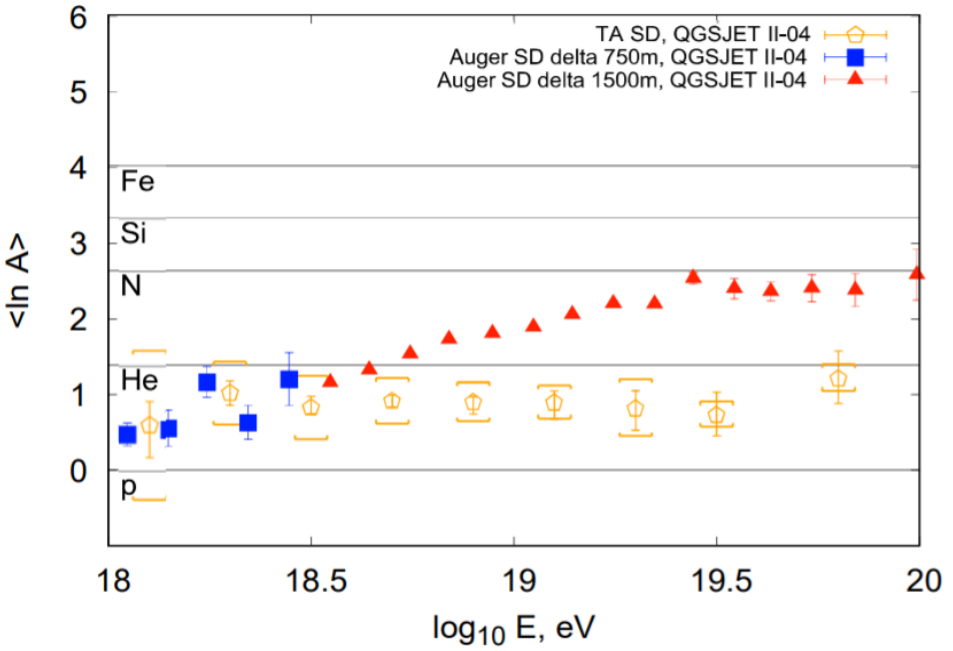


TA SD composition

Machine Learning based on BDT

- 16 composition-sensitive observables
- 12 years of TASD data



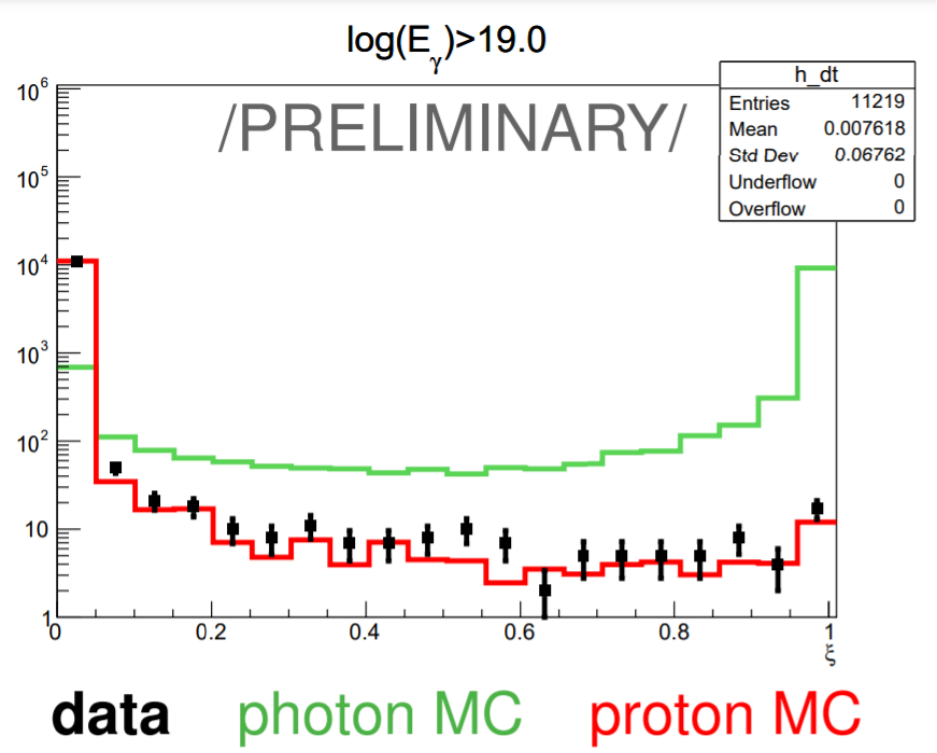


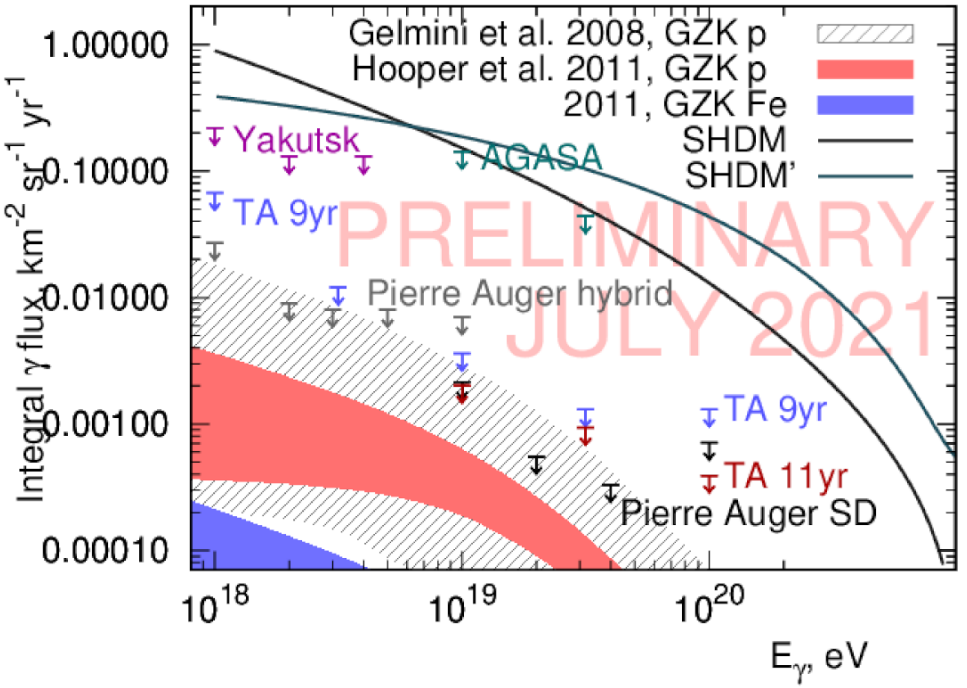
TA SD UHE photon limits

New p-γ classifier based on neural network

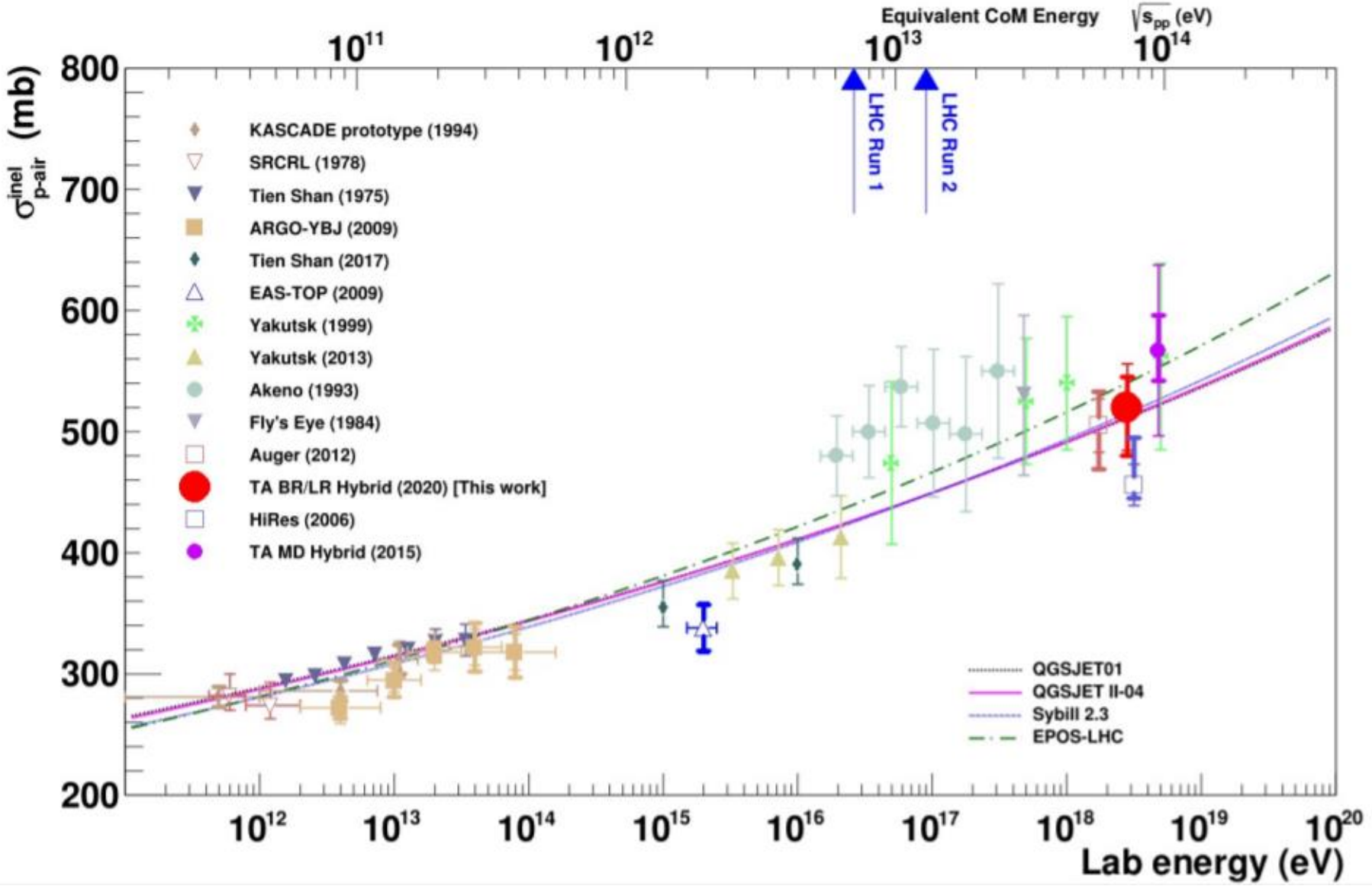
- 16 composition-sensitive observables
- Full time-resolved signals from all triggered SD

E_0, eV	$10^{19.0}$	$10^{19.5}$	$10^{20.0}$
γ candidates	2	1	0
$\bar{n}$ <	6.72	5.14	3.09
A_{eff}	3428	5546	7875
F_γ <	2.0×10^{-3}	9.3×10^{-4}	3.9×10^{-4}





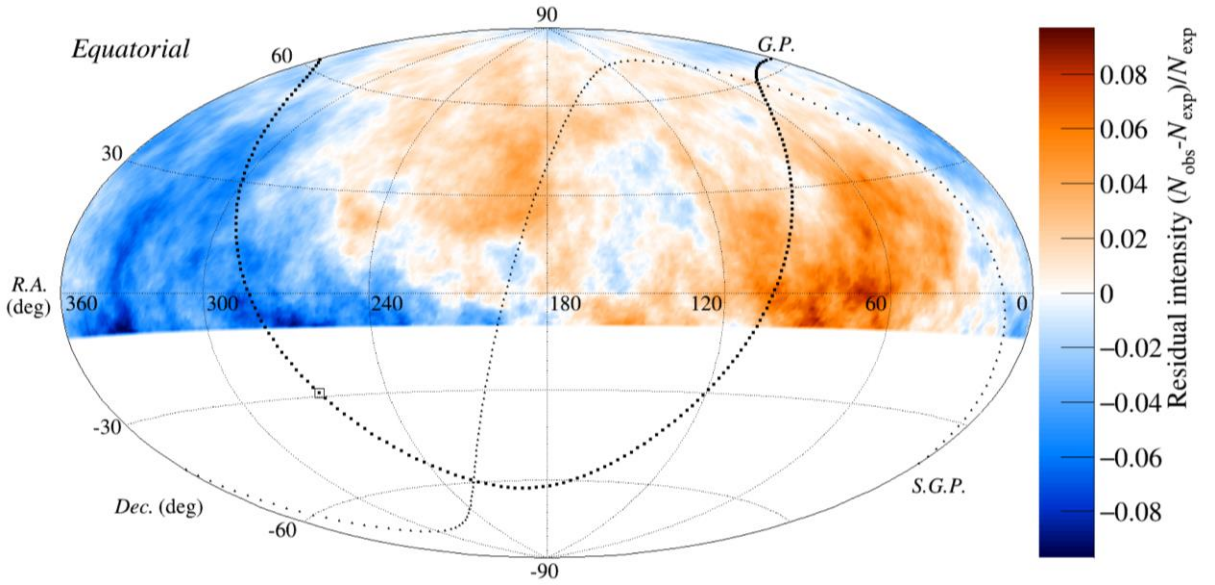
TA p-air cross-section

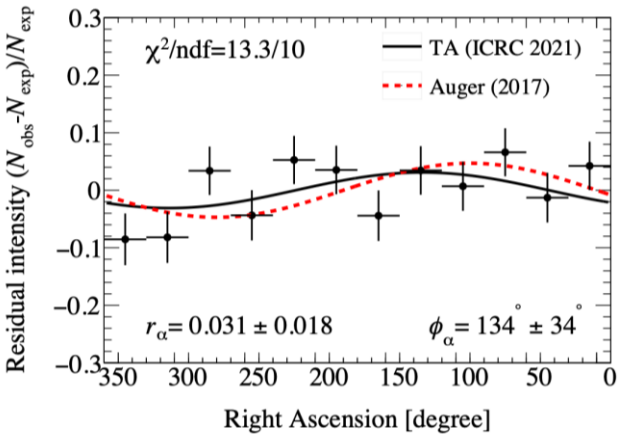


Anisotropy : Dipole

Residual intensity between data and isotropic distribution

- Energy threshold E > 8.8 EeV (Corresponding to Auger threshold E > 8 EeV)
- TASD 12 years data



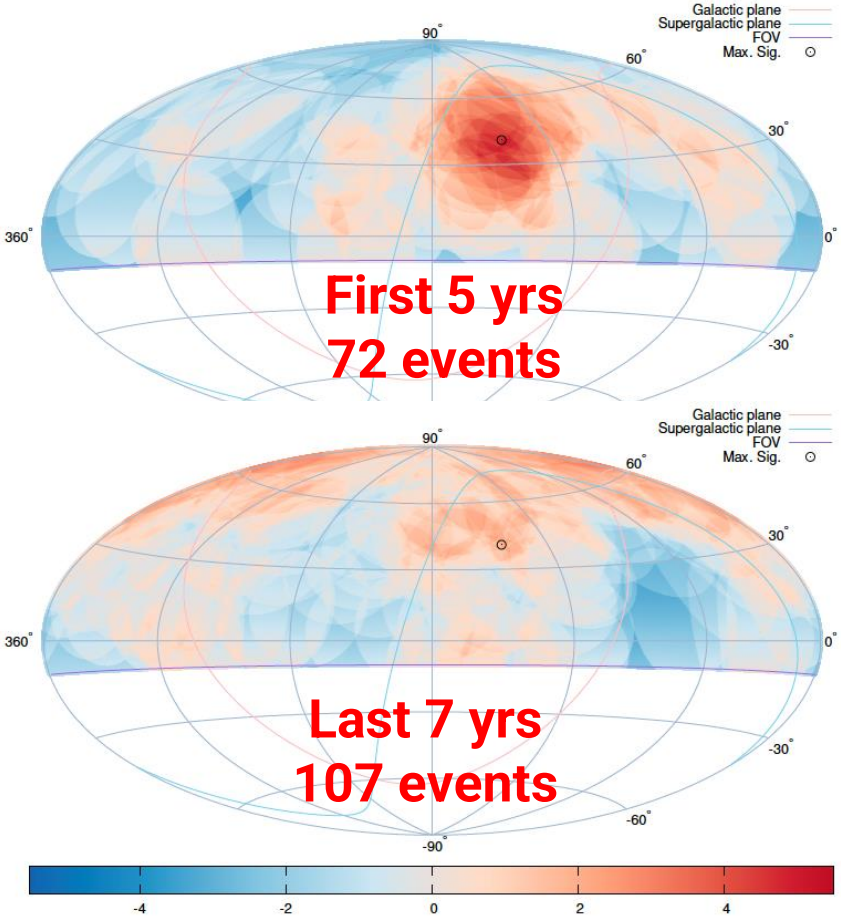


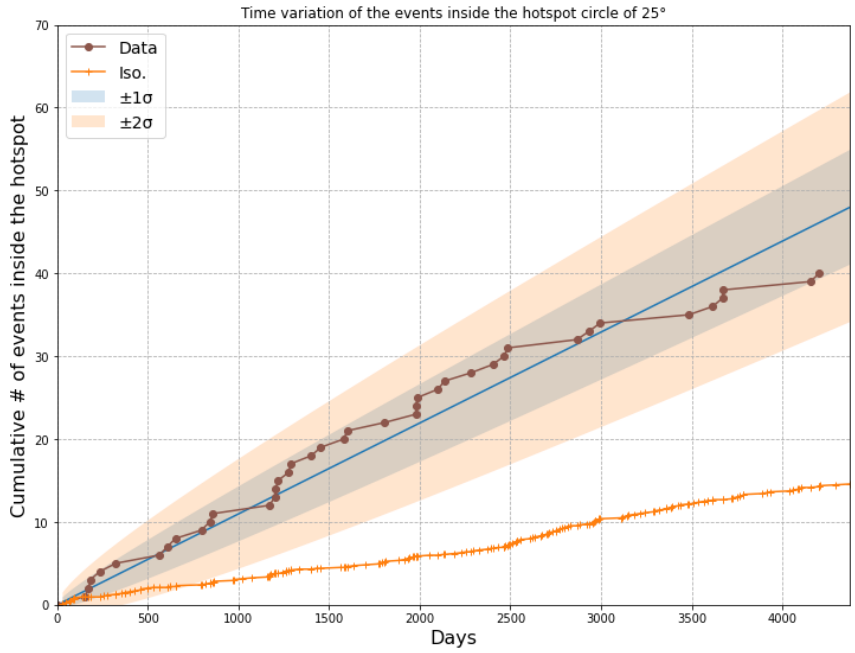
- TA result : r_α ~ 3.1 % Φ_α ~ 134°
- Auger result : r_α ~ 4.7 % Φ_α ~ 100°

Anisotropy : Hotspot

12 years Hotspot update

- Energy threshold E > 57 EeV
- Overall post-trial significance from 3.4 σ to 3.2 σ
- Growth rate of events inside the hotspot : Consistent with the linear in 1 σ

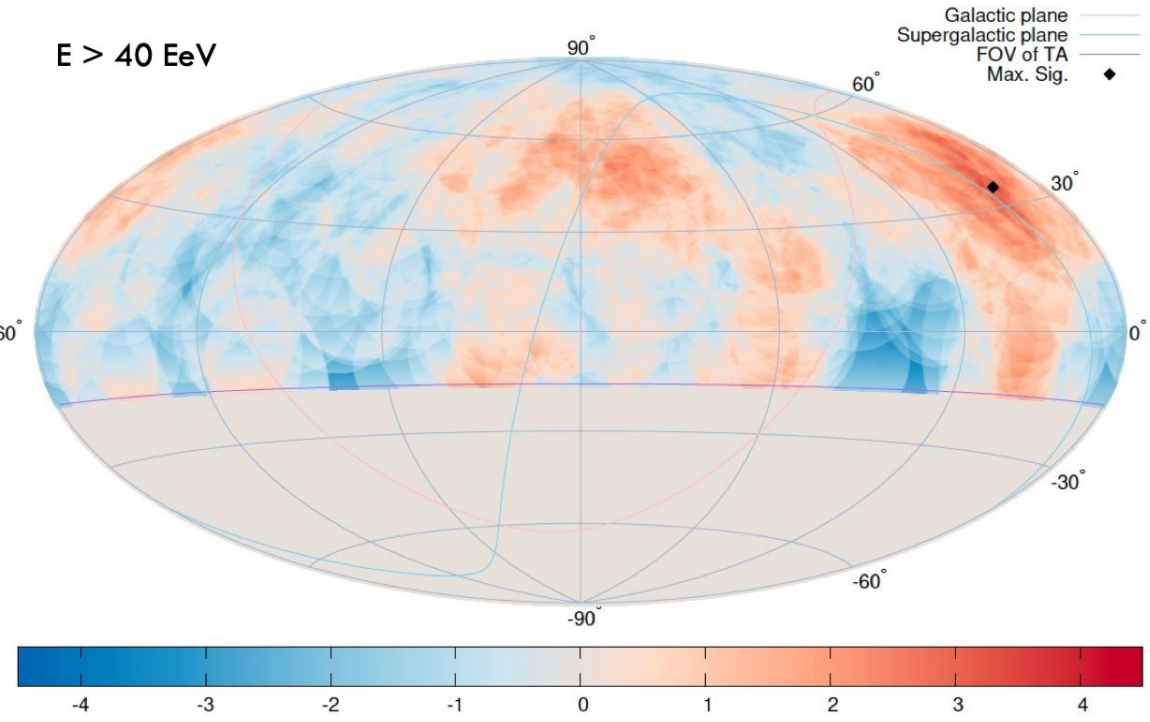


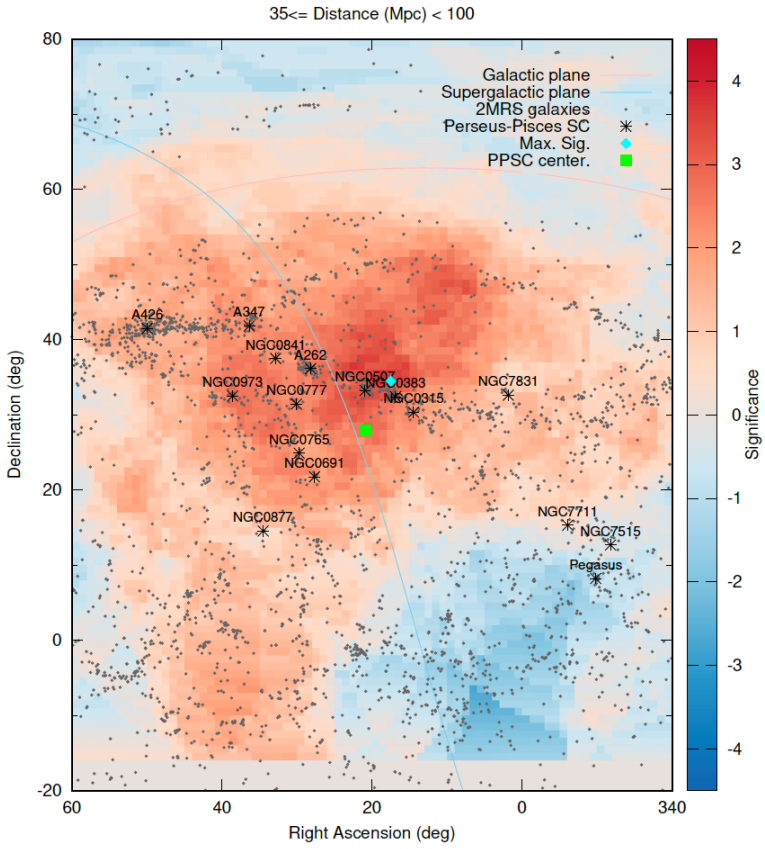


Anisotropy : Medium scale

Hint of excess in the direction of Perseus-Pisces supercluster

- Energy threshold E > 40 EeV

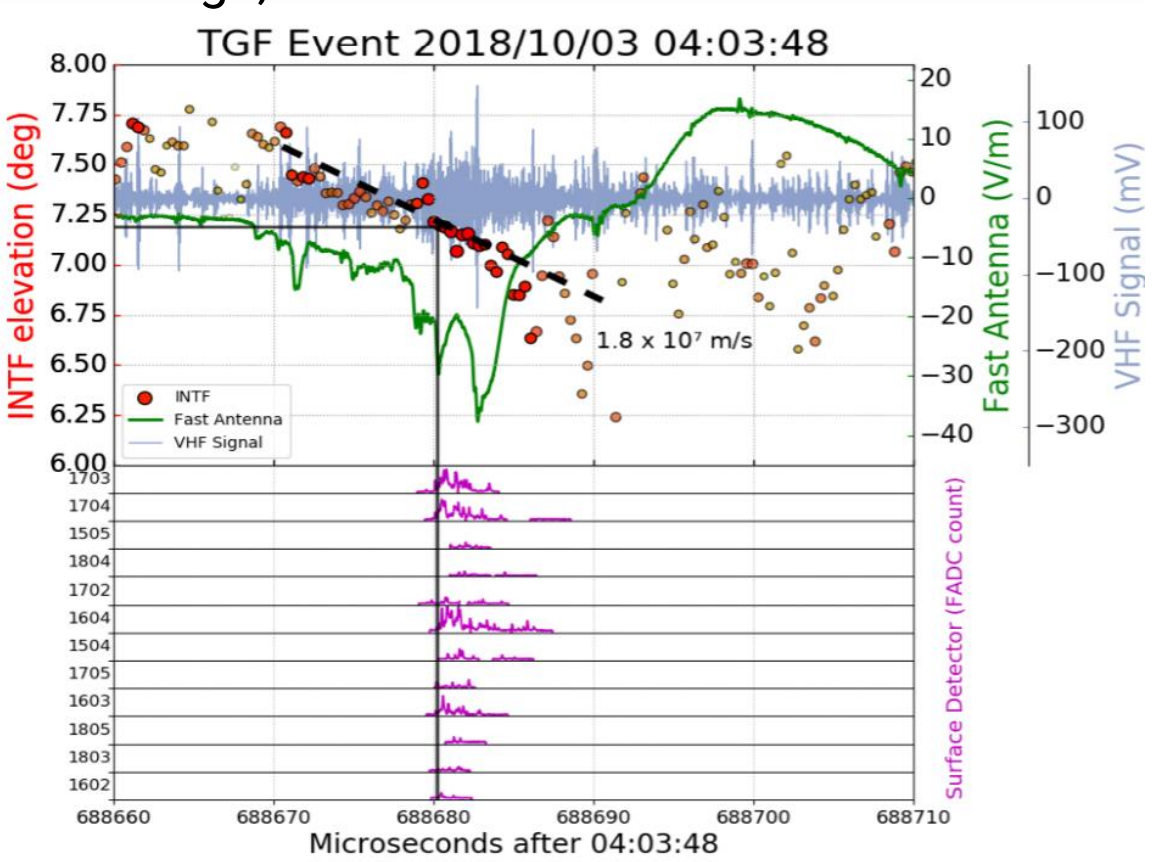




Terrestrial Gamma-ray Flash

Observation of TGF with TASD

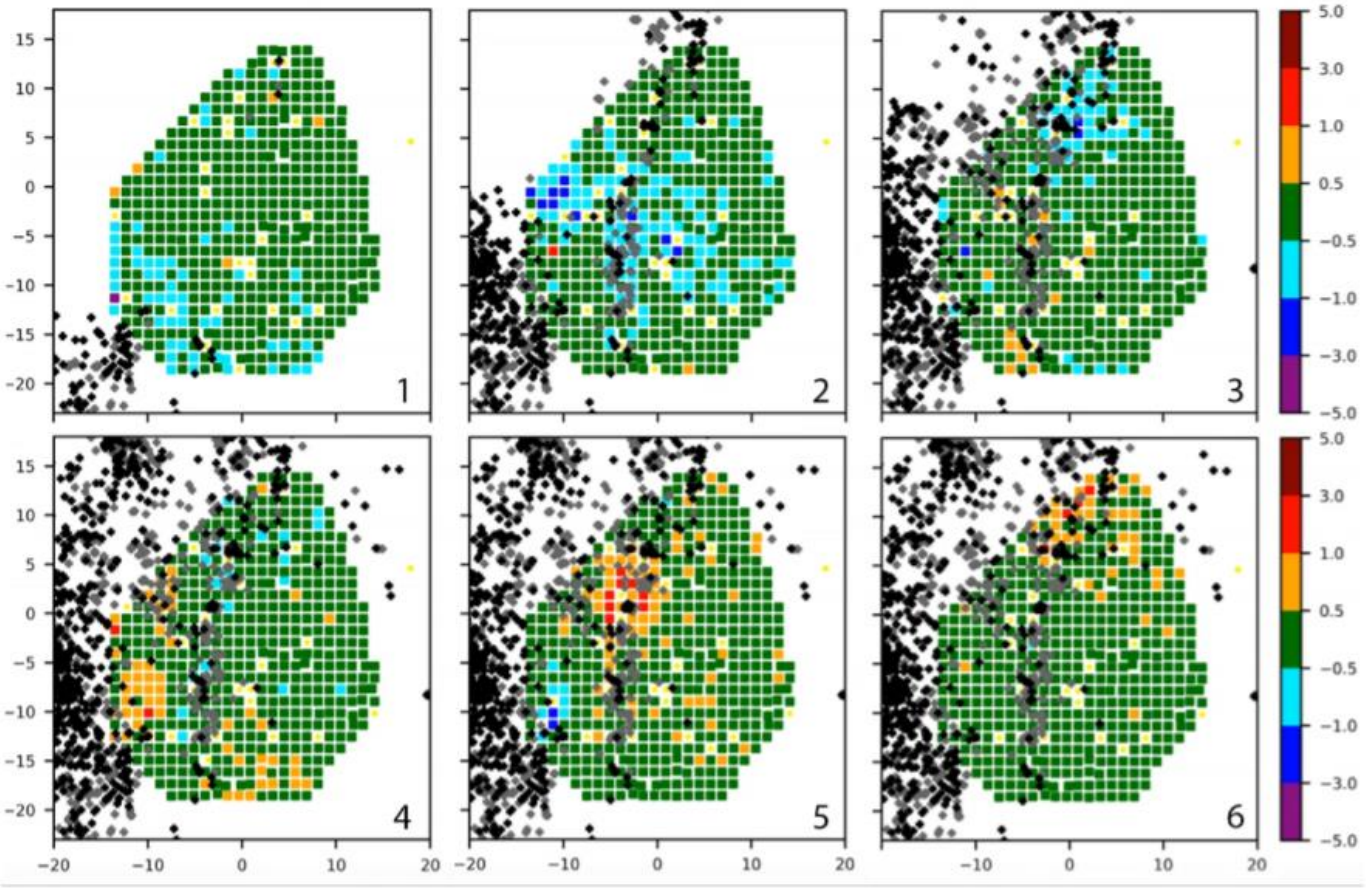
- Broadband interferometer (INTF)
  2D high-resolution reconstruction with three 20 - 80 MHz flatplate antennas
- Fast Sferic Sensor (FA)
  Detects E-field change, Identifies substructure of initial breakdown pulses



Thunderstorm

TASD trigger rate variation during thunderstorms

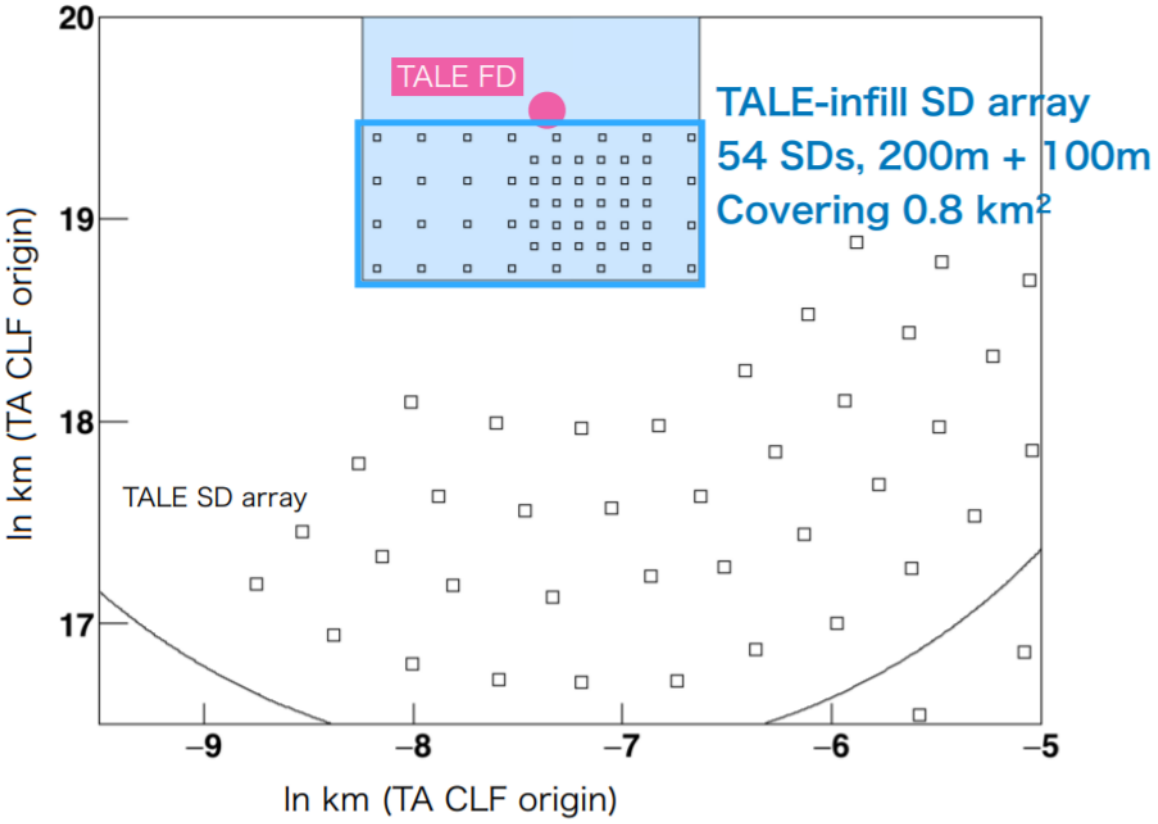
- Level-0 trigger rate is monitored at 10 minutes resolution
- Result may be interpreted by using EFIELD option of CORSIKA
- Trigger rate increase or deficit depends on E-field type of thunderstorm



TALE-infill

Ongoing extension plan for TALE for extra low-E sensitivity

- Aiming the physics of PeV cosmic ray
- 100 m + 200 m spacing covering 0.8 km^2



Summary

1. Energy spectrum measured for 5 decades, $10^{15.5}$eV to $10^{20.5}$eV
   - New feature “Instep” in the energy spectrum at ~$10^{19.3}$eV
   - TALE energy spectrum indicated that 2nd knee may be resulted from Peters cycle

2. TALE Xmax shows composition becoming heavier between knee and 2nd knee

3. TA Hybrid data is compatible with predominantly light elements between $10^{18.0}$eV and $10^{19.1}$eV

4. Indications of anisotropy at highest energy
   - Hotspot from 12 years of data in the direction of Ursa Major (3.2σ)
   - Hint of excess in the direction of Perseus-Pisces E > $10^{19.3}$eV

5. TA×4 started operation and preliminary energy spectrum is measured

6. More expansion plan – TALE infill is ongoing