Recent results and status of the Telescope Array Experiment

Eiji Kido for the Telescope Array Collaboration

Riken

Outline

- The Telescope Array (TA) Experiment
  - Detectors
  - Energy Spectrum
  - Anisotropy
  - Composition
- Extension of the TA Experiment
  - The TAx4 Experiment
- Summary

Telescope Array collaboration

S. Ogio, ICRC2019

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TA Detectors

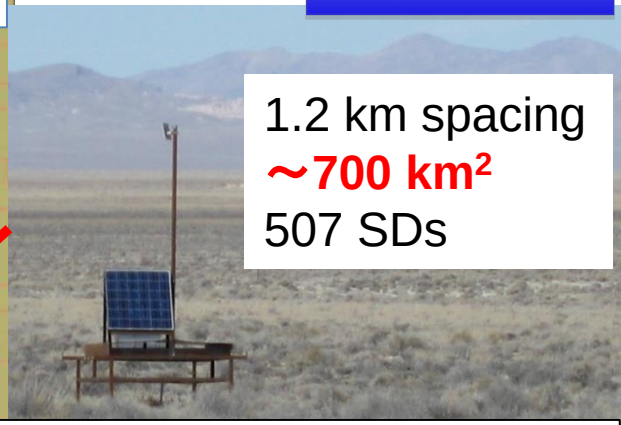
FD station

MDFD

TALE SD array

SD array

Surface Detector (SD)



1.2 km spacing
~700 km²
507 SDs

Latitude 39.30° N
Longitude 112.91° W
Height: 1382 m

CLF

LRFD

28km

BRFD

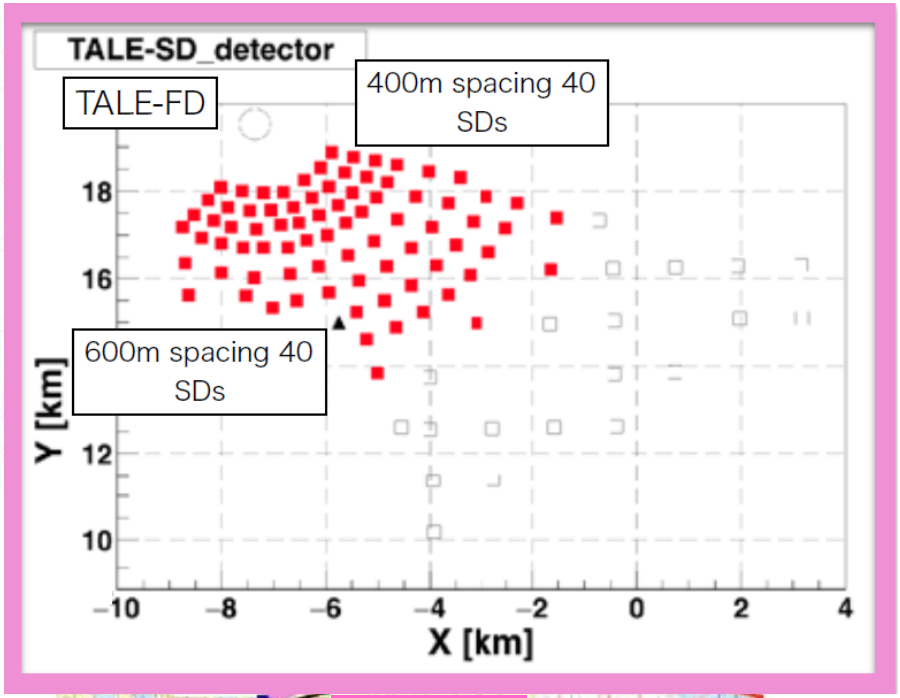
- **Largest cosmic-ray observatory in the northern hemisphere**
- **Hybrid observation by SD and FD**

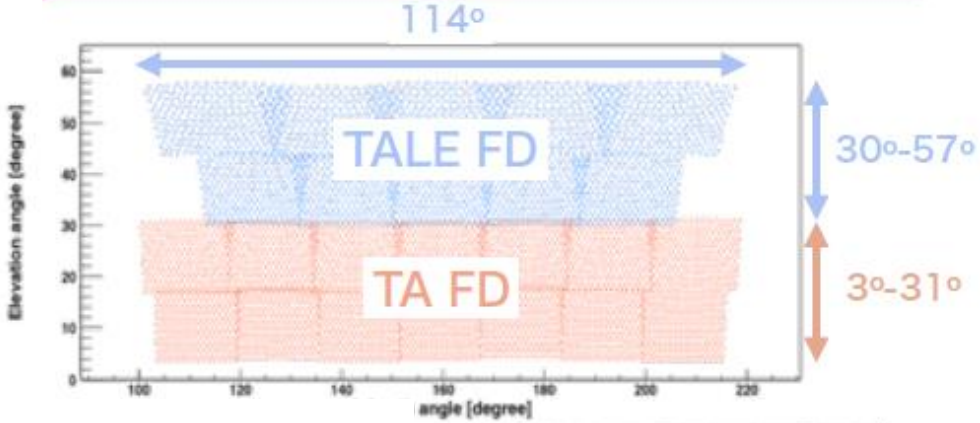
Fluorescence Detector (FD) station

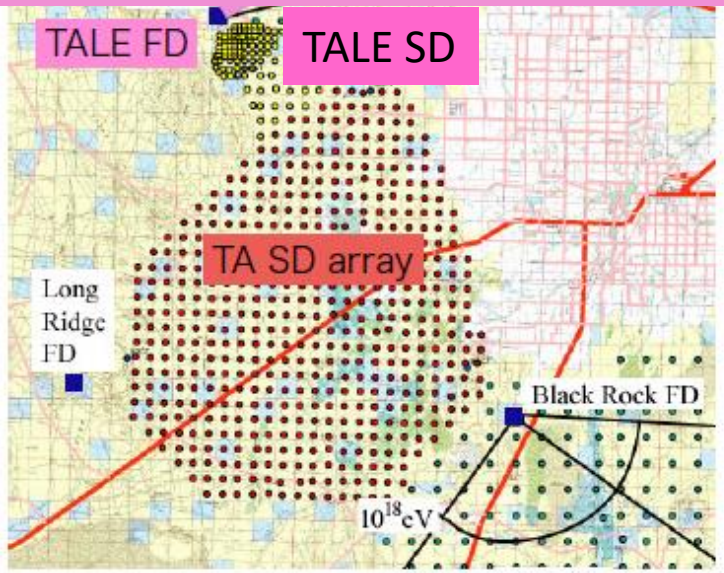
12 telescopes

Full operation from May 2008
Utah, USA

TALE (TA Low-energy Extension) Detectors





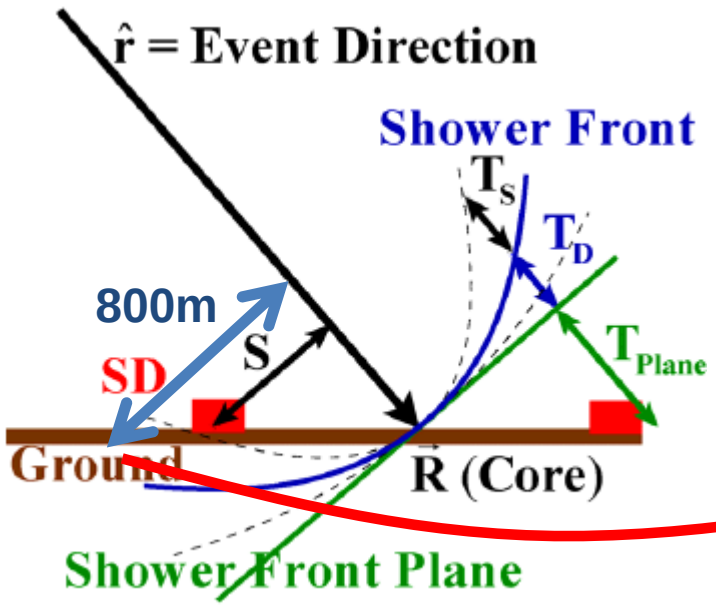


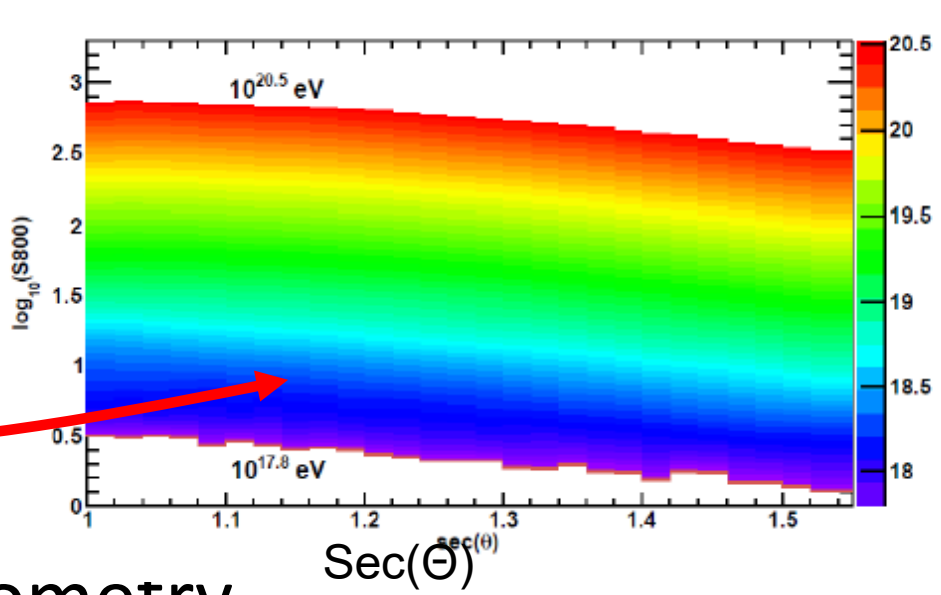
TALE FD was installed in Nov. 2012

Operation since Sep. 2013

Hybrid trigger: Sep. 2018

Event Reconstructions with SDs





- Timing fit→Shower Geometry
- Lateral distribution fit →S(800)→Energy from MC

→ rescale to calorimetrically measured E_{FD} using SD and FD hybrid events

S(800): energy depositions which are converted in VEM unit.

Event reconstruction

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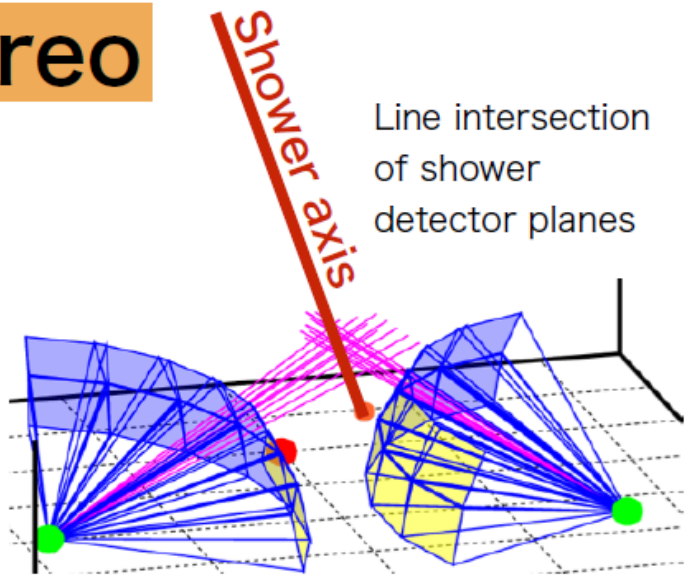
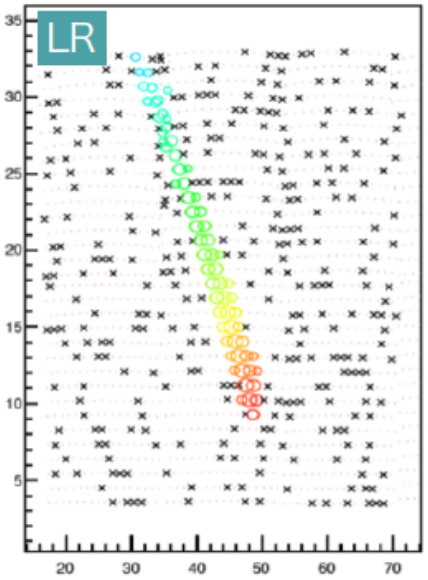
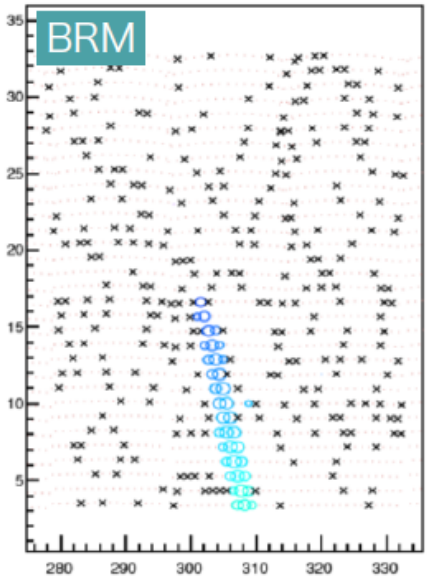
Stereo

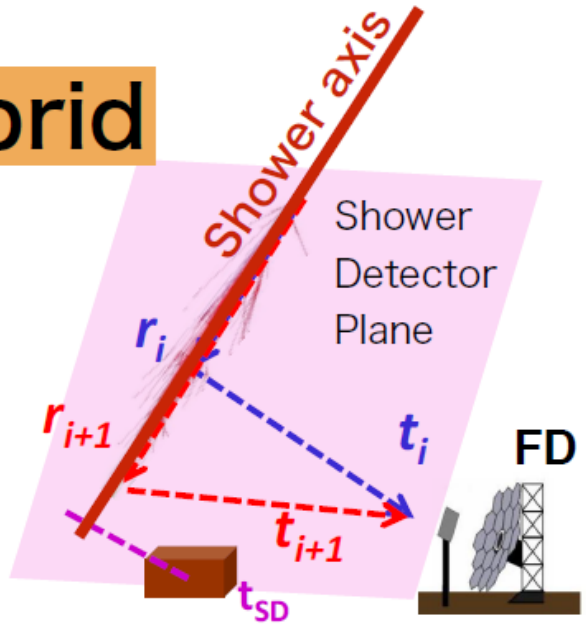


observed images

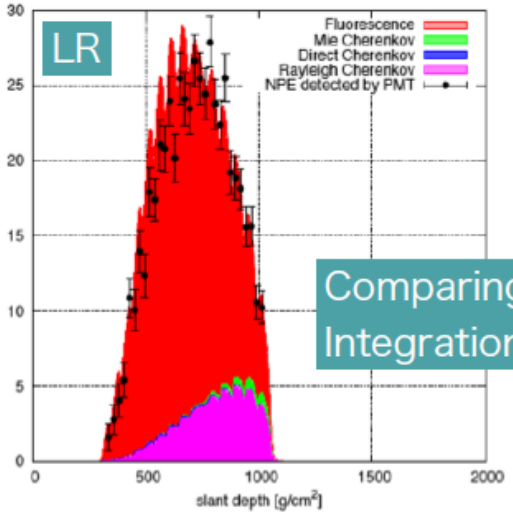


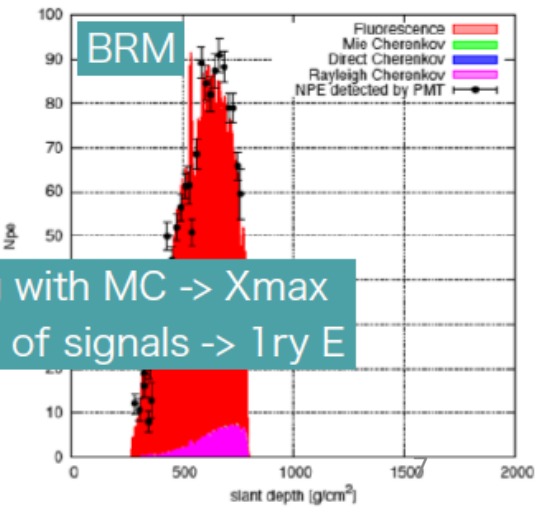


Hybrid



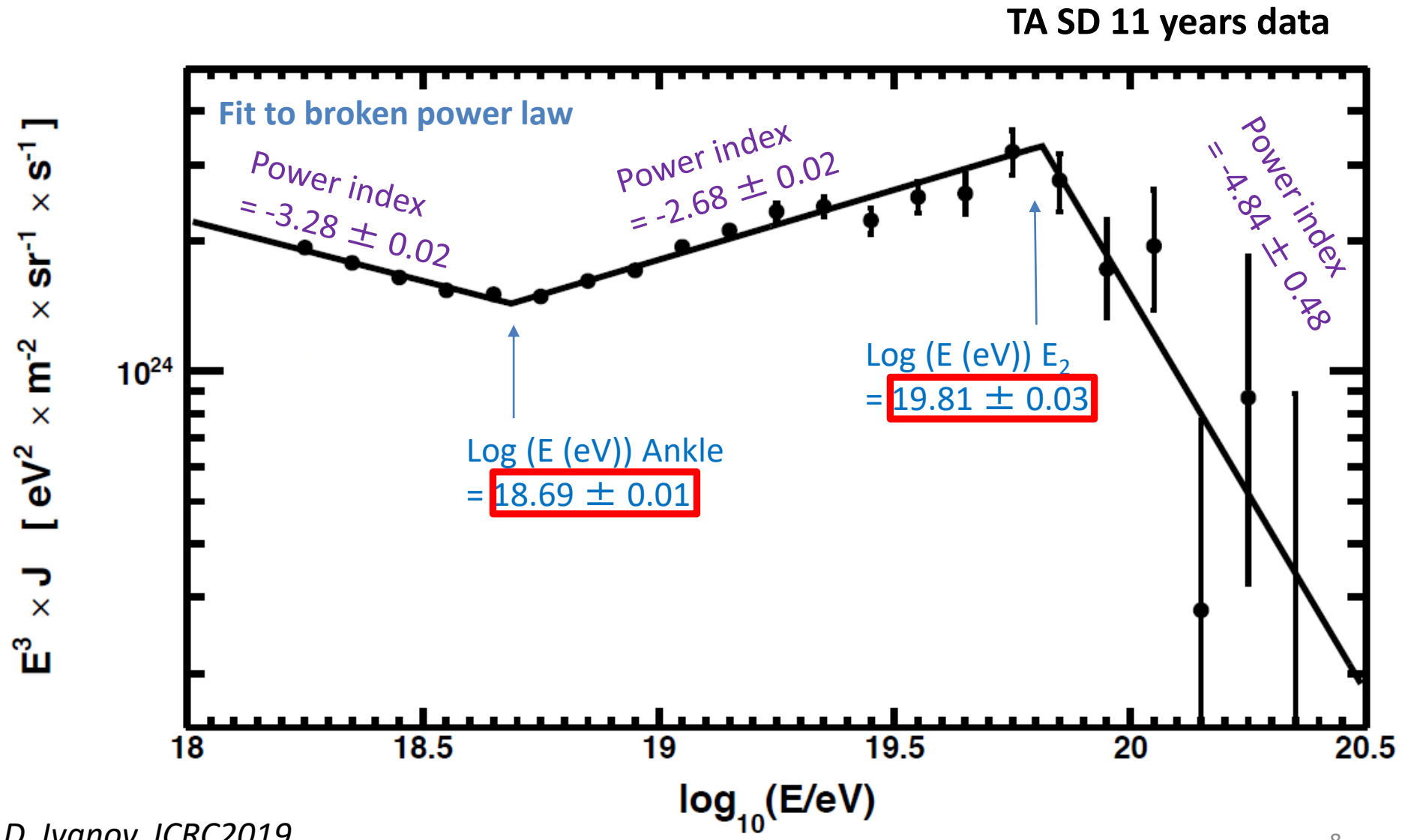
reconstructed shower profiles





Comparing with MC -> Xmax
Integration of signals -> 1ry E

Energy Spectrum with TA SD



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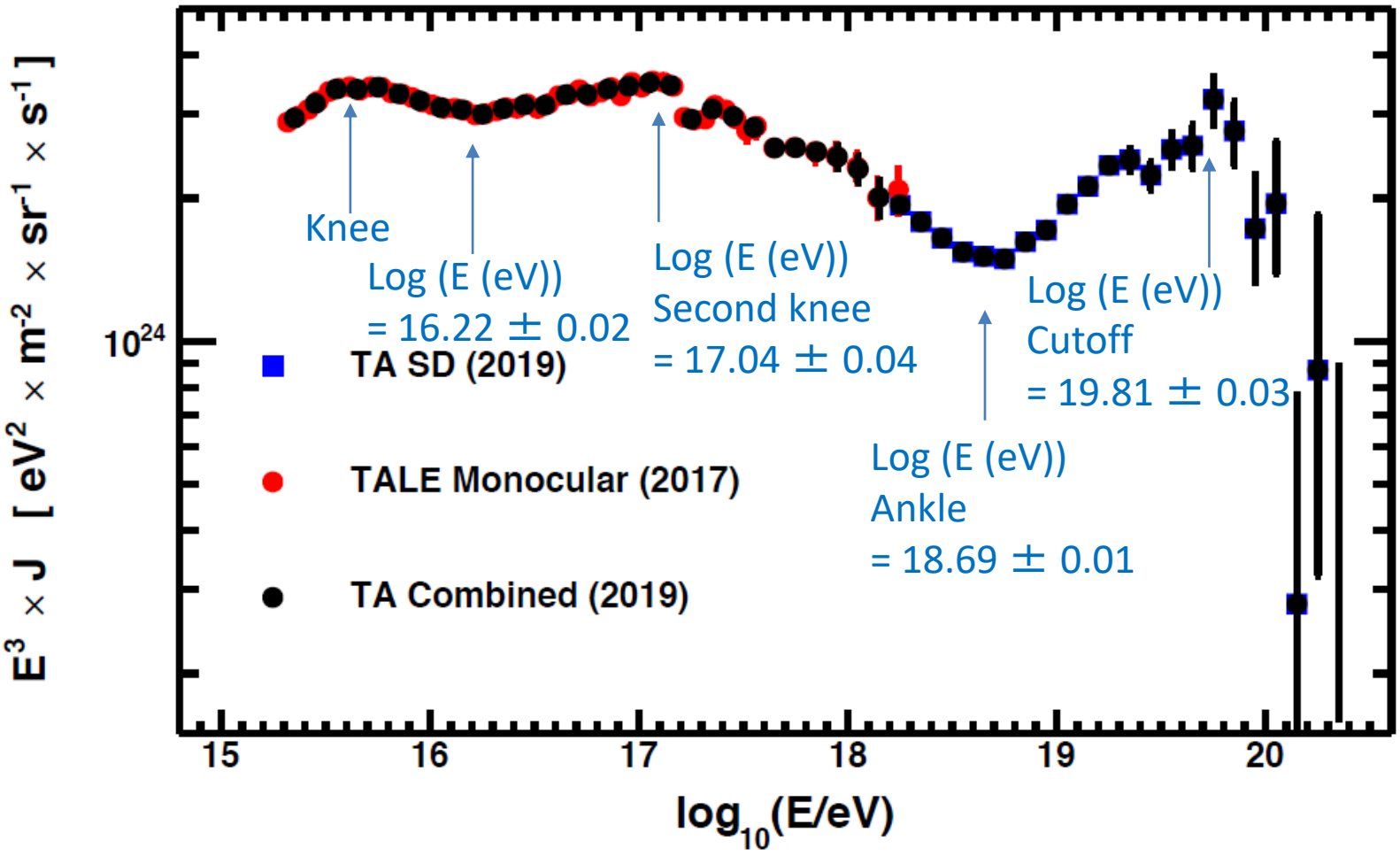
Combined Energy Spectrum with TALE FD Mono

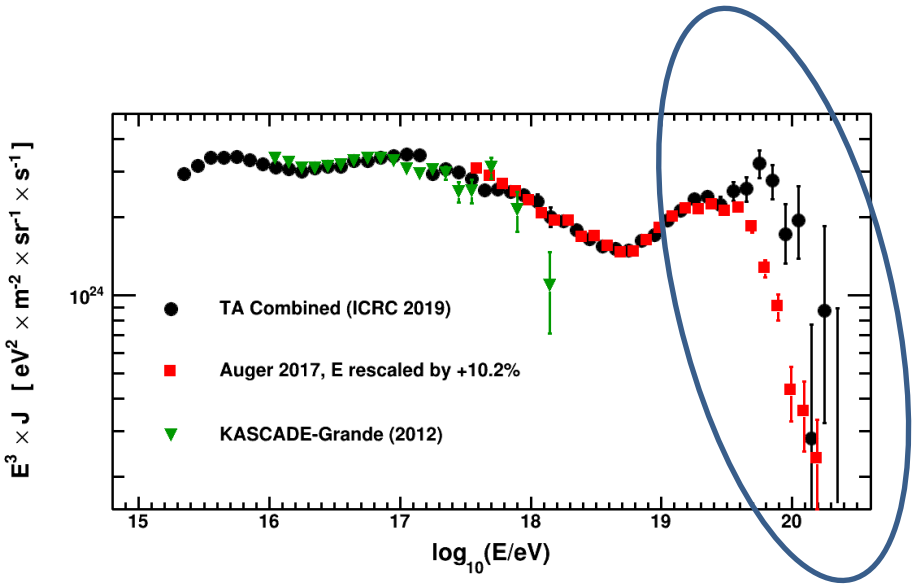


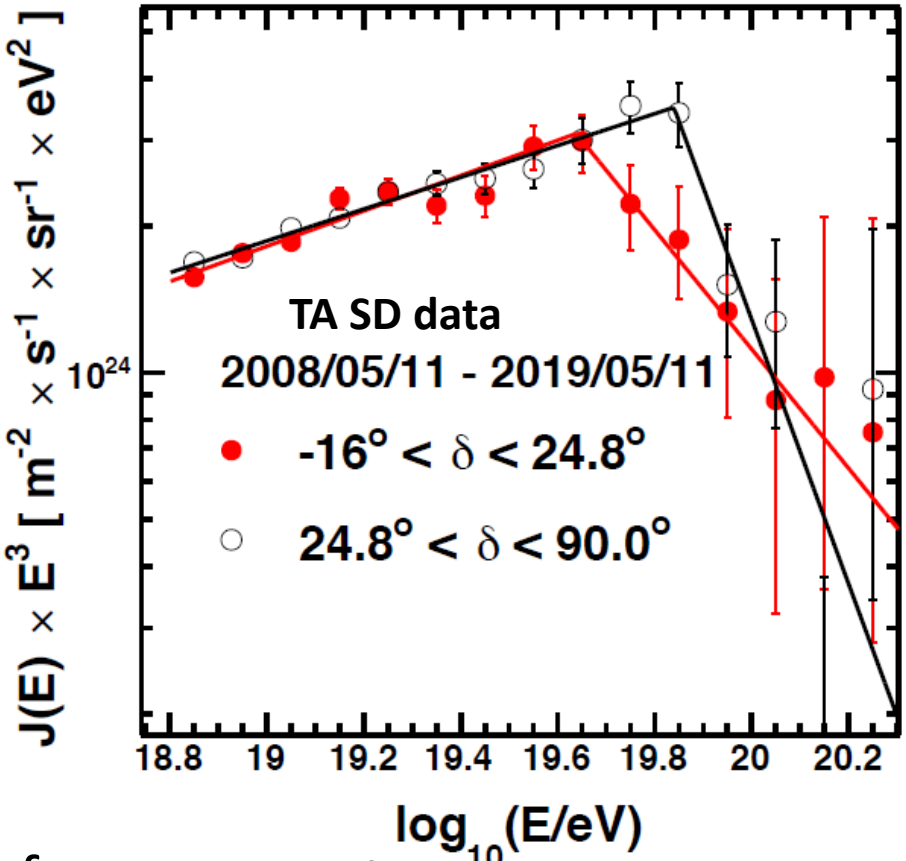
Combined TA spectrum using
22 months TALE FD monocular data +
11 years TA SD data

D. Ivanov, ICRC2019

Declination Dependence of Energy Spectrum

D. Ivanov, ICRC2019





- Difference of the cutoff energies of energy spectra
  - log(E/eV) = 19.64 ± 0.04 for lower dec. band (-16° - 24.8°)
  - log(E/eV) = 19.84 ± 0.02 for higher dec. band (24.8° - 90°)
- The global significance of the difference was estimated to be **4.3σ**

Hotspot: E > 57 EeV

Original hotspot reported in 2014, from 5 years of data

Ap. J., 790, L21(2014)

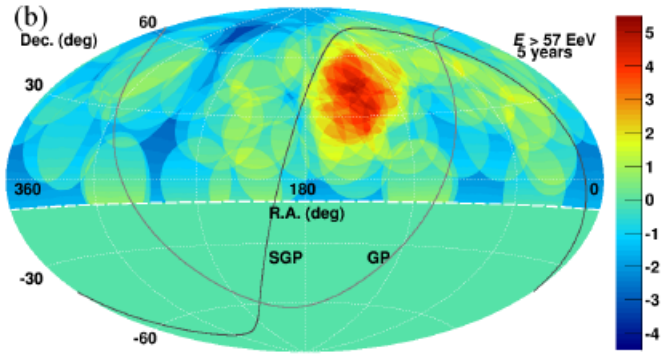
E > 57 EeV (Observed 72 events)

20° over-sampling circle

19 events fall in "Hotspot" centered at (146.7°, 43.2°)

(Expected = 4.5 events)

local significance 5.1σ, post trial significance 3.4σ



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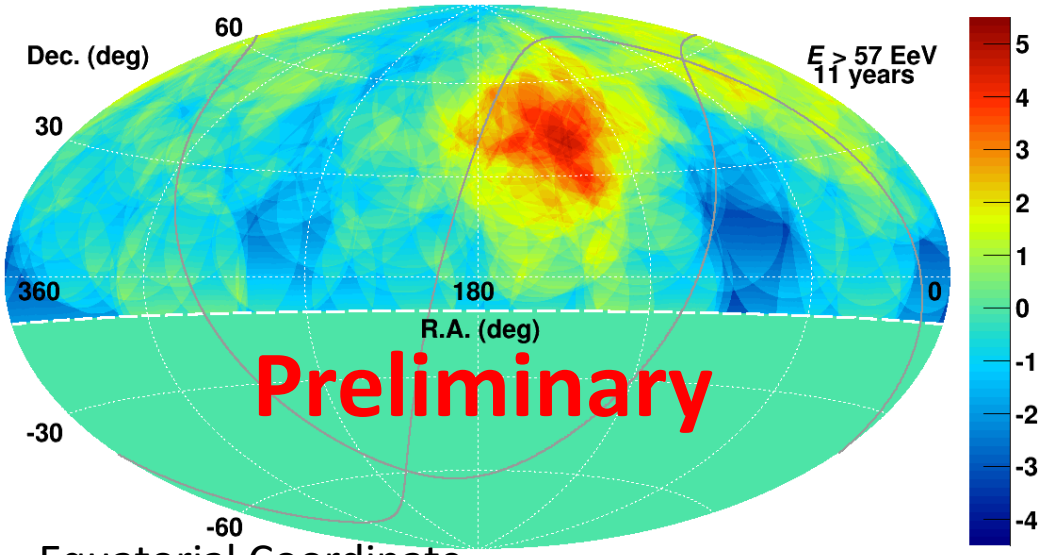
TA SD 11 years data

Significance map from isotropy expectation



Equatorial Coordinate

E > 57 EeV, in total 168 events

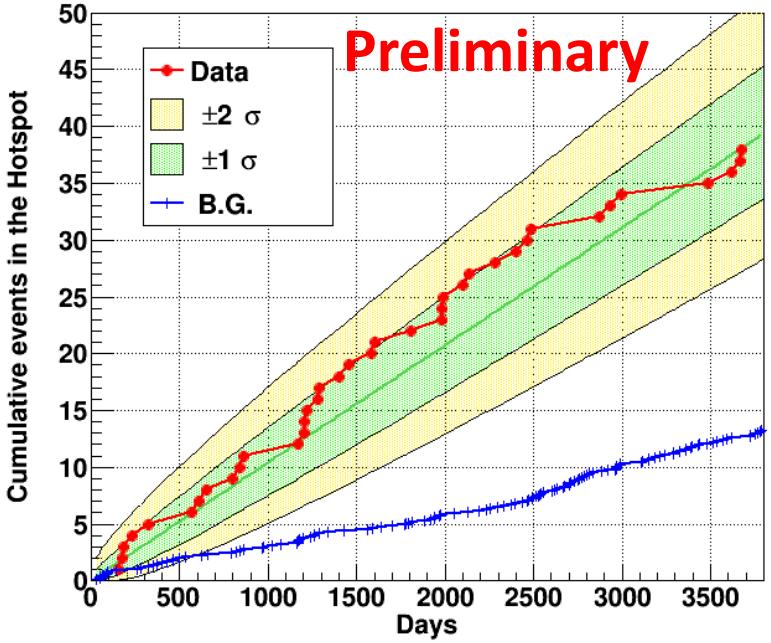
38 events fall in Hotspot (α=144.3°, δ=40.3°, 25° radius, 22° from SGP), expected=14.2 events

local significance = 5.1 σ, chance probability → 2.9σ

25° over-sampling radius shows the highest local significance (scanned 15° to 35° with 5° step)

Hotspot : E > 57 EeV

Events within hotspot circle



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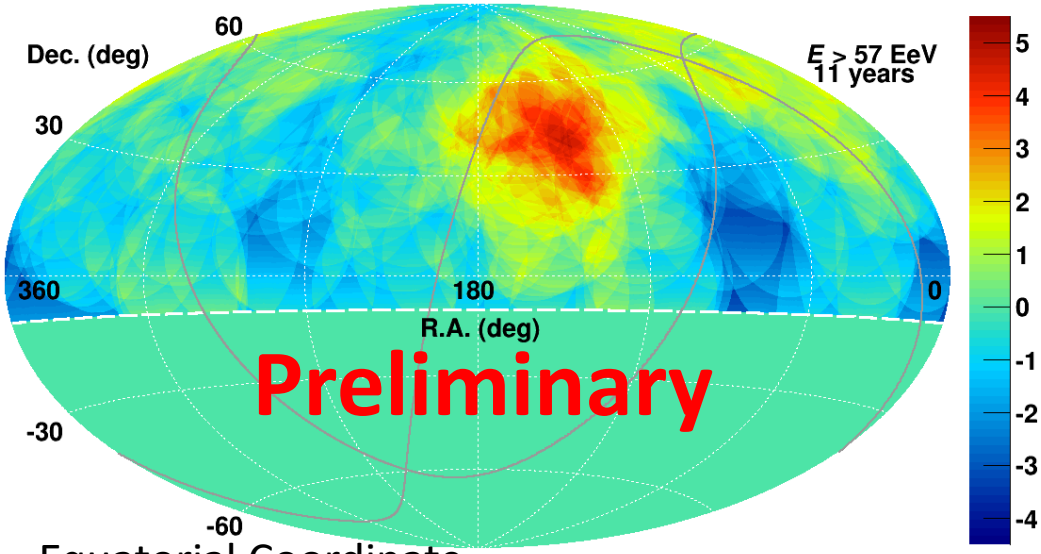
Significance map from isotropy expectation

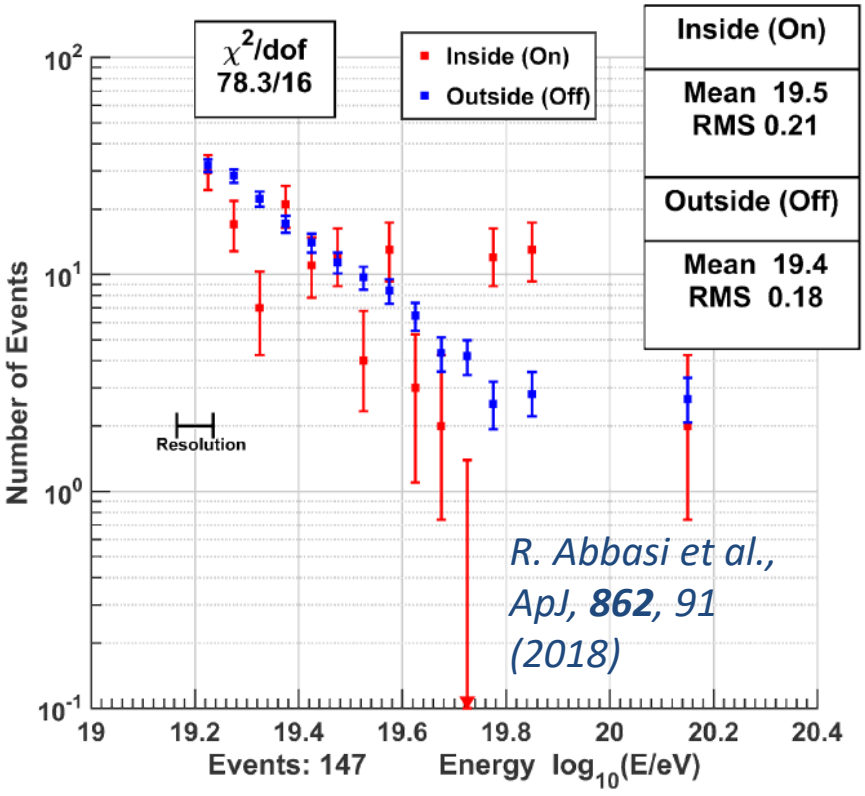


Equatorial Coordinate

The cumulative events inside the hotspot circle (25°-radius cirlce) defined by the 11-year.
The increase rate of the events inside the hotspot circle:

Consistent with the linear increase within ~1σ

Energy Spectrum at around the Hotspot



*R. Abbasi et al., ApJ, **862**, 91 (2018)*

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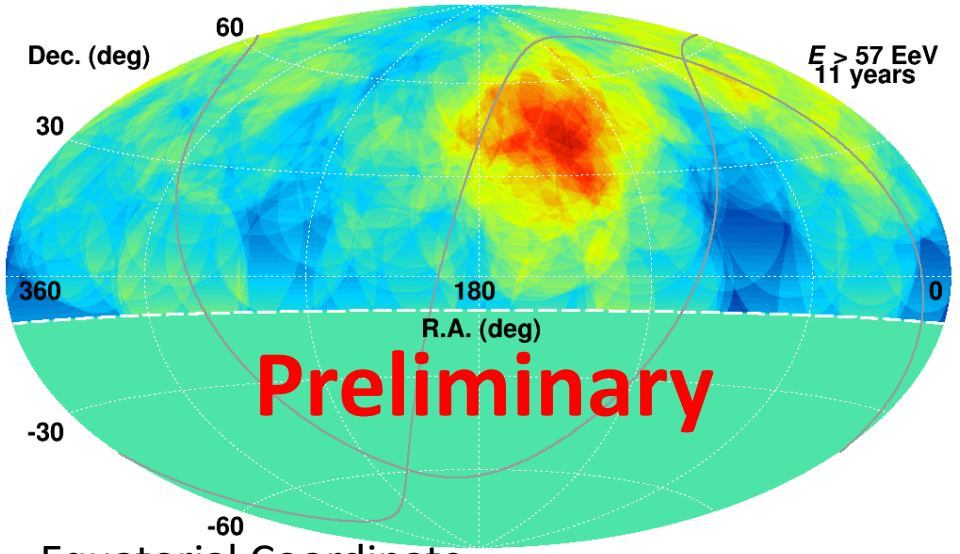
Significance map from isotropy expectation



Equatorial Coordinate

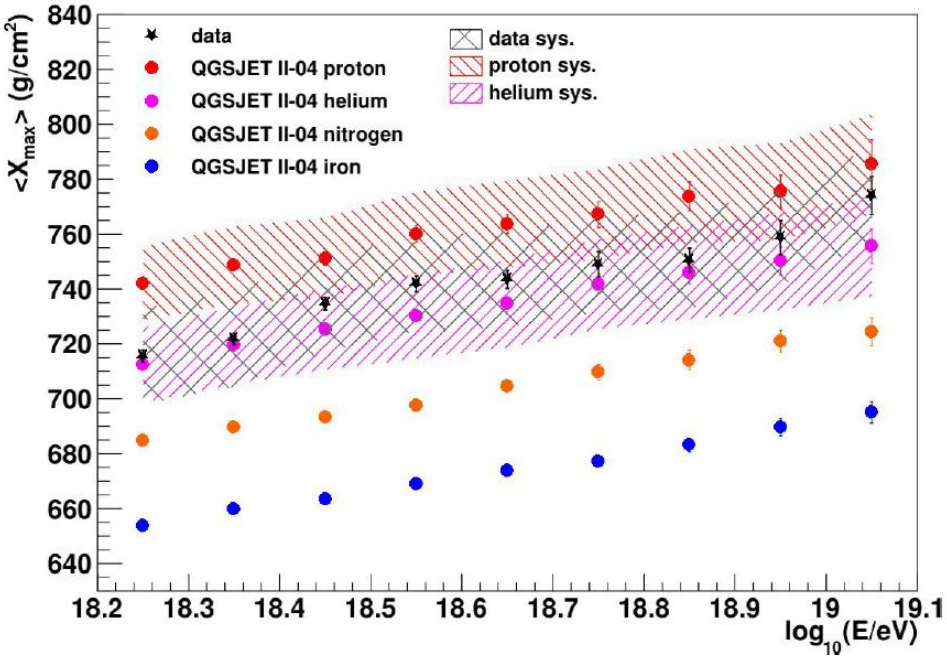
Energy spectrum anisotropy E > $10^{19.2}$ eV
@7° from hotspot, ～30 deg. circle
post trial significance:**3.7σ**

Composition Analysis with TA SDFD Hybrid Xmax

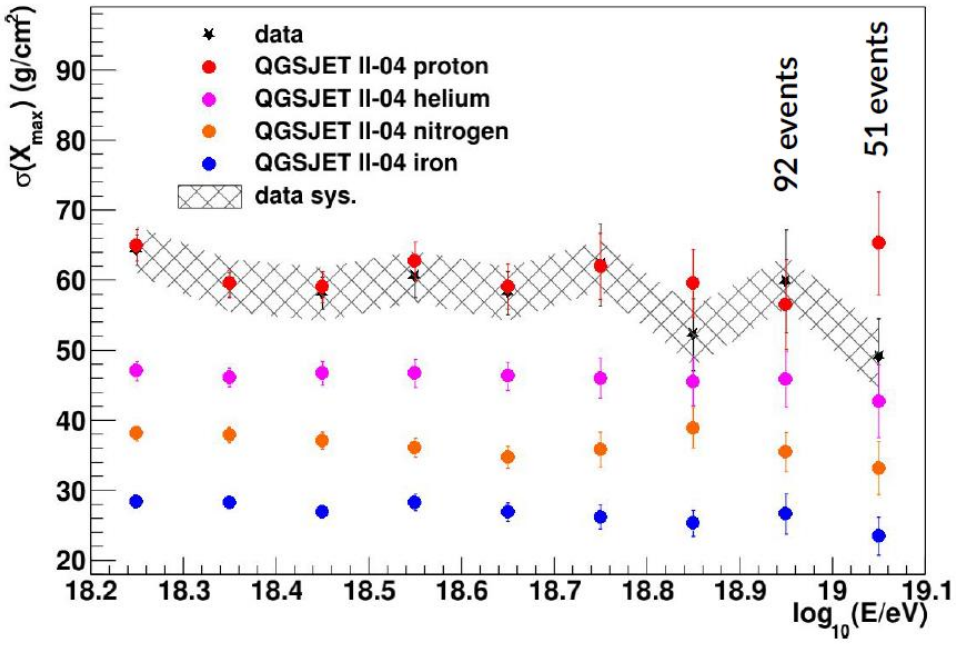
W. Hanlon, ICRC2019

10 years SD and FD hybrid data

Mean Xmax



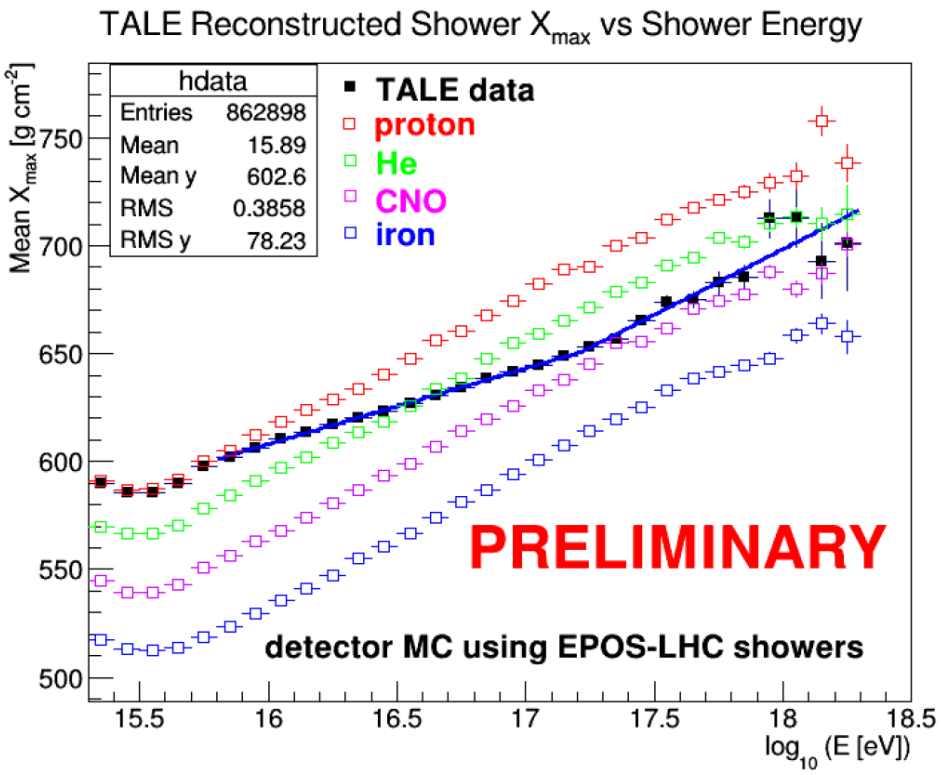
σ (Xmax)

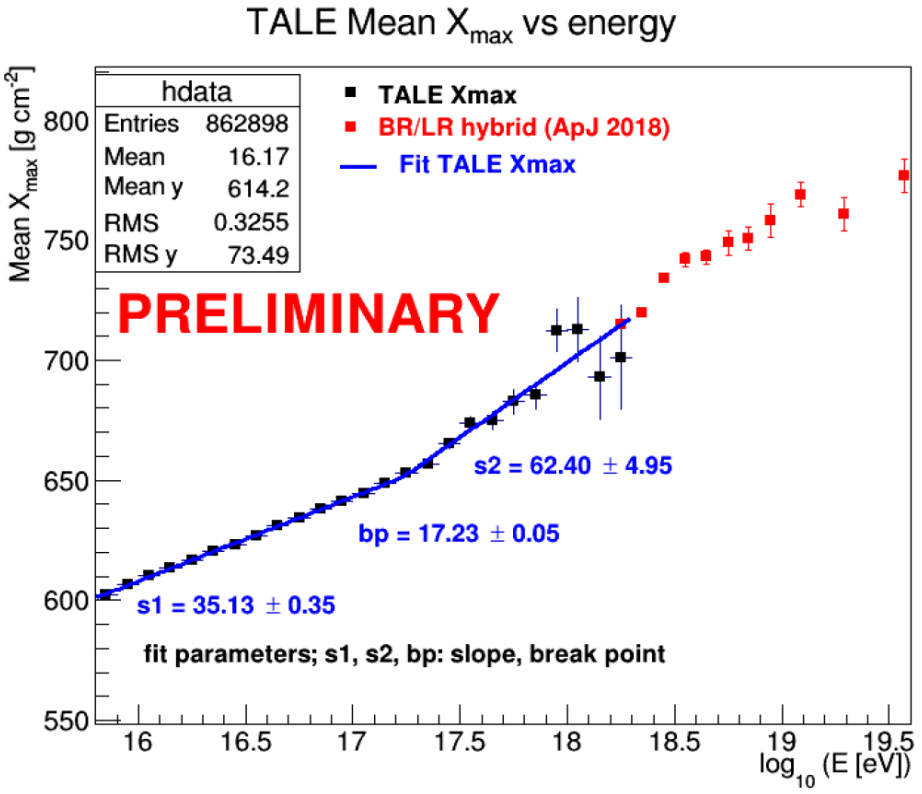


- Energy Range: $10^{18.2}$ eV – $10^{19.1}$ eV
- 3560 events after the quality cuts
- Systematic uncertainty of <Xmax>: ± 17 g/cm^2
- QGSjetII-04 interaction model was compared with the data
  → agreement with light composition
- More events are needed to study highest energies

Composition Analysis with TALE FD Mono Xmax

T. Abu-Zayyad, ICRC2019

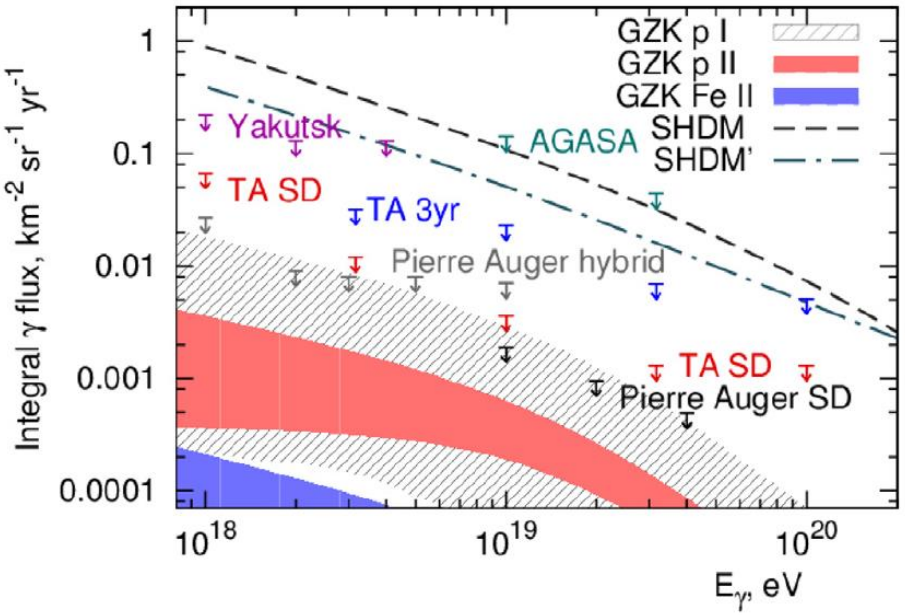




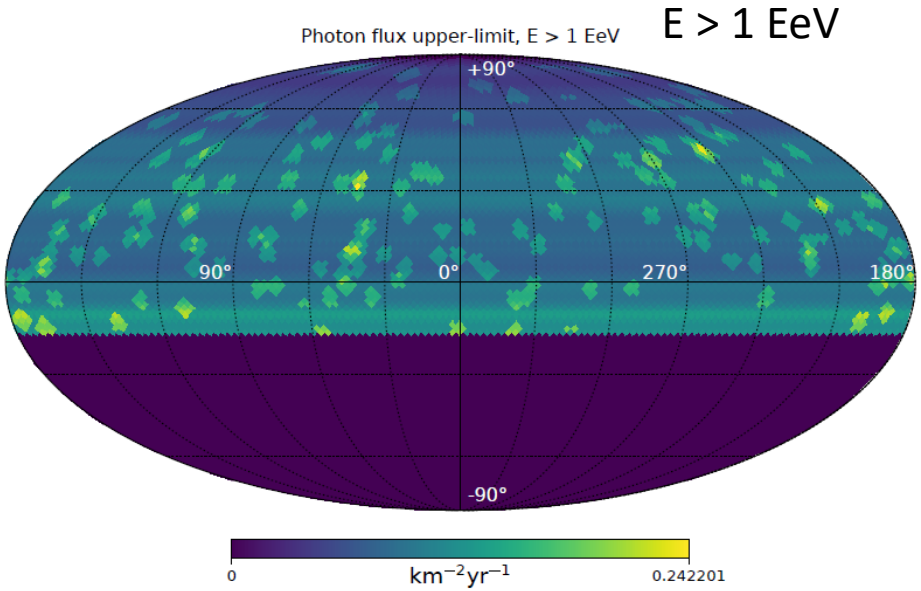
- Jun. 2014 – Nov. 2018 TALE FD mono data
- Energy Range: $10^{15.3}$ eV – $10^{18.3}$ eV
- Break point log (E/eV) = 17.23 ± 0.05

Photon Search

Astropart. Phys. ***110****, 8 (2019)*

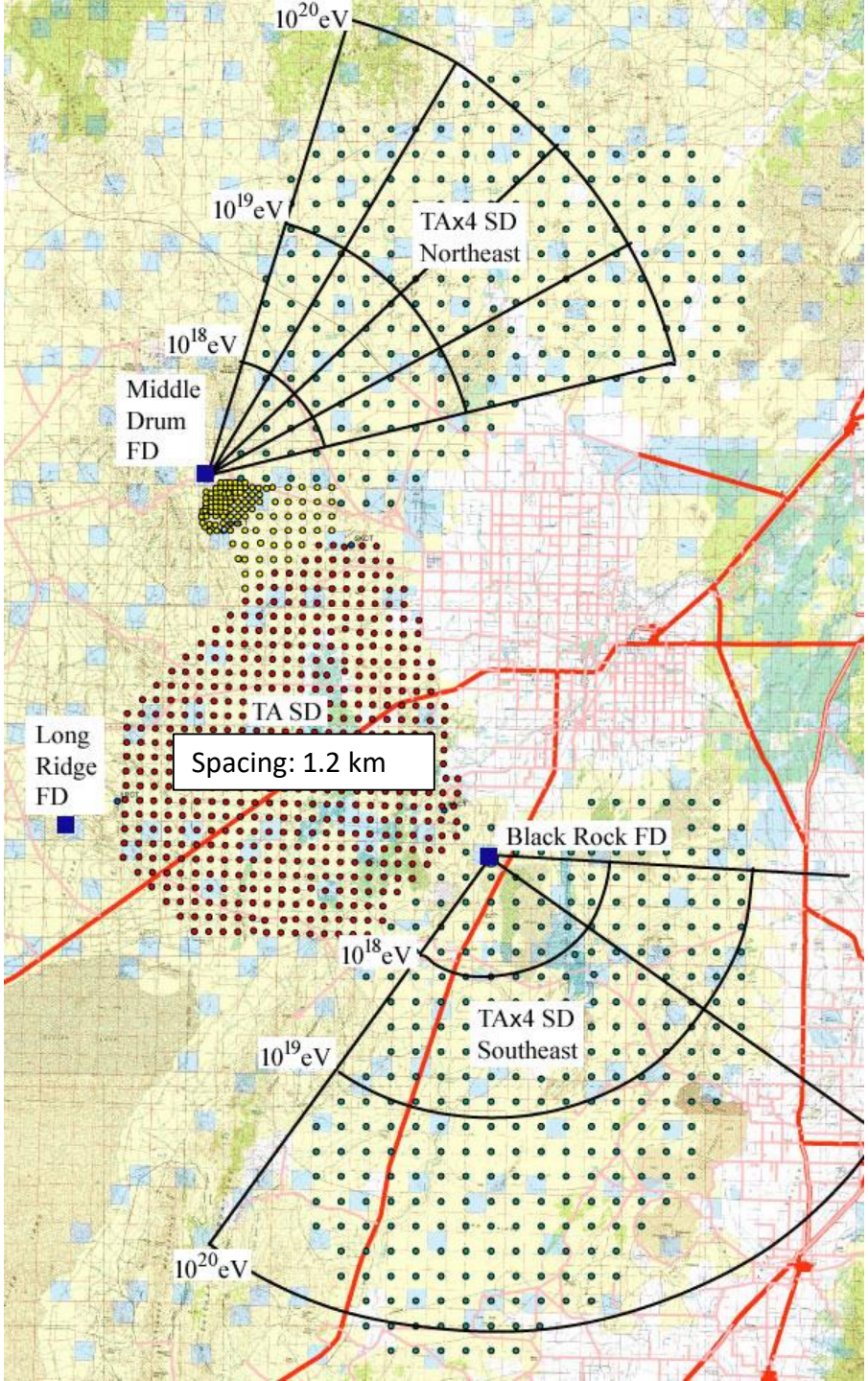


M. Kuznetsov, ICRC2019



- Left: updated upper limit on GZK photons with 9 years TA SD data
  - Multivariable classifier is built on 16 reconstructed parameters
- Right: upper limit for directions in the field of view

The TAx4 experiment



To study more about the highest energies and examine the implications obtained by TA

500 new SDs with **2.08 km** spacing

E > 57 EeV:

- Reconstruction efficiency > 95%
- Angular resolution: 2.2°
- Energy resolution: ～25%

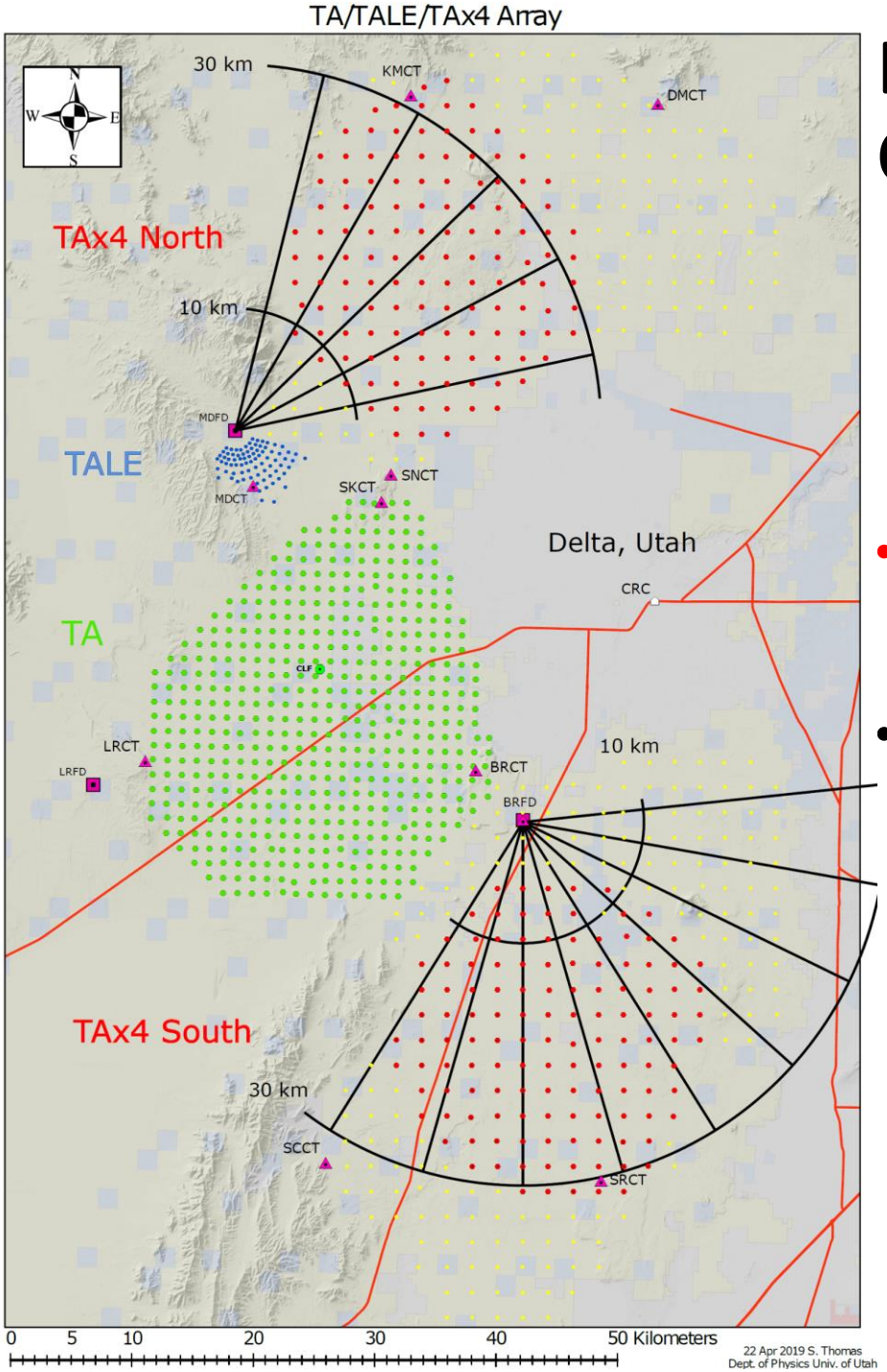
and TA SDs cover
4 × TA SD detection area (~3000 km^2)

2 new Fluorescence Detector (FD) stations (4+8 HiRes Telescopes)

Deployment of Assembled SDs

https://www.flickr.com/photos/142880279@N06/albums/72157689940402503

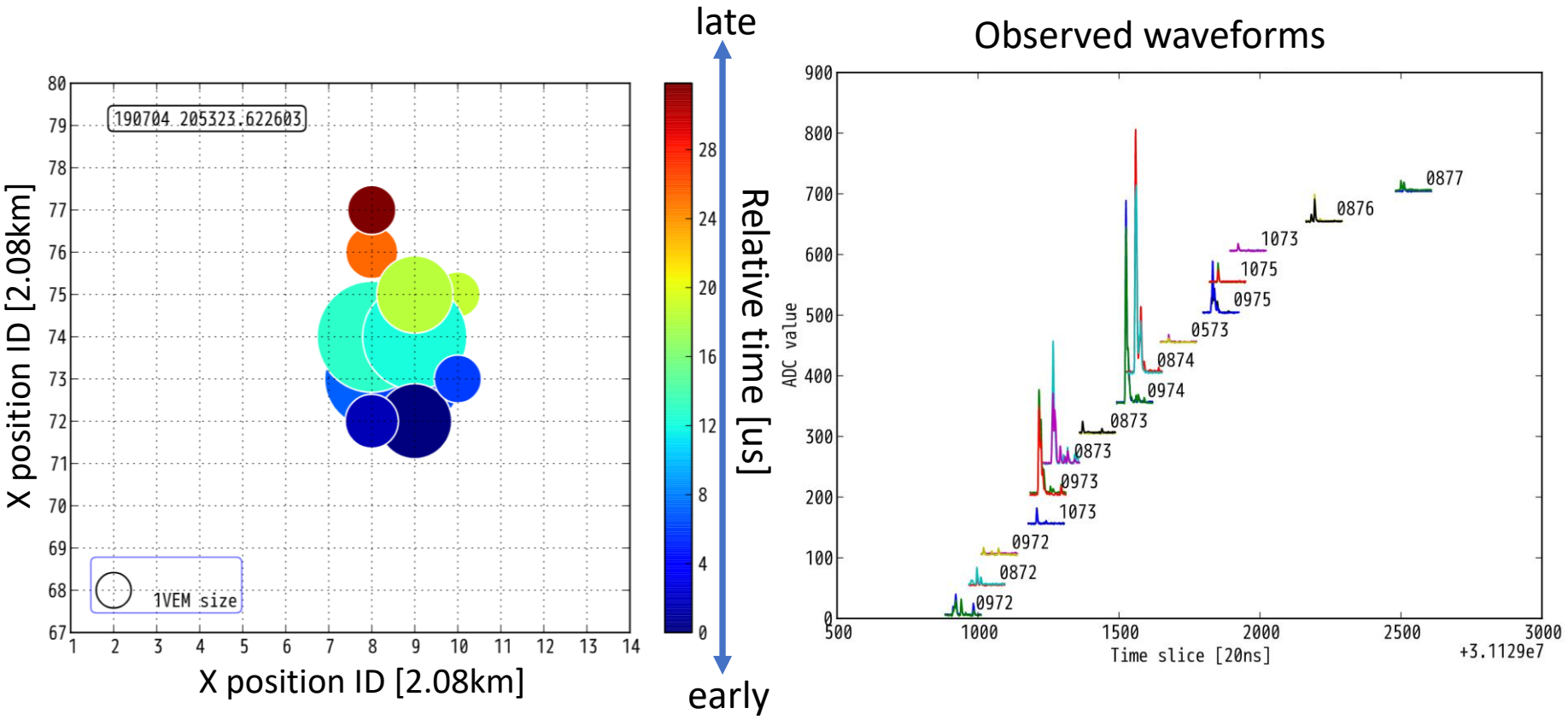
Helicopter for the transportation of SDs



Deployed SDs and Communication Towers

- **More than half of SDs** (257 SDs) were deployed on 19 Feb. – 12 Mar. 2019.
- Locations of SDs were decided to optimize hybrid events above 10 EeV and consider practical conditions of wireless communications

Cosmic Ray Event



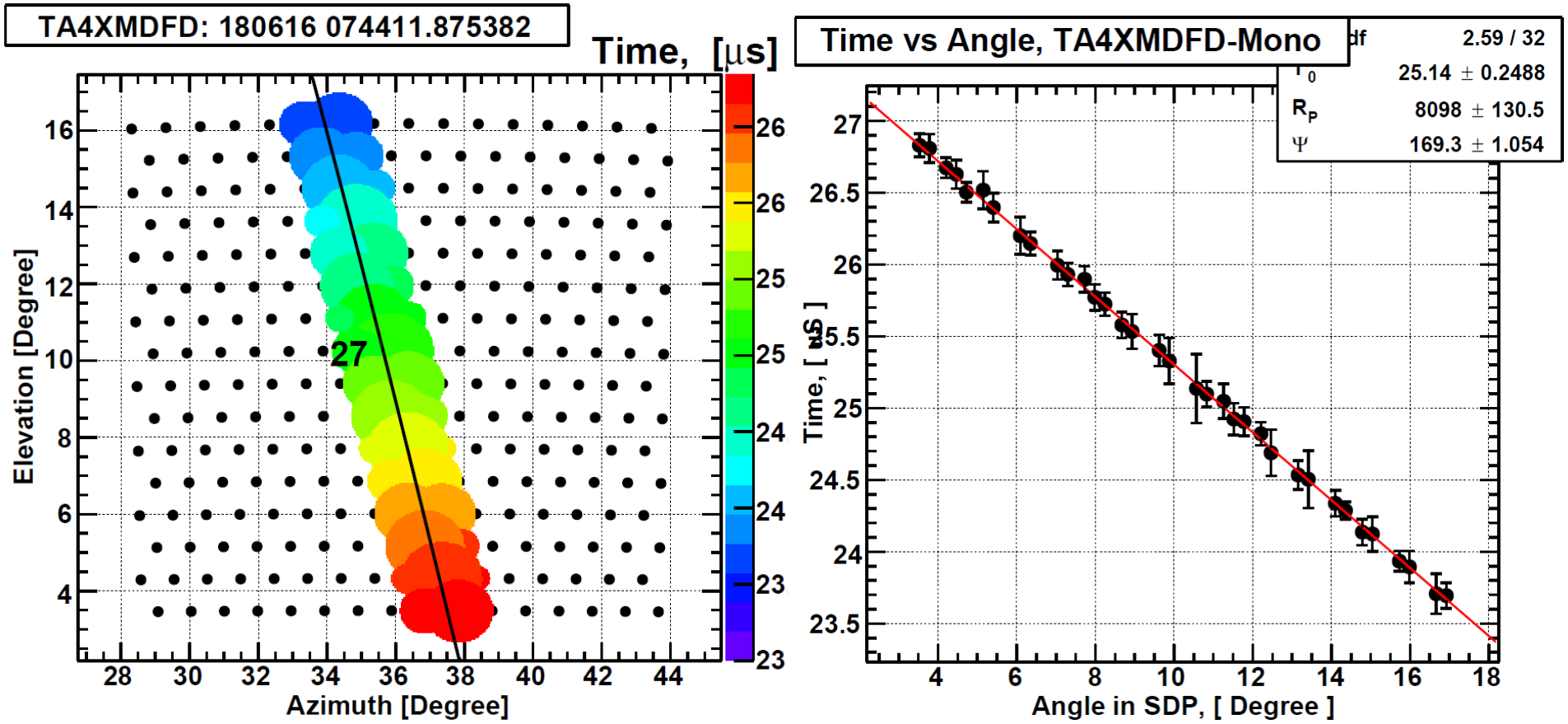
- Largest number of SDs were fired in this event
- **DAQ of each sub-array was started** from the end of Apr. 2019 when the sub-array is ready.
- **Cosmic ray events** are being collected.
- ～**4**×TA SD equivalent cosmic ray events are collected when the full operation is started.

Construction of FD Station

16th Feb. 2018 **First light** at the north FD station

22nd Oct. 2019 **First light** at the south FD station

Cosmic Ray Event



- Stable operation of north FD station was started from 8th June 2018.
- Data analysis is ongoing.
- Xmax: ～**3**×TA SDFD equivalent events are collected at the highest energies when the full operation is started.

Summary

- Energy Spectrum
  - Combined spectrum of TA SD with TALE FD mono

  → Energy spectrum with log (E/eV) > **15.3** was obtained.
  - Declination dependence of TA SD energy spectrum was implicated in **4.3σ**
- Anisotropy
  - Hotspot (> 57 EeV): ～**3 σ** global significance was obtained from 11 years TA SD data
- Composition:
  - TA SD and FD hybrid: consistent with light composition with log (E/eV) > **18.2** and log (E/eV) < **19.1**
  - TALE FD mono: preliminary Xmax results were obtained with log (E/eV) > **15.3**
- Photon limit was updated with 9 years TA SD data and the dependence of the arrival directions was also obtained.

- Implications on anisotropy were obtained by the TA experiment.

→ TAx4 experiment is **in operation**

- TAx4 detectors:
  - **500 new** SDs with **2.08 km** spacing + TA SDs → Coverage of **4×TA SDs** ～3000 km^2
  - **2 new** Fluorescence Detector (FD) stations (4+8 Telescopes)
- More than half of TAx4 SDs were deployed, and 2 TAx4 FD stations were constructed.
- Data acquisition was started. SD: from **Apr. 2019**, FD: from **Jun. 2018.** Cosmic ray events are being collected.
- Prospects
  - ～**4×TA SD** equivalent cosmic ray events with E > 57 EeV will be collected when the full operation is started.
  - ～**3×TA SDFD** equivalent hybrid events will be collected especially for Xmax at the highest energies when the full operation is started.

Backup