

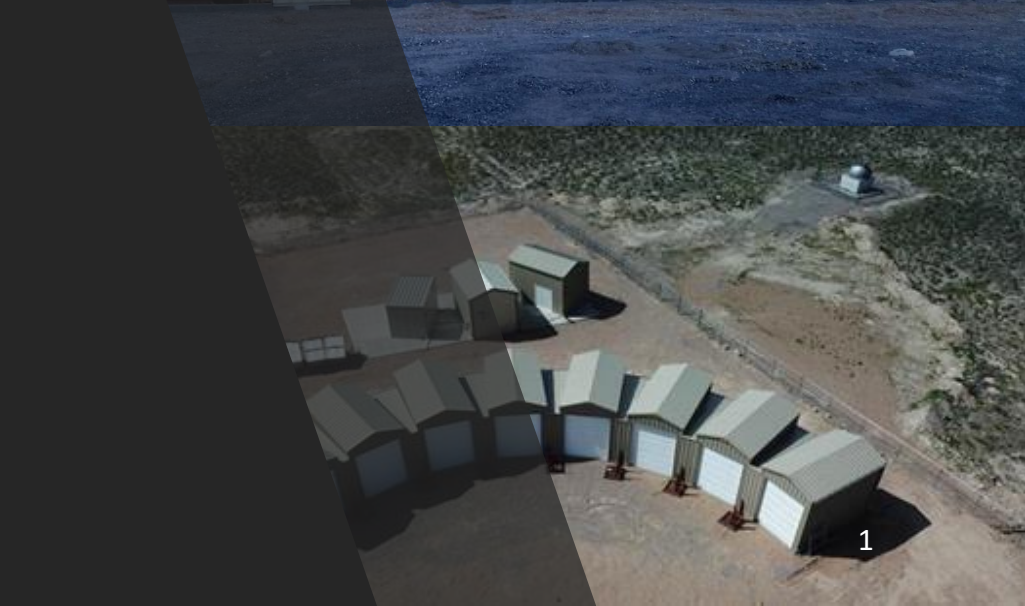
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RIKEN Cluster for Pioneering
Research

Current status and prospects of surface detector of the TAX4 experiment

arXiv: 2103.01086 [astro-ph.IM]

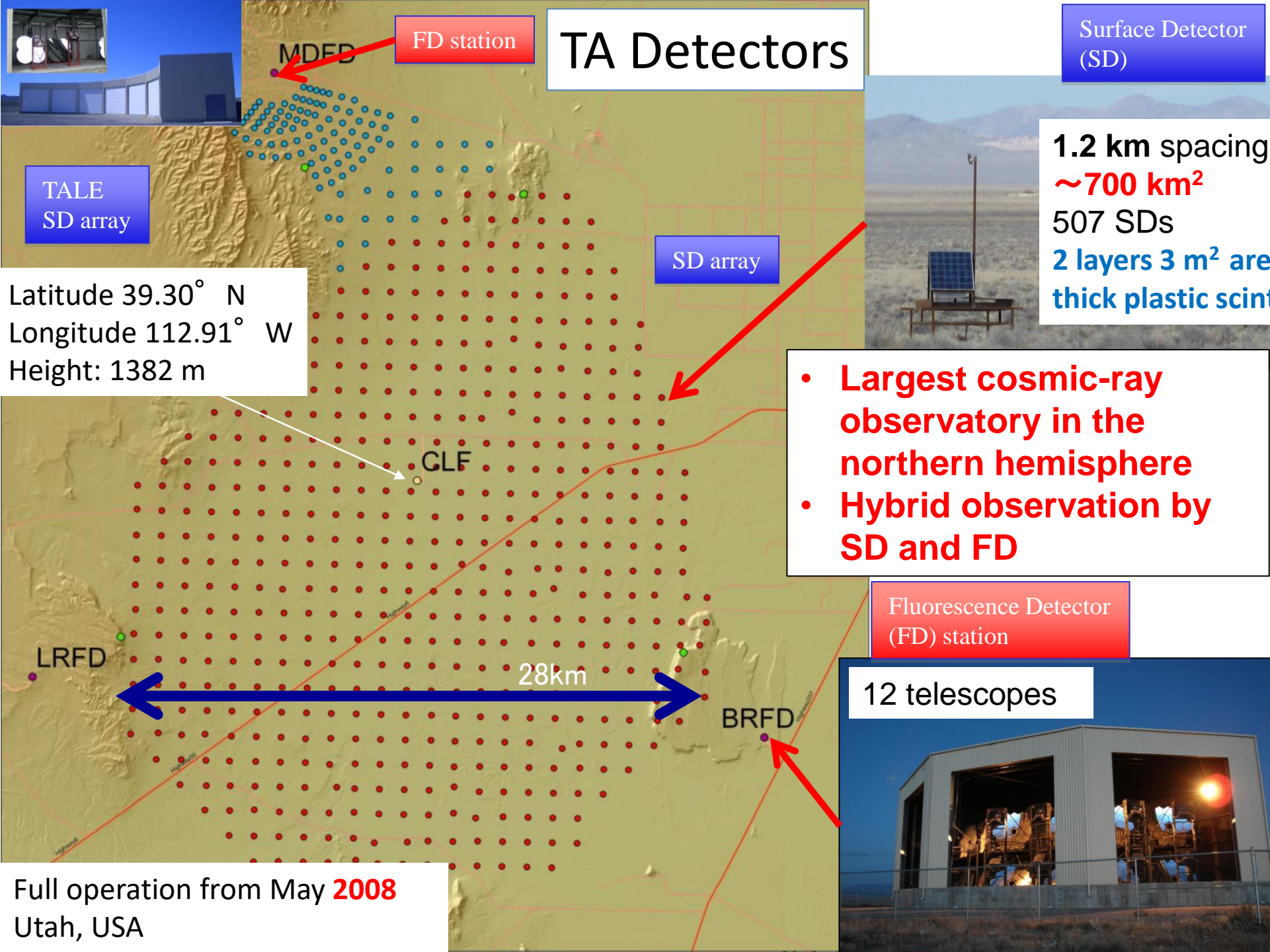
(submitted to NIM-A journal)



Outline

- The results of the Telescope Array (TA) experiment
- Design and performance of the TAx4 SDs
- Current status and prospects of the TAx4 SDs
- Summary

TA Detectors



TALE
SD array

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

SD array

Surface Detector
(SD)

1.2 km spacing
~700 km²
507 SDs
2 layers 3 m² area 1.2 cm
thick plastic scintillators

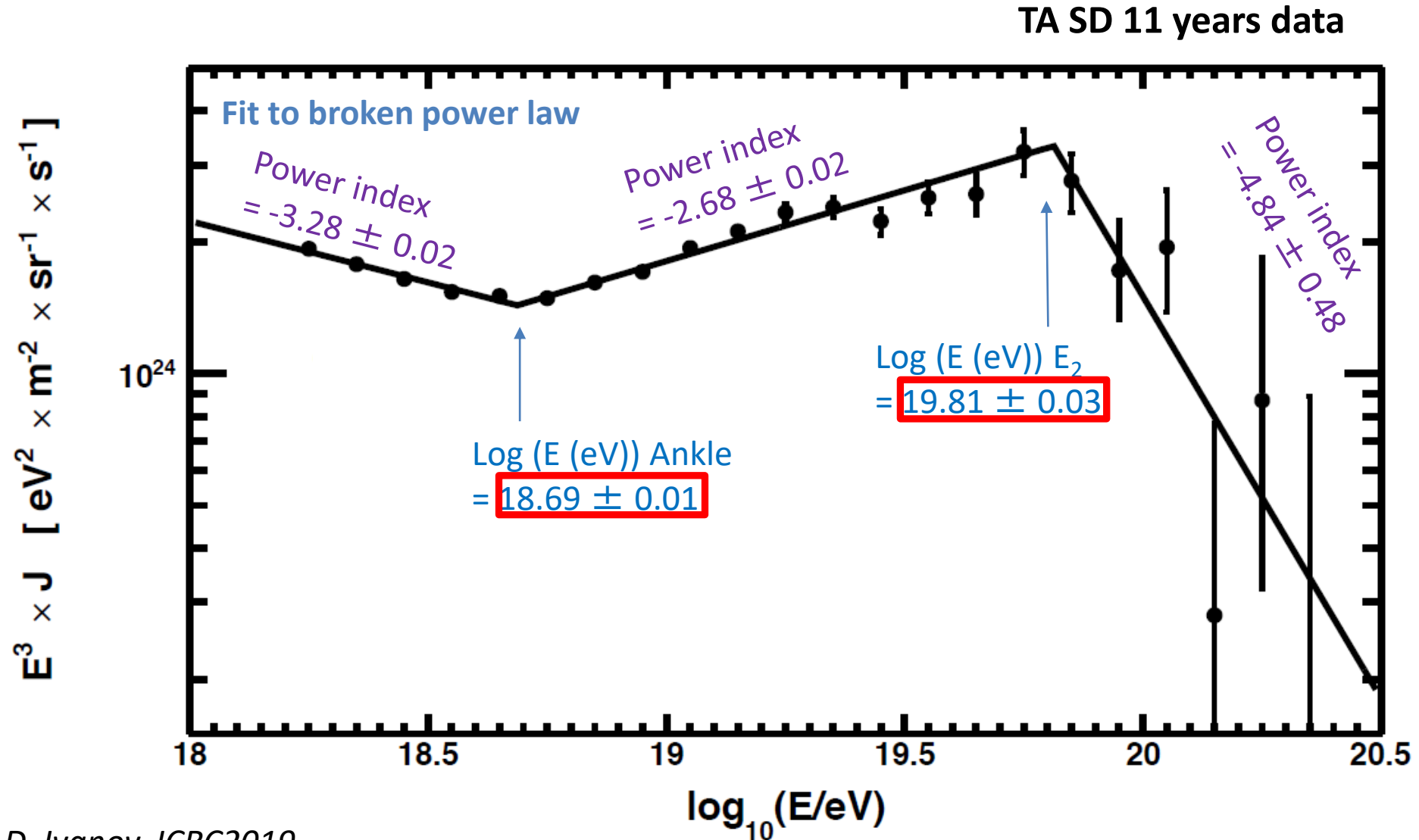
- Largest cosmic-ray observatory in the northern hemisphere
- Hybrid observation by SD and FD

Fluorescence Detector
(FD) station

12 telescopes

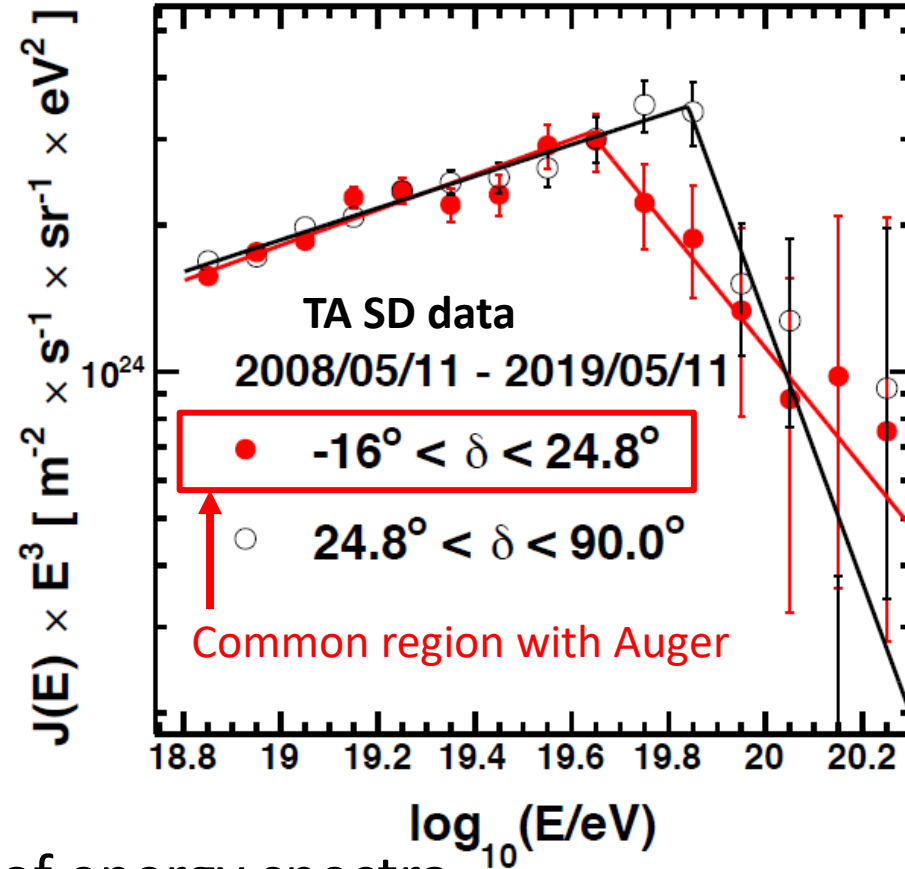
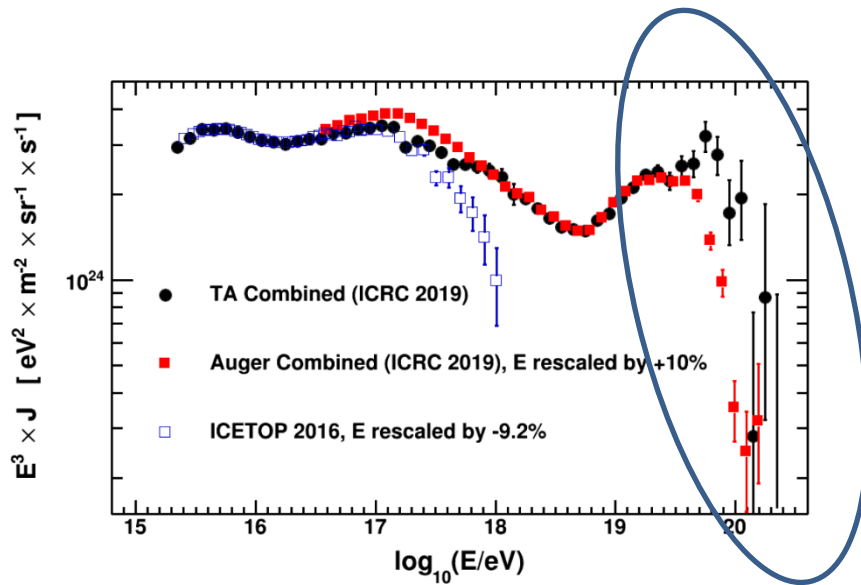
Full operation from May 2008
Utah, USA

Energy Spectrum with TA SD



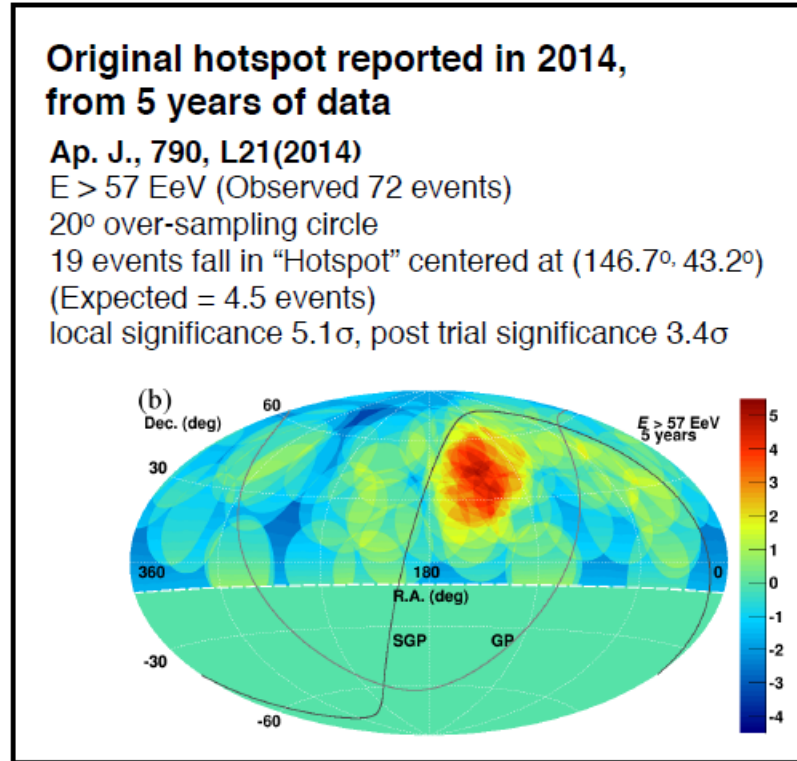
Declination Dependence of Energy Spectrum

D. Ivanov, ICRC2019



- Difference of the cutoff energies of energy spectra
 - $\log(E/\text{eV}) = 19.64 \pm 0.04$ for lower dec. band ($-16^\circ - 24.8^\circ$)
 - $\log(E/\text{eV}) = 19.84 \pm 0.02$ for higher dec. band ($24.8^\circ - 90^\circ$)
- The global significance of the difference was estimated to be **4.3 σ**

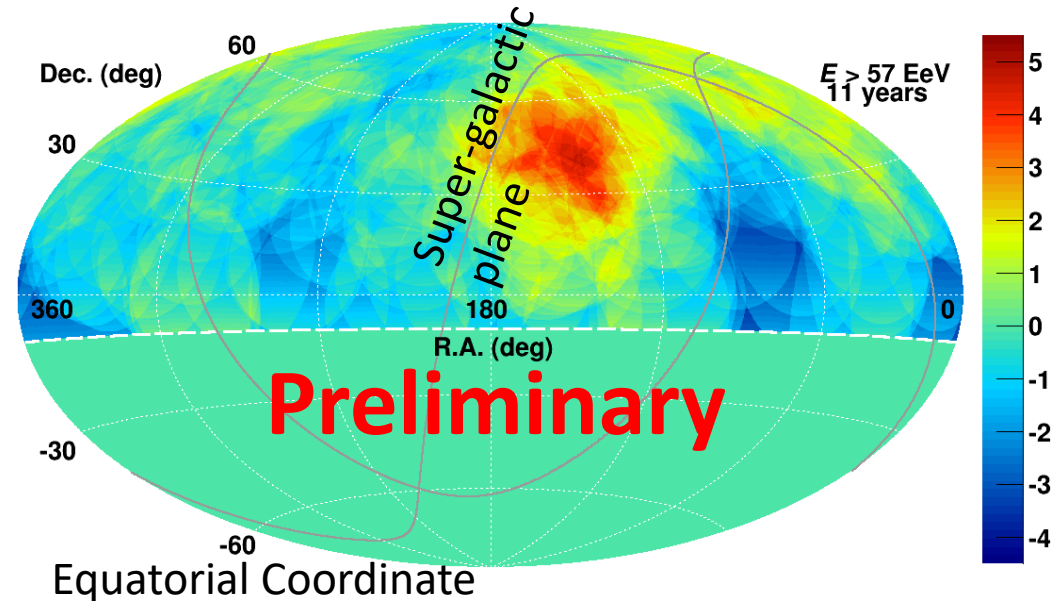
TA hotspot in the arrival directions of cosmic rays with $E > 57$ EeV



K. Kawata, ICRC2019

TA SD 11 years data

Significance map from isotropy expectation



$E > 57$ EeV, in total 168 events

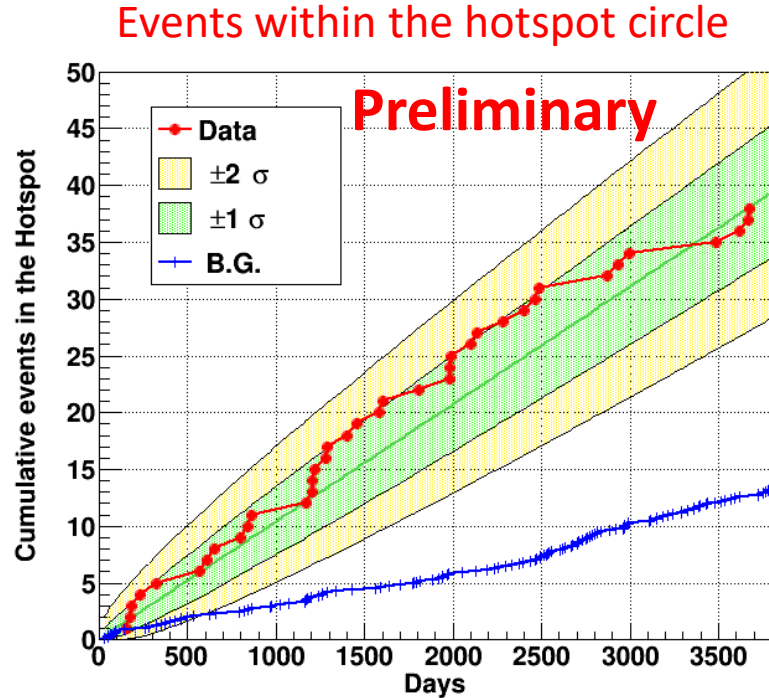
38 events fall in Hotspot ($\alpha=144.3^\circ$, $\delta=40.3^\circ$, 25° radius, 22° from SGP), expected=14.2 events

local significance = 5.1σ , chance probability $\rightarrow 2.9\sigma$

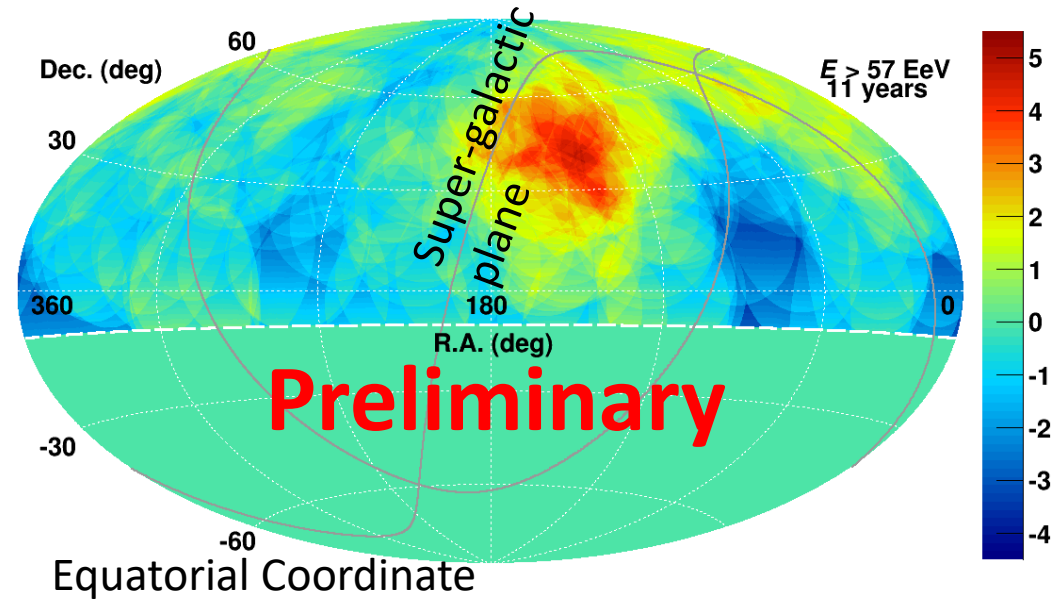
25° over-sampling radius shows the highest local significance (scanned 15° to 35° with 5° step)

TA hotspot in the arrival directions of cosmic rays with $E > 57$ EeV

K. Kawata, ICRC2019



Significance map from isotropy expectation



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

Consistent with the linear increase within $\sim 1\sigma$

The TAx4 experiment

In order to examine the implications of anisotropy at the highest energies obtained by TA, TAx4 was developed to accelerate the pace of data collection at the highest energies.

500 new SDs with 2.08 km spacing

New SDs and TA SDs totally cover

4 × TA SD detection area (~3000 km²)

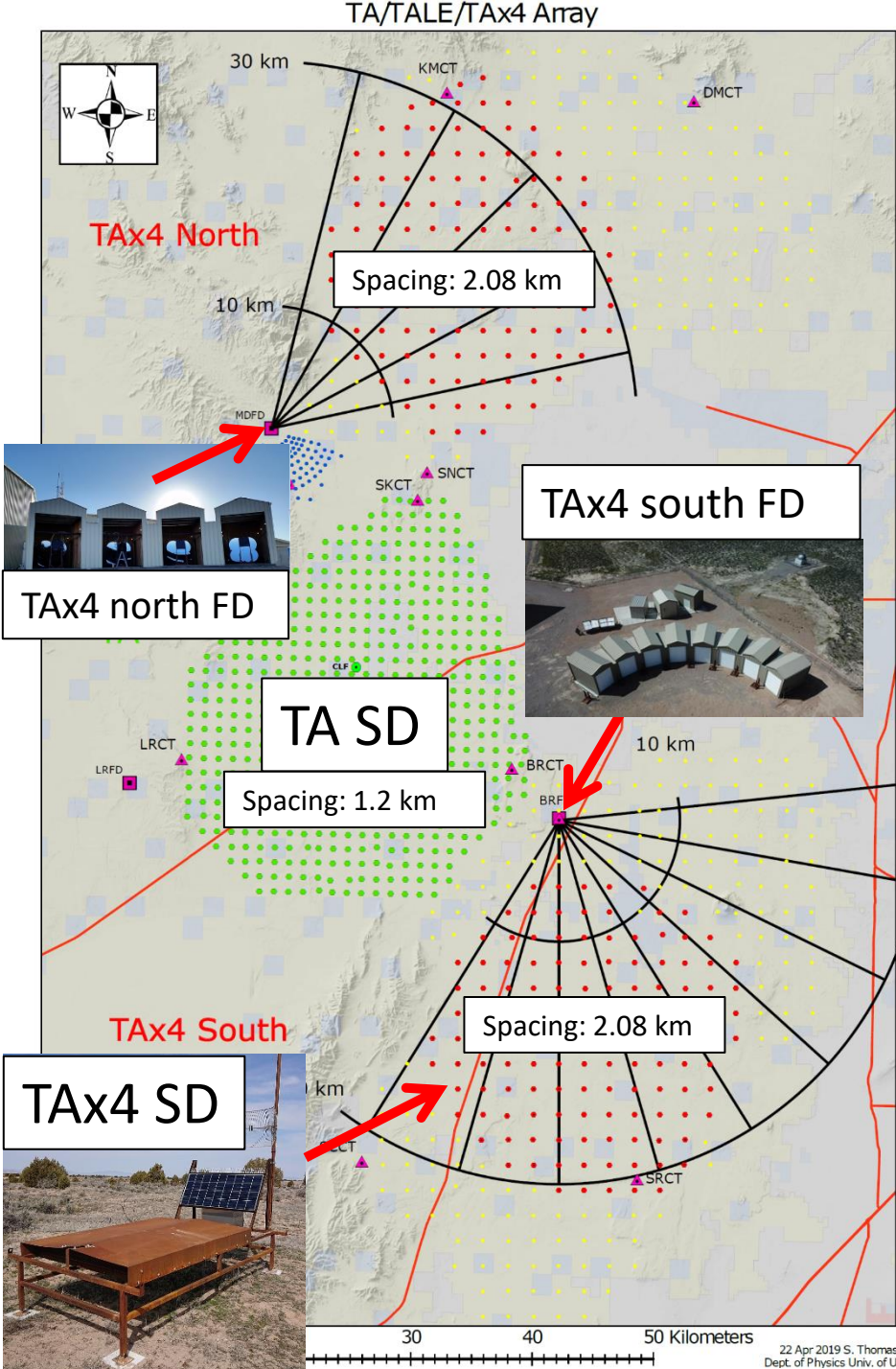
More than half of new SDs (257 SDs) were deployed in 2019.

Deployed SDs are running stably from 2019 Nov.

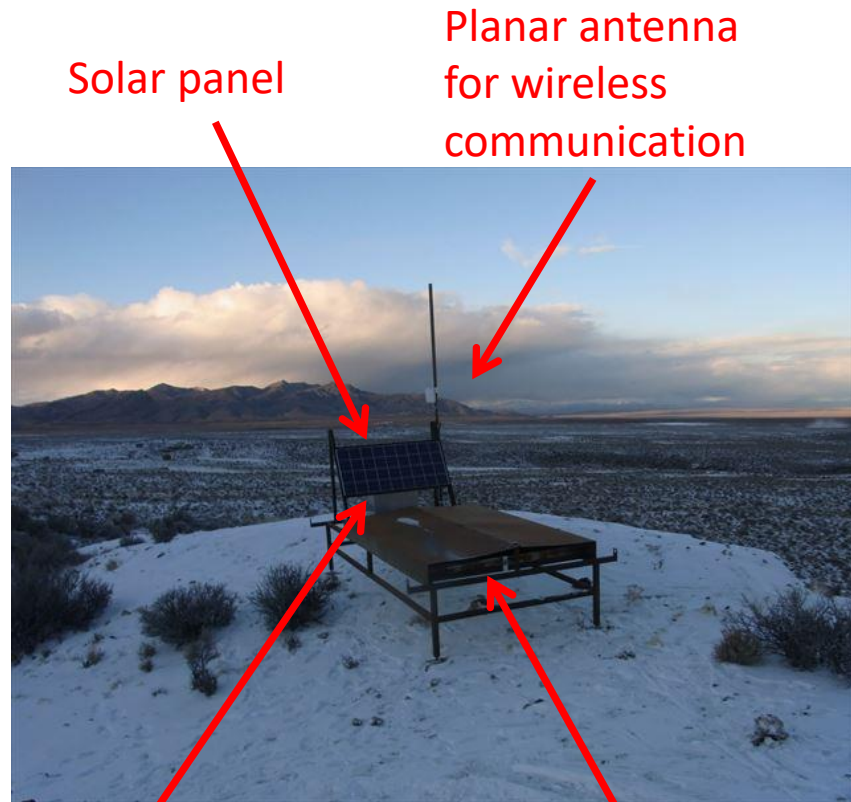
2 new Fluorescence Detector (FD) stations (4+8 HiRes Telescopes)

FD(north): stable run from 2018 Jun.

FD(south): stable run from 2020 Sep.

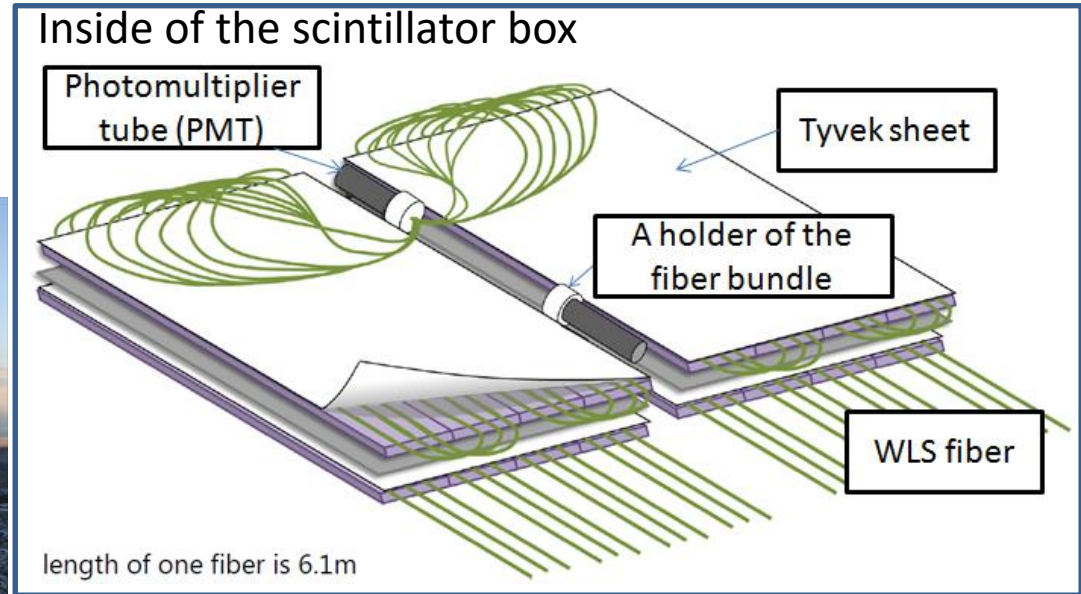


Design of SDs



Stainless steel box for the electronics and a battery

Scintillator box



- **2 layers 3 m² 1.2 cm thick plastic scintillators**
- Calibration of signals using single muons
- Data acquisition from the communication towers using 2.4 GHz wireless communication

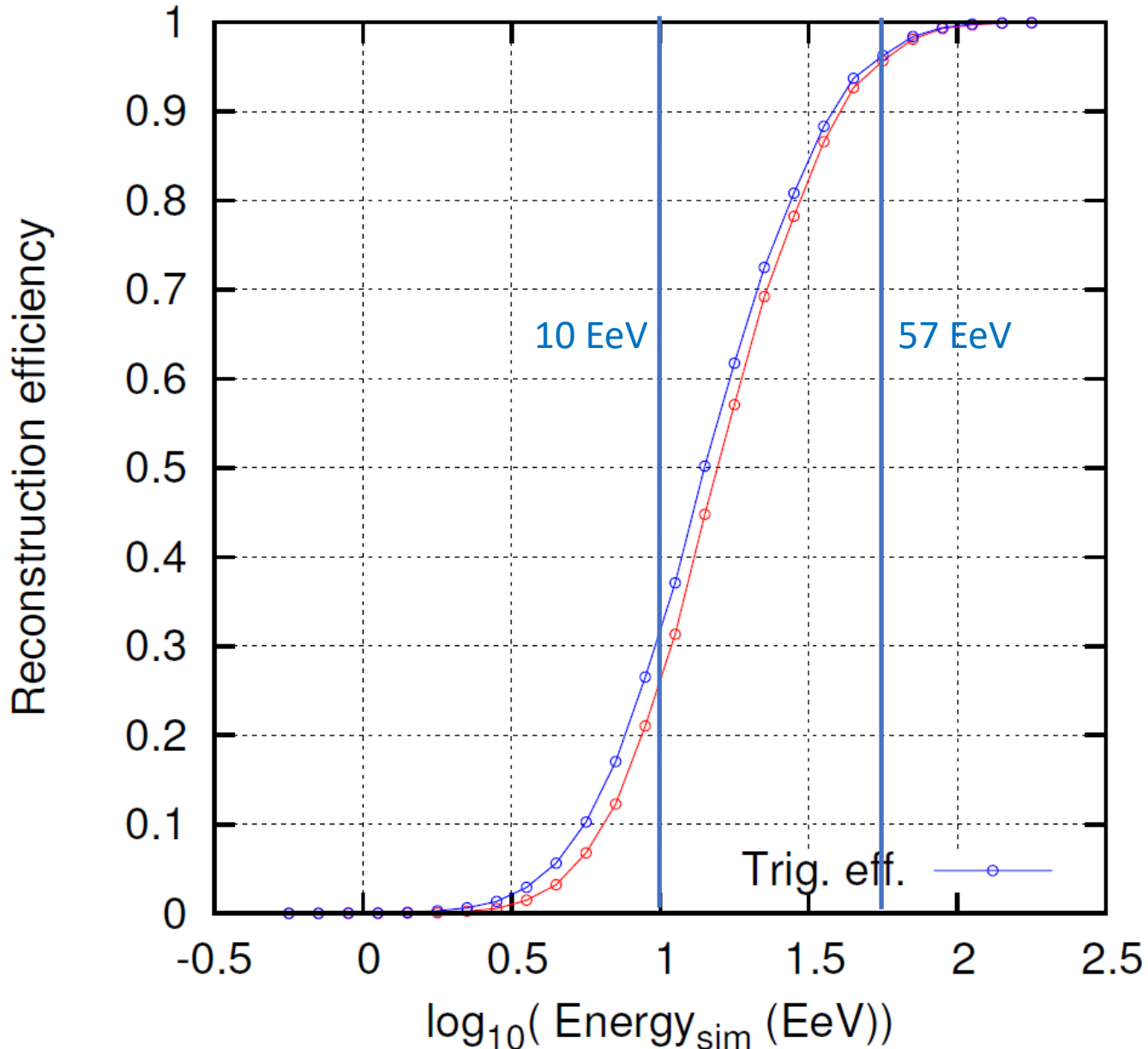
PMT and arrangement of WLF fibers was changed from TA SD for the cost reduction

Single peak: **23 p.e.** in average ($\sim 0.9 \times \text{TA SD}$)

Non-uniformity: **< 15 %**

Pulse linearity: **50 mA** ($\sim 2 \times \text{TA SD}$)

Expectation of the Performance of New SD Array



Blue line: trigger efficiency

Red line: reconstruction efficiency
with a loose quality cut

SD array: square grid with 2.08 km spacing

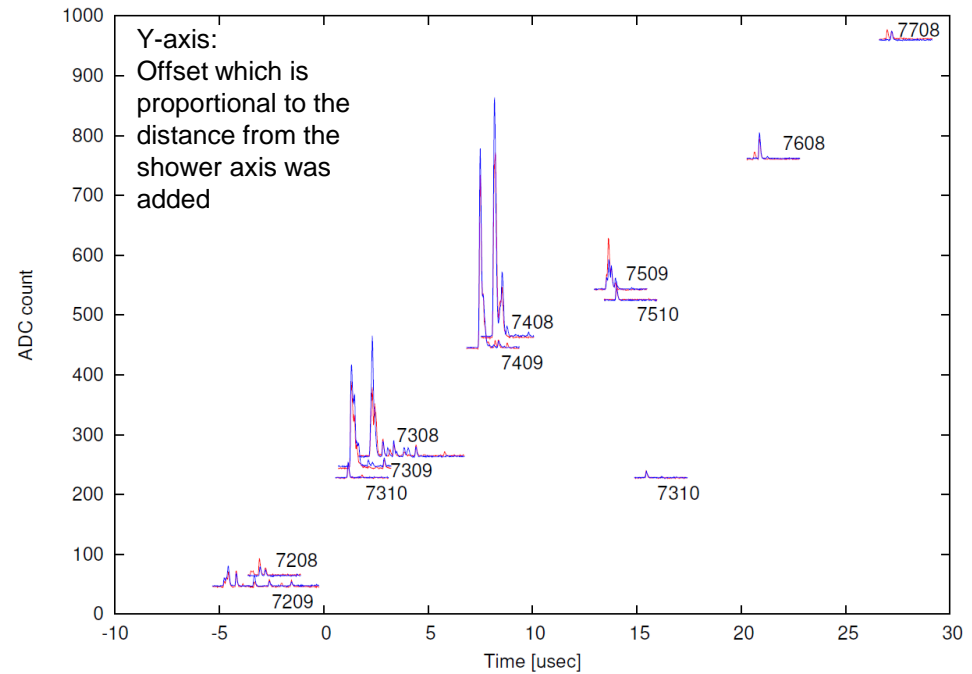
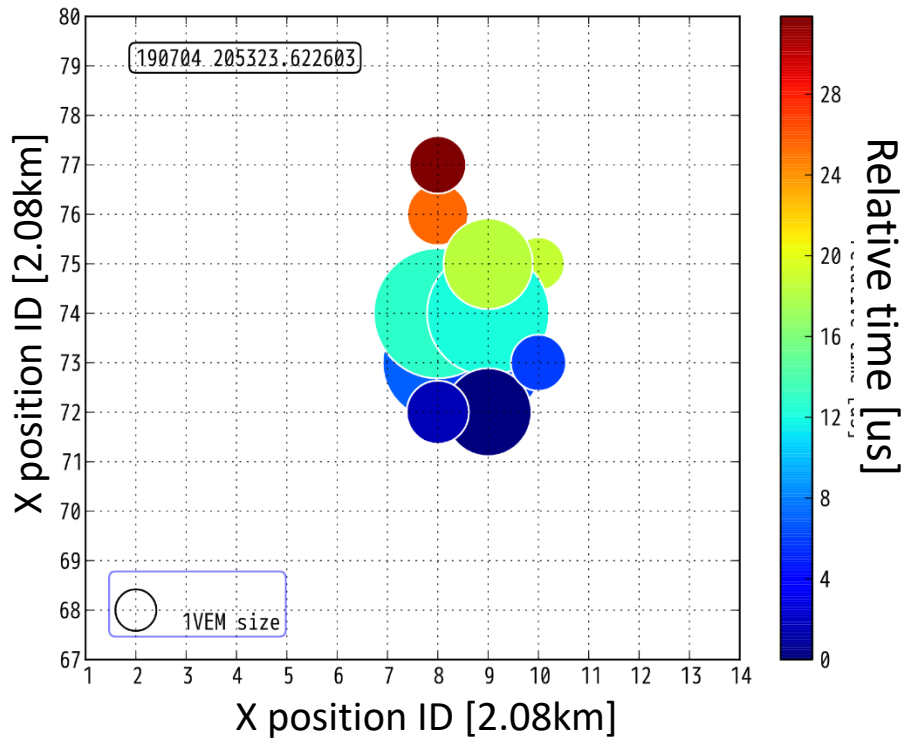
Trigger condition: adjacent 3 SDs within 14 μs

$E > 57 \text{ EeV}$:

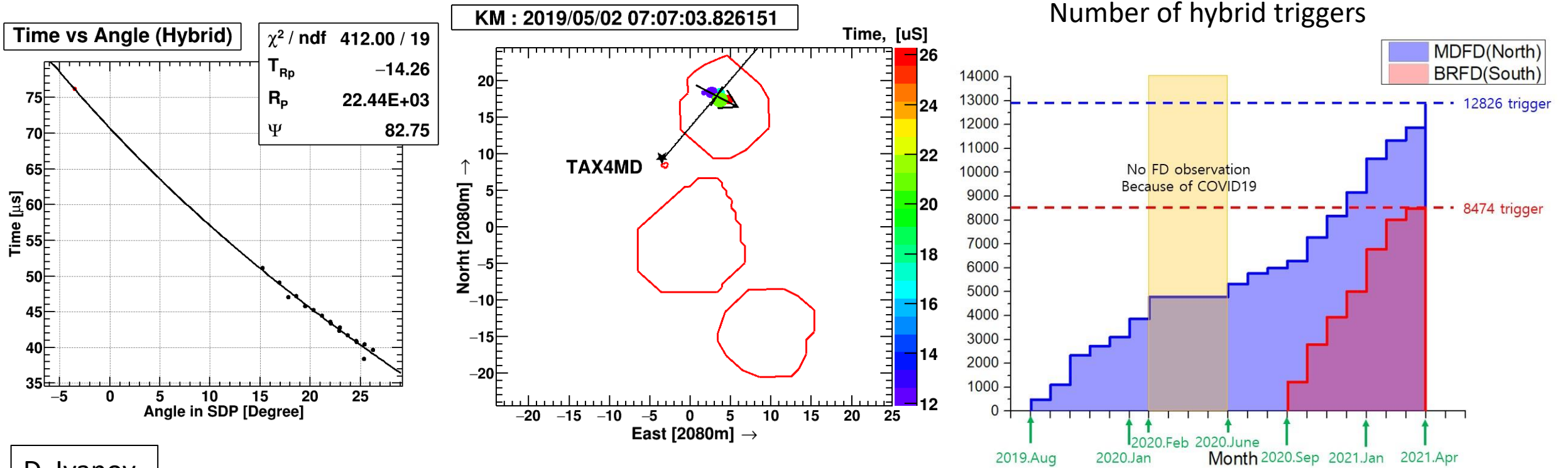
- Reconstruction efficiency $> 95\%$
- Angular resolution: 2.2°
- Energy resolution: $\sim 25\%$

Cosmic Ray Event ($E > 57 \text{ EeV}$)

Detail in
J. Hyomin's
talk in this
ICRC2021



Data acquisition of SDFD hybrid events



D. Ivanov

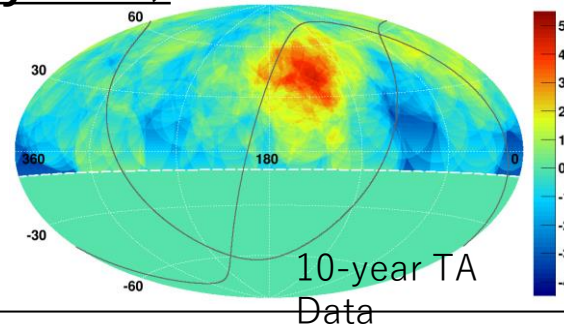
Detail in
K. Sang Woo's
poster in this ICRC2021

- Tax4 SD trigger efficiency: $\sim 30\%$ at around 10 EeV
 - Stable run of **hybrid triggers** started from **2020 June** for higher efficiency.
 - FDs send trigger timings to communication towers of the SDs in order to get waveforms around the timings.
 - **$\sim 3 \times$ TA SDFD** equivalent hybrid events in total for $E > 10$ EeV
 - Similar X_{max} resolution ($\sim 13-17 \text{ g/cm}^2$) to the TA SDFD hybrid is expected.

Expectation of Hotspot in the Next 5 Years

Hypothesis (10-yr observation from May 2008):

- Total # of events: 157 events
→ 15.7 events/yr
- Hotspot # of events: 36 events
(25° radius circle)
→ 3.6 events/yr

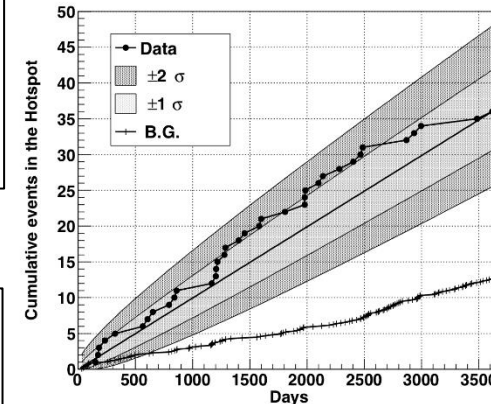


Simple extrapolation

Expectation (as of May 2025):

12-yr TA + 5-yr TA x 2.5 = 24.5-year TA

- Total # of events: 384 events
- Hotspot # of events: 88 events (25° radius circle)
→ Local Li-Ma Significance: 7.8σ
Global Significance: $7.8\sigma - 2\sigma = \sim 6\sigma$



Summary

- Implications on anisotropy were obtained by the TA experiment.
 - Energy Spectrum
 - **Declination dependence** was claimed at **4.3σ** in the energy spectrum using T ASD 11 years data
 - Anisotropy
 - **2.9σ hotspot, oversampling radius: 25°** $E > 57$ EeV was obtained using T ASD 11 years data
- Arrangement of the TAx4 detectors:
 - **500 new** SDs with **2.08 km** spacing + TA SDs
 - Coverage of **$4 \times$** TA SDs ~ 2800 km² → **$\sim 4 \times$ TA SD** equivalent events for $E > 57$ EeV
 - **2 new** FD stations (4+8 HiRes Telescopes) → **$\sim 3 \times$ TA SDFD** equivalent hybrid events for $E > 10$ EeV
- **More than half of new SDs (257 SDs)** were deployed in 2019.
- Construction of new FDs was finished.
- **Stable run of the data acquisition of the new detectors was started.**
SD: from **Nov. 2019**, FD(north): from **2018 Jun.** FD(south): from **2020 Sep.**
Hybrid trigger runs from **2020 June.**
- Global significance of the TA hotspot will reach about **6 sigma** in **2025** by the TAx4 SDs (T ASD 24.5 years equivalent data) from the simple expectation.