

TAx4実験地表検出器による 超高エネルギー宇宙線エネルギースペクトル解析 Analysis of the ultra high cosmic ray energy spectrum with the TAx4 surface detector array

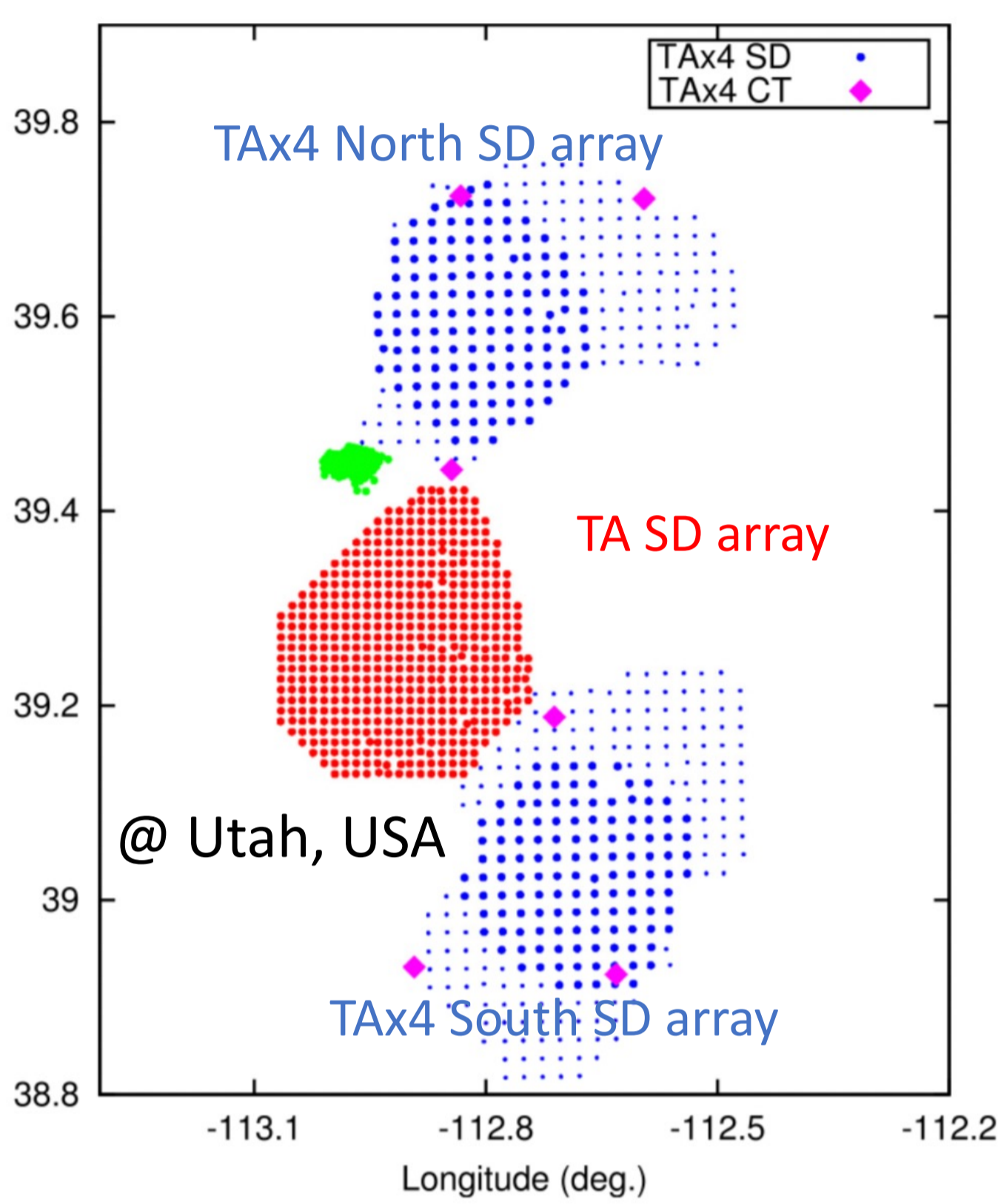
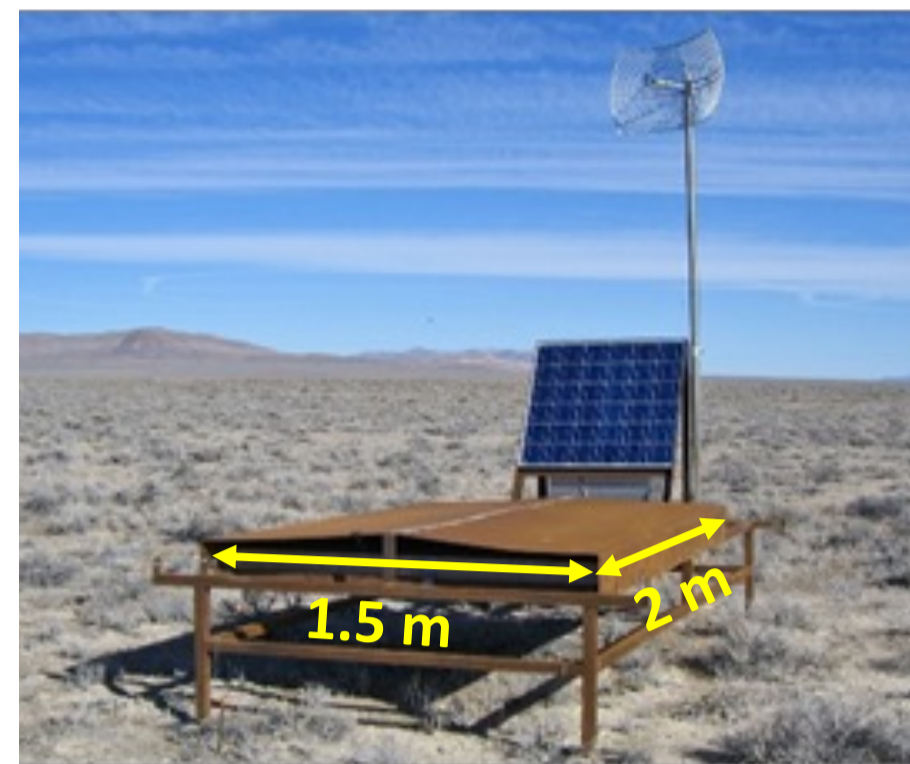
TA collaboration, D2 Kozo Fujisue

Telescope Arrays (TA) experiment observes ultra high energy cosmic rays (UHECR) with surface detectors (SD) and fluorescence detectors (FD) to reveal the origins. TAx4 experiment aims to enhance the data observation speed of UHECR by expanding observation area. TAx4 SD array started the observation in 2019. We will report on the comparison between the observed data and simulation to validate the simulation, and UHECR energy spectrum with 1.5-2 years TAx4 SD array observation data. It is consistent with the energy spectrum measured by TA SD 11 years data, and the cut off structure is observed with 3.6σ .

TAx4 SD array

Surface Detector (SD)

- 2-layers plastic scintillators with 3 m^2 area
- Autonomous operation by solar power
- Shower trigger : adjacent 3 SDs record more than 150 FADC counts (corresponding to 3 MIP) in $14 \mu\text{sec}$



- **TA SD** : 507 SDs, 1.2 km spacing covering $\sim 700 \text{ km}^2$, started observation in 2008
- **TAx4 SD** : 257 SDs, 2.08 km spacing covering $\sim 1700 \text{ km}^2$ including TA SD array (It is about half expansion of the final goal), started observation in 2019
- The basic design of TAx4 SD and TA SD are same

Data/MC comparison

1.5 years data for TAx4 Northern SD array & 2 years data for TAx4 Southern SD array are used in following analysis.

Objective

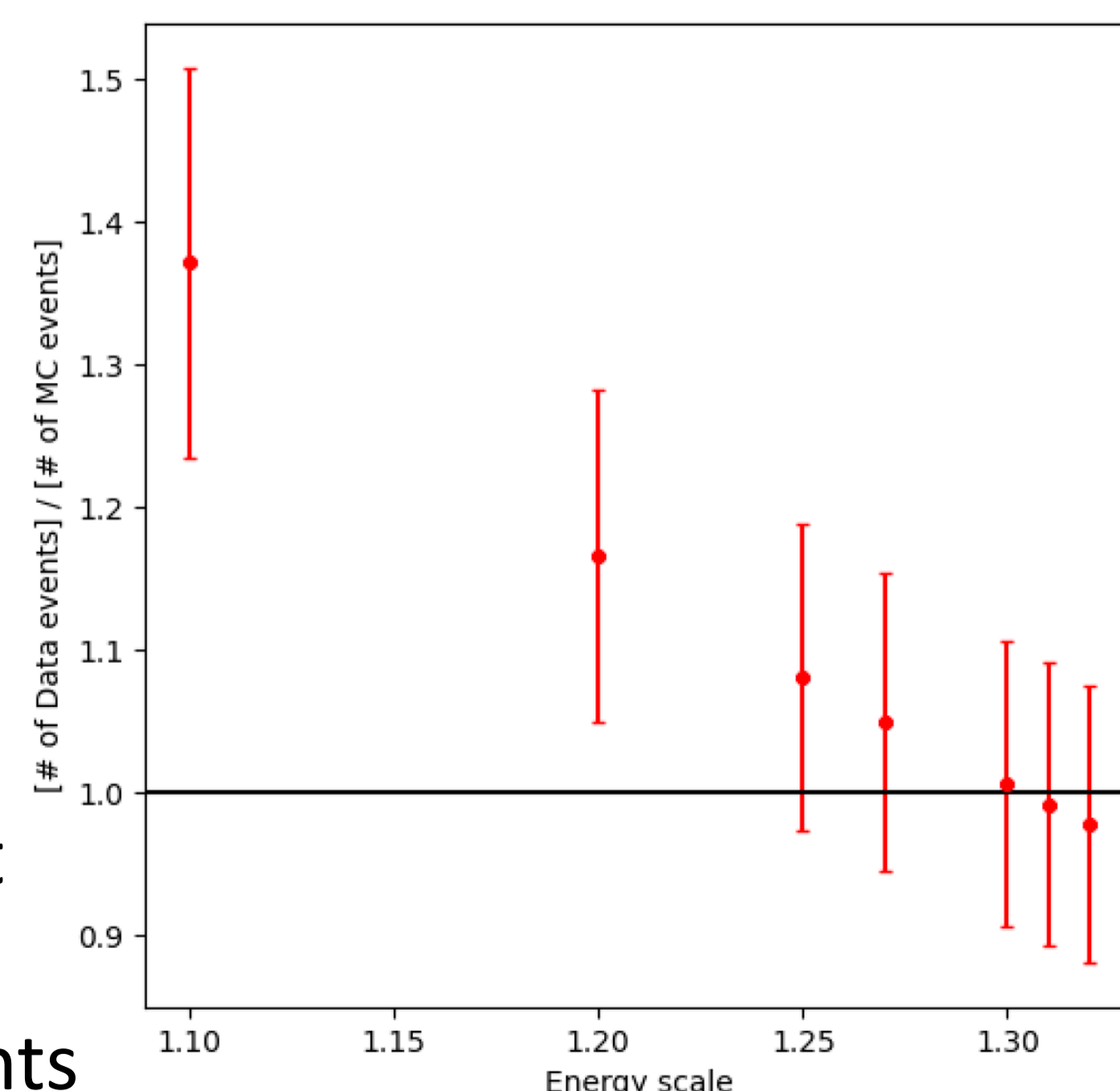
Monte Carlo (MC) simulation is used for analysis, such as aperture estimation, reconstruction optimization, etc., so it is important that MC simulation reproduces real data. We validate it by comparing various parameters between real observation and the simulation.

MC simulation

- Shower generator : CORSIKA
- Hadronic interaction model : QGSJET II-04 ($E > 80 \text{ GeV}$)
FLUKA ($E < 80 \text{ GeV}$),
- Energy range : $10^{17.5}$ to $10^{20.5} \text{ eV}$
(200 showers are generated in each $\Delta \log_{10}(E/\text{eV}) = 0.1$ bin)
- Primary particle : proton
- Calibration data obtained by real SDs are used, so the simulates air shower events are comparable with the observation.

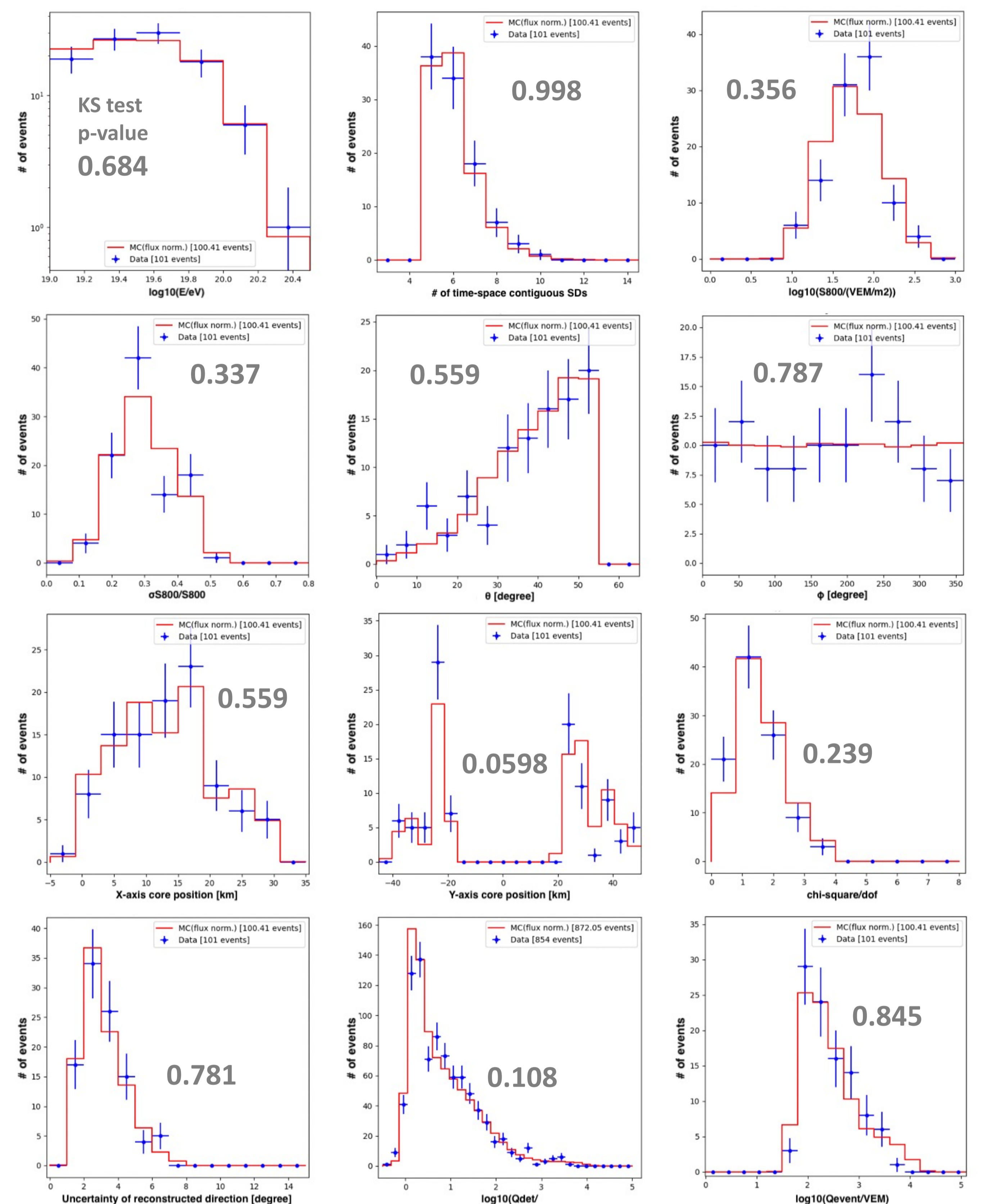
Energy scale of TAx4 SD array

- The number of MC events are normalized to match that of events expected by TA SD 11 years energy spectrum. This normalization highly depends on an energy scale, which is a scale between reconstructed energy by SD and that by FD.
- However, there are not enough events to determine the energy scale experimentally
- Here, we temporally determined the scale in terms of number of events $\rightarrow 1.3$ (with this energy scale, the number of MC events is expected by TA SD 11 years energy spectrum is the same as observation)

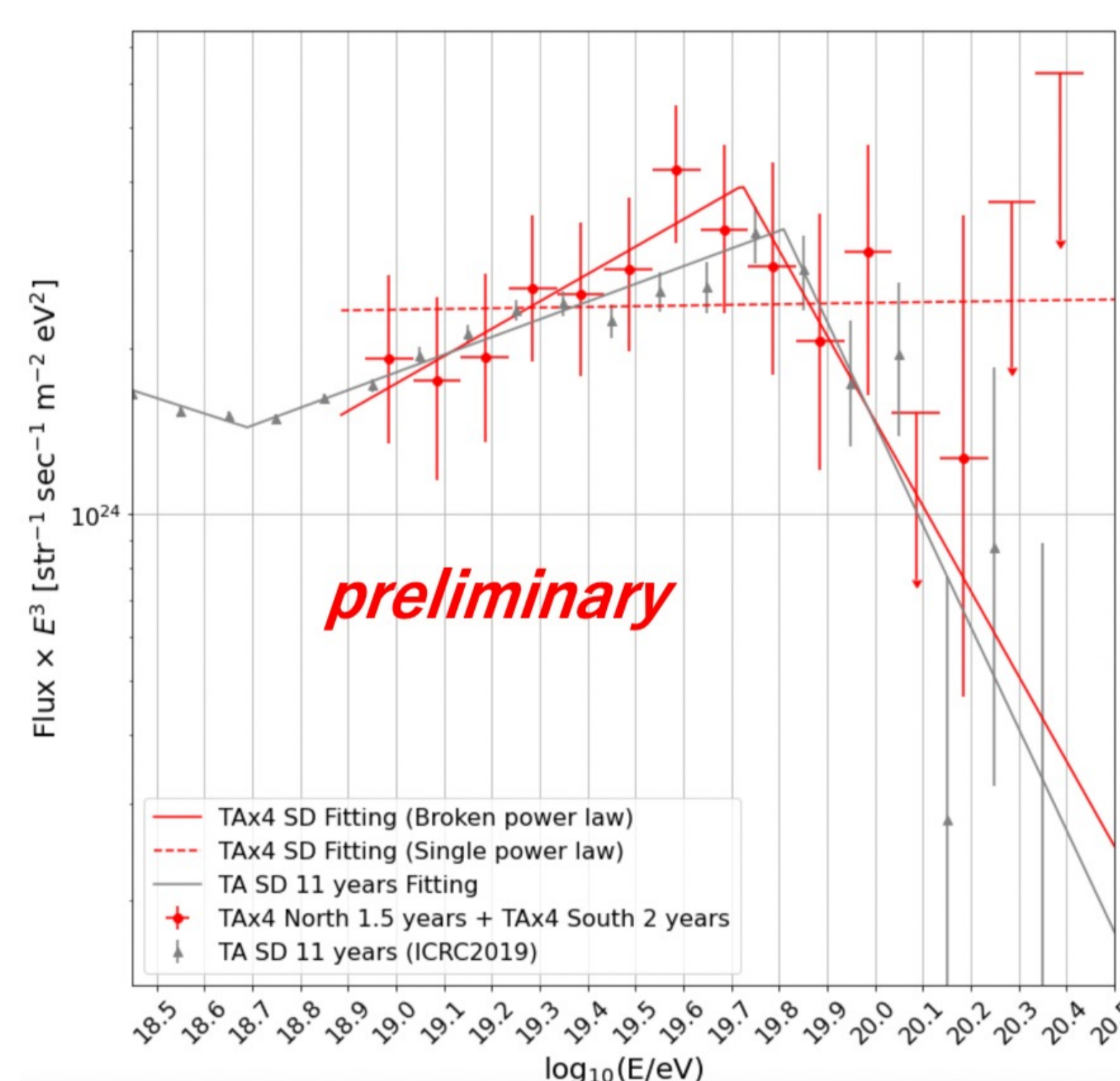


Comparison of parameters

- **Red histograms** : MC simulation, **Blue dots** : observed data
- KS test p-values are also displayed
- They agree statistically



UHECR Energy spectrum



- Bin-by-bin correction unfolding method is used (the same as TA SD analysis).
- The TAx4 SD energy spectrum is consistent with TA SD
- The cut off structure is also observed by TAx4 SD (Fit w/ the cut off is preferred)
- The number of observed events above $10^{19.84} \text{ eV}$ is 10, while the number of expected events w/o the cut off is 27.14
This is $1.48 \times 10^{-4} (\sim 3.6\sigma)$

Summary & Outlook

Summary

- TAx4 SD MC simulation agrees the observation statistically.
- The energy spectrum measured by TAx4 SD array using 1.5-2 years data is consistent w/ TA SD measurement with the temporally determined energy scale: 1.3.
The cut off significance is 3.6σ .

Outlook

- Analysis for further period.
- Optimization of reconstruction.
- Study of uncertainties to combine TAx4 SD + the original TA SD array analysis