Energy spectrum and the shower maxima of cosmic rays above the knee region measured with the NICHE detectors at the TA site

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for the Telescope Array collaboration

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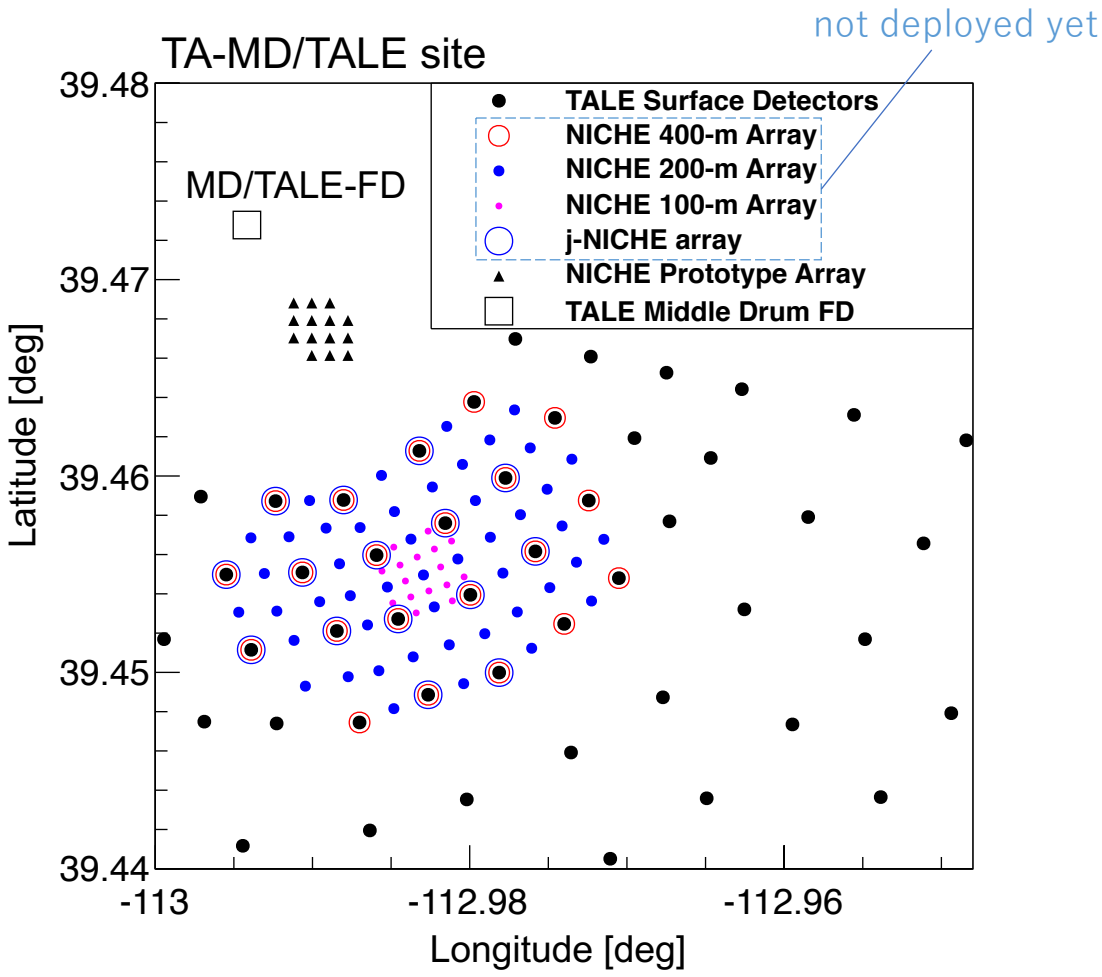
Outline

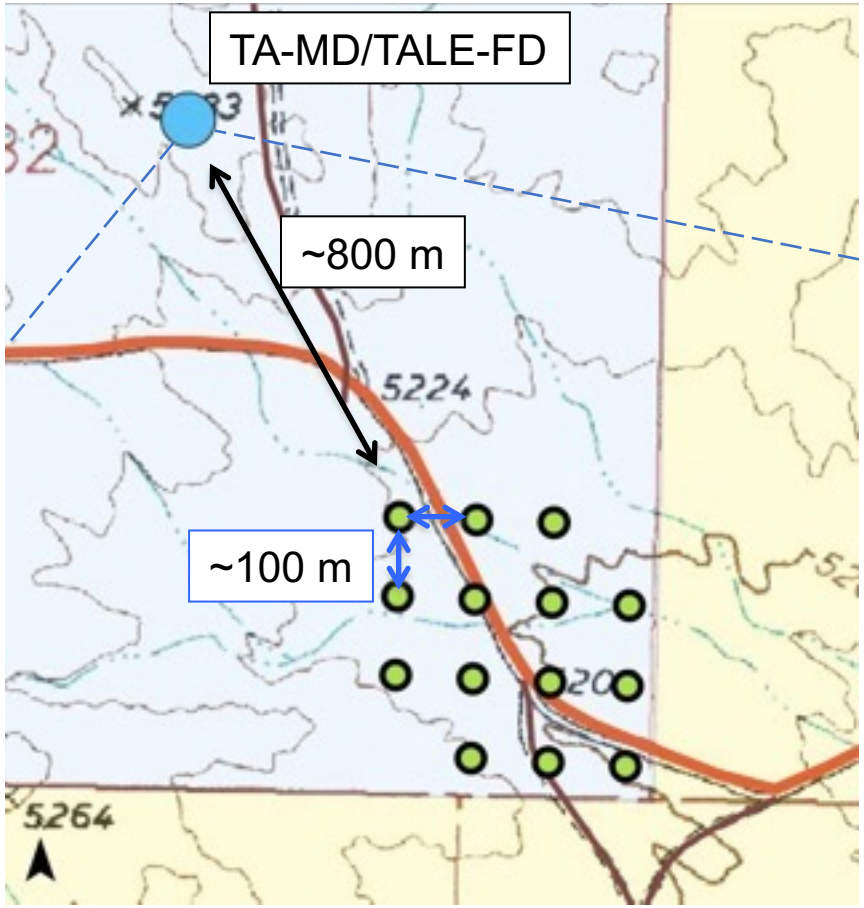
- NICHE experiment
- Monte-Carlo Simulation
  - Reconstruction Method
  - Reconstruction Resolution
  - Comparison between MC and Observation Data
  - Aperture
- 1-year Observation Data
  - Energy Spectrum
  - Xmax distributions and Composition

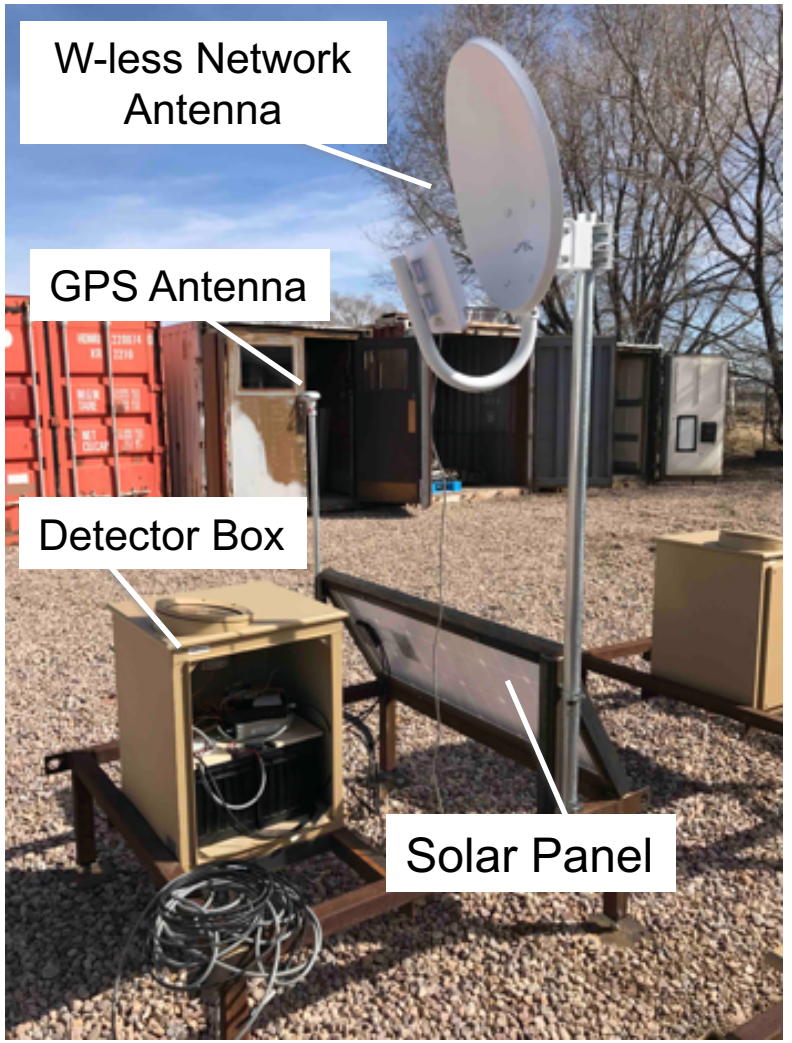
NICHE(Non-Imaging CHErenkov)

- CR composition at $10^{15\text{-}18.5}$ eV
- Cherenkov light lateral distribution and profile
- “Full NICHE” with ~70 counters
- jNICHE goes first with 14 counters



NICHE Prototype Array





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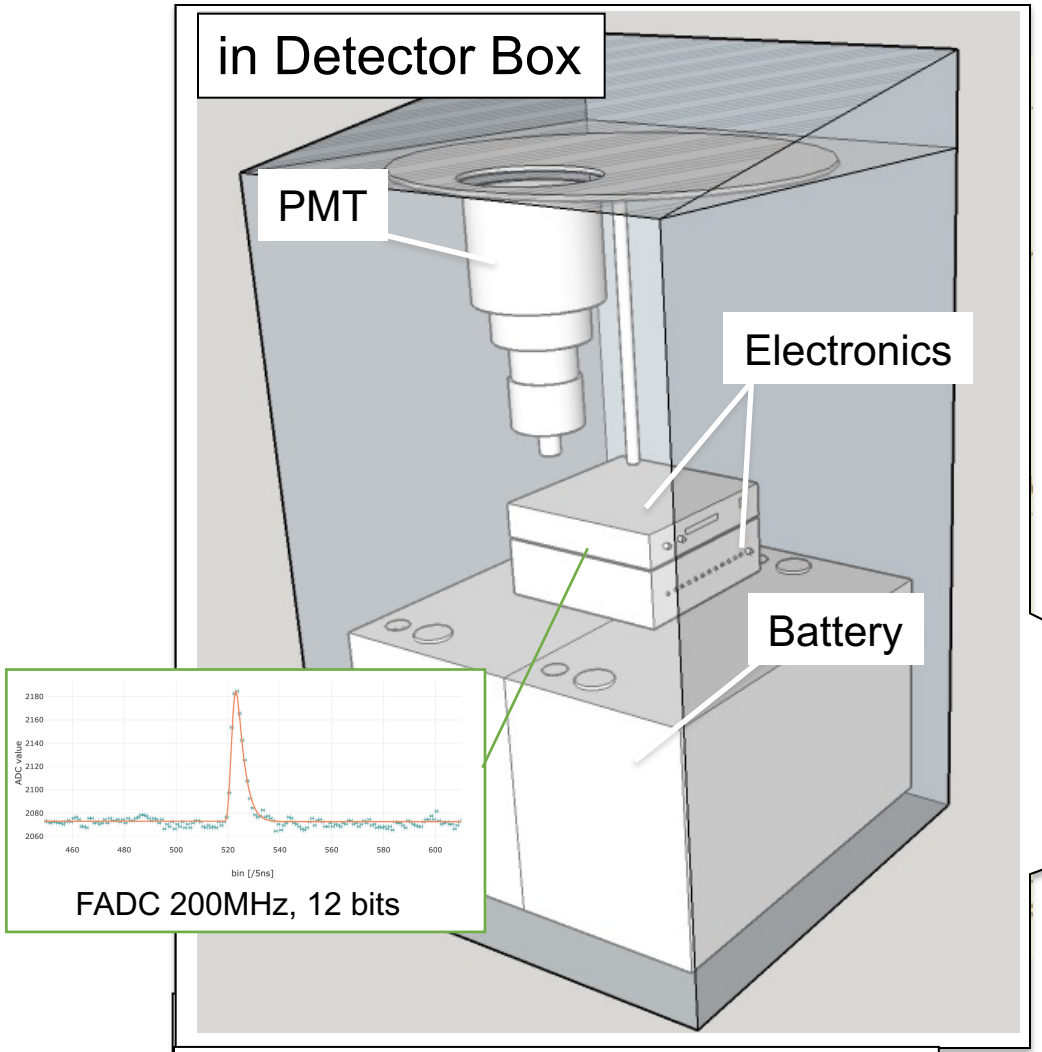
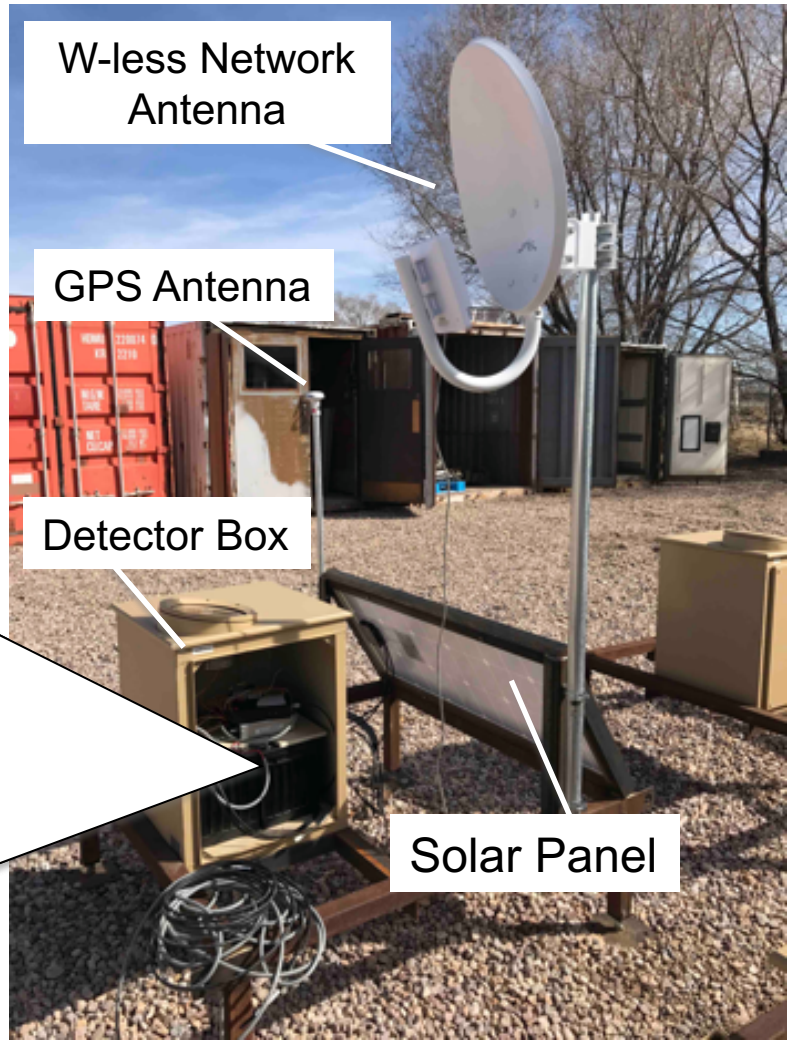
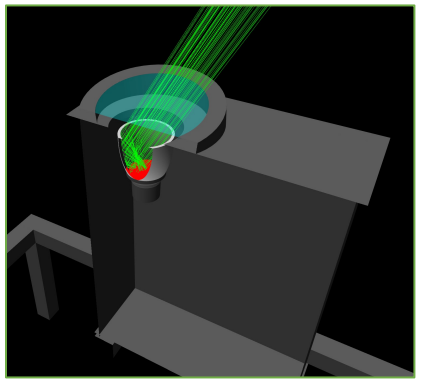




Monte-Carlo Simulation

- Air-Shower Simulation:
  - 10 million shower events sampled randomly with replacement from the 5,042 original showers generated by CORSIKA, so that it follows different 3 distributions in each energy bin:
    - zenith-angle distribution ($\propto \cos\theta \sin\theta\,, 0 \leq \theta\ [\mathrm{deg}] \leq 40$)
    - uniform core-position distribution for both X and Y ($-500 \leq X/Y\ [\mathrm{m}] \leq 500$)
    - energy distribution $\left(\frac{dN}{dE} \propto \mathrm{E}^{-3}, 10^{15} \leq E\ [\mathrm{eV}] \leq 10^{17}\right)$.
  - QGSJET-II/GHEISHA
  - "High resolution": no THINning and CERSIZ=1
- Detector-Response Simulation:
  - Ray-tracing using ROBAST
  - Impulse response and transit time of PMT
  - Self triggering and baseline fluctuation on electronics
  - Status of real available detector



Reconstruction Method

- Arrival direction is determined by the plane fitting assumed as its going with light speed.
- Core position, shower energy and Xmax are determined by the LDF-fitting result:

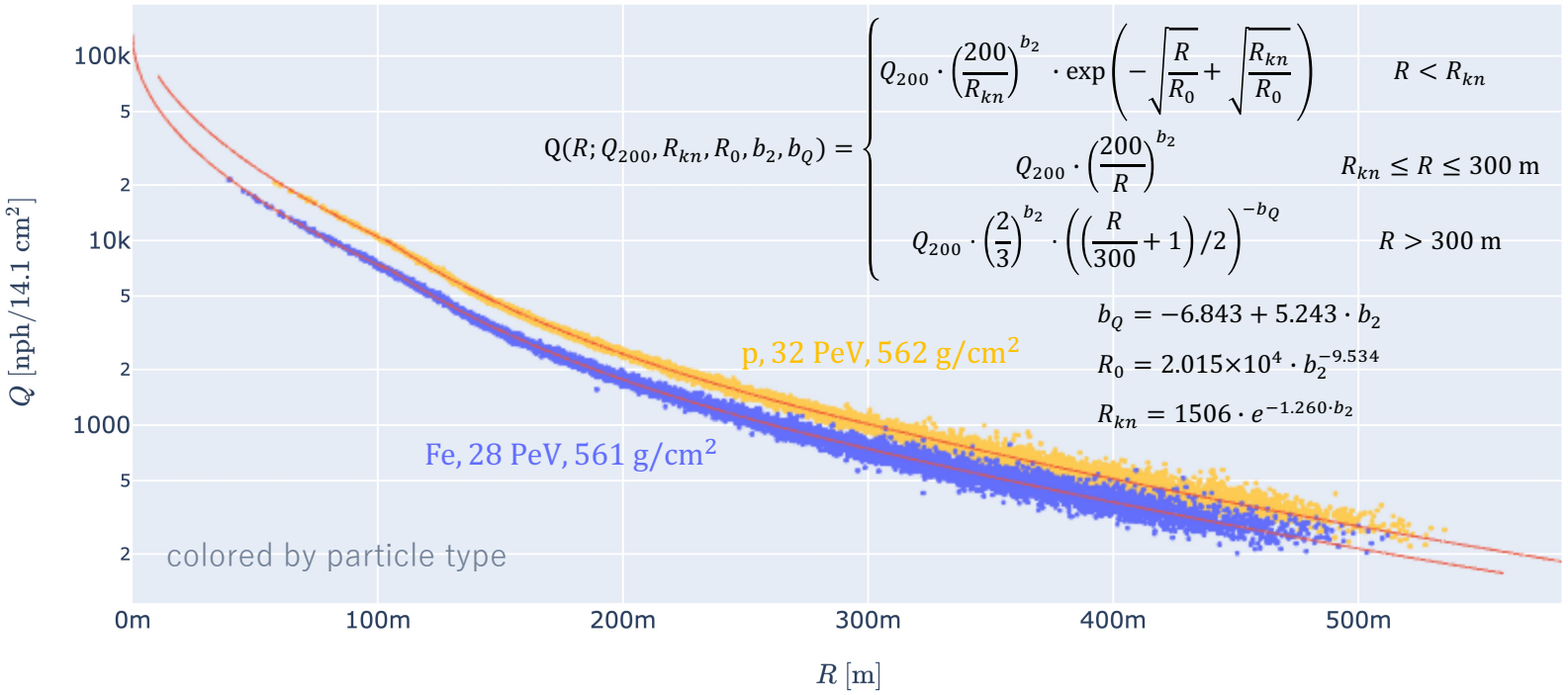
Typical Example of Lateral Distribution Function Fitting

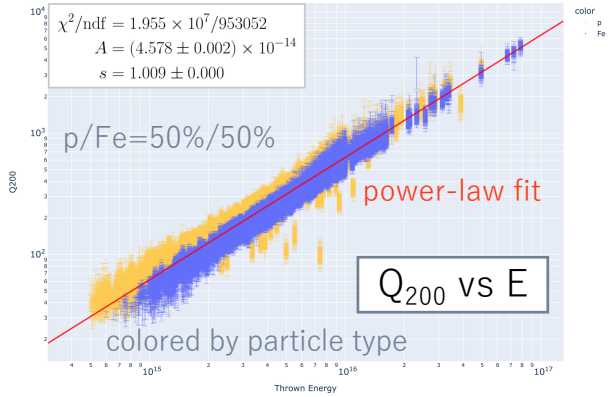
$$\mathrm{Q}(R; Q_{200}, R_{kn}, R_0, b_2, b_Q) = \begin{cases} Q_{200} \cdot \left(\frac{200}{R_{kn}}\right)^{b_2} \cdot \exp\left(-\sqrt{\frac{R}{R_0}} + \sqrt{\frac{R_{kn}}{R_0}}\right) & R < R_{kn} \\ Q_{200} \cdot \left(\frac{200}{R}\right)^{b_2} & R_{kn} \le R \le 300\ \mathrm{m} \\ Q_{200} \cdot \left(\frac{2}{3}\right)^{b_2} \cdot \left(\left(\frac{R}{300} + 1\right)/2\right)^{-b_Q} & R > 300\ \mathrm{m} \end{cases}$$

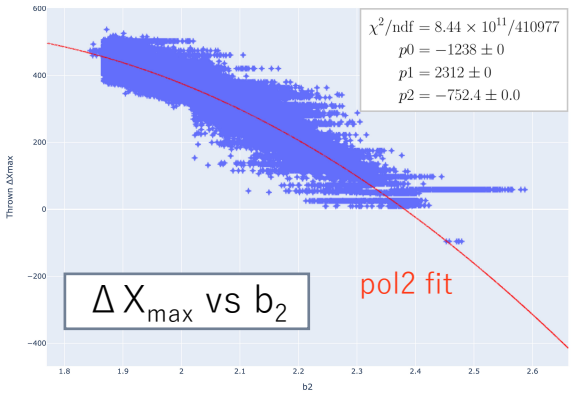
$$b_Q = -6.843 + 5.243 \cdot b_2$$

$$R_0 = 2.015{\times}10^4 \cdot b_2^{-9.534}$$

$$R_{kn} = 1506 \cdot e^{-1.260 \cdot b_2}$$







Data Cleansing and Resolutions

There are 287,751 events (19.7%) of 1,461,961 matched with the following 2-steps quality criteria:

1st quality criterion:

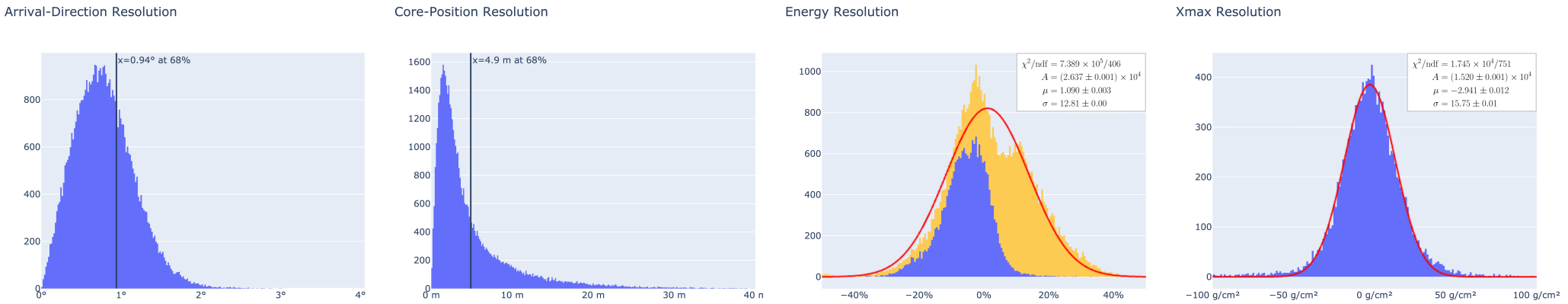
- Zenith Angle $< 30°$
- The number of detectors $\geqq 5$
- Core distance from the center of the array $R_p < 200$ m
- Whether optimization of LDF fitting looks okay

2nd quality criterion:

- the largest 5% cut of LDF χ^2 distribution for each of different NDF

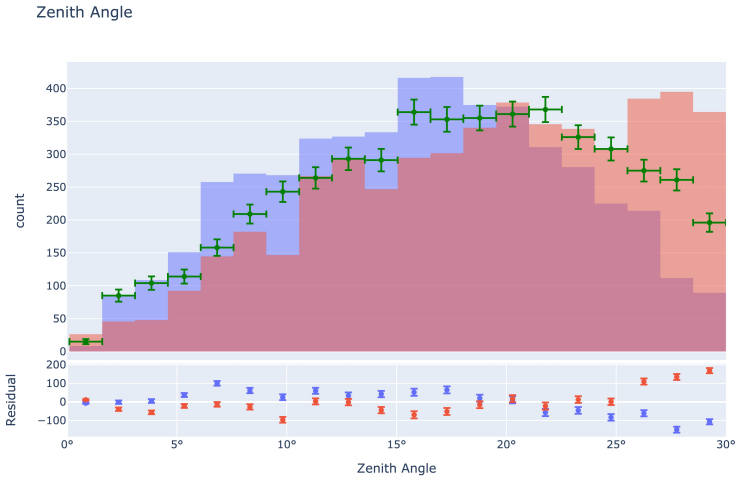
Note that, for determining Xmax,
more strict quality criterion are met:
・$R_p < 100$ m (instead of 200 m)
・the number of detectors $\geqq 6$ (instead of 5)

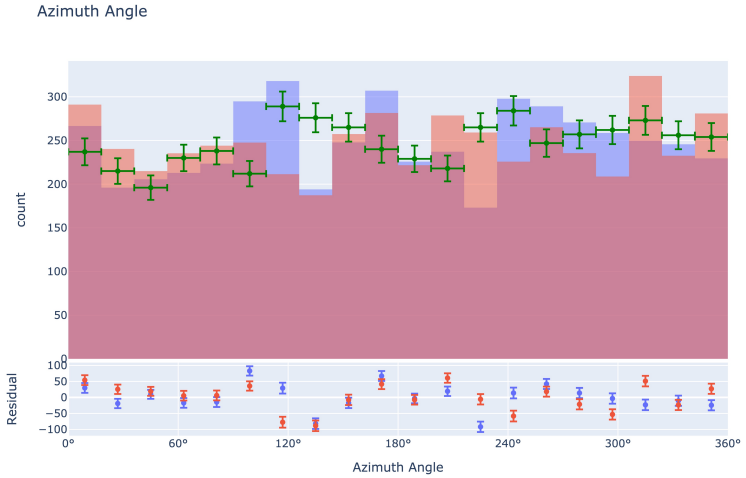
Resolutions for E = 6 PeV

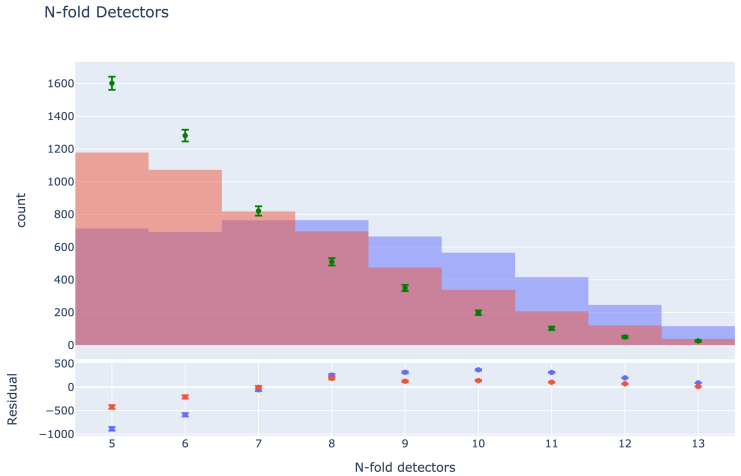


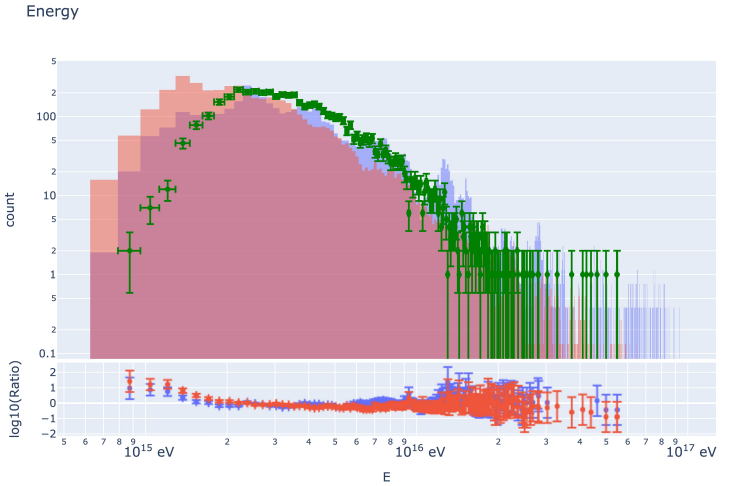
Compare my MC Simulation to Real Data

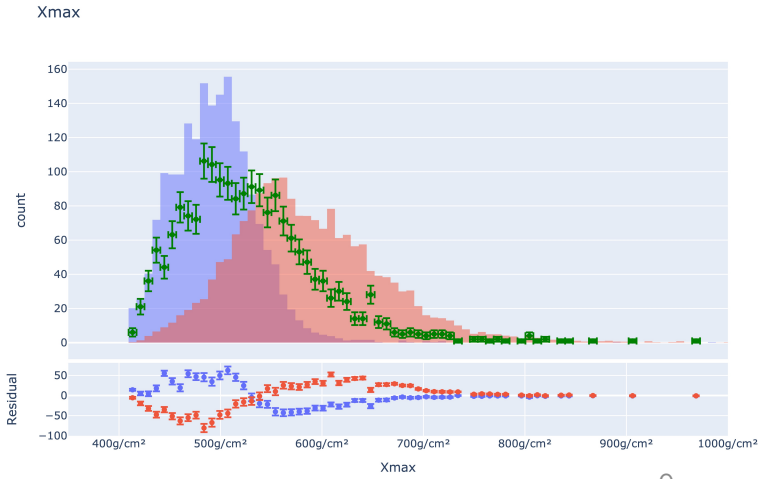
Overlaid histogram and its residual plot, drawn with observation data and MC data with pure proton/iron











Aperture

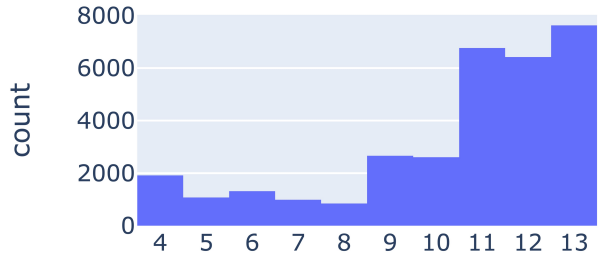
Aperture is calculated by the following equation:

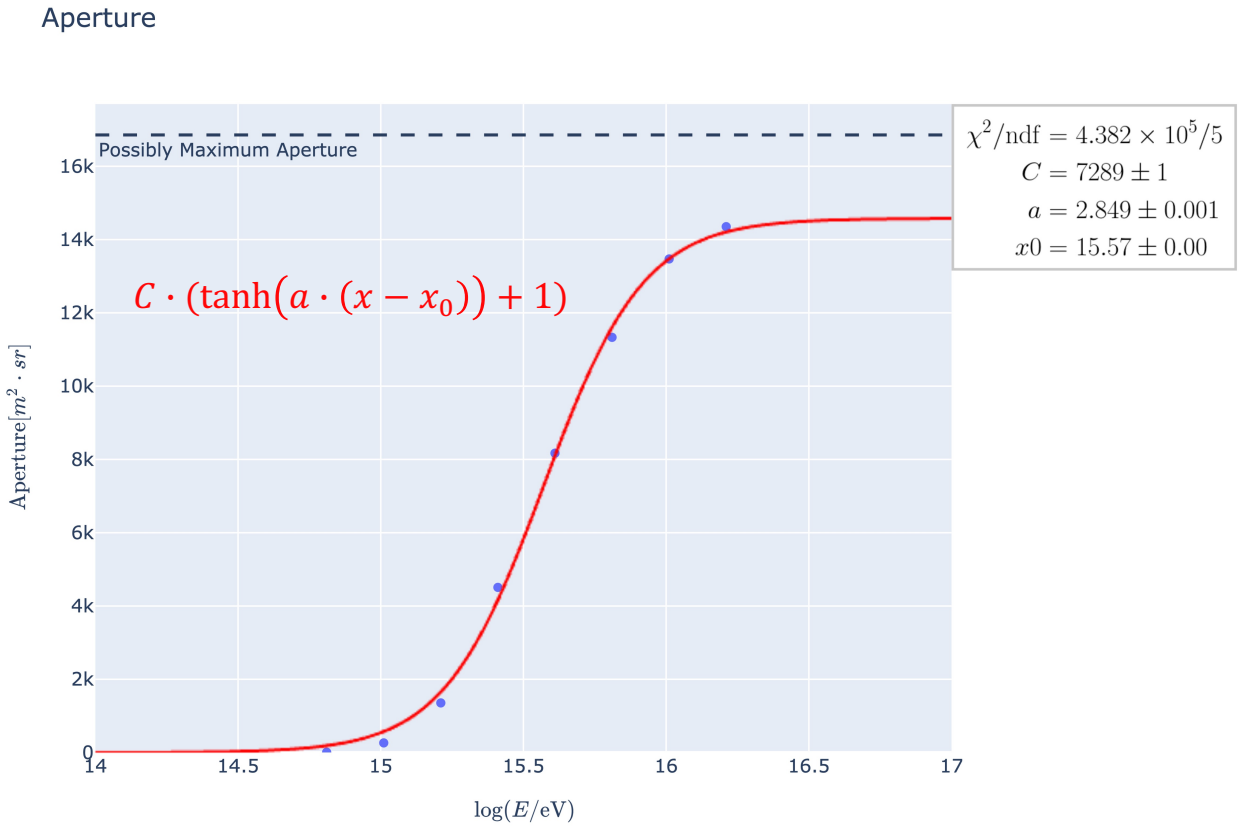
$$A(E) \sim \frac{\pi}{4} \cdot \frac{N_{\mathrm{sel}}(E)}{N_{\mathrm{all}}(E)} \cdot S_{\mathrm{max}}$$

N_{sel} is the number of events after the data cleansing.
N_{all} is the number of shower events used in MC.
S_{max} is the area of the uniformly-distributed core positions.

Note that this aperture is calculated just for the case that all 13 detectors are available, but real detector status must be considered.

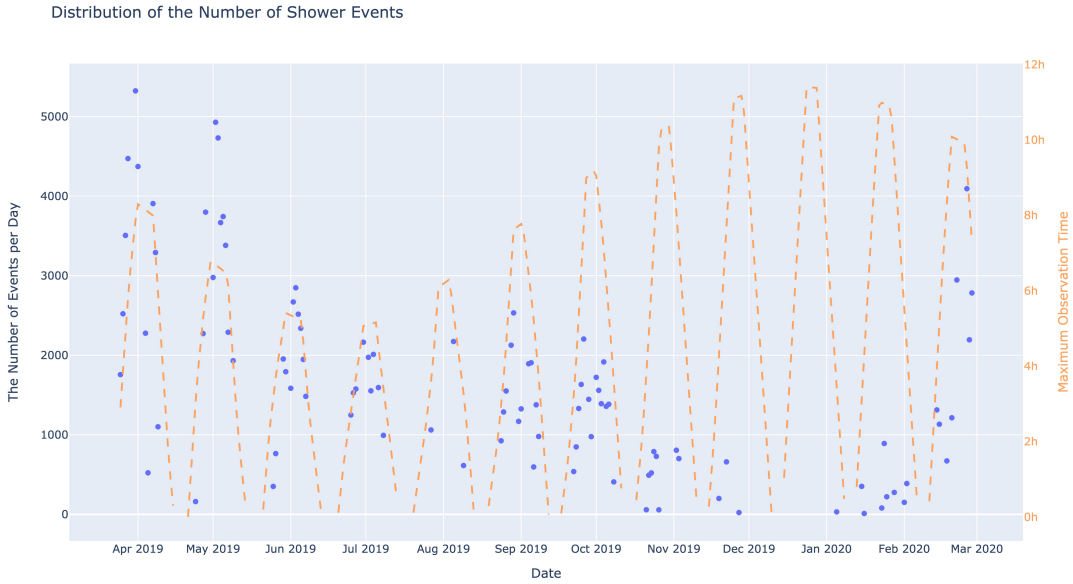
cf. the number of real available detectors



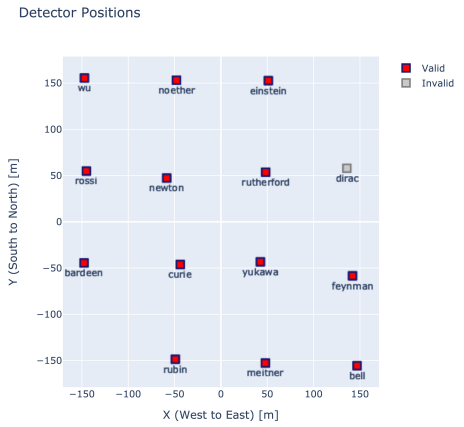


1-year Observation Data

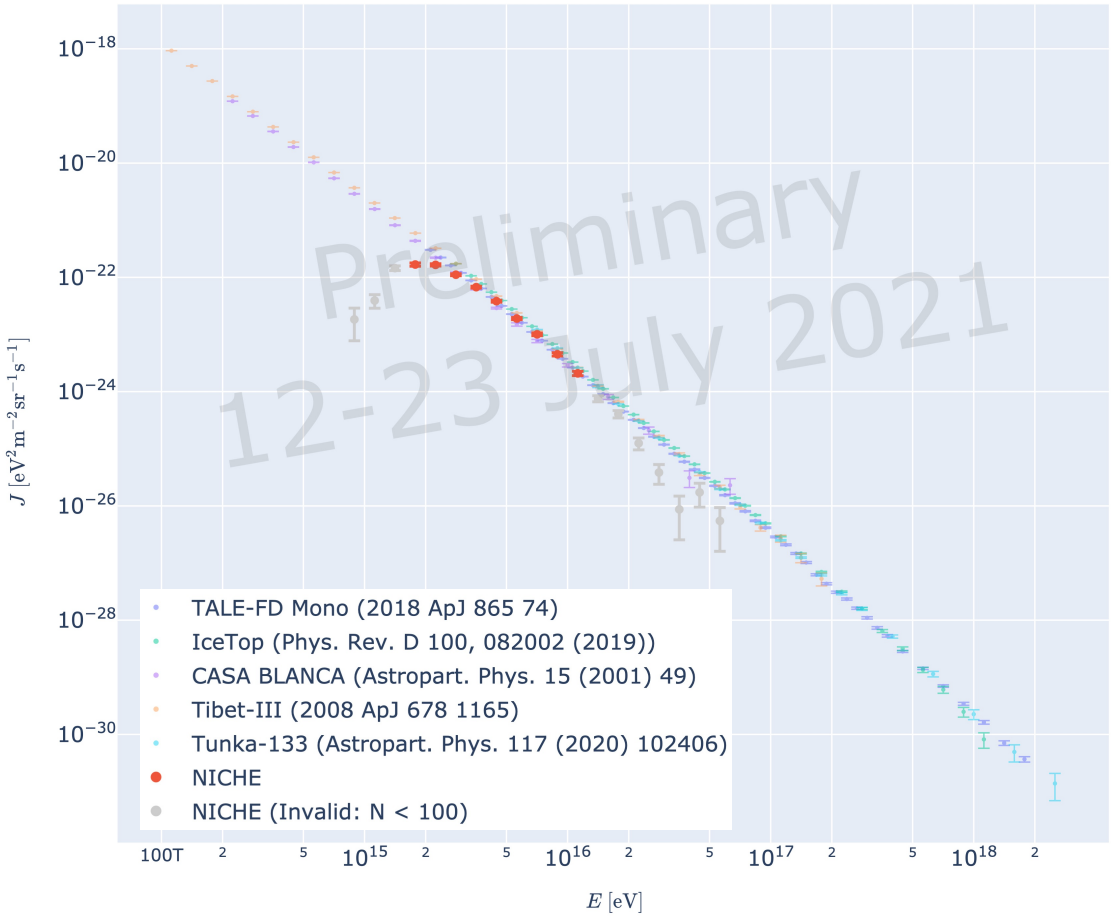
- 1-year observation data for March 2019 to 2020
  - The total number of shower events is 165,839
  - The total observation time is 536.9 h
  - Used 13 detectors out of 14 (except for dirac)
  - Calibrated by the NICHE-TALE hybrid analysis (detector-wise relative calibration and absolute calibration mainly based on TALE-FD)

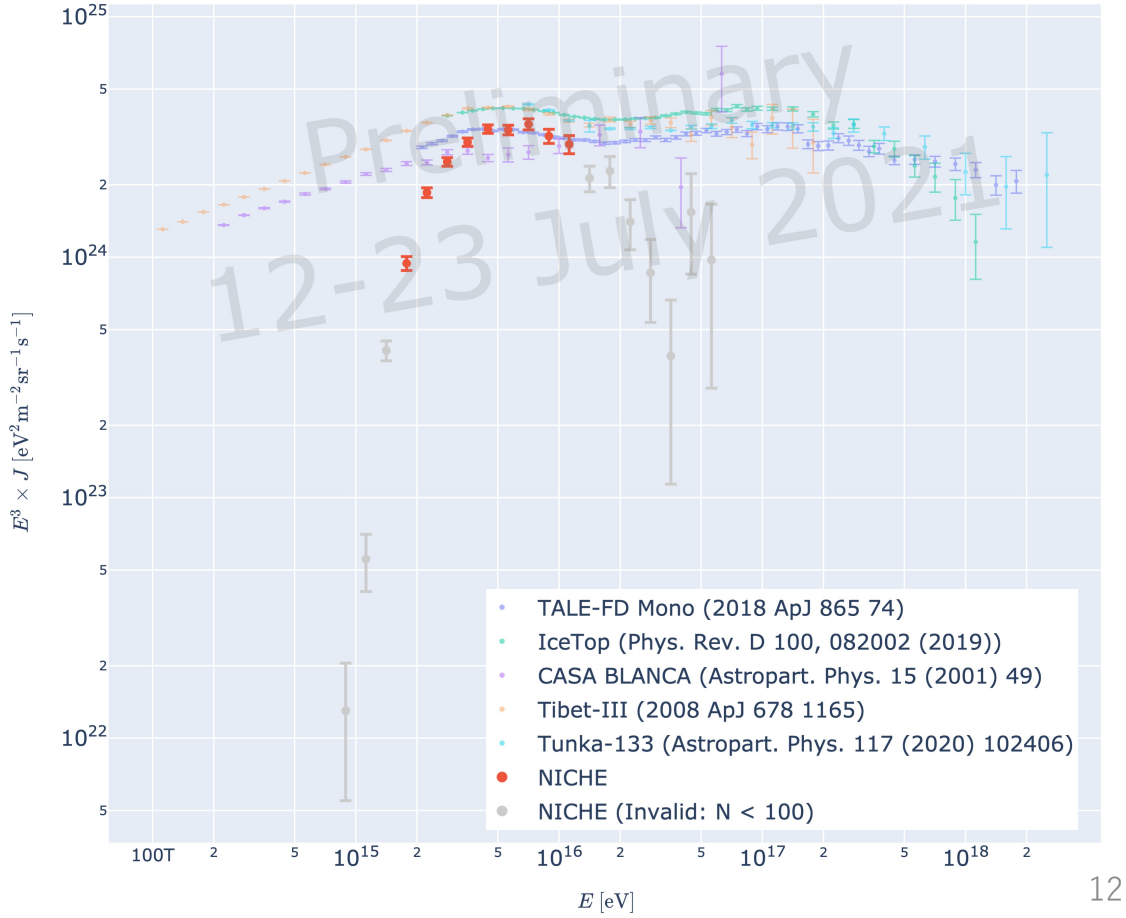


- There are just 4,943 events (3.0%) left of 165,839 by the data cleansing.

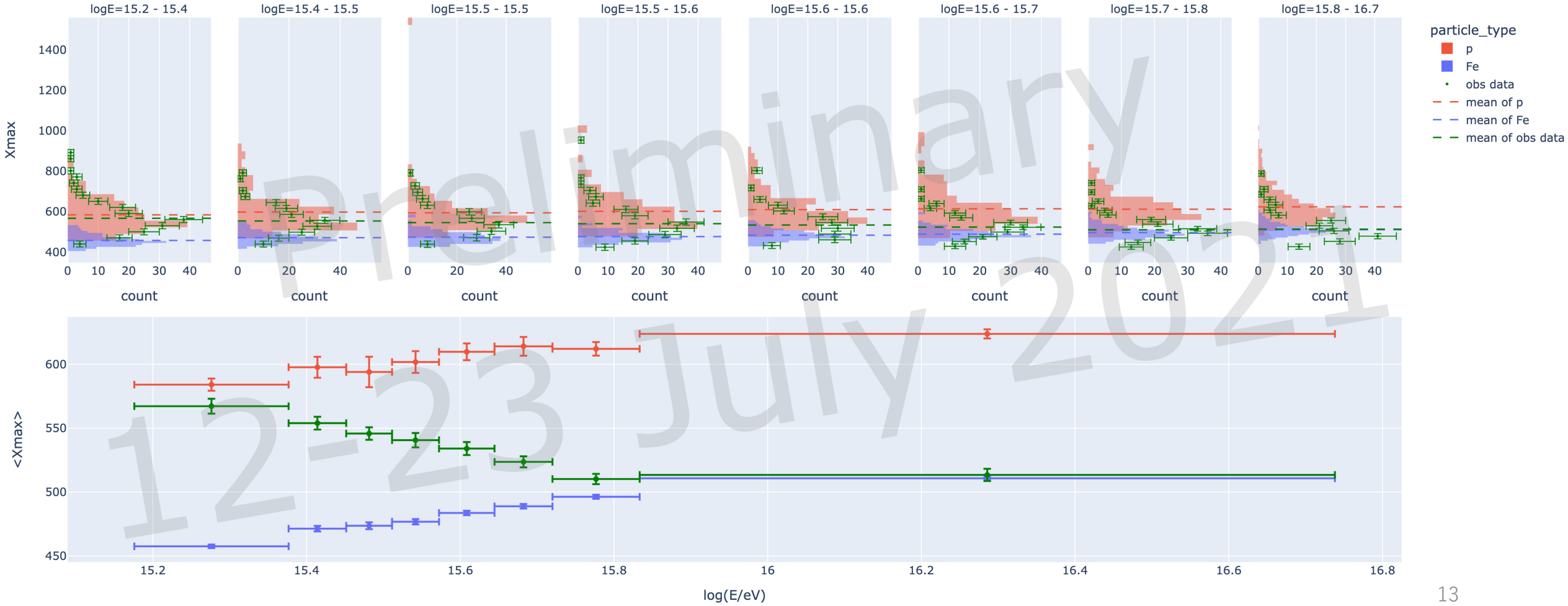


Energy Spectrum

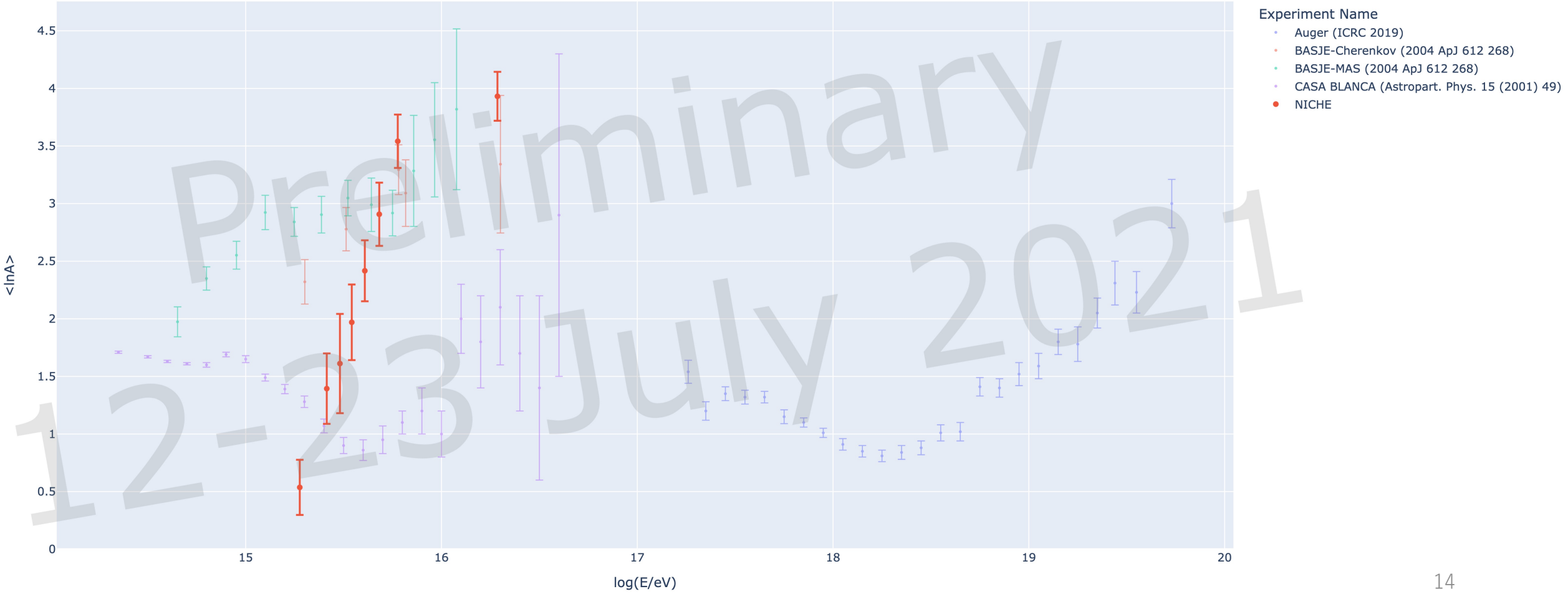




Xmax Distributions



Composition



Summary

- The main purpose of NICHE experiment is to investigate the energy and the composition of the primary cosmic ray at the 2nd knee region.

- First results of preliminary cosmic-ray energy spectrum and composition are shown.