



Cosmic Ray Composition measurement between 3PeV to 30PeV with TALE Hybrid Detector

Nov. 20, 2024
Keitaro Fujita

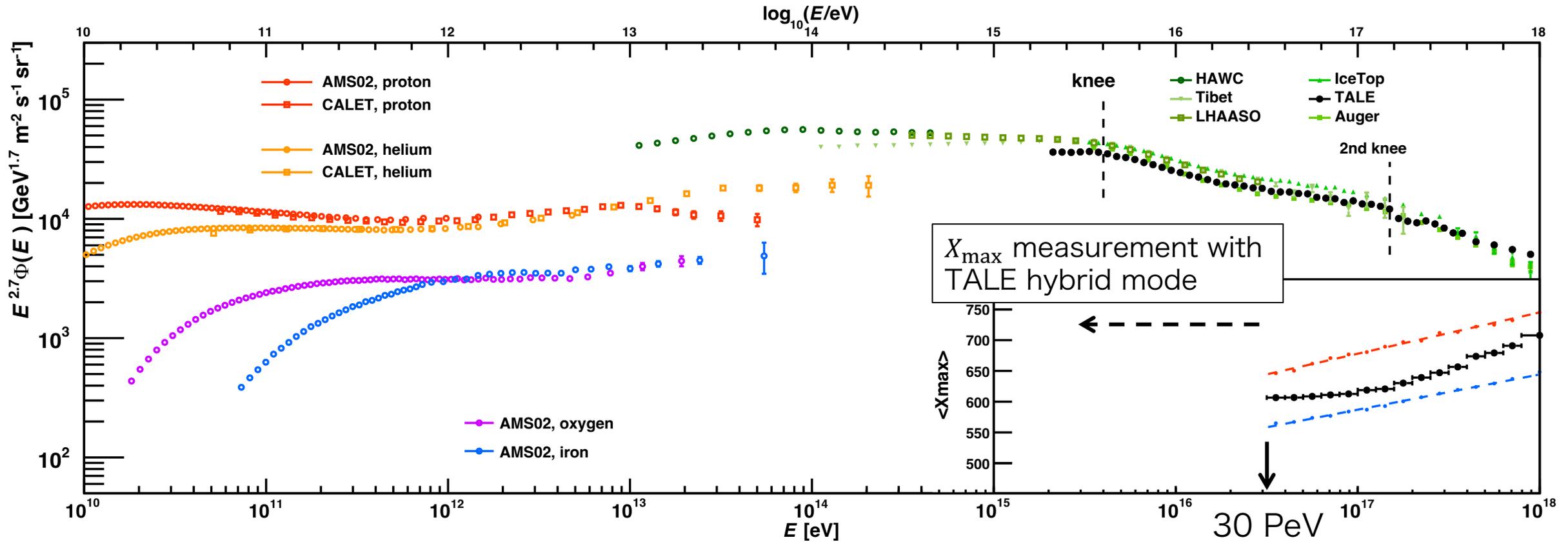
ICRR, The University of Tokyo
for the Telescope Array Collaboration

7th International Symposium on Ultra High Energy Cosmic Rays
(UHECR2024)

17 – 21 November, 2024
Malargüe, Mendoza, Argentina



Motivation



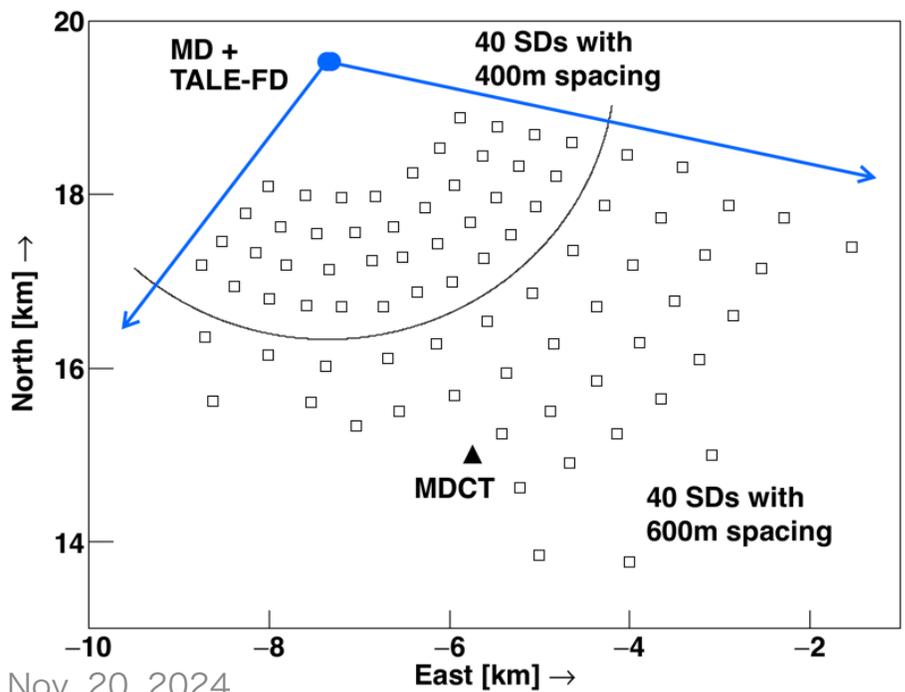
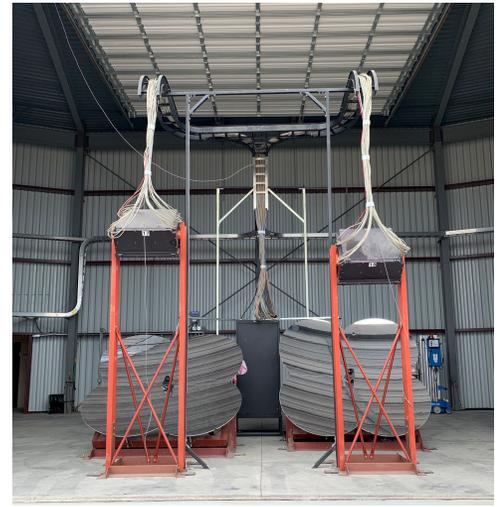
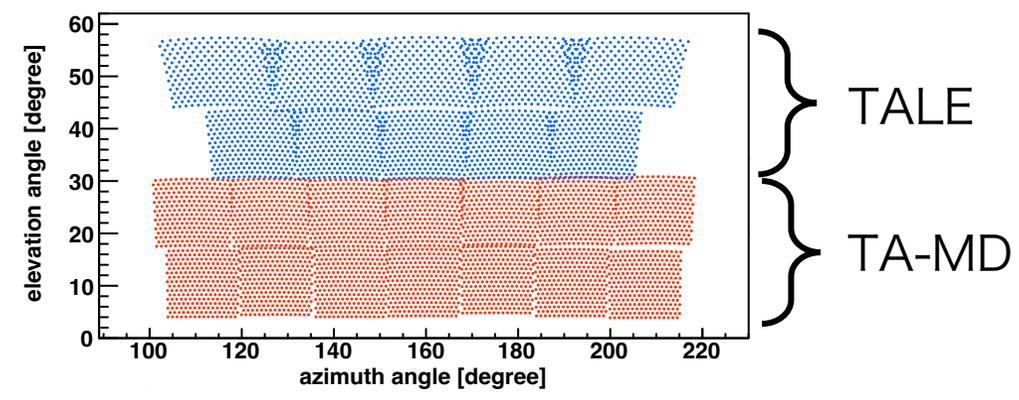
- Spectrum and X_{\max} measurements with TALE FD monocular mode: 2 PeV to 2 EeV
- X_{\max} measurement with TALE FD + TALE SD hybrid mode : 30PeV to 3 EeV
- Starts operation of 100m spacing SD array in Nov. 2023
 - X_{\max} measurement from 3 PeV to 30 PeV by TALE FD + new SD hybrid mode

Telescope Array Low-energy Extension

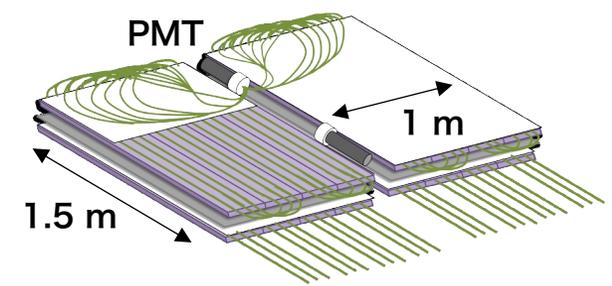
- Upgrade TA hybrid detector sensitivity down to PeV range → TALE



- 10 High-elevation telescopes ($31^\circ - 59^\circ$)
 - 256pixel, 8bit 10MHz FADC readout
 - Started observation since 2013



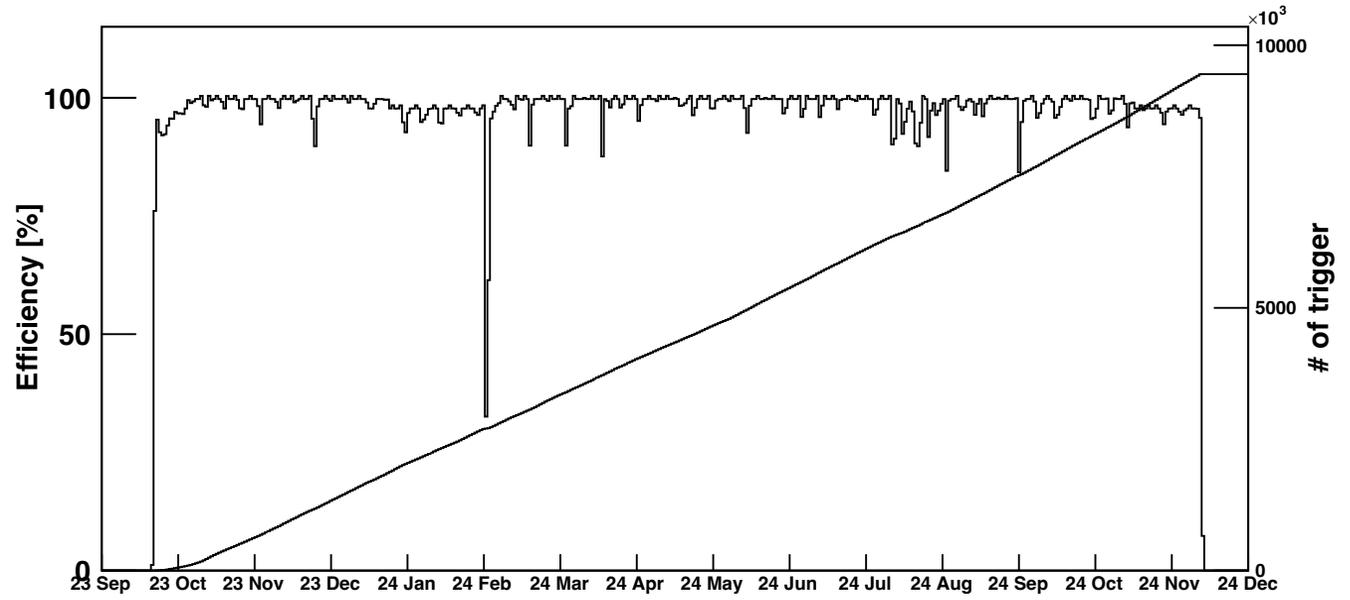
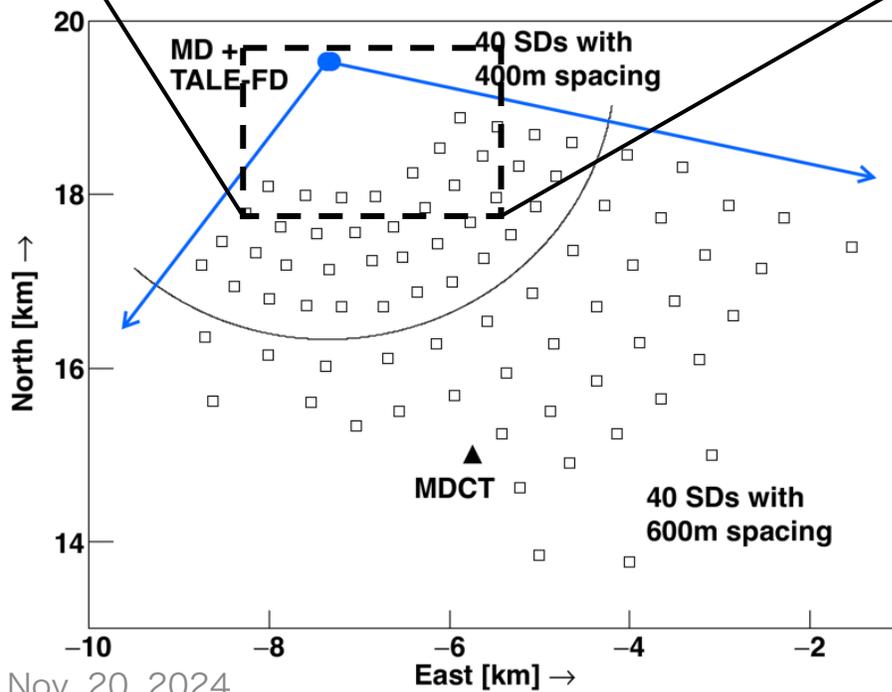
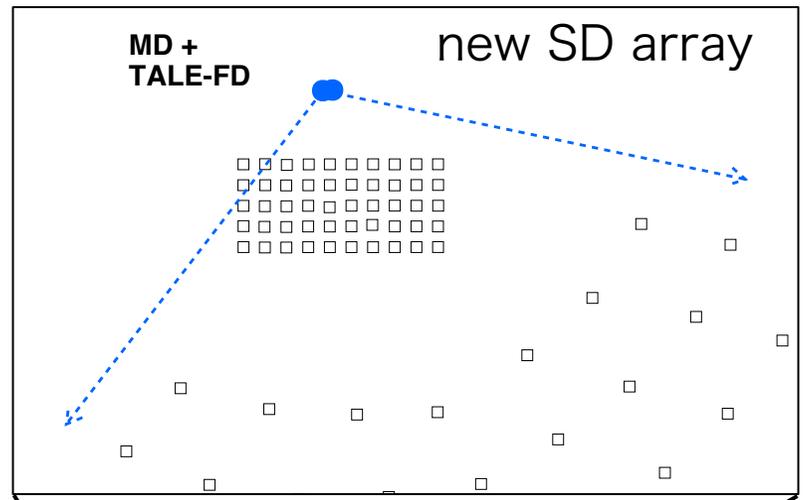
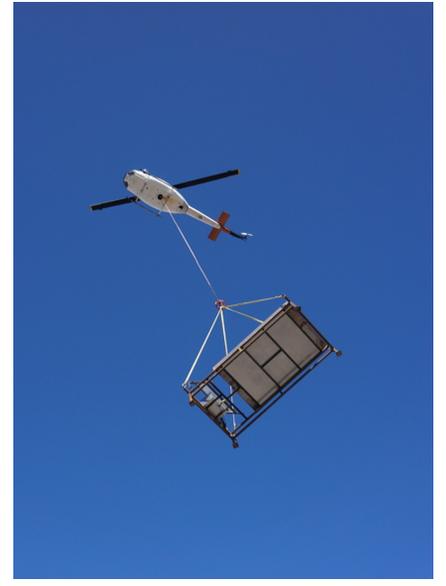
- SD array
 - 40SDs with 400m, 40SDs with 600m
 - 2 layers Scintillation counter, $3m^2$
 - Started observation since 2017



Telescope Array Low-energy Extension

- Upgrade TA hybrid detector sensitivity down to PeV range → TALE

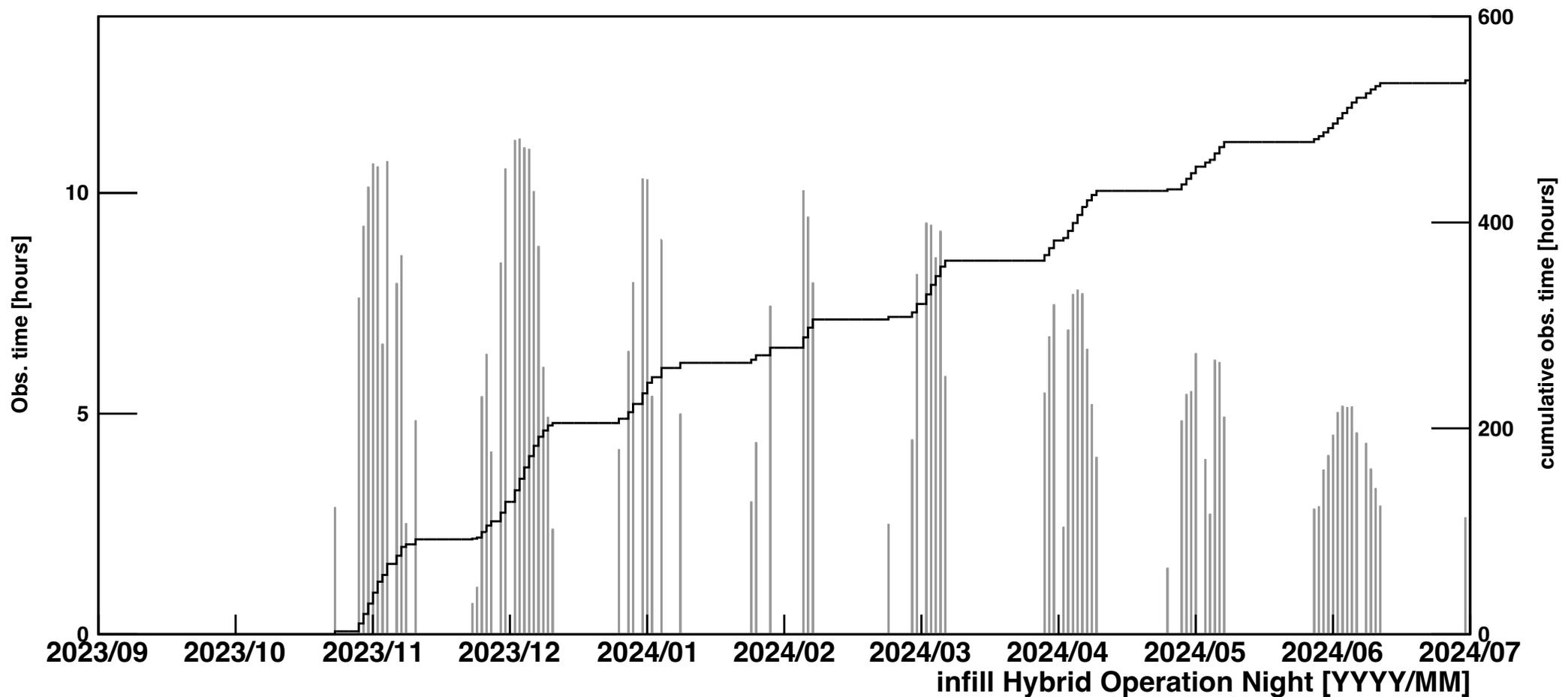
- Further dense SD array
 - 50SDs with 100m spacing
 - 2 layers Scintillation counter
 - trigger condition: 5 adjacent SDs hit within 3μs
 - Started observation since Nov. 2023
 - duty cycle: > 98%



TALE FD + new SDs hybrid observation time ⁵

- TALE FD + new SD array hybrid started on 2024/11/04
 - accumulated observation time: 540 hours (at end of Jun. 2024)

infill Hybrid Operation Time

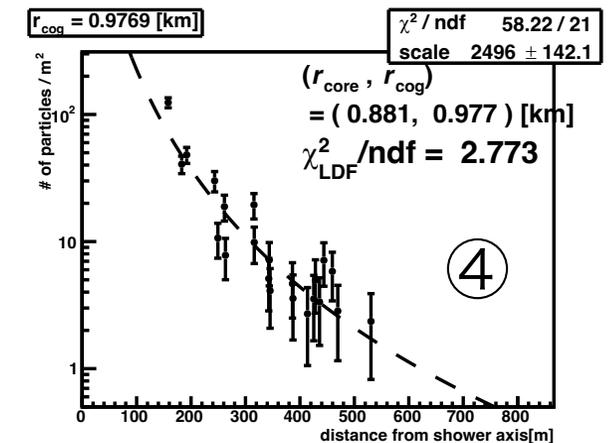
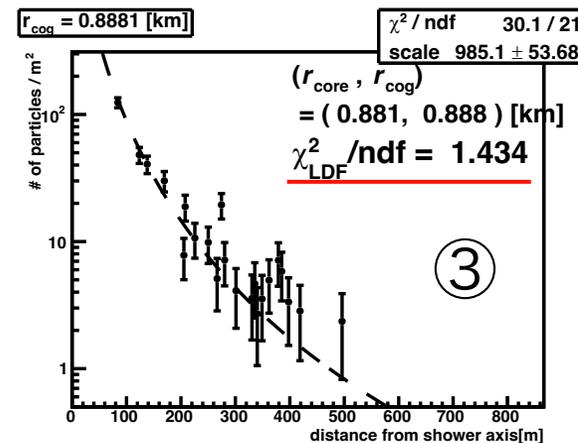
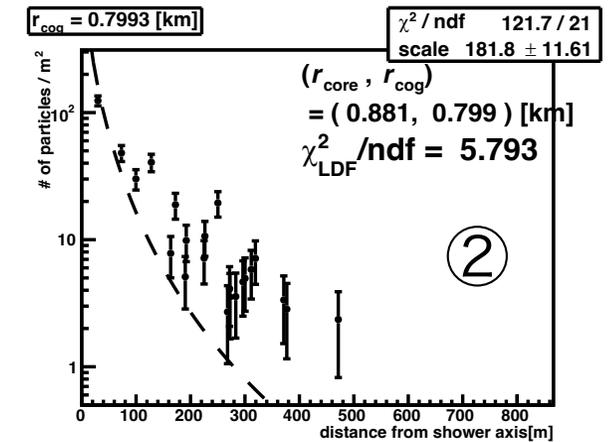
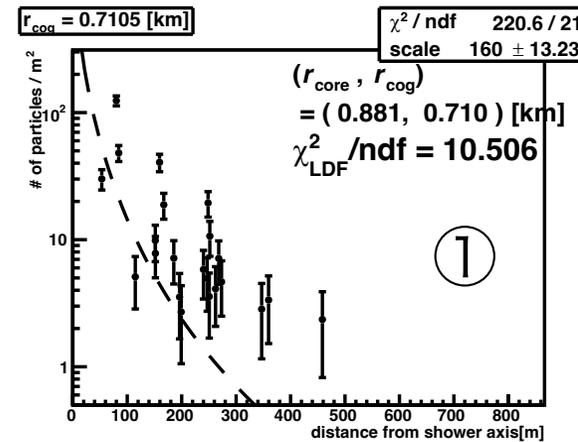
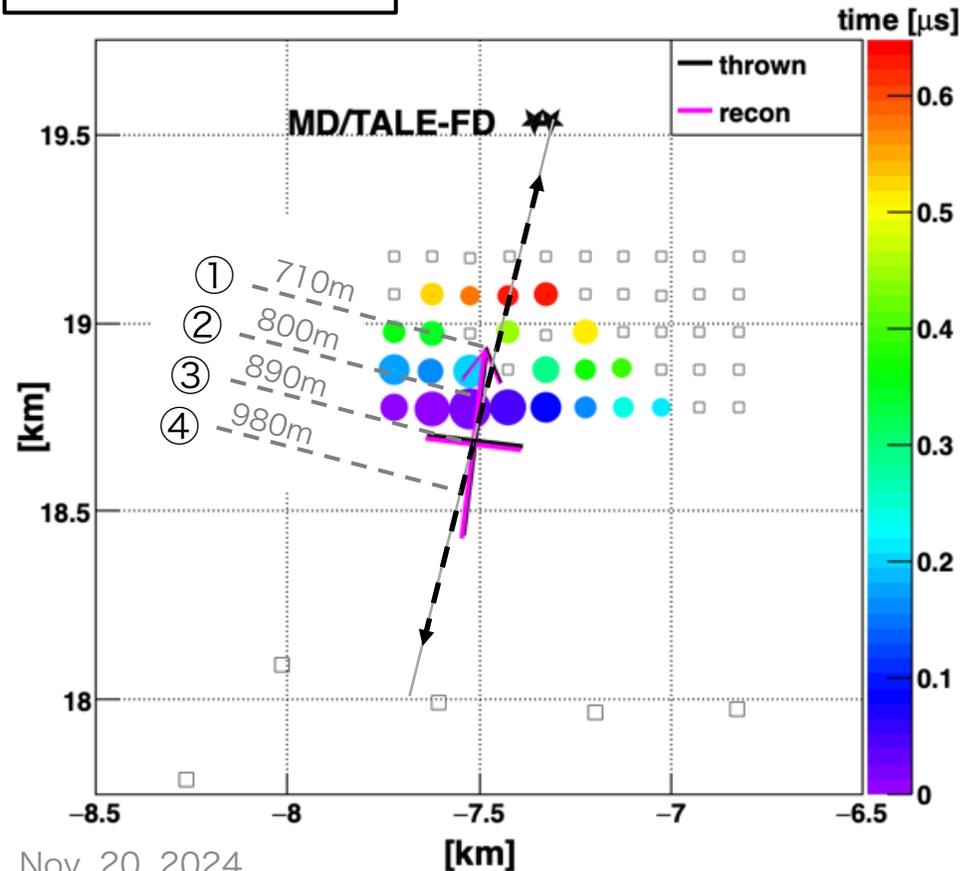


Event reconstruction

- In previous hybrid geometry reconstruction : FD tube timings + 1SD hit timing
- This work: Constrained by lateral fit \leftrightarrow provide good resolution in low energies

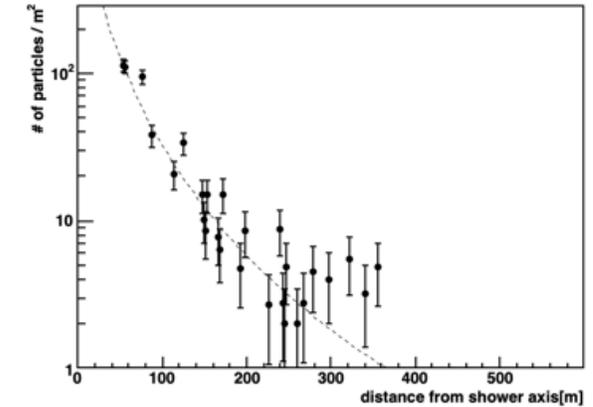
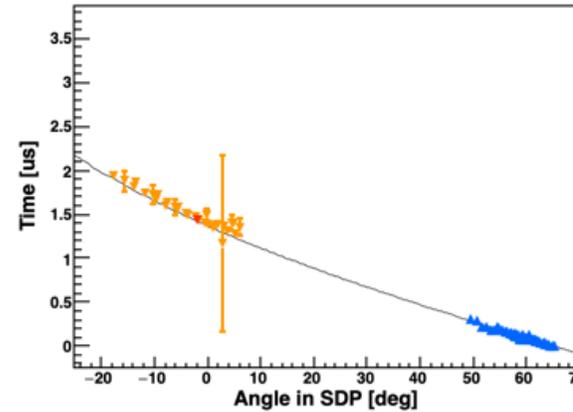
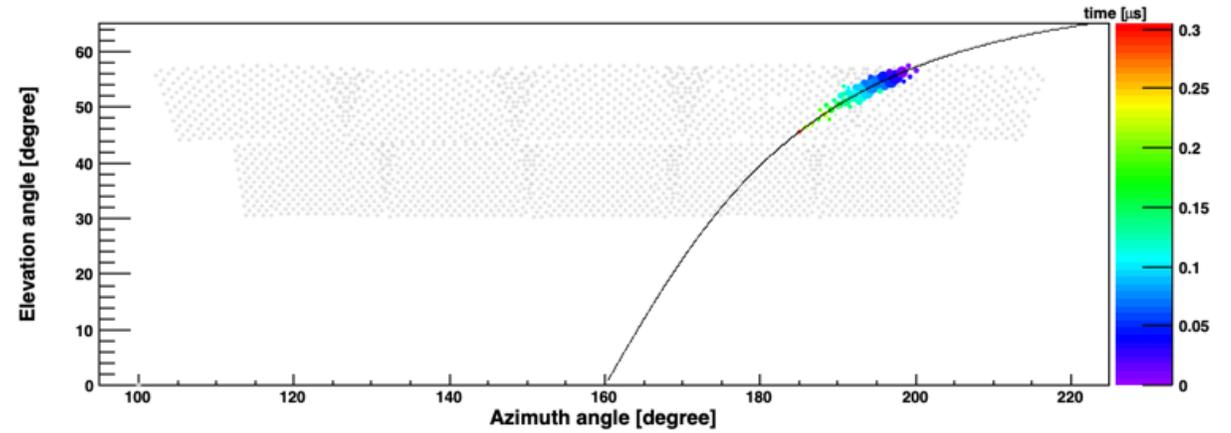
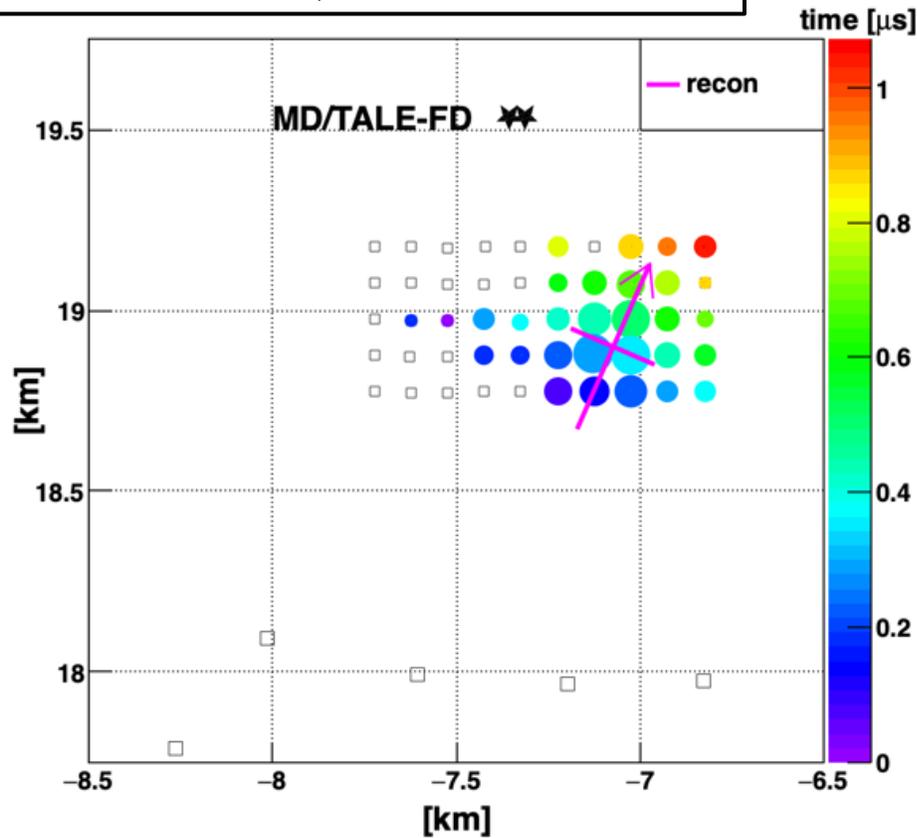
$$\chi_{\text{geo}}^2 = \sum \left\{ \frac{(t_{i, \text{obs}} - t_{i, \text{exp}})^2}{\sigma_i^2} \right\} + \frac{(r_{\text{core}} - r_{\text{LDF}})^2}{\sigma_{\text{core}}^2}$$

MC event



TALE FD + new SD array, event sample 7

Observed event, 20231215 02:20:36



TA Preliminary

Result.	θ [deg]	ϕ [deg]	Rp[km]	ψ [deg]	coreX[km]	coreY[km]	X_{\max} [g/cm ²]	log(E/eV)
Hybrid	31.1	66.8	0.63	112.3	-6.99	18.89	586	16.04
SD	30.7	65.0	-	-	-7.07	18.91	-	16.01

Datasets & selection

- MC datasets

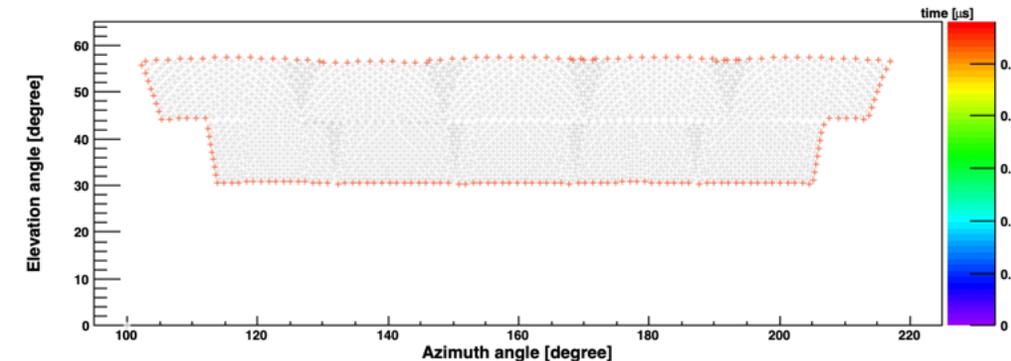
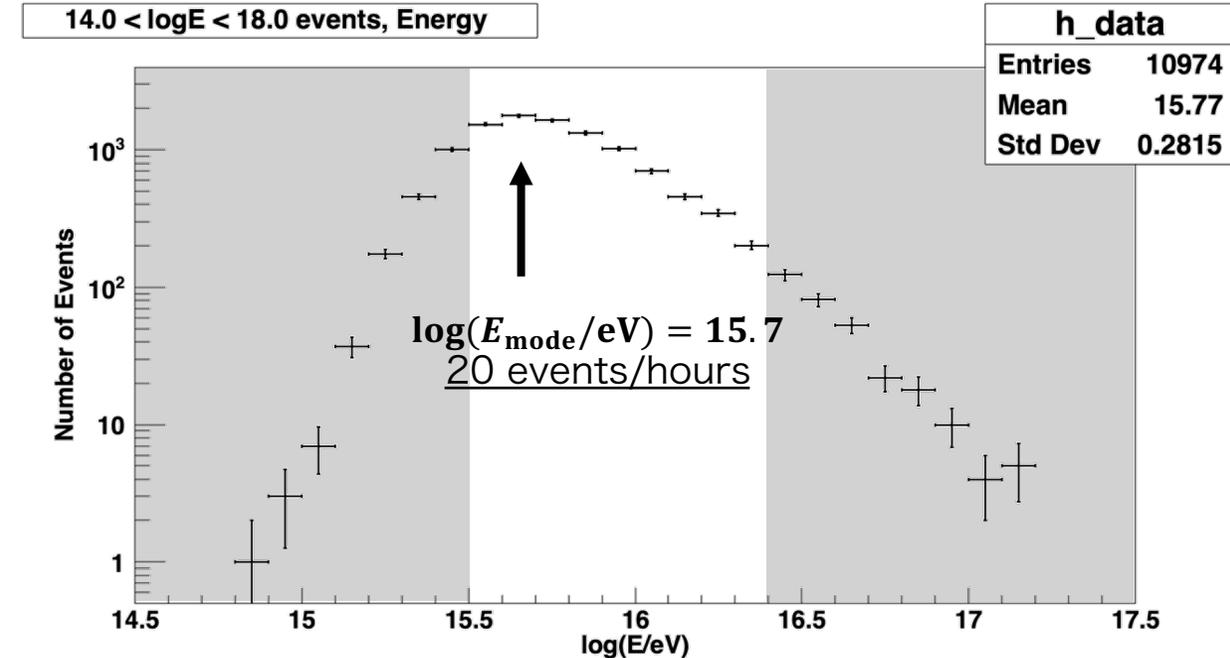
- proton/iron primary
- interaction model: QGSJETII-04
- Energy: $10^{15.25} - 10^{16.55}$ eV
- calibration data used in simulation

- Event selection

- good weather
- X_{\max} brackting cut
- # of Photo-electrons > 1000
- # of Photo-electrons / # of PMT > 50
- Event duration > 100 ns
- # of PMT in edge of FD F.O.V < 5 (red pixels in right)
- brightest PMT is not edge of F.O.V
- view angle > 1.5°
- distance of shower axis and largest signal SD < 100m

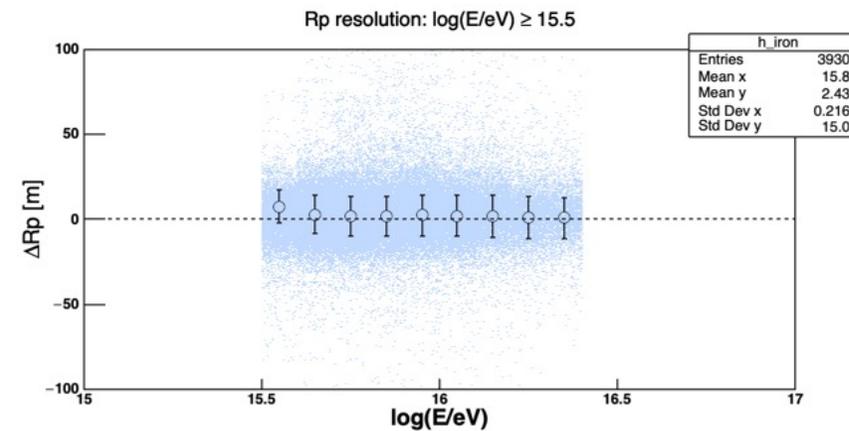
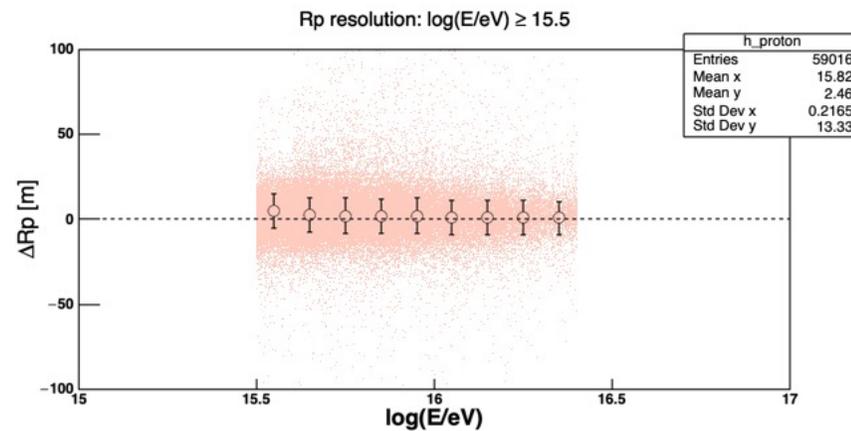
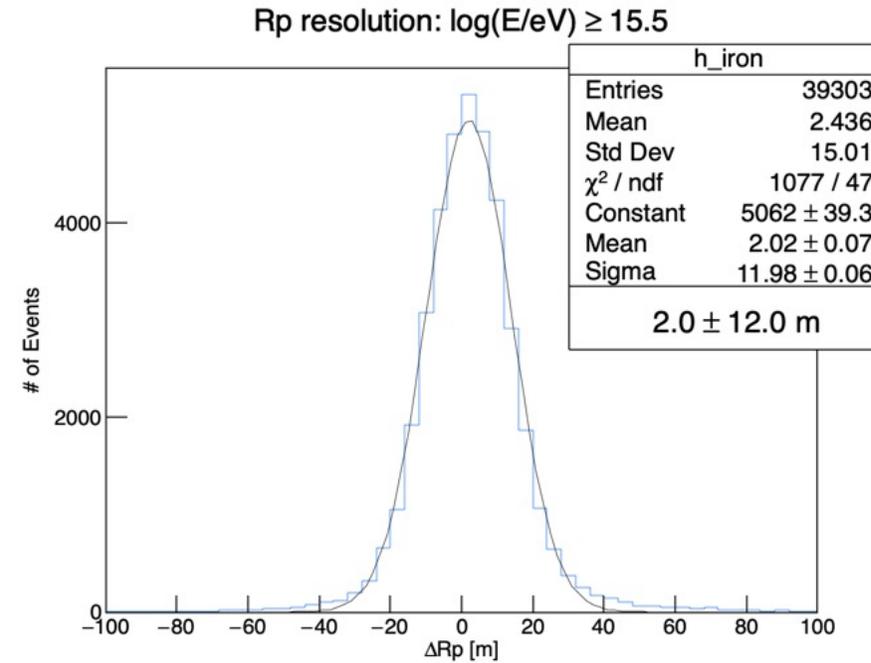
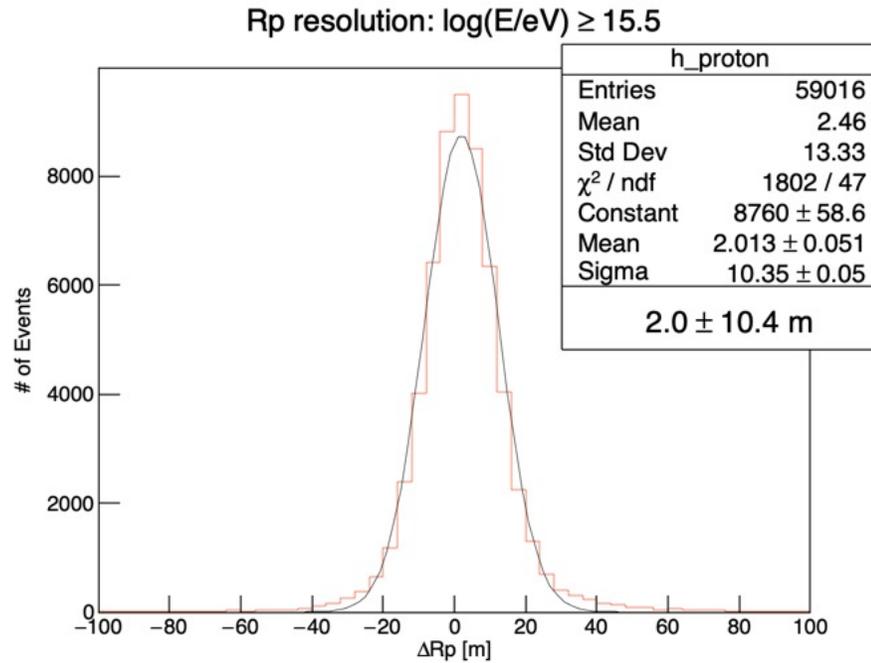
- Observation dataset

- 540 hours of hybrid observation data used in this work



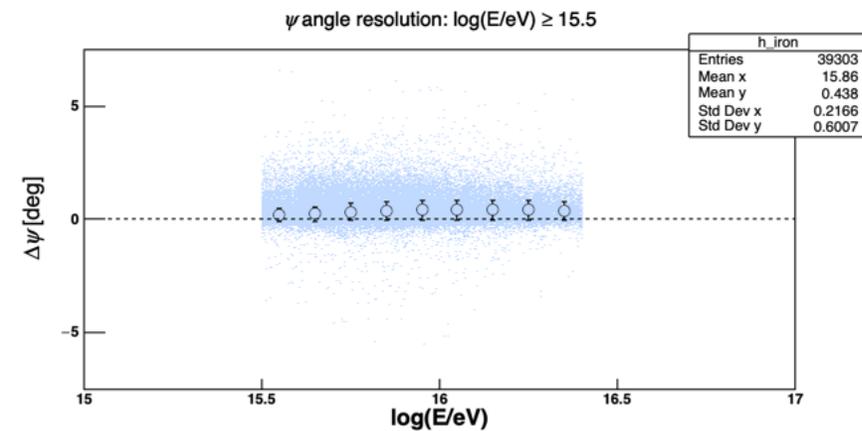
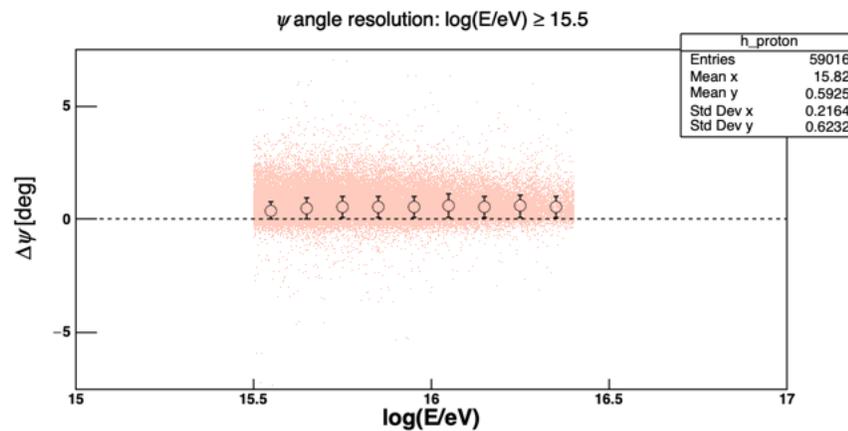
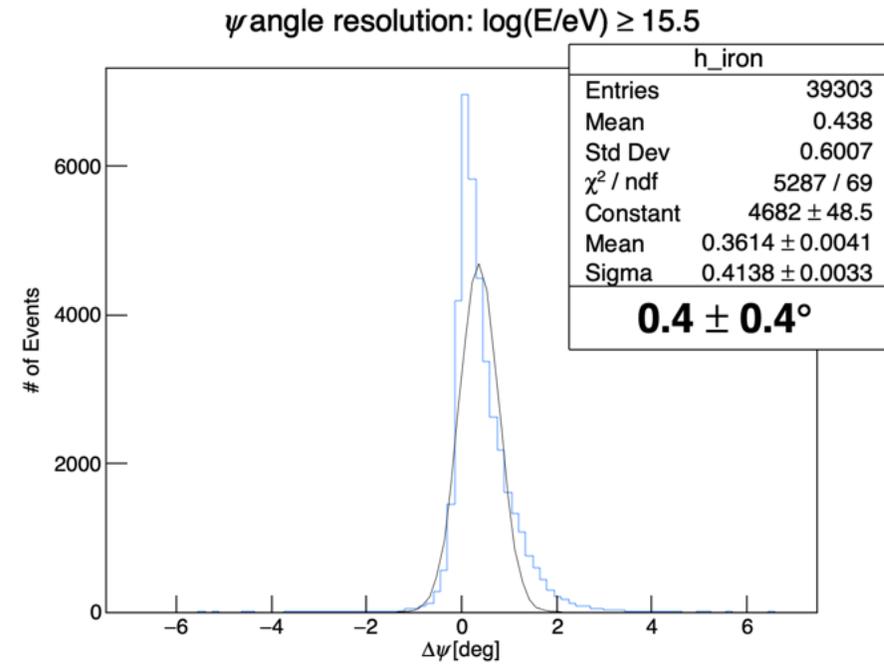
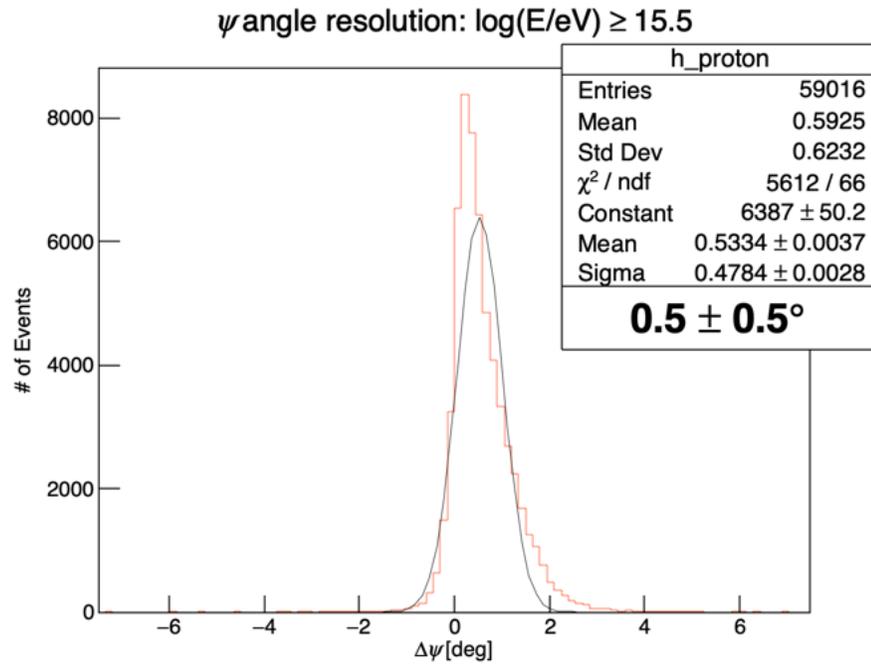
Reconstruction resolution

- Rp resolution: 10 m



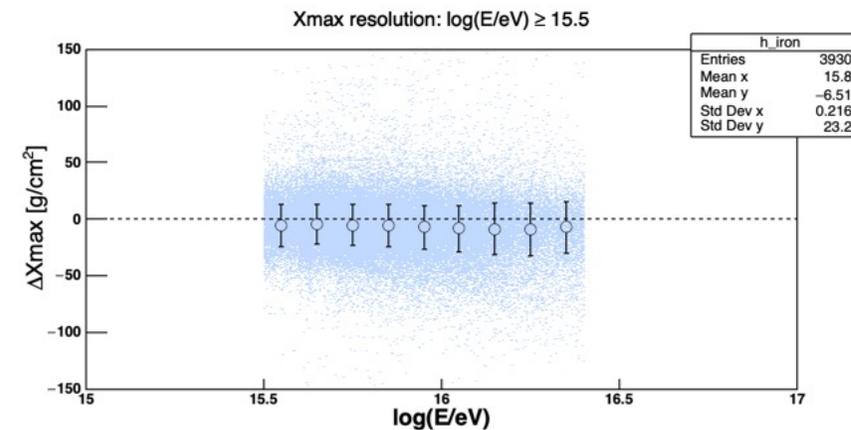
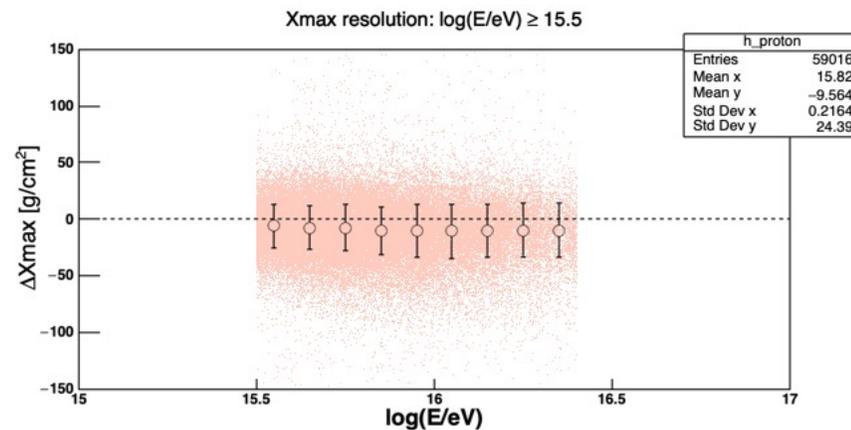
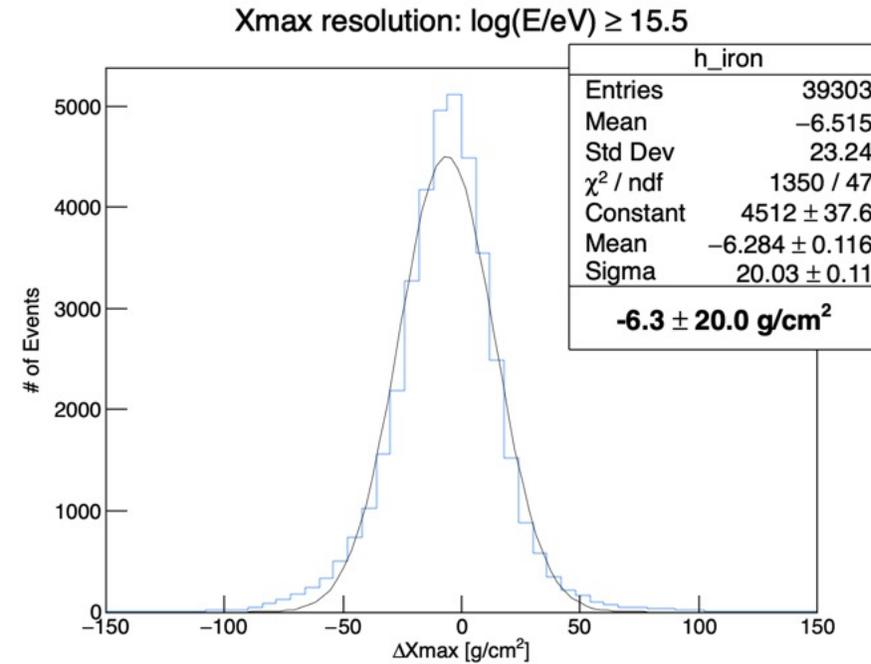
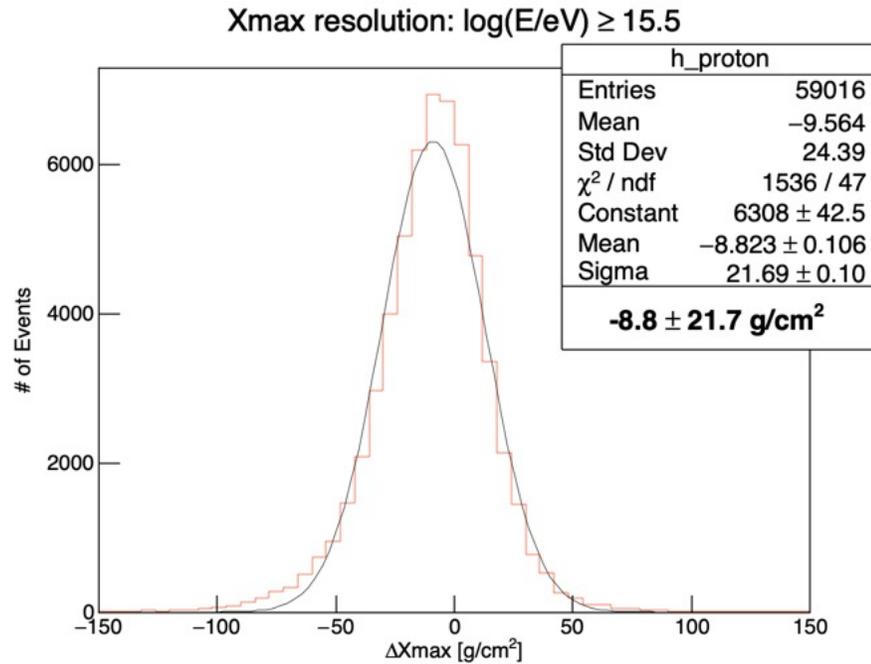
Reconstruction resolution

- ψ angle resolution: 0.5 deg



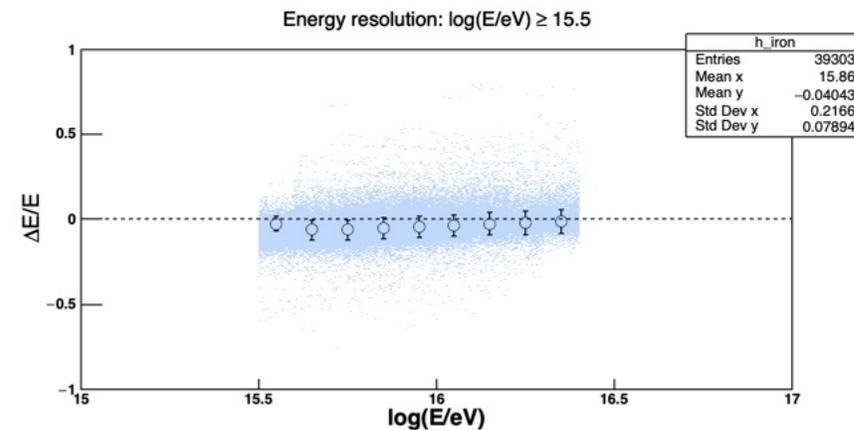
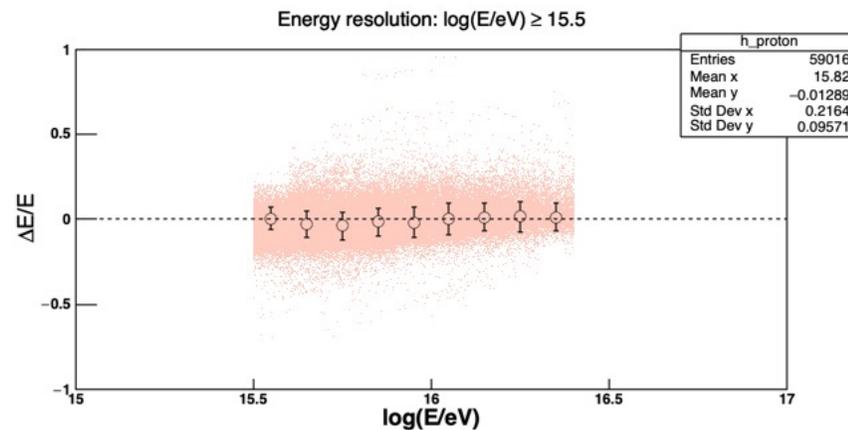
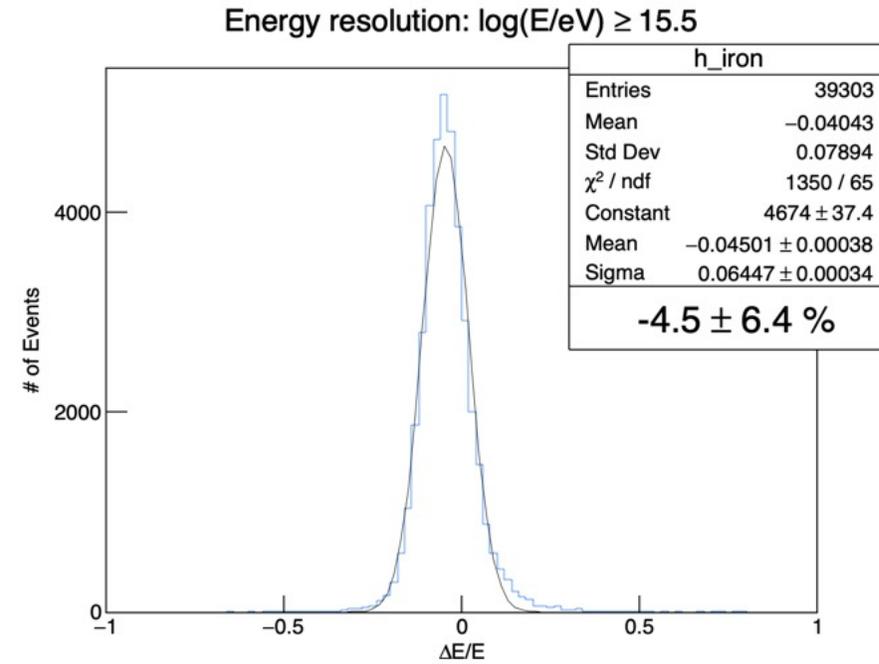
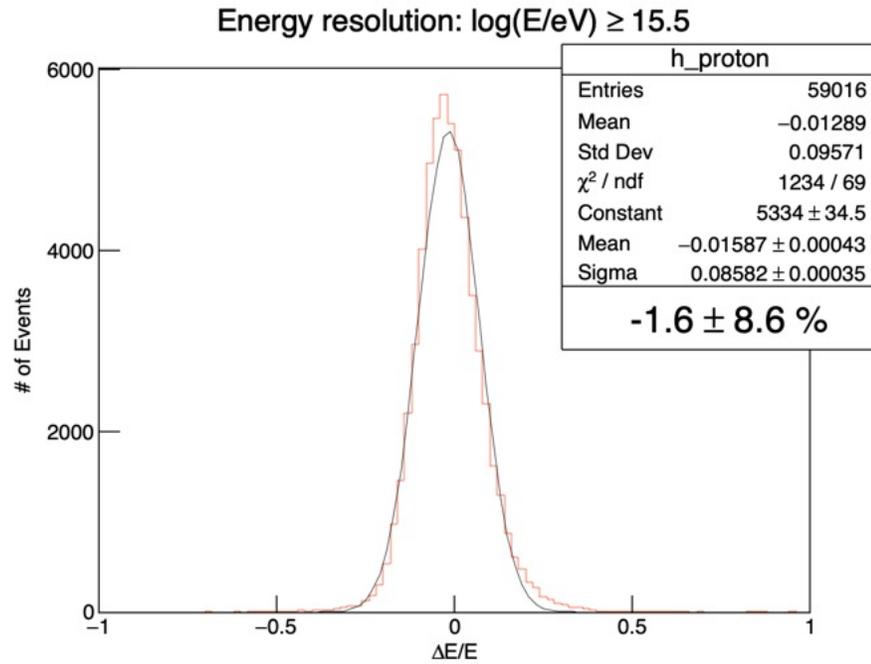
Reconstruction resolution

- X_{\max} resolution: $< 25 \text{ g/cm}^2$



Reconstruction resolution

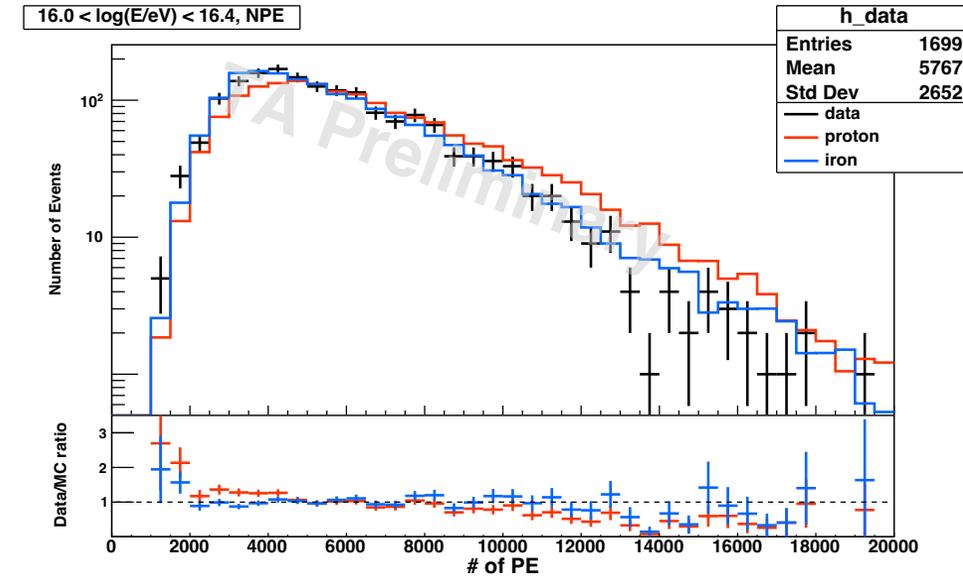
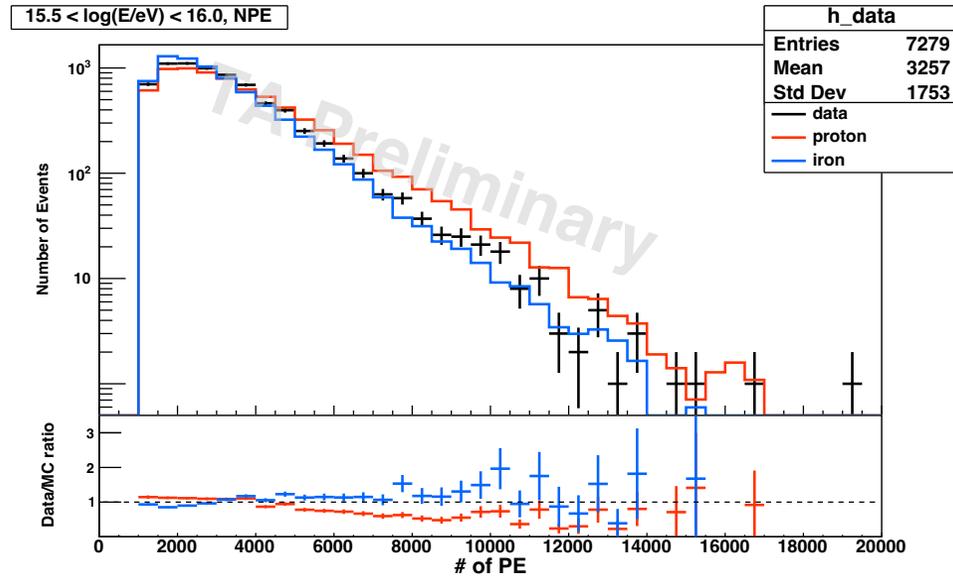
- energy resolution: $<10\%$



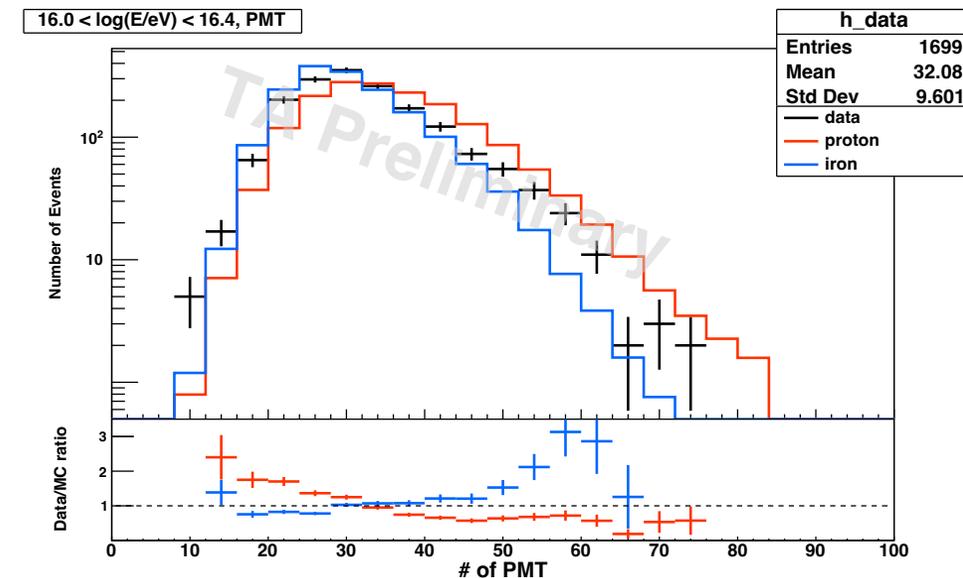
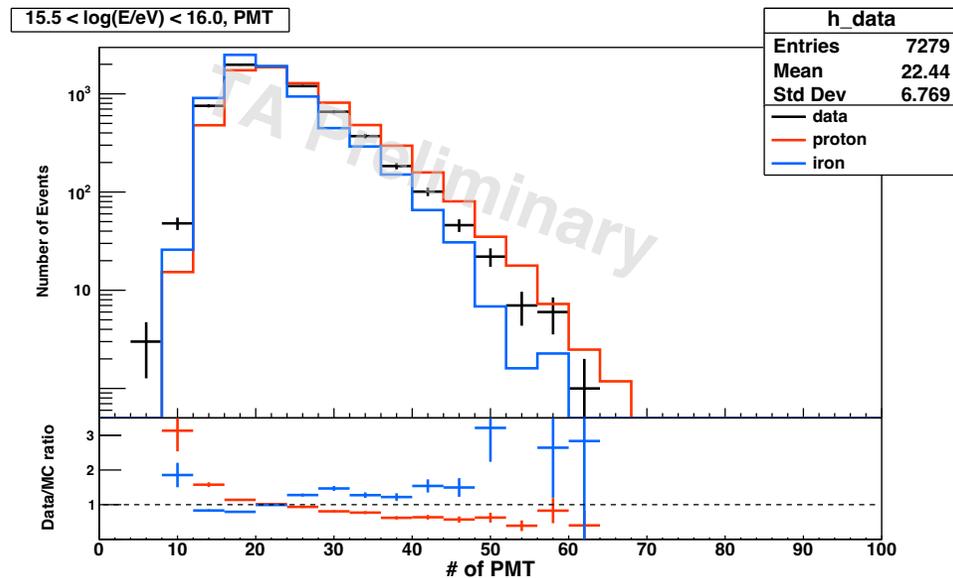
Data/MC comparisons(1/3)

- Left: $15.5 < \log_{10}(E/eV) < 16.0$, Right: $16.0 < \log_{10}(E/eV) < 16.4$

of P.E.



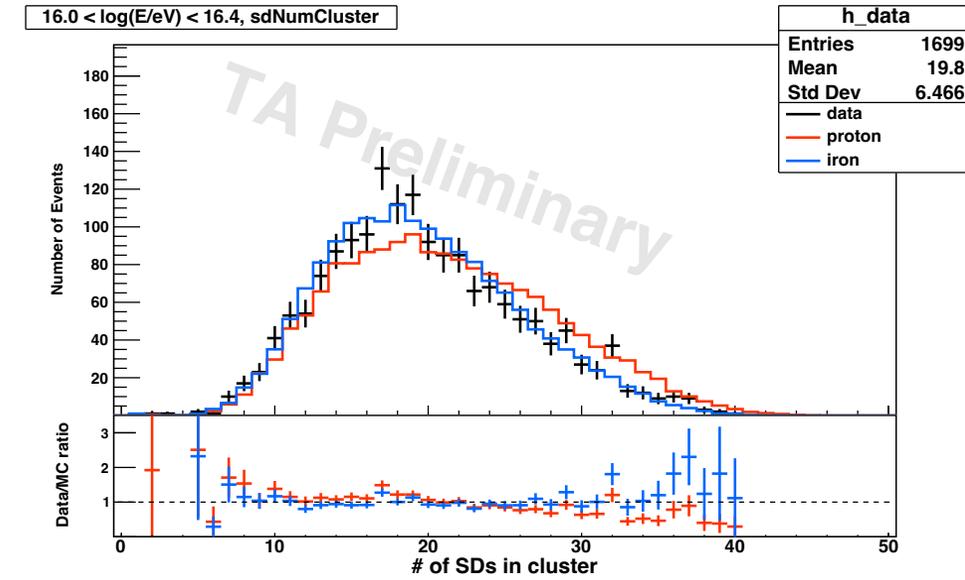
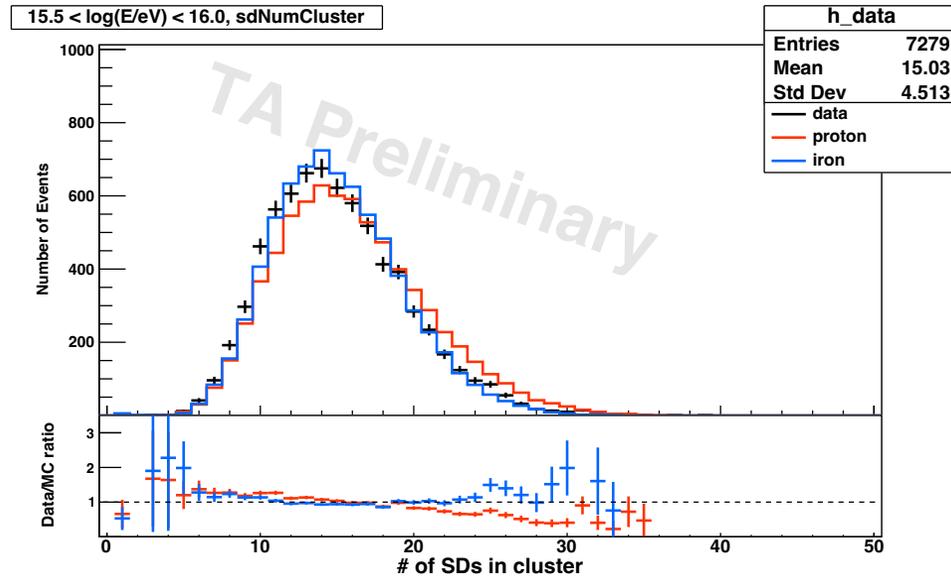
of PMT



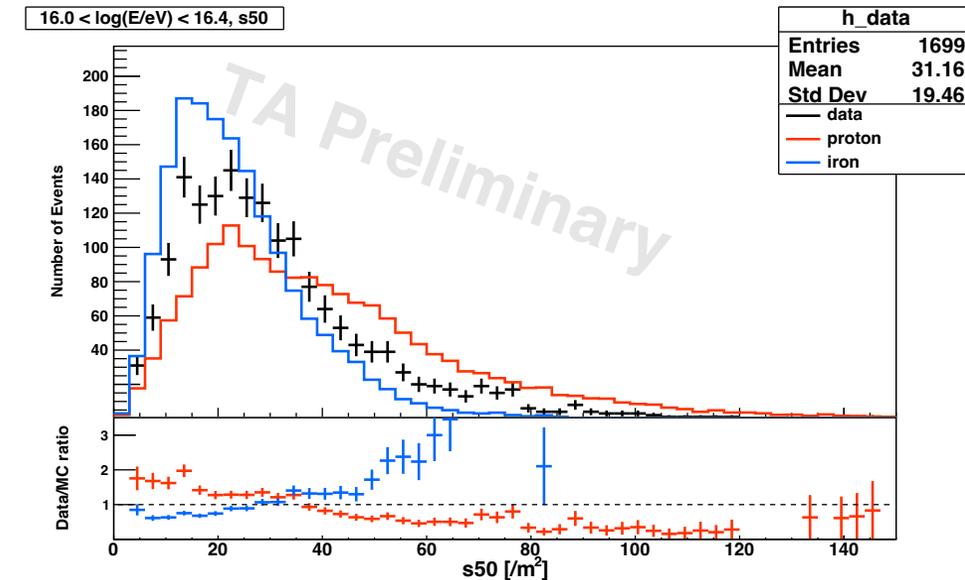
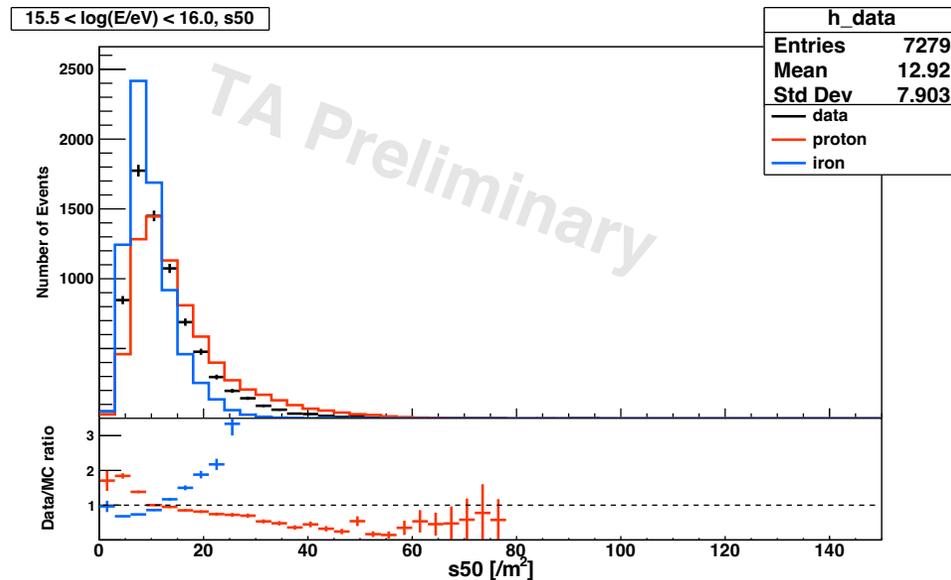
Data/MC comparisons(2/3)

- Left: $15.5 < \log_{10}(E/\text{eV}) < 16.0$, Right: $16.0 < \log_{10}(E/\text{eV}) < 16.4$

of SDs



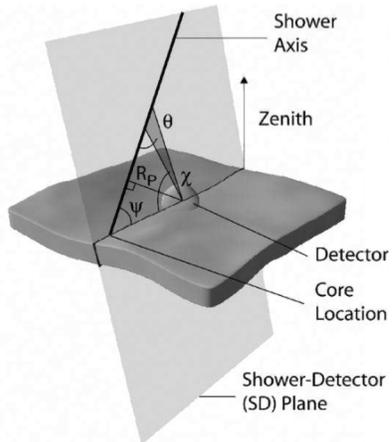
shower size at 50m
far from axis



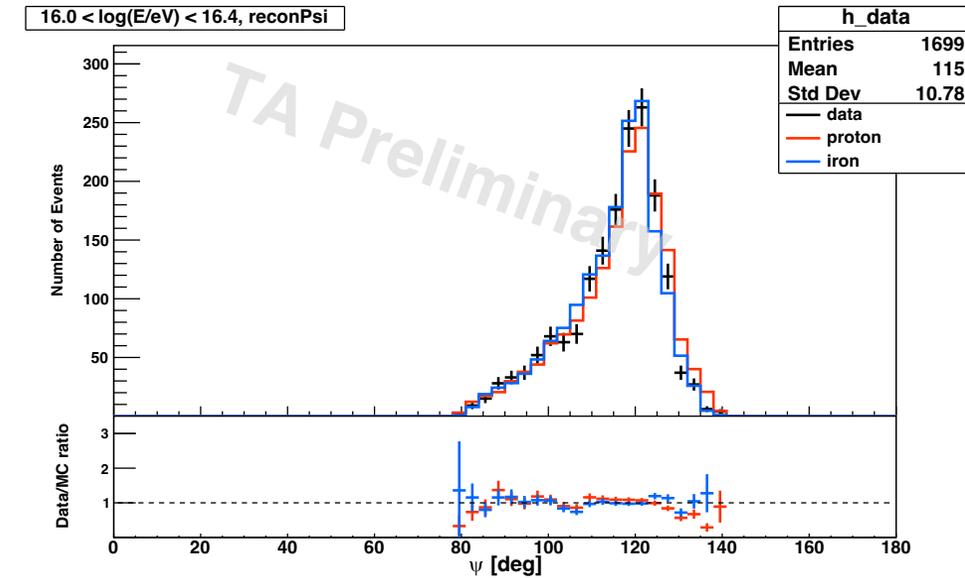
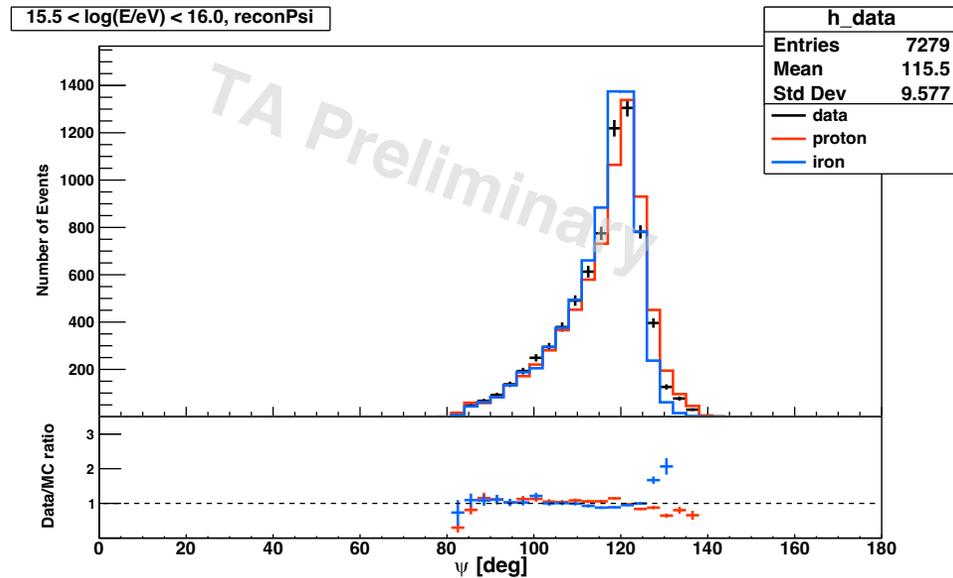
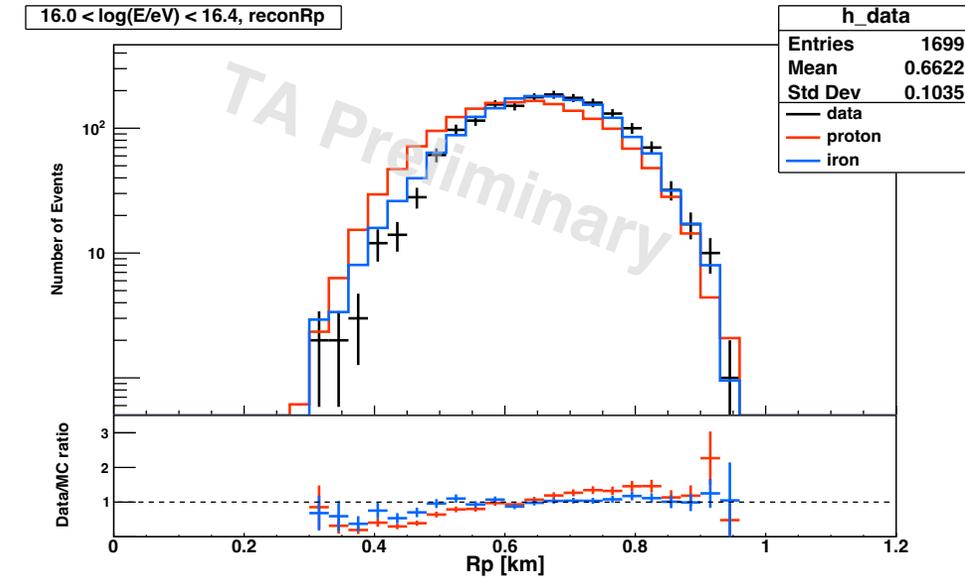
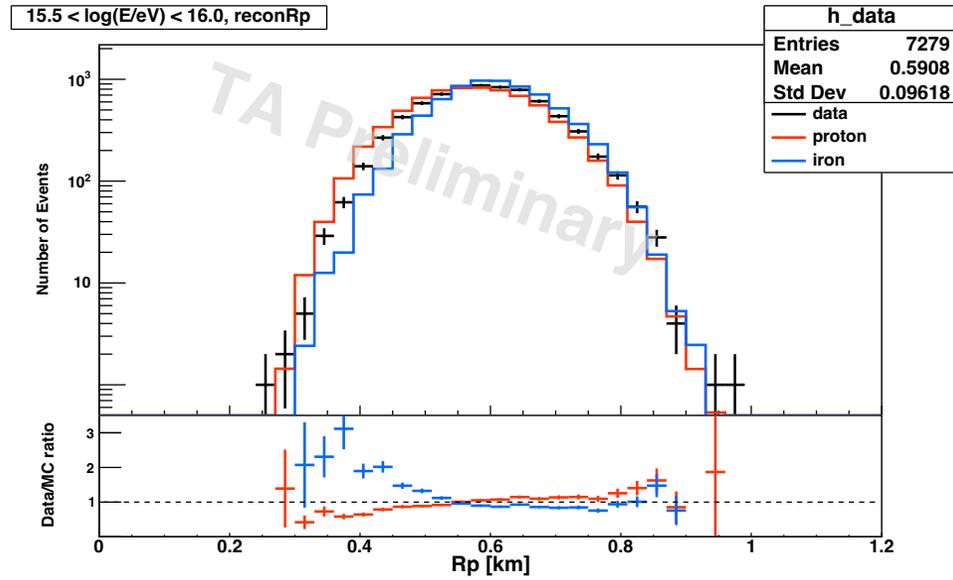
Data/MC comparisons(3/3)

- Left: $15.5 < \log_{10}(E/\text{eV}) < 16.0$, Right: $16.0 < \log_{10}(E/\text{eV}) < 16.4$

R_p
(impact parameter)

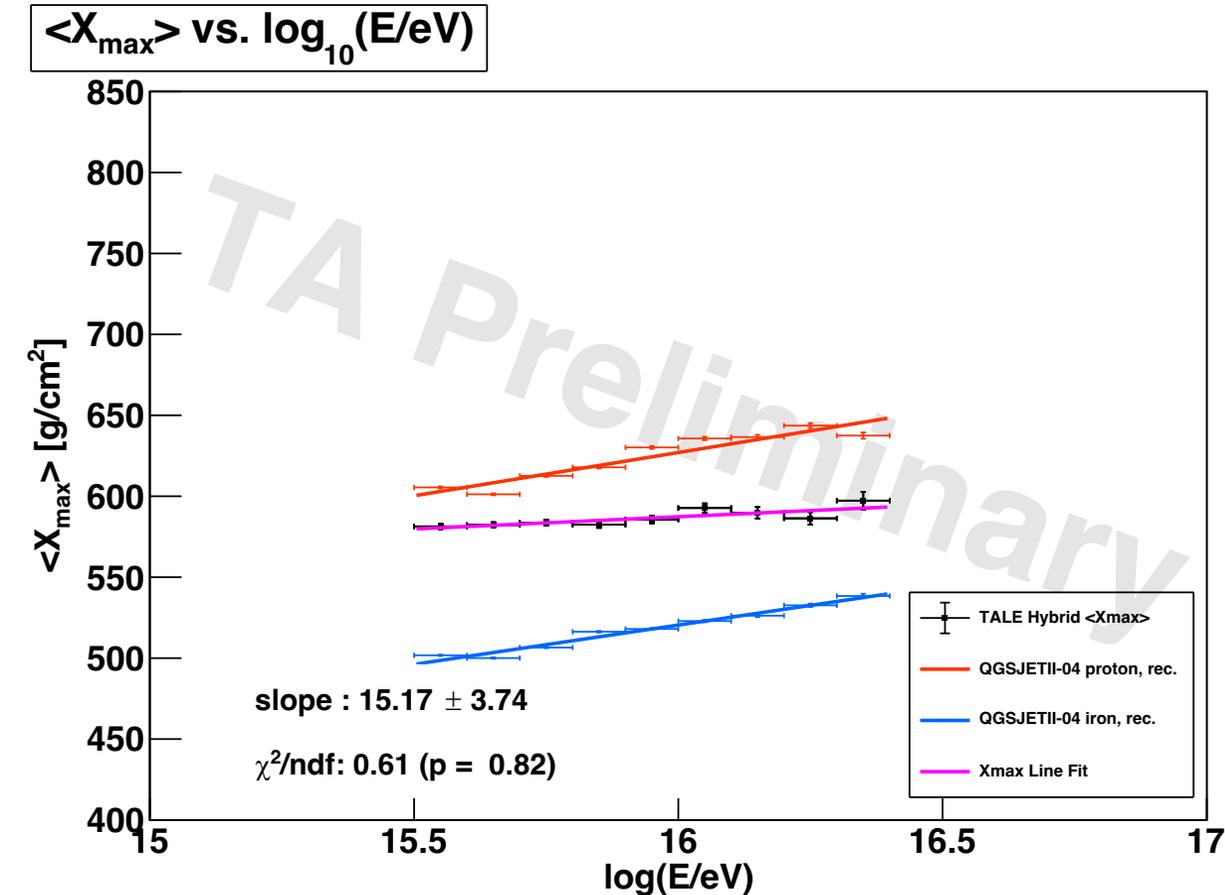


ψ angle



X_{\max} measurement

- Observed $\langle X_{\max} \rangle$ vs. shower energy
 - 540 hours observation data (Nov. 2023 - Jun. 2024)



- $\langle X_{\max} \rangle$ measurement with TALE FD + new SD array
- Energy range: $15.5 < \log(E/eV) < 16.4$
- Elongation rate
 - observation data: $D_{10} = 15 \pm 4$ g/cm²/decade
 - MC case [g/cm²/decade]

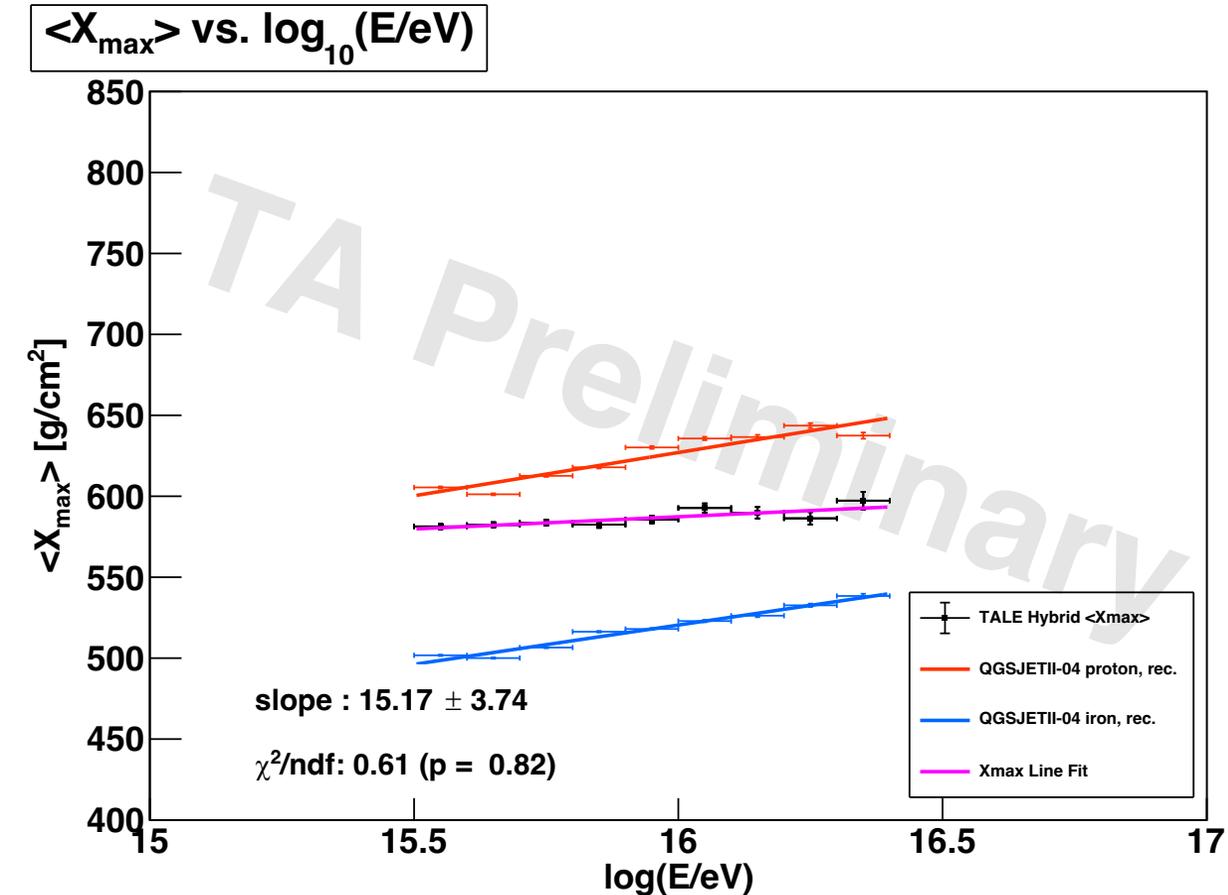
	proton	iron
D_{10}^{MC}	53 ± 2	48 ± 2

- This work indicates mean mass becomes heavier as the energy increases

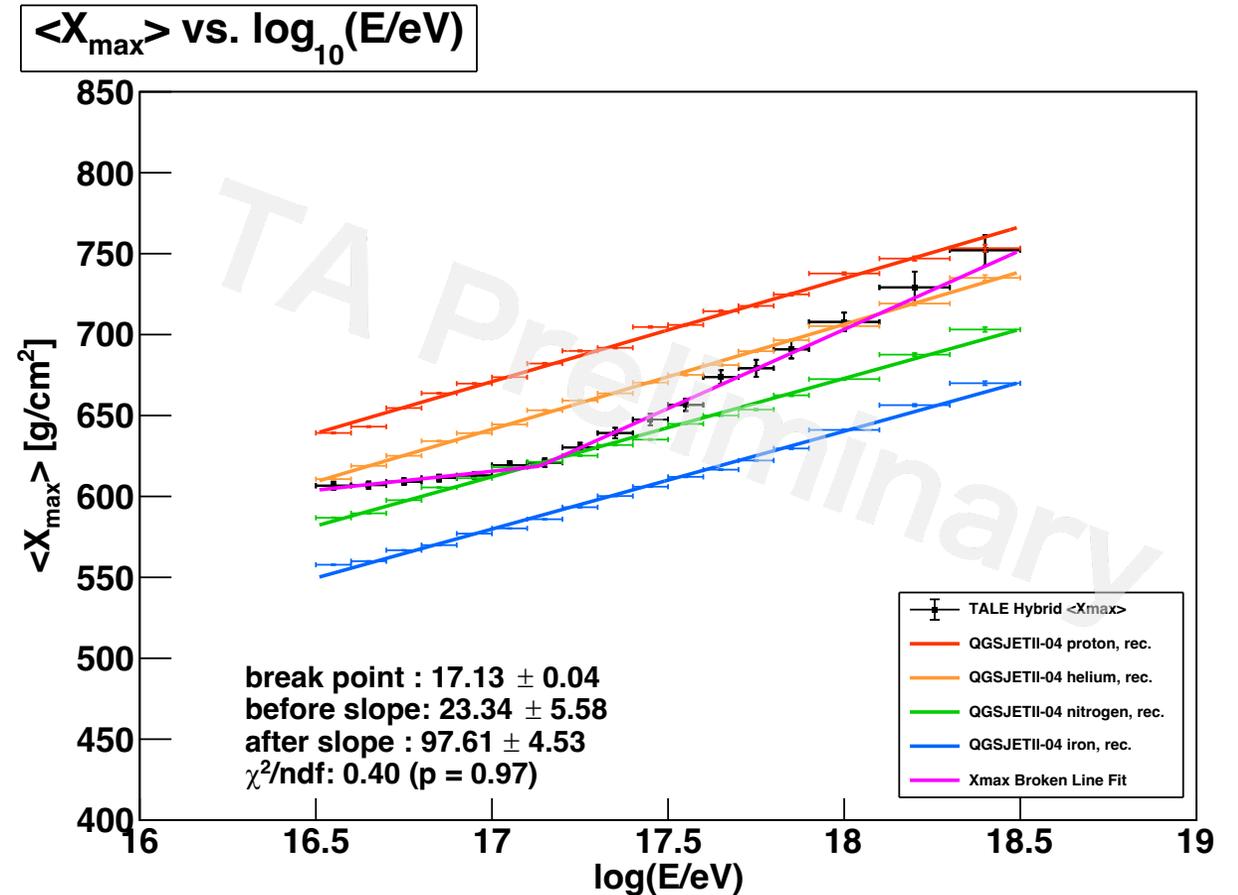
X_{\max} measurement

- Observed $\langle X_{\max} \rangle$ vs. shower energy

TALE FD + new SD array hybrid measurement



TALE FD + TALE SD array hybrid measurement



Summary

- Starts hybrid observation with TALE FD + new SD array
 - Nov. 04, 2023 -
 - target energy range: 3 PeV – 30 PeV
 - accumulated observation time: 540 hours (at end of Jun. 2024)
- Resolution @ $\log(E/eV) = 15.5$
 - Rp: 10 m, ψ : 0.5 deg, $X_{\max} < 25 \text{ g/cm}^2$, energy <10%
 - no primary dependence
- Data/MC comparisons show agreement
- Preliminary composition measurement result is shown
 - Elongation plot indicates mean mass becomes heavier as the energy increases
 - Covering energy range $15.5 < \log(E/eV) < 18.5$ by hybrid measurement