

Cosmic Ray Composition in the Second Knee Region as Measured by the TALE Hybrid Detector

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Outline

- Introduction
 - TA and TALE Detectors
- Hybrid Reconstruction and Performance
- Data analysis
 - Data/MC comparisons
 - Composition analysis
 - Spectrum analysis
- Summary

Telescope Array Detectors

Fluorescence Detectors(FDs)
 Middle Drum(MD) station
 14 telescopes
 + TA Low energy Extension (TALE) 10 telescopes



Surface Detector(SD) array
 507 scintillation detectors, each 3m²
 1.2 km spacing
 total coverage ~ 700km²



Long Ridge FD

FDs
 Long Ridge(LR) station
 12 telescopes

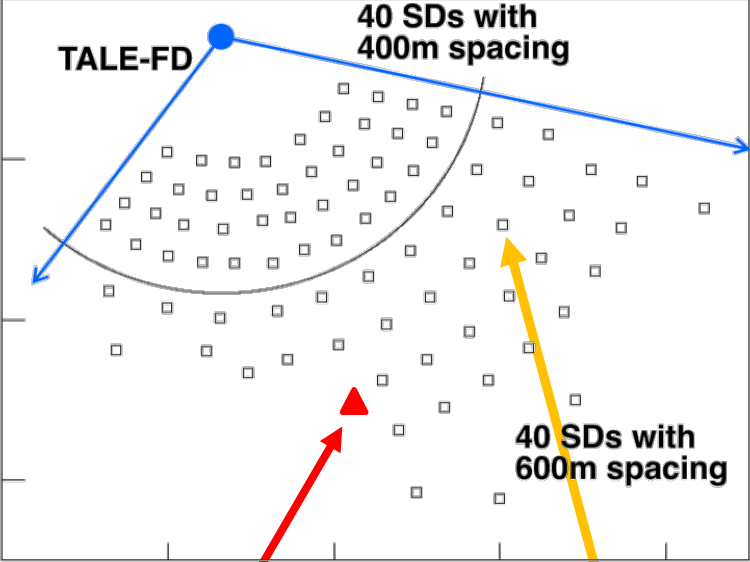
36 km

FDs
 Black Rock Mesa(BRM) station
 12 telescopes

Black Rock Mesa FD



TA Low energy Extension(TALE) Detectors

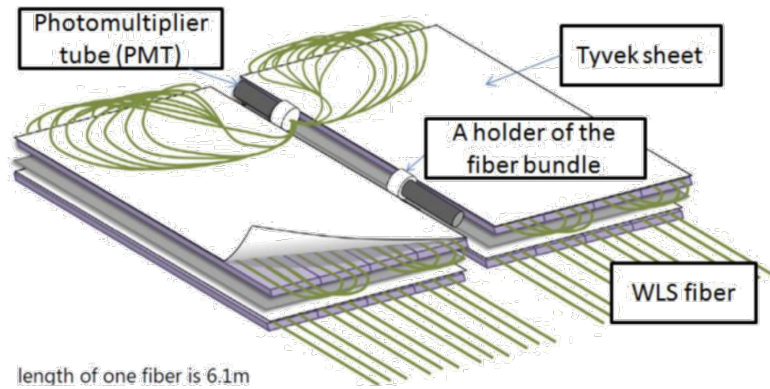


Middle Drum station

TA-FD(MD) TALE-FD

Azimuth angle [degree]

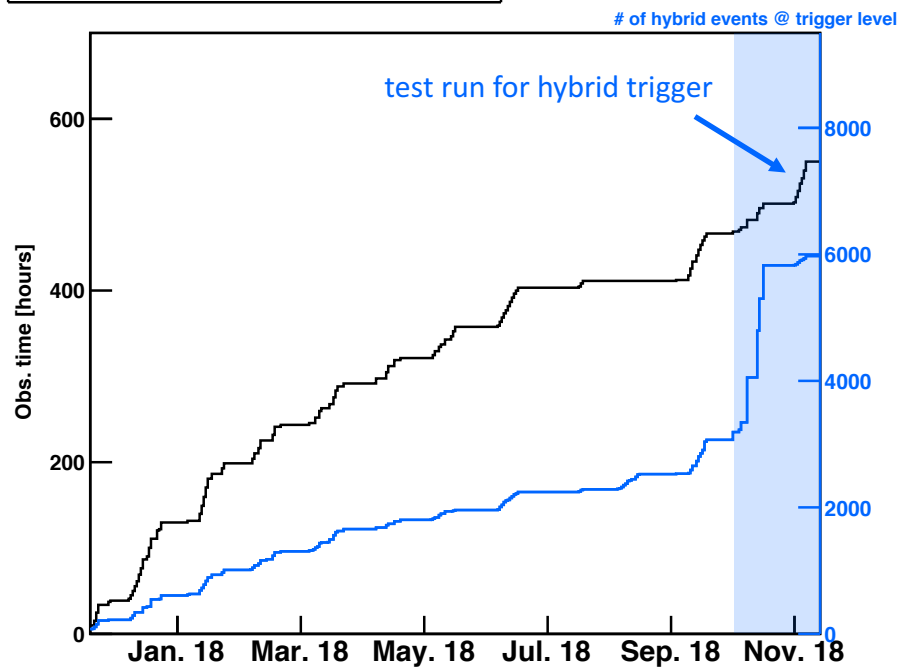
The complex block contains a photograph of the Middle Drum station building with labels 'TA-FD(MD)' and 'TALE-FD'. Below the photo is a plot of detector distribution versus azimuth angle (100 to 220 degrees) and elevation (0 to 60 degrees). The plot shows a blue shaded region labeled 'TALE-FD' and a red shaded region labeled 'TA-FD (MD)'. To the right of the plot is a photograph of detector components, including a photomultiplier tube (PMT) and fiber bundles, mounted on a structure.



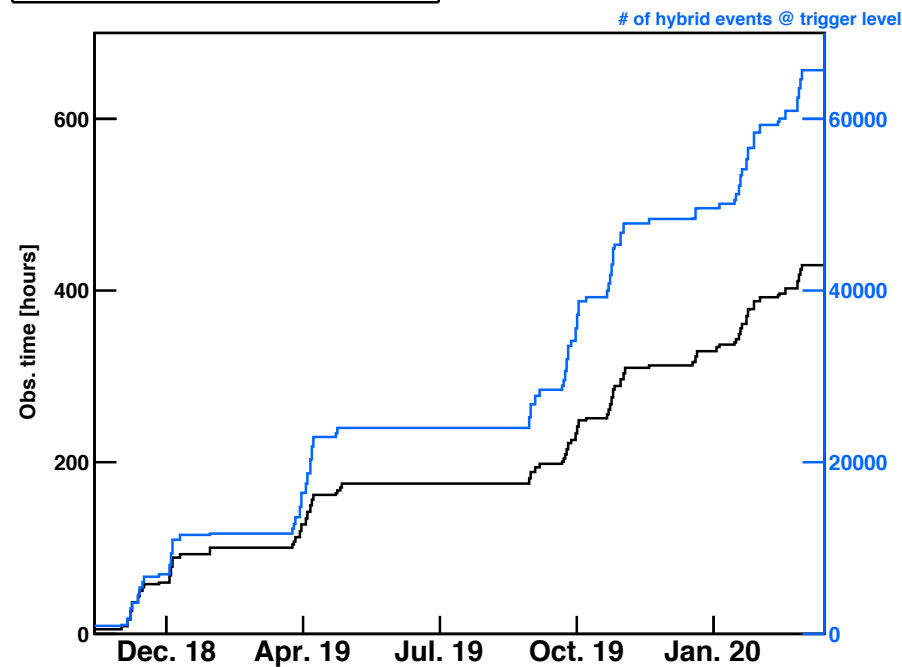
TALE-Hybrid On-time

- 2017/11/19 - 2018/11/13, 550hours (5974 events in trigger)
 - Both detector running independently, self trigger (any 5) mode
- 2018/11/14 - 2020/02/29, 430hours (65670 events in trigger)
 - hybrid trigger system working, hybrid trigger mode

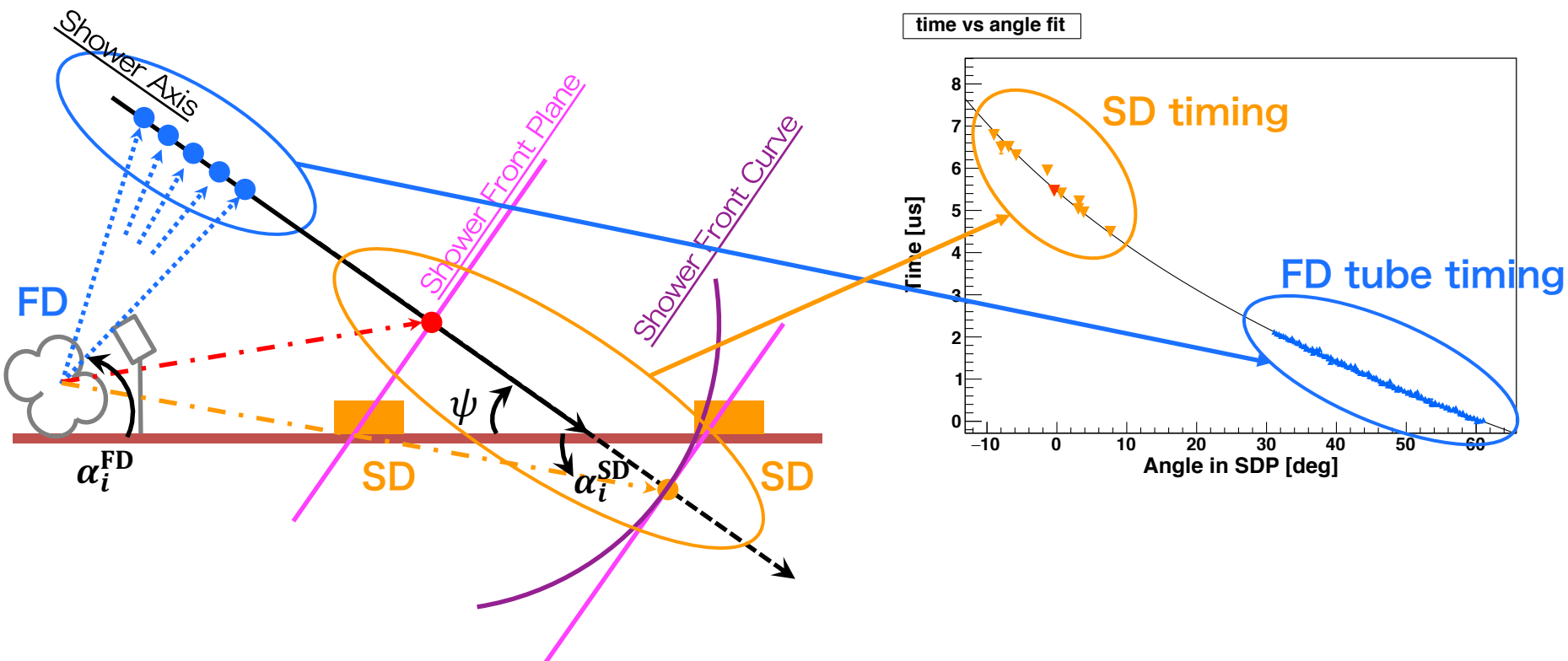
tale, self trigger mode(any 5)



tale, hybrid trigger mode



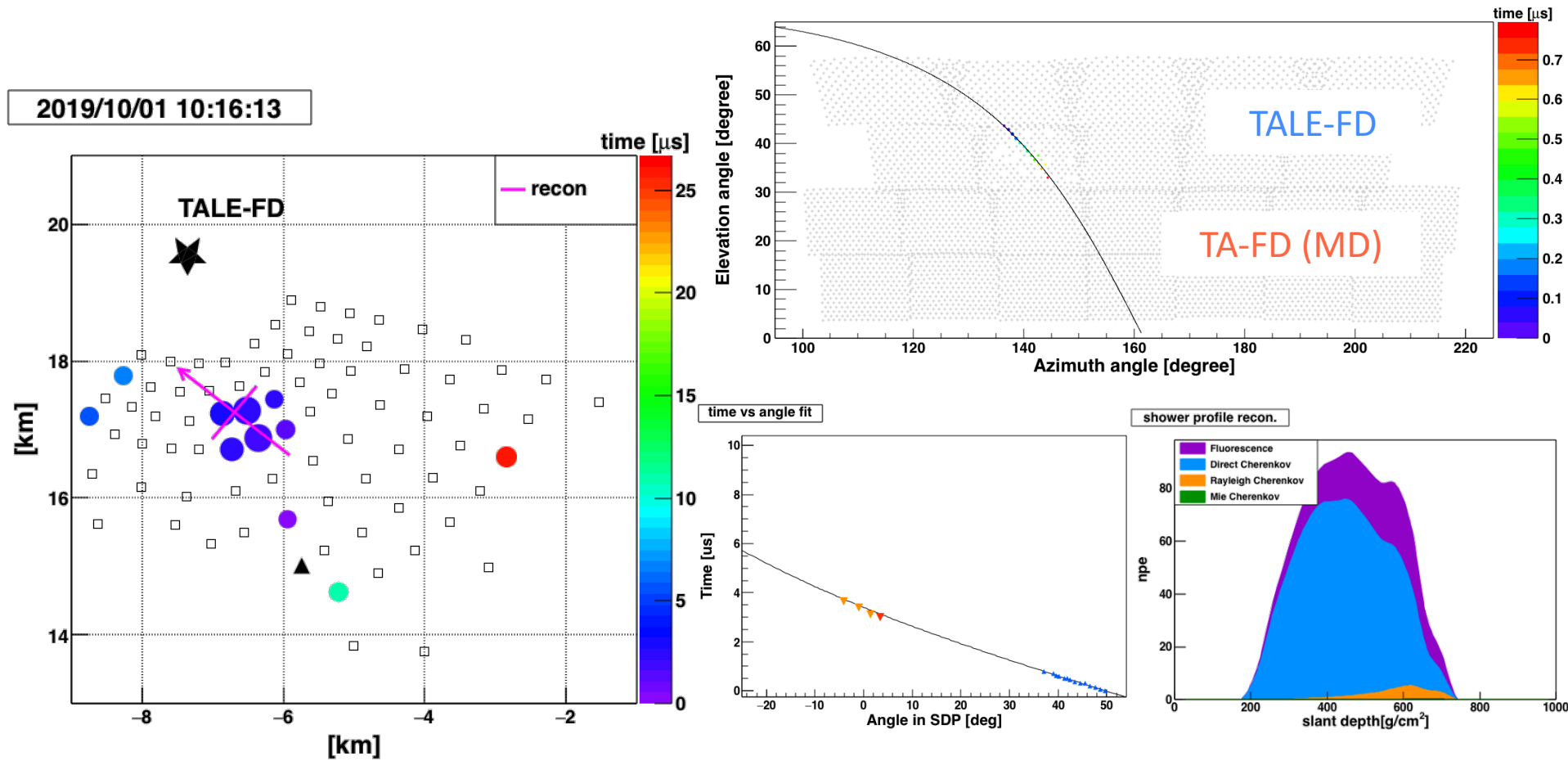
Hybrid Reconstruction



- Hybrid geometry reconstruction
: **FD tube timings** and **SD timing** at the ground
- Profile-Constrained Geometry Fit also applied
: we are successful to reconstruct low energy events

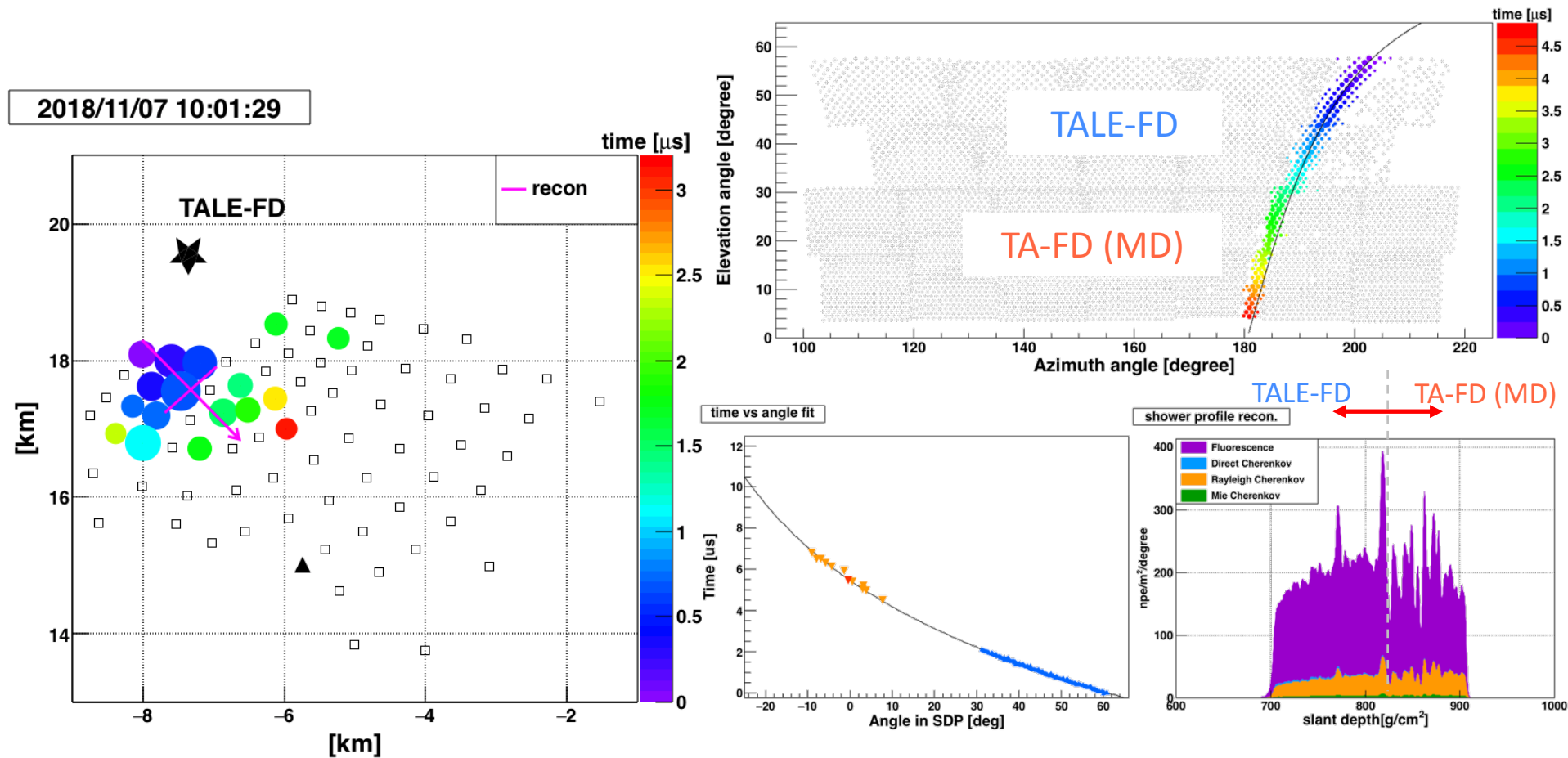
→ Go down Low energy with Good accuracies

Hybrid event sample 1



result	zen[deg]	azi[deg]	Rp[km]	ψ [deg]	core X[km]	core Y[km]	Xmax[g/cm^2]	Energy[eV]
Hybrid	39.3	-128.7	2.1	122.2	-6.7	17.3	512	$10^{16.7}$

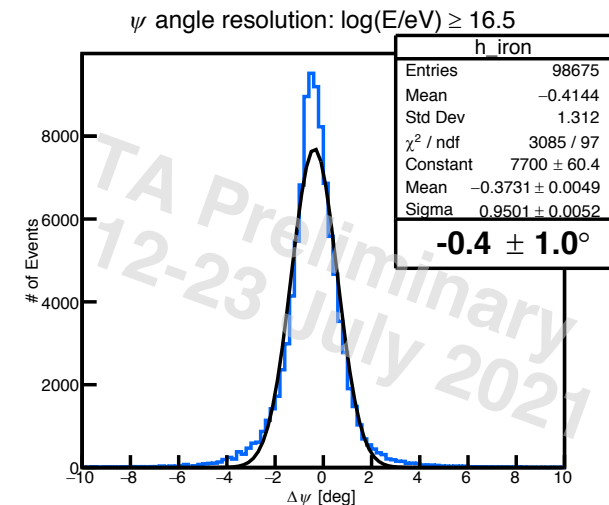
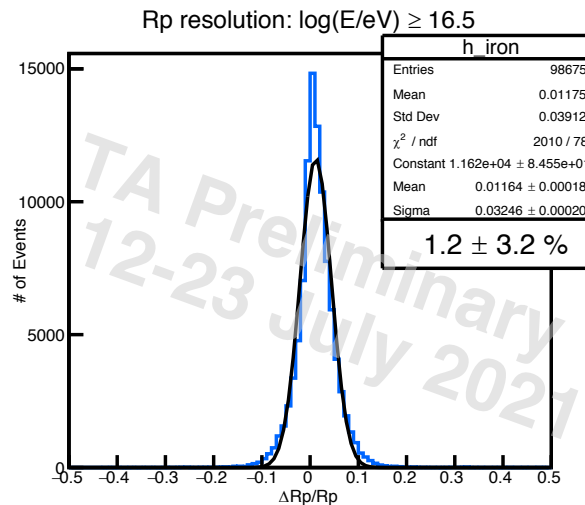
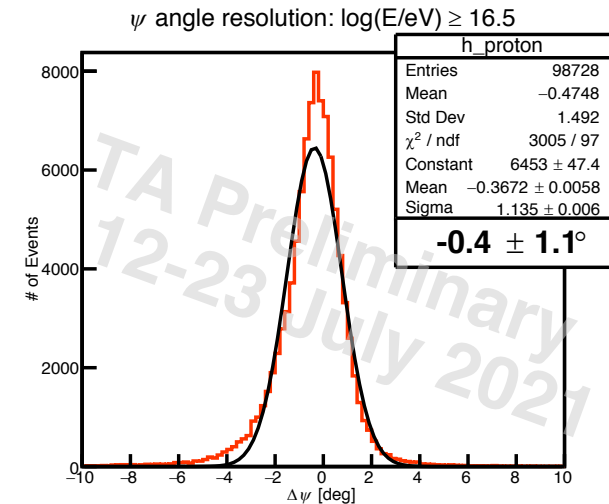
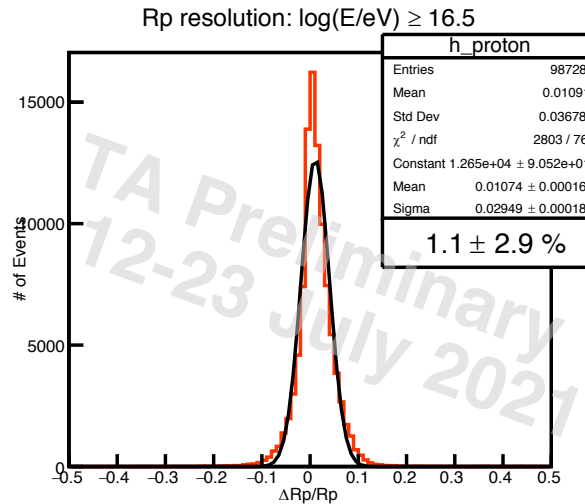
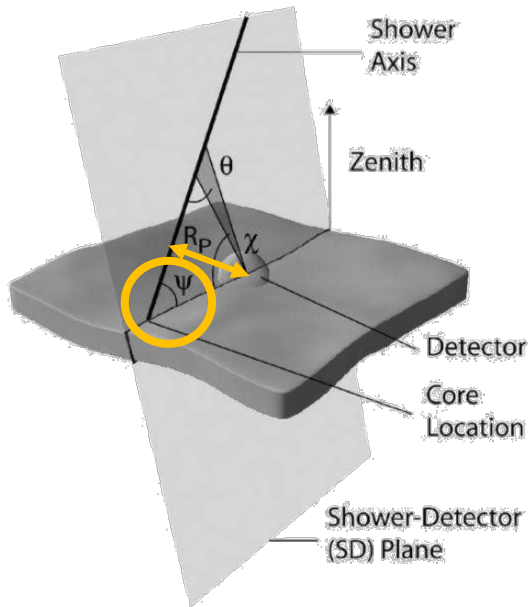
Hybrid event sample 2



result	zen[deg]	azi[deg]	Rp[km]	ψ [deg]	core X[km]	core Y[km]	Xmax[g/cm ²]	Energy[eV]
Hybrid	19.7	-43.2	1.9	76.1	-7.4	17.6	766	$10^{17.9}$

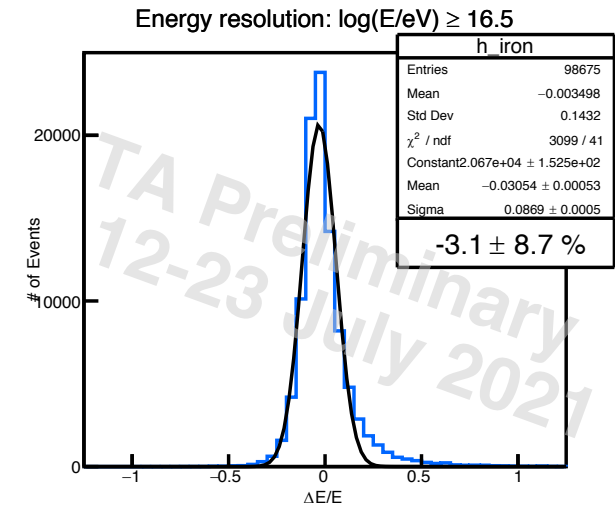
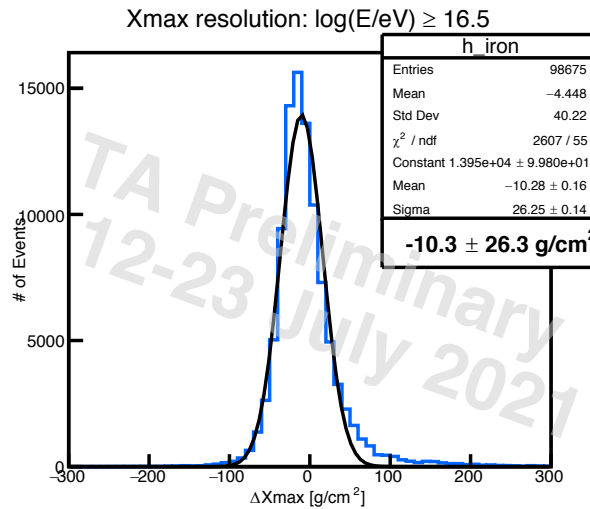
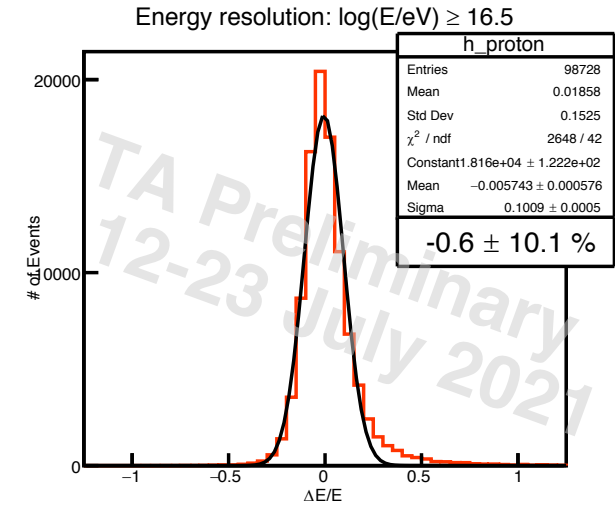
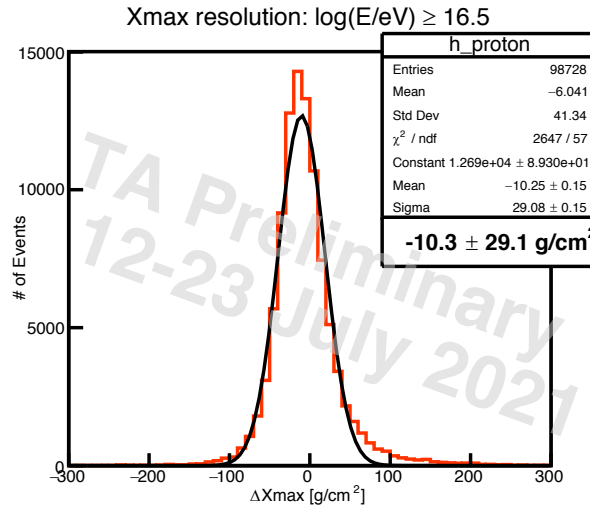
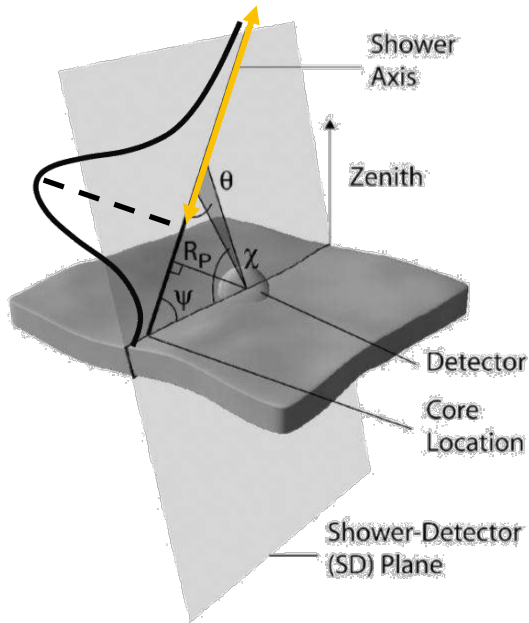
Performance

Shower geometric resolutions



Performance

Shower profile resolutions



Data/MC Comparison

- Hybrid Dataset
 - 2017/11/19 - 2018/11/13
550hours, self trigger mode
 - 2018/11/14 - 2020/02/29
430hours, hybrid trigger mode
- MC Dataset
 - Corsika QGSJETII-04 **proton**, **iron**
 - Energy : $\log(E/eV) = 16.35 - 18.55$
slope: $-2.9, \log(E/eV) < 17.1$
 $-3.2, \log(E/eV) > 17.1$
 - Zen. angle: $0 \sim 65^\circ$
 - Azi. angle: $0 \sim 360^\circ$
 - Area: Semi-Circle in bottom Fig.
- Quality Cuts in this study
 - FL is define as fluorescence light $> 75 \%$
 - CL is as fluorescence light $< 75 \%$

Variable	CL	FL
No saturated PMTs in FD		applied
SD detected ≥ 3 MIPs		applied
X_{\max} bracketing cut		applied
Angular track-length [deg]	track $> 6.5^\circ$	
Event duration [ns]	> 100	
# of PMTs	> 10	
# of Photo-electrons / # of PMTs	> 50	
# of Photo-electrons		> 2000

Generation Area

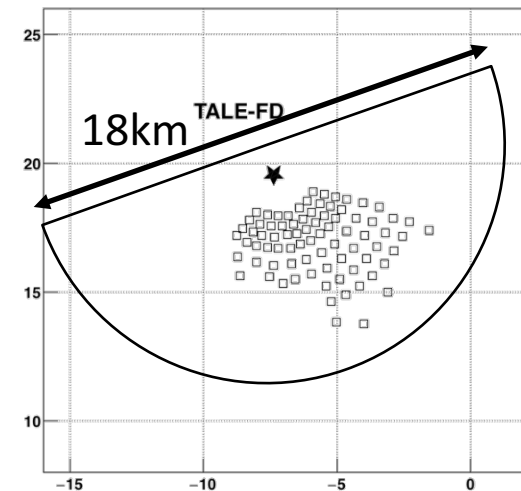
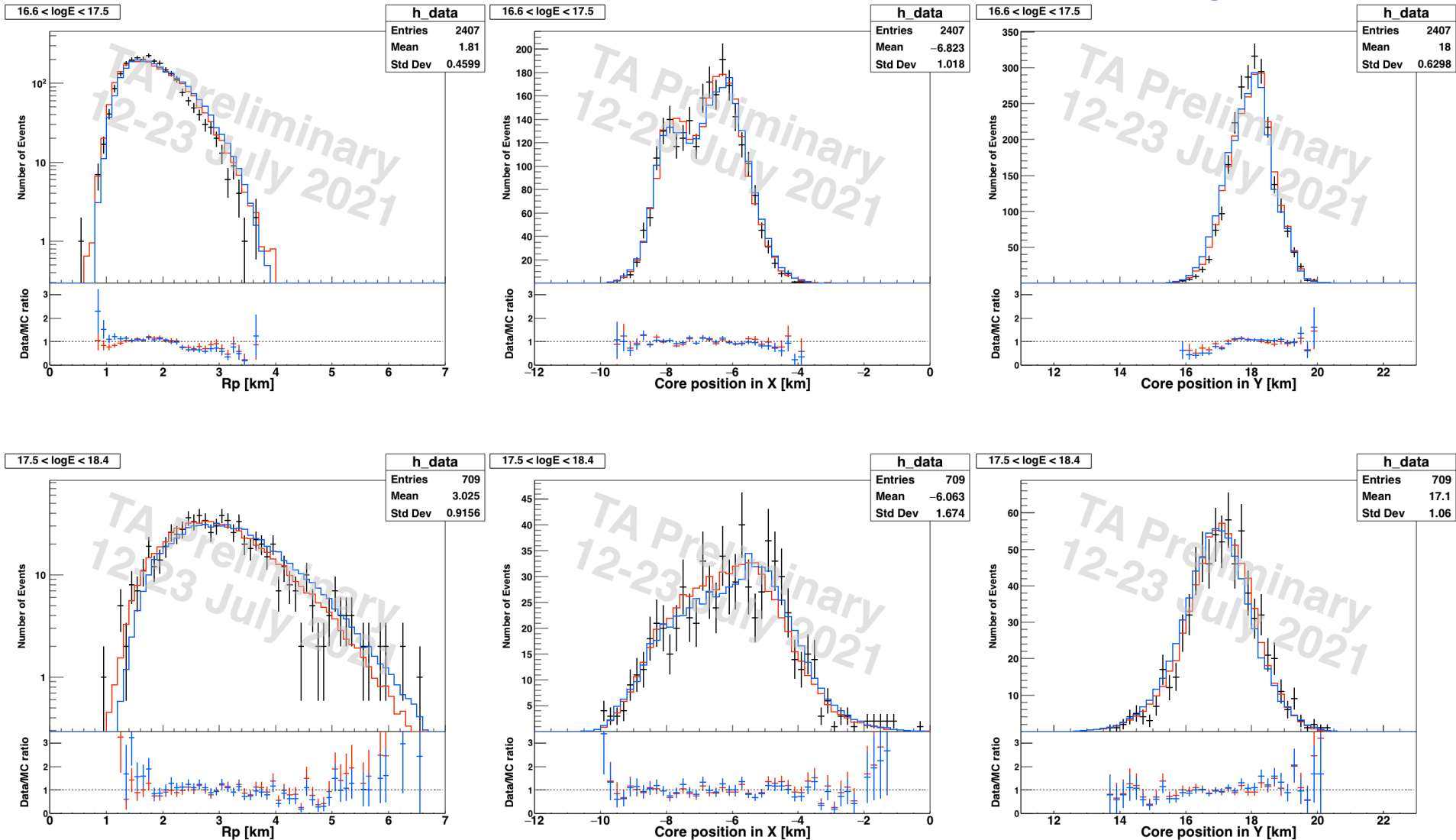


Table 1: Quality Cuts Applied in this study

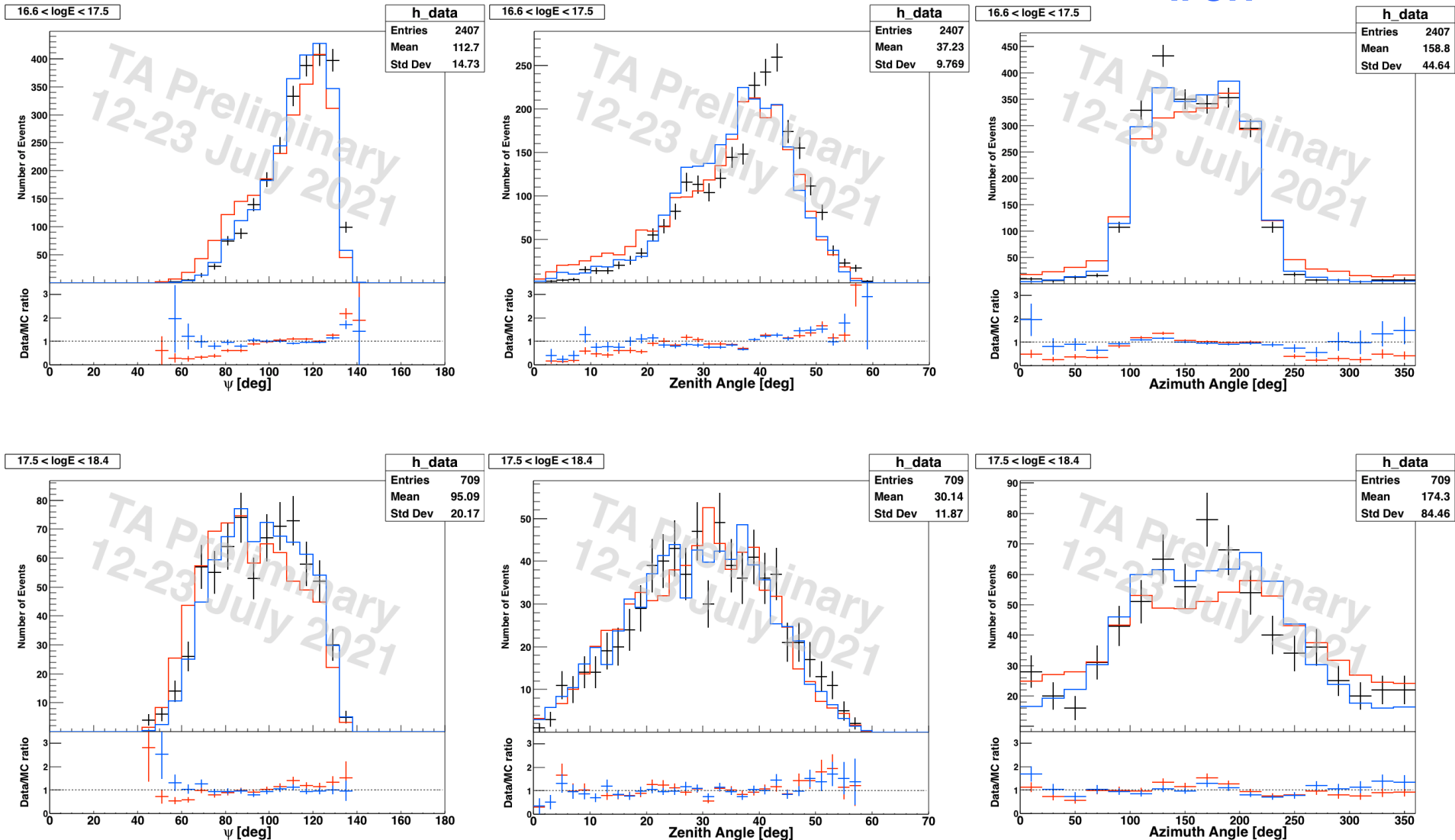
Data/MC Comparison

- TALE data
- proton
- iron



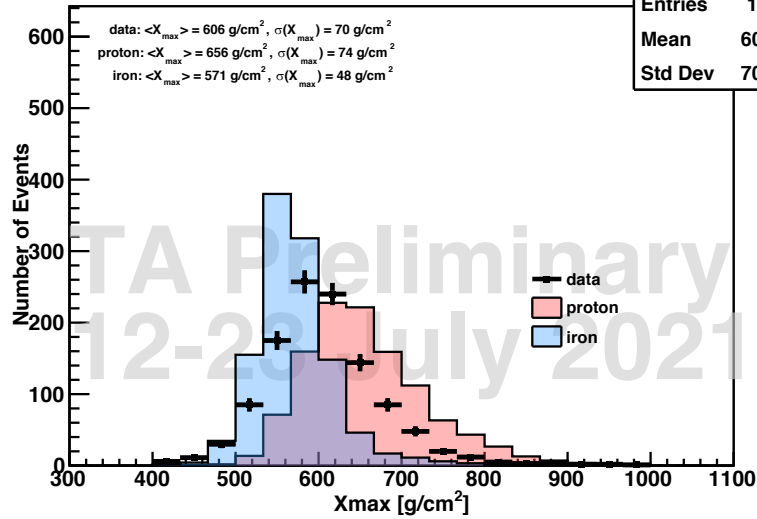
Data/MC Comparison

- TALE data
- proton
- iron



Composition analysis

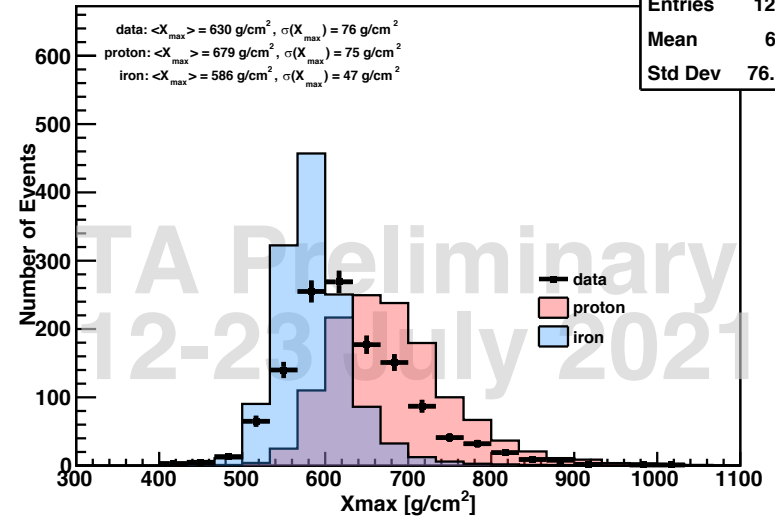
16.6 < logE < 17.0 events



h_data

Entries	1129
Mean	606.4
Std Dev	70.23

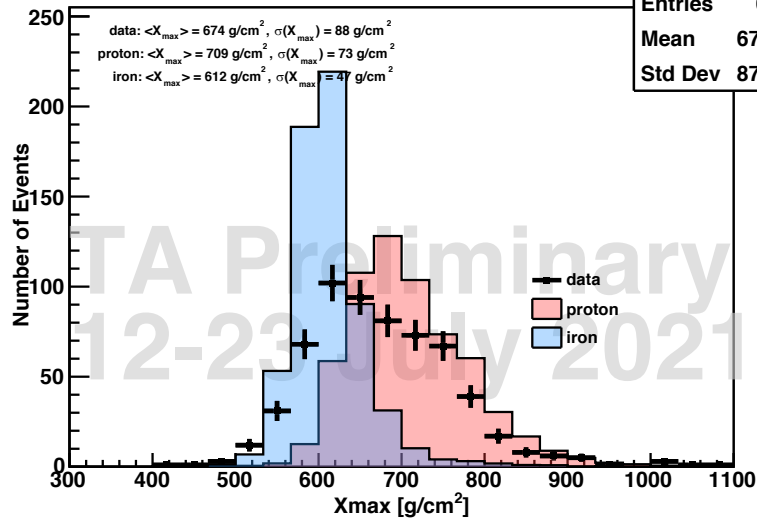
17.0 < logE < 17.5 events



h_data

Entries	1278
Mean	630
Std Dev	76.07

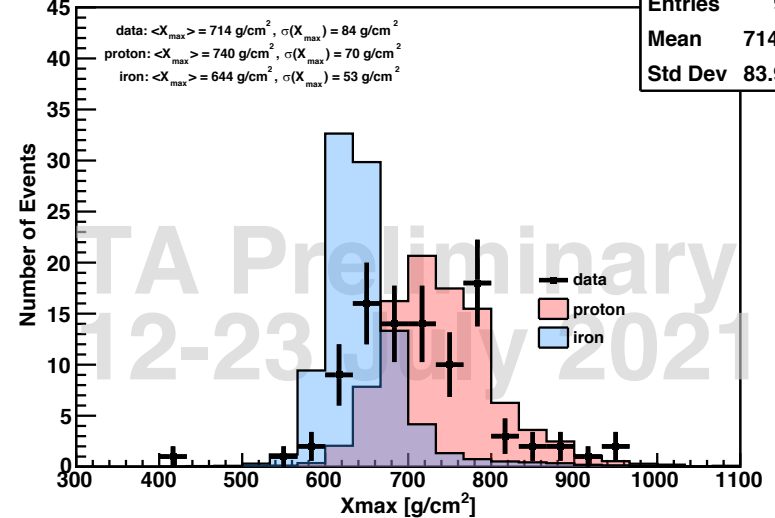
17.5 < logE < 18.0 events



h_data

Entries	614
Mean	674.3
Std Dev	87.99

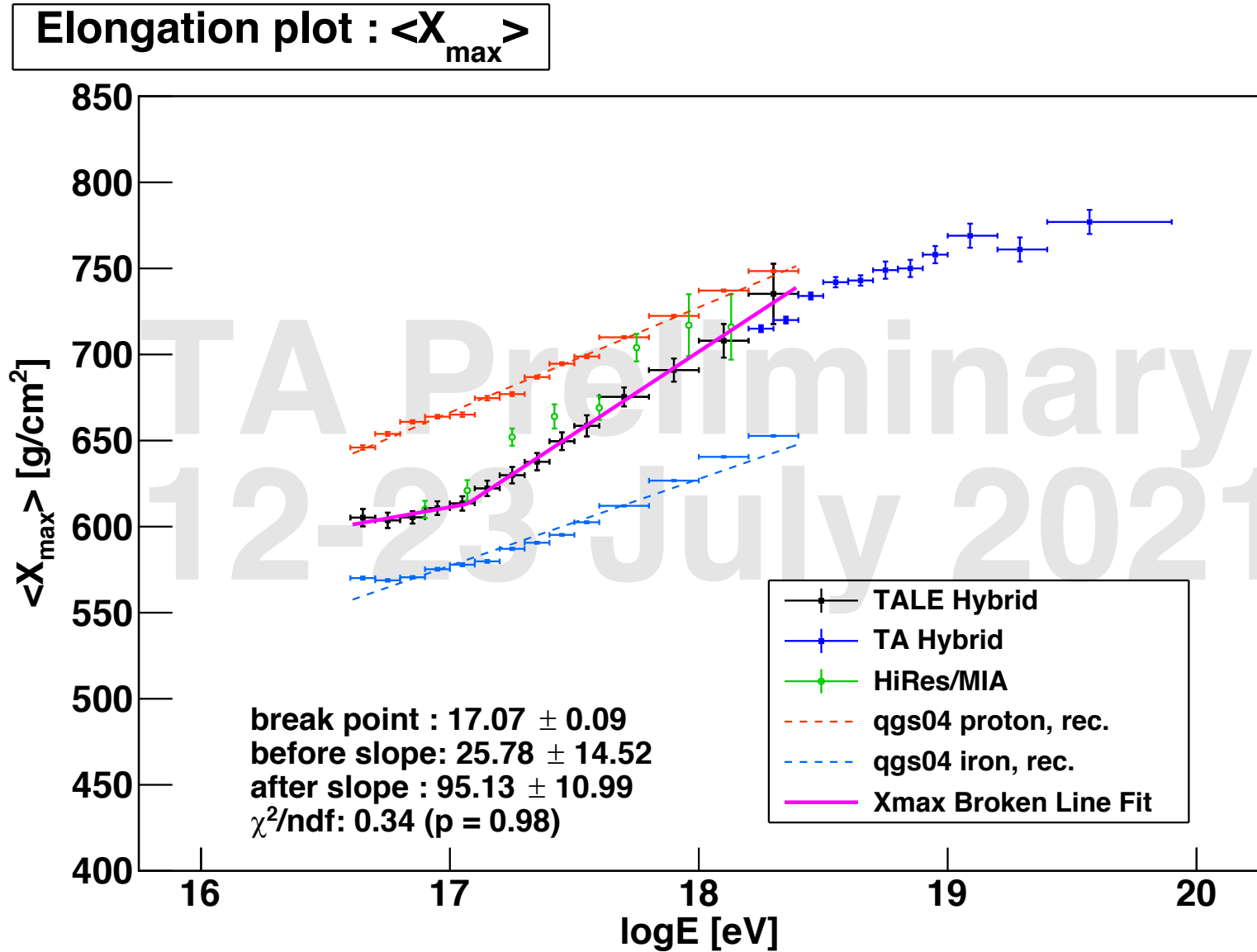
18.0 < logE < 18.4 events



h_data

Entries	95
Mean	714.3
Std Dev	83.98

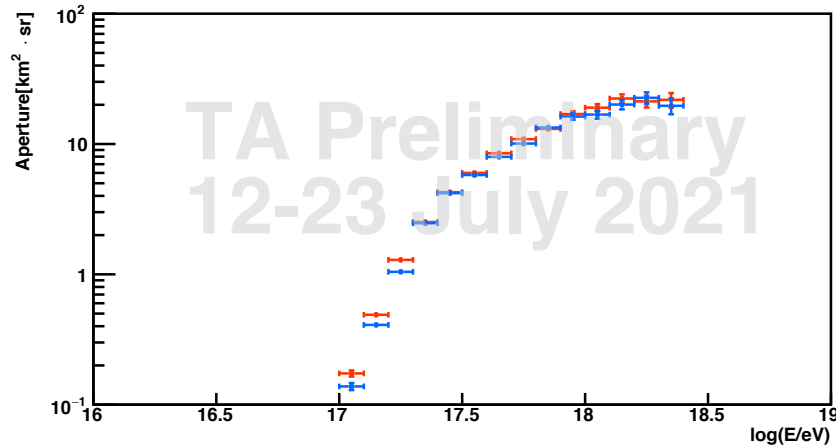
Composition analysis



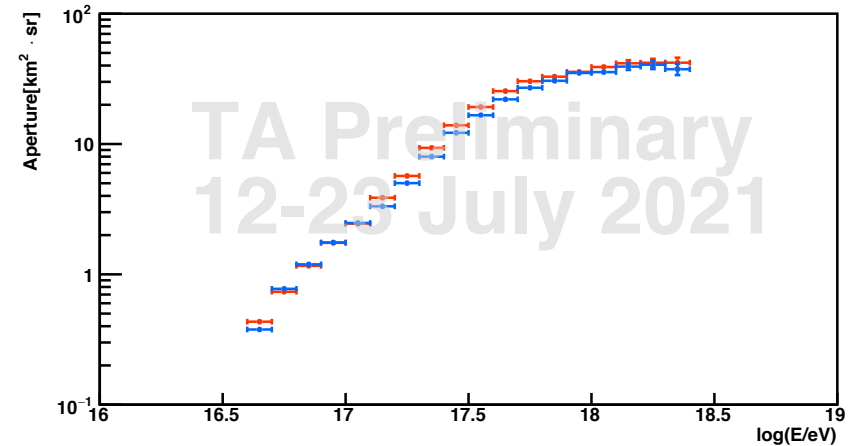
Aperture and Exposure

- $\text{Aperture} = A_0 \Omega_0 \cdot \frac{N_{\text{recon}}(E)}{N_{\text{thrown}}(E)}$, $A_0 \Omega_0 = \frac{1}{2} \cdot (\pi R_{\text{max}} \sin \theta_{\text{max}})^2$

tale hybrid aperture, self trigger mode



tale hybrid aperture, hybrid trigger mode



- Combined exposure

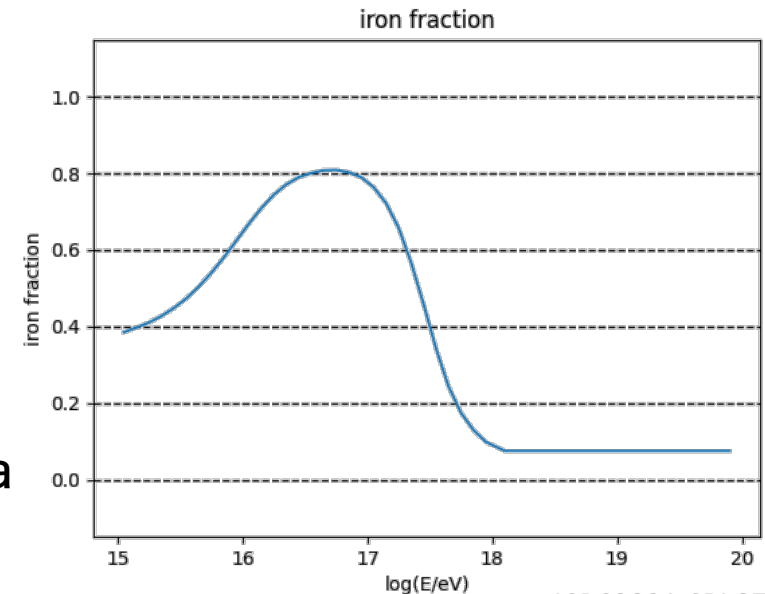
$$\omega^{\text{com}}(E) = A\Omega^{\text{self}}(E) \cdot t^{\text{self}} + A\Omega^{\text{hyb}}(E) \cdot t^{\text{hyb}}$$

- for the mixed composition,

$$A\Omega^{\text{mix}} = A\Omega^{\text{iron}}(R + f \cdot (1 - R))$$

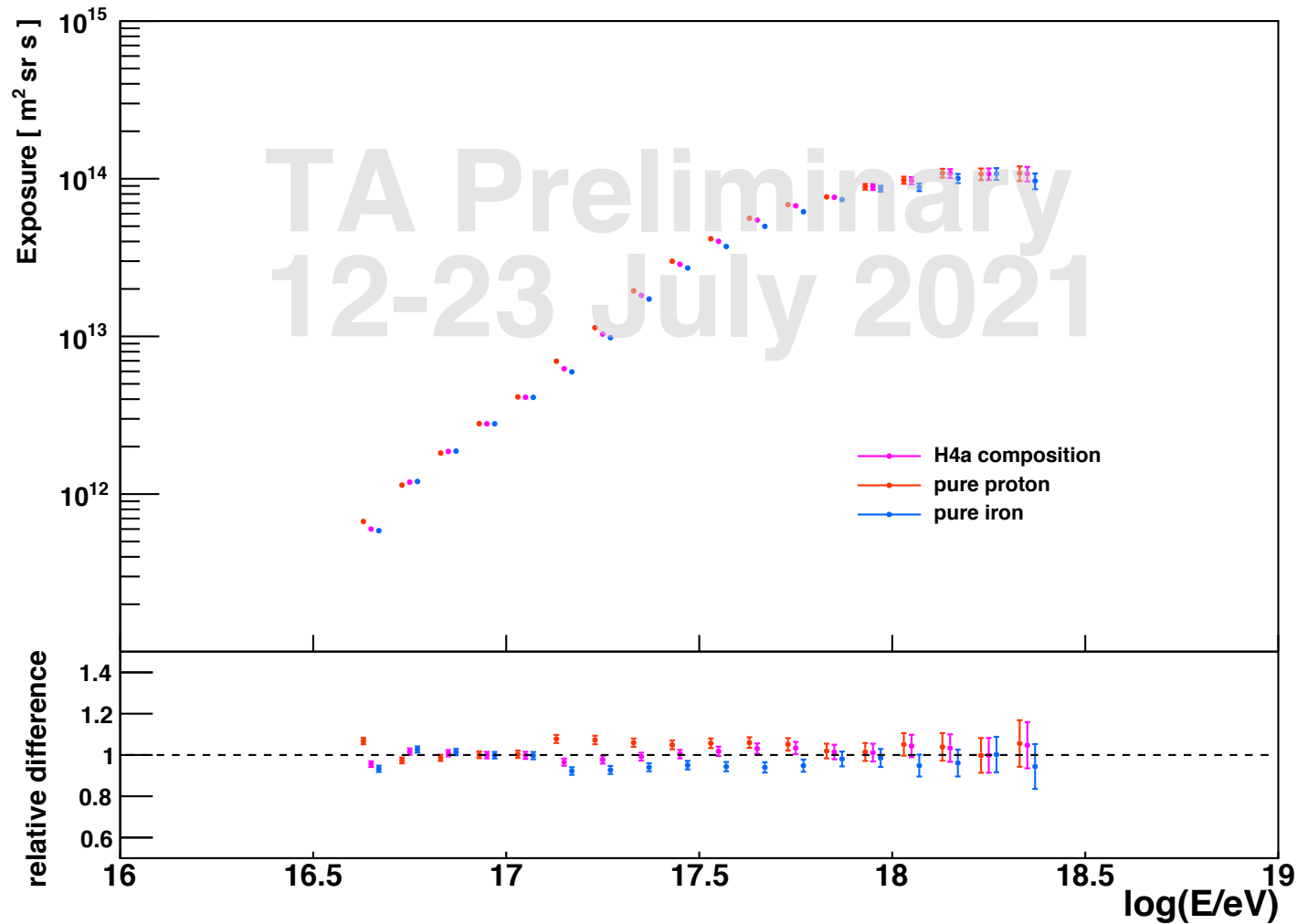
$$R = \frac{A\Omega^{\text{proton}}}{A\Omega^{\text{iron}}}, f: \text{iron fraction}$$

- iron fraction: assumed using H4a model
- Missing energy also estimated using H4a



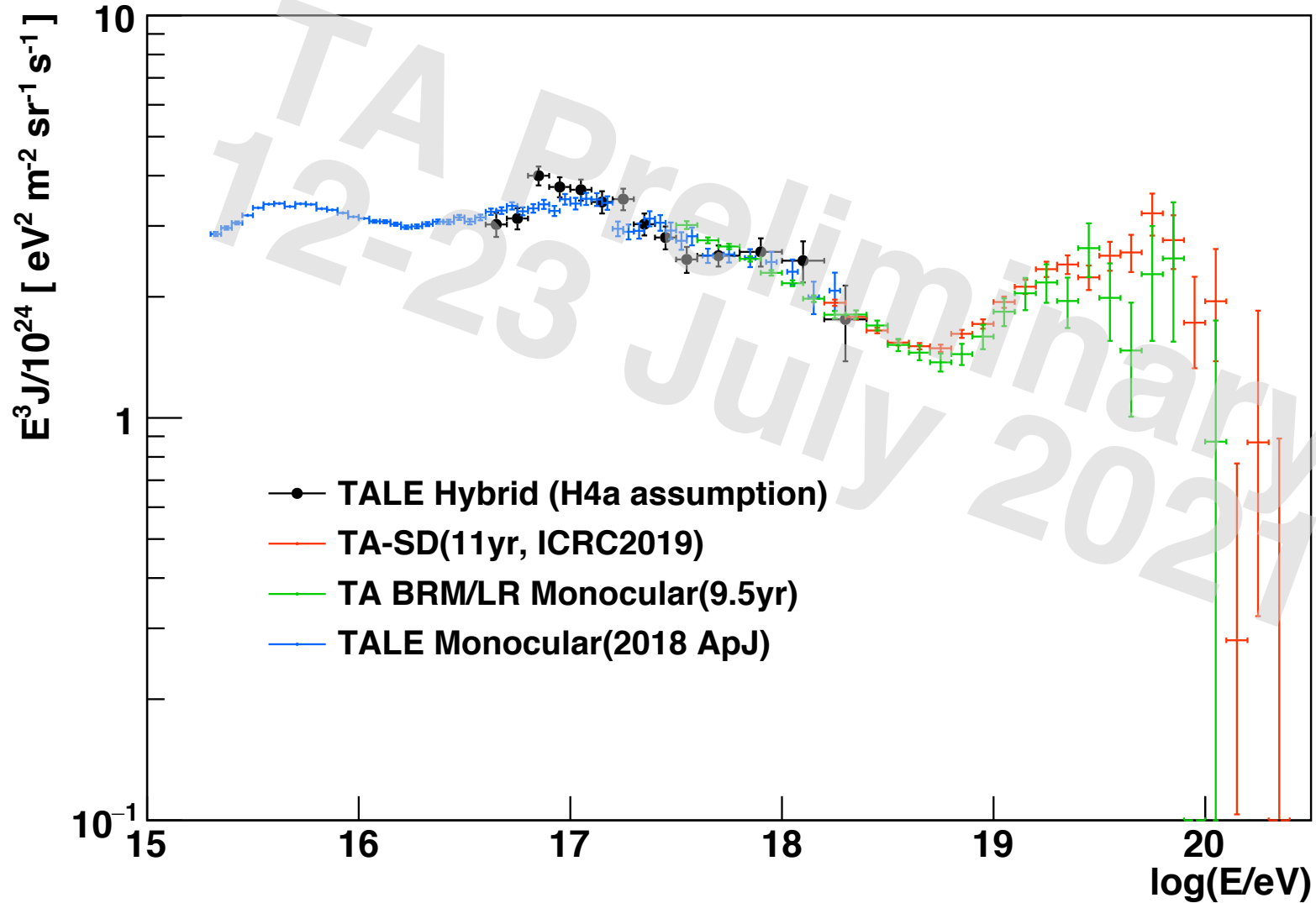
Aperture and Exposure

- TALE Hybrid exposure
 - Relative differences in the exposure to proton, iron and H4a assumption with respect to the 50% proton + 50% iron mixture



Spectrum

TALE Hybrid Spectrum with TA result



Summary

- Present first results measured by TALE Hybrid
 - Energy range: $10^{16.6} - 10^{18.4}$ eV
 - Data/MC is agreement
 - Composition
 - Energy Spectrum
 - Consistent with our previous result

