Monocular Energy Spectrum using the TAx4 Fluorescence Detector

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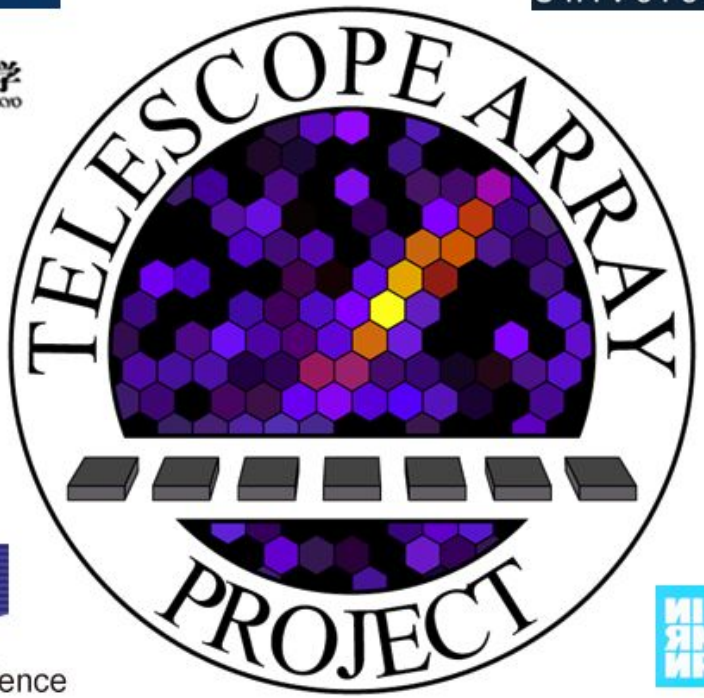
Presenter : Mathew Potts

Telescope Array (TA) Collaborators



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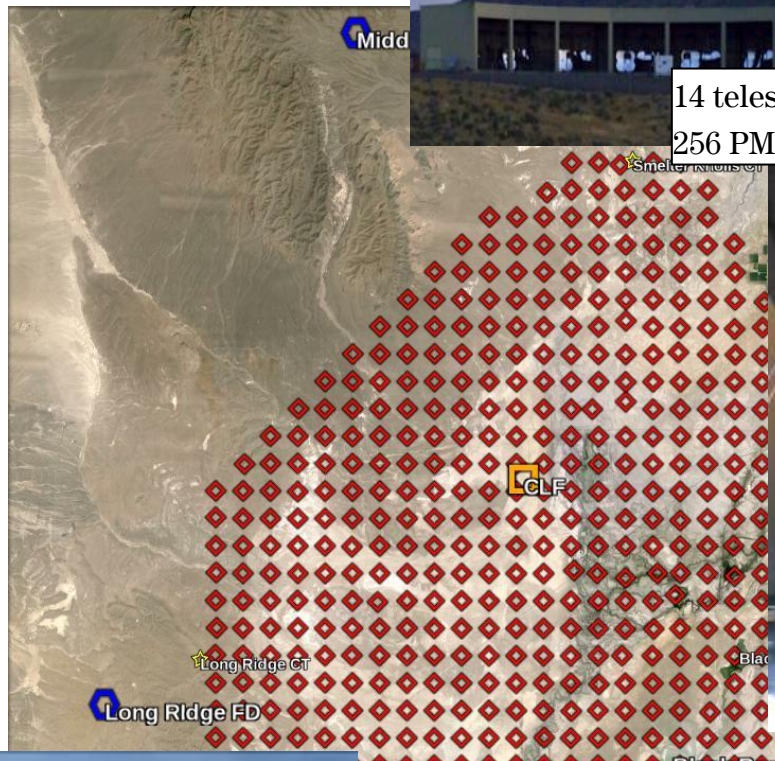
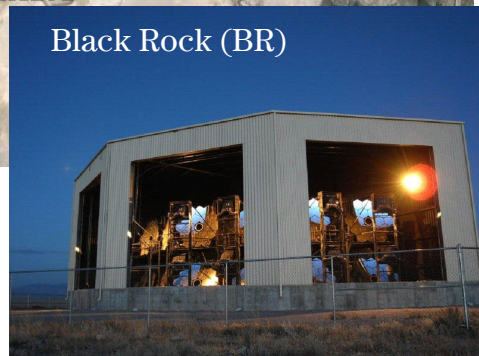
Telescope Array (TA)

- Largest UHE cosmic ray detector in the Northern Hemisphere
- Surface detectors (red diamonds) coverage: ~700 km^2 with 1.2 km spacing.
- Three fluorescence stations (blue octagons)
  - Black Rock (BR), Long Ridge (LR), Middle Drum (M

14 telescopes/station
256 PMTs/camera



12 telescopes/station
256 PMTs/camera



Excess of Events: TA Hot Spot

- TA has seen indications of possible *nearby* source of ultrahigh energy cosmic rays
- 72 Cosmic Rays with E > 57 EeV

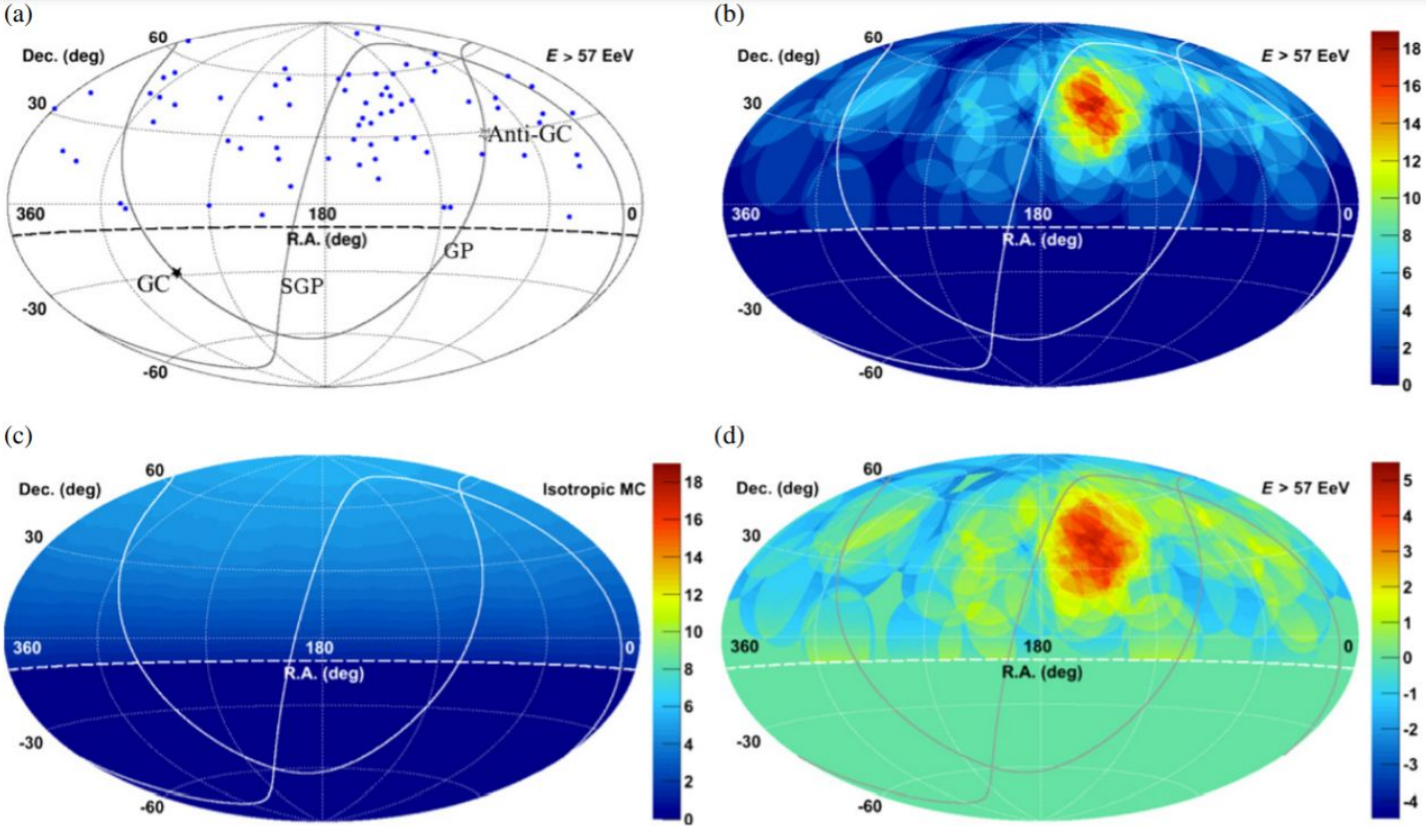
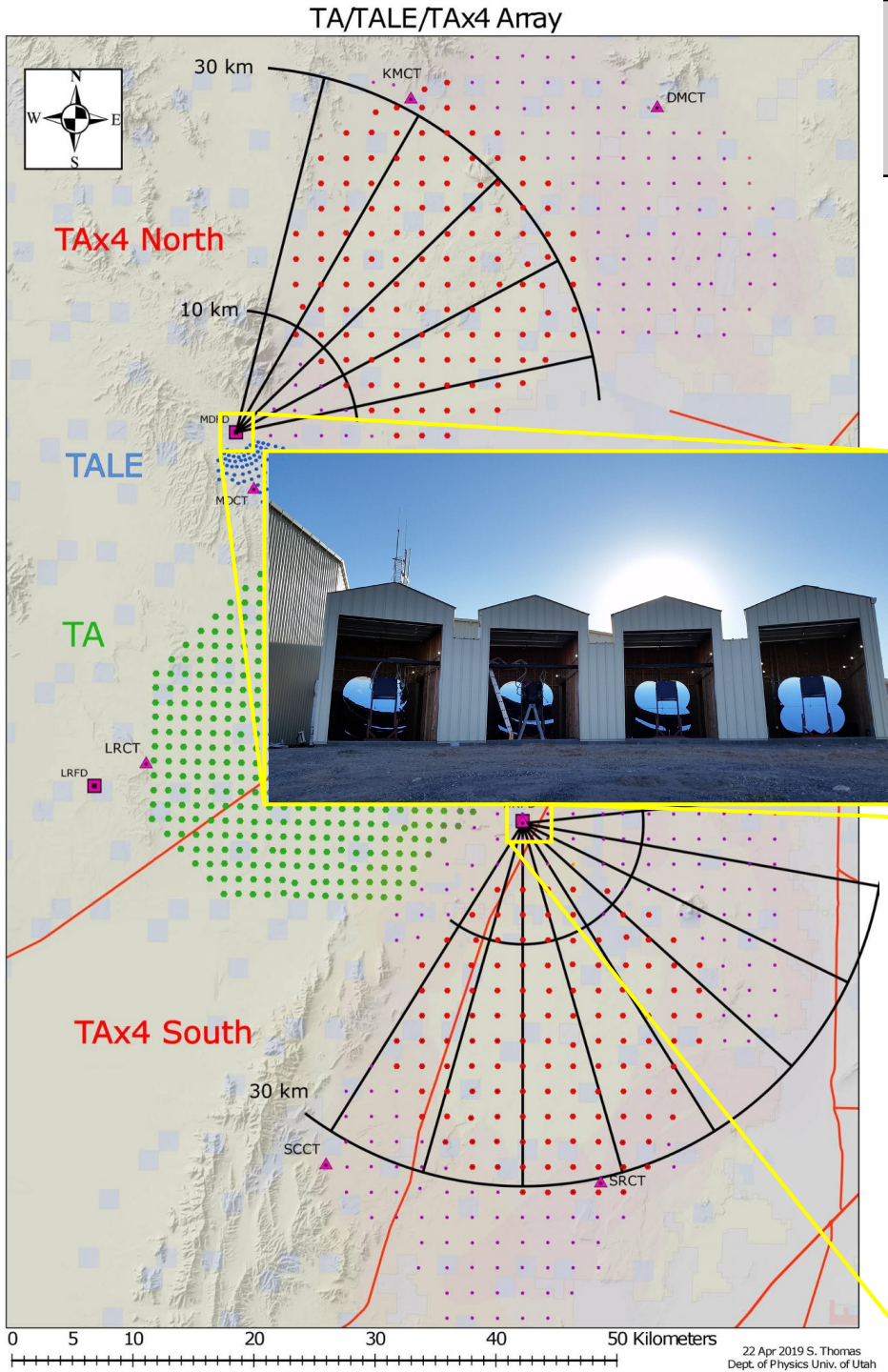


Figure 1. Aitoff projection of the UHECR maps in equatorial coordinates. The solid curves indicate the galactic plane (GP) and supergalactic plane (SGP). Our FoV is defined as the region above the dashed curve at decl. $= -10^{\circ}$. (a) The points show the directions of the UHECRs $E > 57$ EeV observed by the TA SD array, and the closed and open stars indicate the Galactic center (GC) and the anti-Galactic center (Anti-GC), respectively; (b) color contours show the number of observed cosmic-ray events summed over a 20° radius circle; (c) number of background events from the geometrical exposure summed over a 20° radius circle (the same color scale as (b) is used for comparison); (d) significance map calculated from (b) and (c) using Equation (1).

[1]

TAx4



- Fourfold increase in size of TA SD array.
  - Plan to add 500 scintillators SDs at 2.08 km spacing
  - Added 2 FD stations, 12 telescopes
- The goal of TAx4 is to increase the statistics for the highest energy range (E > 20 EeV)
  - In ~5 years of collecting data it will triple the TA data set

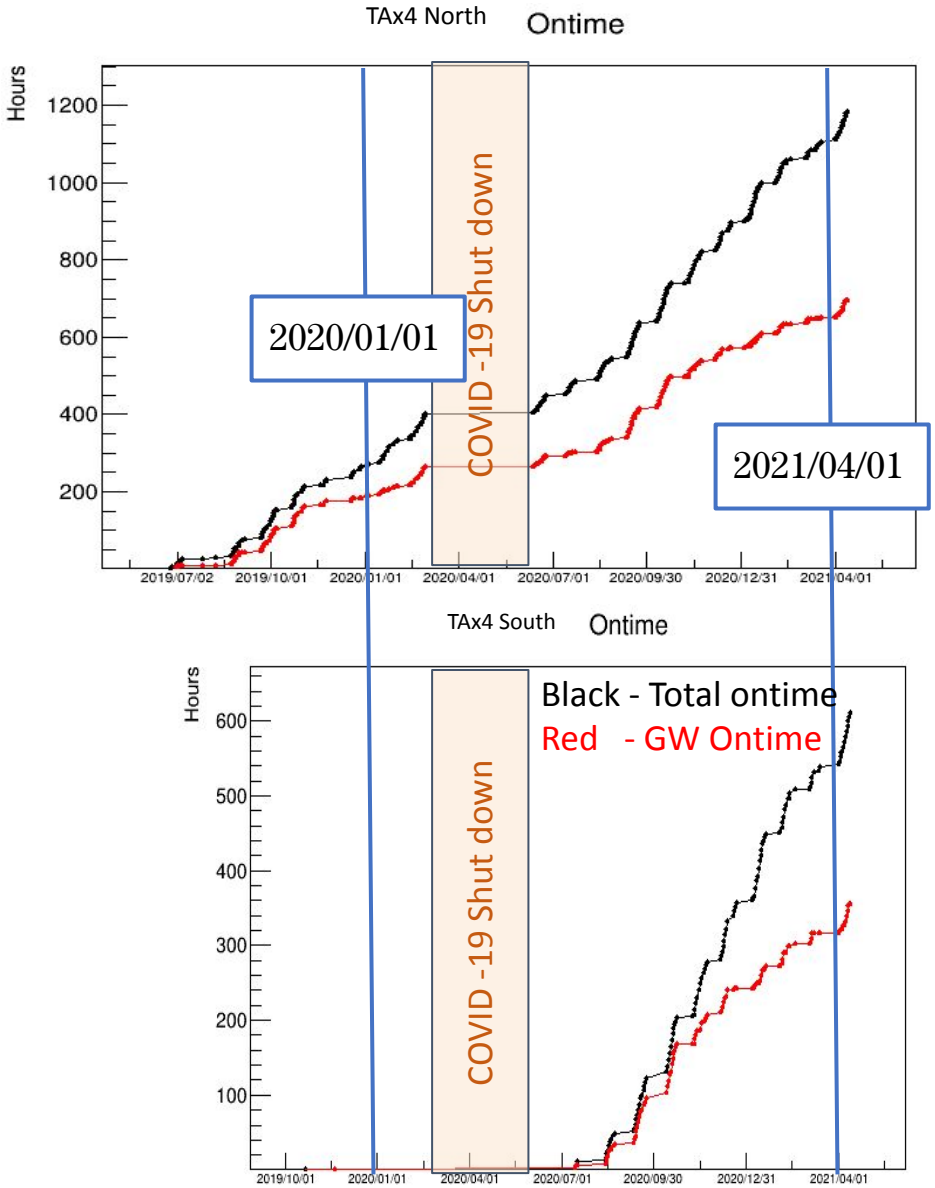
Status of TAx4 North (TAx4 MD)

- Construction completed in February 2018, started commissioning detector
- Data collection started in July 2018
- Vertical shower trigger enhancement in May 2019
- Nearest neighbor trigger upgrade in June 2019

Status of TAx4 South (TAx4 BR)

- Construction completed in July 2019, started commissioning detector
- Due to COVID-19 pandemic data collection with TAx4 BR was curtailed
- Remote data collection started in July, 2020

TAx4 On-time (2019/06/26-2021/04/14)



- **TAx4 Detector total ontime: 1,799.723 hrs**
  - GW on-time : 1,051.6531 hrs
- **TAx4 North total on-time: 1186.1486 hrs**
  - on-time for m25 : 1158.0305 hrs
  - on-time for m26 : 1161.1839 hrs
  - on-time for m27 : 1106.6300 hrs
  - on-time for m28 : 1126.2058 hrs
  - GW on-time : 696.7853 hrs
    - No clouds overhead and no horizon clouds to the north and east
- **TAx4 South total ontime: 613.5744 hrs**
  - on-time for m29 : 604.9336 hrs
  - on-time for m30 : 603.6375 hrs
  - on-time for m31 : 608.3016 hrs
  - on-time for m32 : 539.5418 hrs
  - on-time for m33 : 604.9152 hrs
  - on-time for m34 : 575.9278 hrs
  - on-time for m35 : 598.5456 hrs
  - on-time for m36 : 555.6276 hrs
  - GW on-time : 354.8678 hrs
    - No clouds overhead and no horizon clouds to the south and east

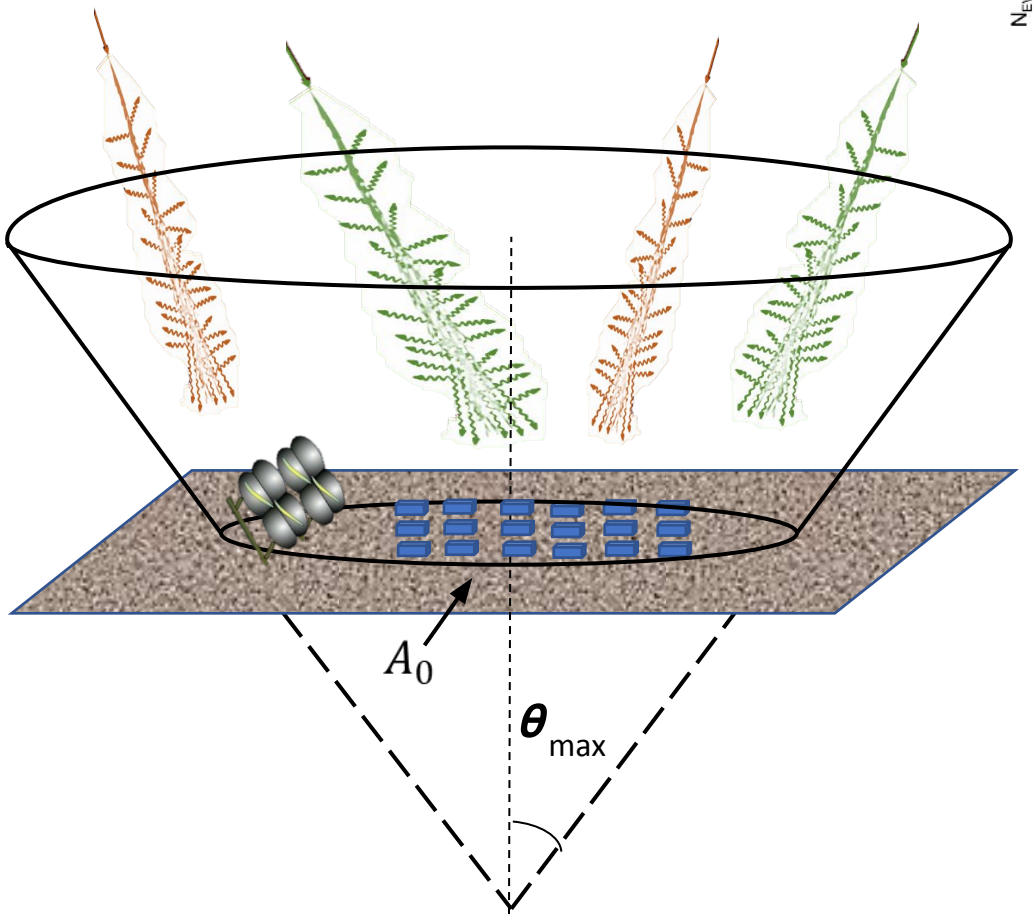
Monocular Quality Cuts

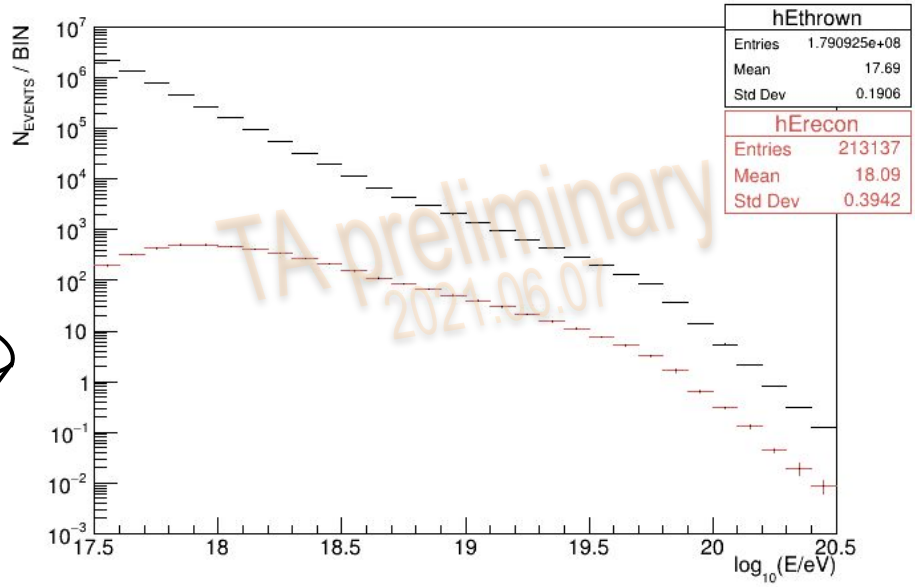
Event Reconstruction Cuts	
Rayleigh Filter	$P_{log_{10}} \geq 2$
Brightness Cut	$\Sigma N_\gamma / N_{ngtube} \geq 200$
Track length	>7.9°
Track width RMS	$\theta_{RMS} \leq 1°$
Profile Fit	$\chi^2/\text{ndf} < 14$
Angular Speed Cut	$\leq 5.73 \mu s/\circ$
First Interaction	$X_0 \leq 1200$

Table 1: TAx4 monocular event reconstruction quality cuts.

Monte Carlo Simulations

- Performance of our detectors, reconstruction programs, and the aperture are evaluated using a Monte-Carlo (MC) program.
  - Shower simulation
  - Detector simulation



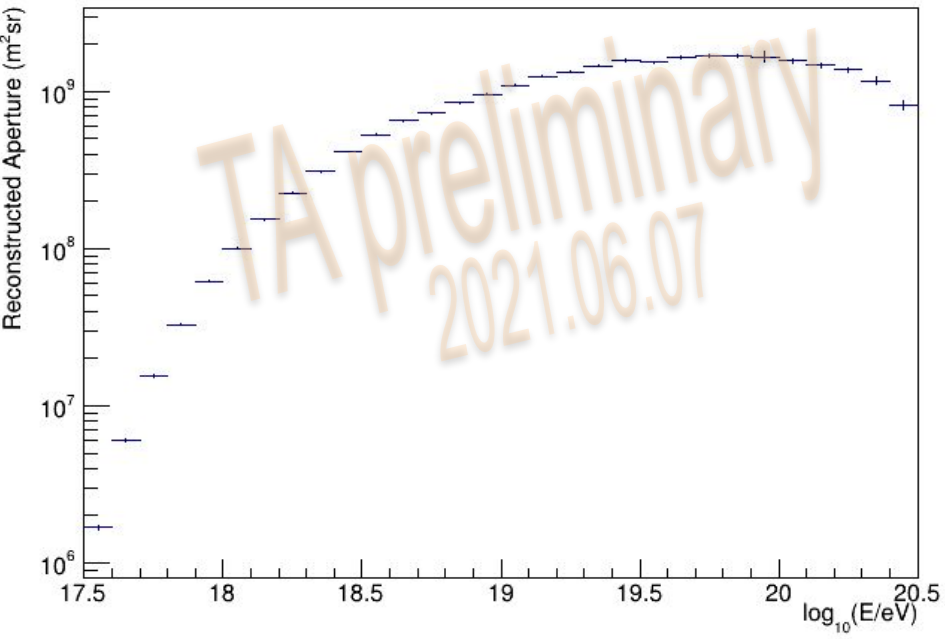


- 50k QGSJetII-03 protons thrown at E^{-2} per data part (data part is ~20 mins)
  - Events are reweighted with spectral indices reported in the combined ICRC 2019 spectrum.
  - Reconstructed MC has quality cuts and protonic missing energy correction applied.

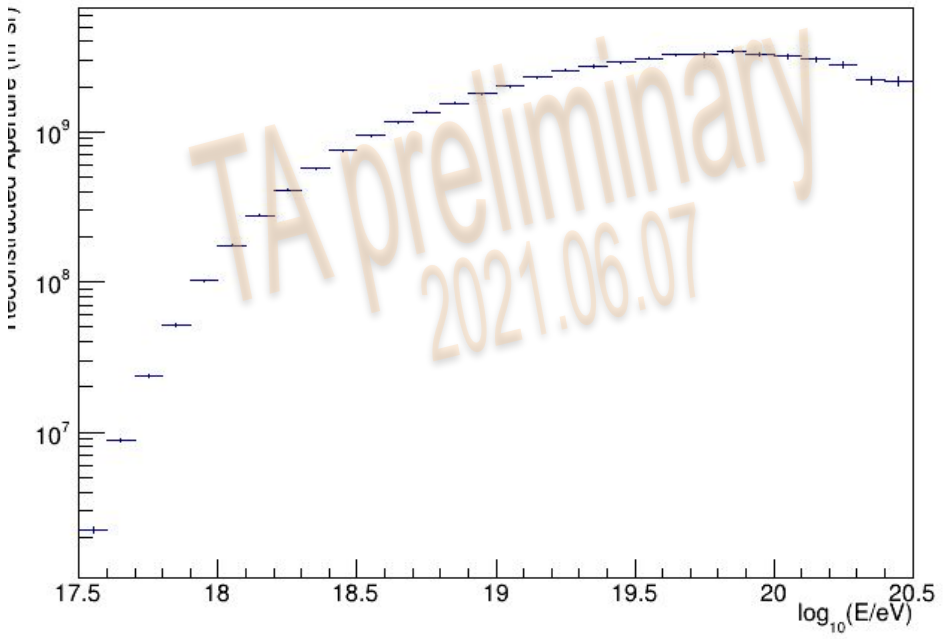
TAx4 Monocular Aperture

$$A\Omega = (N^{MC}_{Recon}/N^{MC}_{Thrown})A_0\Omega_0$$

$$A_0\Omega_0 = 2\pi^2(R^2_{p,max} - R^2_{p,min})(1 - \cos\theta_{max})$$



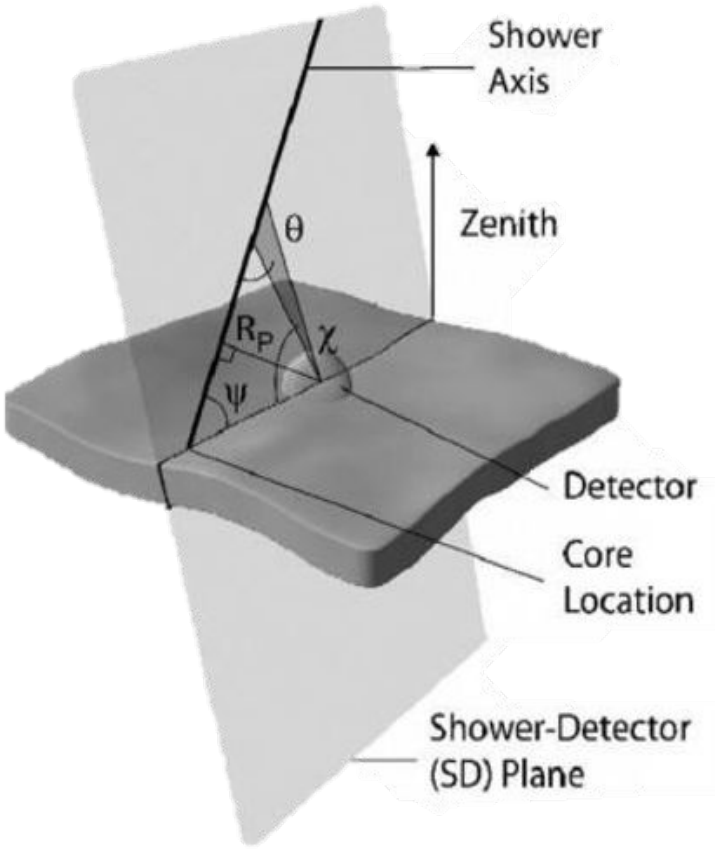
TAx4 North

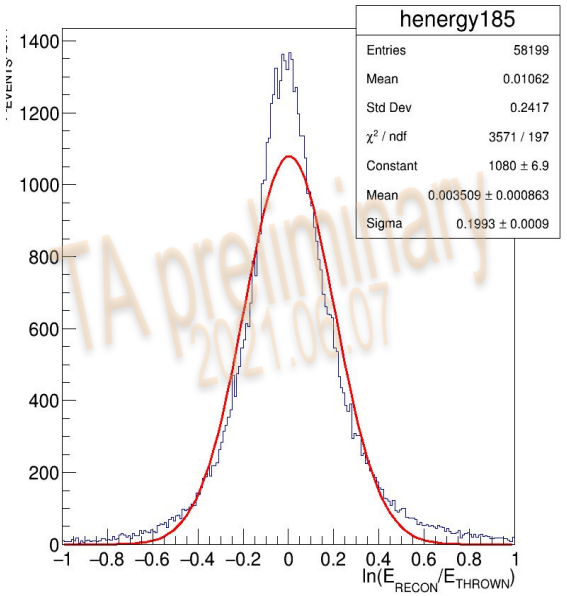


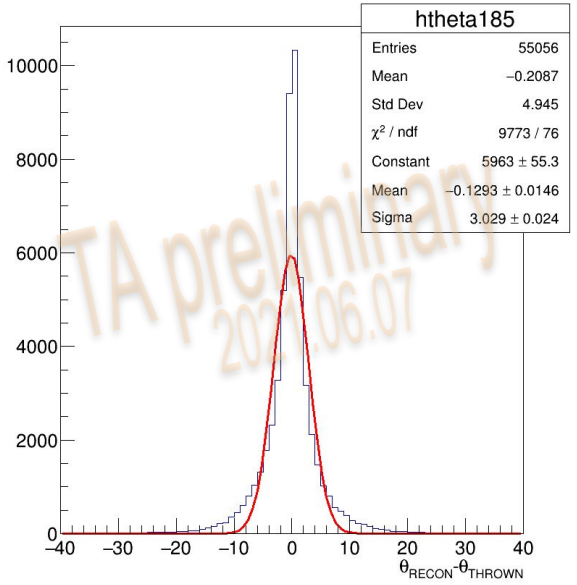
TAx4 South

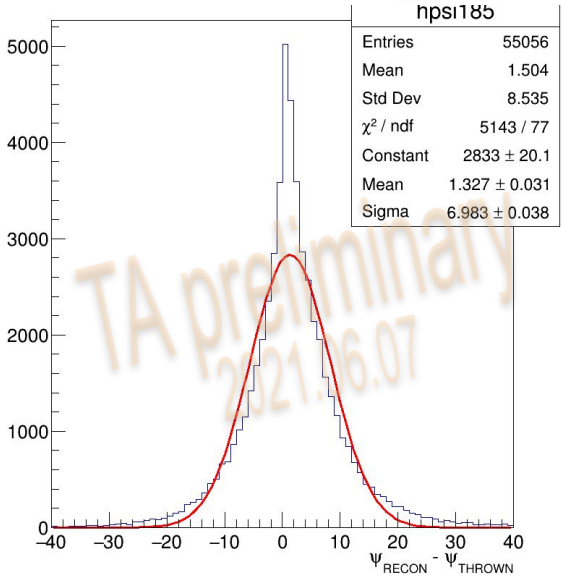
Resolutions

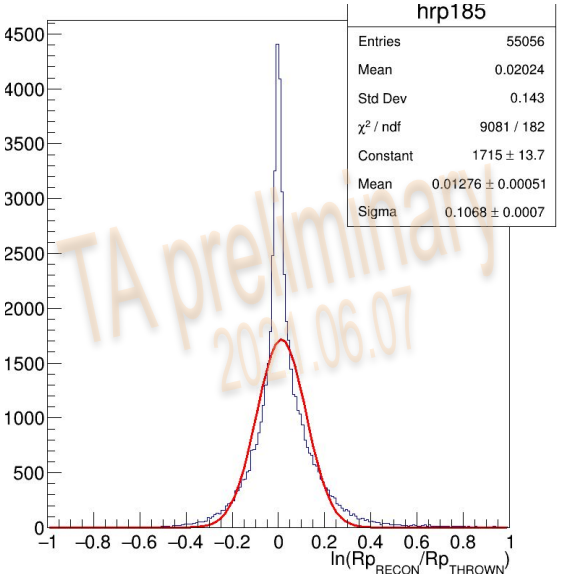
- Energy Resolution: ~20%
- Zenith Angth Resolution: ~3°
- Ψ Resolution: ~7°
- Impact Parameter Resolution: ~11%





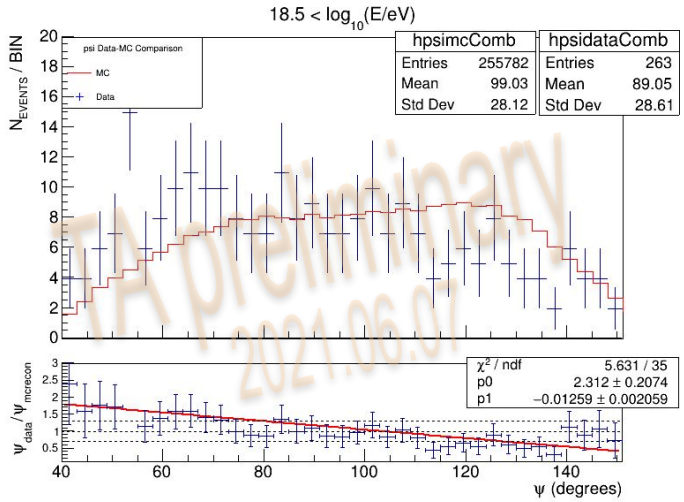


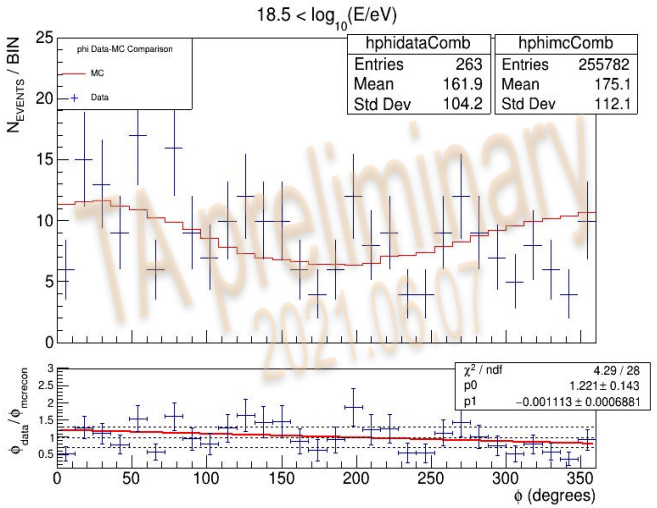


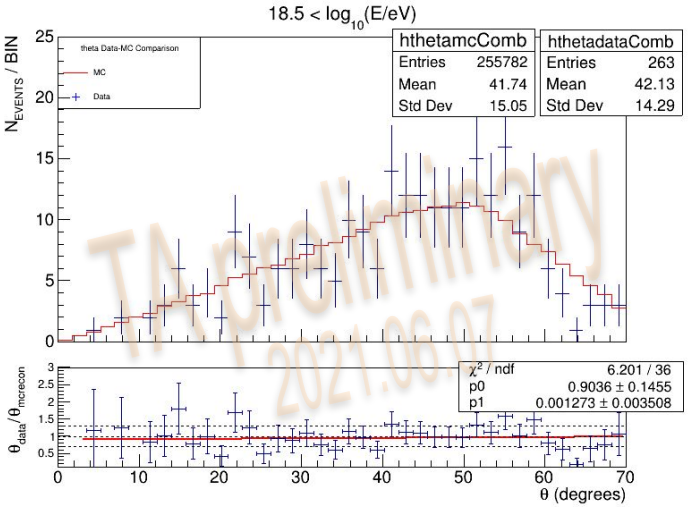


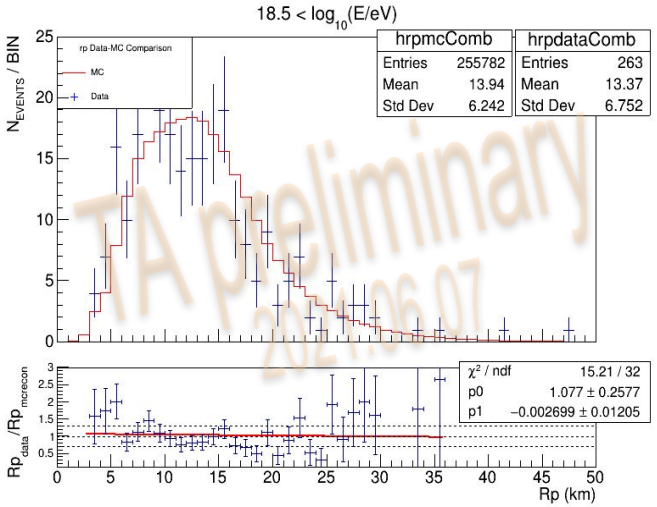
Data-MC Comparisons

- Blue points are data, the red line is the MC
- All geometrical parameters appear to be in reasonable agreement with the MC









TAx4 Energy Spectrum

$$N_{\mathrm{TAx4}}\left(E_i\right) = N_N\left(E_i\right) + N_S\left(E_i\right),$$

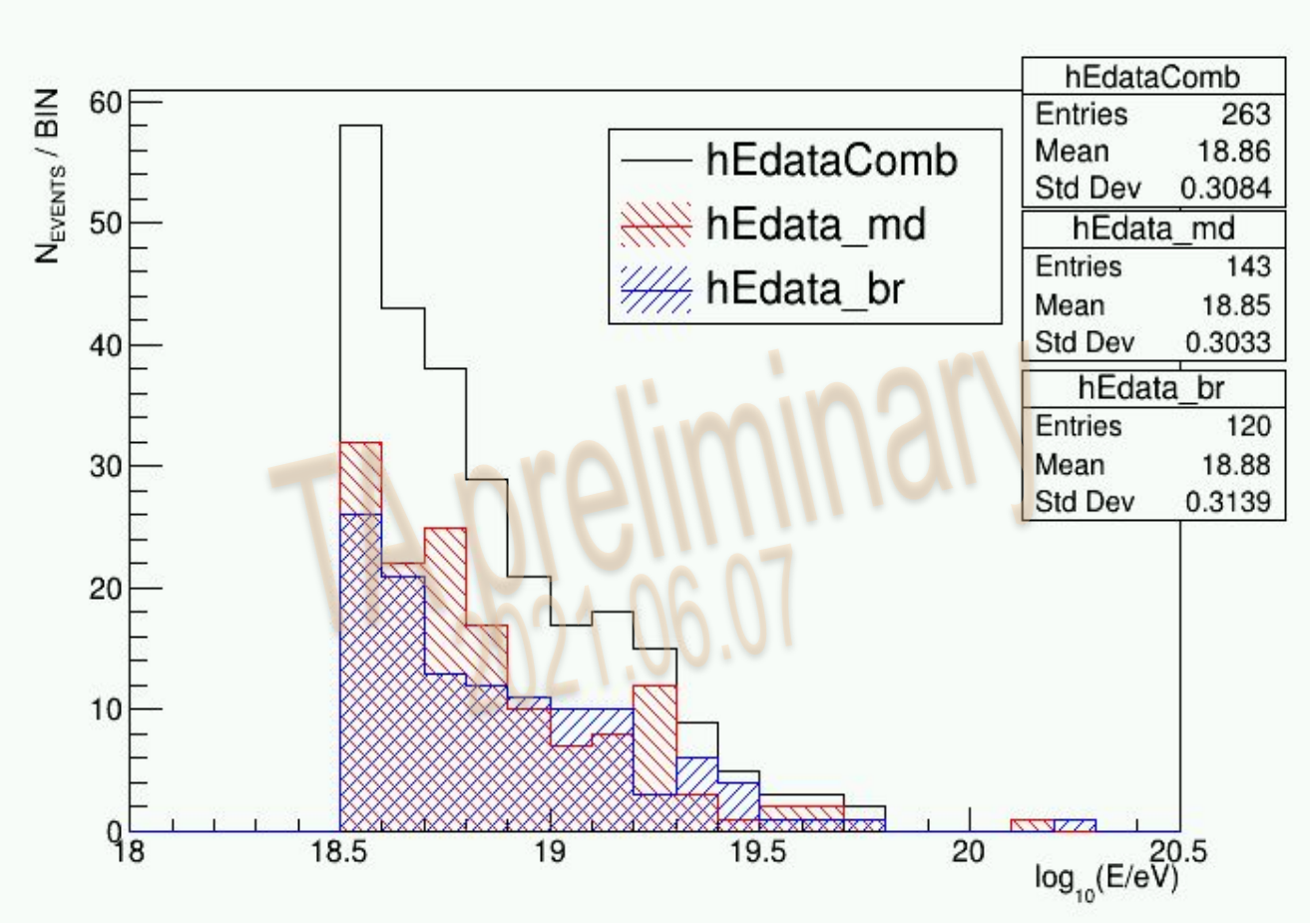
$$\epsilon_{\mathrm{TAx4}} = A\Omega_N T_N + A\Omega_S T_S,$$

$$J_{\mathrm{TAx4}}\left(E_i\right) = \frac{N_{\mathrm{TAx4}}\left(E_i\right)}{\Delta E_i \cdot \epsilon_{\mathrm{TAx4}}\left(E_i\right)},$$

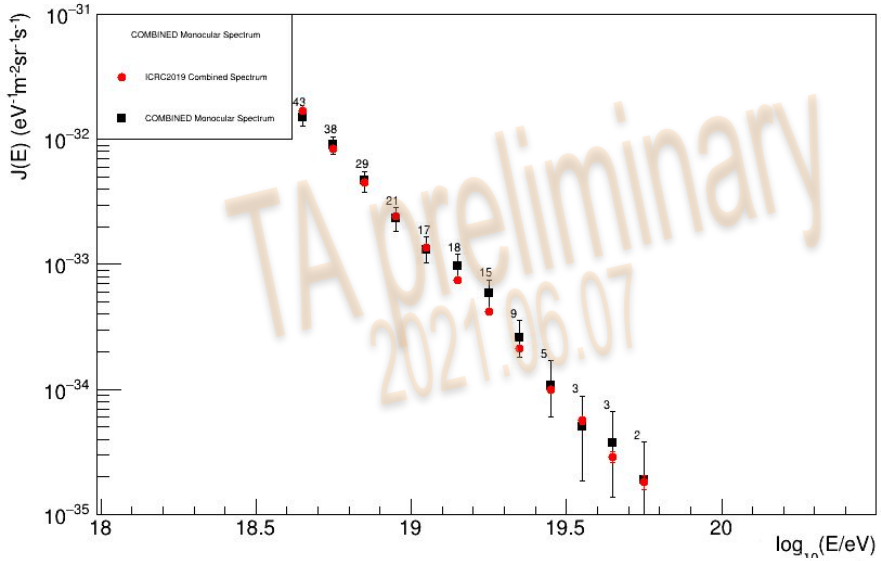
- The TAx4 combined number of events and combined exposure is simple to calculate since there is no overlap of the detector's FOVs. Thus, the combined number of events and combined exposure simplifies to sums.

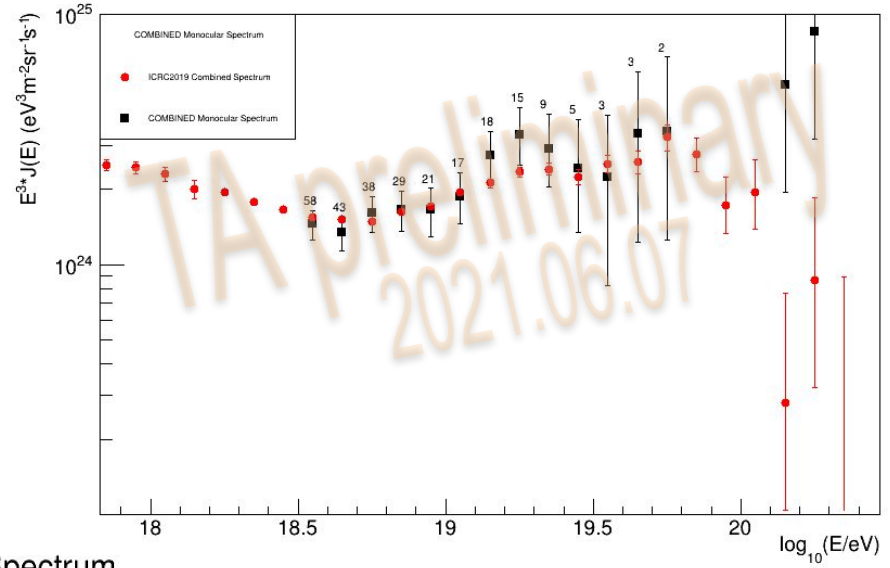
Combined Energy Distribution

- 263 TAx4 events with E ≥ $10^{18.5}$ eV
  - 143 TAx4 North events
  - 120 TAx4 South events

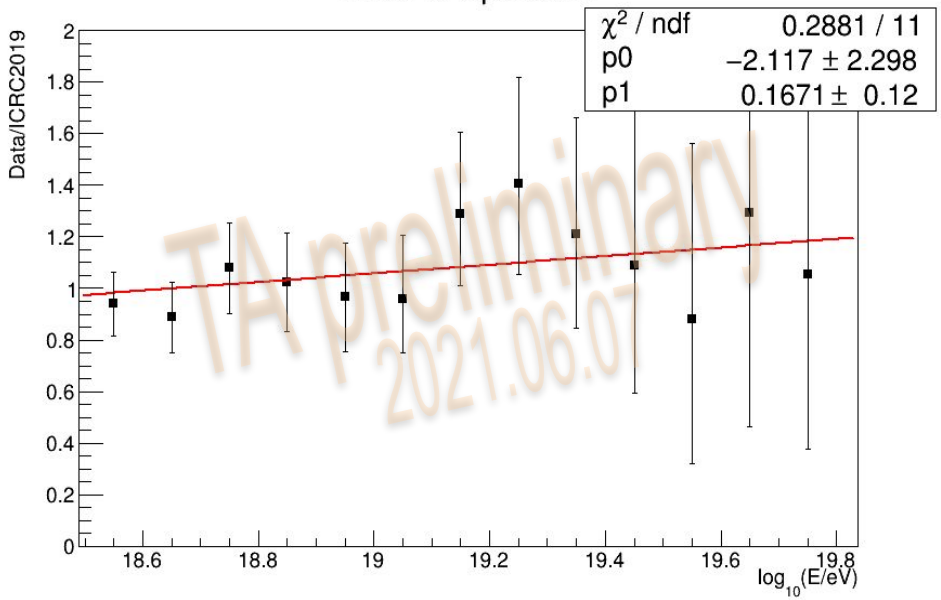


TAx4 Monocular Spectrum



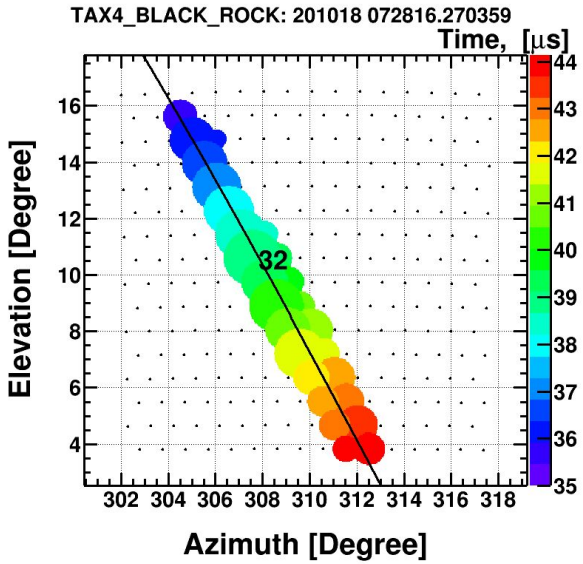


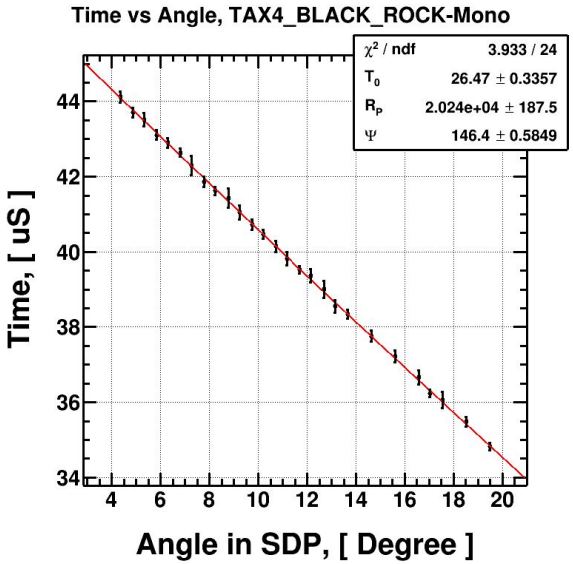
Ratio of Spectrum

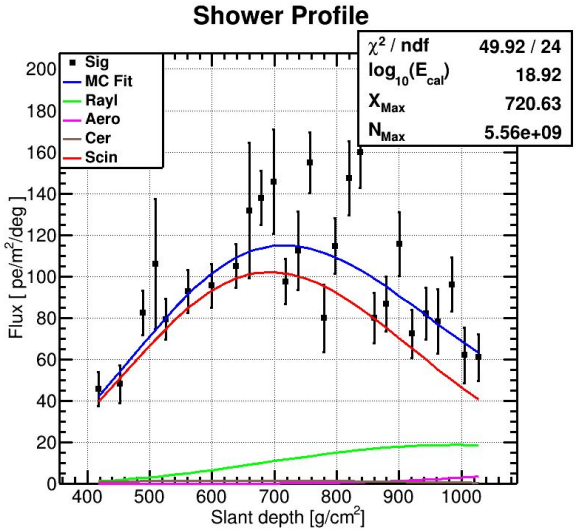


Hybrid Event

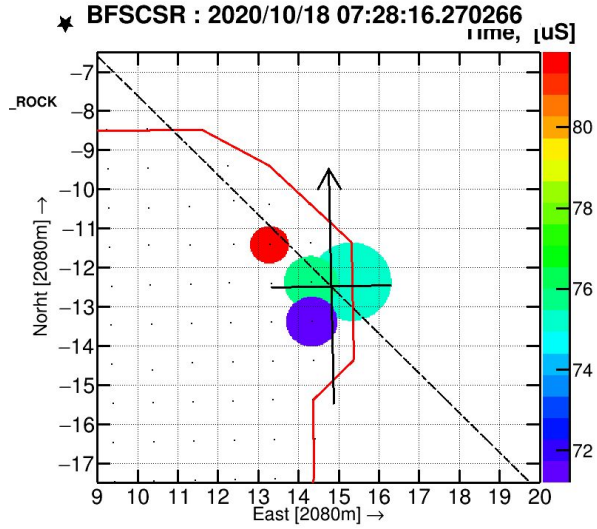
TAx4 South Monocular

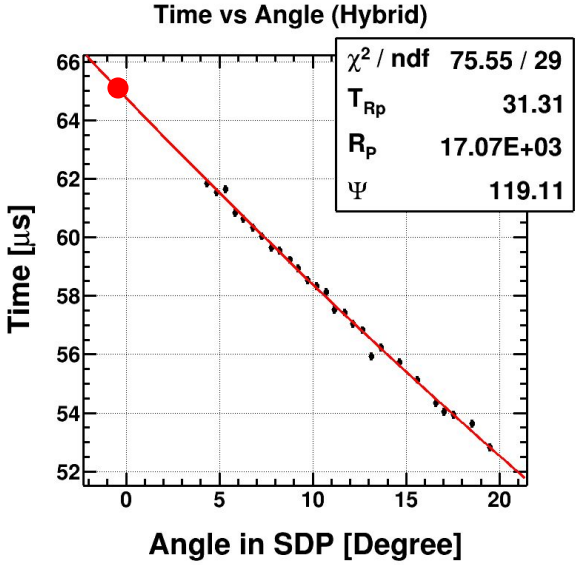


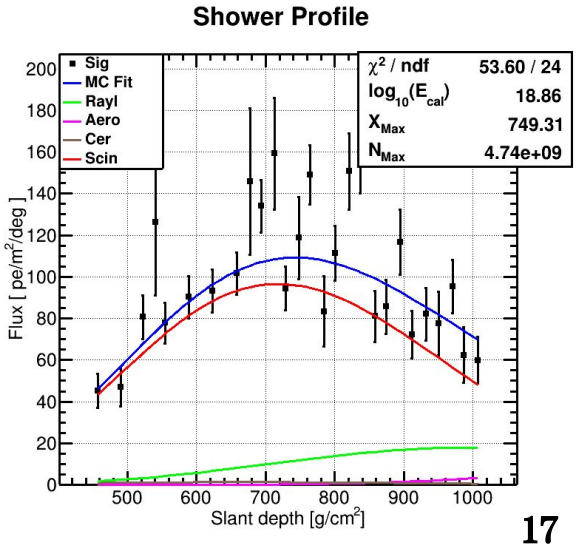




TAx4 South Hybrid







Summary and Plans

- The TAx4 North and TAx4 South sites were completed in 2018 and 2019, respectively. Both sites are now taking data continuously on clear moonless nights.

- All geometrical parameters in the data appear to be in agreement with the MC.

- This works monocular energy spectrum using TAx4 is in agreement with the TA ICRC2019 combined spectrum.

- A monocular energy spectrum is the first step towards my goal of generating a hybrid energy spectrum using the TAx4 detector for my Ph.D thesis.
  - Using a parametric hybrid MC to estimate the hybrid aperture and detector resolutions
  - Implementation of full hybrid MC is in progress.
  - I plan on graduating next summer and will be looking for new research opportunities.

References

[1] R. U. Abbasi et al 2014 ApJL 790 L21

[2] K. Kawataet. al. Updated Results on the UHECR Hotspot Observed by the Telescope Array Experiment, PoS(ICRC2019)310.

[3] R. Abbasiet al., Evidence of Intermediate-scale Energy Spectrum Anisotropy of Cosmic RaysE ≥ $10^{19.2}$eV with the Telescope Array Surface Detector, ApJ. 862, 91.

[4] T. Abu-Zayyadet al., The surface detector array of the Telescope Array experiment, NIM-A689, 87A [astro-ph/1201.4964].

[5] T. K. Gaisser and A. M. Hillas, "Reliability of the method of constant intensity cuts for re-constructing the average development of vertical showers", in Proceedings of the InternationalCosmic Ray Conference, vol. 8 (1977) 353-357