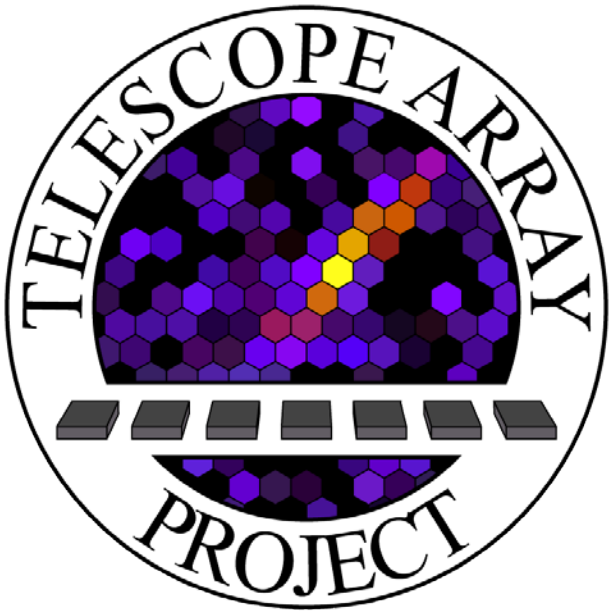
Spectrum of TA



Dmitri Ivanov
University of Utah
2017/10/12, Brussels, Belgium

Outline

- Telescope Array (TA)
- Spectrum Measurements
  - Surface Detector (SD)
  - Fluorescence Detector (FD) Mono
  - TALE Fluorescence and Cherenkov
  - Combined
- Declination dependence
- Summary

Telescope Array

Hybrid detector

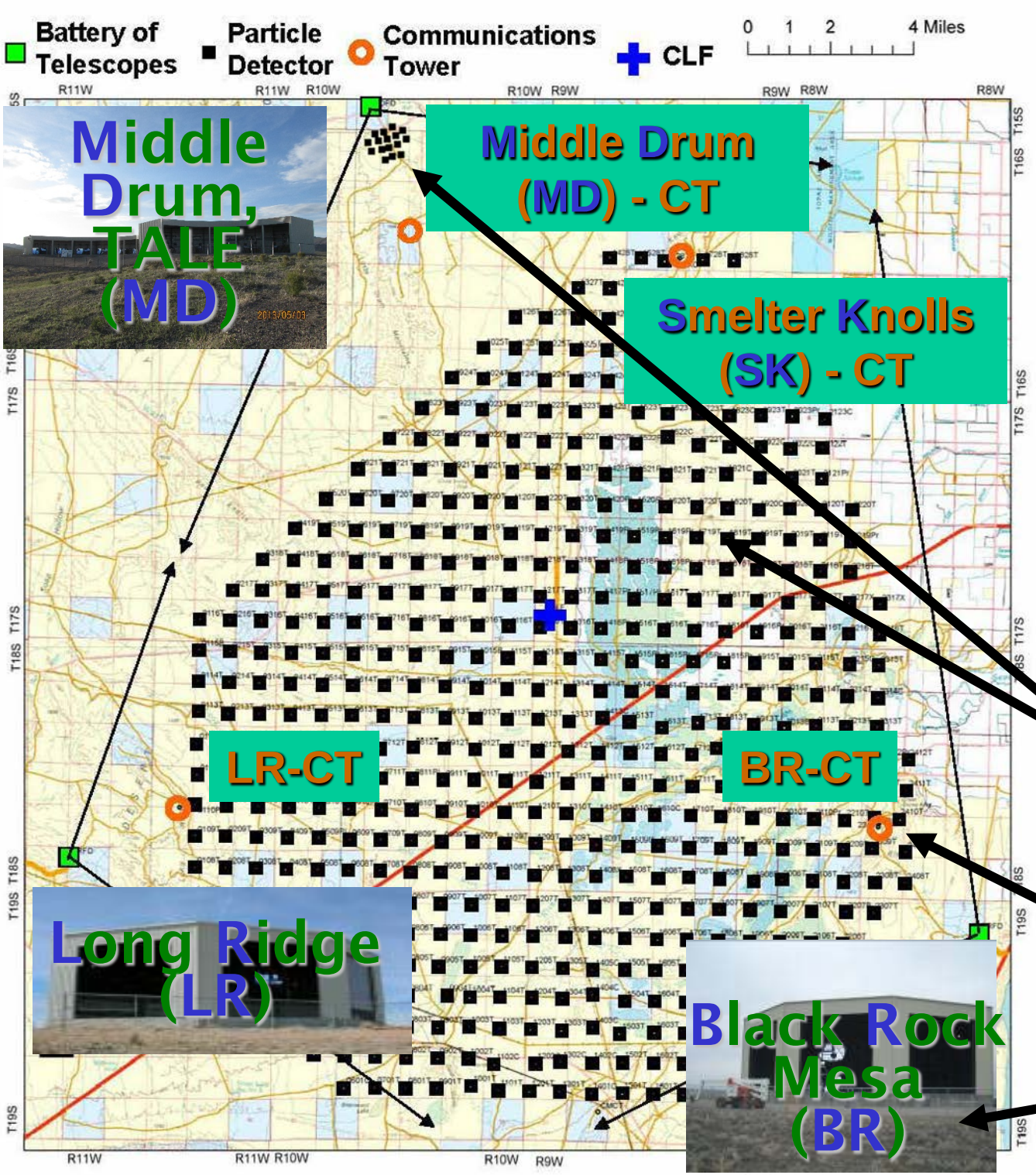
Millard County, UT
39.3˚ N , 112.9˚ W,
Alt. 1400m
~880g/cm²

507 Surface Detector (SD) counters, 1.2km apart

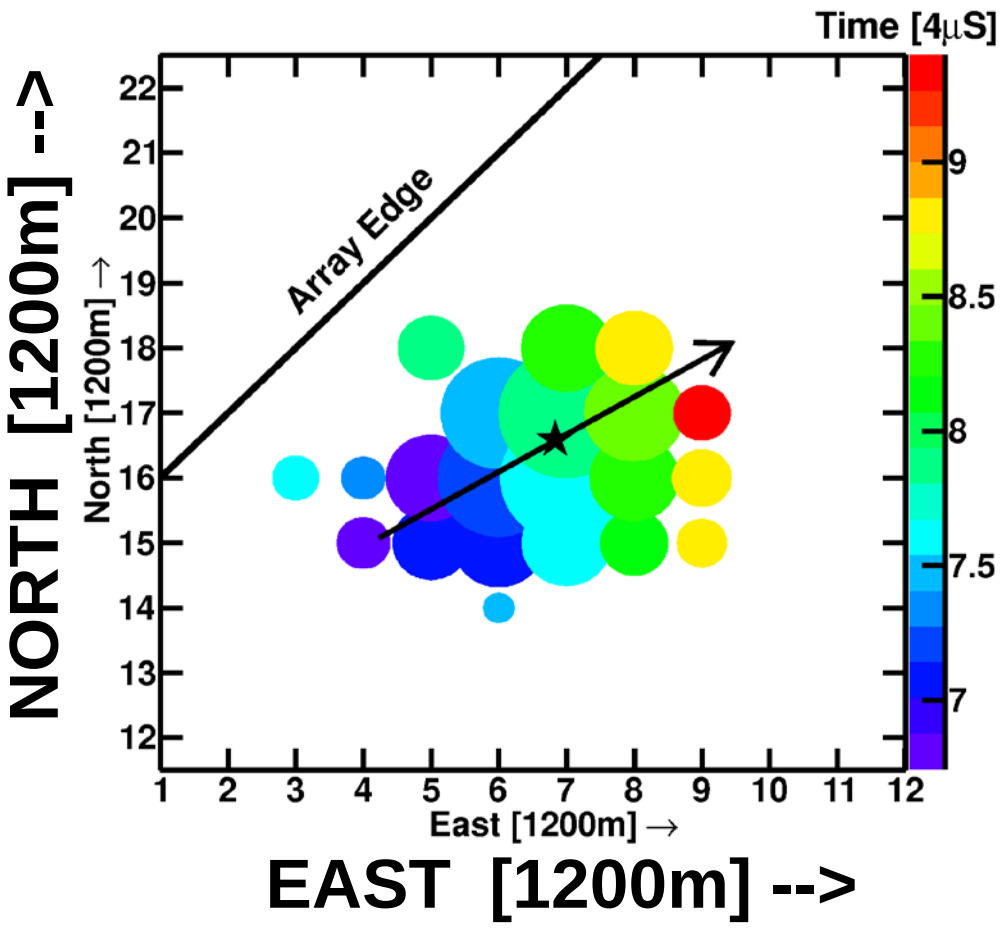
106 active TALE infill array counters, 400m spacing

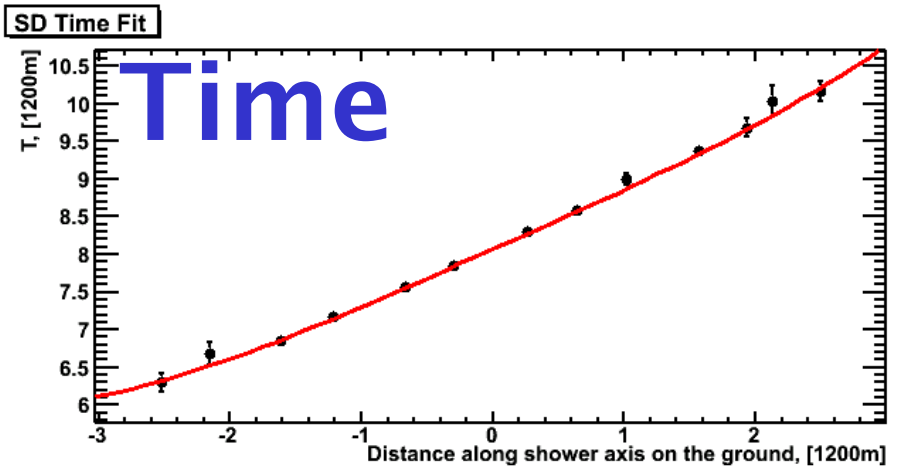
4 Communication Towers(CT): BR,LR,SK,MD

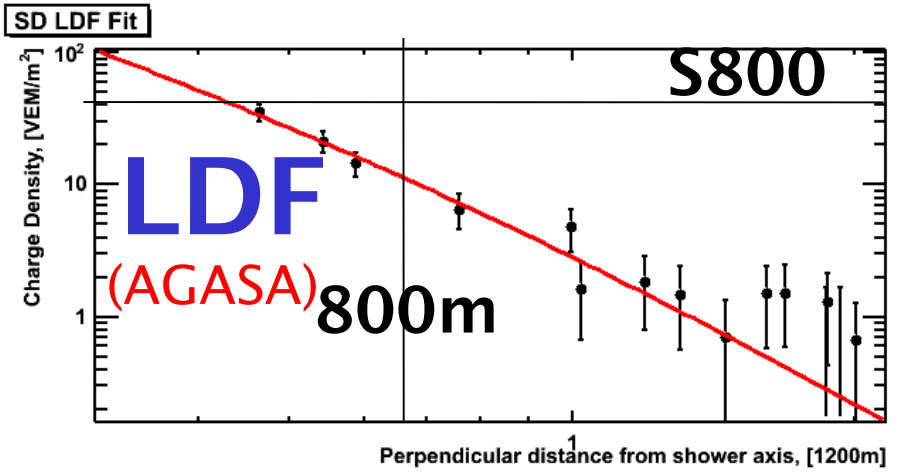
3 Fluorescence Detector sites(FD): BR,LR,MD/TALE



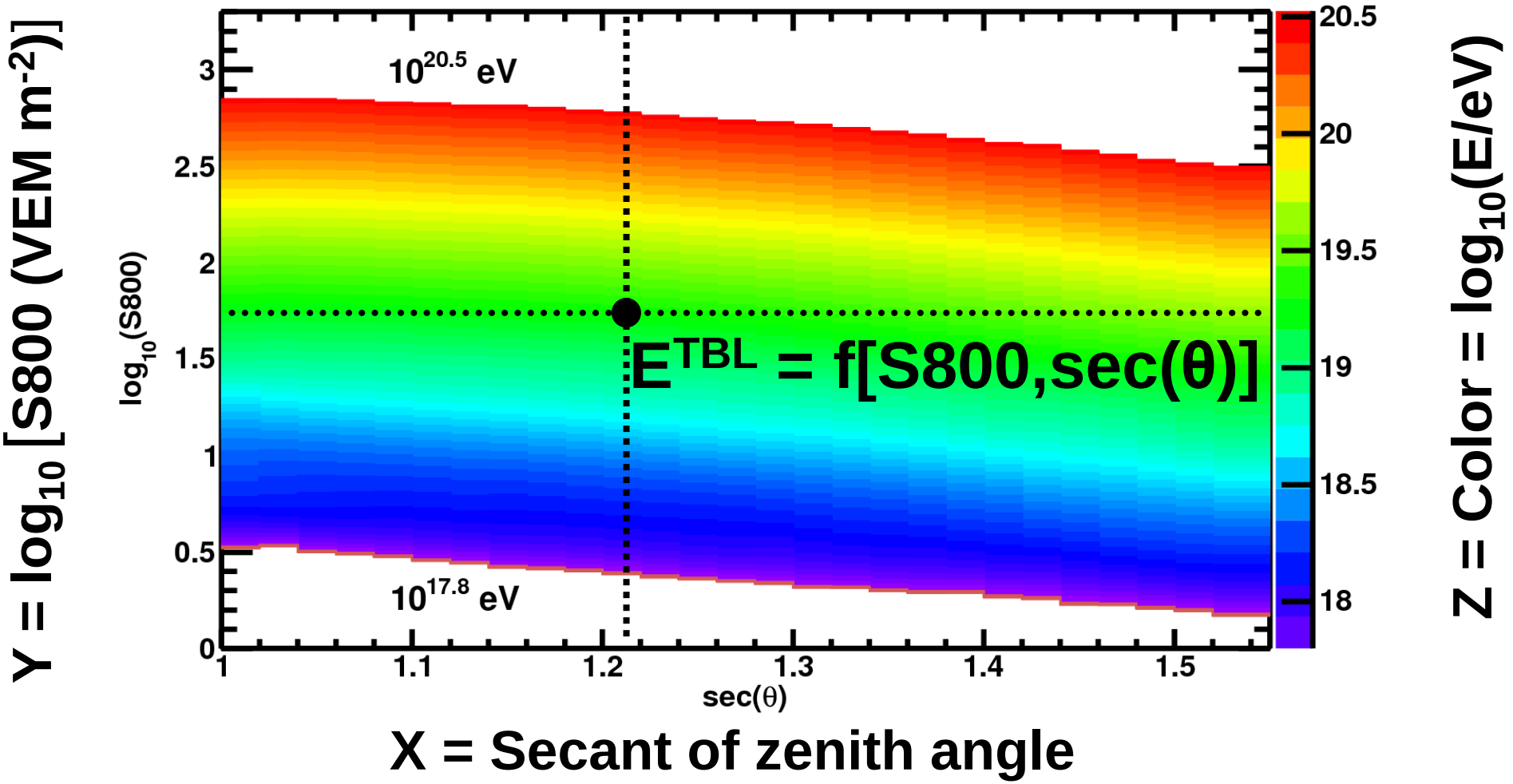
Surface Detector Event





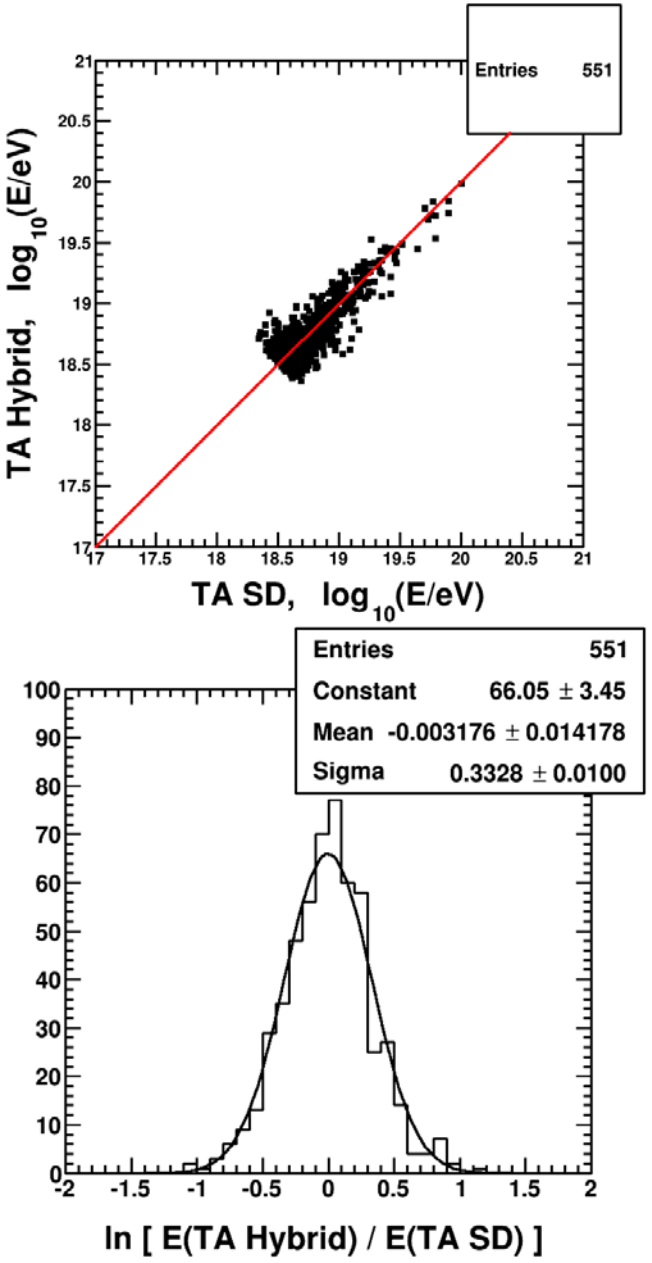


SD Energy 1/2



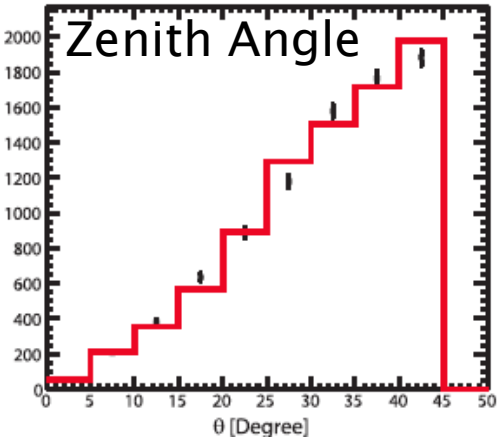
- A look-up table made from the Monte-Carlo
- Event energy (E^{TBL}) = function of *reconstructed* S800 and sec(θ)
- Energy reconstruction ←→ interpolation between S800 vs sec(θ) contours of constant values of E^{TBL}
- The overall energy scale locked to the fluorescence detector

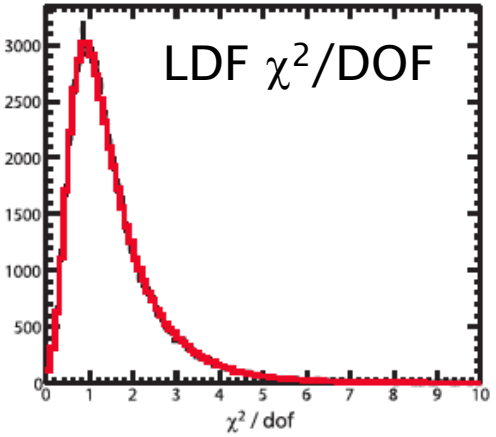
SD Energy 2/2: Energy Scale Set to FD

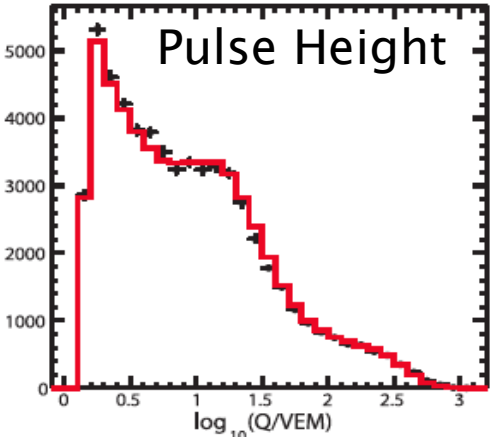


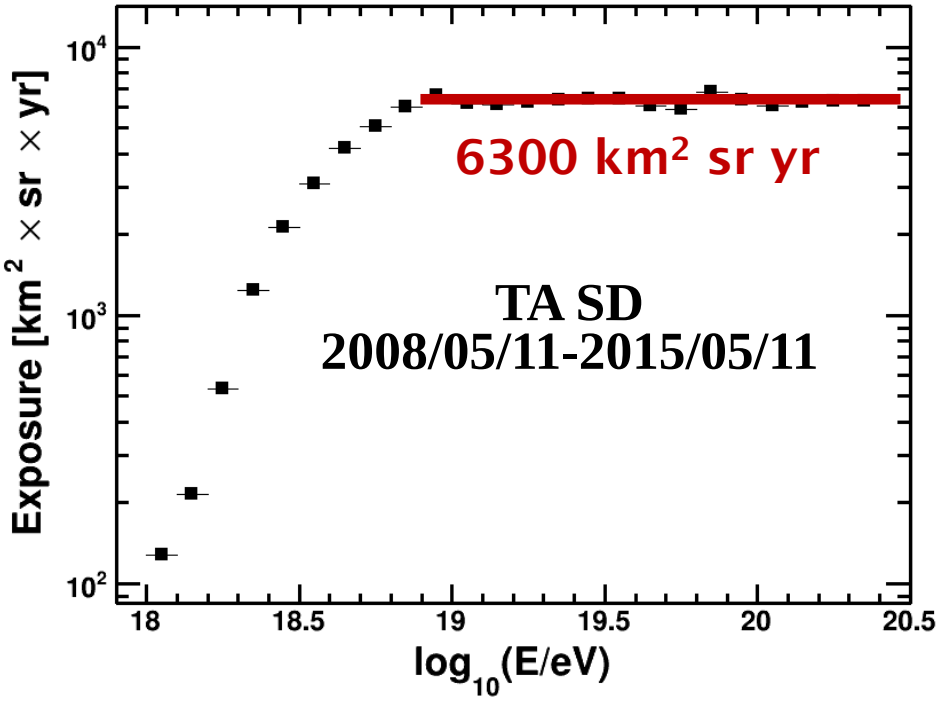
- Energy scale locked to the FD to reduce the systematic due to the model
- Use events well reconstructed separately by SD and FD in hybrid mode:
  - SD ∩ [BR U LR U MD Hybrid]
- $E^{FINAL} = E^{TBL} / 1.27$
- TOP figure: E^{FINAL} vs E^{FD} scatter plot
- BOTTOM figure: histogram of E^{FINAL} / E^{FD} ratio
- 2008/05/11-2013/05/04

Exposure from Monte Carlo



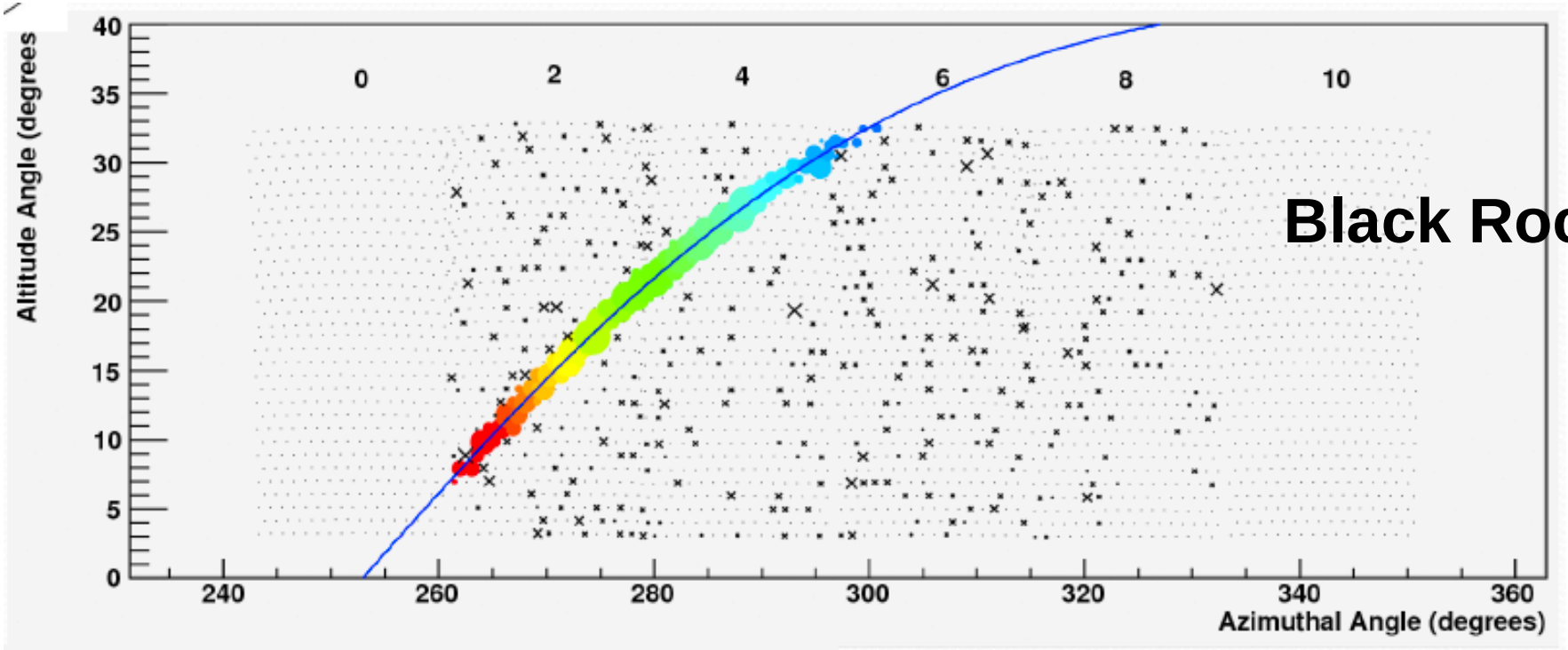




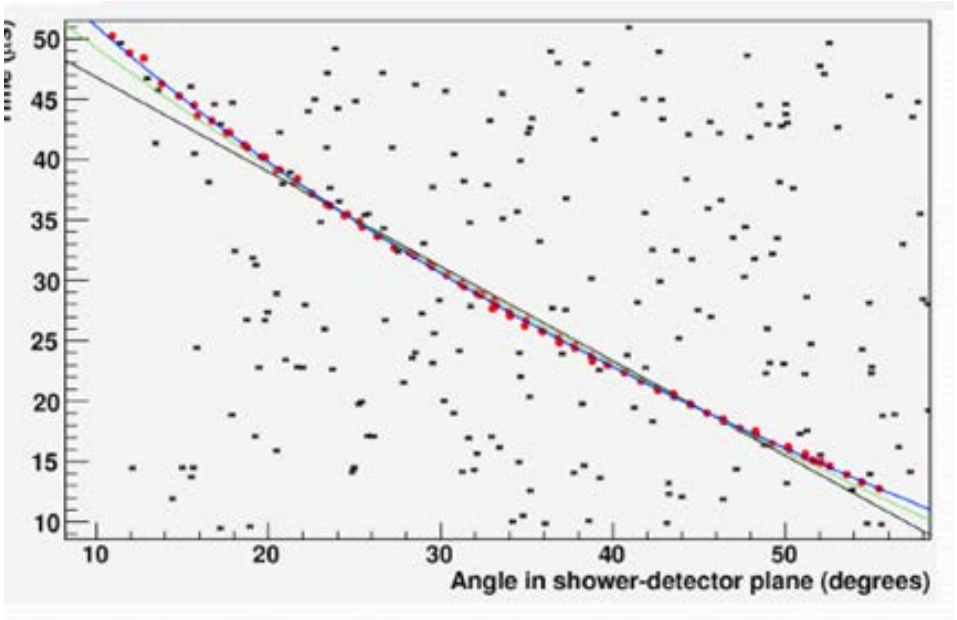


- Detailed Monte Carlo used for exposure calculation in all measurements of TA

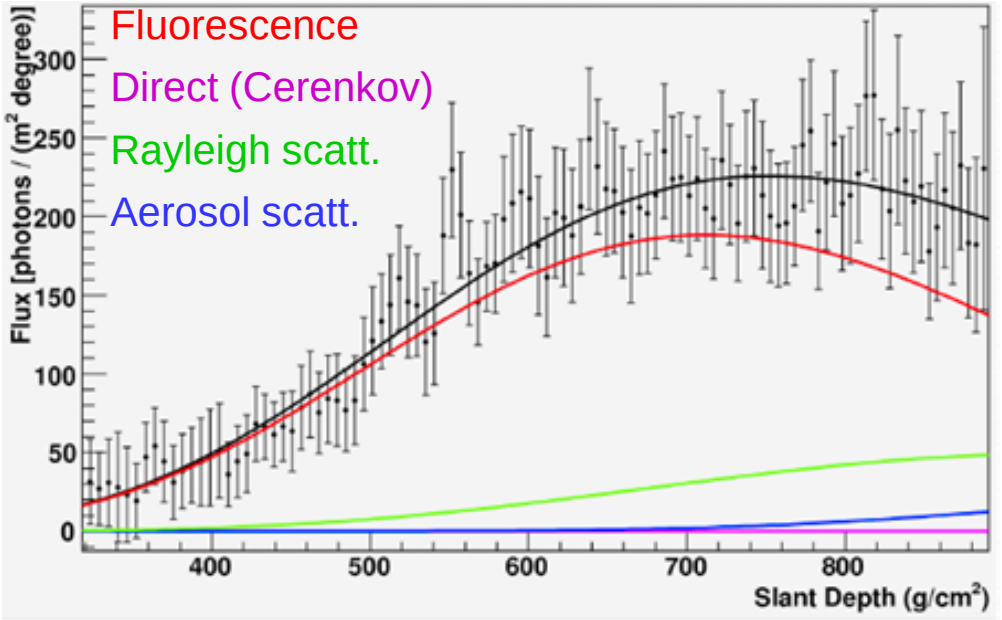
Fluorescence Mono Analysis



Black Rock Mesa



Time fit



Profile fit

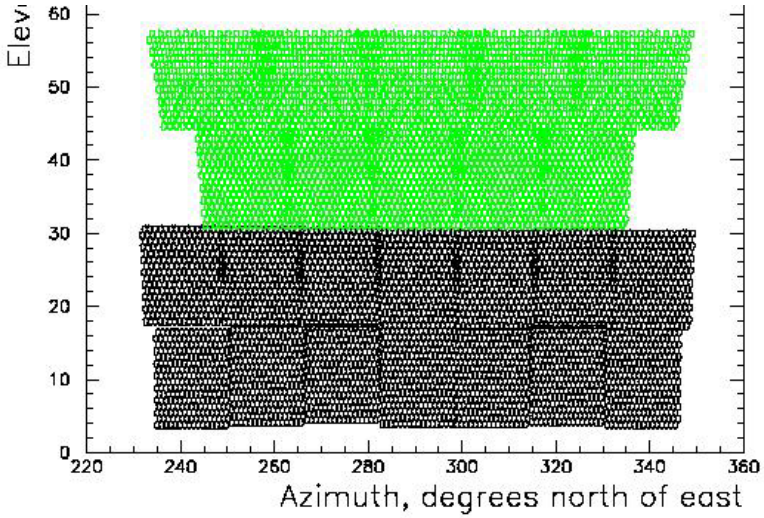
TA Low Energy Extension (TALE)

- Study the 10^{15} ,10^{16} and 10^{17} eV decades with a hybrid detector.
  - End of the rigidity-dependent cutoff that starts with the knee (at 3×10^{15} eV).
  - The second knee,
  - galactic-extragalactic transition
- High energy physics measurements:
  - σ(p-air) and σ(p-p) from LHC energy (10^{17}) to 10^{19} eV.

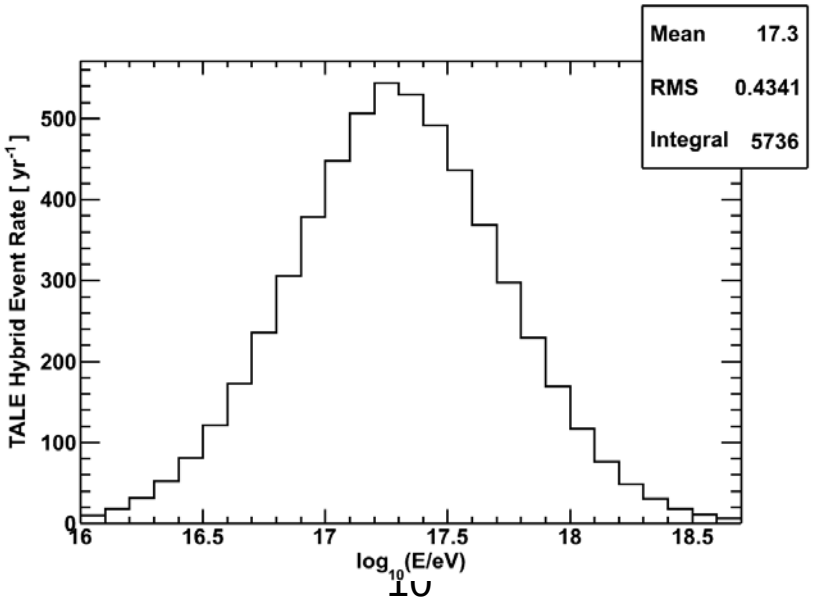
TALE FD

- Additional10 telescopes at the Middle Drum site, looking from 31°-59° in elevation.
- Operate in together with the TA Middle Drum FD.

TALE telescopes



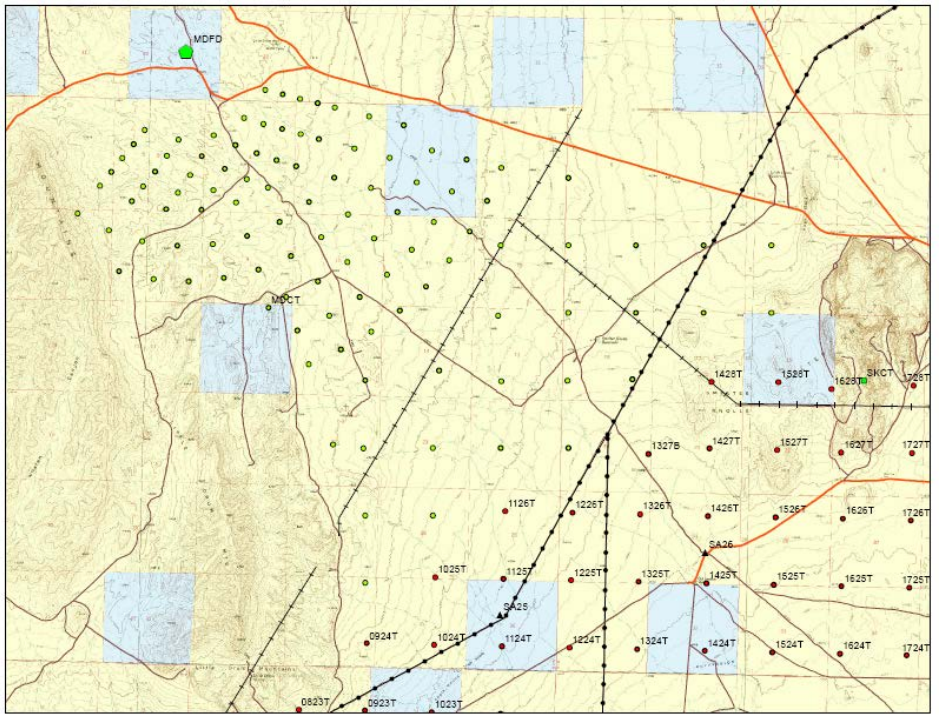
TA MD telescopes

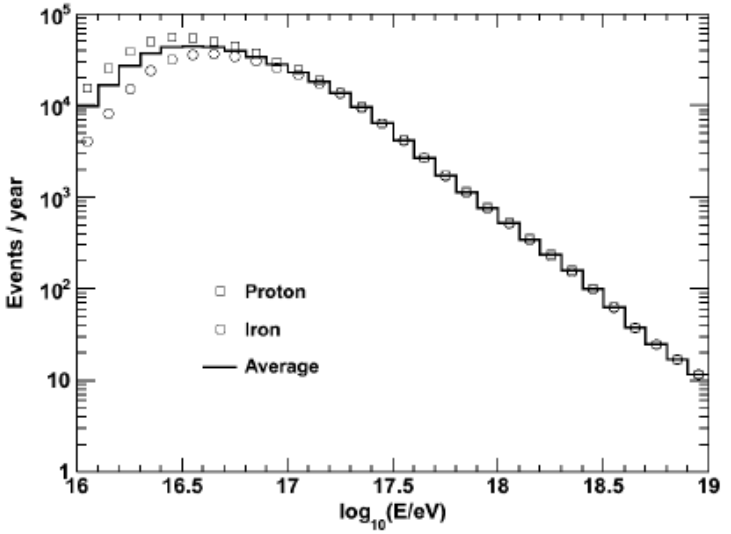


TALE hybrid events per year

TALE Infill Array

- Add infill array (400m and 600m spacing) for hybrid and stand-alone observation.
- 106 counters started taking data

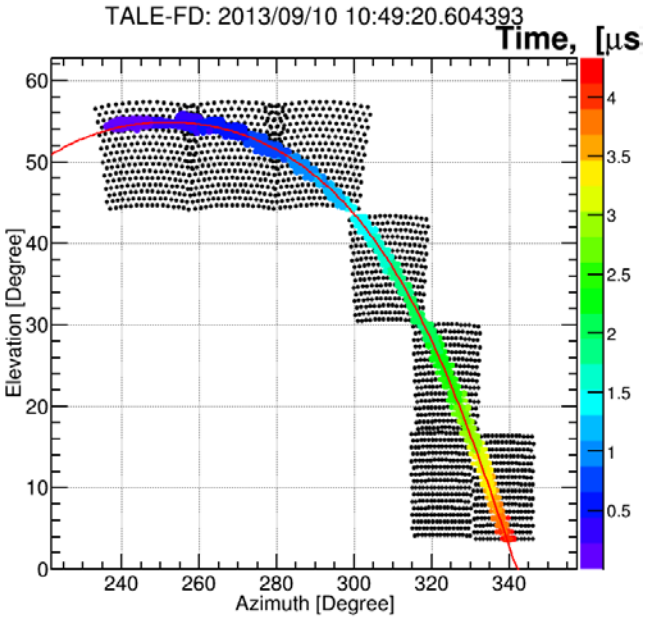


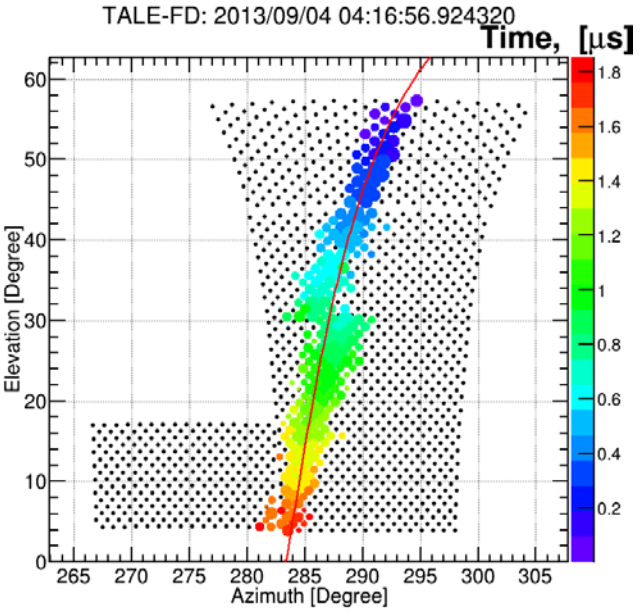


Events per year

TALE Events

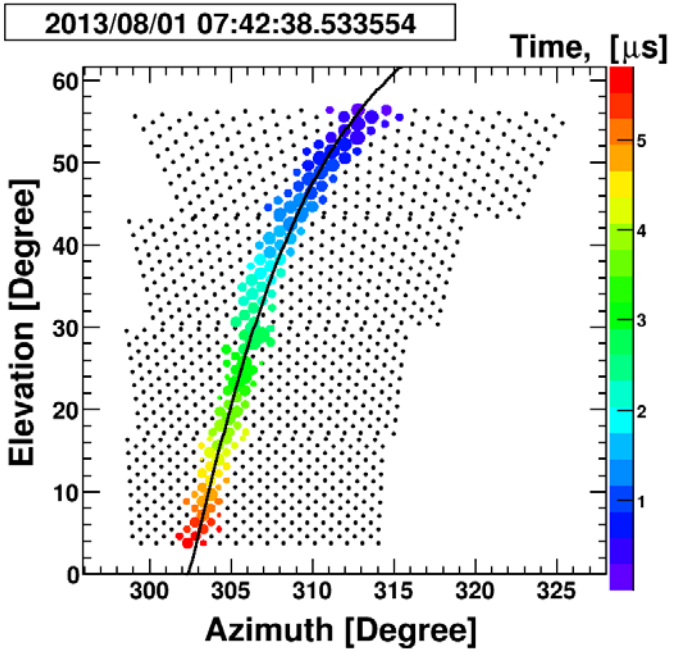
7 mirror event, log(E) = 16.5

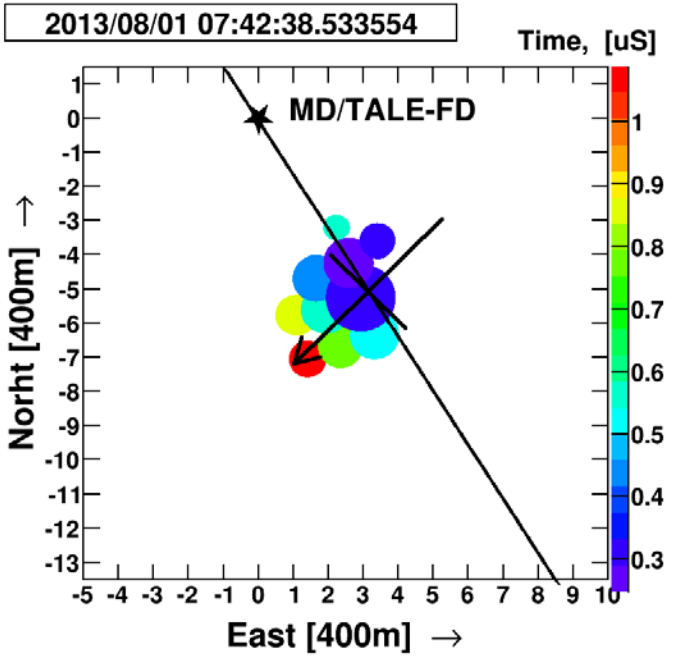




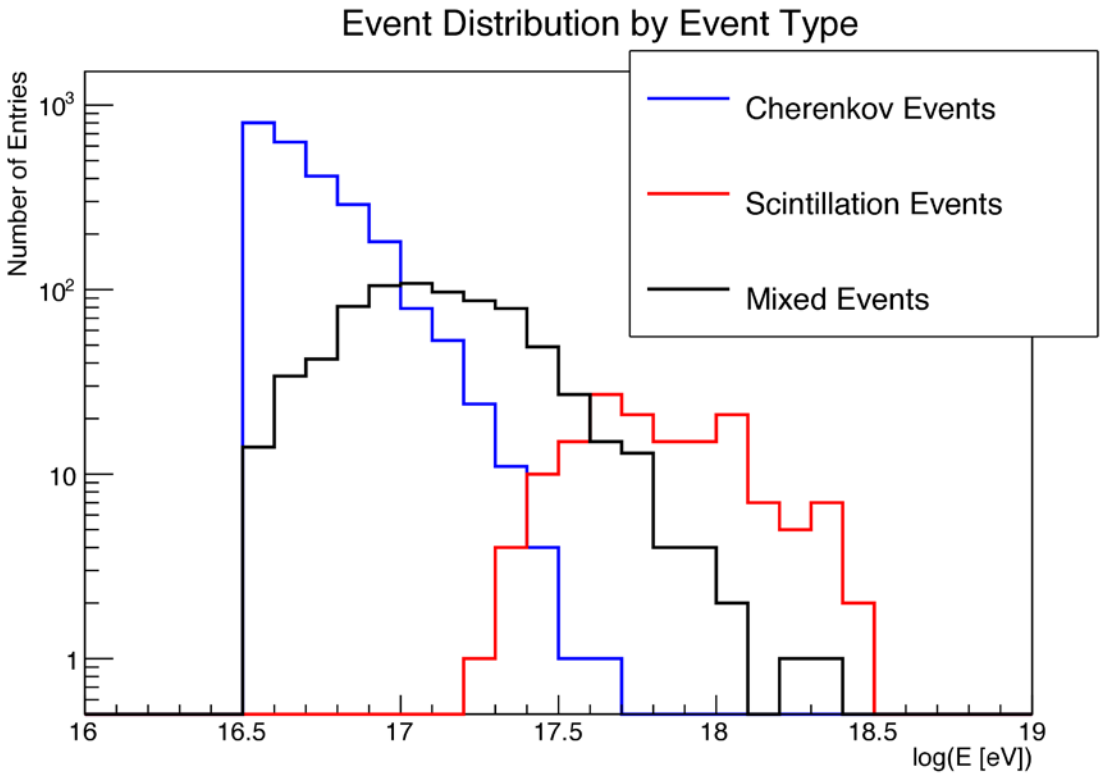
Parallax event, R_p=800m

Hybrid event



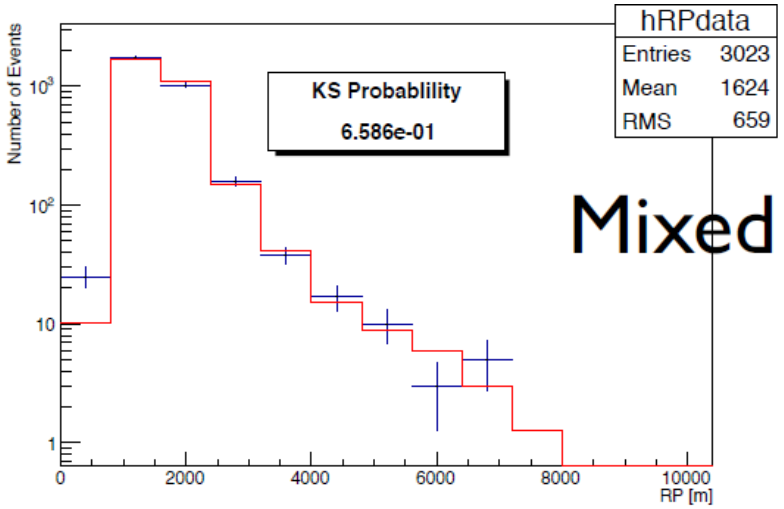


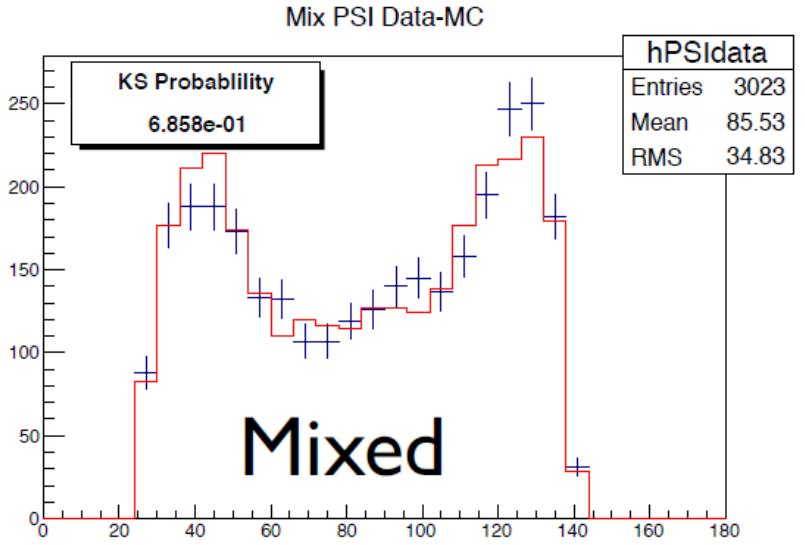
TALE Cherenkov vs. Fluorescence

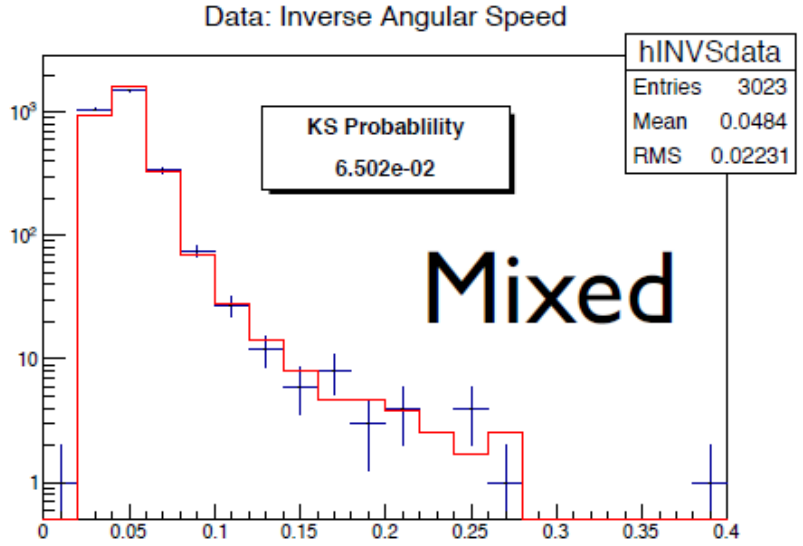


Unexpected result: many Cherenkov events are seen as tracks (most land ~0.5 km from FD).
Use profile constrained reconstruction.
Cherenkov light is bright ➔ can go lower in energy than expected.

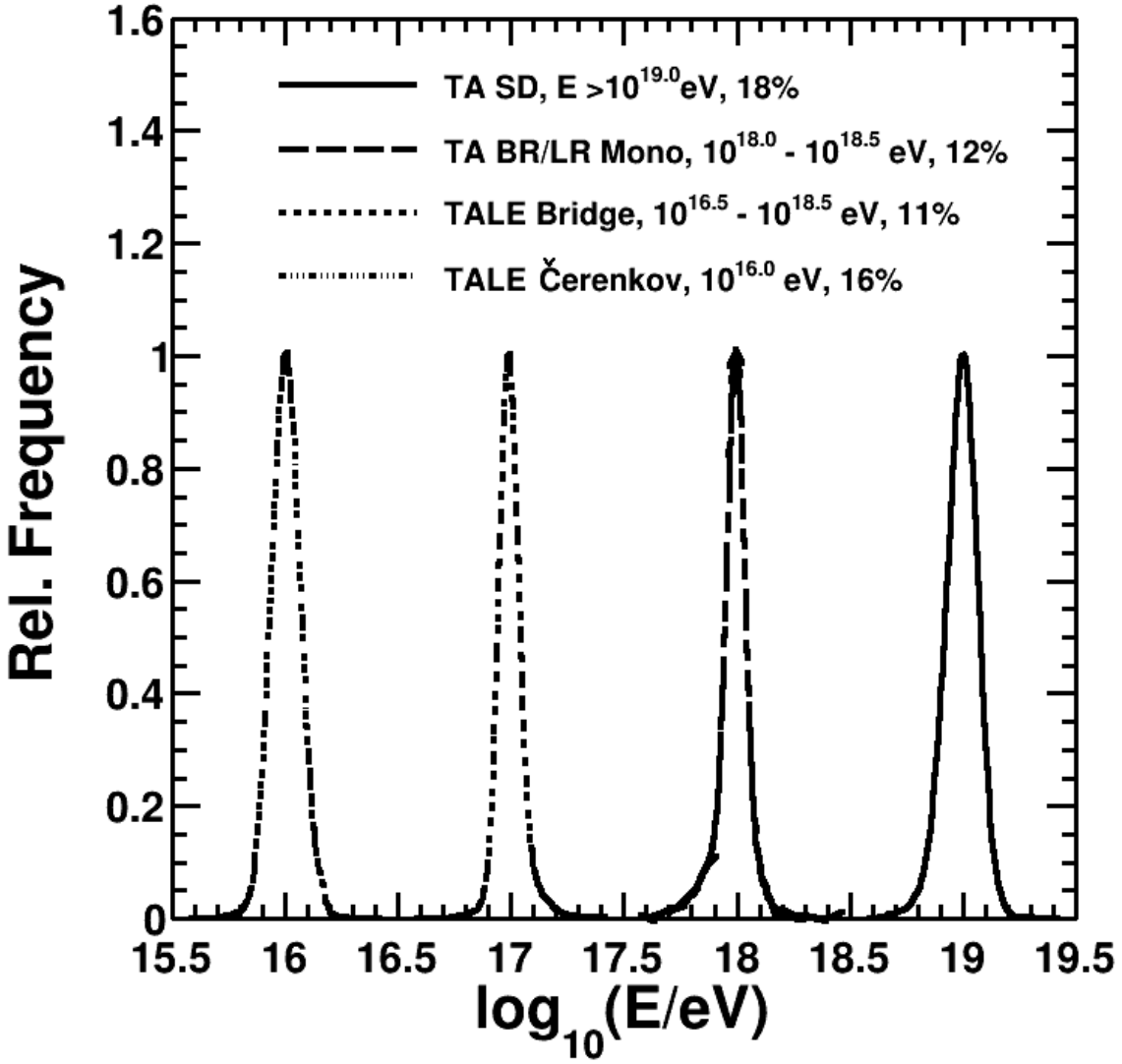
TALE DATA/MC Comparisons



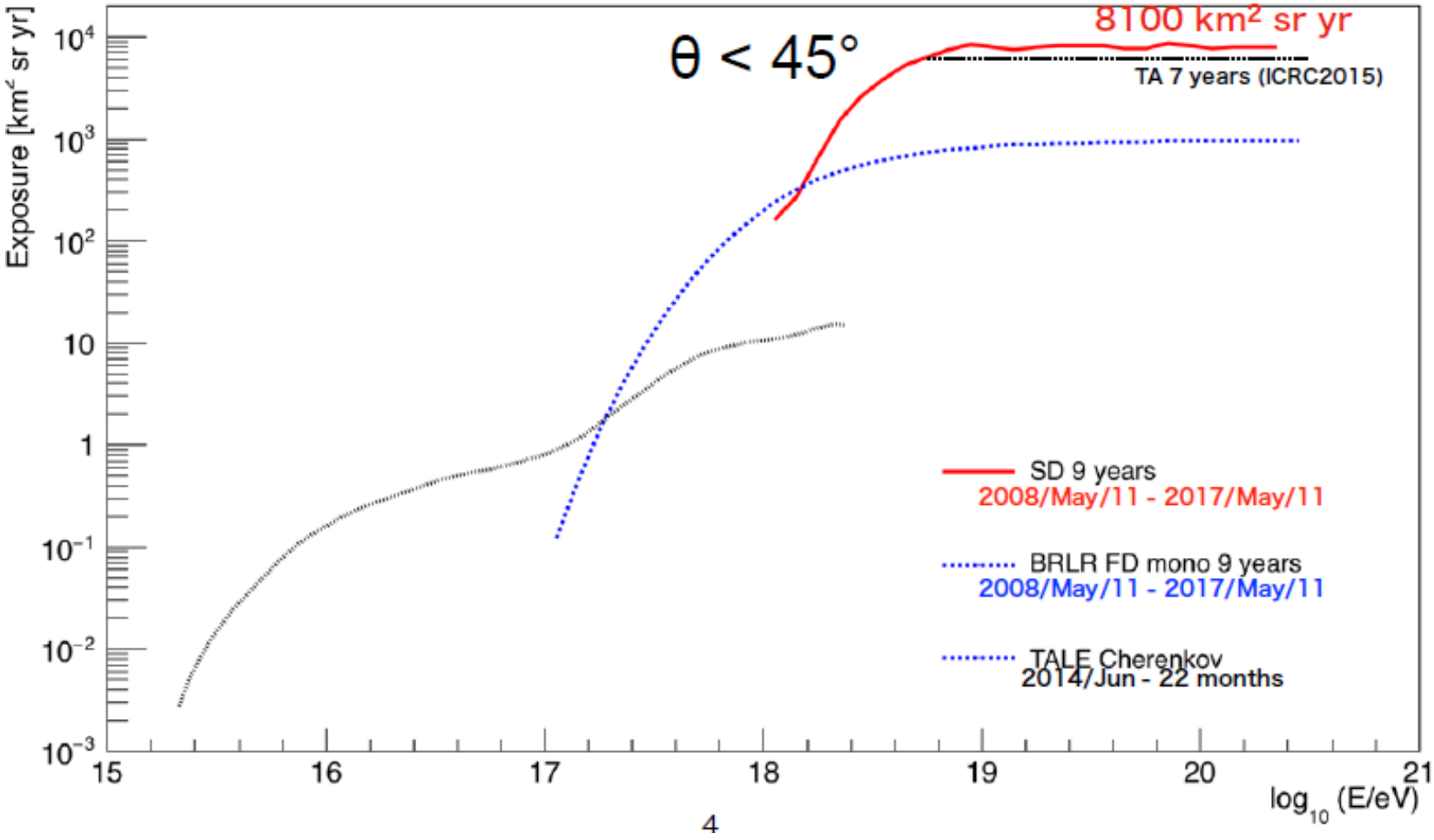




TA Resolution

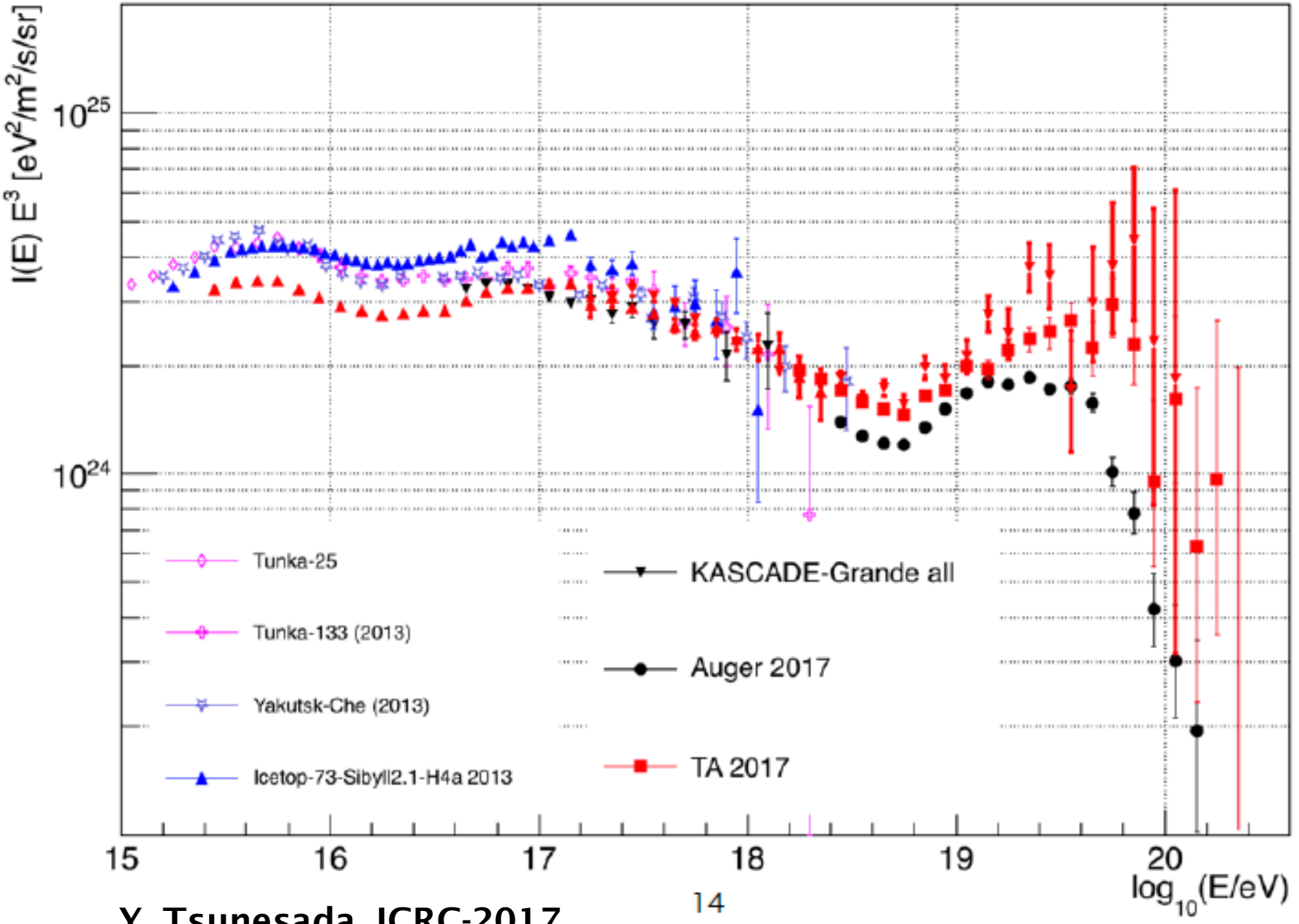


TA Exposure



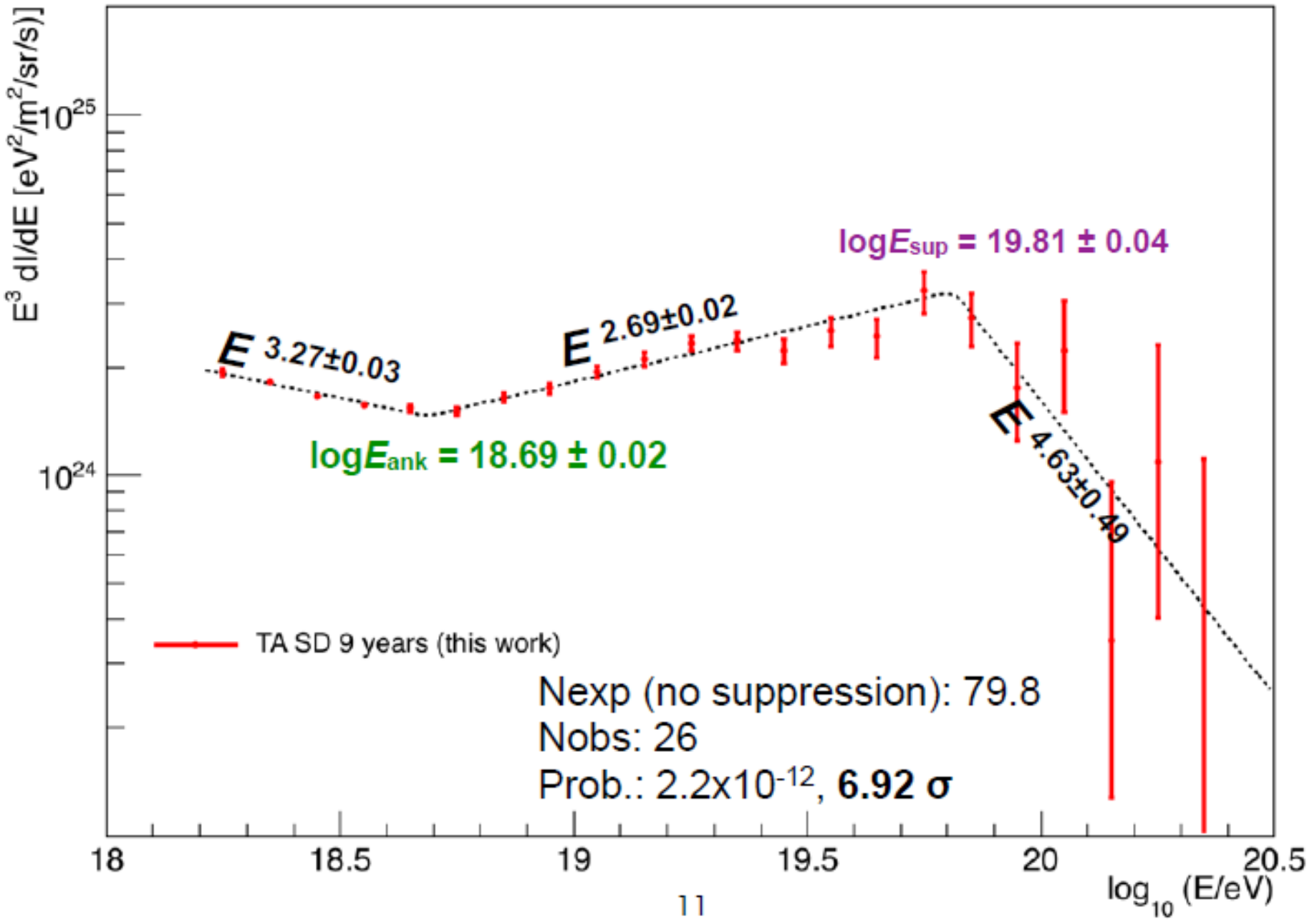
Y. Tsunesada, ICRC-2017

TA Full Range Spectrum



Y. Tsunesada, ICRC-2017

Power-Law Fit



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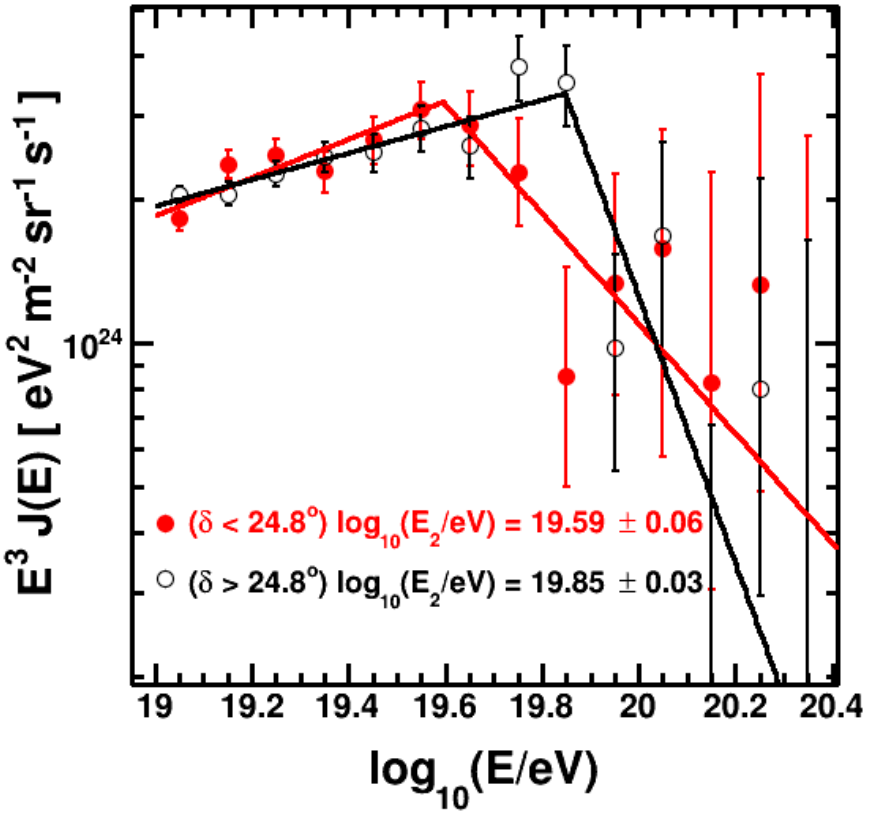
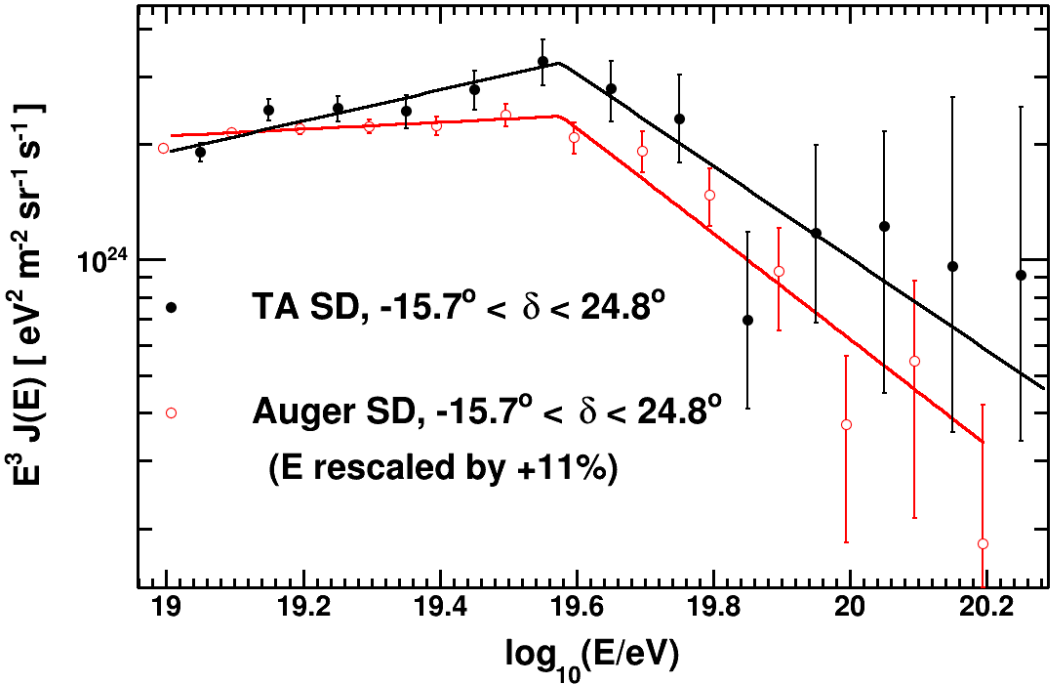
Declination Dependence

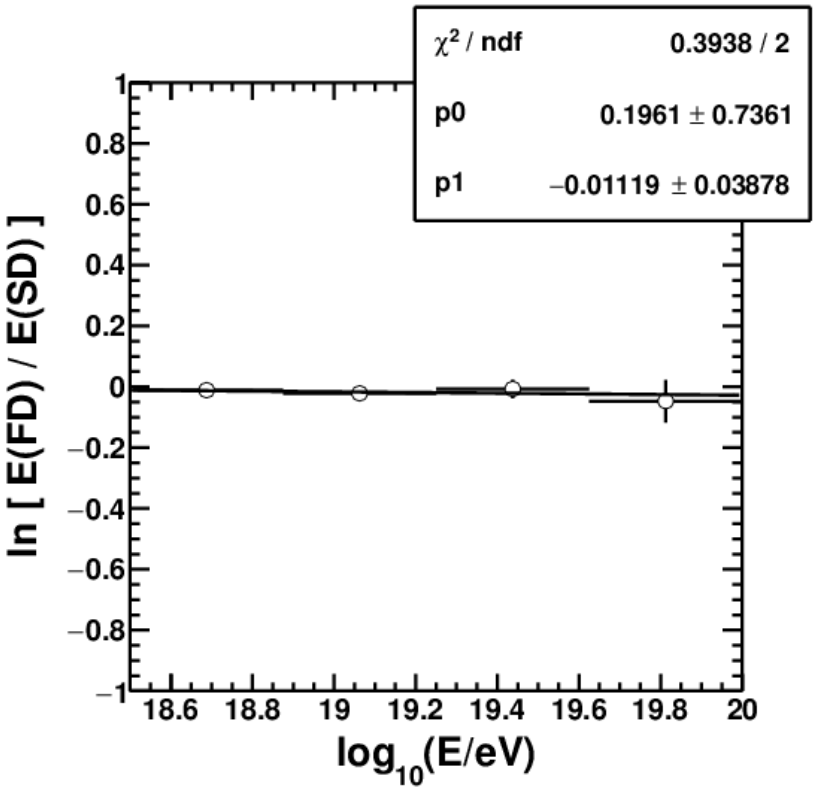
- TA, 24.8° < δ <90°, high energy break at 19.85±0.03
- TA, -15 < δ < 24.8°, 19.59±0.06; **TA difference: 3.9 σ**
- Auger, -15 < δ < 24.8°, 19.58±0.02; **TA-Auger difference: < 0.5 σ**
- **2008/05/11 – 2017/05/11 data used here**

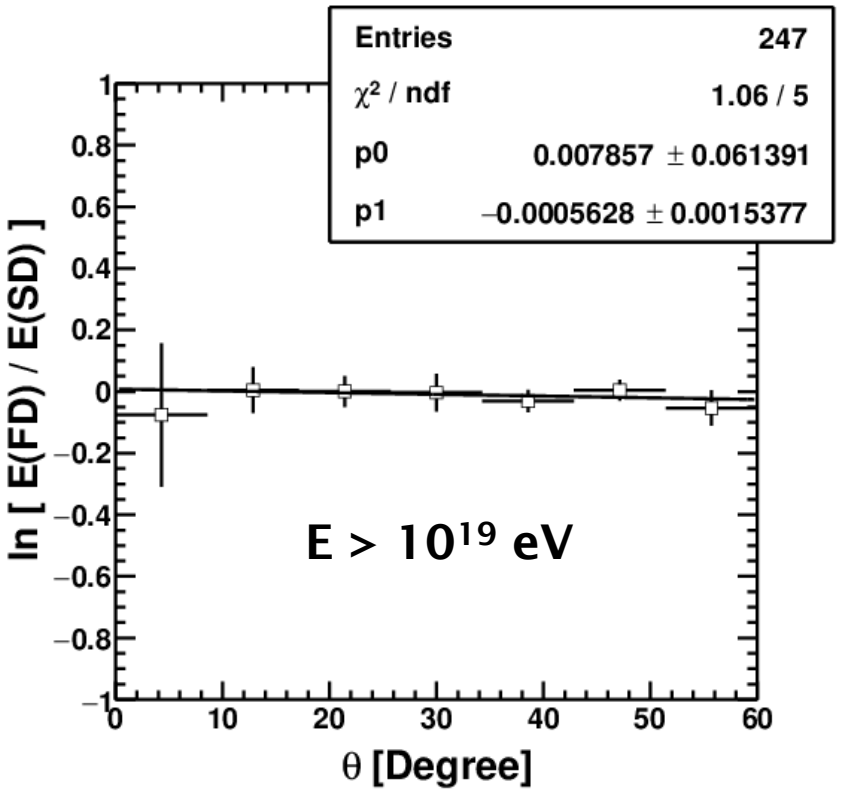




broken power law fit

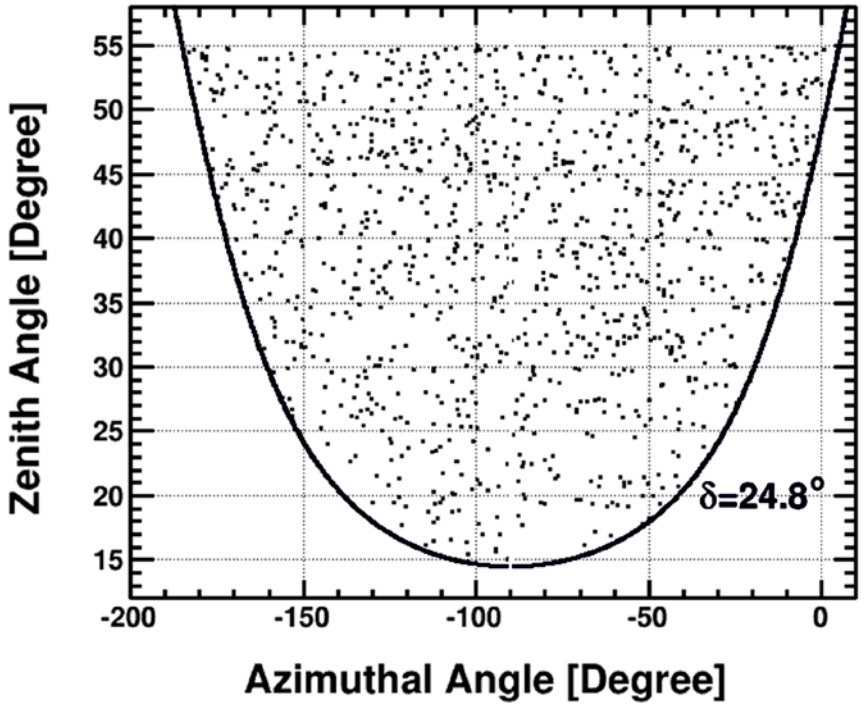
Check of the TA SD Energy Reconstruction Bias Using FD





- TA SD energies compared to TA FD using hybrid events above $10^{18.5}$ eV (left) and $10^{19.0\ eV}$(right)
- ~4%. uncertainty on the slope
- **No significant energy reconstruction bias found**

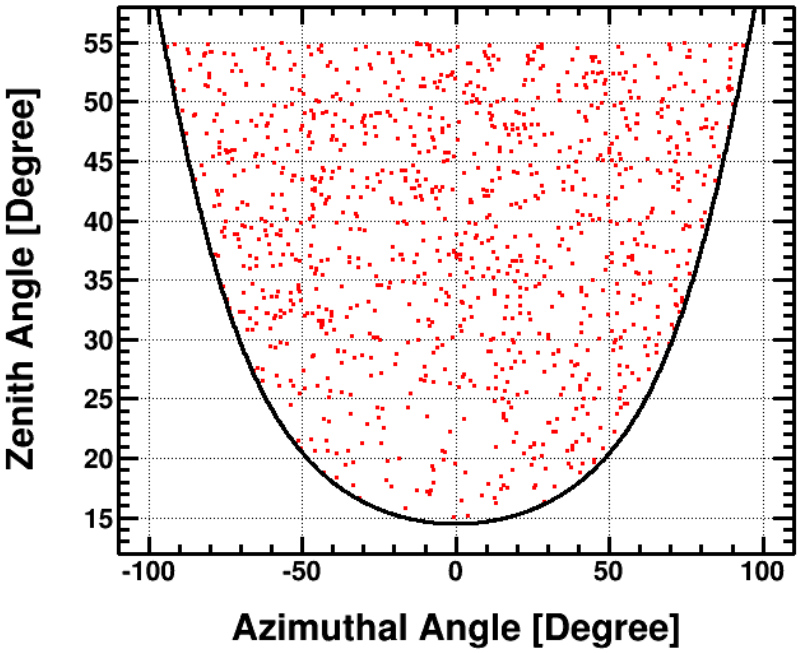
Check by cutting on theta vs phi phase space (1/4)

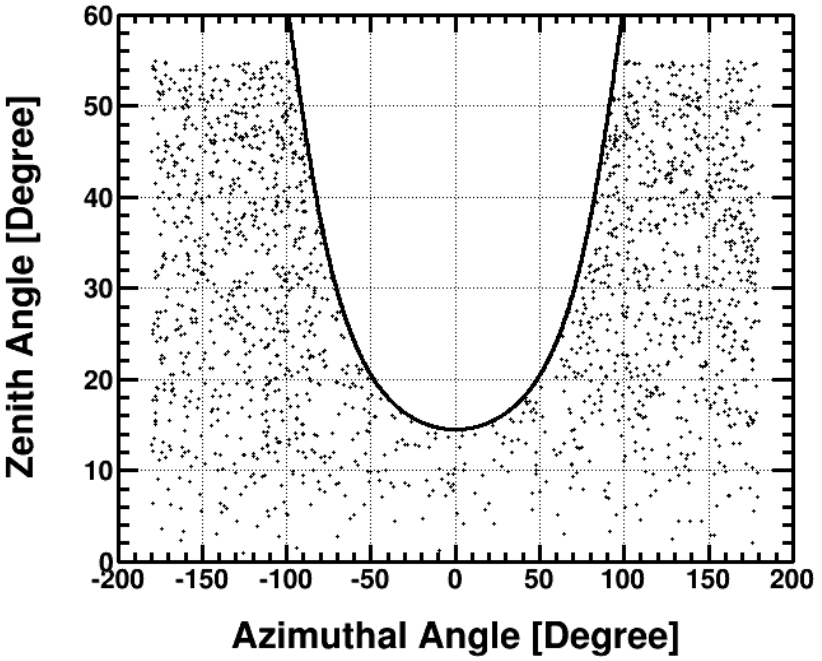


- Cutting on points above and below the contour line is mathematically equivalent to cutting on declination below and above 24.8 degrees, respectively

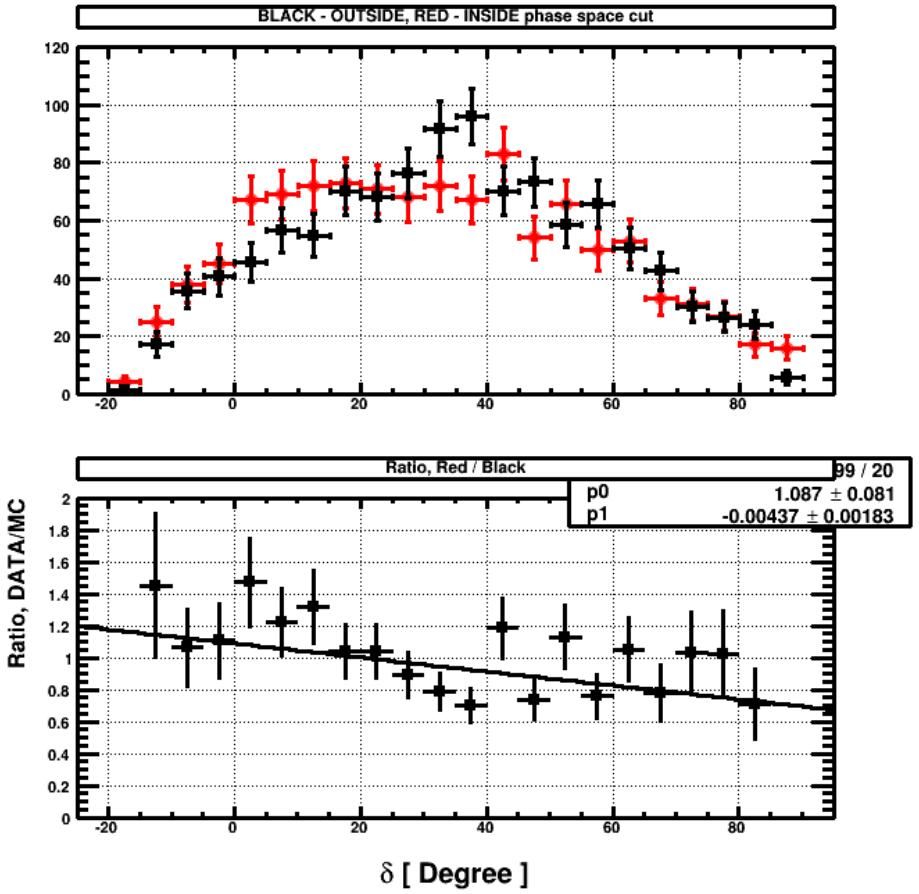
Check by cutting on theta vs phi phase space (2/4)

- Next: artificially move the curve by +90 degrees to the right in phi.
- Cutting on points above and below the blue line will not be the same thing as cutting on declination below and above 24.8 degrees.



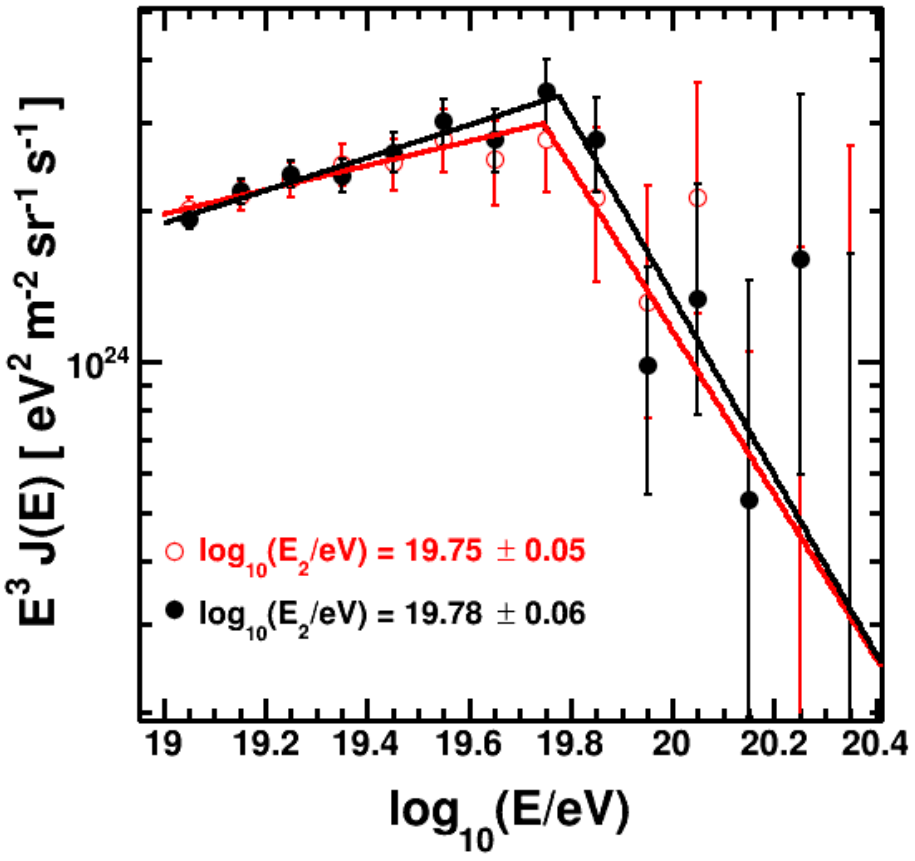


Check by cutting on theta vs phi phase space (3/4)



- Declination histograms of the two sets of events are nearly similar
- If the effect is due to cutting on declination and there is no instrumental effect associated with cutting on theta, phi, the energy spectrum should be the same for the two data sets.

Check by cutting on theta vs phi phase space (4/4)



- Result: spectra made using these data sets are consistent with each other and with the full sky TA SD spectrum: 2nd break point occurs at $10^{19.75}$ eV

Summary

- 5 Features seen in TA spectrum:
  - Knee at $10^{15.5}$ eV
  - Low Energy Ankle at $10^{16.3}$ eV
  - 2^{nd} knee at $10^{17.1}$ eV
  - Ankle at $10^{18.7}$ eV
  - 2^{nd} Break point (aka GZK break) at $10^{19.8}$ eV
- 3.9 σ declination dependence of the second break point
- Better agreement with Auger in the common declination band