

TALE

Physics and Fluorescence Detection of
Cosmic Ray Air Showers with Energies
Between $10^{16.5}$ eV and $10^{18.5}$ eV

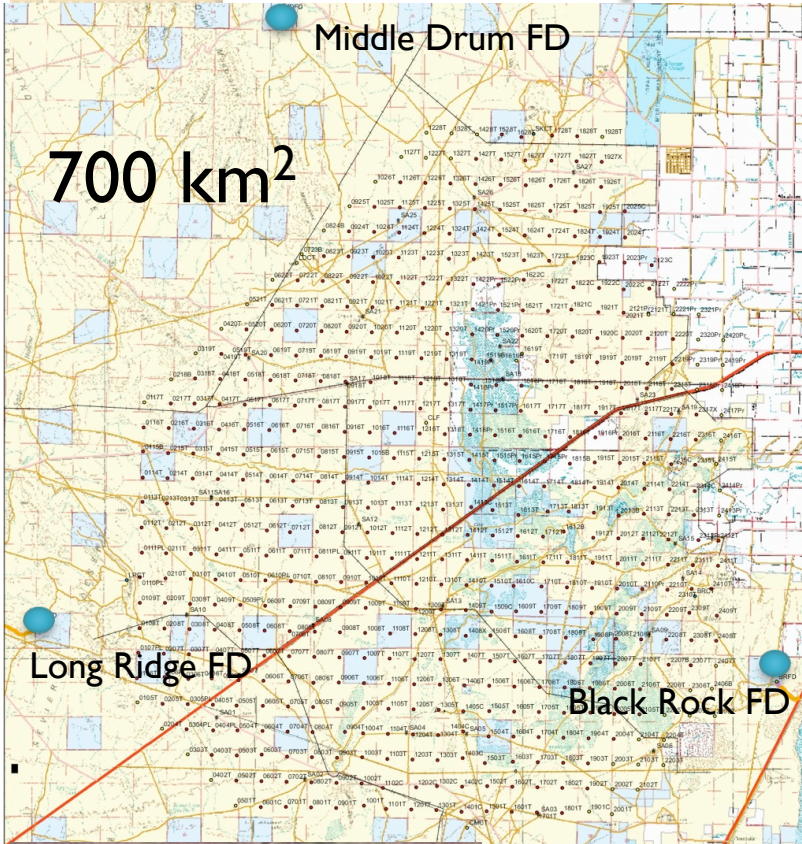
Zachary Zundel

University of Utah

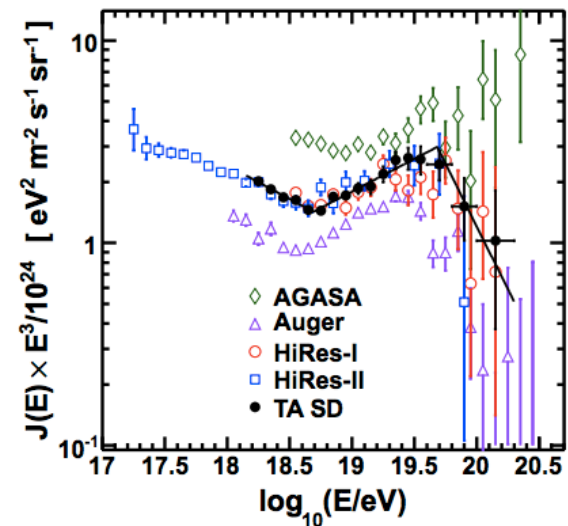
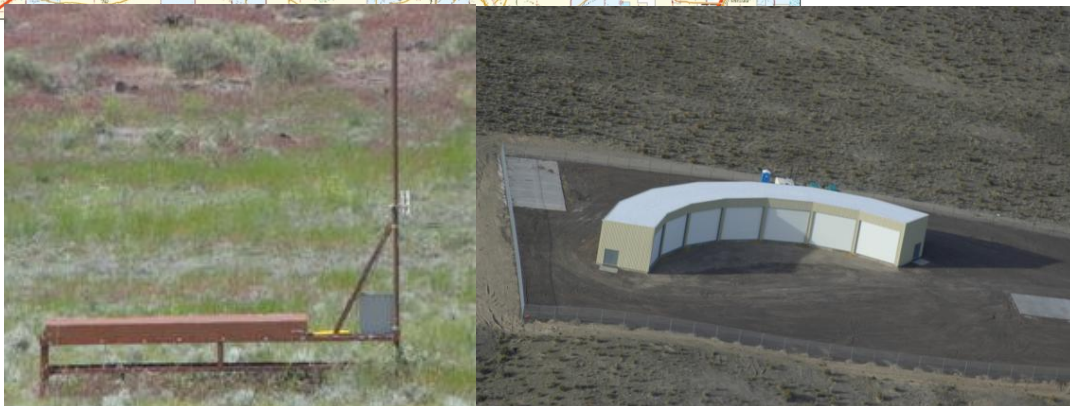
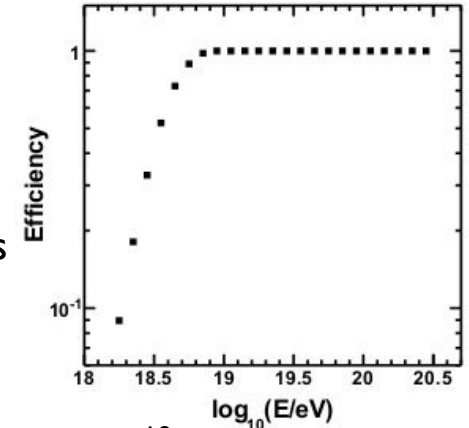
for

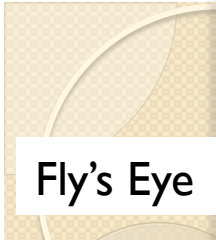
The Telescope Array Collaboration

Telescope Array Experiment

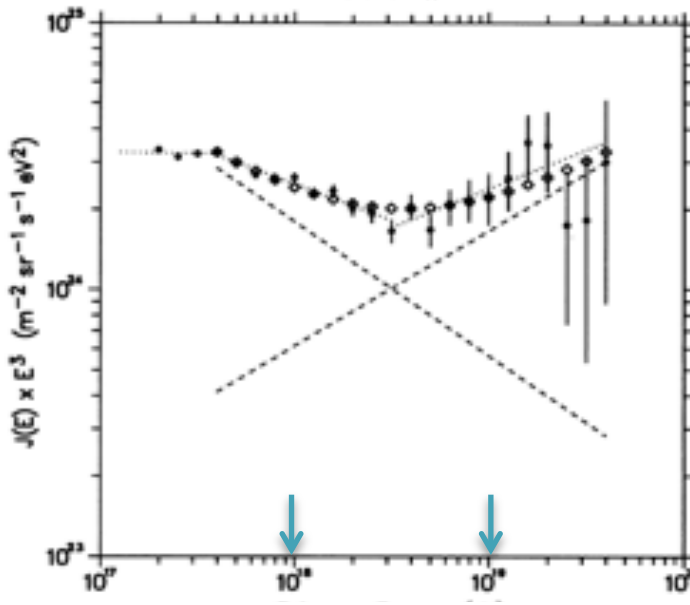
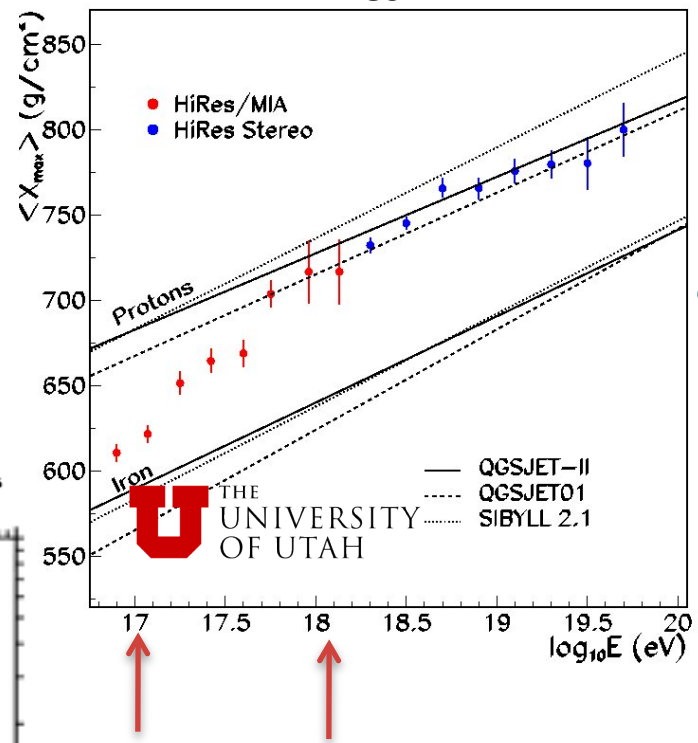
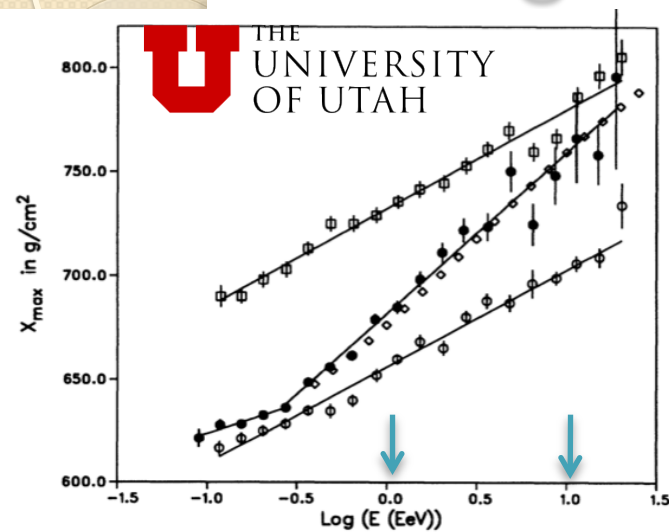


- Array of 507 Plastic Scintillator Counters
 - 1.2 km spacing
 - Fully efficient above 10¹⁹ eV
- 3 Fluorescence Detector Stations
 - 12 or 14 cameras per station
 - View 3°-31° in elevation
- Designed for detecting showers above 10¹⁸ eV
 - Many Interesting features not in this energy Range



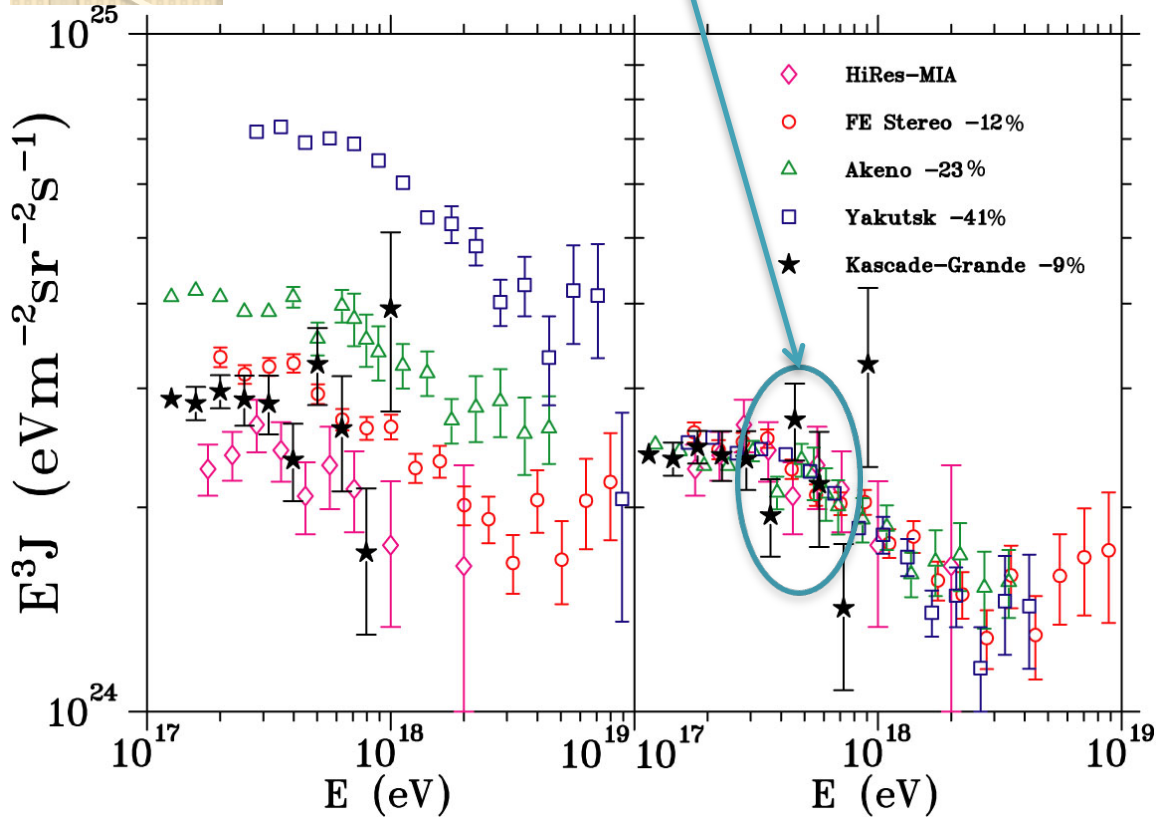


Cosmic Ray Galactic to Extragalactic Transition



- Fly's Eye 1986-1992
 - Change in composition at $10^{18.5}$ eV
 - Spectrum two component fits consistent with transition at $10^{18.5}$ eV
- High Resolution Fly's Eye (HiRes) 1994-2006
 - Better Control of Systematics
 - Better X_{max} resolution
 - $35g/cm^2$ vs $55g/cm^2$
 - Change in composition measured at $10^{17.5}$
 - Lower end of HiRes sensitivity
 - Higher end of MIA sensitivity

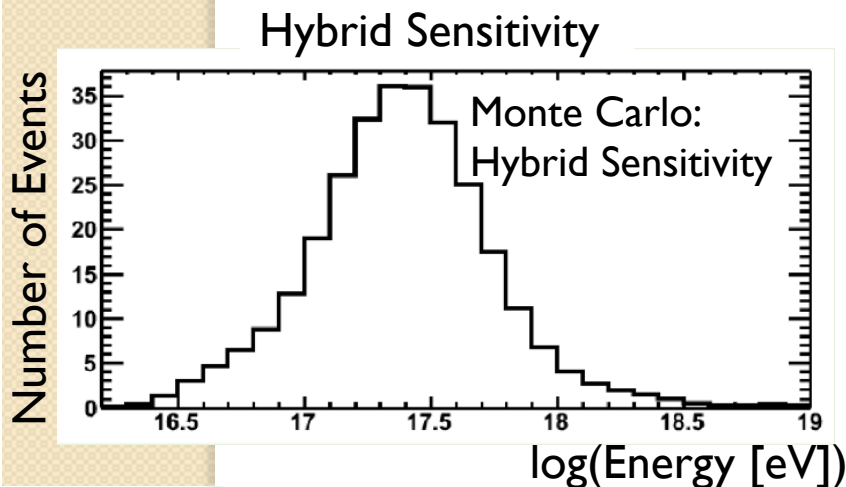
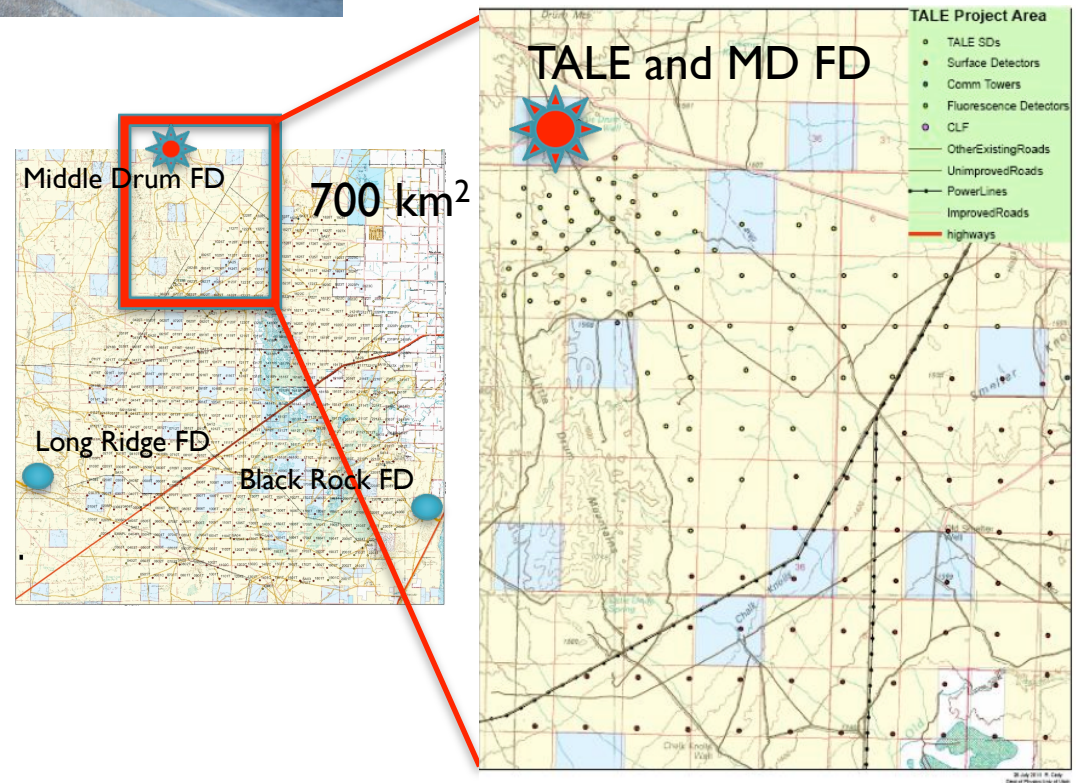
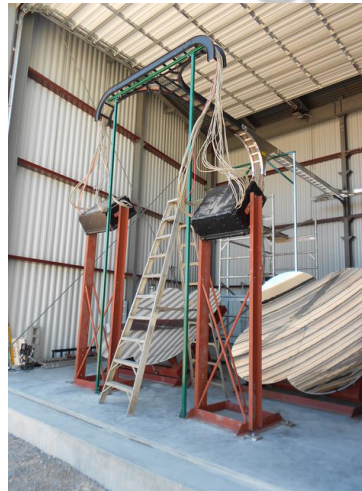
Second Knee



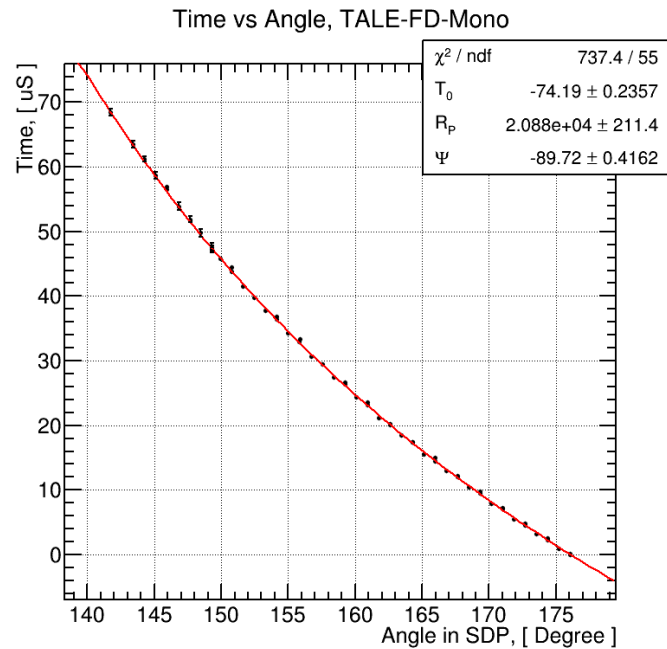
- Measured by many experiments
 - Different Energy Scales
- Consistent with location of HiRes composition change
 - Need simultaneous spectrum and composition measurement
- At same energy as observed composition change by HiRes

Telescope Array Low Energy Extension (TALE)

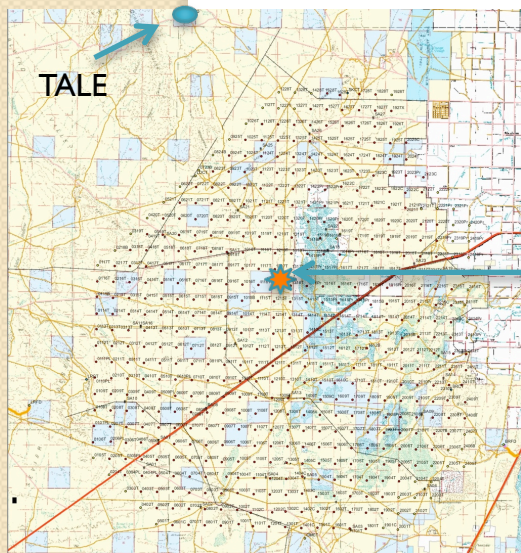
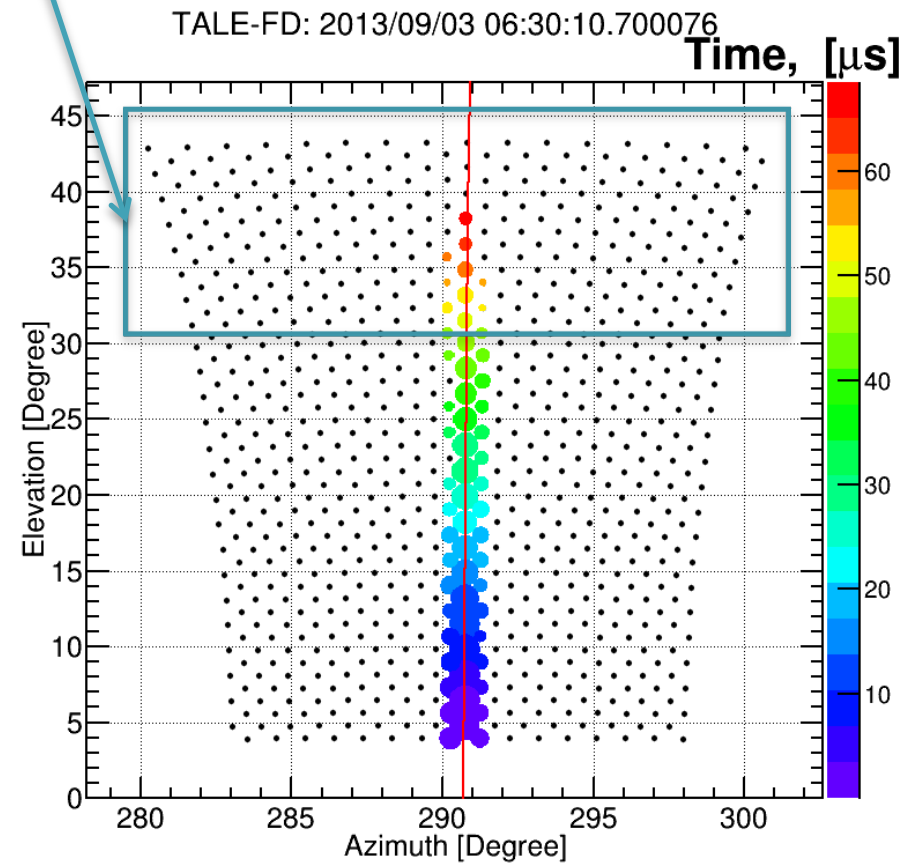
- Designed for the region of the Second Knee
- Overlaps in energy range of the current detector
- Surface Detectors
 - Graded Infill Array
 - 0.4km, 0.6km and 1.2km spacing
- Fluorescence Detectors
 - 10 Refurbished HiRes 2 Telescopes
 - Covering 31-59 degrees
 - Higher than existing telescopes
- Sensitive from $10^{16.5}$ to $10^{18.5}$



Observation of Central Laser Facility (CLF)

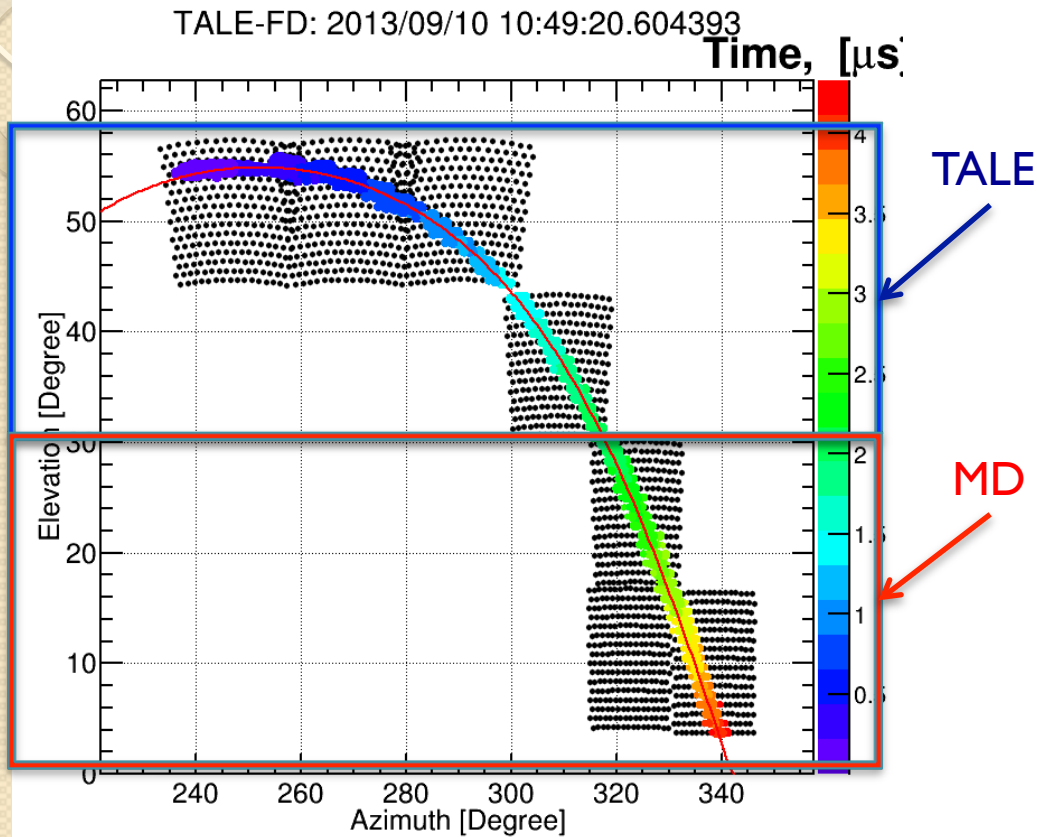


CLF Observable in Ring 3: Mirror 19

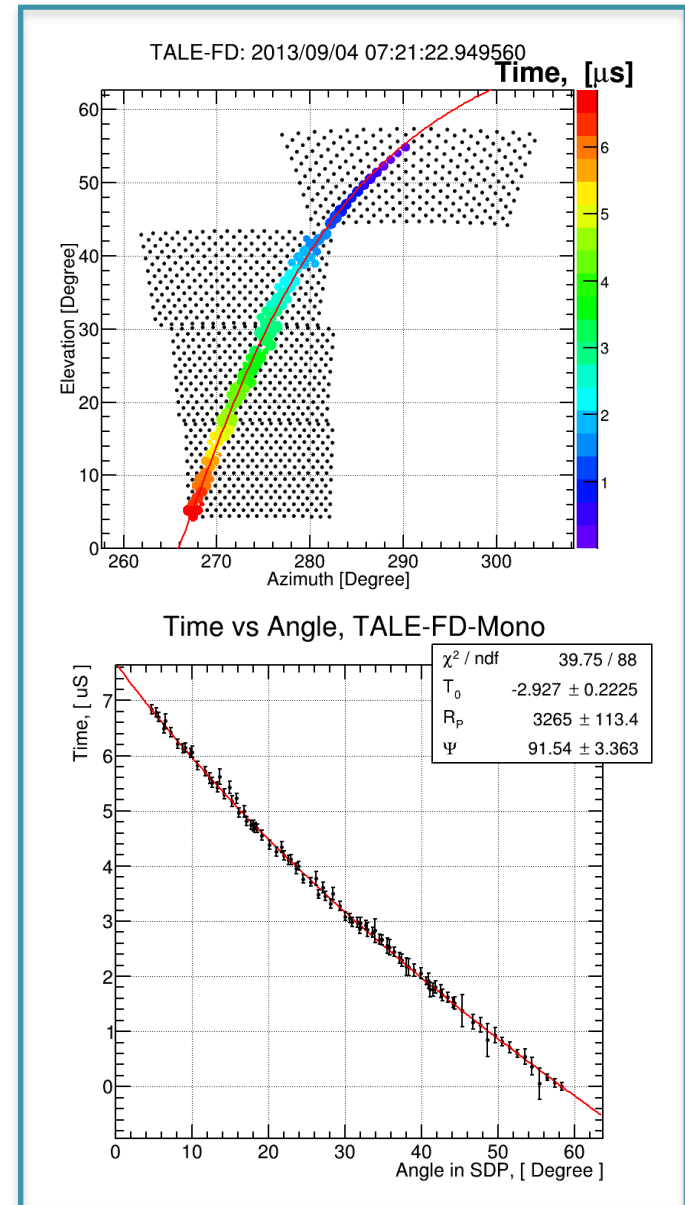


The CLF is used to monitor the atmosphere during observation nights

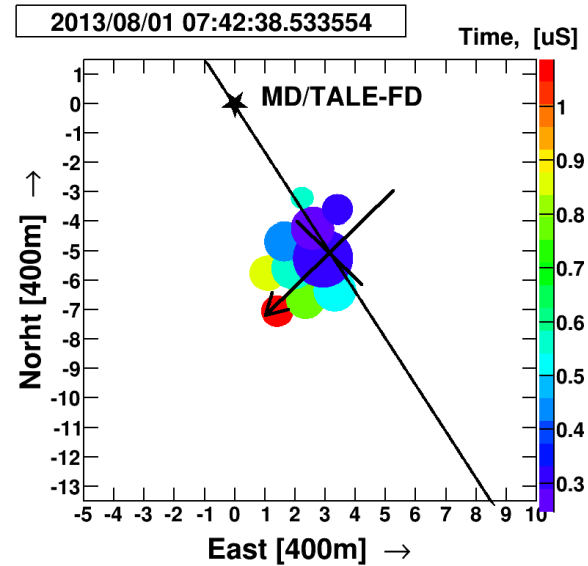
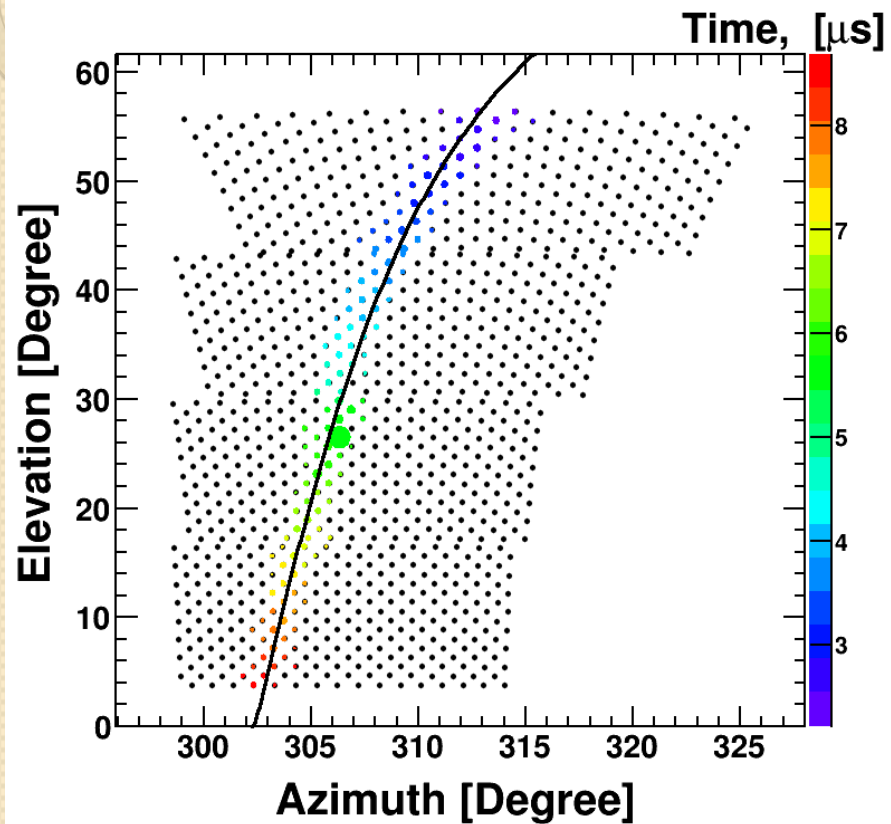
Coincident Air Shower Events: Middle Drum



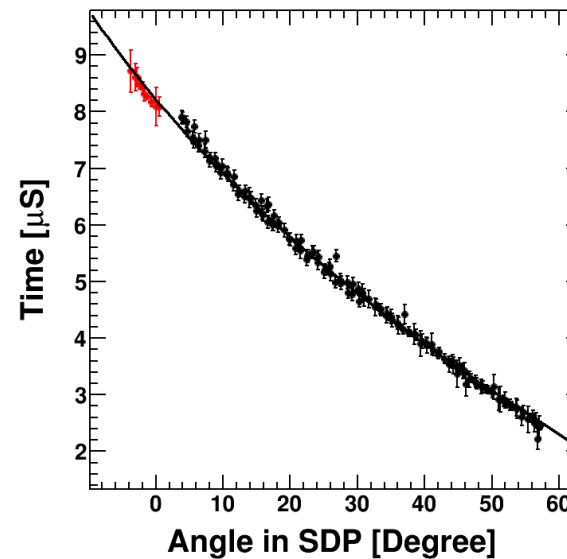
Same Light Source (Roving Xenon Flasher)
Used to Calibrate Both TALE and MD



Coincident Air Shower Event: Surface Array

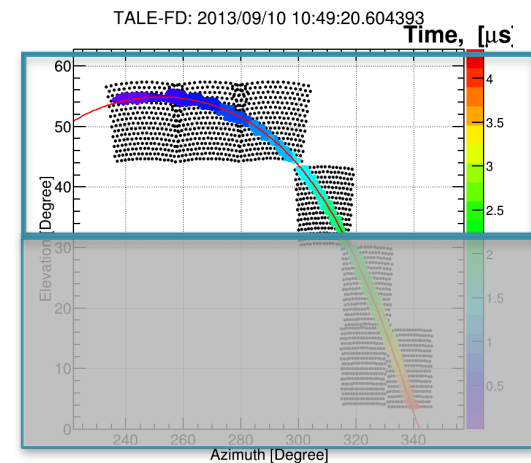


Time vs Angle TALE-Hybrid



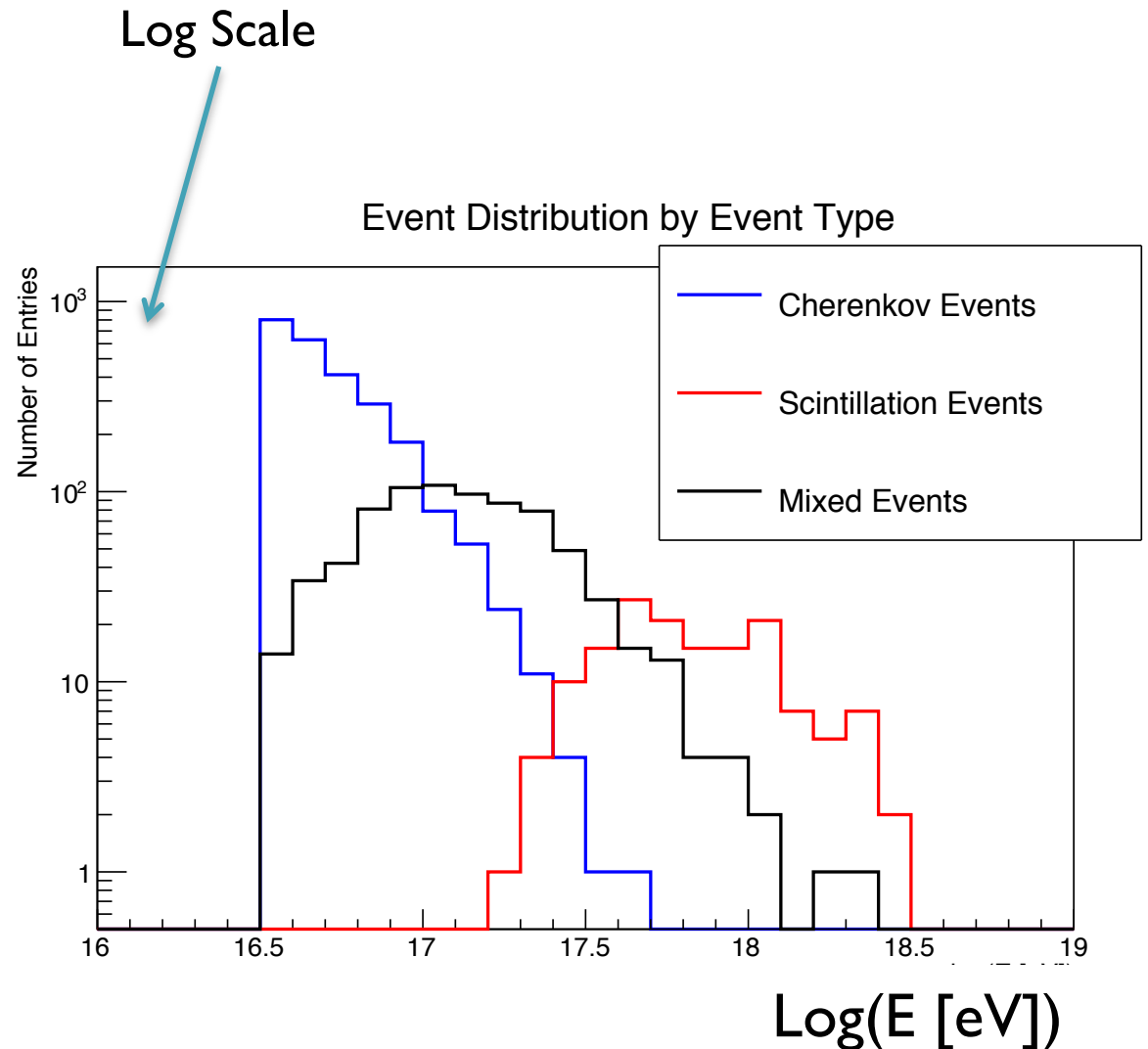
Preliminary TALE Only Spectrum Motivation

- Calculating the Energy Spectrum using TALE Mono events (ring 3 and ring 4 only) is an end to end check of:
 1. Detector Operation
 2. The Analysis Toolchain
- Data Set
 - Sept 2013-Dec 2013
 - 140 hours Data subset used (Good Weather Only)
 - Minimal Quality Cuts. Events with dominant Scintillation, Cherenkov, mixed light contributions all used.
- Simultaneous spectrum and composition measurements will be made with hybrid data set



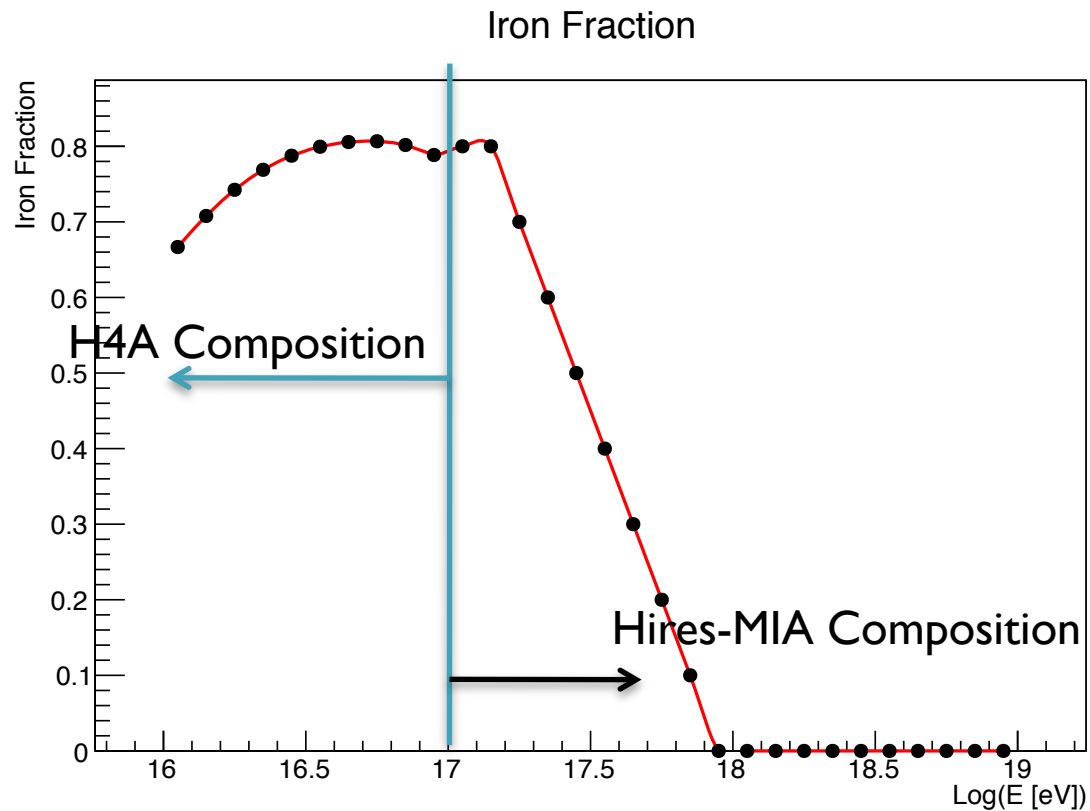
Event Types

- Cherenkov Events:
 - Cherenkov Fraction of light $>80\%$
- Scintillation Events:
 - Scintillation Fraction of light $>80\%$
- Mixed Events:
 - $20\% < \text{Cherenkov Fraction} < 80\%$

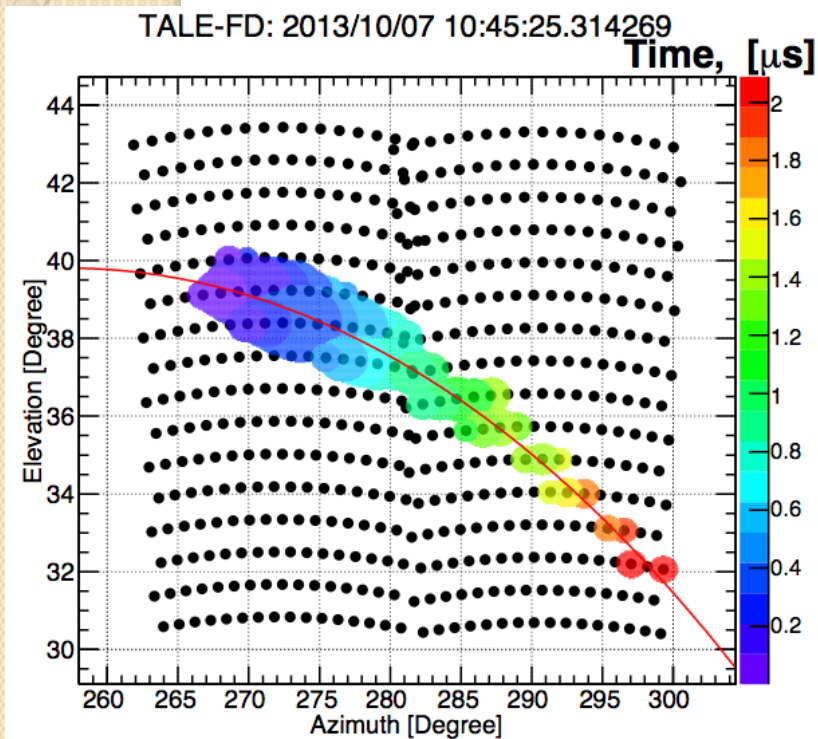


Assumed Composition

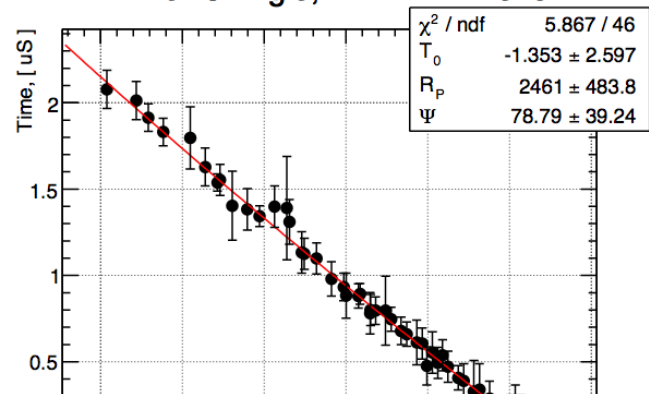
- Missing energy correction is composition dependent
- Aperture is composition dependent



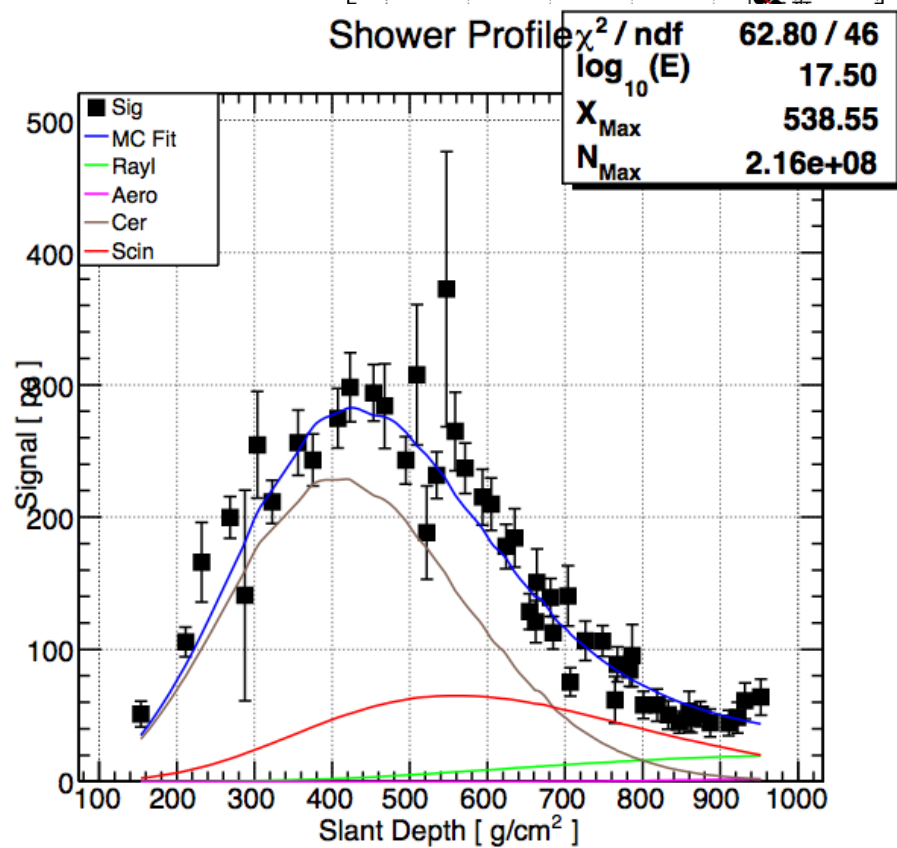
TALE Cherenkov Dominant Event



Time vs Angle, TALE-FD-Mono



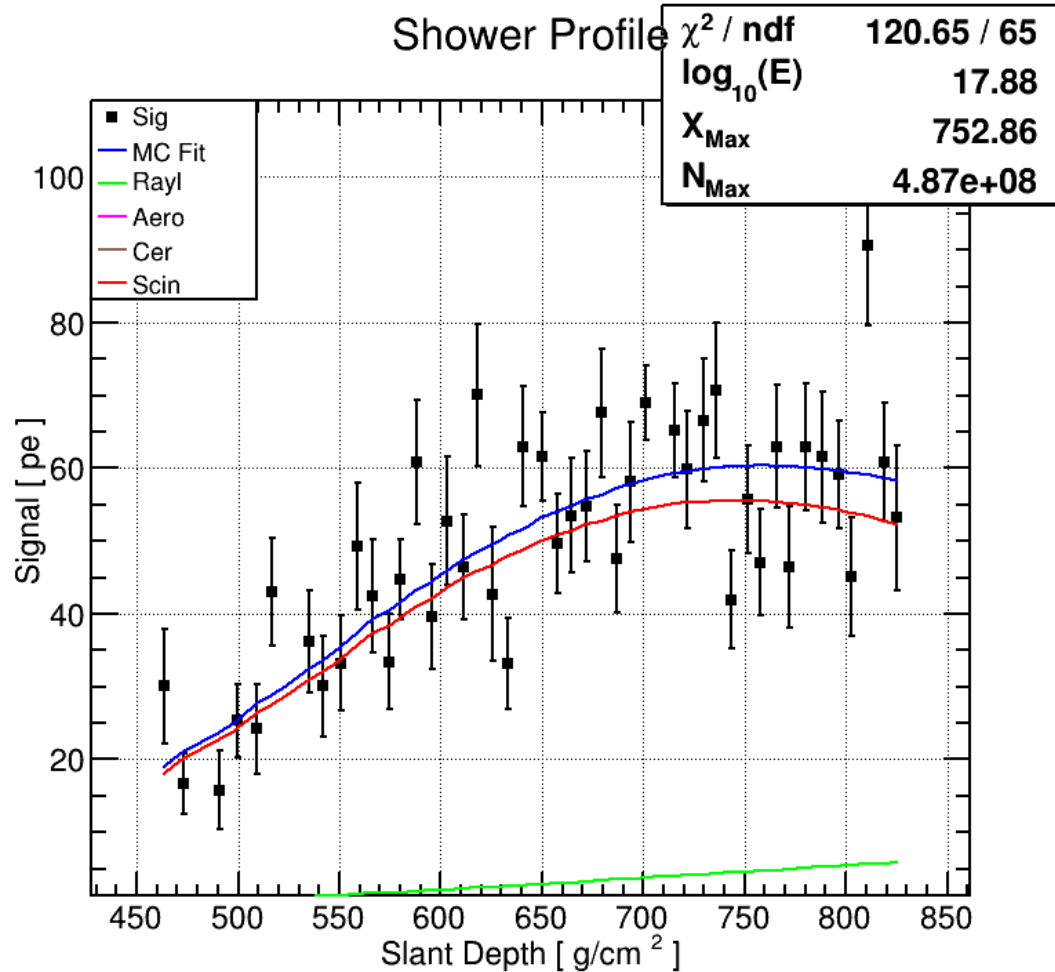
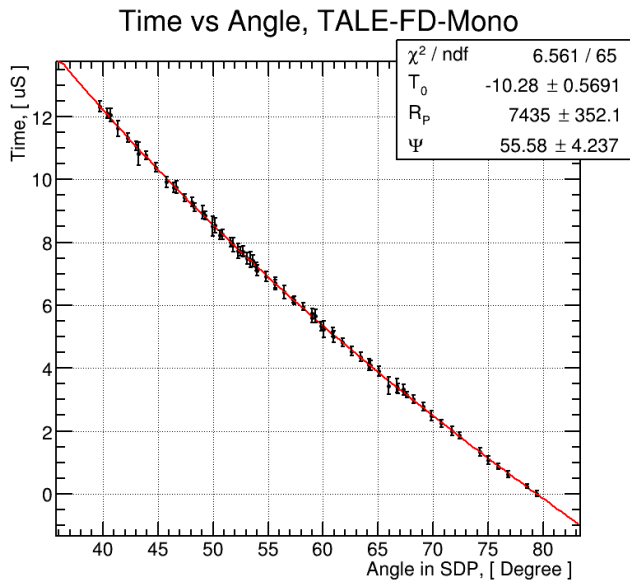
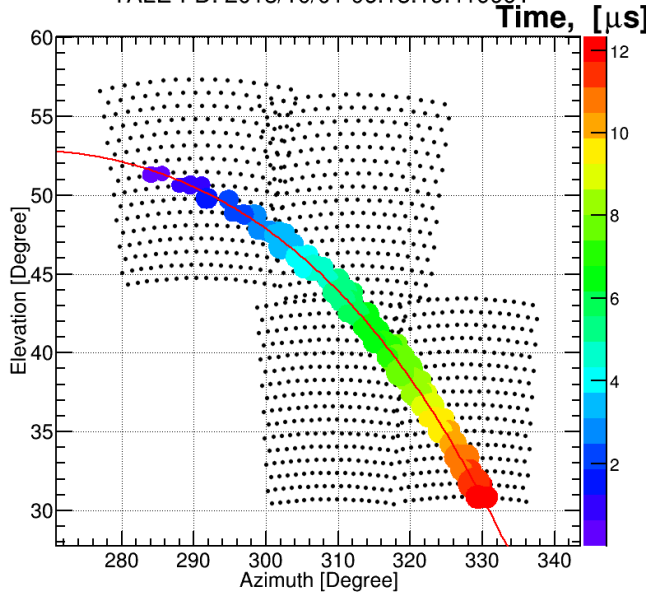
Shower Profile





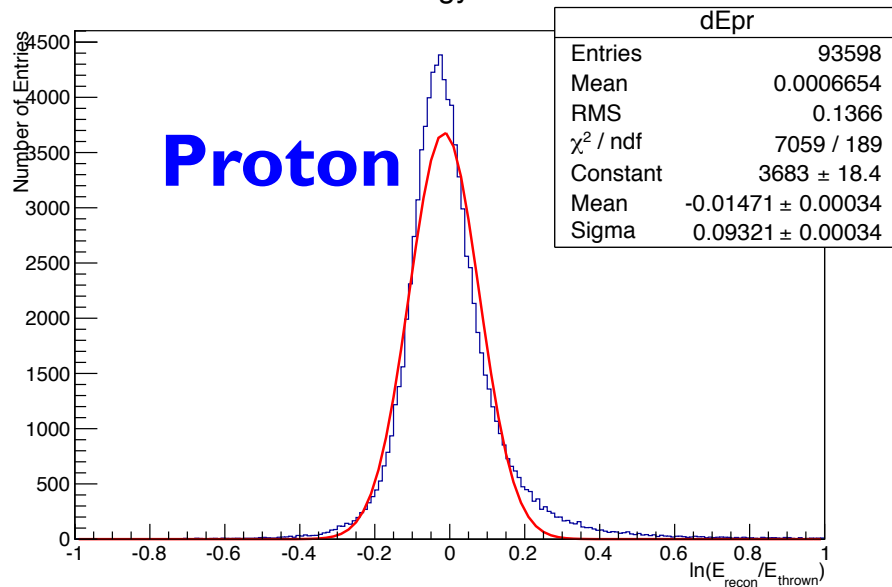
TALE Scintillation Dominant Event

TALE-FD: 2013/10/01 06:18:19.419991

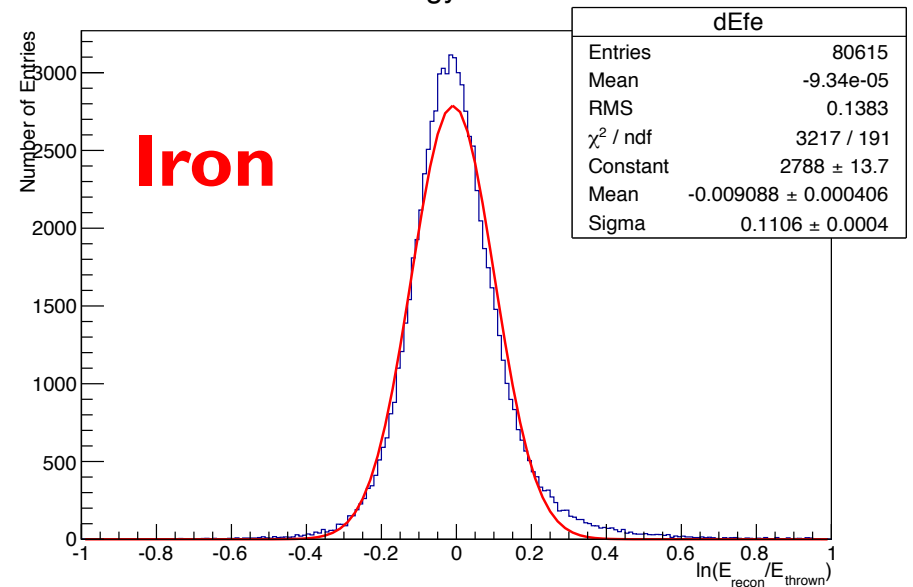


Energy Resolution

Proton Energy Resolution



Iron Energy Resolution



~ 10% Energy Resolution for Both Proton and Iron MC

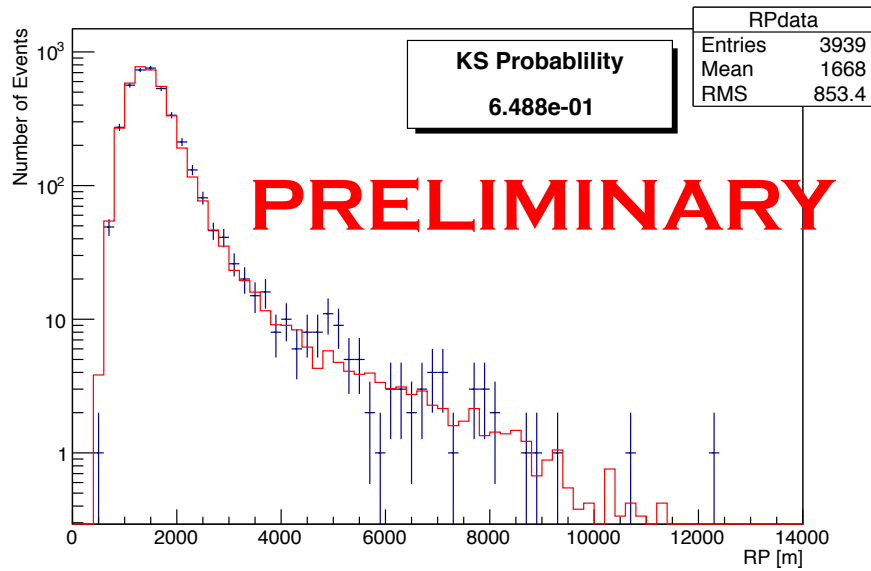


Data Monte Carlo Comparisons

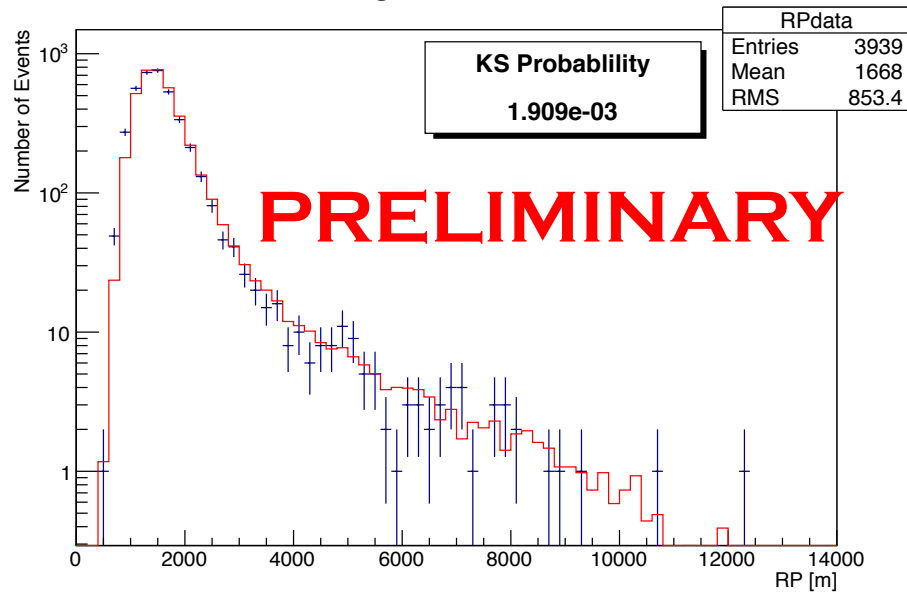


RP Data-MC Comparison

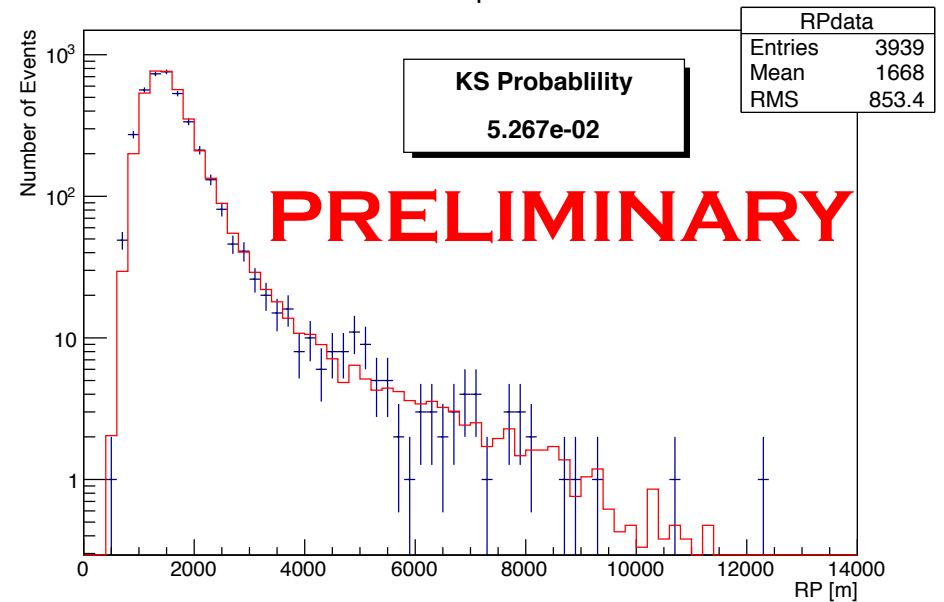
Proton Data-MC



Iron Data-MC

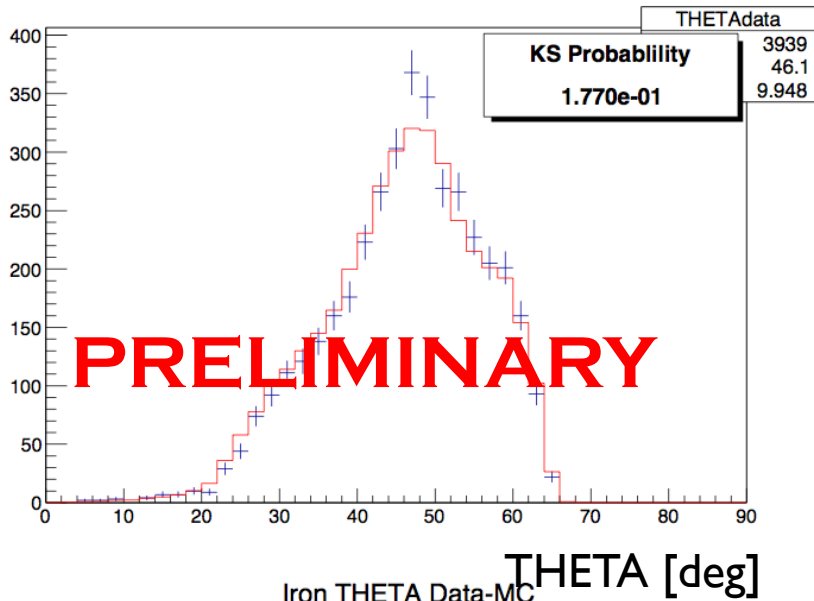


RP Mixed Composition Data-MC

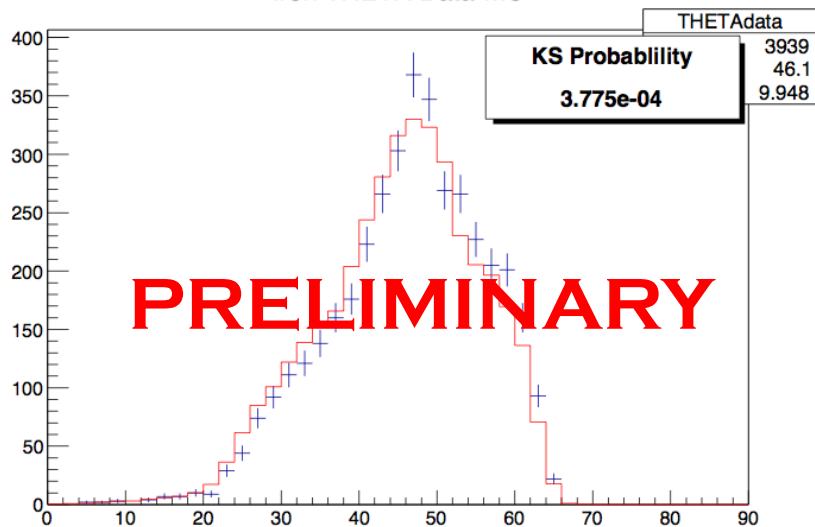


THETA Data-MC

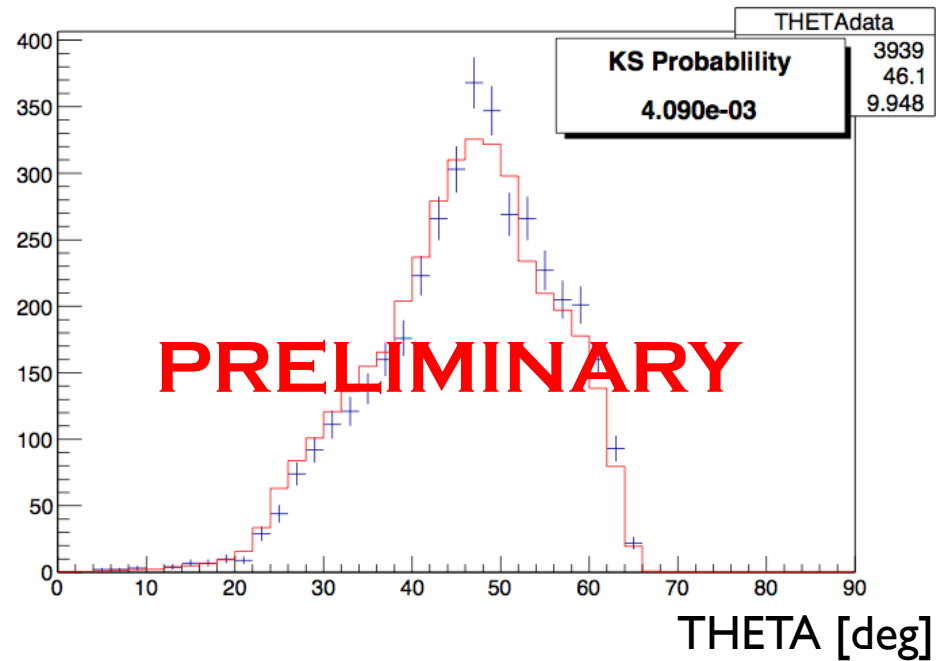
Proton THETA Data-MC



Iron THETA Data-MC

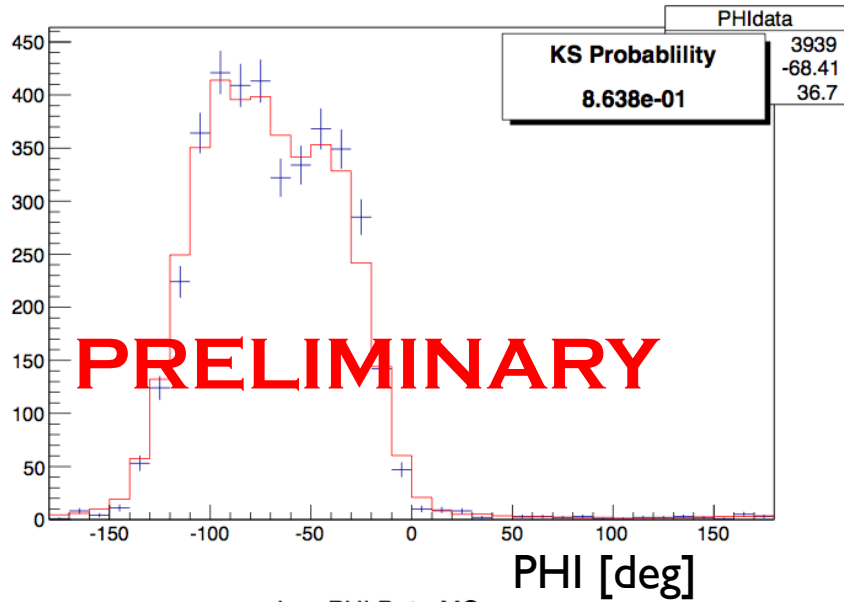


Mixed RP Data-MC

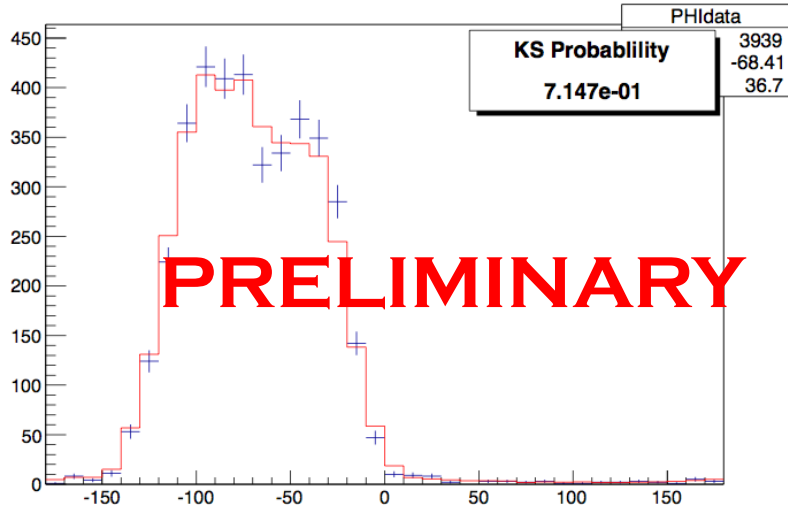


PHI Data-MC

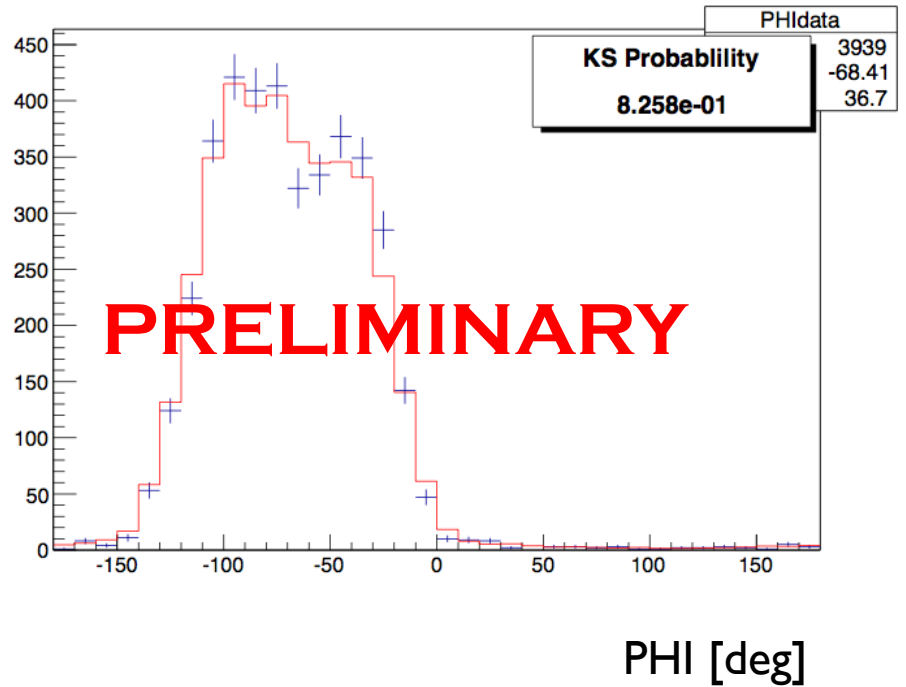
Proton PHI Data-MC



Iron PHI Data-MC

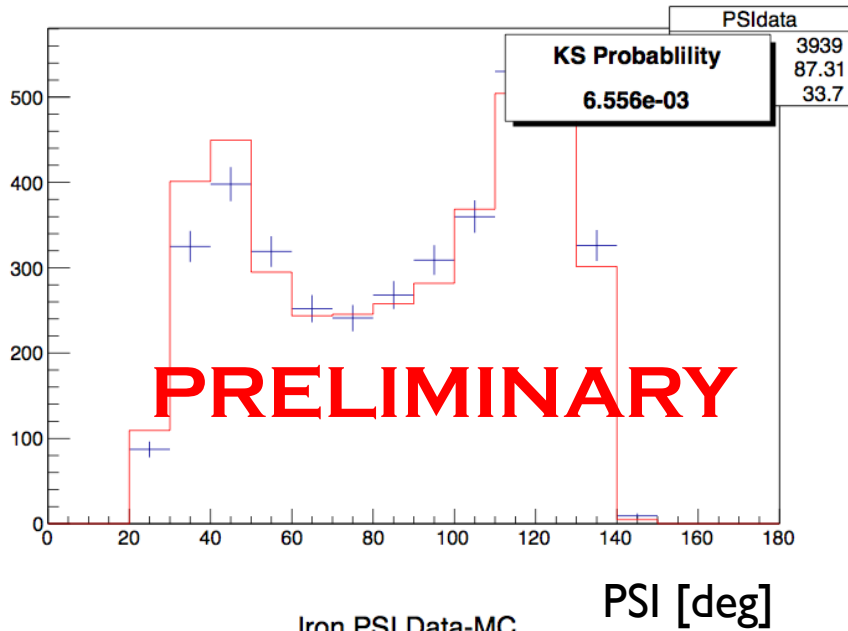


Mixed PHI Data-MC

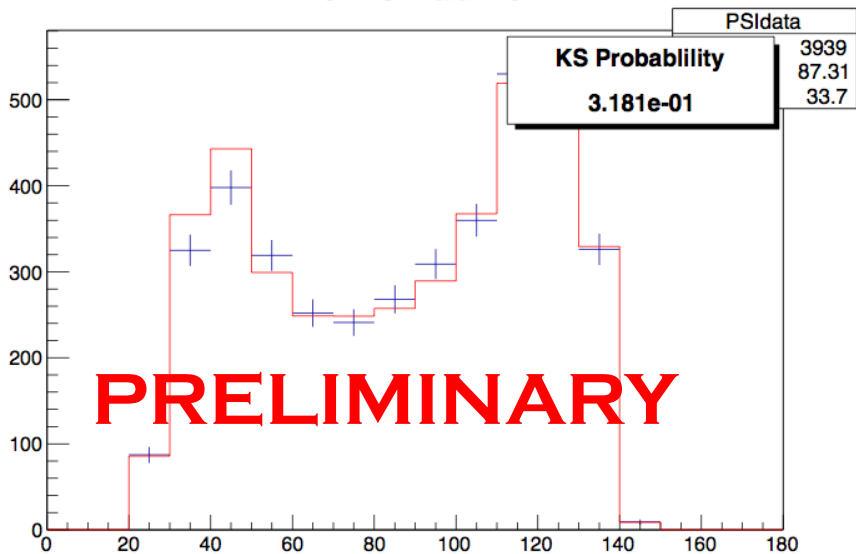


PSI Data-MC

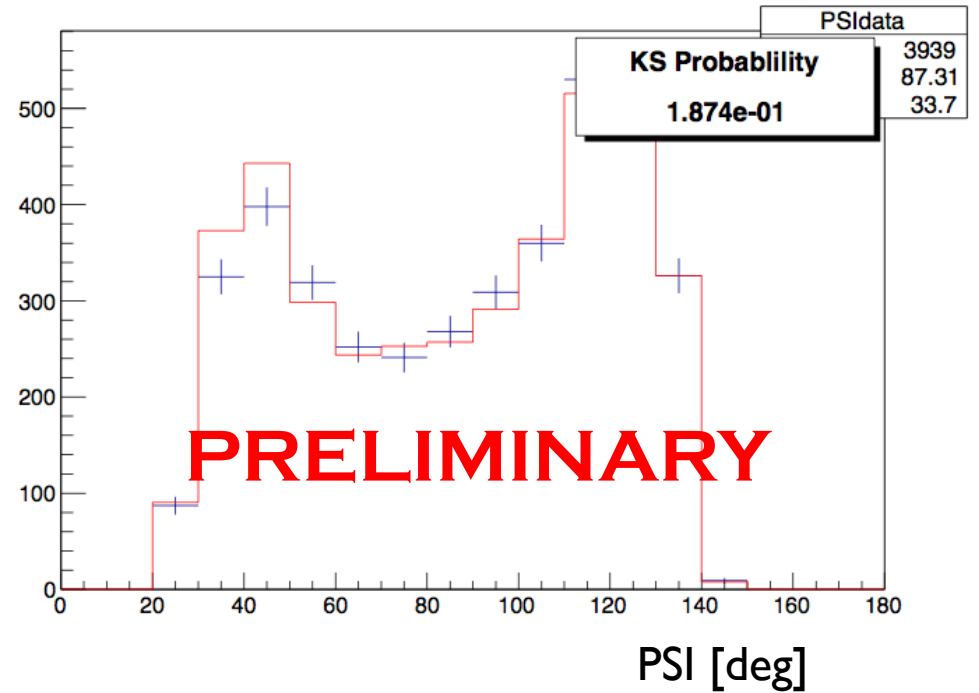
Proton PSI Data-MC



Iron PSI Data-MC



Mixed PSI Data-MC





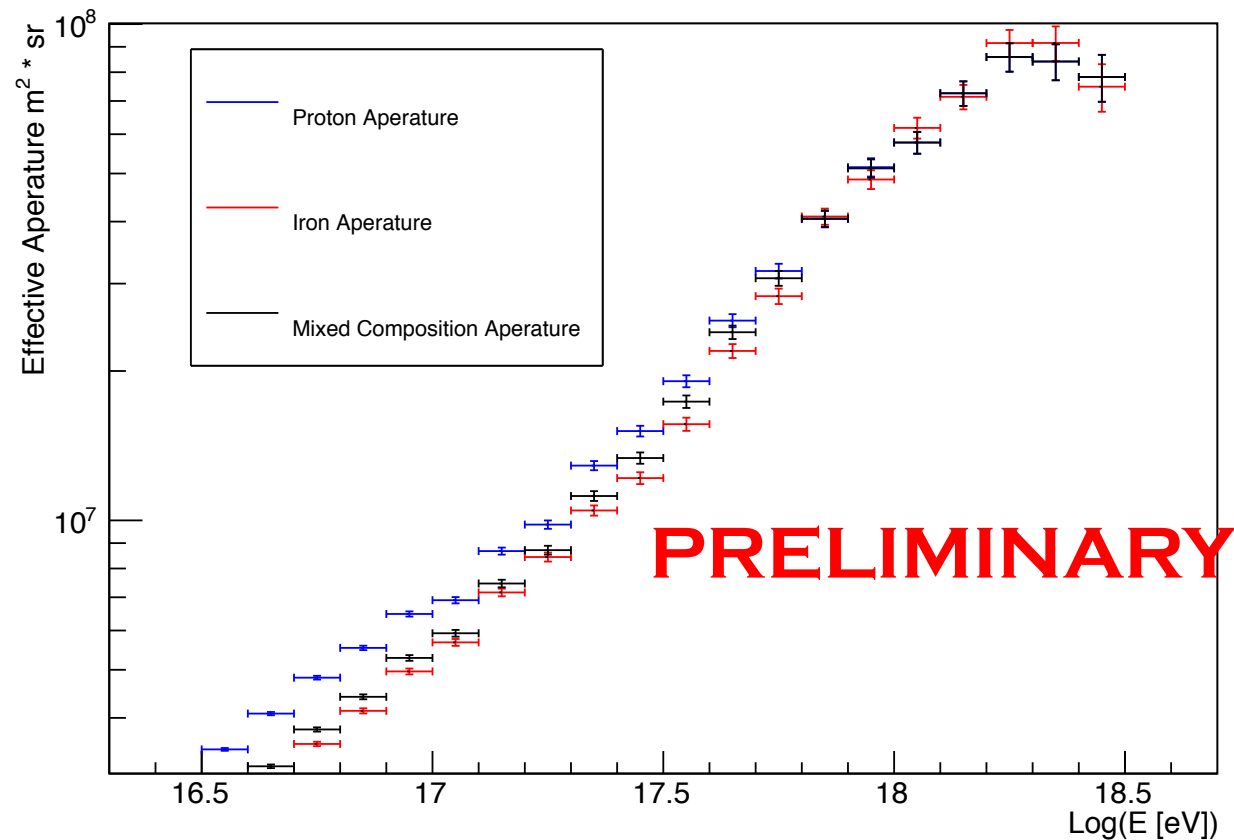
Aperture and Spectrum

Aperture Calculation

- Geometrical Factor
 - $A_0 \Omega_0 = 2\pi^2(RP_{\max}^2 - RP_{\min}^2)(1 - \cos \theta_{\max})$
- Account for energy reconstruction bias
- After Cuts Are Applied for each energy bin
 - $A \Omega = (\text{Events_remaining}/\text{events_thrown})A_0 \Omega_0$

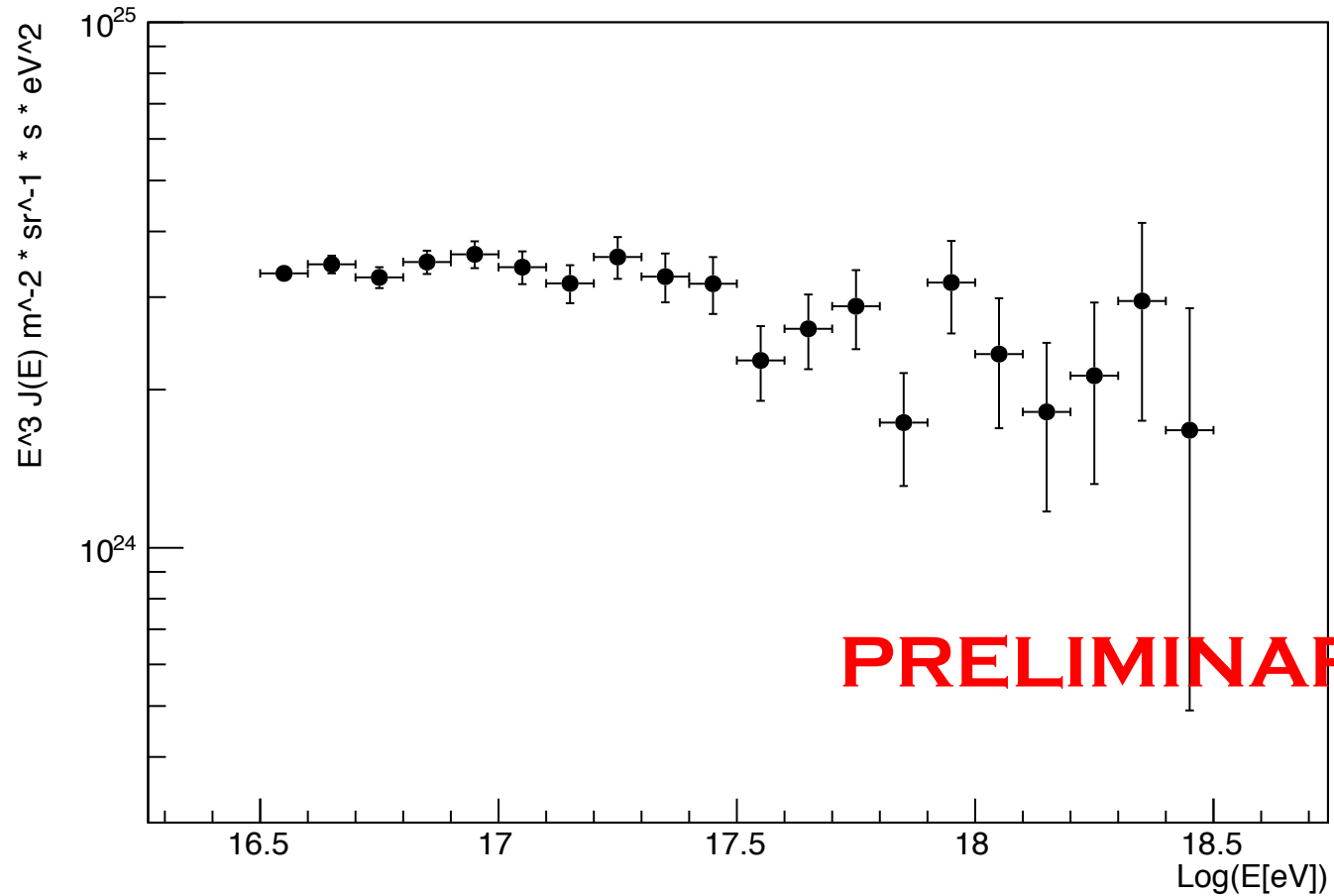
Cuts provide an Aperture
With limited sensitivity
to composition

Aperture



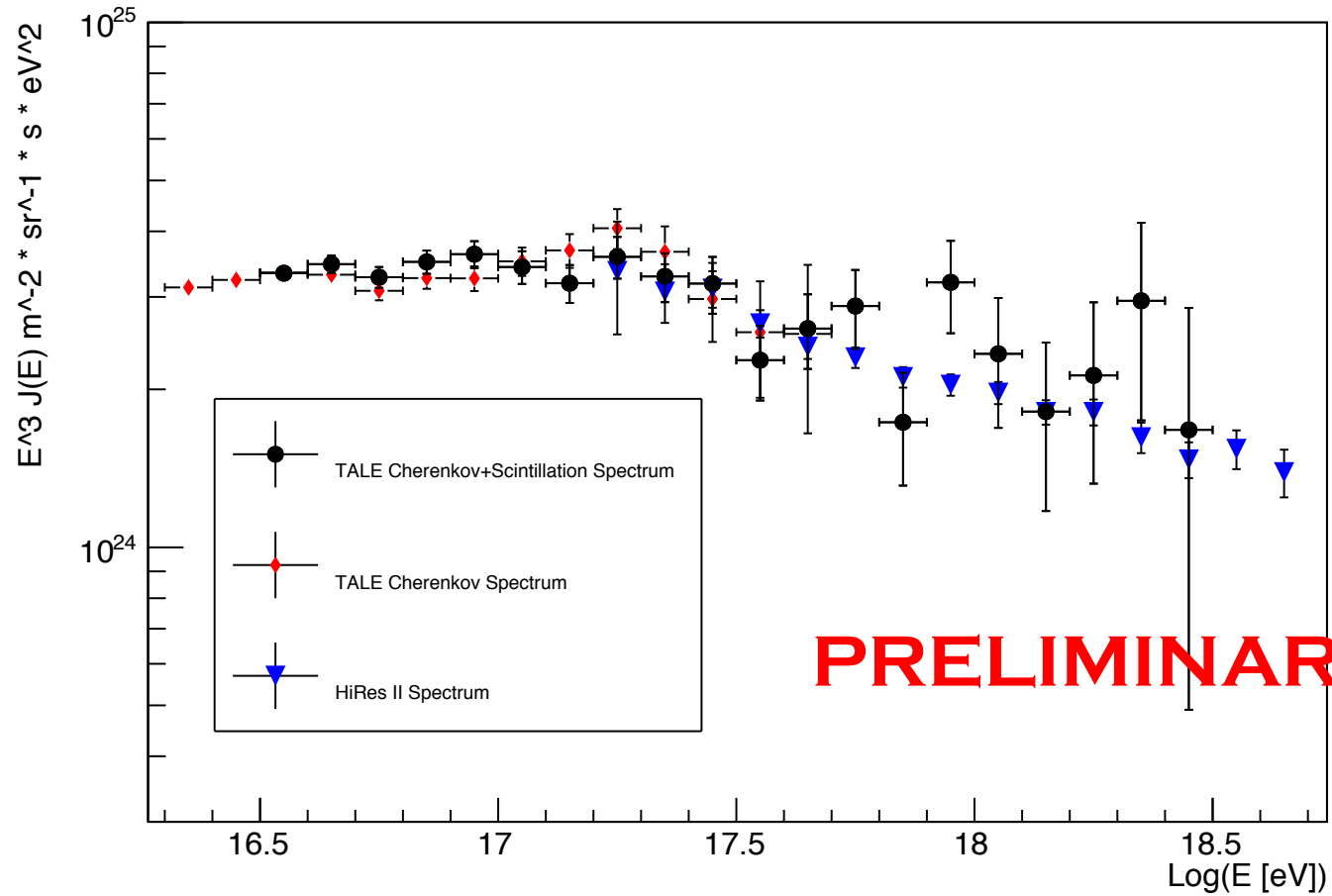
TALE Cherenkov+Scintillation Spectrum

TALE Scintillation+Cherenkov Spectrum



TALE Scintillation + Cherenkov Spectrum

Spectrum Comparisons



Conclusions

- 10 of 10 TALE Fluorescence Detector Telescopes deployed
- First 35 surface detectors have been deployed in UT, remaining being constructed
- Production data currently being taken
- TALE will be able to provide valuable data for the investigating the
 - Second knee
 - CR galactic to extragalactic source transitions



Backup

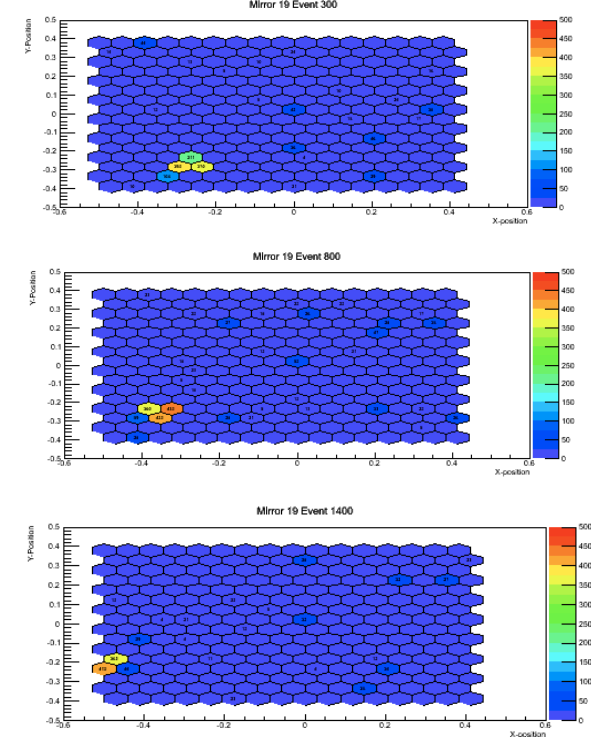
Challenge: Bright Stars

- Can cause telescopes to fill up trigger buffer and become unresponsive
- Particularly Problematic for RING 4 mirrors

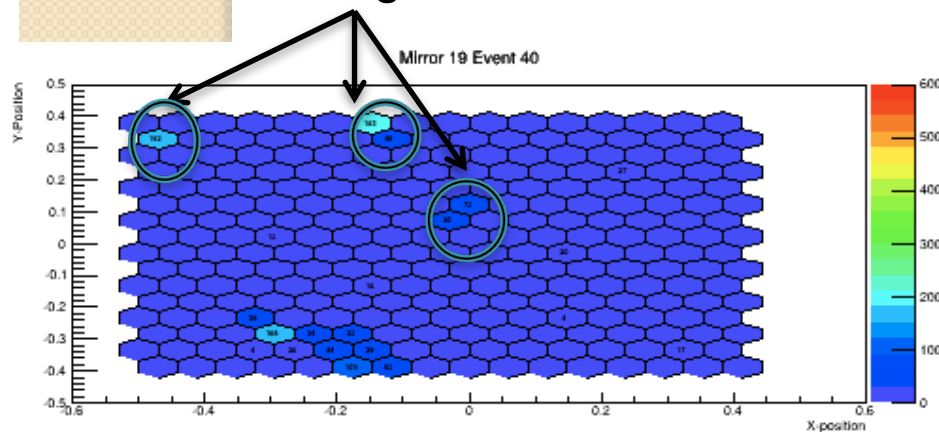
Solution: Disable Tubes Looking at Bright Stars

- Track bright objects with [STARS](#) program
- Disable and revive tubes as stars pass in front of them
- Signal gain for Tubes within 1 degree of the star are set to zero.

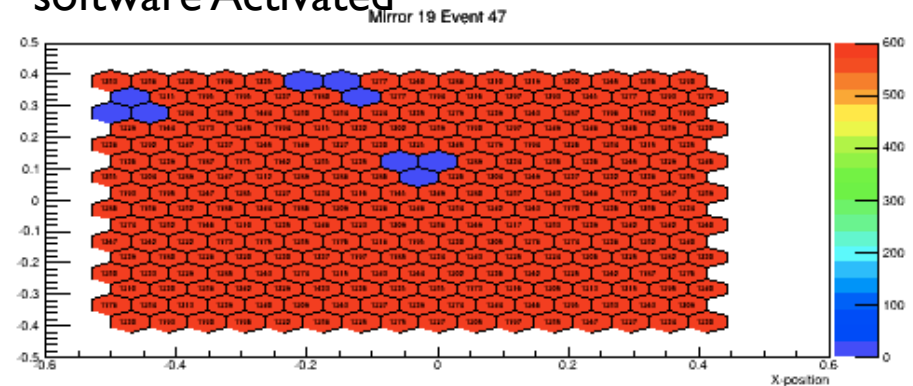
Transit of Sirius



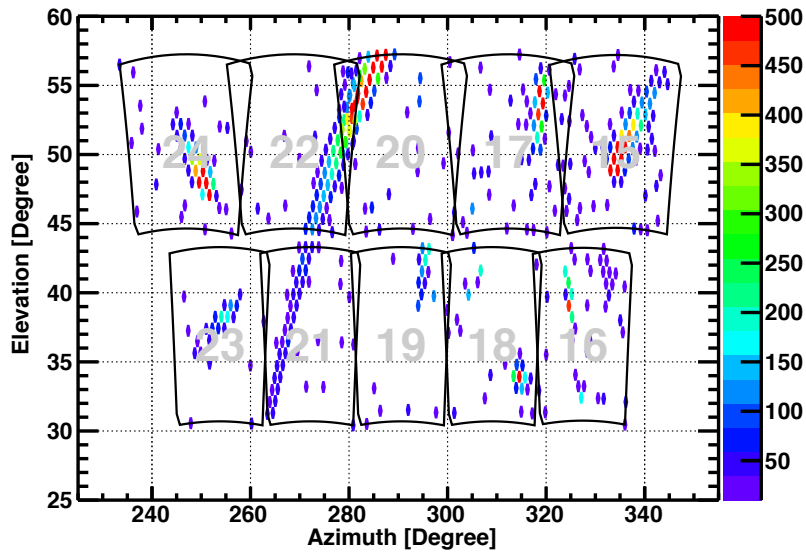
Example with UV Bright Stars in FOV:
No Tube Disabling Software



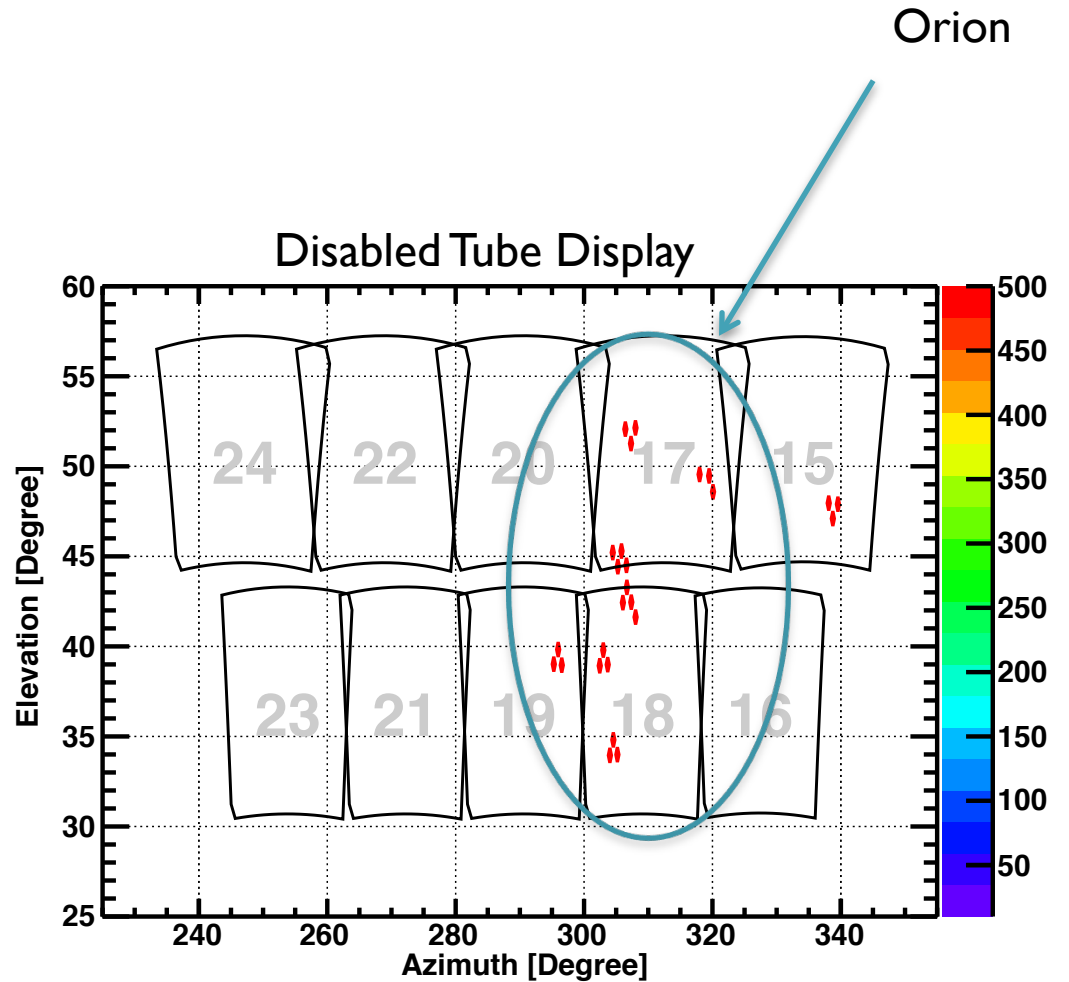
UVLED FLASH with tube disabling software Activated



Bright Stars: Continued



Events Display

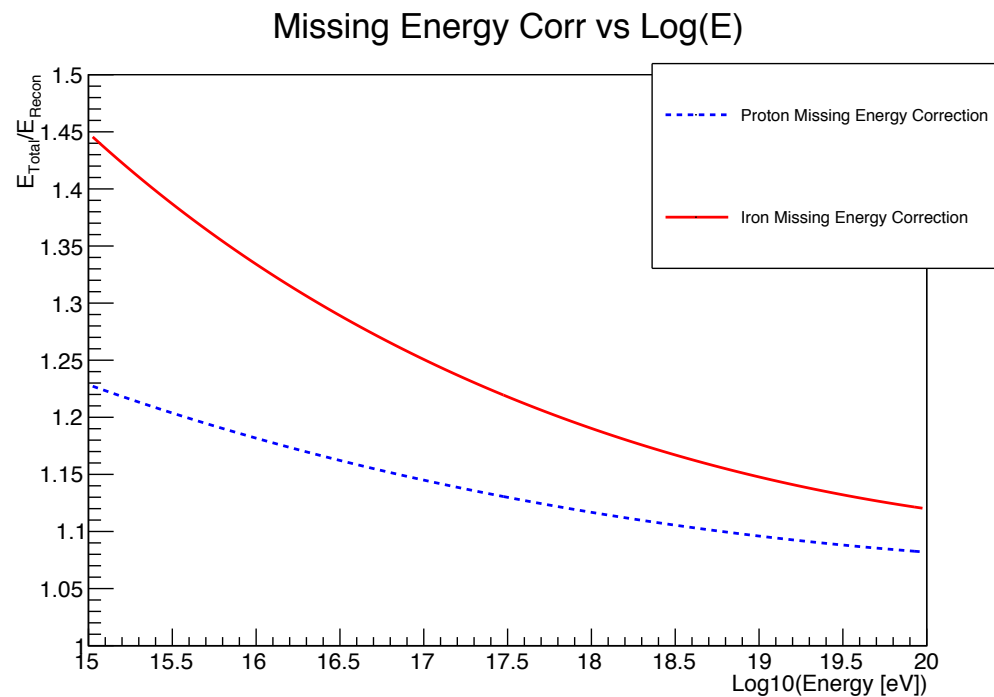


All Cuts used in this Analysis

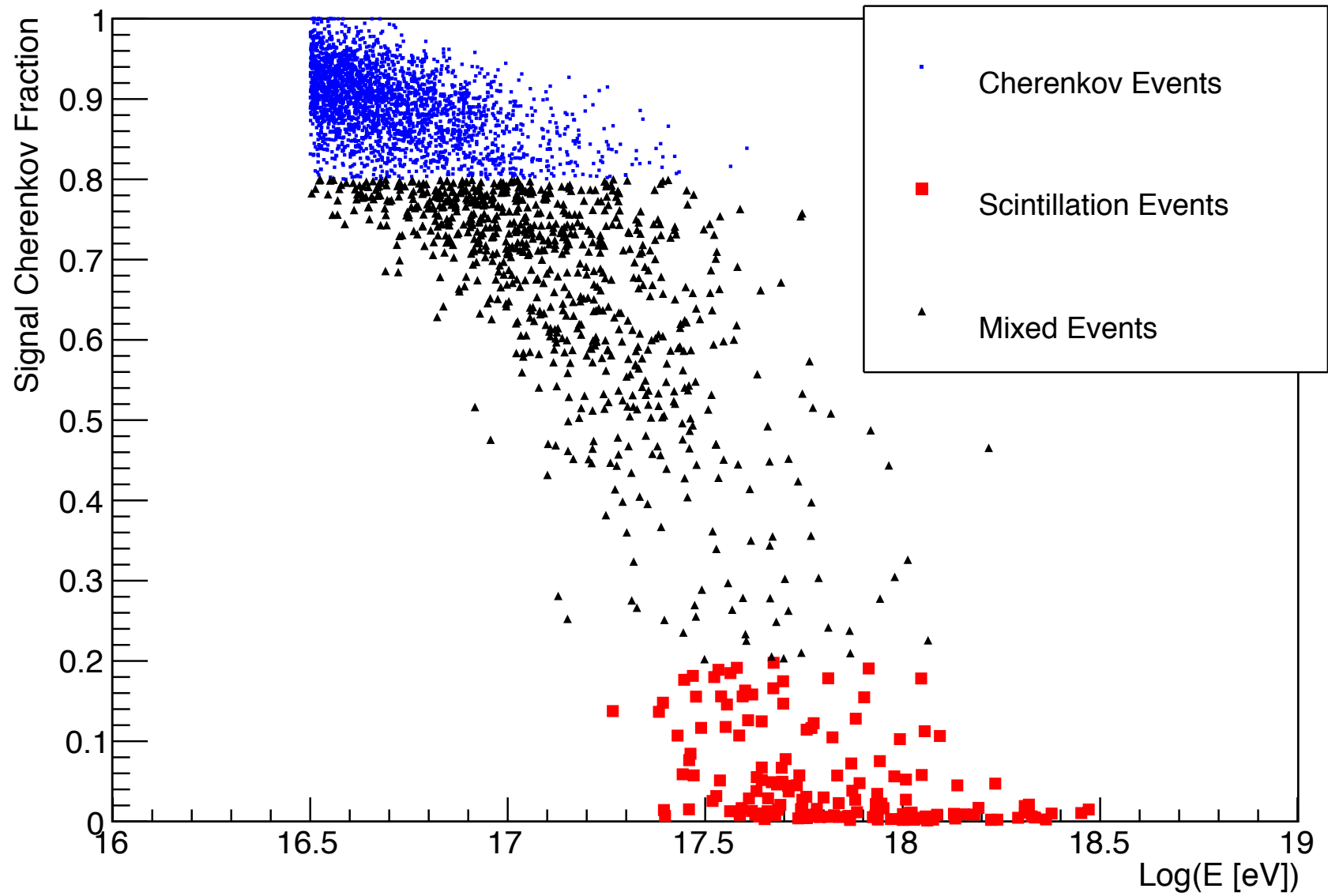
- Inverse Angular Speed >0.01
- RP > 500 m
- THETA < 65 degrees
- $415 < X_{MAX} < 915$
- $\chi^2_P/ndf < 4.5$
- $\chi^2_T/ndf < 3.5$
- Visible Transit Depth $> 200 \text{ g/cm}^2$
- $X_{bottom} < 1100 \text{ g/cm}^2$
- Tracklength > 4.5 degrees
- $Pepgt6 > 35$
- $X_{MAX} > X_{top}$

Missing Energy Corrections Based on Composition (QGSJET II-3)

- All events had a missing energy correction applied which was weighted by the assumed composition.

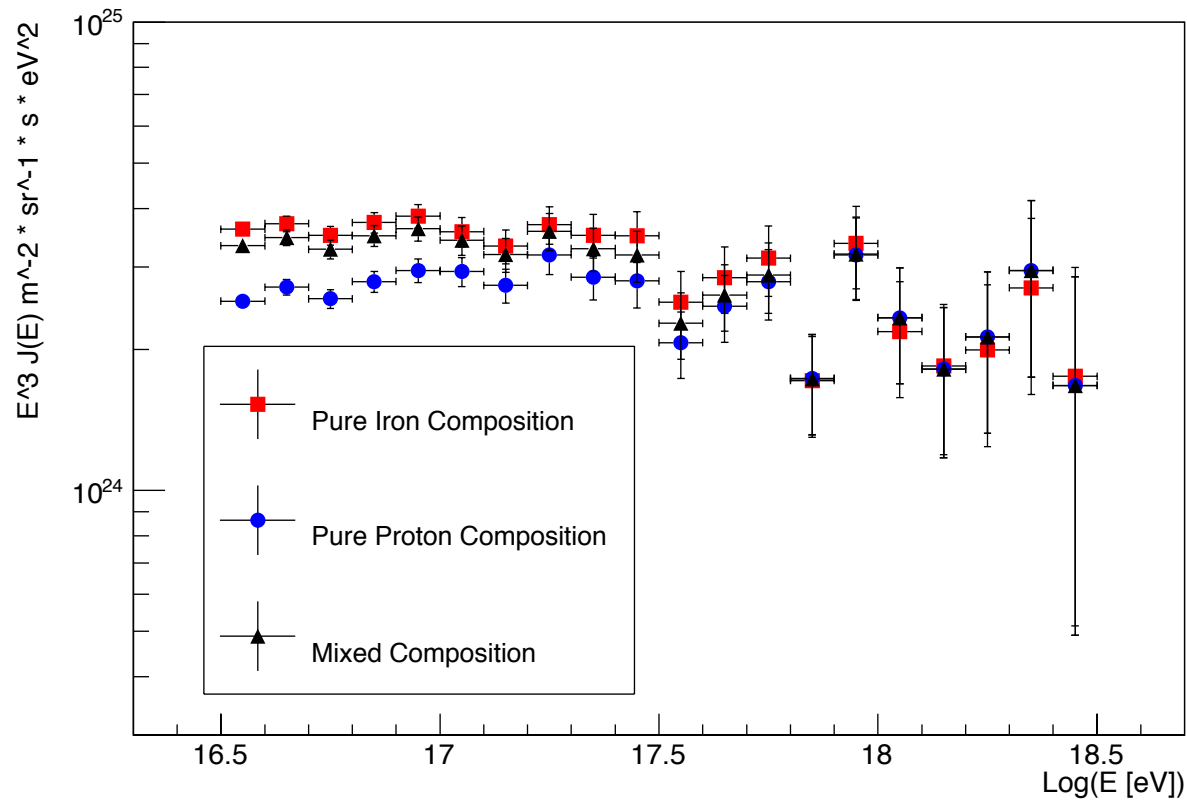


Cherenkov Fraction v. Log(E [eV])

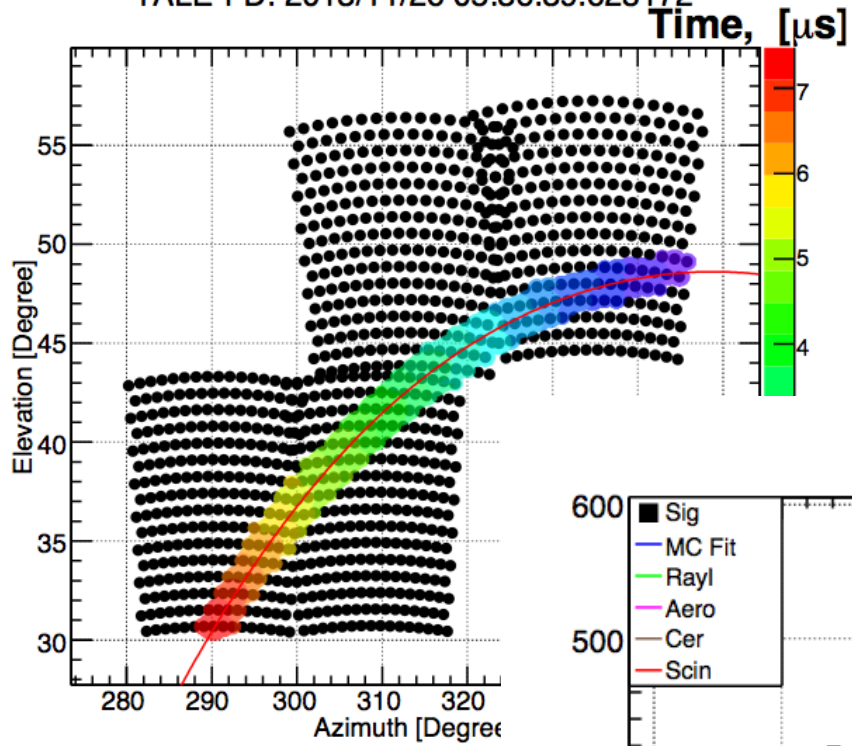


Effects of Assumed Composition on Spectrum

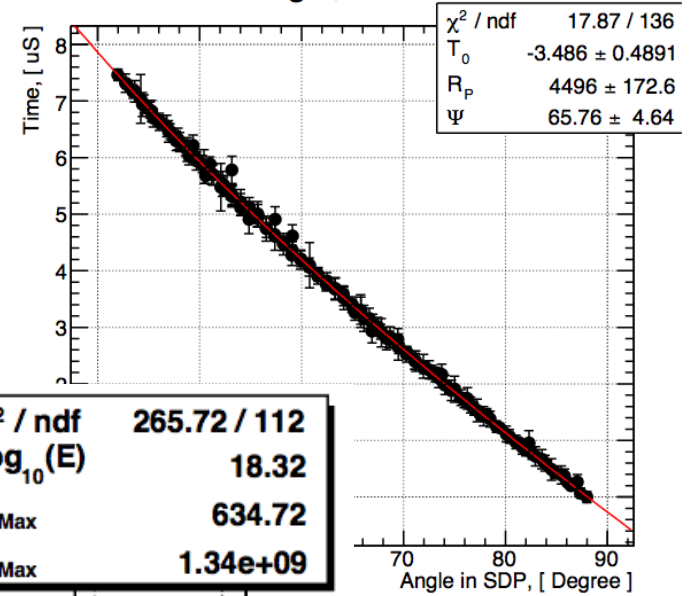
Spectrum Comparisons



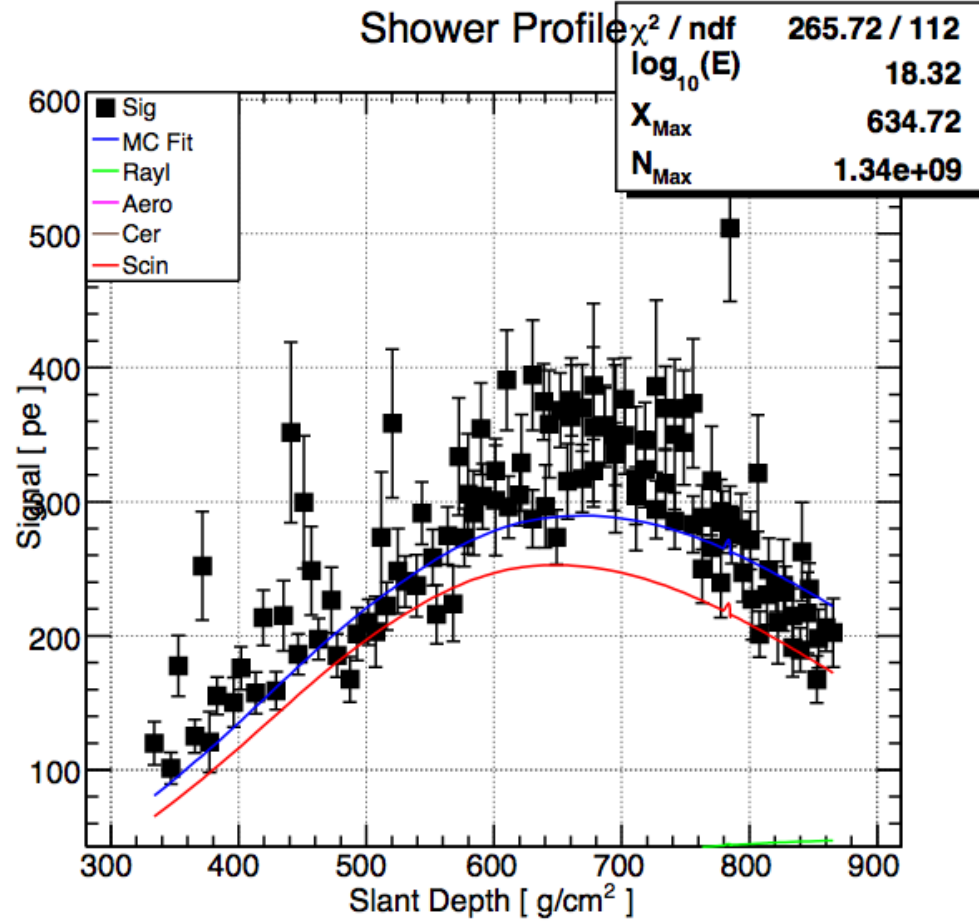
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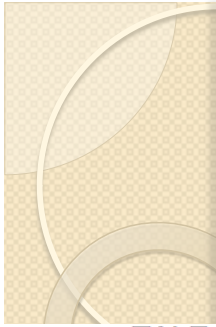


Time vs Angle, TALE-FD-Mono

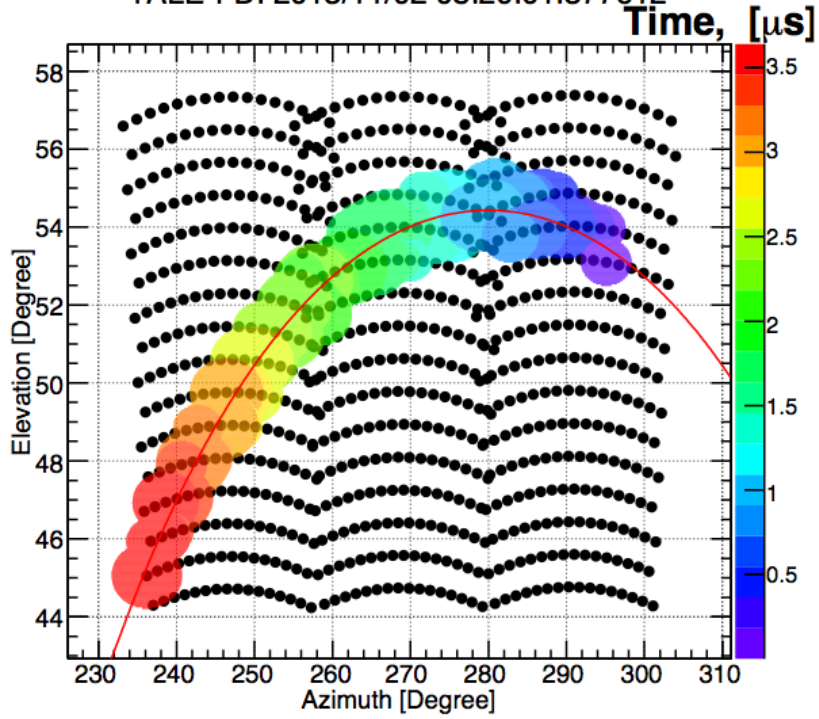


Shower Profile

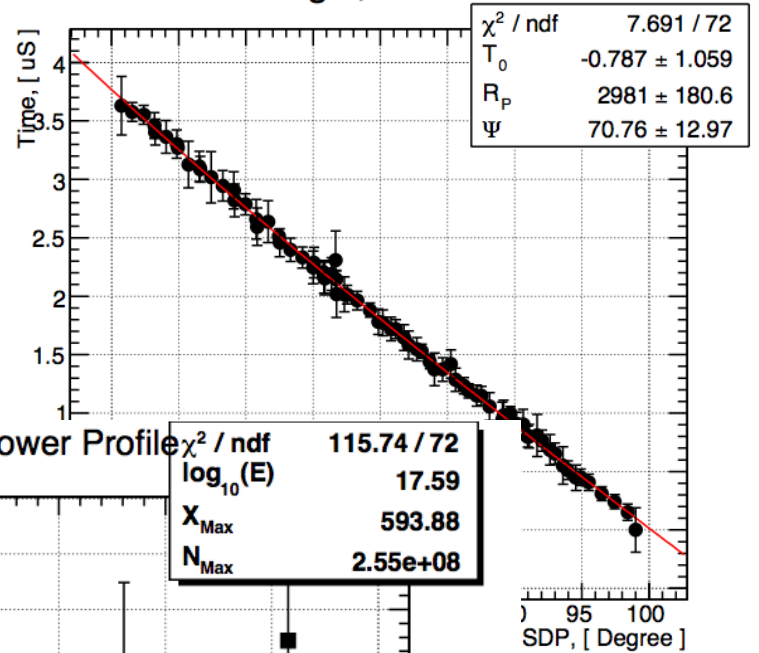




TALE-FD: 2013/11/02 08:20:01.377612



Time vs Angle, TALE-FD-Mono



Shower Profile

