TALE Cosmic Rays Composition

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ICRC 2019
Madison, WI
2019/07/25

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- Data and Analysis
- Results
  - Primary fractions
  - Mean log(A)
  - Xmax elongation
- Summary

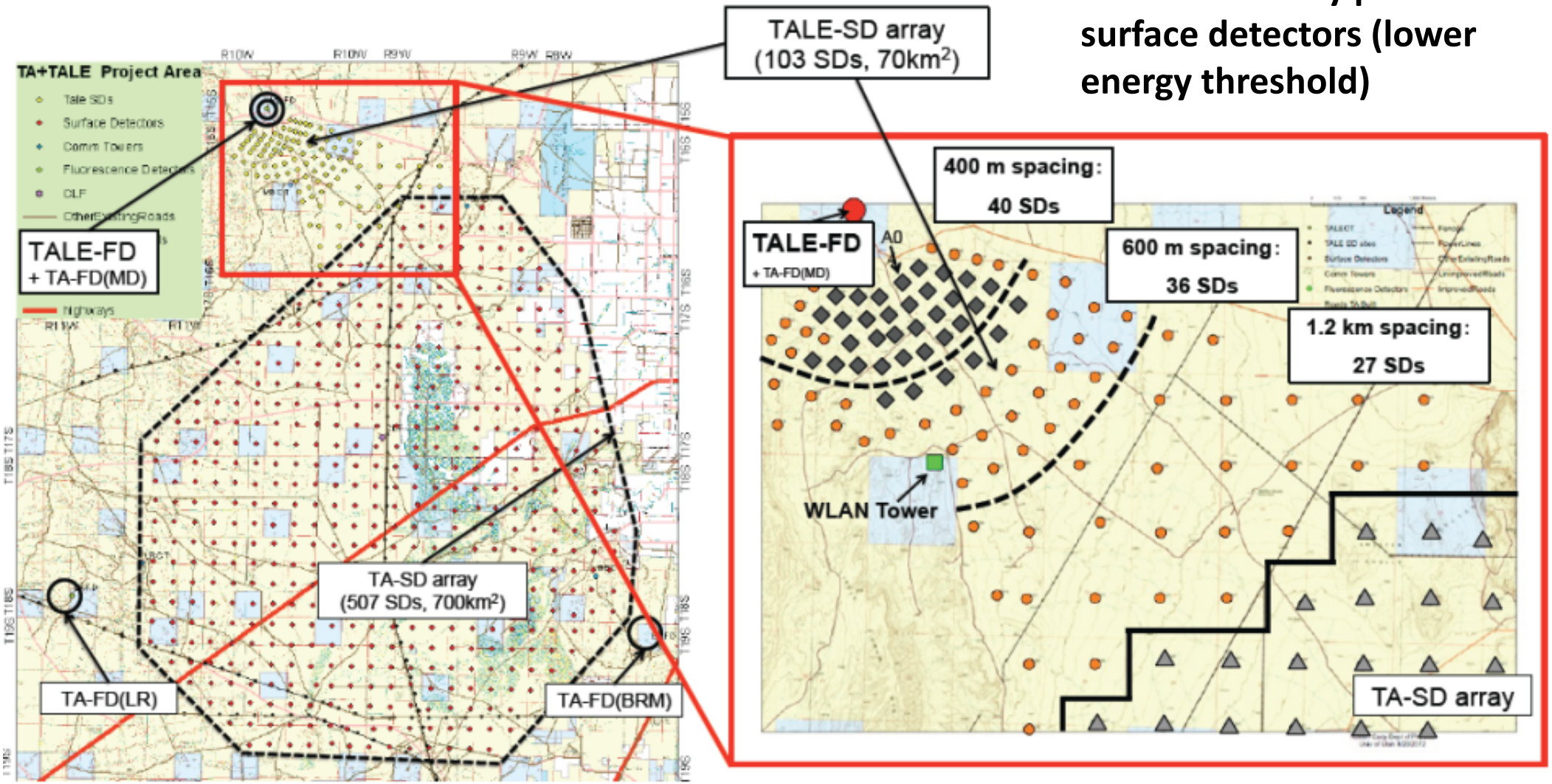
Introduction

- We present results on a measurement of the cosmic rays composition using the Telescope Array Low Energy Extension (TALE) fluorescence detector (FD).
- We infer composition through measuring the shower development Xmax.
- The measurement covers the cosmic rays energy range $10^{15.3}$ – 10^{18} eV

Telescope Array (TA) Low Energy Extension (TALE)

10 new telescopes to look higher in the sky (31-59°) to see shower development to much lower energies

Infill surface detector array of more densely packed surface detectors (lower energy threshold)



All 10 Telescopes installed and in operation **since fall 2013**

103 (out of 105) scintillation surface detectors deployed. Majority started operations in **summer of 2017**.

Data and Analysis

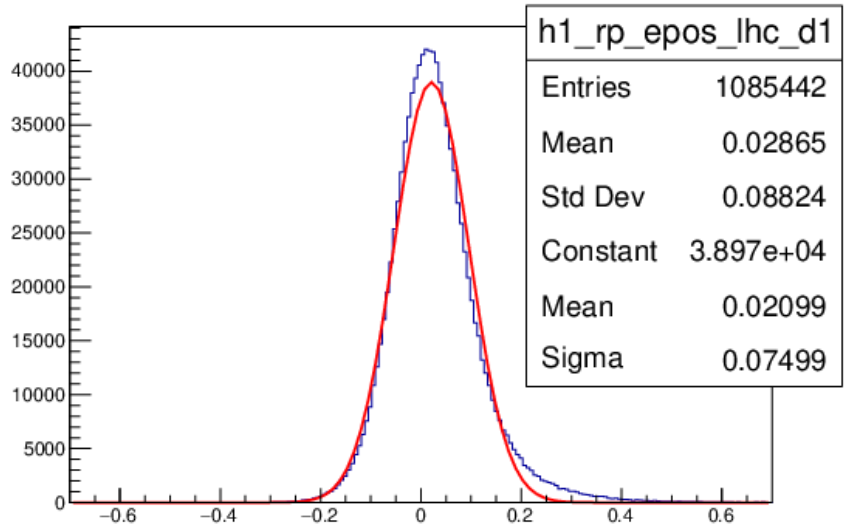
- TALE FD monocular data (Cherenkov light dominated).
- Data collection period: 06/2014 – 11/2018
  - ~2700 hours of observation
- Monte Carlo: EPOS-LHC hadronic model (using CONEX generator) [Start at $10^{15.0}$ eV]
- Monte Carlo: QGSJetII-03 hadronic model (using CONEX generator) [Start at $10^{15.5}$ eV]
- Work in Progress; QGS simulations at lower energies in the process of being added to the analysis.

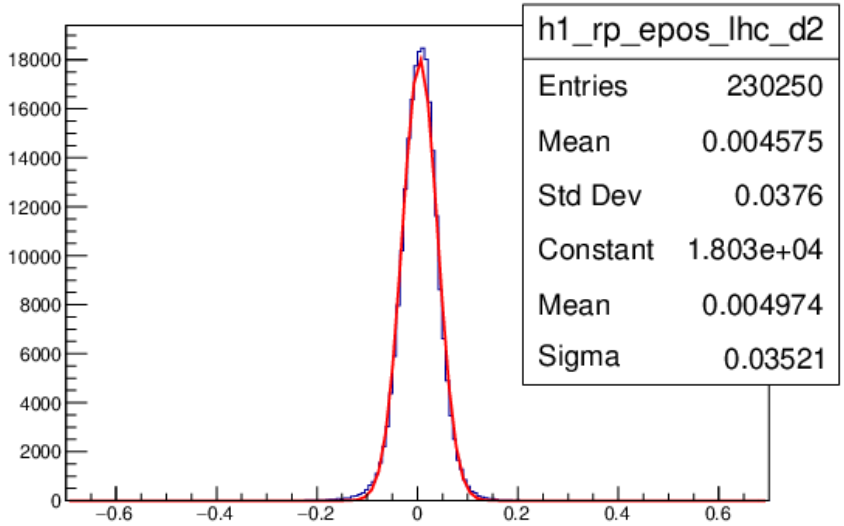
Analysis: Primary Fractions (Xmax Fits)

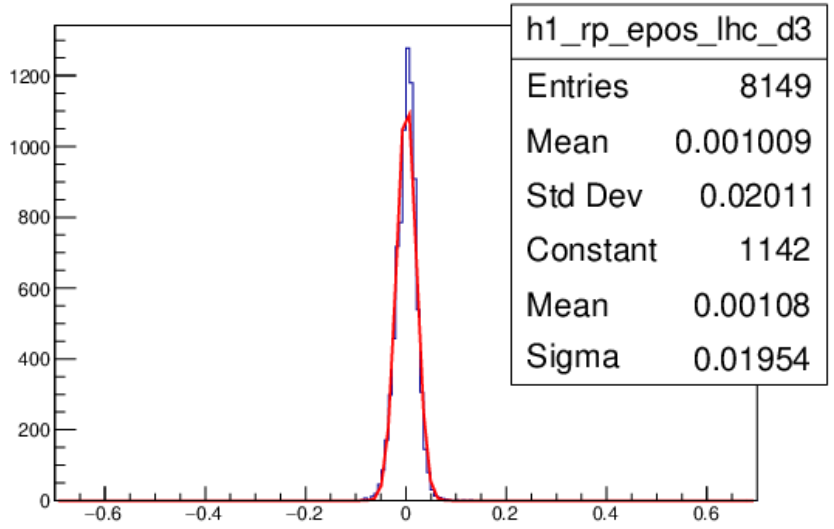
- Event reconstruction: Shower calorimetric energy, shower Xmax for each event.
- Events (Data & MC) binned in energy; bins [0.1 in log(E)]
- At each energy bin:
  - Fit Data Xmax distribution histogram as a sum of four (MC) primary Xmax distributions:
    - Primaries: proton, helium, nitrogen (CNO), iron.
    - MC / Data reconstructed, filtered identically.
- Energy range: $15.2 < \log10(E_{cal}\ [eV]) < 18.0$
  - Run out of statistics above 10^{18} eV.
- Use ROOT's TFractionFitter to do actual fit.

Reconstruction Resolution (Geometry) (1)

- One histogram per decade in energy starting at E = $10^{15.3}$ eV
- Shower Track R_p [m]
- Histogram: ΔR_p / R_p

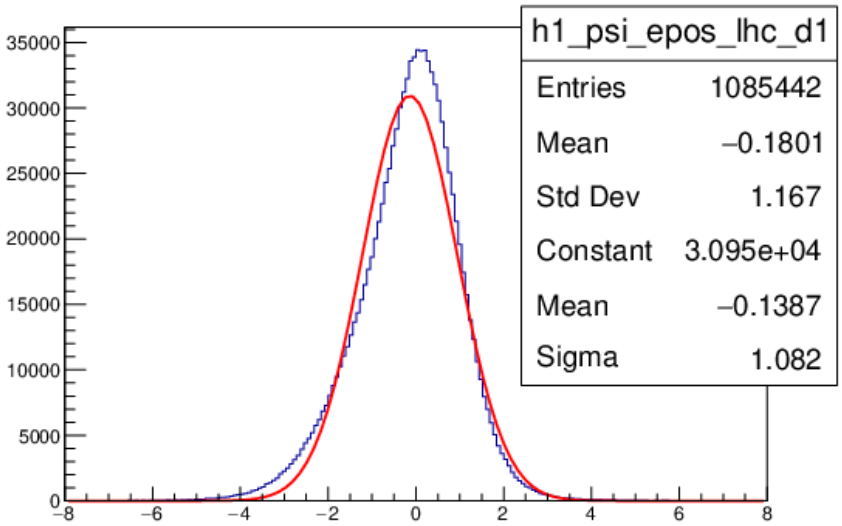


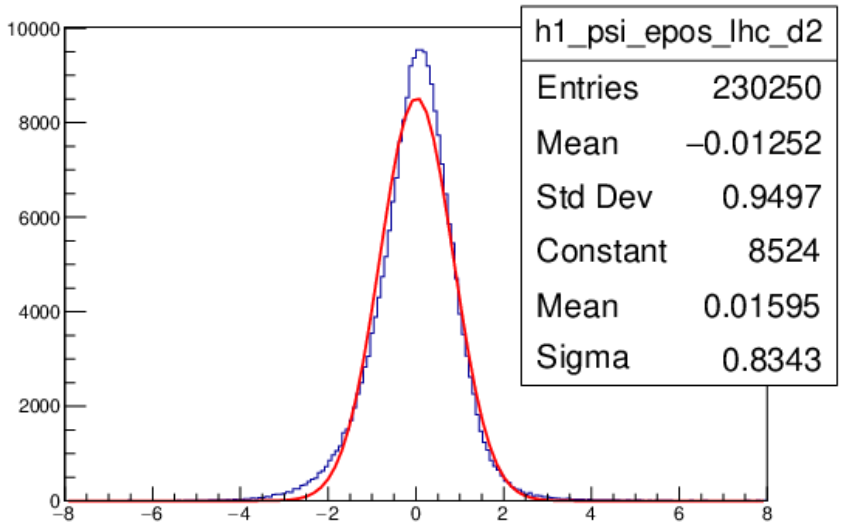


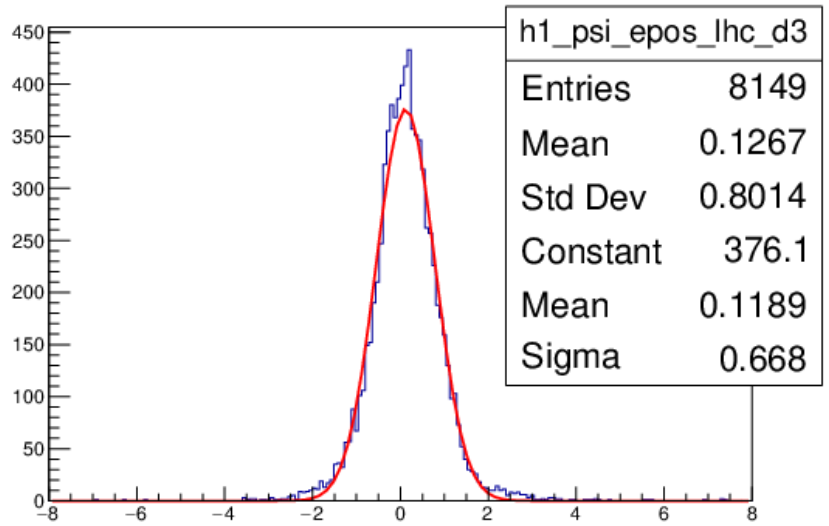


Reconstruction Resolution (Geometry) (2)

- One histogram per decade in energy starting at E = $10^{15.3}$ eV
- Shower Track ψ angle (degree)
- Histogram: $\Delta\psi$ (degree)

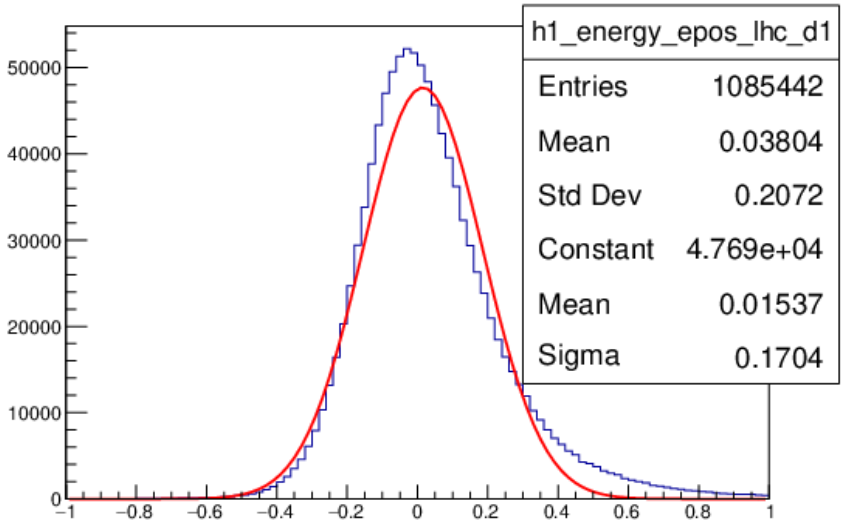


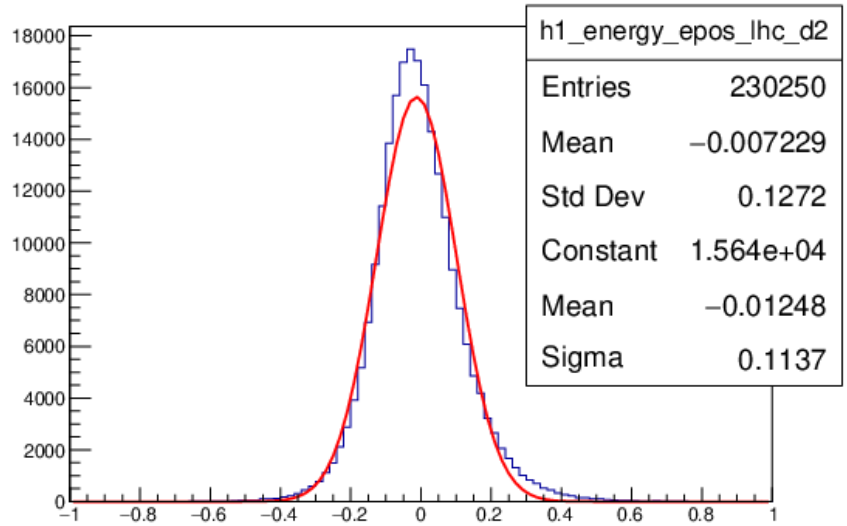


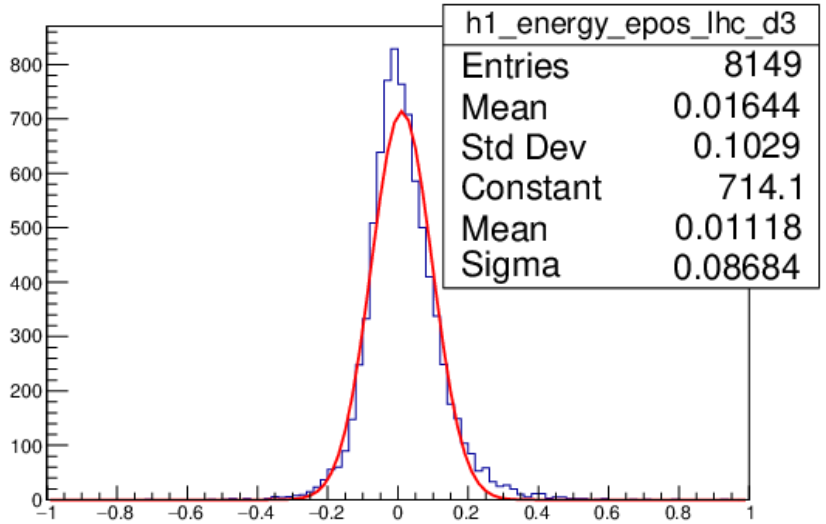


Reconstruction Resolution (Energy)

- One histogram per decade in energy starting at E = $10^{15.3}$ eV
- Shower Energy [eV]
- Histogram: ΔE / E

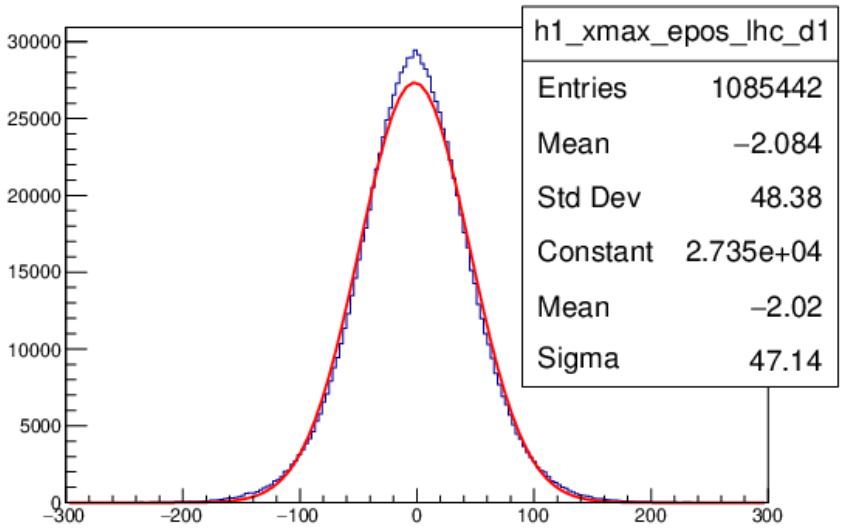


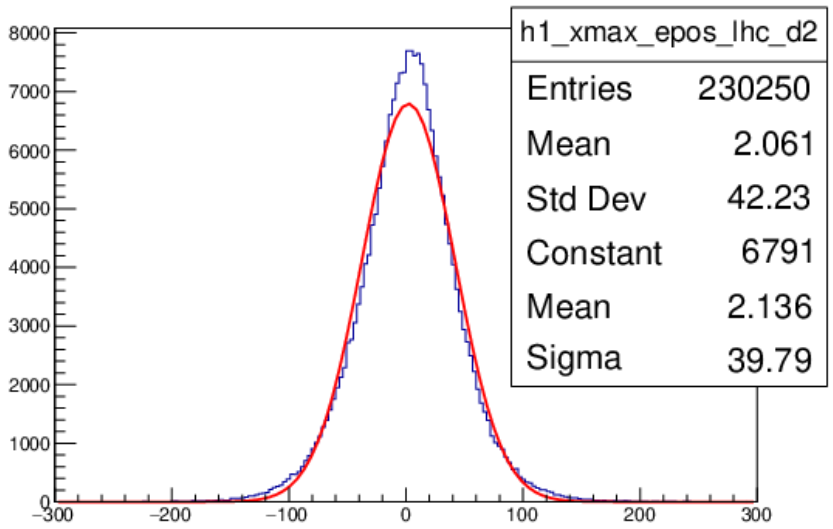


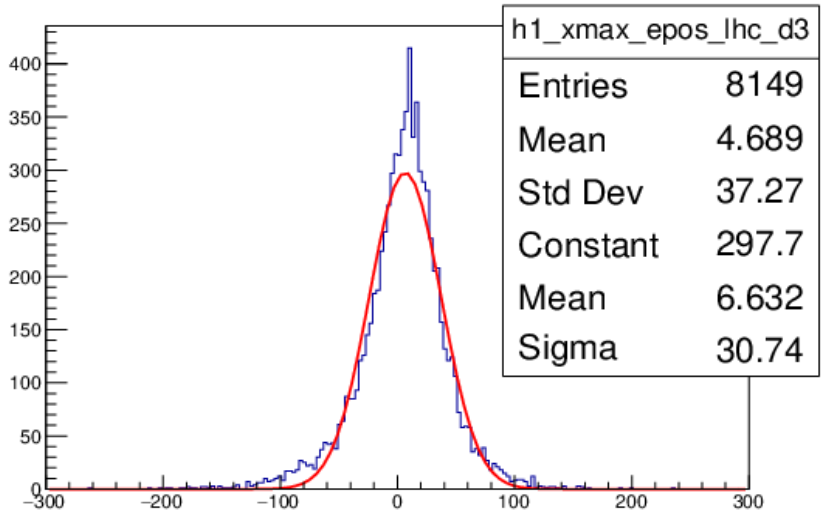


Reconstruction Resolution (Xmax)

- One histogram per decade in energy starting at E = $10^{15.3}$ eV
- Shower X_{max} [g / cm^2]
- Histogram: ΔX_{max} [g / cm^2]

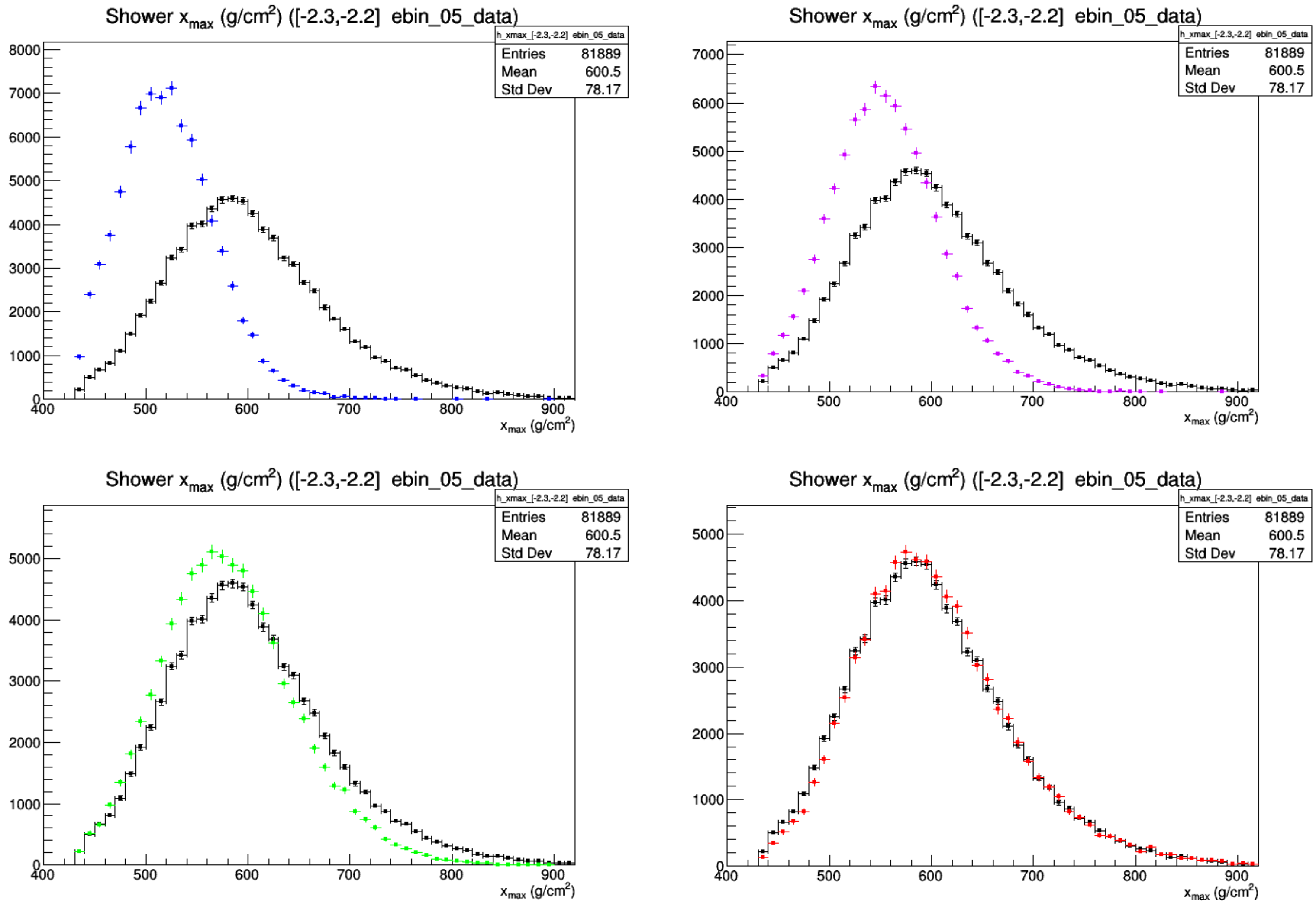






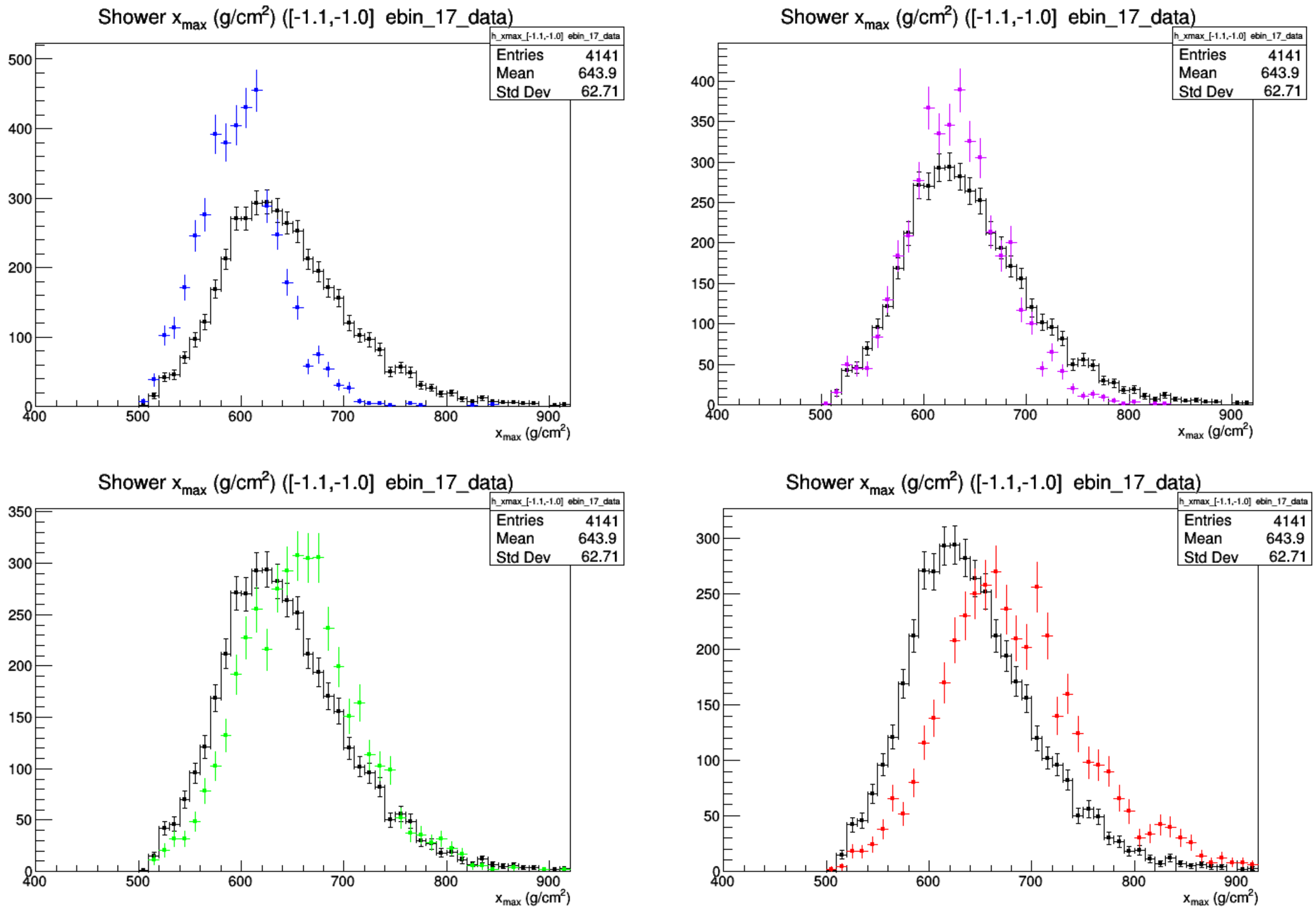
Example Xmax distributions (1)

- $15.7 < \log_{10}(E_{cal}) < 15.8$
- All Plots: (Black) **Data**
- Top left: **Iron**
- Top right: **CNO**
- Bottom left: **Helium**
- Bottom right: **Proton**



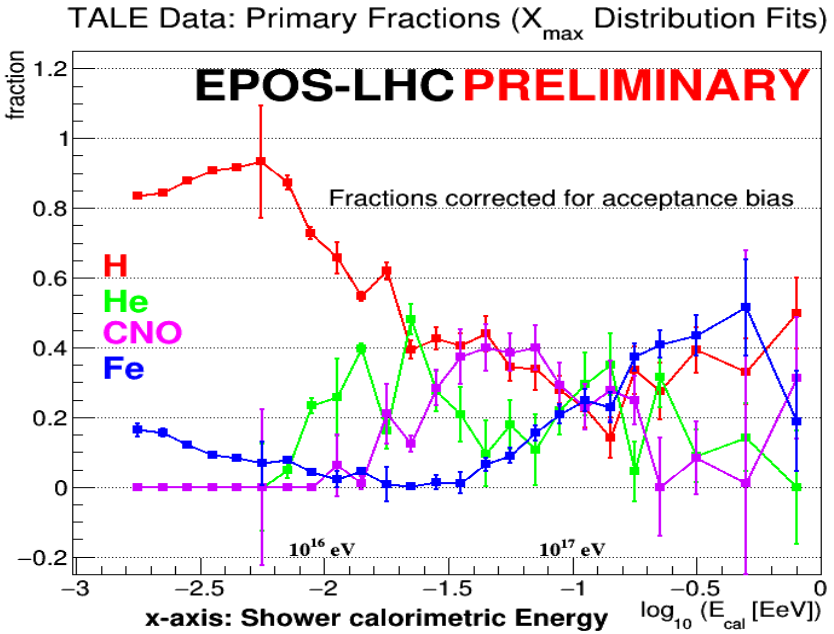
Example Xmax distributions (2)

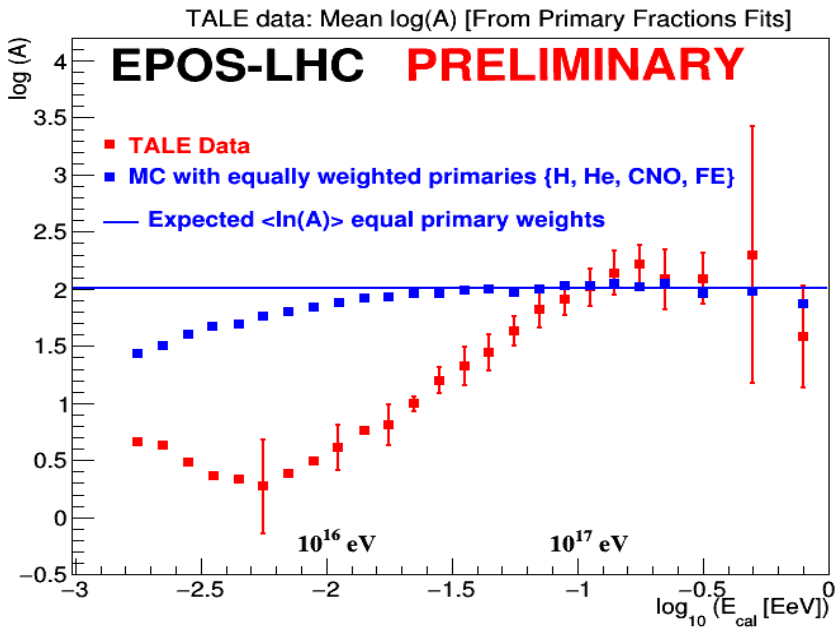
- $16.9 < \log_{10}(E_{cal}) < 17.0$
- All Plots: (Black) **Data**
- Top left: **Iron**
- Top right: **CNO**
- Bottom left: **Helium**
- Bottom right: **Proton**



Fit results (EPOS-LHC)

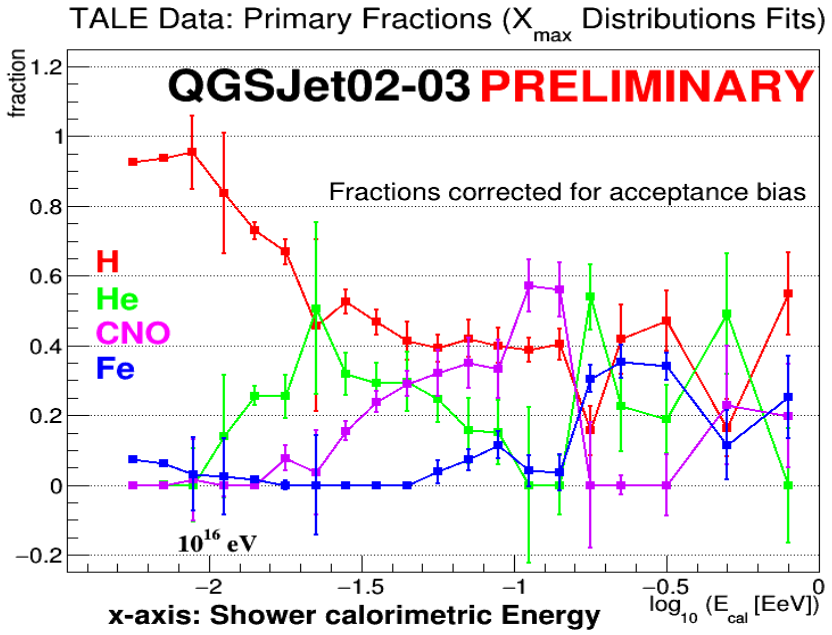
- Lowest Energy bin starts at: $\log_{10}(E_{cal}) = 15.2$
- Mean log(A) calculated as a weighted sum of log(A) for each of 4 fit primaries.
- MC thrown with equal number of primaries: <ln (A)> = 2.01
- Reconstructed MC <ln (A)> blue squares.
- TALE data (corrected fractions) shown in red.

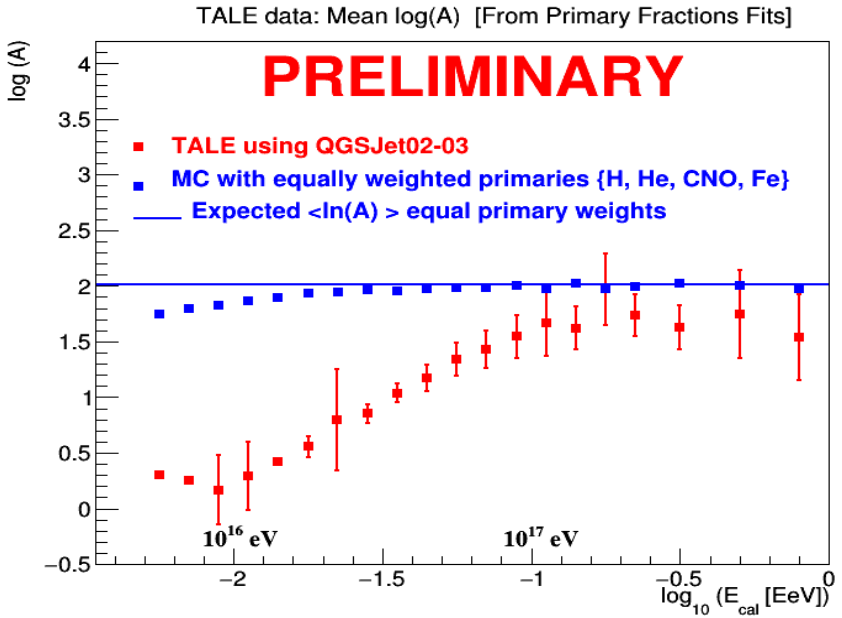




Fit results (QGSJetII-03)

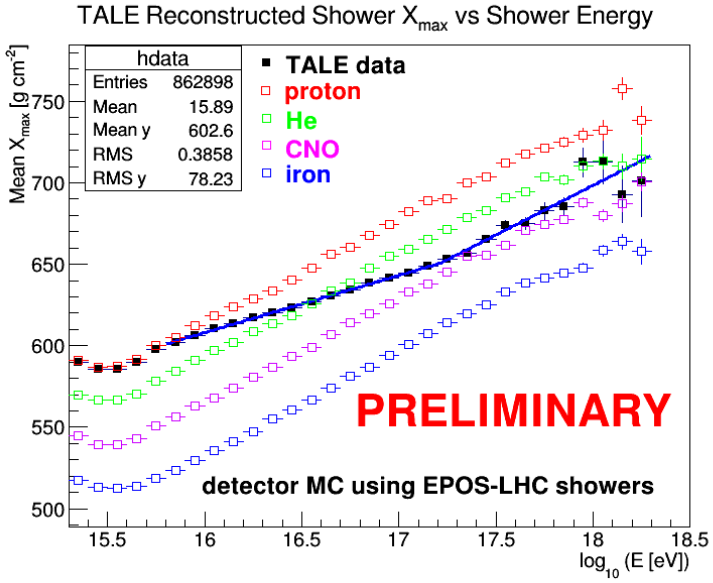
- Lowest Energy bin starts at: $\log_{10}(E_{cal}) = 15.7$
- Mean log(A) calculated as a weighted sum of log(A) for each of 4 fit primaries.
- MC thrown with equal number of primaries: <ln (A)> = 2.01
- Reconstructed MC <ln (A)> blue squares.
- TALE data (corrected fractions) shown in red.

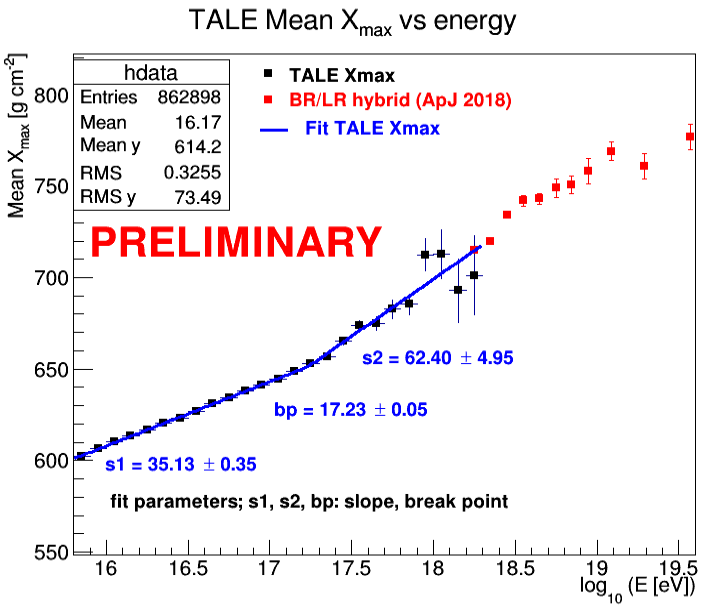




Mean Reconstructed X_{max} vs. Shower Energy

- (Top Figure): Reconstructed Data $<X_{max}>$ vs. Shower total Energy starting at log(E [eV]) = 15.3
  - Also shown, results for 4 MC primaries.
- (Bottom Figure): A broken line fit to TALE data $<X_{max}>$
  - Break point: 17.23 +/- 0.05
  - Slope before: 35.13 +/- 0.35
  - Slope after: 62.40 +/- 4.95
- (Bottom Figure): Also shown (red squares) are $<X_{max}>$ reported by TA using hybrid events from Black Rock / Long Ridge FD's and the main SD array.





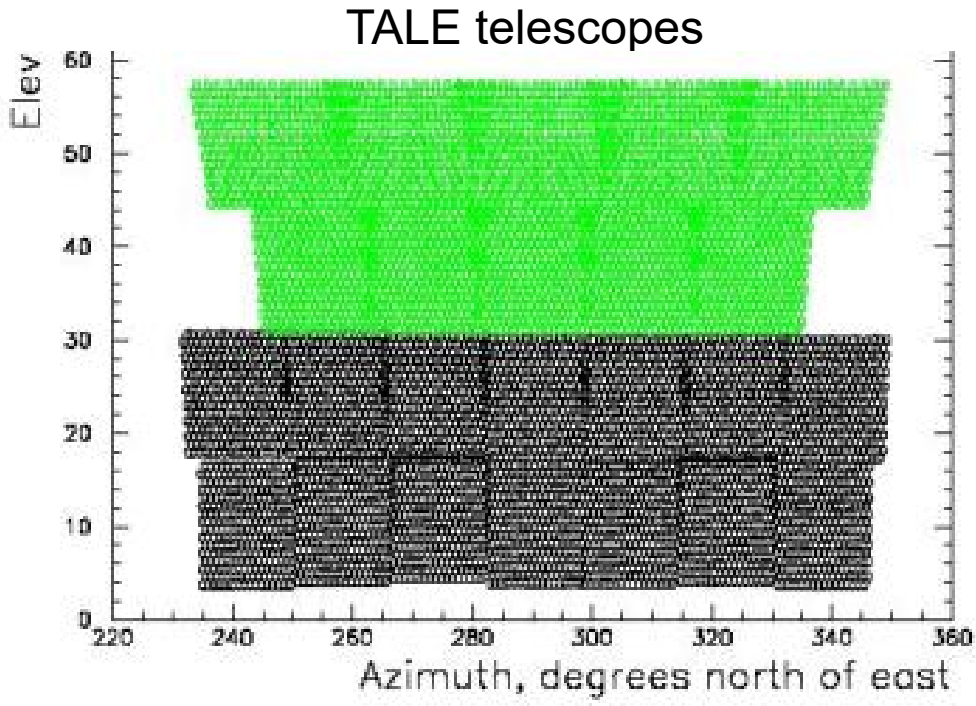
Summary

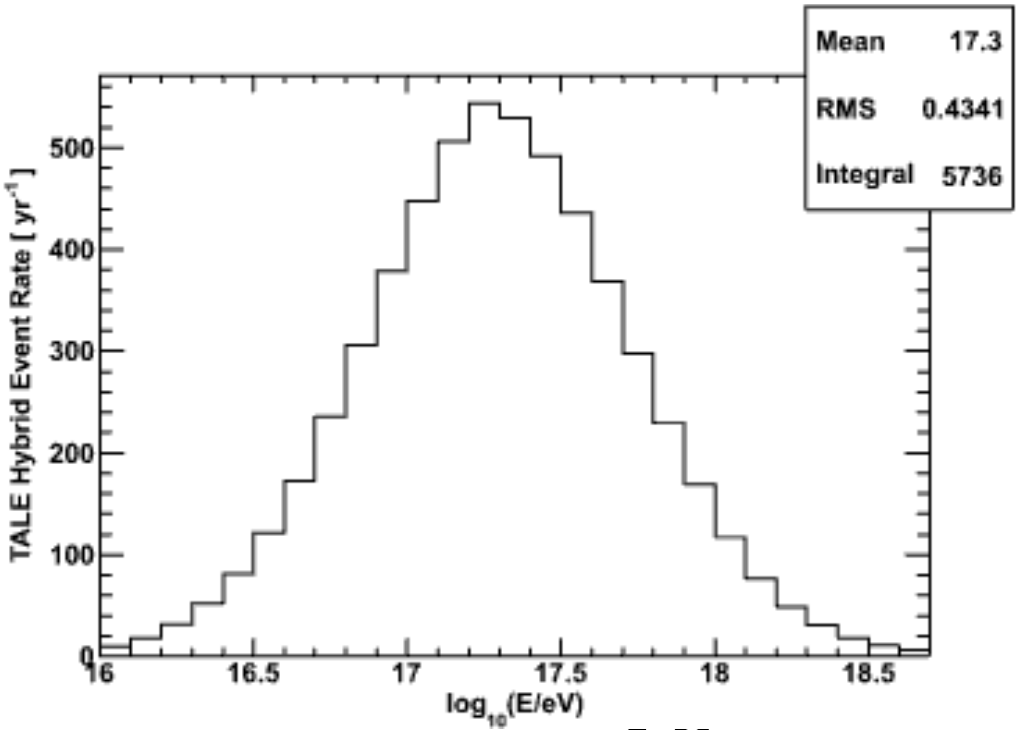
- Presented a TALE measurement of cosmic rays composition
- Data X_{max} distributions were fit to a mix of four primaries (p, He, CNO, Fe)
- Results: Fit primary fractions; mean log (A) calculated from fit primary fractions
- Mean X_{max} variation with shower energy shows a break in the elongation rate at $E = 10^{17.2}$ eV.

BACKUP SLIDES

TALE Fluorescence Detector

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





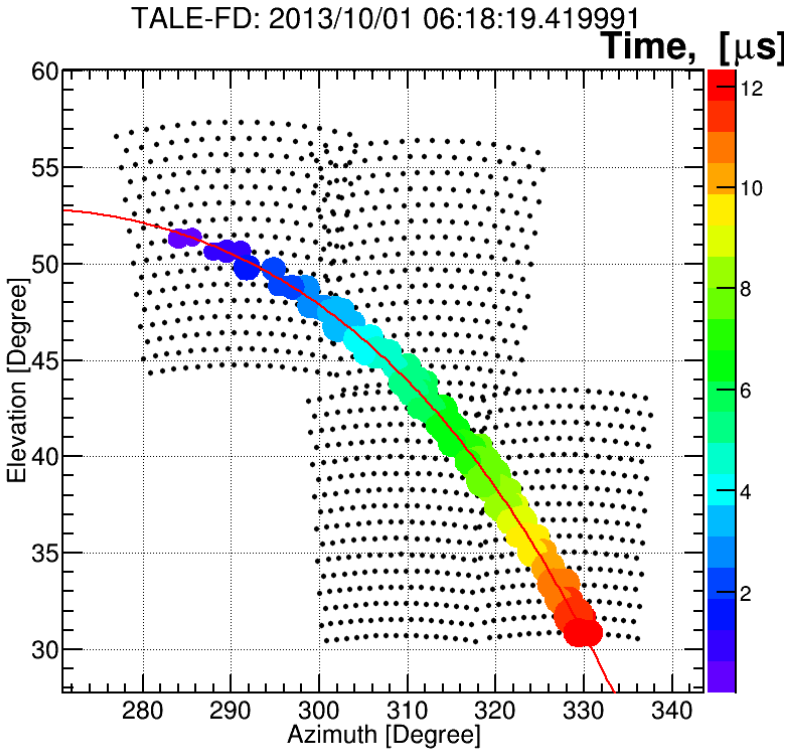
Expected TALE hybrid events per year

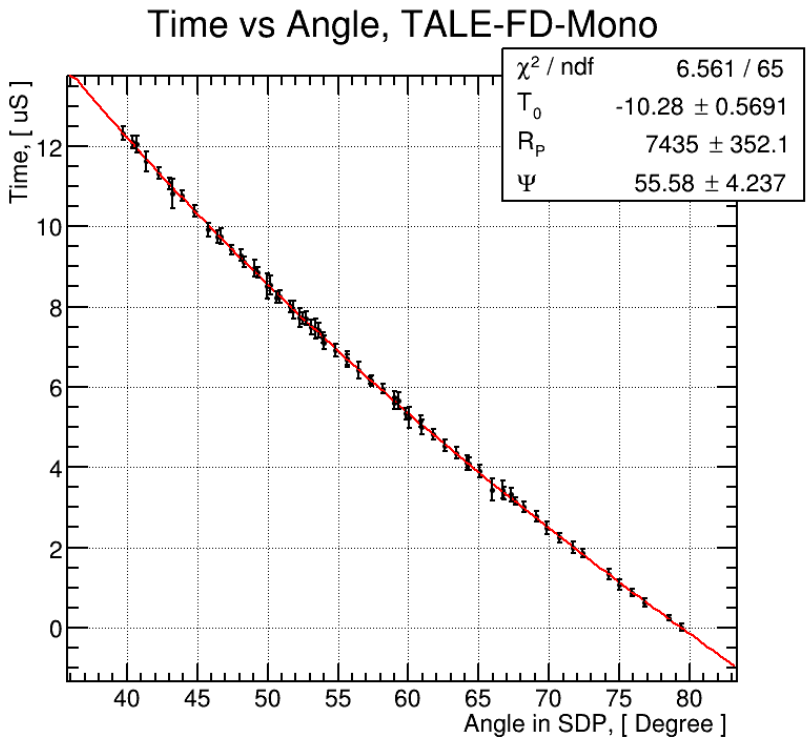
19

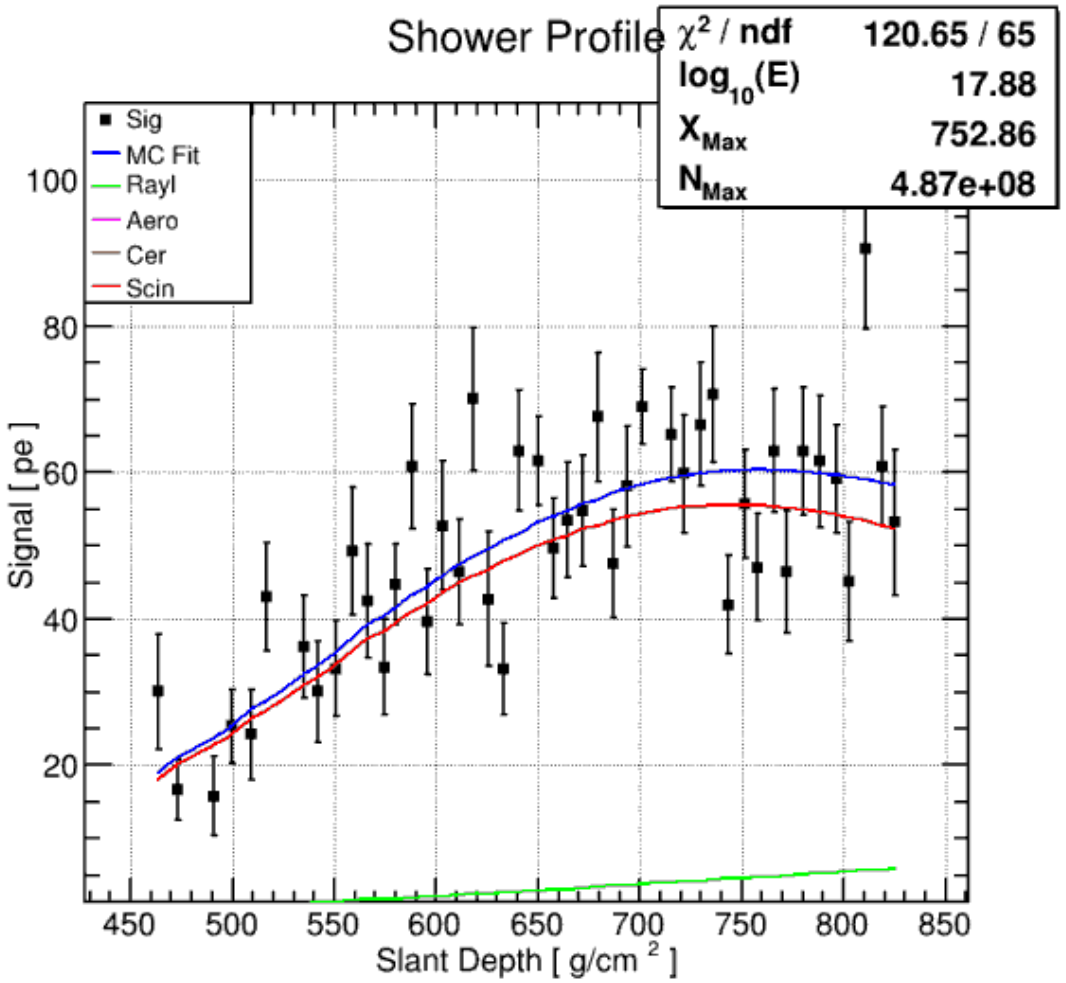
TALE FD Event

For TALE FD reconstruction: we combined the time and profile fit: simultaneous Profile Constrained Geometry Fit (PCFG)

originally developed for HiRes monocular analysis



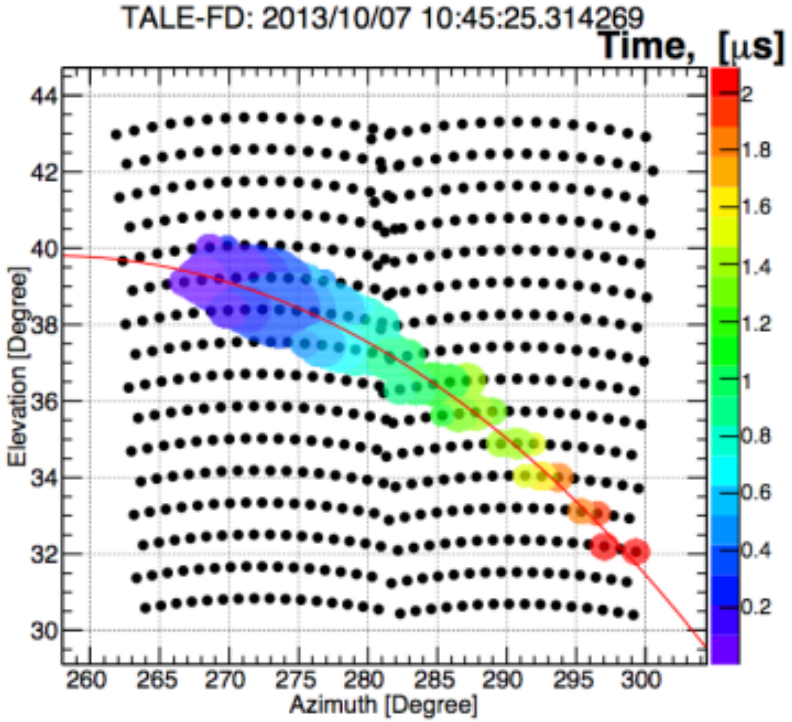


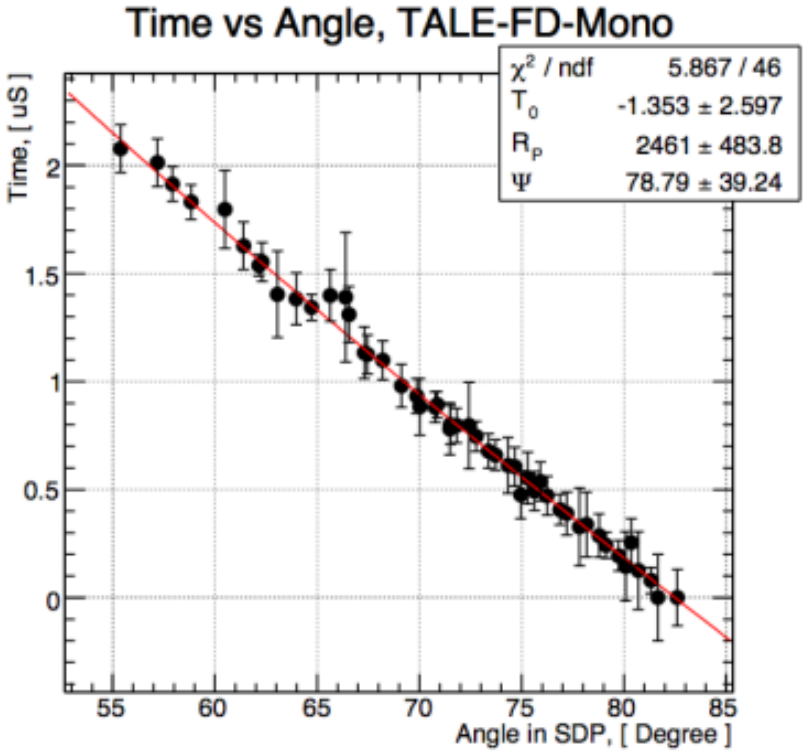


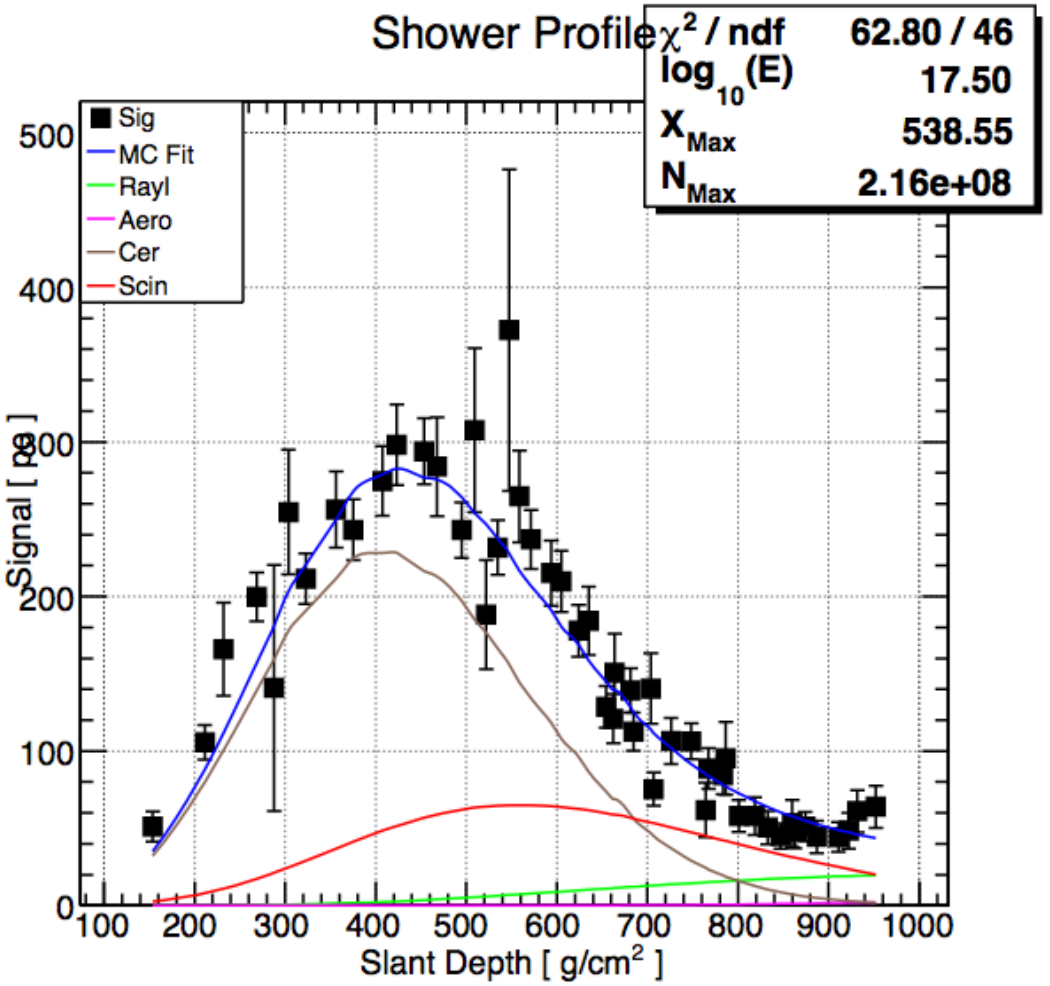
TALE Cherenkov Event

PCGF turns out to work very well on

Cherenkov light dominated events







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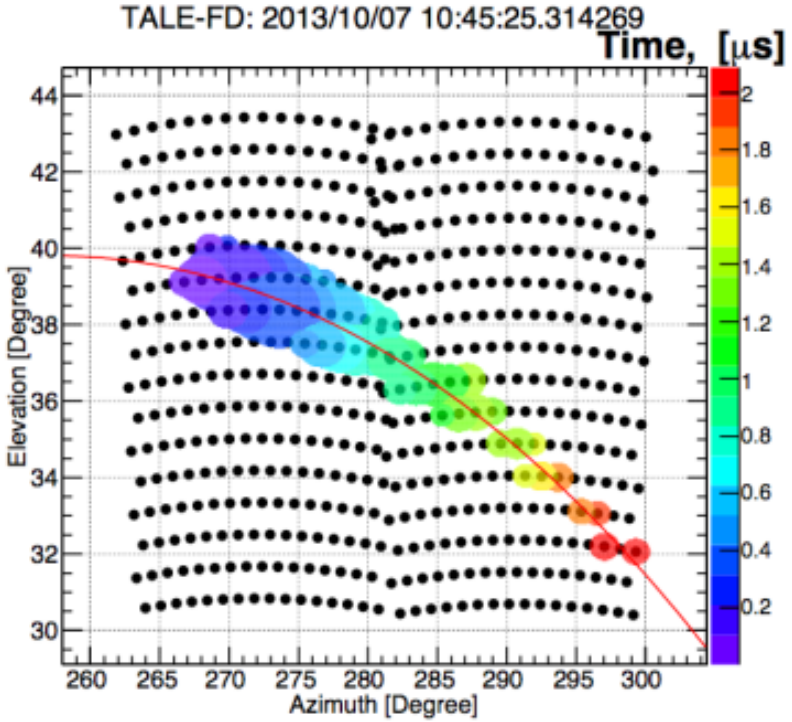
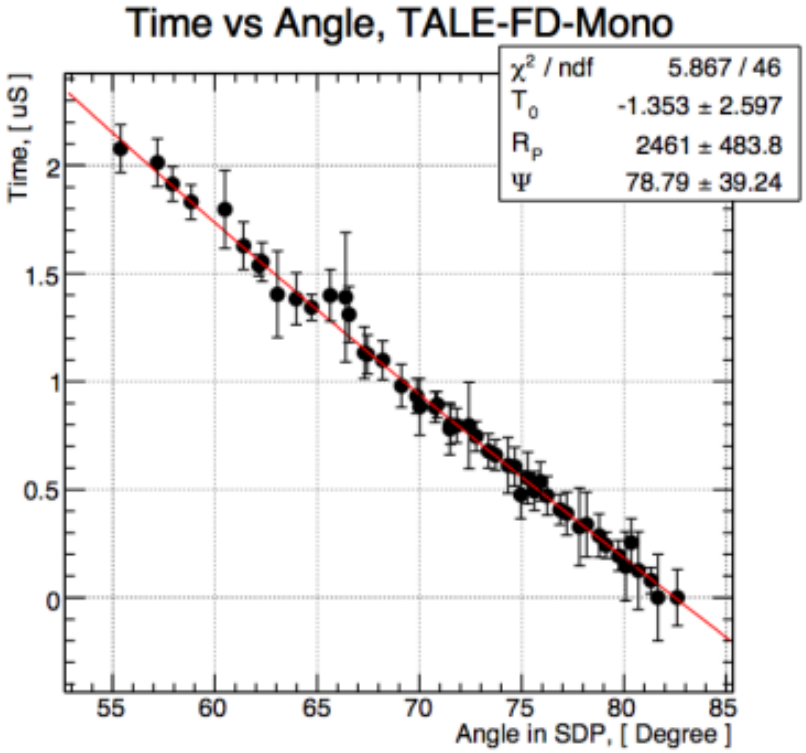
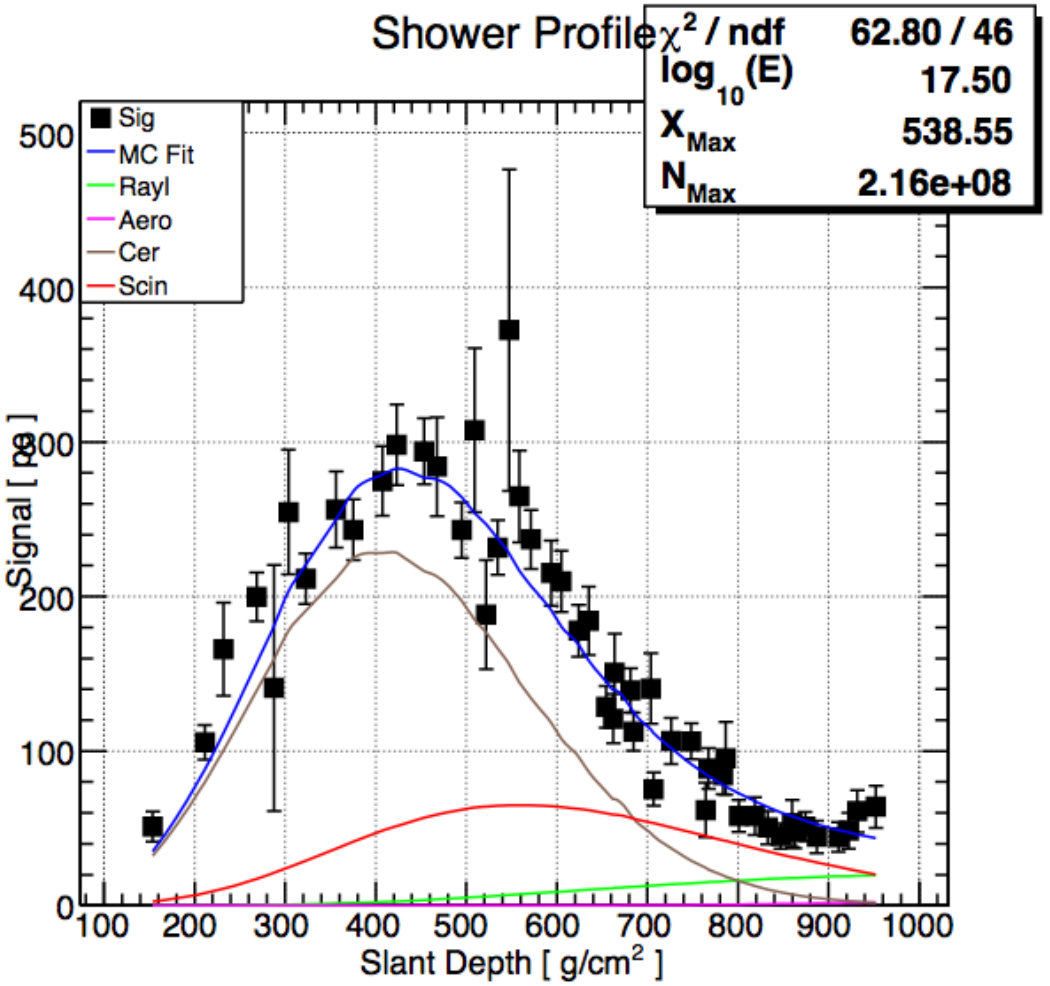
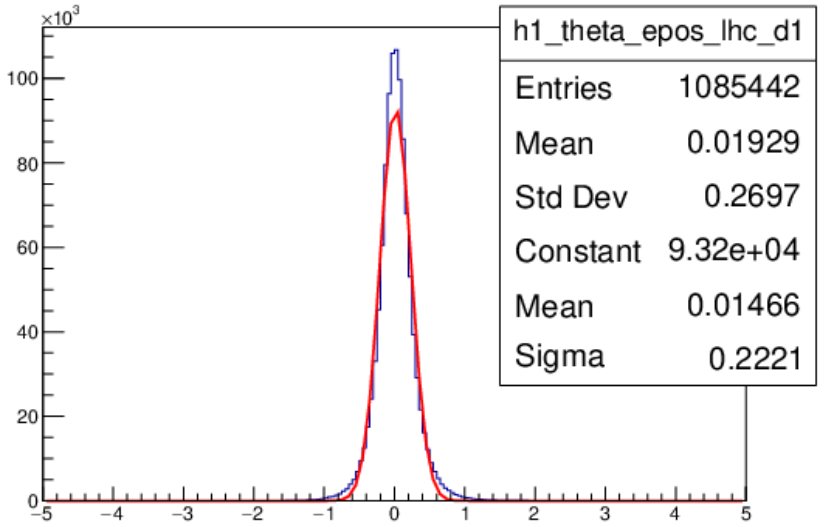


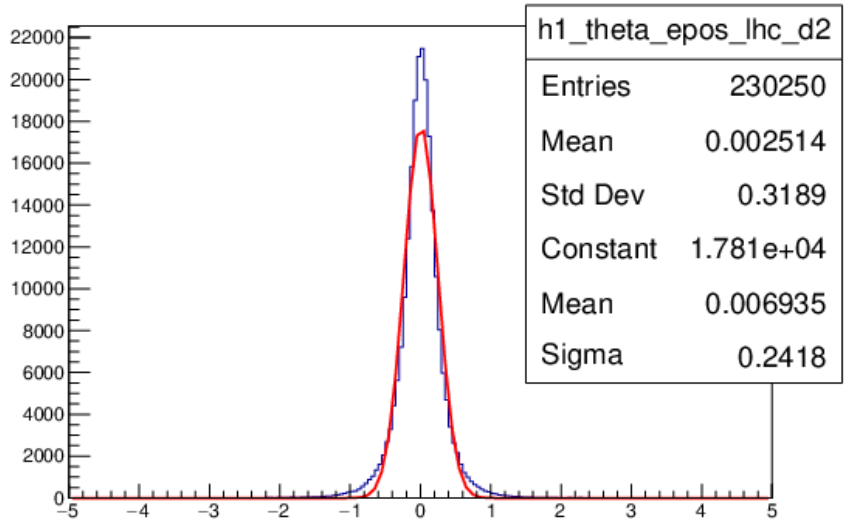


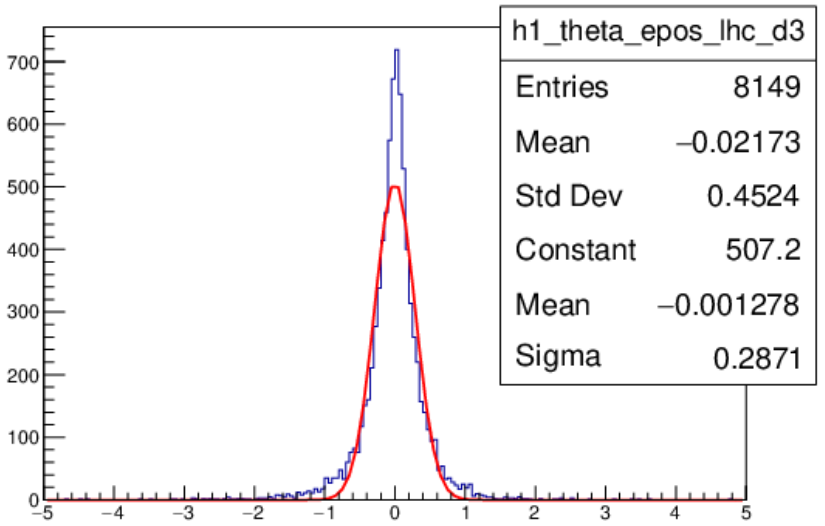


Reconstruction Resolution (Geometry) (3)

- One histogram per decade in energy starting at E = $10^{15.3}$ eV
- Shower Track zenith angle (degree)
- Histogram: $\Delta\theta$ (degree)







Reconstructed MC Primary Fractions (Equal fractions thrown)