TALE Cosmic Rays Composition

Tareq AbuZayyad
for the Telescope Array Collaboration
ICRC 2021
Berlin, Germany
2021/07/13

Outline

- Introduction
- TALE Detector
- Data and Analysis
- Results
- Summary

Introduction

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

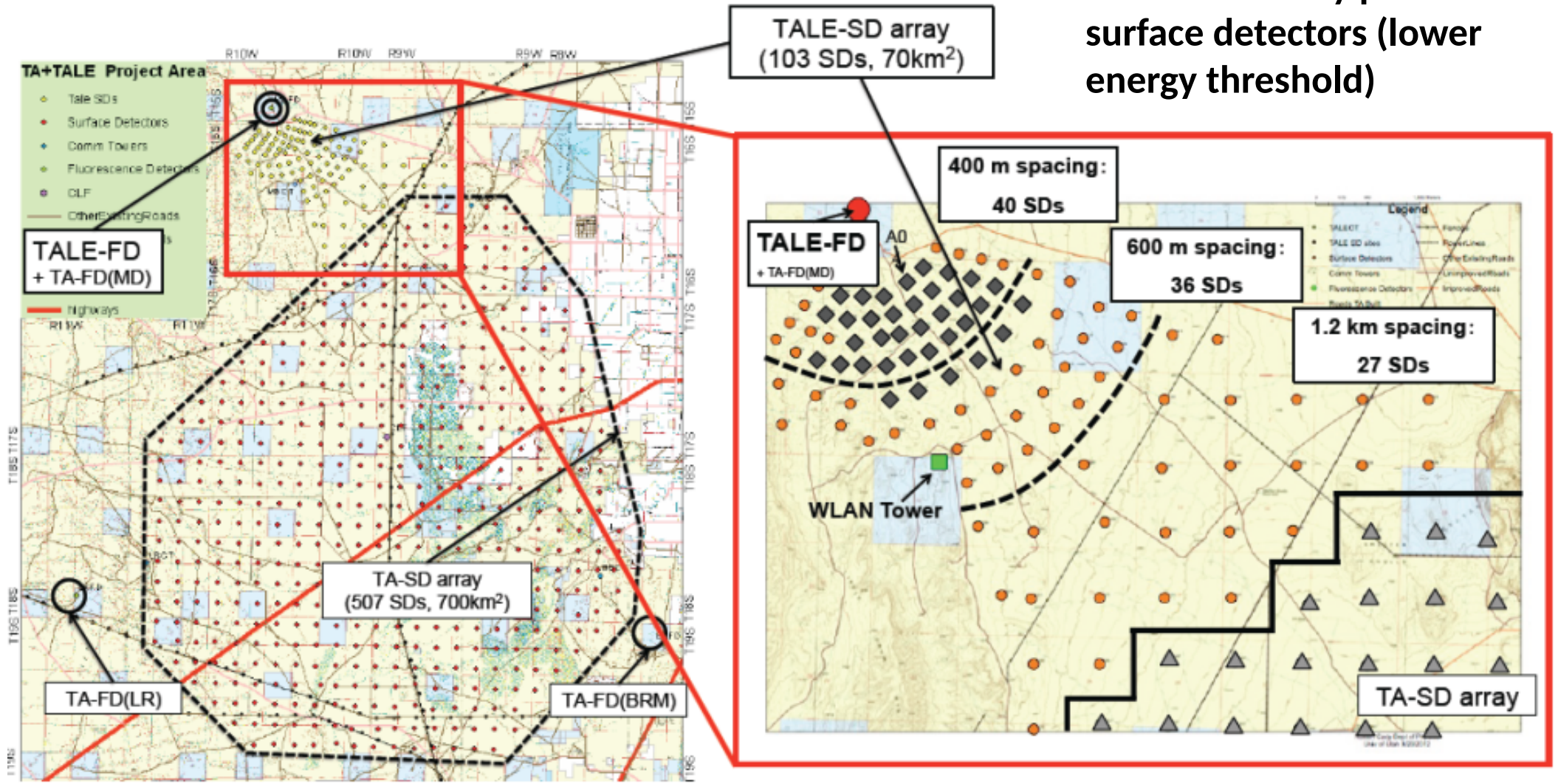
Introduction

- CR composition results based on four years of observation were recently published in Astrophysical Journal: DOI: 10.3847/1538-4357/abdd30
- We will discuss these results, and present updated results using seven years of data (~30% larger data set)

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

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



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

80 scintillation surface detectors deployed:

40 SDs with 400m spacing

40 SDs with 600m spacing

Majority started operations in **summer of 2017**.

Data and Analysis

- TALE FD monocular data (Cherenkov light dominated).
- Data collection period: 06/2014 – 11/2018 (*published*)
  - 2633 hours of observation
- Data collection period: 06/2014 – 04/2021 (*this conference*)
  - 3456 hours of observation
- Monte Carlo: EPOS-LHC hadronic model (using CONEX generator)

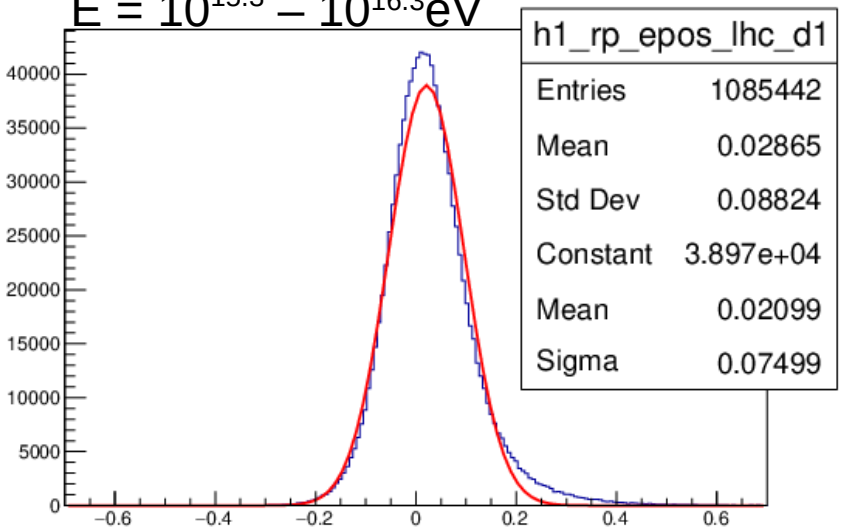
Analysis: Primary Fractions (Xmax Fits)

- Event reconstruction: Shower calorimetric energy (E_{cal}), 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.

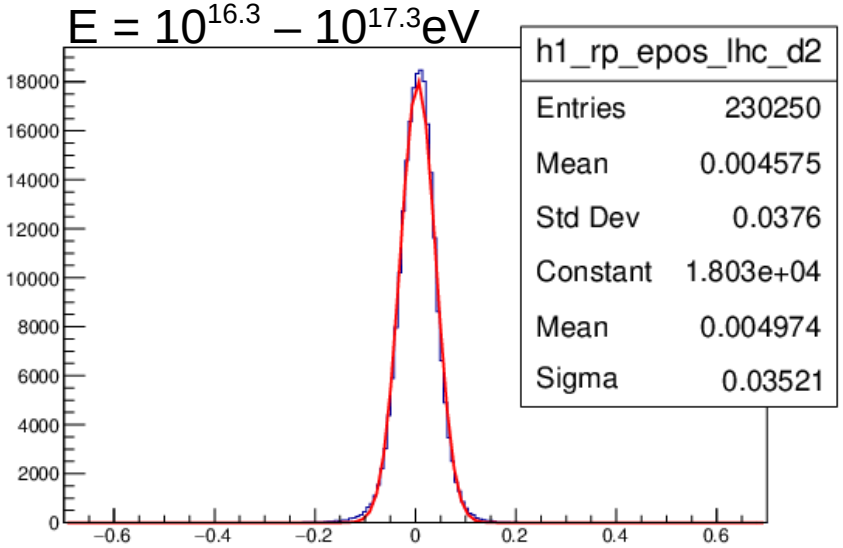
Reconstruction Resolution (Geometry) (1)

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

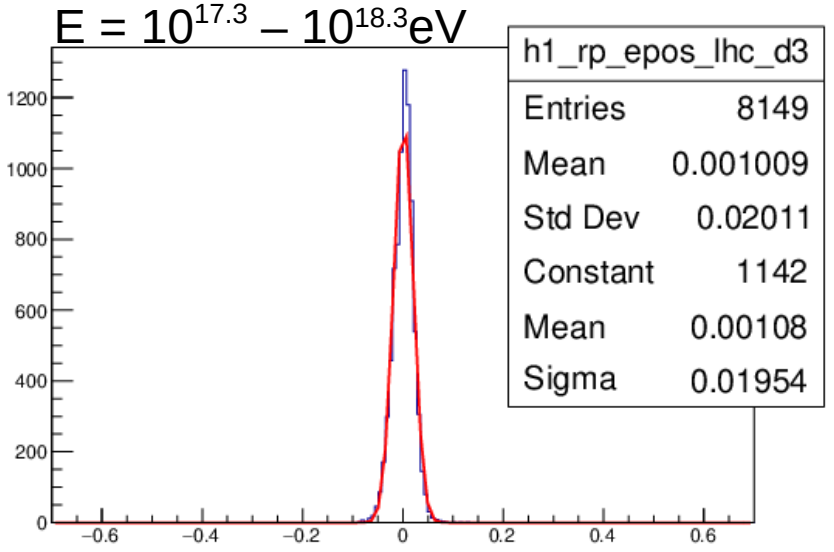
E = $10^{15.3}$ – $10^{16.3}$eV



E = $10^{16.3}$ – $10^{17.3}$eV



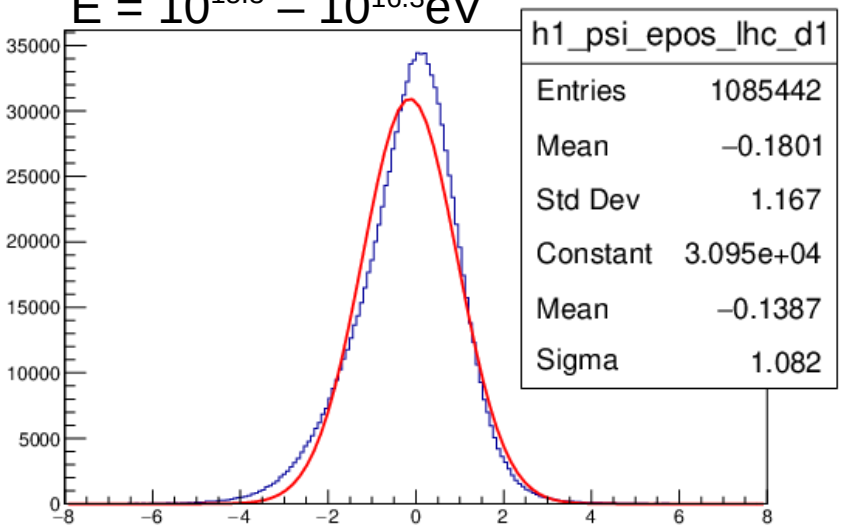
E = $10^{17.3}$ – $10^{18.3}$eV



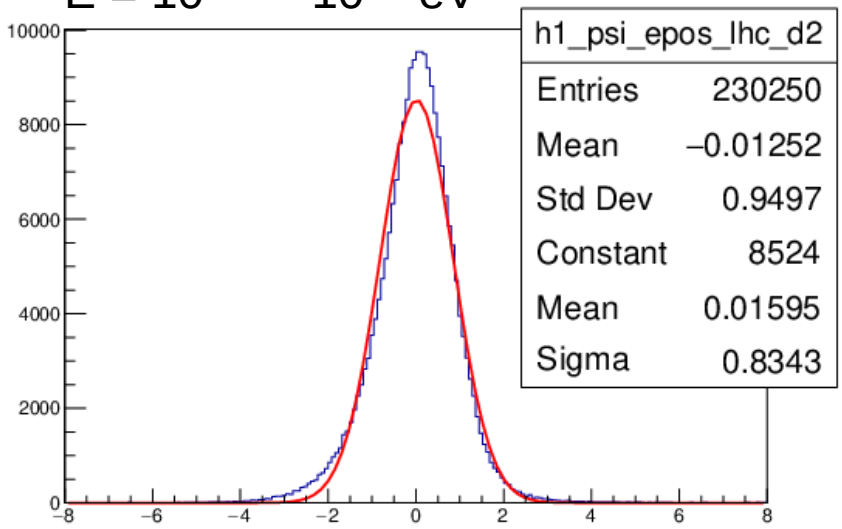
Reconstruction Resolution (Geometry) (2)

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

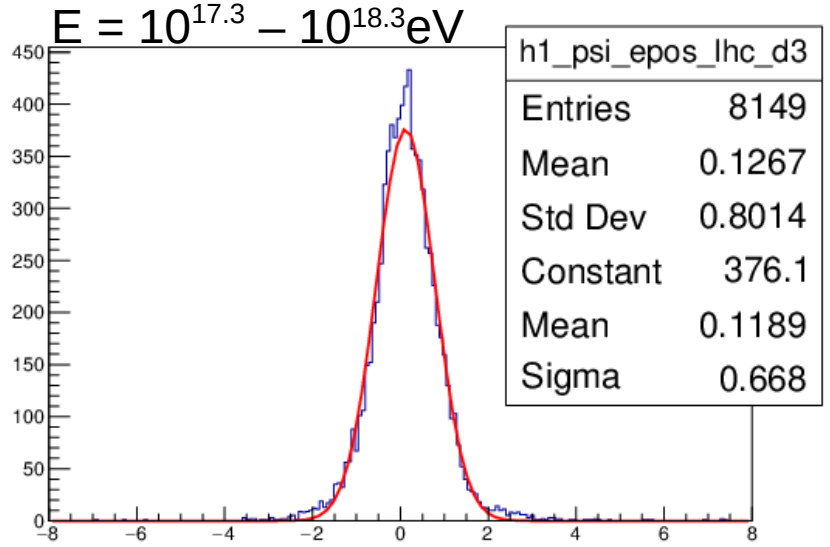
E = $10^{15.3}$ – $10^{16.3}$eV



E = $10^{16.3}$ – $10^{17.3}$eV



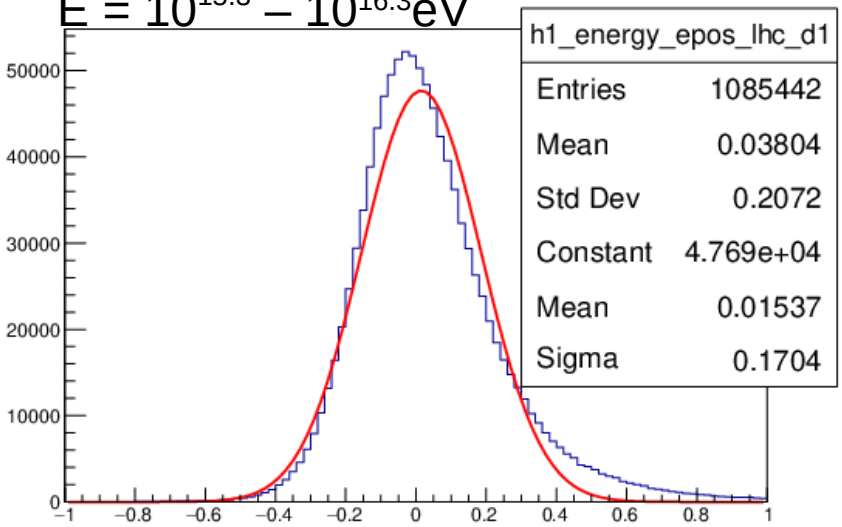
E = $10^{17.3}$ – $10^{18.3}$eV



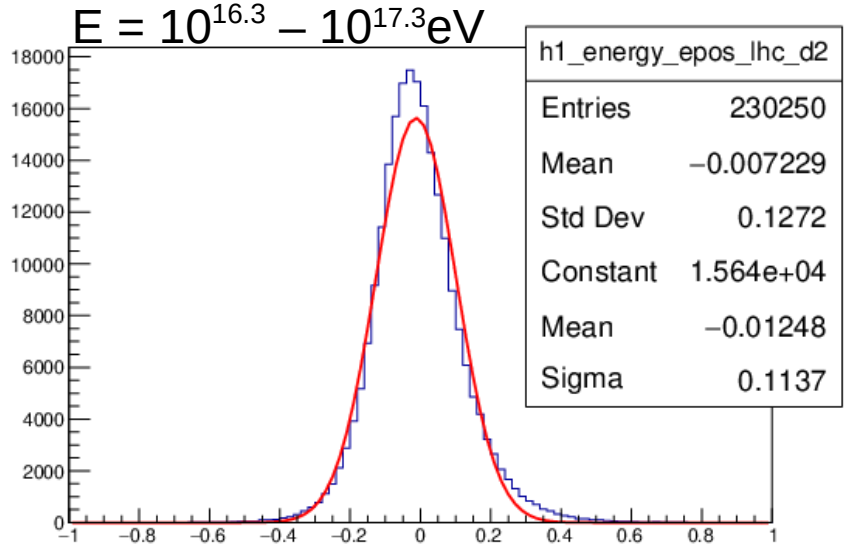
Reconstruction Resolution (Energy)

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

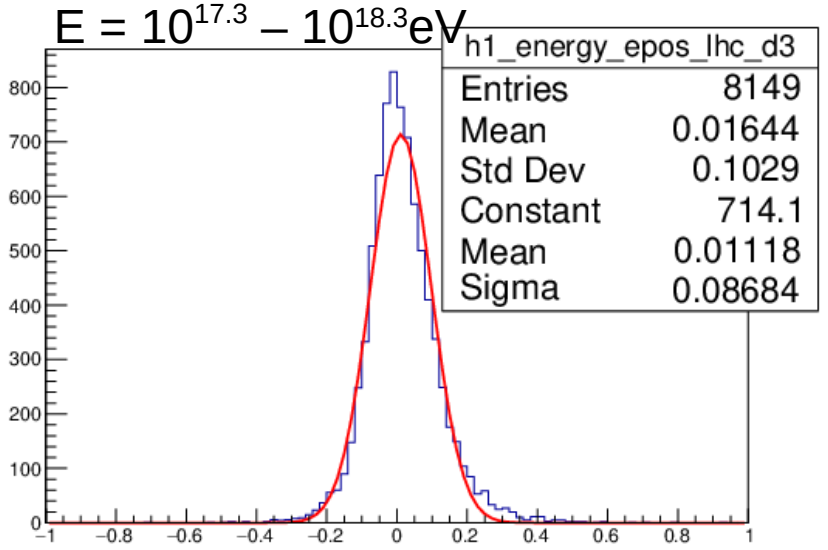
$E = 10^{15.3} – 10^{16.3}$eV



$E = 10^{16.3} – 10^{17.3}$eV



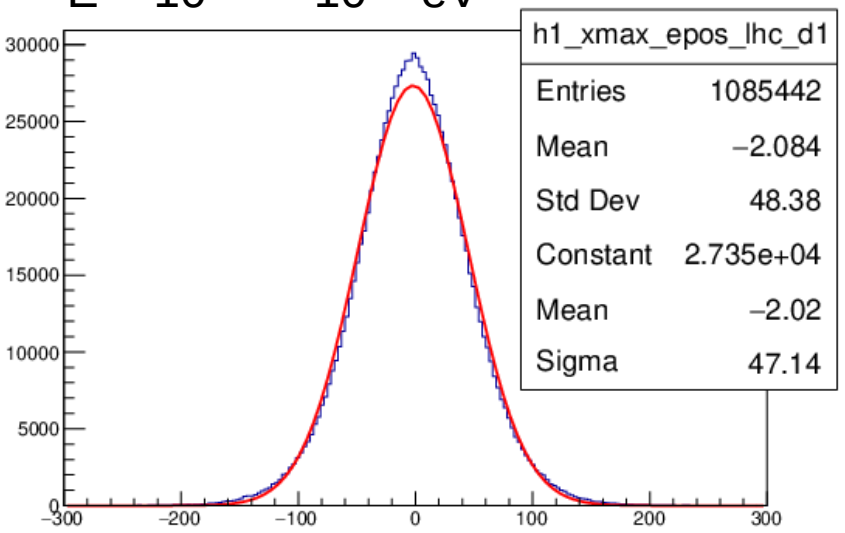
$E = 10^{17.3} – 10^{18.3}$eV



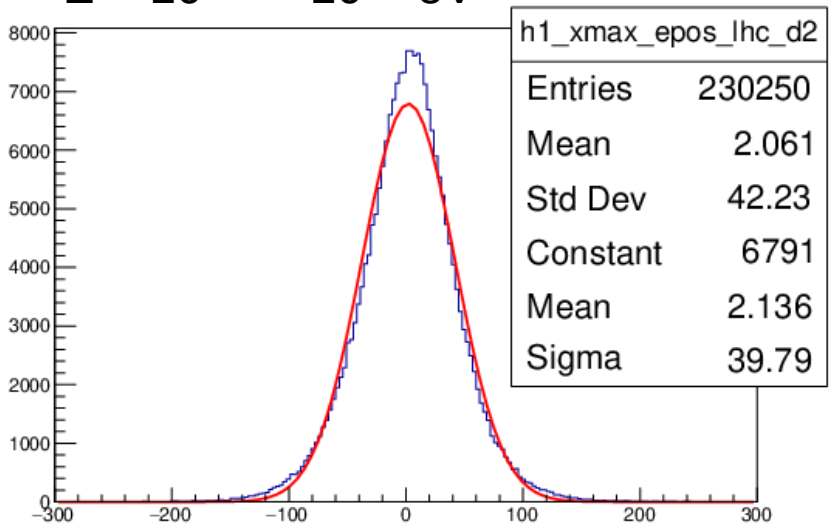
Reconstruction Resolution (Xmax)

- 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]

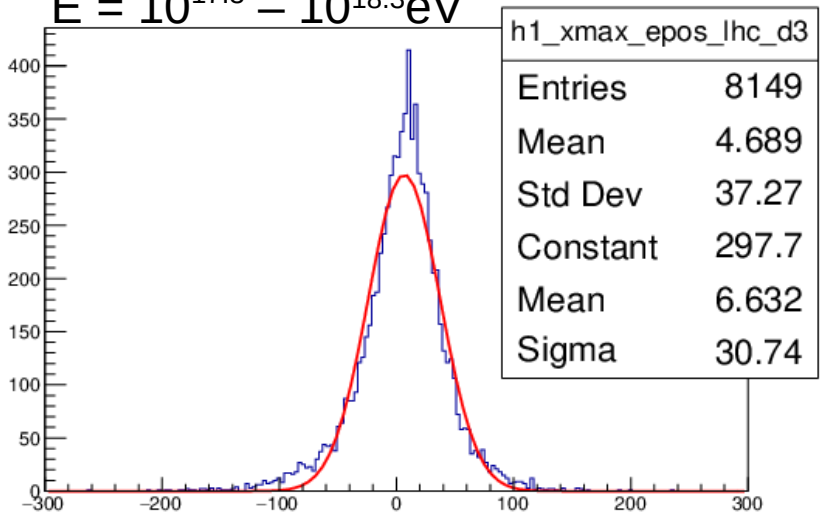
E = $10^{15.3}$ – $10^{16.3}$eV



E = $10^{16.3}$ – $10^{17.3}$eV



E = $10^{17.3}$ – $10^{18.3}$eV

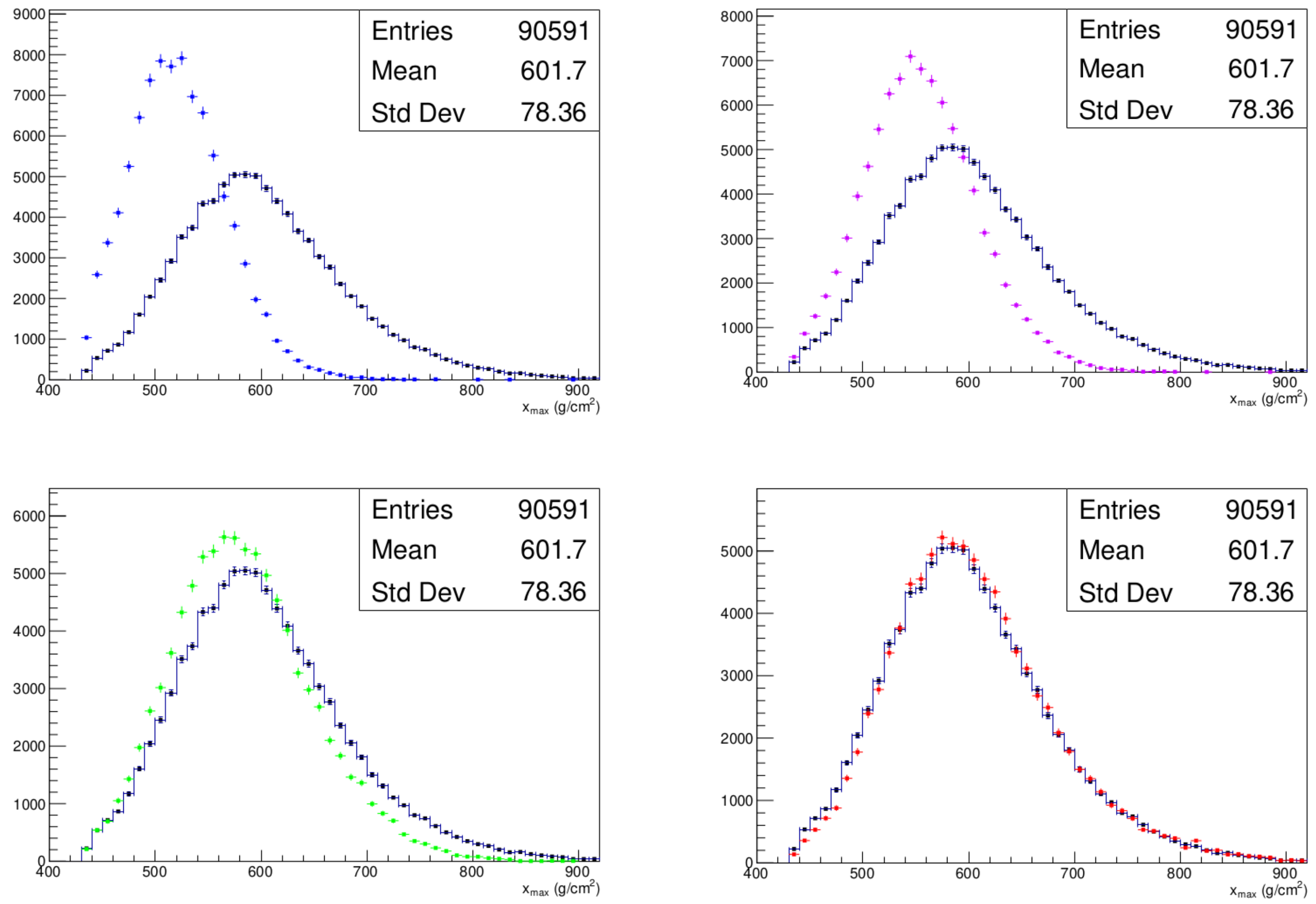


Example X_{max} distributions (1)

- Data and MC events reconstructed with energies in the range of:

$$15.7 < \log_{10}(E_{cal}) < 15.8$$

- All Plots: (Black) **Data**
- Top left: **Iron**
- Top right: **CNO**
- Bottom left: **Helium**
- Bottom right: **Proton**

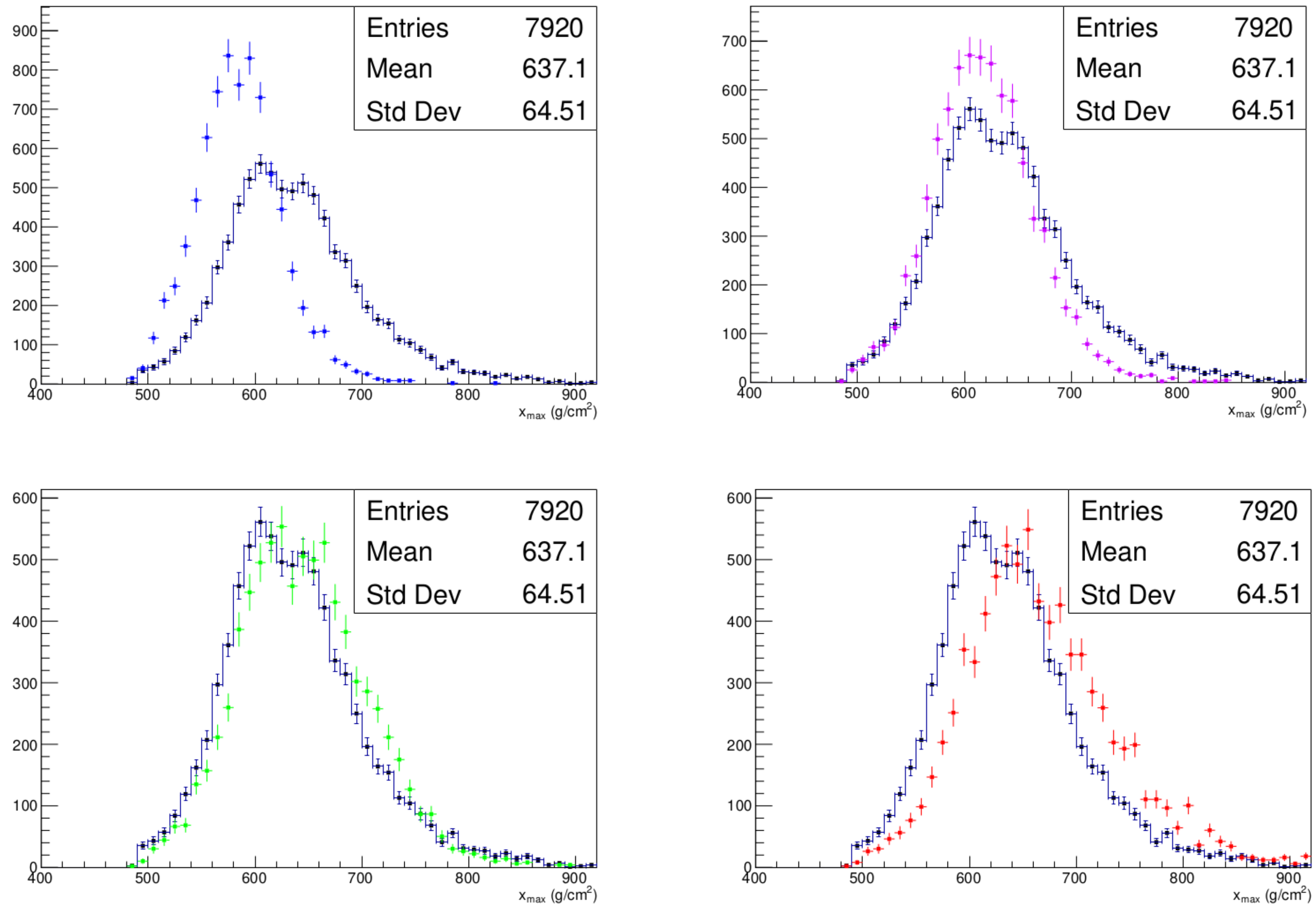


Example X_{max} distributions (2)

- Data and MC events reconstructed with energies in the range of:

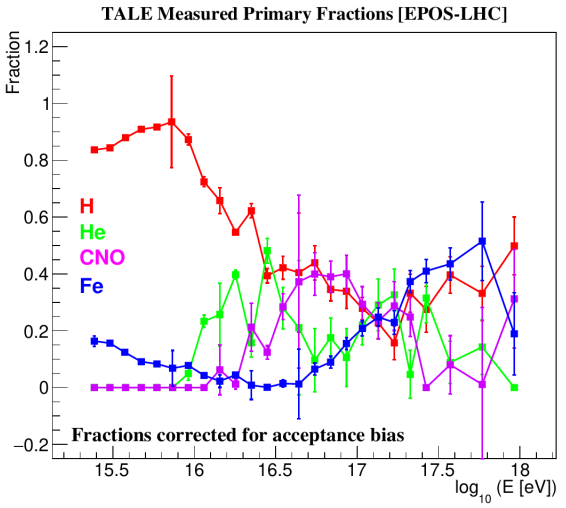
$$16.7 < \log_{10}(E_{cal}) < 16.8$$

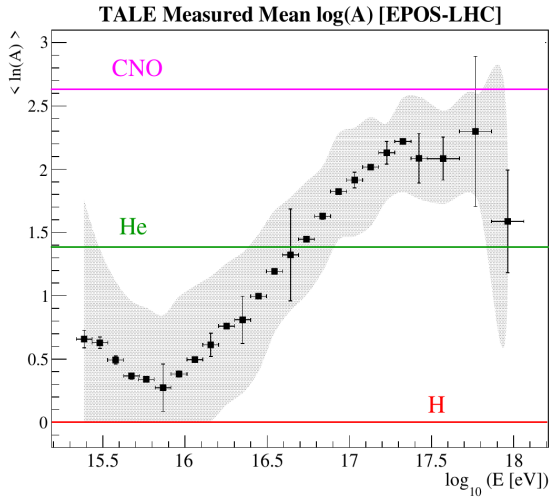
- All Plots: (Black) **Data**
- Top left: **Iron**
- Top right: **CNO**
- Bottom left: **Helium**
- Bottom right: **Proton**



Fit results (EPOS-LHC)

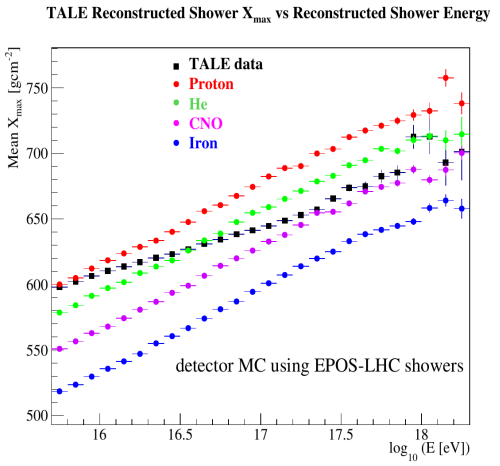
- Published results based on four years of data.
- Lowest Energy bin starts at: $\log_{10}(E_{cal}) = 15.2$
- Mean log(A) calculated as a weighted sum of log(A) for each of 4 fit primaries.
- TALE data <ln (A)> from fractions in top figure.

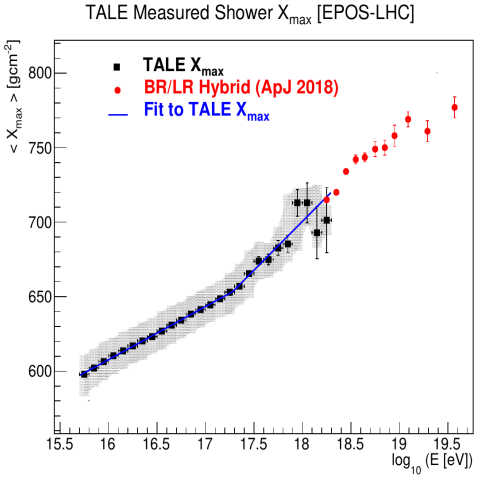




Mean Reconstructed X_{max} vs. Shower Energy

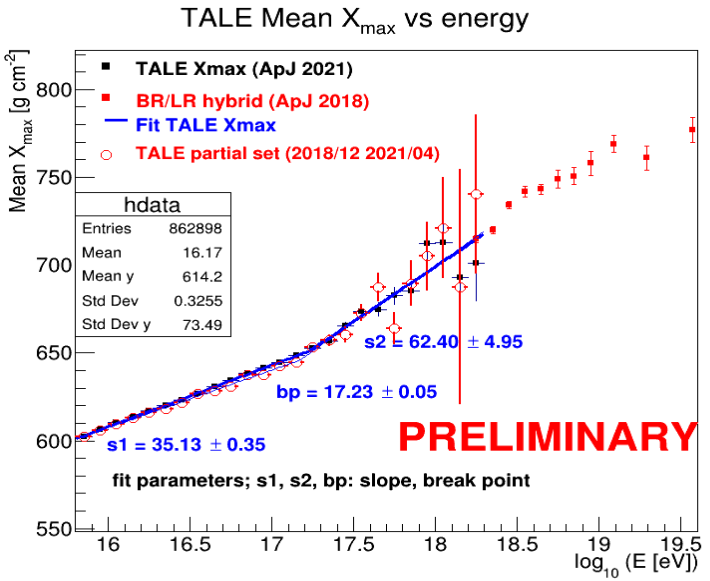
- (Top Figure): Reconstructed Data $<X_{max}>$ vs. Shower total Energy starting at log(E [eV]) = 15.3
  - Also shown, results for 4 MC primaries.
- (Bottom Figure): A broken line fit to TALE data $<X_{max}>$
  - Break point: 17.23 +/- 0.05
  - Slope before: 35.13 +/- 0.35
  - Slope after: 62.40 +/- 4.95
- (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.

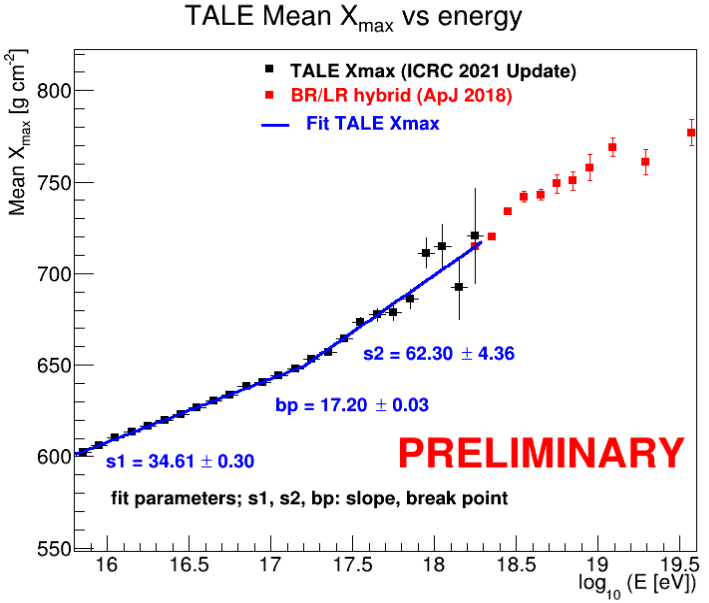




Mean Reconstructed X_{max} vs. Shower Energy

- Including data collected between 2018/12 through 2021/04
- (Top Figure): New Data $<X_{max}>$ compared to published data (2014/06-2018/11)
- (Bottom Figure): All data along with updated broken line fit to data $<X_{max}>$
- (Both Figures): 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;
  - Updated through April 2021
- 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.