

# Cosmic Rays Energy Spectrum measured by the TALE Detector

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for

The Telescope Array Collaboration

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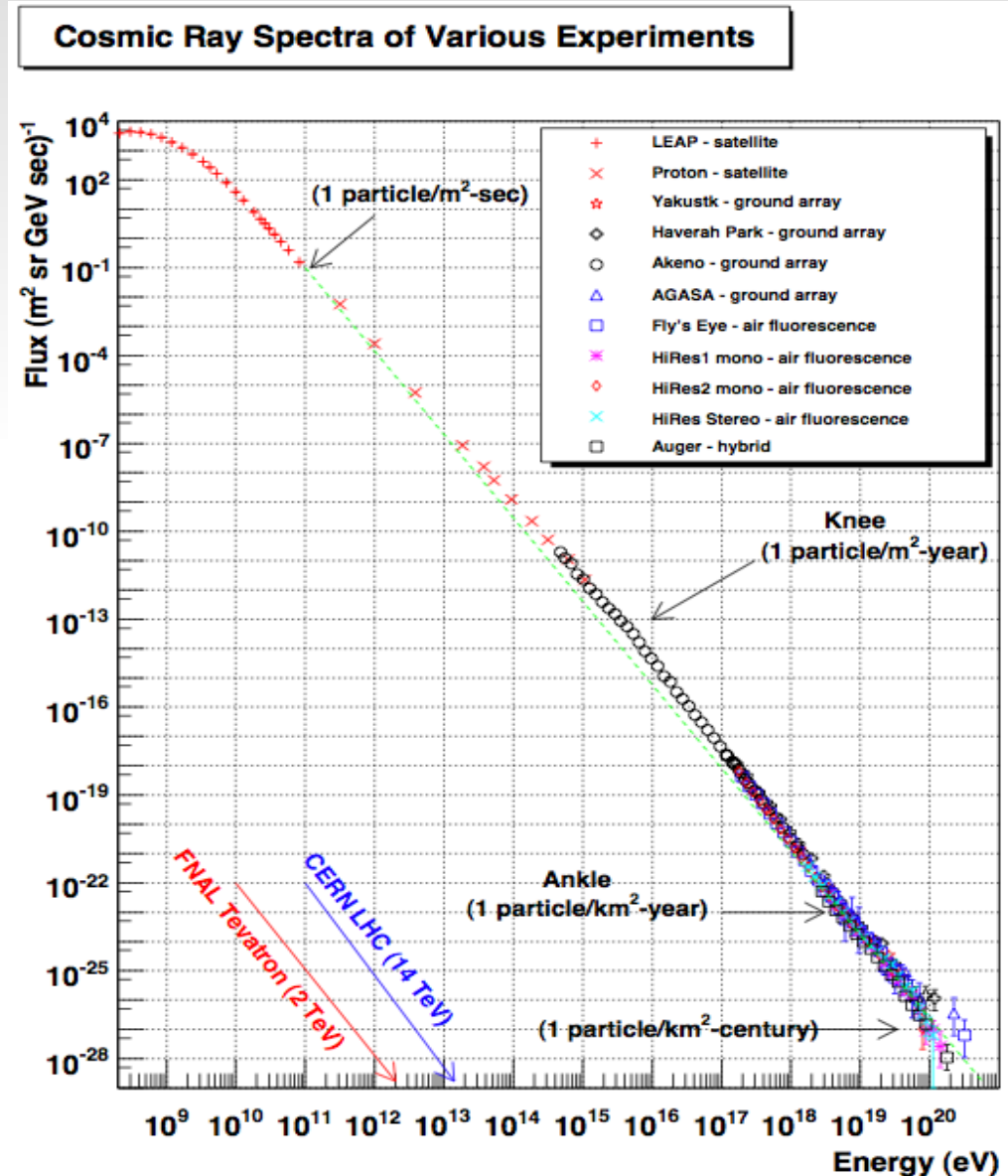


# Outline

- **TA Low Energy extension (TALE) Fluorescence Detector.**
- Spectrum data.
- Energy Spectrum
- Summary.

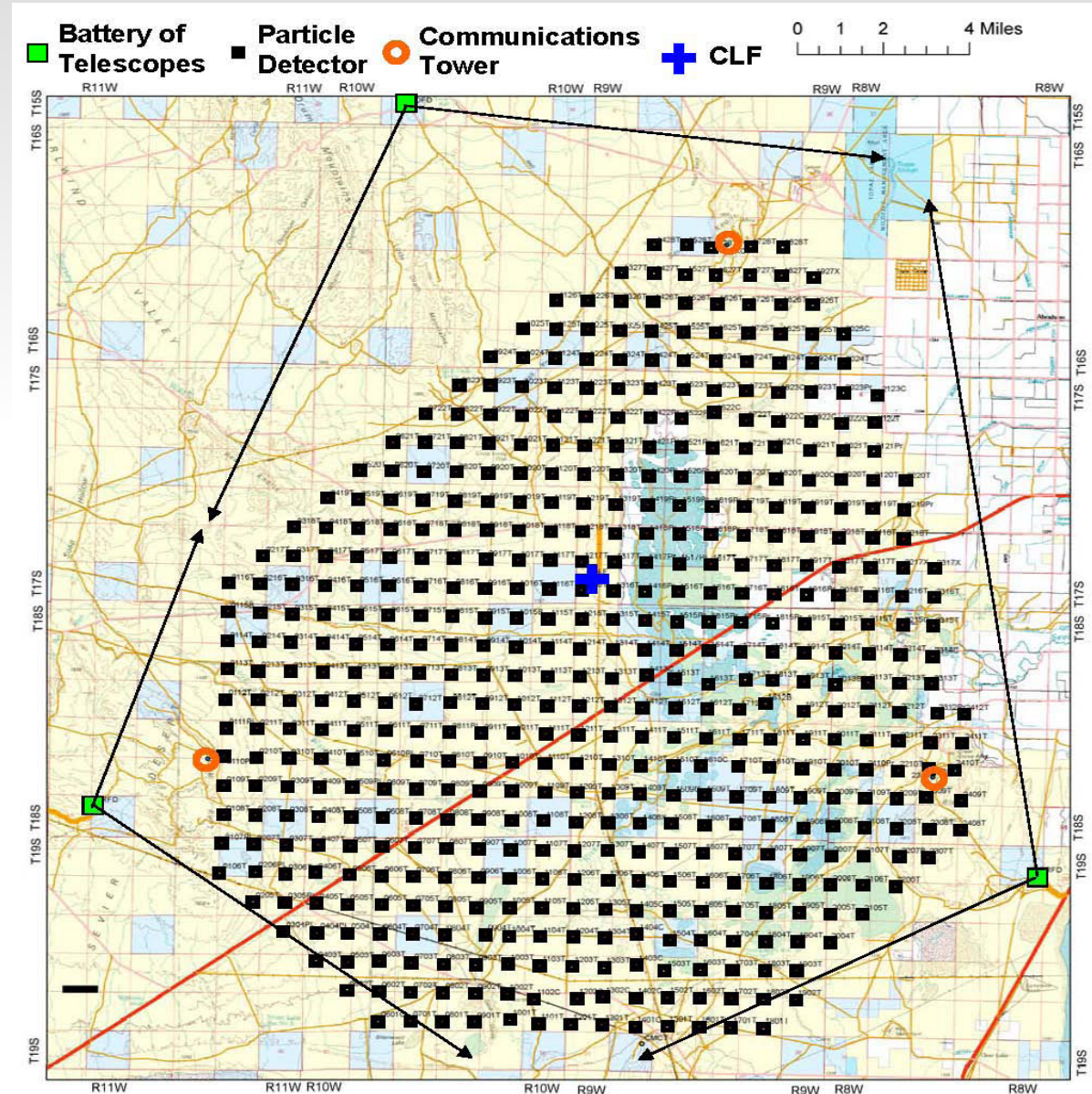
# Telescope Array Experiment

- The Telescope Array (TA) experiment was originally designed for the study of ultra high energy (above  $\sim 1 \times 10^{18}$  eV) cosmic rays.
- TA Low Energy extension (TALE) aims to lower the energy threshold of the experiment to well below  $10^{17}$  eV.



# Telescope Array Experiment

- TA is located in Millard County, Utah, ~200 km southwest of Salt Lake City.
- Surface Detector: 507 scintillation counters 1.2 km spacing.
- Three Fluorescence Detectors overlooking SD:
  - Middle Drum (MD)
  - Black Rock (BR)
  - Long Ridge (LR)

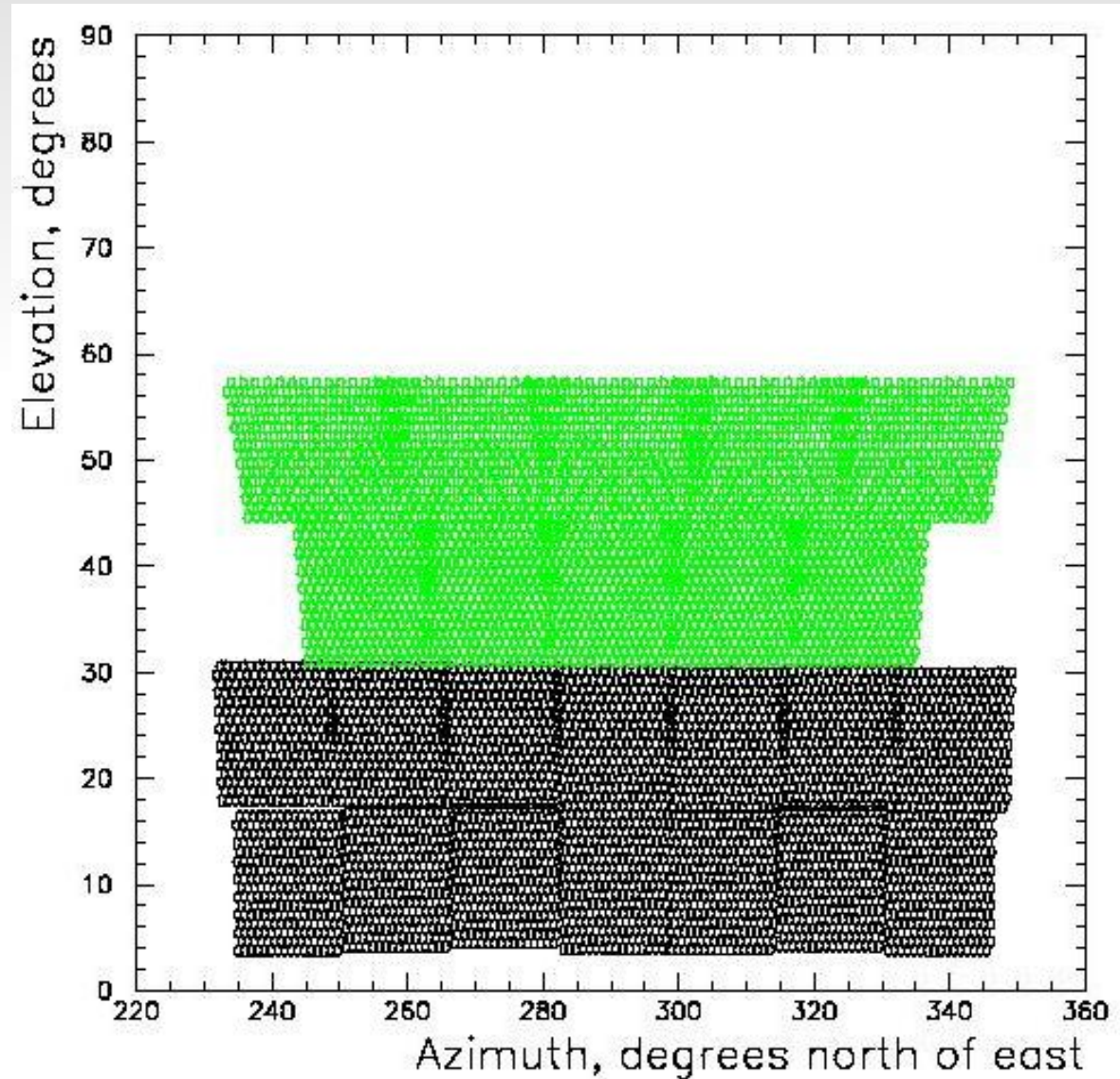


# Middle Drum TALE Observatory Site (14+10 Telescopes)



# Middle Drum TA/TALE Viewing Range

- TAMD + TALE
- 14 lower pointing telescopes make up TA (Middle Drum) Detector.
- 10 higher pointing telescopes make up the TA-Low Energy extension Detector (Rings 3 & 4).
- TALE telescopes equipped with (HiRes2) FADC electronics.



# Spectrum data

# TALE Data collection period

- Data set goes from 06/20/2014 to 03/31/2016 (*22 months*)
- Good weather selection “clear overhead” + “no haze”
  - A comparison of event data rates vs. MC expectation is used to determine periods of significant attenuation due to haze.
- Total on-time **1080.0 hours**.
- For data analysis we define three data epochs, as explained on next slide.
- Energy Spectrum presented in this talk is based on data collected during epochs 2 & 3. (epoch 1 lacks nightly gain calibration)



# Data Epochs

Epoch	Start	End	PMT Gain	Trigger Gain	Moments / Clusters
1	09 / 2013	01 / 2014	0.63	1.0	Yes
2	06 / 2014	01 / 2015	1.0	0.63	Yes
3	01 / 2015	current	1.0	0.63	No

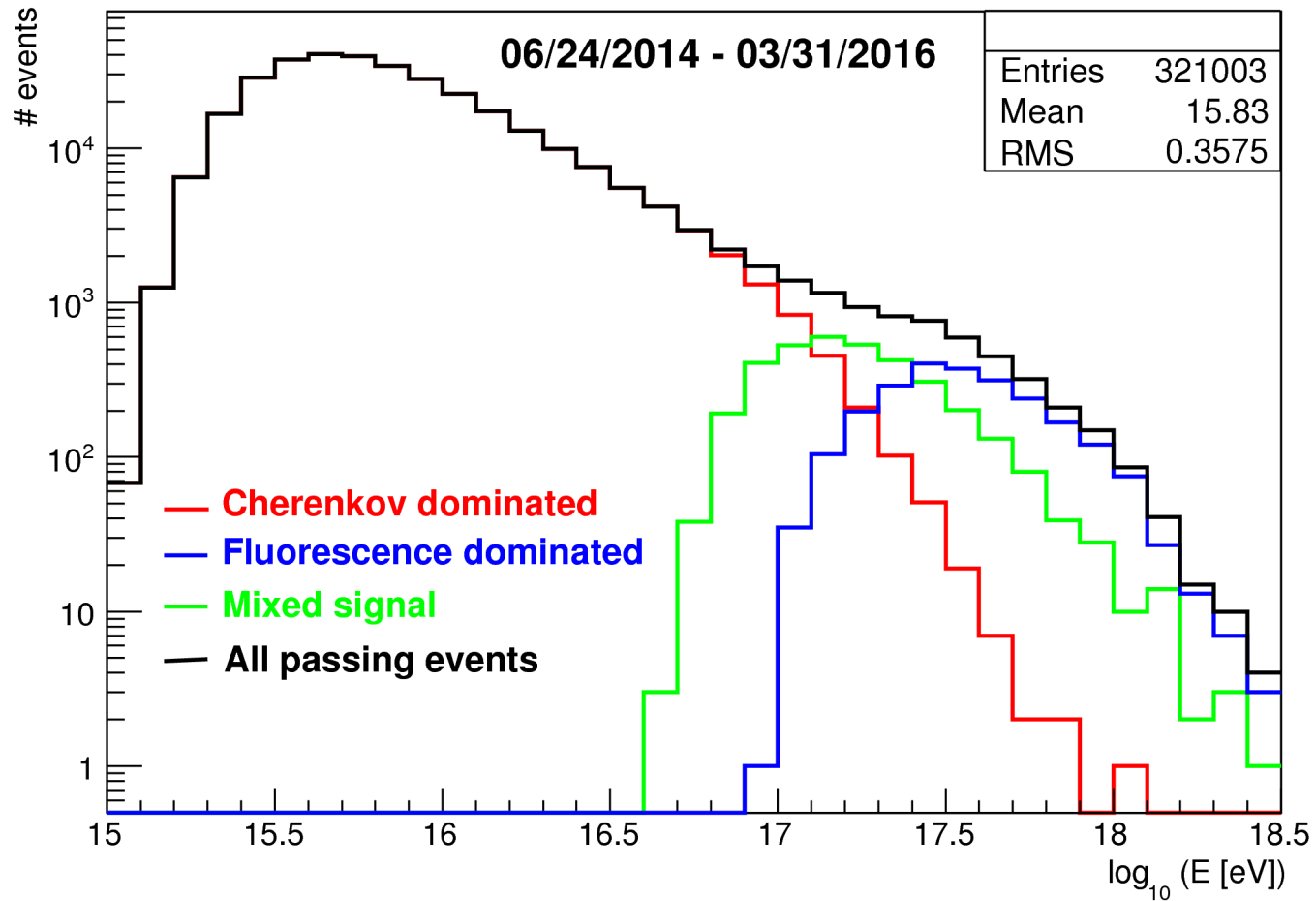
- Note changed gain settings (epoch 1 & 2)
- Note disabled “C'kov blast filter” (epoch 2 & 3)
- Moments / Clusters: High level trigger, meant to reject triggers based on trigger pattern (main use is to reject C'kov blasts.)

# Data Division (Event energy/type)

- Once an observed event is reconstructed it can be placed into one of three subsets:
  - Cherenkov dominated events (C'kov > 75% of total)
  - Fluorescence dominated events (Scin. > 75% of total)
  - Mixed signal events (All other events).
- The three subsets span different but overlapping energy ranges.
- Different, appropriate, event selection criteria (quality cuts) are applied to each set.
- A combined set is used to measure the energy spectrum.

# Event subsets

Energy distribution of TALE event subsets

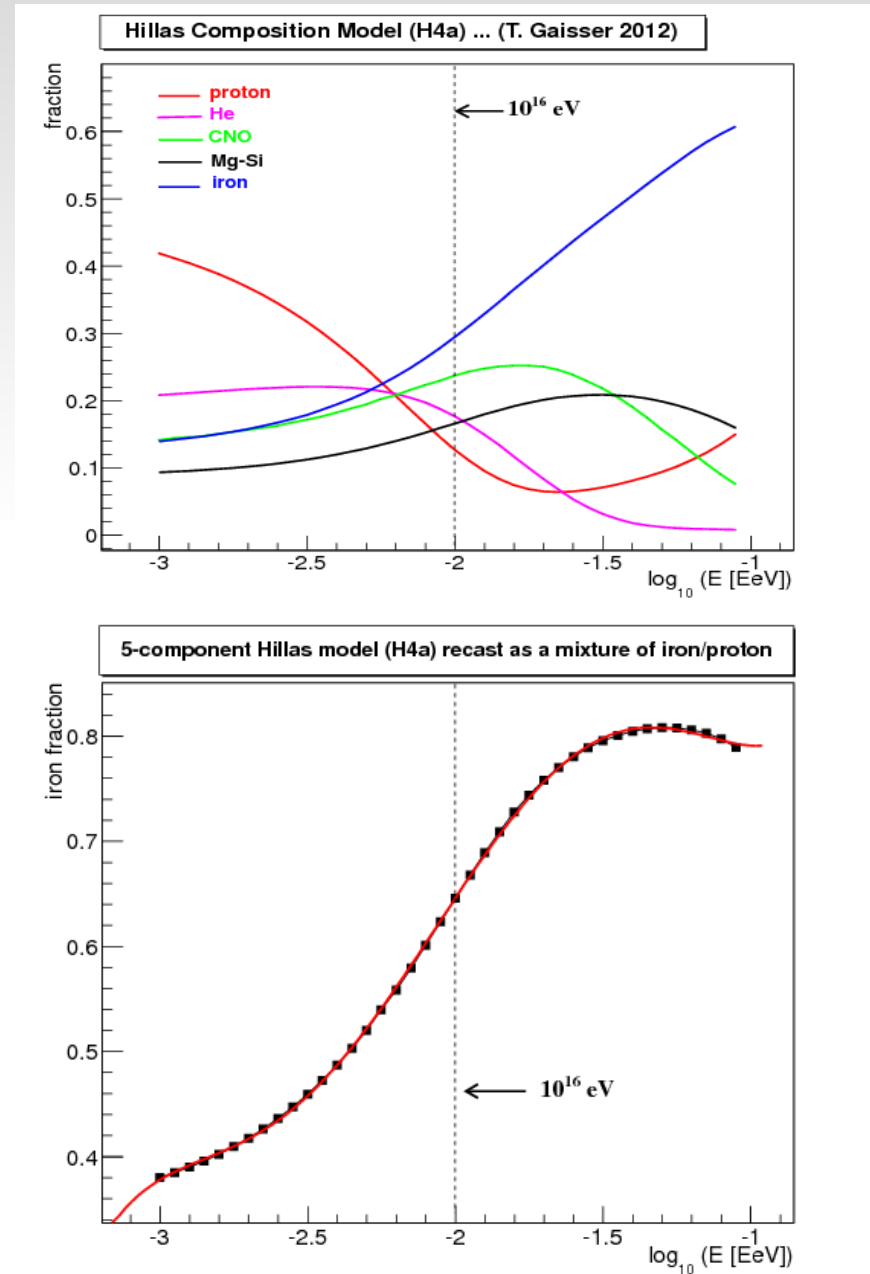


# Spectrum Calculation

- Aperture Calculation (Simulation):
  - Shower library created with CONEX and the **QGSJetII-03** model.
  - Mixed Composition following the **H4a model**
- Detector simulation:
  - Hourly atmospheric profile (**GDAS**).
  - Actual Mirror live-times (for each data part)
  - Nightly PMT Gains from DB (using UVLED data collected at the start of the run)
  - Noise background raised (from epoch1) but still no time dependence.
- Event reconstruction:
  - Monocular (profile constrained fit)
  - Nightly gain calibration.

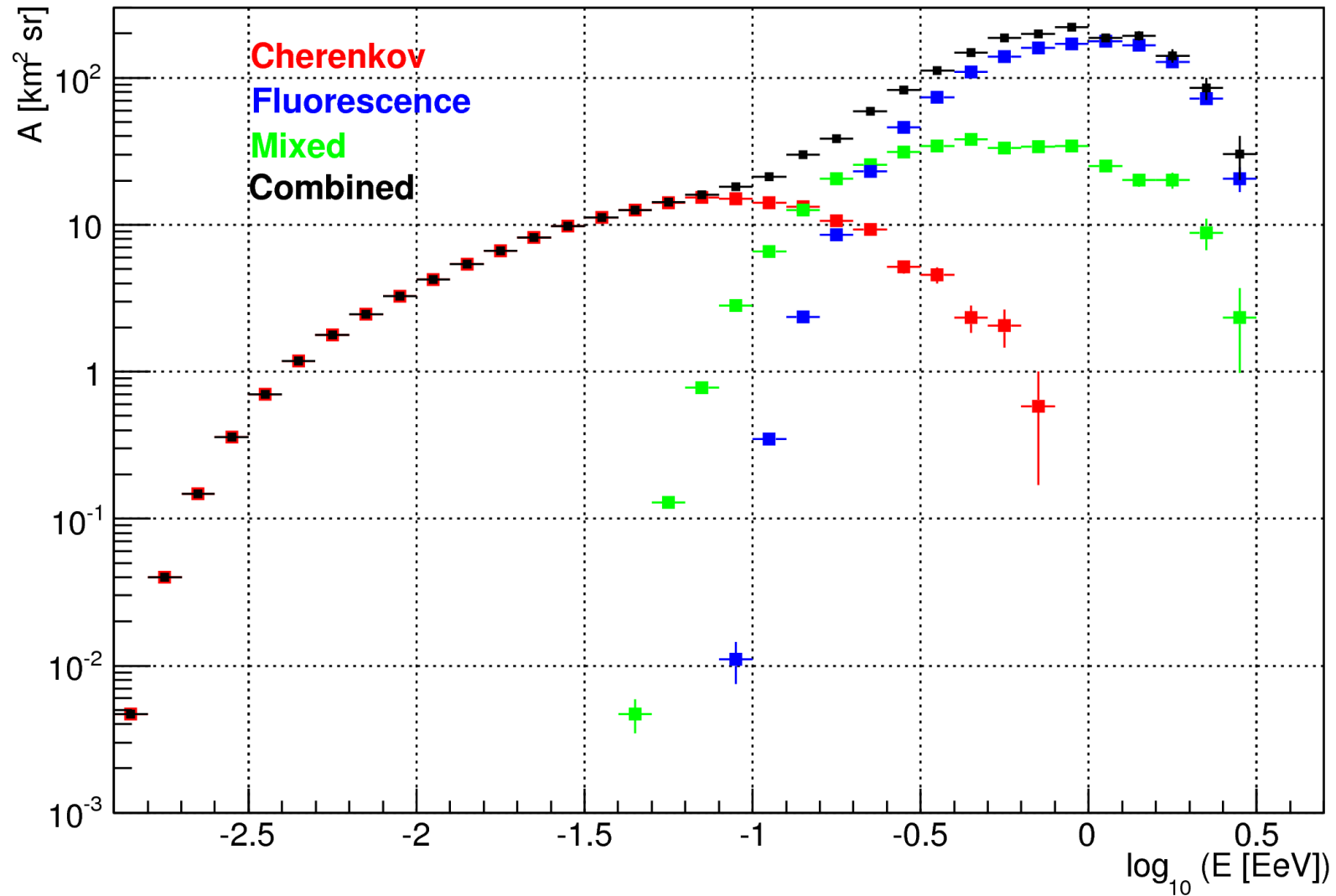
# Composition Assumption

- H4a composition model by T. Gaisser [arXiv:1111.6675v2]
- In the second plot intermediate nuclei are assigned to either proton or iron components based on their atomic mass.



# TALE Aperture

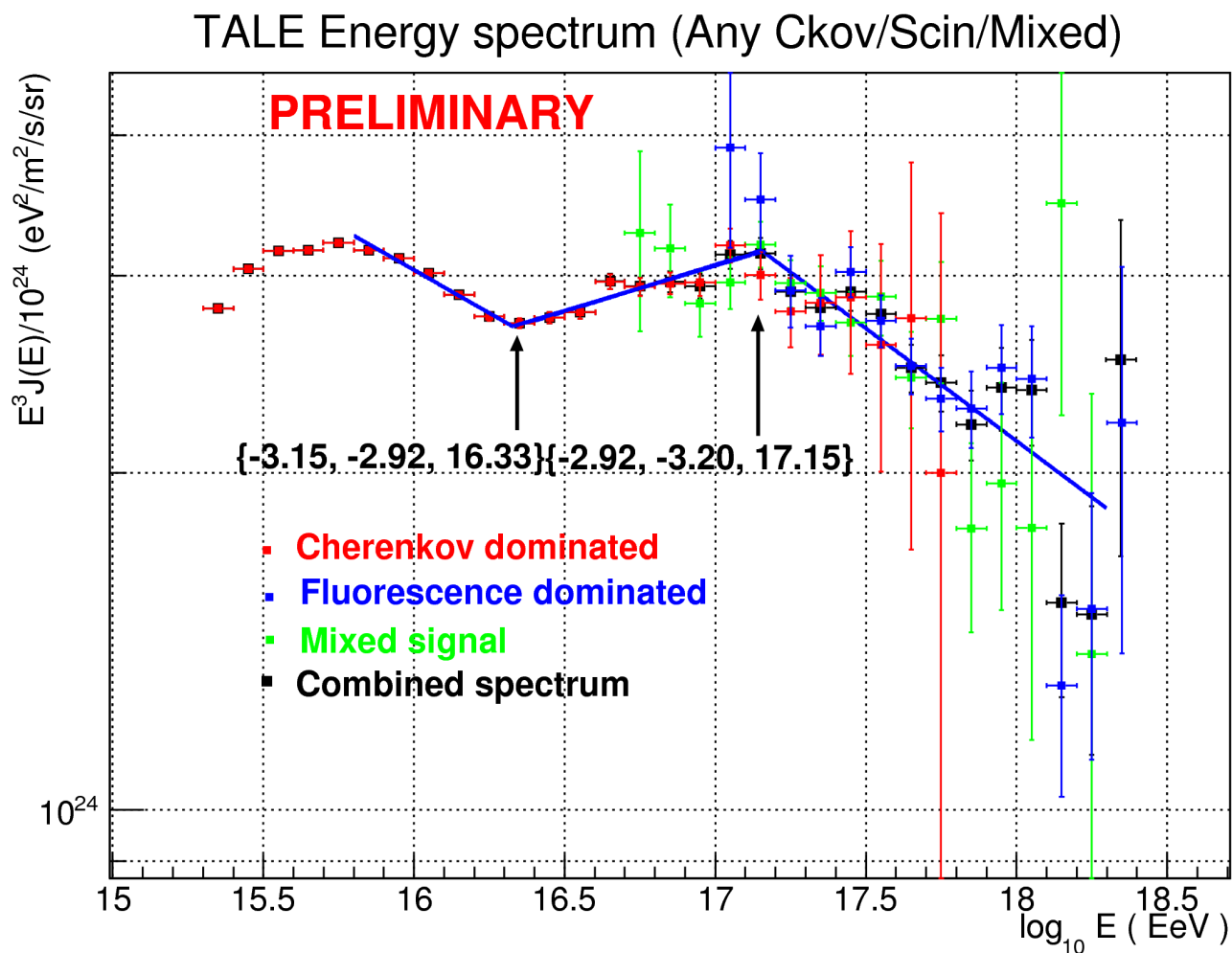
TALE (Ring3,4) Aperture (H4a mixed composition)



# Energy Spectrum

# Energy Spectrum

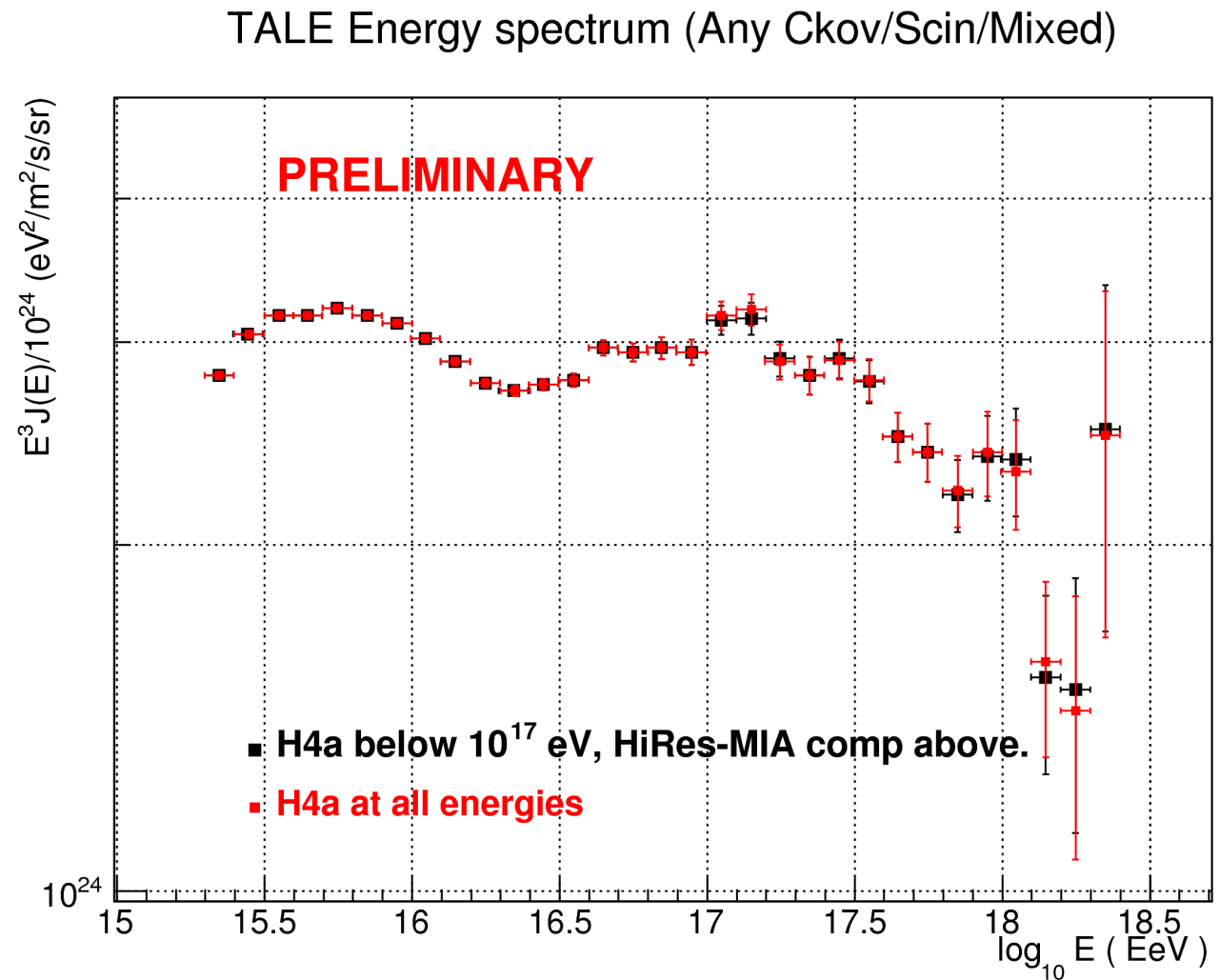
- Spectral breaks: slopes before/after and energy are indicated on the figure.
- HiRes-MIA measured composition used for energies above  $10^{17}$  eV.





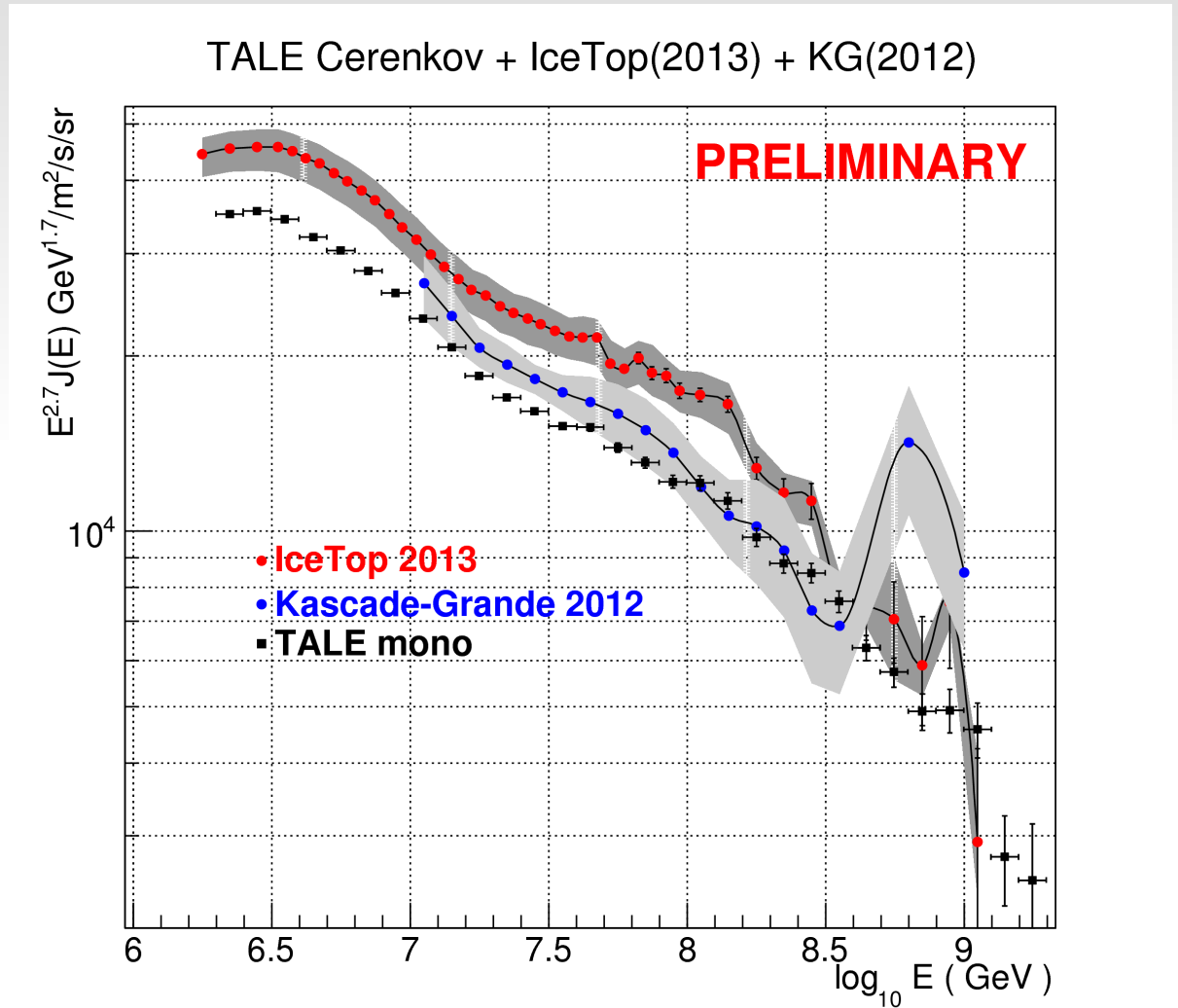
# Energy Spectrum(2)

- Effect of changing composition assumption above  $10^{17}$  eV.



# Energy Spectrum (3)

- Comparison to other experiments.



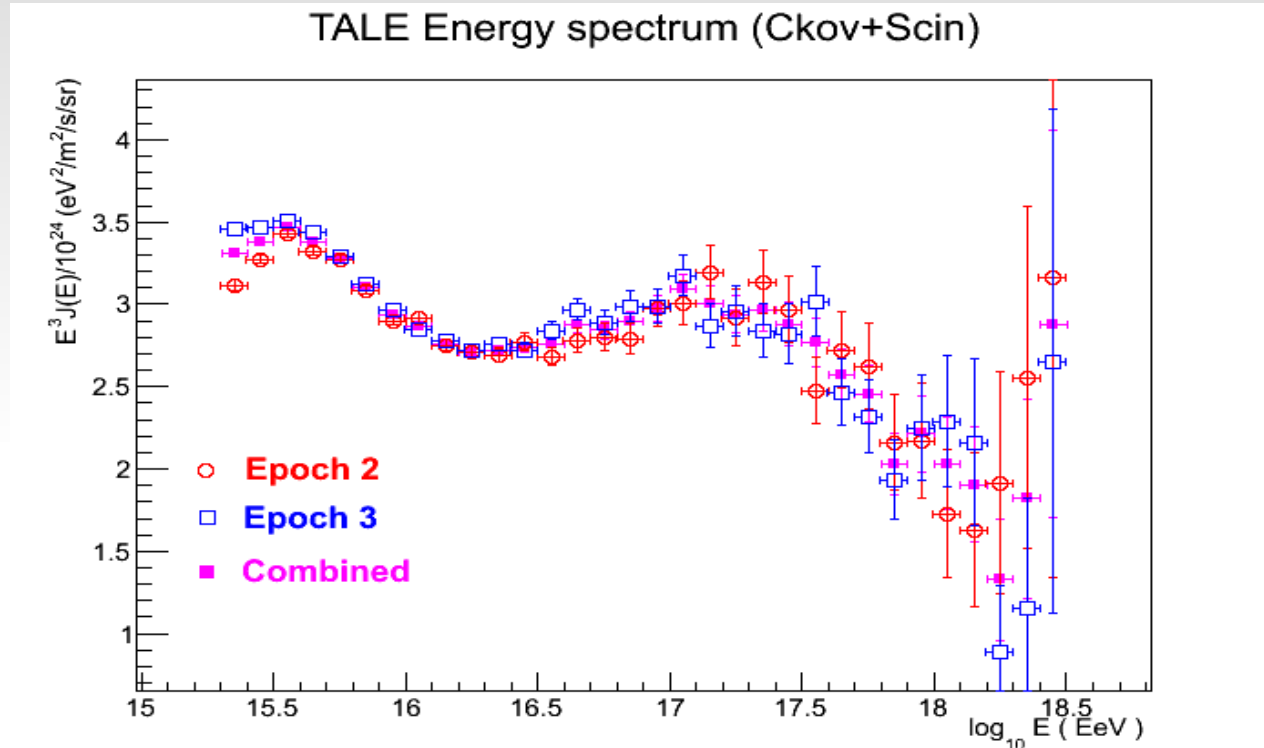
# Summary

- We presented a measurement of the cosmic rays energy spectrum using the TALE fluorescence detector.
- The measured spectrum spans the energy range from  $10^{15.3}$  –  $10^{18.4}$  eV, using a combined set of Cherenkov/Fluorescence and mixed signal events (as defined in the talk).
- The flux values below about  $10^{15.6}$  eV may be subject to too large systematic uncertainties for a claim of “reaching the knee” with TALE mono ... wait for NICHE.
- Two features are observed:
  - a hardening of the spectrum at an energy of  $\sim 10^{16.33}$  eV.
  - a steepening of the spectrum at an energy of  $\sim 10^{17.15}$  eV.

# Backup Slides

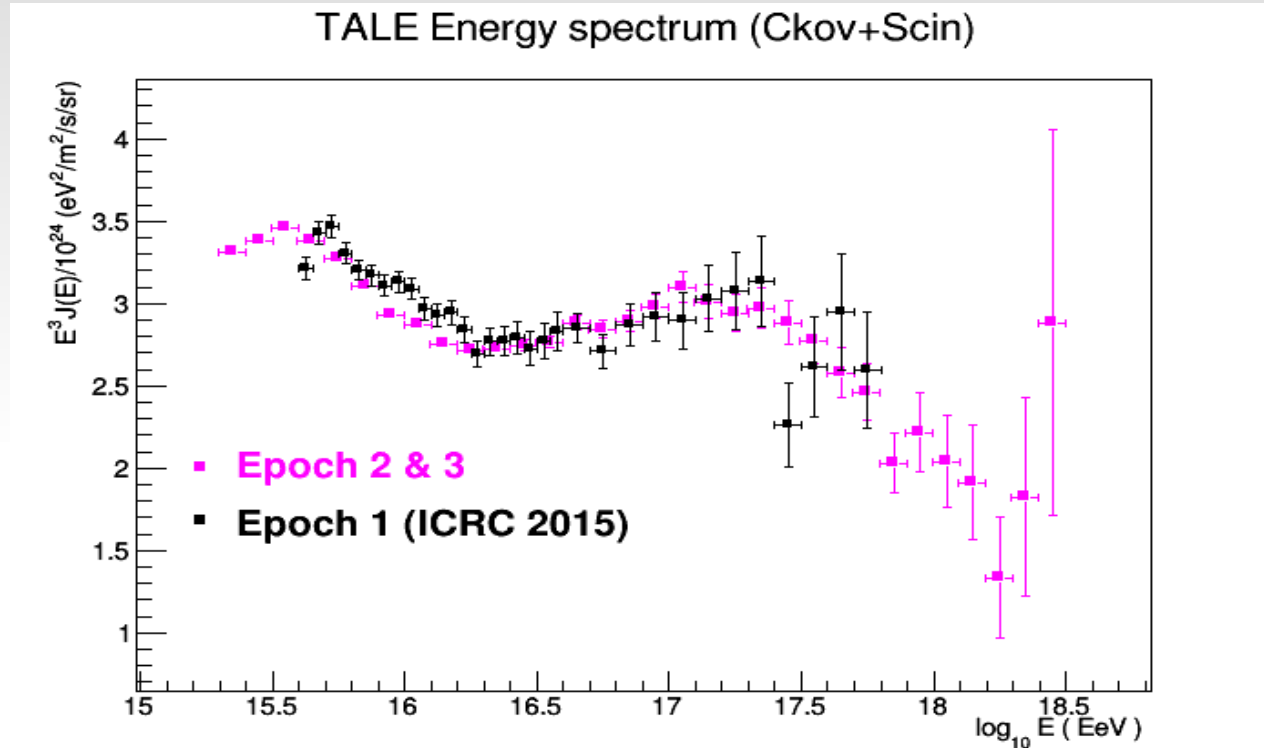
# TALE Spectrum

- TALE combined epoch 2&3 compared to separate epochs.
- Data through 2015/10/16



# TALE Spectrum

- TALE epoch 2&3 compared to epoch 1 spectrum
- Data through 2015/10/16



# Event Reconstruction / Performance

# TALE Event Reconstruction

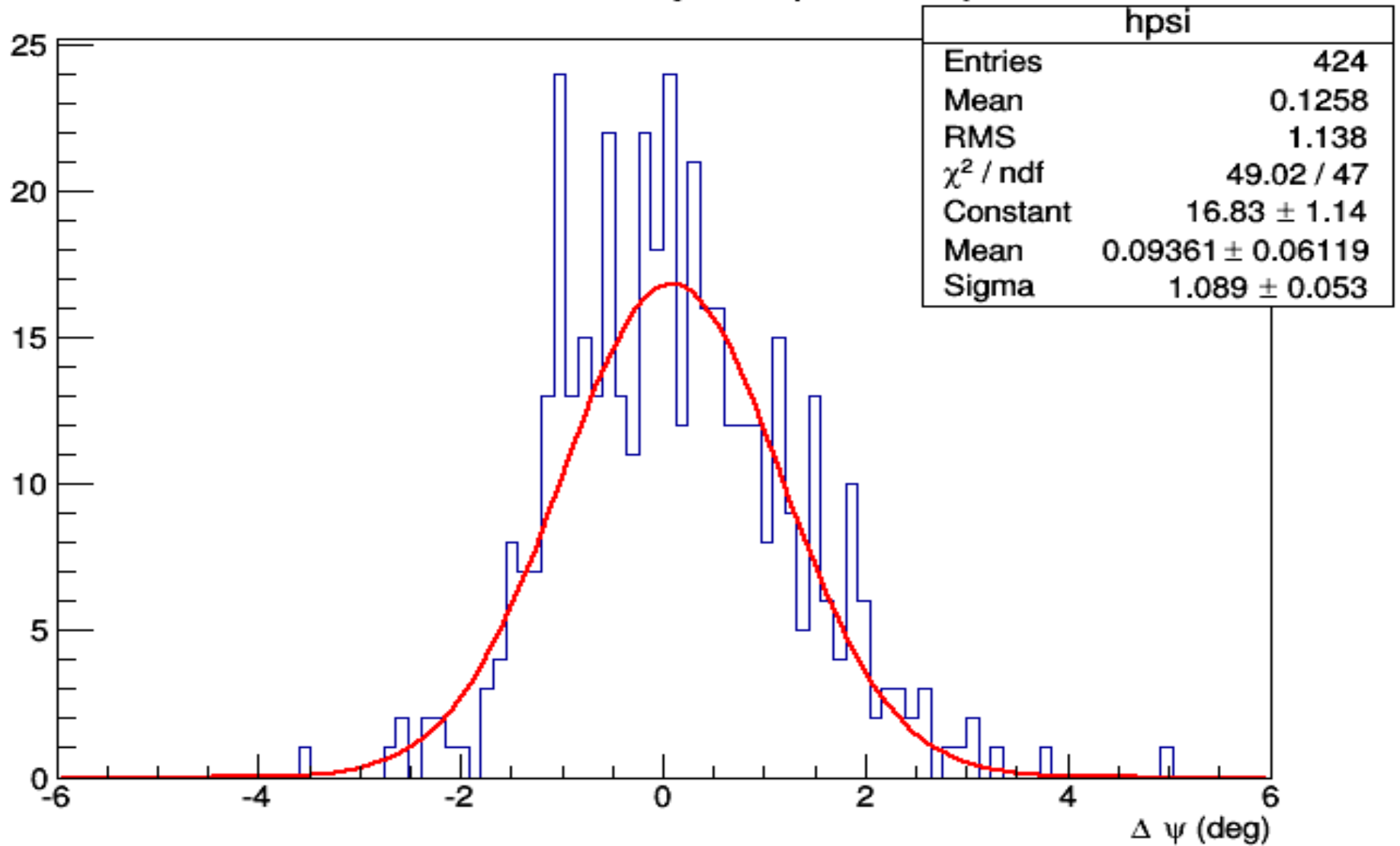
- Event reconstruction entails reconstructing:
  - Shower geometry
  - Shower profile/energy.
- Cerenkov events are reconstructed as *monocular* events.
- Profile constrained Geometry Fit (PCGF) method (developed and used for the HiRes-I analysis) is adapted for TALE:
  - Unlike for HiRes-I, the shower  $x_{max}$  parameter is fixed *only* at the start of the fit but is turned into a *free fit parameter* at a later step in the reconstruction process.



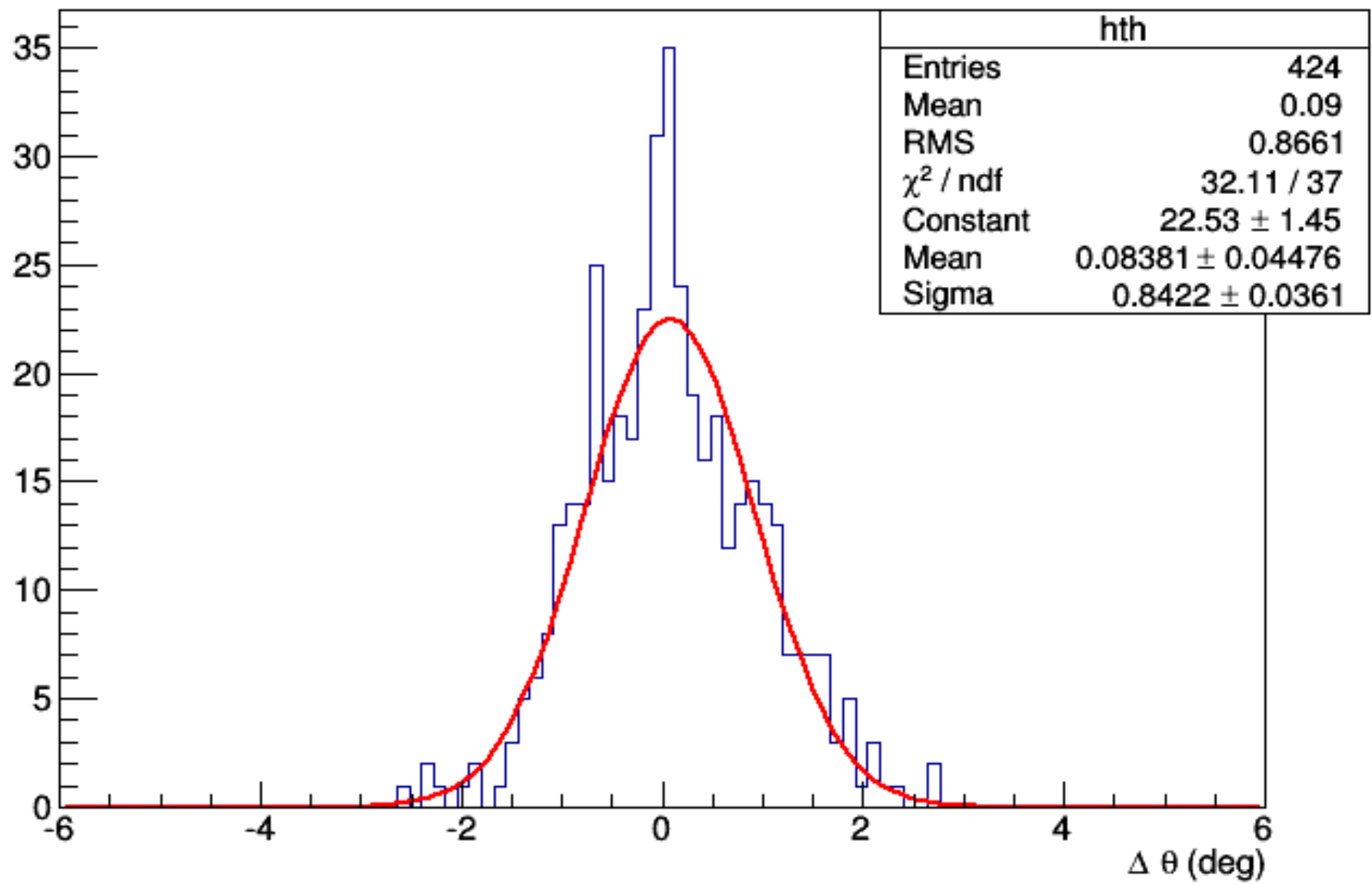
# Mono vs Hybrid reconstruction.

- Reconstruction validation using Hybrid data.
- This study was presented in the March 2016 extended analysis meeting. More details can be found there.

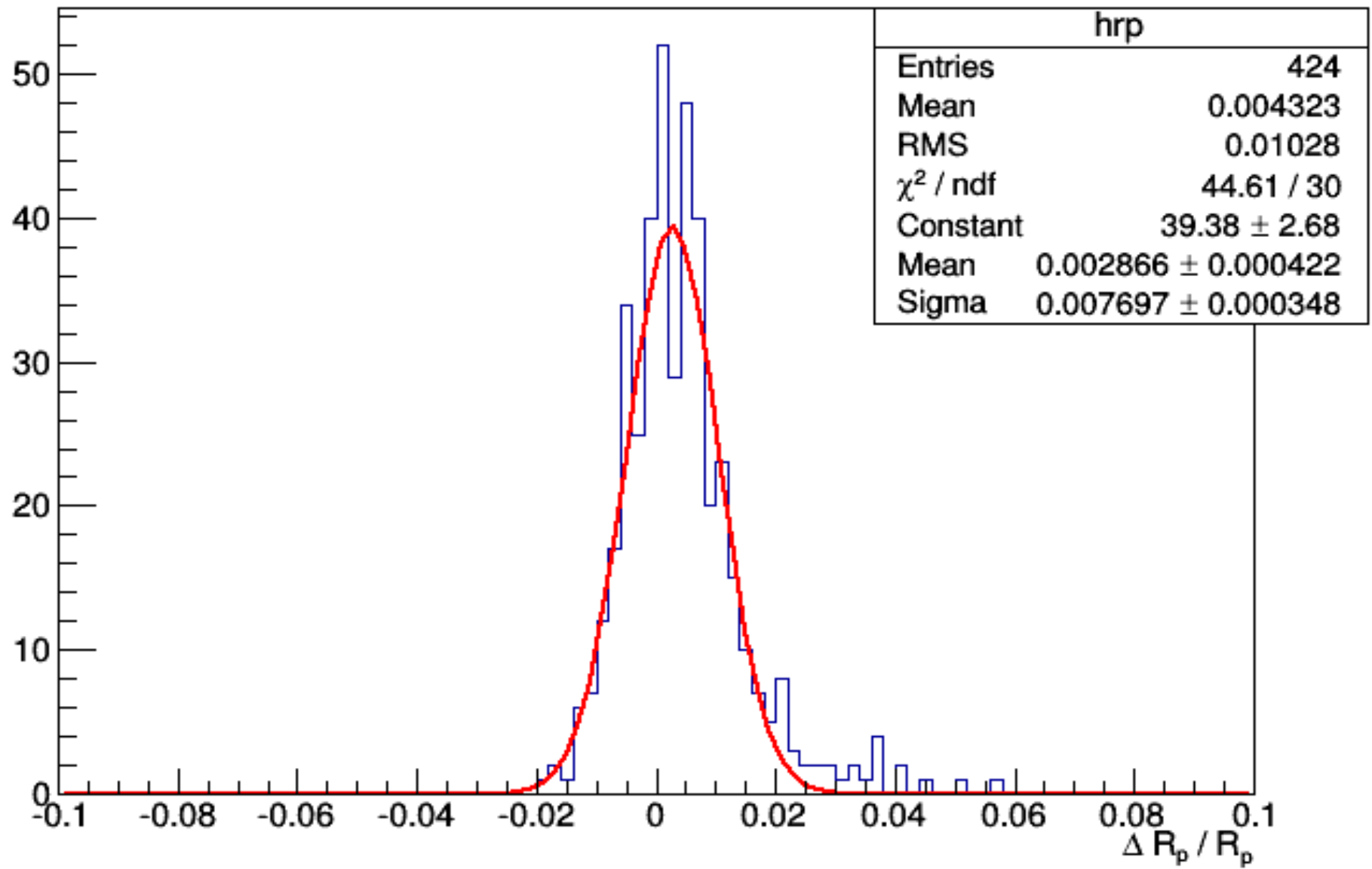
# TALE C'kov mono - hybrid psi comparison



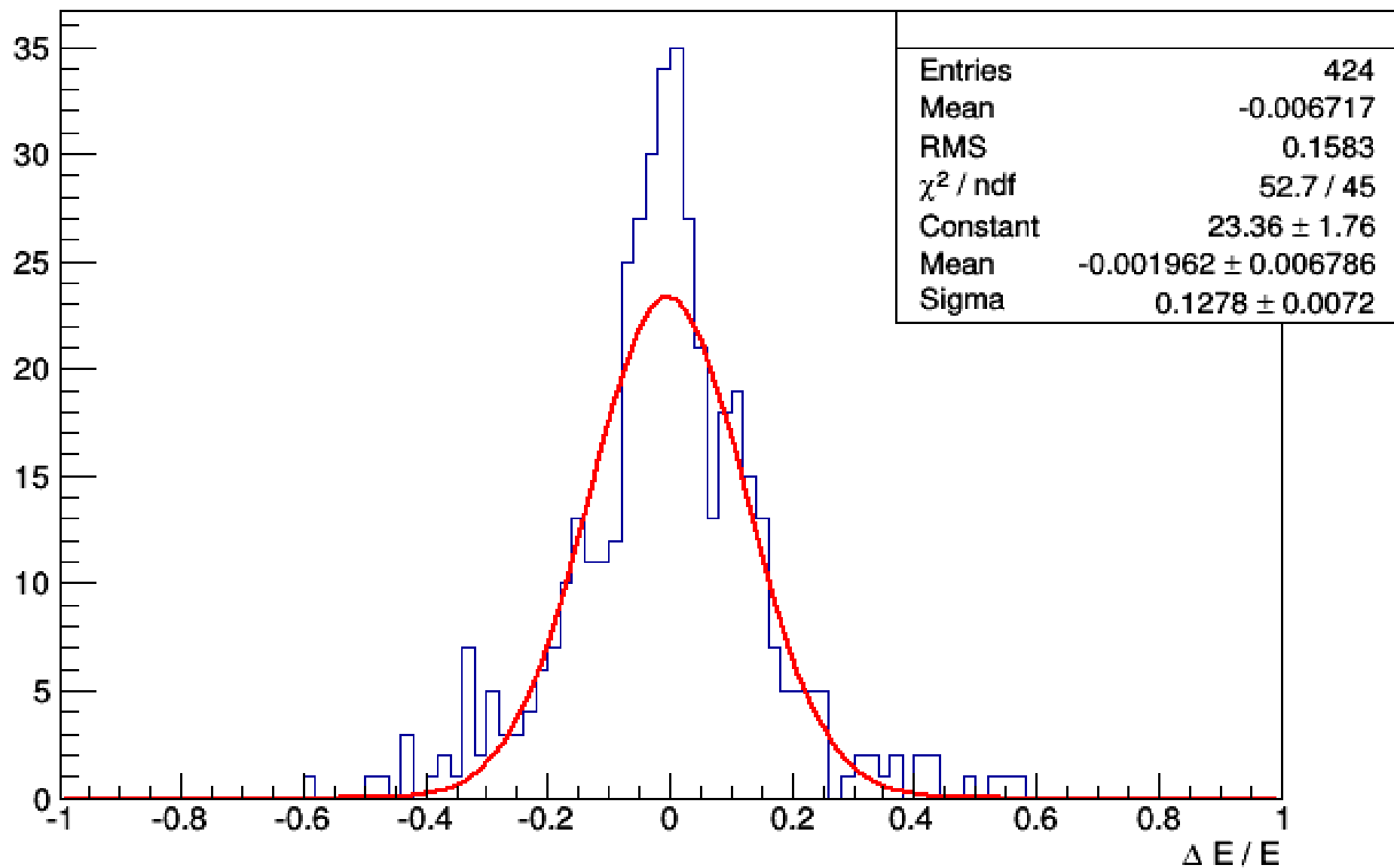
# TALE C'kov mono - hybrid theta comparison



# TALE C'kov mono - hybrid Rp comparison



# TALE C'kov mono - hybrid energy comparison



# TALE C'kov mono - hybrid xamx comparison

