UHECR Composition

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Outline

I. Composition from Xmax Studies

A. Xmax measurements by HiRes, TA, Auger.

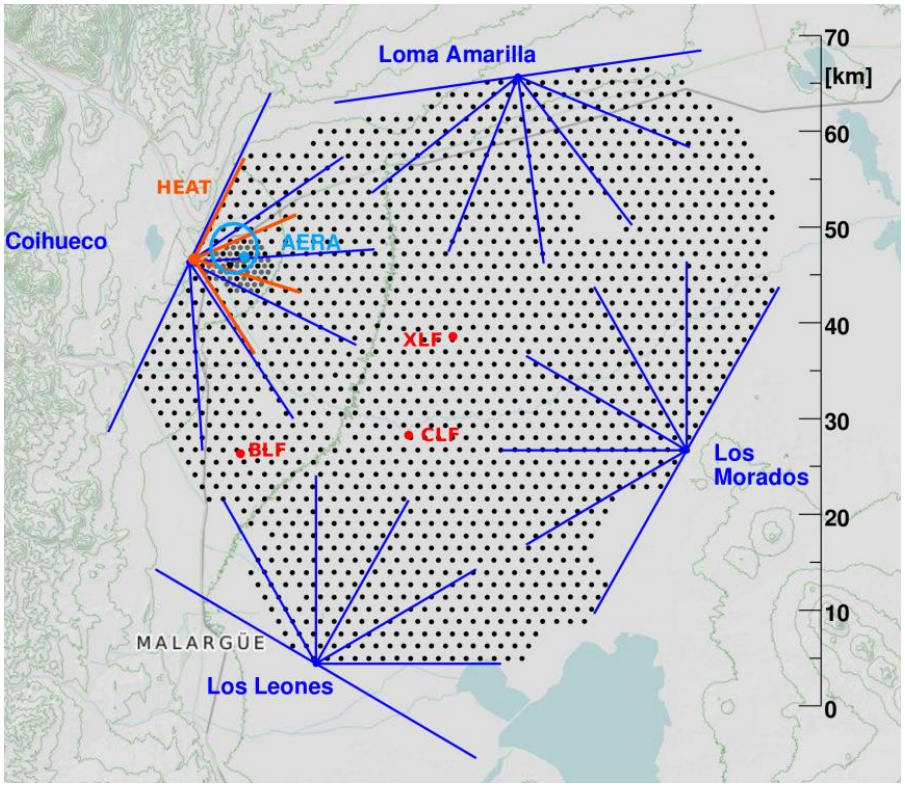
B. Systematics: extrapolation of HEP measurements.

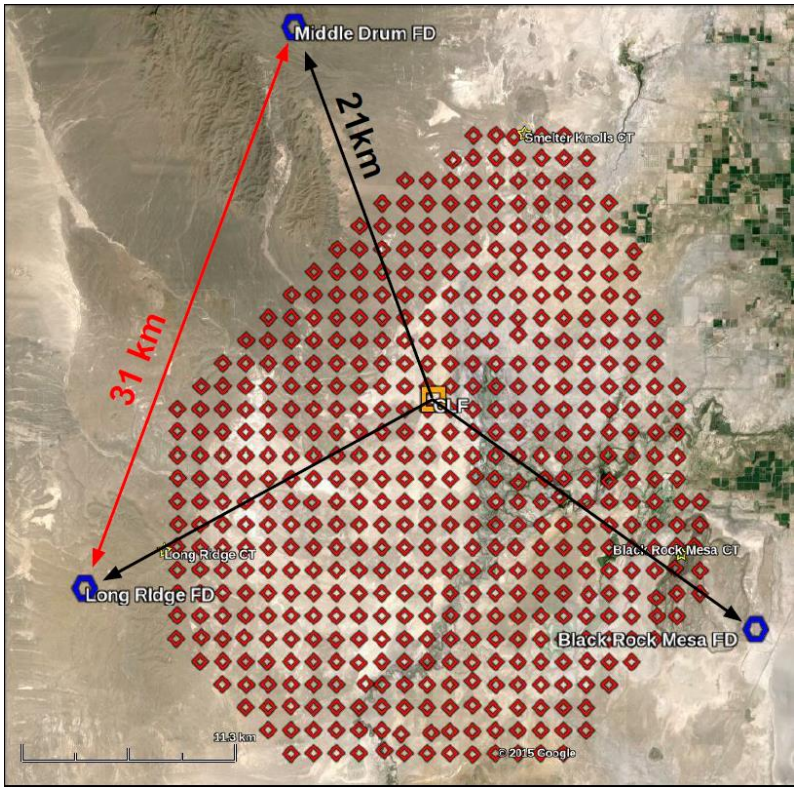
II. Composition from Spectral Studies

A. Spectrum measurements by HiRes, TA, Auger.

B. Spectrum systematics.

Auger + TA Black Rock, Long Ridge, and Middle Drum Detectors

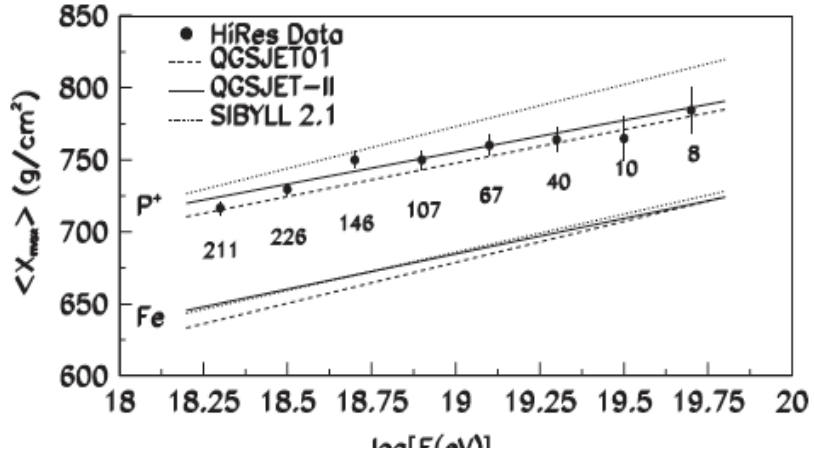


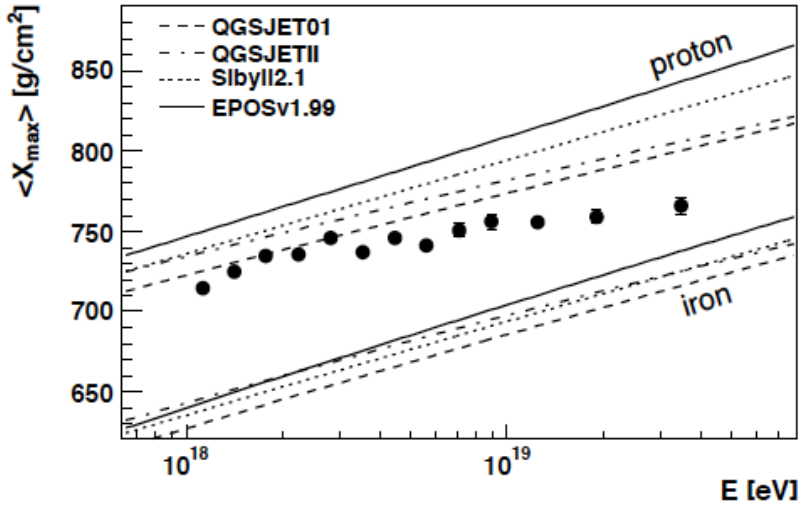


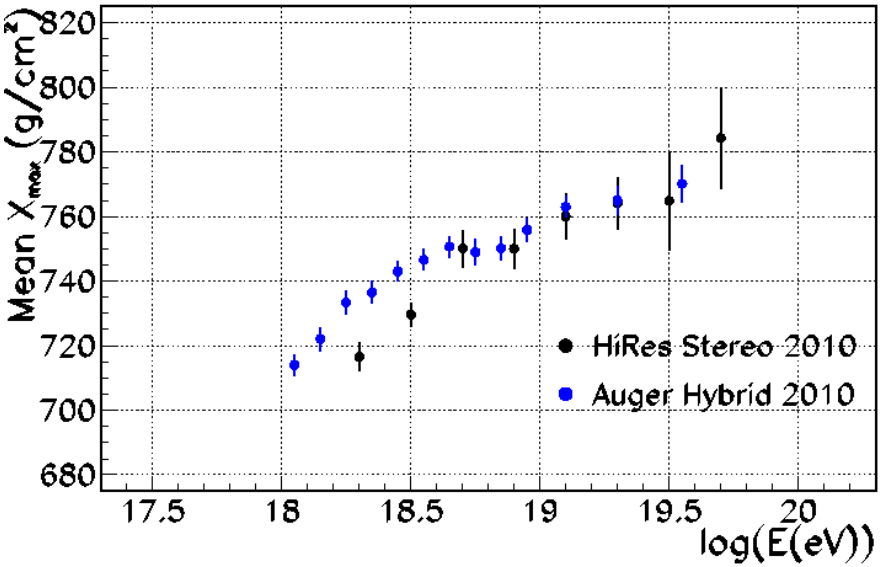
Xmax techniques

- Auger uses hybrid; HiRes used stereo; TA hybrid.
- Auger uses very tight cuts; HiRes used looser cuts; TA getting tighter.
- Auger adjusts cuts to make observed <Xmax> of MC protons and iron equal to thrown <Xmax>, reducing biases. Plots data and thrown MC.
- HiRes and TA choose cuts for quality, retain remaining biases, and put both data and MC through the same analysis program.

Xmax: HiRes and Auger

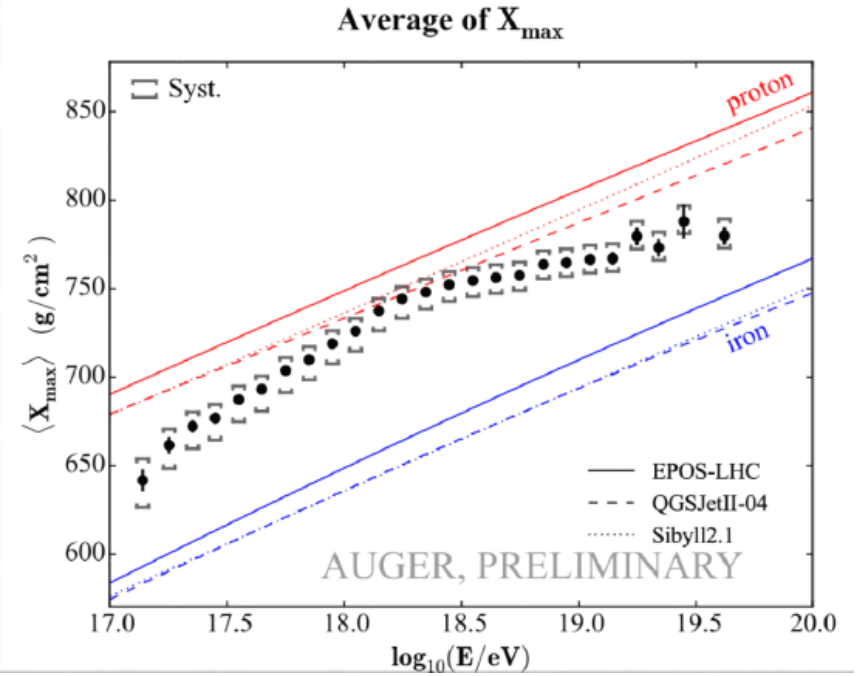


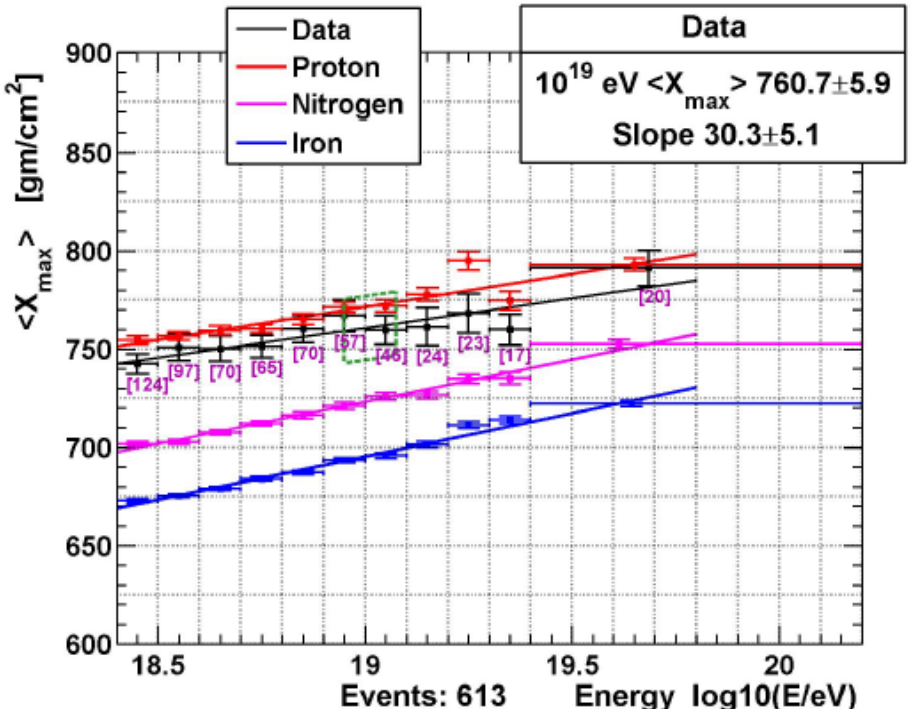


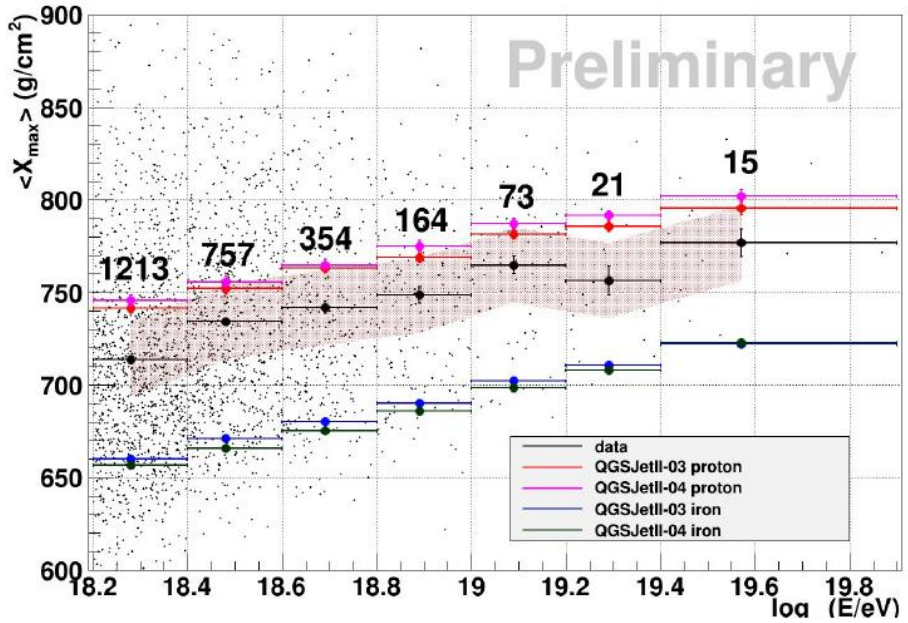


HiRes and Auger data agree within systematics

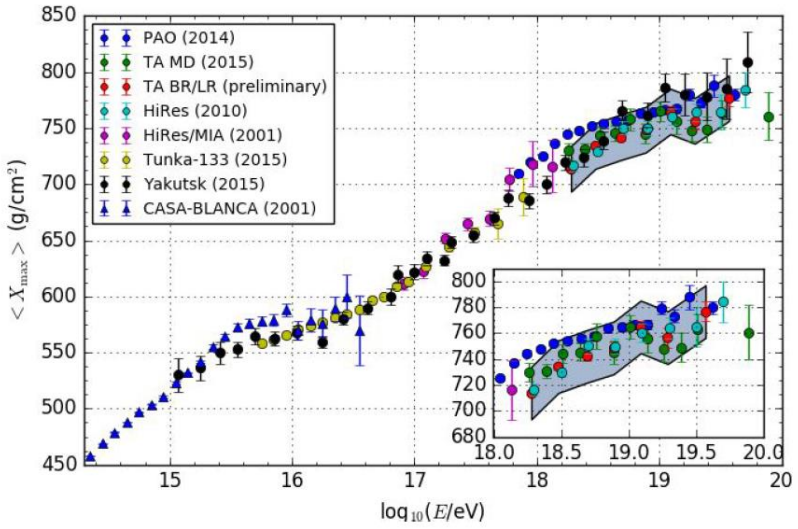
Xmax: TA and Auger

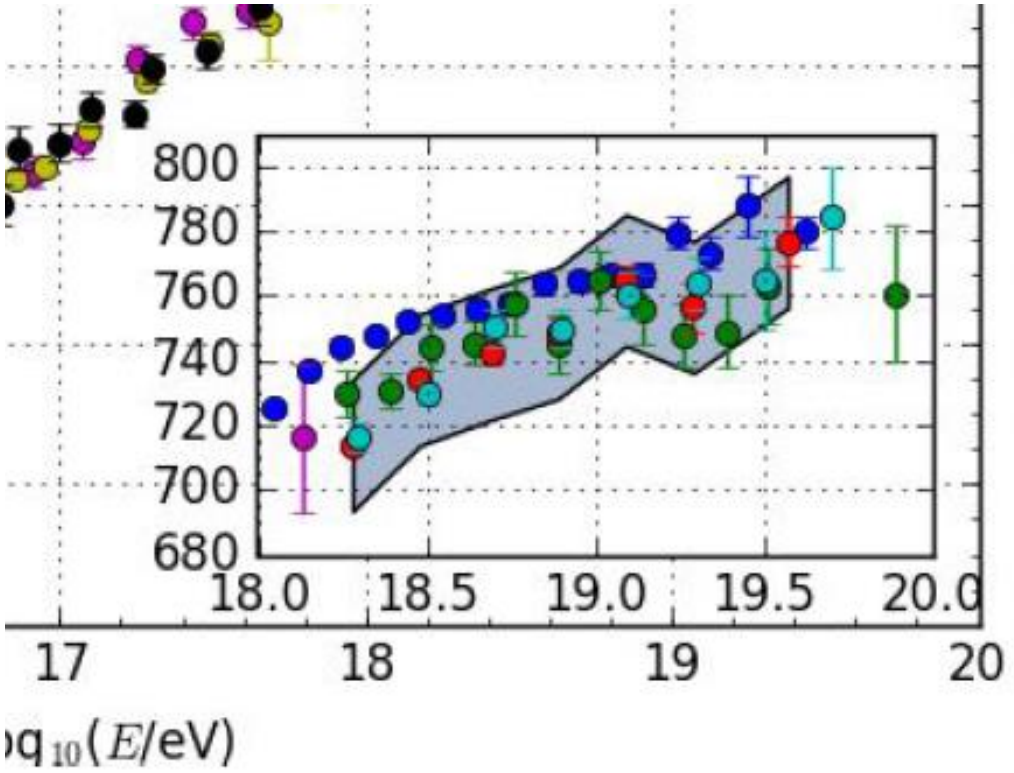






Xmax Measurements Summary

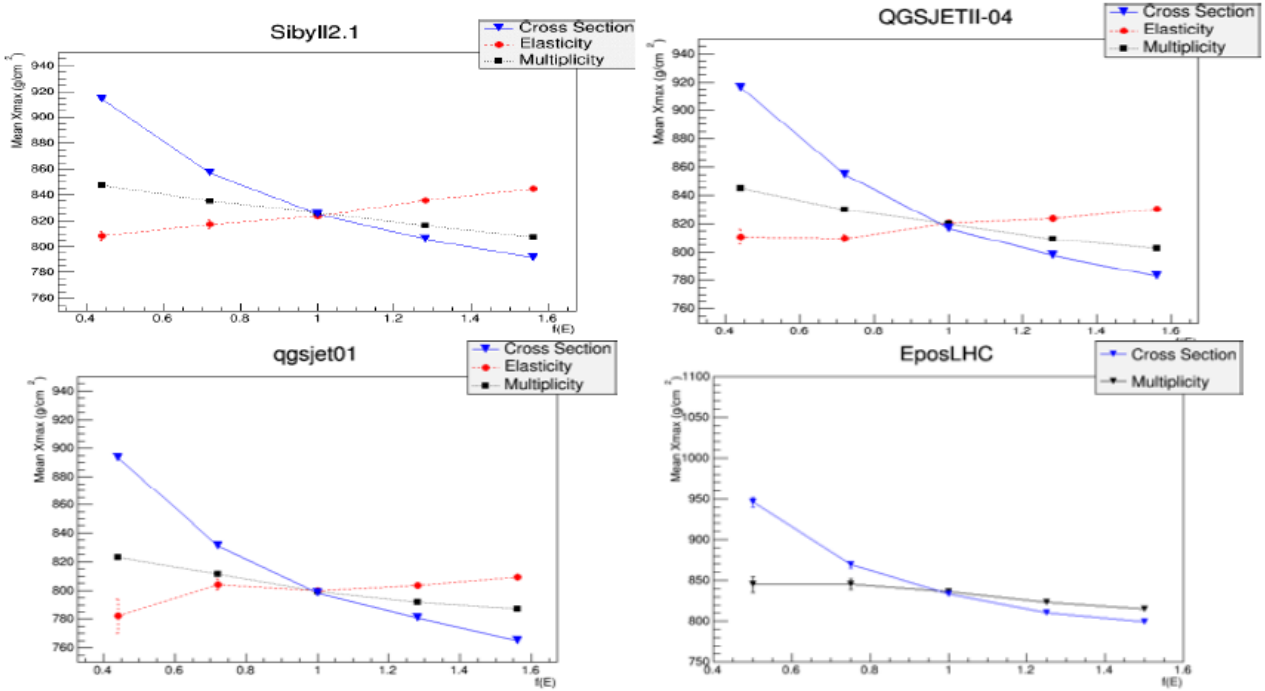




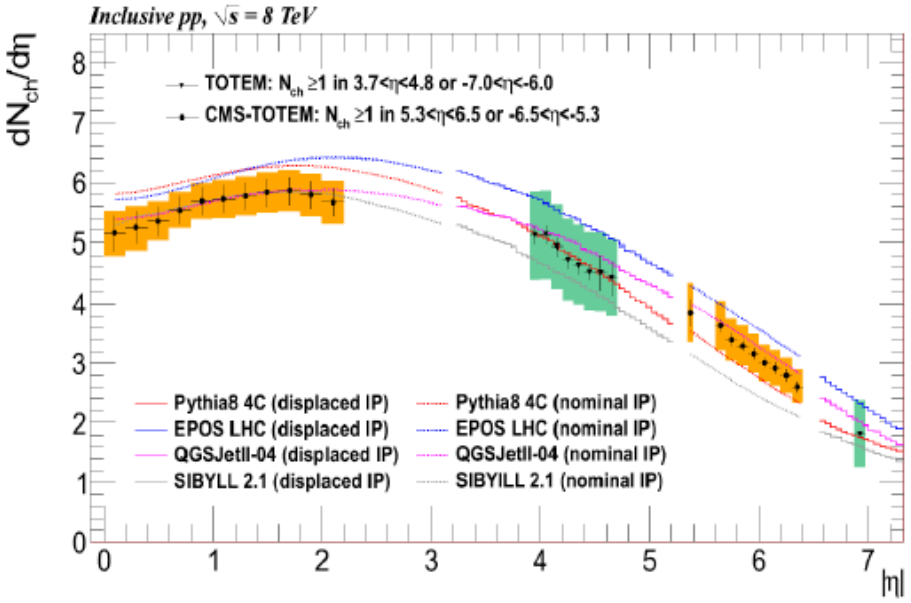
TA and Auger data agree within systematics.

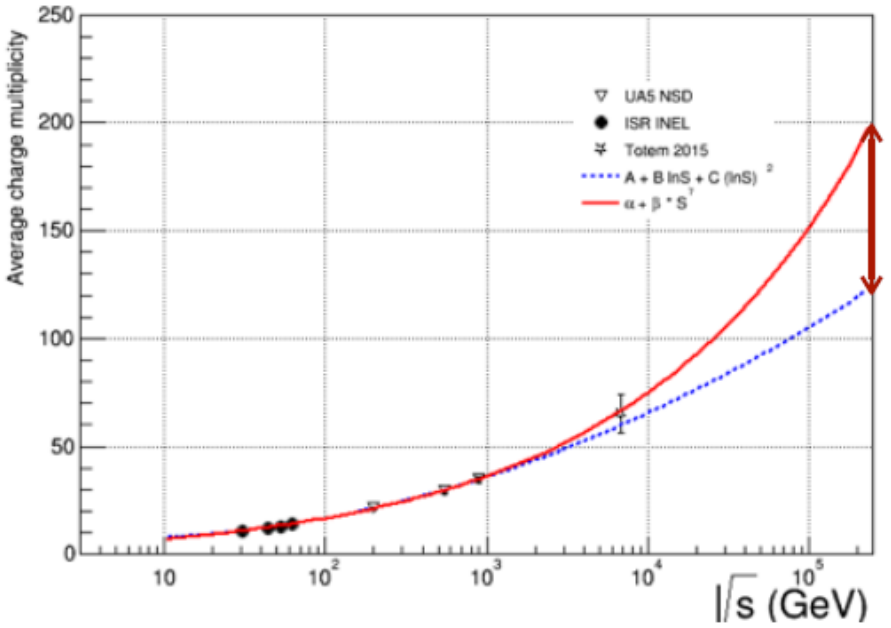
<Xmax> Uncertainties from Extrapolation of Cross Sections

- Ulrich, Engel, and Unger investigated sensitivity of Sibyll <Xmax> to changes in σ_T, $\langle n_{ch} \rangle$, and elasticity.
- Ulrich gave Rasha Abbasi the Conex package they used. She reproduced their Sibyll results, and also ran QGSJet 01c, QGSJet II-4, and EPOS-LHC.



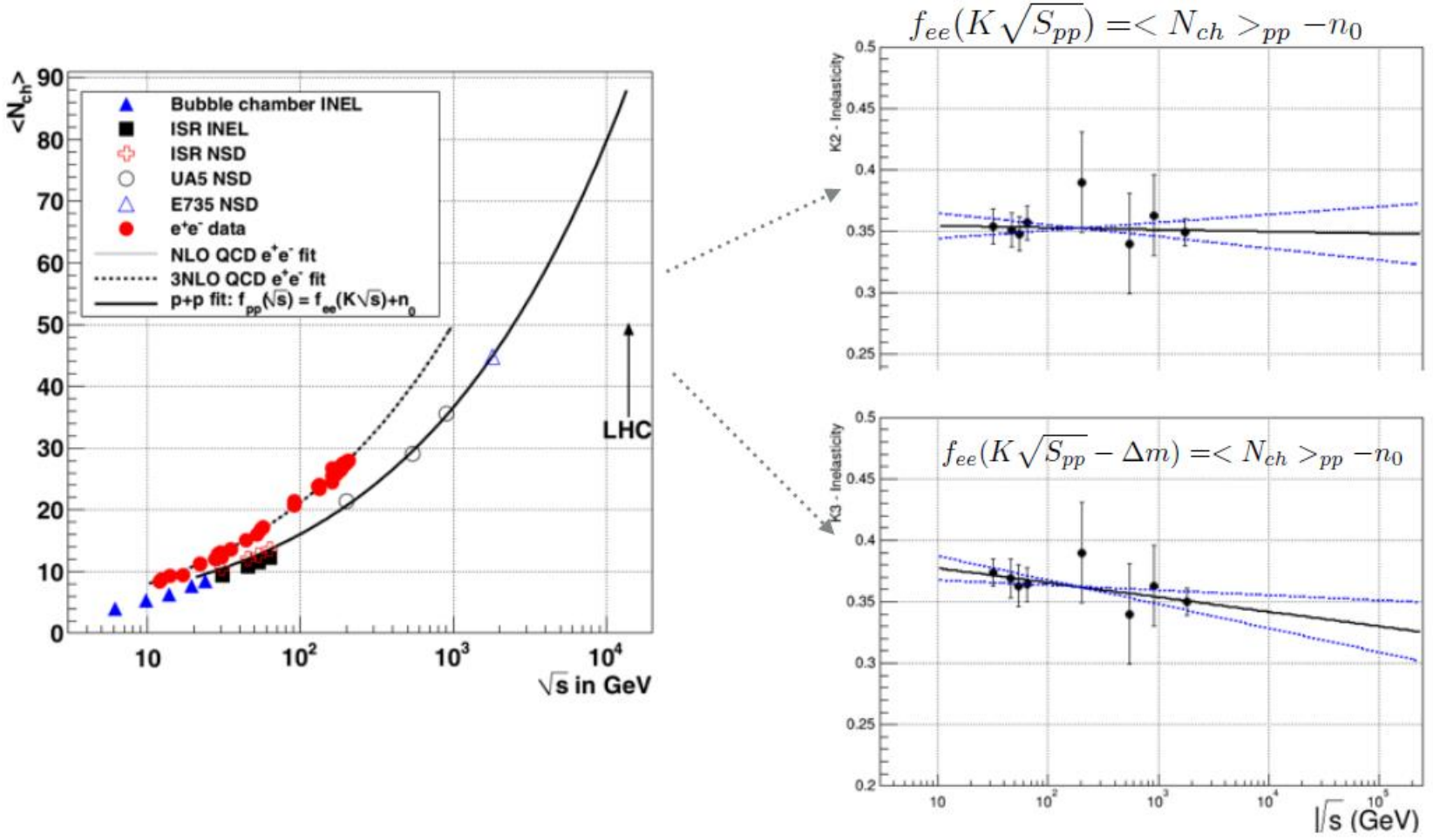
Multiplicity





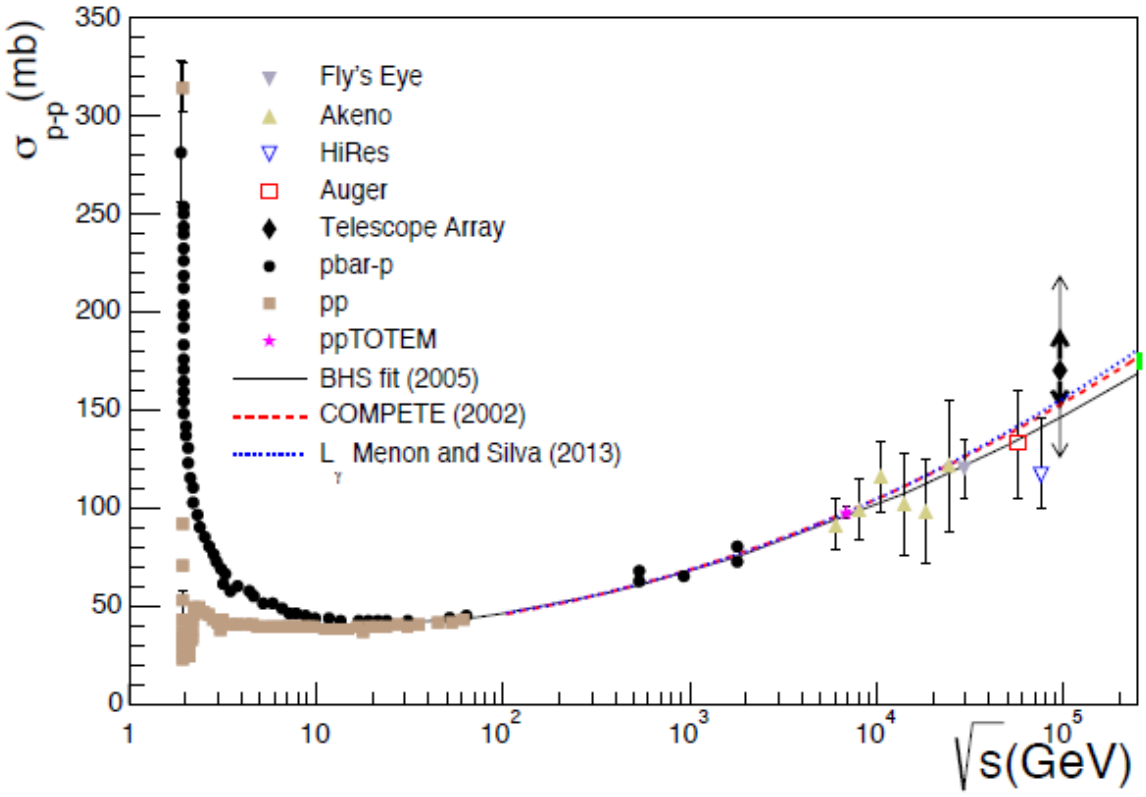
$$\Delta_{\text{multiplicity}} \approx \pm 13\ \text{g/cm}^2$$

Elasticity



$\Delta_{elasticity} \approx \pm 2$ g/cm^2

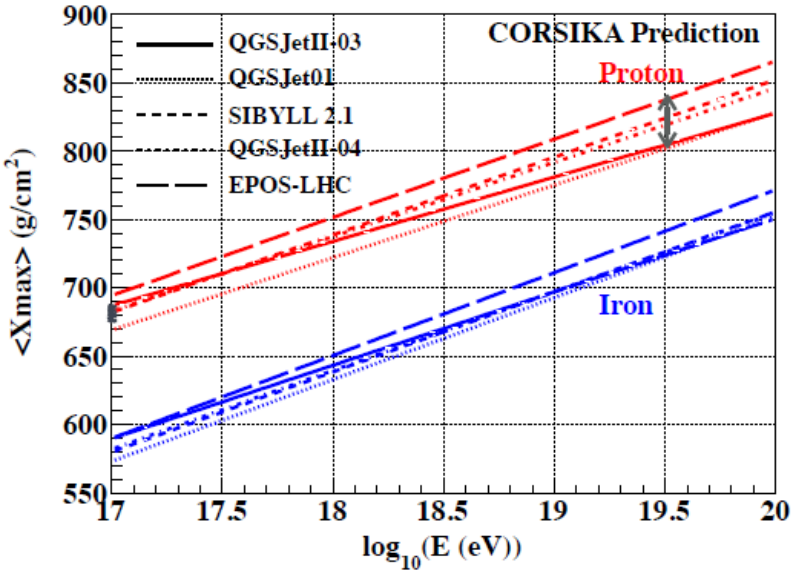
Total Cross Section



$$\Delta_{\sigma p\text{-air}} \approx \pm 6.5 \text{ g/cm}^2$$

Estimating Extrapolation Uncertainties

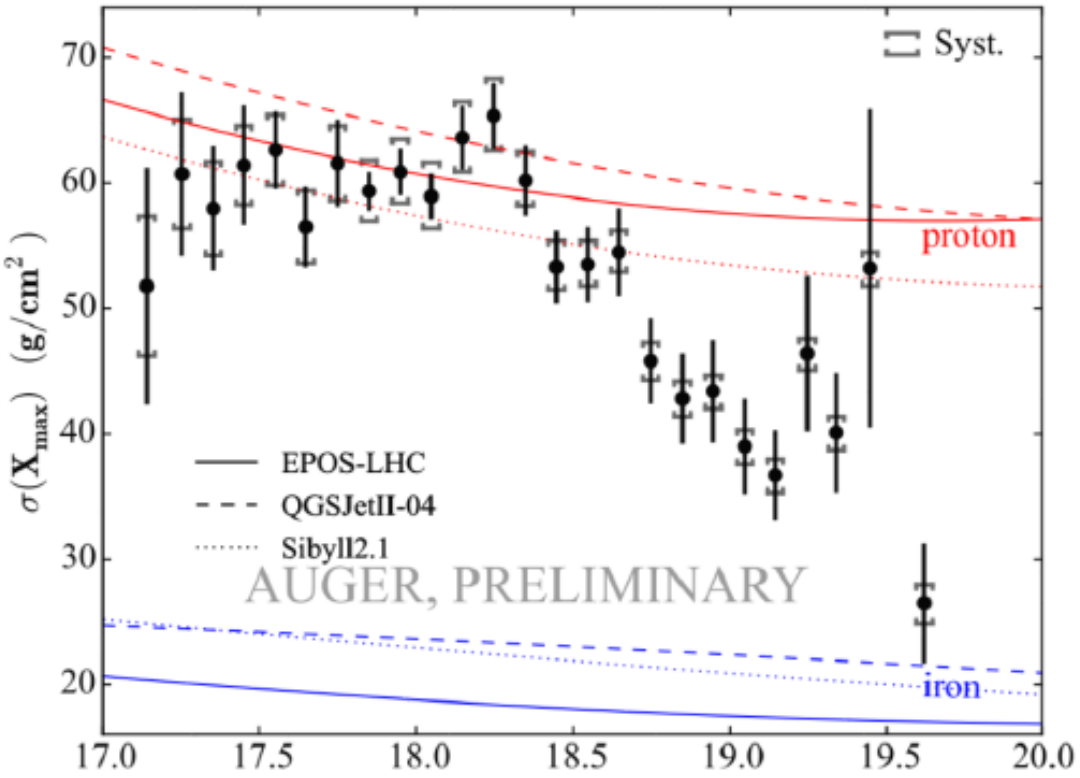
Model	<Xmax> uncertainty 10^{17}eV	<Xmax> uncertainty $10^{19.5}$eV
SIBYLL2.1	±3 g/cm2	±18 g/cm2
QGSJETII4	±3.5 g/cm2	±16 g/cm2
QGSJET01	±3 g/cm2	±18 g/cm2
EPOS-LHC	±3 g/cm2	±18 g/cm2



Uncertainty at 250 TeV (= $10^{19.5}$ eV) encompasses all the models at the ± 1σ level; smaller at 10^{17} eV.

Uncertainty is less for RMS(Xmax).

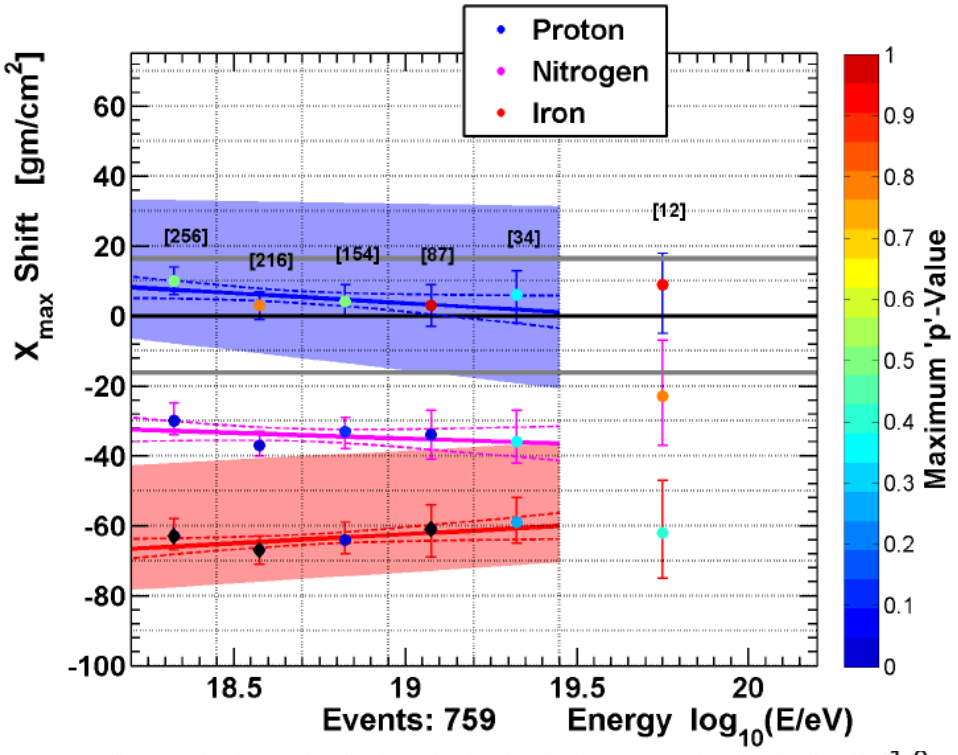
Auger RMS(Xmax)

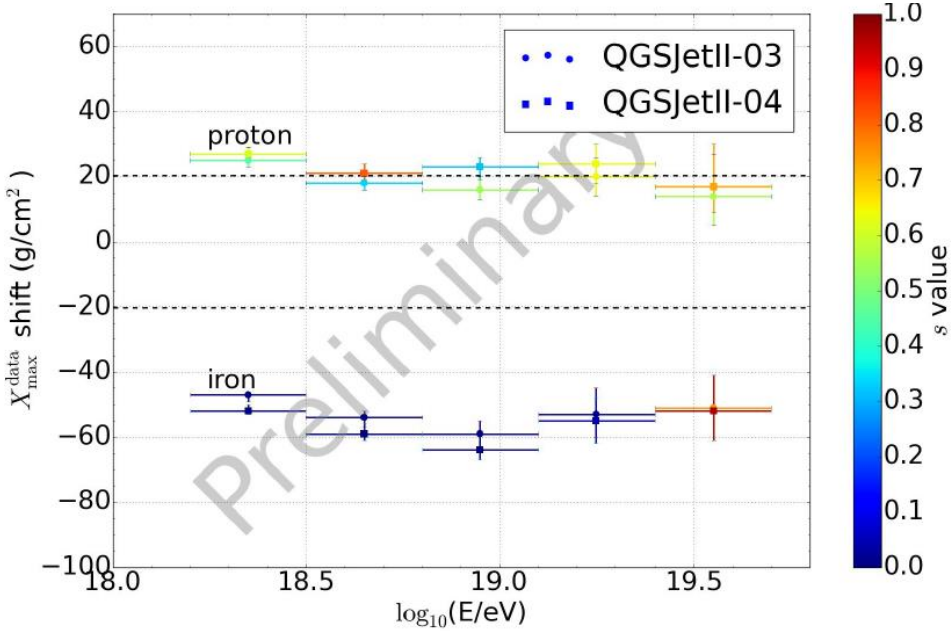


TA doesn't quote RMS(Xmax) . See next slide. But disagreement exists.

Model Testing 1

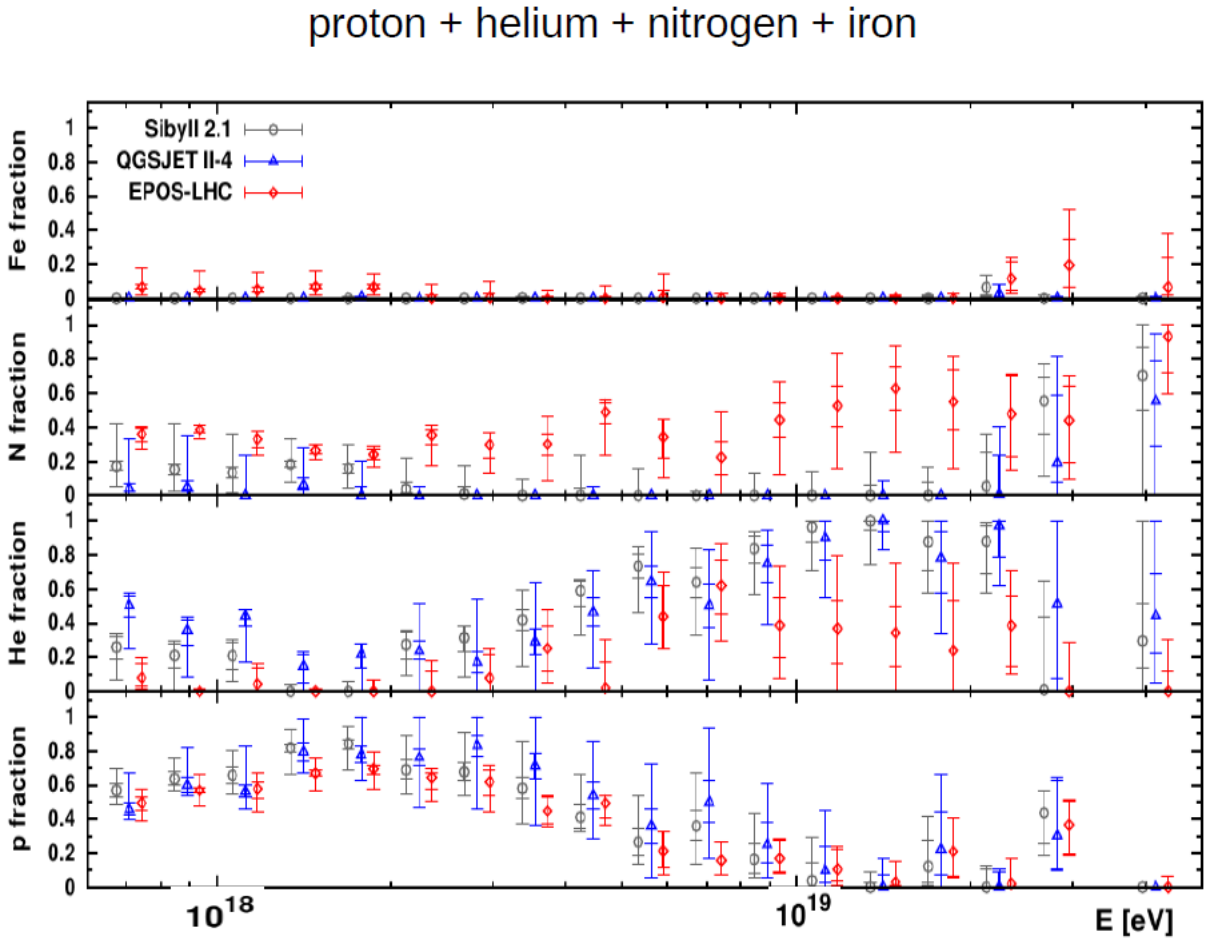
- Shift model Xmax histogram to data, then compare shapes using the Cramer-VonMises test.
- Proton/He region favored.
- No iron.
- We cannot disprove Nitrogen, but probably disfavored.
- Need TAx4 to answer nitrogen question.





Model Testing 2

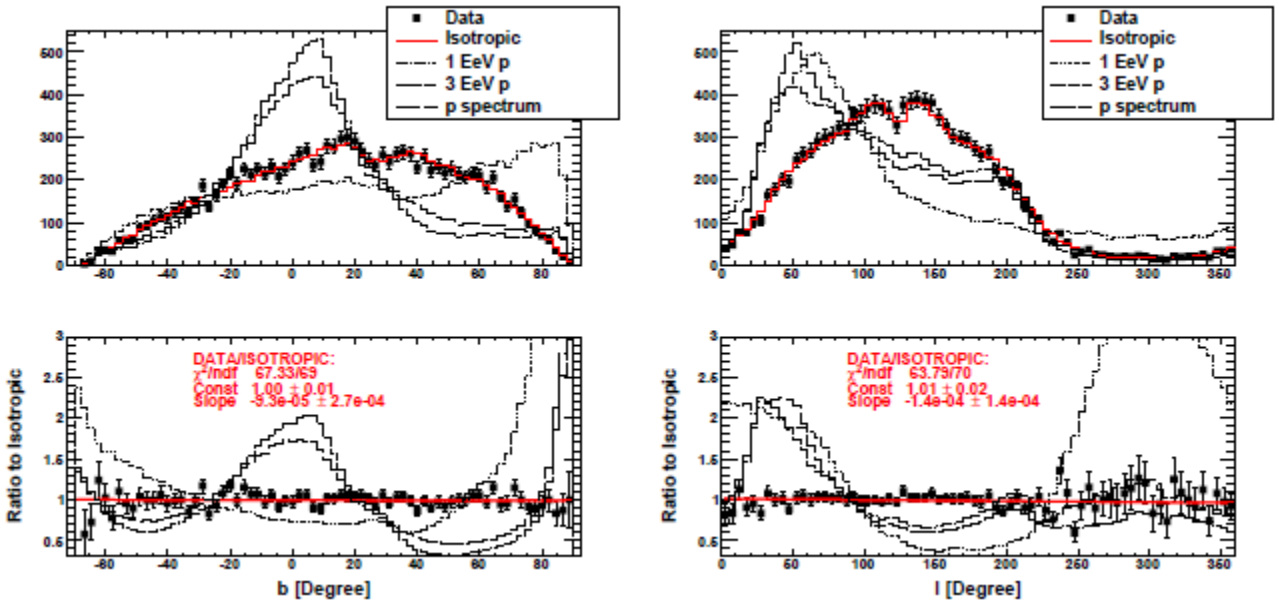
- Fit to Auger <Xmax> and RMS(Xmax).
- Protons/He.
- Some Nitrogen in EPOS.
- No iron.



HiRes, TA, and Auger results have similar interpretations.

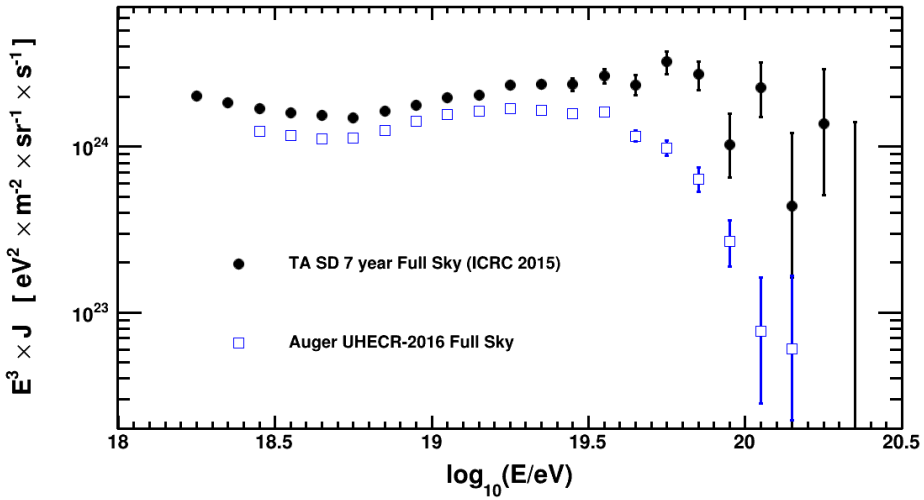
EeV Protons are Extragalactic

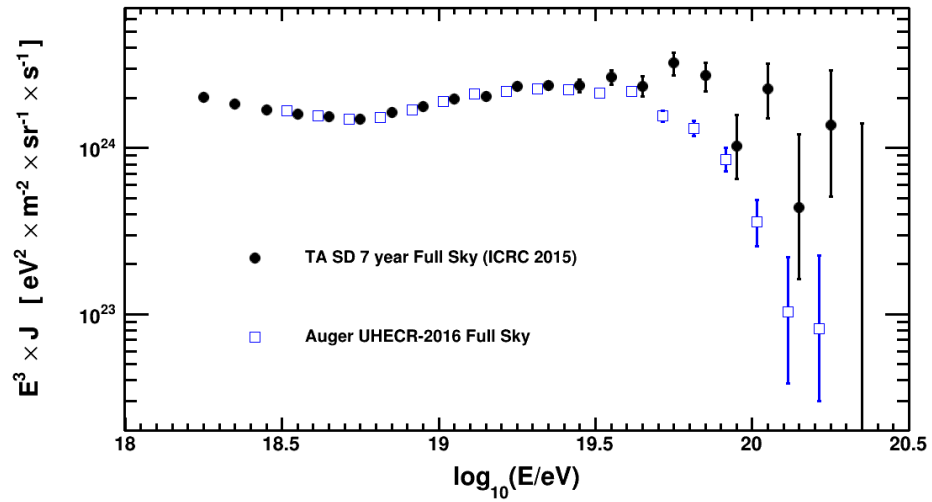
- All experiments see a protonic composition in the range, 18.0 < log(E) < 18.5
- If of galactic origin there would be an enormous anisotropy, which is absent. Both Auger and TA have published that their data are isotropic.
- TA's 95% CL upper limit is <1% galactic.



Composition Information in Spectrum

- Compare Auger and TA spectra.
- Rescaling by 16% aligns the ankle region.
- Difference above $10^{19.4}$ eV.

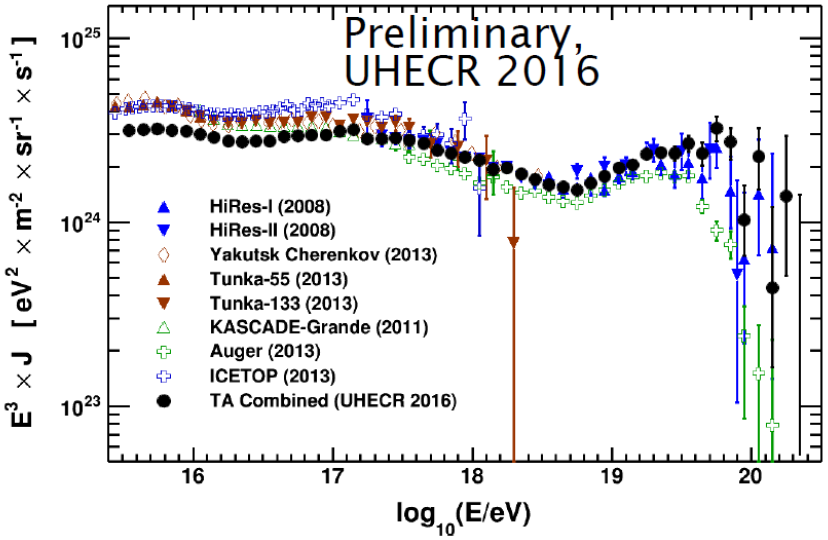


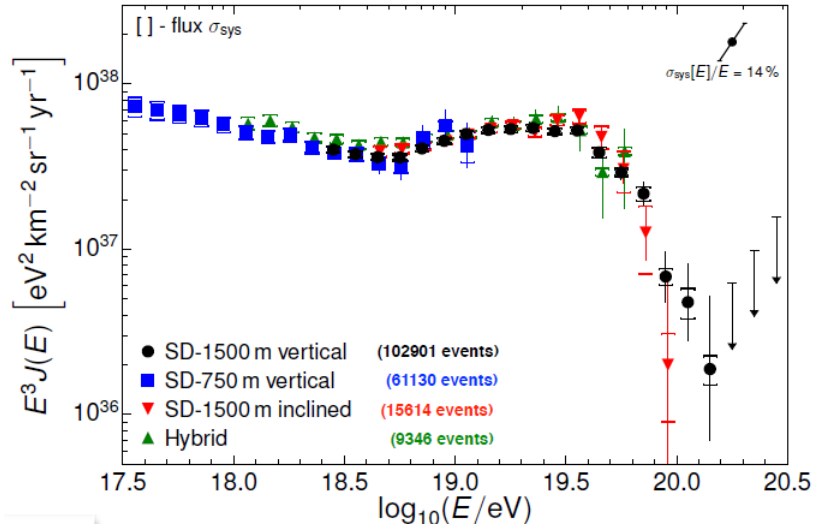


TA and Auger FD and SD Spectra

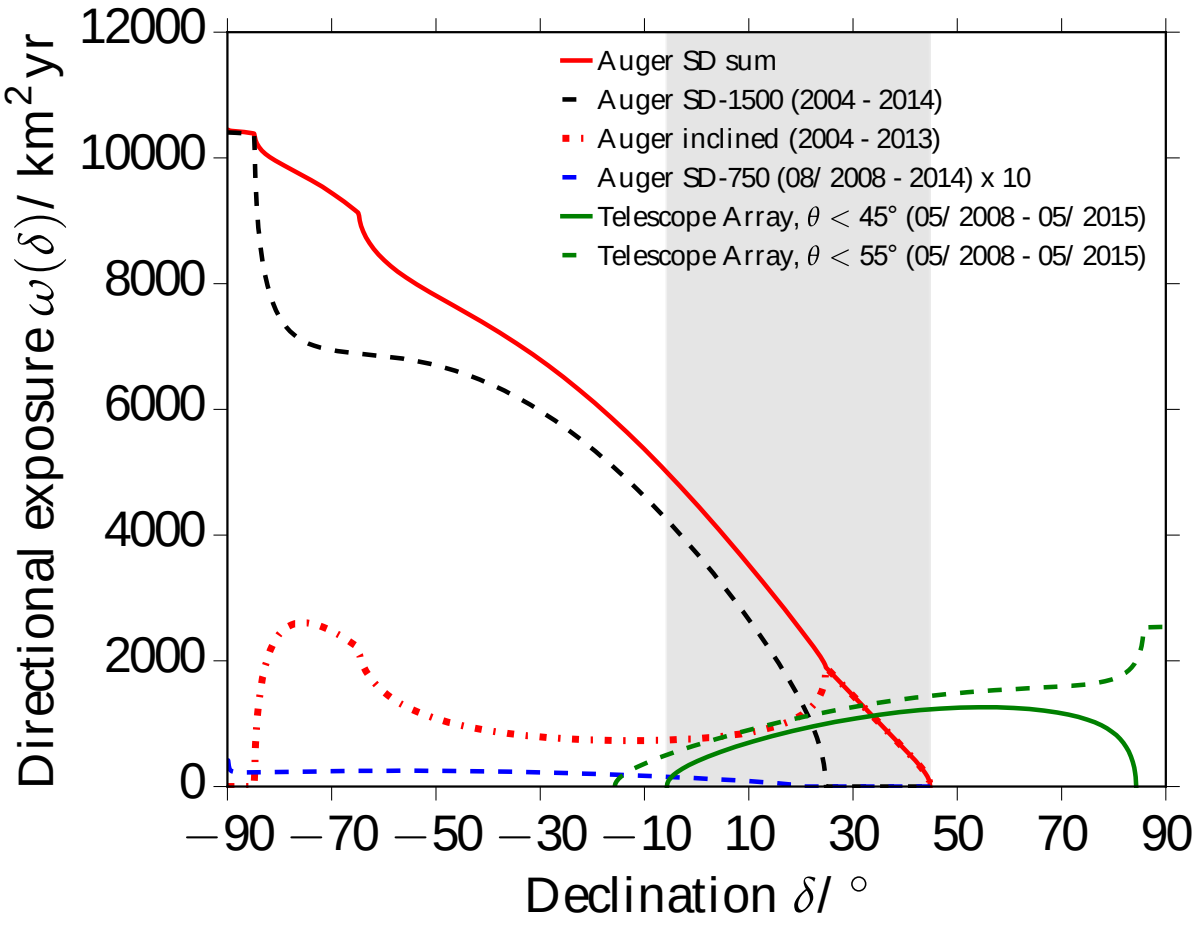
- Measure the spectrum in 2 ways
  - Use SD data
  - Use FD data
    - in monocular mode
    - In hybrid mode
- Good agreement in both experiments
- SD and FD have different systematics and biases

  ➔ good confidence.



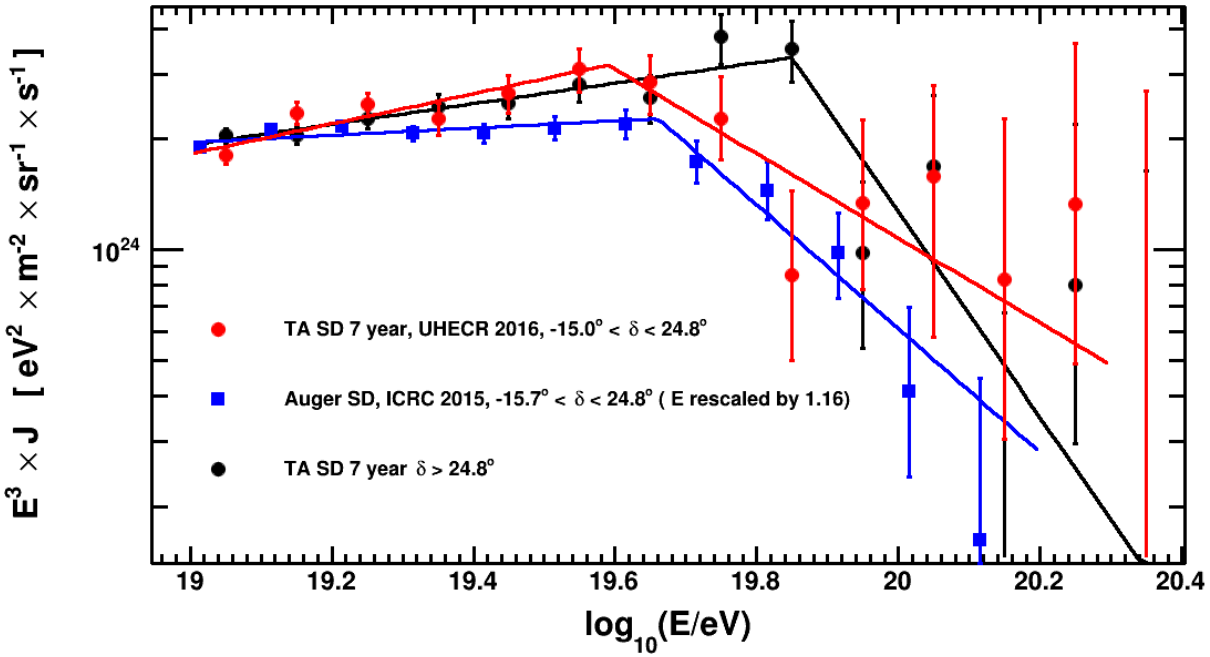


UHECR 2016 Spectrum WG

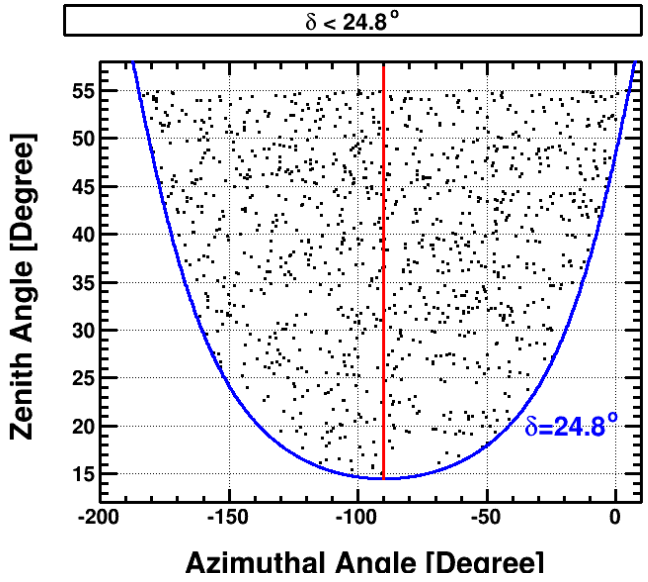


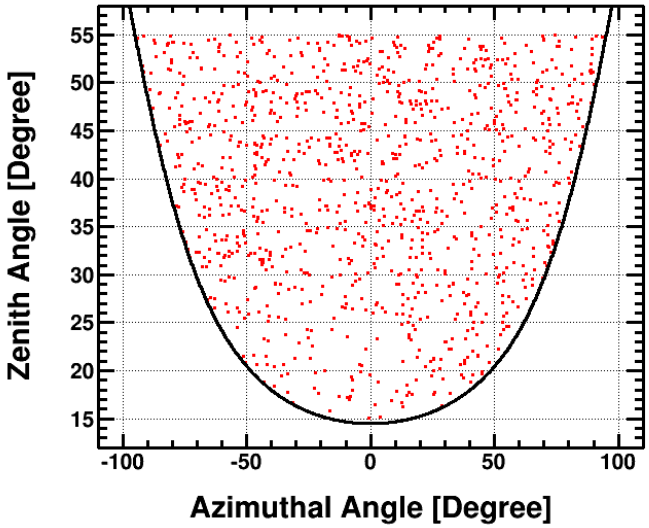
UHECR Spectrum WG

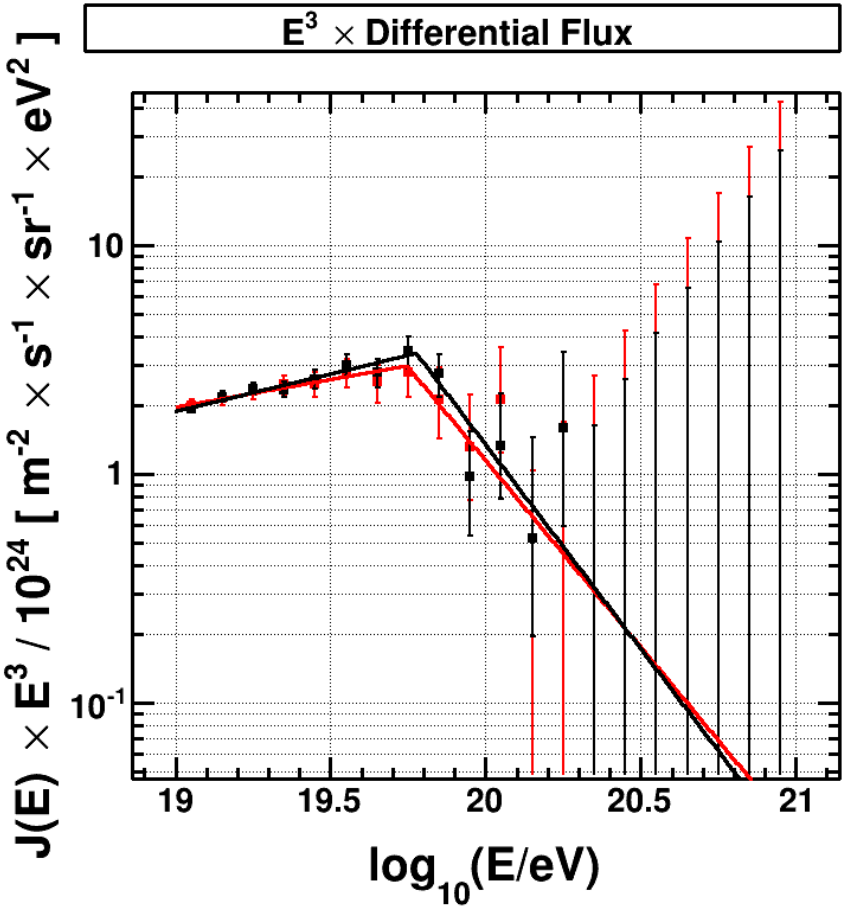
- TA and Auger WG members compared spectra in the common declination band: $-15° < \delta < 25°$
- TA, $\delta > 25°$, high energy break at 19.85±0.03
- TA, $-15 < \delta < 25°$, 19.59±0.06; **TA difference: 3.9 σ**
- Auger, $-15 < \delta < 25°$, 19.66±0.04; **TA-Auger difference: 1 σ**



Test by Looking to the East

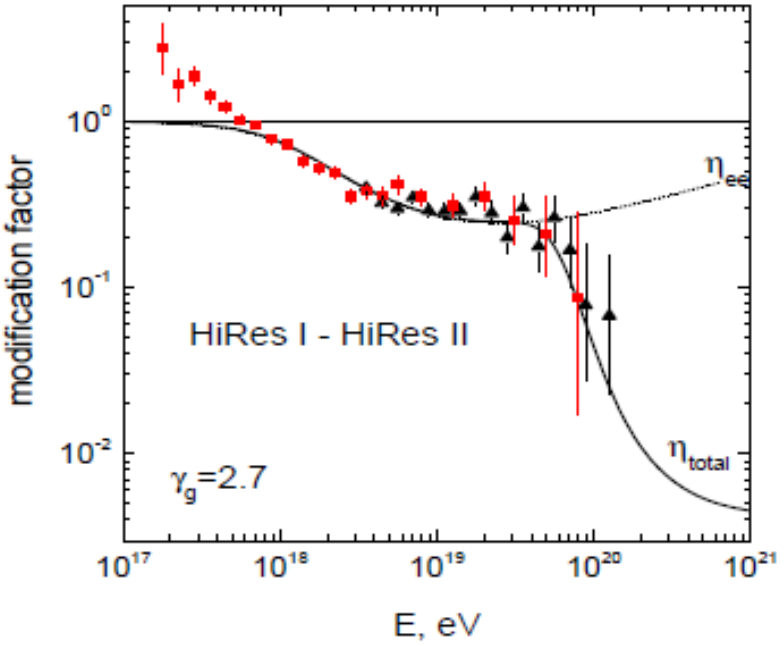


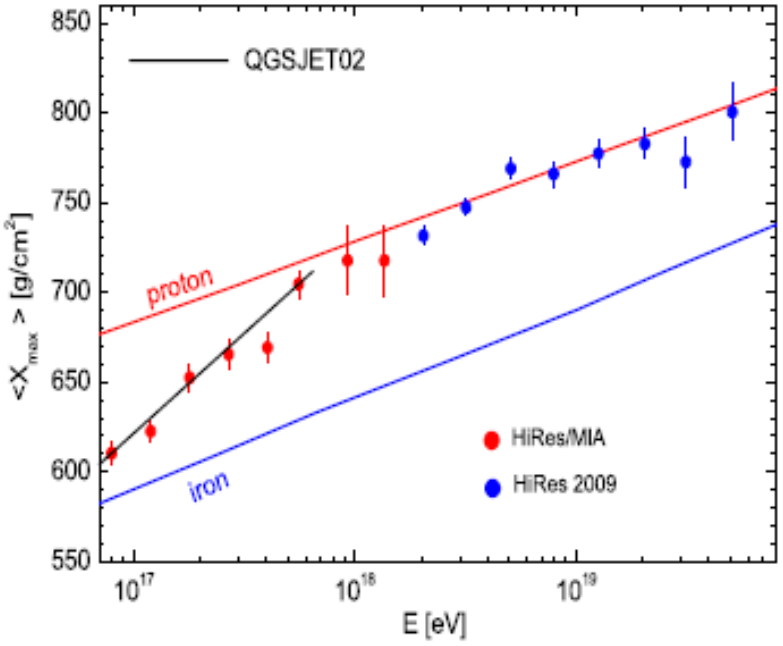




Fits to Proton-Dip Model

- Berezinsky *et al.* modification factor fits.
- Assumes protons, and uses both spectrum and Xmax results. Galactic component visible for log(E) < 17.8 as departure from extragalactic modification and as heavy composition. Domination by protons above at least 17.6.





Summary

- Xmax Measurements
  - HiRes, TA, and Auger Xmax measurements are quite similar. Their interpretation are: p/He is present, iron is not, and N appears in Auger EPOS fits.
  - We can't tell protons from Helium.
- Anisotropy search: protons in log(E) range, 18.0-18.5, are extragalactic.
- Extrapolations of cross sections yield considerable uncertainty in models' Xmax predictions.
- Evidence exists that the TA and Auger spectrum measurements are consistent, and that the spectrum varies in the northern hemisphere.
- TAx4 will answer many questions at high energy: 20 TA-equivalent years of data will be collected by 2020.