Mass Composition Working Group

HiRes/TA: Elliott Barcikowski, John W. Belz,
Yuichiro Tameda, Yoshiki Tsunesada

Yakutsk: Stanislav Knurenko, Yuri Egorov

Auger: Michael Unger, Vitor de Souza,
Jose Bellido

UHECR 2012 Symposium,

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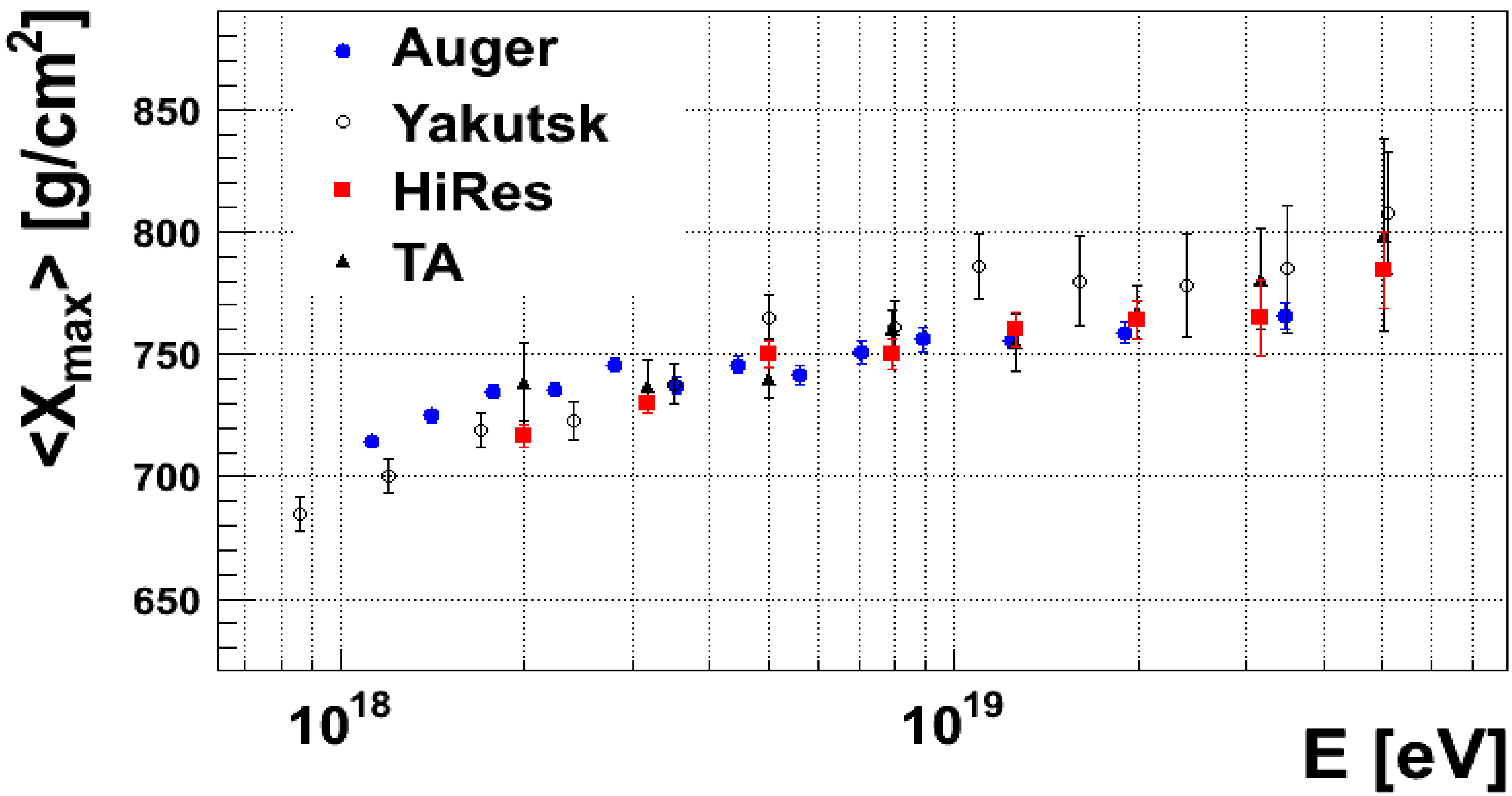
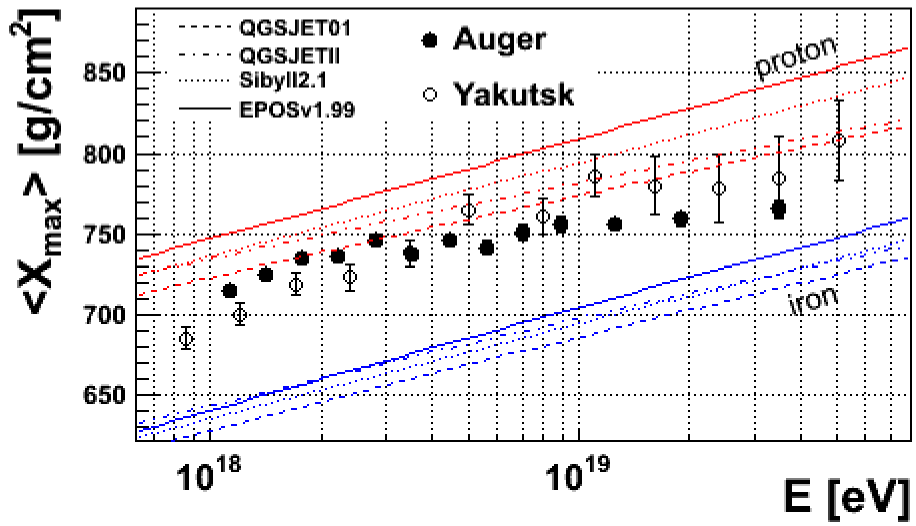
<Xmax> measurements above 10^{18} eV

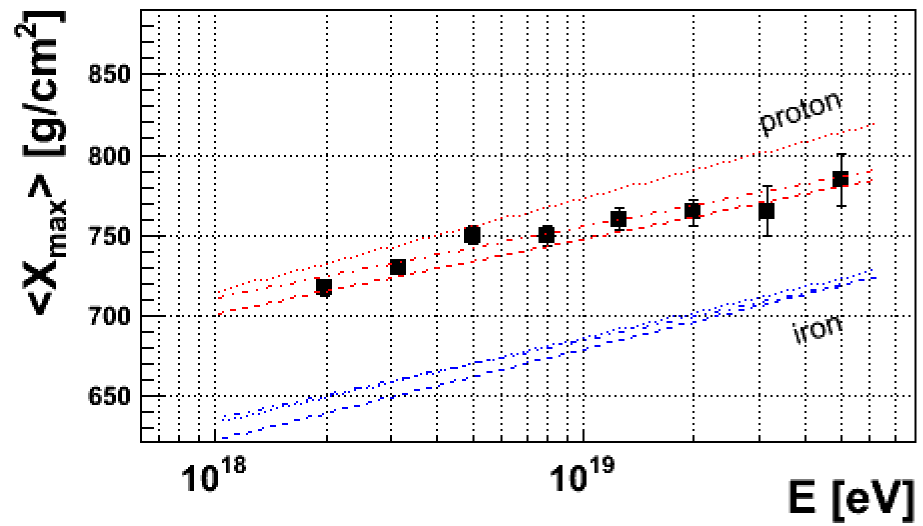


due to differences in the analyses the above <Xmax> values can not be directly compared

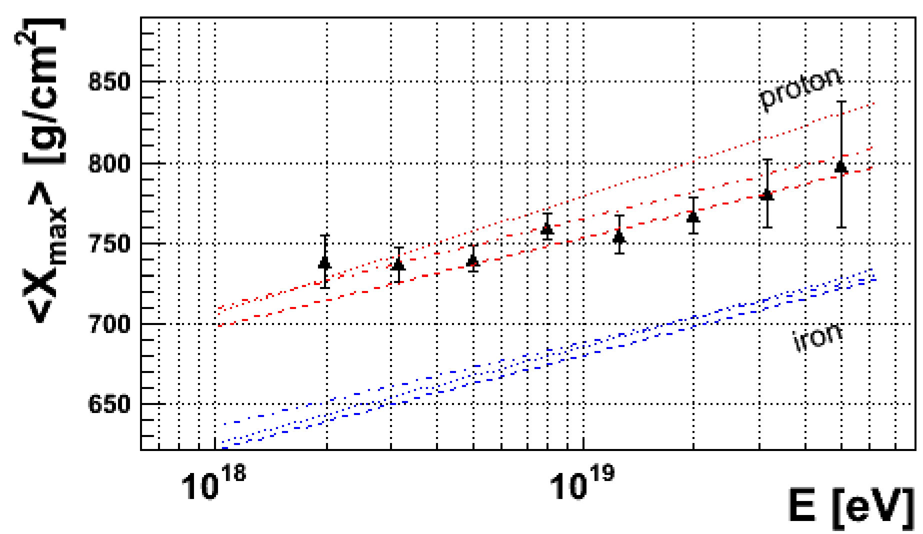
Comparing the observed <Xmax> values with the expectations for proton and iron



HiRes



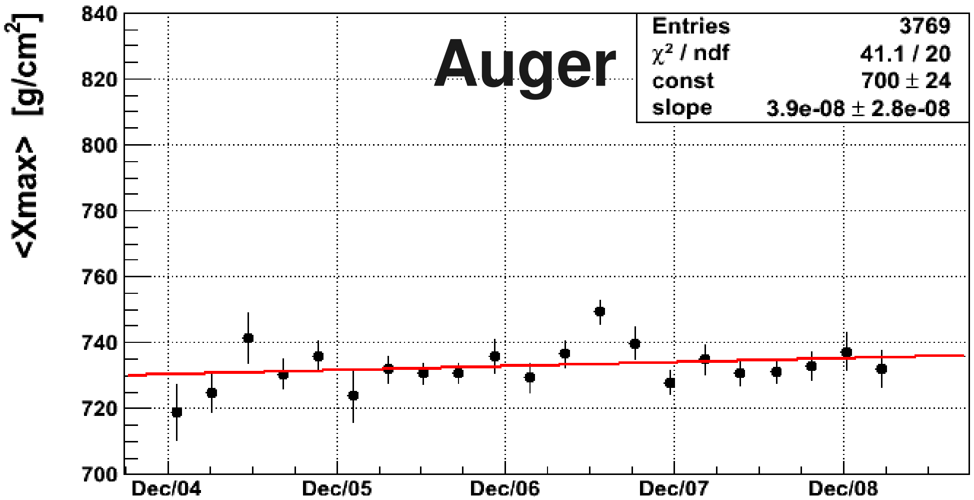
TA

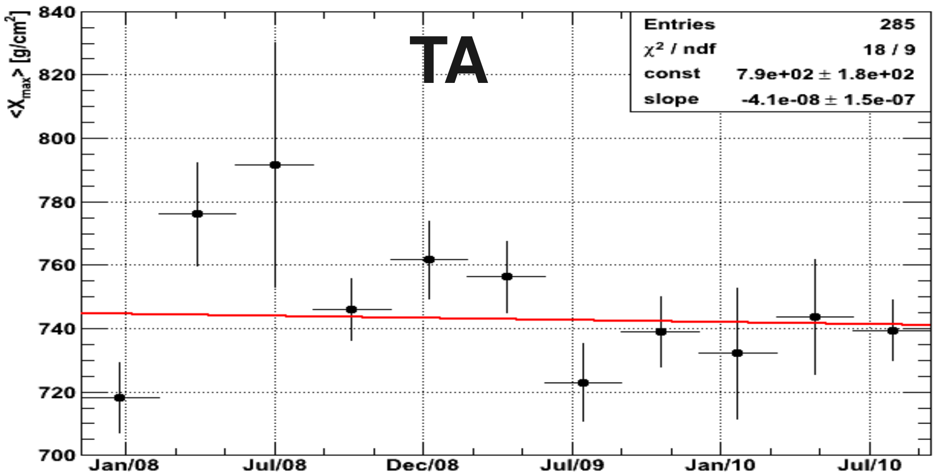


- Are the differences due to issues in any of the analysis?
- Are the differences within systematic uncertainties?
- Are the Southern and Northern sky different in terms of composition?

Are the differences due to issues in any of the analysis?

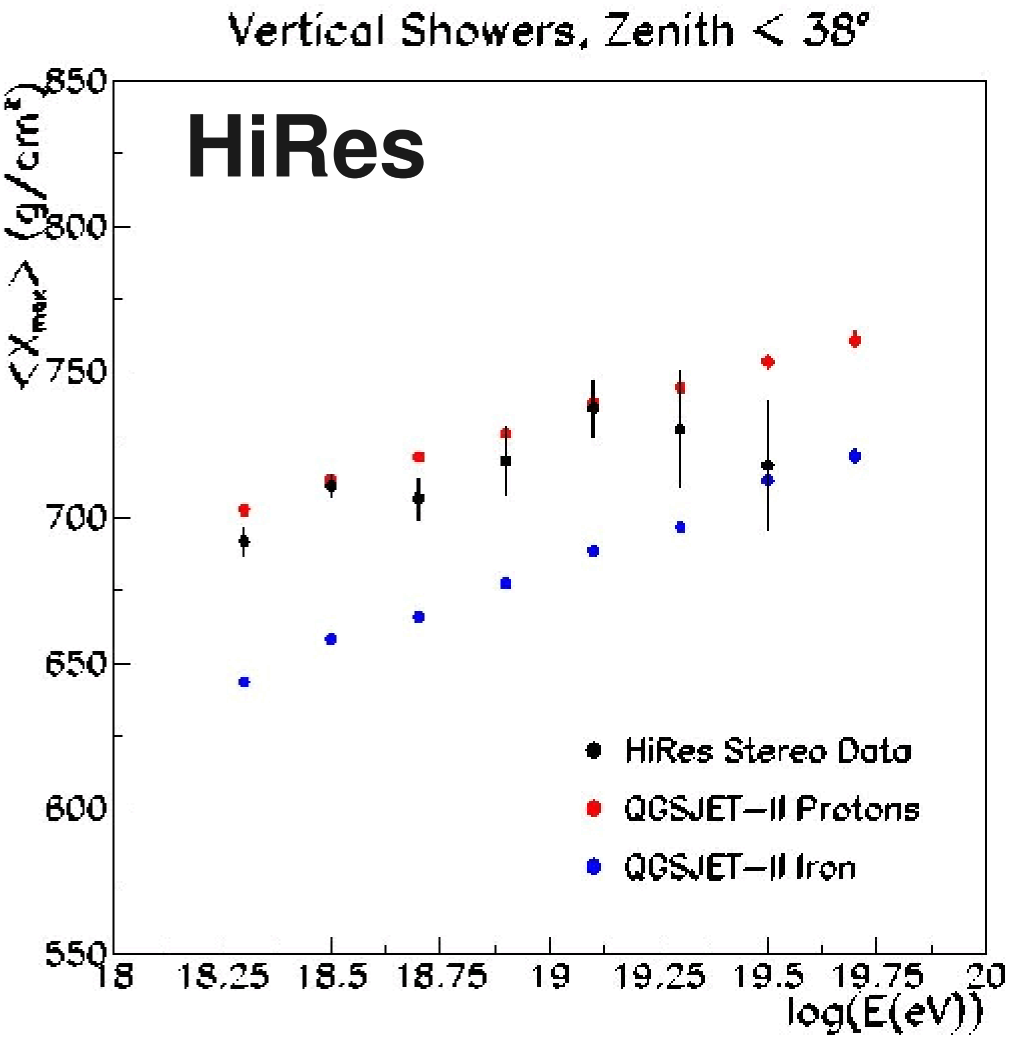
<Xmax> as a function of time

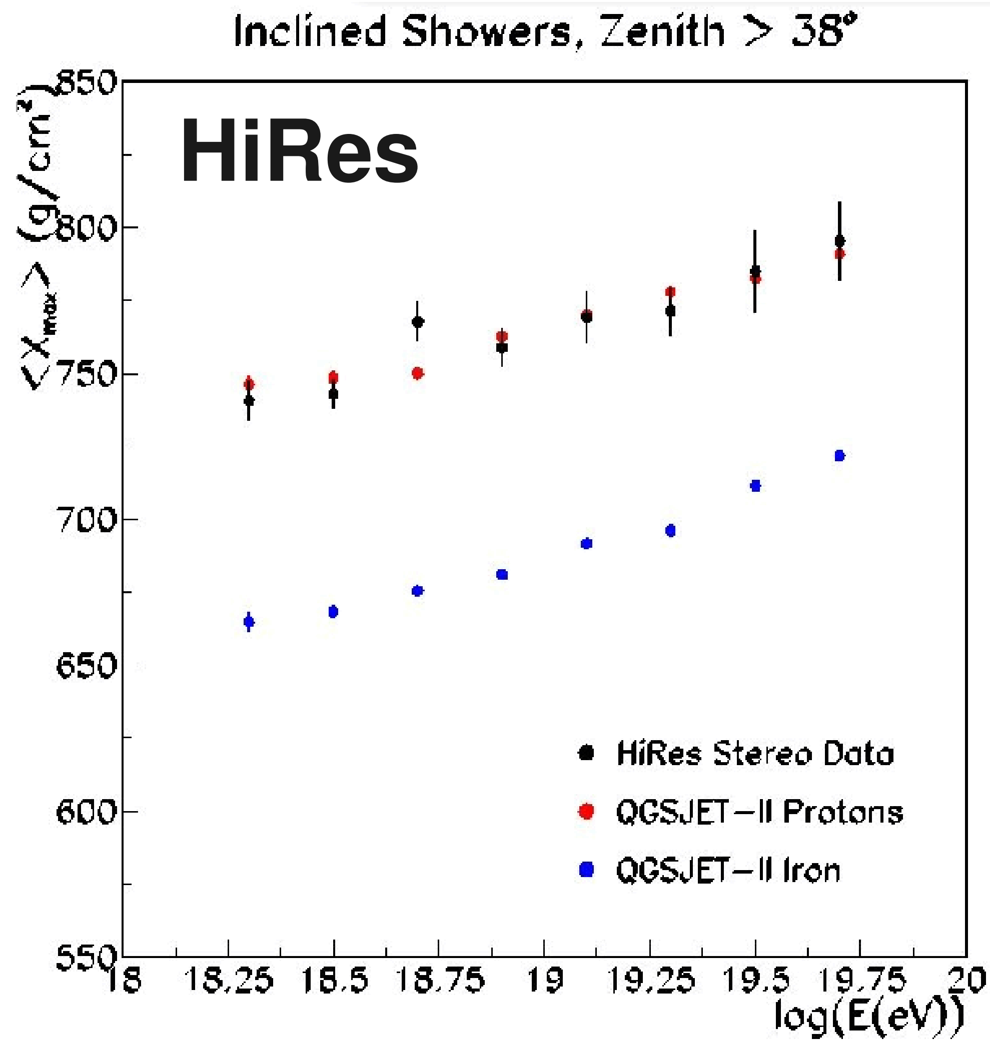




Are the differences due to issues in any of the analysis?

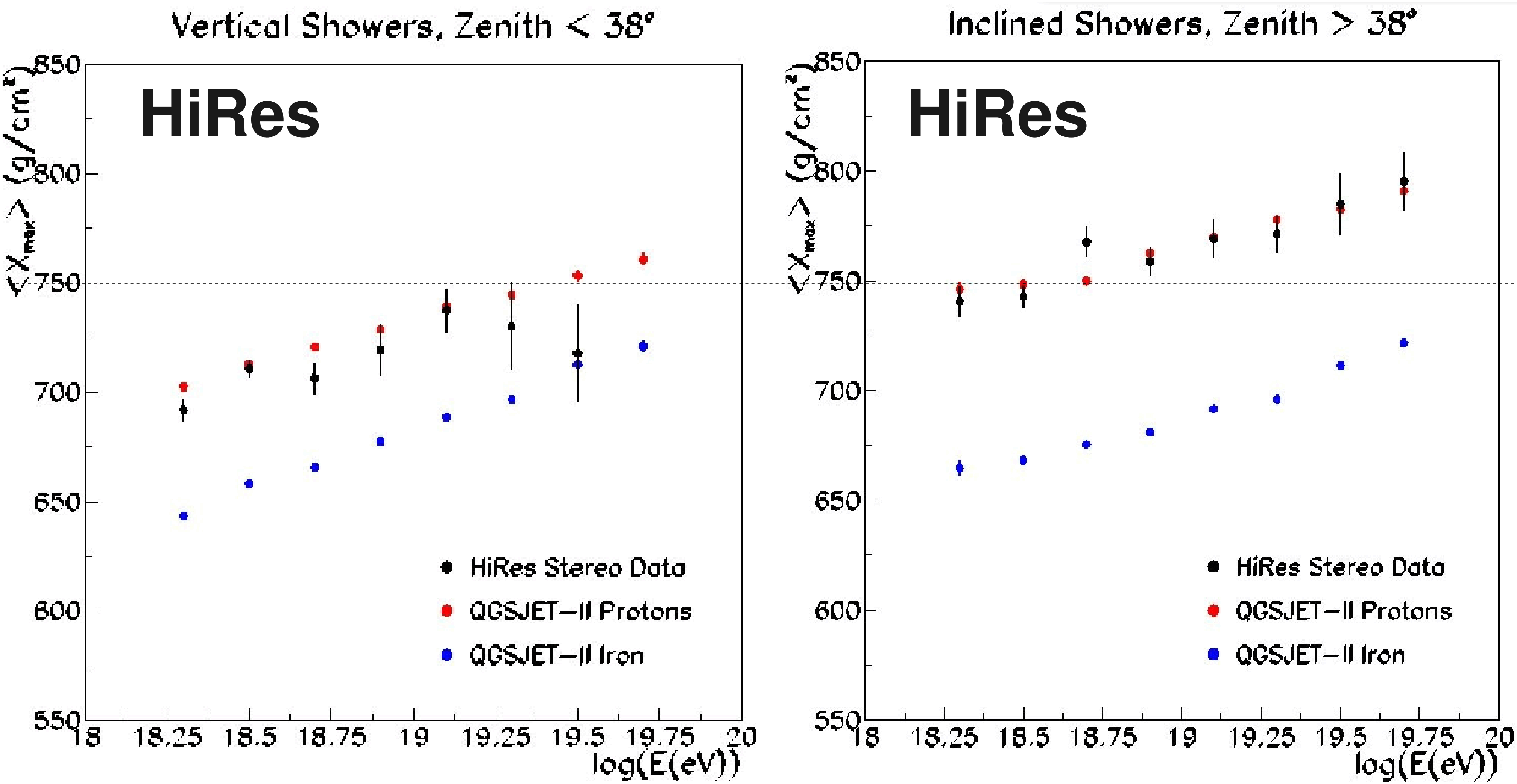
<Xmax> for vertical and inclined showers





Are the differences due to issues in any of the analysis?

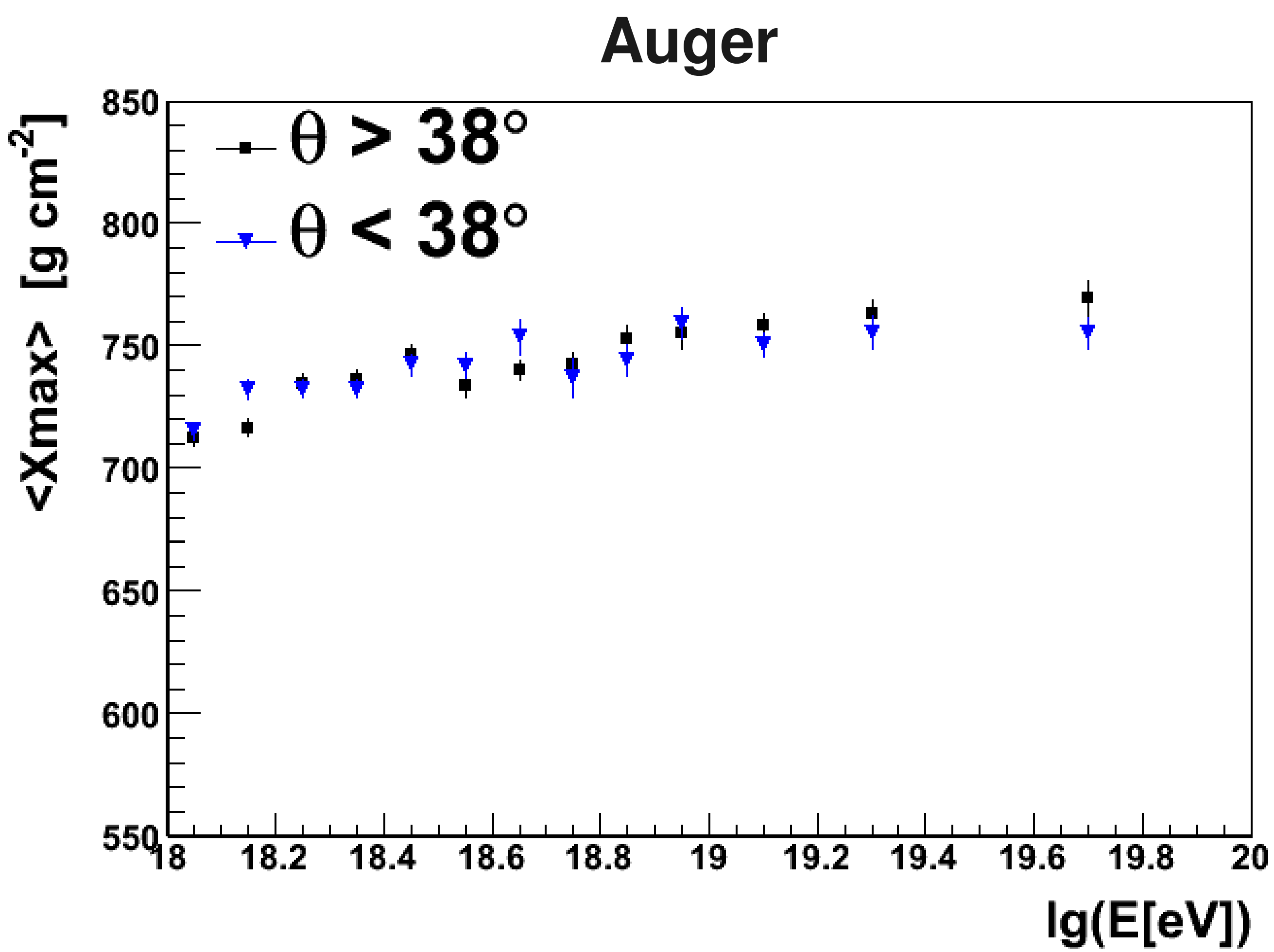
<Xmax> for vertical and inclined showers



The measured <Xmax> values change, but the expected <Xmax> values also change by a similar amount. Therefore, in both cases the data is statistically consistent with proton-QGSJET-II.

Are the differences due to issues in any of the analysis?

<Xmax> for vertical and inclined showers



The <Xmax> values fluctuate within statistical uncertainties.

Are the differences due to issues in any of the analysis?

Validation of the detector simulations

Auger uses detector simulations to estimate:

- the average *Xmax reconstruction bias* as a function of energy. This is used to correct the observed mean Xmax values. (after applying fiducial volume cuts, this correction is smaller than 4 g/cm²).

- the average *Xmax resolution* as a function of energy. This resolution is used to correct the observed RMS(Xmax). (the resolution is about [20-25] g/cm²)

HiRes/TA uses detector simulations to estimate:

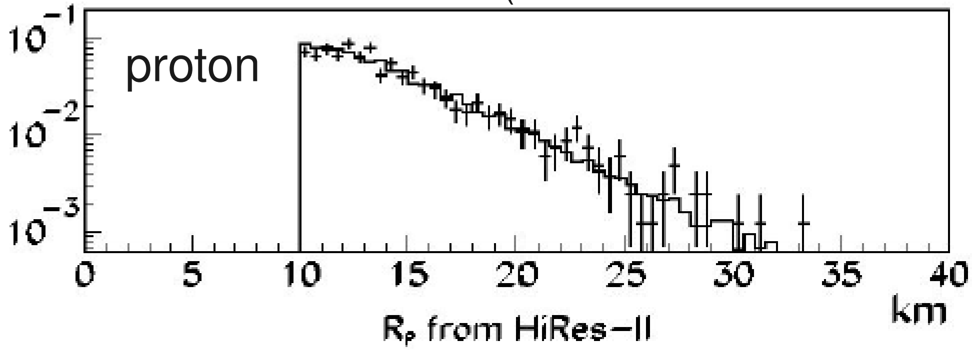
-the *expected Xmax distributions after all detector effects*. These expectations are estimated for different cosmic ray primaries. The expected and observed Xmax distributions are compared to infer the average cosmic ray composition.

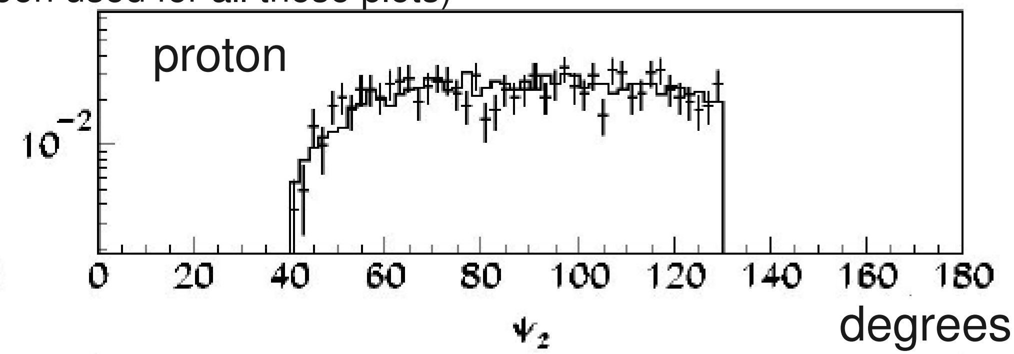
... so, it is important to provide evidence of the validity of the MC simulations ...

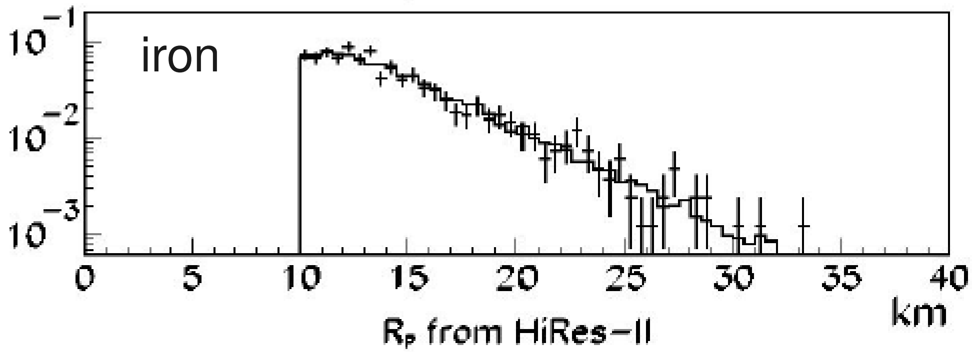
Validation of the detector simulations (HiRes)

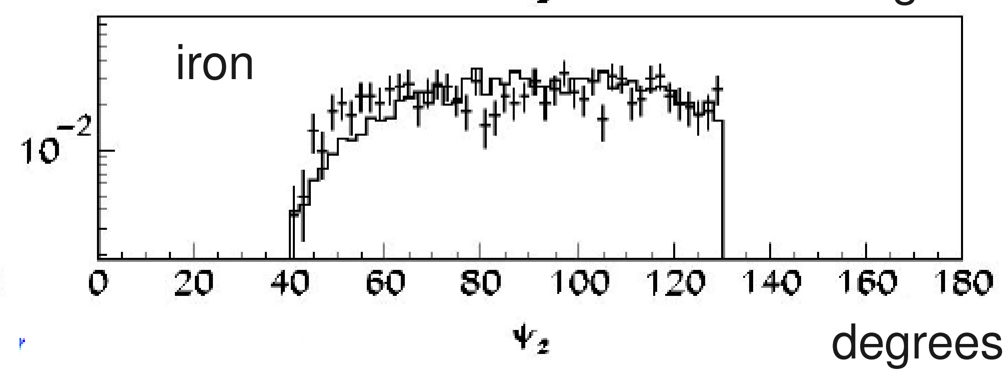
Comparing real data distributions with expectations from detector simulations (solid lines).

(the model QGSJETII has been used for all these plots)

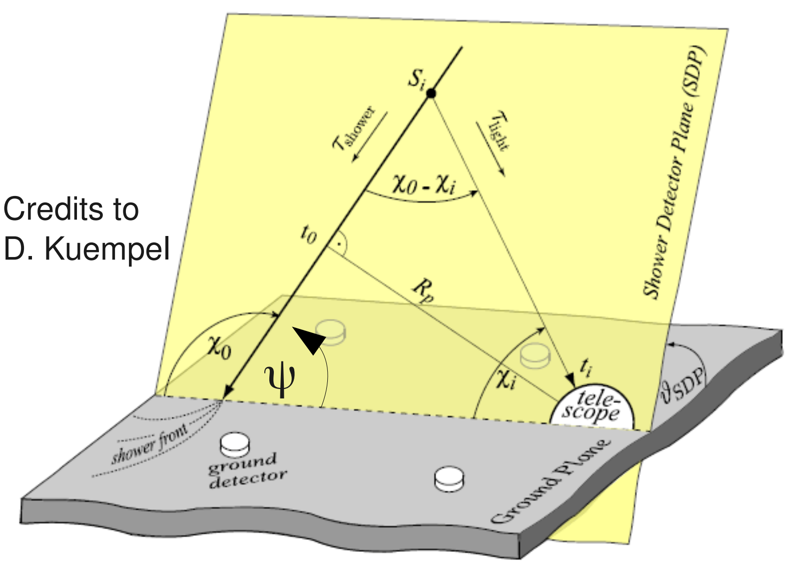


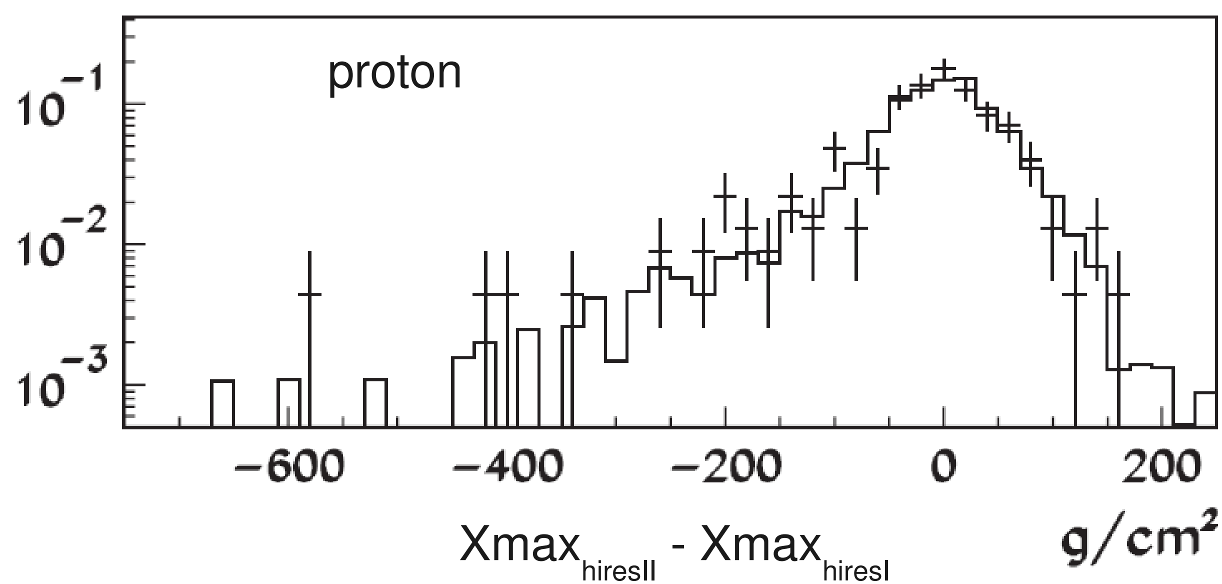






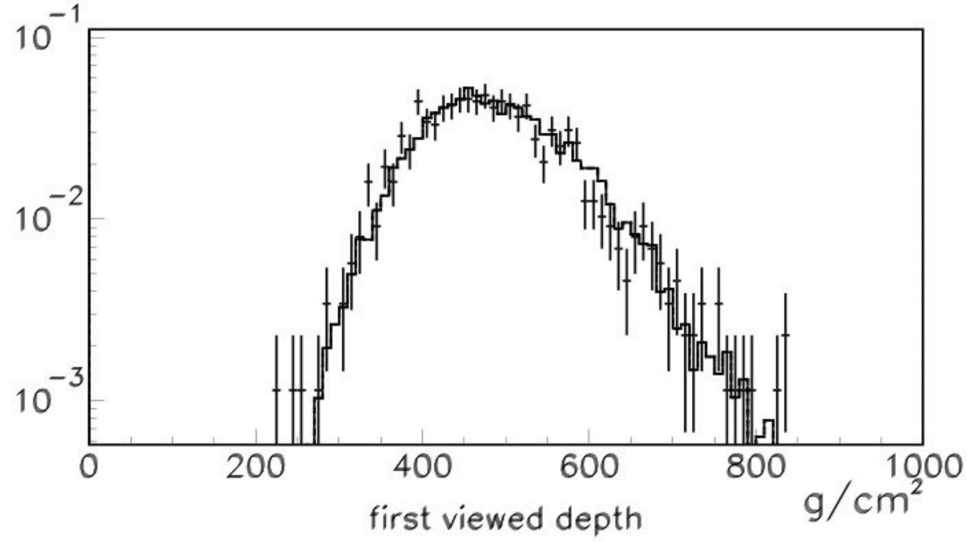
Credits to D. Kuempel



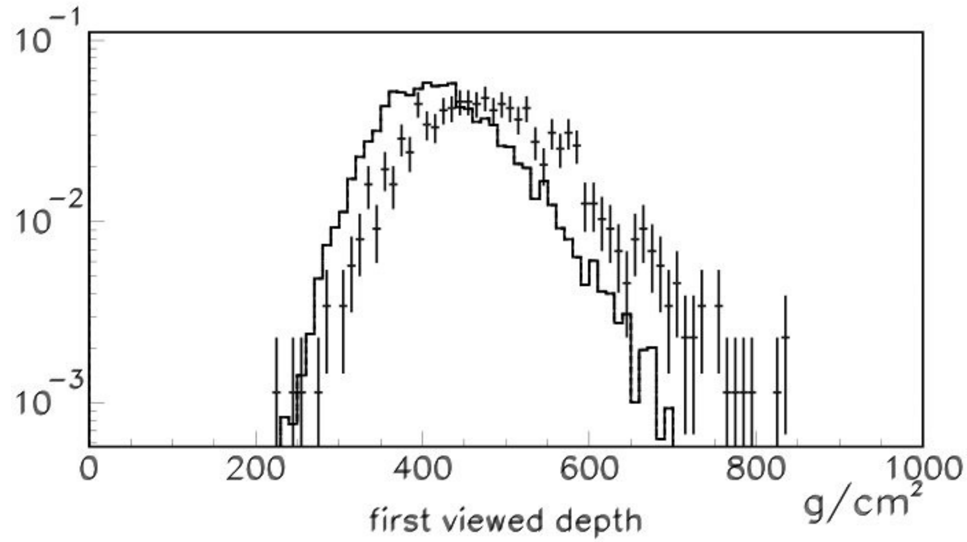


HiRes Data (points) versus QGSJET-II Monte Carlo (histogram)

Protons



Iron



HiRes Data (points) versus QGSJET-II Monte Carlo (histogram)

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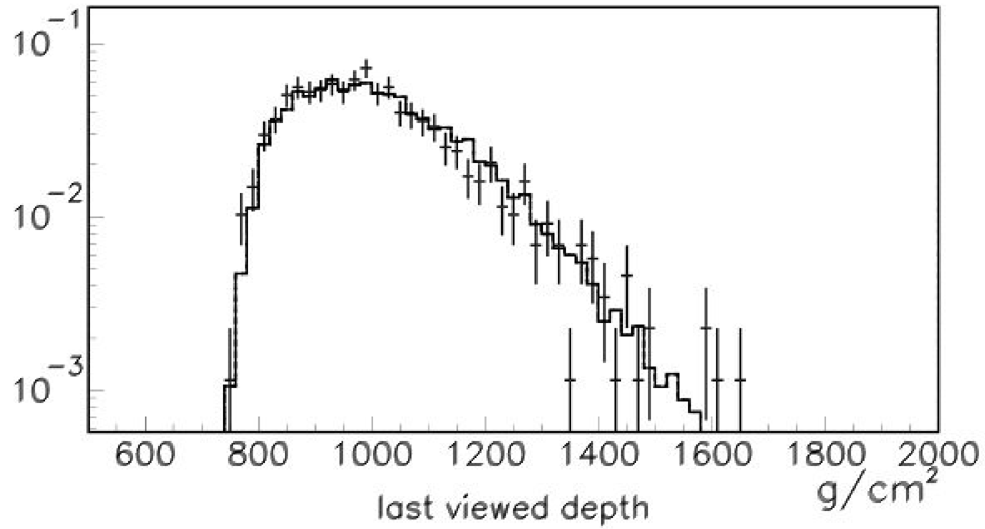
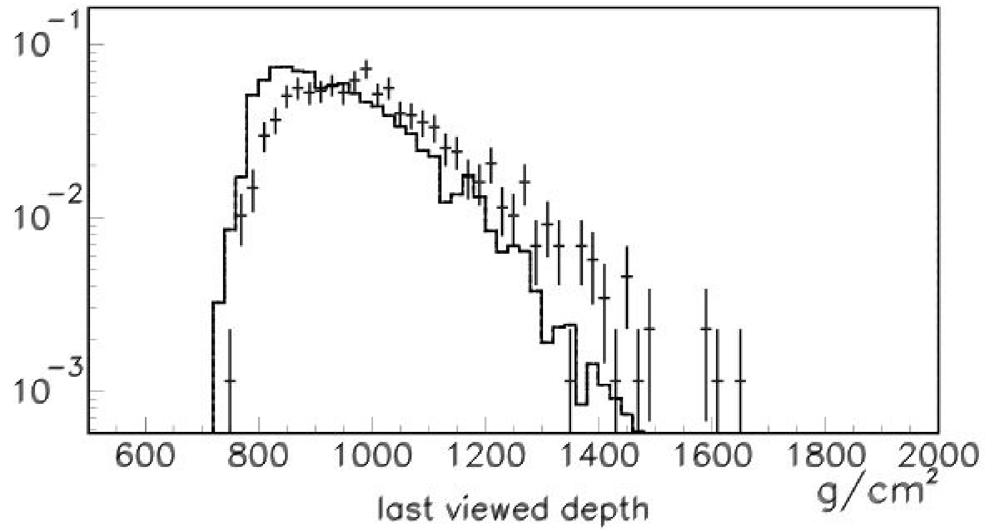


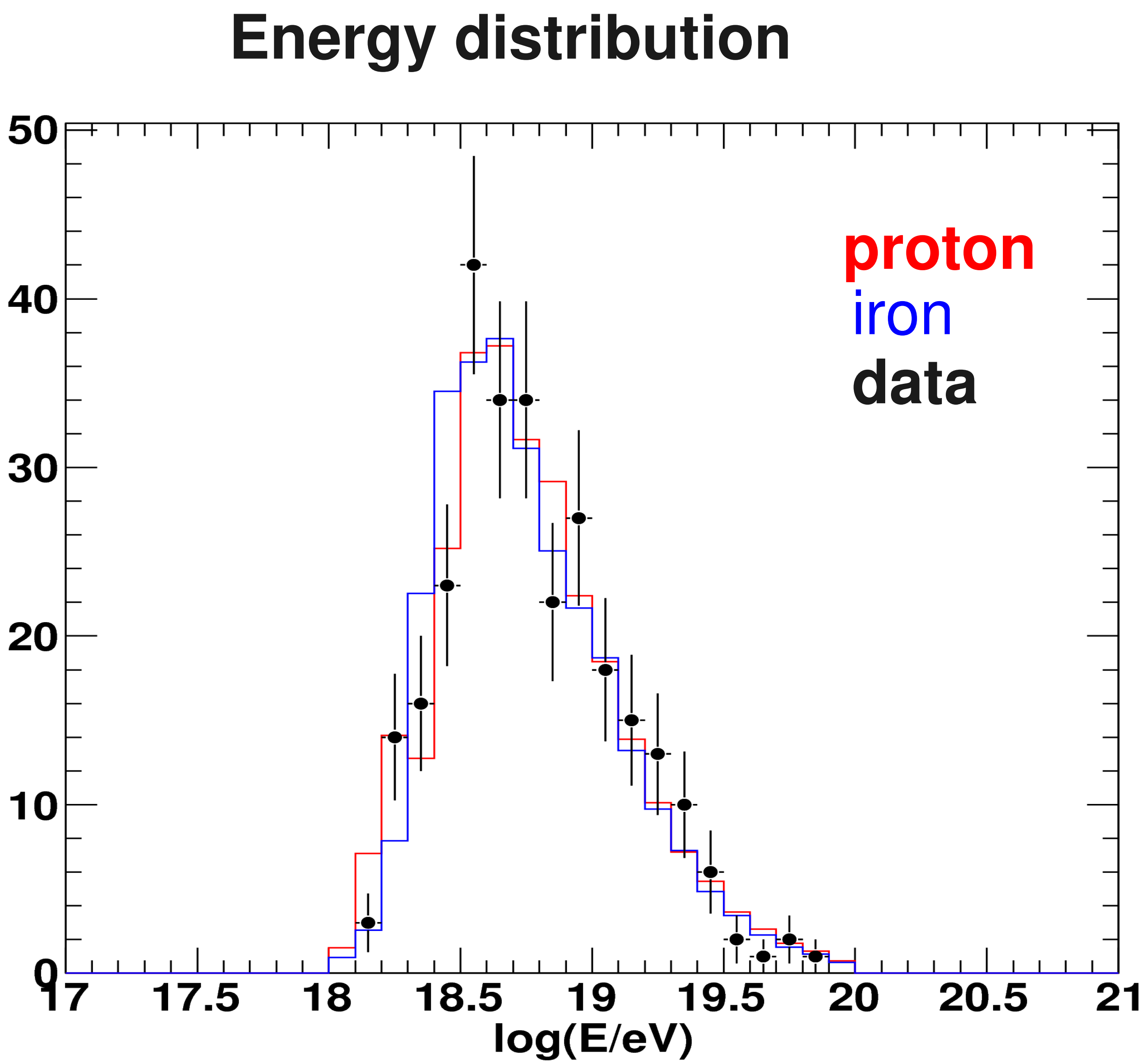
Iron



Validation of the detector simulations (TA)

Comparing real data distributions with expectations from detector simulations (solid lines).

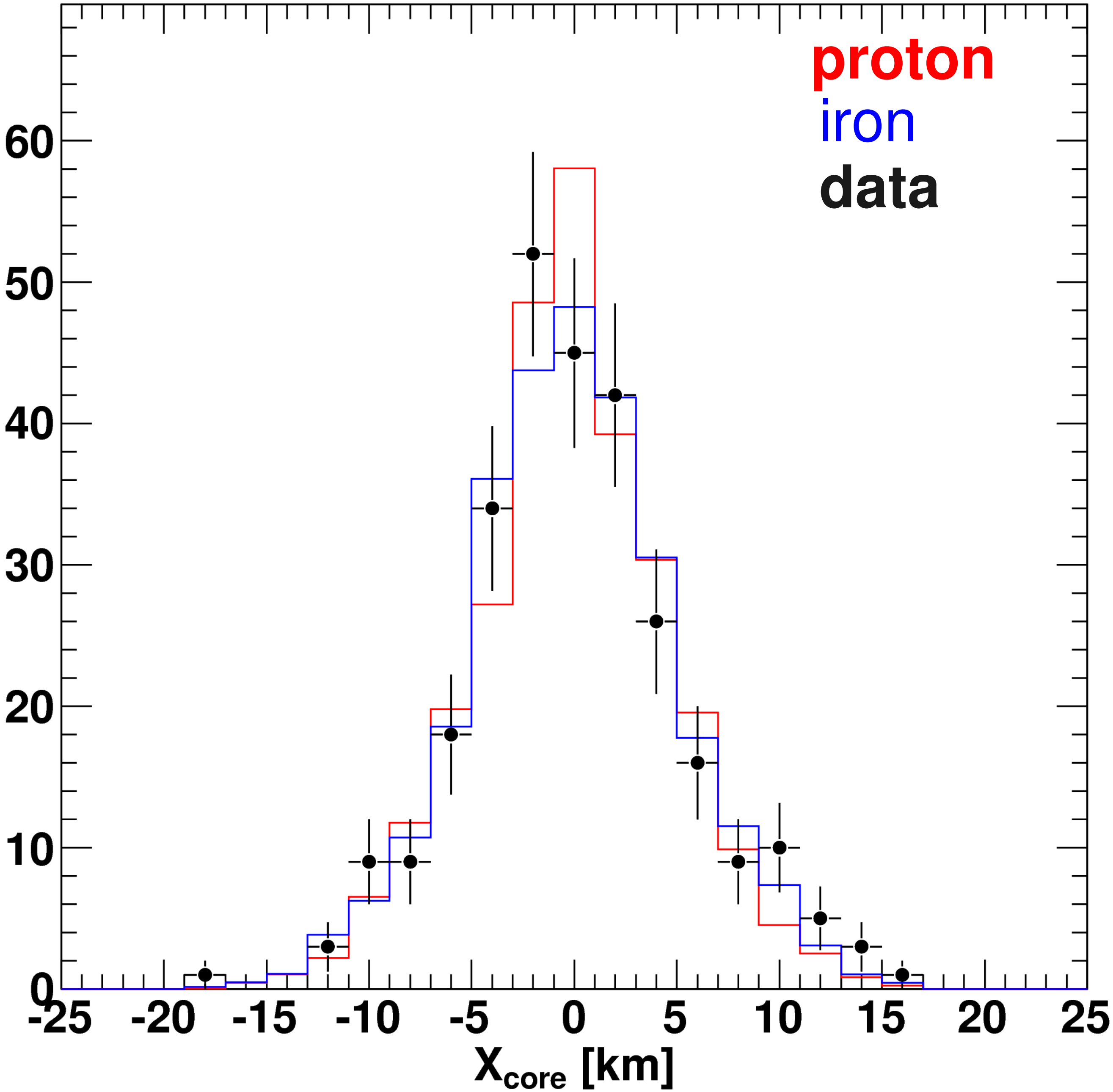
(the model **QGSJETII** has been used for all these plots)



Validation of the detector simulations (TA)

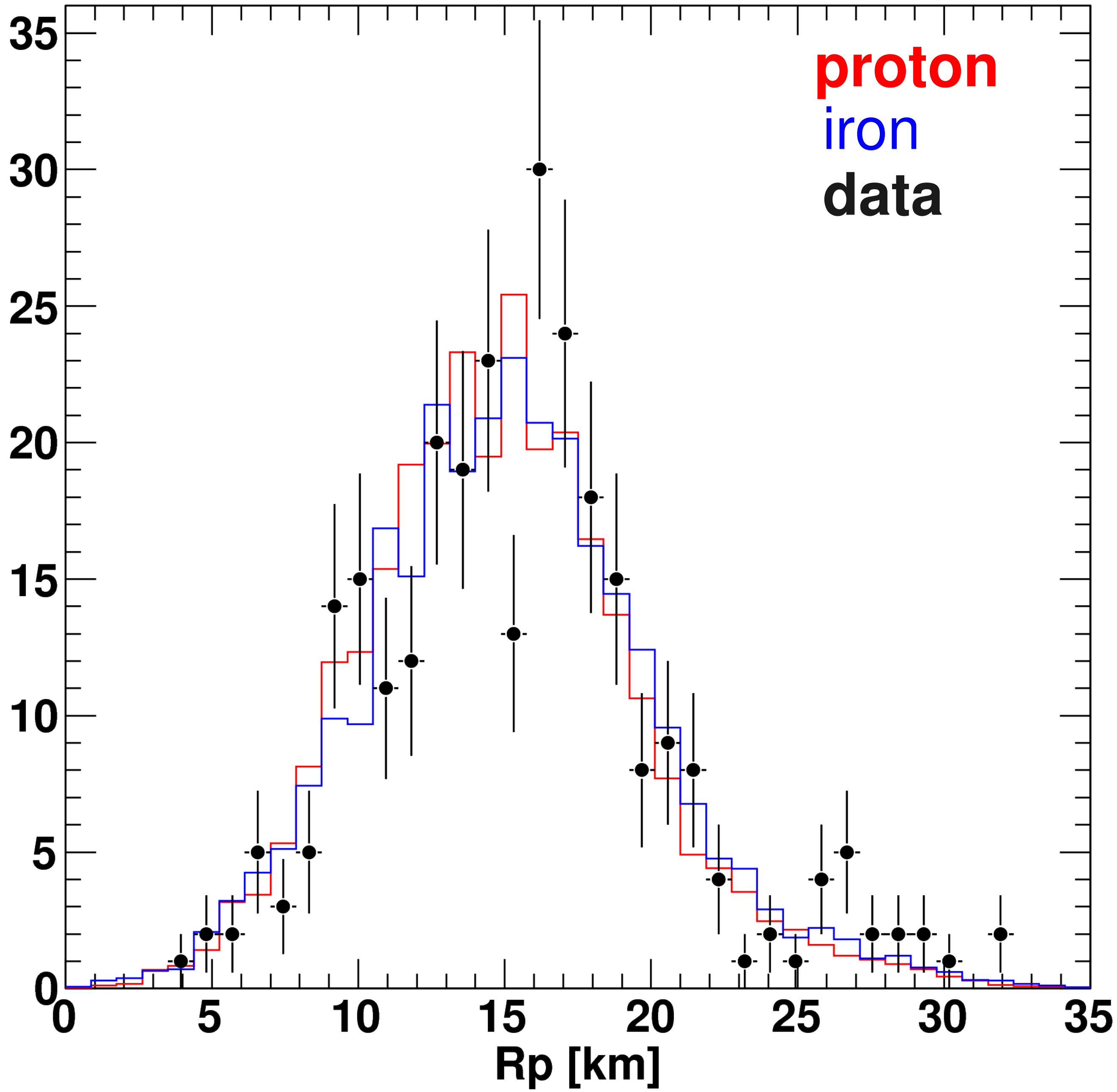
Distribution of core location

(0 means showers landing at the center of the array)

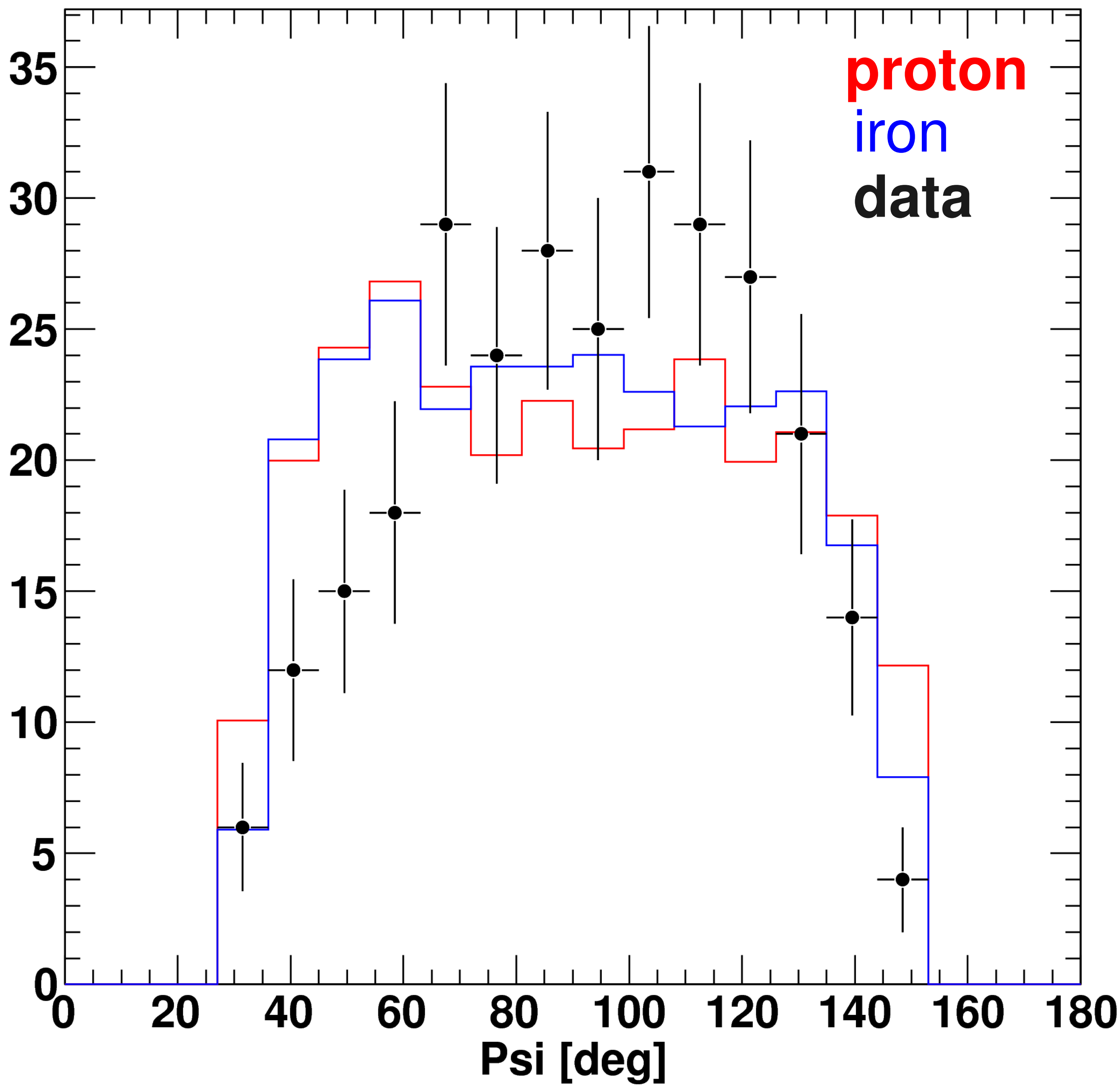


Validation of the detector simulations (TA)

Distribution of shower-detector distance



Distribution of shower inclinations within the SDP

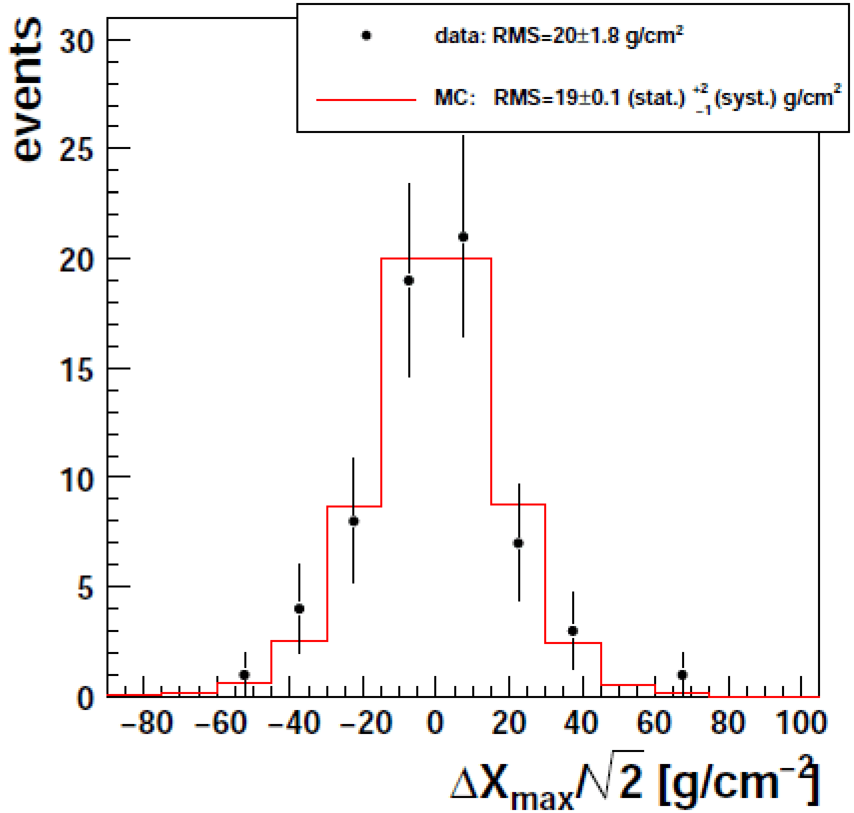


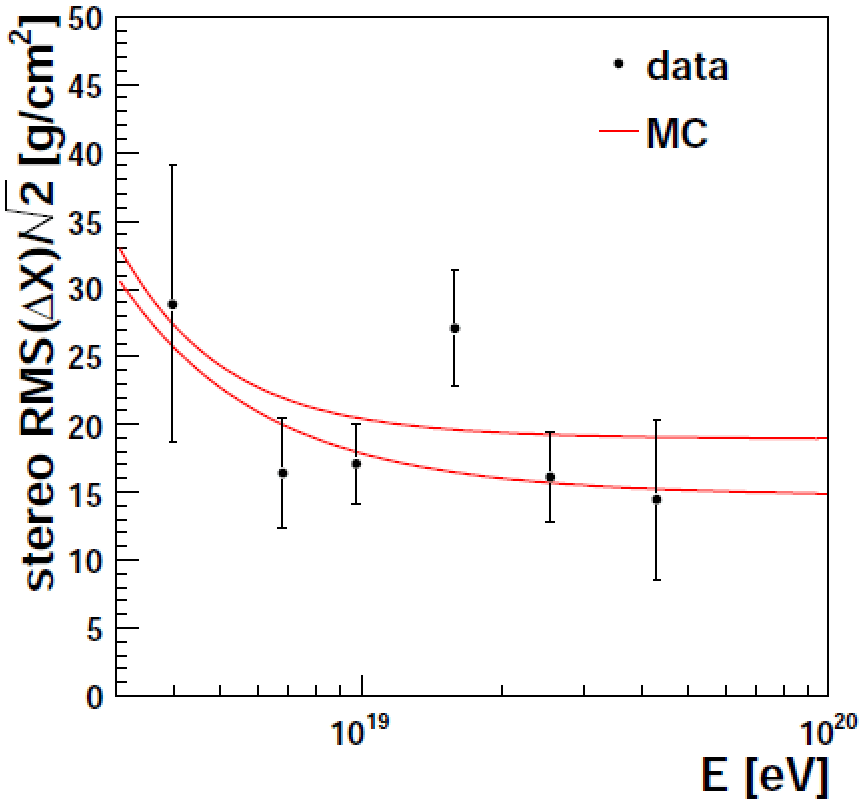
Validation of the detector simulations (Auger)

Comparing real data distributions with expectations from detector simulations (solid lines).

(the model QGSJETII has been used for all these plots)

Difference in the reconstructed Xmax values in stereo events for real data and MC



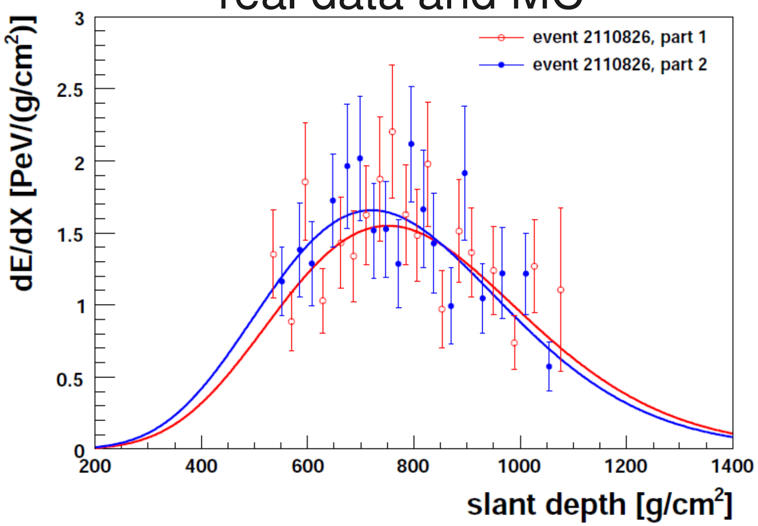


Validation of the detector simulations (Auger)

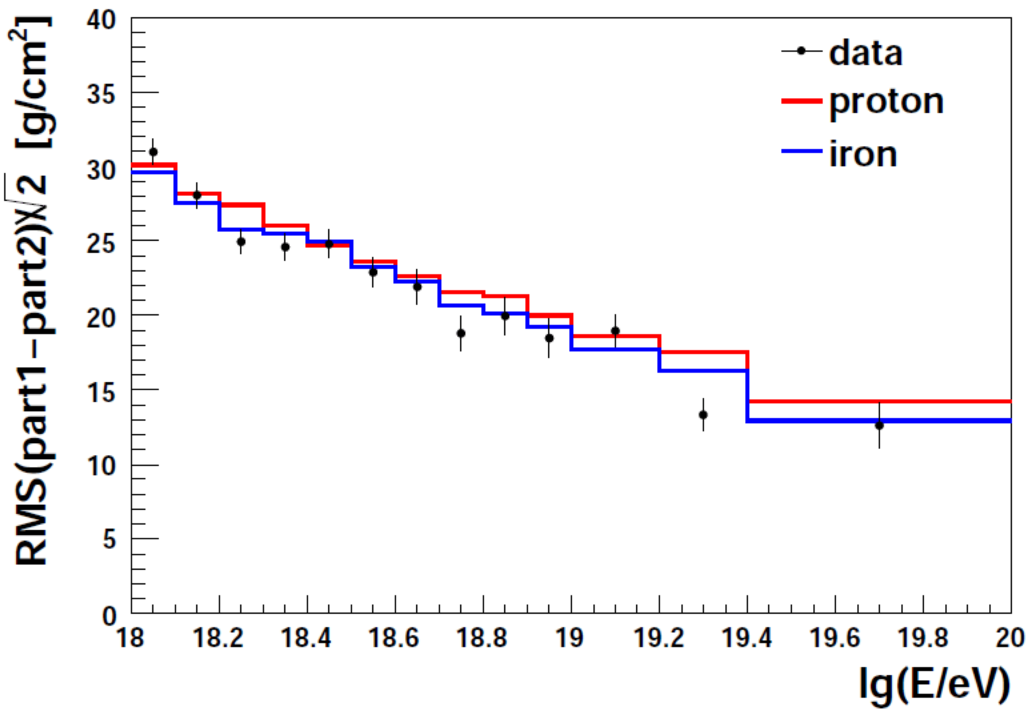
Comparing real data distributions with expectations from detector simulations (solid lines).
(the model QGSJETII has been used for all these plots)

Partitioning observed profiles profiles

Partitioning each event profile to form two independent profiles for real data and MC



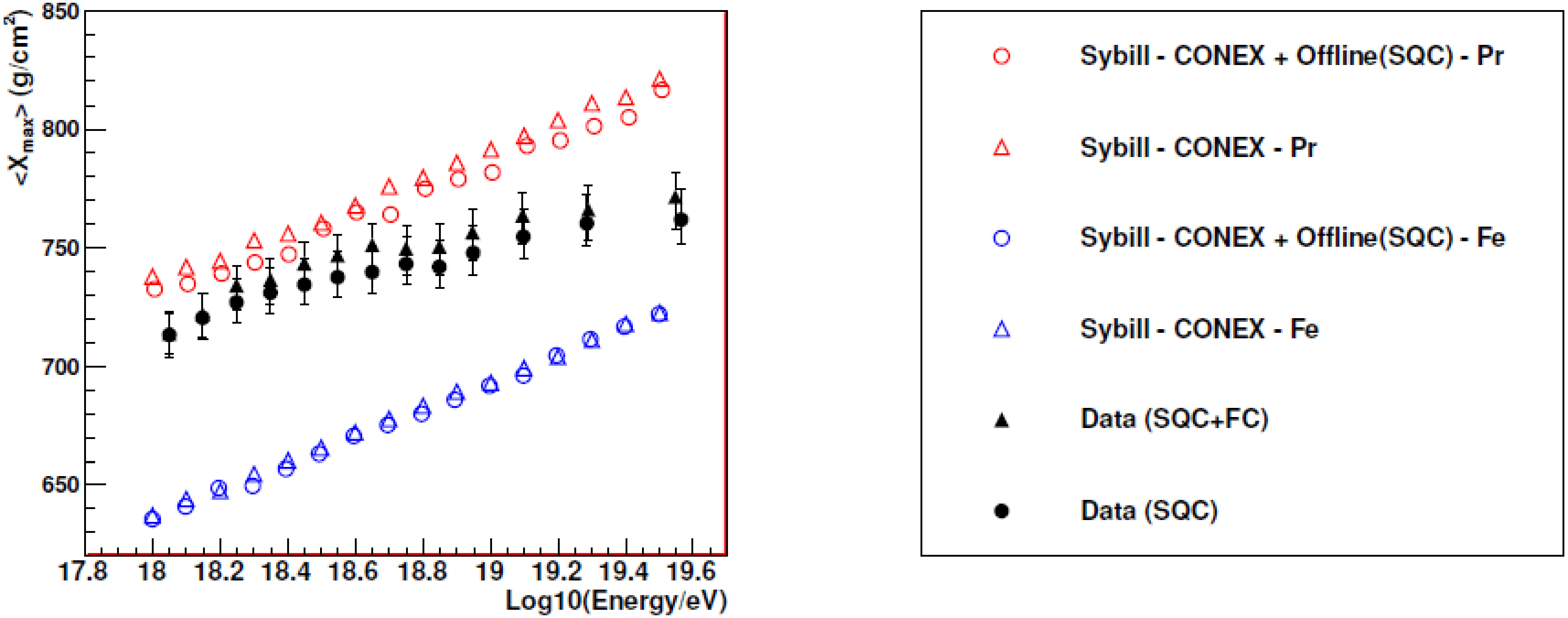
Example of profile partitioning. All points of this graph belongs to the same event. The event is divided in two: red points and blue points.



RMS of profile partitioning as a function of energy

Questions relevant to the Auger analysis

(a) Have you performed an analysis in the style of HiRes/TA, in which you perform detector response and triggering simulations and then compare data to Monte Carlo with identical cuts? What, if any, is the outcome of that analysis?



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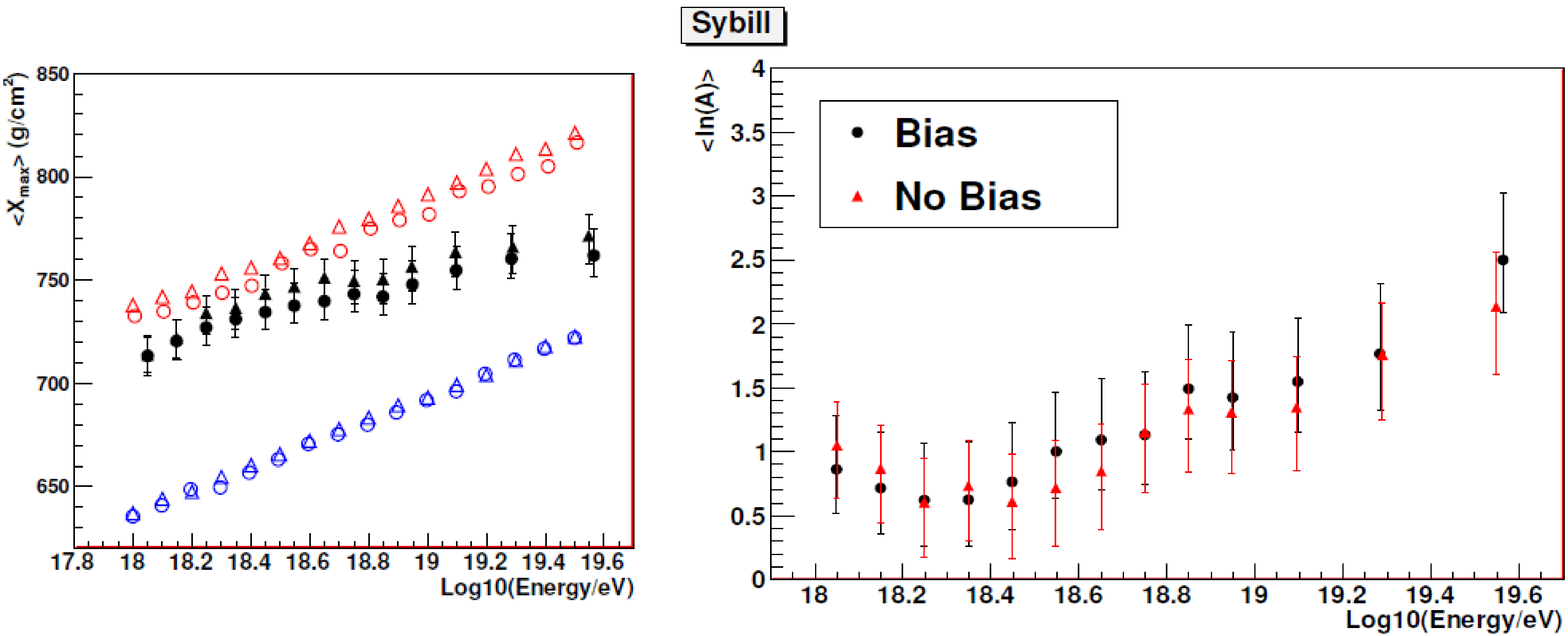
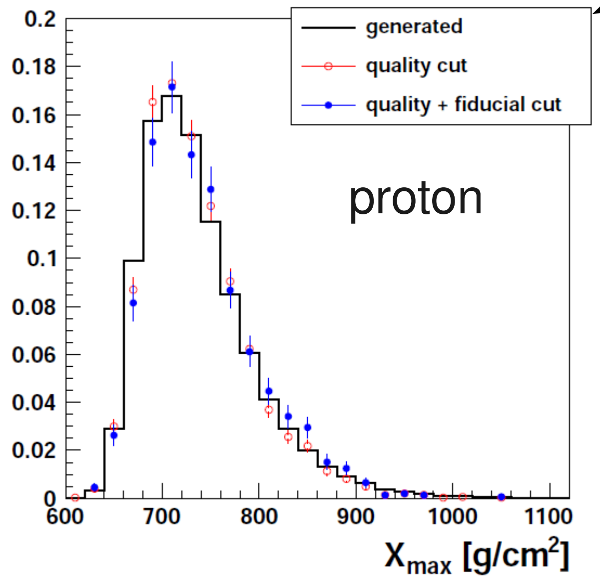


Using : $$\langle \ln A \rangle = \frac{\langle X_{max} \rangle_p - \langle X_{max} \rangle_{data}}{\langle X_{max} \rangle_p - \langle X_{max} \rangle_{Fe}} \ln 56$$ to transform <Xmax> to <lnA>

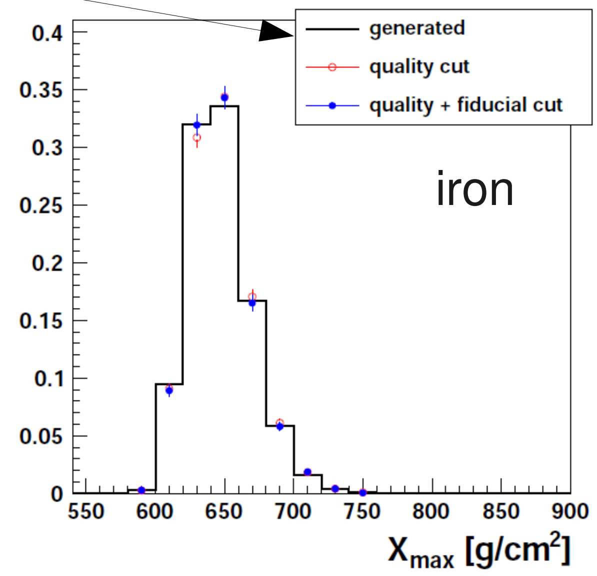
Questions relevant to the Auger analysis

(b) Can you show, in energy bins, overlays of as-thrown and accepted Xmax distributions for proton and iron Monte Carlo, with full detector response and triggering simulations, with and without the fiducial volume cuts? Also their ratios (i.e. the acceptance)?

generated values for Xmax have been used in all three levels to focus on acceptance effects.
(i.e. resolution and reconstruction systematic effects are not considered).



(a) $10^{18.0}$ eV $< E < 10^{18.1}$ eV.



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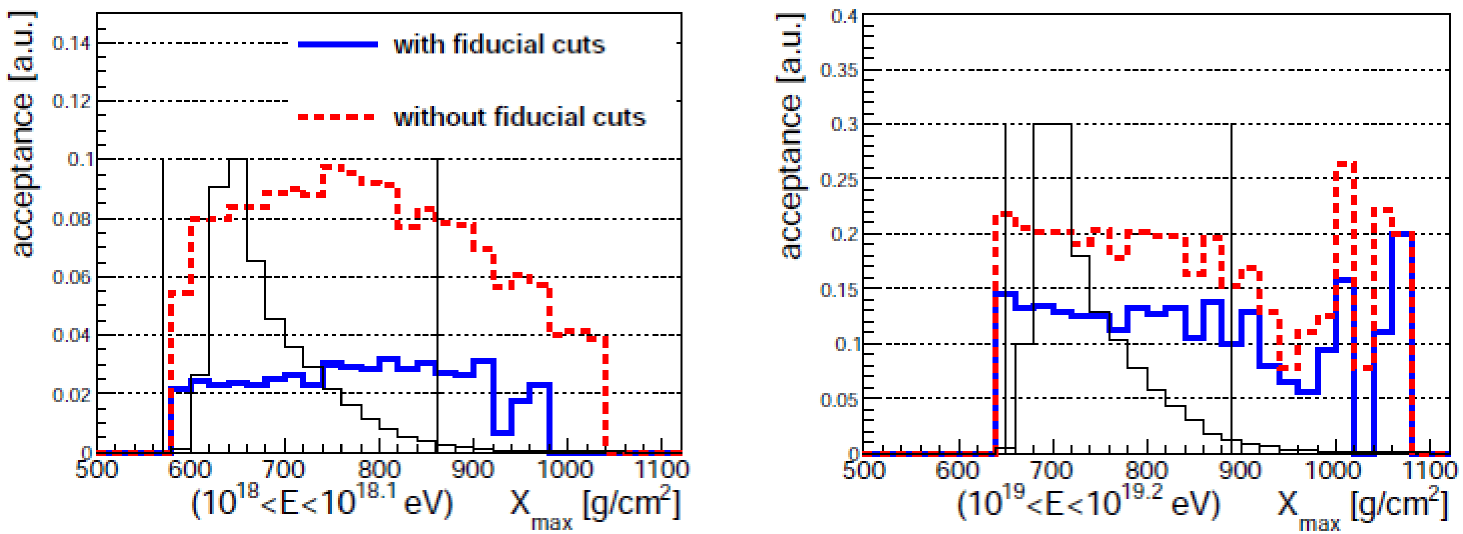
Questions relevant to the Auger analysis

(b) Can you show, in energy bins, overlays of as-thrown and accepted Xmax distributions for proton and iron Monte Carlo, with full detector response and triggering simulations, with and without the fiducial volume cuts? Also their ratios (i.e. the acceptance)?

Acceptance: Ratio of Selected / generated



The input Xmax distribution (shown with solid black lines) correspond to a 50/50 mix of proton and iron.

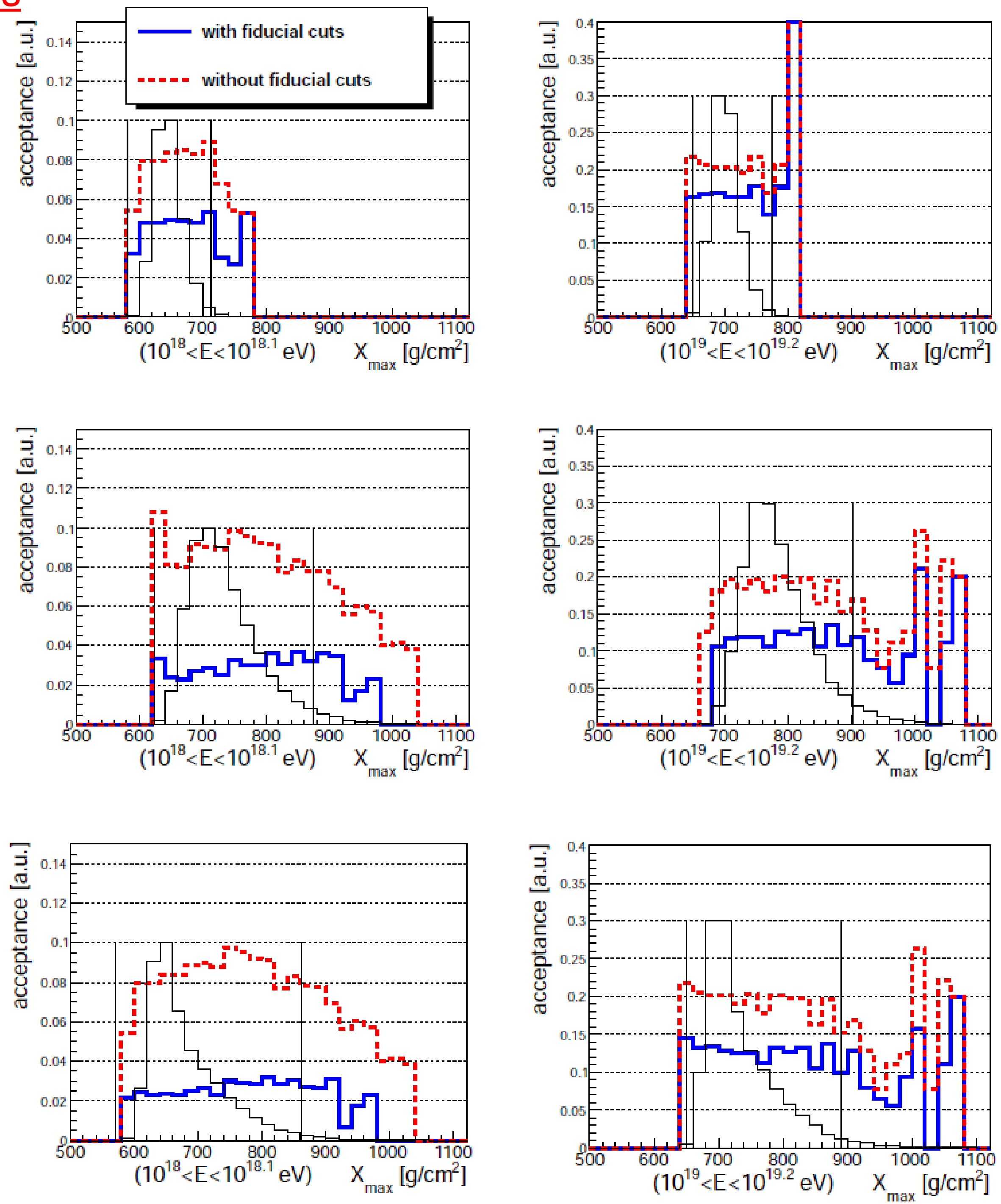
Questions relevant to the Auger analysis

Acceptance:
Ratio of Selected / generated

pure iron.

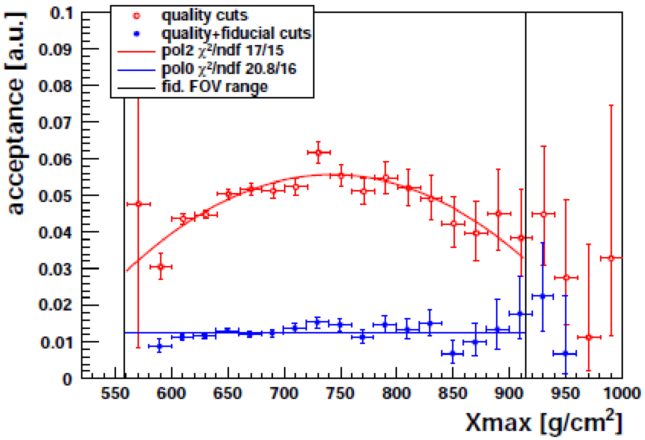
pure proton.

50% proton 50% iron.

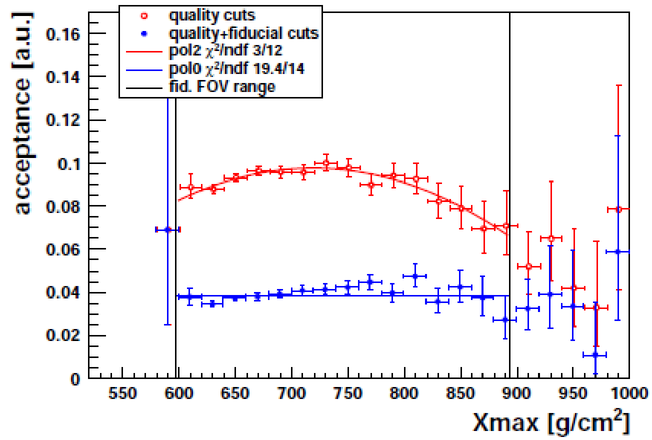


Questions relevant to the Auger analysis

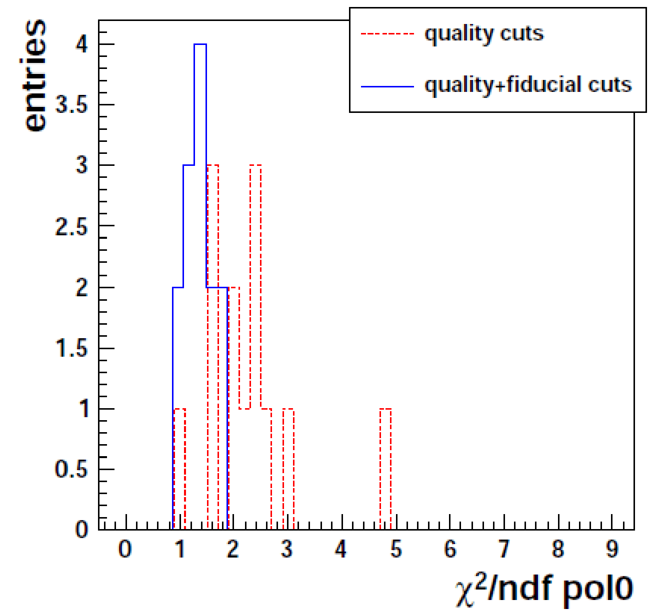
Quantifying the flatness of the acceptance after fiducial cuts



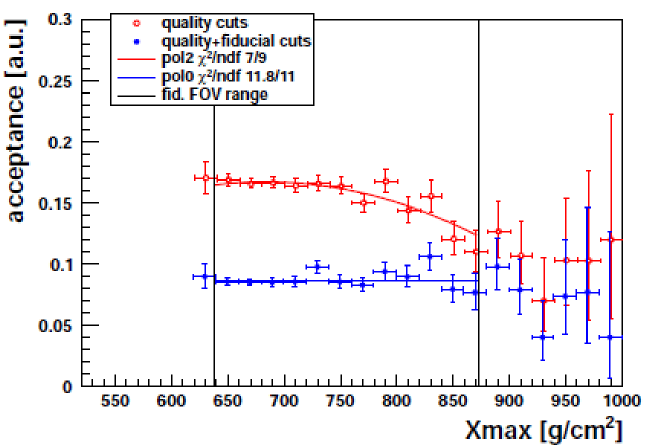
(a) $10^{17.8}$ eV $< E <10^{17.9}$ eV.



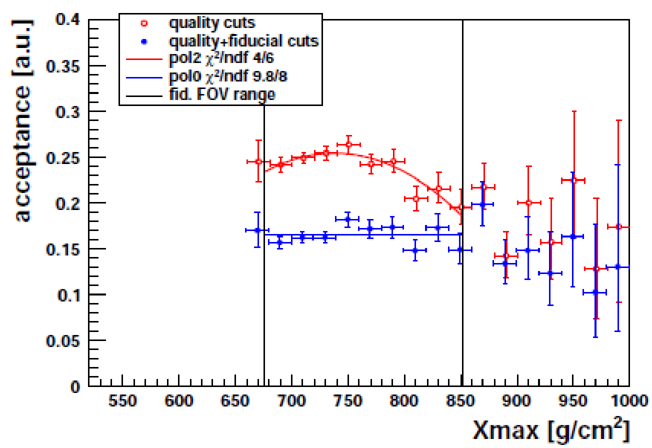
(b) $10^{18.1}$ eV $< E <10^{18.2}$ eV.



(e) χ^2/Ndf values of a fit with a constant (pol0) to the acceptance in the fiducial X_{max} range for all 13 bins of the elongation rate analysis.



(c) $10^{18.5}$ eV $< E <10^{18.6}$ eV.



(d) $10^{19.2}$ eV $< E <10^{19.4}$ eV.

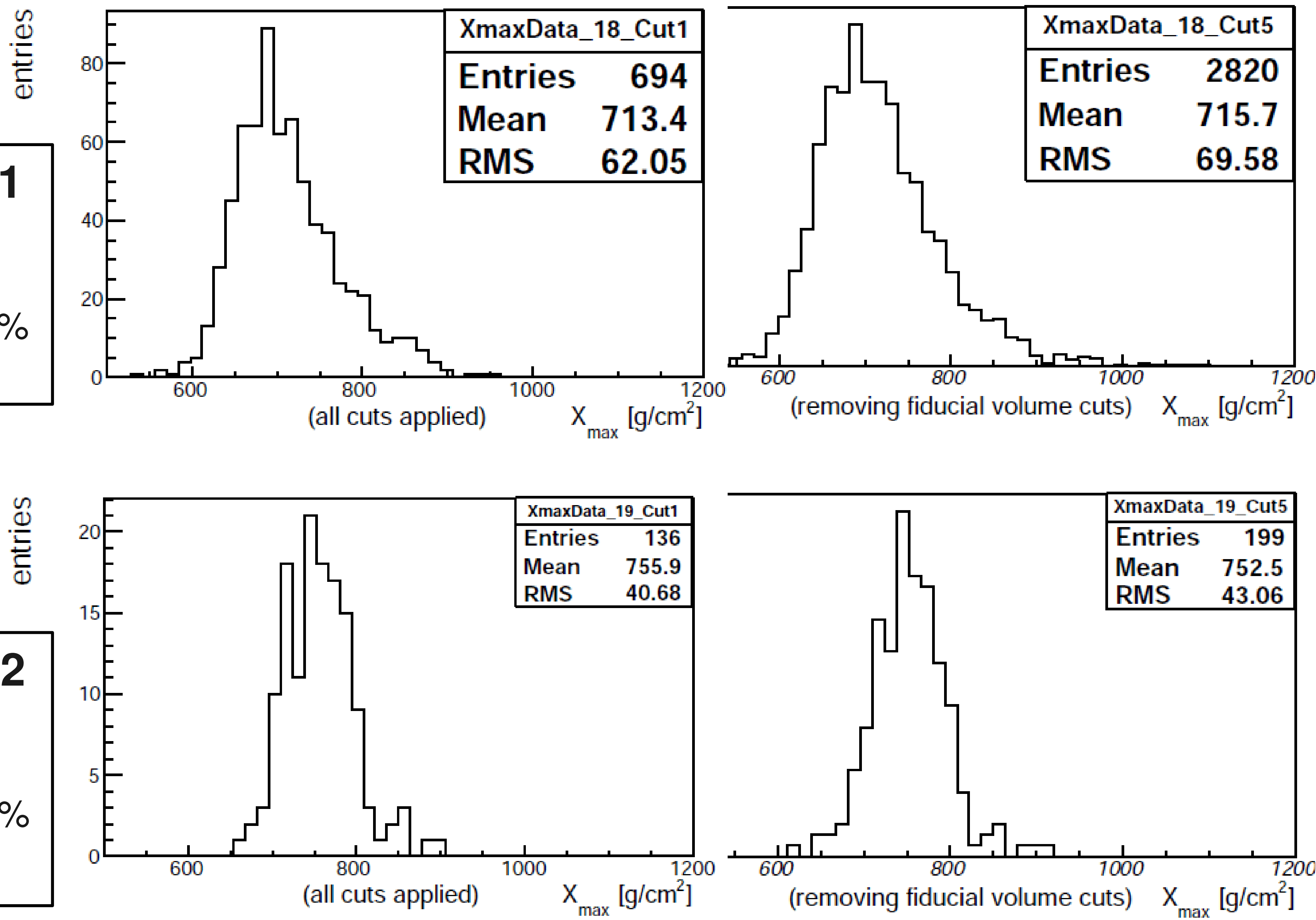
Xmax distributions with and without applying the fiducial cuts

18 < lgE < 18.1

At this energy range the fiducial cuts removes 75% of the events.

19 < lgE < 19.2

At this energy range the fiducial cuts removes 32% of the events.

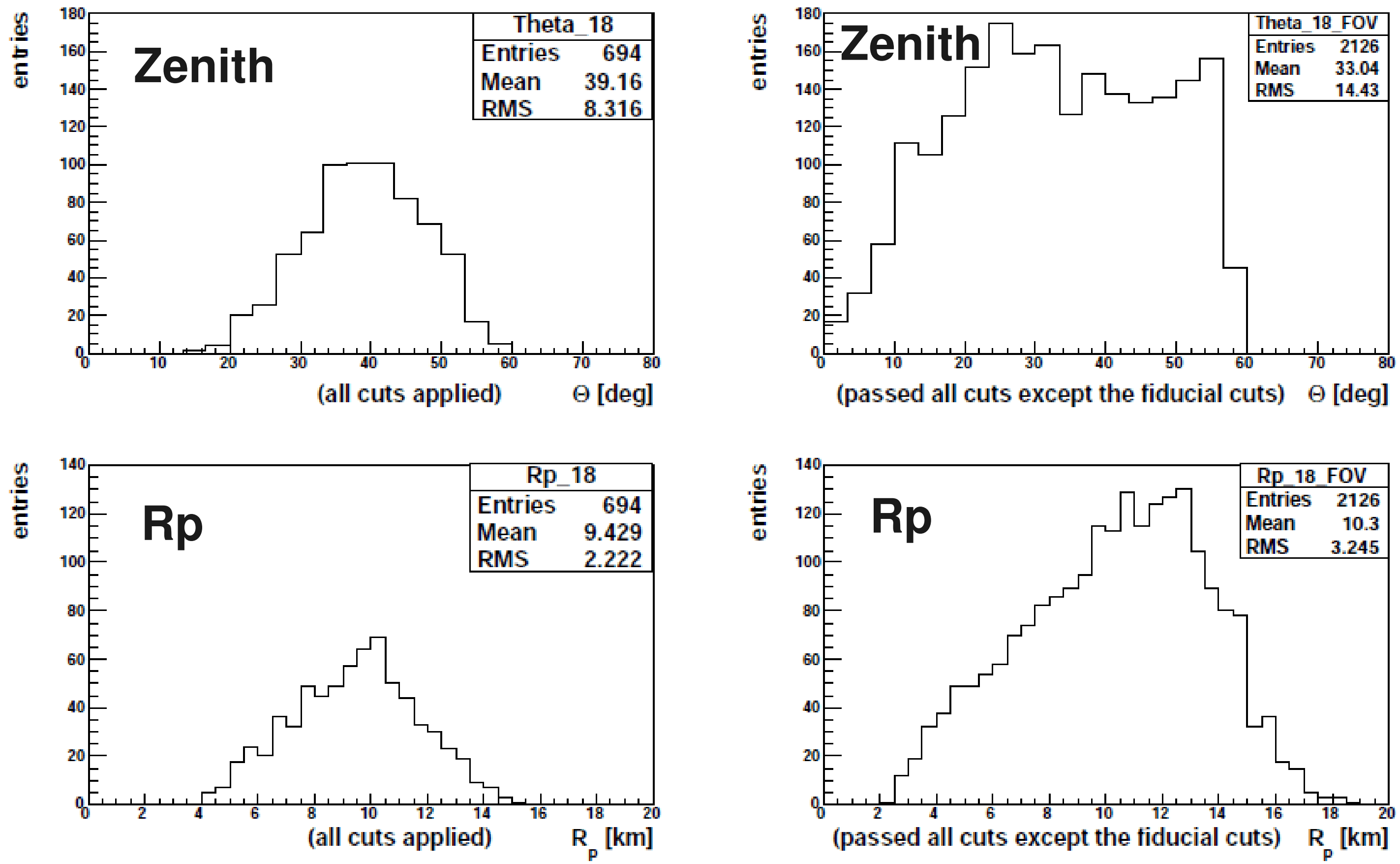


Questions relevant to the Auger analysis

(d) Please show the zenith, R_p and core position distributions of the hybrid events used in the X_{max} analysis in the same energy bins as the X_{max} histograms. Similarly for events that dont pass the fiducial cuts and the X_{max} resolution cuts.

Events that did pass the fiducial cuts | **Events that did not pass the fiducial cuts**

18 < lgE < 18.1

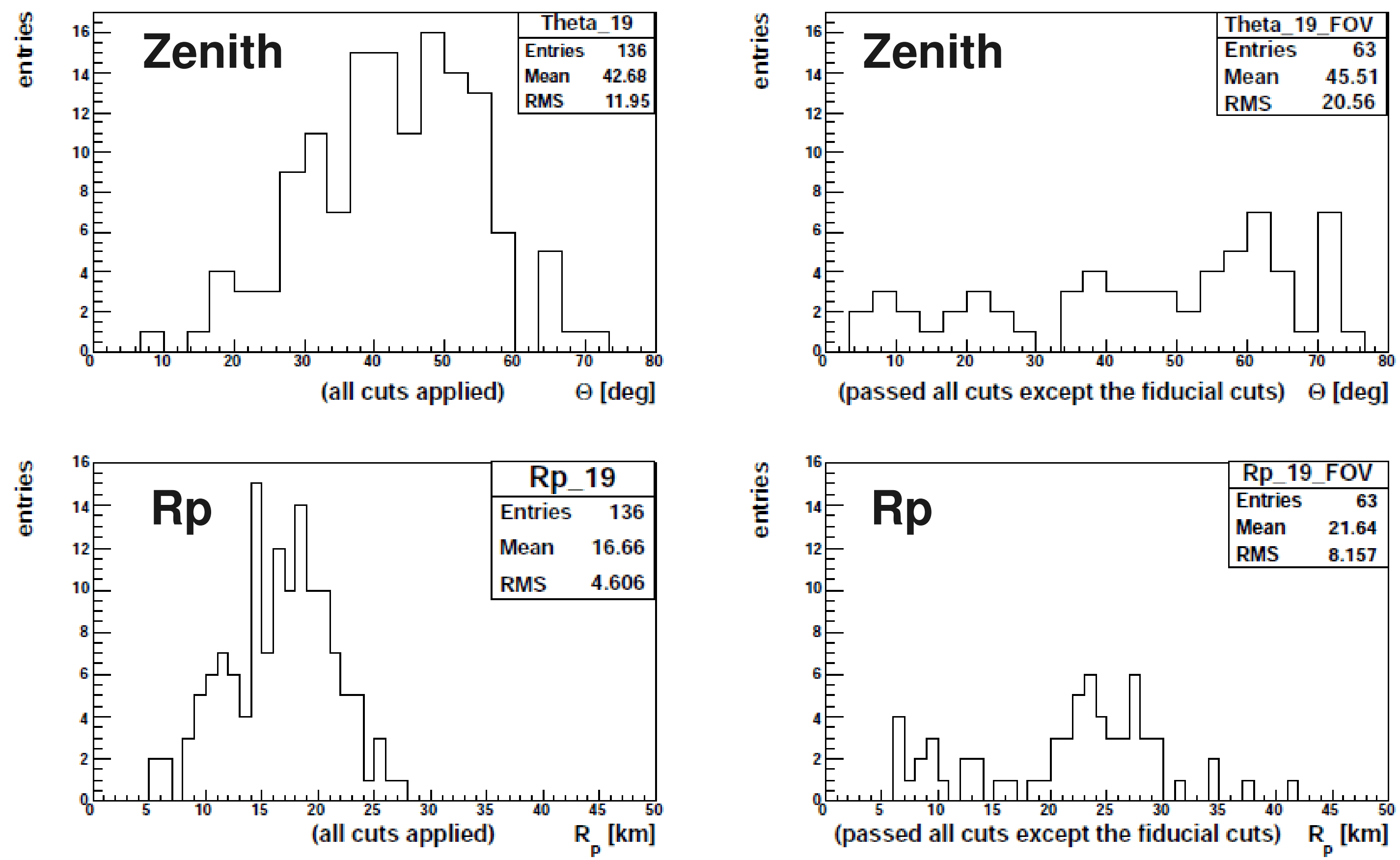


Questions relevant to the Auger analysis

(d) **Please show the zenith, R_p and core position distributions of the hybrid events used in the $X_{\max}$ analysis in the same energy bins as the $X_{\max}$ histograms. Similarly for events that dont pass the fiducial cuts and the $X_{\max}$ resolution cuts.**

Events that did pass the fiducial cuts | **Events that did not pass the fiducial cuts**

19 < lgE < 19.2



Questions relevant to the Auger analysis

(e) **Please show data/Monte Carlo energy comparison for events used in the X_{max} analysis. Show this for events passing all cuts, and for events passing all but the fiducial volume cuts.**

Quality cuts

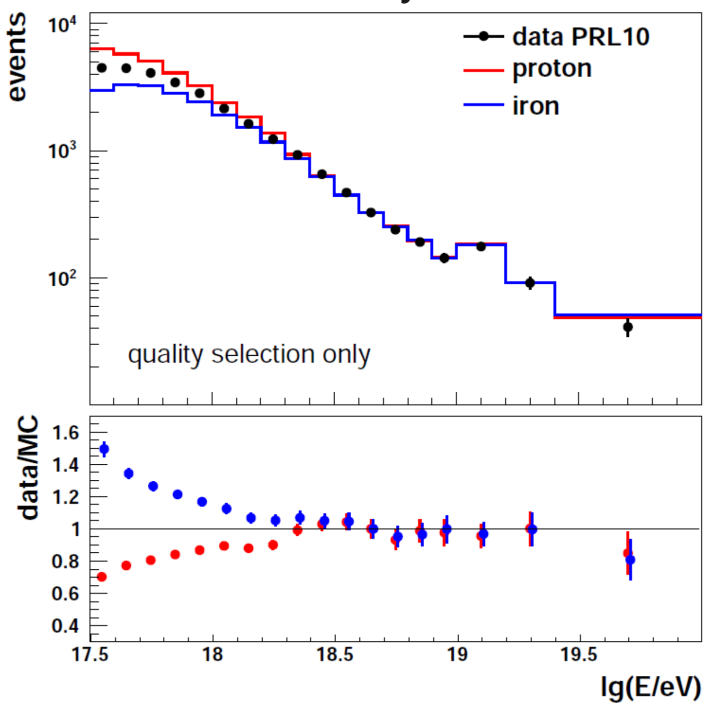


Figure 6: Energy distribution of selected events (quality cuts only). MC histograms have been normalized to the data at $10^{18.6}$ eV.

Quality cuts + fiducial cuts

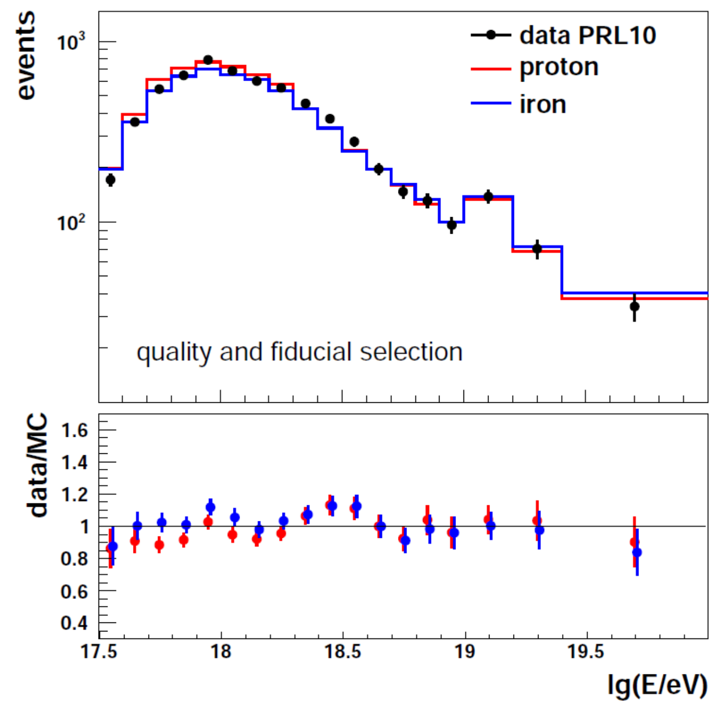


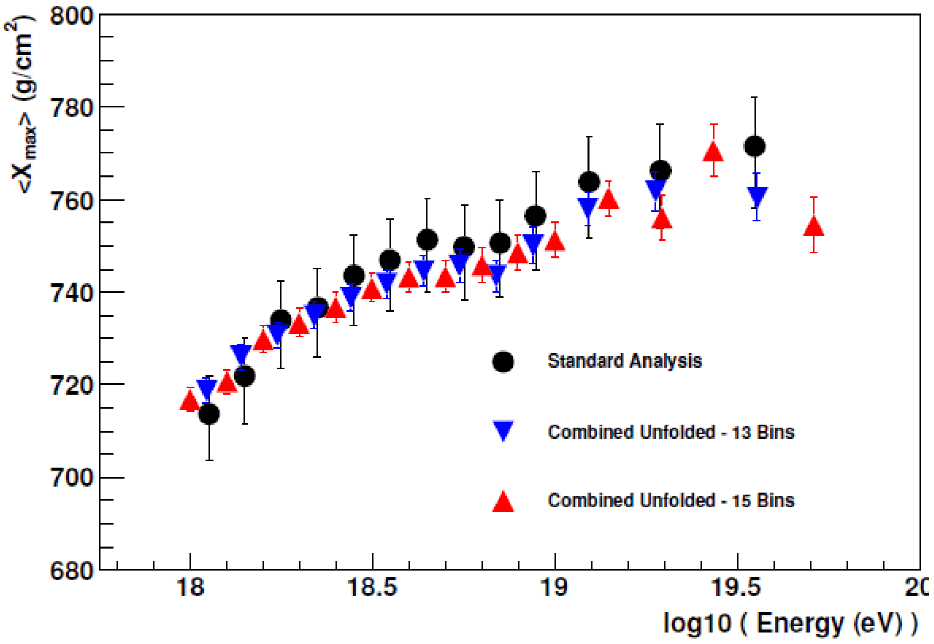
Figure 7: Energy distribution of selected events (quality and fiducial cuts). MC histograms have been normalized to the data at $10^{18.6}$ eV.

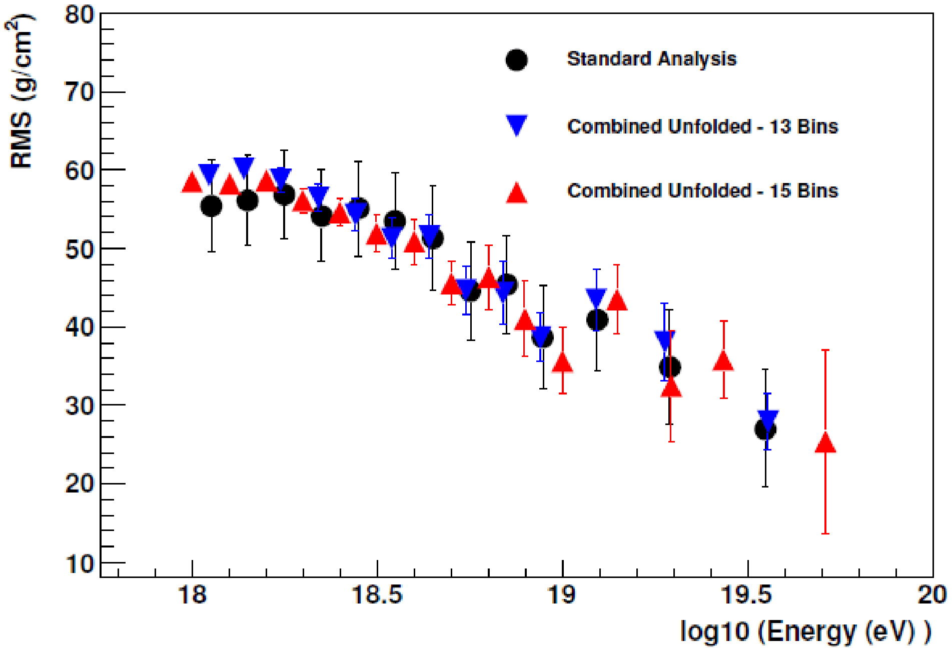
Answer:

The corresponding plots are shown in Figs. 6 and 7. Here we show the energy distribution of the data from [8] compared to proton and iron MC for the two event selections. The MC events were re-weighted at generator level to match the spectral shape of the CR flux measured by the surface detector [9] and normalized to the data at $10^{18.6}$ eV. As expected, the spectral shape of MC does not match the data without fiducial selection, because the acceptance depends on the composition (or, more precisely, on the distribution of shower maxima in the atmosphere). After application of the fiducial field of view, the spectral shape of both, the proton and iron simulations, agrees well with the data.

Questions relevant to the Auger analysis

(a) Have you tried applying the "unfolding method" used by KASCADE and in the Auger spectrum analysis to the composition analysis ? Have you compared the advantages and disadvantages, i.e. non-robustness of the unfolding method and reduction of data in the fiducial volume cut ?





Answer: Yes, we have unfolded the X_{max} distributions using two unfolding methods. In this analysis the fiducial volume cuts were not applied. The biased data was unbiased using the unfolding methods and the evolution of the $\langle X_{max} \rangle$ and RMS(X_{max}) are equivalent to the one obtained in the analysis using the fiducial volume cuts. Figures 21 and 22 show the comparison of the unfolding analysis with the analysis based on the fiducial volume cuts.

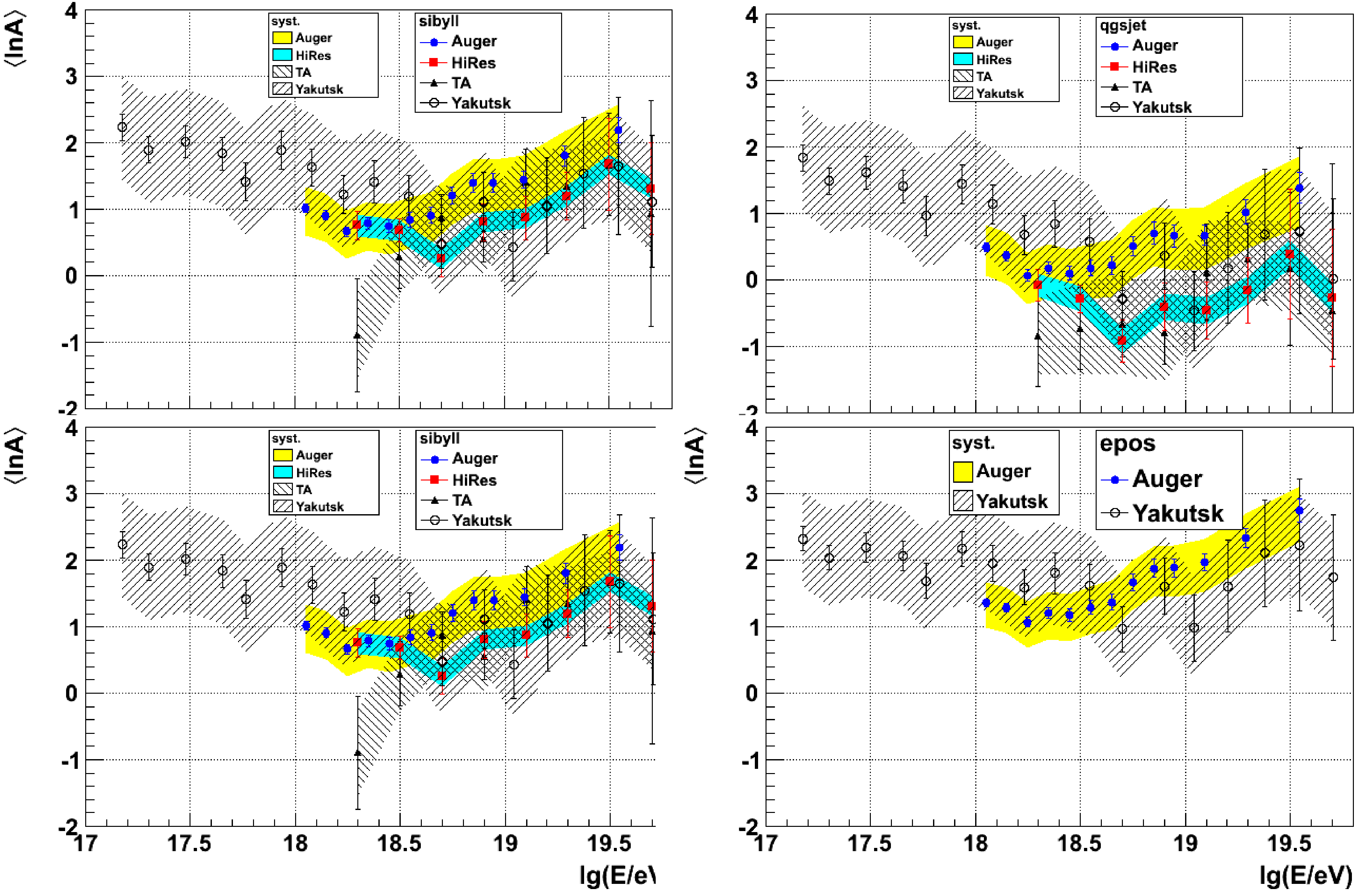
Are the differences in <Xmax> within systematic uncertainties?

To compare the different measurements of <Xmax>, we will transform <Xmax> values to <lnA> using:

$$\langle \ln A \rangle = \frac{\langle X_{max} \rangle_p - \langle X_{max} \rangle_{data}}{\langle X_{max} \rangle_p - \langle X_{max} \rangle_{Fe}} \ln 56$$

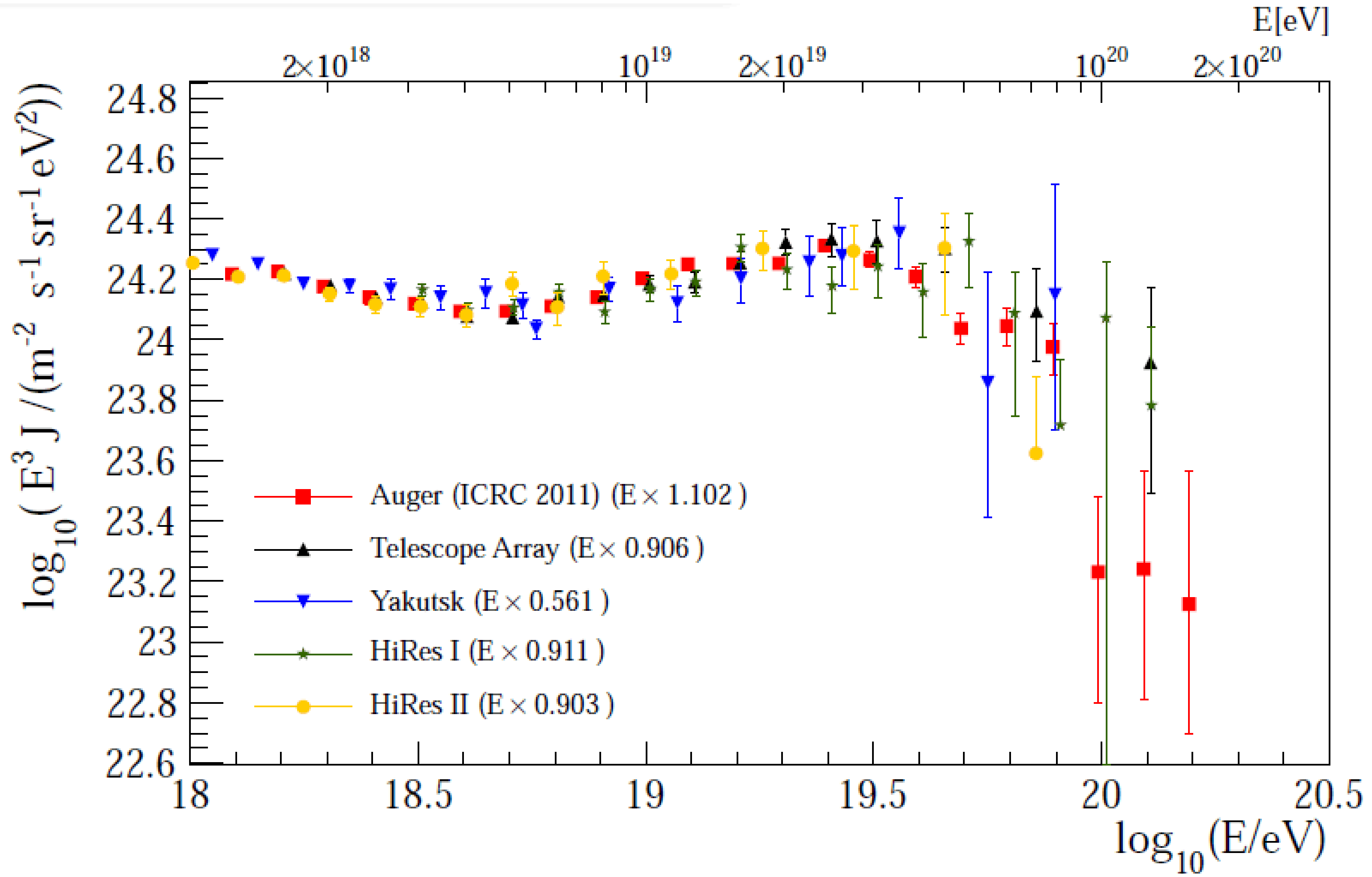
This is model dependent

Are the differences in “<Xmax>” within systematic uncertainties?



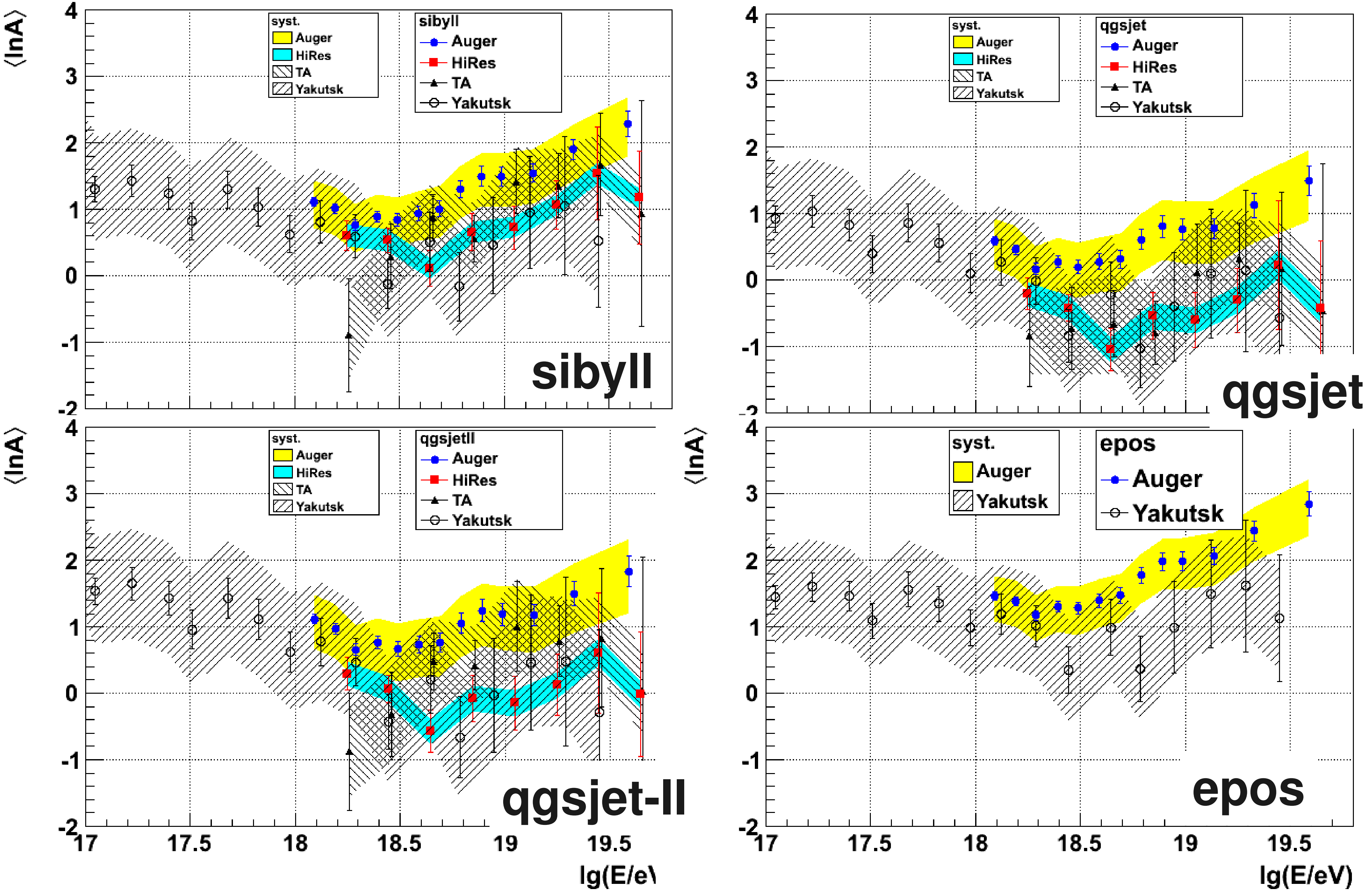
By comparing the shape of the energy spectrums, the energy scales can be normalized.

(plot provided by the Energy Spectrum WG)

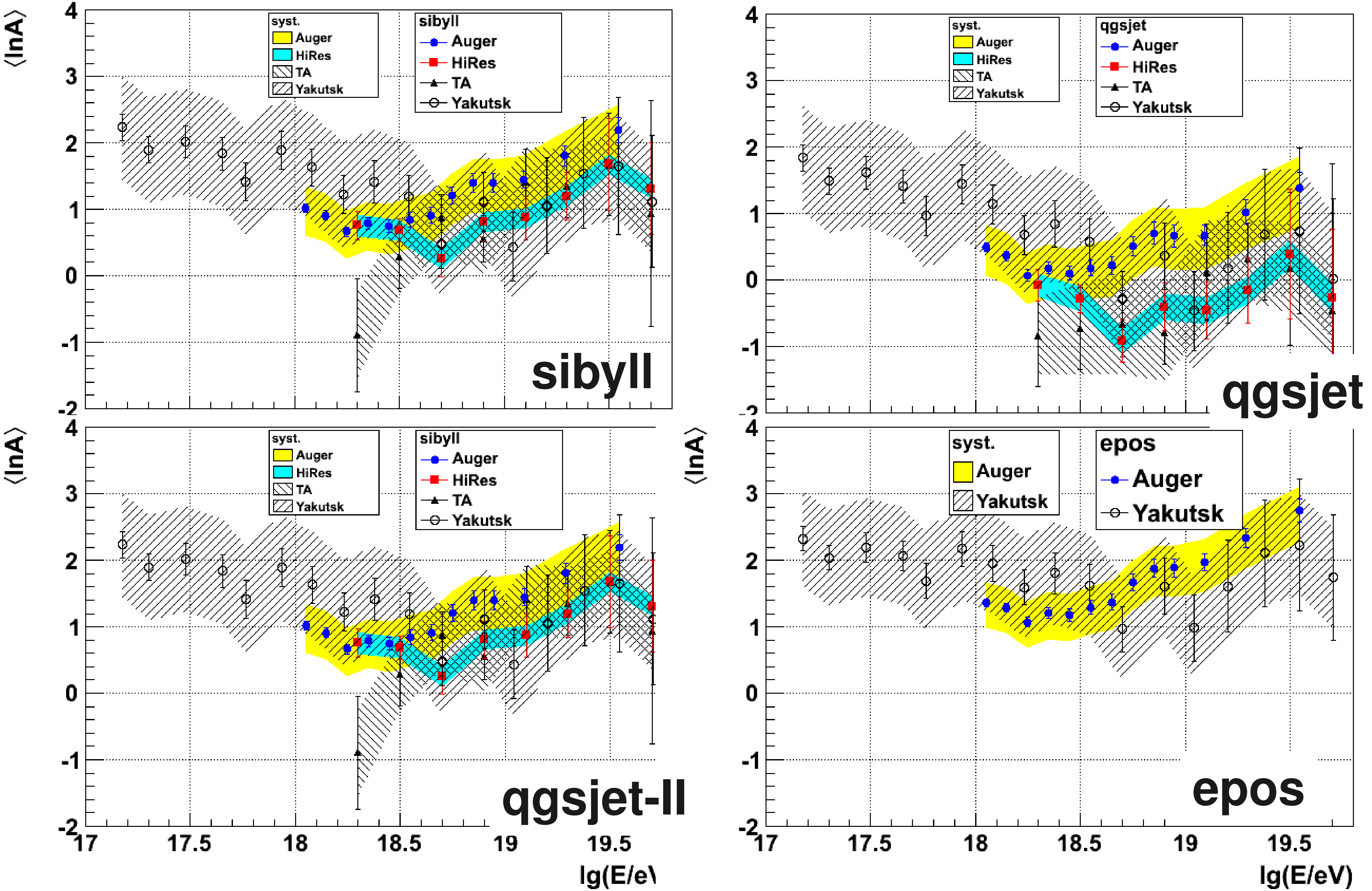


After normalizing the energy scales to half way between TA and Auger spectrums

corrections in lgE: TA =-0.042, Auger=0.042, HiRes=-0.054, Yakutsk=-0.256

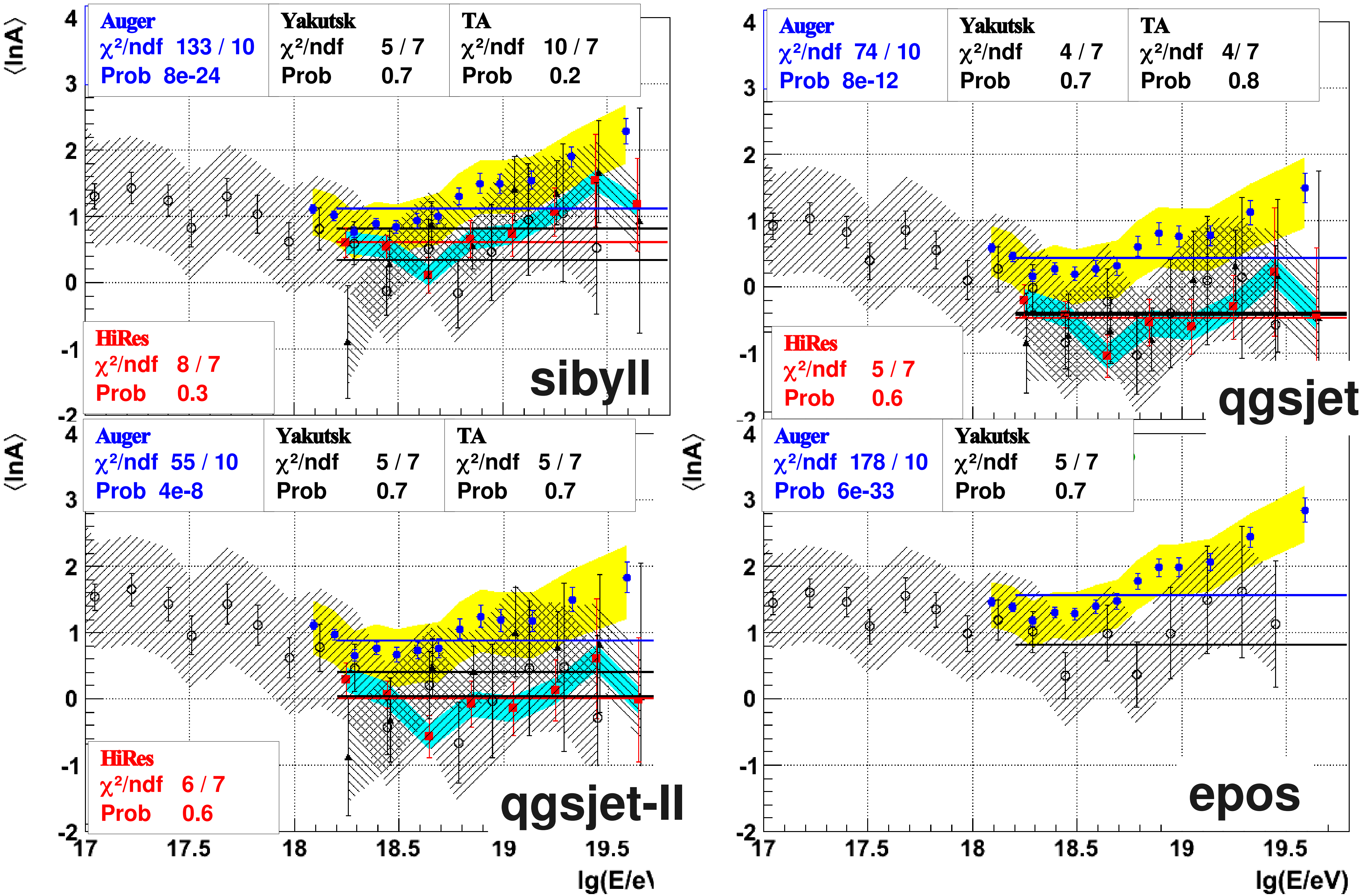


Before normalizing the energy scales



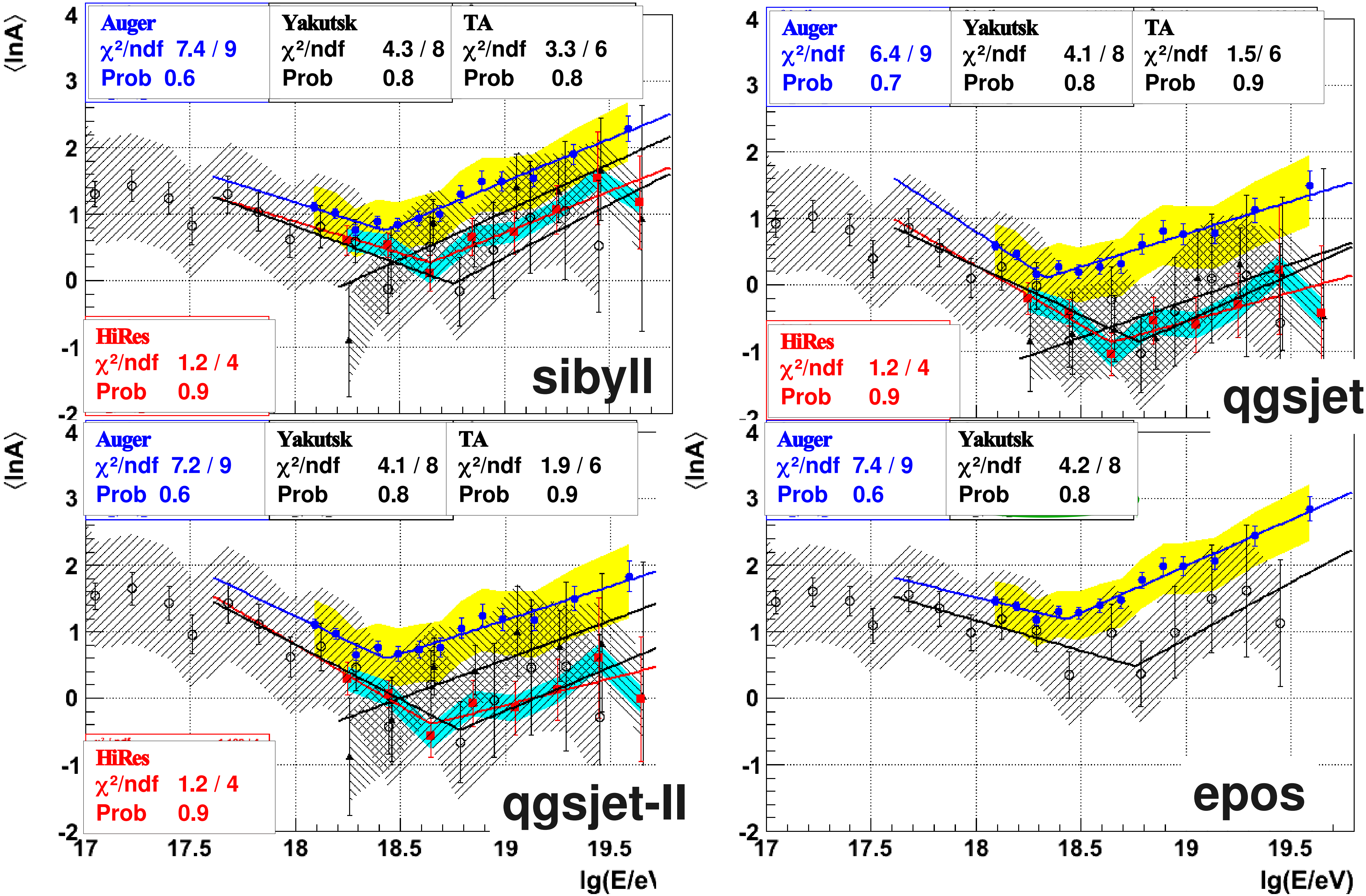
After normalizing the energy scales to half way between TA and Auger spectrums

Are the results consistent with a constant composition?



After normalizing the energy scales to half way between TA and Auger spectrums

Are the results consistent with a changing composition?

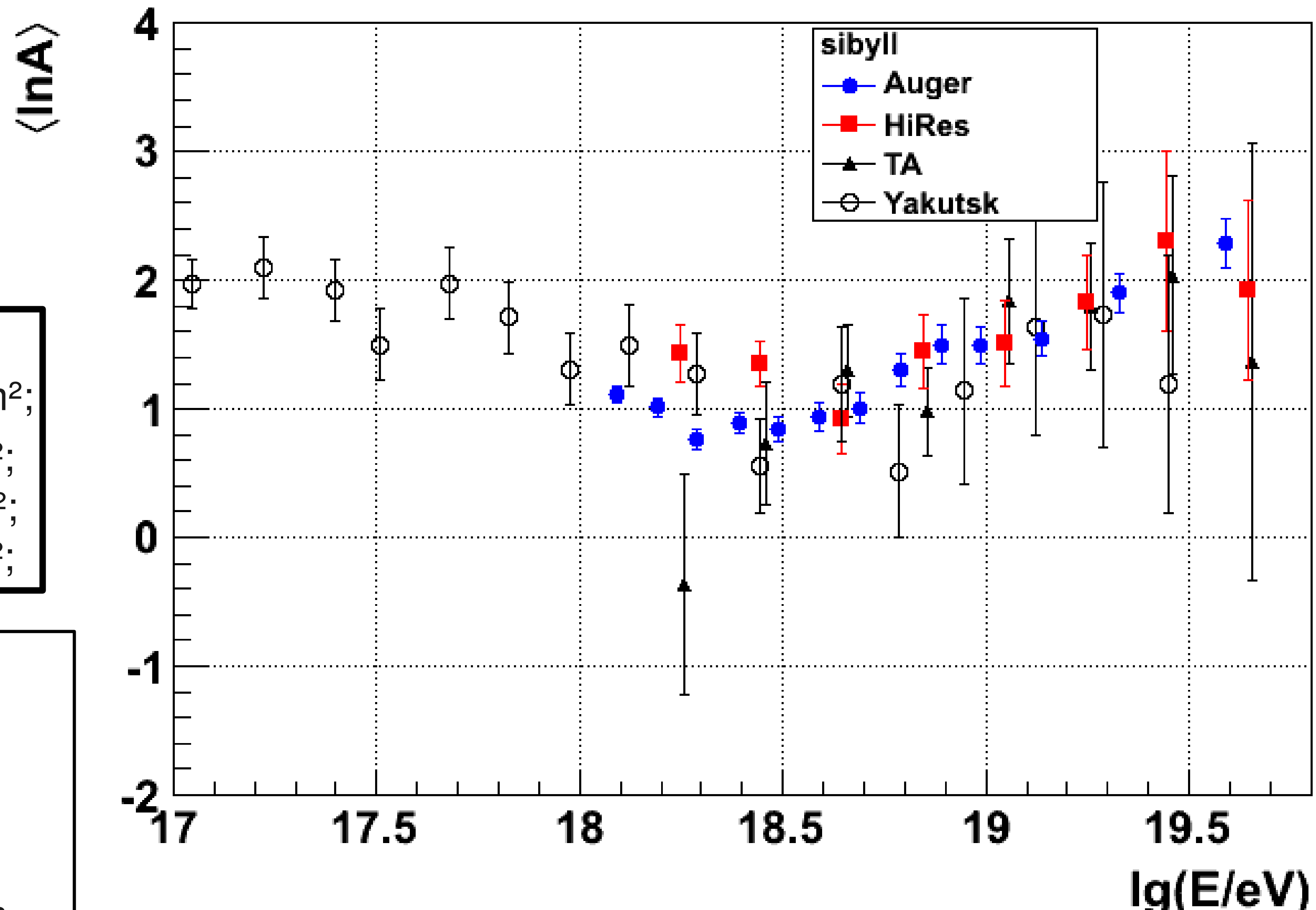


Does a shift in <Xmax> bring the results to agreement?

(After normalizing the energy scales to half way between TA and Auger spectrums)

Xmax shifts:

Auger = +16 g/cm²;
TA = -10 g/cm²;
HiRes = -17 g/cm²;
Yakutsk = -17 g/cm²;

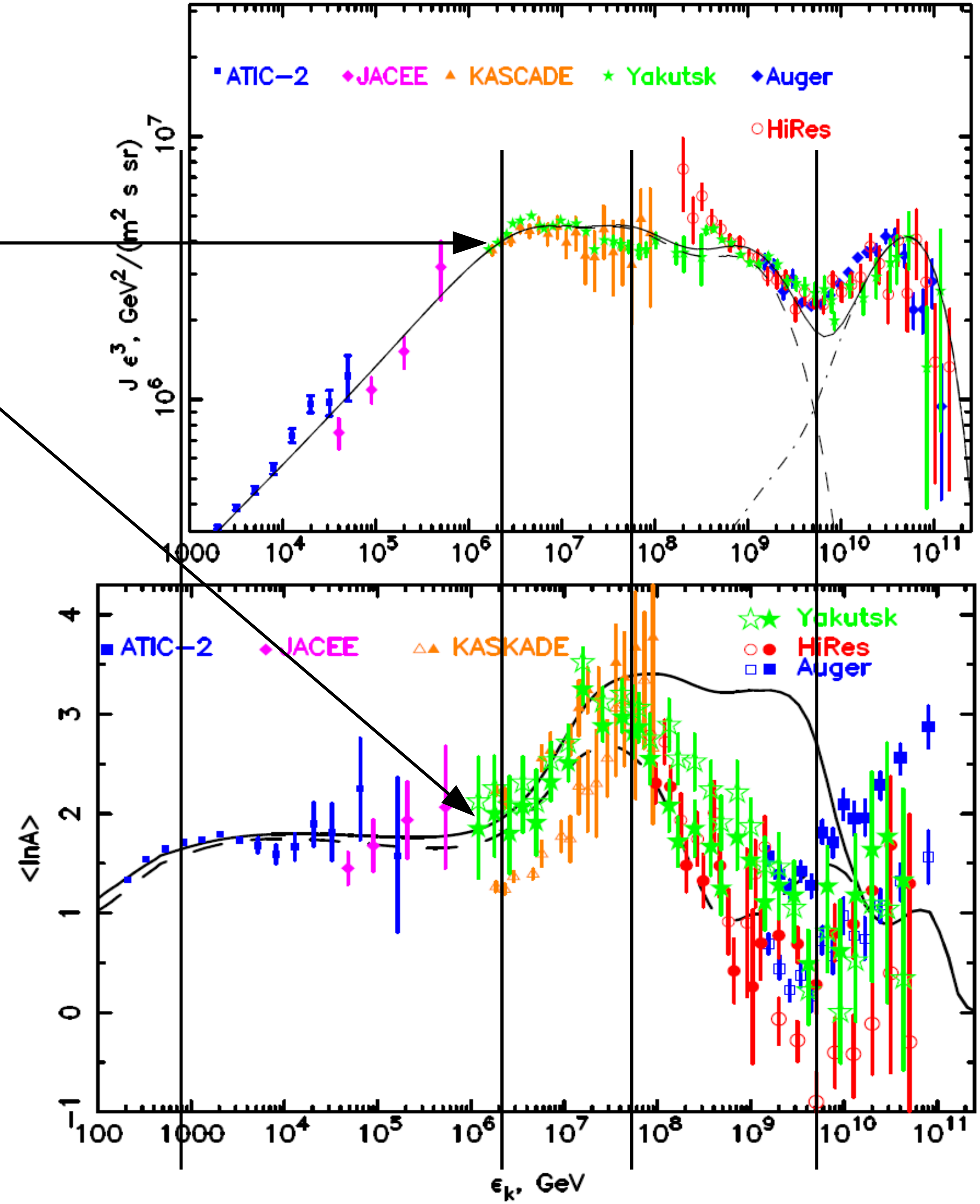


Quoted syst. uncertainties

Auger	**12 g/cm²**
HiRes	**3.3 g/cm²**
TA	**12.4 g/cm²**
Yakustk	**20 g/cm²**

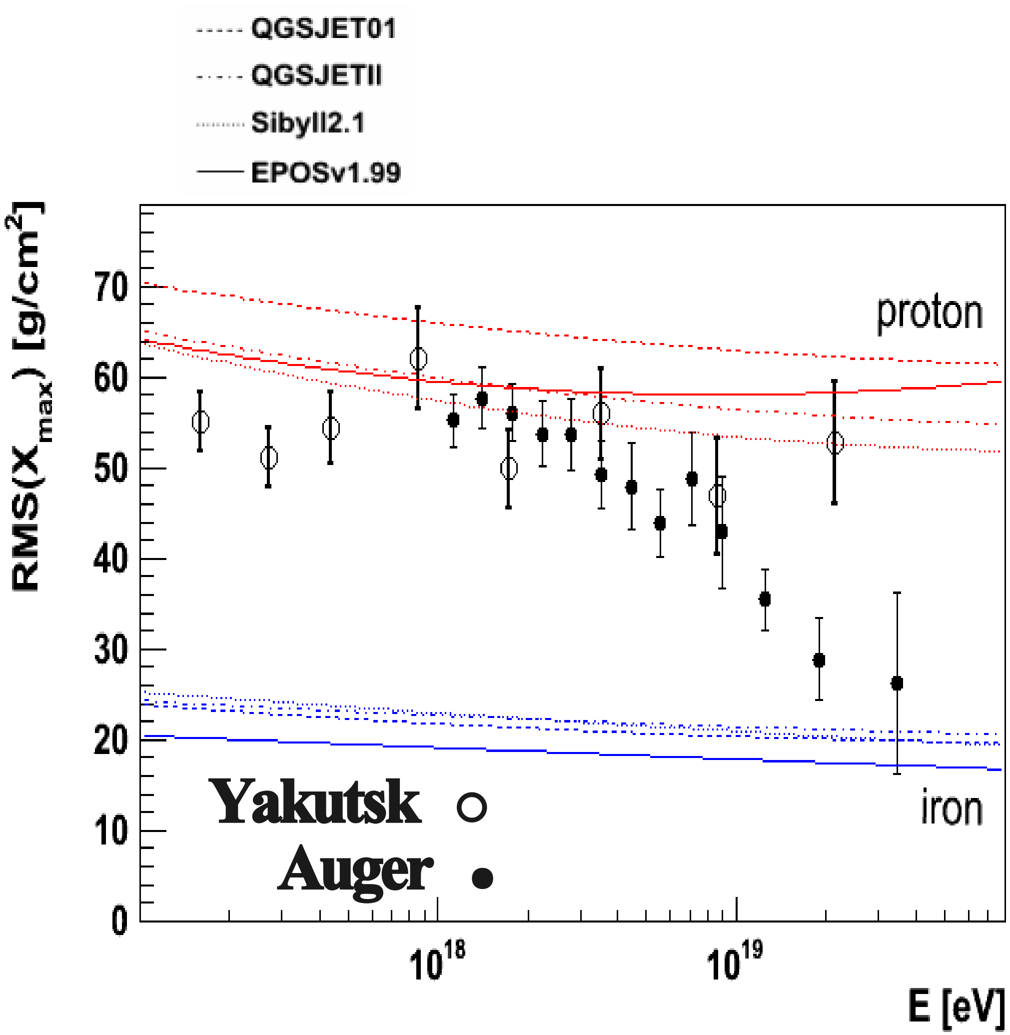
The Big Picture

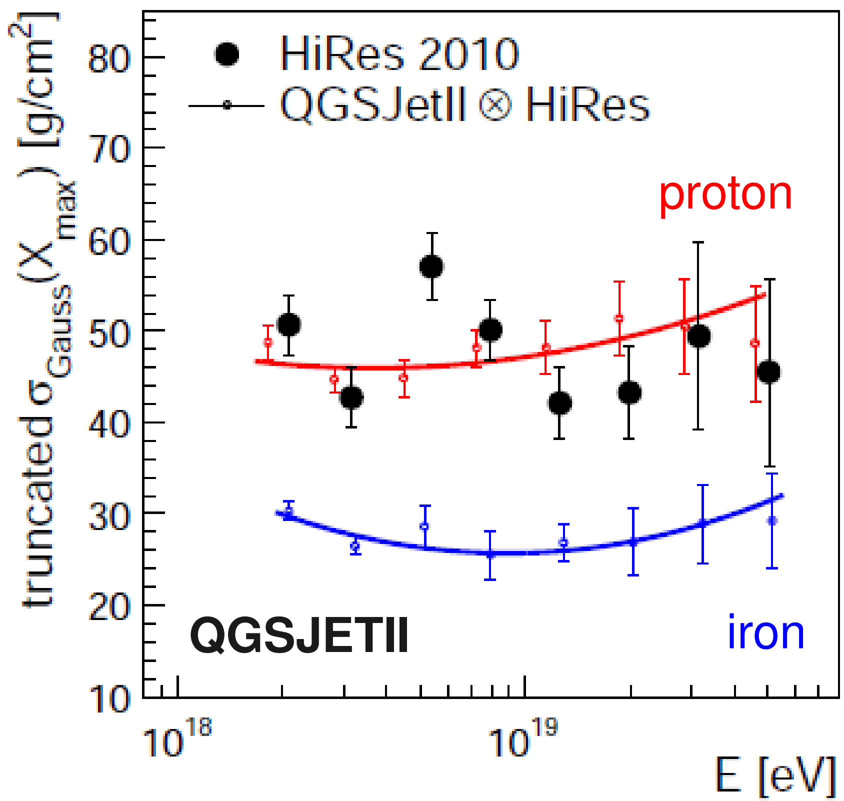
Features in the evolution of <lnA> with energy seem to correlate with features in the energy spectrum.



Plots provided by our Yakutsk colleagues (to be published this year).

RMS(Xmax) from: Auger, HiRes and Yakutsk

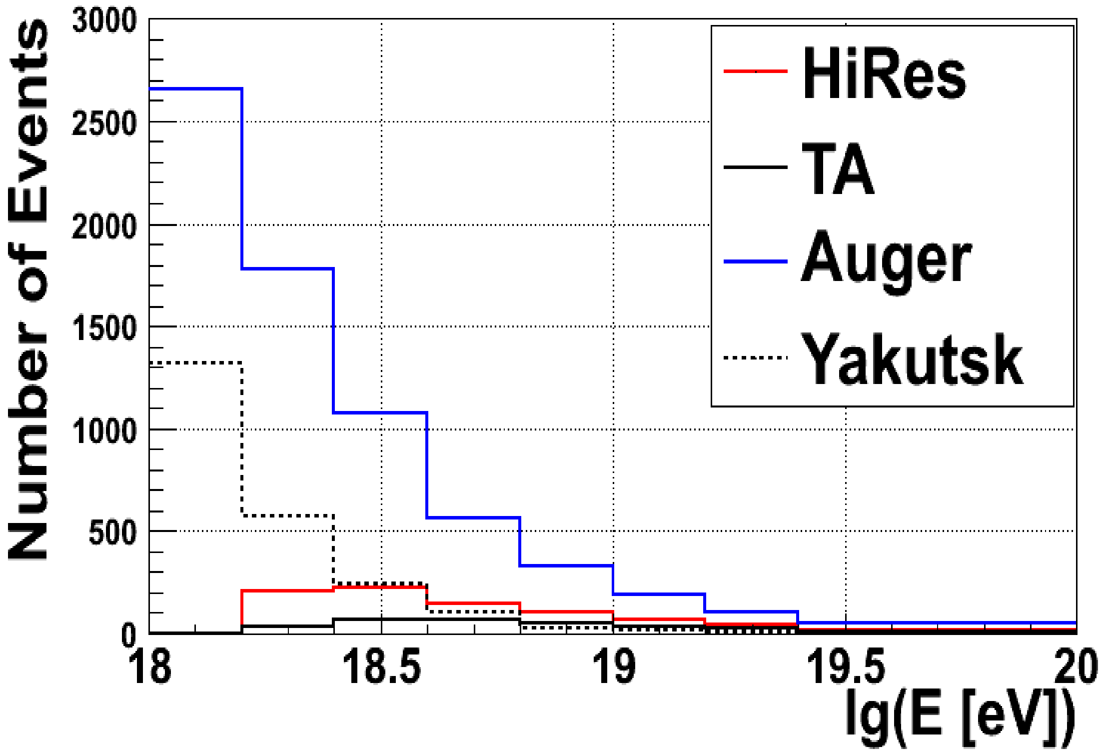




Yakutsk energy scale normalized to the Auger energy scale.

Total number of events above lgE=18

6744 Auger
2301 Yakutsk
815 HiRes
279 TA



Zoomed

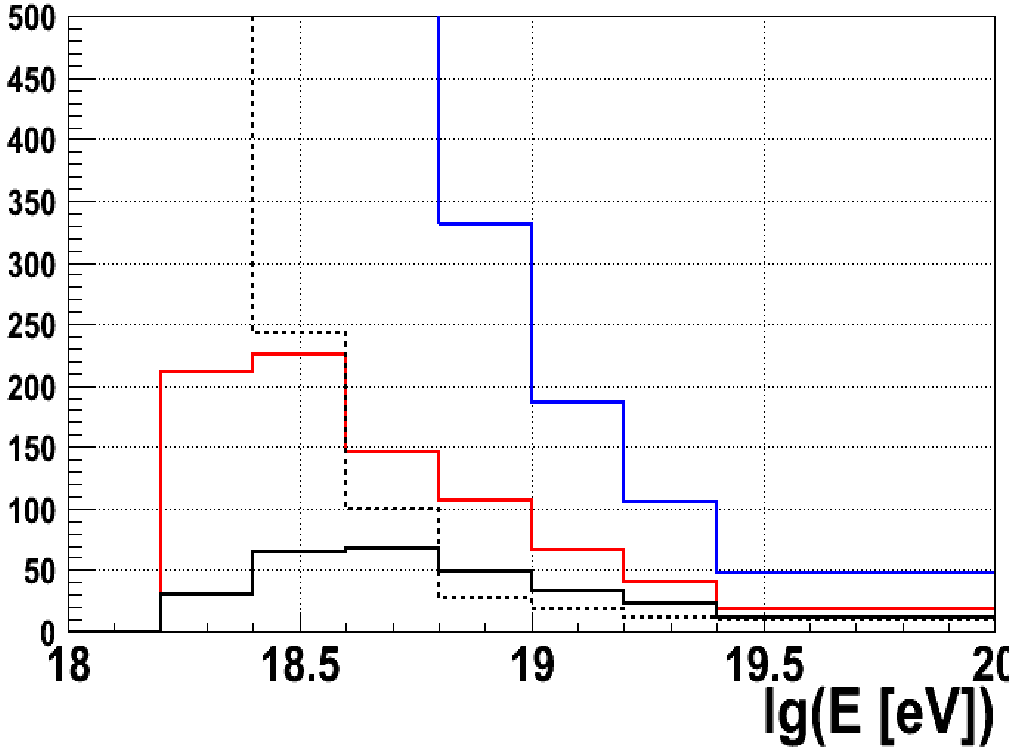


Table with quoted systematics

	Auger	HiRes	TA	Yakutsk
atmospheric density profile	≤ 6 g/cm^2	negligible	12.4 g/cm^2	20 g/cm^2
$X_{\rm max}$ reconstruction	≤ 5 g/cm^2	n/a		
shower geometry	≤ 6 g/cm^2	n/a		
multiple scattering	5 g/cm^2	negligible		
alignment	3 g/cm^2	3.3 g/cm^2		
MC predictions for <Xmax>	n/a	0.7 g/cm^2		
acceptance E>10^{18} eV	≤ 4 g/cm^2	n/a		
Total syst. uncertainty	**12 g/cm^2**	**3.3 g/cm^2**	**12.4 g/cm^2**	**20 g/cm^2**

Conclusions

•Are the differences due to issues in any of the analysis?

Apparently no.

• Are the differences within systematic uncertainties?

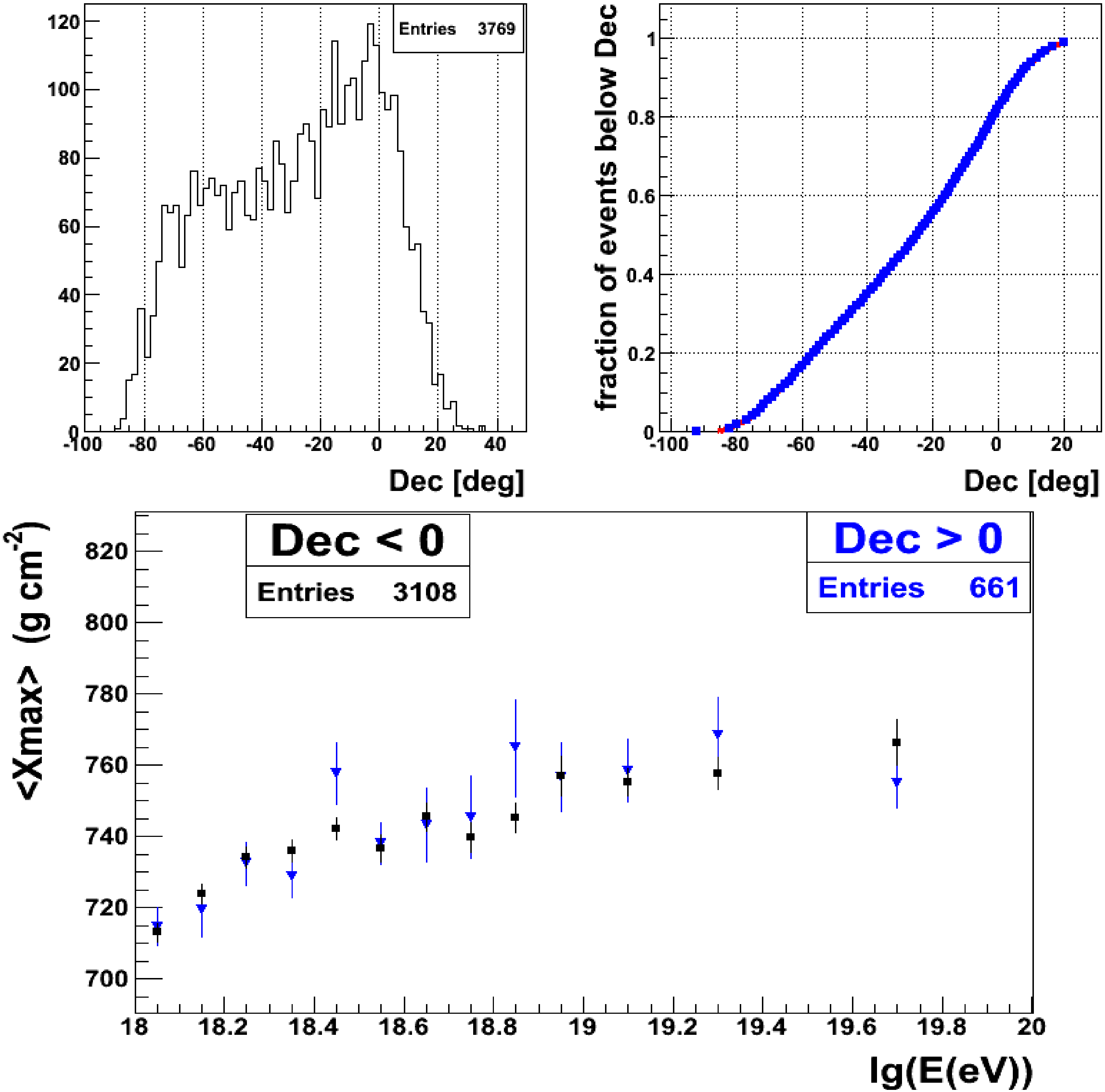
Auger and HiRes are not consistent within the **quoted** systematic uncertainties.

• Are the Southern and Northern sky different in terms of composition?

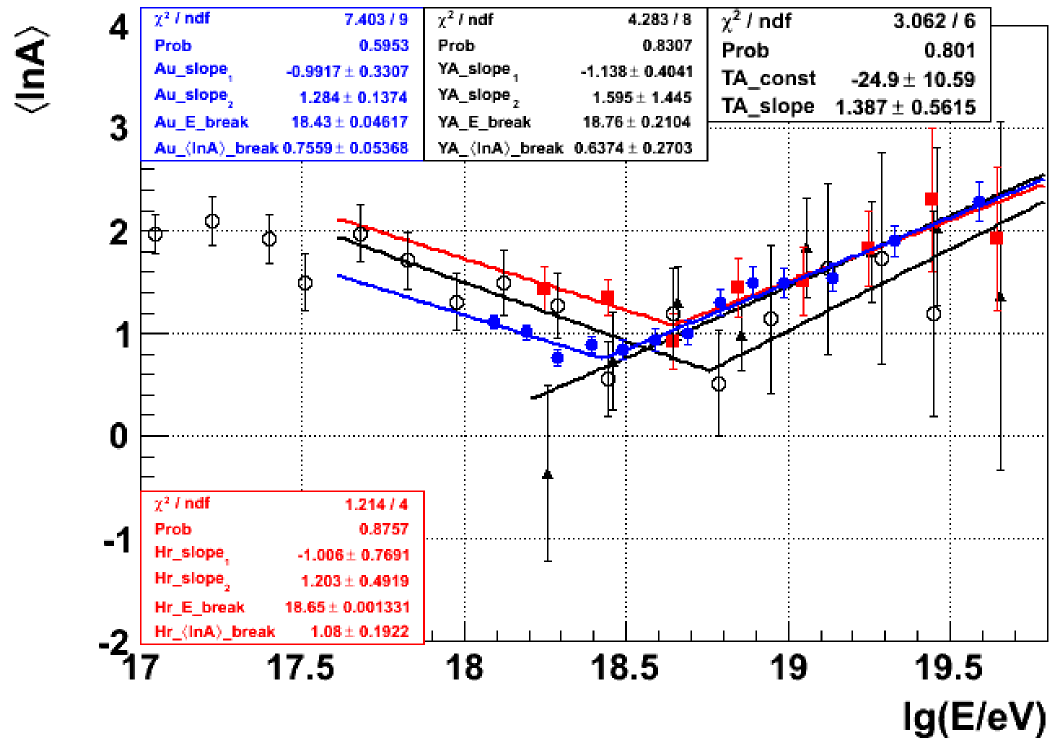
We need more statistics in the Northern hemisphere (about 4 times the current statistics) to give a conclusive answer. The current statistics in the northern hemisphere do not allow to discriminate between a constant composition or a changing composition as suggested by Auger. More statistics is also necessary to establish whether there is a systematic difference in the RMS(Xmax) at higher energies.

• It is interesting to point out that all three experiments (Yakutsk, HiRes and TA) are consistent (within ~5g/cm^2). But, there is a large systematic difference in <lnA> equivalent to about 30 g/cm^2 between Auger and the other experiments.

Back up slides



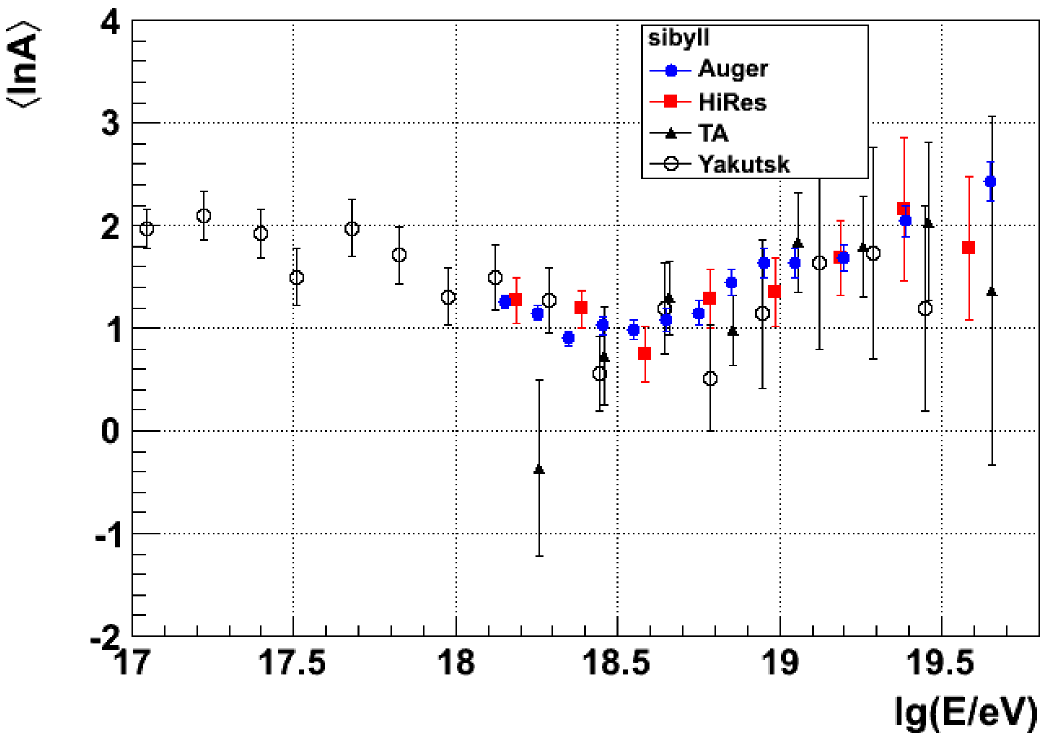
Entries 3769
Dec [deg]
fraction of events below Dec
Dec [deg]
Dec < 0
Entries 3108
Dec > 0
Entries 661
<Xmax> (g cm^{-2})
lg(E(eV))

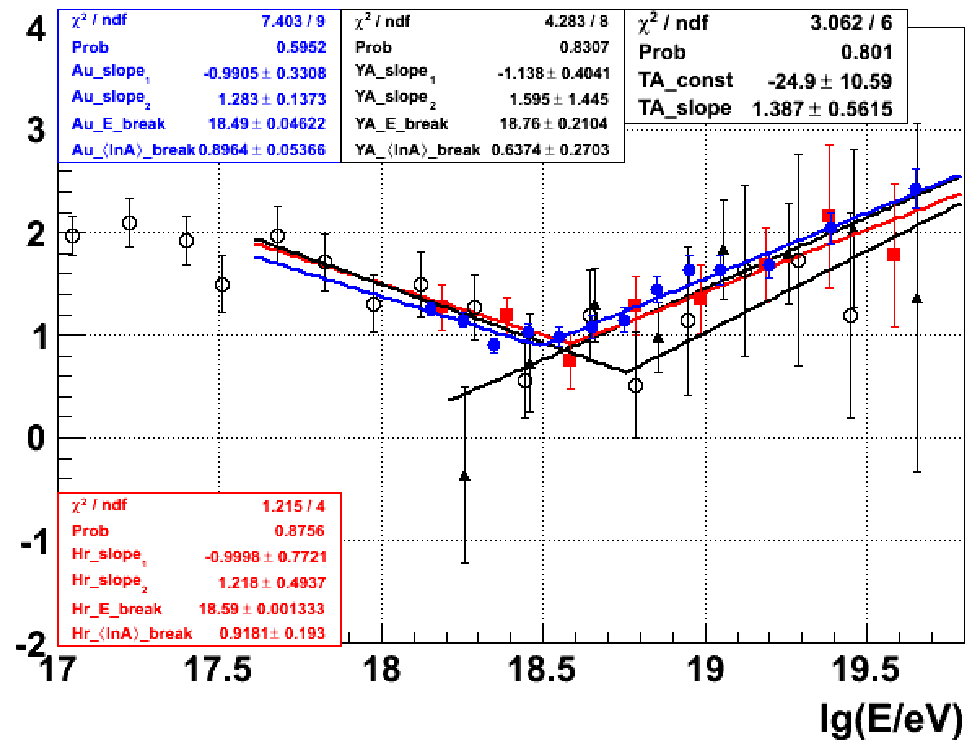


Xmax shifts:

Auger = +16 g/cm²;
TA = -10 g/cm²;
HiRes = -17 g/cm²;
Yakutsk = -17 g/cm²;

Does a shift in <Xmax> and Energy bring the results to agreement?





Xmax shifts:

TA = -10 g/cm²;
Auger = +16 g/cm²;
HiRes = -17 g/cm²;
Yakutsk = -17 g/cm²;

LgE shifts:

TA = -0.042;
Auger = +0.102;
HiRes = -0.114;
Yakutsk = -0.256;

HiRes <Xmax> resolution