Measurement of UHECR Mass Composition by TA FD Stereo

8th Air Fluorescence Work Shop @ Karlsruhe, Germany

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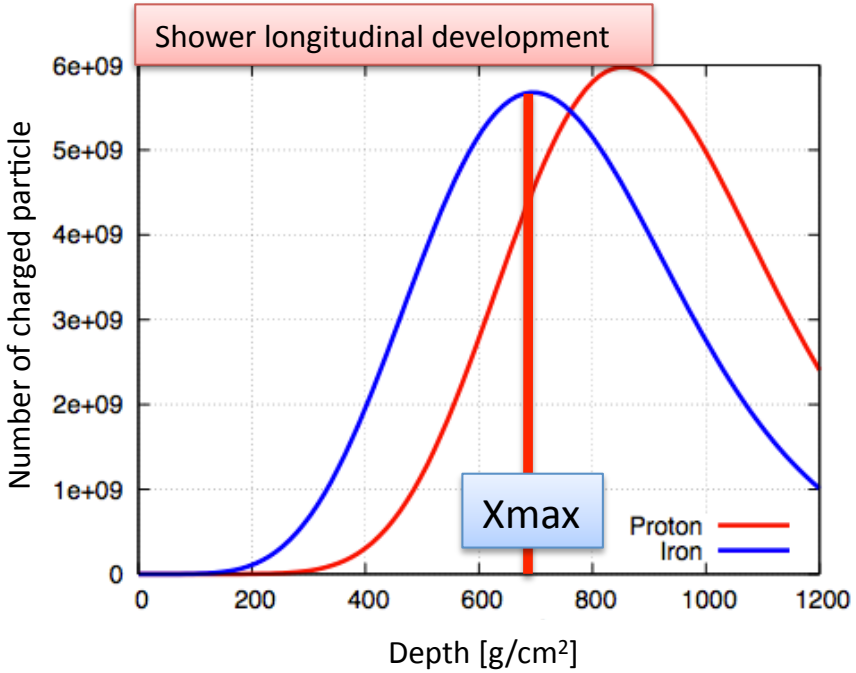
ICRR, The University of Tokyo

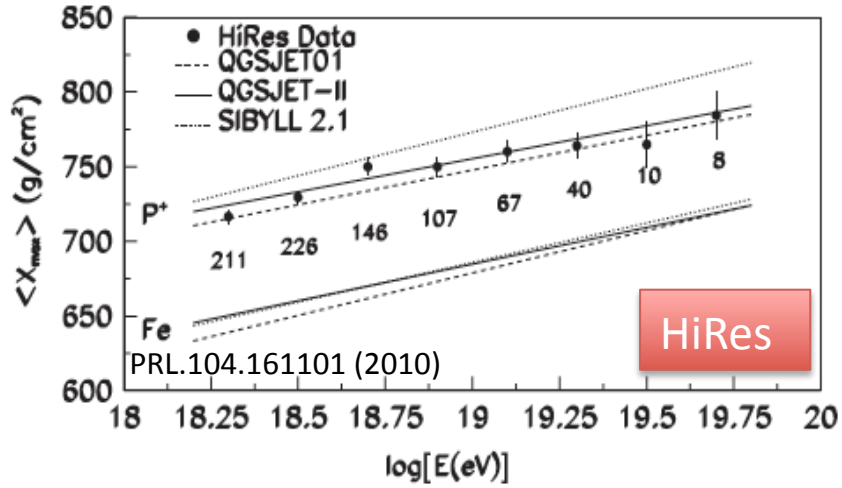
Outline

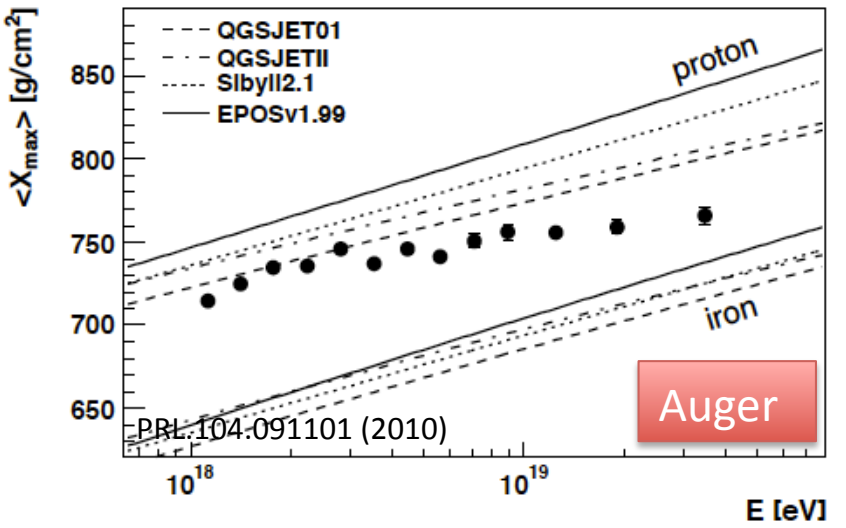
- Xmax Technique
- FD Stereo Measurement
- Monte Carlo Simulation
  - Data/MC Comparison
  - Xmax bias estimation
- Result

Xmax technique

- Shower longitudinal development depends on primary particle type.
- FD observes shower development directly.
- Xmax is the most efficient parameter for determining primary particle type.







FD Stereo measurement

Geometrical reconstruction

Determination of Shower detector plane

$$\chi^2 = \sum_i w^i (\boldsymbol{n} \cdot \boldsymbol{k}^i)^2$$

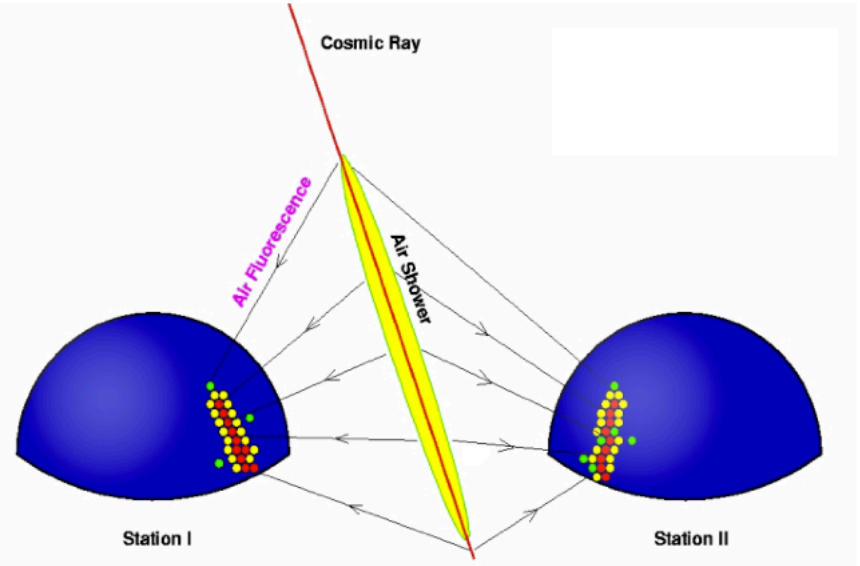
n: vector of SDP
k^i: direction vector of ith PMT

Determination of Shower axis

Intersection of SDPs

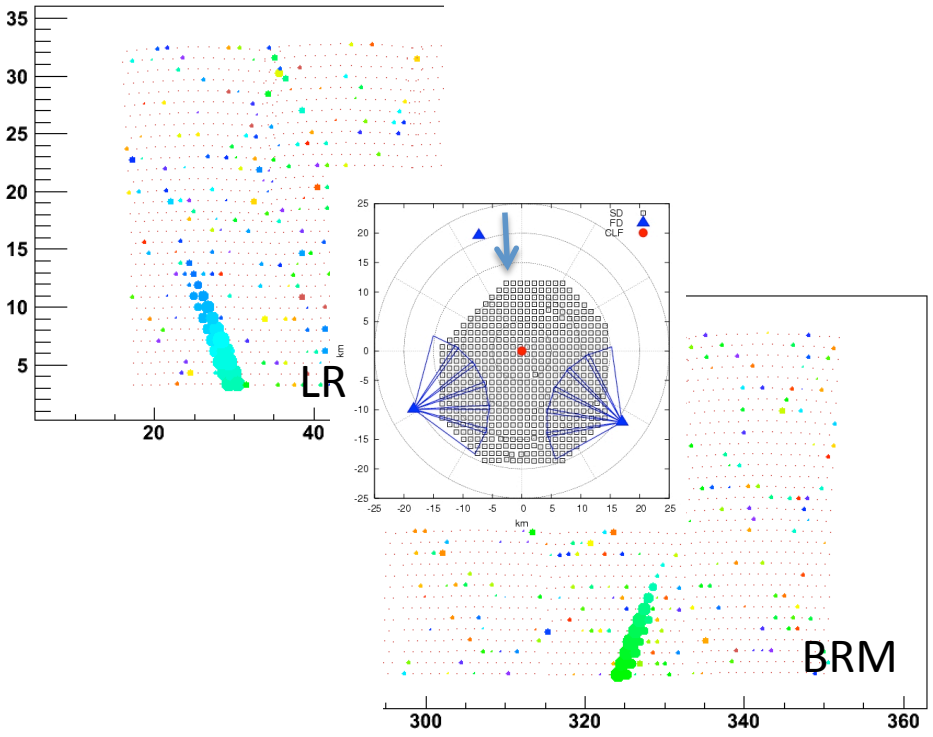
$$\boldsymbol{s} = \boldsymbol{n}_1 \times \boldsymbol{n}_2$$

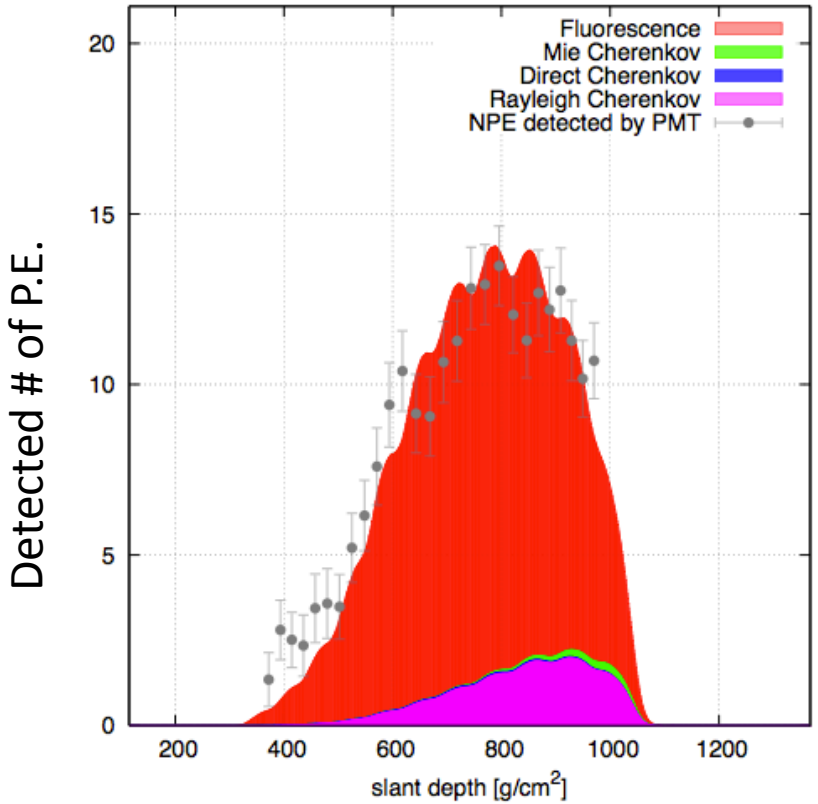
s: vector of shower axis
n_i: vector of SDP of each station



Determination of shower axis by stereo reconstruction is much better than monocular reconstruction.
Opening angle by monocular reconstruction is ～5deg(1σ).

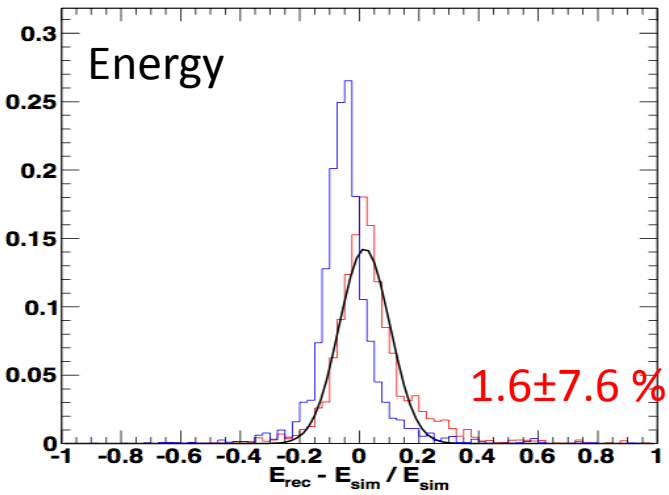
FD Stereo Event

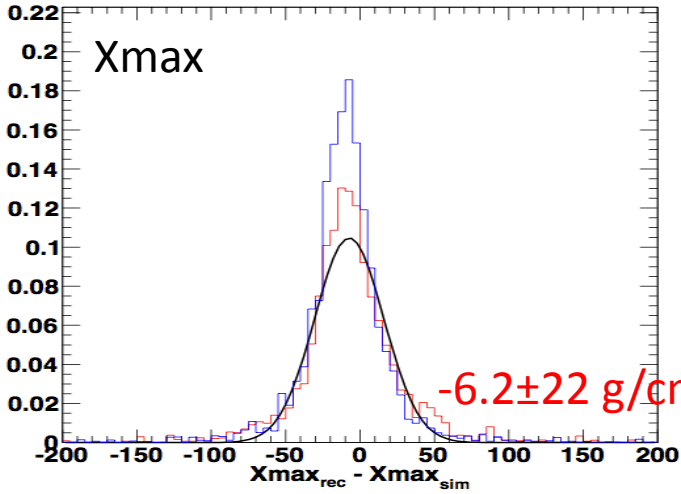




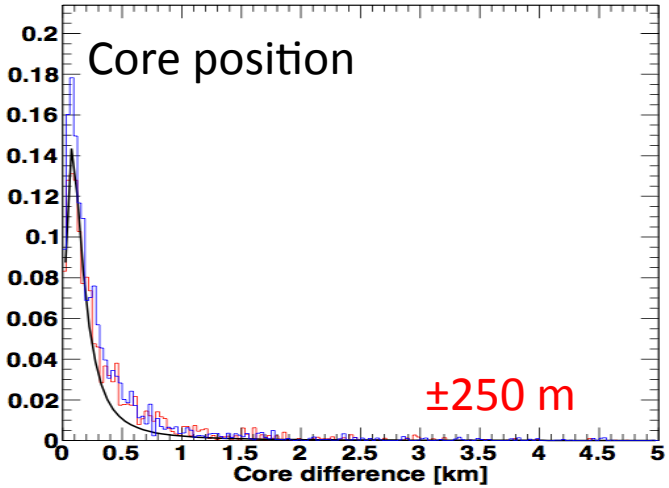
Date	log(E/eV)	Xmax	zenith	azimuth	Xcore	Ycore
2008/09/04	19.77	892 g/cm^2	44.4^o	-3.0^o	-3.1	14.2

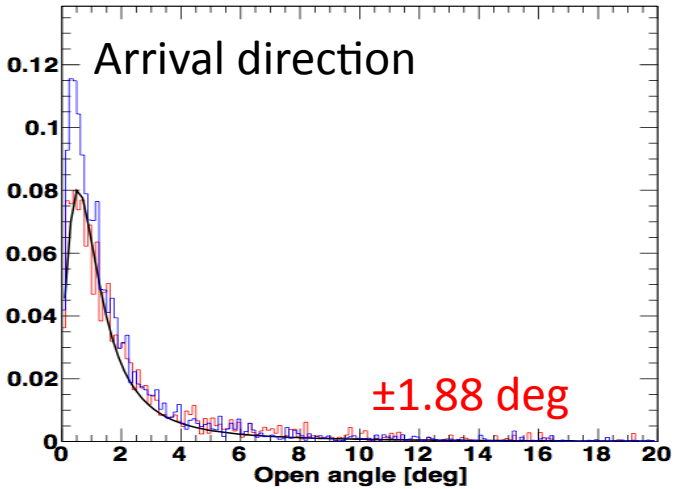
Reconstruction Accuracy (logE>19)





QGSJETII
Proton
Iron

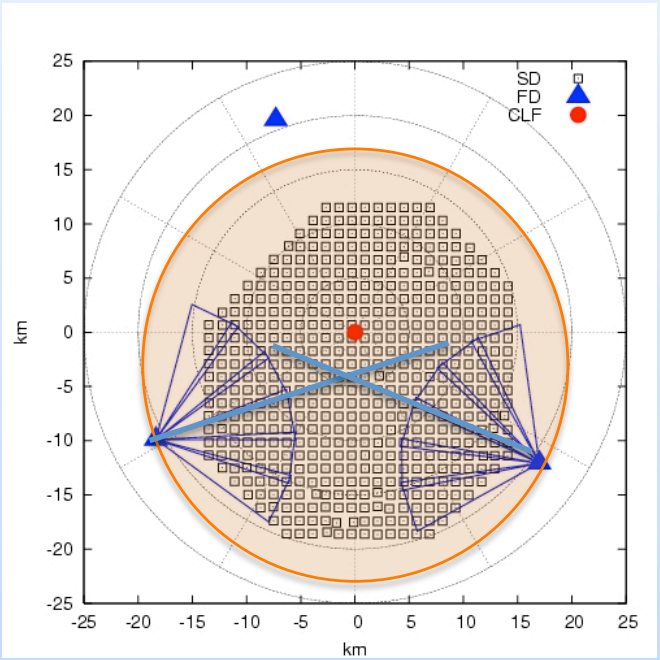




Monte Carlo Simulation

Detector simulation

- Shower generator : CORSIKA
- Energy spectrum
  slope : -3.3($E<10^{18.71}$eV), -2.72($E>10^{18.71}$eV)
- Shower cores:
  within 20km from the center of F.O.V. of each station.
- Actual detector configuration
- Typical atmosphere
  Radiosonde
  Aerosol : typical value observed by LIDAR
  scale height : 1.0km, mean free path : 29km
- Fluorescence model: Kakimoto et al., Flash (spectrum)

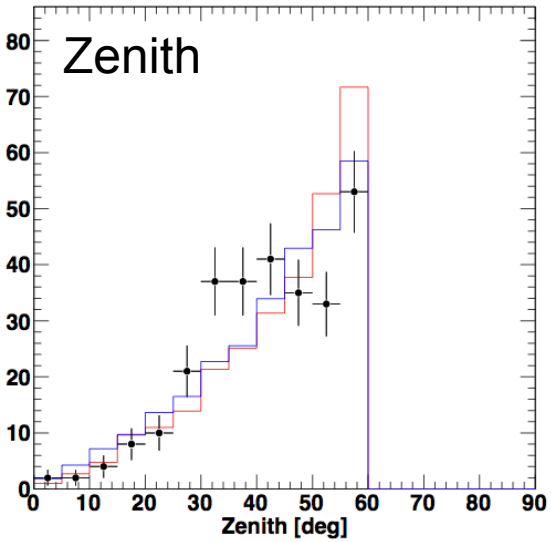


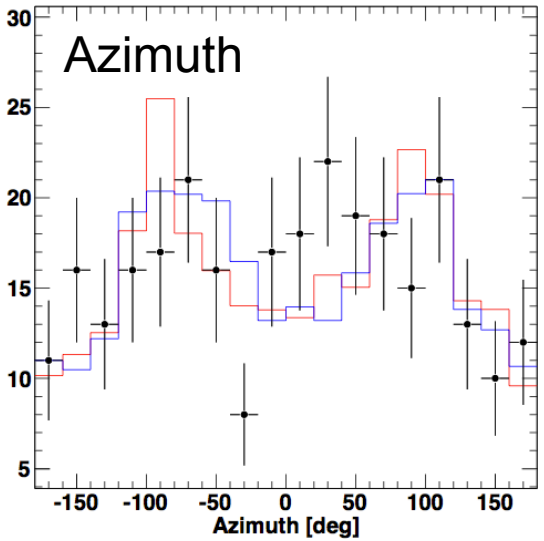
Event Reconstruction

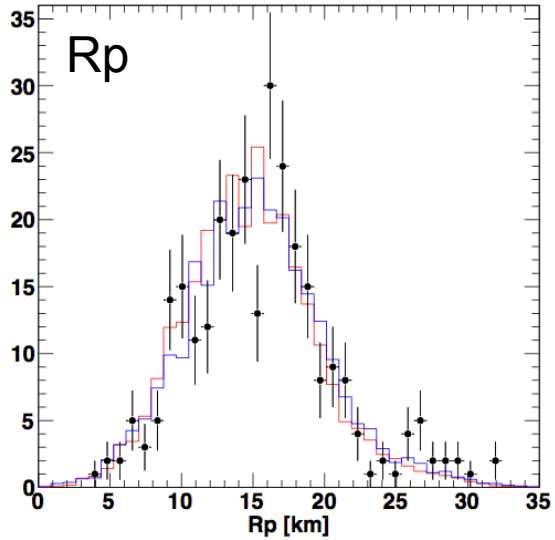
- Quality Cut
  Xmax observed , Zenith < 60°, Core within 19.6km circle, χ^2 cut

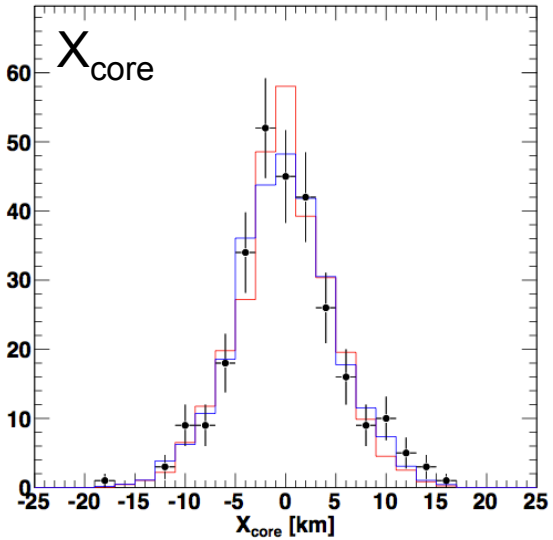
Data/MC Comparison (logE>18)

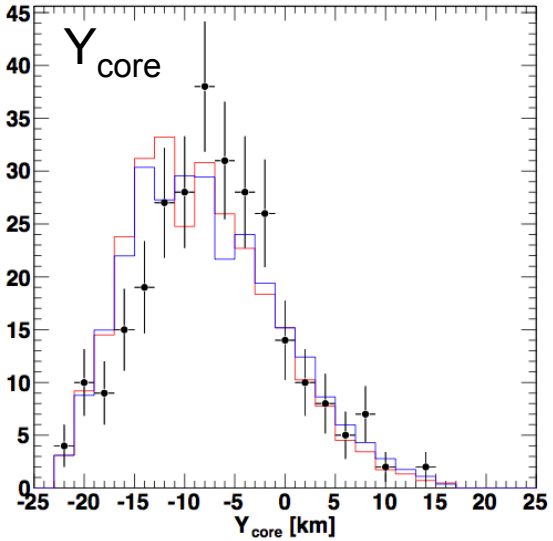
QGSJETII
Proton
Iron

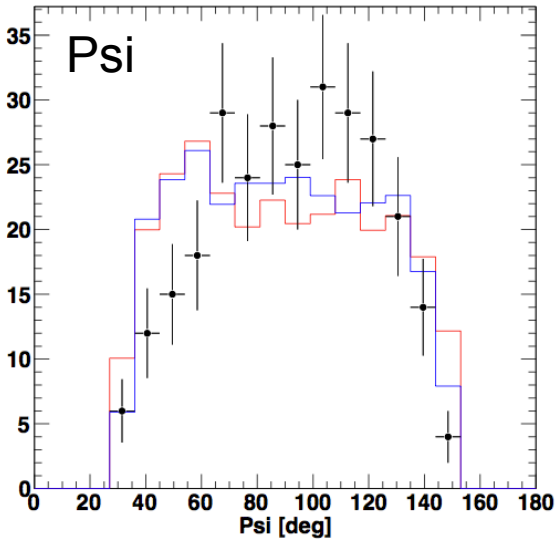






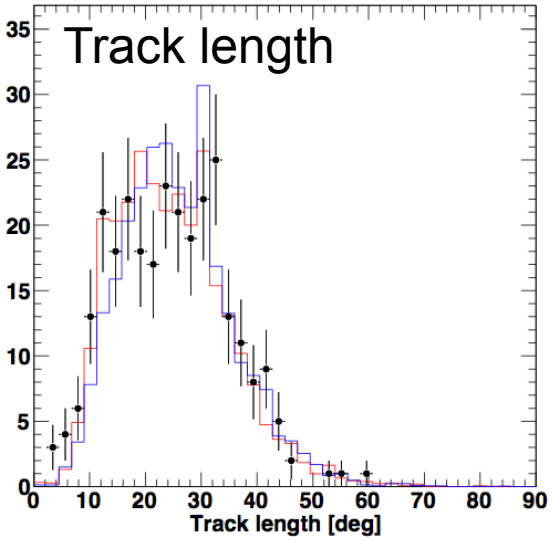


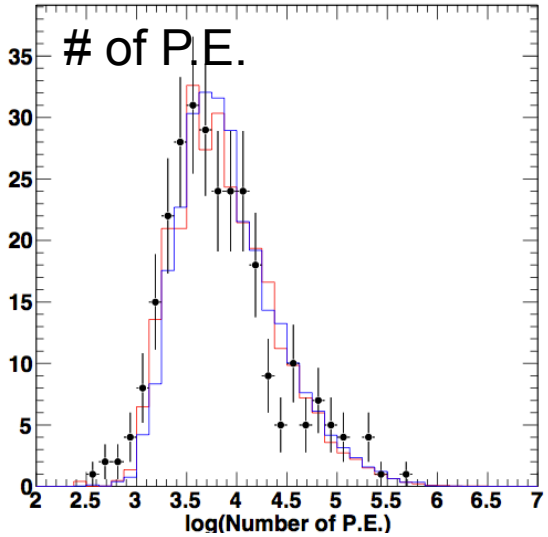


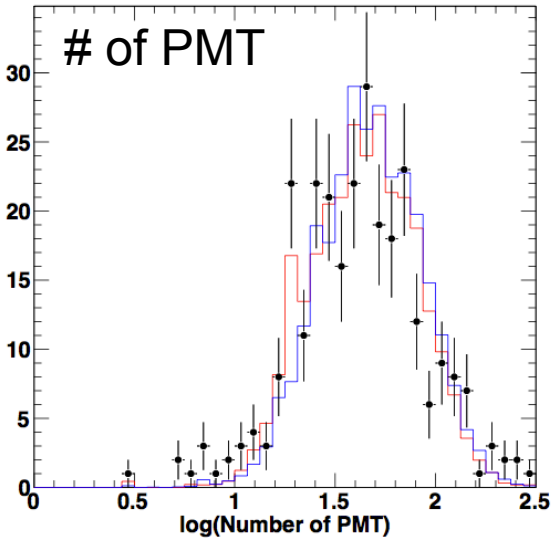


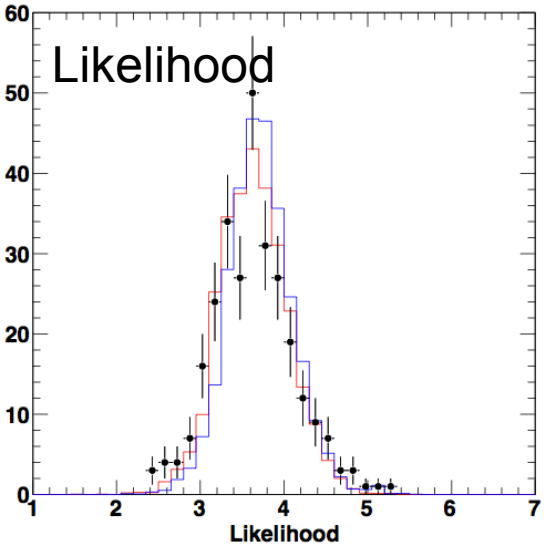
Data/MC Comparison (logE>18)

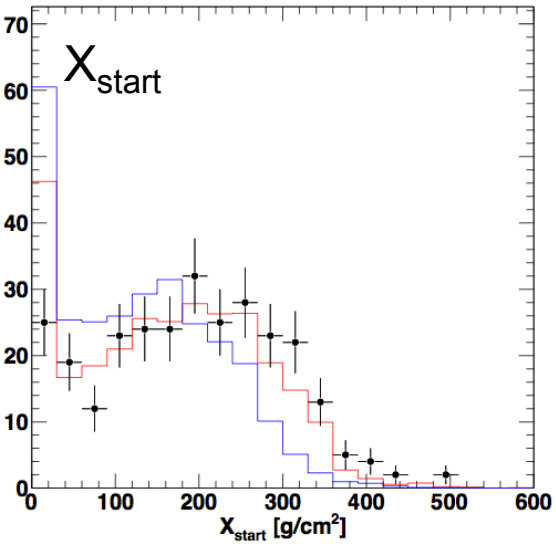
QGSJETII
Proton
Iron

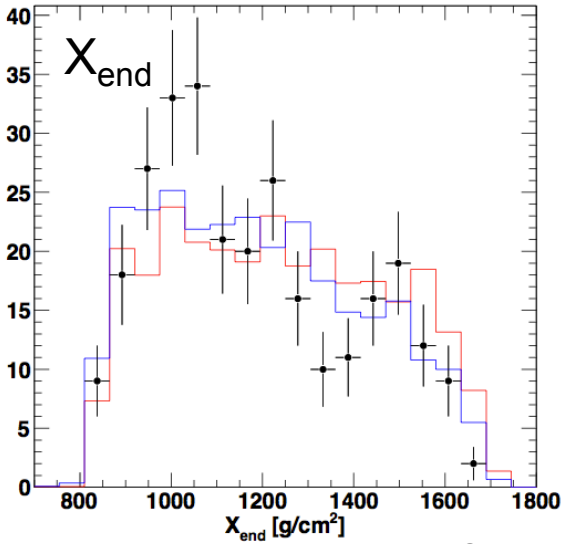




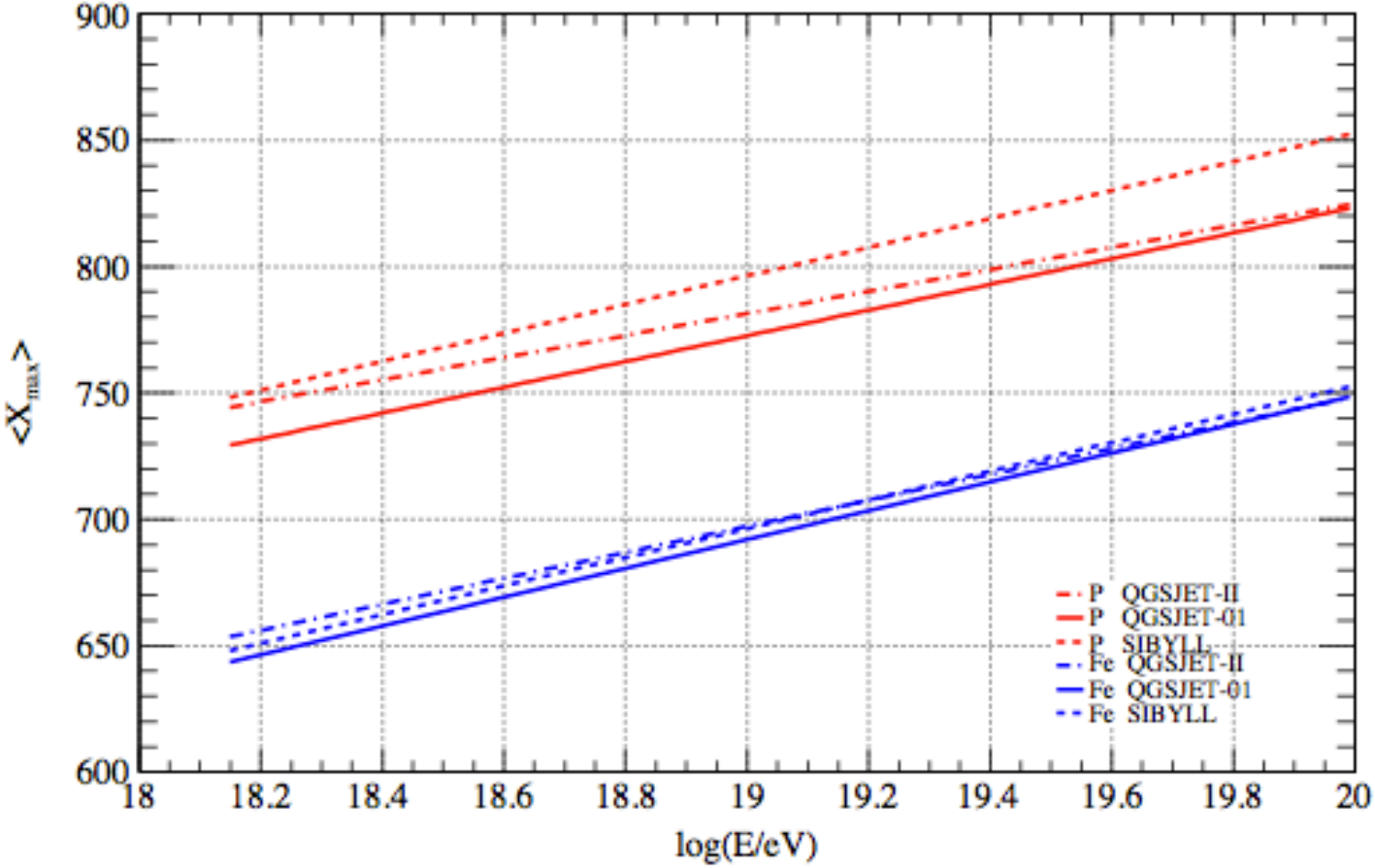




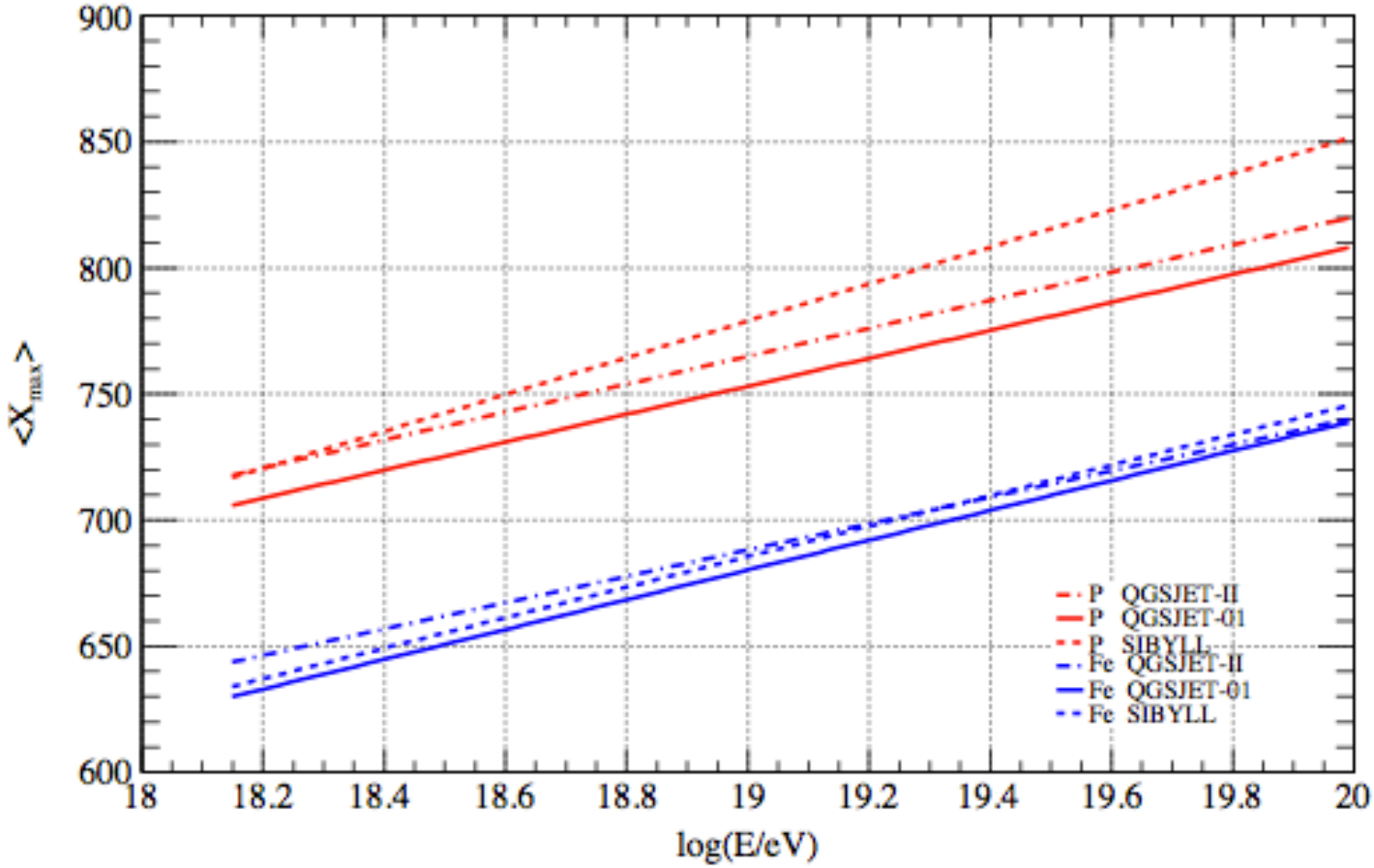




Prediction of Averaged Xmax CORSIKA shower simulation

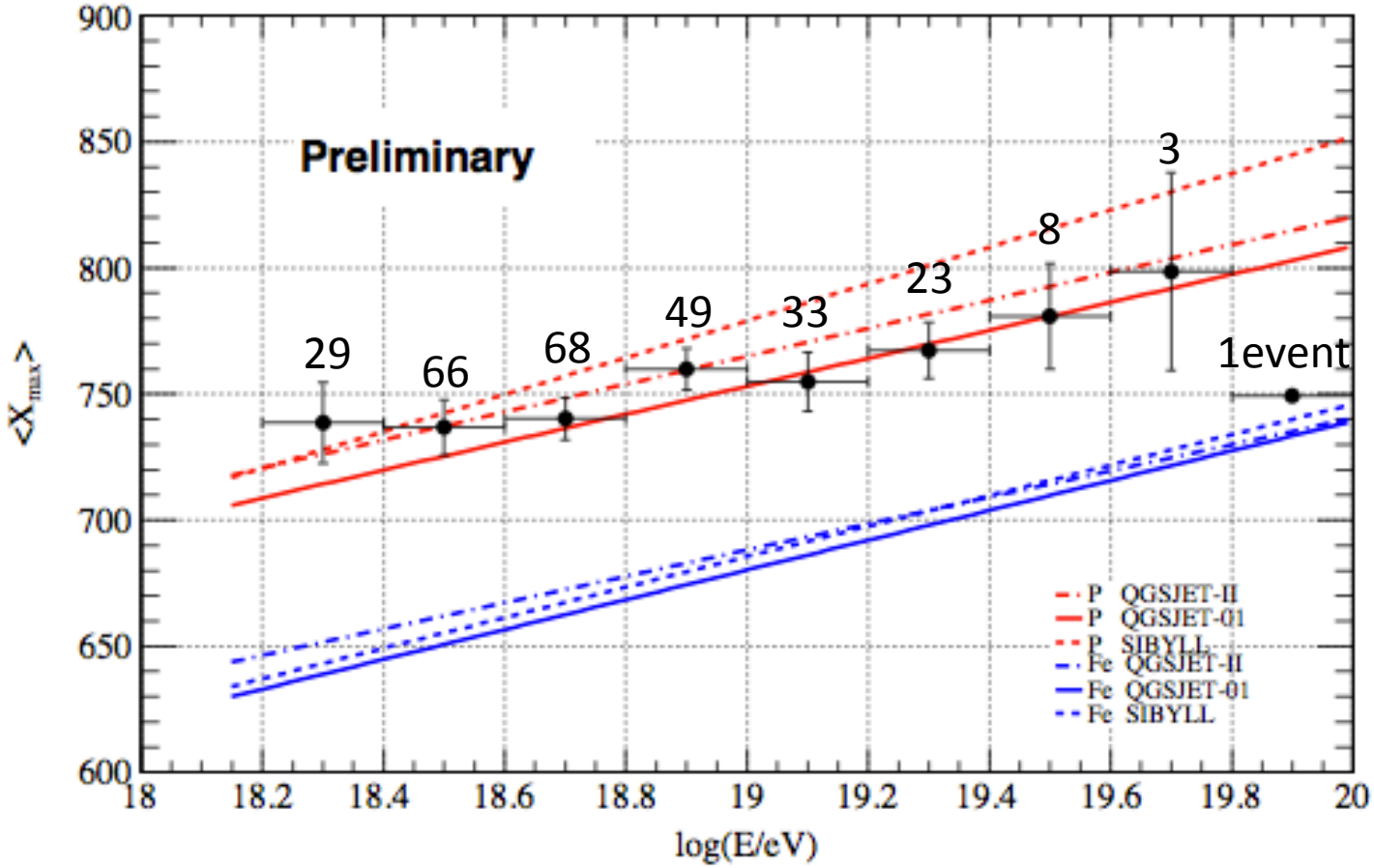


Prediction of Averaged Xmax CORSIKA with TA-FD Detector MC



These rails which include acceptance and reconstruction bias can be compared with data

Energy vs <Xmax>

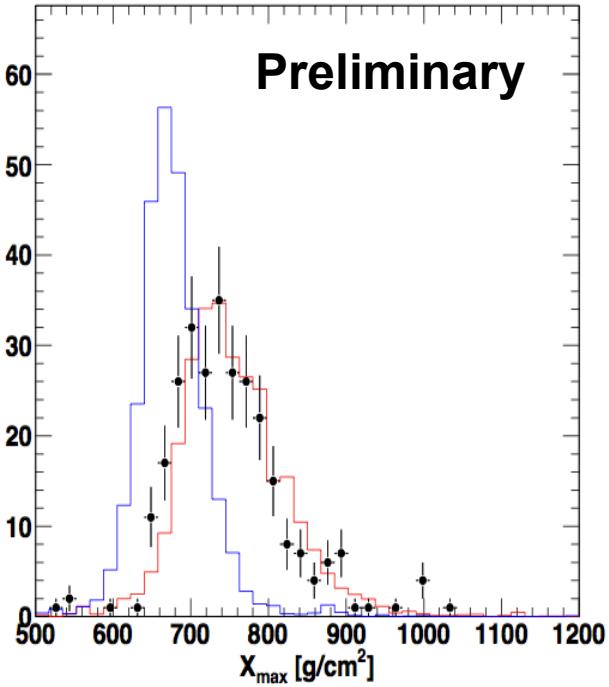


Data set : 2007/Nov – 2010/Sep

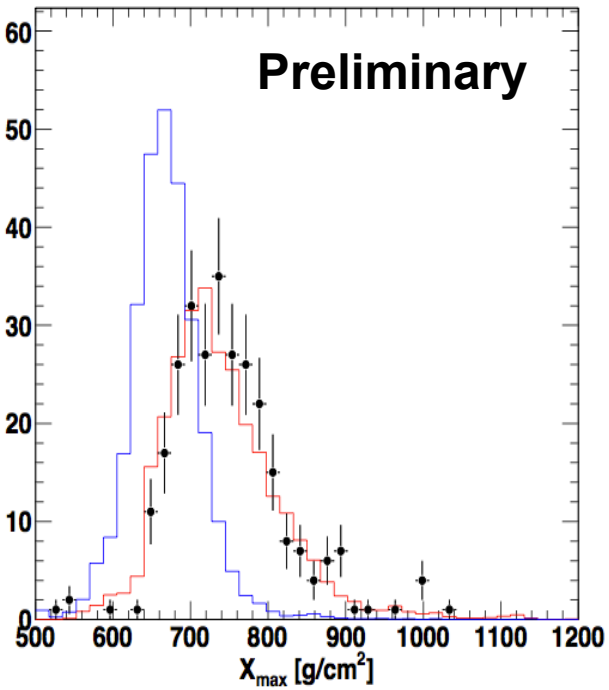
Xmax distribution ($10^{18\text{-}20}$eV)

Proton
Iron

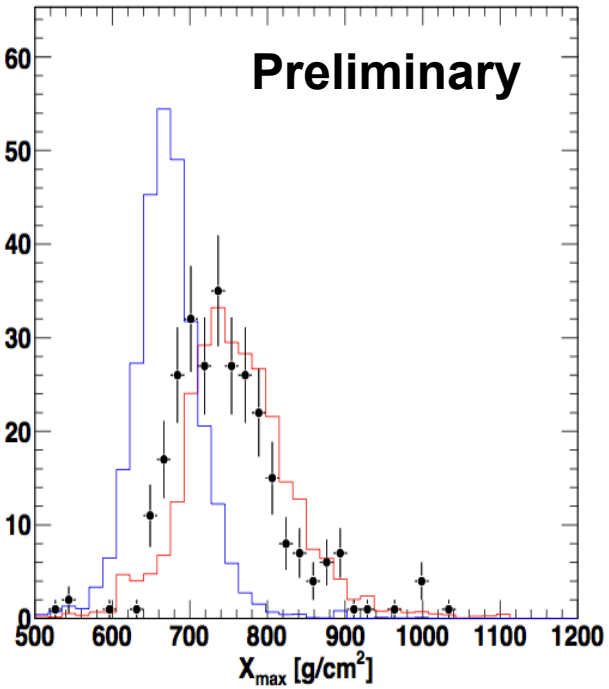
QGSJET-II



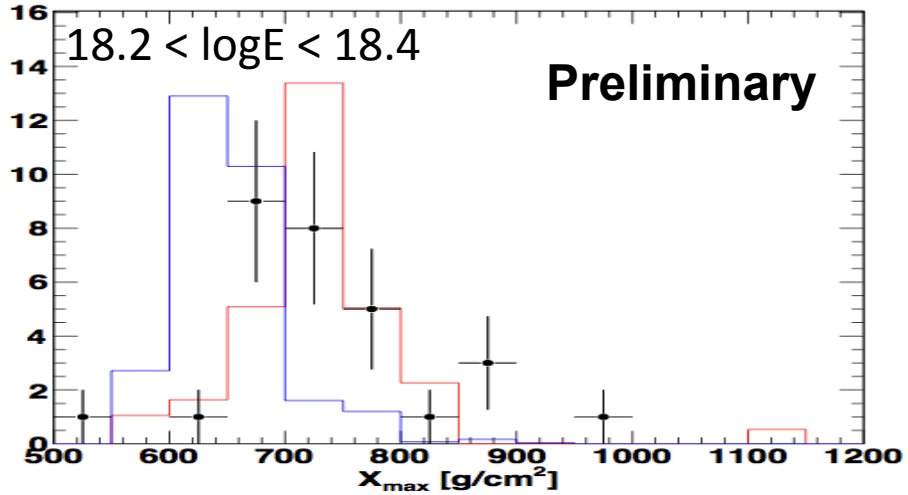
QGSJET01

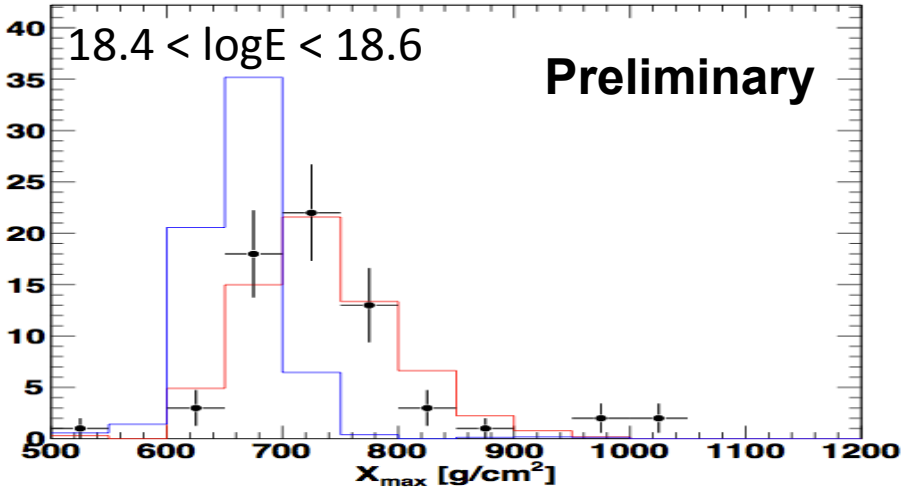


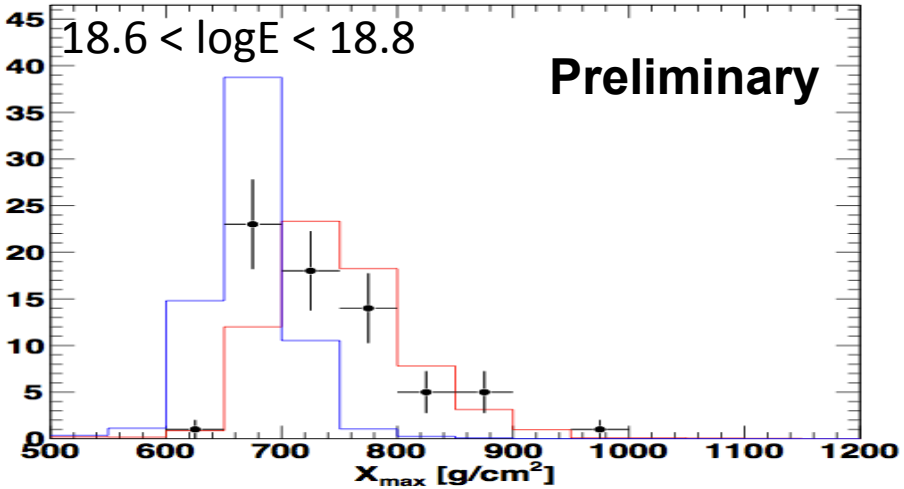
SIBYLL

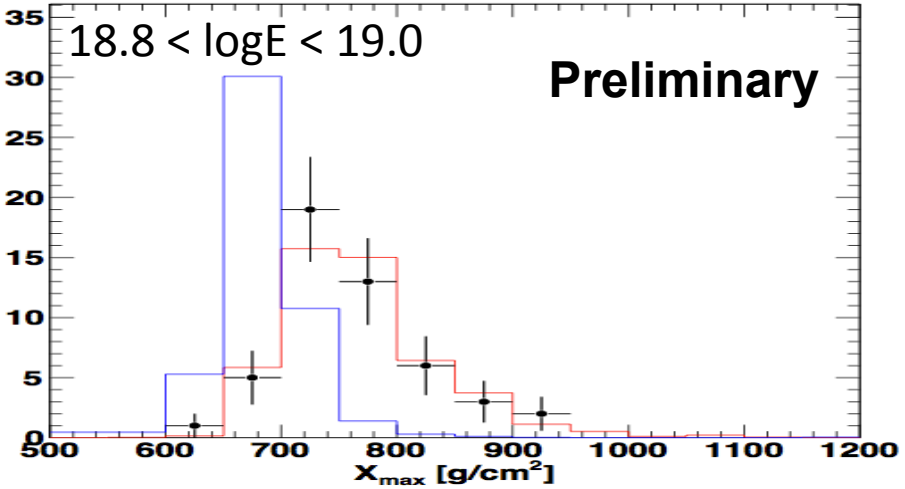


Xmax dist. QGSJET-II

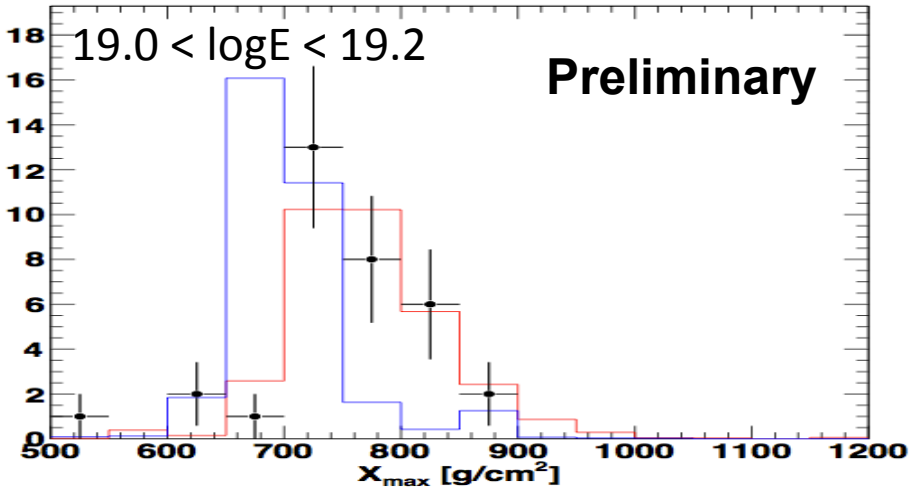


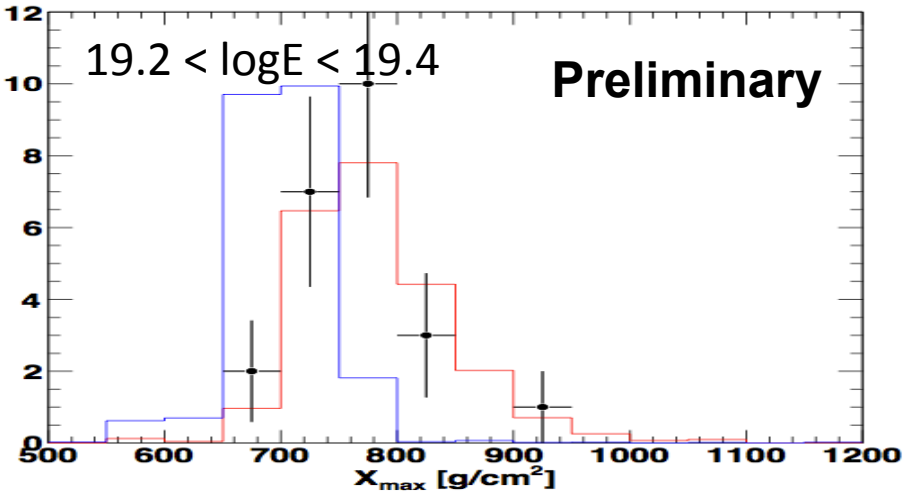


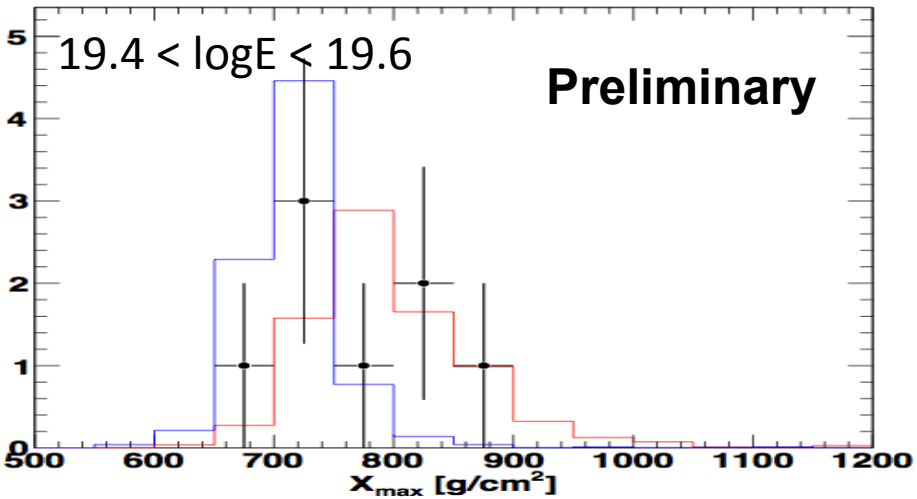


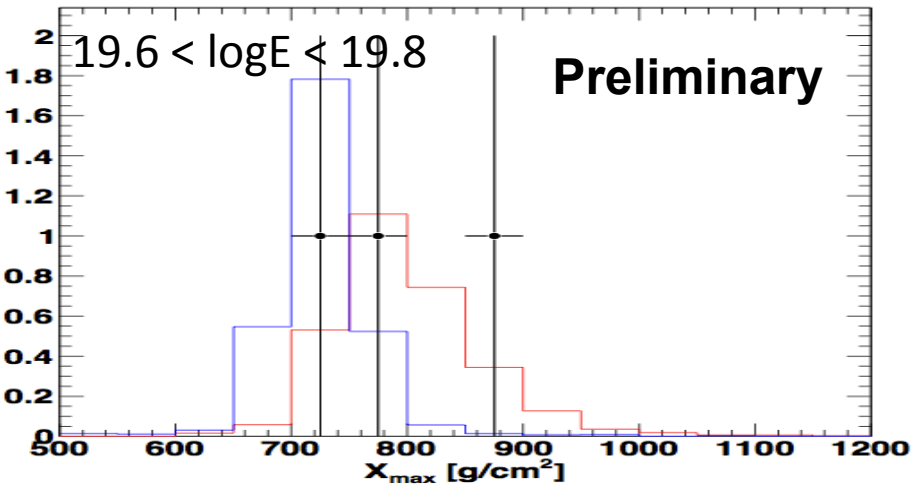


Xmax dist. QGSJET-II

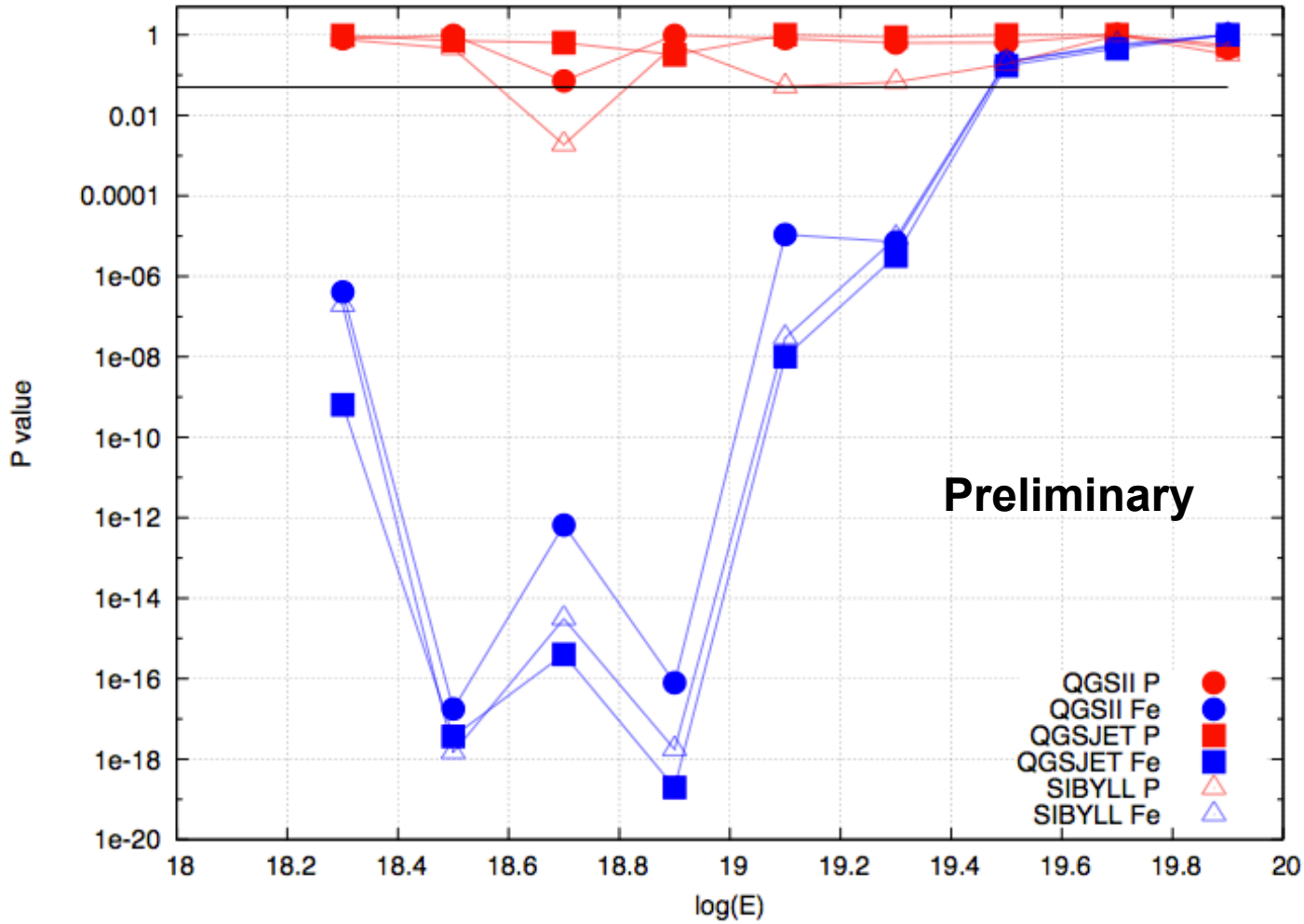






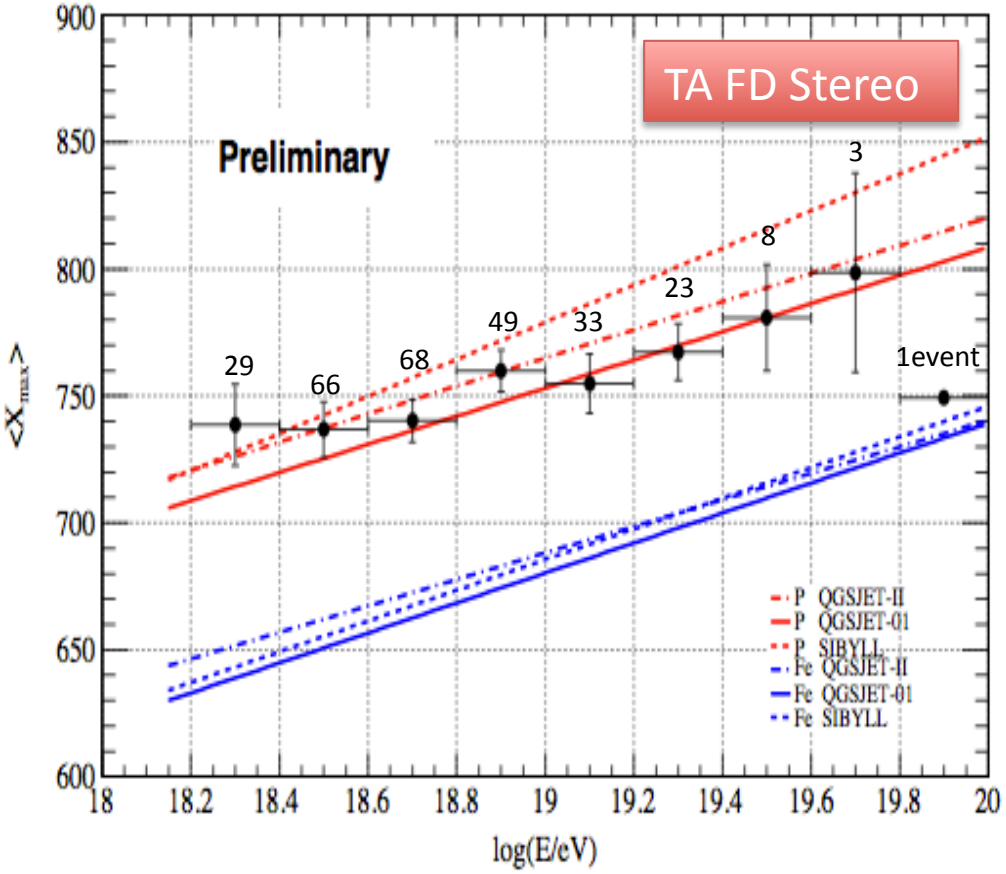


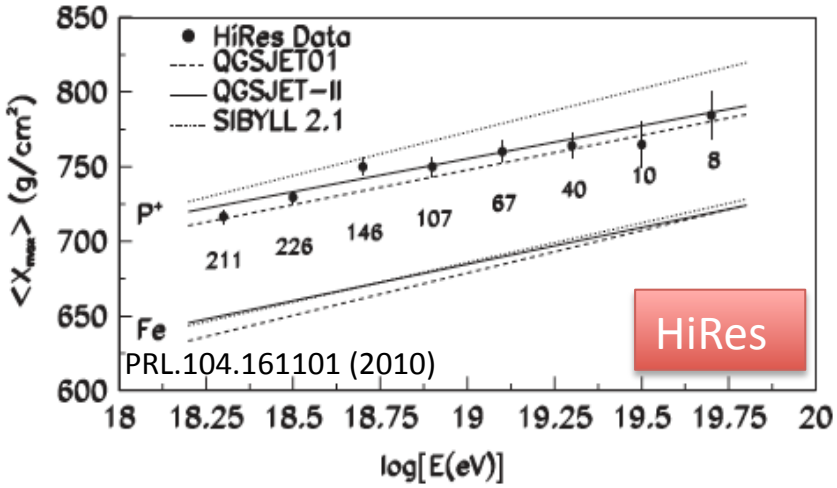
Xmax dist. : KS Test

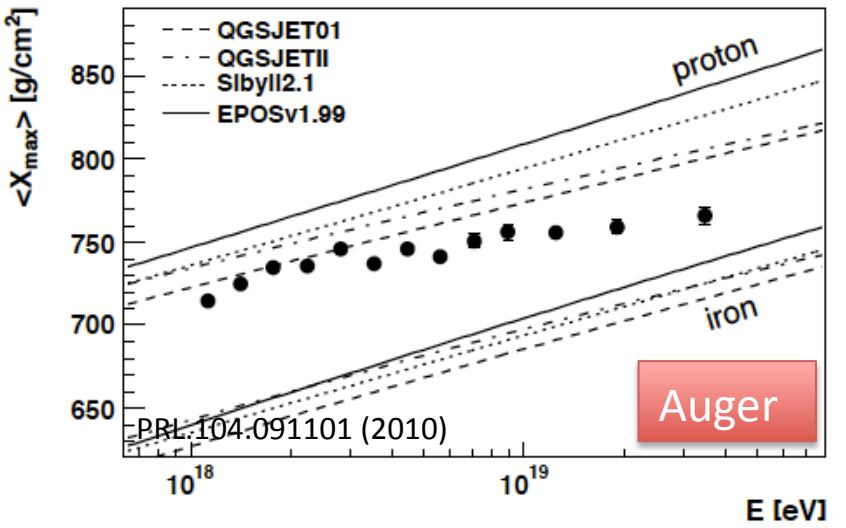


95% C.L.

<Xmax>


TA FD Stereo
Preliminary
29
66
68
49
33
23
8
3
1event
P QGSJET-II
P QGSJET-01
P SIBYLL
Fe QGSJET-II
Fe QGSJET-01
Fe SIBYLL
<Xmax>
log(E/eV)


HiRes Data
QGSJET01
QGSJET-II
SIBYLL 2.1
P+
Fe
211
226
146
107
67
40
10
8
HiRes
PRL.104.161101 (2010)
<Xmax> (g/cm²)
log[E(eV)]


QGSJET01
QGSJETII
Sibyll2.1
EPOSv1.99
proton
iron
Auger
PRL.104.091101 (2010)
<Xmax> [g/cm²]
E [eV]

Conclusion

- Data: Stereo events 2007/Nov – 2010/Sep
- Good agreement in Data/MC comparison
  Detector performance is well understood by MC.
- Energy vs Xmax distribution expected to be observed at TA-FD is estimated by CORSIKA for hadronic models of QGSJET-II, QGSJET01 and SIBYLL with detector simulation.
- Composition is determined by the comparison between Data and MC.
- Averaged Xmax is consistent with Proton (QGSJET).
- Distribution of Xmax is consistent with Proton (QGSJET).
  Xmax dist. of Fe can be excluded between **$10^{18.2}$ – $10^{19.4}$eV** with 95% C.L.