Measurement of UHECR composition by TA

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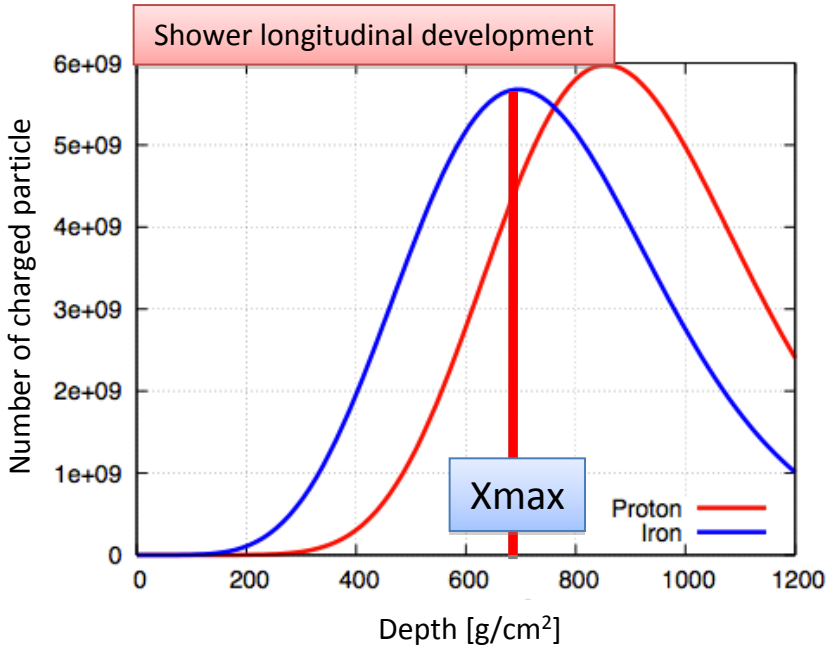
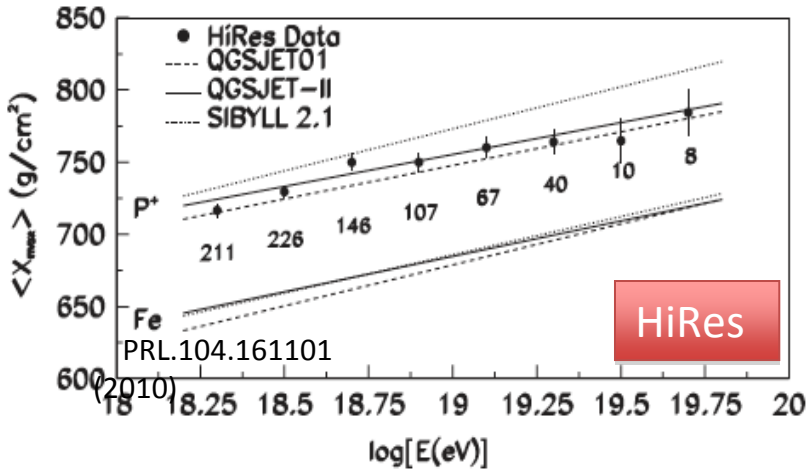
Outline

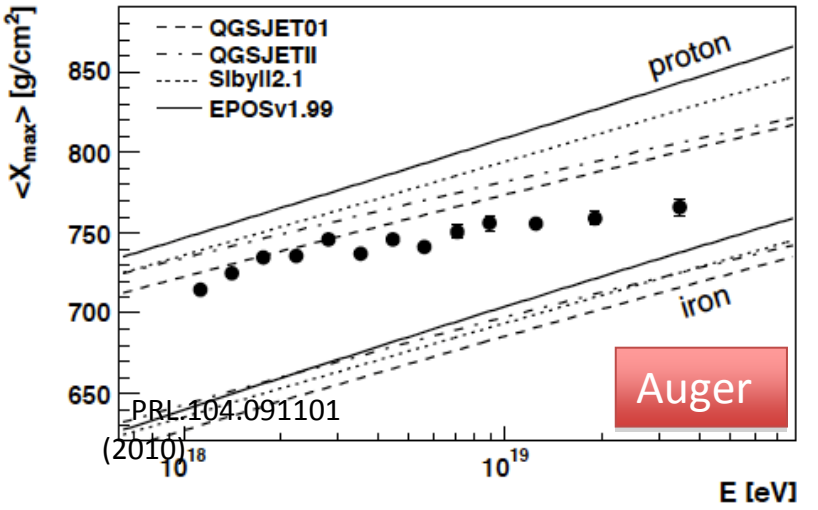
- Xmax Technique
- FD Stereo Measurement
- Monte Carlo
  - Air Shower Monte Carlo
  - Detector Monte Carlo
  - Data/MC Comparison
- Results

Xmax technique

- Shower longitudinal development strongly depends on their primary particle type.
- FD observes shower development directly.
- Xmas is one of 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

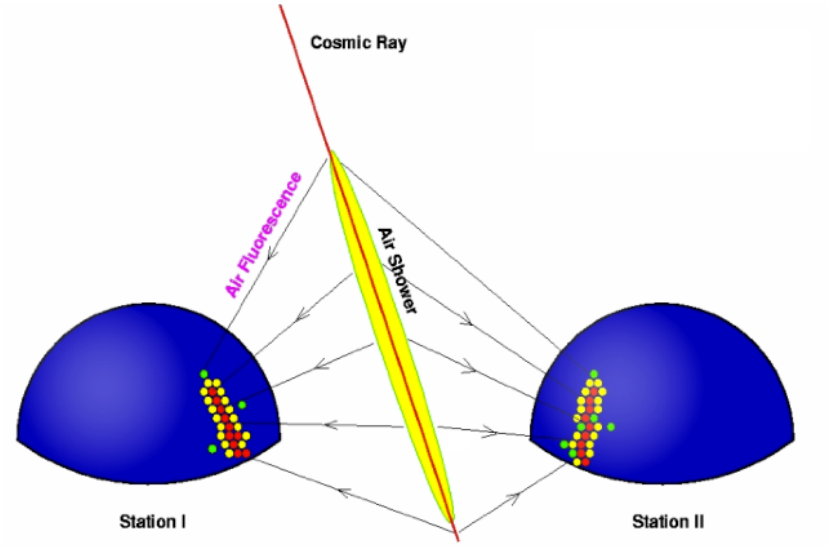
Determination of Shower axis

Intersection of SDPs

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

s: vector of shower axis

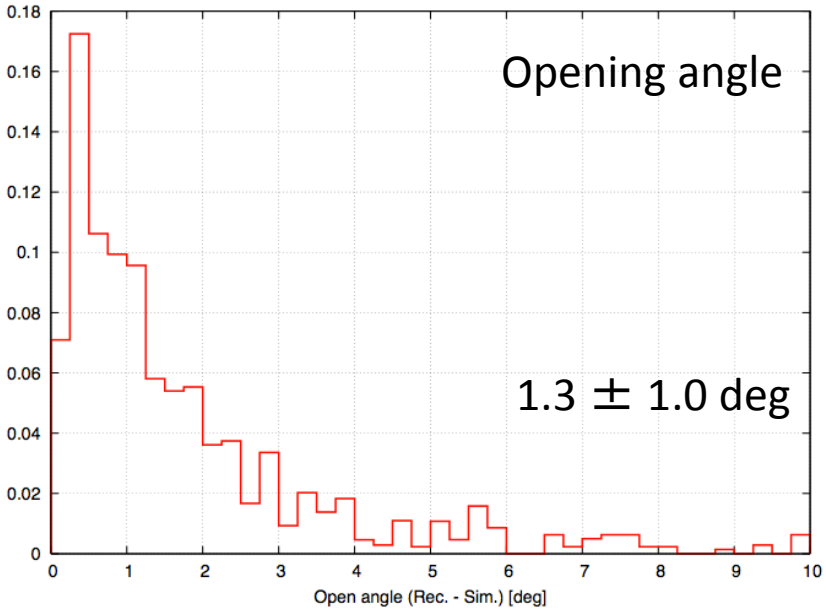
n_i: vector of SDP of each station

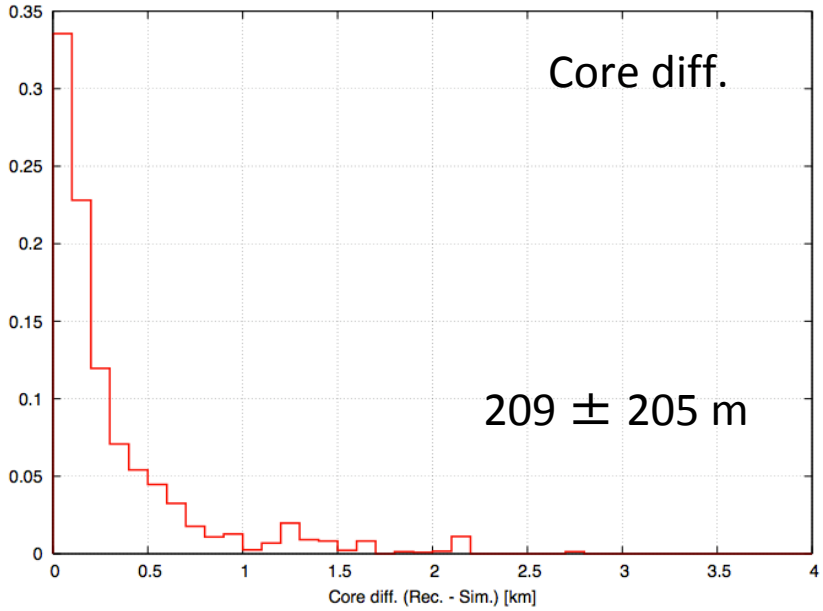


Determination of shower axis by stereo reconstruction is much better than monocular reconstruction.

Opening angle by monocular reconstruction is $\backsim 5\mathrm{deg}(1\sigma)$.

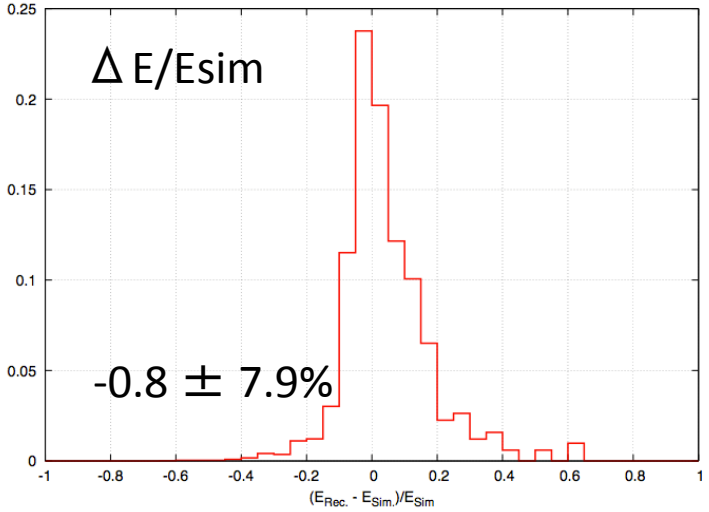
Resolution of TA-FD Stereo analysis @$10^{19\text{-}19.2}$eV

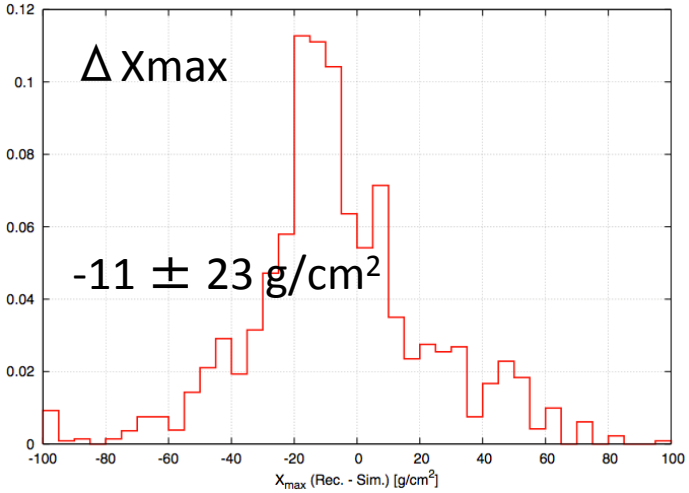




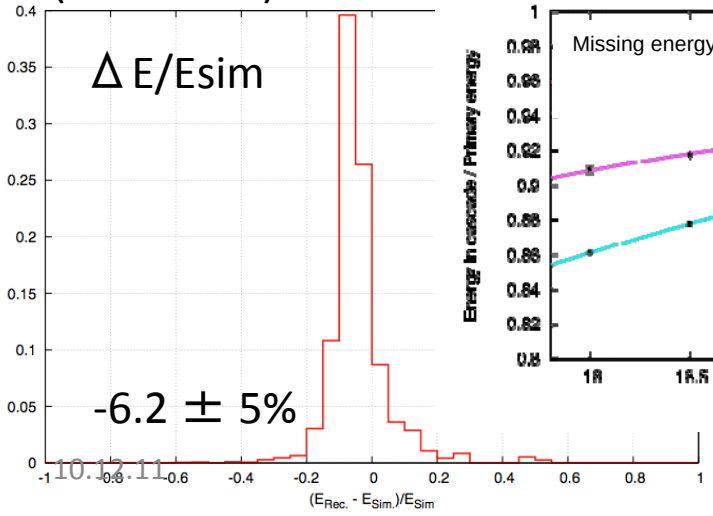
Resolution of TA-FD Stereo analysis @$10^{19\text{-}19.2}$eV

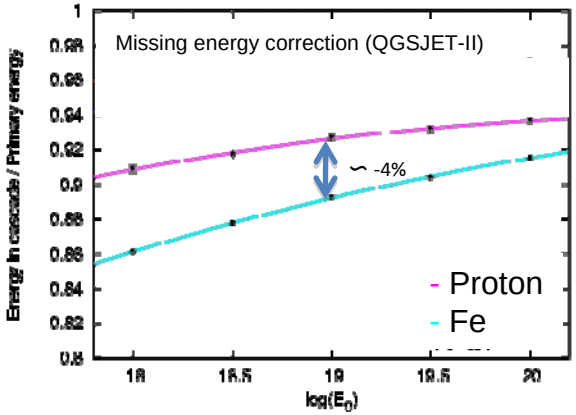
Proton (QGSJET01)

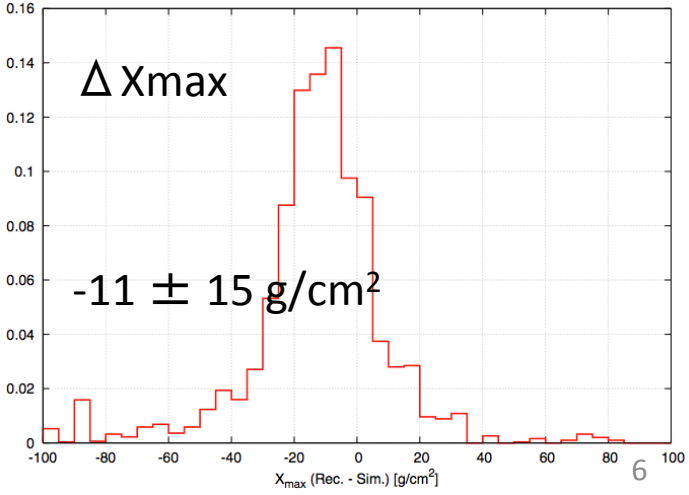




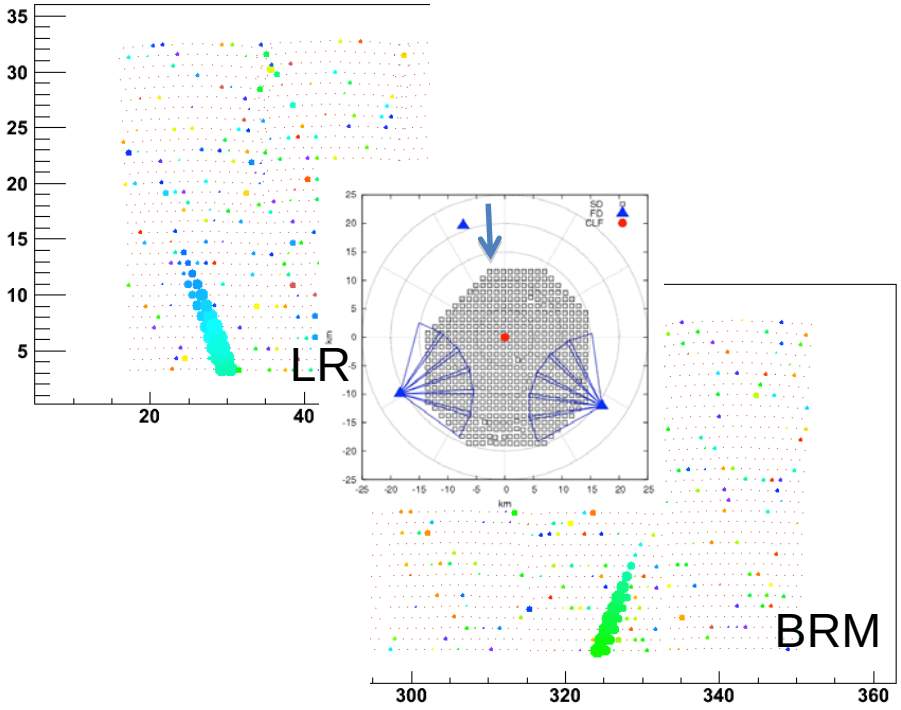
Iron (QGSJET01)

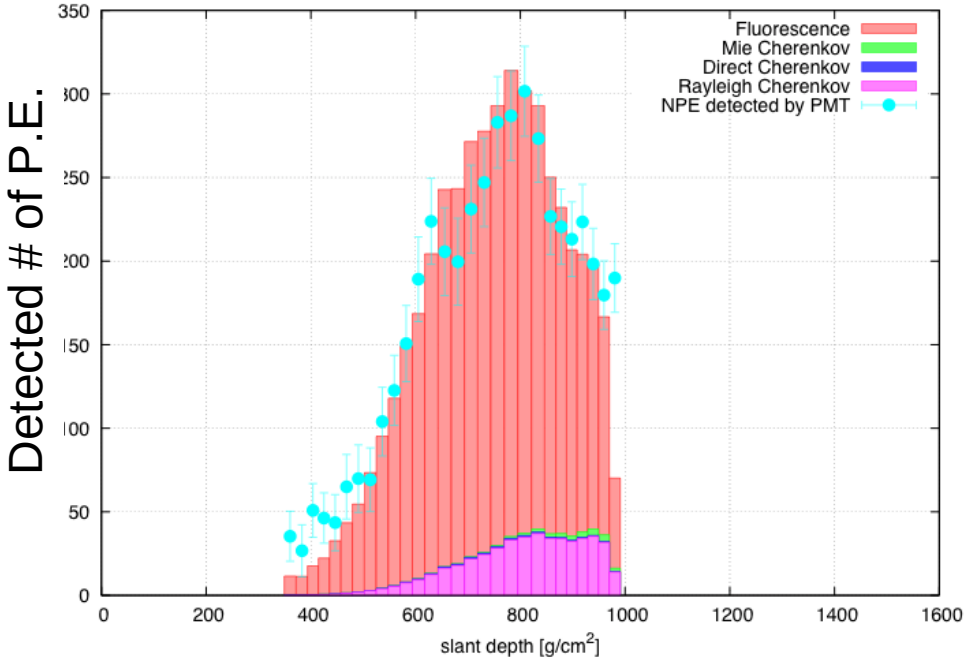






FD Stereo Event





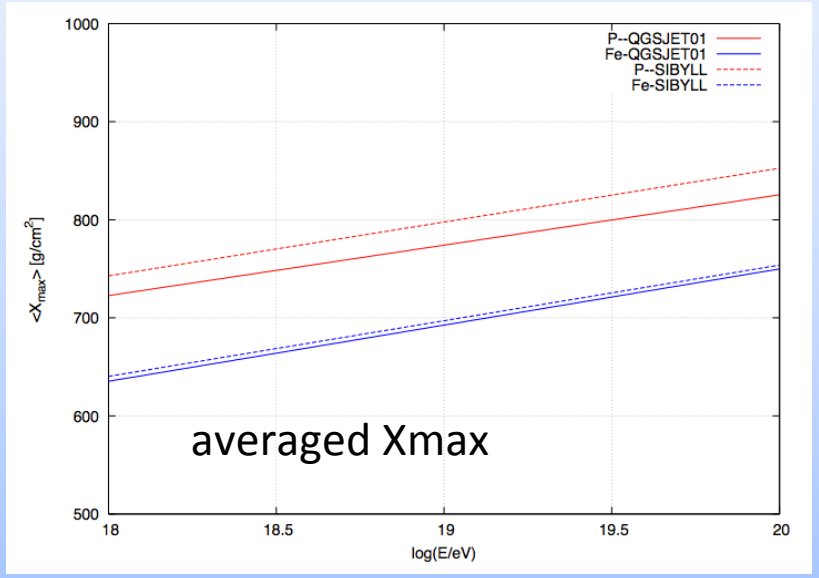
Date	log(E/eV)	Xmax	zenith	azimuth	Xcore	Ycore
2008/09/04	19.71	890 g/cm^2	44.3^o	-3.0^o	-3.1	14.2

Air Shower Monte Carlo

1. Distribution of Energy and Xmax
2. Systematic study for TA FD stereo
3. Expected Energy vs Xmax observed by TA FD

CORSIKA v6.9

- Hadronic interaction model
  QGSjet-01, SIBYLL
- Primary : P, Fe
- Energy :
  log(E) = 18.0 – 20.0
- Zenith angle : 0 – 65 deg
- ~1400m a.s.l (Height of TA Site)
- Thinning factor : 10^{-4}
  Ecut: EM100keV, hadron100MeV



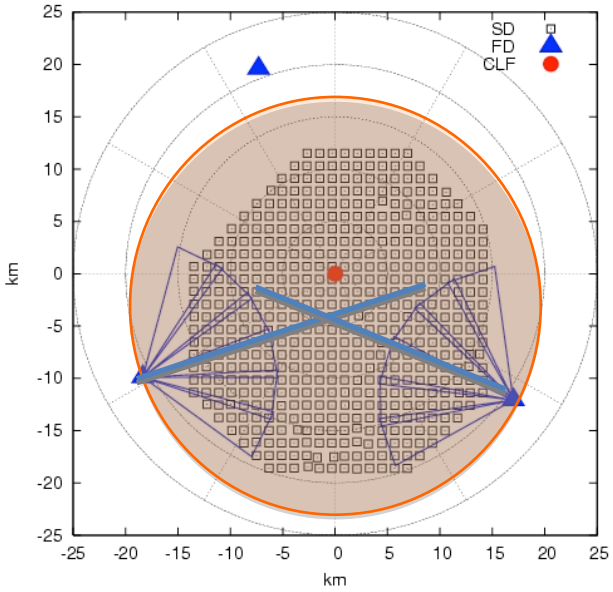
Detector Monte Carlo

Detector simulation

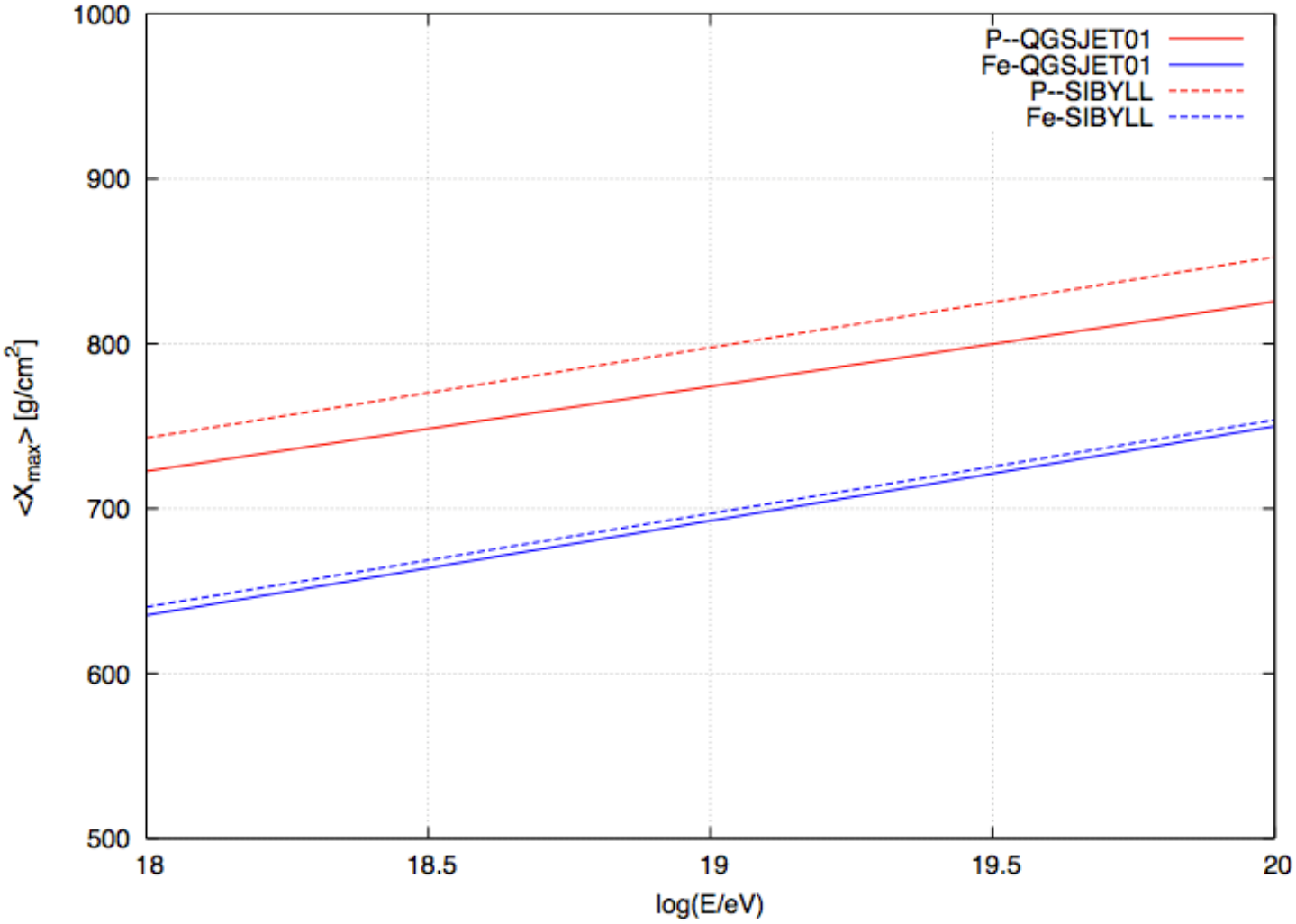
- Shower generator : CORSIKA
- Shower cores: within 20km from the center of F.O.V. of each station.
- Actual detector configuration
- Typical atmosphere

  Aerosol : typical value observed by LIDAR

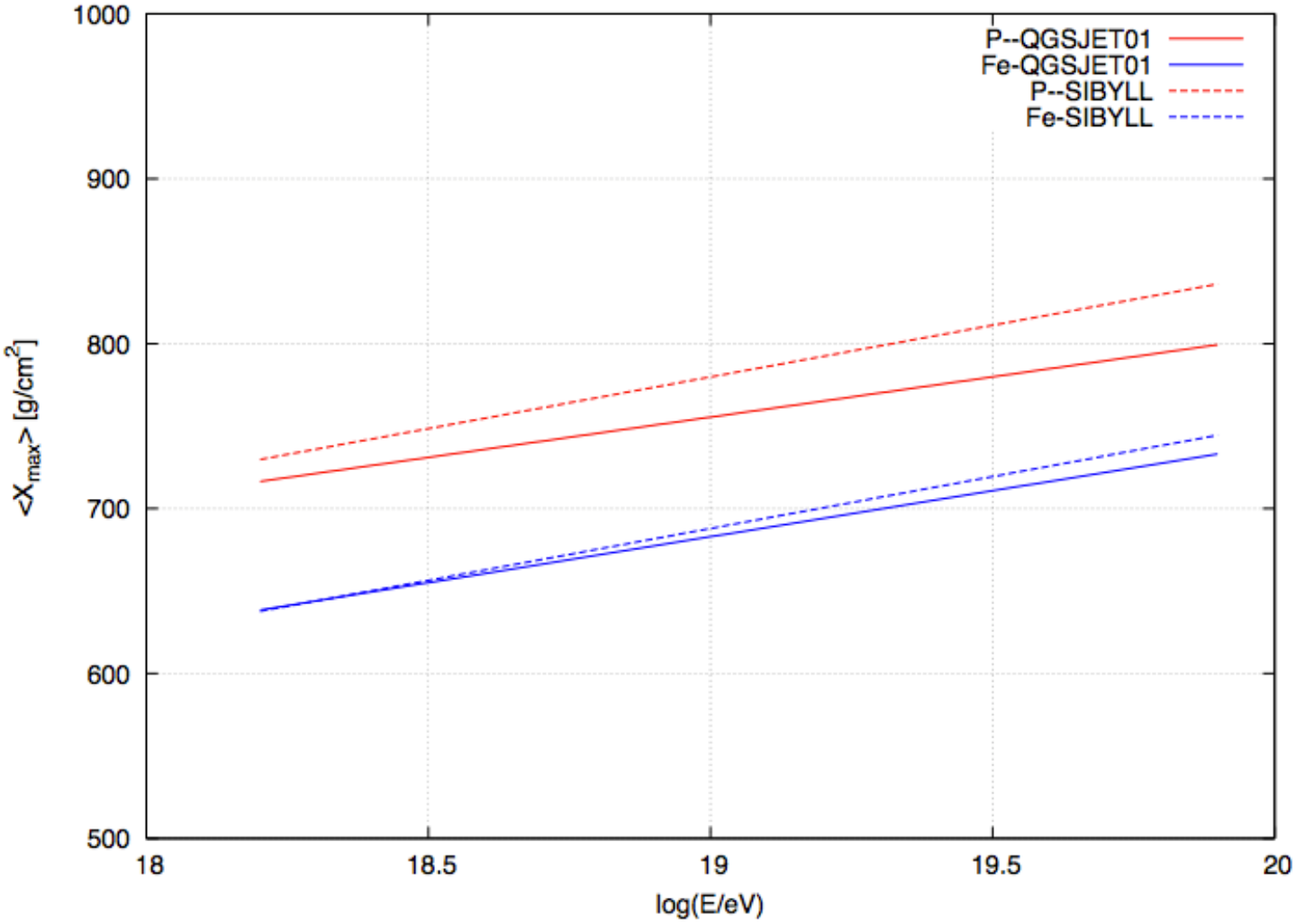
  scale height : 1.0km, mean free path : 29km
- Fluorescence model: Kakimoto et al., Flash (spectrum)



Prediction of Averaged Xmax
CORSIKA

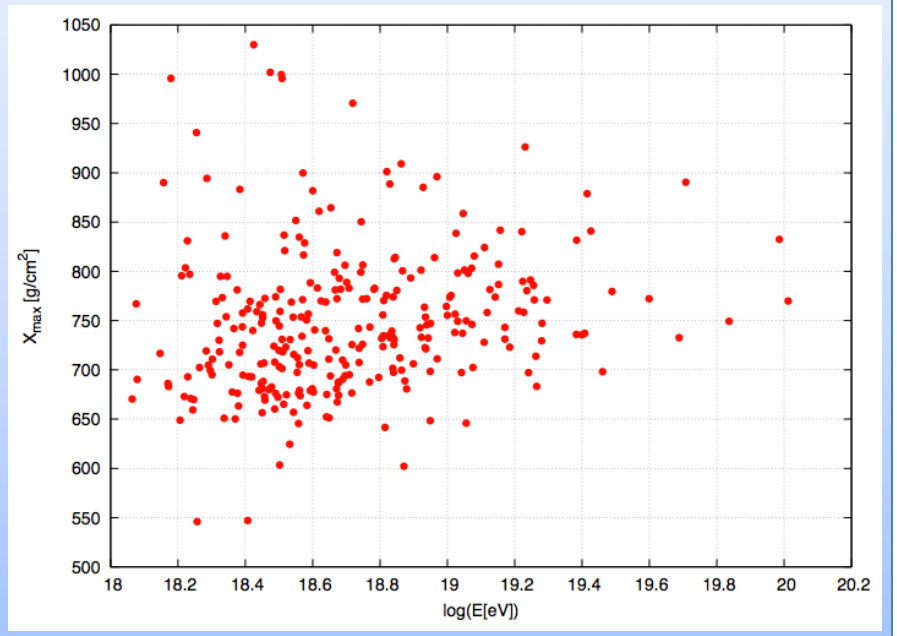


Prediction of Averaged Xmax CORSIKA with Detector MC



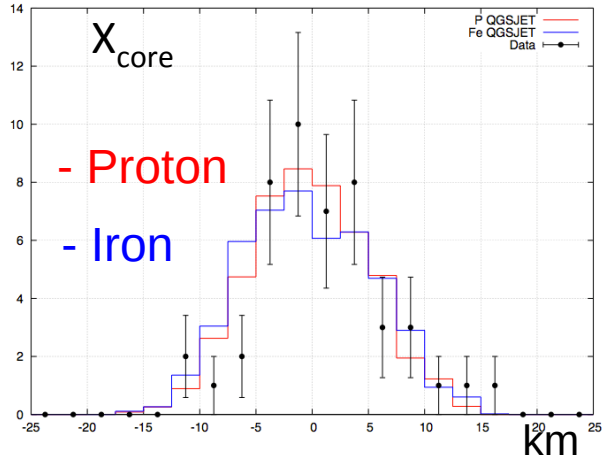
MC/Data Comparison

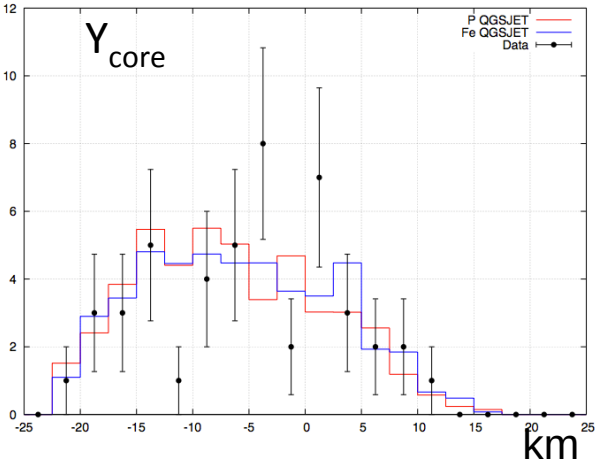
- Data set: 2007/Nov – 2010/Sep
- FD Stereo events
- Comparison with MC
- Quality Cut
  - Xmax observed
  - Zenith < 60^{o}
  - Core within 19.6km circle
  - Energy > $10^{18.0}$eV
  - χ^2 cut

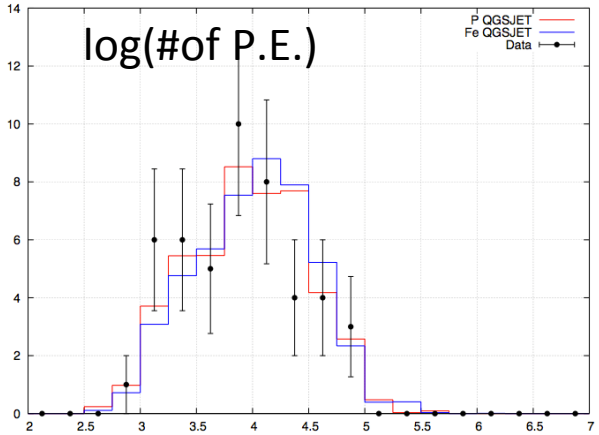


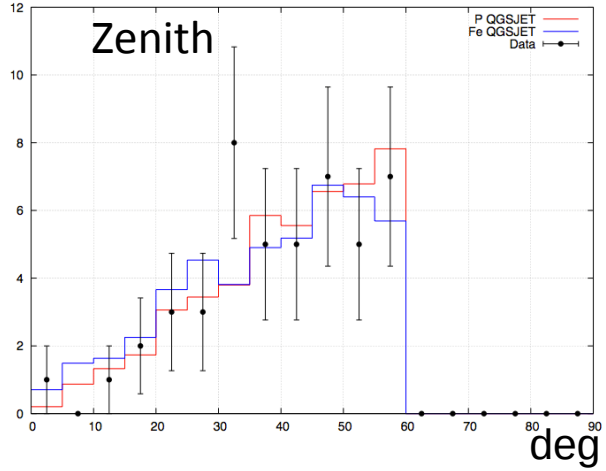
MC/Data Comparison (QGSJET01)

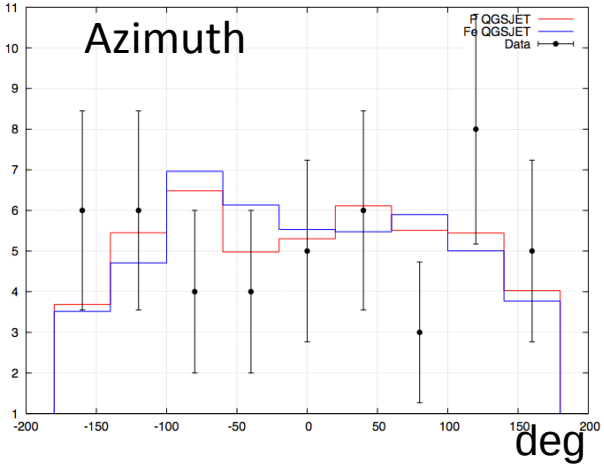
$10^{18.8\text{-}19.0}$eV (47events)

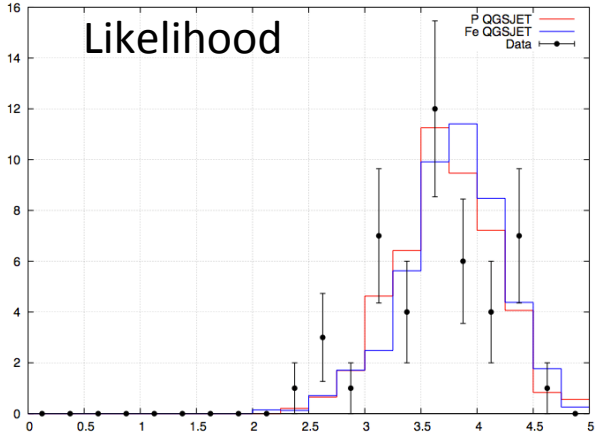






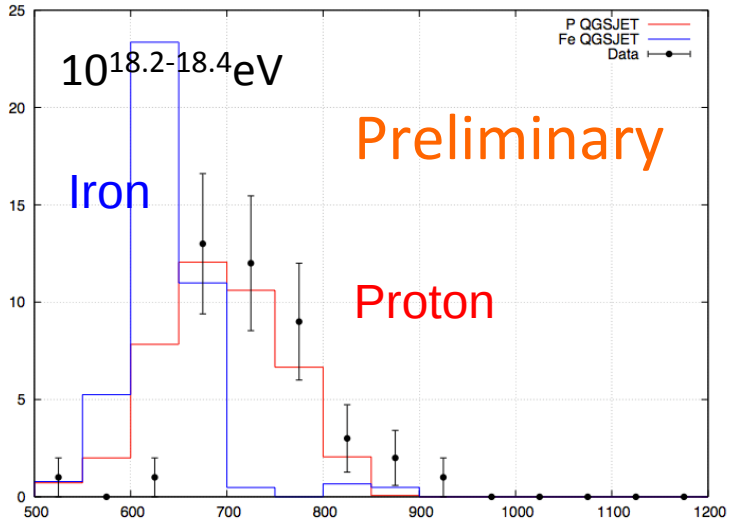


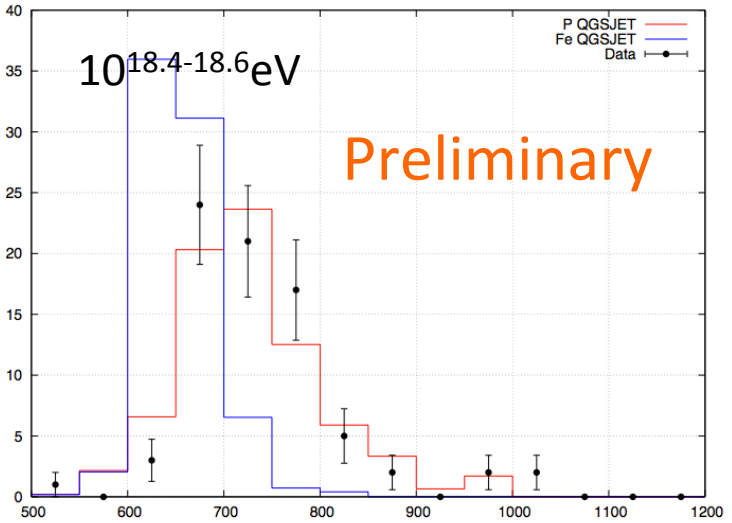


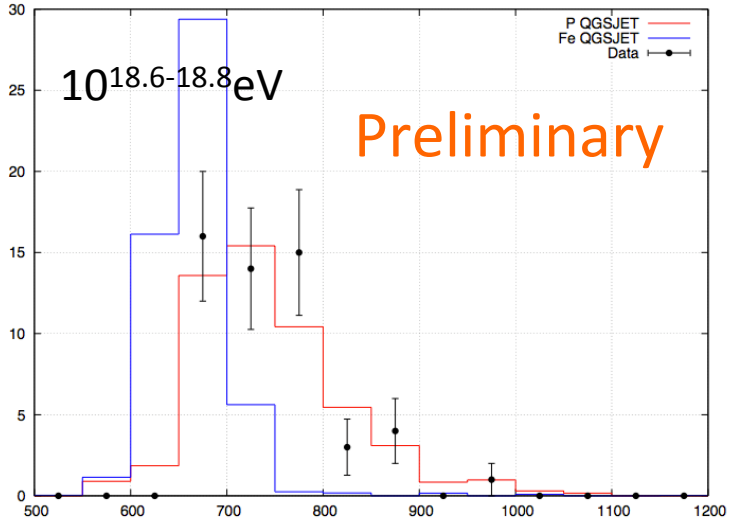


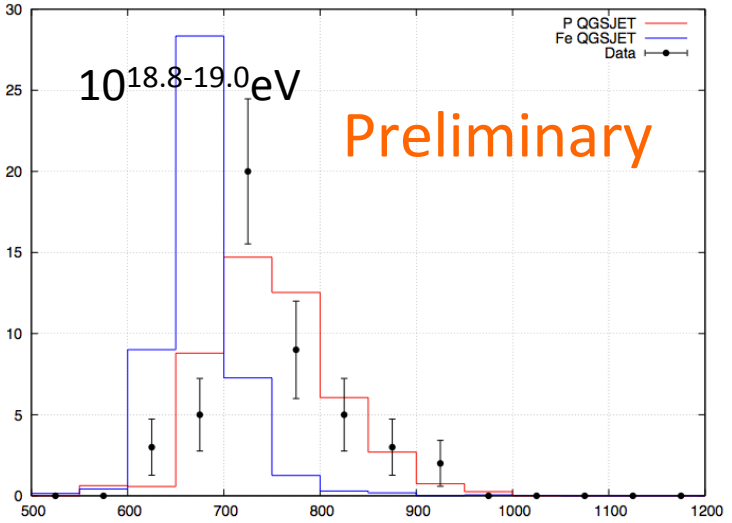
Results

Xmax Distribution (QGSJET01)









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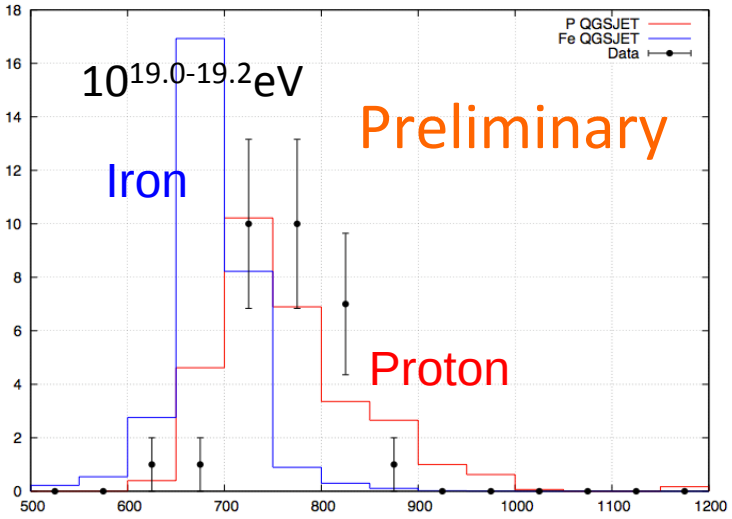
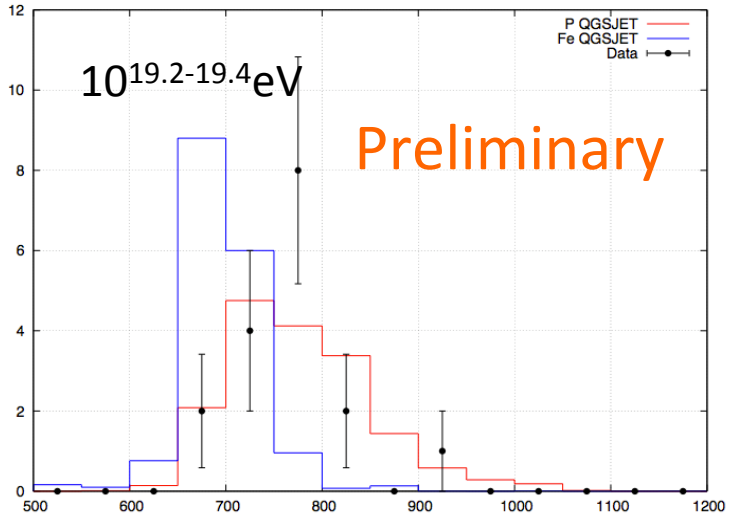
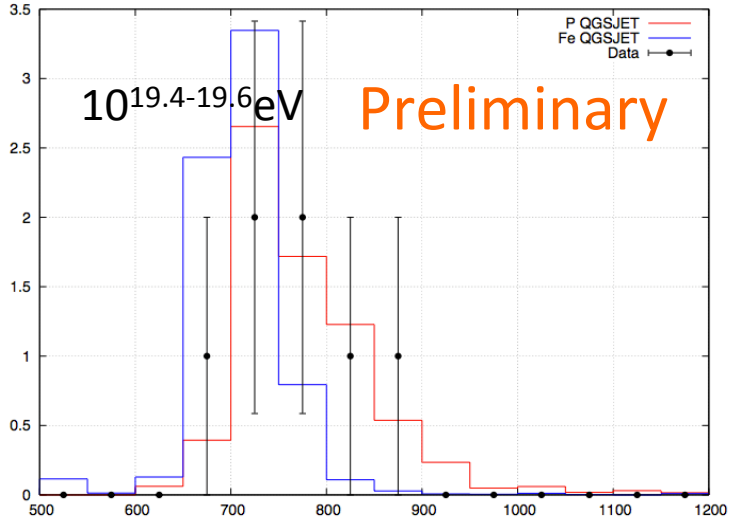
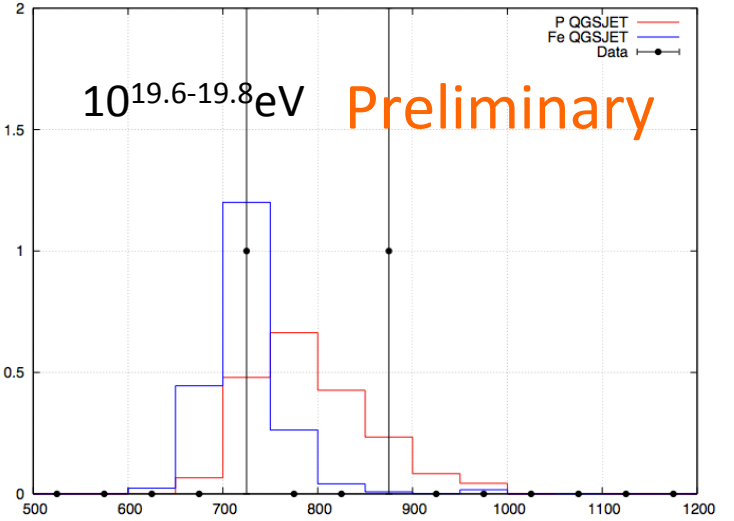
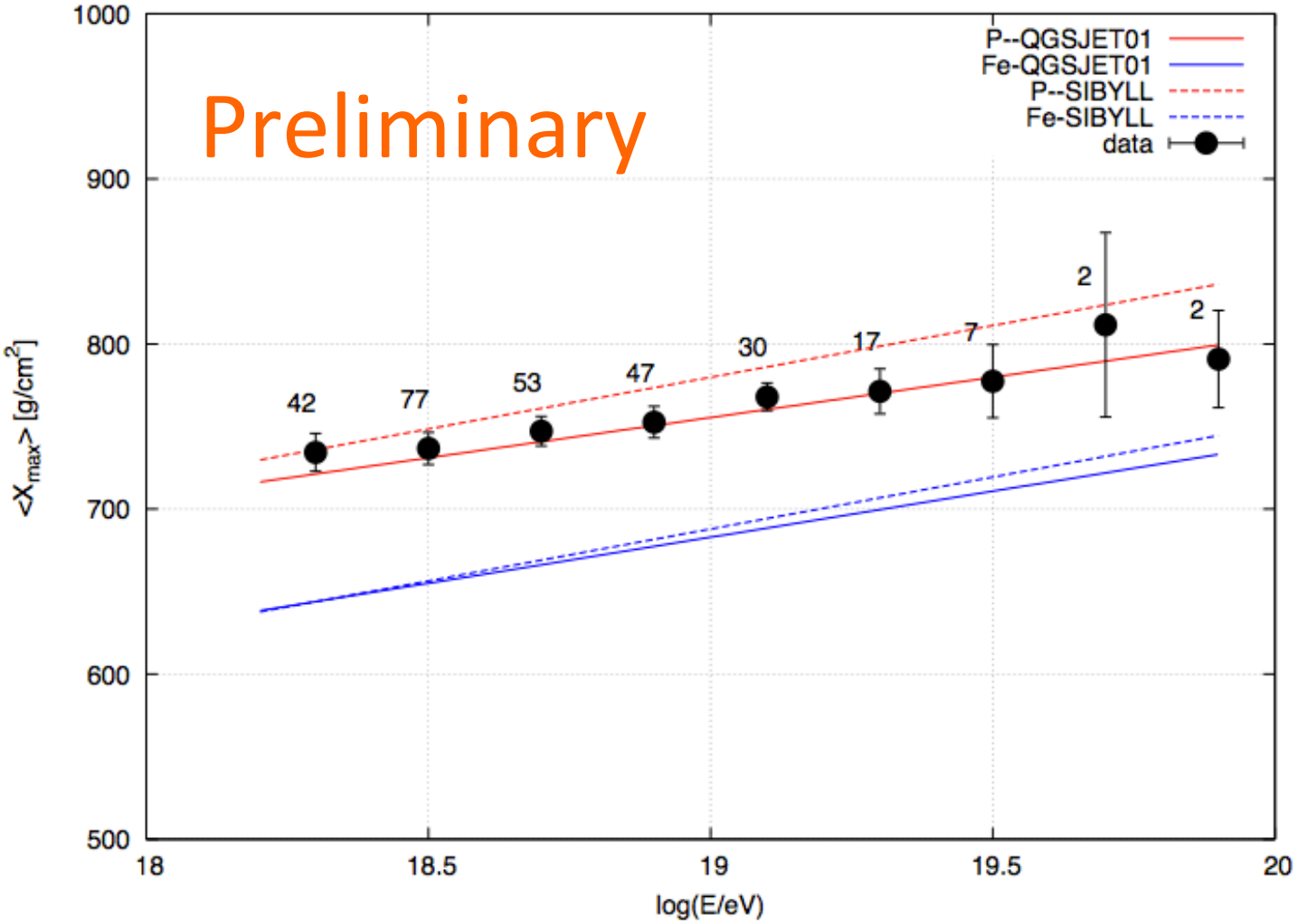




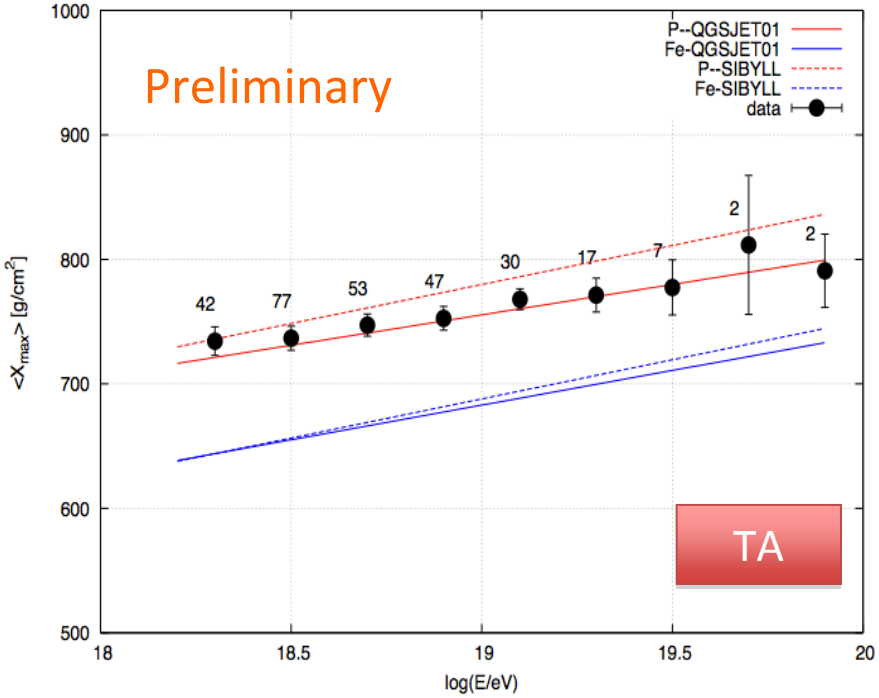


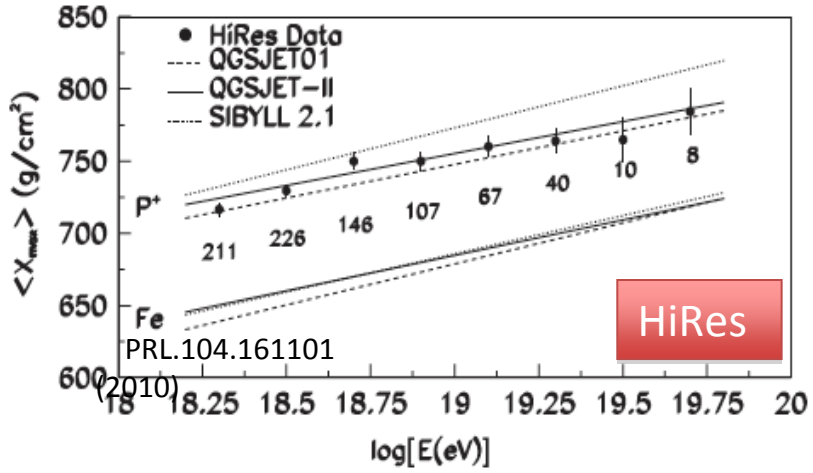


Averaged Xmax

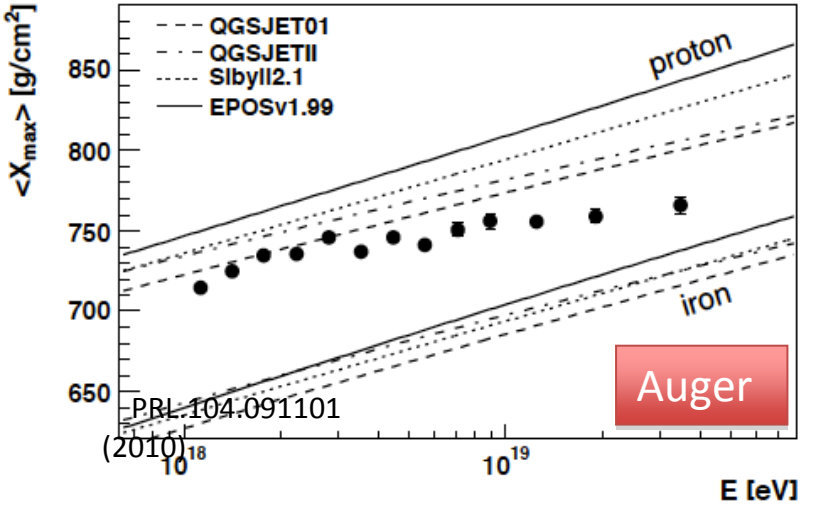


Averaged Xmax





PRL.104.161101 (2010)



PRL.104.091101 (2010)

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 QGSJET01 and SIBYLL with detector simulation.
- Composition is determined by the comparison between Data and MC.
- Distribution of Xmax is consistent with Proton (QGSJET01).
- Averaged Xmax is consistent with Proton (QGSJET01).

profile fitting

$$L = \sum_{\mathrm{PMT}} \left\{ N_{\mathrm{pe,raw}}^{\mathrm{PMT}} \log \left(\frac{N_{\mathrm{pe}}^{\mathrm{PMT}}}{N_{\mathrm{pe}}^{All}} \right) \right\}$$

$$N_{\mathrm{pe}}^{All} = \sum_{\mathrm{PMT}} N_{\mathrm{pe}}^{\mathrm{PMT}}$$

N_{pe}^{PMT} : detected photoelectrons for PMT

N_{pe}^{All} : photoelectrons of All

$N_{pe,raw}^{PMT}$: photoelectrons from raw data