TA実験の結果と ニュートリノ検出の可能性

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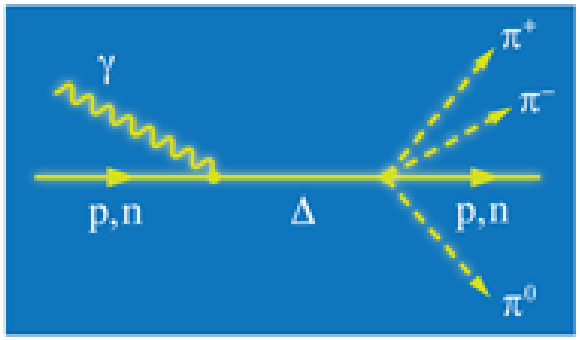
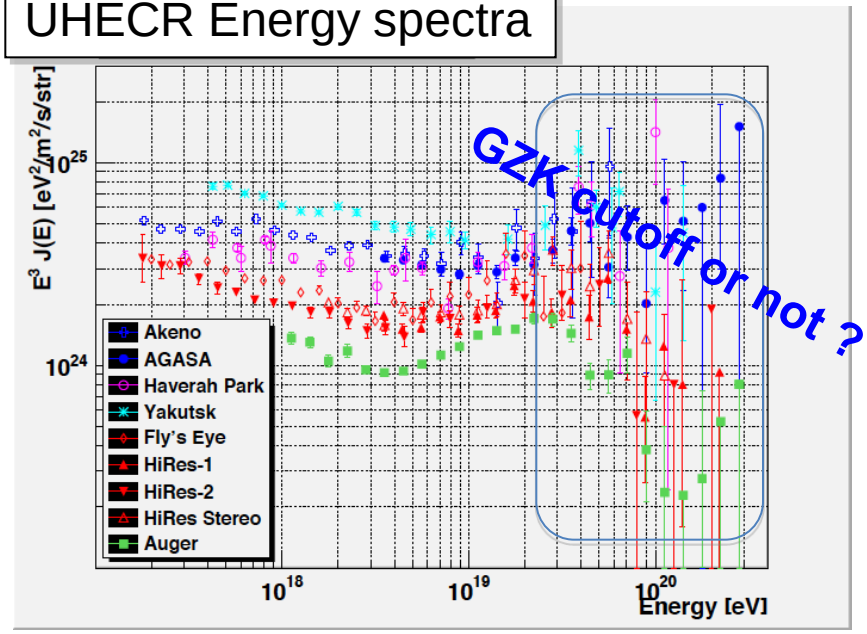
Outline

- Ultra High Energy Cosmic Ray
- Telescope Array Experiment
- TA Result
  - Energy Spectrum
  - Mass Composition
- Summary

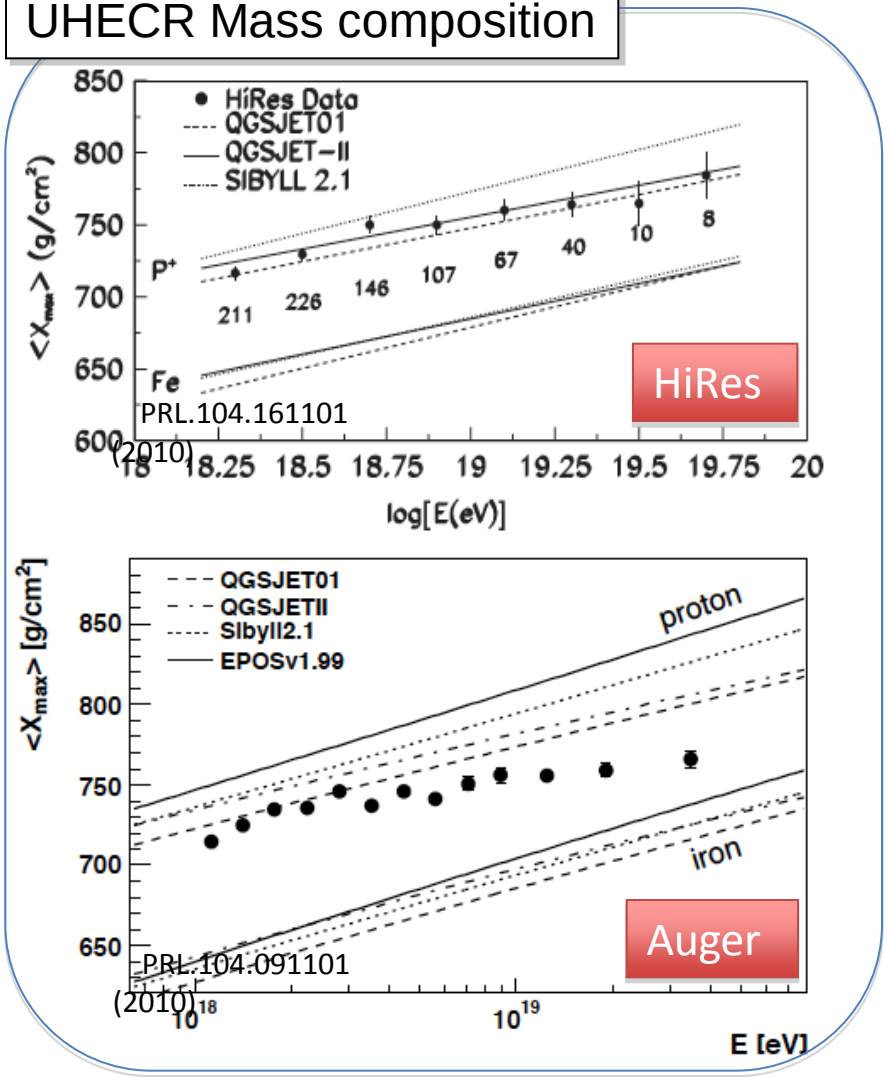
Ultra High Energy Cosmic Ray



UHECR Energy spectra

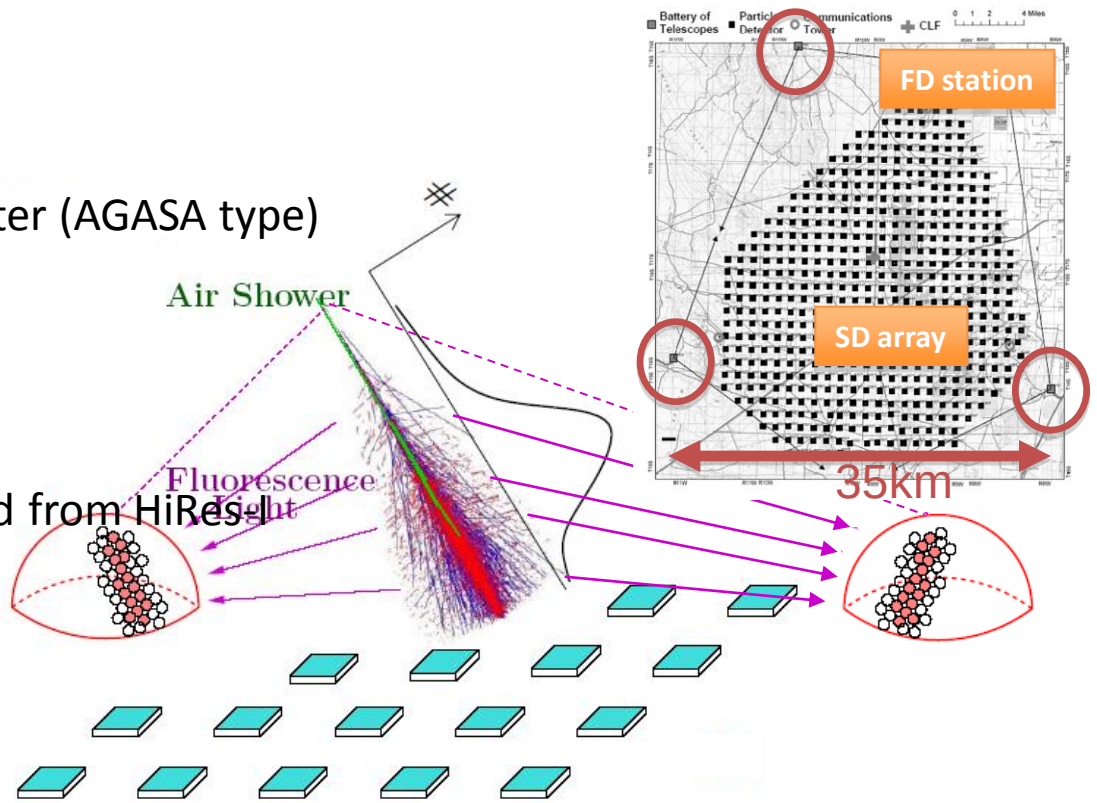


UHECR Mass composition

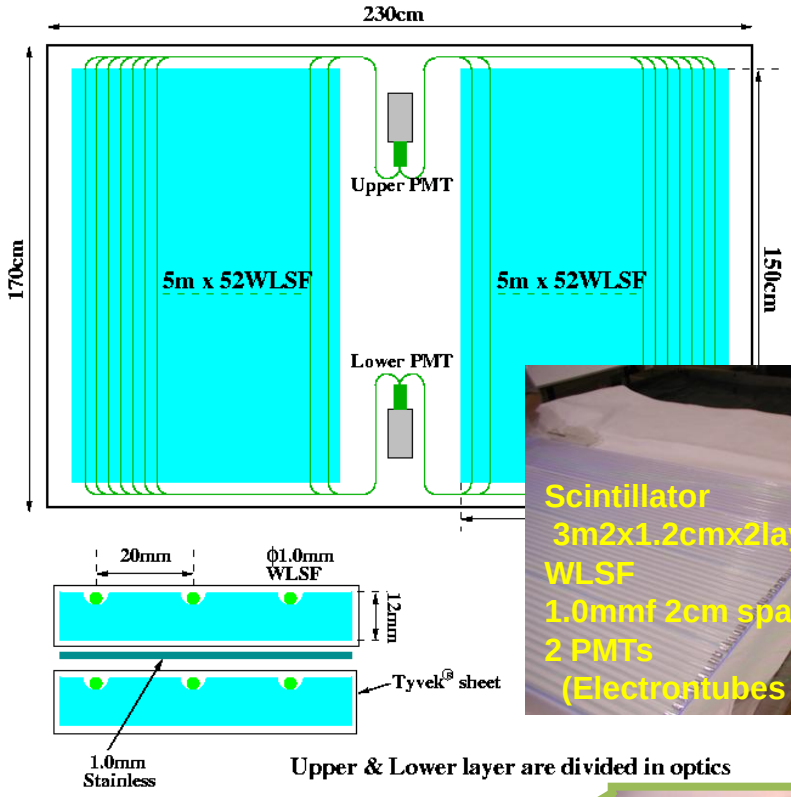


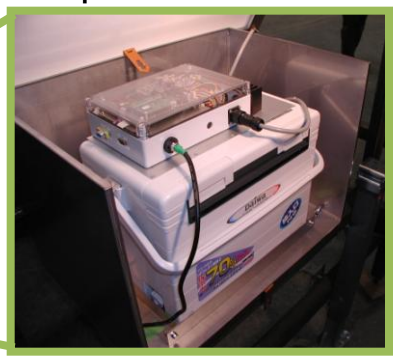
Telescope Array Experiment

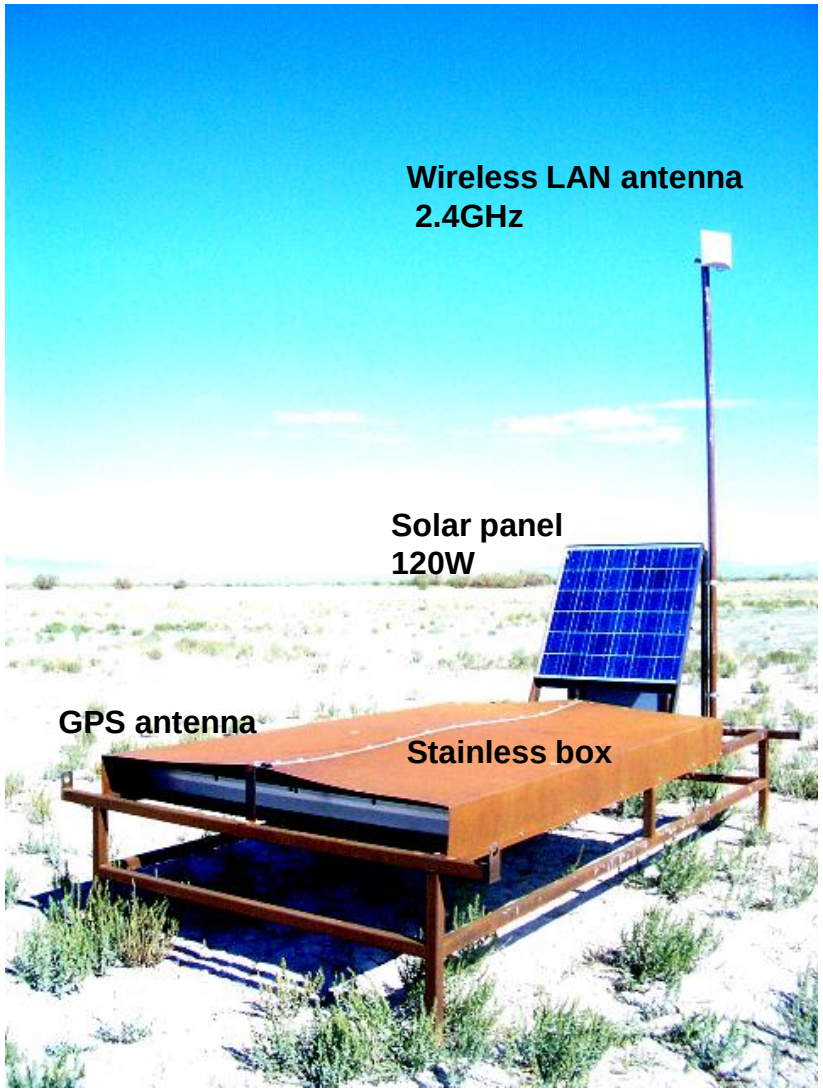
- The largest cosmic ray detector in the northern hemisphere
- Hybrid detector for UHECRs
  - Western desert in Utah, USA
- Surface detector
  - 507 plastic scintillation counter (AGASA type)
  - 1.2 km spacing, 678 km^2
  - Particle density
- Fluorescence detector
  - Three FD stations
  - Northern site was transferred from HiRes-I
  - Longitudinal development
- FD obs. started : Oct, 2007
- SD obs. started : May, 2008



Surface Detector

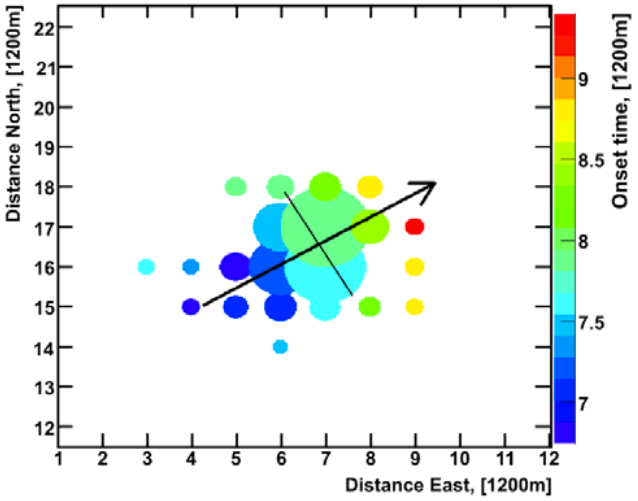


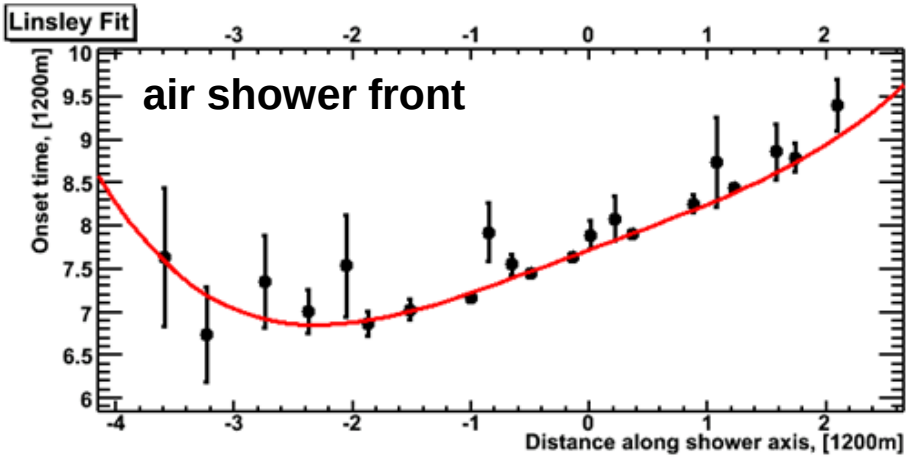


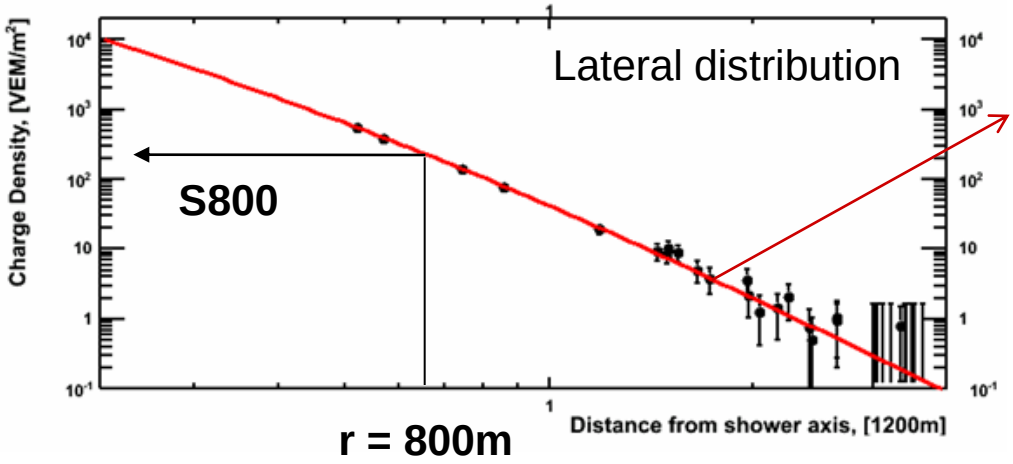


SD Event example

2008/Jun/25 - 19:45:52.588670 UTC







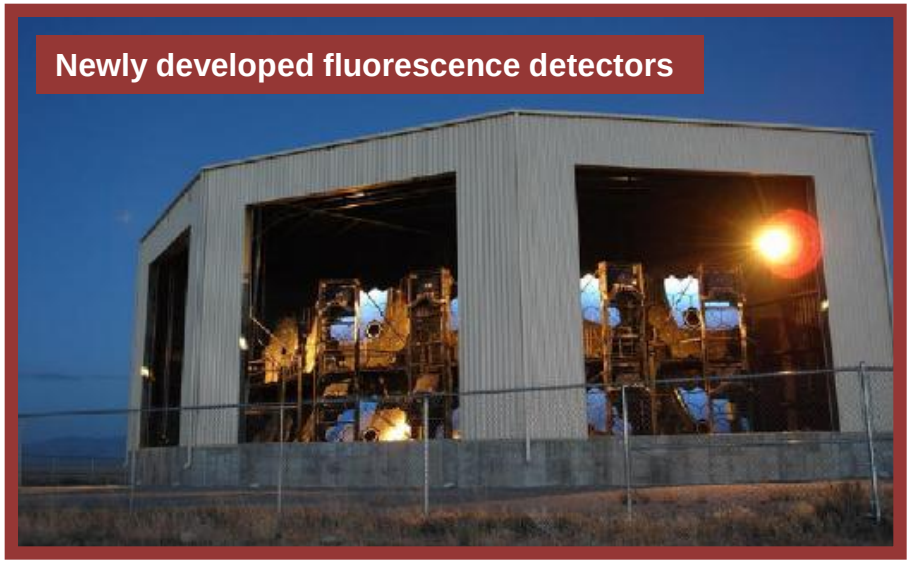
AGASA fitting function

$$\rho(r) \propto \left(\frac{r}{R_M}\right)^{-1.2} \left(1+\frac{r}{R_M}\right)^{-(\eta-1.2)} \left\{1+\left(\frac{r}{1000}\right)^2\right\}^{-0.6}$$

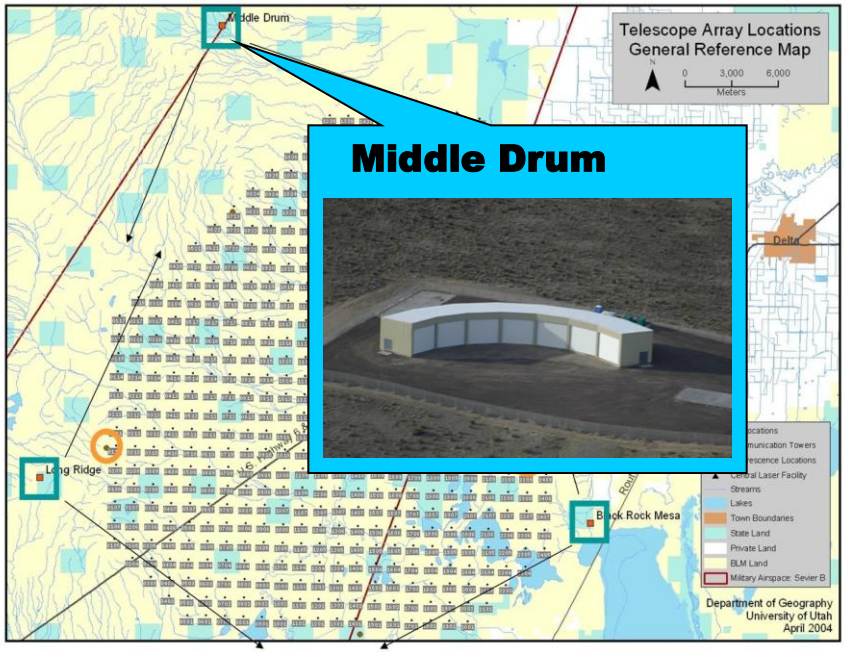
$$\eta = (3.97 \pm 0.13) - (1.79 \pm 0.62)\,(\sec\theta - 1)$$

S800 : energy estimator

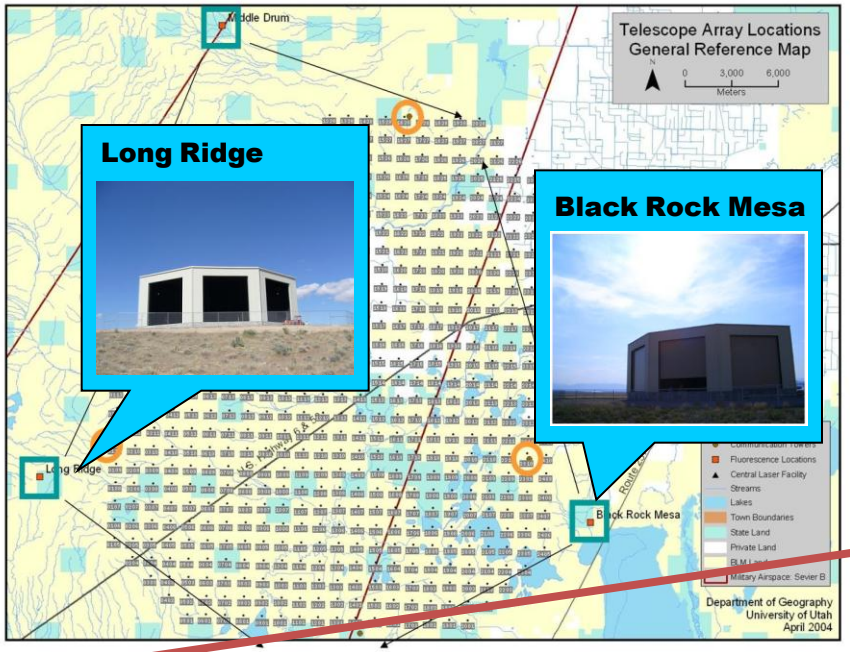
Fluorescence detector



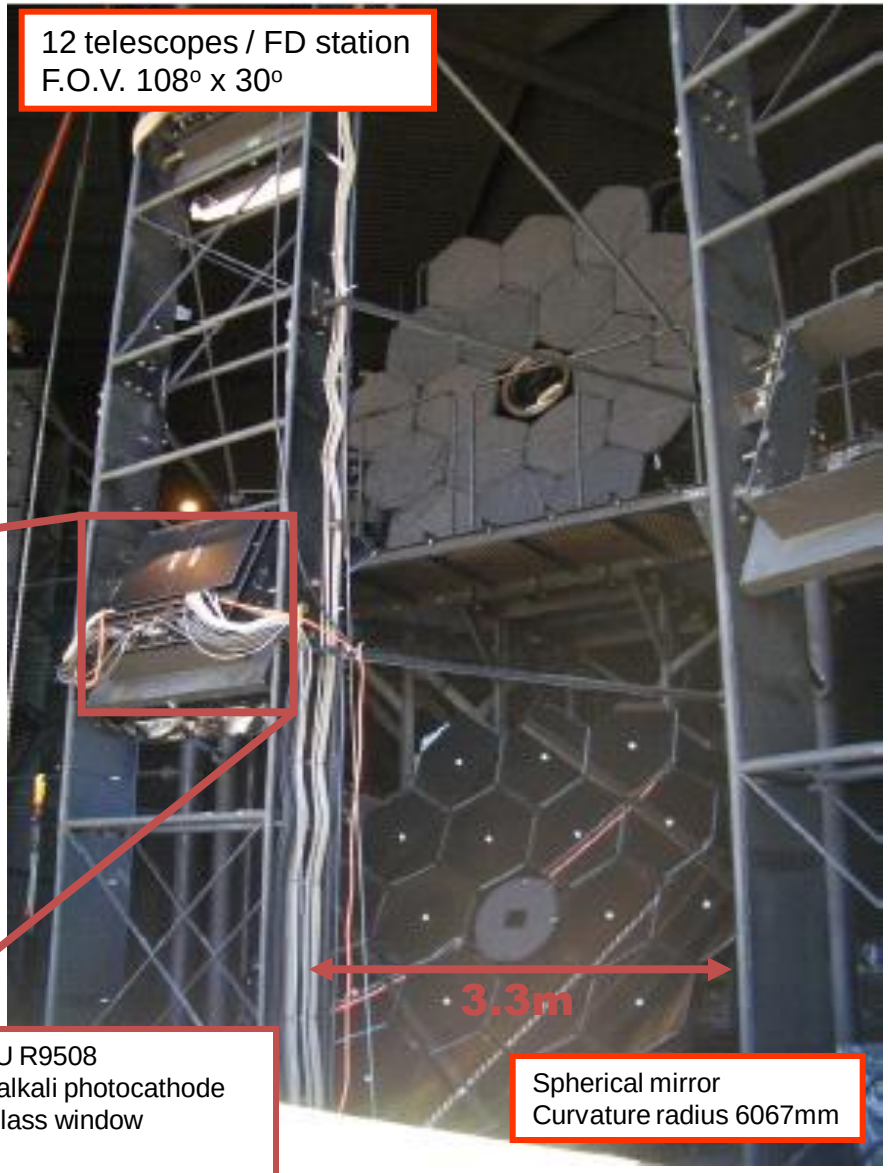
MD transferred from HiRes-I

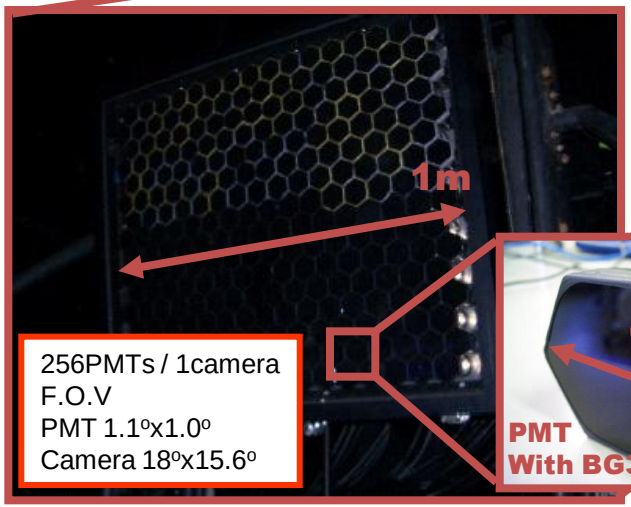


Fluorescence Detector (FD)



12 telescopes / FD station
F.O.V. 108º x 30º



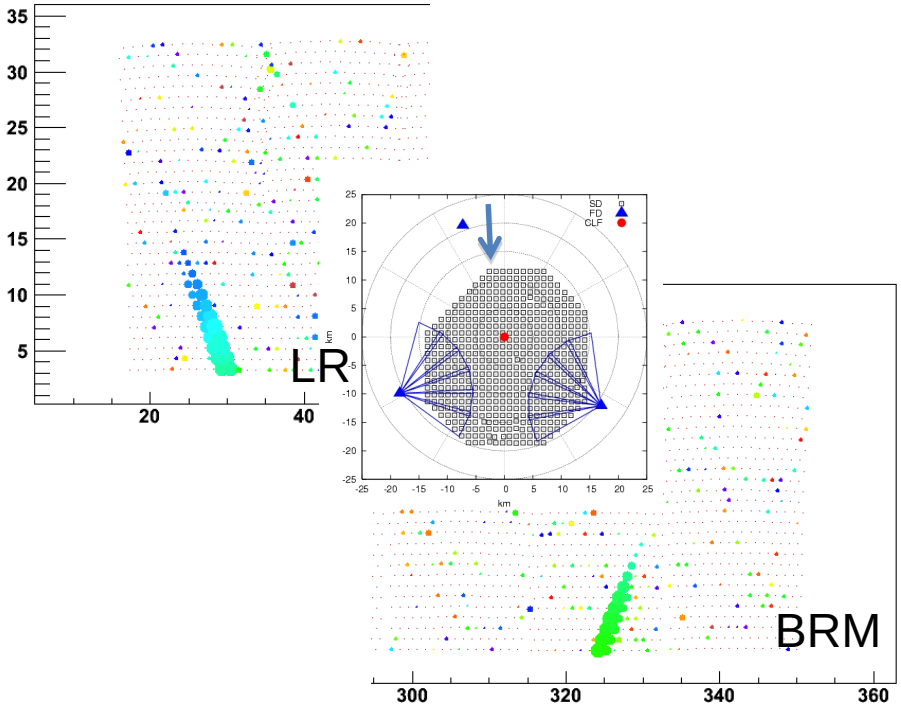


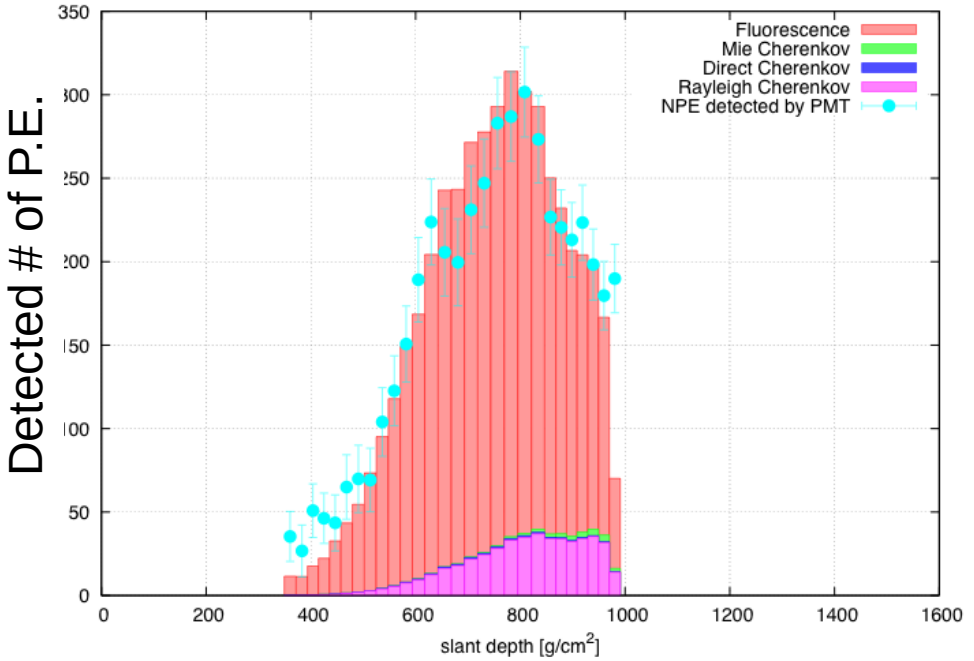
256PMTs / 1camera
F.O.V
PMT 1.1ºx1.0º
Camera 18ºx15.6º

HAMAMATSU R9508
Hexagonal bialkali photocathode
Borosilicate glass window
8dynodes
Q.E.:30%(350nm)
Gain:8.0x10^4(800V)

Spherical mirror
Curvature radius 6067mm

TA FD Stereo Event





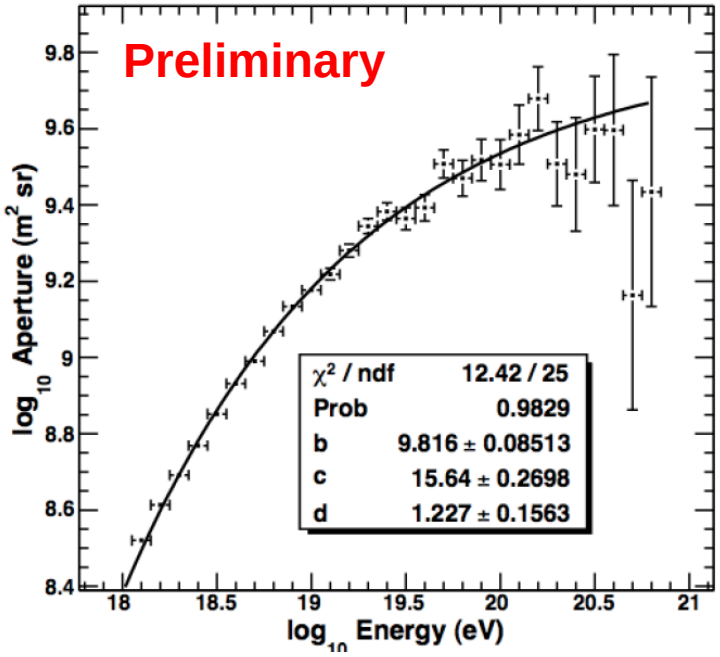
Date	log(E/eV)	Xmax	zenith	azimuth	Xcore	Ycore
2008/09/04	19.71	890 g/cm^2	44.3^o	-3.0^o	-3.1	14.2

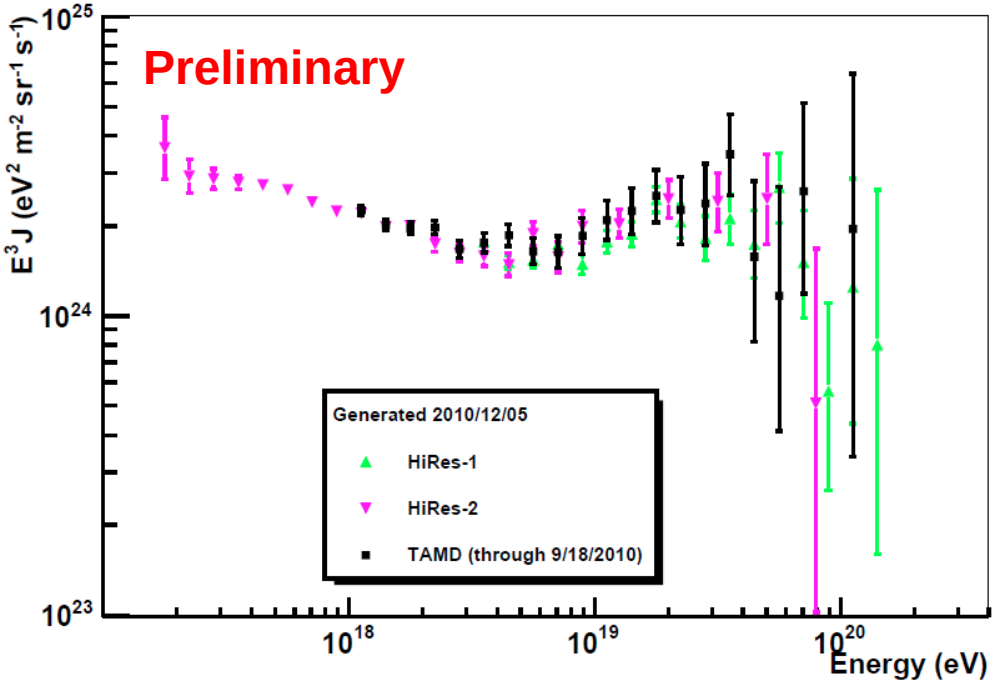
TA Results

- Energy spectrum
  - TA MD mono
  - TA Hybrid
  - TA SD
- Mass Composition
  - TA FD Stereo

TA MD mono energy spectrum

- Data: 2007/Dec~2008/Sep
- MC: CORSIKA/QGSJET events
- ~1/2 HiRes





TA FD & SD Hybrid

TA Hybrid analysis

- Using signal arrival timing of FD and SD
- Angular resolution ~ 1.1deg (mono : ~4.7deg)

Using SD aperture

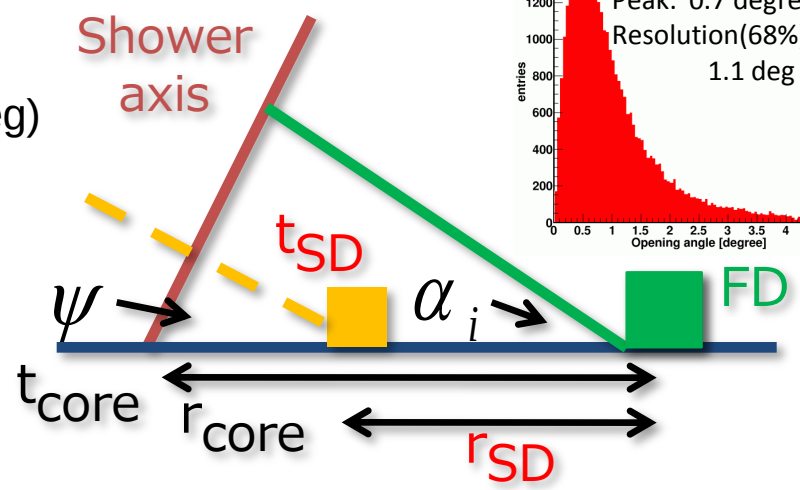
Constant above 10^{19}eV

Data set: BR + LR

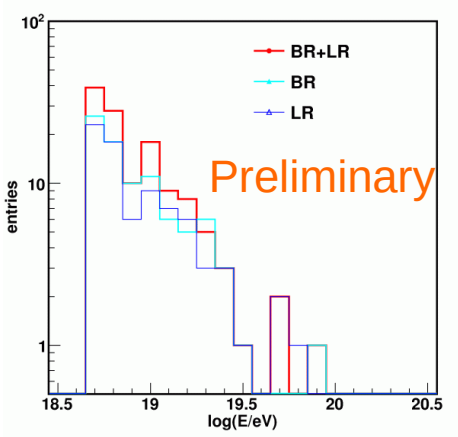
May/27/2008 – Sep/28/2009 (~1.5 years)

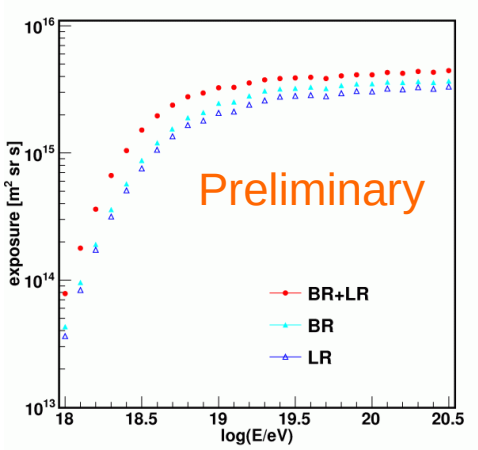
MC: Shower simulation : COSMOS

SD detector response : GEANT4

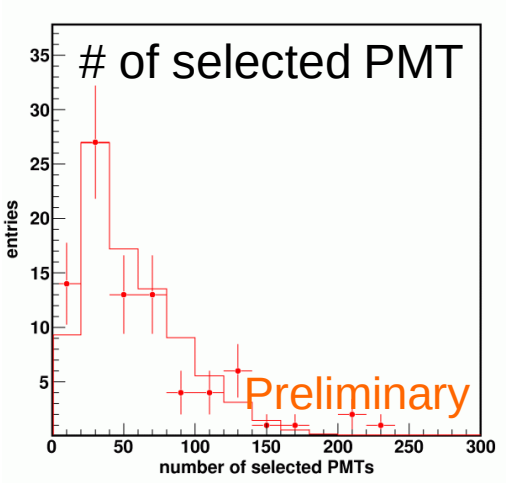


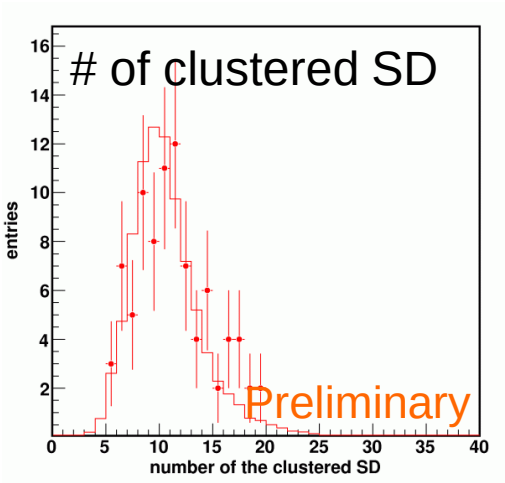
Primary energy	10^{18}eV ~ $10^{20.5}$eV with $E^{-3.1}$
Zenith angle	cosθ=0.65 (≒50degree) ~ 1
Primary particle	Proton
Thinning ratio	10^{-4} (≤10^{20}eV), 10^{-5}(> 10^{20}eV)
Interaction model	QGSJET II (> 80GeV) DPMJET III (<80GeV)
Cut threshold	100keV

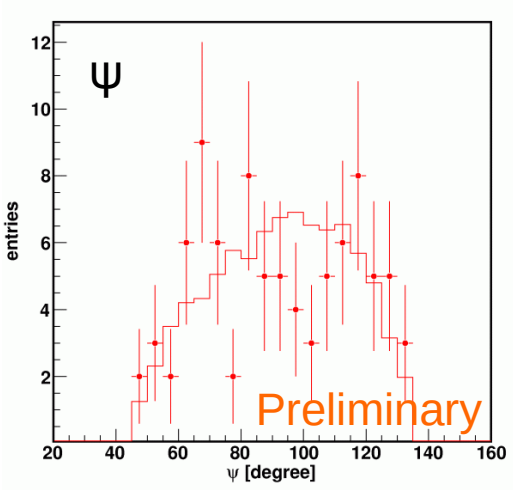


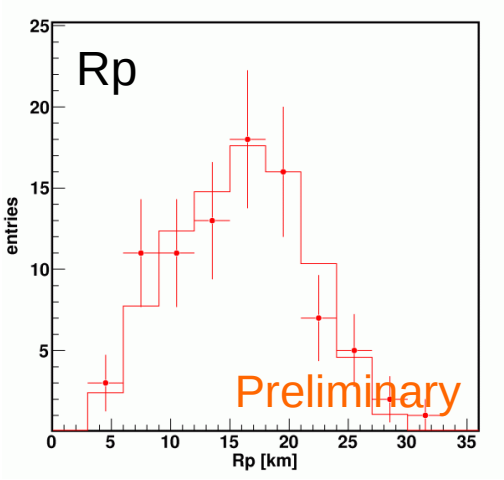


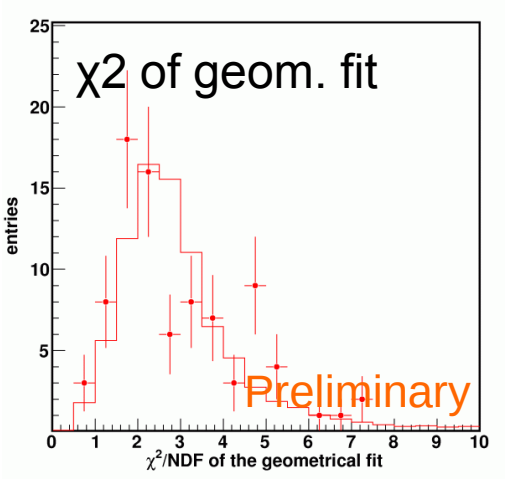
TA-Hybrid: Data MC Comparison

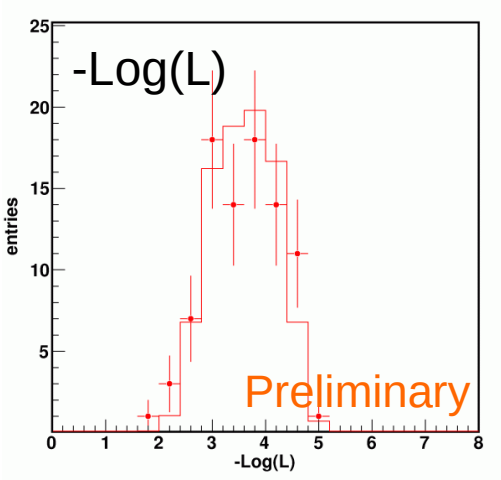




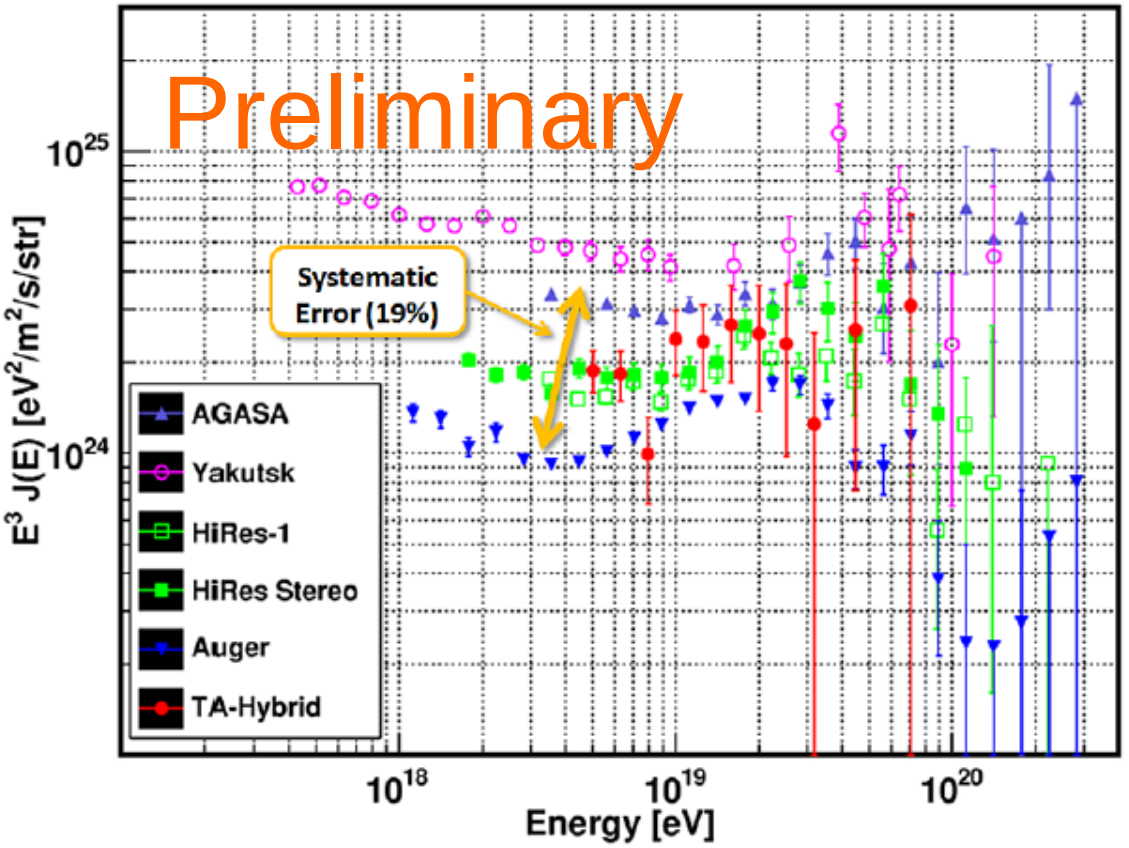








TA-Hybrid : Energy Spectrum



Systematic errors

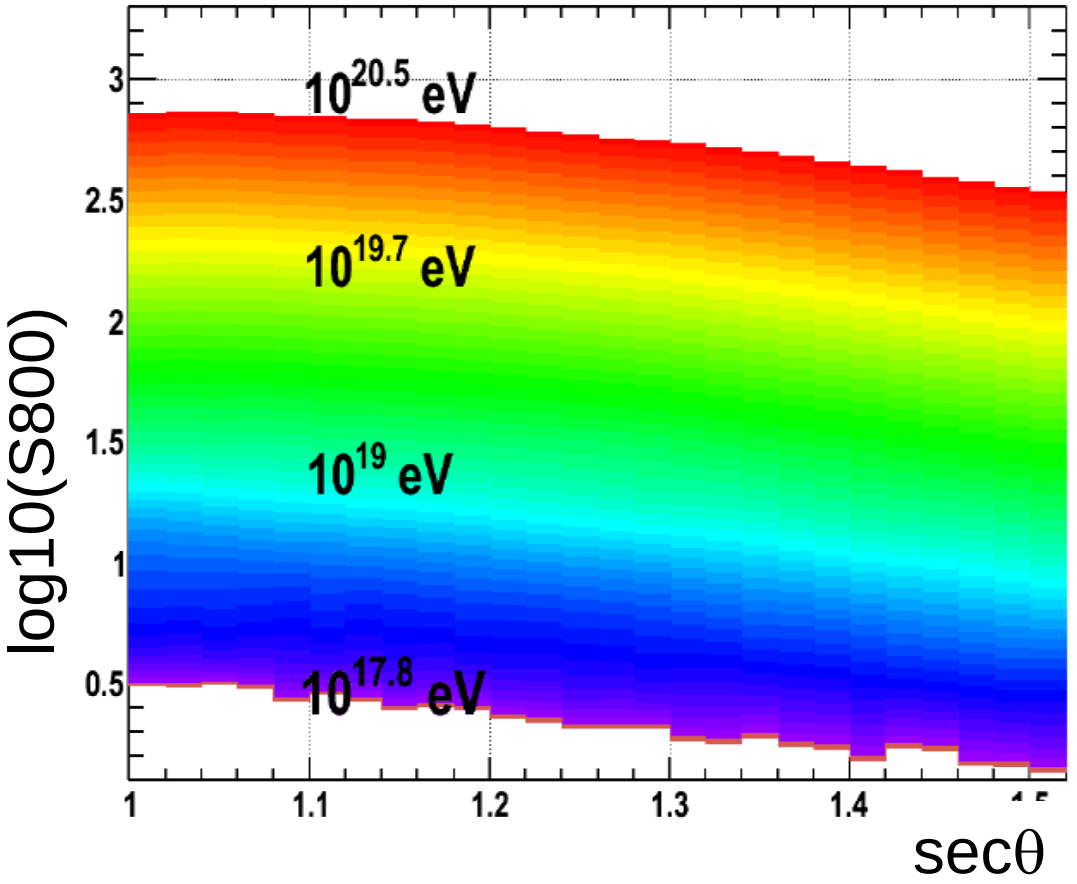
Item	Systematic error
Fluorescence yield	12%
Detector	10%
Atmosphere	11%
Primary particle mass	5%
MC correction	3%
Total	19%

SD Analysis

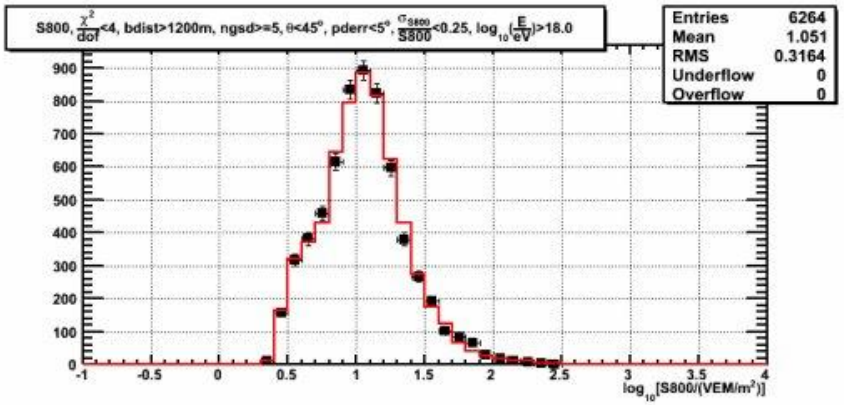
- Good data fits:
  - χ^2/d.o.f.: > 4.0
  - Pointing direction resolution: < 5^o
  - Fractional S800 uncertainty: < 25%
- Good shower geometry:
  - Border Cut > 1200m
  - Zenith Angle Cut: < 45^o
- May/2008 –Feb/2010
- **1.75 years, 6264 events** (May/2008 – Feb/2010)

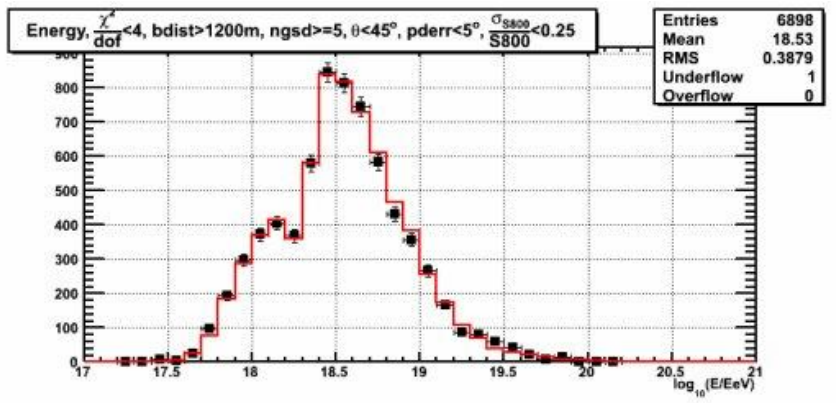
SD Analysis: Energy Determination

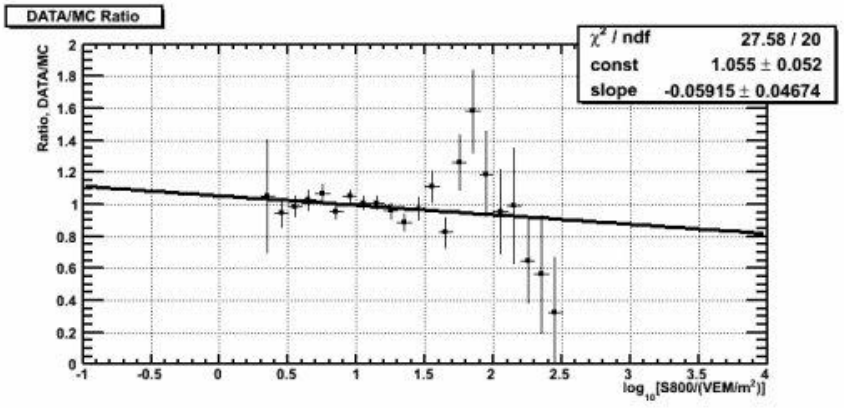
- Energy determination table is constructed from the fitting results of the Monte Carlo.
- First estimation of the event energy is done by interpolating between S_{800} vs. secθ isoclines.

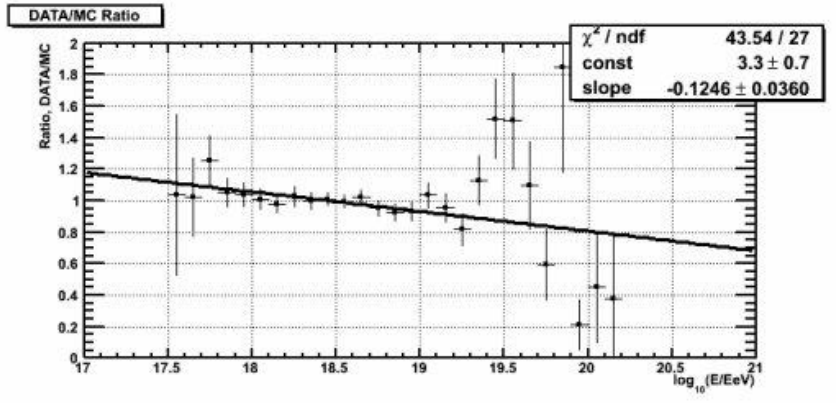


SD Analysis: Data/MC Comparisons



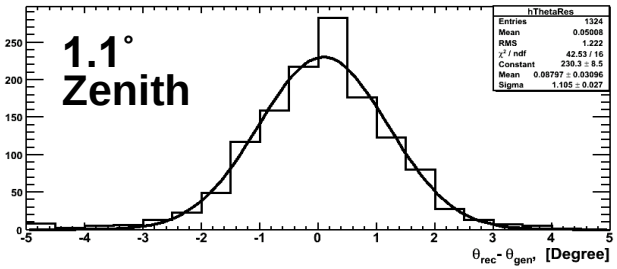


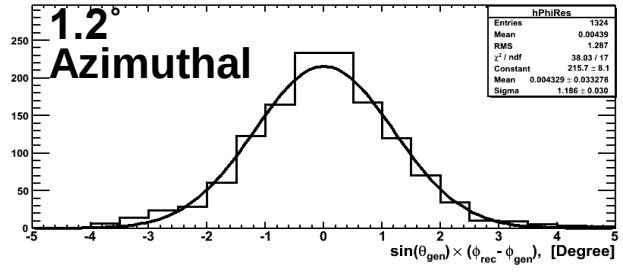


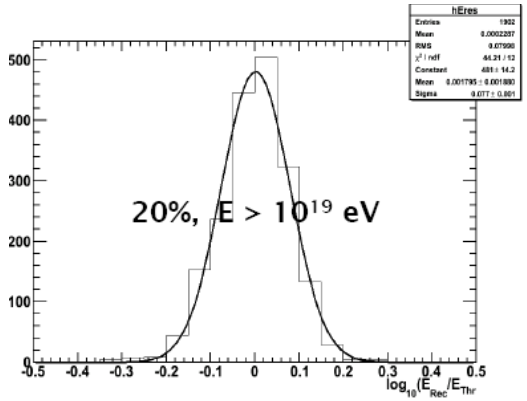


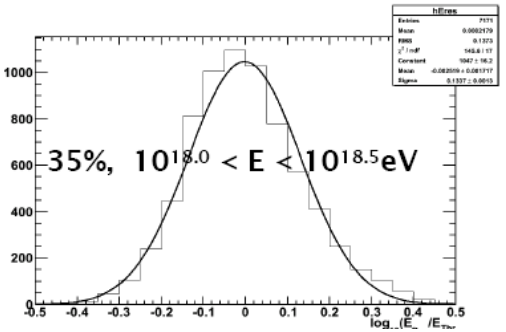
S_{800} **Energy**

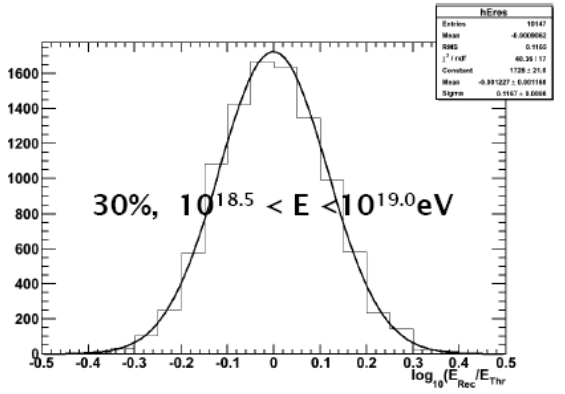
SD Analysis

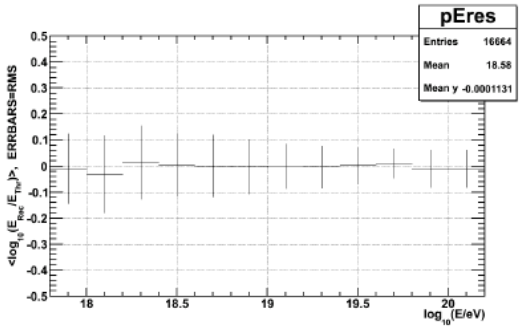

1.1°
Zenith
hThetaRes
Entries 1324
Mean 0.05008
RMS 1.222
χ² / ndf 42.53 / 16
Constant 230.3 ± 8.5
Mean 0.08797 ± 0.03096
Sigma 1.105 ± 0.027
θrec - θgen, [Degree]


1.2°
Azimuthal
hPhiRes
Entries 1324
Mean 0.00439
RMS 1.287
χ² / ndf 38.03 / 17
Constant 215.7 ± 8.1
Mean 0.004329 ± 0.033278
Sigma 1.186 ± 0.030
sin(θgen) × (φrec - φgen), [Degree]

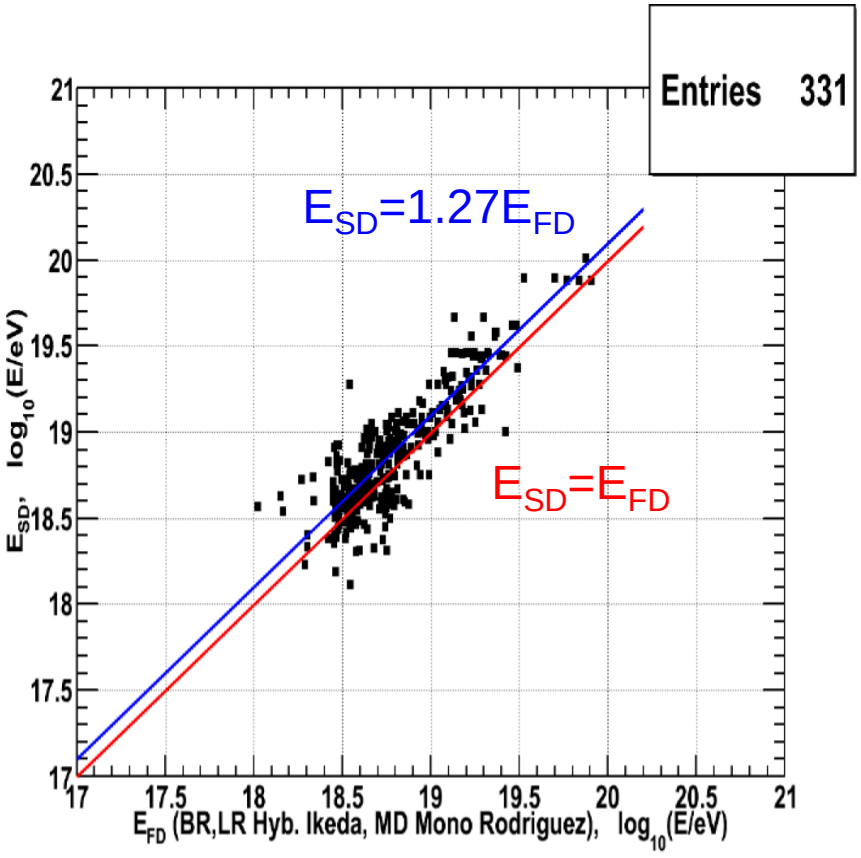

hEres
Entries 1902
Mean 0.0002237
RMS 0.07996
χ² / ndf 44.21 / 12
Constant 481 ± 14.2
Mean 0.001795 ± 0.001880
Sigma 0.077 ± 0.001
20%, E > 10^19 eV
log10(ERec/EThr)


hEres
35%, 10^18.0 < E < 10^18.5eV
log10(ERec/EThr)


hEres
Entries 10147
Mean -0.0006062
RMS 0.1162
χ² / ndf 40.35 / 17
Constant 1728 ± 21.8
Mean -0.001227 ± 0.001168
Sigma 0.1167 ± 0.0008
30%, 10^18.5 < E < 10^19.0eV
log10(ERec/EThr)

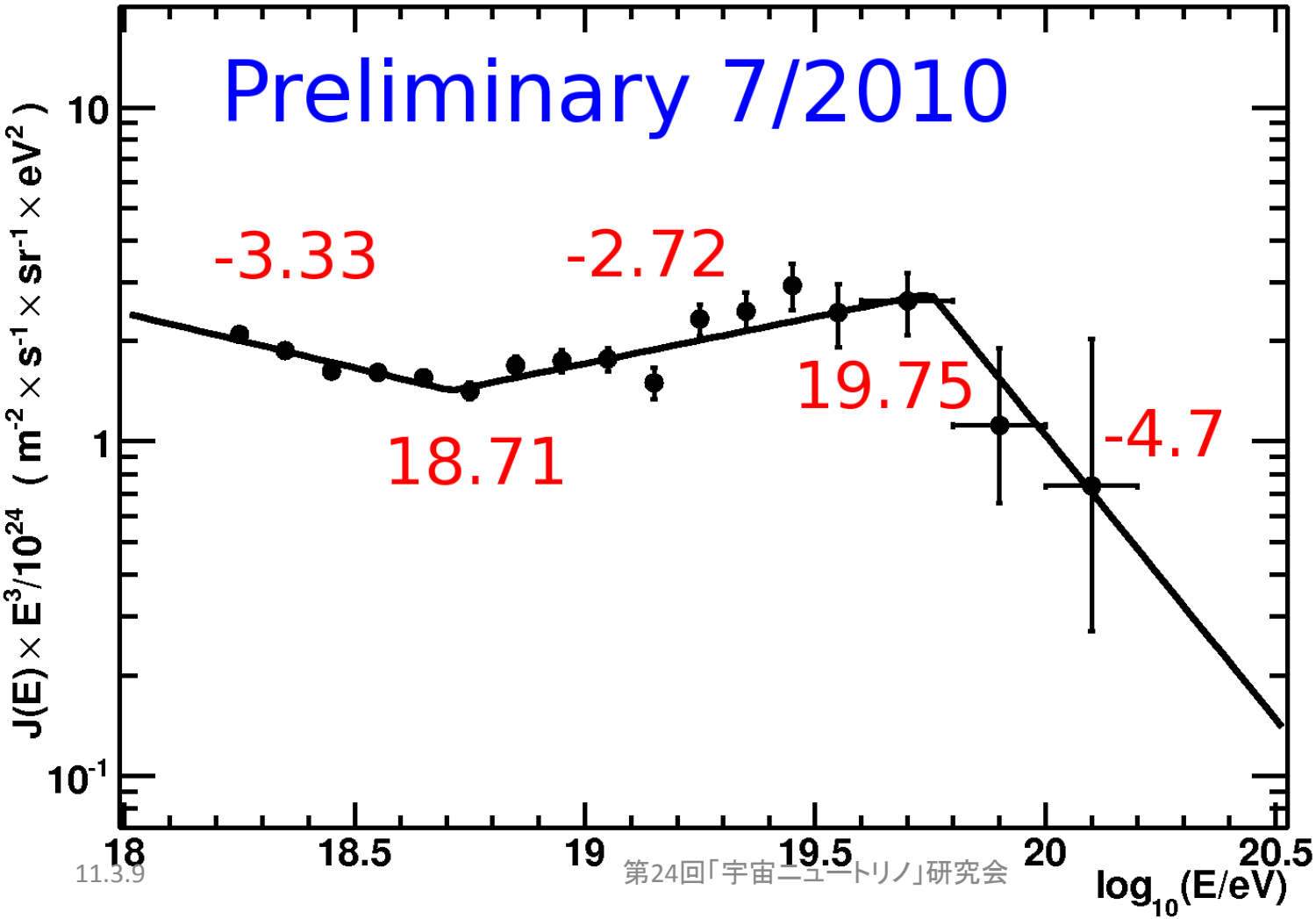

pEres
Entries 16664
Mean 18.58
Mean y -0.0001131
<log10(ERec/EThr)>, ERRBARS=RMS
log10(E/eV)

SD Analysis: Energy Scale

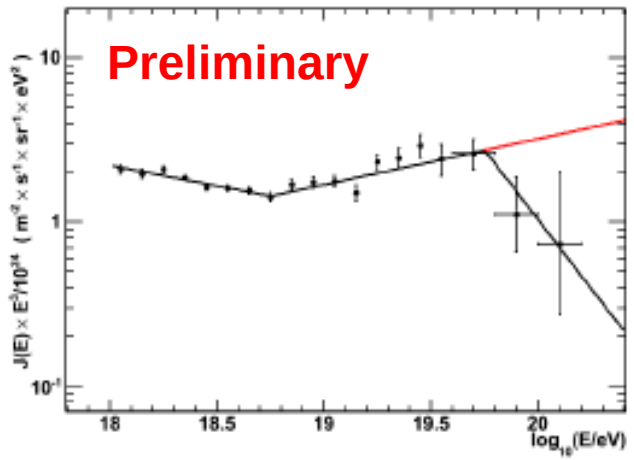


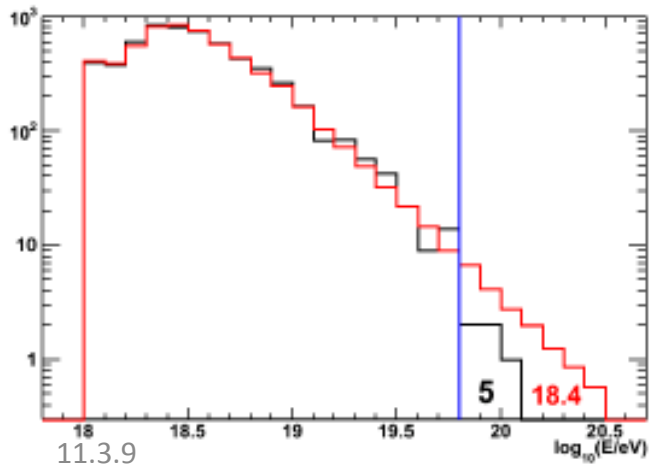
- Energy scale is determined experimentally by FD without referring to MC.
- Set SD energy scale to FD energy scale using well-reconstructed events detected by both detectors.
- **27% renormalization.**

TA Surface Detector Energy Spectrum



SD Energy Spectrum: GZK Feature



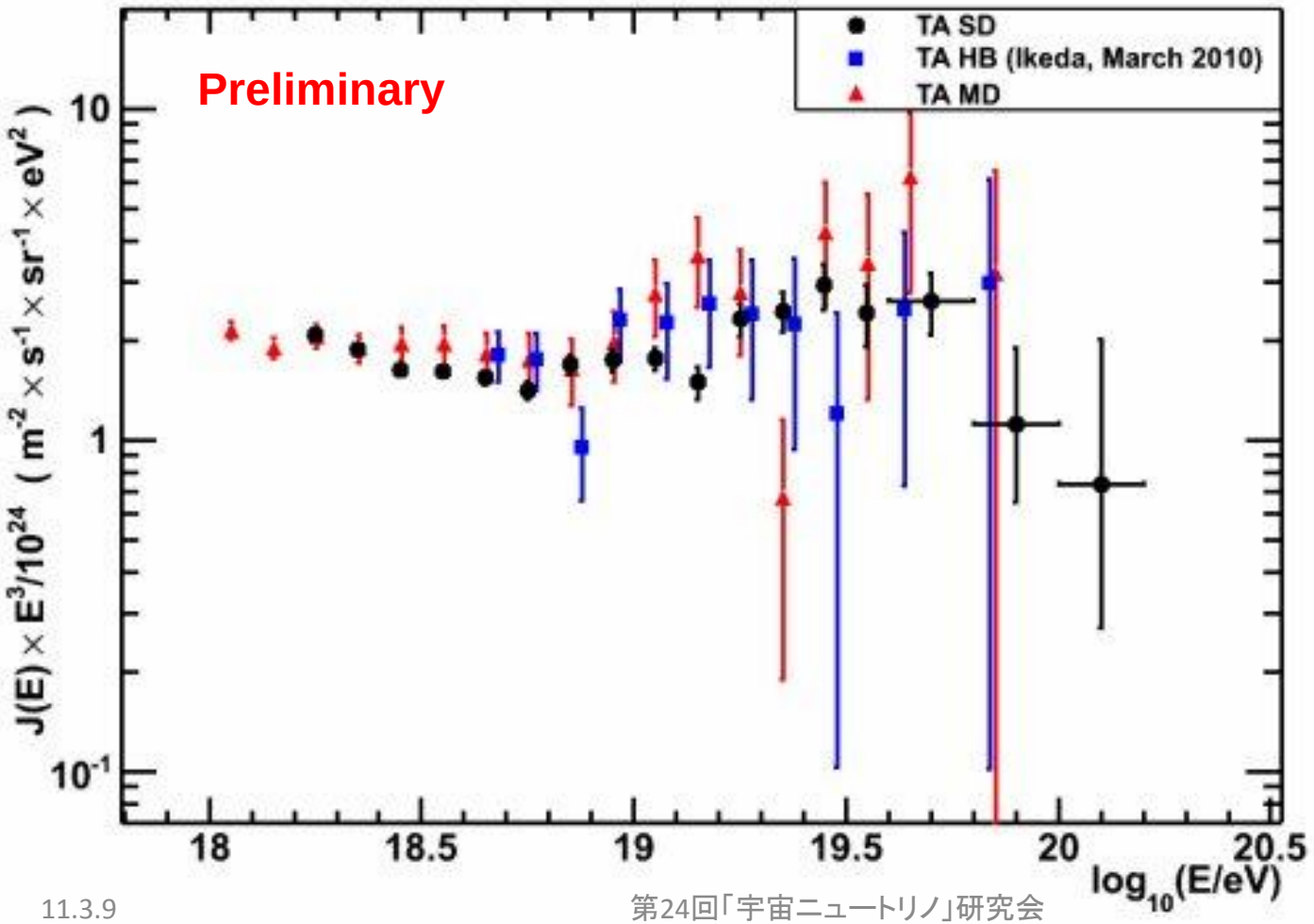


- Assume no GZK cutoff and extend the broken power law fit beyond the break
- Apply this extended flux formula to the actual TASD exposure, find the number of expected events and compare it to the number of events observed in $\log_{10}$E bins after $10^{19.8}$eV bin:
  - $N_{EXPECT} = 18.4$
  - $N_{OBSERVE} = 5$

$$\text{PROB} = \sum_{i=0}^{5} Poisson(\mu = 18.4; i) = 2.41 \times 10^{-4}$$

(3.5σ)

SD Energy Spectrum: Comparison

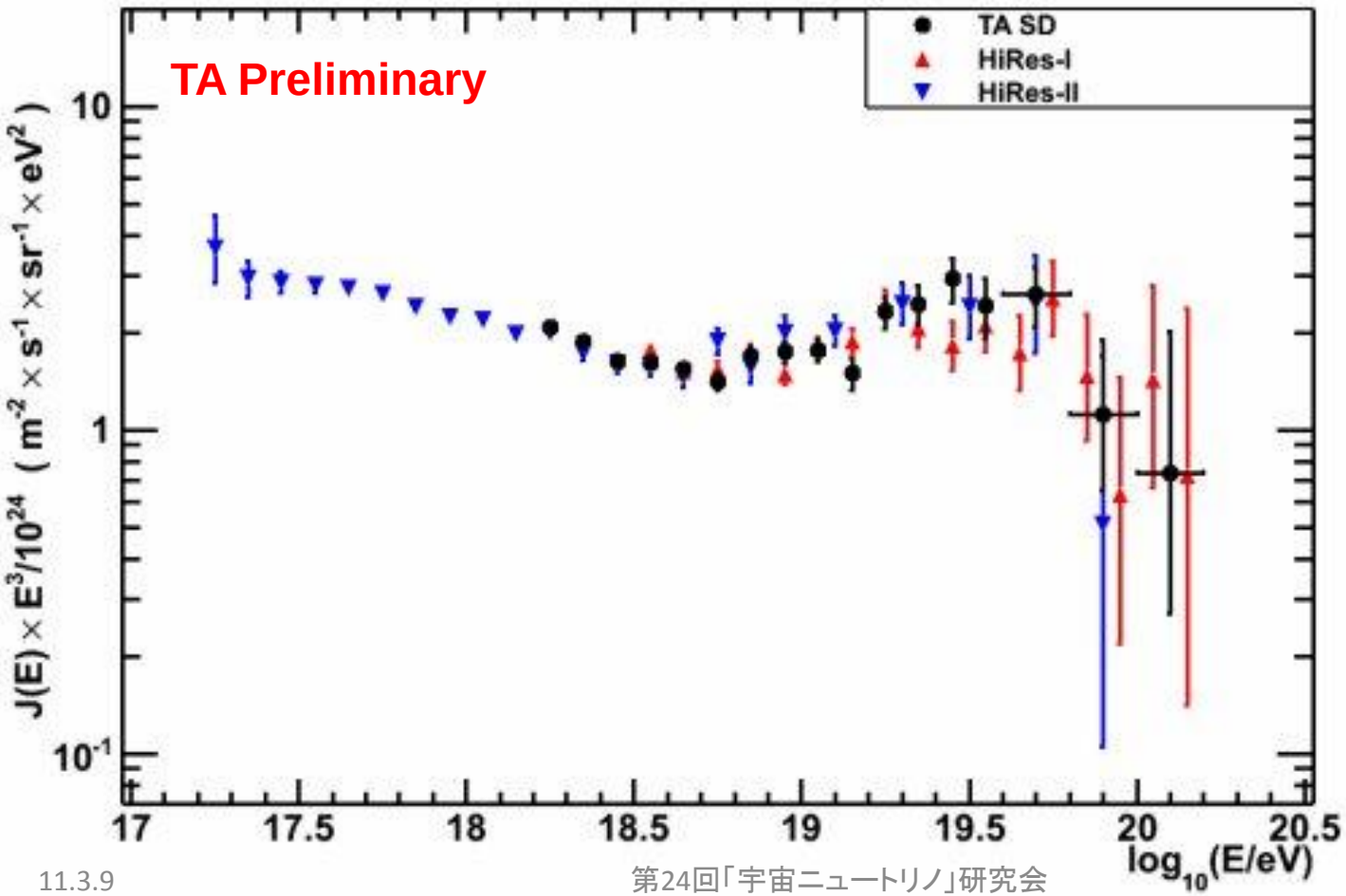


● TA SD

■ TA Hybrid

▲ TA MD

SD Energy Spectrum: Comparison

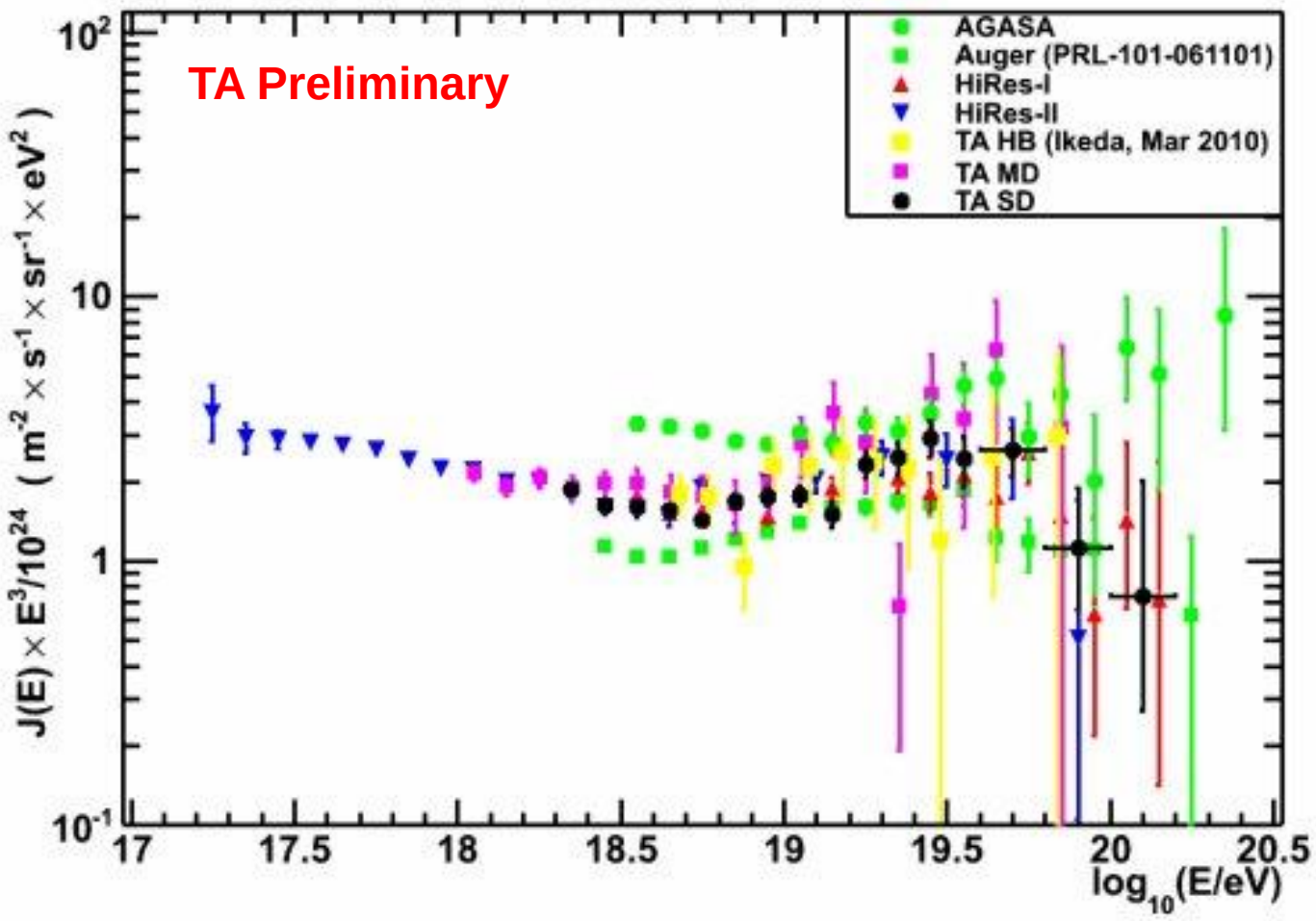


● TA SD

▲ HiRes-I

▼ HiRes-II

SD Energy Spectrum: Comparison



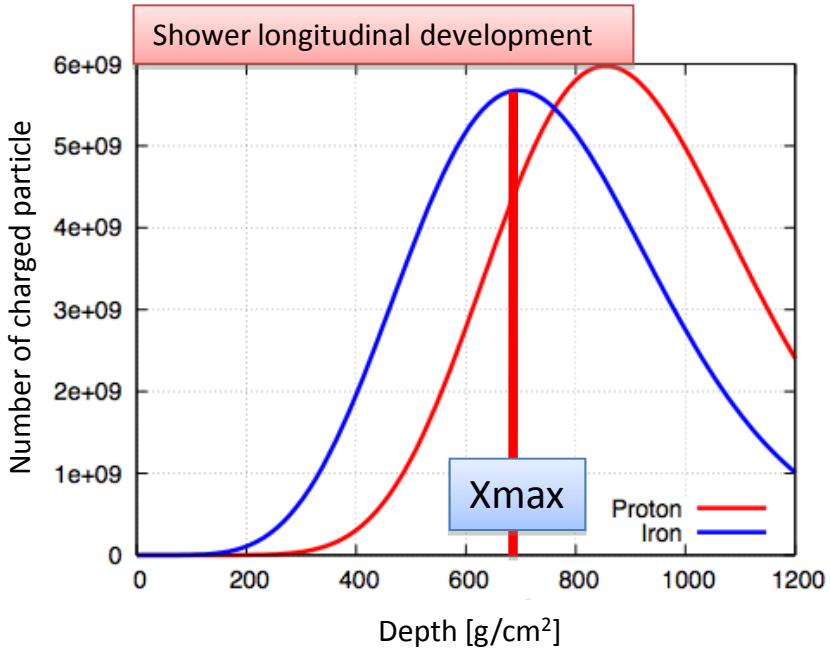
AGASA
Auger
HiRes-I
HiRes-II
TA Hybrid
TA MD
TA SD

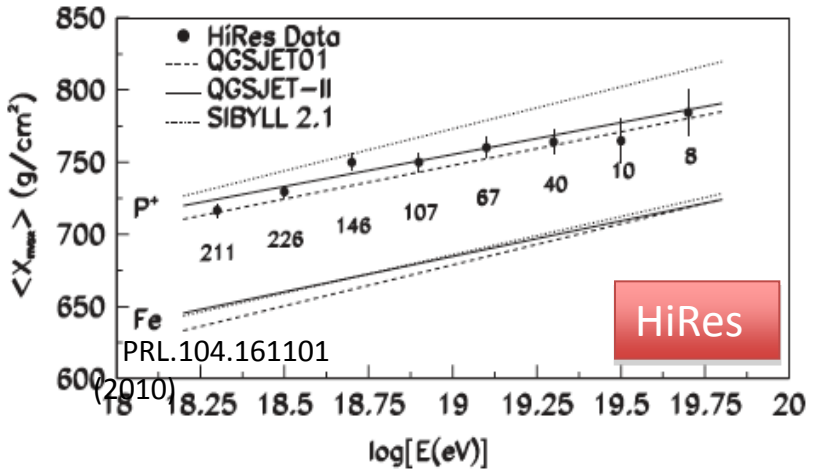
TA Results

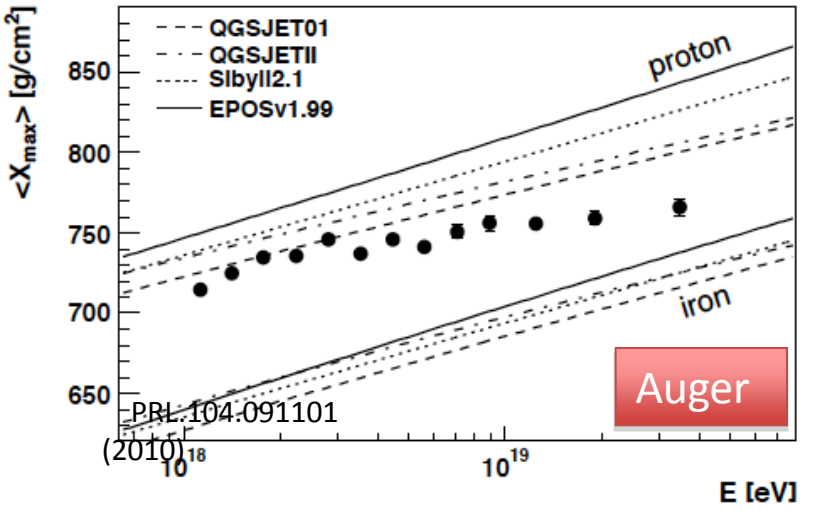
- Energy spectrum
  - TA MD mono
  - TA FD Hybrid
  - TA SD
- Mass Composition
  - TA FD Stereo

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.





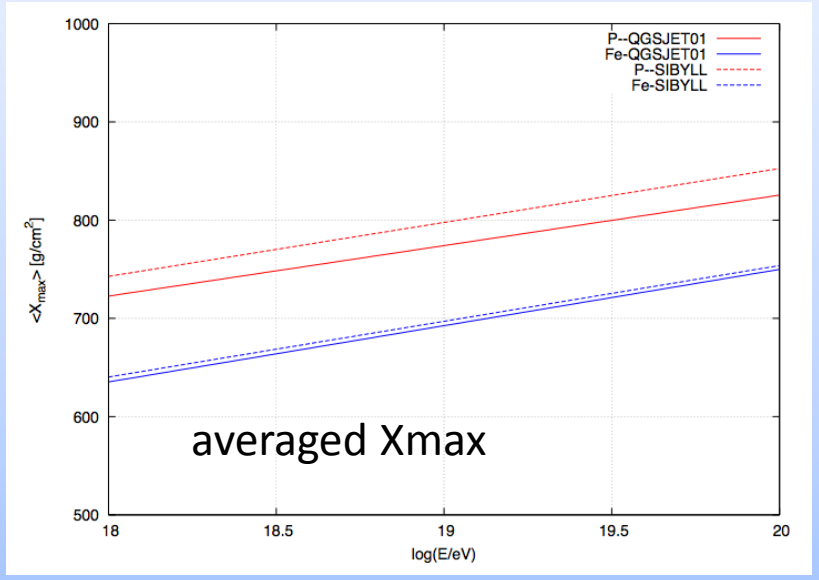


Air Shower Monte Carlo

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



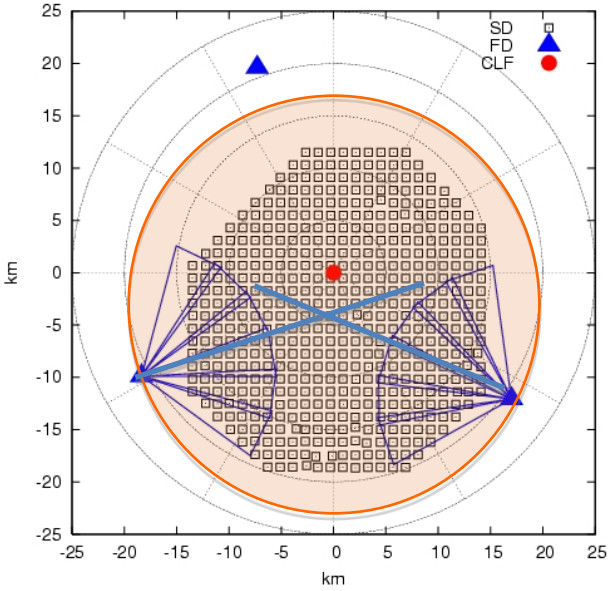
Detector Monte Carlo

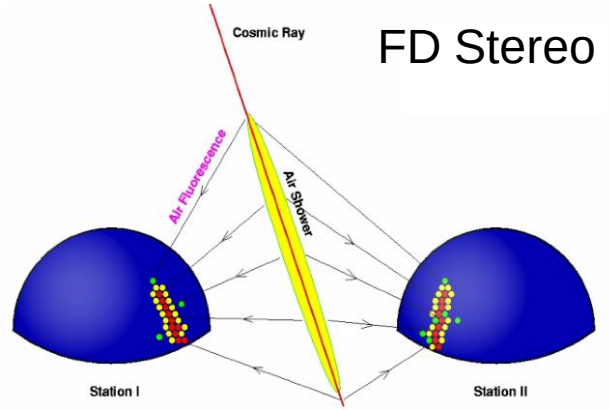
Detector simulation

- 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)





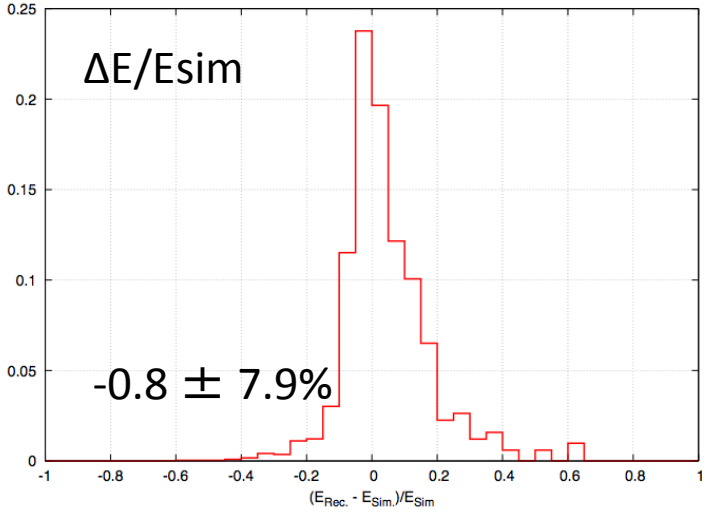
FD Stereo reconstruction

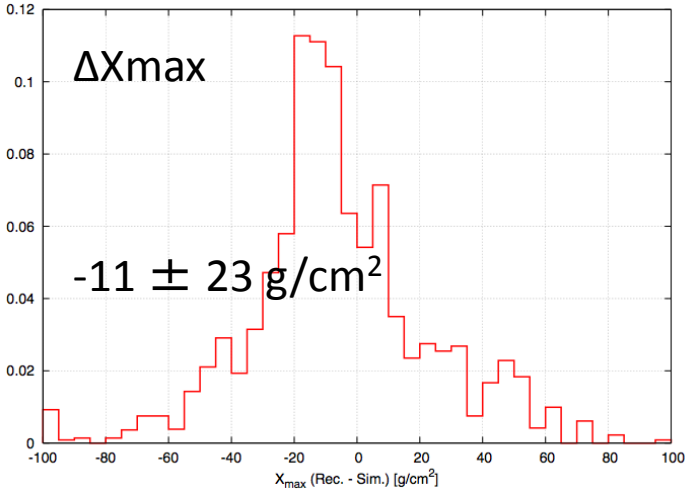
Determination of shower axis by stereo reconstruction is much better than monocular reconstruction.

Opening angle by monocular reconstruction is ～5deg(1σ).

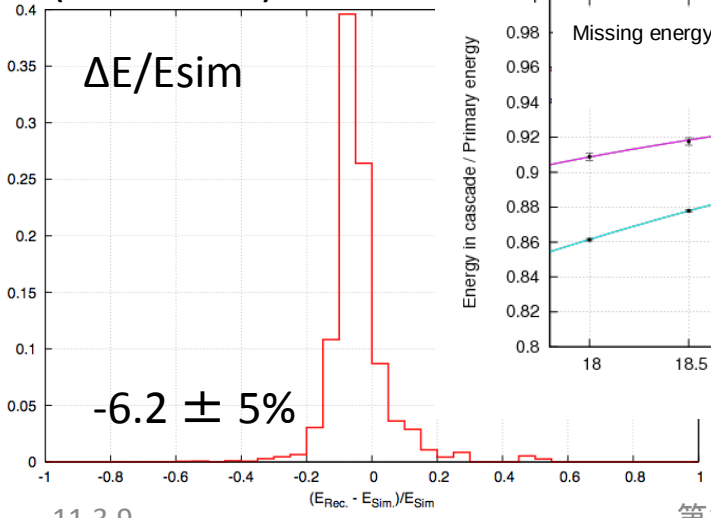
TA-FD Stereo analysis @$10^{19\text{-}19.2}$eV

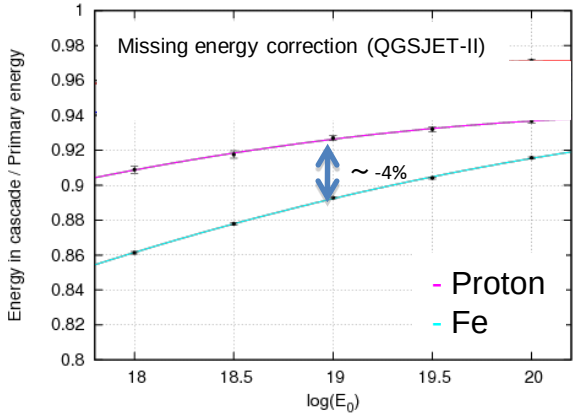
Proton (QGSJET01)

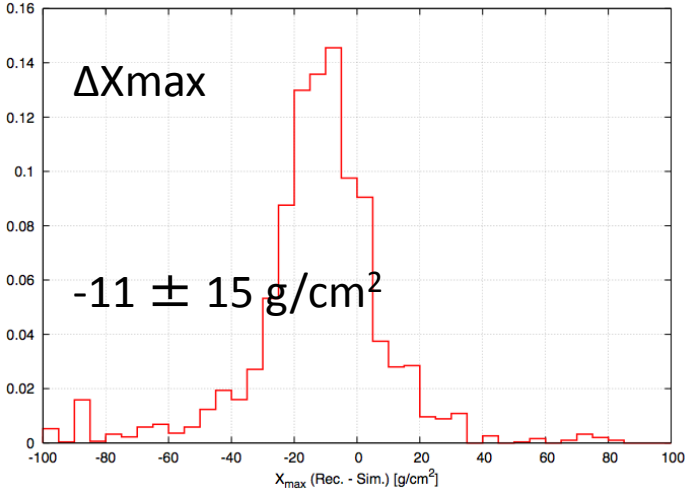




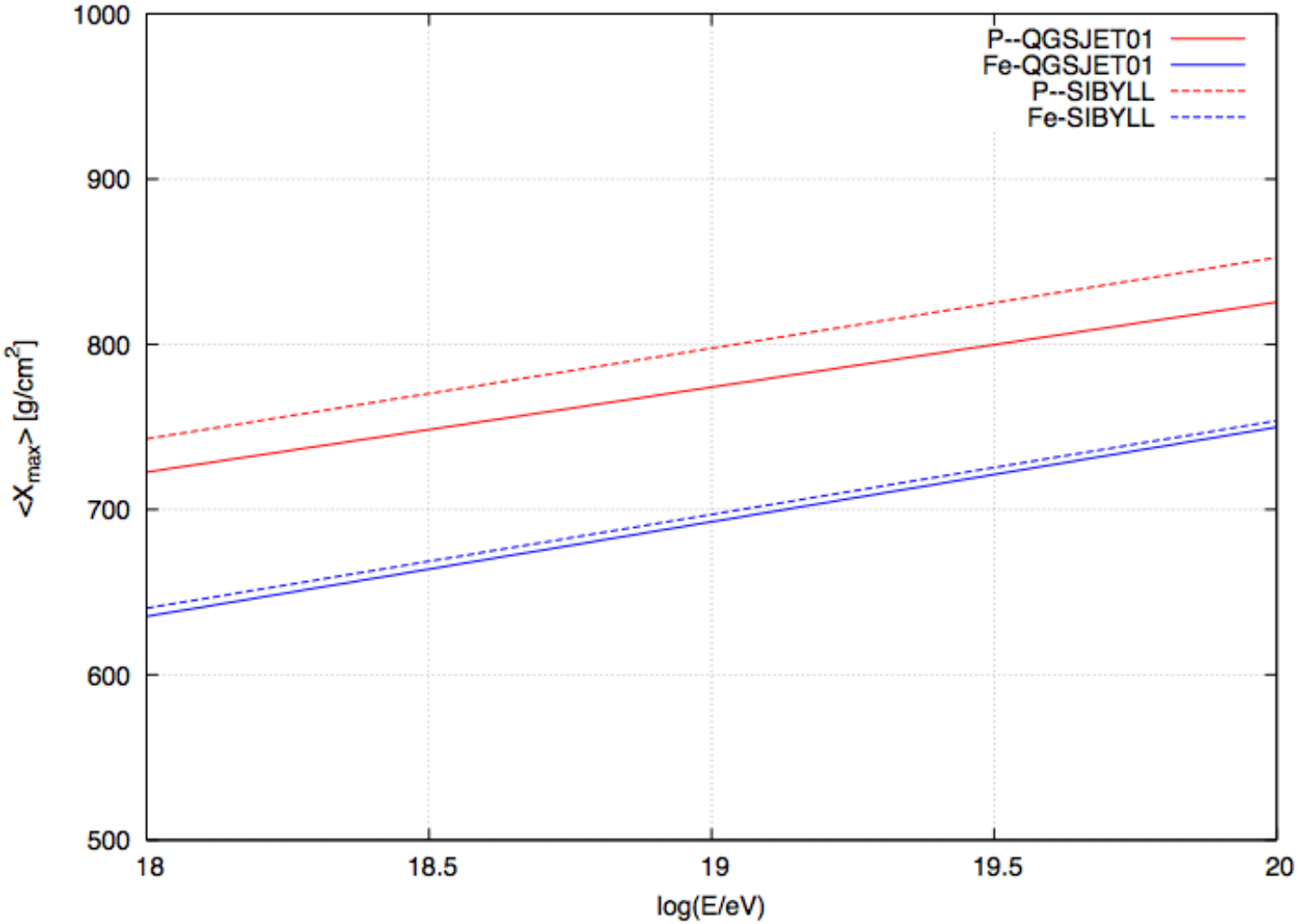
Iron (QGSJET01)



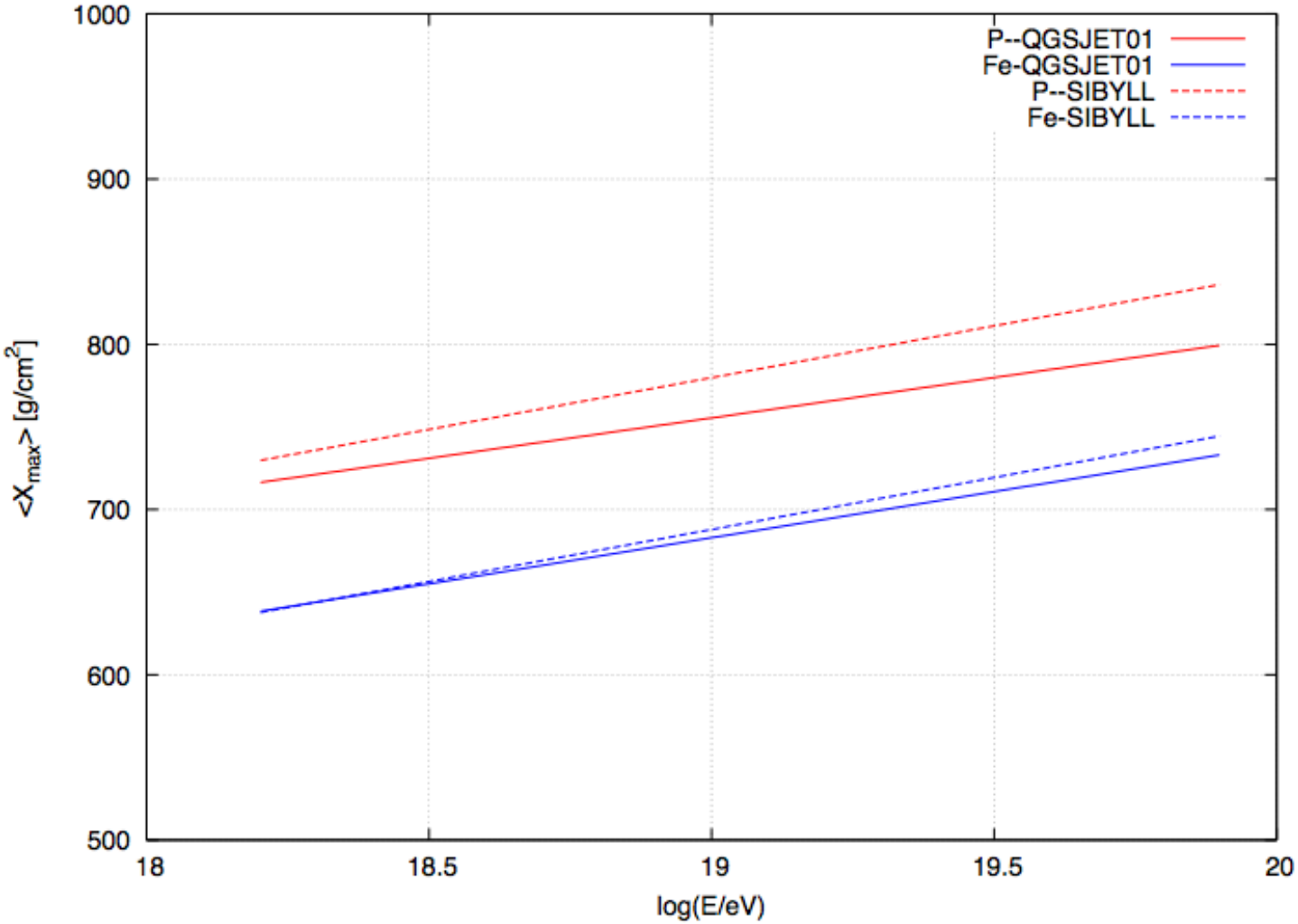




Prediction of Averaged Xmax
CORSIKA

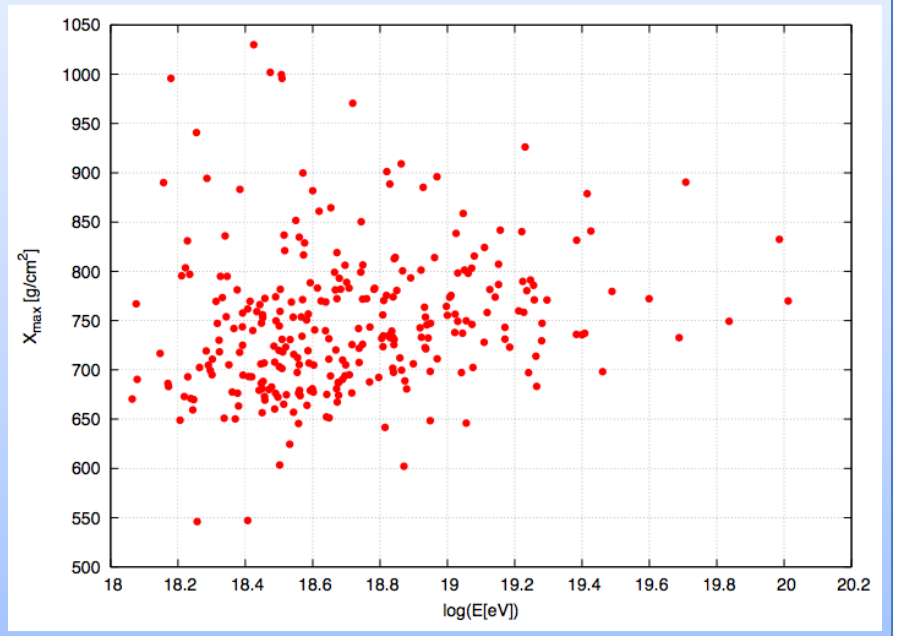


Prediction of Averaged Xmax CORSIKA with Detector MC



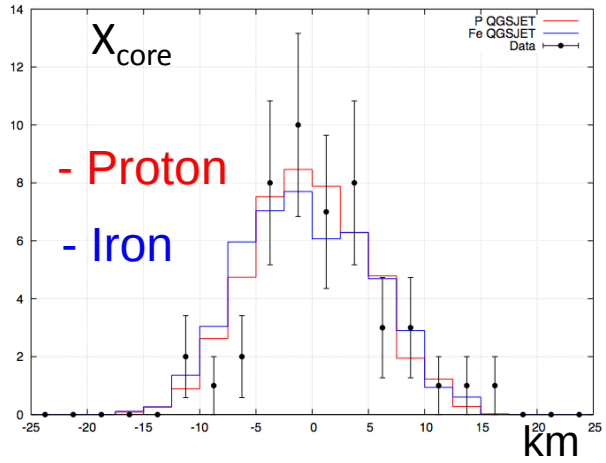
MC/Data Comparison

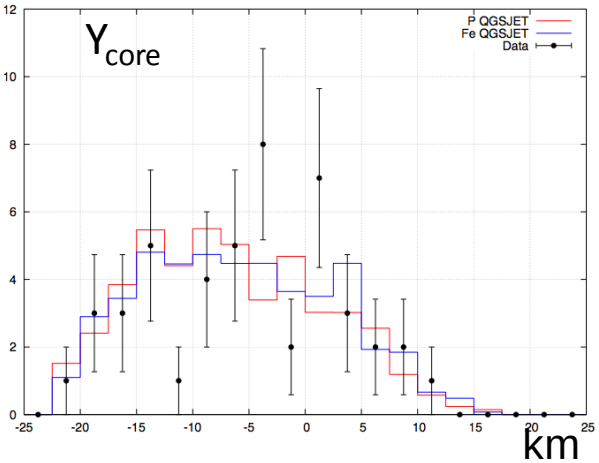
- Data set: 2007/Nov – 2010/Sep
- FD Stereo events
- Comparison with MC
- Quality Cut
  - Xmax observed
  - Zenith < 60^{o}
  - Core within 19.6km circle
  - Energy > $10^{18.0}$eV
  - χ^2 cut

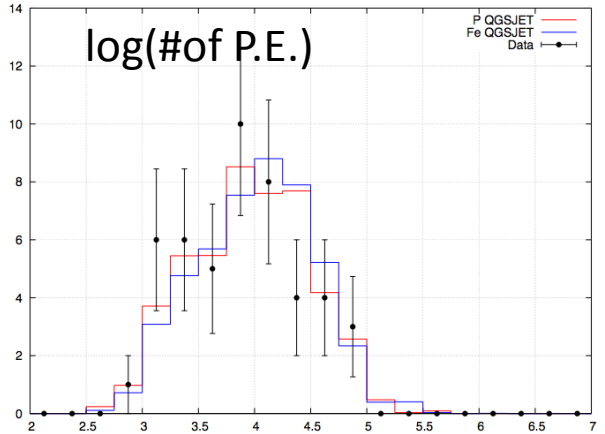


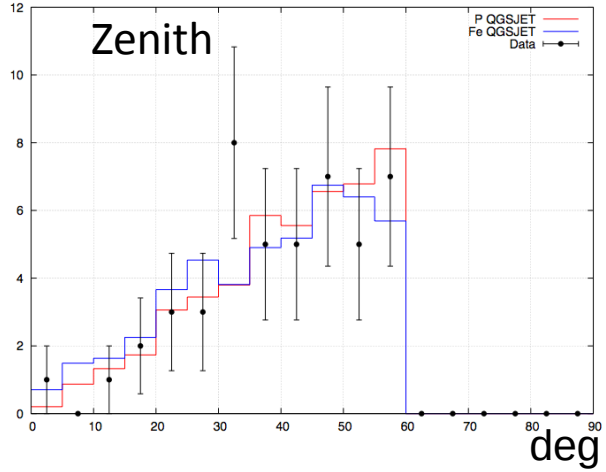
MC/Data Comparison (QGSJET01)

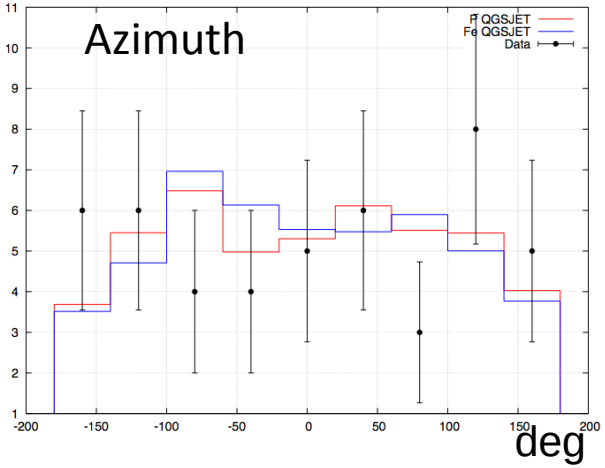
$10^{18.8\text{-}19.0}$eV (47events)

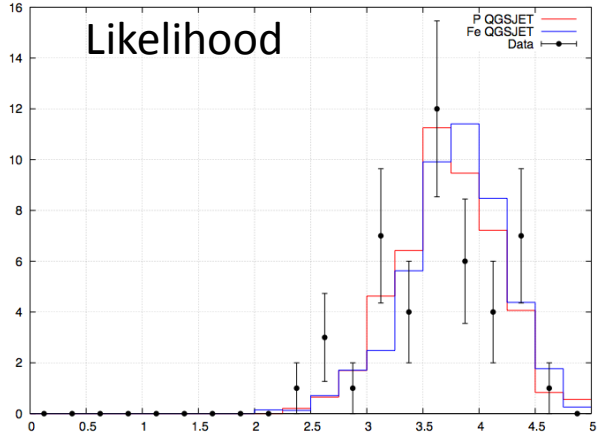




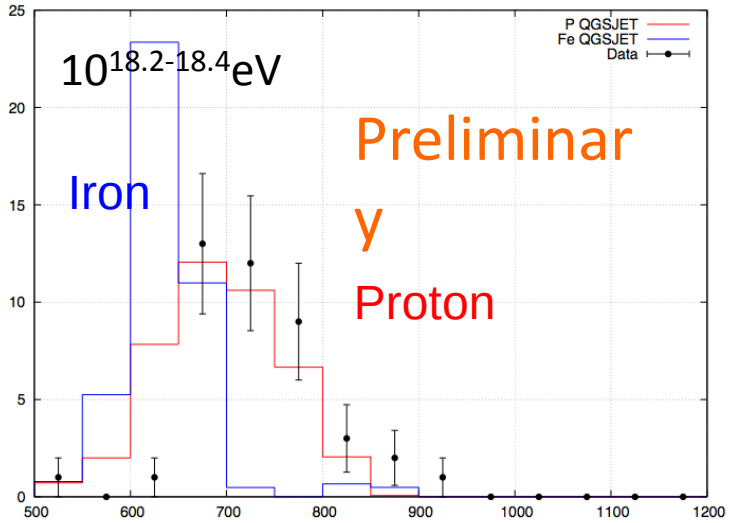


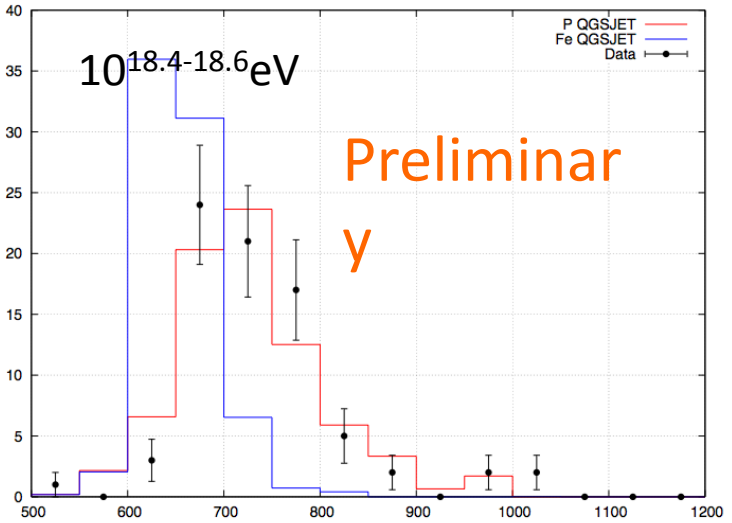


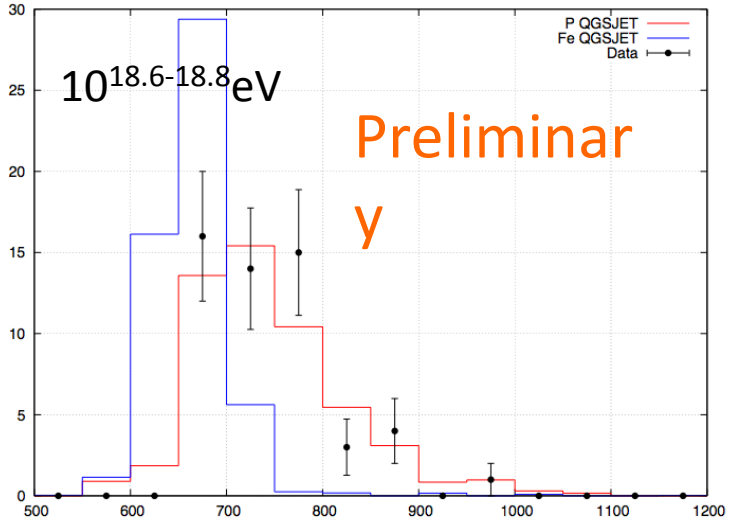


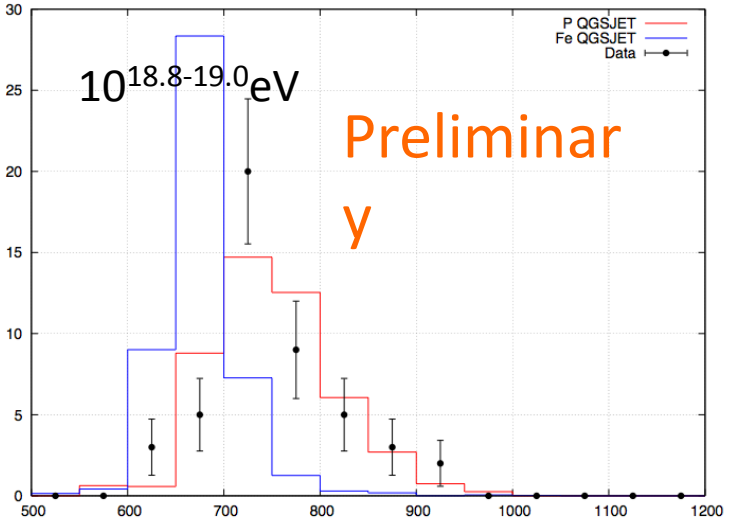


Xmax Distribution (QGSJET01)

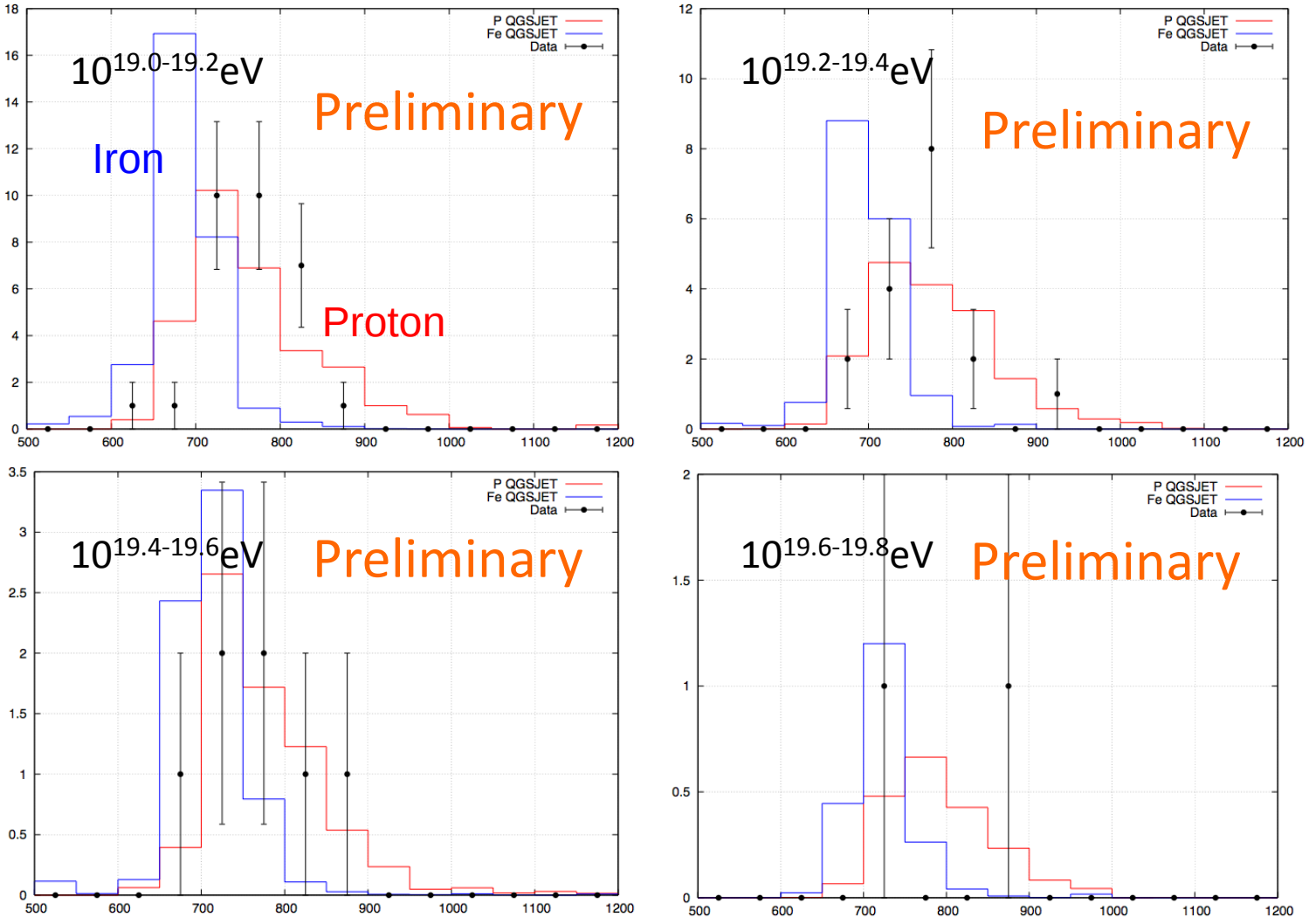




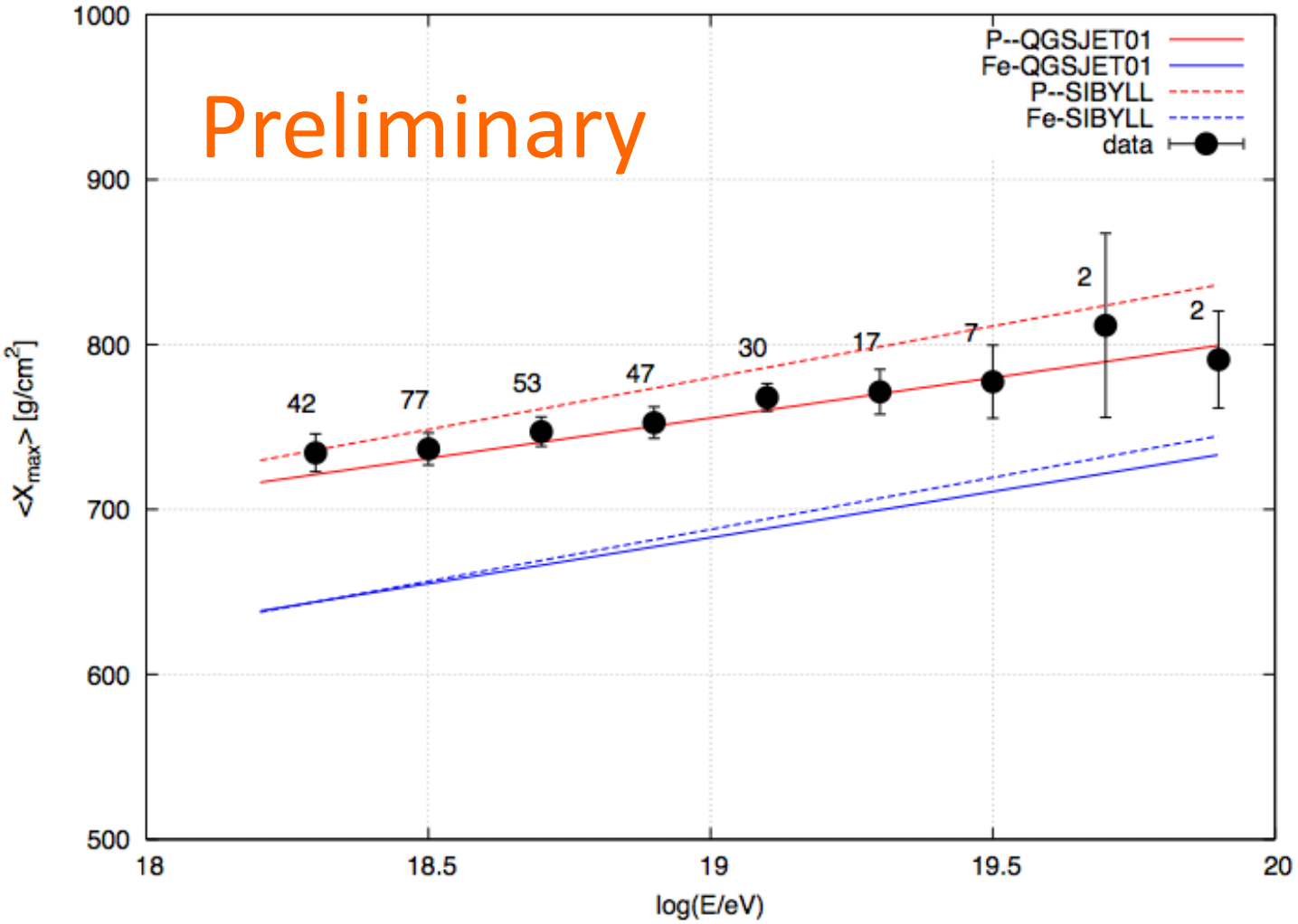




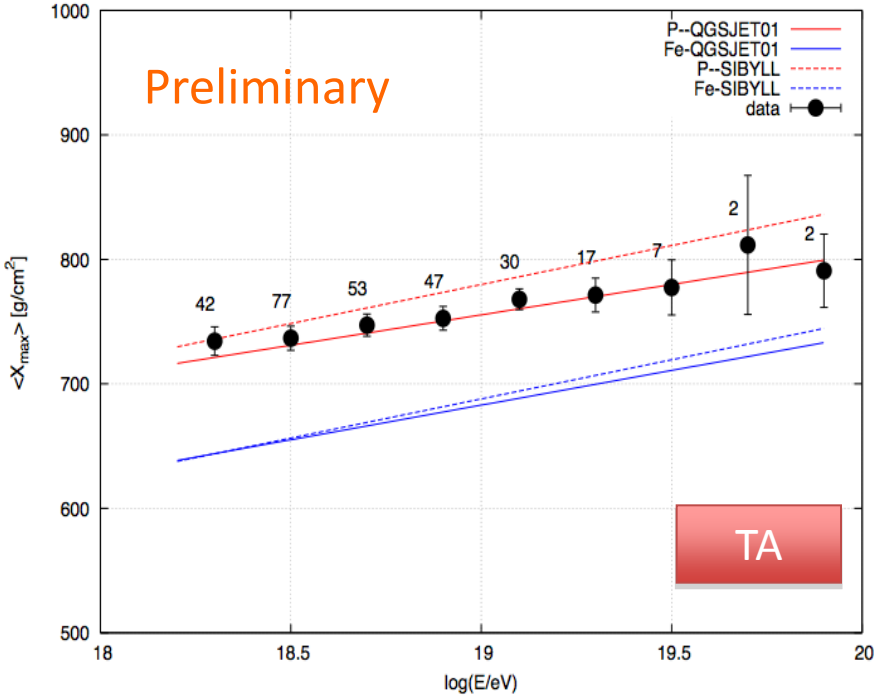
Xmax Distribution (QGSJET01)

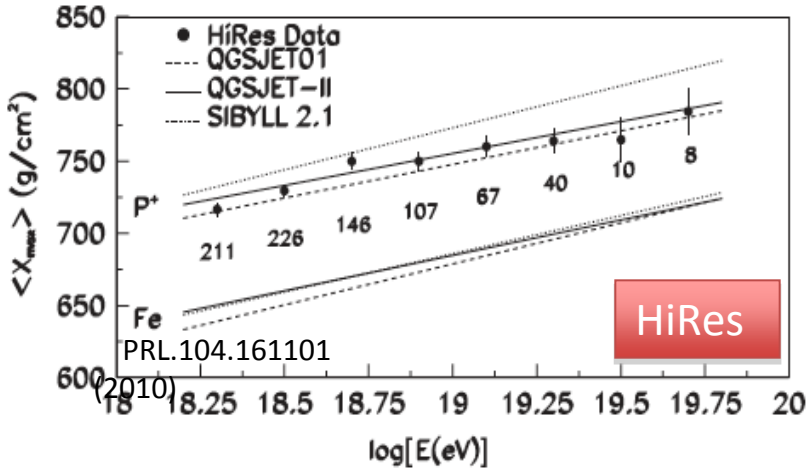


Averaged Xmax

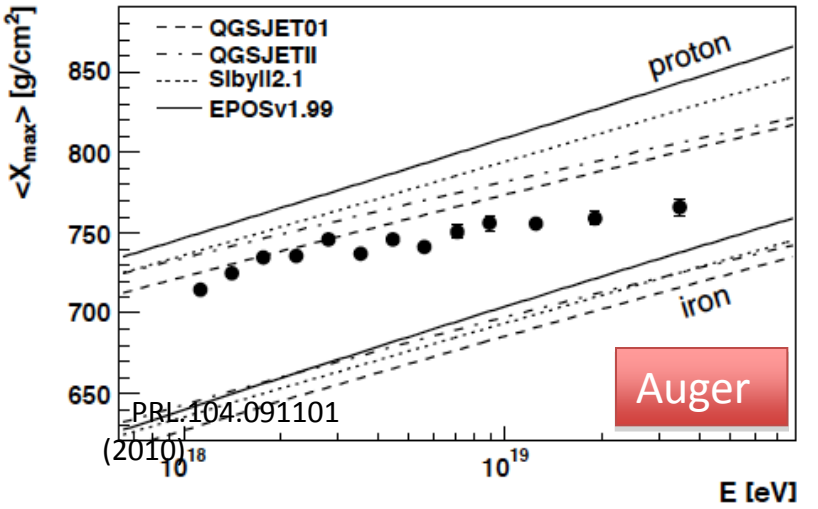


Averaged Xmax





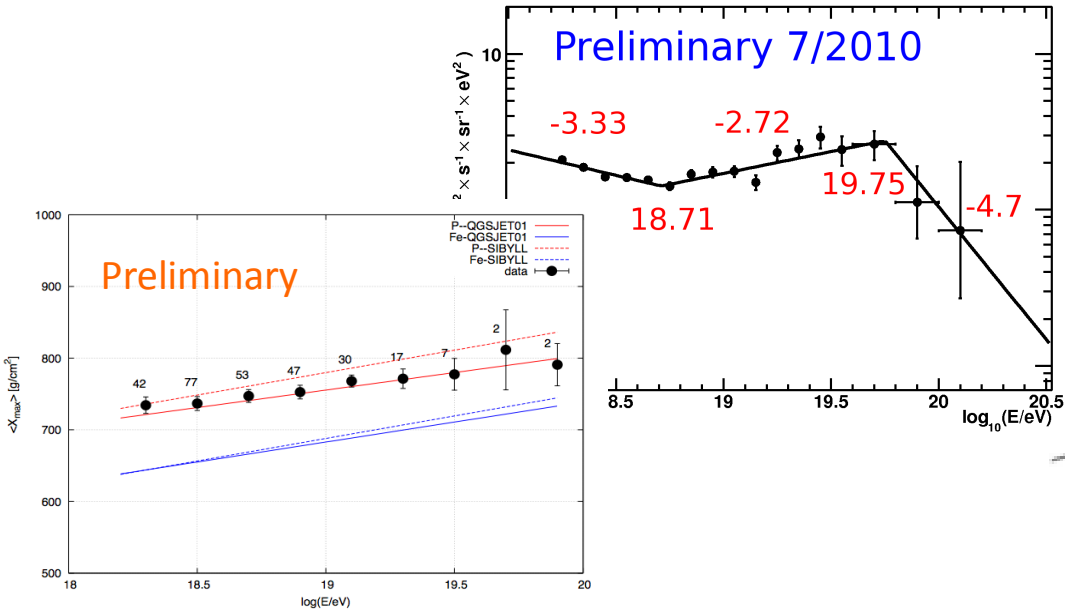
PRL.104.161101 (2010)

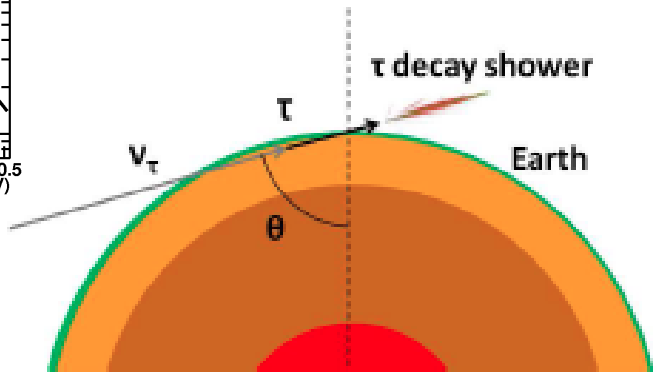


PRL.104.091101 (2010)

Neutrino detection @ TA

TA results : GZK suppression favor
GZK neutrino : expected to be observed
Neutrino search by FD and SD
Earth-skimming tau neutrinos, etc.





Conclusion

- TA : the largest detector in the northern hemisphere
  - FD : 2007/Nov. -
  - SD : 2008/Mar. -
- Energy spectrum
  MD mono, TA hybrid, SD : Suppression
- Mass Composition
  FD stereo : Consistent with proton composition
- TA Result is consistent with GZK suppression
  GZK neutrino is expected to be observed.