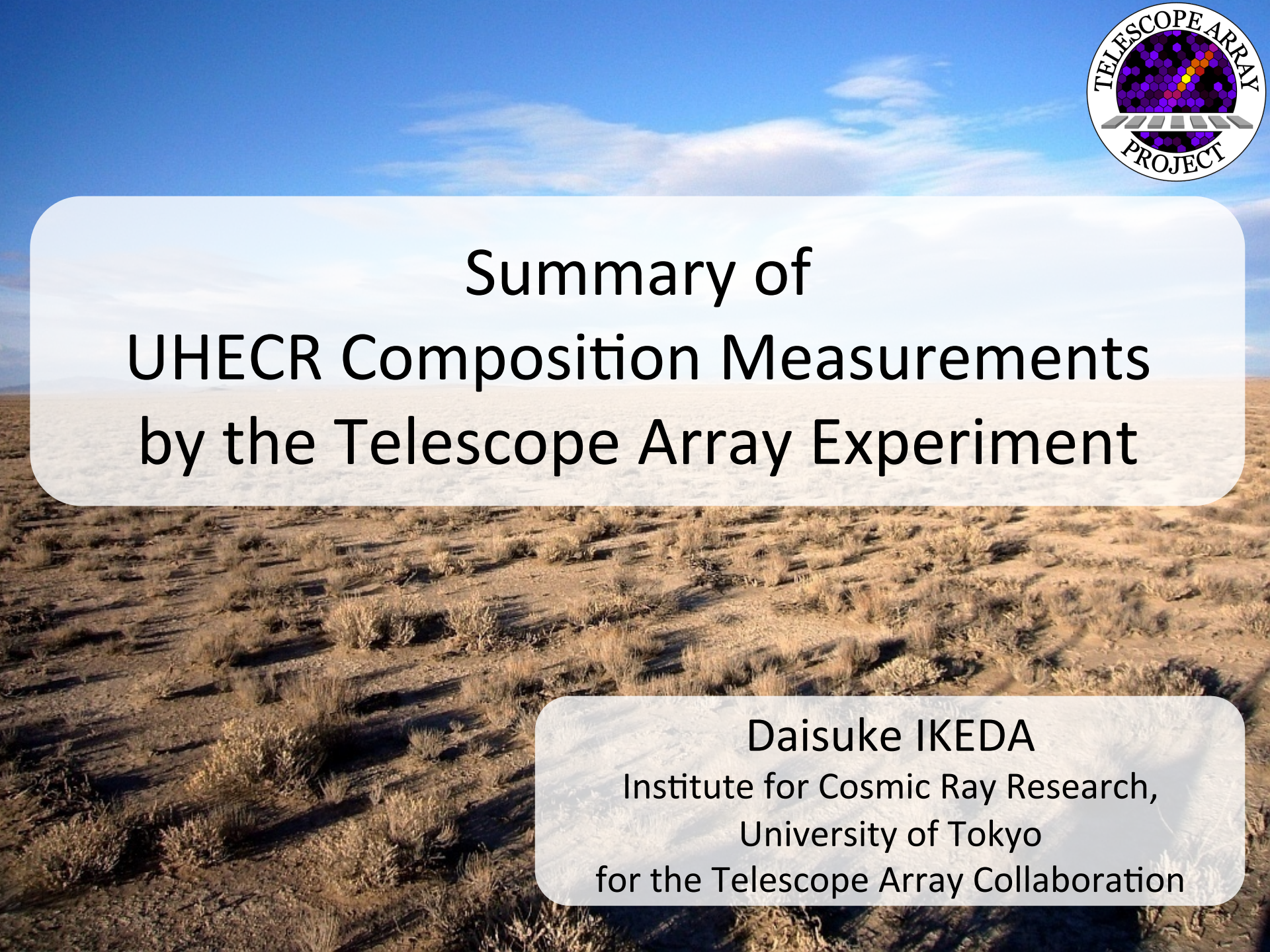
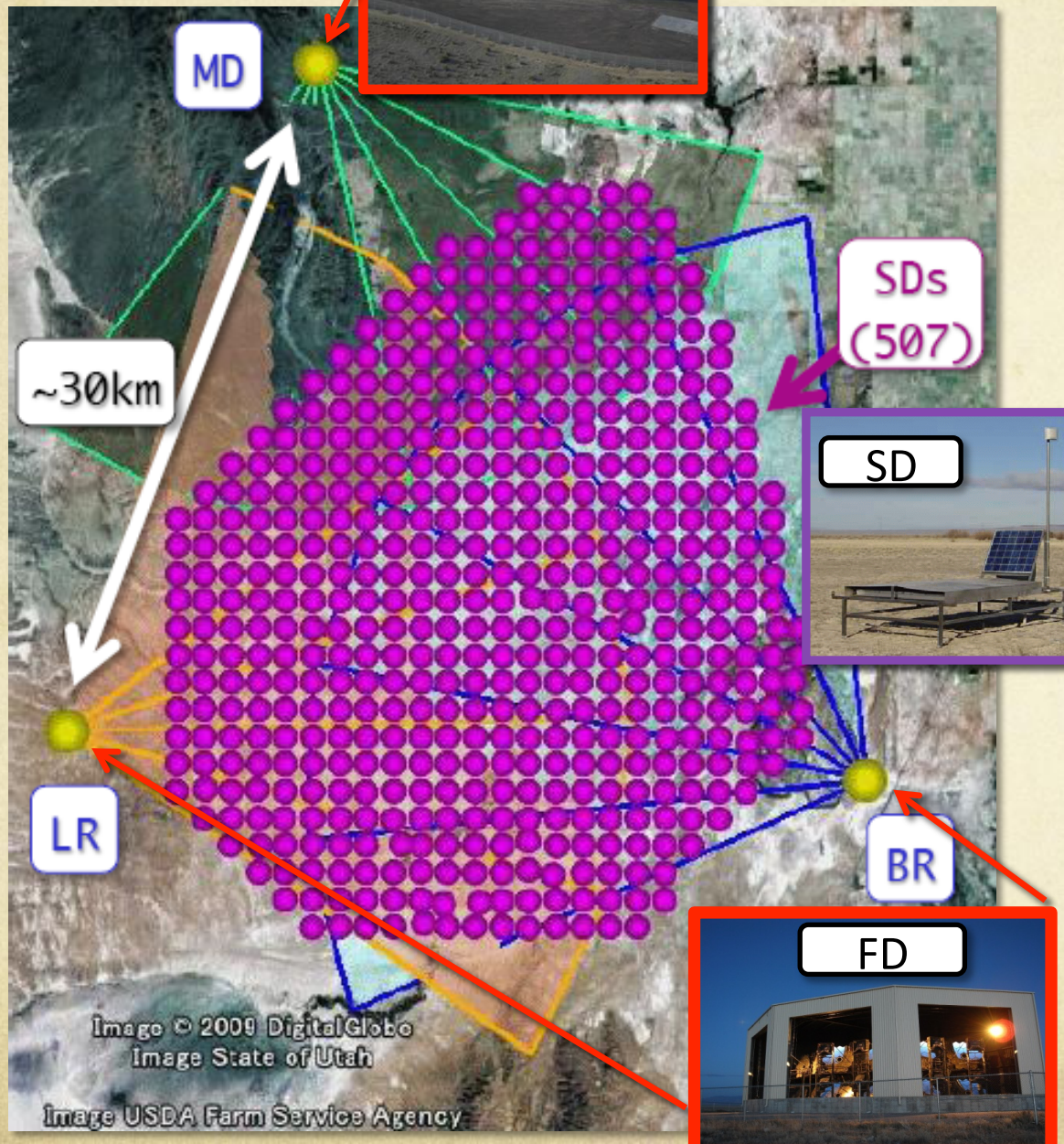


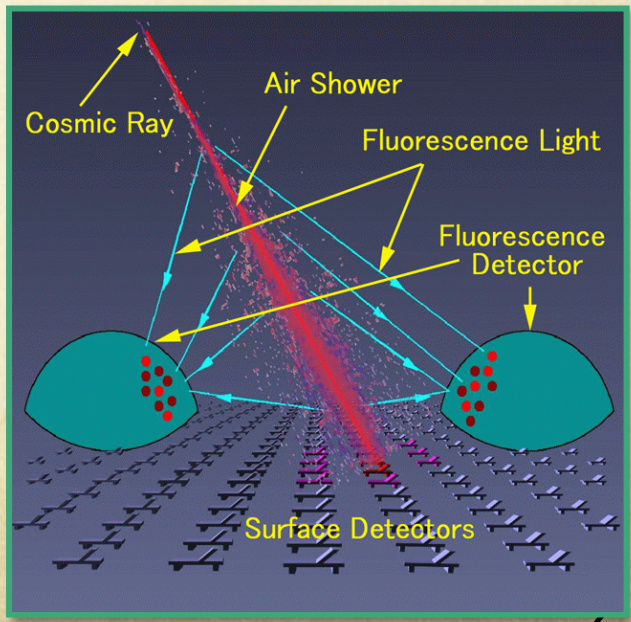
Summary of UHECR Composition Measurements by the Telescope Array Experiment

Daisuke IKEDA
Institute for Cosmic Ray Research,
University of Tokyo
for the Telescope Array Collaboration

Telescope Array Experiment

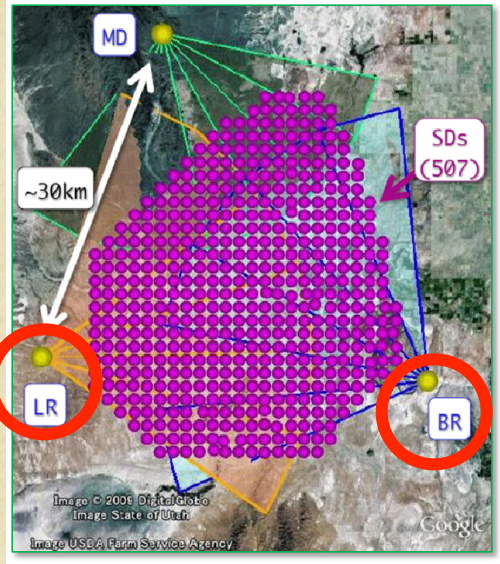


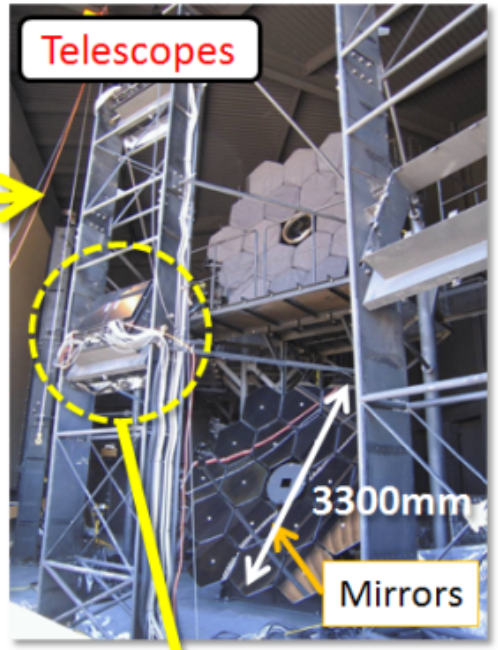
- Desert in Utah, US (1400m a.s.l.)
- 507 Surface Detectors (SDs)
  - 1.2km spacing
  - Two layers of plastic scintillator, $3m^2$, 1.2cm thickness
- 3 Fluorescence Detectors (FDs)
  - Middle Drum (MD) station is transferred from HiRes.
  - Black Rock (BR) and Long Ridge(LR) stations are newly built.
- FD observation : from Nov/2007
- SD observation : from Mar/2008

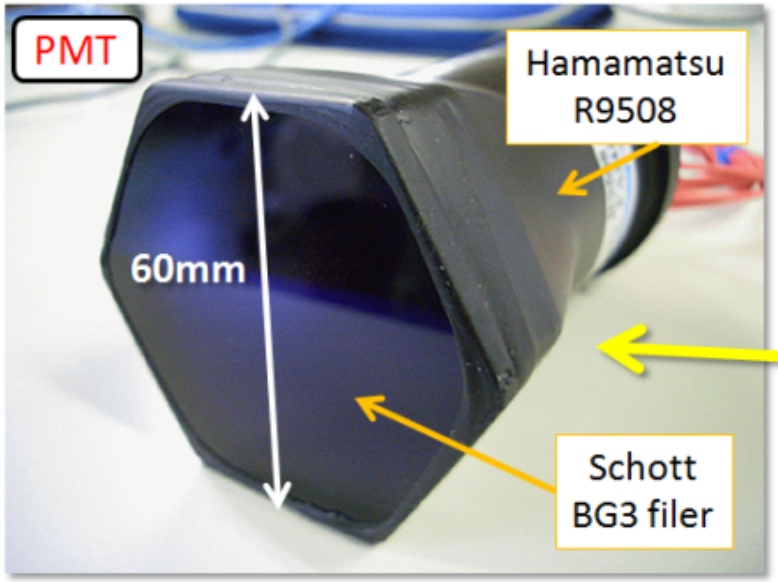


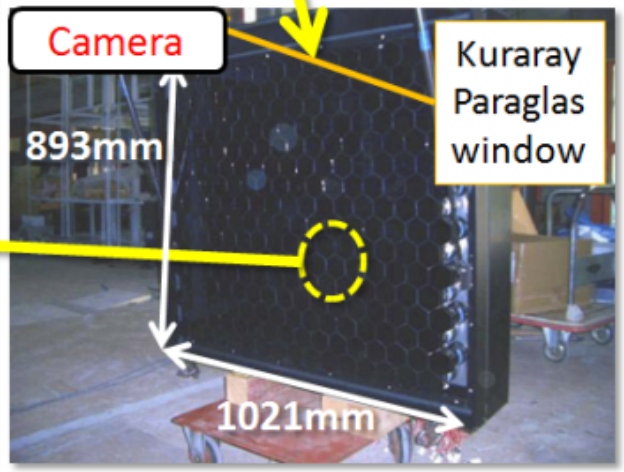
Fluorescence Detector station at BR/LR site

BR/LR site : new telescopes for TA





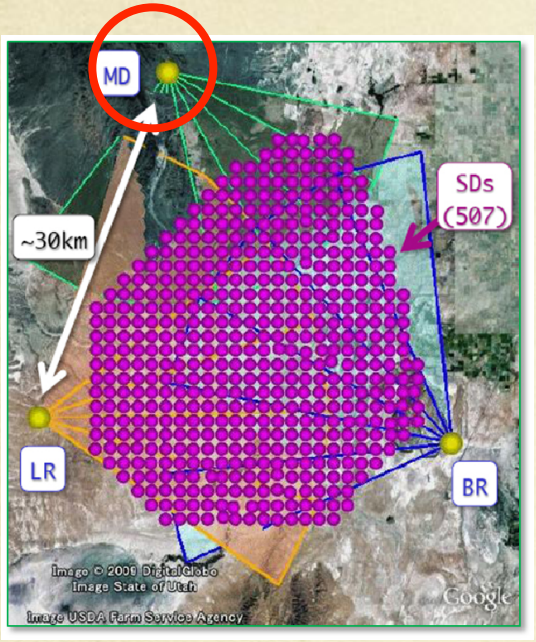




Field of View:

- Elevaton:3~33°
- Horizontal: 108°

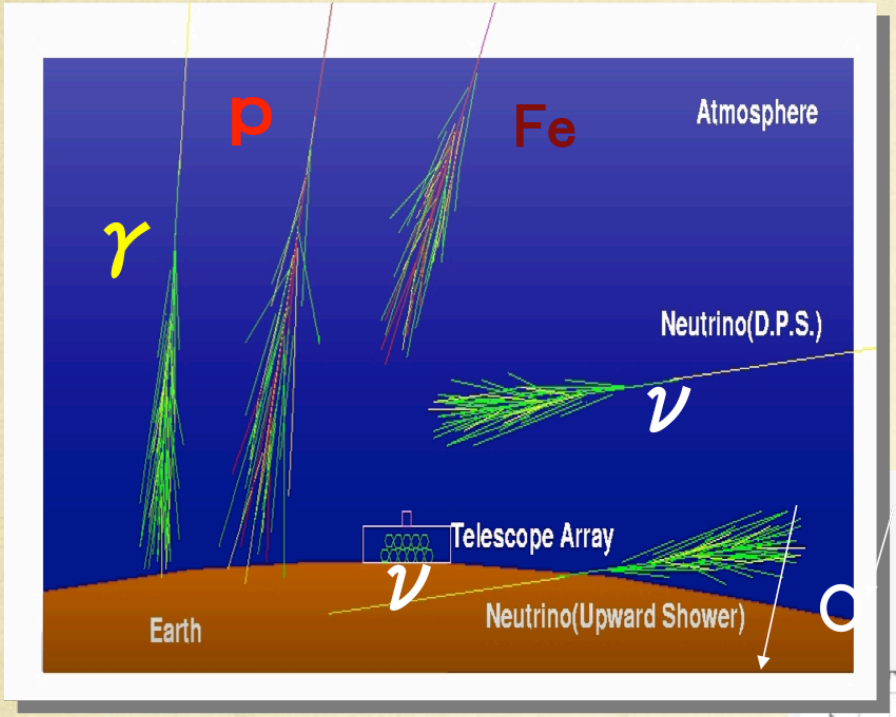
Fluorescence Detector station at MD site



Transferred from HiRes

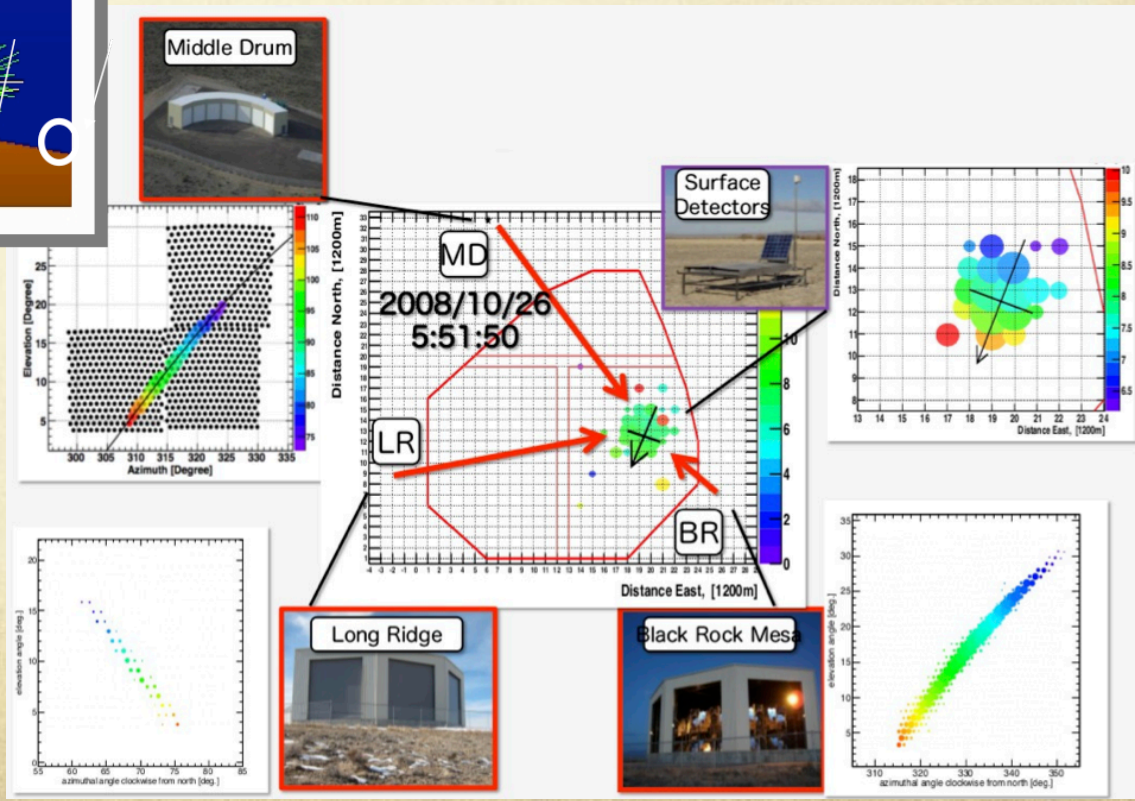
- 14 cameras/station
- 256 PMTs/camera
- 3^o-31^o elevation with 1^o pixel
- 114^o in azimuth
- $5.2m^2$ mirror
- S/H electronics

X_{max} measurement in TA



X_{max}, depth of the shower maximum, is the composition-sensitive parameter

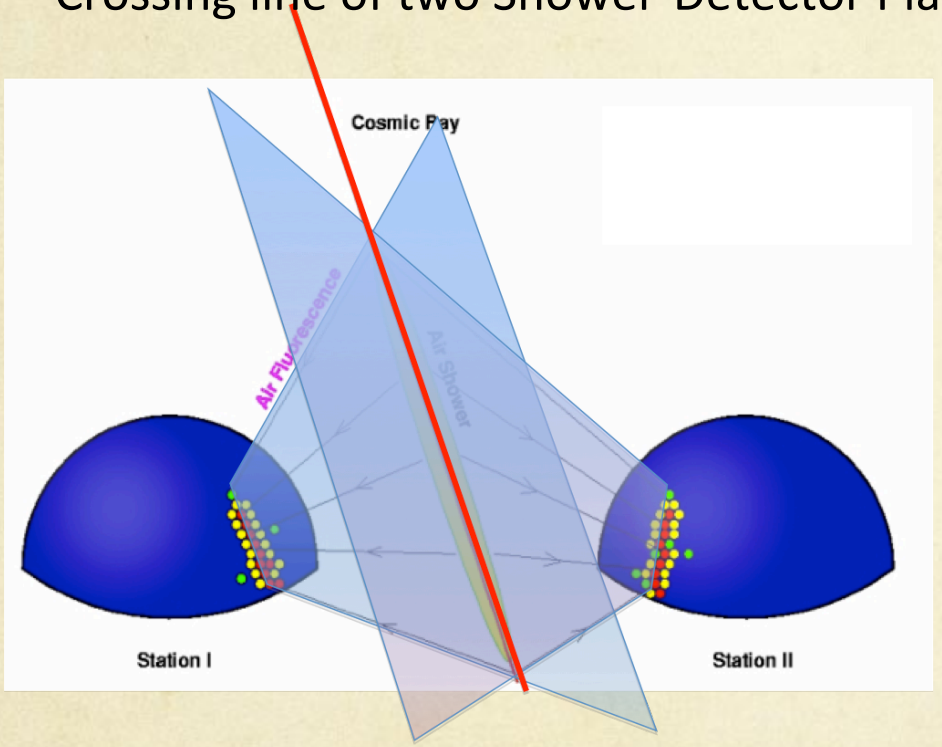
- Multiple X_{max} measurements for the systematic cross check
- Here three results are shown:
  - Stereo
  - BR/LR Hybrid
  - MD Hybrid



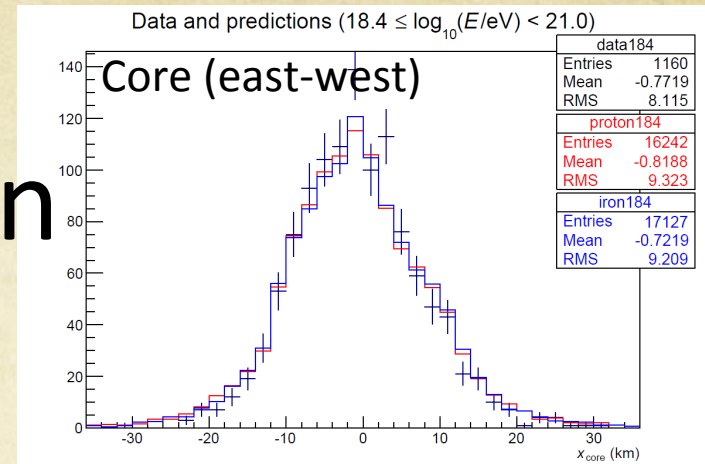
BR/LR/MD stereoscopic observation

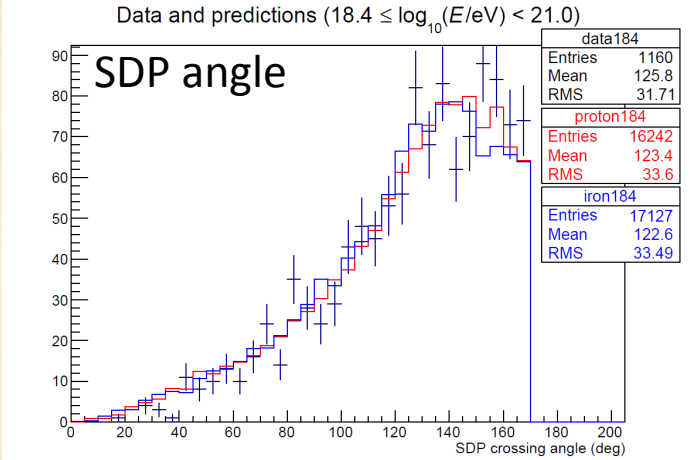
Shower geometry:

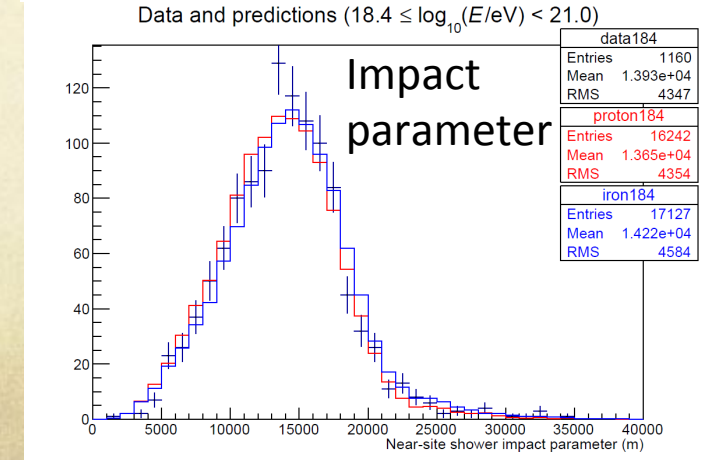
Crossing line of two Shower-Detector Planes



- Xmax resolution: ~19g/cm^2
- 1160 events (logE > 18.4)

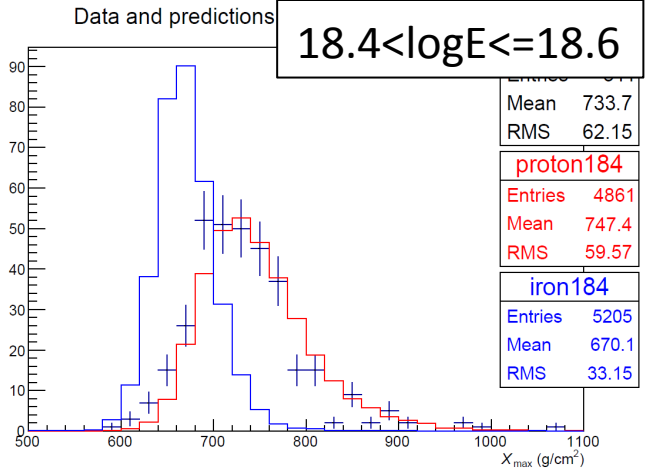


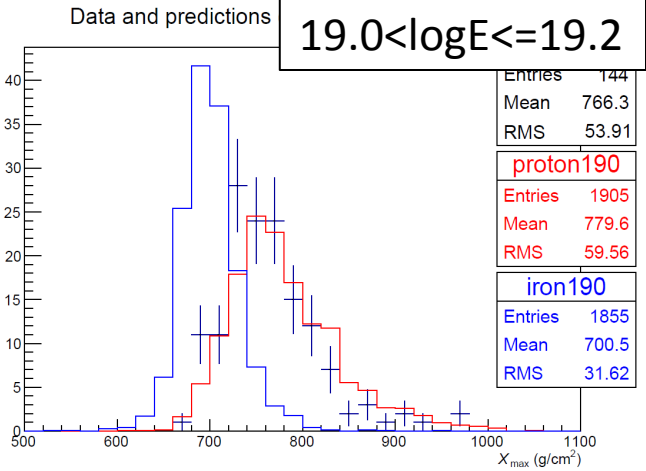


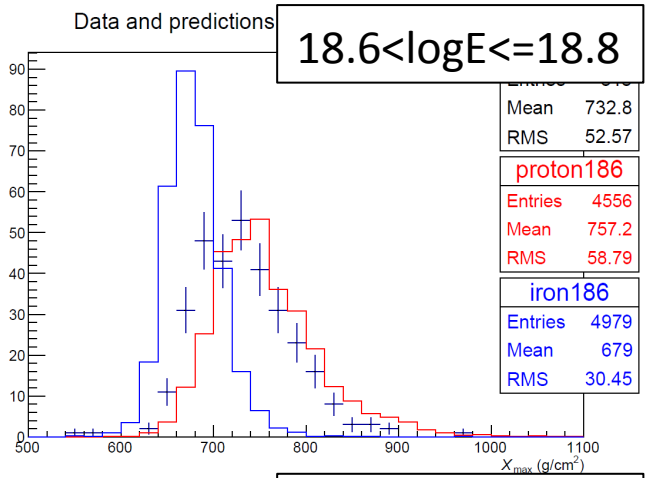


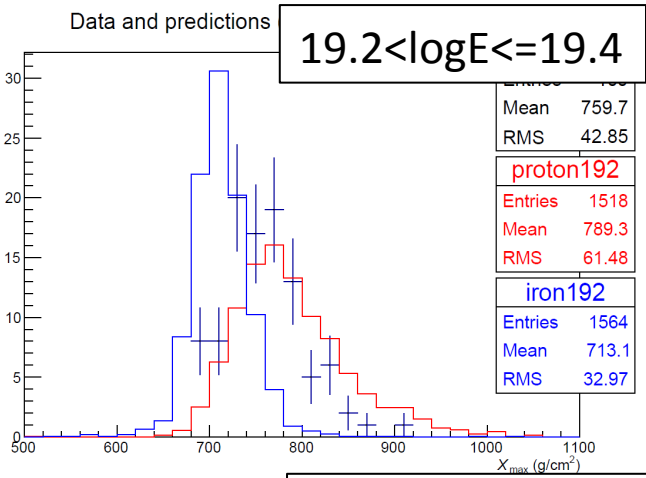
Xmax distribution in stereo analysis

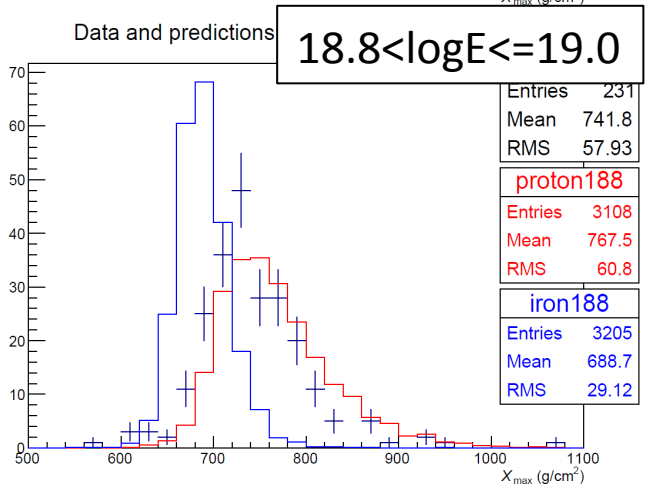
MC: QGSJET-II-03 p/Fe

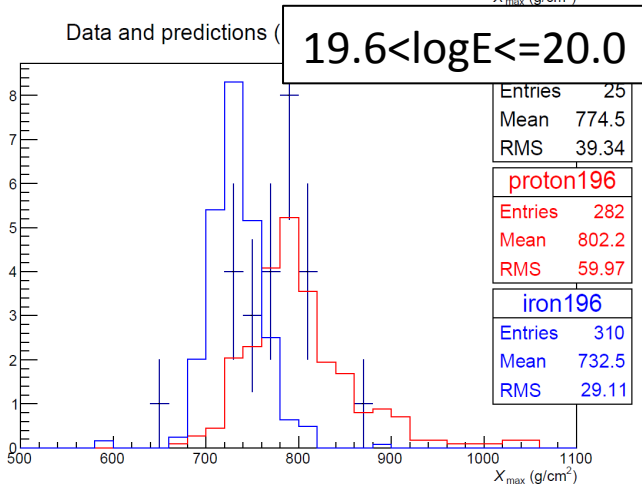




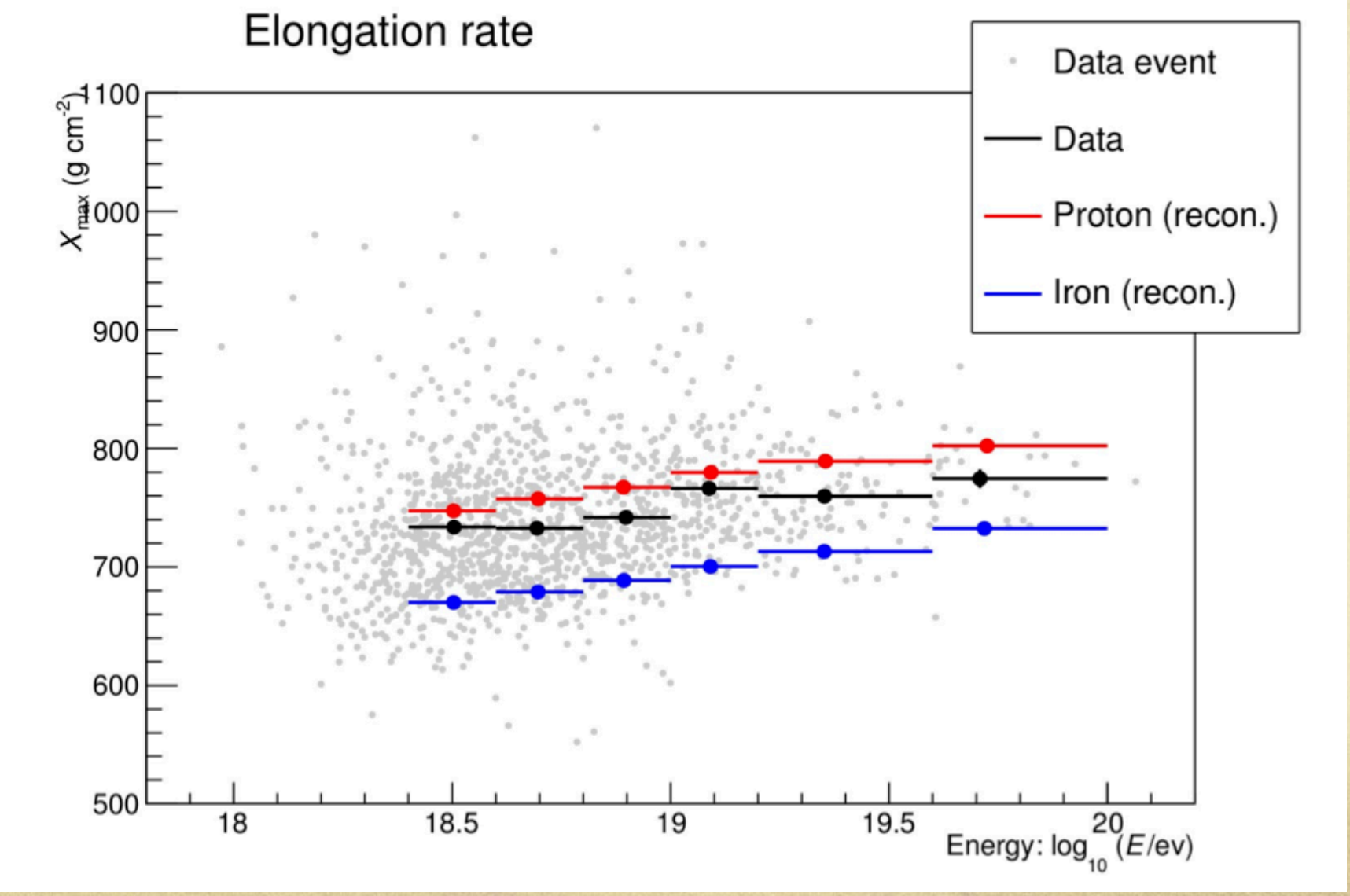




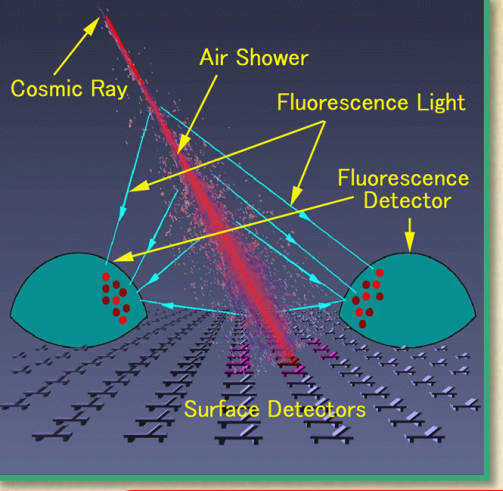


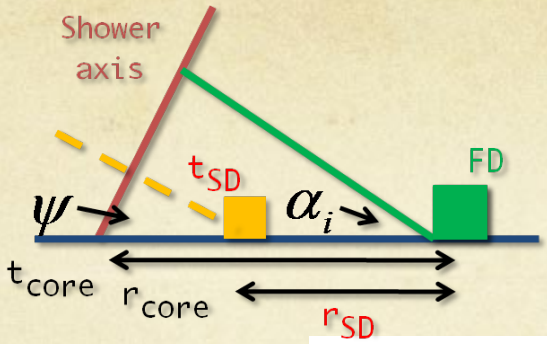


Elongation plot from stereoscopic observation



BR/LR-SD hybrid analysis





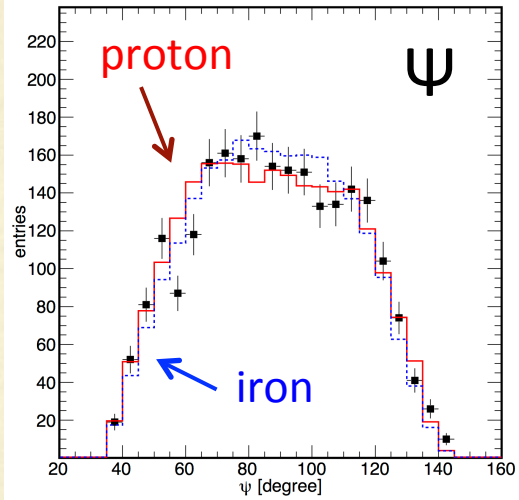
Hybrid reconstruction

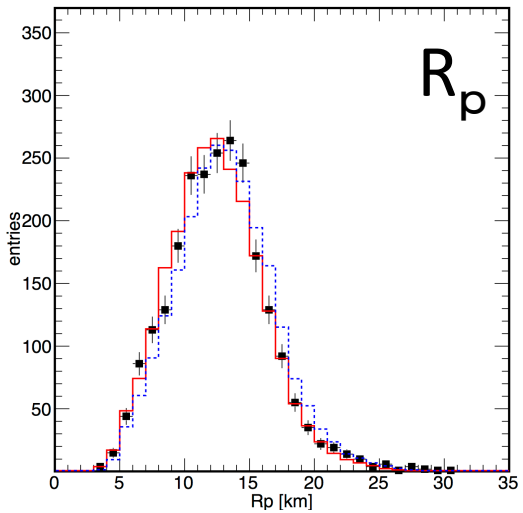
$$t_i = t_{core} + \frac{1}{c}\frac{\sin\psi - \sin\alpha_i}{\sin(\psi + \alpha_i)} r_{core}$$

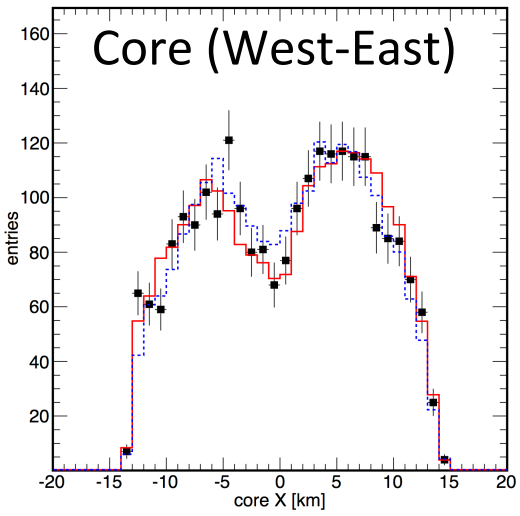
$$t_{core} = t_{SD} + \frac{1}{c}(r_{core} - r_{SD})\cos\psi$$

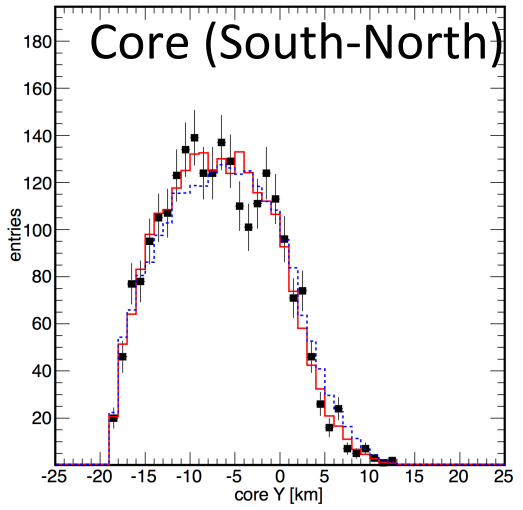
FD monocular reconstruction
+ timing information of SD

- Xmax resolution: ~ 20g/cm^2
- 2211 events (logE > 18.2)

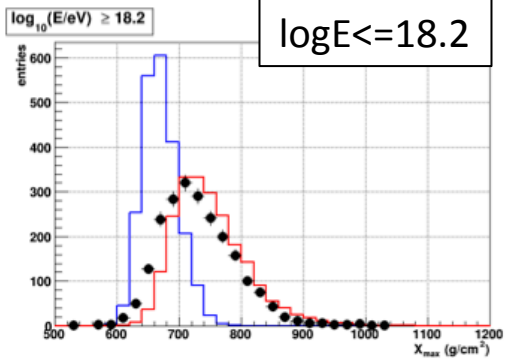




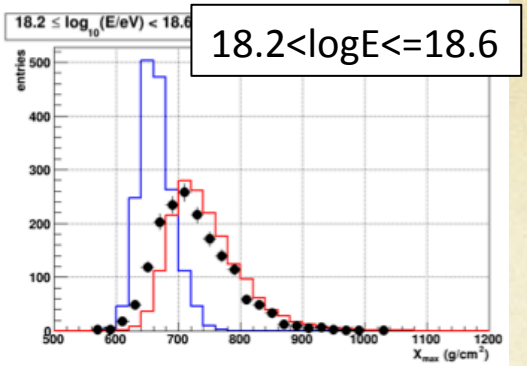




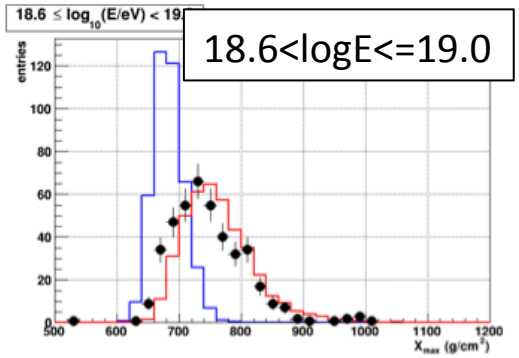
Xmax distribution in BR/LR hybrid



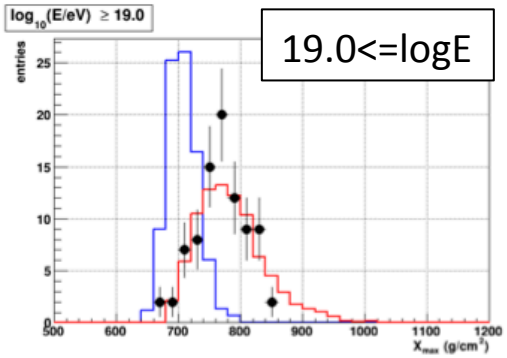
logE<=18.2



18.2<logE<=18.6



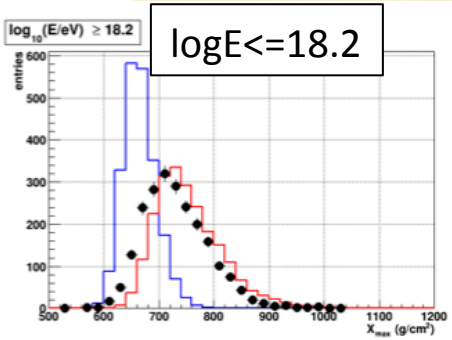
18.6<logE<=19.0



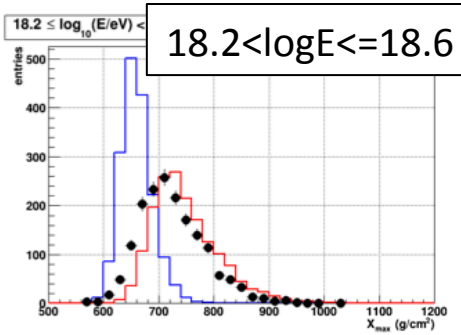
19.0<=logE

QGSJET-II-03

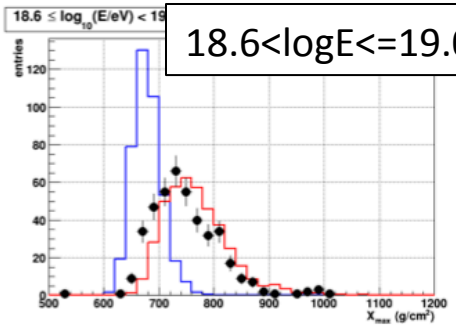
QGSJET-II-04



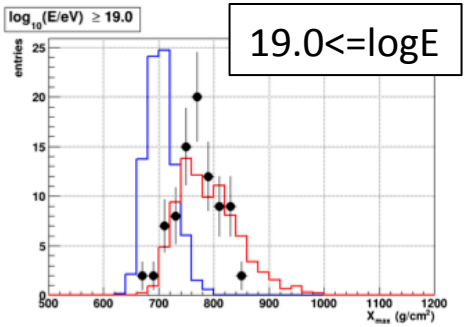
logE<=18.2



18.2<logE<=18.6

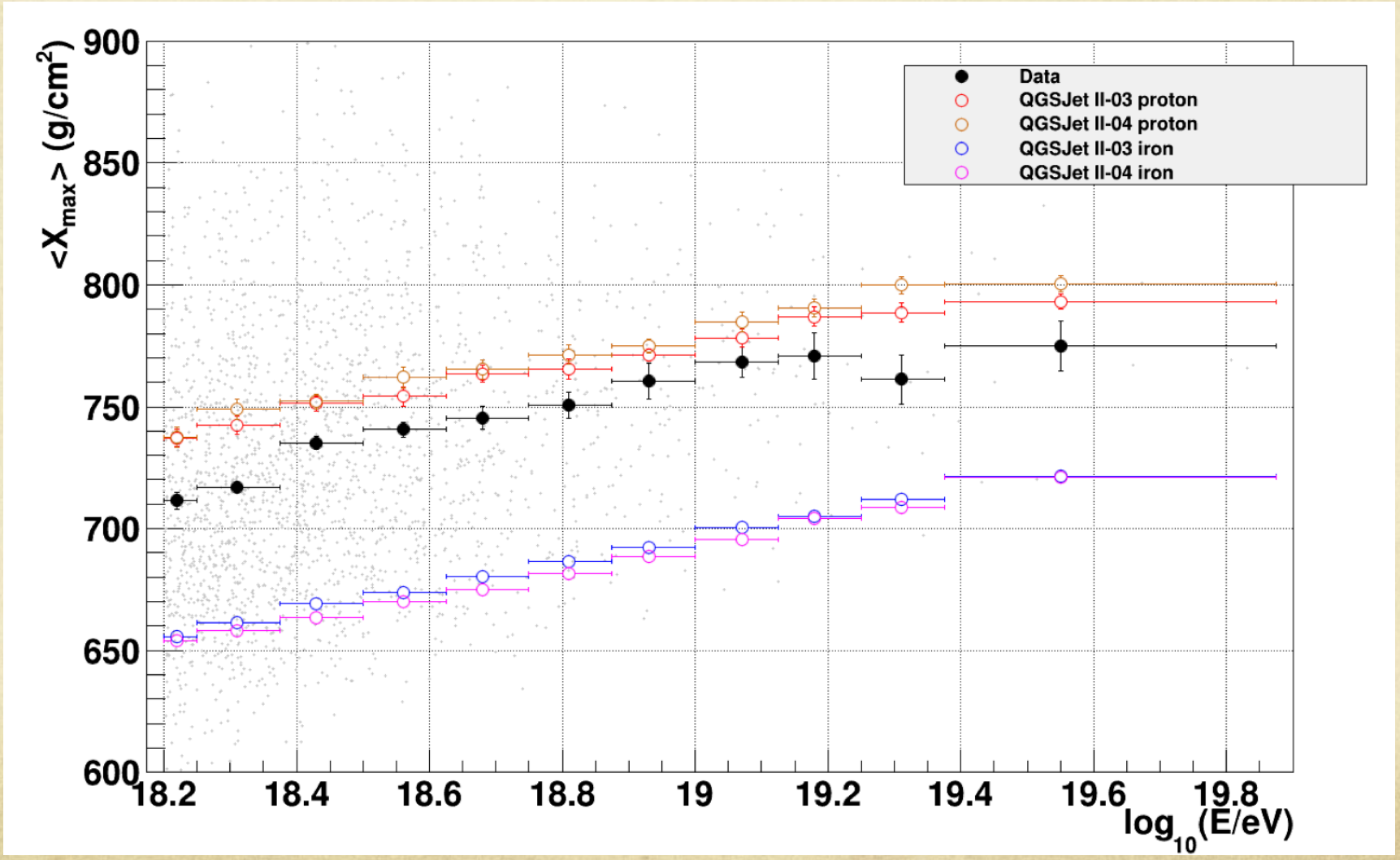


18.6<logE<=19.0



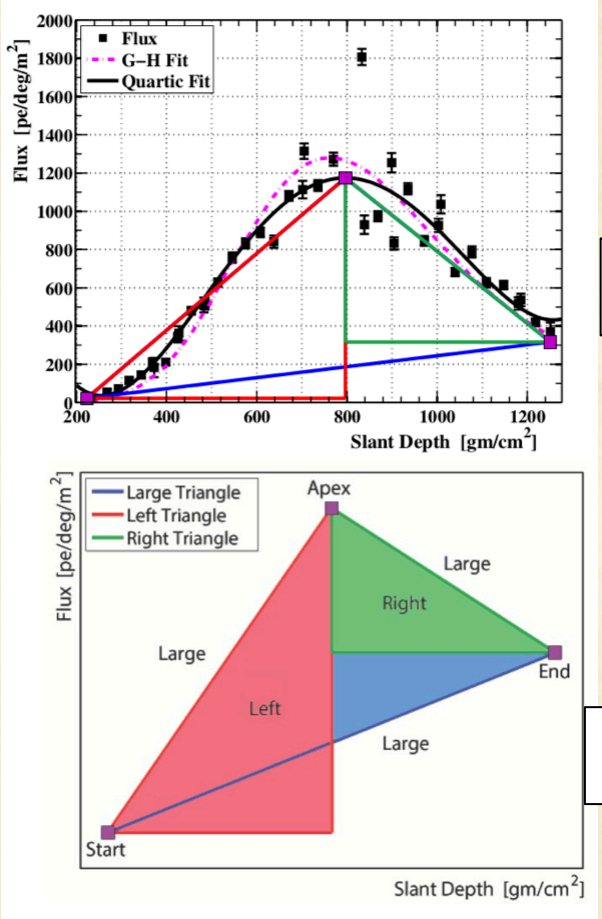
19.0<=logE

Elongation plot from BR/LR hybrid analysis

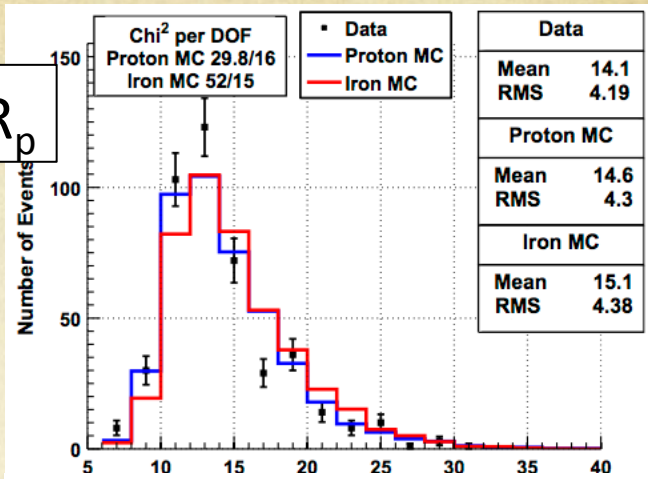


MD-SD hybrid analysis

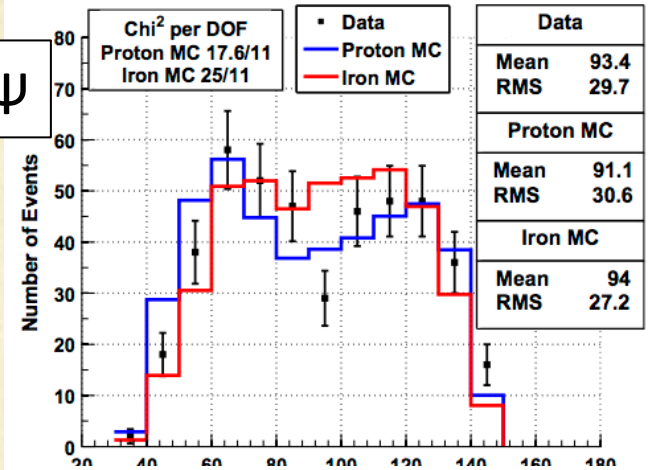
- Main procedure is same as BR/LR hybrid.
- Applied the cuts based on the pattern recognition technique



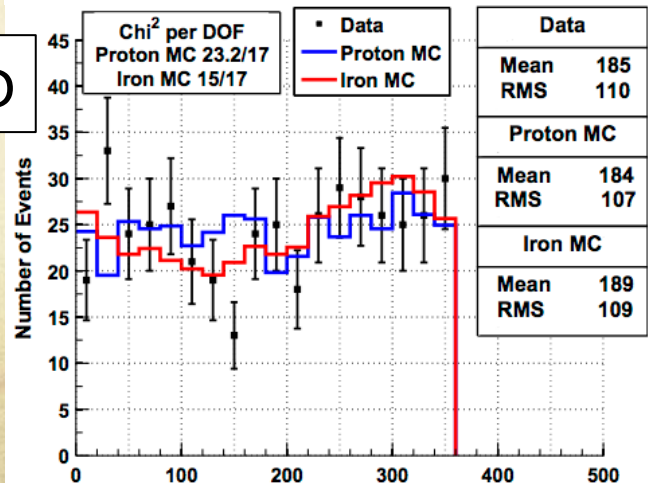
R_p



Ψ



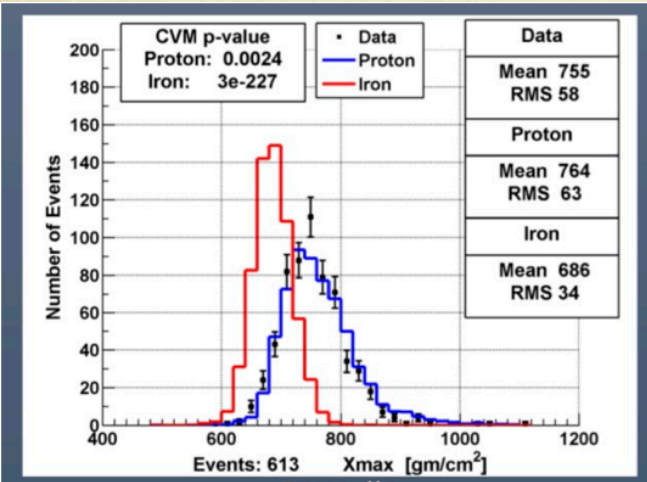
Φ



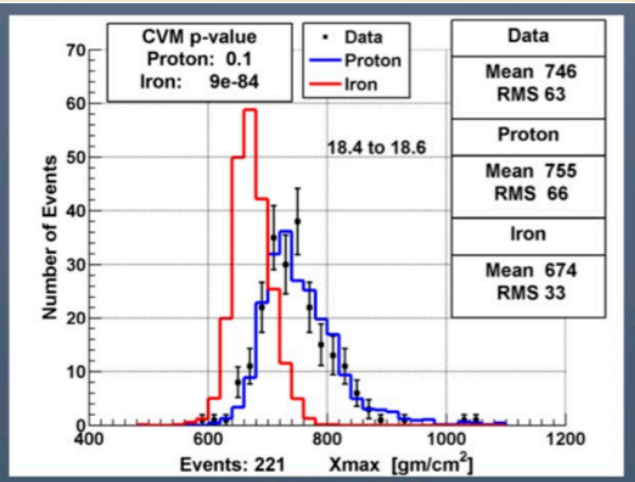
- Xmax resolution: ~20g/cm^2
- 613 events (logE > 18.4)

Xmax distribution in MD hybrid

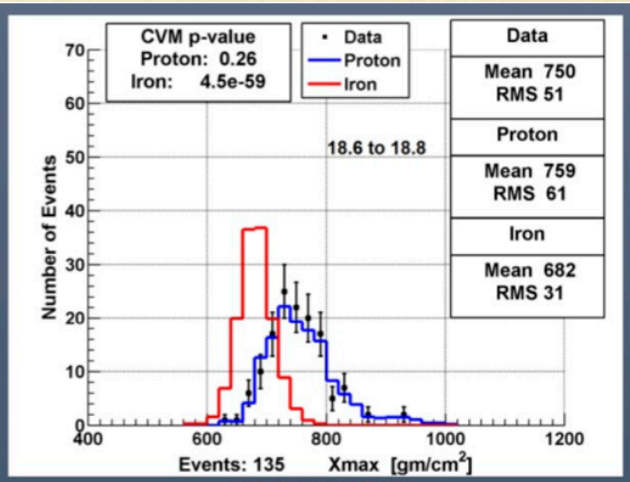
Overall



18.4<logE<=18.6



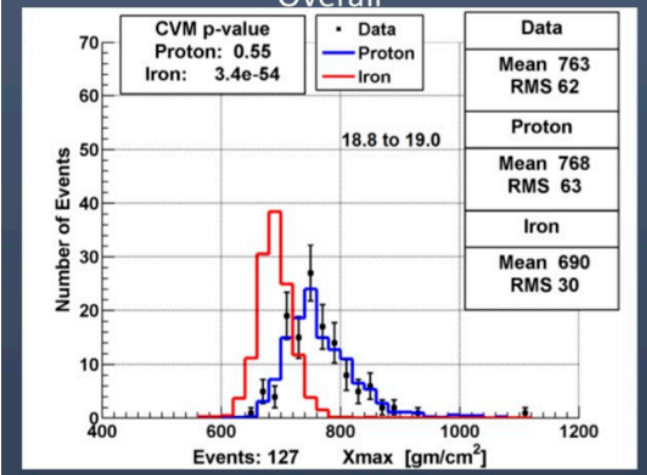
18.6<logE<=18.8

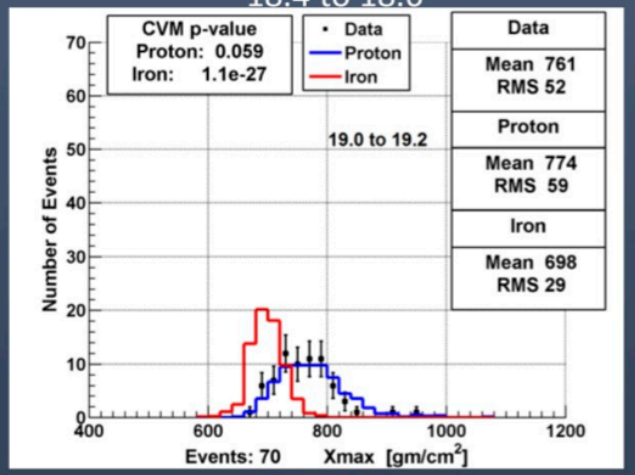


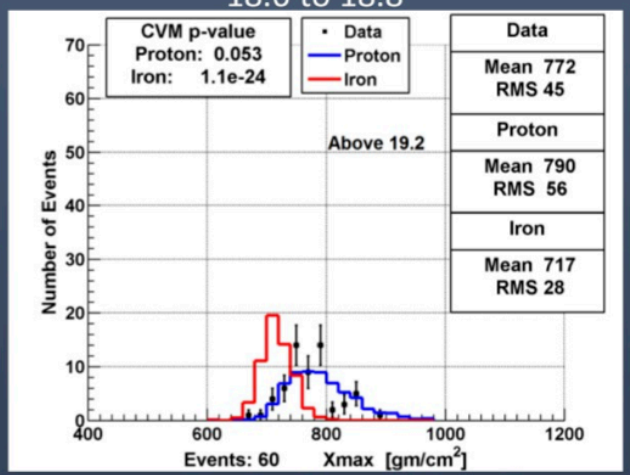
Overall

18.4 to 18.6

18.6 to 18.8







18.8 to 19

19 to 19.2

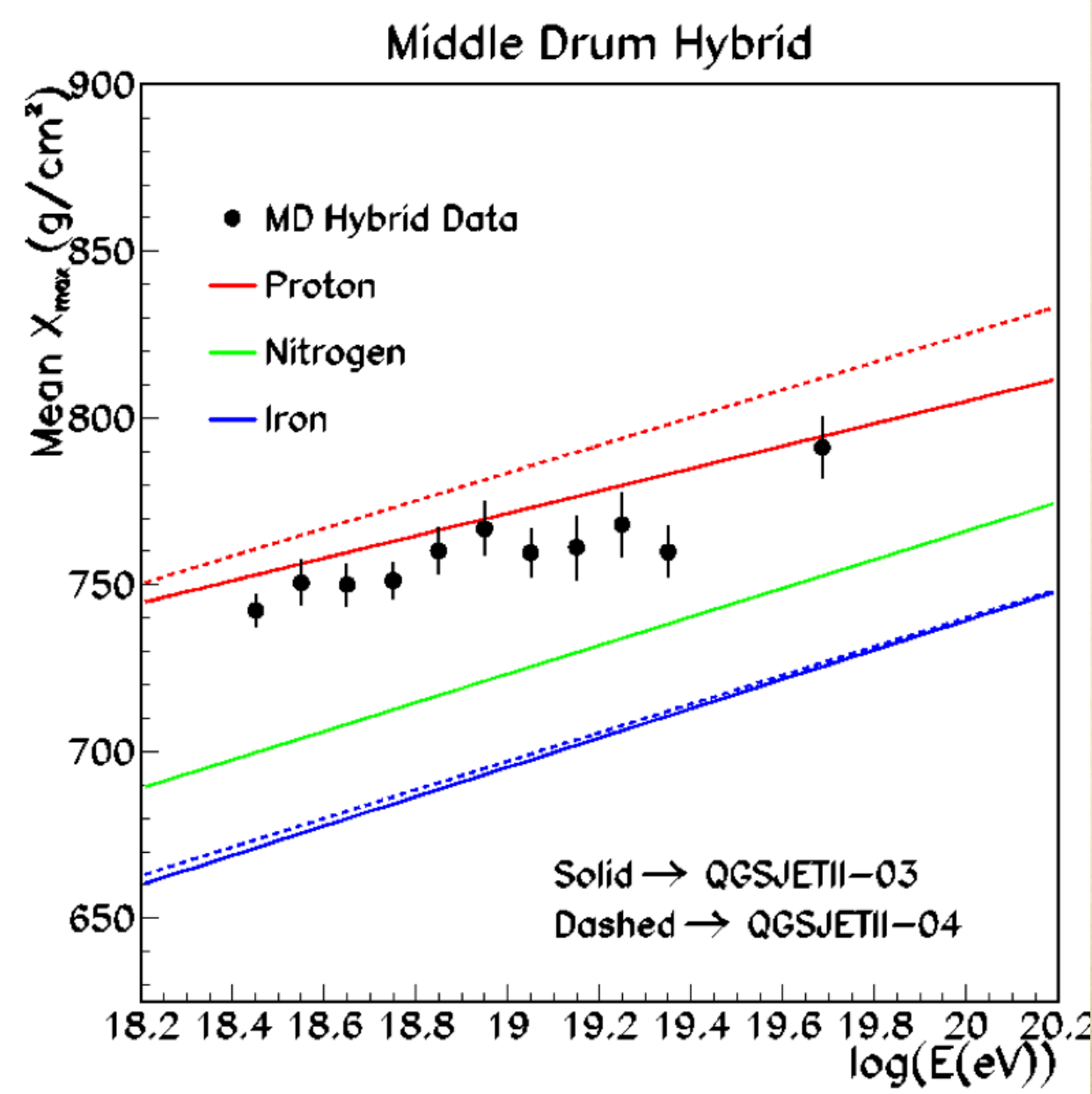
Greater than 19.2

18.8<logE<=19.0

19.0<logE<=19.2

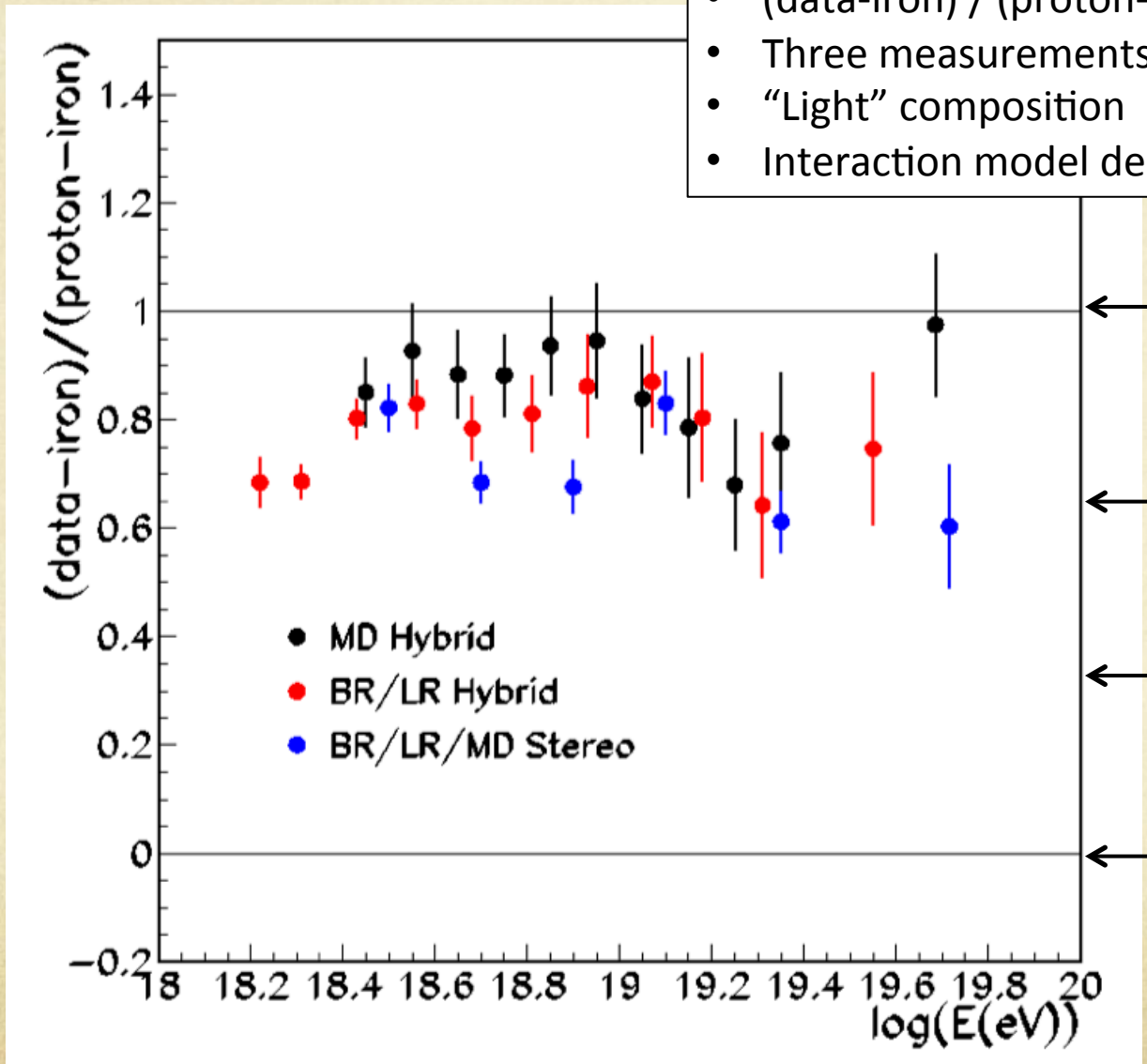
19.2<logE

Elongation plot from MD hybrid



Comparison with QGSJET-II-03

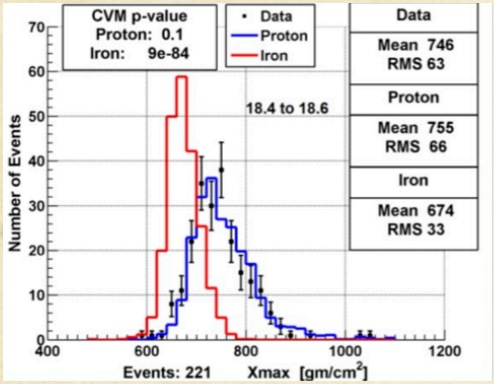
- Comparison with QGSJET-II-03 model
- (data-iron) / (proton-iron)
- Three measurements are consistent
- “Light” composition
- Interaction model dependent

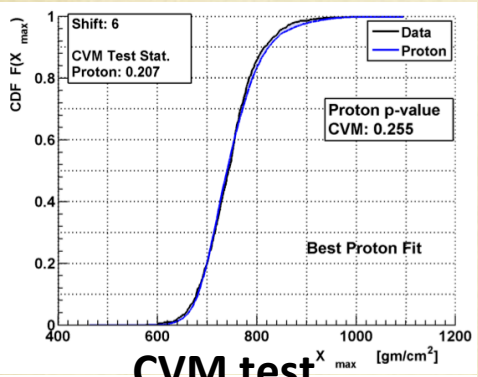


Statistical test

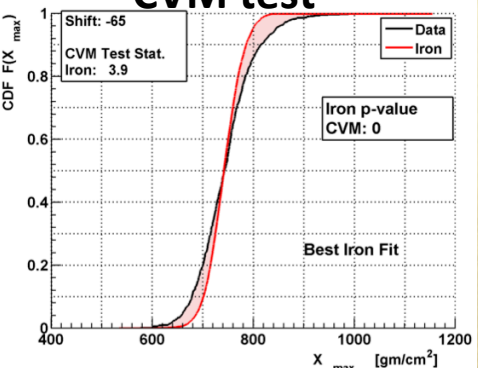
"shift plot"

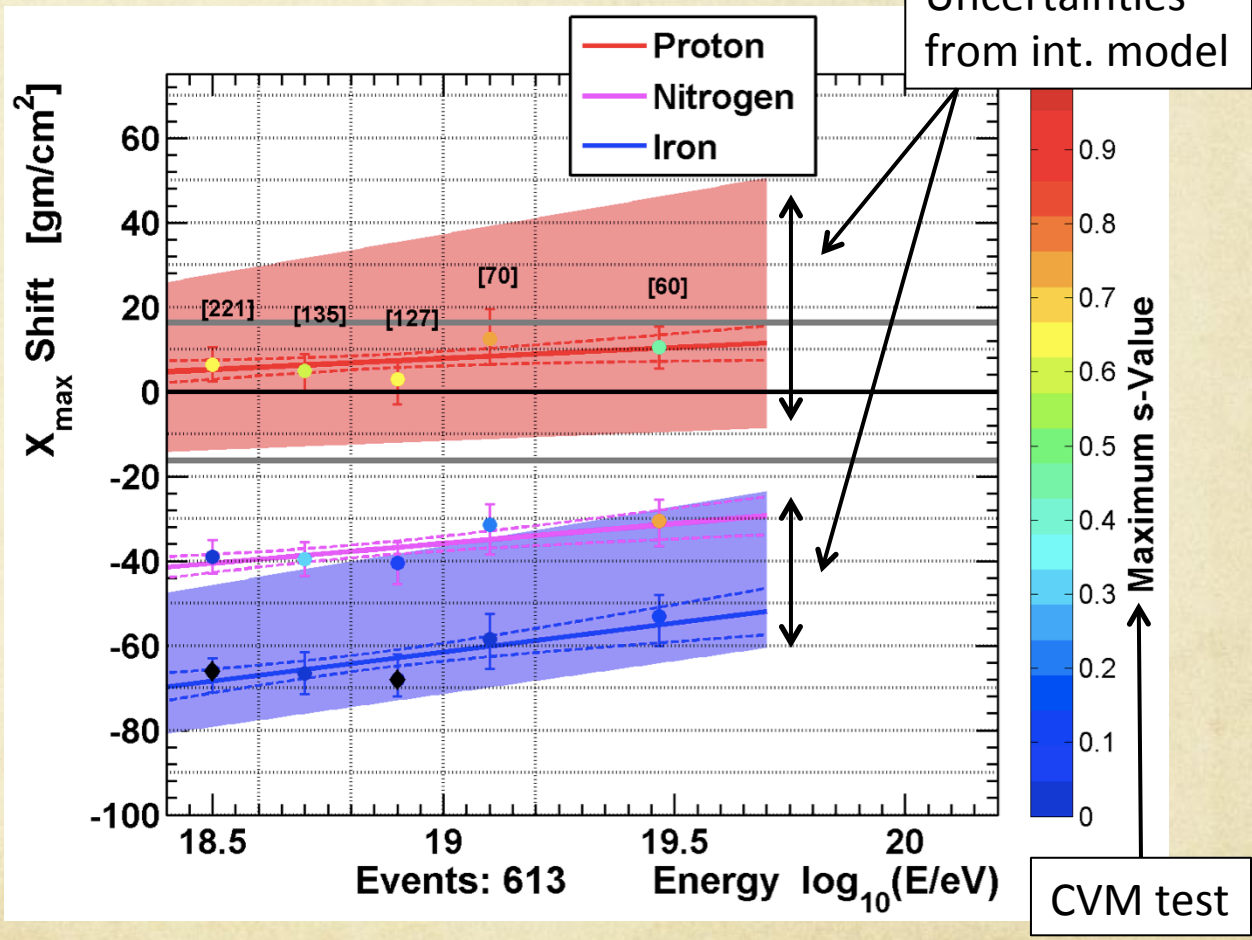
- Check the distribution shape agreement with shifting the MC distribution
- Plot Δ<Xmax> required to maximize the data/MC agreement
- Color bands : shift range required for QGSJET-01c, QGSJET-II-03 and 04, Sibyll 2.1, EPOS p/Fe





CVM test

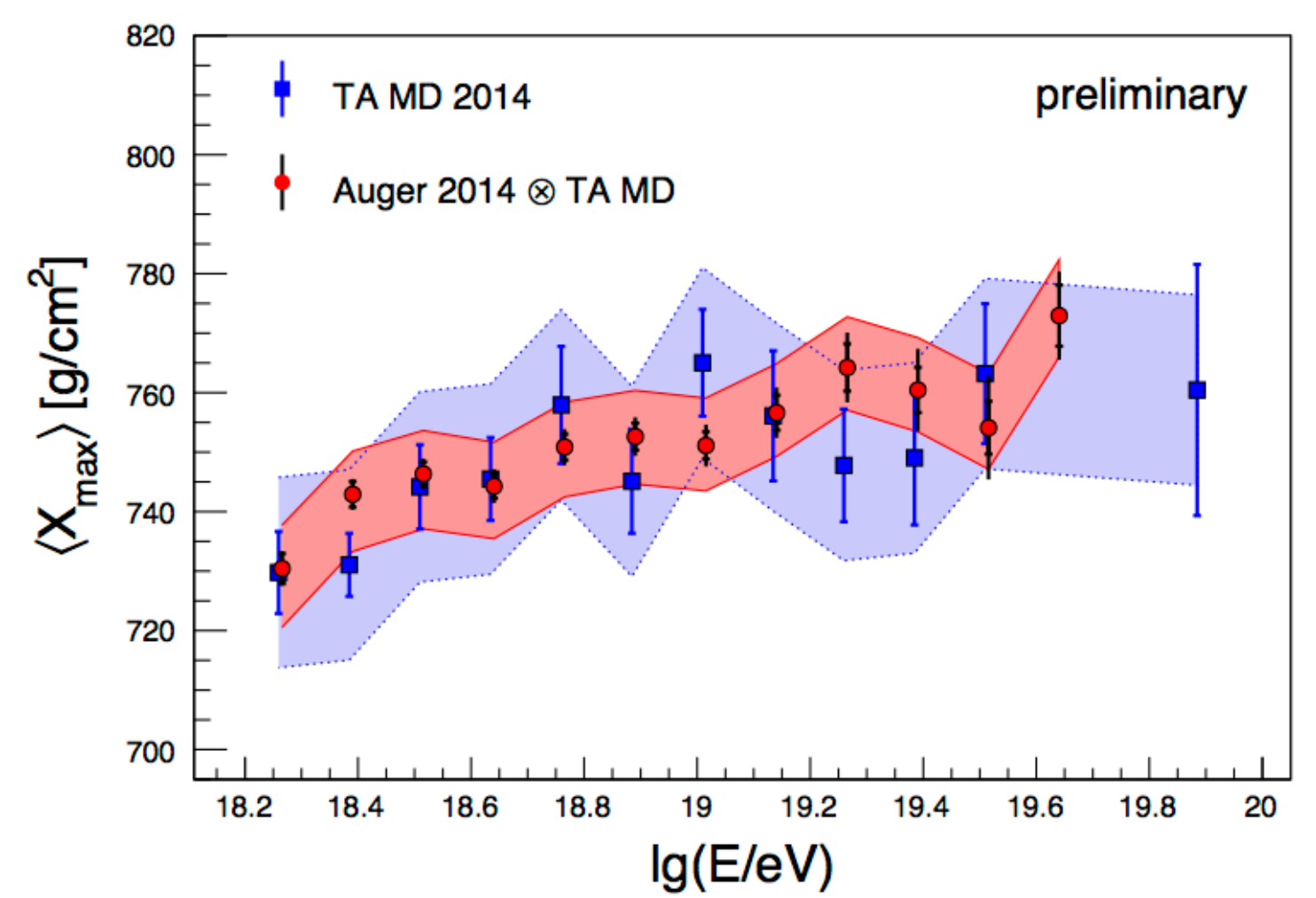




- Proton is compatible with data
- Iron shape with ~60g/cm2 shift is still incompatible with data
- Pure nitrogen is disfavored as well

Meta analysis: Composition WG

- Report from the composition working group in UHECR conference
- TA data cannot distinguish between mix and QGSJET-II-03 protons at this level of systematic uncertainty



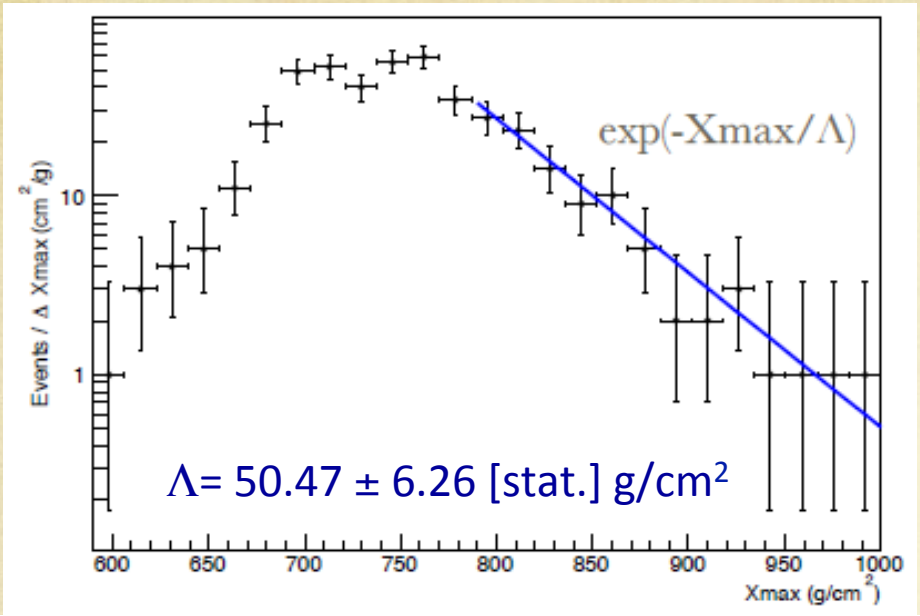
conclusion

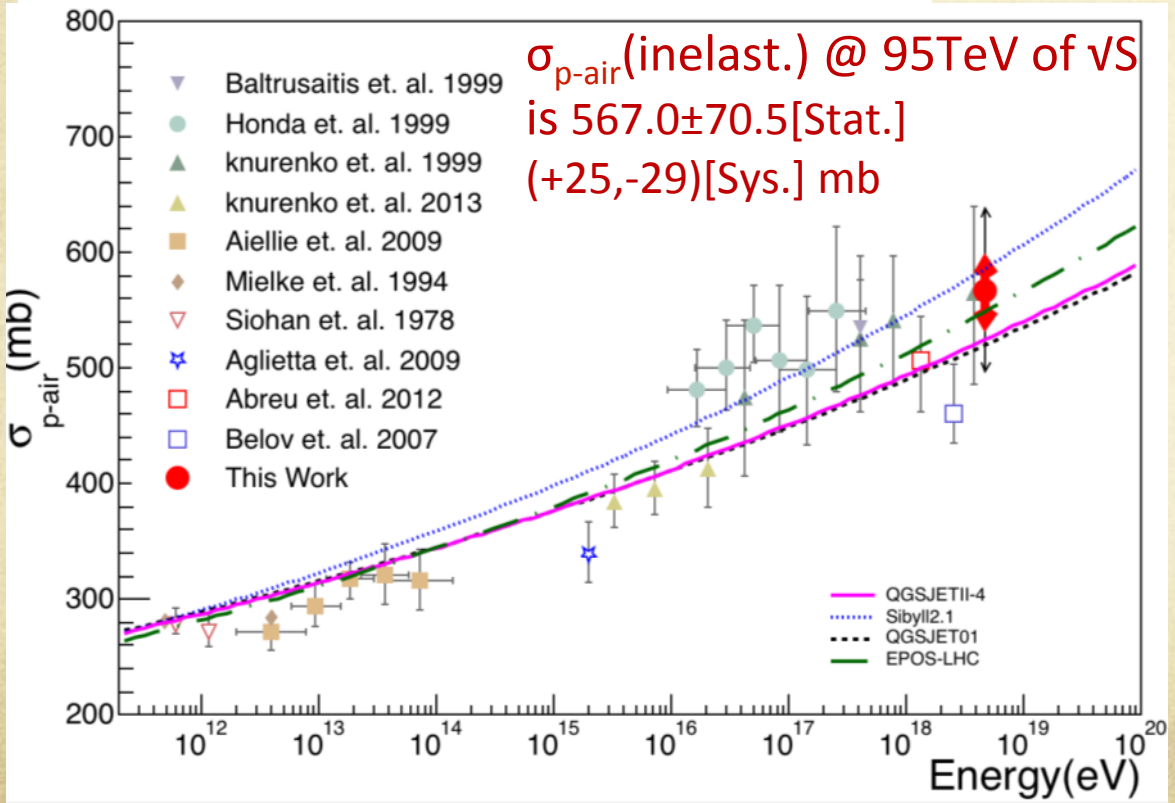
- Three results of the Xmax measurements are presented in detail
  - Stereo
  - BR/LR Hybrid
  - MD Hybrid
- Three results are in agreement within the systematic error
- “Light” composition
  - Statistical test: pure iron and nitrogen are incompatible with data

Backup

p-air cross section

Using deeply penetrating particles :
the tail of Xmax distribution





$\Lambda = K\Lambda_{p\text{-}air} = K(14.45\ m_p/\sigma_{p\text{-}air})$
K: Model dependent factor

sources	Systematic [mb]
Model	+- 17
20% He	+18
Gamma < 1%	-23
Total	(+25, -29)

Telescope Array Collaboration

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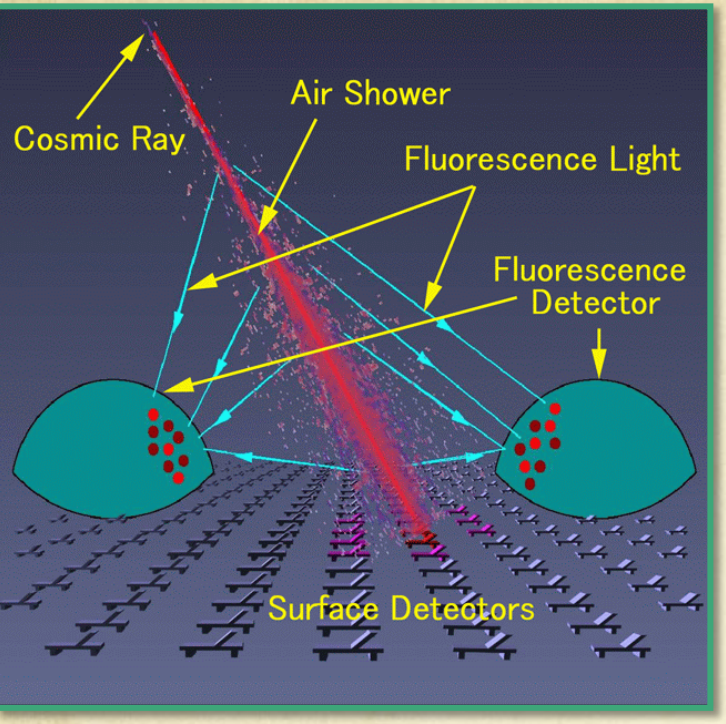
USA, Japan, Korea, Russia, Belgium

Fluorescence technique



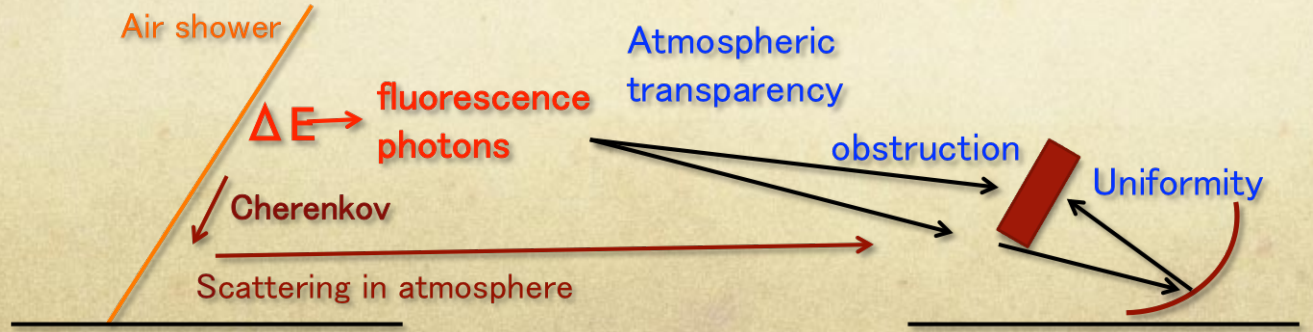
Shower geometry reconstruction:

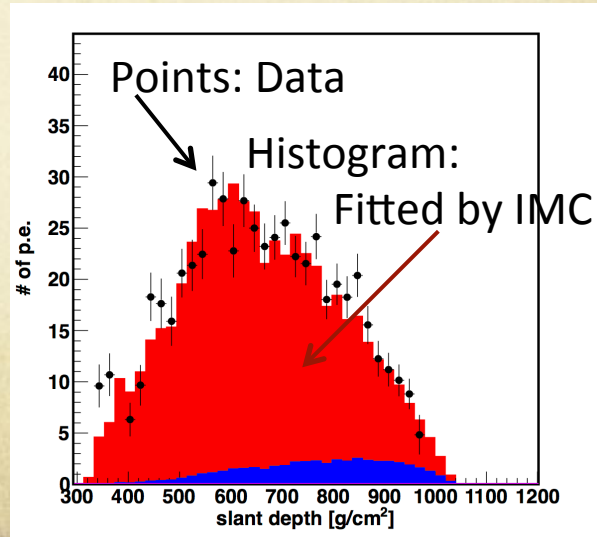
- Stereo : crossing of two shower-detector planes
- Monocular : timing information of each PMT
- Hybrid : monocular + SD timing

Longitudinal development reconstruction:

- Inverse MC method
  - Generate MC event with GH function and compare with data.
  - Search best GH parameters.
- E_{cal} : Integrate obtained GH function
- $E_{primary}$: Correct the missing energy (neutrino) to E_{cal}

Resolutions:
~1degrees of arrival direction
~7% of energy
~ 20g/cm2 for Xmax

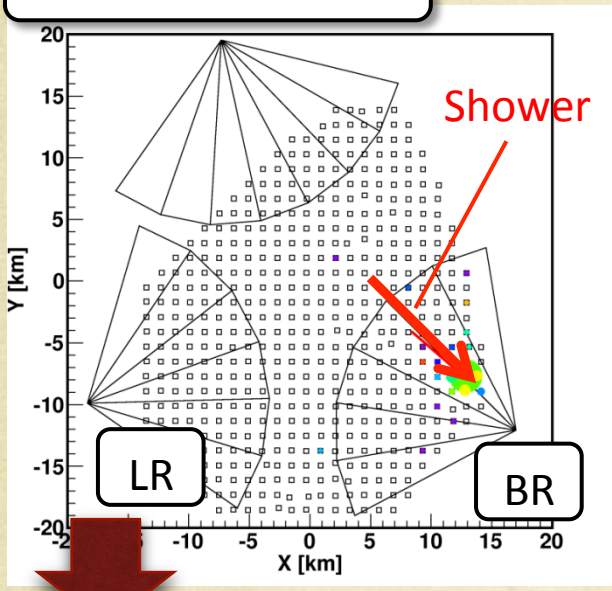


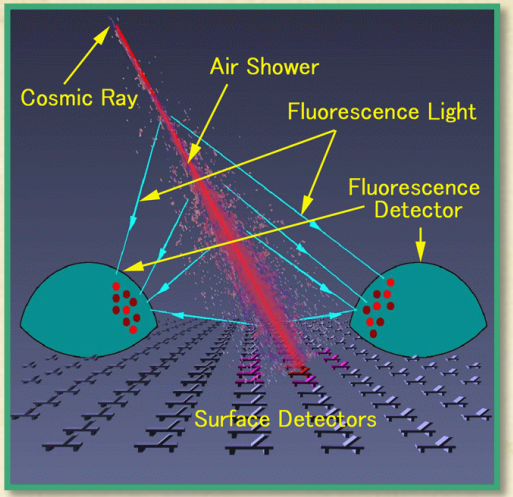


Shower Analysis of FD

Resolutions:
~1 degrees of arrival direction
~7% of energy
~ 20g/cm2 for Xmax

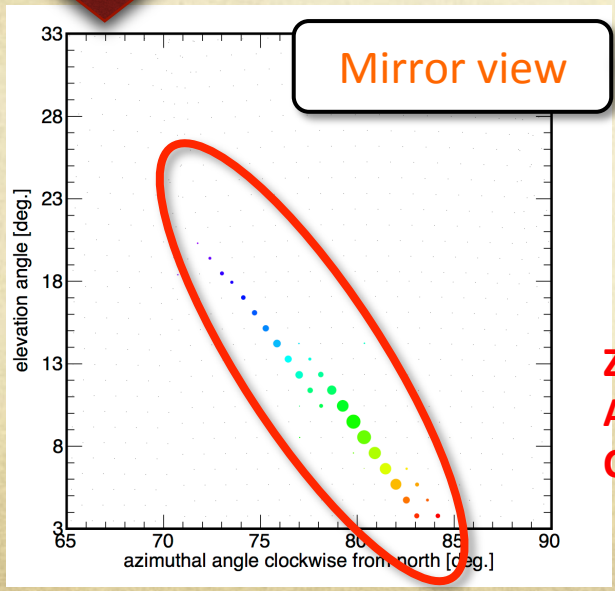
23/Dec/2008, 4:44



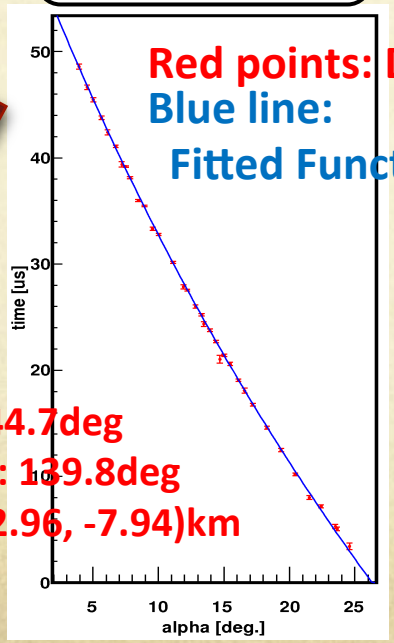


Shower geometry reconstruction:
- Stereo : crossing of two shower-detector planes
- Monocular : timing information of each PMT
- Hybrid : monocular + SD timing

Mirror view

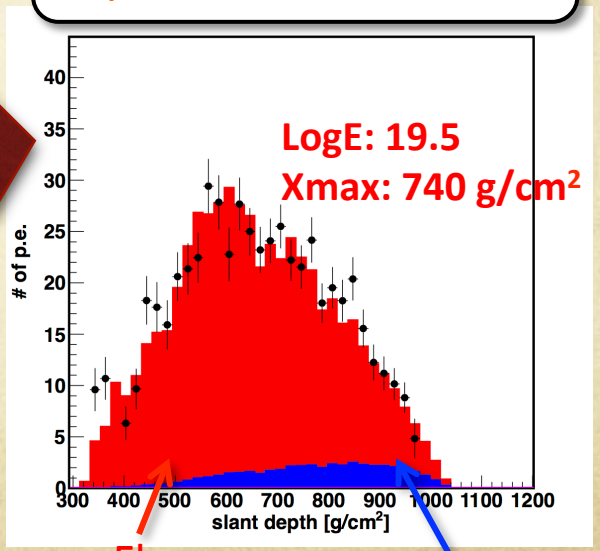


Timing Fit for geometry



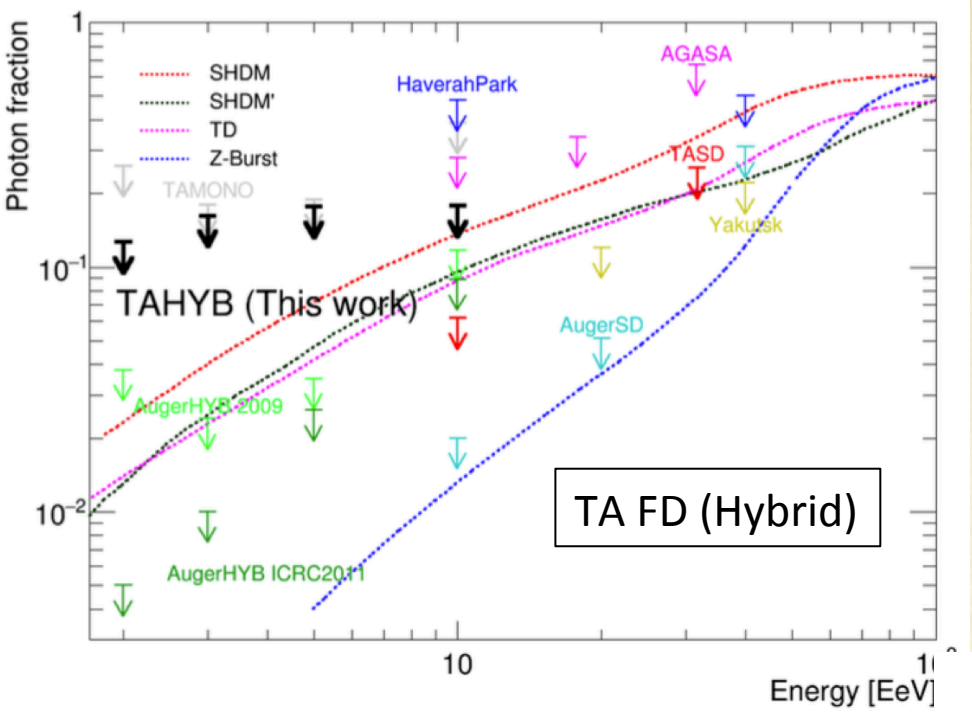
Zenith: 44.7deg
Azimuth: 139.8deg
Core: (12.96, -7.94)km

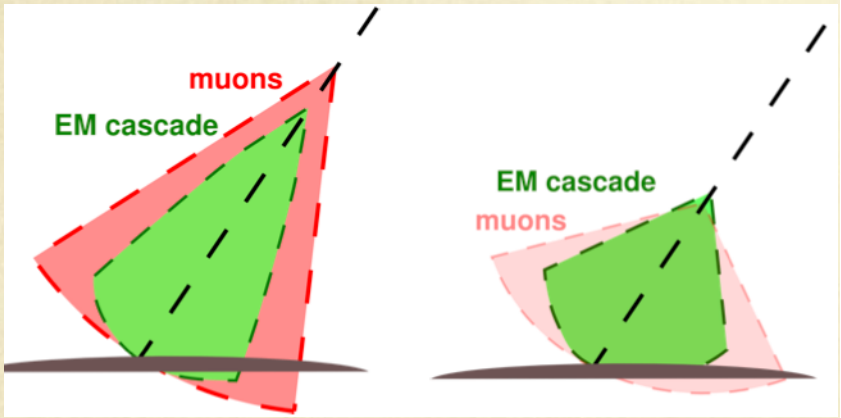
Profile Fit by Inverse Monte Carlo



UHECR photon

Using Xmax measured by the TA FD





- Young shower
- Less muons

→ front coverture, Area-over-peak, number of peaks in FADC, χ2