# The Mass Composition of Ultra-High Energy Cosmic Rays Measured by the Telescope Array Experiment


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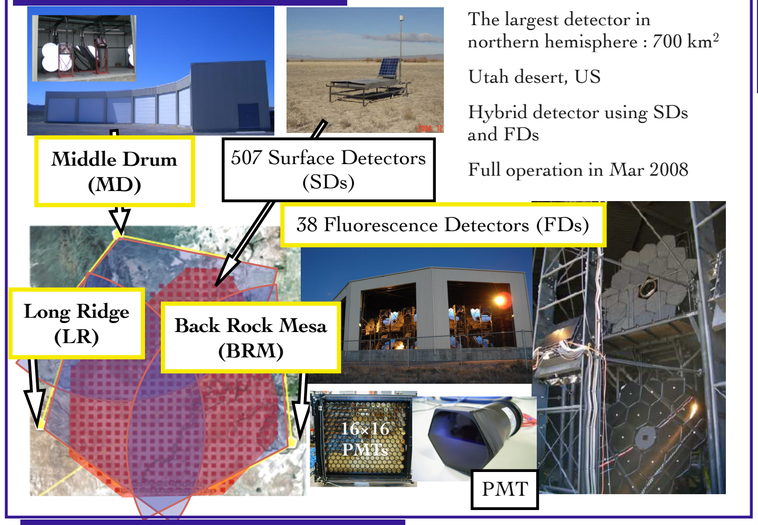
## Abstract


Measurements of the mass composition and its energy dependence are necessary to understand sources and propagations of cosmic rays and to exclude several theoretical models. A longitudinal development of an extensive air shower reaches its maximum at a depth, Xmax, that depends on the species of the primary cosmic ray. Using a technique based on Xmax, we report the mass composition of ultra-high energy cosmic rays from analyses of data observed by fluorescence detectors of the Telescope Array experiment. We summarize results analyzed by three different types of reconstruction procedures which are stereo, monocular and hybrid mode.


## Telescope Array Experiment




The largest detector in northern hemisphere : 700 km$^2$

Utah desert, US

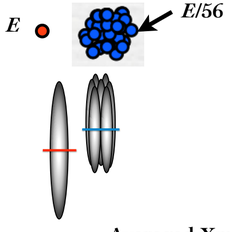
Hybrid detector using SDs and FDs

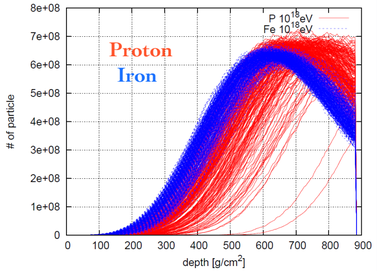
Full operation in Mar 2008

## Mass Composition Measurement

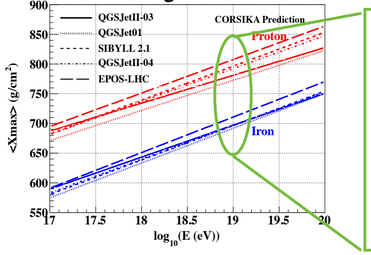
Longitudinal developments for Proton and Iron primaries.

With the same energy, *E*,
Proton(1) Iron(56)

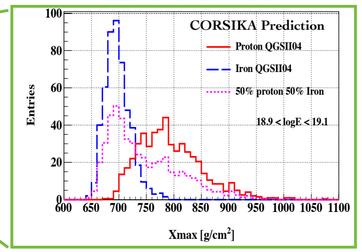



**Averaged Xmax**



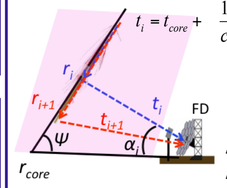

**Xmax distribution**




## Geometry Reconstructions

**Monocular Mode**

Timing fit by one FD station

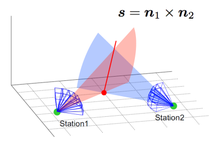



$\Delta\theta \sim 3°$

$\Delta X_{max} \sim 50$ g/cm$^2$

**Stereo Mode**

Intersection of two shower detector planes

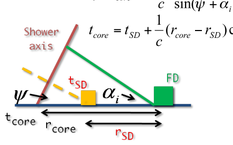



$\Delta\theta \sim 2°$

$\Delta X_{max} \sim 35$ g/cm$^2$

**Hybrid Mode**

Timing fit by both FD and SD




$\Delta\theta \sim 1°$

$\Delta X_{max} \sim 25$ g/cm$^2$

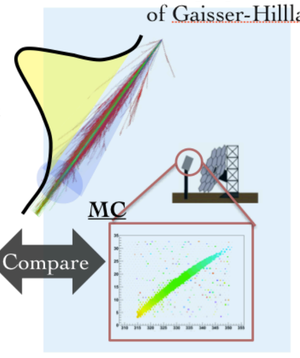
## Shower Profile Reconstruction

Reconstructed Shower Geometry

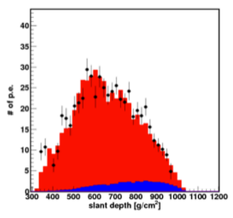
Shower simulation based on G.H.Function

**Inverse Monte Carlo**

Repeatedly simulates shower images with changing longitudinal development parameters of Gaisser-Hilllas (G.H.) function.




Signal at camera




Plot: Data
Histogram(Red): Fluorescence (MC)
Histogram(Blue): Cherenkov (MC)

Size = brightness, Timing Blue⇒Red

## Reconstruction Bias on Xmax (Monocular Mode)

Thrown Xmax (CORSIKA Prediction)

CORSIKA shower generation

Averaged Xmax

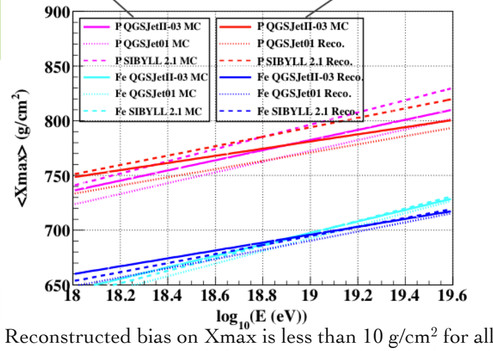
Reconstructed Xmax (With detector simulation)

CORSIKA shower generation

Detector simulation

Reconstruction and quality cuts

Averaged Xmax

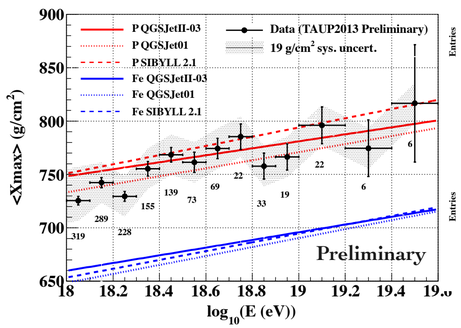


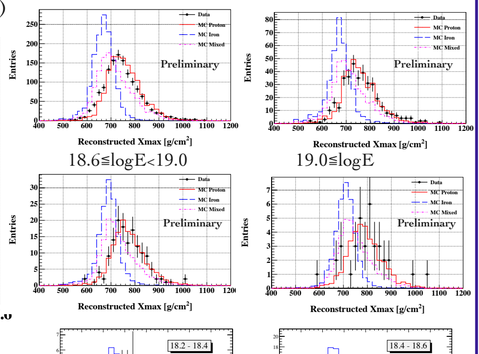

Reconstructed bias on Xmax is less than 10 g/cm$^2$ for all species and models in the monocular analysis

## Mass Composition Result

**Monocular Mode (T.Fujii, TAUP2013)**

(BRM and LR monocular, 2008/Jan ~ 2011/Sep)




**Stereo Mode (Y.Tameda, ICRC2013)**

(BRM and LR stereo, 2007/Nov ~ 2012/Nov)







**Hybrid Mode (M. Allen, ICRC2013)**

(MD hybrid, 2008/May ~ 2012/May)







## Conclusion

The fluorescence detectors of the Telescope Array experiment have been taking steady measurements of ultra-high energy cosmic rays since early 2008. From the monocular, stereo and hybrid analysis, we have measured the mass composition of cosmic rays using the Xmax technique. The obtained averaged Xmax and its distributions indicate a proton dominant composition at energies above $10^{18}$ eV.