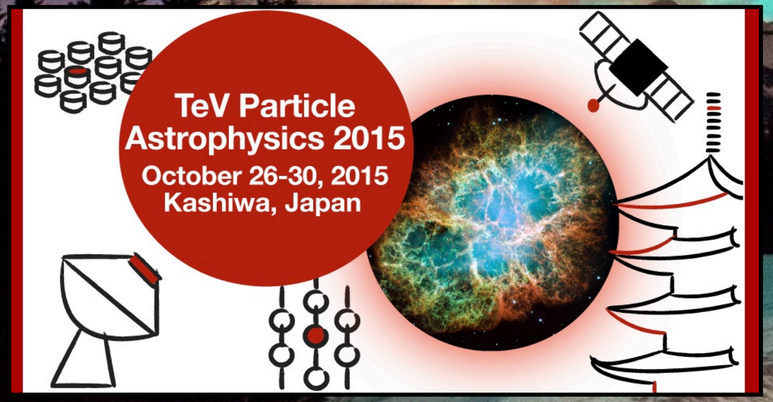
Energy Spectrum Measured by the Telescope Array Experiment in $10^{15.6}$ eV to $10^{20.3}$ eV Range



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October 26th, 2008

Image Credit: Brett Abernethy

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[2] Deceased

Japan, USA, Korea, Russia, Belgium

Telescope Array Experiment (TA)

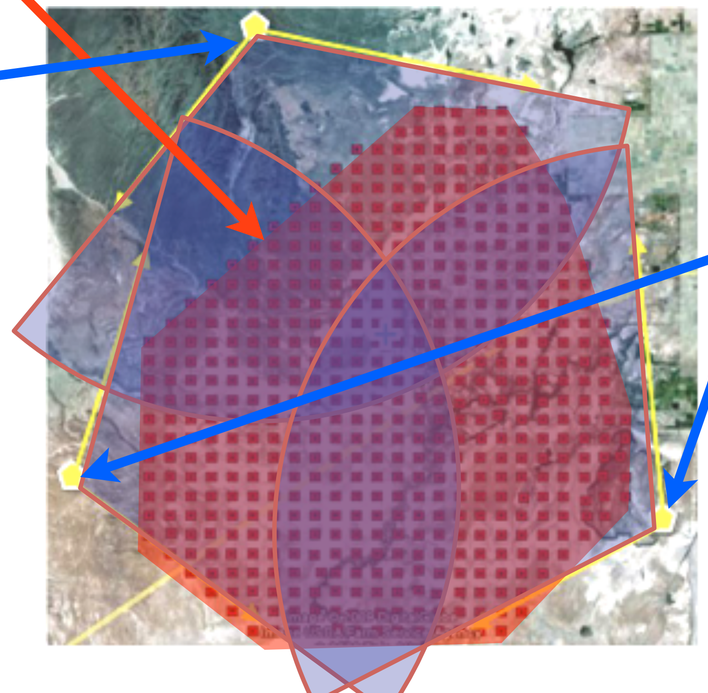
- **Largest cosmic ray detector in the Northern hemisphere**
  ~ 700 km^2 at Utah, USA
- Fluorescence detector + Surface detector array

Surface Detector Array

507 Scintillator, 1.2 km spacing

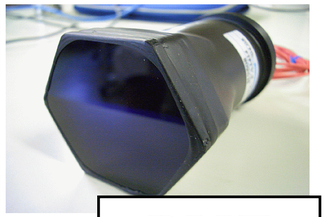
Fluorescence detector at MD station

Refurbished
from HiRes experiment,
Spherical mirror 5.2 m^2,
256 PMTs/camera,
14 telescopes

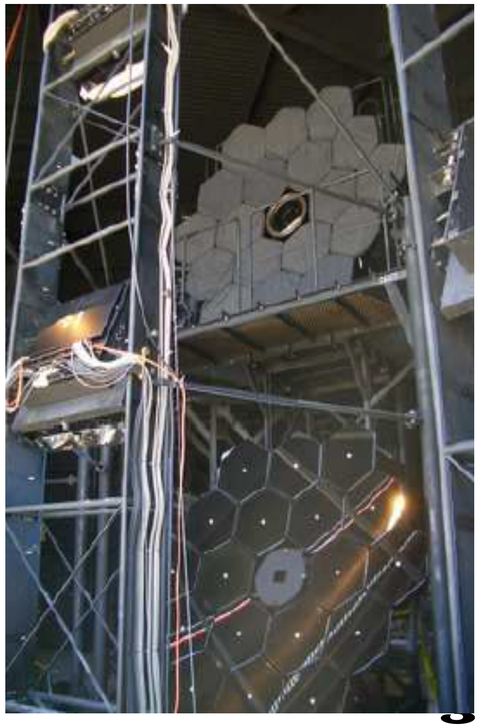


Fluorescence Detector at BRM and LR stations

Spherical segment mirror (6.8 m^2) + 256 Photomultiplier tube(PMTs)/camera, 12 newly designed telescopes

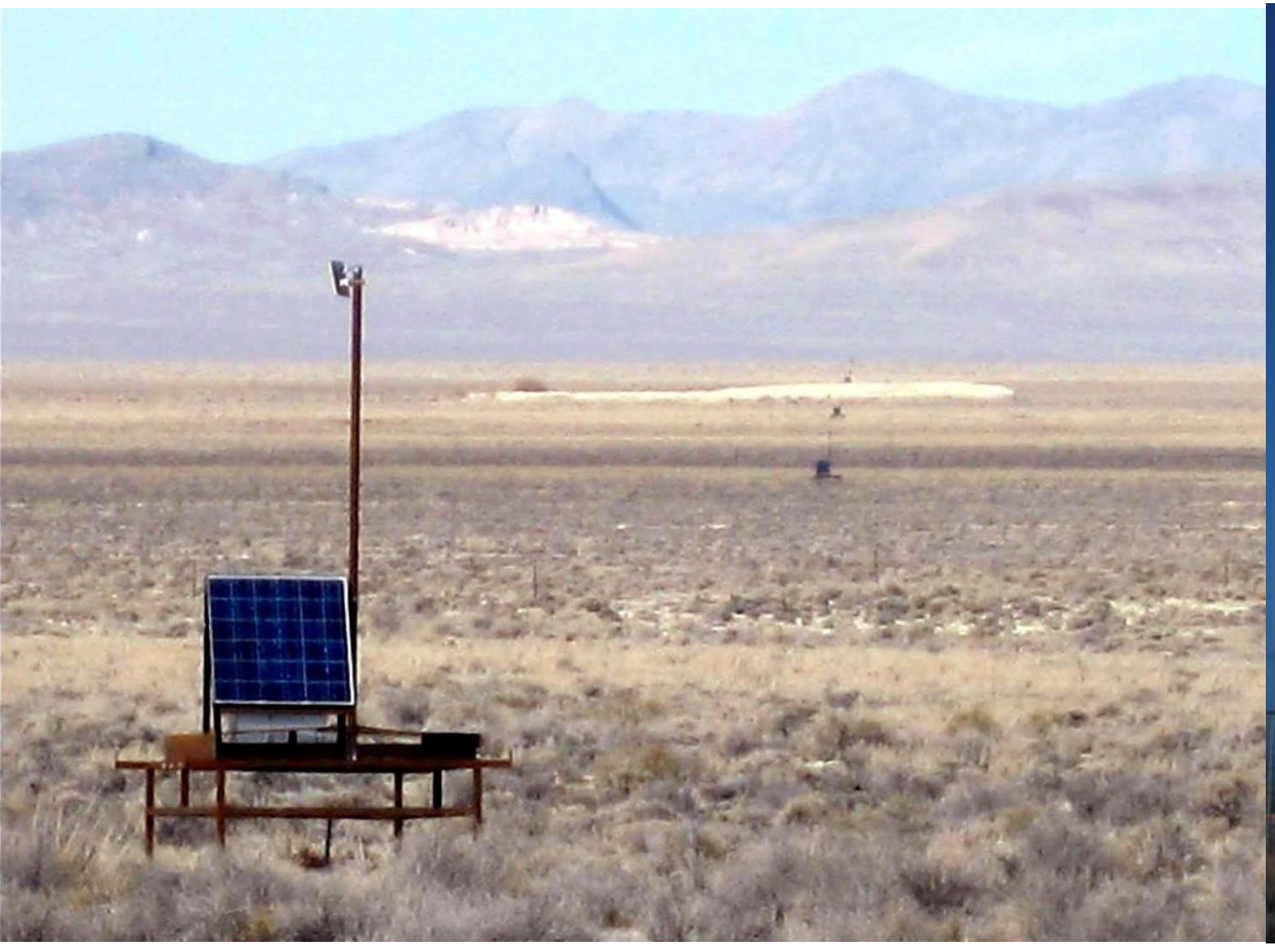


PMT



Telescope Array Experiment (TA)

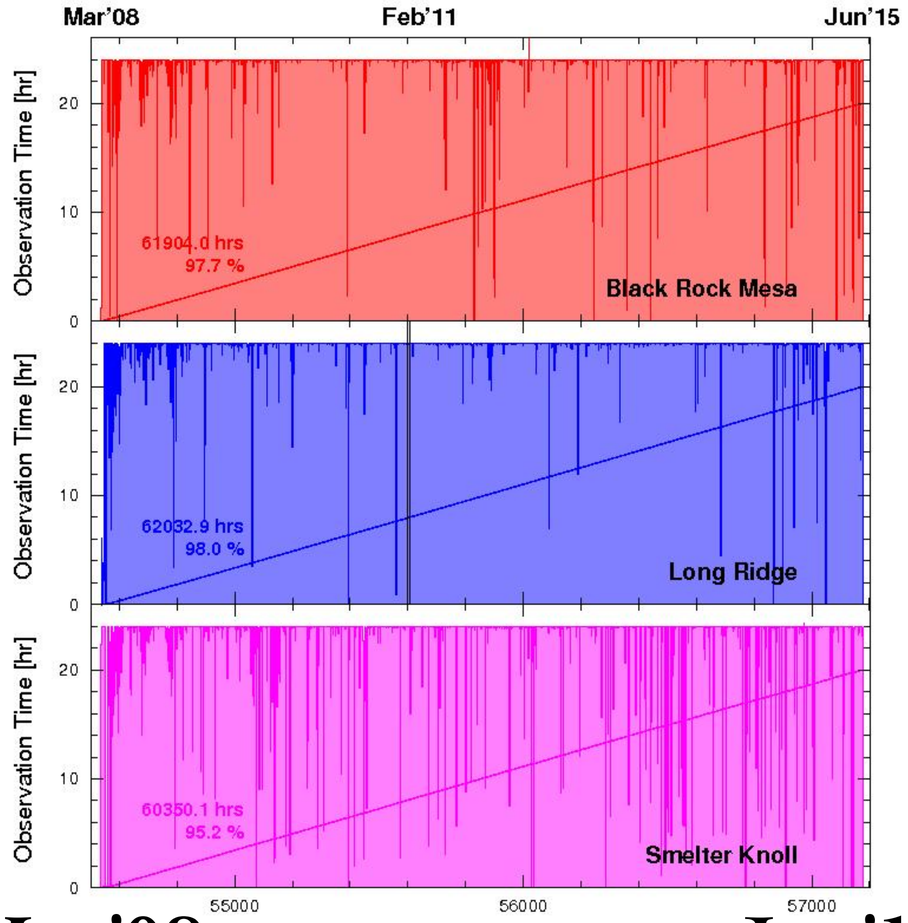
Surface detector array (SD) Fluorescence detector (FD)



7 Years Steadily Operation

Surface detector array (SD)

~100% duty operation

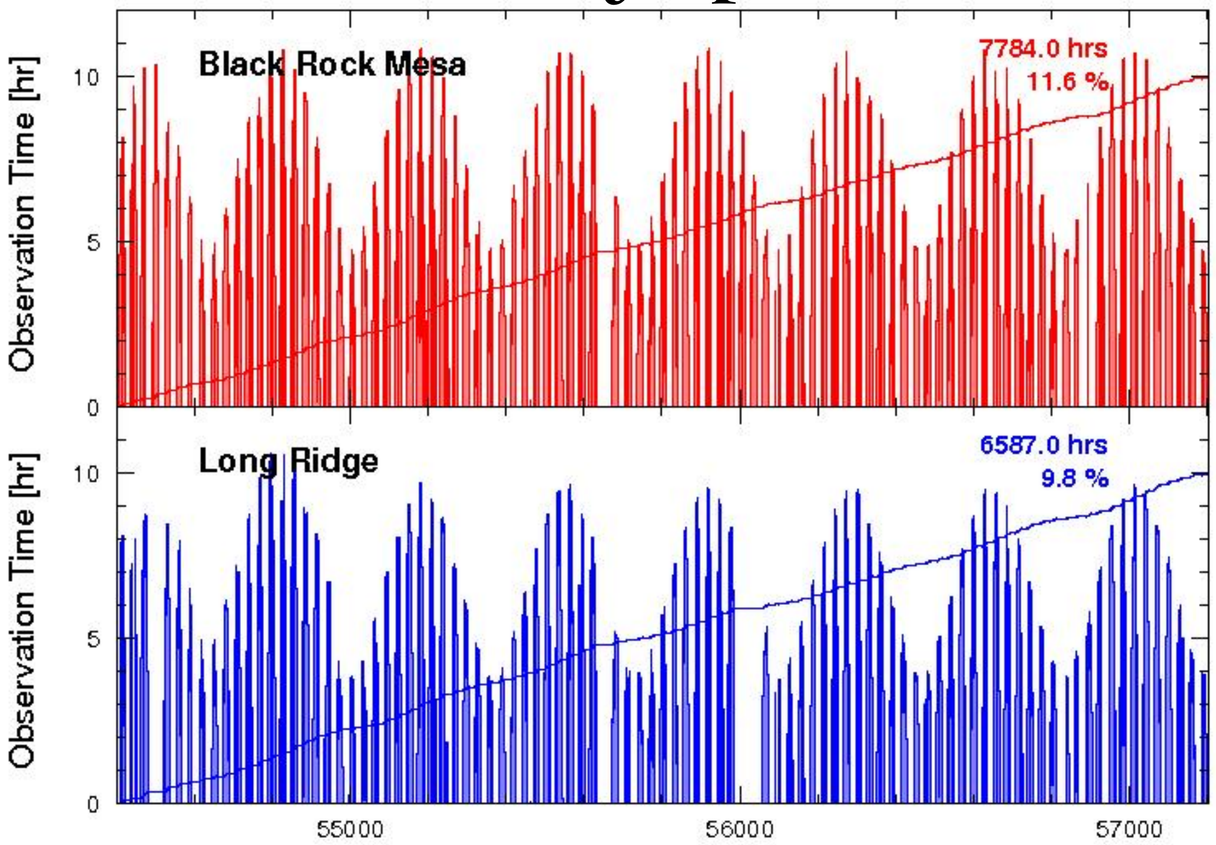


Mar'08 Jun'15

Fluorescence detector (FD)

Clear moonless night

~10% duty operation



Nov'07 Jun'15

... to Observe Extensive Air Shower (EAS) induced by Ultra-High Energy Cosmic Ray (UHECR)

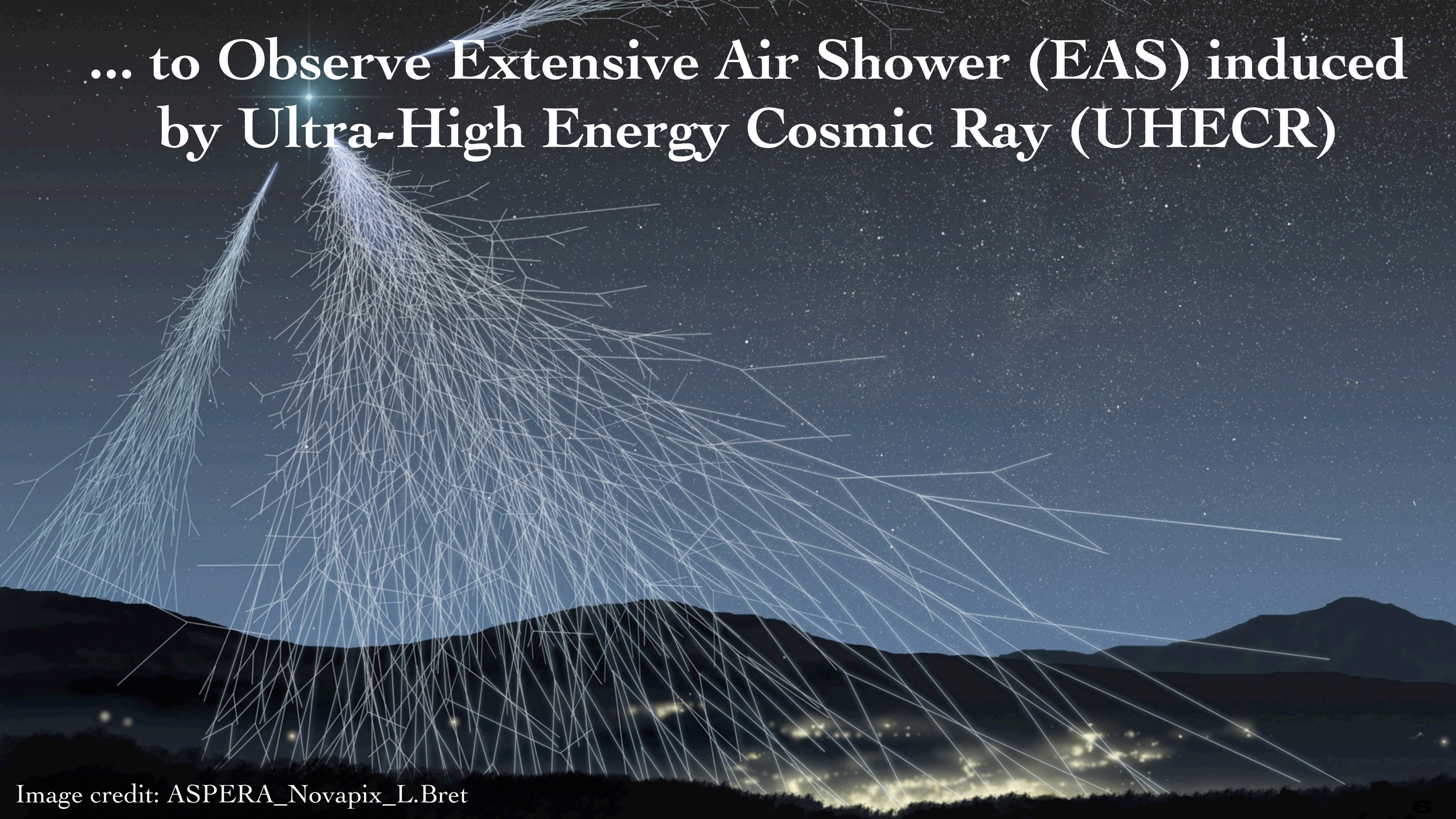
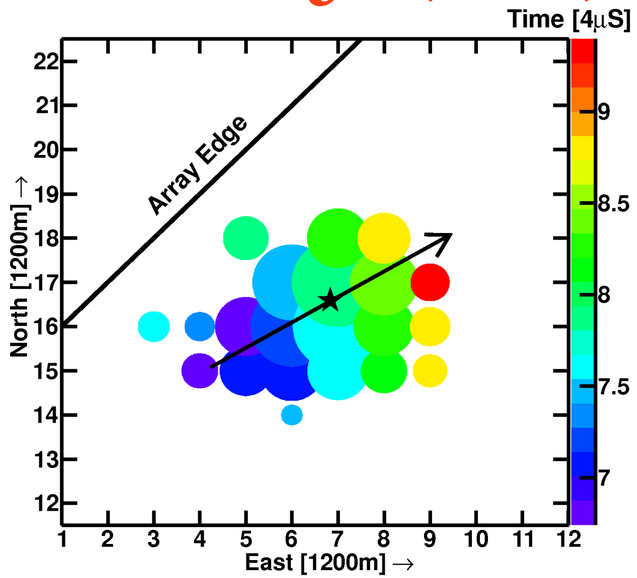


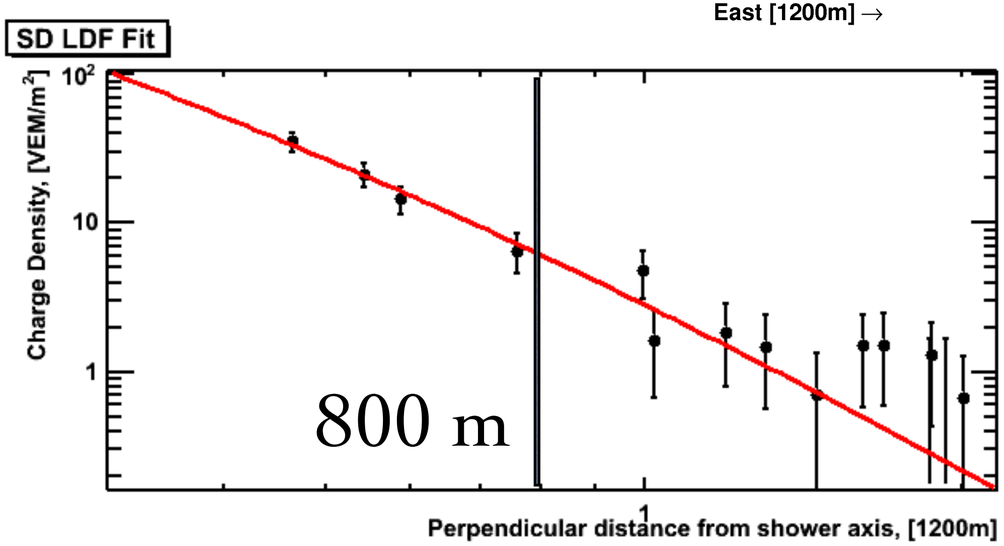
Image credit: ASPERA_Novapix_L.Bret

Observed UHECR Event

Surface detector array (SD)

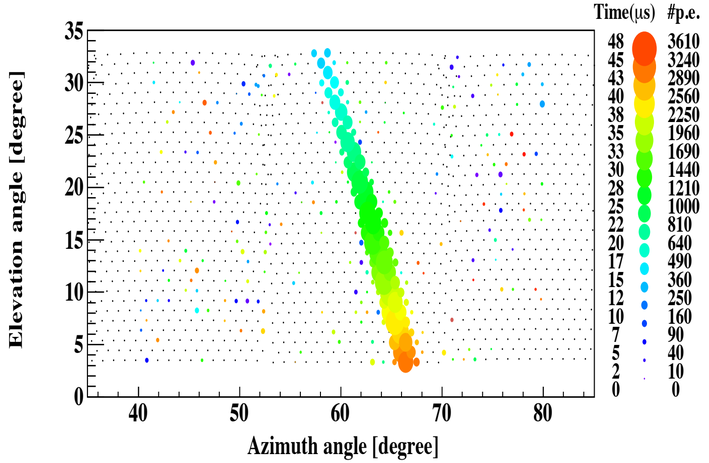
- Observe lateral density distribution
- Charge density at 800 m, S_{800} as energy indicator

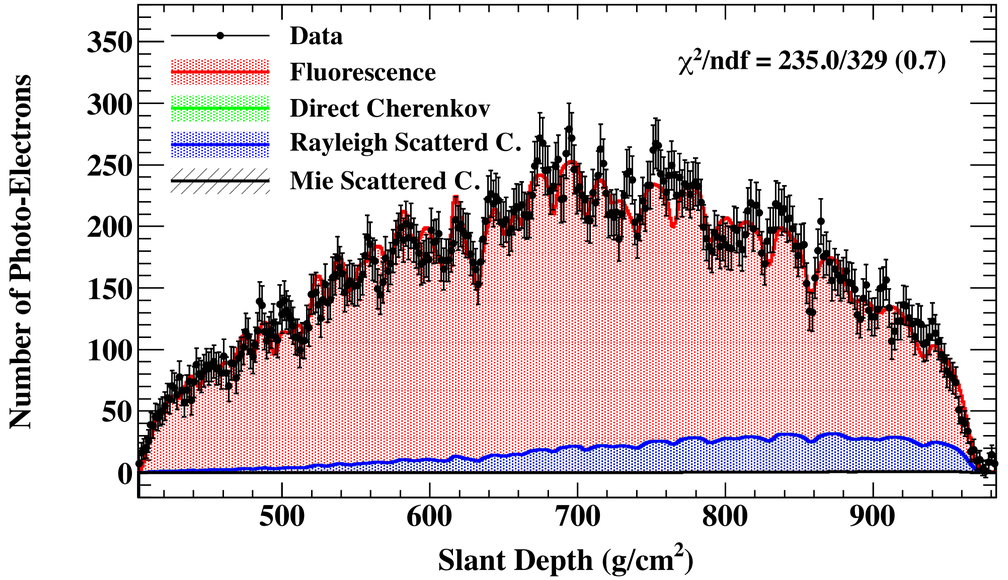




Fluorescence detector (FD)

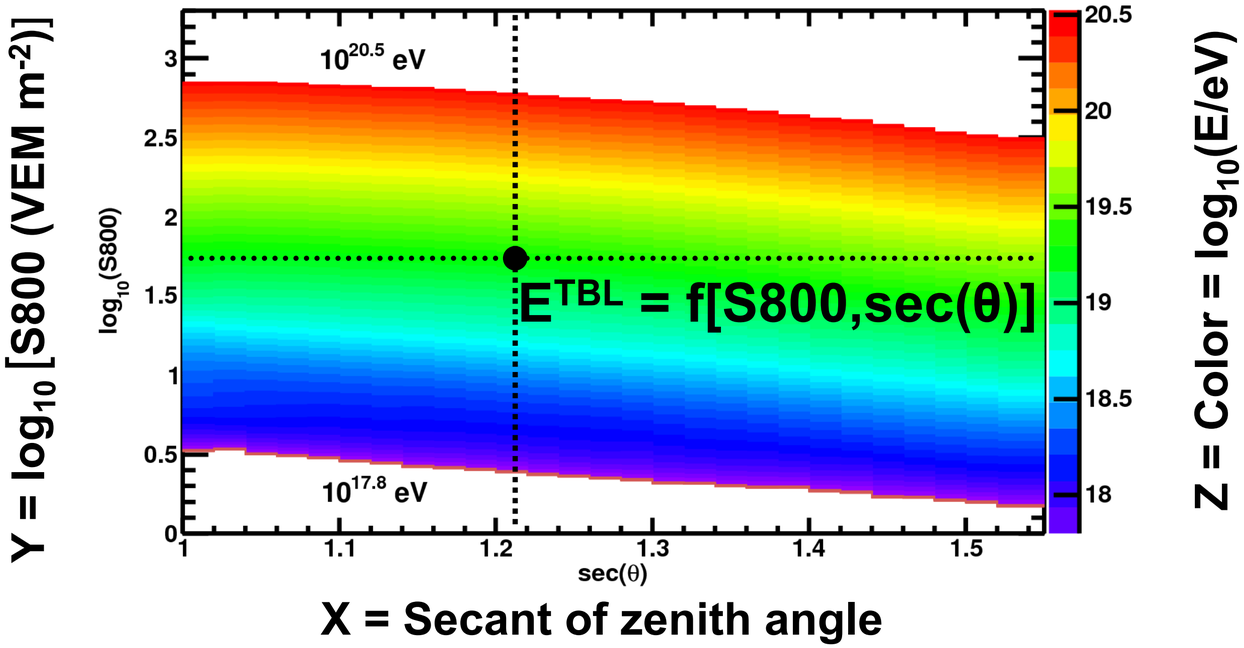
- Observe longitudinal development
- Reconstruct **calorimetric energy**

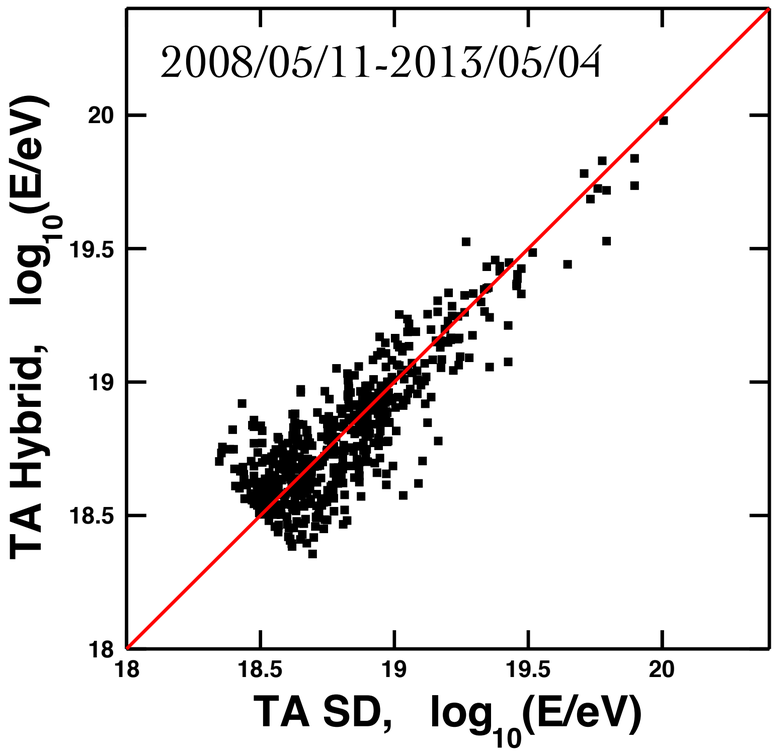




Energy Estimation by TA SD

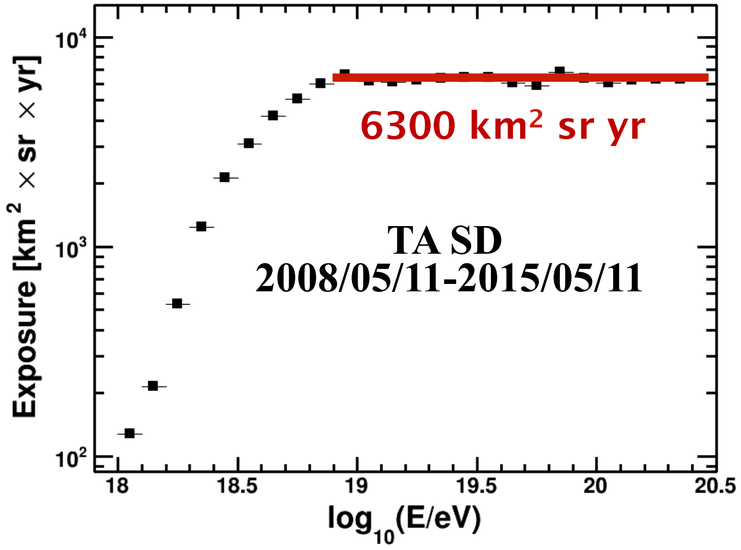
- A look up table made from Monte Carlo simulation
- Event energy E_{TBL} = function of S_{800} and zenith angle, sec(θ)
- E_{TBL} is rescaled by the FD reconstructed energy to estimate final energy of SD, $E_{SD,final}$
- **$E_{SD,final} = E_{TBL}/1.27$,**
- **<20% resolution above 10^{19} eV**

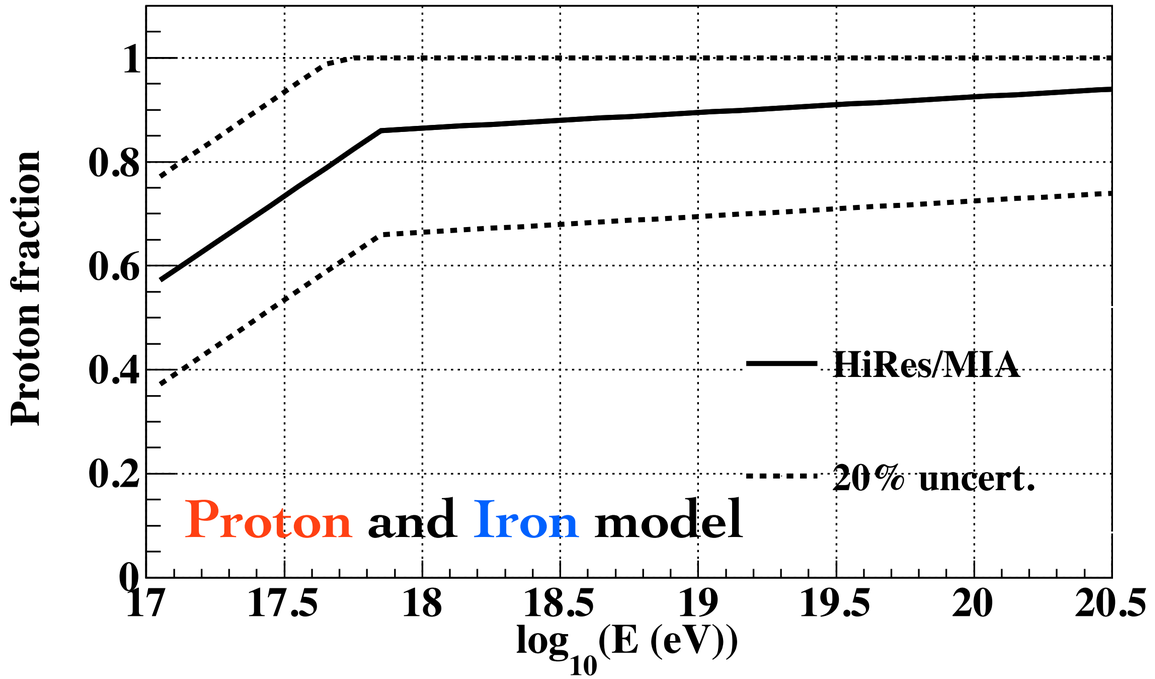


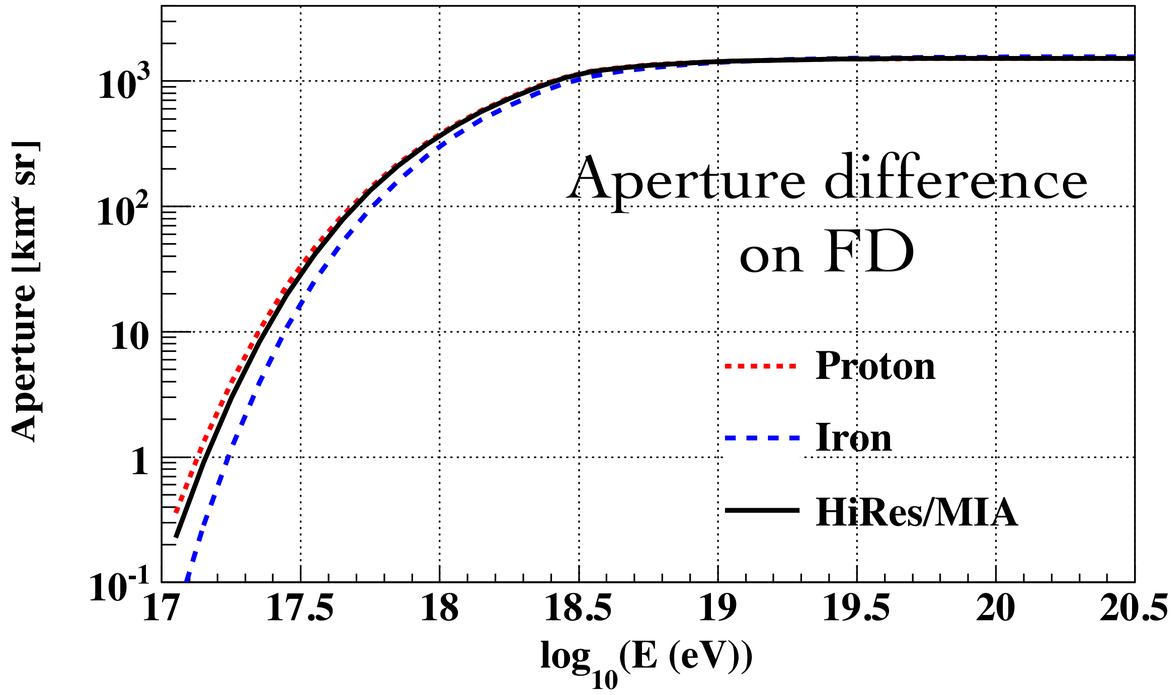


Aperture, Exposure Calculation

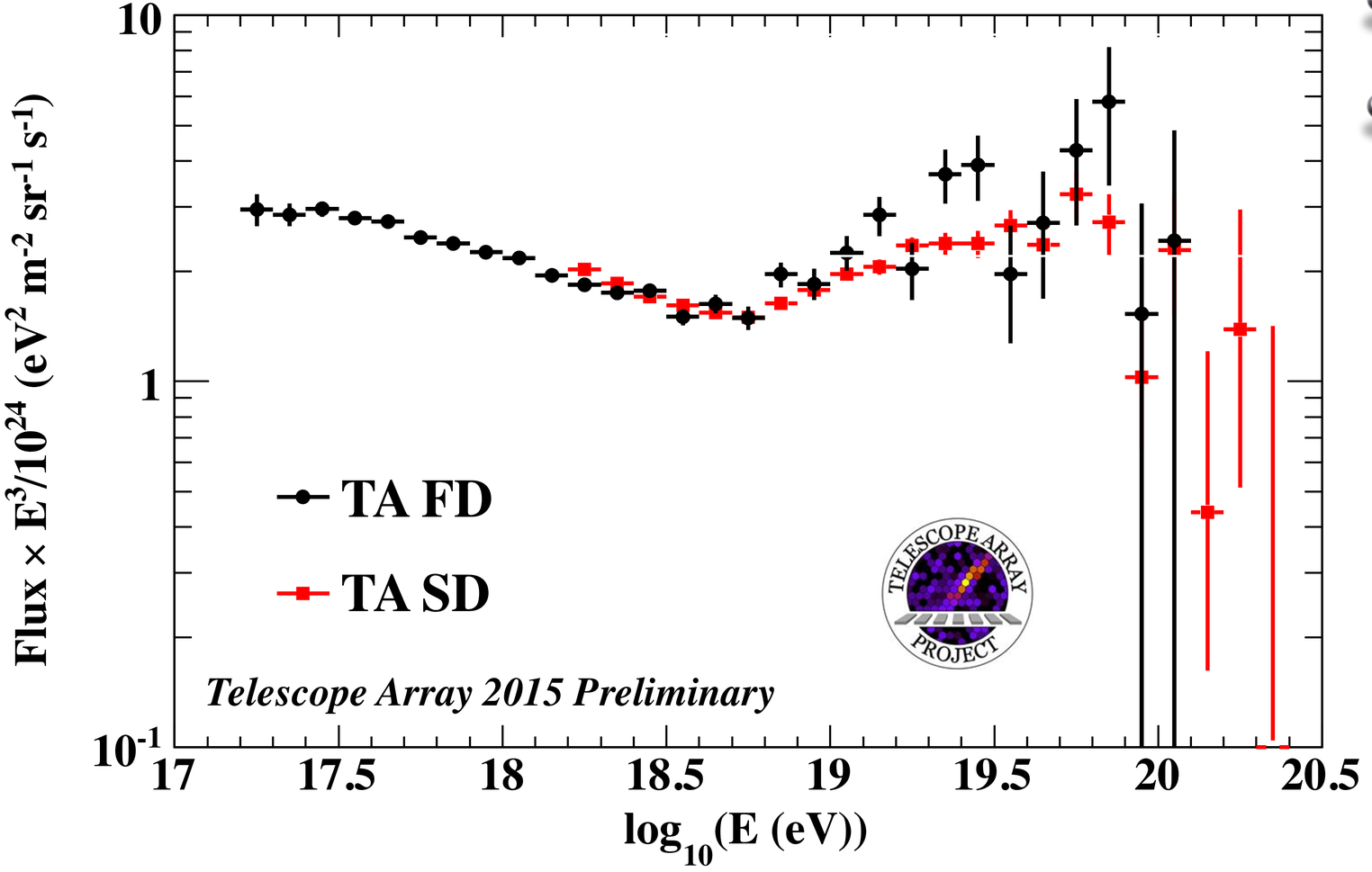
- Detailed Monte Carlo used for aperture calculation in all measurement of TA. Exposure = Aperture × live-time.
- FD aperture needs to assume mass composition.
- Use the proton fraction measured by the HiRes/MIA experiment with 20% uncertainty [Astrophys. J. 622 (2005) 910].







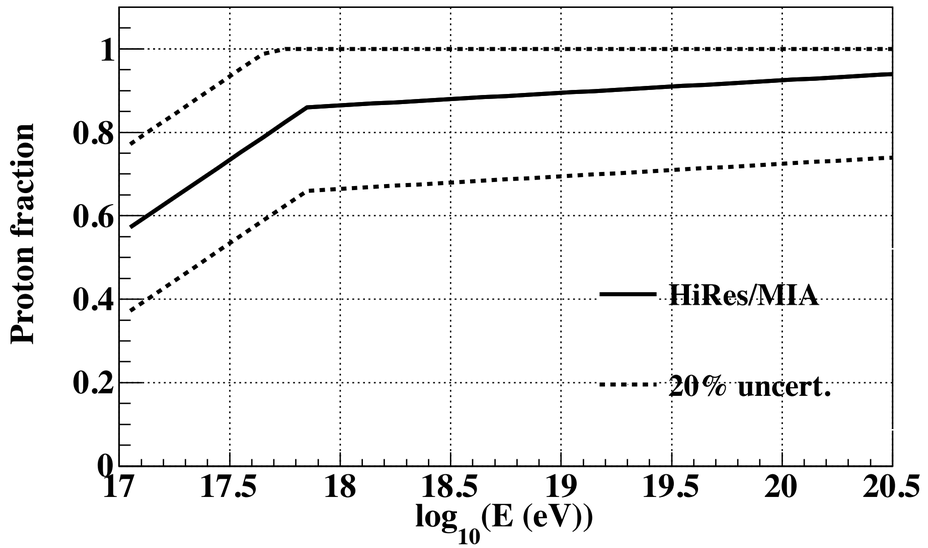
Energy Spectrum from TA FD and SD

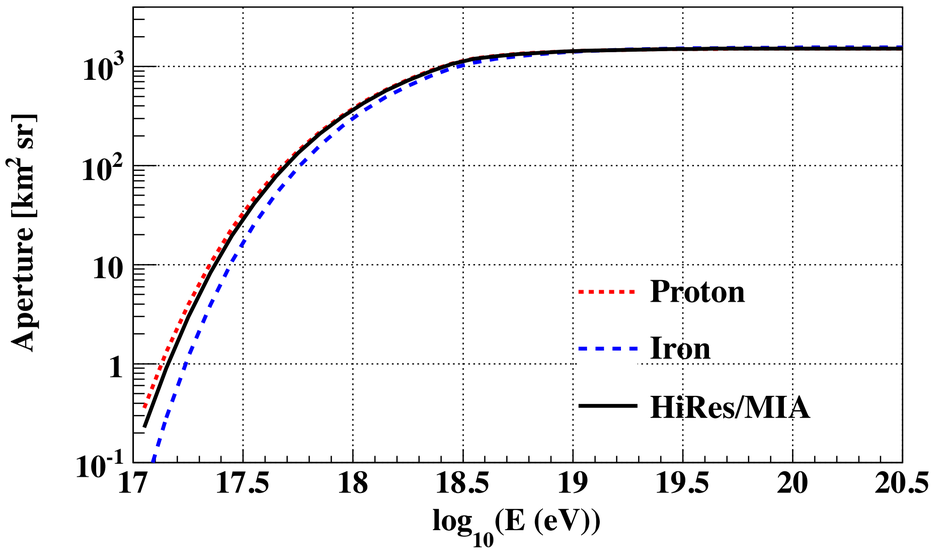


- Ankle at log$E$=18.72±0.02,
- Suppression at log$E$=19.78±0.05

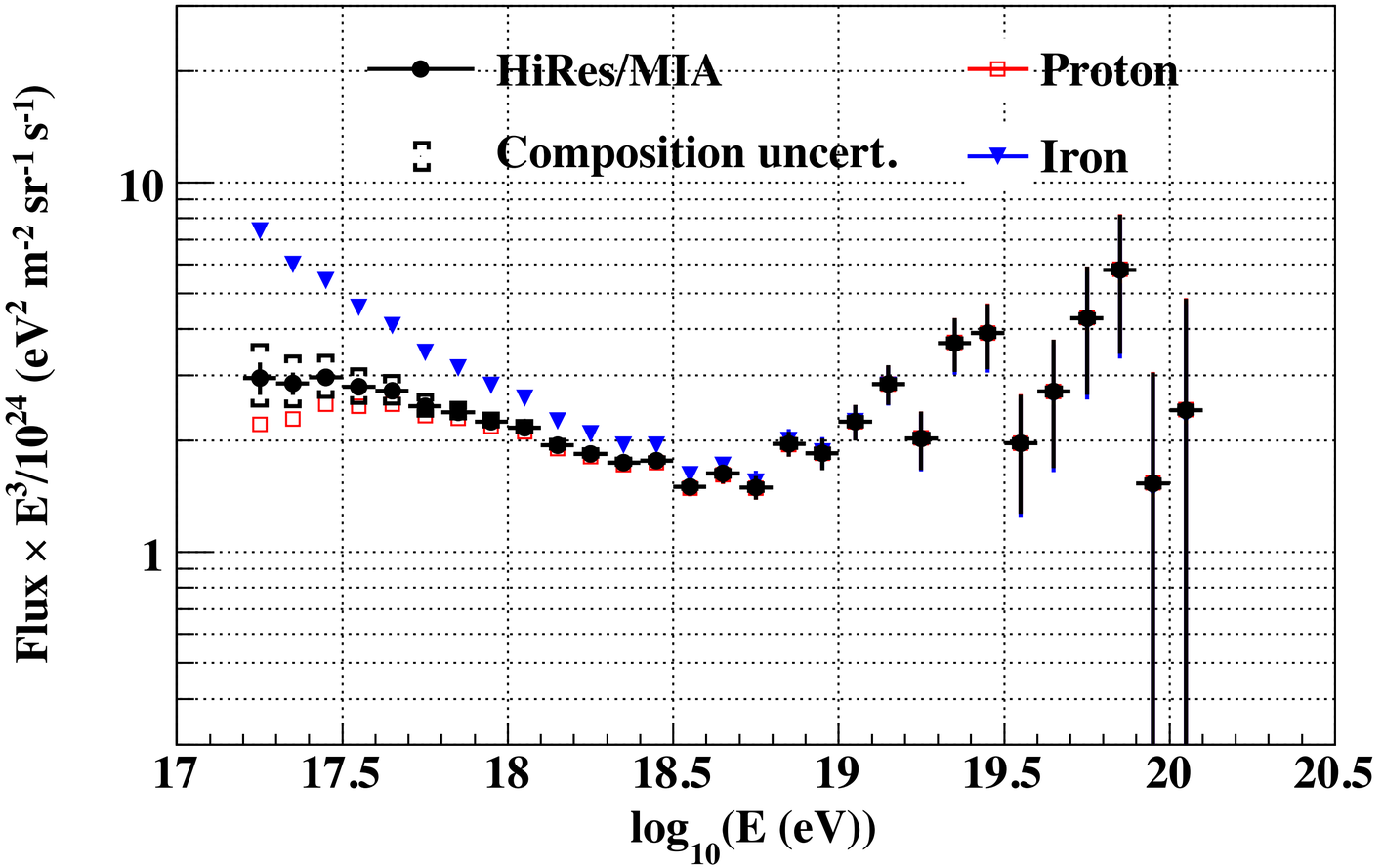
Item	Uncertainty
Fluorescence	11%
Atmosphere	11%
Calibration	10%
Reconstruction	9%
Total	**21%**

Uncertainty attributed to Proton Fraction Assumption

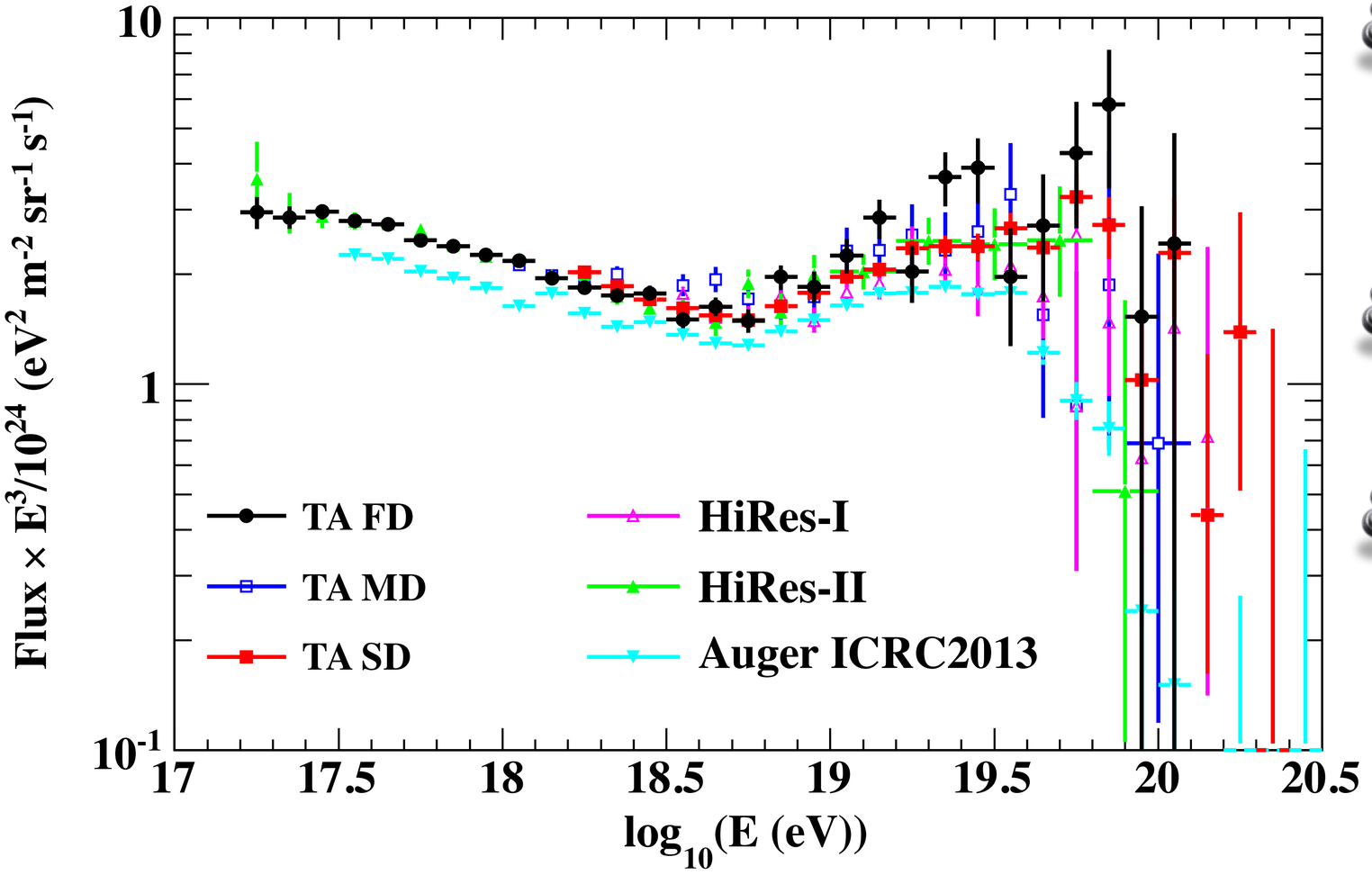




- Change the proton fraction by the uncertainty of HiRes/MIA of ±20%, and recalculate aperture of FD.
- Calculated the energy spectrum with those aperture.

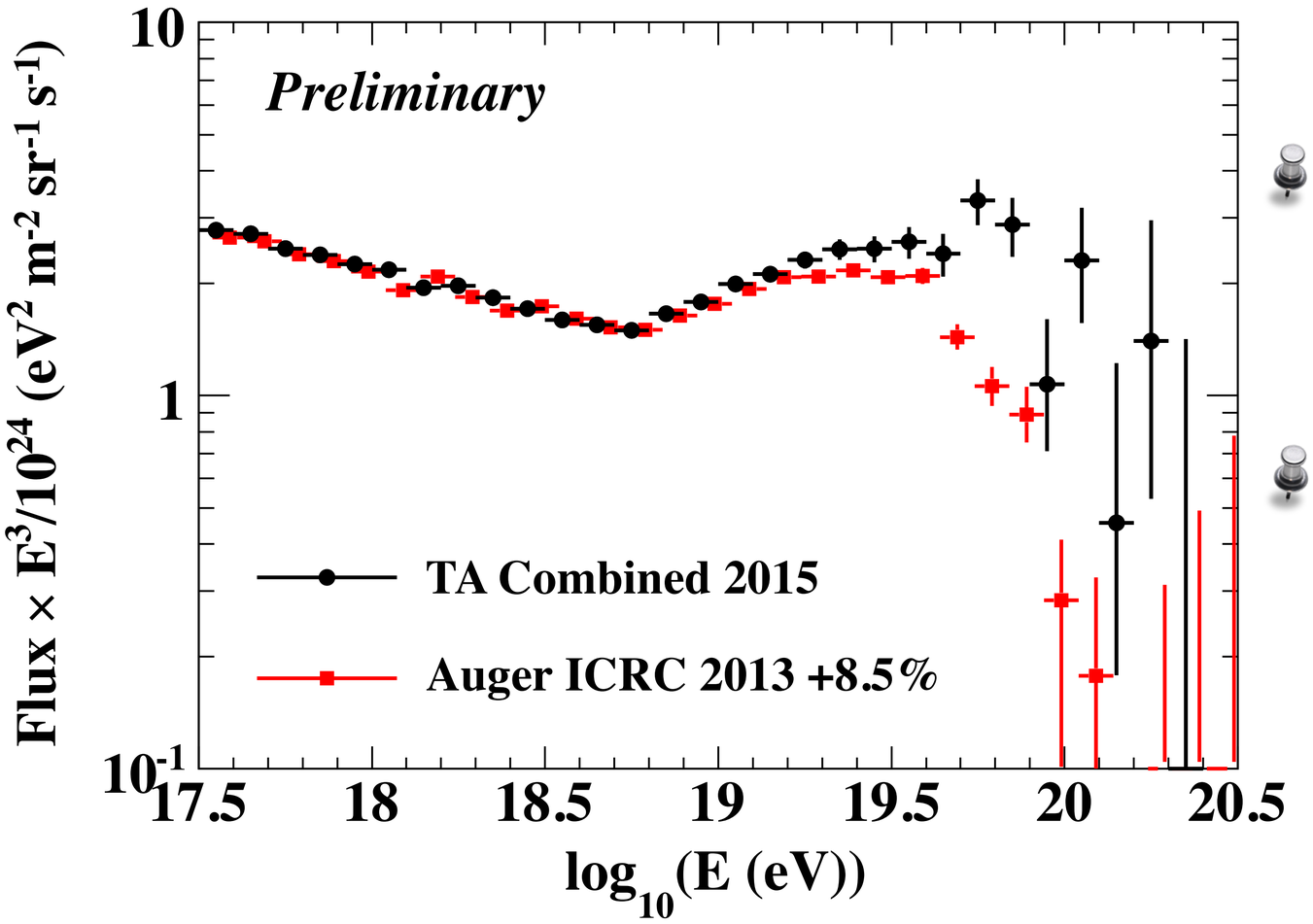


Comparison with Other Measurements



- Consistent with the HiRes result in a broad energy range
- Consistent with TA MD result
- 8.5% difference with Auger result around ankle, however consistent within systematics uncertainty.

Discrepancy on the Suppression

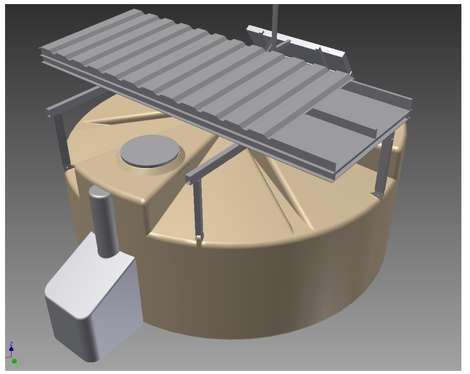


- Even if we correct the energy difference, the suppression shows large discrepancy above $10^{19.3}$ eV.
- Possible reasons of discrepancy: fluorescence yield, atmospheric model, missing energy correction, detector: scintillator or water-tank, Northern/Southern hemisphere.
- **TA×4 : fourfold statistics at the suppression**

Water-tank installed at TA site

R. Takeishi et al, ICRC 2015

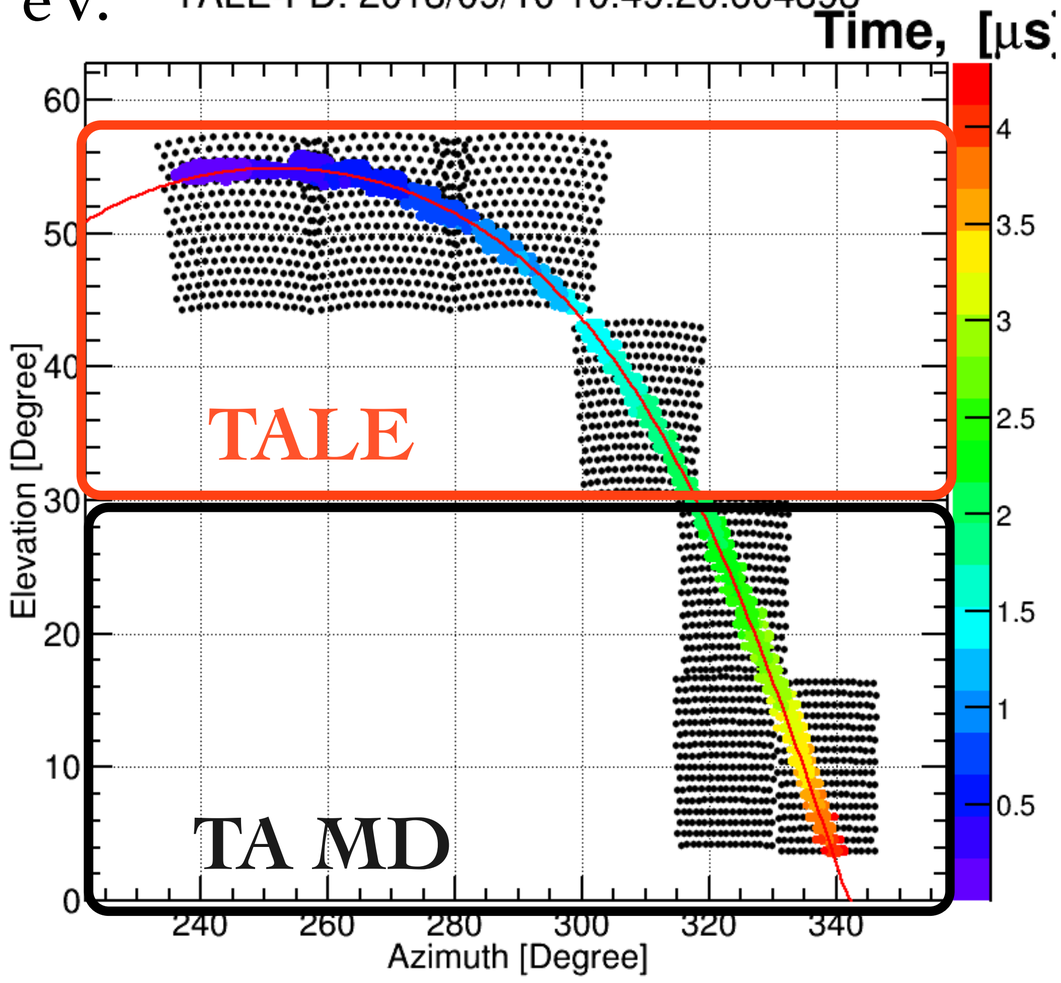
Scintillator on Water-Tank (AugerPrime)



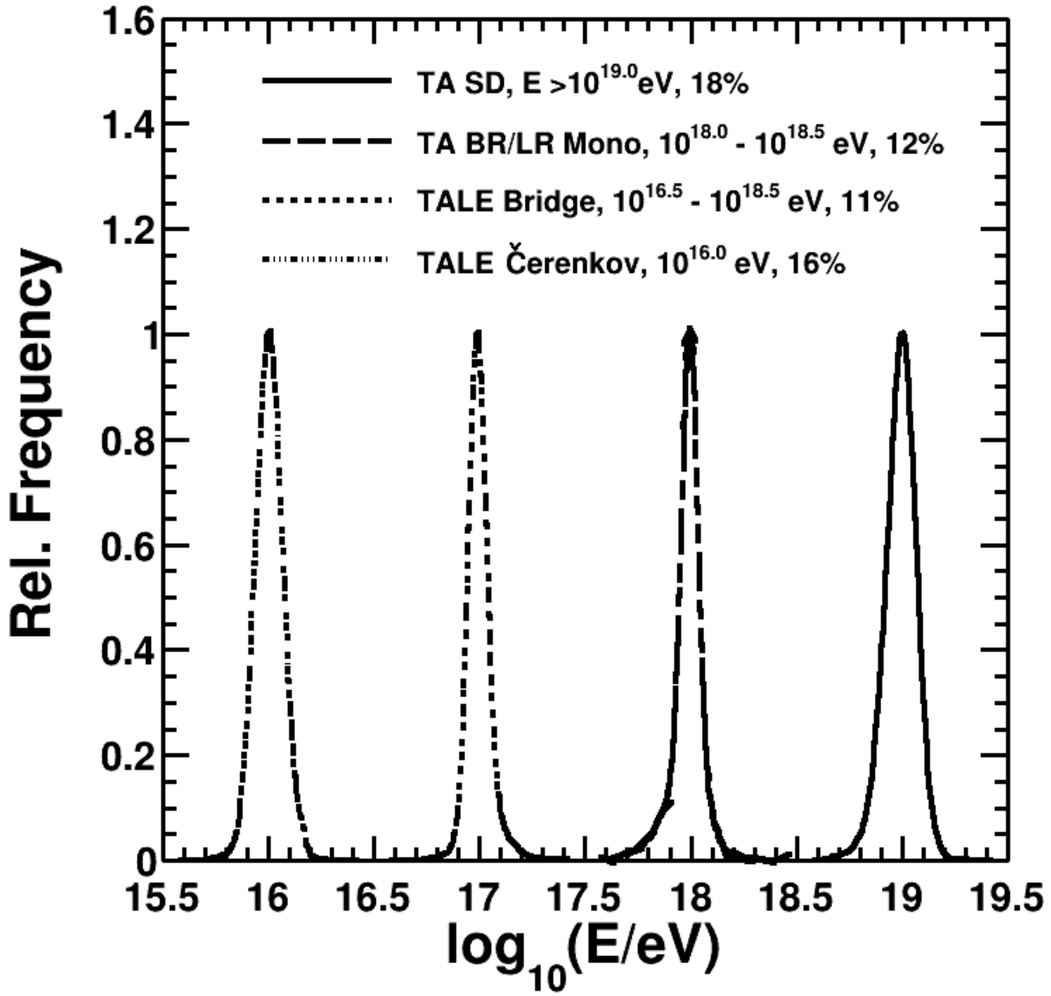
R, Engel et al, ICRC2015

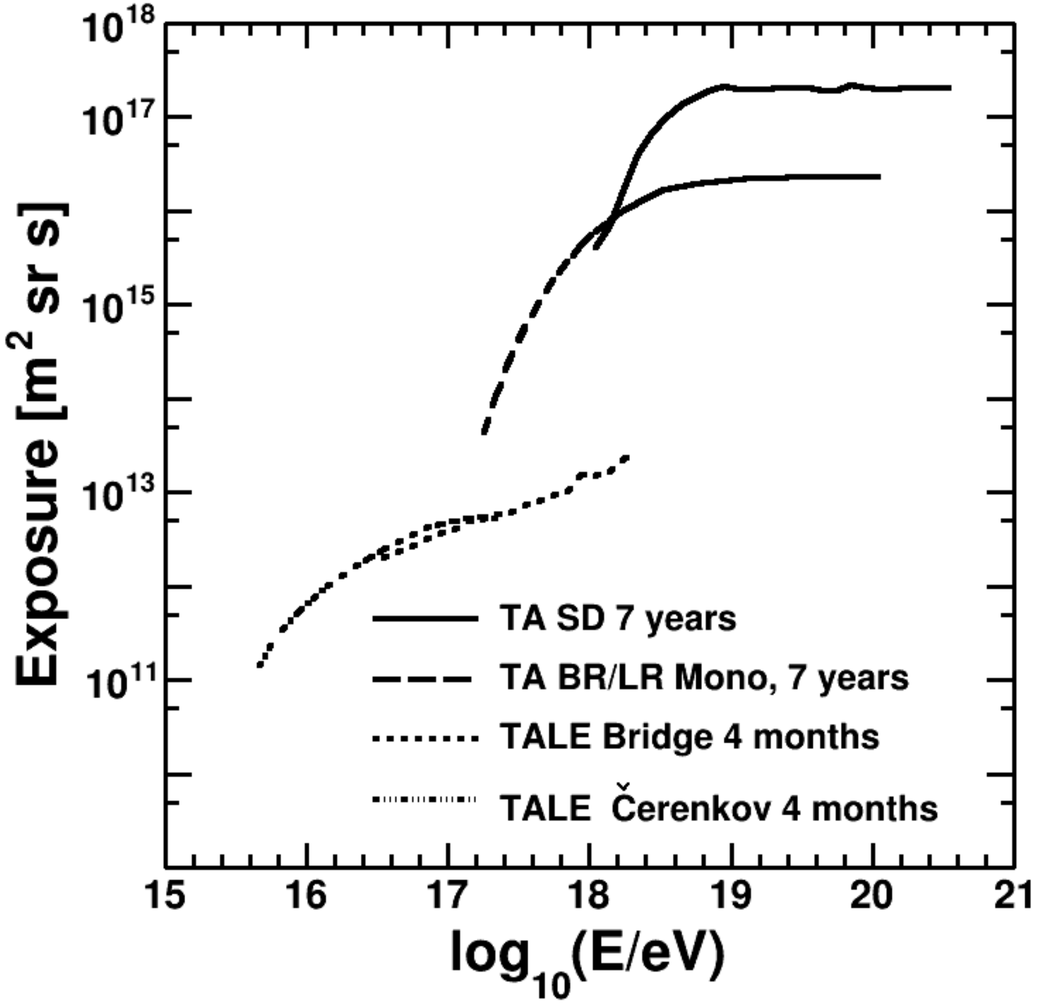
Further Lower Energy = TALE (Telescope Array Low-energy Extension)

- Enlarge field of view of FD in elevation to observe lower energy showers down to $10^{15.6}$ eV.
- > $10^{17.4}$ eV Fluorescence dominated
- < $10^{17.4}$ eV Cherenkov dominated

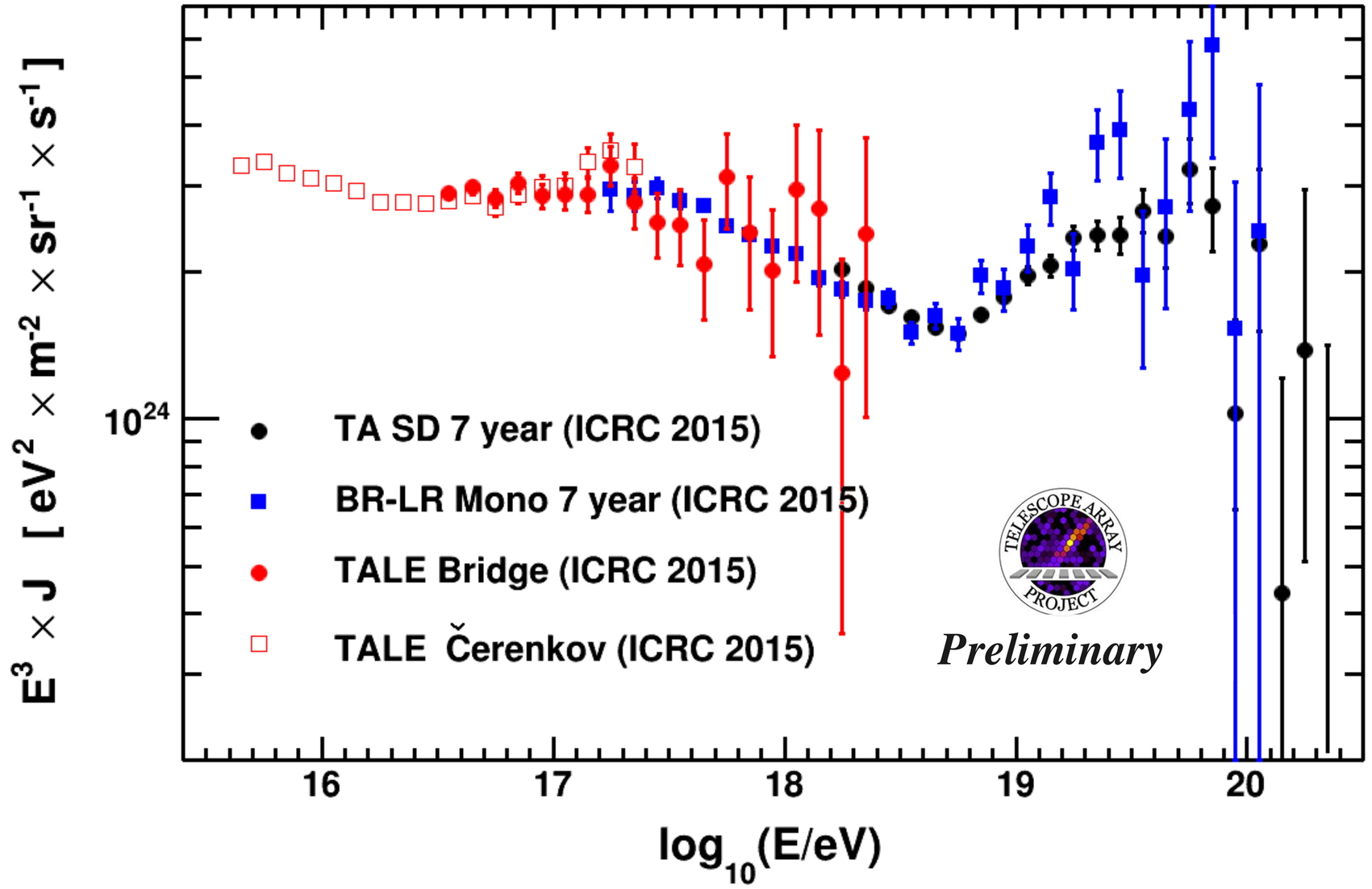


Resolution and Exposure as a Function of Energy

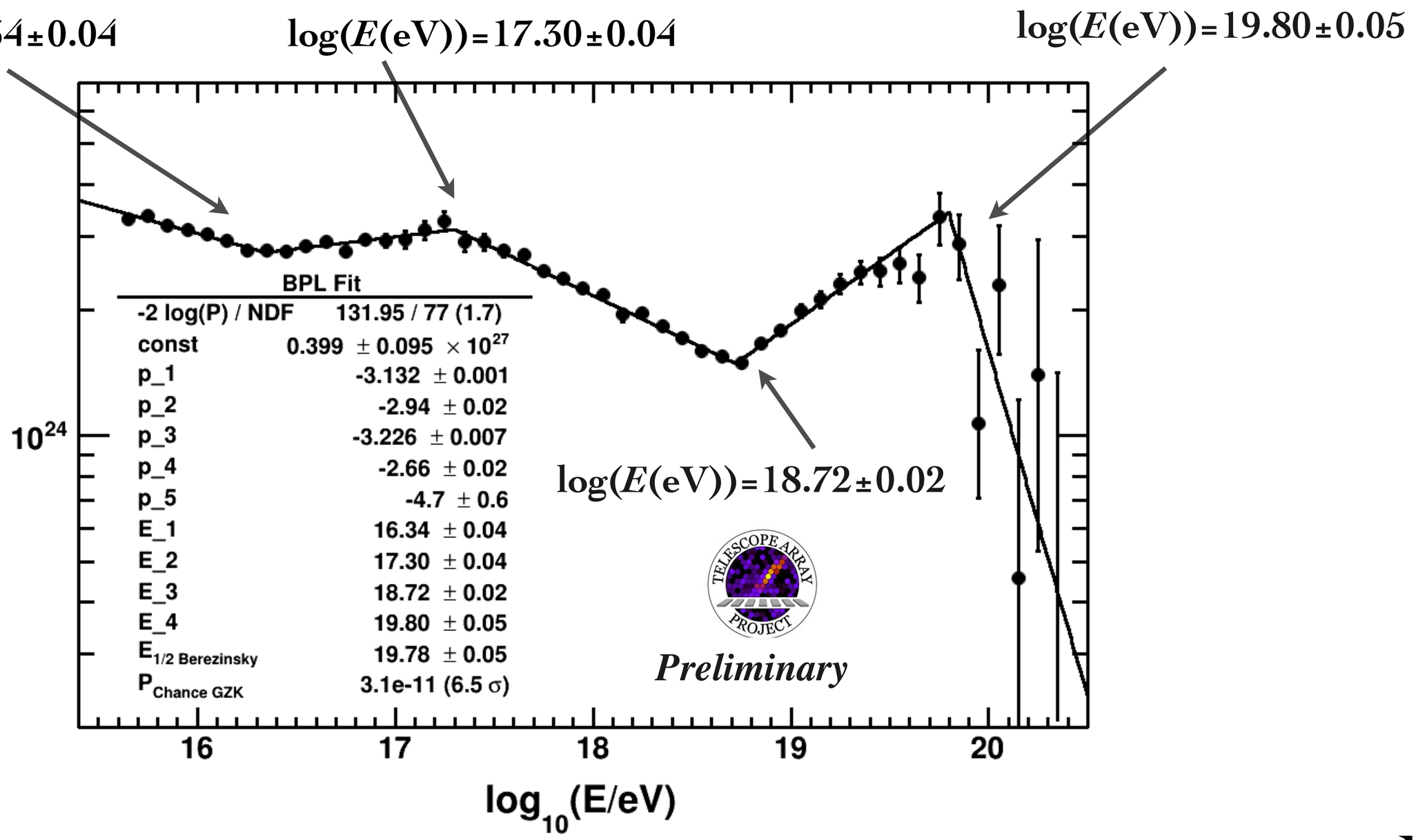




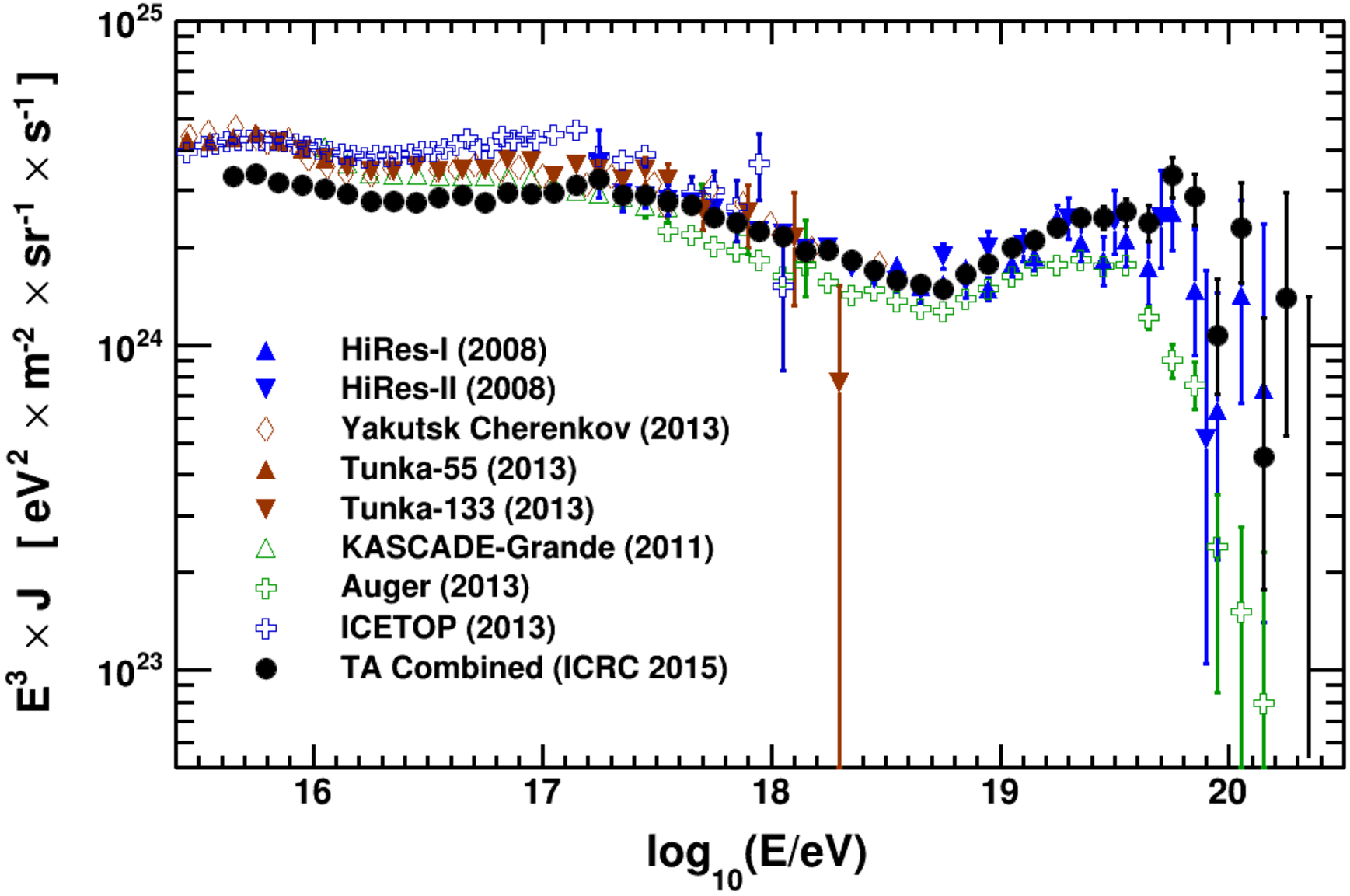
Energy Spectrum in $10^{15.6}$ eV to $10^{20.3}$ eV
TALE + TA FD + TA SD



Combined Spectrum and Fitted Result



Comparison with other Measurements



Summary and Future Plans

- TA measured the energy spectrum over **4.7 orders** of magnitude in **$10^{15.6}$ eV to $10^{20.3}$ eV** range.
- 4 features seen: **low energy ankle at $10^{16.34}$ eV, 2nd knee at $10^{17.30}$ eV, ankle at $10^{18.72}$ eV, suppression at $10^{19.80}$ eV**
- Large discrepancy with Pierre Auger above $10^{19.3}$ eV, which cannot be resolved by rescaling energies of the experiments.
- TA×4 will provide us fourfold statistics at the suppression.
- Activities to understand the suppression discrepancy.