



# **Telescope Array: Status and Upgrades**

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***Snowmass on the Mississippi***

***Minneapolis, 30 July 2013***



# Telescope Array Collaboration

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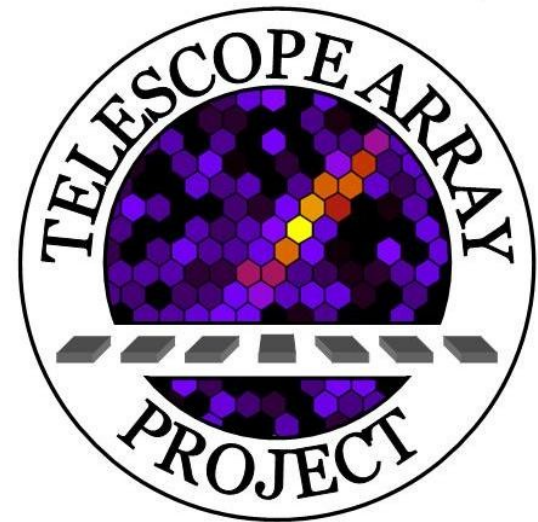
<sup>s</sup>Chiba University, <sup>t</sup>Institute of Particle and Nuclear Studies, KEK, <sup>u</sup>Kochi University, <sup>v</sup>Ritsumeikan University, <sup>w</sup>Sungkyunkwan University,

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# Outline

- Telescope Array Overview
  - Detector
  - Physics
- TA Upgrades
  - TALE
  - TA x 4
  - NICHE
- TA Affiliate Experiments
  - ELS
  - TARA
  - Lightning Detection





# TA detector in Utah

39.3°N, 112.9°W  
~1400 m a.s.l.

14 telescopes

Refurbished HiRes

12 telescopes

3 com. towers

Surface Detector (SD)

507 plastic scintillator SDs

1.2 km spacing

700 km<sup>2</sup>



Fluorescence Detector (FD)

3 stations

38 telescopes

12 telescopes

Black Rock Mesa (BR)

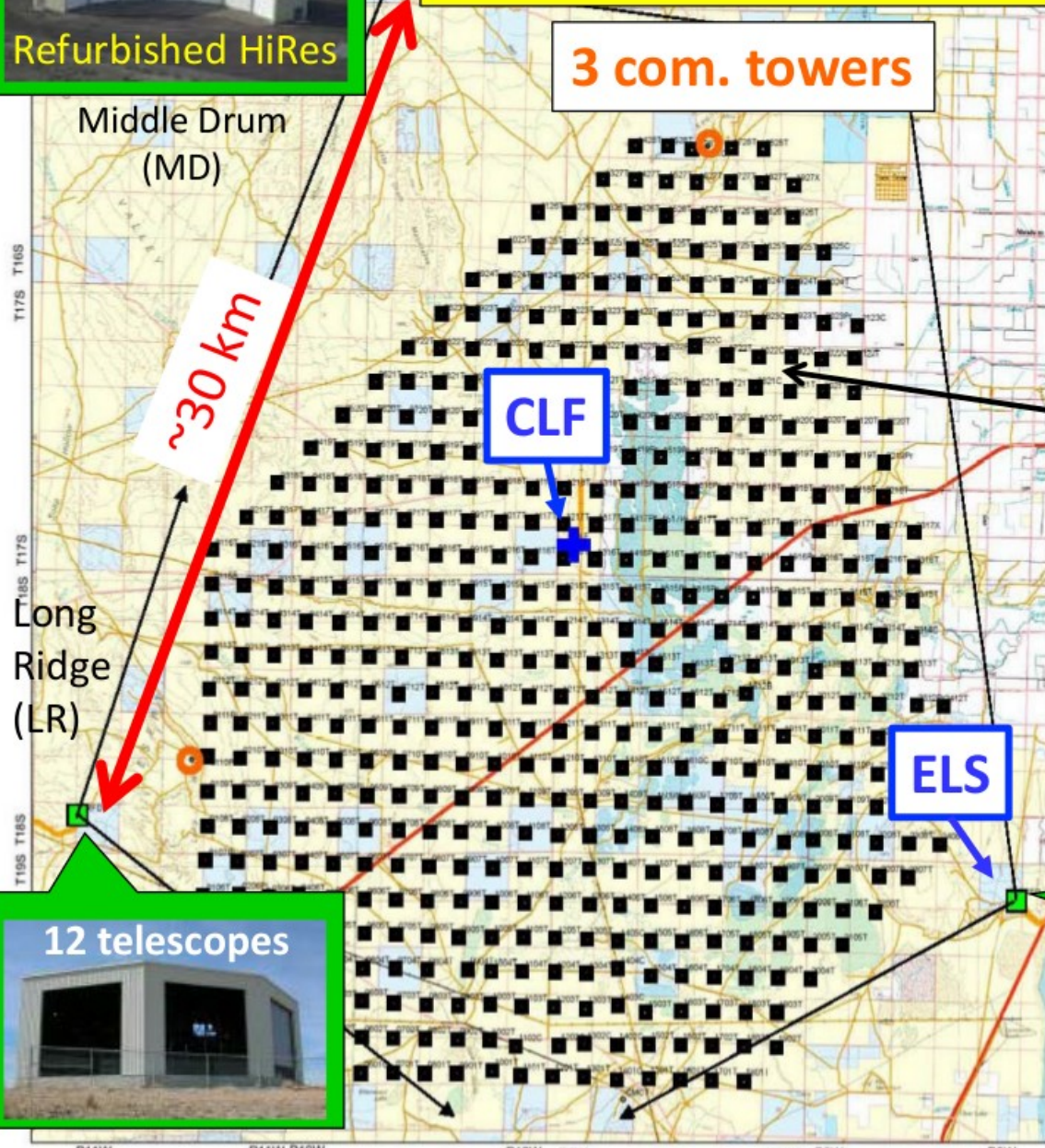
Middle Drum (MD)

Long Ridge (LR)

CLF

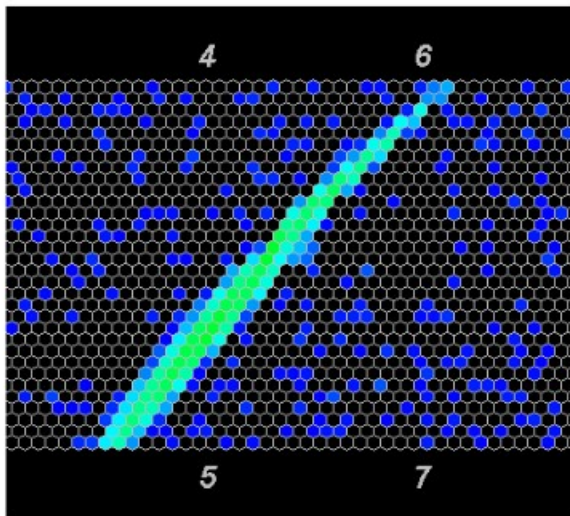
ELS

~30 km

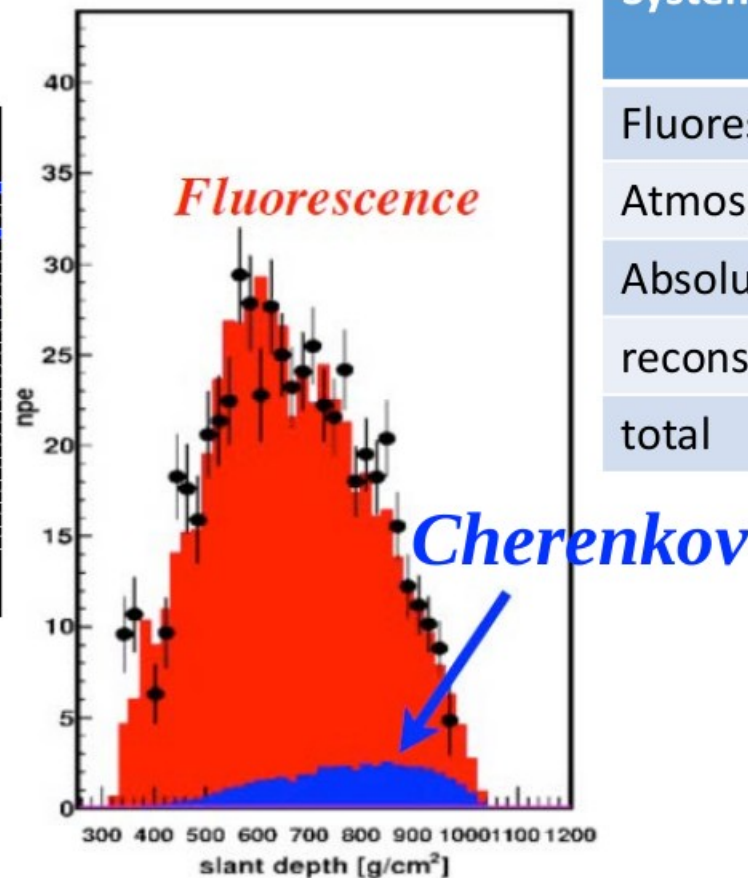


# TA shower analysis with FD

An example of an air shower  
the camera view



Longitudinal shower profile



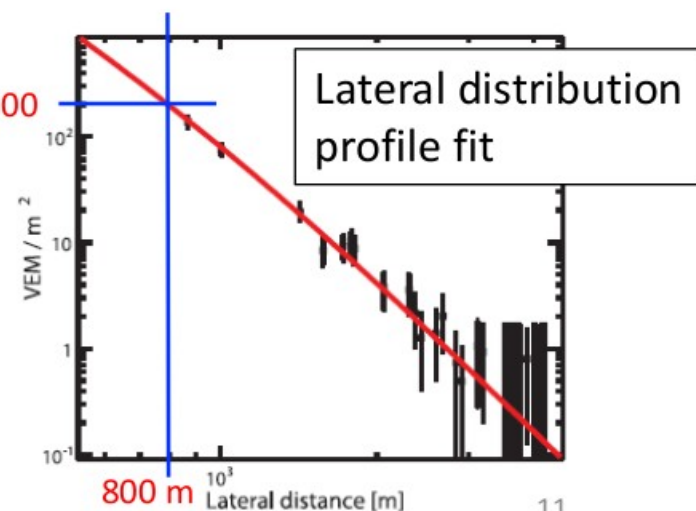
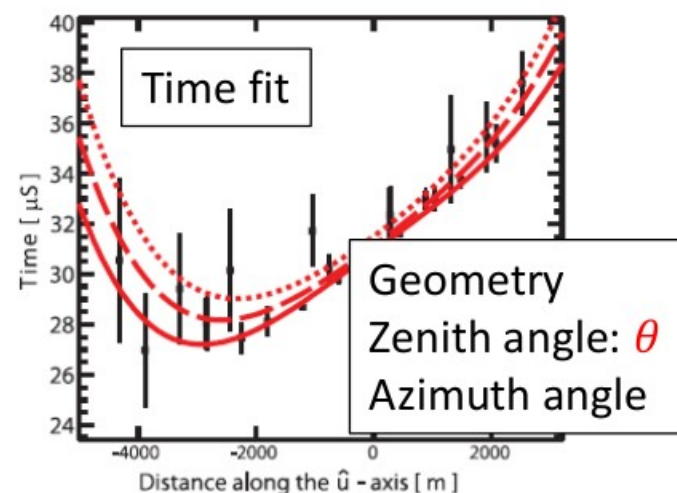
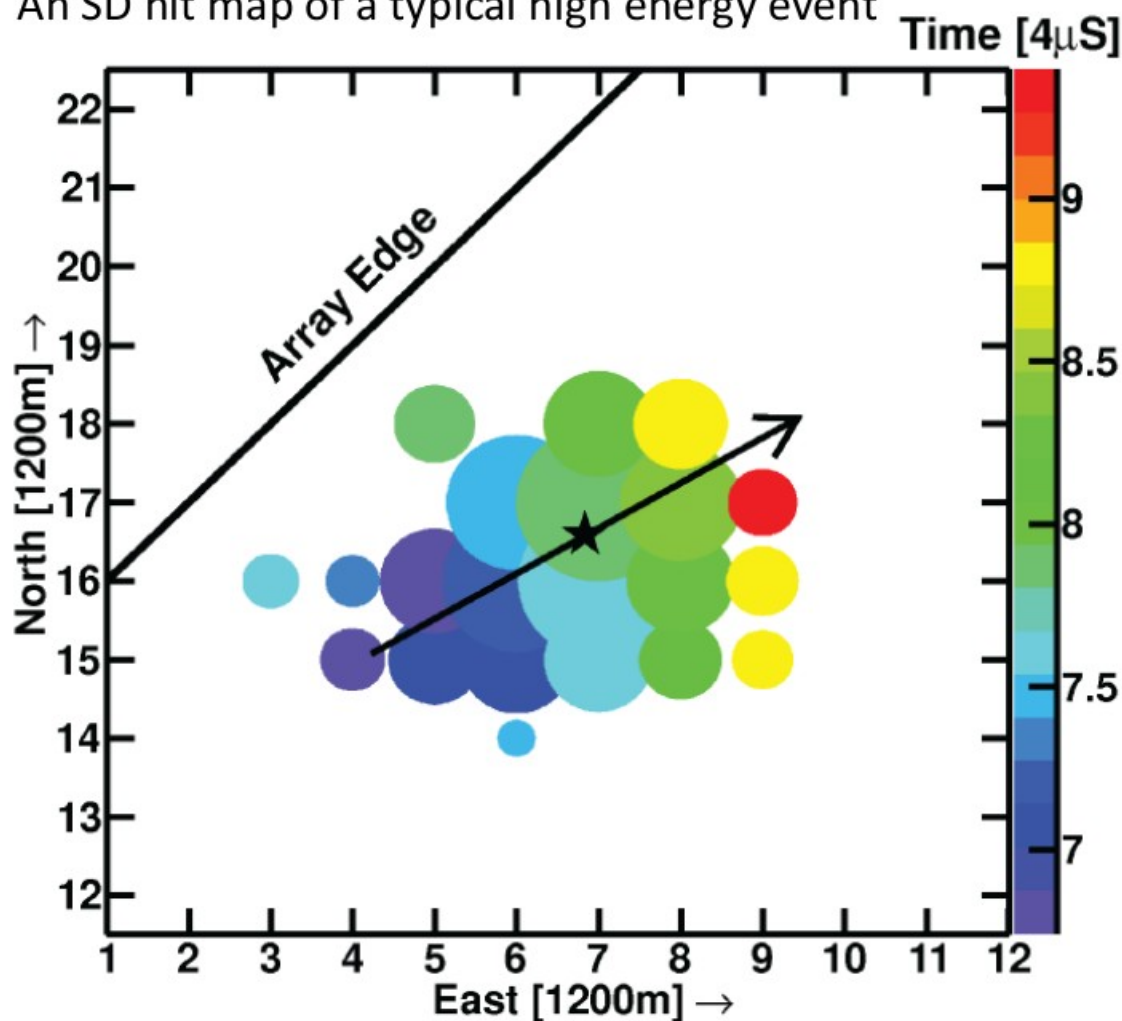
## Systematic uncertainty in energy determination

Fluorescence yield	11%
Atmospheric attenuation	11%
Absolute detector calib.	10%
reconstruction	10%
total	21%

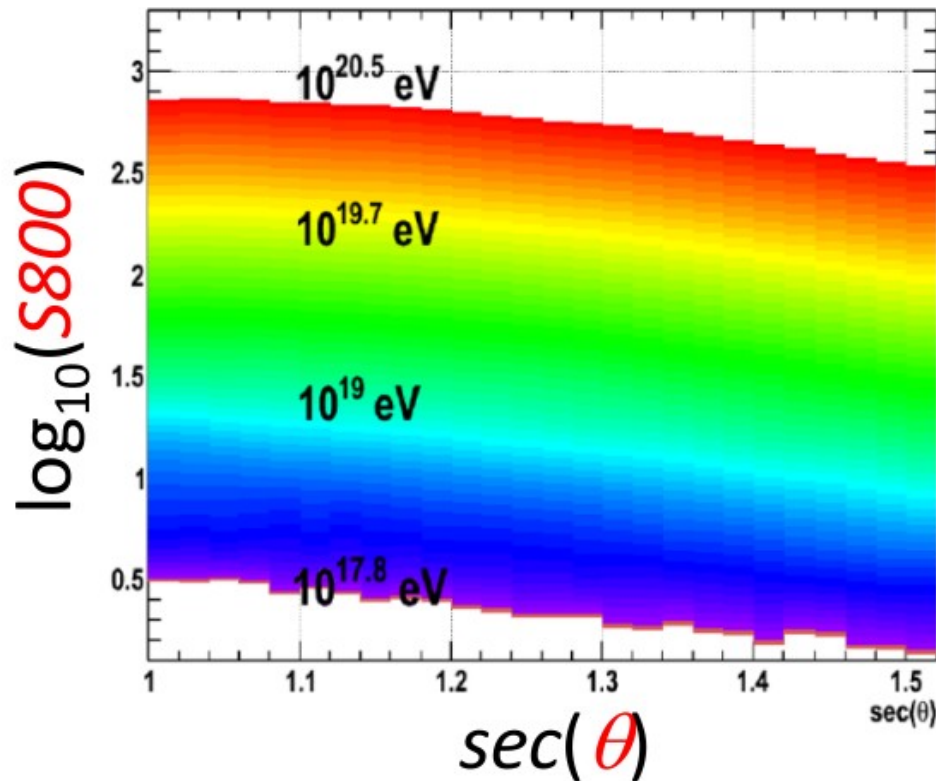


# TA shower analysis with SD

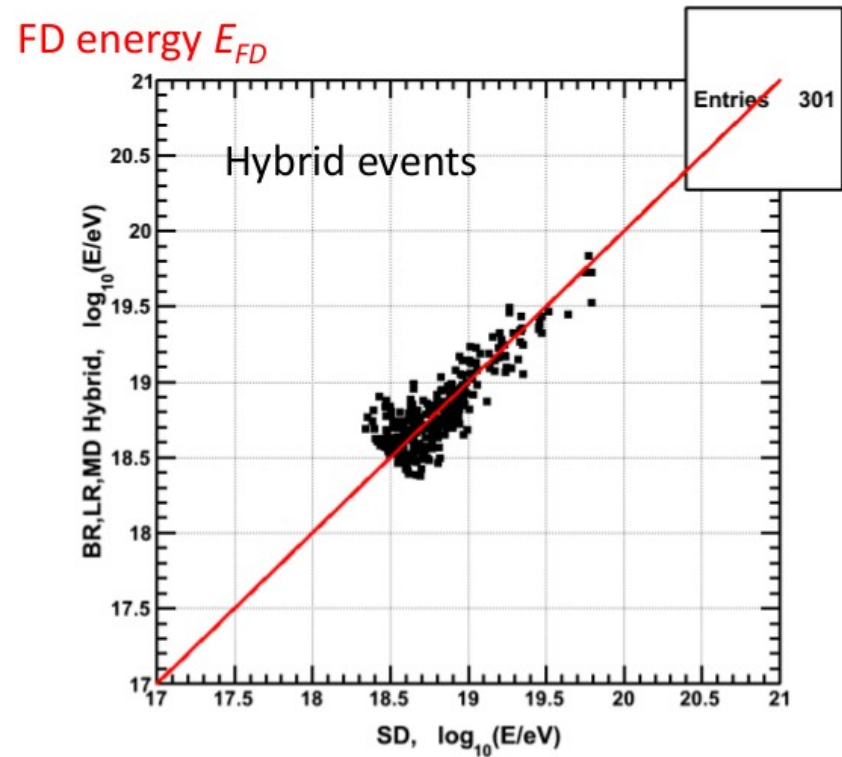
An SD hit map of a typical high energy event



# SD/FD Energy Scale



First estimate of SD Energy: MC lookup table

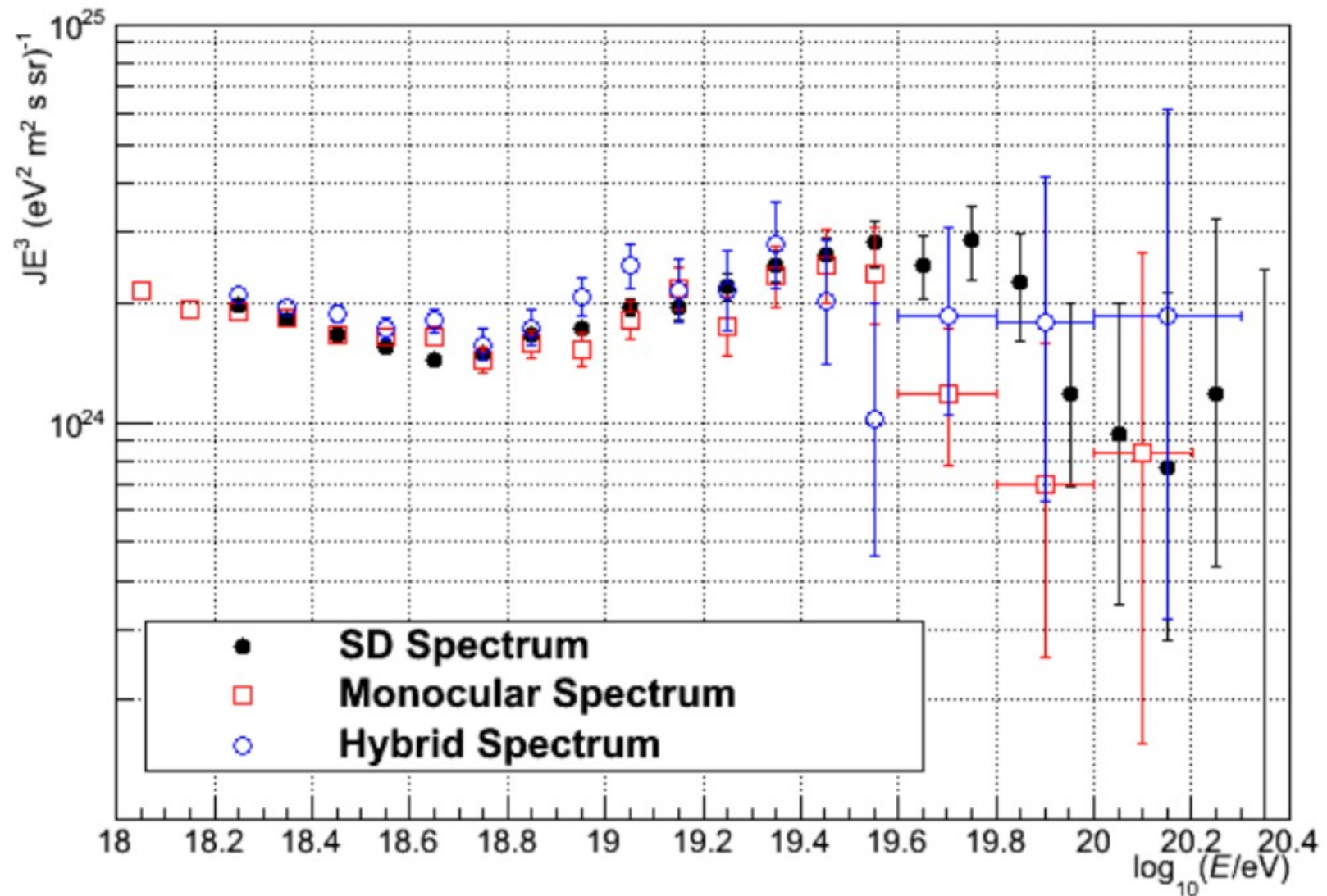


SD energy  $E_{SD}$   
(scaled to FD energy)

$$E_{SD} = E'_{SD}/1.27$$

# Spectrum overview

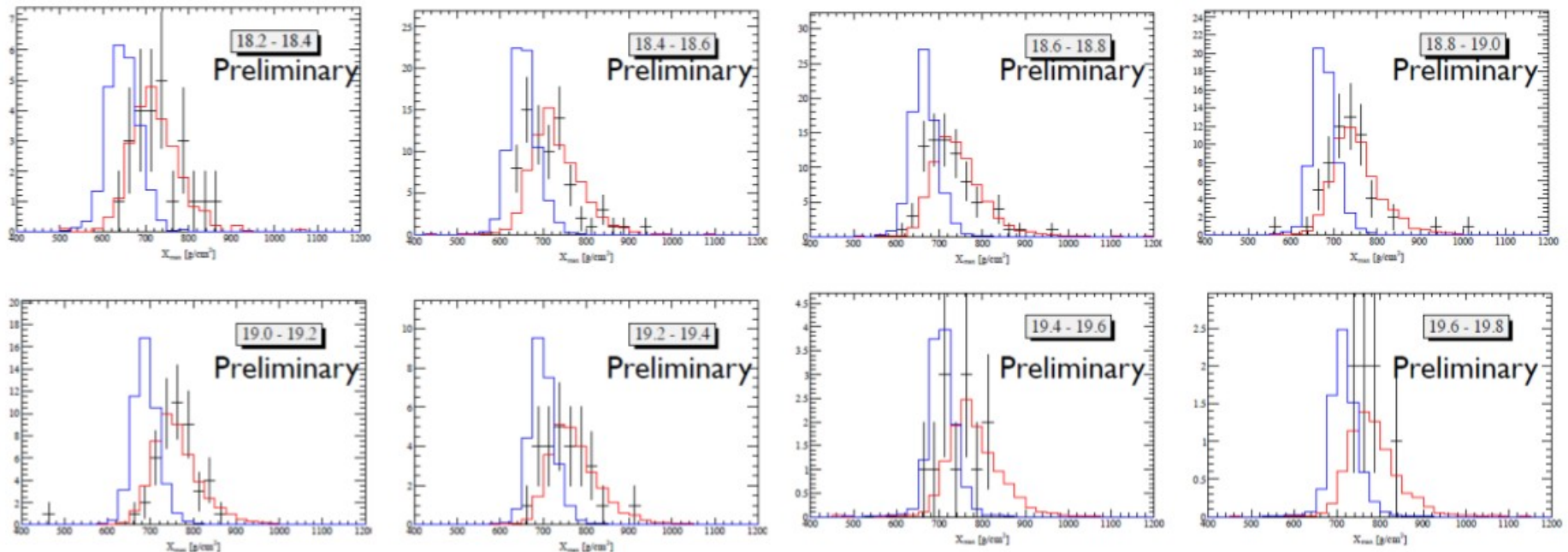
SD, Monocular and Hybrid Spectra





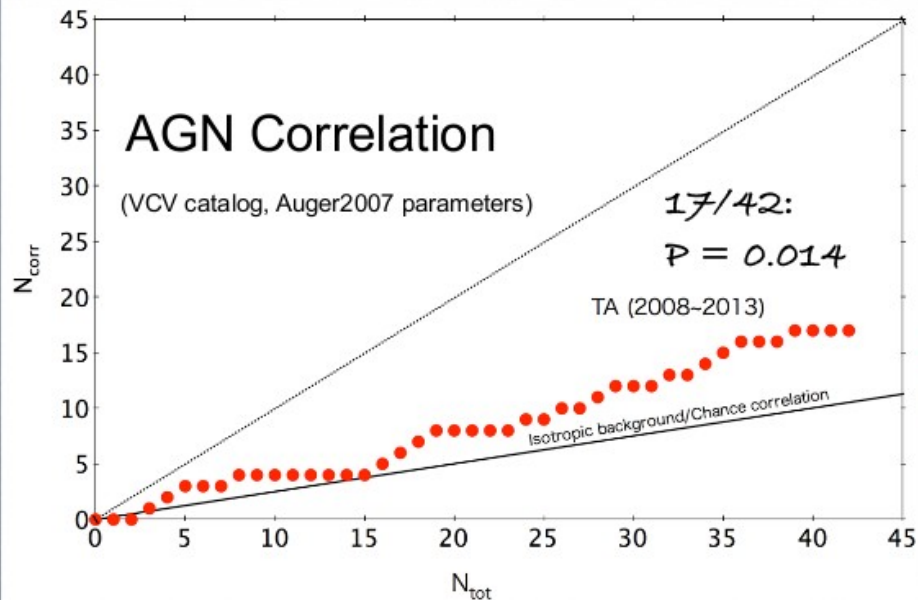
# Composition: Stereo $X_{max}$

- 5-year data (Nov., 2007 – Nov. 2011)
  - Data: TA
  - Red histogram: QGSJET-II **proton** model
  - Blue histogram: QGSJET-II **iron** model



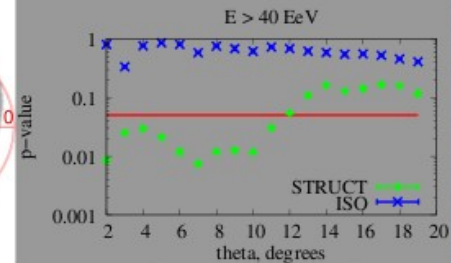
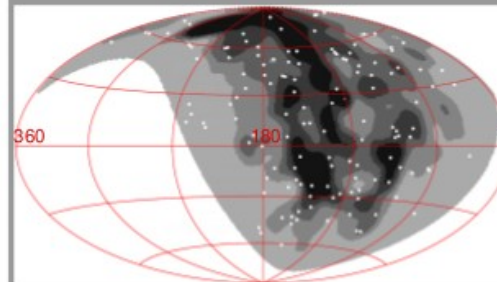
The TA data is consistent with QGSJET-II proton prediction.

# TA Anisotropy Studies

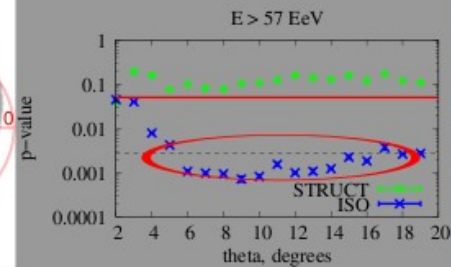
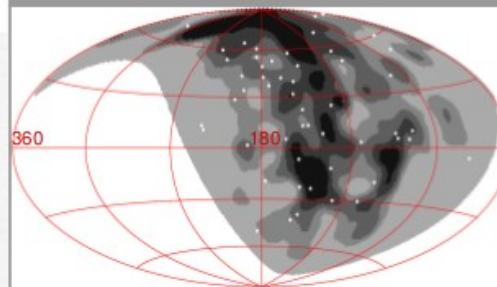


$E > 40 \text{ EeV}$

**1033 Tinyakov**



$E > 57 \text{ EeV}$

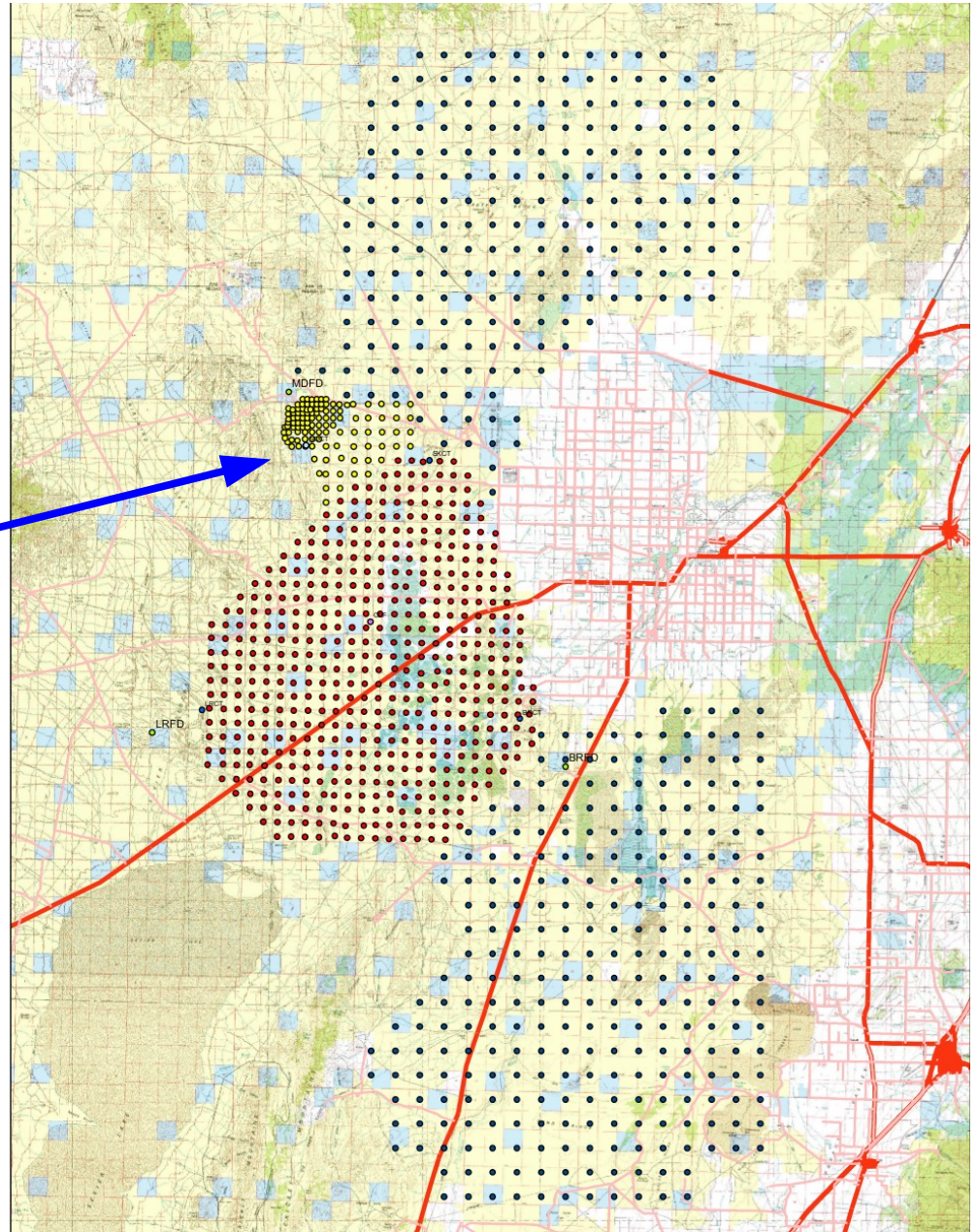


- High energy  $E > 57 \text{ EeV}$  data are not compatible with isotropy at  $\sim 3\sigma$  (pre-trial)



# TA Upgrades

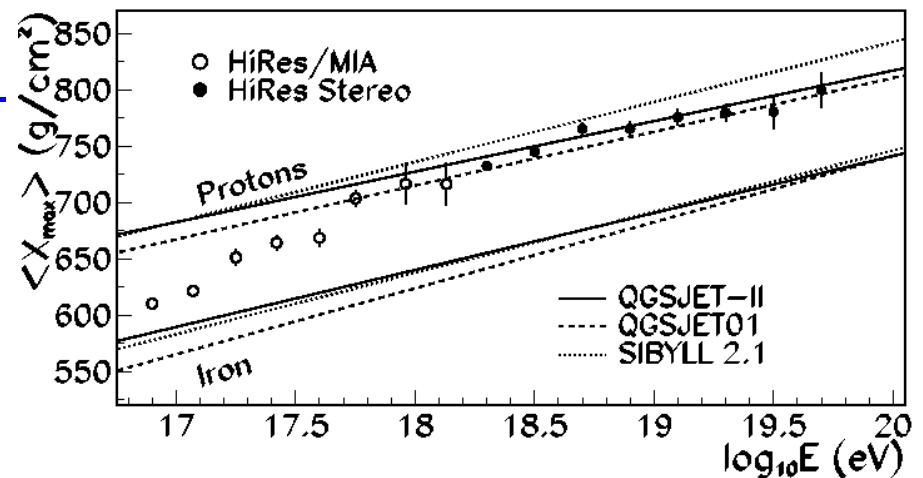
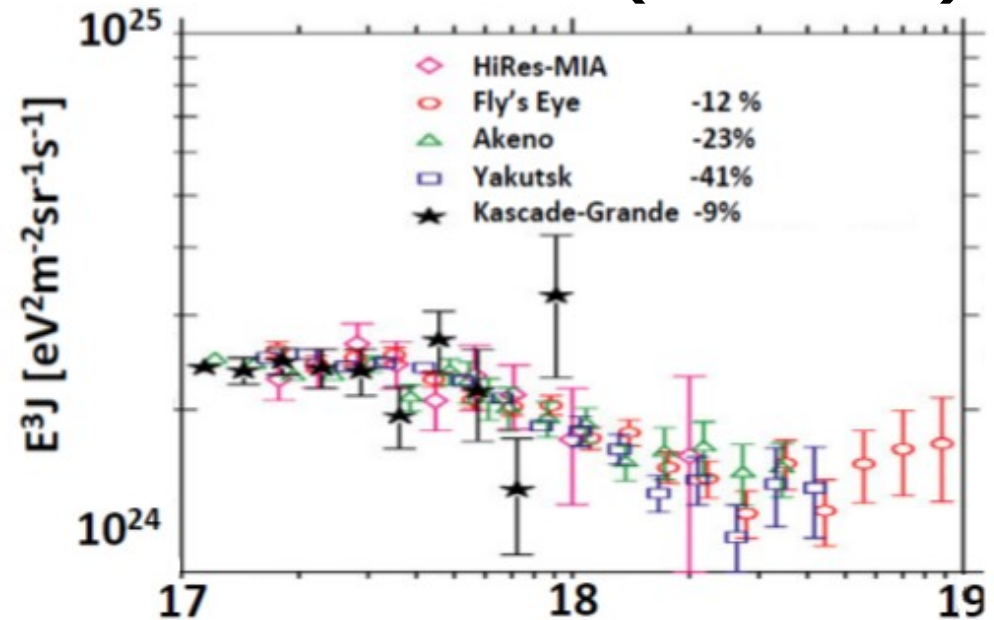
- Low-energy extension; TALE



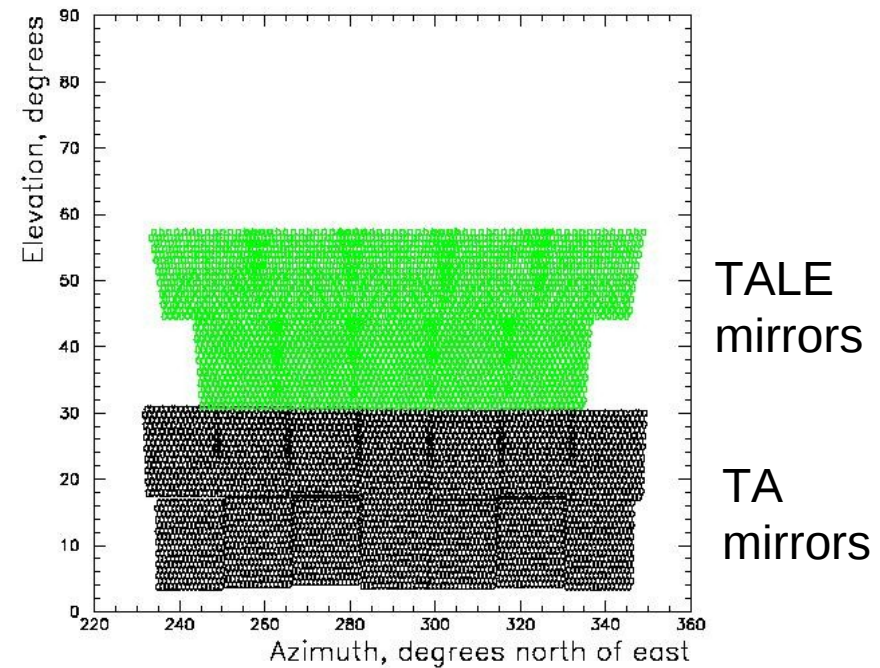
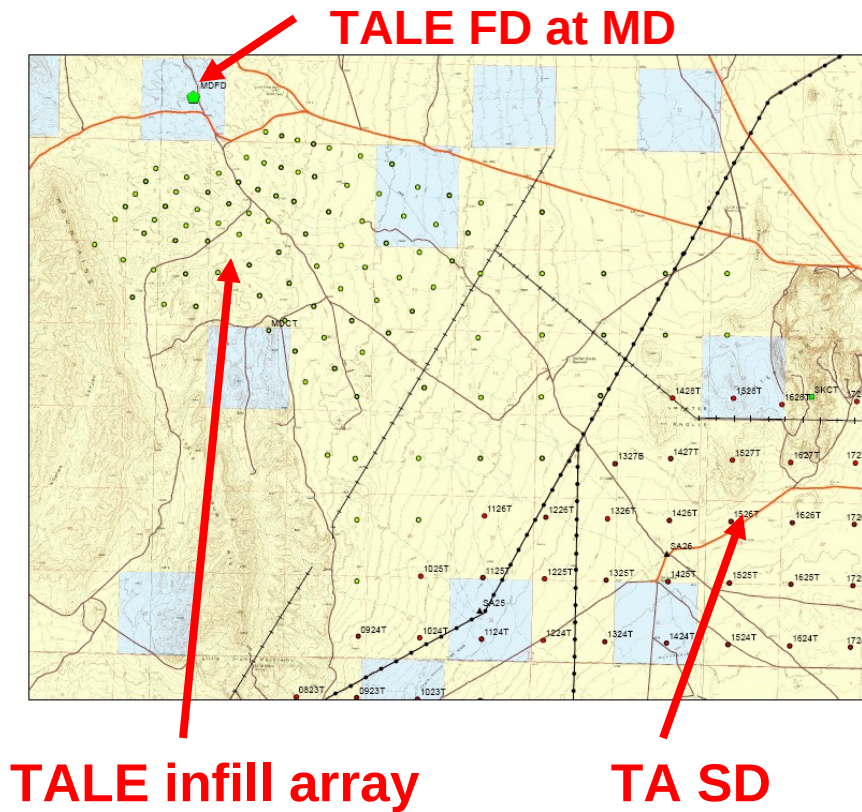


# TA Low Energy Extension (TALE)

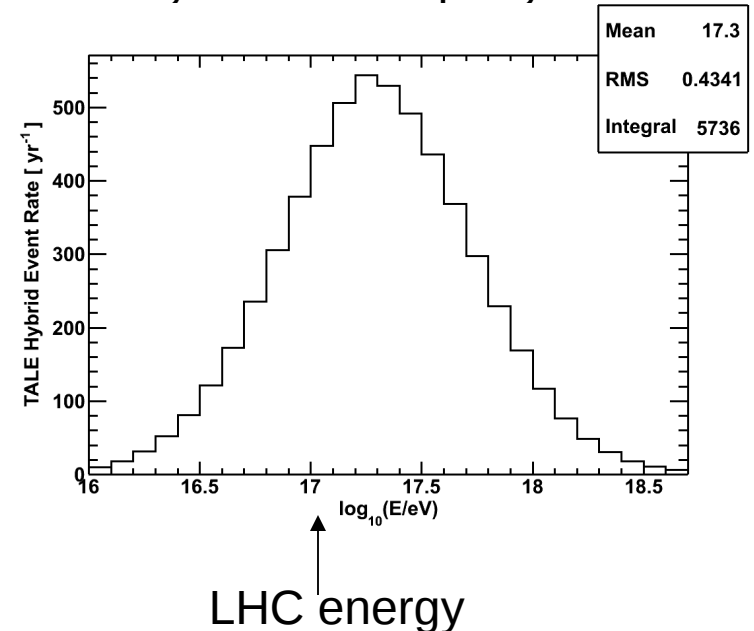
- Study  $10^{16}$  and  $10^{17}$  eV decades in hybrid
- Astrophysics
  - End of “knee”
  - Second knee
  - Galactic-Extragalactic Transition
- High-energy physics: Cross-section measurements overlapping LHC



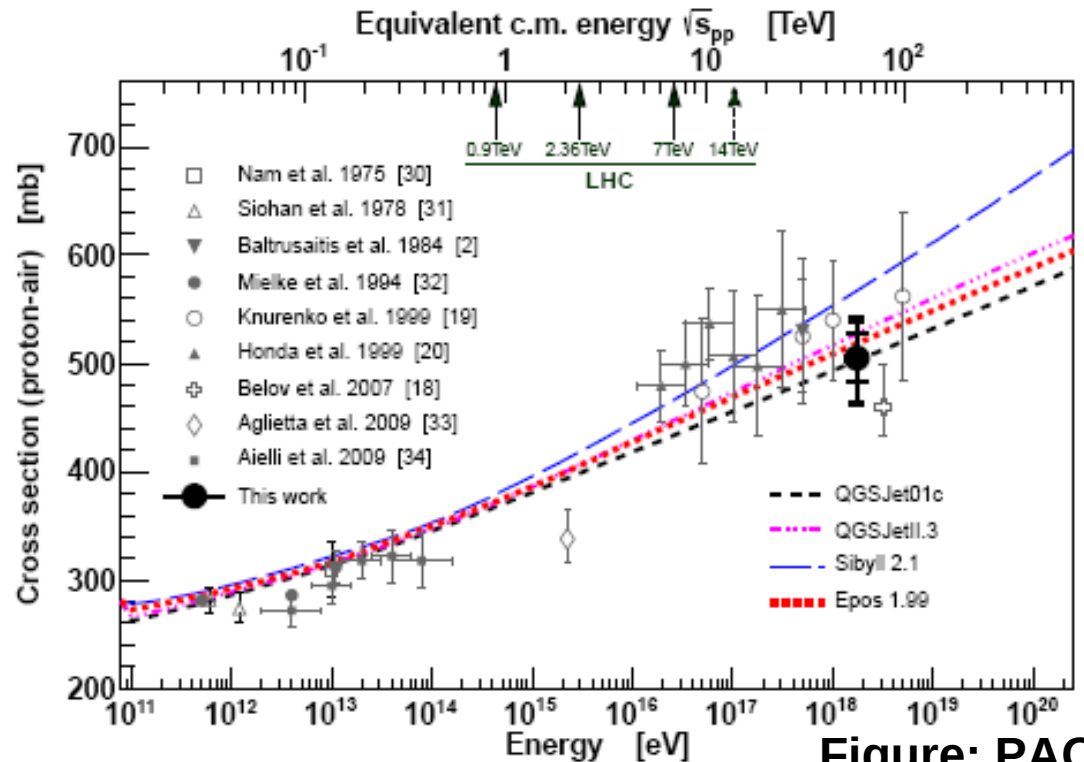
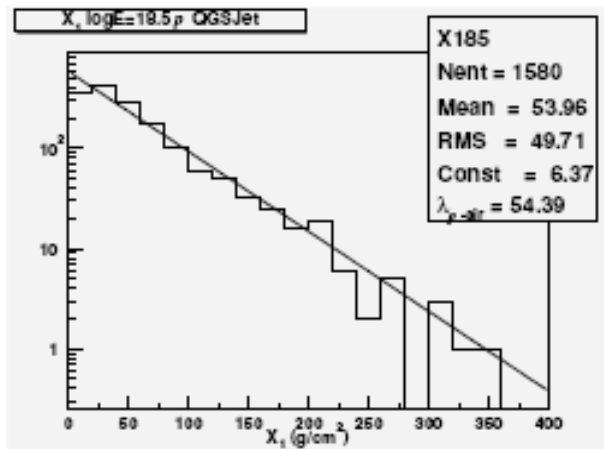
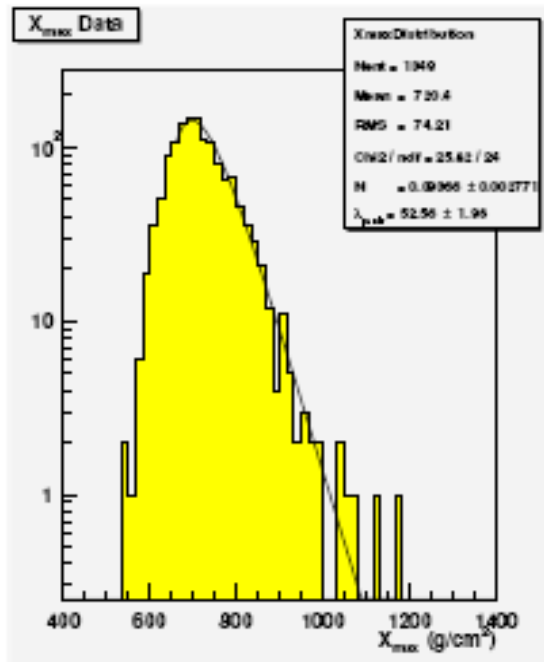
# TALE Detectors are being deployed.



## TALE hybrid events per year



# TALE: P-Air Total Cross Section at LHC Energies



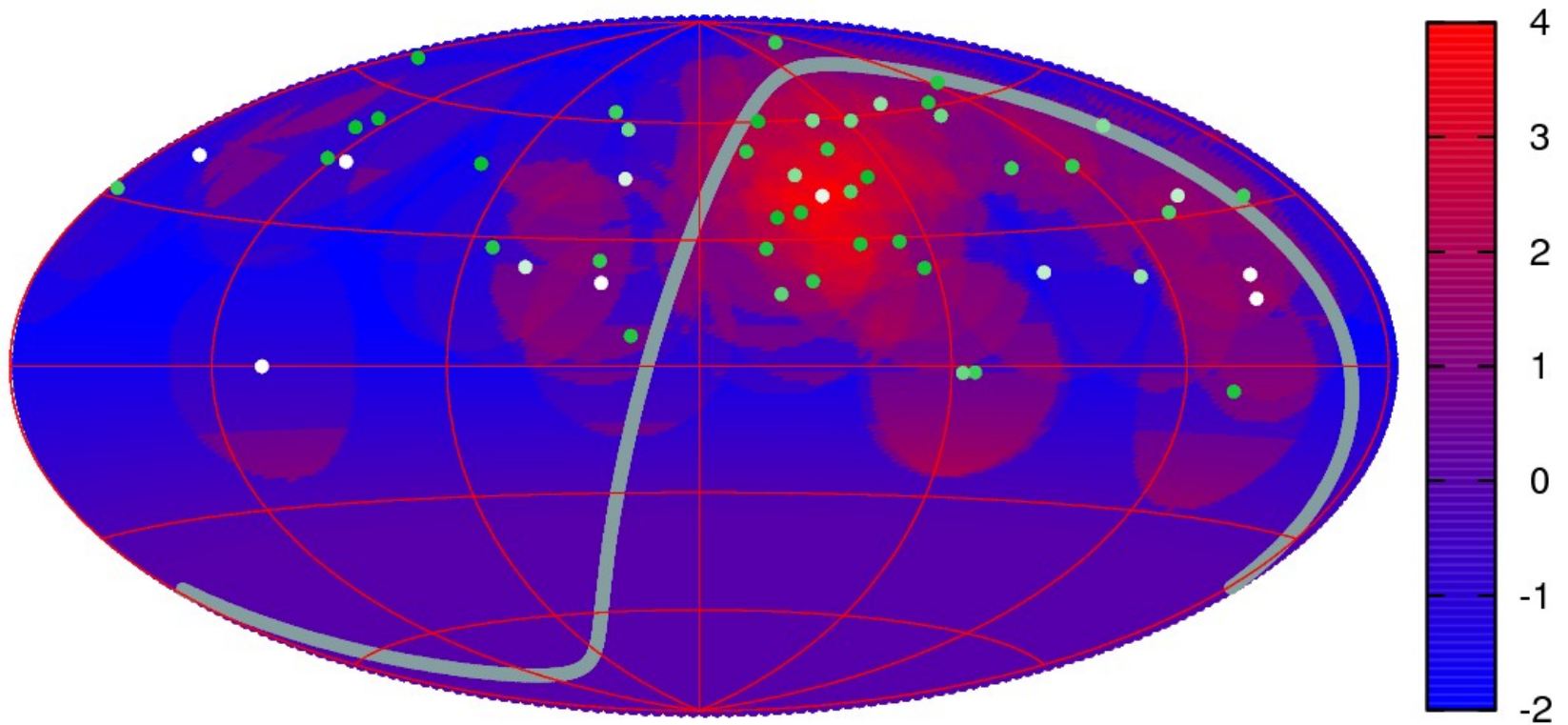
**Figure: PAO**

The falling tail is a convolution of the first-interaction exponential and the variation of depth of  $X_{\text{max}}$ .





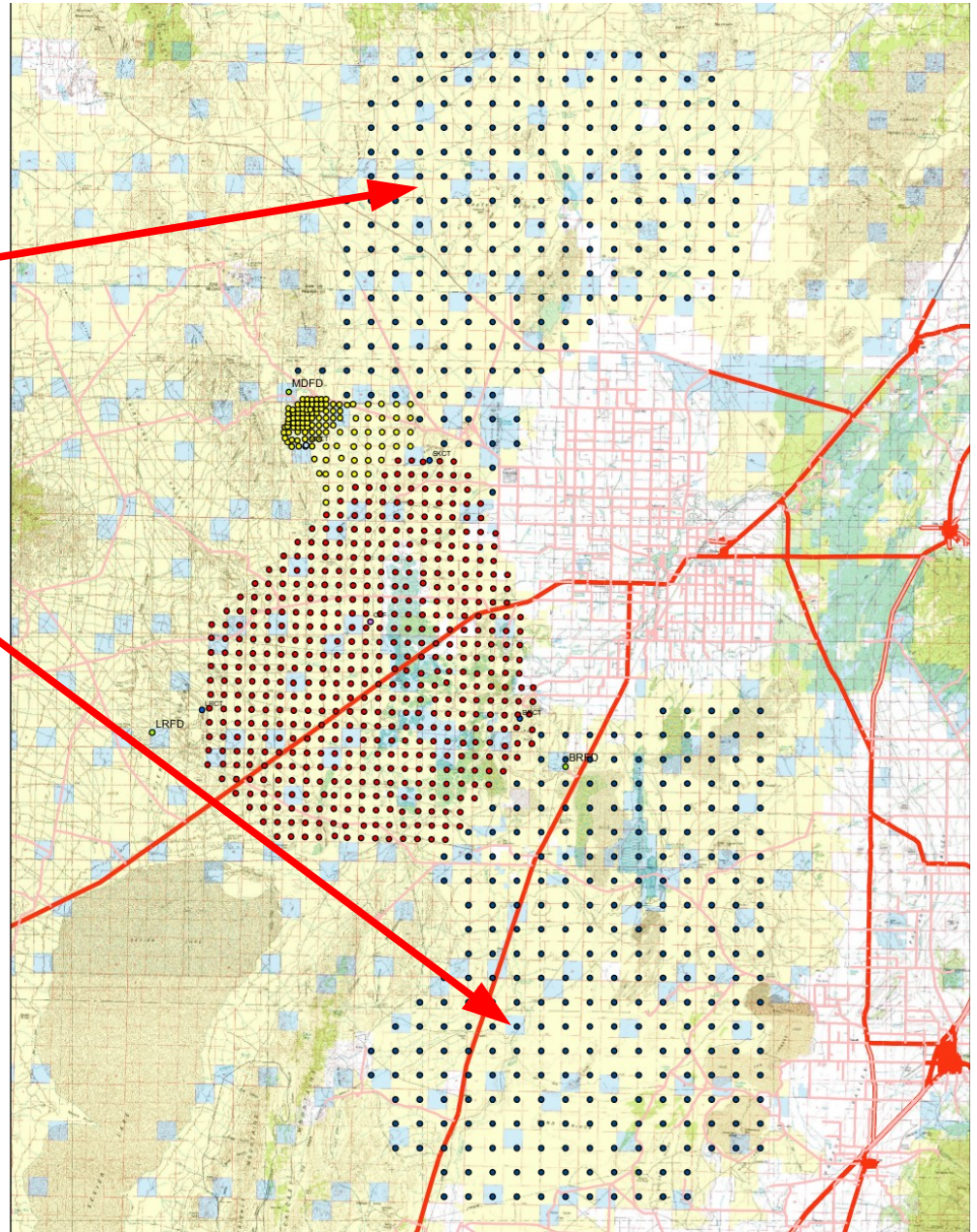
# Unresolved by TA: Anisotropy



- Map of *a priori* significance for TA events  $> 57$  EeV

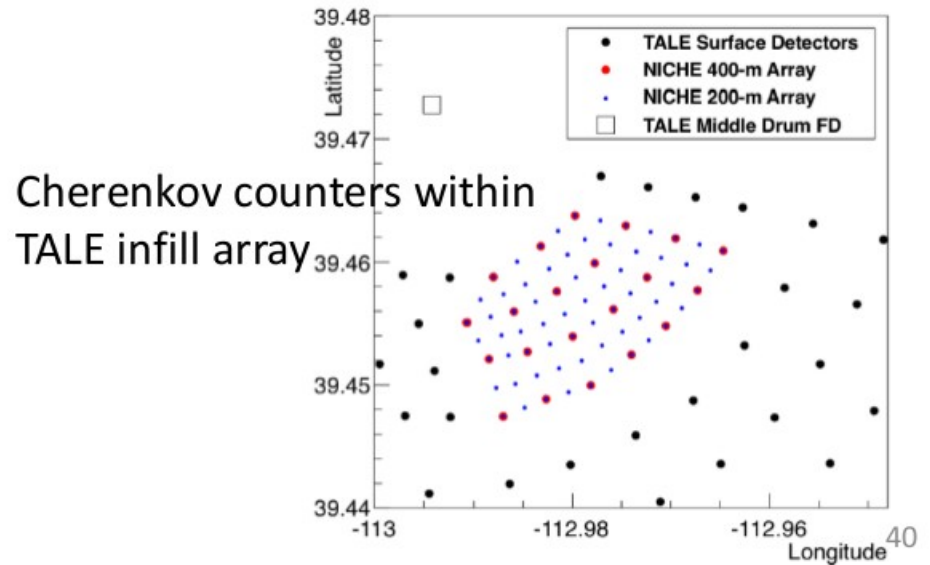
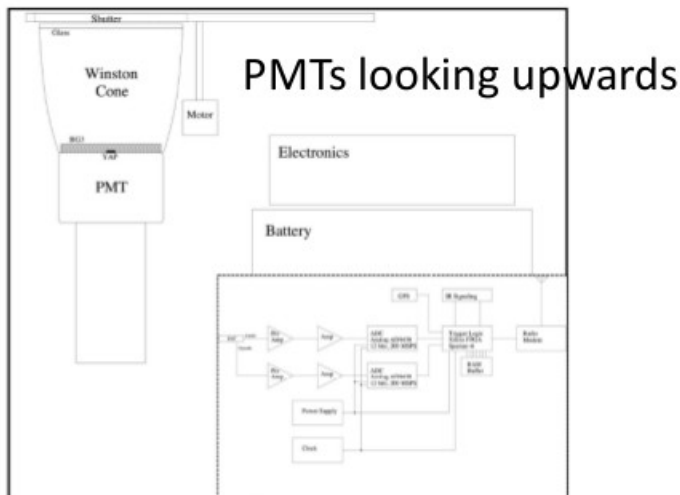
# TA Upgrades

- **TA x 4**
- 3,000 km<sup>2</sup>
  - 500 SD's, 2 km spacing
  - 1 new FD (HiRes refurbished)
- Proposals fall 2013
- Anisotropy: 20 TA-SD years by 2019



# NICHE project

- Non-Imaging Cherenkov Array (NICHIE)
- TA/TALE extension to measure the the **energy** and **composition** (**Xmax**) of very-high energy cosmic rays
  - $E = 10^{15.5}$  to  $10^{17}$  eV
  - Proposed but not yet funded

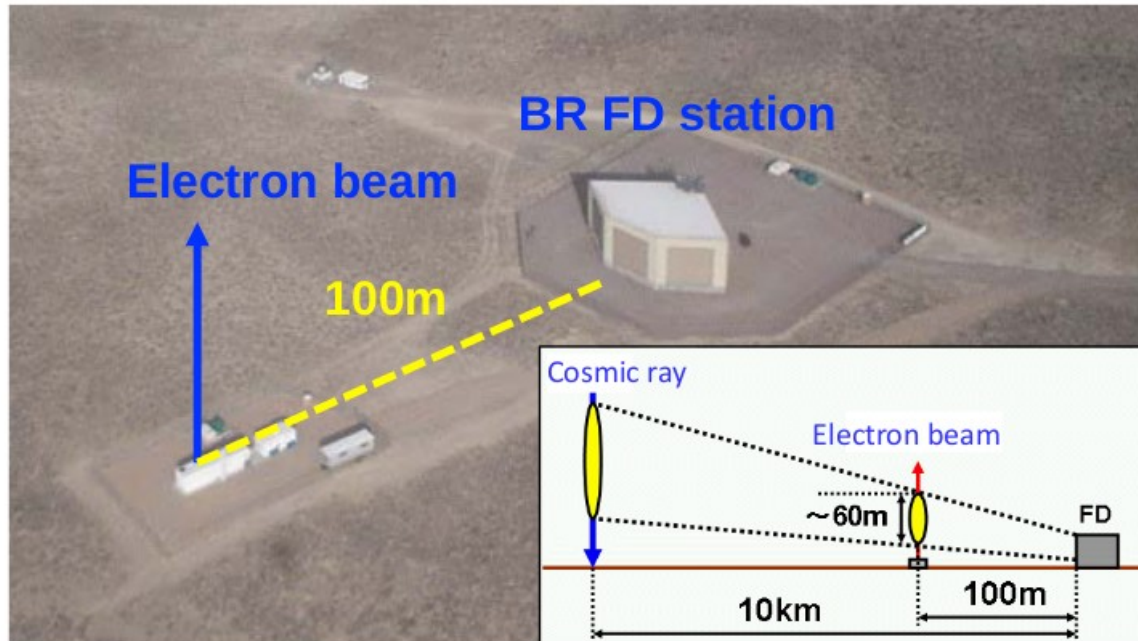




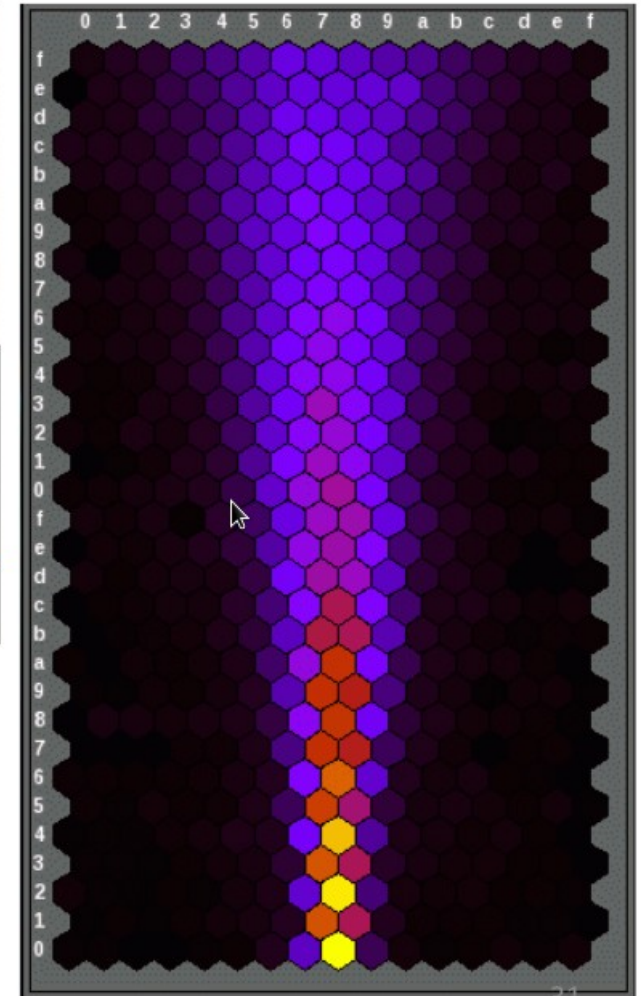
# **Telescope Array Affiliate Experiments**

# Electron Light Source (ELS)

An image of data  
Measured with FD

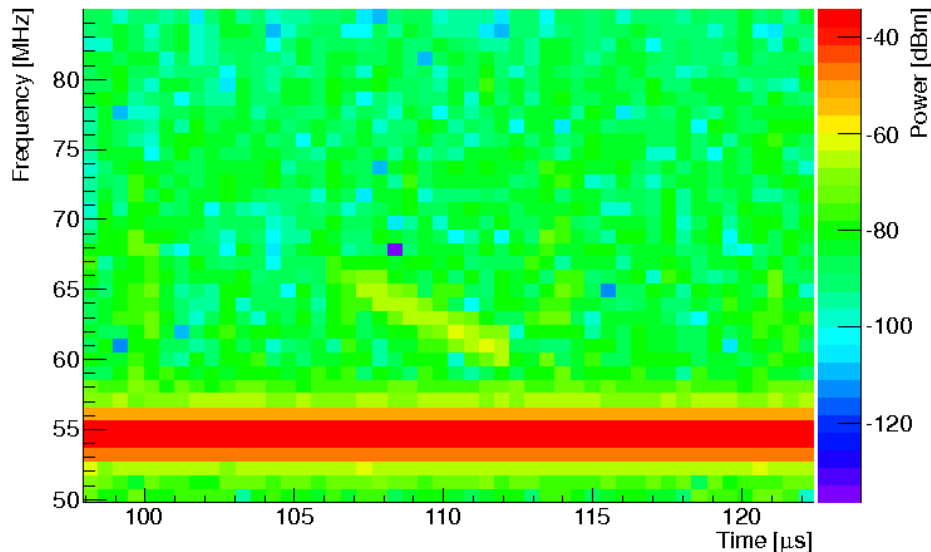
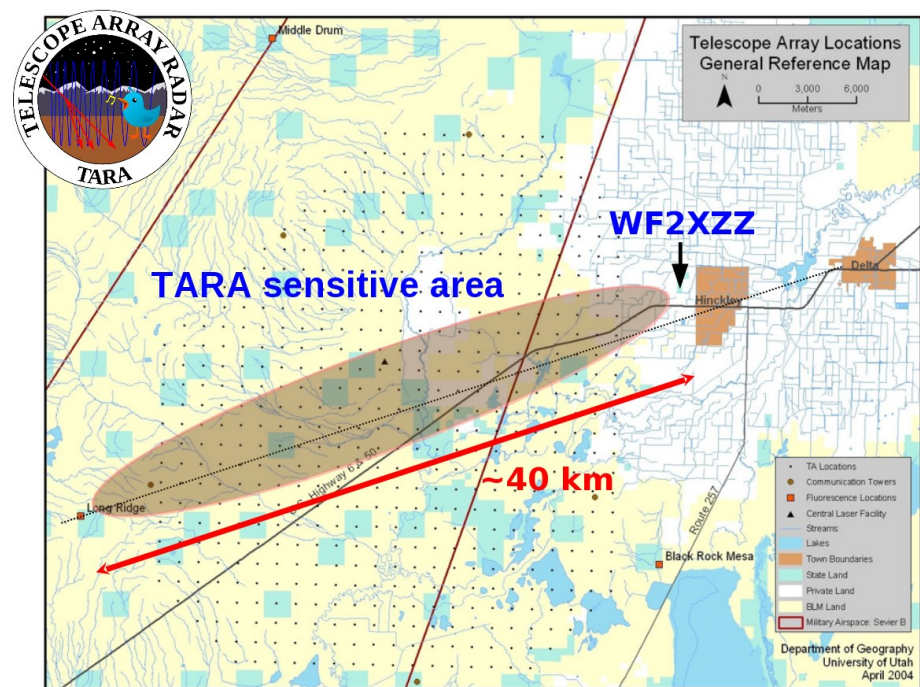


- 40-MeV,  $10^9$  electrons (typical)
- End-to-end FD energy calibration

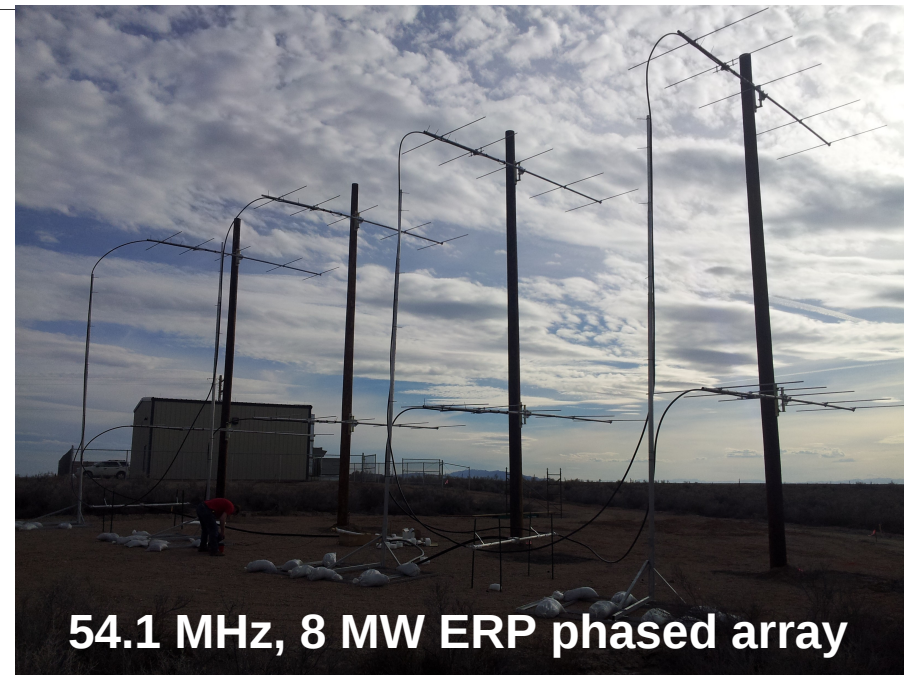


# TARA: Radar Detection of Cosmic Ray Showers

- Low rates at high energies  
→ need aperture!
- Bistatic radar
  - Remote sensing
  - Inexpensive
  - 100% duty cycle



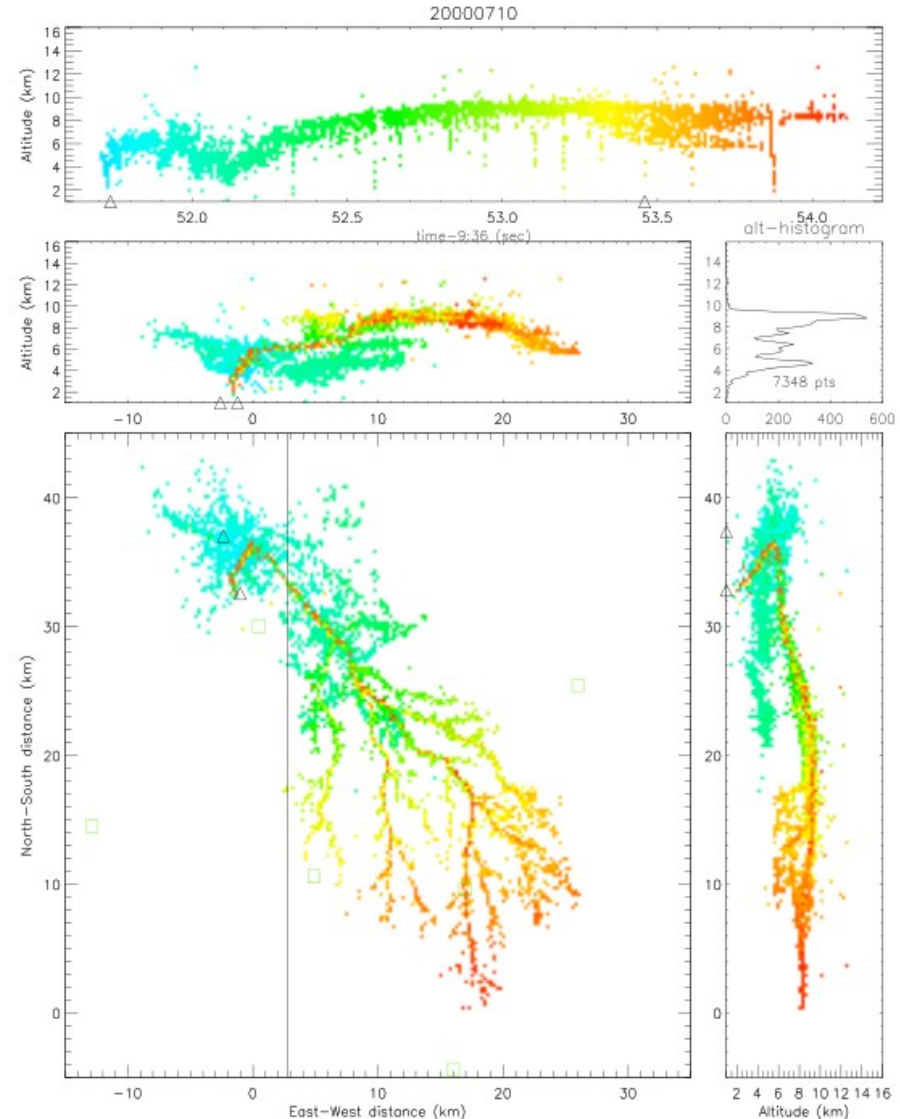
Simulated “chirp” detected at -10 dB SNR





# TA/LMA: Lightning Mapping

- Cosmic rays *may* trigger lightning strikes.
- Lightning *does* emit air shower-like bursts of particles.
- Proposing to deploy lightning mapping array (LMA) at TA to study these phenomena.





# Summary



- *Telescope Array* is the largest cosmic ray observatory in the Northern Hemisphere.
- Has measured spectrum, composition and anisotropy above  $10^{18}$  eV.
- Planned upgrades will:
  - Increase aperture x4 (anisotropy)
  - Increase range to nearly 5 orders of magnitude(!)
  - Measure cross-sections at LHC energies
- Rich program of affiliate experiments