Recent Results of the Telescope Array Experiment

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University of Utah

VHEPA, January, 2016

Outline

- Telescope Array Experiment
- TA Results
  - Spectrum
  - Anisotropy
- Future Plans
- Conclusions

- See John Belz talk for:
  - TA composition results
  - Radar detection
  - Lightning detection

Telescope Array Collaboration

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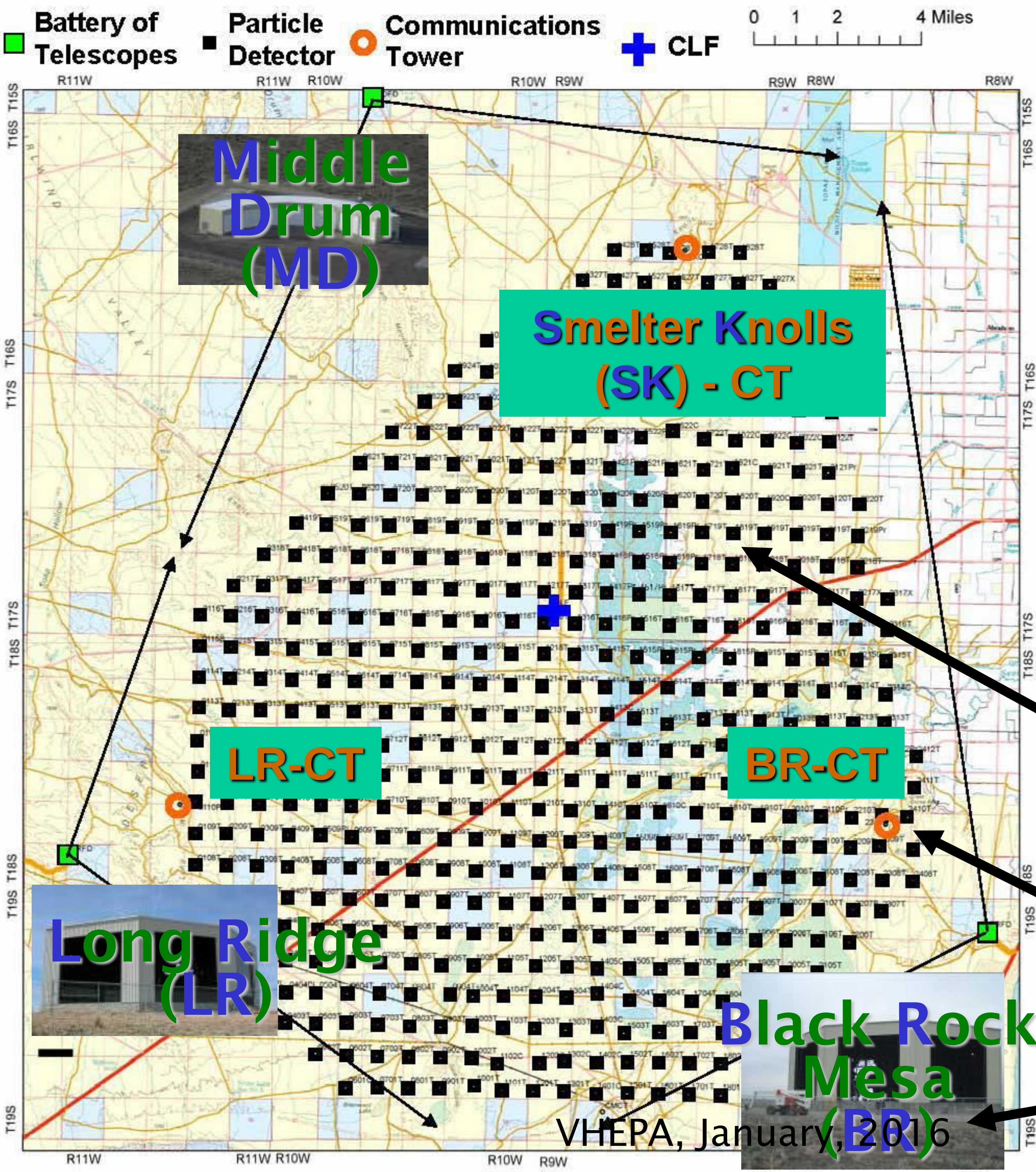
USA, Japan, Korea, Russia, Belgium



Telescope Array(TA)

Hybrid detector

Millard County, UT
39.3° N , 112.9° W,
Alt. 1400m
~880g/cm²

507 Surface Detector (SD) counters, 1.2km apart, cover 680km²

3 Communication Towers (CT): BR,LR,SK

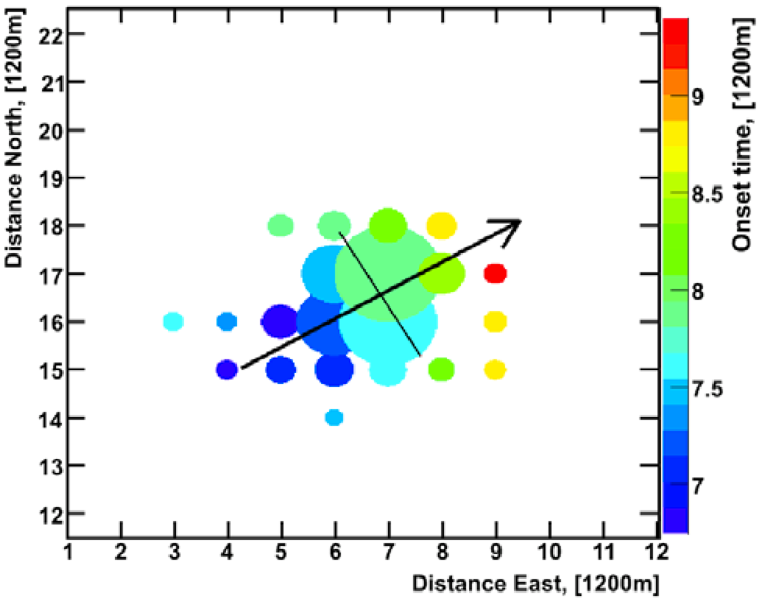
3 Fluorescence Detectors (FD): BR,LR,MD

TA Surface Detector

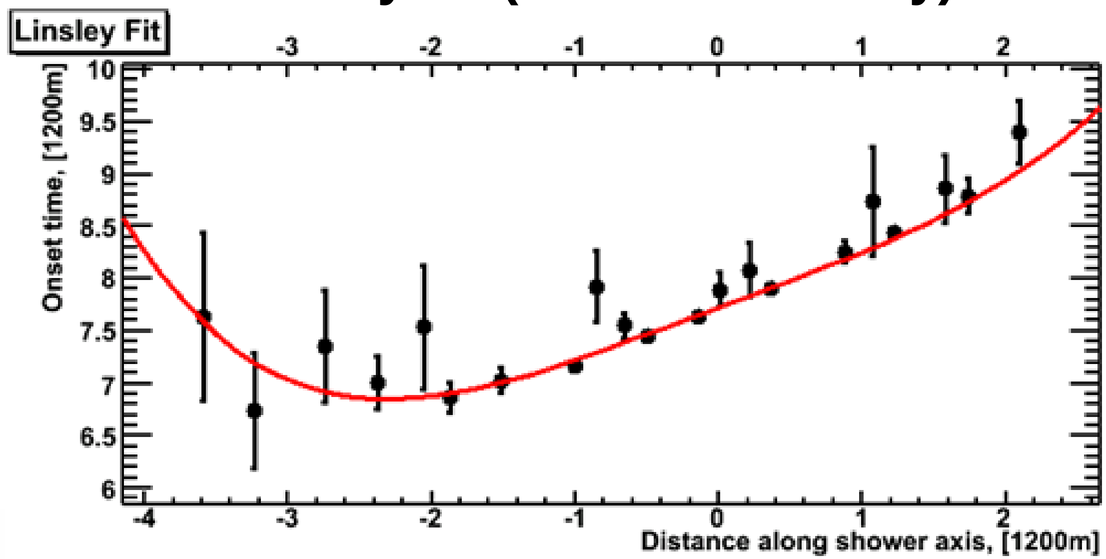
- Scintillation counters, area = 3 m^2.
- Powered by solar cells; radio readout.
- In operation since March, 2008.
- Self-calibration using single muons.

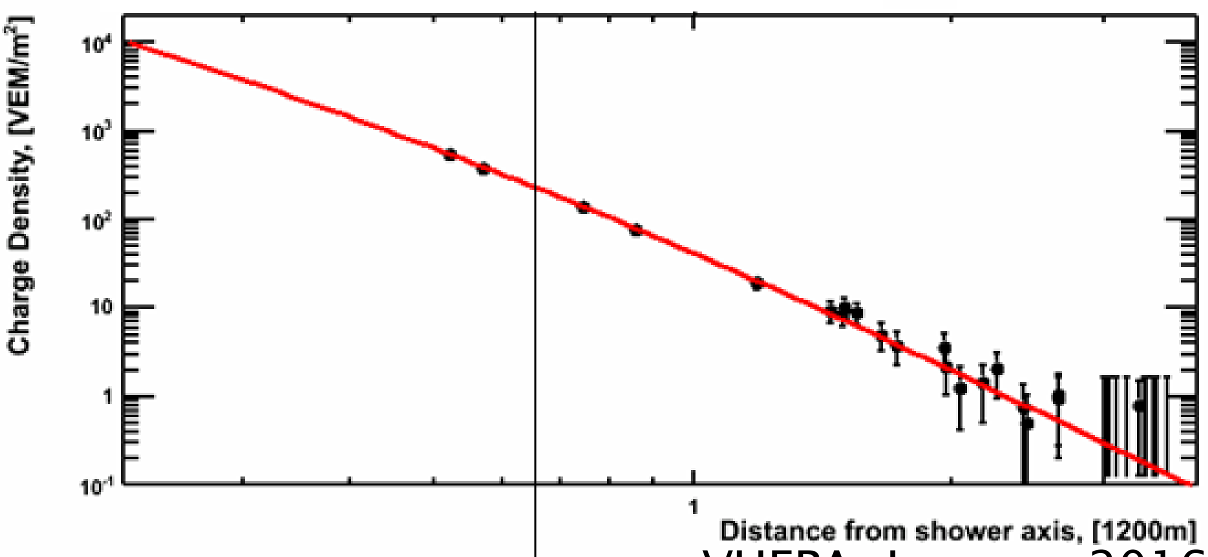
Typical surface detector event

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



Geometry Fit (modified Linsley)





Fit with AGASA LDF

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

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

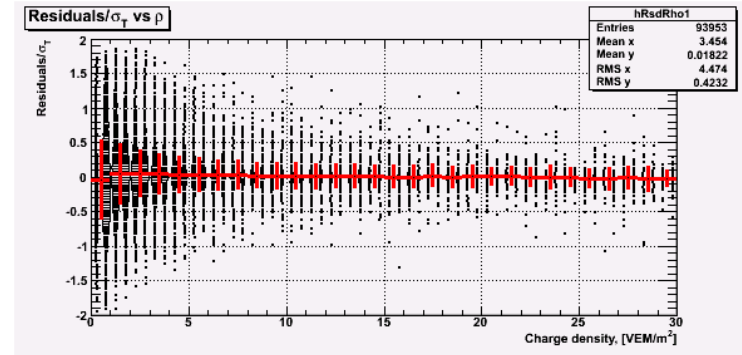
- S(800): Primary Energy
- Zenith attenuation by MC (not by CIC).

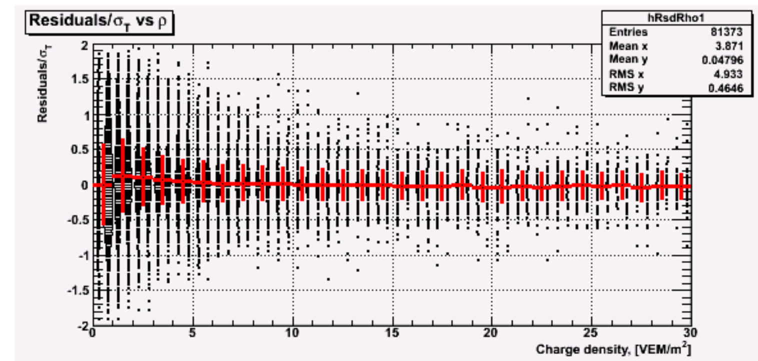
Lateral Density Distribution Fit

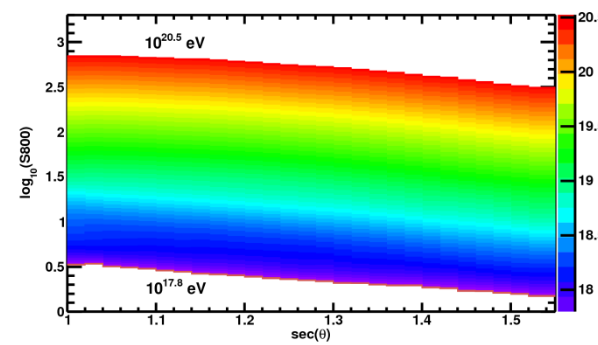
r = 800m

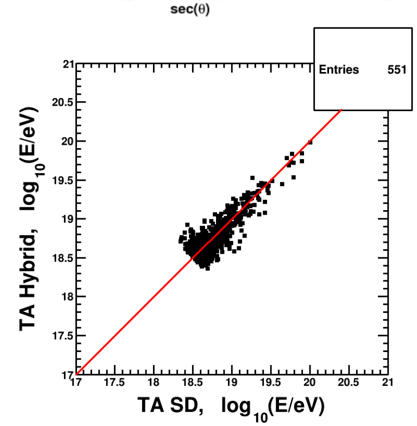
SD Energy Determination

- We solve the thinning problem:
  - Not the accuracy of models
  - Reconstruction same in data and MC
- Determine energy in model; compare with hybrid events
  - See 1.27 factor difference.

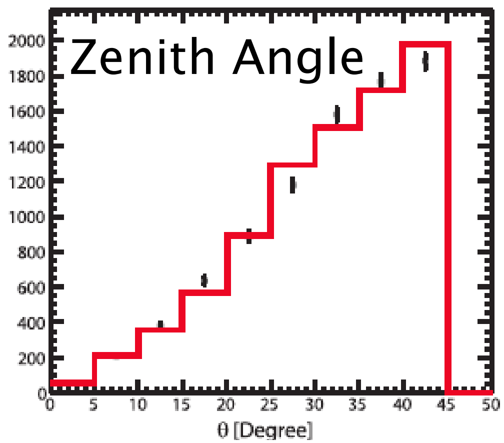


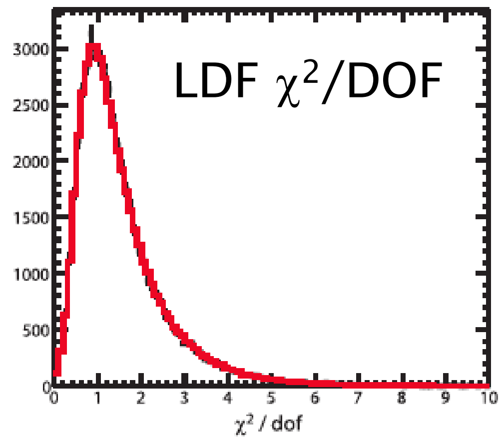


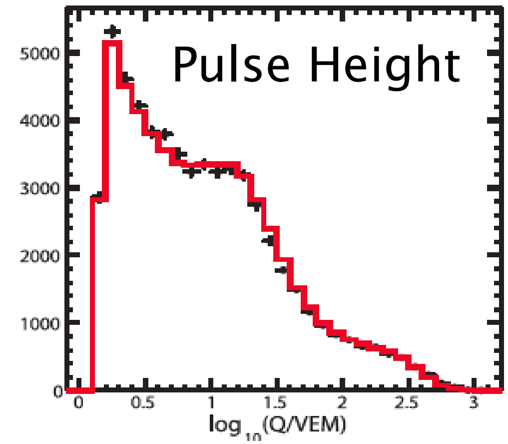


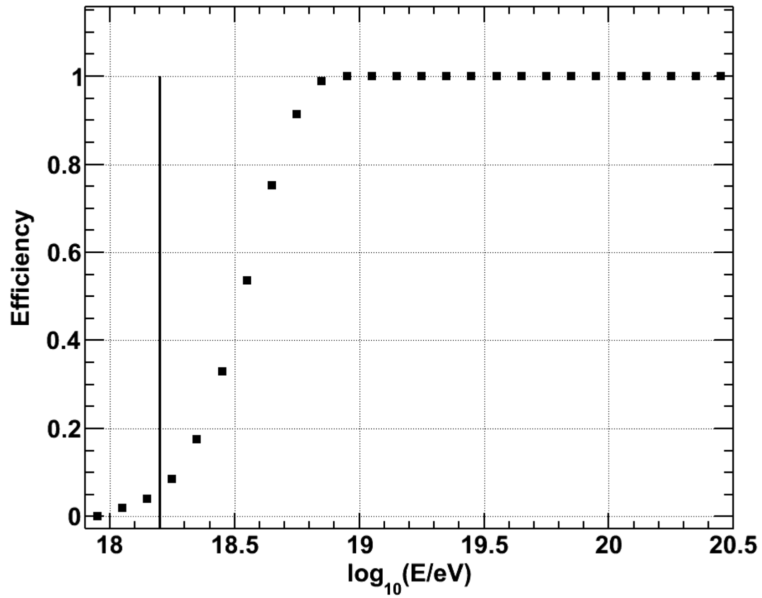


SD Data/MC Comparisons





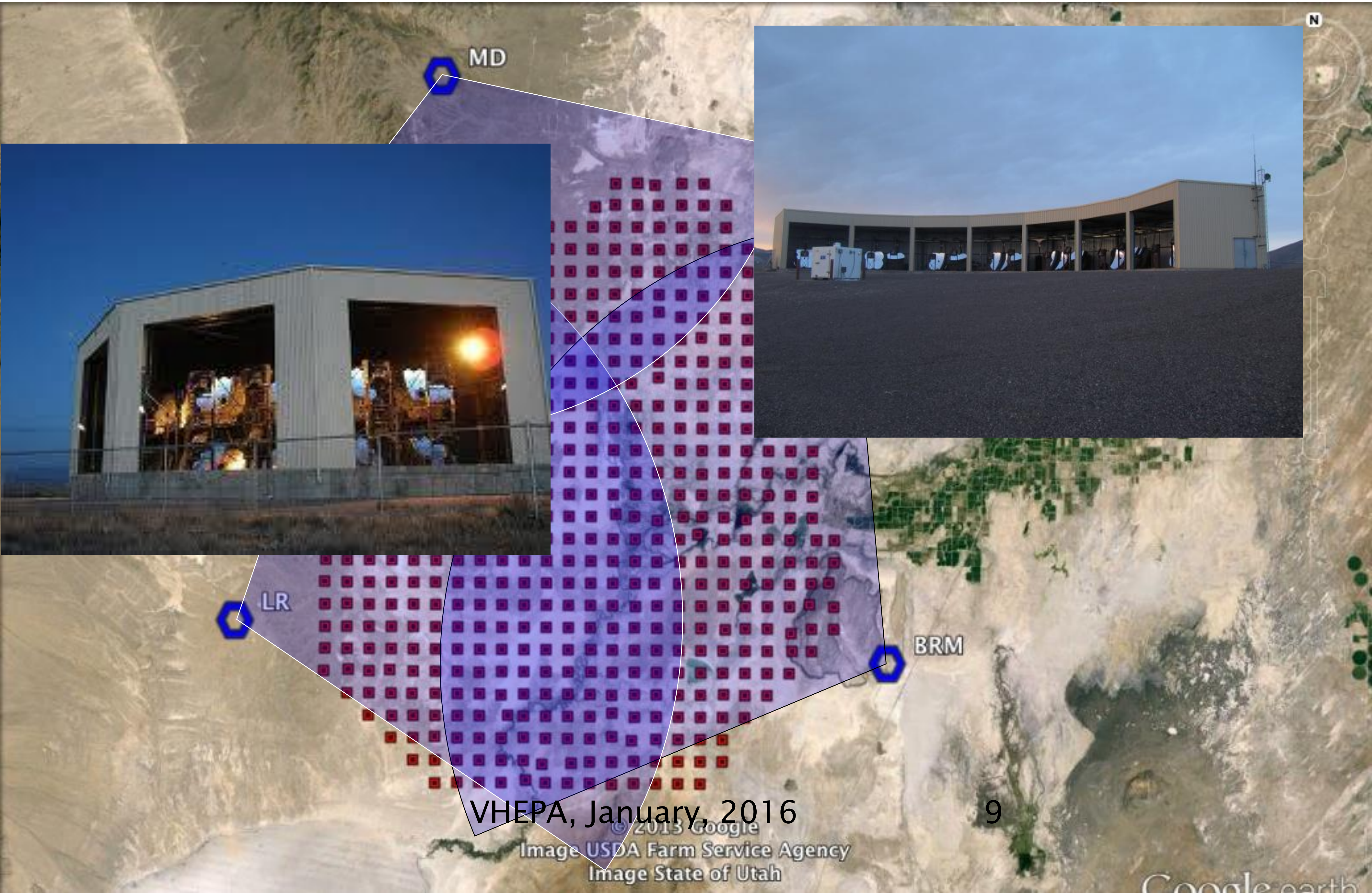




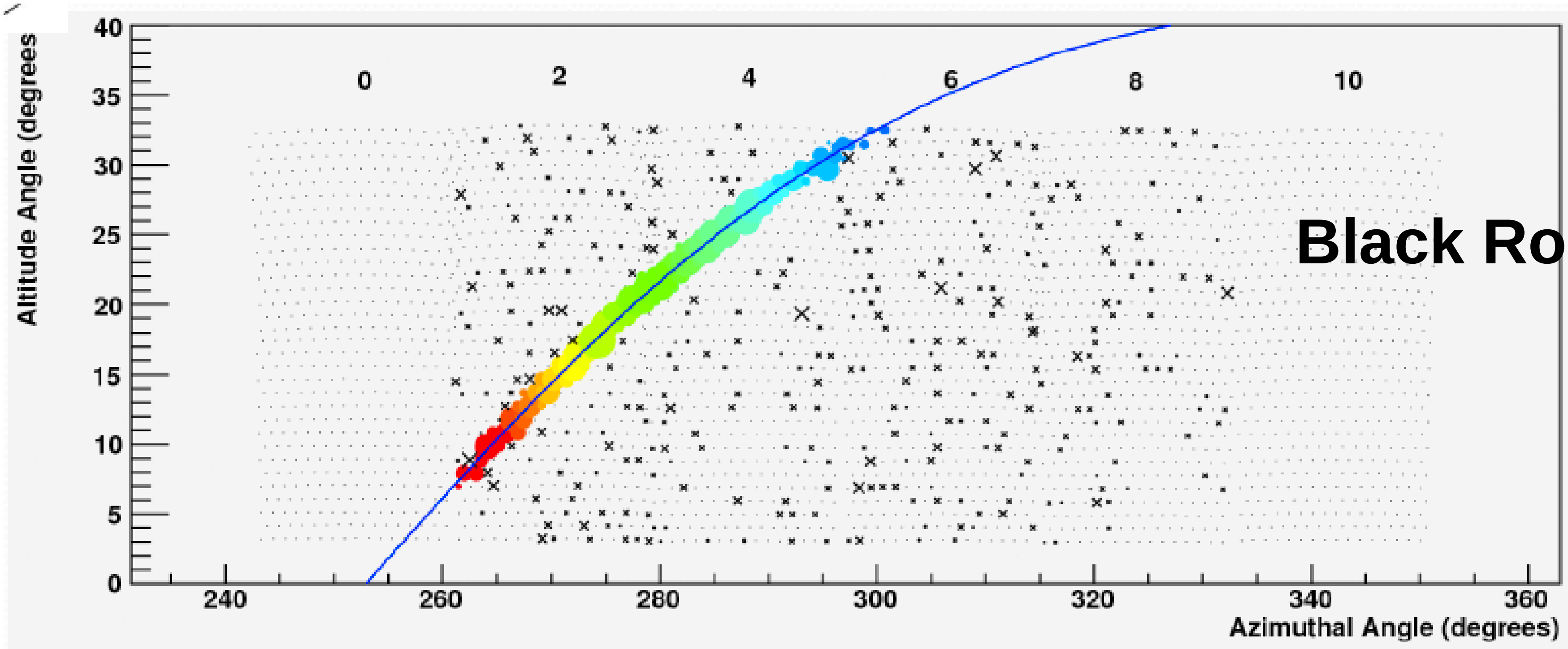
Detailed detector simulation and DATA/MC comparisons are done in all TA analyses.

Understand down to 8% efficiency

TA Fluorescence Detector (FD)

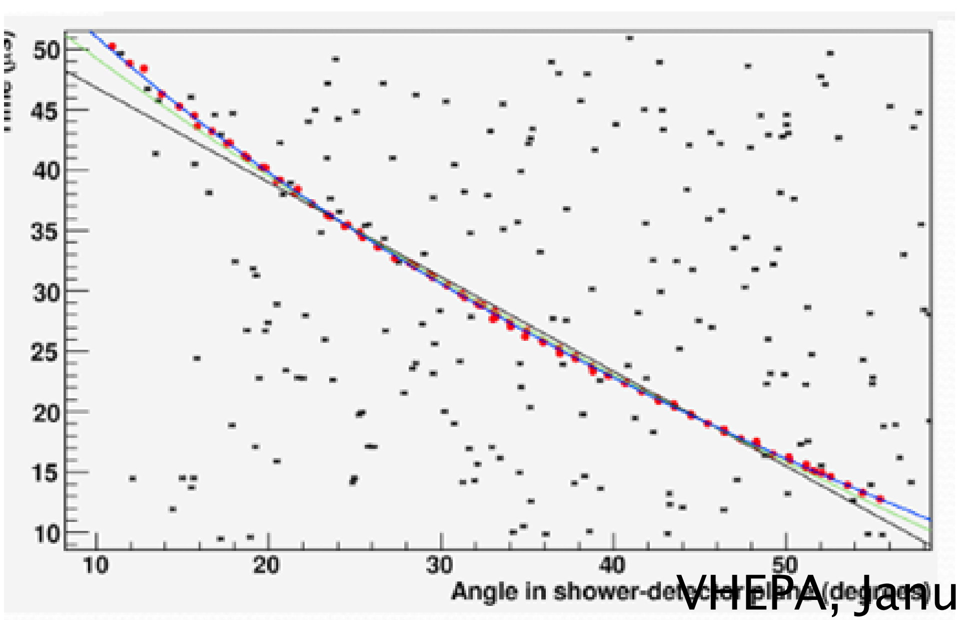


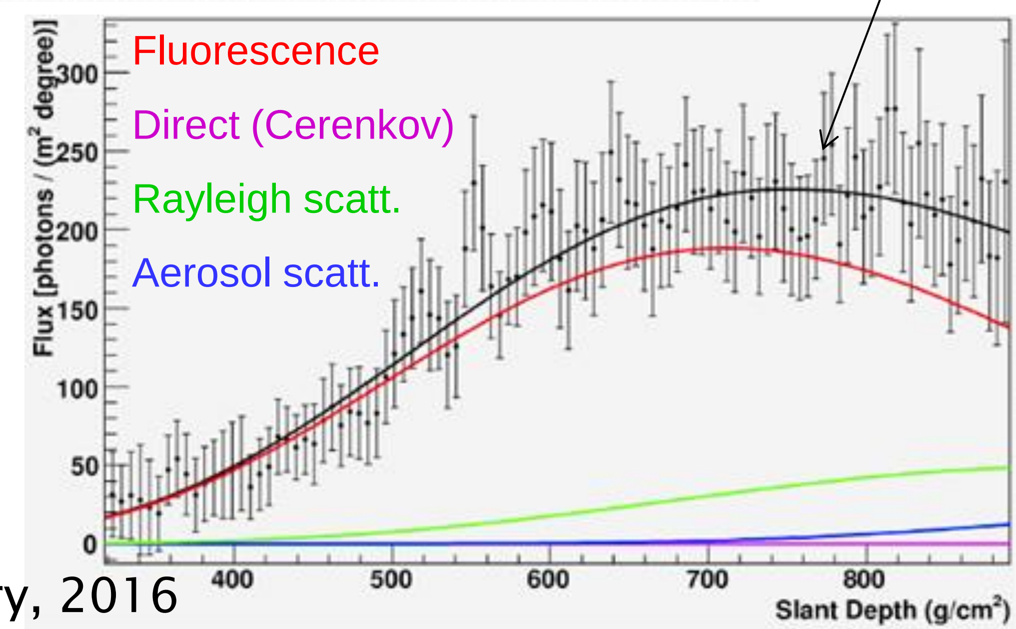
Fluorescence Analysis



Black Rock Mesa

Xmax

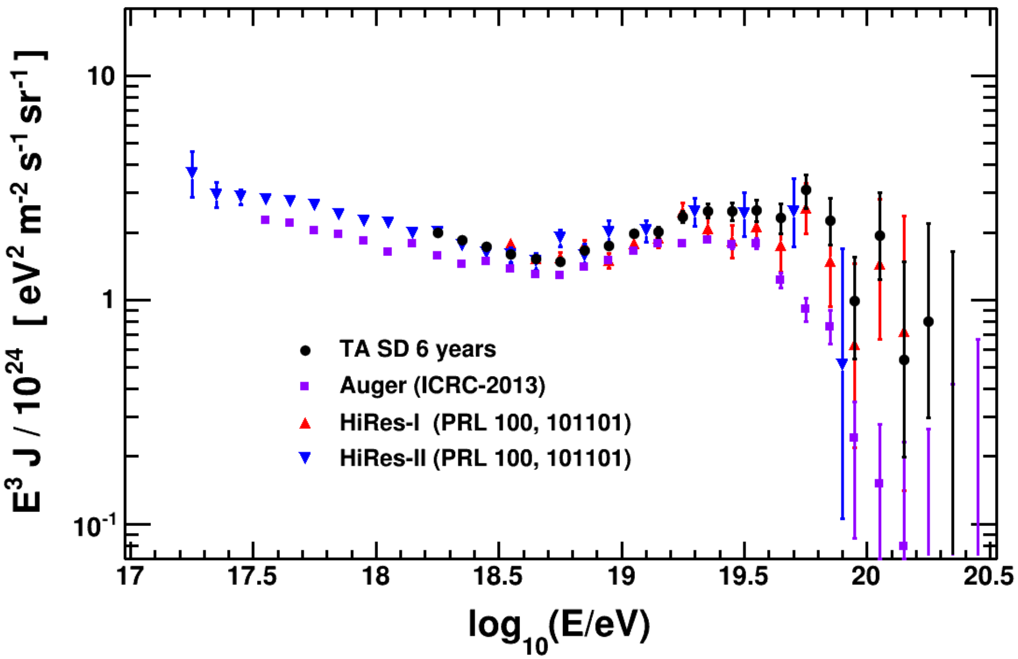




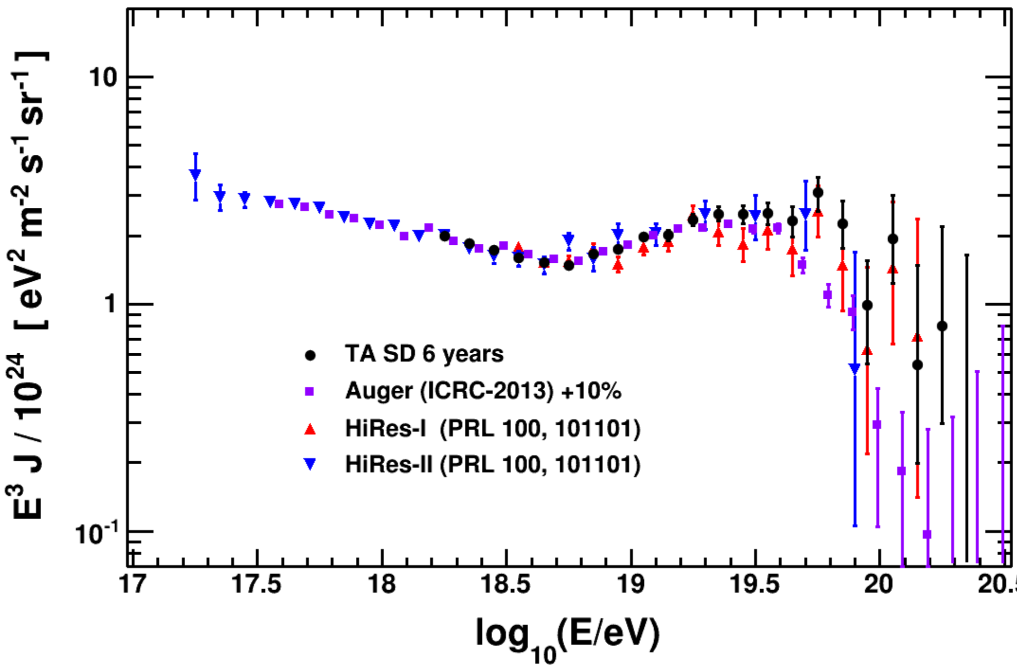
Time fit **Profile fit**

TA, HiRes, and Auger Spectra

as published



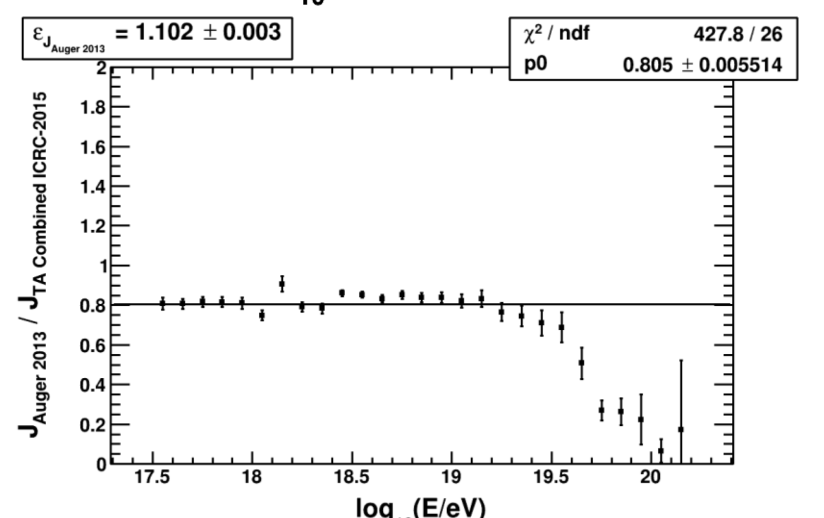
10% energy shift



Difference above $10^{19.3}$ eV.

Spectrum WG at UHECR2014 did not find an instrumental cause of the difference.

VHEPA, January, 2016



TA Low Energy Extension (TALE)

- Study the 10^{16} and 10^{17} eV decades with a hybrid detector.
  - End of the rigidity-dependent cutoff that starts with the knee (at 3×10^{15} eV).
  - The second knee
  - The galactic-extragalactic transition
- High energy physics measurements:
  - σ(p-air) and σ(p-p) from LHC energy (10^{17}) to 10^{19} eV.
- Need to observe from 3×10^{16} eV to 3×10^{20} eV all in one experiment. That is TA and TALE.

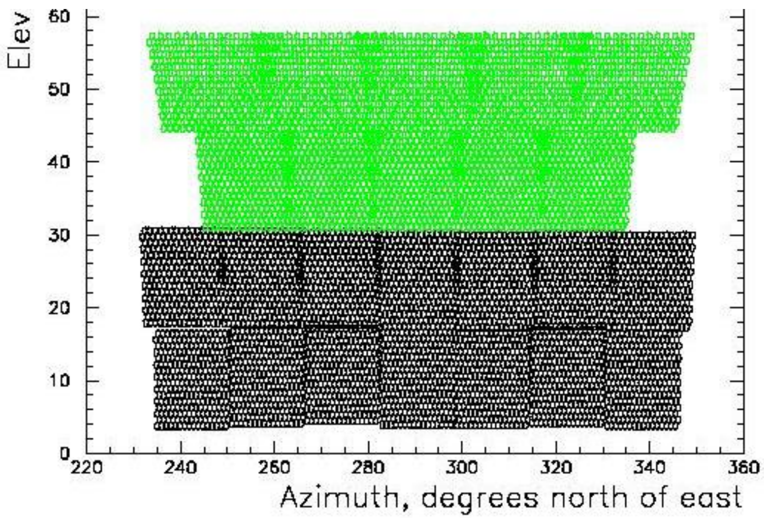
TALE FD

- Add 10 telescopes at the Middle Drum site, looking from 31˚-59˚ in elevation.
- Operate in conjunction with the TA Middle Drum FD.
- $10^{16.5} < E < 10^{20.5}$ eV

  together

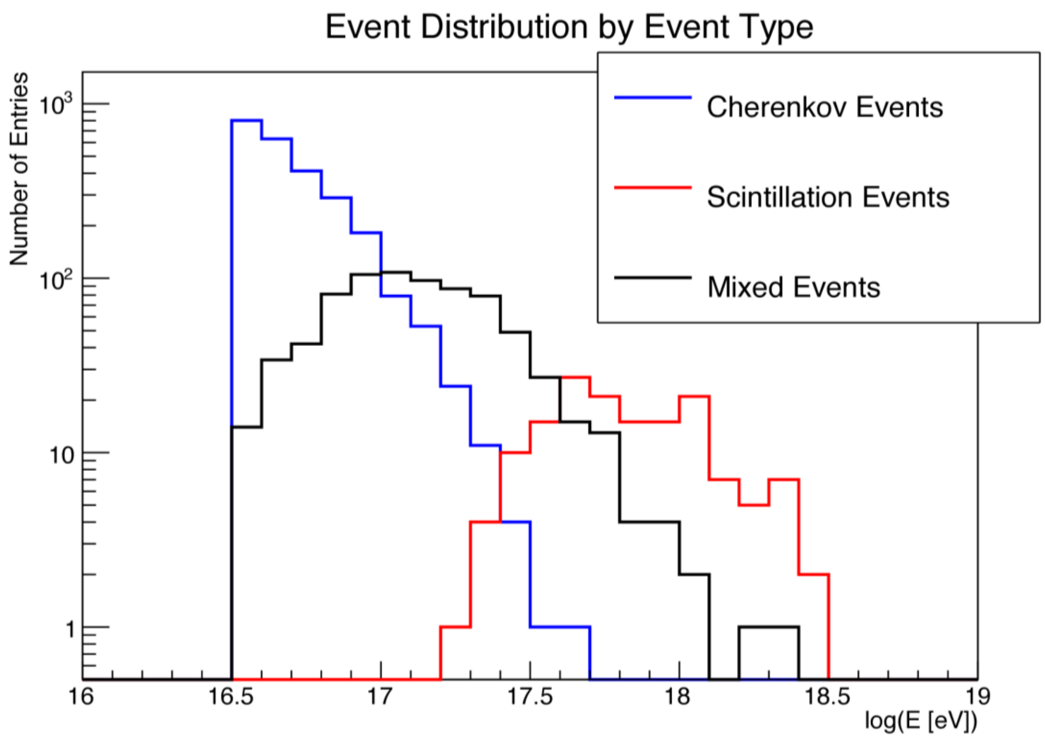
- Infill array is being deployed

TALE telescopes



TA MD telescopes

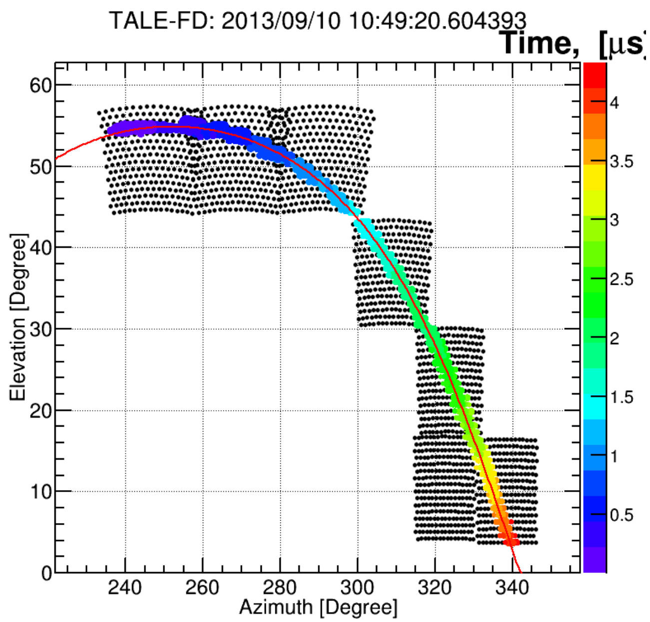
TALE Cherenkov vs. Fluorescence



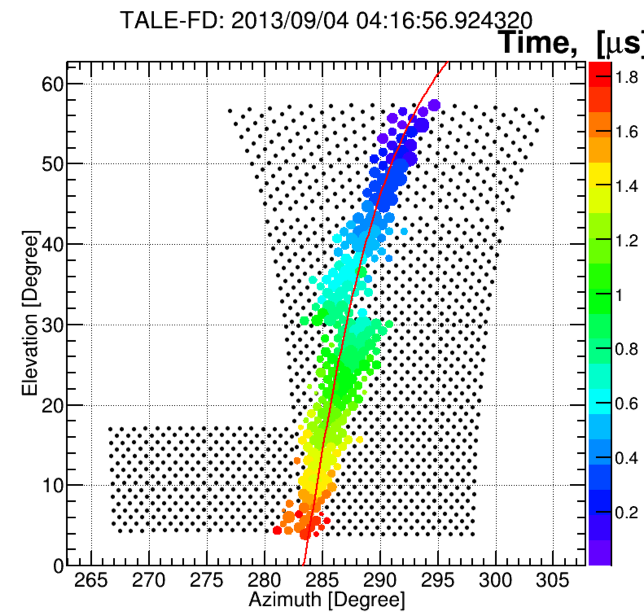
Unexpected result: many Cherenkov events are seen as tracks (most land ~0.5 km from FD).
Use profile constrained reconstruction.
Cherenkov light is bright ➔ can go lower in energy than expected.

TALE Events

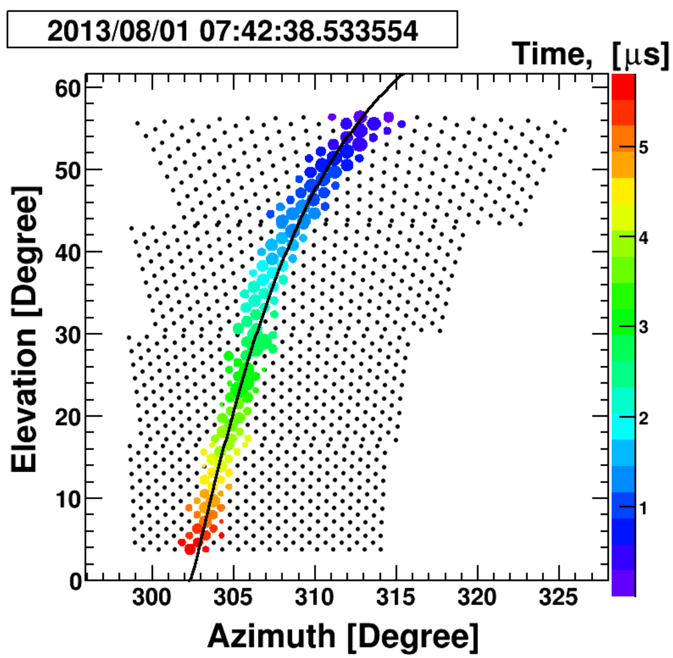
7 mirror event, $10^{16.5}$ eV

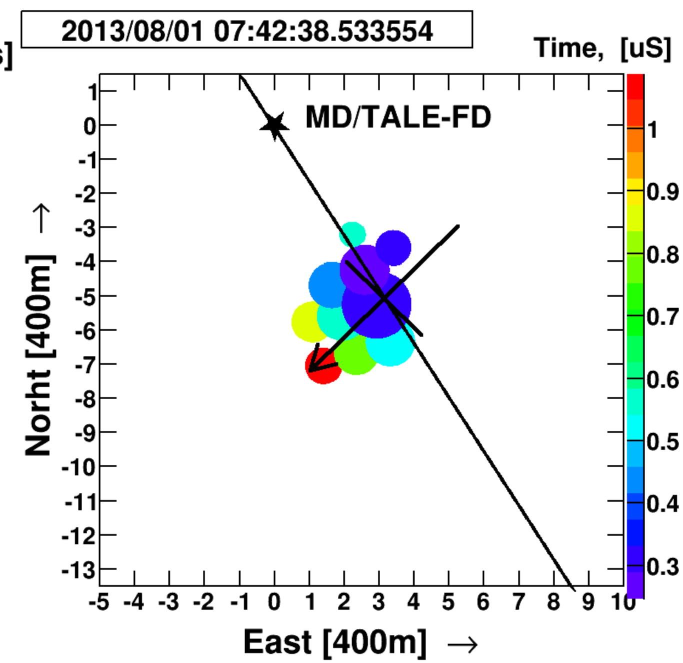


Parallax event, R_p=800m

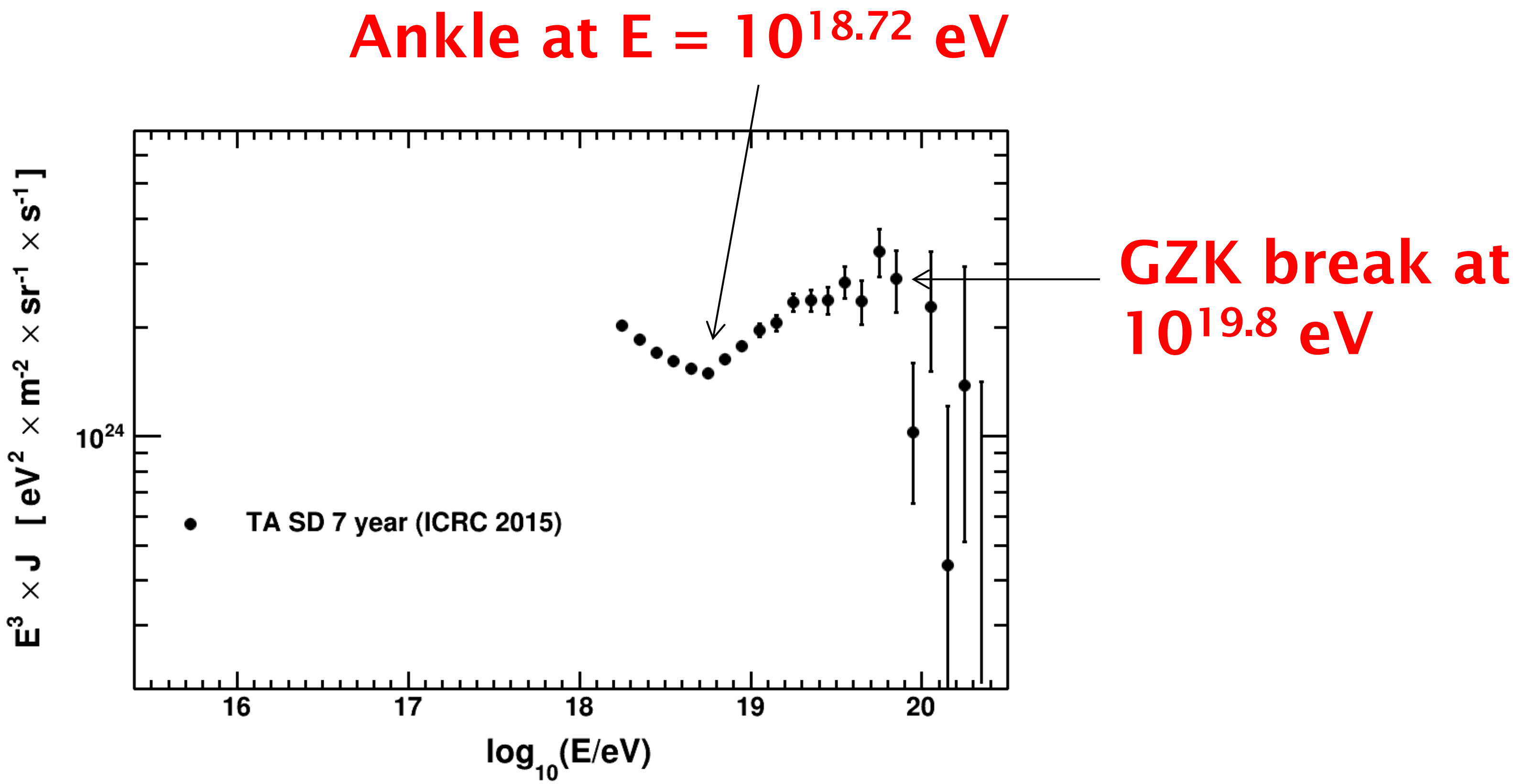


Hybrid event

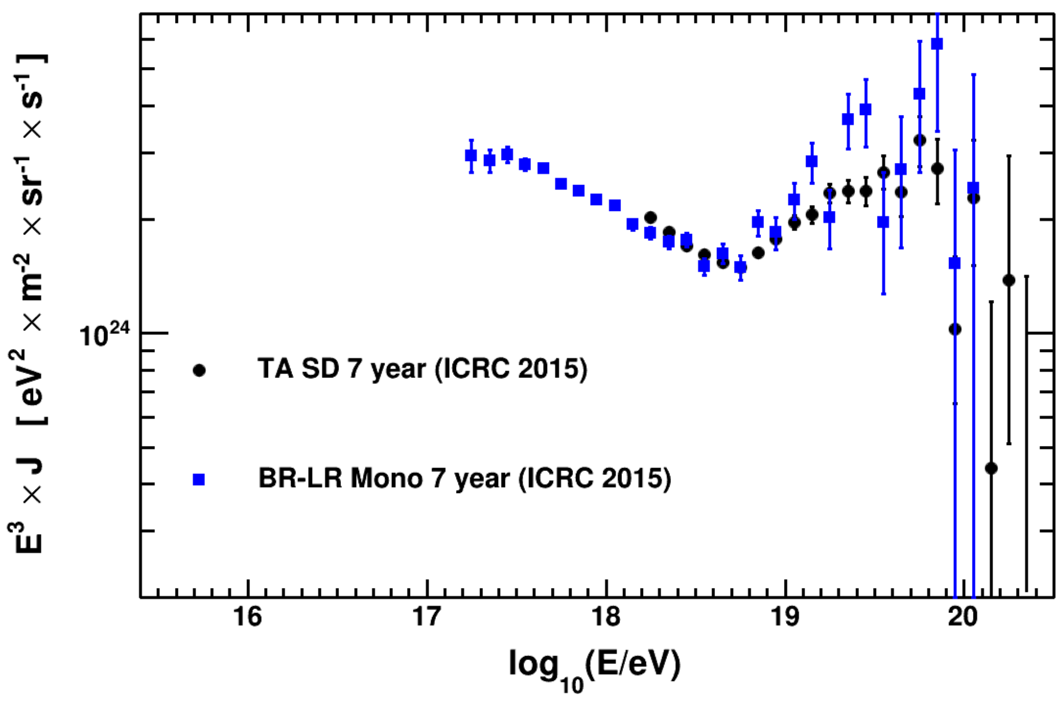




TA SD, $E > 10^{18.2}$ eV

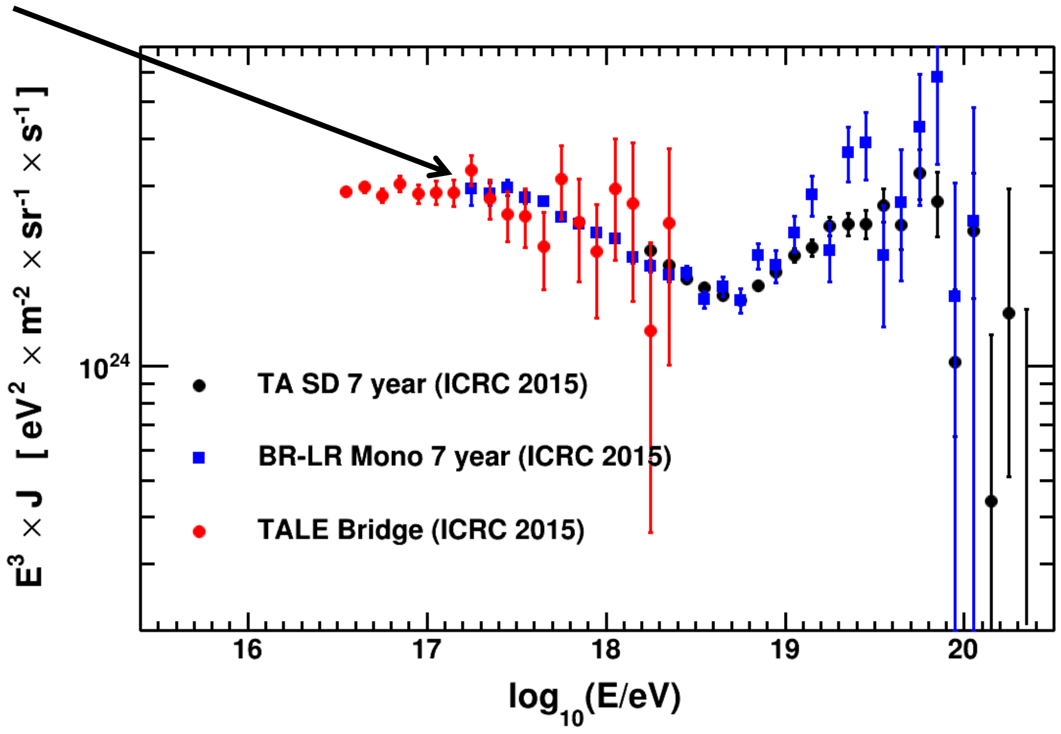


Add TA FD Mono, $E > 10^{17.2}$ eV



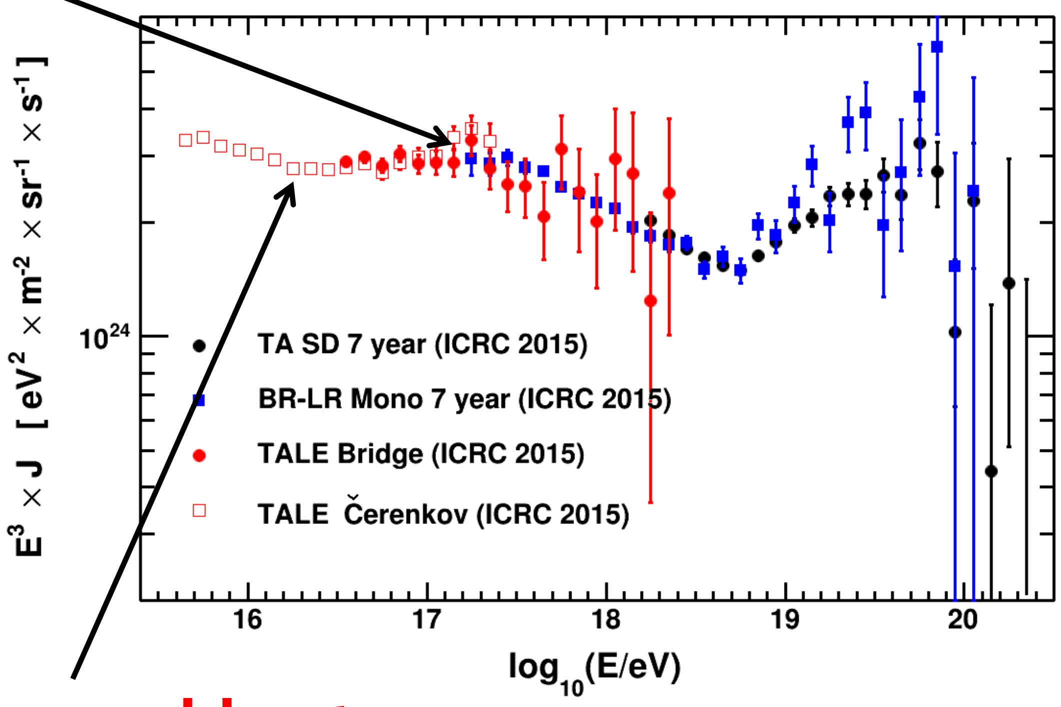
Add TALE FD Mono, Mixed+Fluorescence, $10^{16.5}$ eV < E < $10^{18.4}$ eV

Second knee at E = $10^{17.3}$ eV



Add TALE Mono, Cherenkov, $10^{15.6}$ eV < E < $10^{17.4}$ eV

Second knee at E = $10^{17.3}$ eV

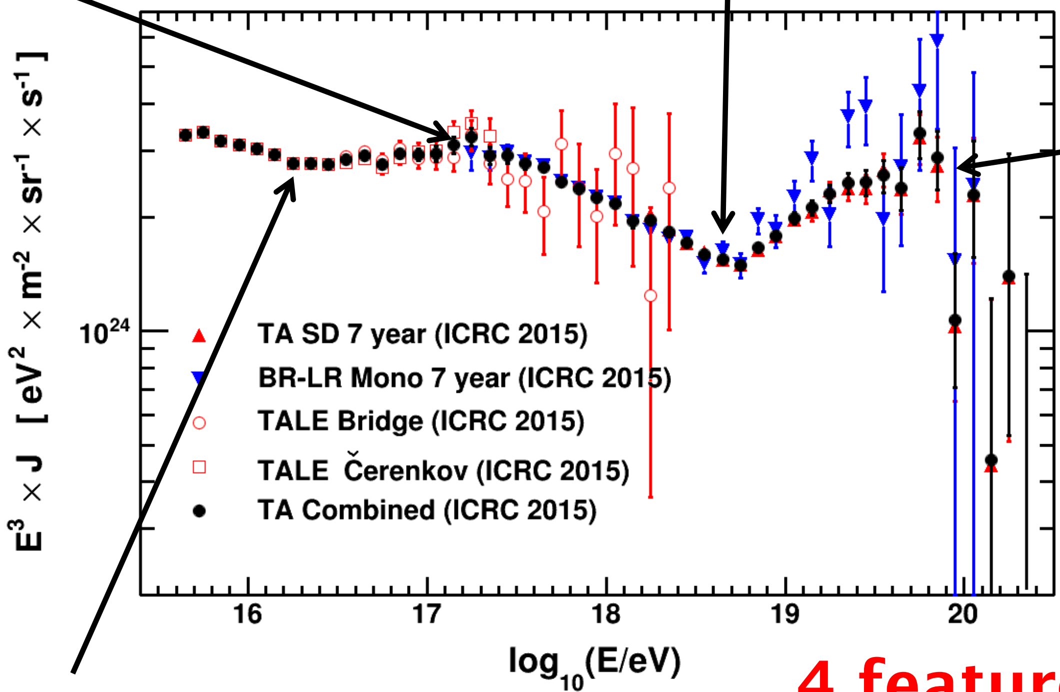


Low energy ankle at $10^{16.3}$ eV (Preliminary)

Combined TA Spectrum

Second knee at E = $10^{17.3}$ eV

Ankle at E = $10^{18.72}$ eV



GZK break at $10^{19.8}$ eV

Low energy ankle at $10^{16.3}$ eV

4 features over 4.7 orders of magnitude in energy

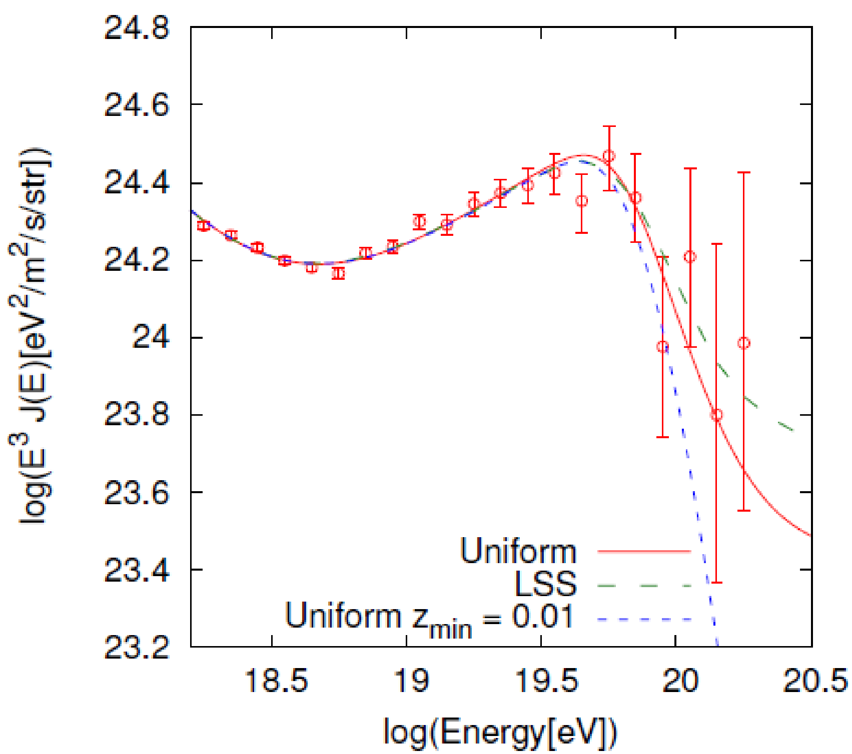
Fit SD spectrum to energy-loss model

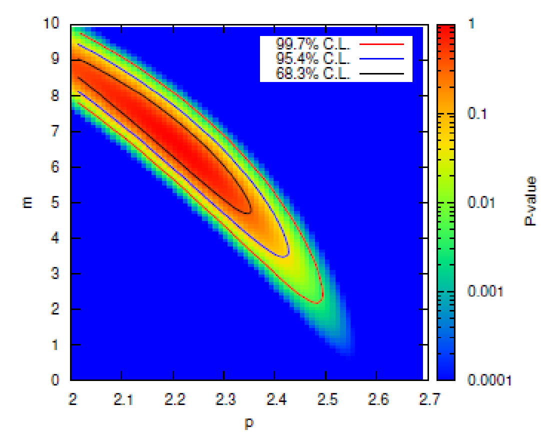
Inputs:

1. Protonic composition.
2. Pion photoproduction and e+e- pair production on CMBR.
2. Hubble expansion.

Fitting parameters:

1. Power law at the source, E^{-p}
2. Evolution of the sources, $(1+z)^{m}$



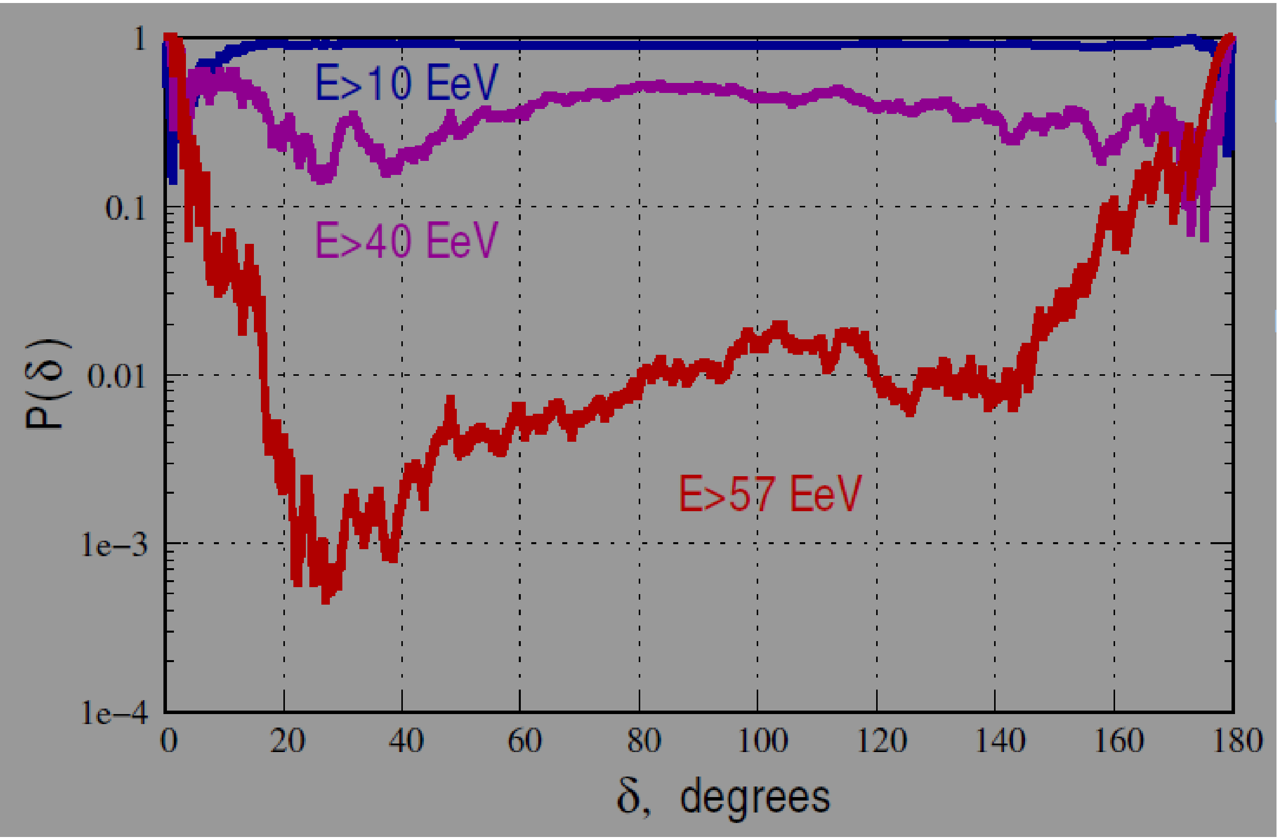


TA Anisotropy Searches

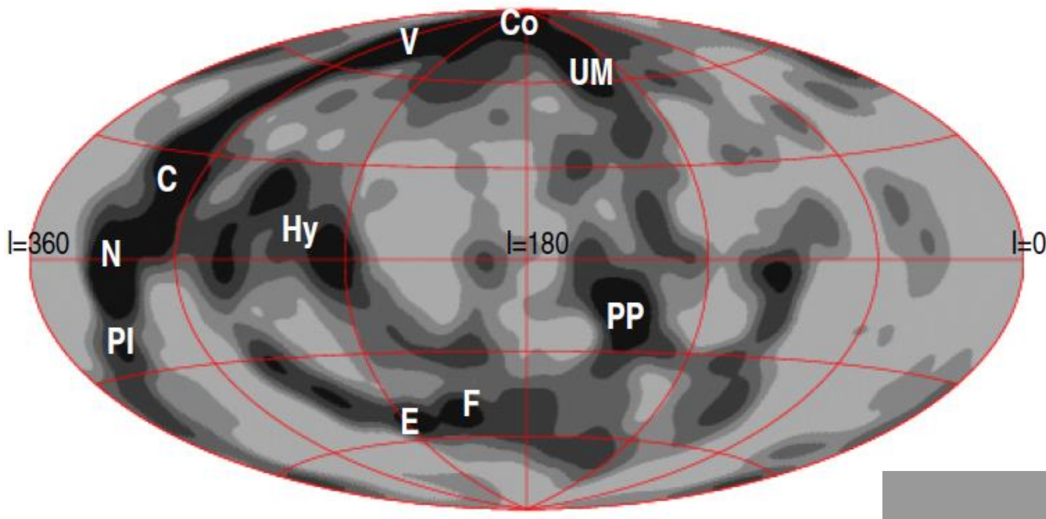
- Autocorrelation search.
- Correlations with the local large scale structure (LSS).
- Search for evidence of EeV protons of galactic origin.
- The TA hotspot.

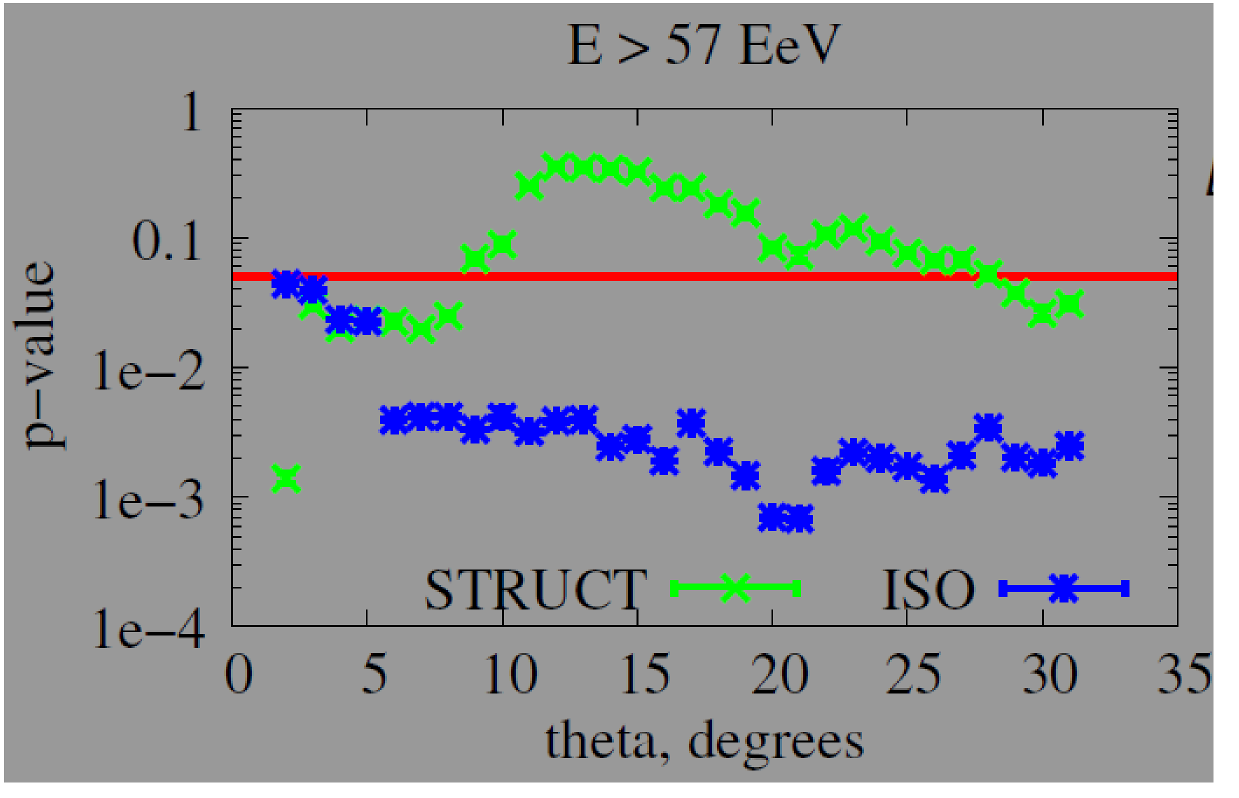
Autocorrelation Search

- count number of pairs separated by the angle δ
- compare to isotropic distribution



LSS Correlations

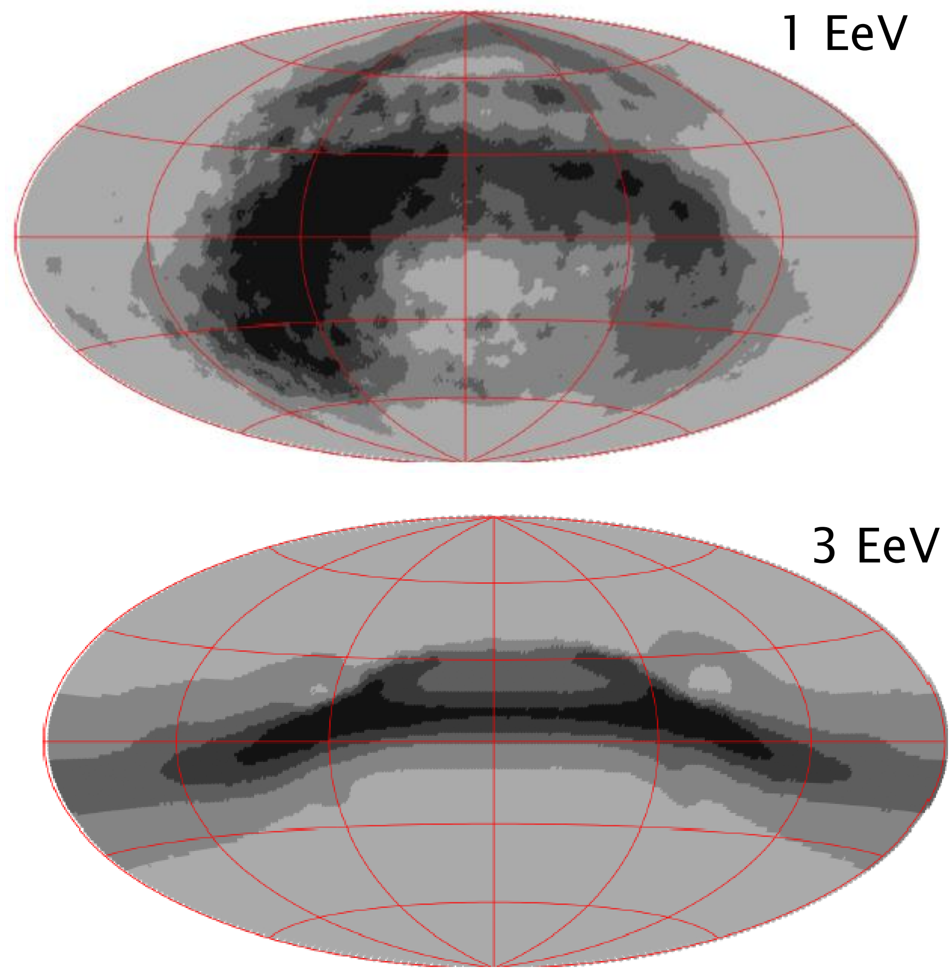




Search for EeV protons of galactic origin

- In the 1-3 EeV energy range,
  - All experiments (HiRes, Auger, TA) see a dominantly protonic composition.
  - This is just above
    - the critical energy for galactic protons (0.3 EeV)
    - the transition from diffusive to ballistic propagation.

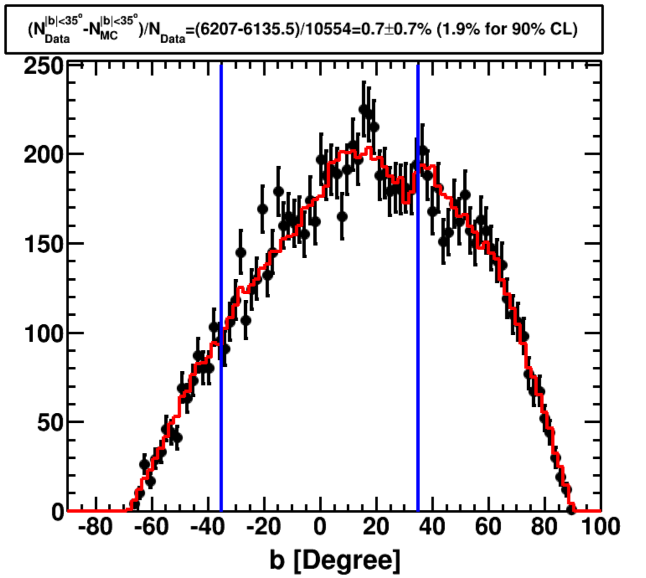
➔ There should be strong anisotropy for protons of galactic origin.

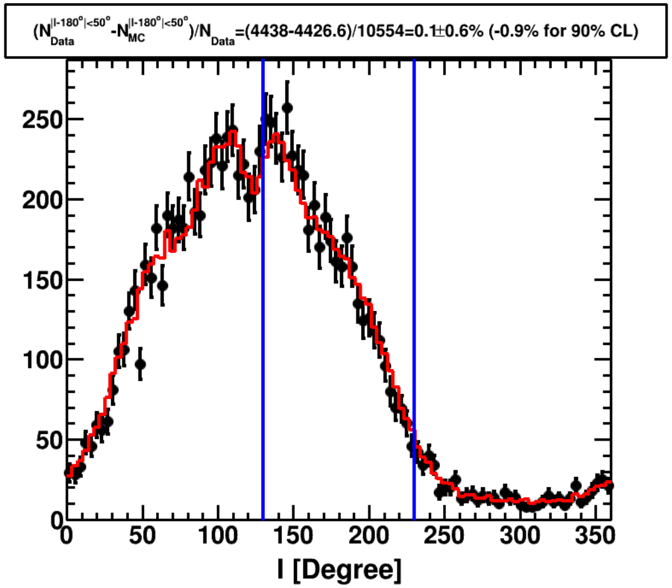


Galactic coordinates, GC at center

EeV Protons - 2

- Expect enhancement in b of width 35˚.
- Expect deficit in l, centered on galactic anticenter, of width 50˚.
- **None is seen.**
- 95% cl upper limit of 1.9% (b) and 0.9% (l)





TA Hotspot

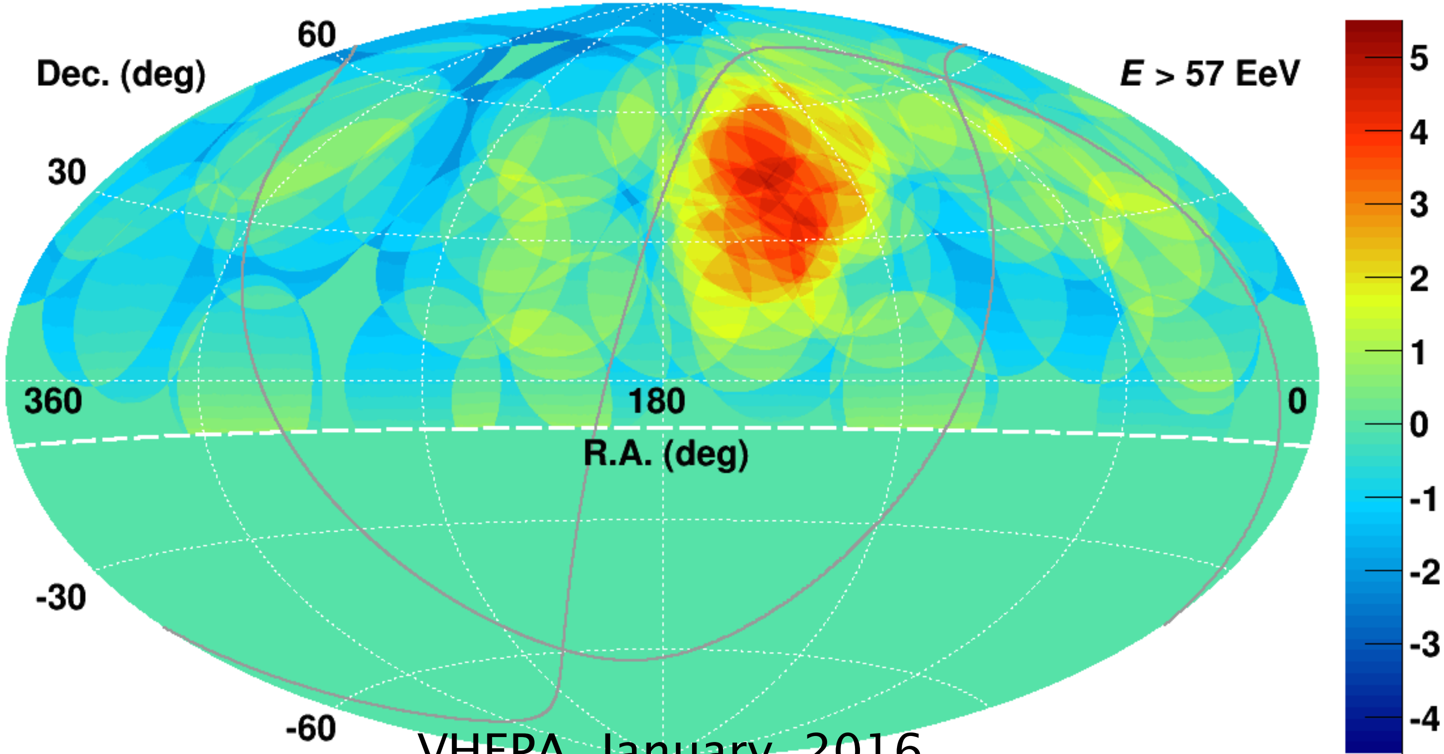
There is a cluster of just south of the supergalactic plane, "the hotspot". Plot uses oversampling, r = 20˚.

5-year SD data: 72 ev. > 57 EeV, 19 corr. (expect 4.5)

26% of events in 6% of sky.

Li-Ma significance = 5.1σ

Chance probability = 3.4σ

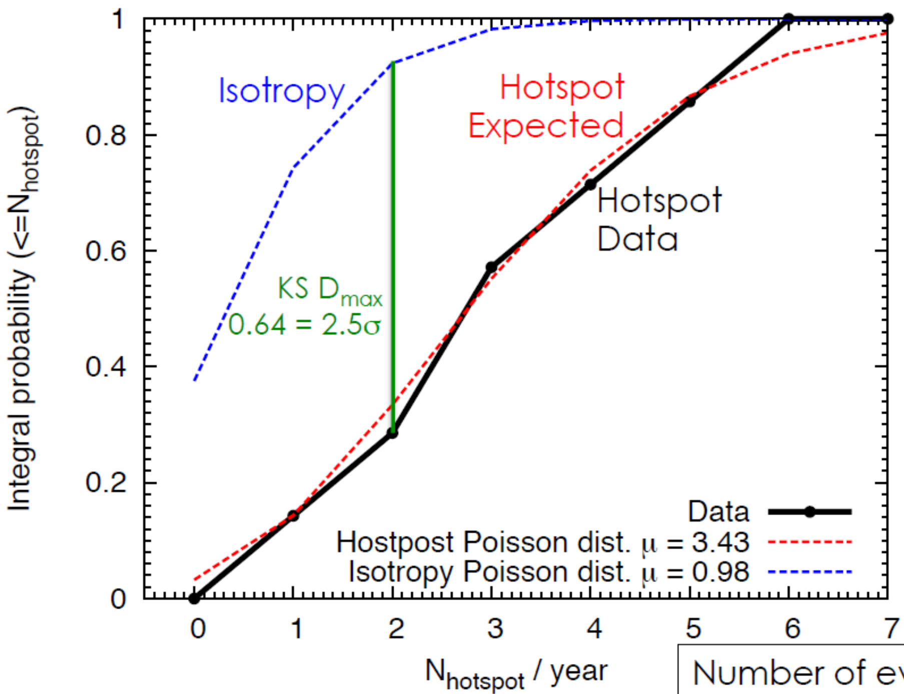


Ap.J. **790**, L21 (2014)

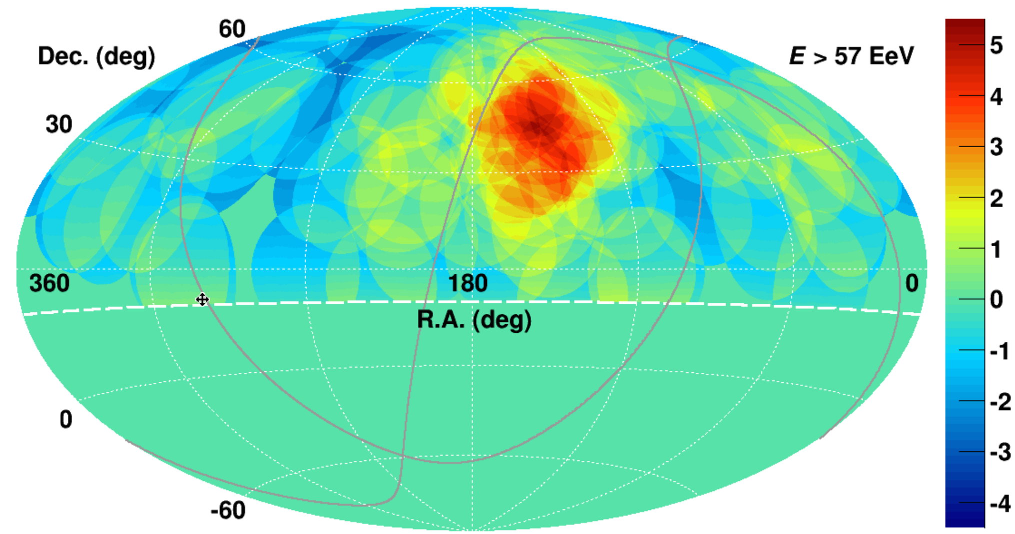
Hotspot, 7-years of SD Data

Li-Ma significance = 5.1σ

Chance probability = 3.4σ



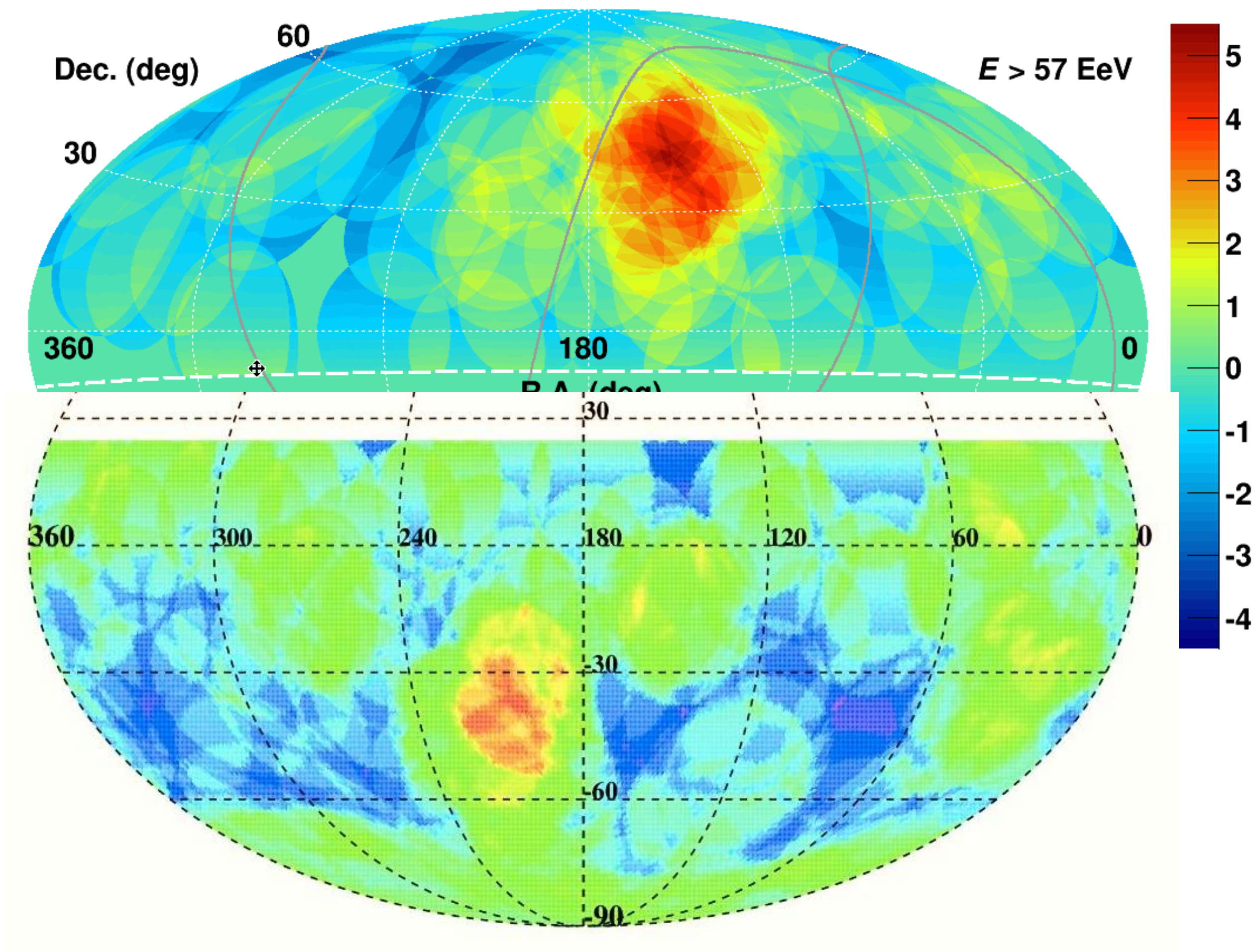
Number of events / year
In the hotspot region



Significance map; equatorial coordinates, 2008/05/11-2015/05/11

Auger "Warm Spot"*

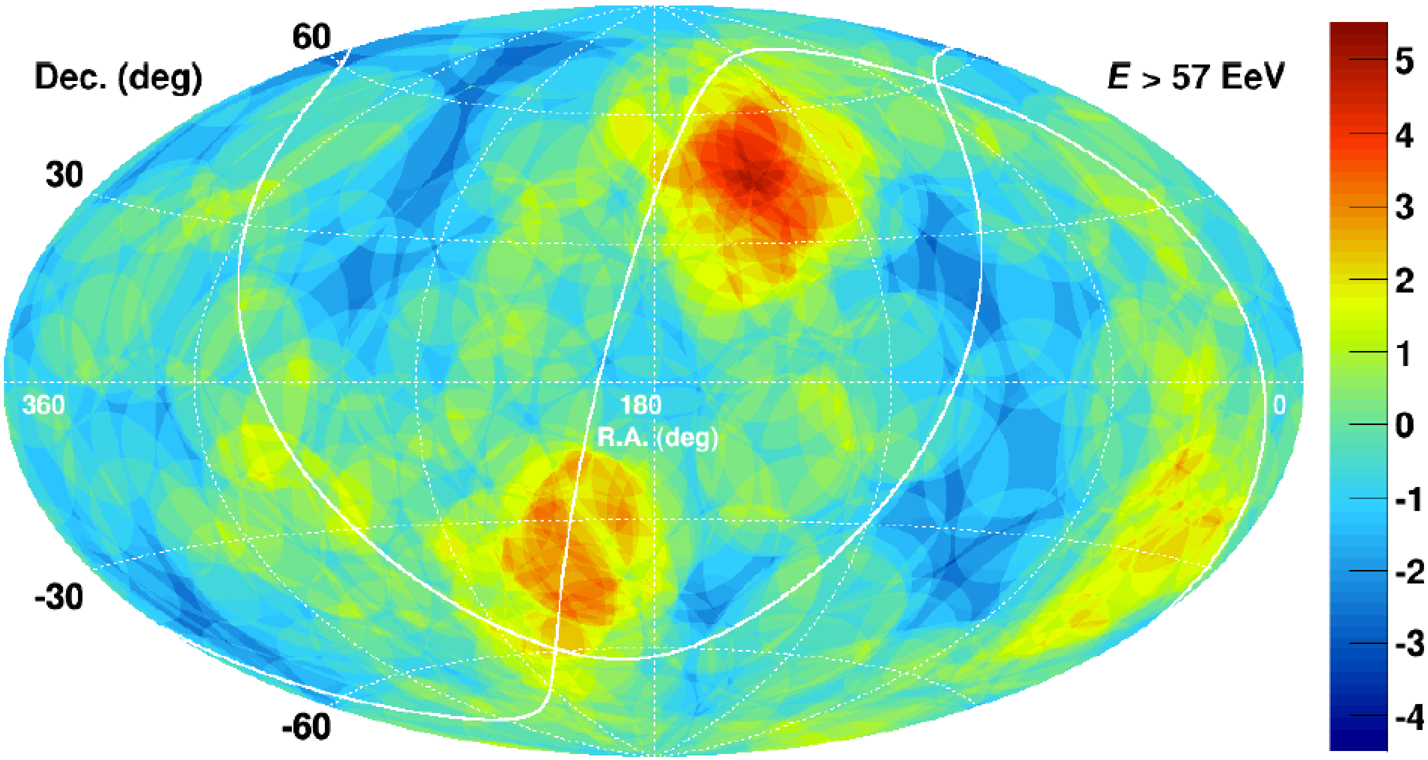
PAO sees cluster of events near CEN-A: 3.1σ



* K.-H. Kampert

Attempt at full-sky coverage

- E > 57EeV
- r = 20˚



TAx4 Project

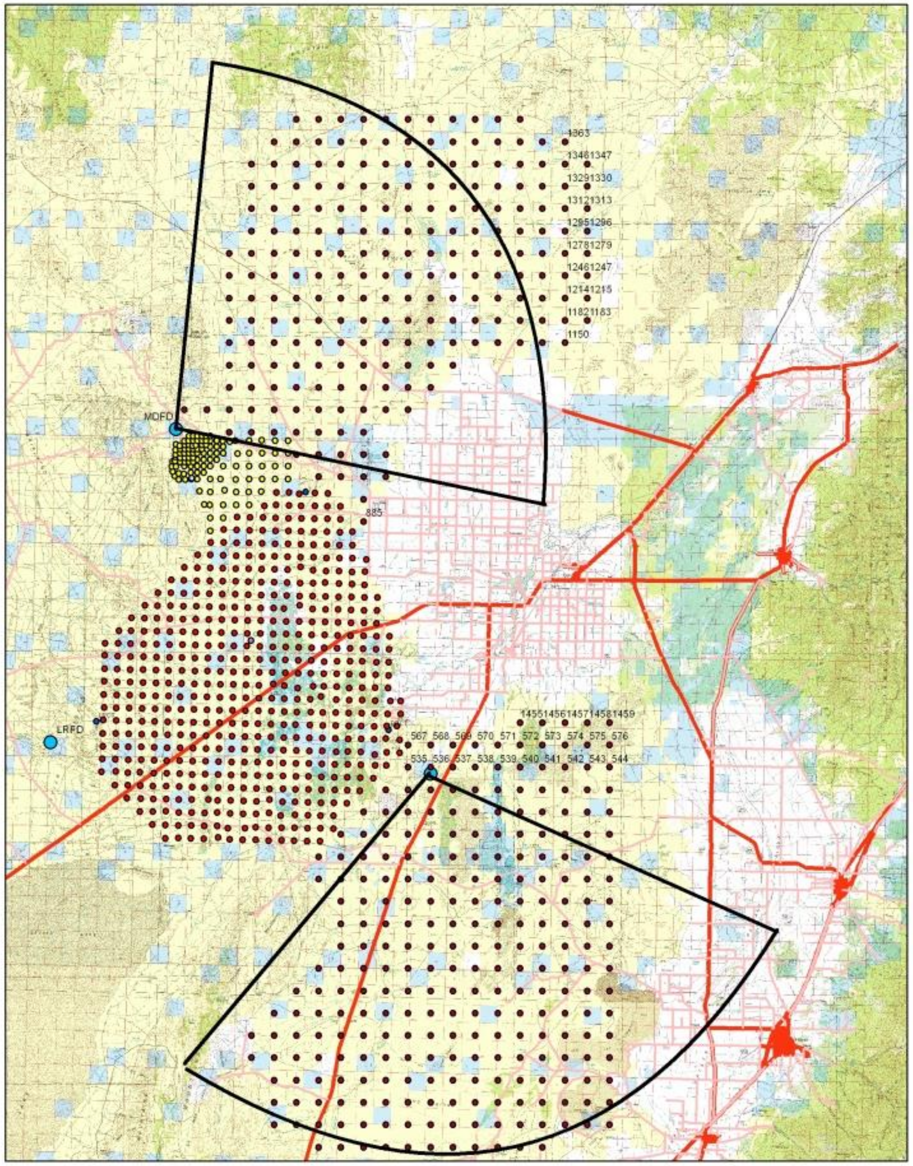
Fourfold increase in size of TA SD.

- Add 500 SD counters, at 2.08 km spacing.
- Add 2 FD sites, 28 telescopes

Get 21 TA-years by 2020: look for structure within hotspot.

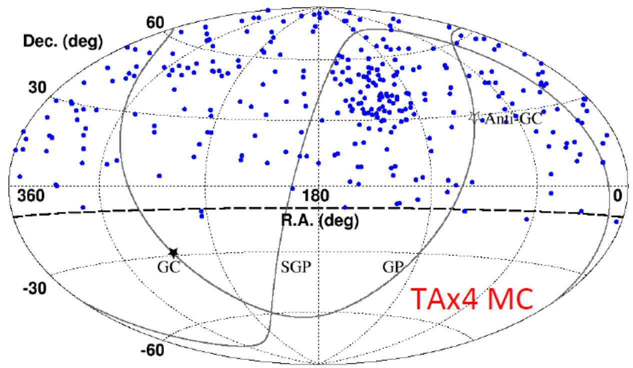
Proposals:

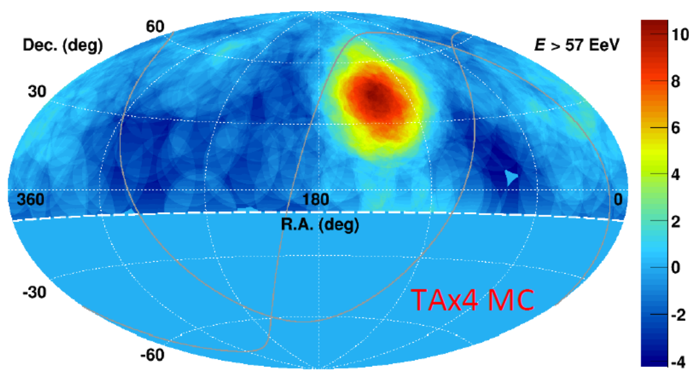
- SD = Japan (**successful!**)
- FD = U.S. (October, 2015)



21 TA-years of SD Data by 2020

(1) One Hotspot



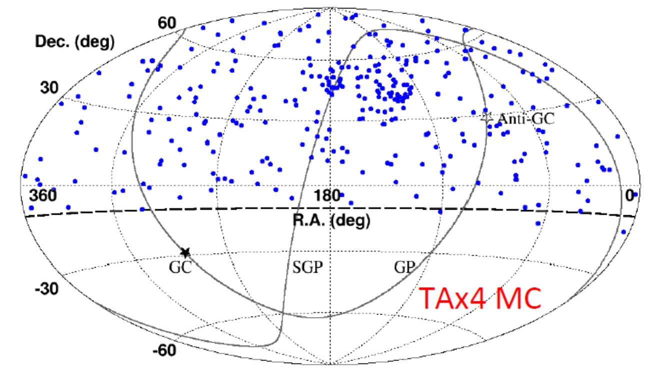


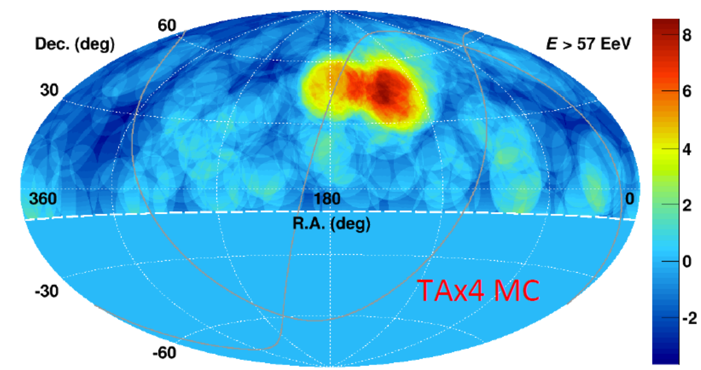
<u>Hotspot Signal</u>
80-18.9=61events
(RA, Dec)=(145°,45°)
Gaussian σ=10°

<u>Isotropic B.G.</u>
305-61=244events

Oversampling
20° radius circle

(2) Double Hotspot





<u>Hotspot Signal</u>
Total 61 events

1. 41events
   (RA, Dec)=(145°,40°)
   Gaussian σ=10°
2. 20events
   (RA, Dec)=(175°,40°)
   Gaussian σ=5°

<u>Isotropic B.G.</u>
305-61=244events

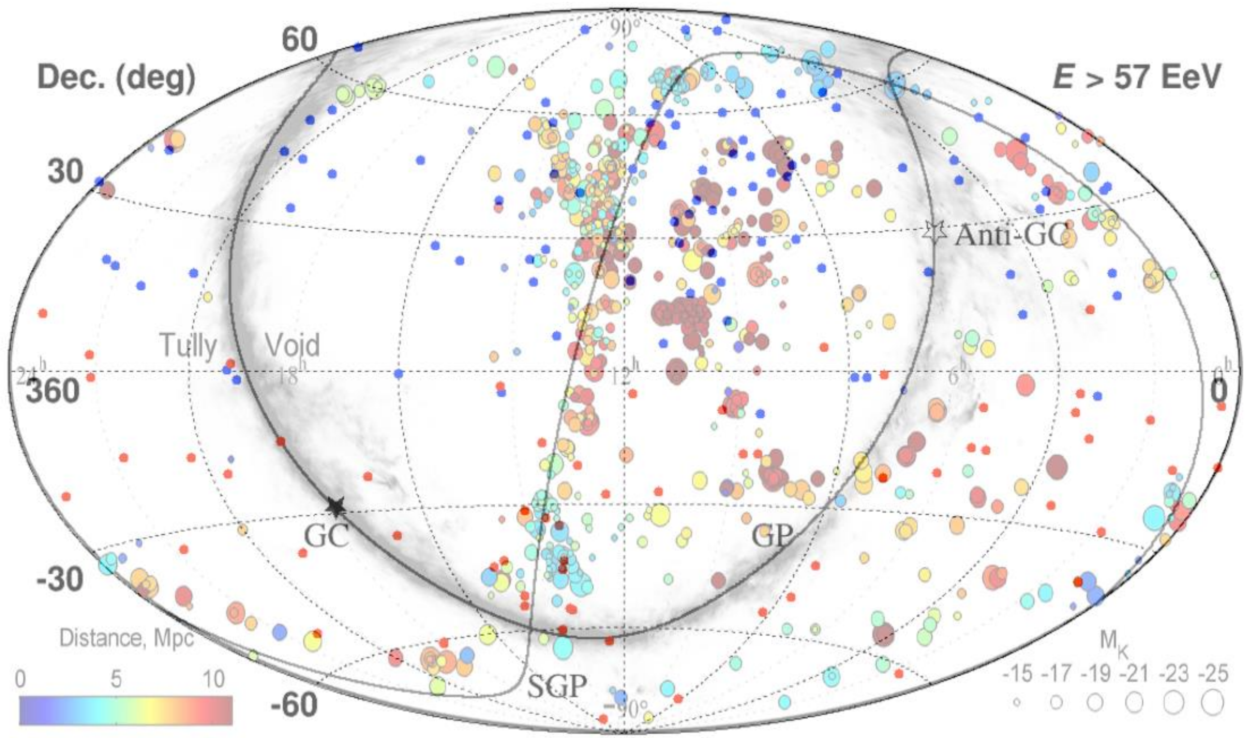
Oversampling
15° radius circle

Clarify the nature of the hotspot!

Conclusions

- TA is a LARGE experiment which has important results and excellent control of systematic uncertainties.
- **TA/TALE spectrum covers 4.7 decades in energy, and sees 4 spectral features.**
- TA spectrum results above 2 EeV are consistent with protons propagating through CMBR.
- No evidence is seen for galactic protons in the low-EeV energy range: fraction<1%.
- **TA sees 3.4σ evidence for anisotropy in the northern hemisphere.**
- Build TAx4 to see what is in the hotspot.

Filament in the Local Large Scale Structure of the Universe

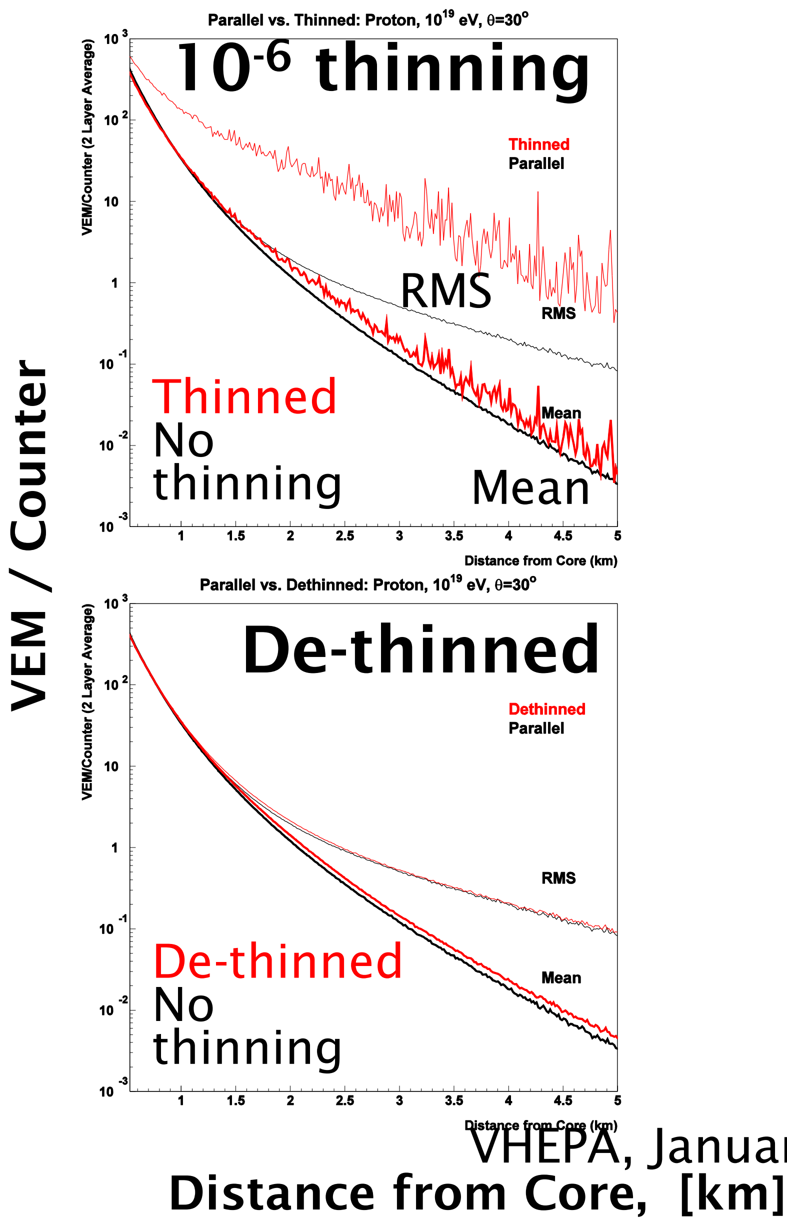


r < 11 Mpc

Blue dots: TA events

Red dots: Auger events

How to Use CORSIKA Events in Simulation of SD



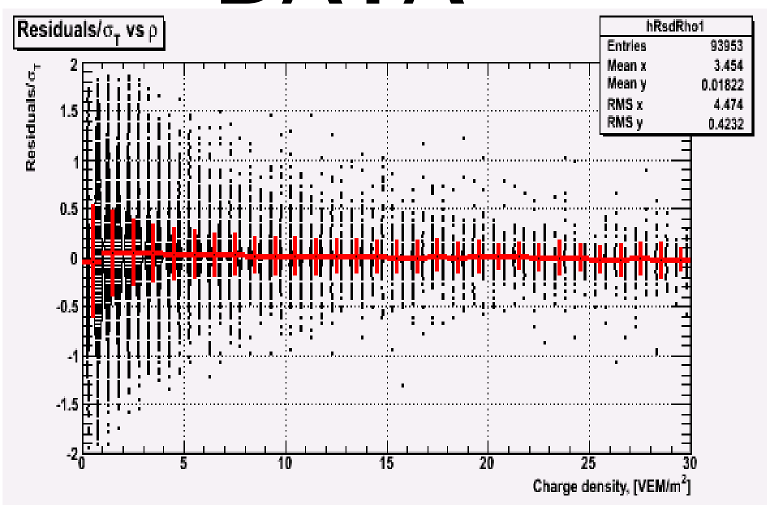
Use 10^{-6} – thinned CORSIKA QGSJET-II proton showers that are de-thinned in order to restore information in the tail of the shower.

De-thinning procedure is validated by comparing results with un-thinned CORSIKA showers, obtained by running CORSIKA in parallel

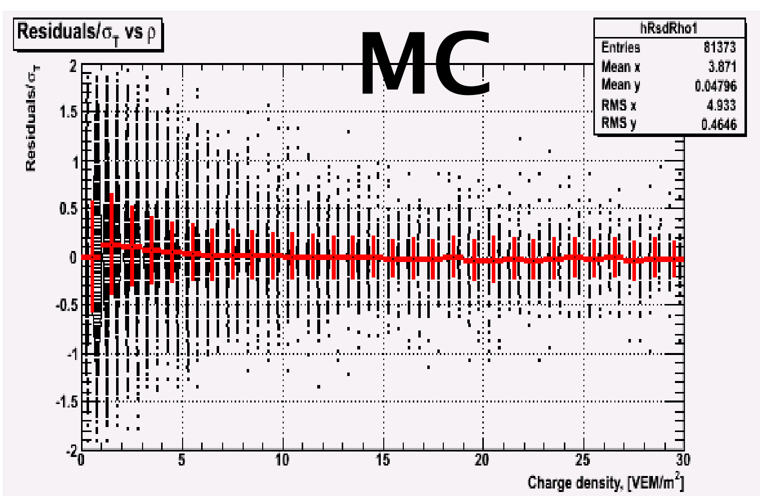
We fully simulate the SD response, including actual FADC traces

SD Time Fit Residuals

DATA



MC



Time fit residual over sigma

Counter signal, [VEM/m²]

Fitting procedures are derived solely from the data

Same analysis is applied to MC

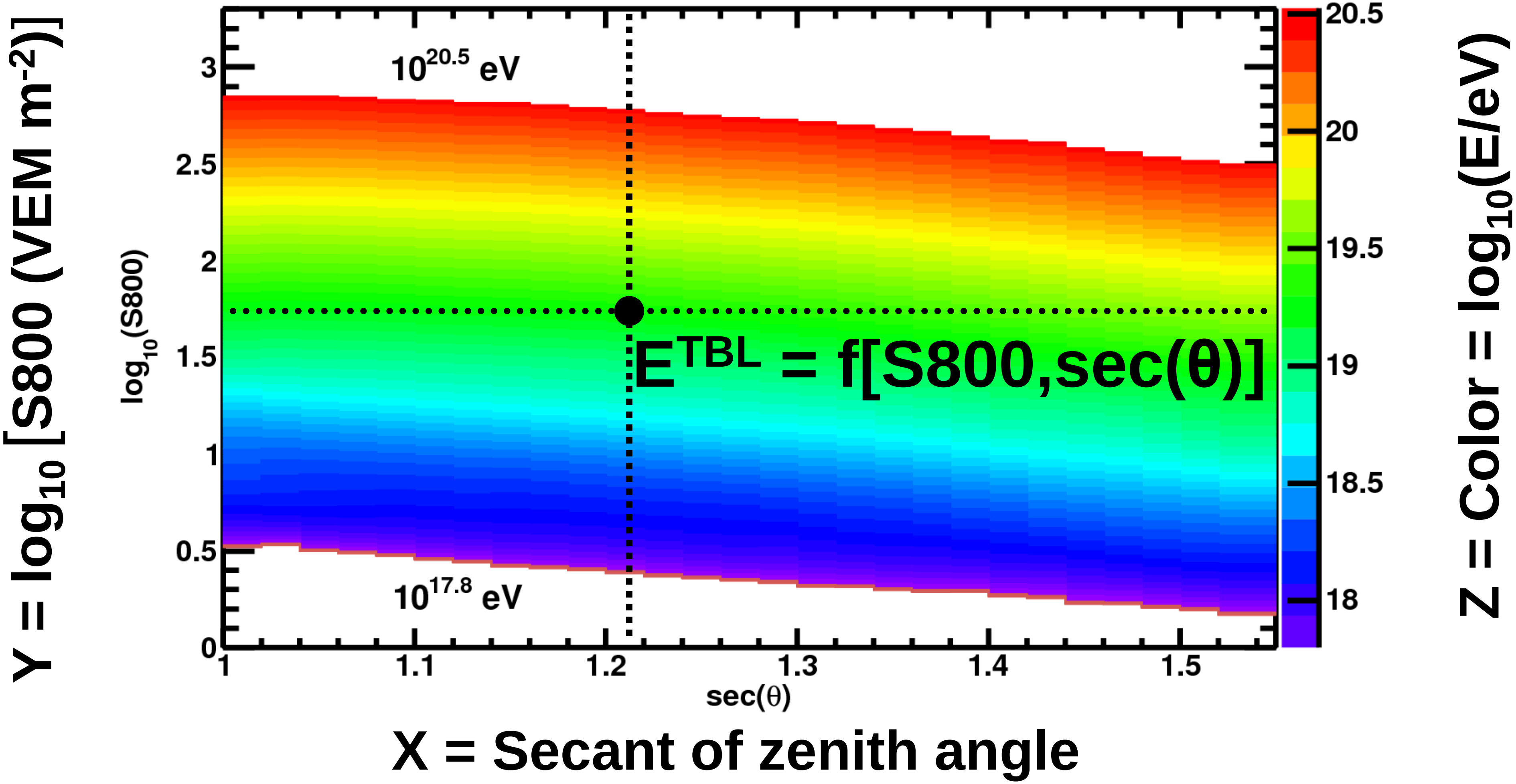
Fit results are compared between data and MC

MC fits the same way as the data.

Consistency for both time fits and LDF fits.

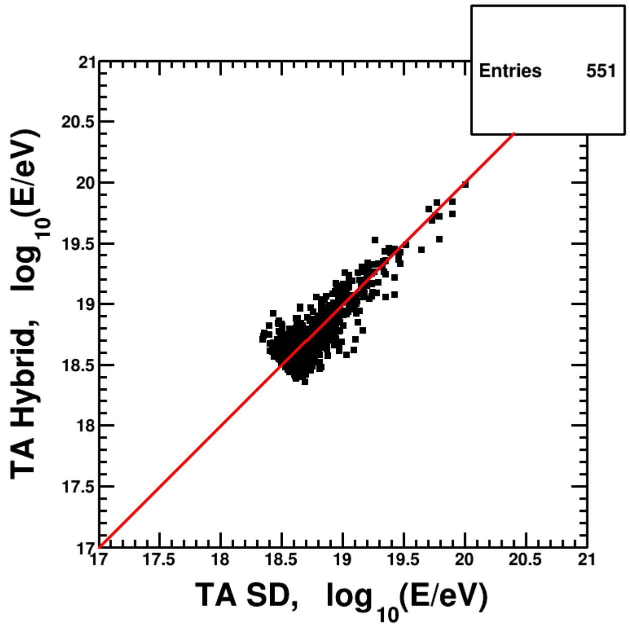
Corsika/QGSJet-II and data have same lateral distributions!

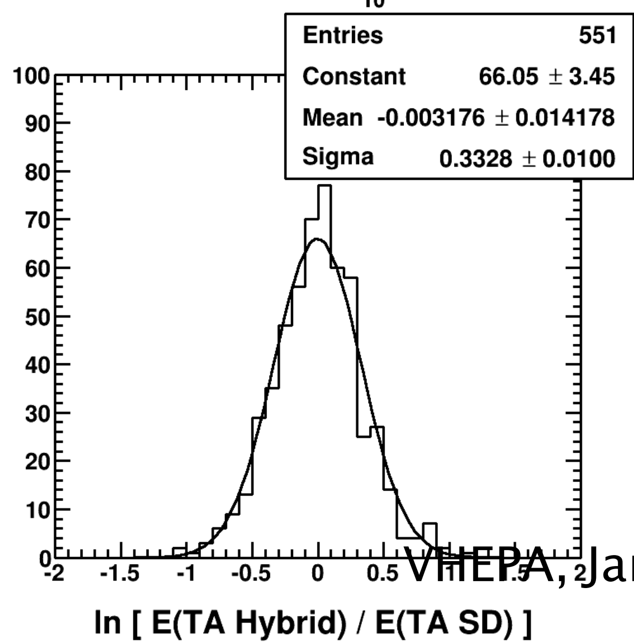
SD Energy



- A look-up table made from the Monte-Carlo
- Event energy (E^{TBL}) = function of *reconstructed* S800 and sec(θ)
- Energy reconstruction ←→ interpolation between S800 vs sec(θ) contours of constant values of E^{TBL}
- The overall energy scale locked to the fluorescence detector

SD Energy: Energy Scale Set to FD





- Energy scale locked to the FD to reduce the systematic due to the model
- Use events well reconstructed separately by SD and FD in hybrid mode:
  - SD ∩ [BR U LR U MD Hybrid]
  - $E^{FINAL} = E^{TBL} / 1.27$
- TOP figure: E^{FINAL} vs E^{FD} scatter plot
- BOTTOM figure: histogram of E^{FINAL} / E^{FD} ratio
- 2008/05/11-2013/05/04