Results from the Telescope Array Experiment

Charlie Jui

University of Utah

TeVPA 2013 Irvine, CA

Aug. 27, 2013

http://www.physics.utah.edu/~jui/ta-tevpa2013.pdf

Telescope Array Collaboration

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V. Kuzmin[q], Y. J. K … atsuyama[j],
J. N. Matthews[a], … ura[u], H. Nanpei[j],
T. Nonaka[h], A. N … n, A. Oshima[j],
S. Ozawa[r], I. H. P … N. Sakurai[j],
A. L. Sampson[a], L … , T. Shirahama[m],
J. D. Smith[a], P. So … Takamura[e],
A. Taketa[z], M. Takita[h], Y. Tameda[k], H. Tanaka[j], K. Tanaka[aa], M. Tanaka[t], S. B. Thomas[a],
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K. Yashiro[e], Y. Yoneda[j], S. Yoshida[s], H. Yoshii[ad], R. Zollinger[a], Z. Zundel[a]

~120 collaborators in 5 countries

Japan, USA, Korea, Russia, Belgium

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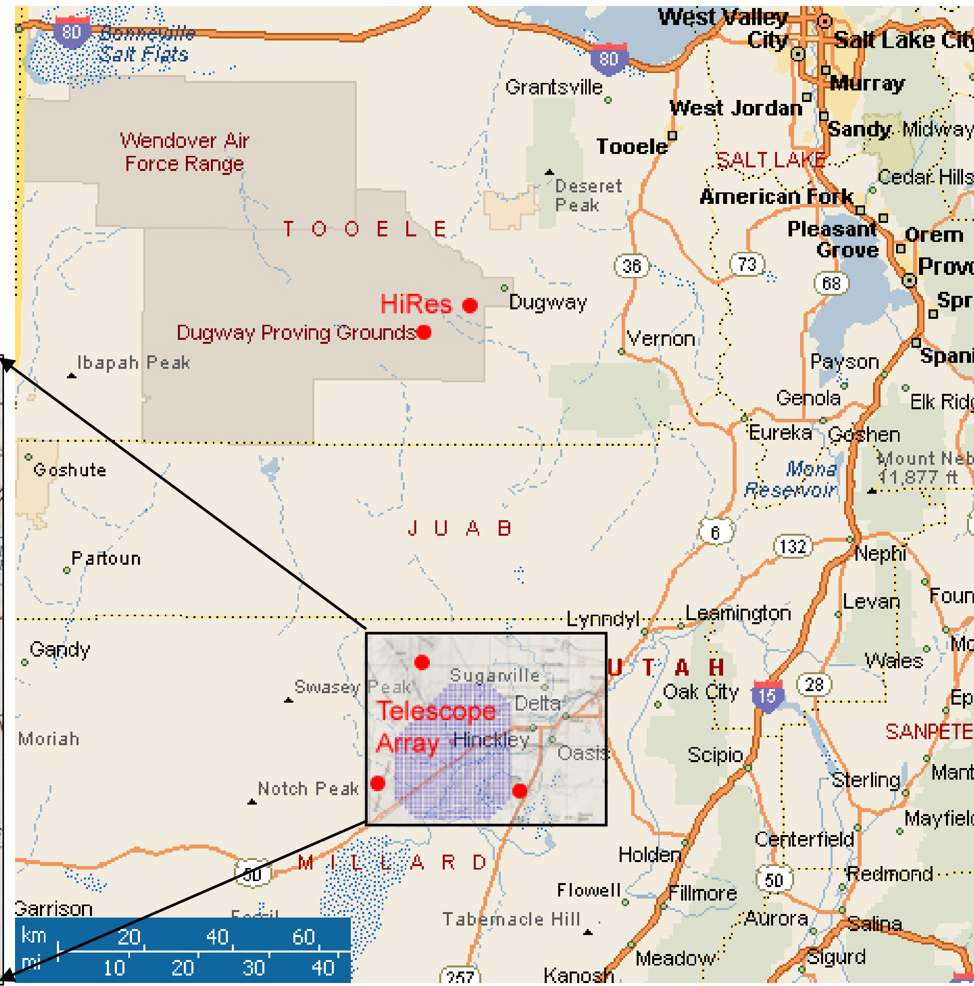
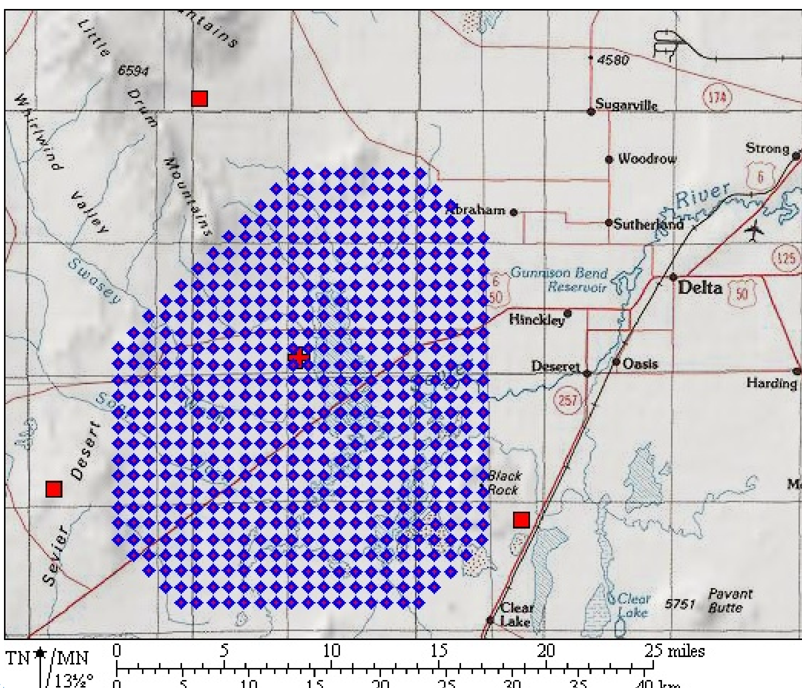
Telescope Array Experiment

- TA is a ultrahigh energy (>10^{17} eV) cosmic ray observatory located in the West Desert of Utah: largest in the northern hemisphere



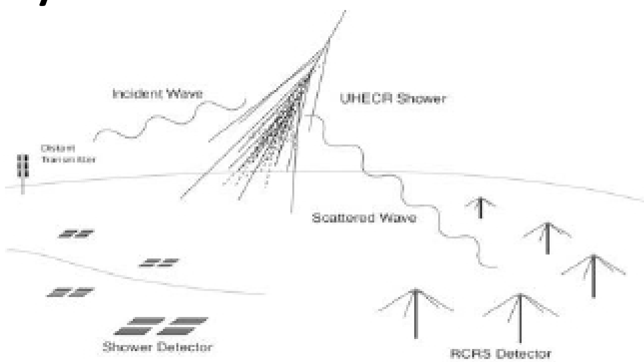


TA

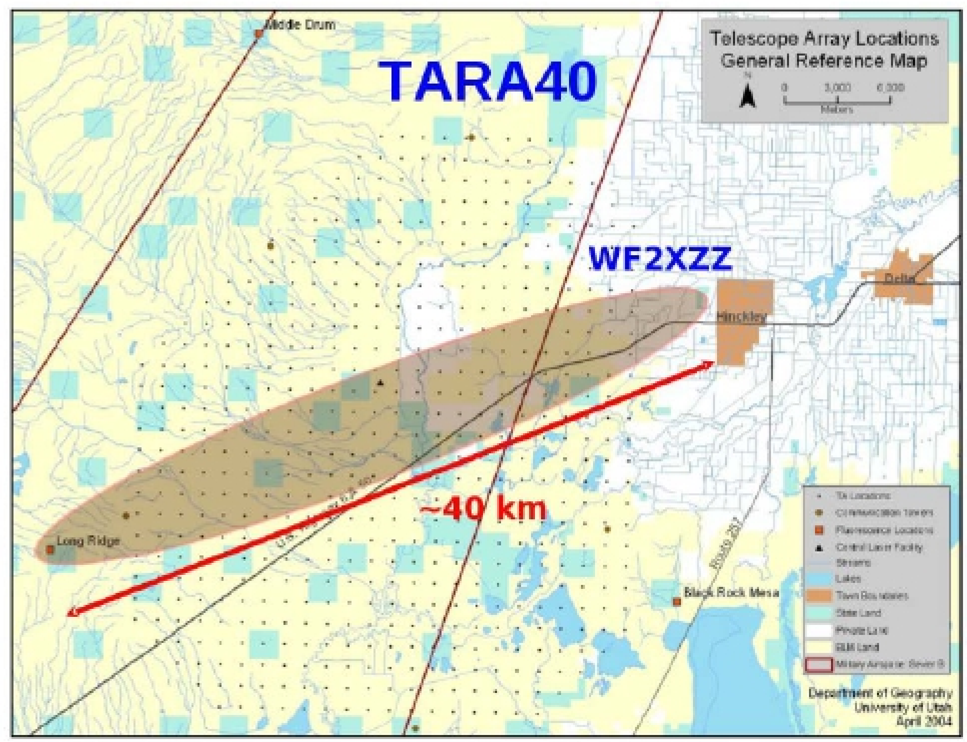
TARA (TA Radar)

TARA Presentations at TeVPA2013:
Tue. Aug 27
14:24 *Jordan HANSON*
14:48: *Samridha KUNWAR*

- An R&D project to observe radar reflections form cosmic ray air showers



- TARA1.5
  - April 2011 to July 2012
  - 54.1 MHz @ 1.5 kW
- TARA40
  - Summer 2013~
  - 54.1 MHz @ 40 kW



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Outline

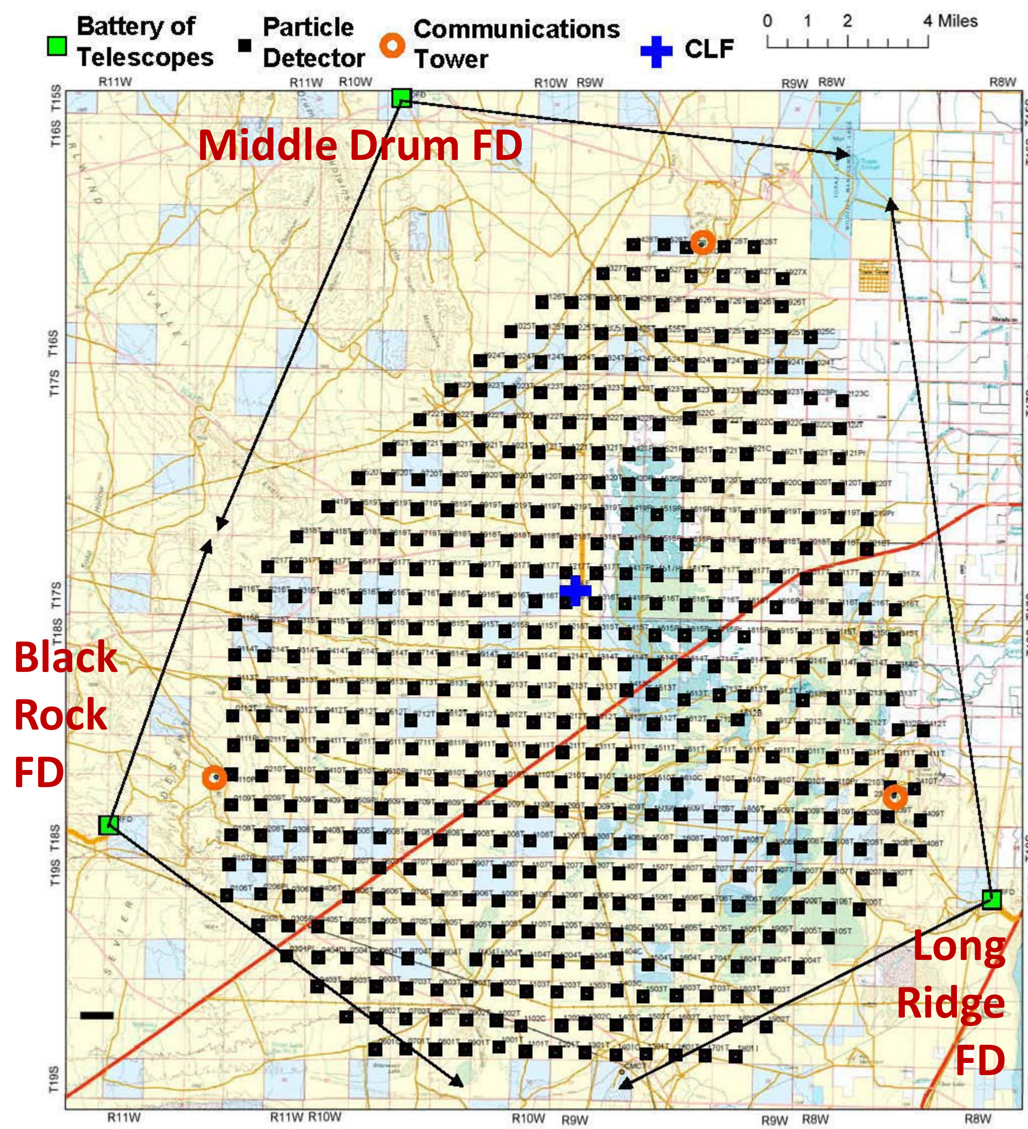
1. Introduction to Telescope Array
2. Data Analysis Techniques
3. Energy Spectrum
4. Composition
5. Photons and Neutrinos ???
6. Anisotropy

1. Introduction

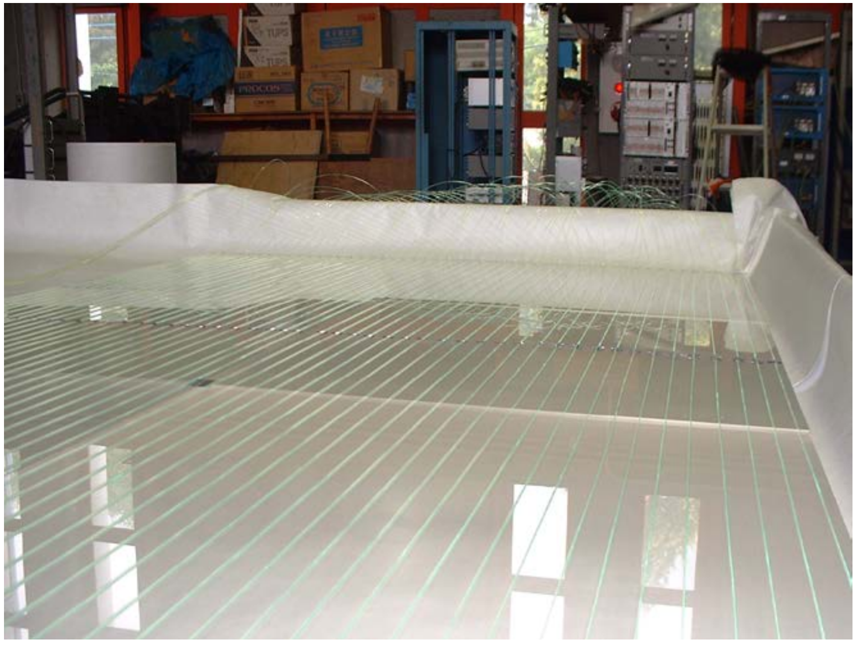
TA Detectors

TA is a <u>hybrid</u> experiment

- 507 scintillation counters surface detector (SD)
  - Covers 730 km^2.
- 3 fluorescence detector (FD) stations
  - Located at the corners of the SD array

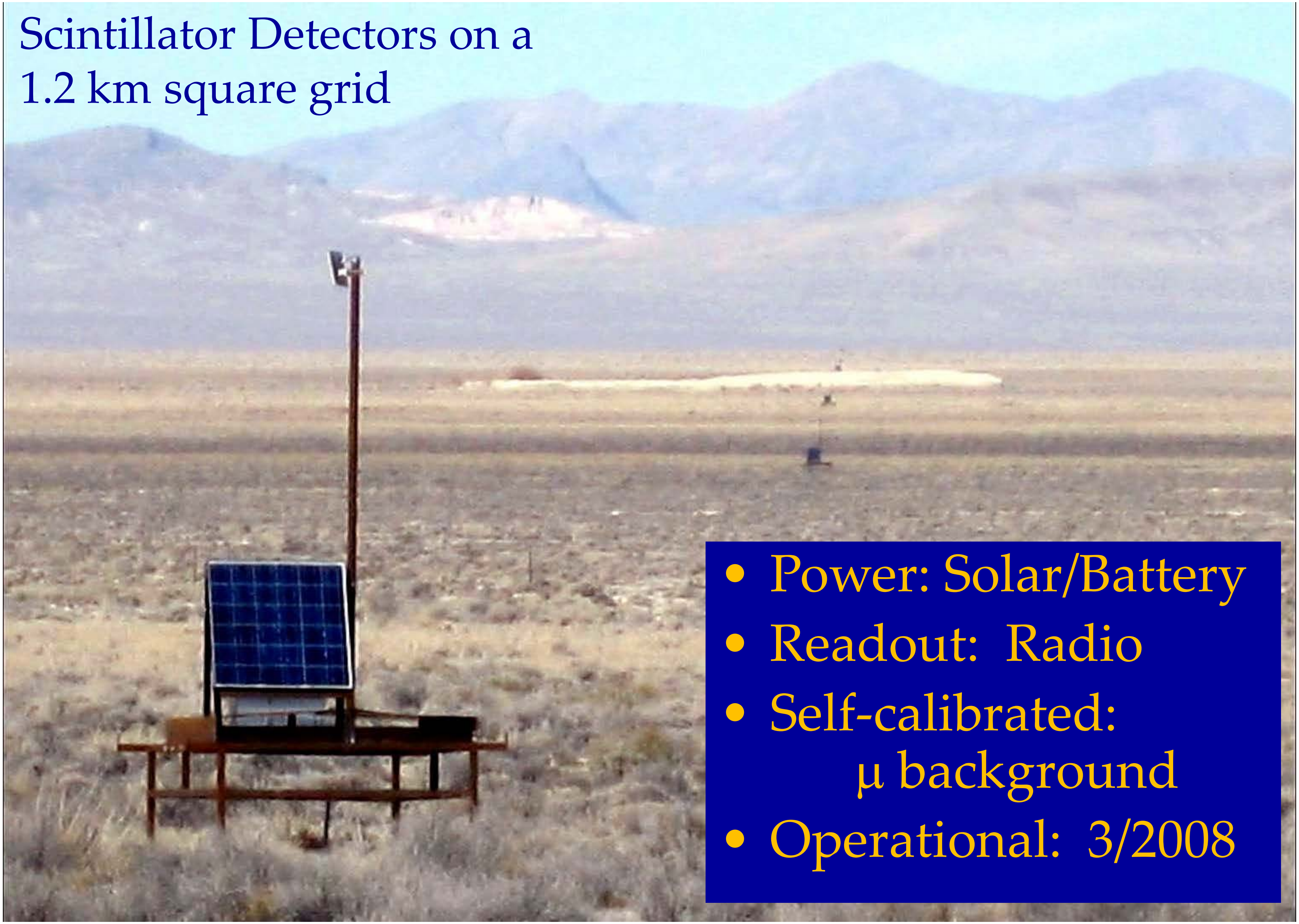


Scintillation Counters



Pre-assembled in Japan, Final Assby/testing in Delta: 2 layers, 1.25 cm scintillator, $3m^2$ area

Scintillator Detectors on a 1.2 km square grid



- Power: Solar/Battery
- Readout: Radio
- Self-calibrated:
  μ background
- Operational: 3/2008

TA Fluorescence Detectors

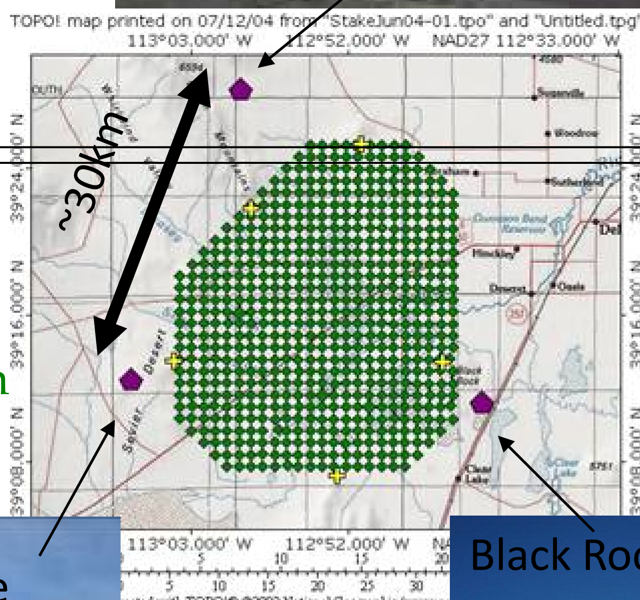
Refurbished from HiRes-I

Observations since ~10/2007

Middle Drum

14 telescopes@station
256 PMTs/camera

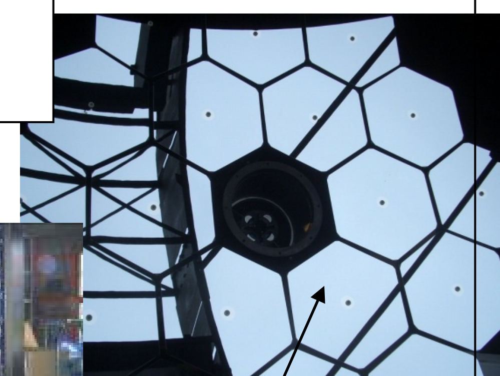
5.2 m^2



New FDs

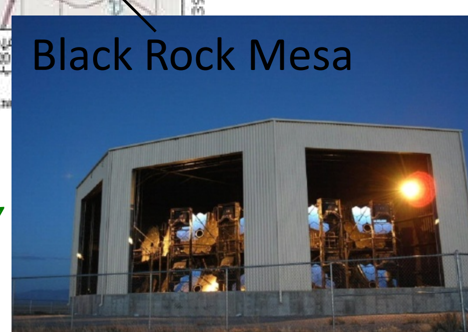
Observation since ~11/2007

12 telescopes/station
256 PMTs/camera
Hamamatsu R9508
FOV~15x18deg



6.8 m^2

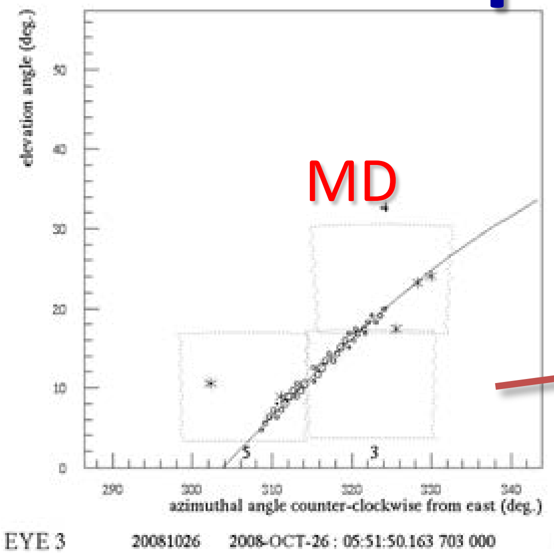
Observation since ~6/2007

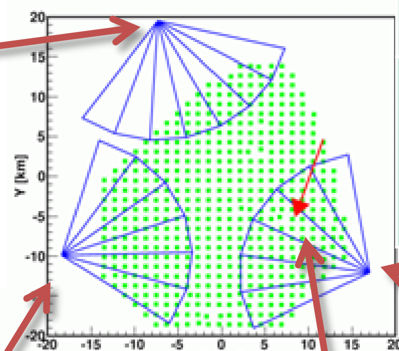


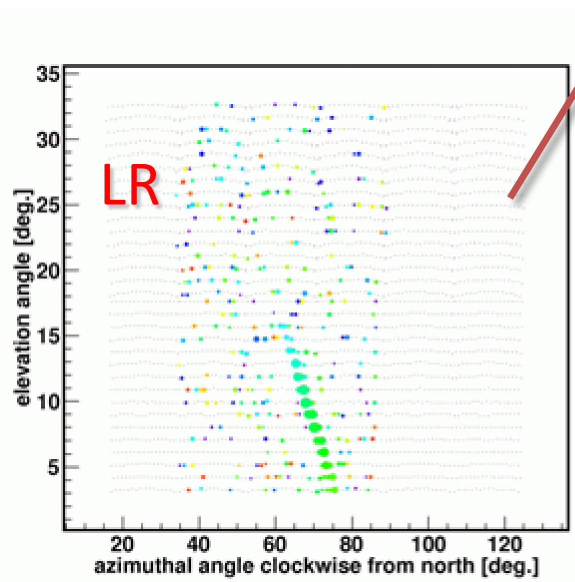
~1 m^2

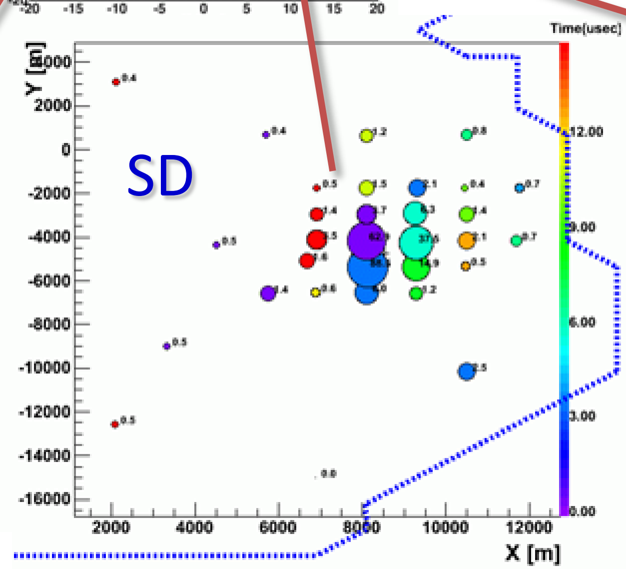
Example Event from 2008-10-26

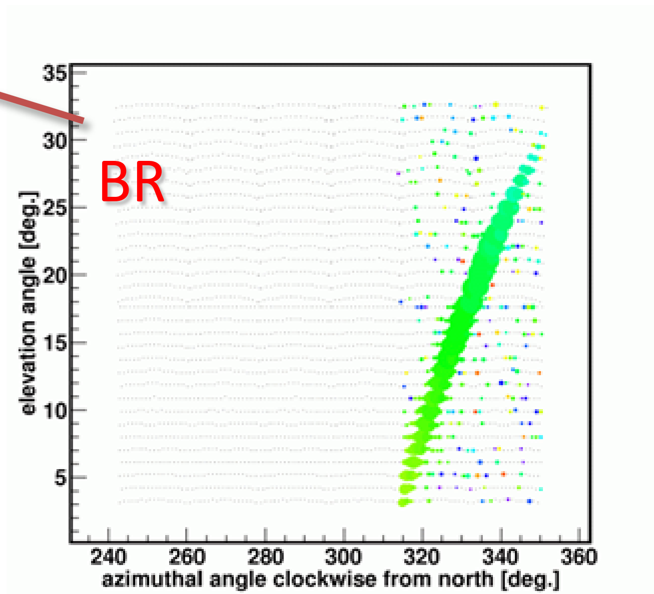
	θ[º]	ϕ[º]	x[km]	y[km]
MD mono	51.43	73.76	7.83	-3.10
BR mono	51.50	77.09	7.67	-4.14
Stereo BR&LR	50.21	71.30	8.55	-4.88











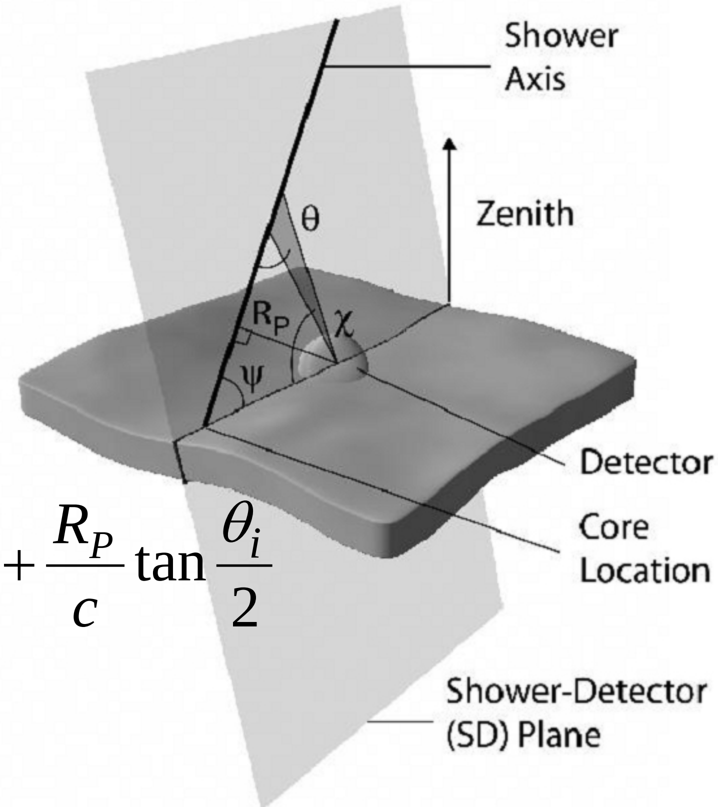
2. Data Analysis

FD Geometrical Reconstruction

The trajectory of the EAS can be determined in one of two ways:

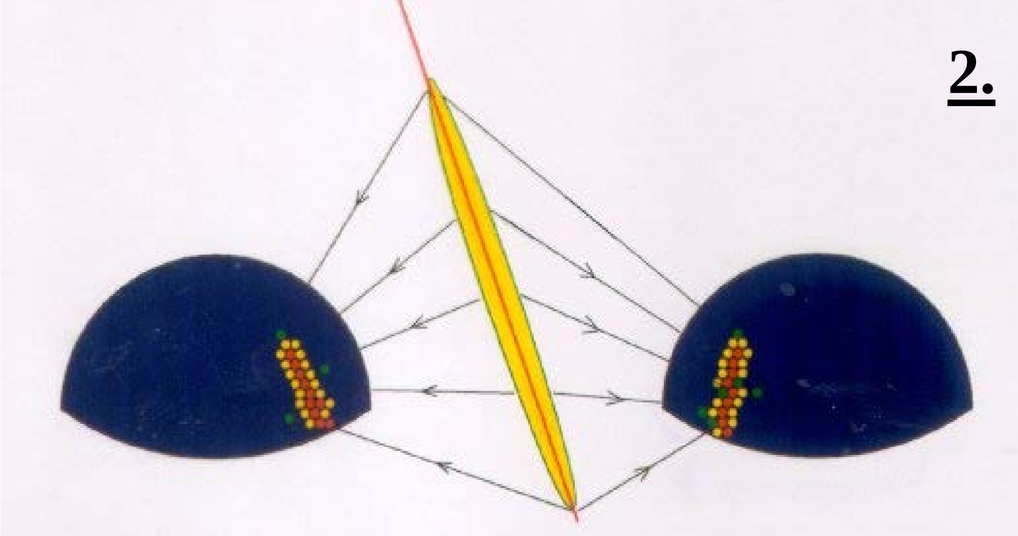
1. Monocular reconstruction using the arrival time of light signal at the detector.
2. By intersecting the shower-detector planes (SDP) seen from the two detector sites.

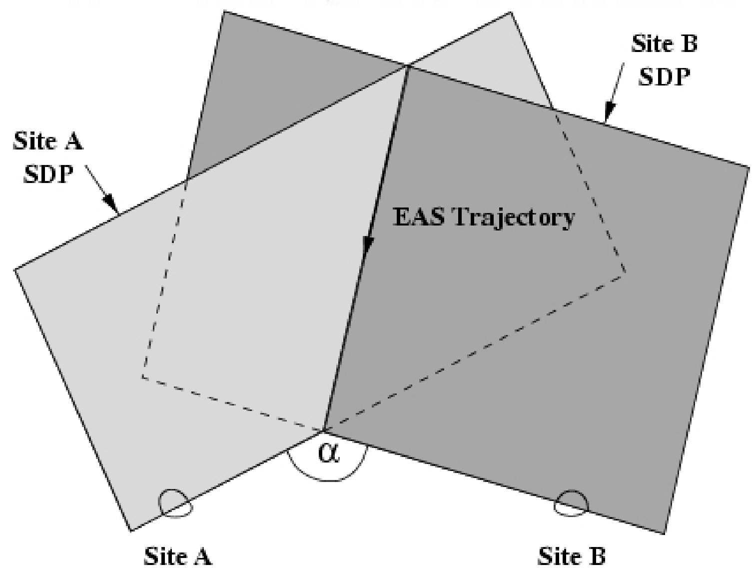
1.



$$t_i = t_0 + \frac{R_P}{c}\tan\frac{\theta_i}{2}$$

2.





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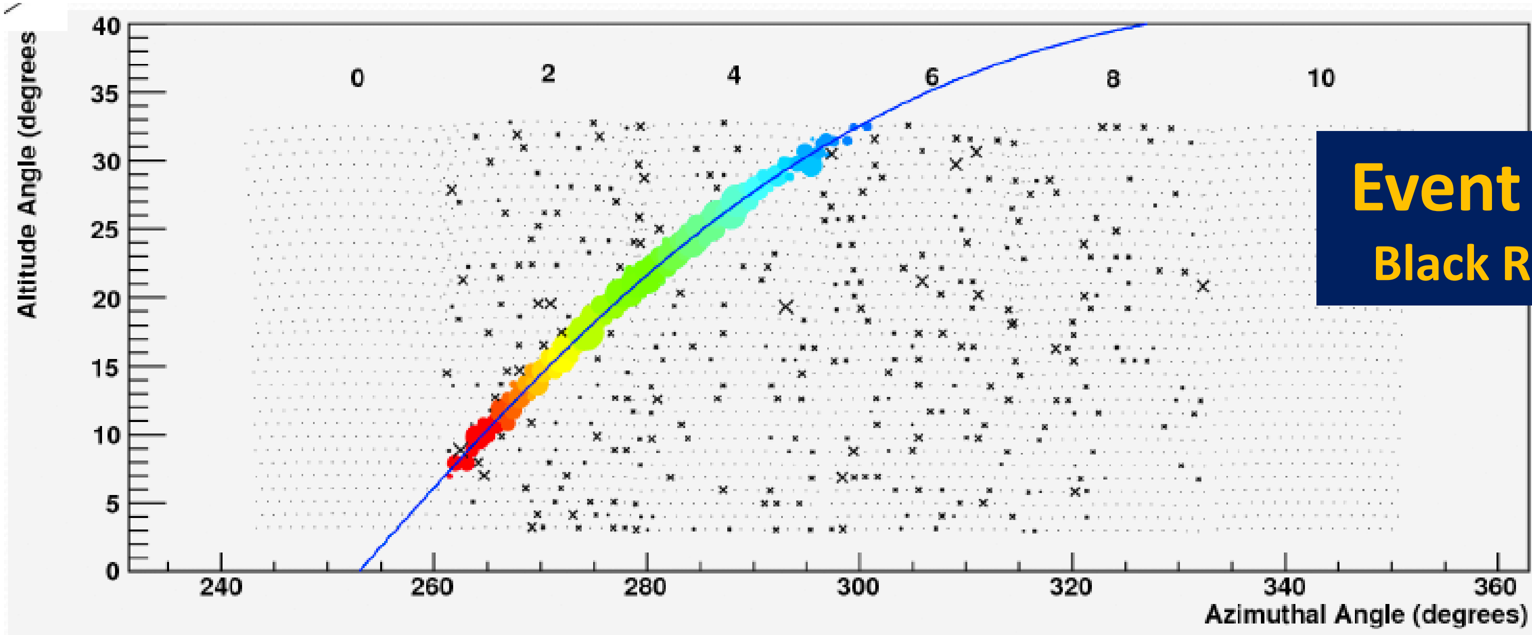
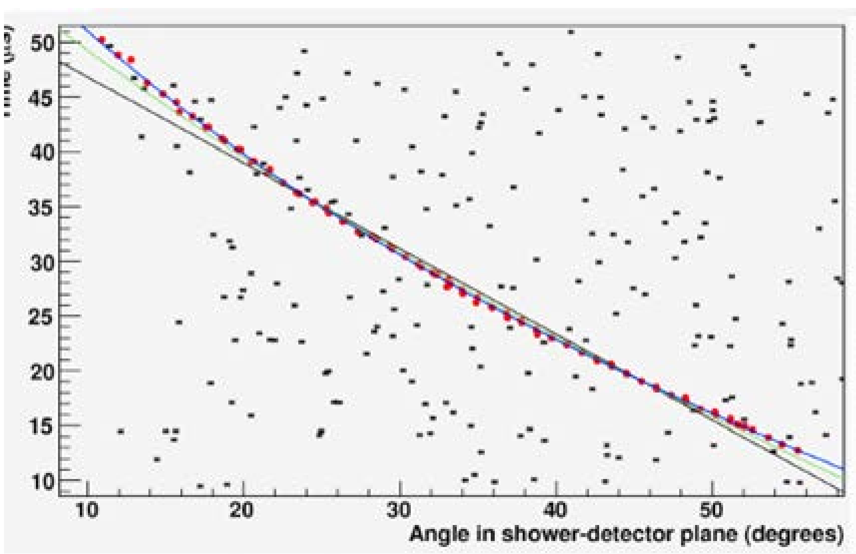
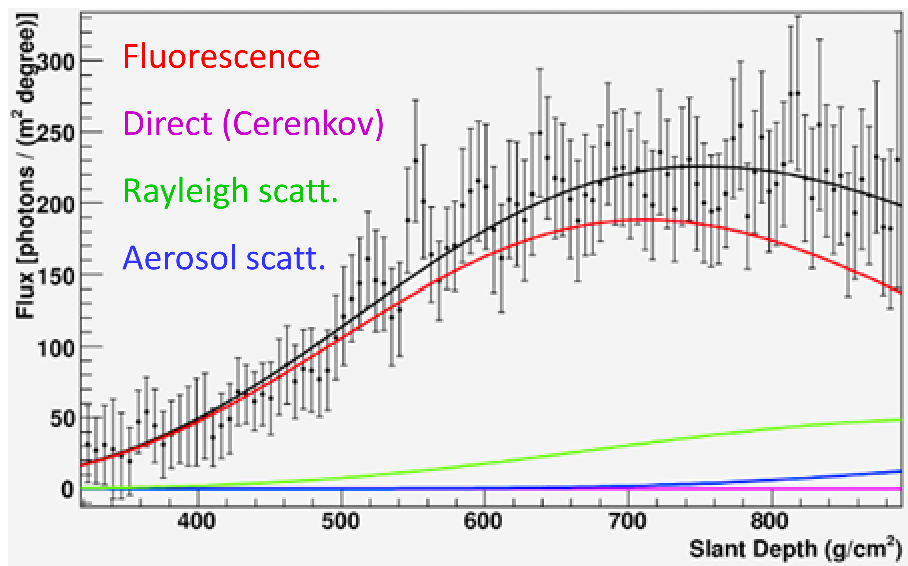
Measurement of a fluorescence Event



Event Display
Black Rock Mesa

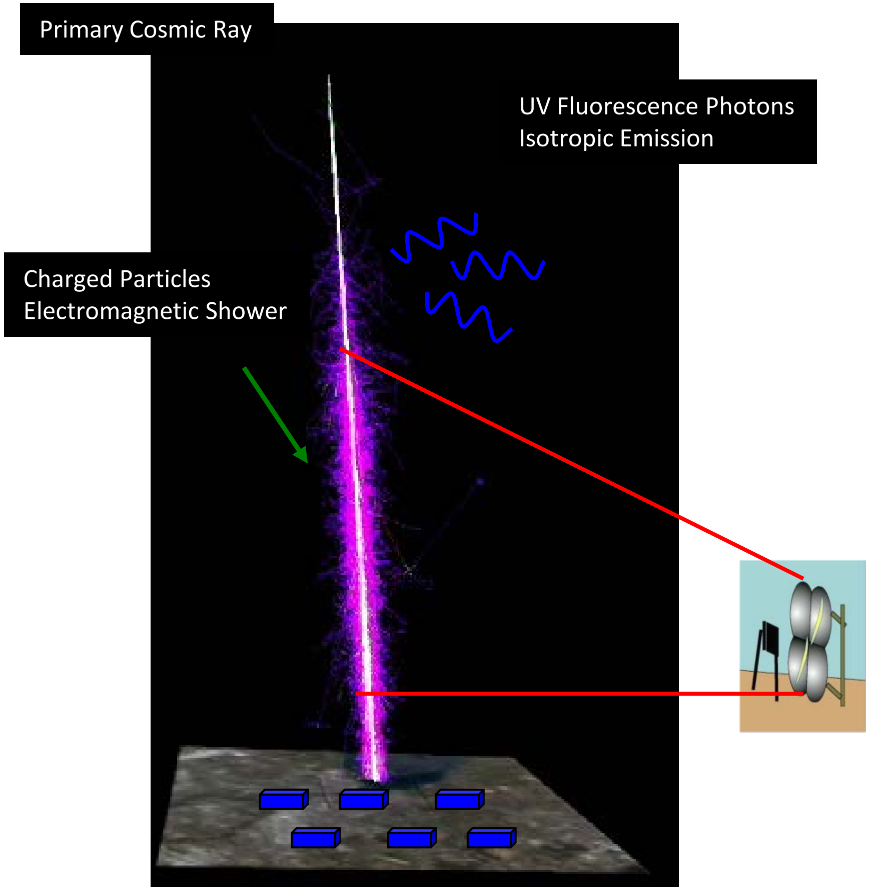


Monocular timing fit



Reconstructed Shower Profile

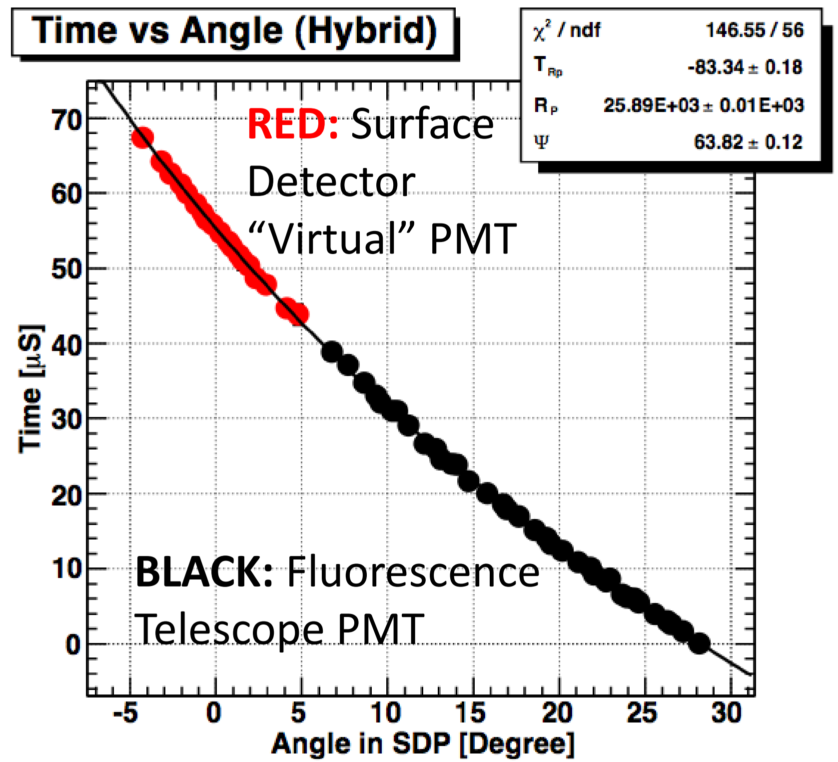
Hybrid Reconstruction



FD mono has ~5° ang. resolution

Adding SD → ~0.5° resolution.

(Stereo FD resolution ~0.5°)

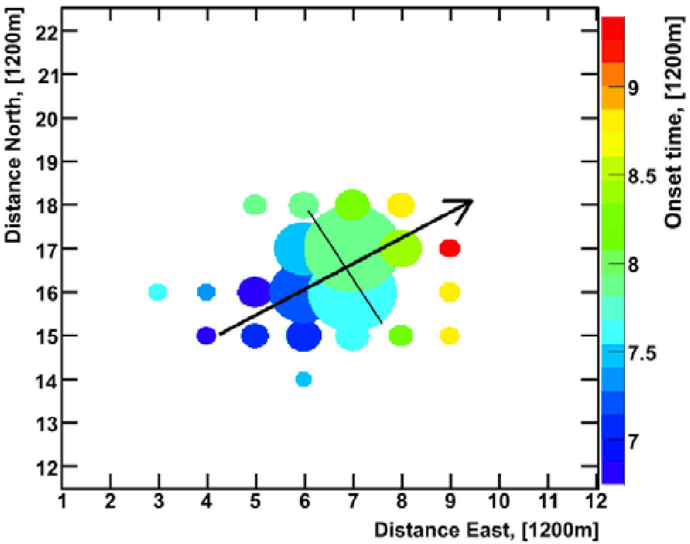


3. Hybrid reconstruction:

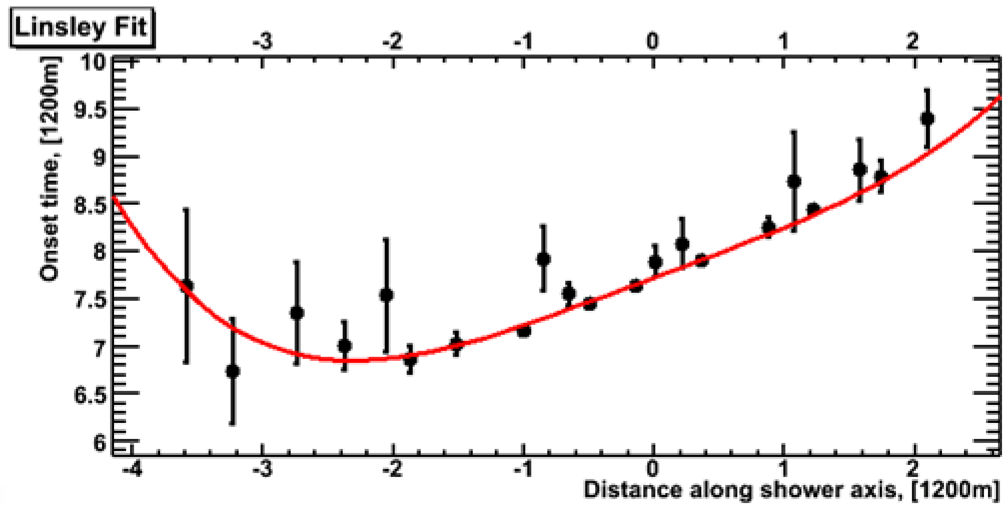
Incorporating timing information of SD into FD geometry fit

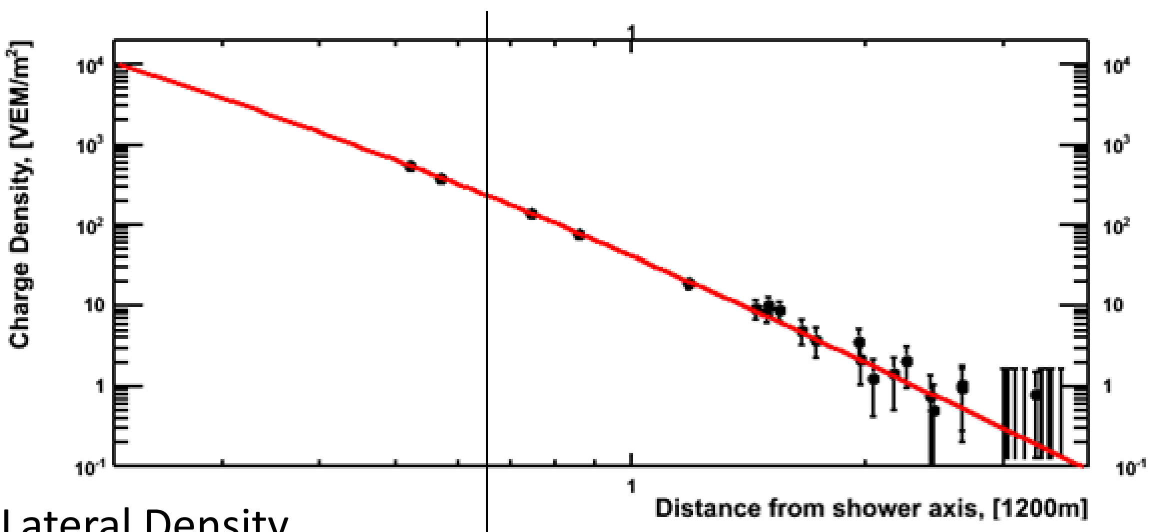
Analyzing SD Event

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



Geometry Fit (modified Linsley)





Lateral Density Distribution Fit

r = 800m

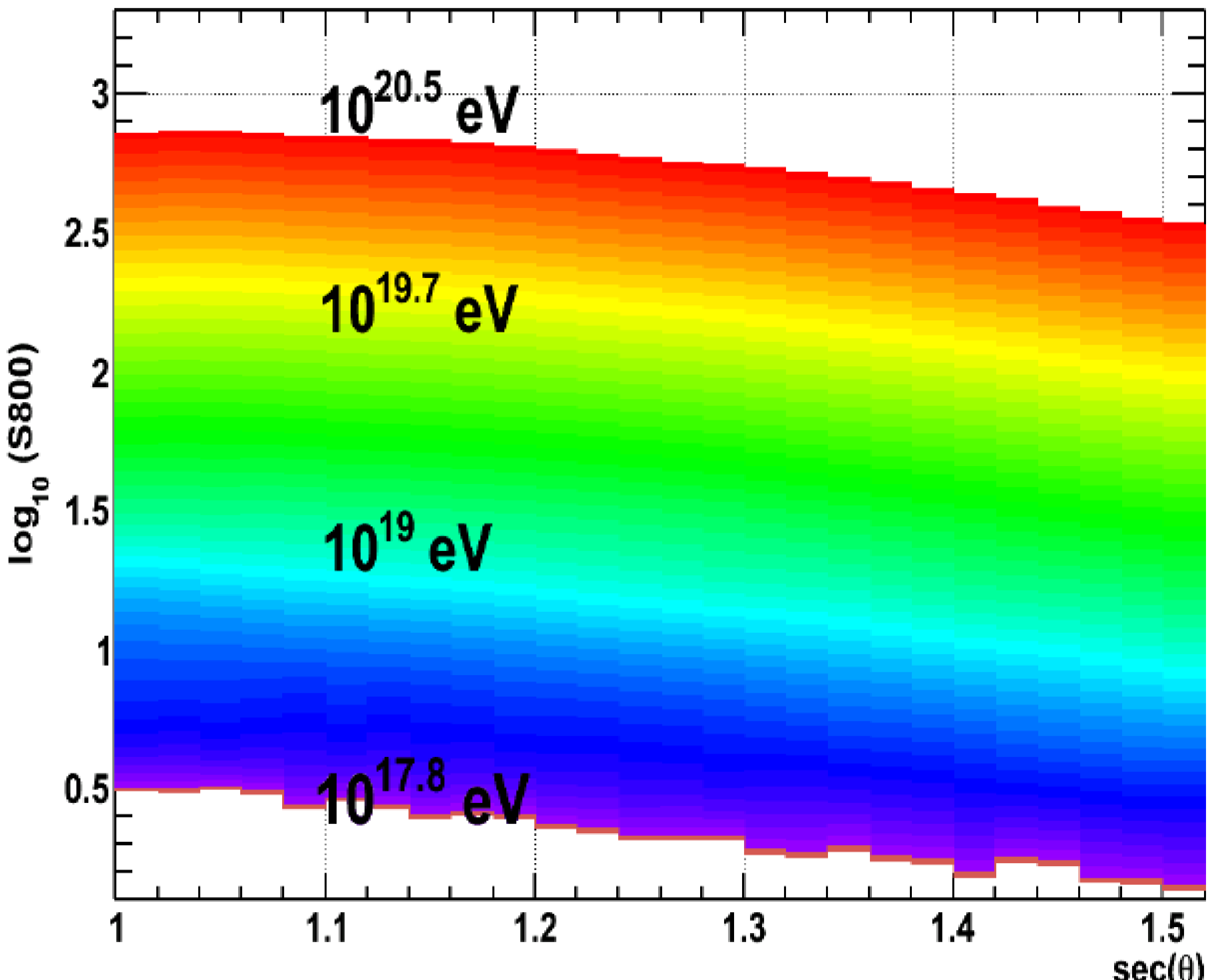
Fit with AGASA LDF

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

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

- S(800): Primary Energy
- Zenith attenuation by MC

Surface Array Energy Measurement

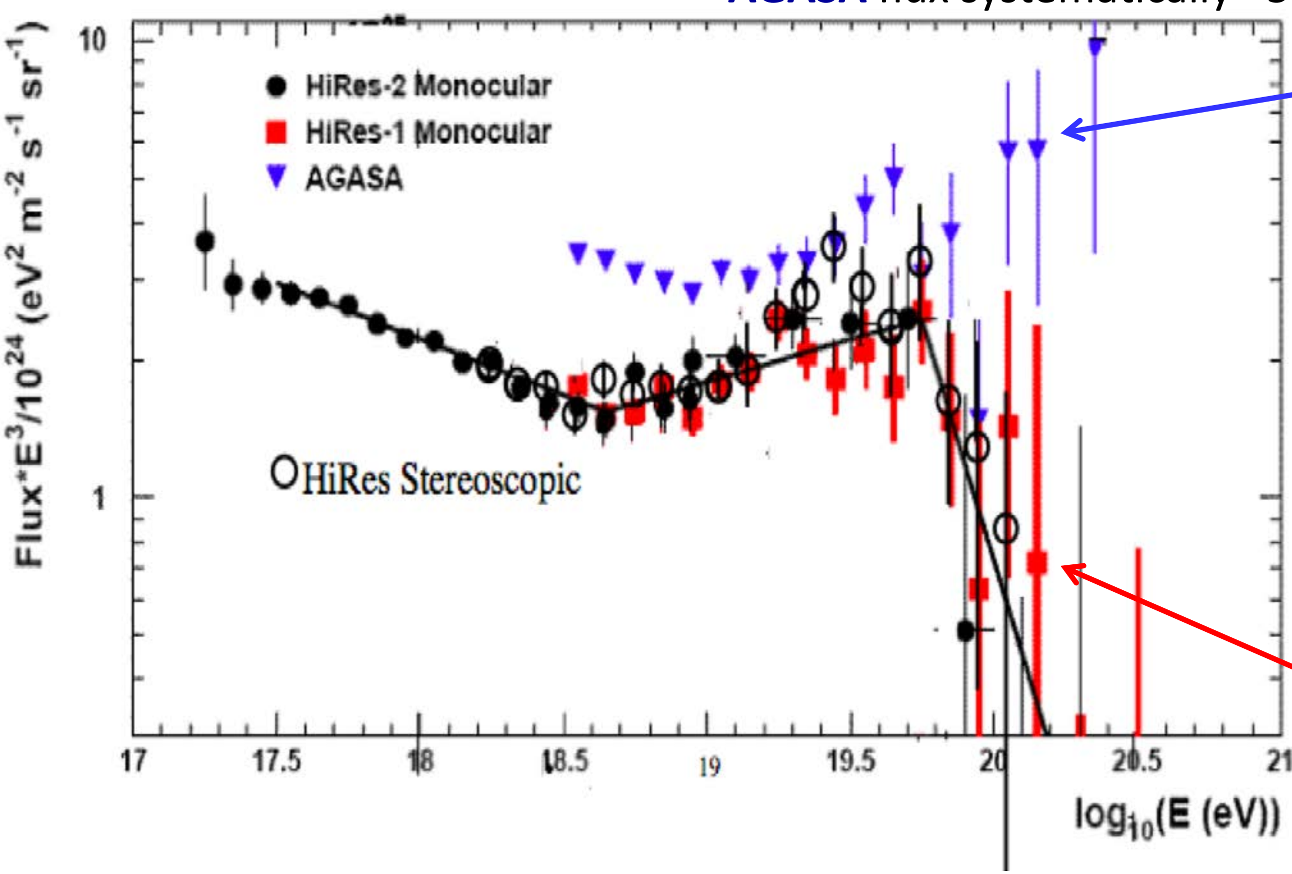


- Energy table is constructed using the MC (CORSIKA)
- Determination of event energy by interpolating between S800 vs. sec(θ) lines
- Uses novel “de-thinning” of CORSIKA (paper draft in internal review)

3. Energy Spectrum of UHECR

- The TA Collaboration was in part a merger of the High Resolution Fly's Eye (HiRes) and the Akeno Giant Air Shower Array (AGASA)

AGASA flux systematically ~50% higher than HiRes



AGASA: continuing spectrum seen

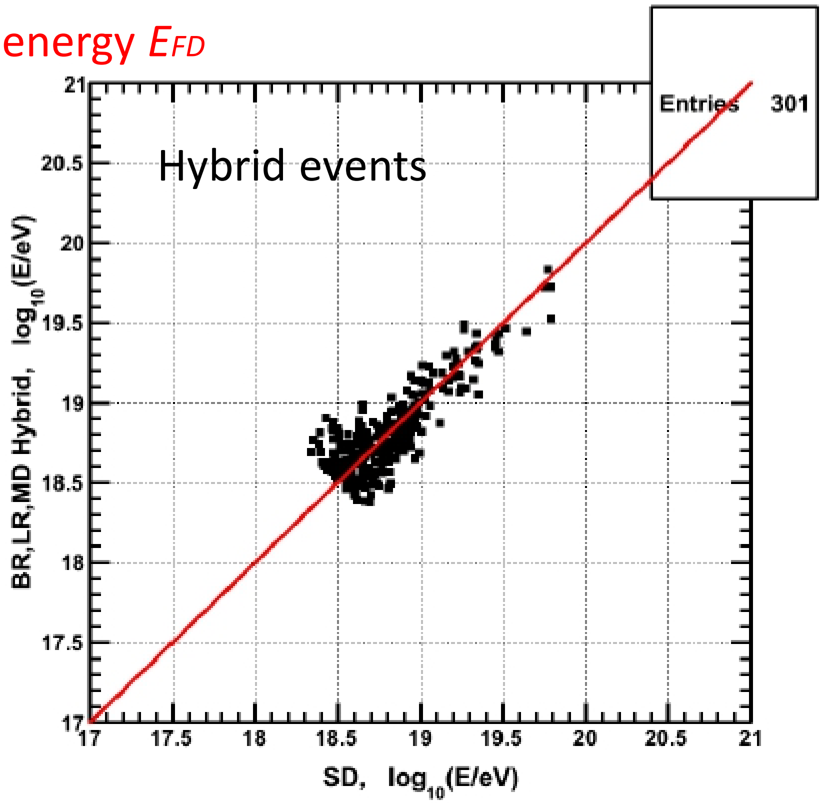
Differential flux multiplied by E^3
To highlight the subtle features in a steeply falling spectrum

HiRes: GZK suppression
At 5σ significance

R.U. Abbasi et. al., Phys. Rev. Lett., 2008, 100: 101101

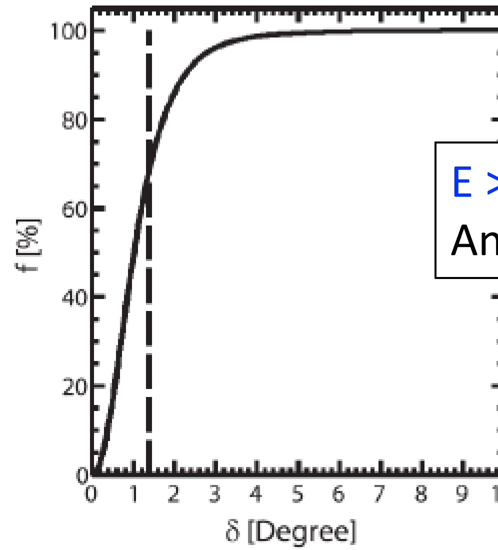
Energy Scale Check and resolution

FD energy E_{FD}

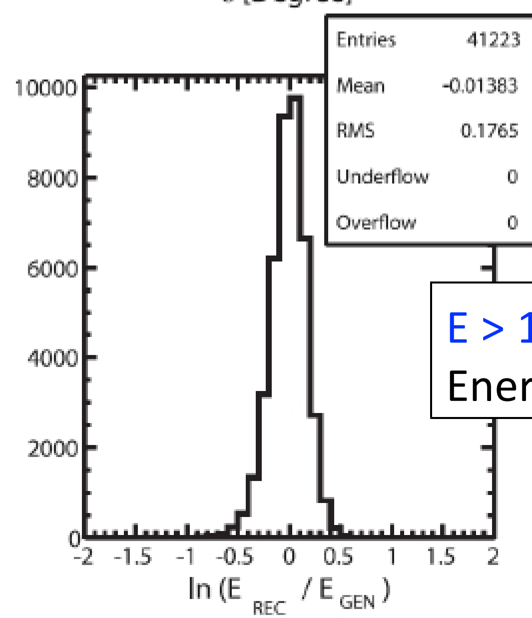


SD energy E_{SD}
(scaled to FD energy)

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

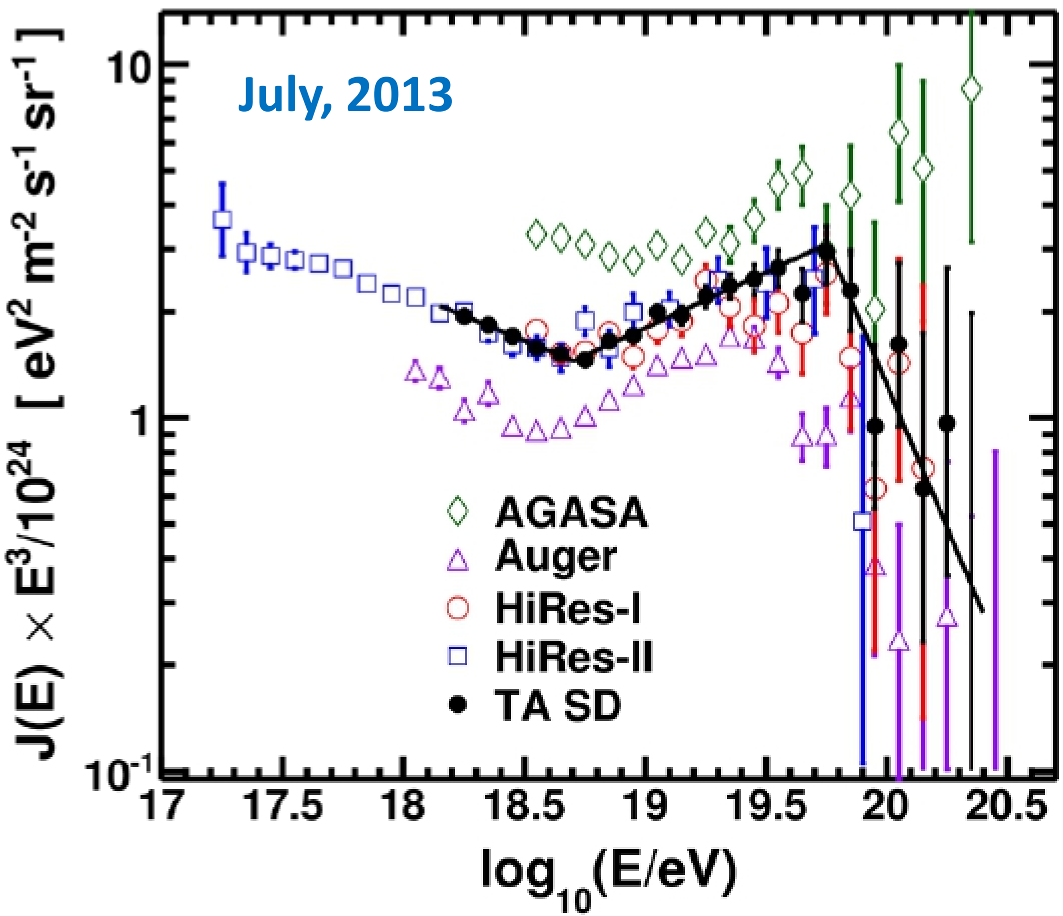


$E > 10^{19}$ eV
Angular resolution = 1.4^{o}



$E > 10^{19}$ eV
Energy resolution < 20%

5 year TA SD spectrum



TA data

May, 2008 – May, 2013

Zenith angle < 45^{o}

14787 ev. (E > $10^{18.2}$ eV)

Exposure 4500 km^2 sr yr

Broken power law fit

γ_1 = -3.283±0.032

E_{ankle} = (5.04±0.27)×10^{18} eV

γ_2 = -2.685±0.030

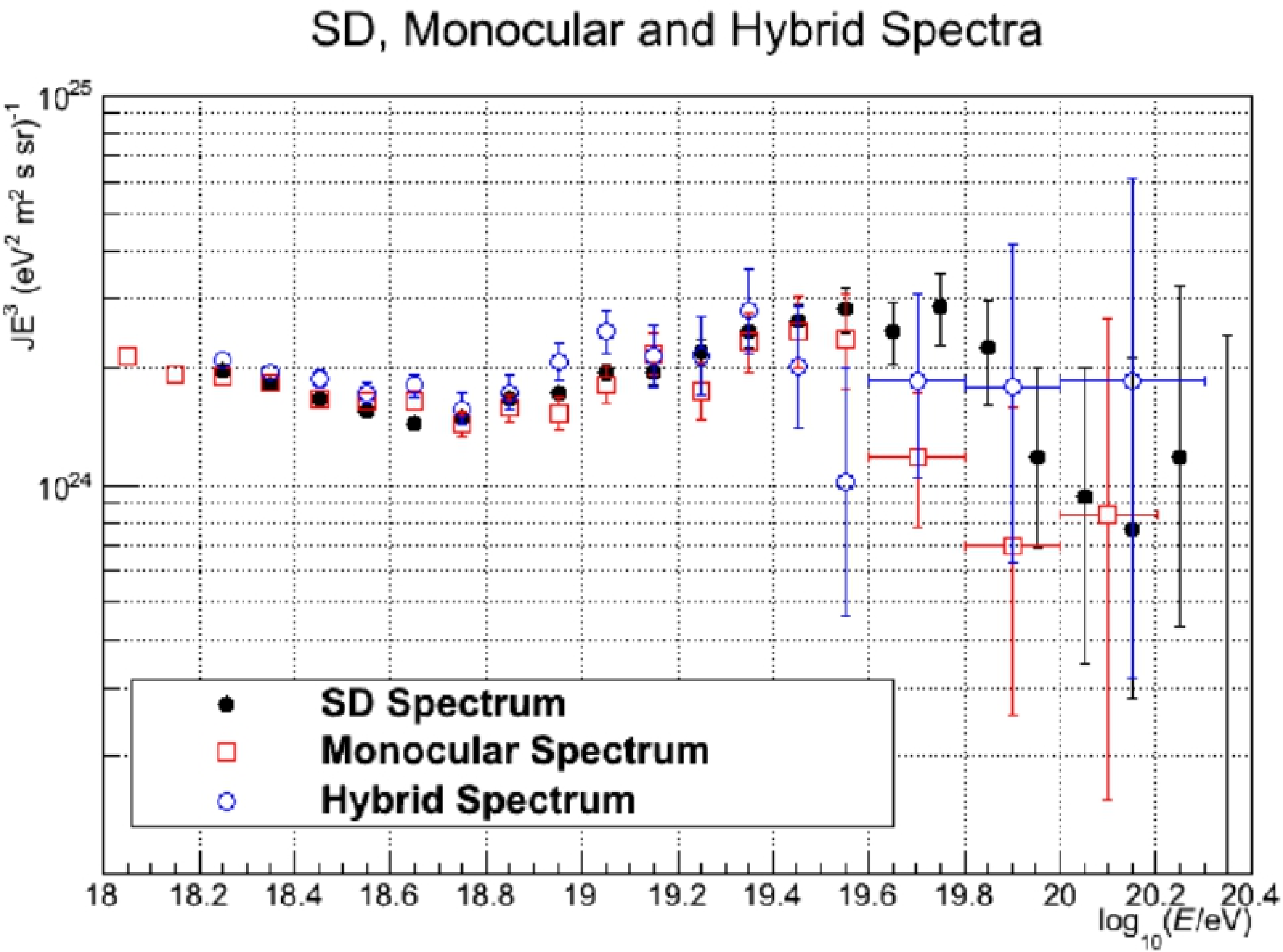
E_{GZK} = (5.68±1.05)×10^{19} eV

γ_3 = -4.62± 0.74

4-year TA surface detector spectrum

Astrophysical Journal Letters 768 L1 (2013)

Spectrum Summary



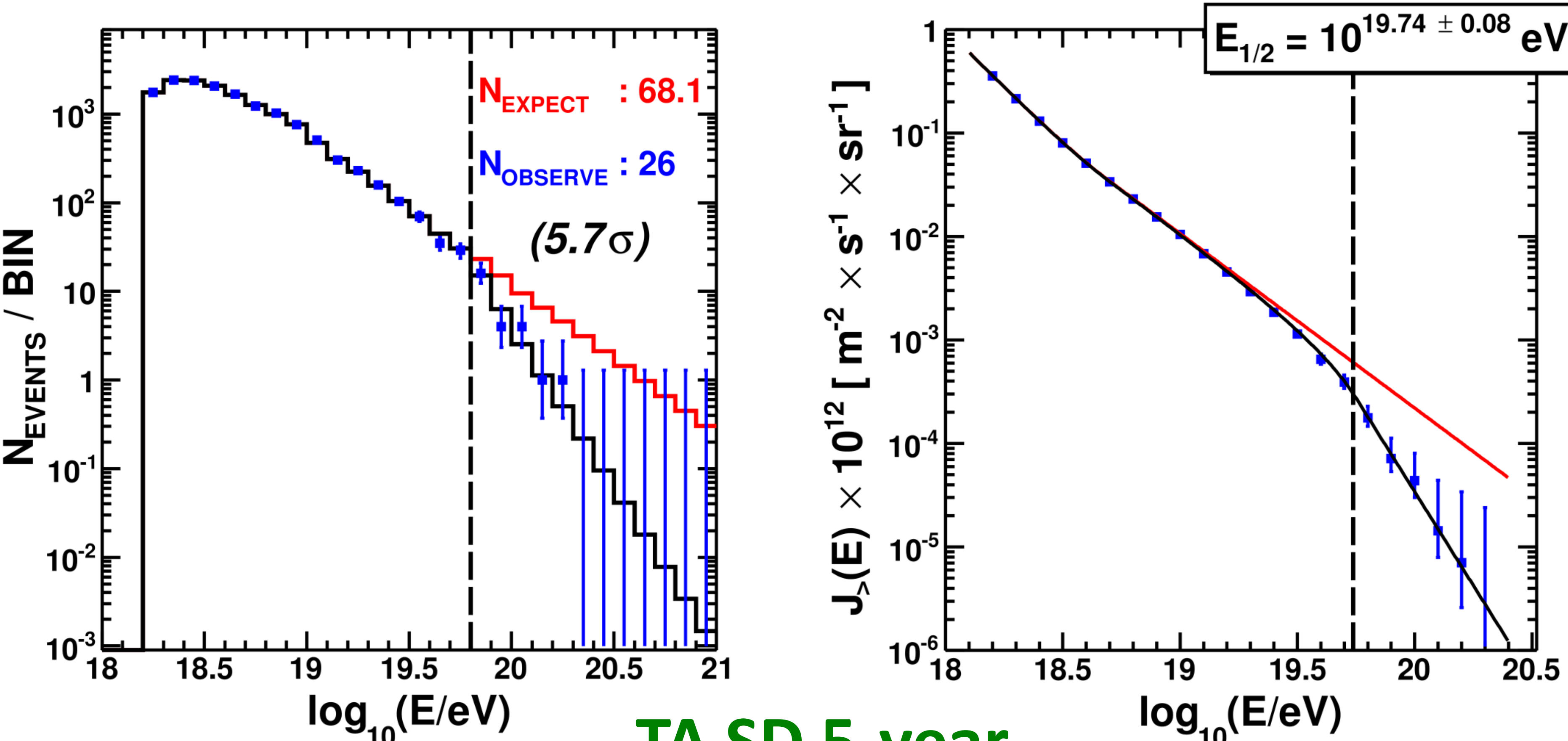
Doug Bergman for the TA Colaboration: ICRC 2013

http://143.107.180.38/indico/getFile.py/access?contribId=221&sessionId=3&resId=0&materialId=slides&confId=0

TA Hybrid Spectrum papers
arXiv:1305.7273 [astro-ph.HE], submitted to Astroparticle Physics

TA Monocular FD spectrum papers
Astroparticle Physics 39–40 (2012) 109–119
Astroparticle Physics 48 (2013) 16–24

Significance and energy of suppression



TA SD 5-year

Locations of the "ankle/dip" and of the suppression are consistent with interaction of protons with the CMBR

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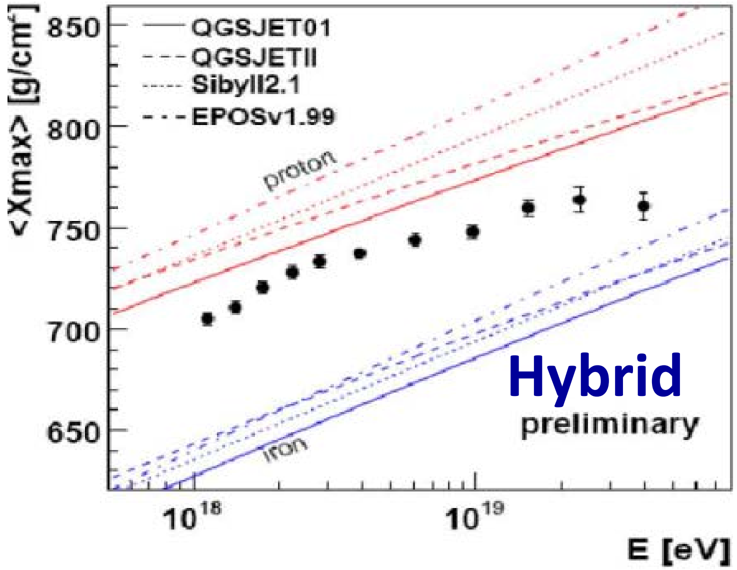
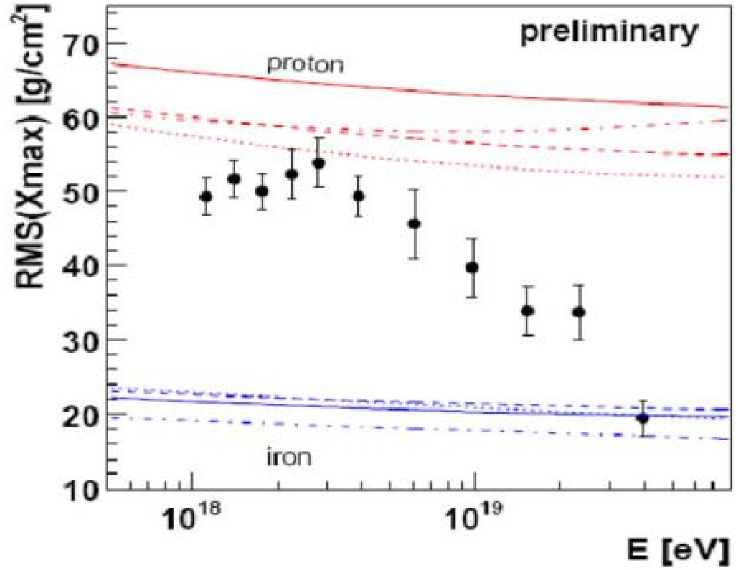
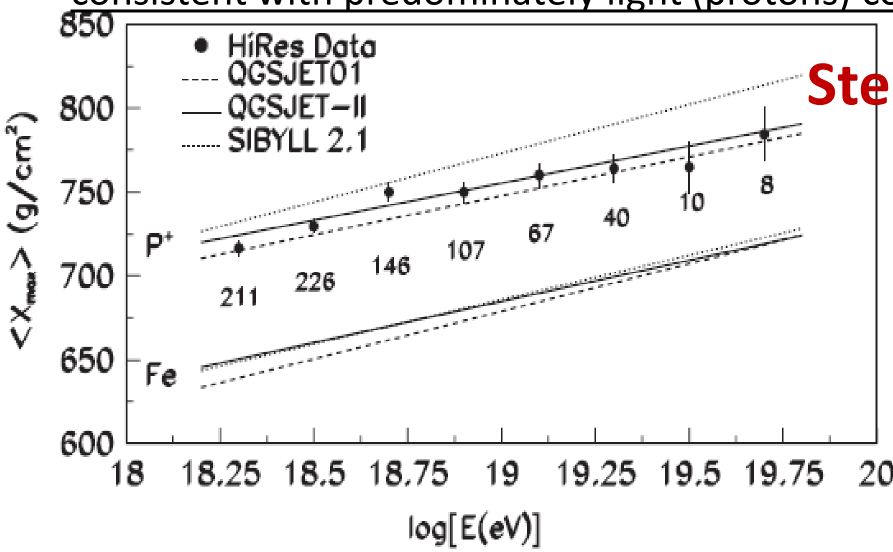
4. Composition

AUGER: Phys.Rev.Lett.104:091101,2010
Suggests shift to heavier composition at higher energies:

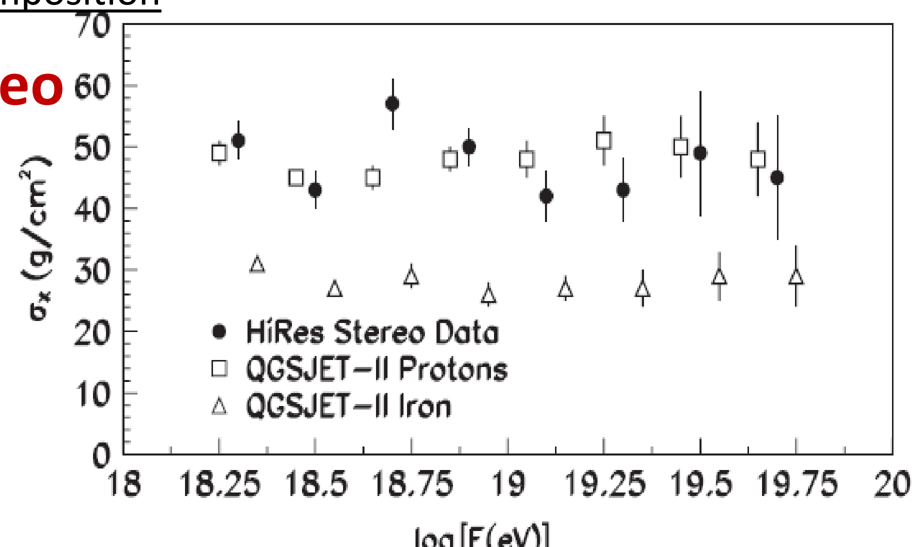




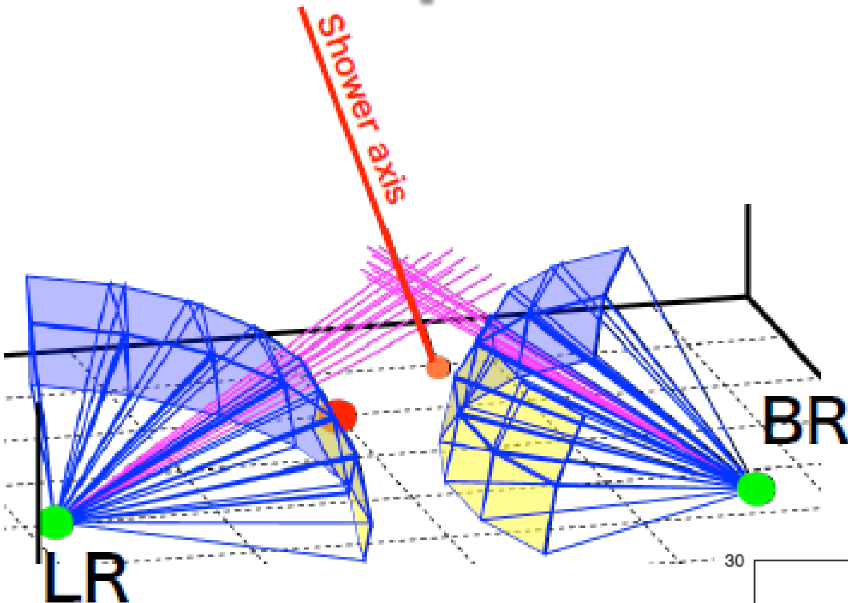
HiRes: Phys.Rev.Lett.104:161101,2010 (with Xmax data suppl.)
consistent with predominately light (protons) composition



Stereo

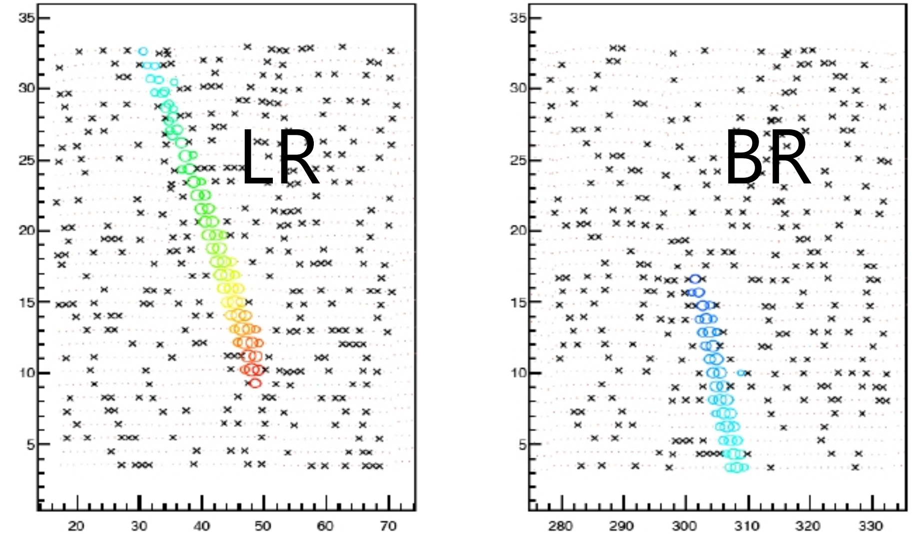


TA Stereo Composition

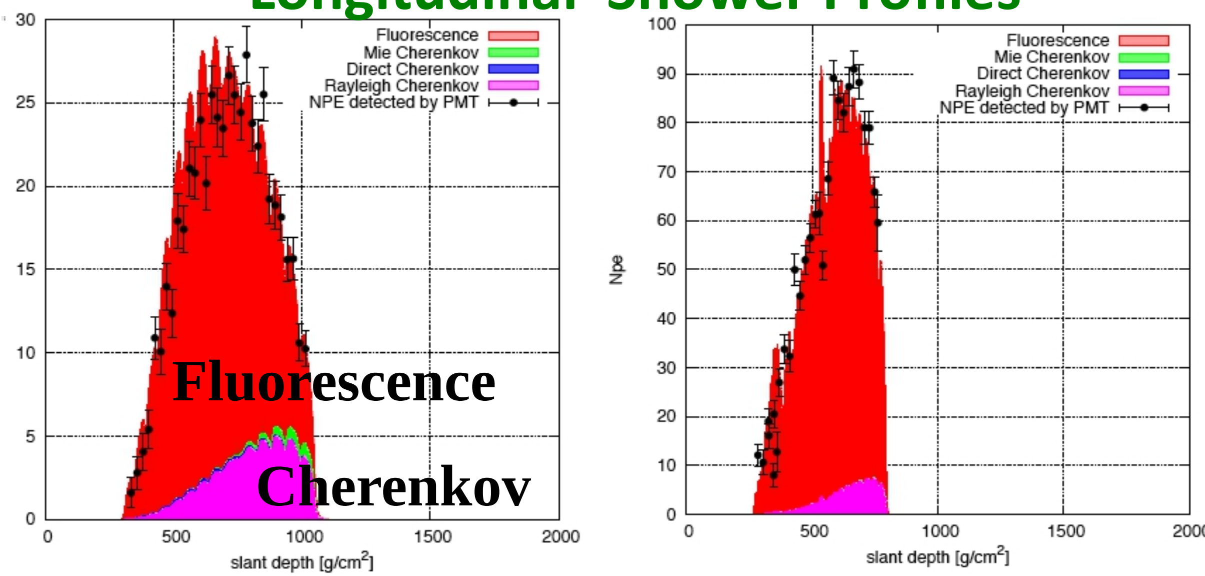


$$\sigma_{X_{\max}} \sim 20\,\mathrm{g/cm^2}$$

Camera images



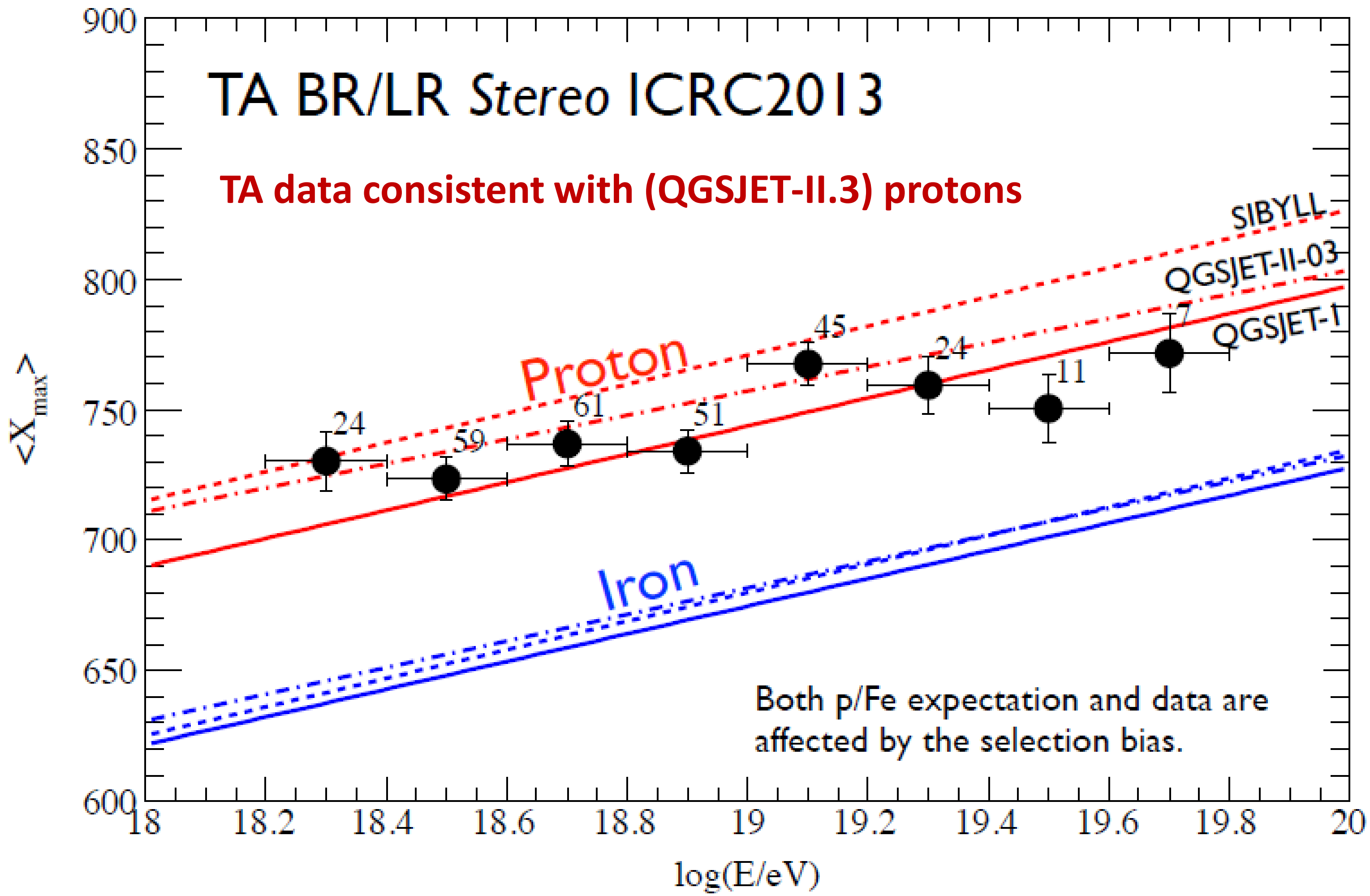
Longitudinal Shower Profiles



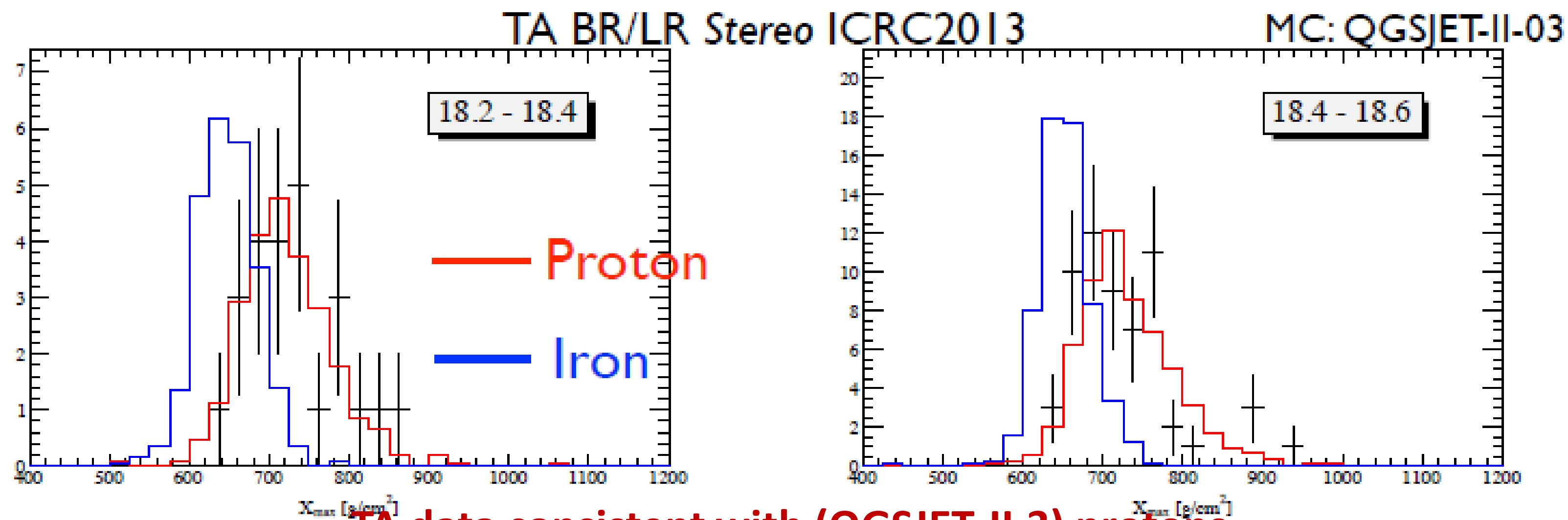
<Xmax> vs LogE

Y. Sunesada for the TA Collaboration
ICRC2013
http://143.107.180.38/indico/getFile.py/access?contribId=132&sessionId=3&resId=0&materialId=slides&confId=0

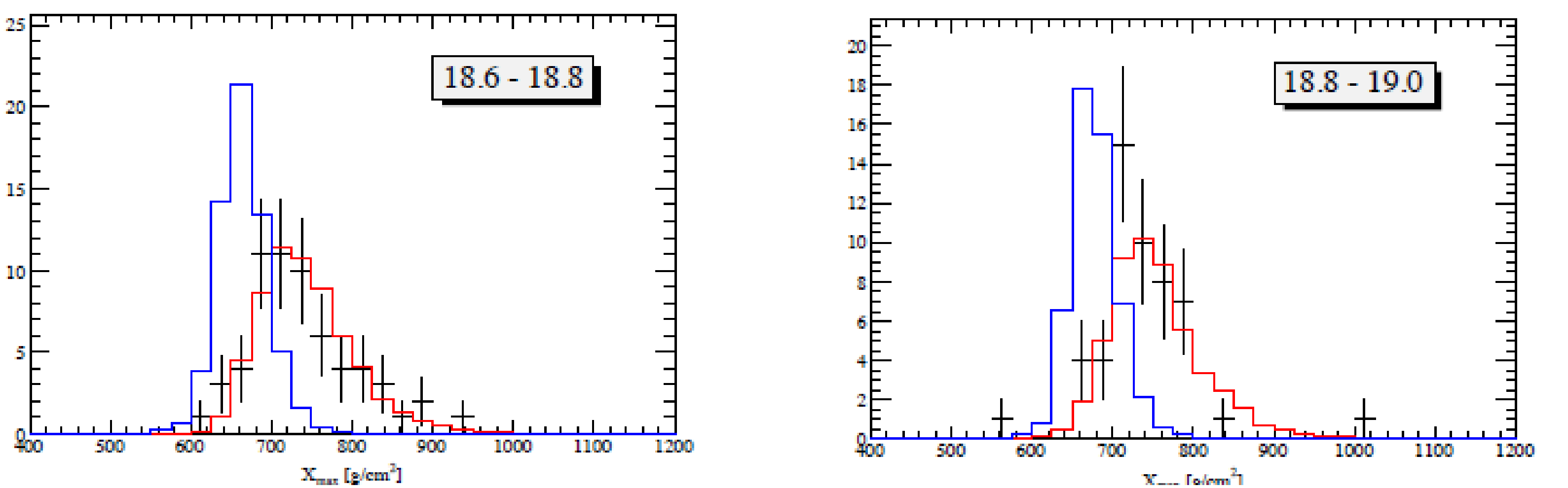
5-year data (Nov., 2007 – Nov. 2012)



Comparing Xmax Distribution with MC p/Fe expectations: Stereo

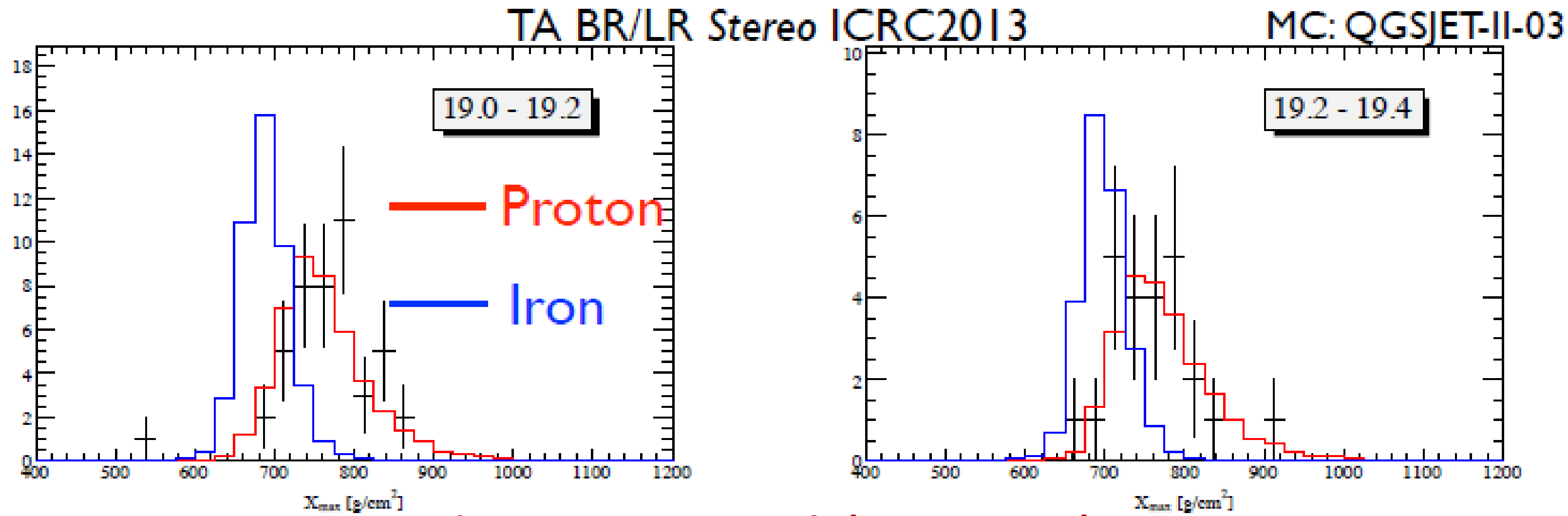


TA data consistent with (QGSJET-II.3) protons

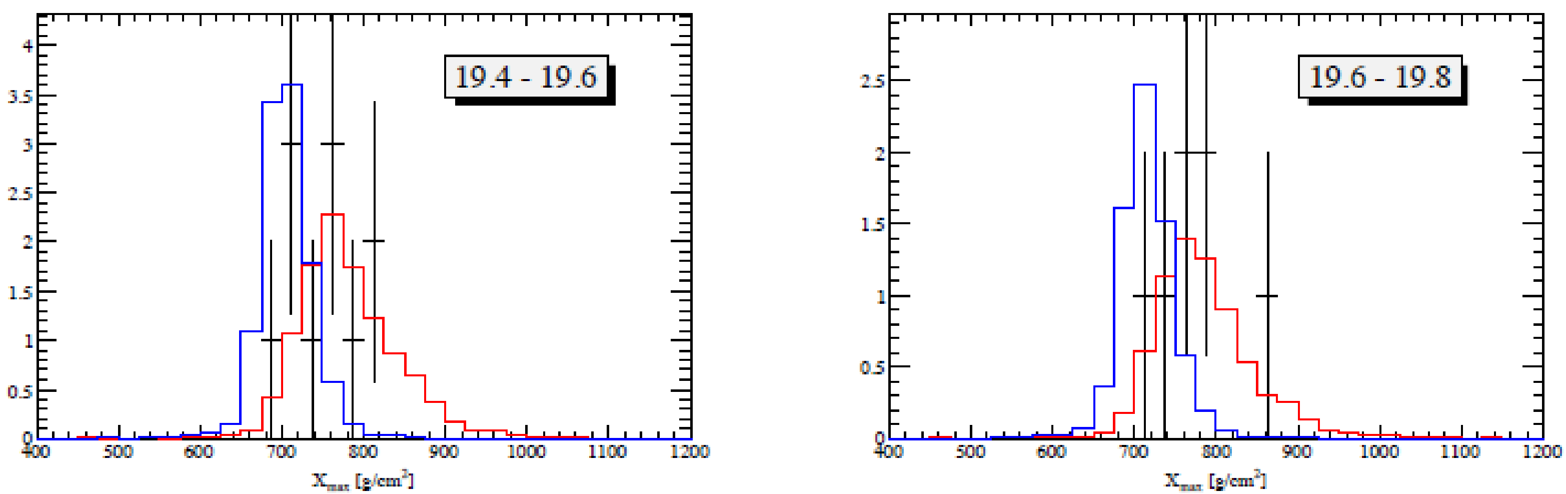


TA, TeVPA2013

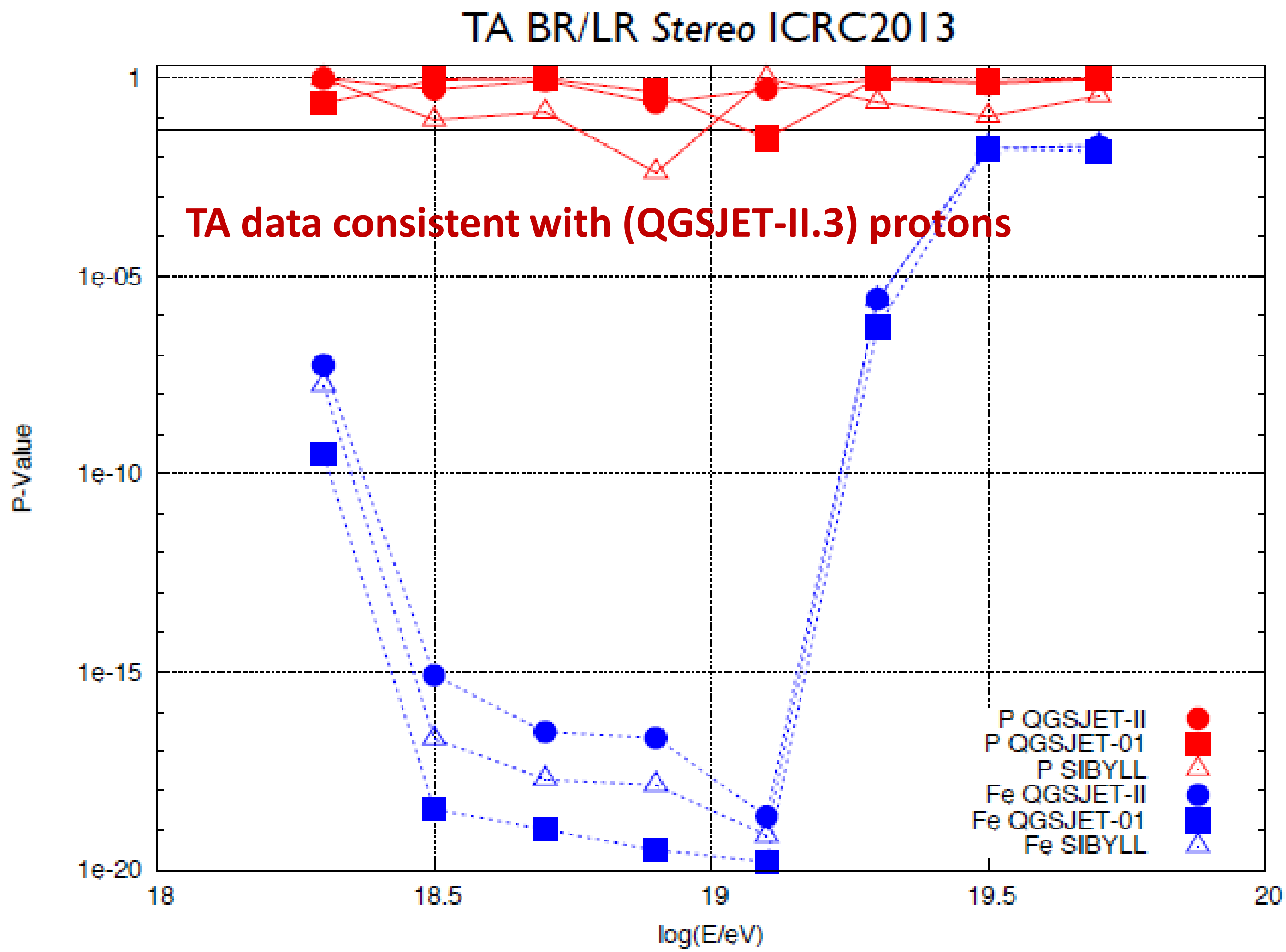
Comparing Xmax Distribution with MC p/Fe expectations: Stereo



TA data consistent with (QGSJET-II.3) protons



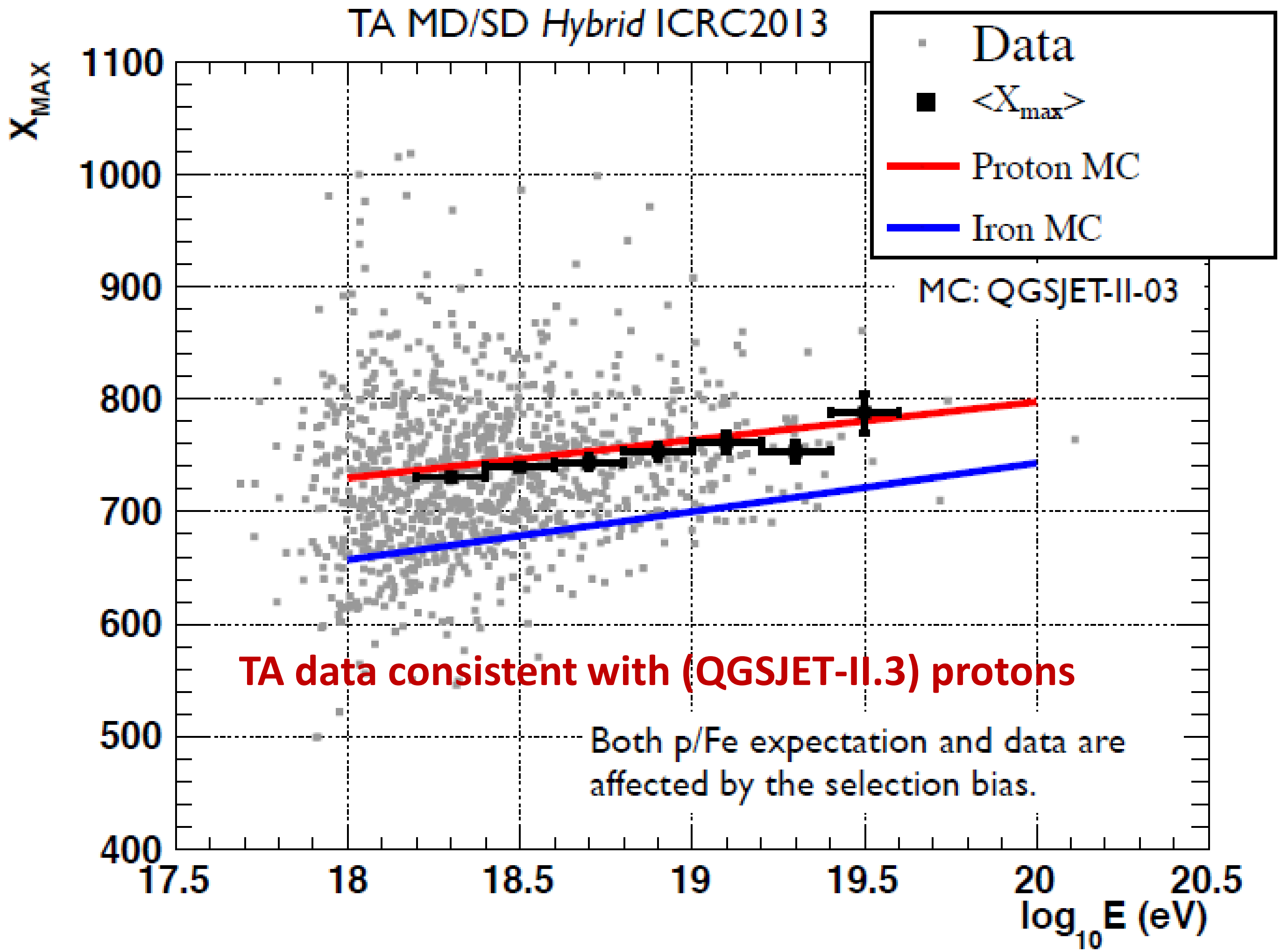
Comparing Xmax Distribution with MC p/Fe expectations: Stereo



TA, TeVPA2013

Hybrid Analysis
<Xmax> vs LogE

4-year data (May, 2008 – May, 2012)

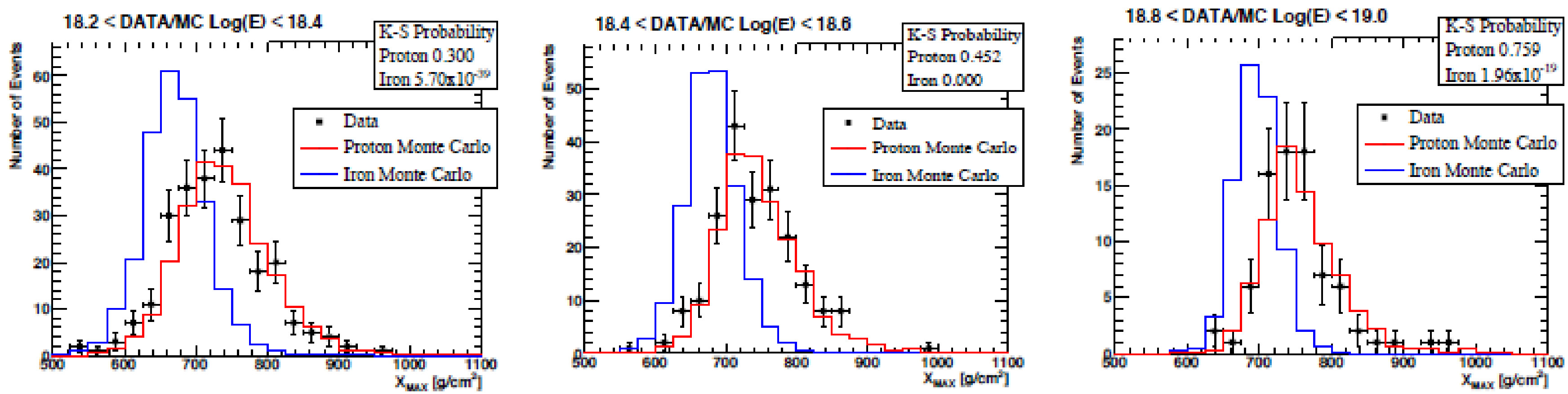


TA, TeVPA2013

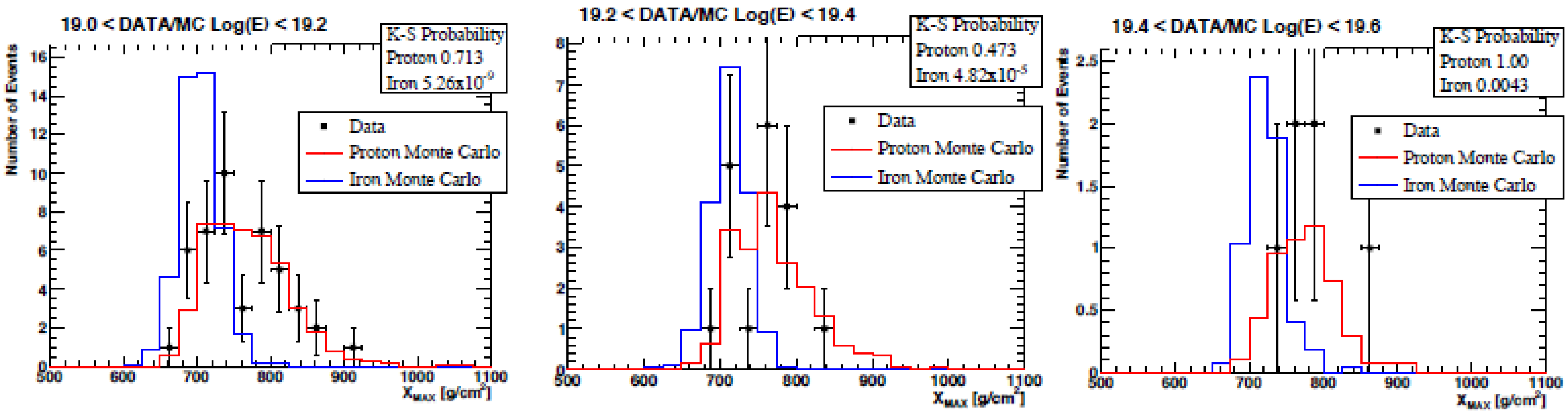
Comparing Xmax Distribution with MC p/Fe expectations: Hybrid

TA MD/SD *Hybrid* ICRC2013

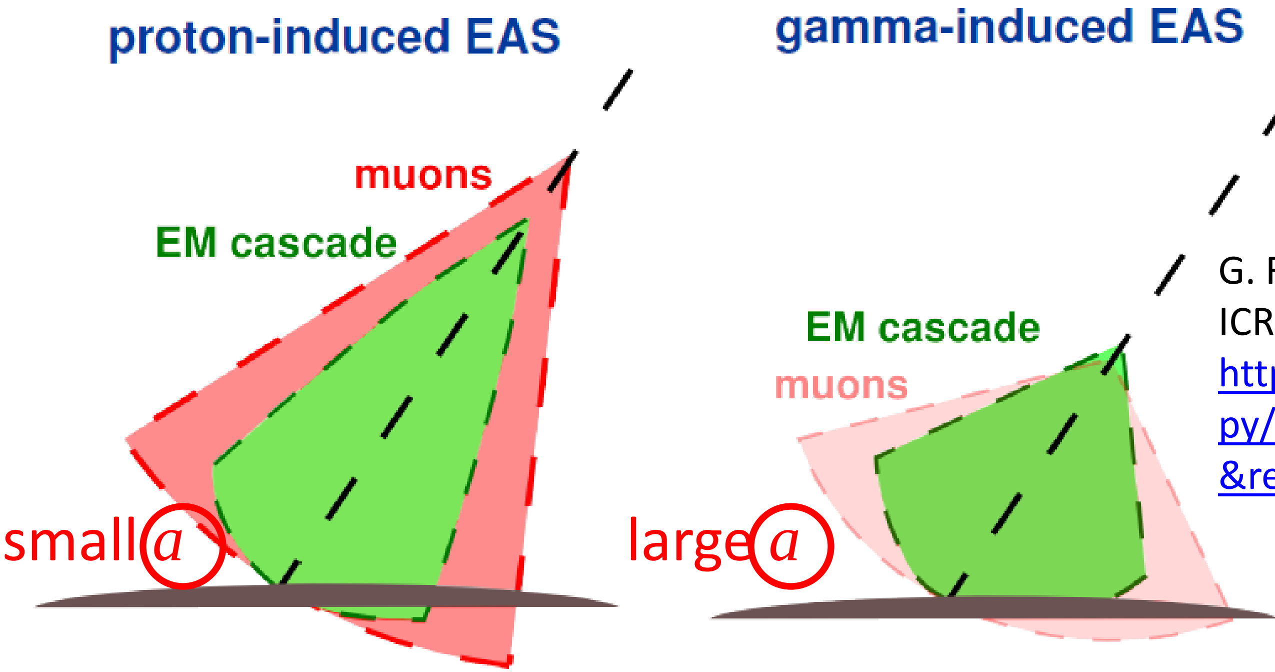
MC: QGSJET-II-03



TA data consistent with (QGSJET-II.3) protons



TA Surface Detector Photon Search



G. Rubtsov for the TA Collaboration
ICRC 2013
http://143.107.180.38/indico/getFile.py/access?contribId=149&sessionId=3&resId=0&materialId=slides&confId=0

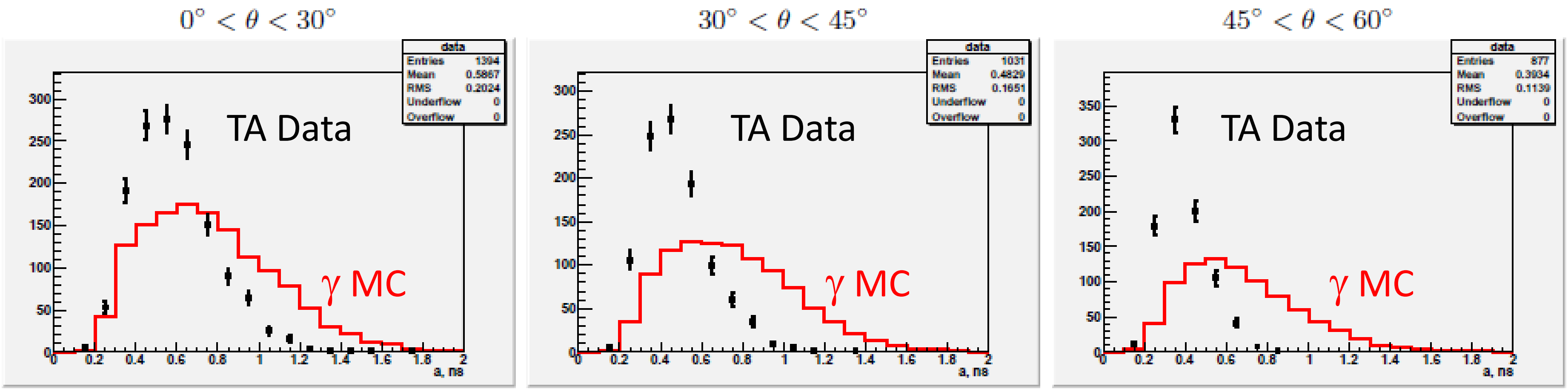
a = Linsley curvature parameter

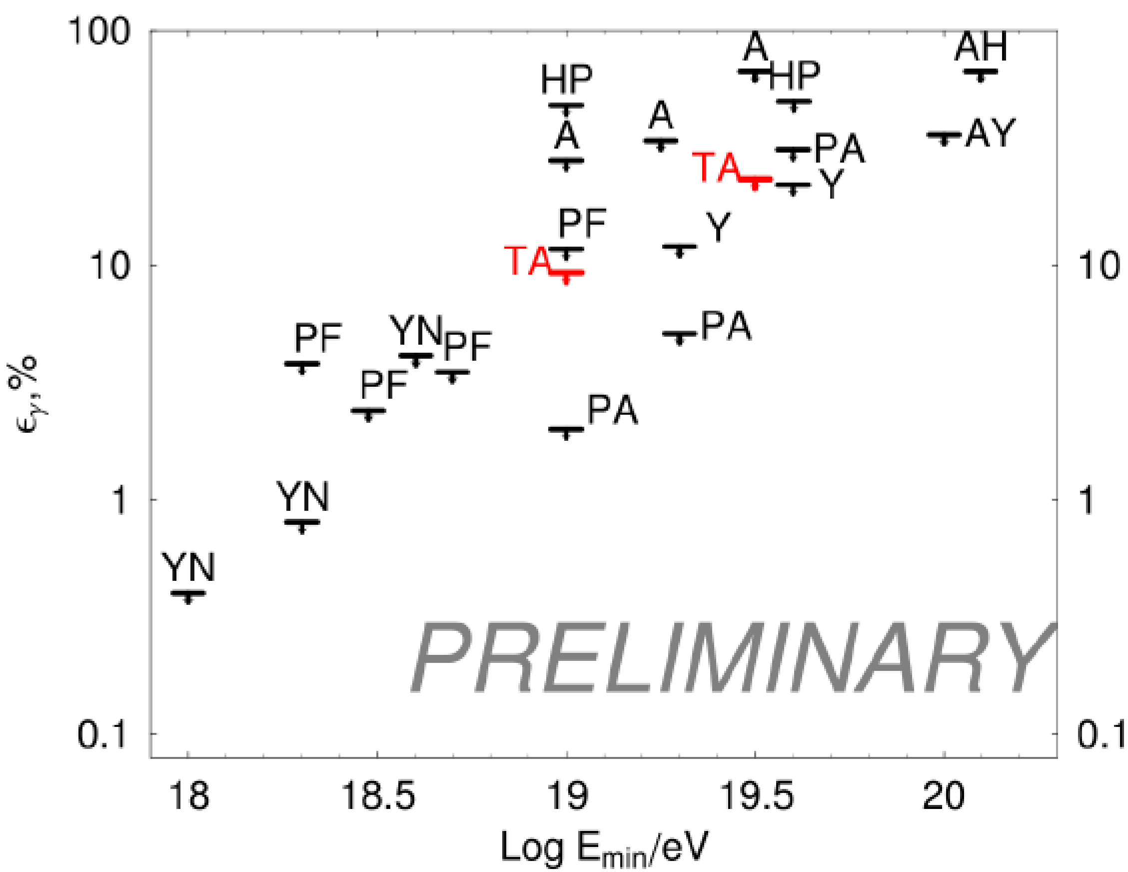
$$S(r) = S_{800} \times LDF(r)\,,$$

$$t_0(r) = t_0 + t_{plane} + a \times 0.67\,(1 + r/R_L)^{1.5} LDF^{-0.5}(r)$$

$$LDF(r) = f(r)/f\,(800\,\mathrm{m})\,,$$

$$f(r) = \left(\frac{r}{R_m}\right)^{-1.2} \left(1 + \frac{r}{R_m}\right)^{-(\eta-1.2)} \left(1 + \frac{r^2}{R_1^2}\right)^{-0.6}$$



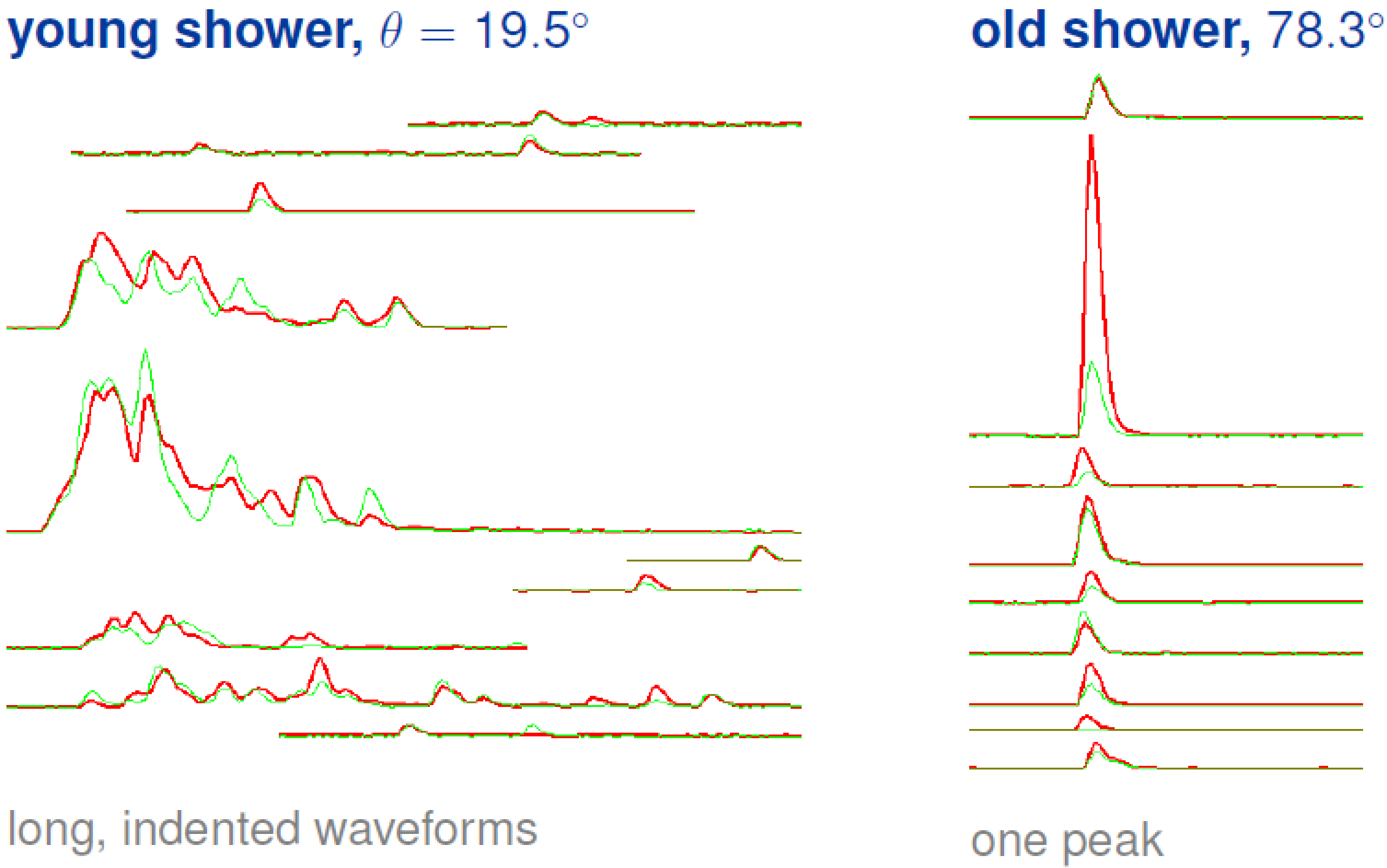


arXiv:1304.5614 [astro-ph.HE]

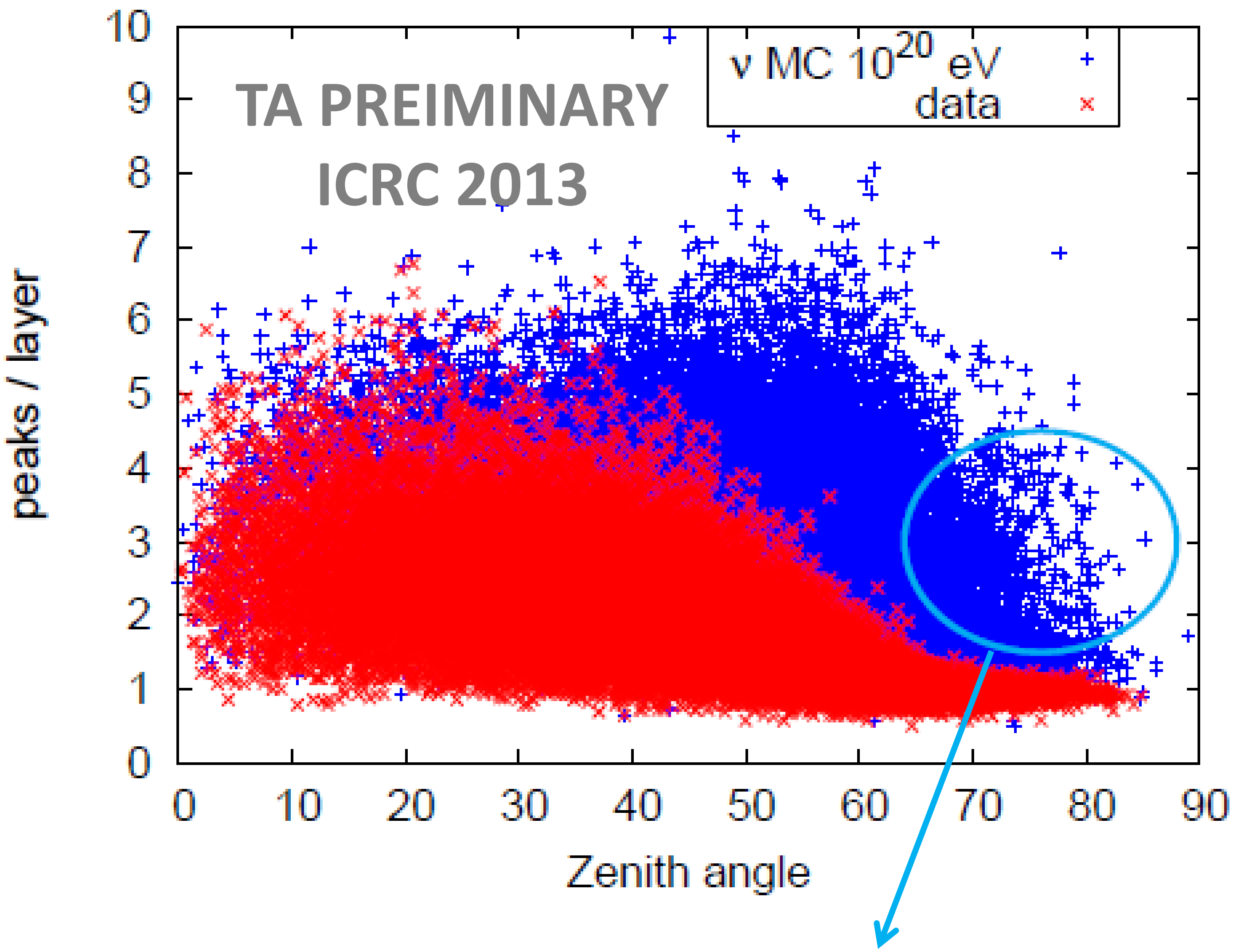
Submitted to Phys Rev D

TA SD Neutrino Search

Surface Detector Recorded Waveforms



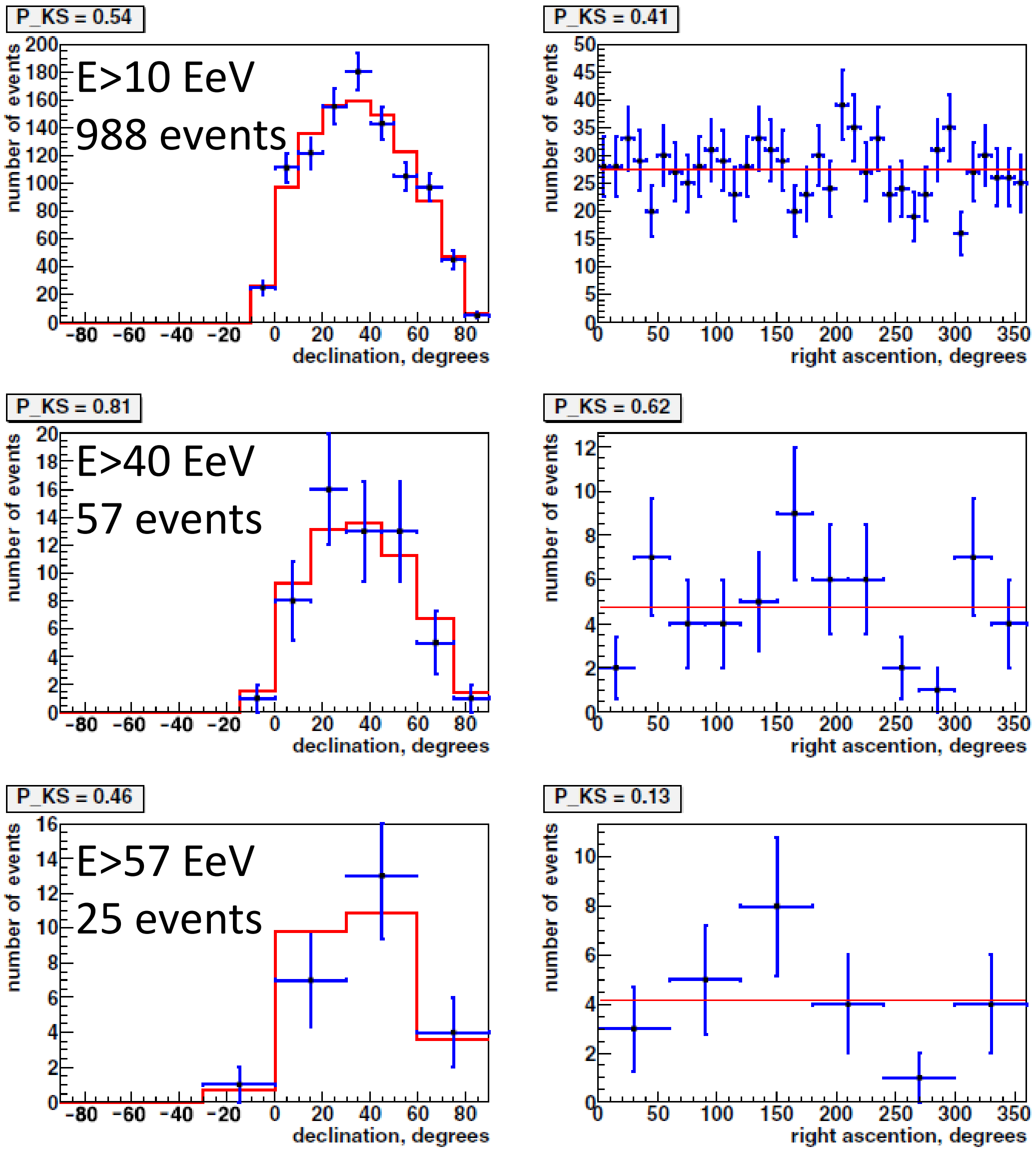
Neutrinos primaries produce YOUNG (many peaks in waveform) but HIGHLY INCLINED showers



NO INCLINED YOUNG showers in TA data

➔ ZERO neutrino candidates

6. Anisotropy



Equatorial Coordinates

Search based on 3.3 year (May 2008-Sep 2011) data published:
Astrophysical Journal, 757:26 (2012)

zenith < 45 deg

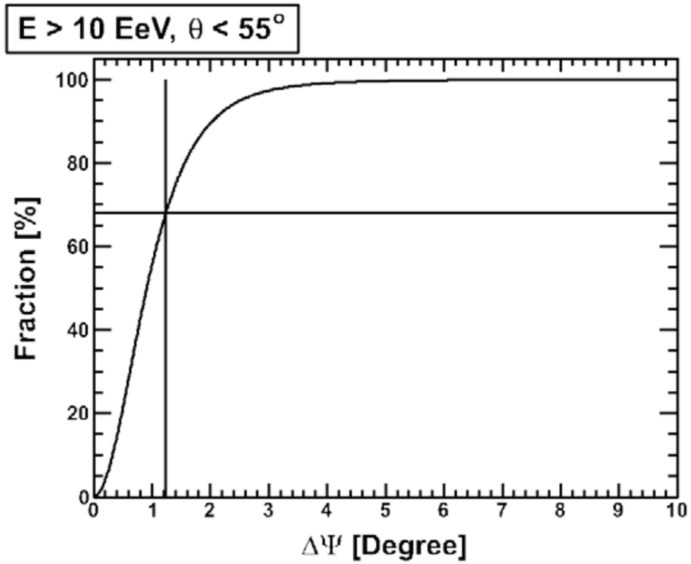
Results were consistent with Isotropic Source Model

TA Anisotrpy Update 2013

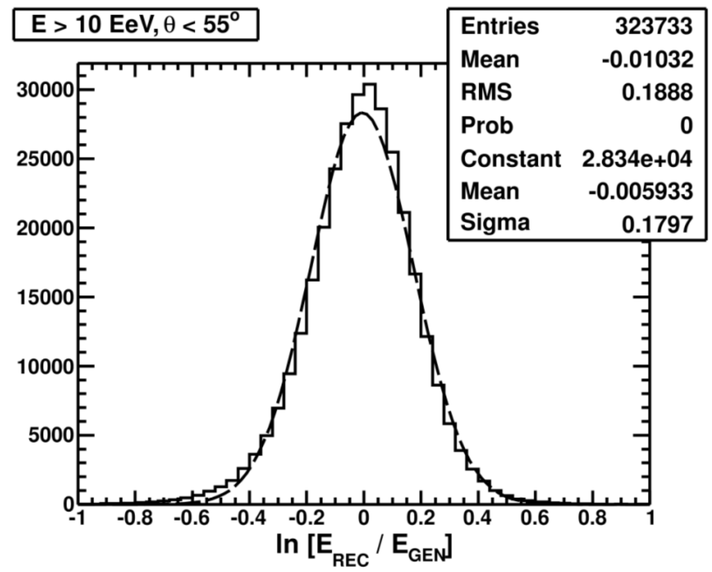
5 full years of Data:
May 2008 – May 2013
Zenith < 55 deg

E>10 EeV: 2130 events
E>40 EeV: 132 events
E>57 EeV: 52 events

Angular resolution better than 1.5 deg.

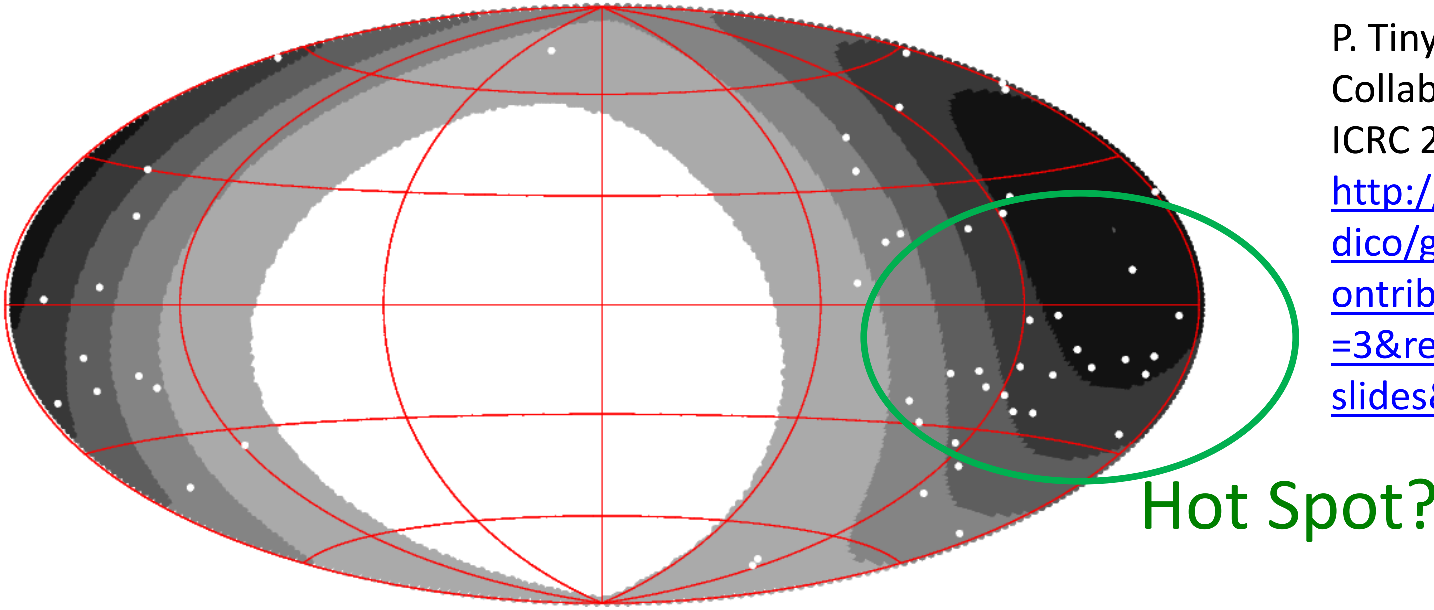


Energy resolution ~20%

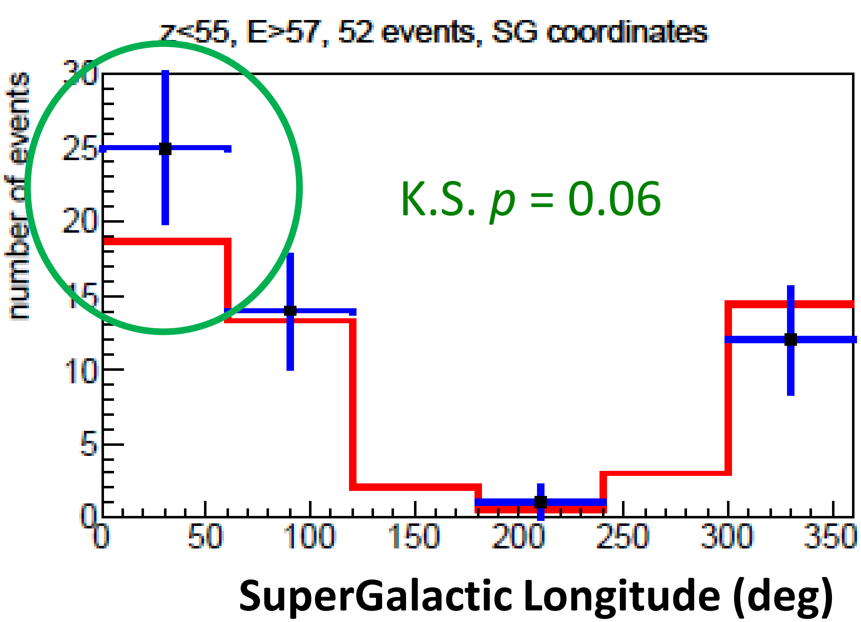


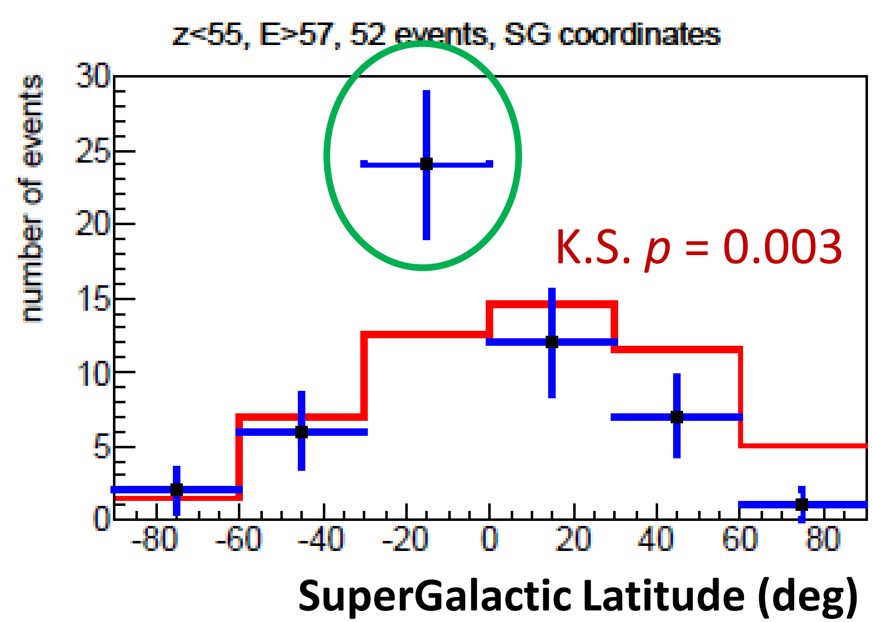
Results are still largely consistent with isotropy, but…

E > 57 EeV, SuperGalactic coordinates



P. Tinyakov for the TA Collaboration
ICRC 2013
http://143.107.180.38/indico/getFile.py/access?contribId=1033&sessionId=3&resId=0&materialId=slides&confId=0

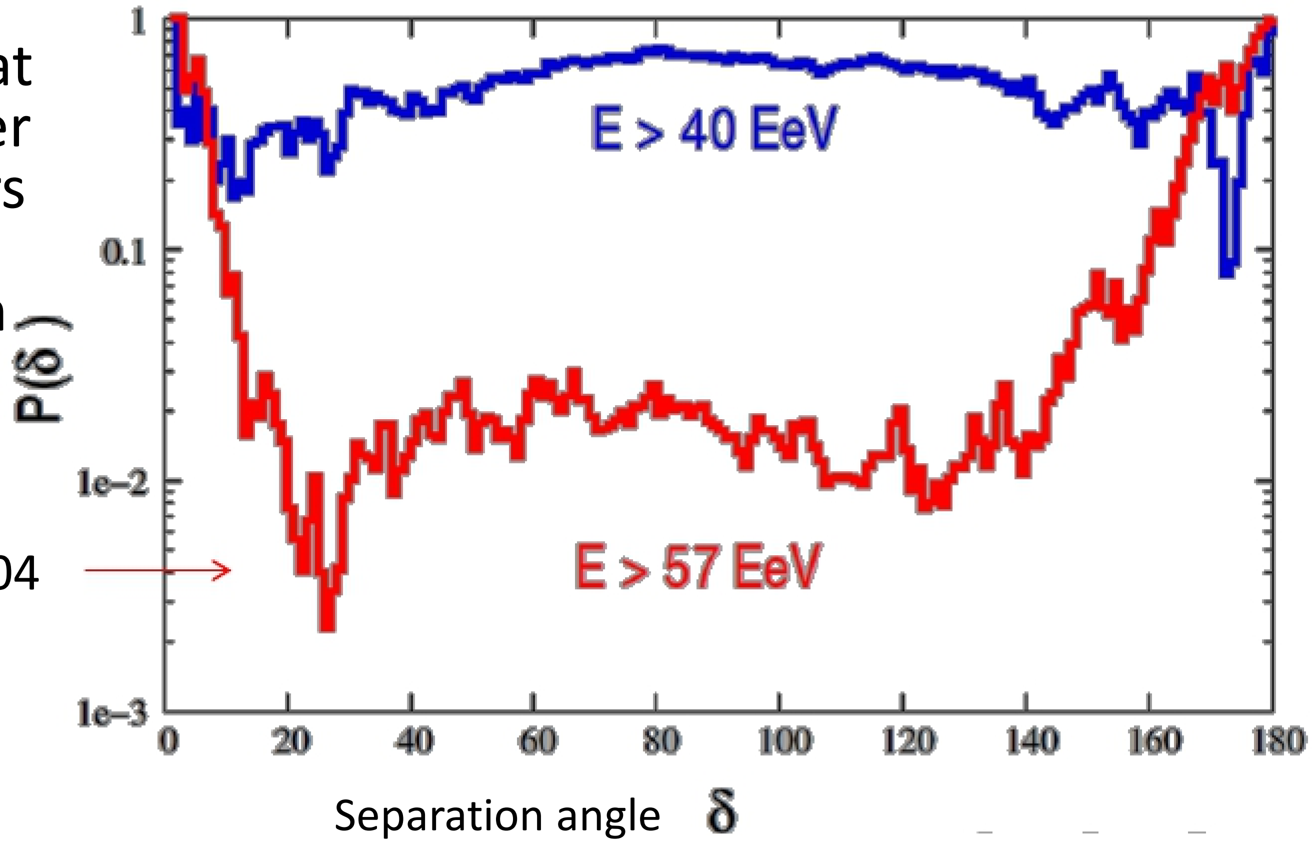




Clustering (autocorrelation)

P(δ) = Probability that the observed number of pairs (at <δ) occurs by chance from an isotropic distribution

0.004



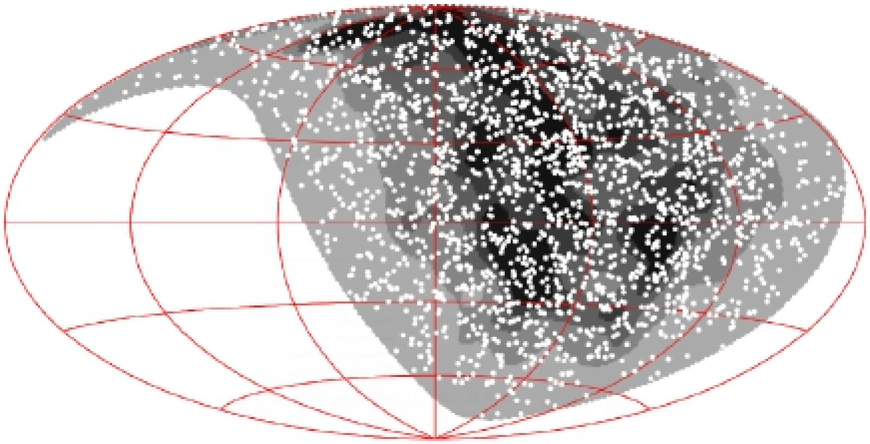
Small P(δ): Clustering at angular scale ~δ

P(δ)~0.004 at δ~20° for E > 57 EeV

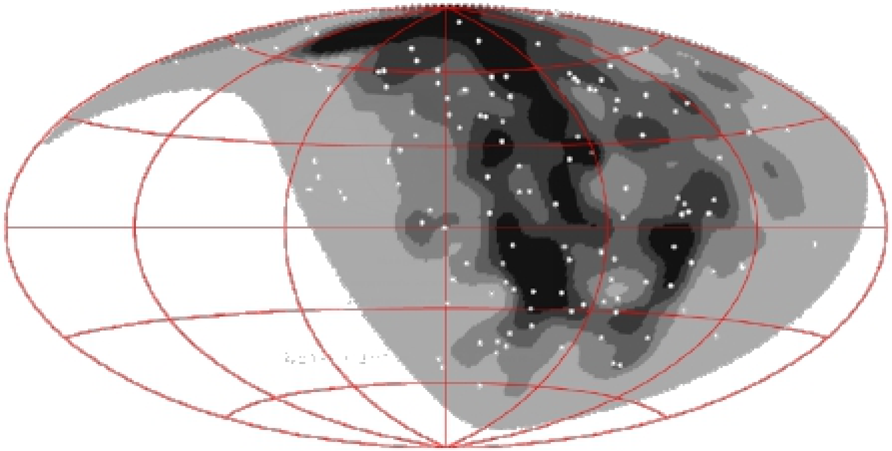
TA, TeVPA2013

Comparison with Large-Scale Structure (LSS)

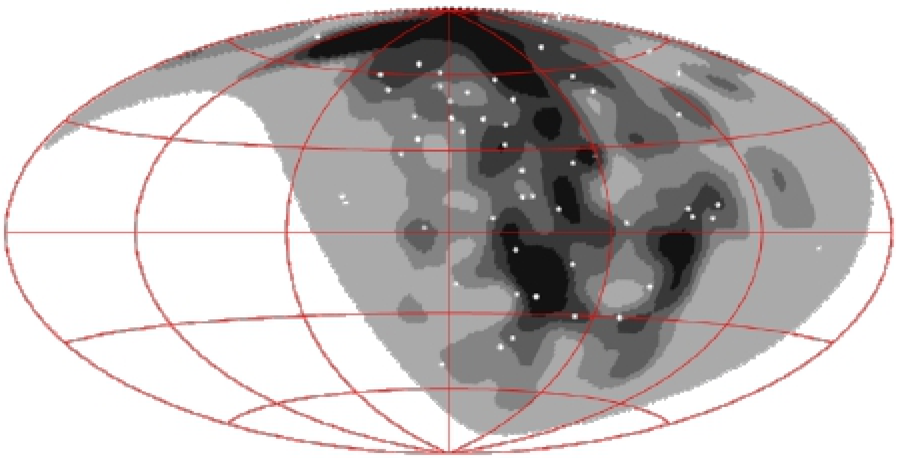
E > 10 EeV: 2130 events



E > 40 EeV: 132 events



E > 57 EeV: 52 events



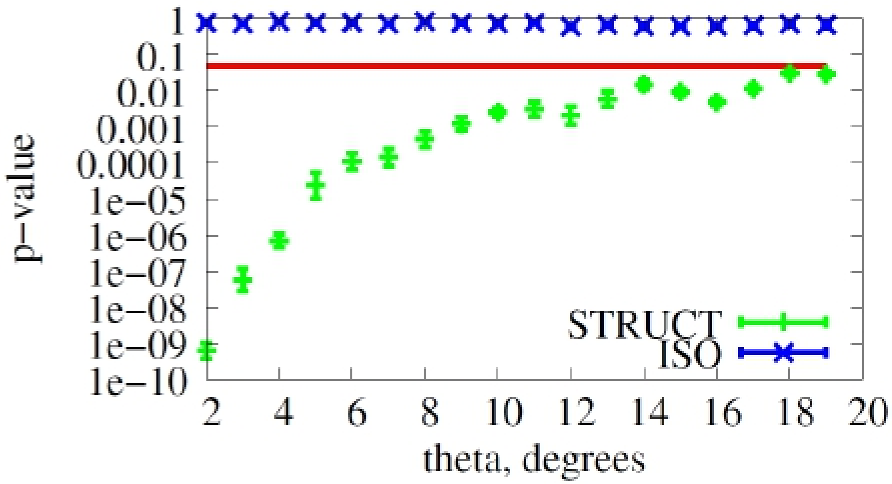
White dots: 5-year TA data with zenith angle < 55 deg.

Gray patterns:
expected flux density from
proton LSS 2MASS Galaxy
Redshift catalog (XSCz)

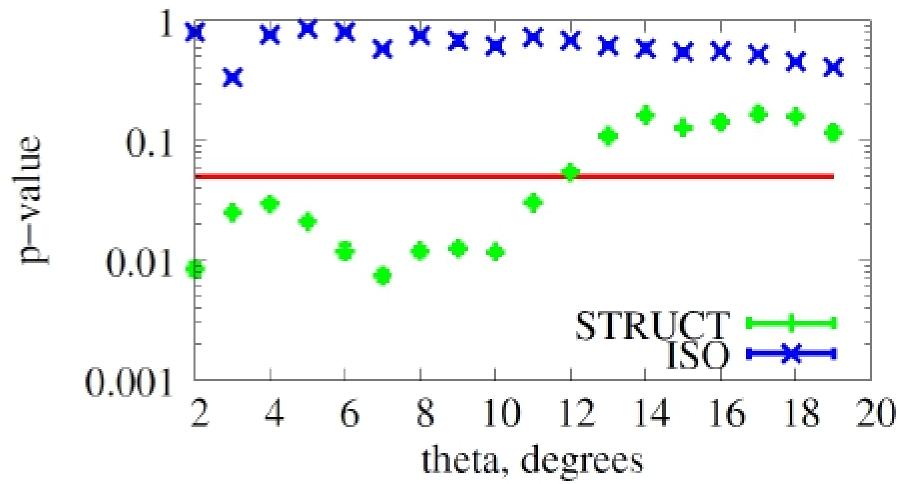
TA, TeVPA2013

Comparison with Large-Scale Structure (LSS)

E > 10 EeV

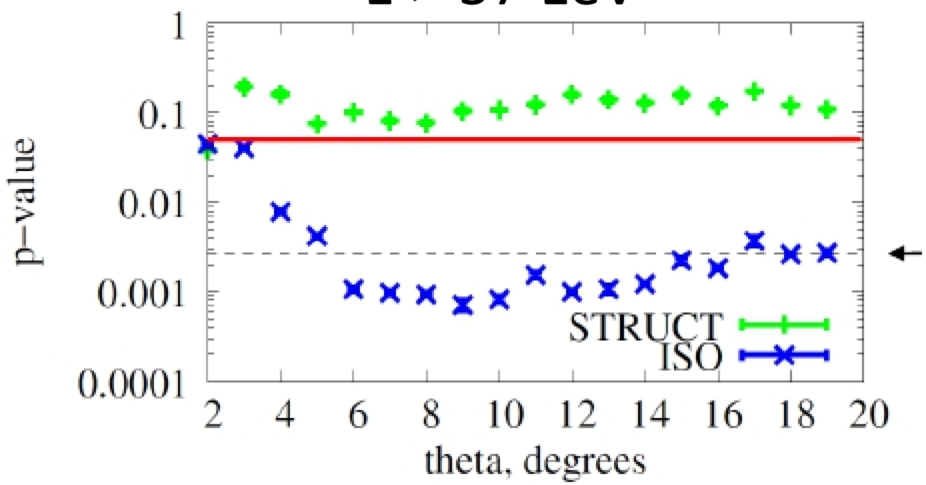


E > 40 EeV



Theta: deflection angle

E > 57 EeV



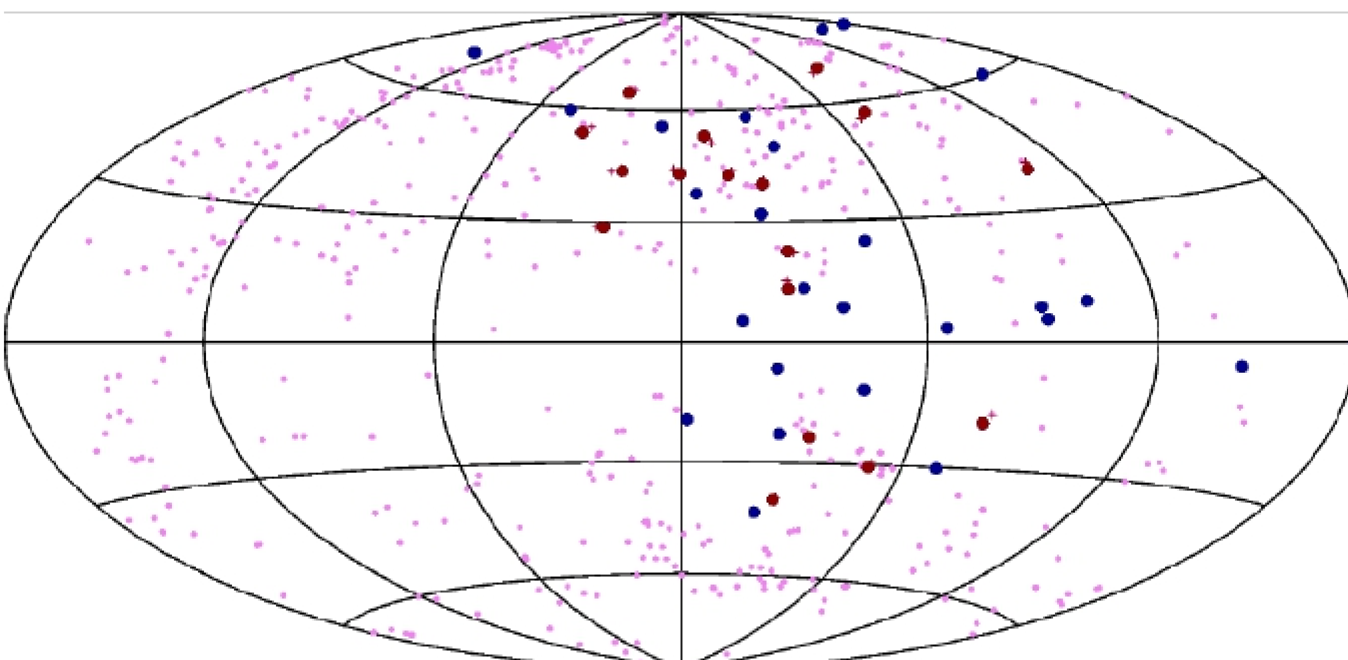
Need more data!

Conclusions

- TA Energy spectrum consistent with light composition
  - ***TA surface scintillator array consistent with GZK cut-off
- Preliminary <Xmax> composition result from both stereo and hybrid analyses **consistent with light (proton) composition**
- **No UHE photon or neutrino**
- TA SD data largely **consistent with isotropy**
  - Small Excess seen in SG
  - Hint of Clustering at ~20 deg
  - Marginally incompatible with isotropy at E>57 EeV but compatible with Large Scale Structure (LSS)
- TA Low Energy Extension (TALE) nearly completed
- Plans for TAx4 expansion

Correlations with AGN

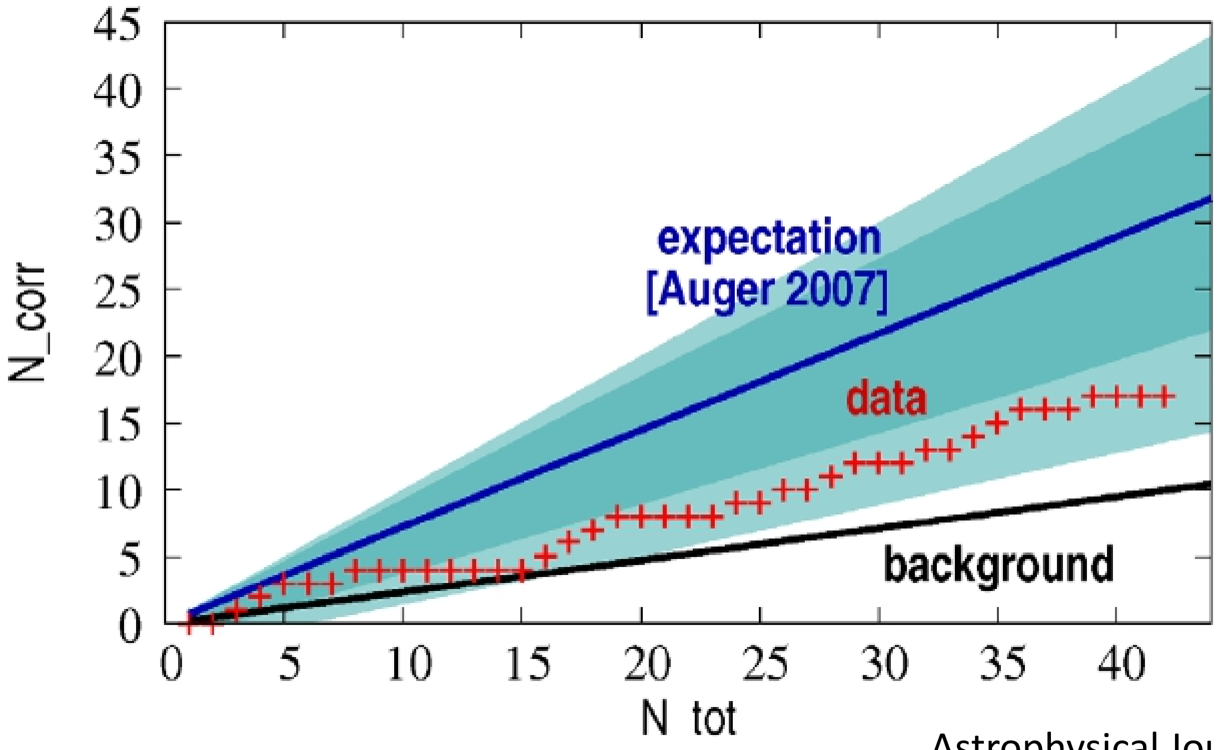
- 472 AGN from 2006 Veron catalog with $z < 0.018$
- $E > 57$ EeV, zenith angle < 45_{o}, $N = 42$ (5 yr)
- Separation angle = 3.1_{o}



TA, TeVPA2013

Correlations with AGN

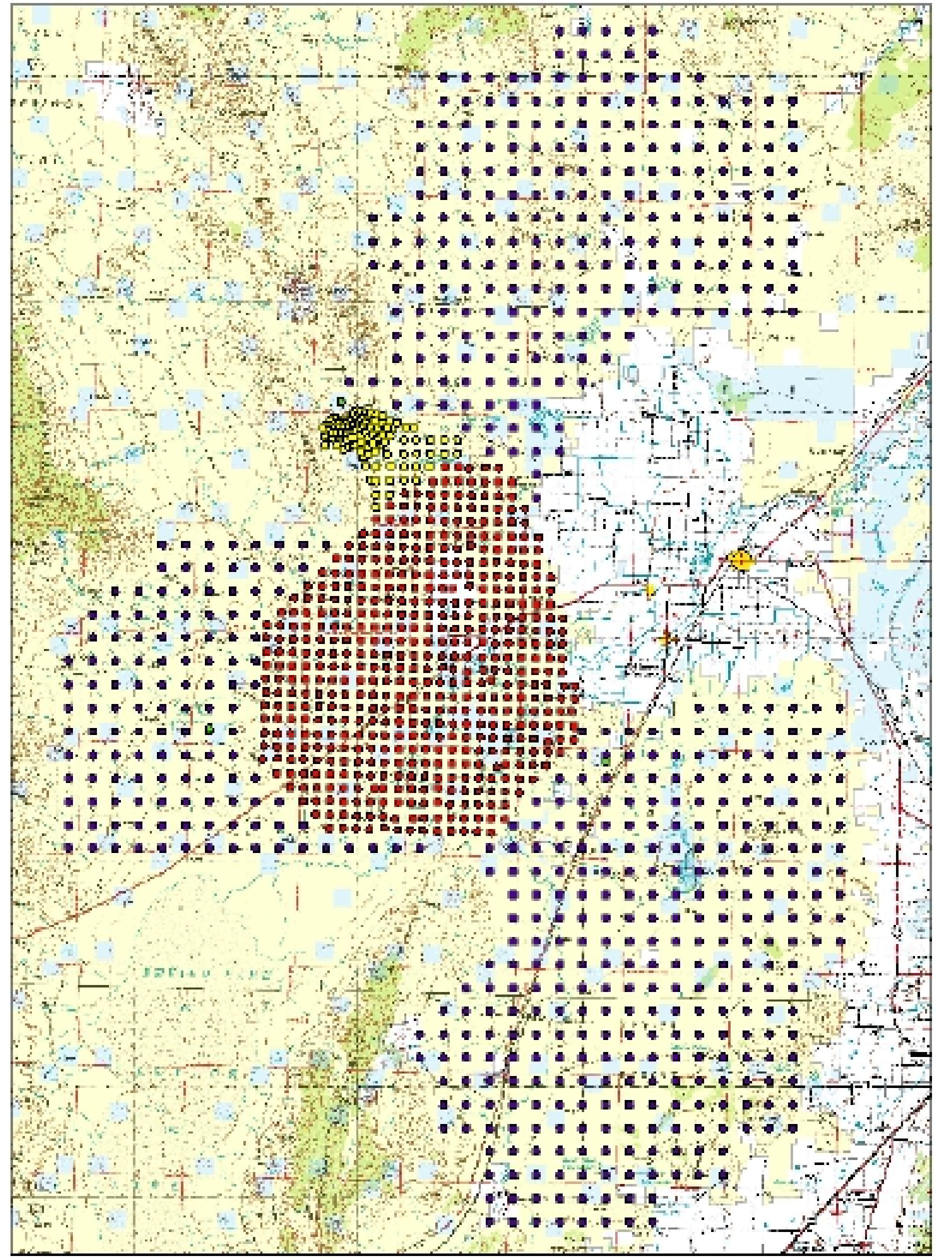
- Probability to hit AGN with a single event $p_o = 0.24$
- 17 events correlate out of 42 $\Longrightarrow$ $p = 0.014$



Astrophysical Journal, 757:26 (2012)

TA×4 Expansion

- A project to expand the TA surface detector by a factor of 4 (~3000 km^2)
  - 500 more scintillation counters with 2.08 km spacing
  - A fluorescence detector of 10 telescopes from HiRes telescopes
  - The proposal is being prepared for submission in fall, 2013.
- Anisotropy studies with more significance
  - By March, 2019
    - 20 TA years of SD data
    - 14 TA years of hybrid data



TALE Surface Detector Array