The Telescope Array
Решетка Телескопов

John Matthews/Джон Мэтьюс

for the Telescope Array Collaboration

Университет штата Юта

Институт астрофизики высоких энергий

Кафедра физики и астрономии

Кварки'2014

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Telescope Array (TA)

- **Telescope Array Collaboration was forged by Members of HiRes and AGASA**
  - **Study Ultra High Energy Cosmic Rays (spectrum, composition, anisotropy, …)**
  - **Understand the differences between AGASA and HiRes**
  - **Study the galactic to extra-galactic transition: measure cosmic rays over the second knee, ankle, and GZK with one cross-calibrated detector**
- **Current collaboration from the US, Japan, Korea, Russia, and Belgium**

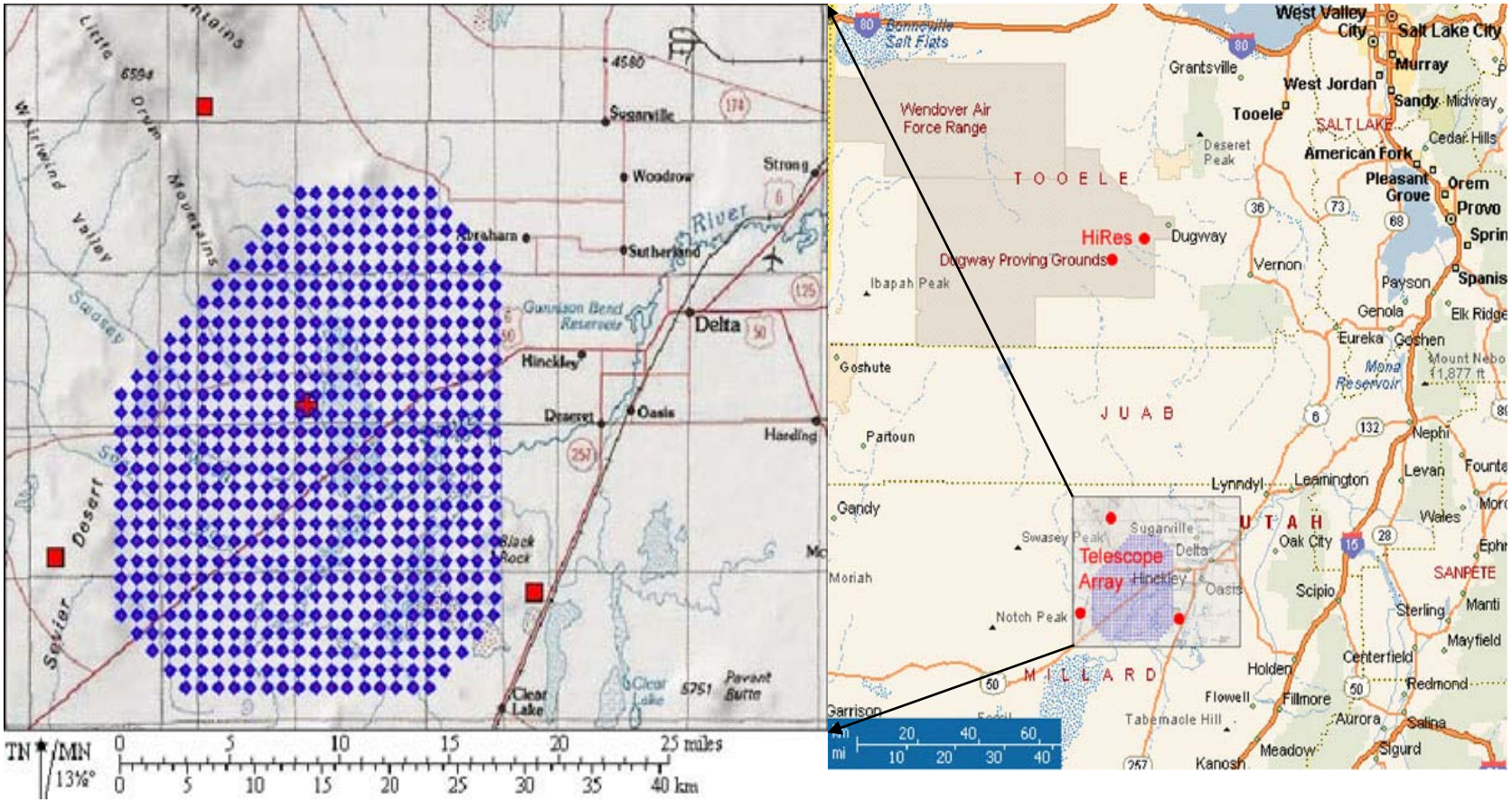
Telescope Array Collaboration

~120 collaborators in 5 countries
Japan, USA, Korea, Russia, Belgium

T. Abu-Zayyad[a], M. Allen[a], R. Anderson[a], R. Azuma[b], E. Barcikowski[a], J. W. Belz[a], D. R. Bergman[a], S. A. Blake[a], R. Cady[a], M. J. Chae[c], B. G. Cheon[d], J. Chiba[e], M. Chikawa[f], W. R. Cho[g], T. Fujii[h], M. Fukushima[h,i], K. Goto[j], W. Hanlon[a], Y. Hayashi[j], N. Hayashida[k], K. Hibino[k], K. Honda[l], D. Ikeda[h], N. Inoue[m], T. Ishii[l], R. Ishimori[b], H. Ito[n], D. Ivanov[a,o], C. C. H. Jui[a], K. Kadota[p], F. Kakimoto[b], O. Kalashev[q], K. Kasahara[r], H. Kawai[s], S. Kawakami[j], S. Kawana[m], K. Kawata[h], E. Kido[h], H. B. Kim[d], J. H. Kim[a], J. H. Kim[d], S. Kitamura[b], Y. Kitamura[b], V. Kuzmin[q], Y. J. Kwon[g], J. Lan[a], J.P. Lundquist[a], K. Machida[l], K. Martens[i], T. Matsuda[t], T. Matsuyama[j], J. N. Matthews[a], M. Minamino[j], K. Mukai[l], I. Myers[a], K. Nagasawa[m], S. Nagataki[n], T. Nakamura[u], H. Nanpei[j], T. Nonaka[h], A. Nozato[f], S. Ogio[j], S. Oh[c], M. Ohnishi[h], H. Ohoka[h], K. Oki[h], T. Okuda[v], M. Ono[n], A. Oshima[j], S. Ozawa[r], I. H. Park[w], M. S. Pshirkov[x], D. C. Rodriguez[a], G. Rubtsov[q], D. Ryu[y], H. Sagawa[h], N. Sakurai[j], A. L. Sampson[a], L. M. Scott[o], P. D. Shah[a], F. Shibata[l], T. Shibata[h], H. Shimodaira[h], B. K. Shin[d], T. Shirahama[m], J. D. Smith[a], P. Sokolsky[a], R. W. Springer[a], B. T. Stokes[a], S. R. Stratton[a,o], T. A. Stroman[a], M. Takamura[e], A. Taketa[z], M. Takita[h], Y. Tameda[k], H. Tanaka[j], K. Tanaka[aa], M. Tanaka[t], S. B. Thomas[a], G. B. Thomson[a], P. Tinyako[q,x], I. Tkachev[q], H. Tokuno[b], T. Tomida[ab], S. Troitsky[q], Y. Tsunesada[b], K. Tsutsumi[b], Y. Uchihori[ac], F. Urban[x], G. Vasiloff[a], Y. Wada[m], T. Wong[a], H. Yamaoka[t], K. Yamazaki[j], J. Yang[c], K. Yashiro[e], Y. Yoneda[j], S. Yoshida[s], H. Yoshii[ad], R. Zollinger[a], Z. Zundel[a]

[a]University of Utah, [b]Tokyo Institute of Technology, [c]Ewha Womans University, [d]Hanyang University, [e]Tokyo University of Science, [f]Kinki University, [g]Yonsei University, [h]Institute for Cosmic Ray Research, Univ. of Tokyo, [i]Kavli Institute for the Physics and Mathematics of the Universe (WPI), Todai Institutes for Advanced Study, the University of Tokyo, [j]Osaka City University, [k]Kanagawa University, [l]Univ. of Yamanashi, [m]Saitama University, [n]Astrophysical Big Bang Laboratory, RIKEN, [o]Rutgers University, [p]Tokyo City University, [q]Institute for Nuclear Research of the Russian Academy of Sciences, [r]Waseda University, [s]Chiba University, [t]Institute of Particle and Nuclear Studies, KEK, [u]Kochi University, [v]Ritsumeikan University, [w]Sungkyunkwan University, [x]Universite Libre de Bruxelles, [y]Chungnam National University, [z]Earthquake Research Institute, University of Tokyo, [aa]Hiroshima City University, [ab]Advanced Science Institute, RIKEN, [ac]National Institute of Radiological Science, [ad]Ehime University

Telescope Array



The High Energy component of Telescope Array – 38 fluorescence telescopes (9728 PMTs) at 3 telescope stations overlooking an array of 507 scintillator surface detectors (SD) - complete and operational as of ~1/2008.

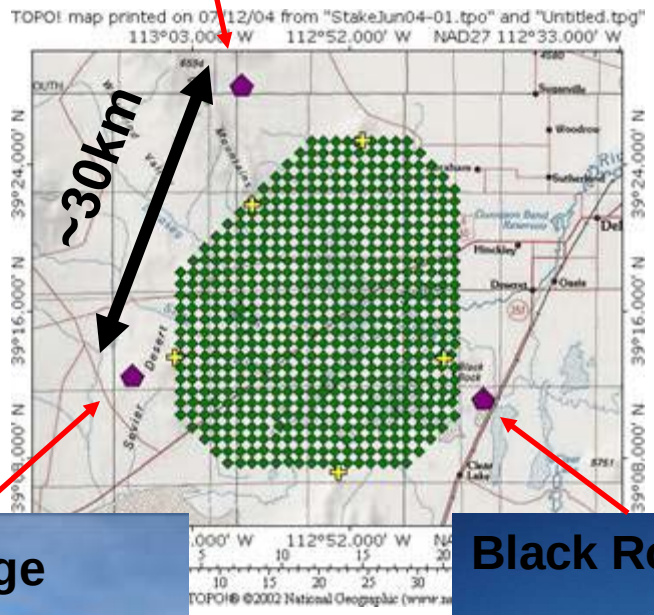
TA Fluorescence Detectors

Middle Drum

14 telescopes @ station
256 PMTs/camera

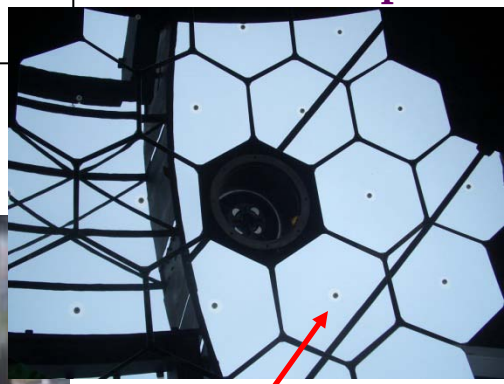
5.2 m^2

Reutilized from HiRes-I



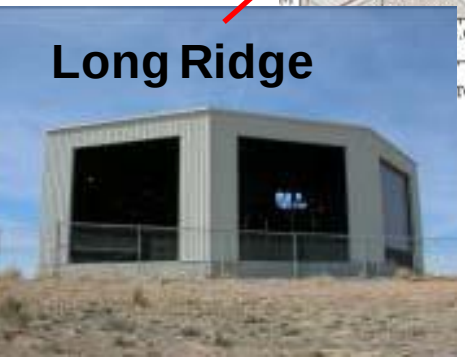
12 telescopes/station
256 PMTs/camera

New Telescopes

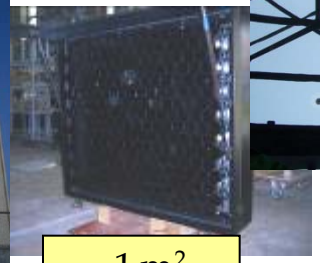


6.8 m^2

Long Ridge

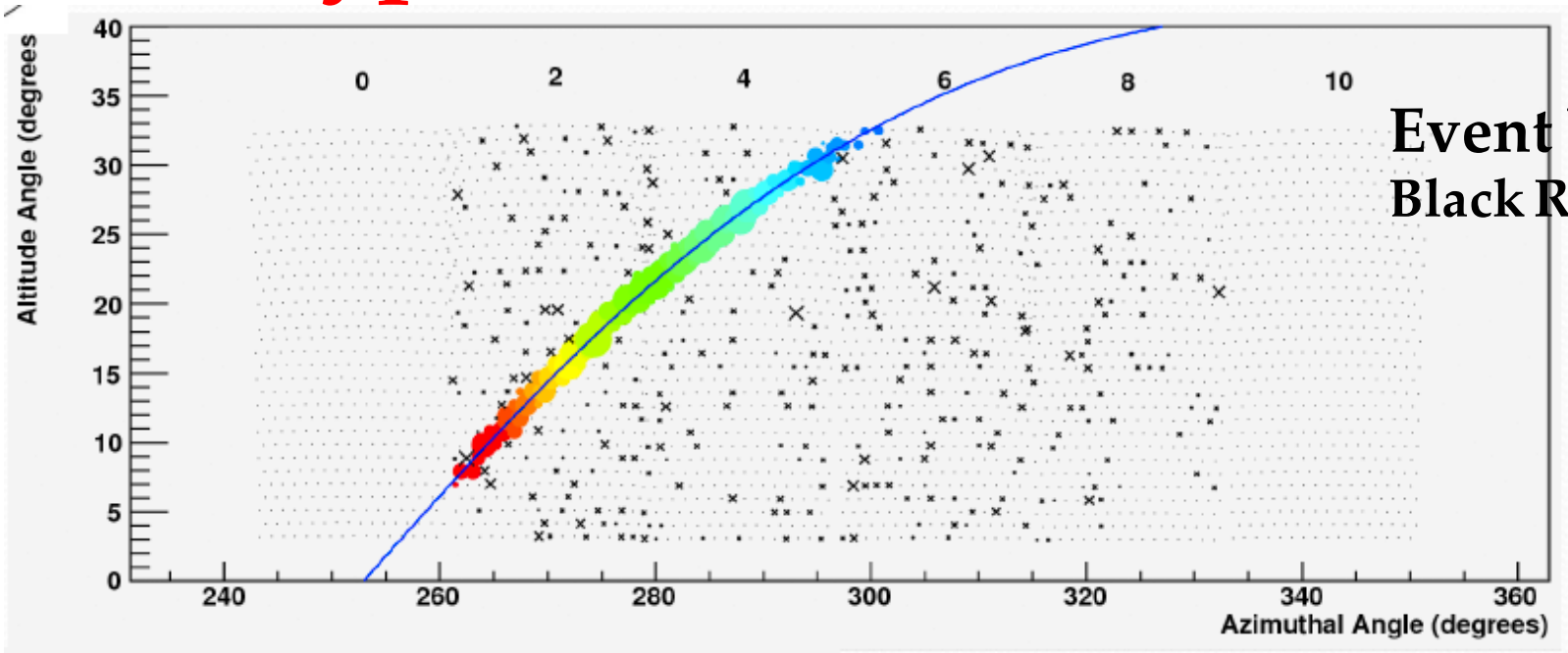


Black Rock Mesa

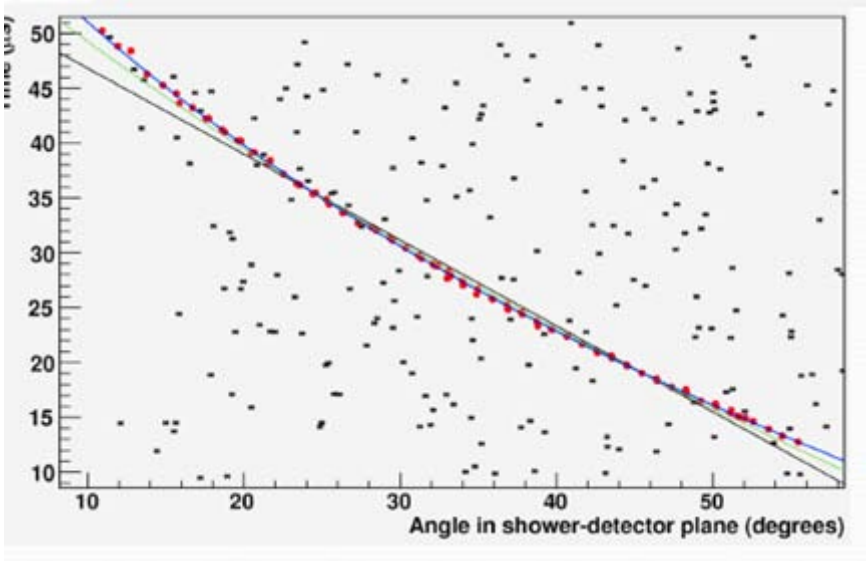


~1 m^2

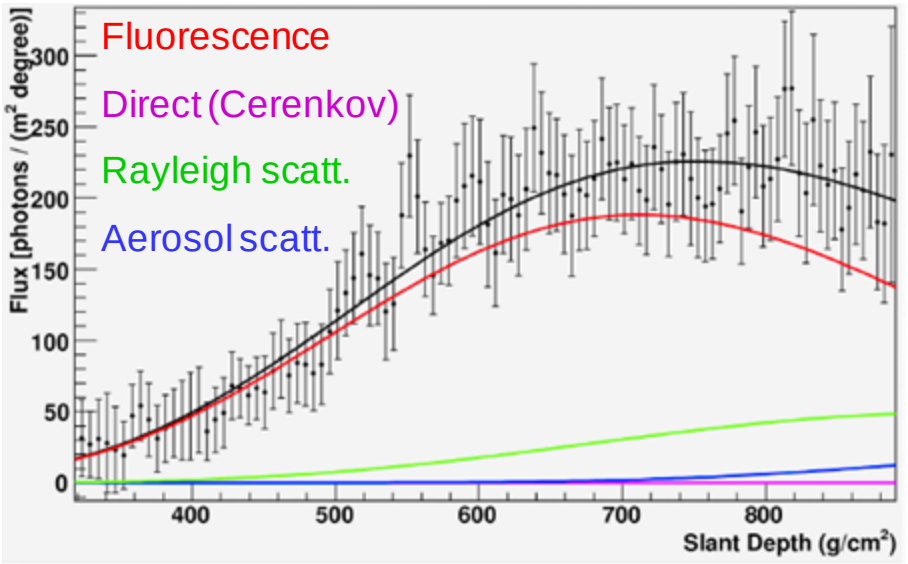
Typical Fluorescence Event



Event Display
Black Rock Mesa



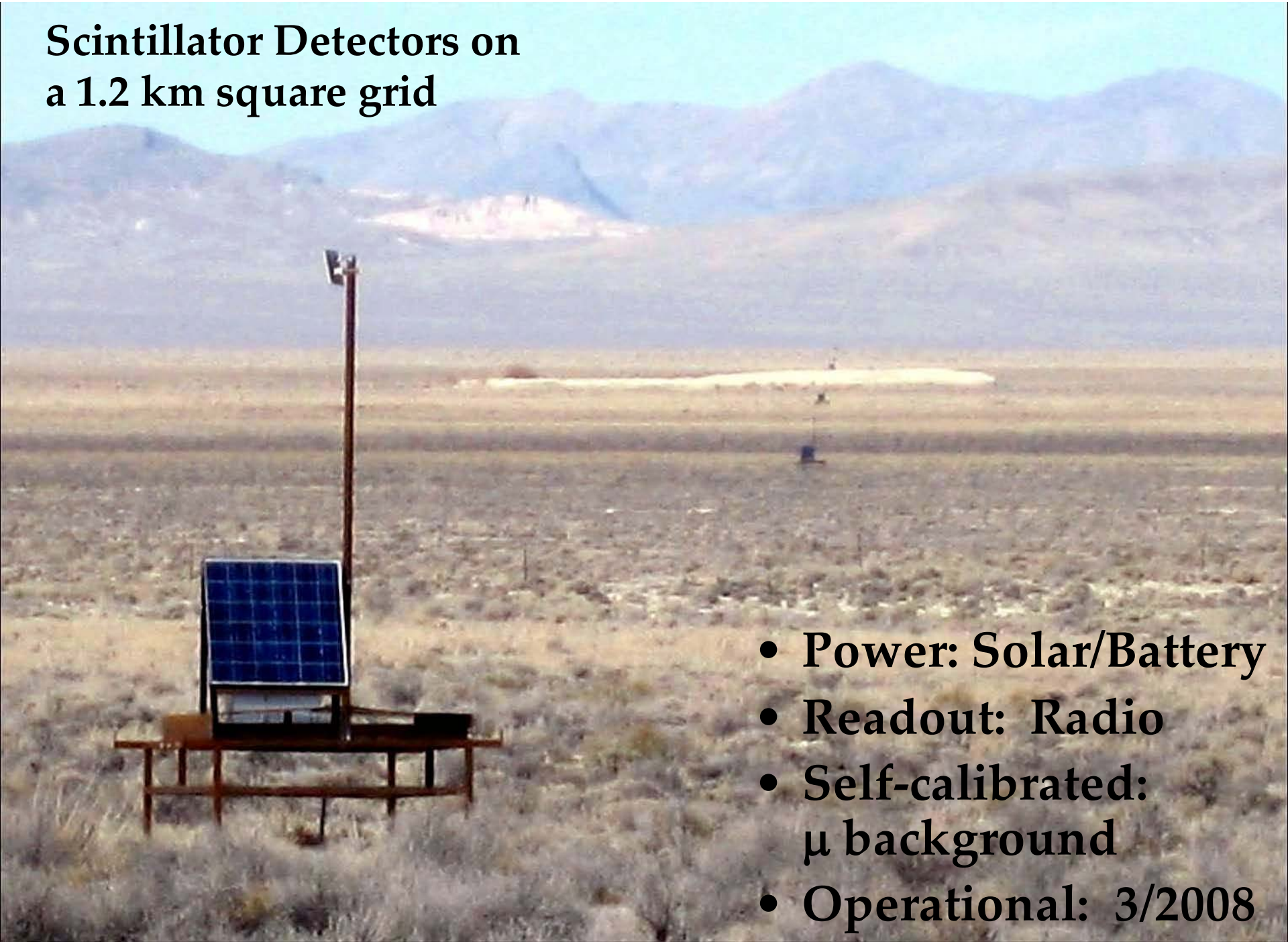
Monocular timing fit (time vs angle)



Reconstructed Shower Profile

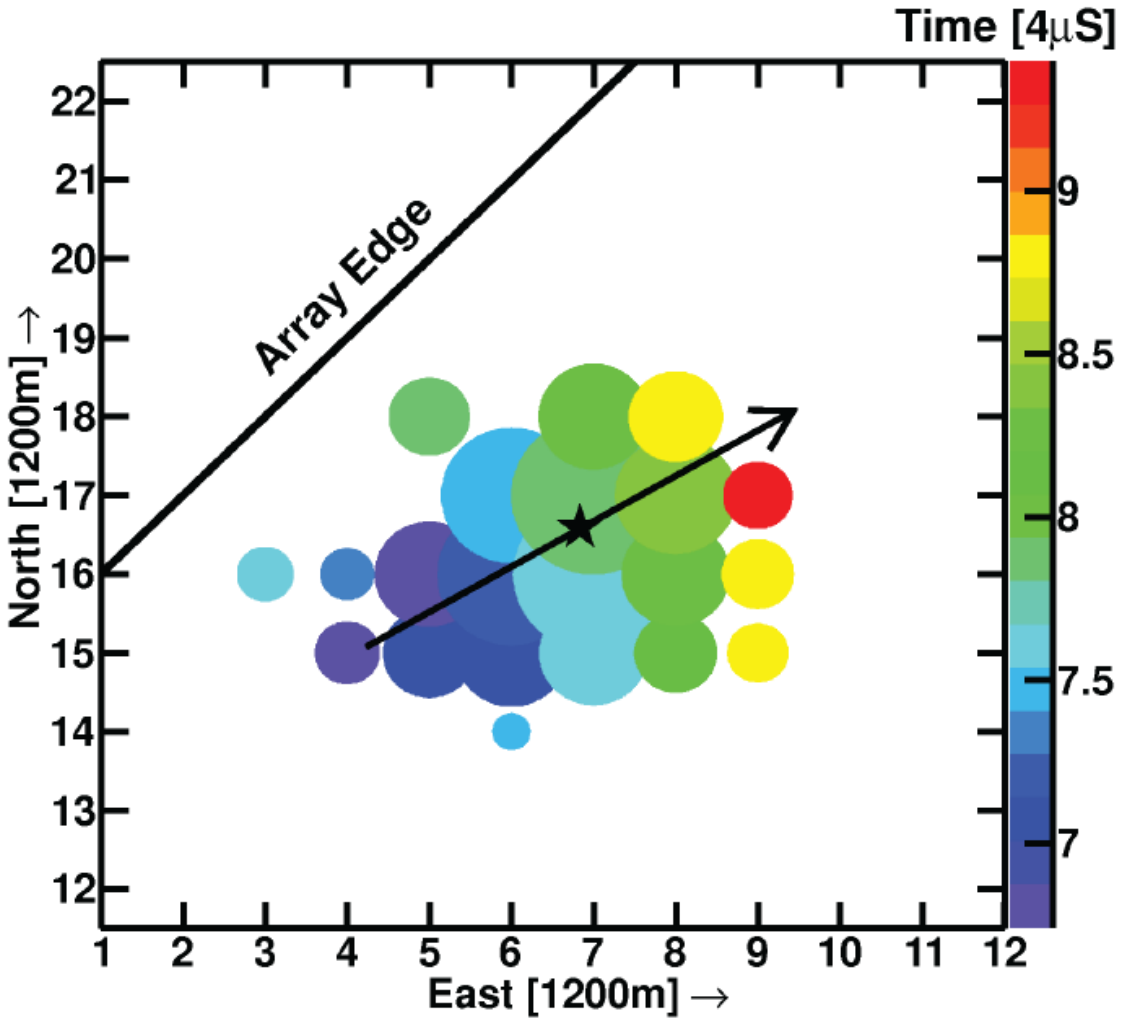
Scintillator Surface Detectors

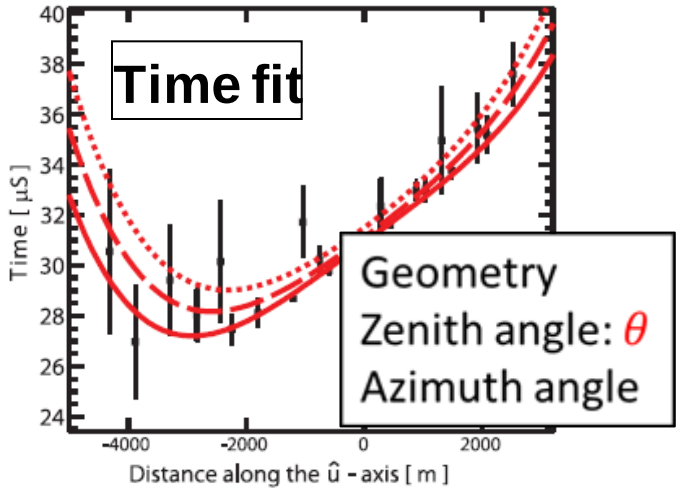
2 layers scintillator
1.25 cm thick, 3m^2 area
Optical fibers to PMTs

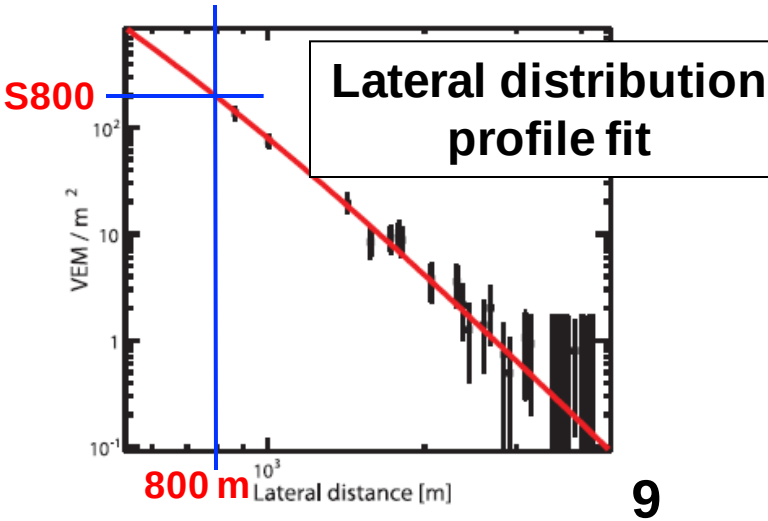

Scintillator Detectors on
a 1.2 km square grid
• Power: Solar/Battery
• Readout: Radio
• Self-calibrated:
μ background
• Operational: 3/2008

TA shower analysis with SD

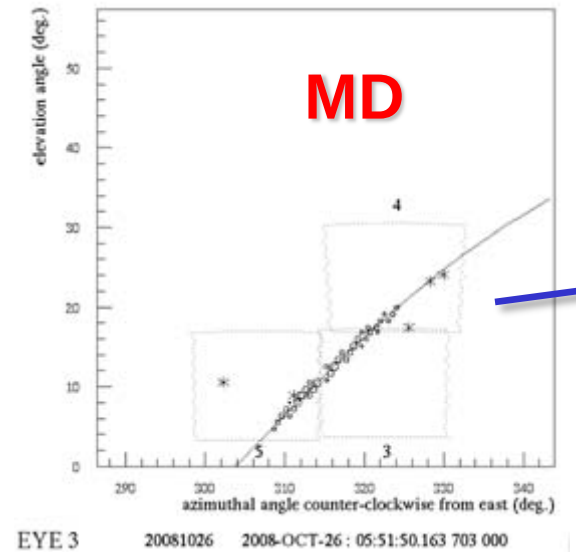
An SD hit map of a typical high energy event





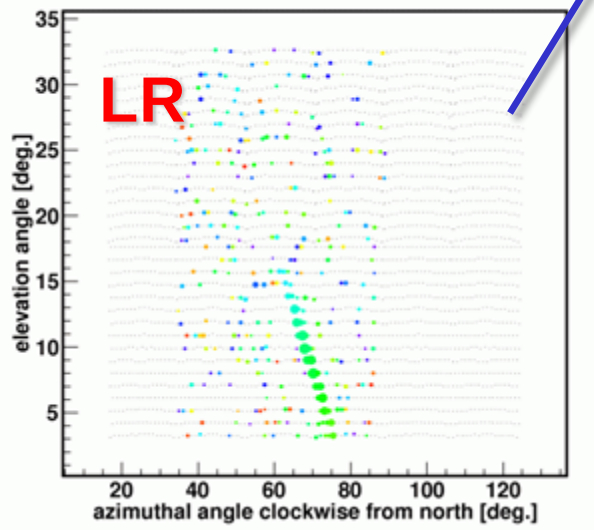


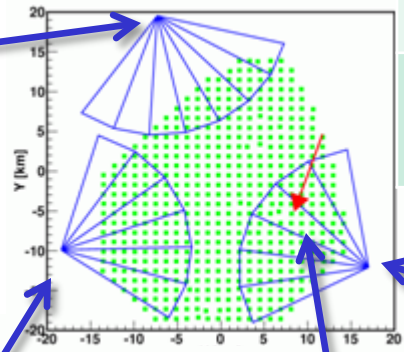
Example Event

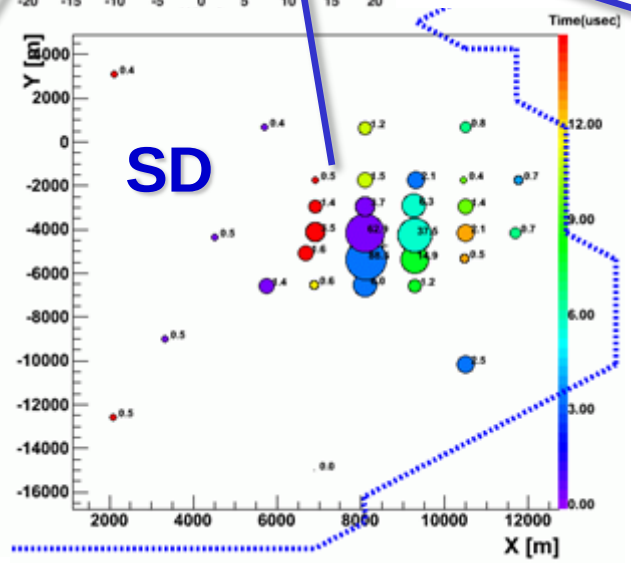


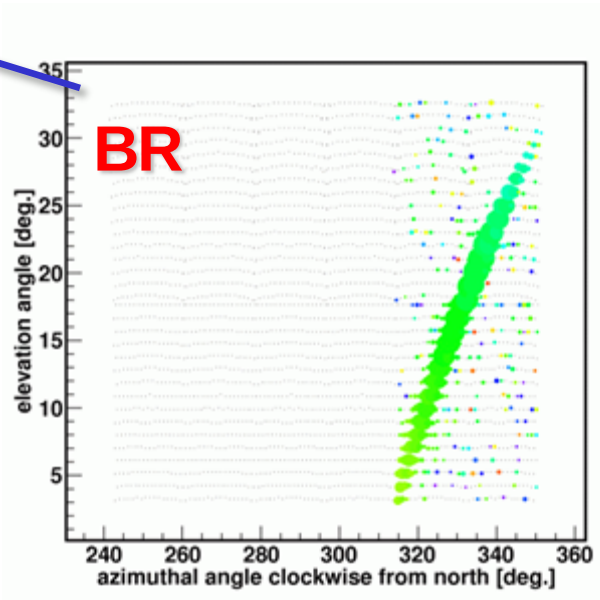
	θ[º]	ϕ[º]	x[km]	y[km]
MD mono	51.43	73.76	7.83	-3.10
BR mono	51.50	77.09	7.67	-4.14
Stereo BR&LR	50.21	71.30	8.55	-4.88

Event from 2008-10-26





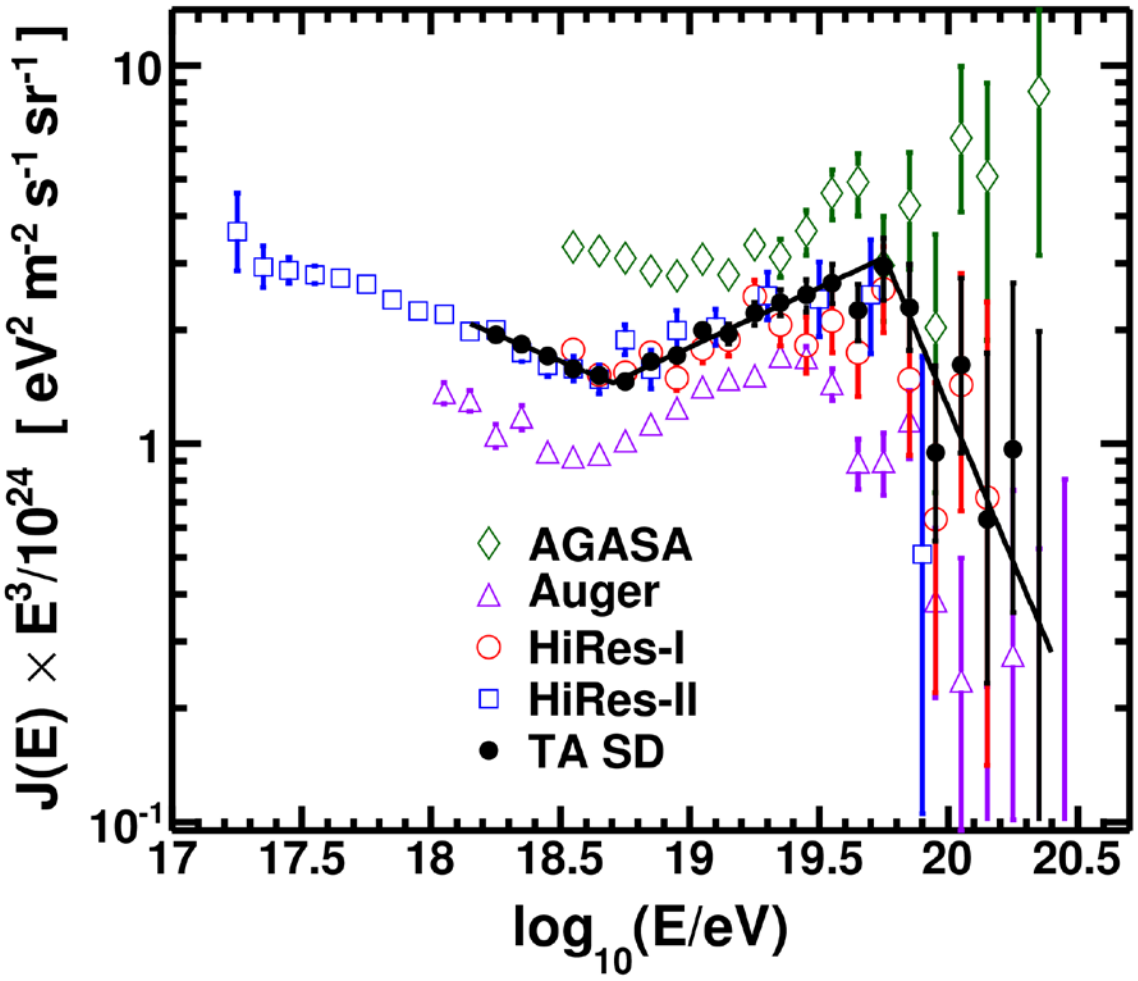




The Energy Spectrum

- **Surface Detector array – highest statistics (operational 24/7)**

TA SD Spectrum (5 year)



TA Data
May, 2008 – May, 2013
Zenith angle < 45°
14,787 evts ($E > 10^{18.2}$ eV)
Exposure 4500 km² sr yr

Broken power law fit

$\gamma_1 = -3.283 \pm 0.032$

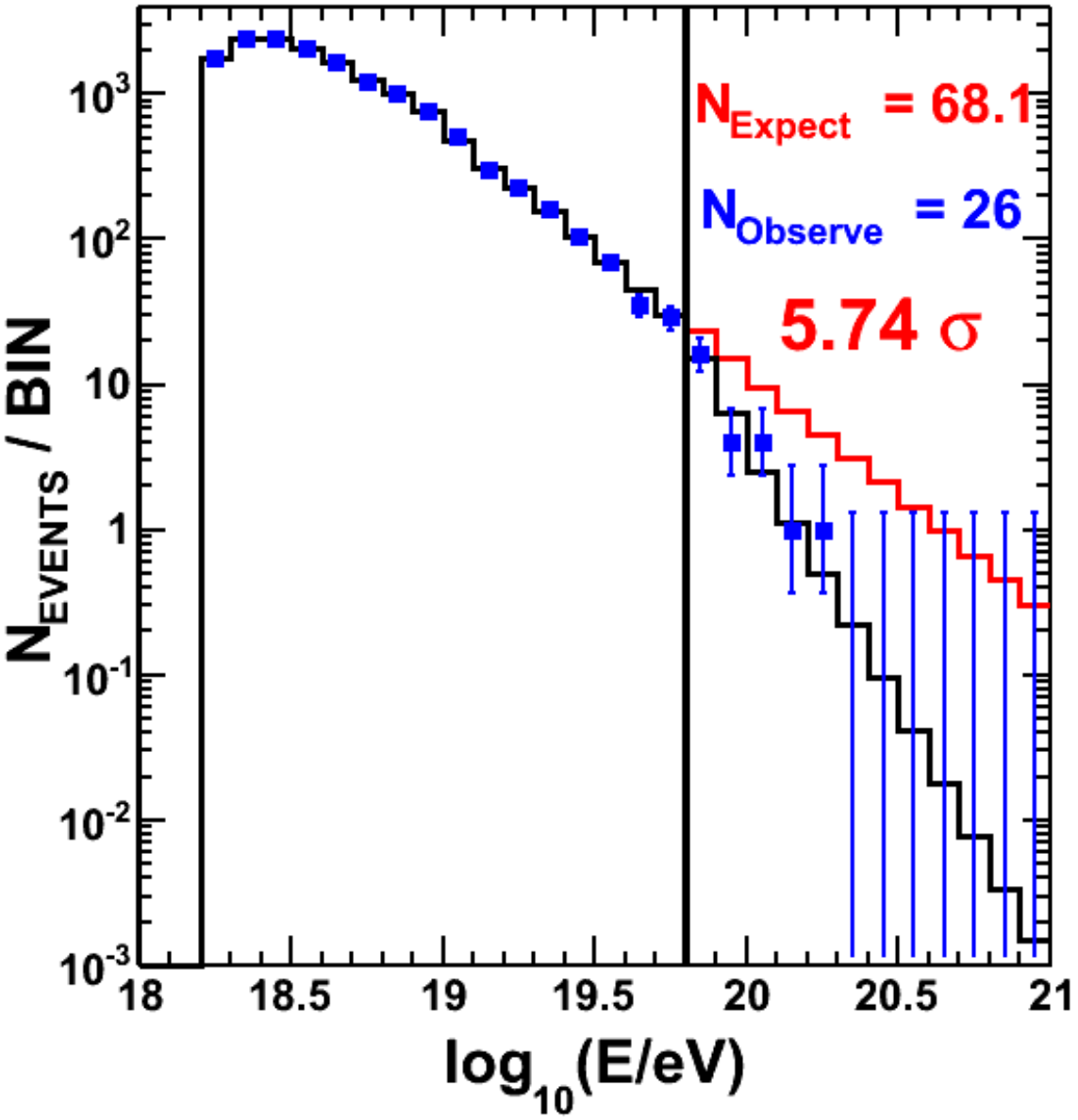
$E_{ankle} = (5.04 \pm 0.27) \times 10^{18}$ eV

$\gamma_2 = -2.685 \pm 0.030$

$E_{GZK} = (5.68 \pm 1.05) \times 10^{19}$ eV

$\gamma_3 = -4.62 \pm 0.74$

GZK Effect

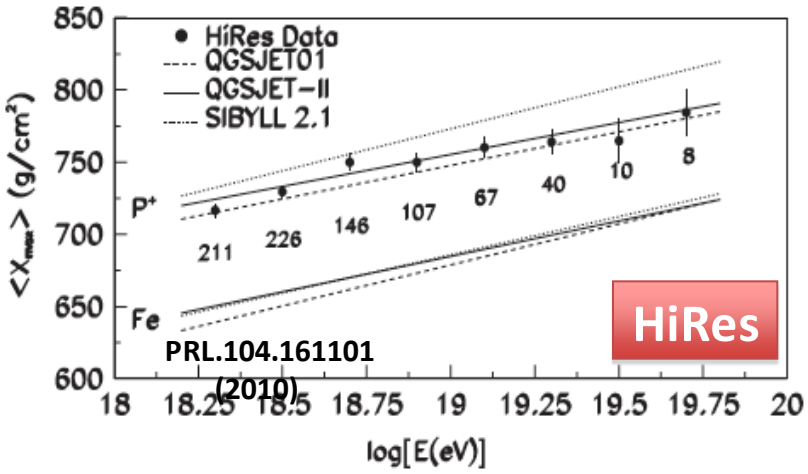

N_{Expect} = 68.1
$N_{Observe}$ = 26
5.74 σ
N_{EVENTS} / BIN
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
18
18.5
19
19.5
20
20.5
21
$\log_{10}$(E/eV)

Chemical Composition

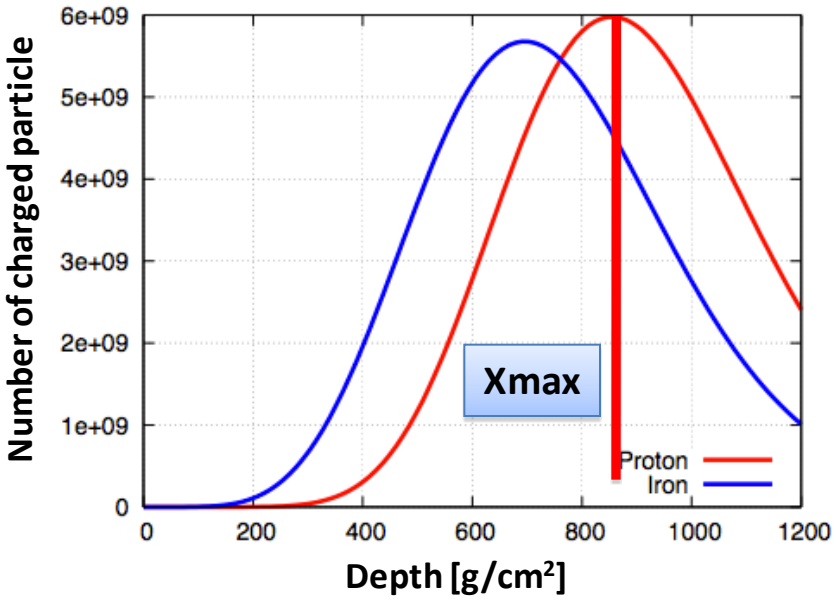
- **Use hybrid or stereo to constrain geometry and know Xmax**
- **Stereo also provides a redundant measurement of Xmax**

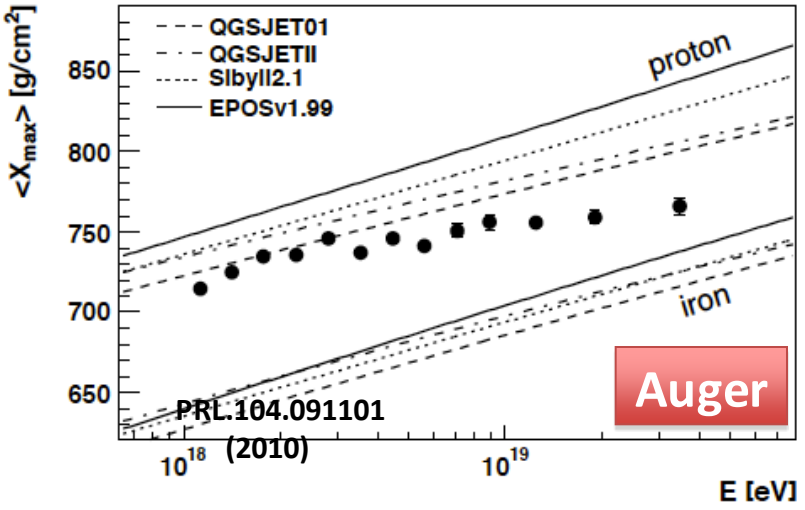
Xmax Technique

- Shower longitudinal development depends on primary particle type.
- FD observes shower development directly.
- Xmax is the most efficient parameter for determining primary particle type.

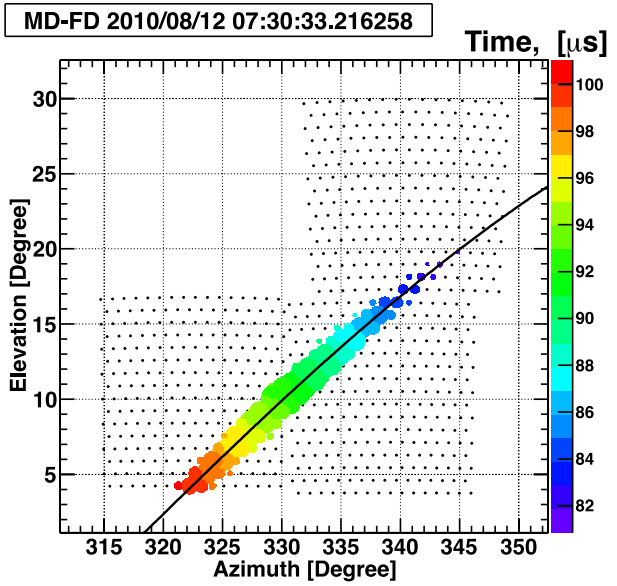


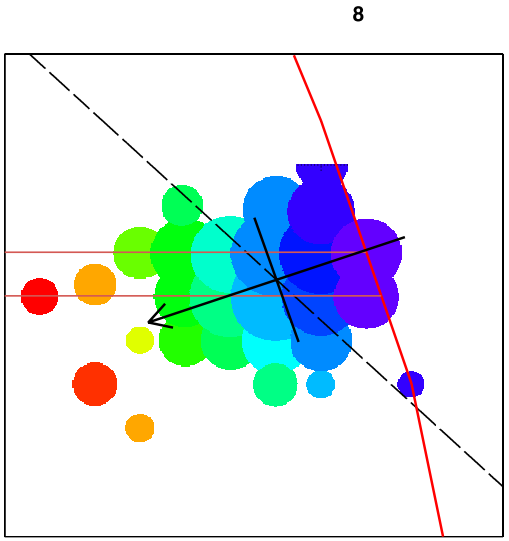
Shower longitudinal development

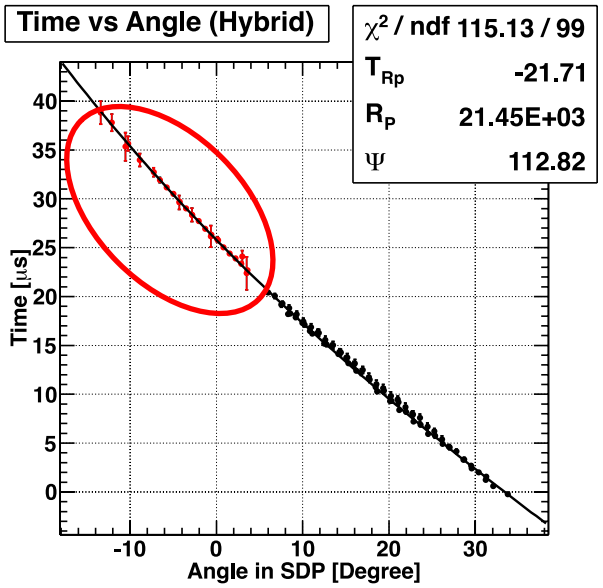


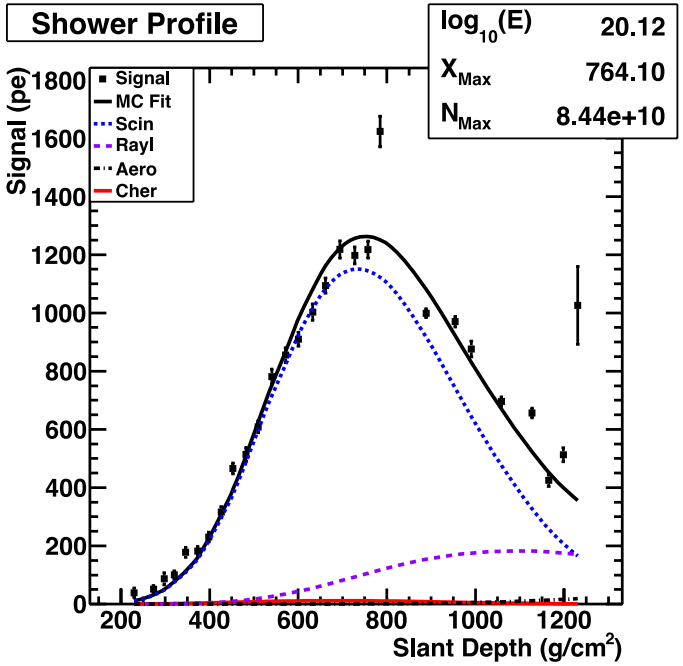


High Energy Hybrid Event









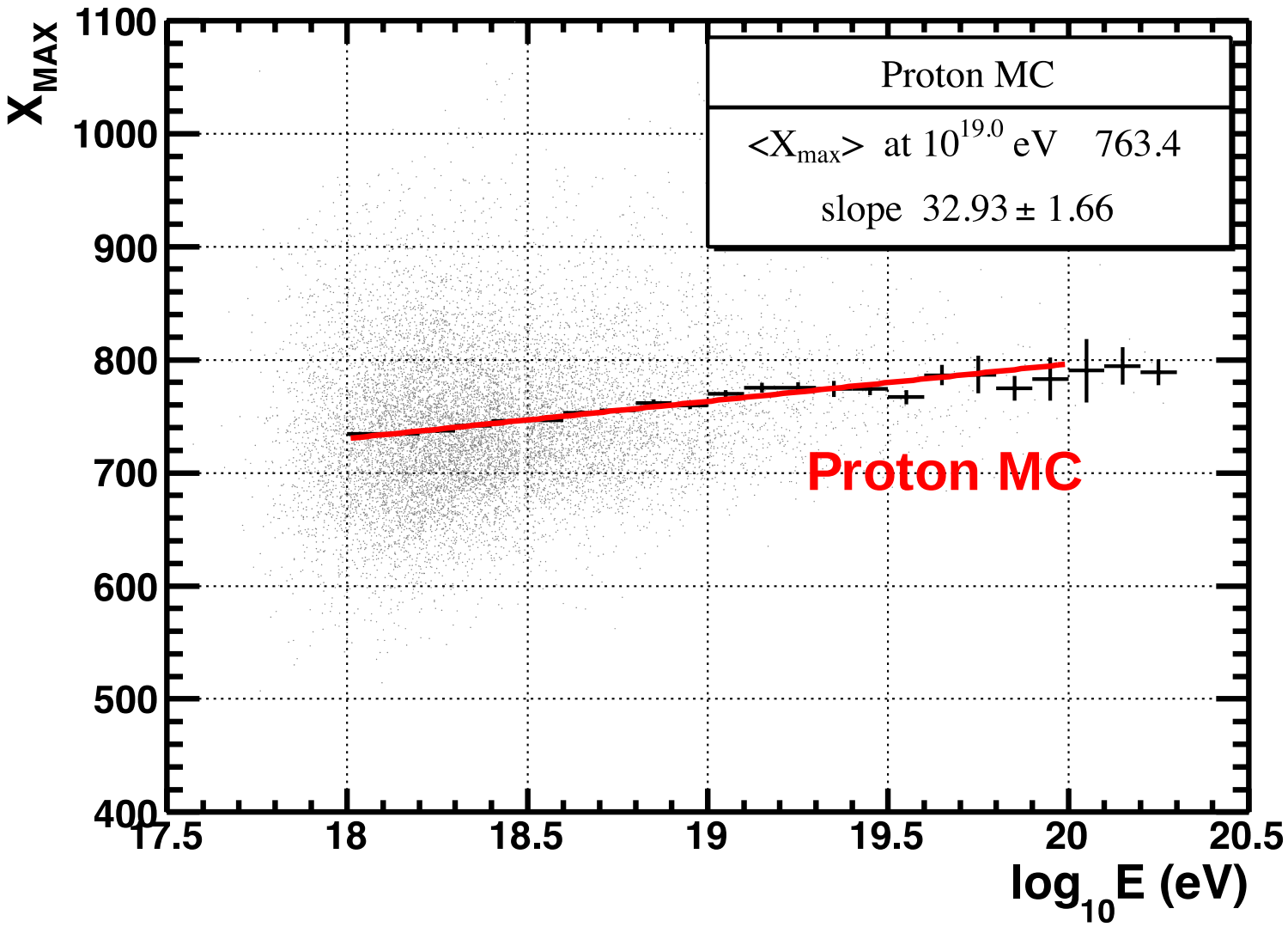
Energy: 1.282 10^{20} eV

Zenith Angle: 55.7°

Surface array constrains geometry fit via extra timing & core information

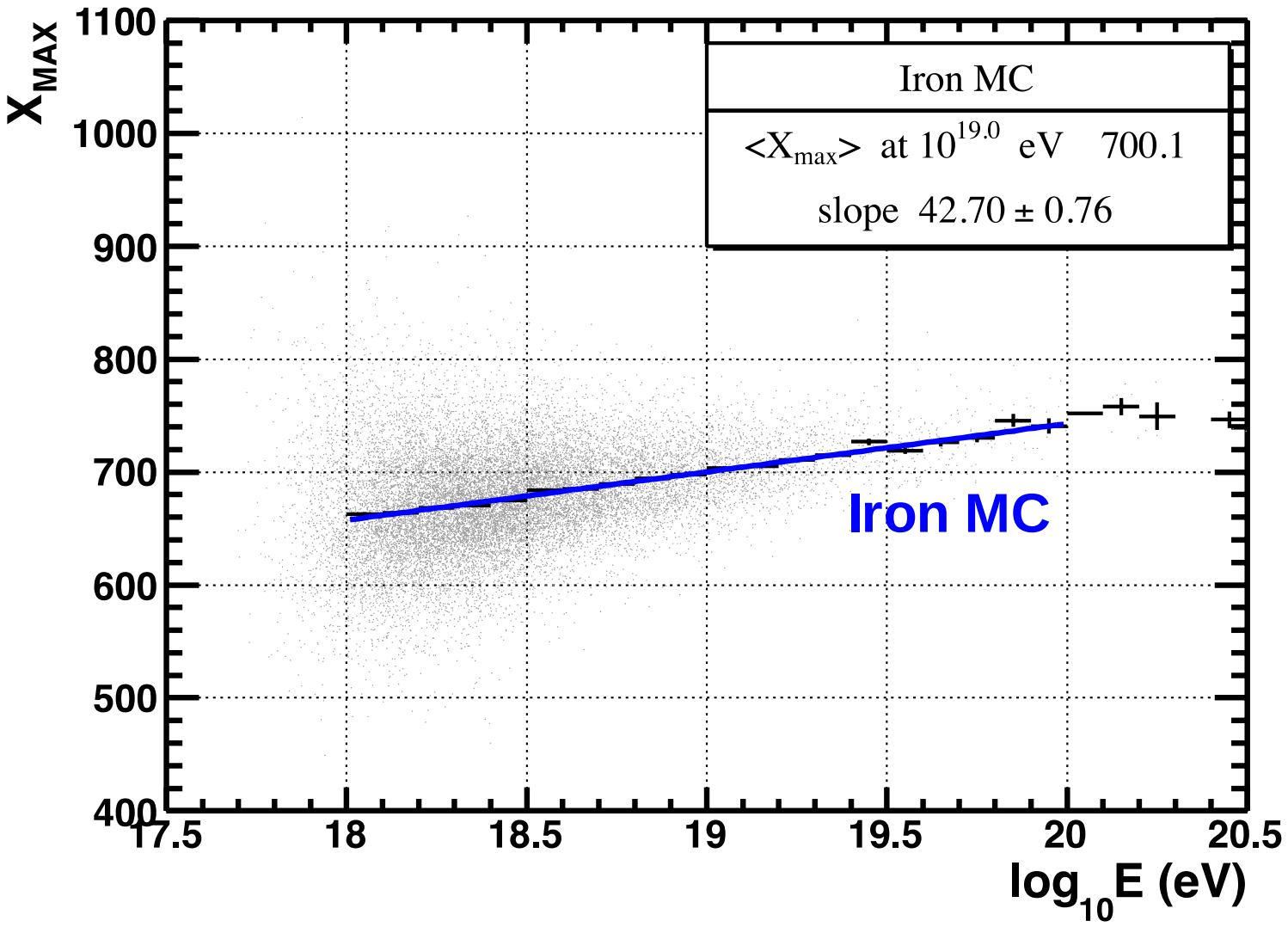
Proton MC $\langle X_{max} \rangle$ Vs. Log_{10}(Energy)

After Reconstruction and Event Selection

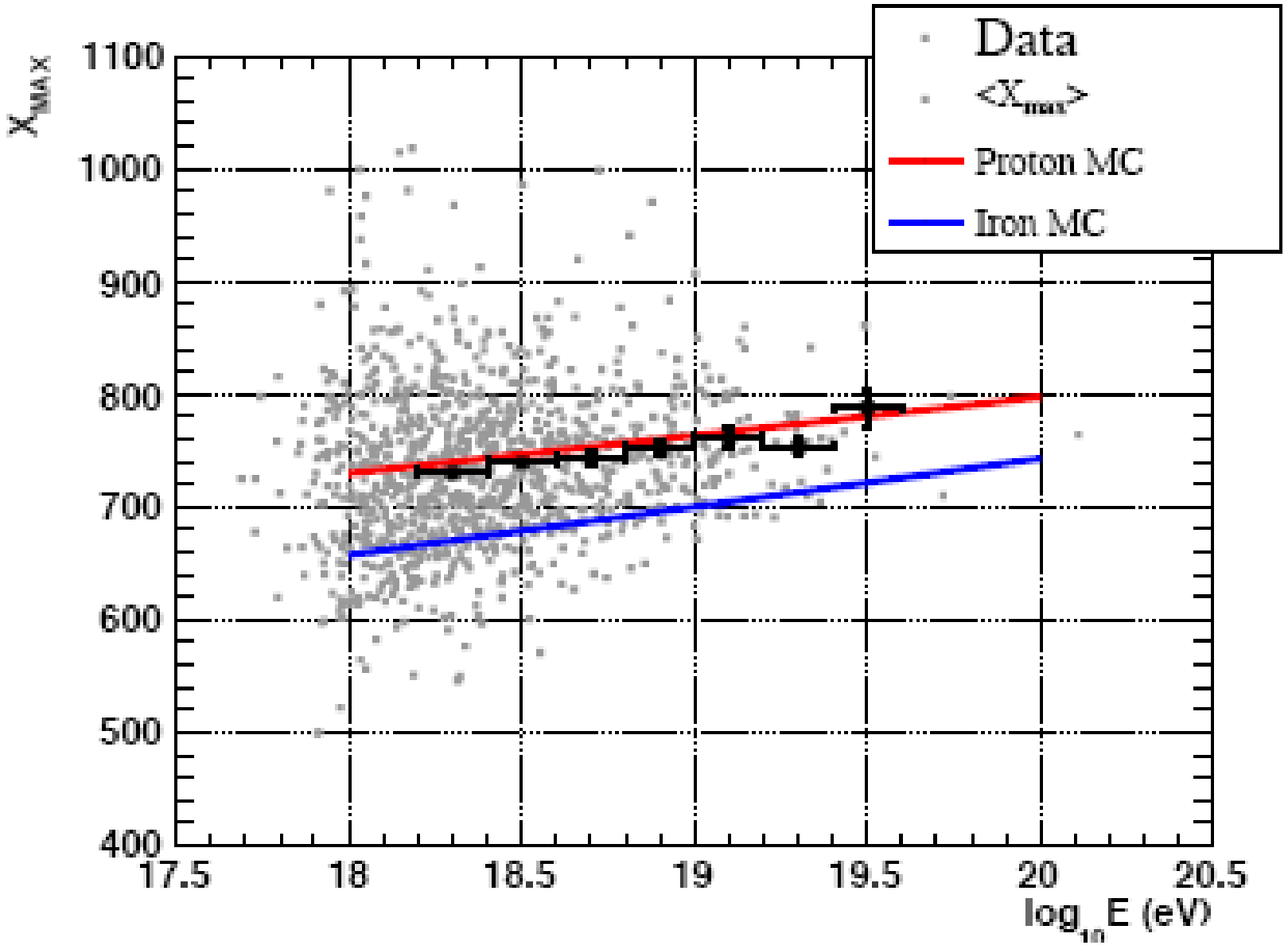


Iron MC $\langle X_{max} \rangle$ Vs. Log_{10}(Energy)

After Reconstruction and Event Selection

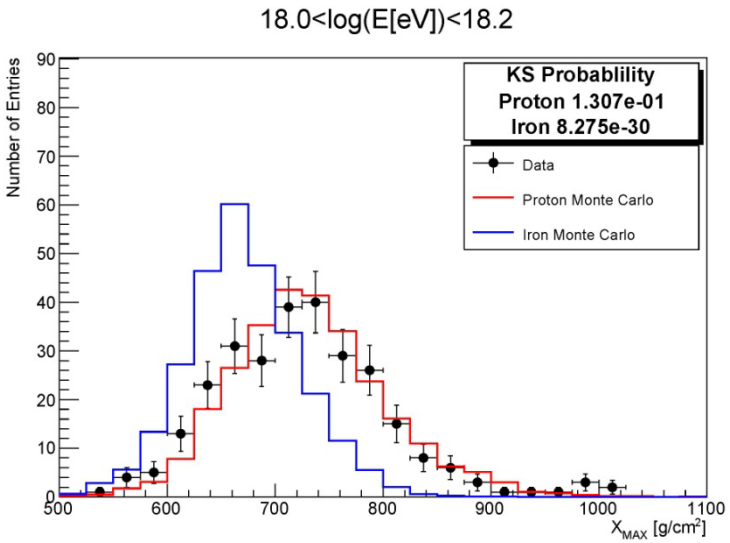


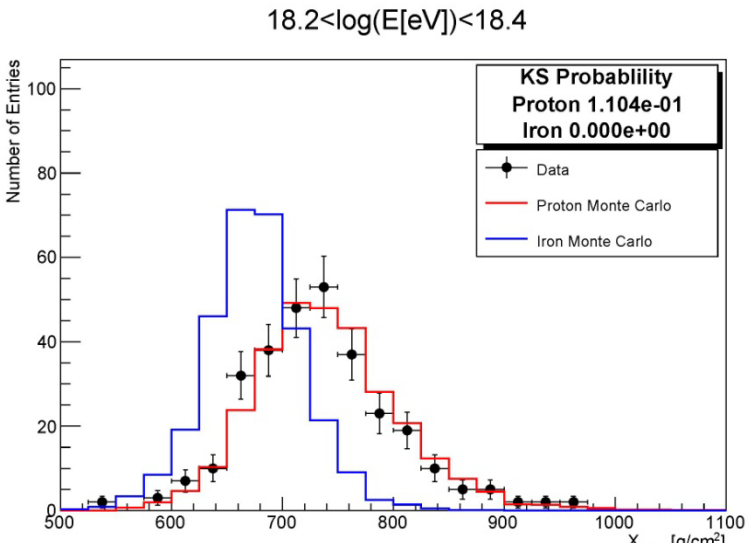
MD Hybrid Elongation (5 Yr Data)

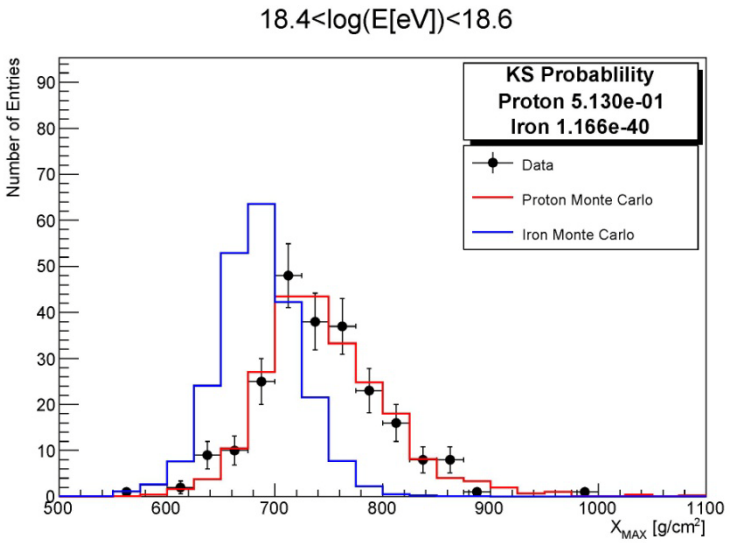


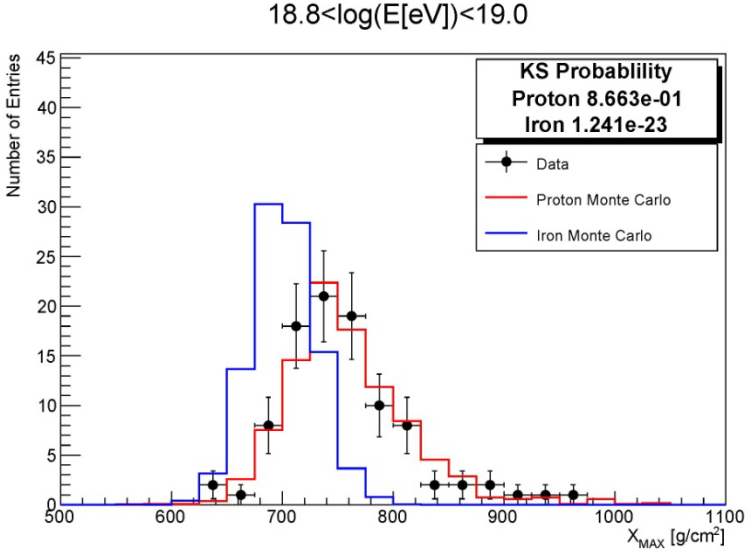
MD Hybrid 5 years data

Xmax in Energy Slices Comparison to p/Fe MC



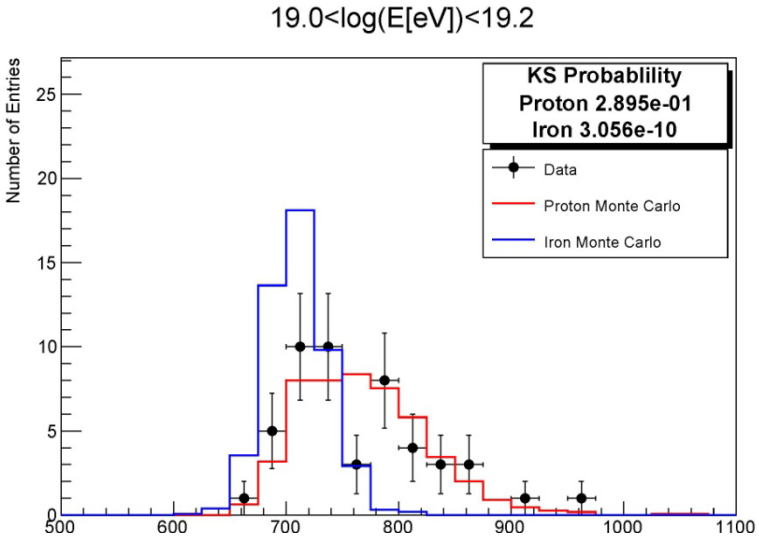


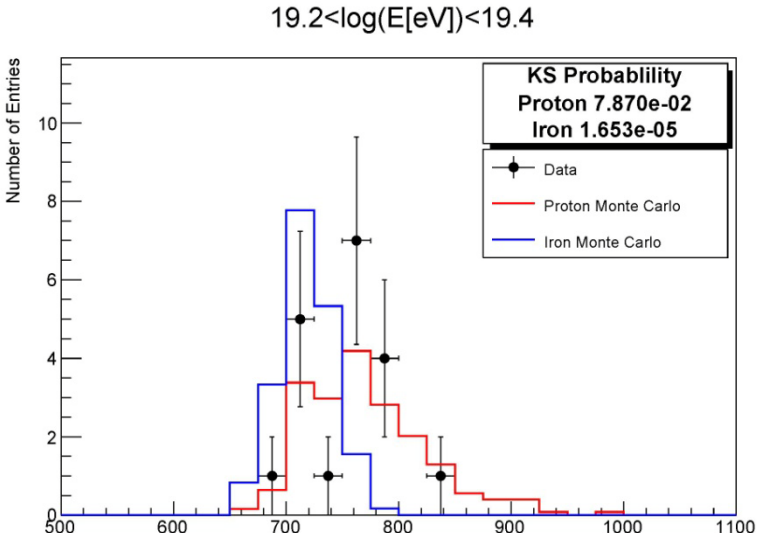


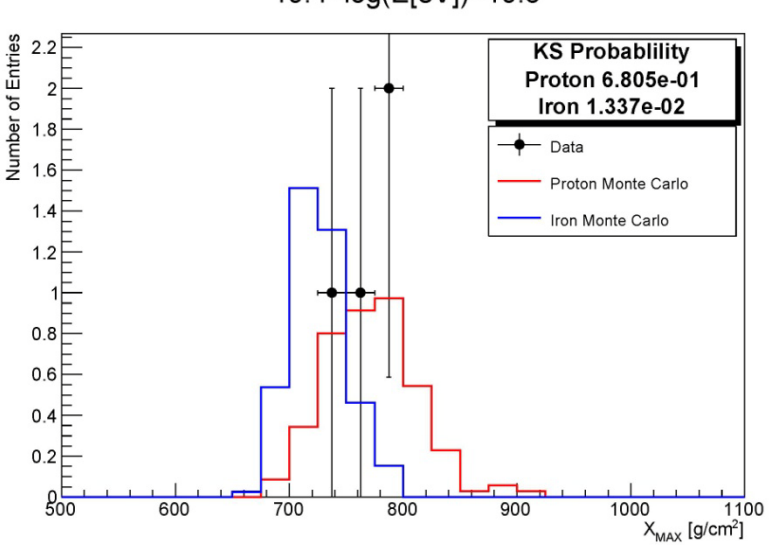


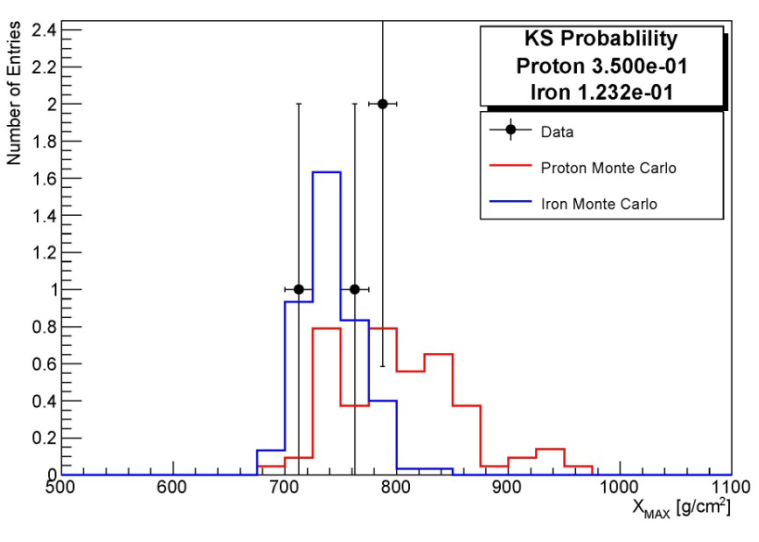
MD Hybrid 5 years data

Xmax in Energy Slices Comparison to p/Fe MC

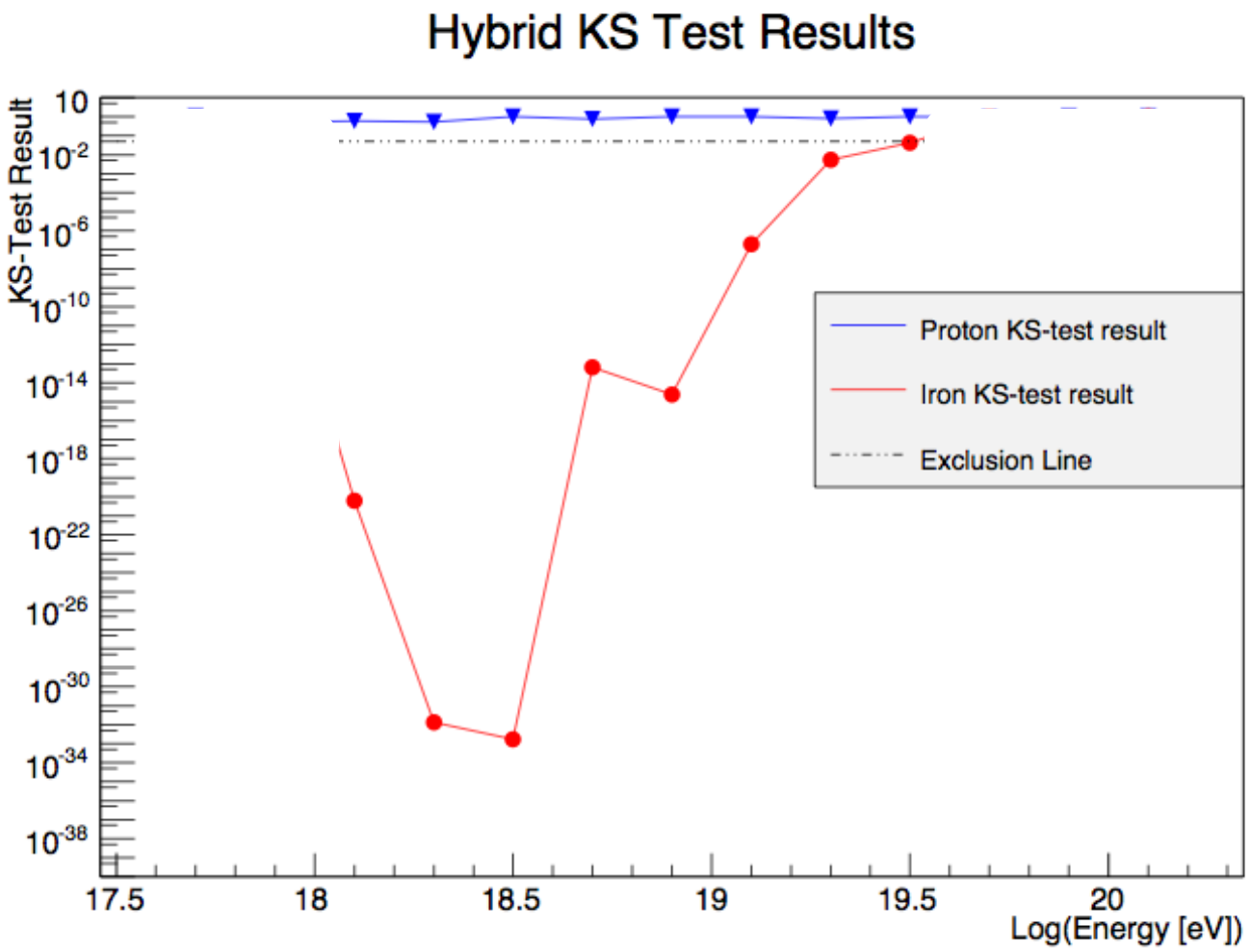






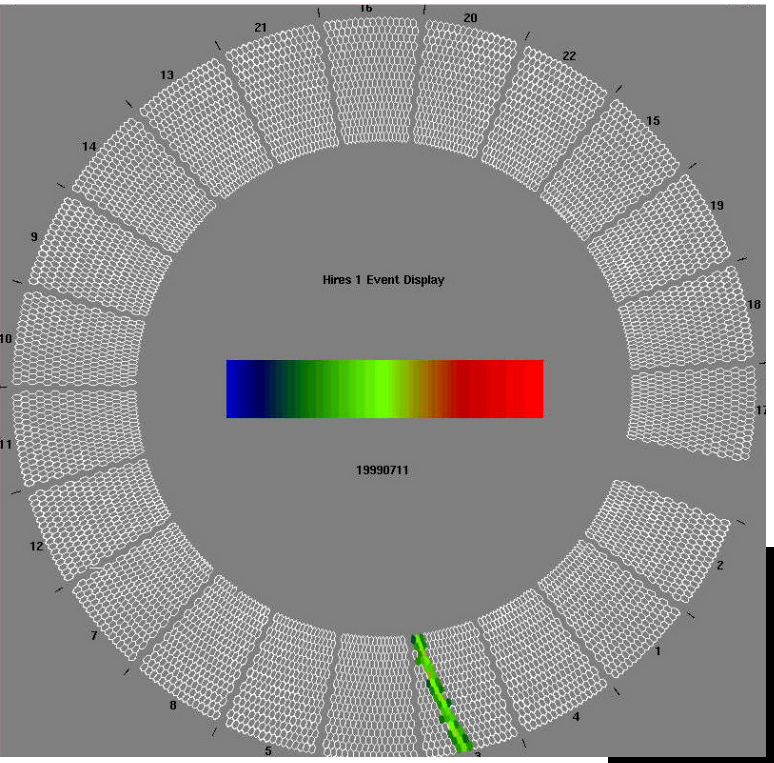


KS Test on 5 year Data

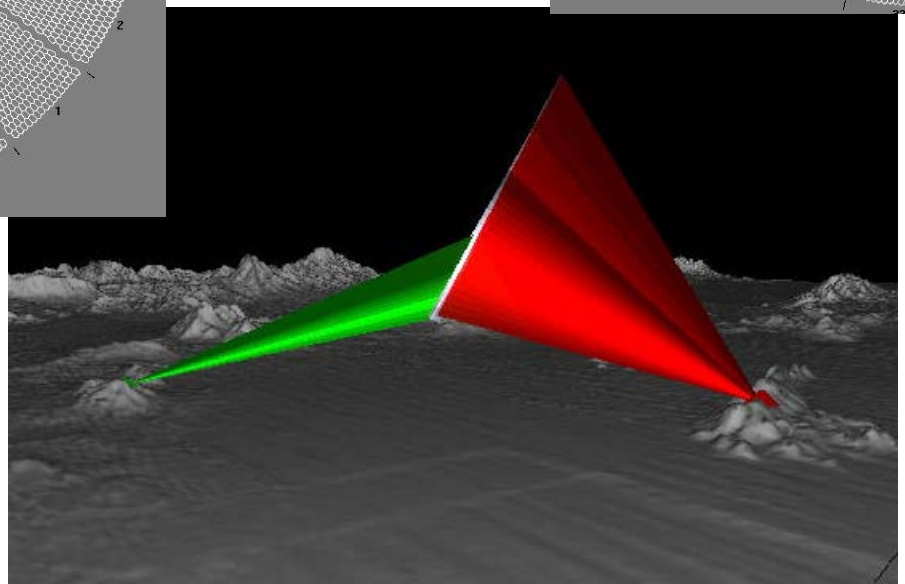


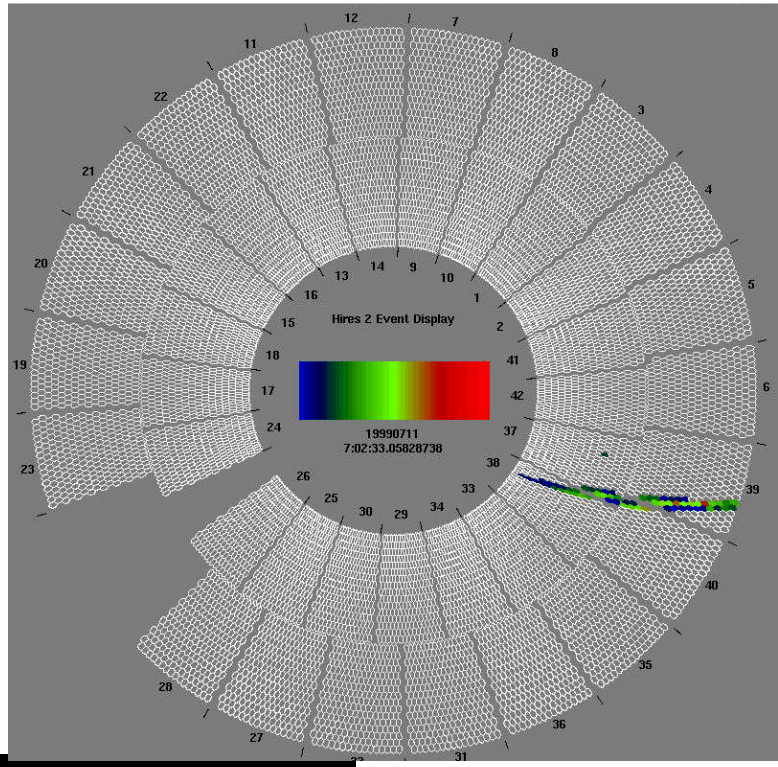
Stereo Events

Sample event from the High Resolution Fly's Eye (HiRes)



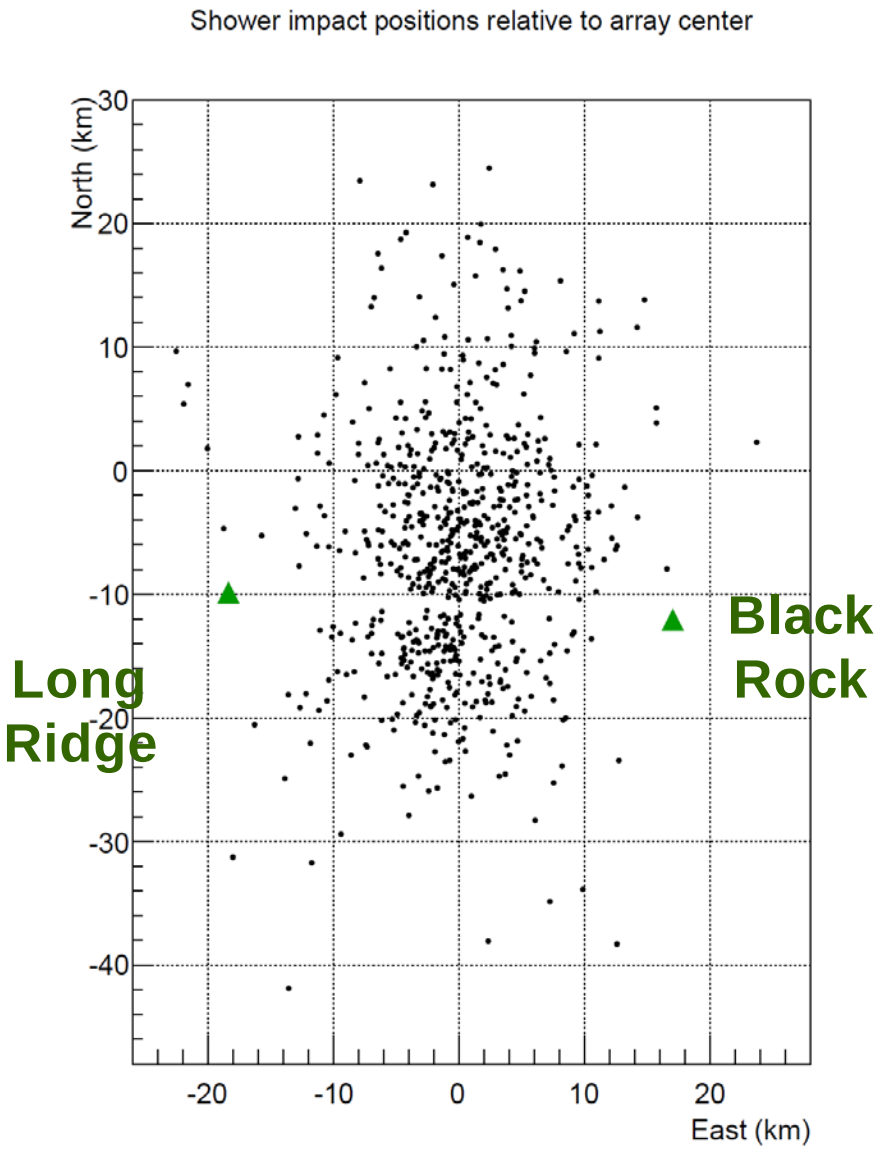
Site #1

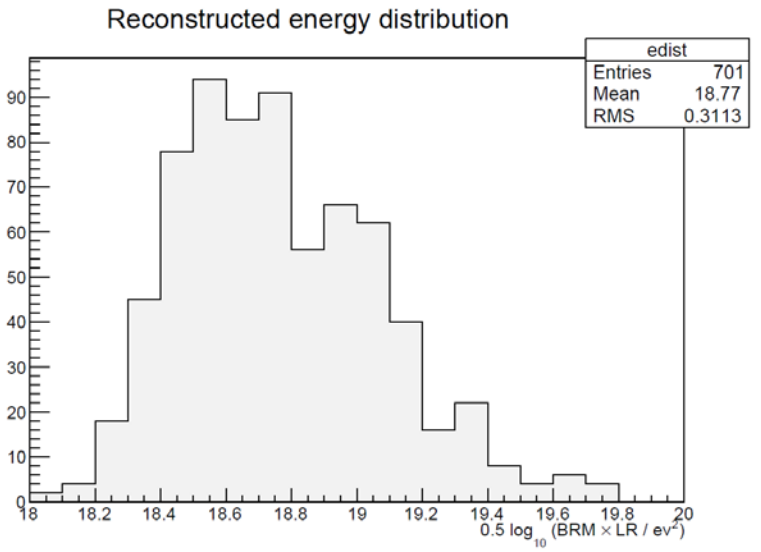


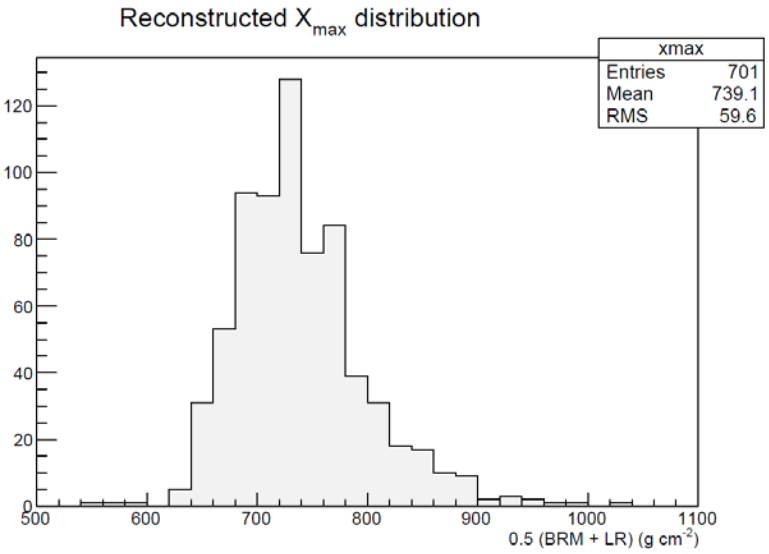


- Site #2

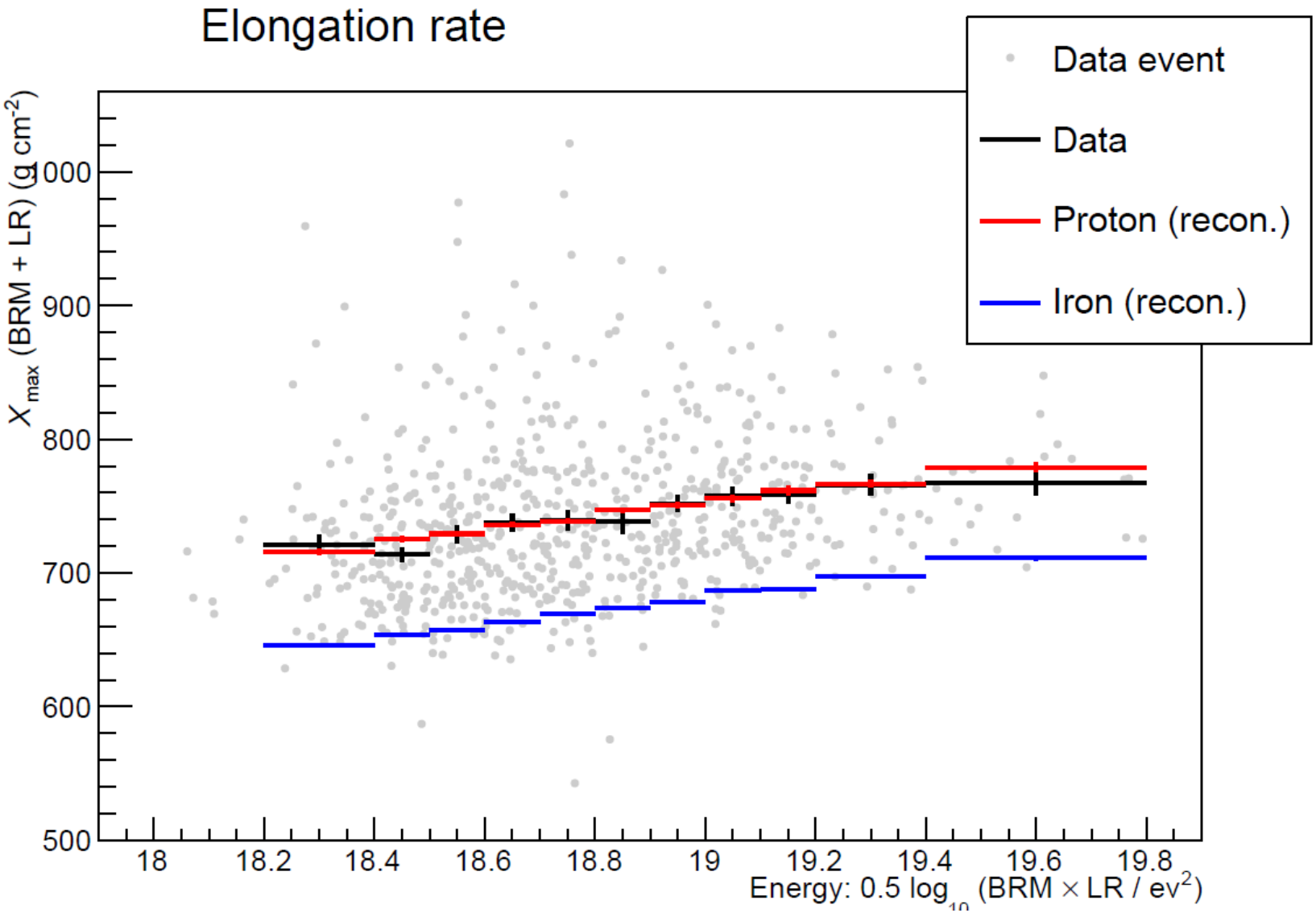
Composition via Stereo Data



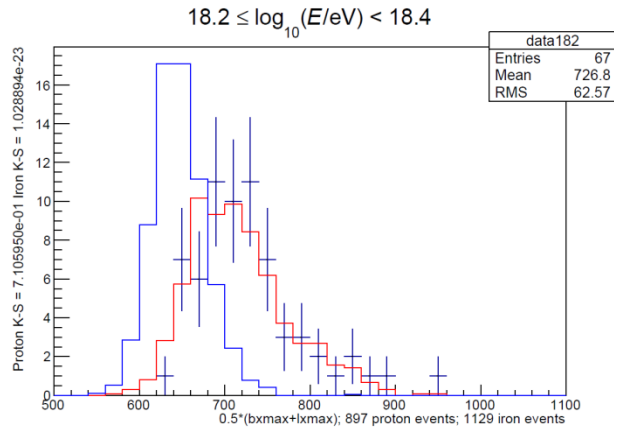


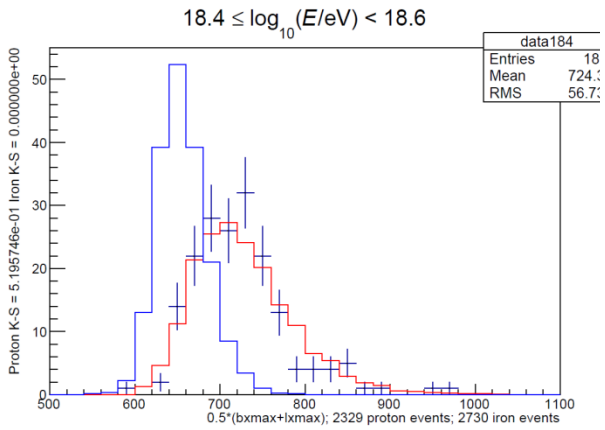


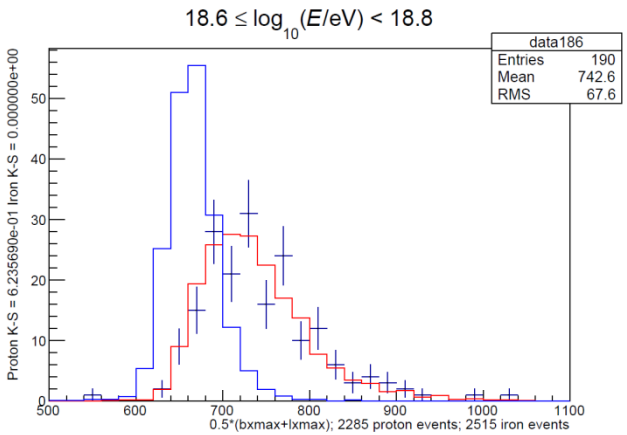
BR+LR Stereo Elongation

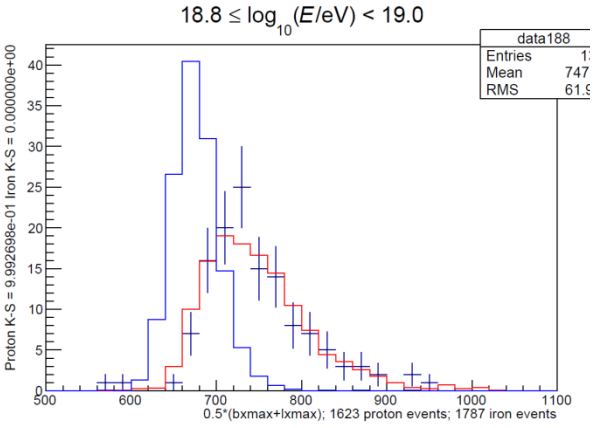


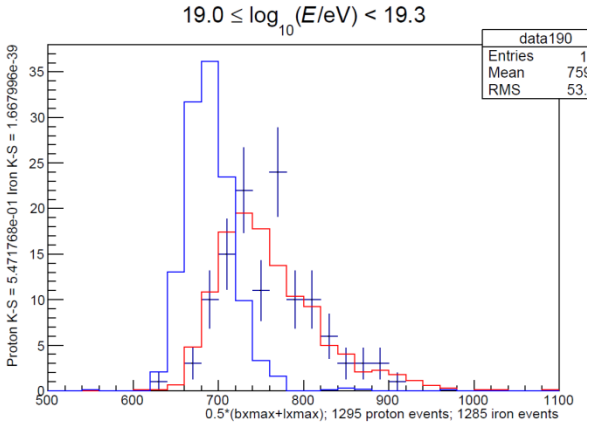
Stereo Composition by Energy Slices

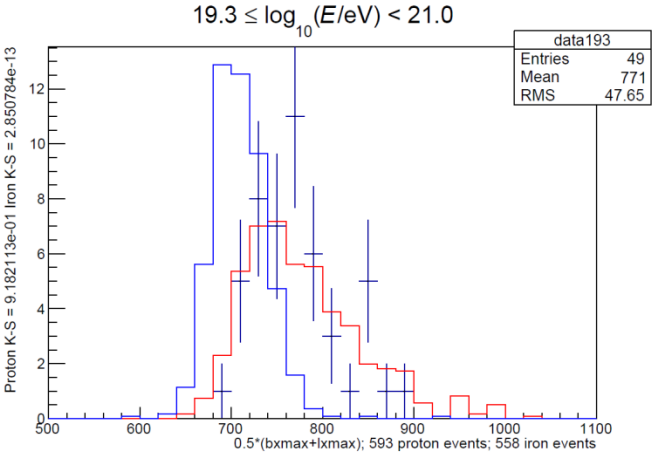




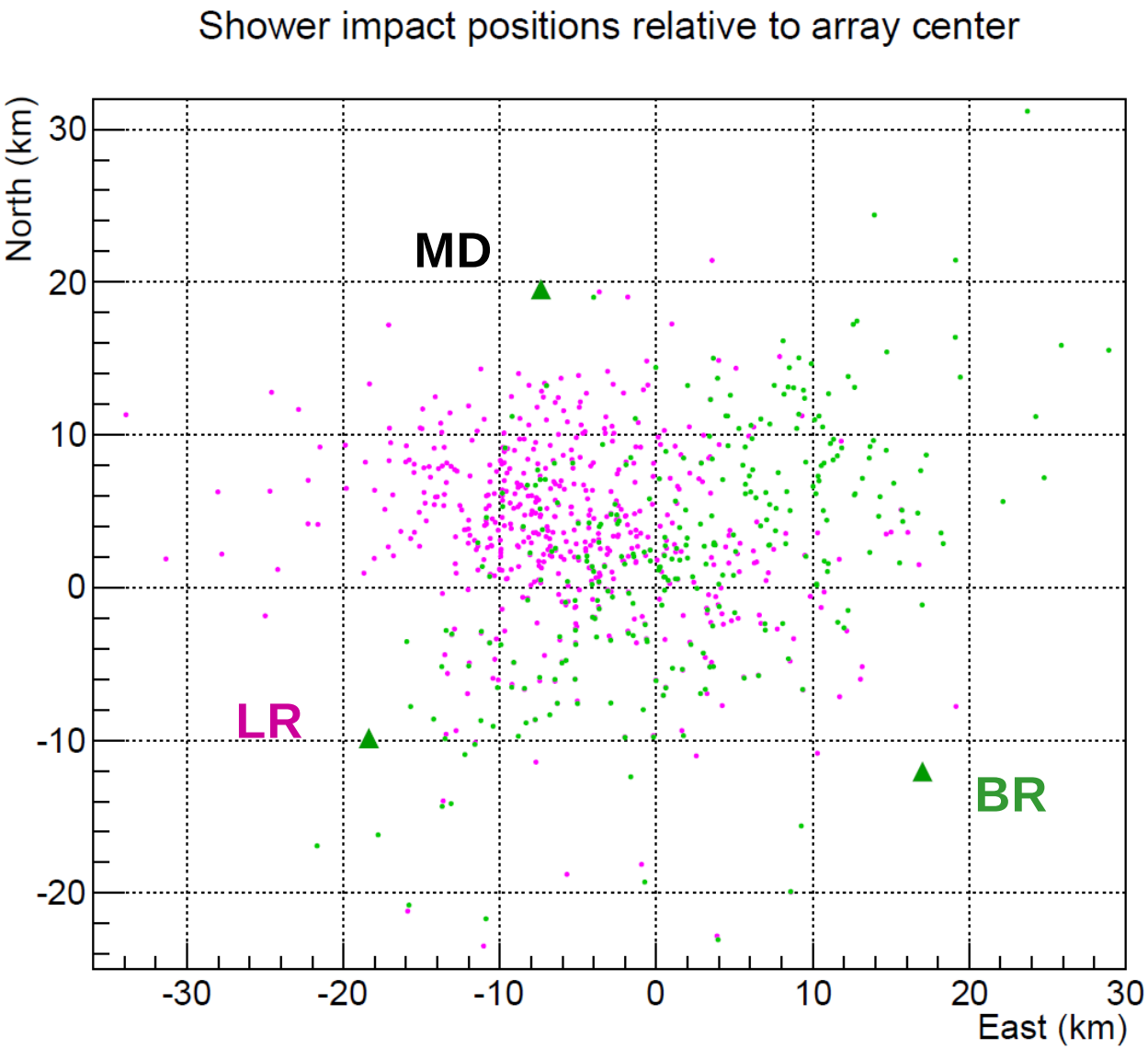






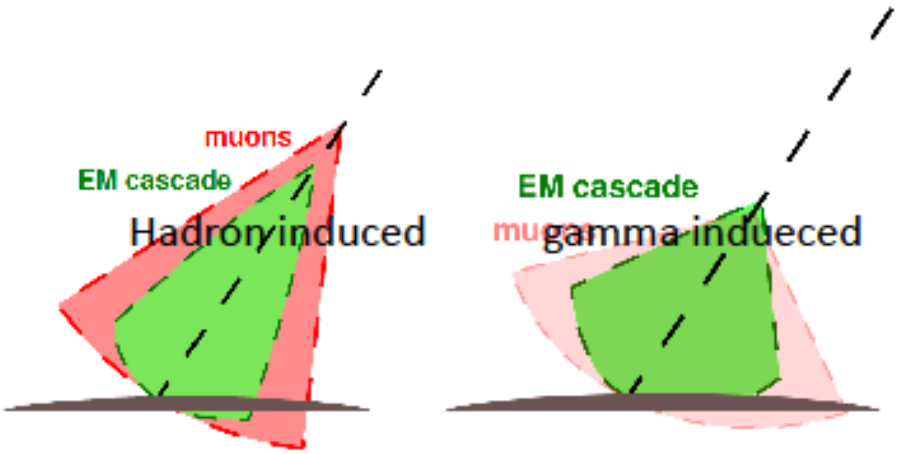


Middle Drum + BR/LR Stereo

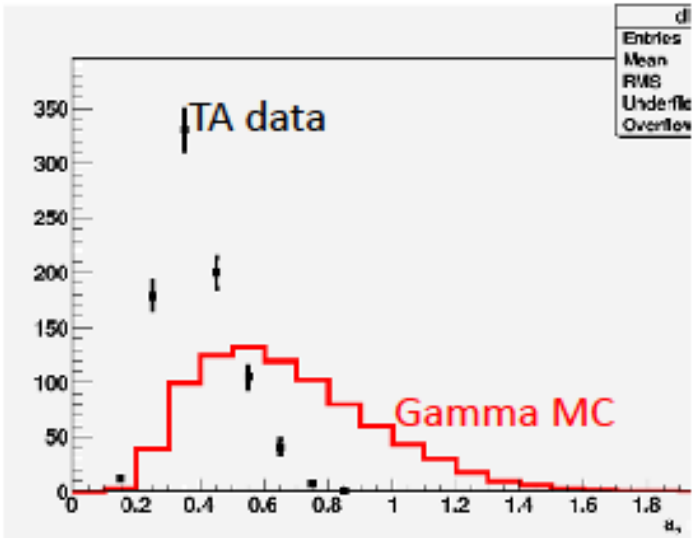


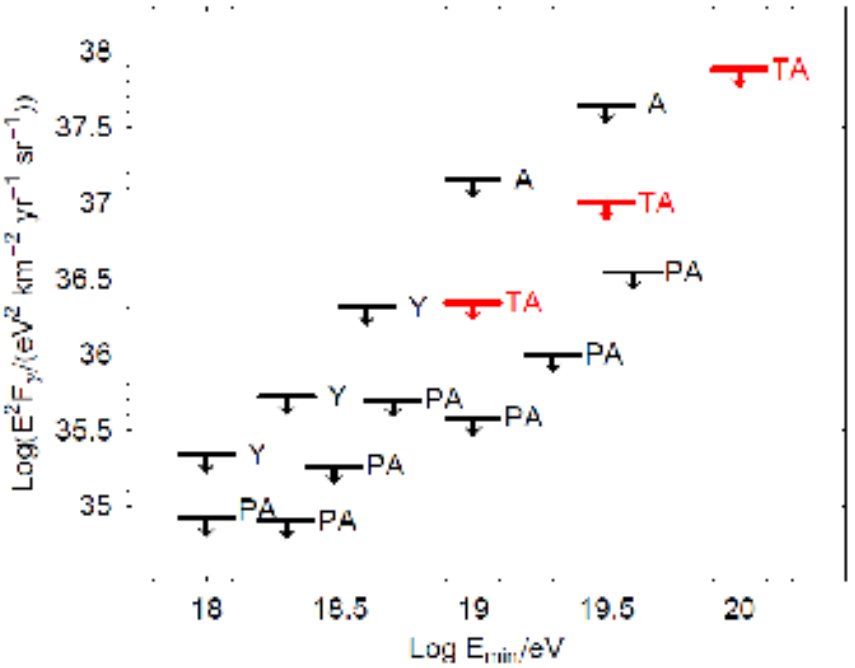
Photons and Neutrinos?

Photon search



$45^\circ < \theta < 60^\circ$

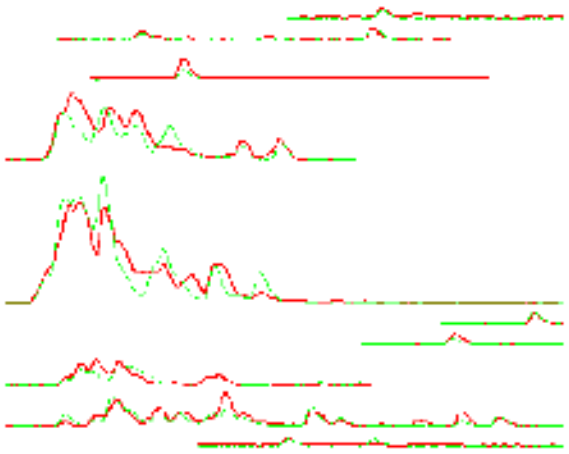




Neutrino search

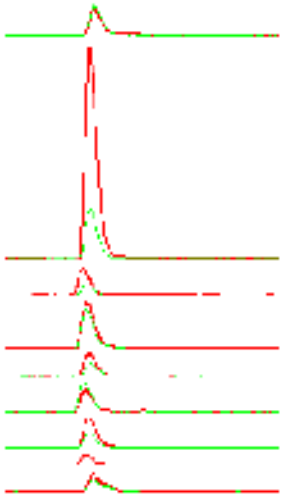
- Neutrino produces very inclined young shower

young shower, $\theta = 19.5°$

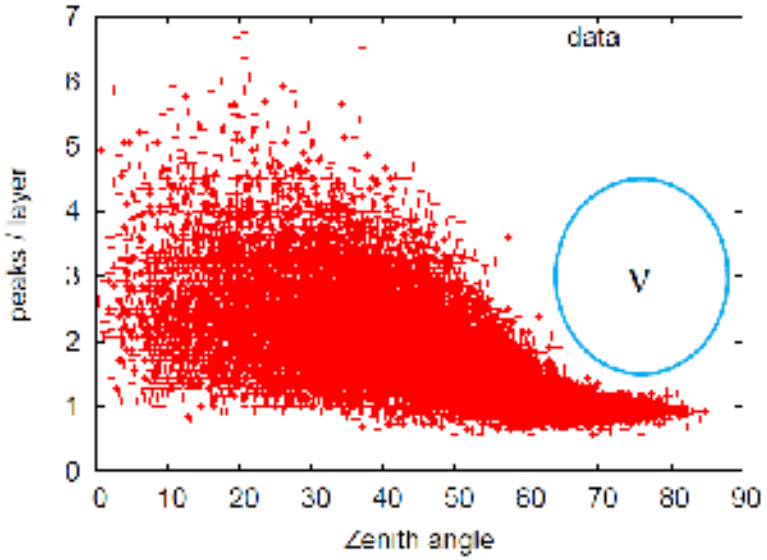


long, indented wafeforms

old shower, 78.3°



one peak

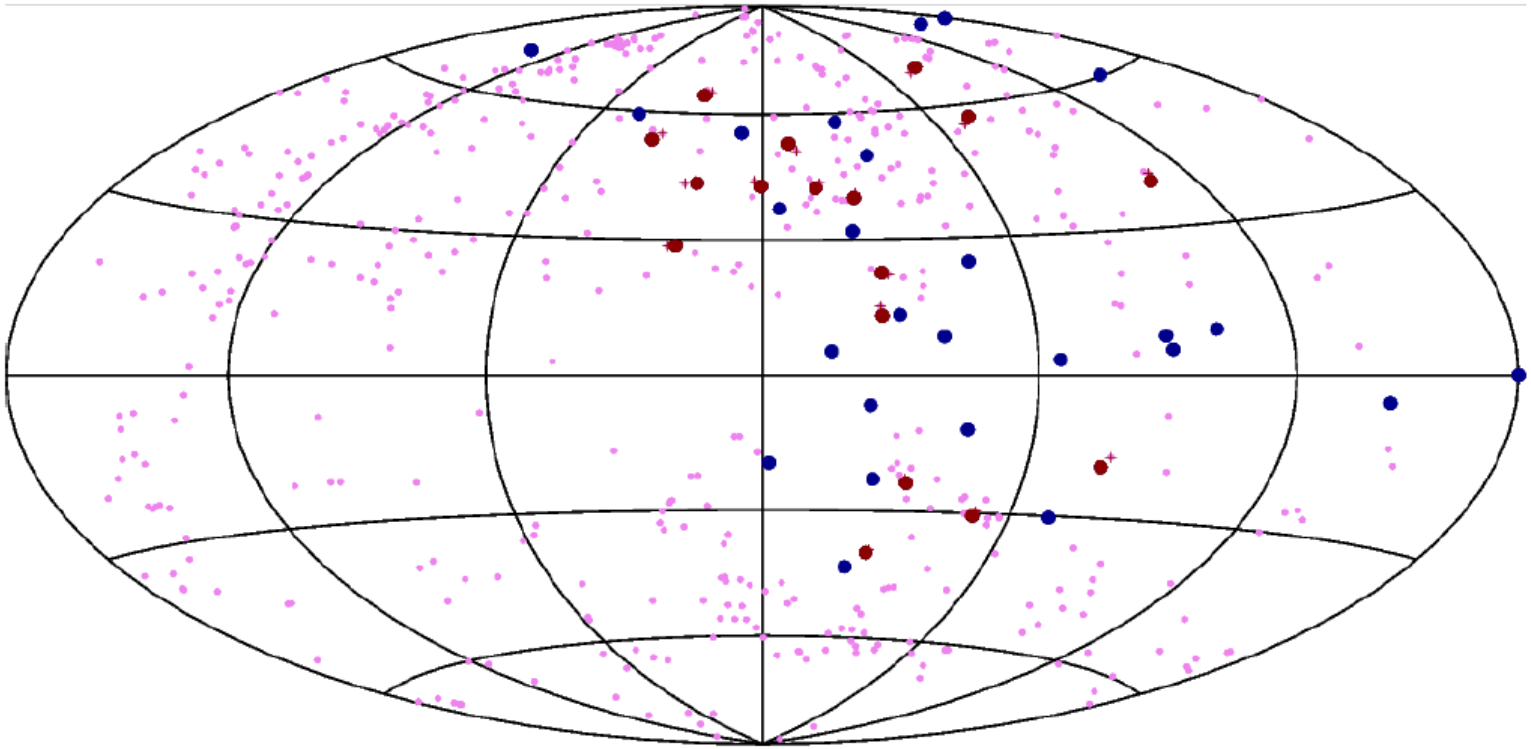


No young inclined showers in the dataset
→ no neutrino candidates.

Anisotropy/Sources?

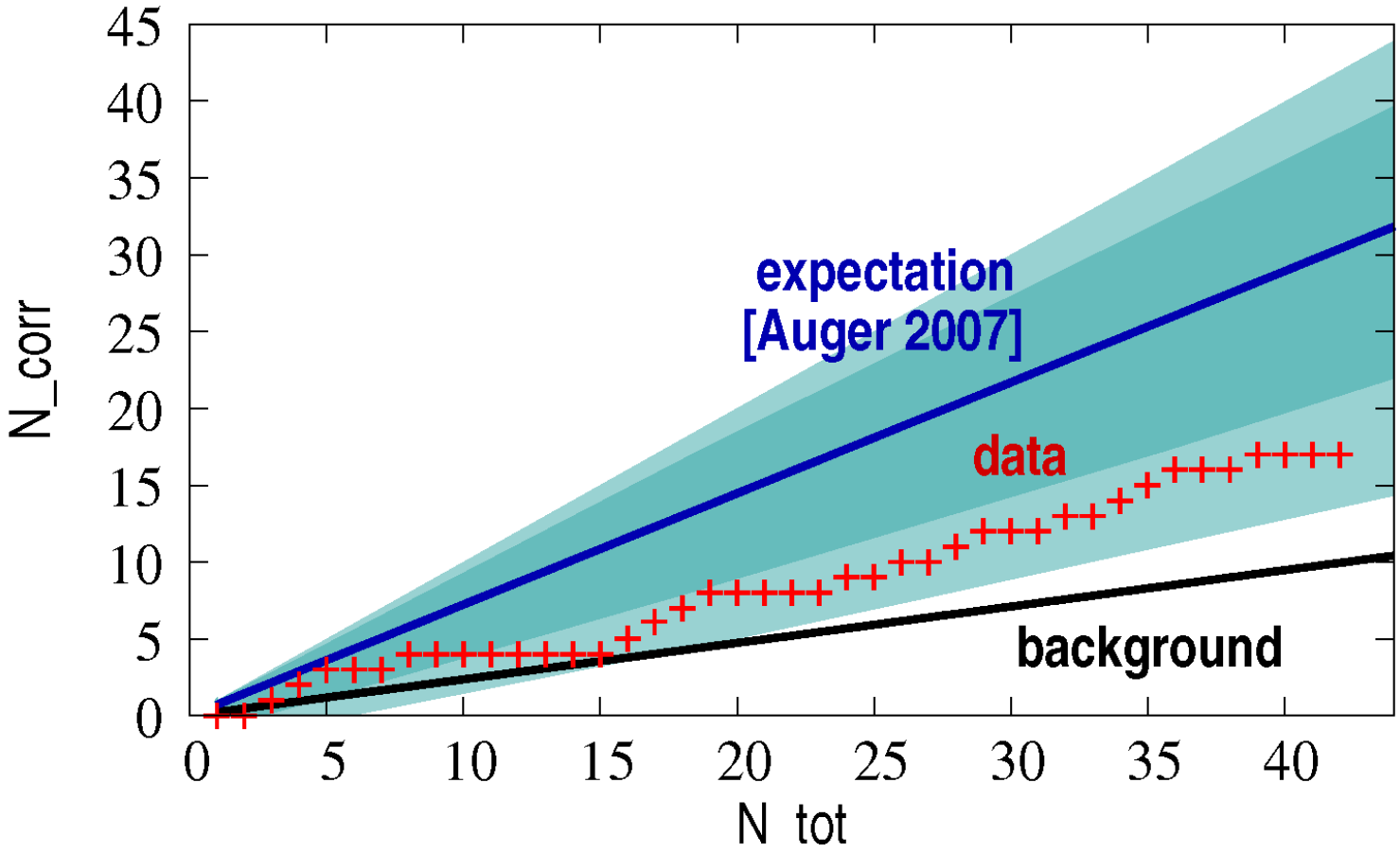
Correlations with AGNs

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

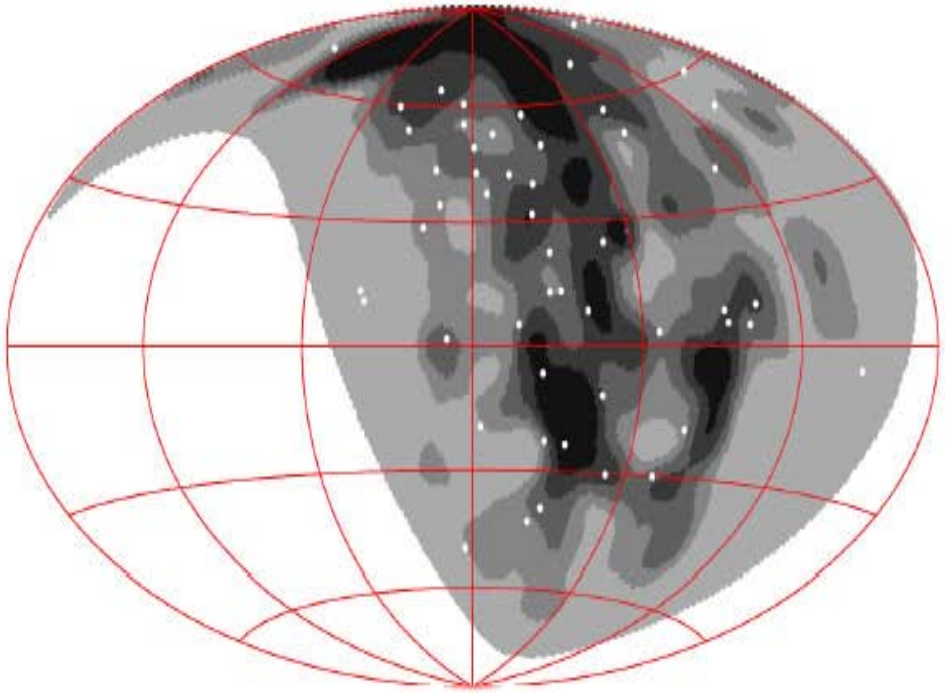


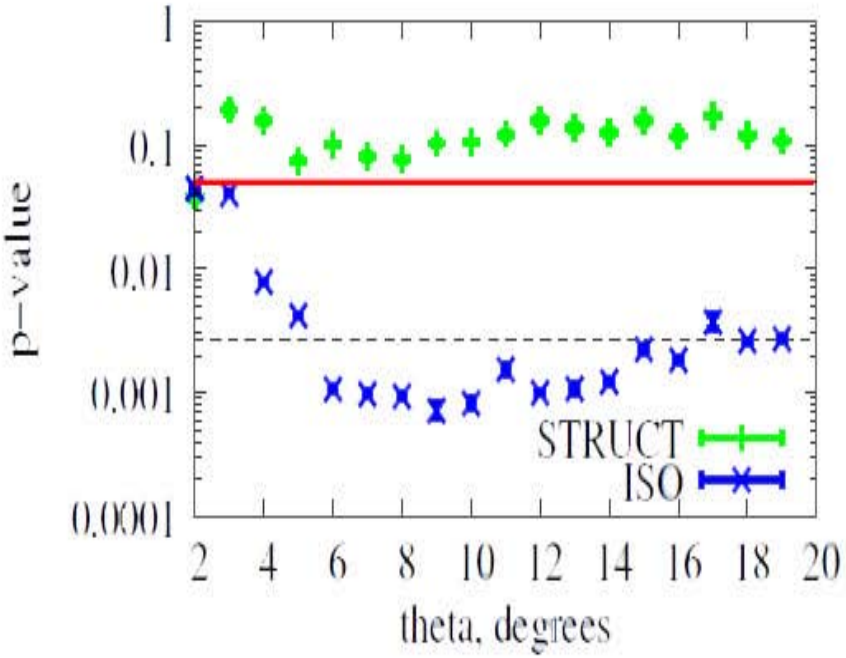
Correlations with AGNs

Probability of event overlapping with AGN is $p_o = 0.24$
Find 17 events correlate of 42 ⇨ $p = 0.014$



Correlation with Galactic Large Scale Structure (5 yr data)

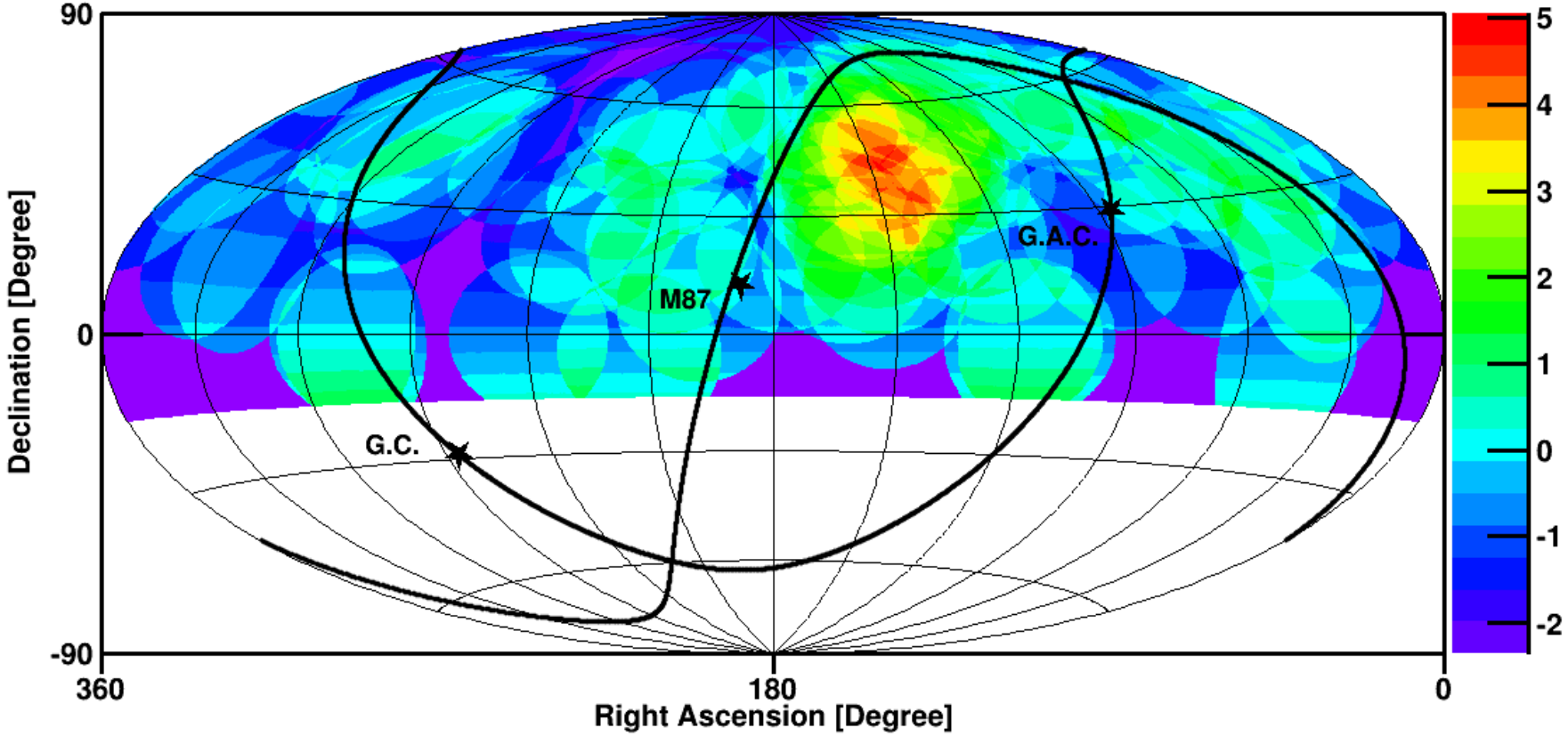




Flux map in galactic coordinates, from the LSS model with magnetic smearing angle of 6°, E>5.7×10^{19}eV.

LSS from 2MASS XSCz galaxy catalog

Hotspot

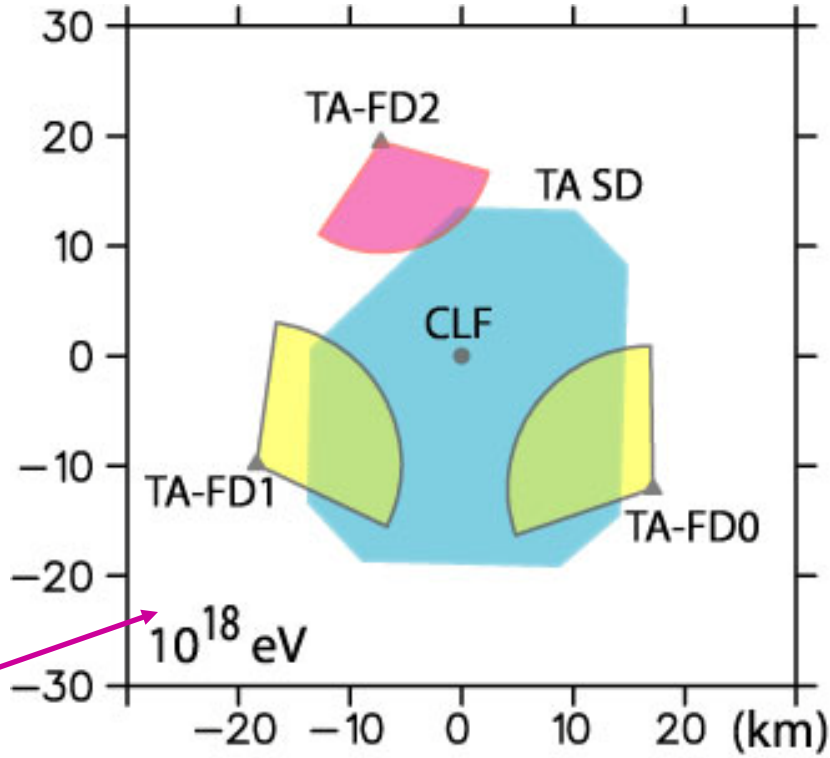


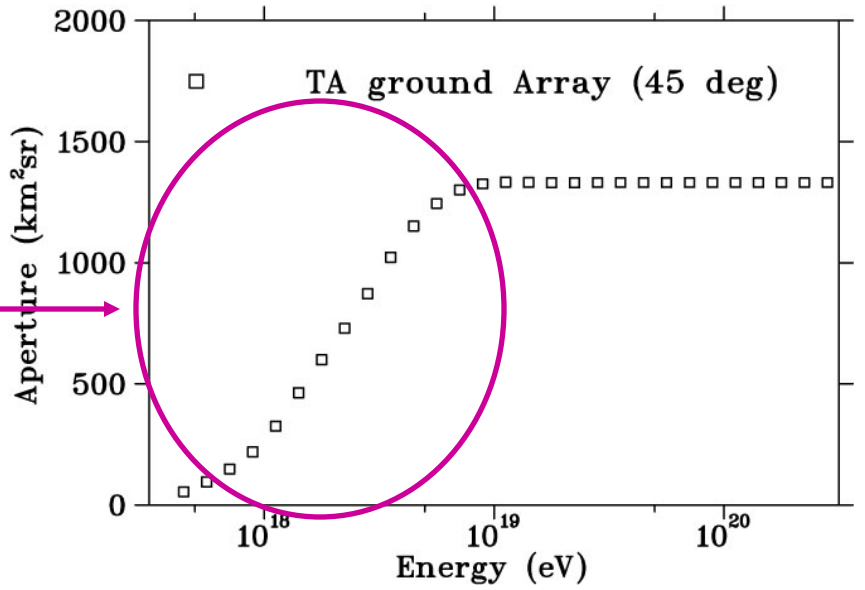
E>5.7x10^{19} eV (72 events)
Events over-sampled using 20^{o} circles
19/72 events fall in hotspot (4.5 events expected)
Estimate 3.4σ significance (RA,dec) ~ (145 ,40)
Aitoff projection in Equatorial Coordinates

New….

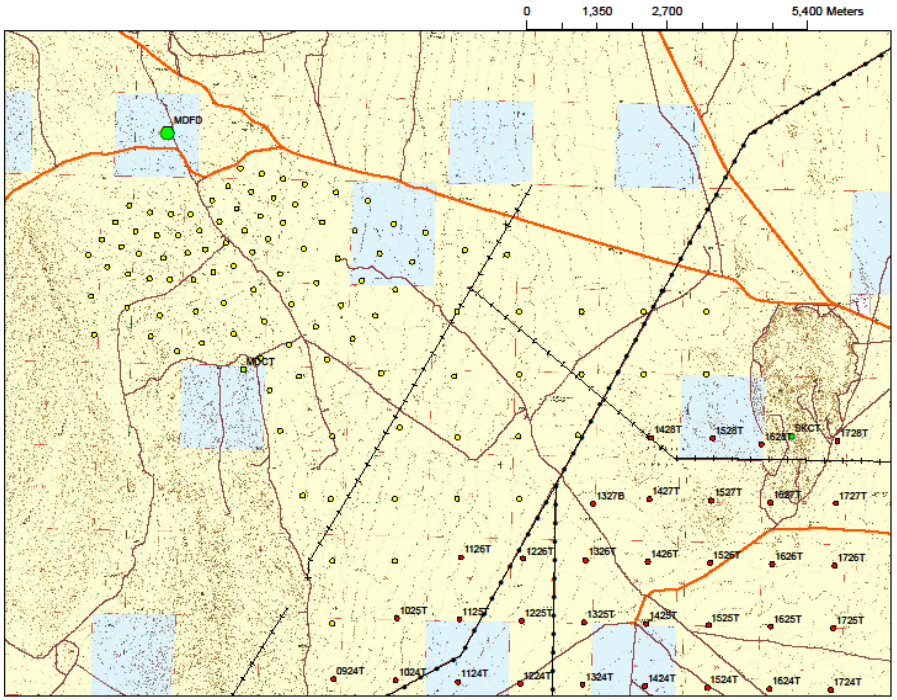
Below 10^{19} eV

- However, Stage-1 of TA was not designed for physics below 10^{19} eV
- There is no overlap at all in the aperture of the three fluorescence detectors at 10^{18} eV
- The ground array efficiency drops quickly in the 10^{18}-10^{19} eV decade





TALE: TA Low Energy Extension

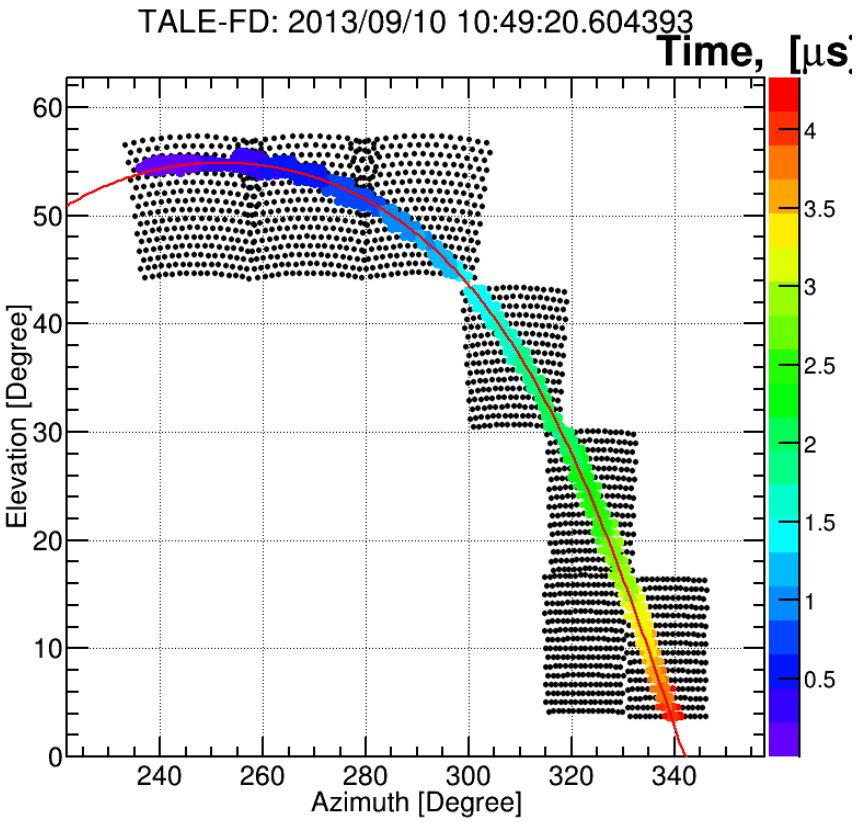


Infill array of more densely packed surface detectors (lower energy threshold)

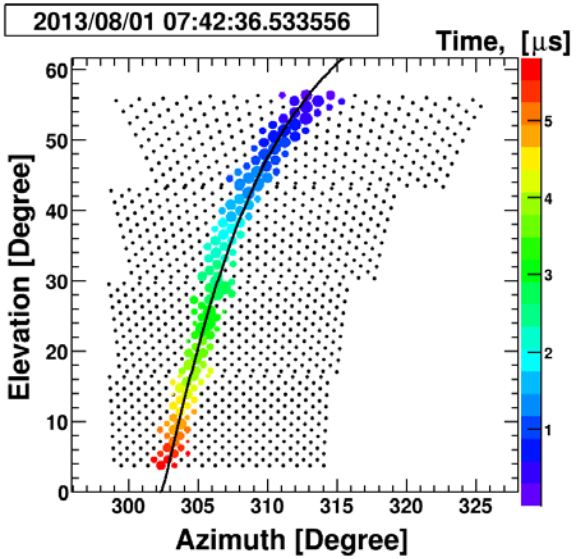
New telescopes to look higher in the sky (31-59^{o}) to see shower development

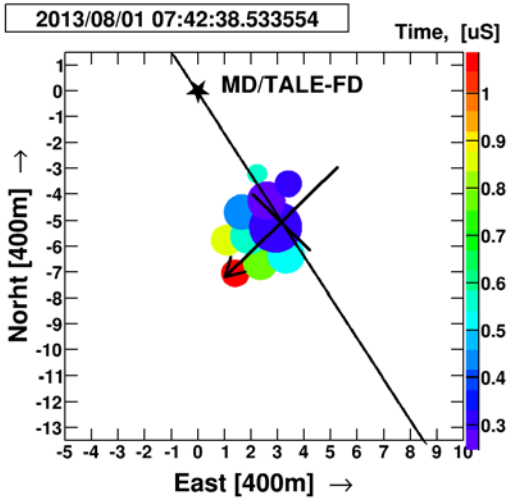
- ✓ Civil Construction Done
- ✓ All 10 Telescopes installed
- ✓ First 35 scintillators detectors deployed
- ✓ Commissioning of detectors is underway

TALE Events



$E = 10^{16.5}$ eV





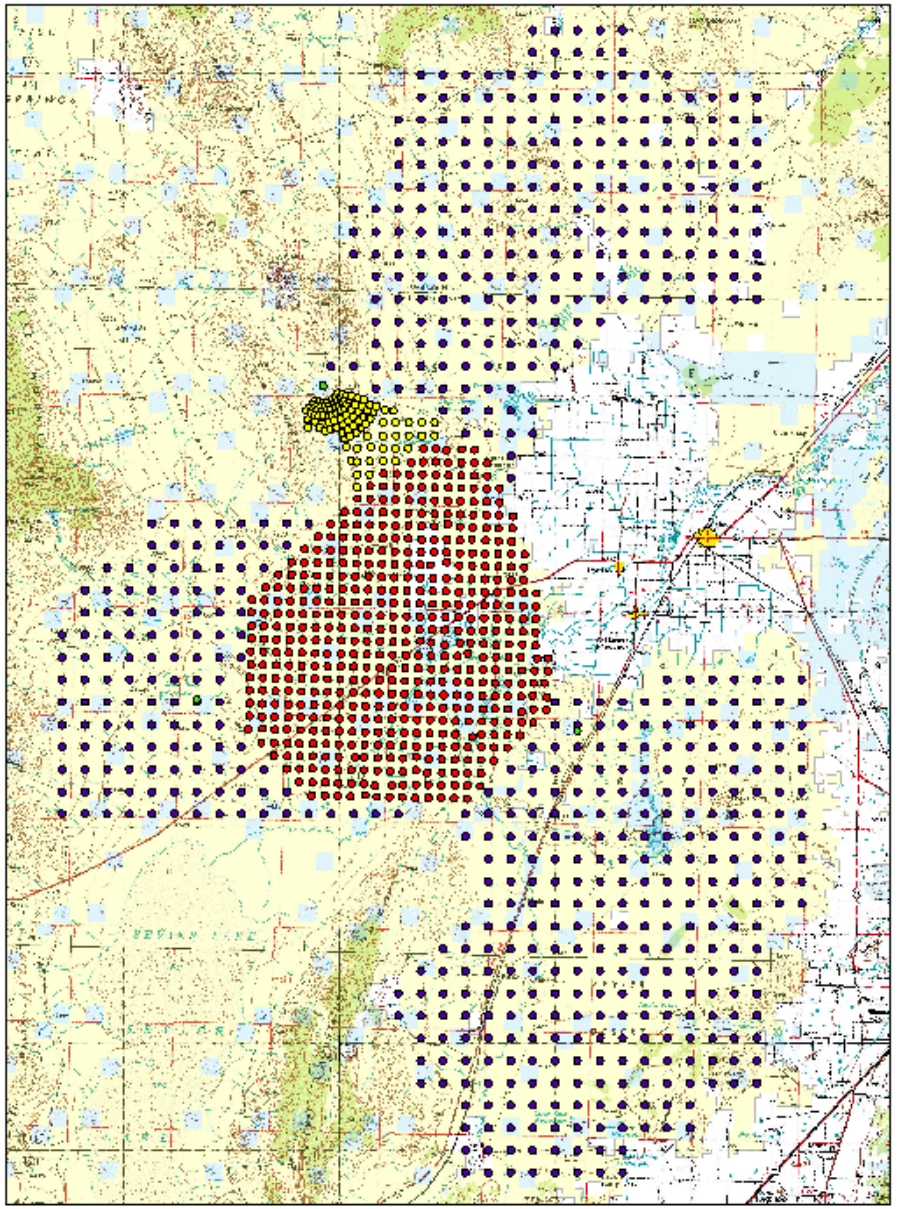
Hybrid event

Next: TAx4

Proposing to expand Telescope Array by a factor of 4 (3000 sq km)

Answers to anisotropy questions much more quickly

Add
- 500 new scintillator detectors (2.08 km spacing)
-new telescope station (14 telescopes)



Conclusions

- The Telescope Array (TA) Experiment is a large experiment carefully controlling systematic uncertainties
- It has picked up where HiRes left off, collecting UHE cosmic ray data in the northern hemisphere
- Multiple analyses of various data sets are ongoing:
  - FD mono, Stereo, SD mono, Hybrid, Hybrid-Stereo
- Ankle and GZK suppression (HiRes) are confirmed
- Composition is constant and light in this energy range
- No signs of photons, neutrinos
- Anisotropy may not be too far off…. (LSS & hotspot)
- TALE – the Low Energy Extension to TA is extending the reach of TA down to ~3×10^{16}eV to study the galactic to extra-galactic transition
- TAx4 proposed