HIRES AND TA SPECTRUM MEASUREMENTS

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HiRes

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Columbia University

J.F. Amman, M.D. Cooper, C.M. Hoffman, M.H. Holzscheiter, C.A. Painter, J.S. Sarracino, G. Sinnis, T.N. Thompson, D. Tupa

Los Alamos National Laboratory

J. Belz, M. Kirn

University of Montana

J.A.J. Matthews, M. Roberts

University of New Mexico

D.R. Bergman, G. Hughes, D. Ivanov, S.R. Schnetzer, L. Scott, B.T. Stokes, S. Stratton, G.B. Thomson, A. Zech

Rutgers University

N. Manago, M. Sasaki

University of Tokyo

R.U. Abbasi, T. Abu-Zayyad, G. Archbold, K. Belov, J. Belz, D.R. Bergman, A. Blake, Z. Cao, W. Deng, W. Hanlon, P. Huentemeyer, C.C.H. Jui, E.C. Loh, K. Martens,J.N. Matthews, D. Rodriguez, J. Smith, P. Sokolsky, R.W. Springer, B.T. Stokes, J.R. Thomas, S.B. Thomas, G.B. Thomson, L. Wiencke

University of Utah

HiRes

- HiRes was a stereo fluorescence detector, operated from 1997-2006 on Dugway Proving Grounds in Utah
- Observe the air-showers created by CR's by collecting fluorescence light

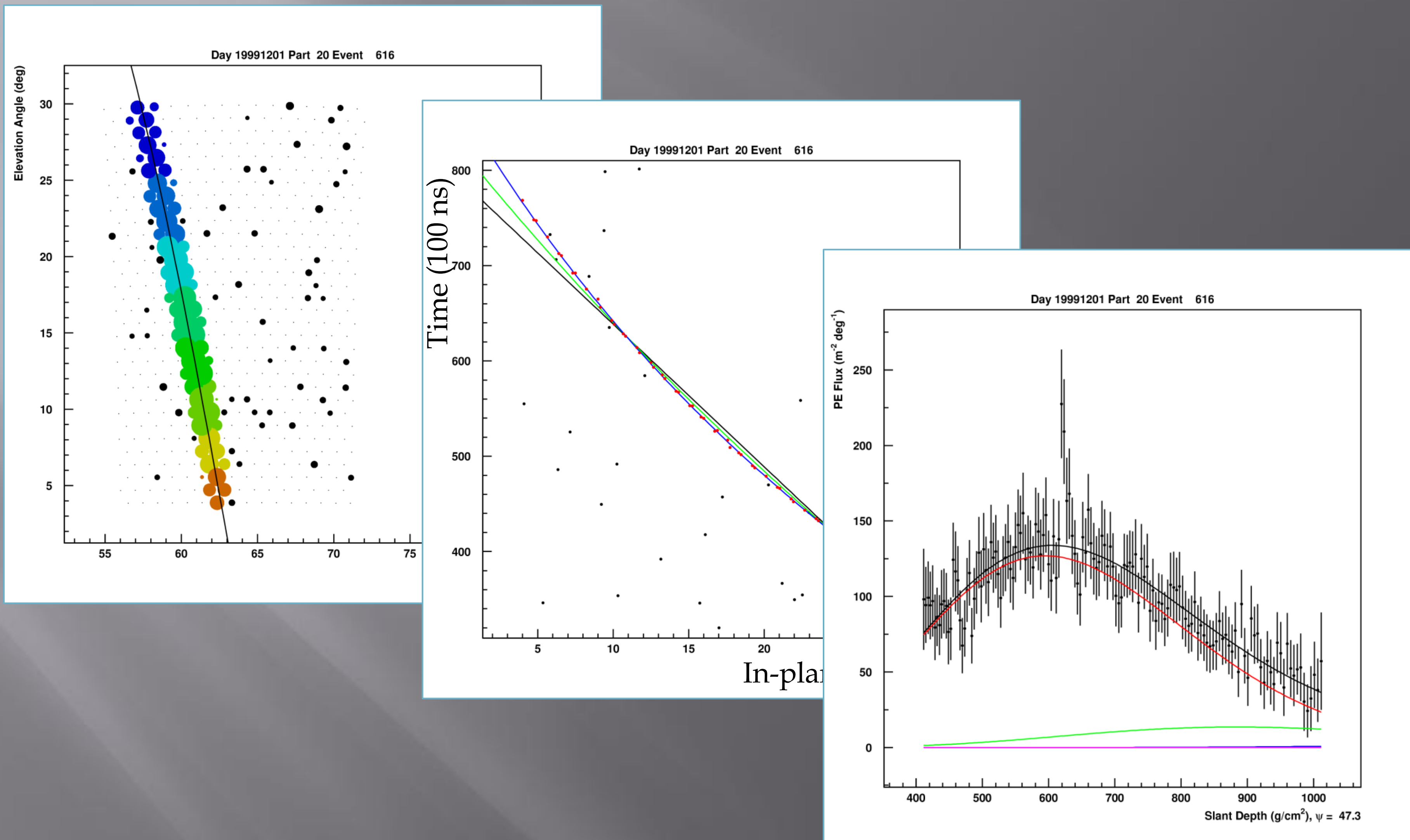
HiRes

- Light collected by 5 m^2 mirrors onto an array of 256 (16×16) of PMT's
- Each PMT sees 1° cone
- Each PMT records time and amount of light seen

HiRes

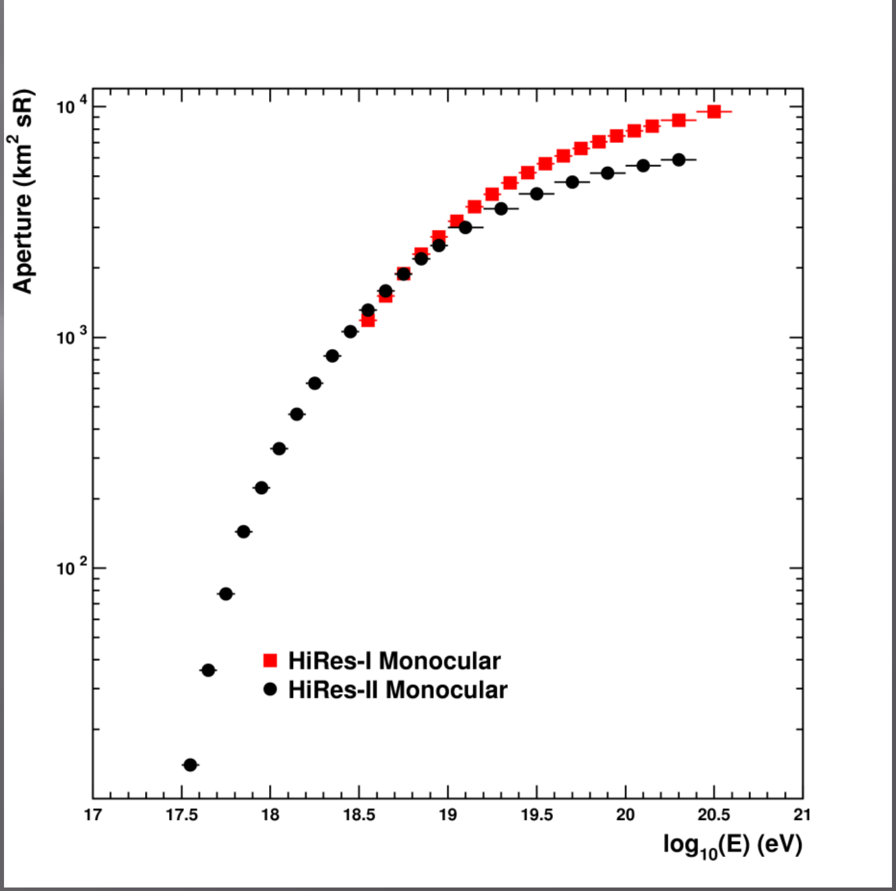

Dugway
HiRes-I
HiRes-II
20 km
© 2012 Google
Image © 2012 TerraMetrics
Google earth
40°11'45.80" N 112°52'12.34" W elev 1373 m
Eye alt 66.35 km

HiRes Monocular Analysis



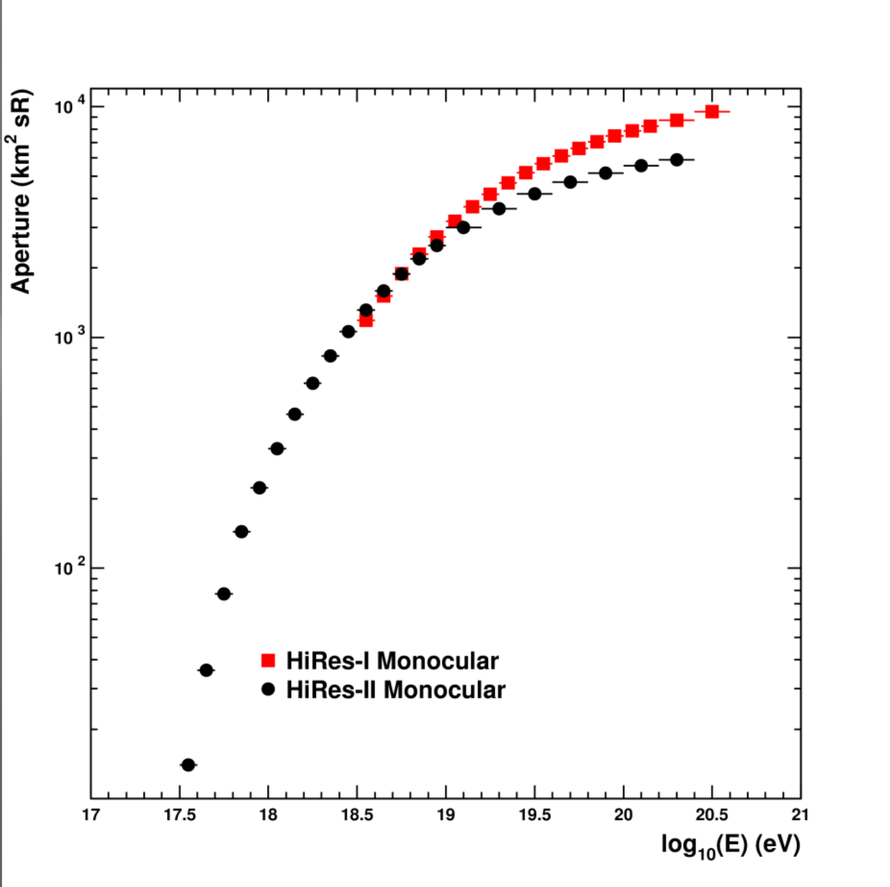
HiRes Monocular Spectrum

- Aperture
  - The aperture varies with energy…



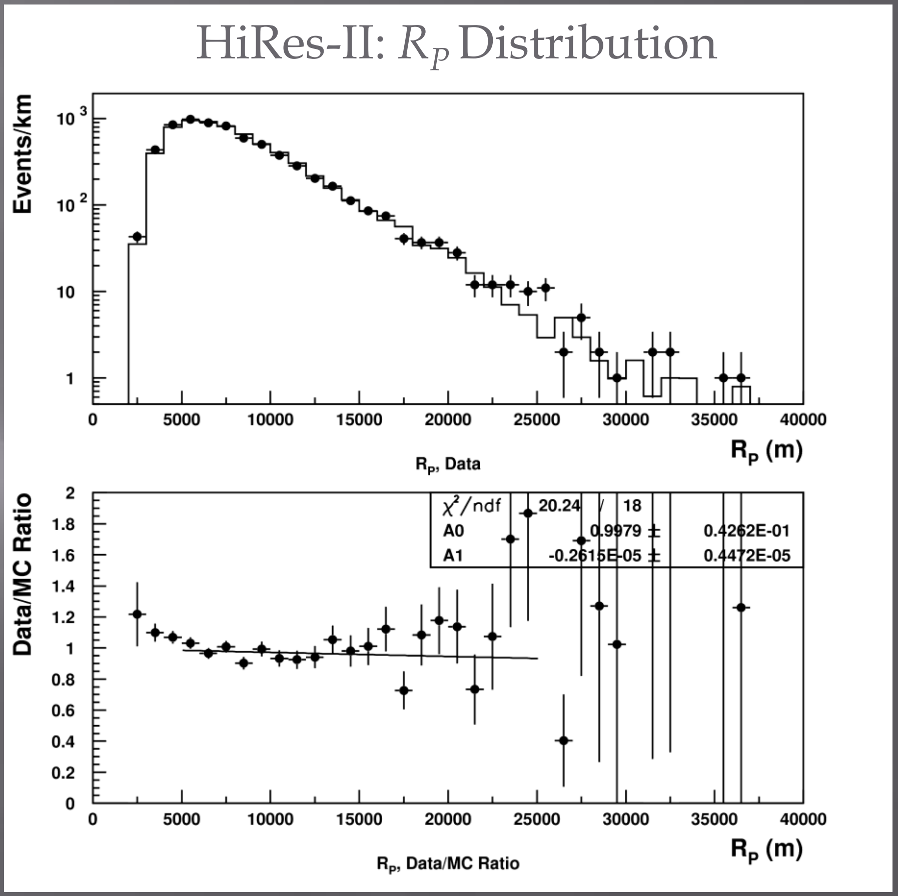
HiRes Monocular Spectrum

- Aperture
  - The aperture varies with energy…
  - … but HiRes triggers on brightness
    - Systematic uncertainties from *detector* model **not** from *shower* model
    - Look at *bulk* of shower
    - Demonstrate understanding of the detector by Data/MC comparisons



HiRes Data/MC Comparisons

- Distance to shower
  - Constrains atmosphere
  - Constrains trigger threshold



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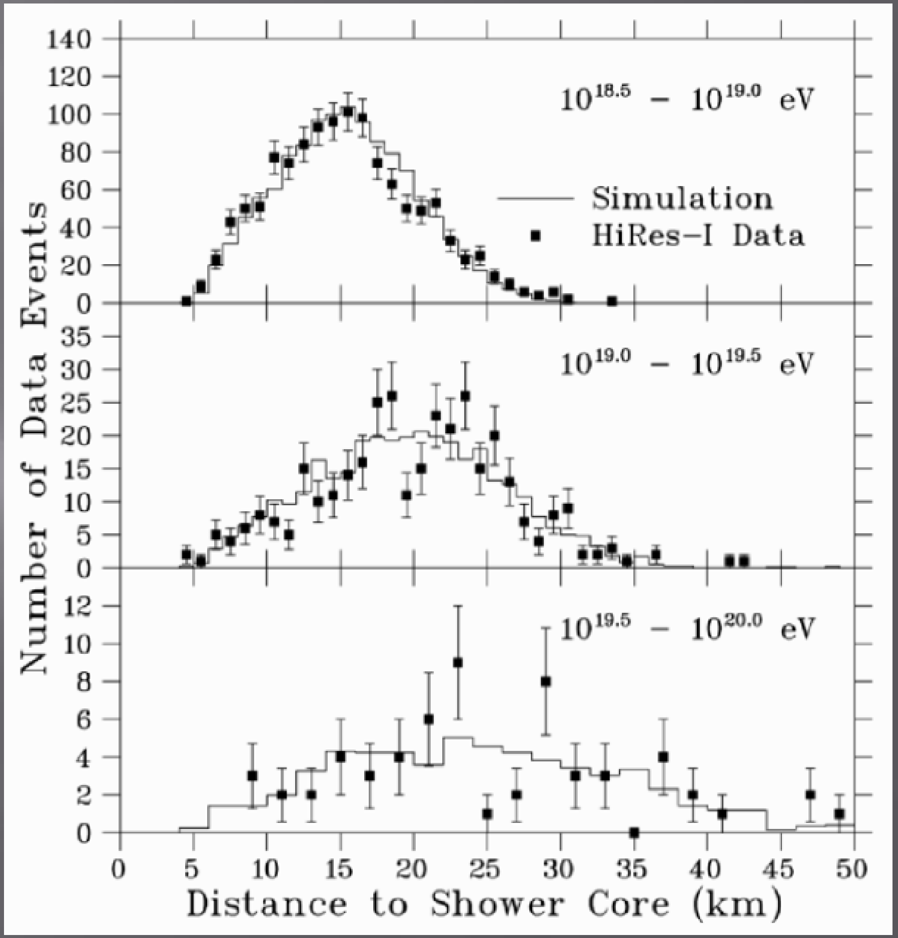
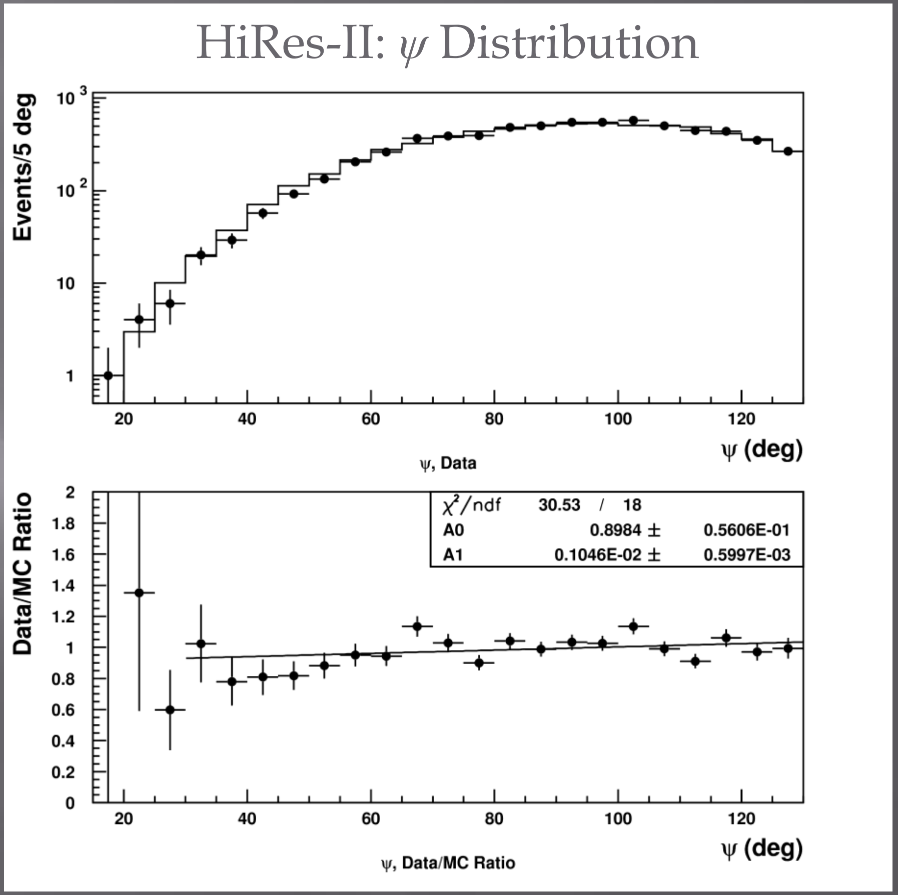


HiRes Data/MC Comparisons

- Distance to shower
  - Constrains atmosphere
  - Constrains trigger threshold
- Shower angle
  - Constrains atmosphere (Cherenkov)
  - Constrains resolution



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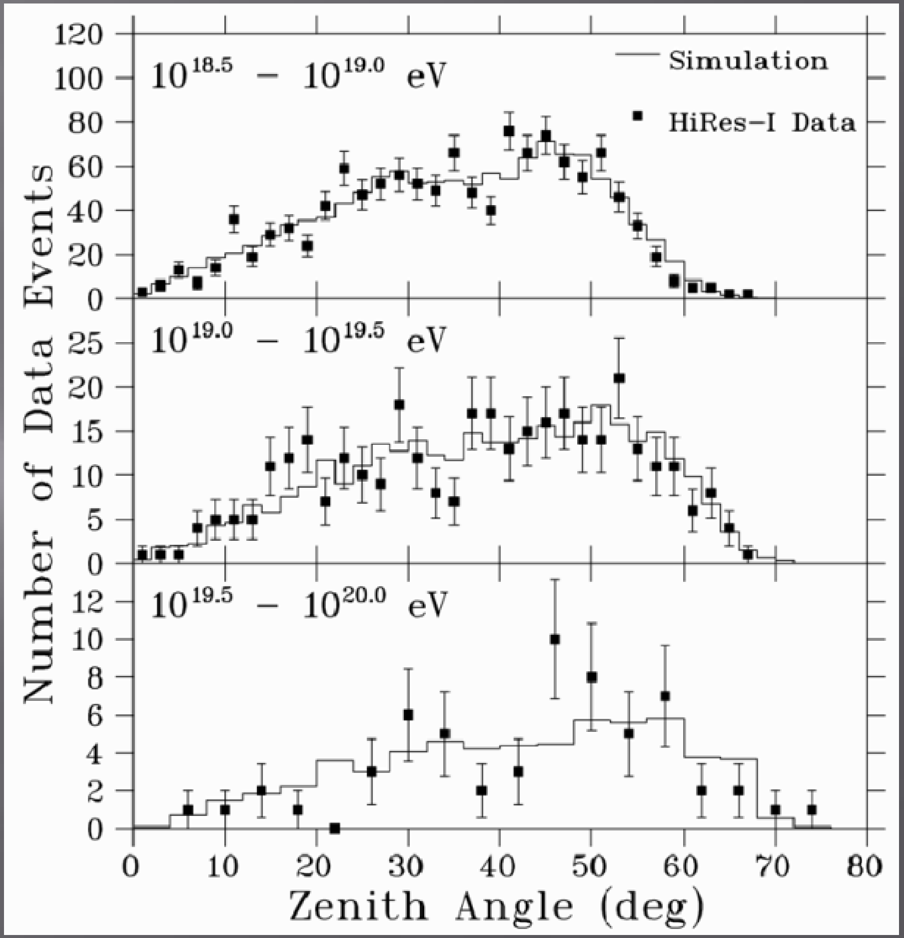

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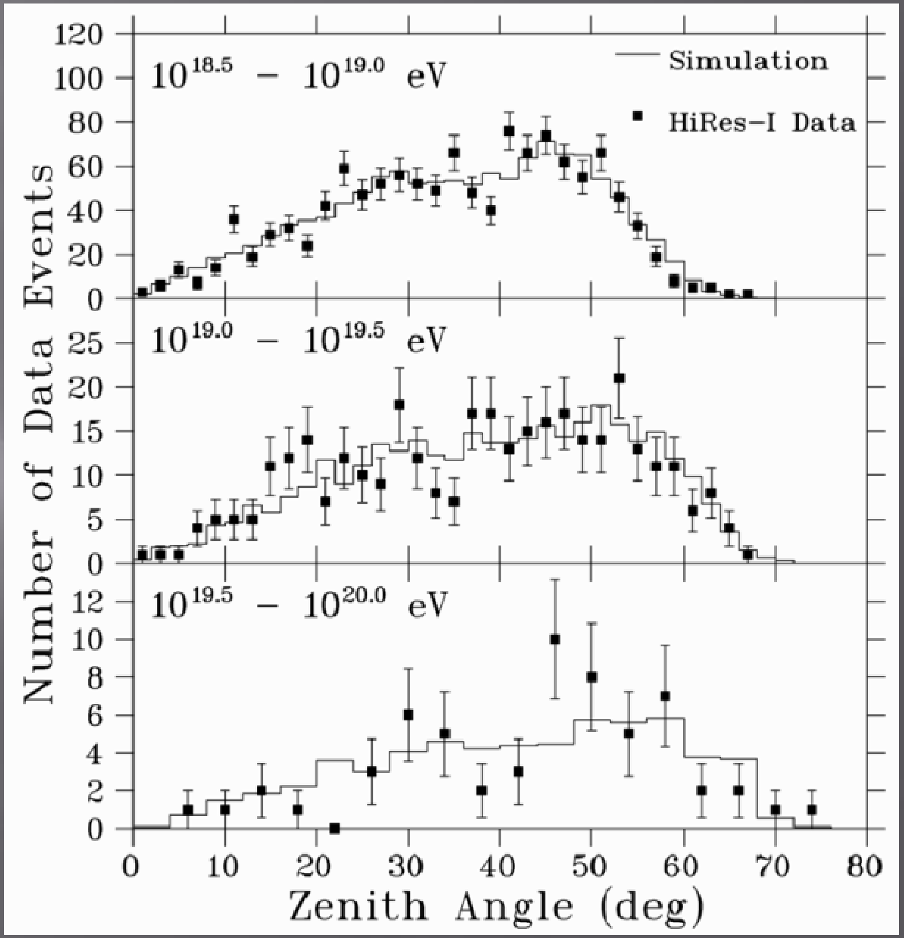
- Angle and distance (range) *are* the aperture



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- Shower angle
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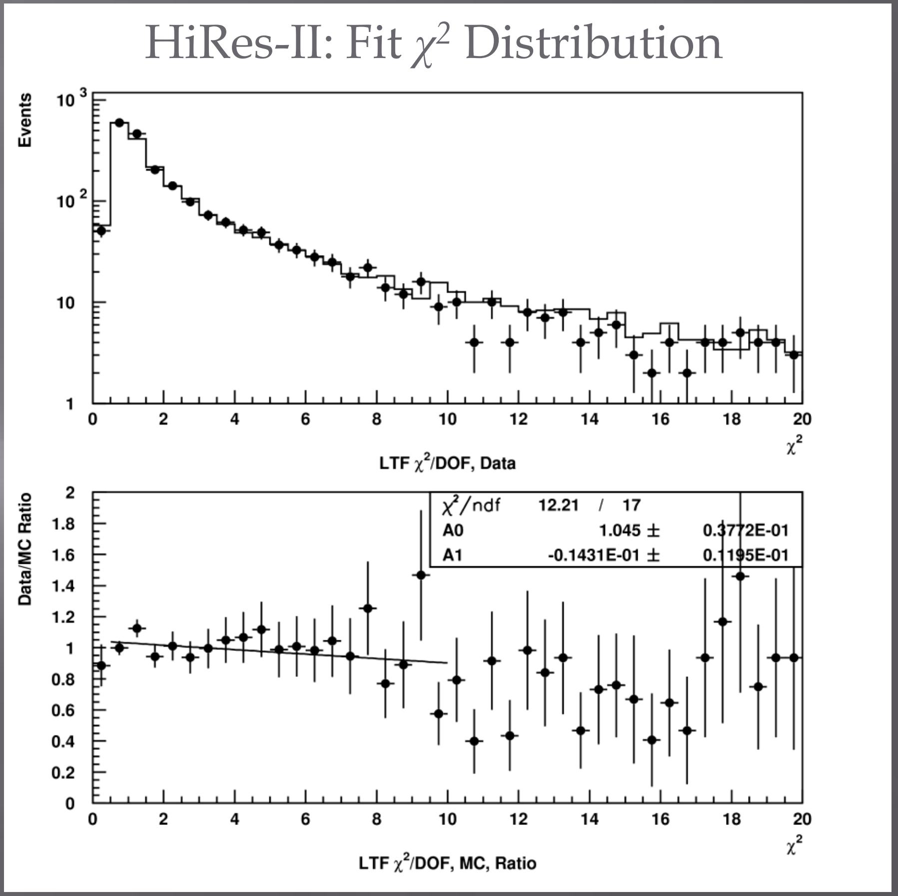
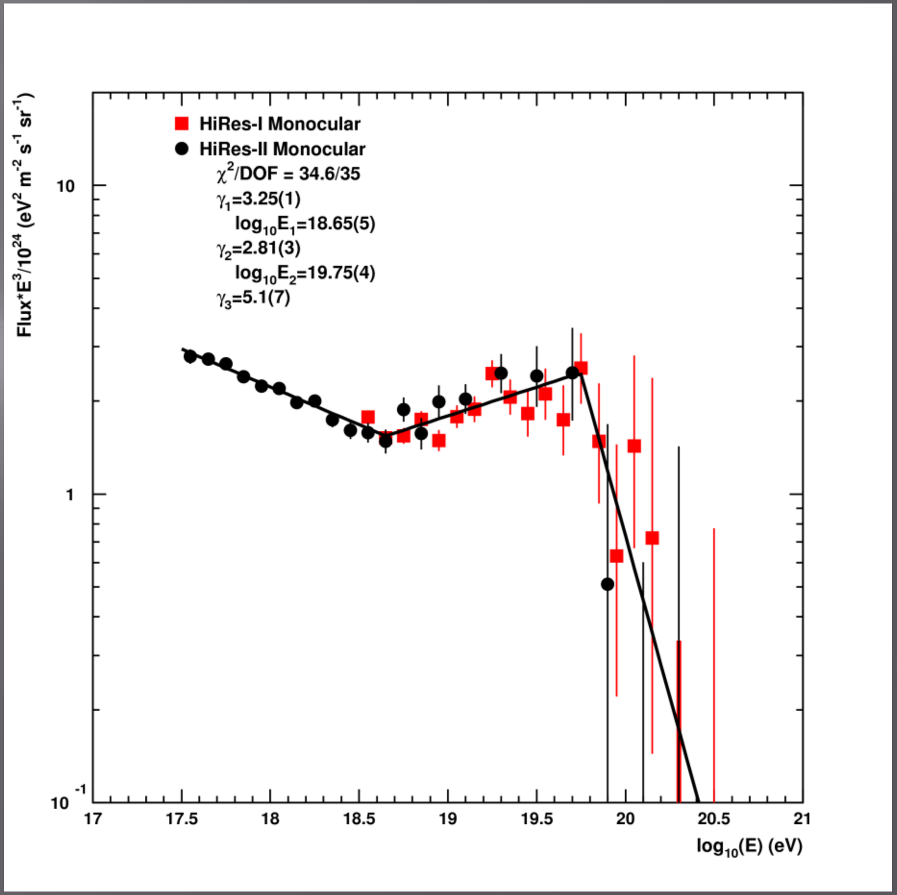
  - Constrains resolution
- Angle and distance (range) *are* the aperture
- Check resolution by check of χ^2 distribution



HiRes Monocular Spectra

- The HiRes monocular spectra were the first to see a UHE Cutoff
  - Most of the cutoff significance comes from HiRes-I
  - Ankle measurement largely due to HiRes-II



HiRes Monocular Spectra

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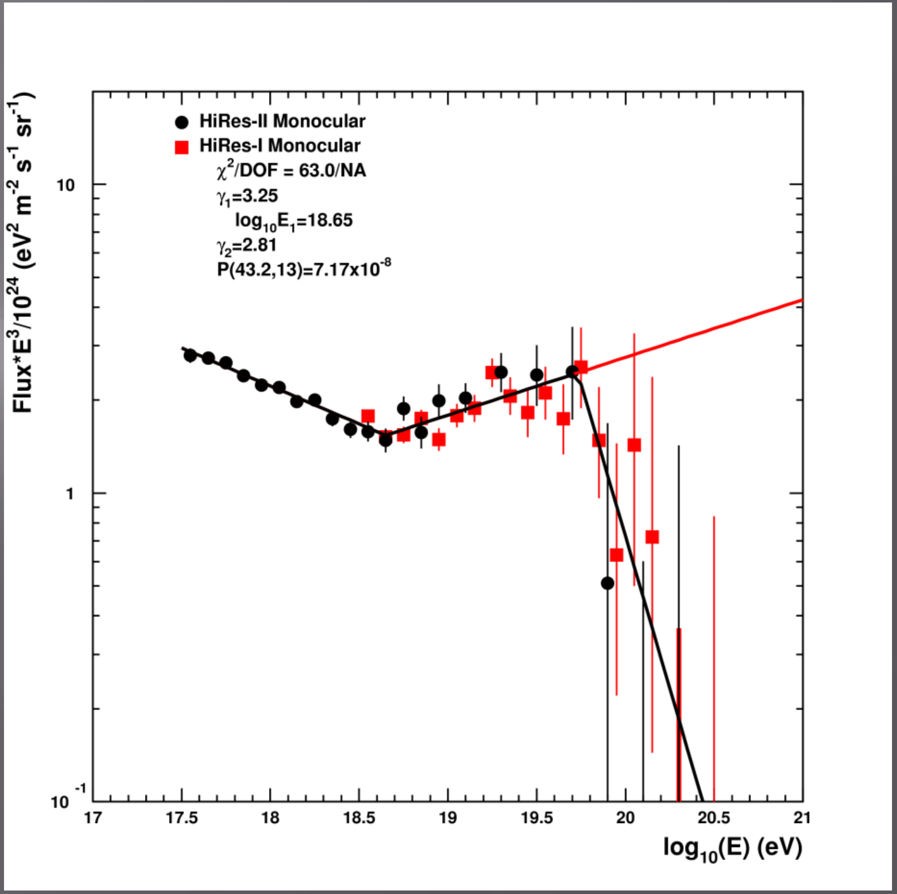
  - Ankle measurement largely due to HiRes-II
- 5-σ significance of cutoff: expect 43, see 13.



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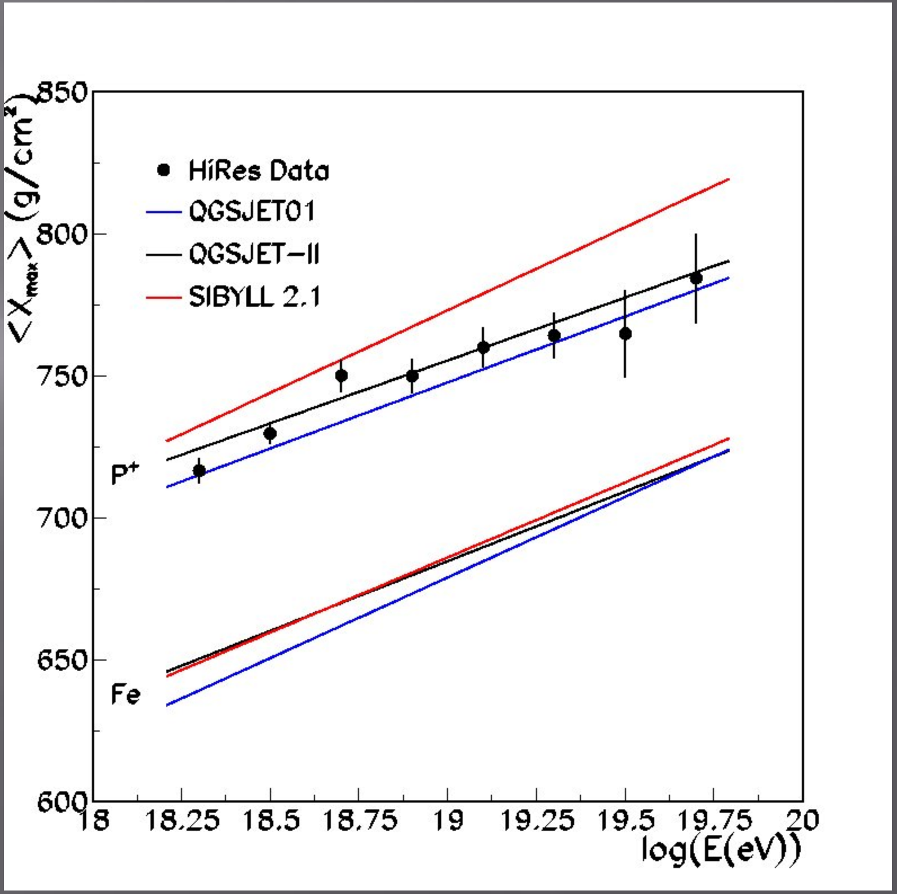

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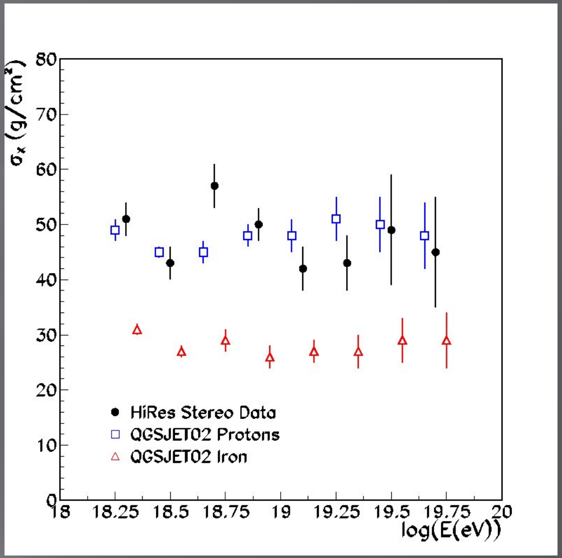

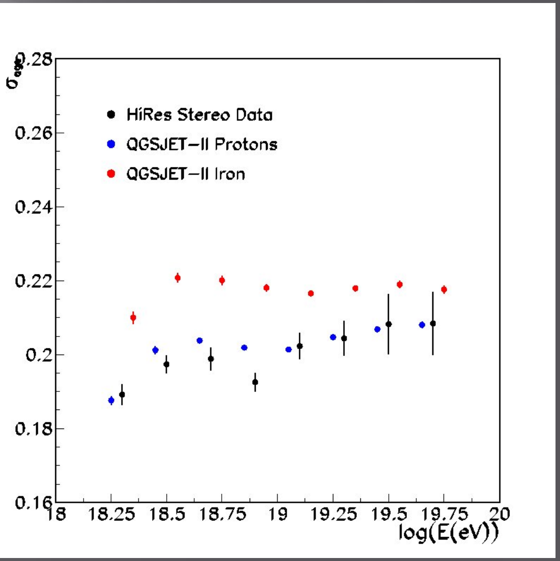

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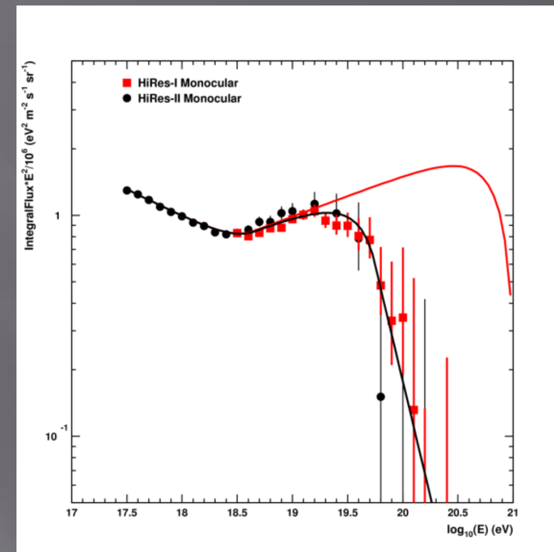

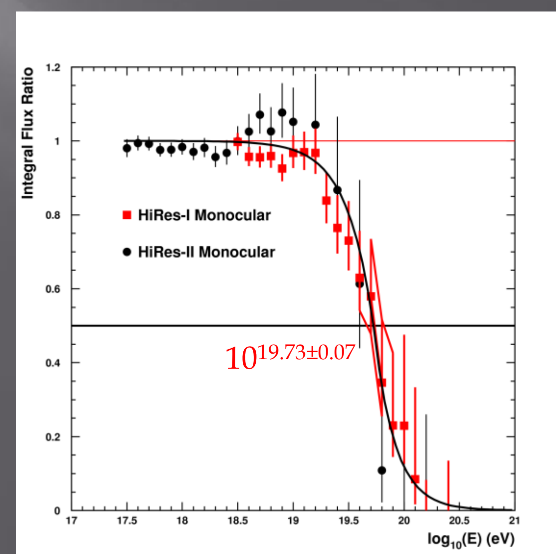

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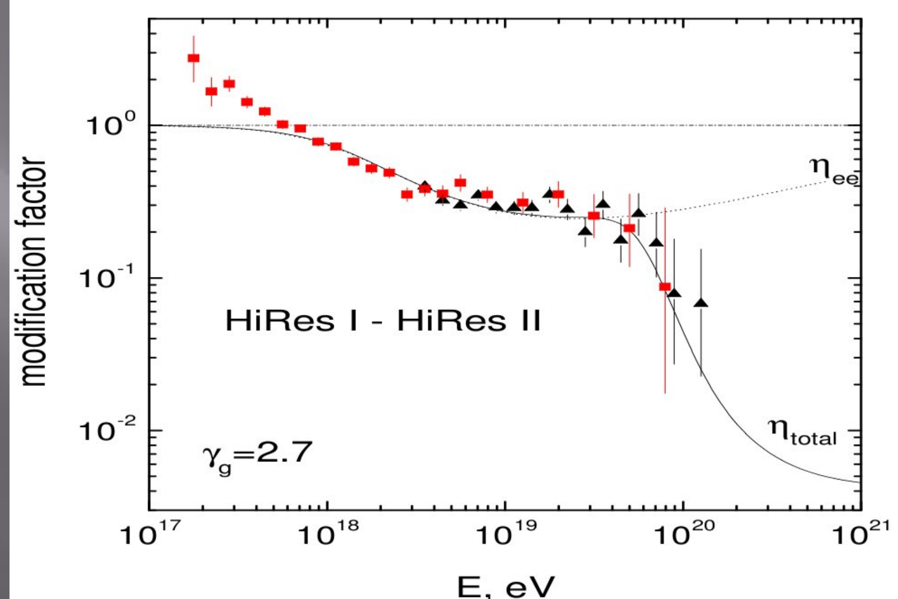

Aloisio *et al*, *Astropart. Phys.* **27** (2007).

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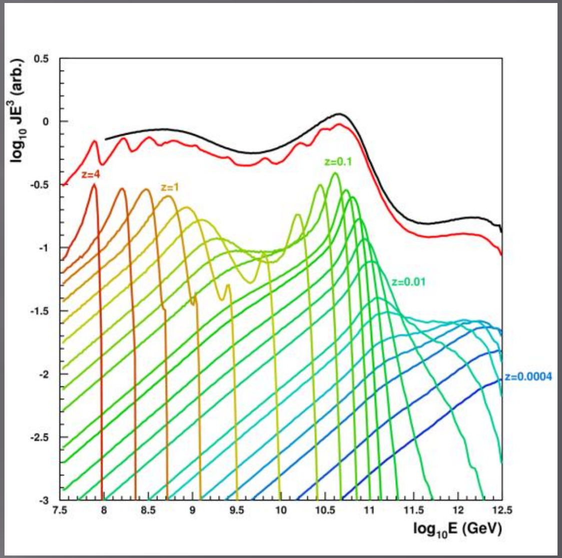
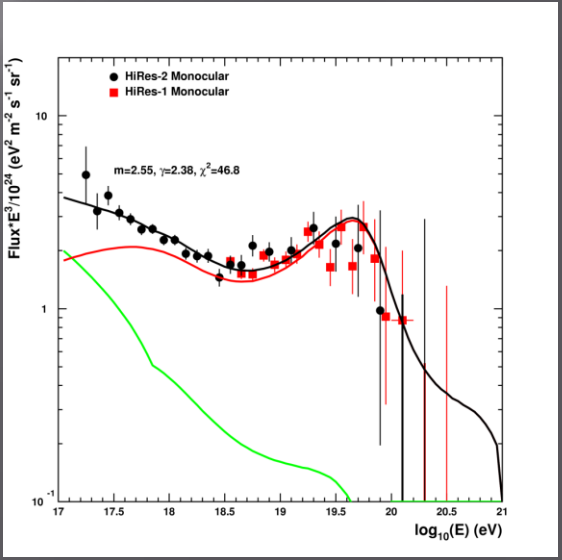
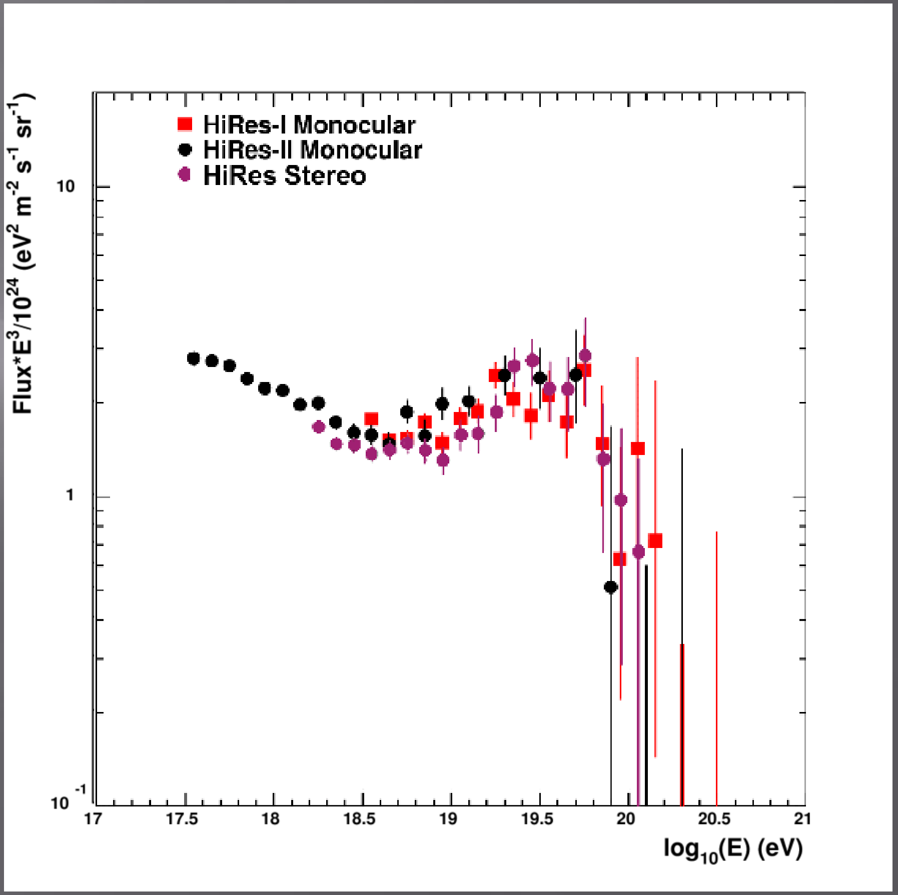
  - Cutoff energy should match prediction from Δ-production threshold
  - GZK *and* Ankle agree with CMD energy loss





HiRes Spectra

- HiRes observes the Ankle and a High Energy Cutoff
- Observed first in monocular, confirmed in stereo
- The cutoff is consistent with the GZK Cutoff in the *strict* interpretation as a result of *protons* interacting *in transit* with the CMB



Telescope Array

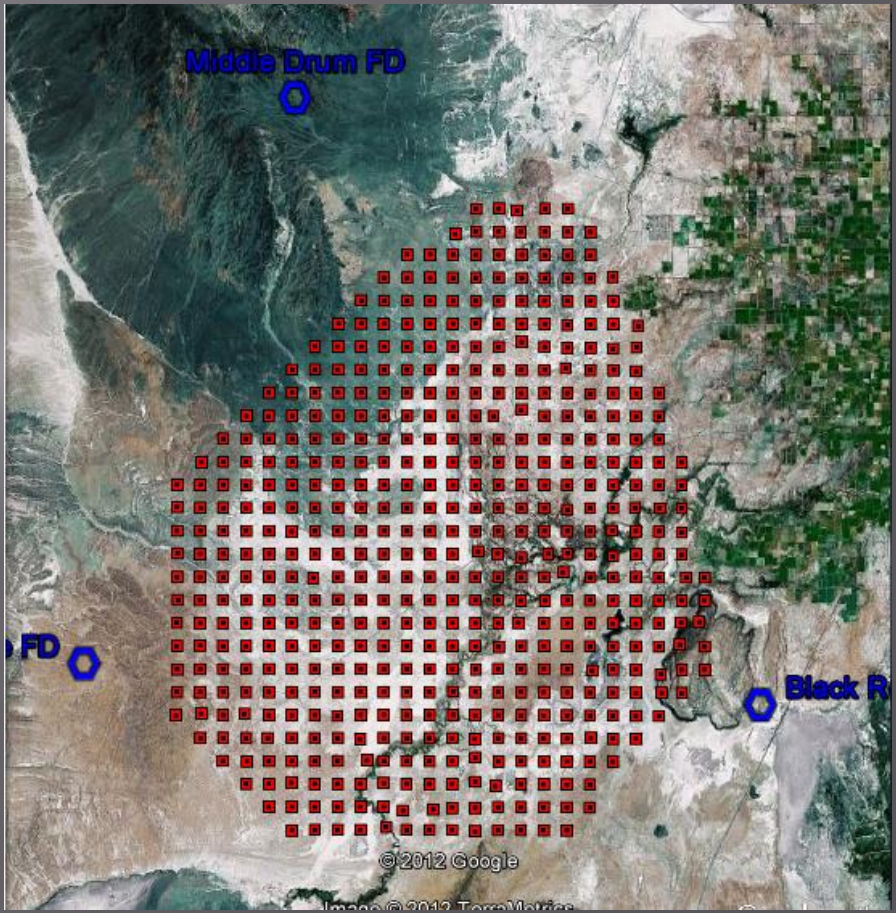
T Abu-Zayyad[1], R Aida[2], M Allen[1], R Azuma[3], E Barcikowski[1], JW Belz[1], T Benno[4], DR Bergman[1], SA Blake[1], O Brusova[1], R Cady[1], BG Cheon[6], J Chiba[7], M Chikawa[4], EJ Cho[6], LS Cho[8], WR Cho[8], F Cohen[9], K Doura[4], C Ebeling[1], H Fujii[10], T Fujii[11], T Fukuda[3], M Fukushima[9, 22], D Gorbunov[12], W Hanlon[1], K Hayashi[3], Y Hayashi[11], N Hayashida[9], K Hibino[13], K Hiyama[9], K Honda[2], G Hughes[5], T Iguchi[3], D Ikeda[9], K Ikuta[2], SJJ Innemee[5], N Inoue[14], T Ishii[2], R Ishimori[3], D Ivanov[5], S Iwamoto[2], CCH Jui[1], K Kadota[15], F Kakimoto[3], O Kalashev[12], T Kanbe[2], H Kang[16], K Kasahara[17], H Kawai[18], S Kawakami[11], S Kawana[14], E Kido[9], BG Kim[19], HB Kim[6], JH Kim[6], JH Kim[20], A Kitsugi[9], K Kobayashi[7], H Koers[21], Y Kondo[9], V Kuzmin[12], YJ Kwon[8], JH Lim[16], SI Lim[19], S Machida[3], K Martens[22], J Martineau[1], T Matsuda[10], T Matsuyama[11], JN Matthews[1], M Minamino[11], K Miyata[7], H Miyauchi[11], Y Murano[3], T Nakamura[23], SW Nam[19], T Nonaka[9], S Ogio[11], M Ohnishi[9], H Ohoka[9], T Okuda[11], A Oshima[11], S Ozawa[17], IH Park[19], D Rodriguez[1], SY Roh[20], G Rubtsov[12], D Ryu[20], H Sagawa[9], N Sakurai[9], LM Scott[5], PD Shah[1], T Shibata[9], H Shimodaira[9], BK Shin[6], JD Smith[1], P Sokolsky[1], TJ Sonley[1], RW Springer[1], BT Stokes[5], SR Stratton[5], S Suzuki[10], Y Takahashi[9], M Takeda[9], A Taketa[9], M Takita[9], Y Tameda[3], H Tanaka[11], K Tanaka[24], M Tanaka[10], JR Thomas[1], SB Thomas[1], GB Thomson[1], P Tinyakov[12,21], I Tkachev[12], H Tokuno[9], T Tomida[2], R Torii[9], S Troitsky[12], Y Tsunesada[3], Y Tsuyuguchi[2], Y Uchihori[25], S Udo[13], H Ukai[2], B Van Klaveren[1], Y Wada[14], M Wood[1], T Yamakawa[9], Y Yamakawa[9], H Yamaoka[10], J Yang[19], S Yoshida[18], H Yoshii[26], Z Zundel[1]

[1]University of Utah, [2]University of Yamanashi, [3]Tokyo Institute of Technology, [4]Kinki University, [5]Rutgers University, [6]Hanyang University, [7]Tokyo University of Science, [8]Yonsei University, [9]Institute for Cosmic Ray Research, University of Tokyo, [10]Institute of Particle and Nuclear Studies, KEK, [11]Osaka City University, [12]Institute for Nuclear Research of the Russian Academy of Sciences, [13]Kanagawa University, [14]Saitama University, [15]Tokyo City University, [16]Pusan National University, [17]Waseda University, [18]Chiba University [19]Ewha Womans University, [20]Chungnam National University, [21]University Libre de Bruxelles, [22]University of Tokyo, [23]Kochi University, [24]Hiroshima City University, [25]National Institute of Radiological Science, Japan, [26]Ehime University

US, Japan, Korea, Russia, Belgium

Telescope Array

- Hybrid experiment
- Surface
  - 507 scintillation counters
  - 1.2 km spacing
  - 3 m^2, two layers.
- Fluorescence
  - 3 sites
  - Each 120° azimuth
  - 3°–31° elevation
- Over 3 years of data have been collected.



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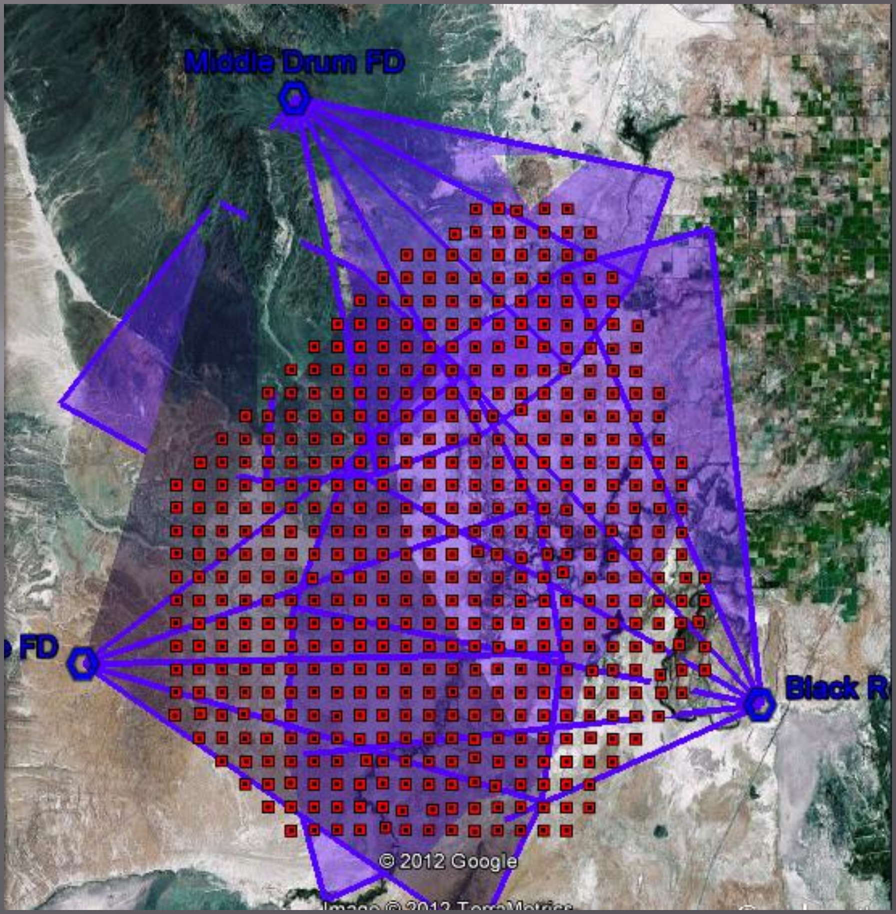
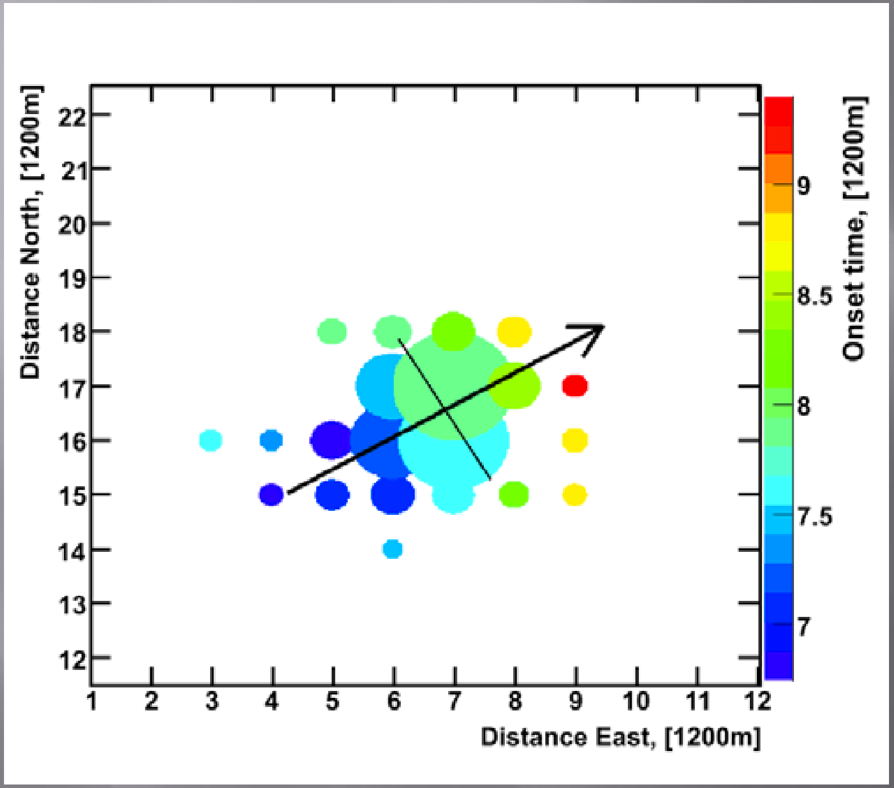
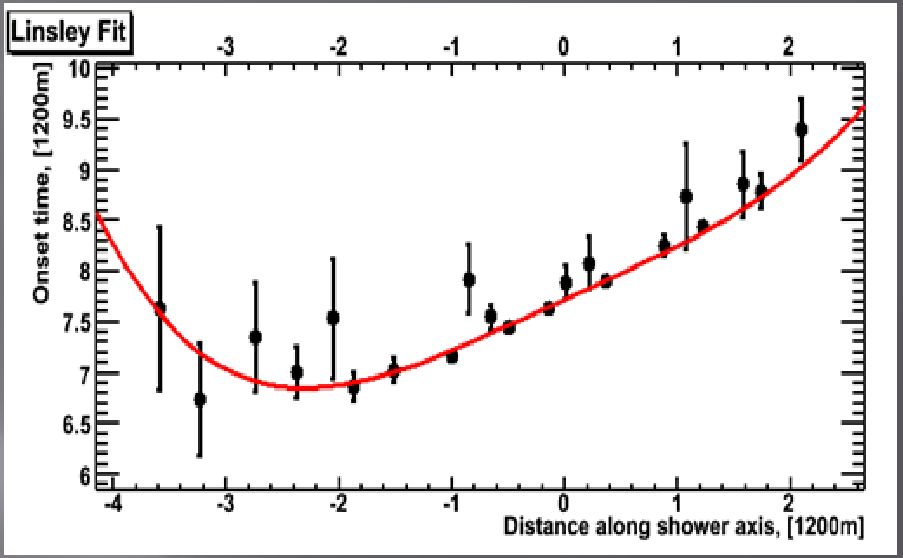
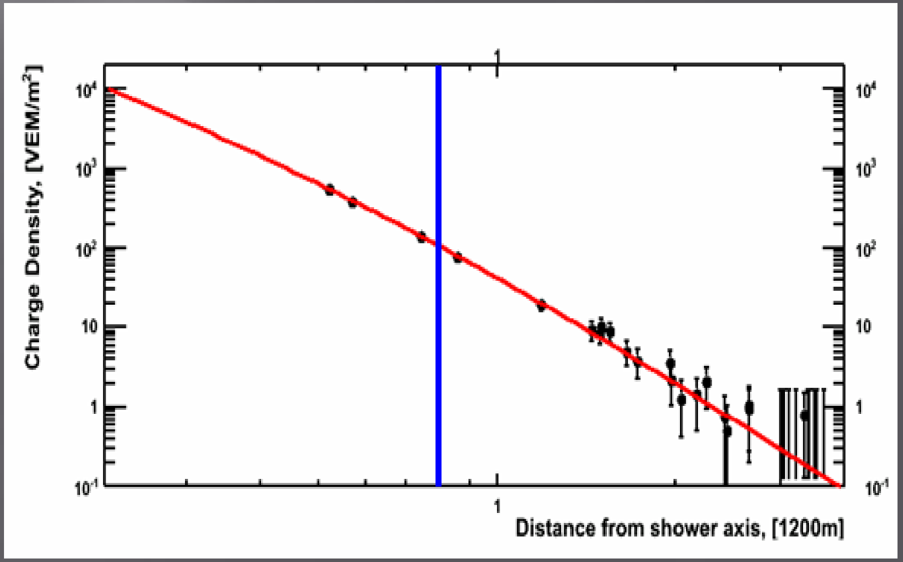


Typical Surface Detector Event

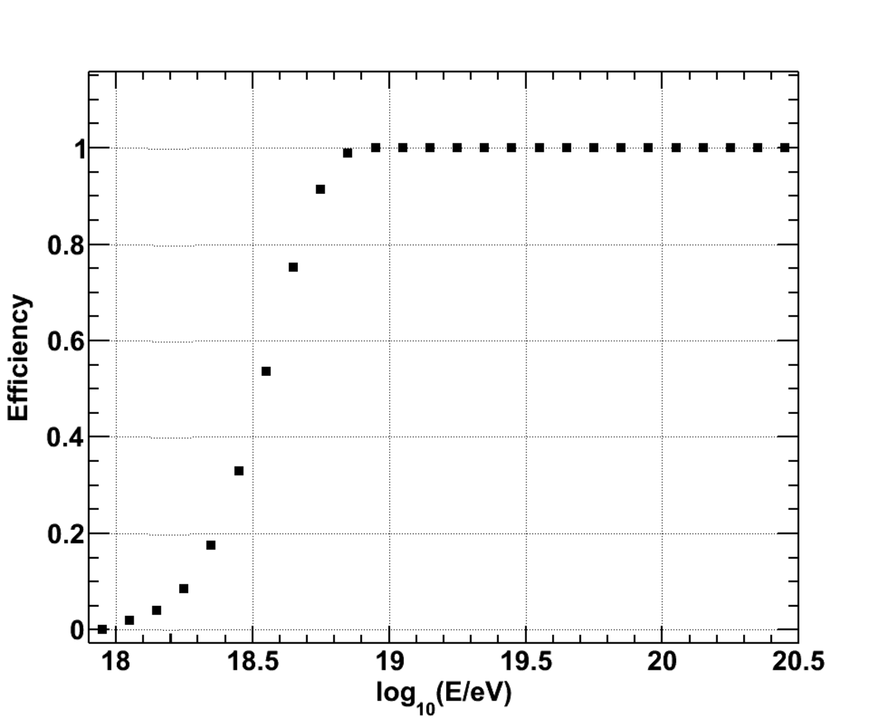






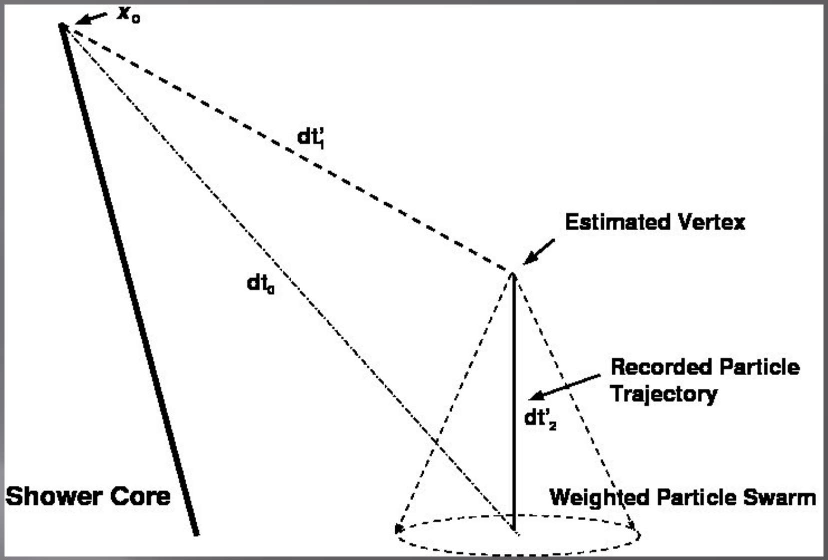
TA SD Spectrum

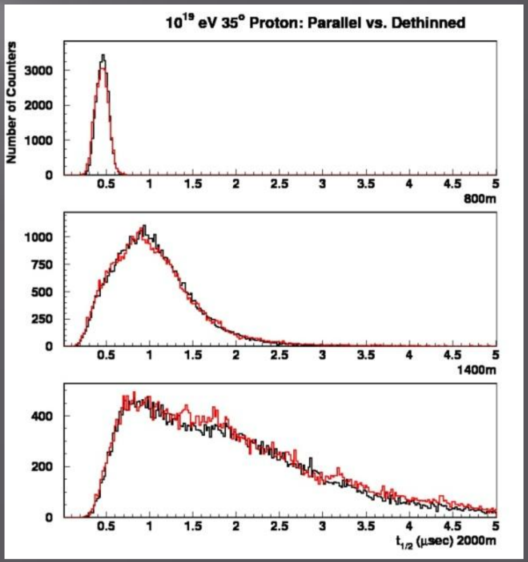
- Aperture
  - Unlike fluorescence, aperture constant above some threshold
  - Like fluorescence, aperture changes below that threshold
- By understanding detector response, can push well off efficiency plateau



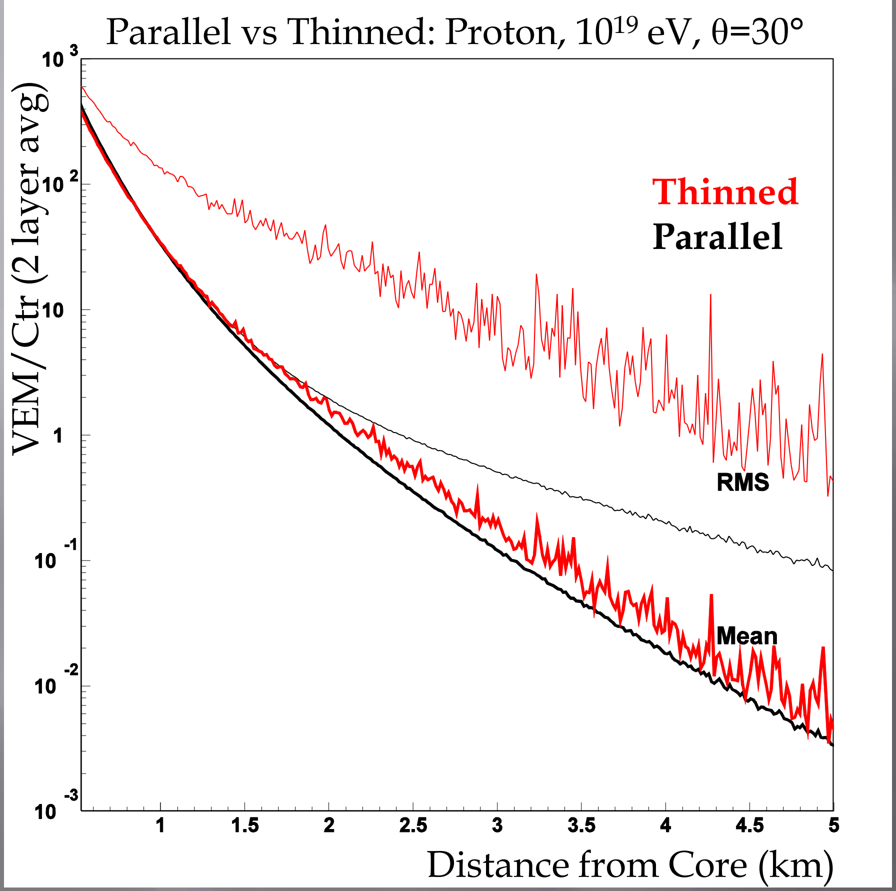
De-thinning

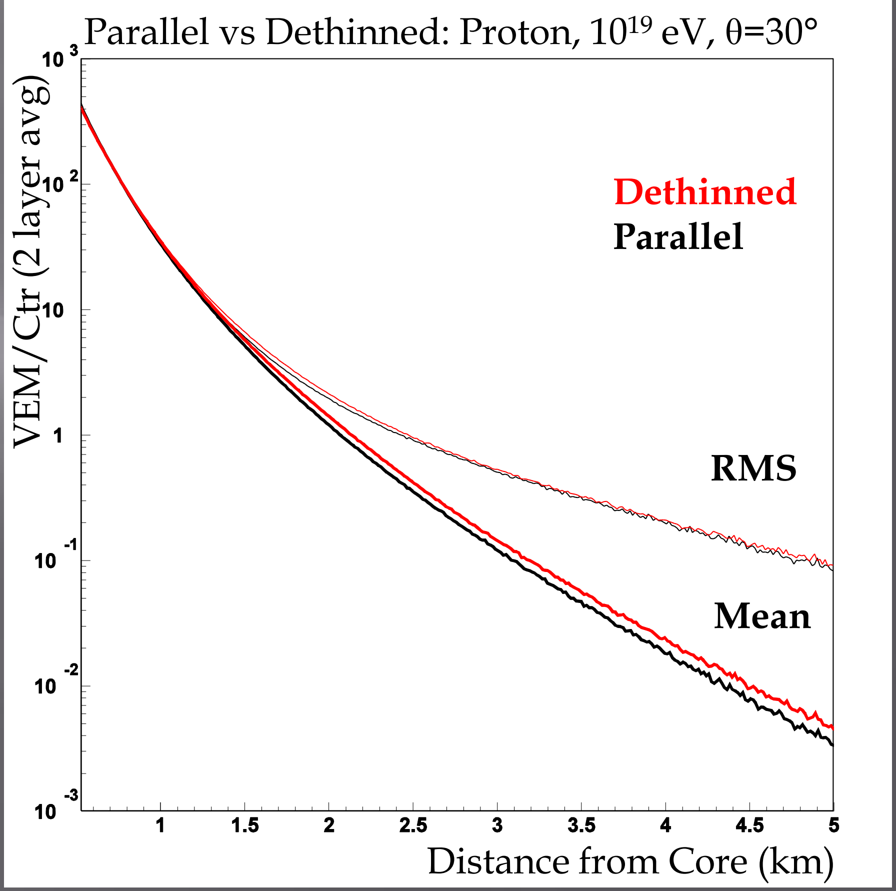
- To model detector need to produce lots of showers
- Can remove most of the statistical effects of thinning by spreading out weighted shower particles from Corsika as a swarm of particles coming from a calculated vertex
- Allows accurate reproduction of particle arrival times



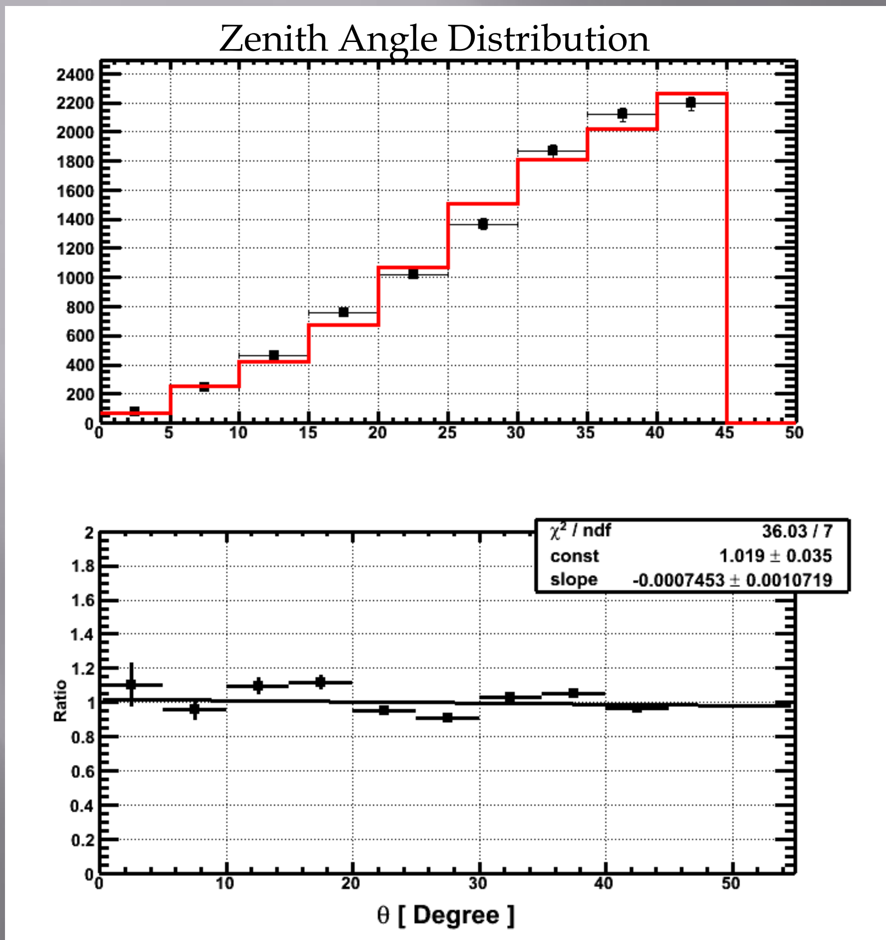


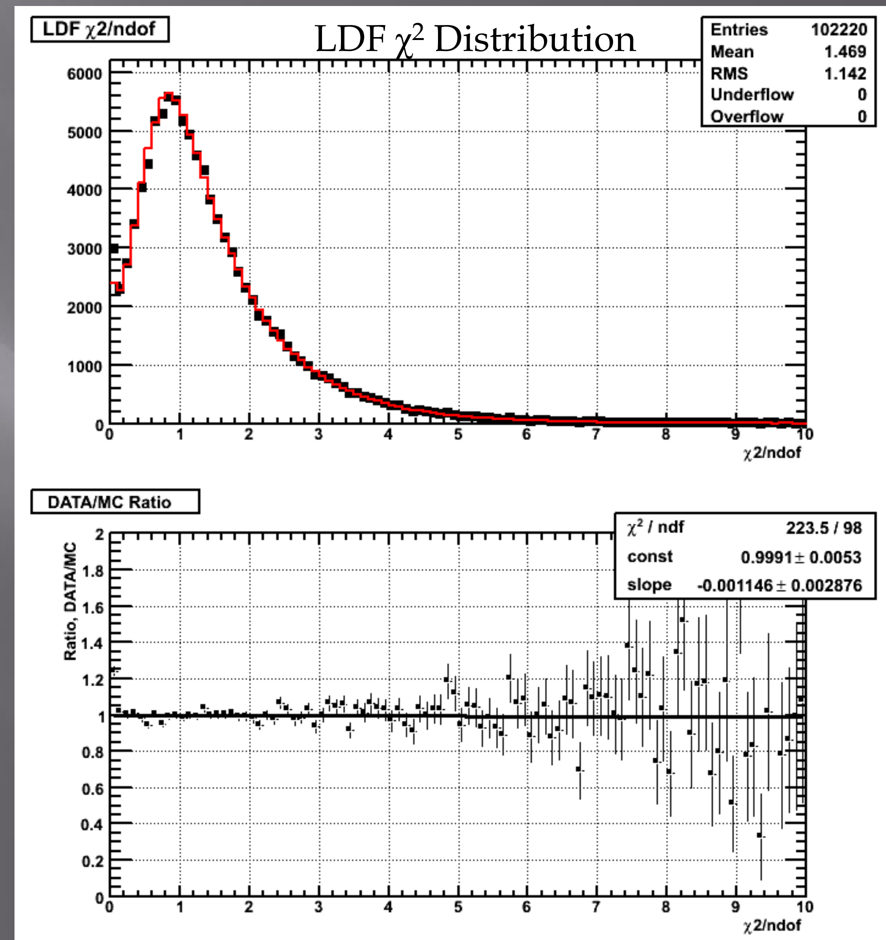
Thinned & De-thinned vs Full





Data/MC Comparisons





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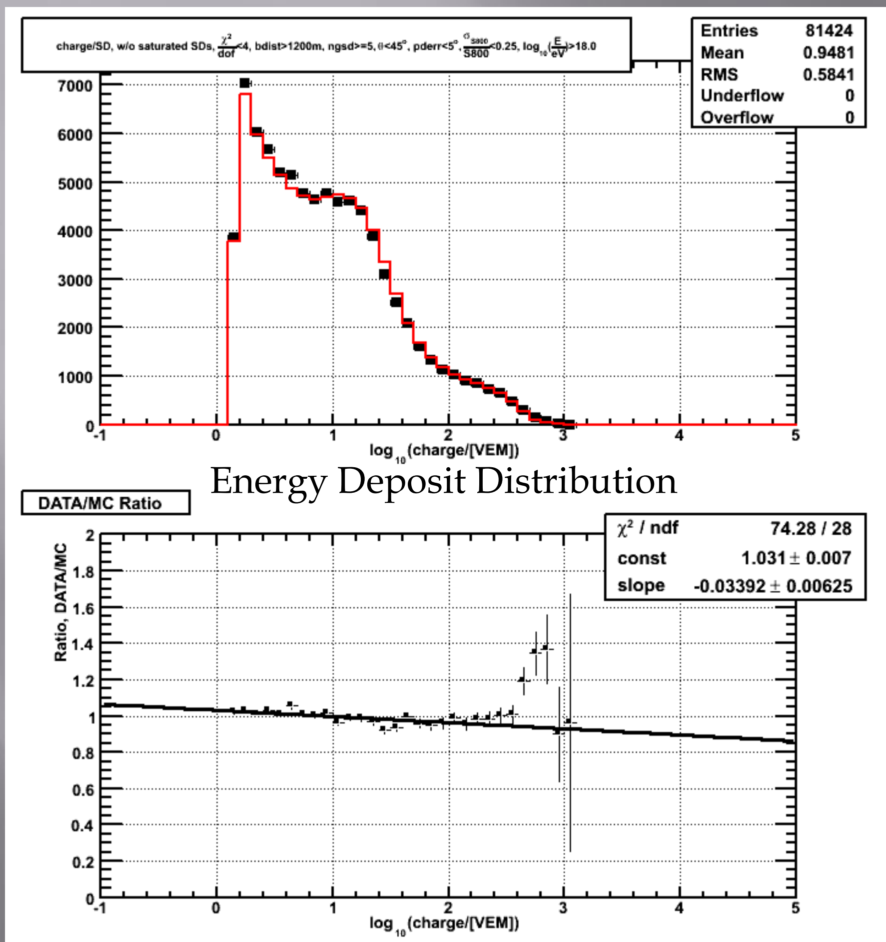
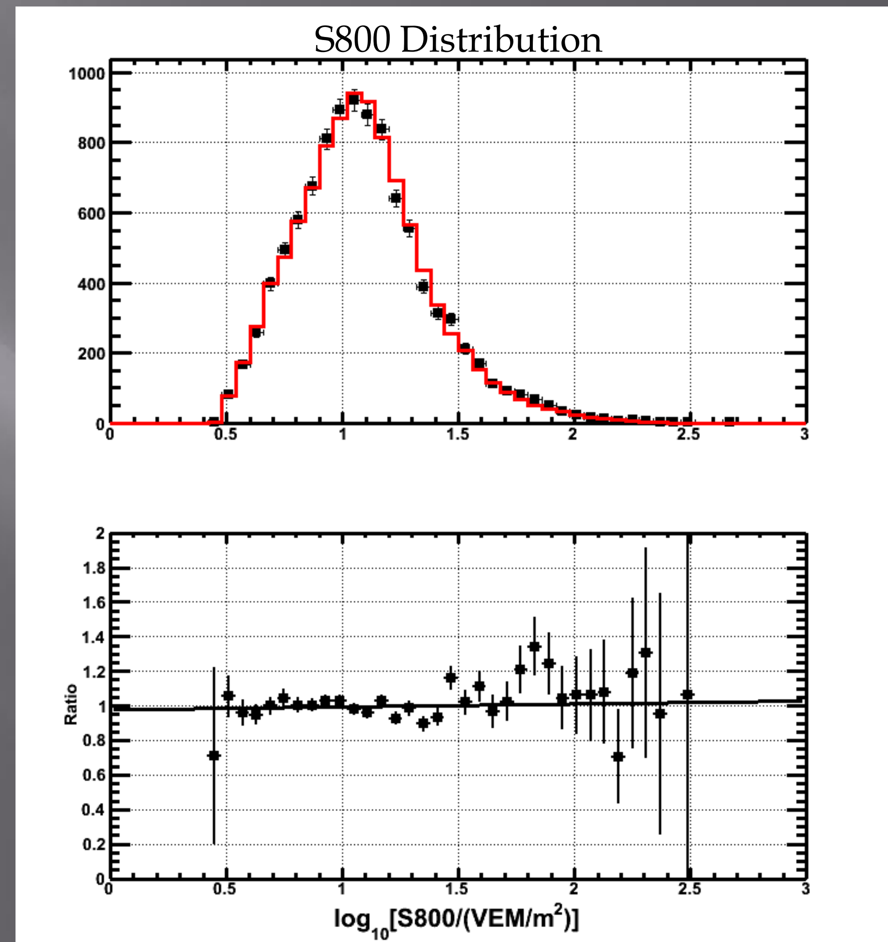
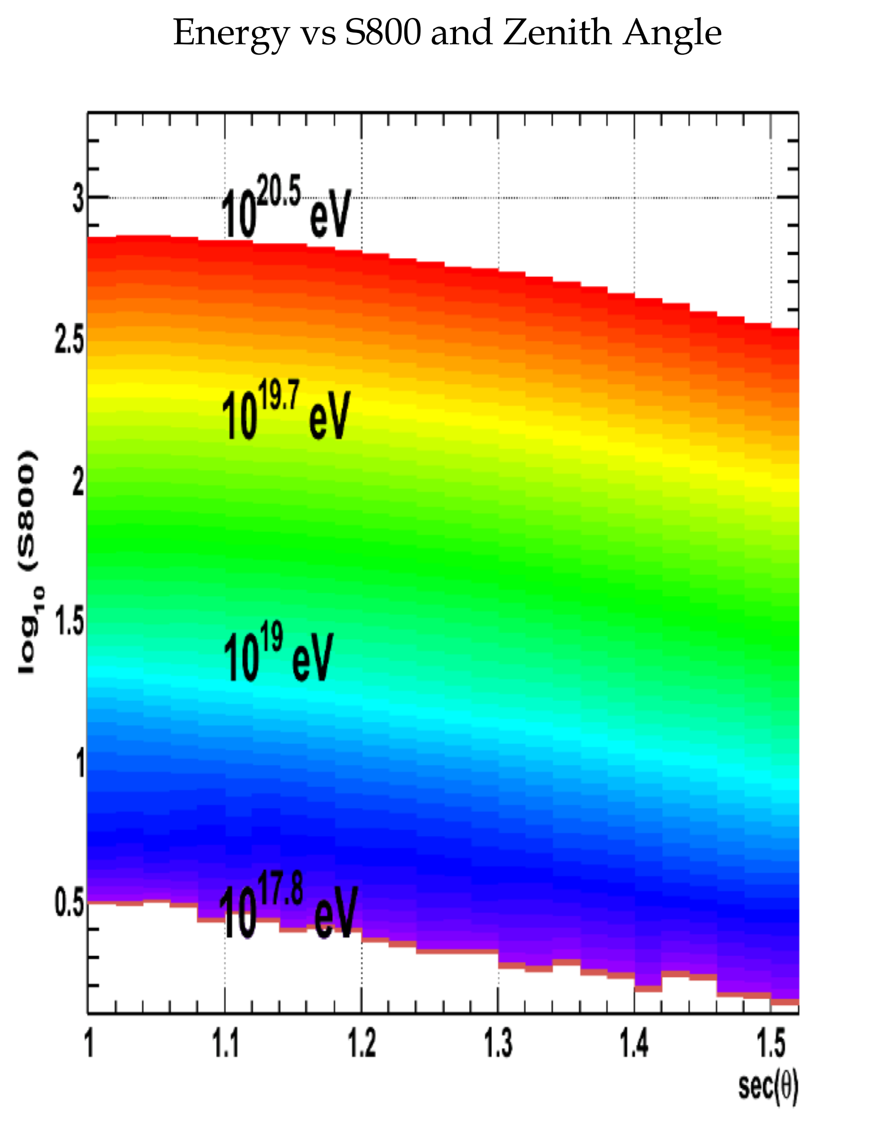
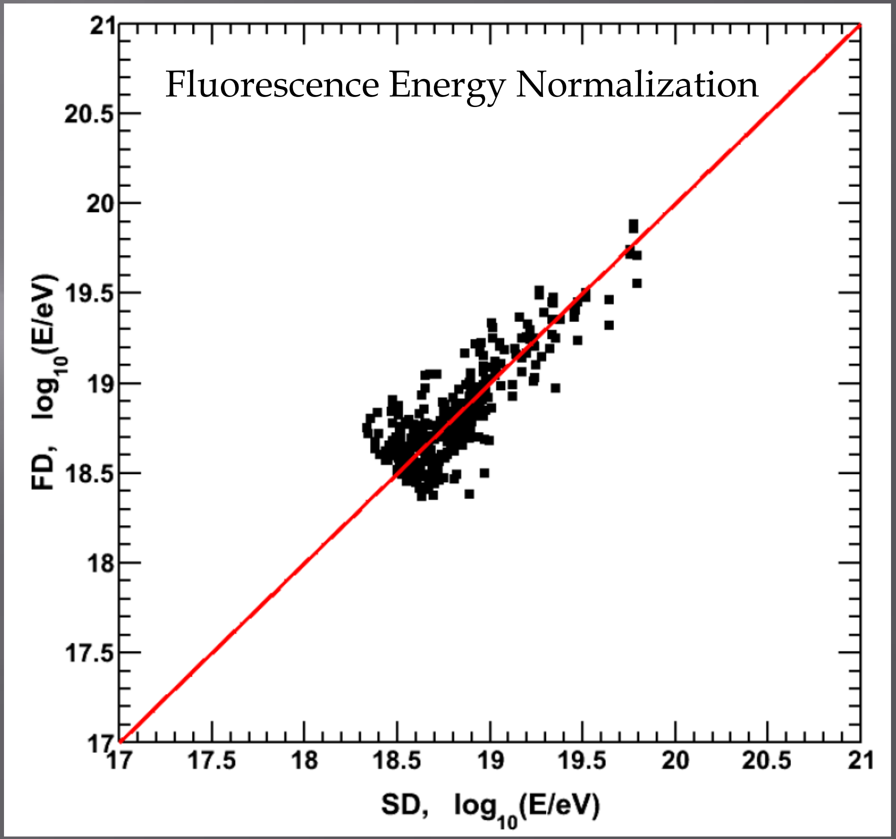




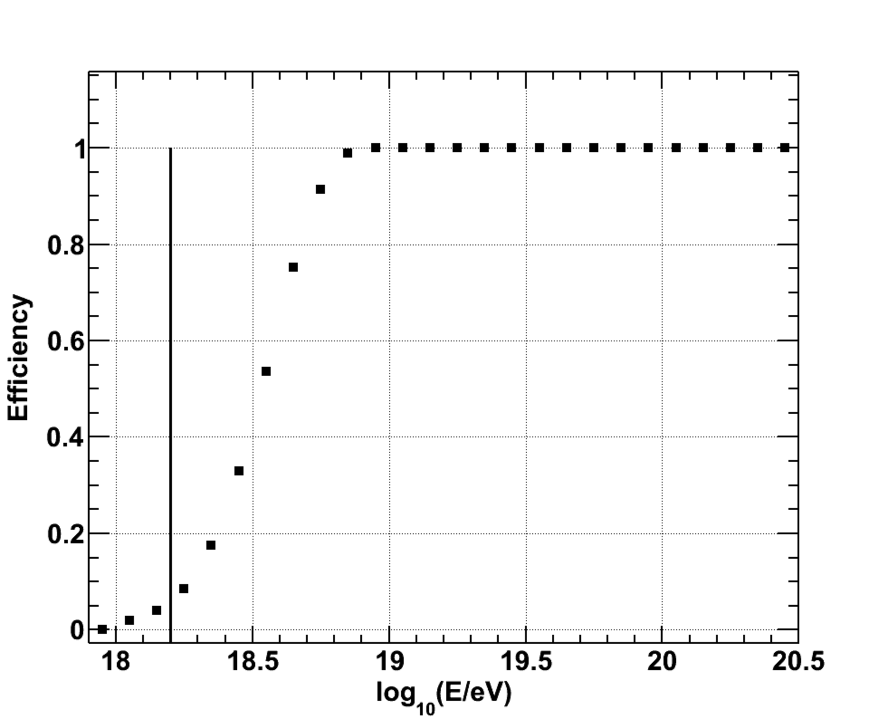
Energy Determination





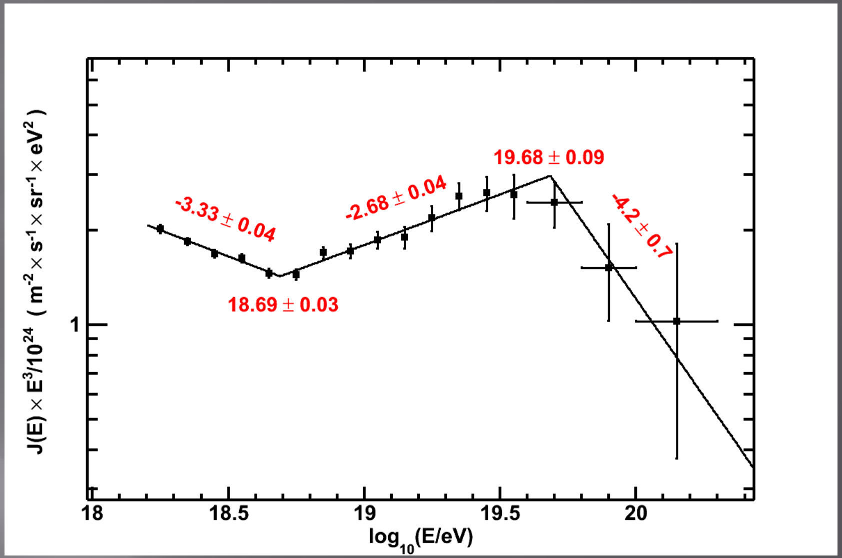
Final Acceptance

- We trust out acceptance calculation down to $10^{18.2}$ eV, where the acceptance is 8% of the maximum
- Need Data/MC agreement to push this far off the plateau



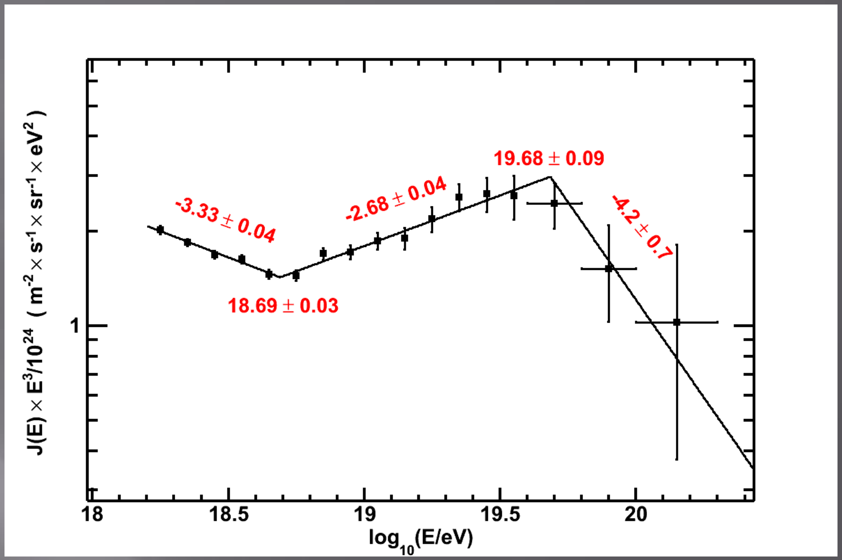
TA SD Spectrum

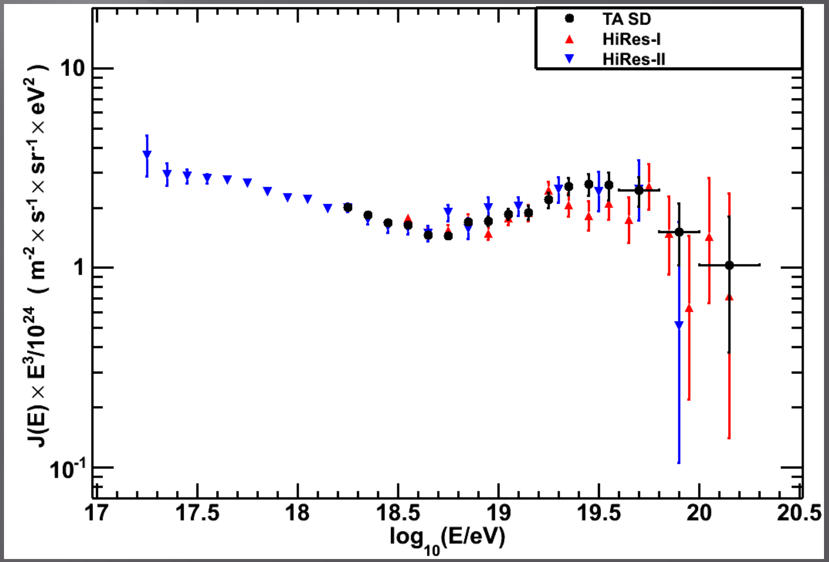
- Spectral Slopes and Break Points in agreement with HiRes



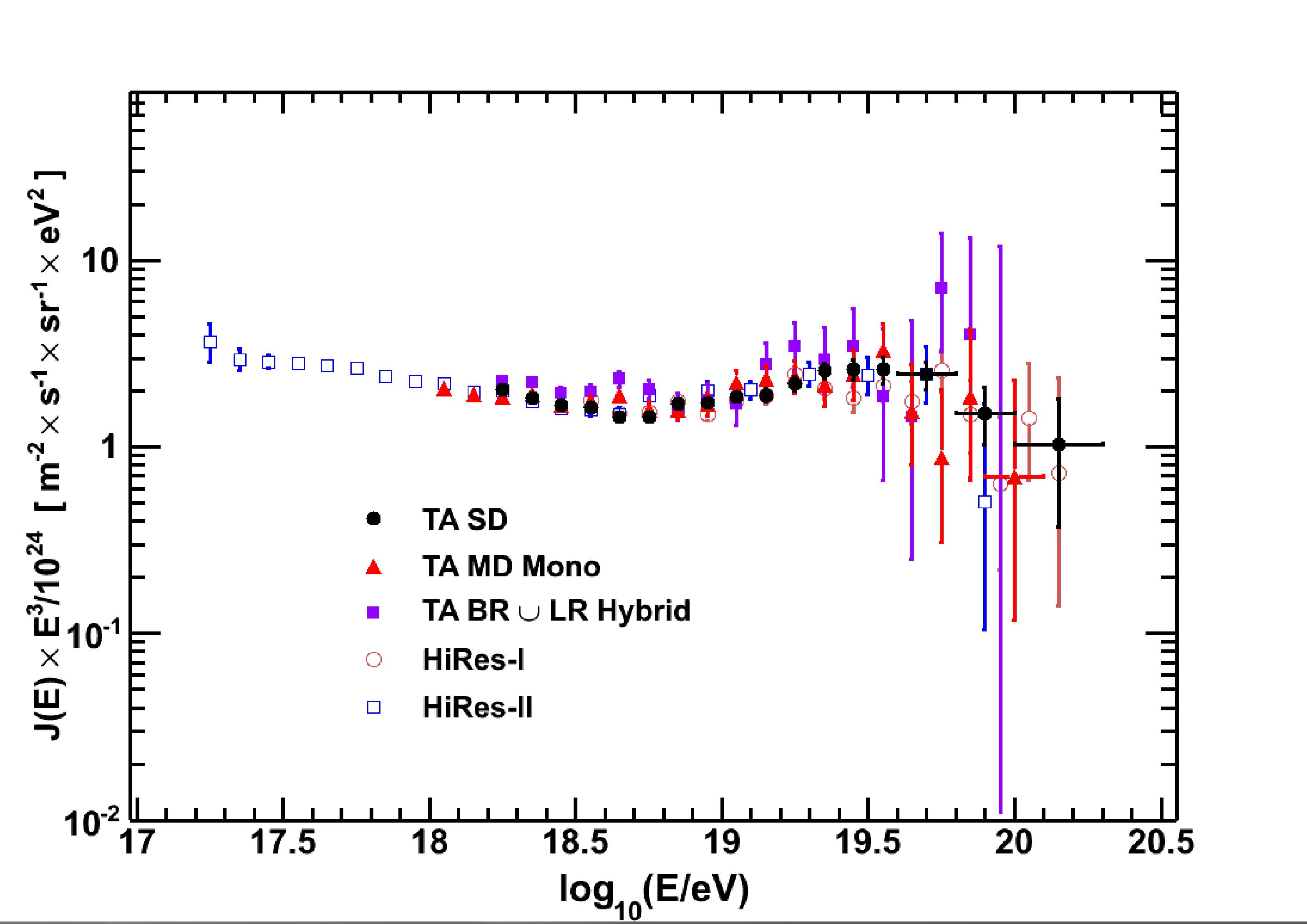
TA SD Spectrum

- Spectral Slopes and Break Points in agreement with HiRes
- Flux also in agreement with HiRes
  - Not a given
  - Energy normalization done with *all* TA FD detectors, not just Middle Drum (HiRes)





HiRes and TA Spectra



Conclusion

- HiRes and TA spectra show remarkable agreement
  - Spectral slopes
  - Break points
  - Normalization
- The secret to our success:
  - Simulate the detector well: Data/MC comparisons
  - Remove *shower* model uncertainty by looking at or normalizing to the bulk properties of the shower