Recent Results from the High-Resolution Fly's Eye (HiRes) Experiment

PANIC!

October, 2005

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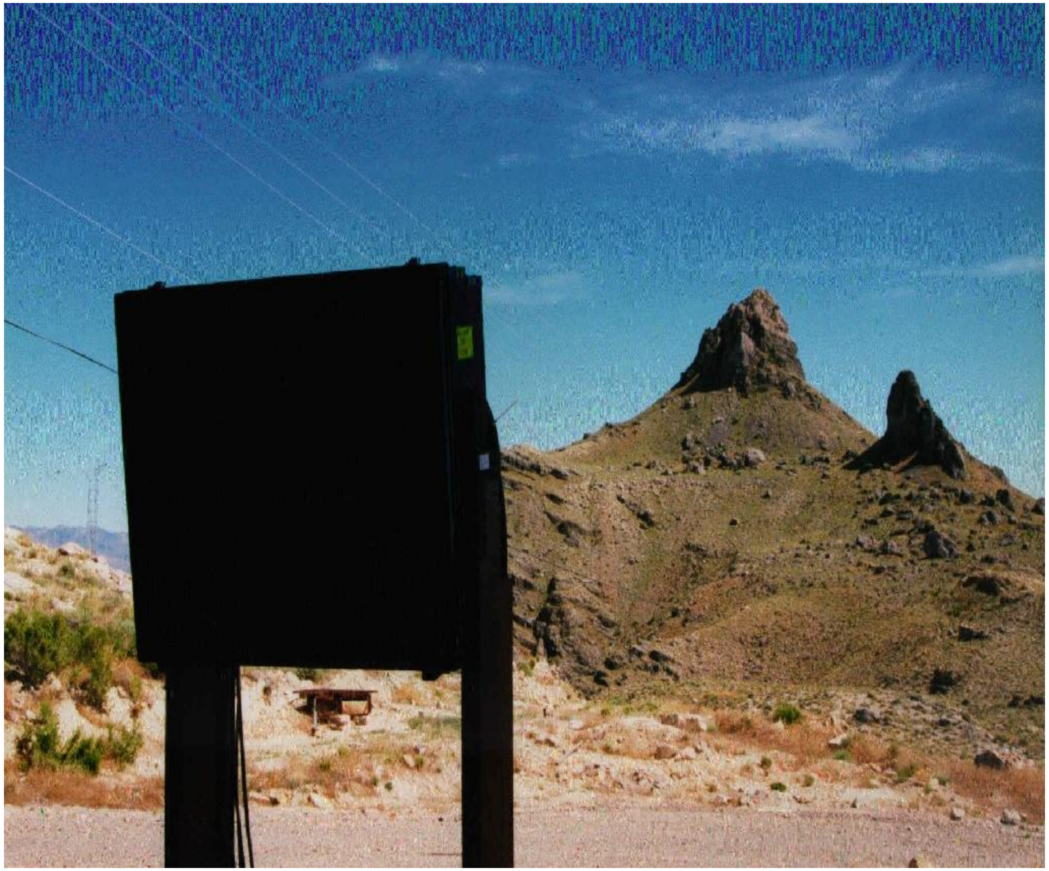
University of Utah

Outline

- Introduction of the High-Resolution Fly's Eye (HiRes) Experiment
- Energy spectrum and features
- Composition and p-air cross-section measurements
- Anisotropy
- The Future: TA and the Low Energy Extension (TALE).

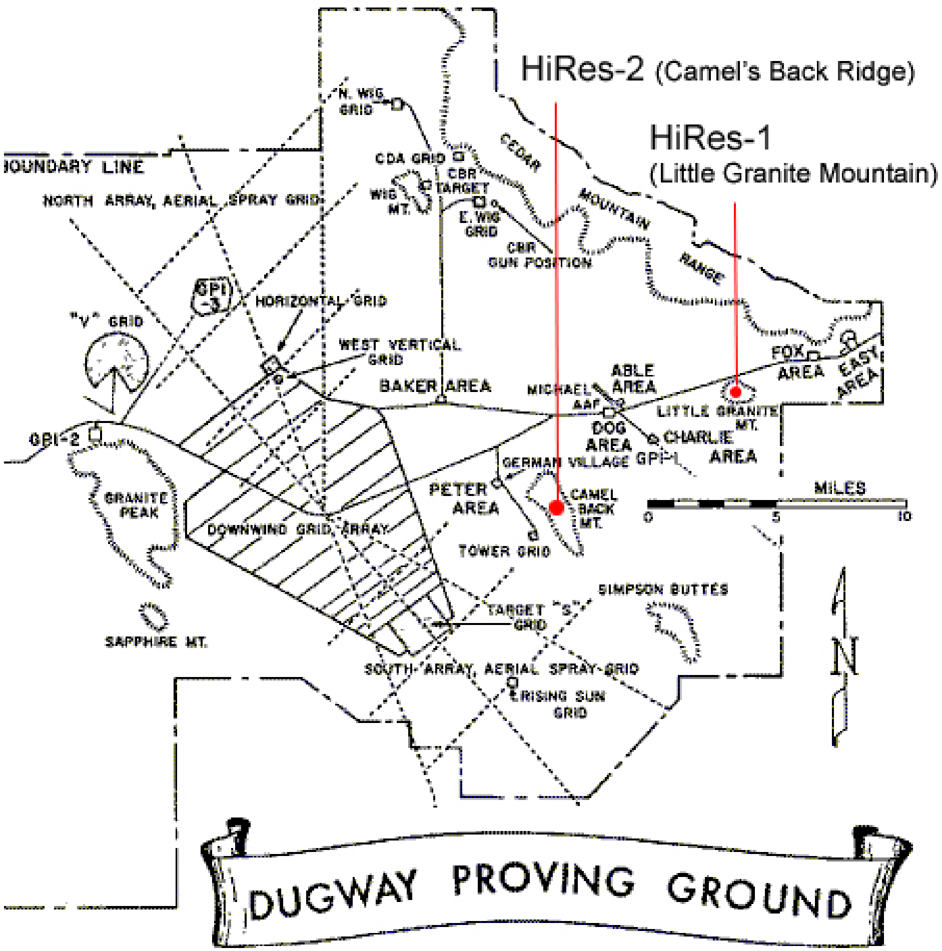
Introduction to the High Resolution Fly's Eye (HiRes)

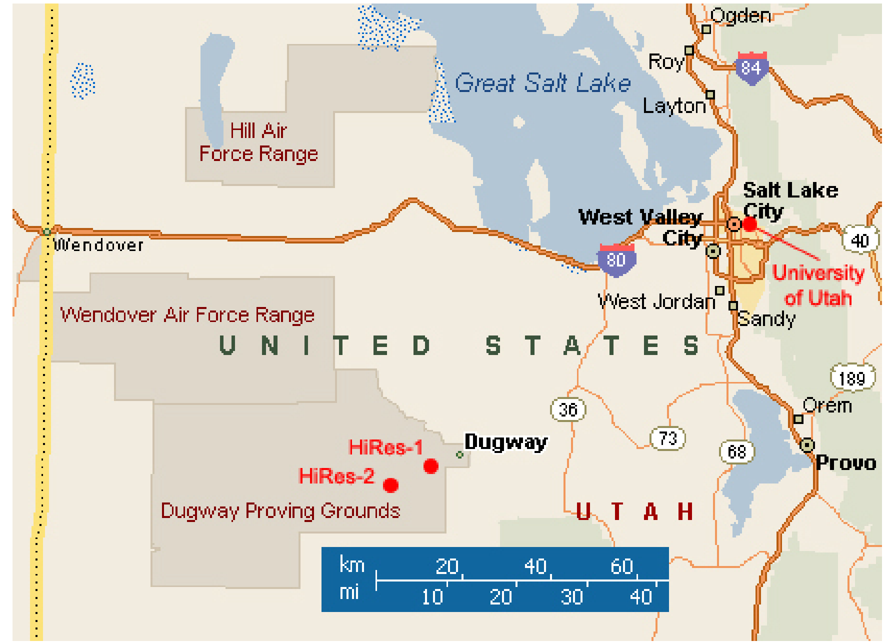


HiRes Collaboration:

- ***University of Utah***
- ***Columbia University***
- ***Rutgers University***
- ***University of New Mexico***
- ***University of Montana***
- ***Los Alamos National Laboratory (LANL)***
- ***University of Tokyo***
- ***IHEP (Beijing, China)***

HiRes Location

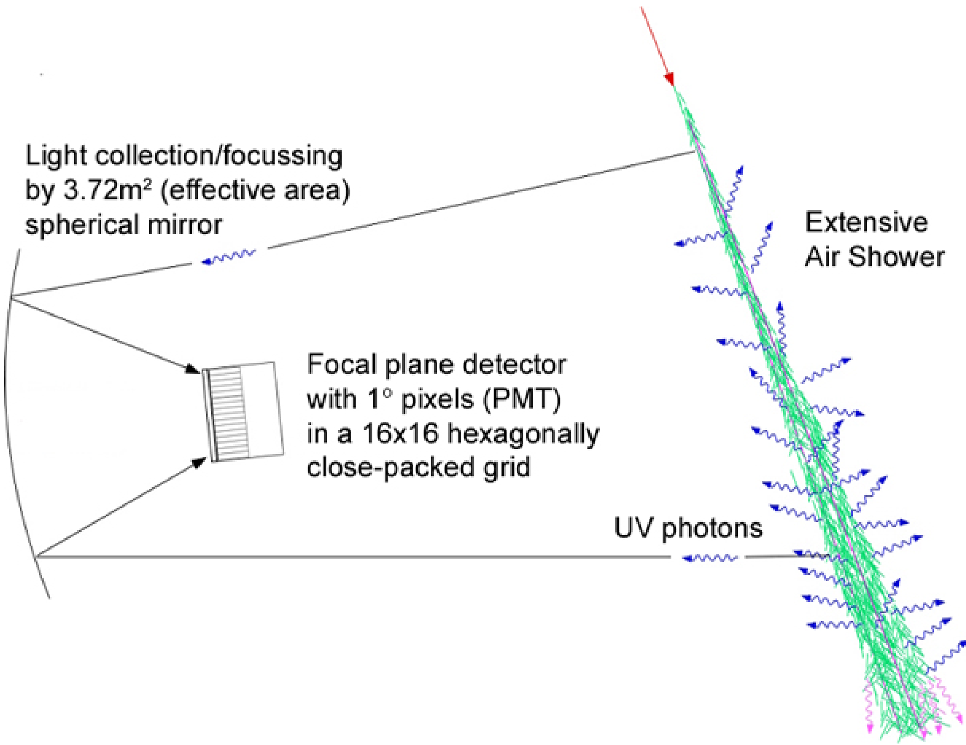




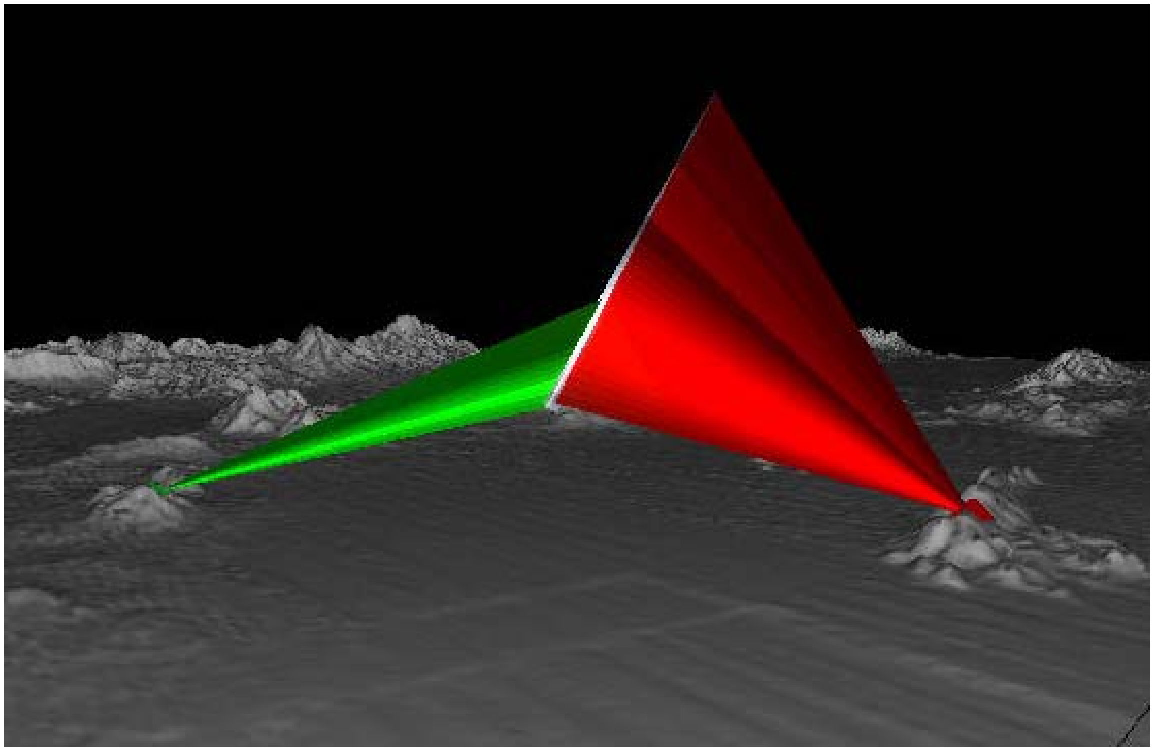
- HiRes is located on the U.S. Army Dugway Proving Ground, ~2 hours from The University of Utah campus.
- The two detector sites are located 12.6 km apart at Little Granite Mountain and Camel's Back Ridge

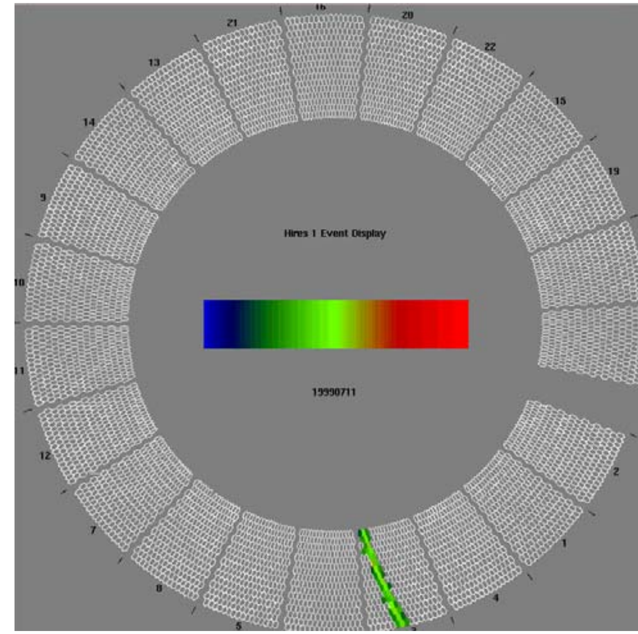
Detector Design

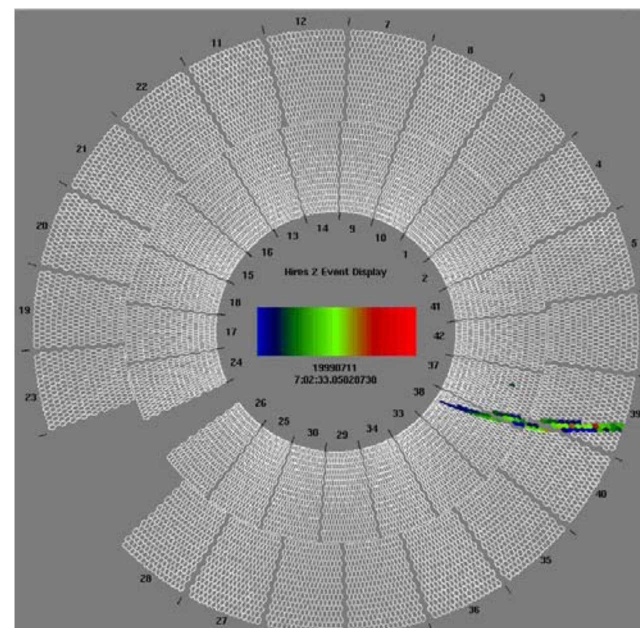
- Each HiRes detector unit ("*mirror*") consists of:
  - spherical mirror w/ ***3.72m²*** unobstructed collection area
  - 16x16 array (hexagonally close-packed) of PMT pixels each viewing ***1° cone*** of sky: giving ×5 improvement in S:N over FE (5° pixels)
  - UV-transmitting filter to reduce sky+ambient background light
  - Steel housing (2 mirrors each) with motorized garage doors



Typical HiRes Event





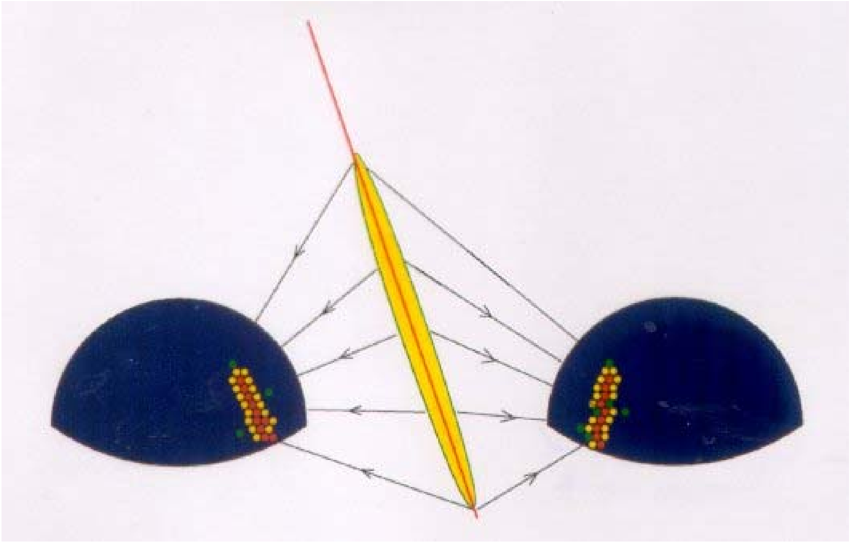


~2×10^{19}eV event seen in 1999

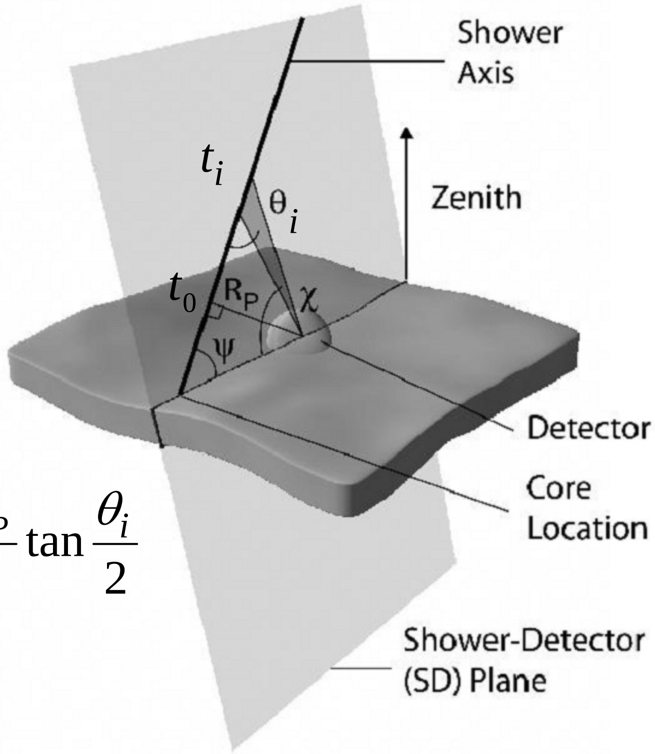
(3× vertical scale)

Reconstruction of EAS from HiRes Data

- 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.

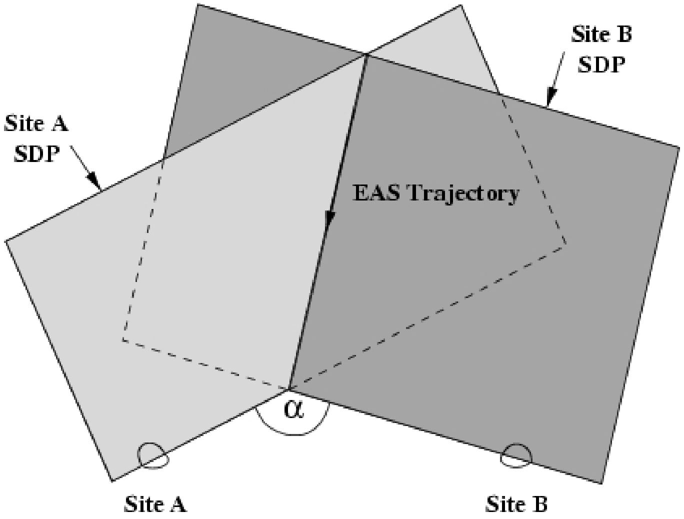


1.)



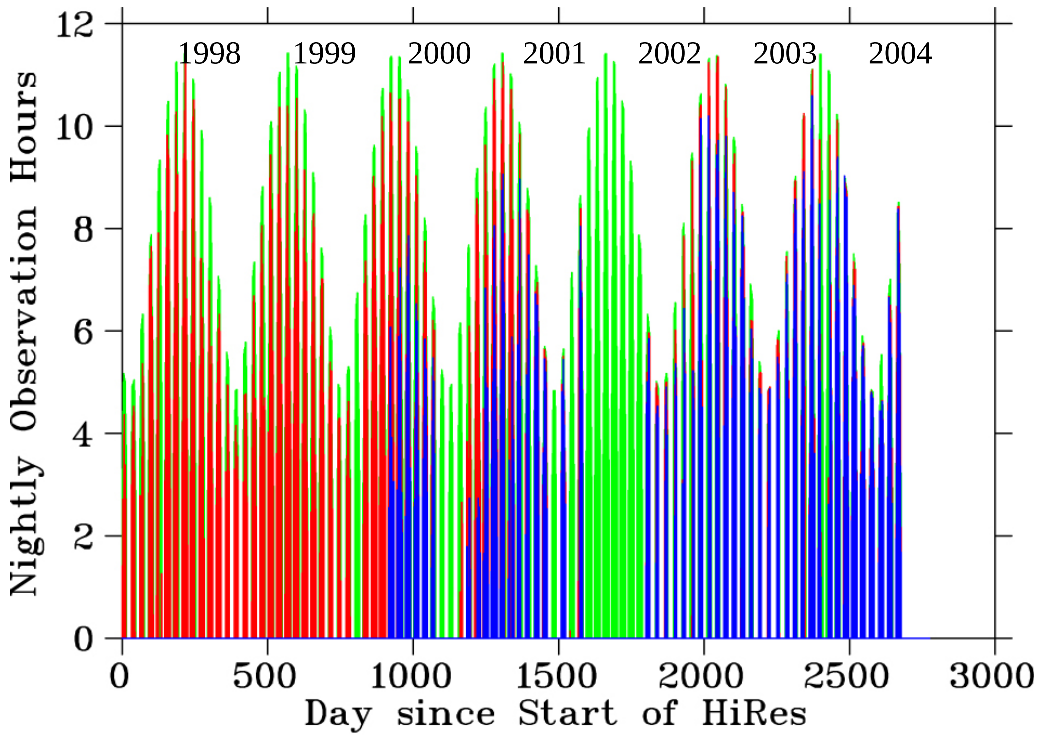
$$t_i = t_0 + \frac{R_P}{c} \tan \frac{\theta_i}{2}$$

2.)



HiRes Operations

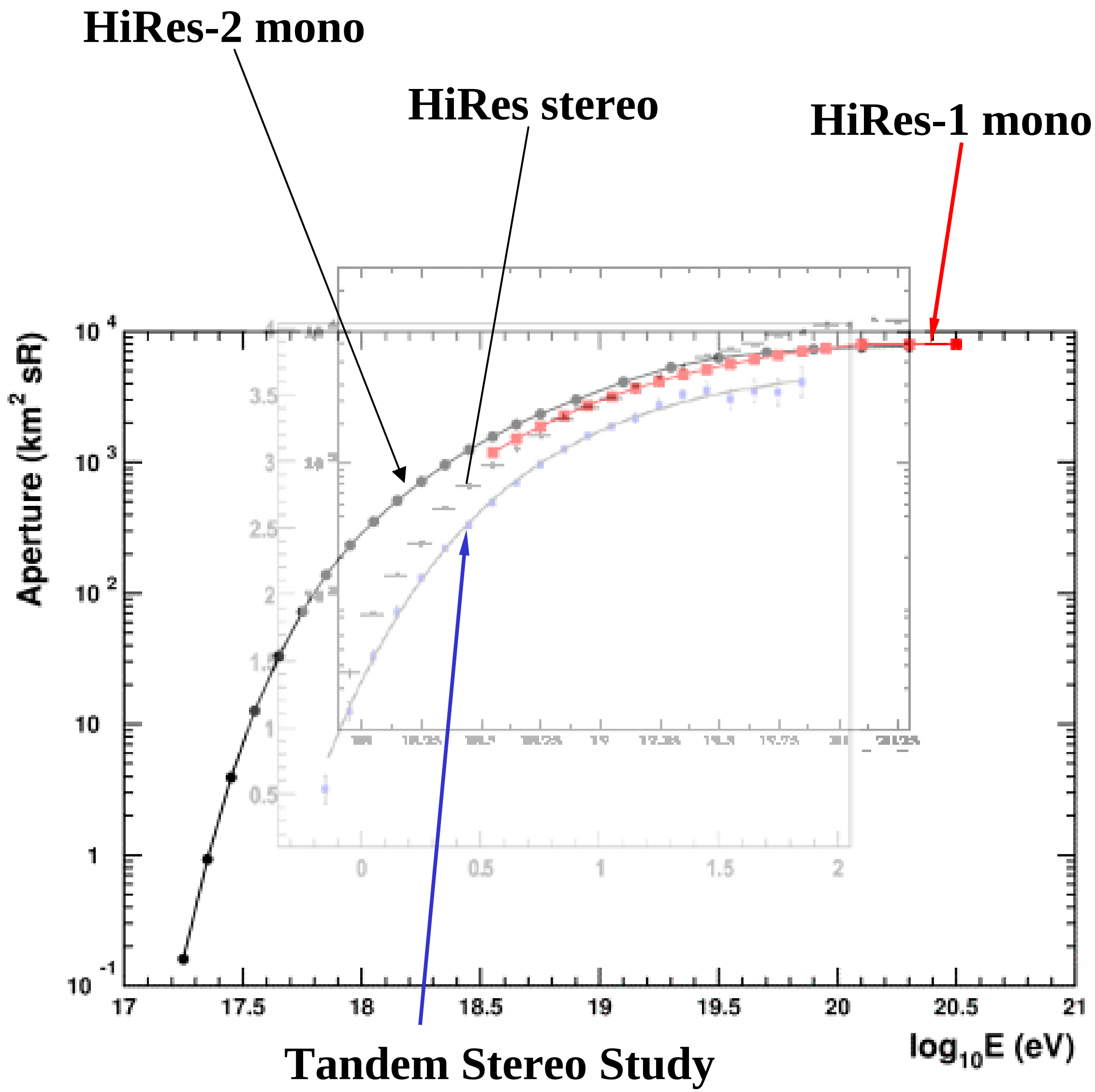
- Continuous operation of HiRes-1 detector since 1997 with 4 major down periods (7 months off after anthrax episode)
- Has been operating at 10% duty cycle since 2001-2002 shutdown



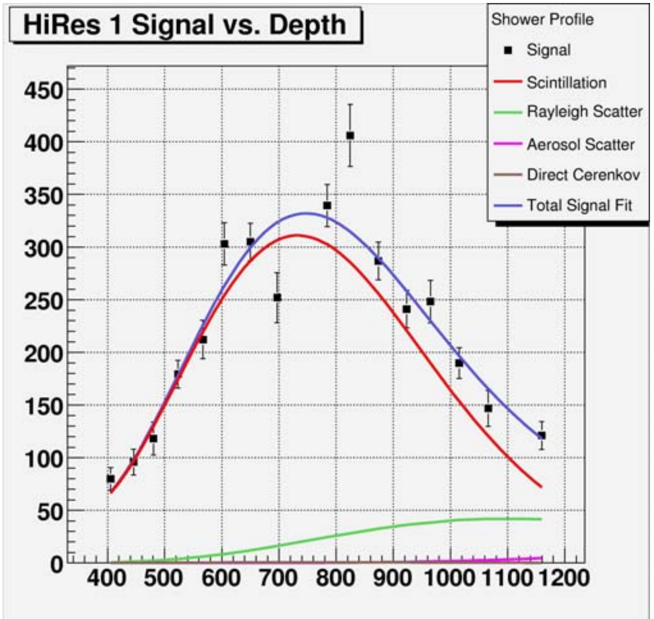
Experiment/ Data Set	Exposure(km^2sr-yr)
AGASA (100 km^2)	~1000
Fly's Eye (stereo)	150
Fly's Eye (monocular)	930
Haverah Park (12 km^2)	270
Yakutsk (25 km^2)	490
Total	2,740
HiRes-1 monocular	**~5,000**
HiRes Stereo	**~3,000**

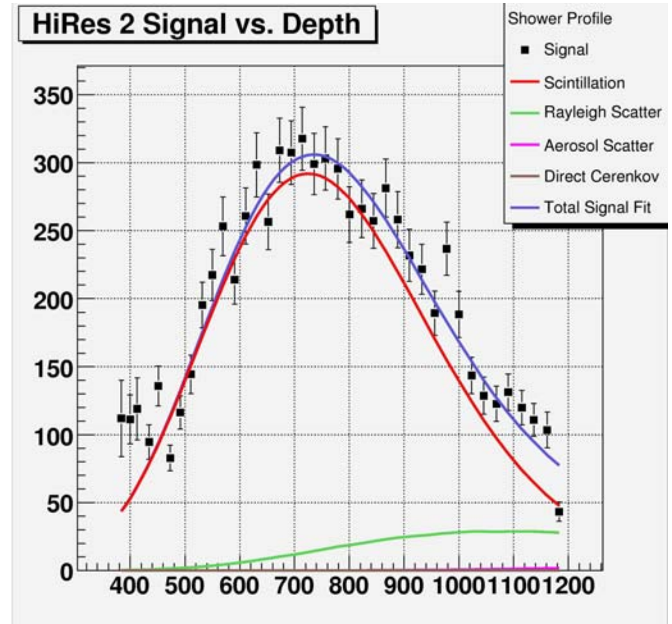
Physics with HiRes Data

- ***Stereo data***: best resolution, optimized for ***$E>3\times10^{18}$eV***
- ***HiRes-2 monocular***: can reach down to as low as ***$10^{17.2}$eV***
- ***HiRes-1 monocular*** data began ~3 years earlier: ***largest statistics***,



Measured shower profile.





Measured shower parameters.

Event by event:

- X_{max} in g/cm^2;
- Total energy of the primary particle:
- Arrival direction

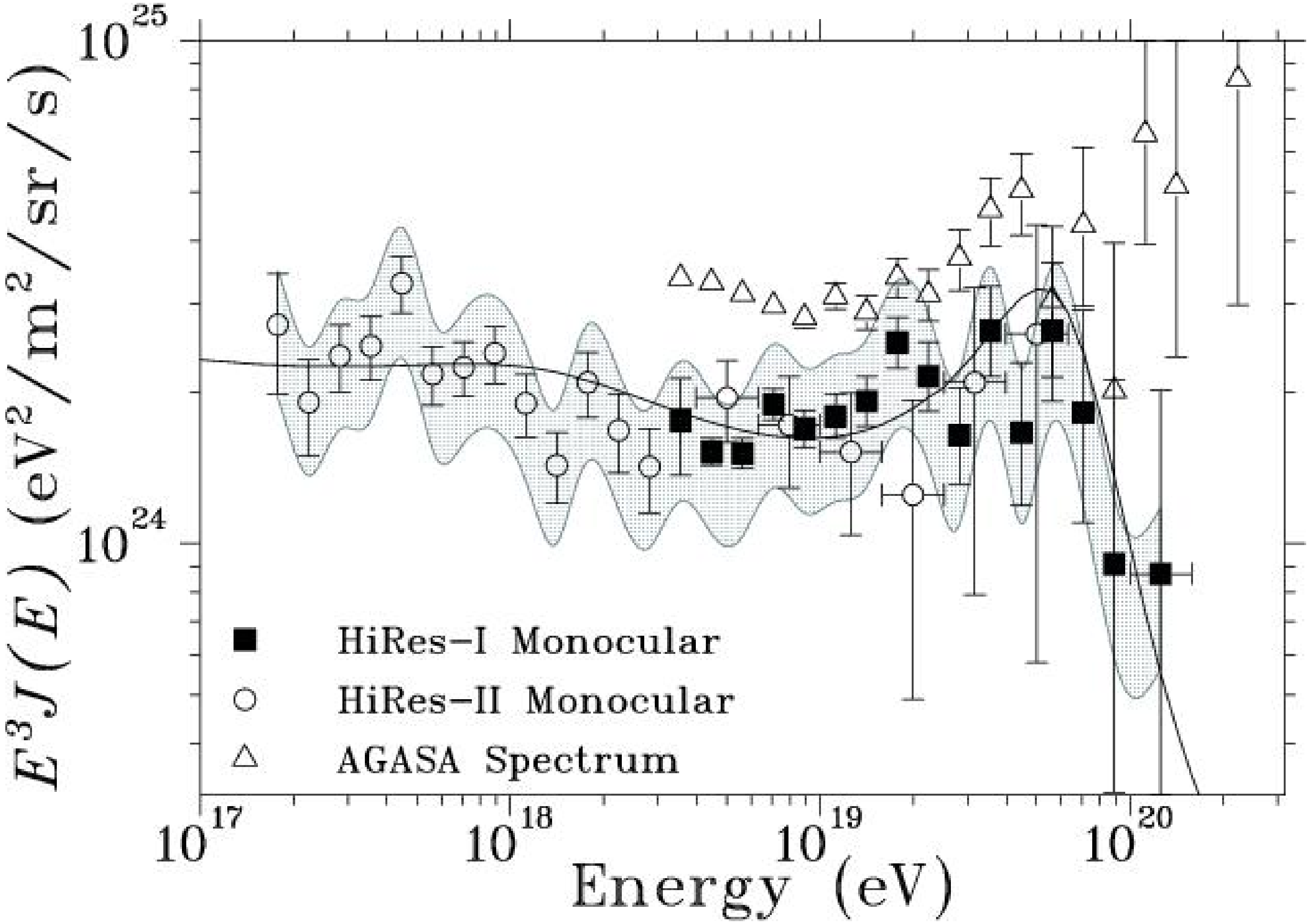
Statistically:

- composition.
- *p*-air inelastic cross-section;

Measurement of UHECR Energy Spectrum

- Combined HiRes-1 and HiRes-2 monocular spectra published:

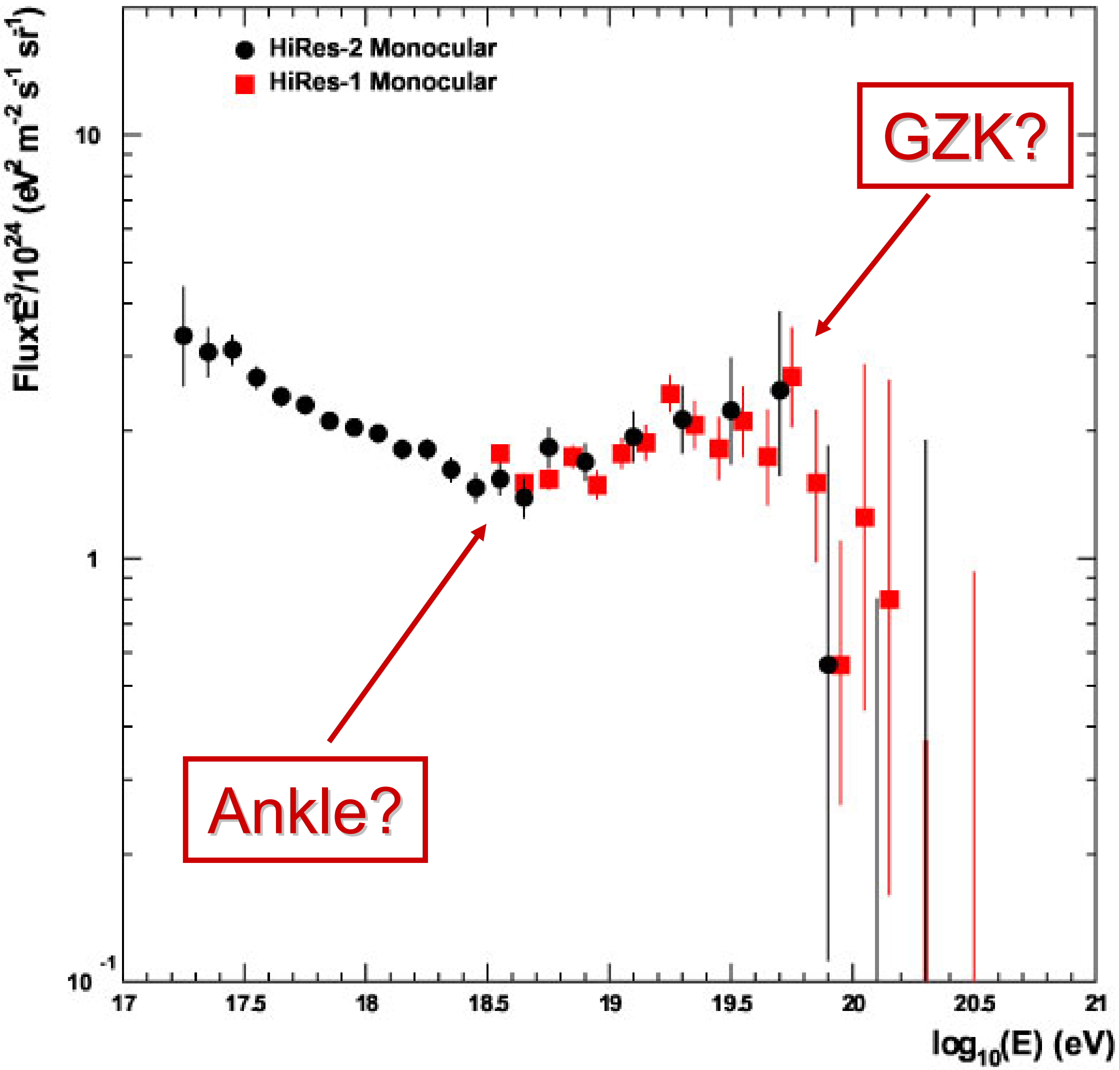
  Phys. Rev. Lett. 92, 151101 (2004)



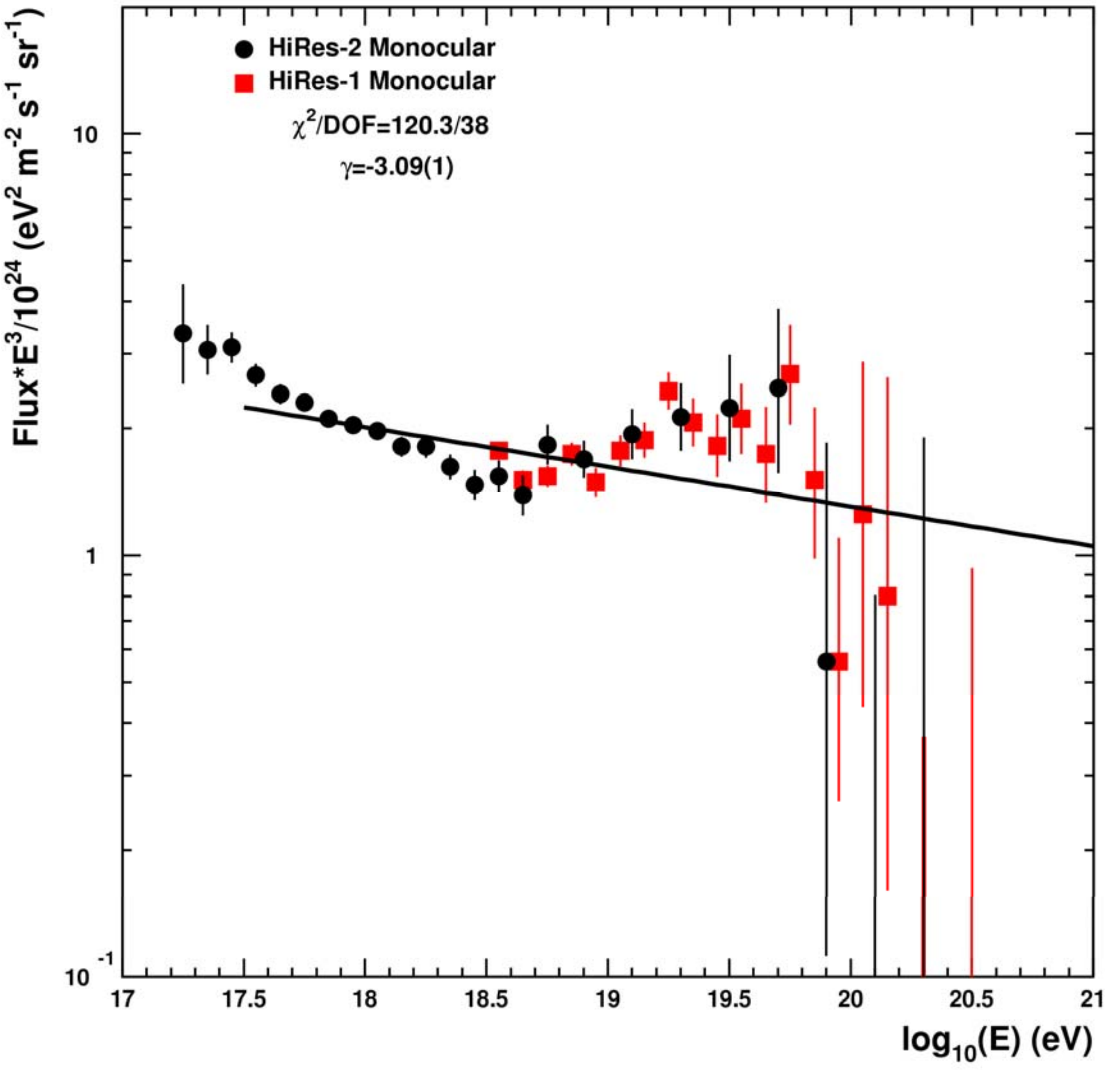
HiRes

Updated monocular spectrum:

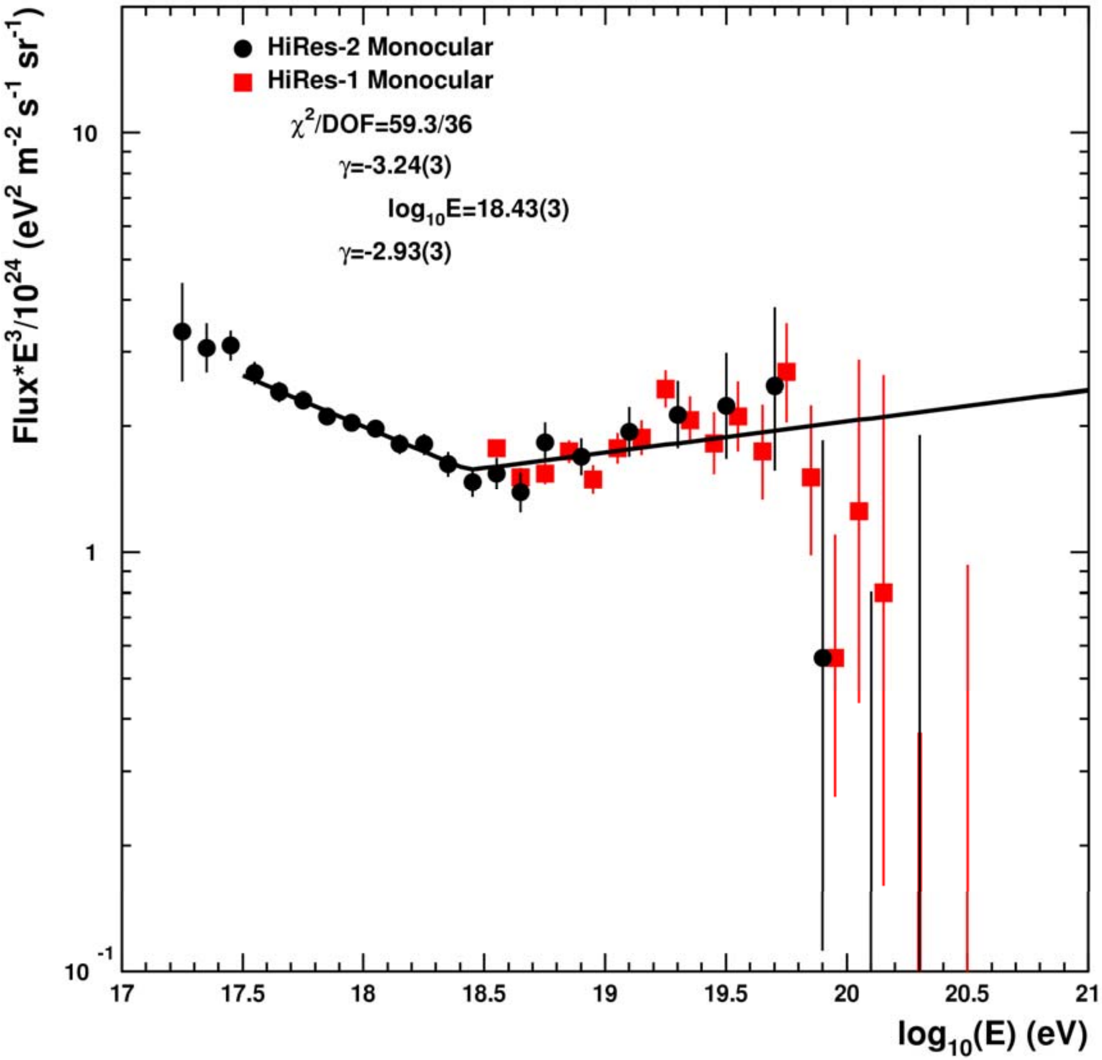
Are spectral features seen?



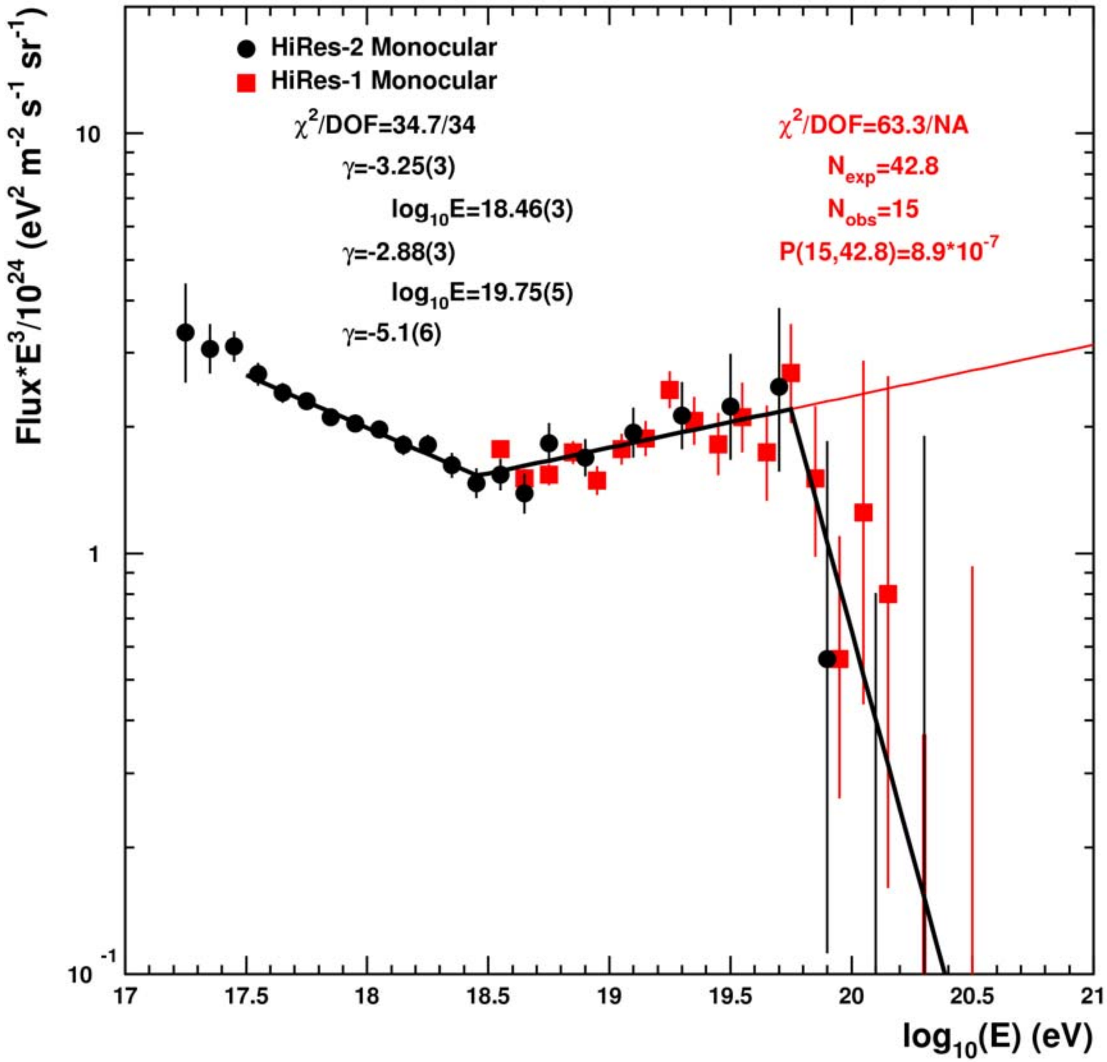
1. Single power law fit:



2. Improved fit using two-power laws with a single floating break



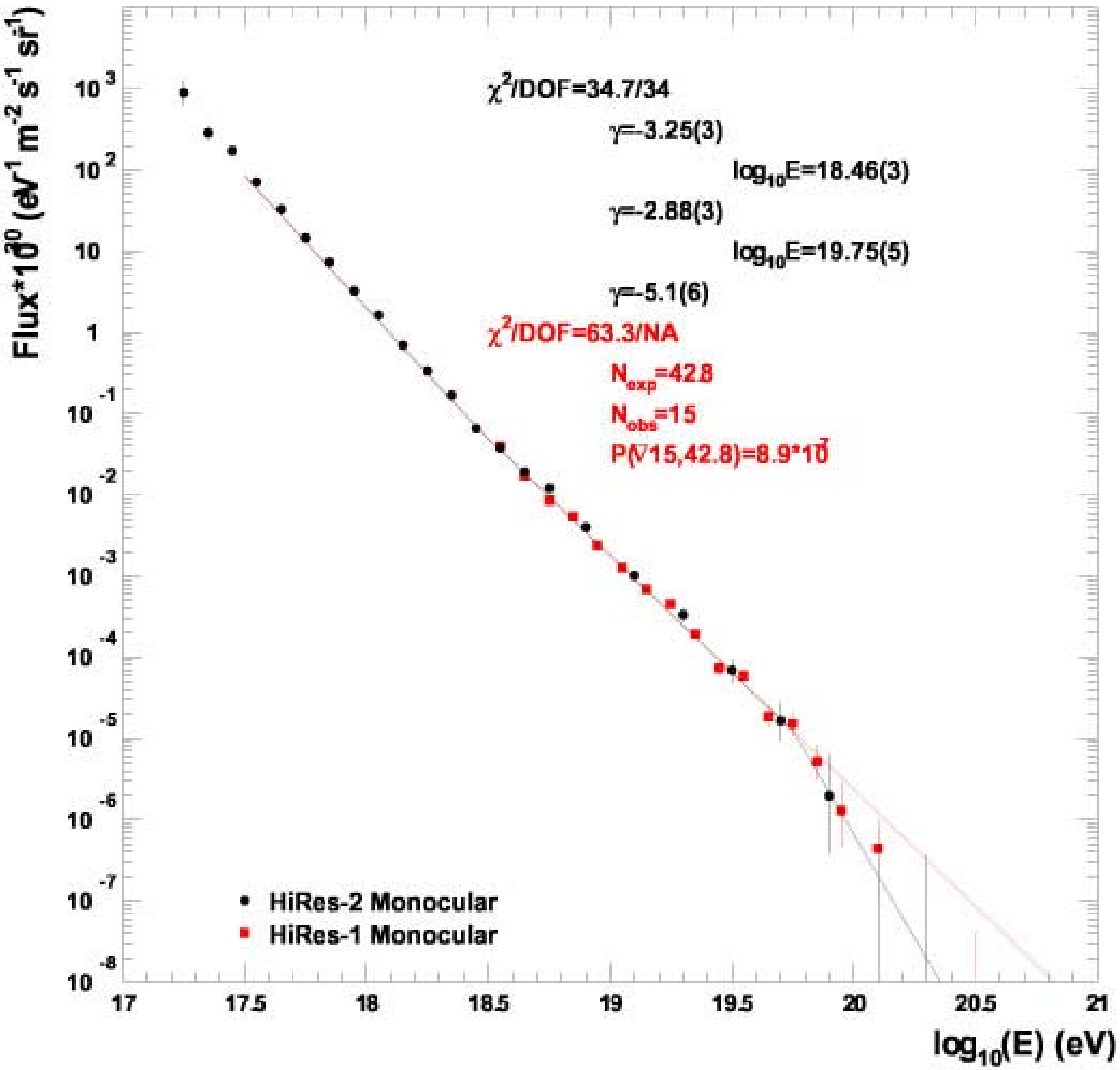
3. Still better fit using three power laws with two floating breaks



HiRes

- Significance of the deficit at high energy end relative to continuation of power law ?
- Extrapolate middle section:
  - Expect 42.8 events
  - Observe 15
  - Poisson

    $p = \sim 10^{-6}$

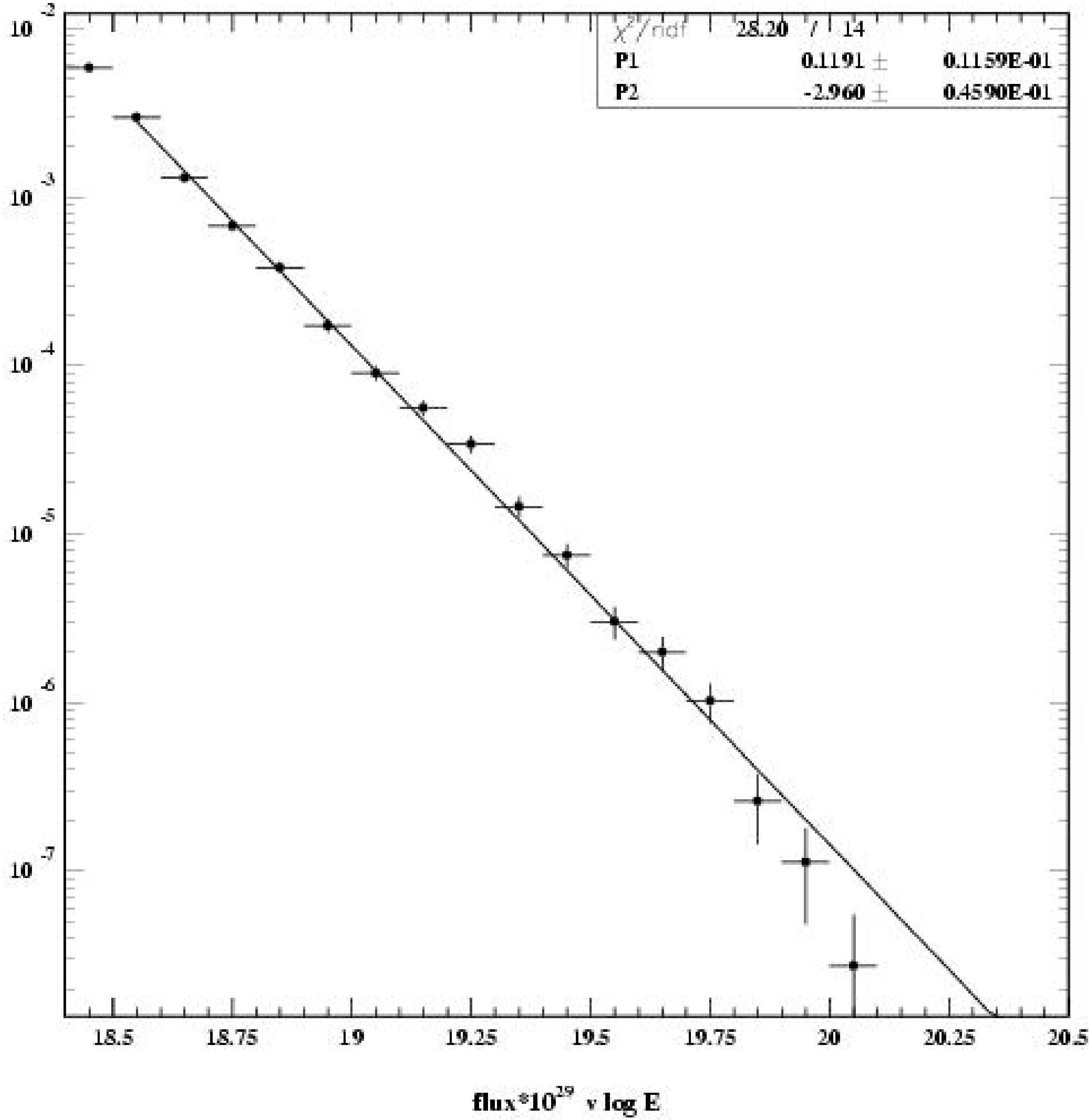


4σ is 3×10^{-5}

5σ is 3×10^{-7}

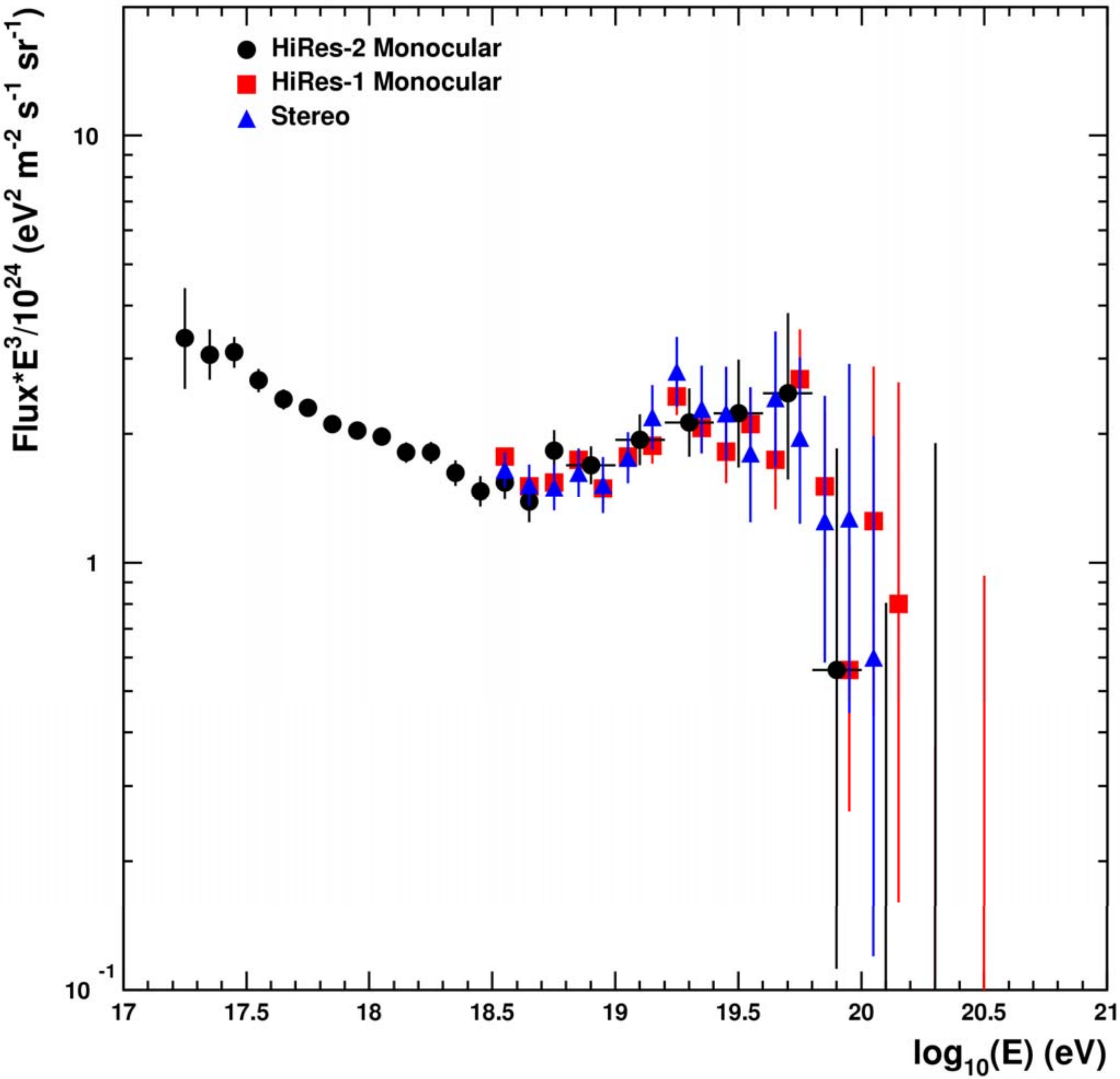
Preliminary Stereo Spectrum

- Fit to power law.
- Single index gives poor χ^2
- Evidence for changing index near $\sim 10^{19.8}$ eV

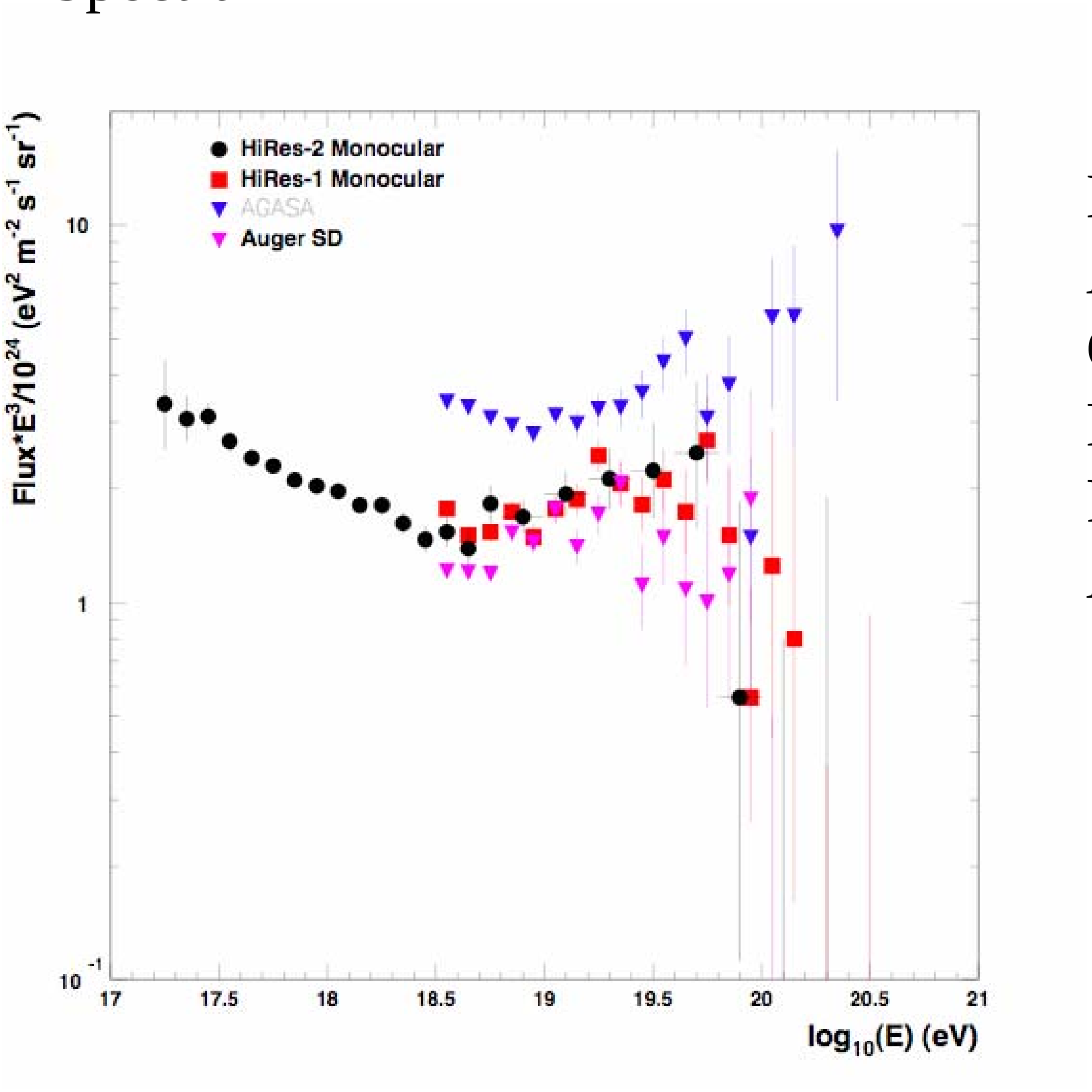


HiRes Monocular & Prelim Stereo Spectra

(Stereo Normalized to Monocular)



Comparison of HiRes, AGASA and Auger (prelim) Spectra



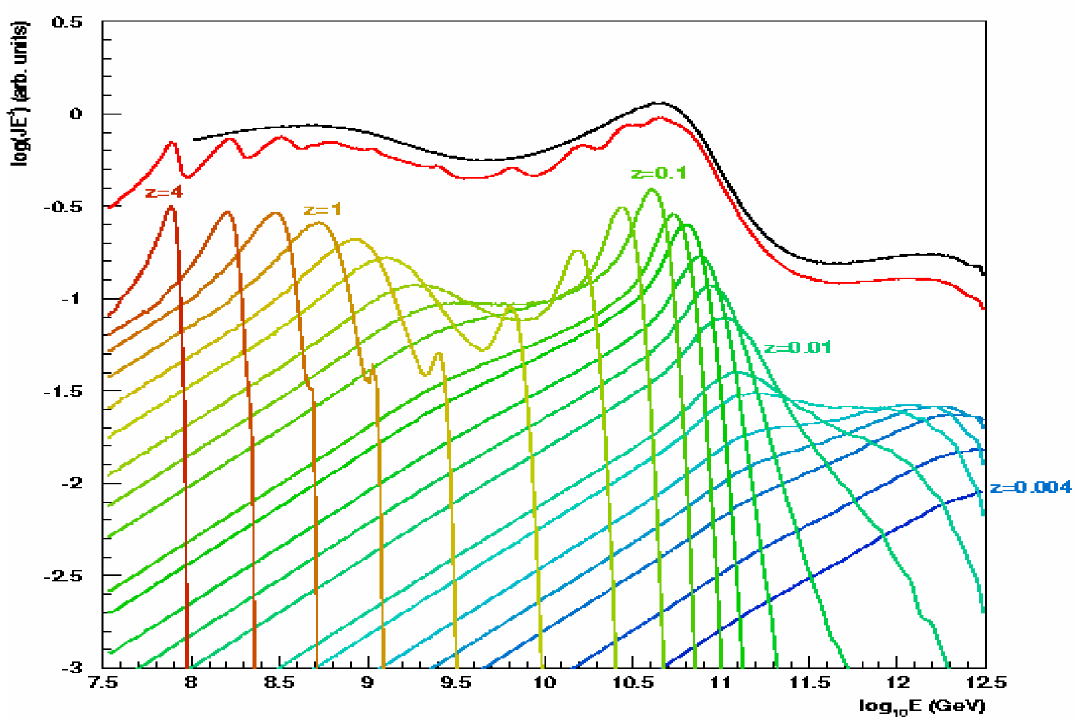
Blue triangles AGASA

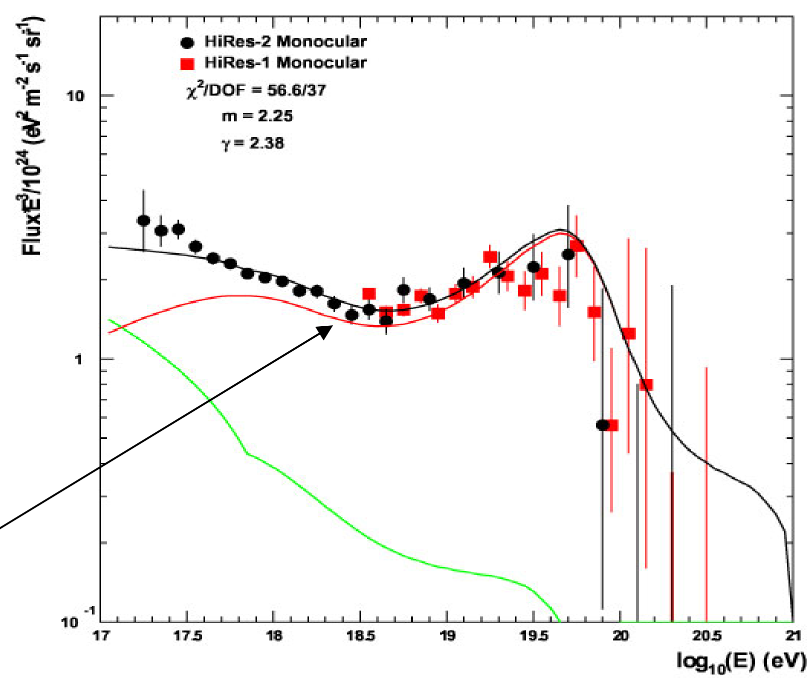
Circles - HiRes Mono

Purple triangles Auger (prelim)

Interpretation of the UHE Spectrum

- Interaction with the CMBR fractionates the extragalactic flux of protons by red-shift/age
- Observed structures can be attributed to this process
- Pile-up from pion-production causes the bump at $10^{19.5}$ eV.
- e^+e^- pair production excavates the ankle.





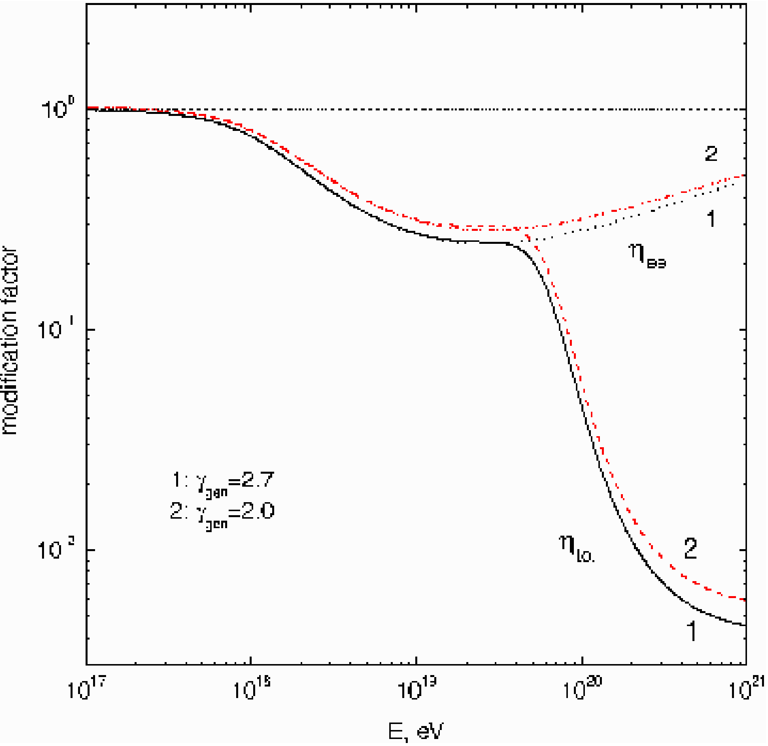
see **Phys. Letters B, in press (2005)** (arXiv:astro-ph/0501317) update shown

DIP as SIGNATURE of PROTONS INTERACTING with CMB
From V. Berezhinskii

(model independent analysis in terms of **modification factor**)
Definition:

$$h(E) = J_p(E)/J_p^{unm}(E) \qquad (3)$$

$J_p(E)$ is calculated with all energy losses included.
$J_p unm(E)$ - only adiabatic energy losses included.



Dip is stable:

- to propagation modes (rectilinear or diffusive),
- to variation of source separation (d=1-60 Mpc),
- to inhomogeneities in source distribution,
- to fluctuations in interaction.

- Transition energy $E_c \approx 1\times10^{18}$ eV is a universal value, independent of propagation mode, including different diffusion regimes.

- Prediction of the shape of the dip is robust. It is practically not modified by all known phenomena:

• propagation modes,

• inhomogeneities in source distribution,

• different distances between sources,

• fluctuations in interaction.

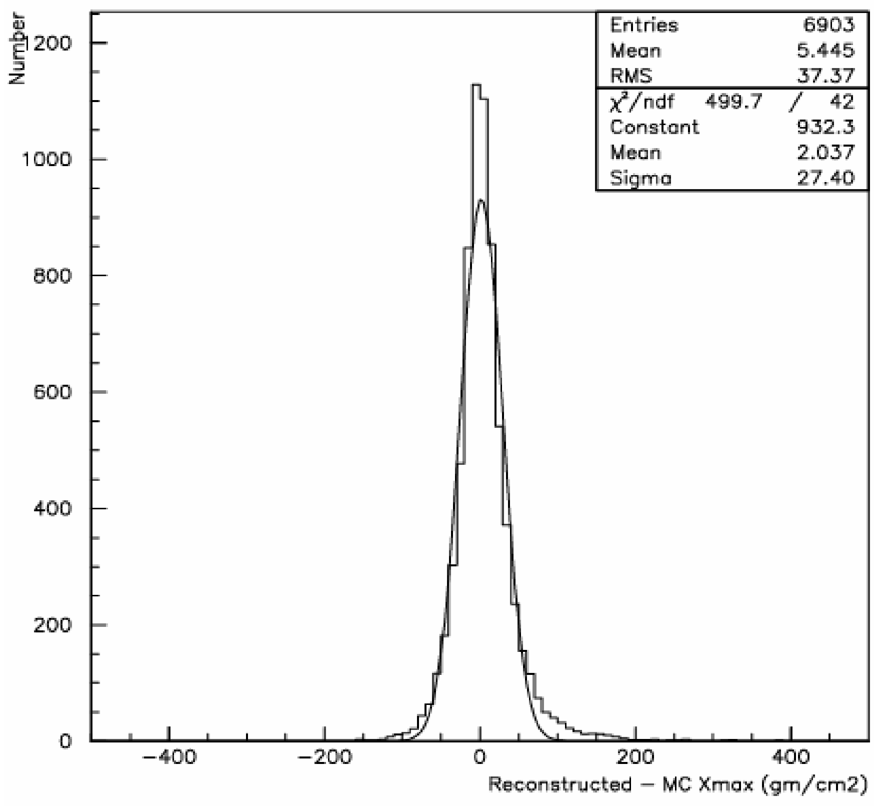
This makes the dip a more reliable signature of interaction with CMB than GZK cutoff. From V. Berezhinskii

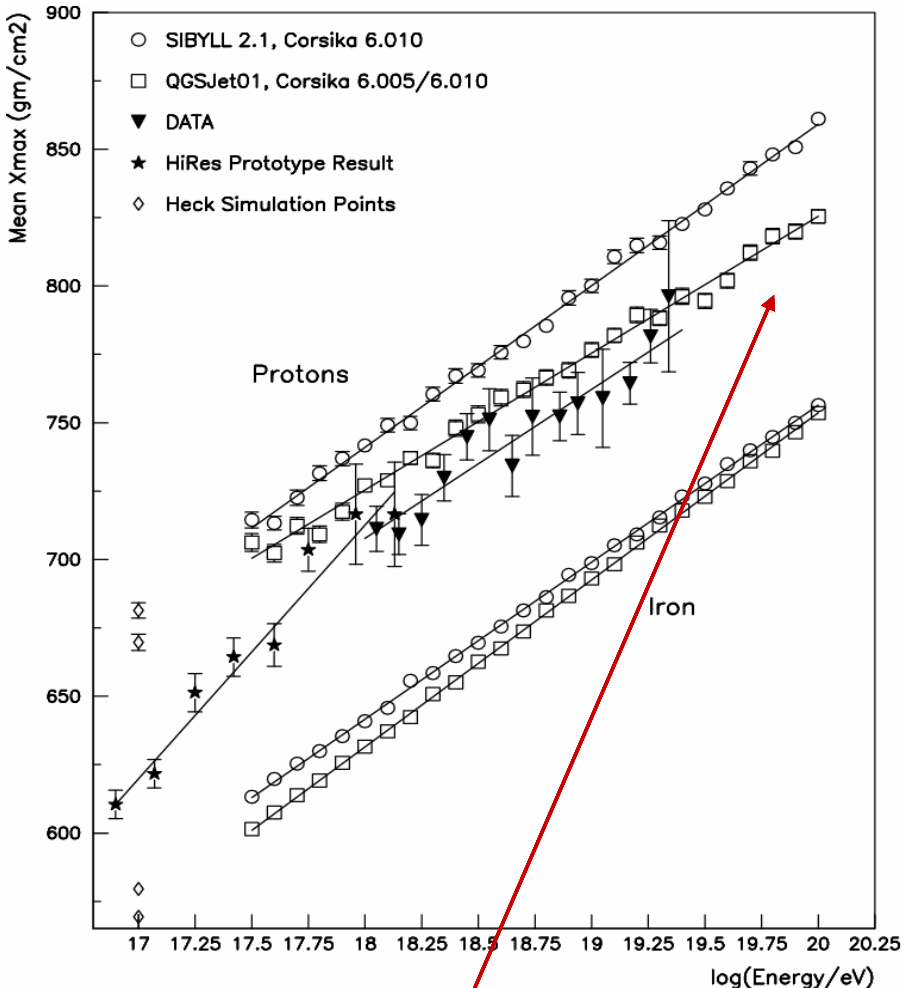
Summary of Spectrum Results

- **Monocular Spectrum**
  - Using the latest monocular data, HiRes has observed the GZK suppression
  - Ankle at ~$10^{18.6}$eV
- **Stereo Spectrum**
  - Shape consistent with monocular spectrum at 2.5x AGASA statistics
  - GZK suppression seen in stereo
  - Studies to understand absolute normalization in progress

HiRes Composition Measurement

- **Astrophysical Journal 622 (2005) 910-926**

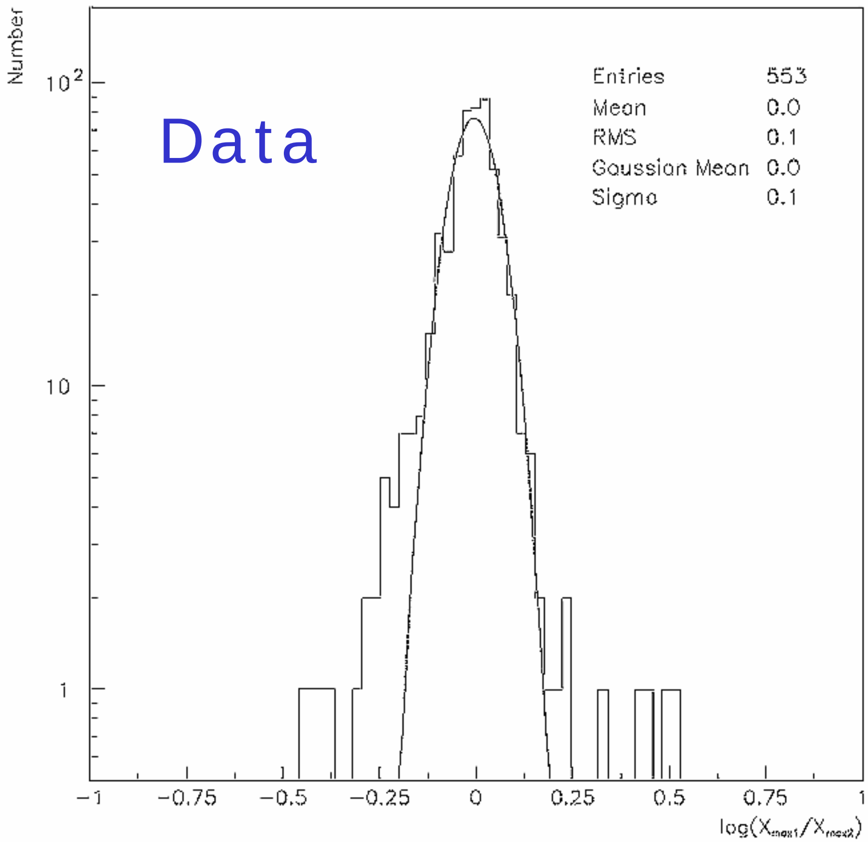


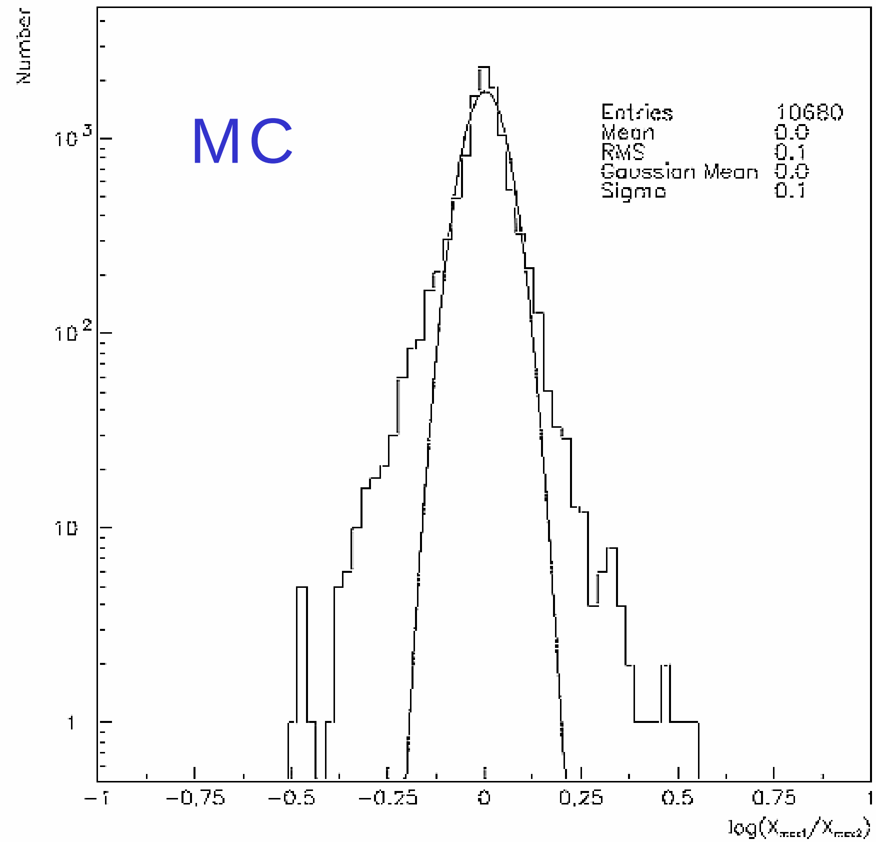


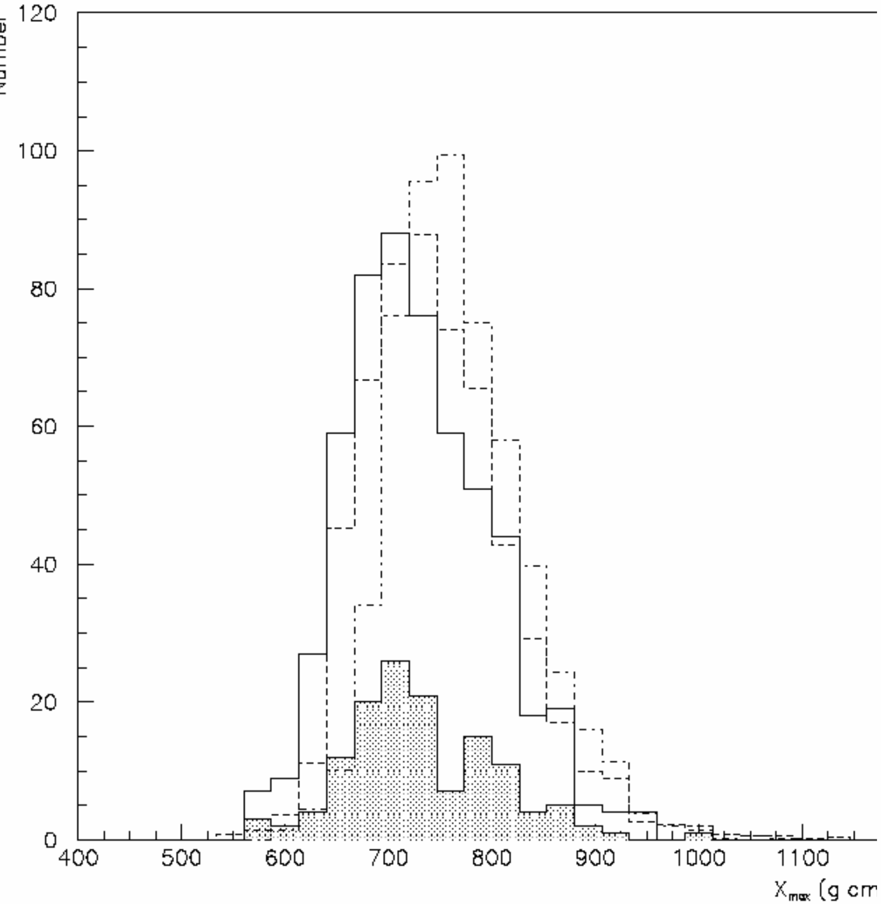
- ***Higher statistics needed to extend analysis up to the GZK Threshold!***

Stereo Xmax Measurement

- Two simultaneous measurements of the Xmax allows for ***direct verification*** of the MC resolution







g. 25.— All-energy distribution width result, protons. The solid line is the da
aded area represents the 24% of the events reconstructed with the average a
he dashed line is the QGSJet model, and the dotted line is the SIBYLL mode
gs. 22 and 26.

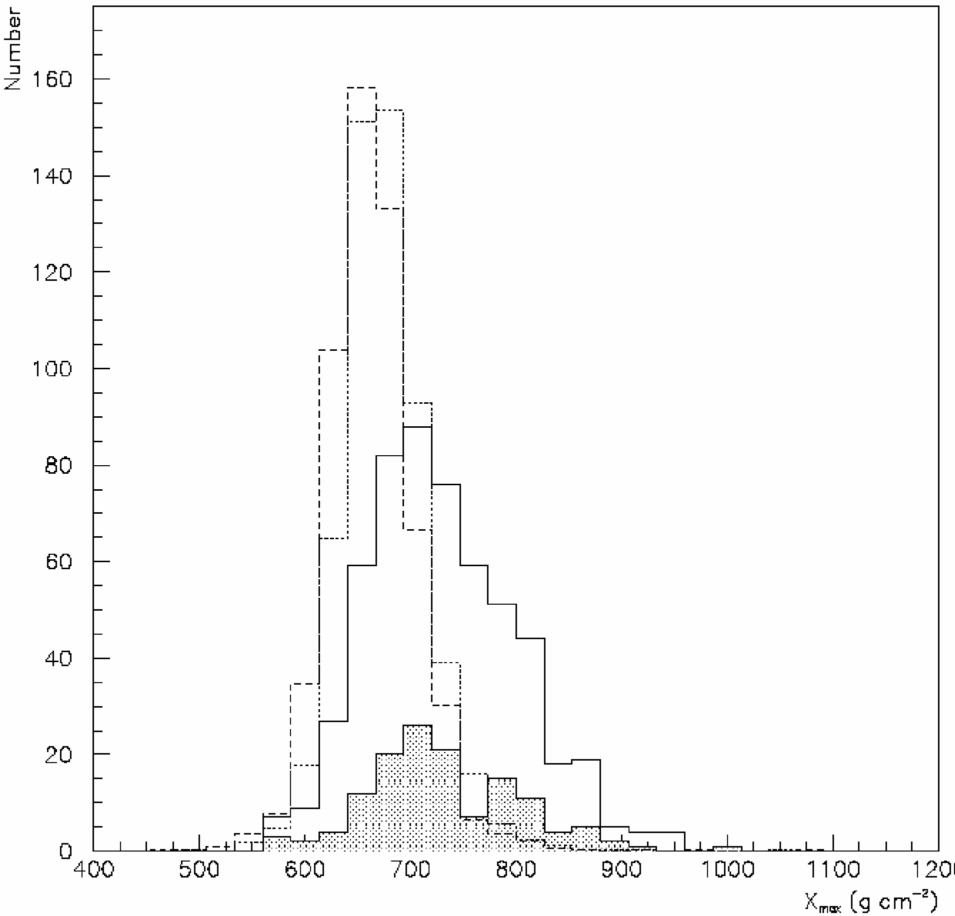
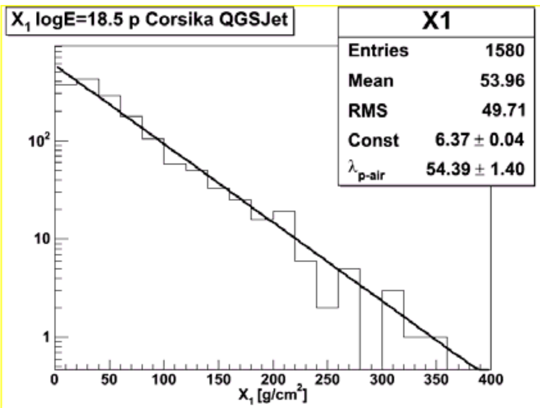


Fig. 26.— All-energy distribution width result, iron. The solid line is the data, and
shaded area represents the 24% of the events reconstructed with the average atmosph
The dashed line is the QGSJet model, and the dotted line is the SIBYLL model. Com
Figs. 22 and 25.

Measuring Cross-Section: De-convolution Method.

Point of first interaction distribution. Exponential index reflects inelastic Cross-section



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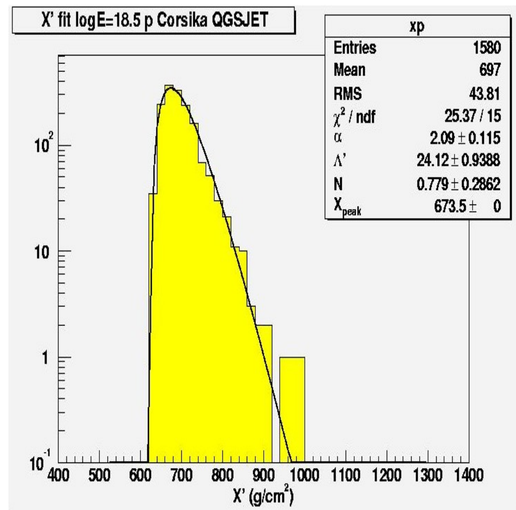
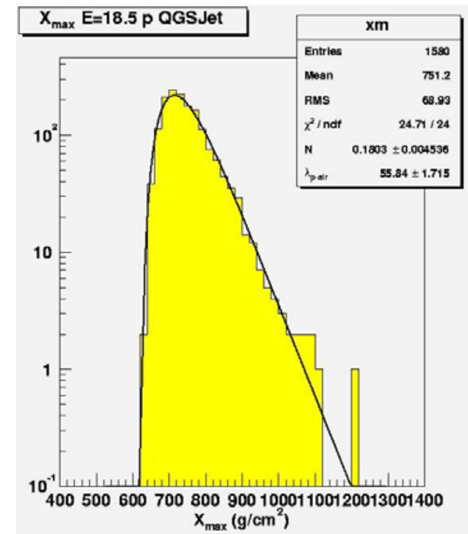
Atmospheric part of air shower fluctuations



$=$

X_{max} distribution



$$f_{\text{int}} = e^{-\frac{x_1}{\lambda_{p-Air}}};$$

$$\lambda_{p-Air} = \frac{1}{\tilde{n}\,\sigma^{inel}_{p-air}};$$

$$X' = X_{\max} - X_1$$

$$f_{fluct} = \left[\frac{x_{\max} - x_{peak} - x_1 + \Lambda'\alpha}{e}\right]^{\alpha} e^{-\frac{x_{\max} - x_1 - x_{peak}}{\Lambda'}}$$

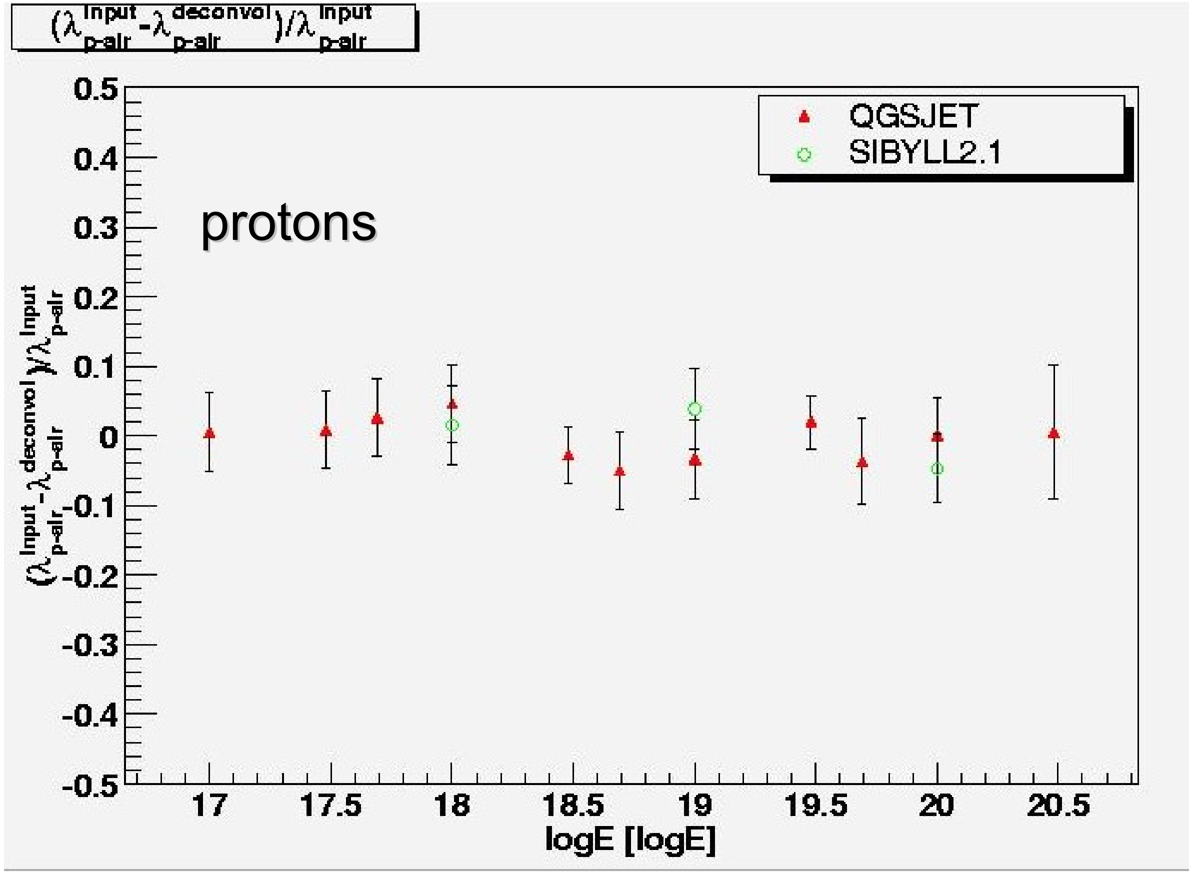
$$f_{fluct}(x_{peak}(E), \Lambda'(E), \alpha(E)) \Rightarrow f_{fluct}(E)$$

$$P_m(x_m) = N \int_0^{x_m - x_{peak} + \Lambda'\alpha} e^{\frac{-x_1}{\lambda_{p-Air}}} \left[\frac{x_{\max} - x_{peak} - x_1 + \Lambda'\alpha}{e}\right]^{\alpha} e^{-\frac{x_{\max} - x_1 - x_{peak}}{\Lambda'}} dx_1;$$

Test of De-convolution Method

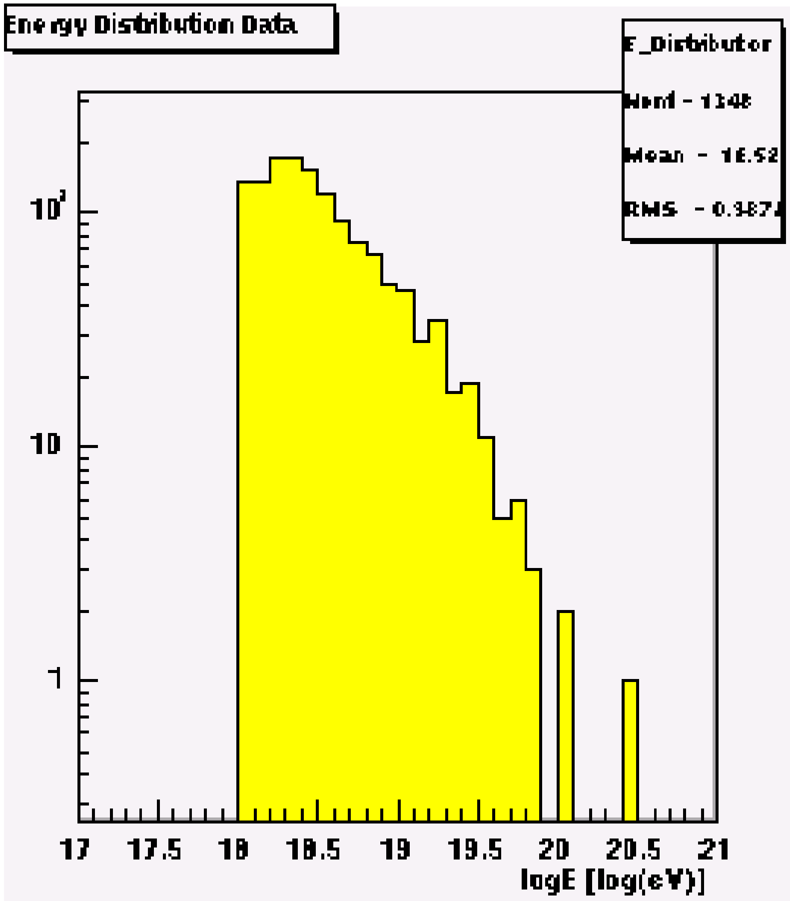
$$\frac{\lambda_{p-air}^{input} - \lambda_{p-air}^{deconvol}}{\lambda_{p-air}^{input}}$$

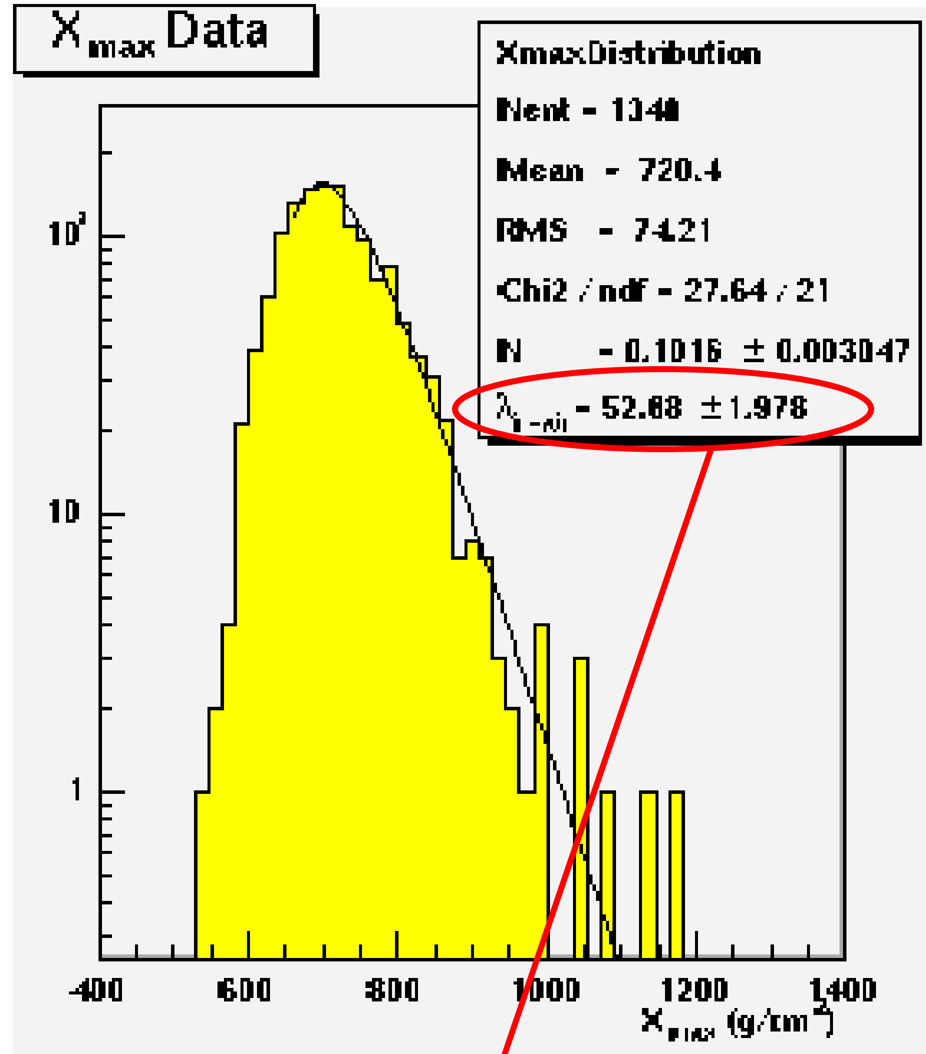
Correct within fitting errors



Deconvolution is identical for QGSJet and SIBYLL. (events through detector simulation)

Data and Deconvolution Result

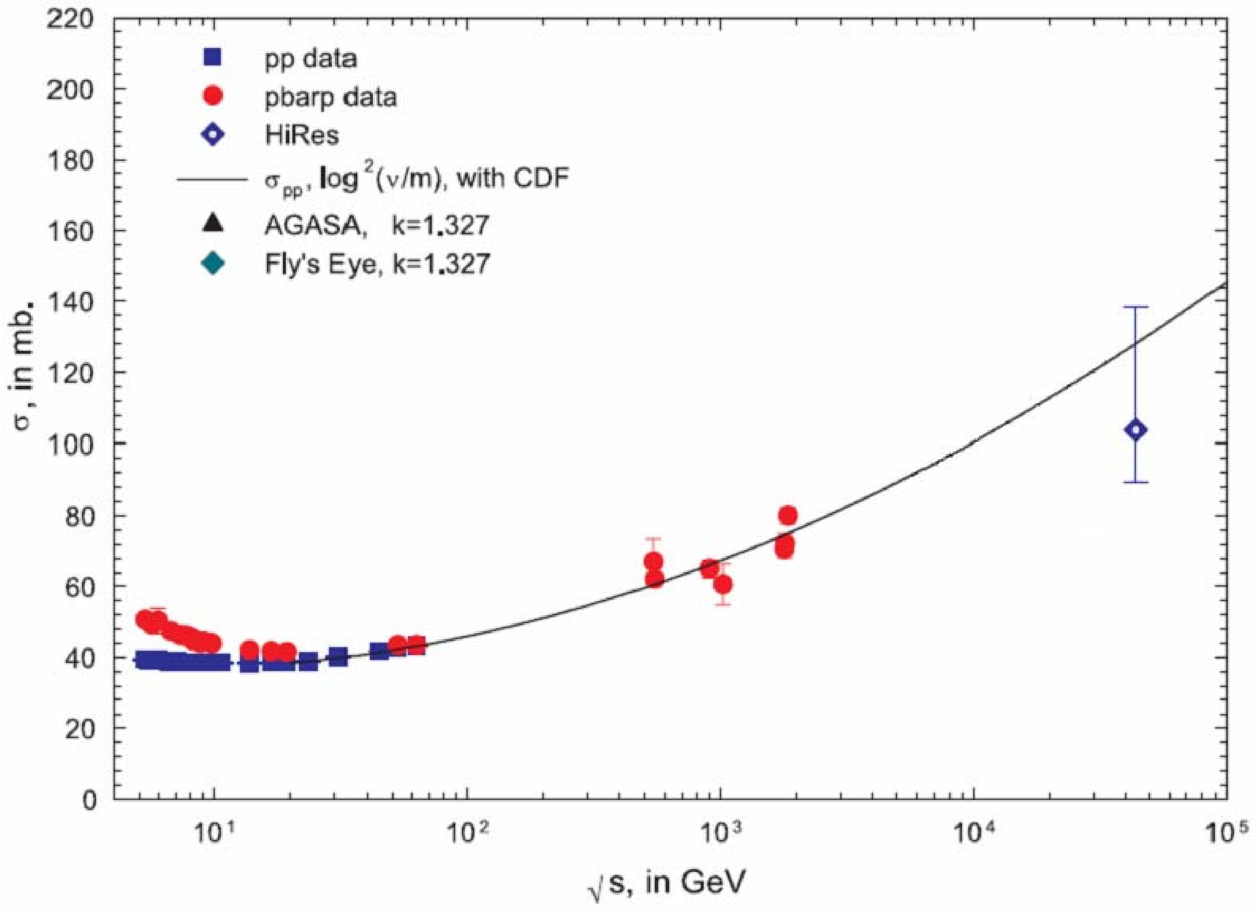




- 1348 out of 3346 stereo events pass the quality cuts (data:12/1999-3/2003)

$$\sigma_{in}^{p-Air} = 456 \pm 17\ mb$$

HiRes Measurement



- HiRes: $\sigma_{in}^{p-Air} = 456 \pm 17\,(stat) + 39(sys) - 11(sys)\ mb$ at $10^{18.5} eV$

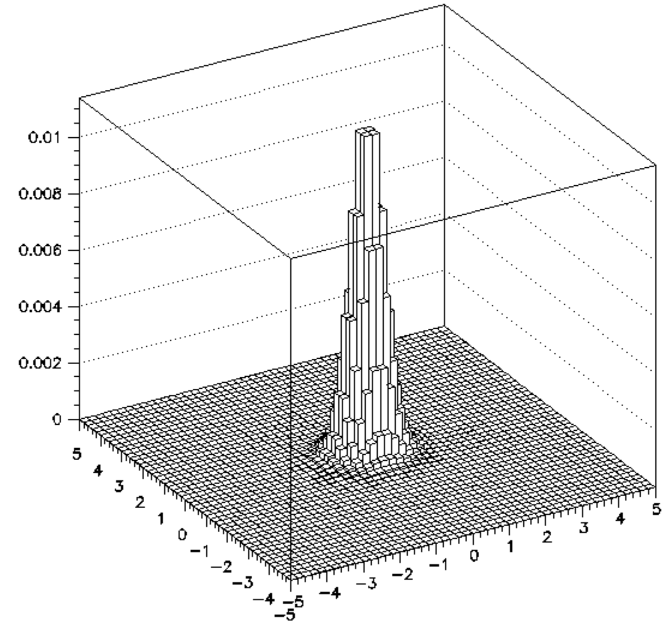
HiRes Anisotropy Results

Monocular Anisotropy Results

- ***Autocorrelation functions*** (histogram of $\cos\theta$ between all possible pairs) for HiRes-1 monocular (left) and AGASA (right) events above ~4×10^{19}eV
  Astropart. Phys. 22, 139 (2004)
- Search for dipole enhancement in the direction of nearby a-priori sources: ***null results*** for the ***Galactic Center, Centaurs A, and M87***
  Astropart. Phys. 21, 111 (2004)
- Point source search: null result
  Submitted to Astropart Phys.
- Search for cross-correlation with AGASA doublets and triplet:
  - Observed overlap no greater than that expected by chance from an isotropic

  Submitted to Astropart Phys.

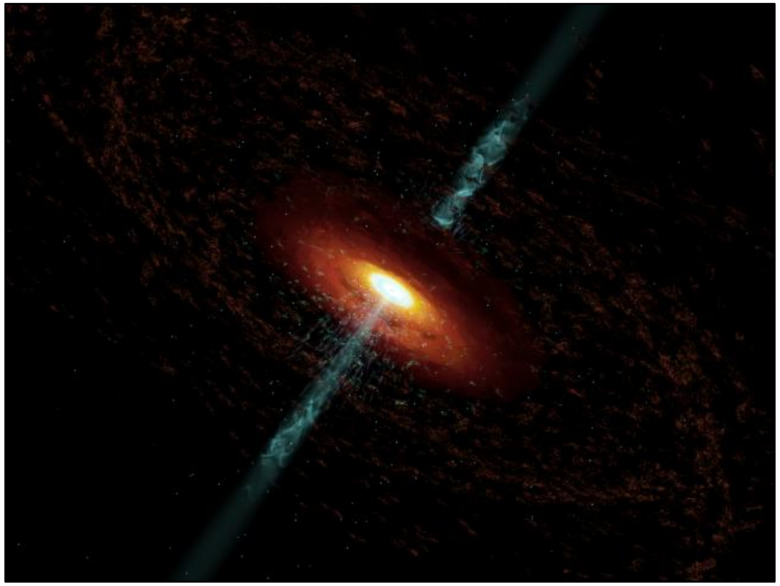
Stereo point spread function



Stereo Anisotropy Results

- Stereo angular resolution ***~0.6°***
- HiRes stereo data ($E > 10^{19}$ eV) is consistent with isotropy at all small angular scales
  Astrophys. J. Lett. 610 (2004) L73
- Search for Point Sources of Ultra-High Energy Cosmic Rays above 4.0 10^{19} eV Using a Maximum Likelihood Ratio Test
  Astrophys. Journal 623 (2005) 164

Correlation with BL Lacertae Objects



- BL Lacertae Object - special type of blazar, active galaxy with jet axis aligned with our line of sight.
- Blazars are established sources of TeV gamma-rays
- Candidates for accelerating cosmic rays to EeV energies

Somewhat controversial recent history regarding correlations of UHECR with BL Lac objects:

Tinyakov and Tkachev, JETP 74 (2001) 445.
Tinyakov and Tkachev, Astropart. Phys. 18 (2002) 165.
Gorbunov et al., ApJ 577 (2002) L93.
Evans, Ferrer, and Sarkar, Phys.Rev. D67 (2003) 103005.
Torres et al., Astrophys.J. 595 (2003) L13.
Gorbunov et al., JETP Lett. 80 (2004) 145.
Stern and Poutanen, ApJ 623 (2005) L33.

Gorbunov BL Lac Correlation: New Claim

Magnitude	Redshift	6cm Radio Flux	# Obj.	CR Sample	# CRs	Bin Size	# Pairs	Prob.
Catalog: Veron (10th Ed.) BL Lacs			156	HiRes > 10 EeV	271	0.8°	10	10^{-3}
m < 18	no cut	no cut		Need to test with new data				

The 0.8° angular bin size was optimized by Gorbunov et al.

It is preferable to perform an ***unbinned*** maximum likelihood analysis, using the individual errors of each event.

We performed an analysis similar to that used in the point source search, modified for a multiple-source hypothesis. We find for E > 10 EeV:

Estimated number of source events: $n_s = 8.0$

(~ *excess* of events correlating with BL Lacs)

Fraction *F* of isotropic MC sets with stronger signal: $F = 2\times10^{-4}$

HiRes

Maximum Likelihood Method for Multiple Sources

We hypothesize that n_s events come from a source, and $(N-n_s)$ come from background. For just one source, the partial probability for the ith event is

$$P_i(n_s) = n_s Q(x_i) + (N-n_s)\, B(x_i)$$

$Q(x_i)$ is the probability that the ith event could come from the source, give angular resolution of the event and the distance to the source.

$B(x_i)$ is the probability that the ith event could come from background, giv HiRes acceptance to the location x_i of the event in the sky.

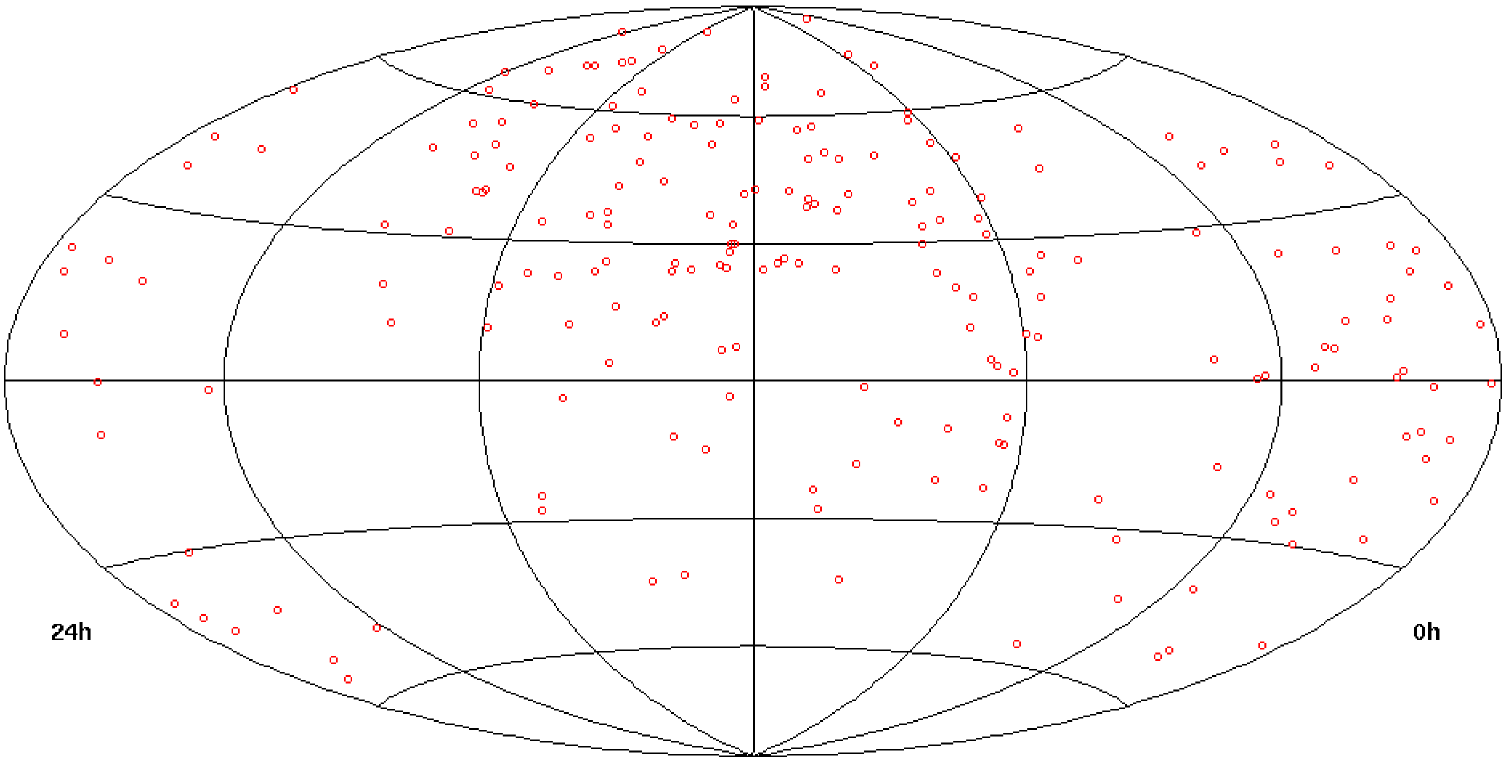
We let $L(n_s)$ = Product $P_i(n_s)$, and find the value of n_s which maximizes t

$$R = L(n_s) / L(0)$$

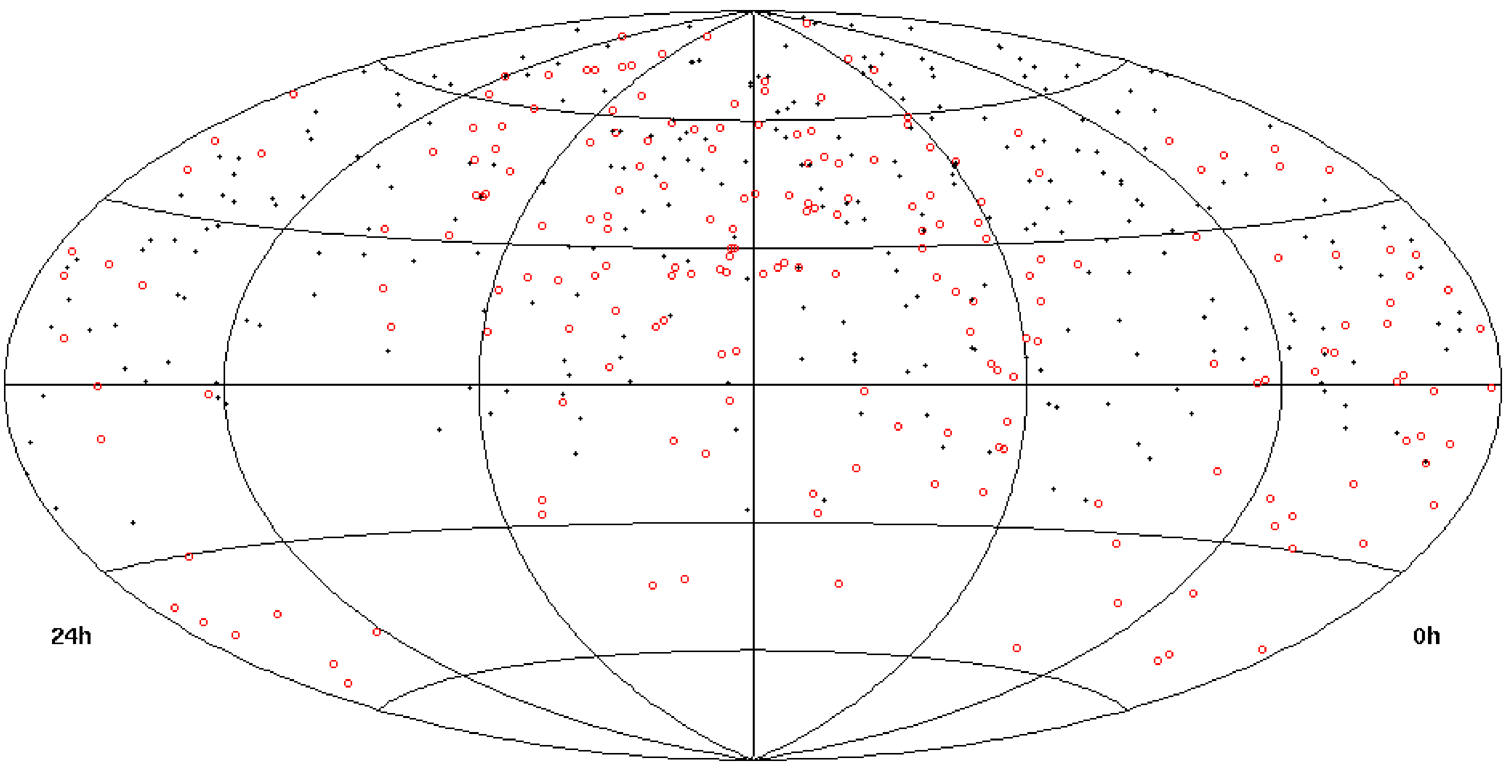
For the present case with many sources, we adopt the following simple hy an ensemble of equal luminosity sources, where the jth source is weighted HiRes exposure to the source's location:

$$Q(x) = \text{Sum} \left(Q_j(x)\ W_j / (\text{Sum } W) \right)$$

Confirmed BL Lacs m>18 (10th Veron)



+ HiRes Events E>10^{19} eV



BL Lac Correlation: Energy Dependence

- Modify Energy Threshold:

  10^{19} eV threshold is due to the fact that HiRes originally published only the arrival directions of events above this energy.

  In the event these particles are neutral, an energy cut doesn't make sense.

  If we perform the analysis on ALL the events below 10^{19} eV , there is a weaker correlation: $n_s = 22$ with $\ln R = 3.10$.

  The fraction of isotropic MC sets with stronger signal is $F = 6\times10^{-3}$. This is an independent data set, not used previously.

  For the combined HiRes data set (all energies), the result is: $n_s = 31$, $F = 2\times10^{-4}$

BL Lac Correlation: Source Sample

- Confirmed BL Lacs in the Veron Catalog are classified as "BL" or "HP" (latter for relatively high degree of polarization).
- So far, only "BL" have been considered. Not clear why.
- If we perform the analysis on the 47 "HP" BL Lacs (using the same m<18 cut as was used for "BL") and HiRes events above 10^{19} eV , we find: $n_s = 3.0$, with $F = 6\times10^{-3}$.
- For the complete set of confirmed BL Lacs (i.e. "BL" + "HP") with m<18, and HiRes events above 10^{19} eV , we find: $n_s = 10.5$, with $F = 10^{-5}$.
- We have performed all of the same tests using BL Lacs with m>18, and no correlation is found.

TeV BL Lac Correlation

- Six BL Lacs are confirmed sources of TeV g-rays. Five are in the northern hemisphere and well observed by HiRes.
- We perform the maximum likelihood analysis on each source individually using all HiRes events:

Name	z	V Mag	n_s	F
Mrk 421	0.03	12.9	0.3	0.2
H1426+428	0.13	16.5	0	0.4
Mrk 501	0.03	13.8	3.3	6×10^{-4}
1ES1959+650	0.05	12.8	2.0	8×10^{-3}
1ES2344+514	0.04	15.5	0	0.7

- For the TeV blazars taken as a set, the ML analysis yields:

All energies: ns = 5.6 with $F = 10^{-3}$

Summary of BL Lac Correlation:

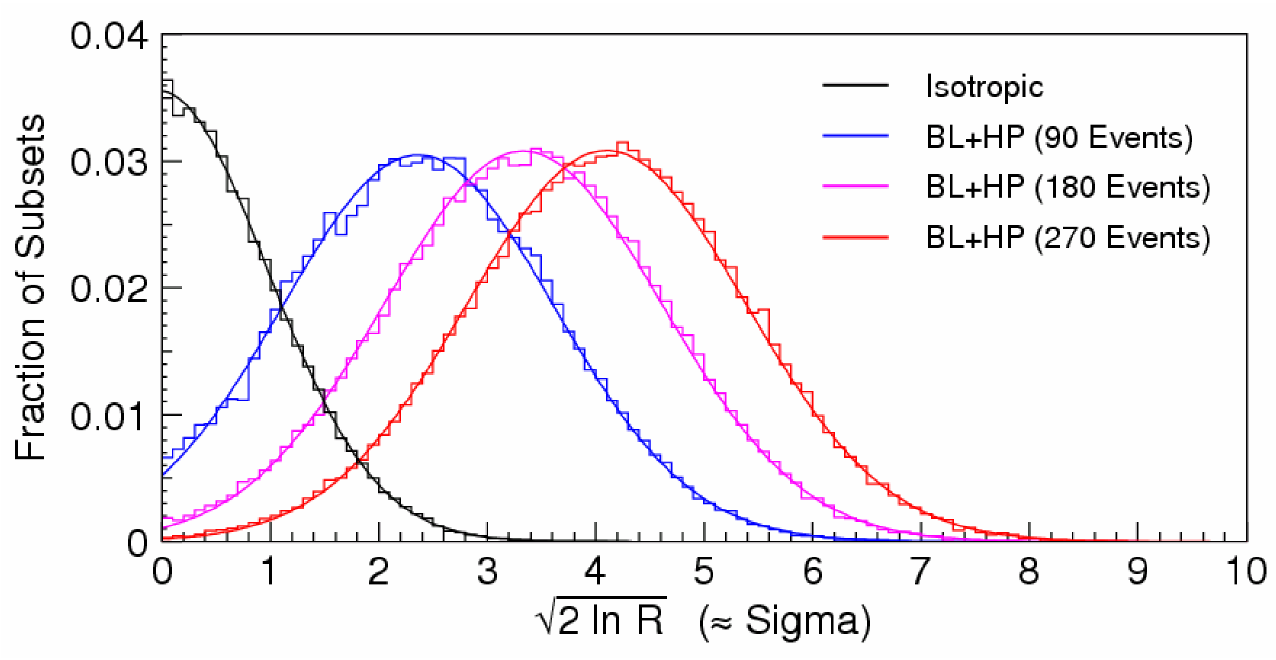
- "BL", m<18, all HiRes events (no E cut): ***F* = 2×10^{-4}**
- "BL+HP" with m<18, HiRes E>10 EeV: ***F* = 10^{-5}**
- Confirmed TeV blazars, all HiRes events (no E cut): ***F* = 10^{-3}**
- **These are not independent results: the samples overlap.**
- Analysis has been *a posteriori*, so above *F* values are not true chance probabilities.
- **Correlations must be tested with independent data before any claim can be made.**
- Arrival directions of past year of data have not been analyzed. Data taking through March 2006 will yield an independent data set ~70% of the current sample size: Independent test of BL Lac correlations should be possible

BL Lac Correlation: Sensitivity of Future Data

We estimate the sensitivity which future HiRes data will have by resampling the real HiRes events (Bootstrap resampling)

We simulate 1, 2, 3 years of new data to estimate the distribution of possible signal strengths if the observed correlations are real.

(Arrival directions of past year of data have not been analyzed.)



Proposal for the U.S. Part of the Telescope Array (TA) Experiment, Including the TA Low Energy Extension (TALE)

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*University of Utah**

J. Belz
*University of Montana**

D.R. Bergman and G.B. Thomson
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Institute for High Energy Physics, Beijing

H. Kawai and S. Yoshida
Chiba University

J. Ormes
University of Denver Research Institute

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P. Gorham
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Musashi Institute of Technology

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National Institute of Radiological Sciences

M-H. A. Huang
National United University, Taiwan

Y. Hayashi, S. Kawakami and S. Ogio
Osaka City University

N. Inoue
Saitama University

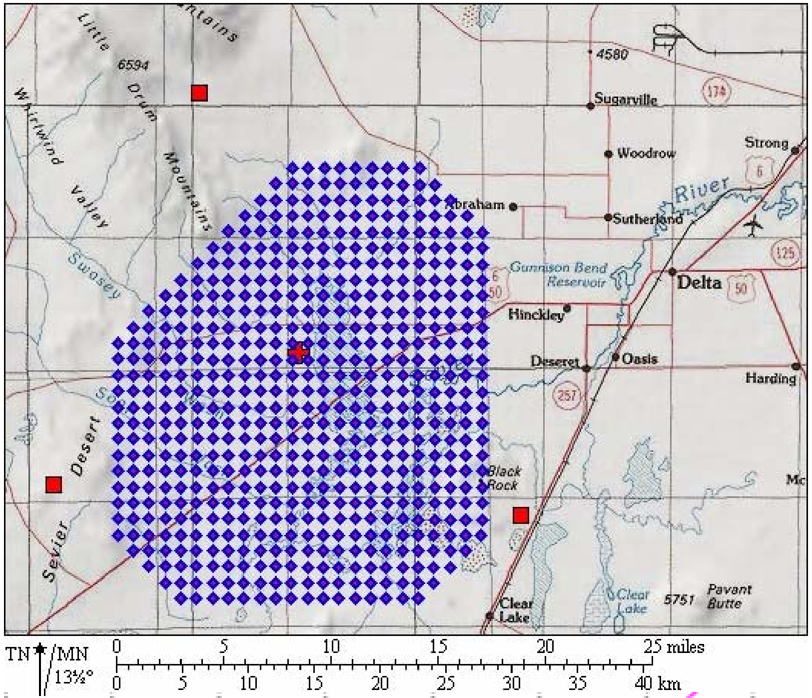
K.Kasahara
Shibaura Institute of Technology

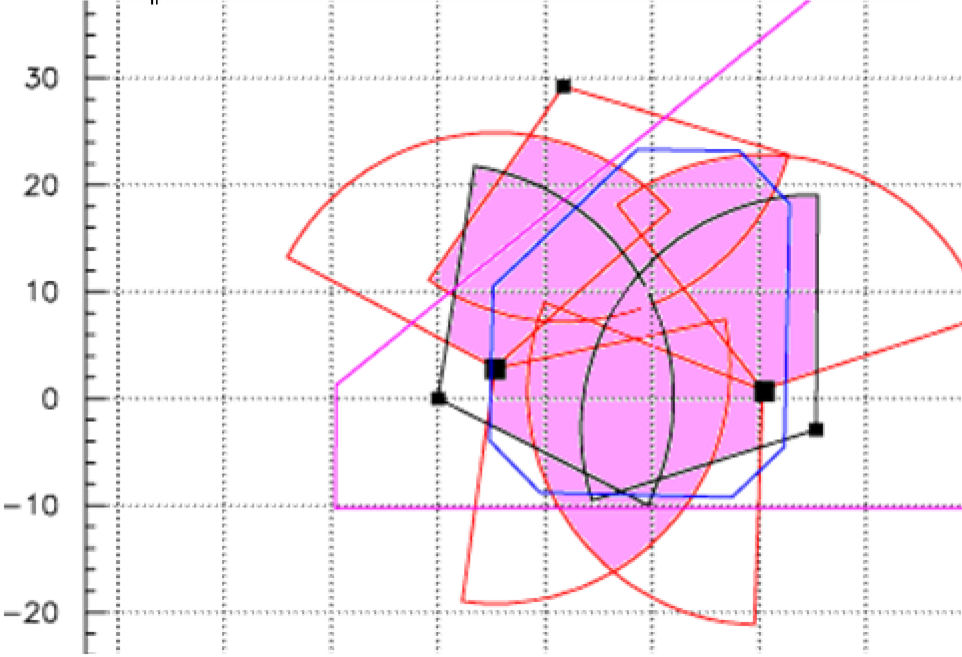
F. Kakimoto and Y. Tsunesada
Tokyo Institute of Technology

K. Honda and T. Ishii
Yamanashi University

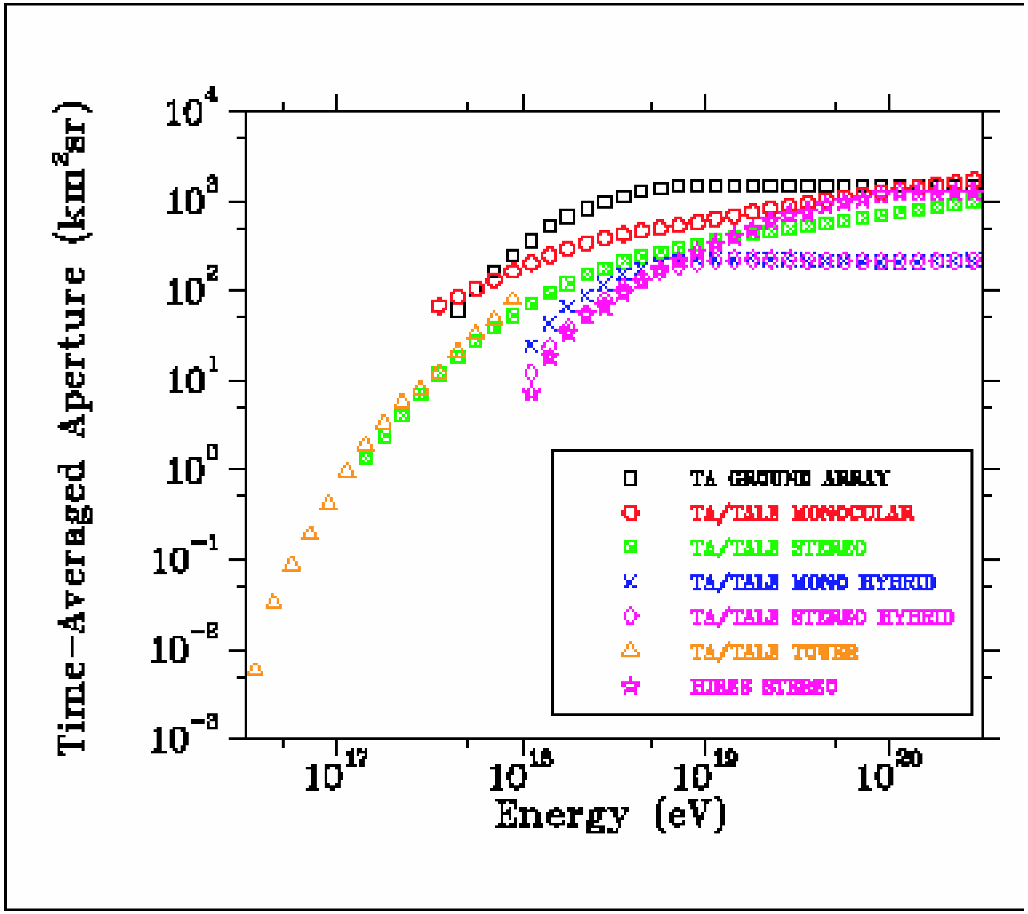
Future Prospects

- HiRes will cease operation at the end of March 2006
- Analysis of major topics to be completed by summer of 2007 (30th ICRC)
- Subgroups of HiRes have joined the Telescope Array (Delta, UT, USA)
  - Grond array of 576 (1.2km spacing) scintillation counters
  - Three fluorescence sites looking inward
- US contribution: low-energy extension down to $10^{16.5}$ eV
- TALE will also make TA into a fully stereo-hybrid detector





Apertures of TA nested detectors



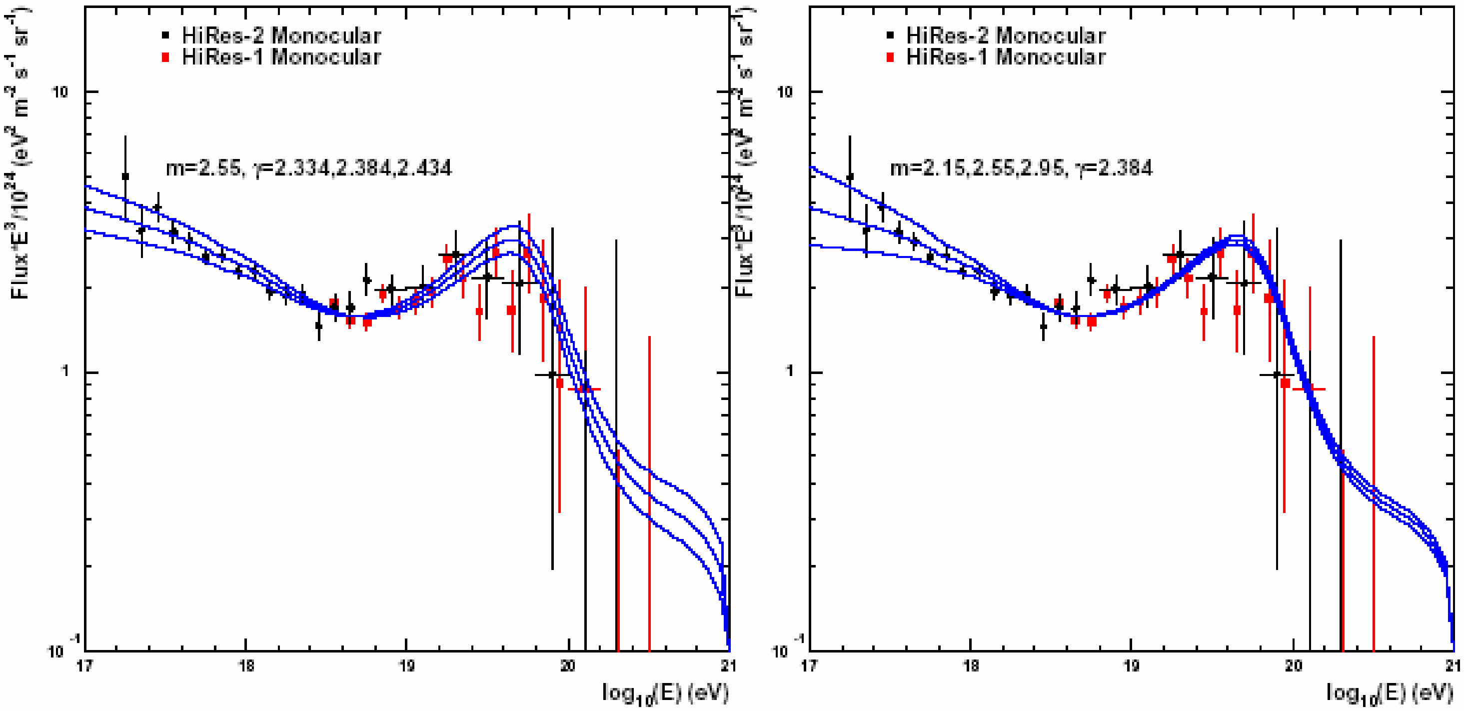
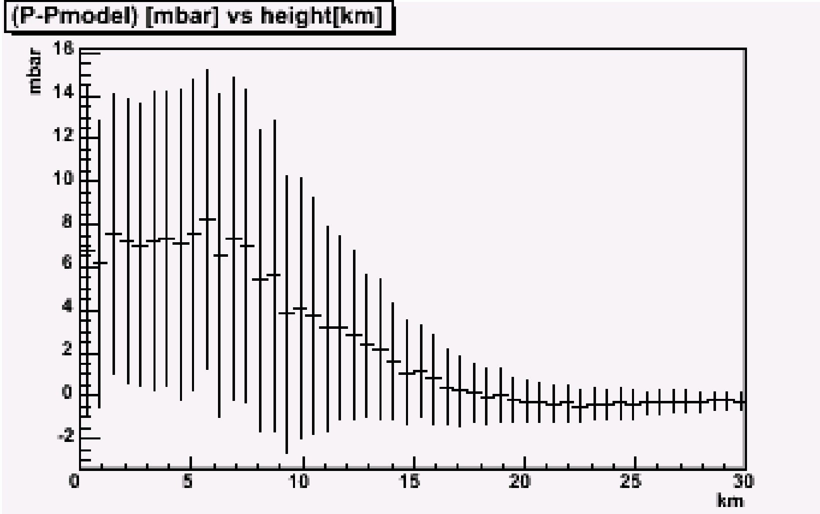


Figure 2: Effect of changing the spectral index, γ, and evolution parameter, m, in fits to the HiRes spectrum, showing that the ankle region is sensitive to γ, and that the region just below the ankle is most sensitive to m.

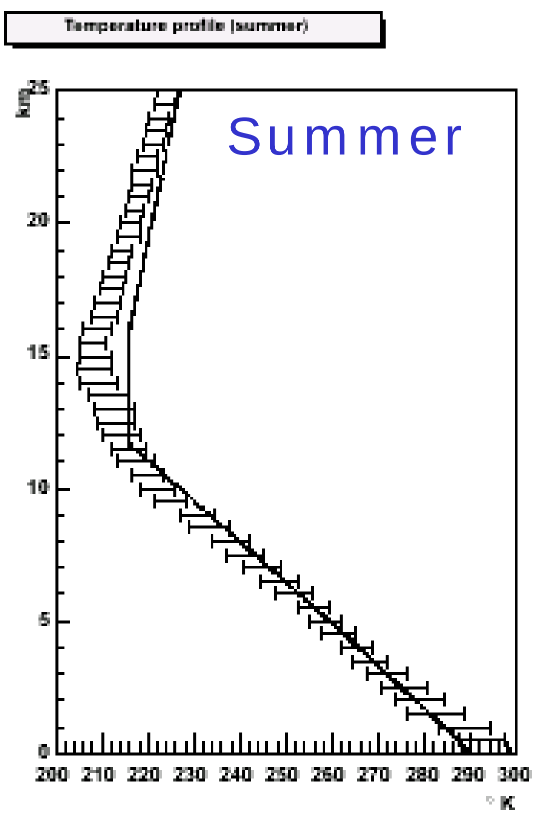
Physics Goals of TA

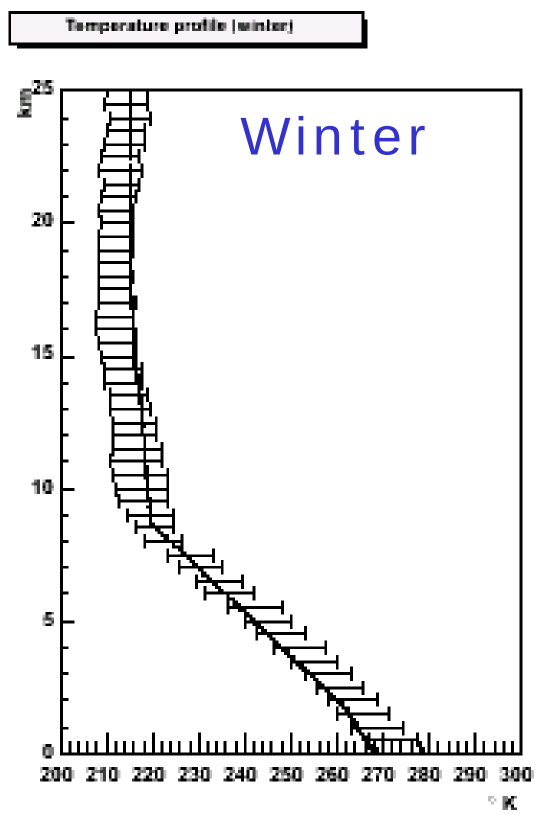
- Understand the AGASA/HiRes discrepancy above 10 EeV with hybrid array
- Study the ankle region in Stereo with slowly changing aperture. 1 - 10 EeV
- Study second knee region with tower detector and infill array .03 - 1 EeV
- Study composition with same methodology from .03 to 100 EeV.
- Definitive result on BL-Lac correlations and other anisotropies.

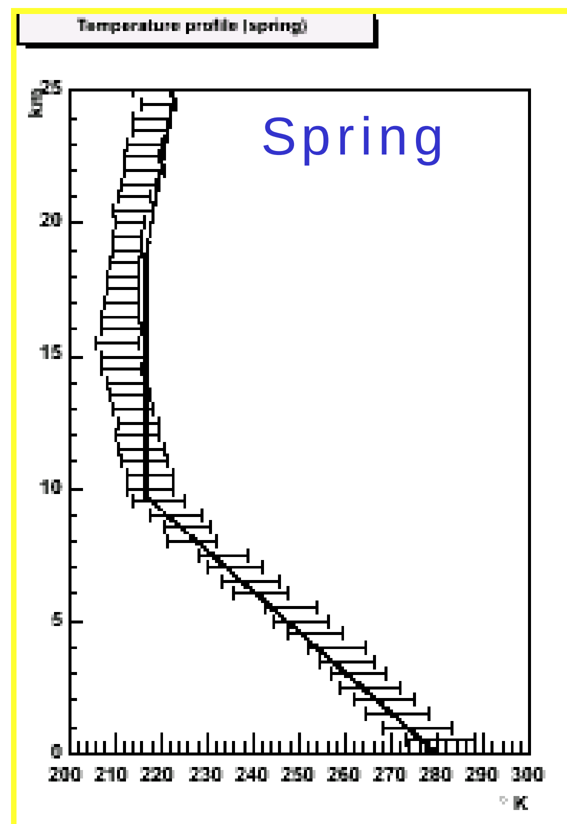


Updated Atmospherics

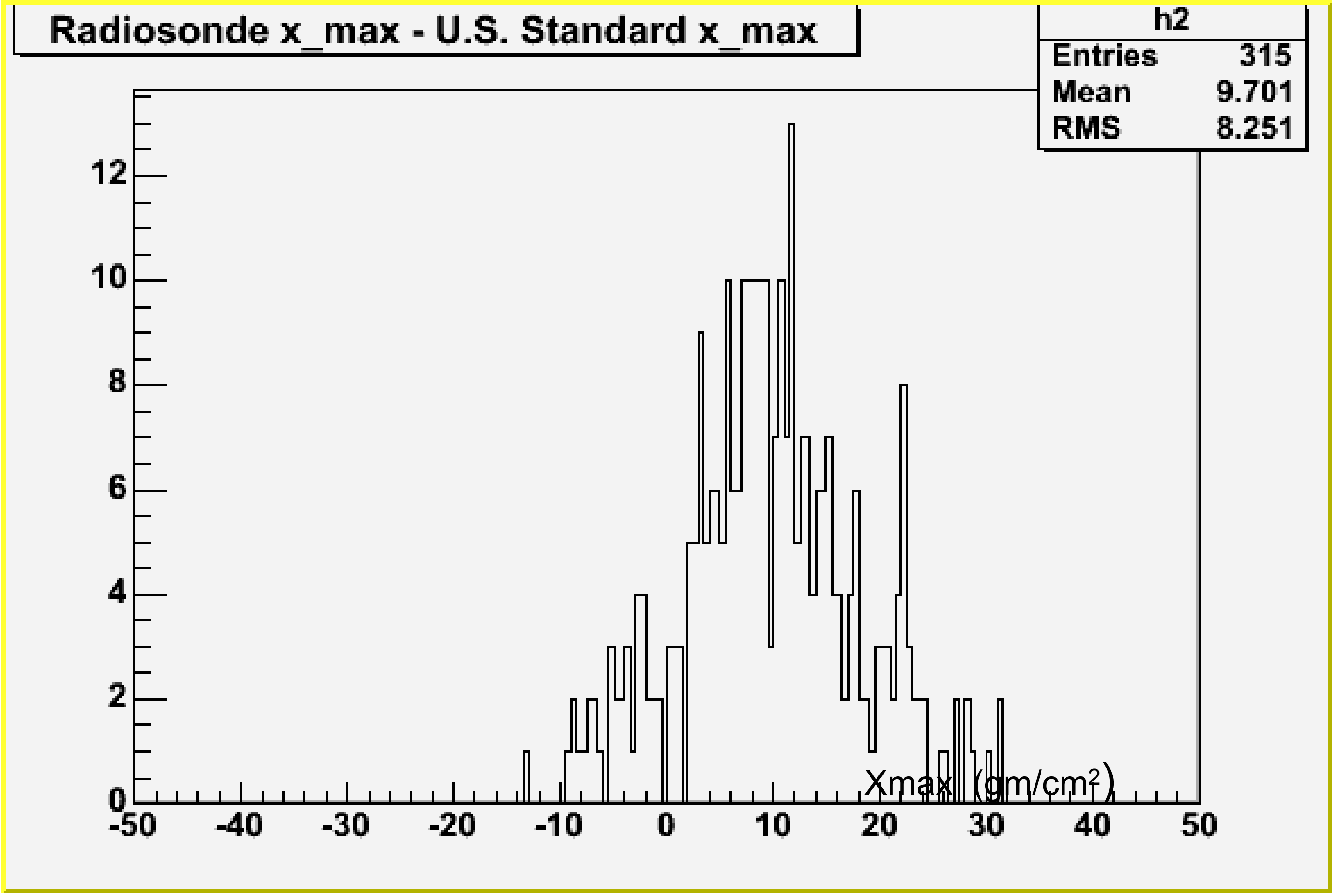
- The atmosphere over Utah appears stable and in good agreement with seasonal “Standard atmosphere” Models
- Residuals between measurements and model are typically less than ~10 mBar in the troposphere.







How much does the reconstructed shower X_{max} shift using Radiosonde data (SLC) vs. using the US standard atmosphere model?



Systematic Errors

- All three experiments quote systematic errors ~ 25 gm/cm^2.
- Dominant contributions
  - `Mirror survey
  - Cherenkov subtraction
  - Atmospheric profile
  - Aerosol corrections

Composition Comparison

- Fly's Eye Stereo - Xmax resolution ~45 gm/cm^2 measured resolution function
- HiRes/MIA - hybrid experiment. Resolution function estimated from simulations ~ 45 gm/cm^2.
- HiRes stereo - Xmax resolution measured, 30 gm/cm^2.

Estimating Systematics

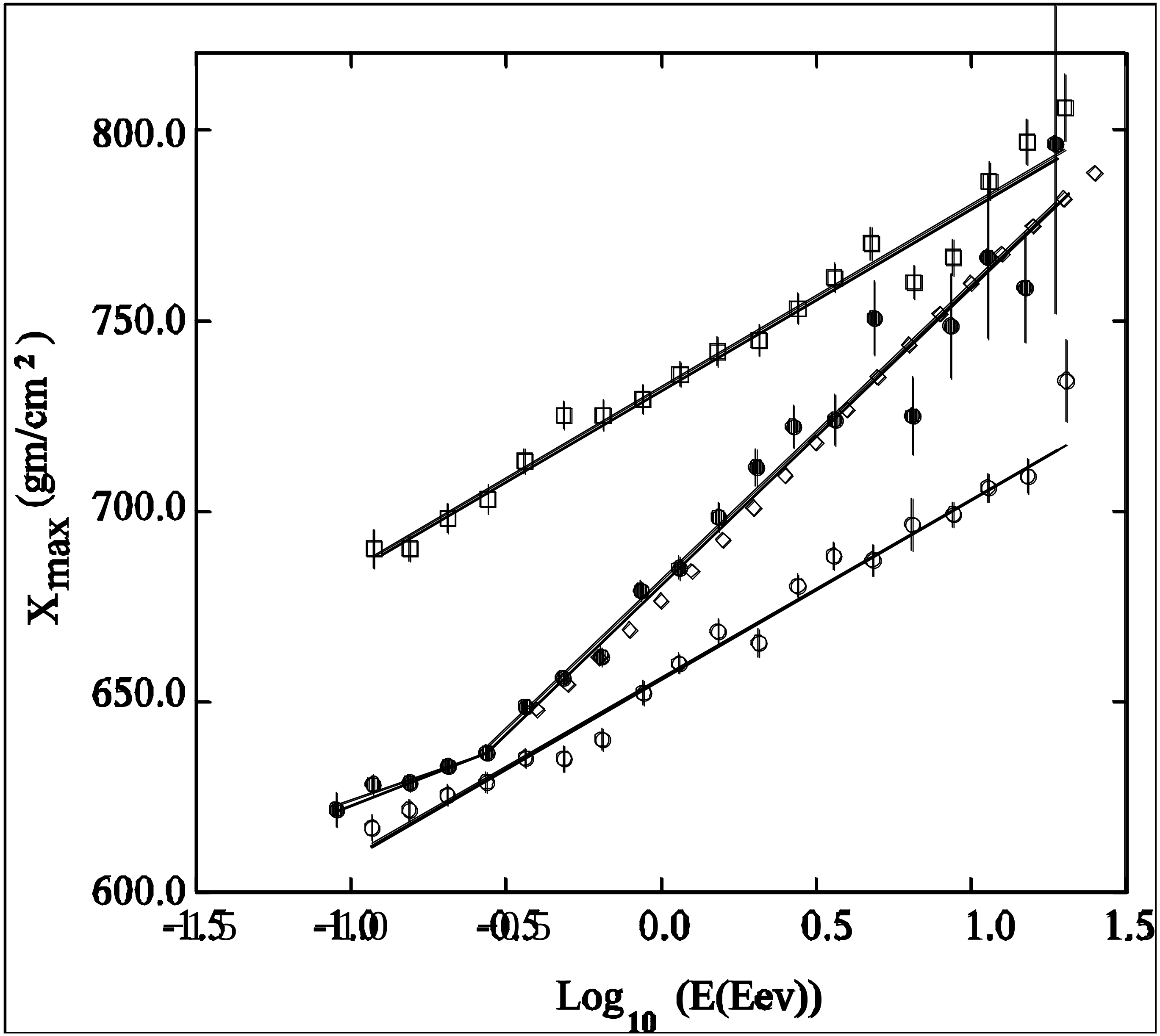
- Highest energy data is best measurements
  - most complete profile
  - minimum Cherenkov subtraction

  Energy scale for all three experiments is consistent (location of ankle and second knee).

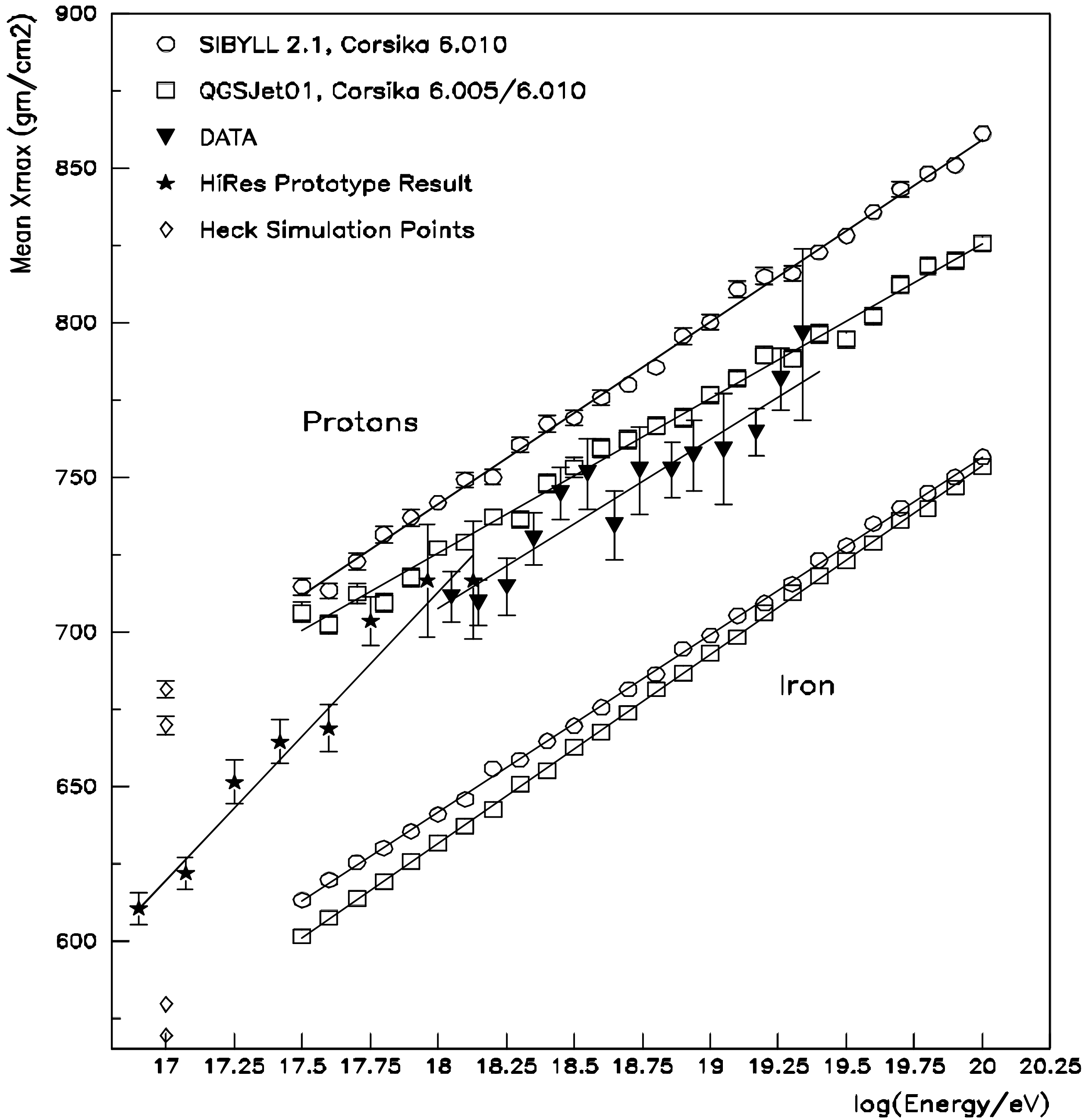
  Use HiRes stereo average Xmax and Fly's Eye stereo average Xmax above 10^{18} eV.

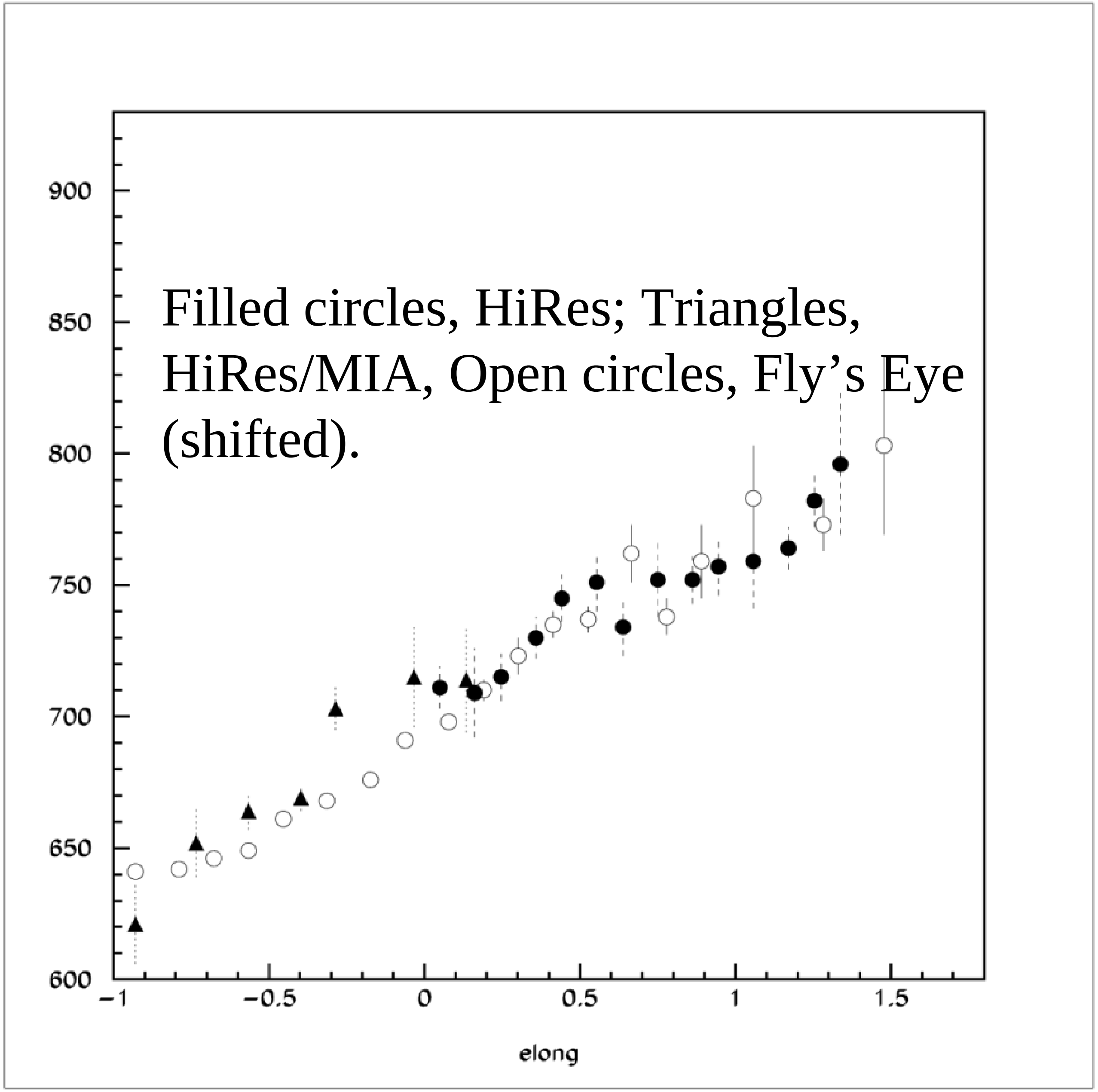
  Require a 13 gm/cm^2 upward shift for Fly's Eye to bring means into agreement

  Shift all Fly's eye Xmax data points by the same amount.



800.0
750.0
700.0
650.0
600.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
X_{max} (gm/cm^2)
Log_{10} (E(Eev))


SIBYLL 2.1, Corsika 6.010
QGSJet01, Corsika 6.005/6.010
DATA
HiRes Prototype Result
Heck Simulation Points
Protons
Iron
Mean Xmax (gm/cm2)
log(Energy/eV)
900
850
800
750
700
650
600
17
17.25
17.5
17.75
18
18.25
18.5
18.75
19
19.25
19.5
19.75
20
20.25


900
850
800
750
700
650
600
−1
−0.5
0
0.5
1
1.5
elong
Filled circles, HiRes; Triangles, HiRes/MIA, Open circles, Fly's Eye (shifted).

Elongation Rate

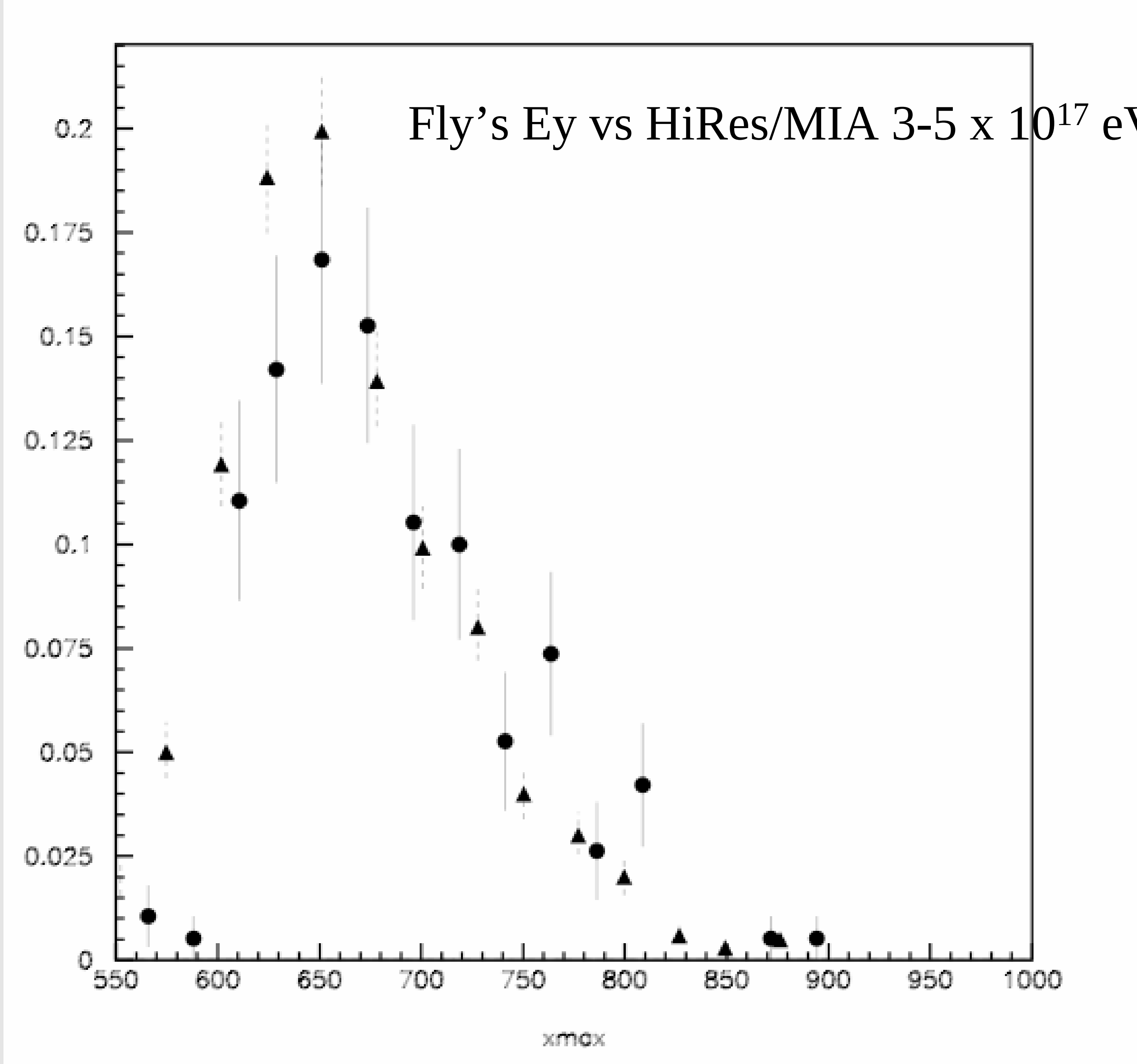
- Simple shift of Fly’s Eye data brings all date into reasonable agreement.
- Fly’s Eye and HiRes data are in excellent agreement above 10^{18} eV.
- HiRes/MIA shows earlier transition to “protons”, but point by point discrepancy is small.
- HiRes/MIA systematics are better understood, however.

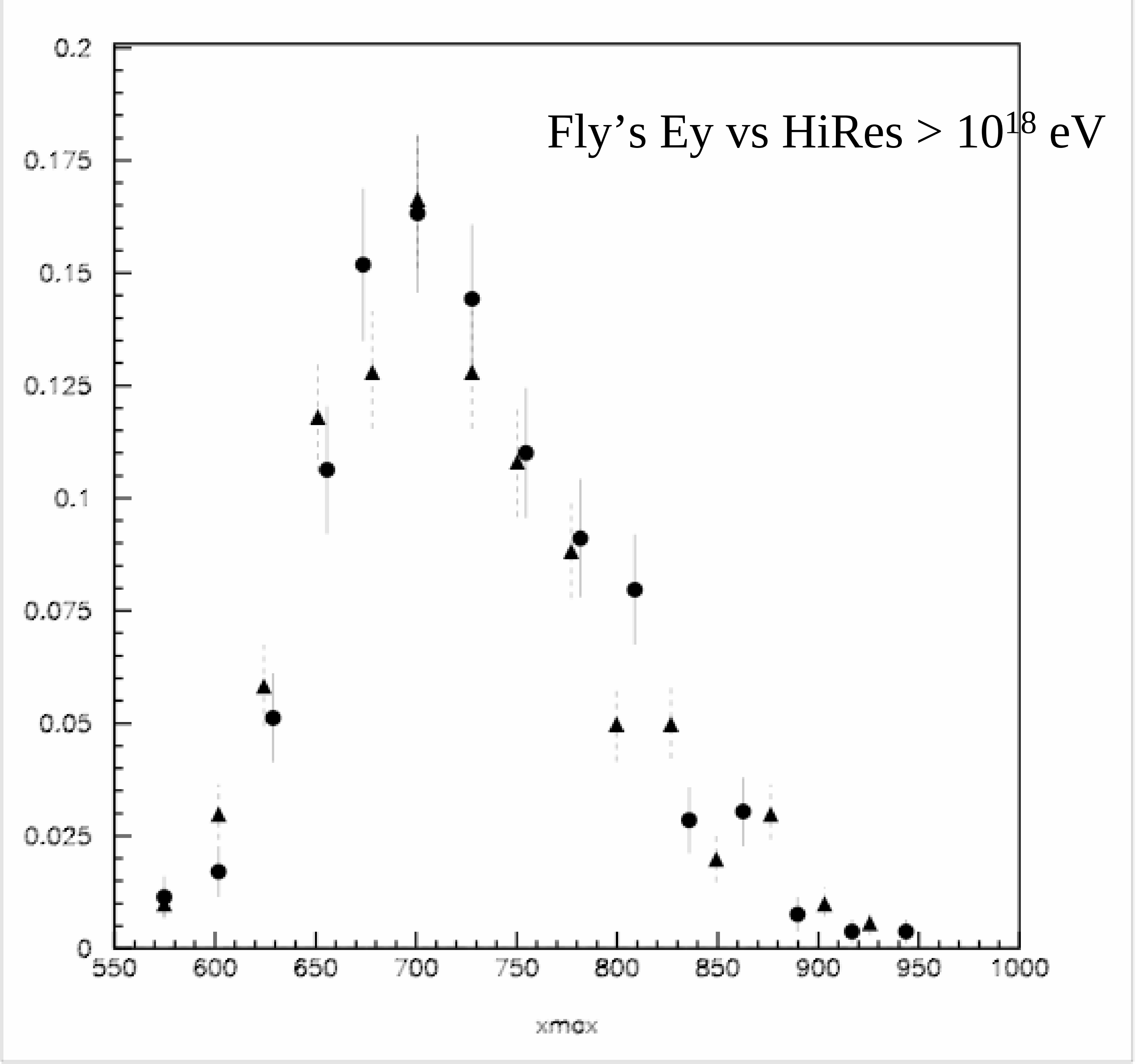
What about Xmax distributions?

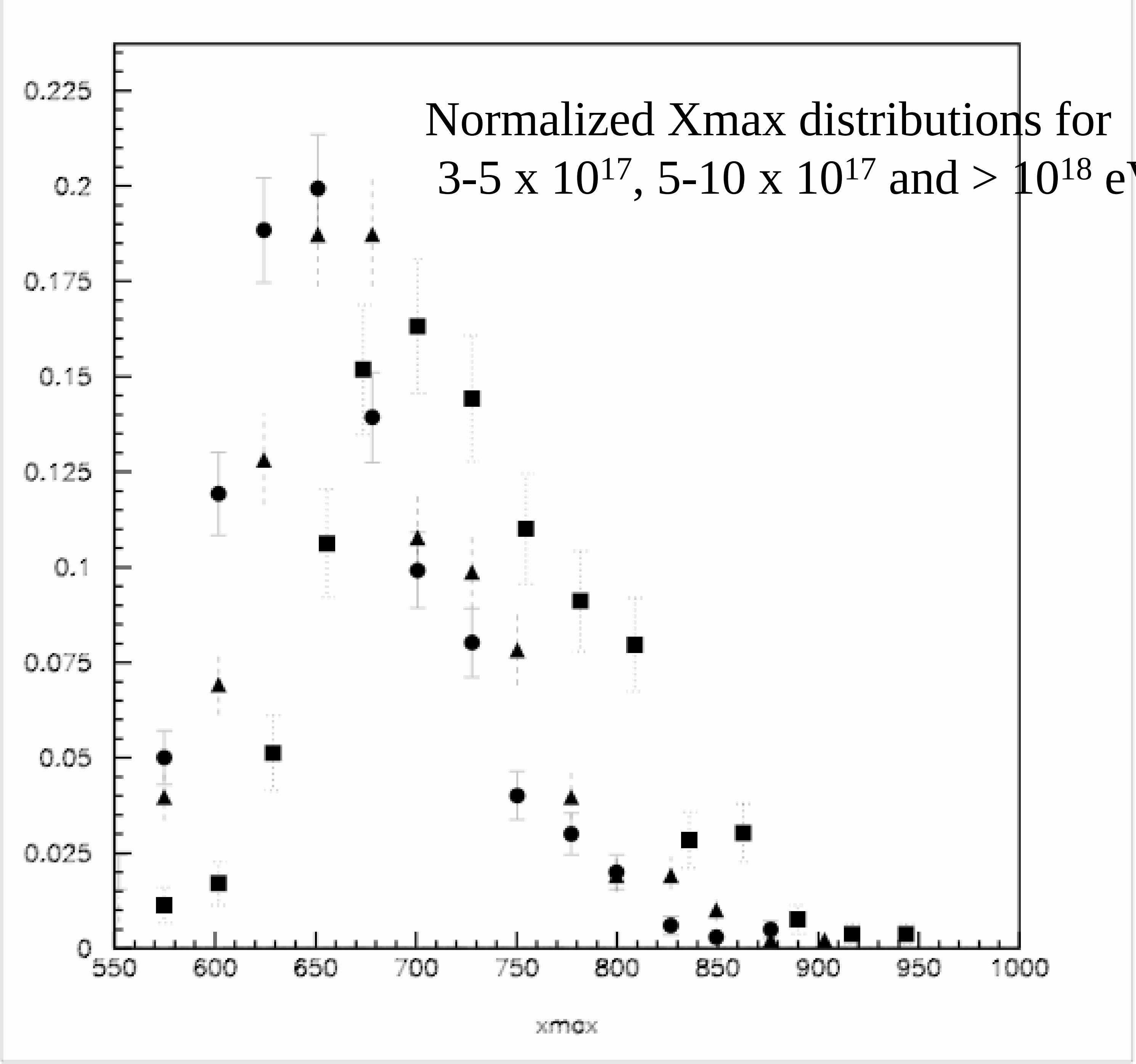
- Are Xmax distribution widths consistent?
- Two overlap regions
  - \- Fly's Eye and Hires/MIA in 3×10^{17} to 5×10^{17} eV bin.
  - Fly's Eye and HiRes stereo in > 10^{18} eV bin.

No evidence of discrepancy in distribution widths.

Fly's Ey vs HiRes/MIA 3-5 x 10^{17} eV




Fly’s Ey vs HiRes > 10^18 eV
0.2
0.175
0.15
0.125
0.1
0.075
0.05
0.025
0
550
600
650
700
750
800
850
900
950
1000
xmax



Normalized Xmax distributions for $3\text{-}5 \times 10^{17}$, $5\text{-}10 \times 10^{17}$ and $> 10^{18}$ eV.

Conclusions

- A simple Xmax shift brings all three experiments into reasonable agreement.
- Widths of Xmax distributions are in agreement.
- Normalized Xmax distribution show jump to wider distribution above 10^{18}, consistent with change to protons.
- Interpretation of elongation rate over limited energy range is problematic - Need large dynamic range in a single experiment!

Systematic Uncertainty in Xmax

- Effect of pointing accuracy – 15 gm/cm^2
- Effect of atmospheric variation – 10 gm/cm^2
- Effect of using Std Atmosphere –10 gm/cm^2
- Reconstruction bias – 5 gm/cm^2
- Sum in quadrature – 21.2 gm/cm^2
- 3-season model shifts published Xmax vs E results 10 gm/cm^2 larger/deeper
- Will use 3-season-model in future work with composition:

BL Lac Correlation: Previous Claims

Magnitude	Redshift	6cm Radio Flux	# Obj.	CR Sample	# CRs	Bin Size	# Pairs	Prob.
Catalog: Veron (9th Ed.) BL Lacs			22	AGASA >48 EeV Yakutsk >24 EeV	65	2.5°	8	$< 10^{-4}$
m < 18	z > 0.1 or unknown	S_{6cm} > 0.17 Jy		HiRes > 24 EeV	66	2.5°	0	1.00
Catalog: Veron (10th Ed.) BL Lacs correlated with EGRET sources			14	AGASA >48 EeV Yakutsk >24 EeV	65	2.9°	8	10^{-4}
no cut	no cut	no cut		HiRes > 24 EeV	66	2.9°	1	.70
Catalog: Veron (10th Ed.) BL Lacs			156	AGASA > 40 EeV	57	2.5°	12	.02
m < 18	no cut	no cut		HiRes > 40 EeV	27	2.5°	2	.78
Catalog: Veron (10th Ed.) BL Lacs			156	HiRes > 10 EeV	271	0.8°	10	10^{-3}
m < 18	no cut	no cut						

Tinyakov & Tkachev, JETP 74 (2001) 445.
Tinyakov and Tkachev, Astropart. Phys. 18 (2002) 165.
Gorbunov et al., ApJ 577 (2002) L93.

BL Lac Correlation: New Claim

Most recent claim by Gorbunov is based on published HiRes data. It uses a 10 EeV threshold, so it is a new claim.

Magnitude	Redshift	6cm Radio Flux	# Obj.	CR Sample	# CRs	Bin Size	# Pairs	Prob.
Catalog: Veron (9th Ed.) BL Lacs			22	AGASA >48 EeV Yakutsk >24 EeV	65	2.5°	8	$< 10^{-4}$
m < 18	z > 0.1 or unknown	S_{6cm} > 0.17 Jy		HiRes > 24 EeV	66	2.5°	0	1.00
Catalog: Veron (10th Ed.) BL Lacs correlated with EGRET sources			14	AGASA >48 EeV Yakutsk >24 EeV	65	2.9°	8	10^{-4}
no cut	no cut	no cut		HiRes > 24 EeV	66	2.9°	1	.70
Catalog: Veron (10th Ed.) BL Lacs			156	AGASA > 40 EeV	57	2.5°	12	.02
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m < 18	no cut	no cut						

Gorbunov et al., JETP Lett. 80 (2004) 145.