

Search for Small-Scale Anisotropy of UHECR with HiRes Stereo Data

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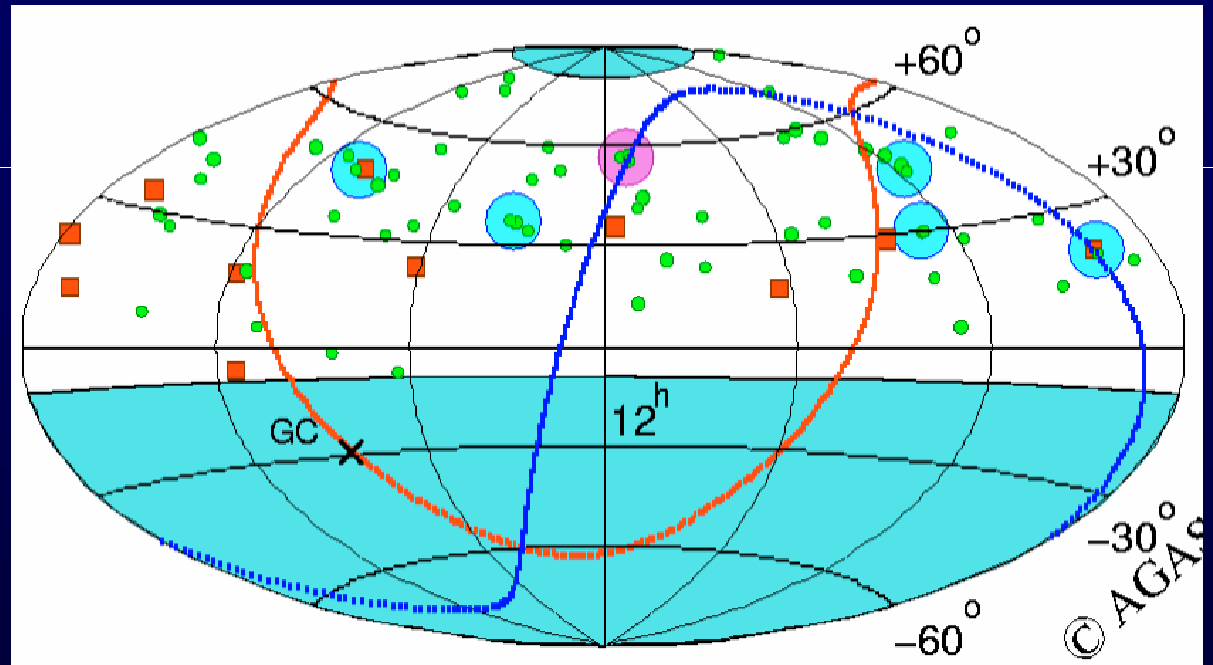
HiRes Collaboration



DPF 2004 UC Riverside

Small-Scale Anisotropy: Motivation

- Clustering could be evidence of nearby extragalactic sources, and could offer clues to the origins of these particles.
- There have been hints of small-scale clustering in previous experiments.
- Observed pairs of events are not clearly identified with astrophysical objects, and may be due to chance.
- World data set is small and has been thoroughly studied. Need to test clustering claims with independent data.

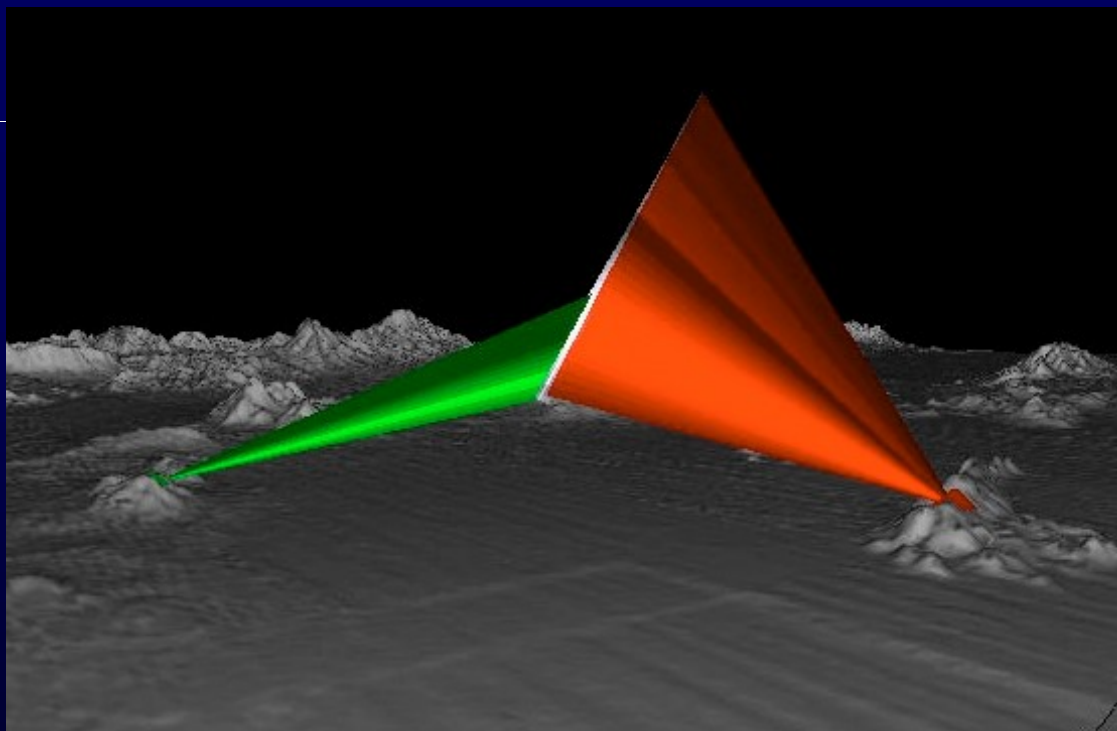


AGASA events above 4×10^{19} eV (1990-2002)

HiRes Stereo Observation

HiRes:

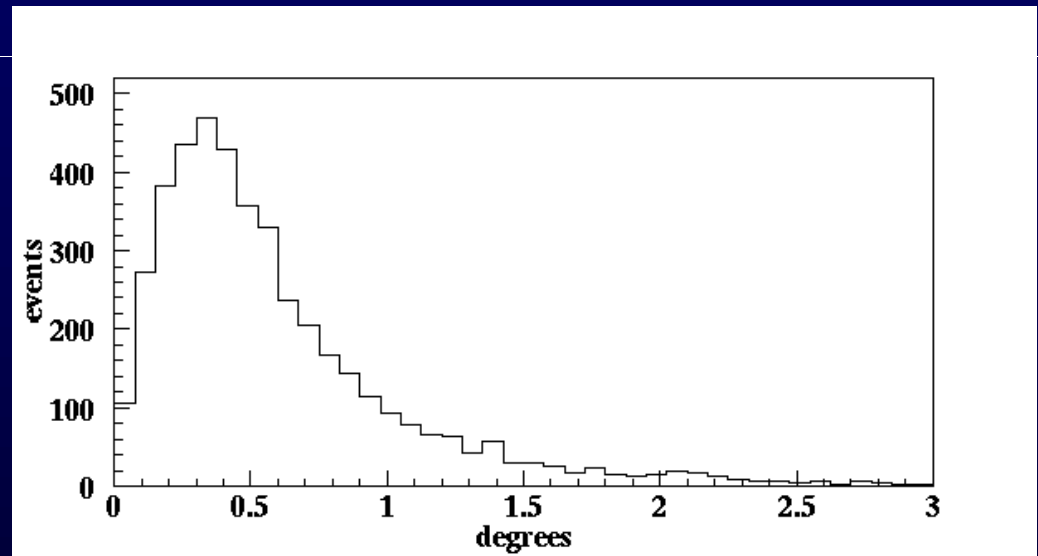
- Located in the Utah desert, on the Dugway Proving Ground
- Consists of two air-fluorescence detectors, 12km apart
- When a cosmic ray air shower is observed by both detectors, the stereo geometry results in excellent reconstruction of the arrival direction



HiRes I and HiRes II observation of an air shower

HiRes Angular Resolution

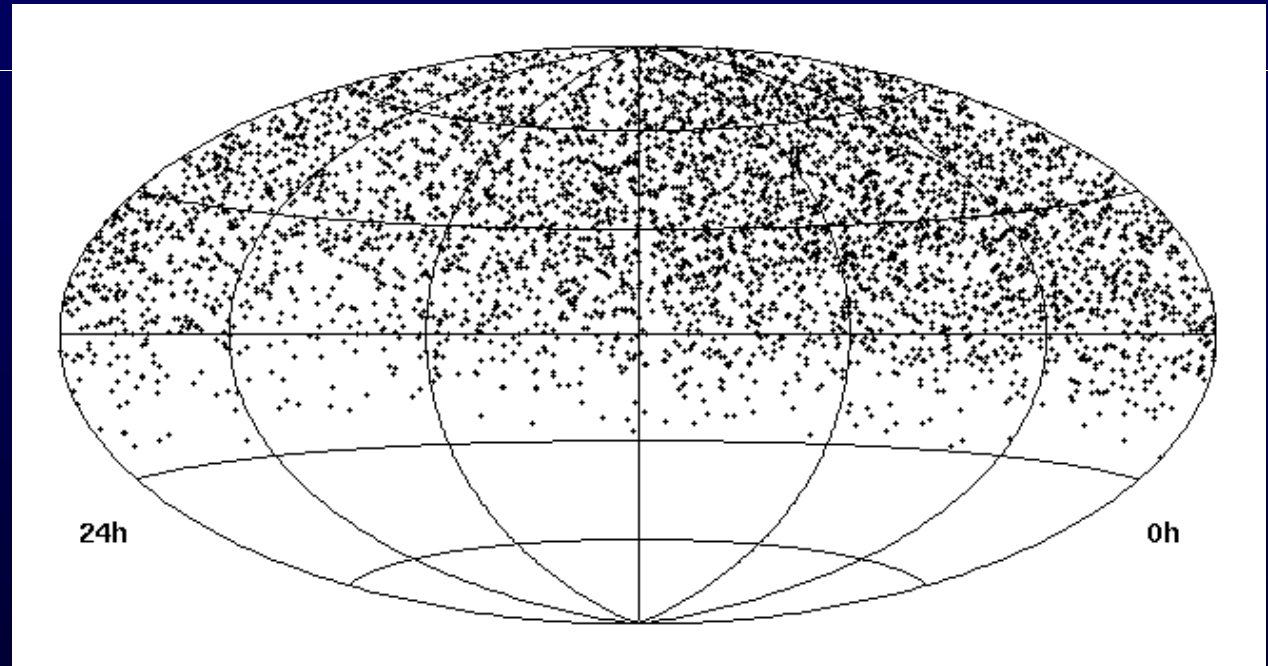
- HiRes stereo observation has sharp angular resolution
- In Monte Carlo simulations, 68% of events are reconstructed within 0.6° of their true arrival direction
- Stereo data set is ideal for small-scale anisotropy study



Distribution of opening angles between true and reconstructed arrival directions for HiRes Monte Carlo events.

HiRes Stereo Data Set

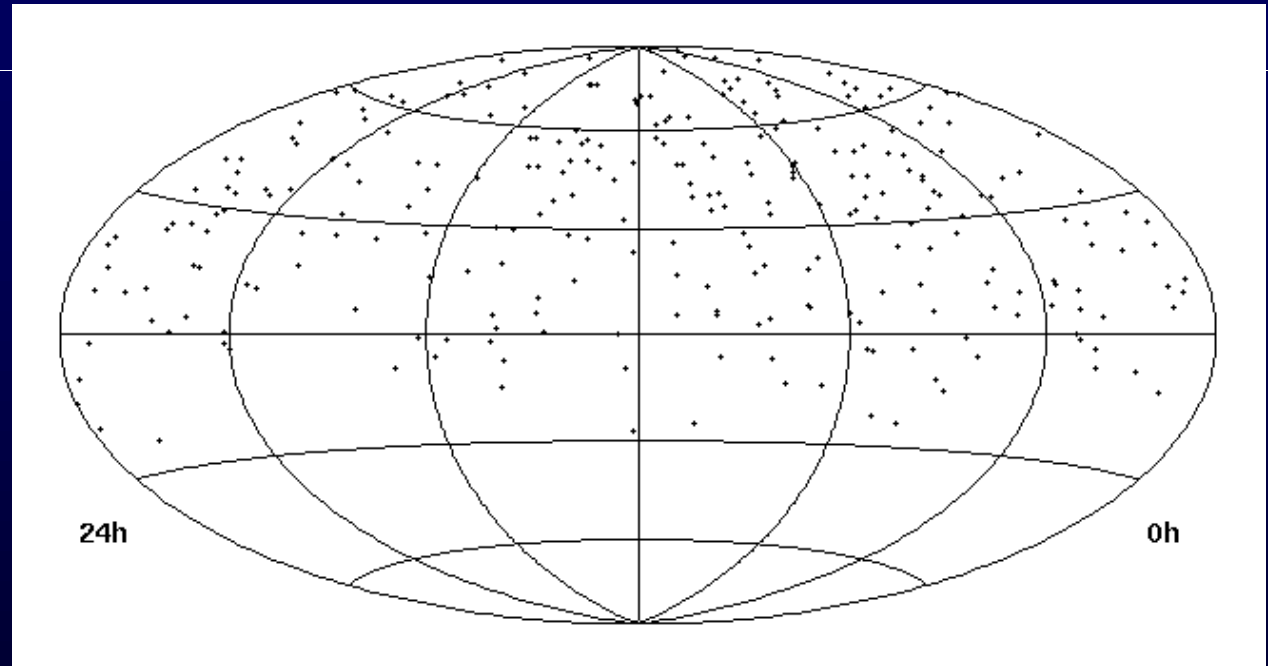
All data from
Dec. 1999
through
Jan. 2004



Equatorial Coordinates

HiRes Stereo Data Set ($>10^{19}$ eV)

- 271 well-reconstructed events above 10^{19} eV
- Angular resolution $\sim 0.6^\circ$

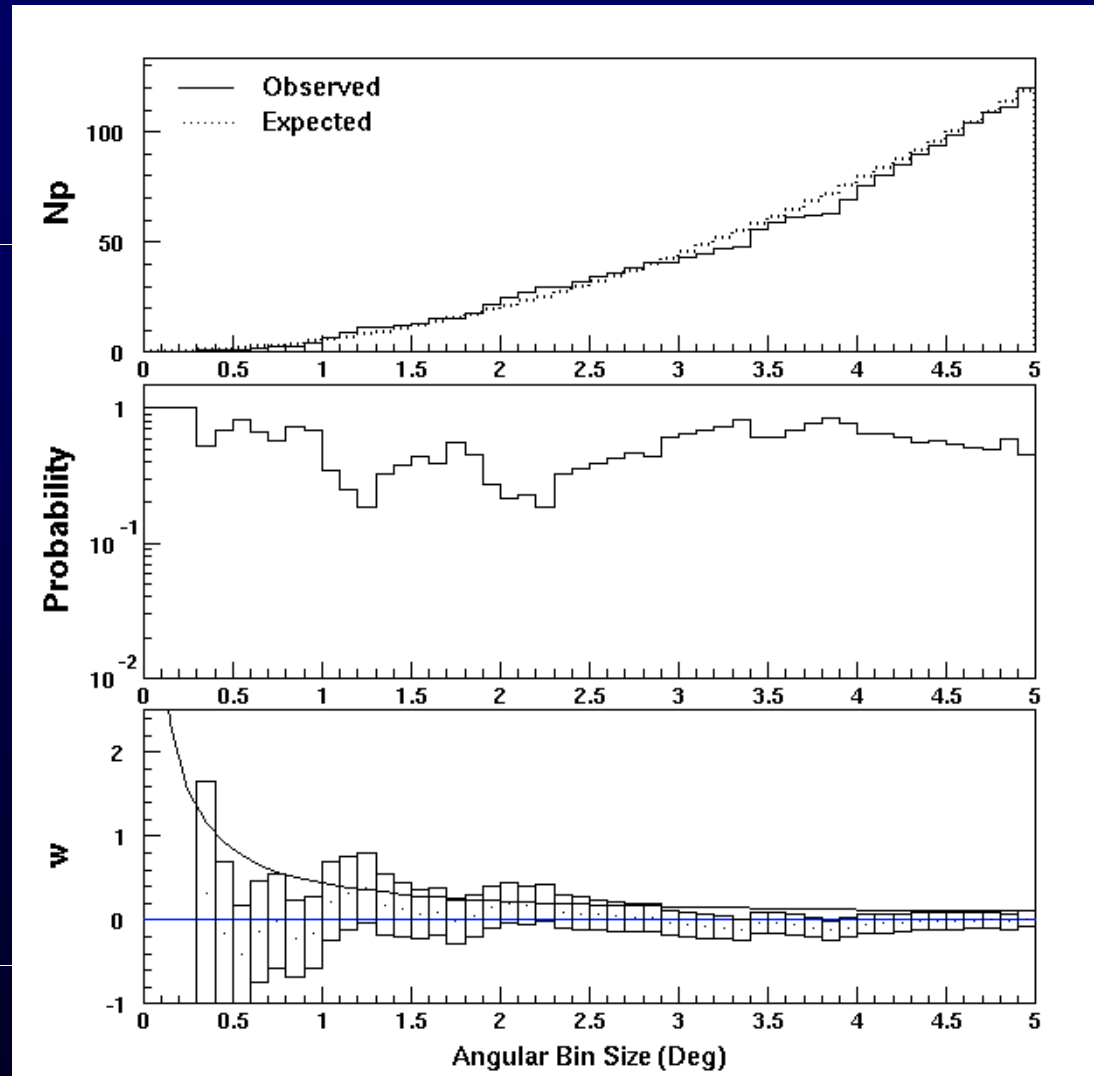


Equatorial Coordinates

Autocorrelation

Autocorrelation:

- Count number of pairs N_p with separation $< \theta$
- Use Monte Carlo with isotropic distribution to:
 - find probability of observing N_p
 - determine expected value for $\langle N_p \rangle$
- $w = N_p / \langle N_p \rangle - 1$
- HiRes ($E > 10$ EeV) is consistent with isotropy at all small angular scales.



271 HiRes events above 10^{19} eV

Autocorrelation

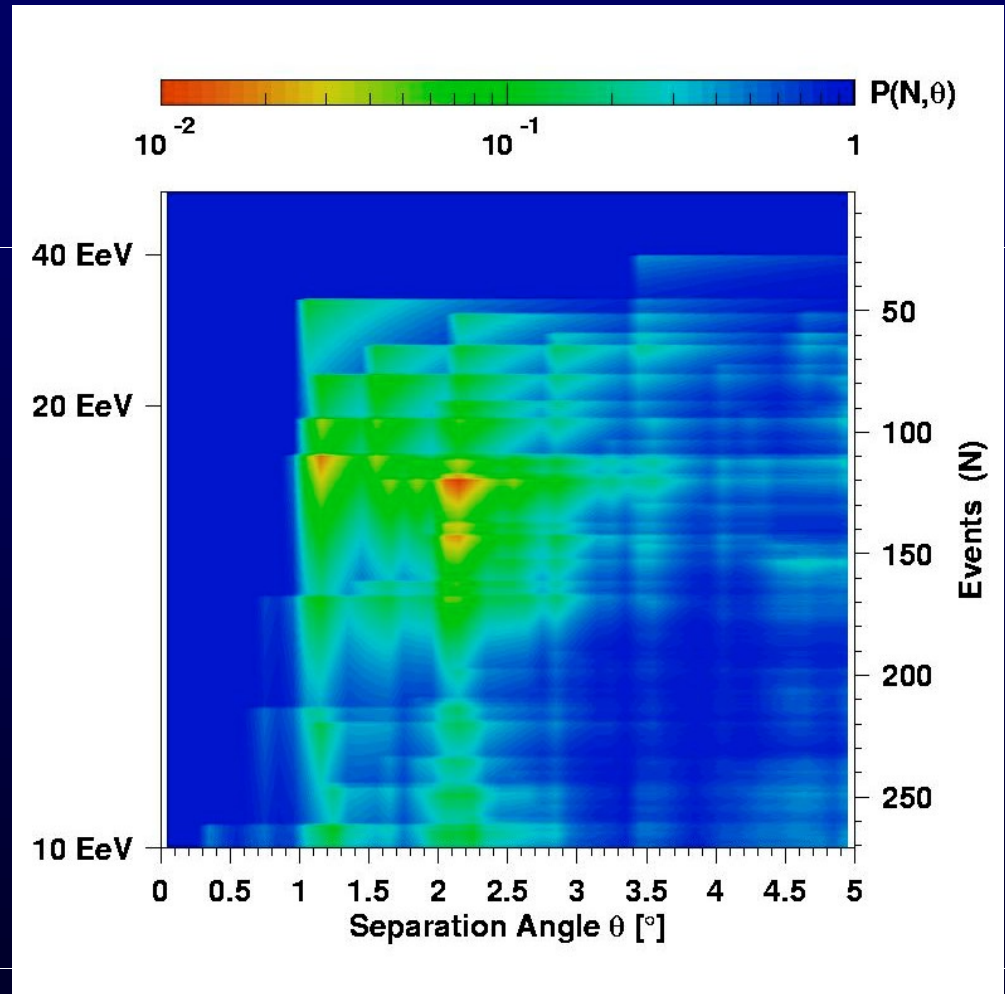
Evaluating Significance:

- A limitation of the correlation function is the necessity of choosing a minimum energy for the data set:
 - A higher energy threshold may reduce deflections of charged cosmic ray primaries by magnetic fields...
 - ... but it also weakens the statistical power of the data set.
- No *a priori* optimal choice for energy threshold or angular separation exists for clustering searches.

Autocorrelation Scan

Solution:

- Scan over angular separations and energy thresholds simultaneously
- Identify the angular separation and energy threshold which maximize the clustering signal (lowest probability = P_{min})
- Evaluate the significance by performing identical scans over Monte Carlo data sets
- Count what fraction of MC sets have same or lower P_{min} as real data

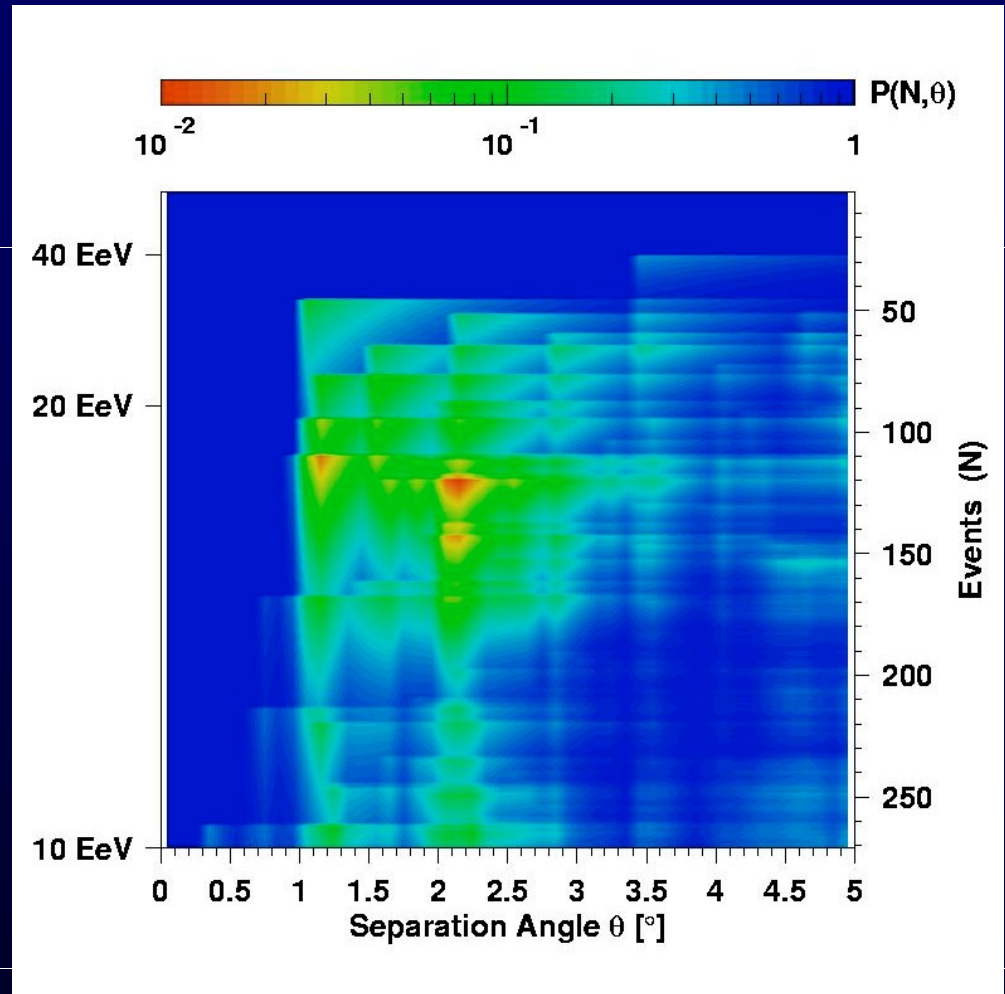


Scan of HiRes Stereo Events $> 10^{19}$ eV

Autocorrelation Scan

HiRes Results:

- Strongest clustering signal:
 - $E = 1.7 \times 10^{19}$ eV
 - $\theta = 2.2^\circ$
 - $n_{pairs} = 10$ ($N = 120$)
 - $P_{min} = 1.9\%$
- Actual significance is chance probability for scan of Monte Carlo data to have the same or lower minimum:
 - $P_{chance} = 52\%$
- No significant clustering signal observed



Autocorrelation Scan

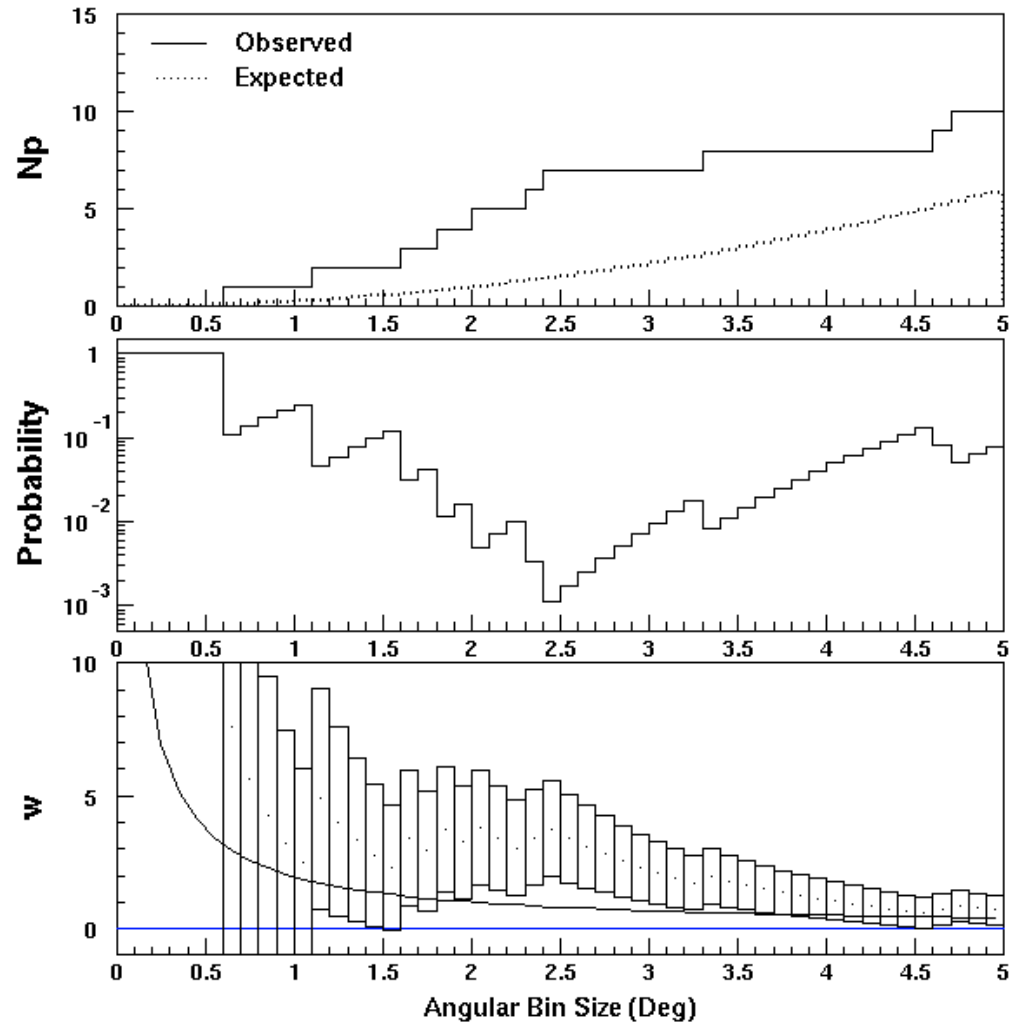
Sensitivity to clustering:

- By simulating data with clusters, we can determine the sensitivity on a given angular scale and above a given energy threshold.
- For example, we can simulate cosmic rays from point sources, with the arrival directions smeared by the HiRes angular resolution.
- For two such sources, each adding one pair of events above 4×10^{19} eV to an otherwise isotropic data set, the typical final significance is $P_{\text{chance}} \sim 1\%$.
- Conversely, the observed value $P_{\text{chance}} = 52\%$ excludes this possibility (that two sources each contributed a pair) at more than 99% confidence level.

Combined Autocorrelation

AGASA:

- 57 events above 40 EeV
- $N_p = 7$, for $\theta < 2.5^\circ$
- Prob $\sim 0.1\%$



57 AGASA events above 4×10^{19} eV

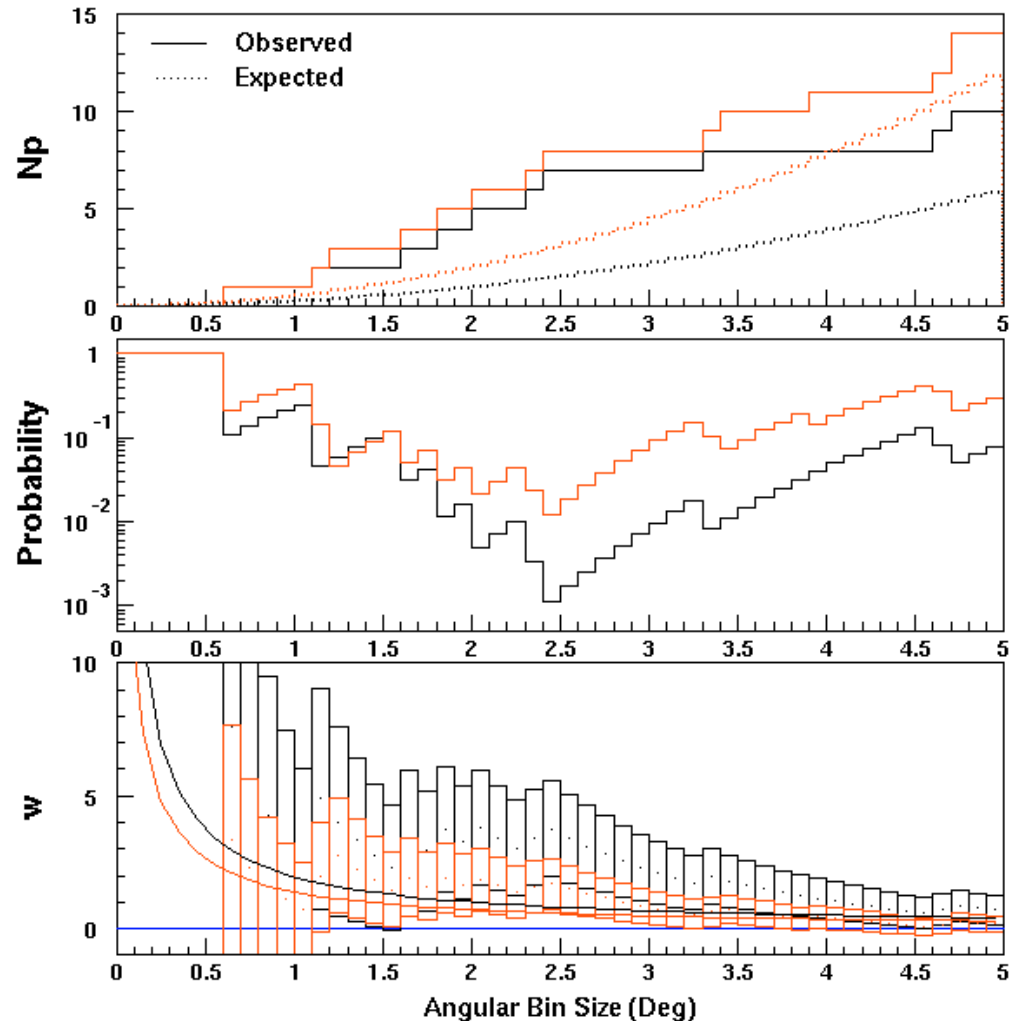
Combined Autocorrelation

AGASA:

- 57 events above 40 EeV
- $N_p = 7$, for $\theta < 2.5^\circ$
- Prob $\sim 0.1\%$

AGASA + HiRes:

- 57 + 27 events (>40 EeV)
- $N_p = 8$, for $\theta < 2.5^\circ$
- Prob $\sim 1\%$



57 AGASA events above 4×10^{19} eV

57 AGASA + 27 HiRes events above 4×10^{19} eV

BL Lac Correlation

First claim that UHECR correlate with BL Lacs :

Tinyakov & Tkachev, JETP 74 (2001) 445.

- Set of 22 BL Lacs, with
 - $z > 0.1$ or unknown
 - $m < 18$
 - $F_6 > 0.17$ Jy
- Set of 65 cosmic rays (AGASA $E > 48$ EeV , Yakutsk $E > 24$ EeV)
- Result:
 - 8 events within 2.5° of these BL Lacs
 - chance probability $< 10^{-4}$

Test with HiRes events above 24 EeV:

- Set of 66 events
- **Result: 0 events within 2.5° of BL Lacs**

BL Lac Correlation

Second claim that UHECR correlate with BL Lacs :

Gorbunov et al., *ApJ* 577 (2002) L93.

- Set of 14 BL Lacs, with
 - no cuts on z
 - no cuts on m
 - no cuts on F_6
 - select gamma-ray-loud BL Lacs based on correlations with EGRET catalog
- Set of 65 cosmic rays (AGASA $E > 48$ EeV , Yakutsk $E > 24$ EeV)
- Result:
 - 8 events within 2.9° of these BL Lacs
 - chance probability $\sim 10^{-4}$

Test with HiRes events above 24 EeV:

- Set of 66 events
- **Result: 1 event within 2.9° of BL Lac , chance probability $\sim 70\%$**

BL Lac Correlation

Most recent claim that UHECR correlate with BL Lacs :

Gorbunov et al., astro-ph/0406654

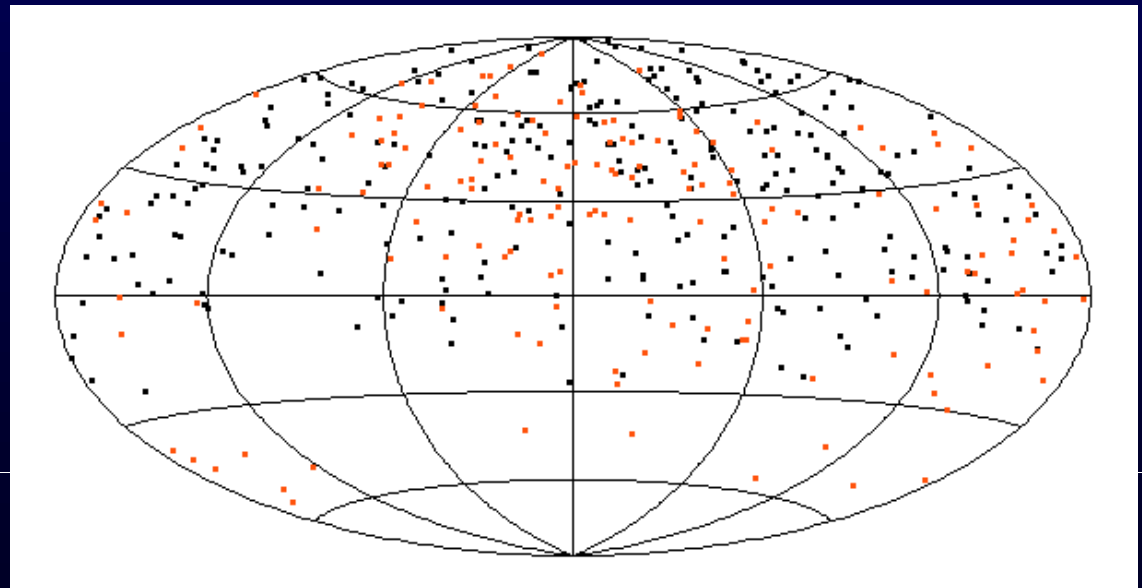
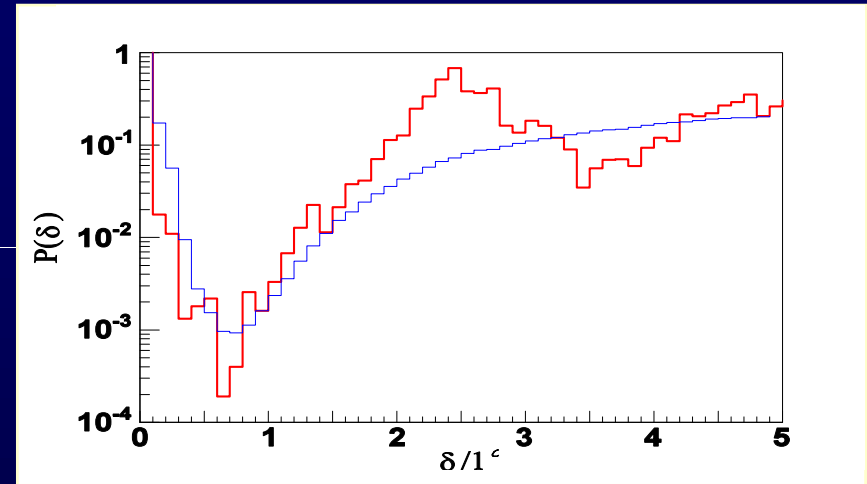
- Set of 156 BL Lacs, with
 - no cuts on z
 - $m < 18$
 - no cuts on F_6
 - no criteria for correlation with EGRET catalog
- Set of HiRes events with $E > 10$ EeV (271 events)
- Result:
 - 11 events within 0.8° of these BL Lacs
 - chance probability $\sim 10^{-3}$

BL Lac Correlation

The authors claim that the HiRes data supports the BL Lac source hypothesis.

In fact, the HiRes data contradicts the two previous BL Lac hypotheses, which were based on AGASA and Yakutsk data.

The current claim represents a new hypothesis, with new cuts on BL Lacs and cosmic ray events.

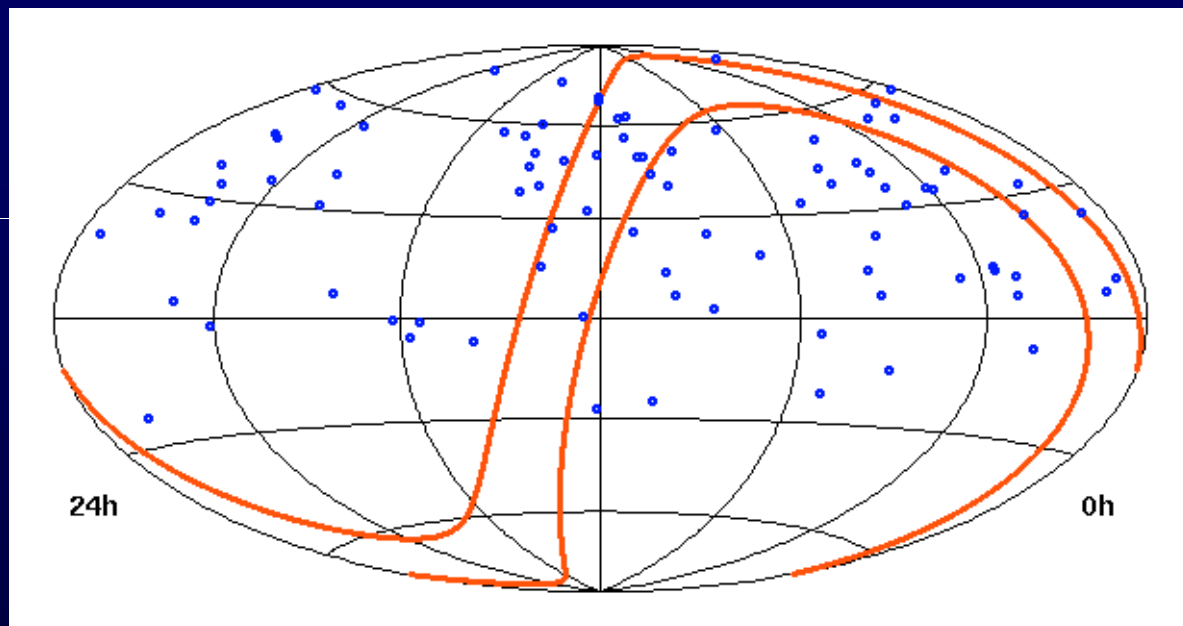


HiRes (black) , BL Lacs (red)

Supergalactic Plane Correlation

- Many possible accelerator sites have been identified near the supergalactic plane.
- Possible excess UHECR flux from within 10° of the plane has been previously reported.

Uchihori et al., *Astropart. Phys.* 13 (2000) 151.



HiRes events ($>2 \times 10^{19}$ eV) and Supergalactic plane (lat. B = $+10^\circ$, -10°)

- We count the number of events within 10° of the plane, and compare with Monte Carlo.

Energy Threshold:	2×10^{19} eV	4×10^{19} eV
Mean:	17.1	5.2
Observed:	18	5
Chance Probability:	46%	65%

Conclusions

- Autocorrelation for HiRes Stereo data above 10^{19} eV:
 - Scanning over energy and angular separation identifies the strongest clustering signal – but statistical penalty for the scan must then be determined
 - Scanning HiRes events (> 10 EeV), no significant small-scale clustering observed
- Cross Correlations:
 - Combined HiRes and AGASA sets show reduced autocorrelation
 - No correlation between HiRes events and previously identified BL Lacs
 - Correlation between HiRes and newly selected BL Lacs is a new claim, and must be tested with new data
 - No excess near Supergalactic Plane
- Future:
 - Three more years of operation will double the data set (Power of autocorrelation tests $\sim N^2$)
 - HiRes is producing the largest, sharpest picture of the Northern sky in ultrahigh energy cosmic rays

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