The Ultrahigh Energy Cosmic Ray Spectrum Measured from the Tandem Stereo Analysis of HiRes Data

Bridging the HiRes Monocular and Stereo Analyses

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Outline

1. Introduction and Motivation for the Tandem Stereo Analysis
2. Comparison of Profile-Constrained Monocular and Tandem Stereo Reconstructions
3. Tandem Stereo Spectrum Data Set
4. Data/MC Comparison (validate aperture calc.)
5. Spectrum Results
6. Epilogue

1. Introduction and Motivation for the Tandem Stereo Analysis

Motivation

- The Tandem stereo analysis evolved from mono/stereo comparison studies
- The current tandem stereo analysis is intended to provide an intermediate “bridge” between the published monocular spectra to the stereo analysis.

Stereo Validation of Monocular Reconstruction

- The dominant contribution to the recontrsuction errors (especially for HiRes-1) comes from the geometrical recontsruction errors
- We have analyzed a subset of the monocular data which were observed in stereo, and compared energy reconstruction alternately using the monocular and stereo geometries. Results shown in section 2.

Tandem Stereo Analysis

- With the machinery developed for monocular analyses and using stereo geometry, we can also construct a stereo spectrum:
  - apply monocular event selection criteria to stereo events .
  - Use SD planes from two sites to find shower track
  - Resume monocular analyses independently.
  - Obtain event distribution separately for the two sites

Tandem Stereo Analysis (2)

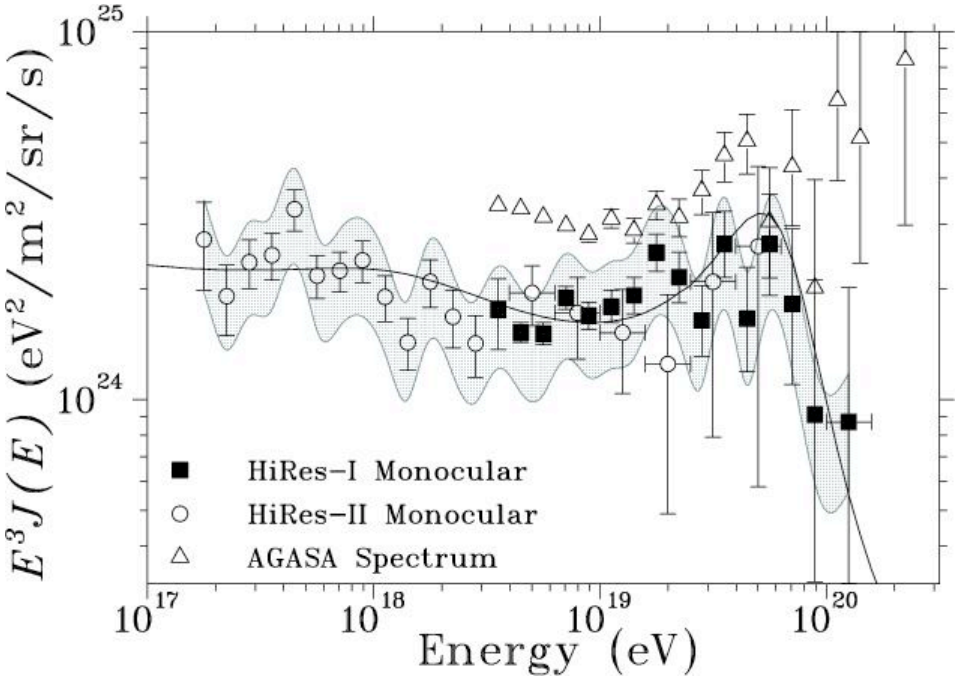
- In addition to event reconstruction and selection, we also need an aperture and exposure calculation
  - On-time calculated according to stereo observation times
  - Aperture is calculated by running HiRes-1 and HiRes-2 Monocular simulation codes in sequence (in tandem).
  - Final reconstruction and analysis cuts applied separately for the two sites-resulting in two different aperture curves for HiRes-1 and HiRes-2.

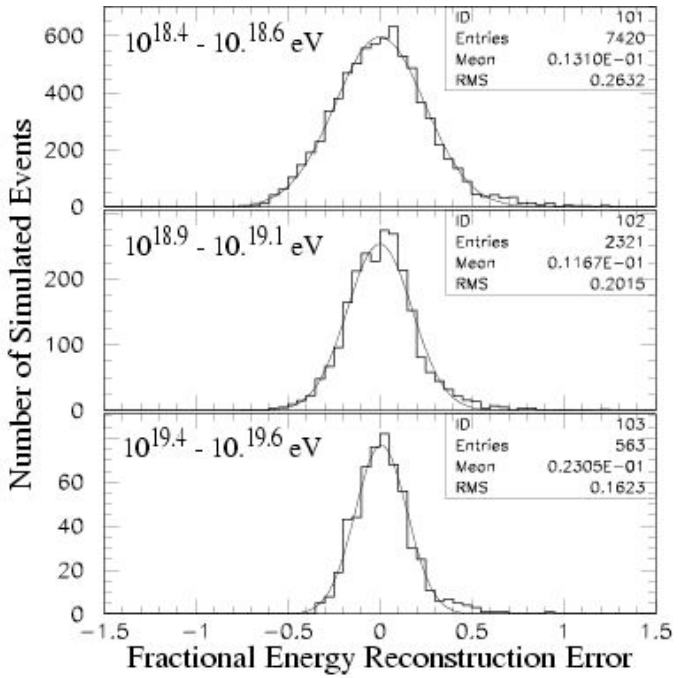
Tandem Stereo Spectrum

- Obtain separate tandem spectra for HiRes-1 and HiRes-2.
  - These provide additional, ***global*** validation of the monocular results.
- **In addition, this effort serves to provide a "bridge" between monocular and stereo spectra.**

2. Validation of Monocular Event Reconstruction

Published monocular spectrum

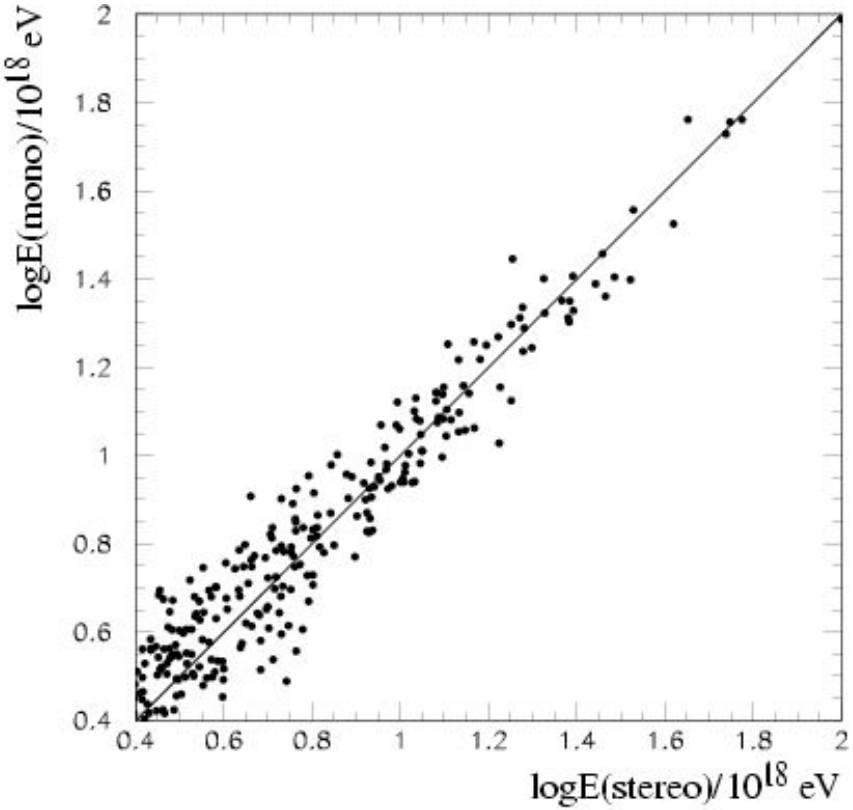




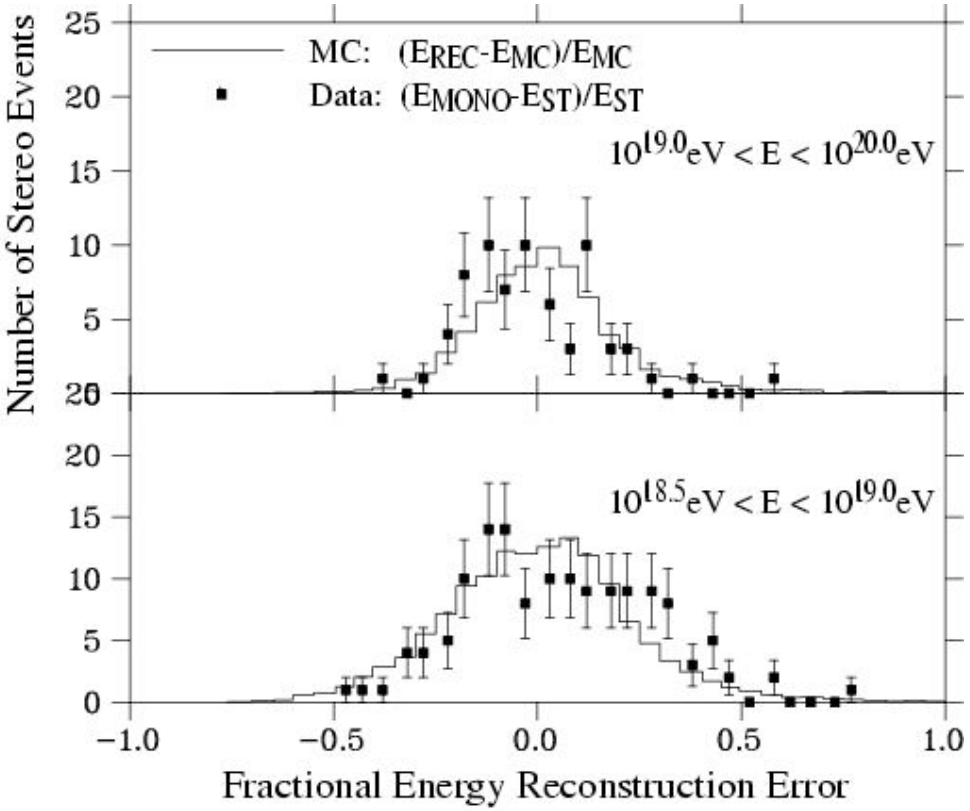
Left: published spectrum from Phys. Rev. Lett. **92**, 151101

Roght: Simulated HiRes-1 Energy resolution at three energies

Comparison of Reconstructed Energies for Stereo subset of Monocular Events



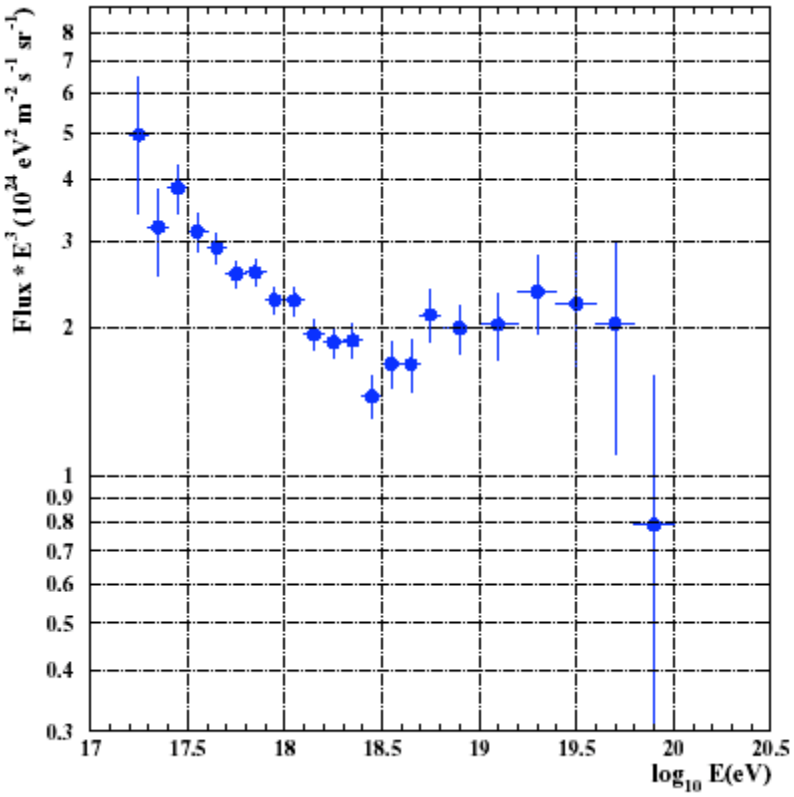
Energy Resolution: mono-stereo comparison overlaid with MC



3. Tandem Stereo Spectrum Data Set

Tandem Stereo Spectrum Data Set

- Data taken between December 1999 to September 2001.
- Overlap in the data set used between latest HiRes-1 and HiRes-2 monocular spectra (astro-ph/0208301) Astrophys.**23**:157-174, 2005
- Slightly smaller stereo data set than was used in the mono/stereo resolution studies in section 2

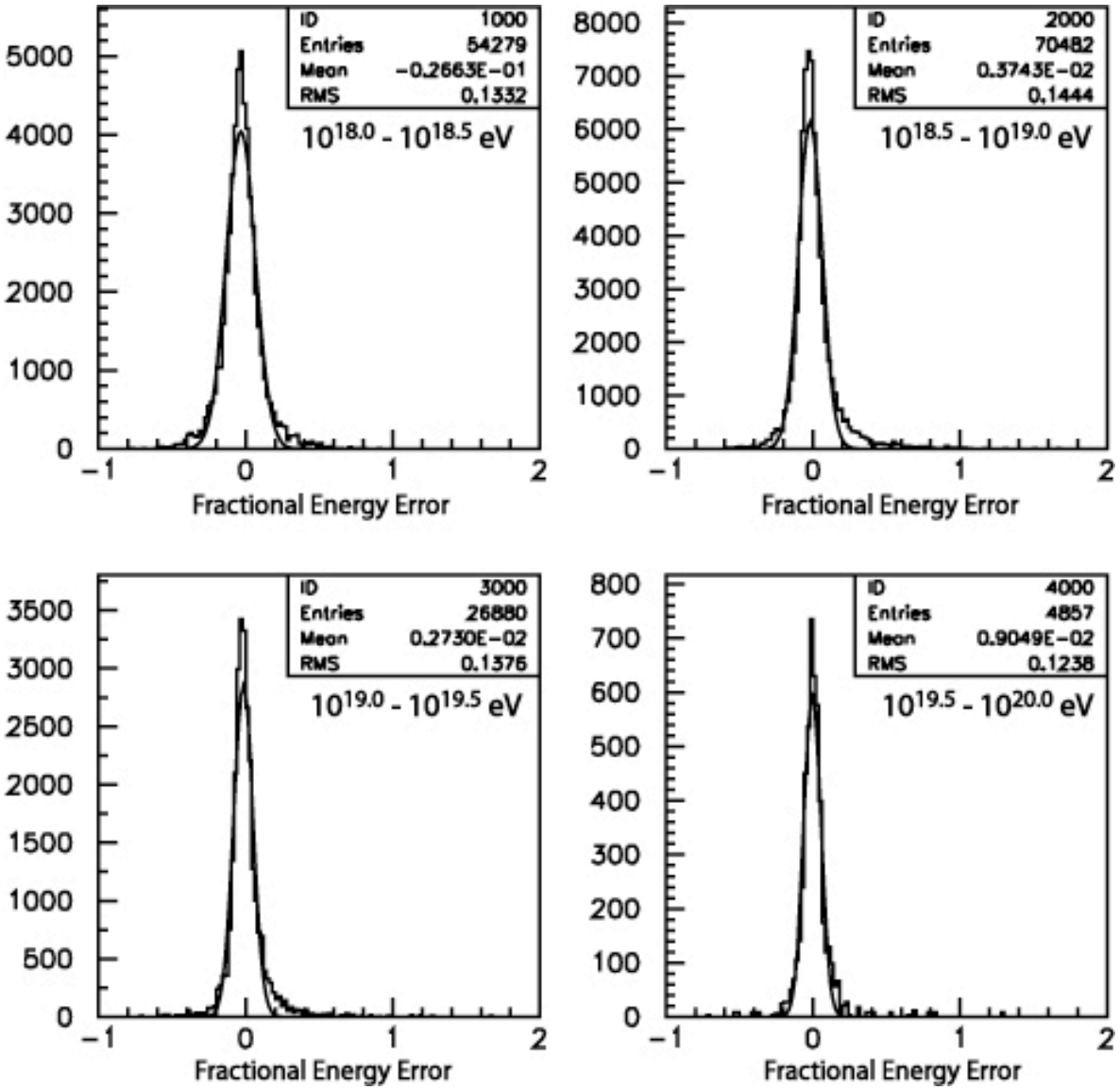


HiRes-2 Monocular Spectrum for data taken between Dec. 1999 and Sep. 2001.

Data Selection

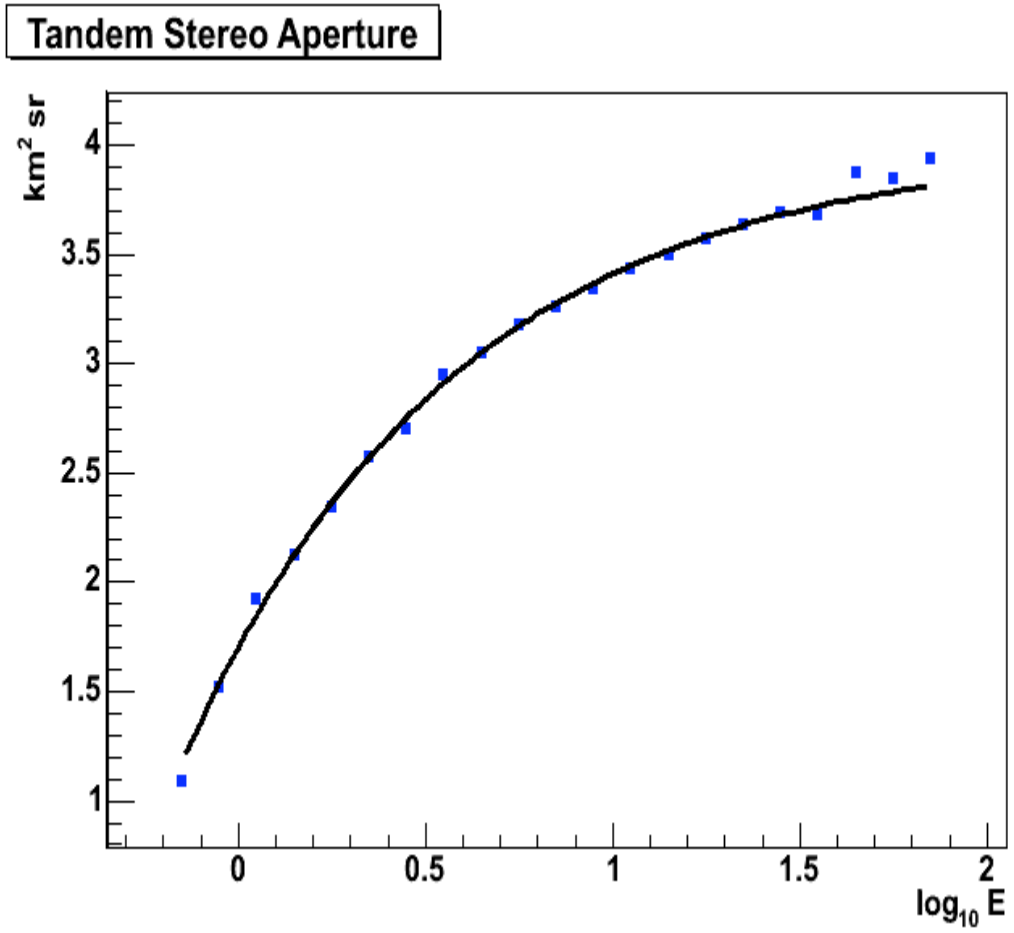
- Total on-time: 573 hours of data over 124 nights
- ~1100 stereo events with successful SD plane at both sites.
- We are starting with significantly tighter cuts than used for just mono/stereo comparison. These requirements include:
  - Angle between HR1 and HR2 SD planes > 5°.
  - In-SD-plane angle Ψ (HR1) < 120°.
  - Observed track depth > 150 g/cm^2.
  - 500 < Xmax < 1150 g/cm^2.
  - Xmax – Xfirst (depth of first triggered PMT) > –300 g/cm^2.
  - Xmax – Xlast (depth of last triggered PMT) < + 100 g/cm^2.

HiRes-1 Tandem Energy Resolution



Event Distribution

Calculated Aperture



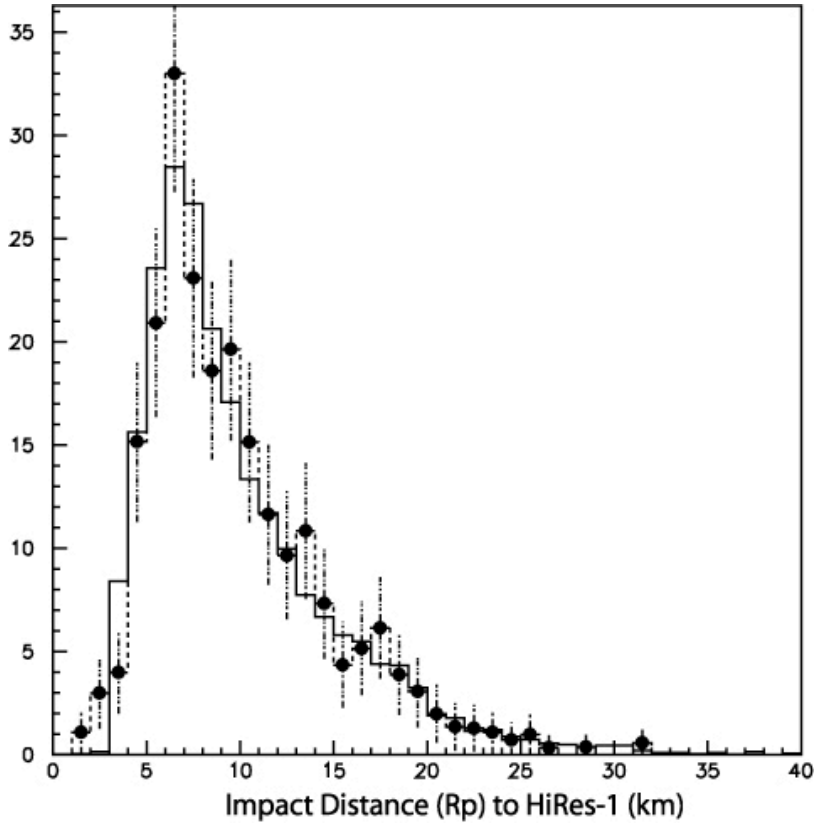
4. Data/MC Comparison

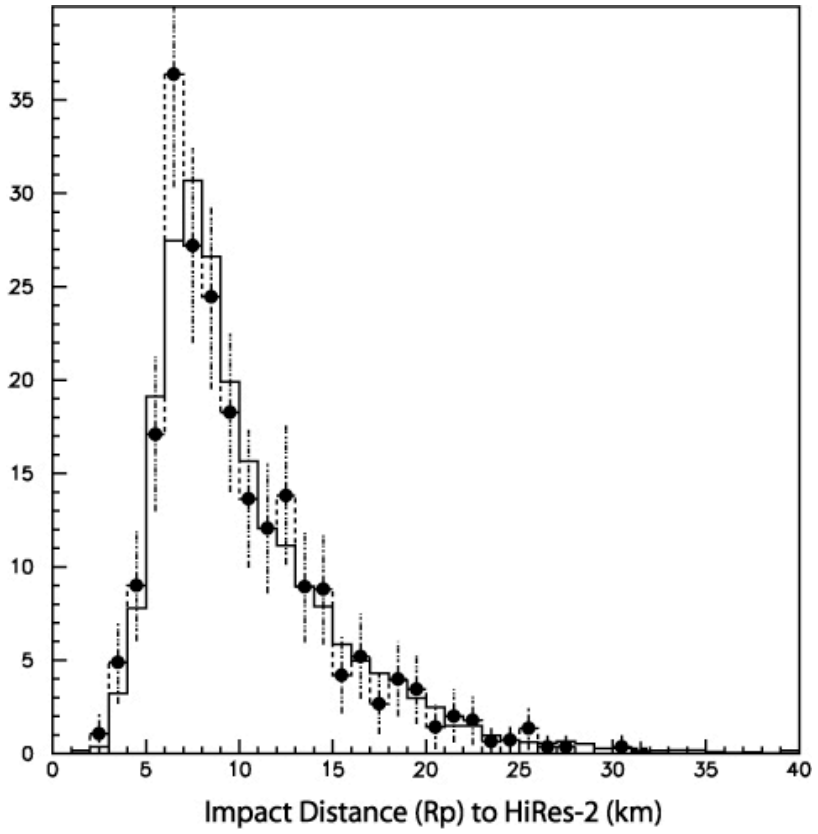
Validation of the Aperture calculation

Data / MC comparisons

- Using the MC to calculate aperture makes the assumption that the simulation gives a good description of the data set.
- In particular, the detector aperture is characterized by the Rp, Ψ, and θ (zenith) angle distributions.
- In the following slides we compare the observed distributions to those of the simulated data set used in the aperture calculation.

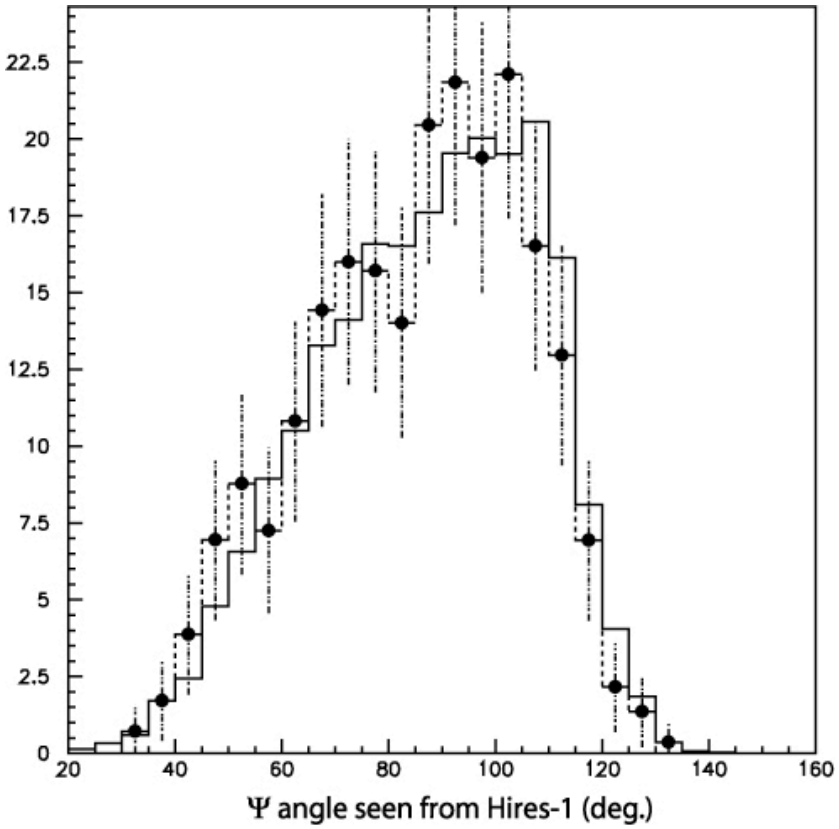
1. Shower Impact Distance (Rp)

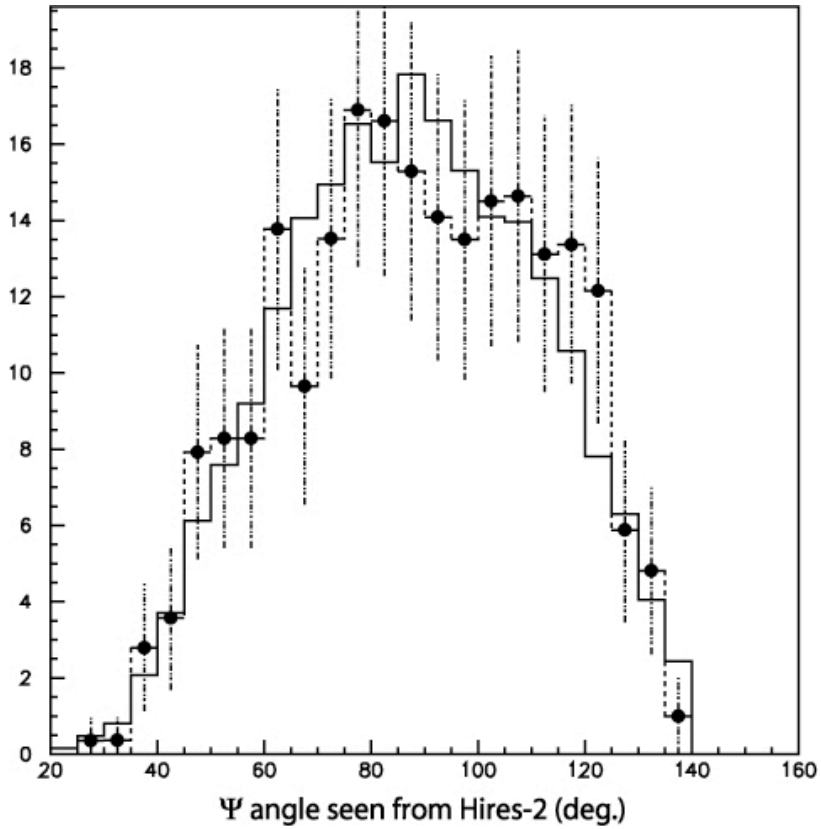




Data points with error bars: stereo data, Histogram: tandem simulation

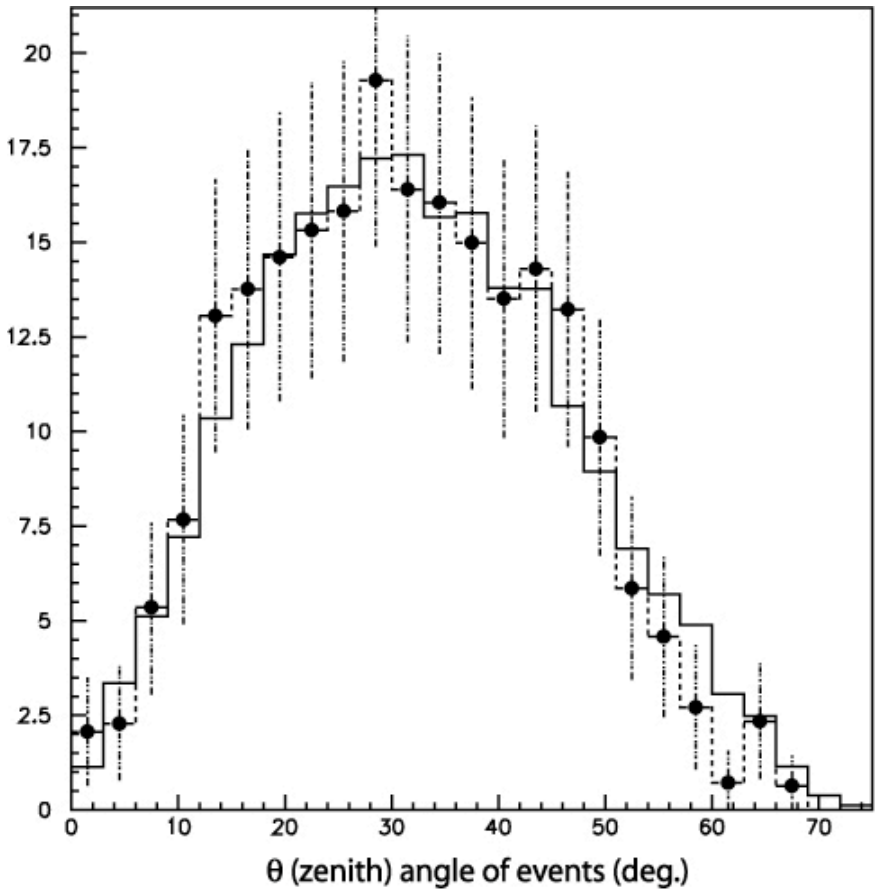
2. Shower Viewing Angle Ψ





Data points with error bars: stereo data, Histogram: tandem simulation

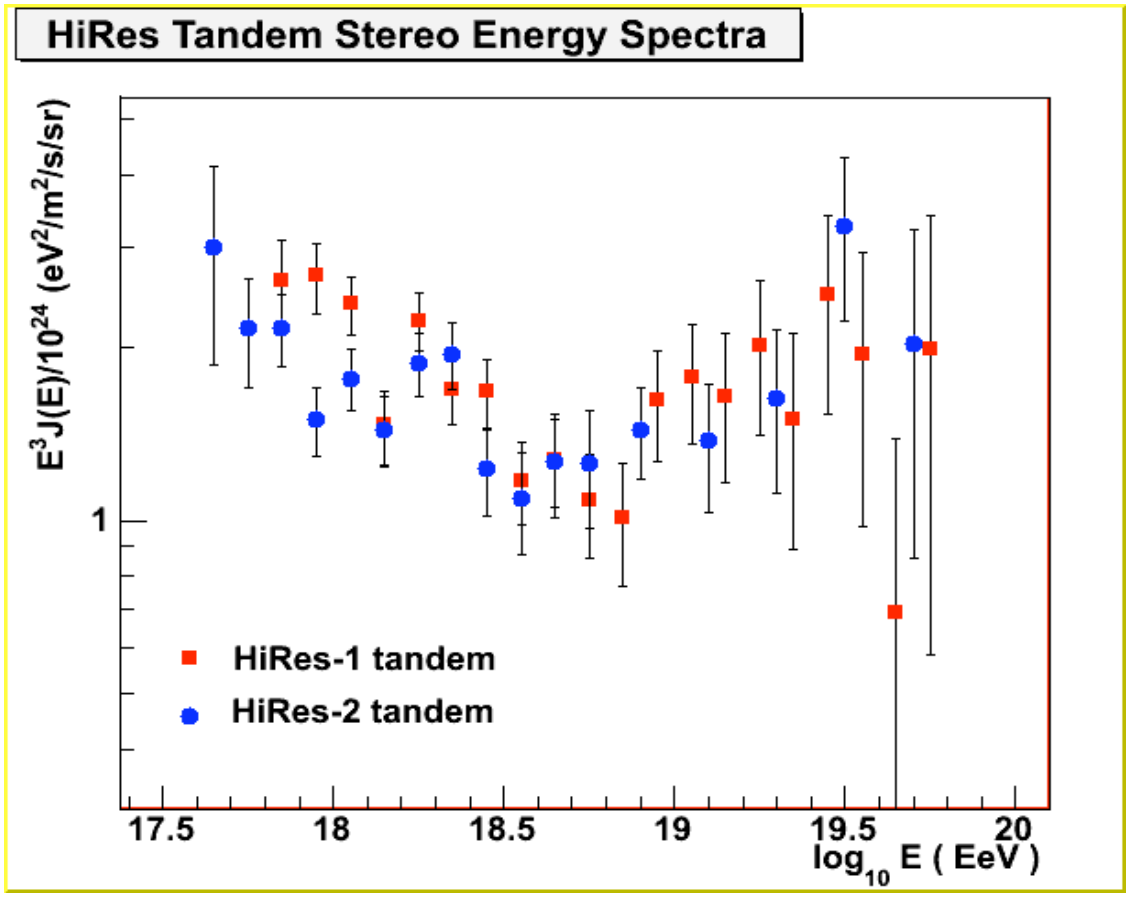
3. Shower Zenith Angle θ



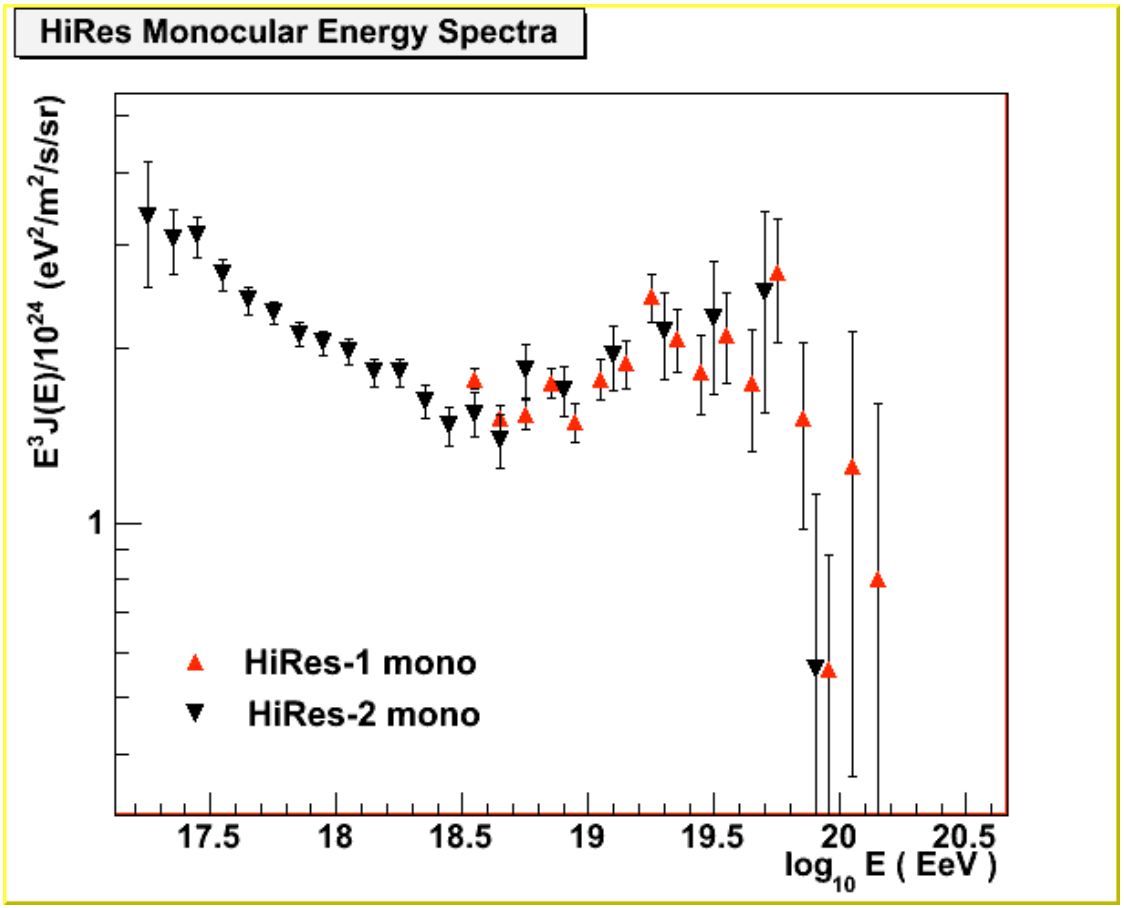
- <u>Conclusion:</u> Data and MC distributions are in good agreement for the key quantities which characterize the aperture

5. The HiRes Tandem Stereo Spectrum

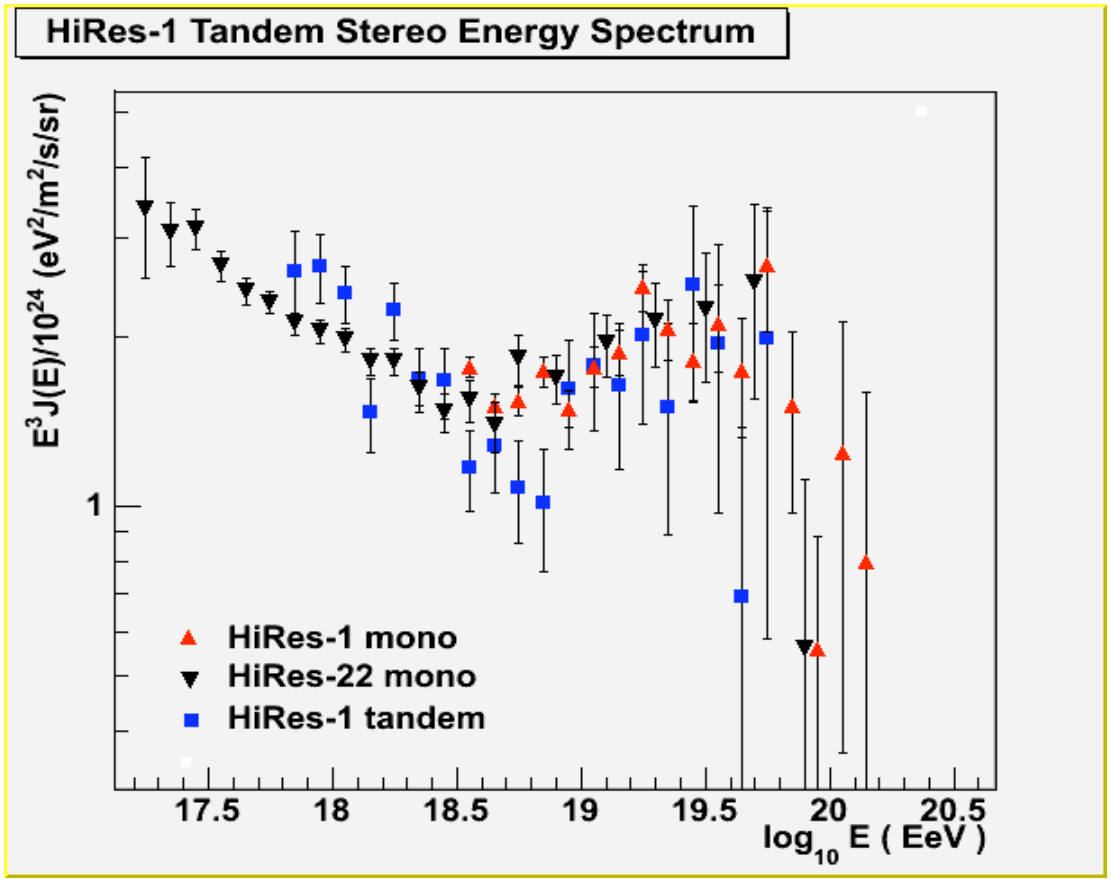
HiRes Tandem Stereo Energy Spectrum



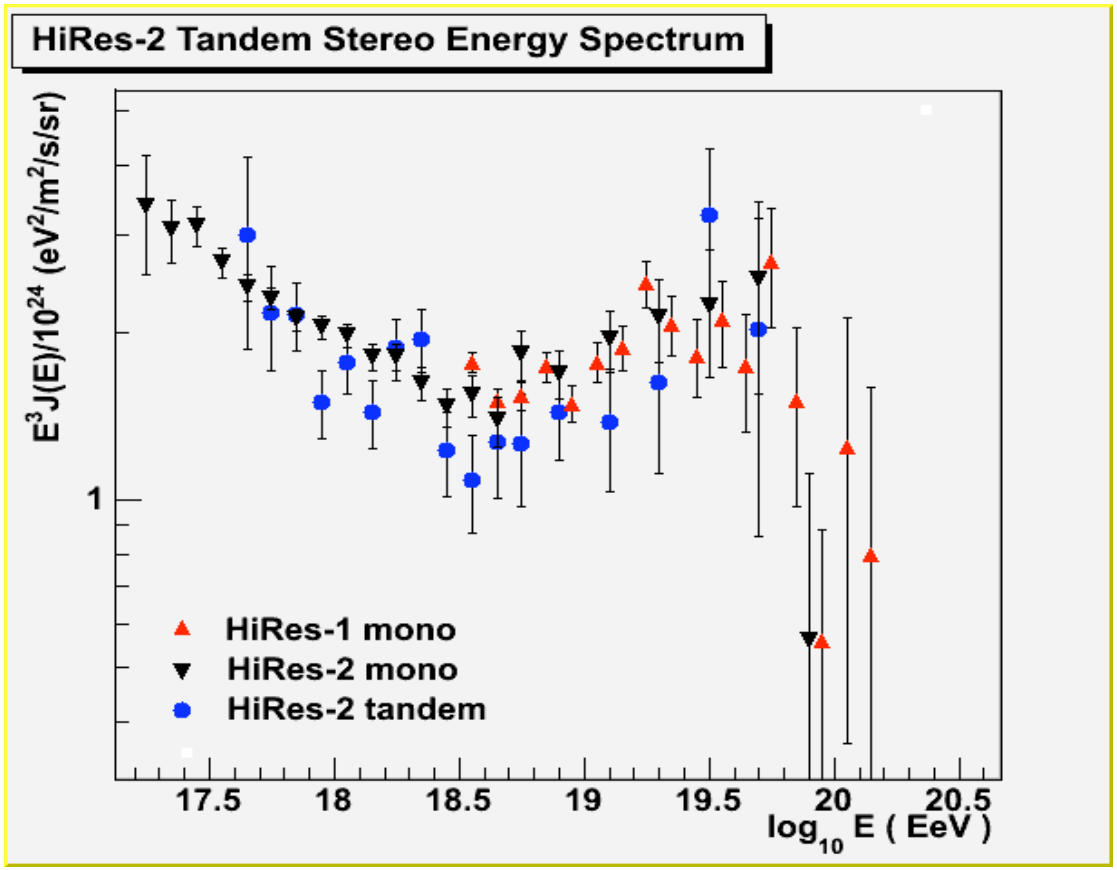
HiRes Monocular Spectrum



HiRes-1 Tandem / HiRes Mono



HiRes-2 Tandem / HiRes Mono



6. Epilogue

Epilogue

- Tandem stereo analysis under way (a) to cross-check the monocular spectra using stereo geometry and, (b) to **provide a "bridge" between the published monocular spectra and the stereo analysis.**

Epilogue (2)

- Tandem Reconstruction gives significantly better energy resolution than HiRes-1 monocular.
- MC/data comparison shows good agreement, especially in those quantities characterizing the aperture.
- First results from the HiRes tandem study show good agreement with monocular spectra.

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