Analysis Techniques Used for Telescope Array Surface Detector Data

Dmitri Ivanov
Rutgers University, University of Utah
ISVHECRI 07-01-10
Outline

- Telescope Array Detector
- Telescope Array Surface Detector (TA SD) Event Reconstruction
- TA SD Monte-Carlo
- TA SD DATA/MC Comparison
- Preliminary Results
- Conclusions
Telescope Array

Hybrid detector

Millard County, UT
39.3° N, 112.9° W, Alt. 1400m

507 plastic scintillator counters, 1.2km apart, cover 680km² area

Middle Drum (MD)

Black Rock Mesa (BR)

Long Ridge (LR)

3 FD detectors: BR, LR, SK
TA Surface Detector

- Powered by solar cells; radio readout.
- Self-calibration using single muons.
- In operation since March, 2008.
Introduction

- Basic TA SD event reconstruction is done in a Monte-Carlo-independent way:
  - As a starting point, we use results of the AGASA experiment (LDF, shower front timing)
  - Reconstruction procedures and formulas are adjusted to fit TA SD data by applying self-consistency tests to the results of fitting
  - This is sufficient for reconstructing event geometry, as well as lateral distribution profile
- We then use carefully tested MC set, which shares all the characteristics of the real data to estimate the event energy and calculate the aperture.
SD Event Reconstruction

- Two fits:
  - Time fit to determine event geometry
  - Lateral distribution fit (LDF) to determine S800 (signal size 800m from the shower axis)

- Fitting procedure and formulas are adjusted using only the real data

- Use Monte-Carlo to obtain the first estimate of the energy from event geometry and signal size 800m away from the shower axis

Use AGASA LDF
SD Fitting Procedure

- Event direction is found by minimizing:

\[ \chi^2 = \sum_{i=1}^{nSDs} \left( \frac{(t_i - T_0 - T_{\text{Plane}} - T_D)^2}{T_S^2} + \frac{(\vec{R} - \vec{R}_{\text{COG}})^2}{(180\text{m})^2} \right) \]

- Time of the core hitting ground \( T_0 \)
- Time of the shower front plane \( T_{\text{Plane}} \)
- Time delay (Modified Linsley) \( T_D \)
- Fluctuation of time delay (Modified Linsley) \( T_S \)
- (Fitted) core position \( \vec{R} \)
- Core position found from the center of gravity of charge \( \vec{R}_{\text{COG}} \)

- S800 is found by fitting the lateral profile to AGASA LDF function
Fitting results

- Fitting procedures are derived solely from the data
- Same analysis is applied to MC
- Fit results are compared between data and MC
- MC fits the same way as the data.
- Consistency for both time fits and LDF fits.
First Energy Estimation

- Energy table is constructed from the MC
- First estimation of the event energy is done by interpolating between S800 vs sec(θ) lines

\[ E = 10^{20}\text{eV} \]

\[ E = 10^{19}\text{eV} \]
Next Step

- Must cut out events with bad resolution
- Must calculate aperture by Monte Carlo technique.
- TA uses same analysis techniques based on DATA/MC comparisons that were first introduced to UHECR physics by HiRes experiment.
SD Monte-Carlo: Methodology

- Simulate an event set which has all known characteristics of the real data:
  - Energy distribution is continuous and follows power laws measured by HiRes:
    - $E^{-3.25}$, $E < 10^{18.65}$ eV
    - $E^{-2.81}$, $E > 10^{18.65}$ eV
  - Angular distribution is continuous and isotropic in the local sky, in a way appropriate for the ground arrays ($\sin^2 \theta$)
  - Use the composition measured by HiRes

- Record the MC in the same format as the data

- Run the same reconstruction programs on MC as on the data

- Validate the SD MC by comparing the distributions of its reconstructed variables with the real data.
Simulating SD Events

- Use $10^{-6}$ – thinned CORSIKA QGSJET-II proton showers that are de-thinned in order to restore information at the shower tail needed by the ground array.
  - De-thinning procedure is validated by comparing results with un-thinned CORSIKA showers, obtained by running CORSIKA in parallel.
- We fully simulate the SD response, including the details of the detector electronics.
Data/MC Comparison

- Run reconstruction program on data and MC in the same way
- Histogram a common observable for data and MC
- Normalize MC histogram to the real data
  - Data and MC histograms have same integral
- Form the ratio of the two histograms
DATA/MC: SD Information

Number of good SDs / event

VEM / SD
DATA/MC Event Direction

Zenith angle

Azimuthal angle
DATA/MC: S800, Energy

S800 Energy
TA SD Resolution

- To achieve good resolution one applies quality cuts
- Correct aperture is calculated from MC which:
  - Agrees with the data
  - Analyzed in the same way as the data, including the quality cuts
Energy Scale

- Energy scale is determined more accurately by FD than by CORSIKA QGSJET-II
- Set SD energy scale to FD-Mono using well reconstructed events seen by both detectors
TA SD and FD results agree
Conclusion

- Calculated SD energy spectrum using new techniques
- Geometry and LDF reconstruction are based solely on characteristics of the data
- Generated MC set with all characteristics of the real data
- Verified the validity of our MC by comparing with the data
- Tied SD energy scale to FD
- TA SD and FD energy spectra are in agreement
Thank You

The Telescope Array Experiment is funded by NSF and the Ministry of Education, Culture, Sports, Science, and Technology of Japan.