A Preliminary Analysis of Large Scale Anisotropy of UHECR based on EA April-August 2002 Data

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Abstract

The purpose of this note is to present the first set of reconstructed events from the Engineering Array collected from April through August 2002. Since the statistics at this stage is poor, the intention of the authors is not to make physical conclusions about the energy spectrum or anisotropy; rather, it is to make certain procedures and methods for future analysis.

1. Introduction

Since the anisotropy of sources of high-energy cosmic ray events reconstructed in this early stage of operation of the Engineering Array could help in debugging the code (e.g. large excess of the number of events in some direction with such low statistics will most likey would be because of some systematic effect), we have performed this preliminary study. In order to achieve this, we have reconstructed events from April through August 2002 using CDAS software Er v2r2. Several conditions were imposed on the reconstructed events:

- number of triggered stations is at least 5
- distance from the core to the nearest triggered station is less than 1.5 km

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- shower front curvature R> 0

2. Monte Carlo for the Isotropic Sources

We have performed Monte Carlo simulations for the isotropic sky in order to estimate deviation from isotropy of reconstructed events and compare our results to previous experiments to see if the values are reasonable. Also, this provides regions of the sky that can be covered depending on the opening angle of the detector (e.g. zenith angle 45° or 60°).

Events in the simulation are obtained by taking random distribution in zenith and azimuth angles and time. The probability distribution function for the zenith angle is

$$f(\theta) = N \sin(\theta)\cos(\theta) \tag{1}$$

where θ is the zenith angle and N is a normalization factor which depends on the opening angle:

$$N = \frac{2}{\sin^2 \theta_{\max}} \tag{2}$$

sin(θ) comes from the size of the solid angle and cos(θ) from the transverse surface area of the array. Azimuth angle and time of an event are uniformly distributed. Results for 300,000 random events are shown on plots below

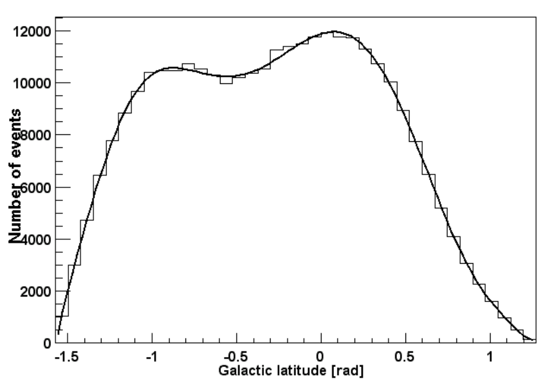

Fig. 1- Monte Carlo for the isotropic sky, location is Malargue, zenith angle less than 45 degrees

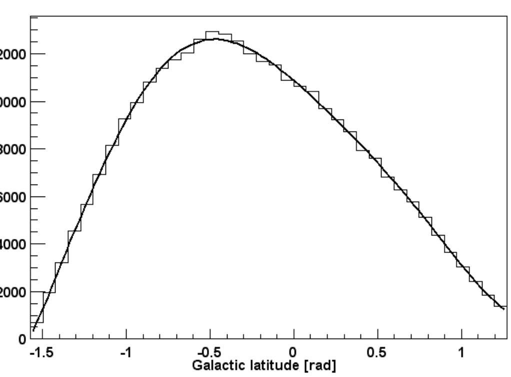

Fig.2- Monte Carlo for the isotropic sky, zenith angle is less than 60 degrees

Solid lines are tenth-order polynomial fit to histograms.

Sky Maps - Monte Carlo: Equatorial Coordinates

Auger – Malargue AGASA

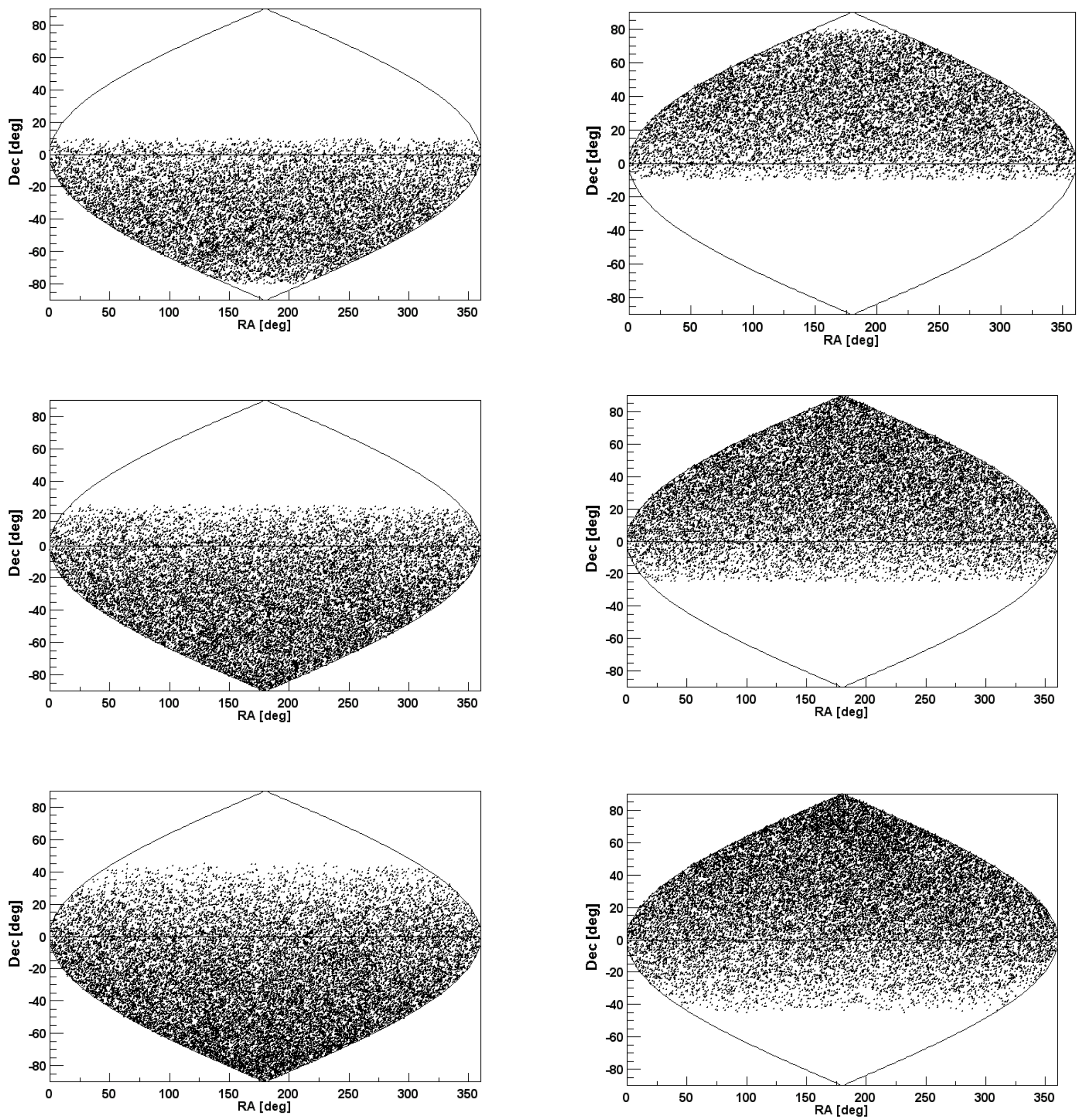

Fig. 3 – Monte Carlo simulation results for maps of the sky in equatorial coordinates, zenith angle up to 45°, 60° and 80° respectively. Results for Auger and AGASA are shown for comparison

Sky Maps - Monte Carlo: Galactic Coordinates

Auger – Malargue AGASA

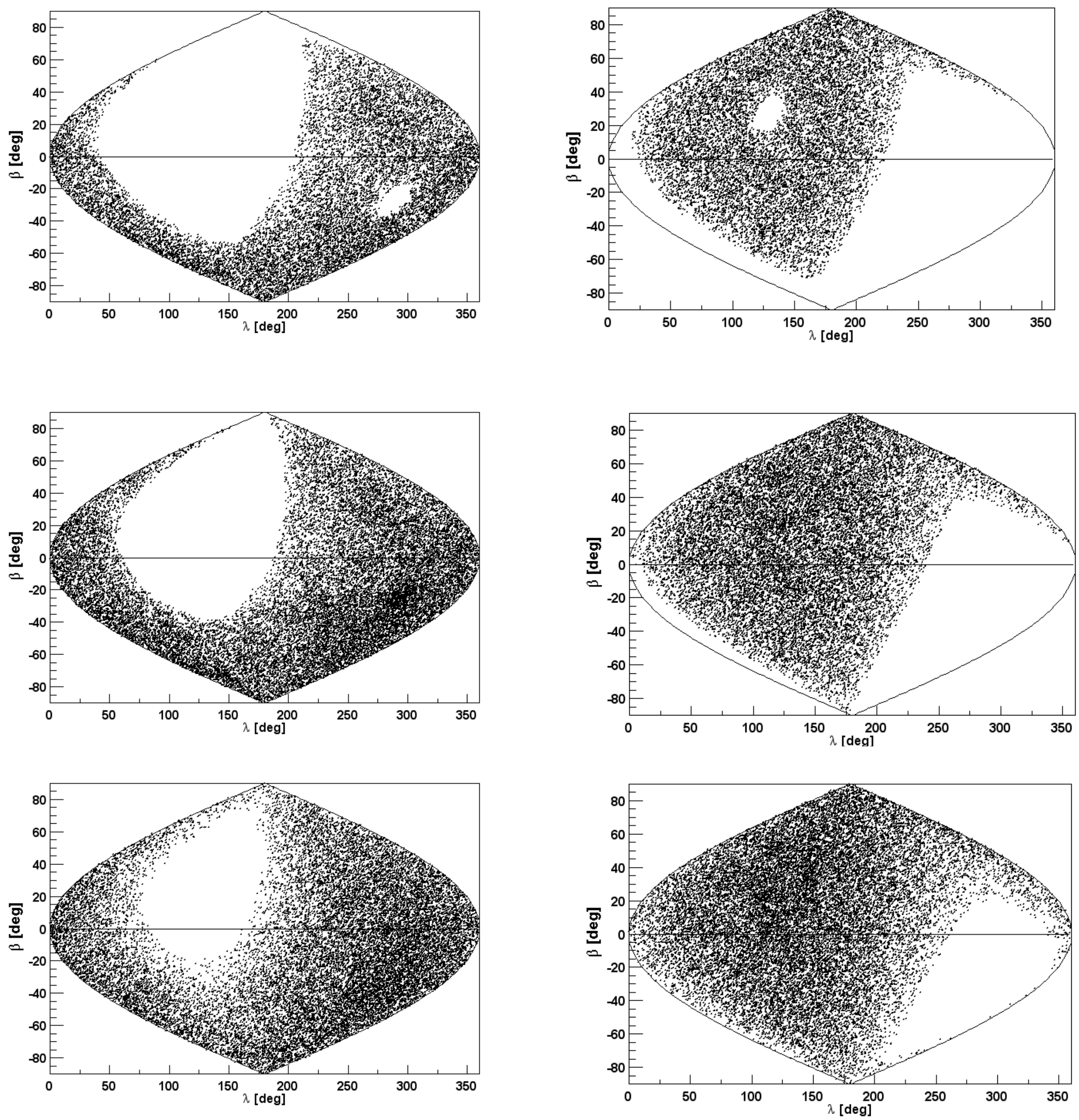

Fig. 4 – Monte Carlo simulation results for maps of the sky in galactic coordinates, zenith angle up to 45°, 60° and 80° respectively. Results for Auger and AGASA are shown for comparison

3. Reconstructed EA events: April-August 2002

For events detected in the period from April through August 2002, there were 270 events with energy above 10^{18} eV, according to the CDAS reconstruction code. The resulting sky map in equatorial coordinates is shown below. No anisotropy is visible.

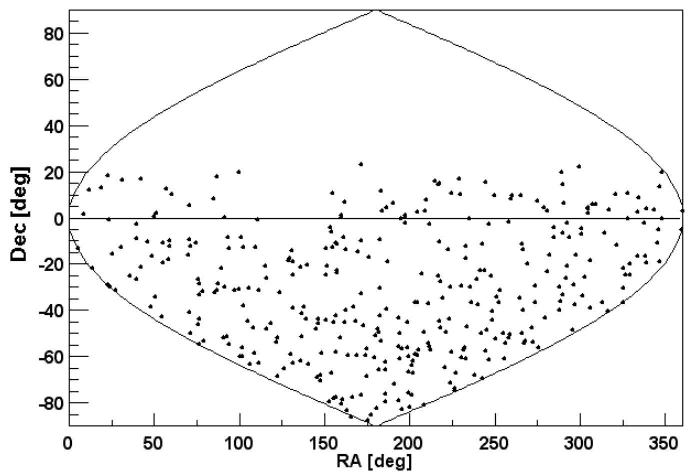

Fig. 5 Map of the sky in equatorial coordinates, reconstructed events April-August 2002, energy > 10^{18} eV, zenith angle up to 60°

Declination distribution of these events is shown in Figure 6. The solid line corresponds to a uniform sky. Again, the data is consistent with uniform sky.

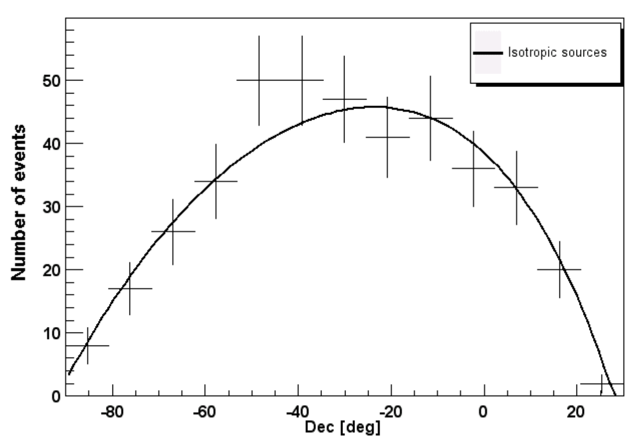

Fig.6 Declination distribution, zenith angle<60°, energy > 1 EeV.

Based on the errors from the reconstruction, we estimate the angular resolution to 1.2°. We have also made an estimate of the galactic plane enhancement factor f_E by comparing our data to the isotropic sky as predicted by Monte Carlo. This factor depends on the energy and is defined as [1]:

$$\frac{I_{obs}(\beta)}{I_{iso}(\beta)} = 1 - f_E + 1.402 f_E \exp(-\beta^2) \qquad (3)$$

where β is the galactic latitude. Results of the EA data are shown below in Figure 7. The solid line is the expectation from a uniform sky, and the dashed line is the result of the fit.

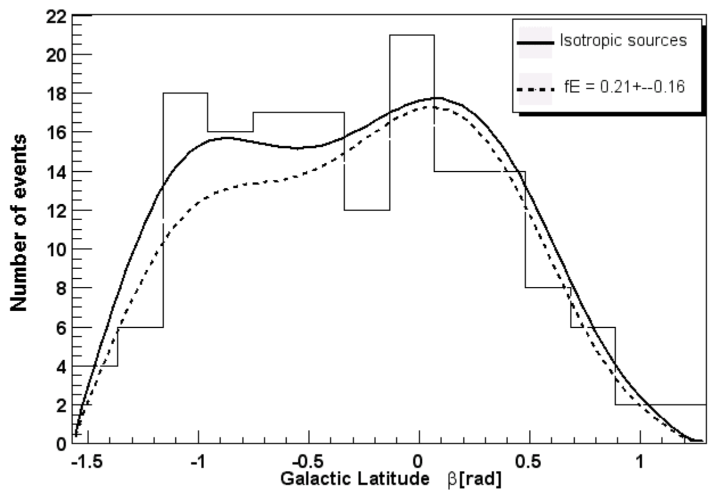

Fig.7 Number of events vs. galactic latitude, zenith angle<45°, energy is greater than 10^{18} eV. Solid line is the distribution of isotropic sources; broken line is the fit with function (3)

The value for f_E that was obtained f_E=0.21±0.16 has large error bars due to poor statistics, and is consistent with an isotropic sky.

If we fit the data with a more general form

$$\frac{I_{obs}(\beta)}{I_{iso}(\beta)} = 1 - h_E + g_E \exp(-\beta^2) \qquad (4)$$

we get h_E=*0.05+-0.23* and g_E=*0.10+-0.28* . Figure 8 shows the data (histogram), uniform sky MC (solid line) and the result of this generalized fit (dashed line). Figure 9 shows the comparison between data and MC for the cosine of the angle with respect to the galactic center.

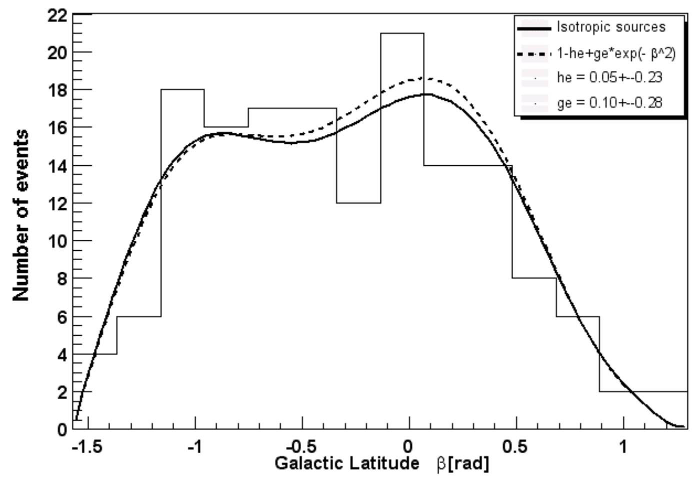

Fig.8 Number of events vs. galactic latitude, zenith angle<45°, energy is greater than 10^{18} eV. Solid line is the distribution of isotropic sources; broken line is the fit with function (4)

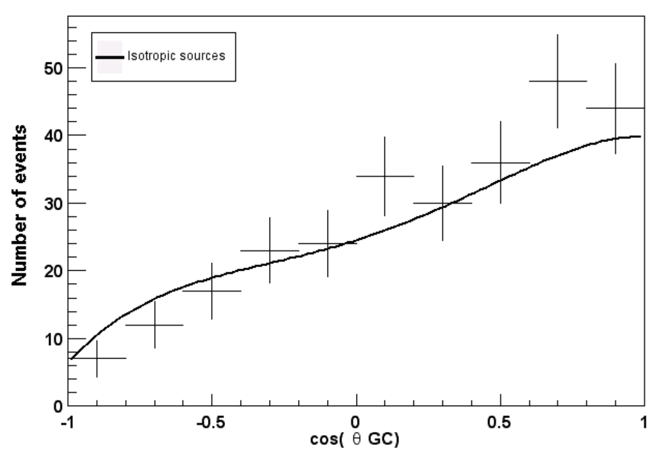

Fig.9 Number of events vs. cos(θ_{GC}) , where θ_{GC} is the angle between the direction of the event and Galactic centre, zenith angle<60°, solid line is the distribution of isotropic sources

In the period April-August number of events with energy above 10^{19} was 30 for zenith angle up to 60°, and 15 for zenith up to 45°. The later number can be compared to AGASA results [2]. AGASA reported 522 events in a period of 9 years which, when normalized to 5 months of EA operation (and assuming half the aperture, which is an approximation), scales to 12 events. EA data gives 15 events with the energy greater than 10^{19} eV and zenith angle up to 45° and that is, at least in the order, close to AGASA's result.

4. Conclusion

The EA data collected during April through August 2002 shows an angular distribution consistent with an isotropic one, which is also, within the error, consistent with AGASA. Even though the Surface Detector is in its early stage, no strange behaviour in the distribution on the sky has been observed. An analysis of events with large zenith angles (up to 80°) is desirable since it provides a better sky coverage and comparison with AGASA results. The knowledge of angular resolution is crucial to study clustering, and this work is in progress.

References

1. Wdowczyk, J. & Wolfendale, A.W. 1984, J.Phys. G,10,1453
2. Takeda et al. 1999 ApJ 522, 225
3. D.J.Bird et al. arXiv:astro-ph/0205324