

Application of Monte Carlo simulations in the study of cosmic rays

Carola Dobrigkeit (PQ), D. Pakk Selmi-Dei (PQ), Gabriel P. Alves (IC).

Abstract

In the study of the arrival directions of cosmic rays, data from the Pierre Auger Observatory encourage the search for anisotropies in its distribution [1,2]. When studying the arrival direction distribution, one of the first approaches is looking for a possible dipole in the distribution. In this project we use the Monte Carlo method to simulate cosmic-ray arrival directions from a dipole distribution of a given intensity and for the exposure of the Auger Observatory. We then smear the simulated directions, mimicking the experimental angular resolution. Finally we reconstruct the dipole distribution from the smeared distribution, and compare it with the one originally simulated. This comparison allows one to estimate the number of cosmic rays the Observatory needs to detect in order to observe a dipole of same intensity as the simulated one in its data with a significance of five standard deviations.

Key words: Cosmic rays, Monte Carlo, simulations.

Introduction

In this study we consider a dipole distribution in the arrival of cosmic rays to Earth, in which the dipole vector points to the Galactic center. Using the Monte Carlo method we simulate a data set that takes into account the dipole distribution of events, the exposure of the Auger Observatory [3], and the known angular resolution in directional measurements. In possession of simulated data, we reconstruct analytically the coefficient α that represents the dipole intensity, and compare the reconstructed value with the initial one used in the simulation.

Results and Discussion

Following the method briefly described above, we can build a model that reproduces the behavior expected of arrival of rays. Figure 1 below shows a sketch of the result.

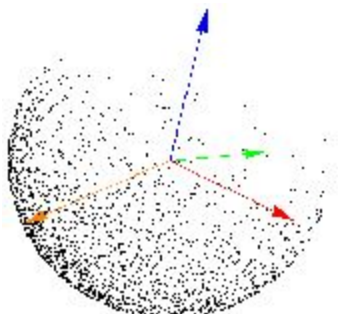


Figure 1. Sketch of a set of simulated arrival directions. The orange axis represents the dipole vector (pointing to the Galactic center), where most events are concentrated. The blue axis points to the equatorial north pole, the red one points to the vernal point and the green one is a reference to the equatorial plane.

We reconstruct the value of the coefficient α for

several values of dipole intensities. The result is a comparison between the α_{SIM} coefficient used to create the model, and α_{CALC} , result of reconstruction. Table 1 shows as an example the values of α_{CALC} and its significance when $\alpha_{SIM} = 0.10$.

Table 1. Number of events and significance.

#events	α_{CALC}	α_{SIM}	α_{CALC} / σ
30000	0.11 ± 0.02	0.10	4.63
40000	0.11 ± 0.02		5.76
50000	0.10 ± 0.02		5.76

Note that there is good agreement between the values α_{SIM} and α_{CALC} . We can also see that for a dipole with intensity 0.10, the number of events that Auger Observatory should observe to obtain a significance of five standard deviations is less than 40000. There was good agreement with that presented in [4].

Conclusions

For a dipole of intensity 0.10, we could determine the number of events required to detect anisotropy. For different dipole intensities, we have obtained different results, ranging from 1000 events to values above 10^5 . That is, the number of events to be observed is highly dependent on the value of the intensity of dipole. More specifically, the lower the intensity, the greater the number of events that we should observe.

1 The Pierre Auger Collaboration, ApJ 802, 111 (2015)

2 The Pierre Auger Collaboration, ApJ 804, 15 (2015)

3 SOMMERS, P., Cosmic ray anisotropy analysis with a full-sky observatory, Astroparticle Physics 14, 271-286 (2001).

4 PASCON, A. M., Anisotropia de larga escala em raios cósmicos de altíssima energia no Observatório Pierre Auger, Master Thesis (IFGW/UNICAMP) (2008).