Study on large-scale CR anisotropy with ARGO-YBJ experiment

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Abstract: The ARGO-YBJ experiment is a full coverage Extensive Air Shower detector. It has successfully been functioning since June 2006 at 4300 m a.s.l. in Tibet, China. Benefiting from its high duty cycle and large field of view, this experiment can survey north sky for the study of the cosmic rays distribution. We present the observation results of large-scale cosmic ray anisotropy by ARGO-YBJ experiment with the data from 2008 to 2009. A two-dimensional skymap is presented and the energy dependence for this anisotropy at median energies is also presented in this work.

Keywords: Anisotropy, ARGO-YBJ, Equi-zenith Method

1 Introduction

Cosmic rays (CRs) at TeV energy are mainly considered as Galactic origin and are accelerated by shock waves at supernova remnants. A weak anisotropy of it is observed by many experiments with an amplitude about 0.1% [?][?]. Previously, several experiments[?][?][?][?]have reported a one-dimensional large scale anisotropy as the sidereal time variation at the spinning Earth using underground detectors or ground-based air shower arrays. Recently, benefiting from the large statistics and the wide field of view,some experiments [?][?][?][?] have measured the two-dimensional anisotropy of multi-TeV CRs, and the so-called "tail-in" and "loss-cone" anisotropy features has been obtained. The large-scale anisotropy phenomenon may contain information close to the nearby cosmic rays source or the magnetic field structure in our surrounding environment [?]. The long term modulation of the cosmic rays intensity includes both Sun and celestial anisotropy. The celestial anisotropies are caused by the Earth motion in the cosmic rays reference system (solar anisotropy: Compton-Getting effect[?])and by the solar system location inside the Galaxy (sidereal anisotropy).
In this paper, we present the results on the observation of large-scale cosmic ray anisotropy by ARGO-YBJ experiment. In addition, we also present energy dependence effect on CRs relative intensity and compare it with Tibet ASγ experiment. The effect of energy dependence will be helpful to understand the possible nature of the large-scale anisotropy.

2 The ARGO-YBJ Experiment and Data Selection

The Argo-YBJ experiment is an Extensive Air Shower (EAS) array, located at the Yangbajing Cosmic Ray Laboratory (Tibet, P.R.China) at an altitude of 4300 m a.s.l. The detector consists of a single layer of Resistive Plate Chambers (RPCs) operating in streamer mode and of a modular structure, with the basic module being the Cluster (5.7 $\times$ 7.6 m^2), made up of 12 RPCs (2.850 $\times$ 1.225 m^2) . The central area like a carpet (about 74 $\times$ 78 m^2) is fully covered by 130 clusters, which is surrounded by 23 sampling guard ring clusters with a detection area of 6700 m^2 and about 93% of active area. The detector is connected with two different DAQs corresponding to two operation modes: the shower and the scaler modes. In shower mode, for each event the location and timing of the secondary particles are recorded, allowing the reconstruction of the lateral distribution and the arrival direction with a threshold energy of a few hundred of GeV. The data used in this analysis was collected by ARGO-YBJ from 2008 January to 2009 December. The events selected condition is based on the following criteria:

1. Reconstructed zenith angle $\leq$45deg;
2. Number of hits of event $\geq$40;
3. χ^2 of events reconstructed $\leq$80.

These criteria could help to guarantee the quality of the events.

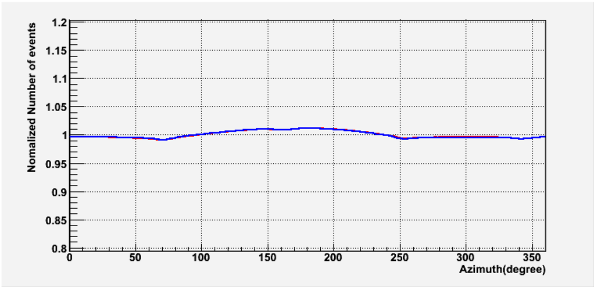

Figure 1: The azimuth distribution of ARGO-YBJ reconstructed data in one year. The dotted red line is of the data in 2008, and solid blue line is of in 2009. Both of them are normalized to 1, and x-axis direction is labelled by azimuth value in the unit degree. From this figure we can see the azimuth distribution is very stable.

3 Analysis Method

Equi-zenith angle method has some advantages in analyzing the CR work, as it can eliminate various detecting effects caused by instrumental and environmental variations, such as changes in pressure and temperature. So we use χ^2 iteration equation based on equi-zenith angle method[**?**][**?**][**?**]. The detectors are towards the same sky region at the same Local Sidereal Time(LST), we can connect the sky points in the horizonal coordinate with those in the equatorial coordinate. $I_{i,j}$ denotes the relative intensity of sky cell (α_i–Right Ascension,δ_j–Declination). We take N(α_i,δ_j) as the number of CRs from direction (α_i,δ_j), and $N_b(\alpha_i$,$\delta_j)$ as the background events from the same direction which are estimated by averaging the different azimuth directions in the same zenith angle.

$$I_{i,j} \equiv \frac{N(\alpha_i, \delta_j)}{N_b(\alpha_i, \delta_j)} \tag{1}$$

From general knowledge , we know that $I_{i,j}$ is very close to unit 1. So we can construct the χ^2 function as below :

$$\chi^2 = \sum_{m,n,l} \frac{N(m,n,l)/I_{i,j}^{(k+1)} - \overline{N(m,n,l')/I_{i,j}^{(k)}}}{N(m,n,l)/{I_{i,j}^{(k+1)}}^2 + \overline{N(m,n,l')/{I_{i,j}^{(k)}}^2}} \tag{2}$$

here m, n ,l stand for the Local Sidereal Time,Zenith angle, and Azimuth in the horizonal coordinate system respectively. And l' means other azimuth direction besides l at the same zenith angle and the same LST . k and $k+1$ is labeled for the iteration times. After twenty or more times iterating, through the process of minimizing the value of χ^2 , $I(i,j)$ can be determined. Significance can be calculated by

$$s = \frac{I_{i,j}}{\sigma_{I_{i,j}}} \tag{3}$$

4 Correction on the Azimuth Distribution

The construction of the χ^2 function is based on an assumption that CRs azimuth distribution is uniform or it is very close to uniform. But actually it is a different case for experiment. Fig**??** shows CRs events azimuth distribution recorded by ARGO-YBJ experiment, which is obviously a non-unform distribution. Our study result shows that the non-uniform distribution is stable and persistent, due to the asymmetry of detectors array and the effect of geomagnetic field. However, as non-uniformity is irrelevant to the study of azimuth distribution, it could be removed for the moment. In this way, the correction is made on the azimuth distribution (by different zenith angle band), and then, the Equi-Zenith method could be applied.

5 Results

5.1 Sidereal Anisotropy

The rotation of the Earth enables a ground-based experiment to scan the sky in right ascension direction therefore allowing the detection of a modulation in the intensity of the primary cosmic rays with a period of one sidereal day. Fig**??**(A) shows the significance skymap after smoothing within 5° solid circle angle in equatorial coordinates system. There are two main parts in the map: a large deficit area named "loss-cone" and a high rise area called "tail-in". Also the Cygnus region has been detected with 13σ far beyond the background level. Fig**??**(B) shows the relative intensity varies in Right Ascension direction, which can be described by the first and second-order cosine harmonics function like $1 + A_1cos(2\pi(x - \phi_1)/360) + A_2cos(2\pi(x - \phi_2)/180)$. The fit amplitudes and phase are $A_1 = 6.8 \times 10^{-4}$, $A_2 = 4.9 \times 10^{-4}$ and $\phi_1 = 39.1°$,$\phi_2 = 281°$. The results agree with that from Tibet AS_γ experiment (located at the same observation site as ARGO-YBJ experiment).

5.2 Energy Dependence

The intensity amplitude of anisotropy is a measurable vector which connects with the changes in the external environment such as Interplanetary Magnetic Field. We have searched for energies dependent effects using our data. We divide the events into six groups according to the number of hits recorded by the detectors (N_{hits}=40 $\sim$ 60, 60 $\sim$ 100, 100 $\sim$ 160, 160 $\sim$ 300, 300 $\sim$ 700, 700 $\sim$). The median energies of the six group events are estimated by full Monte-Carlo simulation, and they are 0.9TeV, 1.52TeV, 2.41TeV, 3.58TeV, 7.17TeV and 18.31TeV respectively. Fig.**??** shows the intensity skymaps for six N_{hits} bins. The pictures from top to bottom present low-N_{hits} to high-N_{hits} bins. Each 2-dimensional skymap is projected to 1-dimensional variations in RA. In comparison to previous experiments the 1-dimensional RA distribution is fitted with a first harmonic function. Fig**??** shows

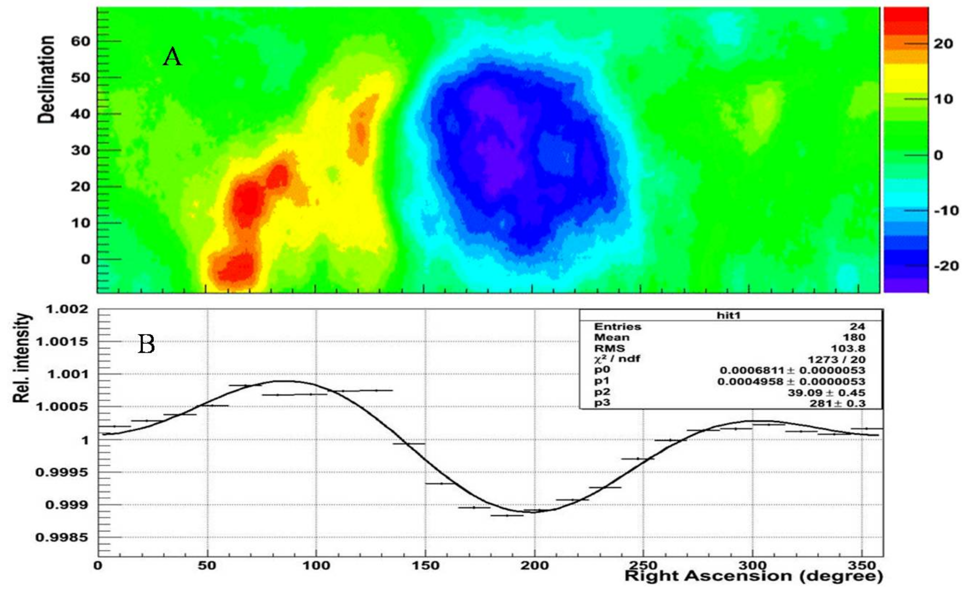

Figure 2: (A)Significance skymap of CRs in equatorial coordinate system with the data collected from January 2008 to December 2009 by ARGO-YBJ experiment. The different colors represent different significance value marked on the right of figure.(B)Relative intensity of CRs distribute as a function of Right Ascension. The smooth fitting line is the second-order cosine harmonics function $1 + P_0 cos(2\pi(x - P_2)/360) + P_1 cos(2\pi(x - P_3)/180)$

the amplitude vs. energy of this analysis (in red filled circles) in comparison to Tibet ASγ experiment (in blue empty squares). The amplitude of anisotropy increases at sub-TeV region and it tends to decrease in above 10 TeV energy region. These results are correlated with previous experiments and they provide a helpful message in understanding the origin of anisotropy.

6 Conclusion and Discussion

The measurement of large scale anisotropy is discussed at this work. We have detected the large-scale anisotropy of CRs by ARGO-YBJ experiment with two years data from 2008 to 2009. We report the anisotropy energy dependent effect with six groups events divided by the vector N_{hits}. The profile of intensity variation with energy is correlated with that of Tibet ASγ experiment and it can be used to understand the origin of anisotropy phenomenon. Still, more interesting study work is on the way.

7 Acknowledgement

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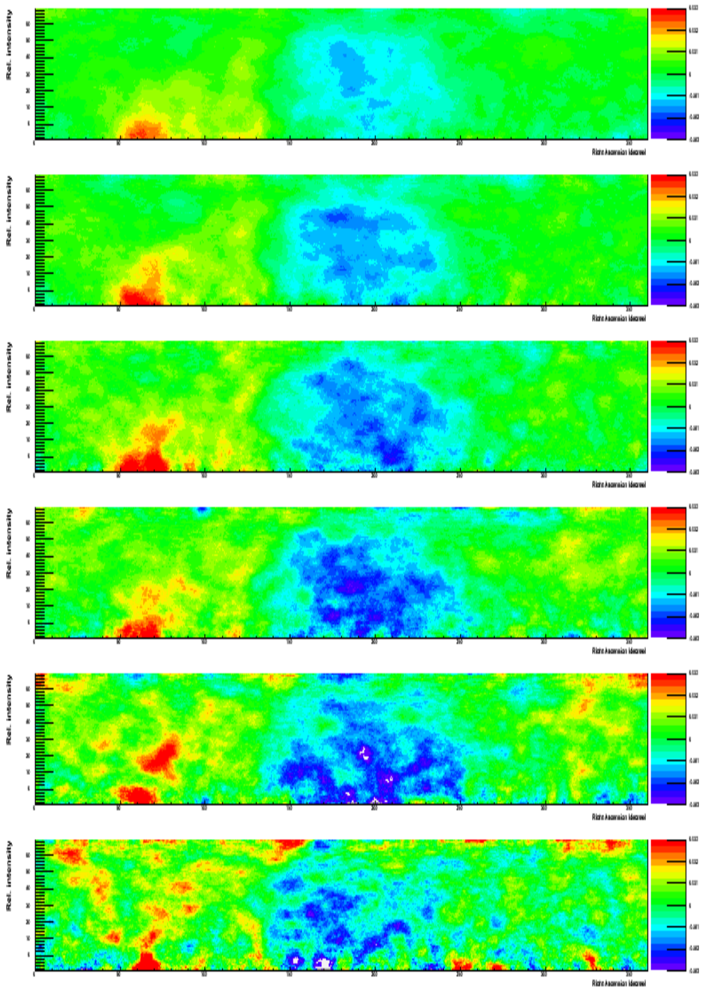

Figure 3: CRs intensity skymaps for six N_{hits} bins. The pictures From top to bottom present low-N_{hits} to high-N_{hits} bins.

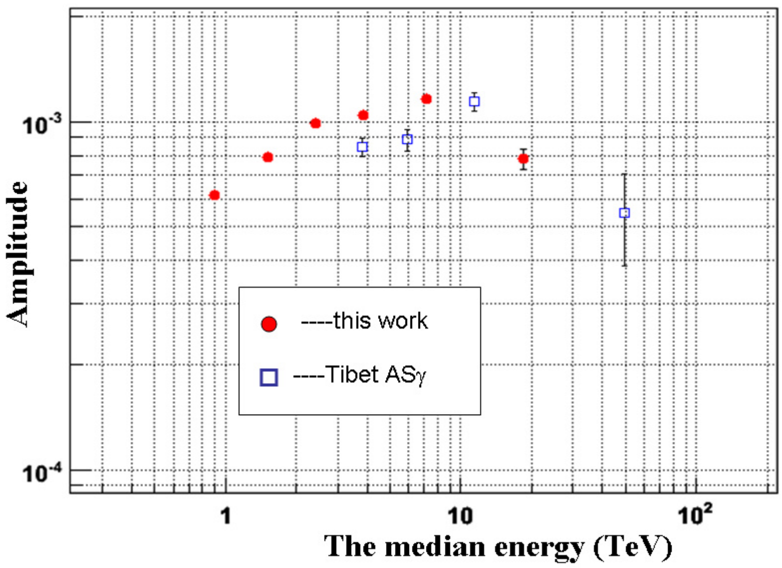

Figure 4: The amplitude of CR anisotropy intensity variation as a function of CR's primary energies(in the unit of: TeV). The red filled circles markers are the results of this analysis and the blue empty square markers are the result from Tibet ASγ experiment.