Study of the long time-scale variability of cosmic rays with the ARGO-YBJ experiment

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Abstract: The long term modulation of the cosmic ray intensity includes both Sun and celestial anisotropies. The solar activity is due to high energy flares producing a decrease (known as Forbush Decrease, FD) in the cosmic ray intensity, with a time scale of the order of a few days, often accompained by a Ground Level Enhancement, due to direct Sun emission during the solar flare. The celestial anisotropies are due to the Earth motion in the cosmic rays reference system (solar anisotropy: Compton-Getting effect) and to the solar system location inside the Galaxy (sidereal anisotropies). These anisotropies are studied in ground-based experiments by means of EAS arrays, and the high energy solar emission is mainly studied from ground by neutron monitors. In the ARGO-YBJ experiment these phenomena are investigated by means of the "scaler mode" technique: the detector counting rates of four low multiplicity channels from singles to four-fold coincidences are recorded in a fixed time window of 0.5 s. The signal corresponds to a significant enhancement of the observed counting rate, after correcting the data for enviromental and instrumental parameters. In this paper we present the sensitivity of the ARGO-YBJ detector and the first results for both cosmic ray anisotropy studies and solar physics.

Introduction

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. Besides if the intensity depends on the direction relative to the Sun, a modulation with a period of one solar day is recorded. Furthermore emission of high energy particles by the Sun in correlation with flares and Coronal Mass Ejection events has been widely studied but the energy limit of the emitted particles has not yet been determined. In order to understand the nature of the acceleration processes near the Sun, it is important to extend the study of the particles spectra in the GeV energy range. Ground-based instruments with large geometrical effective area, low energy threshold and high duty cycle, as the ARGO-YBJ detector working in "scaler mode", can be used in correlation with Neutron Monitors to investigate the high energy range of the emitted particles.

The detector and the Scaler Mode technique

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 experiment site is characterized by an effective geomagnetic rigidity of R = 13.98 GV for vertical direction [5]. The detector consists of a single layer of Resistive Plate Chambers (RPCs) operating in streamer mode and has a modular structure, the basic module being the Cluster (5.7×7.6 m^2) (see [2] and references therein for a complete apparatus description). The whole carpet is made of 154 Clusters, of which 130 are now in data taking, with a detection area of $\sim$ 6700 m^2 and $\sim$ 93% of active area. The detector is connected to 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 is recorded, allowing the reconstruction of the lateral distribution and the arrival direction with a threshold energy of a few hundreds of GeV. A lower energy limit (E∼1 GeV) is reached by the scaler mode technique, in which the total counting rates of each Cluster are recorded every 500 ms, with no information on the arrival direction and spatial distribution of the detected particles. Four low multiplicities channels in each Cluster are implemented for event multiplicities from ≥ 1 to ≥ 4. The mean measured counting rates are respectively $\sim$ 40 kHz, $\sim$ 2 kHz, $\sim$ 300 Hz and $\sim$ 120 Hz. The counting rate for a given multiplicity is obtained using the following relation: $C_i = C_{\geq i} - C_{\geq i+1}$, where C_i is the counting rate for the ith multiplicity.

The study of long term modulations in the cosmic rays intensity of solar and celestial origin, requires a detailed analysis of the statistical behaviour of the detector over different time scales. It has been verified that the Cluster counting rate for each multiplicity channel follows a Poissonian distribution for time intervals shorter than 30 minutes. For time scales greater than this threshold meteorological effects, mainly related to pressure and temperature variations in the atmosphere, begin to influence the cosmic ray counting rate. The dominant effect in the modulation of the background cosmic rays is expected to be induced by the diurnal pressure variation in the atmosphere which modifies the total atmospheric mass overburden above the detector, resulting in a change in the absorption probability of the secondaries. This effect can reach amplitudes up to a few per cent of the total counting rate. The ground level temperature also affects the detector performance, changing the bakelite electrode resistivity of the RPCs. In order to correct the data for the combination of these two effects, correlation coefficients both for pressure and gas temperature were determined for each Cluster from observations, resulting in a mean barometric coefficient of 0.4 %/mbar and a mean thermal coefficient of 0.3 %/$^{\circ}C$ for scaler $\geq$1 and 0.9 %/mbar and 0.3 %/$^{\circ}C$ for all the higher multiplicities. The fact that the counts from scaler $\geq$1 seem less correlated to the environmental parameters than the counts from the other multiplicities is explained assuming that part of $\geq$1 counts are not due to cosmic rays. Measurements are scheduled on site to check the possible presence of a radioactive background.

Search for anisotropies

The study of anisotropies with ARGO-YBJ operating in scaler mode has to be done on a set of data covering a long-time period to avoid any seasonal effect. Due to the necessity to analyse together data acquired in different periods of the year, the corrections for environmental and instrumental paramaters explained in the previous section are applyed.

In the first part of the work the search for anisotropies is focused on a daily analysis. For each recorded rate the sidereal, the anti-sidereal and the solar time are calculated, therefore allowing the estimation of corresponding first harmonics. For a complete discussion of this technique see [3].

The comparison between the sidereal and the anti-sidereal analysis will give information about sidereal anisotropies: the study of the anti-sidereal harmonics is a useful cross-check to eliminate spurious modulations [3]. Otherwise, in solar time, we expect to detect the Compton-Getting effect, due to the motion of the Earth around the Sun. Since a high temporal precision in this long time-scale analysis is required, a calculation of the DAQ dead-time is needed.

Moreover, a study of the behaviour of each Cluster is required: using in this analysis Clusters that show a non-Poissonian distribution of the counting rates could introduce fake modulations in the cosmic ray intensity. This check is done every day, to avoid any instability of the apparatus. Finally, for all time intervals the counting rates of the selected Clusters are added and stored in a vector on which the calculation of the Fourier coefficients is performed.

A test analysis has been performed on six days of data (11, 12, 17, 18, 19, 20/01/2007) using the counting rates of Cluster 109. The table 1 summarizes the amplitude and the phase of the first harmonic in solar, sidereal and anti-sidereal time. It is interesting to notice that the first harmonic in solar time is compatible with the Compton-Getting effect (see [1]). The analysis on a longer time period (5 months of data) is in progress.

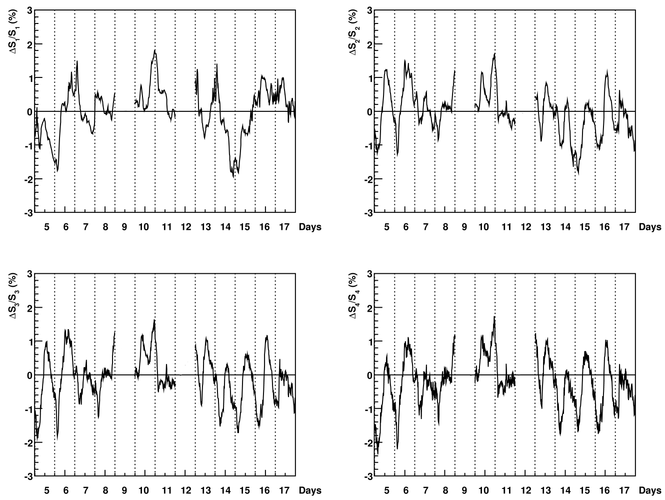

Figure 1: Percentage variations of the corrected data for each multiplicity for the period from December 5 to 17, 2006

	amplitude $\times 10^4$	phase (hours)
solar time	6.1 ± 0.5	22.7
sid. time	11.3 ± 0.5	8.9
antisid. time	7.0 ± 0.5	9.1

Table 1: Test analysis with Cluster 109

Solar phenomena

During the descending phase of the 23^{rd} solar cycle a considerable increase of the solar activity occurred, starting from December 5, 2006 (10:18 UT) with a powerful X9 flare, followed by other impulsive events the next days. The primary proton flux, as observed by the GOES11 satellite, exceeded the threshold energy of 100 MeV during two periods of time, i.e. from December 7 to 10 and from December 13 to 17.

On Earth this highly perturbed period was observed as a series of Forbush Decreases of different amplitudes, accompanied on December 13 (from 02:48 UT) by a Ground Level Enhancement (GLE70), detected by several Neutron Monitors with low geomagnetic rigidity cutoff, such as, among others, Oulu (R = 0.81 GV), Apatity (R = 0.65 GV), Novosibirsk (R = 2.91 GV). Low latitude Neutron Monitors, such as Beijing (R = 10 GV), did not record any increase.

The ARGO-YBJ detector working in scaler mode, allows to perform an integral measurement above the energy threshold for solar hadronic cosmic rays. In the past the detector already showed a good sensitivity in observing events linked to solar activity. On January 2005 a Forbush Decrease was detected in coincidence with the YBJ Neutron Monitor with maximum amplitude of $\sim$5% and $\sim$4% for the singles and the doubles channel respectively [4].

Data from December 5 to 17, 2006 (with the exception of two days, i.e. 9 and 12, when no reliable data are available) have been analyzed in search for any possible signal. The counts from each Cluster have been corrected for the environmental modulations by applying the corresponding barometric and thermal coefficients. The percentage variations of each multiplicity counting rate ($S \geq 1$, $S \geq 2$, $S \geq 3$, $S \geq 4$), summed over all the Clusters that show Poissonian behaviour on the entire period within 10% and averaged over 20 minutes, have been calculated with respect to the total mean counting rate and are shown in Figure 1. On December 5 and 14 a decrease is observed in the singles channel, with maximum amplitude of

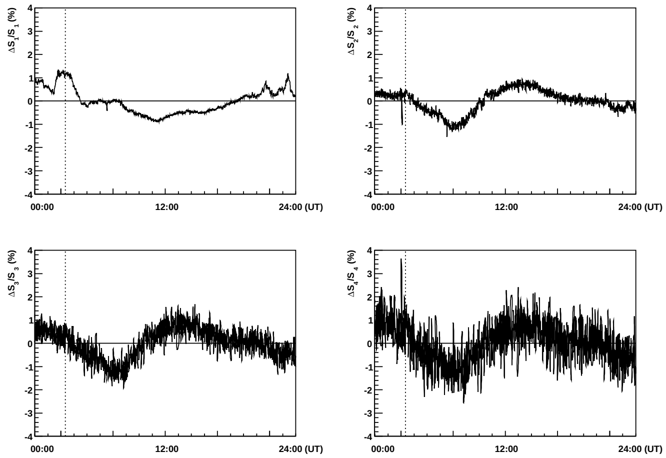

Figure 2: Percentage variations of the corrected data for December 13, 2006 with a time resolution of 1 minute for each multiplicity. The dashed line indicates the onset time of the GLE70, as recorded by the worldwide network of Neutron Monitors

$\sim 2\%$, while no significant decrease is detected in the other multiplicity channels.
In order to study in more detail the GLE event occurred on December 13, a preliminary analysis has been performed, calculating the percentage variation of each multiplicity counting rate with a time resolution of 1 minute. Results are shown in Figure 2. Though in the singles channel a peak is observed in coincidence with the onset time of the GLE70, as recorded by the worldwide network of Neutron Monitors, the detected percentage variations are compatible with those measured during days in which no physical signals are expected. Therefore it can be deduced that no compelling evidence for any significant enhancement has been observed, in agreement with data from other low latitudes detectors.

Conclusions

The ARGO-YBJ detector is now completed, with 130 Clusters out of the total 154 already in data taking. The scaler mode technique allows to work at an energy threshold of a few GeV where possible signals of solar and celestial origin are expected. The study of the long time-scale anisotropies is in progress. Furthermore on December 2006 an increase of the solar activity was observed both from space and ground, with a GLE detected on December 13 by several Neutron Monitors. Data from December 5 to 17 have been analyzed, resulting in an observed decrease with maximum amplitude of $\sim 2\%$ in the singles channel during December 5 and 14. No significant enhancement in the counting rate of any of the 4 multiplicity channels has been observed in correlation with the GLE event occurred on December 13.

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