Yield and Response Functions of the Baksan EAS-Array Andyrchy for Single Component

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Abstract

The significant increases (>3 st.dev.) were recorded at two Baksan EAS-arrays Andyrchy and Carpet in 6 events from 10 Ground Level Enhancements (GLE), which were registered in current cycle of solar activity. It signifies, that the Solar Cosmic Rays (SCR) of high energy are observed approximately in 50% of GLE. It is necessary to take into account a difference of the response functions of EAS-arrays and neutron monitors to prolong the SCR spectra up to 5.8 GeV (Baksan geomagnetic cut-off). With this purpose the account of the yield and response functions was executed for single component of the Andyrchy.

1. Introduction

A study of (GLE) in energy range from 1 up to 15 GeV is usually conducted with the help of Neutron Monitors (NM). During some GLE the increases of SCR are registered on the Extensive Air Shower (EAS) arrays in counting rate of single component. First reliable registration of SCR on EAS-array has been realized on the Baksan detector the Carpet during powerful solar flare on Sep.29, 1989 [1, 2]. In current 23rd cycle the increases of SCR are fixed on other EAS-arrays also: Nov.6, 1997 – MILAGRITO [3] and Apr.15, 2001 – GRAND [4]. However, for present time the Andyrchy and the Carpet give the largest quantity of high energy events in 23rd cycle [5]. They show, that SCR with energy $\geq$5.8 GeV are observed approximately in 50% of GLE. It was supposed earlier, that in the majority of these events the particles of such energy are not present.

EAS-arrays register also single particles – muon and electromagnetic components. The range of primary particles energy in this case is close to the same for the neutron monitors located at close latitude. The main advantage of EAS-arrays is the greater counting rate. So the Andyrchy and the Carpet allow registering in 10 times weaker fluxes of particles, than NM [5]. At reception of the SCR spectra it is necessary to take into account difference of the response functions of EAS-arrays and of NM. For this the calculation of the secondary particles yield function and of the response function for the Andyrchy has been executed.

pp. 3457–3460

2. Method of Calculation of the Response Function

Research of the cosmic ray (CR) variations frequently reduces to solution of an inverse task [6, 7]. Namely, the energy spectrum of primary variations is determined from experimentally observable data for various secondary components of CR. To search for the solution for the Andyrchy the following conditions were accepted: 1) pressure h_0 at a registration level (depth of atmosphere) is fixed value and it is equal 800 g/cm^2 (2060 m above sea level); 2) geographical coordinates are equal 43.28°N and 42.69°E; 3) effective rigidity of geomagnetic cut-off is fixed and makes 5.7 GV; 4) the CR flux outside atmosphere is isotropic; 5) calculation is carried out for the CR primary protons. Taking into account these assumptions, relative value of observable intensity will look like [6, 7]:

$$\frac{\delta N}{N} = \int\limits_{Emin}^{\infty} \frac{\delta D(E)}{D(E)} \, W(E) \, dE, \tag{1}$$

where $\delta D(E)$ is a variation of the primary CR flux, $D(E)$ is a differential energy spectrum of galactic cosmic rays (GCR), E_{min} is threshold energy of the Andyrchy. Function $W(E)$ is so called a connection factor:

$$W(E) = \frac{D(E)}{N} \, m(E) = \frac{R(E)}{N} \tag{2}$$

Yield function $m(E)$ for the isotropic primary CR flux looks like:

$$m(E) = \int\limits_{0}^{2\pi} d\varphi \int\limits_{0}^{\pi/2} m(\vartheta, E) \, \sin(\vartheta) \, d\vartheta, \tag{3}$$

where ϑ and φ are zenith and azimuth angles. Numerator $R(E)$ in (2) is the response function. The value $\delta N/N$ is observed experimentally. Yield function $m(\vartheta, E)$ for fixed ϑ and E is calculated by Monte Carlo method. At integration by formula (3) the function $m(\vartheta, E)$ was approximated by expression:

$$m(\vartheta, E) = \mu(E) \cdot \cos^{n(E)}(\vartheta) \tag{4}$$

Yield function $m(E)$ in this case is equal $\mu(E) \, / \, (n(E) + 1)$. Passage of particles through the atmosphere up to a level of EAS-array was modeled with the help of CORSIKA code. Process of particles registration in detectors of the Andyrchy was simulated also by Monte Carlo method with using of own programs. The real configuration of the array and the detector construction were taken into account. The Andyrchy consists of 37 detectors constructed from plastic scintillator with area 1×1 m^2 and with thickness 5 cm. Distance between detectors is 40 m. Threshold energy of registration of each detector is 5 MeV. Average amount of matter above scintillator is 4.7 g/cm^2. Total counting rate mainly consists of single particles detection (about 99% counts). It is defined both hard component (high energy muons, about 60% of counts) and soft component (low energy muons and electromagnetic component, near 40% of counts).

3. Results of Calculation

Yield functions of the Andyrchy for the isotropic primary flux and for $\vartheta = 0$, 20, 30 and 45 degrees are submitted on the left panel of fig.1. The differential response function of the Andyrchy is obtained after multiplication $m(E)$ to primary spectrum of GCR. It is shown on the right panel of fig.1. The approximating function of the GCR spectrum is taken from work [8].

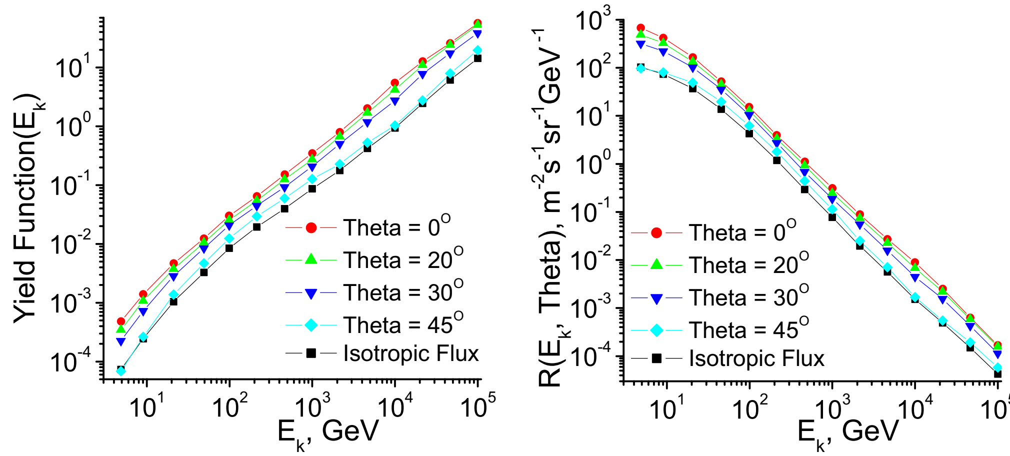

Fig. 1. Differential yield and response functions of EAS-array Andyrchy.

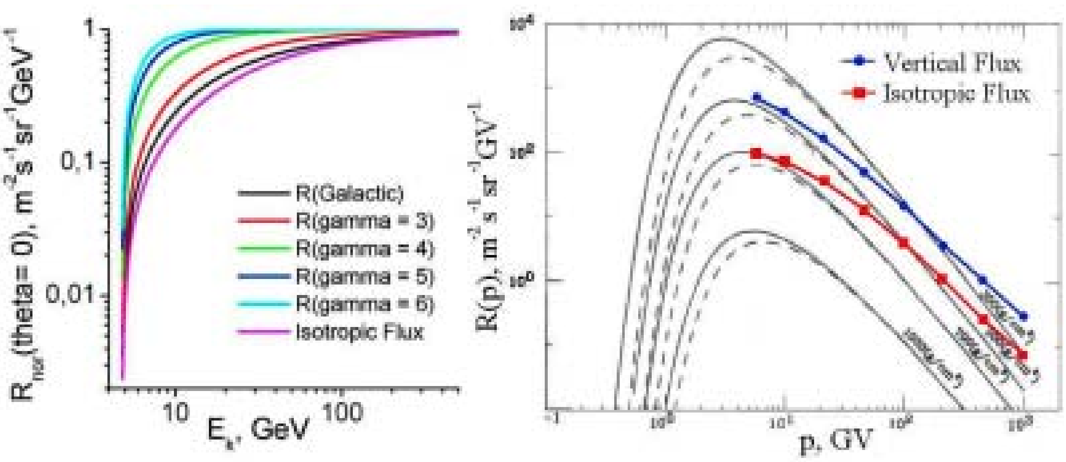

Fig. 2. Left panel: The normalized integral response function $R_{nor}(E)$ for various spectra. Right panel: Differential response functions of NM and Andyrchy.

The normalized integral response function $R_{nor}(E)$ is received for definition of a sensitivity range of the Andyrchy to particles of various energies. It shows a share of particles with energy from threshold up to E from the total number of particles. The values of median energy E_{med} (50% of particles have energy $< E_{med}$ and so much $> E_{med}$) and upper limit of sensitivity range $E_{0.95}$ (95% of particles have energy from threshold up to $E_{0.95}$) are defined with using of $R_{nor}(E)$. These energies strongly depend on the shape of a primary spectrum. The $R_{nor}(E)$ for the GCR spectrum and for the various power function spectra $dN/dE \sim E^{-\gamma}$ is shown on left panel of fig.2. The account of other directions results in small increase of all energies. Values E_{med} and $E_{0.95}$ for different spectra are in table 1.

Table 1. Energy E_{med} and $E_{0.95}$ for various kinds of a primary spectrum.

Spectrum	Vertical Flux		Isotropic Flux	
	E_{med}, GeV	$E_{0.95}$, GeV	E_{med}, GeV	$E_{0.95}$, GeV
galactic	23	800	30	950
power, γ= 3	16	210	20	250
power, γ= 4	8.5	34	9.1	42
power, γ= 5	6.8	18	7.1	20
power, γ= 6	6.2	13	6.3	14

The response function of the Andyrchy is received as function $R(p)$ of a primary particle pulse for comparison with neutron monitors. $R(p)$ of NM it is submitted on right panel of fig.2, taken of work [7]. Here the response functions of the Andyrchy for isotropic and vertical fluxes of particles are shown.

4. Conclusions

The yield and response functions for single component of EAS-arrays are similar to the same for neutron monitors. But median energy and sensitivity range of EAS-arrays strongly depend on the form of a primary spectrum.

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5. References

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