29th International Cosmic Ray Conference Pune (2005) **00**, 101–104

Coupling coefficients for the ground and underground muon detectors

G.F. Krymsky, P.A. Krivoshapkin, V.G. Grigoryev, S.K. Gerasimova

Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy, 31 Lenin Ave., 677980 Yakutsk, Russia

Presenter: S.K. Gerasimova (s.k.gerasimova@ikfia.ysn.ru), rus-gerasimova-SK-abs1-sh36-poster

The differential coupling coefficients for the muon azimuth ground and underground telescopes (0, 7, 20, 40 and 60 m w.e.) have been calculated on the basis of a pion generation model with a wide distribution of the inelasticity coefficient giving the proper multiplicity. Model calculations of the pion multiplicity are in satisfactory agreement with the characteristics of muons observed on the Earth's surface, i.e. the latitudinal change, angular distribution, absolute intensity and energy spectrum.

1. Introduction

Cosmic ray variations reflect dynamic processes in the solar wind and their study allows to judge about the heliosphere dynamics. The high energy particles give information about the most large-scale processes up to the changes of the heliosphere features on the whole. The continuous registration of such particles is mainly carried out with ground-based detectors. The secondary cosmic rays, registered with such detectors, are produced by the primary particles of different energies and it makes difficult to receive information about the energy spectrum of variations. To receive information about the primary spectrum, the coupling coefficient method developed by Dorman [1] is used. The coupling coefficients are normalized distributions in energy of the primary particles showing the relative contribution of different energies to the radiation intensity observed with one or the other of detectors. As the different detectors are sensitive to different regions of the spectrum, then the primary spectrum of variations could be inferred on the basis of their observational data.

To determine the coupling coefficients, the latitudinal variations of secondary component are used. The geomagnetic field cuts off the low-energy particles. The geomagnetic cut off threshold depends on latitude, and corresponding changes allow to obtain the coupling coefficients. However, the muon, i.e. "hard" component is mainly generated by the particles whose energy higher than geomagnetic thresholds. In this case, it is necessary to calculate the generation of muons in the Earth's atmosphere in detail.

The main characteristic to be calculated is the differential muon multiplicity $m(E_0, E_\mu)$, i.e. their energy spectrum calculated per one primary nucleon with the energy E_0. By using this characteristic, the integral multiplicity $m(E_{\mu,thr}, E_0)$ for the detector with threshold energy $E_{\mu,thr}$ can be calculated. Multiplying the integral multiplicity by the energy spectrum of primary particles and normalizing a function obtained so that the integral of its in energy of the primary particles is equal to 1, we obtain the coupling coefficient $W(E_0)$ for the detector with the above threshold of the muon registration. If the direction diagram of detector is such that the particles moving at an angle to the vertical give significant contribution, then corresponding calculations must be carried out for the different zenith angles and their results must be averaged.

2. Discussion

The intermediate particles, pions, are produced at collision of a primary nucleon with nuclei of air atoms during the multiple birth process. For the calculation of the coupling coefficients that process is key. To obtain the satisfactory description, take advantage of known concept of the multiple birth of pions, simplify the model and compare its parameters with accelerator data. As about 90 % of primary particles are the protons, the first simplification will be concerned with the cosmic ray composition and it will be considered as consisting of protons only. Further, the interactions of primary particles with the nuclei will be considered as nucleon-nucleon impacts. The distribution of secondary particles in the center-of-mass system will be considered as exactly symmetric. The most important characteristic, the inelasticity coefficient, fluctuates from event to event. In our calculations, the change of the real inelasticity coefficient by its average value would mean a large systematic error. In the literature concerning to the multiple pion birth three channels of their generation are discussed: fragmentation, pionization and periphery interactions. The corresponding three mechanisms describe the pion birth as a result of the decay of excited nucleons (isobars), as the birth of pion "bunches" (clusters, fireballs) and formation of pion "sprays" between interacting nucleons. In the center-of-mass system of two interacting nucleons, the fragmentation pions have the highest energies, and the cluster pions have the lowest energies. The pions of sprays full out the interval between two their extreme values more of less uniformly. Correspondingly, the multiplicity of the cluster pions increases very fast with the energy of interacting particles. The multiplicity of fragmentation particles is practically constant, and spray particles give a logarithmic increase of the multiplicity with the energy. Introduce a model for the cluster forming in the interacting nucleon system and including itself nucleon. A mass of cluster m minus the nucleon mass M is easily determined by means of the inelasticity coefficient K in the center-of-mass system:

$$m = \frac{KM}{1-K}. \tag{1}$$

The kinematical limits for K are defined by limits

$$m_{min} = m_\pi, m_{max} = E_c - M, \tag{2}$$

where E_c is the nucleon energy in the center-of-mass system. The cluster at K, close to the maximum value $K_{max} = 1 - M/E_c$, provides the pion birth channel analogous to the pionization channel, and near $K_{min} = m_\pi/(M + m_\pi)$ it behaves according to the fragmentation model. To describe all intermediate states, take, as a hypothesis, the inelasticity coefficient distribution in the plane form:

$$\rho(K) = 1/(K_{max} - K_{min}). \tag{3}$$

Let us describe the decay of a cluster to the pions by the Planck's spectrum with $kT = m_\pi$ (as it was suggested in [2]). In the cluster system the pion spectrum must tend to zero at $E_\pi = m$. As a result, the spectrum in this system can be represented in the form (it is accepted $m_\pi = 1$):

$$F(E_\pi, m)dE_\pi = C(m)\frac{\sqrt{E_\pi^2 - 1}\cdot E_\pi}{e^{E_\pi - 1}}[1 - e^{-(m-E_\pi)}]dE_\pi. \tag{4}$$

The multiplier in square brackets realizes the above cut-off. $C(m)$ is a normalized constant. To check how much close this model corresponds to experimental data, calculate the mean multiplicity of the charged pions:

$$< n_\pm > = \frac{4}{3}\int_{K_{min}}^{K_{max}} \frac{m(K)}{\varepsilon(m)}\rho(K)dK. \tag{5}$$

Here the function $\varepsilon(m)$ is the average energy of pions in the cluster system. It equals 1 at $m = 1$ and $\varepsilon_\infty = 3.25017$ at $m \to \infty$. The multiplier $4/3$ arises because of the contribution of front and back clusters and also excepting the contribution of neutral pions. Substituting $\rho(K)$, divide the integral to two and pass to m in the capacity of a new variable of integration:

$$< n_\pm >= \frac{4}{3}\frac{M}{(K_{max} - K_{min})}(I_1 - I_2). \tag{6}$$

The integral $I_1 = \int_1^{m_{max}} \frac{\varepsilon_\infty}{\varepsilon(m)} \cdot \frac{m}{(M+m)^2} dm$ does not practically depend on the upper limit and, therefore, on the nucleon energy because of fast attenuation of the first bracket. Its value (at $M = 6.7$) is equal to 0.119. The integral

$$I_2 = \int_1^{m_{max}} \frac{m}{(M+m)^2} dm \tag{7}$$

gives the logarithmic rise with the energy E_c. Expressing of E_c in terms of the energy in the laboratory system, we obtain for the enough high energies

$$< n_\pm >= \frac{4}{3}\frac{M+1}{\varepsilon_\infty} lnE + const. \tag{8}$$

The substitution of numerical values gives:

$$< n_\pm >= 1.58 lnE - 3.91, \tag{9}$$

where E is in GeV. Experimental data on the average multiplicity of charged pions and proton-proton impacts [3] give the dependence for $4 < E < 2000$:

$$< n_\pm >= 1.86 lnE - 1.74. \tag{10}$$

As seen, the model underestimates the multiplicity, therefore the two-parameter distribution function of the inelasticity coefficient has been introduced:

$$\rho(K) = const \cdot e^{-a(K-K_m)^2}, \tag{11}$$

whose parameters are fitted so that the proper mean multiplicity of pions is obtained.

3. Conclusions

Calculations of the muon multiplicity carried out on the basis of this model give the satisfactory agreement with muon characteristics observed at the Earth's surface: latitudinal change, angular distribution, absolute intensity and energy spectrum. In particular, for the latitudinal effect at the Earth's surface for an isotropic detector (ionization chamber) we obtain 8.8 %.

The calculations have been carried out for the vertical and 30° and 60° zenith angles. The Figure presents the coupling coefficients for the Yakutsk underground muon telescope complex for 0, 7, 20, 40 and 60 m w.e.

The work has been carried out at the support of grants of leading scientific school N422.2003.2 and RFFI N05-02-16924-a.

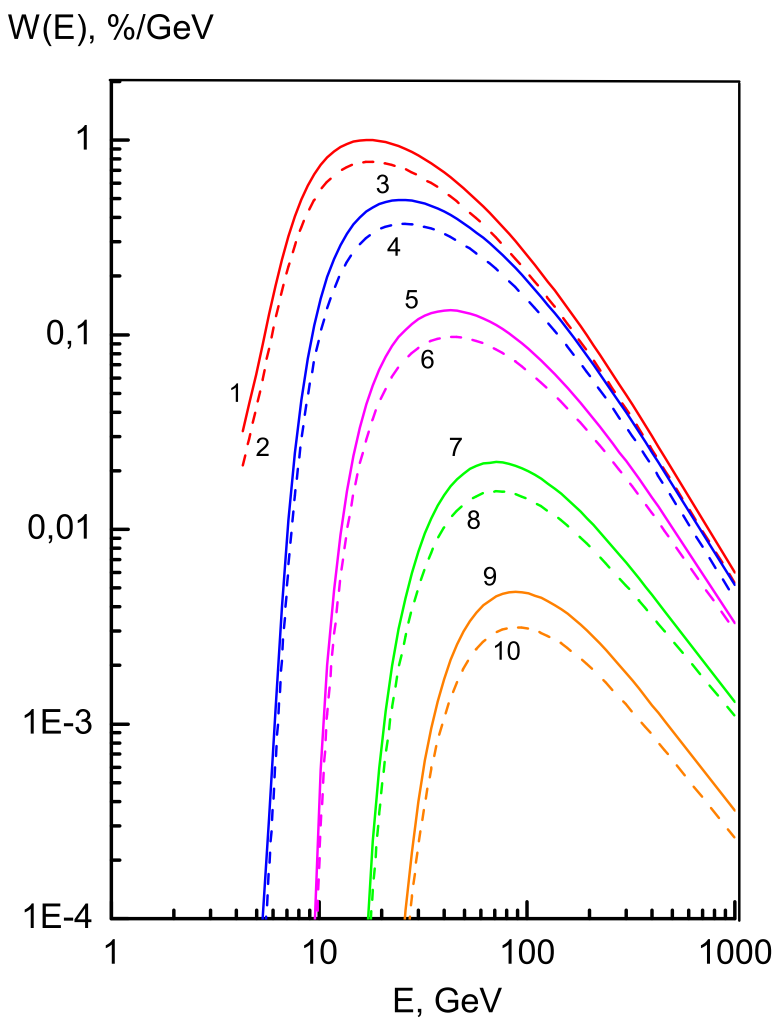

Figure 1. Unnormalized coupling coefficients for vertical (solid) and inclined (30° to the zenith, dash) muon telescopes on the Earth's surface (1, 2) and underground at the depths of 7 (3, 4), 20 (5, 6), 40 (7,8) and 60 (9, 10) m v.e.

References

[1] L.I. Dorman, Cosmic ray variations, Moscow, 492, 1957.
[2] E.L. Feinberg, UFN. 3, 539 (1971).
[3] T.P. Amineva and L.I. Sarycheva, Fundamental interactions and cosmic rays, 165, 1999.