ICRC 2001

The Small Muon Telescope for 5 GeV muon flux registration in the underground laboratory in Lodz

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Abstract. The muon telescope is placed in the underground laboratory at the depth of 13 m. It is registering directions of muons which have minimum energy of 5 GeV at the ground level. These muons originate from interactions of cosmic rays (mainly protons) of energy from 20 to 5000 GeV in the Earth atmosphere. The variability of Solar activity leads to variation of cosmic ray (CR) proton flux entering the atmosphere and – in consequence – the variation of the flux of created muons.
The telescope has 4 layers of 20 Geiger–Müller tubes each. The hardware trigger selects clear 4-fold coincidence events, which allow reconstruction of the muon direction. The counting rate is about 5 Hz. The barometric coefficient is equal to -0.0006/mb. Photo, description and results of 3 Forbush decreases registered during period September–November 2000 can be viewed on http://ipj.u.lodz.pl
The detailed description, method of data reduction and first results are presented.

1 Introduction

The Sun is nowadays at the maximum of its 11–years cycle of activity. During the solar maximum there are many sunspots, solar flares, and coronal mass ejections, all of which can affect communications and weather on Earth. Increased solar activity leads also to the variation of cosmic ray (CR) intensity near the Earth. Changes of cosmic ray flux can be of two types:

- increased emission of low energy particles (solar wind) can obstruct galactic CR penetration of the Solar System and cause decrease of their intensity at the Earth;
- big solar flares themselves can be a source of energetic particles with energies sometimes exceeding 20 GeV, which can cause observed short increases of CR flux in the space surrounding the Earth and even at the Earth surface.

We are especially interested in the second process as an example of a source of energetic particles. Although the Sun is not an significant CR source in our Galaxy, its proximity to the Earth enables very detailed studies of processes and mechanisms leading to particle acceleration.

Studies of low energy (below $\sim$ 20 GeV) cosmic ray flux variations have been performed from many years mainly by use of neutron monitors.

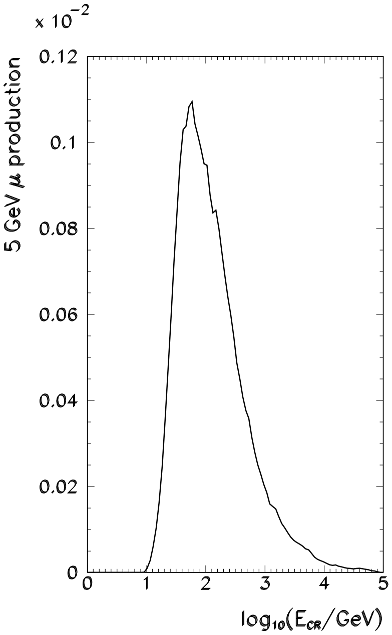

Fig. 1. Production of muons ($E \geq 5$ GeV) by CR protons in the Earth atmosphere.

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2 Muon production in the atmosphere

We have built a detector capable of registering changes of CR intensity at energies significantly exceeding 20 GeV. Placed in the underground laboratory (at the depth of 13 m) it can detect only muons of energies above 5 GeV. Production rate of such muons in the atmosphere by CR particles G_μ can be described by the formula:

$$G_\mu \sim \int F_\mu d(\log E_{cr}) \quad (1)$$

We performed Monte Carlo calculations of muon production in the Earth atmosphere using the CORSIKA code version 5.62 (Capdevielle et al., 1992; Knapp and Heck, 1998). The results are shown in the Figure 1, which shows production of muons F_μ as a function of $\log E_{cr}$. As can be seen from the Fig. 1 muons of energy above 5 GeV originate from interactions of cosmic rays of energy from 15 to 5000 GeV; median energy of CR producing such muons in the atmosphere is equal to $\sim$ 100 GeV. 5% change of CR flux in the energy range 15 – 100 GeV will give 2.5% variation in the registered muon flux. Respectively, 5% change of CR flux in the energy range 15 – 50 GeV will cause 1.5% variation of μ flux.

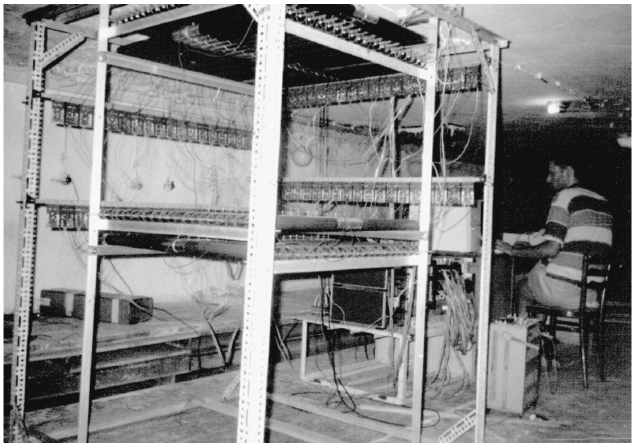

Fig. 2. Muon telescope photo; 4 layers of Geiger–Müller's tubes can be seen.

3 Construction of the device

The telescope is built of 4 layers of Geiger–Müller's tubes (see the picture on the Fig. 2). The length of the effective area of the counter is equal to 80–81 cm, the diameter of the counter equals 3.7 cm. Each layer consists of 20 counters, so 80 counters in total. The random noise of individual GM counter is at the level of 25 Hz.

The telescope is triggered by 4–fold coincidence such that only one tube from each layer has been hit. The trigger is realised by electronic systems forming impulses, analysing coincidences and registering events with single muons. The electronics is not fully efficient; not all signals from muons are registered, and on the other hand some coincidences with more than 4 counters can be not rejected. Such events are stored on the computer disk, but they are eliminated by the *off–line* program analysing data.

All coincidence events are registered on the computer disk by the *on–line* program. The state of hit GM counters and PC time with accuracy of 1 second are registered for each event. PC clock works in UTC time. Time changes are continuously monitored and are generally smaller than 0.5 sec per 24 hours. Time corrections are introduced *off–line*.

The data files are saved every hour. The computer is connected to the local network Ethernet. Program *on–line* allows for data transmissions to the network computers without interrupting the registrations.

5 GeV muons in most cases fly in the direction deflected by not more than 3° from the direction of parent particle, and are scattered by $\sim 2°$ in the ground. They can be registered in our telescope with accuracy $\sim 2°$.

4 Performance.

The registration has started in September 2000. Soon we have noticed that some of GM tubes do not work smoothly. As we are monitoring counting rate of separate GM we were able to reject bad counters during the *off–line* analysis. Faulty GMs have been replaced, however such procedure causes the pause in registration. Faulty GMs complicate the analysis, and make it difficult to compare different observation periods.

The device is small. The counting rate of 5 Hz is not sufficient to have a statistically secure results collected within a few hours. However, the daily rates can secure a relative accuracy of about 0.002.

5 Barometric coefficient

Changes of registered muon flux can be influenced by atmospheric pressure and its variations. Such changes are slow and can be easily correlated with CR intensity variations. The relation between the barometric pressure was obtained during a relatively quiet time between the 25^{th} January and 10^{th} March 2001 (1210 hours of registration). In the Figure 3 the daily counting rate varaition (top figure) can be compared with the local pressure changes (recorded every two hours) (bottom part). In the Figure 4 the numerical relation in the form of line fitted to relative counting rate – pressure dependence is presented. The slope of the line equals to $(-6.04 \pm 0.56) \cdot 10^{-4}$ with $\chi^2/(605) = 1.10$.

6 Registration of Forbush effects

Other changes of muon flux can be due to astrophysical processes. We can expect that particles of energies above several tens GeV are not strongly influenced by interplanetary

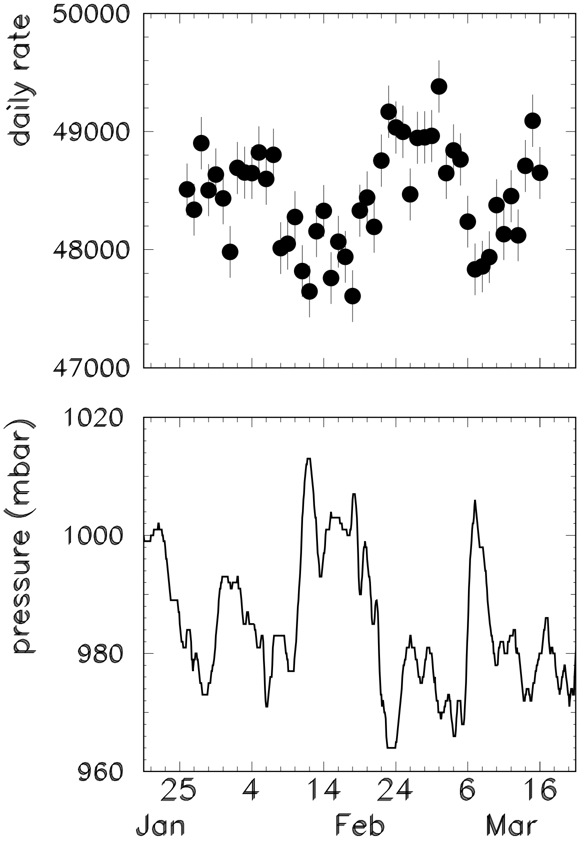

Fig. 3. Muon daily rate (top) and atmospheric pressure variation (down) for the period 25 January – 10 March 2001.

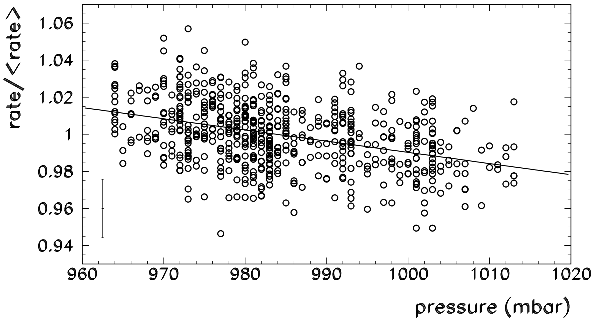

Fig. 4. Relative counting rate (per 2 hours) vs. atmospheric pressure. Typical statistical error bar for counting rate is shown. Line represents χ^2 fit.

magnetic field, so registrations of incoming muon directions could be of great value. 5 GeV muons in most cases fly in the direction deflected by not more than 3° from the direction of parent particle, and are scattered by $\sim 2°$ in the ground. They can be registered in our telescope with accuracy $\sim 2°$.

As 5 GeV muons correspond to much higher cosmic ray energies than just geomagnetic cut–off, the variation of muon intensity differs significantly from variation observed in neutron monitors. We are observing most of Forbush decreases which occured after September 2000, and the recorded intensity change is typically on the level 1–1.5 %. Figure 5 presents comparison between the daily data from our telescope and some neutron monitor data during the sequence of Forbush decreases occuring in March–April 2001.

We have not noticed observed in neutron monitors cosmic ray intensity excesses of 15^{th} and 18^{th} of April 2001.

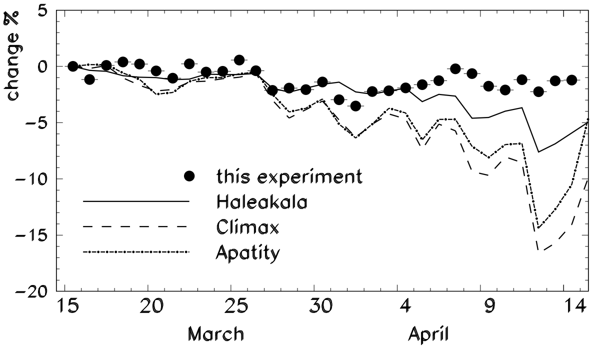

Fig. 5. Results of registration during the series of Forbush Decreases in March – April 2001. The difference between high energy Cosmic Ray variations (muon flux) and lower energies (neutron monitors) are apparent. Apatity neutron monitor (Vashenyuk et al., 2001) has geomagnetic cutoff of 0.6 GV, Climax (Simpson et al., 2001) 3 GV and Haleakala (Simpson et al., 2001) 13 GV.

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