Astrophys. Space Sci. Trans., 7, 365–367, 2011
www.astrophys-space-sci-trans.net/7/365/2011/
doi:10.5194/astra-7-365-2011

Astrophysics and **S**pace Sciences **Tra**nsactions

Hadrons with energies of $E_h > 50\,\mathrm{MeV}$ in EAS with $N_e = 10^5 - 10^7$

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Received: 15 October 2010 – Revised: 18 March 2011 – Accepted: 22 May 2011 – Published: 8 September 2011

Abstract. The characteristics of hadrons with $E_h > 50\,\mathrm{MeV}$ in EAS have been obtained. The measurements were performed at the CARPET-2 extensive air shower array. For showers with $E_0 > 6\cdot 10^{13}\,\mathrm{eV}$ the duration of hadronic cascade in NM has been estimated. The dependence of the mean neutron multiplicity in the neutron monitor on the total number of the change particles for EAS with $N_e = 10^5 - 10^7$ at a distance of $17 - 30\,\mathrm{m}$ from EAS axis has been measured.

1 Introduction

Study of nuclear composition and energy spectrum of primary cosmic rays from below the knee ($3\cdot 10^{14}\,\mathrm{eV}$) to ultrahigh energy of $10^{18}\,\mathrm{eV}$ by the use of ground based indirect observations with air shower arrays is an important instrument in understanding the production and propagation of cosmic rays. Measurements made with large arrays of detectors are expected to provide more definitive information on this subject. It is obvious that solution of the knee problem demands measuring all possible EAS parameters with high precision. In order to achieve this goal at the Baksan Neutrino Observatory of the Institute for Nuclear Research, Russian Academy of Sciences the new multi-component array Carpet-3 would be designed (Szabelski et al., 2009). The Carpet-3 array would be constructed on the basis of the existing Carpet-2 shower array. This array will allow us to measure the electron-photon, muon and hadronic components of EAS. In this paper, we have presented the characteristics of hadronic component of EAS with hadrons energy $E_h > 50\,\mathrm{MeV}$.The measurements were performed using the neutron monitor 6NM64 (NM). The neutron monitor provides continuous records of the hadronic components. Now it is equipped with registration system which enables time intervals between pulses to be recorded with accuracy 1 µs. It allows studying such phenomenon as a neutron multiplicity, induced by hadrons of EAS.

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2 The experiment

The Carpet-2 shower array is located in Baksan Neutrino Observatory INR RAS at the altitude of 1700 m a.s.l. (atmospheric depth $840\,\mathrm{g/cm^2}$, 43:28° N, 42:69° E) (Dzhappuev et al., 2007). It consists of the Carpet for detecting the electron-photon component of EAS, the muon detector and the neutron monitor. The Carpet consists of 400 liquid scintillation detectors arranged as a square with a side length of 14 m covering continuously an area of $200\,\mathrm{m^2}$. Each detector of the Carpet measures the energy losses in a range of $10 - 5000$ relativistic particles (r.p.). For this detector 1 r.p. corresponds to 50 MeV (the most probable energy losses of a single muon). Six outer stations(18 scintillator detectors in each) are located at distances of 30 m (four) and 40 m (two) from the Carpet's center. The signals from the latter are used for timing and for EAS's direction reconstruction. Neutron monitor 6-NM-64 with an area of $6\,\mathrm{m^2}$ consists of the lead generator, polyethylene moderator and six proportional boric counters of the type CNM15 $(15\times 200)\,\mathrm{sm^2}$. The counters are filled with gas $^{10}BF_3$ under pressure 0.2 atm (Karpov et al., 2005). The data acquisition system (DAQ) of the neutron monitor is shown in Fig. 1. The DAQ writes the time of arrival of each pulse from counters of the neutron monitor and the pulses of Carpet's shower trigger with the accuracy up to 1µs. The system generates two types of files. The first file, F1, contains standard data on the counting rate in the channels over 1 min, including data on pressure and temperature. The second file, F2, contains information on each received pulse: the duration of time interval between the instant and the previous pulses in the microseconds and the channel number. Shower trigger

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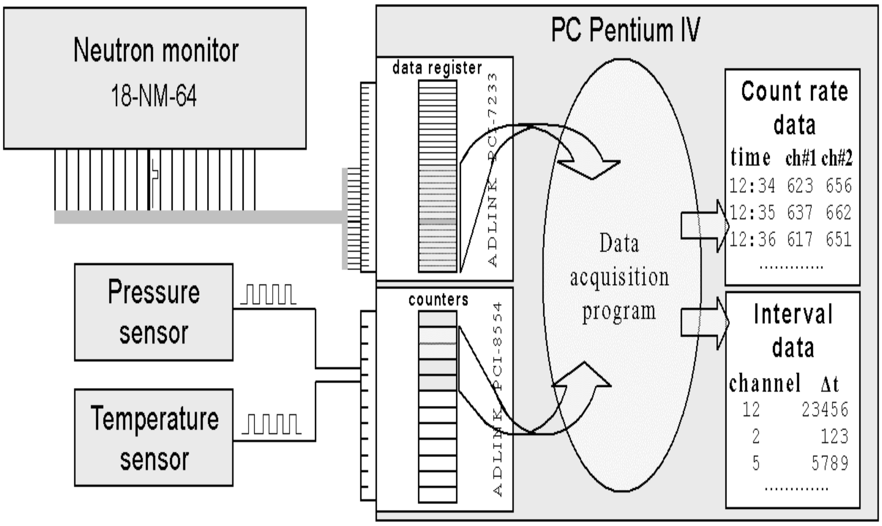

Fig. 1. The DAQ of the Baksan neutron monitor.

is created by 5-fold coincidences of pulses from four nearby outer stations, and Carpet's pulse. The energy threshold of pulses from outer stations is about 25 MeV, and the threshold of Carpet's pulse is 2.5 GeV. These conditions allow us to select EAS with energy $E_0 > 6 \cdot 10^{13}$ eV in the circle with $r = 50$ m from the center of Carpet. The rate of such events is $\approx 1.2\,\mathrm{s}^{-1}$. The distance between the centers of CARPET and NM is 23 m. It allows detecting shower's hadrons at distances of $17-30$ m from the EAS's axis located inside Carpet. A standard NM is sensitive to single hadrons with energy up from ~ 50 MeV, therefore the energy's threshold of hadrons associated with an EAS is also 50 MeV.

3 Results

To detect shower's hadrons by NM, it is necessary to define a time interval after passage EAS in during which multiplicity of neutrons (number of pulses) is measured. The following algorithm was used for data processing and selecting the NM pulses directly associated with an EAS: As the master pulse occurs, time window T_0 opens, during which the NM pulses and the intervals between them are counted. A pause with duration T_p is then held, after which the control window for collecting reference data far from the EAS opens. Nevertheless, a $T_p = 25$ ms was assumed. The result of such data processing with $T_0 = 1000\,\mu$s a set of the information of 175 days is shown in Fig. 2. The results from processing the NM data show that the number of pulses in the working window(up to 200 μs) was twice over that in the reference window. In too time already to value $t \approx 1000\,\mu$s the numbers are compared. It means, that total duration of the hadronic cascade in an EAS is equal to 1 ms.

Each EAS was analyzed using the following algorithm:

1) Showers are selected with axes inside Carpet;

2) Having the position of EAS's axis the lateral distribution function of charged particles (LDF) with correction for transition effect in the detector and in the roof of the building is determined;

3) The total number of charged particles N_e and parameter s (EAS's age) are obtained.

Thus, for each shower the following parameters are defined: coordinates of an axis (X_0, Y_0), total number of charged particles N_e and s. It is necessary to notice that for EAS with axis located inside Carpet, parameters are measured with high accuracy: $(\Delta X_0 = \Delta Y_0 = 0.35$ m, $\Delta N_e/\overline{N}_e = 0.1$, $\Delta s/\overline{s} = 0.02)$ for showers with $N_e = 10^5 - 5 \cdot 10^6$. For 70 days of a set of the information it was registered 500 showers for whose axes are located in a circle with radius of 6 m from the center of “Carpet”, and $N_e > 10^5$, $s < 1.6$, $\theta < 30°$. For those showers the dependence of average multiplicity of neutrons $\overline{m}$ in NM on N_e for an interval of distances $17-30$ m from axis EAS was obtained. This dependence is shown in Fig. 3 and approximated by the following expression:

$$\overline{m} = 0.003 \cdot \overline{N}_e^{0.58\pm0.01} \qquad (1)$$

The dependence (1) measured in our experiment to be in a good agreement with the result presented in reference (Danilova, 1965) where the hadronic component of EAS was investigated and the results were obtained with EAS array and the neutron monitor at height of 3300 m a.s.l. for $N_e = 2 \cdot 10^3 - 10^7$. The dependence of the integrated multiplicity neutrons in NM on N_e was obtained in the following form:

$$\overline{m} \sim \overline{N}_e^{0.59\pm0.02} \qquad (2)$$

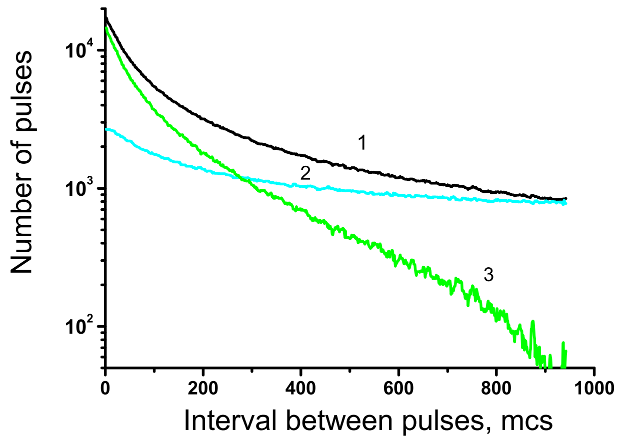

Fig. 2. Distribution of time intervals between pulses NM in time window $T_0 = 1000\,\mu$s. 1-for trigger SHAL, 2-for control window, 3-difference between 1 and 2.

In Adamov et al. (1983) the dependence of energy of shower's hadrons E_h on multiplicity of the neutrons $\overline{m}$ was investigated. In order to achieve this goal one section of the neutron monitor was used, including six boric counters. The following dependence was obtained:

$$E_h\,(\text{GeV}) = 0.1 \cdot \overline{m}^{0.25} \quad (3)$$

We used this formula for estimated of the energy's range of hadrons which registered by NM in our experiment. In order to the values of the multiplicity of neutrons $\overline{m}_{\min} = 3.5$ and $\overline{m}_{\max} = 42$ (Fig. 3) were substituted in formula (3) and the values $E_h\min = 1$ GeV and $E_h\max = 200$ GeV are obtained. Thus, the energy's range of EAS's hadrons which investigated in our experiment is about $1 - 200$ GeV. From formulae (1) and (3) it is possible to obtain the dependence of average energy of hadrons on N_e for distances $17 - 30$ m from an axis:

$$E_h\,(\text{GeV}) = 8.2 \cdot 10^{-7} \cdot \overline{N}_e^{1.19} \quad (4)$$

4 Conclusions

Baksan shower array "Carpet - 2" measurements of the characteristics of hadrons with $E_h > 50$ MeV in EAS with the neutron monitor 6NM64 have been carried out. For showers with $E_0 > 6 \cdot 10^{13}$ eV the duration of hadron cascade in NM has been measured.It is about $1000\,\mu$s. The dependence of average multiplicity of neutrons in NM on N_e for EAS with $N_e = 10^5 - 10^7$ axes located in Carpet,

$$\overline{m} = 0.003 \cdot \overline{N}_e^{0.58\pm0.01}$$

is obtained. The new array "Carpet - 3" is planned to be used for measurements of characteristics of EAS hadron components by two new methods. The first is to measure the flux accompanying passage of EAS's thermal neutrons (this flux is proportional to number reached a level of supervision hadrons) will be measured. Second, hadronic component of EAS with $E_h \sim 30$ GeV will be registered with the muon detector (Dzhappuev et al., 2009). Thus,using the neutron monitor as the hadron detector will allow us to measure "Carpet - 3" the characteristic hadronic components in one power range with $E_h \sim 50$ MeV.

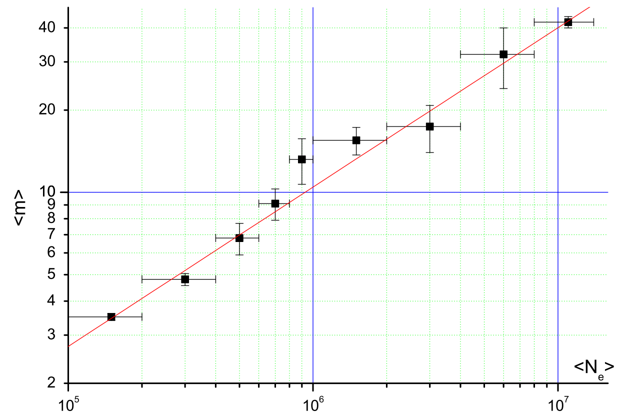

Fig. 3. Dependence of multiplicity of neutrons in NM on N_e.

Acknowledgements. This work was supported by the "Neutrino Physics and Astrophysics" Program for Basic Research of the Presidium of the Russian Academy of Sciences and by the RFBR grant N 10-02-00735-a.

Edited by: T. Suomijarvi
Reviewed by: two anonymous referees

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