A study of hadrons and muons in EAS at the “Carpet-2” shower array

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***Abstract*- New results are presented for hadrons and muons with energies E_h>30GeV and E_μ>1GeV respectively, for EAS sizes of $10^5 < N_e < 10^6$ and for core distances of 40 to 56 m. The experimental data are compared with results of CORSIKA code (model QGSJET) based on Monte-Carlo simulations.**

1. INTRODUCTION

Experimental data on the characteristics of the muon component of Extensive Air Showers (EAS) provide information both on the chemical composition and on the nuclear interactions of the particles responsible for the origin and development of showers in the atmosphere. It is considered that a substantial increase in the area of muon detectors would allow us to understand the nature of the knee of the primary spectrum in the region of 10^{15}eV, to determine the chemical composition of primary cosmic rays, and to reliably distinguish showers originating from primary nuclei and γ-quanta.

In previous studies [1]-[3] it has been proved that events registered by the “Carpet-2” array with cores inside the “Carpet” with density ≥10 relativistic particles(r.p.)/m^2 in the muon detector (MD) are EAS hadrons. The thickness of the absorber is equal to ~20 radiation lengths and it is enough to absorb the electromagnetic component, but it is not thick enough for the hadronic cascade (only ~5 hadron interaction lengths). Hadrons interact with the absorber of the MD and produce hadronic cascades. Hadronic cascades developing in the absorber can produce high-energy signals in the scintillator.

The calculation is performed for hadrons with E_h=5÷500GeV, and it gives the average size of the hadron cascades in MD $\bar{r}$~0.01÷4m^2 [2]. Another consequence of this work is very interesting from a methodic point of view. A muon detector with thin absorber can also be used as a hadron detector. Moreover, in a case similar to ours, when the muon detector has a large continuous area that consists of many individual detectors, it is able to measure the energy deposit, and then it can be used as a hadronic calorimeter.

2. “CARPET-2” SHOWER ARRAY

The “Carpet-2” shower array (Fig.1) of the Baksan Neutrino Observatory is located in Southern Russia, in the North Caucasus region, near mount Elbrus (at 1700 m above see level, latitude 43.3°N, longitude 42.7°E). In this work we use two parts of this array: the ground level detector called “Carpet” (196m^2) and the underground muon detector. “Carpet” that consists of 400 individual liquid scintillator detectors of 0.5 m^2 each. The range of energy deposit measurements for an individual detector is 1-5000 r.p.. One r.p. is the most probable energy deposit produced by a single cosmic ray particle crossing the detector, and equals 50 MeV. Six outside points have 18 scintillator detectors, each of the same type. Four of them are placed in the form of a square at a distance of 30m from the center of “Carpet”, and two are at a distance of 40m. The signals from these detectors are used as stopping pulses in the time measurement system to measure delays and reconstruct arrival directions. The “Carpet” can measure the shower parameters with good accuracy: ΔX=ΔY=0.35; $\Delta N_e / N_e$=0.1; Δs/s=0.02 in the EAS size interval of N_e=10^5÷10^6. The muon detector of 5×35m^2 is situated at 48m from the “Carpet”’s center and consists of 175 plastic scintillator detectors of 1m^2 each, under a soil absorber of 2.5m thickness (500g/cm^2) in

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an underground tunnel, attached to its ceiling. Each detector can measure the energy deposit in the interval of 1÷100 r.p.. For this kind of detectors one

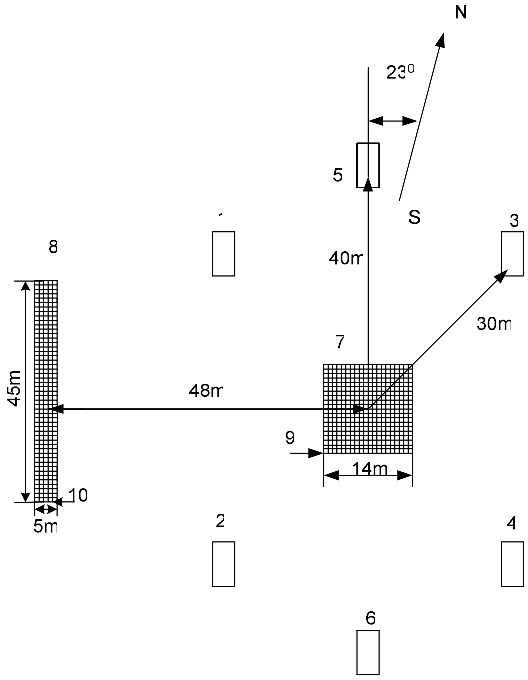

Fig.1 .A schematic view of the “Carpet-2” EAS array. 1-6–outside points, 7–“Carpet”, 8 – muon detector, 9-liquid scintillator detector, 10 - plastic detector.

relativistic particle corresponds to 10 MeV. The large size of the MD and its good enough granularity give a possibility to observe the structure of penetrating cosmic ray components, including muons with 1 GeV threshold energy.

3. SEPARATION OF MUON AND HADRON COMPONENTS IN EAS

The muon detector of the “Carpet-2” shower array detected events with high density (ρ>10 r.p. per m^2 or energy deposit ≥100MeV) [2]. It was shown that these events were produced by hadrons with energy E_h>30ГэВ. For this purpose the dependence of the barometric coefficient β for different energy thresholds (Fig.2), measured for MD events, was used.

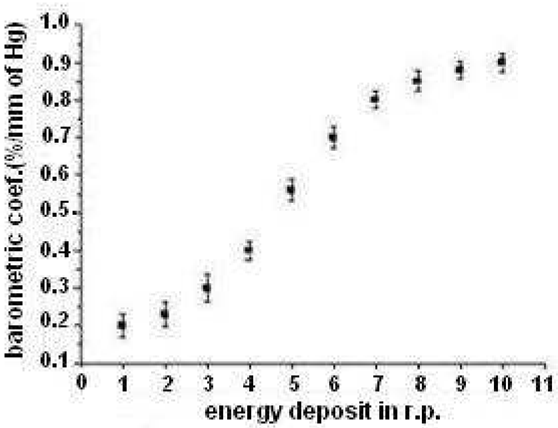

Fig.2. Barometric coefficient of MD events as a function of the energy deposit threshold.

One can see that the barometric coefficient β of cosmic ray components producing events at energy deposit thresholds >10 r.p. (<3r.p.) (Fig.2) is very close to hadrons (muons). Those calculations were confirmed also in [2],[3]. Hadronic cascade developing in the absorber can produce high energy deposit ε in the scintillator because it is situated just near the hadronic cascade maximum. The results of Monte-Carlo simulation for single hadrons (protons and π-mesons) interacting in the absorber of 500 g/cm^2 thickness are presented in Fig.3.

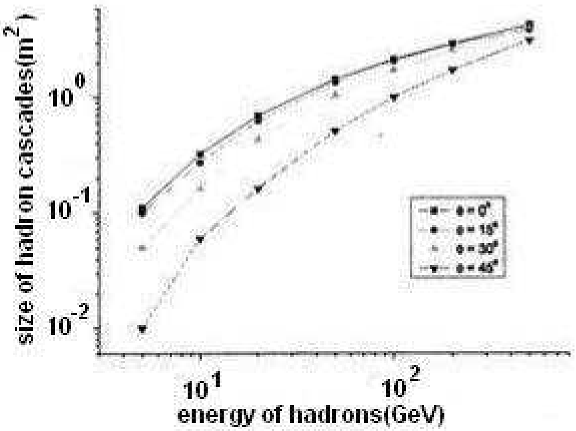

Fig.3. The average size of “spots” of hadron cascades in MD as function of hadron energy.

Fig.3 displays that the average size of hadron cascades in MD depends on hadron energy and on zenith angle. The “spots” with local density ≥ 10 particles per m^2 in MD and with no more than 5 detectors in the “spot” can be considered as hadrons.

4. RESULTS

A. HADRON COMPONENT

Nearly vertical showers (sec(θ)<1.15) with $10^5 < N_e < 10^6$ and cores located inside the “Carpet” were selected for analysis. The experimental dependence of the mean number of hadrons with E_h>30GeV in MD per EAS on the total number of particles is presented in Fig.4. Experimental data can be fitted by a power law: $N_h \sim N_e^{\alpha}$, where the index α=0.89±0.08. The dependence of the total number of hadrons on the total number of EAS particles at a mountain level was measured in papers [5]-[7] for the same range of $10^5 < N_e < 10^6$.

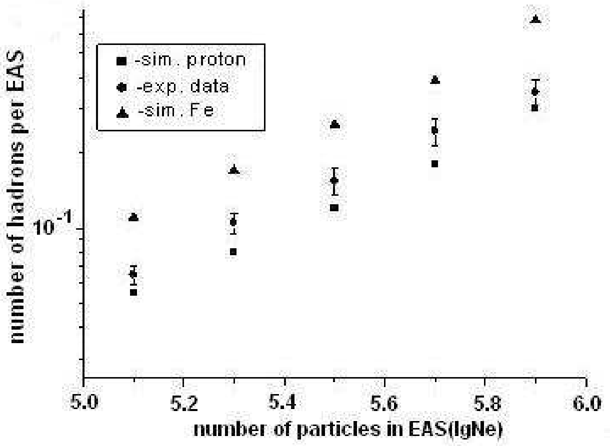

Fig.4. Dependence of the average number n of hadrons per EAS on the total number of particles N_e in EAS, compared with results of simulation obtained by the program CORSIKA code(model QGSJET).

In Fig.4 also is shown a comparison of experimental data with simulation results obtained by the CORSIKA code for proton and for nuclear iron Fe.

In this experiment an M3-trigger was also used. M3 is an MD trigger produced by coincidence of 3 from 5 MD modules (every 35=5×7 detectors of MD are grouped in 5 modules). Results of calculations with CORSIKA code (model HDPM) show that trigger M3 is produced by EAS with E_o>10TeV for primary proton and with E_o>100TeV for iron nuclei, by cores in a circle with radius 10m, when the center is near the center of MD. For these showers the differential size spectrum of hadrons was also obtained (Fig.5), which can be described by a power law: $dN/dN_h \sim N_h^{\beta}$, β=-2.8. At the KASCADE shower array the differential size spectrum of hadrons (E_h>50GeV) was measured near cores of EAS, and is described by power law with index of spectrum γ=-2.81±0.05 [4]. The spectra in both experiments agree fairly well.

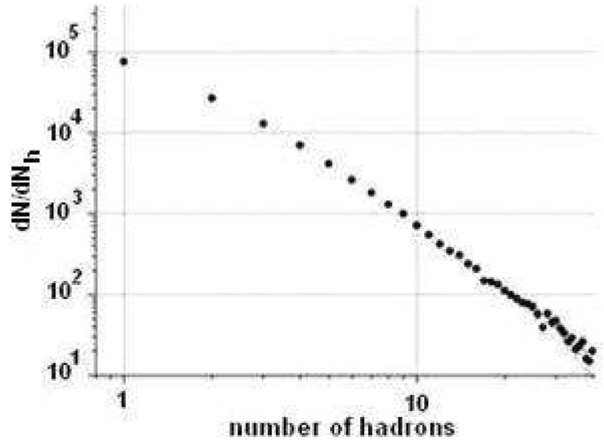

Fig.5.Differential size spectrum of hadrons

The experimental decoherence curve, without correction for efficiency of registration, was obtained using the experimental data of MD for hadrons with energy E_h>30GeV (Fig.6).

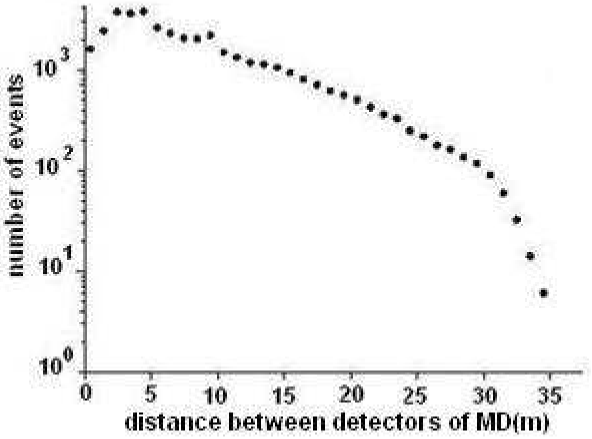

Fig.6. Experimental decoherence curve for hadrons without correction for efficiency of registration.

In Fig.7 the experimental decoherence curve is presented for hadrons, taking into account a correction for efficiency of registration.

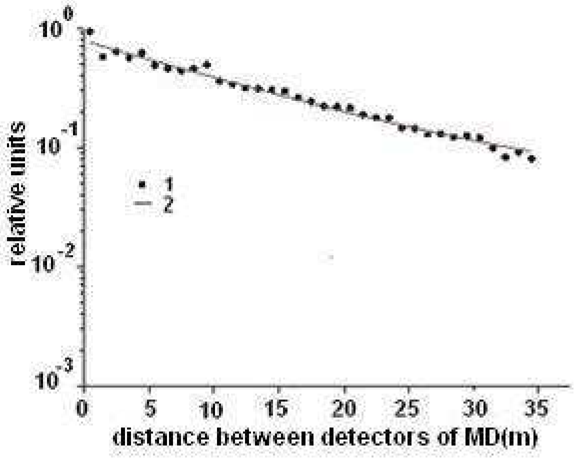

Fig.7. Experimental decoherence curve with correction for efficiency of registration (1 – experimental decoherence curve, 2 – F(d)~exp(-d/d_o) with d_o=13.1m).

As can be seen in Fig.7, the slope of the decoherence curve corresponds to 13.1m.

B. MUON COMPONENT

The mean numbers of muons n_μ per shower are plotted in Fig.8 for experimental and simulated events for primary protons and iron nuclei. The measured and the simulated data are fitted by the usual relationship: $n_\mu = k \cdot N_e^\alpha$, with α=0.73 for the present experimental data, while α=0.74 was obtained for the experimental data of the EAS-TOP shower array [8].

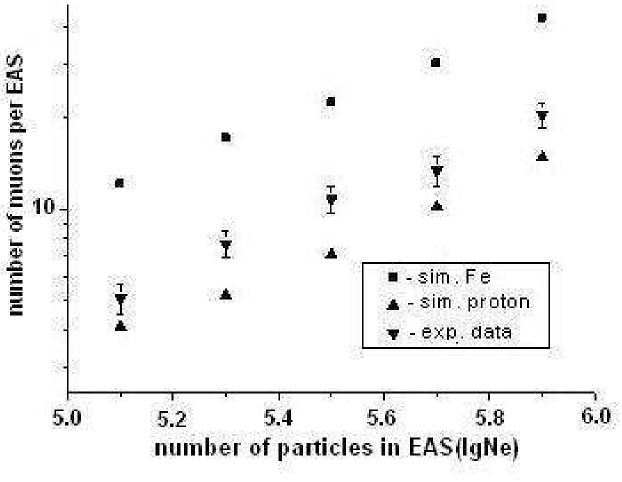

Fig.8 Dependence of the average number of muons per EAS for experimental data on the total number of particles N_e in an EAS. Compare experimental data with results of simulation by CORSIKA code (model QGSJET) for proton and nuclear iron Fe.

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