Possibility to search for VHE muons with Baksan Underground Scintillation Telescope

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Abstract

Rate of interactions of VHE muons (> 100 TeV) in matter differs from that of muons with lower energies due to electron-positron pair production. MC simulations for BUST using GEANT4 package have been performed, and some criteria for VHE muons selection are proposed. The results of calculations are compared with experimental data of BUST during its operation in 1983 – 1989.

1. Introduction

The problem of VHE muons (≥ 100 TeV) is interesting from two points of view. Firstly, muon energy spectrum, the important characteristics of cosmic rays, is measured up to several tens TeV only. Secondly, if the knee in the cosmic ray energy spectrum is connected with inclusion of new physical processes or objects, then some excess of VHE muons must appear [1]. In the interval of hundreds TeV, it is impossible to use well-known methods as magnetic spectrometer (very small deviations of trajectory of particles in accessible magnetic field) and absorption curve (the fluxes of such muons and neutrino-induced muons are comparable). Two other methods of muon energy evaluation are: ionization calorimeter (measurements of big electromagnetic cascades with energy $\sim E_\mu$) and pair meter technique (measurements of multiple cascades with energies $\ll E_\mu$). In this paper, possibilities of BUST [2] to search for VHE muons by these two methods are considered. For simulations, GEANT4 code (version 5.0) was applied.

2. Simulation of BUST response for VHE muons

To estimate the capability of BUST as a calorimeter for VHE muon studies, the expected spectrum of muon-initiated cascade showers was calculated. A usual muon energy spectrum (from π and K-decays) with asymptotic integral slope $\gamma = 2.7$ was assumed. Calculations show that maximum cascade energy attainable

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for 6 years of measurements in BUST is about 20 – 30 TeV and correspondingly the maximum muon energy is limited by about 50 TeV. Therefore, this method is not efficient for investigations of muons above 100 TeV in BUST.

For another method (pair meter technique) simulations were performed for a power type spectrum of muons with the integral spectrum index $\gamma = 2.0$ in order to increase the number of high-energy muons in the simulation. Calculations were made for 4 values of threshold muon energies, listed in Table 1. Distribution of muons in zenith and azimuth angles was taken isotropic, and it was required that muon passed through the center of the setup, crossing all four horizontal planes of the telescope. Simulated events with the energy deposit in scintillation planes $E \geq 10$ GeV (cascade energy ≥ 100 GeV) were saved for the further analysis. Number of selected events and their percentage are also given in the Table 1.

Table 1. Summary of BUST response simulation for high energy muons.

E_μ^{th}, TeV	N_μ	$N(\geq 10$ GeV)	N/N_μ, %	$N_{VHE\mu}$
0.35	10^6	2044	0.2	0
1	5×10^6	43475	0.9	2
10	5×10^4	5073	10.1	4
100	5×10^3	2515	50.3	26

3. Selection of VHE muons

To suppress the contribution of the processes of bremsstrahlung and inelastic interaction with nuclei and to distinguish multiple electron-positron pair production, "two-hump" events with a clear minimum between the maximums in the longitudinal profile were selected. After consideration of various variants for separation of these events, the following parameters were finally chosen: energy deposit in the lower hump ≥ 20 GeV (lower sub-cascade energy more than about 200 GeV), and the gap coefficient (the ratio of the lower hump energy deposit to the signal measured in the minimum) ≥ 20. The number of events selected with these criteria is given in the last column of Table 1.

It is important to note that all these events correspond to muon energies in the interval 70 – 1600 TeV, that means that the background of relatively low energy muons ($\sim$ TeV) appeared completely suppressed. Two samples of these events are shown in Fig.1 (left, center). Corresponding muon energies are 150 and 74 TeV; total energy deposit in scintillator planes is 90 and 71 GeV respectively; number of interactions with pair production in each event exceeds 10.

After that, the same criteria have been applied to experimental data accumulated at BUST in 1983 – 1989. In all, during 2169 days of telescope operation, about 9×10^5 events with the measured energy deposit ≥ 10 GeV were registered; 9 events that satisfy the above selection criteria have been found. In Fig.2 (left,

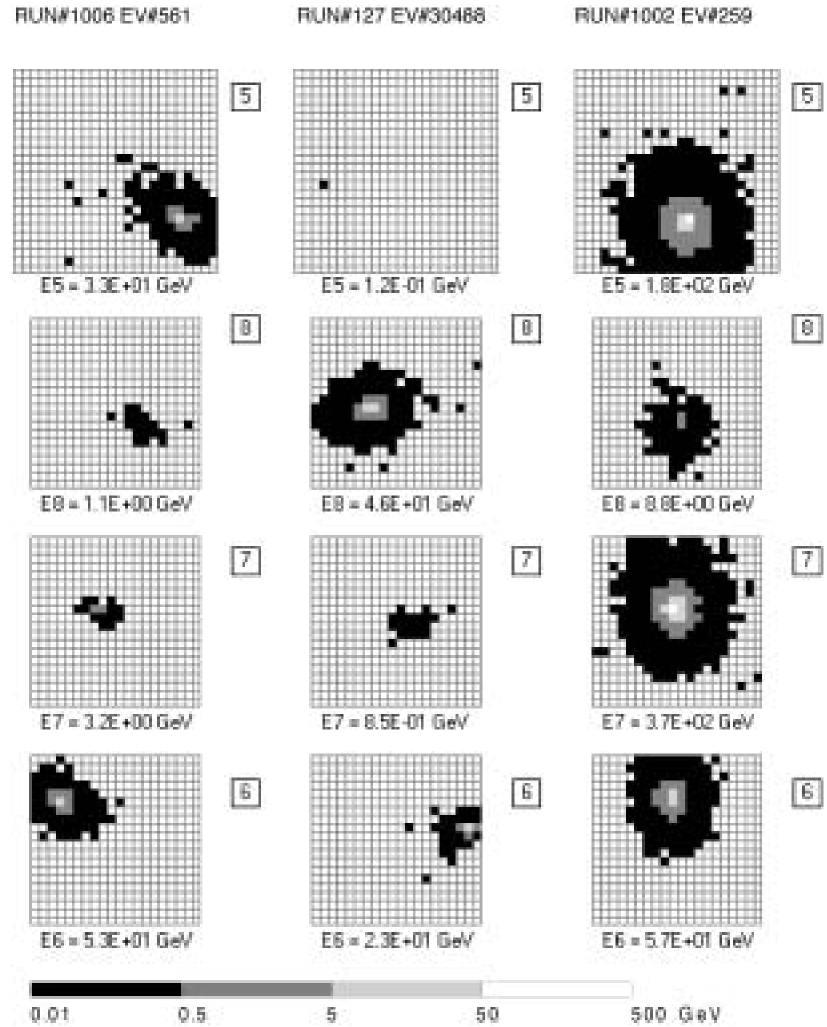

Fig. 1. Simulated events.

center), two of these experimental events (with total deposited energies 180 and 45 GeV) are shown.

An important feature of 1983 - 1989 measurements was a possibility to detect $\pi \to \mu \to e$ - decays after registration of showers in the telescope, that provided the additional signature for identification of nuclear showers. In the selected VHE candidates, either no such decays or only one decay were found. For comparison, at the right in Fig.2 the experimental event with a high-energy nuclear shower (E = 450 GeV, 21 $\mu \to e$ decays) is shown. In Fig.1 (right) a similar event from simulated data (nuclear interaction with energy deposit equal to 610 GeV) is given. But primary energy of this muon was 180 TeV.

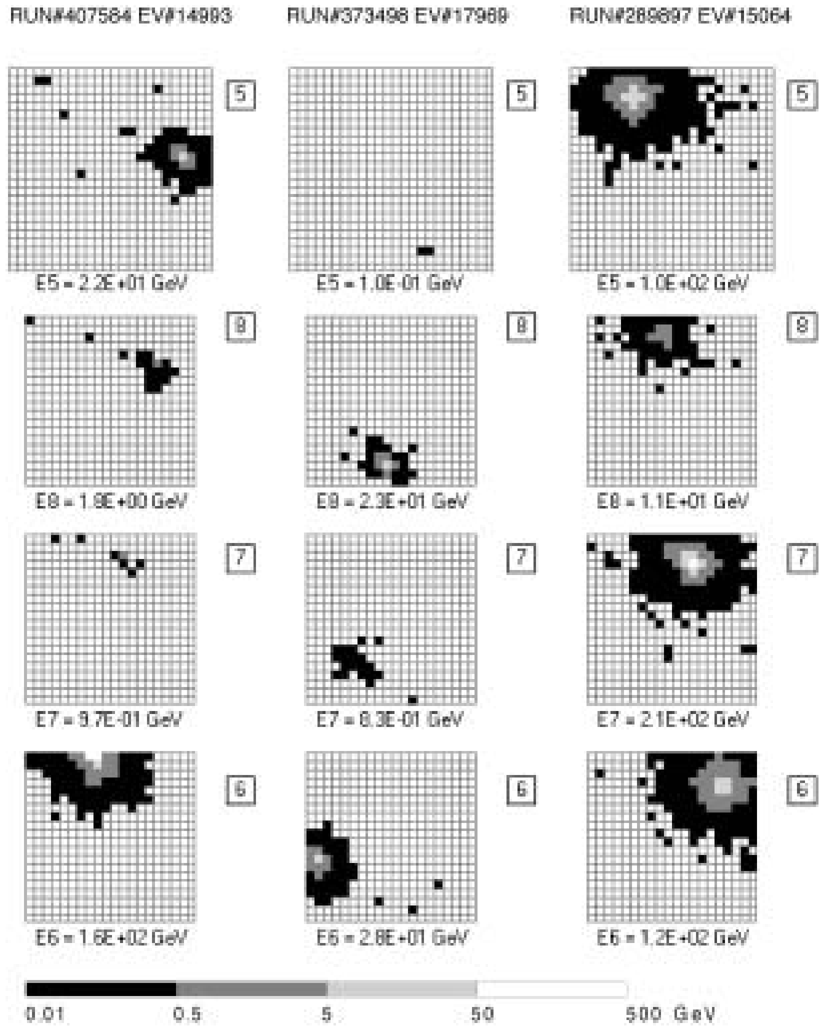

Fig. 2. Experimental events.

4. Conclusion

As a whole, the obtained results allow to affirm that a principal possibility to select VHE muons in BUST exists. Of course, we understand that further investigations of this problem are required, in particular, the increase of statistics of simulated events is necessary.

5. References

1. Petrukhin A.A. 2001, in Proc. 27th ICRC 5, 1768
2. Chudakov A.E. et al. 1979, in Proc. 16th ICRC 10, 188