Investigation of muon bundles in horizontal cosmic ray flux

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Abstract

A new large area coordinate detector DECOR is deployed around water Cherenkov calorimeter NEVOD and is intended for studies of various cosmic ray components at the Earth's surface. On the basis of data accumulated during experimental runs 2002 – 2003, the first results on cosmic ray muon bundles are obtained. Preliminary data on zenith angle dependence of the ratio of muon group intensity and that of single particles in the range $60^\circ - 90^\circ$ are presented and compared with MC simulation of EAS muons with CORSIKA. A special attention is paid to muon groups of large multiplicity near horizon.

1. Introduction

Investigations of near horizontal muon bundles are of great interest, since due to properties of the atmosphere the main trivial mechanism of multi-muon event generation (EAS muons) is strongly suppressed, and it is possible to expect the appearance of less studied and also of new processes. The analysis of experimental data on zenith angle distribution of muon bundles and comparison with expectation will allow to study the processes of energy transformation related with muon group production. For generation of such events in the angular range $60^\circ - 90^\circ$, primary particles in the energy interval 1 – 10 PeV are responsible, where the change of the slope of cosmic ray energy spectrum is observed.

2. Experimental setup

The coordinate detector DECOR [1] represents a multi-layer system of streamer tube chambers and is arranged in the building of experimental complex NEVOD around the Cherenkov water calorimeter. The detection system of water

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detector NEVOD [2] with sensitive volume 2000 m^3 is formed by a spatial lattice of quasisphrerical measuring modules (QSM). DECOR consists of two parts: the side detector (8 supermodules - SM, each of eight vertical planes with area 8.4 m^2), and the top one (4 supermodules with horizontal chamber planes, total sensitive area 45 m^2). Thus, the area of the coordinate detector is about 115 m^2. The general lay-out of the experimental complex is shown in Fig.1.

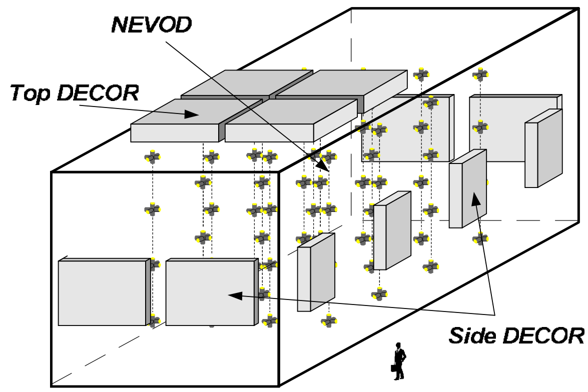

Fig. 1. Experimental complex NEVOD-DECOR.

The basic element of the coordinate detector is a plastic streamer tube chamber with resistive cathode coating and external two-coordinate readout strip system. The side coordinate detector is partitioned into three groups of supermodules: SM arranged in a long gallery (group *Long*), and SM located in two opposite short galleries (two groups *Short*). The fourth group consists of four horizontal SM of the top coordinate detector – *Top*. Selection of events by the triggering system is based on coincidences between signals from SM of different groups and signals formed by the system of Cherenkov detector.

3. Selection of muon bundles

For muon bundle studies, data accumulated during experimental runs 2002-2003 (about 5060 hr live time) were used. The technique of selection of muon bundles is based on the fact that tracks of particles produced in the atmosphere (far from detector) are nearly parallel in the setup. For analysis of muon groups of low multiplicity ($N \geq 2$ tracks) the following algorithm was realised.

Triggering conditions provide detection of muons crossing any two SM of the side detector, located in different galleries (see Fig.1). Angular accuracy of reconstruction of such tracks is about 0.2° and is limited by multiple scattering in water. In total, about 7.05×10^7 events with such "reference" track were found. Then the events containing at least one additional track, parallel (within 5° cone) to the reference one, were selected as muon bundle candidates (6.09×10^5 events).

However, among these events there are many imitations of two kinds: electromagnetic component coming from the atmosphere together with muons, and locally generated secondaries. In order to suppress this background, additional selection criteria were applied: firstly, only particles crossing water volume of Cherenkov calorimeter (energy threshold from 2 up to 7 GeV, depending on the event geometry) are retained; secondly, the distance D between the reference track and additional one must be greater than 1 m.

After that, the number of selected candidates was reduced down to 6785. The distribution of these events in the angle between the reference and additional tracks is shown by solid histogram in Fig.2a. Main part of events is characterised by angles less than 3°. For comparison, distribution of tracks detected in input supermodules (before the NEVOD volume) is shown by dashed histogram. Contribution of the component with a wide angular dispersion is clearly seen.

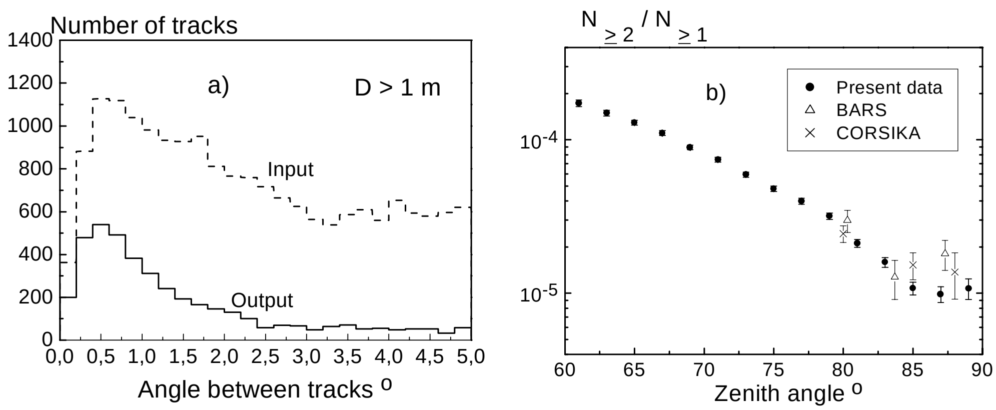

Fig. 2. Left: Distribution of bundle candidates in the angle between the reference and additional tracks. Right: Ratio of the number of groups to that of single muons (normalised to 10 m^2 area).

4. Angular dependence of muon bundle intensity

The measured zenith angular dependence of the ratio of muon group intensity to that of single muons is shown in Fig.2b (circles). This ratio depends on the detector sizes, therefore for quantitative comparison the points in the figure are normalised to a "standard" effective area 10 m^2. Statistical errors are shown only; systematic uncertainties are estimated as $\pm 10\%$. In general, the intensity of muon bundles at the surface decreases with zenith angle faster than the intensity of single muons. However, the flattening of the above ratio at angles $\theta > 84°$ is noticeable. A similar behaviour (but with lower statistics) was found in the data of liquid-argon spectrometer BARS [3] (triangles). The crosses represent preliminary results of EAS muon simulation with CORSIKA-CURVED code (version 6.020). Simulation results are compatible with the experiment (including the absolute value of the ratio); however, for quantitative conclusions calculation accuracy has to be improved.

5. Large multiplicity events

In 2002 run (3030 hr live time), 51 muon bundles with more than 10 parallel tracks at zenith angles exceeding 75 were found. Such events have very bright signature in the coordinate detector, and may be unambiguously selected. An example of multi-muon event is shown in Fig.3.

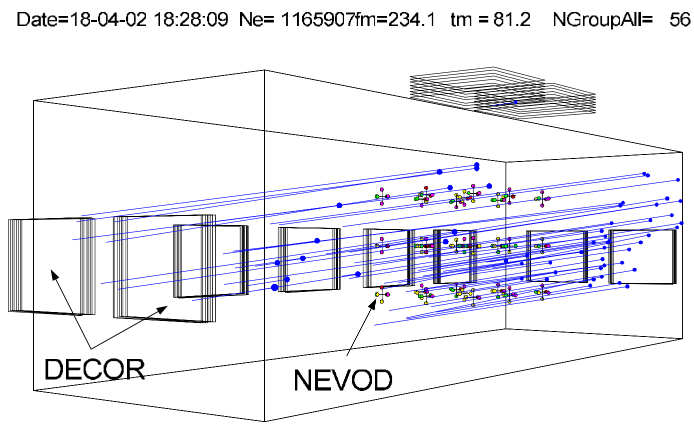

Fig. 3. Multiple muon event, $\theta = 81.2^{\circ}$ (56 reconstructed tracks)

As follows from simulation with CORSIKA, for bundles with such muon density (> 0.3 particles/m^2) at zenith angles close to 80° interactions of primary particles well above the knee energies ($> 10^{16}$ eV) are responsible. Analysis of bundle multiplicity spectra and distributions of energy deposit in Cherenkov detector in the accessible angular range will give the possibility to compare spatial-energy characteristics of multi-muon events below and above the knee.

6. Acknowledgements

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7. References

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