Search for aligned events in muon groups measured by BUST

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A search for aligned events has been done throughout the muon groups events measured by Baksan Underground Scintillation Telescope (BUST) during a period of 7.7 years. Only groups of multiplicity > 3 for muon threshold energy equal to 0.85 TeV were selected for the analysis. A distribution of the events on alignment parameter λ has been obtained and compared with the results of Monte-Carlo simulation made for this experiment. The upper limit for aligned muon event flux as low as $5 \cdot 10^{-15} \text{cm}^{-2}\text{sec}^{-1}\text{sr}^{-1}$ is given.

1. Introduction

The muon bundle data cover an energy range between the data of direct methods (balloons, satellites) and the Extensive Air Showers (EAS) data: from $\sim 10^{13}$ up to $\sim 10^{17}$ eV for primary cosmic ray (i.e. includes the "knee"). High energy muons are produced in the highest energy part of the EAS cascade at high altitudes. The muon bundle events give information on the transverse momenta of the secondaries in high energy collisions, which affects a lateral spread of muons in the bundles. On the other hand, the "knee" energy range is related to interesting phenomena observed in cosmic rays, in particular, to the phenomenon of the alignment of most energetic subcores of gamma-ray-hadron (γ − h) families (particles of highest energies in the central EAS core) found in the "Pamir" emulsion chamber experiment [1]. In this work we performed a search for aligned events among the muon groups observed in BUST. The first search for aligned muon bundle events has been done with MACRO detector [2] without certain results.

2. The experiment

The BUST detector [3] is located in Baksan Valley (North Caucuses, Russia) at a height of 1700 m. a. s. l. in the underground laboratory at a distance of 550 m from the tunnel entrance. Its effective depth is 850 $\text{hg/cm}^2$, and the effective threshold energy is 220 GeV. The depth varies from 800 $\text{hg/cm}^2$ for nearly vertical directions up to 6000 $\text{hg/cm}^2$ for slant trajectories where the energy threshold is about 6 - 10 TeV. The telescope looks like a four-storeyed building with a size of $16.7 \times 16.7 \times 11.1 \text{m}^3$. Four vertical scintillator layers and four horizontal scintillator planes are formed by liquid scintillation detectors of standard type. The total number of detectors is 3150. The standard detector ($0.7 \times 0.7 \times 0.3 \text{m}^3$) consists of an aluminum tank filled with liquid scintillator viewed by a 15-cm diameter PMT (FEU-49).

In this experiment additional requirements were applied to select the so called aligned events. We used the standard λ parameter introduced by the "Pamir" experiment [1], which is varying from $\sim -0.5$ to $\sim 1$ (for aligned events). It is equal to near zero values for isotropic events. Inclined tracks with zenith angles inside a range of 50-70° were selected to make the muon energy threshold higher. The effective depth for such a selection was equal to 2500 $\text{hg/cm}^2$, which corresponds to muon threshold energy of 0.85 TeV.

3. Experimental results

The experimental normalized distributions on the λ parameter is shown in Fig.1 for visible muon multiplicity m=4, 5 and 6. As one can see we have no any significant access near λ = 1. In fact, aligned events do exist as it is seen in Fig.1, but, very similar spot configurations can be realized
by chance as it is shown below.

4. Simulations

A Monte Carlo simulation of EAS propagation in the atmosphere has been carried out. Muon groups were first simulated in the framework of the MC0 code [5] (close to QGSJET), which reproduces well the results obtained by the PAMIR experiment emulsion chamber experiments and does not include unusual processes. To analyze the alignment phenomena, a simplified model of particle coplanar generation (PCGM) in the first interaction of a primary particle with an air nucleus has been used. This model reproduces PAMIR’s data on aligned $\gamma - h$ families. Conclusions found on the basis of the simulations are as follows:

1. The influence of magnetic field on alignment of muons is strong and it doubles the background fraction of aligned muon bundles caused by the cascade development.

2. In accordance with the PAMIR’s concept assuming the coplanar generation of several most energetic particles, which cannot actually decay into muons, the appearance of coplanar generation has no influence on the features of muon groups formed mainly by muons produced by lower-energy secondary particles in further generations. Figure 3 demonstrates this: the results of simulations made in the framework of both the MC0 and PCGM algorithms coincide for all the muon multiplicities while there exists a dependence on the detector dimensions. For $\sim 10 - m$
Figure 2. Comparison of the experimental $\lambda$-distributions with random spots simulations for $m=4$ (a), $m=5$ (b) and $m=6$ (c).

set-ups (BUST dimensions) it is close to that being characteristic for $\gamma - h$ families. As one can see, a fraction of aligned events on a level of about several percent is normal and this is in agreement with our experimental data shown in Fig. 1. Fig.4 shows the same behaviour for the average alignment $<\lambda_{N_{\mu}>}$.

3. A significant alignment of muons could only be produced in case of direct coplanar muon generation.

5. Summary

An experimental search has been performed for aligned events in muon groups with threshold energy equal to 0.85 TeV. The measured distributions on the alignment parameter $\lambda$ agree very well with simulated event distributions and there is no evidence of the existence of such events among the muon groups underground (at least for threshold energy 0.85 TeV) at a level beyond the expectations obtained for simulated events with a random track distribution. Moreover, even in EAS’s simulated in the framework of a model including the coplanar particle generation there exists no visible effect of alignment in muon groups because only a small fraction of muons could be generated in the first interaction via the decay of the most energetic aligned secondaries. Fluctuations of cascade development and a huge number of muons produced in later generations make this process random. Therefore, the observed muon alignment is only determined by random fluctuations of muon tracks on the detector area. Taking into account the detector area ($\sim 200 \, m^2$) and the trigger selected solid angle ($\sim 0.38 \, sr$) and the
duration of the experiment (7.7 y) we can put an upper limit to the flux of aligned muon groups on a one sigma level as low as $F_{\text{aligned}} < 5.3 \times 10^{-15}$ $cm^{-2} sec^{-1} sr^{-1}$.

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