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Search for coplanar emission of secondaries in nuclear interactions at energy $E_0 > 10^{13}$ eV in RUNJOB experiment data

V. I. Galkin[1], **V. V. Kopenkin**[1], **A. K. Managadze**[1], **S. N. Nazarov**[1], **V. I. Osedlo**[2], **I. V. Rakobolskaya**[2], **T. M. Roganova**[1], **and L. G. Sveshnikova**[1]

[1]D. V. Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia
[2]Physical Department of Moscow State University, Moscow, Russia

Abstract. The phenomenon of coplanar emission (alignment) was discovered in Pamir emulsion experiment at $E_0 > 10^{16}$ eV. In contrast to mountain experiments, where repeated cascade interactions distort the picture of a primary interaction, the data of joint Russia-Japan balloon experiment RUNJOB have some advantages. They enable to analyse directly the secondaries of a single nuclear interaction, to study the correlation of alignment effect with primary type, to examine the probability of coplanar emission at lower energies.

1 Introduction

If emission of secondaries in a nuclear interaction occurs as coplanar scatter, the correspondent traces of particles in a normal plane are to locate on a film along a straight line. Such arrangement is called "alignment".

The phenomenon of secondariy particles alignment occuring in cosmic ray interactions at energy $10^{15} - 10^{17}$ eV was detected in Pamir experiment (altitude 4360 m or 600 g/cm^2) (Pamir Collaboration, 1985, @; Pamir Collaboration, 1991, @; Kopenkin et al, 1995, @). A few most energetic objects in some families formed a rank. The effect was analysed to be beyond fluctuation expectations.

Later the alignment phenomenon was confirmed with XEC experiments at Kanbala mountain (Tibet, 520 g/cm^2) (Xue et al., 1999, @) and at Concord (17 km or 105 g/cm^2) (Capdevielle, 1997, @).

The study of alignment within Pamir Collaboration showed that this effect appeared significantly above interaction energy threshold $E_0 \approx 10^{16}$ eV.

The alignment effect was analysed also at low energy $E_0 = 250$ GeV for accelerator data of NA22 experiment, and there was found the fractions of events with alignment correspondent to calculated fluctuation background level, hence at so low energy the meaningful effect does not show (Kopenkin et al., 1994, @).

The design of RUNJOB emulsion chambers (RUNJOB Collaboration, 1997, @) gives a possibility to study the geometry of secondary emission after interactions of primaries in an installation body at an energy intermediate between accelerators and very high energy cosmic rays. In this analysis the result of a single interaction is available in contrast to mountain experiments where atmospheric cascade results are under consideration. Besides here is possible to consider a primary particle type.

2 Experiment

Here the data of 4 RUNJOB balloon flights of 1995 and 1996 (total exposure is about 230 $m^2 \cdot hour$ at 10 g/cm^2 altitude) are used.

RUNJOB chambers contain a target, a spacer block and a lead quasicaloremeter. Secondaries after interaction of a primary have a sufficient pathlength to diverge and gamma component of the secondaries is detected in the caloremeter block as a group of "gamma cores" in nuclear emulsion. Just such objects are under analysis here.

Only events with $\Sigma E_\gamma > 3$ TeV were selected in the present analysis, so about one half available events were discarded. Thus 43 interactions of 1995 and 127 interactions of 1996 are included in the present consideration. These events comprise the range $\Sigma E_\gamma = 3 - 50$ TeV. The difference of event numbers between two years is due to high selection threshold in 1995 because of dark X-ray films.

As an example of alignment in the experiment in Fig. 1 nuclear emulsion photo with "gamma cores" is shown.

To characterize alignment parameter λ (Pamir Collaboration, 1988, @) is used:

$$\lambda_N = \frac{\sum_{i \neq j \neq k} \cos 2\varphi_{ijk}}{N(N-1)(N-2)},$$

where N is the number of points under consideration, φ_{ijk}

Correspondence to: A. K. Managadze
(mng@dec1.sinp.msu.ru)

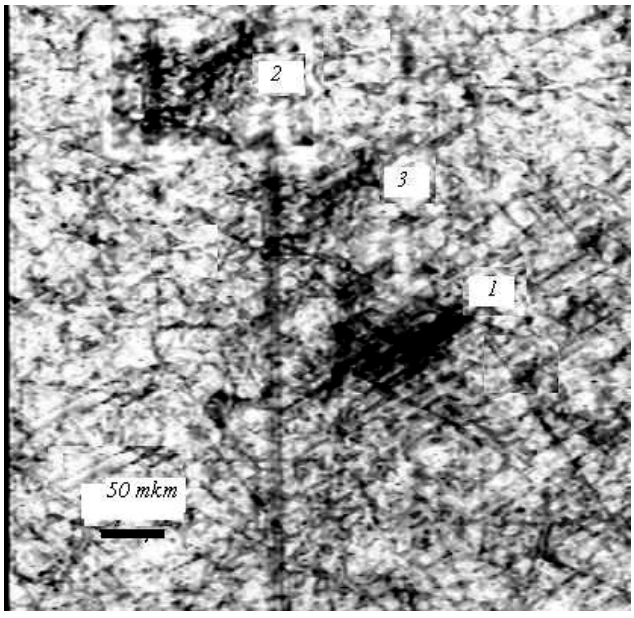

Fig. 1. An expample of aligned gamma cores in nuclear emulsion.

is the angle between vectors $\overline{ki}$ and $\overline{kj}$. $\lambda = 1$, if all points stand definitely along a straight line.

In the analysis this criterion is applied in turn to 3, 4 and more most energetic particles of an event.

3 Simulations

To estimate the level of fluctuations imitating aligned configuration without any special mechanism of coplanar scatter it is necessary to simulate artificial events under the given registration conditions. By 1000 events for primary proton and He and by 500 events for C, Mg and Fe were simulated with QGSJET generator (Kalmykov and Ostapchenko, 1993, @) with CORSIKA fragmentation model. Modern quasi-dynamic QGSJET model based on the description in terms of quark-gluon strings takes into account also semihard processes (Burnett et al., 1987, @). Of course it has no special mechanism for coplanar emission. As a target C nucleus was used (lucite target).

Obtained secondaries in every artificial event were analysed for alignment separately in gamma component and in hadrons (including fragments) according to the real situation in RUNJOB experiment.

4 Results and discussion

Fig. 2 show the fractions of events with alignment in simulated events for 3 and 4 most energetic particles under consideration. For gamma component such fraction does not depend practically on primary type, obtained fluctuation levels are consistent with calculated ones in Pamir experiment with various models (Kopenkin et al, 1995, @; Borisov et al., 1997, @). The results on alignment in gamma and hadron

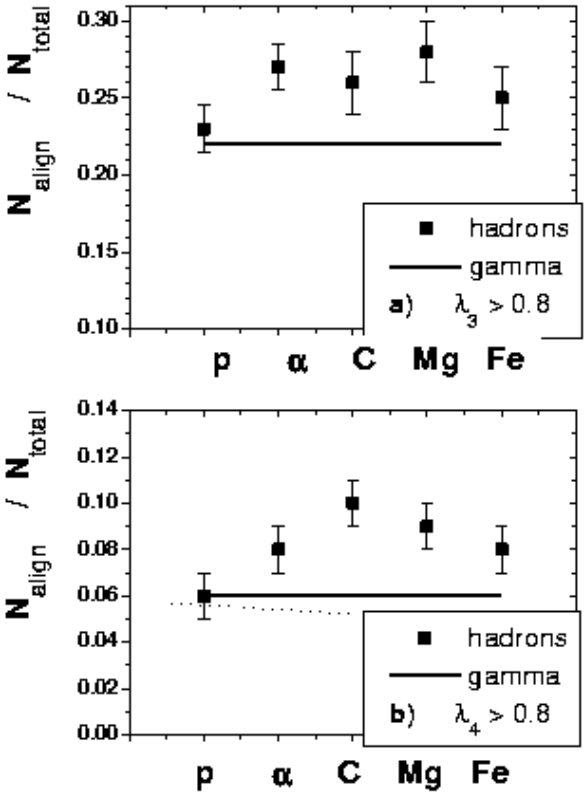

Fig. 2. Fractions of artificial events (QGSJET model) with alignment for various primary types: a) for 3 most energetic particles, selection criterion $\lambda_3 > 0.8$; b) for 4 most energetic particles, selection criterion $\lambda_4 > 0.8$. Squares stand for hadron component of secondaries, a line stands for gamma component of secondaries.

components for primary proton do not differ. For other primaries the fractions of events with alignment for hadron component are significantly higher than for gamma component of same events. This abundance for various selection criteria (including those beyond presented plots) varies from 1.25 upto 4 times. The stronger the criterion, the larger the difference between gamma and hadron alignment. It seems to be especially prominent for medium primary nuclei. More simulations with increased statistics and higher energy are necessary to elucidate precise dependence of hadron component alignment on nucleus type.

Unfortunately only gamma component of secondaries was measured in the experiment at the present, so only that is compared with calculated background here. Since for gamma component the fluctuation level of alignment does not depend on primary type, it is possible to combine the data of various primaries altogether. For selection criterion $\lambda_3 > 0.8$ the fraction of events with alignment is $(31 \pm 4)\%$ in RUNJOB experiment and $(22 \pm 1)\%$ in model simulations. For selection criterion $\lambda_4 > 0.8$ such fraction is $(3 \pm 1)\%$ in the experiment and $(6 \pm 1)\%$ in the simulations. Thus for the most popular criterium $\lambda_4 > 0.8$ (used as standard one in Pamir experiment) no alignment effect is observed

in experiment RUNJOB data, experimental values are even less than the calculated fluctuation background. But for the weaker criterium $\lambda_3 > 0.8$ one can see significant abundance of events with alignment of 3 particles above the calculated background.

If it is not due to statistical fluctuations, that may mean that at energy $E_0 = 10^{13} - 10^{14}$ eV coplanar emission begins to reveal itself slightly before prominent appearance at energy $E_0 > 10^{16}$ eV (Pamir results).

Further investigations, especially on hadron and fragment component of experimental events, seem to be rather desirable.

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