Alignment effect and the possibilities of its study at LHC

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***Abstract*. Alignment effect in CR gamma-hadron families is the arrangement of the most energetic objects along a straight line in the plane of target diagram (that is a normal plane for interaction axis). The alignment phenomenon was detected in emulsion chamber experiments and is an evident consequence of the coplanar scatter of secondaries in nuclear interactions of very high energy. This effect is of a great interest, but it has not yet unambiguous interpretation. Statistics of such events is limited in CR experiments. Alignment examples are presented and the possibility of alignment effect study at LHC is considered.**

***Keywords*: alignment, nuclear interaction, LHC**

I. Introduction

The alignment effect, that is the arrangement of most energetic secondary particles after nuclear interaction along a straight line in a normal plane, is the consequence of coplanar scatter of particle (or energy) fluxes in the interaction producing the event.

This effect was discovered in Pamir mountain experiment with XEC (X-ray emulsion chamber) installations [1], [2]. The alignment phenomenon was observed in gamma-hadron superfamilies of CR from nuclear interactions with rather high E_0 (around 10^{16} eV and above that). In mountain experiments the phenomenon exhibited as an alignment of so-called energy distinguished cores or EDC in a gamma-hadron family, those are most energetic objects (halos, gamma-clusters, hadrons and gamma-quanta) formed from coplanar scattered secondaries with inclusion of the atmospheric cascade influence. Later the alignment effect existence was confirmed in mountain XEC experiment at Kampala (Tibet) [3] and in stratospheric emulsion experiments [4], [5].

Alignment manifestations observed in cosmic ray interactions have disadvantages for their study due to uncertainty of primary energy and primary type and of the distance from an interaction point to a detector. Though sometimes those parameters can be more or less estimated. Statistics of very high energy events, where alignment effect appears, are limited in CR experiments, that complicates the phenomenon analysis. This phenomenon is of a great interest, but it has not yet unambiguous theoretical interpretation.

All that gives evidence to suggest a great importance of alignment effect study at accelerators. LHC is able to provide necessary high energy for such study. Let us construct and consider expected alignment effect patterns for selected examples of CR superfamilies reduced to an accelerator experiment.

II. CR interaction picture in center-of-mass system

The best example of an experimental event with alignment in CR data is the "STRANA" superfamily. The unique gamma-hadron family "STRANA" was detected during the flight of the emulsion chamber aboard a stratospheric balloon [4]. The balloon started from Kamchatka and landed in the Volga region. The balloon flew at 30–33 km altitude, the average flight altitude corresponded to air pressure $\sim 10.2\ g/cm^2$. Therefore it was reasonable to assume, that in this case we can observe the result of a single nuclear interaction of a CR primary in contrast to events in mountain XEC experiments, where families are the results of ramified cascade showers.

In the "STRANA" superfamily there were estimated [6] the interaction energy as $E_0 \geq 10^{16}$ eV and the interaction height above the chamber as H $\approx$ 300 m. If we like to envisage the picture of such event at a collider, these evaluations simplify the conversion of secondary particle parameters to the center-of-mass system.

The conversion was made using transformation formula for forward cone, where * stands for center-of-mass system variables and L stands for the laboratory system:

$$E^* \approx \frac{E^L}{exp(\eta^0)} ;$$

$$\eta^0 = \ln \frac{\sqrt{s}}{m_2} ;$$

$$\sqrt{s} = \sqrt{2E_0^L m_2} ;$$

$$\eta^* = -\ln (tg\frac{\theta^*}{2}) ;$$

$$\mathrm{tg}\,\frac{\theta^*}{2} = \gamma_c\,\mathrm{tg}\,\theta^L ;$$

$$\gamma_c = \sqrt{E_0^L/(2m_2c^2))} ;$$

$$\varphi^* = \varphi^L .$$

Here E_0^L is a CR primary energy, m_2 is a target particle mass, E^* and E^L are secondary energy in corresponding systems, η^* is pseudorapidity, η^0 stands for pseudorapidity shift between two coordinate systems,

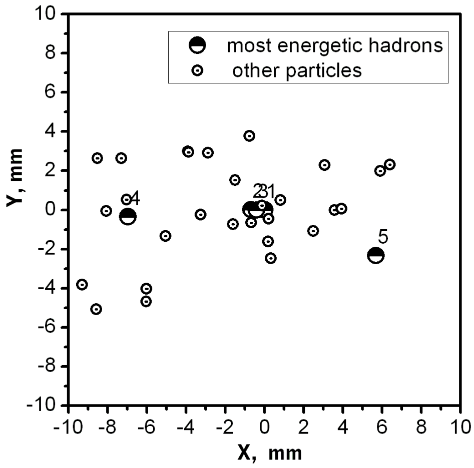

Fig. 1: The target diagram of the central area of the "STRANA" superfamily with alignment of 5 most energetic particles (numbers stand in the order of decreasing energy).

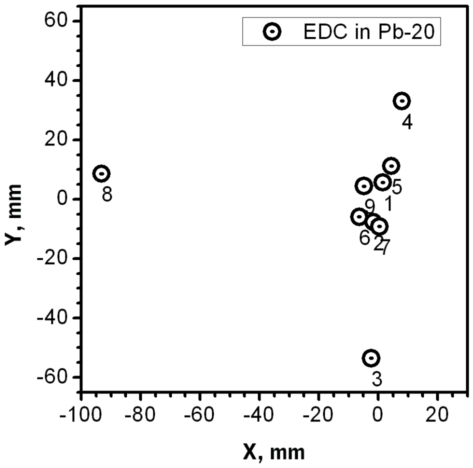

Fig. 3: The target diagram of 9 leading objects (EDC) in the superfamily Pb-20 from Pamir deep lead chamber (numbers stand in the order of decreasing energy).

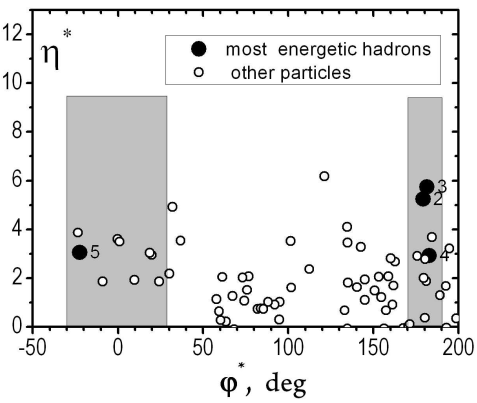

Fig. 2: The diagram $\eta^* - \varphi^*$ in the center-of-mass system for particles from the interaction responsible for "STRANA" superfamily generation.

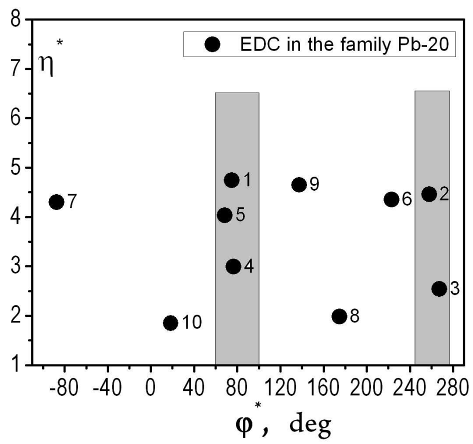

Fig. 4: The diagram $\eta^* - \varphi^*$ in the center-of-mass system for particles responsible for EDC production in the superfamily Pb-20 from Pamir deep lead chamber.

θ^L and θ^* are zenith angles in corresponding systems, φ^L and φ^* are azimuthal angles.

Let us consider concurrently a registration picture of the same event in a normal plane in the laboratory system (target diagram) and a diagram $\eta^* - \varphi^*$ in the center-of-mass system.

The target diagram for the "STRANA" superfamily is presented in Fig. 1 (being more precise there is shown only its central area with the aligned configuration).

One can see the aligned disposition of 5 most energetic particles (here specifically hadrons) in this family. The parameter λ characterizes an arrangement along a straight line (see about λ in the paper ID=1159 at this Conference or in [2, 4]). λ = 1 for an ideal straight line and in practice an event is concidered to be aligned, when $\lambda \geq 0.8$. Here λ values indicate a high degree of alignment: λ_3 = 0.98, λ_4 = 0.99, λ_5 = 0.90 (certainly bigger than criterion λ = 0.8).

The diagram $\eta^* - \varphi^*$ in the center-of-mass system for "STRANA" superfamily interaction is presented in Fig. 2. Coplanar scattered particles have to be disposed here within 2 narrow ranges of φ^* with relative difference 180^o (grey bands in Fig. 2). Just such disposition is apparent for most energetic particles 2, 3, 4 and 5. Deflection of a particle from the center of a grey band corresponds to declination of the same particle in Fig.1 from the line of arrangement. The very energetic object N^o1 disposed in this event at the interaction axis "goes into a tube" (has an infinite η^*) and cannot be properly displayed here.

A superfamily with alignment in Pamir experiment cannot be referred on the whole to some certain altitude since any superfamily at mountain level is the result of cascade process. But aligned objects in it are obviously from one the same interaction, and for our purpose that altitude may be assumed as H = 1000 m (more or less probable value in the absence of long-flying component). Minimal value E_0 for such family may be estimated very roughly as $E_0 \approx \Sigma E_\gamma + (\Sigma E_h^{(\gamma)}/k_\gamma)/K_{eff} = \Sigma E_\gamma + (\Sigma E_h^{(\gamma)}/0.3)/0.5$, where k_γ stands for the energy fraction released from a hadron into gamma-component while an interaction and detected in a chamber and K_{eff} is the efficiency of hadron registration by a non-infinite chamber. Exact real E_0 and H values are not very important here, since we pretend only to a demonstrable example.

In Fig. 3 there is presented the target diagram of the superfamily Pb-20 from Pamir deep lead chamber. Numbering of family objects is in the order of energy decreasing, only 9 leading objects (energy distinguished cores or EDC — see [2]) are shown. Other particles are not important here for our purpose. One can see the aligned disposition of 5 first EDC in this family. The alignment indicators here are λ_3 = 0.95, λ_4 = 0.97, λ_5 = 0.94 (all significantly exceed 0.8).

Using E_0 = 5 PeV and H = 1000 m the parameters of particles scatter in this event were converted to the center-of-mass system.

The diagram $\eta^* - \varphi^*$ in the center-of-mass system for superfamily Pb-20 is presented in Fig. 4. As well as in Fig. 2 five first (most energetic) objects (EDC) are disposed here within two narrow grey bands regarding φ^* with the displacement 180^o. Just such patterns for most energetic particles will help investigators to identify alignment cases in collider detectors.

III. CONCLUSION

Two presented here examples (Fig. 2, 4) show the expected appearance of alignment effect in collider detectors. If experimentally observed, such pictures can give us more detailed information about energy and positions of all aligned particles. It is worth to remind that in CR experiments some members of aligned ensemble may be lost due to cascade effects in atmosphere or due to non-ideal detection efficiency of emulsion chambers (their limited depth). Perhaps the alignment detection at LHC could help to identify eventually the mechanism of this coplanar scatter phenomenon.

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