On the Problem of High Transverse Momenta in the Interactions of Hadrons at Energies about $10^{16}\,eV$

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Abstract

In several cosmic ray experiments with X-ray chambers exposed on mountain altitudes and in stratosphere there have been observed cases interpreted as a result of interactions, in which particles with extremely high transverse momenta are produced. Such particles could be produced in semihard parton interactions but it is known that the cross-section for such on interaction is very small.

In this paper we try to find out how many particles with the highest energies in a family can have a very high p_t without contradiction to the fundamental laws of physics i.e. the principles of quantum mechanics and relativistic mechanics. We formulate a simplified model of the nucleon - nucleus collision and we calculate the average number of semihard interactions in nucleon - air nucleus collision at $2 \cdot 10^{16}\,eV$.

The calculations was made for two different sets of the model parameters. For the first we obtain one semihard interaction resulting in two partons with transverse momenta close to $20\,GeV/c$ per one nucleon - nucleus collision. For the second set we obtain one semihard interaction producing parton with transverse momenta close to $60\,GeV/c$ per sixty collisions.

1. Introduction

In several experiments [1, 2, 3, 4, 5] in which gamma - hadron families with energies higher than $10^{15}\,eV$ were registered, it has been observed that in some families points of crossing the target plane by particles with the highest energies concentrate around straight lines (it is so called alignment). The efforts to explain this phenomenon were unsuccessful [6] For one family with energy around $2 \cdot 10^{16}\,eV$ and 107 particles registered in balloon flight [4] it was possible to estimate p_t values for some of the particles and an average value of $20\,GeV/c$ was obtained. Transverse momenta in another families with alignment are higher than the other ones too [3].

In this paper we try to estimate an upper limit to the probability of production of high p_t particles which is still not contradictory to fundamental laws of physics.

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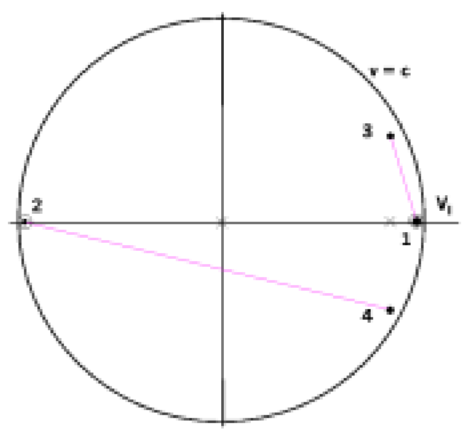
2. Calculations

We have used a simple model of high energy interactions, with specially chosen parameters. In this model particles with very high p_t are produced in semihard parton - parton interactions.

We assume that every nucleon consists of several energetic and a lot of wee partons and partons of each kind carry half of the nucleon's energy. Alignment of the family of particles is created in the following way: after semihard interaction of energetic parton with wee parton two strings are created between partons and hadrons from which these partons had been striken out and then the strings brake and create chains of hadrons. Velocities and momenta which can be obtained by those hadrons are schematicly shown in Figures 1 and 2.



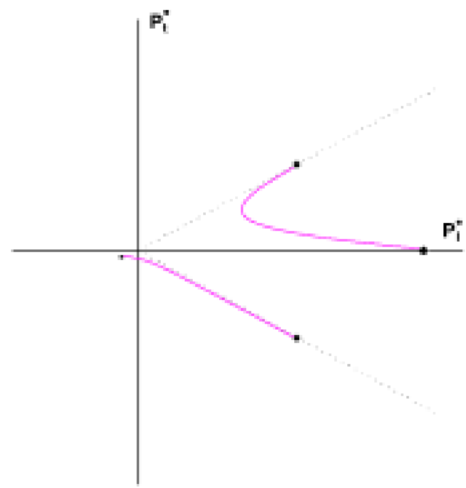


Fig. 1. Velocities of partons in the system of equal velocities of interacting hadrons (proportions are not preserved)1 - energetic parton of striking proton (projectile); 2 - wee parton of air nucleus; 3 and 4 - both partons after semihard interaction for the case of scatering angle $\theta' = 90^o$ (in center of mass system of both partons). Lines 1-3 and 2-4 show the velocities which might be obtained by particles created from strings.

Fig. 2. Momenta which can have the particles created from decomposition of the strings presented in Figure 1 in the system of equal velocities of interacting hadrons.

If both interacting partons are to get transverse momenta equal or almost equal to the wished value p_{to}, the energy of each of them measured in their common centre of mass system must be not smaller than $p_{to}c$. In our calculations we assumed, unrealistically, that this energy is exactly $p_{to}c$ in all energetic - wee parton - parton interactions at the primary nucleon energy $E_o = 2 \cdot 10^{16}\, eV$.

We treat a semihard collision of partons as a diffraction on a black disc.

Of course radius of the disc should be as big as possible. There is however an upper limit to the value of this radius, because we want to obtain a lot of p_t values close to p_{to} and few of those close to zero. The distribution of parton's p_t is described by a distribution of scattering angles θ' (measured in the common CMS of a pair of interacting partons). When $\theta' = 90^o$, $p_t = p_{to}$, so that in a distribution of θ' angles, there should be a lot of values close to 90^o. Therefore, the radius of the black disc should be not greater than $h/4p_{to}$.

The average number of the parton - parton interactions in one collision of a proton with an air nucleus can be calculated from the following equation:

$$< N >= \frac{n_1 n_2 \sigma_{12}}{\sigma_{pA}} \tag{1}$$

n_1 - number of energetic partons in the primary particle;
n_2 - number of wee partons in the air nucleus;
σ_{12} - cross section for energetic - wee parton - parton interaction;
σ_{pA} - cross section for proton - air nucleus interaction.

The model parameters have been chosen so as to obtain wished p_{to} at $E_o = 2 \cdot 10^{16}\, eV$.

To calculate the $n_1 n_2$ product the following relations have been used:
$n_1 = (\,(1/2)\,E_o)/(2p_{to}c\gamma_o)$
$n_2 = (\,(1/2)\,Amc^2\gamma_o)/(p_{to}c)$
where

γ_o - Lorentz factor of the center of mass system of the interacting partons measured in the laboratory system, A - mass number of air nucleus (we take A=15), m - nucleon mass,

and we obtain that:

$$n_1 n_2 = \frac{Amc^2 E_o}{8(p_{to}c)^2} \tag{2}$$

We assume that the cross section σ_{12} equals:

$$\sigma_{12} = \pi R_{12}^2 T(\lambda, R_{12}) \tag{3}$$

where $R_{12} = h/(4\,p_{to}) = \lambda_o/4$

and $T(\lambda, R_{12})$ - transmission coefficient for the circular hole with the radius R_{12} at the wave length λ calculated with the generalized Kirchhoff integral at Neumann boundary condition.

3. Results and conclusions

For $p_{to} = 20\, GeV/c$ at $E_o = 2 \cdot 10^{16}\, eV$ we get that
$n_1 n_2 = 0.9 \cdot 10^5$
$R_{12} = 1.6 \cdot 10^{-17} m$
$\sigma_{12} = 3.9 \cdot 10^{-34} m^2$
$T(\lambda, R_{12}) = T(\lambda_o, R_{12}) = T(4R_{12}, R_{12}) = 0.5$

Taking the above values and the value $\sigma_{pA} = 270$ mb, we obtain that:

$$< N >= 1.25 \tag{4}$$

Thus for $n_1 n_2 = 0.9 \cdot 10^5$ and $\sigma_{12} = 3.1 \cdot 10^{-34} m^2$ we would have on average one semihard collision of an energetic parton per one high energy proton - air nucleus interaction. At $E_o = 2 \cdot 10^{16}\, eV$ the maximum value of p_t of both partons in these semihard collisions equals to $20\, GeV/c$.

The value $< N >= 1.25$ is sufficient to create the alignment [6] but it is too low explain the results of an analysis of the family with energy $2 \cdot 10^{16}\, eV$ [4].

At $E_o < 2 \cdot 10^{16}\, eV$ energies of interacting partons are smaller (if n_1 is constant) and their transverse momenta after the collision are consequently smaller. At $E_o = 5 \cdot 10^{15}\, eV$ we obtain $p_{tmax} = (20/\sqrt{4})\, GeV/c = 10\, GeV/c$. The transmission coefficient $T(\lambda, R_{12})$ at $\lambda = 2\lambda_o = 8R_{12}$ is smaller then 0.2 and consequently $< N >< 0.5$ This value is lower than required to observe aligned families on mountain altitudes [6].

We have made our calculations for the second set of parameters also. The model parameters have been chosen so as to obtain $p_{to} = 60\, GeV/c$ at $E_o = 2 \cdot 10^{16}\, eV$ (this p_{to} is sufficient to produce six hadrons with $< p_t >= 20\, GeV/c$).

We get:

$n_1 n_2 = 0.10 \cdot 10^5$

$R_{12} = 0.52 \cdot 10^{-17} m$

$\sigma_{12} = 0.44 \cdot 10^{-34} m^2$

For these parameters, the average number of semihard interactions of an energetic parton for one nucleon - air nucleus interaction equals:

$$< N >= 1/63 \tag{5}$$

The bottom line is that the Semihard interaction model (whether with the first, or the second parameter set used) does not explain the experiment results discussed here.

4. References

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