LONG RANGE CORRELATIONS IN HADRON-HADRON COLLISIONS AND THE PARTON MODEL

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(Received March 28, 1977)

We present a model of multiparticle production in high-energy $h_1h_2 \to X$ collisions, based on the "bremstrahlung" analogy and the parton model. Long range correlations in rapidity are obtained as a consequence of hadron structure.

1. Introduction

Experimental regularities observed in high-energy hadron-hadron collisions seem to show evidence for the existence of long range effects in rapidity. They are apparent in charged multiplicity distributions $\left(\frac{D_{ch}}{n_{ch}} \approx \text{const}\right)$ and in the two-particle rapidity correlation function $C_2(y_1, y_2)$ [1].

The origin of long range correlations is yet unclear. Two-component models [1] look for it in the coexistence of two noninterfering components, pionisation and diffraction, with different multiplicity distributions and different mean multiplicities. It seems, however, that agreement with experiment requires too large a portion of the cross section to be diffractive in origin. It suggests, that one should search for long range correlations in the pionisation component itself. In our model we get them as a consequence of hadron structure, considered in the framework of the parton model [2].

2. The model

Our assumptions are the following:

(a) Hadrons energies are so high, that parton energy distribution function f scales, being dependent on the variable $x = E_{\text{parton}}/E$ only, where E is the hadron energy. The number of partons with their energy between xE and $(x+dx)E$ is then $f(x)dx$. Parton transverse momentum is negligible.

(b) In a collision of h_1 and h_2 all particles, except leading hadrons are produced in a "bremstrahlung"-like process in which one parton from h_1 and one from h_2 brake in

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their interaction field, radiating the particles and all the other partons are spectators (Fig. 1).

(c) Rapidity distribution of particles produced by a parton with fraction x_1 of energy E_1 of the h_1 is flat in the interval $\left(0, \log \frac{2x_1E_1}{m}\right)$ and vanishes elsewhere. Thus the distribution $N(x_1, x_2; y)$ of particles produced by one x_1, x_2 pair is constant, equal to C in the interval

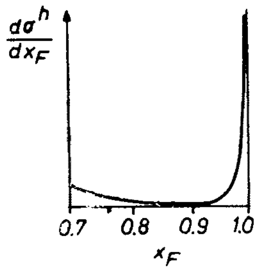

Fig. 1. The assumed course of multiparticle production in a high energy hadron-hadron collision

$\left(-\log \frac{2x_1E_1}{m}, \log \frac{2x_2E_2}{m}\right)$ and vanishes elsewhere. The multiplicity distribution in this process has the following form:

$$P(x_1, x_2; n) = \sum_{k=0}^{n} P(x_1; k)P(x_2; n-k),$$

where we assume that $P(x_1; n)$ and $P(x_2; n)$ are Poisson distributions with means $\bar{n}(x_1) \sim C \log \frac{2x_1E_1}{m}$ and $\bar{n}(x_2) \sim C \log \frac{2x_2E_2}{m}$, respectively.

Now we get the multiplicity distribution of particles produced in the hadron-hadron collision

$$P(n) = \int_{\frac{K}{E_1}}^{1} dx_1 \int_{\frac{K}{E_2}}^{1} dx_2 f(x_1)f(x_2)P(x_1, x_2; n).$$

The cutoff energy K is the minimal parton energy necessary for production of a particle. If we believe, that observed particles are decay products of directly emitted objects (clusters) [3] with internal quantum numbers of the vacuum, the K equals two meson mass. In principle this cutoff has to increase with n but it is a threshold effect only and it is essential that cutoffs in x_1 and x_2 go to zero with $s \to \infty$ even for a $\log s$ rise of n. From the normalisation condition $\sum_{n=0}^{\infty} P(n) = 1$ we get

$$P(n) = \frac{1}{\int_{\frac{K}{E_1}}^{1} dx_1 f(x_1) \int_{\frac{K}{E_2}}^{1} dx_2 f(x_2)} \int_{\frac{K}{E_1}}^{1} dx_1 \int_{\frac{K}{E_2}}^{1} dx_2 f(x_1)f(x_2)P(x_1, x_2; n).$$

To see some quantitative features of the radiation, assumption about the function f is indispensable. Experiments on the deep inelastic lepton-hadron scattering suggest that $f(x) \sim \frac{(1-x)^\alpha}{x}$, $\alpha \geqslant 3$. It leads to the mean multiplicity

$$\bar{n} = \bar{n}_1 + \bar{n}_2 \sim \frac{C}{2}\left(\log\frac{E_1}{K} + \log\frac{E_2}{K}\right) \underset{E_1, E_2 \to \infty}{\sim} \frac{C}{2}\log s$$

and the second moment

$$f_2 = D_1^2 + D_2^2 - \bar{n}_1 - \bar{n}_2 \underset{E_1, E_2 \to \infty}{\sim} \frac{C^2}{12}\left(\log^2\frac{E_1}{K} + \log^2\frac{E_2}{K}\right).$$

The obtained moment f_2 is not a relativistic scalar as it should be. It is the parton model, applicable in the infinite momentum frame only, which bears the blame. Long range correlations are obtained as a consequence of superposing the independent productions in the collisions of partons with various initial energies. Natural choice of the infinite momentum frame of both incident hadrons is their C.M.S. where $E_1 \approx E_2 \approx \frac{\sqrt{s}}{2}$. Thus

$$\bar{n} \underset{s \to \infty}{\sim} \frac{C}{2}\log s, \quad f_2 \underset{s \to \infty}{\sim} \frac{C^2}{24}\log^2 s.$$

For other shapes of the function f

1. $$f(x) \sim 1, \quad \bar{n} \sim C\log s, \quad f_2 \sim \text{const},$$

2. $$f(x) \sim \frac{1}{\sqrt{x}}, \quad \bar{n} \sim C\log s, \quad f_2 \sim \text{const}.$$

We see, that the long range correlations are appropriate to the particular form of the parton energy distribution function, singular in zero as $1/x$ and consistent with experiment.

Model asymptotic value of the ratio $\frac{D}{\bar{n}} \approx \frac{1}{\sqrt{6}} \approx 0.41$ is equal to the expected ratio $\frac{D_{ch}}{\bar{n}_{ch}}$ because of the following relations:

$$\bar{n}_{ch} = \bar{n}\bar{j}, \quad f_{2ch} = f_2\bar{j}^2 + \bar{n}\overline{j(j-1)}, \quad \frac{D_{ch}}{\bar{n}_{ch}} \underset{s \to \infty}{\sim} \frac{D\bar{j}}{\bar{n}\bar{j}} = \frac{D}{\bar{n}},$$

where $\bar{j}$ is the mean number of charged particles a directly emitted cluster decays into.

Experiment gives $\frac{D_{ch}}{\bar{n}_{ch}} \approx 0.585$ so that our correlations in the pionisation component almost fulfill the data.

Following other authors we assume that a cluster decays into two charged particles in an average. Since experimentally $\bar{n}_{ch} \sim 2\log s \approx 2\bar{n}$ we put $C \approx 2$.

After fitting the parameter C it is easy to obtain the leading hadron energy-loss spectrum. Differential cross section for an inclusive process $hh \to hX$ $\frac{d\sigma^h}{dx_F}$ $\left(\text{where } x_F = \frac{2p_L}{\sqrt{s}}\right)$ is proportional to the probability $p(\varepsilon)$ of the loss of energy $\varepsilon \approx E(1-x_F)$ through emission of particles. In a single collision it is lost by one parton with the energy xE with the probability $p(x, \varepsilon)$. From Stodolsky's paper [4] it follows that for small $\frac{\varepsilon}{xE}$ $p(x, \varepsilon) \sim \varepsilon^{-1}\left(\frac{\varepsilon}{xE}\right)^C$. Since $C \approx 2, p(x, \varepsilon) \sim \frac{\varepsilon}{x^2E^2}$. We expect that partons with $x \gg \frac{\varepsilon}{E}$ only give contribution to the loss of the energy ε. Thus

$$\frac{d\sigma^h}{dx_F} \sim \frac{(1-x_F)}{E} \int\limits_{\beta(1-x_F)}^{1} dx \frac{f(x)}{x^2},$$

where the parameter $\beta > 1$.

As before we take $f(x) \sim \frac{(1-x)^\alpha}{x}$. The cross section $\frac{d\sigma^h}{dx_F}$ is singular at $x_F = 1$ as $(1-x_F)^{-1}$. For example when $\alpha = 3$ and $\beta = 10$ (Fig. 2):

$$\frac{d\sigma^h}{dx_F} \sim \frac{1}{200(1-x_F)} - 0.3 + 1.5(1-x_F) - 3(1-x_F) \log 10(1-x_F) + 10(1-x_F)^2.$$

The result agrees qualitatively with experiment. In addition to the region of slow decrease we have obtained contribution to the maximum near $x_F = 1$, which is usualy taken for

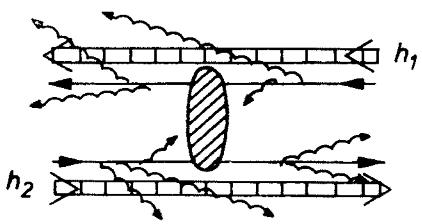

Fig. 2. The shape of the model cross section $d\sigma^h/dx_F$ for the parameters $\alpha = 3$ and $\beta = 10$

diffractive. It is consistent with the preceding result concerning long range correlations for it suggests that in high energy hadron collisions diffractive process need not to have such importance as other models predict.

3. *Conclusions*

The assumptions of our model and the parton energy distribution function taken from the experiments on the deep inelastic lepton-hadron scattering lead to long range correlations in rapidity of the products of hadron-hadron collisions, in their pionisation component. Model asymptotic value of the ratio $\frac{D_{ch}}{n_{ch}}$ is equal to 0.41 whereas experiment gives 0.585. The leading hadron energy loss spectrum in an inclusive reaction hh $\rightarrow$ hX is singular at $x_F = 1$ as $(1-x_F)^{-1}$, which is in agreement with data.

The author thanks dr S. Pokorski for formulating the problem and kind help.

REFERENCES

[1] M. Le Bellac in Proceedings of the XIII Cracow School of Theoretical Physics, Zakopane 1973; *Acta Phys. Pol.* **B4**, 901 (1973).
[2] R. Feynman, *Photon-Hadron Interactions*, Benjamin, New York 1972.
[3] P. Pirilä, S. Pokorski, *Phys. Lett.* **43B**, 502 (1973).
[4] L. Stodolsky, *Phys. Rev. Lett.* **28**, 60 (1972).