Mechanism of production of pairs of particles with large opposite transverse momenta

I. F. Ginzburg

Mathematics Institute, Siberian Division, USSR Academy of Sciences
(Submitted July 17, 1975; resubmitted September 22, 1975)
Pis'ma Zh. Eksp. Teor. Fiz. **22**, No. 9, 470–474 (5 November 1975)

Results of recent BNL experiments are explained by means of a model in which the produced particles "remember" their origin. A number of new relations between the cross sections are predicted.

PACS numbers: 12.40.–y, 13.80.Hm

1. A report of experiments performed at BNL on pBe collisions at 28 GeV was recently published.[2] Pairs were registered in which the particles had in the c.m.s. oppositely directed purely transverse momenta $p_\perp$ of equal magnitude. It turned out that the measured cross sections for the production of these pairs, at one and the same value $M=2p_\perp$ (for 2 GeV $\le M \le$ 4.5 GeV) take on only three values[1)]

$$\pi^- p \approx d\sigma_1;\quad \pi^+\pi^- \approx \pi^- K^+ = p\bar{p} = pK^- = d\sigma_2;\quad \pi^+\bar{p} = \pi^+ K^- = K^+K^- = d\sigma_3. \tag{1}$$

According to the graphs given in[1],

$$d\sigma_1 : d\sigma_2 : d\sigma_3 \approx 100 : 10 : 1. \tag{2}$$

As indicated by the authors, Feynman has noted that the result (1) can be described by assigning to each of the produced hadrons a certain number:

$$F_p = 0 \text{ for } p;\quad F_p = 1 \text{ for } \pi^+, K^+;\quad F_p = 2 \text{ for } K^-, \bar{p}. \tag{3}$$

Then (1) means that the cross sections for the production of particle pairs with equal $F = F_{p1} + F_{p2}$ coincide.

2. Let us make two remarks: (a) the observed values of the effective mass of the pair were close in these experiments to the limit $\sqrt{s} = 7.5$ GeV (per nucleon). (b) the number F_p determines a simple relation between the produced hadron h and the initial proton in the free state or in the Be nucleus: the transition $p \to h$ should be accompanied by formation of at least F_p more known hadrons (allowance for the neutrons in the Be nucleus does not alter the result substantially). Therefore $F_p = 0$ is possessed only by the proton, $F_p = 1$ is possessed by $\pi^\pm$ and K^+, and $F_p = 2$ by $\bar{p}$ and K^- (the possible transitions are respectively $p \to \pi^+(n)$, $\pi^-(\Delta^{++})$, $K(\Lambda)$ and $p \to K^-(K^+p)$, $\bar{p}(pp)$).

These remarks lead us naturally to the following understanding of the mechanism of the reactions in question: In pp collisions, the colliding protons form a weakly excited cloud as they come closer together. However, they continue to move in this cloud towards each other and retain their individuality (in analogy with the leading particles in the hydrodynamic model). In the extremely rare case of almost head-on collisions these residual protons turn sharply, and this leads to the emission of the pp pair of the investigated type (Fig. 1); the corresponding cross section (determined without allowance for the fact that the emitted protons are identical) will be designated by $d\sigma_0$. If the proton goes over into another hadron, then it must discard F_p had-

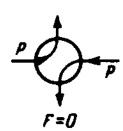

FIG. 1.

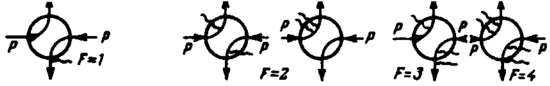

FIG. 2.

rons (Fig. 2). We set in correspondence to each of the hadrons a factor g (the "effective" coupling constant at short distances). Then the observed cross section depends only on the sum $F = F_{p1} + F_{p2}$ of the number of the discarded hadrons, as is indeed observed in the experiment

$$d\sigma_F = d\sigma_0 g^{2F}; \quad F = F_{p1} + F_{p2}. \tag{4}$$

Thus, the cross sections for the production of pairs with different values of F form a geometric progression, likewise in accord with experiment [Eq. (2)], from which it follows that $g^2 \approx 0.1$.[2)]

Let us emphasize two not quite usual features of the proposed description. (a) The effective coupling constants g are equal to each other and are not subject to the relations dictated, for example, by the $SU3$ scheme. (b) At short distances the hadrons retain their individuality, without being dissolved in the quark-parton sea. (A similar approach can apparently claim to explain the appreciable suppression of the K^- and $\bar{p}$ yields in comparison with the K^+ and p yields at large $x_\perp$ in pW collisions at 300–400 GeV. At small $x_\perp$ the reaction mechanism need not be so strongly connected with the nature of the colliding particles, and the corresponding differential cross sections are not determined by the value of F.)

An essentially similar interpretation of the number F_p as the number of pairs of quarks that have changed their motion was proposed, insofar as I know, by V. M. Shekter. In such a scheme, however, it is necessary to make additional assumptions in order to explain the equality of the cross sections with production of K^- and $\bar{p}$.

If this description is correct, then in addition to (1) and (2) there should exist also a number of other identities that can apparently be easily verified by experiment:

$$2pp = d\sigma_0 \approx 10\, d\sigma_1;\ p\pi^+ = pK^+ = p\Sigma^+ = d\sigma_1; \quad K^+\pi^+ = 2\pi^-\pi^- = \Sigma^+\pi^- = \dots = d\sigma_2;$$
$$\pi^-\bar{p} = \pi^-K^- = \pi^-\Sigma^- = \Sigma^+\Sigma^- = \dots = d\sigma_3; \quad \bar{p}K^- = 2\bar{p}\bar{p} = 2K^-K^- = ?\Sigma^-\Sigma^-$$
$$= \Sigma^-\Sigma^- = \dots = d\sigma_4 \approx 0.1\, d\sigma_3. \tag{1a}$$

Account is taken here also of the natural supplement to (3) for hyperon production: $F_p = 1$ for Σ^+ and $F_p = 2$ for Σ^- and $\bar{\Sigma}^+$. In addition, trivial changes introduced by the identities have been taken into account.

Two other consequences are almost obvious: A) The (associative) multiplicity $\langle n \rangle_F$ of the slow particles should increase with increasing F, and apparently at a rate not slower than F. B) In these experiments one should expect an appreciable production of charmed particles. Within the framework of the $SU4$ scheme, $F_p = 1$ for the D^- meson, and we should have $D^-p = \pi^-p = d\sigma_1$. Of course, this equality should take place at sufficiently large $M (M/2 > M_D)$ to avoid the threshold smallness.

3. It is natural to expect a similar picture to be observed when such experiments are repeated in collisions of other hadrons (α and β) at the same energies. The cor the production of the pair AB should be determined by the quantity

$$F = \min(F_\alpha(A) + F_\beta(B),\ \ F_\beta(A) + F_\alpha(B)), \tag{5a}$$

where $F_\alpha(A)$ has the same meaning as above. Thus, if α is a neutron then $F_n = F_p$ for $\pi^\pm$, $K^\pm$, $\Sigma^\pm$, ... and $F_n = 1$ for p; on the other hand if α is π^-, then

$$F_{\pi^-} = 0 \text{ for } \pi^-, \quad F_{\pi^-} = 1 \text{ for } p, \bar{p}, \Sigma^-, \Sigma^-, K^-; \ F_\pi = 2 \text{ for } \pi^+, K^+, \dots \tag{6a}$$

When account is taken of identity considerations, we should have in addition, for the production of AB pairs having the same F, the relations

$$A_1B_1 = 4A_2B_2 = 2CC,$$

if

$$F = F_\alpha(C) + F_\beta(C) = F_\alpha(A_1) + F_\beta(B_1) = F_\alpha(B_1) + F_\beta(A_1)$$
$$= F_\alpha(A_2) + F_\beta(B_2) > F_\alpha(B_2) + F_\beta(A_2).$$

Thus, new relations should appear for π^-p collisions, for example

$$4p\pi^- = d\sigma_0 = 10 d\sigma_1;\ pp = 2p\bar{p} = 2pK^- = 2\pi^-\pi^+ = 2\pi^-K^+ = \pi^-\pi^-$$
$$= 2\Sigma^-\pi^\pm = \dots = \frac{1}{2} d\sigma_1;$$

$$p\pi^+ = 4\bar{p}\pi^+ = 4\pi^+K^- = \pi^-\bar{p} = \pi^-K^- = pK^+ = 4\bar{p}K^+ = 4K^+K^- = \Sigma^-\Sigma^+ = \dots$$
$$= d\sigma_2 \approx 0.1 d\sigma_1; \tag{6b}$$

$$2\pi^+\pi^+ = K^+\pi^+ = 2K^+K^+ = \bar{p}K^- = \Sigma^-\bar{\Sigma}^- = 4\Sigma^+\bar{\Sigma}^+ = \dots = d\sigma_3 \approx 0.1\, d\sigma_2.$$

(The cross sections $d\sigma_i$ for π^-p and pp collisions can in general be different.)

4. On going to higher energies at the same values of M, the quantities $M/\sqrt{s} = x_\perp$ decrease (for example for the Fermilab experiments $M/\sqrt{s} < 0.2$ at $p_L = 200$ GeV/c). The preservation of relation (1) in this region would be evidence of an exceptionally deep "memory" of the produced particles, and this is not very likely. The produced hadrons more readily "forget" the nature of the colliding hadrons, and this violates the relation (1).

Thus, if production from clusters is significant, such measurements can help explain the nature of the hadrons that bind the clusters. For this purpose it is necessary to measure the cross section for the production of pairs AB with momenta $(\mathbf{p}_\parallel, \mathbf{p}_\perp)$ and $(\mathbf{p}_\parallel, -p_\perp)$ as functions of the mass $M = 2p_\perp$ and of the longitudinal momentum $2p_\perp$. At small values of $p_\perp$ in the lab system (e.g., at $p \approx 3$ to 4 GeV/c, as in the BNL experiments), the "parents" of the AB pair should be the target nucleon and the exchange particle E. Let, for example, E be a pseudoscalar meson. Let, furthermore, the probabilities of exchange of various mesons $P(M)$ be of the same order, and let $P(K^+) = P(K^-)$ and $P(\pi^+) = P(\pi^-)$. Then (4) and (5) enable us to obtain relations between the cross sections:

$$p\pi^+ = p\pi^-;\ pK^+ = pK^- \sim d\sigma_0,\ pp = 2p\bar{p},\quad \frac{1}{2}K^+K^+ = K^+K^- = K^-\pi^+$$

$$= K^-\pi^- \sim d\sigma_1;\ \pi^+\pi^+ = \pi^+\pi^- = \pi^-\pi^-,\quad K^+\pi^+ = K^+\pi^- = K^+K^-;$$

$$\frac{1}{2}\pi^+\pi^- \sim d\sigma_1\quad \bar{p}\pi^+ = \bar{p}\pi^-;\ \bar{p}K^- = K^-K^-;\ \bar{p}K^+ \sim d\sigma_2,\quad \bar{p}\bar{p} \sim d\sigma_3$$

$$\approx 0.1\, d\sigma_2;\ 2\bar{p}\bar{p} \approx 0.01 pp;\quad \bar{p}K^+ - \bar{p}K^- \approx 0.05\, pp;\quad K^-\pi^+ \approx 0.1\, pK^-,$$

$$\pi^+\pi^+ \approx 0.2\, p\pi^-;\ \bar{p}K^- \approx 0.01\, pK^-;\ \bar{p}\pi^- \approx 0.1\left(p\bar{p} + \frac{3}{2}\pi^+\pi^-\right).$$

From these cross sections we can determine the probabilities of $K^\pm$ or $\pi^\pm$ exchange or of exchange of neutral mesons.

With increasing $p_{\parallel}$, the "memory" of the nature of the target should vanish, and relations (7) give way to new ones. At still larger $p_{\parallel}$, one of the "parents" becomes the incident proton, and relations (7) are back in force.

[1)]Here and below AB denotes the cross section for the production of the particle pair AB.

[2)]For the pBe collision the only change is that $F_p = 0$ for p in $\sim \frac{3}{4}$ of the cases and $F_p = 1$ for $\sim \frac{1}{4}$ of the cases. Allowance for this fact changes relation (1) little.

---

[1]I. I. Aubert, Paper at International Conf. on Wire Chambers, Dubna, June 1975.