Production of large-P_T momentum-asymmetric hadron pairs in pp collisions at 70 GeV

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The correlation functions R and the production cross sections of momentum-asymmetric hadron pairs ($\pi^+\pi^+$, pp, and π^+p) have been measured in pp collisions in the interval of transverse-momentum differences $0 \leqslant \Delta \leqslant 2.1$ Gev/c at $P_{T1} + P_{T2} = 3.1$ GeV/c. The experimental results are compared with models of inelastic parton scattering.

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We have previously studied the P_T dependence of the behavior of the production cross sections of momentum-symmetric pairs of π mesons and protons.[1,2] In that case the internal transverse momenta of the partons, K_T, essentially cancel out, eliminating one source of uncertainty in interpreting the experimental results.

Another interesting case is that in which the momenta of the pairs of hadrons are in opposite direction and quite different in magnitude. By studying the production of pairs of this type as a function of the transverse-momentum difference $\Delta = P_{T1} - P_{T2}$, we can reach a better understanding of the mechanism by which partons transform into hadrons, and we can estimate the internal transverse momentum of the partons.

In the present experiments we studied the production of asymmetric pairs of hadrons in pp interactions at 70 GeV at an angle of 90° in the c.m. frame as a function of Δ. The sum of the transverse momenta of the two particles, $M = P_{T1} + P_{T2}$, was 3.1 GeV/c. We measured the correlation functions and the invariant cross sections for the production of $\pi^+\pi^+$, pp, and π^+p pairs. We also report here data on the pairs of

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all charged hadrons, h^+h^+. The correlation function is defined as

$$R = \frac{(N_{12}/N_{in})}{(N_1/N_{in})(N_2/N_{in})} , \qquad (1)$$

where N_{12}, N_1, and N_2 are the number of pairs of particles detected and the numbers of single particles detected with momenta P_{T1} and P_{T2}; and N_{in} is the number of inelastic interactions in the target.

The FODS apparatus used for the experiments is described in Ref. 3. The proton beam, slowly extracted from the accelerator, strikes a liquid-hydrogen target 40 cm long. The beam intensity is measured with an absolute accuracy of $\pm 6\%$ and a relative accuracy of $\pm 1\%$ by secondary-emission detectors. Pairs of hadrons are distinguished from random coincidences by a highly precise temporal analysis. The number of protons incident on the target was varied from 5×10^{10} to 7×10^{11}, so that the ratio of the effect to the random-coincidence background was 40–50%. The momentum of a particle in the spectrometer was determined within $\pm 1\%$ by means of deflection in a magnetic field and drift chambers. The identity of the particle was determined by means of threshold Čerenkov counters and a time-of-flight method.

The procedure used to analyze the data is described in Refs. 1 and 4. The background from the target walls did not exceed 8% anywhere in the Δ interval, and the values of R for the empty target at $\Delta = 1$ GeV/c and $\Delta = 1.7$ GeV/c turned out to be in approximate agreement with the results for hydrogen. Consequently, the background due to the target walls was not considered in the calculation of R.

Table I shows the correlation function R vs Δ for the various hadron pairs. Only the statistical errors are shown here. For the h^+h^+ pairs of hadrons, R falls off by a factor of more than two over this interval of Δ. The nature of the Δ dependence of the correlation function is the same for the $\pi^+\pi^+$, pp, and π^+p pairs as for the h^+h^+ pairs; i.e., none of these particles exhibit any distinctive R behavior.

Working from the measured function R and the cross sections for inclusive hadron production from Refs. 4 and 5, we also determined the invariant cross section for the production of the hadron pairs. Figures 1–3 show the Δ dependence of this cross section for the $\pi^+\pi^+$, pp, and π^+p pairs. The nature of this dependence is approximately the same as that of the correlation function.

TABLE I. Δ dependence of the correlation function R.

Δ, GeV/c	h^+h^+	$\pi^+\pi^+$	pp	π^+p	$p\pi^+$
0	11.3 ± 0.6	10.5 ± 1.2	11.4 ± 1.5	11.7 ± 1.0	11.7 ± 1.0
0.376	11.0 ± 0.6	9.3 ± 1.1	11.3 ± 1.5	10.8 ± 1.1	12.2 ± 1.5
1.058	6.5 ± 0.4	5.8 ± 0.5	6.0 ± 1.0	6.4 ± 0.8	7.9 ± 1.2
1.559	4.2 ± 0.8	4.6 ± 1.6	3.8 ± 1.2	4.1 ± 1.2	4.1 ± 1.6
2.107	5.4 ± 1.0	4.3 ± 1.7	5.2 ± 2.5	6.4 ± 1.8	6.8 ± 5.0

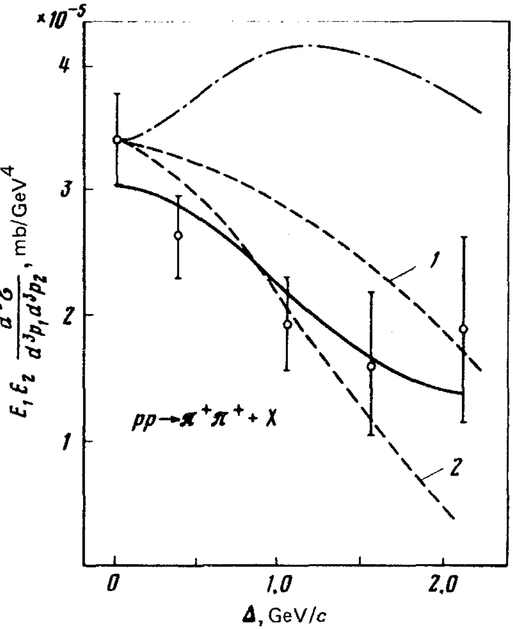

FIG. 1. Δ dependence of the invariant cross section for the production of $\pi^+\pi^+$ pairs. Solid curve—Calculations from a model without fragmentation; dashed curves—calculations from the model of inelastics $qq \to qq$ scattering at $K_T = 0.8$ GeV/c (curve 1) and $K_T = 0.6$ GeV/c (curve 2); dot-dashed curve—calculations from the quantum-chromodynamics model.

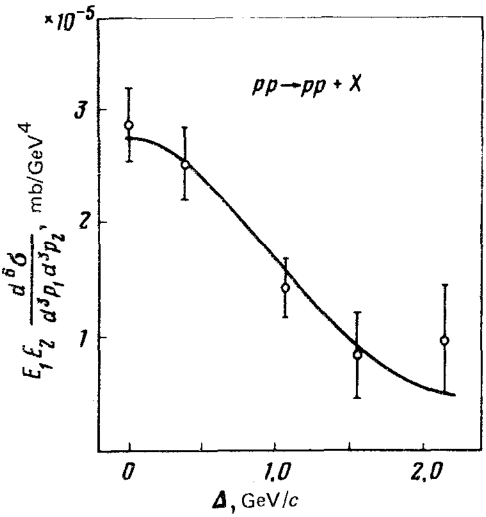

FIG. 2. Δ dependence of the invariant cross section for the production of pp pairs. The curve is calculated from the model without fragmentation.

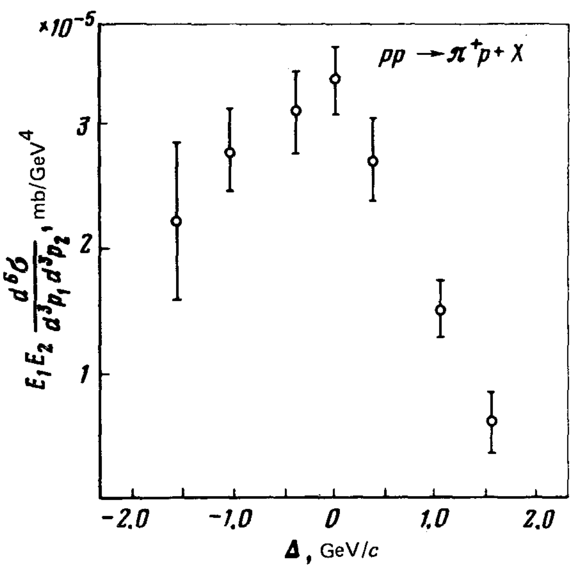

FIG. 3. Δ dependence of the invariant cross sections for the production of $\pi^+ p$ pairs ($\Delta > 0$) and $p\pi^+$ pairs ($\Delta < 0$).

An attempt can be made to explain the experimental results on the dependence of the invariant cross section on the transverse-momentum difference for asymmetric pairs of hadrons on the basis of the parton mechanism for the production of particles. According to certain models, such as the quantum-chromodynamics model of Ref. 6, partons form hadron jets after an inelastic scattering. In this case the momentum asymmetry of the hadrons results from two factors: the internal transverse motion of the partons and their fragmentation into hadrons. If, on the other hand, the partons have the quantum numbers of the hadrons, the latter form without a fragmentation stage. In this case we are left with only one reason for the momentum asymmetry: the internal transverse motion of the partons. This version of the production of a proton pair was studied in Ref. 2.

The dot-dashed curve in Fig. 1 is the prediction of the quantum-chromodynamics model of Ref. 6 for $\langle K_T \rangle = 0.8$ GeV/c and $E = 70$ GeV. This theoretical curve is normalized to the value of the cross section for the production of the symmetric $\pi^+\pi^+$ pair. We see that this model does not describe the experimental data. The cross section not only does fail to decrease as a function of Δ, it in fact rises slightly at small values of Δ. The reason for this rise is that the quarks and gluons have different fragmentation functions, and the $gg \rightarrow gg$ scattering is very important at the energies and transverse momenta involved here. To reconcile the quantum-chromodynamics model with experimental data it is necessary to either substantially reduce the contribution of quark-gluon scattering or increase the hardness of the gluon fragmentation function, in either case reducing the transverse momentum of the partons. We also note that the predictions of this quantum-chromodynamics model differ by more than an order of magnitude from the experimental cross sections for the production of symmetric pairs symmetric pairs of pions.[1] A tendency toward a deviation of the predictions of the quantum-chromodynamics model at $M < 5$ GeV/c from the experimental data can also be seen in the results of Ref. 7, carried out at 400 GeV.

The cross section for the production of a pair of particles without fragmentation is described as a function of Δ by[8]

$$\sigma_{12}(M, \Delta) = \sigma_{12}(M', 0)\frac{M'}{M}\exp\left[-\frac{\Delta^2}{2\langle K_T^2\rangle}\right], \qquad (2)$$

where $M = \sqrt{M^2 - \Delta^2}$, $\langle K_T^2\rangle$ is the mean square internal transverse momentum of the parton, and $\sigma_{12}(M',0)$ is the cross section for the production of a symmetric pair of particles. Our experimental data can be described satisfactorily with $\langle K_T\rangle = 0.62 \pm 0.03$ GeV/c for the $\pi^+\pi^+$ pair and $\langle K_T\rangle = 0.58 \pm 0.03$ GeV/c for the pp pair, in agreement with the value $\langle K_T\rangle = 0.51 \pm 0.05$ GeV/c given by the expression $\langle K_T^2\rangle = (0.0144 \pm 0.0011)\sqrt{S}P_T + (0.075 \pm 0.060)$, found in Ref. 9, where the production of hadron jets in pp interactions was studied.

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