A possible example of subhadronic scattering

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The invariant cross sections of the inclusive process $P + P \to P + P + X$ at 70 GeV, in which the protons with symmetric pulses fly apart at angles close to 90° in the c.m.s., are measured. The obtained results are in agreement with the assumption that a subhadronic, quasi-elastic scattering of a "subproton" by a "subproton" (a system comprised of three valence quarks) exists.

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Using a two-arm, focusing spectrometer (TFS),[1] we have investigated the reaction

$$p + p \to p + p + X \qquad (1)$$

in which two final-state protons with symmetric pulses were recorded at an angle of 160 mrad in the laboratory coordinate system or at 90° in the c.m.s. of two colliding nucleons for relativistic particles at 70-GeV incident proton energy. The investigated region of transverse momenta $P_\perp$ was in the range of 1 to 2 GeV/c.

An interesting characteristic of the reaction is that it releases a large amount of energy (7.3–8.7 GeV at $\sqrt{s} = 11.5$ GeV), whereas the system of valence quarks of two colliding final-state protons is conserved just as in the eleastic scattering. The processes in which the gluons or sea quarks play the main role cannot contribute significantly to the reaction (1), since, as it follows from our experimental data, the cross section for production of proton-antiproton pairs is an order of magnitude lower than that of this reaction. Thus the reaction (1) makes it possible to study the role of valence quarks in a nucleon in the scattering processes with sufficiently large

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transverse momenta.

A proton beam, whose intensity varied from 10^{10} to 10^{12} protons per acceleration cycle, impinged on a 40-cm-long liquid hydrogen target. The location of the beam relative to the target, its divergence, and its intensity were controlled by an array of secondary-emission detectors. The momenta and the angles of production of the particles were measured by using analyzing magnets and an array of drift chambers. The particles were identified in each spectrometer arm by means of two threshold Čerenkov counters. The reaction involving the escape of two protons was identified against a background of random coincidences under a heavy load of the recording equipment of the spectrometer using the method of precision time-delay analysis of particles with an accuracy of 3×10^{-10} sec.

We measured the events involving the production of two protons and one proton, which were normalized to the number of proton interactions in the target. We assumed in determining the cross sections that the spectrometer's acceptance for the recording of two protons is equal to the product of the acceptances of each of the spectrometer's arms for the recording of a single proton, and we also used the cross sections for inclusive production of protons measured previously by us.[1] The results of measuring the invariant cross sections of the reaction (1) are given in Table I.

It would be useful to compare the experimental results with the cross section for elastic proton-proton scattering at 90° angle in the c.m.s. within the context of a simple model, in which a pair of protons with large $P_\perp$ is produced as a result of quasi-elastic scattering of "subprotons." "Subprotons" are defined here as partons with quantum numbers and cross sections for elastic scattering of real protons at large angles. Such partons were analyzed in one of the models of hard scattering of hadrons, which is called CIM (constituent-interchange model) in abbreviated form.[2] The kinematic scheme for scattering in the c.m.s. is shown in Fig. 1.

The cross section for production of a symmetric pair of hadrons with large $P_\perp$ in such parton model can be calculated by using an approximate formula[3] which in our case has the form

$$E_1 E_2 \frac{d^6\sigma}{d^3p_1 d^3p_2} = \frac{1}{2\pi^2 < k_\perp^2 >} [xFp'/p(x)]^2 \frac{d\sigma_{el}}{dt} (pp \to pp) \qquad (2)$$

is the distribution of the probability of finding a "subproton" in a proton with the

TABLE I.
Invariant cross sections of the reaction (1) in μb GeV^{-4}.

$P_\perp$, ГGeV/c	1,0	1,3	1,7	2,0
$E_1 E_2 \frac{d^6\sigma}{d^3P_1 d^3P_2}$	2,84 ± 0,51	$(1,94 \pm 0,35)\cdot 10^{-1}$	$(8,66 \pm 1,47)\cdot 10^{-3}$	$(1,36 \pm 0,27)\cdot 10^{-3}$

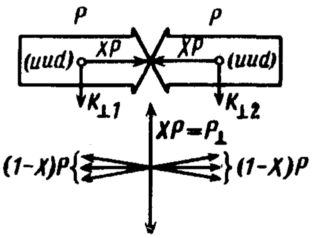

FIG. 1. Kinematic scheme of the reaction $p+p \rightarrow p+p+X$.

momentum xP in the c.m.s., where $x=x_\perp=2P_\perp/\sqrt{s}$ and $t=-2P_\perp^2$. $\langle k_\perp^2 \rangle$ represents the average square of the internal transverse momentum of the "subproton," which we shall assume for future estimates to be equal to 0.5 $(\mathrm{GeV}/c)^2$, as is commonly done in contemporary, hard-scattering parton models.[3]

Here $(pp \rightarrow pp)$ is the experimental cross section of elastic scattering of protons at 90° angle in the c.m.s., which is described well by a known dependence in the region of momentum transfer corresponding to $P_\perp = 1$–2 GeV/c (Ref. 2).

$$\frac{d\sigma_{el}}{dt}(pp \rightarrow pp) = 1{,}2 \cdot 10^9 s^{-10}\ \Gamma\mathrm{GeV}^{-4}. \qquad (3)$$

We can deduce the probability destribution of a "subproton" in a proton from the expression (2). The results are given in Fig. 2.

To determine the soundness of these results, we have plotted in Fig. 2 the calculated probability distribution of a "subproton" in a proton, which was calculated using a modified Kuti-Weiskopf model.[4] The "subprotons" in this case were identified with three valence quarks and $f_{p'/p}(x)$ was calculated by integrating the three-particle distribution function of the valence quarks, which has the form

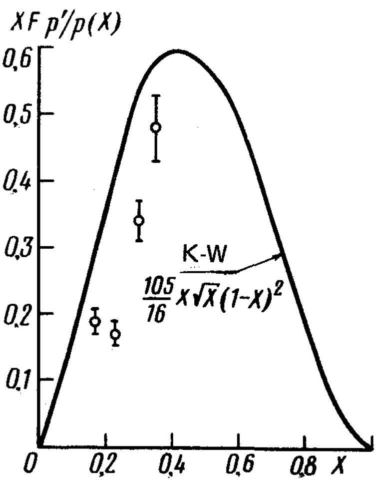

FIG. 2. The probability of finding a "subproton" in a proton with a momentum xP. The solid curve is a plot of the distribution calculated according to the Kuti-Weiskopf quark model.

$$G_{uud/p}(x_1, x_2, x_3) = A\frac{(1 - x_1 - x_2 - x_3)^2}{x_1 x_2 x_3} . \tag{4}$$

The normalization factor A was chosen on condition that the probability of finding one "subproton" by a "subproton" can actually occur.

A good agreement between the experimental and calculated data, provided it is not accidental, gives us reason to assume that the considered subhadronic scattering of a "subproton" by a "subproton" can actually occur.

It would be useful to study the reaction (1) further, in particular, to investigate the accompaniment of two protons, since it must be enriched in the investigated model, presumably by gluon jets in the direction of colliding protons.

We also note that the contribution of the reaction (1) to the invariant cross section of the inclusive production of a single proton at 90° angle in the c.m.s. is only about 1%.

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