less than 3%.

[7]This value of α_s is calculated from the ratio of the leptonic to the hadronic width of the ψ [see T. Appelquist and H. D. Politzer, Phys. Rev. Lett. 34, 43 (1975)]. The predicted direct γ contribution is included as part of the total width of the ψ used in the calculation.

[8]R. Barbieri *et al.*, Nucl. Phys. B154, 535 (1979).

[9]Another experiment [M. T. Ronan *et al.*, Lawrence Berkeley Laboratory Report No. LBL-9256, 1979 (unpublished)] finds evidence of production of direct γ's consistent in magnitude with this experiment.

Correlations between High-Momentum Mesons in $p+p \rightarrow \pi+\pi+X$ at $s^{1/2}=63$ GeV

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In pp collisions at $\sqrt{s}=62.3$ GeV where *each* proton fragments into at least one low-p_T, high-x pion, no significant correlations for $\pi^+\pi^+$, $\pi^+\pi^-$, and $\pi^-\pi^-$ are found, thus excluding quark exchange with Brodsky-Gunion counting rules as the dominant interaction mechanism. This, together with the experimental x dependence of single-particle spectra, suggests the introduction of a new counting rule, which is discussed.

We report a measurement of the process

$$p_1+p_2 \rightarrow \pi_1+\pi_2+X$$

at the CERN intersecting storage rings (ISR) at $\sqrt{s}=62.3$ GeV, in which π_1 (π_2) is emitted at small angle ($18<\theta<40$ mrad) with respect to p_1 (p_2). In this experiment we measure the invariant double-differential cross section

$$\sigma_{\rm INV}(\pi_1,\pi_2) \equiv E_1E_2 d^6\sigma/d^3p_1d^3p_2, \qquad (1)$$

for the combinations $\pi^+\pi^+$, $\pi^+\pi^-$, and $\pi^-\pi^-$, and the correlation coefficient R, defined as

$$R=\sigma_{\rm TOT}\frac{\sigma_{\rm INV}(\pi_1,\pi_2)}{\sigma_{\rm INV}(\pi_1)\sigma_{\rm INV}(\pi_2)}=\sigma_{\rm TOT}\frac{N(\pi_1,\pi_2)}{N(\pi_1)N(\pi_2)}, \qquad (2)$$

where $N(\pi_1,\pi_2)$ and $N(\pi_i)$ are the normalized double- and single-pion yields. R is a function of the variables x_1, p_{T1}, x_2, p_{T2}, φ_1, φ_2, and $\sqrt{s}$. The data cover the ranges $0.2<x_1,x_2<0.95$, $0.2<p_{T1}$, $p_{T2}<1.2$ GeV/c, and $\sqrt{s}=62.3$ GeV. Assuming factorization in p_T and no φ dependence we have $R=R(x_1,x_2)$ for data at fixed $\sqrt{s}$ for each of the three combinations of charges.

The equipment consists of two small-angle spectrometers located on the downstream ends of one intersection of the CERN ISR; see Fig. 1 Each arm consists of a septum magnet (SM), trigger counters (S), five modules of drift chambers (DC), two hodoscopes (H1, H2), and three atmospheric Čerenkov counters (Č).

The acceptance per arm is ~1 msr. The momentum resolution $dp/p \lesssim 1\%$. The first and the last Čerenkov counters in each arm were filled with CO_2, the middle one with 50% N_2/50% He. The threshold momenta for $\pi/K/p$ in CO_2 and 50% N_2/50% He are 4.6/16.2/30.9 and 7.5/26.5/50.1 GeV/c, respectively, resulting in unambiguous identification of pions in the range $6 \lesssim p \lesssim 26$ GeV/c. In the range $26<p<30$ GeV/c the contamination of the π^+ sample by protons and K^+ is calculated to be <2% and <15%, respectively; the K^- and $\bar{p}$ contamination in the π^- sample is neg-

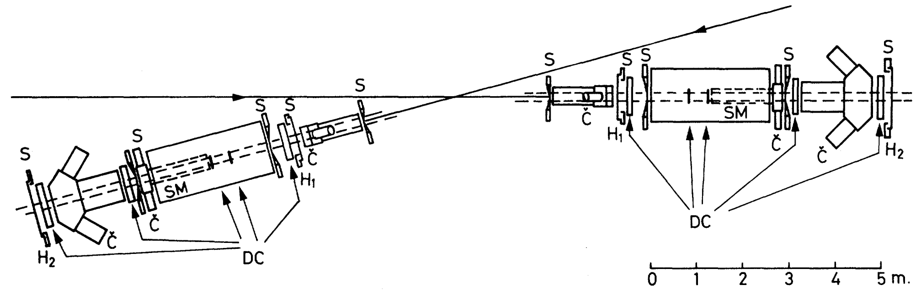

FIG. 1. A diagram of the experimental apparatus at the ISR.

ligible.

The trigger consists of a coincidence between the scintillators in the two arms, a pattern in the hodoscopes defining a high-momentum particle, and a signal in at least two CO_2-filled Čerenkov counters in each arm. In the combinations $\pi^+\pi^+$, $\pi^+\pi^-$, and $\pi^-\pi^-$, 5.6×10^6, 7.9×10^6, and 8.9×10^6 triggers were recorded, respectively, for a total integrated luminosity of 1.7×10^{37} cm^2; these resulted in 0.6×10^6, 0.8×10^6, and 0.5×10^6 identified two-pion events, respectively. Events reconstructed from single- and double-arm runs were normalized and combined into the expression for R in Eq. 2.

The resulting values of R are shown in Fig. 2. They show that in the range $0.2<x<0.9$ the $\pi^+\pi^+$, $\pi^+\pi^-$, and $\pi^-\pi^-$ data are essentially uncorrelated, i.e., $R=1$. In Fig. 3 are shown $\sigma_{\rm INV}(\pi_1,\pi_2)$ at $p_{T1}=p_{T2}=0.75$ GeV/c vs x_2 for various values of x_1. They have been computed with use of the measured values of R and the invariant single-pion differential cross sections of Singh *et al.*[1] They are compared with $\sigma_{\rm INV}(\pi_1,\pi_2)$ for the case $R=1$ (solid lines). It is seen that over a range of five decades in $\sigma_{\rm INV}$ no significant deviations from factorization are observed.

A value of $R=1$ independent of the particle momenta is in accord with any model in which the interaction factorizes, with the protons communicating through the exchange of energy and momentum, but otherwise acting as independent, unconnected entities. In this sense the conclusion of this experiment is quite general.

One example of such models is the one where each proton dissociates into a pion through a triple Regge exchange while the two protons are connected through Pomeron exchange. As shown in Ref. 1 the data on single inclusive π^+ (π^-) production, $pp\to\pi^+X(\pi^-X)$, are consistent with the exchange of an N_α (Δ_δ) trajectory, while data on $pp\to pX$ have been shown[2] to be in good agreement

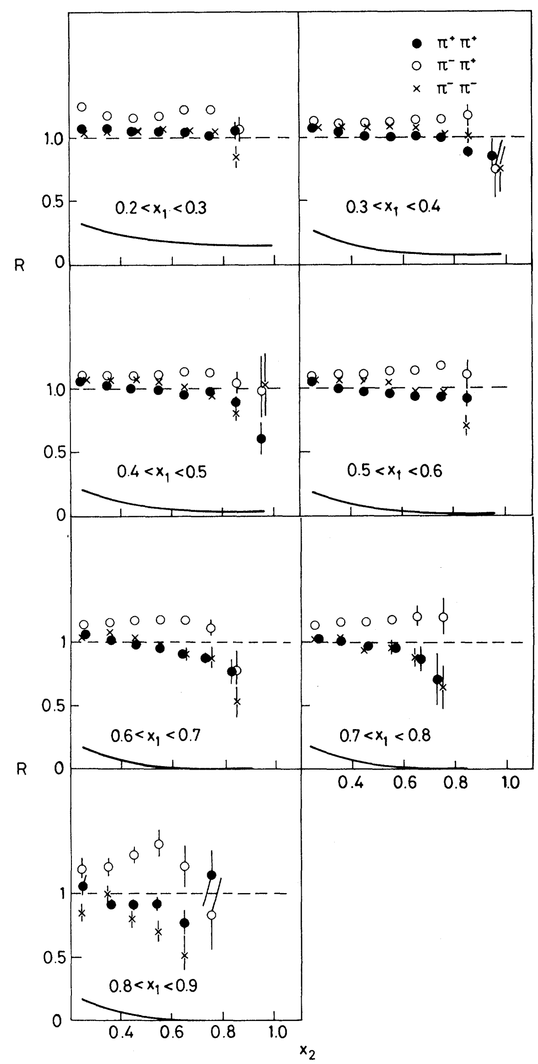

FIG. 2. Correlation coefficient R vs x_2, as a function of x_1, for $\pi^+\pi^+$, $\pi^+\pi^-$, and $\pi^-\pi^-$ at $\sqrt{s}=63$ GeV. The solid curves are the prediction for quark exchange along with the Brodsky-Gunion counting rule; the dashed lines are the prediction for gluon exchange with the Brodsky-Gunion counting rule, and for gluon or sea-quark exchange with the valence counting rule discussed in the text.

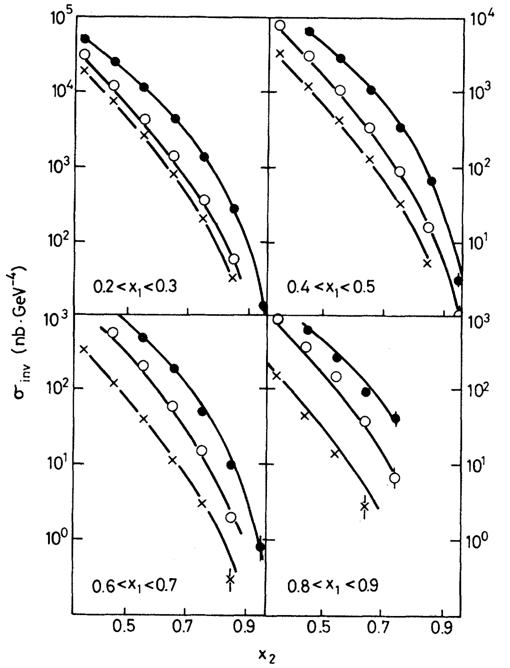

FIG. 3. The double-differential invariant cross section σ_{INV} (integrated over azimuthal angle), versus x_2, for various bands of x_1, for $p_{T1} = p_{T2} = 0.75$ GeV, $\sqrt{s} = 63$ GeV. The solid lines indicate σ_{INV} assuming no correlations, i.e., $R = 1$.

with the notion of pure Pomeron exchange. The triple Regge model with Pomeron exchange predicts a value of $R = 1$, in agreement with our data.

It has been pointed out by Brodsky and Gunion[3] that the presence or absence of long range correlations provides a means of distinguishing between gluon exchange and quark exchange or annihilation as the dominant mechanism through which the protons interact. In what follows we shall distinguish six cases: The interaction is mediated by gluon exchange, sea-quark exchange (or annihilation), or valence-quark exchange while for each exchange we assume the energy to be shared equally among the spectator valence *and* sea quarks (the "BG counting rule") or to be shared among the spectator valence quarks *alone*. This leads to expressions for the single and double cross sections, characterized by α in $(1-x)^\alpha$, and by α and β in $(1-x_1)^\alpha(1-x_2)^\beta + (1 \leftrightarrow 2)$, as indicated in Table I for five categories of reactions ordered by the number of spectators n, with $\alpha, \beta = 2n - 1$.

Inspection of Table I indicates that there are three ways of obtaining the result $R = 1$, i.e., $\alpha = \beta$, as observed in this experiment: with the BG

TABLE I. Exponents α and β, characterizing the momentum dependence of single- and double-proton fragmentation predicted by the counting rules discussed in the text. The cases $\alpha = \beta$ correspond to $R = 1$, i.e., no correlation.

Counting rule	Brodsky & Gunion				Valence			
Energy shared among	q_s and q_v				q_v only			
Exchange	Gluon		q_s or q_v		Gluon or q_s		q_v	
X	α	β	α	β	α	β	α	β
$\Lambda, \Lambda_{1520}, \Sigma_{1385}^+$	3	3	1	5	1	1	-1	3
π^+, π^-, K^+	5	5	3	7	3	3	1	5
Ξ^-, Σ_{1385}^-	7	7	5	9	3	3	1	5
K^-	9	9	7	11	5	5	3	7
$\bar{\Lambda}, \bar{p}$	11	11	9	13	5	5	3	7

counting rule and gluon exchange, and with the "valence-only" counting rule, with either gluon or sea quark exchange. The remaining three cases give rise to long-range correlation ($R \neq 1$, $\alpha \neq \beta$) and are thus in disagreement with the results of this experiment. In particular, the combinations of (sea or valence) quark exchange and the "BG counting rule",[3] drawn as a solid line in Fig. 2 (normalized to $R = 1$ at $x_1 = x_2 = 0$), are ruled out by the data. This is in sharp contradiction with the conclusions of a recent experiment in which *only* single-particle spectra were observed. Table I indicates that a further distinction between the three cases with $R = 1$ is possible by examining the x dependence of the data. At this point the detailed dynamics, ignored in the simplicity of the counting rules, enters and may render a comparison with the data ambiguous.

Data on the momentum dependence of single-particle production have been summarized in Fig. 4.[5] The data have been ordered into seven categories, i.e., the five groups of proton fragmentation reactions listed in Table I, and two groups of meson fragmentation reactions. The two vertical lines drawn for each category refer to the exponent α predicted for the "no correlation" ($R = 1$, $\alpha = \beta$) cases in Table I. New data[7] on Λ, $\bar{\Lambda}/\Lambda$, and $\Lambda(1520)$ production have also been included. A marked systematic grouping of the data for each of the categories is observed. With the exception of the $\bar{p}$'s and $\bar{\Lambda}$'s which might be exceptional because of their being produced in pairs of low Q value, we note that the bulk of the data are qualitatively better described by the mechanism of gluon (or sea-quark) exchange (the solid lines) together with our new valence-quark counting

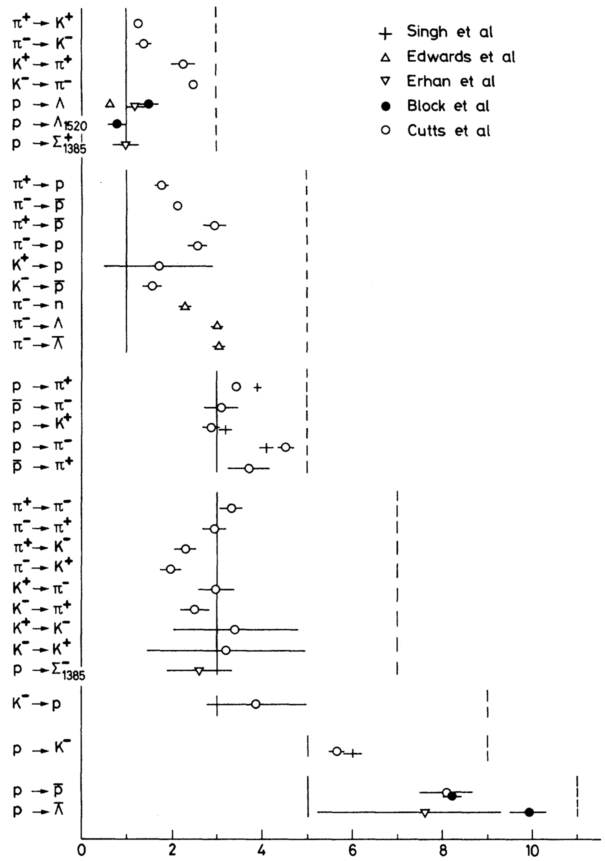

FIG. 4. Fitted exponents α for the momentum dependence $d\sigma/dx \sim (1-x)^{\alpha}$, from Refs. 1 and 4-7 for various reactions. The solid lines follow from the valence counting rule, with either gluon exchange or sea-quark exchange. The dashed lines follow from gluon exchange together with the BG counting rules.

rule, which says that α, the exponent of $(1-x)^{\alpha}$, is given by $2n_v - 1$, where n_v is the number of valence spectator quarks, than by the alternative of gluon exchange with the BG counting rules (the dashed lines). Thus, of the six possibilities summarized in Table I, only two survive comparison with both single- *and* double-particle spectra, i.e., gluon or sea-quark exchange, together with the valence counting rule. We note that this is in qualitative accord with the recombination model proposed by Das and Hwa,[8] in which the role of the sea quarks in the sharing of energy among the spectators in the production process is implicitly reduced, relative to that of the valence quarks, by the relatively strong x dependence of the sea-quark structure function.[9]

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[8]K. P. Das and R. C. Hwa, Phys. Lett. 68B, 459 (1977).

[9]A rather similar counting rule has recently been suggested by J. F. Gunion, University of California, Davis, Report No. UCD-79-4 (to be published).