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High-transverse-momentum hadron-hadron correlations in $\sqrt{s}=38.8$ GeV proton-proton interactions

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Measurements of correlations of nearly back-to-back hadrons produced at a large transverse momentum in $\sqrt{s}=38.8$ GeV proton-proton collisions are presented and compared to previous results with a beryllium target. The correlations of identified unlike-sign hadron pairs in ratio to the correlation for all unlike-sign pairs are compared with predictions of the Lund model. These predictions differ from the data.

A high-transverse-momentum (p_T) hadron produced in a high-energy proton-proton (pp) collision often contains a parton involved in the hard parton-parton interaction.[1] Thus two opposing high-p_T hadrons should often carry both of the partons involved in the hard interaction and should show an increasing correlation as the hardness of the interaction increases. Here an attempt has been made to follow the quantum-number flow in such constituent interactions with the use of a ring-imaging Cherenkov counter to identify both hadrons.

The Fermilab E605 spectrometer is described elsewhere.[2-4] Several changes were made for these data in order to center the regions of phase space studied near 90° in the proton-proton center-of-momentum system with 800-GeV protons incident. We used typically 4×10^{11} protons per 20-sec spill incident on a 20-cm liquid-hydrogen target. Hadrons of each charge were accepted at high p_T over a center-of-momentum solid angle of approximately 0.5 sr. A laser-fiber-optic system was installed to monitor and control the gains of our calorimeter phototubes.

For these data our ring-imaging Cherenkov counter[5] was fully operational. The full experimental aperture (2.6×2.7 m^2) was covered by 16 rectangular mirror segments which focused Cherenkov photons (8 eV) emitted in our helium radiator gas onto two multistep proportional wire chambers[6] which recorded the positions of individual photon hits. Two-thousand fast-encoding analog-to-digital converters (ADC's) were used to record three projections of the hit position of each detected photon. Amplitude matching was used to resolve ambiguities in reconstructing the photon-hit positions from the projections. Since the Cherenkov counter was not in a temperature-controlled environment, muon-triggered data were used to measure the index of refraction of our helium radiator gas as a function of time. The orientation of our mirrors was also somewhat unstable (changes as large as 50 μrad, probably due to differential thermal expansion) and was monitored as a function of time using hadron-triggered data. (This latter step involved the positions of the Cherenkov-ring centers, not the ring radii.)

For a particle well above Cherenkov threshold, an average of 2.5 photons were reconstructed on the Cherenkov ring accompanied by 1.0 noise photons (reconstructed off the ring). For each track (including tracks with zero photons) the relative probability for a π, K, or p to produce the observed photon hit pattern was computed. In each kinematic bin the particle fractions which maximized the likelihood for the per-track relative probabilities were determined by an iterative method. Some of our events had a momentum near or below proton Cherenkov threshold (109 GeV/c). In kinematic regions dominated by such events the measurement of the proton fraction was based largely on counting events with no photons. Typically, unambiguous identification was possible for about 80% of the pions, 70% of the kaons, and 50% of the protons with p_T greater than 6 GeV/c.

The dihadron correlation function $R(h^+h^-)$ is defined[7,8] as the ratio of the probability of observing two unlike-sign hadrons from a single interaction with opposing transverse momenta p_{T1} and p_{T2} to the corresponding probability if the hadrons are uncorrelated. In terms of the single and dihadron inclusive production cross sections and the inelastic pp cross section σ_{in}:

$$R(h^+h^-)=\frac{E_1E_2\dfrac{d^6\sigma}{dp_1^3dp_2^3}\Big/\sigma_{\text{in}}}{\left(E_1\dfrac{d^3\sigma}{dp_1^3}\Big/\sigma_{\text{in}}\right)\left(E_2\dfrac{d^3\sigma}{dp_2^3}\Big/\sigma_{\text{in}}\right)}\ .$$

A measurement of $R(h^+h^-)$ (averaged over the acceptance of a given experiment) can be written in terms of the numbers of single-hadron events (N_1,N_2) and real dihadron events (N_{12}^{real}):

$$R(h^+h^-)=\frac{N_{12}^{\text{real}}/N_{\text{int}}}{(N_1/N_{\text{int}})(N_2/N_{\text{int}})}\ ,$$

where N_{int} is the total number of interacting protons. The number of real dihadron events is the difference between the total number of observed pairs, N_{12}^{tot}, and the number of accidental pairs (two simultaneous hadrons from different interactions), N_{12}^{acc}. The number of accidental pairs is the product of the numbers of single hadrons divided by the effective total number of incident proton bunches, N_{eff},[7,8] so that the previous expression becomes

$$R(h^+h^-)=N_{\text{int}}\left(\frac{N_{12}^{\text{tot}}}{N_1N_2}-\frac{1}{N_{\text{eff}}}\right)\ .$$

The correlation function for the production of two specific hadron species α^+ and β^- relative to all species is simply $r_{\alpha\beta}=R(\alpha\beta)/R(h^+h^-)$.

Figure 1 shows the invariant single-pion cross sections measured in this experiment.[7] Systematic uncertainties (dominated by estimates of our calorimeter trigger efficiency[3,7]) are added in quadrature with the statistical uncertainties to produce the error bars shown. Also shown are extrapolations of previous measurements of charged pions[9,10] based on fits of the form $E\,d^3\sigma/dp^3=Af(x_T)p_T^N$. There is fairly good agreement between these data and the fitted curves.

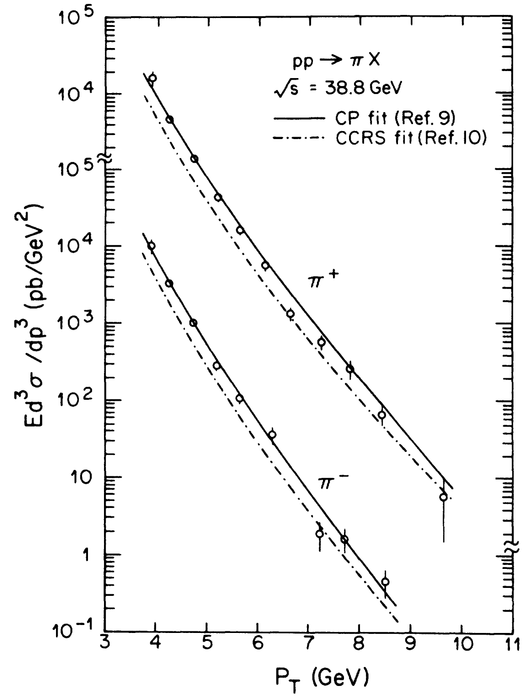

FIG. 1. Measurments of the inclusive cross sections for production of π^+ and π^- in proton-proton collisions are plotted vs transverse momentum and compared to fits summarizing previous work.

The dihadron data cover the region in pseudomass m' from 7.8 to 13.3 GeV. Pseudomass is defined as the sum of the magnitudes of the transverse momenta of the two hadrons and is a simple measure of the hardness of the constituent scattering for hadrons produced roughly back to back. Figure 2 shows the measured unlike-sign correlation function as a function of pseudomass for symmetric pairs (with a net p_T difference of less than 1.1 GeV). The results of this experiment for 3531 dihadrons are shown with the results of the Columbia-Fermilab-Stony Brook (CFS) Collaboration[8] for dihadrons produced in $\sqrt{s}=27.4$ GeV proton-beryllium collisions with a lower m' range. Both results show a similar exponential rise of $R(h^+h^-)$ with m' as the hardness of the interaction increases. A number of factors could be responsible for the differences shown. These factors include the anomalous effect of a nuclear target[2,11-13] in the CFS data, the different azimuthal angular acceptances,[7,8] the different beam energies, and the fact that $R(h^+h^-)$ for pp collisions should be smaller than $R(h^+h^-)$ for a beryllium target due to charge conservation.

Measurements of $R(h^+h^-)$ are insensitive to most uncertainties since they involve the ratio of pair events to single-particle events measured simultaneously in the same apparatus. The dominant systematic uncertainty (included in Fig. 2) involves the ratio of the efficiencies[3,7] of the pair trigger and single-particle triggers.

The dominant systematic uncertainty in the relative correlation, in a similar manner, involves the ratio of Cherenkov identification efficiencies for pair events and single-particle events. The worst problem involves the case when Cherenkov photons from both hadrons in a pair event strike the same photon detector. Projective readout is at times unable to resolve these photons. The largest uncertainties occur for pairs containing a proton or an-

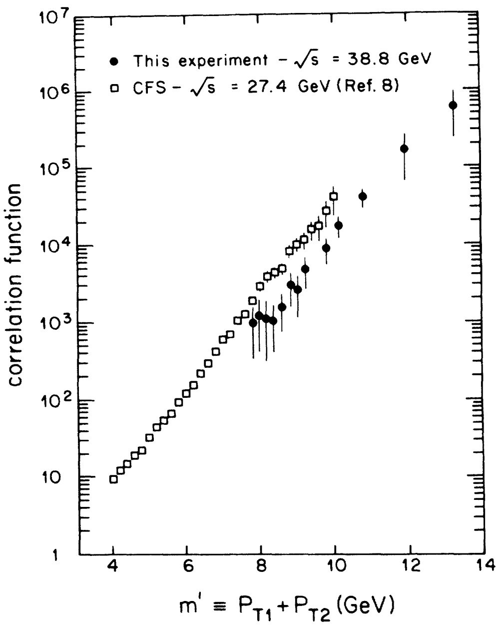

FIG. 2. Measurements of the hadron-hadron unlike-sign correlation are plotted as a function of pseudomass (sum of the transverse momenta) and compared to previous measurements in proton-beryllium collisions. Both experiments use symmetric pairs with a transverse-momentum difference less than 1.1 GeV.

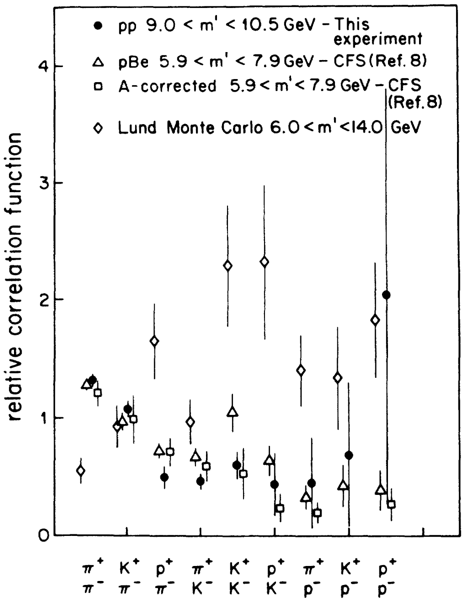

FIG. 3. Measurements of the relative correlation function in proton-proton collisions for each pair species are compared to measurements using a beryllium target and predictions using the Lund model.

tiproton (which are often below Cherenkov threshold). This type of systematic uncertainty was estimated by comparing the pair species composition resulting from events in which Cherenkov photons from both hadrons strike the same detector to the composition resulting when they do not strike the same detector.

In Fig. 3 the relative correlation functions $r_{\alpha\beta}$ measured by this experiment (statistical uncertainties only) and the CFS Collaboration are shown. Table I contains the measured values of $r_{\alpha\beta}$ with the statistical and systematic uncertainties. The CFS points labeled "*A*-corrected" are an extrapolation from proton-beryllium to proton-nucleon collisions, correcting for anomalous nuclear enhancement.[8] Agreement of the *pp* relative correlation functions and the "*A*-corrected" values of the CFS Collaboration confirms the validity of this technique within the precision of the two measurements, and indicates that these relative correlation functions do not depend strongly on m' or $\sqrt{s}$.

If only valence-quark-quark scattering contributed to the production of single hadrons and dihadrons in the kinematic region studied here ($m'/\sqrt{s} \approx 0.26$), then the relative correlation function for all species of unlike-sign pairs would be unity since the mediating gluon carries no flavor. However, some interactions (gluon-gluon and quark-antiquark), involving nonvalence constituents, can introduce flavor correlations between two opposing hadrons. These nonvalence interactions should, for instance, increase the K^+K^- correlation since there is no net flavor in the initial constituent state.

Predictions based on the Lund model[14] are also shown in Fig. 3. The fragmentation portion of this model has been quite successful in parametrizing e^+e^- data. However, the high-p_T event generator (PYTHIA) has not been tested in the kinematic region under study, and Fig. 3 suggests[15] that it gives too much importance to the nonvalence interactions mentioned above.

A mechanism by which the measured relative correlation for K^+K^- can be less than 1 has been previously suggested.[8] Single-hadron events (as opposed to symmetric pairs) select initial constituents with a p_T directed toward the relevant trigger element. Consequently the relative correlation functions need to be corrected for the effects of confinement (constituent p_T) before comparison to free-constituent-scattering models. These corrections[8] are in the proper directions and have sufficient magnitudes (using an average p_T kick of 1 GeV) to bring the corrected values for all species into consistency with one. (Note that this correction should not be made before comparison

TABLE I. Relative correlation functions.

Pair species	$r_{\alpha\beta}$	Statistical uncertainty	Systematic uncertainty
$\pi^+\pi^-$	1.32	0.05	0.04
$K^+\pi^-$	1.08	0.07	0.02
$p^+\pi^-$	0.50	0.10	0.18
π^+K^-	0.47	0.07	0.01
K^+K^-	0.60	0.12	0.05
p^+K^-	0.44	0.26	0.04
π^+p^-	0.45	0.39	0.24
K^+p^-	0.69	0.60	0.18
p^+p^-	2.03	1.79	0.98

to the Lund model—which includes effects of constituent p_T.)

In conclusion, the measured proton-proton relative correlations are consistent with dominance by quark-quark scattering for $m'/\sqrt{s} \approx 0.26$, in agreement with a previous extrapolation using beryllium target data. The Lund model is unable to predict these relative correlations.

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[15] We use the relative correlations—dividing out the steep dependence on m' shown in Fig. 2, which should be similar for all species—in order to concentrate attention on the quantum-number correlations. Hence we do not expect the relative correlation functions to be strongly dependent on m', and we point to the agreement between these data and the CFS "*A*-corrected" points to justify this presumption. Because of the steep dependence shown in Fig. 2, both experiments and the Monte Carlo simulation are dominated by events near their lower limit in m', and it is statistically difficult to study the dependence on m'. A broad range of m' was used in the Monte Carlo simulation to collect as many events as possible.