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Like- and Unlike-Charged Pion Correlations in π^+p and pp Interactions at 100 GeV/c

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(Received 16 September 1974)

Charged-pion rapidity correlations are compared and found to have a similar peaked structure when studied inclusively. However, when the same data are studied semi-inclusively *no correlation* is found for like-charged pions and for unlike-charged pions in the central region. Inclusive correlations in these cases appear then from the convolution of the uncorrelated spectra at each multiplicity and the multiplicity distribution. Correlation in $\pi^+\pi^-$ is observed at small Δy only for y large.

Strong positive correlations between pions with small rapidity separations were observed in experiments at 10 to 30 GeV/c,[1-5] and in pp interactions at 200 GeV/c.[6] These observations were made in terms of the usual inclusive correlation function:

$$C(y_1,y_2)=\frac{1}{\sigma_{\text{in}}}\frac{d^2\sigma}{dy_1dy_2}-\left(\frac{1}{\sigma_{\text{in}}}\frac{d\sigma}{dy_1}\right)\left(\frac{1}{\sigma_{\text{in}}}\frac{d\sigma}{dy_2}\right). \quad (1)$$

This is the difference between the coincidence of two particles at rapidities y_1 and y_2, normalized by the inelastic cross section σ_{in}, and the product of the singles counts at y_1 and y_2, both normalized by σ_{in}. Alternatively one can use

$$R(y_1,y_2)=\frac{C(y_1,y_2)}{\sigma_{\text{in}}^{-2}(d\sigma/dy_1)d\sigma/dy_2}$$
$$=\frac{\sigma_{\text{in}}d^2\sigma/dy_1dy_2}{(d\sigma/dy_1)d\sigma/dy_2}-1. \quad (2)$$

This ratio has experimental advantages over the correlation function (1) in that uncorrelated measurement inefficiencies, as well as the overall cross-section normalization, cancel. One can evaluate it directly in terms of the number of coincidences and the number of inelastic events in the data sample.

The data we used are from an exposure of the Fermi National Accelerator Laboratory 30-in. hydrogen bubble chamber to a mixed, tagged, positive beam and include 1903 inelastic π^+p events and 3477 inelastic pp events. The average charge multiplicities are 6.80 ± 0.14 and 6.49 ± 0.10 for π^+p and pp interactions, respectively.[7] The events were measured twice on a Lawrence Berkeley Laboratory spiral reader, resulting in a better than 96% measuring efficiency for tracks going backward in the center of mass system, independent of multiplicity. An average of 80% for tracks going forward in the c.m. system was obtained, with a decreasing efficiency for increasing multiplicity.[8] Although the correlation behaviors in π^+p and pp interactions are found to be similar, data from both reactions will be presented for comparison.

The correlation function defined in (2) for π^-

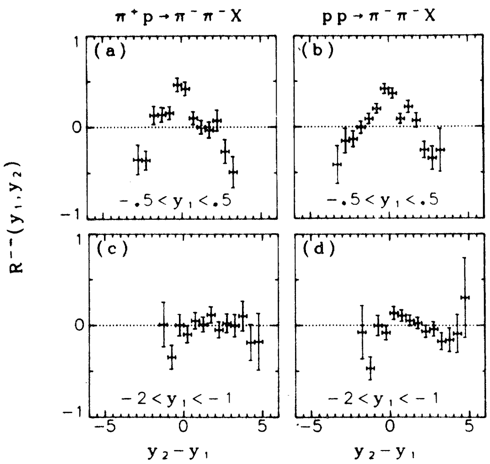

FIG. 1. Inclusive $\pi^-\pi^-$ correlation functions $R^{--}(y_1, y_2)$ at 100 GeV/c.

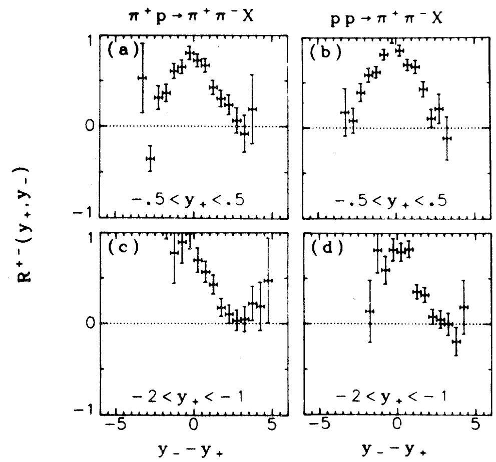

FIG. 2. Inclusive $\pi^+\pi^-$ correlation functions $R^{+-}(y_+, y_-)$ at 100 GeV/c.

and π^- is shown in Fig. 1. When one π^- is confined to be in the central region, $-0.5 < y_1 < 0.5$, a positive correlation is clearly observed with respect to neighboring particles. We take as a measure of the range of correlation the rapidity interval, y_d, over which the value of R drops by one-half unit from its peak value, i.e.,

$$R(0, y_d) = R(0, 0) - 0.5. \tag{3}$$

We find y_d to be 2 units of rapidity. Only a very slight positive correlation is observed when one of the π^- is in the end region, $-2 < y_1 < -1$.

In order to study the correlation between π^+ and π^- mesons, we try to choose a π^+ sample equivalent to that of π^-. Therefore, we always exclude the positive particle with the largest rapidity and exclude the π^+ with the negative rapidity if a proton is not observed. This selection gives a definite number of π^+ for each charged-prong topology and minimizes leading-particle effects so that emphasis will be on the nondiffractively produced particles. The resulting correlation function is shown in Fig. 2. The correlation is positive everywhere and much bigger than for $\pi^-\pi^-$. However, in the central region the shape of R^{+-} is similar to R^{--}, and y_d is again 2.

To investigate correlations further, we will look at the correlation distribution for a fixed number of pions—that is, the semi-inclusive correlation at fixed prong multiplicities. The inclusive correlation distributions reflect this kind of correlation, but also show effects resulting from the convolution of the prong multiplicity distribution with single-particle production spectra for individual multiplicities. With a fixed number n of like pions, the probability that one pion will be located at y_1 is $(n\sigma_n)^{-1}d\sigma_n/dy_1$, where σ_n is the cross section for production of n such pions. Since there are $n(n-1)$ possible combinations, the expected cross section for finding a pair of uncorrelated pions in coincidence at y_1 and y_2 is $n(n-1)(n\sigma_n)^{-1}(d\sigma_n/dy_1)(n\sigma_n)^{-1}d\sigma_n/dy_2$. As a measure of the correlation between n like pions, we may consider the extent to which the function

$$G_n(y_1, y_2) = \frac{d^2\sigma_n}{dy_1 dy_2} - \frac{n-1}{n\sigma_n}\frac{d\sigma_n}{dy_1}\frac{d\sigma_n}{dy_2} \tag{4}$$

differs from zero. Again, as with Eqs. (1) and (2), to minimize bias we divide by $\sigma_n^{-1}(d\sigma_n/dy_1) \times d\sigma_n/dy_2$ to obtain

$$R_n'(y_1, y_2) = R_n(y_1, y_2) + 1/n, \tag{5}$$

where

$$R_n(y_1, y_2) = \frac{\sigma_n d^2\sigma_n/dy_1 dy_2}{(d\sigma_n/dy_1)d\sigma_n/dy_2} - 1. \tag{6}$$

In the absence of correlation R_n' will be zero. Similar arguments apply for unlike pions. However, since there are n_+n_- pairs of pions instead of $n(n-1)$, we do not need the $1/n$ term, and with no correlations, $R_n(y_1, y_2)$ will be zero.

At lower energies (10 to 30 GeV/c), a sharp and striking neighboring (within $\Delta y < 0.5$) correlation is observed[1] in $G_n(y_1, y_2)$. Although attempts have been made to explain this feature by interference terms in the multiperipheral model,[9] resonance production in quasi-two-body reactions is a large effect at lower energies, making interpretation ambiguous. Neighboring correlation between π^- is *not observed* in the π^+p and pp in-

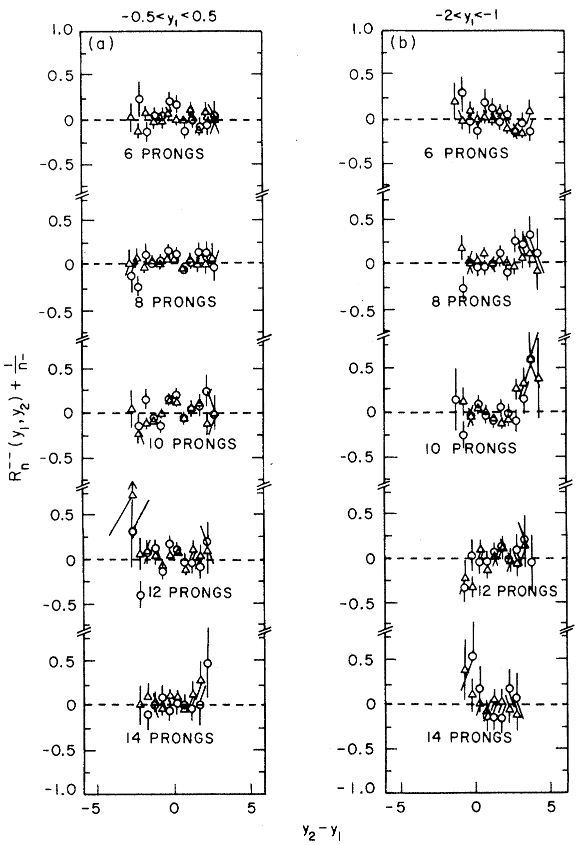

FIG. 3. Semi-inclusive $\pi^-\pi^-$ correlation functions $R_n^{--}(y_1,y_2)$ for different prong multiplicites plus the reciprocal of the number of π^-'s at 100 GeV/c. Triangles are for $pp\to\pi^-\pi^-X$, circles are for $\pi^+p\to\pi^-\pi^-X$.

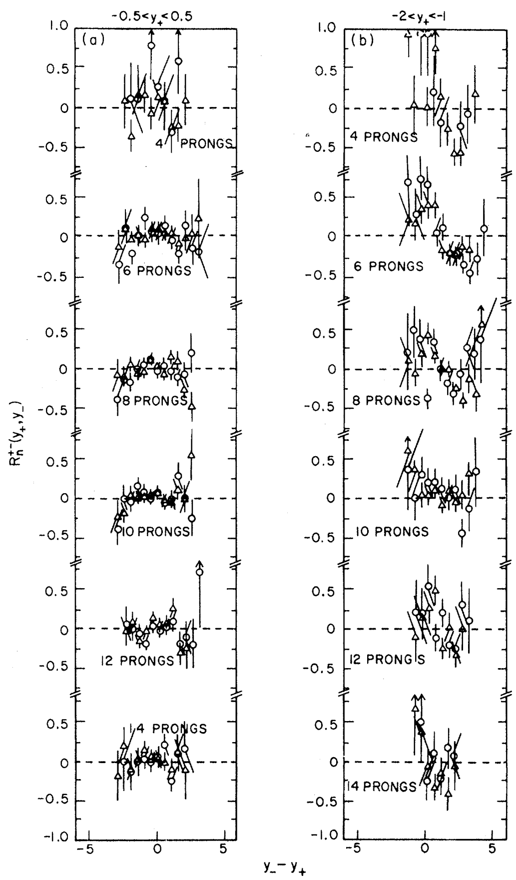

FIG. 4. Semi-inclusive $\pi^+\pi^-$ correlation functions $R_n^{+-}(y_+,y_-)$ for different prong multiplicites at 100 GeV/c. Triangles are for $pp\to\pi^+\pi^-X$, circles are for $\pi^+p\to\pi^+\pi^-X$.

teractions at 100 GeV/c. $R_n'(y_1,y_2)$ is shown in Fig. 3 for different charge multiplicities. In fact, these values are quite *consistent with zero for all multiplicities.* The absence of semi-inclusive correlations among pions is not surprising when y_1 is between -2 and -1 where in fact we saw no inclusive correlation in Figs. 1(c) and 1(d). However, in the central region where a strong inclusive correlation is observed [Figs. 1(a) and 1(b)] it is very interesting that there is *no correlation at a fixed pion multiplicity.* Contrary to lower-energy data, no clustering of π^- is observed.

The data of Singer *et al.*[6] for pp interactions at 200 GeV show negative correlations in R_n that decrease with increasing multiplicity. We note that these negative correlations are in every case consistent with $-1/n$. Therefore the proper interpretation is that there are *no* semi-inclusive correlations.

Without semi-inclusive correlations, the structure and large value of the inclusive correlation function can be understood to be the result of the single-particle distributions, which get narrower as the prong number increases, coupled with the multiplicity distribution. However, inclusive correlations, which are so similar in our reaction [Figs. 1(a), 1(b), 2(a), and 2(b)], still provide a description of the overall dynamics and could yet be of fundamental importance.

In the case of the unlike-pion correlation, shown in Fig. 4, there is again very little or no neighboring correlation when y_+ is in the central region, with the possible exception of the low-multiplicity events. It should be recalled that our observation of weak correlations in $\pi^+\pi^-$ is based on a reduced sample, biased against positive leading particles. This is consistent with pp data at 200 GeV/c[6] where most of the structure in R_n^{+-} is at low multiplicites and can be attributed to events with large rapidity gaps where leading-particle effects are large. We also observe a positive neighboring correlation when one of the pions is close to the end region, $-2 < y_+ < -1$. This demonstrates clustering of unlike charges at the end regions for low multiplicities.

We have presented inclusive and semi-inclusive correlation distributions for pions produced in 100 GeV/c π^+p and pp interactions. Corresponding distributions from different incident particles (π^+ or p) were shown to be very similar. The inclusive correlation distributions are peaked at $\Delta y = 0$, dropping off by 0.5 from their maximum values when $\Delta y = y_d = 2$. At fixed pion multiplicity, however, there is little or no correlation among like-charged pions, and any clustering of $\pi^+\pi^-$ pairs is associated with leading-particle effects. Therefore, at our energy; the inclusive correlation must arise from the relationship between the multiplicity distribution and the single-particle spectra at each multiplicity, rather than from a tendency for pions to be formed in clusters.

We thank the staff of the 30-in. bubble chamber and neutrino laboratory at the Fermi National Acceleration Laboratory for their assistance. The aid of the Proportional Hybrid System Consortium is gratefully acknowledged. We also acknowledge the contribution of the scanning and measuring staffs at both the University of California at Davis and Lawrence Berkeley Laboratory and the help of Randy Smith.

*Work supported in part by the U. S. Atomic Energy Commission under Contract No. AT(04-3)-34 PA 191.

†Work done under the auspices of the U. S. Atomic Energy Commission.

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Strange-Particle Production in Neutrino Interactions*

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Seven examples of strange-particle production by neutrinos are observed in the 12-ft bubble chamber. One event represents the first observation of associated production by the weak neutral current.

In this Letter we present data on strange-particle production in neutrino-nucleon interactions. We observe the first associated-production event induced by the weak neutral current, four events of associated production by the charged current, and two strangeness-changing ($\Delta S = \Delta Q = 1$) charged-current events. Although the data sample is small, it nevertheless provides the first glimpse of the thresh-