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

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ABSTRACT

Inclusive correlations between like and unlike charged pions are observed to be peaked and to drop off by 0.5 with a rapidity separation of two. At each charge multiplicity, π^-'s are uncorrelated in rapidity. The correlation for $\pi^+\pi^-$ is observed to be associated with leading particles.

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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 are made in terms of the inclusive correlation function:

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

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:

$$R(y_1,y_2) = C(y_1,y_2)/\left(\frac{1}{\sigma_{in}^2} \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}\right) \qquad (2)$$

$$= \left(\sigma_{in} \frac{d^2\sigma}{dy_1 dy_2} \Big/ \frac{d\sigma}{dy_1} \frac{d\sigma}{dy_2}\right) - 1 .$$

This ratio has experimental advantages over the correlation function (1) in that the measurement inefficiencies will cancel out if they are uncorrelated, and no absolute normalization problem exists when one counts the number of coincidences and the number of inelastic events in the data sample.

The data we used are from an exposure of the FNAL 30" 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 an LBL spiral reader, resulting in a better than 96% measuring efficiency for tracks going backward in the center of mass,

independent of multiplicity. An average of 80% for tracks going forward in the c.m. was obtained, with a decreasing efficiency for increasing multiplicity[8]. Although the correlation behavior 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^- 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.,

$$R(0,y_d) = R(0,0) - 0.5 \ . \qquad (3)$$

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 smallest rapidity if a proton is not observed. This selection gives a definite number of π^+ for each charged prong topology and minimizes leading particle effect so that emphasis will therefore be on the non-diffractively 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 slope of R^{+-} is similar to R^{--} and y_d is again two.

To further investigate correlations, 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 of like pions, n, the probability that one pion will be located at y_1 is $\frac{1}{n\sigma_n}\frac{d\sigma_n}{dy_1}$ 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 $n(n-1)(\frac{1}{n\sigma_n}\frac{d\sigma_n}{dy_1})(\frac{1}{n\sigma_n}\frac{d\sigma_n}{dy_2})$. As a measure of correlation between n like pions, we may consider the extent to which the function,

$$G_n(y_1,y_2) = \frac{d^2\sigma_n}{dy_1dy_2} - \frac{n-1}{n\sigma_n}\frac{d\sigma_n}{dy_1}\frac{d\sigma_n}{dy_2} \tag{4}$$

differsfrom zero. Again, as with equation (1) and (2) to minimize bias we divide by $\frac{1}{\sigma_n}\frac{d\sigma_n}{dy_1}\frac{d\sigma_n}{dy_2}$ to obtain

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

where

$$R_n(y_1,y_2) = (\sigma_n \frac{d^2\sigma_n}{dy_1dy_2} / \frac{d\sigma_n}{dy_1}\frac{d\sigma_n}{dy_2}) - 1 . \tag{6}$$

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 $\frac{1}{n}$ term and with no correlations, $R_n(y_1,y_2)$ will be zero.

At lower energies, a sharp and striking neighboring (within $\Delta y<.5$) 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 multiperpheral model[9], resonance production in quasi-two-body reactions is a large effect at lower energies making interpretation ambiguous. Sharp neighboring correlation between π^- is not observed in the π^+p and pp interactions 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 consistant with zero for all multiplicities. The absence of semi-inclusive correlation among pions multiplicity is not surprising when y_1 is between -2 and -1 where in fact we saw no inclusive correlation in figures 1c and 1d. However, in the central region where strong inclusive correlation is observed (fig. 1a,1b) it is very interesting that there is still no correlation at a fixed pion multiplicity. Contrary to lower energy data, no clustering of π^- is observed.

At FNAL energies, phase space effects on the correlation should be negligible except at large rapidity separation. Singer et. al.[6,10] have a phase space model which gives $R_n(y_1,y_2)$ approximately constant and equal to $-\frac{1}{n}$ at all but large rapidity differences, a result equivalent to stating $R'_n(y_1,y_2) = 0$.

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 consistant with data at 200 GeV/c[10] where most of the structure in R_n^{+-} is at low multiplicities 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 correlations 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 one 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 within two units of rapidity.

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Figure Captions

Fig. 1. Inclusive $\pi^-\pi^-$ correlation functions $R^{--}(y_1,y_2)$.

Fig. 2. Inclusive $\pi^+\pi^-$ correlation functions $R^{+-}(y_+,y_-)$.

Fig. 3. Semi-inclusive $\pi^-\pi^-$ correlation functions $R_n^{--}(y_1,y_2)$ for different prong multiplicities plus one over the number of π^-'s.

Fig. 4. Semi-inclusive $\pi^+\pi^-$ correlation functions $R_n^{+-}(y_+,y_-)$ for different prong multiplicities.

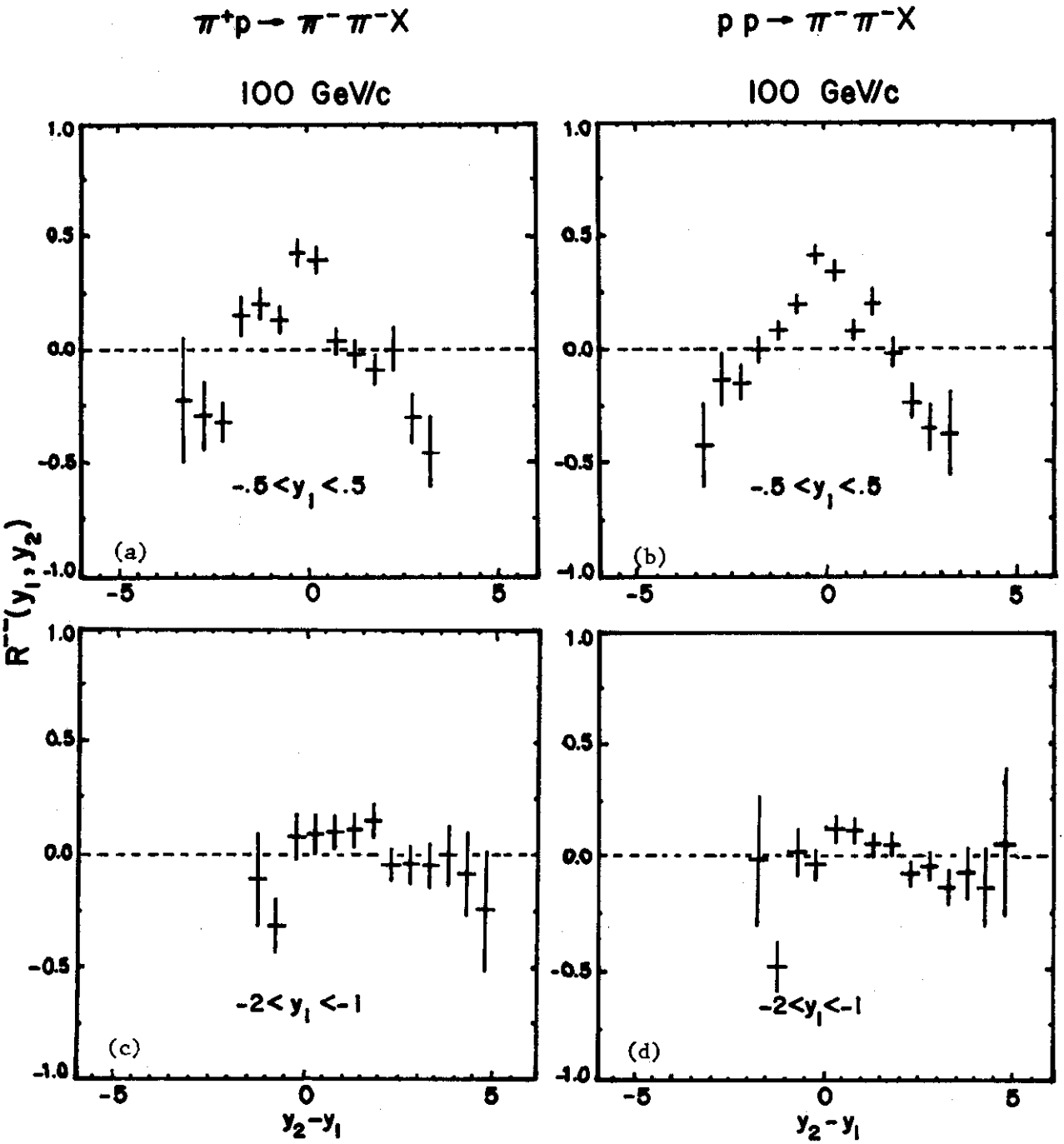
π⁺p → π⁻π⁻X
100 GeV/c
p p → π⁻π⁻X
100 GeV/c
R⁻⁻(y₁, y₂)
-.5<y₁<.5
(a)
-.5 <y₁<.5
(b)
-2< y₁ <-1
(c)
-2<y₁<-1
(d)
y₂-y₁
y₂-y₁

Fig. 1

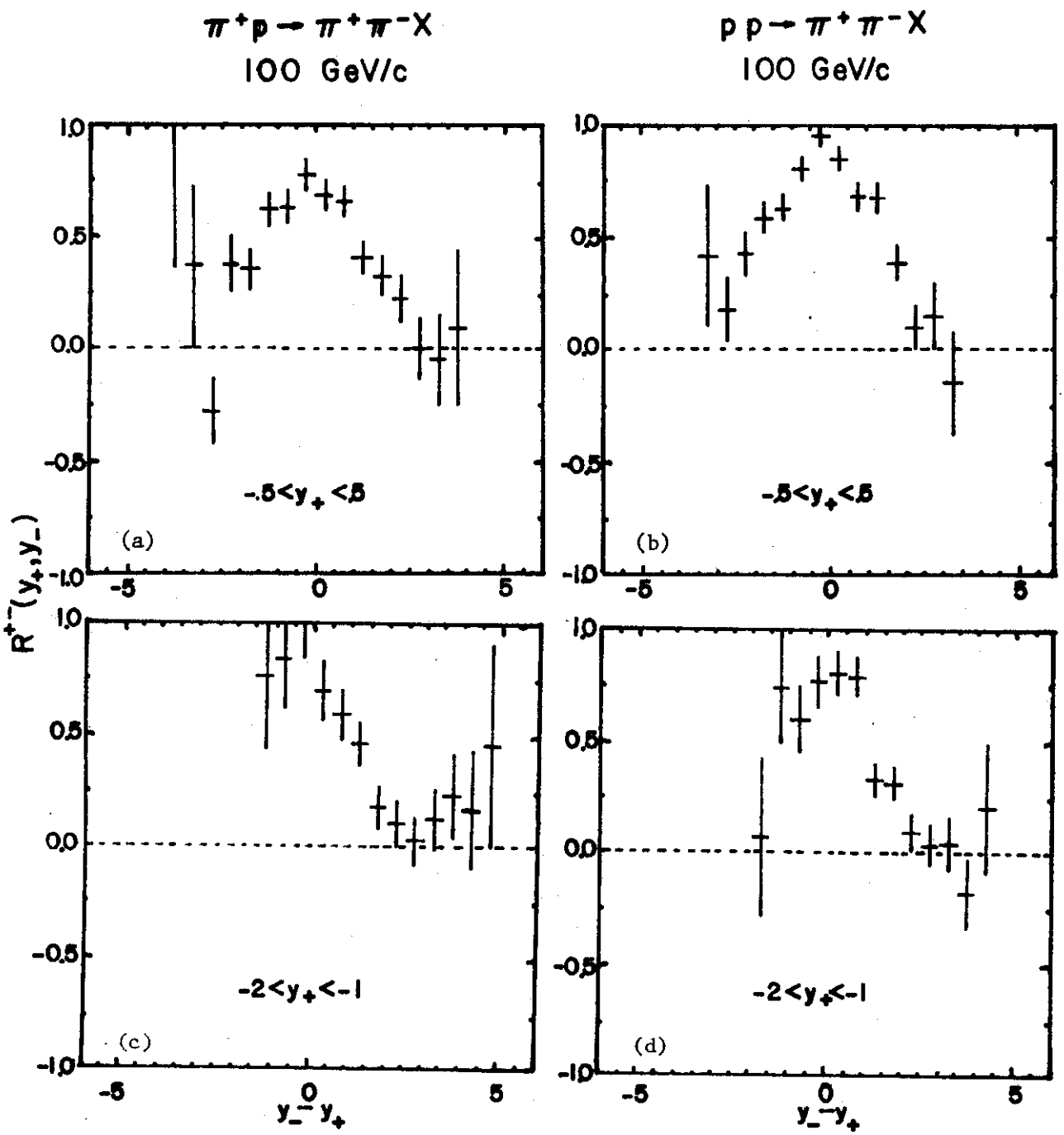

Fig. 2

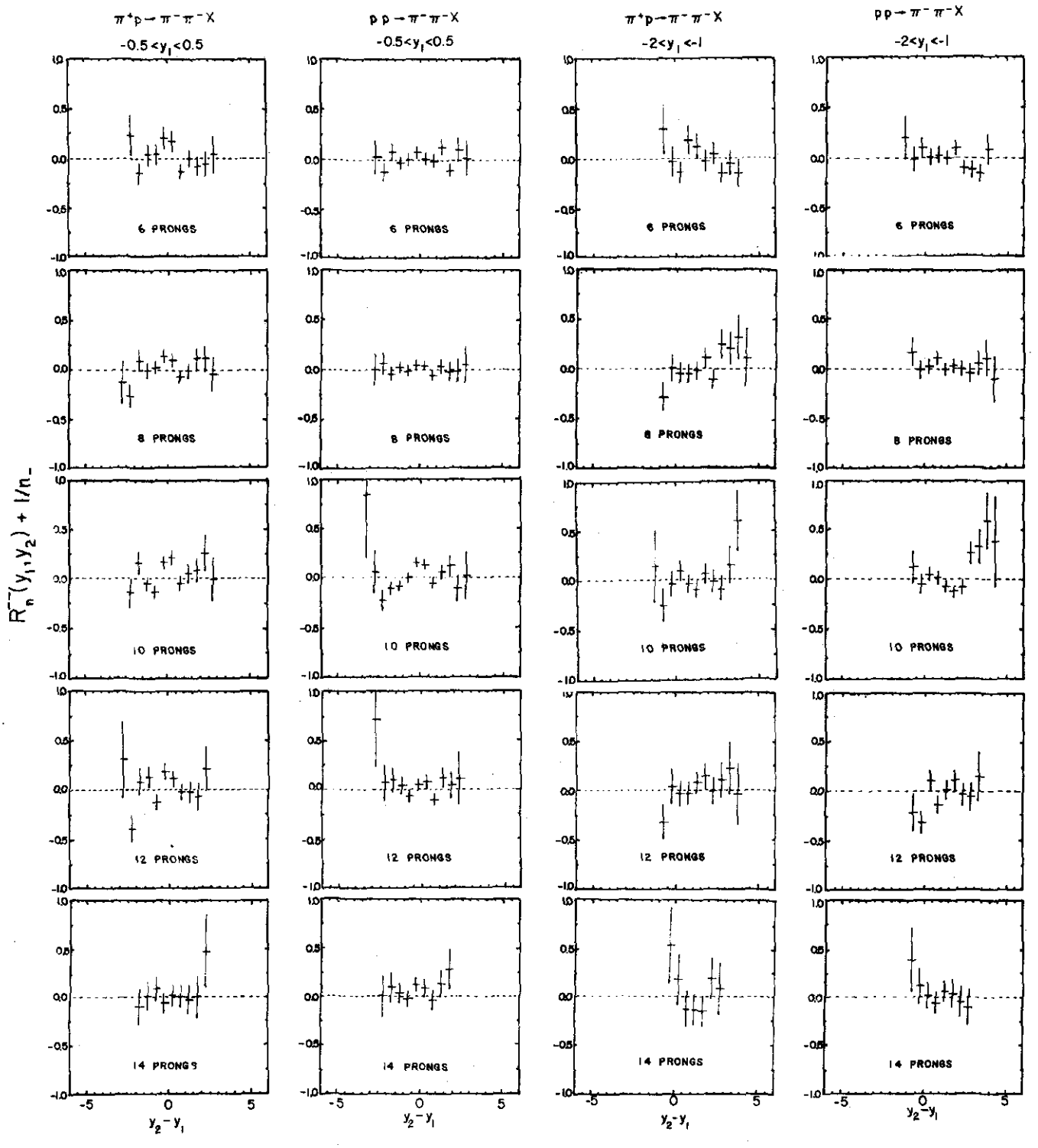
π⁺p → π⁻π⁻X
-0.5<y₁<0.5
pp → π⁻π⁻X
-0.5<y₁<0.5
π⁺p → π⁻π⁻X
-2<y₁<-1
pp → π⁻π⁻X
-2<y₁<-1
6 PRONGS
8 PRONGS
10 PRONGS
12 PRONGS
14 PRONGS
R⁻ₙ(y₁,y₂) + 1/n₋
y₂ − y₁

Fig. 3

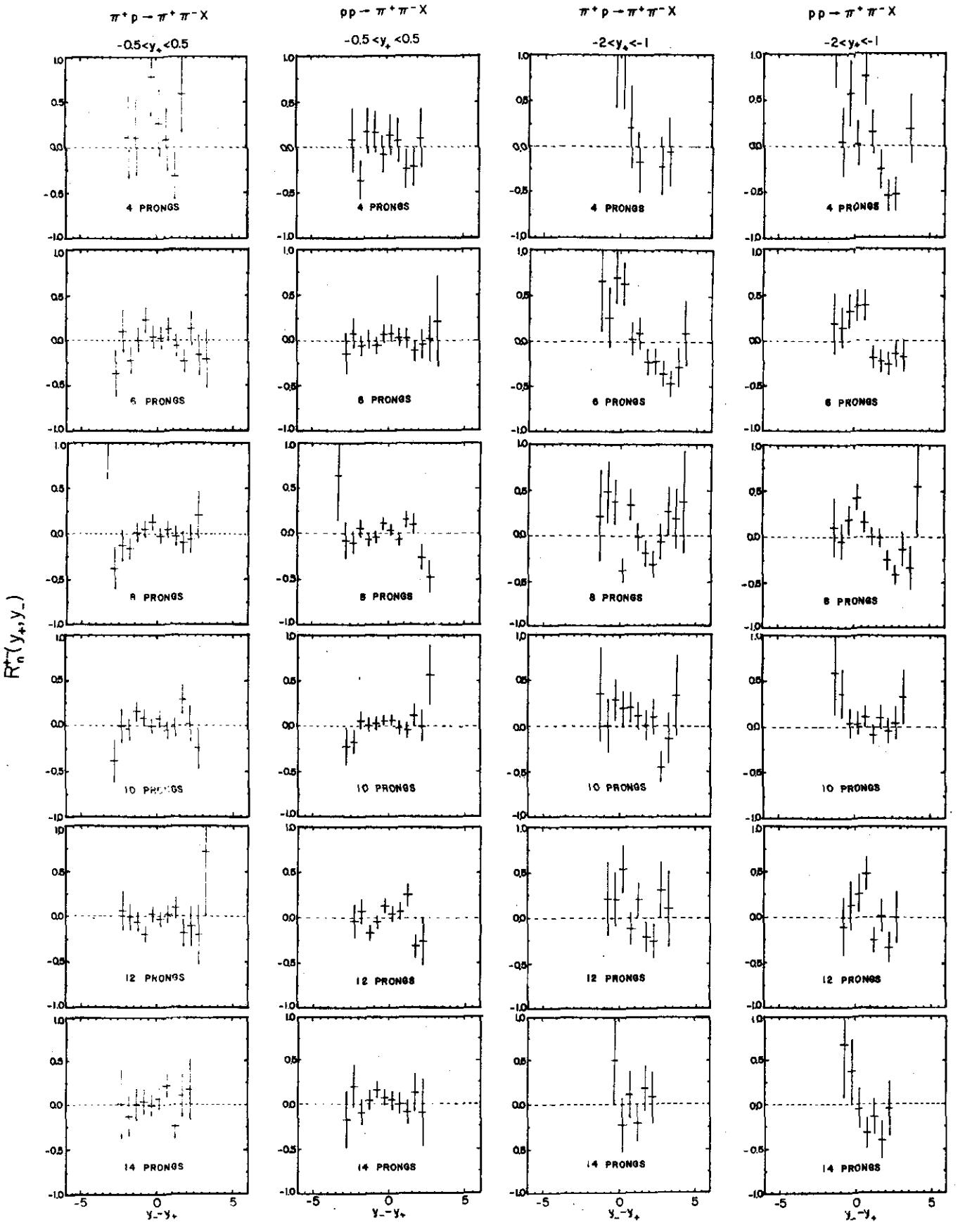
$\pi^+ p \to \pi^+ \pi^- X$
$-0.5 < y_+ < 0.5$
$pp \to \pi^+ \pi^- X$
$-0.5 < y_+ < 0.5$
$\pi^+ p \to \pi^+ \pi^- X$
$-2 < y_+ < -1$
$pp \to \pi^+ \pi^- X$
$-2 < y_+ < -1$
4 PRONGS
6 PRONGS
8 PRONGS
10 PRONGS
12 PRONGS
14 PRONGS
$R_n^{+-}(y_+, y_-)$
$y_- - y_+$

Fig. 4