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Observation of Three-Particle Correlations in Inclusive $\pi^- p$ Reactions at 200 GeV/c

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Abstract

The production of apparent three-particle rapidity correlations from a convolution of real two-particle correlations is studied. Aside from these spurious correlations, a small but statistically significant "real" three-particle correlations is observed for the (-+-) charge state. No corresponding correlation is observed for the (---) system.

Extensive studies [1] of correlation phenomena in high energy inclusive reactions have established the fact that hadrons are produced not independently, but in clusters. The origin and nature of these clusters are not well understood. Early speculation that conventional resonances could account for most of the correlation observed seems to be ruled out by more recent studies [2]. The correlation data do indicate that the cluster multiplicity k_o is typically small, as is the dispersion parameter δ [3].

Two-particle correlations have been studied in a large number of experiments [1]. The possibility of multi-particle correlations in pp inclusive reactions has been investigated by three groups of authors [4, 5, 6]; no clear evidence of three-particle correlations has been observed within the limits of the statistics of these experiments. We report here a search for, and observation of, three-particle correlations in $\pi^- p$ inclusive reactions at 200 GeV/c. The data come from a sample of 17,000 events of all topologies obtained using the 30-inch bubble chamber/wide gap spark chamber hybrid spectrometer at Fermilab. Experimental procedures are described elsewhere [7, 8].

In analogy with previous studies [7, 9] we define the single-particle rapidity density $\rho_1(y) = \sigma^{-1} d\sigma/dy$, the two-particle density $\rho_2(y) = \sigma^{-1} d^2\sigma/dy_1dy_2$, and the three-particle density $\rho_3(y) = \sigma^{-1} d^3\sigma/dy_1dy_2dy_3$. The normalized three-particle correlation function is then written [10]:

$$R_3(y_1, y_2, y_3) = \frac{\begin{bmatrix} \rho_3(y_1, y_2, y_3) + 2\rho_1(y_1)\rho_1(y_2)\rho_1(y_3) \\ -\rho_2(y_1, y_2)\rho_1(y_3) - \rho_2(y_2, y_3)\rho_1(y_1) \\ -\rho_2(y_3, y_1)\rho_1(y_2) \end{bmatrix}}{\rho_1(y_1)\rho_1(y_2)\rho_1(y_3)} \qquad (1)$$

It is useful to define the quantities

$$R_3'(y_1, y_2, y_3) = \frac{[\rho_3(y_1, y_2, y_3) - \rho_1(y_1)\,\rho_1(y_2)\,\rho_1(y_3)]}{\rho_1(y_1)\,\rho_1(y_2)\,\rho_1(y_3)} \qquad (2)$$

and

$$R_3''(y_1, y_2, y_3) = \frac{\rho_2(y_1, y_2)\,\rho_1(y_3) + \rho_2(y_2, y_3)\,\rho_1(y_1) + \rho_2(y_3, y_1)\,\rho_1(y_2) - 3\,\rho_1(y_1)\,\rho_1(y_2)\,\rho_1(y_3)}{\rho_1(y_1)\,\rho_1(y_2)\,\rho_1(y_3)} \qquad (3)$$

Then

$$R_3(y_1, y_2, y_3) = R_3'(y_1, y_2, y_3) - R_3''(y_1, y_2, y_3) \qquad (4)$$

i.e, a true three-particle correlation will appear as the difference between R_3', the excess of the normalised 3-particle density over the combinatorial product of single-particle densities, and a background term R_3'' which represents apparent 3-particle correlations arising from the presence of real 2-particle correlations in the data.

We integrate equations (1), (2), and (3) over y_1 and study the resulting correlation functions $R_3(\Delta y_1, \Delta y_2)$, $R_3'(\Delta y_1, \Delta y_2)$ and $R_3''(\Delta y_1, \Delta y_2)$, where $\Delta y_1 = y_1 - y_2$ and $\Delta y_2 = y_2 - y_3$, for the 200 GeV/c inclusive reactions

$$\pi^- p \rightarrow \pi^-\pi^-\pi^- + \text{anything} \qquad (5)$$

and

$$\pi^- p \rightarrow \pi^-\pi^+\pi^- + \text{anything}. \qquad (6)$$

In Fig. 1A (a) - (e), left, we show the values of $R_3'(\Delta y_1, \Delta y_2)$ (circles) and $R_3''(\Delta y_1, \Delta y_2)$ (triangles), for reaction 5, as a function of Δy_1 for various intervals of Δy_2. The corresponding values of $R_3'(\Delta y_1, \Delta y_2)$ and $R_3''(\Delta y_1, \Delta y_2)$ for reaction 6 are shown in Fig. 1B (a) - (e), to the right. We note that over most of the 3-

particle rapidity space there is essentially no difference between the plotted circle and triangle points, i.e., the convolution of the various possible two-particle correlation effects in $R_3''(\Delta y_1, \Delta y_2)$ accounts for essentially all of the excess in the normalized three-particle rapidity density in $R_3'(\Delta y_1, \Delta y_2)$. There appears to be an exception to this behavior for the (- + -) charge combination, reaction 6, in the data for which the rapidity differences Δy_1 and Δy_2 are both small, in Fig. 1B (c).

The quantity $R_3(\Delta y_1, \Delta y_2) = R_3'(\Delta y_1, \Delta y_2) - R_3''(\Delta y_1, \Delta y_2)$, which represent the true, dynamical correlation, is plotted against Δy_1 for various intervals of Δy_2 for the same data in Figs. 2A (a) - (e) and 2B (a) - (e). (Note the change of scale from the distributions of Fig. 1.) A background (smooth curve) is simulated by using a Monte Carlo calculation to generate events which reproduce the features of single particle inclusive data, and include no explicit short-range correlations, to determine values of $R_3'(\Delta y_1, \Delta y_2)$, from which the observed $R_3''(\Delta y_1, \Delta y_2)$ are subtracted. There is clear evidence of 3-particle correlation for the (- + -) charge combination, reaction 6, when both Δy_1 and Δy_2 are small, Fig. 2B (c).

Values for the 3-particle correlation maxima at $\Delta y_1 = \Delta y_2 = 0$ for (- + -) and (- - -) charge states are compared with maxima for 2-particle correlations at $y_1 = \Delta y = 0$ for (- -) and (- +) charge states measured [7] in the same experiment. In the case of both like- and unlike-charge combinations, the 3-particle correlations are weaker than the 2-particle correlations. These results, which directly measure correlation functions, are in agreement with a study of the same data using a generalised multi-rapidity gap method [11], which suggests that clusters predominantly consist of two charged particles, and that the relative number of 3-particle clusters is less than 15% of the total. The absence of (- - -) clustering, which would require a large charge exchange ΔQ in the rapidity chain, is not unexpected [12].

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Table I. Two- and three-particle correlations at small rapidity separation

Charge Combination	Correlation R
- + -	$R_3(0, 0, 0) = 0.26 \pm 0.17$
- - -	$R_3(0, 0, 0) = 0.01 \pm 0.06$
- -	$R_2(0, 0) = 0.23 \pm 0.07$
- +	$R_2(0, 0) = 0.69 \pm 0.05$

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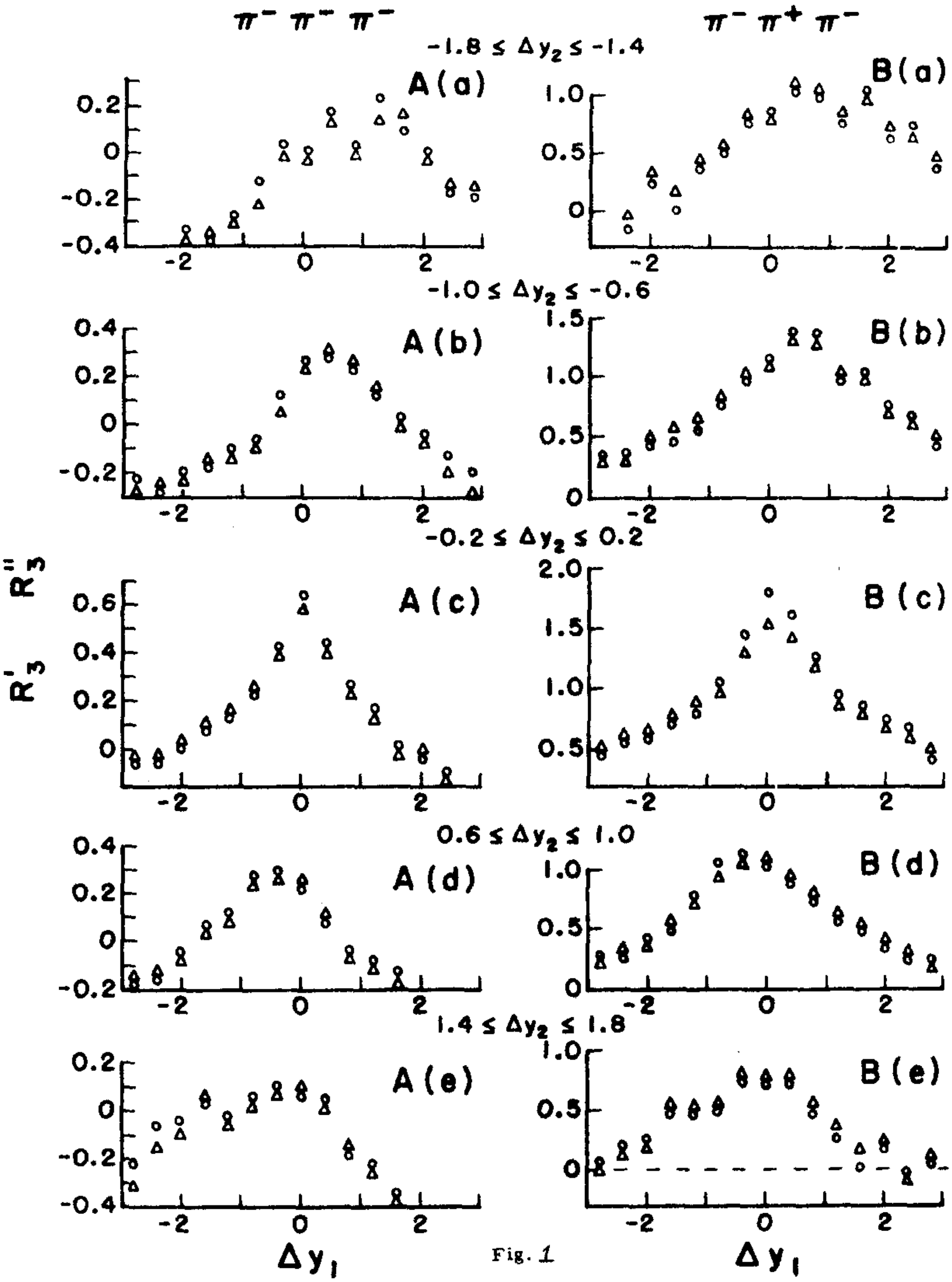
Figure Captions

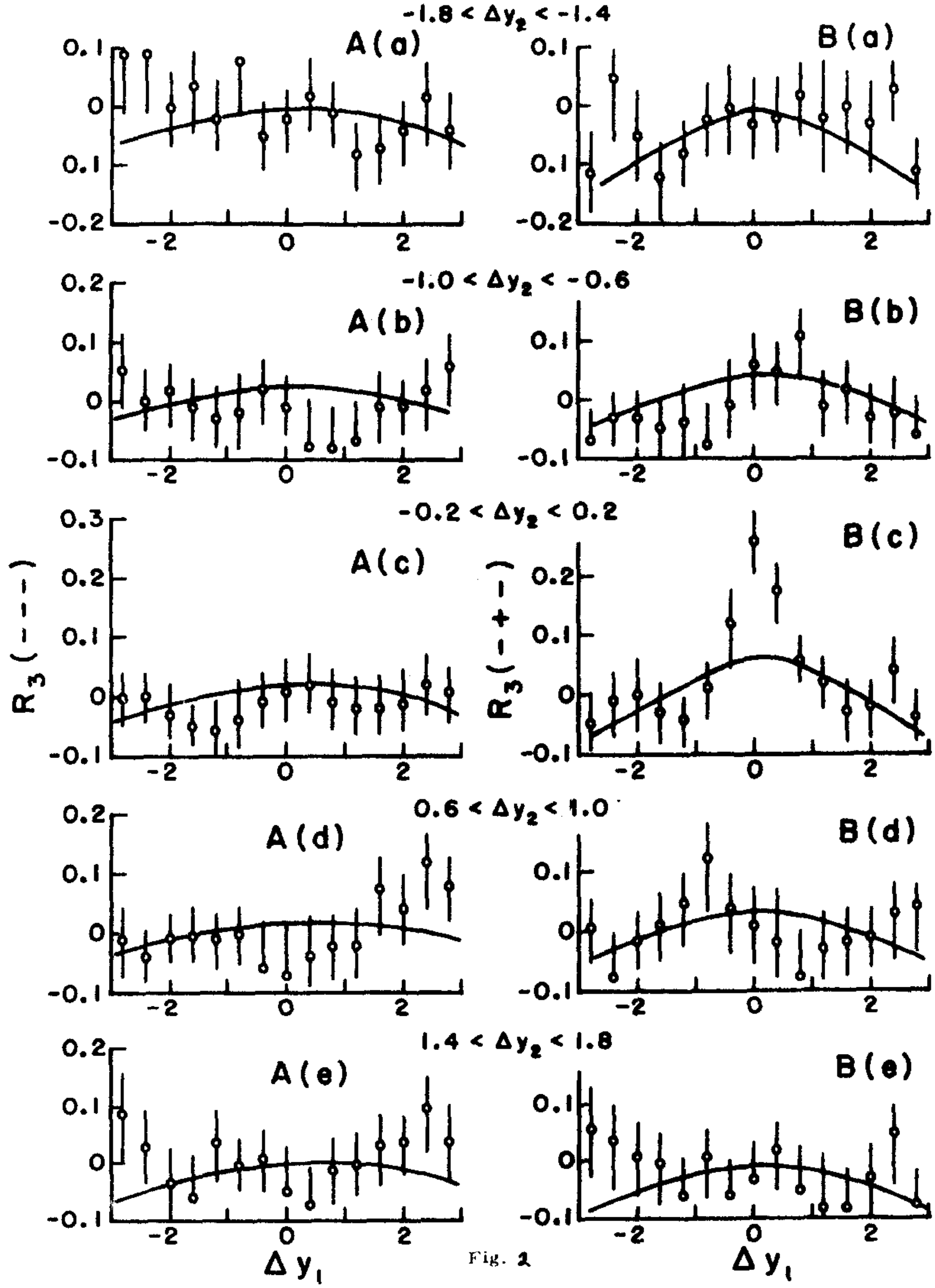
Fig. 1 Values of $R_3'(\Delta y_1, \Delta y_2)$ (circles) and $R_3''(\Delta y_1, \Delta y_2)$ (triangles) as a function of $\Delta y_1 = y_1 - y_2$ for different intervals of $\Delta y_2 = y_2 - y_3$. Values for the (- - -) charge combination are shown on the left, A(a) - (e); values for the (- + -) charge combination are shown on the right, B(a) - (e).

Fig. 2 Values of the true dynamical correlation $R_3(\Delta y_1, \Delta y_2) = R_3'(\Delta y_1, \Delta y_2) - R_3''(\Delta y_1, \Delta y_2)$ as a function of Δy_1 for various intervals of Δy_2. Values for the (- - -) charge combination are shown on the left, A(a) - (e); values for the (- + -) charge combination are shown on the right, B(a) - (e).



$\pi^- \pi^- \pi^-$
$\pi^- \pi^+ \pi^-$
$-1.8 \le \Delta y_2 \le -1.4$
A (a)
B (a)
$-1.0 \le \Delta y_2 \le -0.6$
A (b)
B (b)
$-0.2 \le \Delta y_2 \le 0.2$
A (c)
B (c)
$0.6 \le \Delta y_2 \le 1.0$
A (d)
B (d)
$1.4 \le \Delta y_2 \le 1.8$
A (e)
B (e)
R_3' R_3''
Δy_1
Δy_1

Fig. 1



-1.8 < Δy2 < -1.4
A(a)
B(a)
-1.0 < Δy2 < -0.6
A(b)
B(b)
-0.2 < Δy2 < 0.2
A(c)
B(c)
0.6 < Δy2 < 1.0
A(d)
B(d)
1.4 < Δy2 < 1.8
A(e)
B(e)
R3(- - -)
R3(- + -)
Δy1
Δy1

Fig. 2