PUB-75-095-E
E-0002

(Submitted to Physics Letters B)

#2B

FERMILAB-PUB-75-095-E

Two Particle Correlations in the Central Region of pp and $\pi^- p$ Interactions at 100-300 GeV/c

B. Y. Oh, W. Morris, D. L. Parker, G. A. Smith, J. Whitmore
R. J. Miller, J. J. Phelan, P. F. Schultz, L. Voyvodic, R. Walker,
R. Yaari, E. W. Anderson, H. B. Crawley, W. J. Kernan, F. Ogino,
R. G. Glasser, D. G. Hill, G. McClellan, H. L. Price,
B. Sechi-Zorn, G. A. Snow and F. Svrcek

Michigan State University, East Lansing, Michigan 48824*
Argonne National Laboratory, Argonne, Illinois 60439#
Fermi National Accelerator Laboratory, Batavia, Illinois 60510#
Iowa State University and Ames Laboratory, ERDA, Ames, Iowa 50010#
University of Maryland, College Park, Maryland 20742#

ABSTRACT

Significant positive correlations are seen for all charge combinations of pion pairs with small rapidity separation. Joint rapidity-azimuthal correlations show that this positive correlation occurs when like (unlike) pions are produced with small (large) separation in azimuth.

---

*Research supported in part by the National Science Foundation.
#Research supported in part by the U.S. Energy Research and Development Administration.

Inclusive correlations between two particles in the central region have been studied in several experiments at Fermilab and the CERN ISR.[1] These correlations are found to be nearly independent of the incident beam momentum and short-ranged in nature. Recently, data have become available for fixed charged particle multiplicity (semi-inclusive). Fermilab experiments[2,3] are consistent with little or no correlation between like pions and show indications that the correlations between unlike pions are restricted to low multiplicity final states. An ISR experiment[4] studying joint rapidity and azimuthal correlations shows a strong short-range correlation which is attributed to the independent emission of clusters, possibly resonances. This positive rapidity correlation is strongest when the two particles are travelling in the same or in opposite directions in transverse momentum. However, no measurement of the dependence of these correlations on the charges of the two particles was possible.

We present new data on the rapidity and azimuthal dependence of the two particle correlation functions for like and unlike pairs of pions at 100-300 GeV/c. The data come from a study of 12,203 events produced in 200 and 300 GeV/c pp and 100 GeV/c π^-p interactions in the Fermilab 30-inch hydrogen bubble chamber (5371, 4316 and 2516 events respectively). The following reactions are considered: $p(\pi^-)+p \rightarrow \pi^-\pi^-$ + anything, $\pi^+\pi^+$ + anything, $\pi^c\pi^c$ + anything, and $\pi^-\pi^+$ + anything. For brevity, (--), (++), (cc) and (-+) are used to denote these reactions.

In studying correlations in the central region, it is advantageous to limit the analysis to the charged multiplicity range, $\langle n\rangle \lesssim n \lesssim 2\langle n\rangle$, in order to remove complications due to diffraction in low multiplicity events and phase space restrictions in the high multiplicity events. For this reason, we limit our analysis to 6 through 14 prong events, and take all negative particles to be π^-'s and all positive particles not identified as protons by ionization (up to 1.4 GeV/c laboratory momentum) to be π^+'s. The resultant contamination from protons and kaons in the central region (in fact, for C.M. rapidity $y = 1/2\ \ell n[E+P_L/E-P_L] < 3$) is considered to be negligible within the present level of statistics.

We denote by n the total number of charged particles and by m(p) the number of minus (positive) charged particles in an event. We specify two particles by their C.M. Rapidities, y_1 and y_2, and define single and two particle rapidity densities:

$$\rho_n(y) = \frac{1}{\sigma_n}\frac{d\sigma_n}{dy} \quad \text{and} \quad \rho_n(y_1,y_2) = \frac{1}{\sigma_n}\frac{d\sigma_n}{dy_1\, dy_2}\ , \qquad (1)$$

where σ_n is the cross section for the production of n charged particles. These particles are further specified by the azimuthal angles, ϕ_1 and ϕ_2, of their transverse momentum vectors. Extending the work of Ko[5] and Eggert et al.,[4] we define the semi-inclusive rapidity correlation functions:

$$C_n(1,2) = \frac{\rho_m(1,2)}{m(m-1)} - \frac{\rho_m(1)}{m}\cdot\frac{\rho_m(2)}{m} \qquad (2a)$$

$$C_n(1,2) = \frac{\rho_p(1,2)}{p(p-1)} - \frac{\rho_p(1)}{p}\cdot\frac{\rho_p(2)}{p} \qquad (2b)$$

$$C_n(1,2) = \frac{\rho_n(1,2)}{n(n-1)} - \frac{\rho_n(1)}{n}\cdot\frac{\rho_n(2)}{n} \qquad (2c)$$

for (--), (++), and (cc) respectively, and

$$C_n(1,2) = \frac{\rho_{mp}(1,2)}{m\cdot p} - \frac{\rho_m(1)}{m} \cdot \frac{\rho_p(2)}{p} \qquad (2d)$$

for (-+). The above correlation functions are zero everywhere in the absence of correlations* and, for the first time, treat different charge combinations on an equivalent basis.

By way of introduction to the data, we show in Fig. 1(a) correlation functions for 8 prong events at 200 GeV/c. We select $|y_2| < 0.5$ and plot $C_n(1,2) = C_n(\Delta y)$ as a function of $\Delta y = y_1 - y_2$. As $C_n(\Delta y)$ is symmetric about y=0 for pp reactions, we show $C_n(\Delta y)$ as the average of the $\pm\Delta y$ data. Strong positive correlations at y=0 and negative correlations at $\Delta y \approx 1$-3 are evident and generally similar for all charge combinations. Neither the existence of the (±±) correlations nor the similarities among the different charge combinations has been noted before at these energies.

Plots of $C_n(\Delta y)$ (not shown) for different multiplicities from pp and π^-p reactions indicate similar correlation patterns, although the magnitude of these correlations diminishes with n for a given charge combination. In order to combine $C_n(\Delta y)$ functions for different n, we calculate $J_n \cdot C_n(\Delta y)$, where J_n = (m-1), (p-1), (n-1) and m for (--), (++), (cc) and (-+) respectively. This J_n dependence is suggested in the independent cluster emission model.[6] In Fig. 1(b) we show that $J_n \cdot C_n(|\Delta y| < 0.5)$ for $|y_2| < 0.5$ is, within errors, independent of n.

Motivated by the absences of any significant dependence on n, we define an n-averaged correlation function:

---

*$\rho_{mp}(1,2)$ denotes the two-particle rapidity density with a π^- at y_1 and a π^+ at y_2.

$$\langle J_n \cdot C_n(\Delta y)\rangle = \frac{\Sigma\, J_n \cdot C_n(\Delta y)\ \sigma_n}{\Sigma\, \sigma_n} \tag{3}$$

This function is plotted versus Δy for $|y_2| < 0.5$ in Fig. 2. The similarity in shape among the distributions for different charge combinations is clear. For the $\pi^- p$ reactions, we note that the positive correlations at $\Delta y=0$ are somewhat smaller than for pp and a significant positive correlation is evident near $\Delta y=3$, which may well be evidence for a diffractive effect in the high multiplicity events.

We now turn to the joint correlation function for rapidity and azimuthal angle. In analogy to Eq. (3), we define

$$\langle J_n \cdot C_n(\Delta y,\Delta\phi)\rangle = \frac{\Sigma\, J_n \cdot C_n(\Delta y,\Delta\phi)\ \sigma_n}{\Sigma\, \sigma_n} \tag{4}$$

where

$$C_n(\Delta y,\Delta\phi) = \frac{\rho_m(y_1\phi_1,y_2\phi_2)}{m(m-1)} - \frac{\rho_m(y_1\phi_1)}{m} \cdot \frac{\rho_m(y_2\phi_2)}{m} \tag{5}$$

for (--) and similar expressions in analogy to Eqs. (2b-2d). These joint correlation functions are plotted in Fig. 3 for the same data as in Fig. 2. The most apparent features are strong correlations at Δy and $\Delta\phi \approx 0$ for (±±) and small Δy and $\Delta\phi \approx \pi$ for (-+), as well as somewhat weaker correlations at small Δy and $\Delta\phi \approx 0$ for (-+). The (cc) data, which show a positive short-range correlation throughout the full $\Delta\phi$ range and indicate a shorter range of the rapidity correlation for $\Delta\phi \approx 0$ than for $\Delta\phi \approx \pi$, are in qualitative agreement with those of Eggert et al.[4] However, an important new result from our data is that these features of the (cc) data result from a combination of the dissimilar data for like and unlike pion pairs. Thus, we find that like pairs of pions appear to have a shorter correlation length in rapidity than unlike pairs of pions.

To examine possible origins of these effects, we show in Fig. 4(a) the quantity $\pi d\sigma/d\Delta\phi$ for $|y_2| < 0.5$ and $|\Delta y| < 0.5$ with calculations[7] which include Bose-Einstein statistics for identical and nonidentical particle emission from a single cluster. These calculations are in good agreement with the (±±) data, as well as the (-+) data for $\pi^- p$ reactions. However, there are significant differences in the (-+) case for pp reactions, particularly near $\Delta\phi = 0$ and π.

In order to explore the possibility that ρ° clusters are responsible for the behavior of the (-+) data, we have plotted in Fig. 4(b) (-+) effective mass distributions, with $|y_2| < 0.5$, $|\Delta y| < 0.5$ and $\Delta\phi > \pi/2$. The latter cut is intended to enrich a ρ° signal because of the tendency for π's from ρ° decay to be concentrated near $\phi = \pi$. Also shown is the area normalized sum of the (--) and (++) spectra. The data do not show any significant ρ° signal in the rapidity and azimuthal regions under consideration. This observation is particularly interesting, in view of the ρ° signal which has been reported[1] in different experiments, which however use somewhat different selection criteria.

In summary, we have shown (1) the presence of short ranged rapidity correlations in all charged combinations; (2) that this correlation has different $\Delta\phi$ dependence for different charge combinations; (3) that effects due to Bose-Einstein statistics are probably observed, most prominently in the (±±) spectra near $\Delta y \cong \Delta\phi \cong 0$. However, we may speculate that the effects observed in the (--) data near $\Delta y = \Delta\phi = 0$ could also be due to the presence of charged clusters (for example, charged A_2 type clusters produced with high transverse momentum) or (--++) neutral clusters; and (4) that no significant ρ° production is observed for small Δy in the central region.

REFERENCES

1. W. Ko, "Summary of Particle Correlation Study Results", University of California, Davis, 1974, and Proceedings of the XVIIth International Conference on High Energy Physics, London (1974), p. 76.
2. R. Singer et al., Phys. Letters 49B (1974) 481.
3. J. Erwin et al., Phys. Rev. Letters 33 (1974) 1443.
4. K. Eggert et al., Nuclear Physics B86 (1975) 201.
5. W. Ko, Phys. Rev. Letters 28 (1972) 935.
6. E. L. Berger, Phys. Letters 49B (1974) 369; A. Morel and G. Plaut, Nucl. Phys. B78 (1974) 541; F. Hayot and M. LeBellac, Nucl. Phys. B86 (1975) 333.
7. G. Ranft and J. Ranft, Physics Letters 53B (1974) 188.

FIGURE CAPTIONS

Fig. 1 (a) $C_n(\Delta y)$ for $|y_2| < 0.5$ for 200 GeV/c 8 prong events.

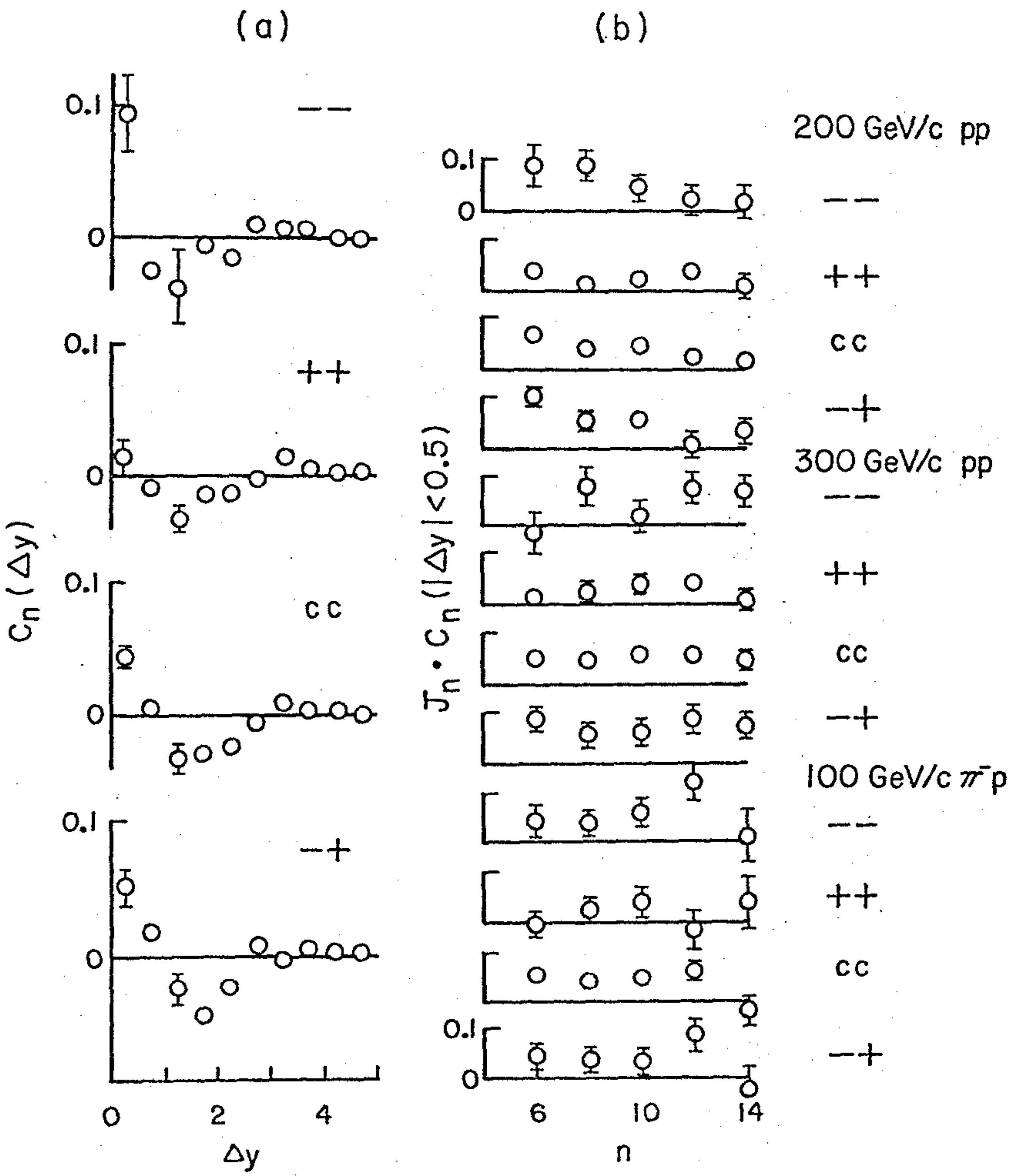
(b) $J_n \cdot C_n(|\Delta y| < 0.5)$ for $|y_2| < 0.5$ versus n.

Fig. 2 $\langle J_n \cdot C_n(\Delta y) \rangle$ for $|y_2| < 0.5$ versus Δy. The curves are hand-drawn to show the trends in the data (averaged between 200 and 300 GeV/c in the pp data). Errors on the pp data are comparable to the size of the open circles.

Fig. 3 $\langle J_n \cdot C_n(\Delta y, \Delta\phi) \rangle$ versus Δy and $\Delta\phi$ with $|y_2| < 0.5$. Four $\Delta\phi$ regions ($0 < \Delta\phi < \pi/4$, etc.) are plotted for each charge combination. The curves are drawn in a similar manner as for Fig. 2. Typical errors are shown.

Fig. 4 (a) $\Delta\phi$ distributions for $|y_2| < 0.5$ and $|\Delta y| < 0.5$. The curves are calculations from Ref. 7.

(b) $m_{\pi\pi}$ distributions for (-+) for the same selections as in (a), plus $\Delta\phi > \pi/2$. The dots represent the sum of the (--) and (++) data normalized to the same area.



(a)
(b)
0.1
0
−−
++
cc
−+
$C_n(\Delta y)$
0
2
4
Δy
200 GeV/c pp
300 GeV/c pp
100 GeV/c π⁻p
$J_n \cdot C_n(|\Delta y|<0.5)$
6
10
14
n

Figure 1

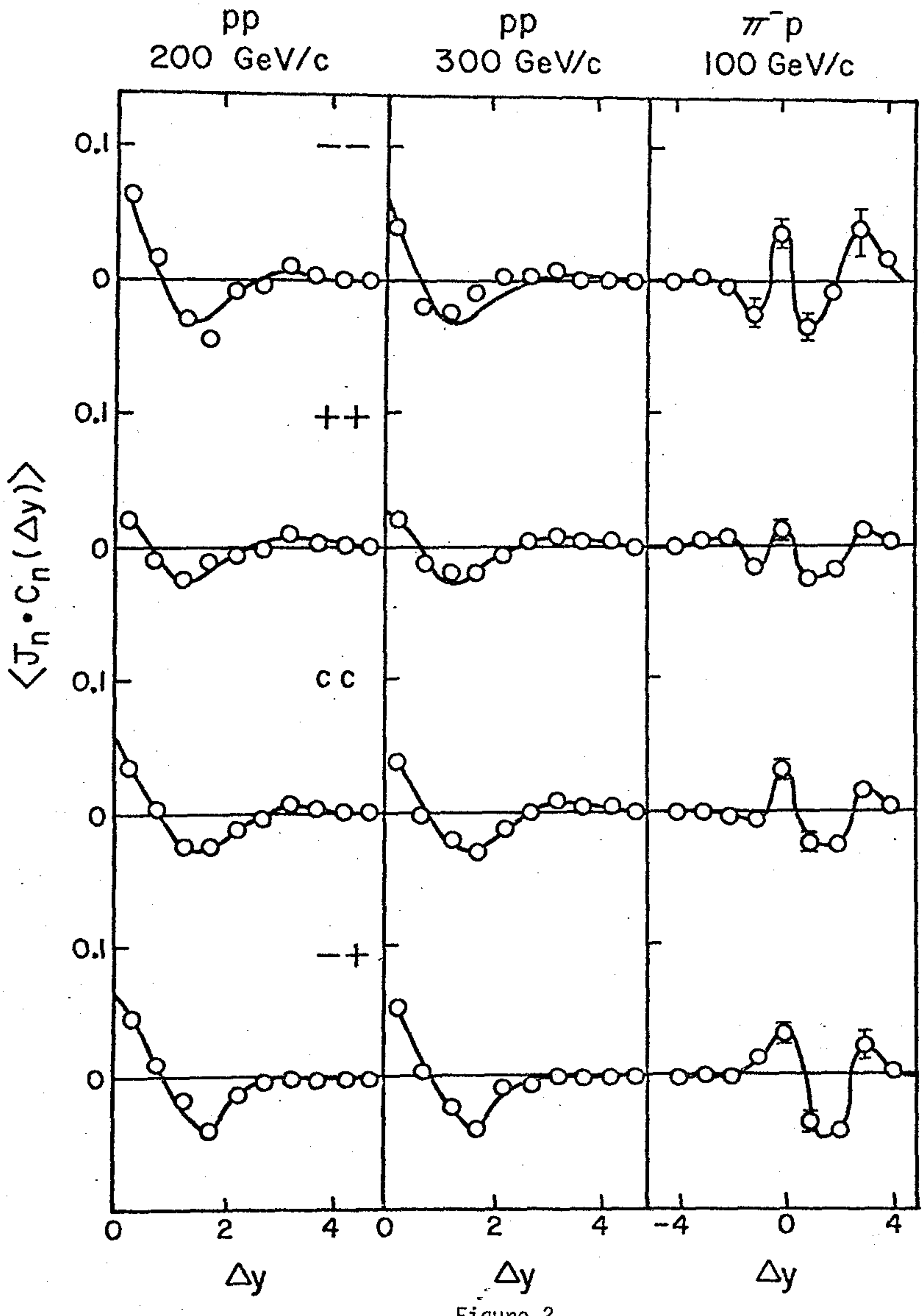
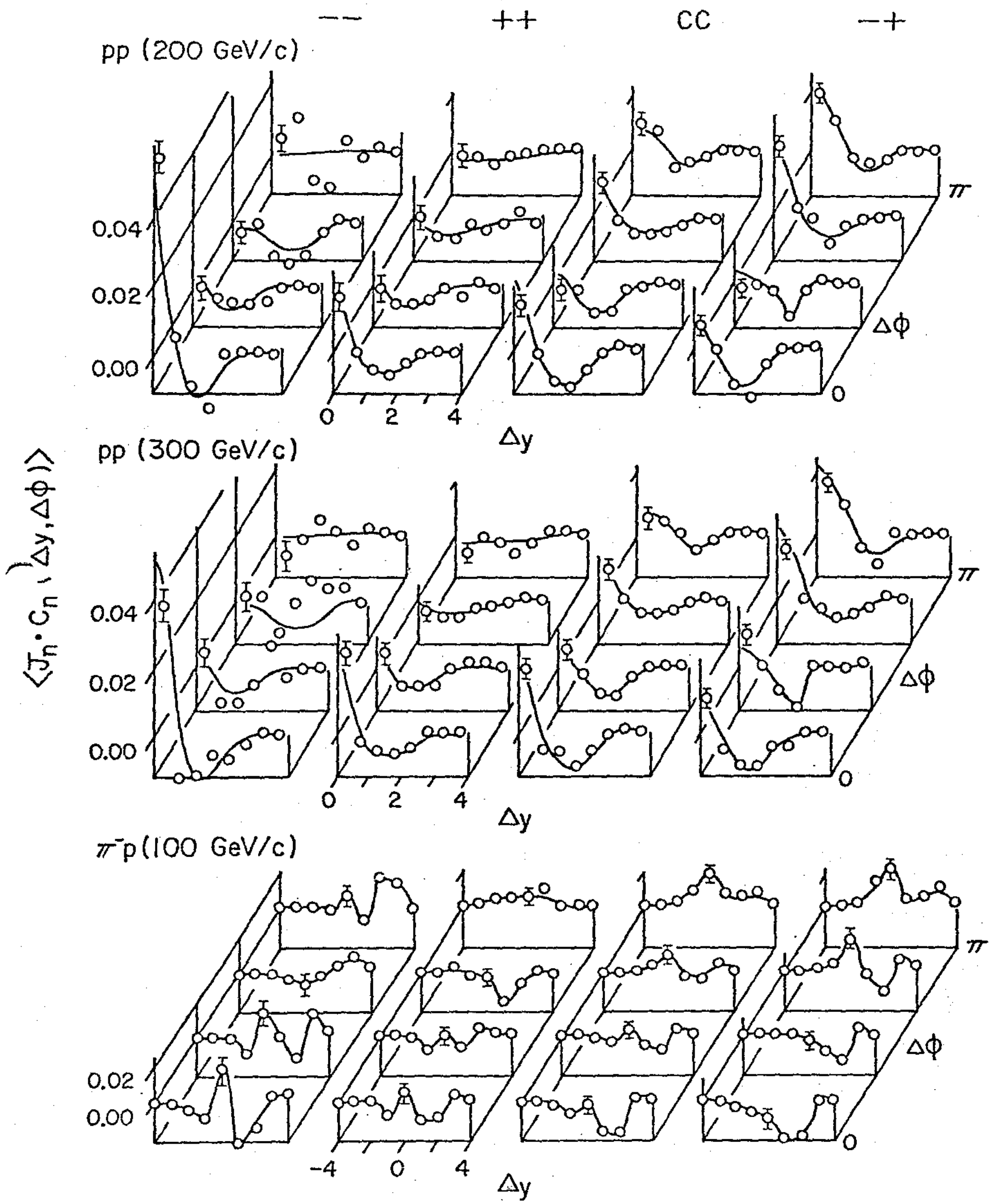

pp
200 GeV/c
pp
300 GeV/c
π^-p
100 GeV/c
0.1
0
−−
++
cc
−+
$\langle J_n \cdot C_n(\Delta y)\rangle$
0
2
4
−4
Δy

Figure 2



−−
++
CC
−+
pp (200 GeV/c)
0.04
0.02
0.00
0
2
4
Δy
π
Δφ
0
pp (300 GeV/c)
$\langle J_n \cdot C_n (\Delta y, \Delta\phi) \rangle$
π⁻p (100 GeV/c)
−4

Figure 3

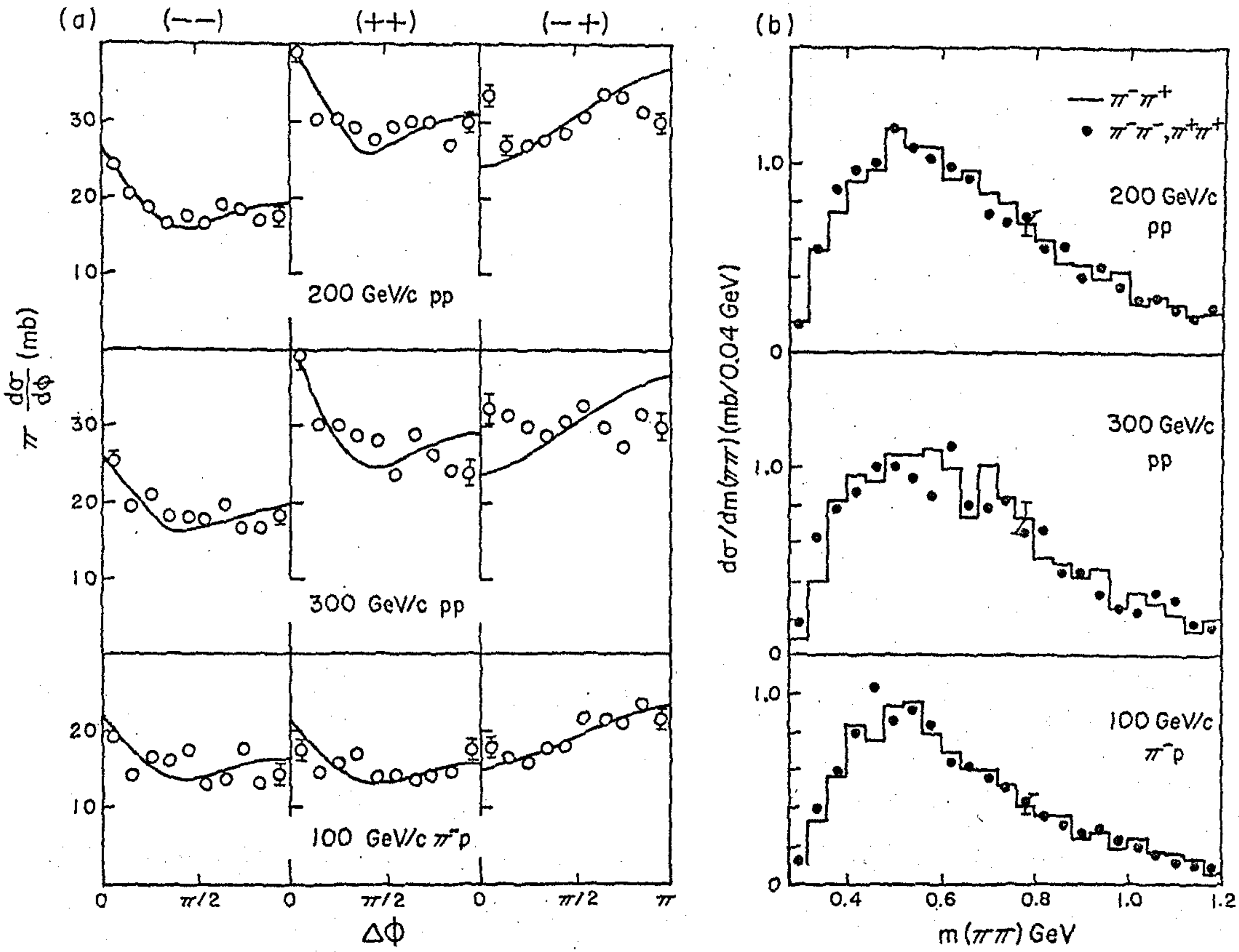

(a)
(−−)
(++)
(−+)
$\pi \frac{d\sigma}{d\phi}$ (mb)
200 GeV/c pp
300 GeV/c pp
100 GeV/c $\pi^- p$
$\Delta\phi$
(b)
$\pi^-\pi^+$
$\pi^-\pi^-, \pi^+\pi^+$
200 GeV/c pp
300 GeV/c pp
100 GeV/c $\pi^- p$
$d\sigma/dm(\pi\pi)$ (mb/0.04 GeV)
$m(\pi\pi)$ GeV

Figure 4