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EVIDENCE FOR CHARGED CLUSTER EMISSION IN 147 GeV/c $\pi^- p$ COLLISIONS

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ABSTRACT

A study of charged particle production in 147 GeV/c $\pi^- p$ collisions yields no evidence for an electrically neutral central region or corresponding rapidity plateau. The results do indicate that electric charge and transverse momentum may be locally conserved over small intervals on the rapidity axis. These results support a picture in which the observed hadrons are emitted in clusters whose quantum numbers vary as a function of rapidity and reflect the incident channel quantum numbers at the extremes of the rapidity scale.

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Studies of multiparticle final states at high energies have focussed attention on two particular modes of particle production: One, involving leading particles and fragmentation products of the beam or target particle, is clearly seen in the diffractive component of inelastic final states. The other, for which evidence is less direct, involves particles produced with small rapidity in the c.m. frame by mechanisms which are characterized by small values of the 2-particle correlation length and which exhibit little or no dependence on the incident channel quantum numbers. Recent analyses of high energy proton-proton collisions have provided evidence for such a "central region" on the rapidity scale in which particles, or clusters of particles, are emitted independently,[1] and for which electric charge, and perhaps other quantum numbers as well, may be locally conserved.[2]

In this paper we present data from $\pi^- p$ collisions at 147 GeV/c incident pion momentum. The leading particle, diffractive component in these data has been discussed in previous publications and is confined to the low-multiplicity events.[3] Here we show that for the total inelastic event sample an electrically neutral central region, with corresponding rapidity plateau, is not in evidence, indicating that fragmentation processes play an important role even in high multiplicity events. Nonetheless, some of the features expected for independent emission in the central region are observed. In particular, we present evidence that electric charge and transverse momentum may be locally conserved over small intervals of rapidity. These results support a picture in which the observed hadrons are emitted in clusters, whose quantum numbers vary as a function of rapidity, and with the incident channel quantum numbers dominating at the extremes of the rapidity scale.[4]

The experiment consists of $\sim 100,000$ exposures of the Fermilab 30-in. bubble chamber to a beam of 147 GeV/c π^- mesons, utilizing the Proportional Wire Hybrid Spectrometer[5] for accurate measurements of momenta and angles of the fast, forward-going tracks. The average charged particle multiplicity of events in this experiment is 7.4 ± 0.04 (topological cross sections and moments are discussed in Ref. 6). In order to have as complete

and accurate a sample as possible for events of all multiplicities, we report here on a subsample of about 1/4 of the data ($\sim$1600 inelastic events in the fiducial volume) for which every event failing to yield a satisfactory geometric reconstruction for all tracks in the first measurement has been examined and remeasured.

The rapidity distributions for final-state charged particles are shown in Fig. 1a, b, c. Protons with lab momentum less than 1.4 GeV/c have been identified by ionization, and all other charged particles are assumed to be pions. Neither the π^+ nor the π^- distribution is symmetric about $y = 0$. There is an excess of positive pions in the backward hemisphere and of negative pions in the forward hemisphere. The pion charge excess, as a function of rapidity, is shown in Fig. 1c. This is simply the difference between the differential cross sections shown in Fig. 1a and 1b. Positive values indicate an excess of positive pions, and negative values indicate an excess of negative pions. The data show a rapid change from positive to negative excess near $y = 0$, with no broad neutral interval near the central region of rapidity. Leading π^- mesons contribute near $y = +4$. The total pion charge excess, adding both positive and negative areas under the histogram, is $\sim$ 25 mb, comparable to the total inelastic cross section. This cannot be attributed to the diffractive, or leading particle component: Similar behavior is observed in the high-multiplicity events (Fig. 1d, e, f), and the distribution in pion charge excess for events of greater-than-average multiplicity (Fig. 1f) is little different from that of the total sample.

Although the electric charge distributions do not indicate a neutral central region, the average transverse momentum of charged pions in the final state, shown in Fig. 2a, is nearly independent of rapidity, over a broad interval extending approximately from $y = -2$ to $y = +3$. Again, a clear asymmetry is seen in the behavior of positive and negative charges (Fig. 2b): Negative tracks have larger transverse momentum in the forward direction, while in the backward direction the average transverse momenta of positive pions systematically exceed those of negative pions.[7] There is a rough

correspondence between positive or negative charge excess and large values of the average transverse momentum. This trend apparently persits in the high-multiplicity final-states (Fig. 2c). For these events the average transverse momentum for π^+ (π^-) with $-3 < y < -1$ is 343 ± 15 MeV (302 ± 16 MeV), and the corresponding values for $1 < y < 3$ are 337 ± 16 MeV (388 ± 14 MeV).

Despite the differences between the average transverse momenta of positive and negative pions in the forward and backward directions, there is a region in rapidity near $y = 0$ over which the average transverse momentum is equal for positive and negative pions, and relatively flat in rapidity for both cases. Thus we do observe a finite interval of rapidity over which the transverse momentum behavior of observed secondaries exhibits little or no dependence on either their charge or rapidity. This result is peculiar to the high energy data. In 16 GeV/c $\pi^- p$ collisions[8] a rapidity-independent interval is observed for π^+ but not for π^-.

As an indication that this behavior is a consequence of local compensation of transverse momentum near $y = 0$, we show in Fig. 2d the correlation function[9]

$$C(\Delta y) = - \langle \vec{p}_{t,f} \cdot \vec{p}_{t,b} \rangle \quad .$$

Here, for a given event, $\vec{p}_{t,f}$ is the net transverse momentum of charged secondaries with

$$y > + \frac{\Delta y}{2} \quad ,$$

and $\vec{p}_{t,b}$ the net observed transverse momentum for

$$y < - \frac{\Delta y}{2} \quad .$$

The average is taken over the entire inelastic event sample. The distribution in $C(\Delta y)$ falls rapidly to zero with a correlation length typical of the

characteristic lengths found in the central region for 2-particle rapidity distributions ($\sim$1.5 units).

Although more definitive conclusions from this data must await similar studies at other energies, and may not be possible without direct information from neutral secondaries, it seems reasonable to draw the tentative conclusion that transverse momentum is locally conserved over a small rapidity interval in the central region.

We next address the question of whether electric charge is locally conserved in rapidity by studying the charge transfer variable

$$u\ (\Delta y) \ = \ 1/2\ (Q_f - Q_b) \ + \ 1\ ,$$

where, for a given event, Q_f is the net charge forward of $y = +\frac{\Delta y}{2}$ and Q_b is the net charge backward of

$$y = -\frac{\Delta y}{2} \quad .$$

The term +1, which is not present in the usual definition for p - p collisions, accounts for the opposite charges of the incident particles. u(0) is a measure of the net charge-transfer across a boundary at y = 0. For non-zero values of Δy, $u(\Delta y)$ measures the charge transferred across an interval of length Δy, centered at y = 0. Quigg (Ref. 2) has discussed the interpretation of this variable in terms of a specific cluster emission model. We draw here on the qualitative aspects of such an interpretation.

For independent particle emission in the central region one expects $\langle u^2(0) \rangle$ to be independent of bombarding energy and of the incident channel quantum numbers. The value of $\langle u^2\ (0) \rangle$ obtained from the data of this experiment is 1.0 ± .1, in good agreement with the results obtained in proton-proton collisions at 105 GeV/c (.90 ± .04, Ref. 10) and 205 GeV/c (.99 ± .03, Kafka et al., Ref. 1).

In Fig. 3 we show the distributions in $D^2(\Delta y) = \langle u^2 \rangle - \langle u \rangle^2$. The variable D^2 measures the width of the distribution in u, or the strength of the

event-to-event fluctuations in the charge transferred across the interval Δy. The data are shown as a function of Δy for various final-state topologies as well as for the total sample. For the inelastic 2-prong data, which are dominated by two-body diffractive processes, D^2 is essentially independent of the rapidity interval except for phase space effects at the kinematic limit.

For the higher multiplicities, if charge is locally conserved in the central and fragmentation regions, we expect large values for $D^2(0)$ due to statistical fluctuations which decrease as Δy is increased. As Δy spans the central region and extends into the fragmentation regions, D^2 should become independent of Δy, as in the case of the diffractive dominated 2- and 4-prong events. The essential result here is that this behavior is clearly observed in the 6-, 8- and 10-prong events: The distributions fall sharply from their values at $\Delta y = 0$, then break and level off before falling again as phase space effects take over at large intervals. This behavior is very similar to that observed in pp collisions at 205 GeV/c.[11] The width of the central region fall-off corresponds well with that observed for the transverse momentum correlations in Fig. 2.

Thus, while our data have as a gross feature clear asymmetries in the forward-backward charged pion distributions for even the high multiplicity channels, there is also evidence of the short-range behavior in the central region which has motivated cluster emission models for particle production. The data support the hypothesis that charge, and perhaps transverse momentum, are locally conserved on the rapidity axis.

If the inelastic scattering process is dominated by the production of clusters of hadrons, the absence of an electrically neutral central region in $\pi^- p$ collisions at Fermilab energies may result from the fact that the net charges of individual clusters vary as a function of the rapidity from target-like quantum numbers in the extreme backward direction to beam-like in the forward direction. If this were the case, a neutral central region would

presumably develop at higher energies. We note, as has been pointed out before,[12] that in such a picture there need be little distinction between the diffractive and high-multiplicity components of inelastic particle production: the former being simply an example of the clustering phenomenon in low-multiplicity final states.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

1. (a) Rapidity distribution for positive tracks. The shaded area is the contribution from protons.

   (b) Rapidity distribution for negative tracks.

   (c) Charge excess as a function of rapidity:

$$\frac{d\sigma\ (+)}{dy} - \frac{d\sigma\ (-)}{dy}$$

   The shaded area includes the contribution from protons.

   (d), (e), (f) same as for (a), (b), (c), respectively, but for events with ≥ 8 charged prongs.

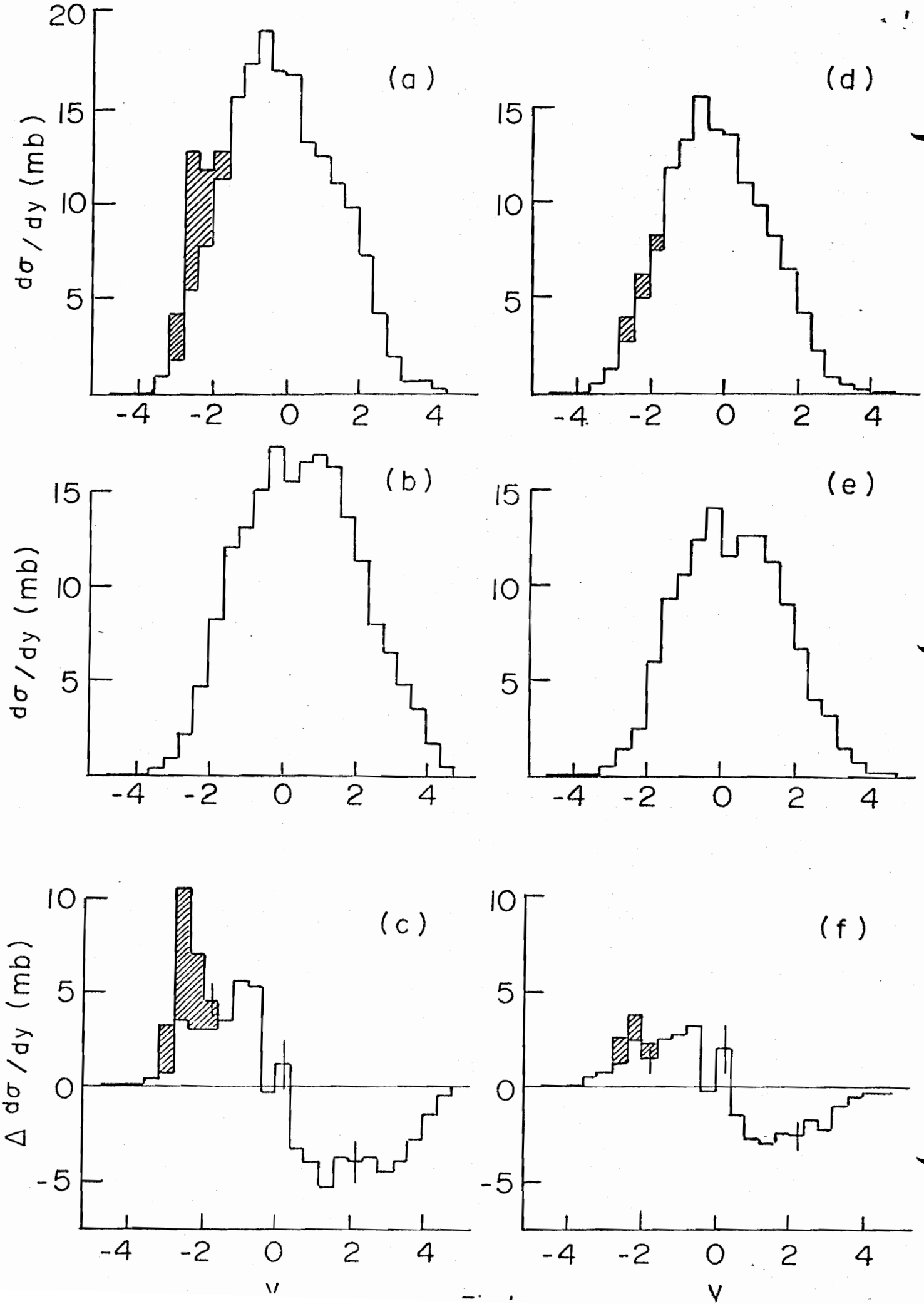
2. (a) Average transverse momentum vs. rapidity for all charged pions.

   (b) Average transverse momentum vs. rapidity for π^+ (open circles), and π^- (x's), all inelastic events.

   (c) Same as (b), but for events with ≥ 8 charged prongs.

   (d) The transverse momentum correlation function $C\ (\Delta y)$, as a function of the rapidity interval Δy (See text). The intervals are centered about $y = 0$.

3. The dispersion of the charge-transfer variable, $D^2\ (\Delta y)$, as a function of rapidity interval (See text). The intervals are centered about $y = 0$. The results labelled "all" include all inelastic events up through 16 prongs. Typical errors are displayed on the inclusive plot but have been omitted from the semi-inclusive plots for the sake of legibility.


(a)
(b)
(c)
(d)
(e)
(f)
dσ/dy (mb)
Δ dσ/dy (mb)
y
20
15
10
5
0
-5
-4
-2
0
2
4

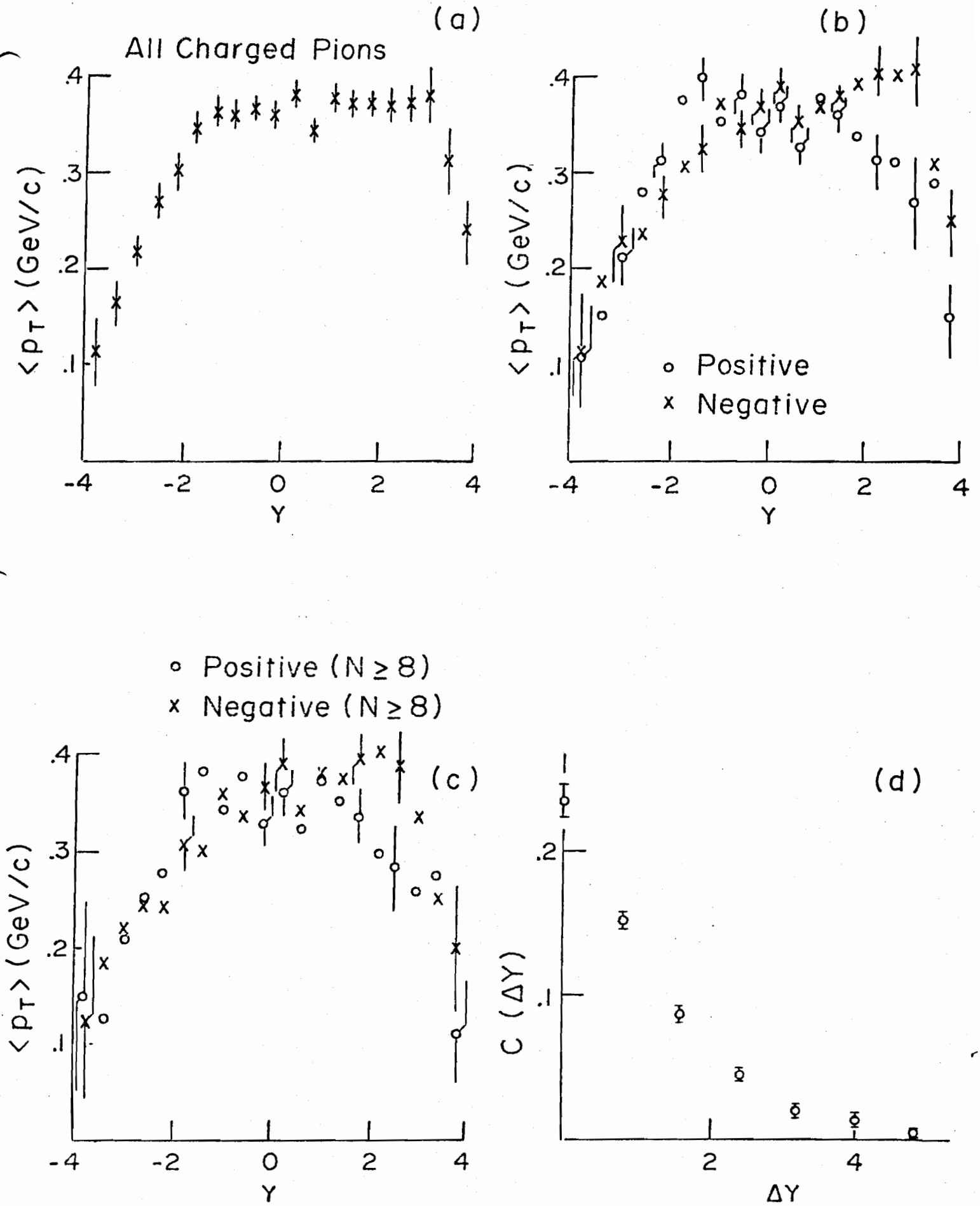

(a)
All Charged Pions
(b)
o Positive
x Negative
(c)
o Positive (N ≥ 8)
x Negative (N ≥ 8)
(d)
⟨p_T⟩ (GeV/c)
Y
C (ΔY)
ΔY

Fig. 2

$$D^2(\Delta Y) = \langle u^2 \rangle - \langle u \rangle^2$$

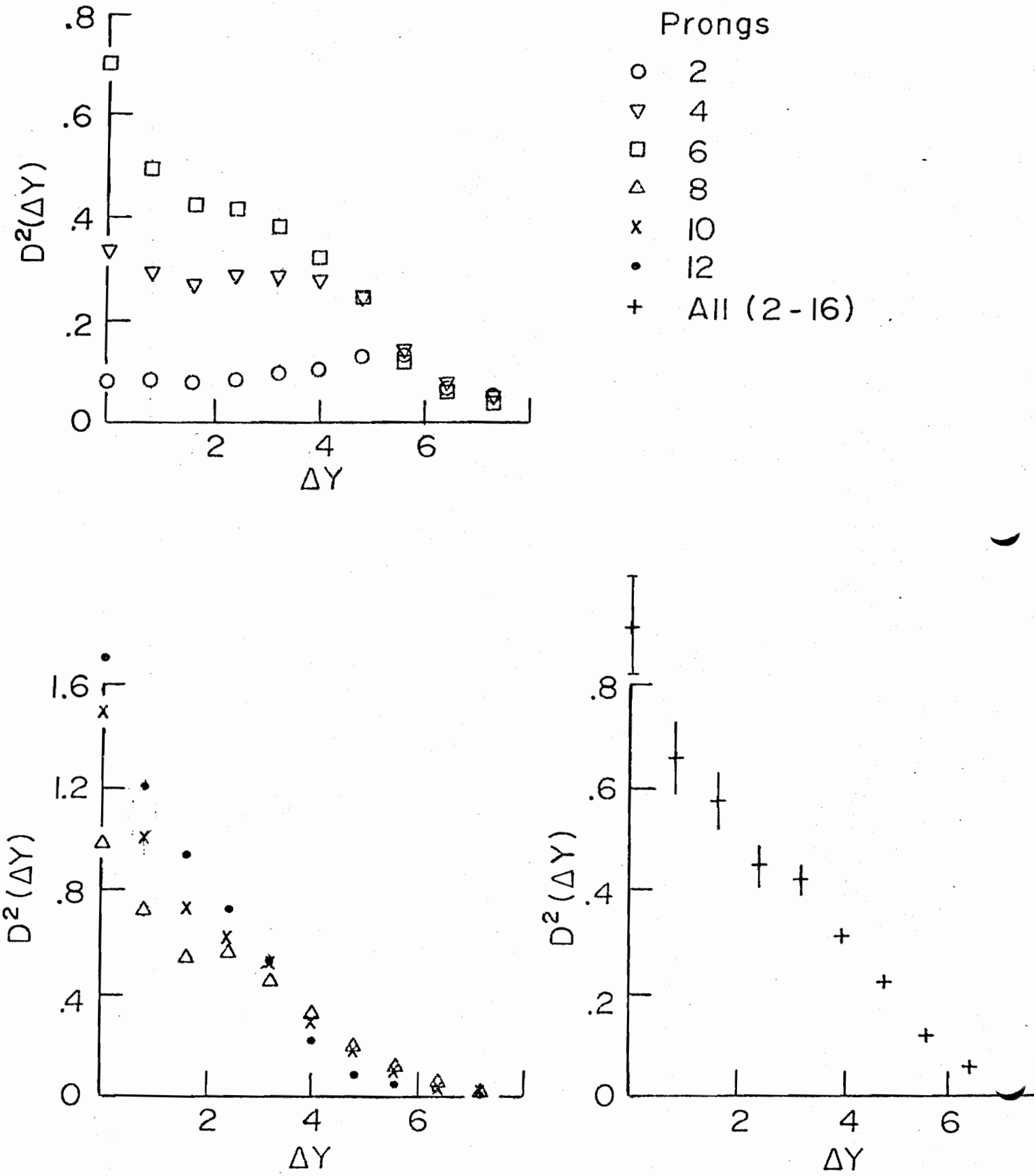


Fig. 3