CONF-75-100-E
E-0002

#28

Leading Particles and Leading Clusters in
$\pi^- p$ Single Particle Inclusive Reactions
at 200 GeV/c*

V.P. Kenney, N.N. Biswas, J.M. Bishop, N.M. Cason,
E.D. Foldis, and W.D. Shephard
University of Notre Dame, Notre Dame, Indiana 46556

L.R. Fortney, A.T. Goshaw, J.W. Lamsa, J.S. Loos,
W.J. Robertson, and W.D. Walker
Duke University, Durham, N.C. 27706

G. Hartner†, G. Levman††, P.M. Patel†,
V.A. Sreedhar††, and T.S. Yoon††
Institute of Particle Physics of Canada

Rapidity distributions for π^- produced in 200 GeV/c $\pi^- p$ inclusive reactions show marked leading-particle effects which extend into the central region. There indeed seems to be no "central region" at this energy which is independent of the nature of the incident particles. Leading-particle effects are not limited to events of low multiplicity or to single fast-forward leading particles, but include higher-multiplicity events in which a "leading cluster" is produced. The formation of leading clusters is evident in the distributions of total charge Q and cluster multiplicity M for all charged secondaries which are forward of the maximum rapidity gap in each event.

One feature of inclusive reactions which is well established by lower-energy data[1] is the preference for a single "leading particle" to emerge with the same quantum numbers, and a large fraction of the momentum, of the incident particle. At Fermilab energies one expects leading-particle effects to dominate the extreme

forward direction, particularly in events of low multiplicity, and to be closely associated with the diffractive process[2]. It is generally assumed that a central region will develop in which particle production is relatively independent of projectile and target. We present new data which demonstrate that leading-particle effects are important over the entire forward cms hemisphere, including the central region, and for events of high, as well as low, multiplicity. The results indicate that "leading clusters" as well as "leading particles" play a major role in the phenomenology of inclusive reactions.

Our data are obtained from a sample of ~10,000 inelastic events of the reactions

$$\pi^- + p \rightarrow \pi^* + \text{anything} \qquad (1)$$

at an incident momentum of 200 GeV/c. A hybrid arrangement[3] of four dual wide-gap optical spark chambers downstream of the FNAL 30-inch bubble chamber was used to improve the momentum resolution for fast forward secondaries. A system of proportional wire chambers[4] upstream of the bubble chamber identified the incident particle which triggered the wide gap system.

For fast forward tracks with cms rapidity $y \geq 2$, we limit ourselves to those events, appropriately normalized, which triggered the downstream spark-chamber system, in order to take advantage of the improved momentum resolution of the hybrid spectrometer[3]. For the slower tracks with $y < 2$, we use data from all events. Combined measurements are used whenever the particles successfully traversed the wide-gap system; bubble chamber measurements alone are used for those wider-angle secondaries which did not. Protons with momentum less than 1.3 GeV/c are identified on the basis of ionization

criteria. The remaining positive particles are called "π^+", and all negative particles are called "π^-", assuming that the small admixture of higher mass particles in the sample will not radically affect the physics results.

Distributions of the cms rapidity for the π^+ and π^- produced in reactions (1) are shown in Fig. 1. For comparison, we show the corresponding rapidity distributions for the reactions

$$p + p \rightarrow \pi^{\pm} + \text{anything} \qquad (2)$$

at essentially the same incident momentum[5], normalized to the $\pi^- p$ inelastic cross section. The factorization hypothesis[6] for target fragmentation is clearly well satisfied for both π^+ and π^- production. It is interesting that the π^+ distributions for reactions (1) and (2) are in remarkable agreement over the <u>entire</u> range of rapidity. We know of no <u>a priori</u> reason to expect the π^+ distributions to be the same for the two reactions. Quite different behavior is found for π^- production in the forward cms hemisphere, where there is a pronounced excess of π^- from reaction (1) compared to reaction (2). It is interesting that this leading-particle effect is not confined to the extreme forward $y \cong y_{max}$ direction, but also extends back into the central region about $y \cong 0$. There seems to be no "central region" which is independent of the nature of the incident particles at 200 GeV/c. It is also clear from Fig. 2a that the forward excess of π^- is not confined to small values of the secondary particle multiplicity n, as might be inferred from missing-mass studies[2,7], but is clearly evident in the events with $6 \leq n \leq 12$, and is present even in events with $n \geq 14$.

To study further the leading-particle excess, we order in rapidity all the secondaries from each individual event, as shown in Fig. 3a. We then exclude

the "single leading π^-" in each event, provided the rapidity gap between this particle and the adjacent particle has the maximum gap length, r_{max}, and that r_{max} is greater than some minimum value. (The choice of the minimum value for r_{max} is somewhat arbitrary in that we see only the charged secondaries in this experiment. We choose $r_{max} \geq 1.0$ so as to select on gaps greater than the typical rapidity spread of a centrally-produced cluster[8].) The effect of excluding the single leading π^-, which typically accompany target dissociation, is shown by the dashed histogram of Fig. 2b. While many of the tracks with large y are removed, most of the leading-particle excess remains.

Beam dissociation into forward pions would clearly be expected to contribute to the leading-particle excess. We next exclude from the distribution all charged secondaries in each event which are forward of the maximum rapidity gap, again requiring $r_{max} \geq 1.0$ (Fig. 3a), with the further requirement that the charged multiplicity M of this "leading cluster" be odd and that it have total charge $Q = -1$. Single leading pions are a subset of the π^- removed. The rapidity distribution for the π^- remaining after this selection is shown as the inner histogram of Fig. 2b. We conclude that this selection does demonstrate and identify a significant production of "leading clusters" in inclusive reactions at Fermilab energies.

In order to study systematic trends in the leading clusters, we now investigate the distributions in the total charge Q and cluster multiplicity M of the charged secondaries which are forward of the maximum rapidity gap in each event. In Fig. 3b, the distribution for Q shows a pronounced peak at $Q = -1$, indicating that a large fraction of the forward clusters have the same

charge as the beam particle[9]. Fig. 3c shows that odd multiplicity predominates and that even out to high M, most of the odd-M clusters have $Q = -1$ (shaded). If the largest gaps were distributed at random one would not expect such a "picket fence" distribution. If we hand-draw a smooth background curve through the even-multiplicity values for $r_{max} \geq 1$, as indicated, the cross section for formation of all $Q = -1$ "leading clusters" selected on this basis is appreciable (~6.6 mb, out of a total inelastic cross section of 21 mb).

In Fig. 3d we show distributions of the leading cluster multiplicity M for the different multiplicities n of charged secondaries in each event with the requirement that $Q = -1$. For all topologies, the largest odd M allowed has the greatest population and single forward π^- emission has the next highest preference. All topologies are thus consistent with a "single dissociation" picture in which a large fraction of the events involves either target dissociation, with a single fast π^- in the forward direction, or beam dissociation into the largest number of charged secondaries allowed. This is particularly evident for the high-multiplicity events. We have made a comparison with a completely-random charge distribution model requiring only that the leading M charged particles have net charge $Q = -1$. The model calculation values are shown dotted in Fig. 3d. It is clear that the model does not account for the effect we see.

We stress that the general features of these distributions are not strongly dependent on our choice for the minimum value of r_{max}. Figs. 3b and 3d explicitly demonstrate that the shapes of the Q and M distributions are substantially the same for the choices $r_{max} \geq 0$ and $r_{max} \geq 1$. The only dis-

cernible difference is that the higher r_{max} cut suppresses high multiplicity events relative to low multiplicity events, as would be expected from kinematical considerations.

In summary, we have presented rapidity distributions for π^+ and π^- mesons inclusively produced in π^-p interactions at 200 GeV/c. The factorization hypothesis for target fragmentation appears to be well satisfied for both π^+ and π^- production when compared with pp interactions at the same energy. Remarkable agreement between π^+ distributions for the two reactions is found at all rapidity values. We find a large "leading cluster" effect that produces greater inclusive π^- cross sections for π^-p than for pp reactions over the entire forward cms hemisphere. These leading clusters are observed for all multiplicities and tend to be associated both with a net cluster charge equal to the charge of the incident particle (zero charge transfer across the largest rapidity gap) and with a largest rapidity gap located at one of the ends of the rapidity chain.

The authors wish to acknowledge the cooperation of the Fermilab staff and their Experiment 2B collaborators, and the help of their own analysis and technical staffs. We are particularly indebted to Drs. E. Berger, J. Dash, and G.H. Thomas for valuable discussions of these data.

References

*Research supported in part by the National Science Foundation, the Energy Research and Development Administration, and the National Research Council of Canada.

† McGill University, Montreal P.Q.
†† University of Toronto, Toronto, Ont.

1. N.N. Biswas et al., Phys. Rev. Letters 26, 1589 (1971); J.T. Powers et al., Phys. Rev. D8, 1947 (1973).

2. M. Derrick, Proceedings of the XVII International Conference on High Energy Physics at London, (J.R. Smith, Ed.) p. I-3 (1974).

3. G.A. Smith, Particles and Fields - 1973, AIP Conference Proceedings No. 14 (H.H. Bingham, M. Davier, G.R. Lynch, Eds.) p. 500 (1973).

4. We appreciate the cooperation of the Exp. 154 consortium in the use of these wire chambers.

5. Studies of 205 GeV/c pp inclusive reactions are described and referenced by M. Derrick in ref. 2 above. We are indebted to R. Singer of Argonne National Laboratory and his collaborators for use of the pp data.

6. A.H. Mueller, Phys. Rev. D2, 2963 (1970).

7. R. Huson, Experiments on High Energy Particle Collisions - 1973, AIP Conference Proceedings No. 12 (R.S. Panvini, Ed.) p. 60 (1973).

8. C. Quigg, P. Pirilä, and G.H. Thomas, Phys. Rev. Letters 34, 290 (1975).

9. In contrast to this predominance of charge transfer zero across the maximum rapidity gap, the charge transfer is zero for only 35% of all gaps.

Figure Captions

Fig. 1 Distributions of the cms rapidity for (a) π^+ and (b) π^- produced in 200 GeV/c π^-p inelastic inclusive reactions. Corresponding distributions for the reactions $p + p \rightarrow \pi^{\pm}$ + anything at 205 GeV/c, normalized to the π^-p inelastic cross section, are shown for comparison (open circles).

Fig. 2 (a) Rapidity distributions (cms) by multiplicity for π^- produced in 200 GeV/c π^-p interactions, for (outer histogram) all π^-, for (x) $2 \leq n \leq 4$, for (o) $6 \leq n \leq 12$, and for (•) $n \geq 14$.
(b) Rapidity distribution for (outer histogram) all π^-, for (dashed histogram) π^- remaining when "single leading π^-" are excluded, and for (inner histogram) π^- remaining when "leading clusters" are removed. Data for 205 GeV/c pp interactions, normalized to the π^-p inelastic cross section, are shown for comparison (open circles).

Fig. 3 (a) Diagrams illustrating rapidity ordering with (above) selection of "single leading π^-" and (below) selection of "leading clusters".
(b) Distribution of total charge Q of all charged secondaries which are forward of the maximum rapidity gap for $r_{max} \geq 0$ (unshaded) and $r_{max} \geq 1$ (shaded).
(c) Distribution of multiplicity M of charged particles for the same events, $r_{max} \geq 1$. The shaded portion corresponds to $Q = -1$. The dashed "background" curve is hand-drawn through the even-multiplicity values.
(d) Distribution of $Q = -1$ leading-cluster multiplicity M by overall event multiplicity n. (Note changes of scale.) The unshaded portion corresponds to $r_{max} \geq 0$ and the shaded to $r_{max} \geq 1$. Results of a model calculation with completely random charge distribution, requiring only that the leading M charged particles have net charge $Q = -1$, are shown dotted.

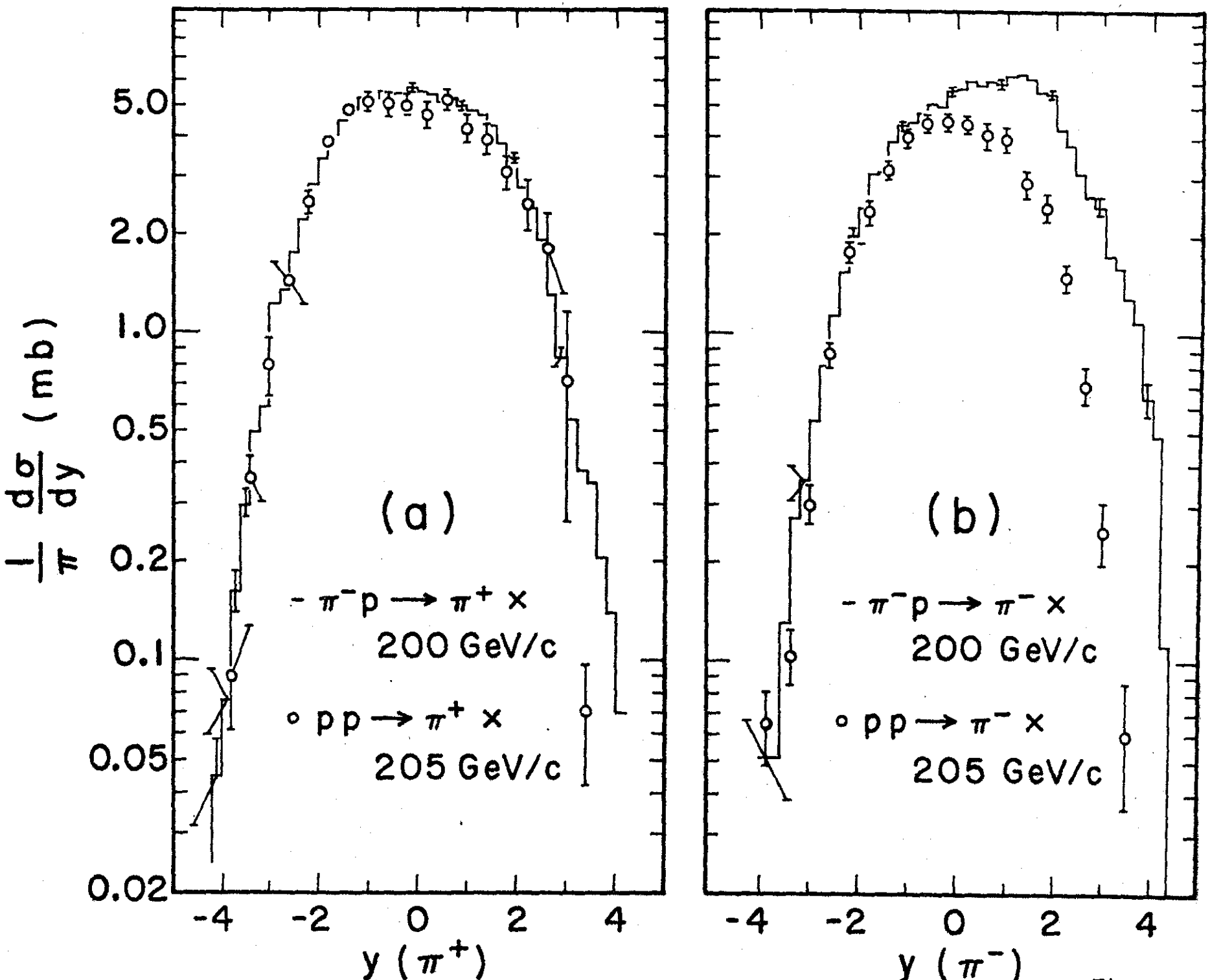

5.0
2.0
1.0
0.5
0.2
0.1
0.05
0.02
$\frac{1}{\pi}\frac{d\sigma}{dy}$ (mb)
(a)
- $\pi^- p \rightarrow \pi^+ x$
200 GeV/c
∘ $pp \rightarrow \pi^+ x$
205 GeV/c
-4
-2
0
2
4
$y(\pi^+)$
(b)
- $\pi^- p \rightarrow \pi^- x$
200 GeV/c
∘ $pp \rightarrow \pi^- x$
205 GeV/c
$y(\pi^-)$

Fig. 1

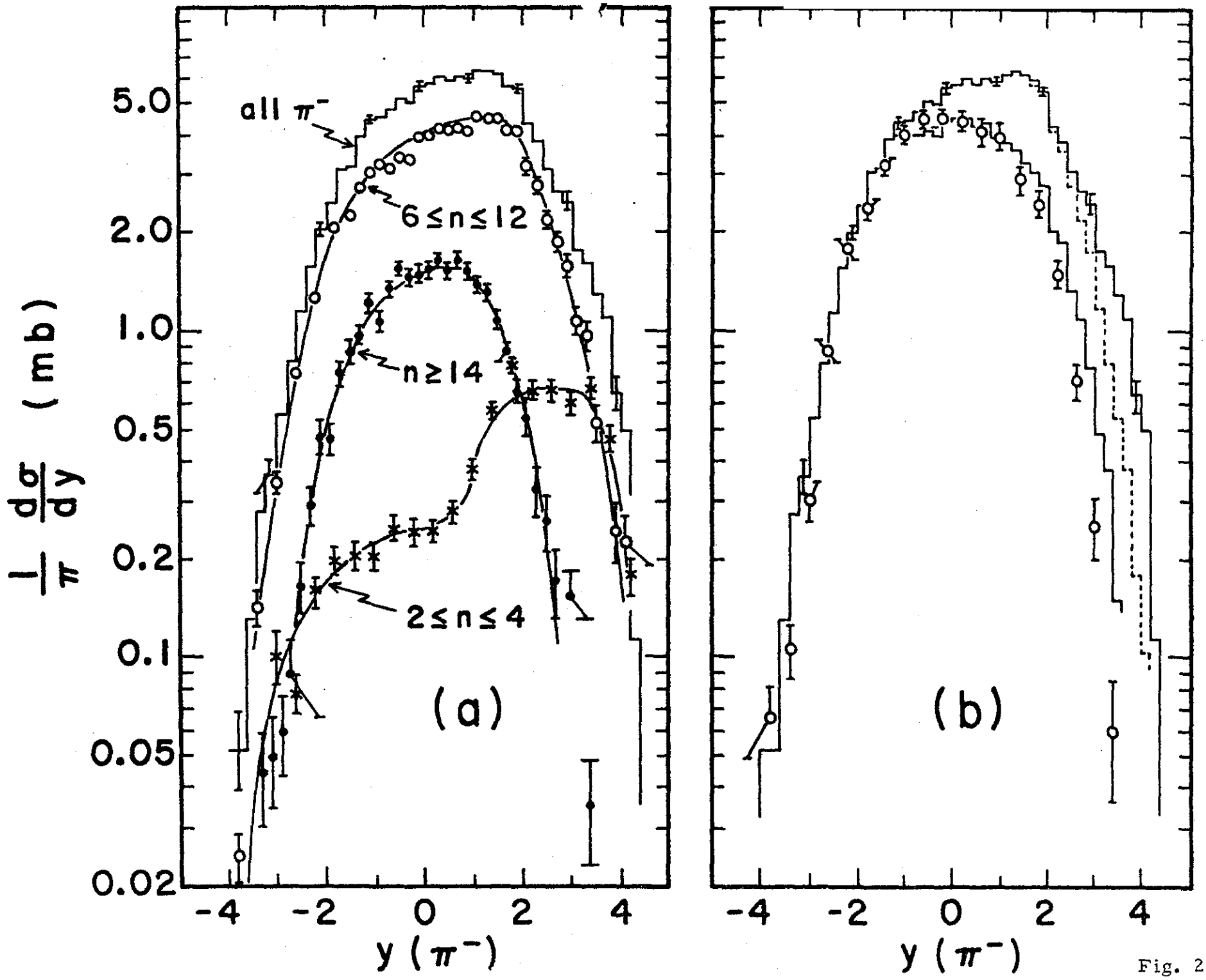
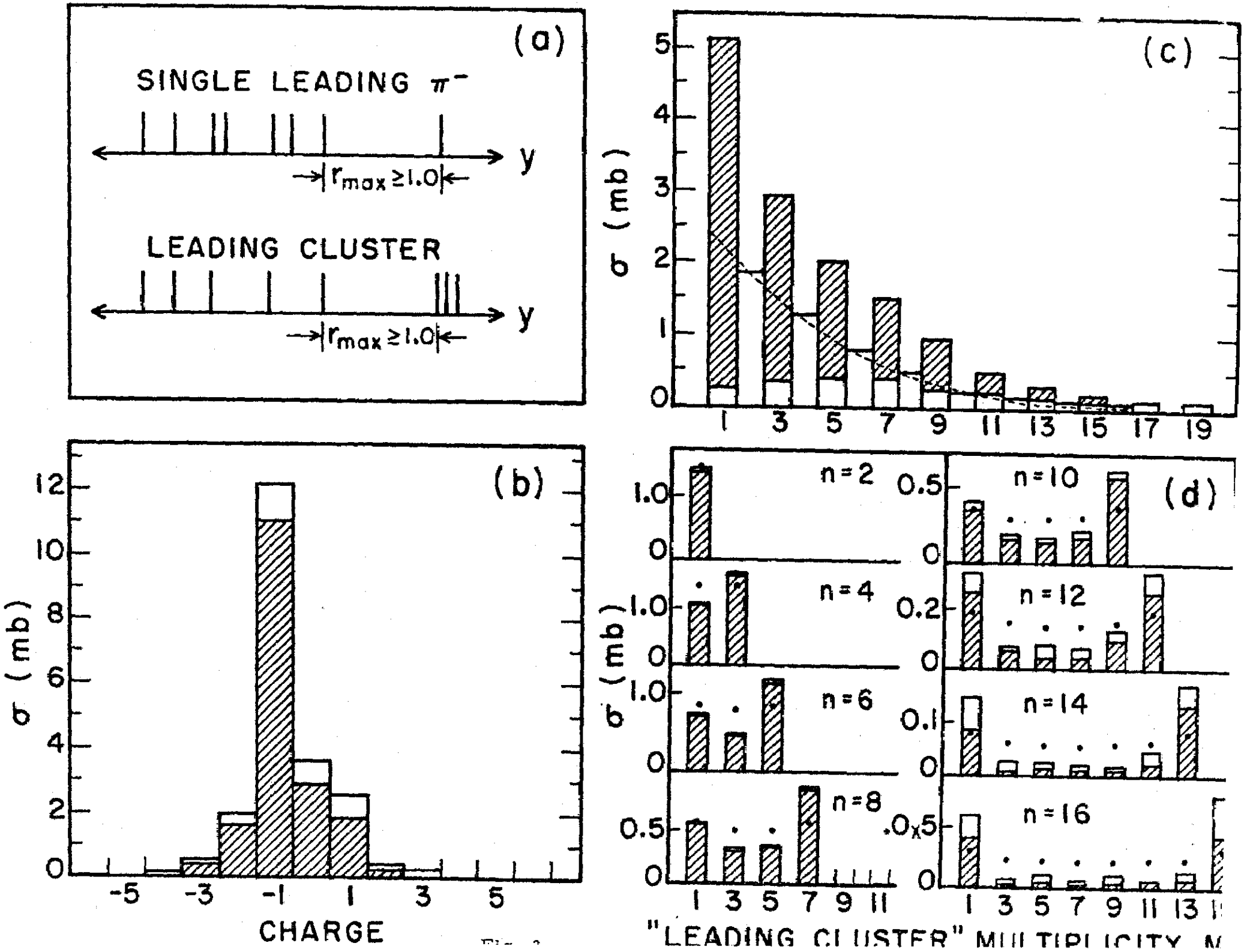

all π^-
$6 \le n \le 12$
$n \ge 14$
$2 \le n \le 4$
(a)
(b)
$\frac{1}{\pi}\frac{d\sigma}{dy}$ (mb)
5.0
2.0
1.0
0.5
0.2
0.1
0.05
0.02
-4
-2
0
2
4
y (π^-)

Fig. 2


(a)
SINGLE LEADING π^-
y
$r_{max} \geq 1.0$
LEADING CLUSTER
y
$r_{max} \geq 1.0$
(b)
σ (mb)
CHARGE
(c)
σ (mb)
(d)
n=2
n=4
n=6
n=8
n=10
n=12
n=14
n=16
σ (mb)
"LEADING CLUSTER" MULTIPLICITY