PHYSICAL REVIEW D VOLUME 14, NUMBER 3 1 AUGUST 1976

$\pi^- p$ charge-transfer cross sections at 205 GeV/c, and an apparent universality of the charge-transfer spectrum*

G. Levman, B. M. Schwarzschild, and T. S. Yoon
Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S1A7

G. Hartner and P. M. Patel
Department of Physics, McGill University, Montreal, Quebec, Canada H3C3G1

L. R. Fortney, A. T. Goshaw, J. W. Lamsa, J. S. Loos, W. J. Robertson, and W. D. Walker
Physics Department, Duke University, Durham, North Carolina 27706

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

(Received 1 March 1976)

We present inclusive cross sections $\sigma(\Delta Q)$ for charge transfers between c.m. hemispheres in $\pi^- p$ interactions at 205 GeV/c. Plotting $\sigma(\Delta Q)/\sigma_{\text{inelastic}}$ for different reactions and energies against $\Delta Q - \langle \Delta Q \rangle$ appears to yield a universal symmetric function which would result in an asymptotic limiting value $\sigma(\Delta Q = 0)/\sigma_{\text{inelastic}} \sim 1/2$ for all hadronic reactions.

INTRODUCTION

It has been widely noted that the inclusive charge-transfer cross sections $\sigma(\Delta Q)$, for pp reactions, show a striking independence of energy over a large range of incident momenta[1-5] (Fig. 1). ΔQ, the charge transfer between c.m. hemispheres, is defined as the net charge in the target hemisphere ($x < 0$) in the final state minus the charge of the target particle. The threshold growth at large $|\Delta Q|$ accounts for a rise of the variance, $D^2 = \langle \Delta Q^2 \rangle - \langle \Delta Q \rangle^2$, at about the same rate as the height of the central, inclusive pion plateau increases with energy. Figure 1 can be interpreted as indicating a mechanism of local charge compensation, such as neutral-cluster production,[5-8] with the $\sigma(\Delta Q)$ spectrum depending only on local properties of particle production near $Y_{\text{c.m.}} = 0$.

In that case one would expect similar behavior from πp and Kp inclusive reactions at sufficiently high energy. The purpose of this note is to present our $\pi^- p$ inclusive (inelastic) charge-transfer cross sections at 205 GeV/c, and to attempt to fit these data into the universal scheme, pointed out by Breitenlohner,[9] which appears to be emerging from the pp data and low-energy Kp and πp data. Our charge-transfer data are based on 10 548 events from the Fermilab 30-in. hybrid bubble-chamber system, with downstream optical spark chambers and upstream beam-defining proportional wire chambers. General experimental details are given elsewhere.[10]

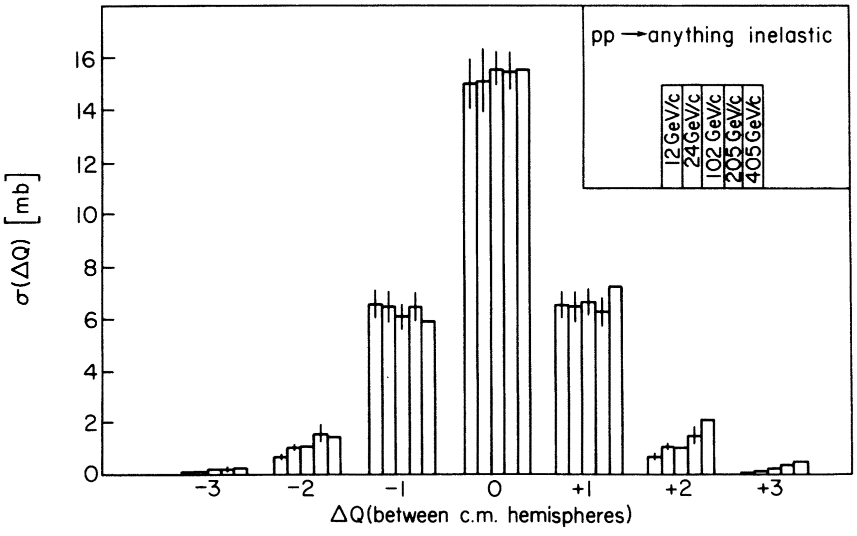

FIG. 1. pp inclusive, inelastic charge-transfer cross sections $\sigma(\Delta Q)$, from 12 to 405 GeV/c. The 12-GeV/c and 24-GeV/c data (Refs. 1, 5) are symmetrized, but the Fermilab data (Refs. 2–4) are not.

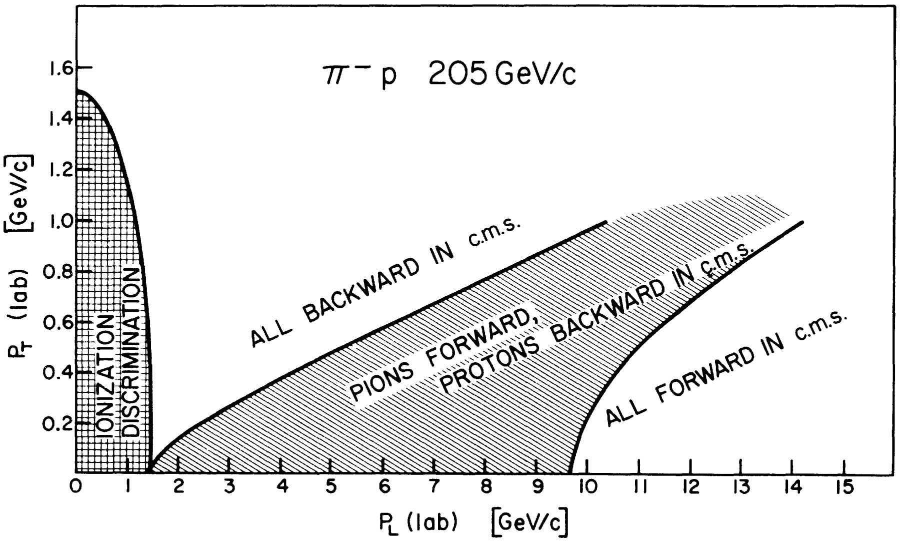

FIG. 2. Regions of lab-momentum space in which barycentric hemisphere assignment does (does not) depend on mass assignment, and in which track bubble density does (does not) permit mass identification. (c.m.s. stands for "center-of-mass system.")

DETERMINATION OF CHARGE-TRANSFER CROSS SECTIONS

In determining the net charge transfer between c.m. hemispheres one is faced with the experimental problem of distinguishing protons from π^+. Figure 2 indicates by a shaded area the central region of momentum space (in the laboratory frame) where a track will be in the forward barycentric hemisphere if it is a pion but will be backward in the c.m. system if it is a proton. In this region one must identify the mass of a positive track in order to assign it to the correct c.m. hemisphere. Below about 1.5 GeV/*c* lab momentum (crosshatched area in Fig. 2) we can generally discriminate between π^+ and p by ionization, but we see that this region has almost no overlap with the crucial central region. At these high energies we may safely neglect the protons in the forward c.m. hemisphere, but we are left with a large number of unidentifiable tracks in the central region of forward-backward ambiguity.

We have therefore determined the inelastic charge-transfer cross sections, given in Table I and Figs. 3 and 4, by two different techniques, assuming that the correct values lie somewhere between these extremes. Method A (see Table I) simply takes every positive track not identified as a proton to be a pion. This technique gives 0.34 protons per inelastic event. On the other hand, by applying factorization to the pp data[11] we are led to expect something more like 0.6 protons per inelastic event.

We therefore force this outcome (0.6 protons/inelastic event) in the second technique (method B of Table I). We attempt roughly to recover the putative unidentified protons by randomly selecting 1970 events with no identified protons and at least one positive track with lab momentum between 1.4 and 9 GeV/*c*. For these events we arbitrarily call the slowest of these tracks (i.e., that with the lowest lab momentum) a proton, thus artificially raising the proton multiplicity to the expected 0.6 per inelastic event. It turns out that 540 (28%) of the tracks thus labeled as protons lie in the central region of Fig. 2. In other words, less than 1% of all outgoing tracks (540 out of 70 000) are assigned to different c.m. hemispheres by methods A and B. But these 540 events (5% of the total) then have ΔQ larger by one in method B than in method A.

TABLE I. Inclusive, inelastic charge-transfer cross sections for $\pi^- p$ at 205 GeV/*c*, normalized to $\sigma_{\text{inelastic}}$.

	$\sigma(\Delta Q)/\sigma_{\text{inelastic}}$	
ΔQ	Method A	Method B
−5	0.0003 ± 0.0002	0.0003 ± 0.0002
−4	0.0047 ± 0.0007	0.0039 ± 0.0006
−3	0.0193 ± 0.0016	0.0164 ± 0.0013
−2	0.0744 ± 0.003	0.0628 ± 0.003
−1	0.251 ± 0.005	0.231 ± 0.005
0	0.461 ± 0.012	0.458 ± 0.012
+1	0.146 ± 0.004	0.165 ± 0.004
+2	0.035 ± 0.002	0.051 ± 0.003
+3	0.0057 ± 0.0008	0.0096 ± 0.001
+4	0.0009 ± 0.0003	0.0018 ± 0.0004
$\langle\Delta Q\rangle$	−0.240 ± 0.011	−0.120 ± 0.011
$D^2 = \langle\Delta Q^2\rangle - \langle\Delta Q\rangle^2$	1.10 ± 0.02	1.17 ± 0.02

$\sigma_{\text{total}} = 24.28 \pm 0.15$ (Ref. 15)
$\sigma_{\text{elastic}} = 3.03 \pm 0.3$ (Ref. 12)

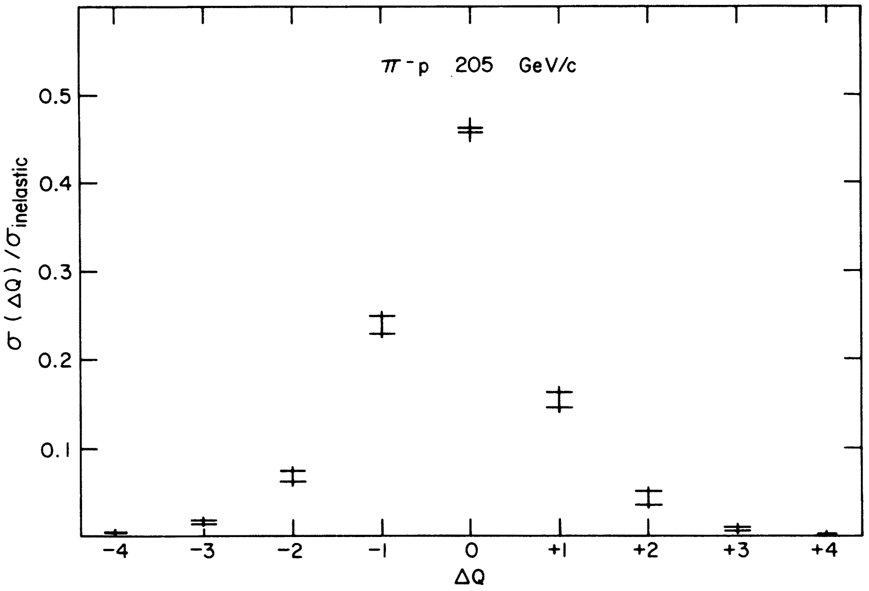

FIG. 3. π^-p inclusive, inelastic charge-transfer cross sections, normalized to $\sigma_{\text{inelastic}}$, at 205 GeV/$c$. The two horizontal lines at each ΔQ indicate the results of methods A and B (see Table I).

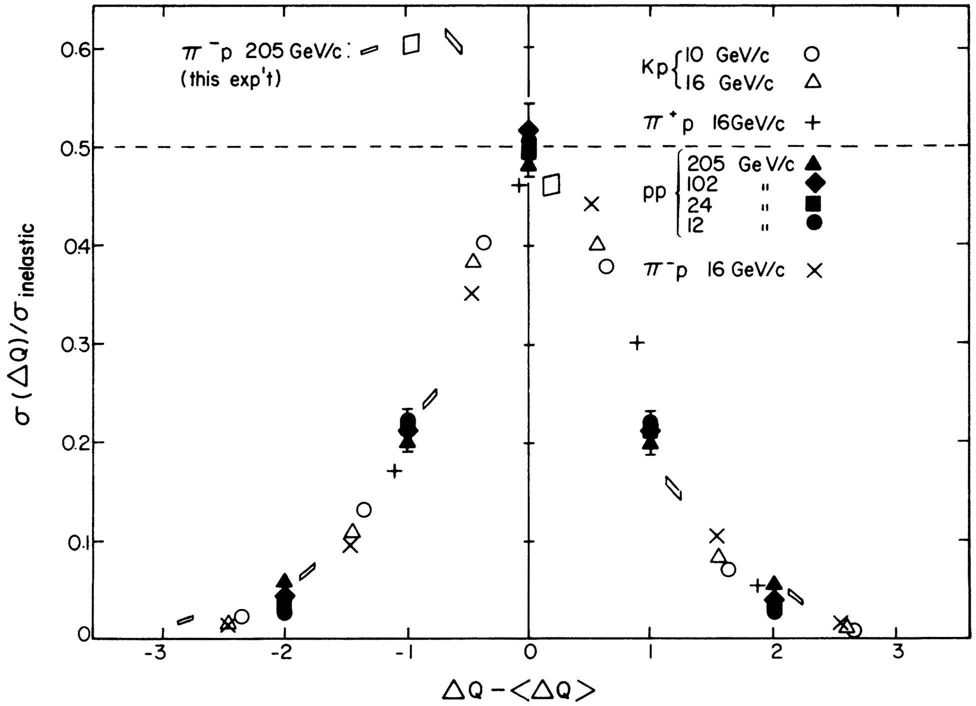

FIG. 4. Inclusive, inelastic charge-transfer cross sections, normalized to $\sigma_{\text{inelastic}}$ and plotted against $\Delta Q - \langle \Delta Q \rangle$. The dashed line at $\sigma(\Delta Q)/\sigma_{\text{inelastic}} = 0.5$ indicates a speculation that this may be a universal asymptotic limit for $\Delta Q = 0$. pp data are from Refs. 1–5, K^-p data are from Ref. 14, and πp data are from Ref. 13 and this experiment.

Since the asymmetry of $\sigma(\Delta Q)$ in $\pi^- p$ favors $\Delta Q<0$, method B results in the less asymmetric distribution about $\Delta Q=0$.

Our event sample was normalized to the relative cross sections of Ref. 12, taking into account a scanning loss of 16% (5%) for low-t elastic (inelastic) 2-prong events. We assume that all elastic events (and lost inelastic 2-prong events) have $\Delta Q=0$.

RESULTS

In Table I the errors quoted for $\sigma(\Delta Q)/\sigma_{\text{inelastic}}$, $\langle\Delta Q\rangle$, and D^2 are mainly statistical. The major uncertainty in these results, coming from the π^+-p ambiguity, is to be read from the spread between the results of methods A and B. In Fig. 3 this is indicated by the two horizontal lines on each data point.

From the asymmetry of $\sigma(\Delta Q)$ about $\Delta Q=0$ in Fig. 3, it is clear that at 205 GeV/c the $\pi^- p$ charge transfer across $y_{\text{c.m.}}=0$ still bears some mark of the nature of the initial particles. We find that $\langle\Delta Q\rangle$ lies between -0.24 ± 0.011 (method A) and -0.12 ± 0.011 (method B). This nonvanishing of $\langle\Delta Q\rangle$ presumably reflects the persistence of the low-energy peripheral charge-exchange mechanism and/or a spillover across $y_{\text{c.m.}}=0$ of the fragmentation products of the incoming particles (primarily the π^-). Both these mechanisms should fall with increasing energy. Indeed, in almost all models it is expected that $\langle\Delta Q\rangle$ will ultimately vanish for any inclusive hadronic reaction. In fact we find the decrease in $|\langle\Delta Q\rangle|$ for $\pi^- p$ between 16 GeV/c[13] and 205 GeV/c to be consistent with $1/\sqrt{s}$, within large errors. Of course, for pp reactions $\langle\Delta Q\rangle$ must always vanish by reason of symmetry.

So long as $\langle\Delta Q\rangle$ for $\pi^- p$ is still distinctly nonzero at Fermilab energies, the most straightforward comparison of Figs. 1 and 3 does not reveal the anticipated universality. But if we follow a suggestion of Breitenlohner,[9] we find (Fig. 4) that our data appear to fall on a universal, smooth curve described by the pp data, together with low-energy πp and Kp data.[13,14] In Fig. 4, the $\sigma(\Delta Q)$ data for each energy and projectile species are normalized to $\sigma_{\text{inelastic}}$ and plotted against $\Delta Q-\langle\Delta Q\rangle$. Thus plotted, these diverse data fall remarkably well on a single curve, with some manifestation of threshold behavior. For our data the ends of the parallelograms correspond to results A and B; their widths represent the statistical errors. Happily, our conclusion is essentially independent of where on these parallelograms the true cross sections lie. We seem to be led then to the following picture: All hadronic charge-transfer spectra $\sigma(\Delta Q)/\sigma_{\text{inelastic}}$ at intermediate and high energies lie approximately on a smooth, symmetric, universal curve, whose height ($\sim\frac{1}{2}\sigma_{\text{inelastic}}$) and width are independent of the incoming particles. The only energy dependence is in the position of the maximum, $\langle\Delta Q\rangle$, which of course depends on the reaction, and in a threshold growth of the tails, leading to a roughly $\ln s$ growth of the variance. Note that the symmetry of the underlying curve does not imply symmetry of the data points $\sigma(\Delta Q)$, except when $\langle\Delta Q\rangle$ is an integer or half integer.

The expectation then is that when $\langle\Delta Q\rangle$ goes asymptotically to zero, $\sigma(\Delta Q)$ (for $|\Delta Q|$ small enough that one may ignore threshold growth) will be the same fraction of $\sigma_{\text{inelastic}}$ for all inclusive hadronic reactions. In particular, the simple—and therefore highly suggestive—fact that $\sigma(\Delta Q=0)$ is almost precisely $\frac{1}{2}\sigma_{\text{inelastic}}$ for pp is expected to become universal, and therefore even more interesting.

ACKNOWLEDGMENTS

We are grateful to the staff of the Fermi National Accelerator Laboratory, and to our measuring and analysis staffs.

---

[*] Research supported in part by the National Research Council of Canada, the Institute of Particle Physics of Canada, the U. S. Energy Research and Development Administration, and the U. S. National Science Foundation.

[1] U. Idschok et al., Nucl. Phys. B67, 93 (1973).

[2] C. Bromberg et al., Phys. Rev. D 9, 1864 (1974).

[3] T. Kafka et al., Phys. Rev. Lett. 34, 687 (1975).

[4] T. Ferbel, Univ. of Rochester Report No. UR-500, 1974 (unpublished).

[5] Bonn-Hamburg-Munich Collaboration, report, Max-Planck-Institut, Munich, 1975 (unpublished).

[6] K. Fiałkowski, report, Max-Planck-Institut, Munich, 1973 (unpublished).

[7] A. Chao and C. Quigg, Phys. Rev. D 9, 2016 (1974).

[8] A. Białas et al., Acta. Phys. Pol. B6, 290 (1975).

[9] P. Breitenlohner, in Proceedings of the IV International Symposium on Multihadron Hydrodynamics, Pavia, 1973 (unpublished).

[10] G. Smith, in *Particles and Fields—1973*, proceedings of the Berkeley meeting of the Division of Particles and Fields of the APS, edited by H. Bingham et al. (AIP, New York, 1974); N. Biswas et al., Phys. Rev. Lett. 35, 1059 (1975).

[11] See Ref. 1; also G. Giacomelli, private communication.

[12] D. Bogert *et al.*, Phys. Rev. Lett. 31, 1271 (1973).

[13] Data of ABBCCHLVW Collaboration cited by K. Zalewski, in *Proceedings of the XVII International Conference on High Energy Physics, London, 1974,* edited by J. R. Smith (Rutherford Laboratory, Chilton, Didcot, Berkshire, England, **1974), p. I-105.**

[14] P. Bosetti *et al.*, Nucl. Phys. B62, 46 (1973).

[15] A. S. Carroll *et al.*, Phys. Rev. Lett. 33, 932 (1974).