huizen for checking some calculations and for discussions.

*Work supported in part by National Science Foundation Grant No. PHY-76-15328.

[1]A. Salam and J. Strathdee, Nucl. Phys. B76, 477 (1974); R. Haag, J. T. Lopuszanski, and M. Sohnius, Nucl. Phys. B88, 257 (1975).

[2]D. Z. Freedman, P. van Nieuwenhuizen, and S. Ferrara, Phys. Rev. D 13, 3214 (1976).

[3]S. Deser and B. Zumino, Phys. Lett. 62B, 335 (1976).

[4]D. Z. Freedman and P. van Nieuwenhuizen, Phys. Rev. D 14, 912 (1976).

[5]S. Ferrara and P. van Nieuwenhuizen, Phys. Rev. Lett. 37, 1669 (1976).

[6]The structure of these representations and their relevance for supergravity have been emphasized for some time by M. Gell-Mann and Y. Ne'eman (private communication).

[7]M. T. Grisaru, P. van Nieuwenhuizen, and J. A. M. Vermaseren, Phys. Rev. Lett. 37, 1662 (1976).

[8]M. T. Grisaru, to be published.

[9]J. Wess and B. Zumino, Nucl. Phys. B78, 1 (1974).

[10]S. Ferrara, J. Scherk, and P. van Nieuwenhuizen, Phys. Rev. Lett. 37, 1035 (1976); S. Ferrara, F. Gliozzi, J. Scherk, and P. van Nieuwenhuizen, Ecole Normale Report No. PTENS 76/19, 1976 (to be published).

[11]D. Z. Freedman and J. H. Schwarz, State University of New York at Stony Brook Report No. ITP-SB-76-41, 1976 (to be published).

[12]S. Ferrara, D. Z. Freedman, P. van Nieuwenhuizen, P. Breitenlohner, G. Gliozzi, and J. Scherk, State University of New York at Stony Brook Report No. ITP-SB-76-46, 1976 (to be published).

[13]K. Johnson and E. C. G. Sudarshan, Ann. Phys. (N.Y.) 13, 126 (1961); G. Velo and D. Zwanziger, Phys. Rev. 186, 1337 (1969).

[14]D. Z. Freedman, State University of New York at Stony Brook Report No. ITP-SB-76-50, 1976 (to be published).

Neutron Fragmentation and Inclusive Charge Exchange in pd and π^+d Interactions at 195 GeV/c*

Y. Eisenberg, B. Haber, D. Hochman, E. Koller,† E. E. Ronat, A. Shapira, R. Yaari, and G. Yekutieli
Weizmann Institute of Science, Rehovot, Israel

and

H. Braun, F. Etienne, A. Fridman, J. P. Gerber, E. Jegham, P. Juillot, G. Maurer, and C. Voltolini
Centre de Recherches Nucléaires, Strasbourg, France

(Received 23 August 1976)

An excess of negative particles and depletion of positive particles in the backward hemisphere (c.m. system) is observed in π^+ and p interactions on neutron target. $d\sigma^-/dy$ is compared with pp interactions and the difference is related to the slow-proton spectrum produced in the pn interactions. A neutron fragmentation component is observed and the inclusive charge-exchange probability at the nucleon vertex is found to be about 0.4.

A number of interesting results have been reported on the inclusive negative-particle distributions in pp[1] and πp[2] interactions at 100–400 GeV and on the diffractive component measured in such interactions.[3] There are relatively few deuterium experimental results on the above subjects and most of them are preliminary or unpublished.[4] We would like to report here results on negative-particle distributions and neutron fragmentation obtained from an exposure of the FNAL 30-in. deuterium bubble chamber and proportional wire hybrid system to a positive π^+/p beam of 195 GeV/c, and on comparison to the relevant hydrogen data.

The experimental setup and other details are given in our previous publication,[5] where we presented also the pn and π^+n multiplicity distributions measured at 195 GeV/c. In particular we find[5] that there is a negative excess in the average number of secondaries (see Table I) in interactions on a neutron target: $\langle n_-\rangle_{pn} - \langle n_-\rangle_{pp} = 0.46 \pm 0.14$ and $\langle n_-\rangle_{\pi^+n} - \langle n_-\rangle_{\pi^+p} = 0.41 \pm 0.18$. [The fractional rate of charge exchange at the nucleon vertex, $\alpha = \sigma(n \to p + (x\pi)^-)/\sigma(n \to \text{all})$, is given by the negative excess: $\alpha = \langle n_-\rangle_n - \langle n_-\rangle_p$. See also Meyer[7] and Eisenberg *et al.*[8]].

Intuitively one expects the extra negative charge in interaction on neutrons to be related to the neutron target fragmentation $n \to p\pi^-X^0$. Therefore, we have made a careful and complete measurement of the backward (c.m. system) tracks in all topologies. Protons below $P_{\rm lab} = 1.4$ GeV/c could be identified by ionization. All negative

TABLE I. Average charged-particle multiplicities for backward- and forward-hemisphere (c.m. system) emissions at 200 GeV/c.

Experiment	$\langle n_- \rangle$ Backward	Forward	All	$\langle n_+ \rangle$[c] Backward	Forward	All	$\langle n_c \rangle$[c] Backward	Forward	All
pp[a]	1.42 ± 0.02	1.42	2.84 ± 0.04	2.42 ± 0.02	2.42	4.84	3.84	3.84	7.68 ± 0.07
π^+p[b]	···	···	2.95 ± 0.12	···	···	4.95	···	···	7.90 ± 0.23
pn	1.74 ± 0.06	1.56	3.30 ± 0.13	1.86 ± 0.07	2.44	4.30	3.60	4.00	7.60 ± 0.25
π^+n	1.62 ± 0.09	1.74	3.36 ± 0.15	1.76 ± 0.10	2.59	4.35	3.38	4.33	7.71 ± 0.30

[a]From Ref. 1, assuming forward-backward symmetry in c.m. system.
[b]From Ref. 6; only overall multiplicity is available.
[c]Because of unidentified protons (Ref. 7), the backward positive multiplicities have to be increased by ~0.07 in this experiment and the corresponding forward multiplicities decrease by the same amount. Note slightly revised multiplicities as compared with Ref. 5.

secondaries and positives above 1.4 GeV/c were assumed to be pions. The misindentified protons have only a small effect on any of our conclusions (see below). Altogether about 8000 events were measured, about a quarter of which were π^+d and the rest pd interactions. In order to obtain a pure sample of neutron interaction we used exclusively the sample of odd-prong events and even-prongs with a visible backward proton spectator in the laboratory system. Absolute cross sections were obtained by normalizing the number of events in each topology to our published topological cross sections.[5]

The overall manifestation of the negative excess in $d\sigma^-/dy$ can be seen best in Fig. 1, from which several very interesting features of the neutron interactions emerge:

(a) Even though the π^+n total inelastic cross section is only about $\frac{2}{3}$ of the pn cross section, the two experiments yield $d\sigma(\pi^-)/dy$ which is *essentially identical* in shape for $y_{\text{c.m.}} < 0$ [see Fig. 1(c)]. This indicates that n fragmentation dominates the backward region of the c.m. system in both experiments.[9]

(b) The cross sections for the reactions $pn \to \pi^-$ and $pp \to \pi^-$ are very different in the regions of large negative $y_{\text{c.m.}}$ and most of the negative excess is located between $y_{\text{c.m.}} = -4.0$ and $y_{\text{c.m.}} = -1.0$. As we approach $y_{\text{c.m.}} \simeq 0$ (Fig. 1), the cross sections become equal within error (± 7%). This justifies our search for differences between n and p targets mainly in the backward hemisphere of the c.m. system.

By integrating the data of Fig. 1(a) we obtain the average negative multiplicity in the c.m system backward hemisphere, $\langle n_- \rangle_B$, which is compared with the pp results in Table I. The negative excess which corresponds to the backward hemisphere is $\alpha_B = 0.32 \pm 0.10$ (the error includes systematic uncertainties). This value contains most of the 0.46 negative excess, and the excess in the forward hemisphere (0.14 ± 0.10) may be largely due to charge transfer between hemispheres. The difference between the pn and pp inclusive negative cross sections in the backward hemisphere is $\alpha_B \sigma_{\text{inel}} = 10.4 \pm 3.3$ mb and is made up from topologies up to 17 prongs [Fig. 2(b)].

Next we examine the fraction of backward (c.m. system) cross section in the various topologies. The results are summarized in Fig. 2. We see that for pn interactions the fraction R of backward *negative* and *positive* secondaries[7] ($R = N_B/N$) is *quite different* from the respective fraction in proton-proton interaction (trivially 0.50). In the low multiplicities R^- is above 0.50 and R^+ well below 0.50. (Coherent inelastic d interactions may increase R in the three-prongs by a few percent.) For π^+n interactions [Fig. 2(a)] R^+ is always below 0.5 while R^- begins at 0.65, crosses 0.5 at nine prongs, and together with R^+ approaches a value of 0.40–0.45. This indicates that the average multiplicity of the π^+ vertex is about 10% *higher* than that of the nucleon vertex, an effect which is clearly seen in Table I and was noticed in π^-p interactions.[10]

Finally we report on slow-proton ($p_{\text{lab}} < 1.4$ GeV/c) production and discuss its possible relation to the negative excess. In *both* pn and π^+n interactions about 21% of the events have an associated slow proton identified by ionization which is emitted backward in the c.m. system; and for pn this corresponds to about 6.6 ± 0.5 mb. The yield of slow p's is the same for π^+ and p beams and changes little with topology—about 23% for three- to nine-prong events and 18% for

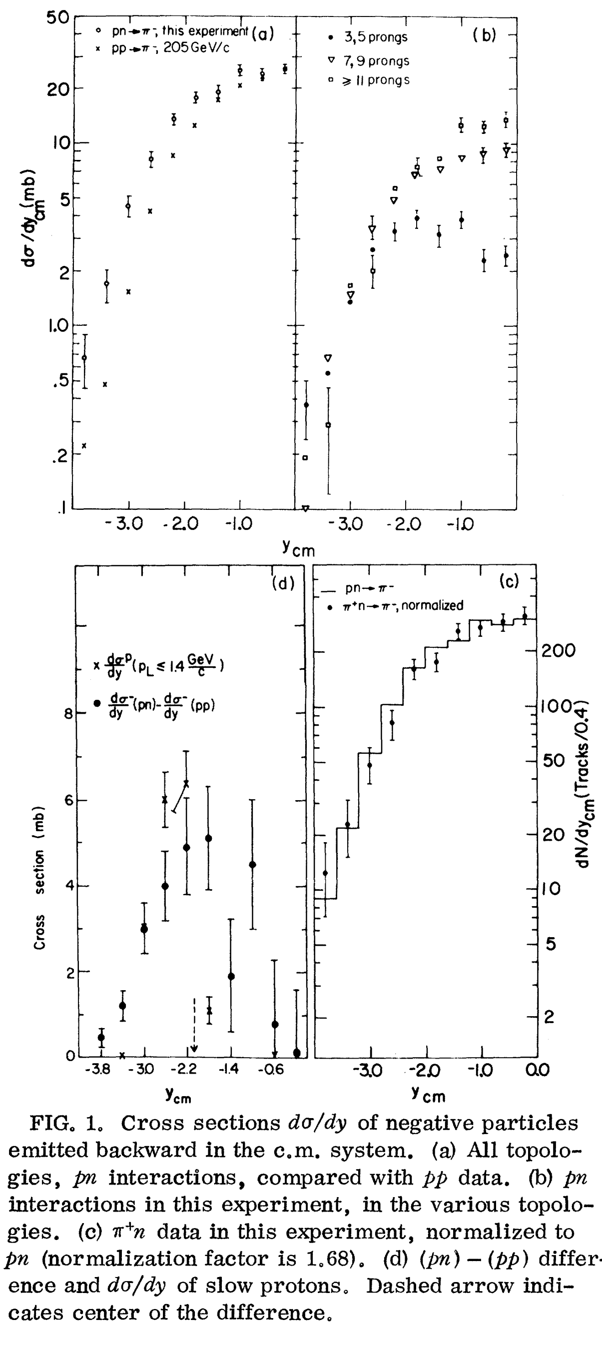

FIG. 1. Cross sections $d\sigma/dy$ of negative particles emitted backward in the c.m. system. (a) All topologies, pn interactions, compared with pp data. (b) pn interactions in this experiment, in the various topologies. (c) π^+n data in this experiment, normalized to pn (normalization factor is 1.68). (d) $(pn)-(pp)$ difference and $d\sigma/dy$ of slow protons. Dashed arrow indicates center of the difference.

eleven prongs or more. The average number of charged particles, $\langle n_c\rangle$, for the events associated with a slow p is 7.5 ± 0.3, like the overall $\langle n_c\rangle$. (Note that the charge-symmetric reaction $p\rightarrow n+\ldots$ is unmeasurable in bubble chambers.) The negative excess and slow-p emission cannot be fully accounted for by a diffractive component $pn\rightarrow p_{\text{fast}}x$ ($x\rightarrow p\pi^-+\ldots$). From pp interactions we know[3] that (a) single diffraction occurs mainly in

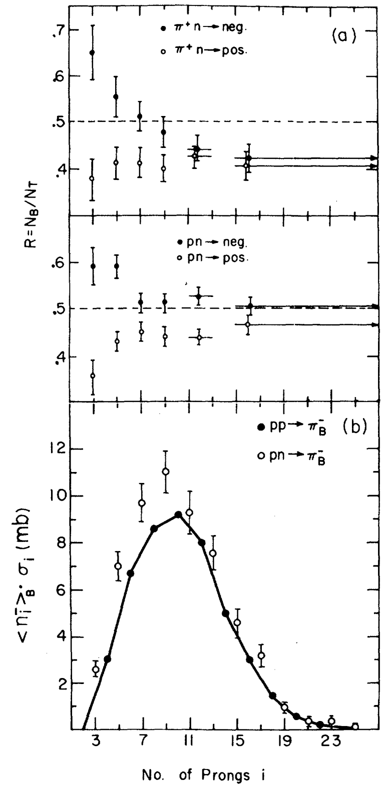

FIG. 2. (a) Fractions of negative and positive charges in the backward hemisphere of the c.m. system as a function of topology in π^+n and pn interactions. (b) The inclusive backward (c.m. system) negative-particle cross section in pn and pp interactions. The pp data are joined by lines to guide the eye.

the two- to four-prong topologies; (b) the reaction $pp\rightarrow p_{\text{slow}}x$, at 205 GeV/$c$, has a cross section[3] of only 3.1 ± 0.35 mb (for one vertex) while our slow-p yield from the neutron vertex is 6.6 ± 0.5 mb; and (c) the inclusive negative cross section from diffraction in pp is $\langle n^-\rangle_D\cdot\frac{1}{2}\sigma_D=2.05\pm0.50$ mb, while our observed negative excess is 10.4 ± 3.3 mb.

The high yield of p_{slow} and the large negative excess in the backward hemisphere suggest a neutron fragmentation mechanism $n\rightarrow(p\pi^-)+\ldots$ occurring near the neutron end of the rapidity axis. At least in part (we do not identify all p's) this fragmentation yields low-mass $M(p\pi^-)$ enhancements (<3 GeV) in all topologies[11] (see Fig. 3). In Fig. 1(d) we compare $d\sigma^p/dy$ of the slow protons with the difference $\delta\sigma^-/dy=d\sigma^-(pn)/dy-d\sigma^-(pp)/dy$. The difference $\delta\sigma^-/dy$ is centered at about $y_{\text{c.m.}}\approx-2.0$ and seems to be symmetric about this value. The negative excess cross section for $y\leq-2.0$ is 5.2 ± 1.6 mb and is

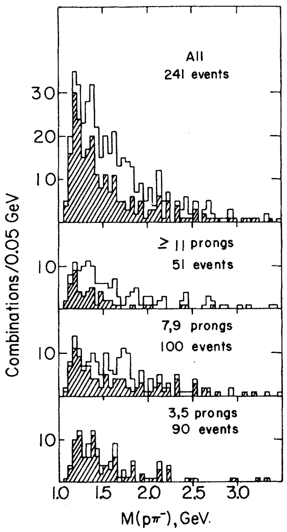

FIG. 3. Distribution of $M(p\pi^-)$ for slow protons ($P_{lab} < 1.4$ GeV/c) and backward-emitted (c.m. system) π^- mesons in the various topologies. Shaded area: Distribution of $M(p\pi_1^-)$ as above, where π_1^- is the pion with smallest rapidity.

close to the slow-proton cross section of 6.0 ± 0.5 mb in the same y region ($y = -2.0$ corresponds roughly to our cut $p_{lab} \leq 1.4$ GeV). It is interesting to note that such a behavior would be expected if the protons and negative excess π^-'s are emitted from a symmetric cluster centered about $\bar{y} \approx -2.0$ in the c.m. system. In this case the $y \leq \bar{y}$ proton yield should be the same as that of the π^-'s, and thus the total inclusive $n \to p$ cross section becomes $2(6.0 \pm 0.5) = 12.0 \pm 1.0$ mb, which yields $\alpha = (12 \pm 1)/32.1 = 0.38 \pm 0.04$. This agrees with the above measure of α based upon the negative multiplicity and with the value of $1 - \alpha$ (0.62 $\pm$ 0.02) measured in pp interactions at 12 and 24 GeV/c.[12]

We thus conclude that within 10%, $\alpha \approx 0.40$ and is roughly energy-independent. We also conclude that we have evidence for neutron fragmentation components in multihadron production, $n \to (p\pi^- \ldots)^0$, in all topologies, which explains the observed negative excess, high yield of slow protons, and low-mass enhancements.

We are grateful to the Fermilab staff and the Proportional Wire Hybrid System Consortium for making this experiment possible. We thank our electronics, programming, and scanning staffs for their efforts in performing this work, and J. Schultz for his contribution in the early stages of the experiment.

*Research was supported by a grant from the United States–Israel Binational Science Foundation (BSF), Jerusalem, Israel.

†On leave from Stevens Institute of Technology, Hoboken, N. J. 07030.

[1]Y. Cho *et al.*, Phys. Rev. Lett. 31, 413 (1973); L. Hyman, private communication; F. T. Dao *et al.*, Phys. Lett. 45B, 73 (1973).

[2]D. G. Fong *et al.*, Phys. Lett. 53B, 290 (1974), and Nucl. Phys. B102, 386 (1976); W. Morris *et al.*, Phys. Lett. 56B, 395 (1975); J. T. Powers *et al.*, Phys. Rev. D 8, 1947 (1973).

[3]A. Firestone *et al.*, Phys. Rev. D 12, 15 (1975); J. Whitmore, Phys. Rep. 10C, 273 (1974); F. C. Winkelmann *et al.*, Phys. Rev. Lett. 32, 121 (1974); J. W. Chapman *et al.*, Phys. Rev. Lett. 32, 257 (1974); S. J. Barish *et al.*, Phys. Rev. Lett. 31, 1080 (1973).

[4]A. Sheng *et al.*, Phys. Rev. D 12, 1219 (1975); S. Dado *et al.*, Phys. Lett. 60B, 397 (1976); E. W. Anderson *et al.*, Bull. Am. Phys. Soc. 21, 52 (1976); A. Brody *et al.*, *ibid.* p. 53; J. Hanlon *et al.*, *ibid.* p. 53.

[5]Y. Eisenberg *et al.*, Phys. Lett. 60B, 305 (1976).

[6]J. Erwin *et al.*, University of California, Davis, Report No. UCD-PRL-9-15-75, 1975 (to be published). σ_2 was assumed to be $\frac{2}{3}$ of $\sigma_2(pp)$ (Ref. 1).

[7]Since all positives with $P_{lab} \geq 1.4$ GeV/c were assumed to be pions, R^+ in Fig. 2 and $\langle n_+ \rangle_B$ in Table I for this experiment should be considered as lower limits. From Monte Carlo runs including Van Hove phase space and low-mass enhancements, and by extrapolating our observed P_{lab} distribution of the identified protons, we estimate that ~40% of the produced protons in the backward hemisphere of the c.m. system have $P_{lab} \geq 1.4$ GeV/c but only ~10% are wrongly assigned to the forward hemisphere. The correct values of R^+ and $\langle n_+ \rangle_B$ are thus ~5–10% higher than our observed values and this does not change our main conclusions.

[8]H. Meyer, in *Proceedings of the Fifth International Symposium on Electron and Photon Interactions at High Energies, Bonn, W. Germany, 1973*, edited by H. Rollnik and W. Pfeil (North-Holland, Amsterdam, 1974), p. 175; Y. Eisenberg *et al.*, Nucl. Phys. B104, 61 (1976).

[9]This resemblance between $\pi^+ n$ and pn in the backward region of the c.m. system manifests itself in *all* π^- distribution that we have examined, such as $d\sigma/dx$, $d\sigma/dp_T^2$, etc. Evidence for dominance of *charged* leading clusters in $\pi^- p$ interactions was observed by D. G. Fong *et al.*, Phys. Lett. 61B, 99 (1976); V. P. Kenney *et al.*, to be published.

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

[11]Such enhancements were reported in an exclusive three-prong reaction: J. Biel *et al.*, Phys. Rev. Lett. 36, 504, 507 (1976).

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