Wetherell, in Proceedings of the Topical Conference on High Energy Collisions of Hadrons, CERN, 15-18 January 1968 (to be published).

[5] W. Czyż and L. Leśniak, Phys. Letters 24B, 227 (1967); R. H. Bassel and C. Wilkin, Phys. Rev. Letters 18, 871 (1967); T. T. Chou, Phys. Rev. 168, 1594 (1968).

[6] R. Rubinstein, A. Ashmore, C. J. S. Damerell, W. R. Frisken, J. Orear, D. P. Owen, F. C. Peterson, A. L. Read, D. G. Ryan, and D. H. White, in Proceedings of the Topical Conference on High Energy Collisions of Hadrons, CERN, 15-18 January 1968 (to be published).

[7] V. Barger, in Proceedings of the Topical Conference on High Energy Collisions of Hadrons, CERN, 15-18 January 1968 (to be published).

[8] L. Durand, III, and R. Lipes, Phys. Rev. Letters 20, 637 (1968).

[9] D. H. Coward, H. DeStaebler, R. A. Early, J. Litt, A. Minten, L. W. Mo, W. K. H. Panofsky, R. E. Taylor, M. Breidenbach, J. I. Friedman, H. W. Kendall, P. N. Kirk, B. C. Barish, J. Mar, and J. Pine, Phys. Rev. Letters 20, 292 (1968); M. Goitein, R. J. Budnitz, L. Carroll, J. Chen, J. R. Dunning, Jr., K. Hanson, D. Imrie, C. Mistretta, J. K. Walker, R. Wilson, G. F. Dell, M. Fotino, J. M. Paterson, and H. Winick, Phys. Rev. Letters 18, 1016 (1967); W. Albrecht, H. J. Behrend, F. W. Brasse, W. Flauger, H. Hultschig, and K. G. Steffen, Phys. Rev. Letters 17, 1192 (1966); W. Bartel, B. Dudelzak, H. Krehbiel, J. M. McElroy, U. Meyer-Berkhout, R. J. Morrison, H. Nguyen-Ngoc, W. Schmidt, and G. Weber, Phys. Rev. Letters 17, 608 (1966); L. N. Hand, D. G. Miller, and R. Wilson, Rev. Mod. Phys. 35, 335 (1963).

DOUBLE CHARGE EXCHANGE IN π^+-HELIUM SCATTERING*

N. Carayannopoulos, J. Head, N. Kwak, J. Manweiler, and R. Stump
The University of Kansas, Lawrence, Kansas

(Received 26 March 1968)

It has been suggested by several authors that the double-charge-exchange reaction might supply information on nucleon-nucleon correlations in nuclei.[1] In the course of an experiment on π^+ interactions in helium we have obtained a limited sample of double-charge-exchange events. Although the number of events is rather small, a simple analysis gives a qualitative picture of the process involved.

The data were obtained from an exposure of 610-MeV/c π^+ in the 10-in. superconducting-magnet bubble chamber at the Argonne National Laboratory. About 17 300 frames were scanned for events in which negative pions were produced, with a scanning efficiency of 97%. Of the 269 events found, 42 fitted the double-charge-exchange hypothesis:

$$\pi^+ + \mathrm{He} \rightarrow \pi^- + 4p. \qquad (1)$$

The remainder were distributed among various two-pion final states. The observed rate corresponds to a cross section of 1.20 ± 0.21 mb.

Since there are no theoretical calculations of double charge exchange in the energy range covered by this experiment, the data are compared with a phase-space model. The model is based on the assumption that the process involved is

$$\pi^+ + 2n \rightarrow \pi^- + 2p \qquad (2)$$

with two spectator protons. Further assumptions include the following: (a) There is no spin flip. (b) The transition amplitude for Reaction (2) is not a function of the momenta of the particles. (c) The spectator protons have a momentum distribution given by the square of the Fourier transform of the nuclear charge density; the kinetic energy of the spectators is neglected.

The fact that the final state contains four protons—two of each spin—is taken into account by using antisymmetrical wave functions in the fi-

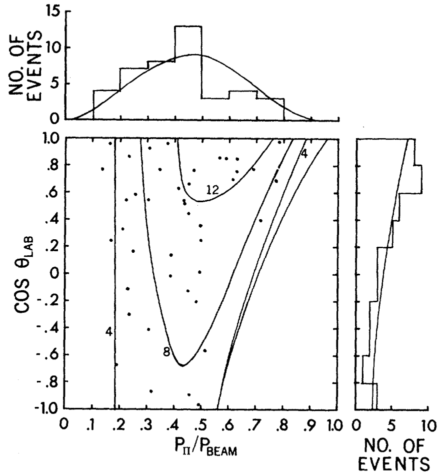

FIG. 1. The ratio of the laboratory momentum of the π^- to the beam momentum plotted against the cosine of the angle between the π^- and the beam. The curves show lines of equal density, on an arbitrary scale, as predicted by the phase-space model. The curve on the extreme right-hand side is the kinematic limit. The curves on the histograms are predictions normalized to the observed number of events.

nal state. Various particle distributions are then given by three-particle Lorentz-invariant phase space modified by the effects of the exclusion principle. Qualitatively the exclusion principal reduces the probability for producing protons of low momentum or, what amounts to the same thing, for producing π^- at 0° in the laboratory with momentum near that of the beam.

Two scatter plots provide a comparison of our experimental results with the phase-space model. Figure 1 shows the ratio of the momentum of the π^- to the beam momentum plotted against the cosine of the angle between the π^- and the beam. Figure 2 shows the proton distribution in the same coordinates; in this case there are four points per event. Predictions of the model are shown as contours of equal density on an arbitrary scale.

In view of the obvious shortcomings of the model and the limited data available, the agreement is satisfactory. The general displacement of the data points to lower momentum is an obvious consequence of neglecting the energy of the spectator protons; the reduction in extremes of density reflects the neglect of the Fermi momentum of the neutrons in the initial state.

An experiment on the reaction

$$\pi^- + \mathrm{He} \to \pi^+ + 4n$$

has been analyzed in terms of a model similar to that which is proposed here.[2]

In this respect, it should also be noted that in counter experiments at higher energies, strong suppression of double charge exchange at 0° and maximum secondary momentum has been observed.[3] Such suppression may be at least partly explained as due to the consequences of the exclusion principle, although detailed predictions are unreliable.

We have attempted to fit the experimental data with other models. A Monte Carlo calculation was made for the cascade process

$$\begin{aligned}&\pi^+ + n \to \pi^0 + p,\\ &\pi^0 + n \to \pi^- + p,\end{aligned} \tag{3}$$

using experimental pion-nucleon cross sections and the appropriate momentum distribution of the target nucleons. A similar calculation was made for the process

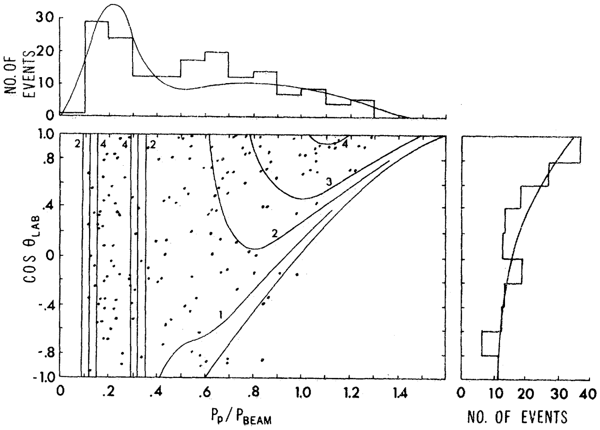

FIG. 2. The ratio of the proton laboratory momentum to the beam momentum plotted against the cosine of the angle between the proton and the beam. There are four points per event. The curves show lines of equal density, on an arbitrary scale, as predicted by the phase-space model. The curve on the extreme right-hand side is the kinematic limit. The curves on the histograms are predictions normalized to the observed number of events.

$$\begin{aligned}&\pi^+ + 2n \to N^* + p\\ &\qquad\qquad\; \hookrightarrow \pi^- + p.\end{aligned} \tag{4}$$

Neither (3) nor (4) gives a fit to the data which is satisfactory as that given by the phase-space model.[1] It should likewise be noted that the energy of this experiment is too low to allow the production of neutral bosons as suggested by experiments at higher energy.[3]

The general agreement of the data of this experiment with the phase-space model indicates that in the momentum range ~600 MeV/c the double-charge-exchange process is mainly a three-particle process involving two nucleons of like charge. The process thus does indeed depend on the nucleon-nucleon correlation. However, to exploit this dependence would require a much more extensive experiment than the present one.

---

*Work supported in part by the National Science Foundation.

[1] M. Jean, Nuovo Cimento Suppl. 2, 400 (1964); Kurt Gottfried, Ann. Phys. (N.Y.) 21, 29 (1963); T. Ericson, CERN Report No. CERN 63-28, 1963 (unpublished).

[2] L. Gilly, M. Jean, R. Meunier, M. Spighel, J. P. Stroot, and P. Duteil, Phys. Letters 19, 335 (1965).

[3] R. A. Lundy, I. A. Pless, D. R. Rust, D. D. Yovanovitch, and Vera Kistiakowsky, Phys. Rev. Letters 20, 283 (1968).