Present address:
†Physics Department, Carnegie-Mellon University, Pittsburgh, PA 15213.

§Department of Nuclear Energy, Brookhaven National Laboratory, Upton, NY 11973.

¶Physics Department, Princeton University, Princeton, NJ 08544.

††Physics Department, Physics Department, Brookhaven National Laboratory, Upton, NY 11973

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MEASUREMENT OF (p,π) AND (p,γ) REACTIONS BY RECOIL DETECTION*

J. Homolka, W. Schott, W. Wilhelm and W. Wagner
Physik-Department, Technische Universitat Munchen Garching, West Germany

R.D. Bent, M. Fatyga† and R.E. Pollock
Indiana University Cyclotron Facility Bloomington, Indiana 47405

R.E. Segel
Northwestern University, Evanston, Illinois 60204 and Argonne National Laboratory, Argonne, Illinois 60439

P. Kienle
Gesellschaft fur Schwerionenforschung Darmstadt, West Germany

K.E. Rehm
Argonne National Laboratory Argonne, Illinois 60439

M. Saber
Northwestern University, Evanston, Illinois 60204

Measurements of the $^{12}C(p,\pi^+)^{13}C$, $^{12}C(p,\pi^\circ)^{13}N_{g.s.}$ and $^{12}C(p,\gamma)^{13}N_{g.s.}$ reactions by recoil detection were continued at incident energies of 153.5, 166.1, 186.0 and 204.0 MeV. The recoils are detected in a focal-plane detector in the QQSP spectrometer.

The recoil products are analyzed by the magnetic spectrometer measuring $\frac{p}{Q}$, where p and Q are the recoil momentum and atomic charge, respectively. Combined with a measurement of time-of-flight through the spectrometer, the ratio $\frac{A}{Q}$ is determined, where A is the recoil atomic mass number. An energy loss measurement fixes the nuclear charge Z. The emission angle Θ is obtained by two position measurements using the heavy-ion detector. For reactions leading to a specific two-body final state the recoil products lie on a half-ellipse shaped contour in the p-Θ plane.[1]

Figure 1 shows the distribution of the $^{13}C^{6+}$ recoils in the $p/p_0 = \Theta$ plane (p_0 denotes the reference recoil momentum) at 186 MeV incident proton energy. The spectrum contains 34700 counts and was obtained in a 3 hour run with an integrated beam charge of ~ 3.5 m Cb. The spectrum contains recoil products from reactions populating the four bound states of ^{13}C. In the forward direction a ^{13}C recoil from the $^{12}C(p,\pi^+)$ reaction in the highest bound state (3.85 MeV) will have about 0.5 MeV less energy than a recoil ion in the ground state. However, the energy spread upon emerging from the target for initially monoenergetic ^{13}C ions was about 1.4 MeV and, therefore, it was not possible to resolve the reactions populating the various bound states. Lines drawn in Fig. 1 show the maximum and minimum momentum recoils expected from the $^{12}C(p,\pi^+)^{13}C$ reaction at E_p = 186 MeV. In Fig. 2 measurements at 186 MeV of the $^{12}C(p,\pi^+)^{13}C$ reaction using the recoil technique are compared to previous work where pions were detected.[2] Agreement is good in the region of overlap and, with the recoil technique, the measurements are extended into the region of backward pion emission where it is difficult to detect the pions directly.

The $^{12}C(p,\pi^+)$ reaction was observed at all incident bombarding energies. At energies closer to threshold, the entire ellipse can be observed. Figure 3 shows the yield in the p-Θ plane for ^{13}C recoils obtained at a bombarding energy at 166 MeV. For Fig. 3a the $\frac{A}{Q}$ window was at 13/6 (i.e. $^{13}C^{6+}$) while the $\frac{A}{Q}$ window was at 13/5 ($^{13}C^{5+}$) for Fig. 3b. As expected, higher momentum recoils are primarily in the 6^+ state while at lower momenta the distribution shifts to lower charge states. Of course, all cross sections must be corrected for the fraction in the particular charge state being examined.

At 186 MeV, the cross section for the previously unobserved $^{12}C(p,\pi^\circ)^{13}N_{g.s.}$ reaction was found to be

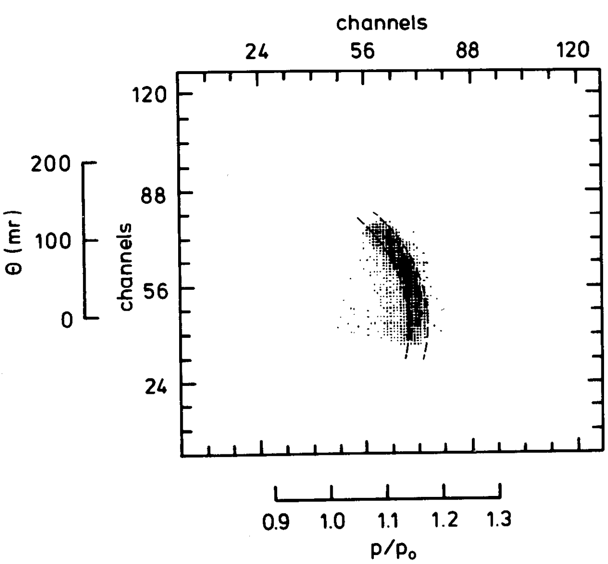

Figure 1. Emission angle vs relative magnetic rigidity of $^{13}C^{6+}$ recoil ions at a bombarding energy of 186 MeV. The spectrograph rigidity, p_0/Q, where Q is the ion charge, is set at 0.339 Tesla-meters. The events shown have been gated by two windows to select A/q = 13/6 and Z = 6. The dotted lines delineate the region in which the recoils from the $^{12}C(p,\pi^+)^{13}C$ reaction are calculated to fall.

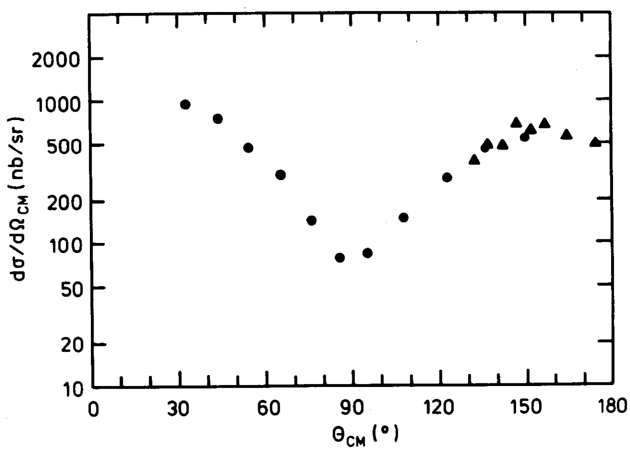

Figure 2. Differential cross section $d\sigma/d\Omega_{CM}$, vs pion emission angle, Θ_{CM}. The full triangles are data from the present experiment. The statistical uncertainties are smaller than the size of the triangles. The full circles are results which were obtained by π^+ detection[2] where the cross sections for forming the four bound states of ^{13}C have been added.

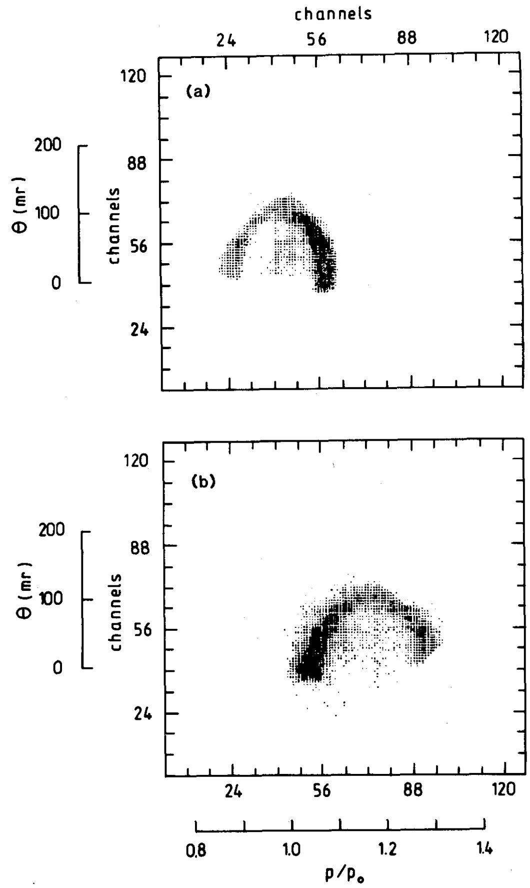

Figure 3. Two dimensional histogram in the $\frac{p}{p_0}$ - Θ plane of recoils from the $^{12}C(p,\pi^+)^{13}C$ reaction at a proton bombarding energy of 166 MeV. (a): For recoil products with $\frac{A}{Q}$ = 13/6 ($^{13}C^{6+}$). (b): For products with $\frac{A}{Q}$ = 13/5 ($^{13}C^{5+}$).

3.4 ± 0.5 nb/sr for pions emitted at 155° (c.m.) rising to 7.4 ± 1.2 nb/sr at 175°. Searches for the $^{12}C(p,\gamma)^{13}N_{g.s.}$ recoils have placed an upper limit of ≈0.5 nb/sr for backward emitted gamma rays. Analysis of the (p,π°) and (p,γ) data at the other bombarding energies is proceeding.

An earlier study of the $^{12}C(^3He,\pi^+)^{15}N$ reaction was published[3] and further data on this reaction were taken.

Analysis is continuing and plans are being made to use the system at the IUCF Cooler where it is expected to achieve an energy resolution of one part in a thousand with the recoil technique and still have luminosities ≈100 times greater than possible with fixed targets where the energy loss of the recoil particles limits the target thickness.

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†Present address: Brookhaven National Laboratory, Long Island, New York, 11973.

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