STUDIES OF HIGH MOMENTUM TRANSFER REACTIONS BY RECOIL DETECTION: (p,π), (p,2π), AND (p,γ)

R.E. Segel, F-J. Chen, P. Heimberg, and Z. Yu
Northwestern University, Evanston, Illinois 60201

J. Brown* and E. Jacobsen
Princeton University, Princeton, New Jersey 08540

J. Homolka and R. Schneider
Physik Department, Technische Universität München, Germany

A. Zhuravlev and A. Kurepin
Institute for Nuclear Research, Moscow, Russia

G. Hardie and P. Pancella
Western Michigan University, Kalamazoo, Michigan 49008

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

R.D. Bent, J. Blomgren, H. Nann, T. Rinckel, M. Saber,† and C. Sun
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

A technique for studying high-momentum transfer nuclear reactions on the Cooler using recoil-ion detection has been developed at IUCF. This program is a continuation of pion production[1,2] and high-momentum transfer (p,N) reaction[3] studies made at the cyclotron. The magnet in the Cooler ring that bends the primary beam 6° sweeps the recoils into a detection system, where they first pass through a parallel grid avalanche counter (PGAC) that measures the time and position of the particles emerging from the magnet. The PGAC has 0.9-micron thick entrance and exit foils and a time resolution of 650 ps. After traversing a 64-cm flight path, the recoils pass through a proportional counter (PC) which measures dE/dx. The recoils stop in an array of silicon microstrip detectors, which has 1 mm position, 800 ps time and 160-keV energy resolution, and is mounted in the same housing as the PC. The detector array is shown in Fig. 1.

The first experiments were carried out in November–December 1992 and February 1993 at bombarding energies of 166, 200, 250, 290, 330, and 350 MeV using carbon fiber and foil skimmer targets. Luminosities of several × 10^{29} $\mathrm{cm^{-2}s^{-1}}$ were achieved. Fig. 2 shows the results of off-line analysis of the 166 MeV p + ^{12}C data taken in the February 1993 run:

(a) ΔE vs. E showing primarily light recoils (He, Li, Be and B) from spallation reactions. A diagonal software cut has been applied to eliminate the intense He and Li recoils.

(b) Magnetic rigidity vs. energy in the silicon detectors E(Si) with the Z=6 window shown in (a) and a mass-13 window in the E/v^2 vs. E(Si) plane (not shown). The forward and backward peaking of the ^{12}C(p,π^+)^{13}C angular distribution is clearly visible in the spectrum of ^{13}C recoils in the q = 5 charge state.

CE-06 Detector Stack

PGAC: *X, Y*
PC: *DE, Y*
SI: *E, X*
PGAC-SI: *TOF*
PC-SI: *Recoil identification*
Raytracing: *P/Q, theta*

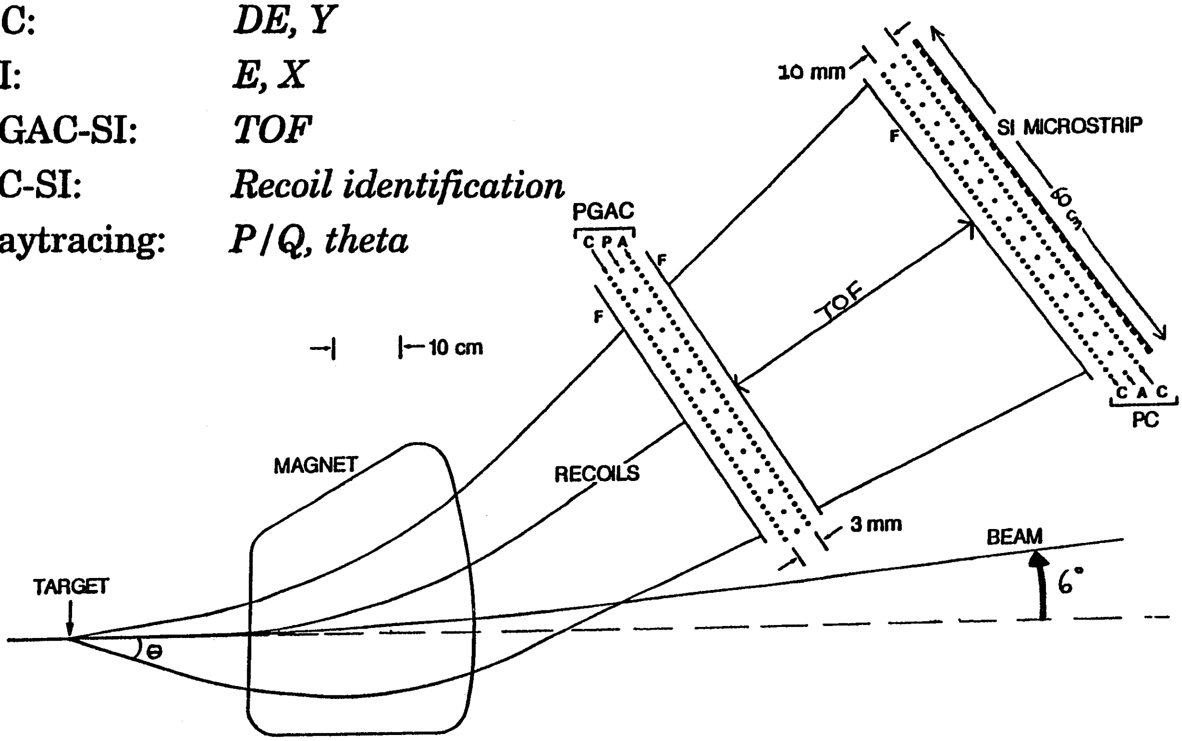

Figure 1. Recoil-ion detector array.

(c) angle of emission (θ_{lab}) vs. magnetic rigidity (p/q) at the target for ^{13}C recoils in the q = 5 charge state from the ^{12}C(p,π^+)^{13}C reaction. At 166 MeV bombarding energy (18 MeV above threshold) the ^{13}C recoils are confined to a 7° cone about the the beam axis. The diagonal cut in the lower right-hand part of the figure is due to the detector acceptance; high-rigidity recoils emitted to the right (looking down stream) aren't bent enough by the 6° magnet to hit the detectors. The well-defined width of the ellipse is probably mainly due to multiple scattering, but wandering of the beam position may also be an important factor.

(d) Same as (c) except for ^{13}C recoils in the q = 6 charge state. Here the detector acceptance includes the entire ellipse.

The angles and rigidities plotted in Figs. 2(c) and 2(d) were calculated from the recoil-ion positions in the PGAC and Si detectors using a backward raytracing program.

Analysis is in progress to determine ^{12}C(p,π^0)^{13}N differential cross sections in the 200–350 MeV region, check the ^{12}C(p,π^0/π^+) cross section anomaly at 166 MeV reported by Homolka, *et al.*,[2] and search for (p,2π) events at 330 and 350 MeV bombarding energy. At bombarding energies above the (p,2π) threshold ($\sim$ 294 MeV), the (p,π) ellipses will be much larger, and (p,2π) events will fill (because of three-body kinematics) small ellipses in the central hole. Reliable relative (p,2π) cross sections for different isospin channels (including those involving neutral pion emission) should be obtainable using the recoil technique, because the various recoils are all detected simultaneously using the same beam, the same target, and the same detection system.

Experiments planned for the future include: measurements of the cross section and isospin selectivity of the (p,2π) reaction near threshold to obtain information about non-linear terms (to third and fourth order in the pion field) in the πN interaction; a search for evidence of a possible quasi-bound two-pion state in nuclei;[4] a search for corroborative evidence of possible resonant two-pion production near 350-MeV bombarding energy;[5,6] and studies of the ($\vec{p}$,γ) reaction with polarized beam. In addition, the possibility of using the detector stack to measure recoils accompanying pion production by heavy ions is being investigated.

* Now at Yale University.

† Now at King Faisal University, Dammam, Saudi Arabia.

1. J. Homolka, *et al.*, Nucl. Inst. Meth. **A260**, 418 (1987); J. Homolka, *et al.*, Phys. Rev. C **36**, 2686 (1988).
2. J. Homolka, *et al.*, Phys. Rev. C **45**, 1276 (1992); J. Homolka, Ph.D. thesis, Technische Universität München (1989).
3. Z. Yu, *et al.*, to be published.
4. P. Schuck, *et al.*, Atomic Nuclei **330**, 119 (1988).
5. V.A. Krasnov, *et al.*, Phys. Lett. **108B**, 11 (1982).
6. J. Julien, *et al.*, Phys. Lett. **142B**, 340 (1984).

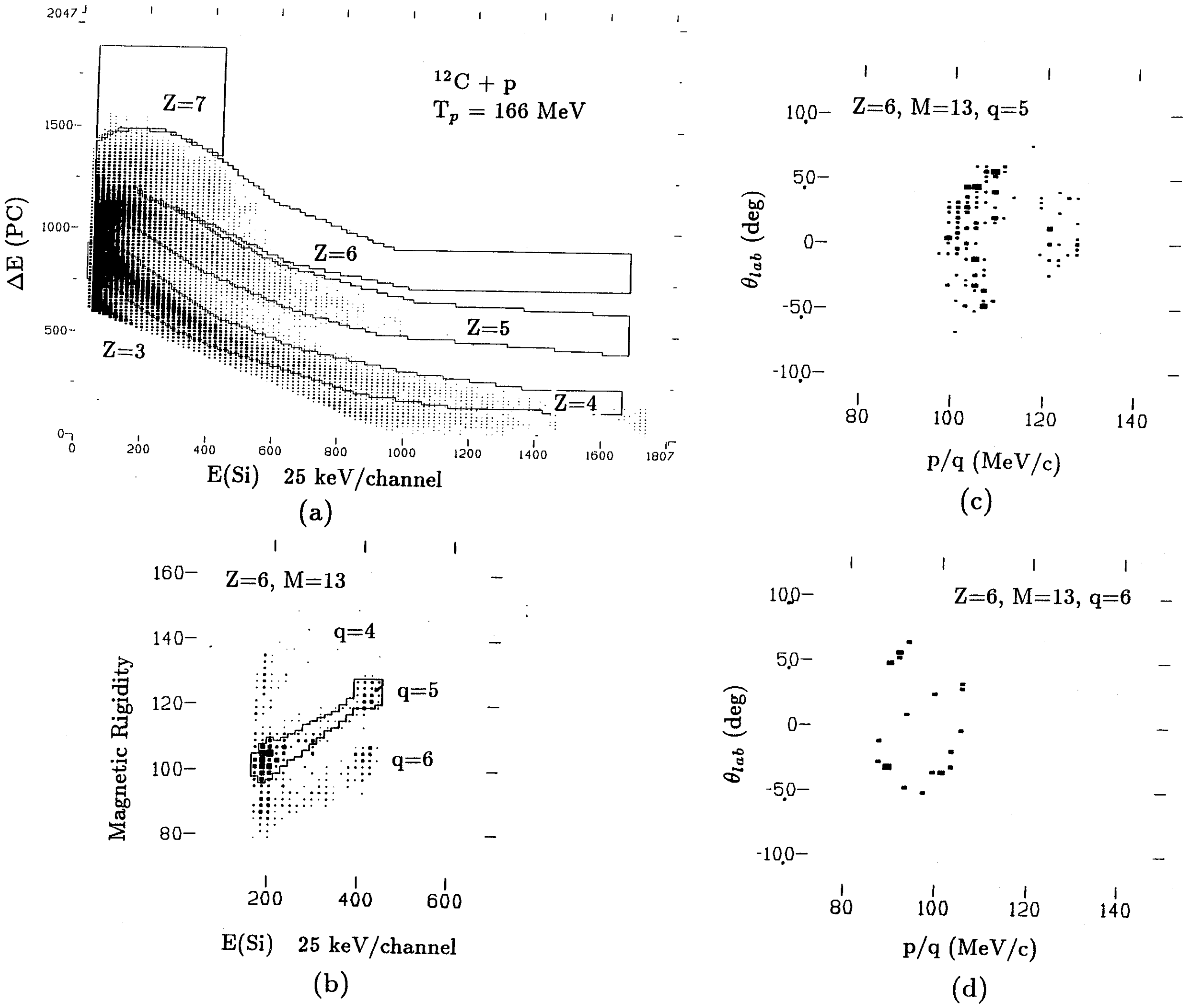

Figure 2. Results of off-line analysis of p + ^{12}C data taken at 166 MeV bombarding energy in February 1993 showing ^{13}C recoils from the ^{12}C(p,π^+)^{13}C reaction.