STUDIES OF (p,π) AND (p,2π) REACTIONS ON THE INDIANA COOLER RING USING RECOIL-ION DETECTION

F.-J. Chen, P. Heimberg, R. Segel, 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. Kurepin and A. Zhuravlev
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. Bent, J. Blomgren, H. Nann, T. Rinckel, M. Saber, and C. Sun
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

A method has been developed for studying high momentum transfer reactions on the Cooler ring using recoil-ion detection. The system employs the dipole magnet in the Cooler ring, which bends the primary beam by 6°, to sweep the recoil ions into a detection system consisting of a parallel grid avalanche counter (PGAC) that measures the (x, y) position, a proportional counter (PC) that measures the energy loss dE/dx and y position, and a silicon microstrip detector that measures the total energy and x position of the recoil ions. With this method, cross sections for single and double pion production in different isospin channels are measured simultaneously with the same target and detection system.

The two-dimensional ΔE(PC) vs. E(Si) spectrum gives nuclear charge separation. The 6° magnet gives a measurement of the rigidity $R = p/Q = Mv/Q$ of the recoil ion, where p is its momentum, Q its atomic charge, M its atomic mass, and v its velocity. The momentum per unit charge, p/Q, and the emission angle, θ, of the recoil ions are determined from the two (x, y) positions by ray-tracing back through the 6° magnet to the target position. By dividing p/Q by the recoil ion velocity v, determined from the TOF between the PGAC and the Si detector, M/Q is determined. The recoil-ion charge and mass are given by $Q = 2E/Rv$ and $M = 2E/v^2$. Taking advantage of the fact that the charge is quantized, two other determinations of the mass are obtained: $M_2 = QR/v$ and $M_3 = Q^2R^2/2E$.

^{12}C(p,π^+)^{13}C at 166 MeV, Q=6

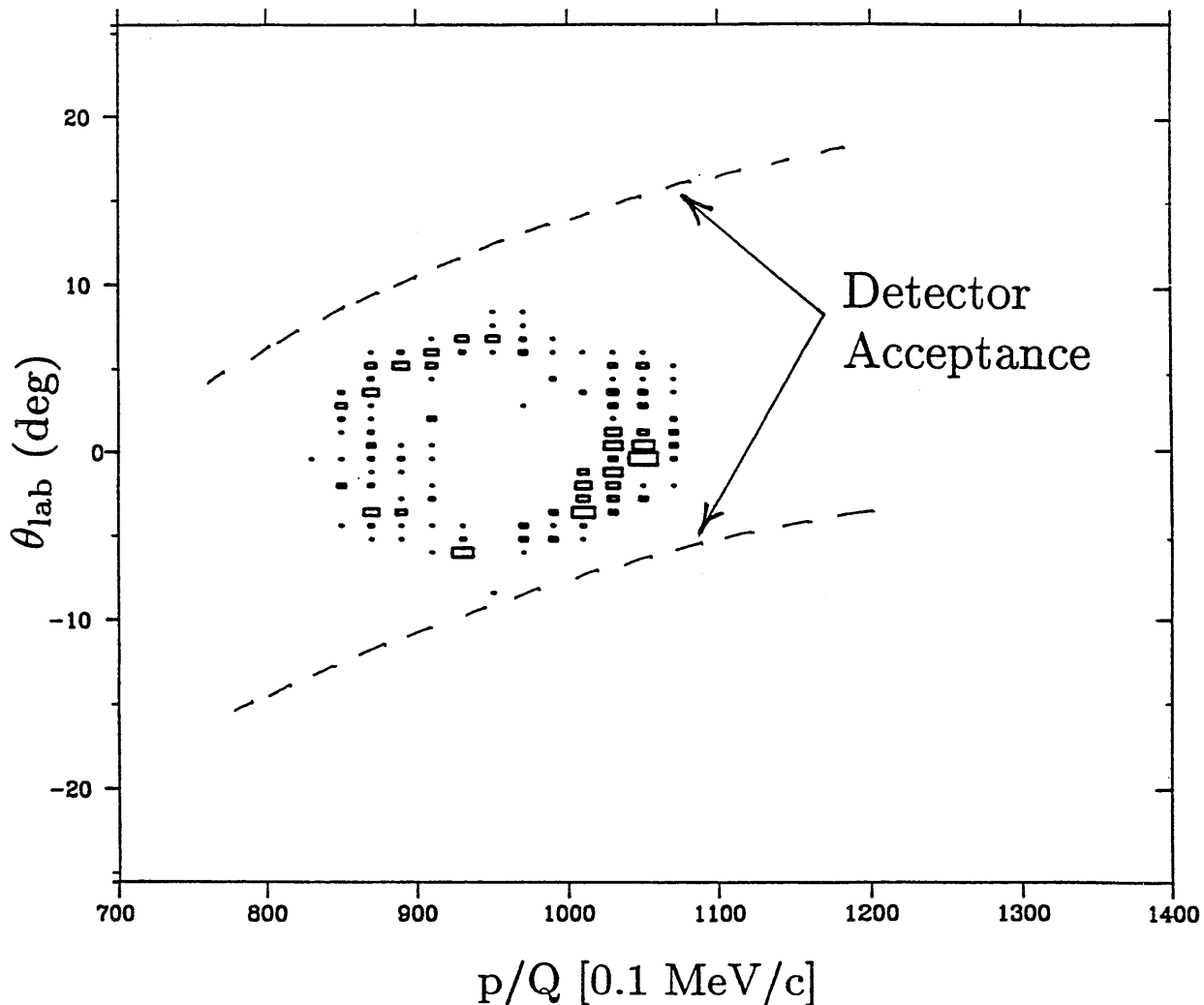*Figure 1.* Laboratory angle of emission of the recoil ions vs. their magnetic rigidity as determined by backward ray tracing for the reaction ^{12}C(p,π^+)^{13}C at $T_p = 166$ MeV.

The first experiments on the ^{12}C(p,π) and ^{12}C(p,2π) reactions 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 from 5×10^{28} to a few $\times 10^{29}$ cm^{-2}s^{-1} were achieved.

Figure 1 is a plot of the angle of emission (θ_{lab}) of the recoil ions vs. their magnetic rigidity (p/Q) as determined by backward ray tracing for ^{13}C recoils in the Q=6 charge state from the ^{12}C(p,π^+)^{13}C reaction at 166 MeV bombarding energy. The recoils are confined to a 7° forward cone about the beam axis and fall completely inside the detector
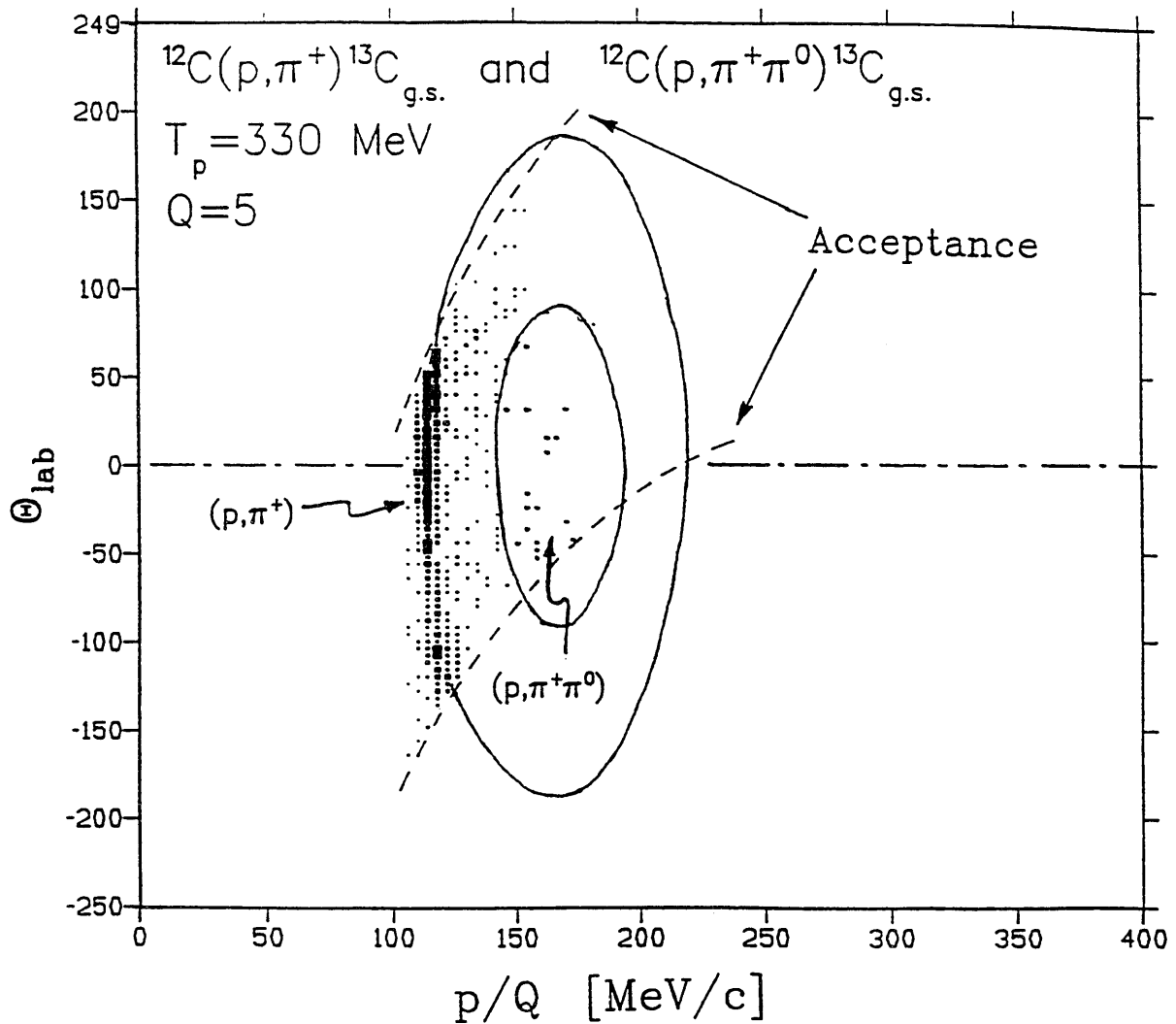
Figure 2. Laboratory angle of emission of recoil ions vs. their magnetic rigidity as determined by backward ray tracing for the reactions $^{12}\text{C}(\text{p},\pi^+)^{13}\text{C}$ and $^{12}\text{C}(\text{p},\pi^+\pi^0)^{13}\text{C}$ at T_p = 330 MeV.

acceptance at this low bombarding energy, which is only 18 MeV above threshold. The highest p/Q events correspond to 180° pion emission and the lowest p/Q events to 0° pion emission. The distribution of events on the ellipse gives the complete pion angular distribution.

Figure 2 is a θ vs. p/Q plot at 330 MeV bombarding energy, which is about 40 MeV above the (p,2π) threshold. At this higher bombarding energy, the recoils from the (p,π^+) reaction are confined to a 19° cone about the beam axis. They fall *on* the large ellipse due to the two-body kinematics. The diagonal cuts in the upper and lower parts of the figure represent the detector acceptance. Recoils from the (p,$\pi^+\pi^0$) reaction are kinematically constrained to fall *inside* the small ellipse and can fill this ellipse because of the three-body final state. Several candidates for $^{12}\text{C}(\text{p},\pi^+\pi^0)^{13}\text{C}$ events are seen.

The background in the 2π region was estimated from similar data taken at 290 MeV bombarding energy, which is just below the (p,2π) threshold. This showed that most of the events in the (p,$\pi^+\pi^0$) region at 330 MeV probably are background, and thus we have been able, so far, to place only an upper limit on the (p,$\pi^+\pi^0$) cross section of about 15 nb at 330 MeV bombarding energy.

PIONIUM PRODUCTION IN THE COOLER

A. Betker, T. Bowyer, J. Cameron, G. Berg, W. Jacobs, H. Nann, T. Peterson, J. Shao, M. Spraker, J. Szymanski, S. Vigdor, and K. Warman
Indiana University Cyclotron Facility, Bloomington, Indiana 47408

W. K. Pitts
University of Louisville, Louisville, Kentucky 40292

Experiment CE-49 is intended to evaluate the rate and cleanliness with which we can produce in the IUCF Cooler a tagged sample of "pionium," i.e., atomic bound states of a π^+ and a π^-. Such an atom has been predicted[1-4] to have a relatively long lifetime ($\tau \gtrsim 10^{-15}$ s) for a system with an allowed strong decay (from the S-states to $\pi^0\pi^0$). To date, there is only indirect experimental evidence for its existence, inferred[5] from the observed strength of $\pi^+\pi^-$ momentum correlations as a function of target thickness in 70 GeV p + Ta collisions. Pionium is worthy of fundamental study because it represents the lightest and, in some senses, simplest system of two interacting hadrons. More specifically, it allows study of the $\pi - \pi$ strong interaction at essentially zero relative energy, an interaction that would vanish in the limit of perfect chiral symmetry. Precise measurements of the interaction at zero energy provide probes of *dynamical* chiral symmetry breaking[6,7] (χSB), over and above the PCAC violation[8] that arises inescapably from the non-zero physical mass of the pion. The extent of such dynamical χSB is parametrized in Chiral Perturbation Theory, but should ultimately be predictable in a more fundamental theory (i.e., non-perturbative QCD solved in the confinement limit).

Our specific long-term interest is to use pionium decay to determine a linear combination ($|a_{T=0} - a_{T=2}|$) of the S-wave $\pi - \pi$ scattering lengths to a precision $\sim \pm 5\%$. This information can be extracted directly from a $\pm$ 10% measurement of the relative rates for the S-states of pionium to decay to 2γ *vs.* $2\pi^0$. For this purpose it is sufficient to measure the *absolute* 2γ branching ratio $B_{2\gamma}$. For pionium produced in a thin Cooler target (where there is negligible probability of ionization of the recoiling atom induced by collisions with electrons), all other decay branches (except $2\pi^0$) can be reliably predicted to be several orders of magnitude weaker than 2γ, so that the ratio of interest is, to excellent approximation, given by

$$W(2\gamma)/W(2\pi^0) = B_{2\gamma}/(1 - B_{2\gamma}). \tag{1}$$