

REPORT ON EXPERIMENT CE06:  
MEASUREMENTS OF NUCLEAR REACTIONS USING RECOIL DETECTION

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I.  $^{12}\text{C}(p,^{12}\text{N})n$ ,  $^{13}\text{C}(p,^{13}\text{N})n$ ,  $^{12}\text{C}(p,^{12}\text{C})p$ , and  $^{13}\text{C}(p,^{13}\text{C})p$  at 200 MeV

This experiment was run at the cyclotron in November, 1988 and analysis of the data is nearly complete. The purpose of the experiment was to study these reactions when the nucleons are emitted near  $180^\circ$ . A study<sup>1</sup> of the elastic scattering of protons by  $^{12}\text{C}$  had reported cross sections at backward angles that were much larger than those predicted by the optical model. At  $157^\circ$  (cm), the largest angle at which data were taken, the differential cross section was found to be 17.5 nb/sr and rising with increasing angle. The present experiment was undertaken not only to extend the  $^{12}\text{C}(p,p)$  measurements out to  $180^\circ$ , but also to broaden the scope of the investigation to a systematic study of (p,n) reactions near  $180^\circ$ . To this end, differential cross sections were also measured for the  $^{13}\text{C}(p,p)$ ,  $^{12}\text{C}(p,n)$ , and  $^{13}\text{C}(p,n)$  reactions. Measurements at nucleon emission angles at or near  $180^\circ$  were made possible by detecting the accompanying C or N recoils.

The experimental arrangement was very similar to that used in previous recoil detection experiments done at IUCF<sup>2</sup>. Foils of  $^{12}\text{C}$  and  $^{13}\text{C}$ , approximately  $200 \mu\text{g}/\text{cm}^2$  thick, were bombarded with 200 MeV protons and the recoil ions were magnetically analyzed by the QQSP spectrometer. The detector stack at the output of the spectrometer consisted of a pair of position sensitive parallel plane avalanche counters, separated by a 12 cm drift

space, and a proportional counter. The QQSP was set to cover the angular range from  $-10^\circ$  to  $+2^\circ$ .

The (p,p) and (p,n) differential cross sections are shown in Figs. 1 and 2, respectively. The present results combined with those of Meyer *et al.*<sup>1</sup> lead to the conclusion that the  $^{12}\text{C}(p,p)$  cross section peaks around  $160^\circ$ . The  $^{13}\text{C}(p,p)$  cross section also falls towards  $180^\circ$  with about the same slope, but is smaller by about a factor of 2.5. The (p,n) cross sections are much smaller and, within the limited statistics, show no obvious trend with angle. The  $^{13}\text{C}(p,n)$  cross section is the larger of the two by a factor of 2-3, perhaps reflecting the loosely bound neutron.

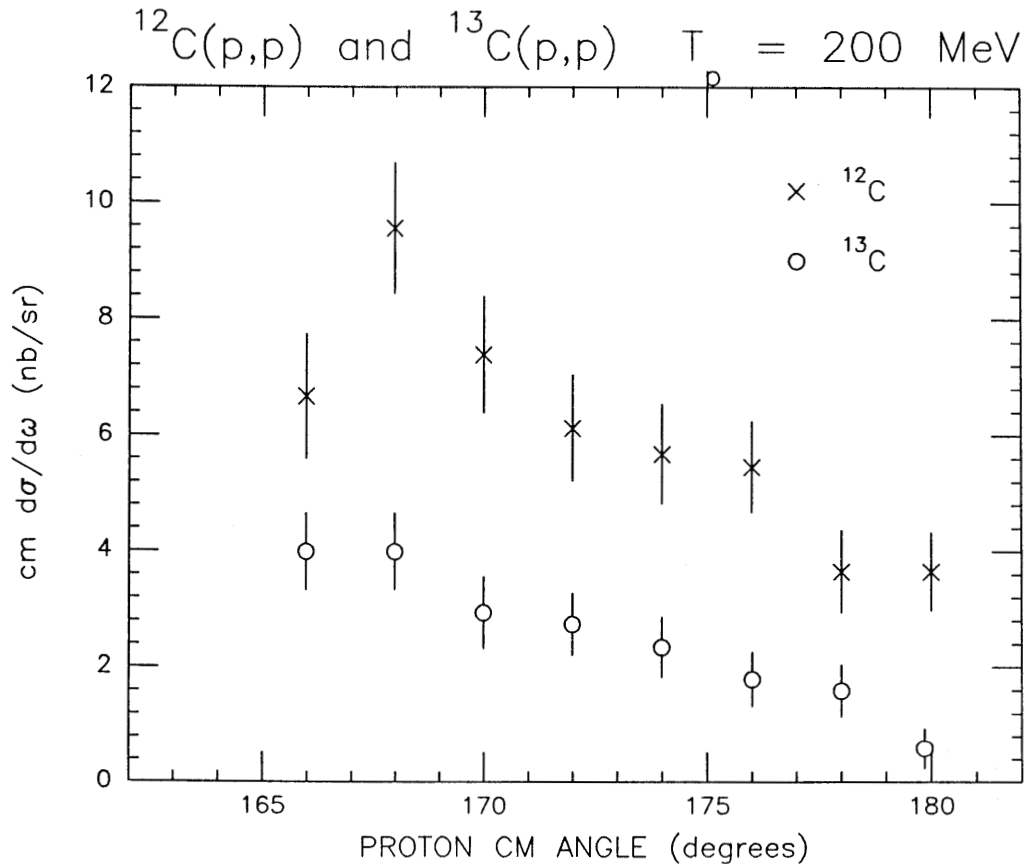


Figure 1. Differential cross sections for the  $^{12}\text{C}(p,^{12}\text{C})p$  and the  $^{13}\text{C}(p,^{13}\text{C})p$  reactions at  $T_p = 200$  MeV. Both the cross sections and the angle are in the center-of-mass system, and the angle is that of the emitted proton relative to the incident beam.

## II. Recoil Detection at the Cooler

It has long been recognized<sup>3</sup> that a storage ring with extremely thin internal targets offers the ideal environment for performing recoil detection experiments. Experiment CE06 has been approved for studying the  $^{12}\text{C}(p,\pi)$  and  $(p,\gamma)$  reactions, and a facility is being installed in the T region of the Cooler ring for this and other future recoil experiments. The  $6^\circ$  magnet that is being placed in this region will be used to bend the recoils away from the beam, magnetically analyze them, and send them through a detector stack. Extensive

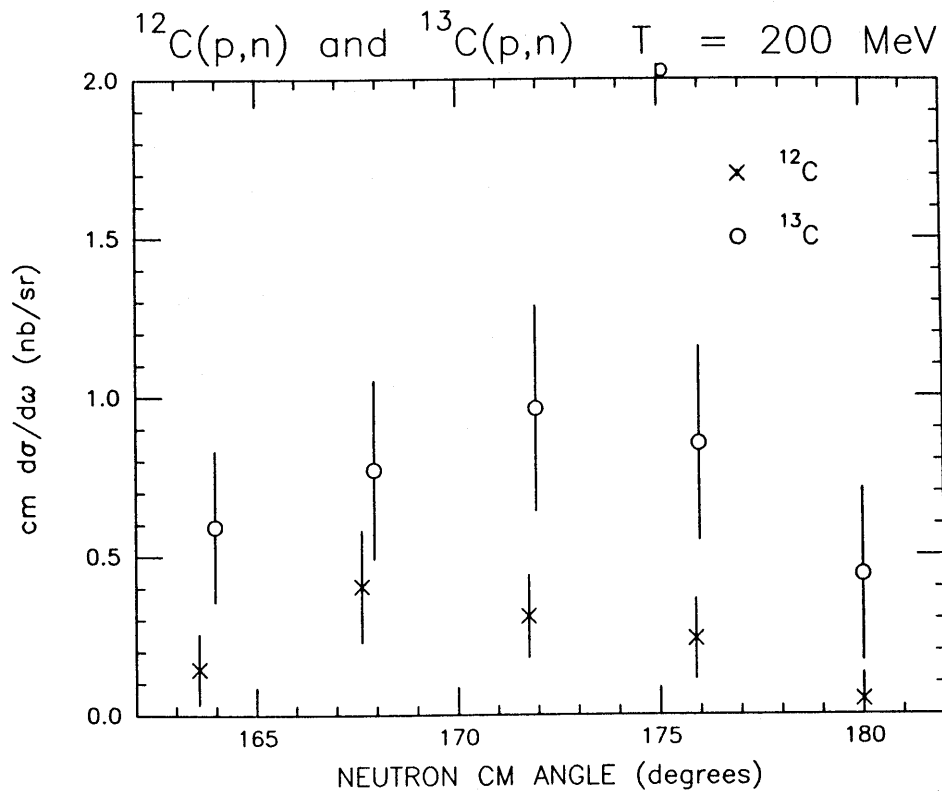


Figure 2. Differential cross sections for the  $^{12}\text{C}(p,^{12}\text{N})n$  and  $^{13}\text{C}(p,^{13}\text{N})n$  reactions.

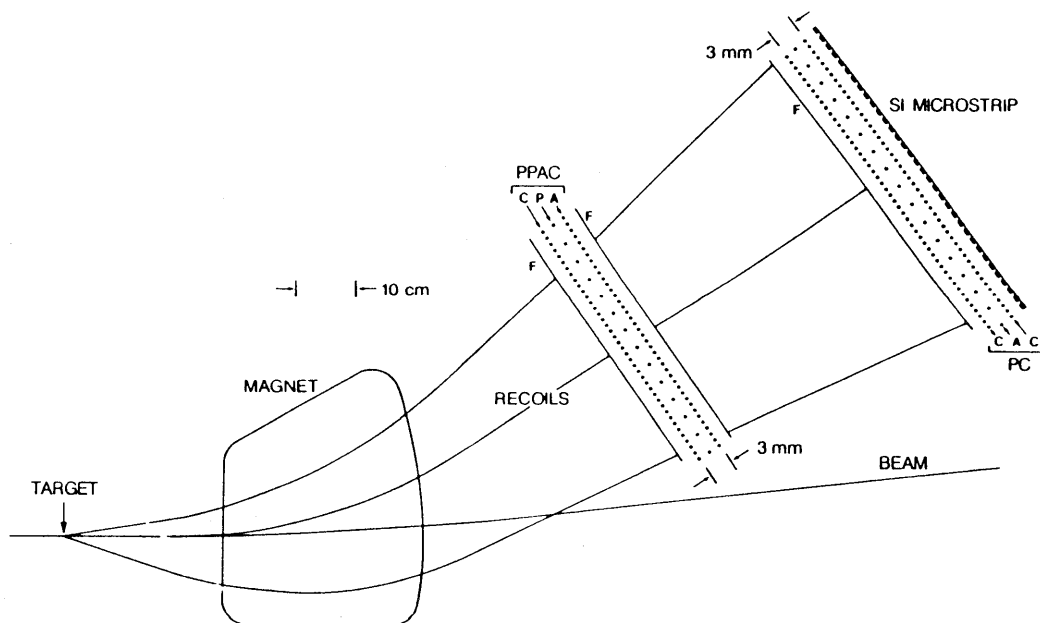


Figure 3. Diagram of the recoil detection system to be installed in the T region of the Cooler ring.

orbit calculations have been performed, and on the basis of these a detector system and its housing have been designed. There will be a parallel plate avalanche counter with position wires in both the bend and the non-bend plane, a proportional counter, and an array of silicon microstrip detectors. A diagram of the system is shown in Fig. 3. At the present time, the avalanche counter has been designed and an order has been placed for the silicon. It is expected that the entire system will be assembled and tested by the end of calendar year 1990.

1. H.O. Meyer, P. Schwandt, W.W. Jacobs, and J.R. Hall, *Phys. Rev. C* **27**, 459 (1983).
2. J. Homolka, W. Schott, W. Wagner, W. Wilhelm, R.D. Bent, M. Fatyga, R.E. Pollock, M. Saber, R.E. Segel, P. Kienle, and K.E. Rehm, *Nucl. Inst. Meth. A* **260**, 418 (1987).
3. Indiana University Cyclotron Group, *The IUCF Cooler-Tripler Proposal to the NSF*, Indiana University (1980).

## PIONIC ATOMS AS COMPOUND STATES IN NUCLEON-NUCLEUS COLLISIONS: STATUS REPORT ON THE COOLER EXPERIMENT CE02

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### 1. Introduction

The formation of pionic atoms in nuclear collisions just below the  $\pi^-$  production threshold has been postulated some time ago.<sup>1</sup> Attempts to observe this process have so far not met with success. The goal of experiment CE02 is to measure a cross section excitation function for  $p+^{13}\text{C}$  elastic scattering, and to look for a resonance near the  $\pi^-$  production threshold.

An update of the original proposal of 1984 was presented during PAC XXIX in December, 1989. In the light of our present understanding of the Cooler performance, the experiment still seems to be feasible, although the demands on energy resolution and luminosity are substantial. It was concluded that in order to find and map out the resonance (corresponding to a pionic  $^{14}\text{O}$  in the 1s state) with 4 keV energy resolution, 25 shifts of beam time should be sufficient. This does not include beam time for the development of the appropriate experimental conditions.

The apparatus for the detection of the scattered protons will be taken over from the CE01 experiment (see elsewhere in this annual report). Since backward angles are of interest, the CE01 detector arrangement will be reversed. In addition, in order to more clearly define the experimental signature, a detector for the recoiling target nuclei will be mounted in the forward direction. Tests with heavy ion beams from the Notre