it would be necessary to compare the (p,π^+) experimental results (especially the state-to-state differences) with calculations based on various models.

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MEASUREMENT OF THE $^2\mathrm{H}(\vec{p},\pi^0)^3\mathrm{He}$ AND $^3\mathrm{H}(\vec{p},\pi^0)^4\mathrm{He}$
THRESHOLD CROSS SECTIONS AND ANALYZING POWERS

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In this experiment (#95) we plan to measure the differential cross sections and analyzing powers for the reactions $^2\mathrm{H}(\vec{p},\pi^0)^3\mathrm{He}$ and $^3\mathrm{H}(\vec{p},\pi^0)^4\mathrm{He}$ within 4.0 MeV of threshold. In few nucleon systems the high momentum components of the nuclear wave functions are well established ((e,e'), (p,p'), Fadeev calculations). With this in mind, the study of pion production from very light nuclei should enable us to separate the effect of particular reaction mechanisms from the influence of the wavefunctions of the participants.

The targets for this experiment are CD_2, and $^3\mathrm{H}$ in a Ti foil. We filter out the $^3\mathrm{He}$ or $^4\mathrm{He}$ recoil nucleus by placing the QDDM spectrometer at 0°, requiring a coincidence with the two gamma-rays from a decaying π^0, detected by Pb glass detectors placed on opposite sides of the target. The distribution in energy of the recoils will give us, after certain corrections, the differential cross section. Because the flight time of the recoils of a given momentum is a function of the angle at which they enter the spectrometer, a measure of that distribution in time will yield the analyzing power for the reaction.

In order to stop the beam we must place a copper block within the QDDM itself. This block also functions as a Faraday cup. The background generated by this arrangement was measured in a short test run and was found to produce a count rate in the QDDM focal plane in excess of 1 MHz at the $\sim$30 nA polarized beam intensities which will be used in the experiment. However, with reduced intensity we were able to identify recoil $^3\mathrm{He}$, presumably from spallation in the CD_2 target. To handle the very high counting rates anticipated in the actual experiment, we are building a 12 element scintillator hodoscope for the focal plane. We hope to initiate the actual measurements in the spring of 1980.

STUDIES OF PROTON INDUCED NEUTRAL PION PRODUCTION NEAR THRESHOLD

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Experiment 18, the first in a series of experiments to investigate features of the (p,π^0) reaction near threshold, is now complete. In the course of this study it was necessary to develop Pb glass Čerenkov detectors whose response was reproducible over long periods of time, and which had close to

optimum light collection efficiency. With the successful completion of this work, we have been able to make the first measurements ever obtained of the (p,π^o) differential cross section to discrete states in nuclei more massive than A=5. We have measured the total cross sections for those reactions to 10% accuracy. Finally, we have made the first measurement of the analyzing power for this reaction.

Each of our detectors consists of a 150 x 150 x 300 mm block of Schott F2 lead glass coupled to a 5 in diameter, 14-stage photomultiplier tube (Amperex XP2041). Coupling the curved face of this large photomultiplier tube to the flat face of the lead glass block is difficult. We found that using a lucite coupling plate and optical grease is effective for short periods of time if one applies a large force to the tube. However, over a period of time the grease tends to leak out. In addition, air bubbles in the grease are extremely difficult to remove. These two problems result in a loss in light collection efficiency that increases with time. These problems were overcome by creating a reservoir between the tube and the glass which was filled with Dow Corning 710, a colorless silicone oil of low viscosity with an index of refraction of 1.53. This refractive index is very close to that giving optimum light transmission between the lead glass, $n_o=1.62$, and the phototube face, $n_o=1.48$. Further, the low viscosity eliminates the problem with air bubbles. This coupling scheme has achieved close to optimum light collection efficiency in a manner that has proven stable over long periods of time.

Using these detectors to observe the decay gamma rays from neutral pions produced in the reactions studied, we have been able to routinely obtain 0.85 ns time resolution relative to the cyclotron RF. This good timing has proven to be invaluable in reducing background from sources other than prompt gamma-rays from the target, and has thereby made possible the difficult measurements reported here.

In our initial measurements we used the geometry illustrated in Fig. 1. The large solid angle resulted in a high detection efficiency that permitted the measurement of an excitation function in a short period of time. However, yields obtained using this geometry could not be converted into cross sections due to:

1) uncertainties in the efficiency due to edge effects and the absorber, as well as,

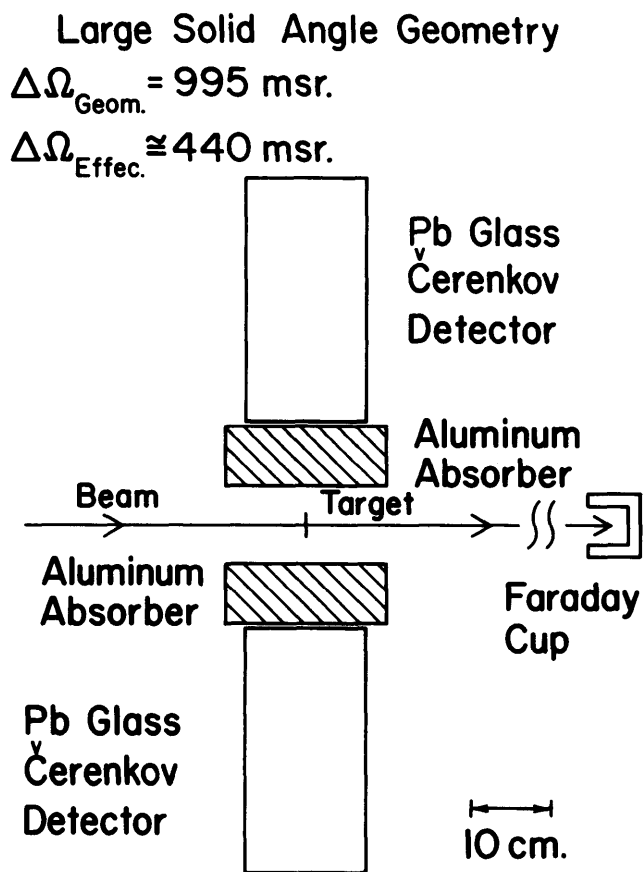2) uncertainties in the efficiency due to the lack of information about the distribution

Large Solid Angle Geometry
$$\Delta\Omega_{Geom.} = 995 \text{ msr.}$$
$$\Delta\Omega_{Effec.} \cong 440 \text{ msr.}$$

Figure 1. Geometry for high efficiency π^o detection during excitation function measurements of the (p,π^o) reaction.

of pions in energy and angle.

The first problem could be solved by measuring the differential cross section to a discrete state, which would be possible only by using a detector arrangement whose efficiency could be calculated or measured. Tests using a tagged photon beam at the University of Illinois showed that the detectors had an efficiency of 1.00 ± 0.02 relative to NaI for detecting 50 MeV gamma-rays. In order to ensure an efficiency of unity for detecting-gamma rays in the energy region of interest (50-90 MeV), lead collimators were placed in front of each Pb glass detector, so that any gamma-ray entering the detector had to pass through a minimum of 300 mm of detector material in
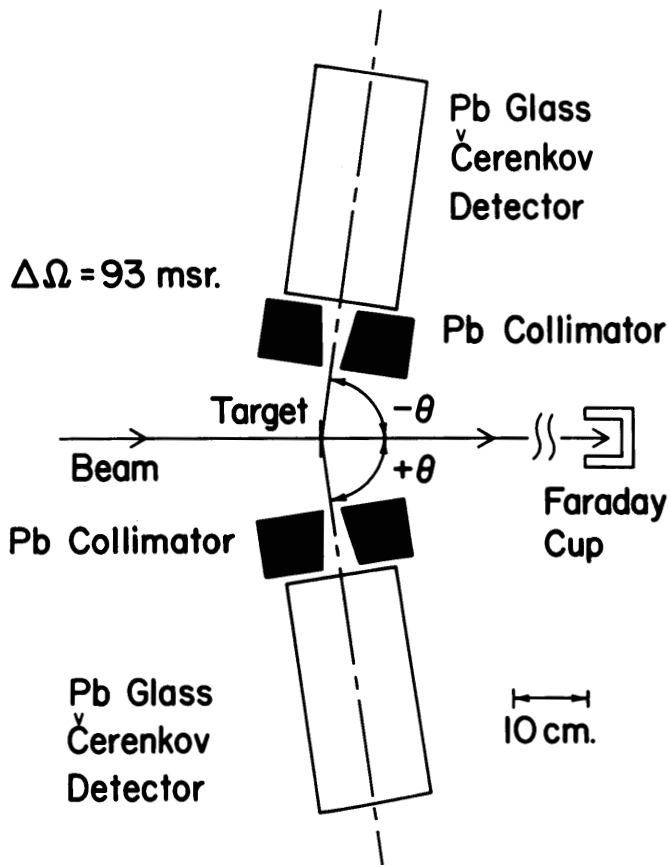
Collimated Detector Geometry

Figure 2. Restricted π^0 detection geometry. Angles to left and right of the beam are matched.

Efficiency in the Center of Mass for $^{11}B(p,\pi^0)\,^{12}C\,(g.s.)$ $T_p = 134.65$ MeV, $T_\pi^{CM} = 3.61$ MeV
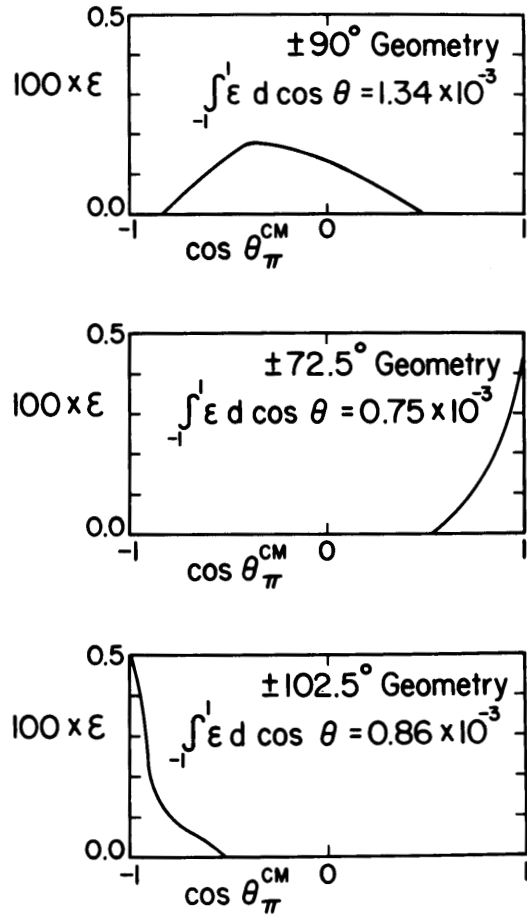
Figure 3. Efficiency distributions for three angle pairs in the restricted geometry of Fig. 2.

order to escape without conversion. To guarantee that we were looking at a single state, we made our measurements below the threshold of the first excited state, thus restricting ourselves to a rather limited range of energies for a given target. Close to threshold one would assume that the reaction should be dominated by s and p wave pions, thus giving rise to a cross section of the form,

$$\frac{d\sigma}{d\Omega_{cm}} = N(1 + a_1\cos\theta_\pi^{cm} + a_2\cos^2\theta_\pi^{cm}) \ .$$

Three independent measurements are sufficient to determine the three parameters in the cross section.

$${}^{11}B(p,\pi^0)\,{}^{12}C\,(g.s.)$$

$$T_p = 134.65 \text{ MeV}$$

$$T_\pi^{CM} = 3.61 \text{ MeV}$$

$$\frac{d\sigma}{dX} \equiv N(1 + a_1 X + a_2 X^2)$$

$$X \equiv \cos\theta_\pi^{cm}$$

$$a_1 \equiv 0.93 \pm 0.10$$

$$a_2 \equiv 0.24 \pm 0.10$$

$$\sigma_{tot} \equiv 191 \pm 19\,nb$$
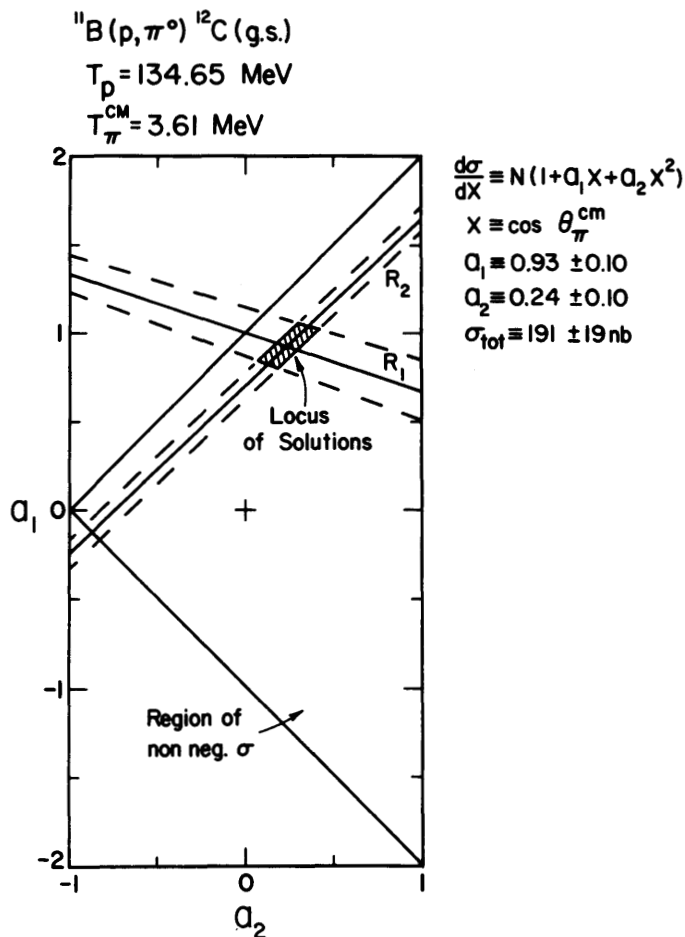
Locus of Solutions

Region of non neg. σ

Figure 4. Sample case showing solution for the angular distribution expansion coefficients, a_1 and a_2, in terms of the ratios, R_1 and R_2, of yields taken with the angle pairs in Fig. 3.

The geometry used for these measurements is illustrated in Fig. 2. The detectors were placed symmetrically about the target at three pairs of angles, $\pm\,\theta_i$, chosen so as to be sensitive to three nearly independent regions in the center of mass. The efficiency curves for three such angle pairs are illustrated in Fig. 3. By taking appropriate ratios of the three measured yields, one can solve for the coefficients a_1 and a_2, as illustrated in Fig. 4. Then, with the form of the angular distribution determined, its normalization is given by the yield at one angle pair. The result for ${}^{11}B(p,\pi^0){}^{12}C(g.s.)$ is illustrated in Fig. 5. Measurements of this type have also been made on the targets ${}^9Be$, ${}^{13}C$, ${}^{16}O$, and ${}^{40}Ca$. Closer

to threshold it generally becomes more difficult to solve for the three parameters simultaneously, but we have been able to extract total cross sections accurate to 10% in most cases. Using these results, one can then put the detectors in the large solid angle geometry (Fig. 1) and obtain an efficiency calibration that eliminates uncertainties due to edge effects and the absorber.

To correct the efficiency of the geometry of Fig. 1 for effects due to the form of the distribution of pions in energy and angle is much more difficult. An attempt to obtain some information about this problem was made by measuring the variation in yield as one varies the opening angle of the detectors in the collimated geometry (Fig. 2). These measurements were made at a beam energy $\sim$ 20 MeV above the ground state threshold for the targets ${}^7Li$, ${}^{27}Al$, and ${}^{181}Ta$. The observed correlation functions are very similar and show promise of providing some information about the distribution in energy and angle of low energy pions produced in such reactions. Using this information we will be in a position to make a better estimate of the
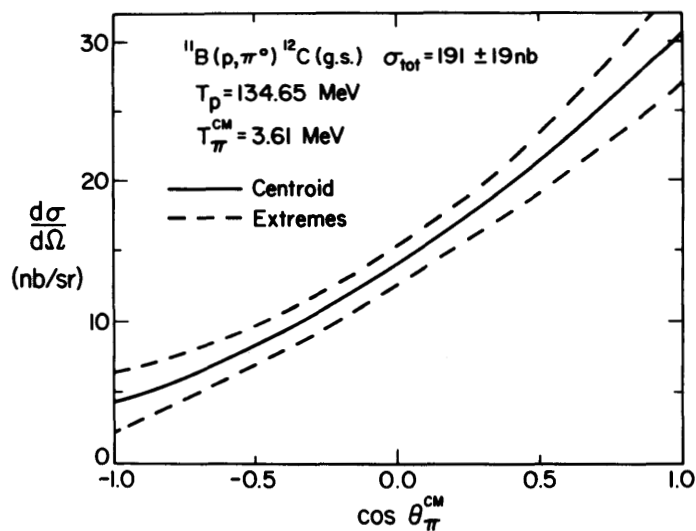

${}^{11}B(p,\pi^0)\,{}^{12}C\,(g.s.)$ $\sigma_{tot} = 191 \pm 19\,nb$

$T_p = 134.65$ MeV

$T_\pi^{CM} = 3.61$ MeV

—— Centroid

- - - Extremes

$\dfrac{d\sigma}{d\Omega}$ (nb/sr)

$\cos\theta_\pi^{CM}$

Figure 5. Cross section angular distribution for ${}^{11}B(p,\pi^0){}^{12}C(g.s.)$ determined from expansion coefficients (see text).

corrections necessary to convert the yields obtained using the geometry of Fig. 1 into cross sections.

We concluded this experiment by making a preliminary measurement of the analyzing power in the reaction $^{11}B(\vec{p},\pi^0)^{12}C(g.s.)$, with the pion having an energy of 3.6 MeV in the center of mass. The geometry used is illustrated in Fig. 6. It has an efficiency response function which is peaked for pions emitted at about 60° to the right in the center of mass. The azimuthal angle is localized to within 30°, while the efficiency in the polar coordinate in the center of mass is nonzero only in the forward hemisphere, has its centroid at about 53°, and a width of about 60°. If one integrates the true asymmetry over $\cos\theta_\pi^{cm}$, weighting it with the appropriate efficiency function, one obtains an observed average asymmetry over that region, of

$$<A(\theta)> = -0.58 \pm 0.22$$

The results from Expt. 18 are being prepared for publication.

As a followup to the first successful $(\vec{p},\pi^0)$ asymmetry measurement reported above, this group has proposed and been allocated time for Expt. 127, "Determination of Analyzing Powers for Neutral Pion Production Near Threshold." In this experiment we
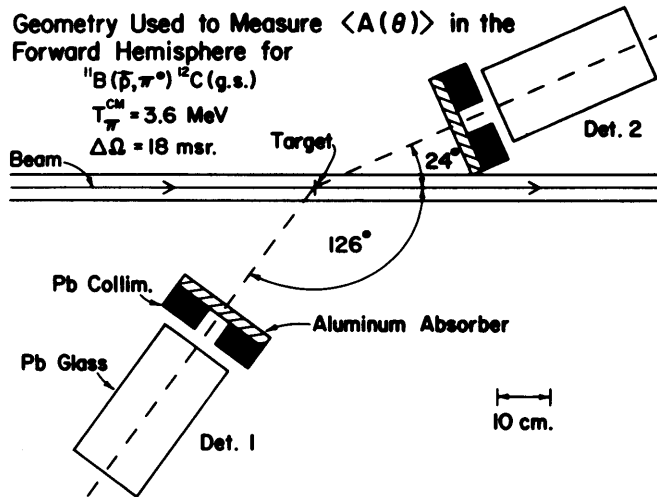

Figure 6. *Geometry used to measure $(\vec{p},\pi^0)$ asymmetry for scattering angles near 60°.*

plan to complete our study of the reaction $^{11}B(\vec{p},\pi^0)^{12}C(g.s.)$, and perhaps examine a few other targets. The basic approach will be the same as that used in Expt. 18; however, we plan to improve both our energy resolution and angular resolution by moving our detectors out of the plane. This will permit us to do measurements at energies above the thresholds of excited states, to about 15 MeV above the ground state threshold, as well as giving us the capability of making measurements on excited states that are well separated from neighboring states. We plan to have this experiment completed by the fall of 1980.

STUDIES OF π^0 PRODUCTION NEAR THRESHOLD

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We have begun a series of measurements which will measure the cross section for (p,π^0) reactions on a range of nuclei with both unpolarized and polarized beams. The energy and angle of the π^0 is inferred from its decay gammas by a measurement of the angle and energy of each gamma.