

STUDIES OF PION PRODUCTION NEAR THRESHOLD

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Studies of the (p, π^0) reaction with bombarding energies near and above threshold have been initiated. Eight targets have been investigated, with thresholds ranging from 127.2 to 145.0 MeV, and neutral pions have been observed for each target.

The experimental method is to observe coincidences between high energy photons from the π^0 decay. Measurements during the period of this report were carried out with two 6" x 6" x 10" lead-glass Čerenkov detectors borrowed from Brookhaven National Laboratory.¹⁾ The detectors were tested and calibrated at the Space Radiation Effects Laboratory using a momentum-analyzed electron beam in the energy range from 20 to 100 MeV.

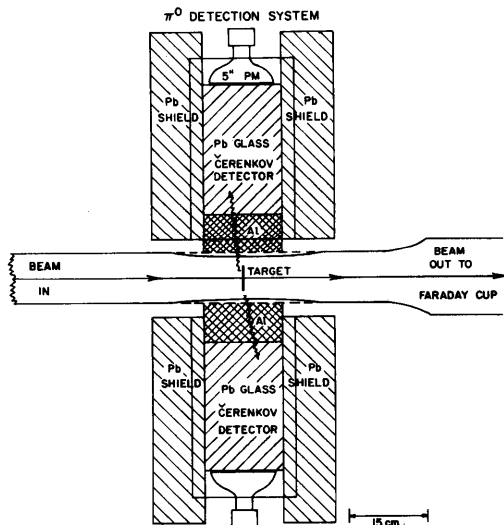


Figure 1. Experimental geometry for the detection of coincident gamma rays from the decay of neutral pions.

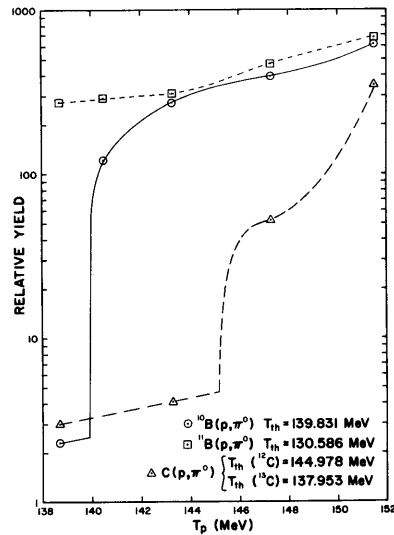


Figure 2. Variation of the coincident gamma yield as a function of proton bombarding energy for enriched ¹⁰B and ¹¹B targets and for a natural carbon target. For the ¹⁰B and C targets the threshold behavior is indicated schematically by the smooth lines. Below threshold the observed yield is consistent with that expected from small isotopic impurities in the targets.

While no Čerenkov light is generated in these detectors by IUCF protons, they did have alpha-source-impregnated sodium iodide chips attached to the front surface for monitoring the pulse height responses from each crystal. Three inches of aluminum absorber was used in front of each detector, therefore, to keep scattered protons from depositing energy in the NaI chips. The experimental geometry is shown in Figure 1. In close geometry with the two Čerenkov detectors positioned at 90° on opposite sides of the beam, each detector subtends a solid angle of 1.0 steradians. Lead shielding around the Čerenkov detectors reduced background from coincident muon events in cosmic ray showers.

made; these range from a few nanobarns to a few microbarns.

The observed yields are larger than expected from a comparison with (p, π^+) cross sections at 154 MeV ²⁾ and are thus in better agreement with recent IUCF measurements ³⁾ of (p, π^+) which are also somewhat larger than the previous work at Orsay. Typical results for the variation of coincidence yield with bombarding energy are shown in Figure 2. The relative cross section (per target nucleus) vs target mass number, at two fixed bombarding energies, is shown in Figure 3, for targets for which one is well above threshold.

To facilitate further analysis of these and future data, we have been developing programs that will calculate coincidence gamma-ray spectra, for comparison with observation, given an initial

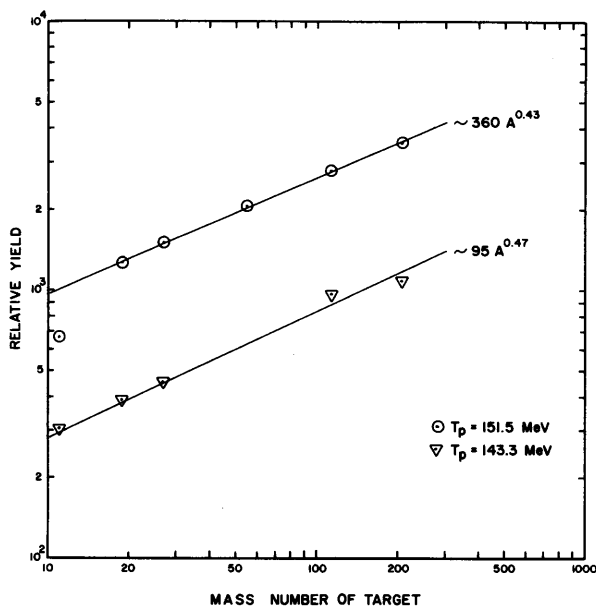


Figure 3. Relative cross sections as a function of the target mass number for targets for which the indicated proton bombarding energy is well above threshold.

Such detectors have rather poor energy resolution for gamma rays in the relevant energy range, 40-100 MeV, so initial work was concentrated on the coincidence yield and its variation with energy. The overall time resolution was typically 15 ns (fwhm). With a target thickness of about 100 mg/cm^2 and beam currents of about 2 nA, random coincidences were no problem and true coincidence rates ranged from about 0.002/sec to about 3/sec. Studies of edge effects on detector efficiency and pulse height spectrum are still in progress, so only preliminary estimates of cross sections can be

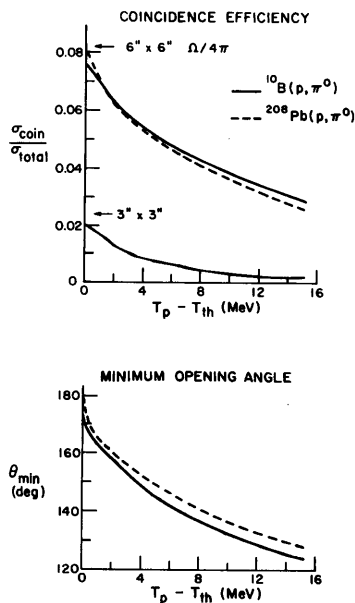


Figure 4. Coincidence efficiency (at the top) for the detection of neutral pions from ^{10}B and ^{208}Pb targets as a function of the proton energy above threshold. Also shown (at the bottom) is the minimum opening angle between the two gamma rays.

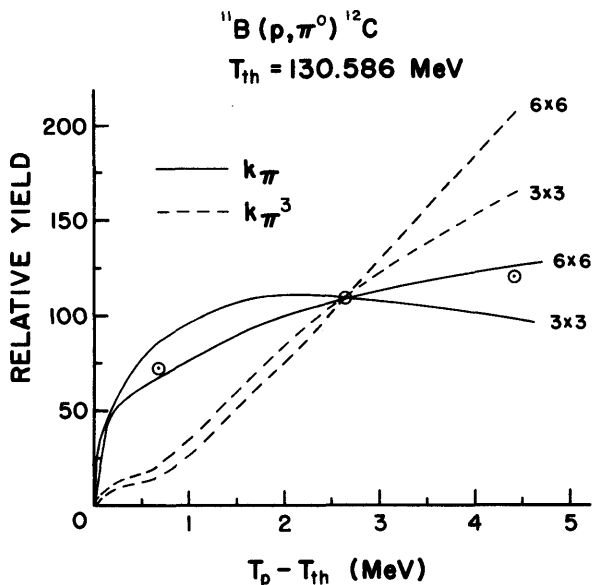


Figure 5. Energy dependence of the neutral pion yield for the $^{11}\text{B}(p, \pi^0)^{12}\text{C}$ reaction compared with the expected dependence for phase space ($\propto k_\pi$) and for the static model ($\propto k_\pi^3$) for two extremes of the effective detector size.

pion angular and energy distribution. The programs are being designed so that the calculations may be done by both analytical and Monte Carlo techniques. Preliminary results, from calculations in which edge effects on efficiency and variations of efficiency with energy have been neglected, have given a fair idea of the variation of coincidence efficiency with bombarding energy. For the detector geometry of Figure 1, and for excitation of a single final state, reasonable variations in the pion angular distribution have only a very small effect on the coincidence efficiency. Results of calculations assuming an isotropic

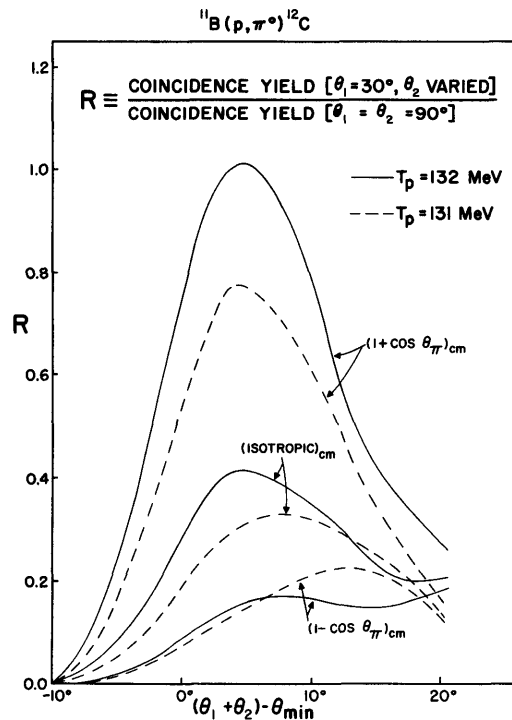


Figure 6. Variation of the coincidence yield ratio, R , as the detector opening angle is changed about the minimum opening angle. Results are shown for the $^{11}\text{B}(p, \pi^0)^{12}\text{C}$ reaction at two values of the proton bombarding energy near the threshold energy of 130.59 MeV.

pion angular distribution in the reaction CM frame are shown in Figure 4. The actual detectors are 6" x 6" in cross section, but one should expect edge effects to reduce their effective size to a somewhat smaller area, of the order of 5" x 5".

Use of these results leads already to some information about the mechanism of pion production near threshold. Phase space for a two-body final state in a (p, π) reaction varies as k_π , the CM pion momentum. In the naive static model of pion production,⁴⁾ the matrix element is also proportional to k_π , leading to expected k_π^3 dependence of the cross section. These expectations, folded in with the calculated variation of coincidence efficiency

with energy, are compared with the experimental data on $^{11}\text{B}(p,\pi^0)^{12}\text{C}$ in Figure 5. Bombarding energies for the three experimental points are such that only the ground state of ^{12}C can be formed. The rise of the cross section from threshold is consistent with phase space, and inconsistent with the expectations of the naive static model.

Calculations have also been made to explore the possibility that detector geometries can be constructed that will allow information to be obtained on the pion angular distributions. This is especially important at energies close to threshold where direct detection of charged pions is not possible. For example, let the detectors be pulled back so that each subtends a solid angle of 0.015 steradians. Fix one detector at a laboratory angle of 30° , and vary the position of the other detector about the minimum opening angle for gamma-ray pairs for pions going forward in the laboratory, $\theta_{\min} = 2 \arcsin (1/\gamma_\pi)$, where γ_π is the relativistic dilatation factor corresponding to the pion energy. The results, shown in Figure 6, indicate that the "searchlight effect", which enhances the coincident pion yield at the minimum opening angle, is strong enough even near threshold to distinguish between isotropic and $(1 \pm \cos \theta)$ angular distributions.

Future calculations will include energy-dependent efficiencies and edge effects. The

present results already indicate that not only total cross sections, but also π^0 angular distributions can be studied, thus facilitating comparison of (p,π^0) with (p,π^+) reactions.

Components for a new detector system have been ordered. The new system includes four detectors, designed to have less background and a slightly better energy resolution, and will include facilities for convenient movement of the detectors. Measurements will focus on those targets for which the threshold energy dependence can be studied for a single final state.

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- 1) We thank T.F. Kycia, Jr., and Brookhaven National Laboratory for the loan of these detectors.
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- 3) R.D. Bent *et al.*, Bull. Am. Phys. Soc. 22, 81 (1977), and this report.
- 4) J.V. Noble, Phys. Rev. Lett. 37, 123 (1976).