# MEASUREMENT OF CHARGED PION YIELDS FROM NUCLEI IN $(p,\pi^+)$ REACTIONS VERY NEAR THRESHOLD

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The $D\bar{D}$ Pion Spectrometer[1,2] has been used to measure differential cross sections and analyzing powers of the $(p,\pi^+)$ reaction on various nuclei. The measurements include selected excited states in the final nuclei.

The $D\bar{D}$ Spectrometer is schematically shown in Figure 1 and its solid angle vs. rho in Figure 2. The solid angle shown was measured with a 100 $mm^2$ detector at the non-dispersed focal point and has a maximum (3.5 msr) which equals the geometric solid angle of the device. The standard detector configuration has become a 100 μm Al absorber followed by a 5 or 10 mil plastic scintillator giving ΔE and timing information followed by a 5 mm (100 $mm^2$) silicon stopping detector. A large area (450 $mm^2$) silicon veto detector is at the rear of the stack. Background levels below 1 nb/sr have been achieved for its full $17^o \rightarrow 150^o$ range. This background level is achievable at the most forward angles only with the use of a condition that the muon decay be observed in the 5 mm stopping detector. This condition is also applied to excited state spectra in order to eliminate high energy tails on the energy peaks due to the muon decay.

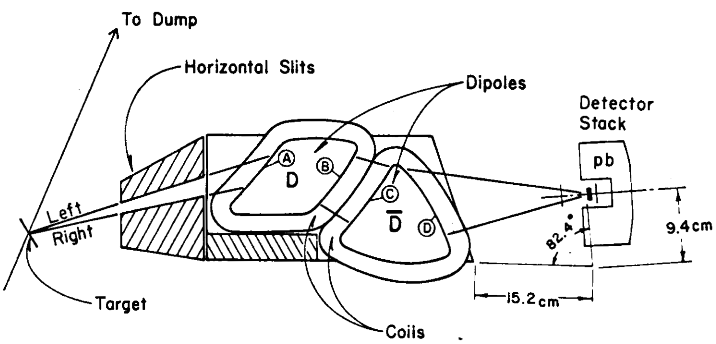


*Figure 1. Schematic drawing of the $D\bar{D}$ spectrometer and detector stack.*

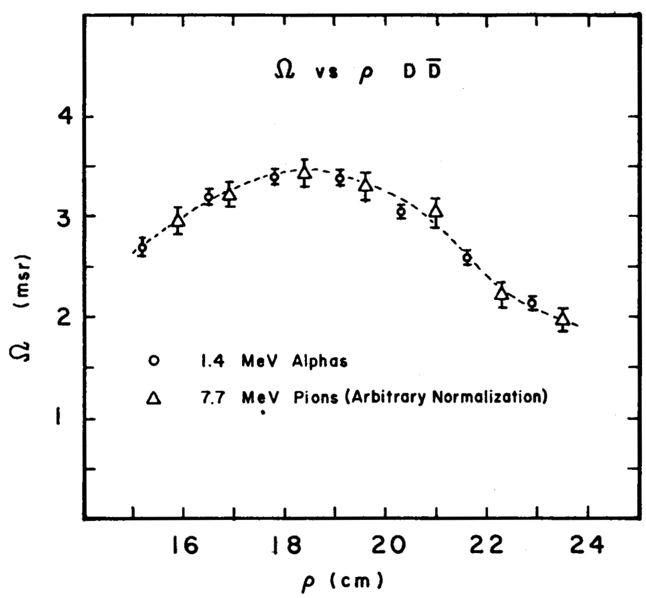


*Figure 2. The radius of curvature (ρ) vs. solid angle (Ω) of the $D\bar{D}$ with a 100 $mm^2$ stopping detector.*

A summary of the data obtained with the $D\bar{D}$ spectrometer is shown in Table I. The $^{40}Ca$, $^{90}Zr$, $^{10}B$, and $^{16}O$ data are part of Ref. 1. The $^{40}Ca$ and $^{10}B$ data obtained with unpolarized protons is included in an article which has been submitted to Phys. Rev. Letters.

An example of a spectrum obtained with the $D\bar{D}$ is shown in Figure 3. The pion laboratory energies range from 4.4 to 12.8 MeV. The muon peak results from pions which are stopped in the target and subsequently

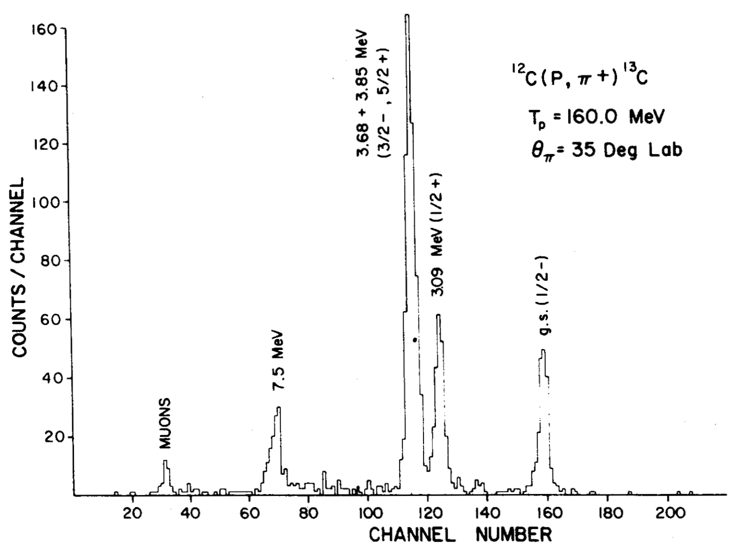


*Figure 3. A $^{12}C(p,\pi^+)$ spectrum taken at a 35 degree laboratory angle and a 160 MeV proton energy.*

Table I.

| Reaction | $T_p$ (MeV) | Remarks |
|---|---|---|
| $^{208}Pb(p,\pi^+)^{209}Pb$ | 149 | One angle only (0-4 MeV) |
| $^{90}Zr(p,\pi^+)^{91}Zr$ | 144 | Angular distributions (0-2 MeV) |
| $^{40}Ca(p,\pi^+)^{41}Ca$ | 140, 144 | Angular distributions (0-2 MeV) |
| $^{30}Si(p,\pi^+)^{31}Si$ | 149 | One angle only (0-4 MeV) |
| $^{28}Si(p,\pi^+)^{29}Si$ | 149 | Angular distributions (0-5 MeV) |
| $^{16}O(p,\pi^+)^{17}O$ | 155 | Angular distributions (g.s.) |
| $^{13}C(p,\pi^+)^{14}C$ | 151 | Angular distributions (0-5 MeV) |
| $^{12}C(p,\pi^+)^{13}C$ | 156, 160 | Angular distributions (0-5 MeV) |
| $^{11}B(p,\pi^+)^{12}B$ | 160 | Two angular distributions and a $\theta_\pi$ = 25 deg (lab) excitation function |
| $^{10}B(p,\pi^+)^{11}B$ | 145-155 | Angular distributions (0-5 MeV) |
| $^{48}Ca(p,\pi^+)^{49}Ca$ | 149 | Angular distributions (0-5 MeV) |
| $^{10}B(\vec{p},\pi^+)^{11}B$ | 154 | Polarization asymmetry (0-4 MeV) |
| $^{12}C(\vec{p},\pi^+)^{13}C$ | 156, 159 | Polarization asymmetry (0-4 MeV) |
| $^{40}Ca(\vec{p},\pi^+)^{41}Ca$ | 147 | Polarization asymmetry (0-4 MeV) |

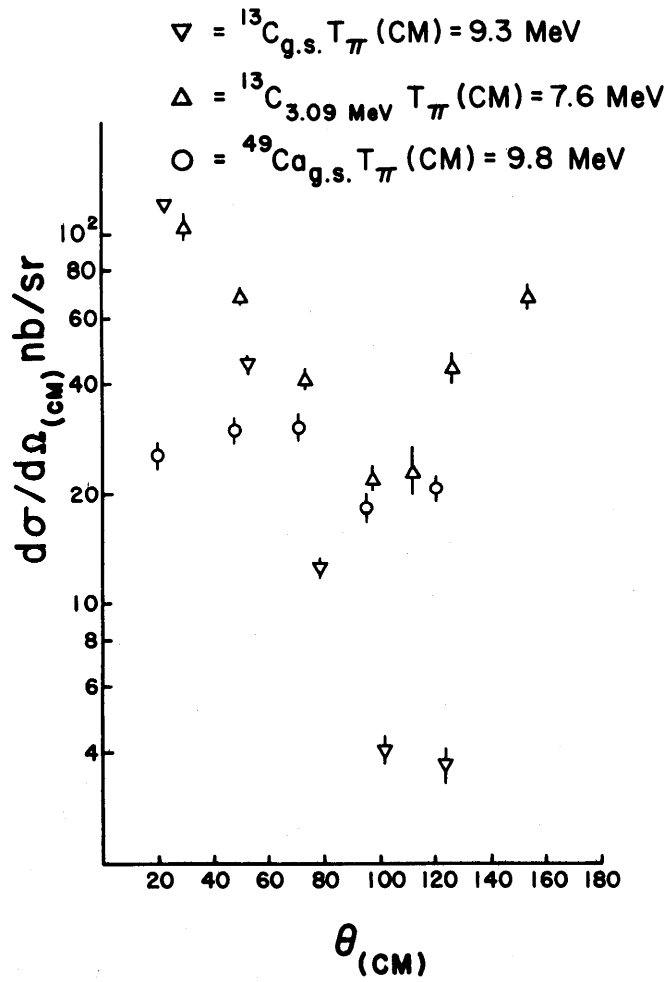


*Figure 4. Differential cross sections for the $(p,\pi^+)$ reaction to three different final states.*

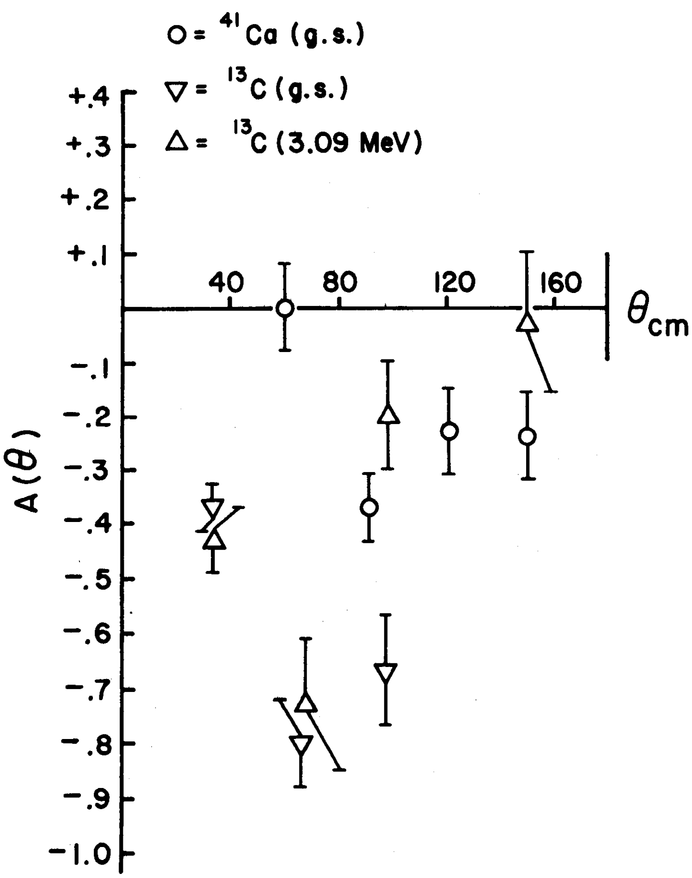


*Figure 5. $A(\theta)$ vs. $\theta_{cm}$ for the $(\vec{p},\pi^+)$ reaction to three different final states.*

decay into 4.1 MeV muons. Only two $D\bar{D}$ magnetic field settings were required to generate this spectrum. The resolution is approximately 300 keV fwhm and is primarily due to the 6.5 degree horizontal acceptance of the $D\bar{D}$, the energy resolution of the proton beam and straggling of the pion in the Al absorber and plastic scintillator.

In Figure 4 three preliminary angular distributions are shown for the $(p,\pi^+)$ reaction to the ground states of $^{49}Ca(3/2^-)$ and $^{13}C(1/2^-)$ and the 3.09 MeV $(1/2^+)$ state in $^{13}C$. The $^{13}C$ angular distributions were measured[3] earlier at Uppsala at a 185 MeV proton energy and display shapes very similar to those in Figure 4. The $^{48}Ca(p,\pi^+)^{49}Ca_{g.s.}$ angular distribution represents, to our knowledge, the first pion production data available on this target and does not display strong features as does the $^{40}Ca(p,\pi^+)$ reaction to the $^{41}Ca$ ground state.

Polarization asymmetry measurements have been made for seven different final states in $^{11}B$, $^{13}C$ and $^{41}Ca$. All of the states observed exhibited a substantial negative asymmetry in the range -0.4 to -0.8, confirming the behavior first observed[4] at TRIUMF at energies much further above threshold for final states in $^{9}Be$ and $^{13}C$. Figure 5 shows preliminary asymmetry measurements for pion production to the ground state $(7/2^-)$ of $^{41}Ca$ and to the ground state $(1/2^-)$ and first excited state $(1/2^+)$ of $^{13}C$. The $^{41}Ca$ data was taken at a 146 MeV proton energy and the $^{13}C$ data at 159 MeV. As can be noted from the figure, the $^{41}Ca_{g.s.}$ asymmetry does not exhibit an asymmetry maximum in the forward hemisphere as do the other two states. In fact, of the seven states measured, only the $^{41}Ca_{g.s.}$ and the $^{11}B_{4.46}$ MeV states did not have maximum negative asymmetries in the forward hemisphere. The fact that different asymmetry characteristics have been observed for different nuclear final states suggests that $(p,\pi^+)$ asymmetry measurements may play an important role in disentangling the pion production process.

1) P.H. Pile, Ph.D. Thesis, Indiana University, 1978.

2) P.H. Pile, R.E. Pollock, R.D. Bent, R.E. Marrs, and M.C. Green, Bull. Am. Phys. Soc. 23, 611 (1978).

3) S. Dahlgren et al., Nucl. Phys. A211, 243 (1973).

4) E. Auld et al., Phys. Rev. Lett. 41, 462 (1978).