

$^{12}\text{C}(p,\pi^+)^{13}\text{C}$ and $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ REACTION CROSS SECTIONS
MEASURED BY RECOIL DETECTION

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The analysis of exclusive (p,π^+) and (p,π^0) reactions on a ^{12}C target by recoil detection using the large solid angle QQSP spectrometer at 0° in conjunction with a heavy-ion focal-plane detector consisting of two parallel-plate avalanche counters and a proportional counter has been finished. The method and earlier results on the $(^3\text{He},\pi^+)$ reaction using the same method have been described previously.¹⁻³

Differential cross sections were measured for the $^{12}\text{C}(p,\pi^+)^{13}\text{C}$ reaction at 166, 186 and 204 MeV incident energies. The results are shown in Fig. 1. At 186 and 204 MeV, the 5^+ charge state of the ^{13}C recoils was used to deduce $d\sigma/d\Omega$ for forward scattering angles and the 6^+ charge state for backward angles. At 166 MeV, both charge states could be used, yielding the same results within the error bars. The curves in Fig. 1 are the angular distributions calculated from existing data^{4,5} obtained by pion spectroscopy. The measured $d\sigma/d\Omega$ data points obtained by pion detection at various incident energies from 156 to 200 MeV for transitions to the ground state and the first 3 particle stable excited states of ^{13}C were approximated by sums of Legendre polynomials

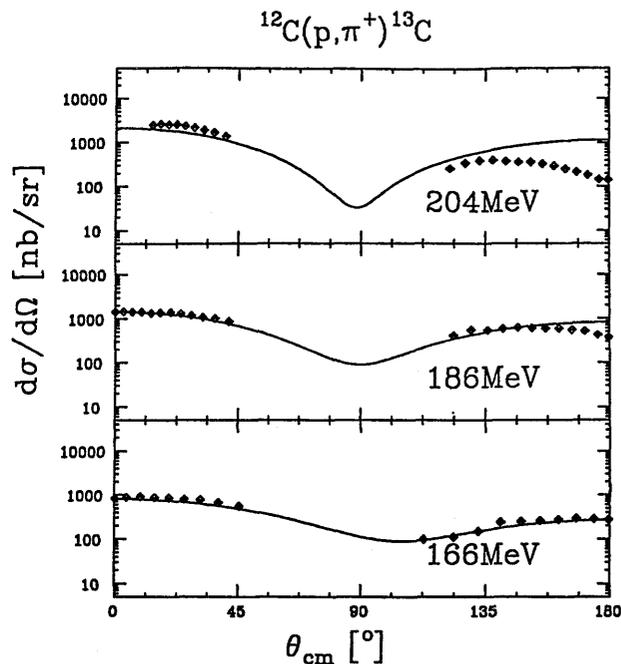
$$d\sigma/d\Omega(\theta) = 1/4\pi \sum_{k=0}^{k_{max}} A_k P_k(\cos\theta) \quad (1)$$

with the total cross section $\sigma_t = A_0$ and the ratios A_k/A_0 as free parameters. The dependence of σ_t and the A_k/A_0 ratios on the incident energy was described by polynomials in the outgoing pion momentum k :

$$A_k/A_0 = a_0 + a_1k + a_2k^2 \dots \quad (2)$$

The polynomials were evaluated at k -values corresponding to 166, 186 and 204 MeV incident energy, and the angular distributions for the ground state and the 3 excited states were summed to compare with the $d\sigma/d\Omega$ values from recoil detection.

Figure 1. Differential cross sections $d\sigma/d\Omega$ for the $^{12}\text{C}(p,\pi^+)^{13}\text{C}$ reaction at 166, 186 and 204 MeV bombarding energies. The curves are angular distributions calculated by interpolating cross section data for the $^{12}\text{C}(p,\pi^+)^{13}\text{C}$ reaction obtained by pion detection.



The recoil data points agree reasonably well with the angular distributions obtained from pion spectroscopy. The discrepancy at 204 MeV is due to the uncertainty of the extrapolation beyond 200 MeV incident energy. The deviation at extreme backward angles, which is most prominent at 204 MeV, is due to the fact that the angular range of the pion data is limited to 30° - 150° , and there are not enough data points to fit all the partial waves required to describe the measured angular distribution.

In Fig. 2, $d\sigma/d\Omega(\theta_{cm})$ data for the $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ reaction obtained using the recoil detection method are shown. The curves are angular distributions calculated from pion spectroscopy data for the $^{12}\text{C}(p,\pi^+)^{13}\text{C}_{g.s.}$ reaction at 170, 183 and 190 MeV, multiplied by a factor of 0.5 according to isospin invariance. Coulomb effects were taken into account by fitting energy independent R-matrix elements to the measured $d\sigma/d\Omega$ and A_y values and describing the energy dependence by Coulomb barrier penetration factors. The shapes of the angular distributions measured by the recoil method are in good agreement with those obtained from the pion data, but the absolute values of the recoil data at 154 and 166 MeV are larger. To treat this effect quantitatively, the calculated angular distributions were expanded using Legendre polynomials and the total cross sections σ_t were fitted to the $d\sigma/d\Omega$ values obtained from recoil spectroscopy for the $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ reaction.

In Fig. 3, the total cross sections for the $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ and $^{12}\text{C}(p,\pi^+)^{13}\text{C}_{g.s.}$ reactions are plotted vs $\eta = P_{\pi^0}/m_{\pi^0}c$. Coulomb barrier calculations for the two reactions are also shown. The cross sections for the $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ reaction have been multiplied by a factor 2. The measured $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ and $^{12}\text{C}(p,\pi^+)^{13}\text{C}_{g.s.}$ cross sections agree at high and low momenta, but there is an unexplained discrepancy at $\eta = 0.55$. At small η values (0.33-0.38), the cross sections are larger than expected from the Coulomb barrier calculations.

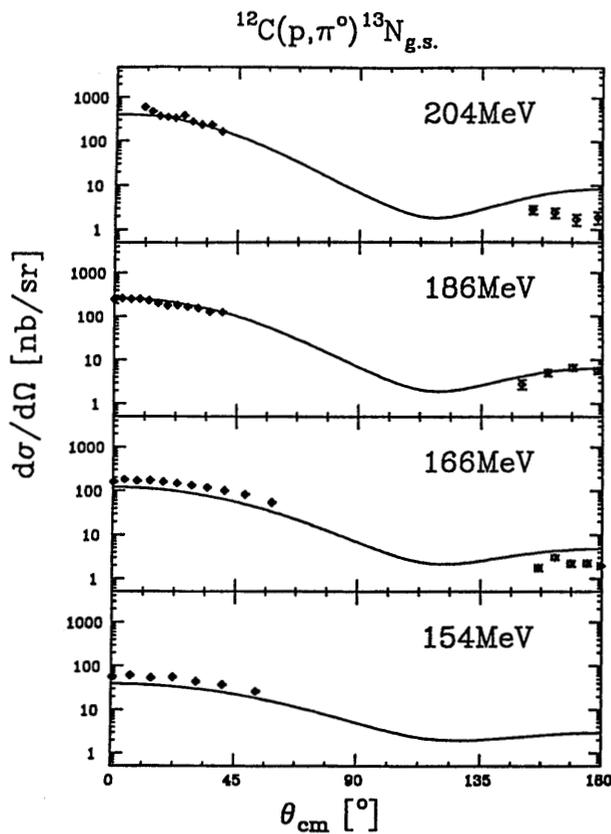
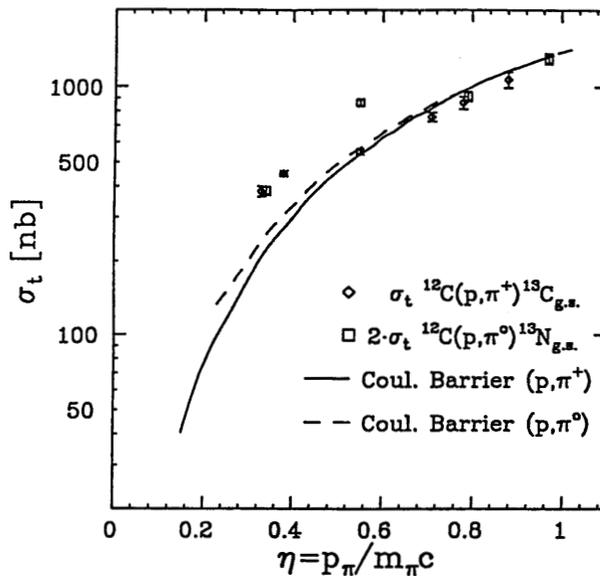


Figure 2. Differential cross sections for the $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ reaction at 154, 166, 186 and 204 MeV bombarding energies. The curves were calculated using $^{12}\text{C}(p,\pi^+)^{13}\text{C}_{g.s.}$ cross sections obtained by pion detection.

Figure 3. Total cross sections for the $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ and $^{12}\text{C}(p,\pi^+)^{13}\text{C}_{g.s.}$ reactions vs. pion momentum in units of $m_\pi c$. The solid and dashed curves are the results of Coulomb barrier calculations for the $^{12}\text{C}(p,\pi^+)^{13}\text{C}_{g.s.}$ and $^{12}\text{C}(p,\pi^0)^{13}\text{N}_{g.s.}$ reactions, respectively.



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