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PION ELASTIC SCATTERING FROM POLARIZED ^{13}C IN THE ENERGY REGION OF THE [3,3] RESONANCE

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Abstract - Analyzing powers, A_y , were measured at the Clinton P. Anderson Meson Physics Facility for π^+ and π^- elastic scattering from polarized ^{13}C in the energy region of the [3,3] resonance. The A_y were found to be small in general and, at small momentum transfers, $q < 1 \text{ fm}^{-1}$, were reproduced best by a first order optical potential description and standard nuclear wave functions. At large momentum transfer, $q \approx 1.8 \text{ fm}^{-1}$, present nuclear structure and π -nucleus reaction models do not reproduce the data.

A new development in experimental techniques has made it possible to measure the right-left asymmetries or analyzing powers, A_y , in pion scattering from polarized nuclear targets^{1,2}. Such measurements provide us with information on the isoscalar spin-flip strength of nuclear transitions which is difficult to obtain otherwise. Differential cross sections, $\sigma(\theta)$, for pion elastic scattering from nuclei with non-zero spin are dominated by the spin-independent ($\Delta S = 0$) amplitudes. Contributions from the smaller spin-dependent ($\Delta S = 1$) amplitudes are usually negligible because the $\sigma(\theta)$ depend on the sum of the squares of these amplitudes. However, the A_y depend on the interference of the spin-independent and spin-dependent scattering amplitudes¹ and are therefore quite sensitive to the spin-dependent terms.

Since A_y depends on the isoscalar spin-flip part of the transition density, our data complement the information obtained from the measurement of the magnetic form factor by electron scattering, which is dominated by the isovector part. By measurement of both π^+ and π^- scattering, however, we also derive information on the isovector part. In addition to the nuclear structure information contained in A_y , our data are expected to provide tests of models of the pion-nucleus interaction. Indeed, inclusion of second-order terms in the theoretical calculations alter the predicted asymmetries more strongly than the differential cross sections.

A recent experiment³ on pion scattering from polarized ^{15}N revealed values of A_y completely consistent with zero in sharp contrast to the large A_y predicted by DWIA calculations. For ^6Li , however, very large asymmetries were measured⁴, and the agreement with DWIA predictions was not completely satisfactory.

In the present work we report measurements of pion elastic scattering from polarized ^{13}C . Angular distributions of the asymmetries and the differential cross sections were measured at one energy below and one above the [3,3] resonance. A search for predicted large asymmetries at momentum transfers near the second minimum of the differential cross sections was also done at several energies across the resonance. Most of the data have been analyzed. Measurements of an angular distribution on resonance, $T_\pi = 162$ MeV, are currently on progress.

The experiment was carried out at the Clinton P. Anderson Meson Physics Facility (LAMPF) using the Large Acceptance Spectrometer (LAS). The target material was 99% ^{13}C -enriched Butanol ($^{13}\text{C}_4\text{H}_{10}\text{O}$) in the form of frozen beads, kept in a liquid ^3He bath at a temperature of about 0.5 K. Polarizations of ^{13}C and ^1H were measured independently by an NMR system. Polarizations of about 28% for ^{13}C and 80% for ^1H were achieved in a magnetic field of 2.5 T by the DNP² technique. Within a systematic error of 3%, the NMR measurement of the ^{13}C polarization agreed with the value calculated from the ^1H polarization assuming equal spin temperatures.

The total angular acceptance of the spectrometer of 8° was divided into two angular bins in replay. The extracted values of A_y at 132 MeV for π^- (Fig. 1) are generally small, but definitely non-zero at some angles. At 132 MeV the π^+ asymmetries are smaller than for π^- as expected for a nucleus with more neutrons than protons. The asymmetries are small and consistent with zero at most angles both for π^+ at 226 MeV and π^- at 231 MeV (Fig.1). No large asymmetry was observed (Fig.2) in the search at the energies across the resonance near the second minimum of the cross sections. Here the angular acceptance was divided into 3 angular bins of 2.7° each. At $T_\pi = 165$ MeV, our data are consistent with zero, as was also observed³ in the experiment on ^{15}N . Below the resonance, there is an indication of small asymmetries at $T_\pi = 132$ MeV and $T_\pi = 145$ MeV. The errors in A_y shown in the figures are only statistical errors which are about 0.03 at small angles and about 0.1 at large angles.

We have calculated⁵ theoretical asymmetries using a first order optical potential. Such calculations of differential cross sections for elastic scattering of π^+ and π^- from nuclei on resonance have been quite successful in reproducing experimental data, provided the pion-nucleon force used in constructing the potential is calculated at an energy about 20 MeV lower than the actual pion-nucleon energy in the pion-nucleus system. This energy shift appears to correct for some second order effects such as multiple scattering. One of us (S.C.) used the first order optical model program PIPIT⁶ (which does not include spin transfer) in conjunction with the inelastic scattering code ARPIN⁷ to calculate the asymmetries⁵. The spin-independent and spin-dependent parts of the elastic transition amplitude were obtained from ARPIN and cross sections and asymmetries were calculated in the DWIA using the distorted waves from PIPIT. An energy shift of 14 MeV for π^+ and 4 MeV for π^- was used and the gaussian off-shell model was employed with a momentum range parameter⁶ of $3 \times 10^{-6} \text{MeV}^{-2}$.

At small momentum transfers where the Cohen-Kurath model (see Ref. 7) provides us with reliable wave functions, we found good agreement between the data at 132 MeV and our DWIA predictions with the first order optical potential. However, at large angles neither the elastic cross sections nor the asymmetries are fitted. This is not unexpected because at large q the asymmetries depend strongly both on the reaction and the nuclear structure model. We note that standard nuclear structure models thus far fail in reproducing the measured magnetic form factor⁸ at $q > 1.6 \text{ fm}^{-1}$. It is thus not surprising that the pion asymmetries are not reproduced satisfactorily near $q = 1.8 \text{ fm}^{-1}$.

Above the resonance the DWIA fits the π^+ data quite well but the fit to the π^- data is poor. For the latter case the Delta-hole model of Thies et al.⁹ appears to reproduce the data better than the simple DWIA (Fig.1). Delta-hole model calculations are not yet available for π^+ at 226 MeV nor for π^+ and π^- at 132 MeV.

Another set of theoretical calculations was done by Mach¹⁰ who also used a first order optical potential but included a phenomenological ρ^2 term which was adjusted to fit cross sections at various energies. In Fig.1 the chain-dashed line is the result of a calculation using Cohen-Kurath wave functions. It is very different from the calculation in which nuclear wave functions, given by Tiator¹¹, were used (dashed line). Using the Cohen-Kurath wave functions in two different reaction models, the calculations of Mach and our calculations give very similar results. However, neither reaction model gives a satisfactory fit to the asymmetries near the second minimum in the differential cross section ($q \approx 1.8 \text{ fm}^{-1}$). We note that the calculations of Thies at 226 MeV demonstrate a strong sensitivity of A_y to the reaction model.

The polarization data of this and other recent work^{3,4} contain new information on nuclear structure and the pion-nucleus reaction mechanism. A separation of nuclear structure and reaction mechanism effects should be possible if the high q behavior of the nuclear wave function is described correctly and higher order terms are included in the reaction models.

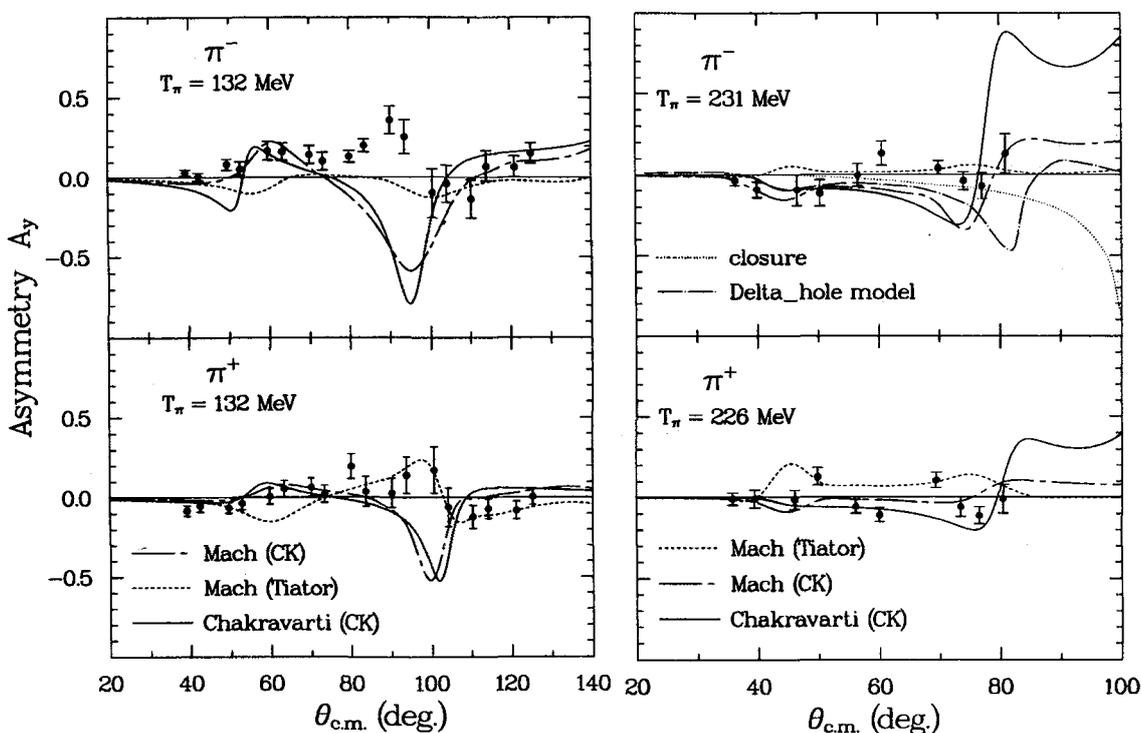


Fig. 1. Asymmetries, A_y , for elastic scattering of π^- and π^+ from ^{13}C at energies below (left) and above (right) the [3,3] resonance. Solid lines: DWIA calculation of Chakravarti (this work); dashed lines: Mach's calculation¹⁰ using the wave functions provided by Tiator¹¹; chain-dashed lines: Mach's calculation¹⁰ using Cohen-Kurath wave function¹⁷; dotted line: Thies' full Delta-hole model prediction⁹; chain-dotted line: Delta-hole model prediction in closure approximation⁹.

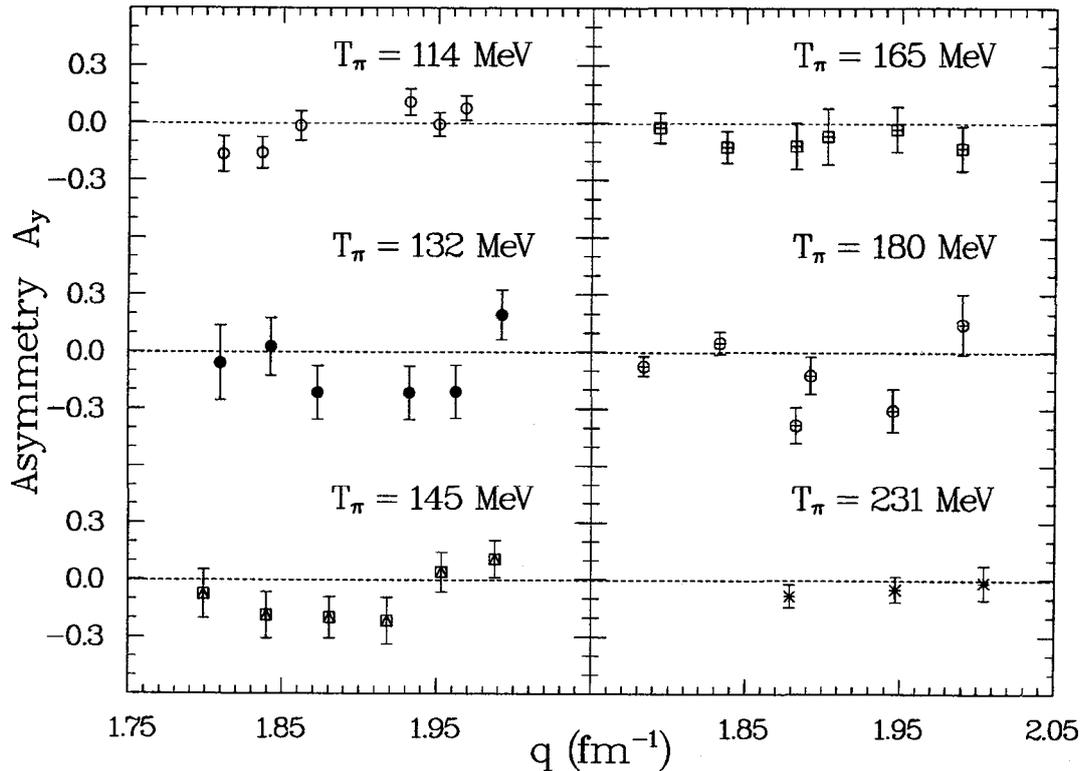


Fig. 2. Asymmetries for elastic scattering of π^- from $^{13}\bar{\text{C}}$ at energies across the $[3,3]$ resonance at momentum transfers near the second minimum of the differential cross sections.

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