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ARTICLES

Pion elastic scattering on ^{28}Si at $T_\pi = 400$ MeV

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Experimental differential cross sections for π^+ and π^- elastic scattering on ^{28}Si at an incident pion energy of 400 MeV are reported. The data fall above the predictions of a calculation using a momentum-space first-order optical potential. The behavior is similar to earlier results for pion scattering at $T_\pi = 672$ MeV and to K^+ nucleus scattering in this energy range, suggesting that there may be a common origin for the observed discrepancy that is not yet understood.

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I. INTRODUCTION

There exist extensive data for pion scattering from nuclei at energies below and on the $J = T = 3/2$, $\Delta(1232)$, pion-nucleon resonance. At energies below the Δ, phenomenological models of the pion-nucleus interaction [1, 2] are capable of describing the elastic data and charge exchange scattering to analog states. These models provide a context within which pions can be used to investigate nuclear structure. The phenomenological work has been extended [3] to the resonance region. The difficulty with the purely phenomenological approach is that the parameters of the model do not have an obvious physical interpretation. In the resonance region, there also exist microscopic models that have led [4, 5] to an understanding of the basic features of the delta propagation in the nucleus. These have shown that the delta-nucleus shell-model potential is nearly equal to the nucleon shell-model potential and that there are large but canceling Pauli and true-pion-absorption corrections.

Relatively little work exists in the energy region above the delta resonance. Here, a number of N^* and Δ^* resonances play an important role in the π-nucleon amplitude. In this region, the π^+-p and π^--p total cross sections are roughly an order of magnitude smaller than at 180 MeV. This isospin dependence of the pion-nucleon amplitude changes in an interesting way as the energy increases; the dominance of the $T = 3/2$ isospin channel gives way to the $T = 1/2$ channel. The weaker two-body amplitude implies [6] that pions can penetrate farther into the nuclear medium and that the conventional high-order corrections to the multiple-scattering theory for the optical potential should only be a few percent. A discrepancy between the theory and the data would thus imply the existence of nonconventional physics—physics that would involve directly either meson or quark degrees of freedom.

The current high-energy pion-nucleus data do not allow a clear picture of what the dynamics are in this region. There exist limited elastic scattering [7] data, and some single-charge exchange [8] and double-charge exchange [9] data. Theoretical predictions [6, 10, 11] are in reasonable agreement with each other and, although close to the data, the discrepancy is beyond the expectation of

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what can be accounted for by higher-order corrections.

The situation is reminiscent of K^+-nucleus elastic scattering. Theoretical calculations [12–14] consistently underpredict the measured data [15, 16]. The K^+ is the only strongly interacting hadron that is more penetrating than the high-energy pion. Possible explanations for this discrepancy include an increased [13] in-medium kaon-nucleon interaction or scattering from an enhanced, heavy-meson cloud [17]. If these exotic effects exist, they may well have an identifiable signature in the high-energy pion-nucleus reaction. In order to understand the origin of the missing piece of physics, additional data are needed. Of particular importance are elastic scattering data. Not only is the elastic channel the easiest channel to model, but the study of other channels can only be done reliably if distorted waves consistent with elastic data are available. We present here the first step in expanding the data base for elastic pion-nucleus scattering above the delta resonance.

II. EXPERIMENT

Elastic differential cross sections were measured with an incident pion energy of 400 MeV for both π^+ and π^- over a laboratory angular range of 7°–47° on ^{28}Si. The experiment was performed at the Pion Particle Physics (P^3) channel of the Clinton P. Anderson Meson Physics Facility (LAMPF) using the Large Acceptance Spectrometer (LAS) [18] in the double-charge exchange (DCX) configuration [8]. The areal density of the ^{28}Si target was 1.05 g/cm^2. An absolute normalization was obtained using hydrogen cross sections measured with a 0.293 g/cm^2 thick CH_2 target.

A sample spectrum for $\theta_{\rm lab}$ =10^0 is shown in Fig. 1. A clear identification of the elastic peak was made at forward angles. At larger angles, in order to properly extract the elastic cross sections, it was necessary to fit adjacent peaks corresponding to the 2^+ (1.7 MeV), 4^+ (4.6 MeV), and 3^- states along with the elastic peak. The 3^- states are seen at 6.87 MeV and 10.18 MeV, with the latter more prominent. The shape of the elastic peak used in the fitting routine was constrained to be the same as that seen at forward angles which is shown in Fig. 1. The background under these peaks was assumed to be linear. We report only the elastic cross sections here, since those for the other states have large statistical errors. From employing various methods of extracting yields, we believe that the systematic error associated with fitting the background is approximately 5%. Other sources of systematic error arise from uncertainties in target thickness, uniformity, and isotopic purity; software gating; chamber efficiencies; beam monitoring; solid-angle variations; and pion survival fractions. Most of these effects are at the level of 1–2%.

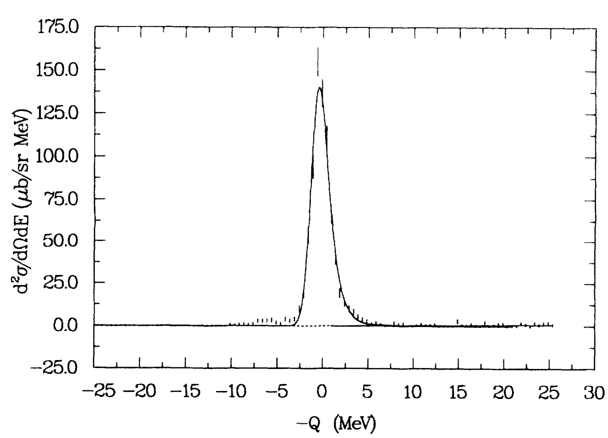

FIG. 1. Missing-energy spectrum is presented for the ^{28}Si$(\pi^+,\pi^+)^{28}$Si reaction at T_π = 400 MeV, $\theta_{\rm lab}$ = 10°. Error bars are symmetric and statistical only. Fitted result is shown in a solid line.

III. DISCUSSION

The elastic cross sections for the 400 MeV data are shown as a function of center-of-mass angle in Fig. 2, along with predictions from the momentum-space code [19] ROMPIN. This code has fully covariant kinematics, exact Fermi-averaging integration, covariant normalizations and phase-space factors, invariant amplitudes, finite range, and physically motivated [20] two-body off-shell amplitudes. It serves as the basis for a microscopic description [5] of the pion-nucleus interaction, which is in quantitative agreement with elastic-scattering data in the resonance region. Recently the ROMPIN code has been tested on the ^{12}C data at resonance energy. Chen *et al.* report [5] a good agreement between the ^{12}C data and

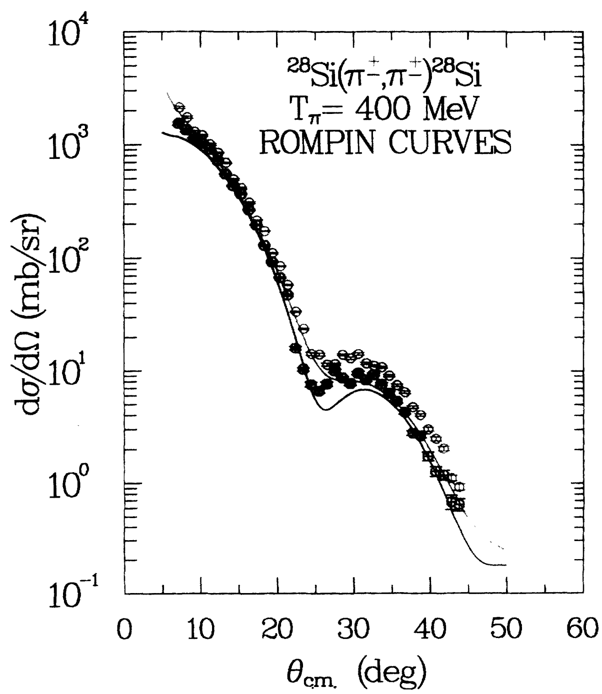

FIG. 2. Angular distribution is shown for ^{28}Si$(\pi^+,\pi^+)^{28}$Si(g.s.) (red curve and data set) and for ^{28}Si$(\pi^-,\pi^-)^{28}$Si(g.s.) (blue curve and data set). The curves are obtained from the momentum-space optical-potential code ROMPIN.

the ROMPIN calculations. Equally good agreement is observed between elastic scattering data on ^{28}Si nucleus at 164 MeV [21] and ROMPIN calculations also at resonance energy.

Here, we present results for a first-order calculation and neglect the higher-order corrections that the theory predicts should be small at this energy. The results underpredict the cross sections, but do have moderate success in reproducing the positions of the minima. We do not believe that the theoretical results depend crucially on the model we use. The factorized momentum-space approach [10], the Glauber multiple-scattering approach [10, 11], and a simple eikonal model utilizing a local optical potential [6] all produce similar results at the higher energy of the Marlow [7] data and should also agree with each other [6] at this energy.

An alternate speculative mechanism for the pion problem has been proposed. If the cancellation between the scalar and vector potentials found in the σ-ω model do not hold for the interaction of the higher-energy N^*'s with the nucleus, then a large effective shift [22] in the mass of these resonances when in the nuclear medium could occur. Further theoretical work to understand the extension of the σ-ω model to these higher resonances is needed, together with a systematic body of data on several nuclei at energies spanning the region of the lowest N^* resonances. Finally, there is evidence from photoabsorption cross sections [23] and inclusive electron scattering data [24] that the N^* resonances do not survive in the nuclear medium. It is not clear what implications this might hold for the high-energy pion-nucleus reaction.

IV. SUMMARY

We have measured differential cross sections for π^+- and π^--elastic scattering on ^{28}Si at an incident pion energy of 400 MeV. A first-order calculation made with the ROMPIN code underpredicts the cross sections. The discrepancy between data and the theory is probably model independent, as quite different theoretical approaches all give similar results for high-energy pion-nucleus elastic scattering in this energy region. The discrepancy found here is of the same magnitude as is found for the other high-energy pion-nucleus [7] elastic-scattering data, as well as for the high-energy kaon-nucleus elastic scattering [15] and total cross-section [16] data. It is not clear if mechanisms [13, 17] proposed to resolve the kaon discrepancy could also help to resolve the pion problem.

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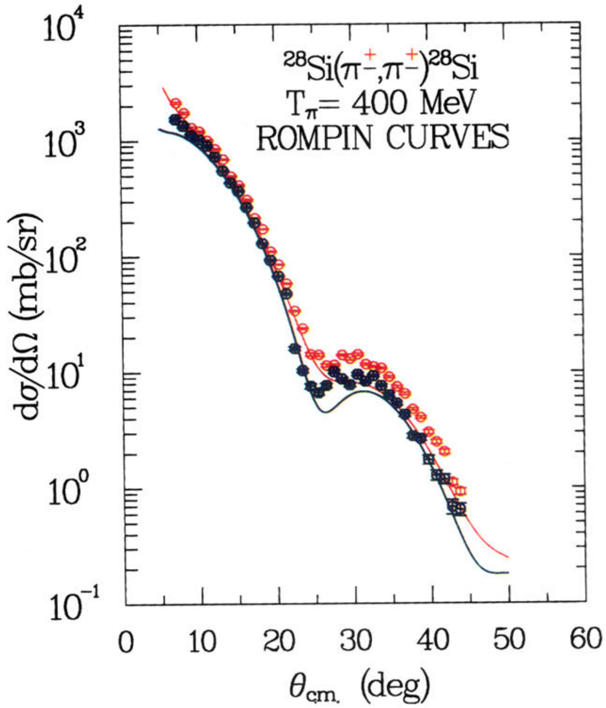

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