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Polarization in p-^{4}He Elastic Scattering at 0.56, 0.80, 1.03, 1.27, and 1.73 GeV*

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The polarization in p-^{4}He elastic scattering has been measured between 0.56 and 1.73 GeV in a range of the square of the four-momentum transfer between 0.006 and 1.2 (GeV/c)^2. The data are characterized by positive polarization maxima at $-t$ near 0.08 and 0.36 (GeV/c)^2. At 0.56 GeV, a sharp peak of large negative polarization at 0.23 (GeV/c)^2 is observed. This structure persists at higher bombarding energies, but is no longer negative and becomes increasingly shallower as the bombarding energy increases to 1 GeV and then is relatively unchanging.

Stimulated by the 1.0-GeV differential cross-section data on p-^{4}He elastic scattering reported by Palevsky *et al.*,[1] a number of theoretical investigations of p-^{4}He elastic scattering have been made. Some of these also predict the induced polarization in elastic scattering.[2-8] To date there have been two polarization measurements at intermediate energies, at 0.72 GeV [$0.01 \leq -t \leq 0.17$ (GeV/c)^2][9] and at 0.54 GeV [$0.006 \leq -t \leq 0.52$ (GeV/c)^2].[10] Both measurements employed polarized beams produced by scattering. In the present experiment, an increase in the range of t investigated and in the statistical accuracy has been made possible by using polarized beams available at the zero-gradient synchrotron at Argonne National Laboratory.

We have recently completed such a measurement using incident proton kinetic energies T_p of 0.56, 0.80, 1.03, 1.27, and 1.73 GeV. We have actually measured the left-right scattering asymmetry (analyzing power), but the analyzing power must equal the polarization in the case of elastic scattering. The experiment used a single-arm magnetic spectrometer to detect scattering from a liquid-helium target. The spectrometer was 30 m long and used four dipole magnets for momentum dispersion and seven quadrupole magnets to create both an intermediate and a final spatial focus. The details of the spectrometer and a plan view are given by Klem *et al.*,[11] although some modifications to that apparatus were made to obtain the large laboratory scattering angles required in this experiment. These changes included bending the incident proton beam with a dipole magnet located just upstream of the helium target and, because of the 10-cm target length, using the second stage rather than the first stage of the spectrometer for momentum analysis. In addition, the dipole magnets upstream and downstream of the target and the entire target assembly were mounted on movable platforms which were remotely adjusted to obtain the desired laboratory scattering angle. The spectrometer momentum resolution ($\Delta p/p$) was typically 0.7% full width at half-maximum (FWHM); the angular resolution was 12-mrad FWHM; and the acceptance was of order 10^{-4} sr. It was determined by Monte Carlo calculation.

The incident proton beam had an intensity of 10^8 protons per 500-msec pulse and an average polarization of 70%. The intensity was monitored by a three-scintillation-counter telescope located in the vertical plane, which viewed a thin polyethylene target placed just upstream of the helium target. The polarization of the incident beam was determined by a carbon polarimeter located at the point where 50-MeV polarized protons were injected into the ZGS. Previous experiments have shown no depolarizing resonances[12] in the synchrotron up to momenta of 3 GeV/c. The direction of the incident beam, which varied up to ± 20 mrad from nominal with a period of many hours, was determined by three wire proportional chambers read out in an integrated mode, which were located upstream of the helium target. The uncertainty in the scattering angle due to beam direction variation was estimated at ± 3 mrad.

The data analysis consisted of determining the momenta of the scattered protons by use of three hodoscopes located in the second stage of the spectrometer and accumulating momentum spectra for all events at each kinematic point. Target-empty and background subtractions were made to determine the number of elastic events separately for incident proton polarizations up and down. Plots from the region of the first cross-section dip at 0.26 (GeV/c)^2 (where the relative background is the largest), at $T_p = 1.03$ GeV, are shown in Fig. 1 for both helium-target-full and -empty runs. The upper spectrum includes all events accepted by the spectrometer; this type of plot was used for the differential cross-section determination which was also measured[13] in this experiment. The lower spectrum was obtained from the upper one by a cut on the horizontal position of the scattered proton at the intermediate focus of the spectrometer. This type of plot, which has less background, was used for the polarization determination.

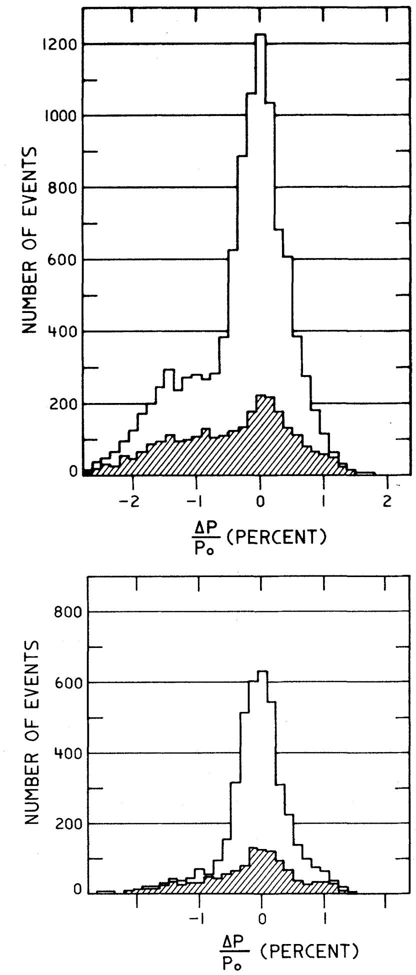

FIG. 1. Momentum spectra for the events at $T = 1.03$ GeV and $-t = 0.26$ (GeV/c)^2, which is in the region of the first minimum in the differential cross section. The shaded spectra are from target-empty runs. The upper plot includes all events; the lower spectra show the effect of a horizontal position cut (see text) in eliminating background.

Figures 2–4 show the polarization measurements. As T_p is increased in this range, a sharp negative peak in the polarization observed at 0.56 GeV no longer goes negative at $T_p = 0.80$ GeV, and becomes less well defined at 1.03 GeV and at higher energies (Fig. 4). At the same time the maxima in the polarization near 0.08 (GeV/c)^2 and 0.36 (GeV/c)^2 are reduced. Above 1.03 GeV, there is relatively little change in the polarization. This same feature, i.e., relatively little change, is observed in the differential cross section.[13-16] The latter as measured by R, the ratio

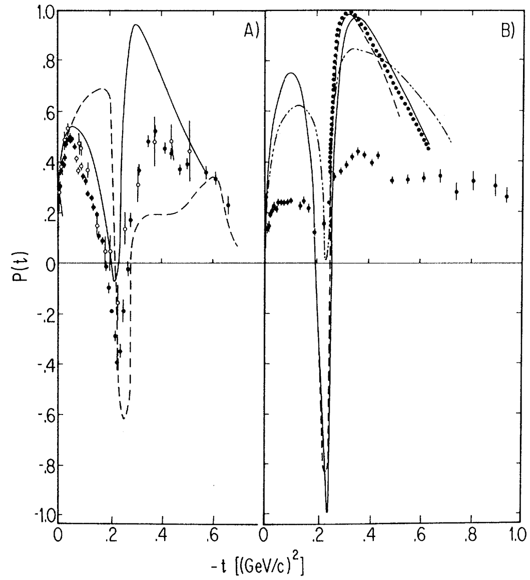

FIG. 2. (a) Polarization at 0.56 GeV (present work, solid circles) and 0.54 GeV(Ref. 10, open circles). Theoretical predictions are by Auger, Gillespie, and Lombard (Ref. 7, solid line) and Lykasov and Tarasov (Ref. 6, dashed line). (b) Polarization at 1.03 GeV from the present work; the dash-dotted curve is a theoretical prediction by Kujawski (Ref. 3). Theoretical calculations by Lambert and Feshbach (Ref. 4) are displayed (solid line, no dynamic correlation; dashed, range of dynamical correlations 0.4 fm; dotted, Reid potential).

of the height of the secondary maximum to the first minimum, changes by only a few percent between 1.05 and 2.68 GeV. The differential cross-section data obtained in this experiment are con-

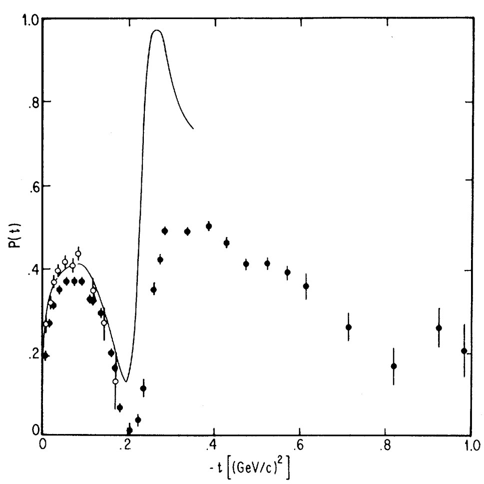

FIG. 3. Polarization at 0.80 GeV (present work, solid circles) and at 0.72 GeV (Ref. 9, open circles). The solid curve is a theoretical prediction by Auger, Gillespie, and Lombard (Ref. 7).

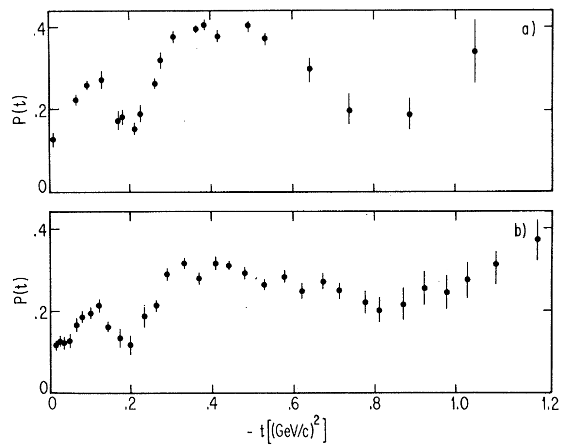

FIG. 4. Polarization in p-^{4}He scattering: (a) $T_p = 1.24$ GeV; (b) $T_p = 1.73$ GeV.

sistent with the data of Refs. 13–16.

Figure 2(a) shows a comparison of the data at 0.56 GeV with the data at 0.54 GeV of Boschitz *et al.*[10] While it is possible that there is a strong energy dependence between 0.54 and 0.56 GeV, it is unlikely that the polarization changes so much in the region of the negative polarization peak as the comparison of the two data sets might suggest. The lack of a sharp, negative dip in the polarization followed by a very fast rise to the maximum positive value in the data of Ref. 10 may be due to finite angular resolution. Also plotted are two theoretical predictions[6,7] using the Glauber model. Both calculations use spin- and isospin-dependent amplitudes in which only one of the five possible spin-dependent operators is employed. The differences are probably due to the nuclear density and nucleon-nucleon parameters used in the two calculations. In Ref. 6, the source and values of the nucleon-nucleon parameters are not stated.

Figure 3 shows a theoretical prediction[7] at 0.72 GeV which is compared with the data of McManigal *et al.*[9] at $T_p = 0.72$ GeV and with our data at 0.80 GeV. As can be seen, the new data at larger $|t|$ are not in accord with a Glauber-model calculation which was in good agreement with the earlier polarization data[9] at small values of $-t$.

Figure 2(b) shows theoretical predictions by Kujawski[3] and by Lambert and Feshbach[4] at 1 GeV compared with the present data. The Kerman-McManus-Thaler (KMT) formalism[17] is used in the work of the latter, and a formalism which is essentially that employed in the Kerman-McManus-Thaler formalism in the former.[3] These calculations were done in conjunction with fits to the

1.0-GeV differential cross-section data[1] which displayed a deeper minimum than the newer data show. As a consequence the theoretical predictions for polarization may be affected. Notwithstanding, the reduction in structure between 0.56 and 1.05 GeV may be difficult to account for on the basis of some theoretical models. The paper of Lambert and Feshbach[4] is also important because it shows that the polarization is relatively insensitive to short-range correlations [see Fig. 2(b)] in this range of $|t|$.

Figure 4 shows the polarization data at $T_p = 1.24$ and 1.73 GeV. It is seen that there is not a great change from the 1.03-GeV data although there is some further reduction in the peak values of the polarization at 1.73 GeV. There is an extremely interesting feature which shows up at the highest value of T_p where larger values of $-t$ can be measured within the limits imposed by the spectrometer. This is the appearance of a distinct minimum in the polarization at 0.84 $(\mathrm{GeV}/c)^2$ followed by a monotonic rise. Such a minimum is attributed in the Glauber model[18] to a region at slightly larger $|t|$ where double- and triple-scattering amplitudes dominate and tend to cancel destructively. The differential cross section data[13-16] between 1.05 and 2.68 GeV display only a change in slope in this range of t.

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