ELASTIC SCATTERING

PRECISE DETERMINATIONS OF PROTON ANALYZING POWERS FOR 180–200 MeV ELASTIC SCATTERING ON ^{12}C AND ^{4}He

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Measurements of reaction analyzing powers (and recently other spin observables as well) frequently achieve statistical accuracies significantly smaller than their corresponding systematic uncertainties. These latter effects are due largely to lack of precise knowledge of the incident beam polarization, either in absolute terms or even in a relative sense, i.e., from one measurement to the next. Though recent progress in the development of in–beam high–energy polarimetry[1] has greatly improved one's ability to monitor these relative fluctuations, such devices must be calibrated against a well–determined analyzing power standard, few of which exist in the intermediate energy regime. Double–scattering experiments provide such information in principle, though in practice the method is subject to many sources of uncertainty, both statistical and systematic.[2–4]

We have employed another technique, previously unused at intermediate energies, which relies on the quadratic relationship that exists among three of the polarization observables in $\frac{1}{2}+0 \to \frac{1}{2}+0$ spin configuration reactions, namely

$$A_y^2 + D_{LL'}^2 + D_{SL'}^2 = 1 \ .$$

(In this case, it is also true that $P = A_y$, $D_{NN'} = 1$, $D_{LL'} = D_{SS'}$ and $D_{SL'} = -D_{LS'}$). By choosing kinematic regimes (bombarding energies and scattering angles) where A_y is known to *approach* ± 1, one can then *determine* A_y very accurately through much less precise measurements of $D_{LL'}$ and $D_{SL'}$, which become very small. This can be seen more clearly by rewriting the above relation as

$$|A_y| = (1 - D_{LL'}^2 - D_{SL'}^2)^{1/2} \ .$$

As an example, if $D_{LL'}$ and $D_{SL'}$ are both measured to be 0.05 ± 0.02, then in this case $|A_y| = 0.9975 \pm 0.0014$.

In addition to this reduction in the statistical error, because one is using a *null* method, i.e., searching for small asymmetries rather than large ones, sensitivities to many potential sources of systematic error are also minimized as $|A_y|$ approaches 1. Accurate knowledge of the magnitude of the beam polarization is not needed to determine a zero–crossing; uncertainties in the effective analyzing power of the focal plane polarimeter become less important for the same reasons. Possible error due to spin–dependent dead–time corrections also disappear, as counting rates become comparable for all in–plane spin orientations. It is also important to realize that a spin–flip at the polarized ion source results in an exact spin–reversal of the in–plane polarization components *even at the spectrometer focal plane*, i.e., after a nuclear scattering. The focal plane polarimeter thus functions as a true double–arm polarimeter, so standard analysis techniques can be employed to eliminate sensitivity to all instrumental asymmetries to at least first–order. Previous detailed calibration measurements[5] for the normal (vertical) polarization, however, have shown no evidence for such asymmetries for this device.

To make these measurements most useful for beam polarization and cross–calibration checks, we have chosen targets that are easy to obtain and handle, and reactions with large cross sections in angle ranges where A_y is known to be close to ± 1. Proton elastic scattering near $T_p = 200$ MeV on ^{4}He and ^{12}C satisfies all these requirements. Moreover, the use of lighter nuclei results in relatively slowly varying angular distributions that do not impose severe restrictions on the angular resolution of the detector system, and allows for easy separation of the elastic peak of interest from those due to contaminent nuclei in the target material. The resolution constraints are therefore minimal and no background subtraction is required, thus removing any possible ambiguities in the extraction of peak yields.

Precise measurements of $D_{LL'}$ and $D_{SL'}$ for proton elastic scattering have now been completed at incident proton energies of 200, 190, and 180 MeV for ^{12}C and at 180 MeV for ^{4}He. At each energy, complete sets of measurements were made at three angles (in 1° steps) that spanned the region where A_y was a maximum. These data were the first measurements of in–plane polarization transfer observables taken with the K600 spectrometer system, and extensive calibration procedures for this experiment (E290) were integrated directly into the in–plane measurements,[6] thus ensuring, for example, that the effective analyzing power assumed for the focal plane polarimeter was determined using the same beam energy, spectrometer angle calibration, and analysis software as were used for the actual measurements. Preliminary results for the ^{12}C data are presented in Figure 1.

The most interesting results were obtained for p + ^{12}C scattering at ~190 MeV, where optical model calculations[7] suggested that A_y should be very close to 1. After completing our first round of off–line event replay at this energy, our best determination of A_y at $\theta_{cm} = 19.0°$ ($\theta_{lab} = 17.3°$) at $T_p = 188.9$ MeV yields a value of $A_y = 0.99963^{+0.00021}_{-0.00030}$. This error includes both statistical uncertainties and our best estimates of systematic contributions that arise due to lack of precise knowledge of the beam polarization magnitude and orientation and the effective analyzing power of the K600 focal plane polarimeter.

Determinations of A_y at other energies and angles have correspondingly larger uncertainties as the analyzing power decreases from unity. In addition, the $D_{LL'}$ and $D_{SL'}$ values shown for 200 and 180 MeV are the on–line results for only two of the three angles measured, and represent only about 30–40% of the total data collected. It is significant nonetheless that the energy dependence is rather smooth, as suggested by the solid lines in Figure 1. Continuity arguments would therefore require that at an energy somewhat below 189 MeV the locus of $D_{LL'}$ and $D_{SL'}$ values will cross the origin; at that energy there will necessarily be an angle (near $\theta_{cm} = 19.0°$) at which A_y is identically equal to 1.

Our goal for this work is to map out a region in scattering angle and bombarding energy over which A_y is known absolutely to within several tenths of a percent. This information can then be used to cross–calibrate other devices, e.g., one could compare the left/right asymmetry seen in an in-beam polarimeter to the spin-up/spin-down asymmetry measured simultaneously in the K600 spectrometer when operating within this energy and angle grid. The ^{4}He results in particular should prove useful for normalization of earlier p-p analyzing power data[8] in which both helium and hydrogen gases were used during data acquisition.

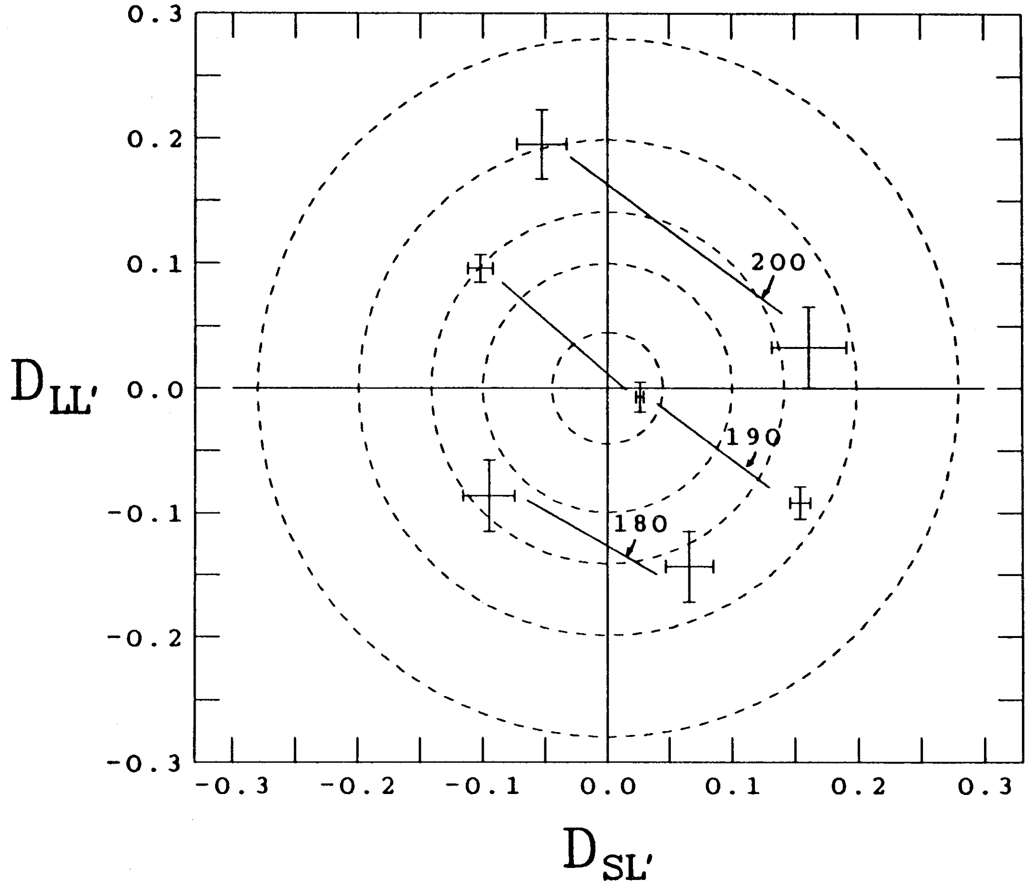

Figure 1. Preliminary results of $D_{LL'}$ and $D_{SL'}$ measurements for p + ^{12}C elastic scattering at 200, 190, and 180 MeV. The solid lines are meant only to guide the eye to suggest the energy dependence of the curves. The dashed circles indicate contours of A_y = 0.96, 0.98, 0.99, 0.995, and 0.999 as one moves towards the origin.

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