DETECTOR DEVELOPMENT AND CALIBRATION

DEVELOPMENT OF AN IN-BEAM POLARIMETER FOR INTERMEDIATE ENERGY PROTONS USING p+d ELASTIC SCATTERING

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We have recently performed some experimental tests to investigate more thoroughly the idea of using p+d elastic scattering as a calibrated reaction to measure all three polarization components of a high–energy proton beam in a non–destructive manner. The primary motivation for the development of a new technique for making these measurements lies with the unreliability of the existing devices. For the last few years, we have relied on polarimeters based on p+^{12}C elastic scattering at $\theta_{lab} = 20°$, using either NaI stopping detectors or various combinations of ΔE–E pairs of plastic scintillator, often with energy degraders. Because one is essentially performing four singles measurements in this case (left, right, up, and down from the beam), it is necessary that either the energy resolution of the detector system be good enough to cleanly separate the ^{12}C ground state from the first excited state at 4.44 MeV, or that the background be low enough that one can sum over a well–defined region of excitation in a precisely reproducible way. The NaI system offers occasionally excellent resolution, but is extremely sensitive to beam halo and scintillator activation when the beam is intercepted by a nearby beam stop, and can be rendered useless by a relatively short period of beam instability. Plastic scintillator schemes, on the other hand, though much more rugged, have never produced satisfactory resolution to allow reliable extraction of beam polarizations at the <2% uncertainty level.

For these reasons, we concluded that we could not depend on any polarimeter scheme based solely on singles detection (the only exception would be p+^{4}He, but gas cells would be impossible for in–beam polarimetry), and various coincidence–detection techniques were considered. By choosing p+d scattering, rather than p+p, one could use the scattered deuteron to separate the elastic events of interest from the quasifree knockout processes that would occur in anything other than a pure hydrogen target. Moreover, for incident proton energies of 100 to 200 MeV, the p+d analyzing powers are generally larger than those of p+p scattering, especially in the kinematic regimes that are most accessible experimentally, i.e., those in which each of the outgoing particles contains roughly half of the total available kinetic energy. Since CD$_2$ targets are fairly easy to produce in thicknesses of 1 mg/cm^2 or so, we were able to perform preliminary measurements with split beam very quickly.

The primary objectives of these tests were to: *i*) measure the p+d relative cross sections and analyzing powers at several incident proton energies and over a reasonable angular range; *ii*) locate the extrema in the analyzing power (as a function of deuteron scattering angle) so as to determine the optimum angle for polarimeter operation; and *iii*) find a relatively simple and efficient means of unambiguously identifying the scattered proton and deuteron such that left–right (or up–down) asymmetries can be reliably extracted even under fairly harsh experimental conditions. This last item involved testing several different types and sizes of scintillator, varying the detector geometry, and examining the effects of various hardware and software cuts.

Because detection of a deuteron would always indicate a valid event, we decided to concentrate on the "d" arm. By choosing a scintillator thickness only slightly larger than the deuteron range, we would detect the full energy of the deuteron, while no proton could deposit an equivalent amount of energy. For example, a 100 MeV deuteron will stop in ~4.3 cm of plastic scintillator, yet protons can deposit a maximum of only 74 MeV in a scintillator this size. A pulse–height spectrum would therefore show the deuterons of interest as the most energetic particles, with a gap between this peak and the knock–out proton continuum. We also chose to use the "d" arm to set the lab scattering angle and coincident solid angle. The "p" arm, on the other hand, was simply a paddle, large enough in area to extend beyond the allowed p+d coincidence range, and thin enough to keep the total volume of the detector small.

Based on these considerations, our final configuration for 200 MeV p+d running consisted of two symmetric detector pairs: two "d" detectors, 5.08 cm thick and collimated to a diameter of 1.43 cm, and two "p" detectors, 0.64 cm thick and approximately 5 cm vertically and horizontally. The actual distance of the "d" detector from the target was varied, but most data were taken at about 60 cm, for a lab $\Delta\Omega_d = 0.47$ msr. Analyzing powers and relative cross sections were measured for lab θ_d values between 37° and 49° (with $\theta_p = 74° - 54°$). For a second run at 120 MeV, we used a similar geometry, but the "d" detectors were only 2.54 cm thick, and values of θ_d varied from 32° to 47°. In all cases, a 1.2 mg/cm^2 CD_2 target was used. We recorded all events in which we had either d_L–p_R or d_R–p_L coincidences, with delays adjusted to put the deuteron from true p+d events about 15 ns after the start of our 60 ns overlap width. CFD outputs were also sent to a TDC, while attenuated anode pulses were sent to an integrating ADC for all four scintillators.

Typical pulse height spectra for the "d" and "p" arms, prior to imposition of any software conditions, are shown in Figs. 1 and 2, respectively, for the d_R–p_L pair. These spectra were taken during the 200 MeV run, at laboratory angles of $\theta_d = 40°$ and $\theta_p \approx 69°$.

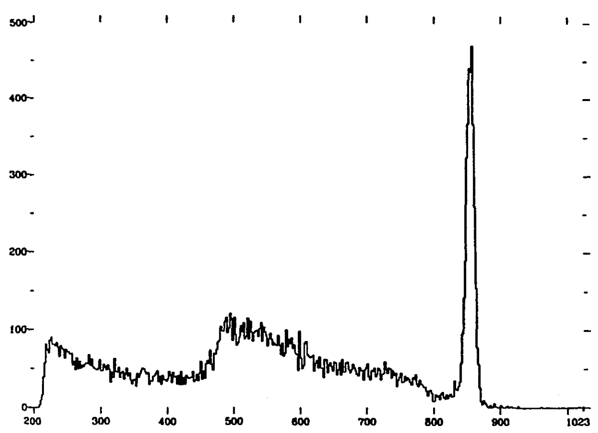


Figure 1. Ungated coincident pulse–height spectrum for the "d" arm, for 200 MeV protons incident on a 1.2 mg/cm^2 CD_2 target. The detector is a plastic scintillator 5 cm thick located at $\theta_{lab} = 40°$.

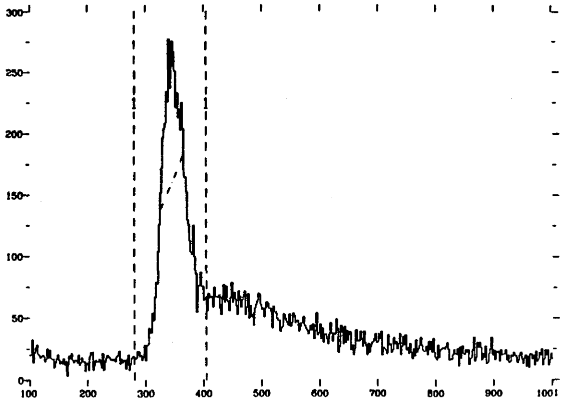
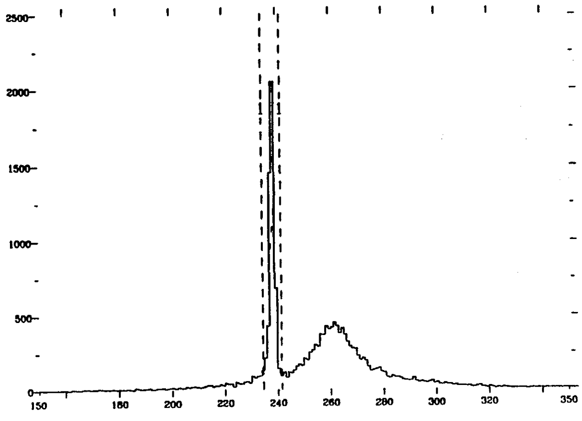


Figure 2. Same conditions as Fig. 1, for the "p" arm. The detector is a plastic scintillator 0.64 cm thick located at $\theta_{lab} \simeq 69°$. The dashed vertical lines indicate the software gate used (see Fig. 4).

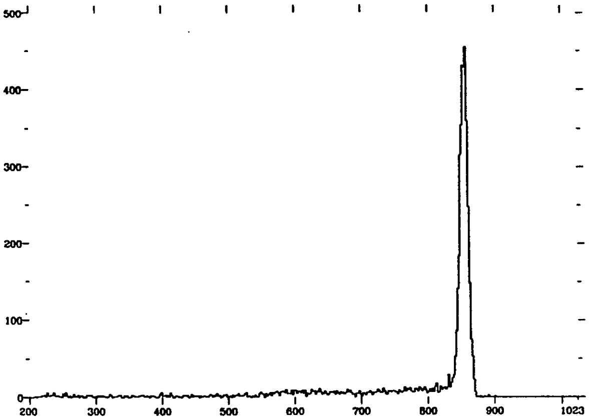
Under these conditions, the deuterons should have just under 100 MeV as they enter the stopping scintillator, while protons should be able to deposit just over 80 MeV in the "d" detector. Thus, one sees a small gap in Fig. 1 between the deuteron peak (centered near channel 860) and the proton edge near channel 800, which already allows for fairly unambiguous peak summing. By adding a gate condition on the coincident "p" detector, as shown in Fig. 2, the deuteron spectrum is cleaned up considerably. A much more stringent software cut, however, is illustrated in Fig. 3, which is the corresponding TDC spectrum, started by the "d" detector and stopped by a delayed "p" signal. With no software conditions, the p+d elastic events are easily distinguished from the background, with typical FWHM resolution of 250 ps. By adding the gates shown in Figs. 2 and 3 as conditions to the "d" detector, we obtain the spectrum shown in Fig. 4, which is an essentially background–free elastic deuteron spectrum. The few counts remaining between channels 550 and 800 are in fact predominantly elastic p+d events in which the deuteron suffered some energy loss, for example, in slit–edge scattering from the collimator, and these counts exhibit a left–right asymmetry comparable to that of the primary peak.

Figure 3. The time–of–flight differences between the "d" and "p" signals, under the same conditions as Fig. 1. The timing resolution attained was less than 250 ps FWHM. The dashed vertical lines indicate the software gate used (see Fig. 4).



To convert the measured asymmetries into p+d analyzing powers, one must be able to determine the polarization of the incident proton beam. During the 200 MeV run,

Figure 4. The same spectrum as shown in Fig. 1, but with two software conditions imposed, as suggested in Figs. 2 and 3. Almost all regions of the spectrum exhibit the same left–right asymmetry.



we installed two NaI scintillators (12.7 cm thick and collimated to a diameter of 0.56 cm at a distance of 58 cm from the CD_2 target) left and right of the beam in a geometry that approximately reproduced that of our standard p+^{12}C polarimeter. Unfortunately, the problems alluded to earlier that often plague these detectors existed during these test runs, and our polarization information was corrupted. Because the p+^{12}C polarimeter had never been calibrated at 120 MeV, we did not use these detectors during the second run. In both cases, therefore, we were forced to deduce beam polarizations based on information from the p+^{4}He polarimeter mounted in BL2. We estimate our uncertainty in the magnitude of the beam polarization (and thus in the magnitude of the calculated analyzing powers) to be about 3–4%.

The angular distributions of the p+d analyzing power, plotted as a function of θ_d in the lab, are shown in Figs. 5 and 6 for incident proton energies of 200 and 120 MeV, respectively. Error bars are purely statistical, and do not reflect any contribution from uncertainty in the beam polarization. Given that the data were taken over several days (since we were using split beam that was available only sporadically), and that BL2 polarimeter measurements were few and far between, the reproducibility of the data is quite good. At each energy,

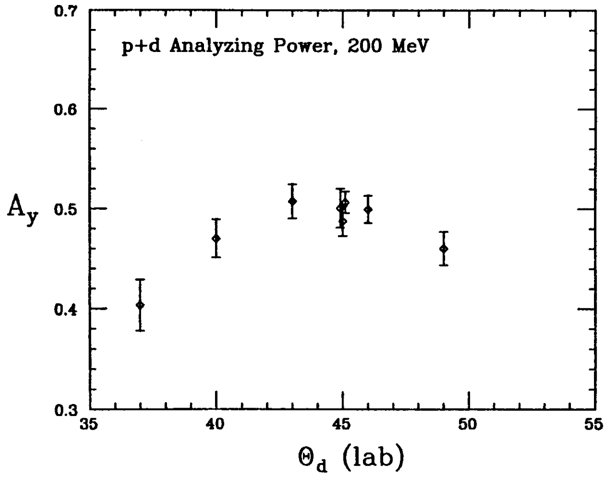


Figure 5. Deduced values for the p+d analyzing power at 200 MeV, analyzed as a function of θ_d in the laboratory frame. Error bars represent only the statistical uncertainties.

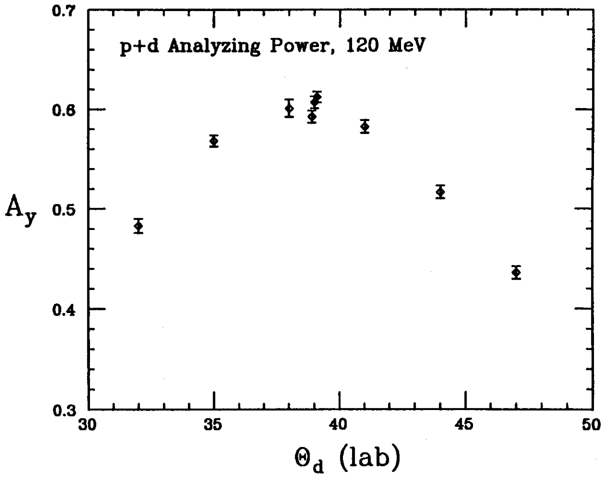


Figure 6. Same as Fig. 5, but for incident proton energies of 120 MeV.

once the peak of the analyzing power had been located, all four scintillators were moved roughly a factor of two closer to the target, which quadrupled our event rate, yet yielded essentially the same A_y values. This more constricted geometry will be the one used in our first prototype p+d polarimeter, since we saw no disadvantages to running with this arrangement.

Based on this initial success, we have now designed a dedicated polarimeter which will use p+d elastic scattering as a calibrated reaction for determining proton polarizations between approximately 100 and 200 MeV. This polarimeter will soon be mounted in BL3, certainly one of the harsher environments in the high–energy beamlines, to see how hard we can "push" the device and continue to obtain useful information. We have also discussed several schemes for performing absolute normalization measurements, i.e., procedures by which we can *deduce* the beam polarization to a much greater precision than can be attained in a conventional asymmetry experiment, which will significantly reduce the systematic error in our A_y angular distributions. In summary, we feel that this device should greatly improve our ability to accurately and continuously monitor the polarization of high–energy proton beams, using an apparatus that is inexpensive and easy to construct, with minimal hardware and electronics requirements, and (hopefully) much less sensitivity to problems associated with high–background or unstable running conditions.