AN ABSOLUTE CALIBRATION OF THE p+d HIGH–ENERGY POLARIMETERS

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Guided by the results of our analyzing-power measurements for p+d elastic scattering at 200 and 120 MeV,[1] we have designed and constructed two proton polarimeters for the IUCF high-energy beamlines. Each polarimeter contains four pairs of scintillators, where each pair consists of a thin ΔE paddle for the proton operated in coincidence with a stopping scintillator for the deuteron. The recoil deuteron detectors are positioned to beam left, right, down, and up, with the left/right and down/up pairs treated as separate event streams. Each scintillator pair can be positioned at three different scattering angles, and, at each angle, the deuteron detector thickness can be optimized to cover four different energy ranges. These polarimeters are presently located in BL3 and in BL5, upstream and downstream, respectively, of BM1–BL3 (a 45° horizontal bending magnet). In this configuration, the normal and sideways polarization information obtained from each polarimeter can be combined to yield complete knowledge of the proton spin orientation at all points in the high-energy beamlines.

Through continued use in a wide variety of experiments, it has been demonstrated that these polarimeters are very reliable and can provide useful information even when located in extremely harsh environments. Initial concerns regarding the large beam spot sizes frequently encountered at their present locations have been addressed through the use of strip or "button" CD_2 targets.[2] However, for high-precision measurements of spin observables, the question of absolute normalization of the beam polarization requires that the effective analyzing power of the polarimeter be calibrated against some known polarization standard. We have recently performed a series of cross-calibration measurements, the results of which are the focus of this report.

Our measurements relied on calibration of the p+d polarimeter analyzing power (A_{pol}) against that of p+^{12}C elastic scattering (A_{ref}). In previous work[3] we determined A_y for the latter reaction with total statistical and systematic uncertainties less than 1×10^{-3} for incident beam energies between 180 and 200 MeV over a limited angle range. These data, combined with earlier A_y measurements at 160 and 200 MeV,[4] were used to describe the p+^{12}C analyzing power over a large energy and angle range where A_y was fairly close to 1, using a parameterization similar to that of Ref. 5. We also incorporated the data from older double-scattering measurements at 153.8 MeV.[6]

Calibration data were taken during two separate running periods. In the initial run, the proton beam first passed through the BL3 polarimeter, and then was alternately sent (using the ~30 ms beam-splitter) down either BL5 to the second polarimeter, or down BL4 to the 64-inch scattering chamber, in which was placed an isotopically enriched 100 μg/cm^2 ^{12}C target. Elastically scattered protons from the p+^{12}C reference reaction were detected to beam left and right in a set of symmetric NaI stopping detectors fronted by thin plastic scintillators. The detectors and collimation system were identical to those used in a previous cross-calibration[5] of p-p analyzing powers against the p+^{12}C data of Ref. 3. In this way polarization asymmetries could be measured essentially simultaneously for the p+d reaction in the two beamline polarimeters and for p+^{12}C scattering in the 64-inch chamber. Incident proton beams of four energies (198, 186, 176, and 154 MeV) were used. By selecting appropriate angles at each energy for which A_{ref} was known, the (vertical) beam polarization could be measured absolutely and used in the determination of A_{pol}.

During the second running period, a very different configuration was employed. After passing through both polarimeters, the beam was sent down BL8 to the K600 spectrometer, which was used to detect the protons elastically scattered from a 6.5 mg/cm^2 ^{12}C target. The advantage of higher energy resolution (~30 keV FWHM) obtainable with the spectrometer was offset, however, by the fact that this serves as a single-arm detector, *i.e.*, it is not left/right symmetric, and is therefore sensitive in first order to various types of systematic error. To compensate for the largest such effect (due to differences in the magnitude of the beam polarization between the "up" and "down" spin states selected at the polarized ion source), the position of the spectrometer was alternated between beam left and beam right for relatively short intervals (~1 hour) over about a ten hour period of data acquisition.

Data were taken in this manner for incident beam energies of 197 and 186 MeV. Once both polarimeters had been calibrated at these energies, a high density (2.21 g/cm^3) ^{12}C degrader of thickness 1.27 cm ($t\rho$ = 2.81 g/cm^2) was positioned in the beamline just downstream of the 45° analysis magnet and upstream of the BL5 polarimeter. This lowered the energy of the transmitted proton beam by approximately 11 MeV. The higher beam energy of 197 MeV (in BL3) was thus reduced to ~186 MeV in BL5, which allowed for a direct comparison of the proton asymmetries observed in the two polarimeters at different energies, assuming no loss of beam polarization occurred in the energy degradation. The statistical quality of this consistency check, however, was severely compromised due to the multiple scattering of the beam introduced by the degrader. Because the beam profile was expanded considerably in this process, the collimating slits immediately upstream of the Lambertson box were used to maintain a beam spot of reasonable dimensions at the strip target of the BL5 polarimeter, i.e., one which strikes only the CD_2 target and not the target frame. This collimation significantly reduced the beam intensity (~2% transmission), so much longer production running was required.

The final results of this work are presented in Fig. 1 for cases where the polarimeter deuteron detector was set at θ_d(lab) = 42.6°. (Lesser amounts of additional data were taken at other angles.) To summarize: all of the values shown at energies above 175 MeV are referenced to the p+^{12}C elastic scattering analyzing power data of Ref. 3 (with weak constraints imposed by including the data of Ref. 4 at other angles and energies). The single lower-energy point is normalized to the data of Ref. 6. The solid points represent data taken during the first running period, *i.e.*, the reference reaction was monitored using NaI stopping detectors in the 64-inch scattering chamber, while the open circles correspond to the non-energy-degraded data taken using the K600. The energy-degraded data acquired during the second running period are statistically consistent with the non-degraded results, though with significantly larger error bars.

The errors shown in Fig. 1 include contributions from three different sources added in quadrature: (*i*) statistical uncertainties in both the p+d and p+^{12}C scattering yields, propagated in the standard way, and including effects of background subtraction for the

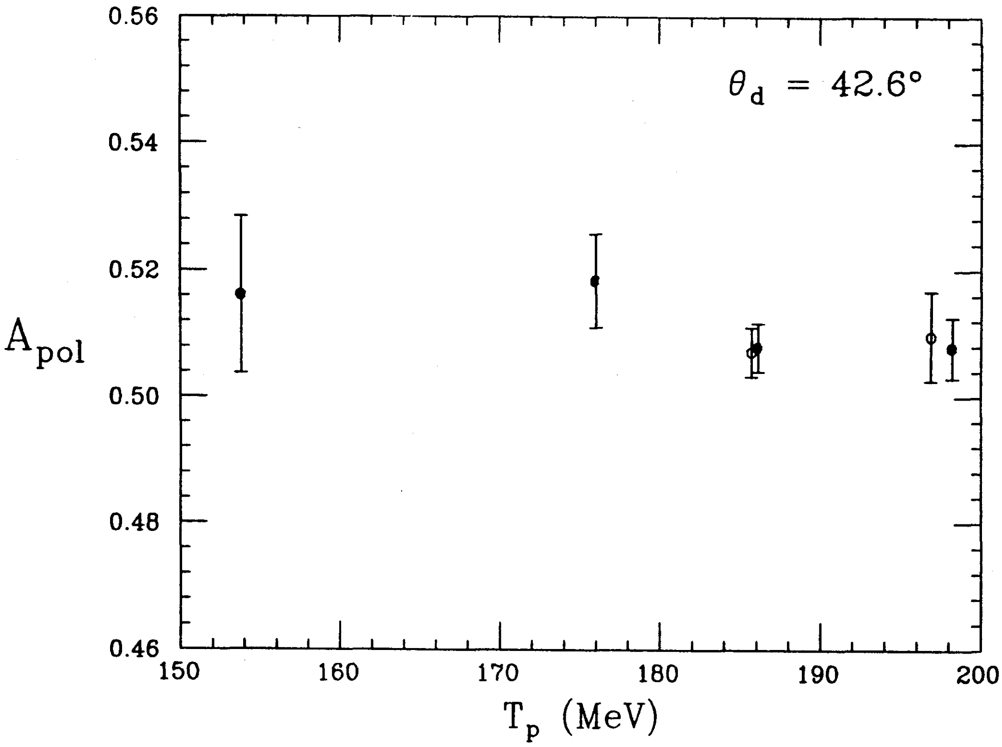

Figure 1. Values of the effective analyzing power A_{pol} at $\theta_d = 42.6°$ for the IUCF high-energy polarimeters based on p+d elastic scattering, as a function of the proton beam energy. Note the suppressed zero. The meaning of the different plotting symbols and the size of the error bars are explained in the text.

latter reaction when studied with the NaI detectors; (*ii*) uncertainties in the value of A_{ref} employed, derived both from the actual data of Ref. 3 plus contributions from errors in the coefficients used to parameterize A_{ref} at the specific energies and angles studied; and (*iii*) our best estimates of possible systematic error associated with beam properties and running conditions that could vary with time. This third category of error is based primarily on observed fluctuations in A_{pol} when the beam properties were intentionally modified from run to run, and also includes changes that arise in A_{pol} due to use of different sets of equally "reasonable" software conditions. The error shown for A_{pol} at 154 MeV does not include any error in A_{ref} beyond that noted in Ref. 6.

It is seen that the calibration data from the second running period reproduce very well the values of the p+d effective analyzing power deduced during the first run at the higher energies. In summary, these data suggest that over a relatively large energy range ($\sim$ 150 to 200 MeV), the effective analyzing power of the p+d polarimeters is quite constant at a value of $A_{pol} \approx 0.51$, with an absolute error on the order of ± 0.005, or a fractional uncertainty of just under 1%.

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PART II.

IUCF COOLER RING