EXPERIMENTAL TECHNOLOGY

PRECISE DETERMINATION OF PROTON SPIN-PRECESSION ANGLES IN THE K600 SPECTROMETER AND BEAMLINE

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Recent spin-transfer measurements for $(\vec{p}, \vec{p}\,')$ reactions, carried out on the IUCF K600 Spectrometer and its Focal Plane Polarimeter (FPP), have provided much information on both the free nucleon-nucleon interaction and on its modifications inside the nuclear medium. These types of experiments require that the proton polarization be accurately determined immediately before and after the nuclear scattering. In practice, however, the polarimeters used to measure the initial (beam) and final (scattered) proton polarization are separated from the scattering chamber by intervening magnetic elements. The beam polarization, as measured by the High Energy Polarimeters (HEP's) located in BL3 and BL5, is affected primarily by transport through a QDDM magnet system in BL8 that is used for momentum dispersion. After the scattering, the proton flux must first pass through the K600 (a QDD magnet system) before its polarization is deduced in the FPP. For highly precise in-plane spin-transfer measurements, such as those of E383,[1] it is crucial that one know accurately the angles by which the proton spin is precessed by these two magnet systems, in order to be able to relate the asymmetries measured in these polarimeters to specific observables in the lab frame.

If one considers only transverse magnetic fields, *i.e.*, fields perpendicular to the proton momentum, then the angle by which the proton's spin is precessed *with respect to its momentum direction* is given by:

$$\alpha = \gamma (\mu_p - 1) \theta_{bend} \qquad (1)$$

where γ is the usual Lorentz factor (dependent on the proton energy), μ_p is the proton magnetic moment, and θ_{bend} is the angle by which the proton's trajectory has been bent due to the magnetic field. Because of this simple proportionality, an accurate determination of θ_{bend} is therefore sufficient to provide complete information on the spin-precession angle α. Using a combination of mechanical measurements and direct measurements of spin precession, as described below, we have thus extracted the bend angles θ_Q and θ_K for the beamline (QDDM) and spectrometer (K600) magnet systems, respectively, to an absolute accuracy of better than 1°.

The change in trajectory experienced by a proton passing through the K600 can be determined through knowledge of two angles: θ_{FP}, defined as the angle of incidence

between the proton trajectory and the wire plane of the first vertical drift chamber (VDC) in the focal plane; and θ_0, the angle between this wire plane and the central ray for protons entering the spectrometer. With precise knowledge of the focal-plane chamber geometry, θ_{FP} can be calculated very accurately for each event from VDC information; our mechanical measurements, therefore, focussed primarily on determining θ_0. This angle will depend on the specific configuration of the spectrometer system, e.g., whether the septum magnet is being used, and whether the focal plane detectors are positioned at the medium- or low-dispersion exit port. Thus, several independent mechanical measurements were made during the past year to establish θ_0 for all modes of K600 operation. In some cases, the determination of θ_0 was fairly direct: these studies required that a transit situated behind the K600 sight along the wire plane, while a front-silvered mirror was carefully aligned at the center of the scattering chamber to determine the path of protons entering the spectrometer. For another, more indirect, determination, we measured the VDC wire-plane angle with respect to the upstream beamline, then relied upon the K600 digital encoder to determine the (relative) angle between this beamline and the entrance to the K600.

Our results are summarized in the first column of Table I, which also provides details on the spectrometer configuration and measurement technique employed. In order to check for consistency among these numbers, we rely on the values determined for two other angles, each independently measured to a high accuracy: the additional bend introduced by the septum magnet, found to be $8.54 \pm 0.05°$; and the angle difference between the VDC wire planes when mounted at the medium- or low-dispersion exit port, which is $12.45 \pm 0.10°$. Using these values, one can convert each measurement to an effective determination of θ_0 for the non-septum, medium-dispersion mode configuration, as listed in the final column of Table I. The close agreement found among these numbers suggests that, for any K600 configuration, θ_0 can be determined to within better than a few tenths of a degree. We also note that these results differ significantly from an earlier measurement[2] of 77.9° for the "standard configuration". The origin of this discrepancy is not known, but the internal consistency seen among the current set of measurements casts significant doubt on the older number.

θ_0	Septum	Dispersion	Method	Converted Value
77.10°	No	Medium	Direct	77.10°
85.78°	Yes	Medium	Direct	77.24°
98.05°	Yes	Low	Indirect	77.06°

Table I.   Values of θ_0 determined for several configurations of the K600 (first column), plus values that take into account known additional bend angles (final column).

We also devised a method to measure directly the total spin precession angle experienced by protons in passing through the QDDM and K600 magnet systems, using $p + {}^{12}C$ elastic scattering. For in-plane spin-transfer measurements in which a spin-1/2 particle

scatters elastically from a spin-0 target, the measured down-up yield asymmetry in the FPP (ϵ_{FPP}), normalized by the in-plane polarization magnitude of the beam (p_h), can be written in the following manner:

$$\frac{\epsilon_{FPP}}{p_h} = A_{FPP} \left(1 - A_y^2\right)^{\frac{1}{2}} \sin(\phi_{BL5} + \alpha_Q + \alpha_K + \beta - \theta_{sc}) \qquad (2)$$

where A_{FPP} is the effective analyzing power of the focal plane polarimeter, A_y is the analyzing power for the reaction being studied, ϕ_{BL5} is the angle between the beam direction and the beam's in-plane polarization vector at the BL5 polarimeter, α_Q and α_K are the spin precession angles in the QDDM and the K600, respectively, β is the spin rotation induced in the nuclear scattering, and θ_{sc} is the lab frame scattering angle. We note that changing the currents in the spin-precession solenoids located in the high-energy beamlines allows us to vary ϕ_{BL5} without altering any other parameter in this equation. By measuring ϵ_{FPP} for multiple values of ϕ_{BL5} (which are determined solely from HEP information), a sine wave can be mapped out.

We now consider the effect on Eq. (2) of rotating the K600 from the left side of the beam to the same scattering angle on the right. In this case, α_Q and α_K (and also A_{FPP} are unchanged, but both β and θ_{sc} reverse sign. Hence, if one again maps out ϵ_{FPP} as a function of ϕ_{BL5}, one can in principle separate the nuclear-rotation component (β) from the magnetically-induced spin-precession terms ($\alpha_Q + \alpha_K$). In practice, of course, slight variations in θ_{sc} (and therefore also in A_y and β) from run to run complicate the data analysis. For each run, we rely on being able to determine θ_{sc} absolutely to very high precision (within a few hundredths of a degree) using a relativistic kinematics program and information from the K600 focal plane. Because β changes very rapidly as a function of scattering angle, it is necessary to make corrections to the measured FPP asymmetries to account for these variations. In order to estimate the size of these corrections, measurements were made at three different scattering angles in 1° steps, and an iterative method was used to estimate the variation of β with θ_{sc}.

θ_{sc}	β	A_{FPP}
23.49	101.64 ± .80	.5333 ± .0075
24.47	93.77 ± .85	.5155 ± .0075
25.45	80.73 ± .91	.5166 ± .0082
-24.39	-94.53 ± .87	.5241 ± .0078

Table II.   Values of the nuclear rotation angle β and the FPP effective analyzing power as a function of scattering angle for $p+^{12}C$ elastic scattering at 198 MeV.

Using this technique, and assuming that α_K can be calculated reliably based on Eq. (1) and the mechanical measurements described earlier, we find that $\theta_Q = 131.1° \pm 0.3°$. The results of these measurements, including our values for the FPP effective analyzing power,

are summarized in Table II. This new measurement of the QDDM bend angle is also in moderate agreement with the best value determined previously,[2] $130.4° \pm 0.4°$. The older number was determined using a completely different method, and the level of agreement found between the two numbers is encouraging. We expect the value of the QDDM bend angle to be somewhat sensitive to details of beam steering in BL5, an idea we plan to explore further in the future.

1. W.A. Franklin *et al.*, "A Complete Set of In-plane Spin-Transfer Coefficients for Small Angle pp Elastic Scattering at 200 MeV," contribution to this report.
2. S.W. Wissink *et al.*, IUCF Sci. and Tech. Rep., May 1989 – April 1990, p. 180.

TRAP TARGET STUDIES

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An elongated electromagnetic trap of a modified Malmberg-Penning variety is under development to test the feasibility of using trapped particles for a storage ring target. Electrons are used for this target prototype, although the eventual conversion to hadronic matter is envisioned. During 1995, the trap geometry was modified to improve the method of applying torque to the trap contents. The resulting electron plasma could be stably confined (up to three weeks on two occasions) using controlled background gas ionization to maintain a constant particle number of order 10^{10} particles.

In March and April, 1996, the filled trap was exposed to a cooled 45-MeV proton beam in the IUCF Cooler. The coasting beam was observed to heat the trapped plasma at a rate consistent with energy transfer through individual particle collisions, while the bunched beam was found to exhibit enhanced heating at a rate that could be varied by changing the length of the plasma column. A preliminary interpretation is that a harmonic of the proton orbit frequency was brought into resonance with one of the standing charge-density wave (Gould-Trivelpiece) modes. The interacting beam-plasma system was found to be stable up a beam current of 10^{15} particles/s, corresponding to a luminosity in excess of 10^{24} $cm^{-2}s^{-1}$, which is sufficient for application to atomic physics experiments.

An unexpected difficulty was encountered in these first beam tests. The passage of beam through the trap gradually deteriorated the electrostatic cylindrical symmetry that is needed to prevent radial growth of the plasma. Apparently the beam interacted with the background gas, leading to an irregular deposit of surface charge on the trap wall, which remained in place at room temperature for periods in excess of one hour. By heating the vacuum chamber, the trap recovered more quickly, allowing the tests reported above to be performed. The trap is being modified to remove stainless-steel surfaces exposed to the plasma, and to coat the copper wall with a thin gold coating to improve the surface conductivity.