Abstract.

An experiment (E497) is underway at TRIUMF to measure the angle-integrated, parity violating longitudinal analyzing power, $A_z$, in proton-proton elastic scattering, to a precision of $\pm 0.2 \times 10^{-7}$. The experiment uses a 221 MeV longitudinally polarized proton beam incident on a 40 cm liquid hydrogen target. The beam energy is carefully chosen so that the contribution to $A_z$ from the J=0 parity mixed partial wave ($^1S_0 - ^3P_0$) integrates to zero over the acceptance of the apparatus, leaving the experiment sensitive mainly ($> 95\%$) to $A_z$ arising from the $^3P_2 - ^1D_2$, J=2 wave. To minimize sources of systematic error, the TRIUMF ion source and cyclotron parameters have been refined to the extent that helicity correlated beam changes are at an extremely low level, and specialized instrumentation on the E497 beamline is able to measure residual helicity correlated modulations to a precision consistent with the goals of the experiment. A data taking run in February-March, 1997 logged approximately 12% of the desired data and produced a preliminary result, $A_z = (1.1 \pm 0.4 \pm 0.4) \times 10^{-7}$, where the error is statistical only.
INTRODUCTION

Figure 1 shows the overall layout of TRIUMF experiment E497. The polarized beam is prepared in an optically pumped polarized ion source, the spin is precessed into the vertical direction by a Wien filter, and the beam is accelerated to 221 MeV in the TRIUMF cyclotron. The extracted beam current is 200 nA and the polarization is typically 80%. The beamline precesses the spin into the longitudinal direction and transports the beam to the parity experimental area, where it passes through a series of beam diagnostic and control devices before it is scattered from a 40 cm thick liquid hydrogen target. Hydrogen filled transverse electric field ionization chambers measure the current before and after the target. Approximately 4% of the incident protons scatter due to the strong nuclear force between the incident and target protons. However, because of the simultaneous presence of the weak nuclear force, the scattering fraction is expected to be enhanced very slightly, by about one part in $10^7$, if the incident proton spin is aligned with the beam direction, and reduced by the same fraction if the proton spin is opposite to the beam direction. This difference is expressed as the parity violating longitudinal analyzing power, $A_z = (\sigma^+ - \sigma^-)/(\sigma^+ + \sigma^-)$, where $\sigma^+$ and $\sigma^-$ are the scattering cross sections for positive and negative helicity. The goal of E497 is to measure $A_z$ with a precision of $\pm 0.2 \times 10^{-7}$.

FIGURE 1. General layout of the TRIUMF parity experiment. (OPPIS: Optically Pumped Polarized Ion Source; SOL: Spin Precession Solenoid; IPM: Intensity Profile Monitor; PPM: Polarization Profile Monitor; TRIC: Transverse Field Ionization Chamber)
Choice of Energy

Figure 2 shows the results of meson exchange calculations by Driscoll and Miller [1] using the Bonn meson exchange potential [2,3] for the strong interaction and the DDH [4] predictions for the weak coupling parameters. The calculated $A_z$ is shown broken down into contributions from the various parity mixed partial waves.

![Diagram showing partial wave contributions to $A_z$. The curves are from Driscoll and Miller[1]. Also shown are data from Bonn[5], SIN[6], Los Alamos[7], and the TRIUMF preliminary result.](image)

**FIGURE 2.** Partial wave contributions to $A_z$. The curves are from Driscoll and Miller[1]. Also shown are data from Bonn[5], SIN[6], Los Alamos[7], and the TRIUMF preliminary result.

Because the variation of $A_z$ with angle is determined only by the well-known strong interaction, one can calculate the energy at which the lowest order, $J=0$, parity mixed partial wave ($^1S_0-^3P_0$) will integrate to zero over the acceptance of the detectors. The 221 MeV energy of the TRIUMF experiment is chosen so that the measured $A_z$ comes exclusively\(^1\) from the $J=2$ parity mixed partial wave ($^3P_2-^1D_2$) which, in the meson exchange model, comes from $\rho$-meson exchange. Theoretical predictions [1,8–11] for $A_z$ at this energy, span a substantial range. It is hoped that the TRIUMF measurement, in selecting the effects of only one partial wave, will provide a definitive result.

\(^1\) At this energy the contribution to $A_z$ from the $^1D_2-^3F_2$ partial wave is only 5% of that from $^3P_2-^1D_2$. 

SYSTEMATIC ERRORS

If beam properties other than the spin direction change when the spin is flipped, it can affect the measured $A_z$. Random changes will appear as noise, and simply increase the time required to achieve a given statistical precision; coherent changes, that is changes which are synchronized with spin reversal, appear as a false $A_z$. Table 1 summarizes the corrections to the February-March 1997 data for all sources of systematic error that are measurable with the parity apparatus. Notice that the corrections are very small and, in most cases are zero to within statistics. This is the result of an exhaustive program of reducing all unwanted helicity correlated modulations to a bare minimum and of minimizing the sensitivity to these modulations.

Transverse Polarization Components

Ideally, the polarization is purely longitudinal. Unwanted transverse components, $P_t = P_x$ or $P_y$, are kept small ($< 0.001$) but couple to the large parity allowed analyzing power and, when combined with an off-center beam, generate a false $A_z$. The sensitivity to transverse components is found by setting the spin precession magnets for large $P_t$ and measuring the false $A_z$ as a function of beam position. This procedure also determines the “polarization neutral axis” – the beam position with minimum sensitivity to transverse polarization components. A beam position servo system then holds the average beam position on this axis to within about 50µm. During data taking, the polarization profile monitors (PPM1 and PPM2 in figure 1) continuously measure the transverse components and a correction is applied.

Even if the average transverse polarization is zero, the first moment of transverse polarization need not be. For example, the polarization may be up

| Item | $10^7(\Delta A_z)$ | Comment |
|------|------------------|---------|
| $P_x$ | 0.01 ± 0.09 | Correction very small |
| $P_y$ | 0.02 ± 0.20 | for all data sets |
| $yP_x$ | -0.001 ± 0.002 | sensitivity extracted |
| $xP_y$ | 0.00 ± 0.02 | from real data correlations |
| $\Delta \sigma$ | -0.07 ± 0.20 | sensitivity from separate measurement |
| $\Delta x$ | -0.03 ± 0.15 | correction ~ 0 for all sets |
| $\Delta y$ | 0.23 ± 0.16 | some cancellation between sets |
| $\Delta I/I$ | 0.05 ± 0.05 | using interleaved CIM data |
| Total | 0.2 ± 0.4 | |

on the left of the beam and down on the right. Such unwanted polarization profiles also cause false $A_z$. For this reason, the first moments of transverse polarization, $<xP_y>$ and $<yP_x>$ are continuously monitored by the PPMs. They show a random variation from run to run, but typical values are a few $\mu m$ for a one hour run, averaging to near zero over a 20 to 30 hour data set. In a drift space, first moments vary linearly with position along the beamline, making it possible to adjust the beam optics so that the first moments pass through zero at a point which minimizes their effect. The sensitivity to intrinsic first moments must be determined by looking at correlations between apparent $A_z$ and the $<xP_y>$ and $<yP_x>$ measured by the PPMs. For the February, 1997 data, this sensitivity was consistent with zero.

**Beam Size Modulation**

Because the beam is different upstream and downstream of the liquid hydrogen target, a beam size change affects the current differently in the upstream and downstream detectors (TRIC1 and TRIC2 in figure 1). Actual coherent size modulation is typically only a few tenths of one $\mu m$ on a $\sigma = 5 mm$ beam, but it can cause a detectable shift in the measured $A_z$. To measure the sensitivity to beam size change, a relatively large coherent beam size modulation is introduced using a pair of fast ferrite-cored quadrupole magnets. The sensitivity measured in this way is then multiplied by the actual coherent size change measured during data taking to obtain the correction.

**Beam Intensity Modulation**

Coherent intensity modulation from the optically pumped polarized ion source is very small, usually only a few parts in $10^5$. The coherent intensity modulation is measured constantly during data taking. In addition, the sensitivity is monitored by interleaving with the normal data a 10% subset with artificially enhanced ($\sim 0.1\%$) coherent intensity modulation (CIM).

**Beam Position Modulation**

If the beam position changes with spin reversal then a false $A_z$ is introduced proportional to the magnitude of the coherent change and the mean position of the beam. The farther the beam is off-axis, the greater the sensitivity to coherent position change. Sensitivity to position modulation is measured by introducing relatively large position modulation using the same fast ferrite-cored steering magnets which are used for the beam position servo. This information is then combined with the actual beam position information recorded during the run to obtain the correction.
Overall Bias

Although corrections for all systematic errors measurable with the E497 apparatus appear to be well under control, the possibility remains that some additional effect could be present which cannot be measured, but which will cause a false $A_z$. One example is energy modulation. Such effects must be handled by reversing the sign of the spin in the beamline relative to that at the ion source or cyclotron. The real asymmetry from $A_z$ will then reverse sign, but the false effect will not, but will simply appear as an overall bias on the measured $A_z$. For this reason, runs were made under four configurations representing all possible combinations of spin direction at the ion source, cyclotron, and parity apparatus (see figure 1). Only four different conditions are needed because changing the spin direction in the ion source is the same as reversing the definition of spin “up”.

![Graph showing the asymmetry vs set number for February-March, 1997 run](image)

**FIGURE 3.** Data from the February-March, 1997 run after correction for all measurable sources of systematic error. In brackets, the left-hand arrow shows the orientation of the spin in the cyclotron and the right-hand arrow shows the direction at the parity apparatus. The sign of the plotted asymmetry is such that it is equal to $+A_z$ for positive helicity at the apparatus and equal to $-A_z$ for negative helicity at the apparatus. (A right arrow indicates positive helicity.)

**RESULTS OF FEBRUARY-MARCH, 1997 RUN**

A total of 231 runs of “real data” were taken during February and March. 80% was polarized, 10% was unpolarized and 10% was unpolarized with intentional coherent intensity modulation. 105 hours of polarized data passed
all the cuts. Figure 3 shows the results from these data. Each point has already been corrected for the effects of coherent change in beam intensity, position, size, transverse polarization, and first moments of transverse polarization. The asymmetry apparently contains a part which is related to spin in the cyclotron and a part which is related to spin in the parity apparatus. To extract $A_z$, it is assumed that only that part of the asymmetry which reverses with spin at the parity apparatus is true $A_z$. In principle, it is enough to reverse the constancy of the offset and the true $A_z$ can be extracted. The reversal of the spin in the cyclotron was done in an attempt to locate the source of the offset.

The last point, set 8, on figure 3 requires some explanation. It was taken with the normal $6\text{ mg/cm}^2$ stripping foil replaced with a $2.5\text{ mg/cm}^2$ foil. This was done to test the theory that the bias might be arising from some interaction with the stripping foil. It appears the bias was reduced by the thin foil, but unfortunately the variation could be statistical. For the Parity data-taking run starting in August, 1997, The experiment will use a very thin, $200\mu\text{g/cm}^2$ stripping foil. This should make clear whether or not the large $A_z$ offset arises from some interaction with the stripping foil.

The raw $A_z$ from February-March, 1997 is $(1.3 \pm 0.4) \times 10^{-7}$ and, after all corrections are applied, the final $A_z$ is $(1.1 \pm 0.4 \pm 0.4) \times 10^{-7}$, where the first error comes from statistical uncertainty in the raw $A_z$ and the second error is dominated by statistical uncertainty in measurement of the helicity correlated quantities. Since the uncertainty in the correction is also statistical, the two errors can be combined, giving $A_z = (1.1 \pm 0.6) \times 10^{-7}$. We consider this number very preliminary because of the relatively large systematic shift which had to be removed by averaging over different beamline helicities.

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