High Precision 5 MeV Mott Polarimeter

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We report on the design and performance of a Mott polarimeter optimized for a 5 MeV electron beam from the Continuous Electron Beam Accelerator Facility (CEBAF) injector. In two separate series of measurements from two different photocathode electron sources, we have measured the Mott scattering asymmetries produced by an approximately 86% transversely polarized electron beam incident on ten gold foils with nominal thicknesses between 50 and 1000 nm. The overall uncertainty of our beam polarization measurement, arising from the uncertainty in the value of the scattering asymmetry at zero foil thickness as determined from our fits to the measured asymmetries versus scattering foil thicknesses, the estimated systematic effects, and the (dominant) uncertainty from the calculation of the theoretical Sherman function, is 0.61%.

KEYWORDS: Electron polarimetry; beam diagnostics

1. Introduction

Many of the highest impact experiments performed at Jefferson Lab have relied on spin-polarized electron beams [1-7]. Unsurprisingly, electron polarimetry is very important at Jefferson Lab and there are many polarimeters [8]. The motivation for our present MeV Mott polarimetry studies has been to further reduce the uncertainty in the measurement of longitudinally polarized electron beams used for parity violation studies at CEBAF. This is because the uncertainty in the beam polarization is the dominant uncertainty in the measured parity-violating asymmetry in the scattering of longitudinally polarized electrons from nuclear or electron targets.

This contribution summarizes only very briefly the conclusions of a multi-year effort to report on the design and performance of a Mott polarimeter optimized for a nominal 5 MeV electron beam at the CEBAF injector. The interested reader is referred to a recent journal article [9] for a thorough and detailed description supporting the conclusions presented below.

2. Design of the Polarimeter

The design of the polarimeter vacuum chamber, shown in Fig. 1, is composed of three segments—a scattering chamber containing the target foils, apertures, and detector ports; an extension section providing a vacuum pump port; and a long drift chamber ending in a beryllium and copper beam dump structure. The polarimeter is connected directly to a beam port 12.5º off the main accelerator beam line, with no intervening vacuum windows. The beam is steered to the polarimeter by a dipole magnet. When not in use, the polarimeter is isolated with a beam line vacuum valve. Vacuum in the chamber is maintained below a nominal pressure of $\approx 10^{-7}$ Pa by several ion pumps and a non-evaporable getter (NEG) pump. The internal surfaces of the chambers have a 12.7 mm thick aluminum liner both upstream and downstream of the target foils to reduce both backscattered electrons and the photon background in the detectors.

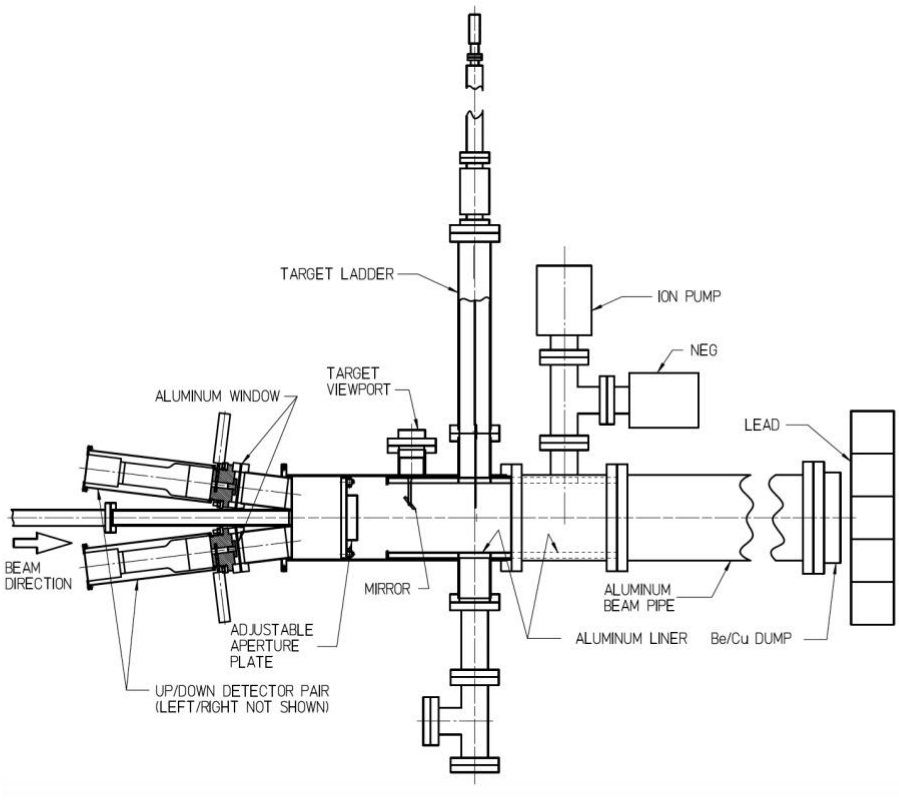

Fig. 1. Elevation view of the Mott polarimeter, including the beam line from the dipole magnet which steers the beam into the polarimeter.

The scattering chamber has four detector ports, each centered on a scattering angle of 172.6º and separated by 90º in azimuth, with two in the horizontal plane and two in the vertical plane, allowing simultaneous measurement of both transverse components of the beam polarization. Scattered electrons that pass through an aperture enter a detector package through a 50 µm aluminum window, immediately followed by 9.7 mm diameter aperture in a 12.7 mm thick aluminum plate centered on the 172.6º scattering angle.

The target ladder is mounted on a bellows-sealed translation mechanism with 600 mm of travel, which is driven by a stepper motor. It has 16 target foil mounting positions, each with a 25.4 mm diameter clear aperture. One of these is left open intentionally, and a second contains a chromox beam viewscreen, leaving 14 positions available for scattering foils.

A 2.5 m section of a 20 cm diameter aluminum vacuum tube terminating in a beam dump follows the vacuum extension section. The dump is an 18.4 cm diameter, 6.35 mm thick disc of Be metal, affixed to a water-cooled reentrant copper flange structure by screws. Beryllium offers excellent thermal conductivity, and a low ratio of radiative to collisional electron energy loss. The use of Be offers high beam power handling capability, and minimizes both electron backscattering and photon production. Operation with 75 μA beam current (375 W beam power) has been conducted with this dump, which is designed to operate with a 1 kW beam power limit.

Four identical detector packages are used. Each package contains two plastic scintillation detectors behind a lead and an aluminum collimator. The first “E” detector is a 1.0 mm thick, 25.4 mm square plastic scintillator, while the second “ΔE” detector is a 76.2 mm diameter by 62.6 mm long plastic scintillator. The ΔE scintillator is optically connected to a 25.4 mm diameter phototube (Hamamatsu R6427) by an acrylic lightguide glued to both the scintillator and the phototube, while the E scintillator is directly glued to the face of a 76.2 mm phototube (Hamamatsu R6091). The surfaces of the E scintillator were painted with a diffuse reflector to improve the optical photon transport to the photomultiplier cathode. The entire four detector package is enclosed in at least 10 cm thick lead shielding constructed from standard 51 x 102 x 203 mm lead blocks.

3. Discussion

In our paper we employed several methods to test and improve both the accuracy and precision of the measured beam polarization. The accuracy was improved by performing theoretical calculations of the Sherman function, applying statistical analyses to the analyzing power dependence on polarimeter target thickness, and developing GEANT4 simulations to model and validate the analyses. The precision of the polarimeter was investigated by detailed examination of the dependence of the measured physics asymmetry on the detector signals that are recorded to isolate the polarization dependent Mott elastic signal, as well as a number of potentially important systematic effects.

For a given beam polarization the measured experimental asymmetry is proportional to the analyzing power of the polarimeter. Theoretically, the analyzing power of Mott scattering from a single atom is known as the Sherman function. Experimentally, in a real target foil, an electron may scatter from more than a single atom, leading to a lower analyzing power known as the effective Sherman function. The usual way to determine the effective Sherman function for a particular foil thickness and unknown polarimeter is to measure the asymmetry for several foil thicknesses and extrapolate to the zero-thickness single-atom value. The extrapolated asymmetry in conjunction with the theoretical Sherman function is then used to determine the beam polarization and also calibrate the effective Sherman function of each target foil tested.

Data obtained over two run periods were used for this paper. The two runs were performed six months apart, each run employing a similar but physically different photocathode to produce the polarized beams. Systematic studies of possible sensitivities of the results on various beam parameters were performed during both run periods. In the sections that follow, the purpose and methods are discussed for each significant aspect of the measurements, and the corresponding systematic and statistical uncertainties associated with each are analyzed.

4. Conclusion

The primary conclusion from our measurements and analyses is that electron polarimetry based on Mott scattering in the MeV range has reached a level we believe is well below 1% uncertainty.

Our polarimeter design is optimized to isolate electrons which only scatter from the target foil. The use of a coincidence ΔE-E detector and measurement of both the energy and timing of the scattered electrons allows for careful isolation of elastic events that carry the full asymmetry of the analyzed beam. The use of the super-ratio method makes the computed asymmetry insensitive to beam intensity and detector solid angles. Systematic studies of the DAQ and of dependence on the meaningful beam properties demonstrate these effects contribute less than 0.25% to the measured asymmetry.

The target thickness extrapolation, a questionable uncertainty owing to the challenges associated with knowledge of the physical dependence, has been especially well characterized. Extensive measurements and statistical analysis have demonstrated knowledge of the zero-thickness foil analyzing power with a precision of ≈0.25%. While the calculation of the theoretical Sherman function remains the large contribution to the absolute uncertainty the modern calculations presented here predict this value convincingly at a level of ≈0.5%. Consequently, we have demonstrated the capability to measure the electron polarization at a beam energy with a total uncertainty ≈0.6% (see Table I).

Table I. Uncertainty budget for the 5 MeV Mott polarimeter.

Contribution to the total uncertainty	Value
Theoretical Sherman function	0.50%
Target thickness extrapolation	0.25%
Systematic uncertainties	0.25%
Energy cut (0.10%)	
Laser polarization (0.10%)	
Scattering angle and beam energy (0.20%)	
Total	0.61%

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