Transmission Polarimetry at MIT Bates


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Abstract. The polarization dependence of Compton scattering in magnetized iron can be used to determine the polarization of an incident photon beam. This can in turn be related to the polarization of the electron beam which radiated the photons. It is difficult to calculate the analyzing power of these devices absolutely, however they are of great utility for rapid, relative measurements of electron beam polarization. These devices have been used at Bates as relative electron polarization monitors at 20 and 200 MeV. Efforts are now being made to use the device at 850 MeV as an online measure of the beam polarization in the South Hall Ring. A technique to calibrate these devices and build an affordable, absolute polarimeter is also being explored.

INTRODUCTION

Transmission polarimeters have been in use at the Bates Linear Accelerator Center over the last several years. The initial design was very similar to a transmission polarimeter used at the Mainz Microtron for a parity violating experiment on Beryllium (1), but subsequent devices at Bates have been modified for optimal performance at various locations throughout the facility. The transmission polarimeter is a simple, inexpensive device with a relatively small analyzing power, 0.1% < A < 5%, but high counting rates. The devices can deliver rapid, precise measurements of the longitudinal electron beam polarization, but to date have relied on calibration against polarimeters with better known analyzing powers, principally Moller (2) and Compton (3).

TRANSMISSION POLARIMETRY TECHNIQUE

The technique of transmission polarimetry is illustrated in Fig. 1. A high energy electron beam is incident on a thin target where high energy photons are radiated. A portion of the electron polarization is transferred to the photon beam. At the photon endpoint, where the photon receives the full momentum of the incident electron, helicity conservation requires full transfer of electron polarization to the photon. This polarized photon beam is subsequently attenuated in a magnetized iron bar. Due to the polarization dependence of the Compton cross section, a helicity dependent asymmetry develops in the downstream photon yield. Although helicity independent processes dominate in the iron absorber, the cumulative effect of the spin dependent
scattering over tens of cm results in asymmetries between 0.1-1% depending on the beam energy and the precise details of the polarimeter.

![Diagram of polarimetry setup](image)

**FIGURE 1.** The technique of transmission polarimetry. See text for details.

Equations 1-4 below describe the details of the asymmetry generating processes. The total cross section, \( \sigma_T \), in the magnetized iron depends on photon wavenumber, \( k \), and includes a helicity independent term, \( \sigma_0 \), and a helicity dependent term, \( \sigma_p \),

\[
\sigma_T(k) = \sigma_0(k) + P_e P_\gamma \sigma_p(k) .
\]  

(1)

The absorption coefficient, \( C(k) \), is then a simple exponential which depends on the cross section, the electron number density in the iron, \( n \), and the absorber length, \( L \),

\[
C(k) = e^{-\sigma_0(k) n L} e^{-P_e P_\gamma \sigma_p(k) n L} .
\]  

(2)

An asymmetry, \( A(k) \), is formed by varying the sign of the magnet polarization (or incident electron polarization) and the spin independent term cancels giving,

\[
A(k) = \tanh(-P_e P_\gamma \sigma_p(k) n L) .
\]  

(3)

For small values of the argument \( \tanh \) is linear and \( A(k) \) can be approximated,

\[
A(k) \approx -P_e P_\gamma \sigma_p(k) n L ,
\]  

(4)

depending linearly on the length. A figure of merit proportional to \( N A^2 \) can be defined, where \( N \) is the counting rate. Optimization of this quantity gives an absorber length of \( \sim 6 \) cm. However, if the counting rate is large, it is sensible to increase the length to maximize the asymmetry and limit the influence of systematic effects.
TRANSMISSION POLARIMETERS AT BATES

The first transmission polarimeter used at Bates was installed at 200 MeV in 1996. The geometry was extremely favorable. A large dipole magnet swept away the low energy shower downstream of the radiator, in this case a thin stainless steel beampipe exit window. The absorber magnet was a 7.5 cm dia. soft iron cylinder 20 cm in length with adequate return so that a 2200 turn coil at 3 A gave a field of 2 T in the bar corresponding to an electron polarization of ~8%. An 8x8x12” lead glass cerenkov detector was used to measure the photon yield 5 m downstream of the absorber. Due to the large peak intensity of the Bates Linac’s 600 Hz pulse structure it was necessary to integrate each pulse and single photons could not be resolved. The measured analyzing power of the device was 0.8 %

Following this result a smaller 15 cm long device was constructed for use at 20 MeV at the beginning of the accelerator. Space constraints here lead to a less favorable geometry so only a 2.5 cm dia. iron cylinder could be used. The radiator was a 0.5 mm BeO viewing screen. The initial use of a 2” dia. x 2” long NaI crystal for the photon detector caused extreme saturation in the first stages of the photomultiplier so a Lucite calorimeter of the same size was used instead. In this location it was necessary to place the photon detector within 10 cm of the absorber magnet so it was not possible to make use of a sweeping magnet. The measured analyzing power of this device was 1.7%.

The 20 MeV transmission polarimeter was used routinely each day during the second and third SAMPLE experiments (4). Each measurement took about ½ hour and the bulk of that time was devoted to switching the beam into and out of a small chicane in the injector. The actual data taking for a 2% absolute polarization error (5% relative) took 5 minutes at 4 μA electron current. Much of this error is still attributed to instrumentation noise and improvements in the signal amplification are planned in the next year.

The 20 MeV polarimeter has also proven useful for rapid calibration of a 60 keV Wien Filter, used to rotate the electron spin, and for verification of the polarization of newly installed photocathodes on the injector.

A transmission polarimeter for use at higher energies, 400 – 1000 MeV, is being installed downstream of the internal gas target in the South Hall Ring. This device will have lower analyzing power ~0.2% due to the higher electron beam energy, but will be useful for optimizing the orientation of the injected polarization into the South Hall Ring. The transmission polarimeter could also provide a redundant online monitor of the stored electron polarization (a laser back-scattering polarimeter has recently been commissioned) using the internal gas target as a radiator.
CALIBRATION OF A TRANSMISSION POLARIMETER THROUGH LASER COMPTON SCATTERING

In conjunction with the laser backscattering polarimeter, a 20 cm long transmission polarimeter has been used to analyze the polarization of the backscattered photons. This is useful for two reasons. First, since the backscattered photon polarization is kinematically determined and follows a cosine like distribution as a function of backscattered photon energy, the measured zero crossing in the asymmetry provides an energy calibration point for the laser backscattering calorimeter. This energy calibration of the calorimeter is one of the largest systematic errors in the Compton polarimeter. The zero crossing in the asymmetry will only be accurate when the energy response of the calorimeter is correctly modeled. Second, since the backscattered photon polarization is determined by the incident laser polarization, it is very high since $P_{\text{Laser}}>99\%$. At the photon endpoint (and at the lowest backscatter photon energy) the backscattered photons have the full polarization of the laser. This provides an accurate calibration of the analyzing power of the transmission polarimeter on polarized photons without any particular knowledge of the processes in the iron.

Figure 2 shows the analyzing power of all transmission polarimeters at Bates scaled to a 15 cm long absorber magnet. The solid curve with the larger analyzing power corresponds to the analyzing power at the photon endpoint. The solid curve with the smaller analyzing power is a weighted with a bremsstrahlung spectrum of the radiated photons with appropriate polarization transfer included. All the measured points fall between these two bounding curves indicating that the scale of the analyzing power can easily be predicted.

The solid line labeled Laser Backscattering Calibration reflects measured data for a laser backscattering run at 850 MeV electron energy and 532 nm laser wavelength. This data should exactly lie on the endpoint analyzing curve, but we find disagreement of order 20%. Future measurements with the laser backscattering polarimeter will investigate this discrepancy in the coming year.

The maximum endpoint analyzing power of this device is predicted to lie at 3 MeV electron energy. The laser backscattering calibration has determined an analyzing power of 5% at 5 MeV photon energy. As indicated by the upright star in Figure 2, Jefferson Laboratory has a low energy beamline where a transmission polarimeter could be installed with an analyzing power between 5-10%. A longer absorber magnet is possible considering both available space (a few m) and available average current ($\sim$10 uA). This device could be absolutely calibrated against laser backscattered photons at the Bates South Hall Ring.
CONCLUSIONS

Over the last several years Transmission Polarimeters have proven very useful at the Bates facility. They provide an affordable, rapid relative measure of the electron polarization. The polarimeters have an optimal operating energy of ~5 MeV, but are being used at higher energies elsewhere in the lab. In the coming year we hope to calibrate the device absolutely, simplify the design and commission an on-line polarimeter for the internal target physics program in the South Hall Ring.

REFERENCES