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A COMPTON TRANSMISSION POLARIMETER FOR DC AND SRF ELECTRON PHOTO-INJECTORS*

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Abstract

Compton transmission polarimetry is an efficient method for measuring the spin polarization of electron beams in the MeV range, thus very well suited for DC and SRF photoinjectors. In this work we discuss the design and construction of a Compton transmission polarimeter and its calibration using a polarized electron beam in the Upgraded Injector Test Facility (UITF) at Jefferson Lab.

INTRODUCTION

When a longitudinally polarized electron beam strikes matter, elliptically polarized bremsstrahlung photons are generated. The circular polarization of these photons can be analyzed by scattering them from polarized electrons in a magnetized target, according to

$$\frac{d^2\sigma}{d\Omega} = \frac{d^2\sigma^0}{d\Omega}[1 + P_t P_\gamma^c A_C(\theta)], \quad (1)$$

where $d^2\sigma^0/d\Omega$ is the unpolarized Compton cross section, A_C is analyzing power of the Compton process, and P_t and P_γ^c are the photon and target polarization, respectively. The photon count after the polarized target depends on the relative sign of the photon circular polarization and target electron spin polarization.

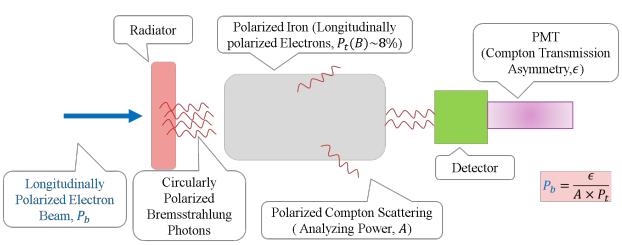

Figure 1: Concept of a Compton transmission polarimeter.

Experimentally this asymmetry can be observed with a scintillating crystal detector (see Fig. 1) sensitive to the bremsstrahlung energy spectrum. By measuring the detector energy deposit between reversed states of the electron or target helicity, one computes an experimental asymmetry A_E which is directly proportional to the electron beam spin polarization

$$A_E = P_e^l P_t \langle \mu_1 \mathcal{T} \rangle L = P_e^l \langle \mathcal{A} \rangle, \quad (2)$$

where L is the length of the target, μ_1 is the polarized Compton absorption coefficient, and $\langle \mathcal{A} \rangle$ is an effective analyzing power of the polarimeter. Consequently, the effective analyzing power of the polarimeter can be experimentally calibrated with a well known electron beam polarization.

POLARIMETER

The radiator is made of high-purity copper with a 0.60 cm-thick front face. This thickness was chosen to completely stop an electron beam of 9.5 MeV kinetic energy. The radiator is water-cooled and serves as a beam dump. The radiator is connected to the beam pipe through a ceramic break to allow for beam current measurement. The collimator is 14.6 cm long with inner diameter of 0.80 cm, outer diameter of 10.2 cm, and made of copper. It is used to stop the large-angle scattered photons and allows the forward photons to the center of the magnets, eliminating the photons that may reach the detector without passing through the magnet core.

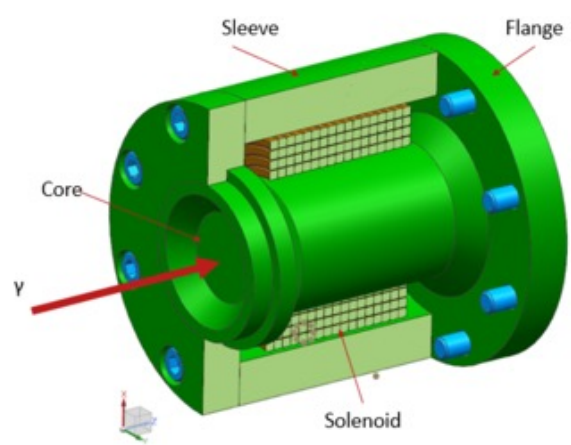

Figure 2: ANSYS Maxwell [1] model of the polarized target.

The polarized target (see Fig. 2) consists of an iron core, a magnetic return path comprised of two iron flanges and the sleeve, and the solenoid coil. All of the iron components, including the core, are machined out of 1005 Steel.

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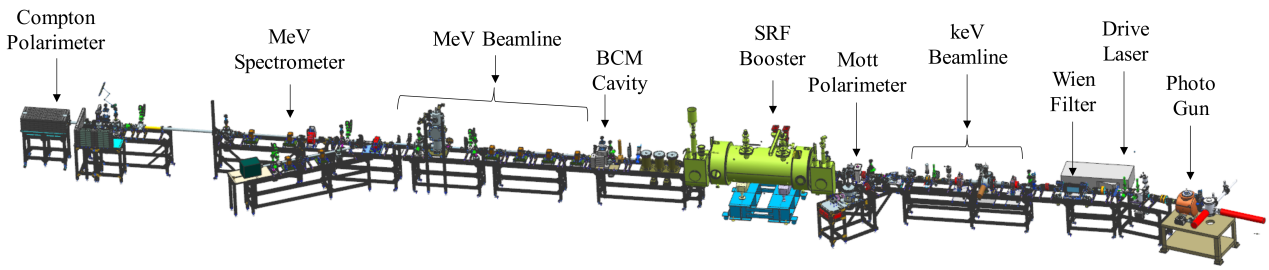

Figure 3: A CAD model of the UITF electron accelerator (beam travels right to left).

In particular, the iron core is the volume (75 mm long and 25.4 mm diameter) where the polarized photons are scattered. The solenoid winding is constructed from four layers of a 2.2 mm × 2.2 mm square copper conductor wet wound around the core and then vacuum impregnated. The magnetic specification is to achieve a field of (~ 1.7 T) within the core. Model calculations indicate this is achieved with a modest operating current of 5 A.

The photon detector consists of a cylindrical BGO ($Bi_4Ge_3O_{12}$) crystal [2], 15 cm long and 5 cm in diameter. The crystal is successively wrapped into a 165 µm-thick VM2000 [3] reflective paper and a 50 µm-thick Tedlar [4] black paper; the former wrapping improves and makes more uniform the light collection while the latter protects the signal from the interference of the outside light. The optical signals is read by a photomultiplier tube R2154-02 [5] equipped with a passive custom base which ensures high linearity properties over a large high-voltage domain (500 V to 1700 V). The full assembly is mounted inside a brass box which provides RF and light shielding. The front face of the box supports up to 3×1.4 cm thick removable copper absorbers allowing for a maximum 1/8 reduction of the photon flux. Its purpose is to minimize the degradation of the optical properties of the crystal in a very high rates environment.

MEASUREMENTS

The UITF polarized electron injector (see Fig. 3) contains several subsystems: a GaAs photoemission gun, a continuous-wave (CW) polarized drive laser to create the electron bunches, a Wien filter spin rotator to orient the spin direction, several RF cavities to temporally shape the individual electron bunches and accelerate them to several MeV, conventional steering and focusing magnets, and beam diagnostic elements to establish the electron beam on the photon radiator.

During a run the PMT signal of the energy deposited in the BGO detector is recorded and matched with the sign of the fast electron beam helicity (drive laser Pockels cell). Between runs the PMT signal was subject to slow electron beam reversal (drive laser half-wave plate HWP) and slow reversal of the target polarization (magnet current). During off-line analysis the quartet asymmetries are computed and reported in a histogram (see e.g. Fig. 4).

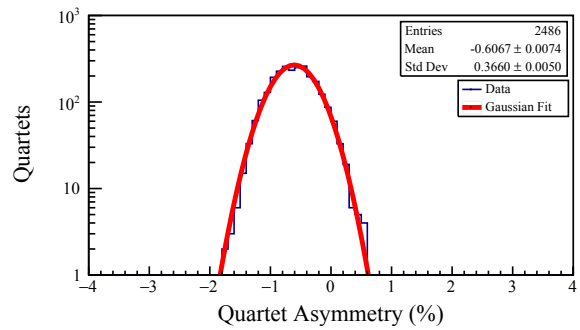

Figure 4: Asymmetry histogram for 5 MeV calibration.

The Compton asymmetry was measured (see Fig. 5) as a function of polarized target current for both 5 MeV and 7 MeV, and for both states of the HWP to check for systematic reversal. For both energies, the calibration of the effective analyzing power was performed when the polarized target current was set to 5 A as the target was demonstrably magnetically saturated (Fig. 6).

The electron beam polarization was previously measured using a Mott scattering polarimeter to be $(37.4 \pm 0.8)\%$; consequently, the Compton transmission analyzing powers for our arrangement at 5 MeV and 7 MeV are

$$\langle \mathcal{A}^{5\,\mathrm{MeV}} \rangle = \frac{(0.452 \pm 0.004)\%}{(37.4 \pm 0.8)\%} = 0.0120 \pm 0.0003, \quad (3)$$

$$\langle \mathcal{A}^{7\,\mathrm{MeV}} \rangle = \frac{(0.481 \pm 0.007)\%}{(37.4 \pm 0.8)\%} = 0.0129 \pm 0.0004. \quad (4)$$

GEANT4 SIMULATIONS

The main components of the polarimeter (radiator, collimator, magnet and detector) were modeled in GEANT4 [6–8], and the polarized electromagnetic physics package was used to simulate the detector response. (see e.g. Fig. 7).

Two longitudinally polarized electrons beam configurations ($P_e^l = \pm 1$) are asymmetric for BGO energy deposit. Computationally, this asymmetry is energy-dependent; however, experimental asymmetries are not energy dependent due to large event counts. Simulation needs an integrated asymmetry to be compared to experiment. This is described via

$$A_S = \frac{\sum_i A(E_i)(E_i^+ + E_i^-)}{\sum_i (E_i^+ + E_i^-)}. \quad (5)$$

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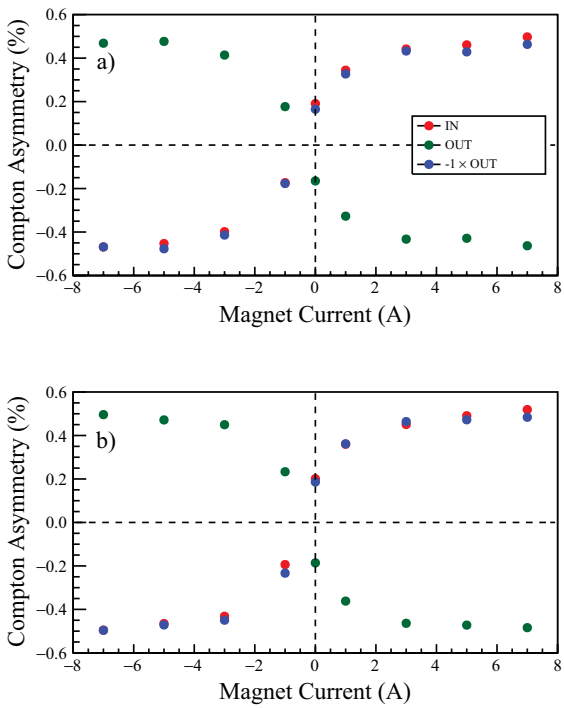

Figure 5: a) Compton asymmetry as a function of magnet current at 5 MeV and b) repeated for 7 MeV

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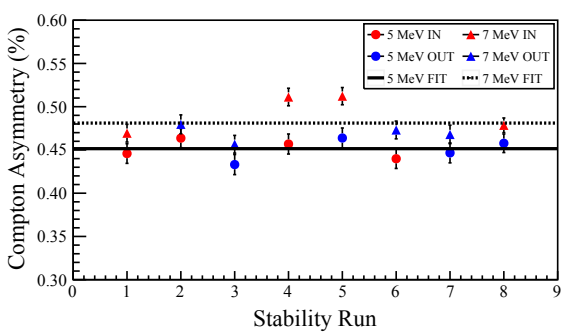

Figure 6: Compton asymmetry measured repeatedly for ± 5 A with beam current 6 nA.

where E_i corresponds to the energy deposit for each photon energy bin, $\pm$ corresponds to longitudinal beam polarization, and $A(E_i)$ is the energy dependent asymmetry. Simulated asymmetries compared to experimental results are shown in Fig. 8.

SUMMARY

A Compton transmission polarimeter was designed, built and calibrated using a polarized electron beam with energies 5 MeV and 7 MeV at the Upgraded Injector Test Facility at Jefferson Lab. The effective analyzing power ranged from 0.12 to 0.13% and was tested in a configuration suitable for

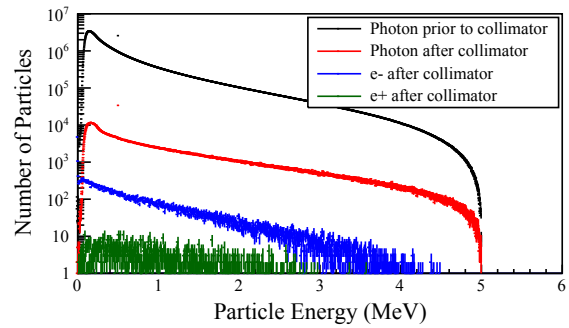

Figure 7: The photon, electron and positron spectra upstream/downstream of the collimator created from a 5 MeV electron beam irradiating the radiator.

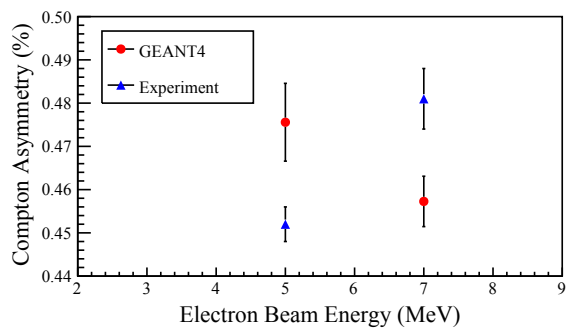

Figure 8: Scaled GEANT4 simulation results compared to experiment for 5 MeV and 7 MeV.

low intensity beams (less than 8 nA). GEANT4 simulations predict the target polarization to be $(7.89 \pm 0.16)\%$.

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