PROCEEDINGS OF SCIENCE

Design of a precise 5 MeV Mott polarimeter operating at high average current

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A high-intensity polarized beam has to be delivered to the P2 experiment at Mainz Energy Recovering Superconducting Accelerator Facility (MESA). The $\Delta P/P$ error of the beam polarization should be $\leq 1\,\%$. To track the polarization, a Mott polarimeter will be installed after the pre-acceleration of the polarized beam to 5 MeV energy. The goal of this work is to deploy a 5 MeV Mott polarimeter for high polarized beam current $\approx 150\,\mu\mathrm{A}$ with $\leq 1\,\%$ precision. For that, feasible geometries and the detection system are under investigation based on 5 MeV Mott polarimeter from Jefferson Lab and 3.5 MeV Mott polarimeter from Mainz Microtron (MAMI).

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1. MESA

The P2 experiment at MESA aims to determine the weak mixing angle $\sin^2\theta_\mathrm{w}$ with a precision of 0.15 % by the measurement of parity-violating asymmetry. It requires a polarized electron beam of polarization > 85 % and a beam intensity of 150 µA at an energy of 155 MeV with an availability of 11 000 h at ≤ 1 % polarization accuracy. To track the beam polarization, MESA can be equipped with three different polarimeters at different beam energies: a double scattering Mott polarimeter (DSMP) 100 keV after the source, a 5 MeV Mott polarimeter after the injector, and a Moller polarimeter at 155 MeV in front of P2 as shown in figure 1 [1].

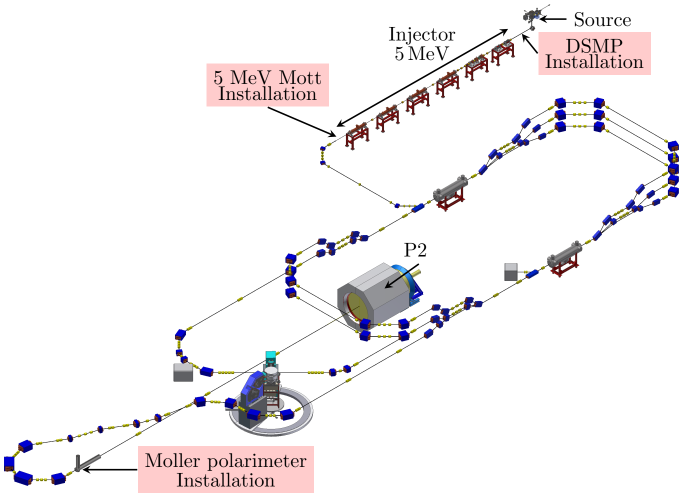


Figure 1: Planned MESA lattice ([2], modified).

2. Mott Scattering of MeV electrons

Due to the spin-orbit interaction, the resulting scattering potential for spin-up electrons ($e\uparrow$) is different from that for spin-down electrons ($e\downarrow$). This causes the observation of up-down count rate asymmetry of scattered electrons from the target if the spin orientation is perpendicular to momentum in a horizontal scattering plane [3, 4].

Mott polarimeters are commonly used for energies in the range of 100 to 120 keV; nevertheless, there are only two MeV Mott polarimeters: JLab 5 MeV Mott [5] and MAMI 3.5 MeV Mott [6] so far. The scattering cross-section is smaller than at lower energies which is enhanced by the maximum of analyzing power (Sherman function) moving towards larger backscattering angles, as shown in figure 2. However, this can be tolerated for our operation with large primary currents. An advantage of MeV energies is that plural scattering has much less influence on the effective analyzing power for the same target thickness; hence, free-standing targets with thicknesses > 100 nm can be used without compromising measurement accuracy.

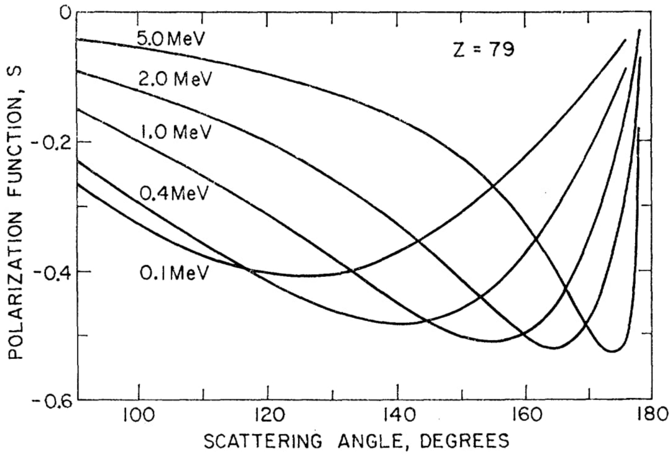


Figure 2: Dependence of the Sherman function S on the gold target at various energies. The plot is valid for scattering in the Coulomb field of a point nucleus with no screening [7].

3. Existing MeV Mott polarimeters

3.1 JLab Mott

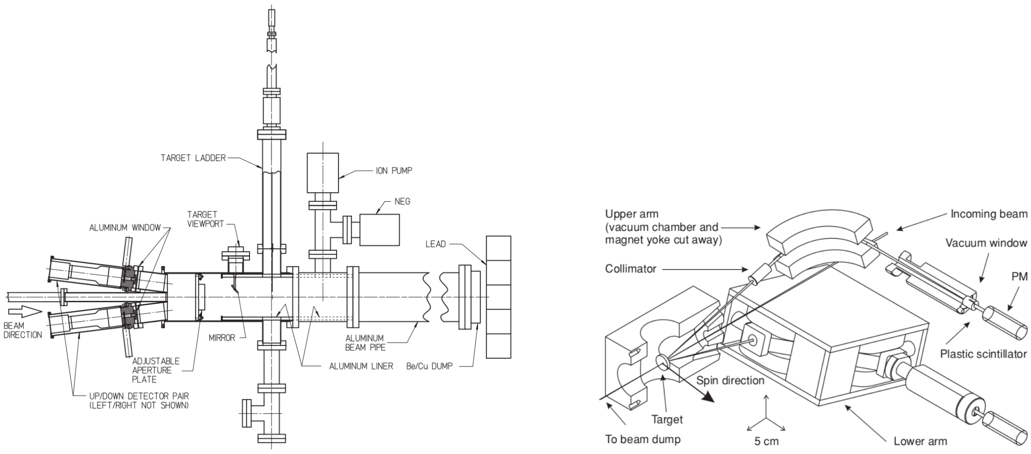
JLab 5 MeV Mott polarimeter apparatus consists of four identical detectors at the target line of sight as shown in figure 3a. The backward scattered electrons at 172.6° are collimated in the vacuum chamber, while the vacuum chamber has an aluminium liner to reduce the backscattered electrons and photons. The beam dump is carefully designed to reduce the background. The operation beam current range reported is 0.245 to 4.3 µA. The contributing factors to uncertainties have been studied carefully and suppressed over several years. The polarimeter has a precision of 0.6 % , where most of the contribution to the uncertainty comes from the theoretical Sherman function [5].

3.2 MAMI Mott

MAMI 3.5 MeV Mott polarimeter apparatus, on the other hand, consists of two detectors out of the line of sight as shown in figure 3b. The backscattered electrons at 164° are collimated outside the vacuum chamber, and their trajectories are bent using spectrometers. This allows energy selection while reducing the background; nonetheless, the background must be carefully studied and estimated. The whole chamber is made of an aluminium block leading to a compact geometry. The operation beam current reported is 1 nA to 30 µA.

4. Planned Mott installation at MESA

To meet the accuracy required by the P2 experiment, a 5 MeV Mott is planned to be deployed. The JLab Mott is already operating in the precision P2 requires, but the new Mott needs to be operated with this precision at beam intensity up to 150 µA. In addition, the geometry has to be custom fit according to the available resources. Therefore, in the first planning phase, the existing designs are carefully studied to compare the pros and cons and selectively implement them in the new design.



(a) JLab 5 MeV Mott polarimeter geometry [5]. **(b)** MAMI 5 MeV Mott polarimeter geometry [6].

Figure 3: Existing MeV Mott polarimeters.

4.1 Computer-Simulation: Geometrical Background study

One of the crucial factors that have to be taken into account while designing a geometry is the geometrical background. Background simulations are done for both simplified geometries using Beam Delivery Simulation (BDSIM). BDSIM is a C++ program that utilises the Geant4 toolkit [10]. In addition, a non-analog approach is used to perform the simulations to increase the backscattered electrons statistics. This approach is used by generating a uniform beam distribution from the center of the 100 nm target position with the corresponding normalised weight. Weight is generated using the theoretical Mott scattering cross-section [11] of the unpolarized beam for a 4π sr with uniform angular steps using

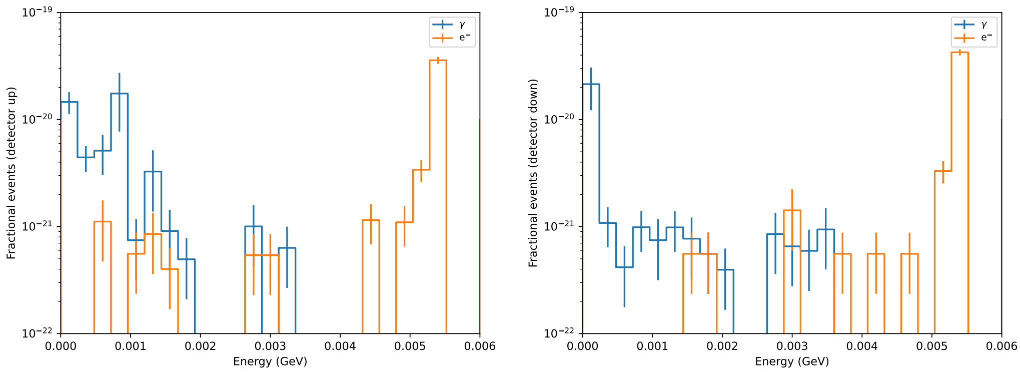
$$
\begin{aligned}
I(\theta) &= \left(\frac{Ze^2}{2mc^2}\right)^2 \frac{(1-\beta^2)(1-\beta^2 sin^2(\frac{\theta}{2}))}{\beta^4 sin^4(\frac{\theta}{2})} && \theta\epsilon[0,\pi] \\
x &= sin(\theta)cos(\phi) && \phi\epsilon[0,2\pi] \\
y &= sin(\theta)sin(\phi) \\
z &= cos(\theta)
\end{aligned}
$$

where, Z = nuclear charge, e = electron charge, m = electron rest mass , $\beta = v/c$, r =1, and $x^2 + y^2 + z^2 = r^2$.

The physics list used for this simulation is electromagnetic single scattering (EM_SS). The volume outside the geometry is considered to be a vacuum. The physics interactions involved are Coulomb scattering, Bremsstrahlung and Electron Ionisation.

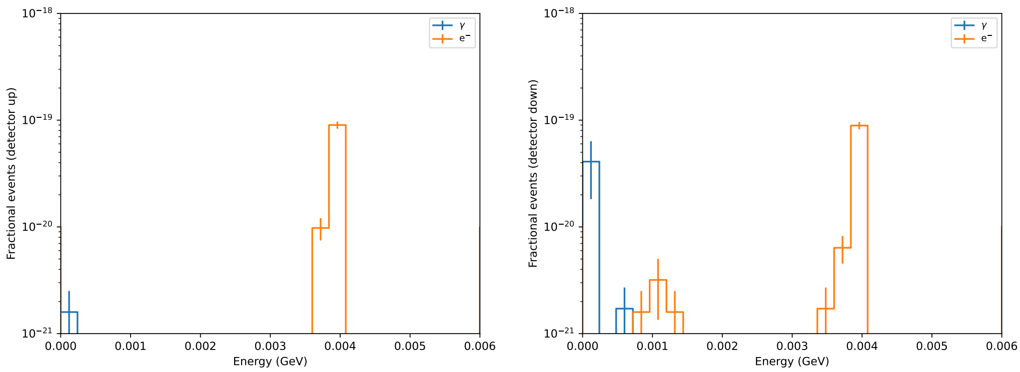
4.1.1 Energy spectra

After collimation, the electrons and photons passing a sampler, a thin vacuum volume with a 1 nm thickness [10], are detected in front of the detector. This sampler volume is referred to as a detector in this case. In the energy spectra of the JLab geometry, as shown in figure 4, it can be observed that the electrons which inelastically scatter multiple times get detected. However, the electrons with much lower energy are multiply scattered from the angular region not blocked by the adjustable aperture referred to as a baffle. Since, in reality, the baffle sits in the baffle holder as shown in figure 3a, the baffle holder works as the shield to these electrons. This baffle holder will be added as well in further simulations. The integrated number of electrons detected on two detectors is similar. However, the number of photons detected is about ten times different, which is significant. The difference in the number of photons likely comes from the electron distribution not having exact symmetry in each quadrant of solid angle, therefore, hitting the geometry at not exactly symmetric positions. This is due to the uniform angular stepping between the interval. This could be tackled using different random steps instead of uniform angular stepping for multiple simulations. In addition, for many primaries, the given approach should converge. However, extensive statistics mean considerable computation time and resources, which must also be considered.



(a) Energy spectra of detector up. **(b)** Energy spectra of detector down.

Figure 4: Energy spectra of up and down detectors from the JLab geometry. Each energy bin is120 keV. The number of primaries used is 4942368. Primaries are the number of initial electrons.



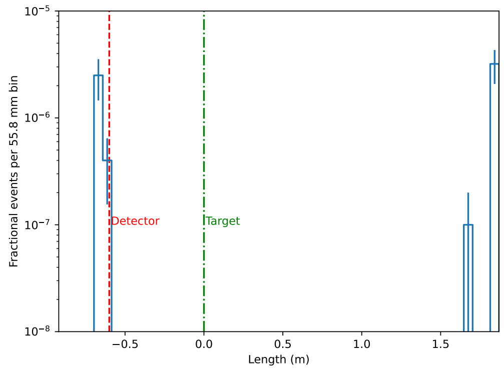
(a) Energy spectra of detector up. **(b)** Energy spectra of detector down.

Figure 5: Energy spectra of up and down detectors from the MAMI geometry. Each energy bin is120 keV as well. The number of primaries used is 4942368.

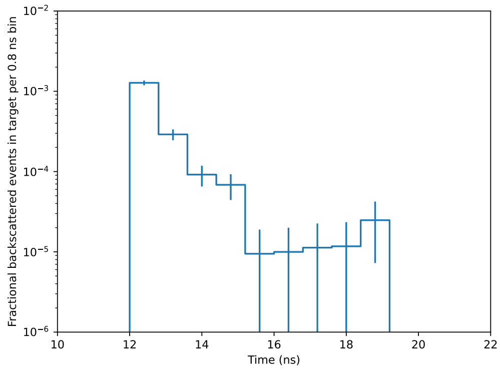
Due to energy selection, only a few inelastic events are recorded in the MAMI energy spectra, as shown in figure 5. The asymmetry between the integrated number of photons exists, and the photon statistics are insufficient for the same number of primaries as in the JLab simulation. The electrons at lower energy are detected as well. This is because the electrons at extreme backscattered angles manage to multiply scatter through the entrance of the Mott and escape into the detector. This is different in the experiment due to the beam pipe at the entrance in figure 3a. The other factor contributing to the inflation of photon numbers in the detector down could be it.

4.2 Dump events

Tracking simulation was done to understand at what distances the photons are being recorded in the accepted solid angle. For this, the conventional approach of scattering, where the pencil beam hit the target, was used. Figure 6a shows that most of the photons are recorded from the dump in the extremum of the length from the target along the beamline at about 1.8 m. On the other hand, the detector also records the photons created in the scintillators, which is not interesting in this case.



(a) The distance at which the photons are created along the geometrical length of JLab Mott. The target is taken as the centre.



(b) Backscattered photons and electrons from the dump to the target. Target is taken as the initial point of beam interaction time.

Figure 6: Backscattered dump events. For figure 6b, one sampler is placed in front of the dump, and the other is after the target to record the events. The events in the plot are extracted by the difference between two sets of data from both samplers.

Figure 6b shows that the maximum backscattered events are recorded in between 12 to 15 ns. The new bunch should not be repeated in that time to avoid scattering of these events into the acceptable solid angle along with the good events.

5. Summary and outlook

Mott scattering of 5 MeV kinetic energy electrons is used to analyze the polarization of the electron beam. The P2 experiment requires polarization measurement with an uncertainty of <1 %. Therefore, a new MeV Mott will be deployed. To implement a geometry design that minimizes the background and enables tackling it in a controlled manner, the geometry-induced background is under study by simulations. The non-analog approach of simulation should be further improvised for realistic spectra.

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The simulations are done at the MOGON II cluster using himster 2 experimental partition.

References

[1] D. Becker *et al.*, *The P2 experiment*, *arXiv:1802.04759 [nucl-ex]*.

[2] M. Dehn *et al.*, *Beam Diagnostics and Instrumentation for MESA.*, in proceedings of *13th Int. Particle Acc. Conf. (IPAC2022)*, Bangkok, Thiland.

[3] J. Sromicki *et al.*, *Polarization in Mott scattering of multi-MeV electrons from heavy nuclei.*, *Phys. Rev. Lett.* **82** (1999) 57.

[4] J. Kessler, "Polarized electrons series on Atoms and Plasmas.", 2nd ed. *Springer Berlin, Heidelberg* (1985).

[5] J. M. Grames *et al.*, *High precision 5 MeV Mott polarimeter.*, *Phys. Rev. C* ***102*** *(2020) 015501*.

[6] V. Tioukine, K. Aulenbacher, and E. Riehn, *A Mott polarimeter operating at MeV electron beam energies.*, *Rev. Sci. Instrum.* ***82*** *(2011) 033303*.

[7] J. Kessler, *Electron spin polarization by low-energy scattering from unpolarized targets.*, *Rev. Mod. Phys.* ***41*** *(1969) 3*.

[8] M. Steigerwald, *MeV Mott polarimetry at Jefferson lab.*, *AIP Conf. Proc.* ***570*** *(2001) 935*.

[9] M. McHugh, *https://github.com/JLabMottGroup/MottG4* (Accessed 2022).

[10] L.J. Nevay *et al.*, *BDSIM: An accelerator tracking code with particle-matter interactions*, *arXiv:1808.10745v2 [physics.comp-ph]* .

[11] K. Aulenbacher *et al.*, *Precision electron beam polarimetry for next generation nuclear physics experiments*, International Journal of Modern Physics E **27** (2018) 1830004.