Status of the 5 MeV Mott polarimeter at MESA

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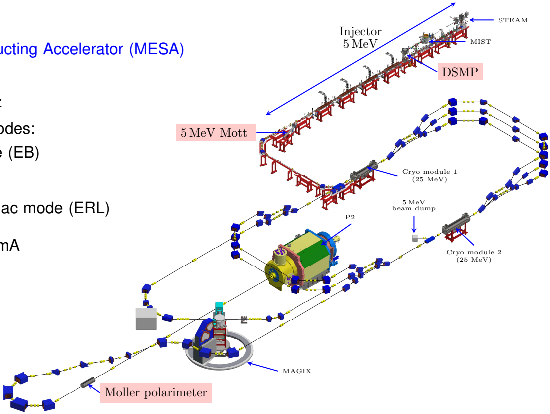
Outline

Introduction and motivation

Mainz Energy-recovering Superconducting Accelerator (MESA)

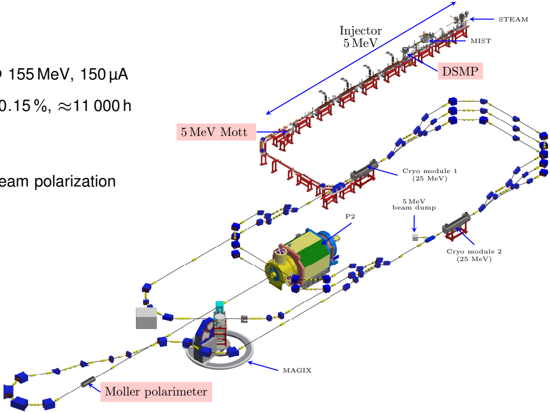
- CW electron accelerator
- Operation frequency 1.3 GHz
- Planned to operate in two modes:
  - External Beam mode (EB)
    Polarized beam
    155 MeV, 150 µA
  - Energy Recovery Linac mode (ERL)
    Unpolarized beam
    105 MeV, Stage I: 1 mA
    Stage II: 10 mA



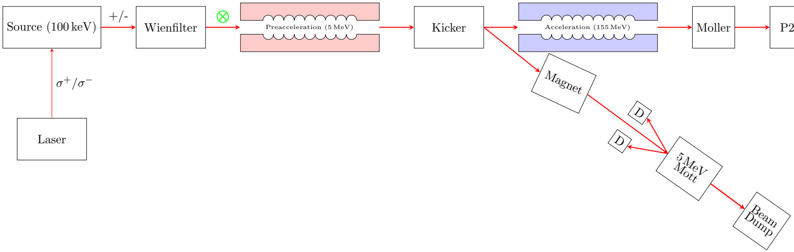
Introduction and motivation

P2 experiment:

- Polarised beam P $>$ 85 % @ 155 MeV, 150 µA
- Weinberg angle ($\sin^2\theta_W$) $\rightarrow$ 0.15 %, $\approx$11 000 h
- Requires $\frac{\Delta P}{P} \leq 1\,\%$
- Polarimeters chain to track beam polarization



Overview of planned spin analyzing process



- Right/left circulary polarized light produces positive/negative helicity electron beam.
- Longitudinal spin is rotated into transverse plane and pre-accelerated to 5 MeV.
- Kicker offers possibility to operate on 100 %, 99 % and 1 % duty factor.
- This further opens possibility of operating Mott and Moller simultaneously.

Mott scattering

Mott cross section

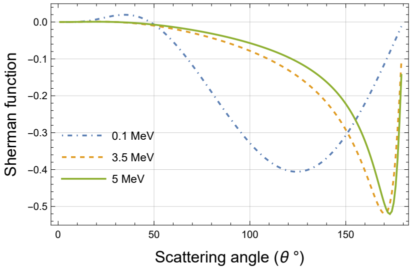
$$\sigma(\theta) = I(\theta)[1 + S(\theta)\vec{P} \cdot \hat{n}]$$

$S(\theta)$ = Sherman function/analysing power
$I(\theta)$ = unpolarised cross-section

- Asymmetric elastic scattering of spin polarised electrons in coulomb field

Theoretical corrections to Sherman function:

- Screening by atomic electrons
- Finite size correction
- Radiative corrections



Sherman function calculation for point nucleus of Au.

Sherman function values will be taken from the existing precise theoretical calculations published.

Mott polarimetry

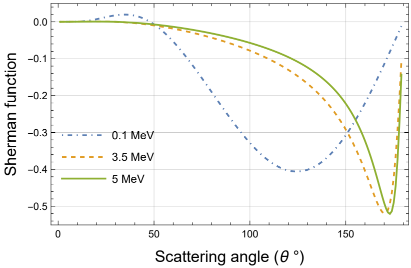
- keV Mott polarimeters are commonly used for source optimisation.
- Two existing Mott polarimeters operating at 3.5 MeV MAMI and 5 MeV JLAB
- Existing MeV mott polarimeters can be used for precision polarization measurements.

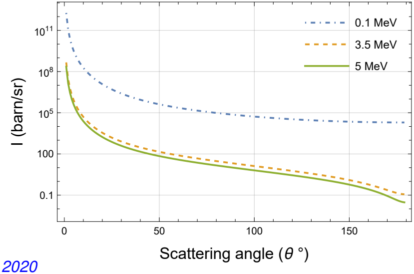
MeV energy mott benefits

- Larger analysing power
- Smaller cross section
- Free standing target

Contribution to the total uncertainty	Value
Theoretical Sherman function	0.50%
Target thickness extrapolation	0.25%
Systematic uncertainties	0.24%
Energy cut (0.10%)	
Laser polarization (0.10%)	
Scattering angle and beam energy (0.20%)	
Total	0.61%

Uncertainity budget of JLab 5 MeV polarimeter. *J. Grames et al., 2020*





Computer simulation: Method

- Simulations are done using BDSIM[1].
- Uniform beam generation from 100 nm target with the corresponding normalised weight.
- Weight is generated using the theoretical Mott scattering cross-section of the unpolarized beam for a 4πsr

$$I(\theta) = (\frac{Ze^2}{2mc^2}\frac{(1-\beta^2)(1-\beta^2 sin^2(\frac{\theta}{2}))}{\beta^4 sin^4(\frac{\theta}{2})}$$

J. Kessler (1985)

$$\theta \rightarrow [0, \pi]$$

$$\phi \rightarrow [0, 2\pi]$$

$$x^2 + y^2 + z^2 = r^2 = 1$$

$$x = sin(\theta)cos(\phi)$$

$$y = sin(\theta)sin(\phi)$$

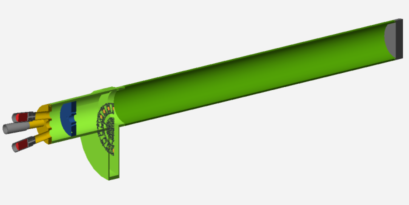
$$z = cos(\theta)$$

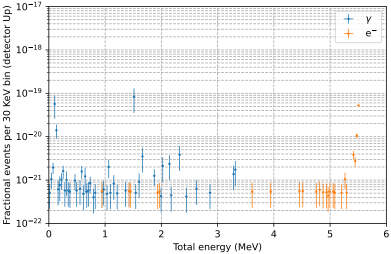
Z = nuclear charge, e = electron charge, m = electron rest mass, $\beta = \frac{v}{c}$

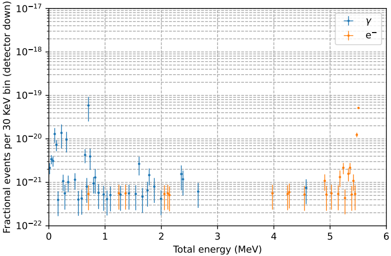
- Physics list: electromagnetic single scattering EM_SS
- Physics interactions: Coulomb scattering, Bremsstrahlung, and Electron Ionisation
- Particles passing through a 1 nm thick volume is detected.

[1] L.J. Nevay et al., BDSIM: An Accelerator Tracking Code with Particle-Matter Interactions, Computer Physics Communications 252 107200 (2020).

Computer simulation of the Mott geometry

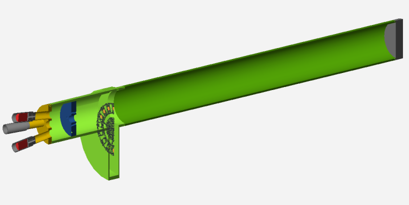


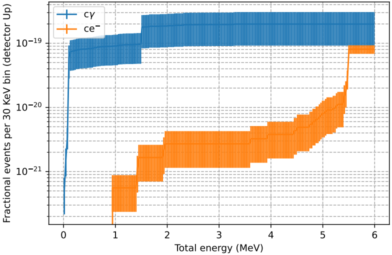




- Both MAMI and JLab geometry were studied.
- Geometry with targets in the line of sight is chosen.
- Background comes from low energy photons and inelastic electrons events.
- Background can be controlled implementing low Z material, shielding and collimation.

Computer simulation of the Mott geometry





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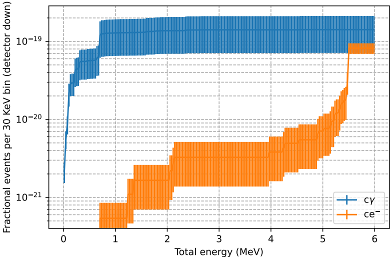
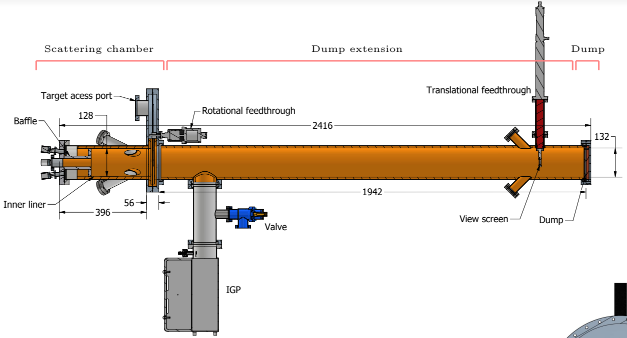
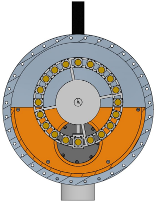


Design of the 5 MeV polarimeter set-up

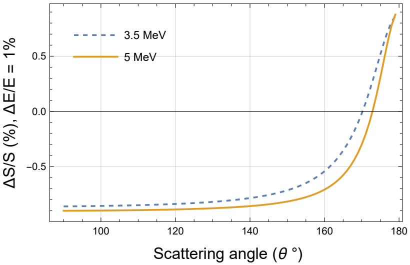


- Beryllium disc to minimize the electron backscattering from the dump.
- Aluminium liner and aluminium dump extension pipe to reduce the backscattering.
- Baffle for the collimation of solid angle.
- Can hold 20 targets .
- View screens for beam alignment.
- View ports for targets and view screen alignment.

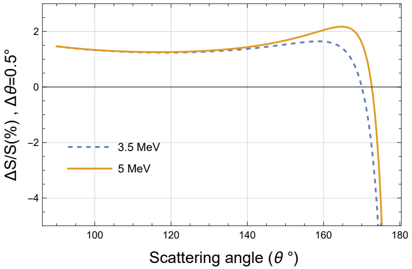


Section view of target system.

Set-up accuracy



Sensitivity of Sherman function to energy.



Sensitivity of Sherman function to angle.

- For E = 5 MeV and $\Delta E/E = 1\,\%$, sherman function changes by 0.02 % at maximum.
- Energy spread can be measured using Dipole magnet.

- At 172.5° Sherman function changes by 0.25 %
- At 173.5° Sherman function changes by 1 %

Statistical accuracy

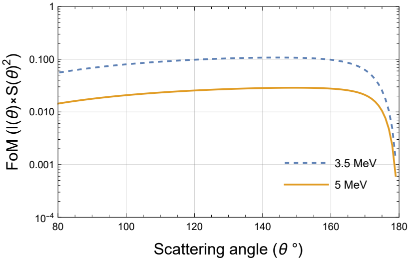
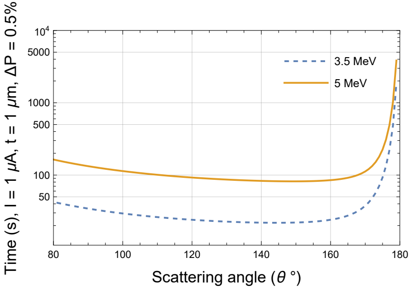


Figure of Merit (FoM) for corresponding angles.

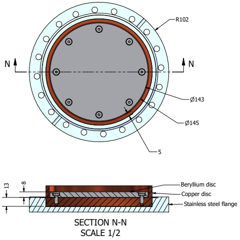


Measurement time required for corresponding angles.

- Statistical efficiency of a polarimeter is defined as FoM.
- FoM is larger for lower energy but can be adapted for beam currents that will be used for 5 MeV Mott.

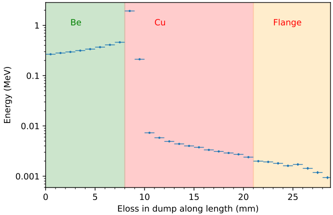
- Since FoM is larger for lower energy, therefore time required for the measurement is larger for higher energy.
- This can be adapted for the beam currents that will be used as well.

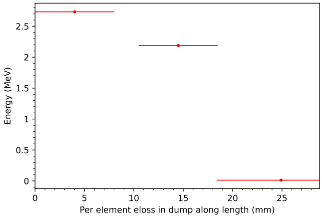
Design of beam dump



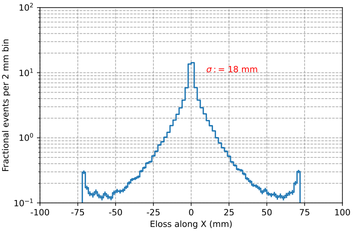
Design of the beam dump. Dimensions are in mm.

- Bdsim simulation with uniform beam of 5 MeV KE.
- 8 mm Be and 13 mm Cu for optimal background reduction.
- Stainless steel vacuum blind flange for vacuum sealing.



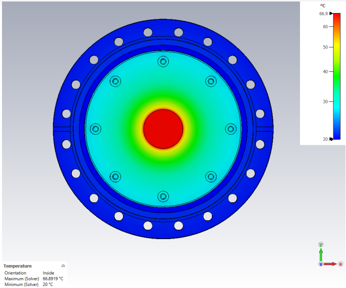


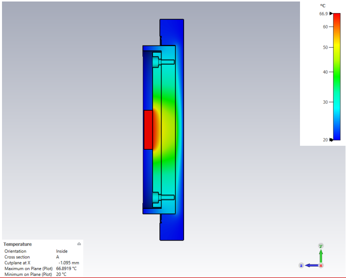
CST thermal simulation of Dump



Bdsim simulation for Eloss along X.

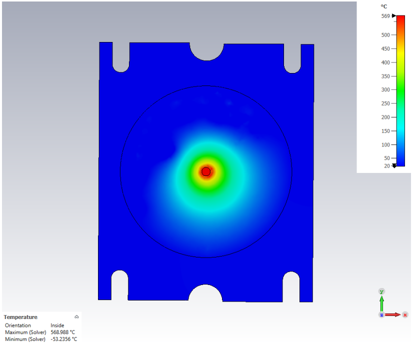
- Simulation of beam through a 100 nm target into the dump
- CST thermal simulation
- 36 mm diameter, 750 W uniform source
- Background vacuum



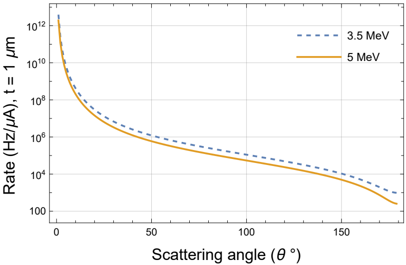


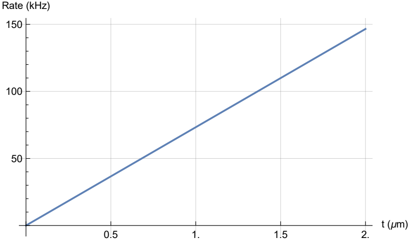
CST thermal simulation of Target

- 2 µm thick gold target, 1 mm thick aluminium holder
- 1 mm diameter, 1 W uniform source
- Background vacuum
- Accuracy needs to be improved.



Detector set-up

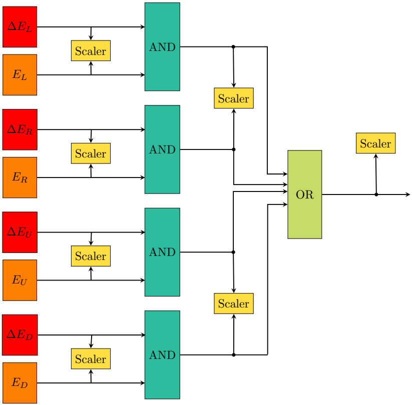




Total scattering rate for I = 150 μA, E = 5 MeV, ΔΩ = 0.23 mSr

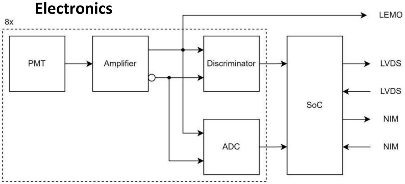
- Total scattering rate expected for up-down/left-right detector with target 2 μm is ≈150 kHz at 150 μA (without background).
- However, for 3.5 MeV it is slightly higher due to energy dependence.

Detector set-up



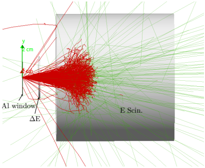
Detector logic

- Detector logic same as JLab.
- Coincidence technique to remove the photons background.
- Energy cuts for removal of inelastic events.
- Expected rate $\gtrsim$300 kHz (with background)
- SoC for readout

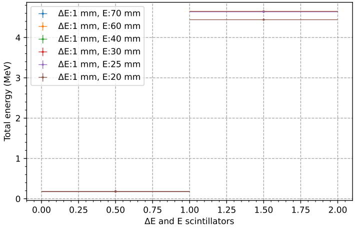


Courtesy of I. Beltschikow. Meeting 20.06.2023

Scintillators size?

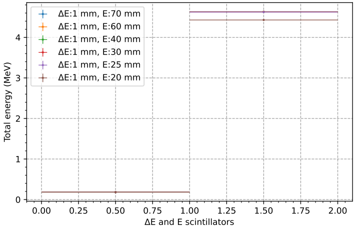


5 MeV beam through Al = 200 µm,
ΔE = 1 mm and E = 76 mmx70 mm.



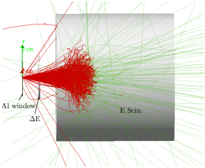
Energy deposited in 76 mm diameter E scintillators.

- Bdsim simulation with 5 MeV uniform beam.
- 200 µm Al window for operational safety.
- Simulation shows no significant energy deposition change for length between 30-70 mm and diameter between 76-51 mm.
- However, in reality due to the background this situation might not be same.



Energy deposited in 51 mm diameter E scintillators.

Scintillators size?



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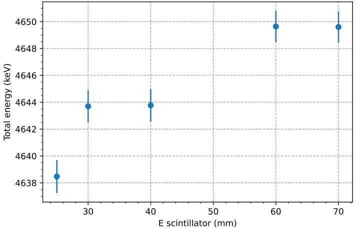
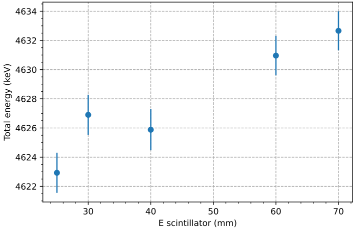


Energy deposited in 76 mm diameter E scintillator vs length.



Energy deposited in 51 mm diameter E scintillator vs length.

Outlook and summary

Outlook

- Fabricate parts
- Conducting mechanical assessment

Summary

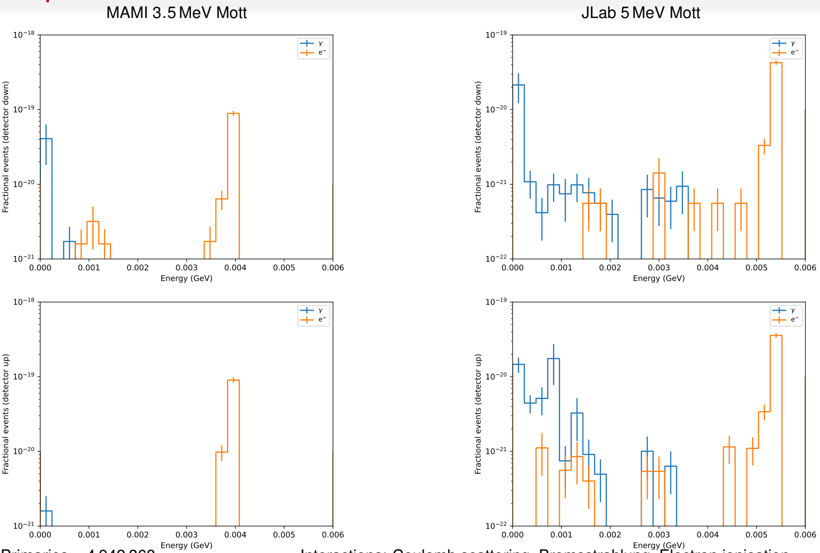
- Mott scattering experiment to analyze polarization.
- Design of the 5 MeV Mott in final stage.
- Experiment requires $\frac{\Delta P}{P} \leq 1\,\%$
- Next step is to implement the design.

Thank you!

Acknowledgements

I am thankful to Prof. Kurt Aulenbacher, Mr. Thorsten Feldmann, our expert constructor, and Dr. Valery Tioukine for the consistent support during the project.
I want to thank B. Ledroit and BDSIM developers, especially L.J. Nevay and S.T. Boogert for the bdsim simulation comments and help. The bdsim simulations are done at the MOGON II cluster using himster 2 experimental partition. I would also like to thank everyone who has directly or indirectly supported me during my work.

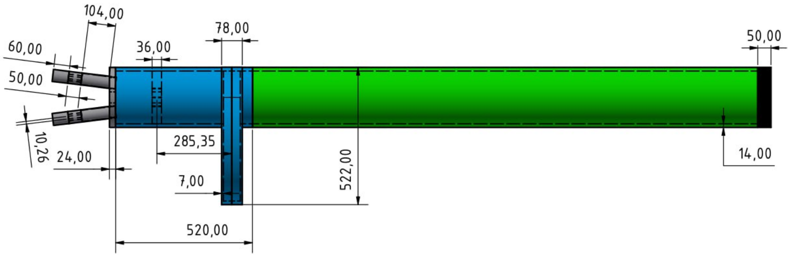
Back up



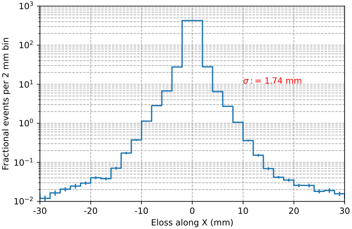
Primaries = 4 942 368

Interactions: Coulomb scattering, Bremsstrahlung, Electron ionisation

Simulated model dimension



CST thermal simulation of 1 kW Dump with focused beam



Bdsim simulation for Eloss along X.

- CST thermal simulation
- 3.5 mm diameter, 1 kW uniform source
- Background vacuum
- Flange temperature less than 30 $^\circ$C.