Low Energy Polarimetry at MESA

Video Workshop on Beam Polarization and Polarimetry at EIC

by Kurt Aulenbacher
MESA-Project - introduction

- MESA: Manz Energy-recovering Superconducting Accelerator
- Main interest: low energy electron scattering experiments
- Energies below 200 MeV, CW spin-polarized beam,
- → low energy polarimeters
MESA Accelerator Layout

Double sided recirculation design with normal-conducting injector and superconducting main linac

Two different modes of operation:

(1300 MHz CW beam)

- EB-operation (P2/BDX experiment): polarized beam, up to 150 μA @ 155 MeV
- ERL-operation (MAGIX experiment): (un)polarized beam, up to 1 (10) mA @ 105 MeV

Picture & lattice layout: D. Simon
New experimental halls
...for more and larger experiments
MESA Civil construction status May/2020

Main accelerator installation cannot begin before winter 21/22!
Polarization – accuracy requirements
P2@MESA: High accuracy measurement of (very small) parity violating asymmetry

\[ A^{PV} = \frac{-G_F Q^2}{4\pi \alpha_{em} \sqrt{2}} \left[ Q_W(p) - F(E_i, Q^2) \right] , \]

But: \( A^{exp} = P \times A^{PV} \)

P2@MESA:
Assumptions concerning error contributions

Statistics: Assuming 150 μA beam current on 55cm lq. Hydrogen for 10000 hours with P=0.85

Average scattering angle at $E_{beam}=155$ MeV

Relative error on $\sin^2$ of weak mixing angle

Polarization error assumed as $\Delta P/P=0.5\%$!

Concept of Polarimeter chain

- Three independent polarimeters forming the chain
- Operating at 0.1; 5; and 155 MeV
- Each having sub-percent accuracy, (aiming at <0.5%)
- One of them operating online
Online requirement!

Observed drift of beam polarization during measurement can reach 1%/day, and may depend on potocathode activation. Measurements by „conventional“ 3.5 MeV Mott-polarimeter at MAMI.
Positions in the chain

- Electron-source
- Double scattering Mott-polarimeter
- 5 MeV Mott-polarimeter
- P2-Experiment
- Hydro-Moeller-Polarimeter
Status of the chain

DSMP @ 0.1 MeV:
Measurements exist

MP @ 5 MeV:
Experience at 3.5 MeV: <1% accuracy possible (limited by theory)

Möller scattering from completely spin polarized hydrogen target: technically demanding, cryostat under construction, detection system under discussion with US-groups. Online capability: see V. Tioukine et al. Proceedings PSTP 2019
Hydro-Möller: A neutral Hydrogen Atomic trap

- Suggested by Chudakov and Luppov
- Trapping H-atoms at 0.3 K. Cooling by collisions with superfluid helium
- Leads to axial trapping by solenoid and radial trapping by wall collisions
- Technology developed at BNL in the 1990ies, but never used in intense beam

Schematic of Hydro-Möller-Target, Dilution refrigerator provides cooling power of ~70mW at 0.3K at Mixing chamber (MC). From: V. Tioukine et al: Proceedings PSTP 2019
Hydro-Möller: Promise

- Areal density about $10^{16}$ spins/cm$^2$ → sufficiently low for online operation
- but reasonable statistical efficiency...
- Hydrogen Polarization $1 - \varepsilon$ with $\varepsilon < 10^{-4}$ → suppression of error from target polarization
- No Levchuk effect
- $\to \Delta P/P < 0.5\%$?

Schematic of Hydro-Möller-Target,

Hydro-Möller: Technical Challenges and status

- Powerful dilation refrigerator needed (50mW at 0.3K)
- Components under construction at Mainz and at JINR-Dubna (group of Y. Usov)
- Trap test planned in 2022
- Hydro-Möller occupies its own „hall“
- MESA Beam available in 2023

Upper frame: Schematic of Refrigerator
Lower frame: cross section of trap with refrigerator
Double Scattering Mott Polarimeter (DSMP)

• The DSMP was perfectioned by the group of Prof. Kessler at University of Münster in the 1990ies:

• The apparatus was transferred to Mainz

• It allows (in first order approximation) to determine the effective analyzing power $S_{\text{eff}}$
  by experimental observation only (no theory, no Monte-Carlo)

• $\Delta S_{\text{eff}}/S_{\text{eff}}$ may be lower than 0.3% $\rightarrow$ experimental verification required!

• Contributions of higher orders $<10^{-3}$
Double elastic scattering of an **unpolarized** beam (1) with two identical scattering processes (2,3,4) (targets, solid angles...)

- **Vertical polarization after first scattering**
  
  \[ P_{\text{vert}} = S_{\text{eff}} \]

- Observed Left/Right asymmetry in second scattering (6)
  
  \[ A = S_{\text{eff}}^2 \]

- The effective Analyzing power is measured as \( S_{\text{eff}} = \sqrt{A} \)
- With the exception of the assumption that in elastic scattering the analyzing power is identical to the polarizing power and the sign of \( S \), no other theory input is needed (**under this ideal assumptions**)
- The second target may be rotated into the (now polarized) beam yielding
  
  \[ P = A(Pol\text{beam})/S_{\text{eff}} \] (this measurement only needs seconds)
Double scattering arrangement: concerns

In a series of papers Kessler showed that a) can also be (to first order) eliminated by (many) measuring processes only. This requires in particular a careful arrangement of monitor counters (5)
b) was also resolved, both at a level of a few $10^{-3}$ relative uncertainty contribution

→ Reproducing these results and further systematic checks during PhD work by M. Molitor at MAMI-type source (which could also be used for MESA)
DSMP: Set up

Sketch of beamline and DSMP
First „success“: DSMP can be operated for weeks without excessively deteriorating the cathode

DSMP and beamline in front of it (beam from the right)
1: Wien filter
2: Viewscreen
3: „Big“ flange
4: Faraday cup
5: Camera
6: DSMP counting electronics

Figures from PhD work by M. Molitor
DSMP: Set up

„Big“ flange open
1 beam (from left)
2 pumping port
3 secondary scattering chamber
4 primary Target position
5 beam dump

Note: Secondary chamber is rotated periodically to exchange counter positions (removes contribution of detector efficiencies, solid angles to false asymmetry)

....but not deviation of beam position and angle from symmetry axis

Figures from PhD work by M. Molitor
Calibration result

Measuring the double scattering asymmetry requires several days of beamtime for a statistical accuracy of 0.5%. After this calibration of $S_{\text{eff}}$ the target can be used in single scattering achieving the same statistical accuracy in less than one minute.

How can we support the statement that the systematic uncertainty is low?

FIG. 5. Histogram of $\approx 1600$ cycles from the measurement of $A$, showing the Gaussian distribution with a mean value of 0.0948(1) and $\sigma = 0.00565(3)$

From M. Molitor et al. Publication in preparation
Removing the „identity“ requirement

In reality the two scattering processes are NOT identical: Case c) in the figure

\[ A = S_T S_{\text{eff}} \]

As realized by Hopster (*), a double scattering apparatus allows solving this by achieving additional asymmetry observables with polarized beam, cases a), b)

- Case a): \[ A_0 = P_0 S_{\text{eff}} \]
- Case b): \[ A_T = P_0 S_T \]
- Case b): \[ A_{\uparrow} = \frac{S_T + \alpha P_0}{1 + P_0 S_T} \]
- Case b): \[ A_{\downarrow} = \frac{S_T - \alpha P_0}{1 - P_0 S_T} \]

This yields five observables with four unknowns

Consistency checks

The over determination of the variables allows extracting them in different fashion – but the results must be identical

\[ S_{\text{eff,(1)}}^2 = \frac{A_0 A}{A_T} \]  \hspace{1cm} (14)

\[ S_{\text{eff,(2)}}^2 = \frac{A_0}{2A_T} \left[ A_\uparrow (1 + A_T) + A_\downarrow (1 - A_T) \right] \]  \hspace{1cm} (15)

\[ S_{\text{eff,(3)}}^2 = \frac{A_0}{4A_T} \frac{[A_\uparrow(1 + A_T)]^2 - [A_\downarrow (1 - A_T)]^2}{A_\uparrow (1 + A_T) - A} \]  \hspace{1cm} (16)

\[ S_{\text{eff,(4)}}^2 = \frac{A_0}{4A_T} \frac{[A_\downarrow(1 - A_T)]^2 - [A_\uparrow (1 + A_T)]^2}{A_\downarrow (1 - A_T) - A} \]  \hspace{1cm} (17)

We first neglected that it is not completely trivial to achieve an unpolarized beam with a GaAs-source.....
Results obtained with a residual beam polarization of 0.7% (2.1% of maximum polarization). After finding this, the result can be corrected.
After determination of the residual polarization, the extractions using the unpolarized beam can be corrected. Then, the results are consistent within 0.1%.
Problem: Cross-check Concerning apparatus asymmetry does not exactly work (yet).
Outlook

DSMP:
- This year we will try to obtain consistent results without correction („true unpolarized beam“) still in the „PKA2“ test-lab
- DSMP will transfered to MESA injector in 2021
- Main open issue is the coonstistency of correction for „false“ asymmetries
- If that can be resolved, an accuracy <0.5 % is possible

5 MeV single scattering Mott
- Extension of MAMI 3.5 MeV Mott (but a lot of work to do)
- 5 MeV injector expected to be ready winter 20/21
- Hope that theory problems can be resolved, i.e by more experimental work

155 MeV Hydro-Möller
- Kryostat under construction (JINR/Dubna and Mainz)
- Testing trap shall happen in 2021/22
- Beam at MESA available 2023
→ Lots of work, cooperation, collaboration or simply help would be greatly appreciated!
Thank you
Source/beam preparation (MELBA) until July 2019

→ Operation with up to 100keV beam and up to 10mA beam current (>150kV possible, but not required)
→ 4 PhD theses finished within this subproject
→ MELBA was dis-assembled and put in storage due to start of hall renovation for MESA
MAMBO Booster Linac

- Design inspired by the robust MAMI injector LINAC
- Energy gain 4.9MeV, beam power up to 50kW
- 4 room temperature RF structures
- RF-Amplifiers: one with ~75 kW (section 1) and 3 x ~60 kW (sections 2-4)
MAMBO Booster: Prototype Cavity

- Prototype needed for testing "multipacting" behavior
  (Prototype is stable also with longitudinal field, if processed correctly)

Pictures: R. Heine
MAMBO Booster: Prototype RF-Amplifier

- 15kW RF-powersource prototype:
- Modular (8*2kW, combined) Solid State Amplifier
- Used for tests of MAMBO RF-section ...and also for Cryomodule tests
- ~25 Amplifiers needed for MESA RF-system
- Redesign/optimization completed

Pictures and Design of MAMBO: R. Heine
SRF-System: MEEC-Cryomodules

3.5 meter

Specs: 25MeV Energy gain at <40 Watt thermal loss at 2Kelvin
Production of 2 Cryomodules

- 2015: 2 MEEC’s ordered at RI Research Instruments GmbH
- Until 2017 SRF testing infrastructure became available at HIM
- 9/2018: First cryomodule does not meet specs at HIM → refurbishment by vendor,
- 3/2019: Second tested cryomodule achieves specs during test at HIM/Mainz
- 3/2020: Refurbished cryomodule tested and fulfills specs.

PhD thesis Timo Stengler
See also: T. Stengler et al. Proc. SRF 2019
doi:10.18429/JACoW-SRF2019-TUP041
BBU investigation

13mA BBU limit at Target in 4pass configuration 2up/2down (without countermeasures)

PhD thesis Christian Stoll,
See also: C. Stoll and F. Hug: proceedings IPAC 2019
doi:10.18429/JACoW-IPAC2019-MOPGW025

Note:
Technical limitation: Heating of HOM coupler in TESLA cavities. (~1mA estimation, but needs to be determined experimentally)