Overview – polarimeters MESA

Status and work(s) in progress

June 15 2023

Presented by Kurt Aulenbacher,

- work by R. Thapa, V. Tioukine & MESA-team

Cluster of Excellence PRISMA+

MESA

MESA-Polarimeter - overview

- Real vs. “perfect”
- The 5 MeV Mott polarimeter
- The “Iron”-Möller
- From Iron Möller to Hydro Möller

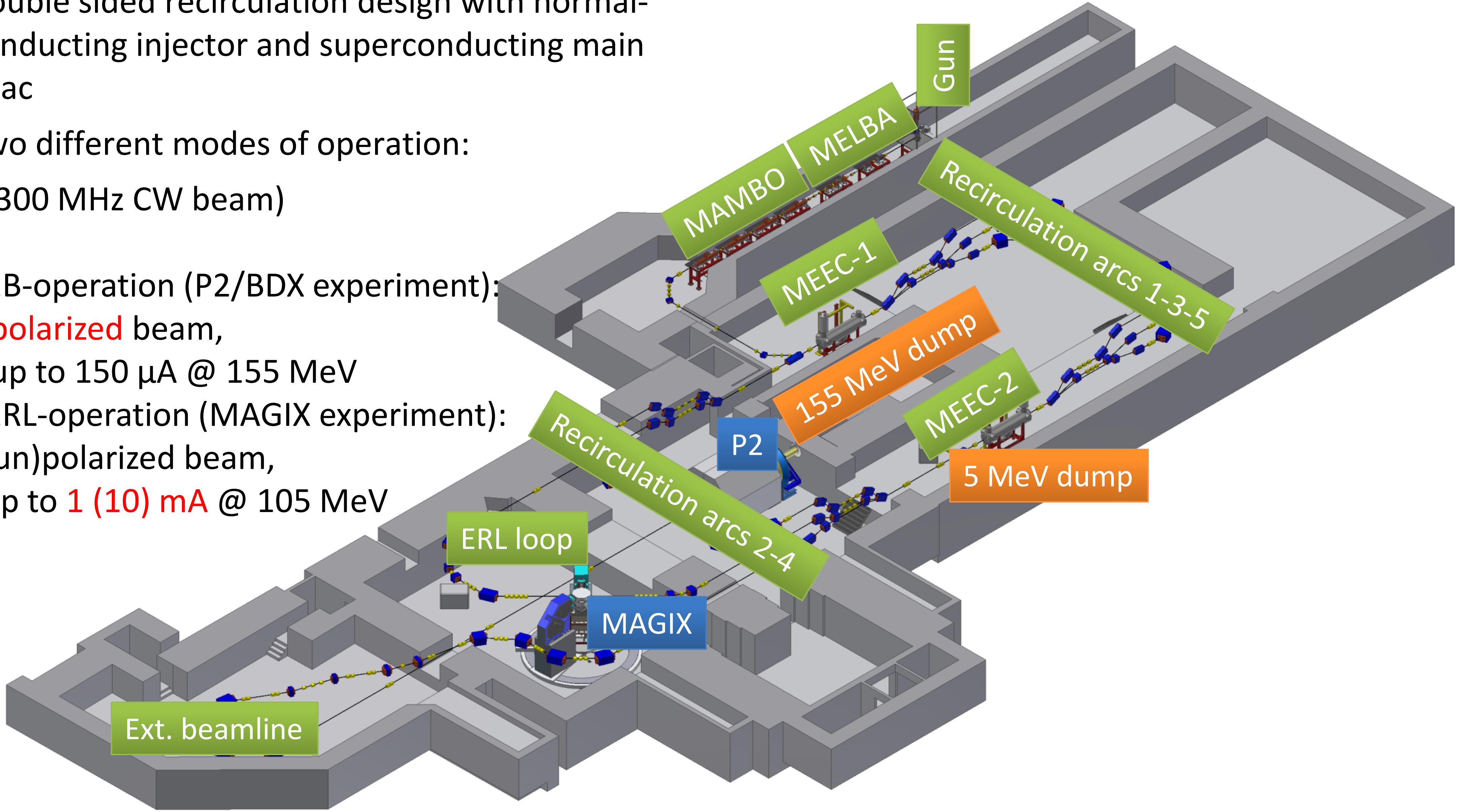
MESA Accelerator Layout

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

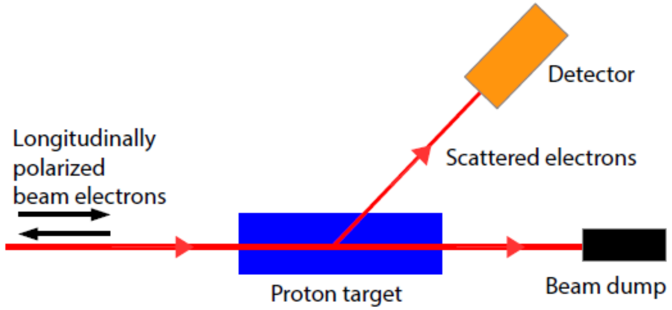
Two different modes of operation:

(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

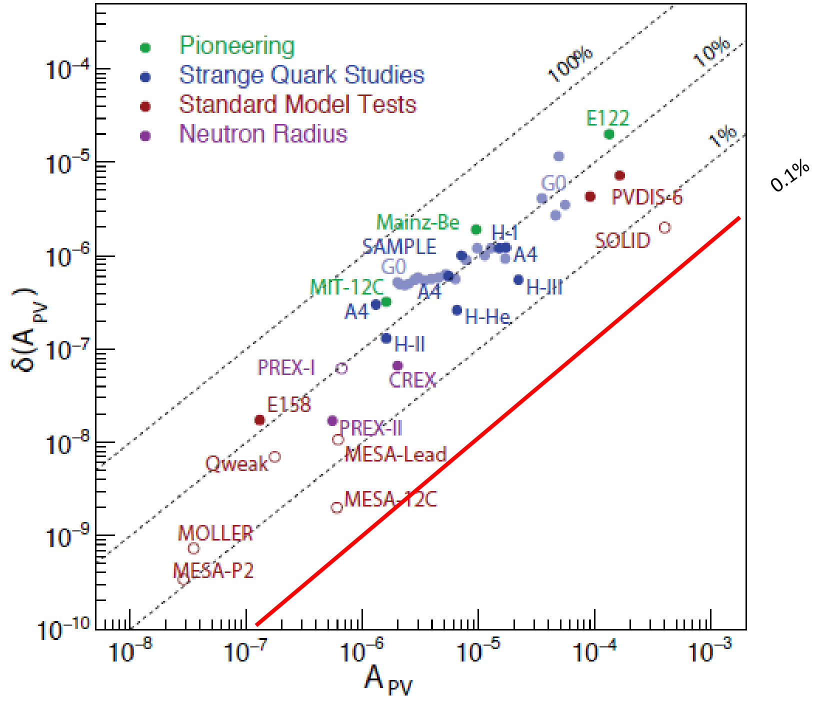


P2@MESA: High accuracy measurement of (very small) parity violating asymmetry



$$A^{\mathrm{PV}} = \frac{-G_{\mathrm{F}}Q^2}{4\pi\alpha_{\mathrm{em}}\sqrt{2}}\left[Q_{\mathrm{W}}(\mathrm{p}) - F(E_{\mathrm{i}}, Q^2)\right],$$

But: $A^{exp}=P*A^{PV}$

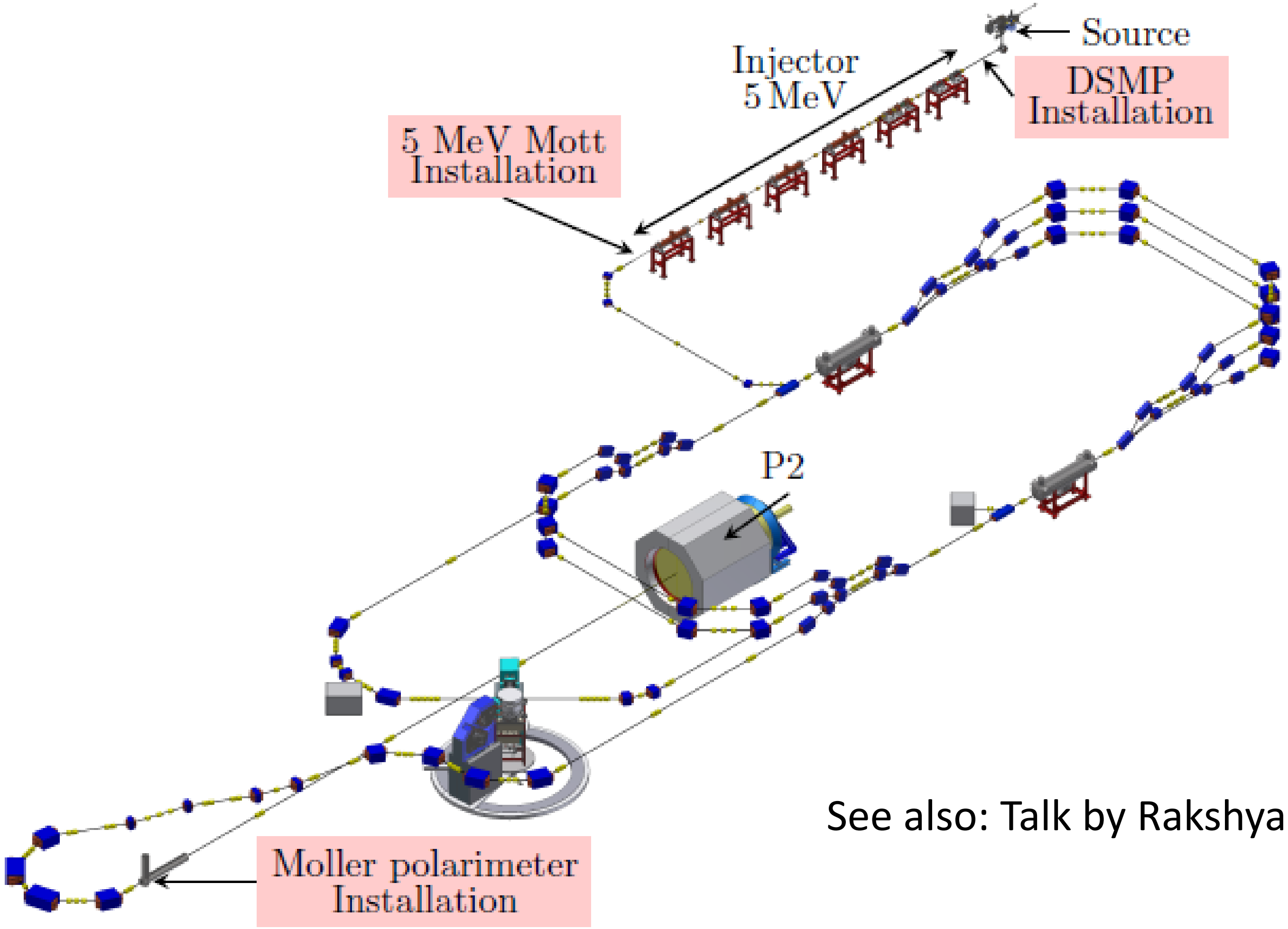


Figures from: D. Becker et al., Eur. Phys. J. A (2018) 54 : 208

The Perfect Polarimeter at MESA

Polarimeter type	Potential accuracy at MESA	Current capability	Online capability	Published ($\Delta P/P$)	Remark
Perfect	0.1 %	>150 μA	YES		Does not exist yet

Polarimeter Chain



See also: Talk by Rakshya this afternoon

Perfect vs. realistic options

Polarimeter type	Potential accuracy at MESA	Current capability	Online capability	Published ($\Delta P/P$)	Remark
Perfect	0.1 %	>150 μA	YES		
5 MeV Mott	<0.6 %?	150 ?	limited	0.61 % (JLAB 2021) At 5 MeV	At 4μA Online to be demonstrated!
Iron Möller	<1 ?	1μA	NO	0.85% (JLAB 2022) At 1 GeV	Inline with experiment!
Hydro Möller	<0.3?	>150 μA	YES	-	Target design exists , realization difficult
DSMP	<0.3	<1μA	NO	0.3 %at 120keV	Manpower issue and unresolved problems
Laser-Compton	??	> 150 μA	YES	0.5% (SLAC, 45 GeV)	Insufficient analyzing power at 155 MeV

Perfect vs. Options with high priority

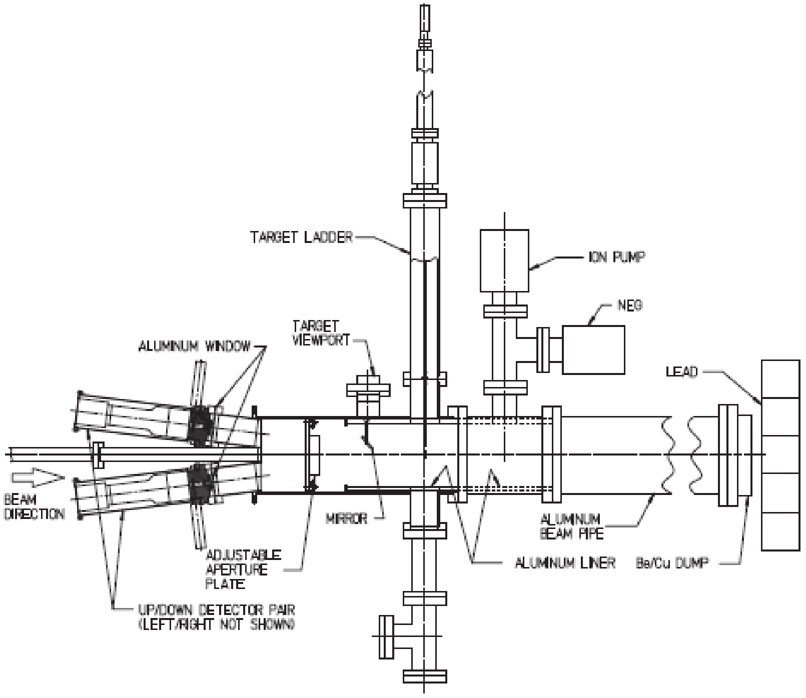
Polarimeter type	Potential accuracy at MESA	Current capability	Online capability at MESA	Published ($\Delta P/P$)	Remark
Perfect	0.1 %	>150 μA	YES		
5 MeV Mott	<0.6 %?	150 ?	limited	0.61 % (JLAB 2021)(*) At 5 MeV	Online to be demonstrated!
Iron Möller	<1 ?	1μA	NO	0.85% (JLAB 2022)(**) At 1 GeV	Inline with experiment! Much lower energy as in (**)

(*) J. Grames et al. PHYSICAL REVIEW C **102**, 015501 (2020) DOI: 10.1103/PhysRevC.102.015501
(**) E. King PSTP2022 --- 19th Workshop on Polarized Sources, Targets and Polarimeters, Proceedings of Science Vol 433 /30

The 5 MeV Mott at JLAB

TABLE III. Uncertainty budget for the 5 MeV Mott polarimeter.

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%

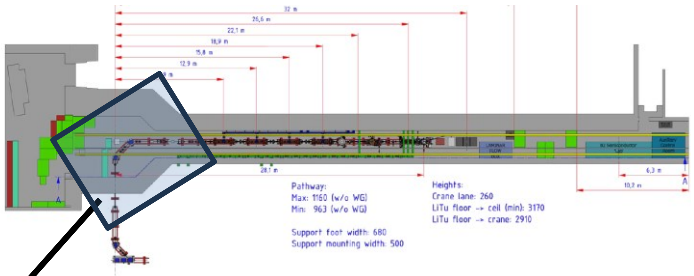


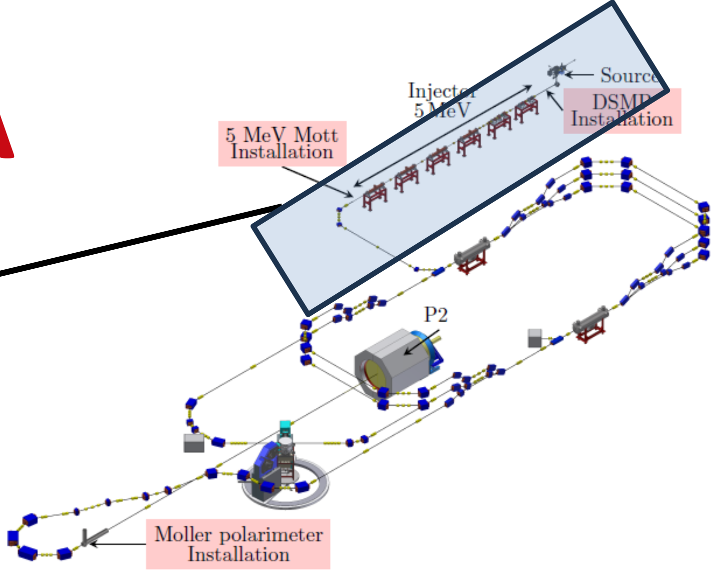
Taken from: J. Grames et al.
PHYSICAL REVIEW C **102**, 015501 (2020)
DOI: 10.1103/PhysRevC.102.015501

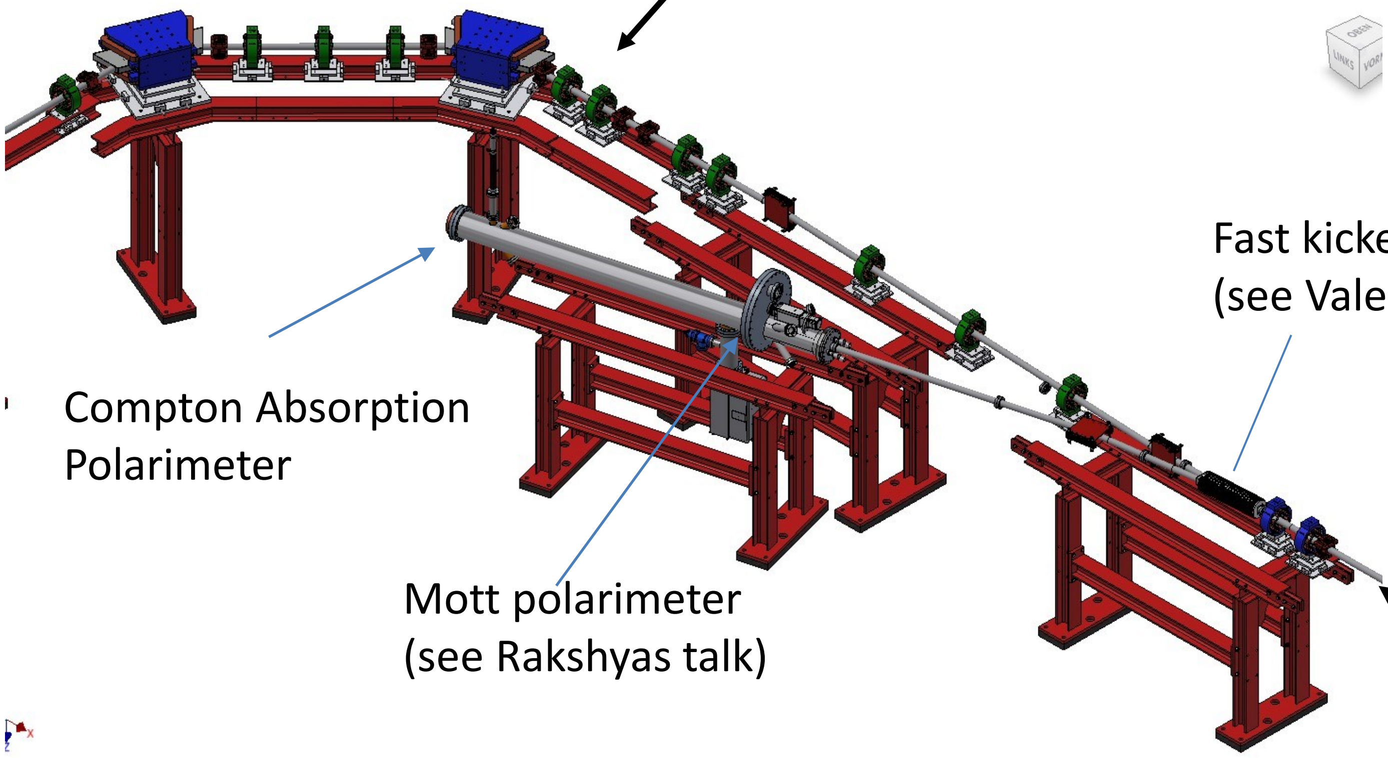
Caveats:

- Source should be operated at full current to exclude change of polarization
- Improved detection system needed ! (31 MHz operation at JLAB (2% d.f.) restricted beam current to ~4 μA)
- Spin rotation between Mott and experiment!

The 5 MeV Mott-Adaptation for MESA







Fast kicker Magnet
(see Valerys Talk)

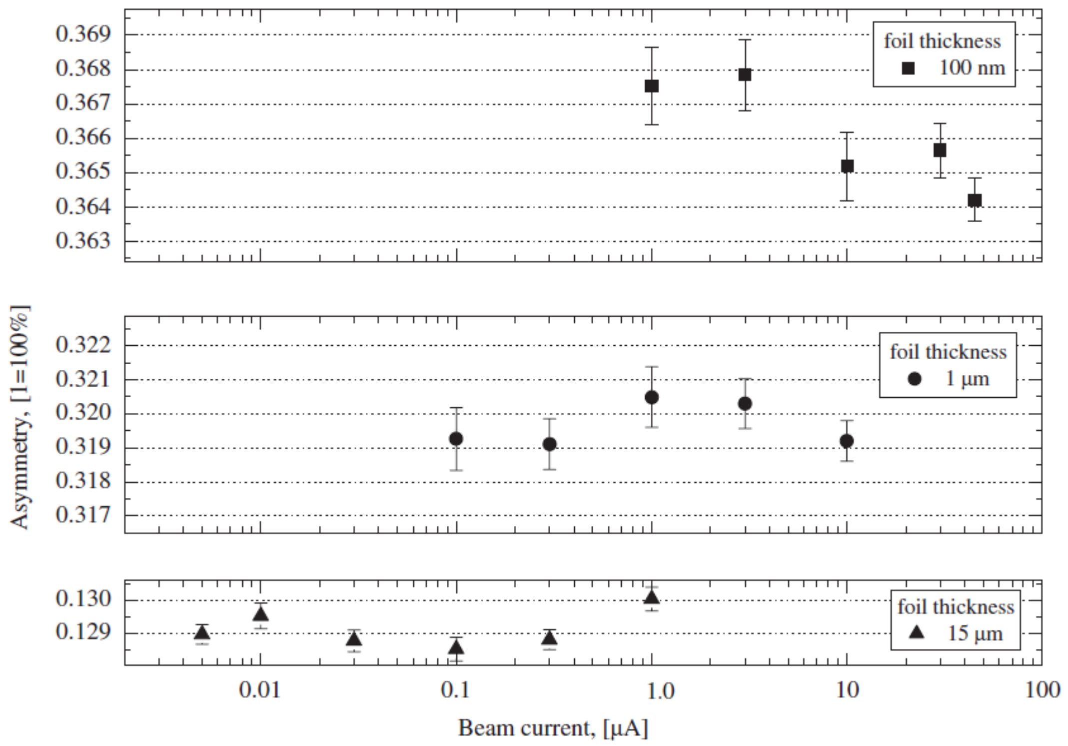
Compton Absorption
Polarimeter

Mott polarimeter
(see Rakshyas talk)

5 MeV Beam
from MAMBO

- Air coil extraction magnet („Kicker“) for reprodicible switching
- „quasi“ online operation posible, if fast kicker system applied (to be demonstrated!)

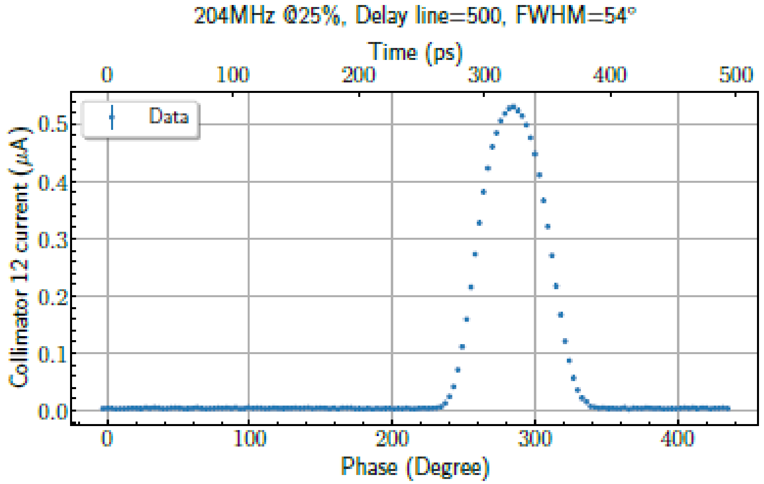
Full current operation ?



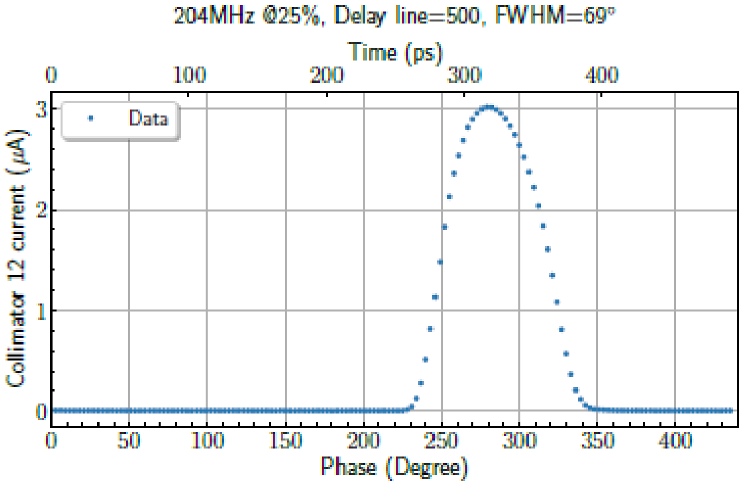
V. Tioukine et al., REV. SC. INSTR. **82**, 033303 (2011)
doi:10.1063/1.3556593

- Change of polarization because of cathode heating at high powers/increased cathode temperatures is possible.
- DAQ/SNR system should be able to handle full current (**Not** the case at JLAB – large dead time corrections)
- Also thermal issues (750 Watt on target/dump)
- Kicker is important

Constant bunch charge operation



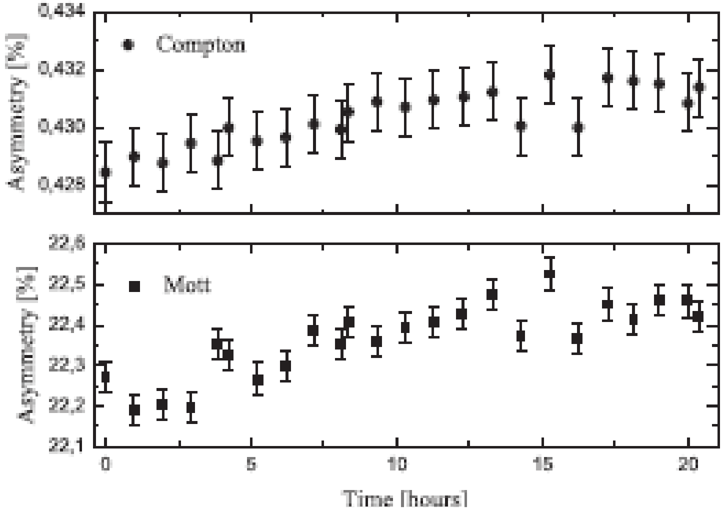
Average beam current
1.7 μA at 204 MHz
(12 th subharmoic of MAMI)
Bunch length 62ps

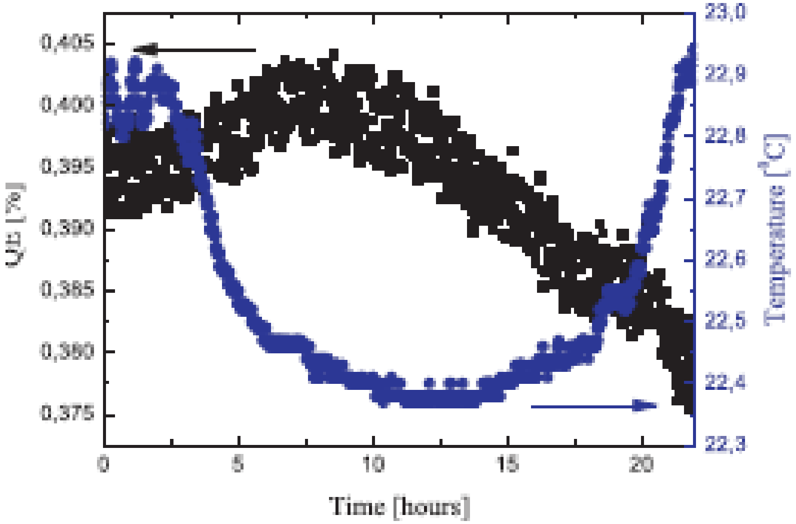


Average beam current
13 μA at 204 MHz
(156 μA at CW)
Bunch length 78 ps

- Systematics to be explored by attenuation at CW and by varying duty cycle→ **Laser system as explored in 2022 at MAMI is well suited** (see internal note by R. Thapa)
- Especially important for „Iron“ Möller → Operation with ~1% duty factor (Alternative 1:99 Möller/Mott kicker?)

Spin rotation towards 155 MeV and Monitoring at 5 MeV

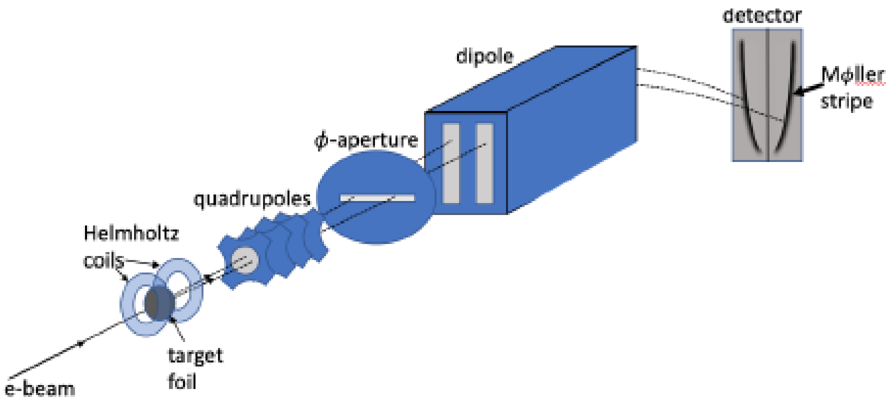




- Depending on the energy chosen for an experiment at P2, the spin vector may not be perpendicular at the Mott and longitudinal at P2 simultaneously
- Longitudinal at P2 requires 8 degree at Mott for 155 MeV
- In this unfavorable situation polarisation monitoring should be done with an (available) Compton transmission polarimeter to avoid changing spin orientation!
- Monitoring is always necessary because of drifts of polarisation

Simulatenous observation of longitudinal and transverse spin components.
Data taken at MAMI at 30µA
From: R. Barday, et al. Proceedings of PESP2010

Iron Möller at JLAB



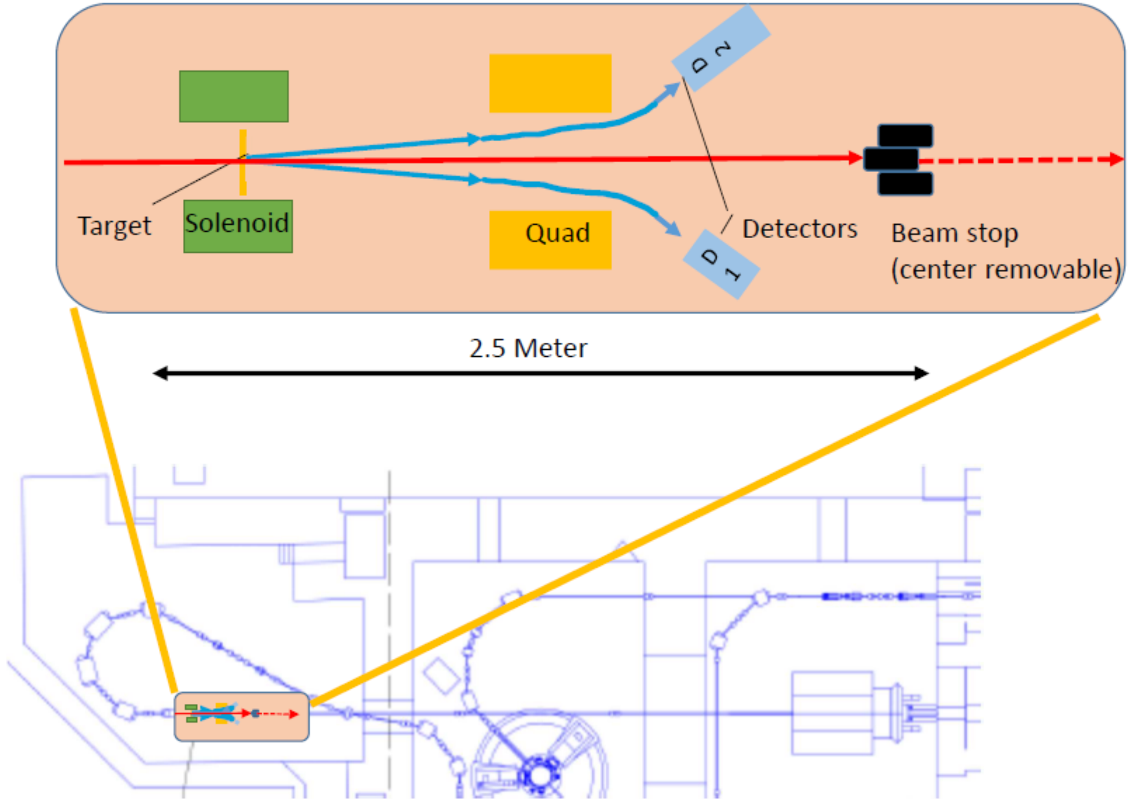
D.E. King et al. Møller polarimetry for PREX-2 and CREX. *NIM-A*, 1045:167506, 2023.

Uncertainty	PREX2	CREX
$\langle A_{zz} \rangle$	0.20	0.16
Beam Trajectory	0.30	0.00
Foil Polarization**	0.63	0.57
Dead Time†	0.05	0.15
Charge Normalization	0.00	0.01
Leakage Currents*	0.00	0.18
Laser Polarization‡ *	0.10	0.06
Accidentals†	0.02	0.04
Current Dependence*	0.42	0.50
Aperture Transmission*	0.10	0.10
Null Asymmetry†	0.12	0.22
July Extrapolation	0.23	–
Total	0.89	0.85

Table 1: Systematic uncertainties for the Hall A Møller polarimeter during PREX-2 and CREX.

Note: current dependence (cathode heating) is taken into account!
Note: The foil polarization error has two components (knowledge of saturation polarization & and unknown degree of saturation)

Adaptation of Iron Möller for MESA



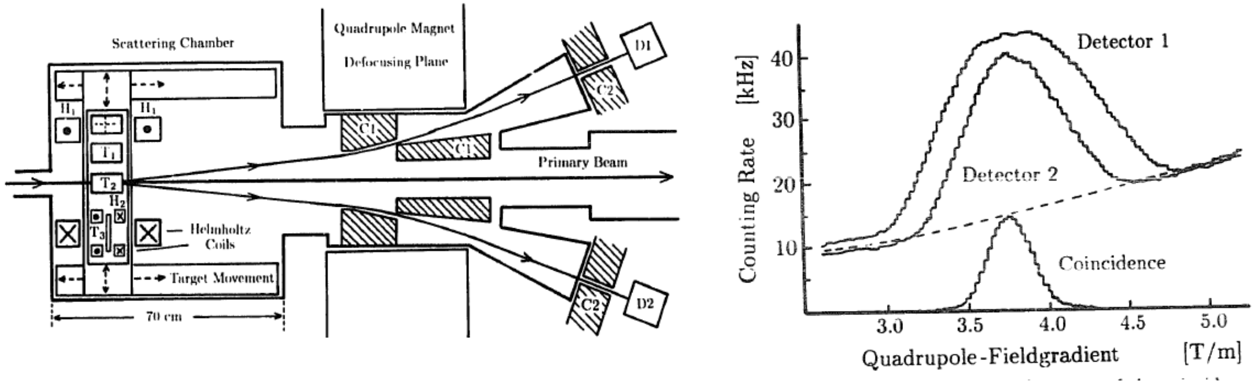
Suggestion for very simple „inline“ set up

Similar to old Möller Polarimeter used at 180 MeV in MAMI-A…

…with the exception of B=8T Solenoid!

Caveat: Beam energy almost one order of magnitude lower than at JLAB!

→ Pro or Con ?



Wagner et al. NIM A 294 541 (1990)

Adaptation of Iron Möller for MESA

Application of 8 T Solenoid offers advantages

+ Less uncertainty in saturation polarization

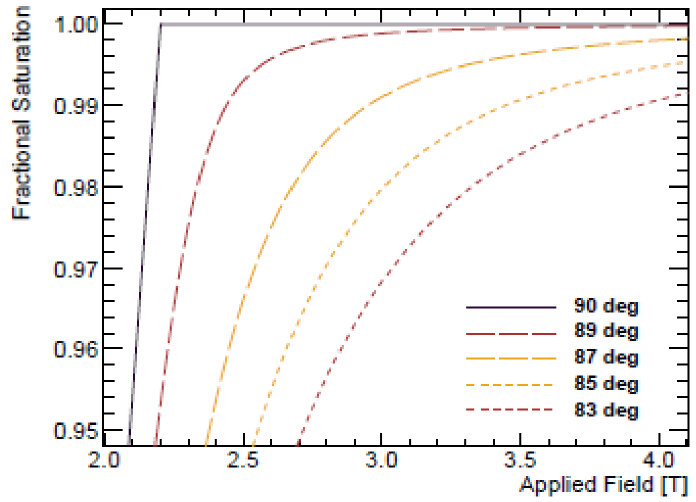
+ Transfer matrix for incident beam $M = 1$ (leave Solenoid on during P2 data taking, only remove target, requires field integral 3.25 Tm at 155 MeV)

+ Spectroscopic effect of solenoid for Möller electrons of different energies (will be amplified by quadrupole magnet)

+ 3.5 Tm Solenoid affordable (Cryocooled & warm bore) and suited for later Hydro-Möller installation

Very long „Do list“ :

- Target moving system design
- Detector system
- Determination of acceptance
- Systematic effects (Levchuk, dead time, current dependance,…)



$$M = \begin{pmatrix} C^2 & SC/K & SC & S^2/K \\ -KS & C^2 & -KS^2 & SC \\ -SC & -S^2/K & C^2 & SC/K \\ KS^2 & -SC & -KSC & C^2 \end{pmatrix}$$

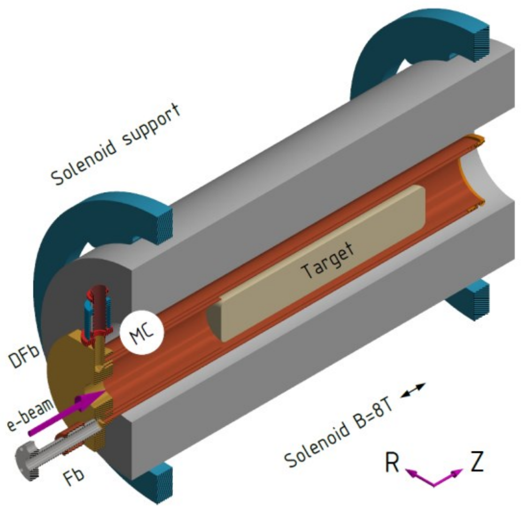
$$\alpha = \frac{eB}{\gamma m}\frac{L}{\beta c}$$

$$C = \cos\left(\frac{\alpha}{2}\right), S = -\sin\left(\frac{\alpha}{2}\right), K = -\alpha/2L$$

From Iron Möller to Hydro-Möller ?

Hydro-Möller: Promise

- Suggested by E. Chudakov and V. Luppov:
  Moller polarimetry with atomic hydrogen targets IEEE Transactions on Nuclear Science 51 (2004) 1533.
- Areal density about 10^{16} spins/cm^2 → sufficiently low for online operation
- but reasonable statistical efficiency…(for specific high acceptance detection system → see talk by Michail)
- Hydrogen Polarization 1-ε with $\varepsilon<10^{-4}$ → suppression of error from target polarization
- No Levchuk effect
- Full current & online cabability
- → $\Delta P/P < 0.5\%$?



Schematic of Hydro-Möller-Target,

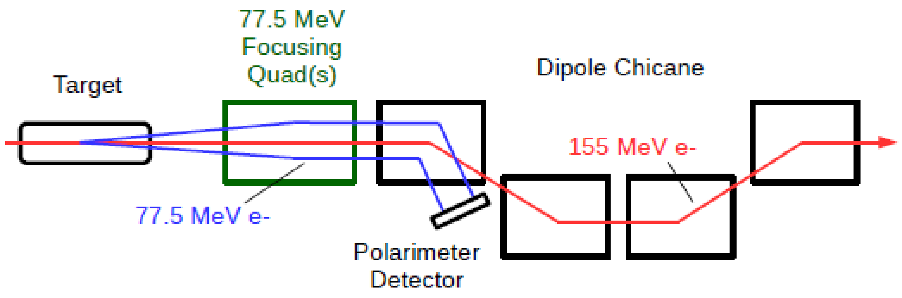
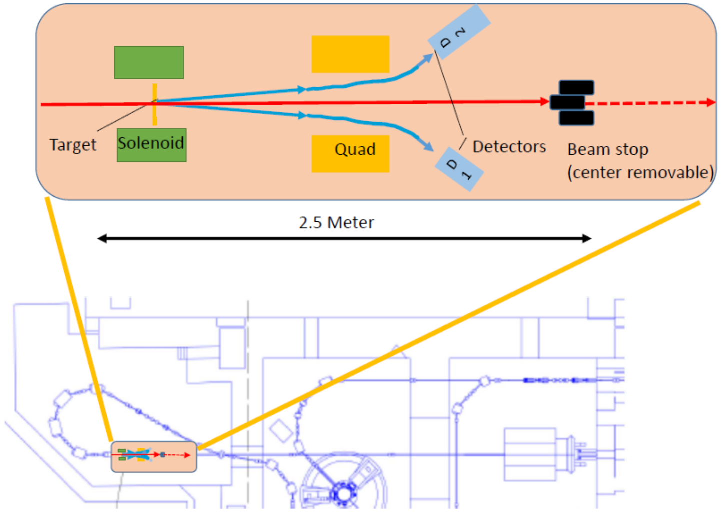
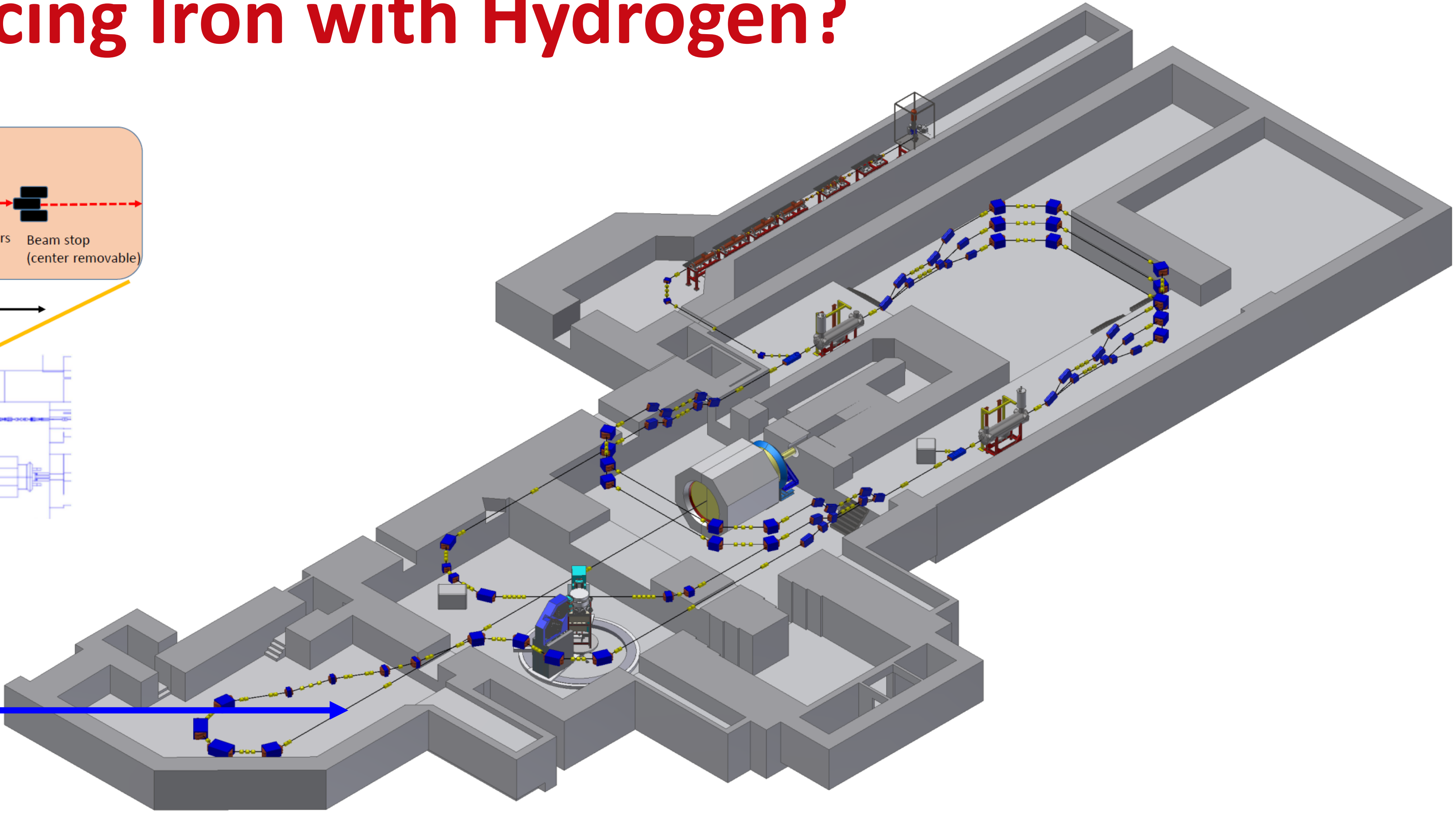


Figure from: D. Becker et al., Eur. Phys. J. A (2018) 54 : 208

Replacing Iron with Hydrogen?

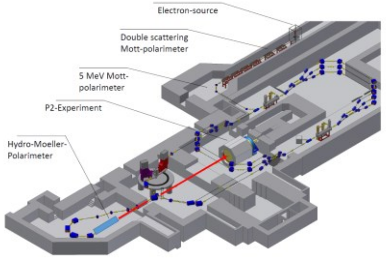
Iron Möller approach

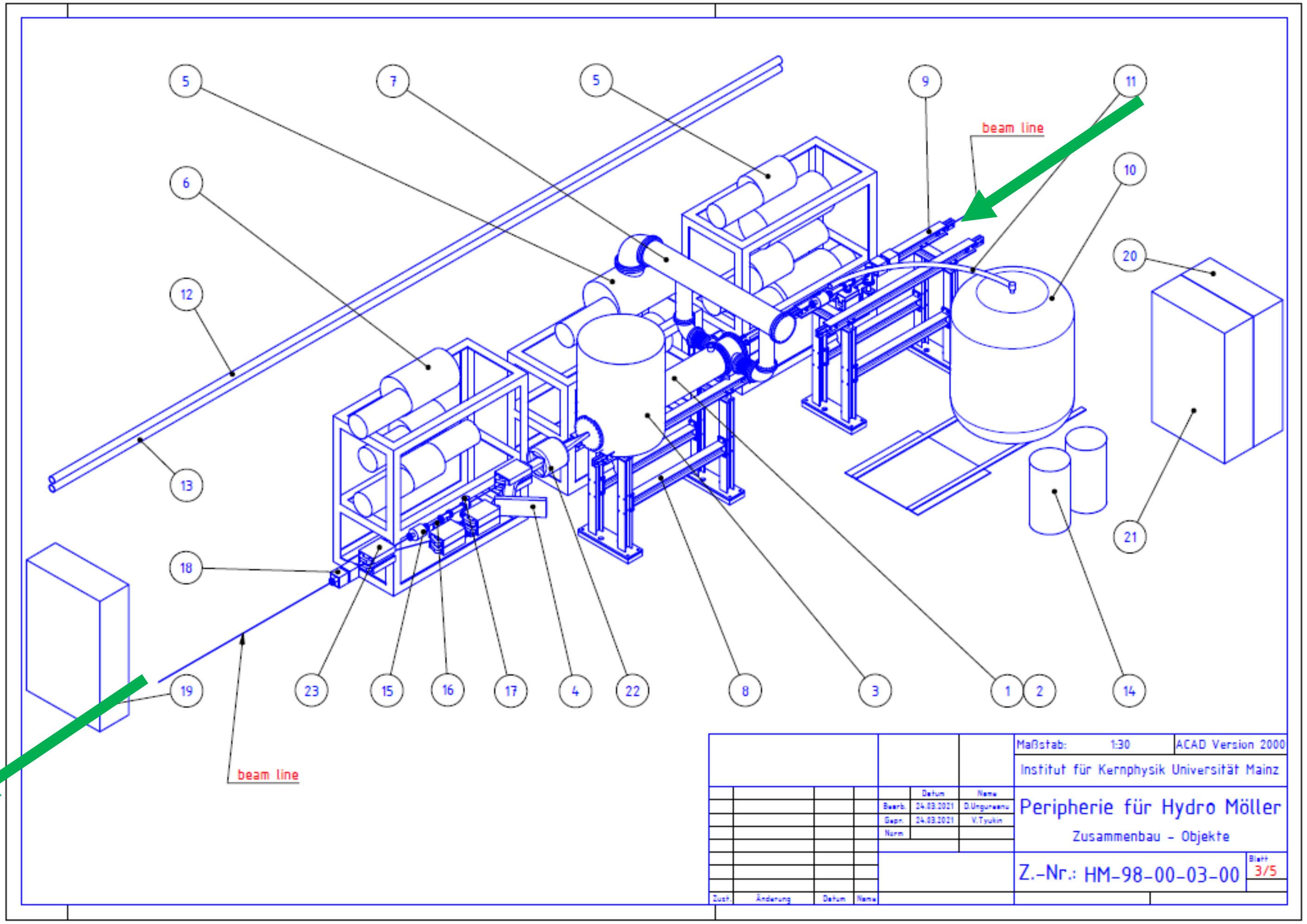




Möller scattering from completely spin polarized hydrogen target: see V. Tioukine et al. Proceedings PSTP 2019

Hydro-Møller infrastructure





To P2

- Length of set up ~8m
- Two Helium circuits needed
- Estimated lq. Helium consumption <10l/h
- Feasible, but technologically demanding!

Hydro-Möller: Technical Challenges and status

- Powerful dilation refrigerator needed (50mW at 0.3K)
- **Detailed design of refrigerator exists**
- Several parts already were fabricated at JINR/Dubna (but not delivered)
- Fabrication of remaining parts will be delayed for unforeseeable time because of the war in Ukraine.
- Iron Möller only possible solution at the moment
- Solenoid of Iron-Möller may be used for the Hydro-Möller trap too.

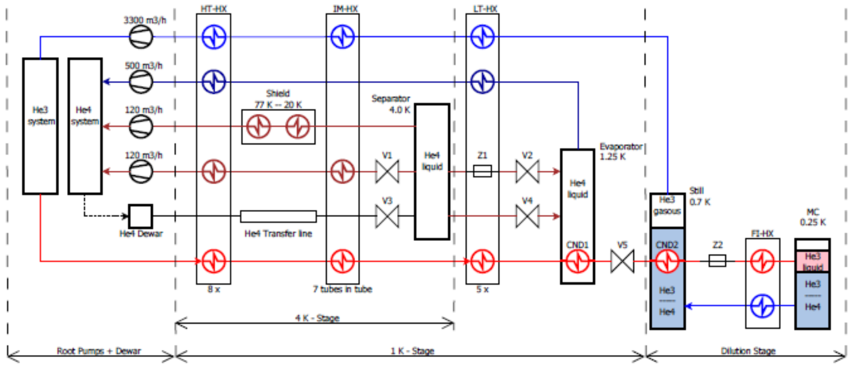


Figure 4: Refrigerator flow chart. HX=Heat exchanger. HT/IM/LT = high, medium and low temperature level of precooling circuit.

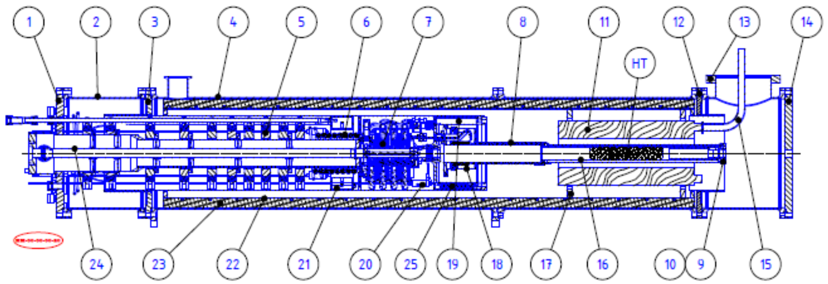


Figure 5: Schematic of the Hydro-Møller atomic trap. 1 - port flange , 2 - cross, 3 - connector flange cryostat, 4 - housing, 5 - high temperature HX, 6 - intermediate temperature HX , 7 - low temperature HX, 8 - final HX, 9 - one-sided film burner, 10 - double-sided film burner, 11 - super conducting solenoid, 12 - connector flange, 13 - tees, 14 - output flange, 15 - He4 - connections, 16 - mixing chamber, 17 - thermally insulated mounting, 18 - still, 19 - evaporator with 25-condenser, 20 - needle valves, 21 - separator, 22 - 77 K shield, 23 - multi layer insulation, 24 - evaporator pumping line

From Iron Möller to Hydro-Möller ?

Moving towards Hydro-Möller is a project that should and can be pursued. It has reasonable chances, but we need partners to be succesful within a meaningful period of time

Summary/Outlook

- 5 MeV Mott is under design and partially under construction (→ talks by Valery, Rakshya)
- Iron Möller under design, can be realized timely.
- Beam for polarimeters becomes available 2024
- MANY systematics to be checked!
- 5 MeV Mott and Iron Möller: May yield sufficient accuracy for P2-Lead, P2-H
- P2-12C needs further improvements …
- ….like Hydro-Möller, improved 5 MeV Mott, DSMP (or all of them)

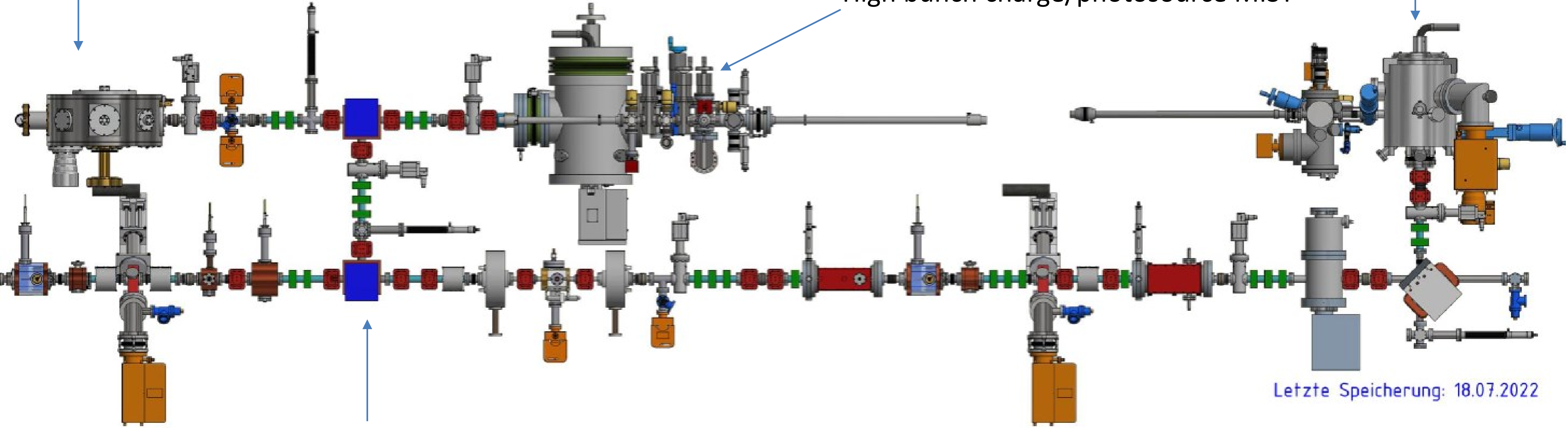
Thank you

The DSMP at MESA – technical issue

Polarized
Photosource STEAM

DSMP

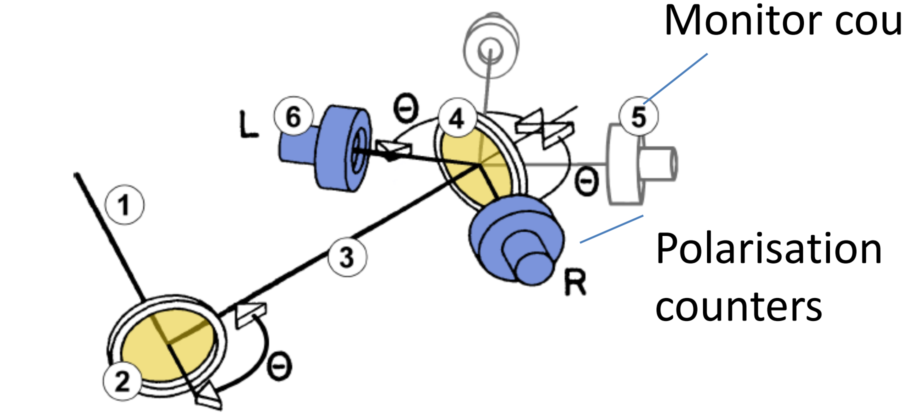
High bunch charge/photosource MIST

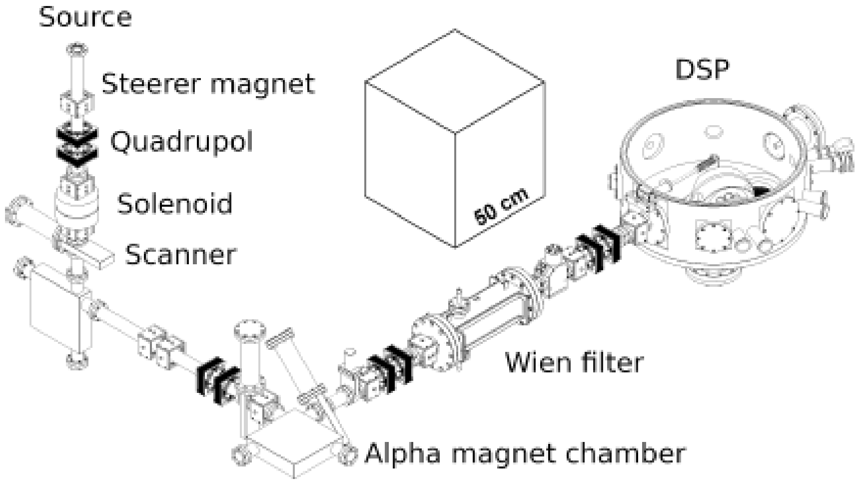


Injection/extraction beamline
(under construction, PhD thesis A. Kalamaiko)

DSMP: Non-compatible vacuum technology → man power needed (installation postponed)

The DSMP at MESA – measurment issue





The DSMP is gift from Univresity of Münster where double scattering was used to MEASURE the effective analyzing power of Mott scattering.

In double scattering, assuming two identical scattering processes and starting from unpolarized beam we observe an experimental asymmetry that is given by $A_{exp} = S_{eff}^2$

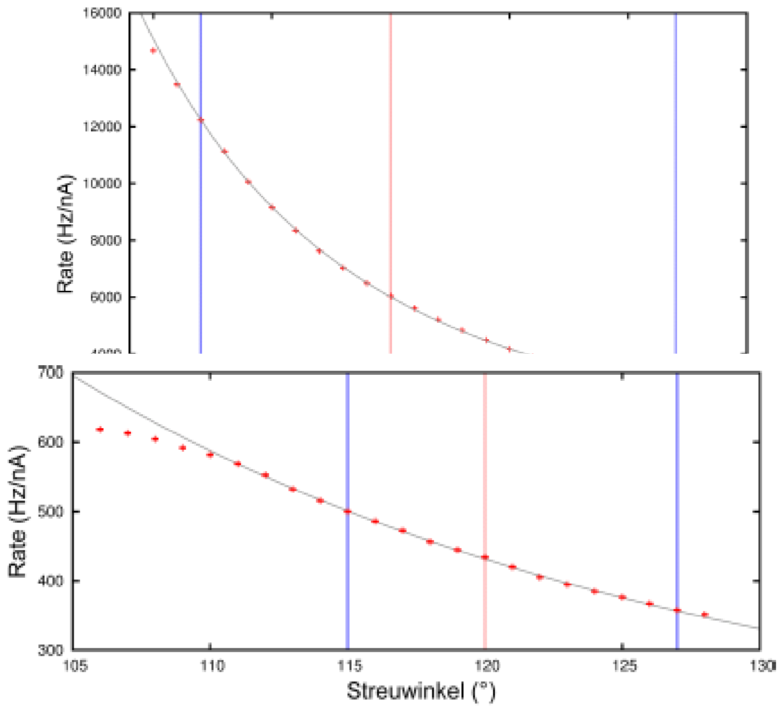
The Münster group quoted an uncertainty for S_{eff} of 0.3%.

Gellrich, A. ; Kessler, J.: Precision measurement of the Sherman asymmetry function for electron scattering from gold. In: Physical Review A 43 (1991), Nr. 1, S. 204

The requirement of having identical scattering conditions can be elliminated if a polarized beam is available and additional measurements are done. Mayer, S. ; Fischer, T. ; Blaschke, W. ; Kessler, J.: Calibration of a Mott electron polarimeter: Comparison of dierent methods. In: Review of scientic instruments 64 (1993), Nr. 4, S. 952{957

Ellimination of instrumental asymmetries is the main difficulty!

The DSMP at MESA – measurment issue



Measurments by M. Molitor, PhD thesis Mainz 2020

A measurement of scattering Rate vs. Angle of first scattering yields the logarithmic derivative of the rate $E(\vartheta) = \frac{dR(\vartheta)/d\vartheta}{R(\vartheta)}$

As shown in Gellrich, A. ; Kessler, J.: Precision measurement of the Sherman asymmetry function for electron scattering from gold. In: Physical Review A 43 (1991), Nr. 1, S. 204 an unabiguous correction of instrumental asymmetries requires a fixed distance ratio of the monitor counters with the polarization counters:

$$\frac{h_m}{h_p} = \frac{\cos(\vartheta_m) - 2E(\vartheta_m)^{-1}\sin(\vartheta_m)}{\cos(\vartheta_p) - 2E(\vartheta_p)^{-1}\sin(\vartheta_p)}$$

Only under this condition the instrumental asymmetry of the monitor counters is always proportional to that of the polarisation counters. Assuming the monitor counters to have purely instrumental asymmetries We have:

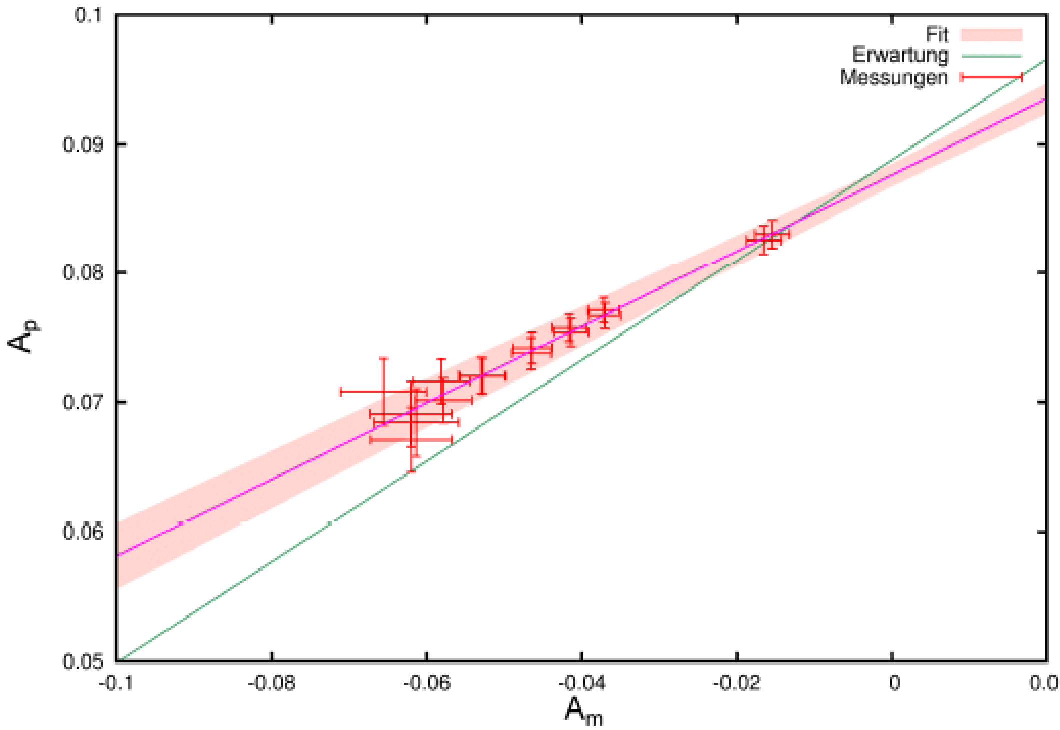
$$A_{inst.,p} = \frac{E(\vartheta_p)}{E(\vartheta_m)} A_{inst.,m} \quad (*)$$

The DSMP at MESA – physics issue

The proportionality constant is then:

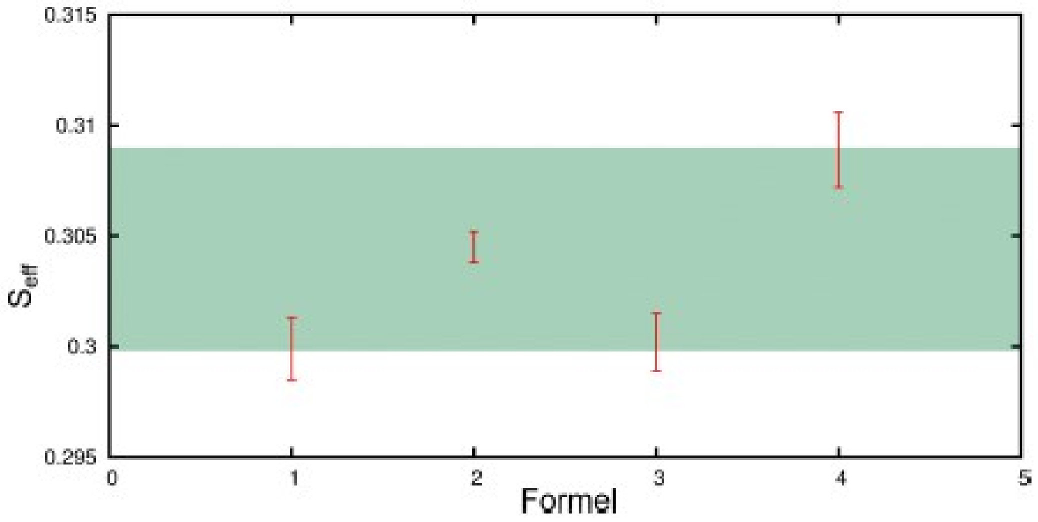
$$A_{inst.,p} = \frac{E(\vartheta_p)}{E(\vartheta_m)} A_{inst.,p} \quad (*)$$

We have not observed the behavior (*):
Artificially induced instrumental asymmetries (by misaligning the beam on the target- red line) do not follow the predicted behavior. (green line). The additional uncertainty associated with an inaccurate correction of instrumental asymmetries was estimated
to be of the order 1%



Measurement by M. Molitor, PhD thesis Mainz 2020

The DSMP at MESA – physics issue



Formel	S_{eff}
$S^2_{\text{eff},2,(1)} = \frac{A_0 A}{A_T}$	0,2989(14)
$S^2_{\text{eff},2,(2)} = \frac{A_0}{2A_T}\left[A_\uparrow(1+A_T)+A_\downarrow(1-A_T)\right]$	0,3036(7)
$S^2_{\text{eff},2,(3)} = \frac{A_0}{4A_T}\frac{[A_\uparrow(1+A_T)]^2-[A_\downarrow(1-A_T)]^2}{A_\uparrow(1+A_T)-A}$	0,2992(13)
$S^2_{\text{eff},2,(4)} = \frac{A_0}{4A_T}\frac{[A_\downarrow(1-A_T)]^2-[A_\uparrow(1+A_T)]^2}{A_\downarrow(1-A_T)-A}$	0,3083(17)
Mittelwert	0,3024(9)

Measurement by M. Molitor, PhD thesis
Mainz 2020

Independend cross checks with polarised beam are only consistent to about plus/minus 1.5%

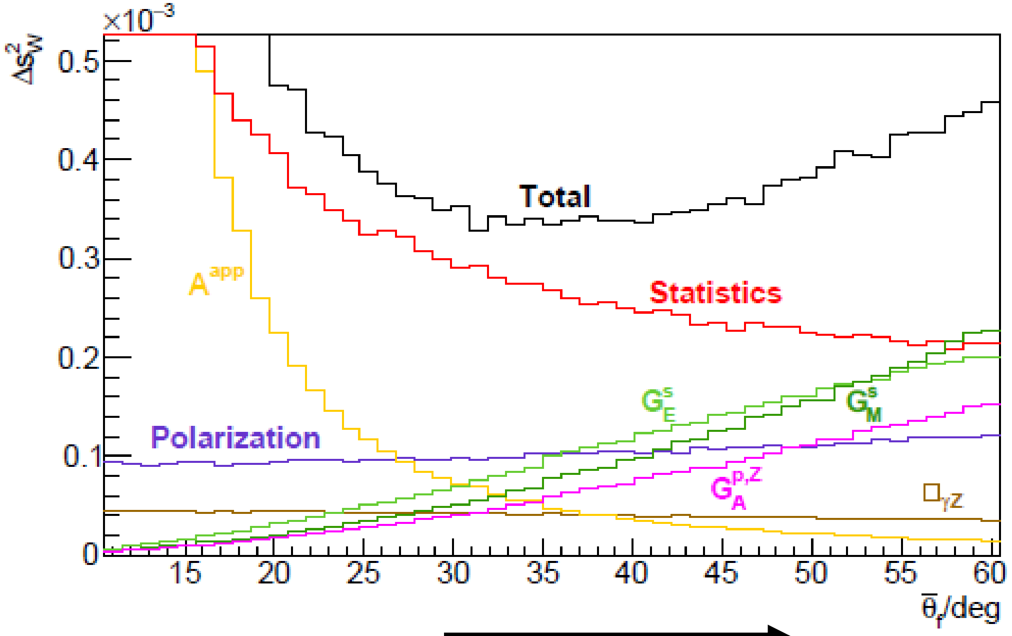
- Supporting the suspicion that the correction for instrumental asymmetries is wrong
- Additional problem was that beam for was not completely unpolarized
- Additional issue is that switching of Wien filter for the cross check measurements may have changed the magnetic field in the DSMP with also adverse effects…

Thank You

P2@MESA:
Assumptions concerning error contributions

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

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

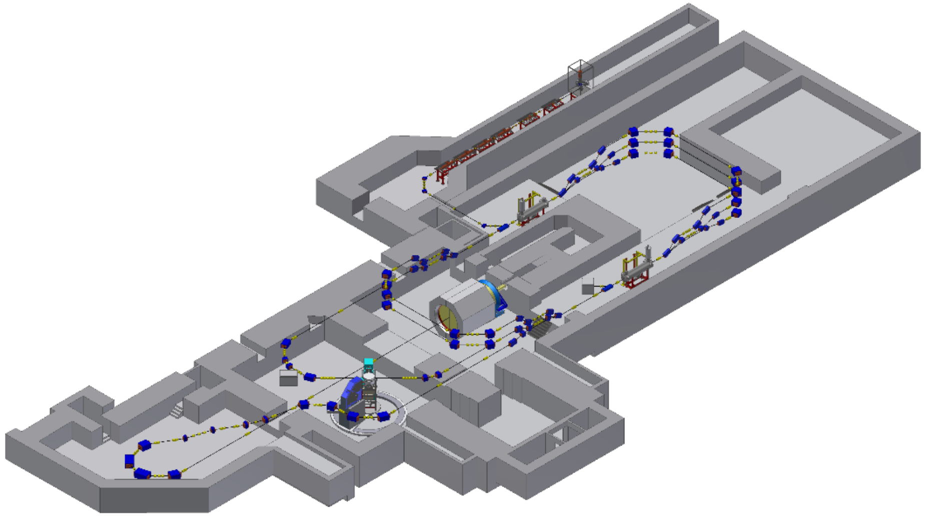


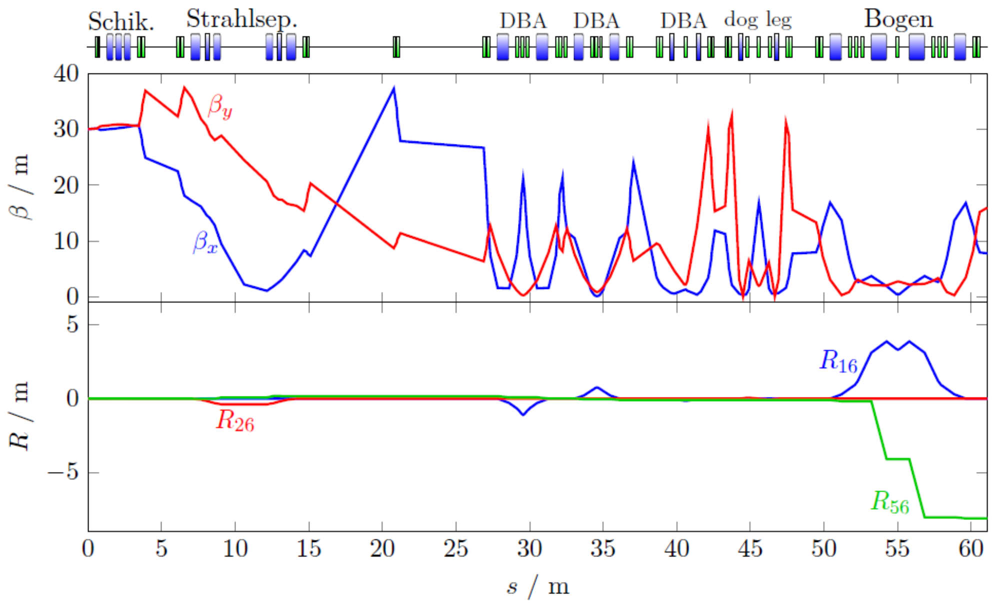
Polarization error assumed as $\Delta P/P=0.5\%$!

Average scattering angle at E_{beam}=155 MeV

Content from: D. Becker et al., Eur. Phys. J. A (2018) 54 : 208

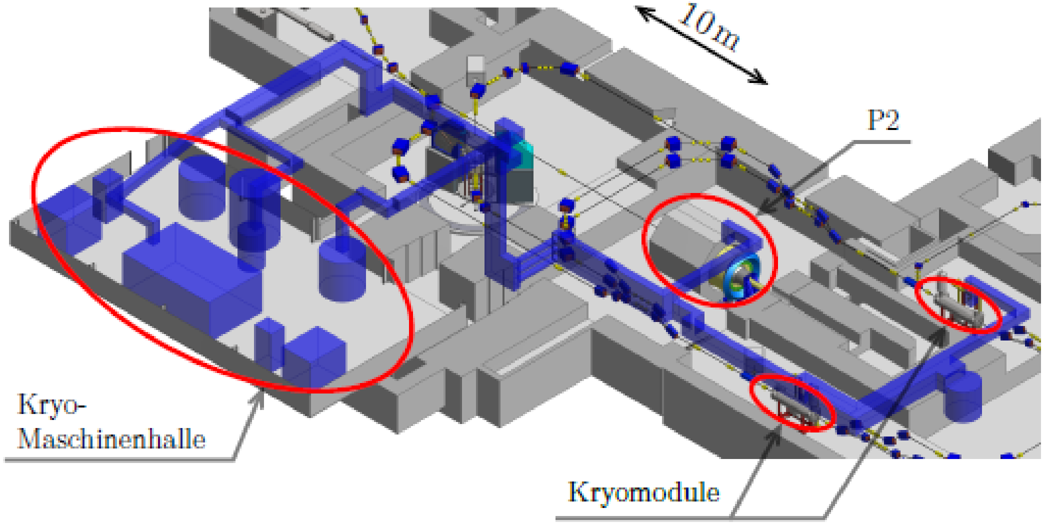
The beamline…

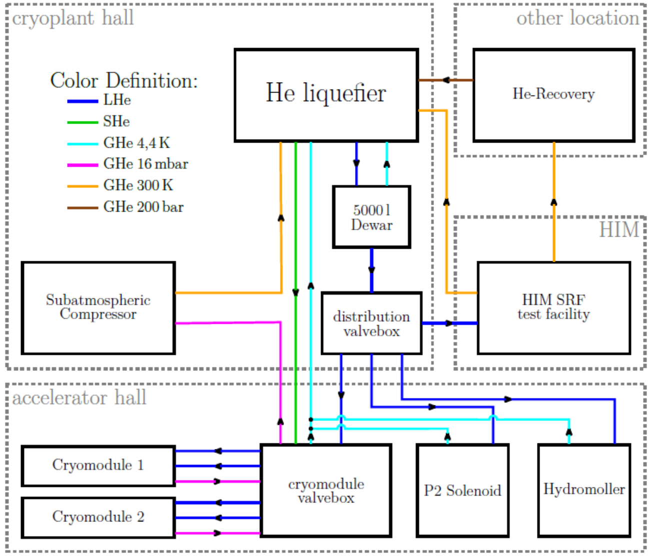




D. Simon Dissertation Thesis
http://doi.org/10.25358/openscience-5809

The cryogenic distribution





“Robust” Refrigerator parts…(fabricated in Germany)

If situation with russian institutions do not improve…
..one may try to fabricate in house/

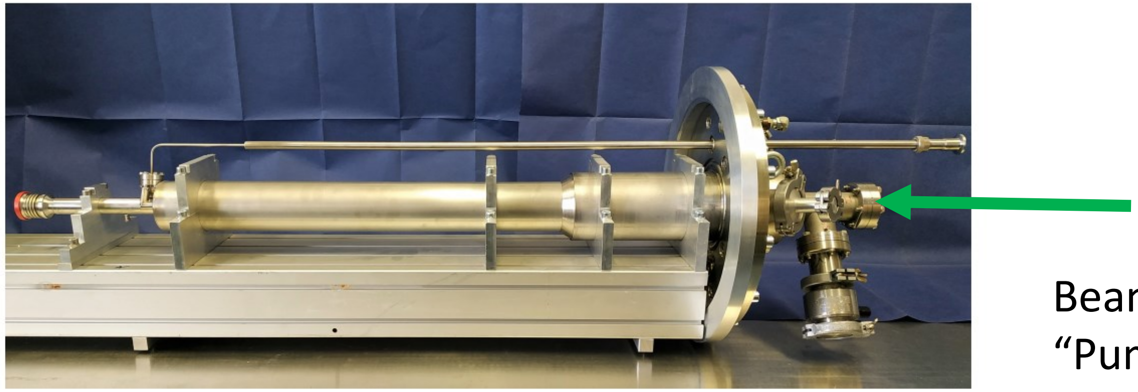


Figure 11: Base flange with pumping line surrounding the beam pipe. Developed by KPH-Mainz in coperation with several industrial suppliers.

Beam insert and
“Pumping line”

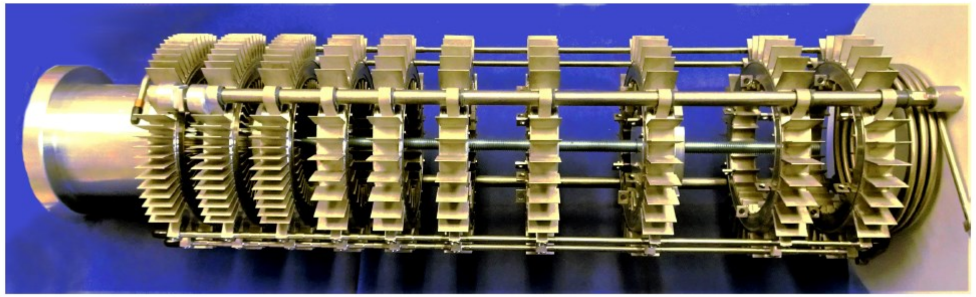
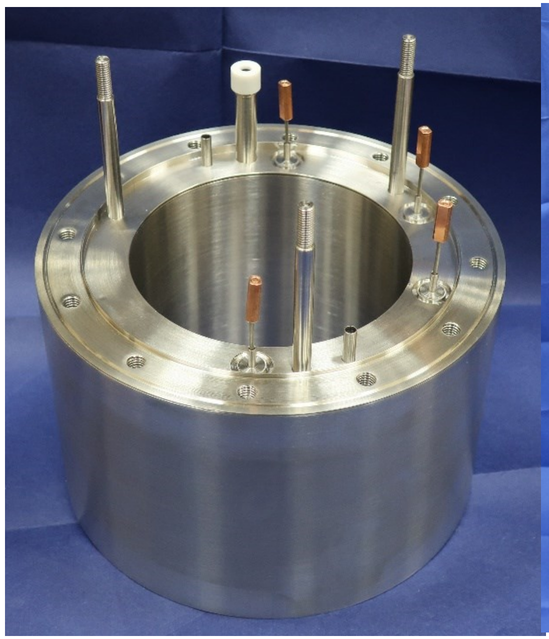
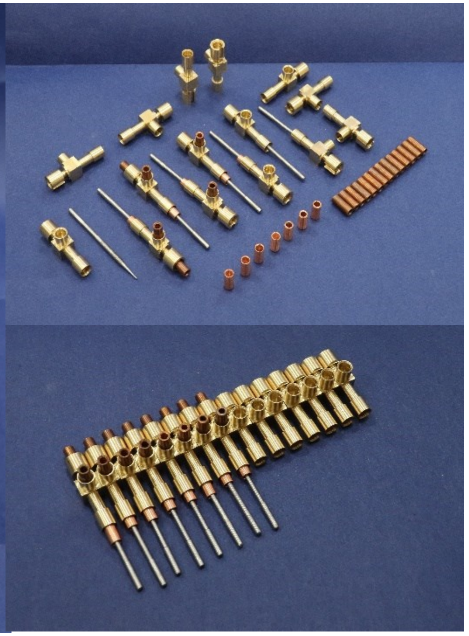


Figure 12: High temperature heat exchanger. Developed by KPH-Mainz in cooperation with several industrial suppliers.

All welded
heat exchangers
For precooling stage

“Precooler ” parts (fabricated in Russia but not delivered)



..one may try to fabricate the missing pieces (many!)
in house/with industry in other cooperations → probbaly impossible to acquire necessary know how , in any many years of delay!