The Spin injector for the P2 experiment at MESA

SPIN2021,

the 24th International Spin Symposium

18. October 2021

Presented by Kurt Aulenbacher,

- work by Monika Dehn, Jennifer Groth, Simon Friederich, Anatolii Kalamaiko, Ruth Kempf, Rakshya Thapa, Valery Tioukine & MESA-team

Cluster of Excellence PRISMA+

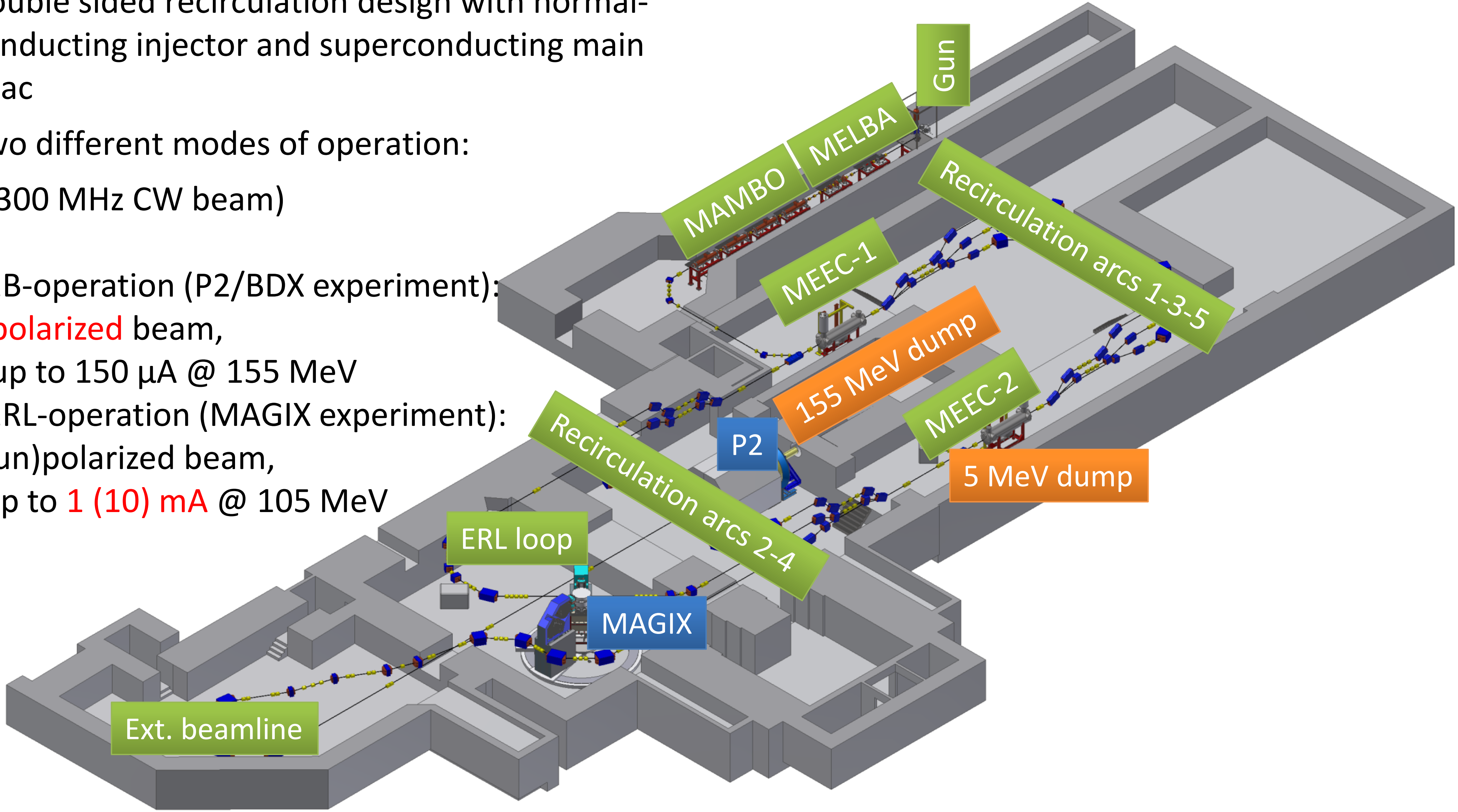
MESA Accelerator Layout

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

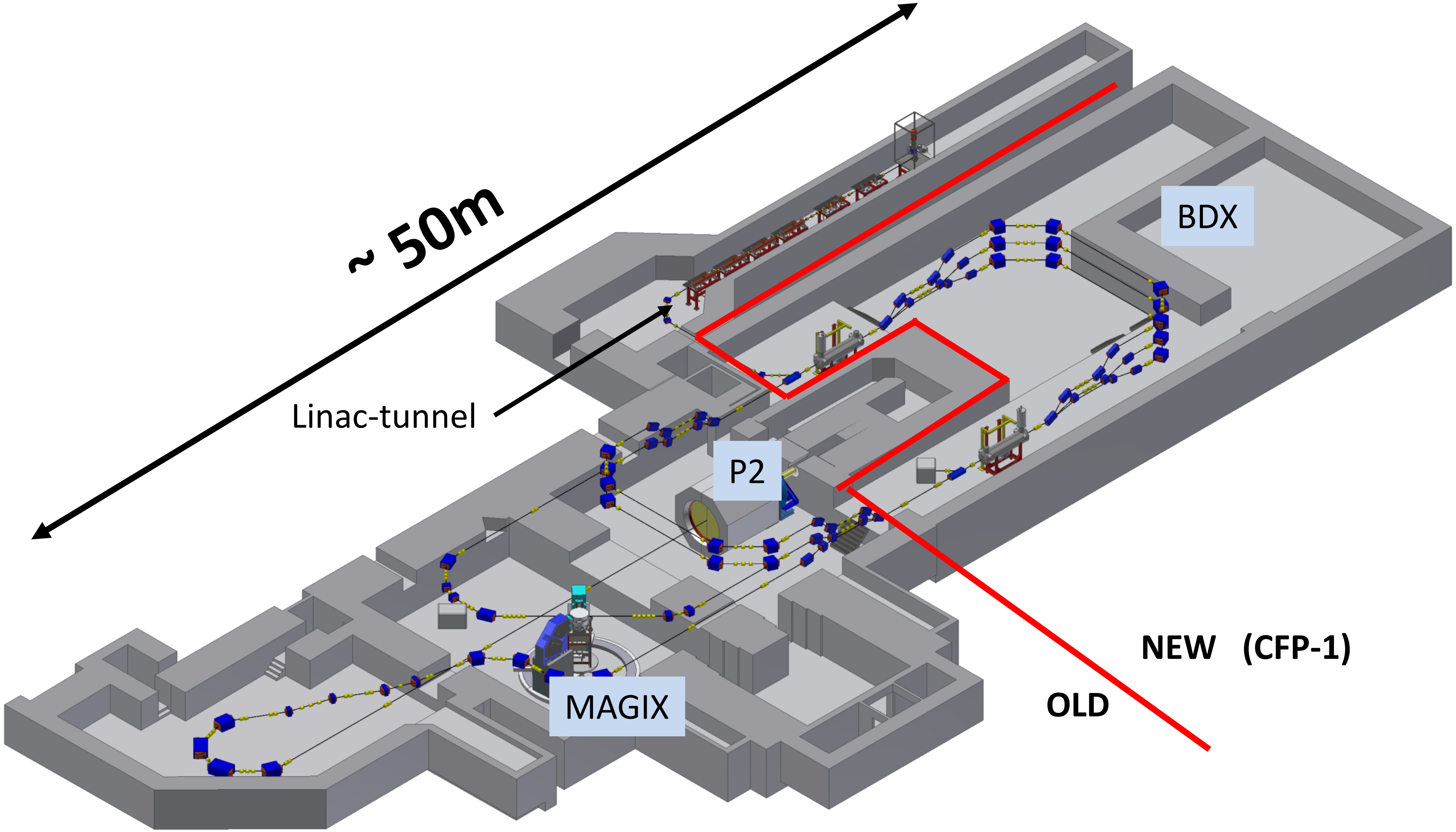
Two different modes of operation:

(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



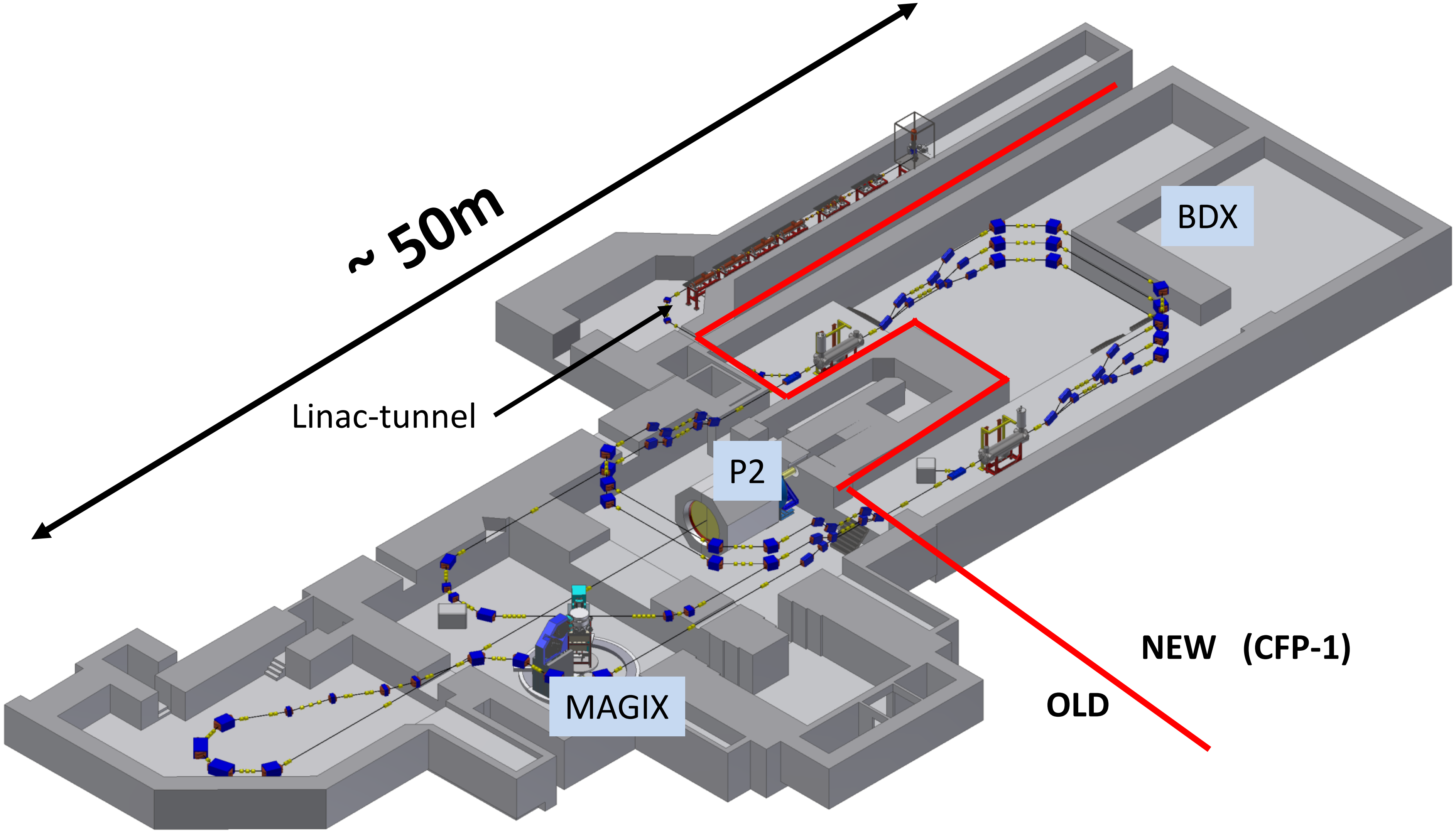
New experimental halls
...for more and larger experiments



MESA Civil construction status September 2021

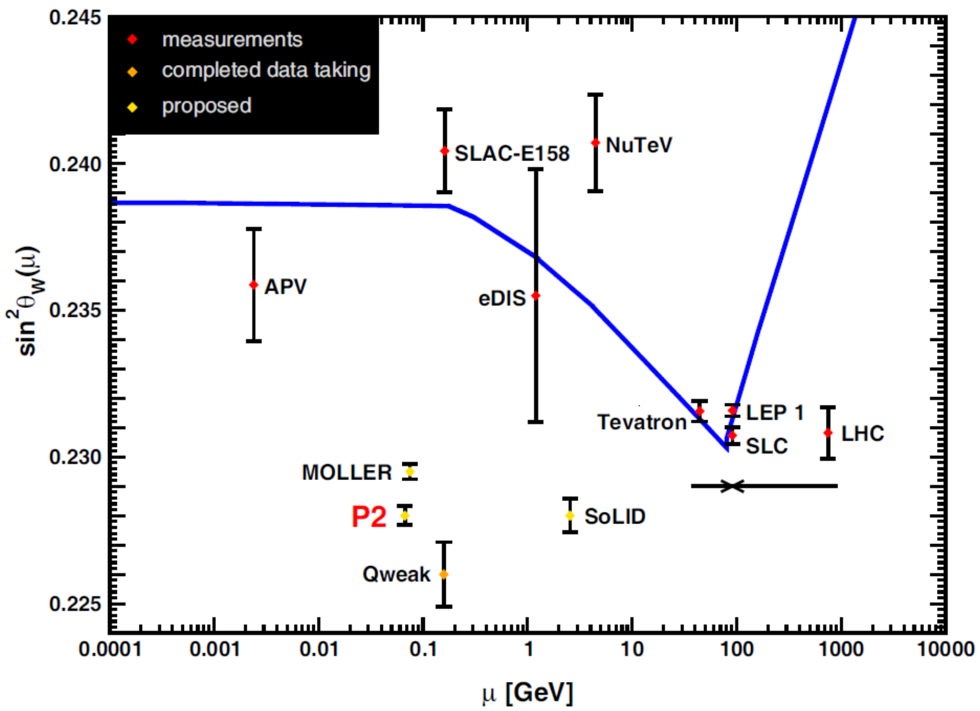
Building shell completed, but installation will take ~year
Main accelerator installation cannot begin before winter 22/23
Beam commissioning for experiments end of 24

Introducing the P2 experiment

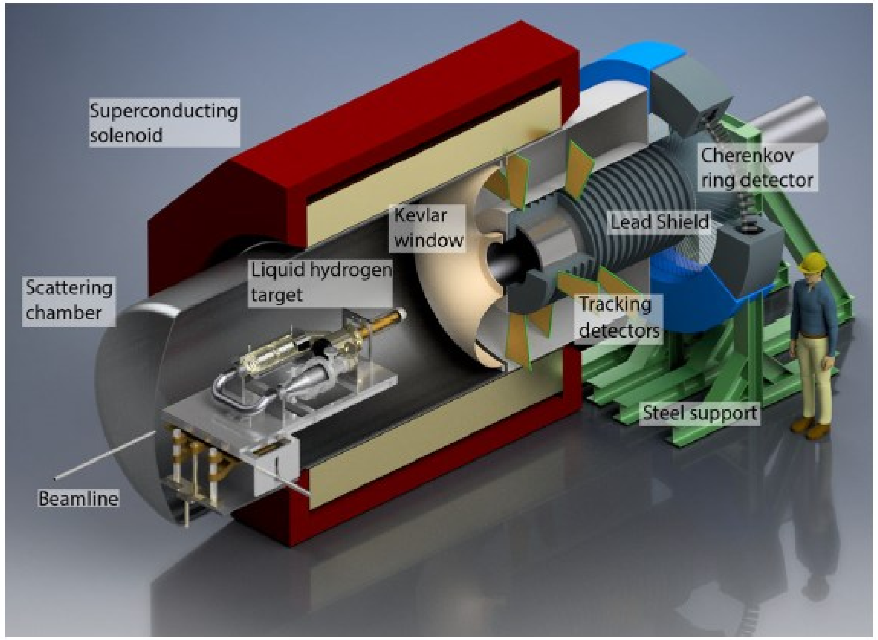


MESA

The P2-experiment



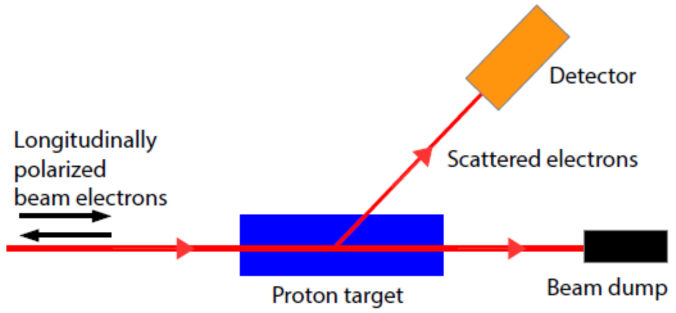
Large solid angle detector with
Superconducting solenoid



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

Goal: Precision determination of EW-mixing angle at low Momentum-transfer

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

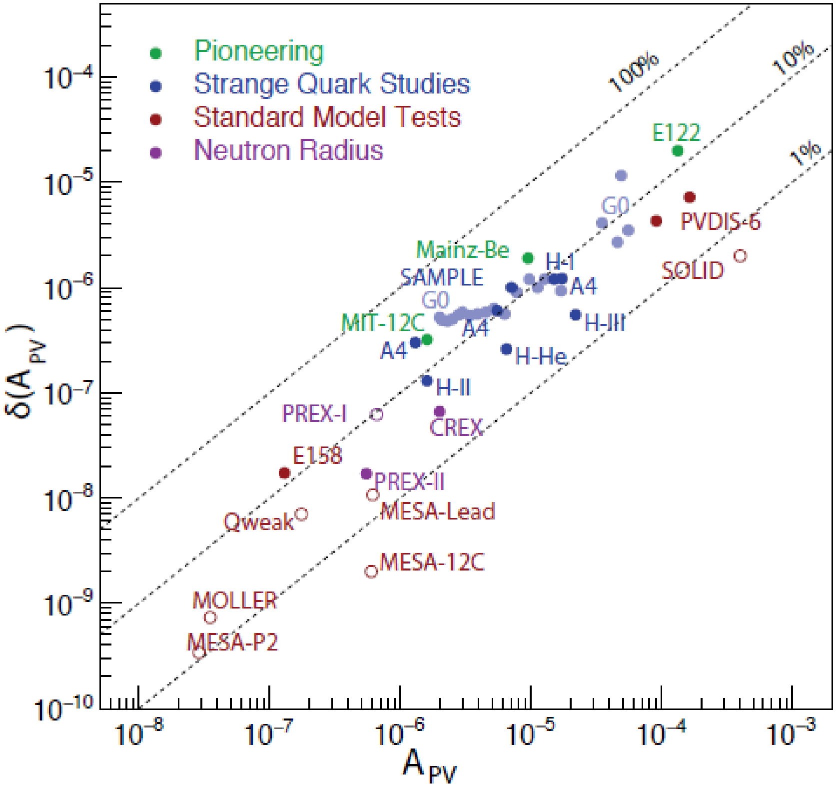


$$A^{\rm PV} = \frac{-G_{\rm F}Q^2}{4\pi\alpha_{\rm em}\sqrt{2}}\left[Q_{\rm W}({\rm p}) - F(E_{\rm i}, Q^2)\right],$$

$$Q_w = (1 - 4\sin^2(\theta_w))$$

Measure A^{PV} of ~30ppb, with about 1.4% accuracy, yields accuracy in weak mixing angle ~ 0.14%

$$A^{Exp} = P \cdot A^{PV} + A^{false}$$



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

P2@MESA: Error contributions

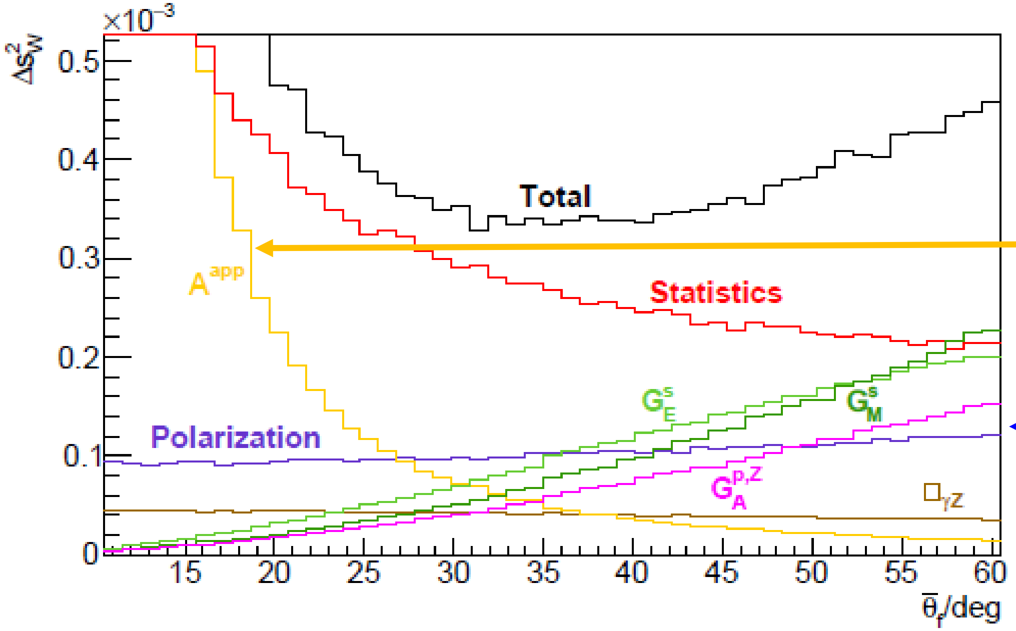
Statistics: Assuming 150 μA beam current with P=0.85

- on 55cm lq. Hydrogen for 10000 hours

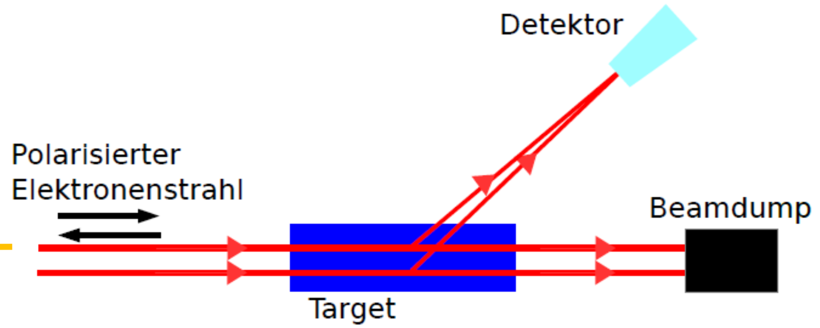
Systematics from accelerator:Two challenges: P must be accurately known and $A^{false} \rightarrow 0$

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

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



Average scattering angle at E_{beam}=155 MeV



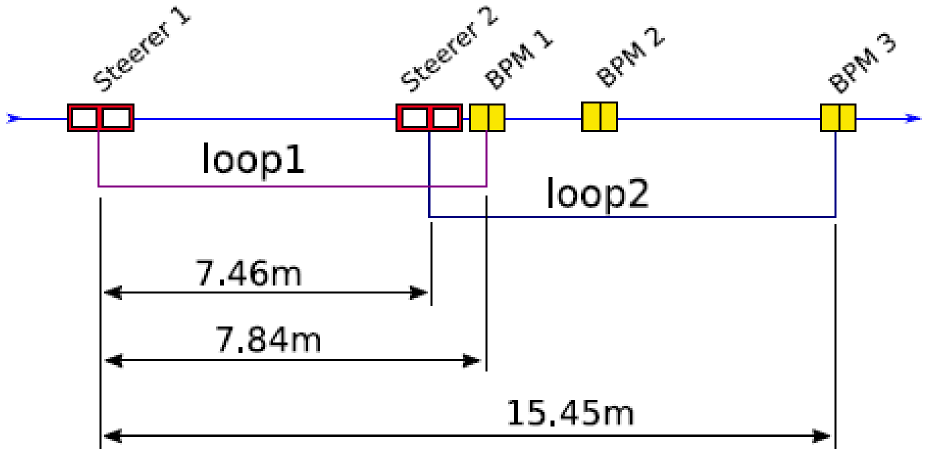
Polarization error assumed as $\Delta P/P$=0.5%!

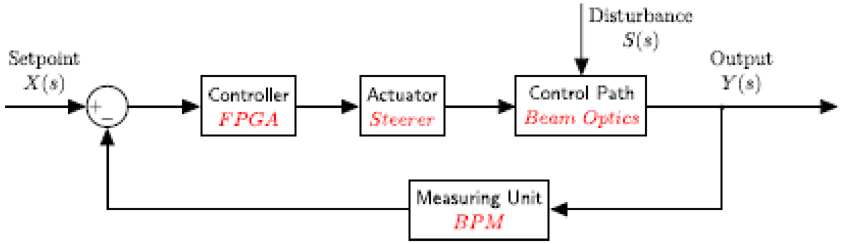
Demands concerning “false” asymmetries

Helicity dependend fluctuations of beam parameters must be measuredwith sufficently small uncertainty
→ Non –destructive (online) measurement
→ High sensitivity
→ Inherently stable beam parameters

Helicity correlated Fluctuation uncertainty	Allowed after run time/100=100hours	Measurement uncertainty after one switching period (2*0.5ms)
Current	0.1ppb	13.4ppm
Position (x,y)	1nm	14 μm
Angle (x’,y’)	0,236 nrad	3.2 μrad
Energy	0.4 eV	5.6keV

Example: Position/angle fluctuations

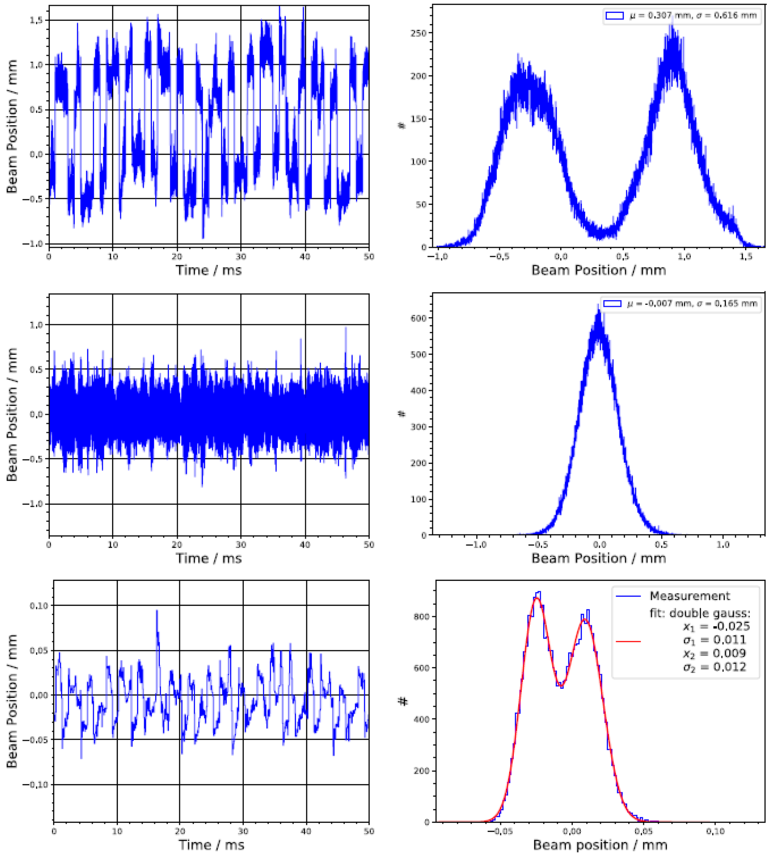




Result: The 14µm goal was achieved with the existing BPM's at MAMI

→ Long set up –I ntermediate optics, if any, has to be well understood

Position angle stabilization test experiment at MAMI (with artificially enlarged fluctuations)



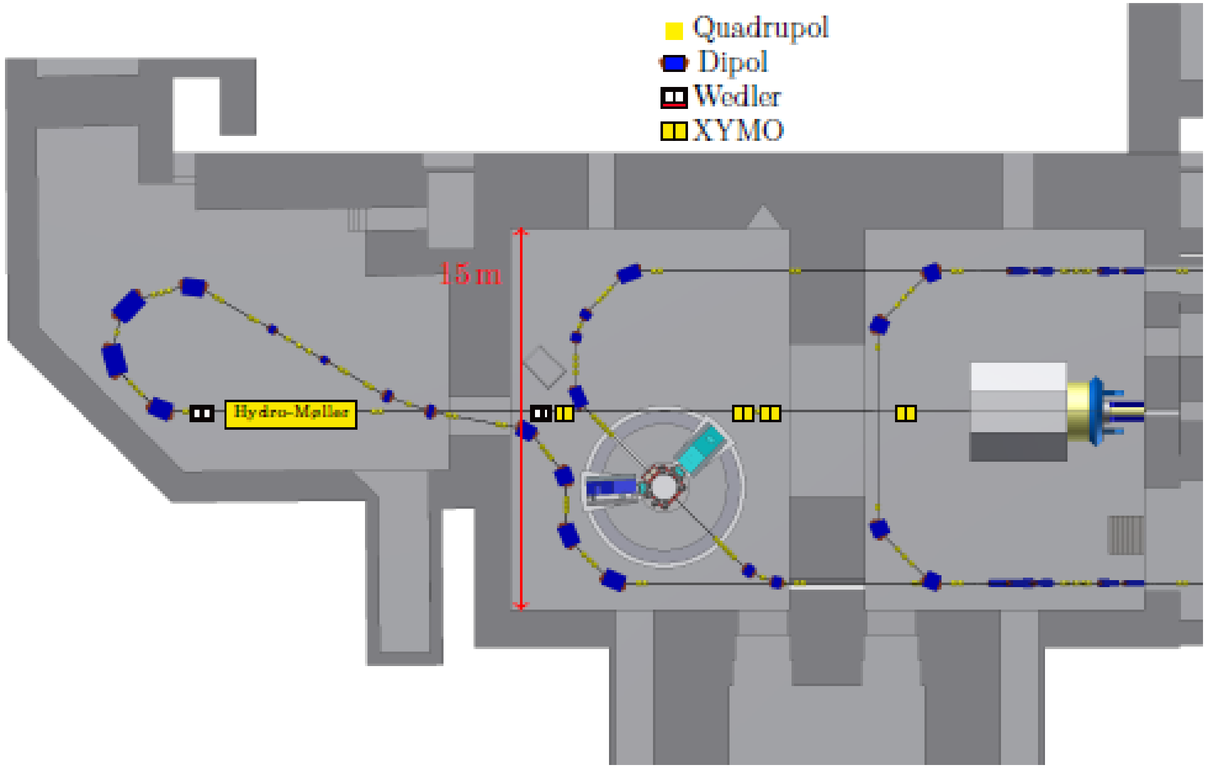
Fast Sampled, no stab.

Fast Sampled, stab.

Stab & averaged

R. Kempf et al. Nuclear Inst. and Methods in Physics Research, A 982 (2020) 164554

Example: Position/angle fluctuations



1.3 GHz “High Q” BPM
PhD Thesis Ruth Kempf
http://doi.org/10.25358/openscience-4991

Polarisation accuracy -Polarimetry

- P2-Hydrogen experiment demand: $0.5\% < \Delta P/P < 1\%$
- P2-Carbon-12 experiment demand $\Delta P/P < 0.3\ \%$

Note: Compton backscattering is not very promising

Concept of Polarimeter chain

- Three independend 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

Positions in the chain

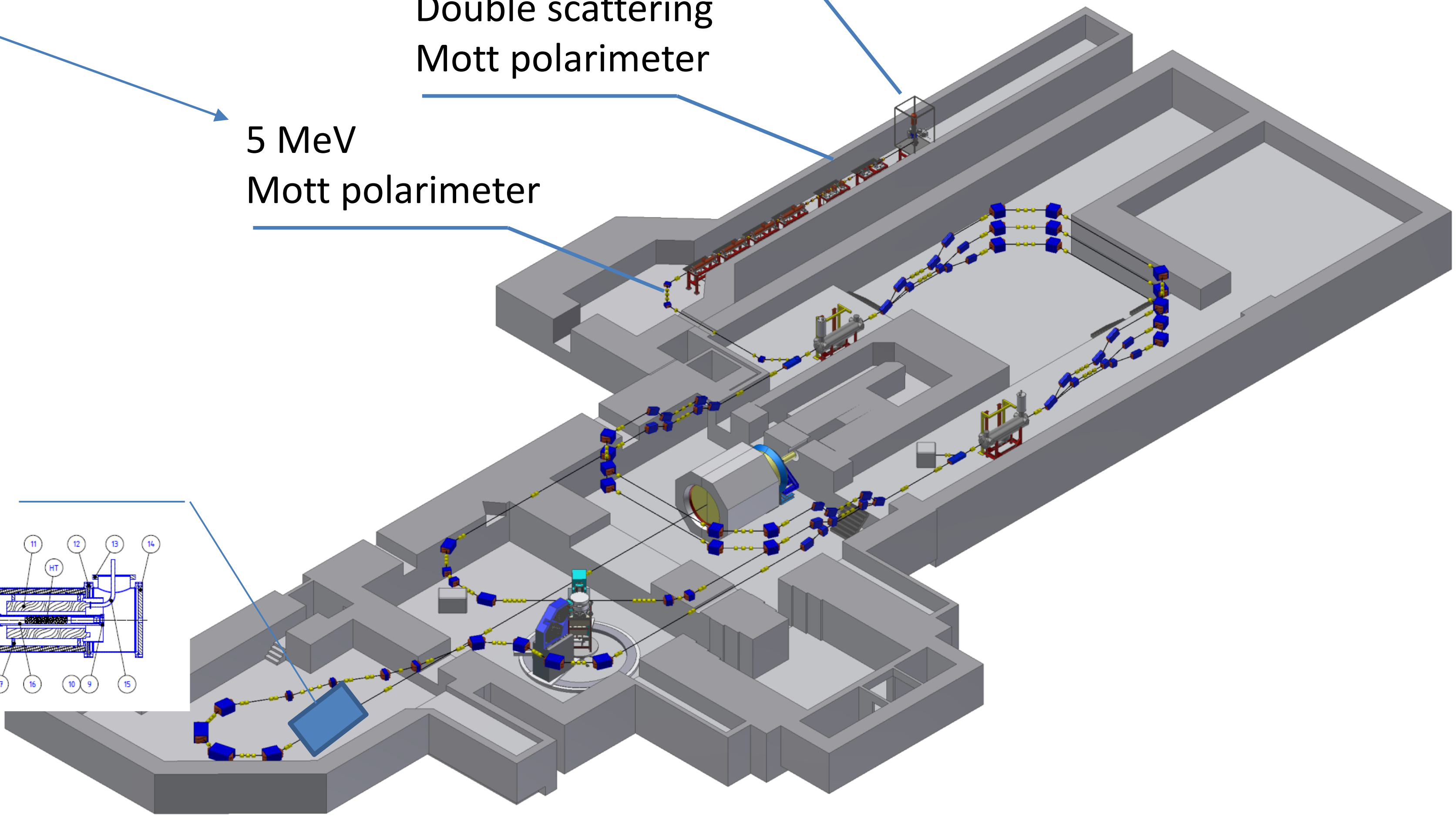
Electron source

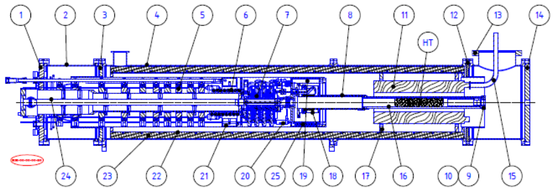
Double scattering
Mott polarimeter

Cooperation
With JLAB

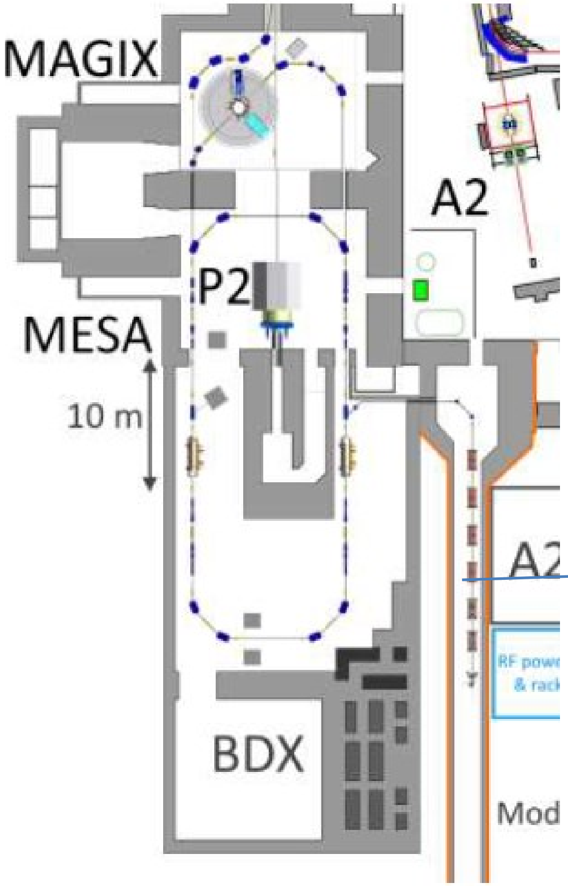
5 MeV
Mott polarimeter

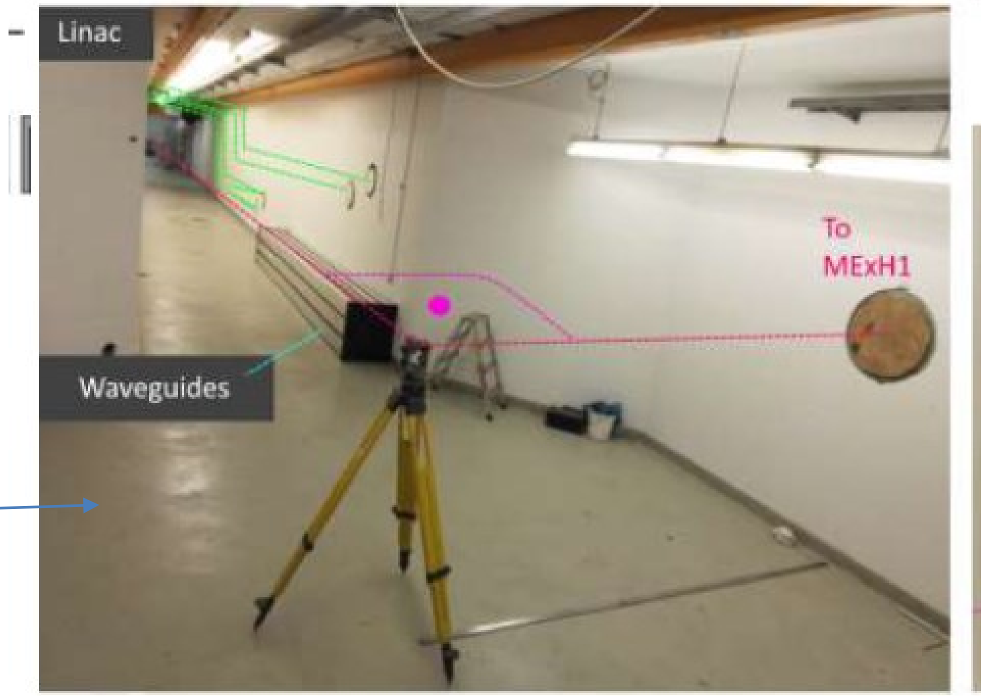
Hydro-Möller
(SPIN2021 # 194)





Status of injector and its polarimeters





- Still empty, but installation almost complete
- Erection of injector will take place in 2022/23
- Most of Mesa Low Energy Beam Apparatus (MELBA) was tested at different site(s)

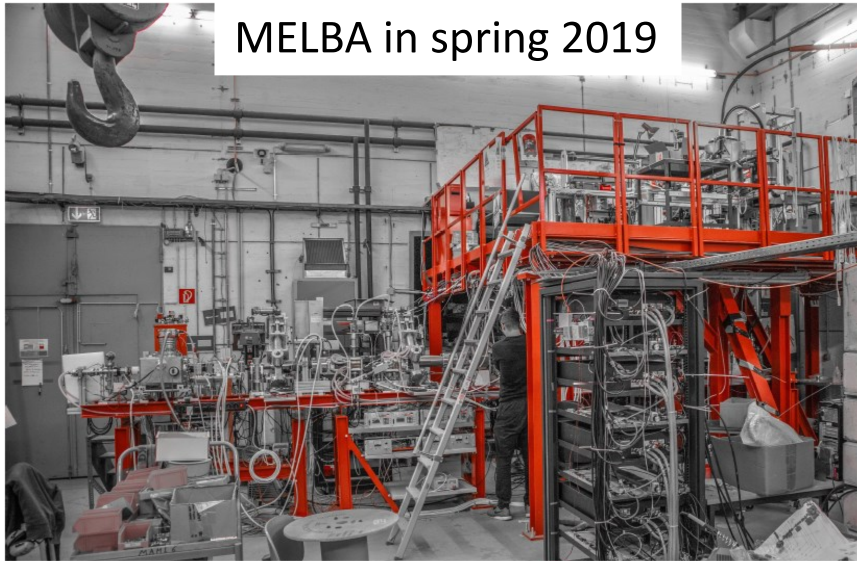
Source/beam preparation (MELBA) until July 2019

→ Operation with up to 100keV beam and up to 10mA beam current (>150kV possible, but not required)

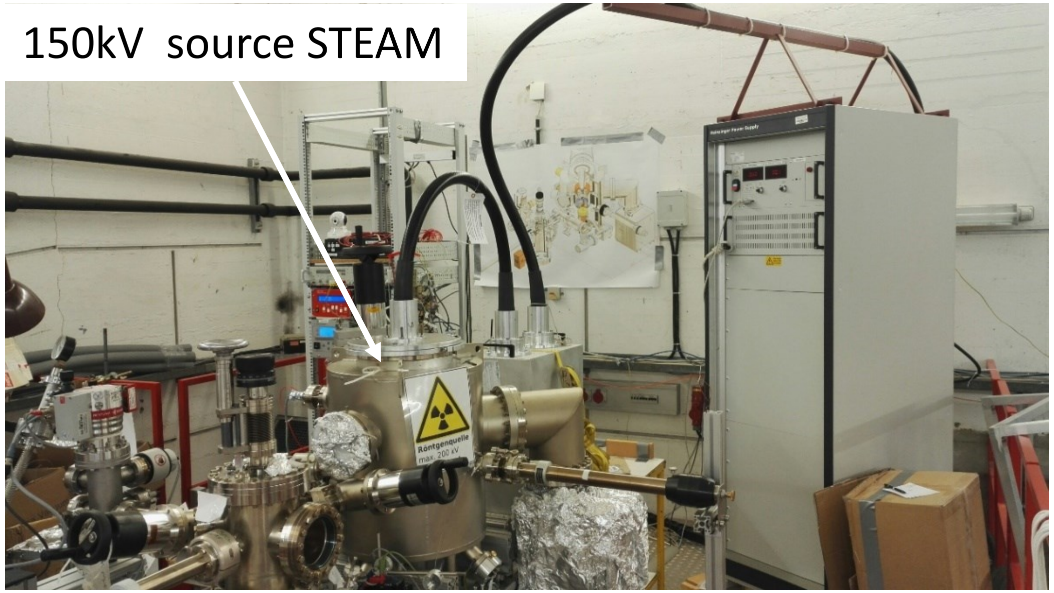
→ 4 PhD theses finished within this subproject

→ MELBA was dis-assembled and put in storage due to start of hall renovation for MESA

MELBA in spring 2019



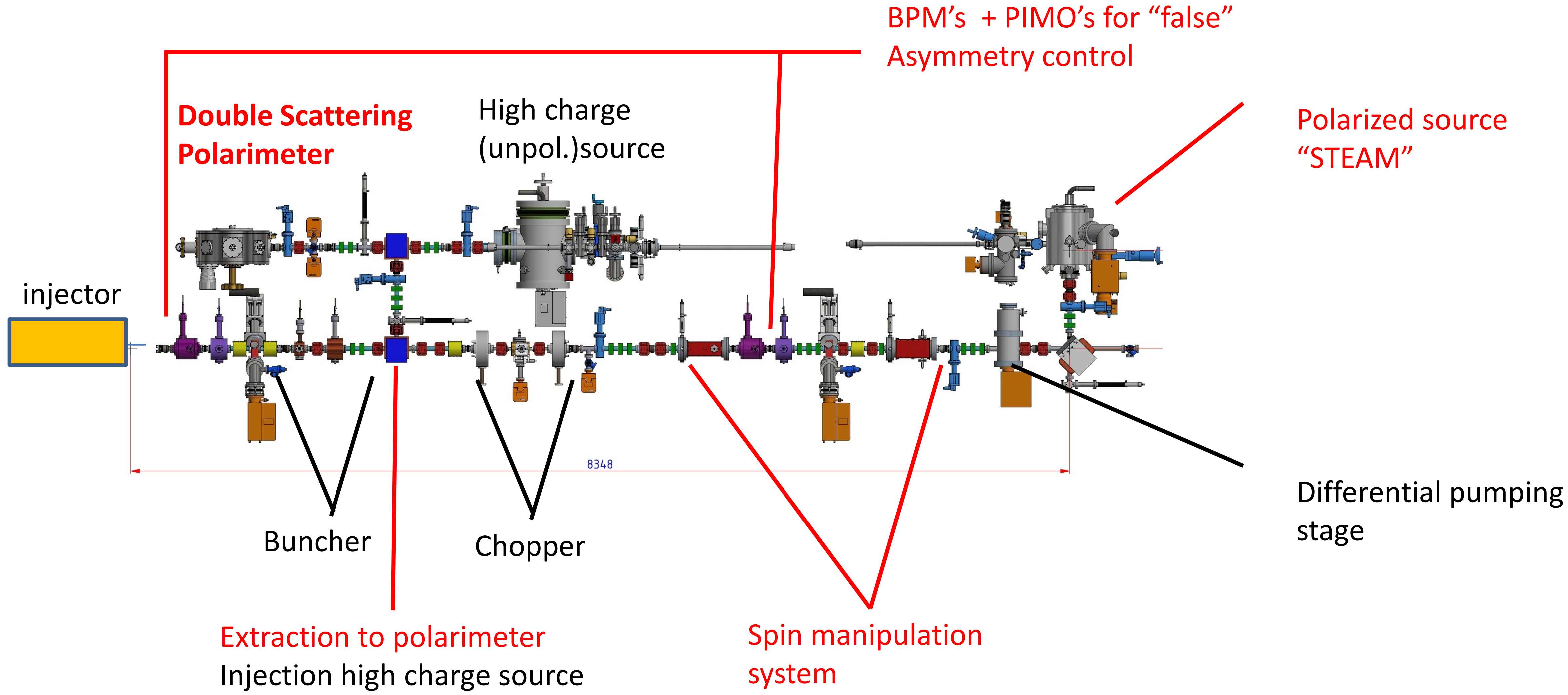
150kV source STEAM



Buncher cavity assembly

MELBA-group:
V. Bechthold, S. Friederich, P. Heil, C. Matejcek

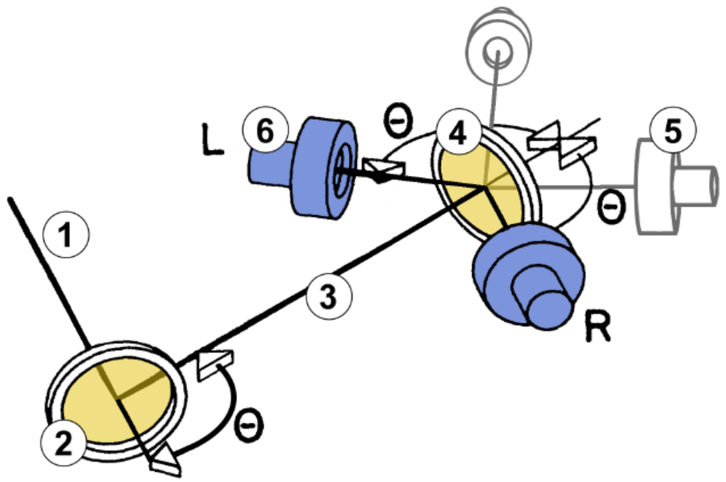
Planned set-up in tunnel



Double Scattering Mott Polarimeter (DSMP)

- The DSMP was perfectioned by the group of Prof. Kessler
  at University of Münster in the 1990ies:
  S. Mayer, T. Fischer, W. Blaschke, and J. Kessler, Review of scientic instruments 64, 952 (1993).
- The apparatus was transferred to Mainz
- It allows (in first order approximation) to determine the effective analyzing power S_{eff}
  by experimental observation only (no theory, no Monte-Carlo)
- $\Delta S_{eff}/S_{eff}$ may be lower than 0.3% → experimental verification required!
- Contribbutions of higher orders <10^{-3}

DSMP: Measurement of analyzing power



Double elastic scattering of an **unpolarized** beam (1) with two identical scattering processes (2,3,4) (targets, solid angles…)

- *Vertical polarization after first scattering*

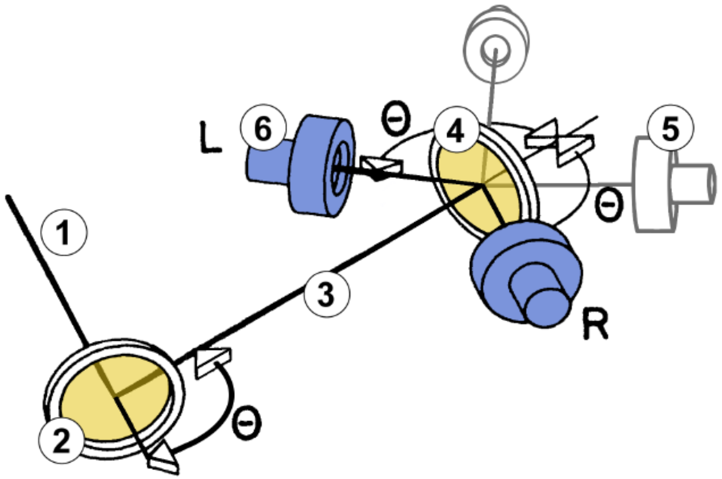
$$P_{vert} = S_{eff}$$

- Observed Left/Right asymmetry in second scattering (6)

$$A = S_{eff}^2$$

- The effective Analyzing power is measured as $S_{eff} = \sqrt{A}$
- With the exception of the assumption that in elastic scattering the anyalyzing 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 $P = A(Polbeam)/S_{eff}$ **(**this measurment only needs seconds**)**

Double scattering arrangement: concerns



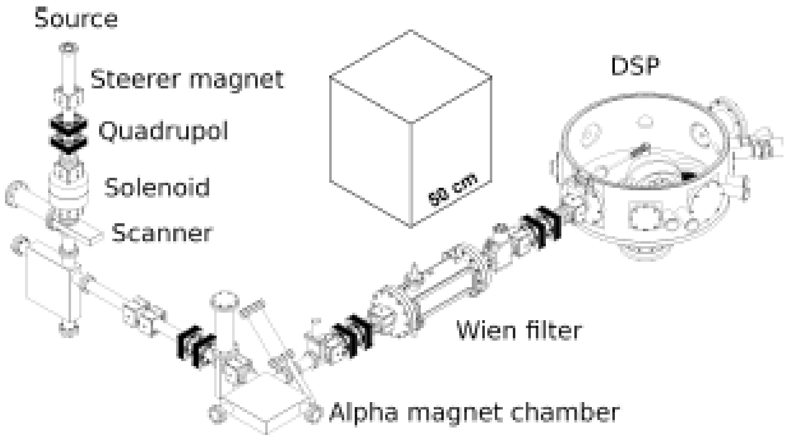
a) „False“ asymmetry cannot be elliminated
by switching the polarization
(since calibration is done by unpolarized beam)

b) Non identical processes and targets , in particular
background contributions

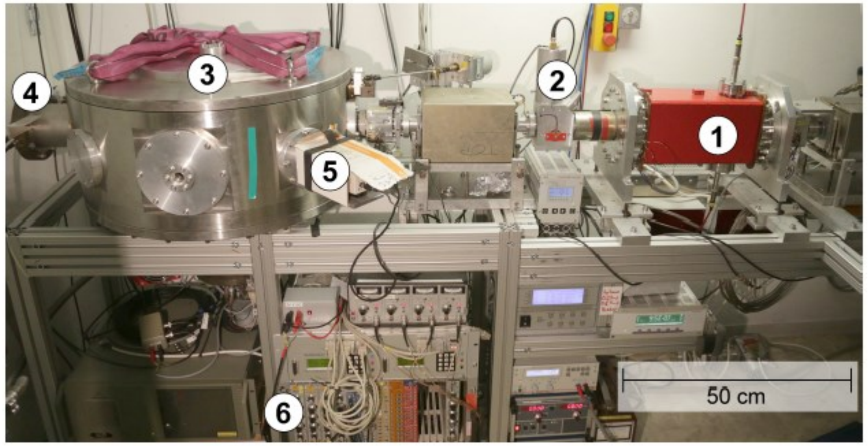
In a series of papers Kessler showed that a) can also be (to first order) eliminated by (many) measuring processes only. This requires in particular a careful arrangement of monitor counters (5)
b) was also resolved, both at a level of a few 10^{-3} relative uncertainty contribution

→ 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 in separate laboratory



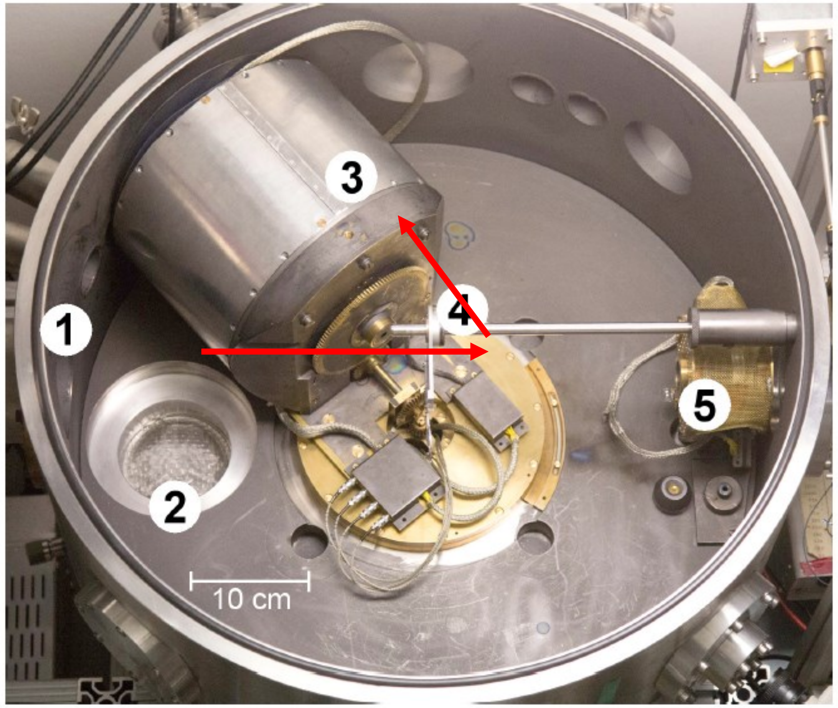
Sketch of beamline and
DSMP
First „success“: DSMP can be operated
For weeks without excessively
deteriorating the cathode



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



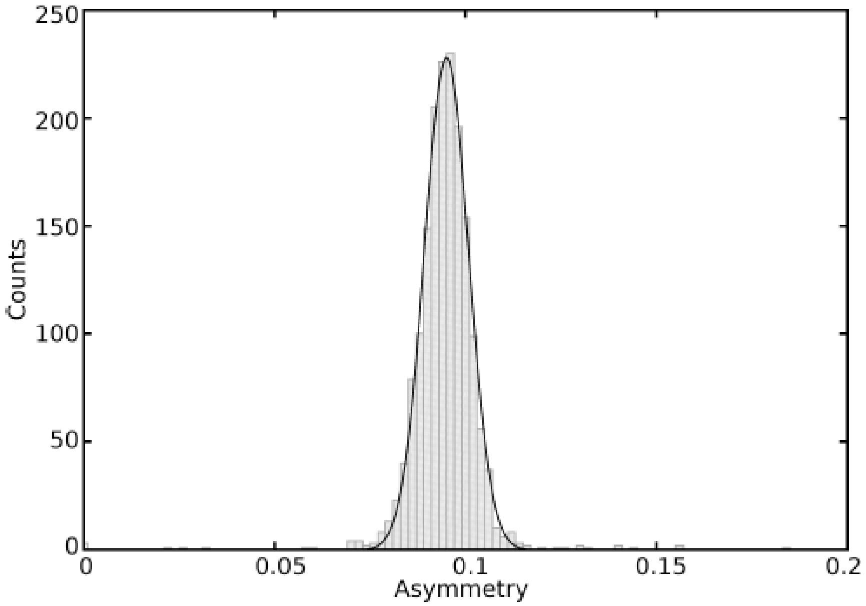
Figures from PhD work by M. Molitor

„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 fasle asymmety)

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

Calibration result



From M. Molitor, PhD Thesis

FIG. 5. Histogramm of $\approx$ 1600 cycles from the measurement of A, showing the Gaussian distribution with a mean value of 0.0948(1) and $\sigma = 0.005\,65(3)$

Measuring the double scattering asymmetry requires several days of beamtime for a statistical accuracy of 0.5%. After this calibration of S_{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 systemaitic uncertainty is low?

Removing the „identity“ requirement

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

$$A = S_{\mathrm{T}} S_{\mathrm{eff}}$$

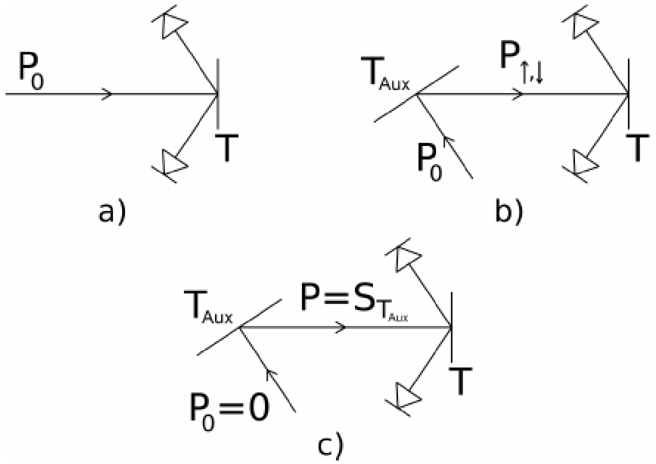
As realized by Hopster (*), a double scattering apparatus allows solving this by achieving additional asymmetry observables with poalrized beam, cases a),b)

$$A_0 = P_0 S_{\mathrm{eff}}$$ Case a)

$$A_{\mathrm{T}} = P_0 S_{\mathrm{T}}$$ Case b)

$$A_{\uparrow} = \frac{S_{\mathrm{T}} + \alpha P_0}{1 + P_0 S_{\mathrm{T}}}$$ Case b)

$$A_{\downarrow} = \frac{S_{\mathrm{T}} - \alpha P_0}{1 - P_0 S_{\mathrm{T}}}$$ Case b)



This yields five observables with four unknowns

(*) Hopster, H ; Abraham, DL: New method for accurate calibration of an electron-spin polarimeter.
In: RSI 59 (1988), Nr. 1, S. 49-51
Mayer, S. ; Fischer, T. ; Blaschke, W. ; Kessler, J.: Calibration of a Mott
electron polarimeter: Comparison of dierent methods. In: RSI
instruments 64 (1993), Nr. 4, S. 952{957

Consistency checks

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

$$S^2_{\mathrm{eff},(1)} = \frac{A_0 A}{A_\mathrm{T}} \qquad (14)$$

$$S^2_{\mathrm{eff},(2)} = \frac{A_0}{2A_\mathrm{T}} \left[A_\uparrow (1 + A_\mathrm{T}) + A_\downarrow (1 - A_\mathrm{T})\right] \qquad (15)$$

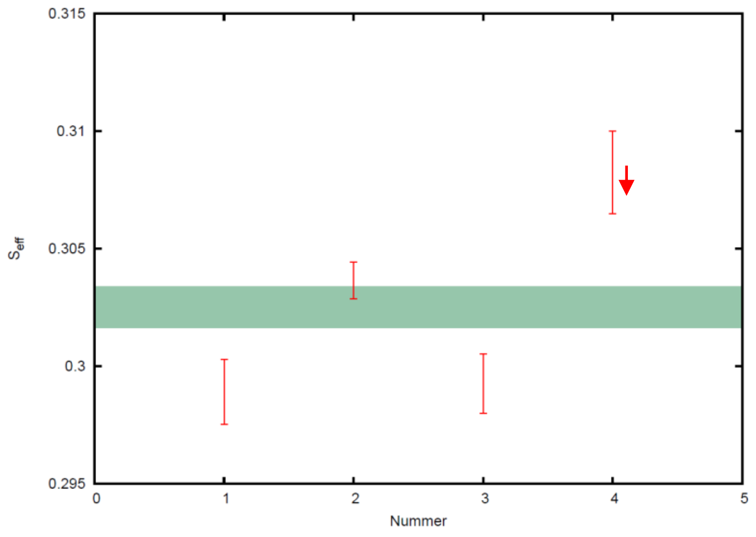
$$S^2_{\mathrm{eff},(3)} = \frac{A_0}{4A_\mathrm{T}} \frac{[A_\uparrow(1 + A_\mathrm{T})]^2 - [A_\downarrow(1 - A_\mathrm{T})]^2}{A_\uparrow (1 + A_\mathrm{T}) - A} \qquad (16)$$

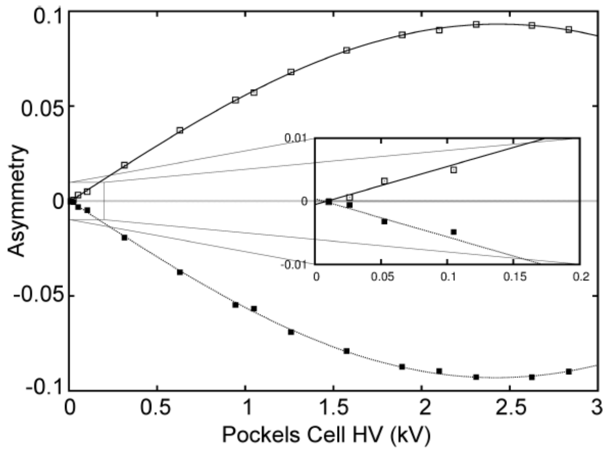
$$S^2_{\mathrm{eff},(4)} = \frac{A_0}{4A_\mathrm{T}} \frac{[A_\downarrow(1 - A_\mathrm{T})]^2 - [A_\uparrow(1 + A_\mathrm{T})]^2}{A_\downarrow (1 - A_\mathrm{T}) - A} \qquad (17)$$

We first neglected that it is not completely trivial to achieve an unpolarized beam with a GaAs-source.....

Consistency checks

M. Molitor et al.





Results obtained with
a residual beam polarization of 0.7%
(2.1% of maximum polarization).
After finding this, the result can
be corrected.

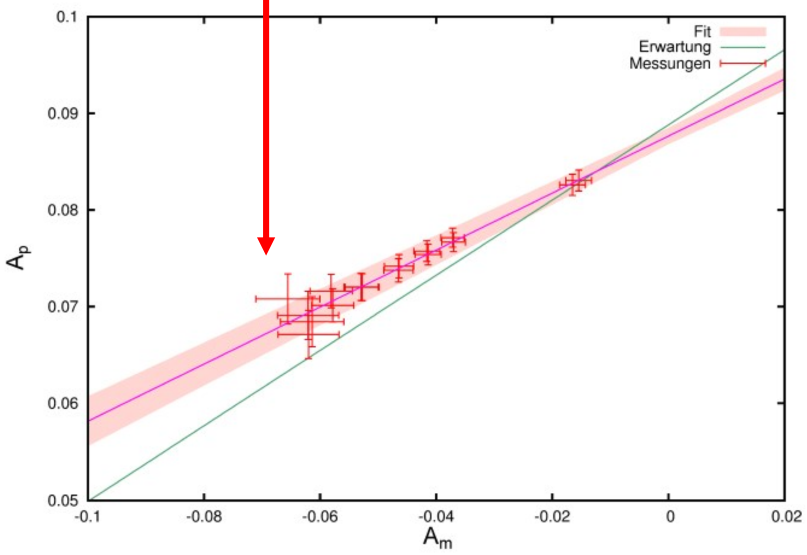
Equation	S_{eff}	S_{eff} w corrections
11	0.2984(8)	0.2992(8)
12	0.3045(4)	0.3045(4)
13	0.2989(3)	0.2995(3)
14	0.3104(1)	0.3096(1)

Discrepancy can probably not be
explained by residual beam polarization

DSMP:Status error budget

Unsicherheiten die $\Delta P/P$ beeinflussen	$\Delta P/P$
Monitorzählerkorrekturfaktor c	1,04 %
Monitorzähler Asymmetrie Korrektur	0,25 %
Gestreuter Elektronenstrahl	0,12 %
Laser-Lichtpolarisation	$\leq$ 0,10 %
Rückstreuung in sekundärer Streukammer	<0,10 %
Annahme: $S_{pol} = S_{eff}$	$\leq$ 0,01 %
Spinrotation im Erdmagnetfeld	< 0,01 %
180° Detektortauschgenauigkeit	< 0,01 %
Summe der zu berücksichtigen Unsicherheiten	$\leq$1,64 %

Problem: Cross-check Concerning apparatus asymmetry does not exactly work (yet).



Perspective: Integration of DSP into MELBA at MESA

Outlook-spin injector (MELBA)

Source/Chopper/buncher

- Was tested and will be reinstalled and commissioned in tunnel in 22
- Extraction beamline to DSMP also incorprated
- Spin manipulation: established system, partial installation 22, full commissioning 23
- 5 MeV beam in 23 (for second Mottpolarimeter)

DSMP:

- DSMP will transfered to MESA injector
- Main open issue is the coonsistency of correction for „false“ asymmetries
- If that can be resolved, an accuracy <0.5 % is possible

Thank you