# Low Energy Polarimetry at MESA

Video Workshop on **Beam Polarization and Polarimetry at EIC**

by Kurt Aulenbacher

Cluster of Excellence
PRISMA+
Precision Physics, Fundamental Interactions and Structure of Matter

# 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

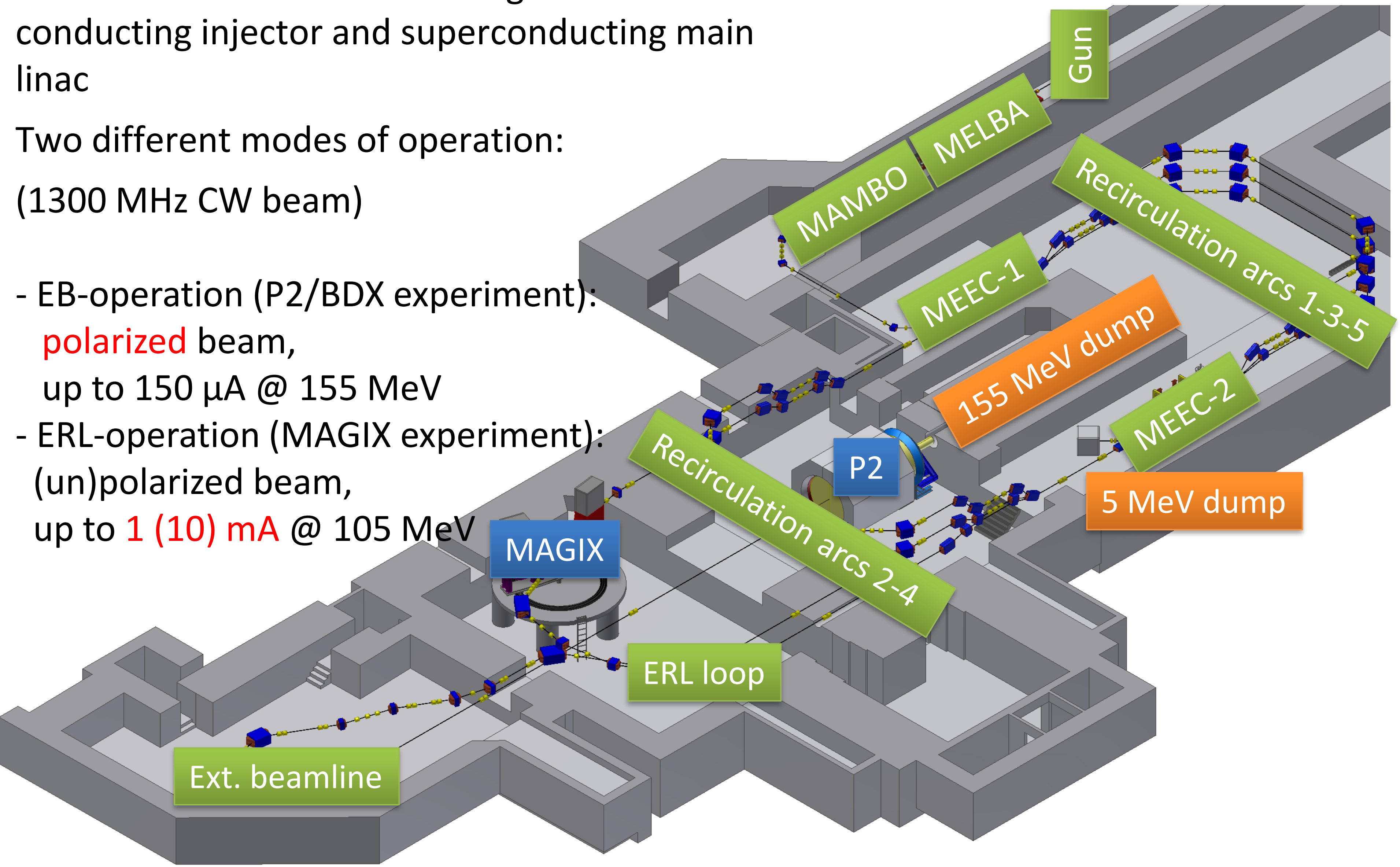
# MESA Accelerator Layout

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

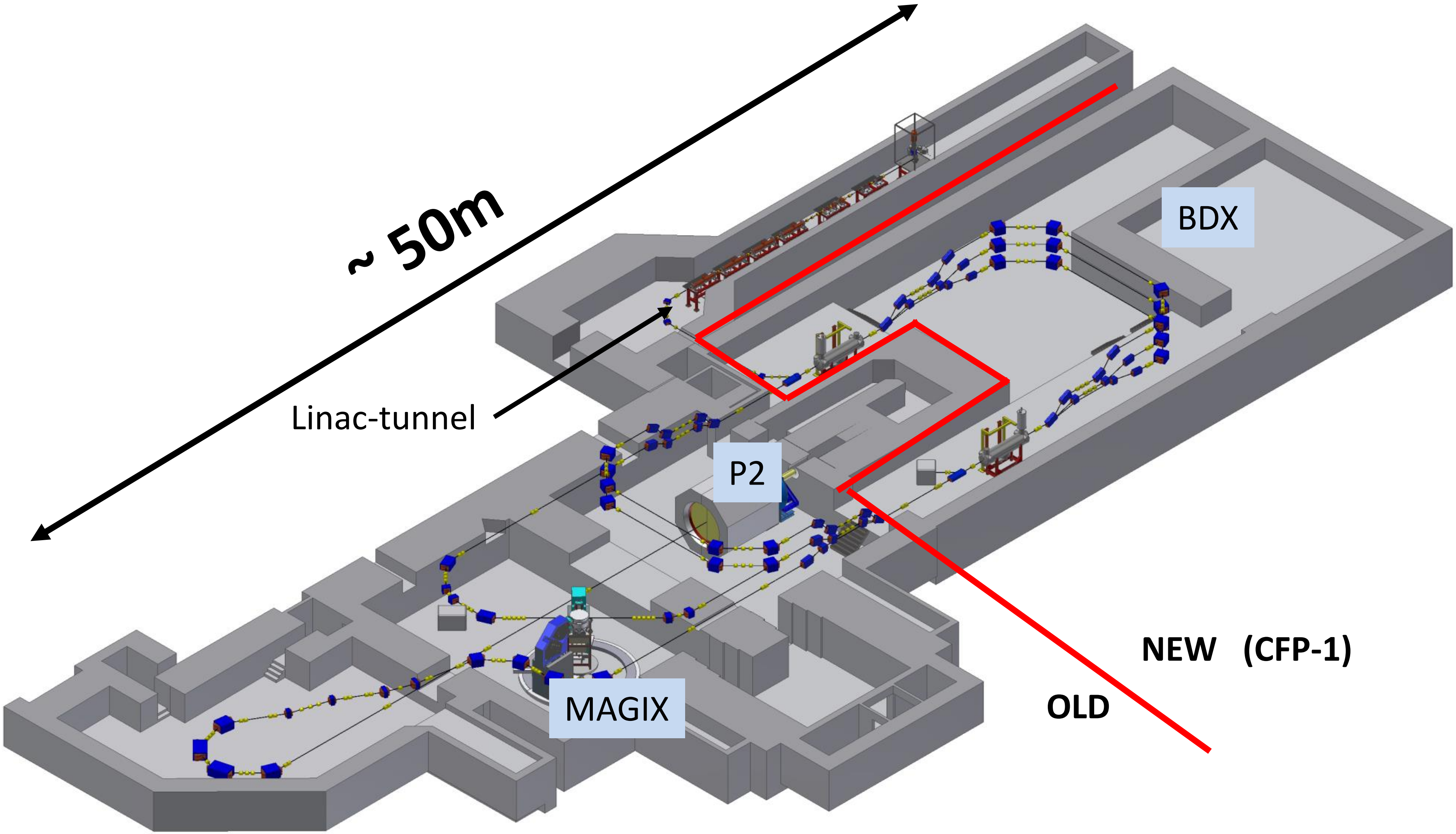
Two different modes of operation:

(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



# New experimental halls
# ...for more and larger experiments

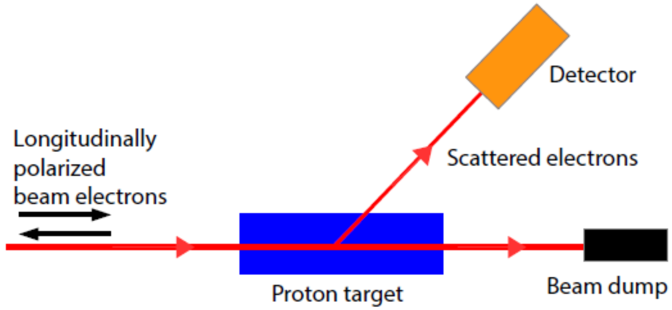


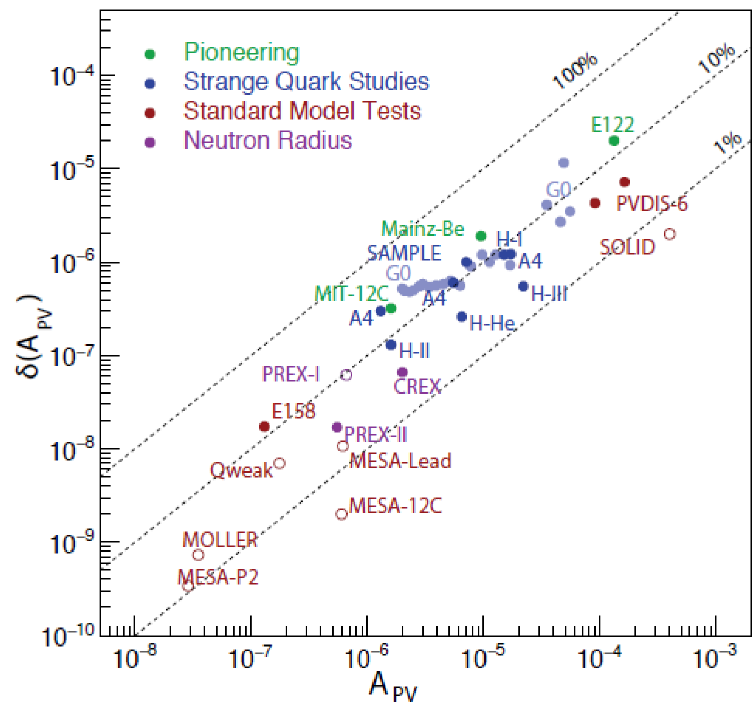
# MESA Civil construction status May/2020

Main accelerator installation cannot begin before winter 21/22 !

# Polarization –accuracy requirements

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




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

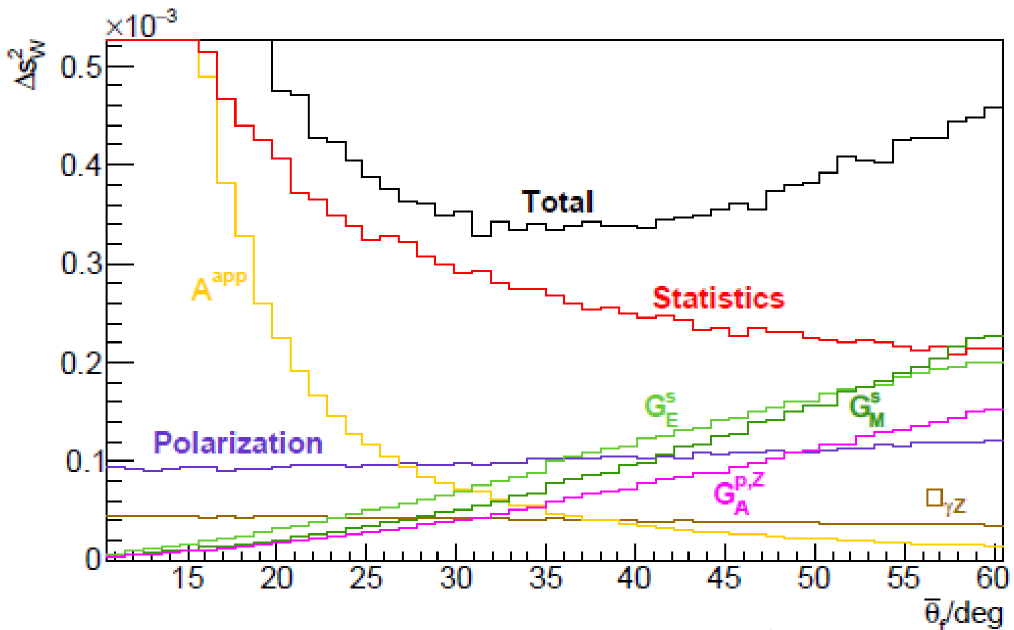
But: $A^{exp}=P*A^{PV}$

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

# 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 $\Delta P/P=0.5\%$!

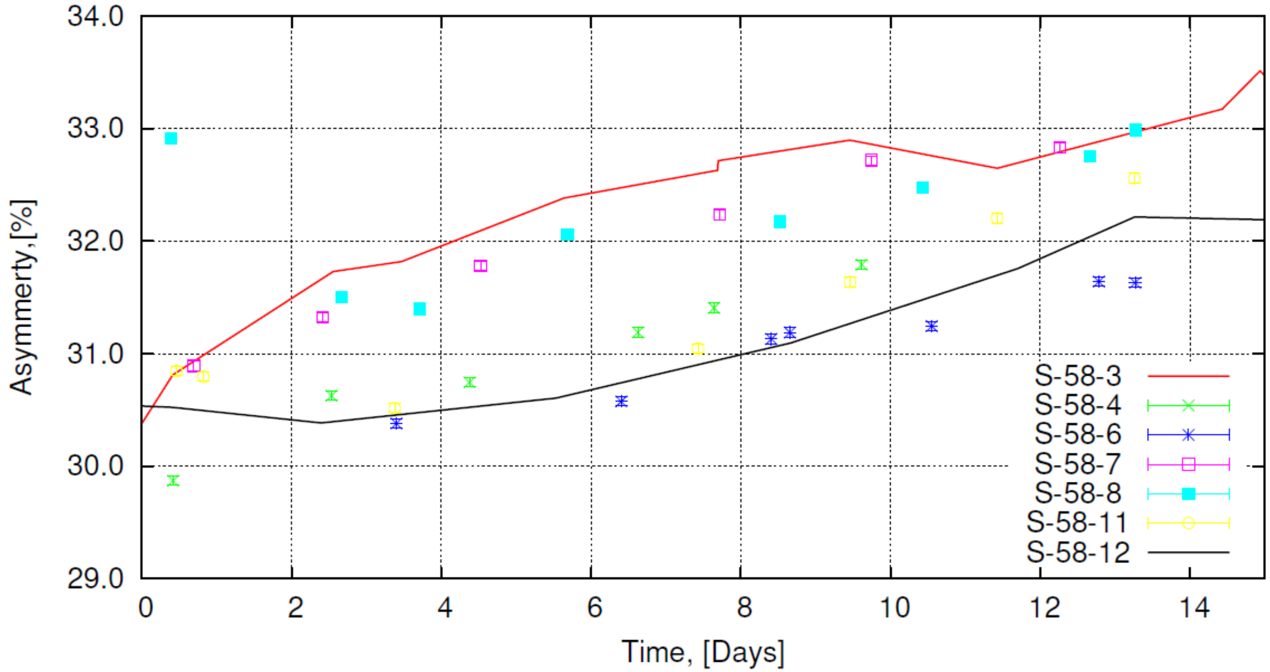
Average scattering angle at $E_{beam}$=155 MeV

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

# Concept of Polarimeter chain

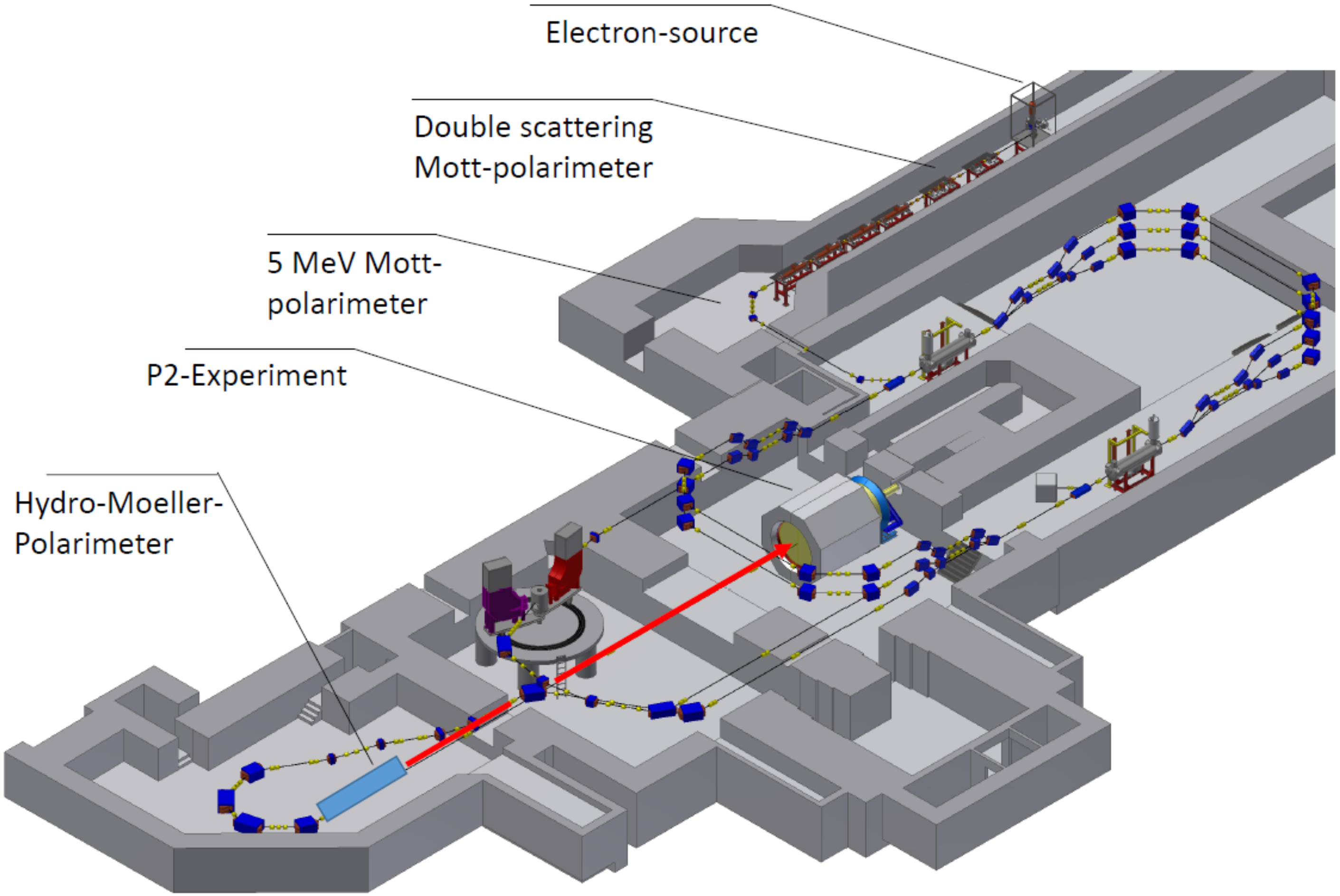
- Three independend polarimeters forming the chain
- Operating at 0.1; 5; and 155 MeV
- Each having sub-percent accuracy, (aiming at <0.5%)
- One of them operating online

# 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

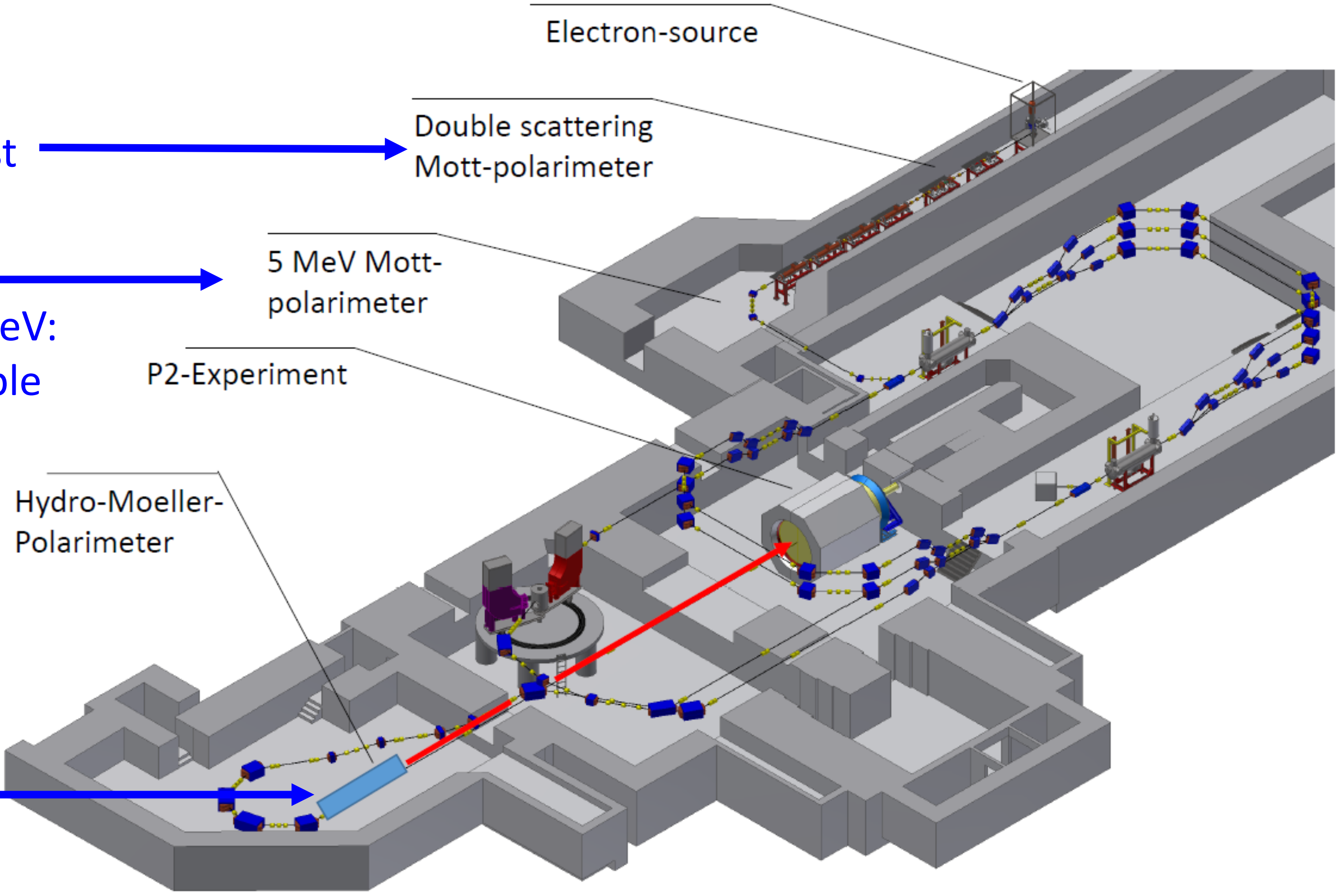
# Positions in the chain



# Status of the chain

DSMP @ 0.1 MeV:
Measurements exist

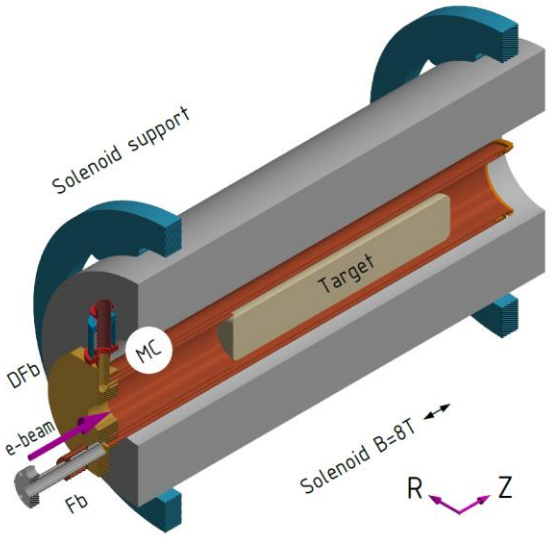
MP @ 5 MeV:
Experience at 3.5 MeV:
<1% accuracy possible
(limited by theory)




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

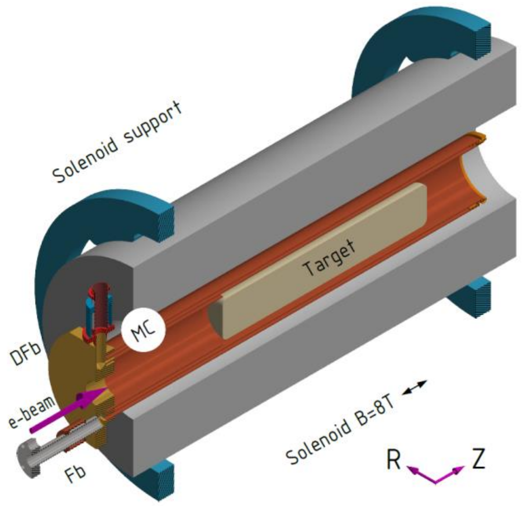
- Suggested by Chudakov and Luppov E. Chudakov and V. Luppov, Moller polarimetry with atomic hydrogen targets Nuclear Science, IEEE Transactions on 51 (2004) 1533.
- Trapping H-atoms at 0.3 K. Cooling by collisions with suparfluid helium
- Leads to axial trapping by solenoid and radial trapping by wall 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-ε with $\varepsilon<10^{-4}$ → suppression of error from target polarization
- No Levchuk effect
- → $\Delta P/P < 0.5\%$?



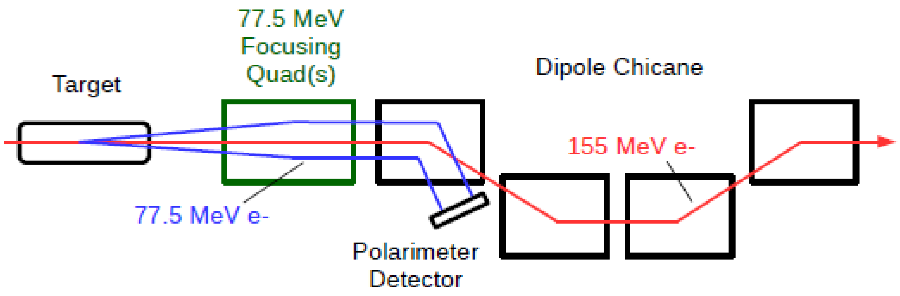




**Figure from: D. Becker et al., Eur. Phys. J. A (2018) 54 : 208**

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

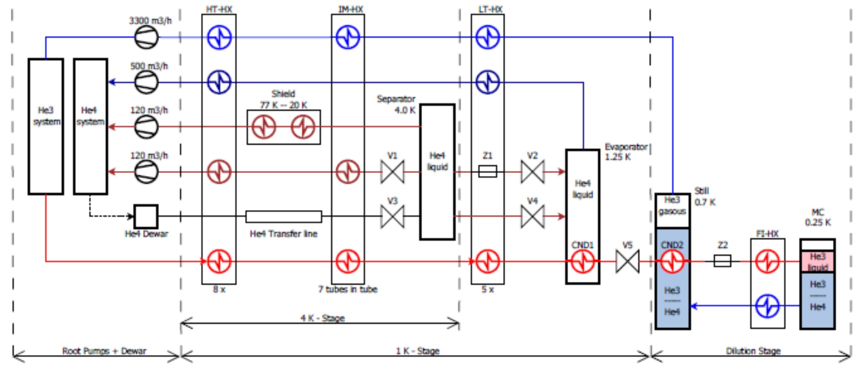



**Figure 4:** Refrigerator flow chart. HX=Heat exchanger. HT/IM/LT = high, medium and low temperature level of precooling circuit.

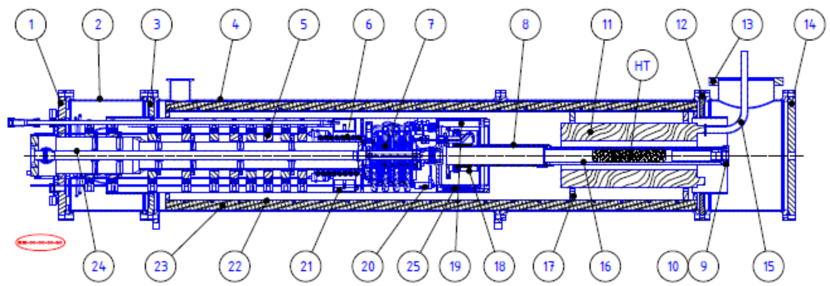
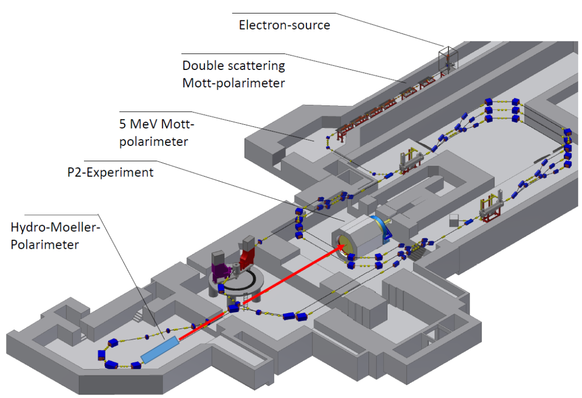



**Figure 5:** Schematic of the Hydro-Møller atomic trap. 1 - port flange , 2 - cross, 3 - connector flange cryostat, 4 - housing, 5 - high temperature HX, 6 - intermediate temperature HX , 7 - low temperature HX, 8 - final HX, 9 - one-sided film burner, 10 - double-sided film burner, 11 - super conducting 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

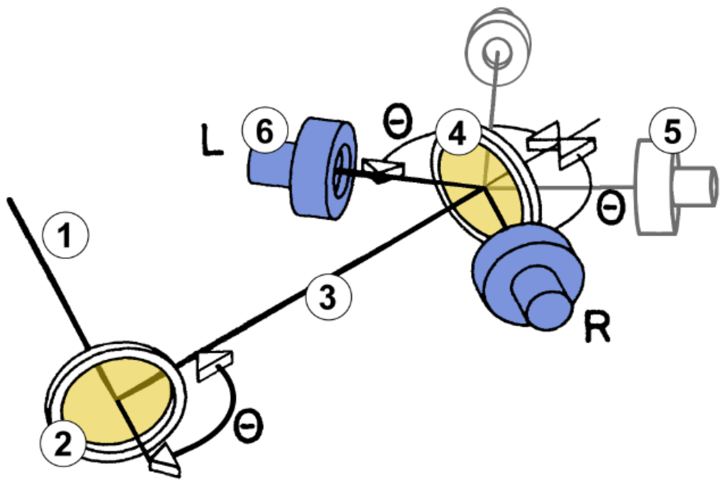



Upper frame: Schematic of Refrigerator
Lower frame: cross section
of trap with refrigerator

# Double Scattering Mott Polarimeter (DSMP)

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

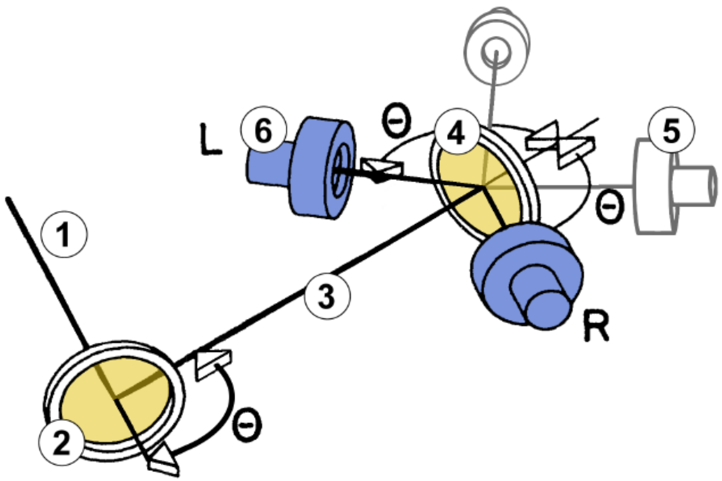
$$P_{vert} = S_{eff}$$

- 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

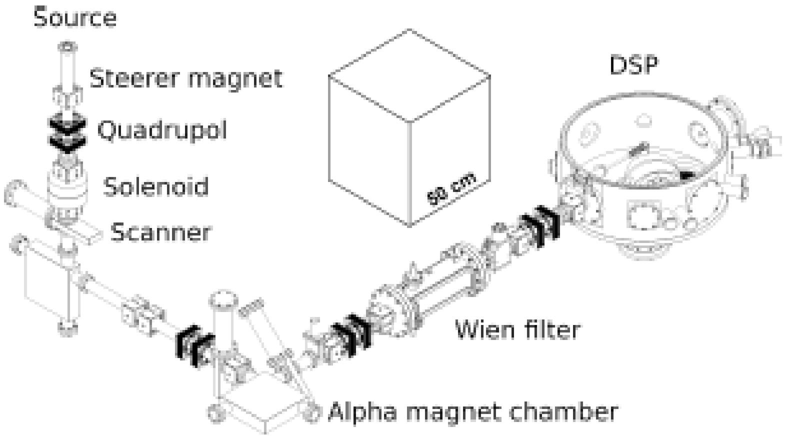



a) „False“ asymmetry cannot be elliminated
by switching the polarization
(since calibration is done by unpolarized beam)
b) Non identical processes and targets , in particular
background contributions

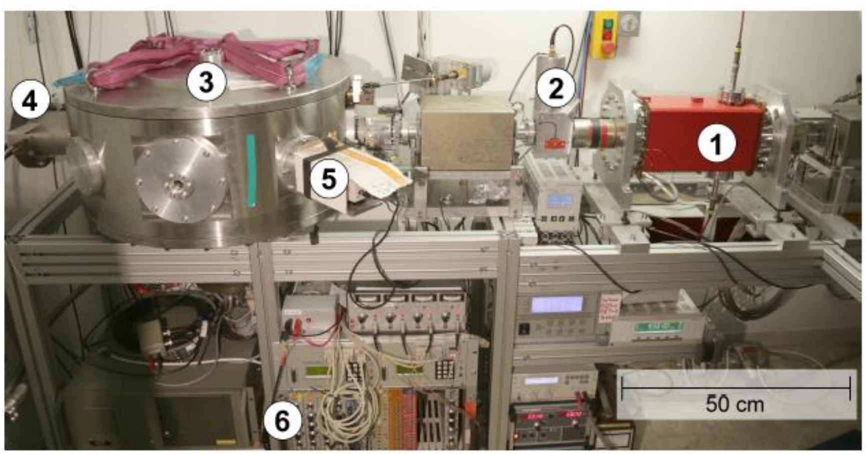
In a series of papers Kessler showed that a) can also be (to first order) eliminated by (many) measuring processes only. This requires in particular a careful arrangement of monitor counters (5)
b) was also resolved, both at a level of a few $10^{-3}$ relative uncertainty contribution

→ 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



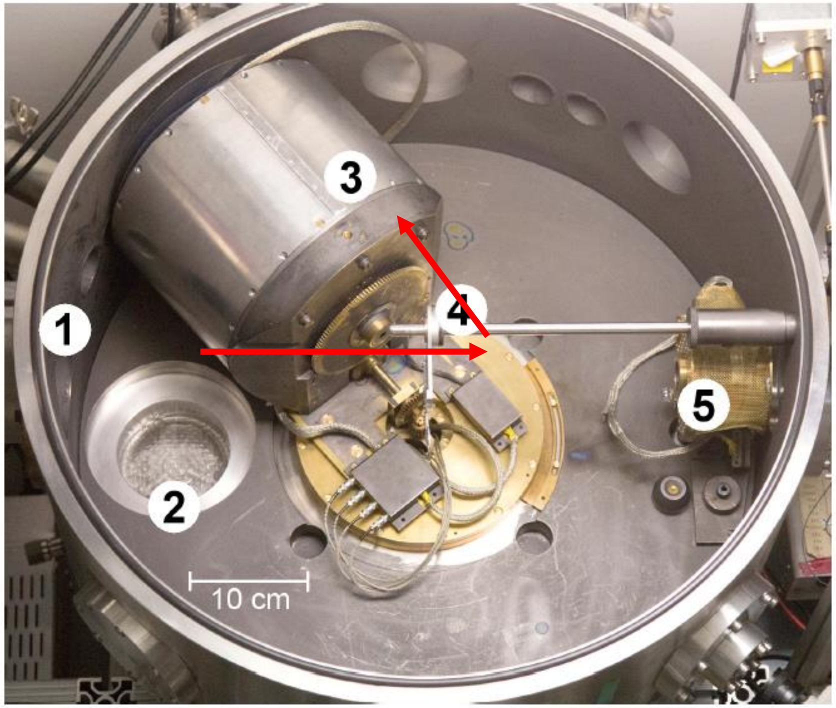

Sketch of beamline and
DSMP
First „success“: DSMP can be operated
For weeks without excessively
deteriorating the cathode




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

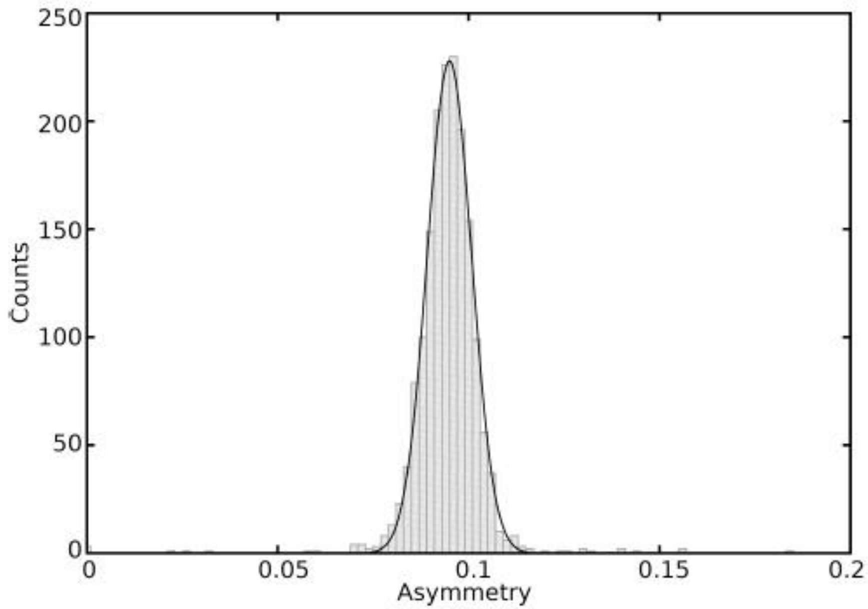



FIG. 5. Histogramm of ≈ 1600 cycles from the measurement of $A$, showing the Gaussian distribution with a mean value of 0.0948(1) and $\sigma = 0.005\,65(3)$

From M. Molitor et al.
Publication in preparation

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

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

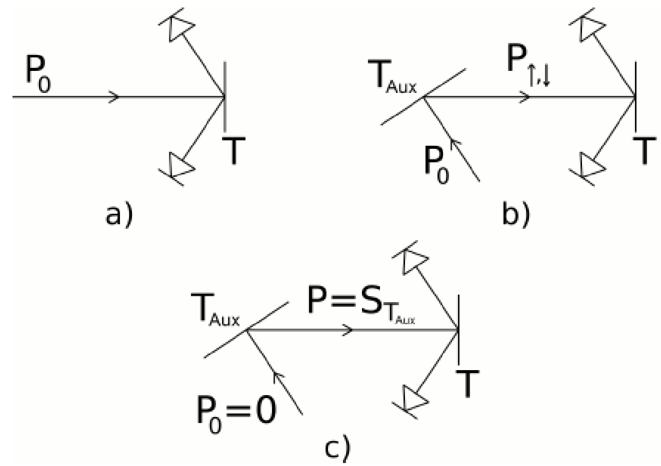
As realized by Hopster (*), a double scattering apparatus allows solving this by achieving additional asymmetry observables with poalrized beam, cases a),b)

$$A_0 = P_0 S_{\mathrm{eff}}$$ 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

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

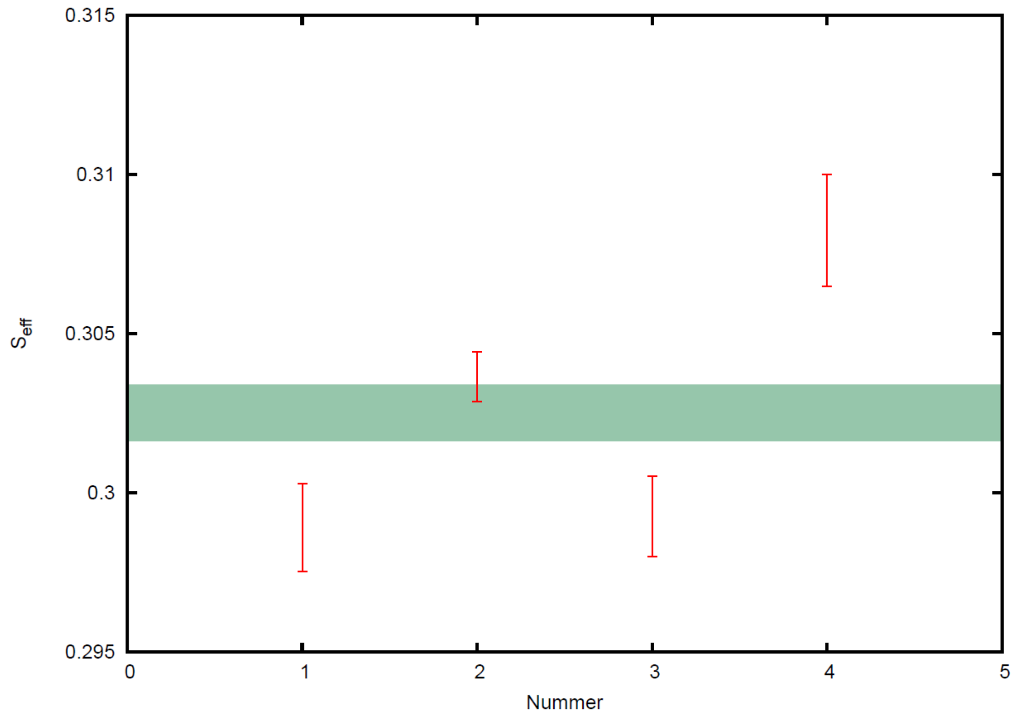
$$S^2_{\mathrm{eff},(2)} = \frac{A_0}{2A_\mathrm{T}} \left[A_\uparrow (1 + A_\mathrm{T}) + A_\downarrow (1 - A_\mathrm{T})\right] \tag{15}$$

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

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

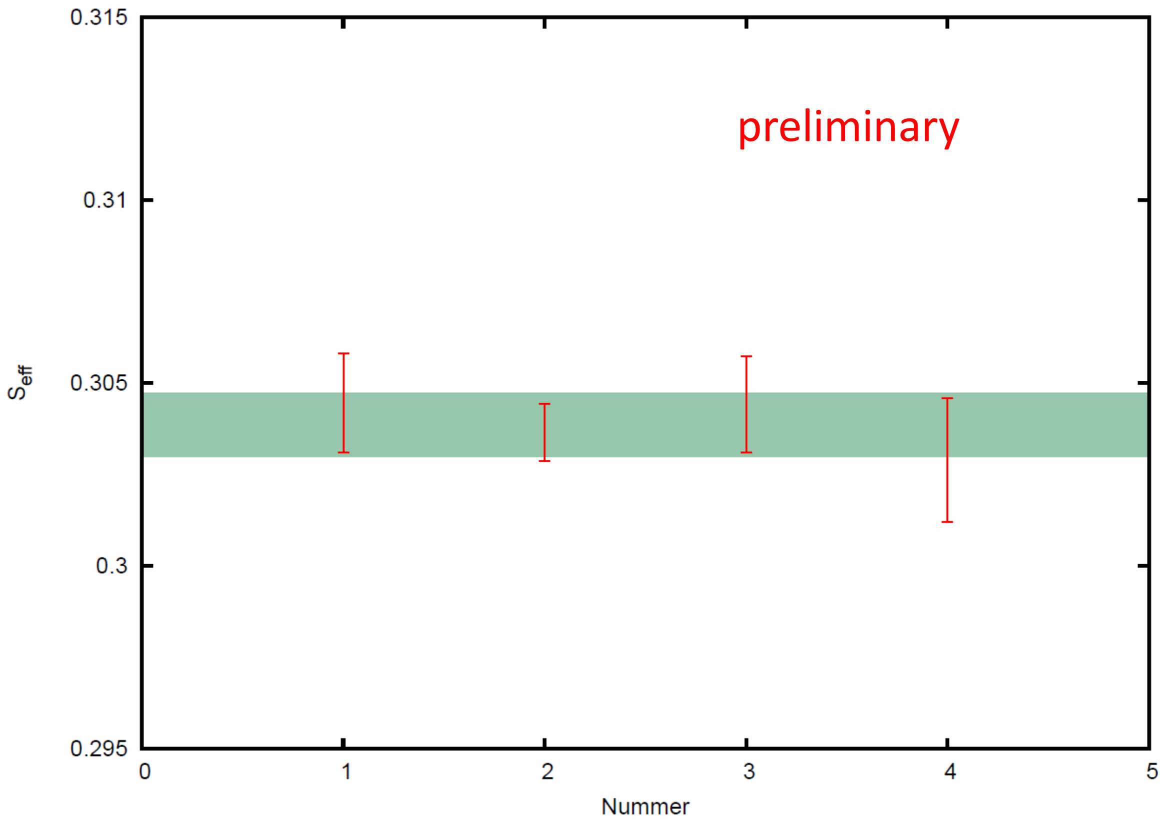
We first neglected that it is not completely trivial to achieve an unpolarized beam with a GaAs-source…..

# Consistency checks




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

# Consistency checks

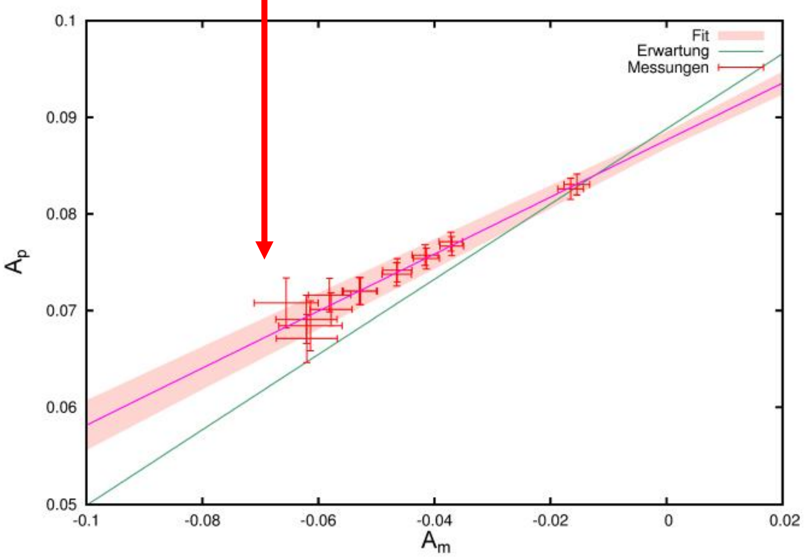



After determination of the residual polarization, the extractions using the unpolarized beam can be corrected. Then, the results are consistent within 0.1%.

# 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).



# Outlook

## DSMP:

- This year we will try to obtain consistent results without correction („true uunpolarized beam“) still in the „PKA2“ test-lab
- DSMP will transfered to MESA injector in 2021
- Main open issue is the coonsistency 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

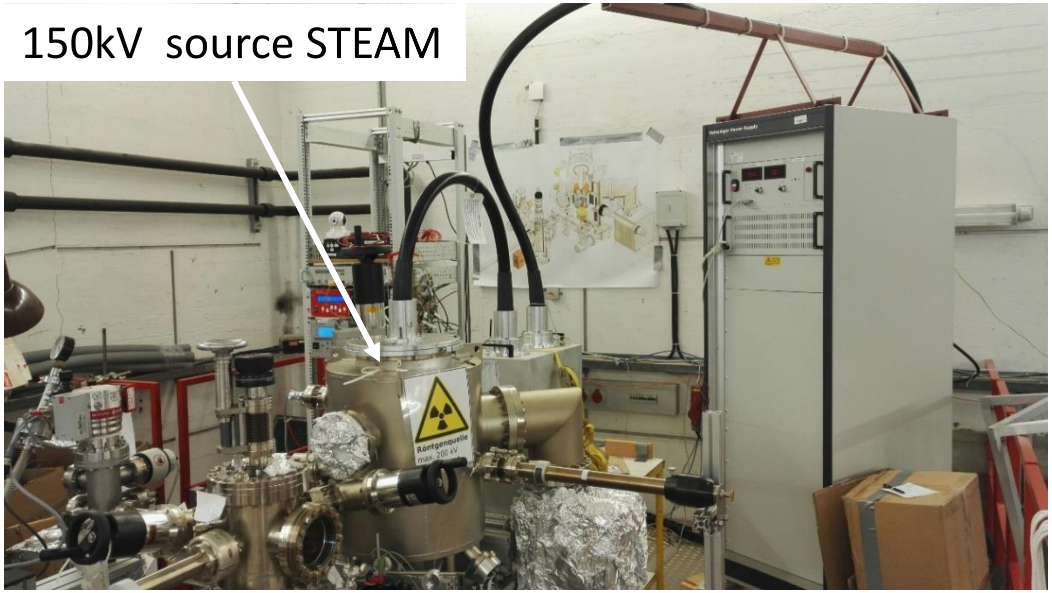
→ Lots of work, cooperation, collaboration or simply help would be greatly appreciated!

# 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**

MELBA in spring 2019



150kV source STEAM

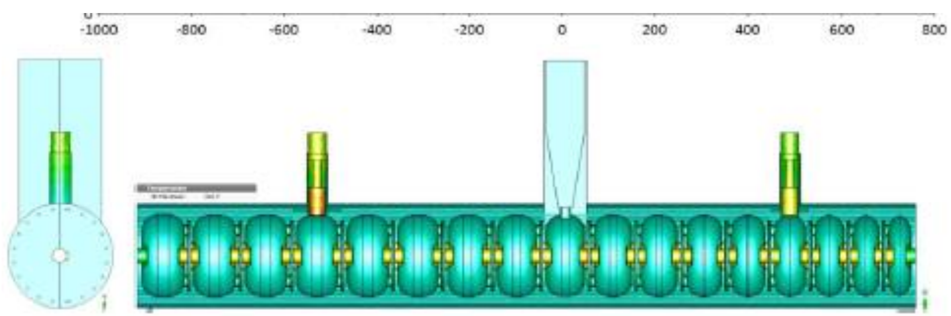
Buncher cavity assembly



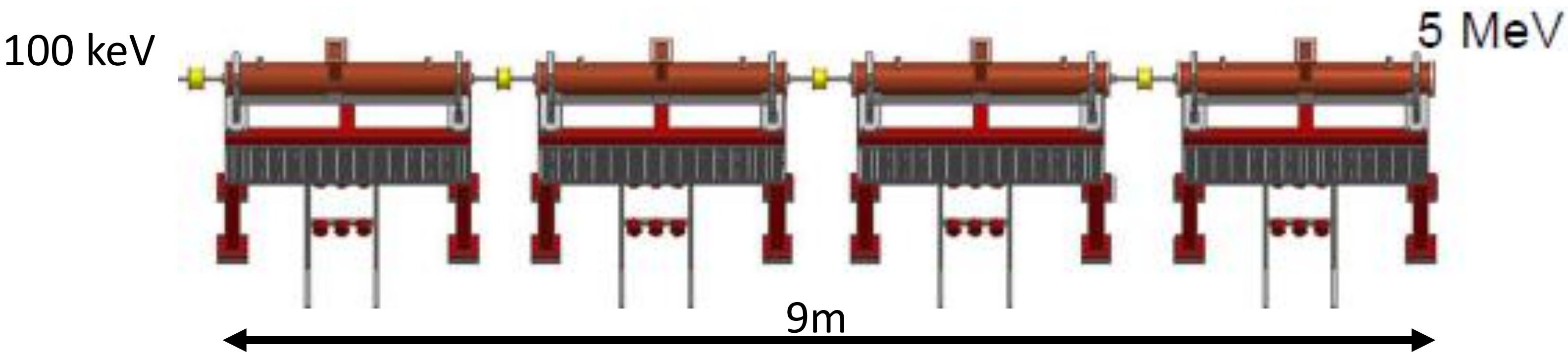
*MELBA-group:*
*V. Bechthold, S. Friederich, P. Heil, C. Matejcek*

# 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)

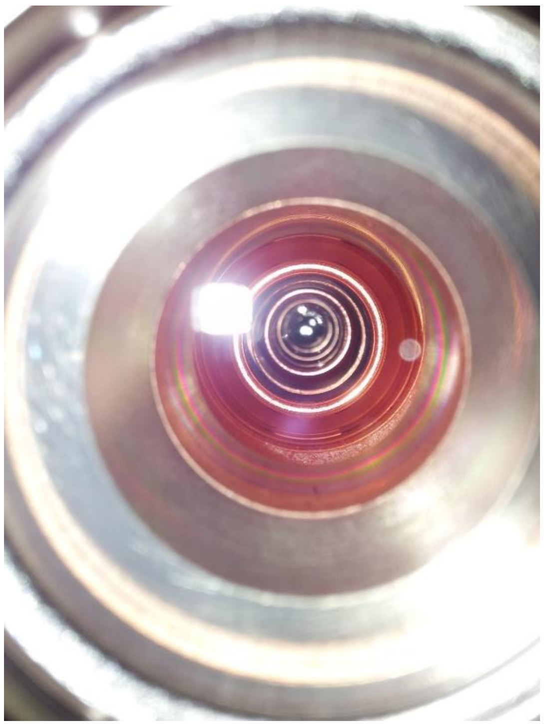


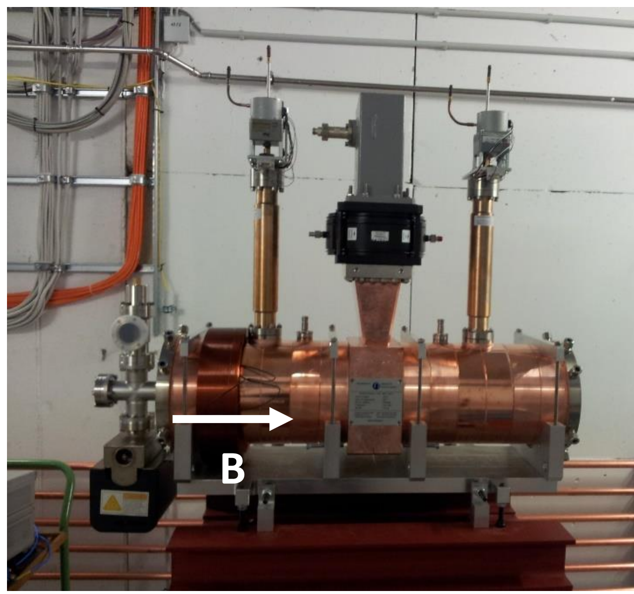

Cross section view

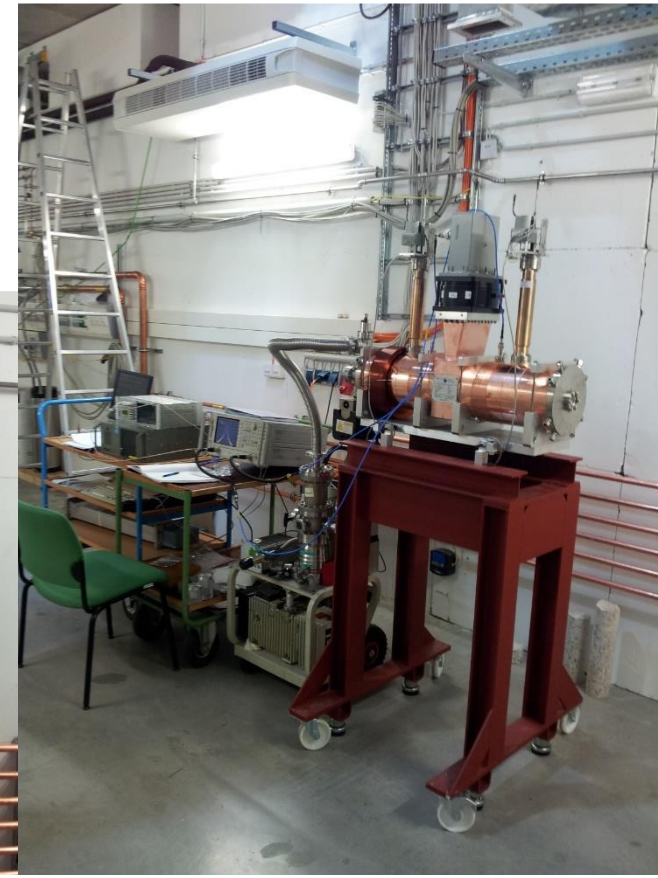


# MAMBO Booster: Prototype Cavity

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



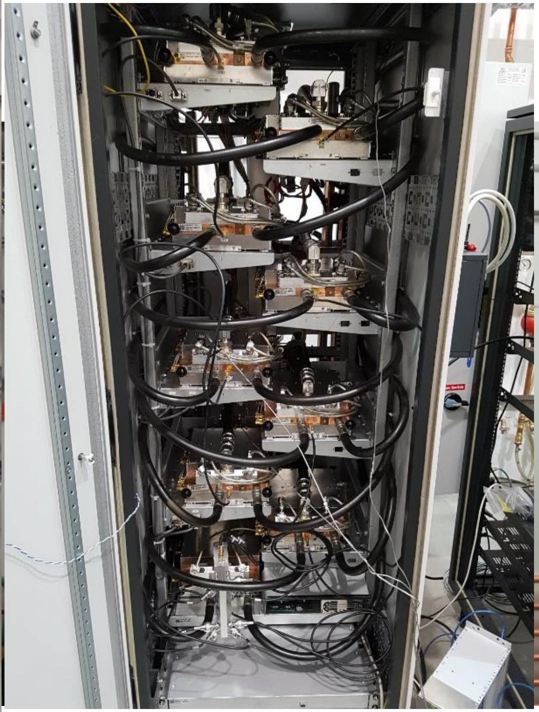


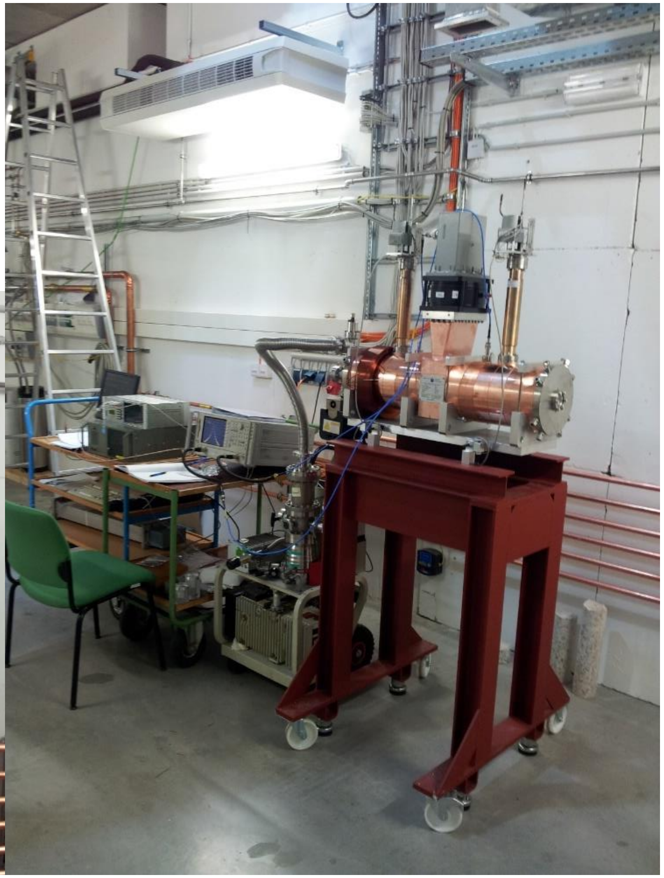



*Pictures: R. Heine*

# MAMBO Booster: Prototype  RF-Amplifier

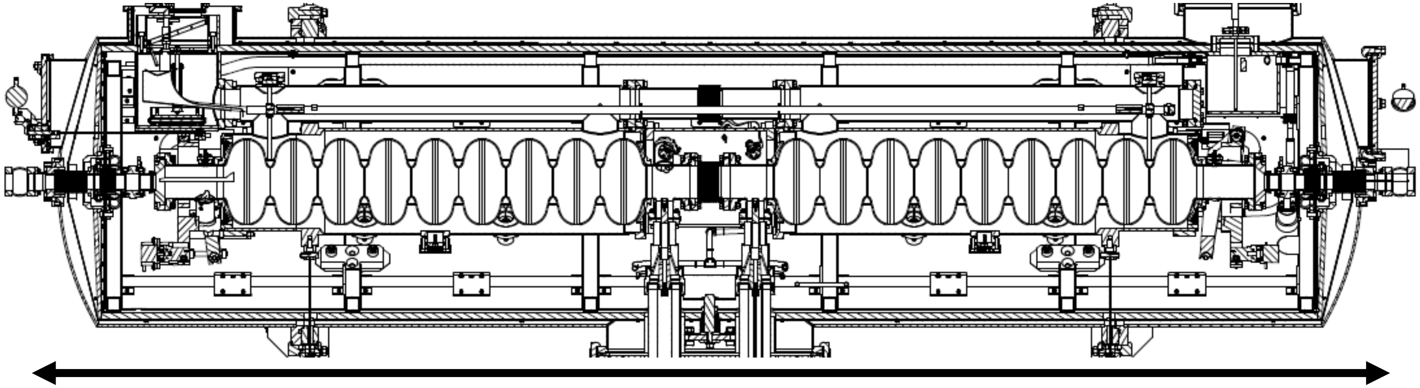
- 15kW RF-powersource prototype :
- Modular (8*2kW, combined) Solid State Amplifier
- Used for tests of MAMBO RF-section  …and also for Cryomodule tests
- ~25 Amplifiers needed for MESA RF-system
- Redesign/optimization  completed



*Pictures: R. Heine*

# SRF-System: MEEC-Cryomodules

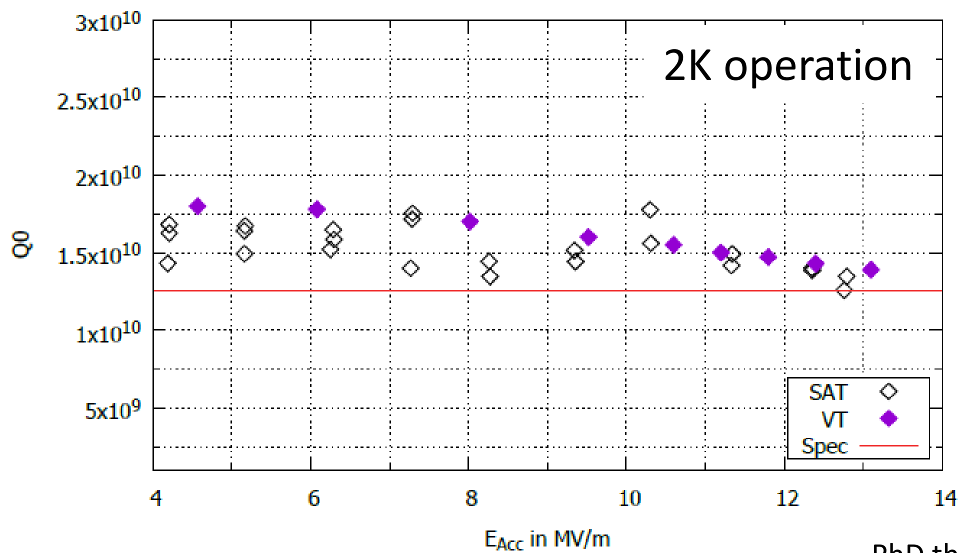



3.5 meter

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

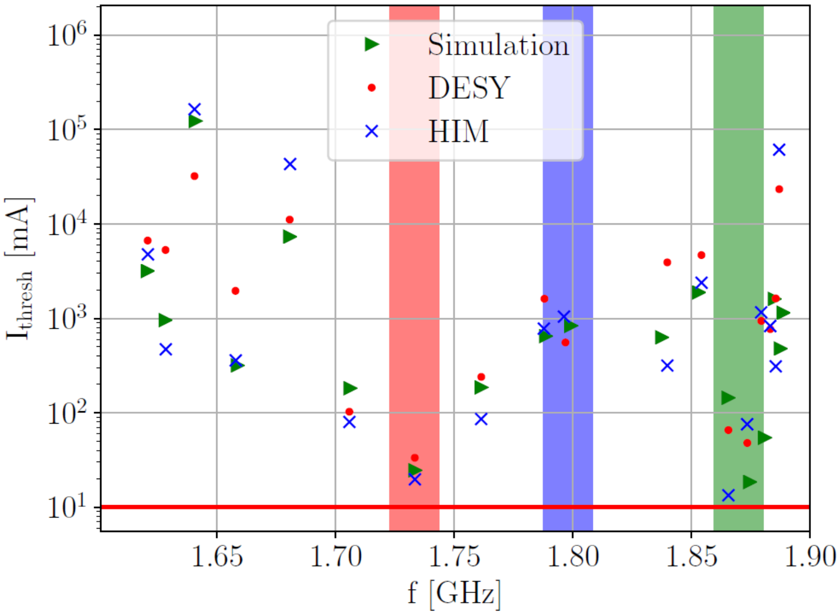
# Production of 2 Cryomodules

- 2015: 2 MEEC's ordered at RI Research Instruments GmbH
- Until 2017 SRF testig 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.



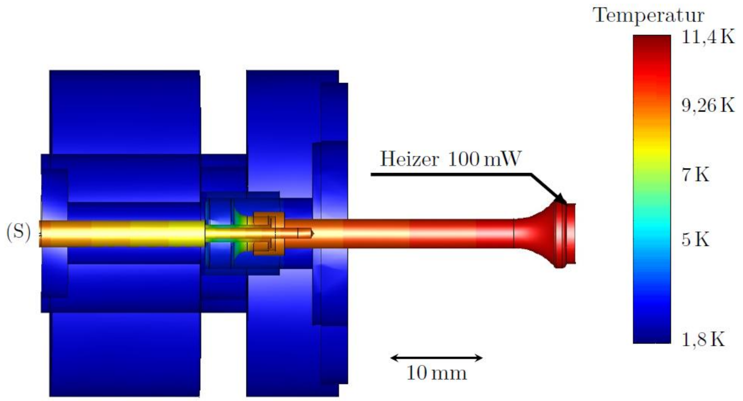

PhD thesis Timo Stengler
See also: T. Stengler et al. Proc. SRF 2019
doi:10.18429/JACoW-SRF2019-TUP041

# 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)