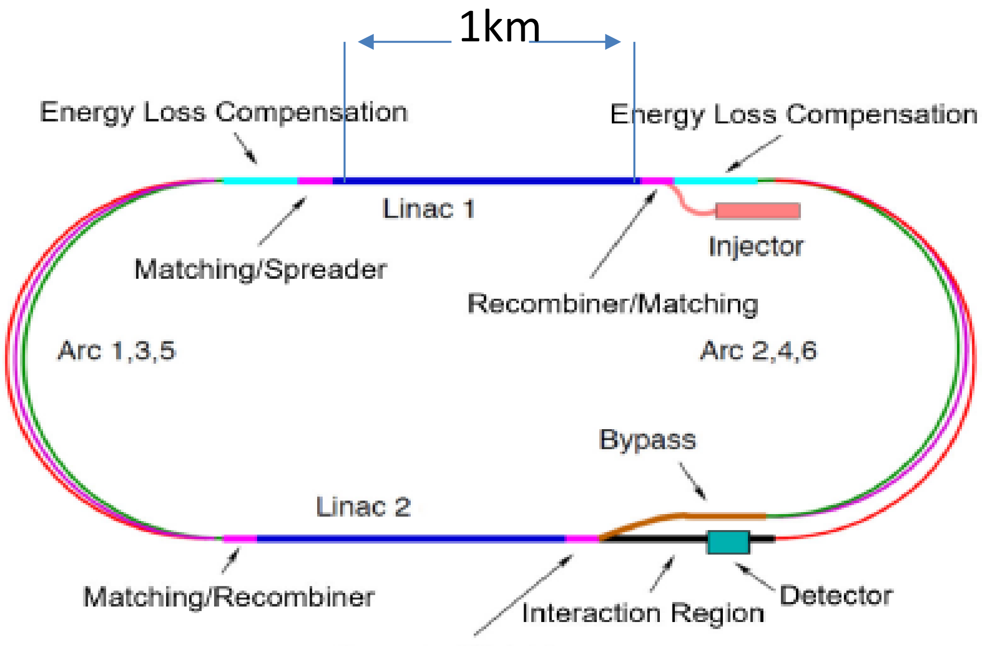
STATUS MESA

SFB Students workshop
Schwäbisch Gmünd, Tue 09/23/25
Kurt Aulenbacher for the MESA team
Institut für Kernphysik, Johannes Gutenberg-Universität Mainz

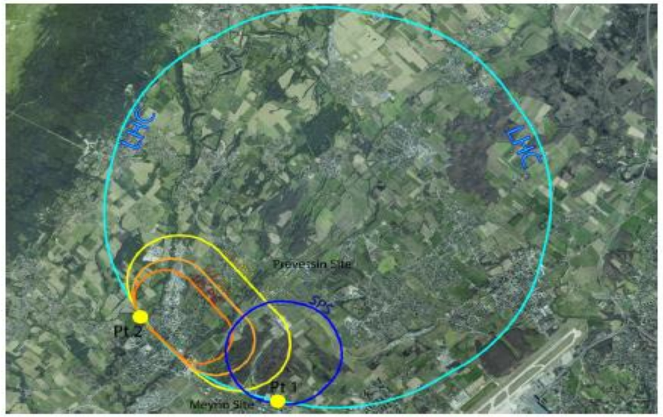
Outline

- ERL‘s and the future of accelerator based particle physics
- Mainz Energy-recovering Superconducting Accelerator (MESA) and its potential impact
- MESA‘s experimental line-up
- Status of the project

Large Scale ERL's: The LHeC



3 recirculations, 50 GeV, 20mA Linac-current…
could be realized „soon“

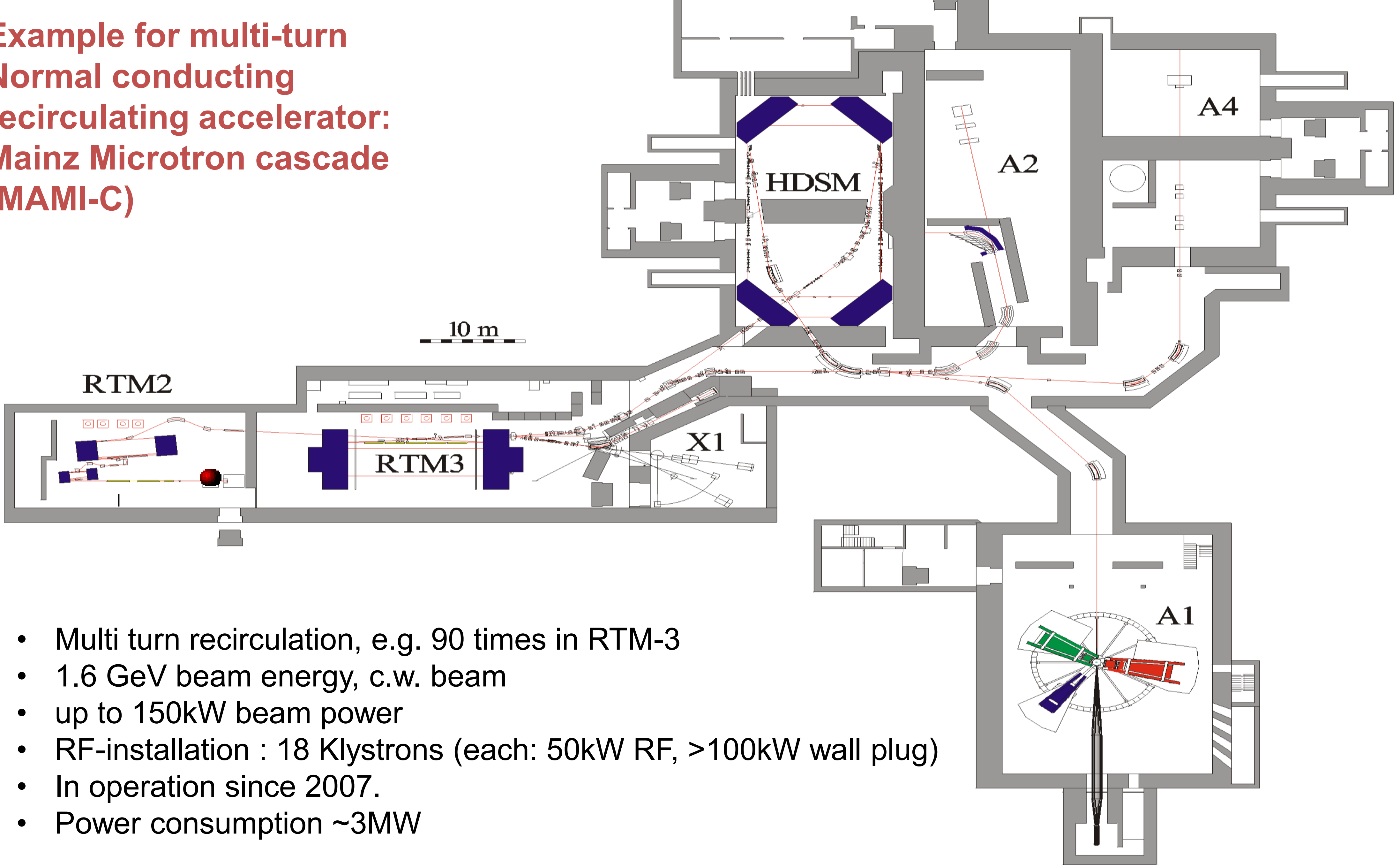


CERN-ACC-Note-2020-0002

Figure 10.49: Racetrack options proposed for LHeC at Point 2 of the LHC. The color coding illustrated different options with 1/3, 1/4 and 1/5 of the LHC circumference, resulting in different electron beam energies.

- low interaction of beam with experiment required
  (colliders, gas targets, undulators…)
- Energy at Experiment $E_0+\Delta E$*#recirculations
- ERL's reduce energy consumption for beamloading by factor G≈ $\#rec\Delta E/E_0$
- (G corresponds to almost a Gigawatt for LHeC
- LHeC plans with #rec=3)

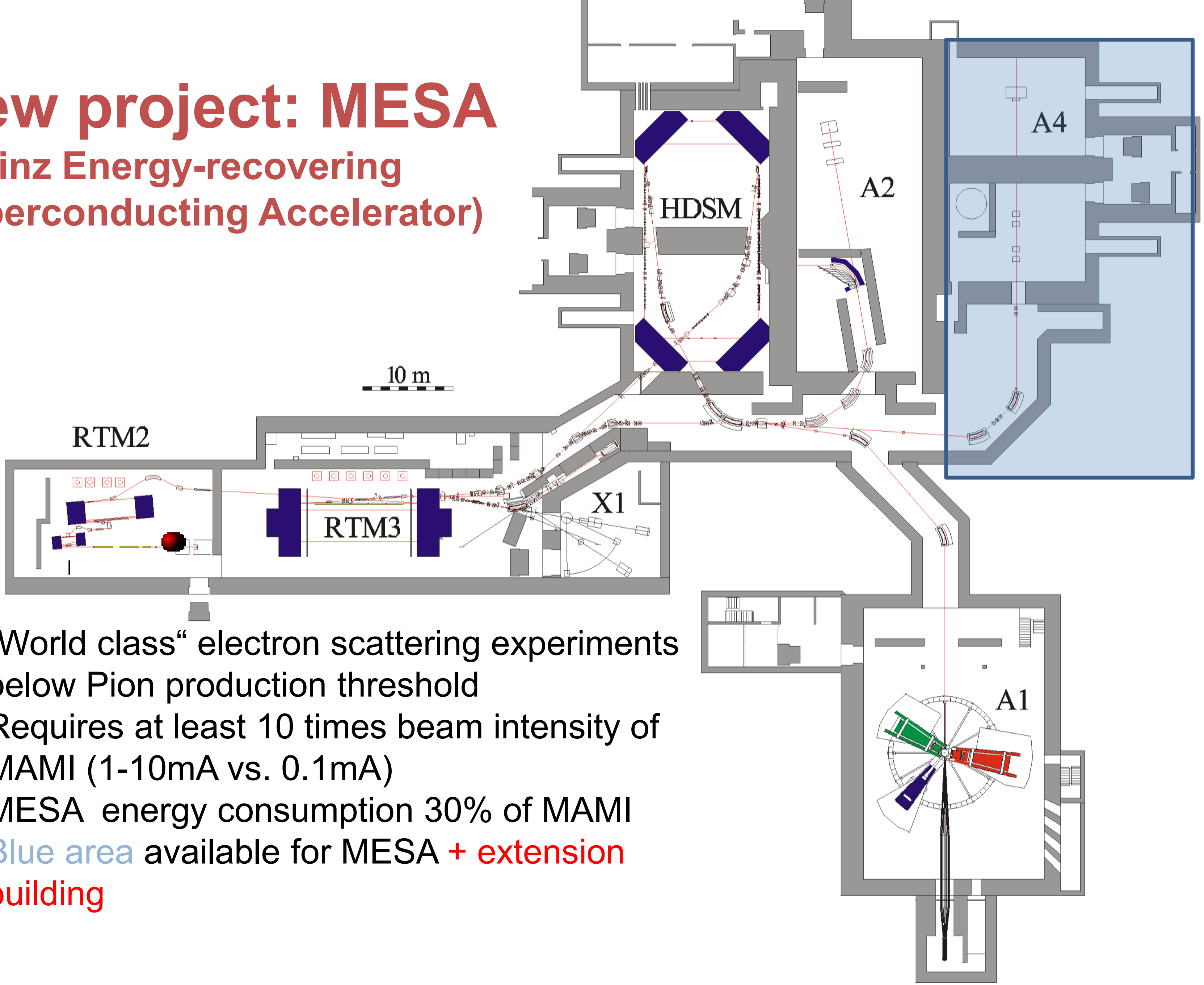
Example for multi-turn Normal conducting recirculating accelerator: Mainz Microtron cascade (MAMI-C)



- Multi turn recirculation, e.g. 90 times in RTM-3
- 1.6 GeV beam energy, c.w. beam
- up to 150kW beam power
- RF-installation : 18 Klystrons (each: 50kW RF, >100kW wall plug)
- In operation since 2007.
- Power consumption ~3MW

New project: MESA

(Mainz Energy-recovering Superconducting Accelerator)



- „World class“ electron scattering experiments below Pion production threshold
- Requires at least 10 times beam intensity of MAMI (1-10mA vs. 0.1mA)
- MESA energy consumption 30% of MAMI
- Blue area available for MESA + extension building

MESA has a goal related to the development of particle acclerators:

MESA as multi-turn SRF ERL will help extrapolating towards large scale ERL-projects, i.e. reduce project risks

MESA in the (future) Landscape

The largest beam power in multi-turn superconducting ERL has been achieved at TU-Darmstadt !

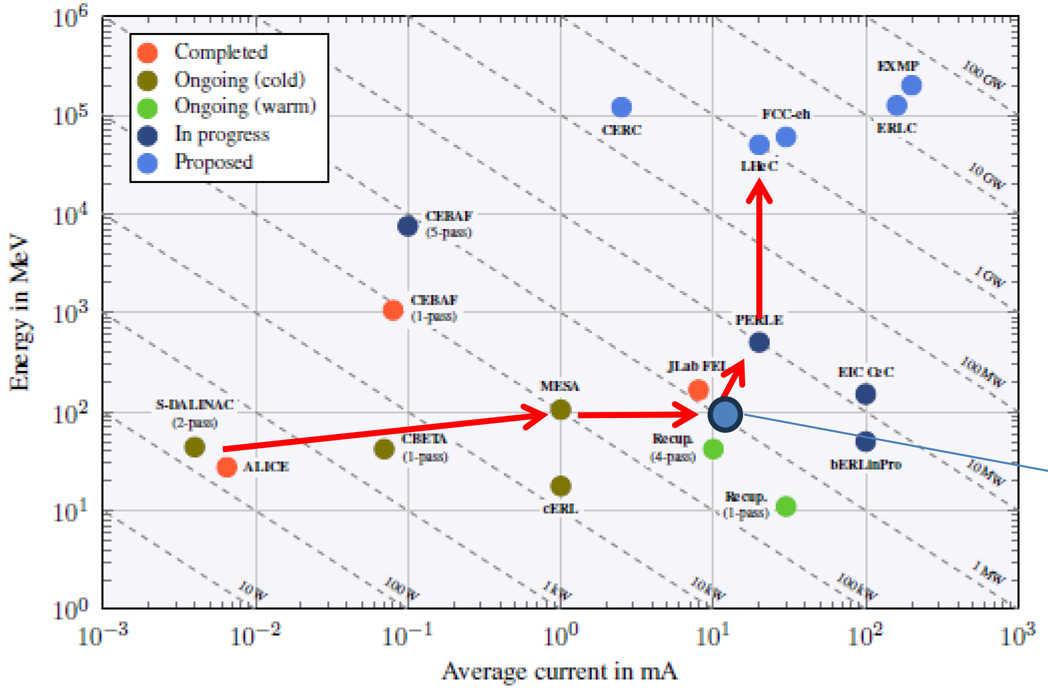


Fig. 6.1: Electron energy E vs. electron source current I for classes of past, present and possible future ERL facilities as are introduced in the text. Dashed diagonal lines represent constant power, $P[\text{kW}] = E[\text{MeV}] \cdot I[\text{mA}]$.

European strategy for particle physics
Accelerator R&D roadmap
CERN 2022-01
(modified)

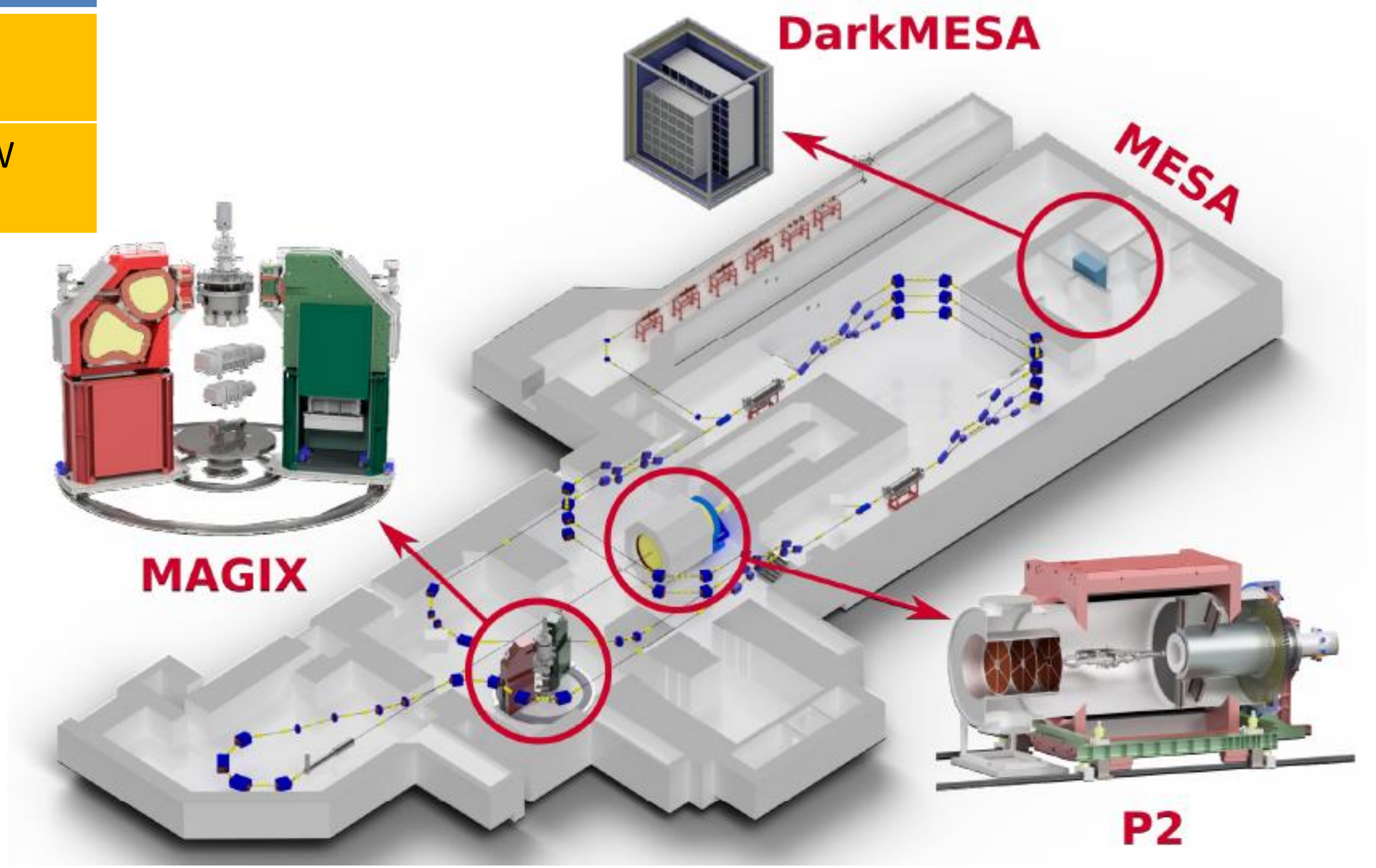
MESA stage 2
(10mA)

MESA has another scientific goal:

MESA is a machine that is optimized to serve specific nuclear and particle physics experiments

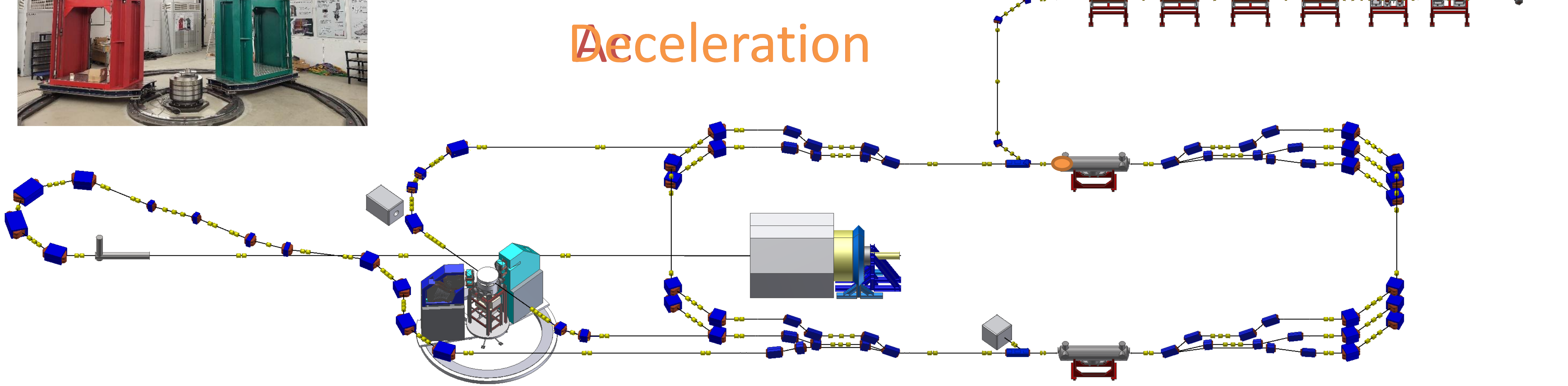
MESA Operational modes & Experiments

Op-mode	Target	Beam power@target
Ext. Beam (EB)	Solid/ Liquid	0-25kW
Energy recovery(ERL)	Gas-jet	0.1-1MW



Energy Recovery Mode – MAGIX

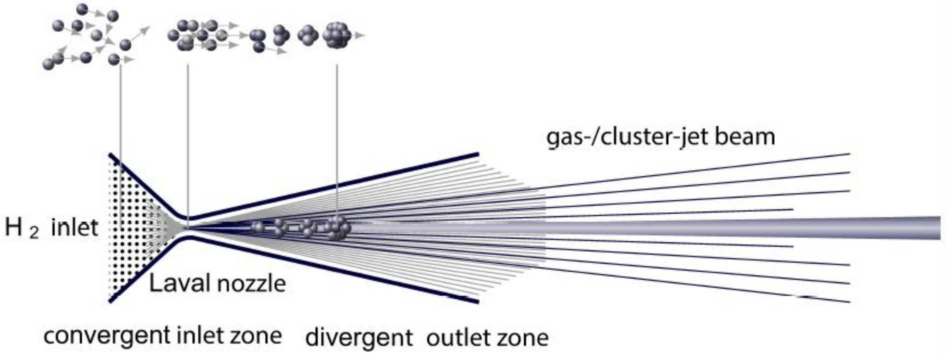
PRISMA

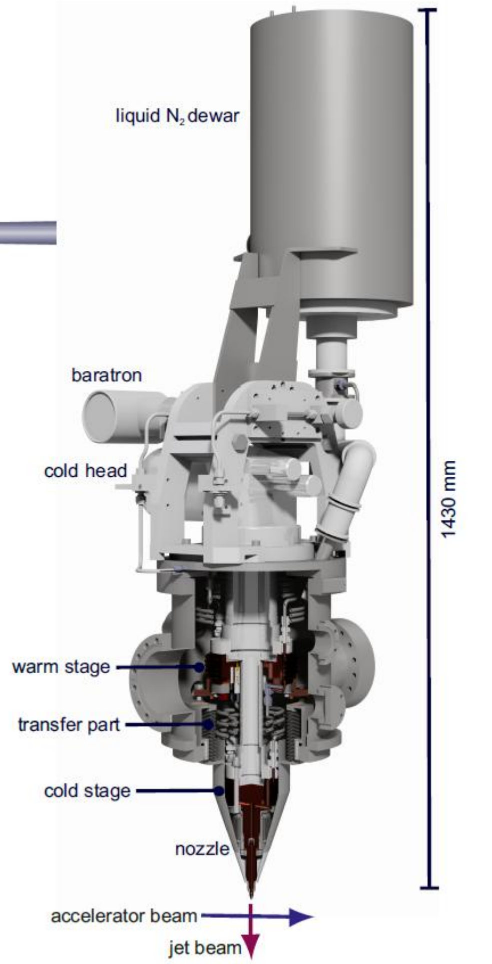


MESA will be a two-turn superconducting ERL

- Aims to demonstrate significantly higher beam currents than at existing multiturn-superconducting ERL's
- Staged approach, adapted to needs of experiments (55 MeV EB, single turn ERL,…)

Gas Jet target at MAMI A1 /MAGIX





Gas Jet target designed by AG Khoukaz from U- Münster
→ And tested with beam at MAMI/A1

H.Merkel Talk at DPG Springmeeting 2022

Experimental program at MAGIX

Hadron Structure

Topic	Reaction	Jet	Observables
p Formfactor	$H(e,e')p$	H	$G_E(Q^2)$, $G_M(Q^2)$, r_E, r_M
d Formfactor	$D(e,e')d$	D	$A(Q^2)$, $B(Q^2)$, r_d
^{3}He Formfactor	$^3\mathrm{He}(e,e')^3\mathrm{He}$	^{3}He	r_E
^{4}He Formfactor	$^4\mathrm{He}(e,e')^4\mathrm{He}$	^{4}He	r_E

Few-Body Systems

d Breakup	$D(e,e'p)$	D	$\mathrm{d}\sigma/\mathrm{d}\Omega$, polarizabilities
^{3}He inclusive	$^3\mathrm{He}(e,e')$	^{3}He	Structure functions, R_L
^{4}He inclusive	$^4\mathrm{He}(e,e')$	^{4}He	Structure functions, R_L
^{4}He monopole	$^4\mathrm{He}(e,e')^4\mathrm{He}^*$	^{4}He	Transition Formfactors $E(^4\mathrm{He}^*)$, $\Gamma(^4\mathrm{He}^*)$
^{16}O inclusive	$^{16}\mathrm{O}(e,e')$	^{16}O	Structure functions, R_L
^{40}Ar inclusive	$^{40}\mathrm{Ar}(e,e')$	^{40}Ar	Structure functions, R_L
^{3}He exclusive	$^3\mathrm{He}(e,e'p/d)d/p$	^{3}He	$\mathrm{d}\sigma/\mathrm{d}\Omega$
^{4}He exclusive	$^4\mathrm{He}(e,e'p/d)$	^{4}He	$\mathrm{d}\sigma/\mathrm{d}\Omega$

Dark Sector

Leptonic Decay	$Ar(e,A' \to e^+e^-)$	^{40}Ar, Xe	Lepton pair mass $m_{A'}$ peak search
Invisible Decay	$p(e,e'p)A'$	H	Missing mass $m_{A'}$ peak search

Astrophysical Reactions

S-Factor Phase 1	$^{16}\mathrm{O}(e,e'\alpha)^{12}\mathrm{C}$	^{16}O	$S_{E1}(E)$, $S_{E2}(E)$
S-Factor Phase 2	$^{16}\mathrm{O}(e,e'\alpha)^{12}\mathrm{C}$	^{16}O	$S_{E1}(E)$, $S_{E2}(E)$

H.Merkel Talk at DPG Springmeeting 2022

Accelerator devices for Experiments-MAGIX

NEW due to ERL/gas target vs. already **established** at MAMI:

- NEW: Kollimation system → example
- Established Non-invasive beam diagnostics & feedback →see P2
- Established Beam dump (concept, installation ongoing)
- Established: Absolute energy calibration

Luminosity limitation ERL gas jet target

Coulomb scattering - expect for fixed power loss and geometry: $L_{max} \propto \frac{1}{Z^2} E_{beam}$

Confirmed by G4 (BDSIM) simulation of deceleration process.

Losses can be concentrated in collimator region separated from experiment and accelerator

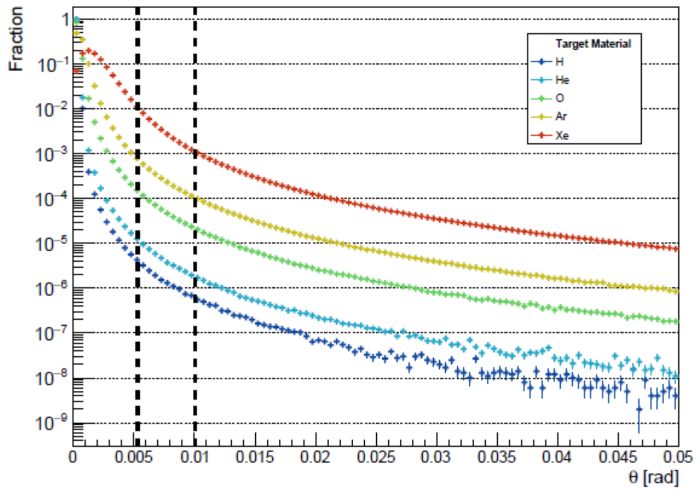


Figure 5.2: Angular distributions of the beam exiting the target for different MAGIX target gases. The vertical lines mark 10σ of the incoming beam (left) and 10 mrad (right). Error bars are according to the statistical error.

Results for „two collimator“ system at 100kW, 105MeV

Total loss <100 Watt, loss in accelerator <0.05 W.

Target	n_{spoiler}	n_{col}	$\mathcal{L}_{\text{max}}$ [$\text{cm}^{-2}\,\text{s}^{-1}$]
H	13	13	7.595×10^{35}
He	13	13	2.505×10^{35}
O	14	14	2.408×10^{34}
Ar	18	18	7.916×10^{33}
Xe	18	20	5.959×10^{32}

Ben LeDroit, PhD thesis Mainz 2021 http://doi.org/10.25358/openscience-5808

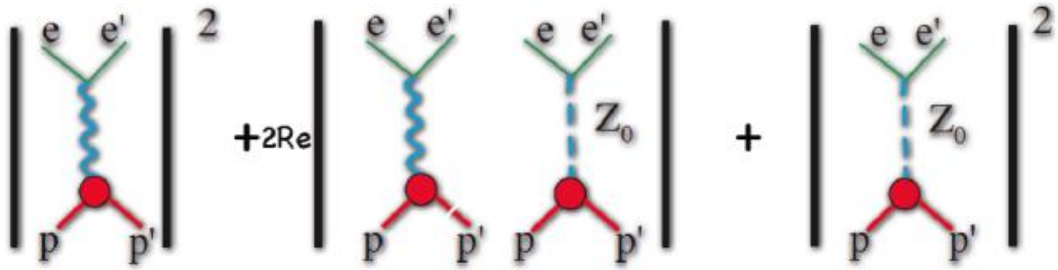
Calculation for realistic MAGIX geometry

Acclerator devices for Experiments-P2

- - nothing fundamentally new, but huge improvements wrt MAMI needed
- Non-invasive beam diagnostics & feedback
- Polarimetry
- Helicity switching speed *20

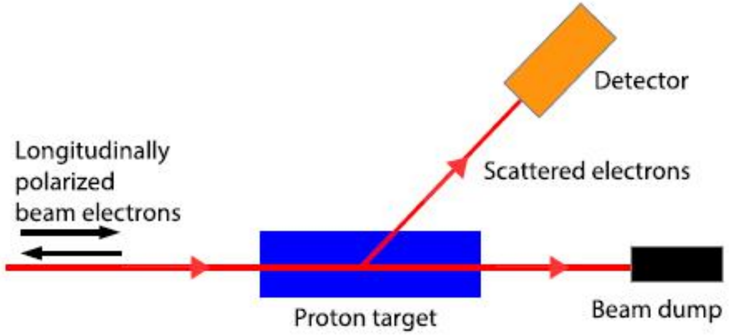
EB-Experiment P2

D. Becker et al. Eur. Phys. J. A **54** (2018) 11, 208
DOI: 10.1140/epja/i2018-12611-6 &166,

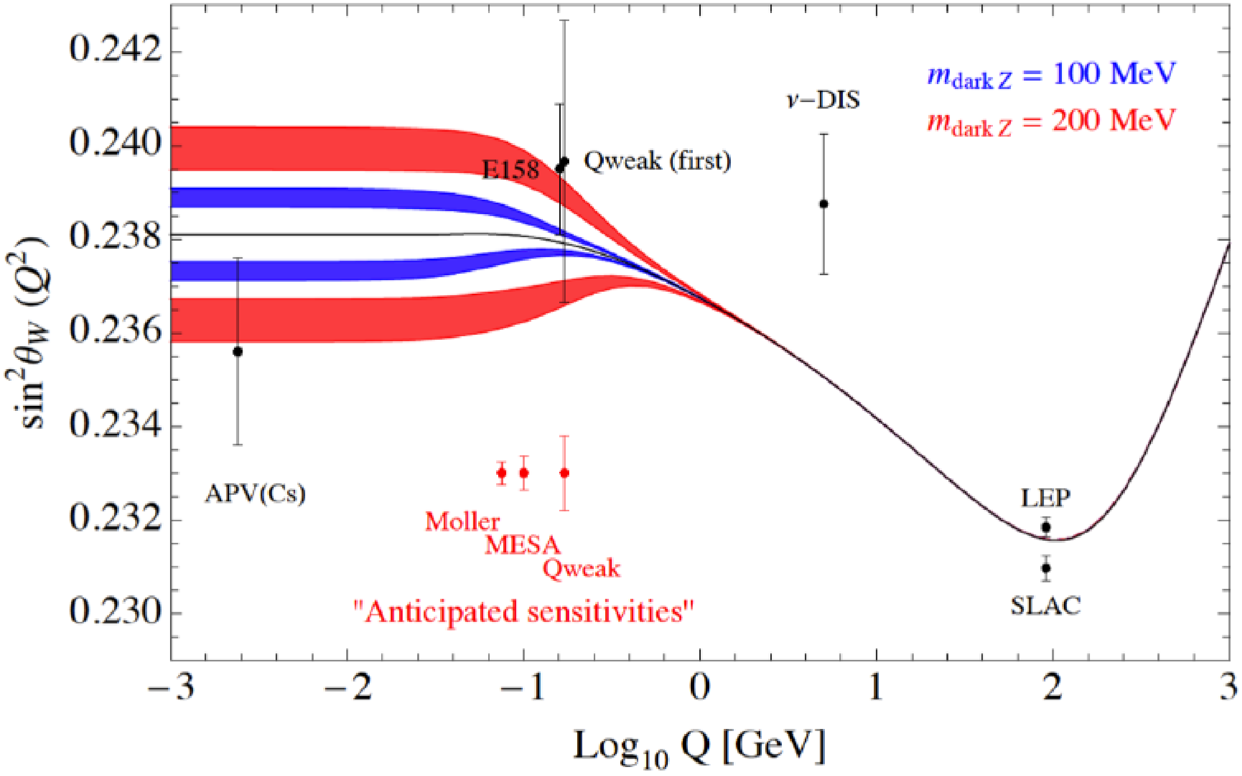


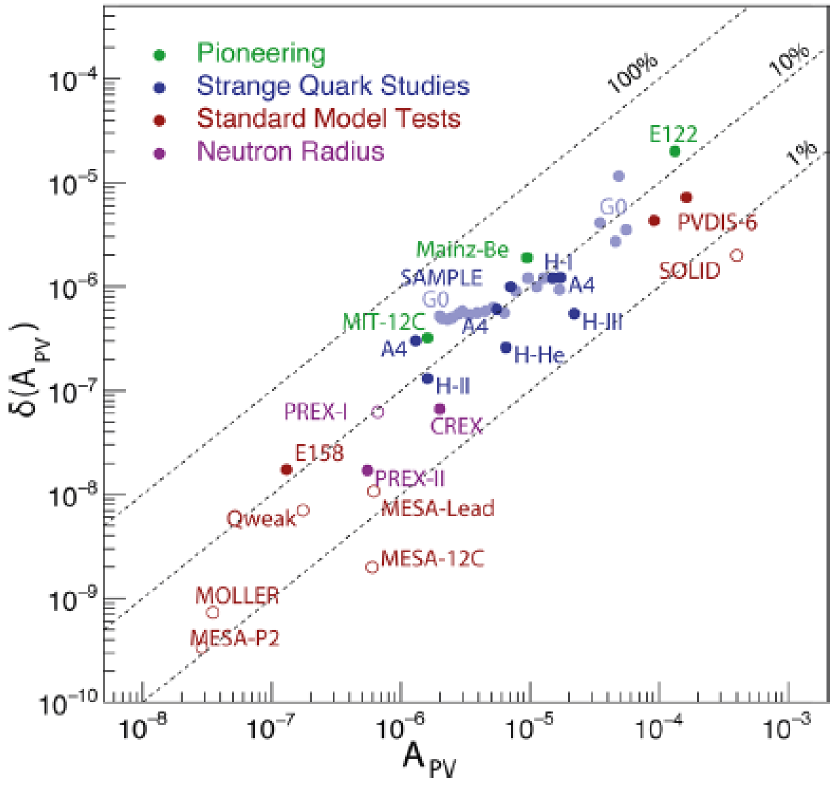
Interference term is parity-violating
Beam helicity asymmetry:

$$\Rightarrow A_{PV} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$



EB-Experiment P2





D. Becker et al. Eur. Phys. J. A **54** (2018) 11, 208
DOI: 10.1140/epja/i2018-12611-6 &166,

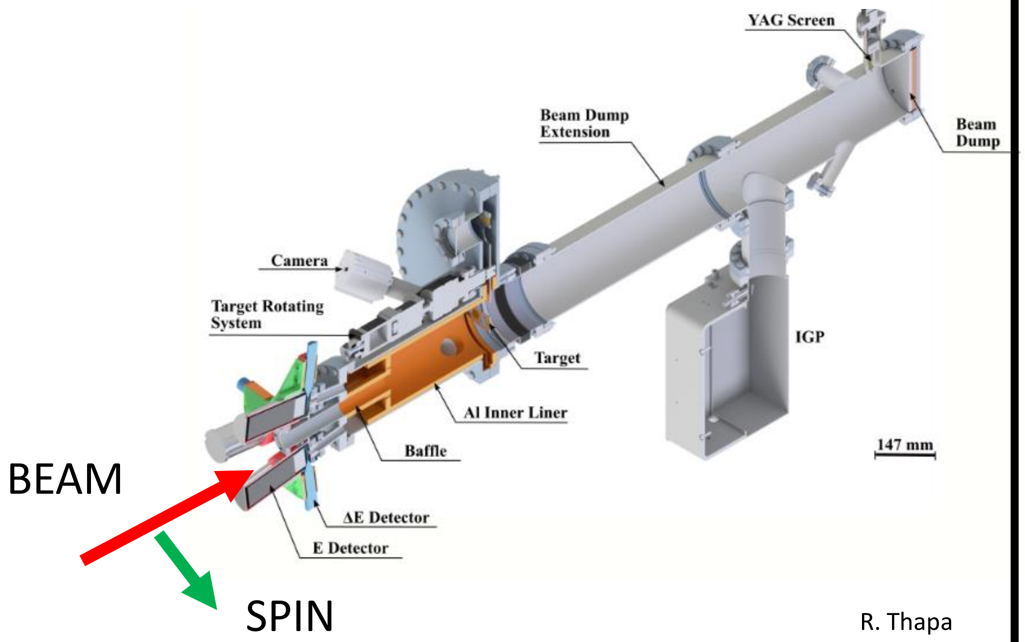
Weak charge of the proton: $Q_w\,(p) = 1 - 4\sin(\theta_w)^2$
A weak charge measurement with accuracy 1.4%
yields an accuracy $\Delta\sin^2(\theta_W)/\sin^2(\theta_W)$ =0.16%.....
The asymmetry is $\propto Q^2$ *and* $\propto P$

See talk by S. Baunack, today

Spin polarized beams at MESA - support of P2 experiment

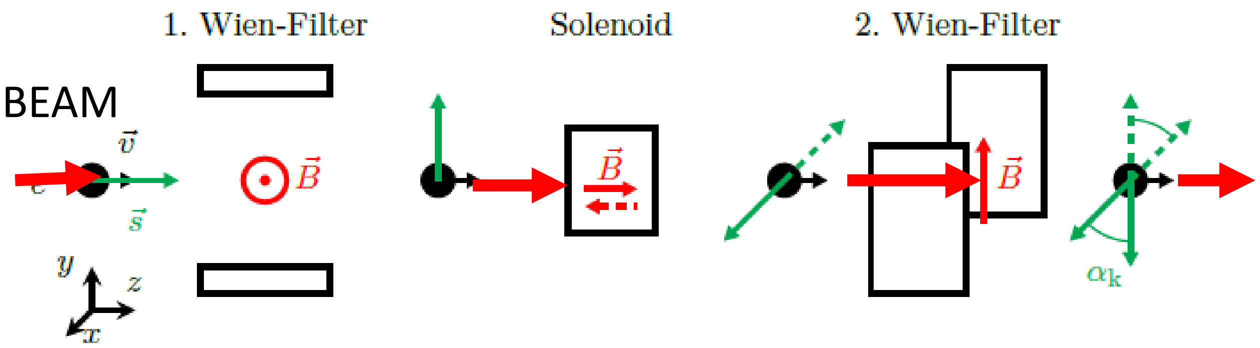
- Accurate spin polarization measurement → Mott polarimeter (5MeV, backscattering)
- Spin manipulation → „double“ Wien filter (100keV) for arbitrary orientation in space
- Non invasive measurement of beam parameters under polarisation switch (various energies) → Resonant cavity monitors

Mott-polarimeter for 174 degree backscattering on gold at 5 MeV



R. Thapa

Operation principle of MESA-Spin-Manipulator (here shown option for 180 degree spin flip in acclerator plane)

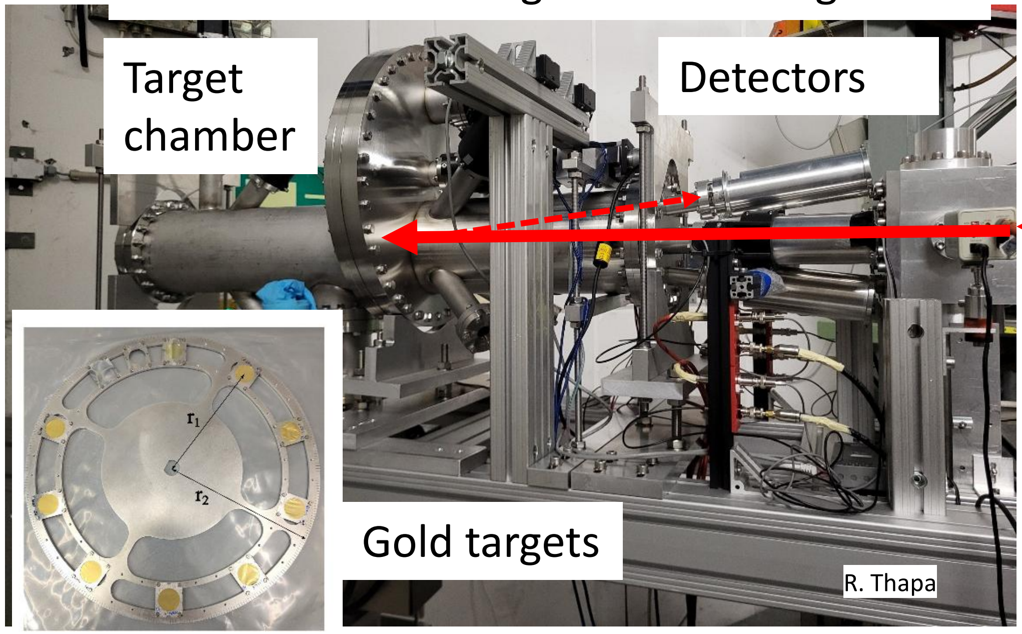


Ch. Matejcek

Spin polarized beams at MESA - support of P2 experiment

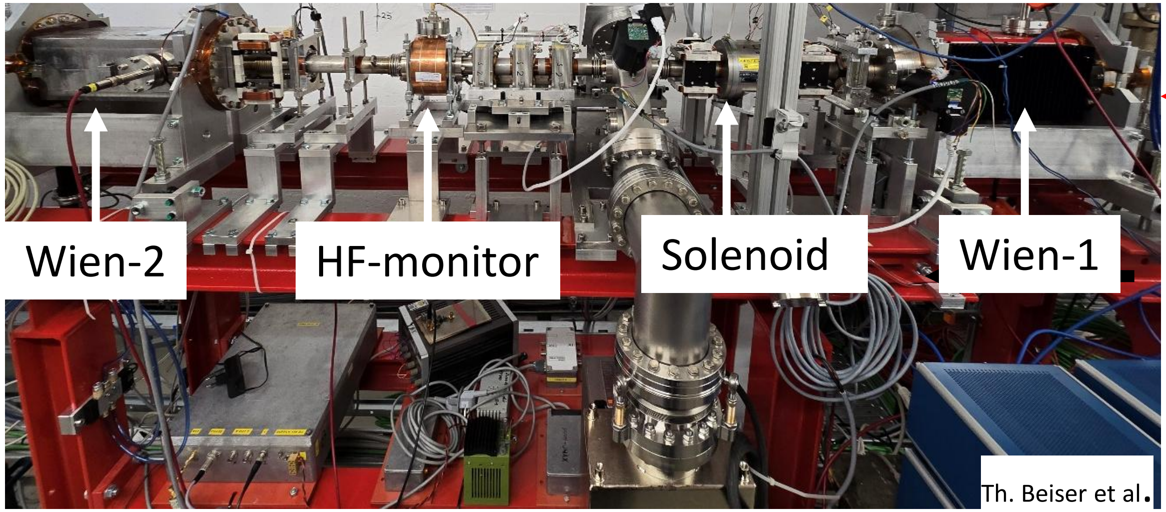
- Mott polarimeter under test at MAMI: Detection system works, first asymmetries on gold targets measured
- „Double“ Wien filter (100keV) both Filters and Solenoid operated with beam at parameters for 90 degree rotation
- kHZ-rate polarization switching obtained and beam current variation detected with 2.6 GHz RF-Monitor
- Bunched polarized beam achieved by photo.source using RF-synchronized high power fiber laser (150ps FWHM)

MESA-Mott under test at MAMI
Elastic backscattering under 174 degree



~2 m

Wien filter assembly/HF-monitor at MESA



~1.8m

Deformation of 2μm Gold Target due to thermal stress(?)
Observation of optical transition radiation at 3.5 MeV

M. Dehn/R. Thapa

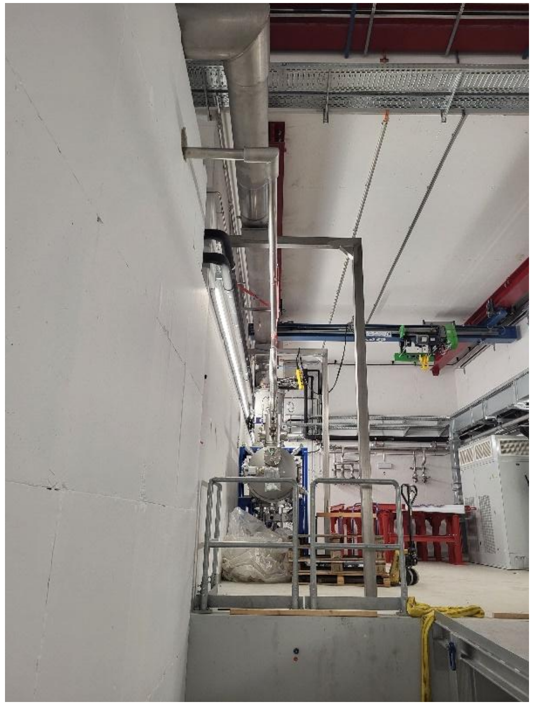
Status of installation

December 24 – installations begin…

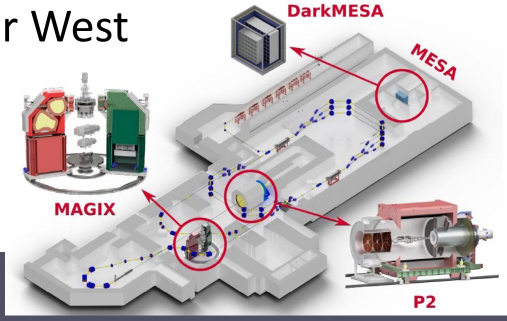
Cryo-lines installed in „Shaft east“

LeHe distribution
In central cryobunker (Hall-1)

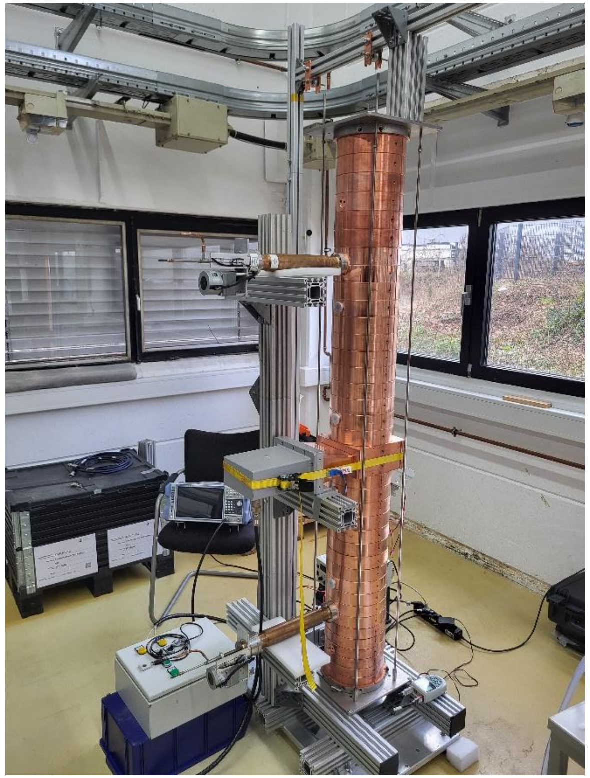
Cryomodule 2 connected to cryo-line in „beam position“ at corridor East



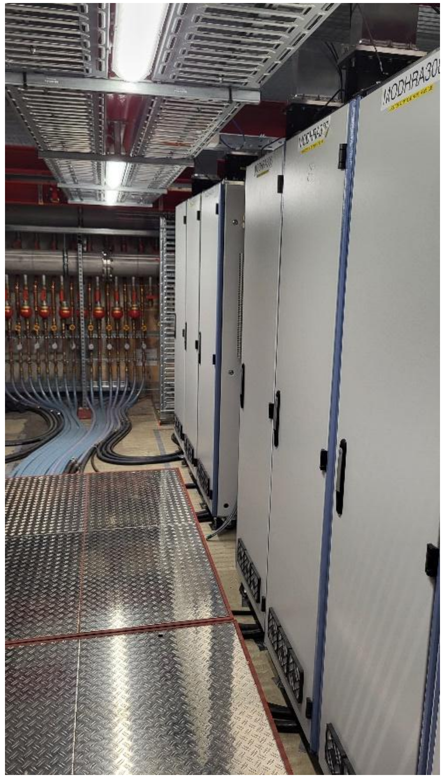
Cryomodule 1 connected to cryo-line in „beam position“ at corridor West



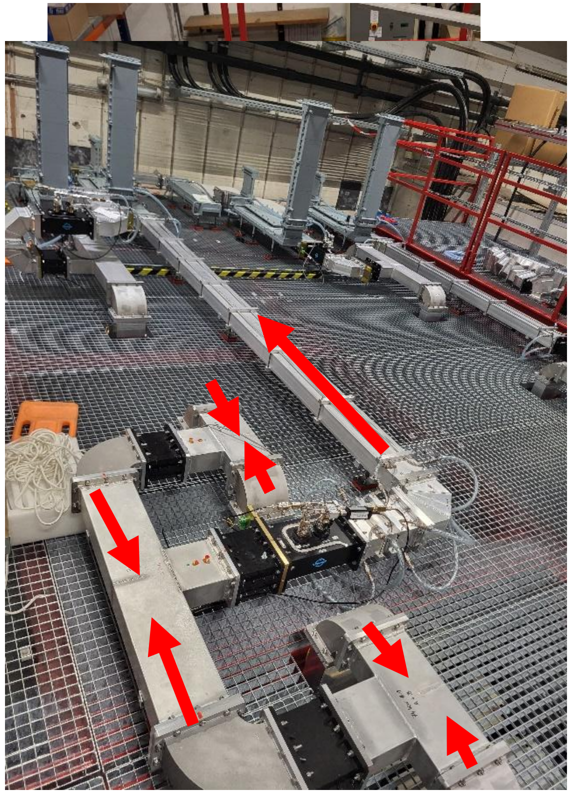
RF system



RF-section-1 („graded beta“)
of normal conducting
CW 5 MeV injector
„MilliAMpere BOoster“
aka „MAMBO“ (10mA)



20kW 1300 MHz
solid state amplifier
modules
total 17 modules



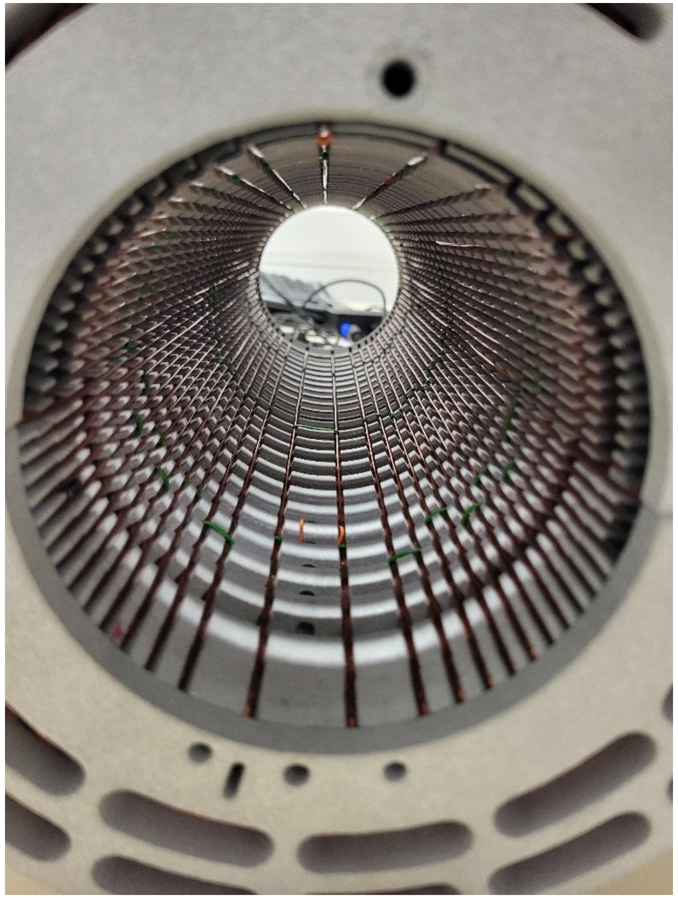
4*20kW get combined
-providing power
for RF-Section MAMBO-1

Waveguides direct
power to circulators and
finally to RF-sections
behind shielding walls

Magnets for accelerator

MESA 45 degree arc magnets

Intermediate storage space... All 105 Dipole magnets delivered . Magnetic measurements ongoing

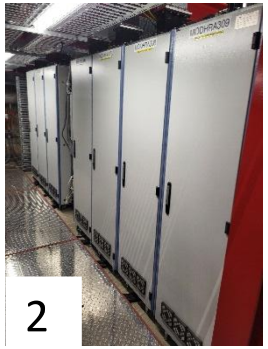


Special magnet: Air coil 7.5 degree deflector for 5MeV Mott polarimeter (V. Tioukine)

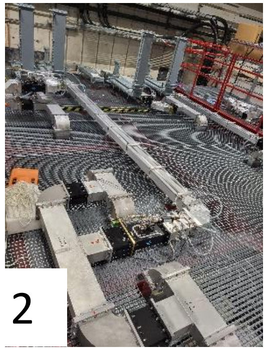
Status: Some of the milestones achieved

1. HIM building functional since 11/24 → Building controlled by KPH→„Schlüsselgewalt!“
2. All RF-transmitters (17 modules) installed and operational (total 300kW RF-power)
3. Cryomodules installed at operating position, Helium liquefier upgrade completed.
4. All Dipole magnets (+ dipole vacuum chambers) delivered, sample specimen tested
5. Cryo-piping completed

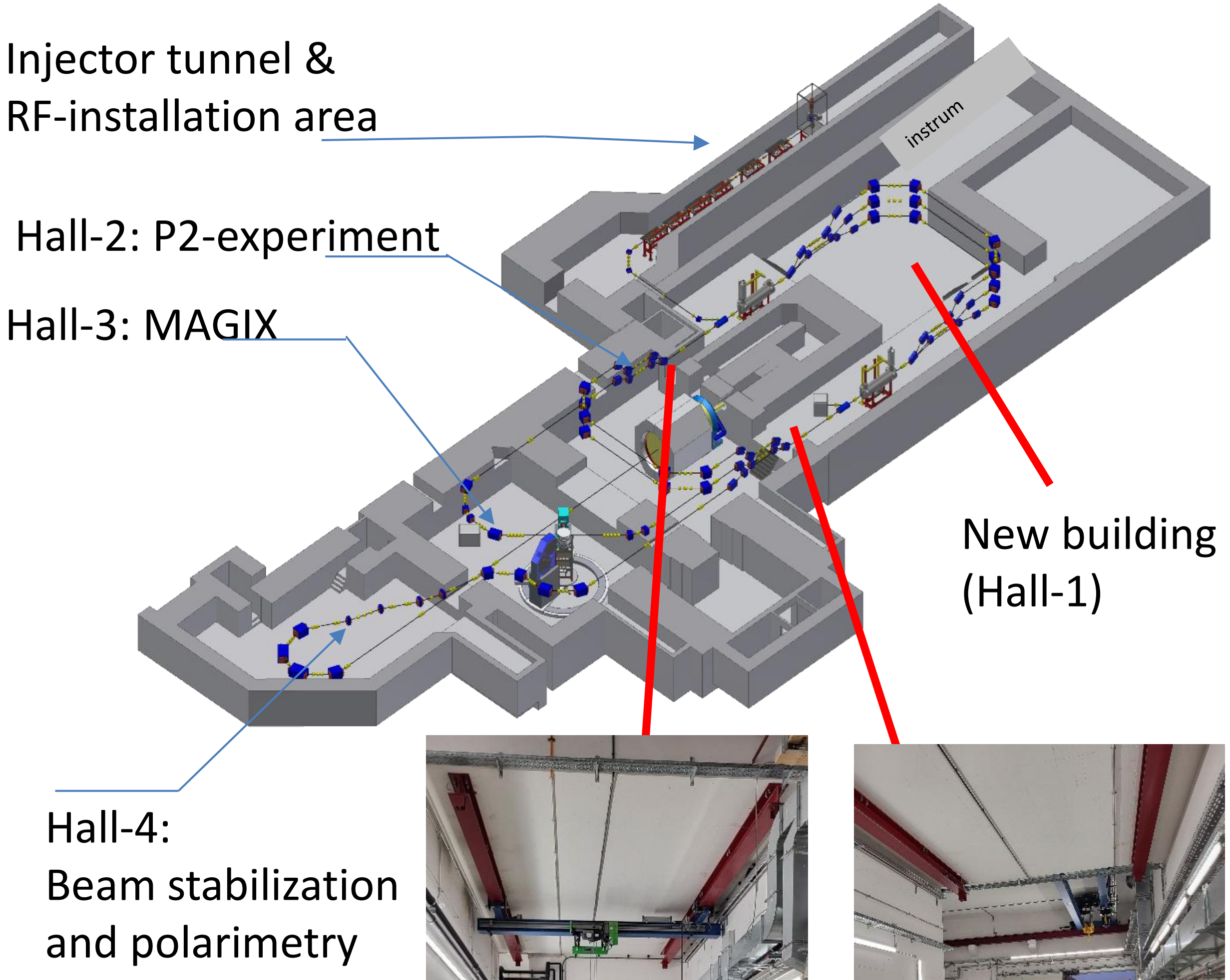

1

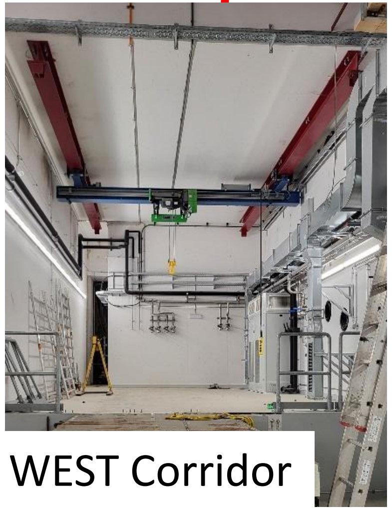

2


1

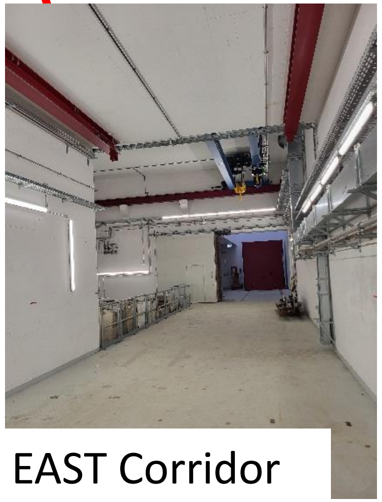

2


3/5





WEST Corridor
(October24)



EAST Corridor
(October 2024)

Next bigger steps and (many smaller ones):

Cool down and test SRF modules as soon as installation of P2 solenoid completed (FEB 26)

Continue installation of 100 meter long beamlines (Accel, MAGIX, P2)

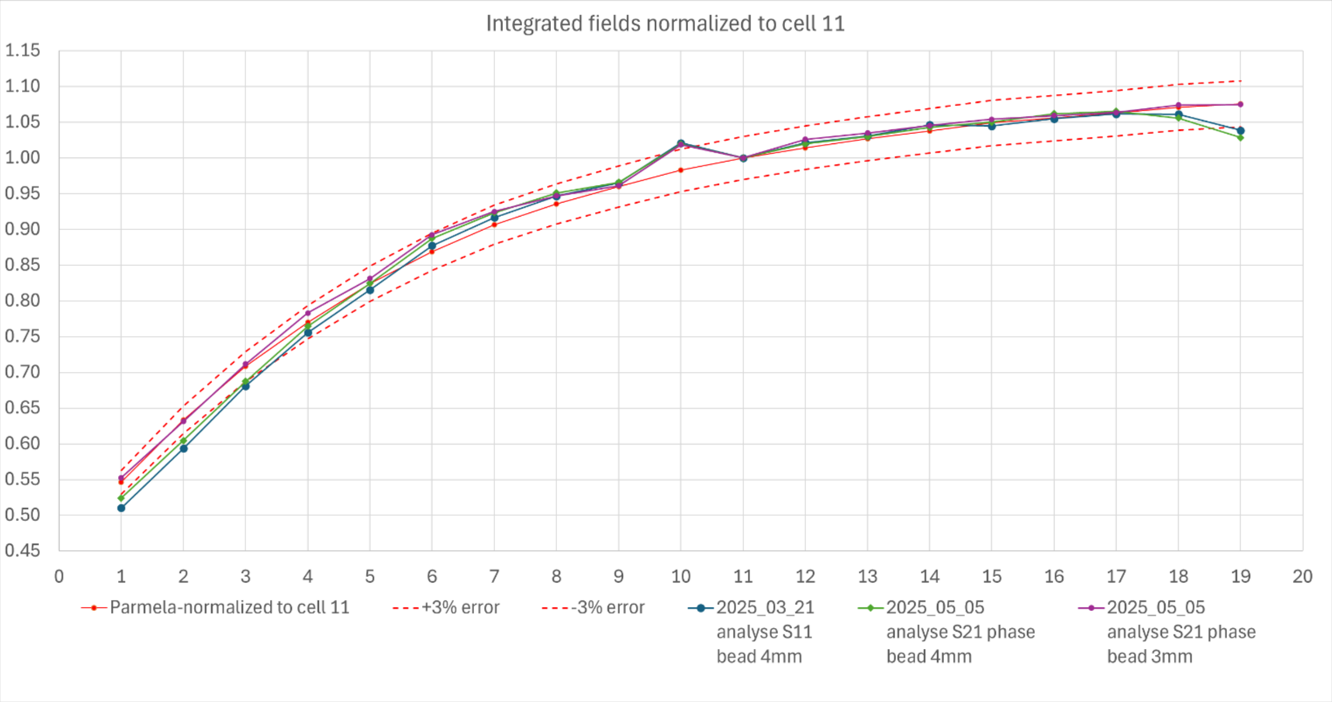
Install MAMBO injector

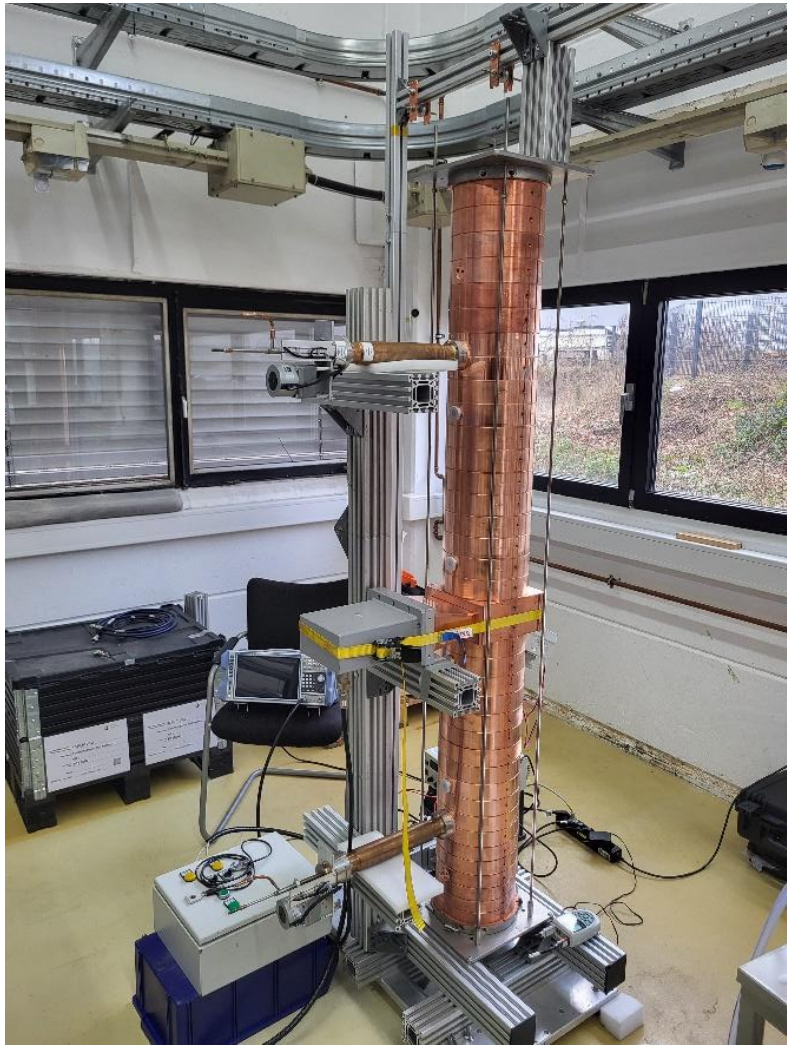
Go for first beam 55MeV EB to experiment in October 2026

Risks (selection)

Risks (Selection)

Last “high-tech” component missing (ordered 12/2019!)
RF-structure MAMBO 1 (“graded beta”):
Manufacturer claims to have solved problems with field distribution.
Final soldering process and FAT **next week!**

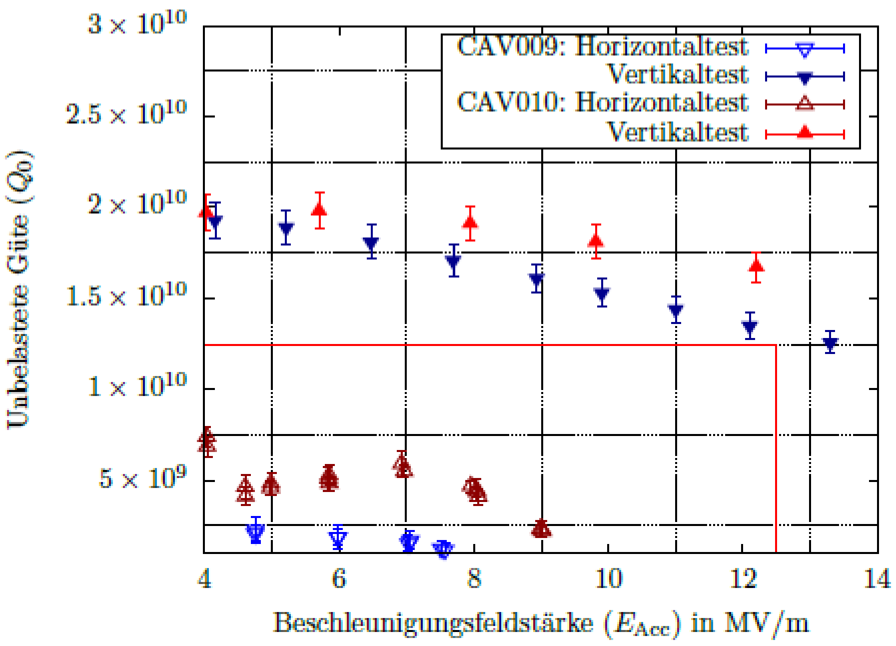




RF-section-1 („graded beta“)
of normal conducting
CW 5 MeV injector
„MilliAMpere BOoster“
aka „MAMBO“ (10mA)

Risks (Selection)

- Cryo-plant : 4 complex components from different vendors interact→ sustained operation?
  Probability: Medium; Impact : costs + several month delay
- Cryomodules: Deterioration of cavity quality factor since tests at HIM? (particulate contamination?)
  Probability: low-medium, Impact: high (costs + 1 year delay)



Effect of deterioration
(PhD Thesis T. Stengler)

But, meanwhile, we can repair cavities!

Refurbishment of MESA Cavities @ HIM

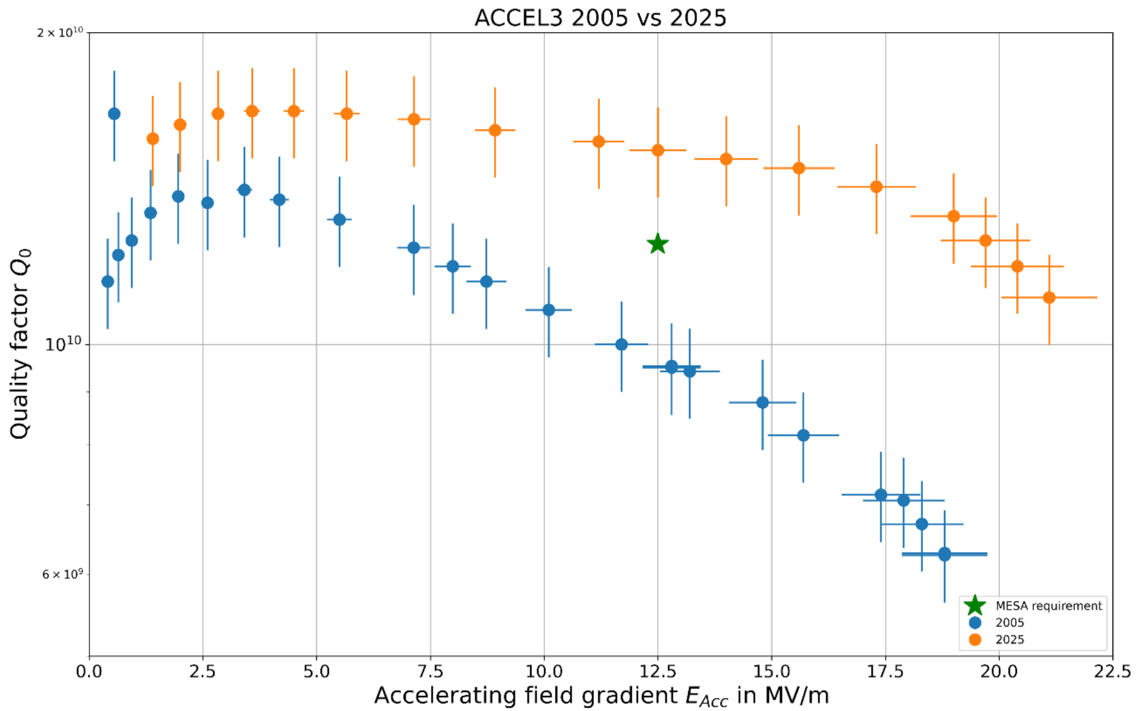
HIM Cleanroom usage for MESA cavities

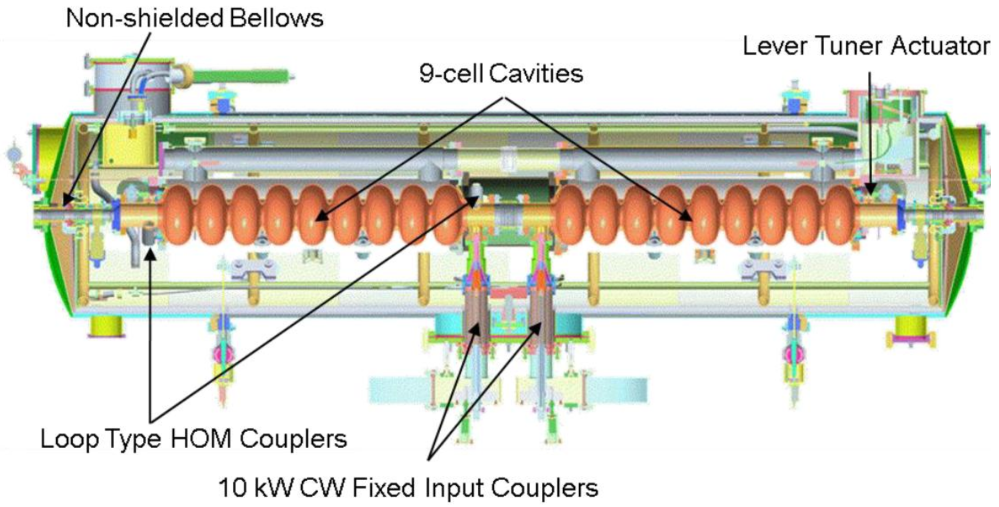
Particle freedom required – ISO-4 limits to avoid field-emission

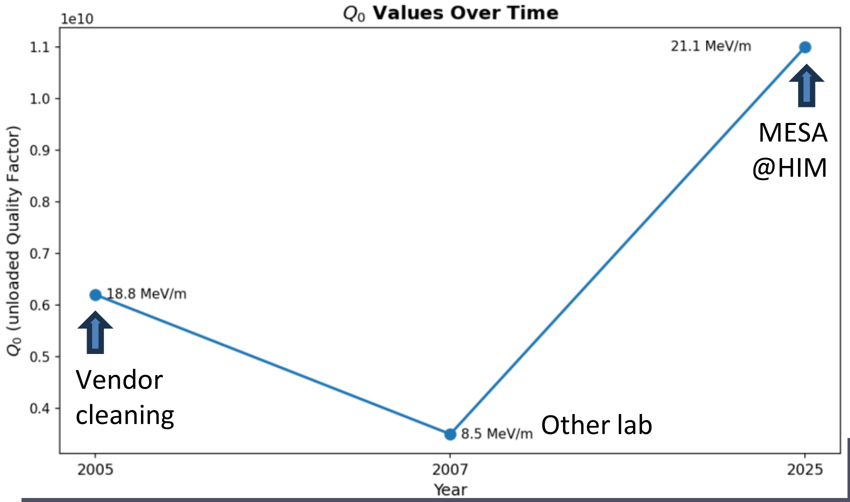
Cleanroom infrastructure @ HIM with high pressure rinsing (100bar) allowed a professional cleaning

Recovery of dirty SRF cavities successful with bad quench limit and quality factor (8.5 MeV/m @ Q_0=3.5e10) to state of the art (21.1 MeV)

State-of-the-art cleaning (equal to DESY, J-Lab) allows cavity usage in MESA and SRF research

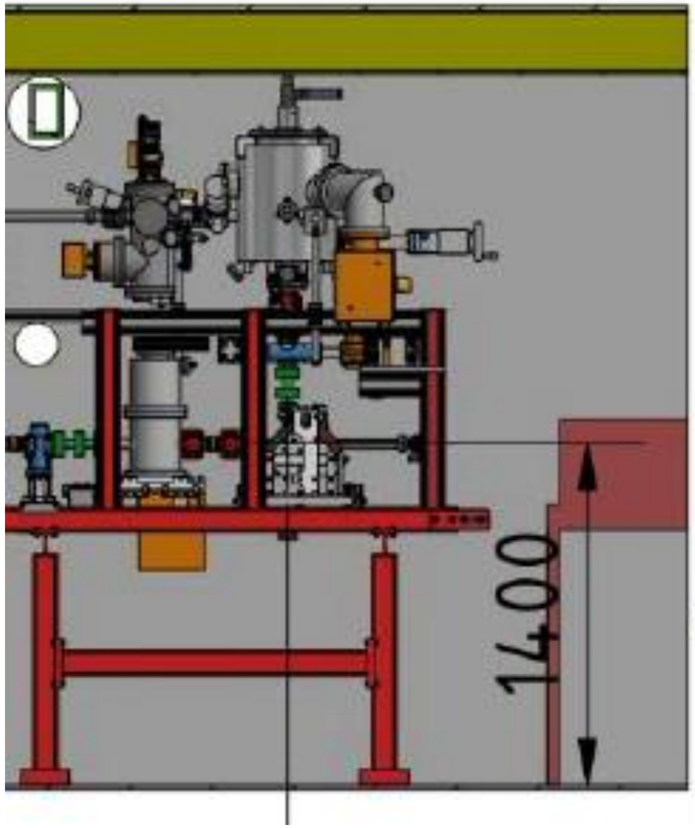




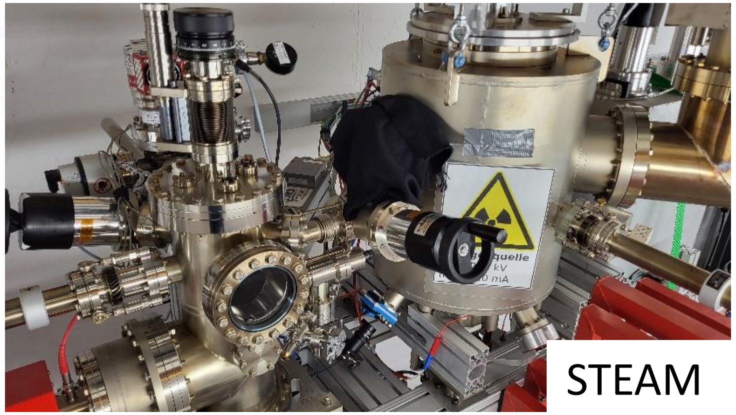


Thank you!

MESA spin polarized photosource „STEAM“



Laser

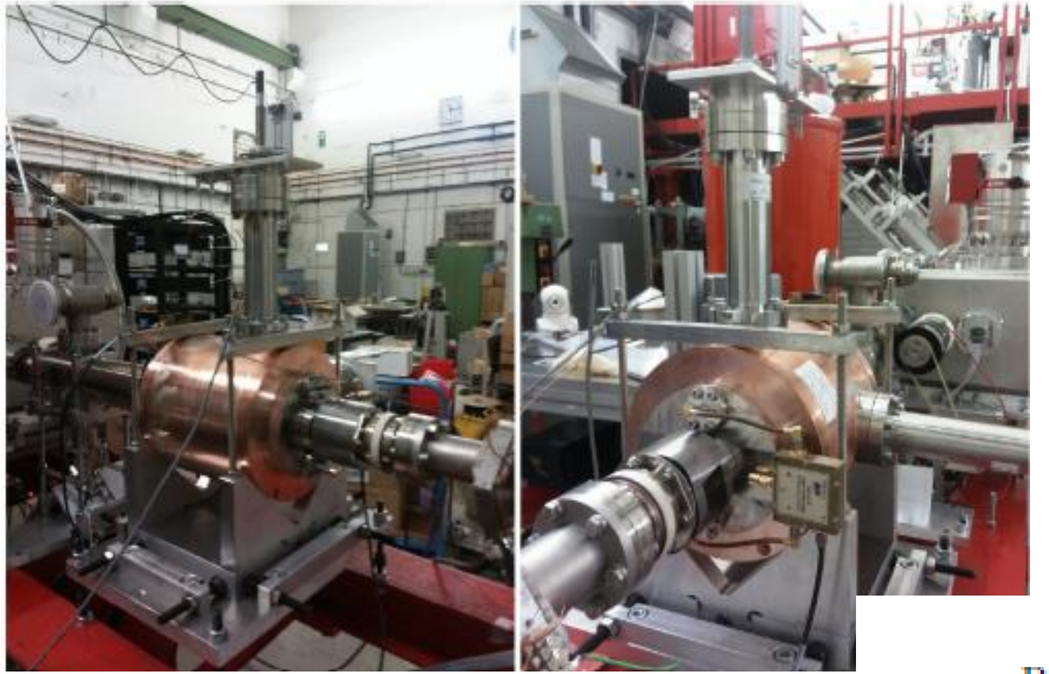


STEAM

Spin-polarized cathodes are „activated“ on-site and transferred to source in UHV

First beam from Spin-polarized Photosource „STEAM“

Laser	
type	Er-doped fiber
wavelength	780nm
Av. power	Up to 4 Watt
Rep-rate	5-1300 Mhz
Pulse length	50-250ps
photocathode	
type	GaAs/GaAsP SL
wavelength	780nm
Spin-polarization	80-90%
Quantum efficiency	~0.5% (3mA/Watt)
Response time	~1ps
Beam current	150µA
Charge lifetime	>100 Coulomb



R. Kempf et al.
Beam parameter stabilization for the P2 experiment at MESA
https://doi.org/10.1016/j.nima.2020.164554

Requirement:
Good S/N, high sensitivity, high bandwidth → determine fasle asymmetry within reasonably short time with sufficient accuracy

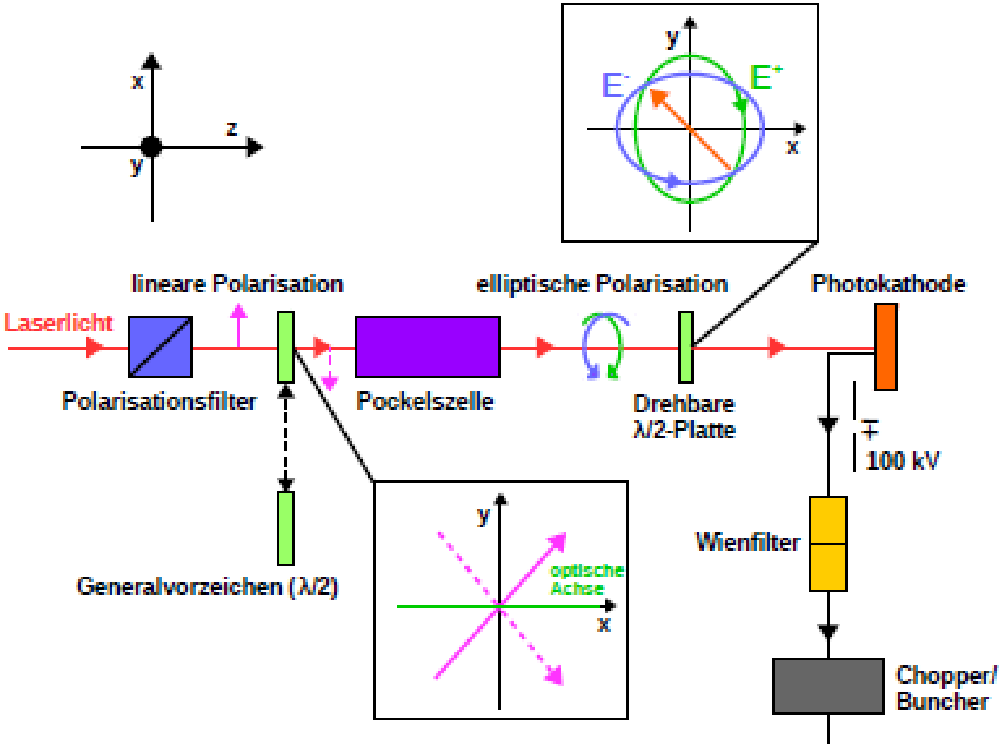
MESA XY Monitor
Sensitivity: ~1Volt/(mm*μA)

Parameter	$\Delta\bar{X}^i$	ΔX^i	ΔX^i mit $\Delta A(X^i) < 1\,\mathrm{ppb}$ nach $t = 1\,\mathrm{h}$
X^1	0,1 ppb	13,4 ppm	1,34 ppm
X^2	1,03 nm	138 μm	13,8 μm
X^4	0,236 nrad	31,7 μrad	3,17 μrad
X^6	0,042 eV	5,6 keV	0,56 keV

Already demonstrated

Beam parameter noise at 1kHz measurement rate
To achieve desired accuracy after 10000 hours
- or 10* less accuracy after 1 hour…

False asymmetries and their compensation



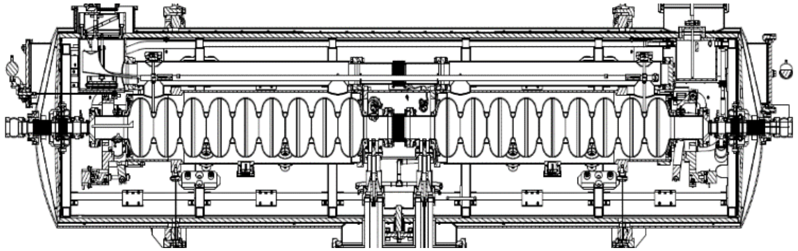
Helicty correlated intensity fluctuation

Caused by inhogeneous strain relaxation in photocathode (~1% asymmetry)

→ Compensation by directing (minimized) linear polarization componenents diaganal wrt strain relaxation

→ This allows few ppm $\Delta X_{current}$

If normal conducting RF and Magnets are‘nt enough trouble – try SRF and SC-magnets! (….but trouble is our business)

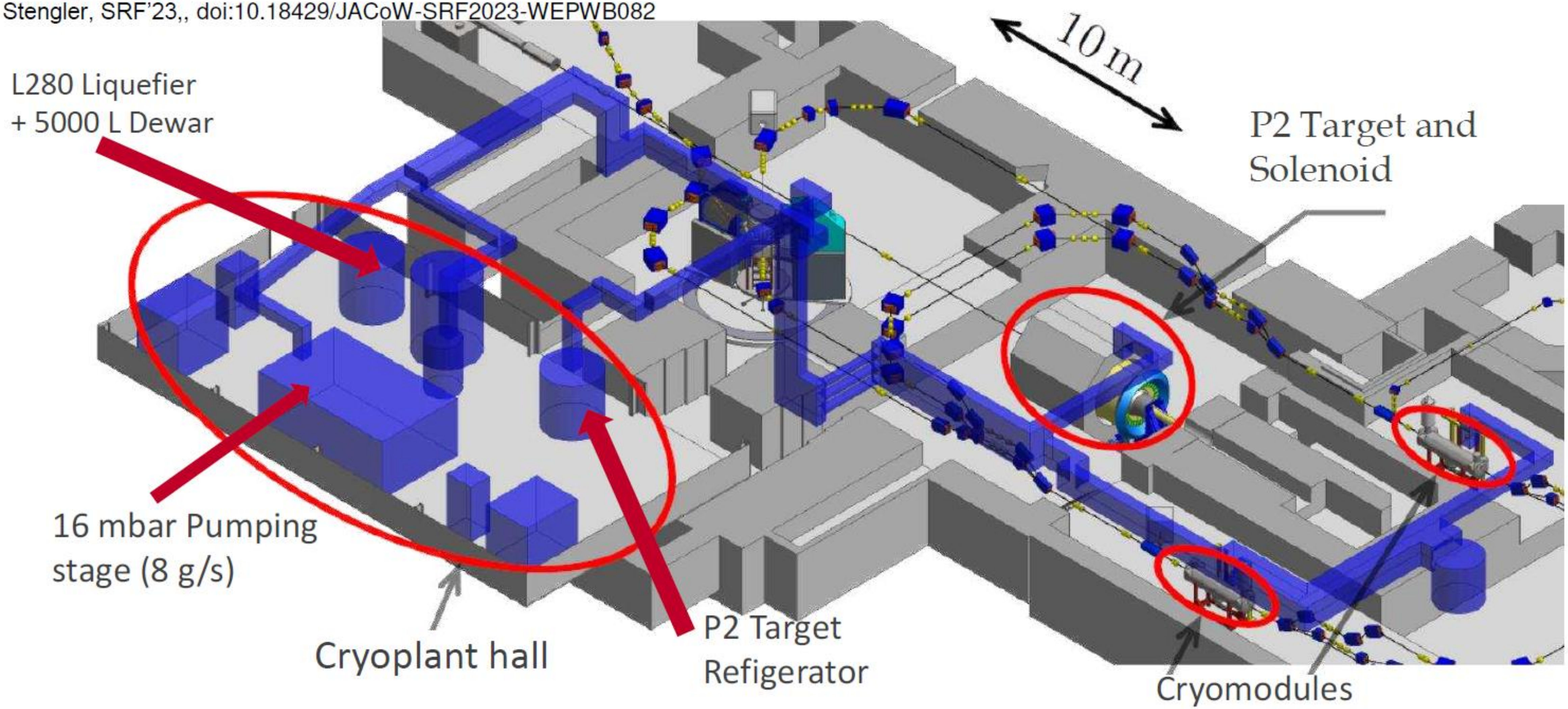


3.5 meter

2-SRF modules Specs: 25MeV Energy gain at <40 Watt thermal loss at 2Kelvin-SAT successfully completed in August 2020 (!)

Cryogenic Infrastructure

T. Stengler, SRF'23,, doi:10.18429/JACoW-SRF2023-WEPWB082

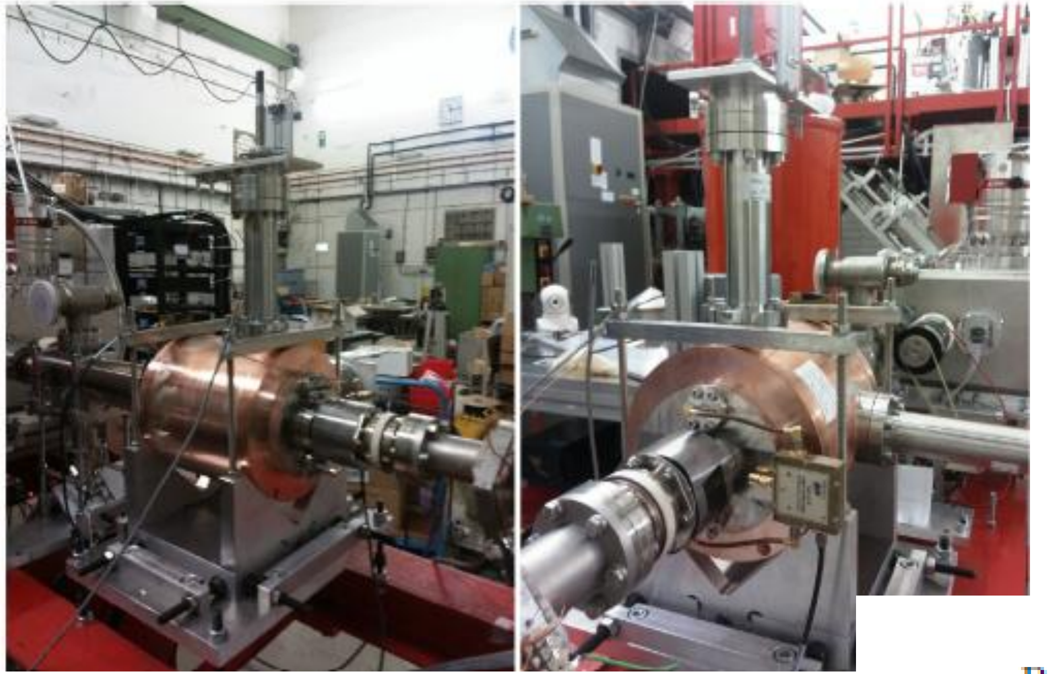


Cryogenic Infrastructure

T. Stengler, SRF'23,, doi:10.18429/JACoW-SRF2023-WEPWB082

Key Components

- Liquefier for one year to upgrade:
  - 80K internal adsorber
  - LN2 pre-cooling for higher output
  - Controll system upgrade
  - SAT (without pre-cooling) last week!
- 16 mbar sub-amospheric compressor for 8 g/s He:
  - Installed and SAT: 30.11.2023
- P2-Refrigerator (15K, 4.5 kW)
  - Delivered and installed
  - SAT forseen in 11.2024



R. Kempf et al.
Beam parameter stabilization for the P2 experiment at MESA
https://doi.org/10.1016/j.nima.2020.164554

Requirement:
Good S/N, high sensitivity, high bandwidth → determine fasle asymmetry within reasonably short time with sufficient accuracy

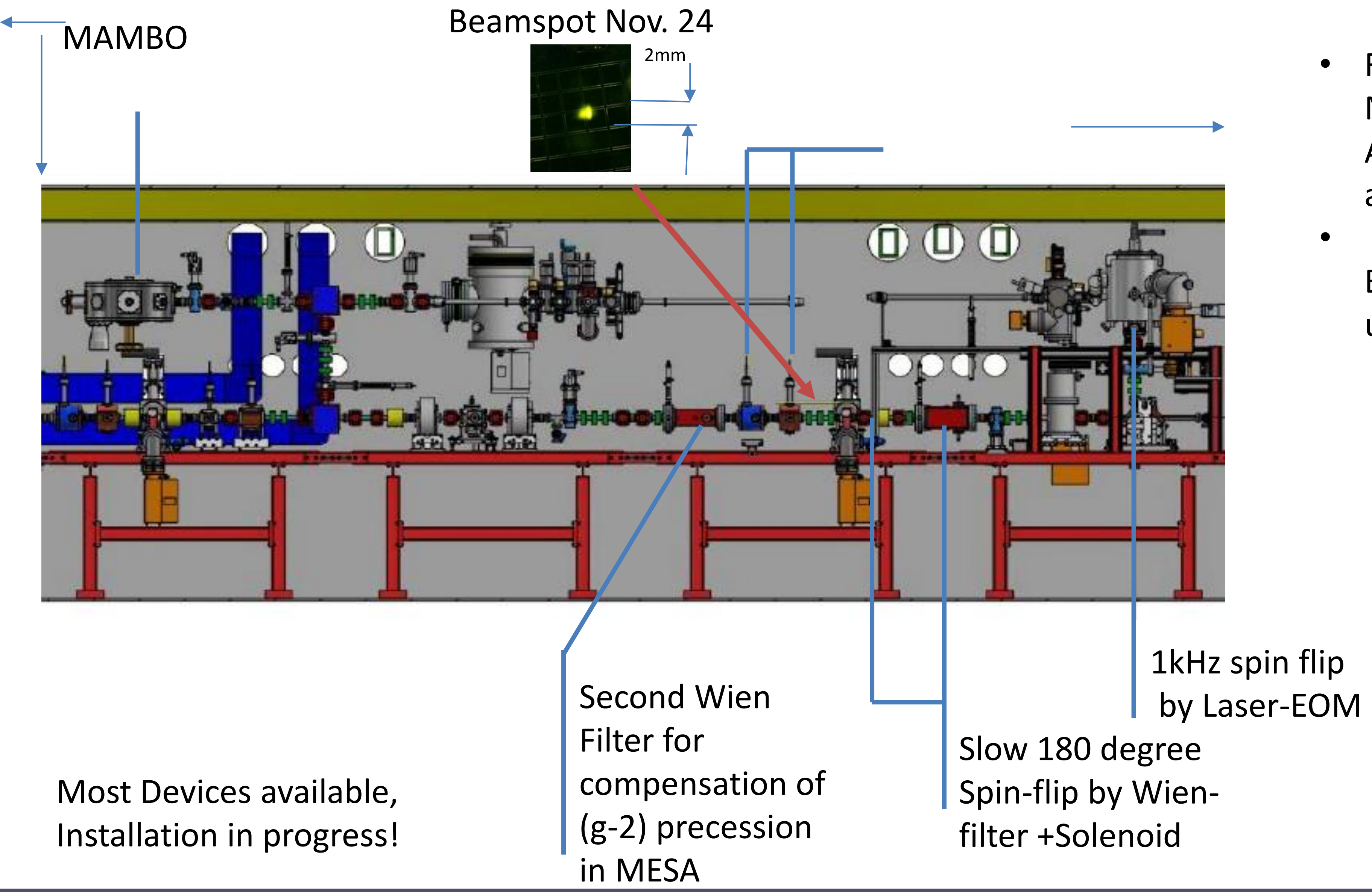
MESA XY Monitor
Sensitivity: ~1Volt/(mm*µA)

Parameter	$\Delta\bar{X}^i$	ΔX^i	ΔX^i mit $\Delta A(X^i) < 1\,\mathrm{ppb}$ nach $t = 1\,\mathrm{h}$
X^1	0,1 ppb	13,4 ppm	1,34 ppm
X^2	1,03 nm	138 µm	13,8 µm
X^4	0,236 nrad	31,7 µrad	3,17 µrad
X^6	0,042 eV	5,6 keV	0,56 keV

Already demonstrated

Beam parameter noise at 1kHz measurement rate
To achieve desired accuracy after 10000 hours
- or 10* less accuracy after 1 hour…

MESA source spin rotation/spin control



- Remaining parts of 100keV-MesA Low-energy Beam Apparatus (MELBA) will be assembled still in 2024
- MAMBO (Milliampere Booster) will be installed until early summer 2025

Most Devices available, Installation in progress!