MESA - an ERL project for particle physics experiments

Florian Hug

on behalf of MESA accelerator and experiment groups

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DFG through the PRISMA cluster of excellence EXC 1098/2014
DFG through the research training group “AccelencE” RTG 2128

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

Outline

- MESA Building Overview and Accelerator Layout

- MESA Accelerator Components
  - Injector
  - Cryomodules
  - Recirculation Arcs

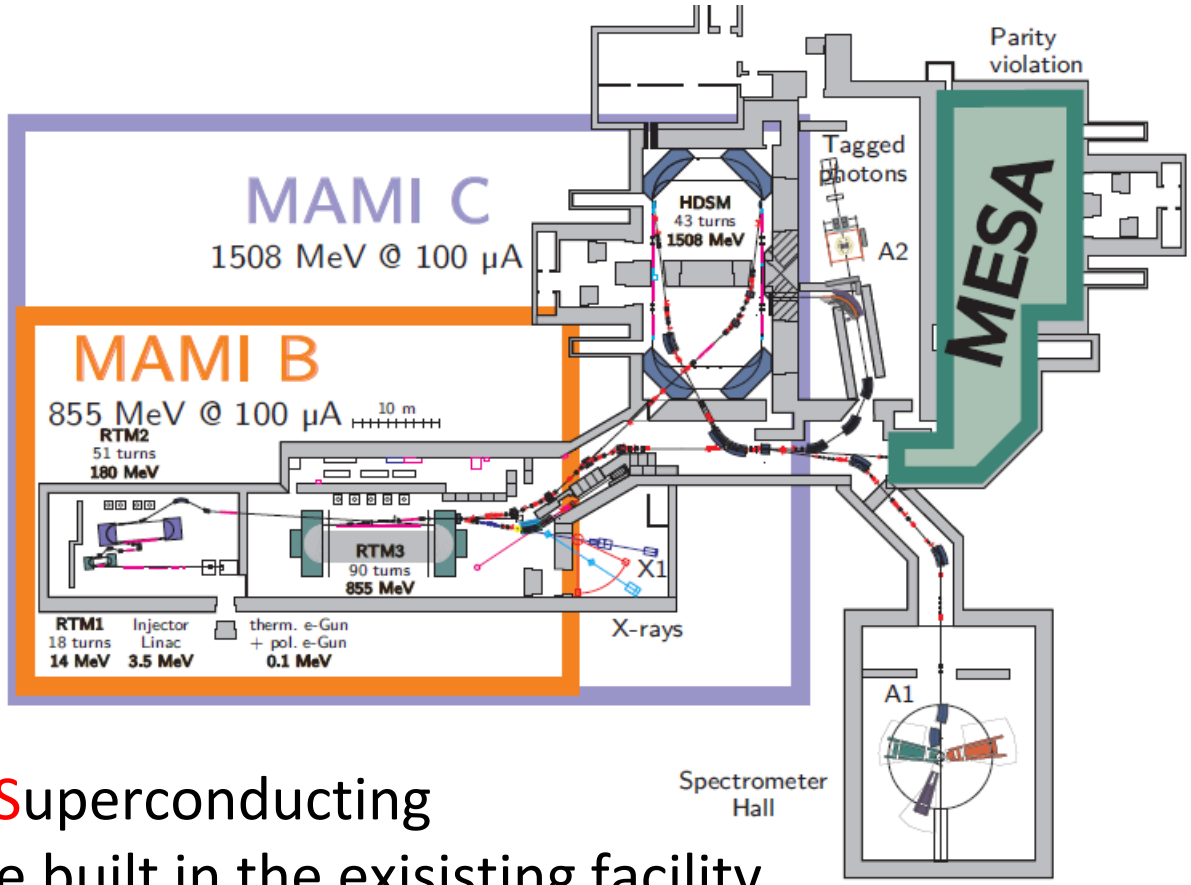
- Experiments
  - with External Beam: P2 and BDX
  - with ERL beam: MAGIX

- Summary & Outlook

MAMI and MESA at KPH Mainz

- MAMI is operating since >25 years at KPH

- In 2012 funding of PRISMA cluster of excellence has been granted including a new accelerator project:

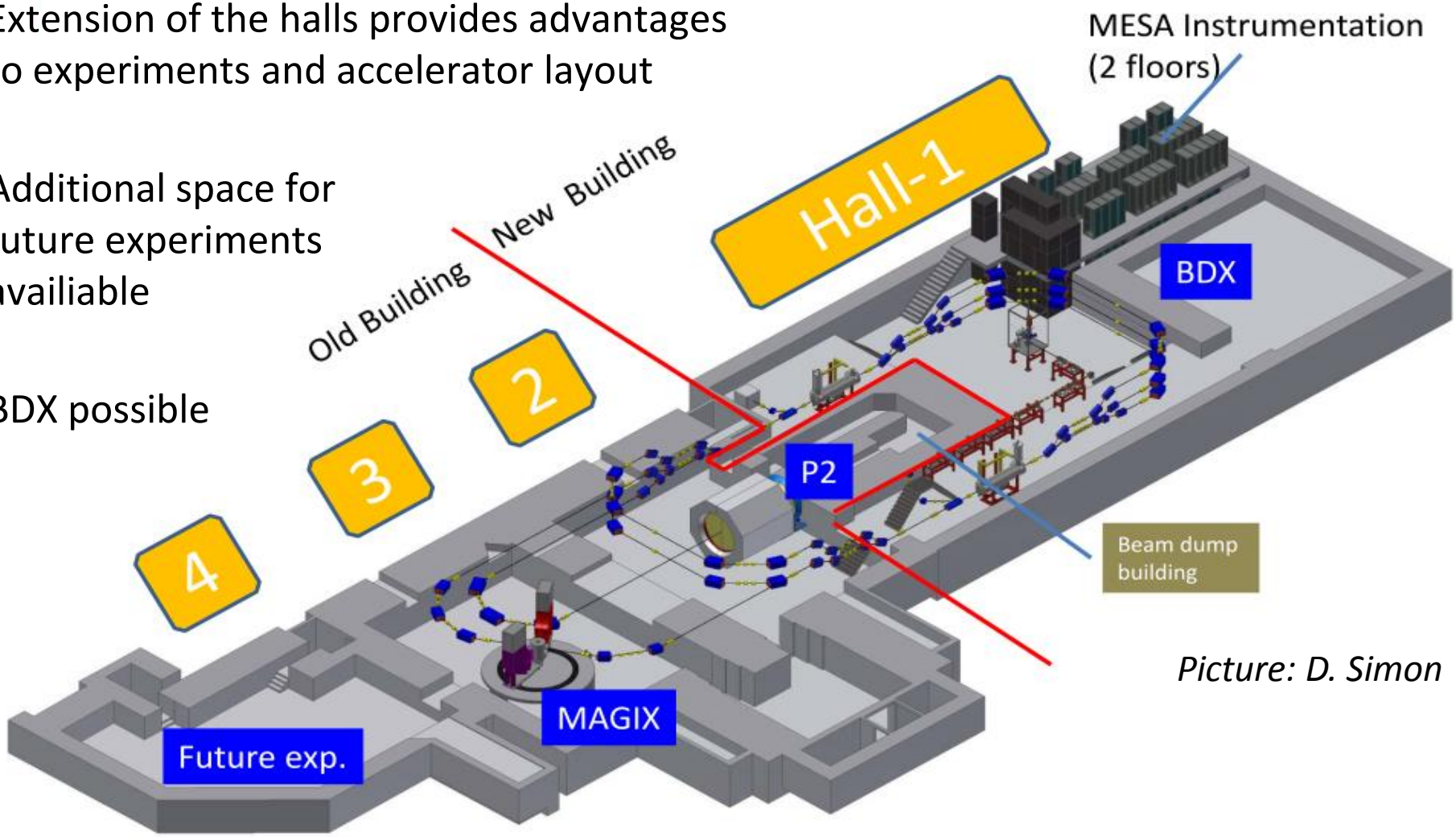


Mainz Energy Recovery Superconducting Accelerator (MESA) to be built in the exisisting facility

- In June 2015 DFG granted a research building to JGU „Center for Fundamental Physics (CFP)“ including an extension for MESA halls

MESA Building Overview

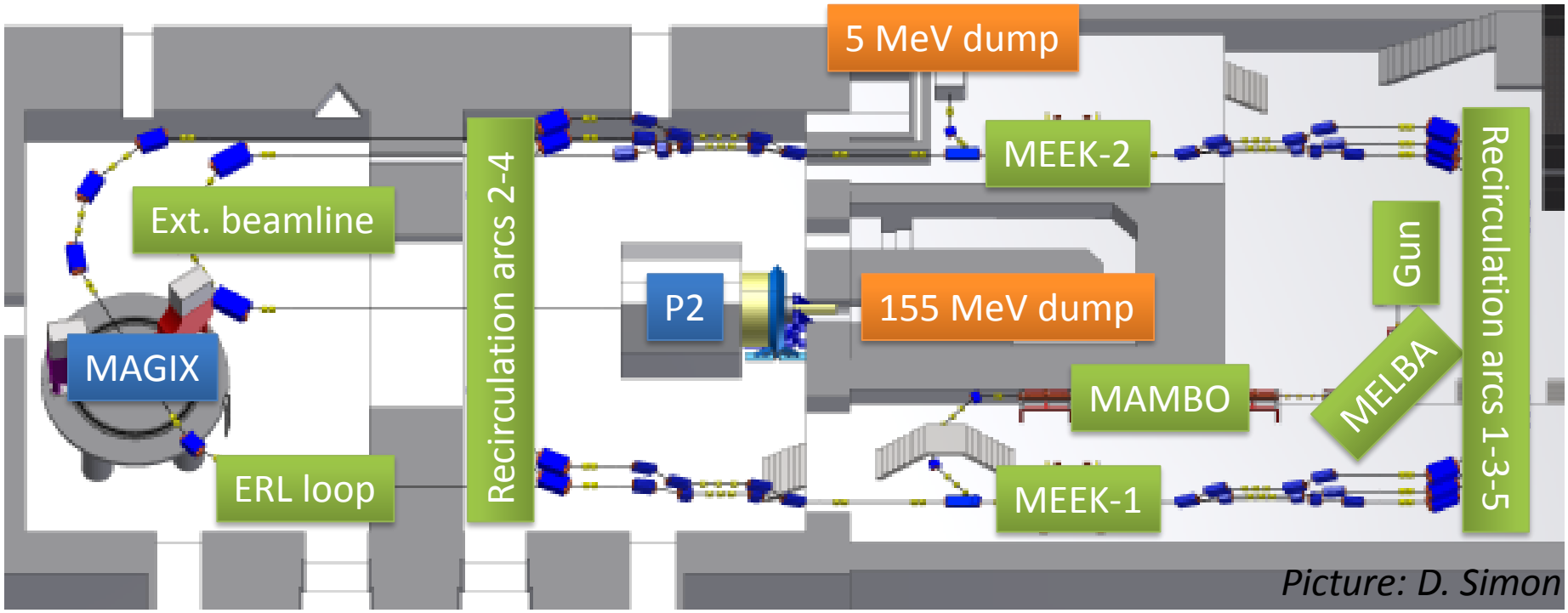
- Extension of the halls provides advantages to experiments and accelerator layout
- Additional space for future experiments availiable
- BDX possible



Picture: D. Simon

Trade off: some project delay due to civil construction time

MESA Accelerator Layout



Double sided recirculation design with normalconducting injector and superconducting main linac

Two different modes of operation:

- 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

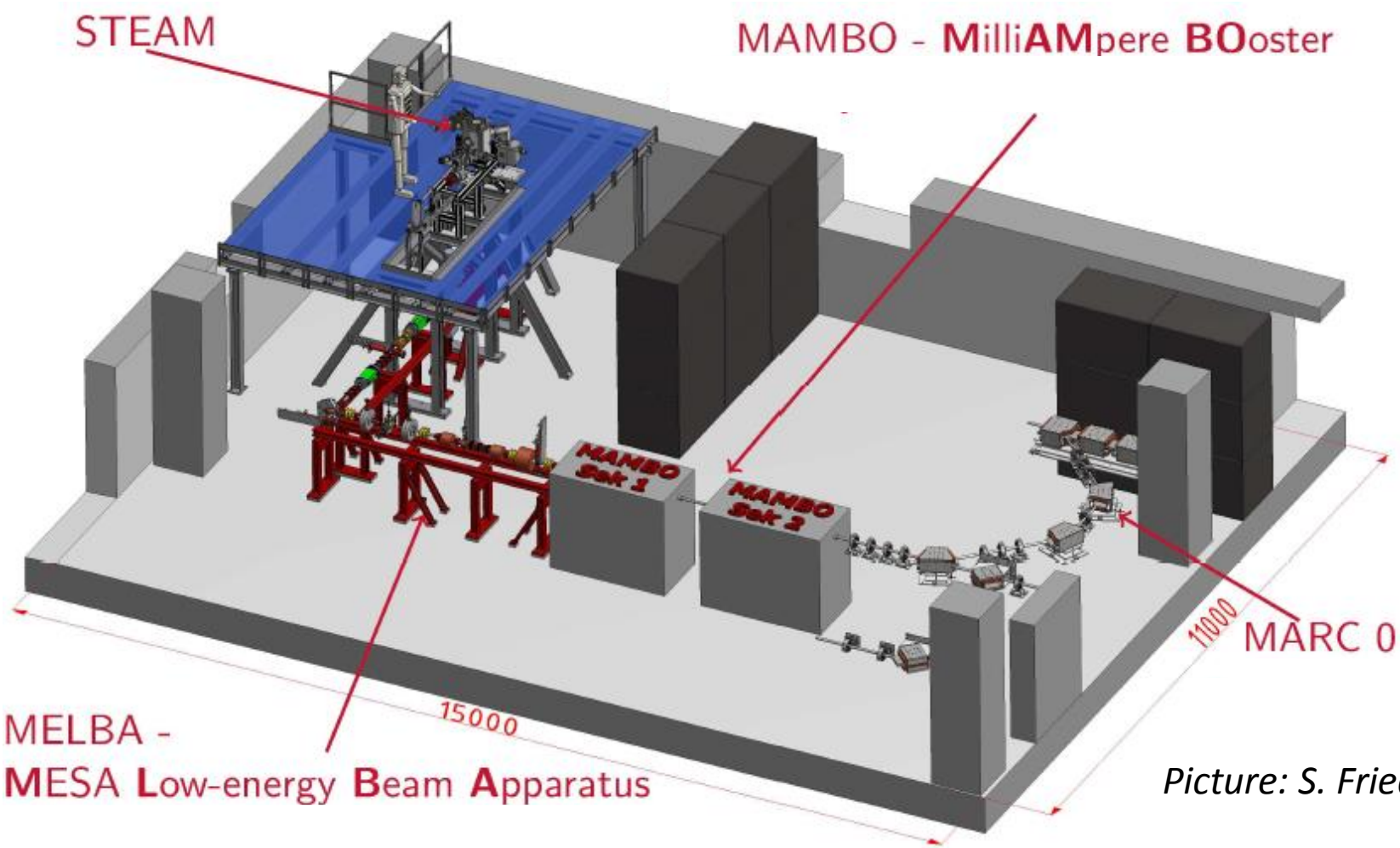
Status Report Building:

- First construction works (workshop and storage buildings) are expected to be finished in **end 2018**
  → afterwards: workshop moves into new building. Existing workshop building can be removed
- Ground breaking for new underground hall in **spring 2019**
- Construction on existing halls will start in **2019**
- Handover of the buildings will be not before **end 2020**

→ Huge impact on MESA construction timeline

→ Existing halls still usable for some time for tests

MESA Injector Test Setup until 2019

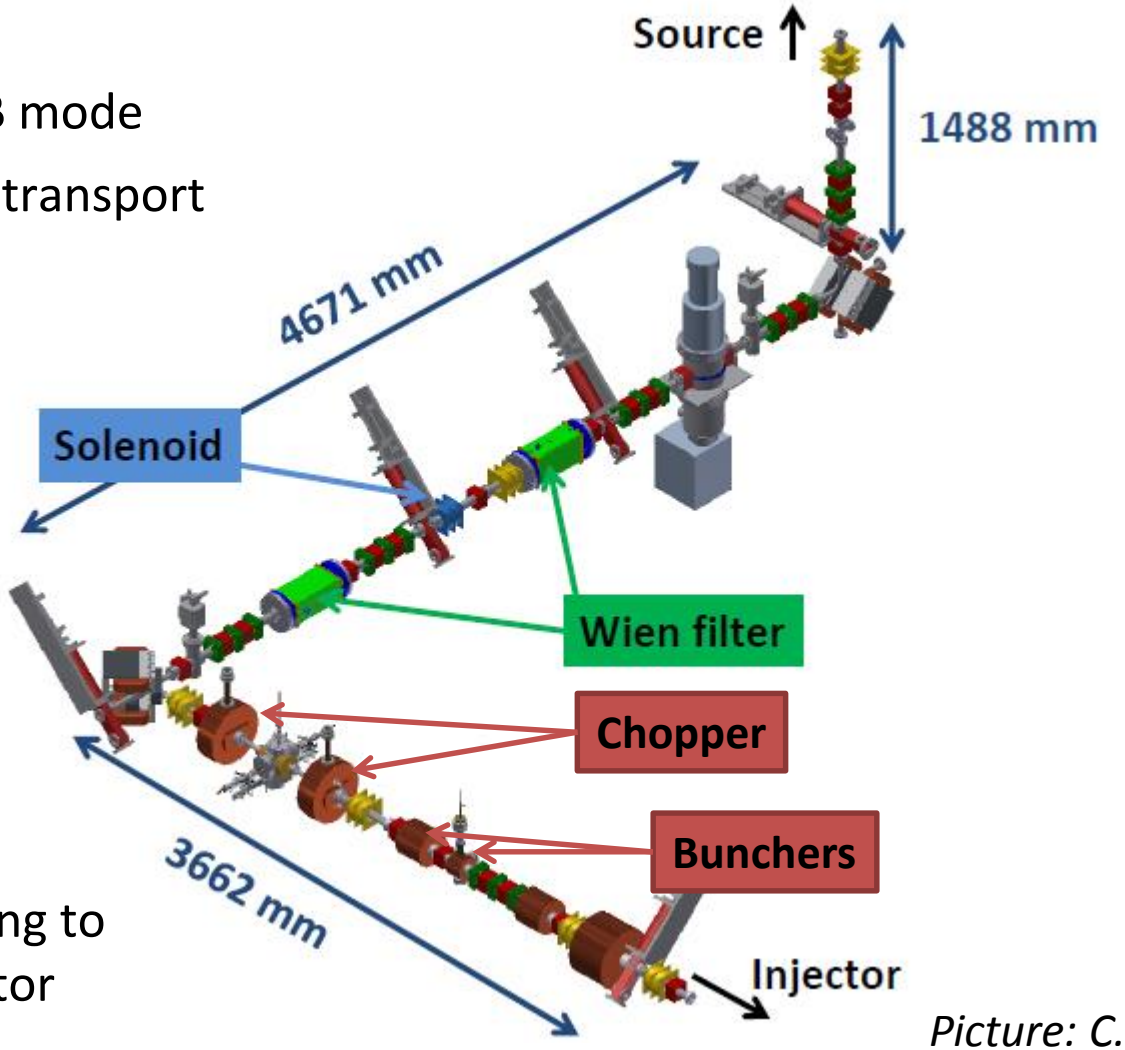


Picture: S. Friederich

MESA Low Energy Beam Apparatus (MELBA)

MELBA will prepare the beam for further acceleration

- Spin rotation in EB mode
- Low energy beam transport
- Beam diagnostics



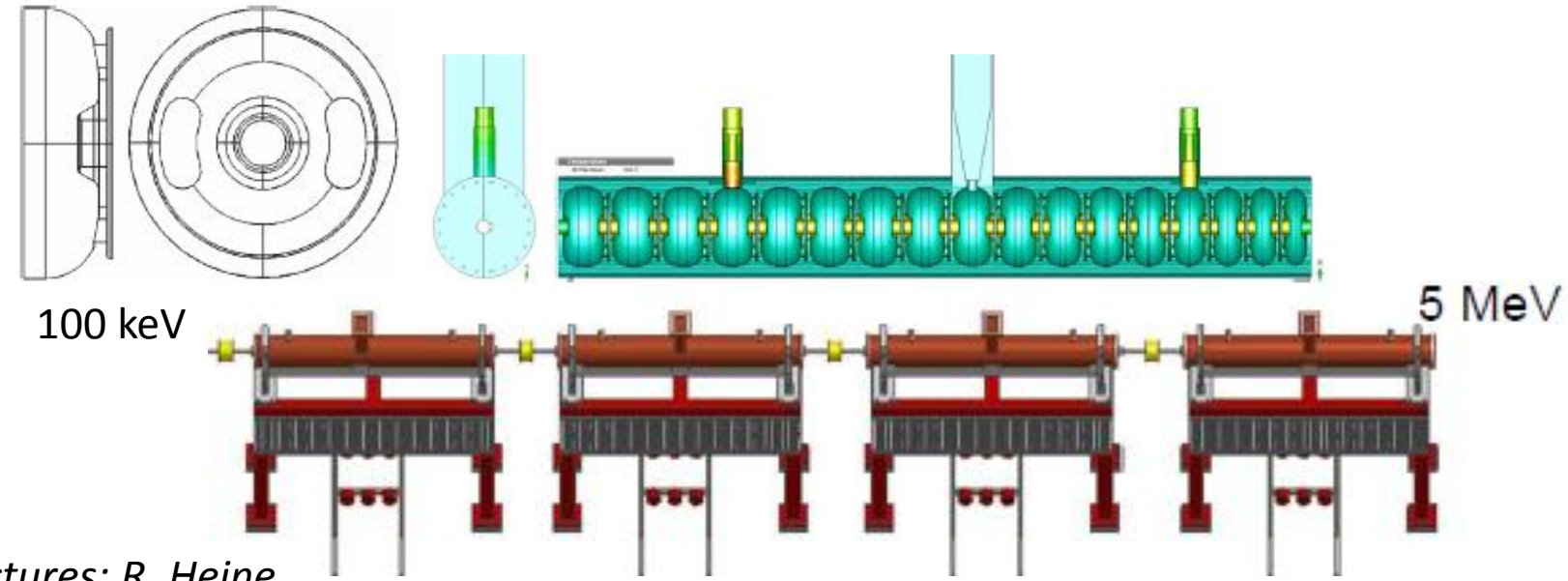
- Longitudinal and transverse matching to the MAMBO injector

Picture: C. Matejcek

MESA NC Injector (MAMBO) Layout

- Design inspired by the MAMI injector LINAC
- 4 room temperature RF bi-periodic pi/2 standing wave structures @ 1.3 GHz
- 1 graded-β , 3 const. β sections; Energy gain ΔE=1.25 MeV/section
- RF-Amplifiers: SSA with ~90 kW (graded β) and 3 x ~60 kW (fixed β)

→ Status: design completed , test cavity and 15 kW SSA-prototype under test

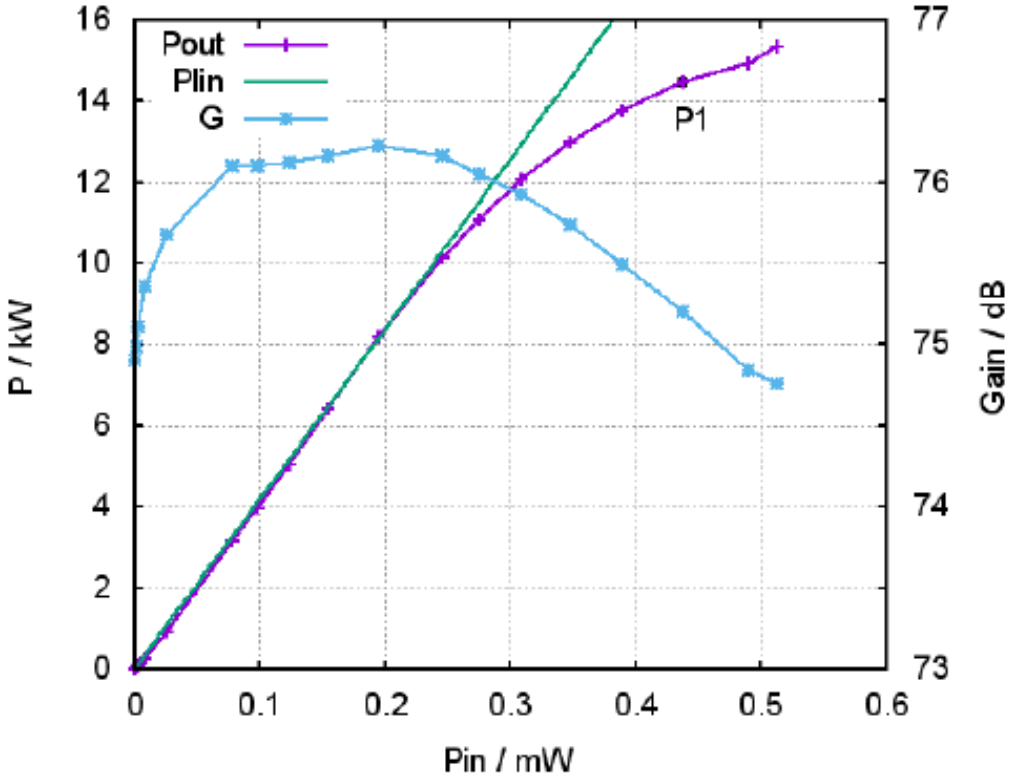


Pictures: R. Heine

SSA Prototype

15 kW SSA-prototype

Test results

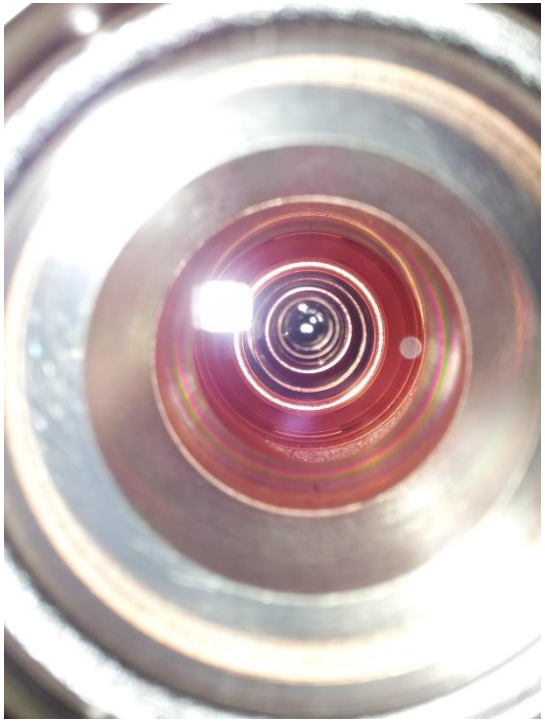


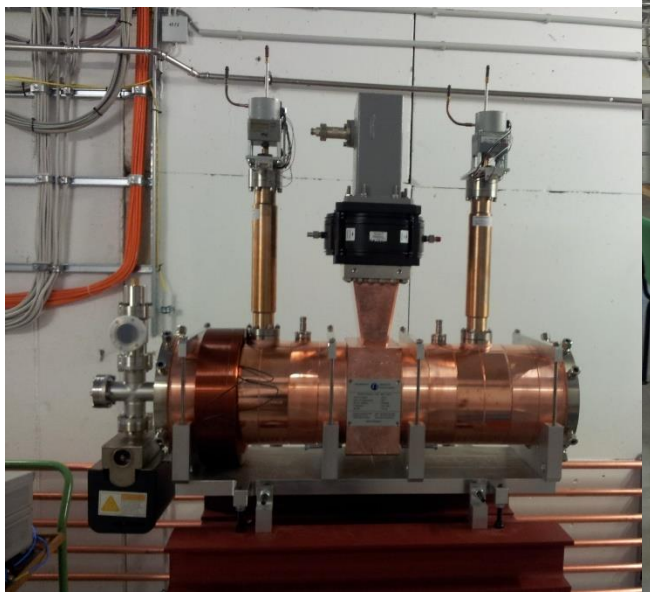
R. Heine, F. Fichtner , IPAC 2018

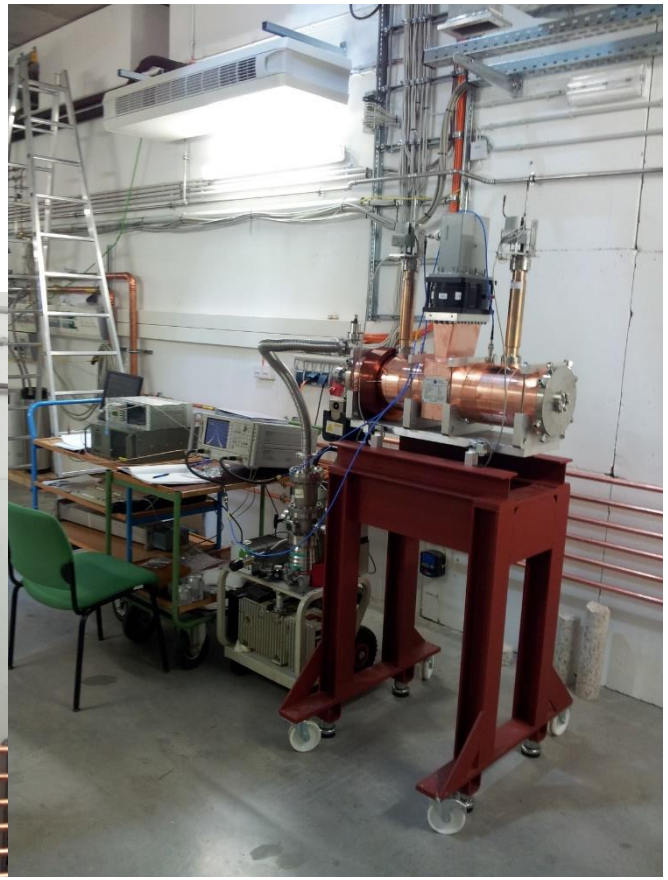
→ SSA will be used for SC cavity tests at HIM

MESA Injector Cavity Prototype

- testing rf-properties of couplers and tuners
- multipacting studies
- First test of PLL for SRF cavity tests (MSc thesis S. Thomas)







Pictures: R. Heine

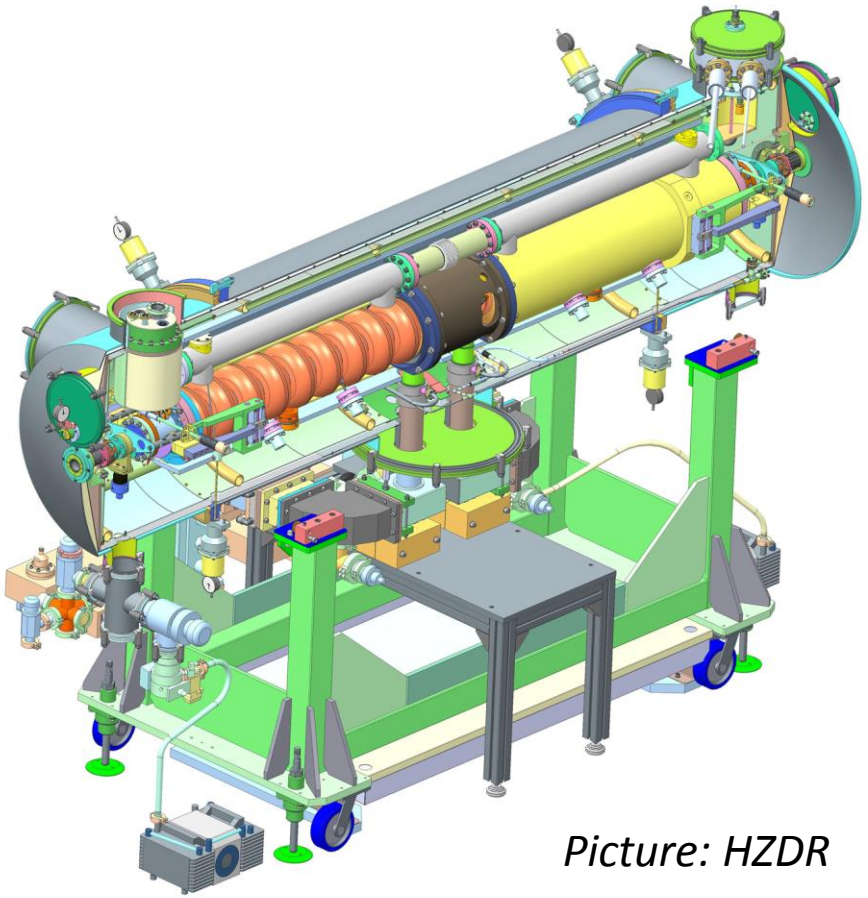
MESA Cryomodules

Cryomodules of the 'Rossendorf'-type
(2 x 9-cell TESLA/XFEL cavities), which are in use at ELBE
(and have been at ALICE) will be used for MESA

→ we applied some adaptations
in order to allow 1 mA ERL operation:

- added tuners with piezo elements (XFEL/Saclay-type)
- used sapphire windows at HOM feedthroughs

→ beam current of 10 mA will not be achievable with that type of cryomodule



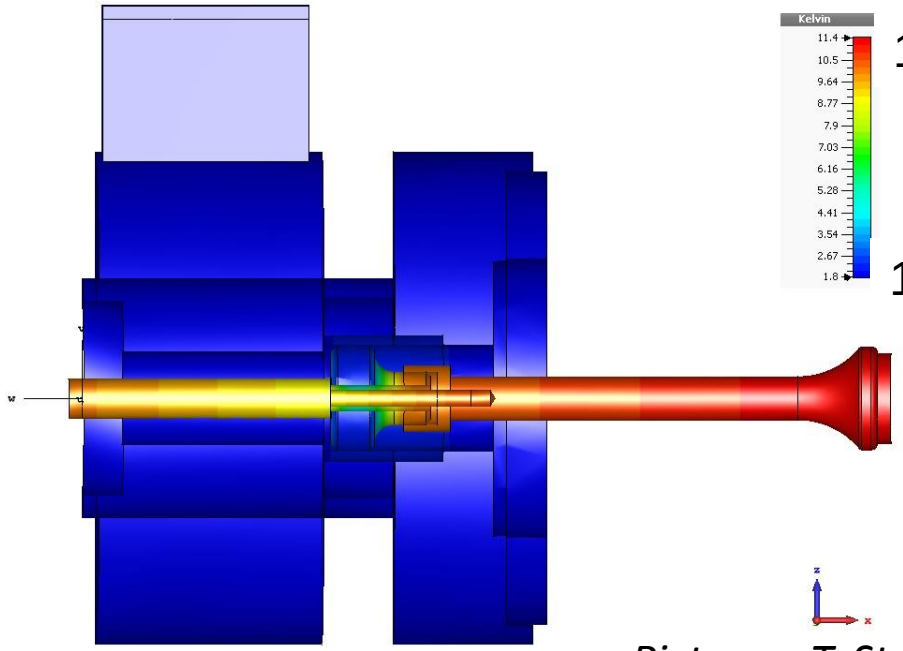
Picture: HZDR

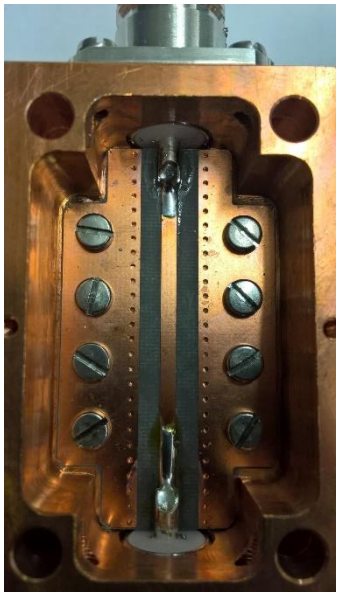
Reduction of HOM Antenna Heating

Thermal calculations at HOM antenna ongoing (T. Stengler):

→ Provide optimised thermal connection design

→ Limitation by heat input from cable, need for heat sink

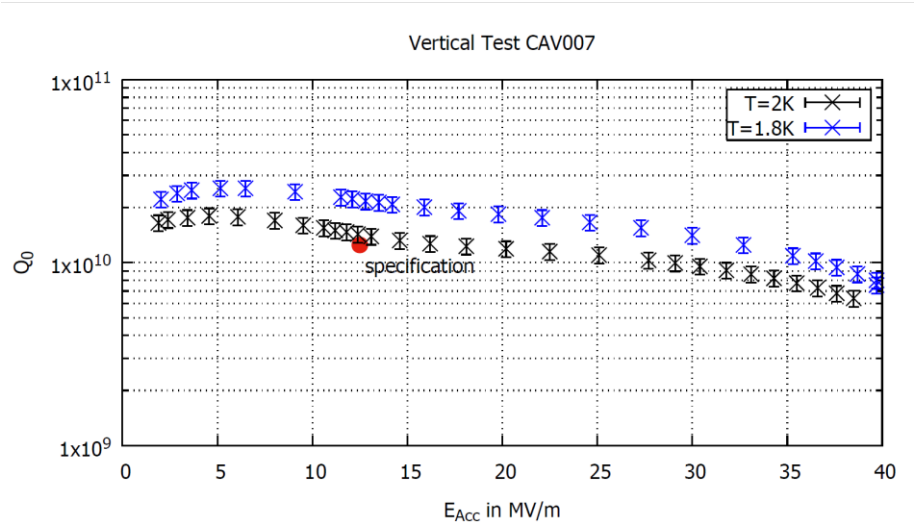


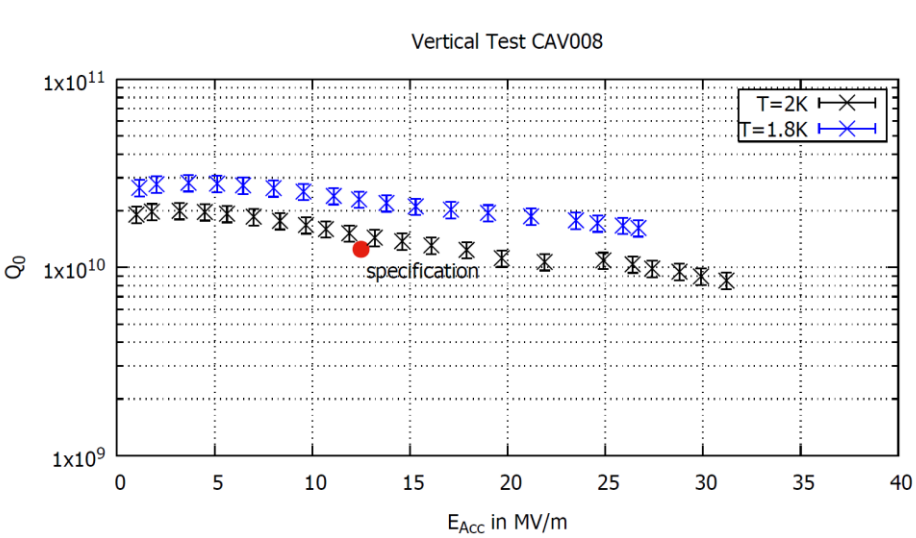


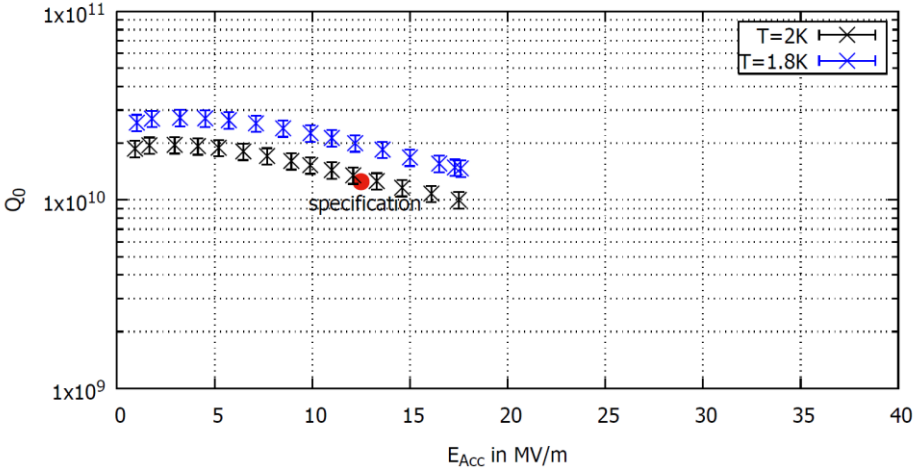
Pictures: T. Stengler

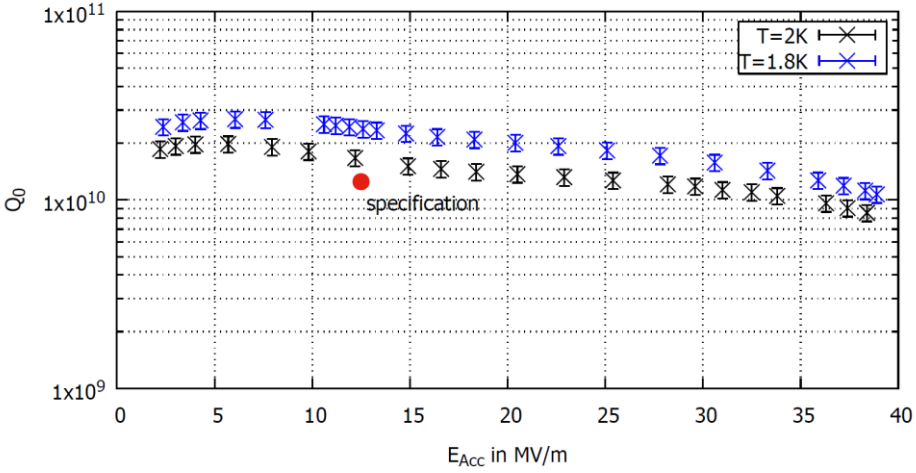
Status: striplines constucted and integrated for better thermal connection

Cavity Performance at Vertical Test









→ all resonators within specs. One with lower quench field of ~16.5 MV/m (breakdown)

Cryomodule Integration into Test Bunker

Milli AMpere BOoster (MAMBO)

Normalconducting Injector MAMBO:

- Design inspired by the MAMI injector LINAC
- 4 room temperature RF bi-periodic pi/2 standing wave structures @ 1.3 GHz
- 1 graded-β , 3 const. β sections
- Energy gain ΔE=1.25 MeV/section
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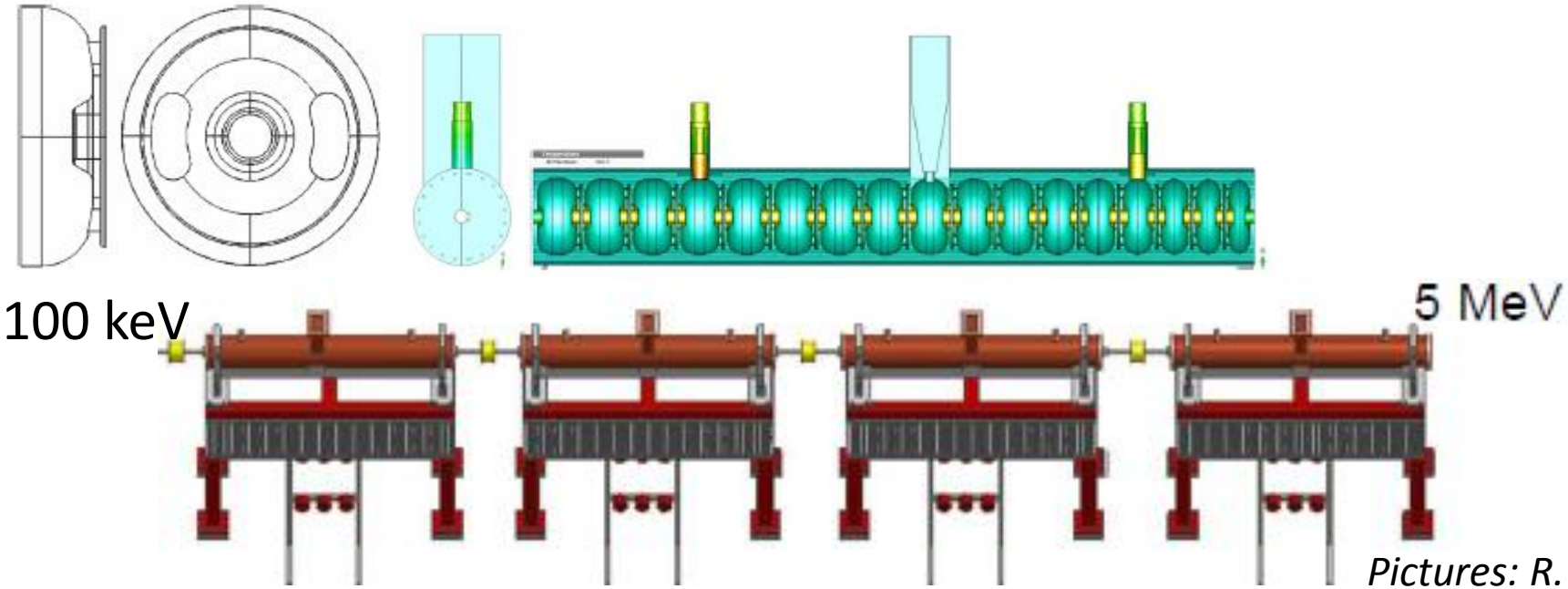


Pictures: R. Heine

Recirculation arcs optics

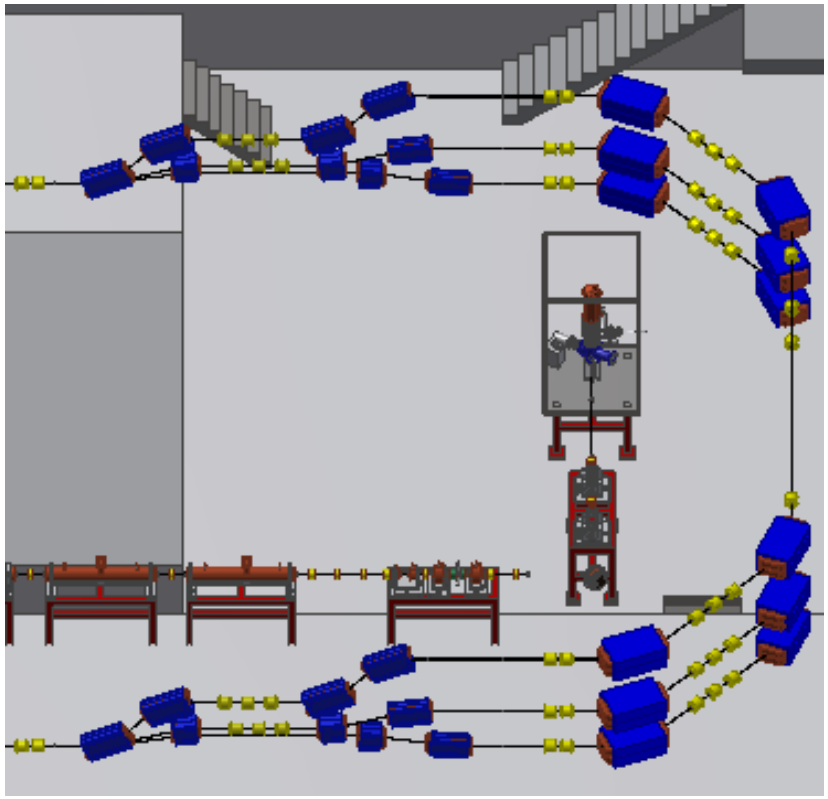
Optics symmetric with respect to the middle of the long straight section.
→ α=0 in the middle of each return arc

Return arc is free of transverse and vertical dispersion

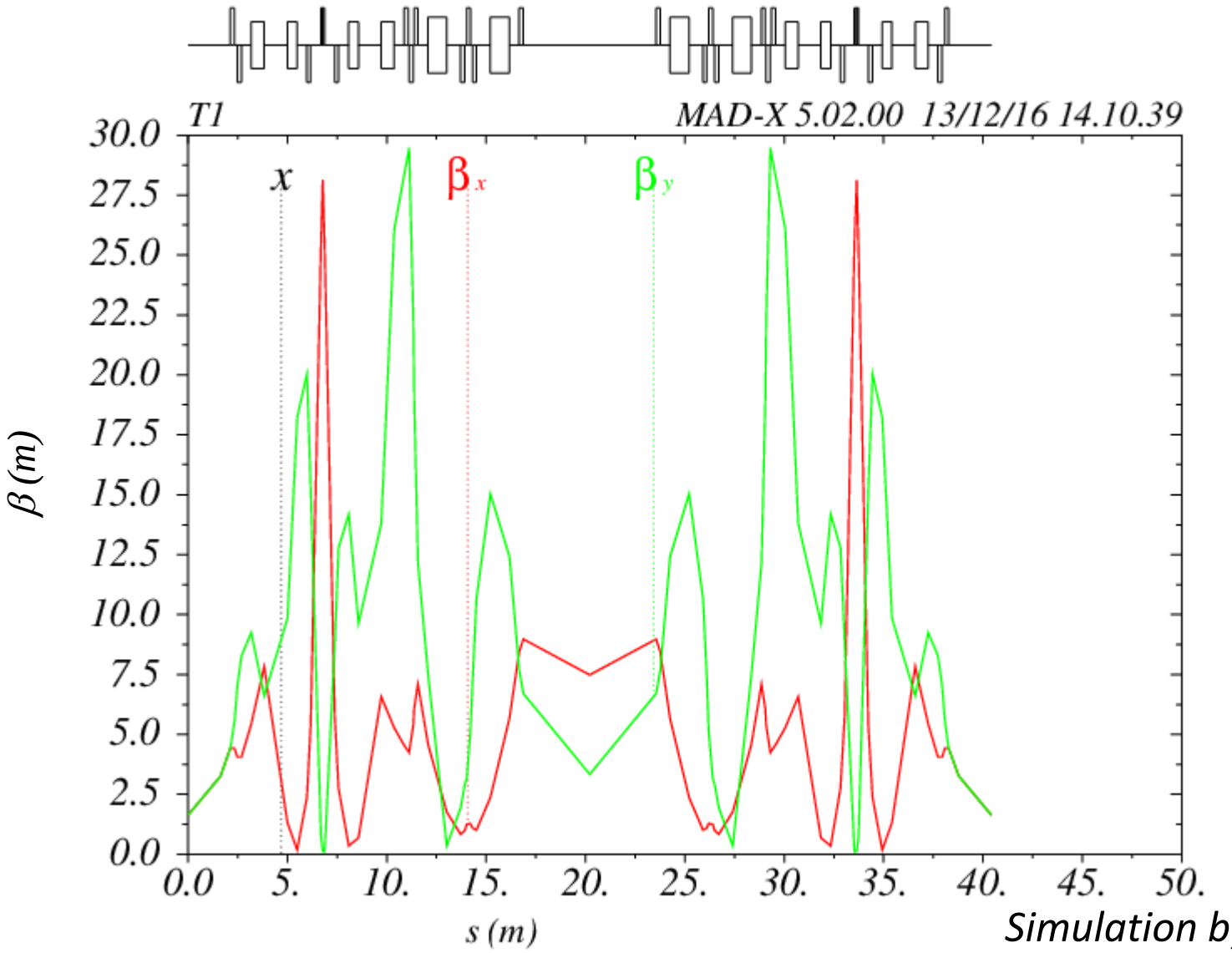
Longitudinal dispersion r_{56} can be adjusted by changing the gradients of the middle quadrupoles
in the 45° sections

Total length of 1st return arc: ~45m
difference in time-of-flight for
beams of 15 MeV and 30 MeV:
Δt=60.5 ps → 2.83° in RF @ 1.3 GHz

Path length adjustment needed
(2 cm minimum) for complete
flexibility in beam energy
(chicane or moveable magnets)

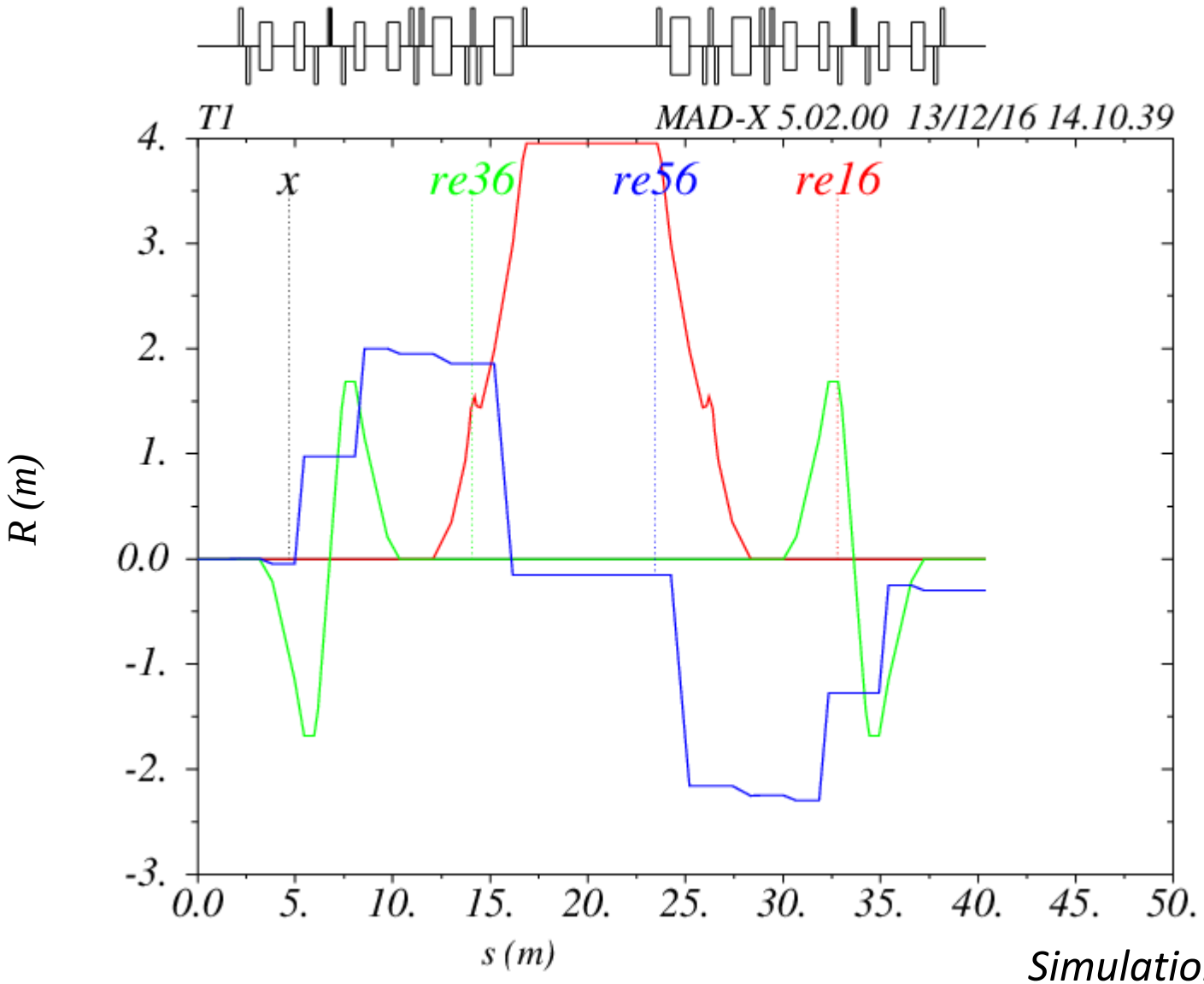


Complete 1st recirculation arc lattice



Simulation by D. Simon

Complete 1st recirculation arc lattice

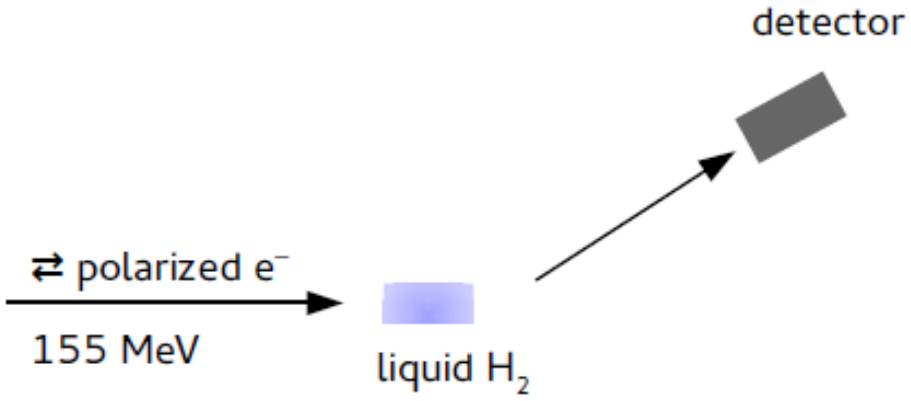


Simulation by D. Simon

Experiments with External Beam: P2

P2 experiment @ MESA:

- Main Goal: precision measurement of electroweak mixing angle θ_W
  → measure $\sin^2\theta_W$ to a precision of 0.13%
- Experimental Method: Measurement of parity violation assymetry in elastic electron proton scattering at low momentum transfer Q^2



$$\frac{N_- - N_+}{N_- + N_+} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(Q_W - F(Q^2)\right)$$

$$Q_W = 1 - 4\cdot\sin^2(\theta_W)$$

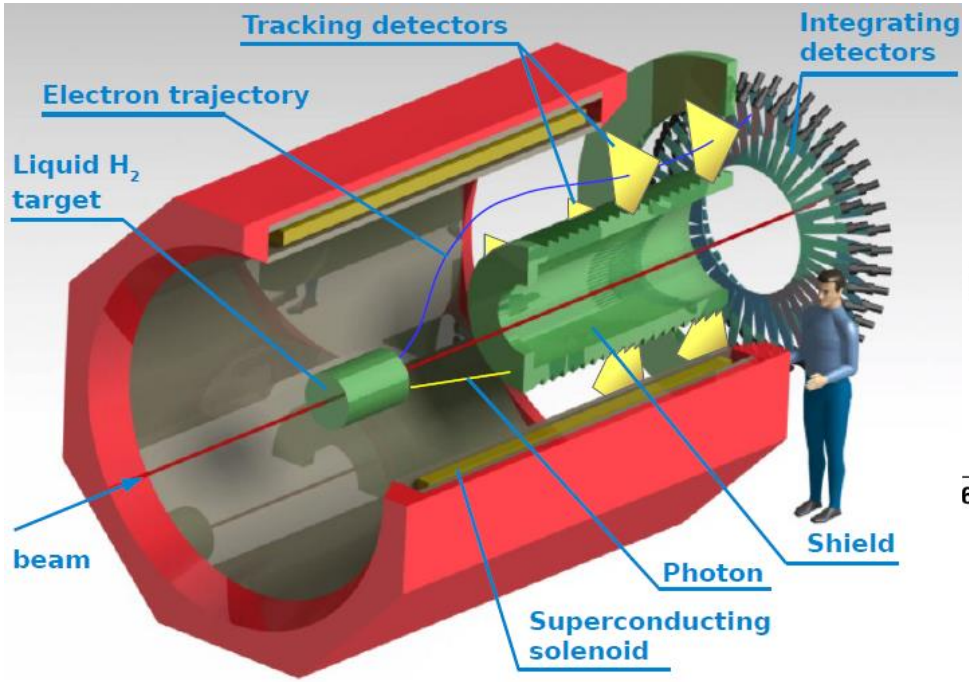
- The exspected assymmetry is very small ~30 ppb

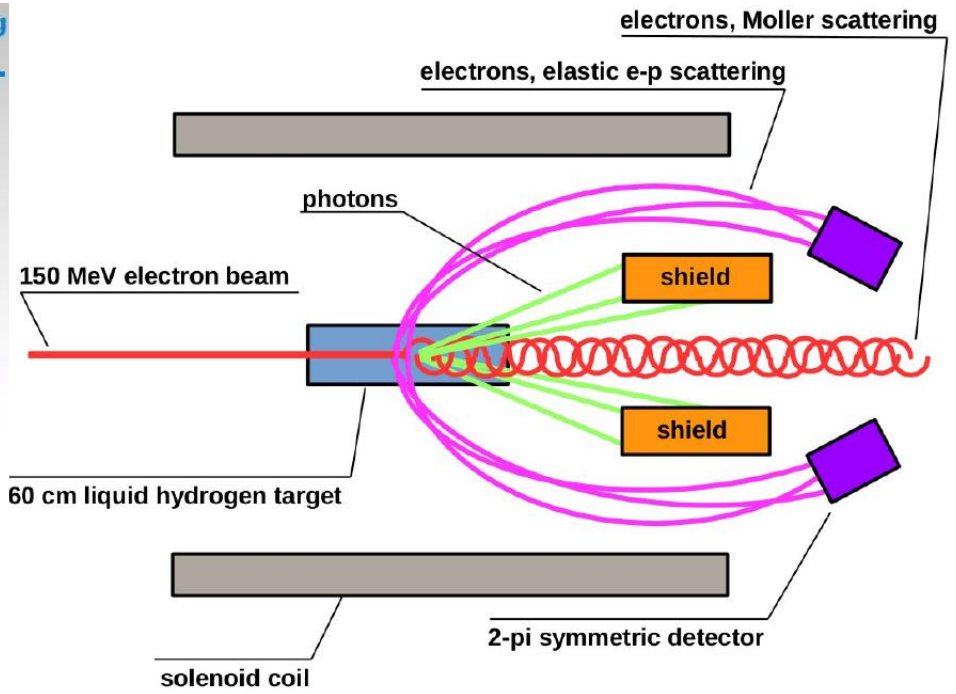
→ High demands on beam quality: We need a polarized beam of 150 µA @ 155 MeV with high polarization and high stability in energy, energy spread, position and angle for a very long time (~10.000 h)

Experiments with External Beam: P2

Experimental setup of P2:

- 60 cm Liquid Hydrogen target, beam deposition 2.8 kW @ 15 K
- 0.6 T superconducting FOPI Solenoid, outer coil diameter 3.8 m
- 2 π symmetric detector plane with Cherenkov detectors, additional tracking detectors

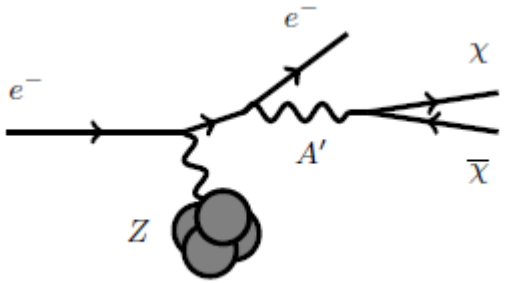


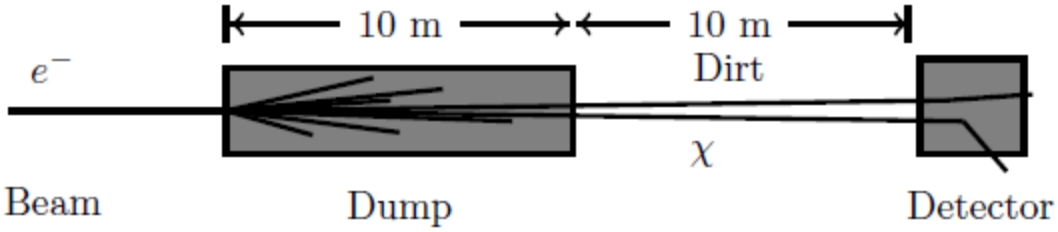


I. Sorokin

Idea of BDX experiment @ MESA:

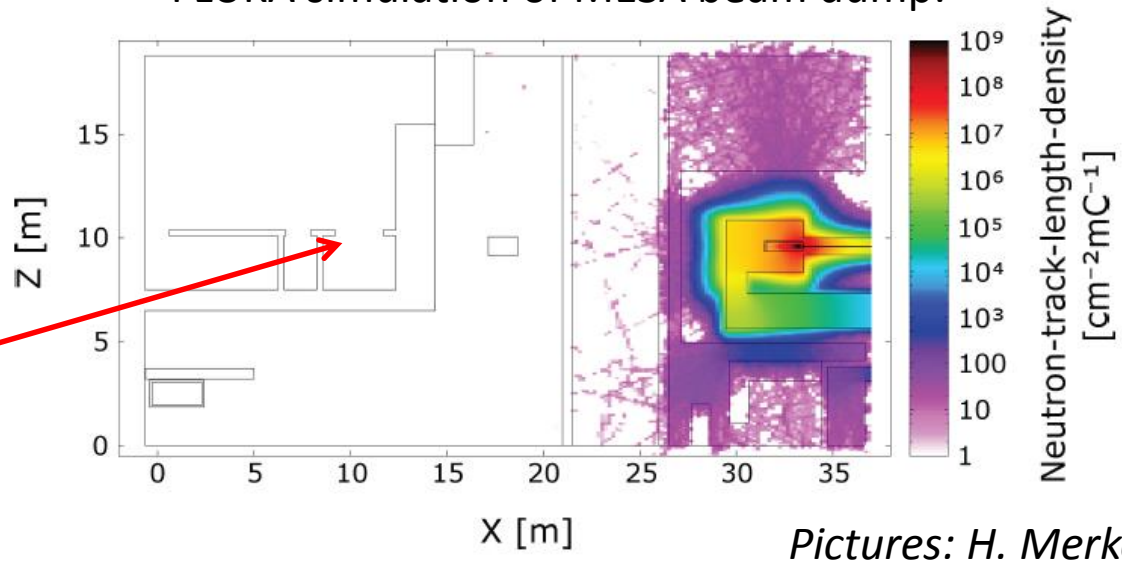
- Dumped beam from P2 might produce a Dark Matter beam via pair production:





- This beam can be very penetrating
  → let it pass some shielding and set up a simple detector (e.g. a scintillator)
- Measure whenever P2 is running

FLUKA simulation of MESA beam dump:



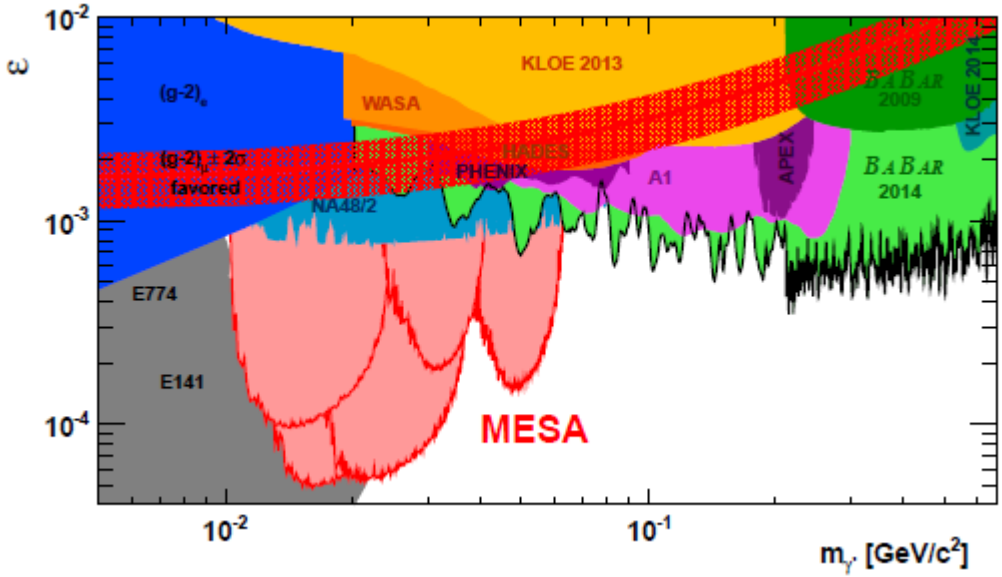
Pictures: H. Merkel, Bormio 2016

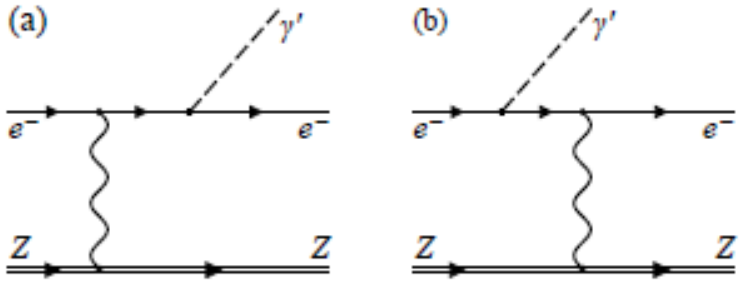
Experiments with ERL Beam: MAGIX

MAGIX experiment @ MESA:

Main Goals:

- Search for dark photons
- Precision measurement of magnetic proton radius
- Determination of Astrophysical S-Factors
- …

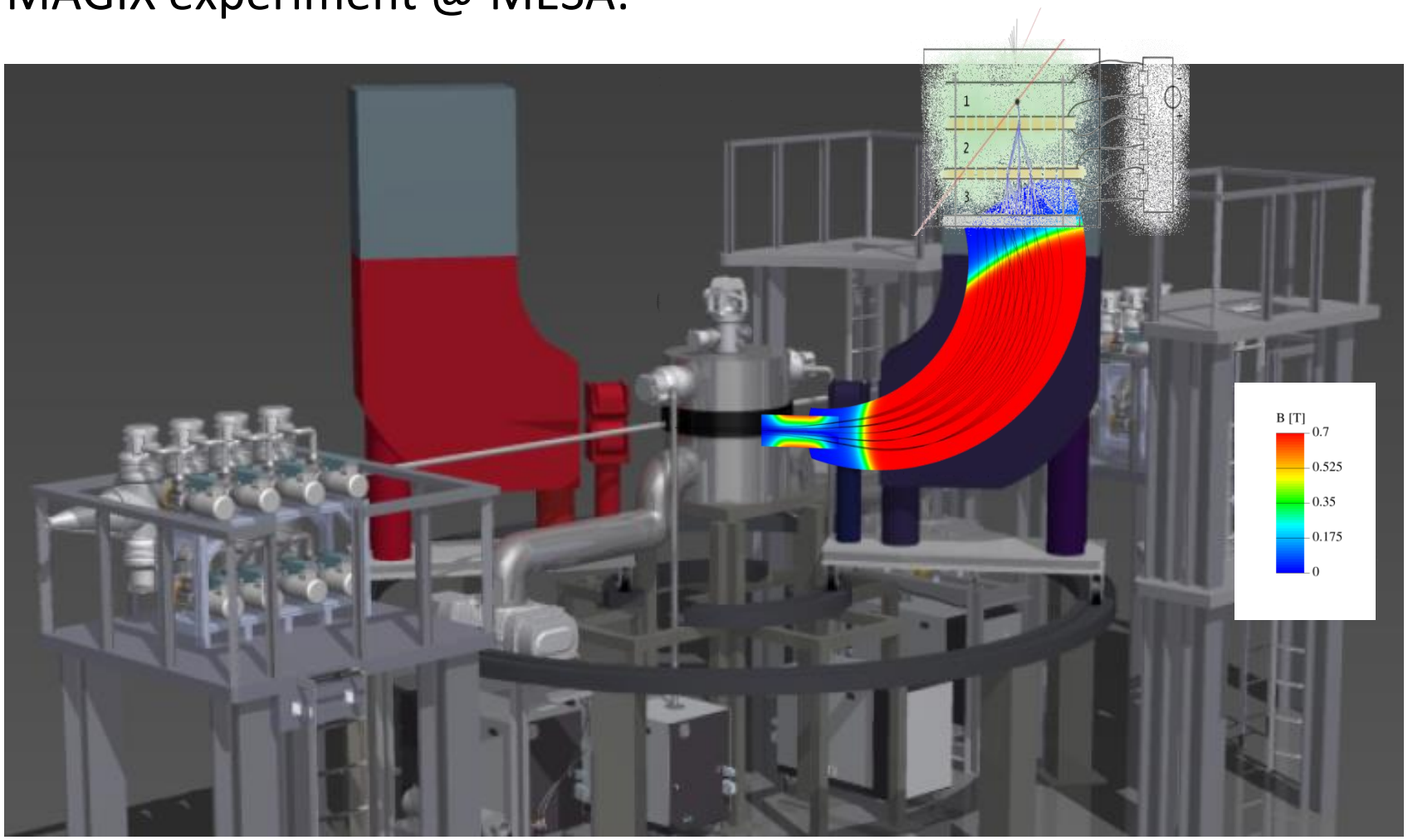




→ Make best use of the ERL-beam with high intensity 1 (10) mA and beam quality

Experiments with ERL Beam: MAGIX

MAGIX experiment @ MESA:



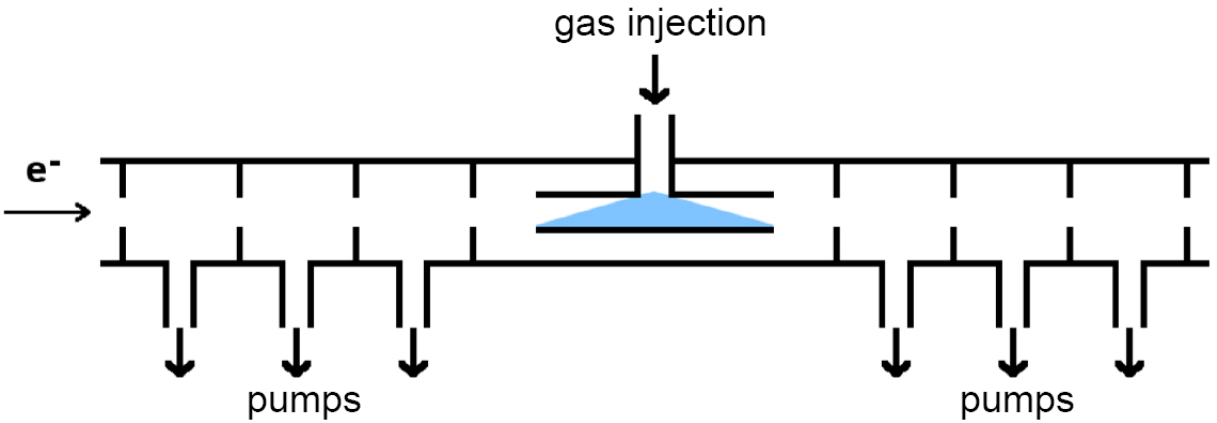
Picture: MAGIX group, S. Aulenbacher

Experiments with ERL Beam: MAGIX

(Pseudo) Internal Targets @ MAGIX:

Tube target:

- Gas polarization possible
- Scattered particles pass tube material
- Focused Beam has to pass thin structures

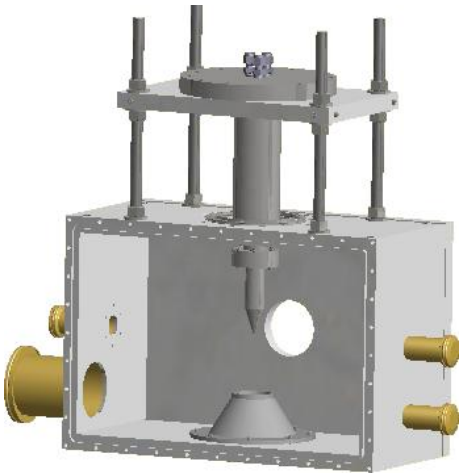


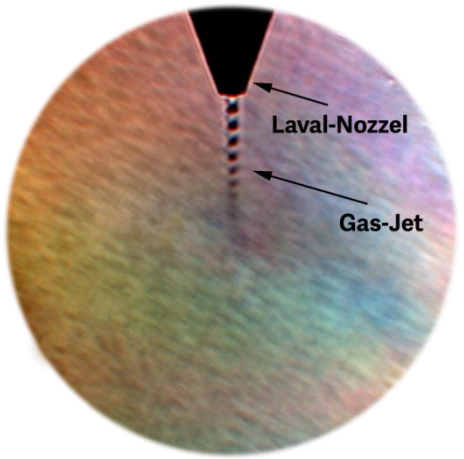
Luminosities:
~10^{36} $cm^{-2}s^{-1}$ ~10^{31} $cm^{-2}s^{-1}$ (pol.)

Jet target:

- No gas polarization possible
- Complete windowless

Luminosity:
~10^{36} $cm^{-2}s^{-1}$



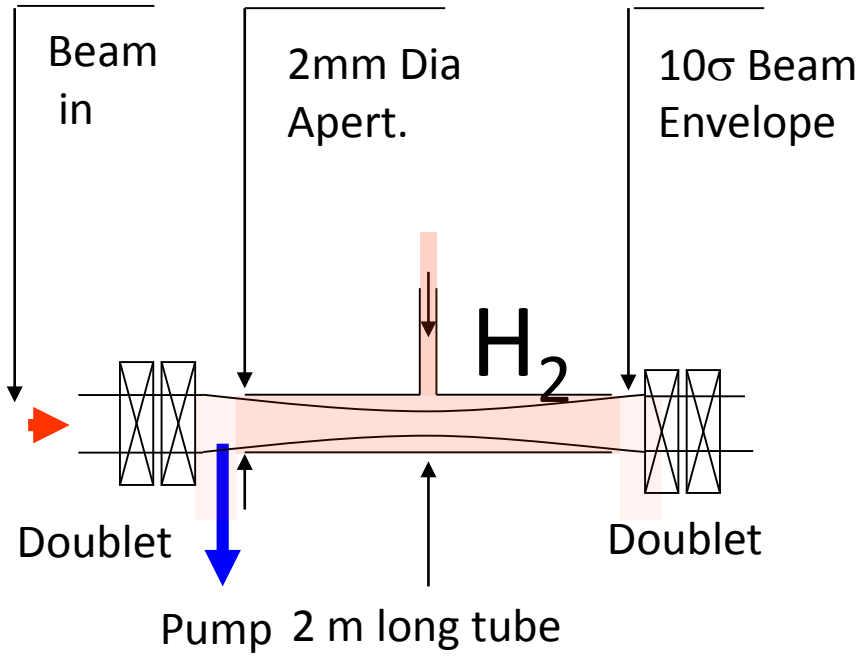


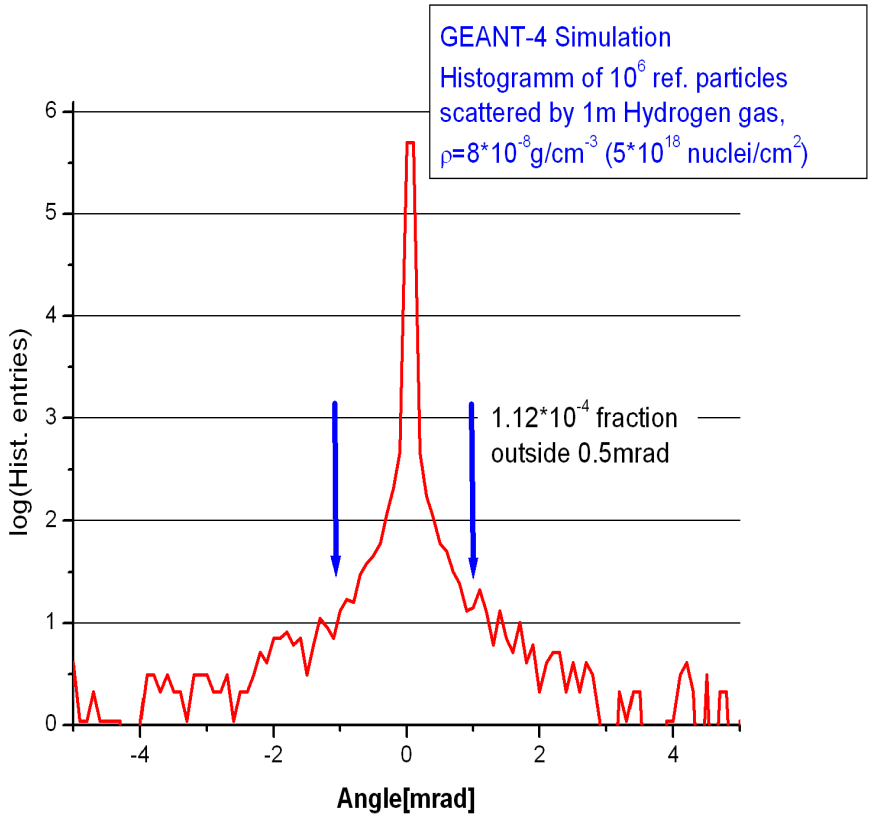
Pictures: S. Aulenbacher

Experiments with ERL Beam: MAGIX

Challenges on ERL operation using Internal Targets @ MAGIX:

- Using the tube target the beam needs to pass a 2m long tube without hitting any structure
- Scattered electrons with small scattering angles can produce beam halo
- Halo particles can get dangerous when hitting the SRF cavities





Pictures: K. Aulenbacher

Summary

- MESA will be a superconducting, recirculating linac for **particle and nuclear** physics experiments

- Two operation modes will be used
  - polarized external beam with up to 150 µA @ 155 MeV
  - unpolarized or polarized ERL beam with up to 1 mA (later 10 mA) @ 105 MeV

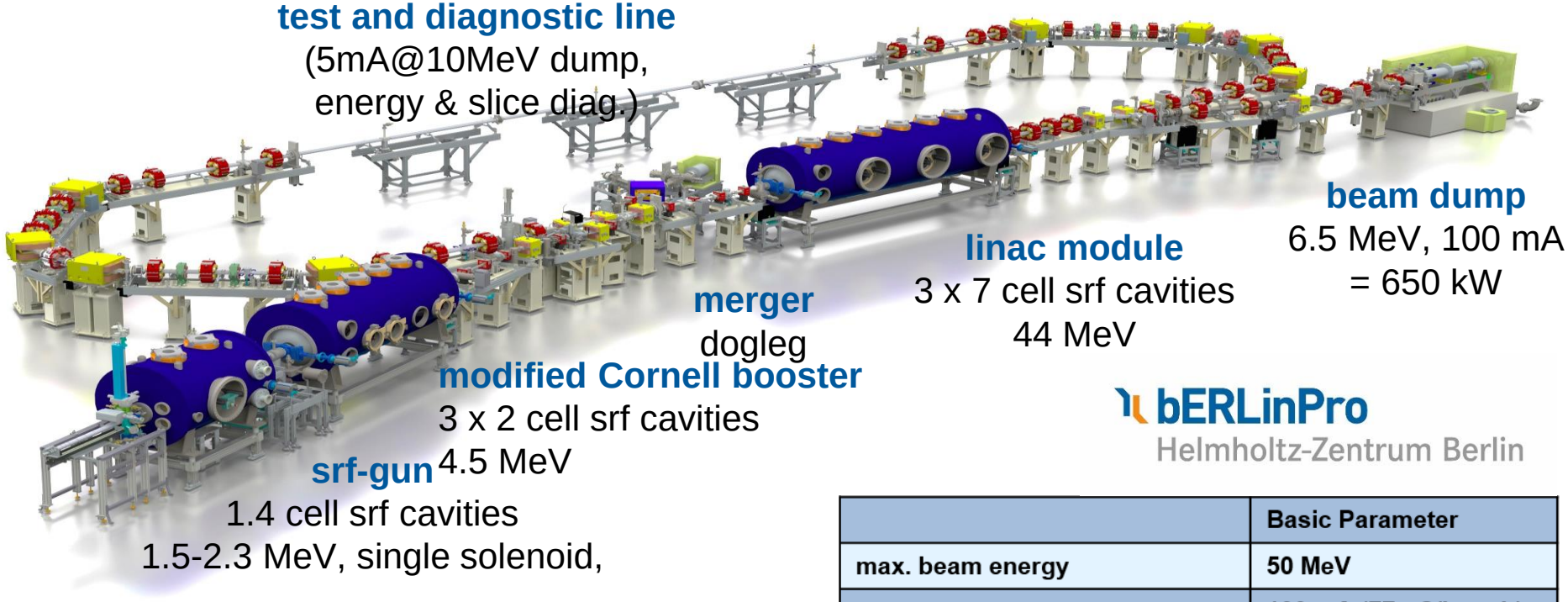
- P2 experiment measures parity violation assymetry and.
  Main task is the measurement of with high accuracy.
  Later research on e.g. neutron skins
  (P2 Design report published: D. Becker et al., arXiv:1802.04759 [nucl-ex])

- MAGIX is a double arm electron spectrometer and can be used for many purpose. Two main goals are the search for dark photons and the measurement of magnetic proton radius

Collaboration with HZB

bERLinPro = Berlin Energy Recovery Linac Project

100 mA / low emittance technology demonstrator (covering key aspects of large scale ERL)



bERLinPro
Helmholtz-Zentrum Berlin

project started 2011, fully funded
building ready 2017
first electrons 2018
recirculation 2019/2020

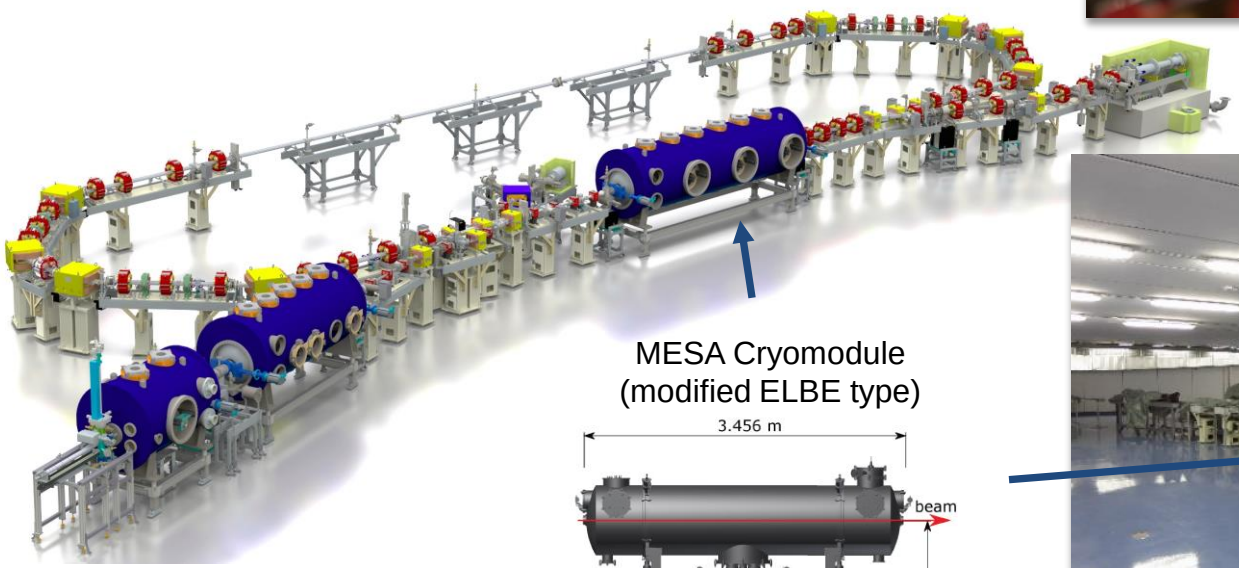
	Basic Parameter
max. beam energy	50 MeV
max. current	100 mA (77 pC/bunch)
normalized emittance	1 μm (0.5 μm)
bunch length (straight)	2 ps or smaller (100 fs)
rep. rate	1.3 GHz
losses	< 10^{-5}

Collaboration with HZB

bERLinPro: existing hall, injector and recirculation
but no linac cryomodule

MESA: existing cryomodule
but no hall, recirculation, …

→ collaborate! (integrate MESA module at HZB)



MESA Cryomodule
(modified ELBE type)

Outlook/Timeline

- Construction of the extended MESA hall will delay the construction start of the accelerator to at least **2020.** Commissioning is planned in **2021**
- But many accelerator parts have been ordered or even built already
- We will test the injector in a test setup in Hall 3 (old part of the building) until civil construction progress requires to empty the underground halls (expected **spring/summer 2019**)
- Cryomodule tests started at HIM **in June 2018**
- Kick-Off Meeting MESA @ bERLinPro took place at Mainz **in April 2018**
  MESA modules can stay at Berlin from **2019 to end 2020**
- Parts of experimental setups, detectors etc. are tested at MAMI as well

Thank you for your attention!