MESA – a fully instrumented ERL project for nuclear and particle physics experiments

- Layout of MESA and experimental setups
- Current status of realization
- MESA schedule

ERL Workshop 2022
October 3rd 2022
Florian Hug presenting work of the MESA group

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

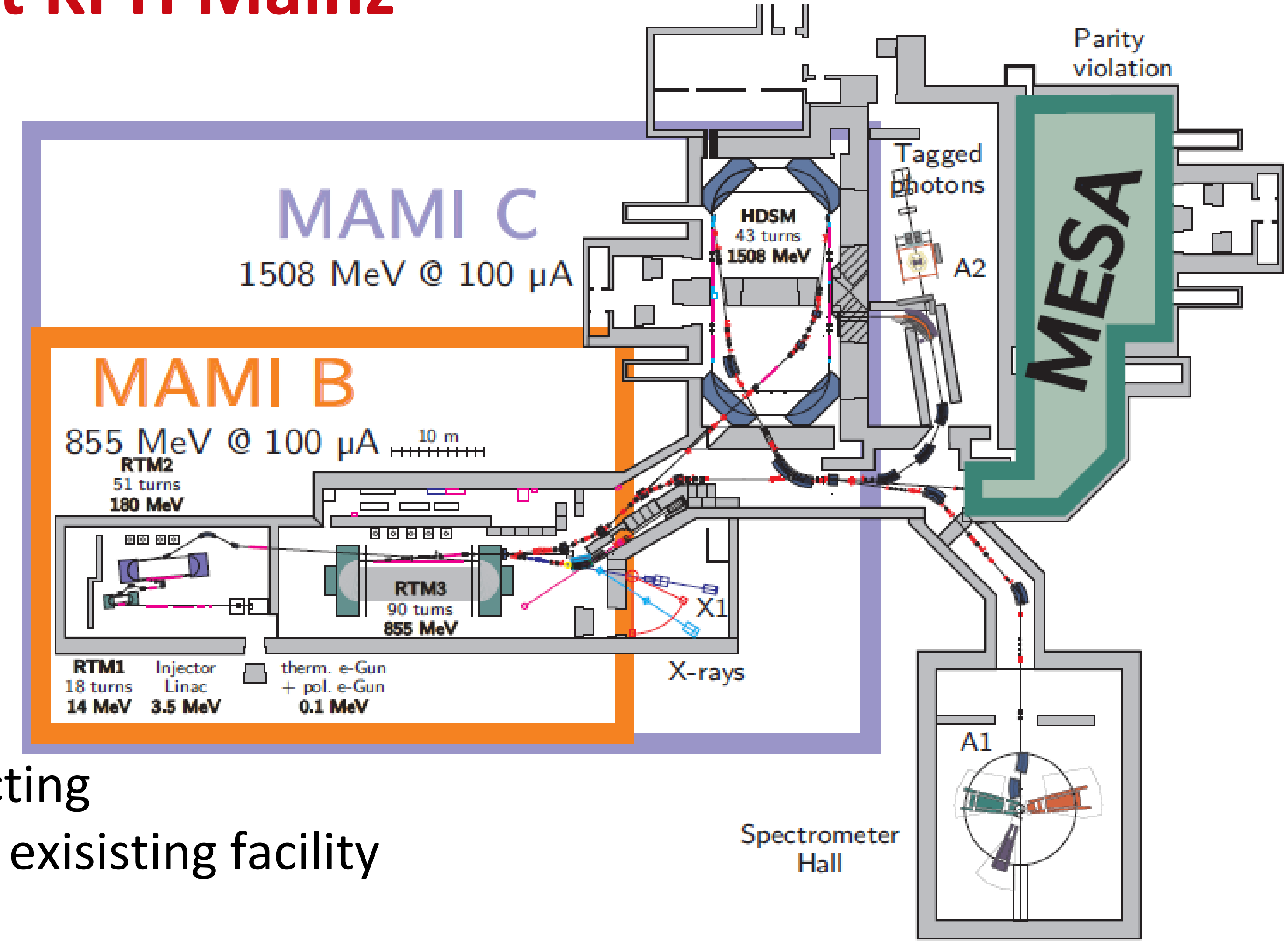
Partially supported by the **European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004730 (iFAST).**

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

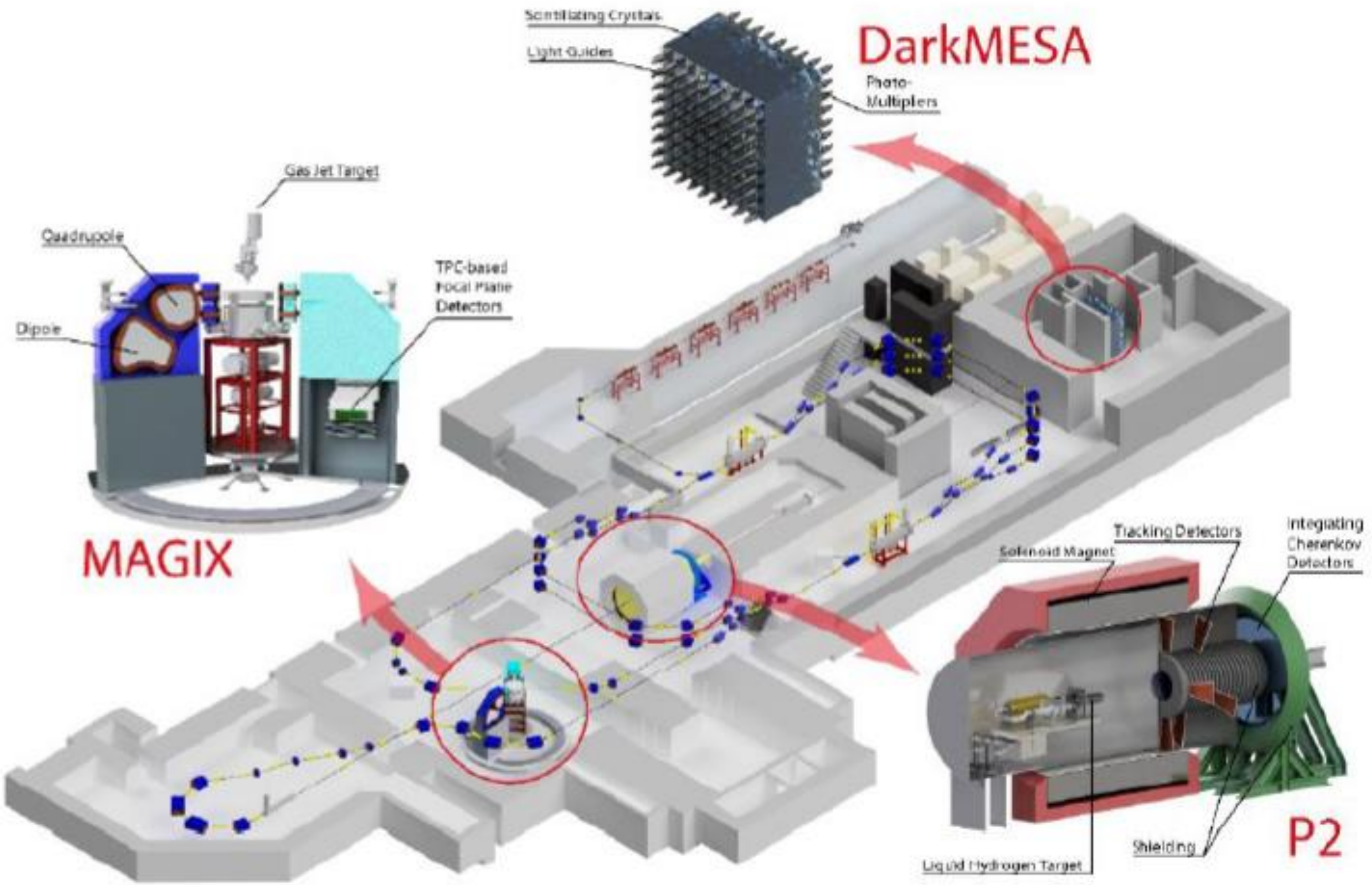
What is MESA and what is it good for?

MESA Mainz Energy-recovering Superconducting Accelerator

ERL is one component in the European accelerator “roadmap”

Quotation from: Andrew Hutton, ERL Roadmap panel symposium, June,3, 21

“Unique feature of MESA: First completely instrumented ERL facility for particle and nuclear physics”



Detailed informations on MESA experiments:
Talk by Kurt Aulenbacher (presented by F. Hug) on Wednesday

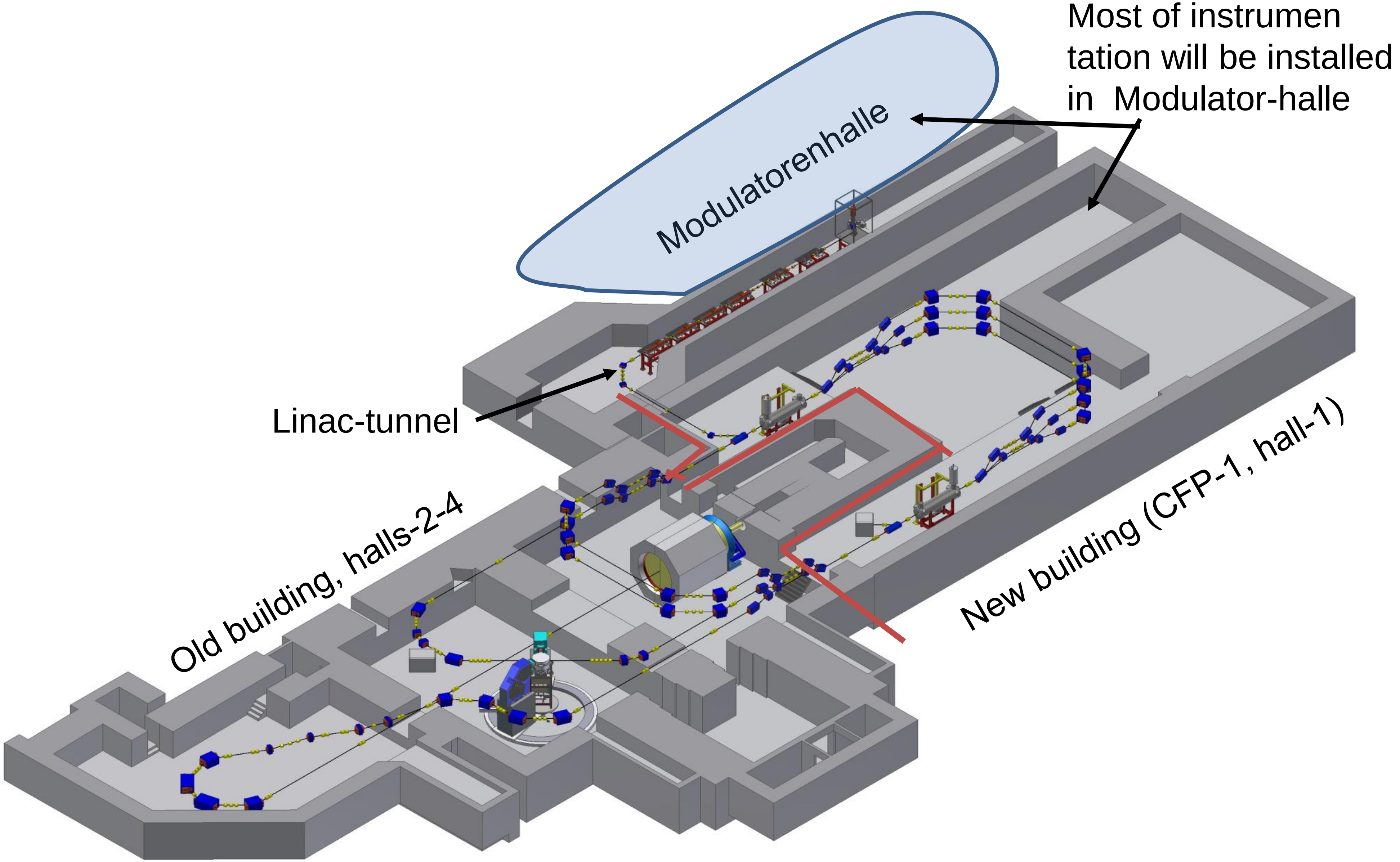
MESA Status

In June 2021
it was offically
announced that
full occupancy of
CFP-1 will be
possible in
mid/end 2023
Representing a
shift by almost
two years

Breakthrough between Experimental CFP-1 and KPH halls (September, 7, 2021)

Delay was anticipated early, Mitigation strategy est. 2019….

Beschleunigte Aufbaumassnahme MESA (BAM)



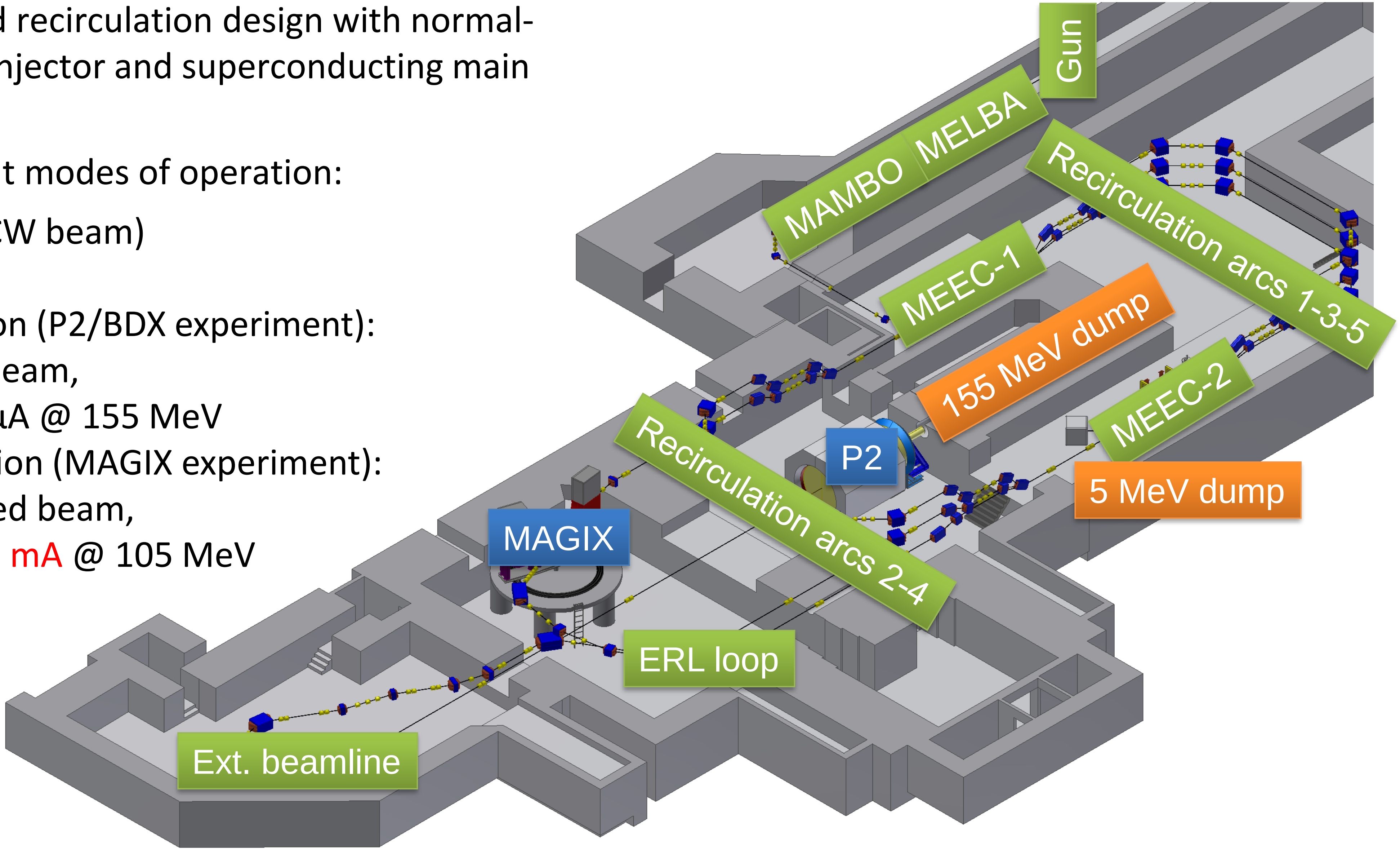
MESA Accelerator Layout

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

Two different modes of operation:

(1300 MHz CW beam)

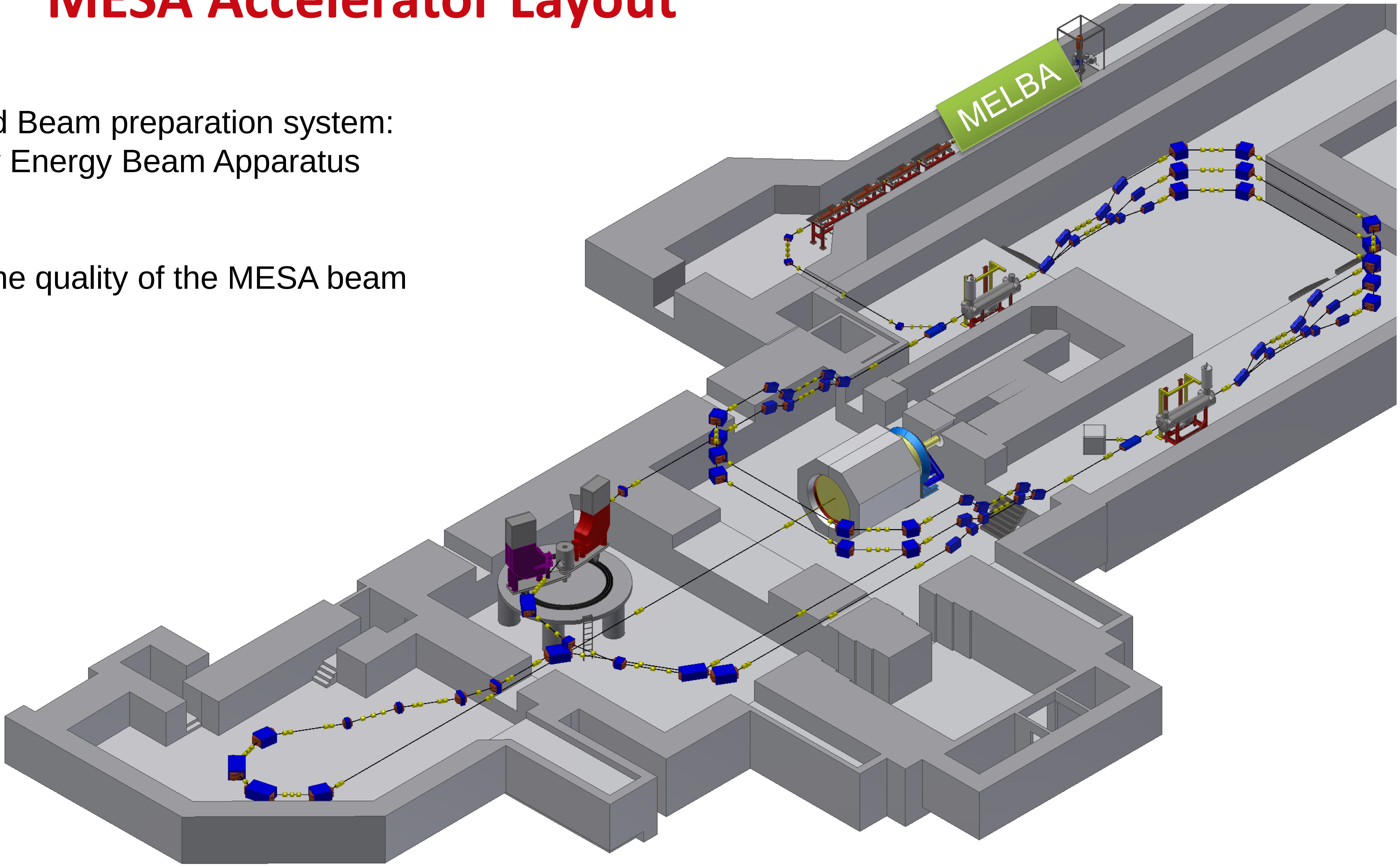
- EB-operation (P2/BDX experiment):
  polarized beam,
  up to 150 µA @ 155 MeV
- ERL-operation (MAGIX experiment):
  (un)polarized beam,
  up to 1 (10) mA @ 105 MeV



MESA Accelerator Layout

Source and Beam preparation system:
MESA Low Energy Beam Apparatus
(MELBA)

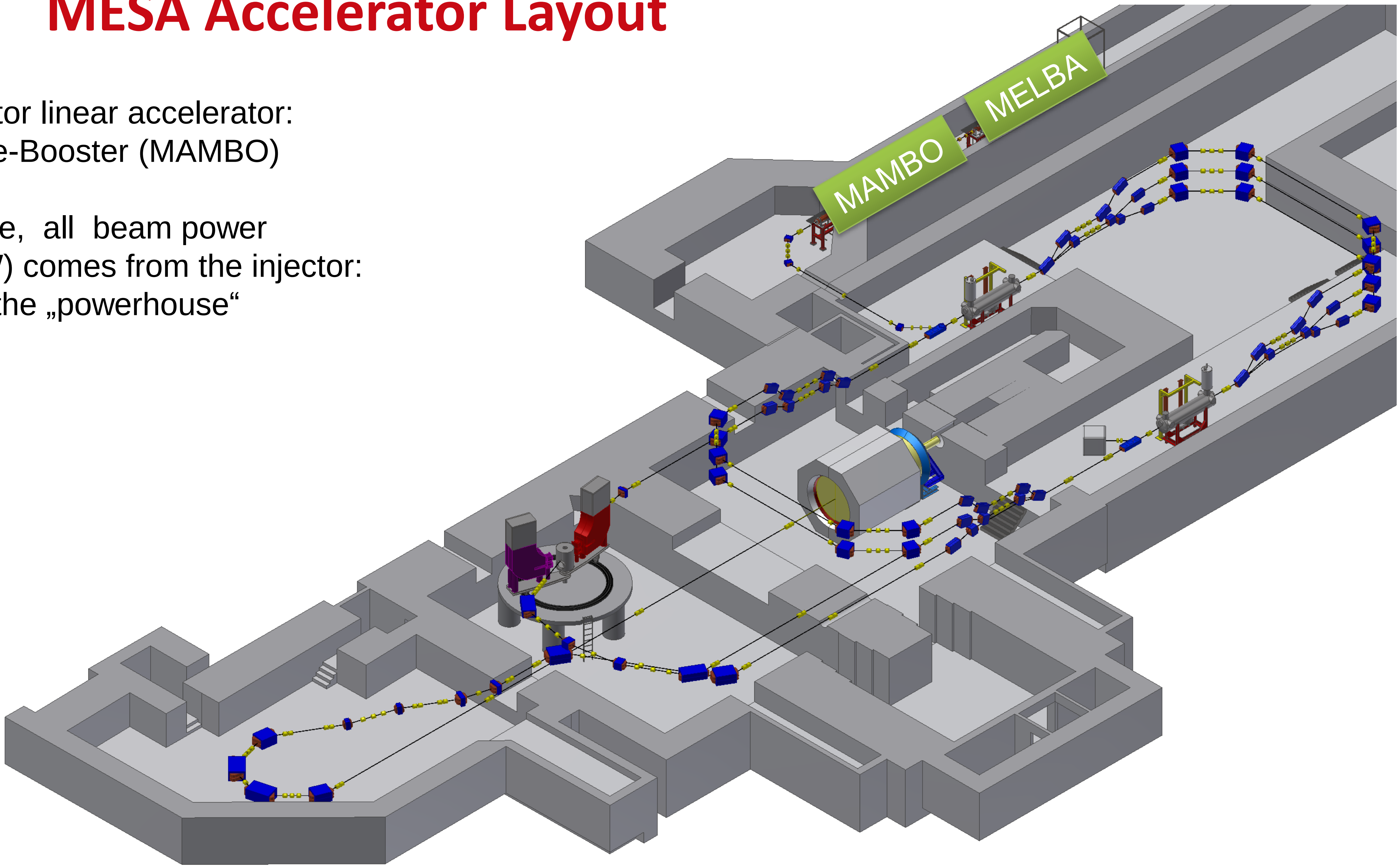
- Defines the quality of the MESA beam



MESA Accelerator Layout

MESA injector linear accelerator:
Milli-AMpere-Booster (MAMBO)

In ERL mode, all beam power
(up to 50kW) comes from the injector:
MAMBO is the „powerhouse“
of MESA



MELBA Tests

Old MELBA Test set-up

→ Operation with up to 150keV beam and up to 10mA beam current

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

PhD Theses completed

S. Friederich (2019)

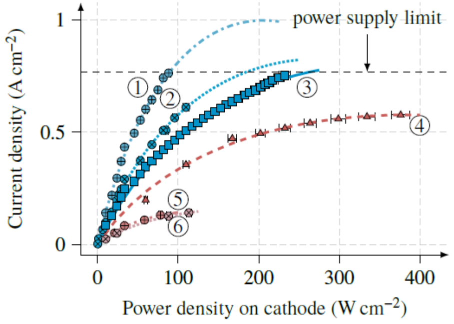
R. Kempf (2020)

C. Matejcek (2021)

P. Heil (2021)

Surface photovoltage in NEA GaAs at 10mA

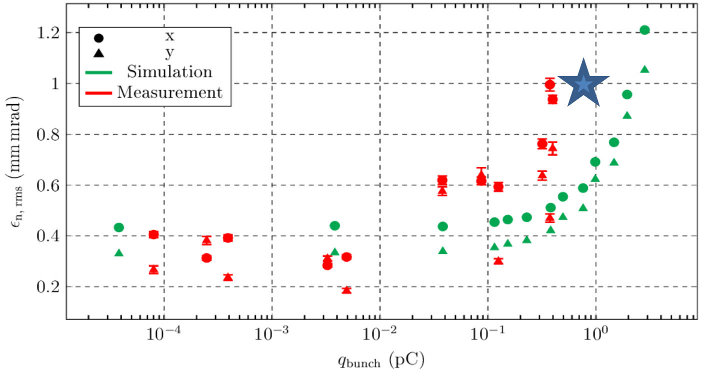
S. Friederich et al .doi:10.18429/JACoW-IPAC2019-TUPGW028



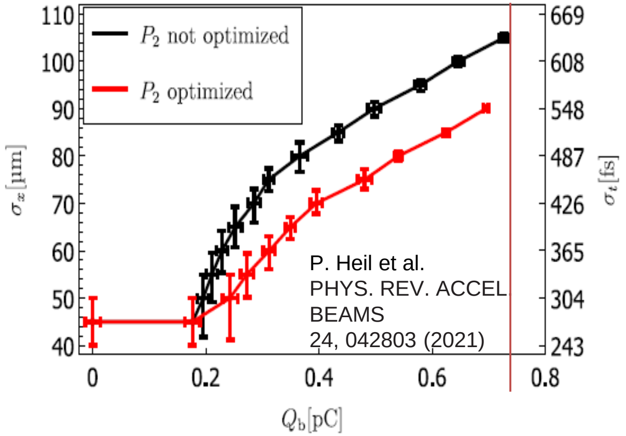
No.	QE_0
①	2.40 %
②	1.55 %
③	1.15 %
④	0.85 %
⑤	0.50 %
⑥	0.39 %

Transverse emittance

C. Matejcek et al. doi:10.18429/JACoW-IPAC2019-TUPGW028



Longitudinal emittance

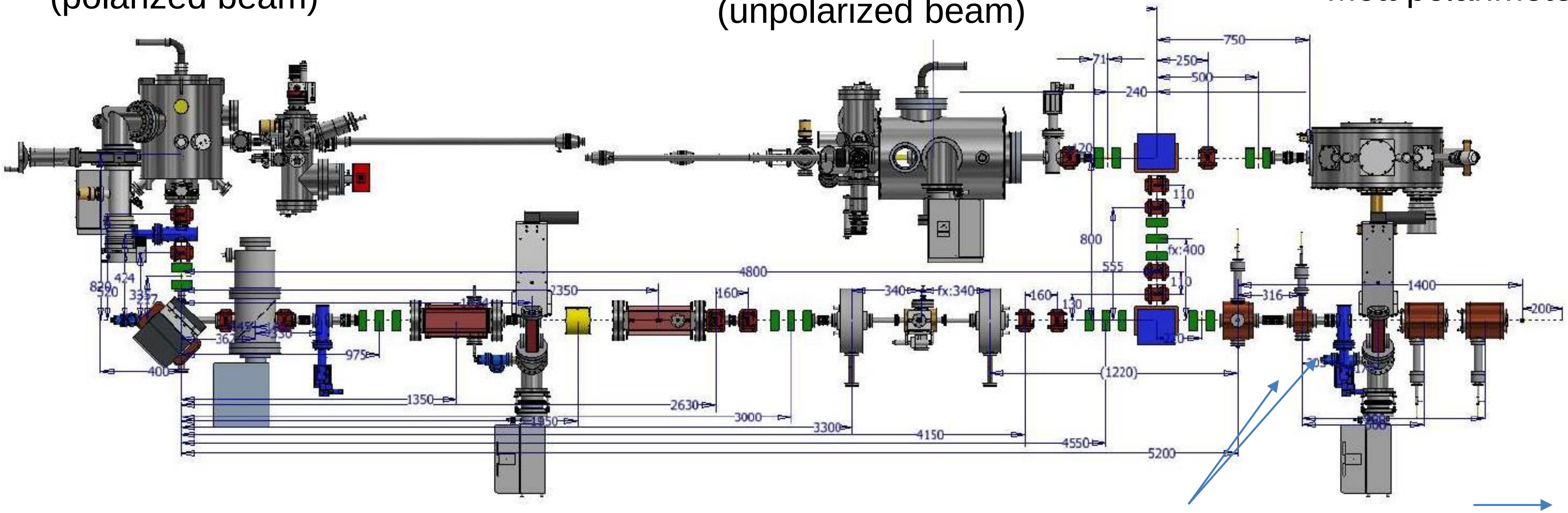


Source/beam preparation (MELBA) layout

Photosource „STEAM“
(polarized beam)

High bunch charge/beam
current source
(unpolarized beam)

Double scattering
Mott polarimeter



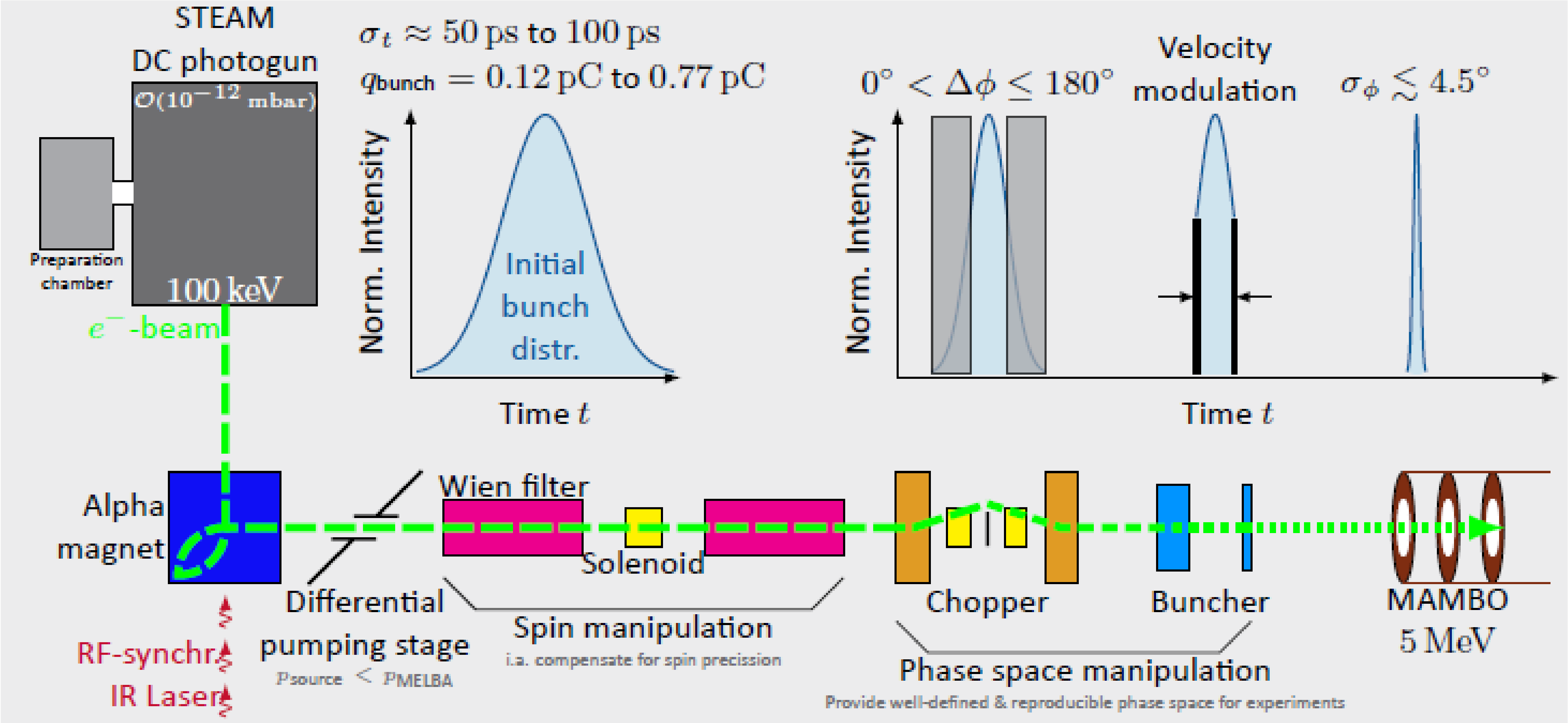
Spin Manipulation

Circular
Chopper

f/2f buncher
cavities

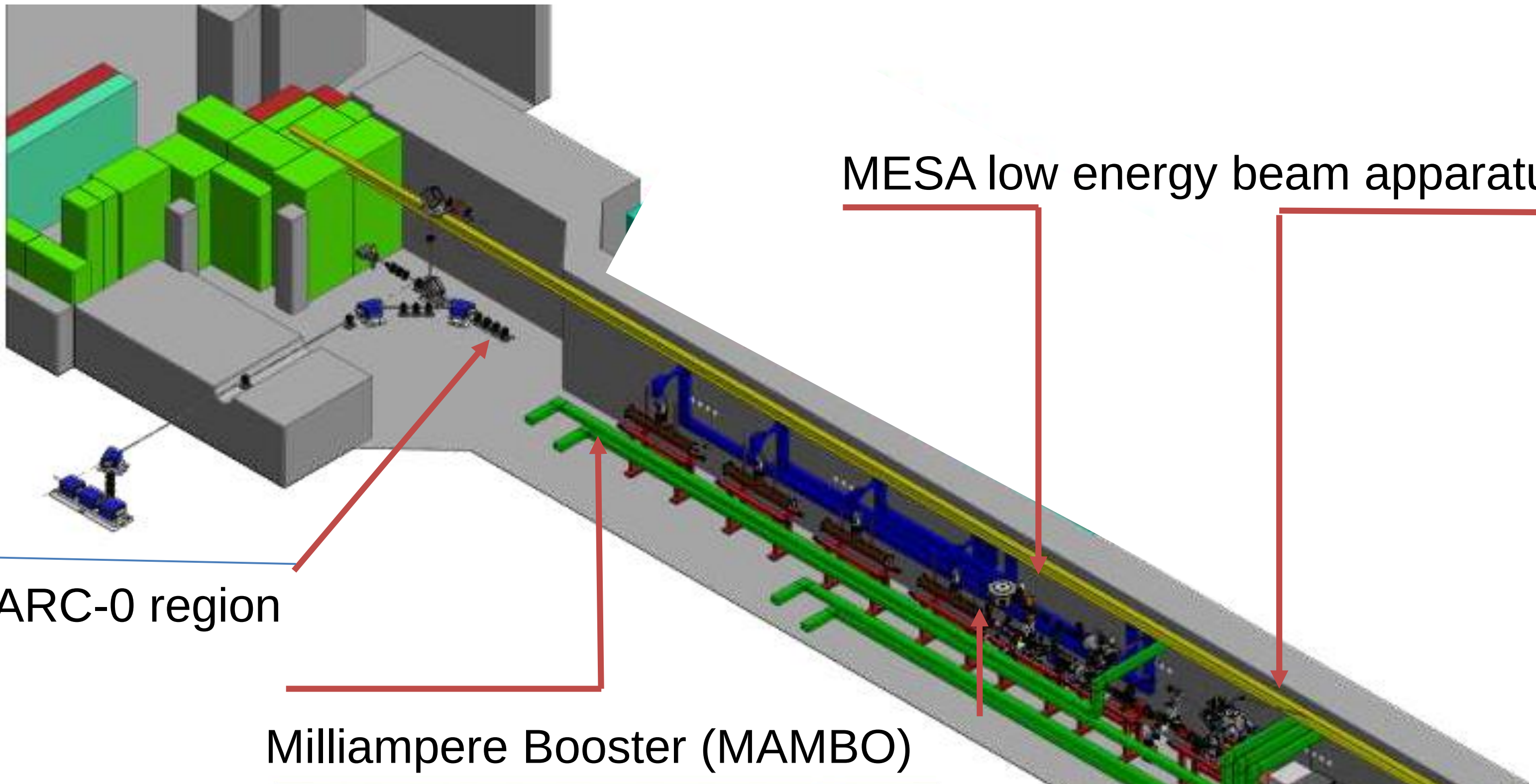
To MAMBO
injector

Injector working principle



S. Friederich at al: IPAC 2021

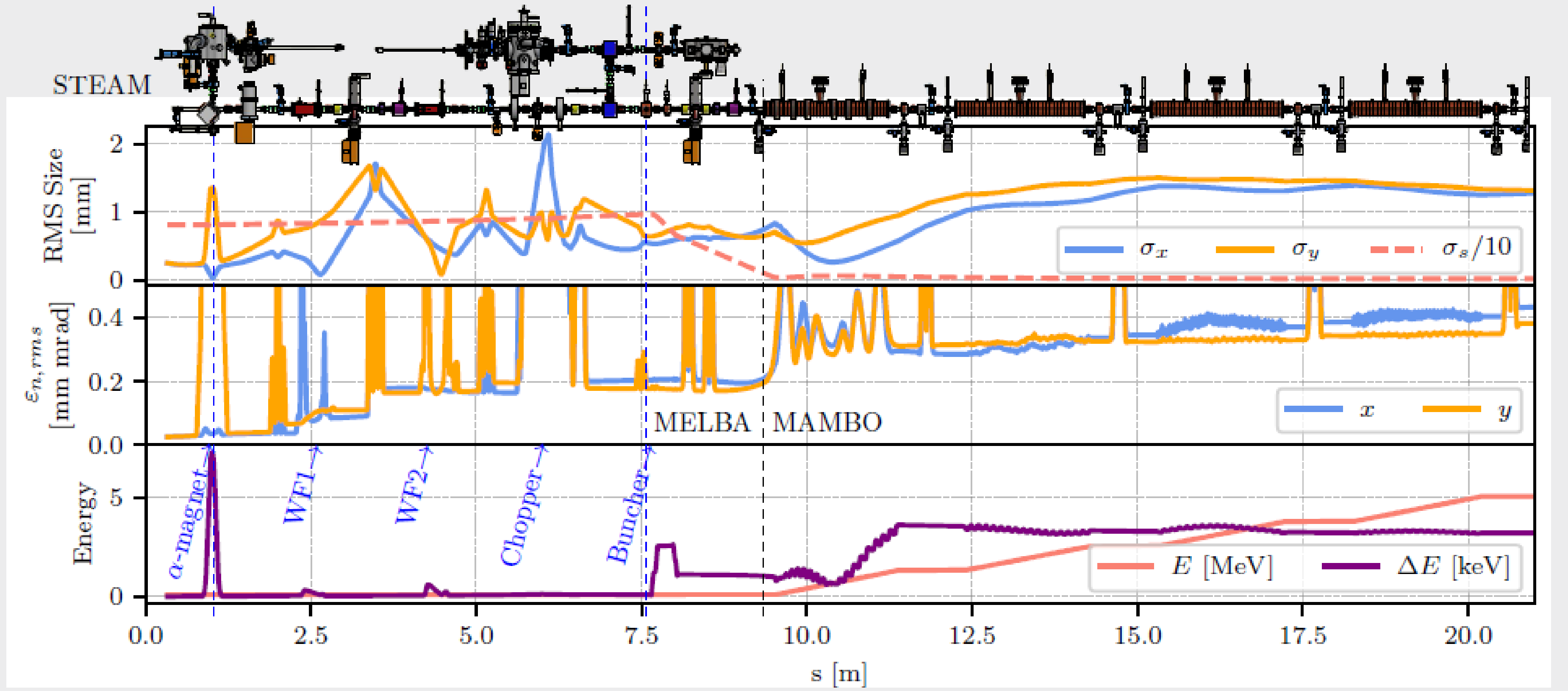
MELBA/MAMBO: final Accelerator Layout



- In a huge number of online meetings the arrangement of components has been planned
- Several issues raised by results of test experiments and MAC suggestions adressed (improved corrector magnets, BPM's for P2, Spin manipulation. 5MeV polarimeter…)
- „freezing" & start assembly in 2/2022

R. Heine: PHYSICAL REVIEW ACCELERATORS AND BEAMS 24, 011602 (2021)

OPAL simulation results for complete injector

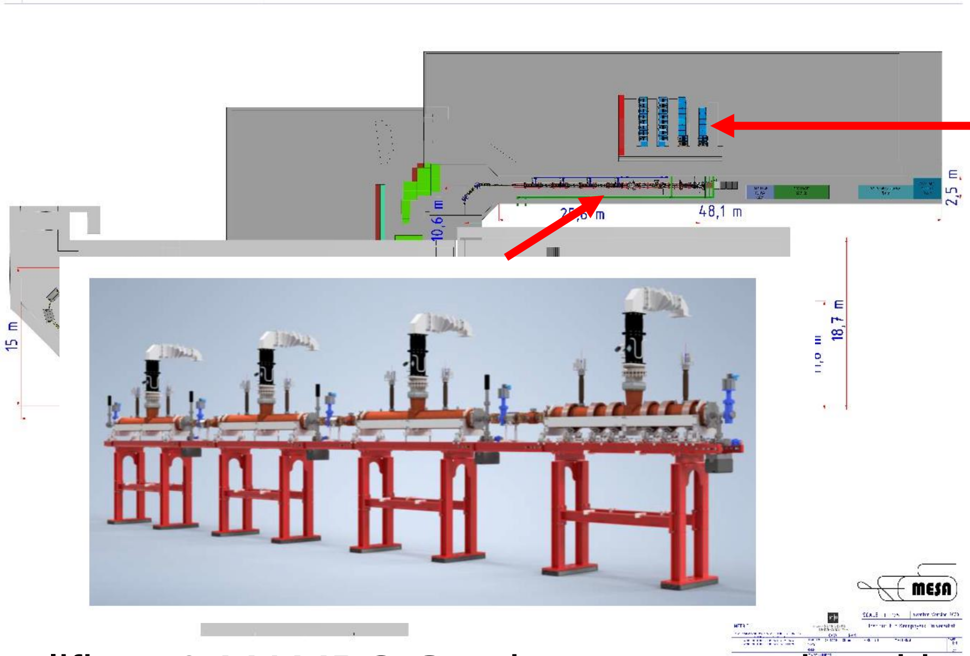


Location	s m	σ_x mm	σ_y mm	σ_s mm | ° | ps	$\varepsilon_{x,n,rms}$ mm mrad	$\varepsilon_{y,n,rms}$ mm mrad	Energy MeV	ΔE_{rms} keV
Initial	0.3	0.2	0.2	8.1 | 23.1 | 50.0	0.03	0.03	0.1	0
MELBA exit	9.4	0.8	0.7	0.8 | 2.3 | 4.9	0.22	0.20	0.1	1
Injector exit	20.4	1.3	1.3	0.2 | 0.3 | 0.6	0.40	0.35	5.1	3

S. Friederich at al: IPAC 2021

Injector Status today

Impact of Pandemic on MESA construction- RF-vendors



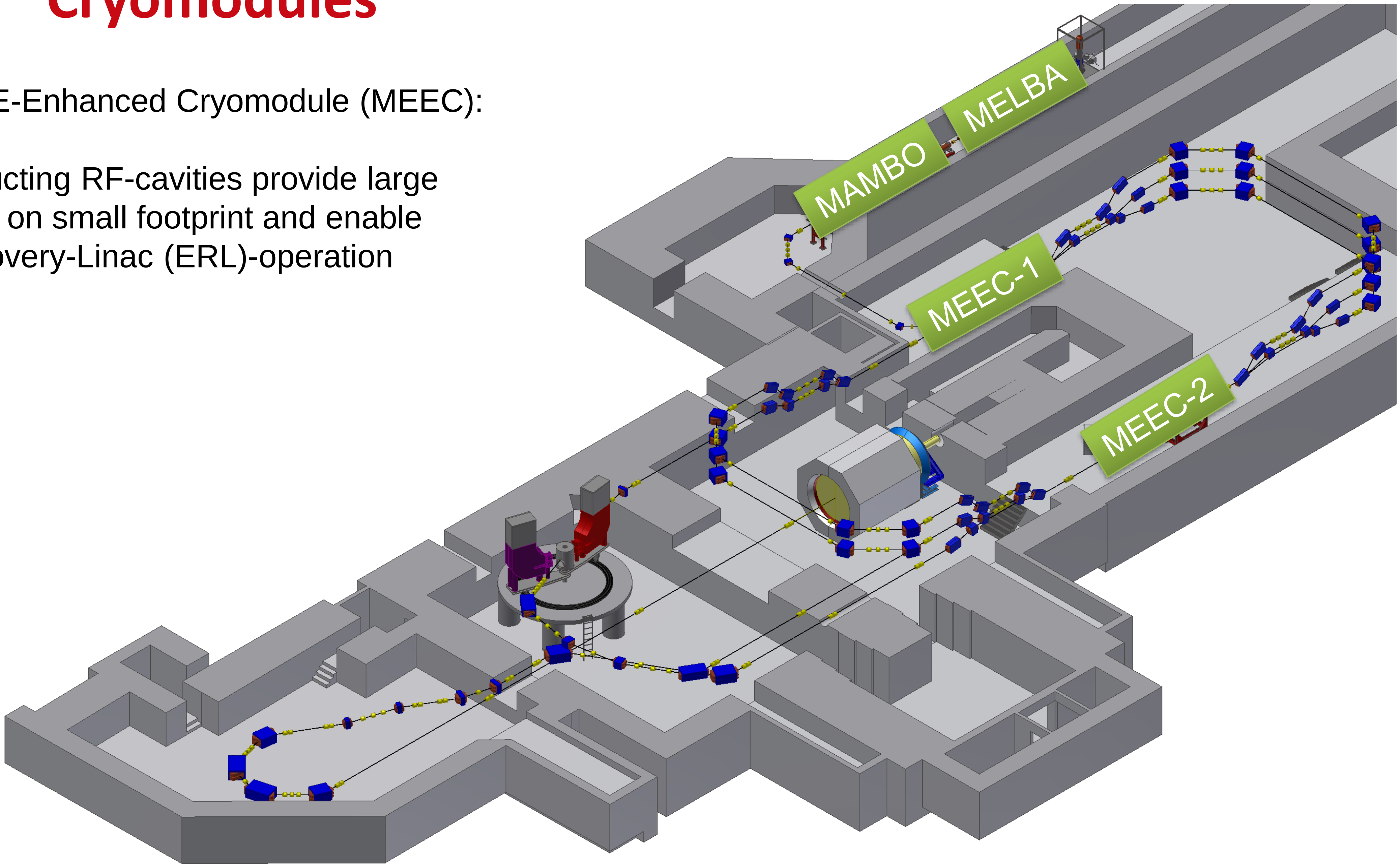
- RF amplifiers & MAMBO Sections were ordered in 2019
- …Based on existing protypes
- Supplier for RF-amplifiers went bankrupt in 12/2020
- New owner JEMA France continues contract
- Successful SAT of 4*550 Watt basic module in 9/2021
- Delivery of first (biggest) amplifier now scheduled for end 22
- Auxiliary systems (LLRF, vacuum, diagnostics), expected to be ready before amplifier delivery

74 kW 1300 MHz amplifier (CAD drawing)
Vendor: JEMA France (former SPE)
Amplifier batch: 1*74, 3*54, 4*15 kW

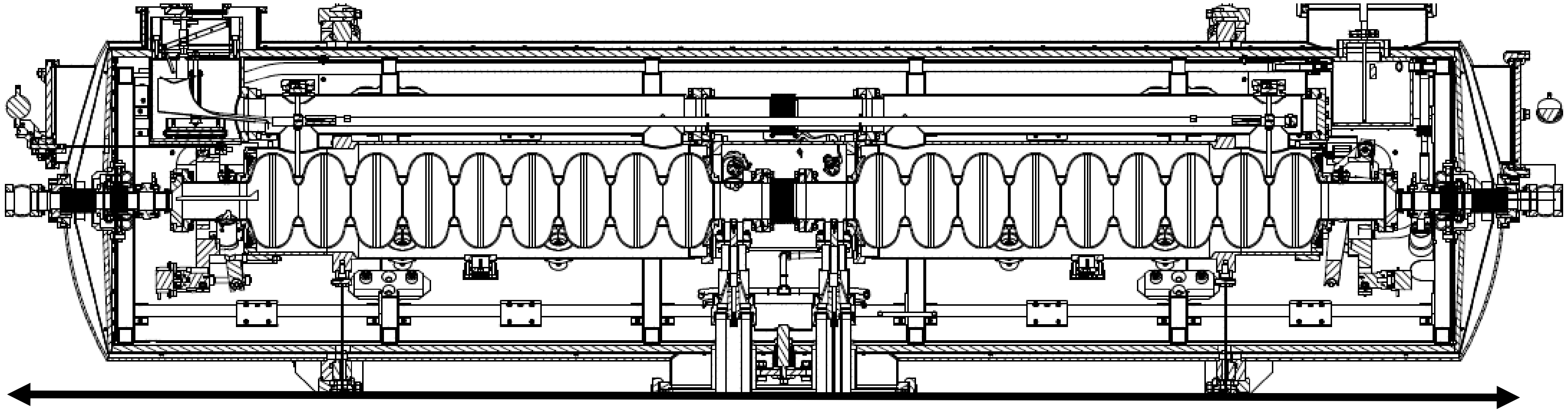
Cryomodules

MESA ELBE-Enhanced Cryomodule (MEEC):

Superconducting RF-cavities provide large energy gain on small footprint and enable Energy-recovery-Linac (ERL)-operation



SRF-System: MEEC-Cryomodules

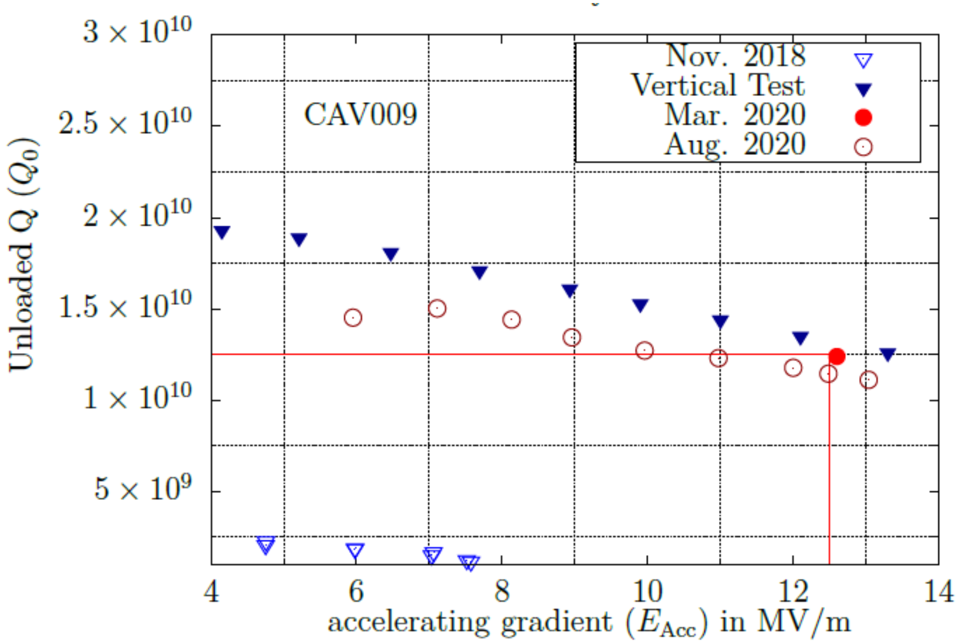


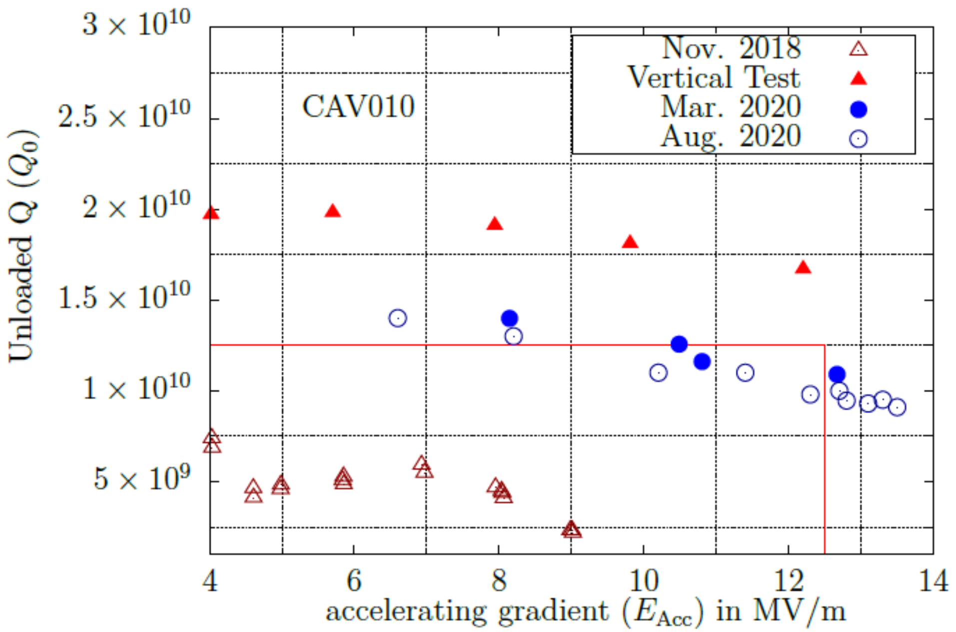
3.5 meter

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

Production of 2 Cryomodules

- 2015: 2 MEEC's ordered at RI Research Instruments GmbH
- Until 2017 SRF testing 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
- 8/2020 :refurbished cryomodule tested and fulfills specs.

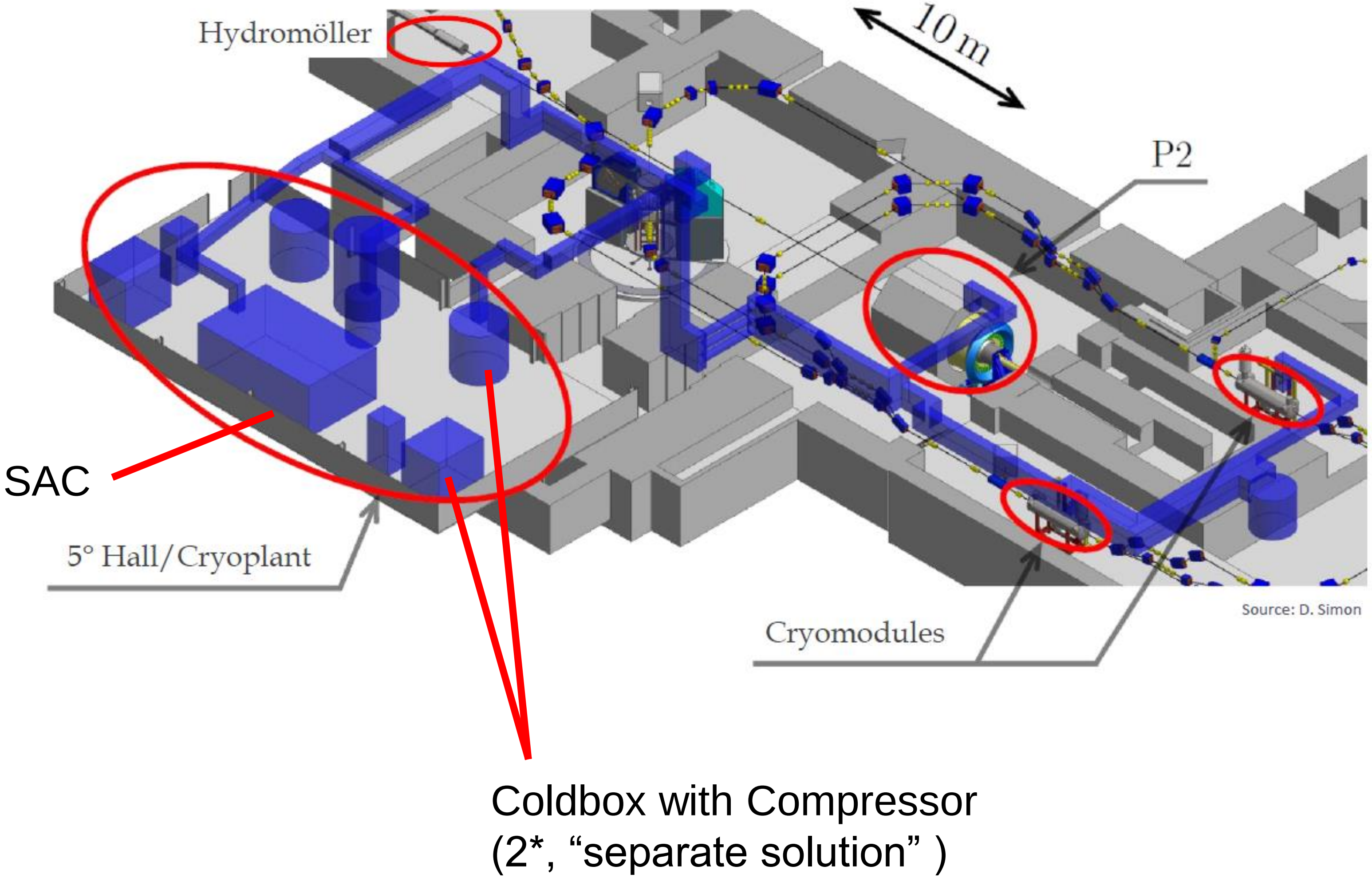




Cryomodules miss dynamical specs slightly but fulfill static specs by wide margin
→ On average the Helium consumption is estimated to be less than anticipated.

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

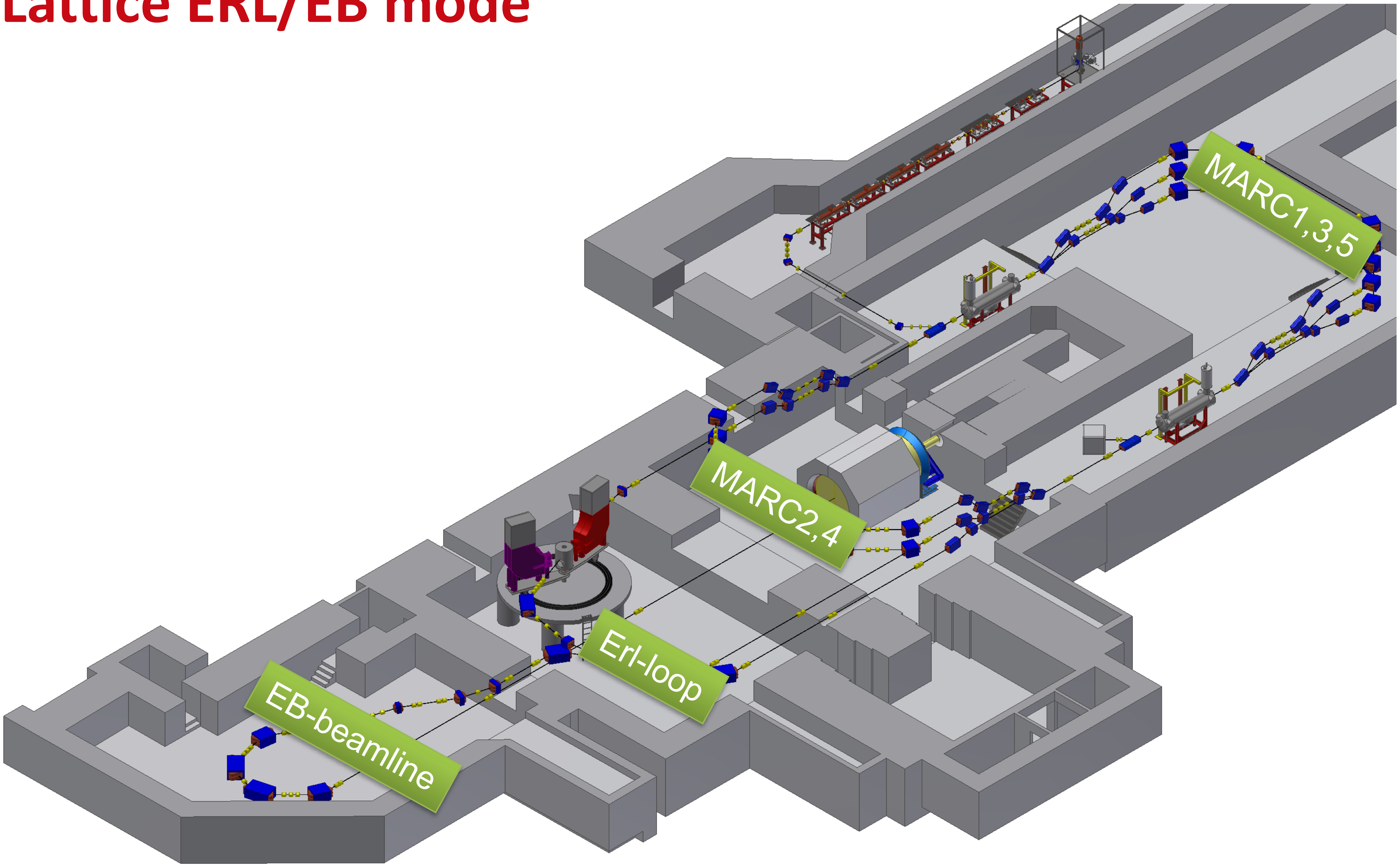
MESA/P2 construction- Cryogenics (main issues only…)



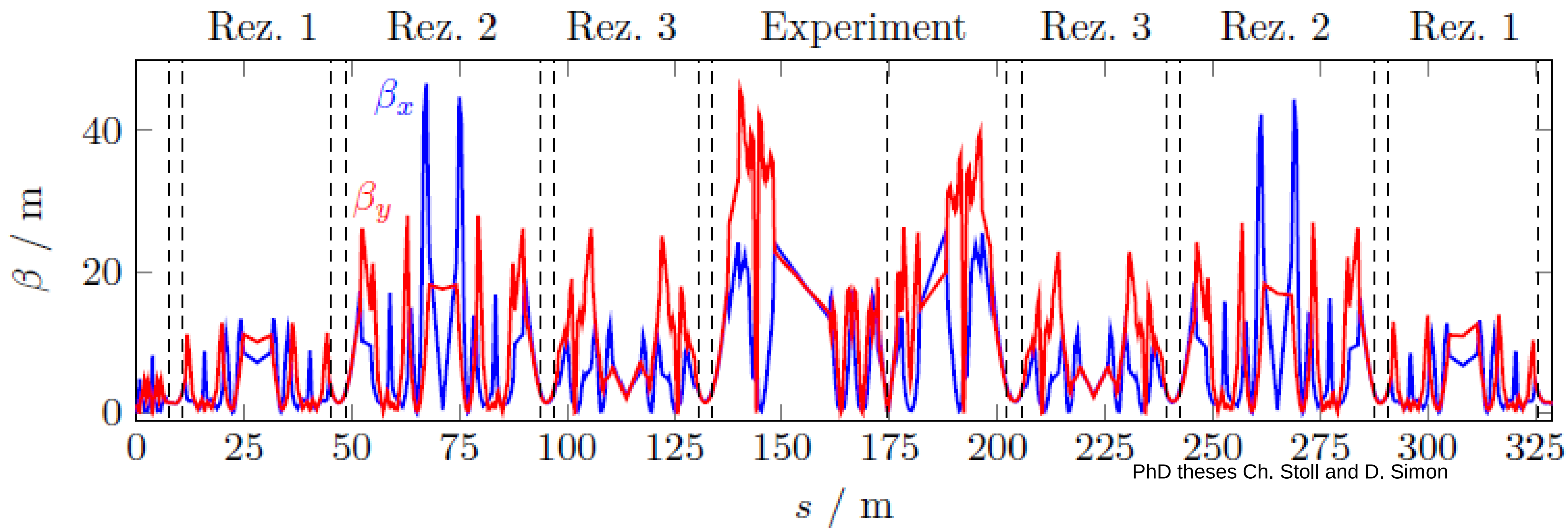
- Upgrade of L280 plant will start May 2022
- Plant can serve MESA + P2 solenoid
- P2-refrigerator – cooling of Hydrogen target - needs separate cryoplant
- Negotiations with companies specialized on cryogenic piping ongoing

(More about MESA SRF in a dedicated talk on Tuesday)

Lattice ERL/EB mode



Lattice: ERL mode start to end simulation

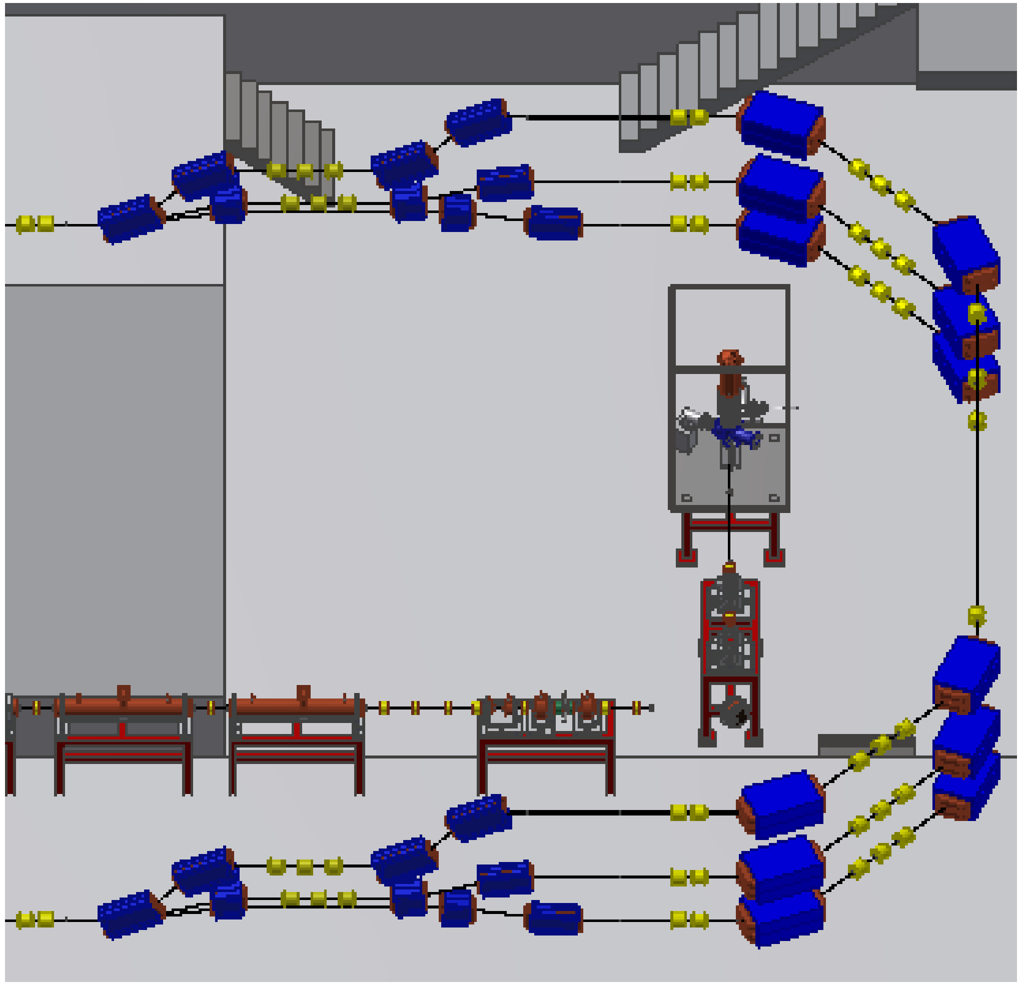


PhD theses Ch. Stoll and D. Simon

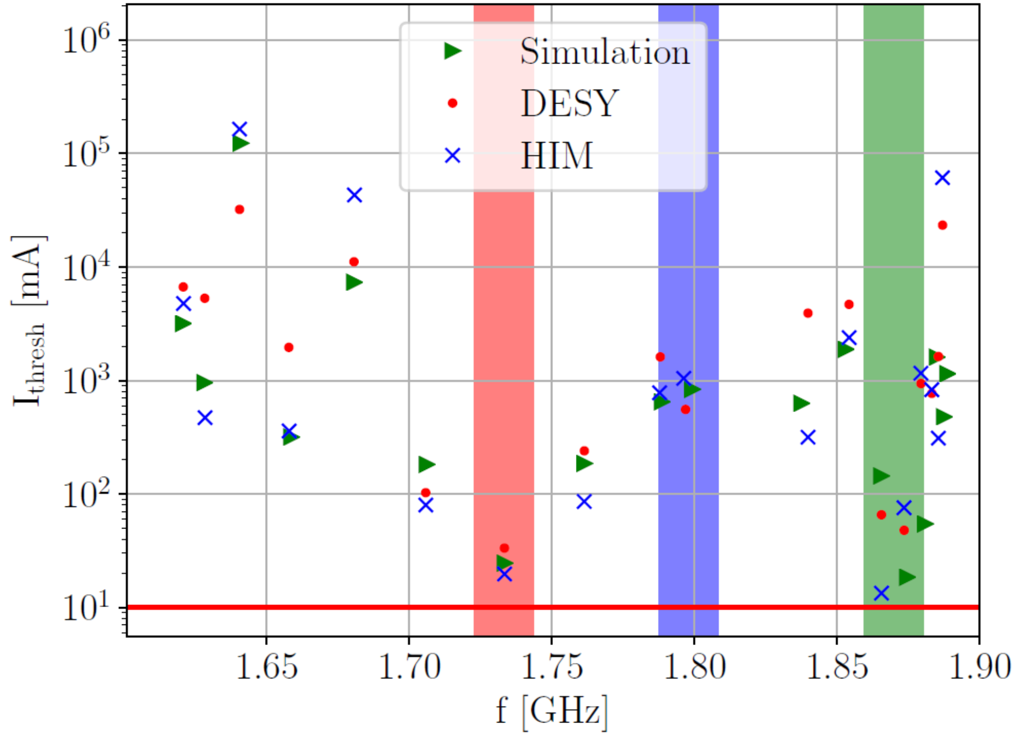
ERL-Lattice – not completely symmetrical due to enery (gain) dependent focussing of RF-structures.

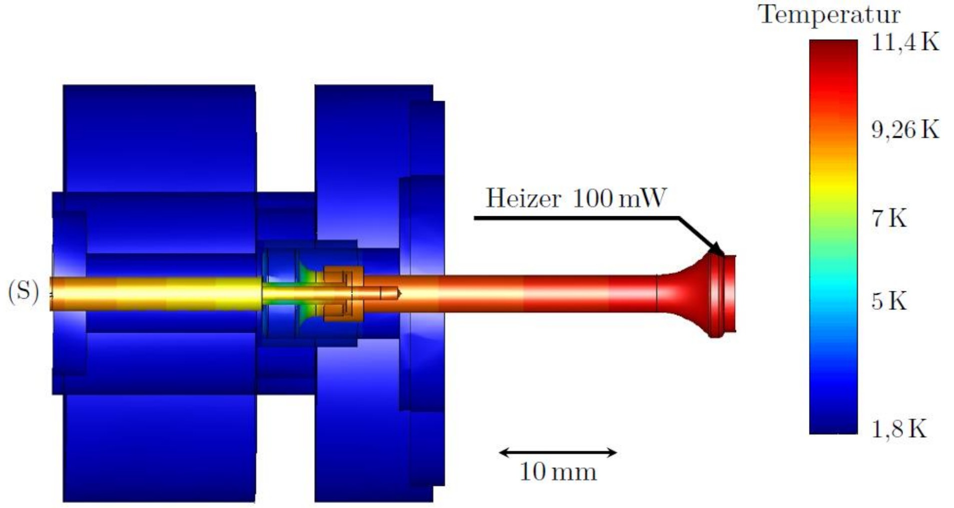
Recirculation arcs optics

- Optics symmetric with respect to the middle of the long straight section.
  α=0 in the middle of the 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 → 28.3° in RF @ 1.3 GHz
- Path length adjustment needed
  (2 cm minimum ≈ 35° RF-phase)
  for complete flexibility in beam energy
  (chicane or moveable magnets)



BBU investigation





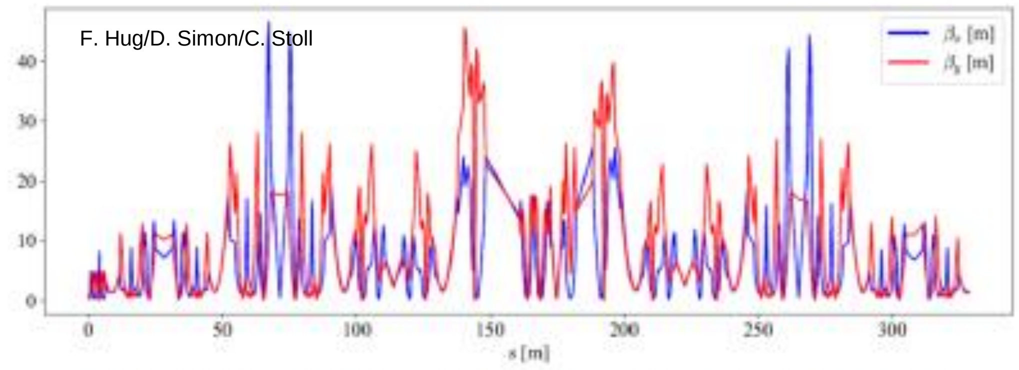
13mA BBU limit at Target
in 4pass configuration 2up/2down
(without countermeasures)

PhD thesis Christian Stoll,
See also: C. Stoll and F. Hug: proceedings IPAC 2019
doi:10.18429/JACoW-IPAC2019-MOPGW025

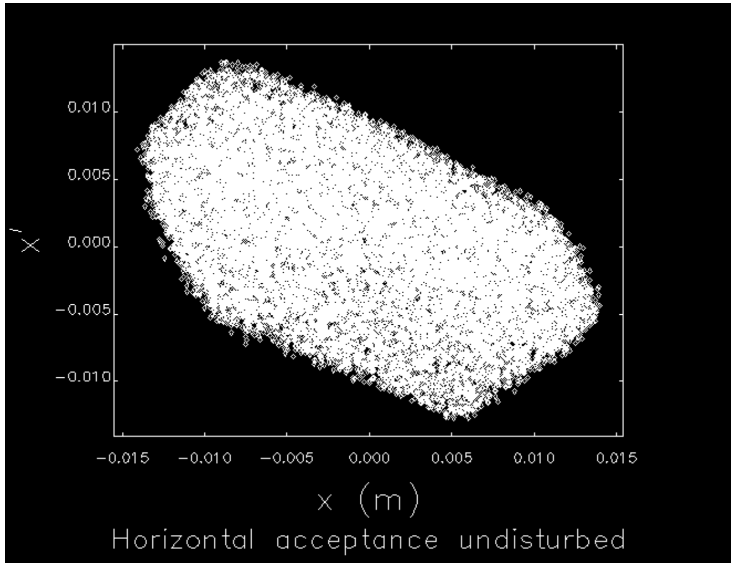
Note:
Technical limitation: Heating of HOM coupler in TESLA cavities.
(~1mA CW estimation, but needs to be determined experimentally)

MESA construction- Magnets

Magnet Basic parameters well known and not demanding
Task before tendering:
 Determine lattice tolerance against field errors
→ avoid unnecessary precision requirements
→Tendering started September 2022



MESA ERL Mode beta-functions



	Quantity	Energy	Angle	Radius	Gap	B-field
MARC 1	4	30 MeV	45°	700 mm	40 mm	143 mT
MARC 2	4	55 MeV	45°	700 mm	40 mm	262 mT
MARC 3	4	80 MeV	45°	700 mm	40 mm	381 mT
MARC 4	4	105 MeV	45°	700 mm	40 mm	500 mT
MARC 5	4	130 MeV	45°	700 mm	40 mm	619 mT

Table 1.1: Parameters of the MARC bending dipoles.

Spreader/recombiner

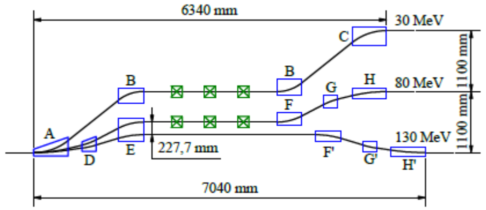


Figure 1.2: Sketch of the beam separation for uneven turns.

Table 1.3: Parameters of the dipoles of the vertical beam separation for uneven turns. For dipoles with multiple beams only the values for the lowest energy are shown.

Dipole	Quantity	Energy	Radius	Angle	Gap	B-field
A[2]	2	30 MeV	989.7 mm	38.79°	40 mm	101 mT
B	4	30 MeV	718.3 mm	38.79°	40 mm	139 mT
C	2	30 MeV	989.7 mm	38.79°	40 mm	101 mT
D[2]	2	80 MeV	1084.6 mm	14.15°	40 mm	246 mT
E[2]	2	80 MeV	966.9 mm	27.74°	40 mm	276 mT
F	2	80 MeV	966.9 mm	27.74°	40 mm	276 mT
G	2	80 MeV	1084.6 mm	14.15°	40 mm	246 mT
H	2	80 MeV	2639.2 mm	13.59°	40 mm	101 mT
F'	2	130 MeV	1571.1 mm	16.64°	40 mm	276 mT
G'	2	130 MeV	1762.4 mm	8.33°	40 mm	246 mT
H'	2	130 MeV	4288.8 mm	8.31°	40 mm	101 mT

ERL-ARC (MAGIX)

1.1.3 MAGIX beam line

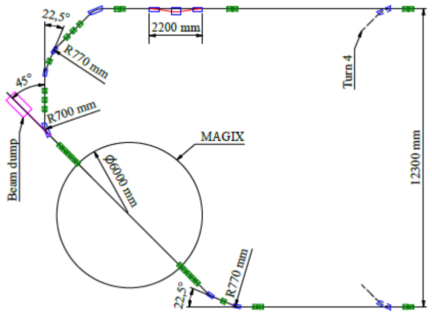


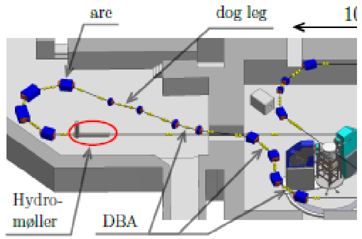
Figure 1.4: Sketch of the beam line for the internal experiment MAGIX.

Table 1.5: Parameters of the MAGIX beam line dipoles. The dipole type R stands for rectangular and S for sector magnet.

Position	Quant.	Type	Energy	Angle	Radius	Gap	B-field
ARC 1	2	R	105 MeV	22.5°	770 mm	40 mm	455 mT
ARC 2[4]	2	S	105 MeV	45.0°	700 mm	TBD	500 mT
ARC 2	2	S	105 MeV	22.5°	770 mm	40 mm	455 mT
Chicane	2	R	105 MeV	12.1°	1917 mm	40 mm	183 mT
Chicane	1	R	105 MeV	24.1°	958 mm	40 mm	366 mT

EB-Line (P2)

1.1.4 P2 beam line



yellow: quadrupoles; blu

Table 1.6: Parameters of the P2 beam line dipoles. The dipole type R stands for rectangular and S for sector magnet.

Position	Quant.	Type	Energy	Angle	Radius	Gap	B-field
DBA 1	2	S	155 MeV	45°	1000 mm	30 mm	517 mT
DBA 2	2	S	155 MeV	40°	900 mm	30 mm	574 mT
DBA 3	2	R	155 MeV	10°	1500 mm	30 mm	345 mT
dog leg	2	R	155 MeV	10°	1500 mm	30 mm	345 mT
ARC	2	S	155 MeV	45°	1000 mm	30 mm	517 mT
ARC	2	S	155 MeV	60°	1000 mm	30 mm	517 mT

Summary

- MESA is a fully instrumented ERL facility for nuclear and particle physics experiments
- Construction of injecctor is ongoing, main accelerator construction will be started as soon as the new building is ready (Jan 2023)
- Most critical components are tested already. „Uncritical“ components are in the process of tendering
- First beams to at low energy (15-55 MeV, 1 Recirculation) to the experiments can be expected 2 years after building occupancy