The MESA Energy-recovery LINAC

-new possibilities for accelerator-based experiments at low energies

GSI accelerator seminar November, 19, 2020

by Kurt Aulenbacher

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

ACCELENCE

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

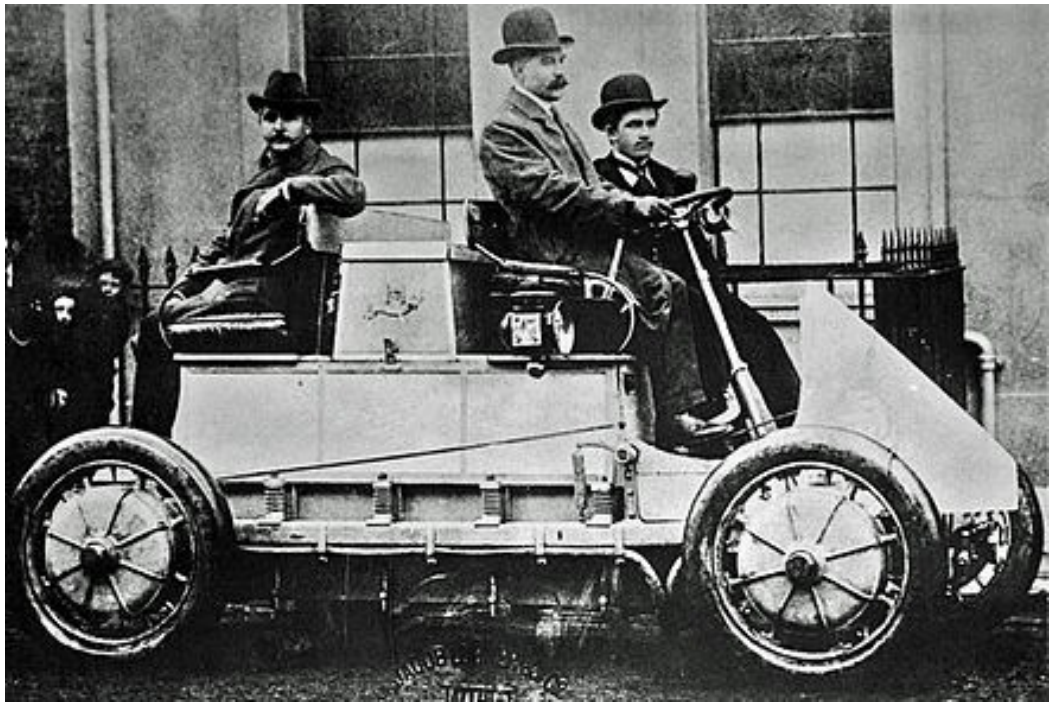
The ERL – not a new idea

MESA
Mainz Energy-recovering Superconducting Accelerator

1960‘s: Maury Tigner proposes to recuperate the kinetic energy of an beam to operate colliders….

…Concept similar to hybrid car recuperation system

- very few ERL‘s have been realized so far - why?

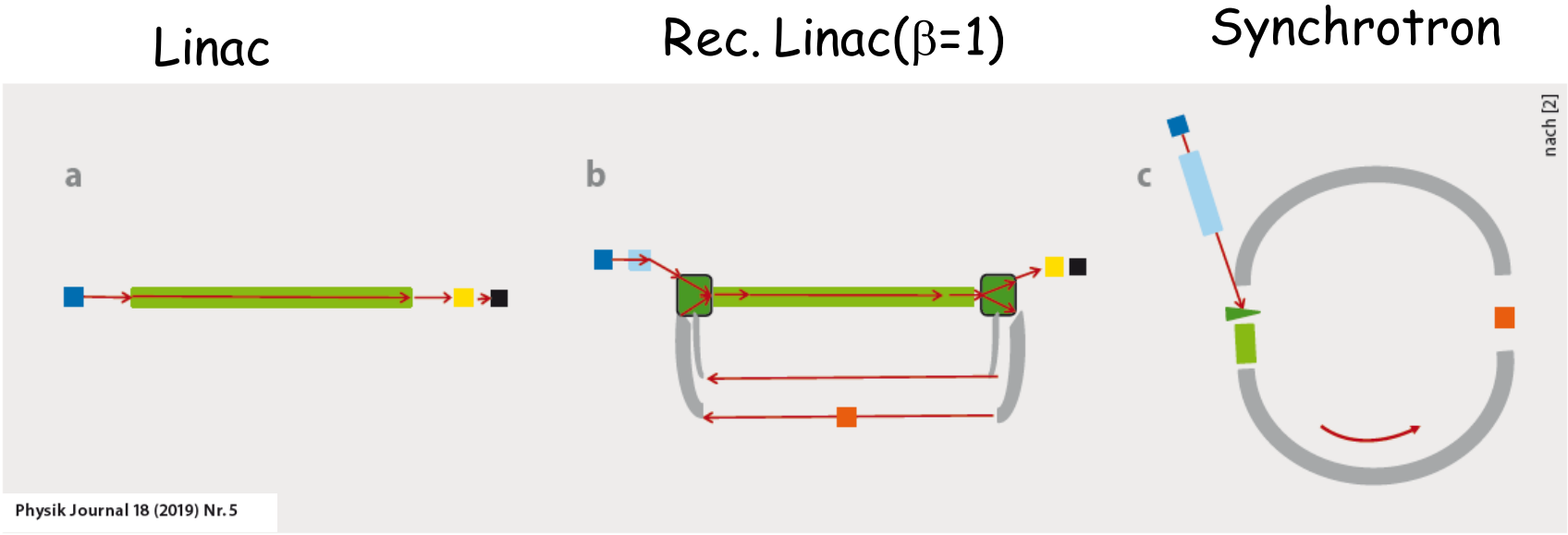


wikipedia

AD 1900: C. Lohner/ F. Porsche: Hybrid electric car:
(look at the all wheel drive!): But - commercial failure!

→ Progress and the appearance of new requirements may change the issue!

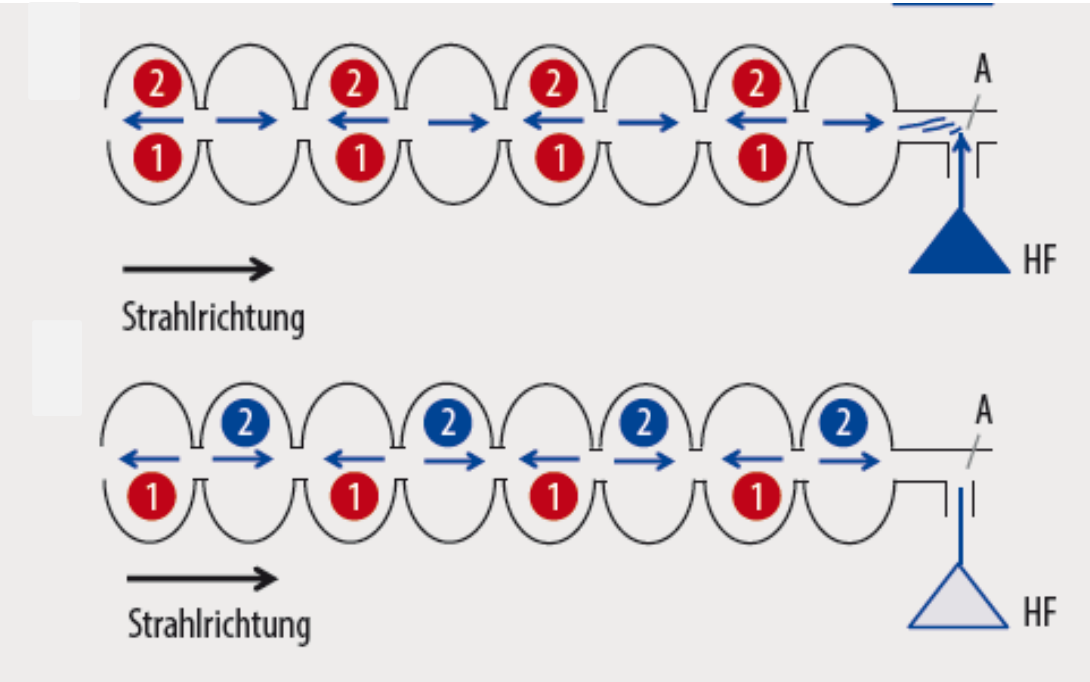
Experiments at RF-accelerators



The synchrotron is cost/energy efficient, the linac experiment is easier:
Combine both advantages by using an ERL:

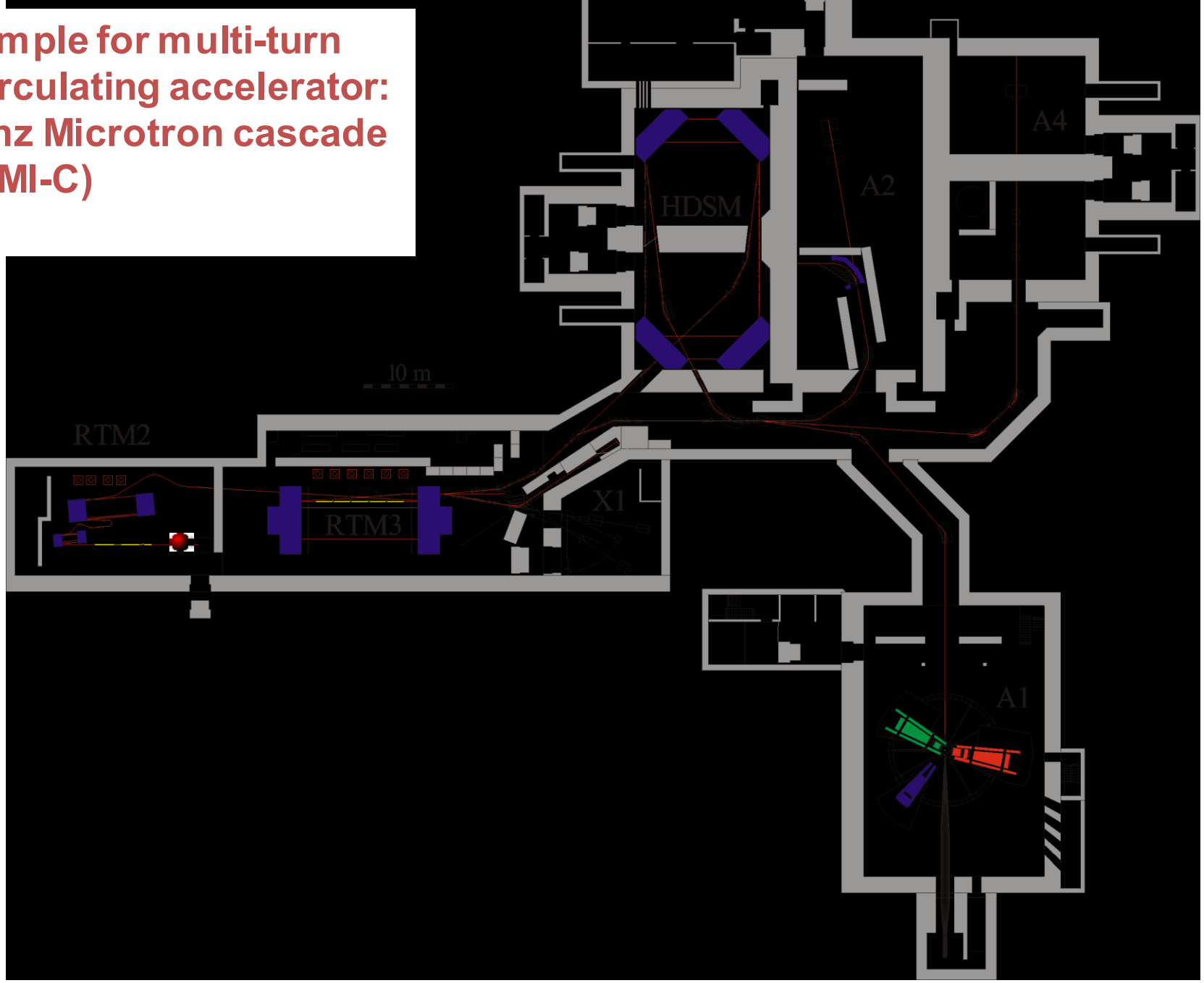
- High luminosity at low costs of RF-system
- Stationary beam conditions, low emittance, no beam cooling required

Recirculating accelerators and ERL‘s



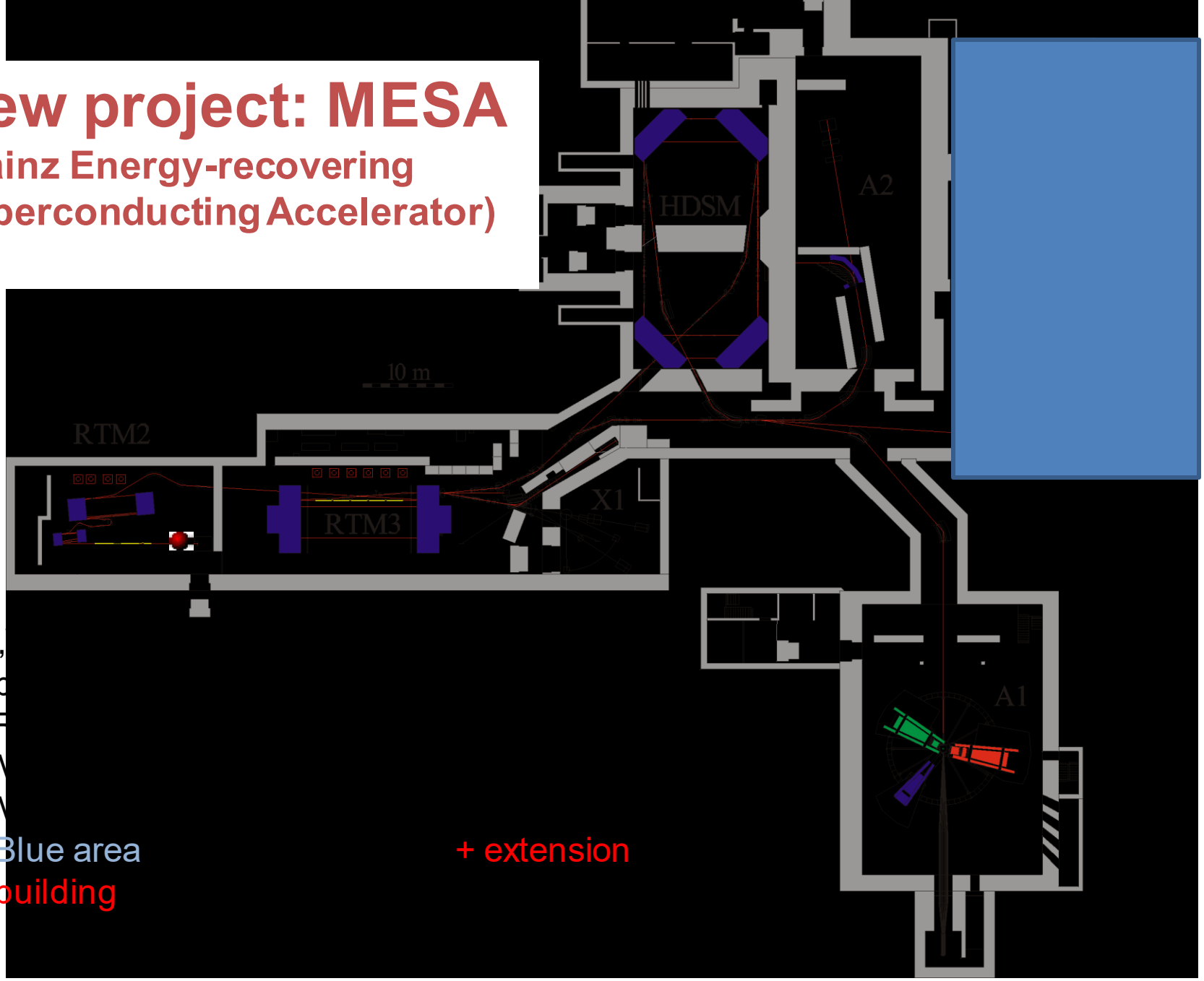
upper picture: „Conventional one turn recirculating linac“:
particles are accelerated twice
lower picture: „One turn ERL“ only one accleration takes place
particles are decellerated in second pass.
– ideally, there is no beam loading

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



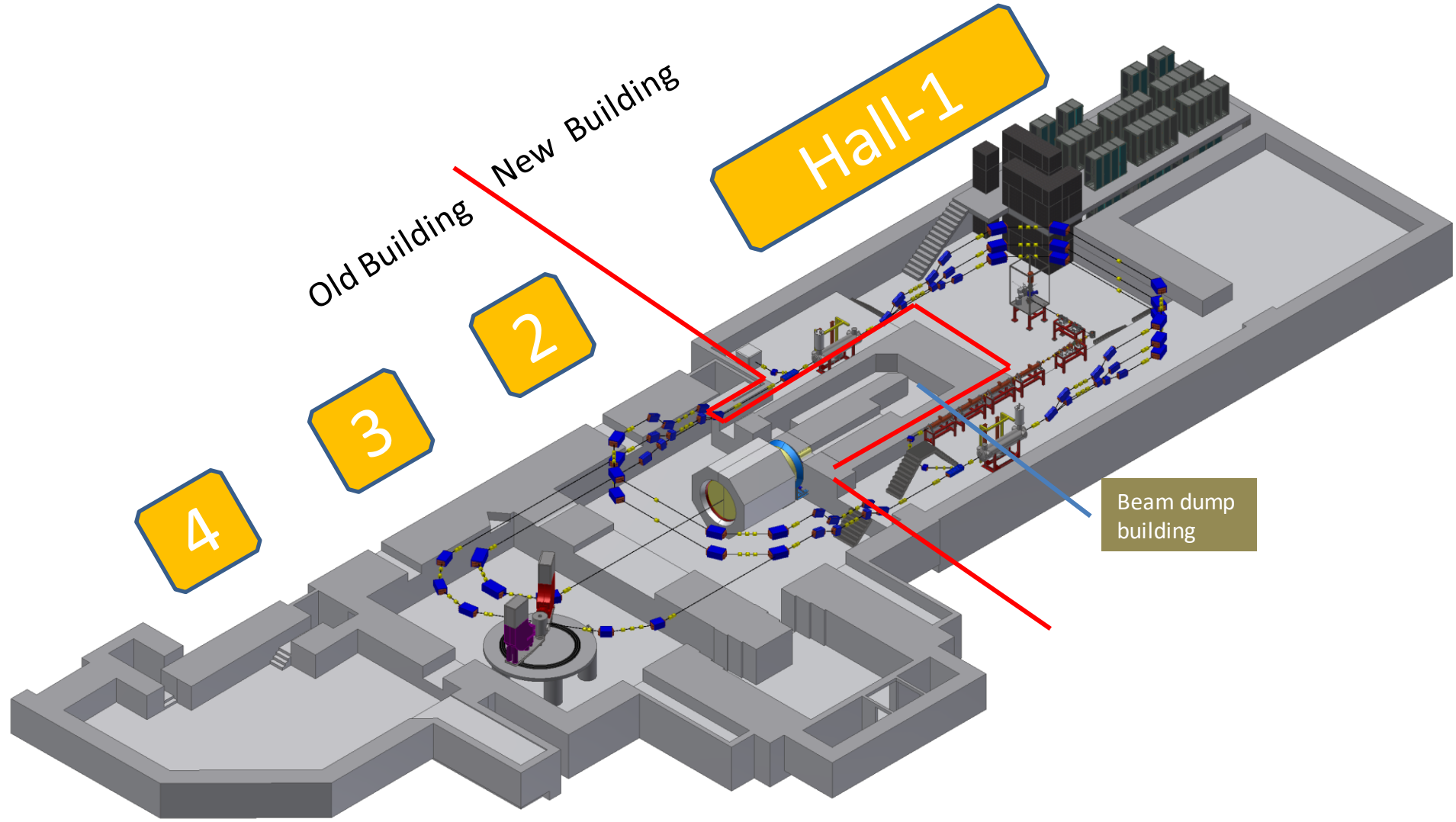
New project: MESA

(Mainz Energy-recovering Superconducting Accelerator)



- „
  b
- F
  M
- M
- Blue area + extension
  building

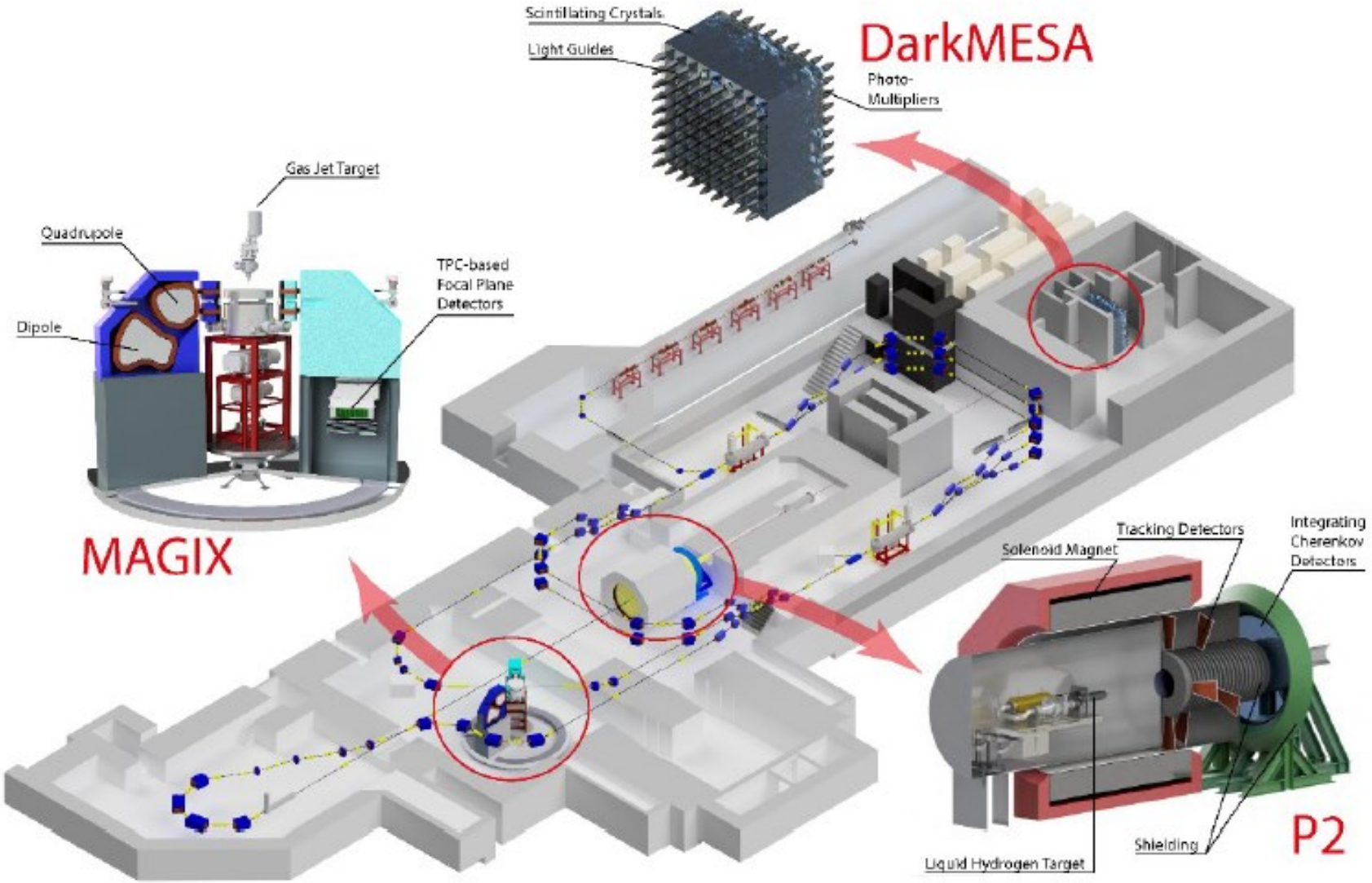
Extension Building “CFP-1” (Hall-1)



Building status November 2020

Occupation readiness planned for November 2021

MESA Experiments



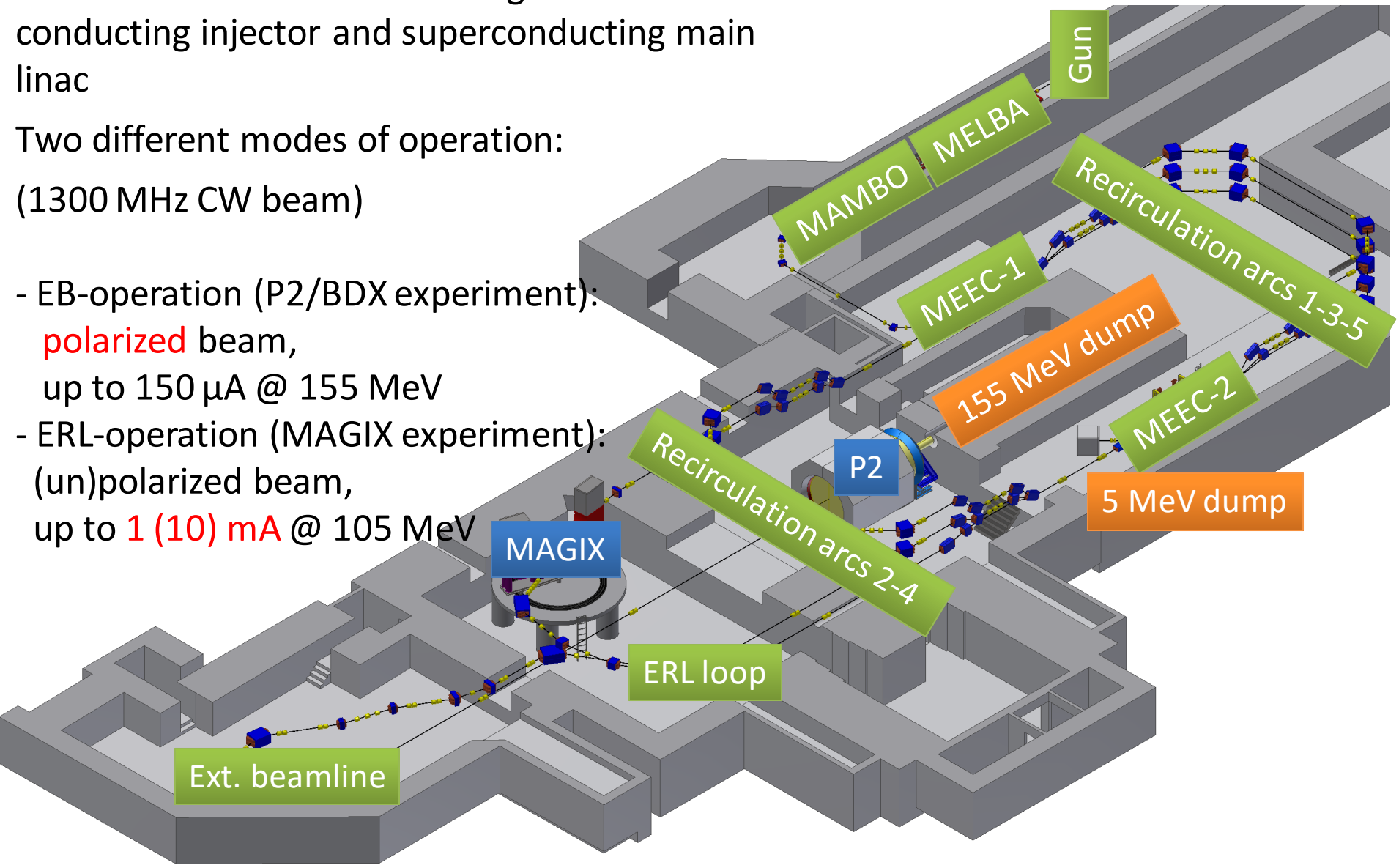
MESA Accelerator Layout

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

Two different modes of operation:

(1300 MHz CW beam)

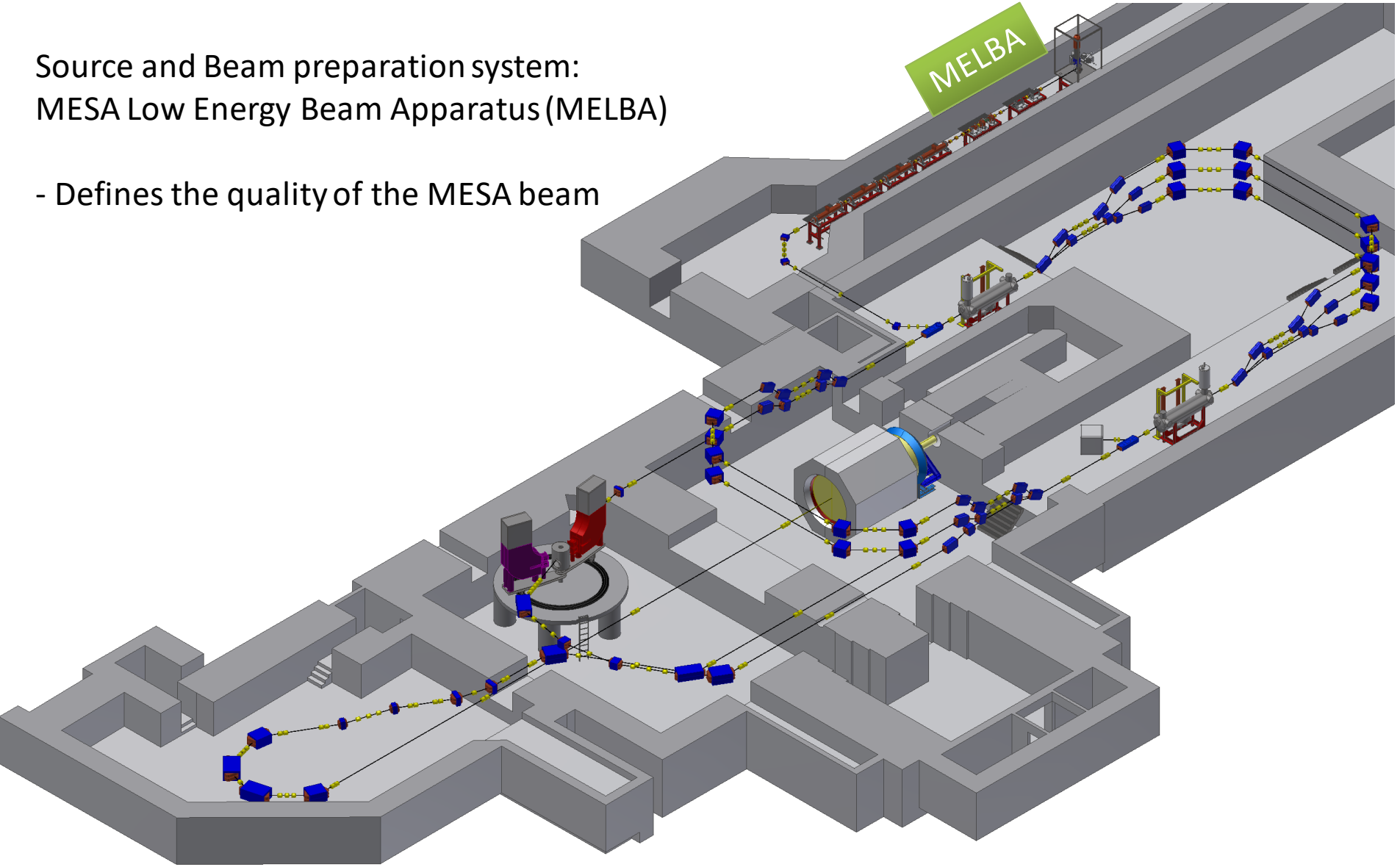
- EB-operation (P2/BDX experiment):
  polarized beam,
  up to 150 µA @ 155 MeV
- ERL-operation (MAGIX experiment):
  (un)polarized beam,
  up to 1 (10) mA @ 105 MeV



MESA Accelerator Layout

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

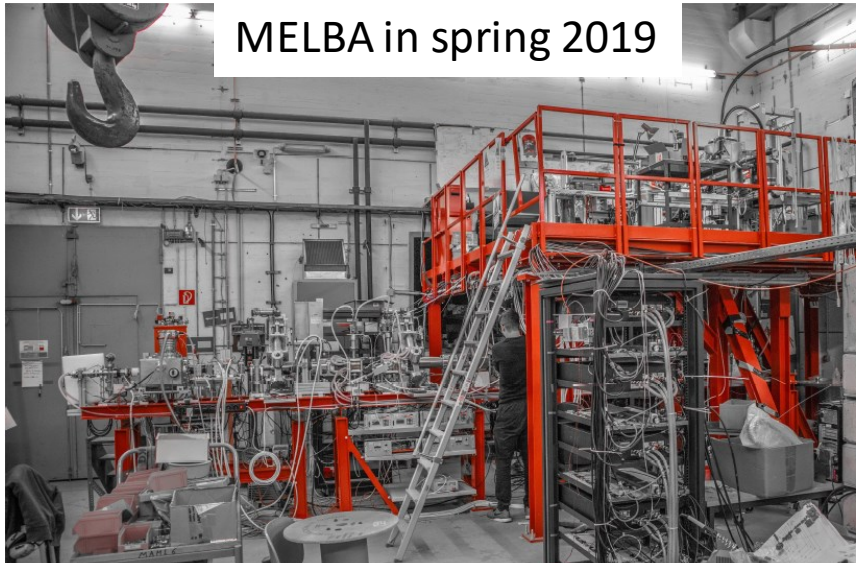
- Defines the quality of the MESA beam



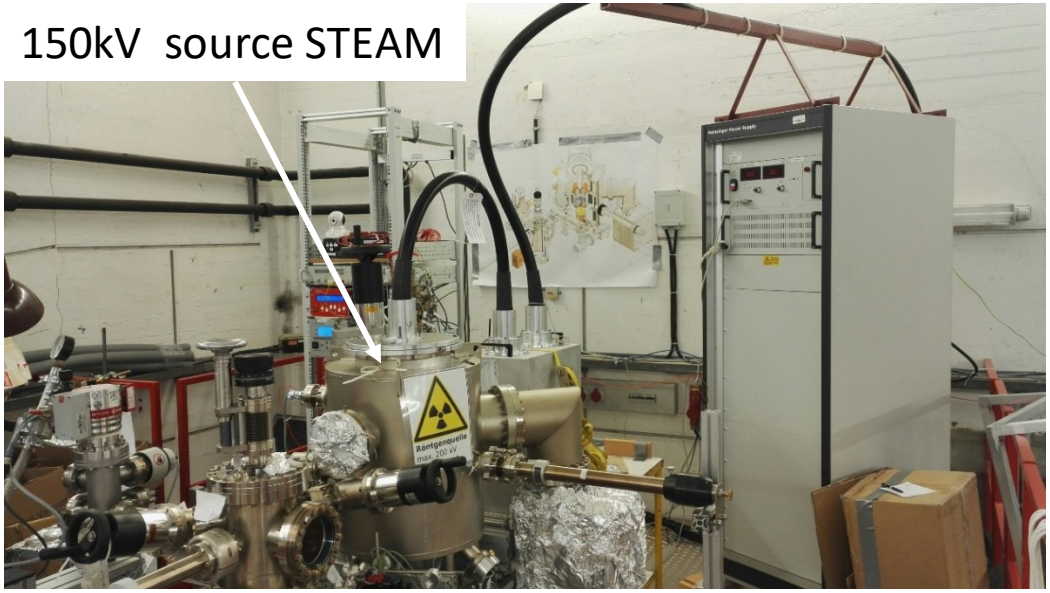
Source/beam preparation (MELBA) until July 2019

- → **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



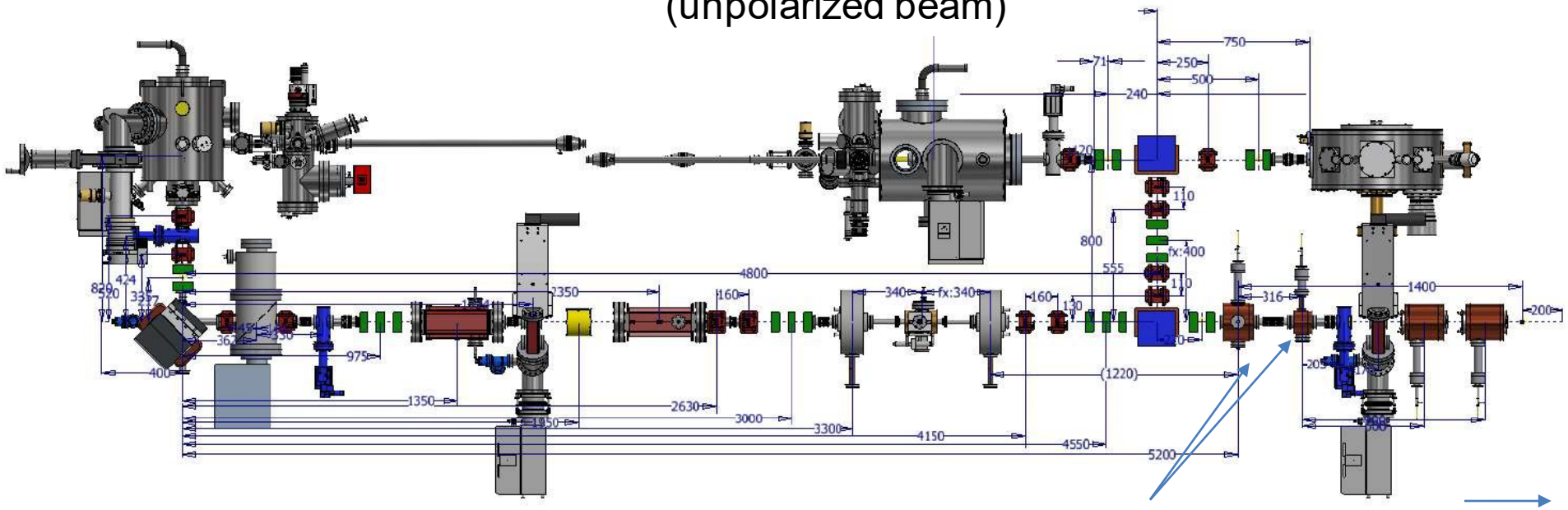
Buncher cavity assembly

Source/beam preparation (MELBA) comissioning in 2021

Photosource „STEAM“
(polarized beam)

High bunch charge/beam
current source
(unpolarized beam)

Double scattering
Mott polarimeter



Spin Manipulation

Circular
Chopper

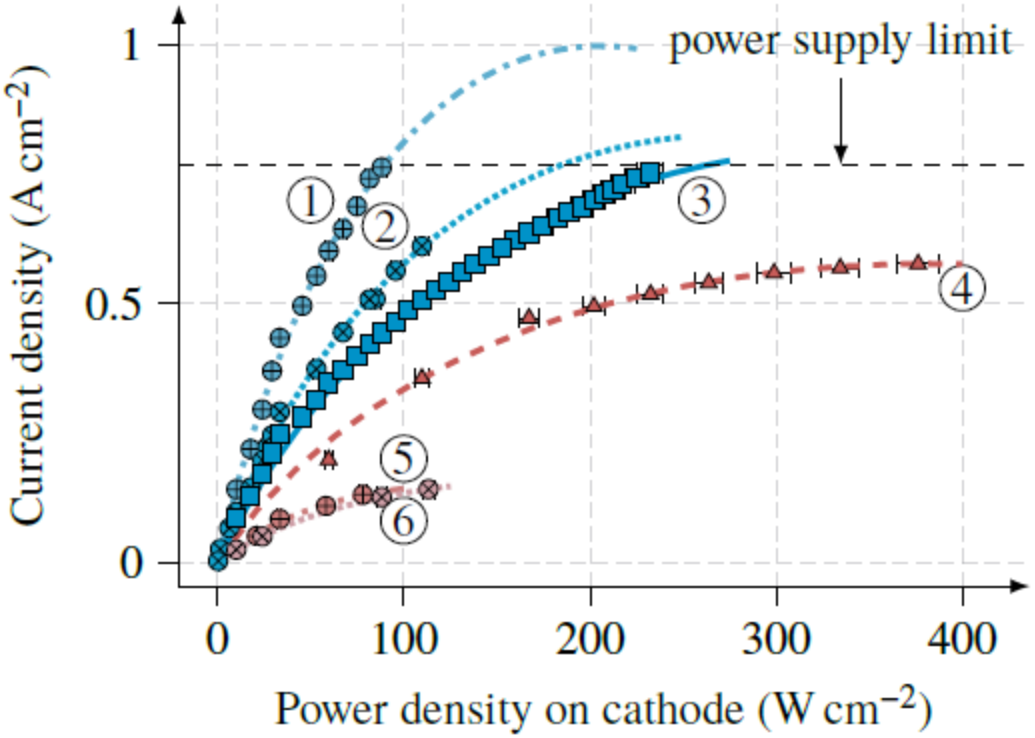
f/2f buncher
cavities

To MAMBO
injector

10mA „ spin-polarized mode“ beam with source „STEAM“

Surface charge limit effect in NEA photocathodes!

S. Friederich et al. IPAC 2019 doi:10.18429/JACoW-IPAC2019-TUPTS011
Fits according to model by G.A. Mulhollan et al. / Physics Letters A 282 (2001) 309–318



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

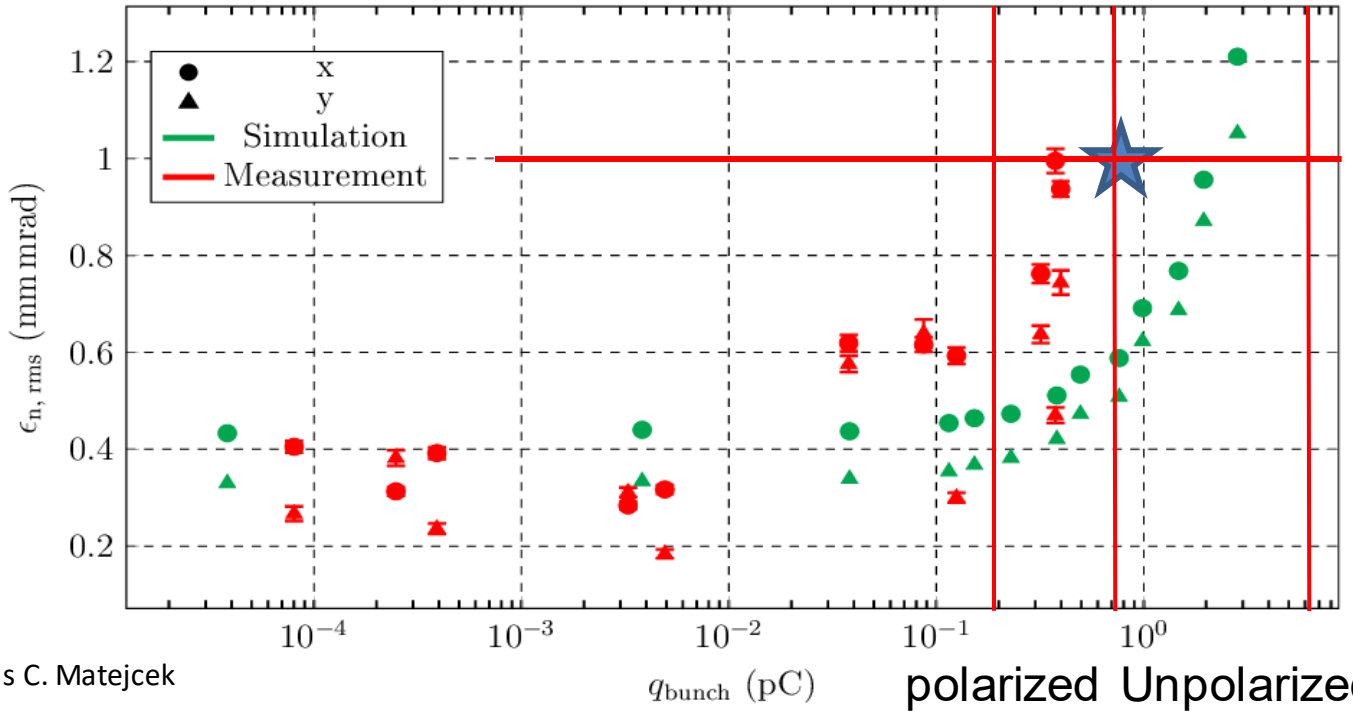
PhD thesis Simon Friederich

steady state-current measurements with the MESA-source at 2.5MV/m, 500µs long pulses, doping level 1-2*10^{19}

For practical purposes it is obviously important **to avoid reduction of q.e.**

MELBA result - spin polarized beam after beam preparation system

Unpolarized (MESA-2)



PhD thesis C. Matejcek

polarized

Unpolarized (MESA-1)

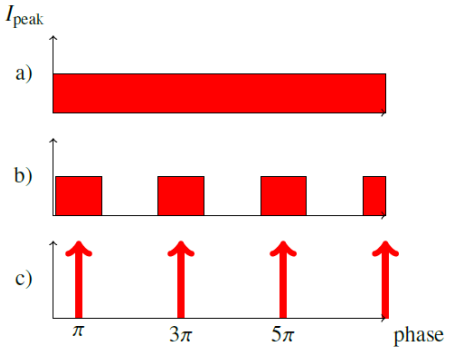
Figure 0.1

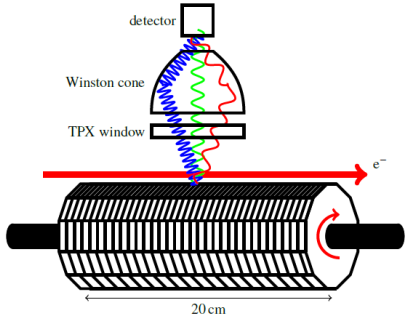
See also proceddings IPAC 2019 CH. Matejcek et al. doi:10.18429/JACoW-IPAC2019-TUPGW028

MELBA with STEAM: Specs for polarized beam achieved/ falls a little short of stage-1 goal for unpolarized beam

Deviation to simulation is attributed to sextupoles of correctors and large excitations because of insufficient magnetic shielding.

Non interfering bunch length measurement at buncher focus by coherent Smith Purcell radiation - controlling function of harmonic buncher

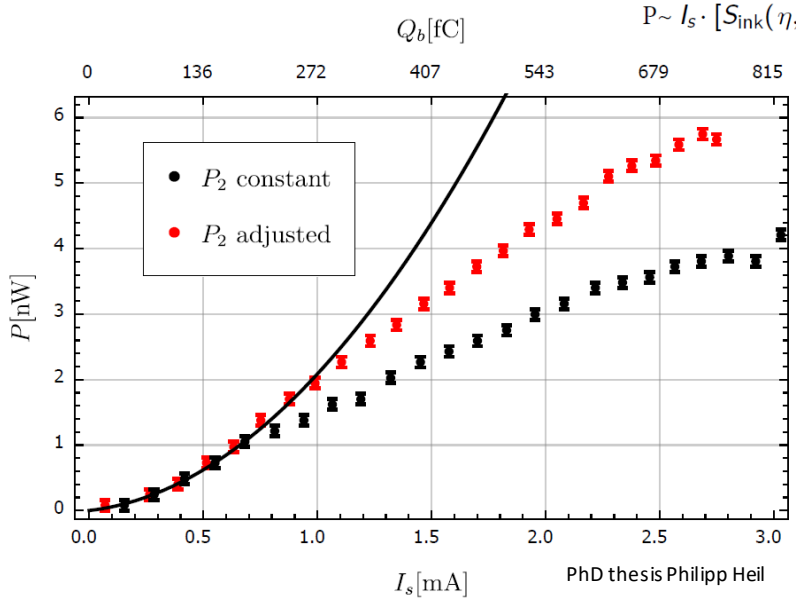




P. Heil et al. Proceedings IPAC 18
doi:10.18429/JACoW-IPAC2018-THPMF062

SPR power P for different beam currents with adjusted second harmonic buncher.

$$P \sim I_s \cdot [S_{ink}(\eta, \zeta) + N_e S_{koh}(\eta, \zeta)]$$



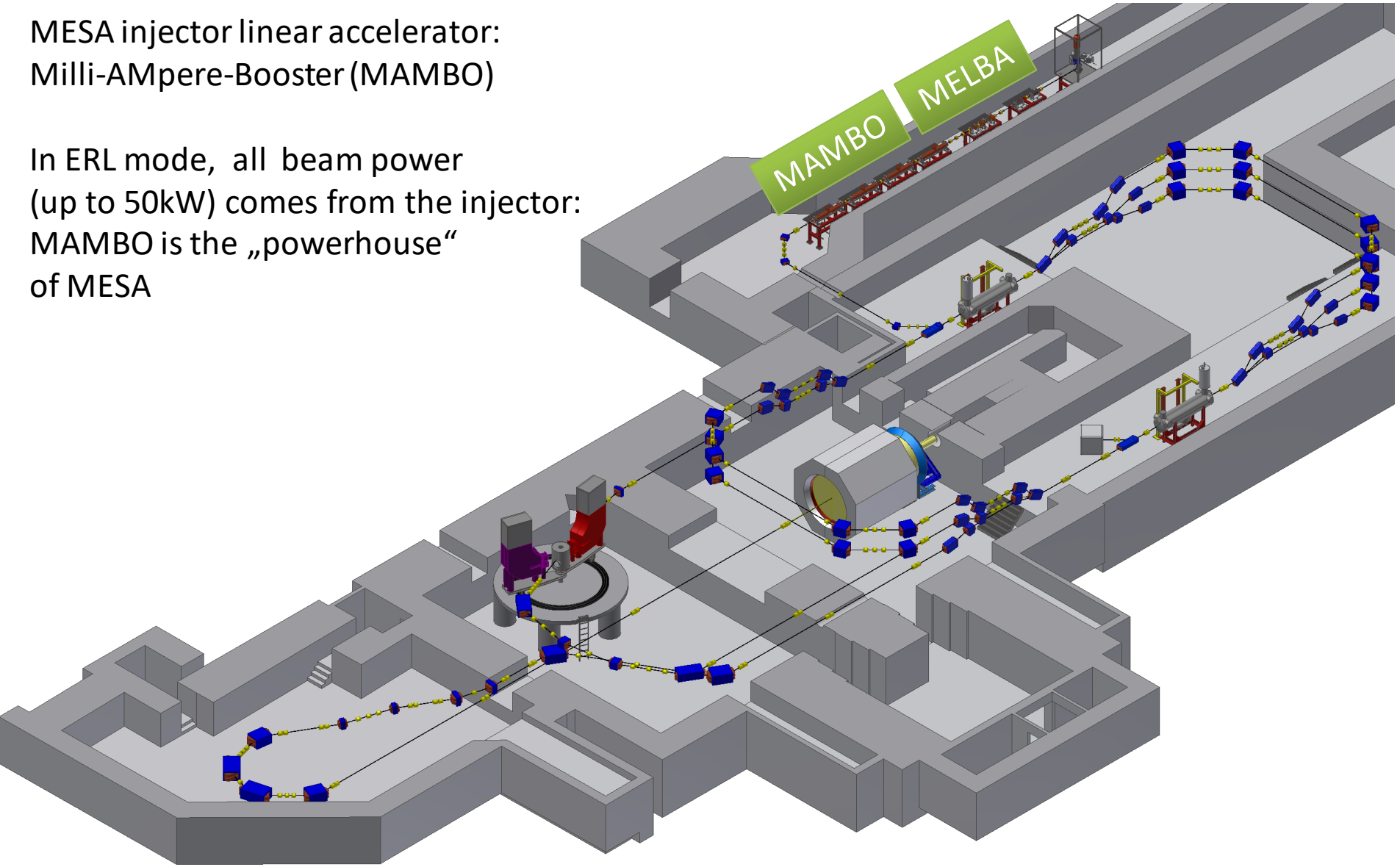
RMS 4ps is required for Injection in MAMBO…

- Achievable for beam currents of a few mA
- Minimum buch length at lower charge <1ps.

MESA Accelerator Layout

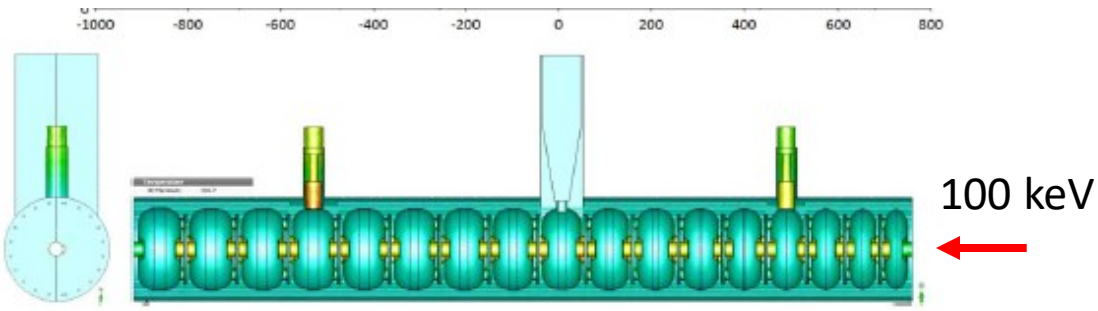
MESA injector linear accelerator:
Milli-AMpere-Booster (MAMBO)

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

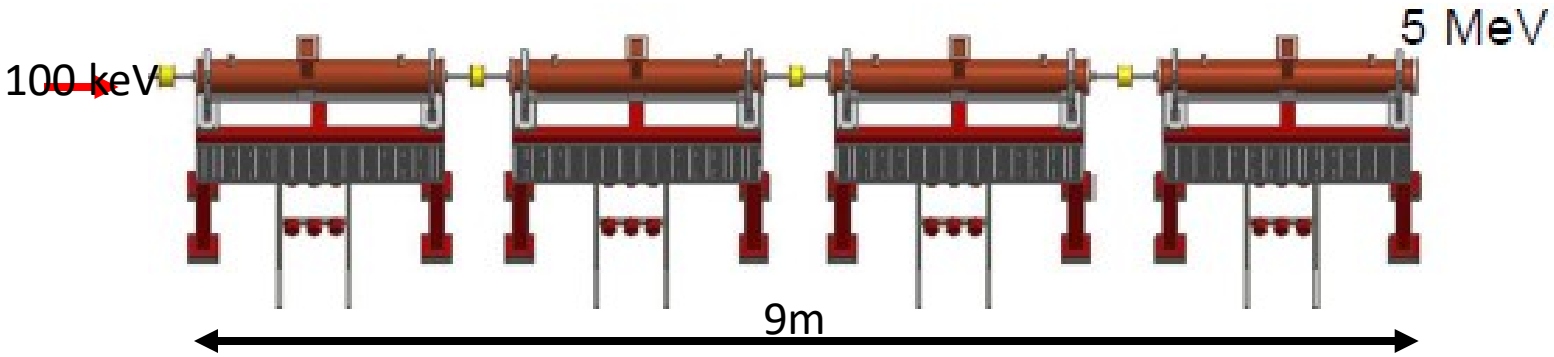


MAMBO Booster Linac

- 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)

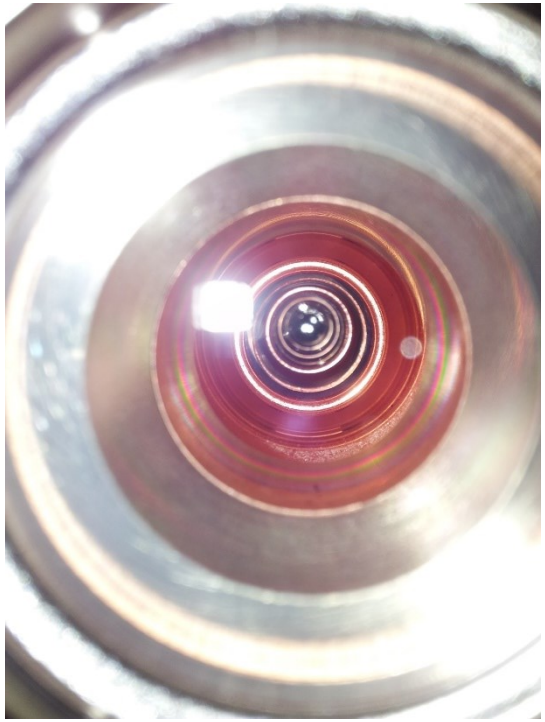


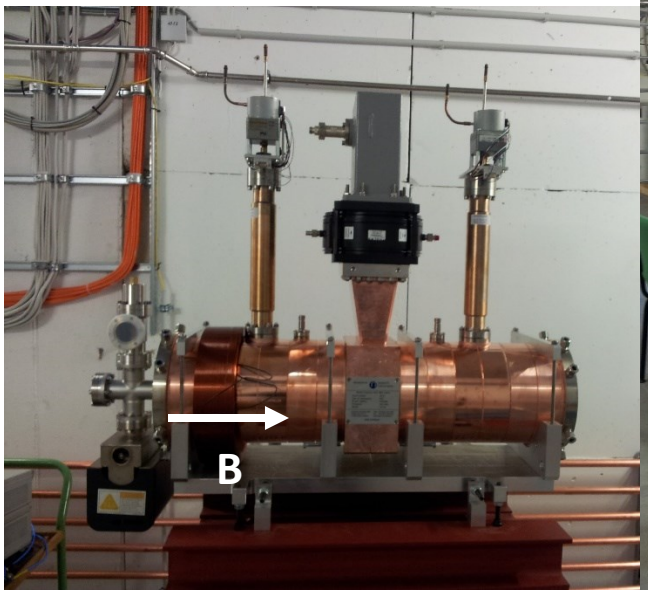
Cross section view

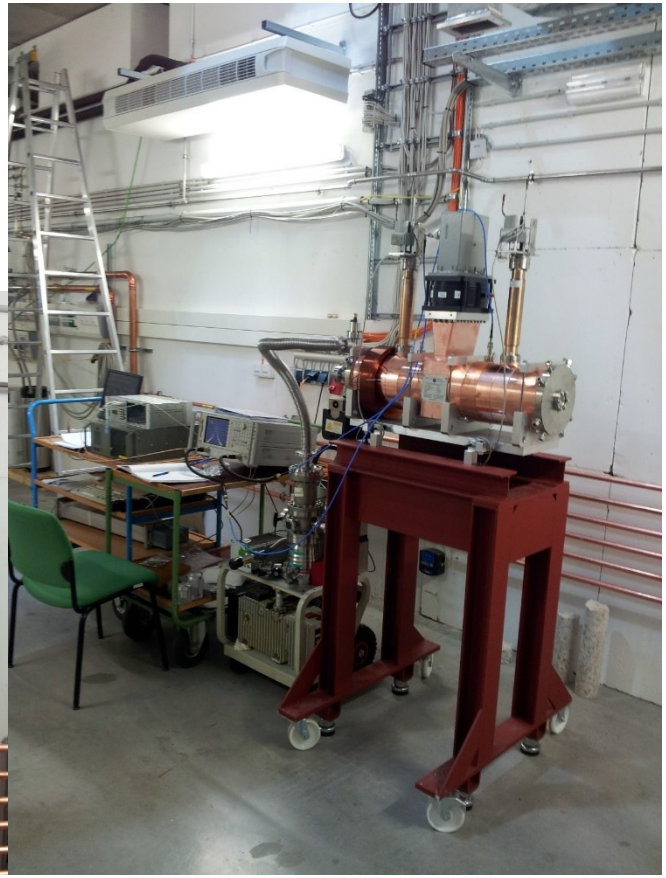


MAMBO Booster: Prototype Cavity

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



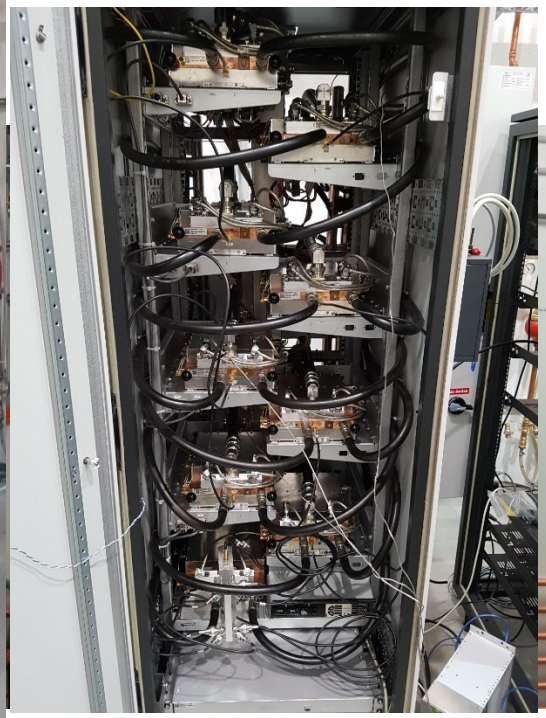


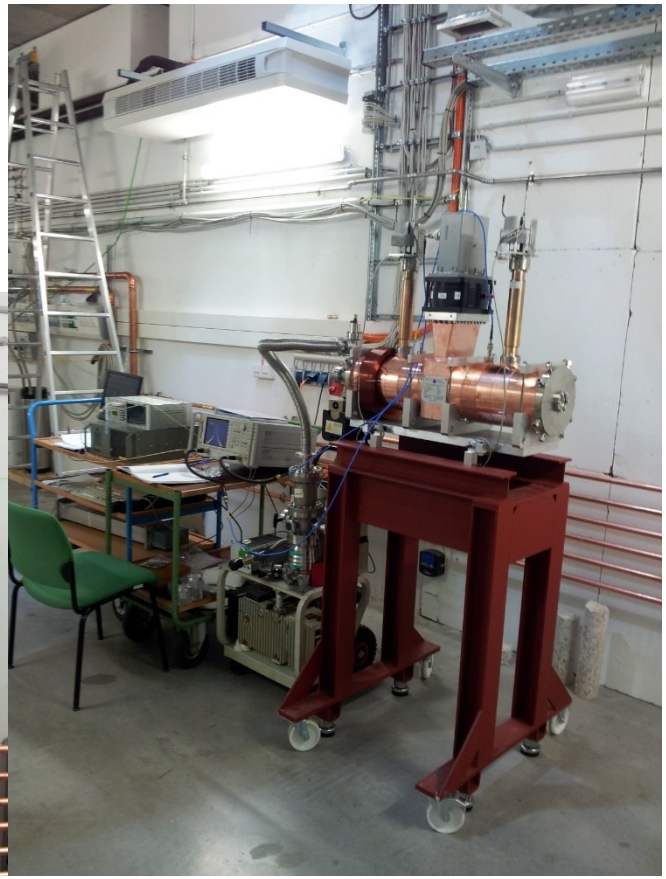


Pictures: R. Heine

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

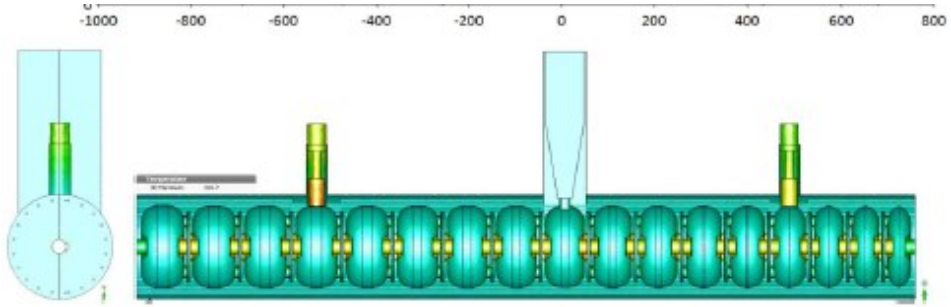


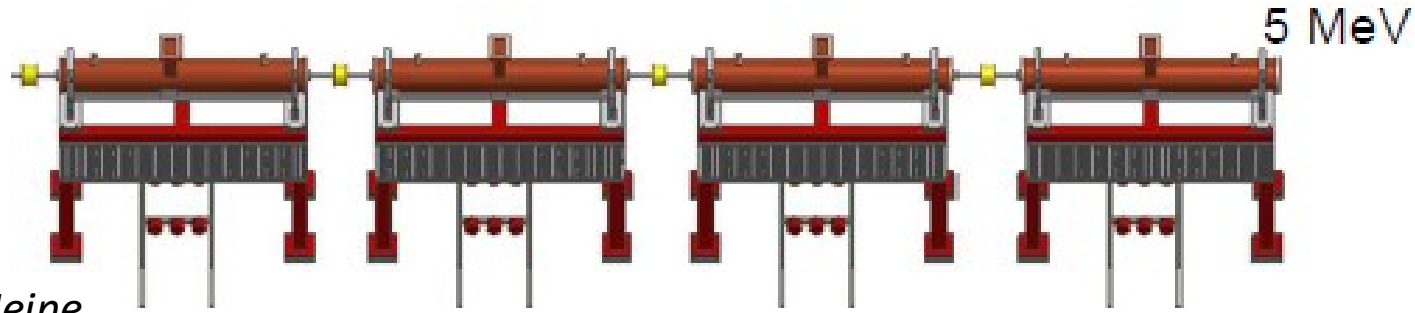


Pictures: R. Heine

MAMBO Booster Linac-Status

- Final design and ordering of Rf-cavities in Spring 19 (delivery starts Jan 21)
- Ordering of Rf-amplifiers: December 19 (delivery of first unit mid 21)



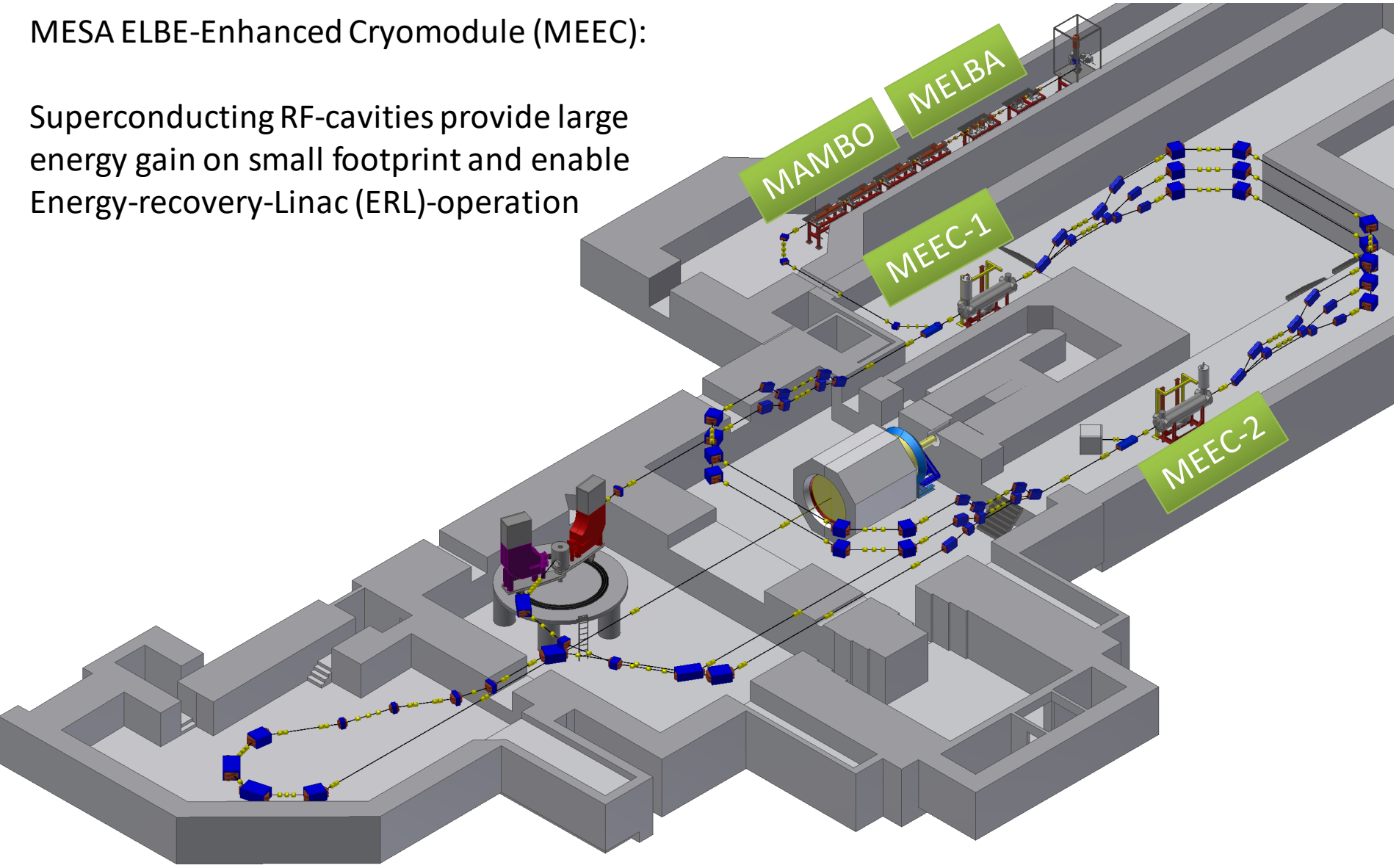


Pictures: R. Heine

Cryomodules

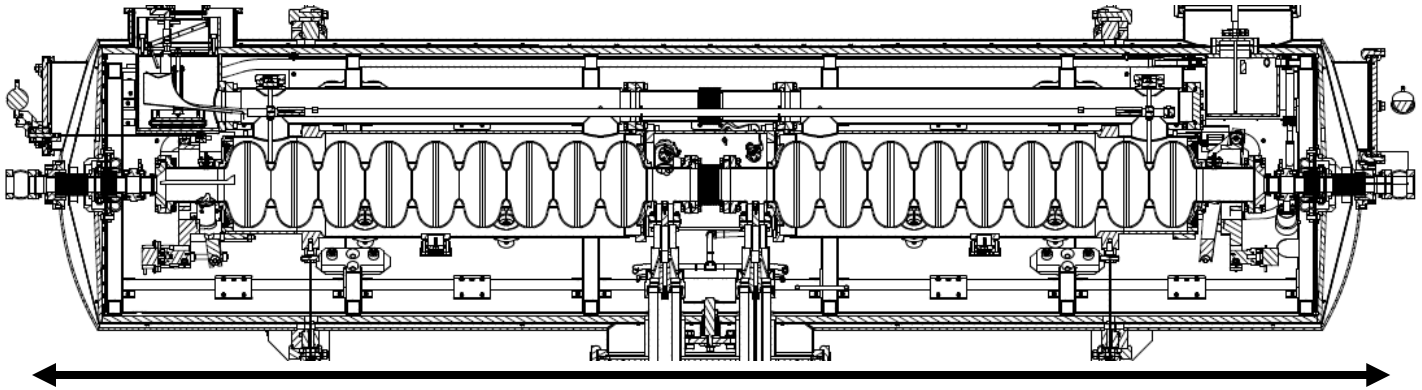
MESA ELBE-Enhanced Cryomodule (MEEC):

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



Picture/beam line&lattice layout : D. Simon

SRF-System: MEEC-Cryomodules

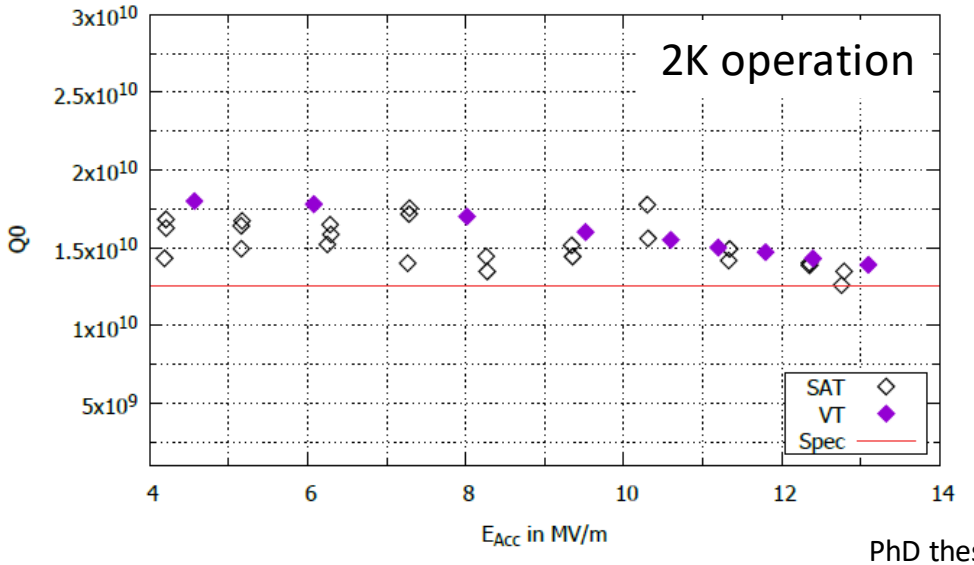


3.5 meter

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

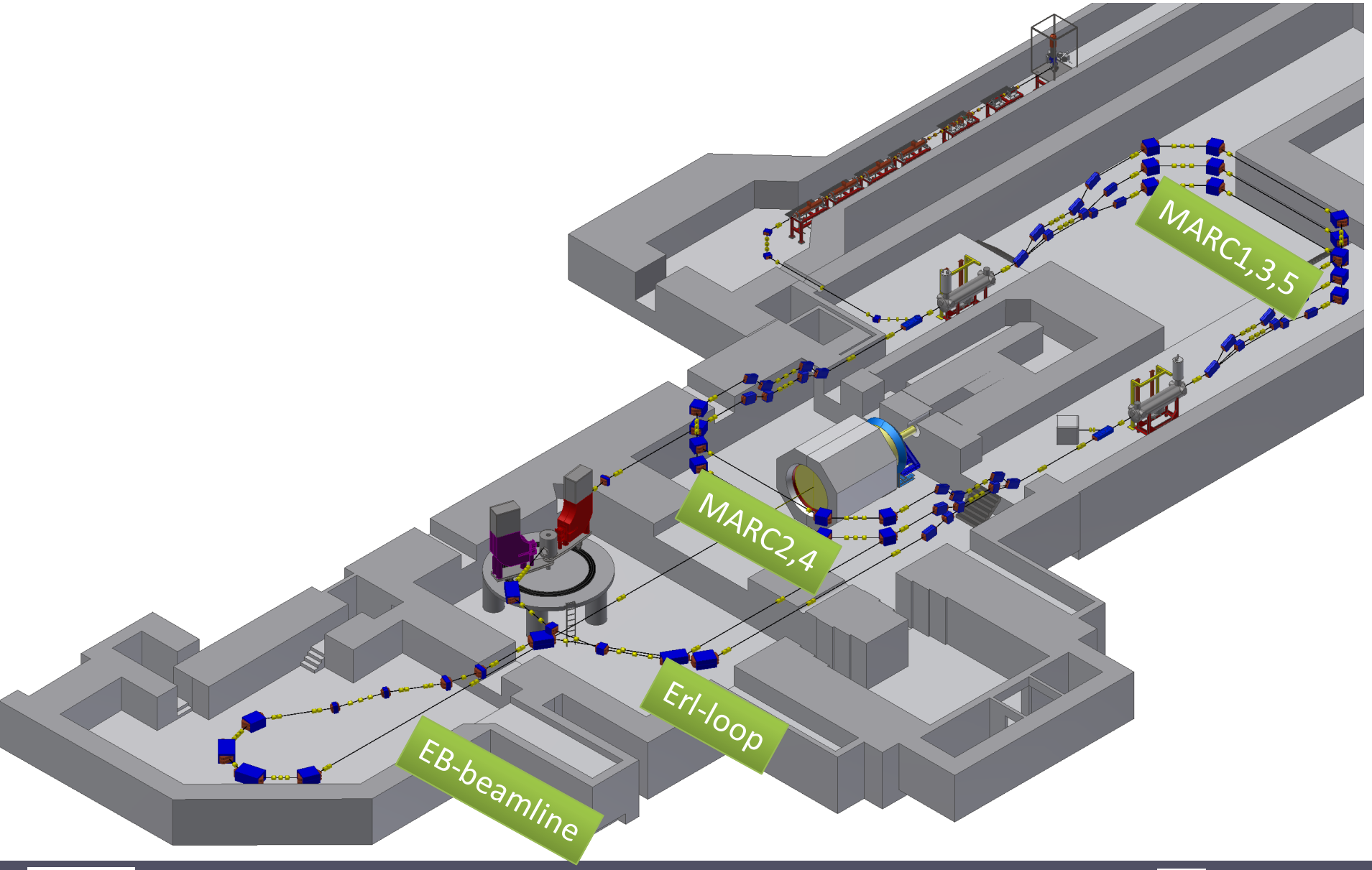
Production of 2 Cryomodules

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



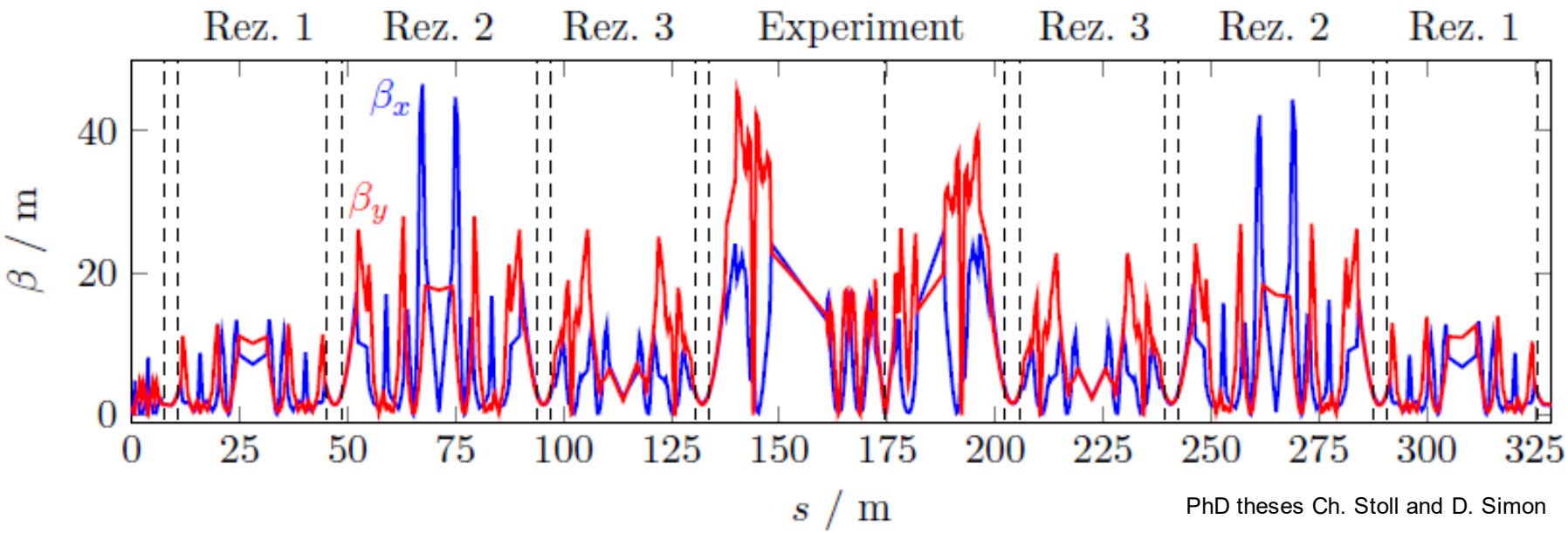
PhD thesis Timo Stengler
See also: T. Stengler et al. Proc. SRF 2019
doi:10.18429/JACoW-SRF2019-TUP041

Lattice ERL/EB mode



Picture/beam line&lattice layout : D. Simon

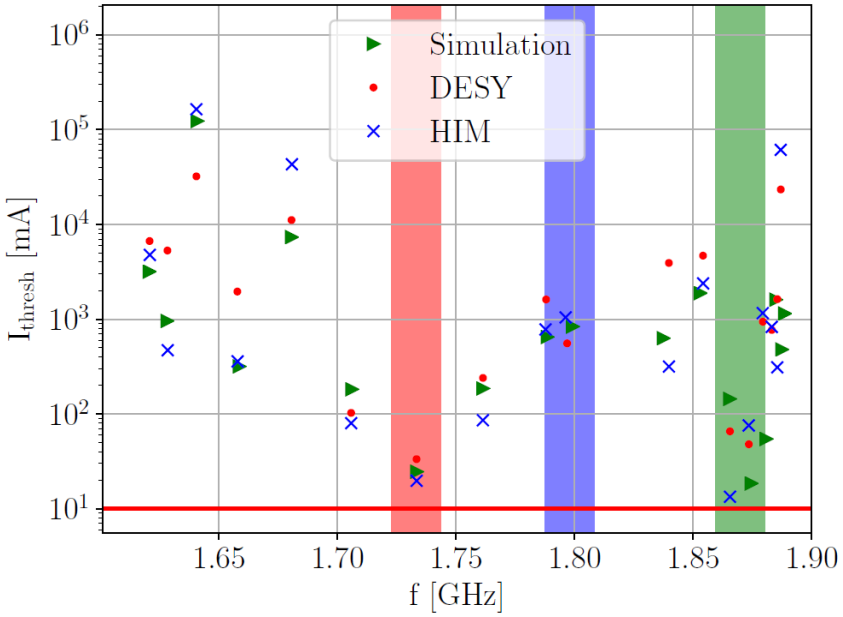
Lattice



PhD theses Ch. Stoll and D. Simon

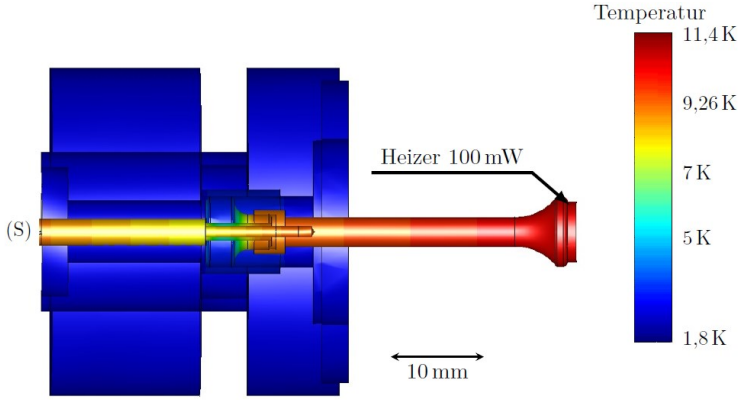
ERL-Lattice – not completely symmetrical due to enery (gain) dependend focussing of RF-structures.

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

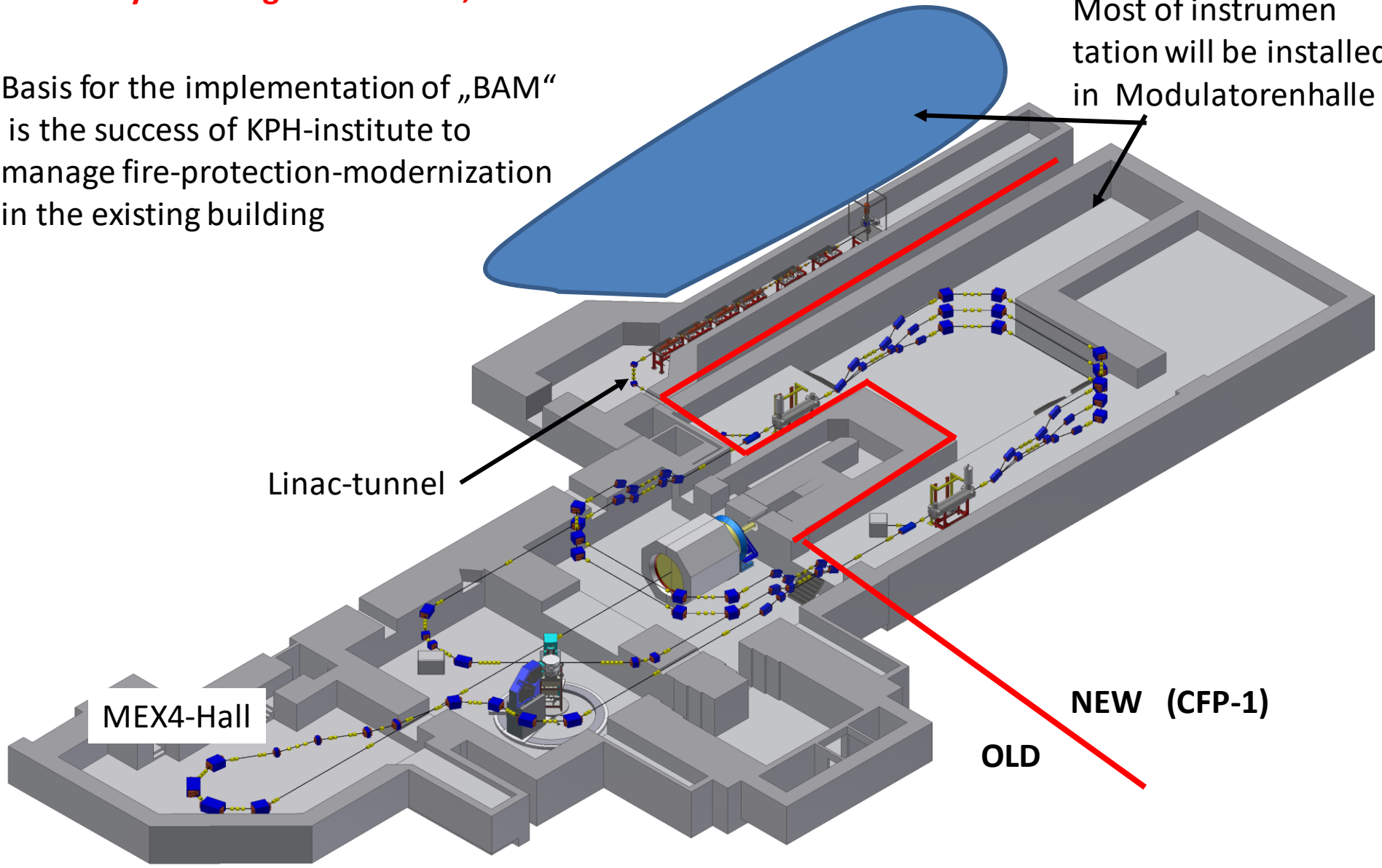


Note:
Technical limitation: Heating
of HOM coupler in TESLA cavities.
(~1mA CW estimation, but needs to
be determined experimentally)

Beschleunigte Aufbaumassnahme MESA (BAM)

2019: Layout using Linac tunnel, Modulatorenhalle and MEX-4

Basis for the implementation of „BAM“ is the success of KPH-institute to manage fire-protection-modernization in the existing building



Status CC/BAM
and implications for schedule

- Our goal: 5MeV injector operational when CFP-1 is finalized
- Installation of MESA recirculator can begin 1/2022
- 15 month installation, 6 month comissioning
- begin of operations for experiments 10/2023

Thank you