# MESA project status

MAGIX workshop February, 17 2017

Kurt Aulenbacher

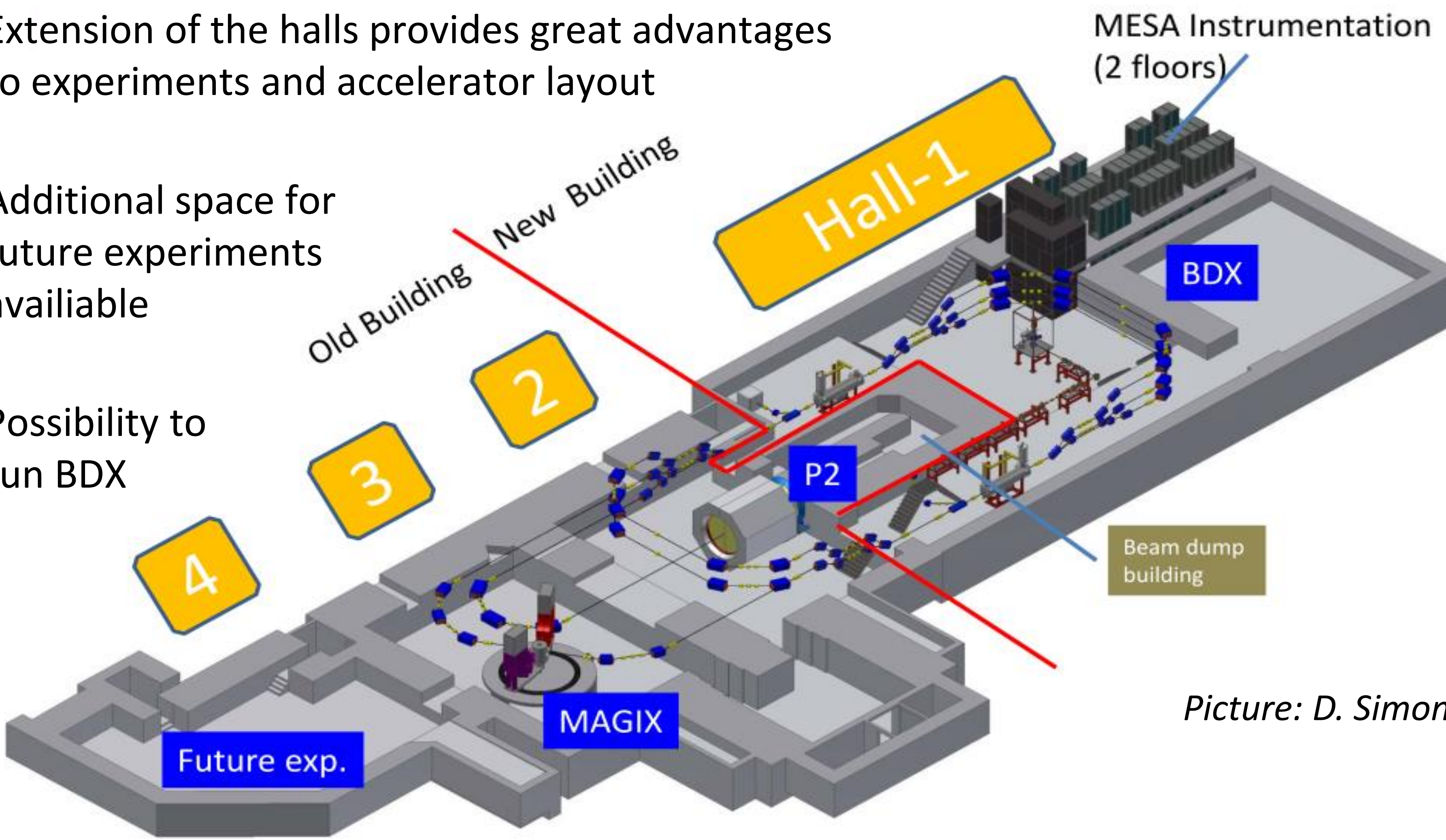
for the MESA project team

# Outline

- Building Overview and Accelerator Layout
- Cryomodule Production Status
- MAGIX beam dynamics issues
- Timelines : components, building, installation, comissioning

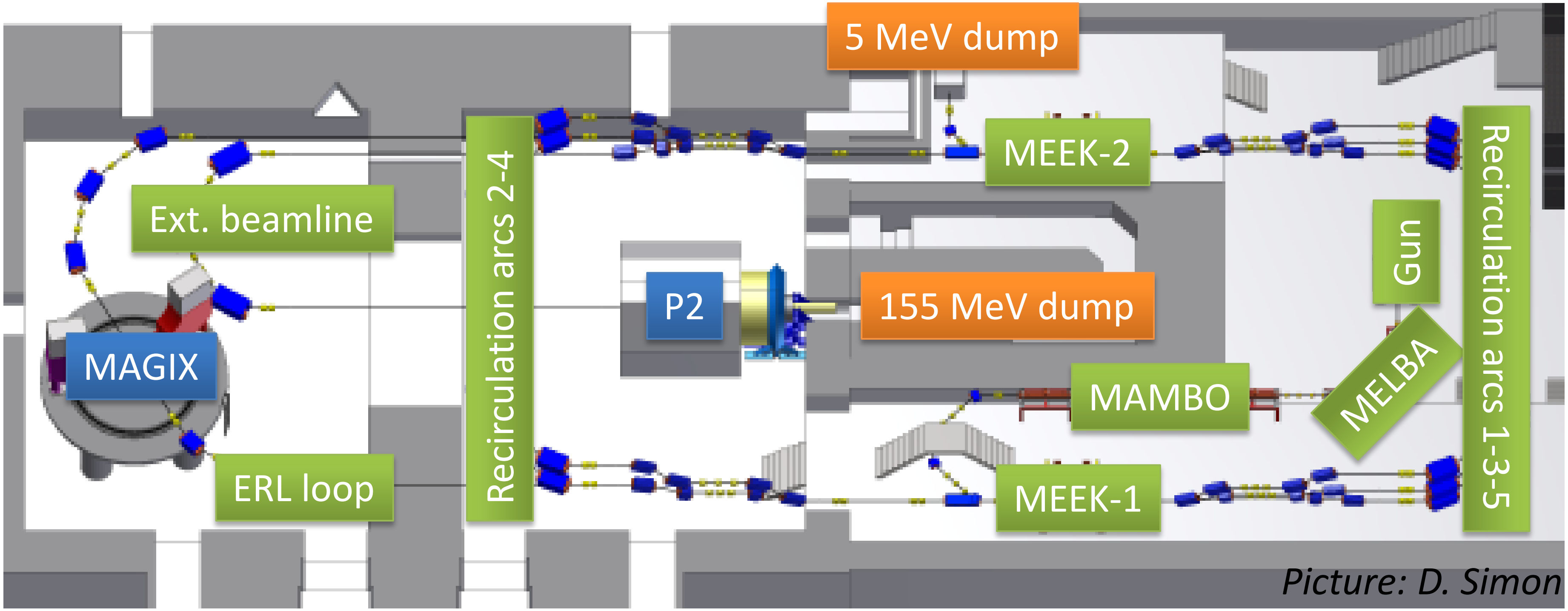
# MESA Building Overview

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




*Picture: D. Simon*

Trade off: Project delay ~3 years due to civil construction time, accelerator layout needed to be adapted to the new situation




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

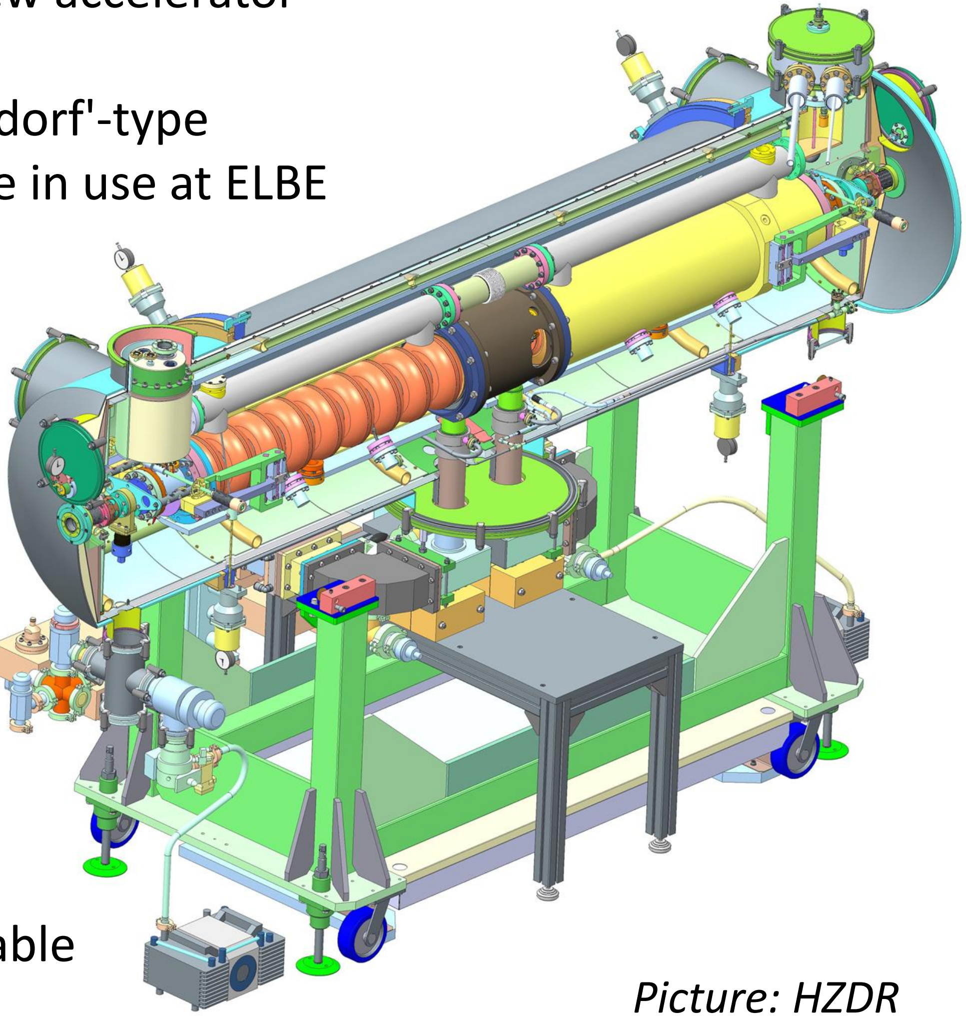
# MESA Cryomodules



Cryomodules are the backbone of the new accelerator

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

→ we applied some adaptations
in order to allow 1 mA ERL operation:
(PhD thesis T. Stengler)



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

→ maximum beam current with reasonable effort currently being investigated in Accelence-PhD project (Christian Stoll), realization is PRISMA+ project.

*Picture: HZDR*

# Cryomodule Project Status

Project duration until today: **20 months**

- Cavities and couplers are completed
- Cavity next step: Helium tank welding and cold acceptance tests at DESY (March)
- Couplers next step: rf power-conditioning at HZDR ( March)
- Cryostat Vessels have been completed (January 2017).
- 4K/2K distribution box developed together with DESY (Final design review 15/Feb)
- After succesful tests (?)cavity string assembly can start in the clean room  at RI

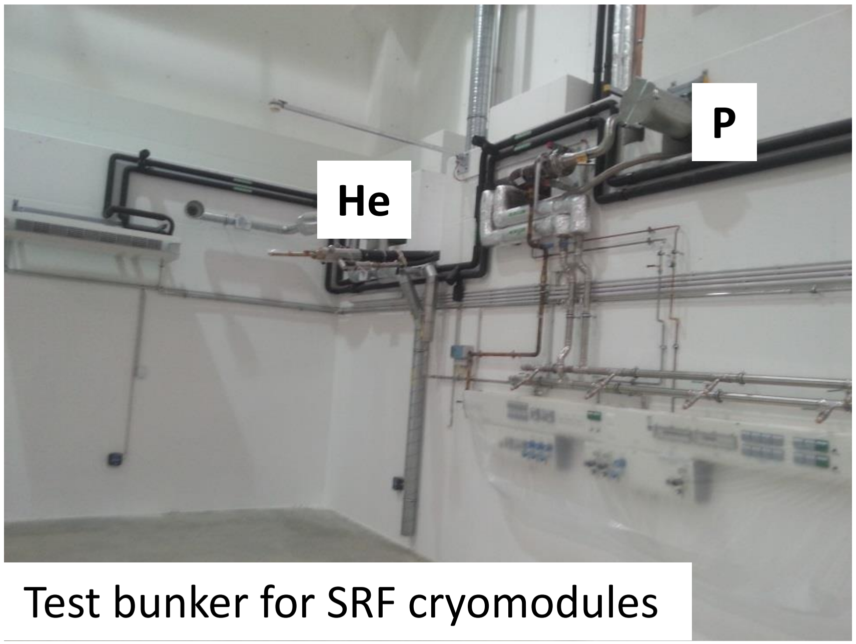
(earliest: April/May)

→ Delivery of the first module planned End June  2017 second in August

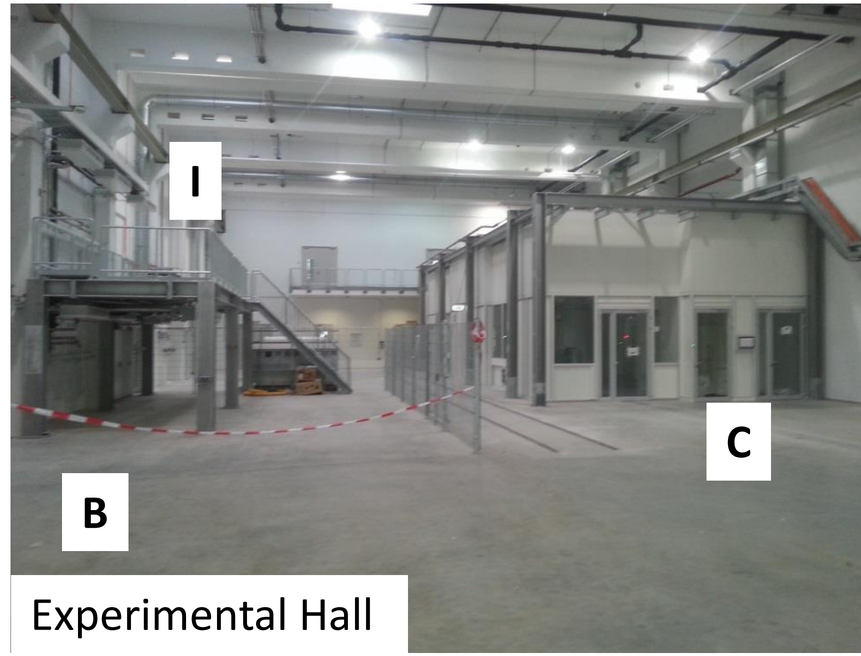
→ Testing still possible at HIM until spring  2018

# Cryomodules-preparing for the test phase

Summer 2016 „Helmholtz Institut Mainz“ (HIM) is now ready for operation (Installations for Cryomodukes need considerable effort!)!




Test bunker for SRF cryomodules




Experimental Hall

01 June 2016

**He:** Lq. Helium supply line from liquifier in nuclear physics institute: >50l/hour through 220 m long pipe demonstrated. **P:** 4g/s pump stage at 16mbar has been ordered.

**I**: Instrumentation platform, 15kW semiconductor amplifier has been ordered, delivery 4/2017

**C**: Clean room for cryomodule maintenance. **B**=Bunker (installed by now…)

# BEAM DYNAMICS FOR MESA/MAGIX
# Energy spread in recirculating electron linacs

Work by Florian Hug, R. Heine , D. Simon

# Outline

**Motivation**

**Acceleration in isochronous vs. non-isochronous recirculators**

**MESA**

- External beam operation
- ERL operation

**MAMBO stability: influence on MESA operation**

**Summary and Outlook**

**Goal: Provide excellent and stable beam for experiments**

e.g. line-width in electron scattering experiments:

$$\Delta E_{FWHM} = \sqrt{(\Delta E_T)^2 + (\Delta E_{Sp})^2 + (\Delta E_B)^2}$$

→ Different error contributions sum up statistically independent

Typical values:

$\Delta E_T/E_T \approx 1.5 \cdot 10^{-4}$ $\Delta E_{Sp}/E_{Sp} \approx 1\text{-}3 \cdot 10^{-4}$

→ Requirements on electron beam (not being the major contribution):

$\Delta E_{rms}/E < 1 \cdot 10^{-4}$ (+excellent long term beam stability )

# Acceleration in electron linacs

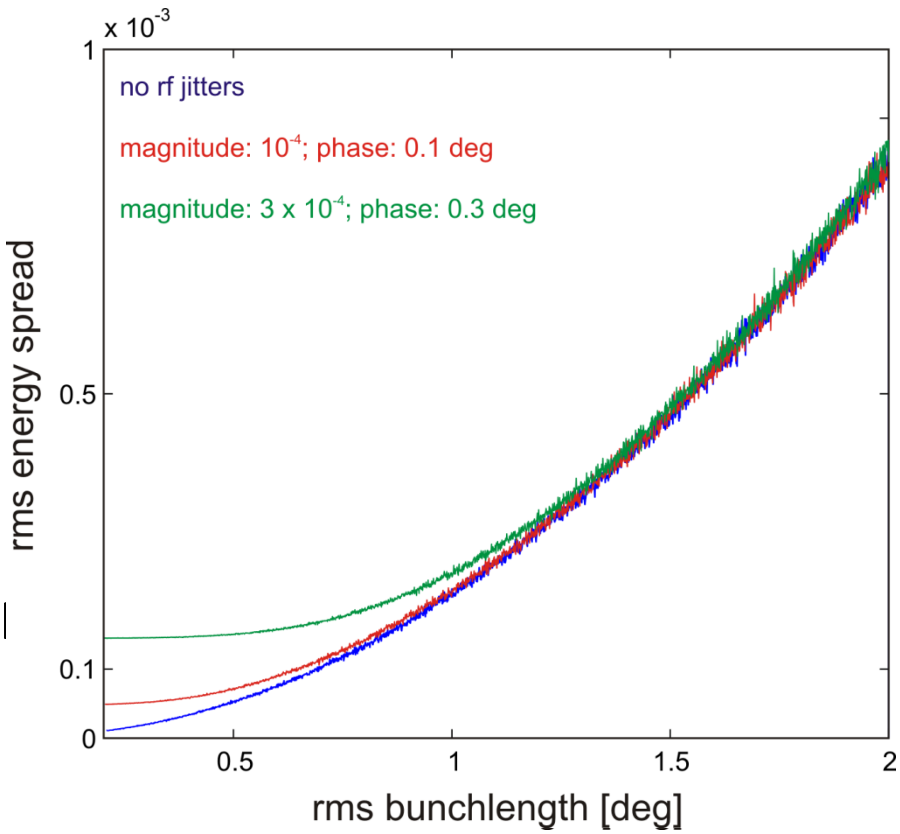


**For relativistic electrons (v≈c):**
**almost no changes**
**in longitudinal position within bunch**

Acceleration on crest of the rf-wave:

→ Short bunches needed because bunchlength causes energy spread!

→ Particles stay "frozen" at their longitudinal position within the bunc



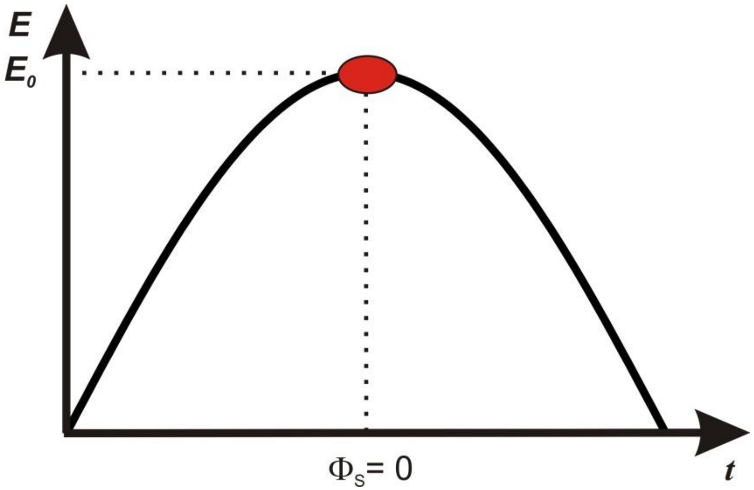
# Isochronous recirculation scheme

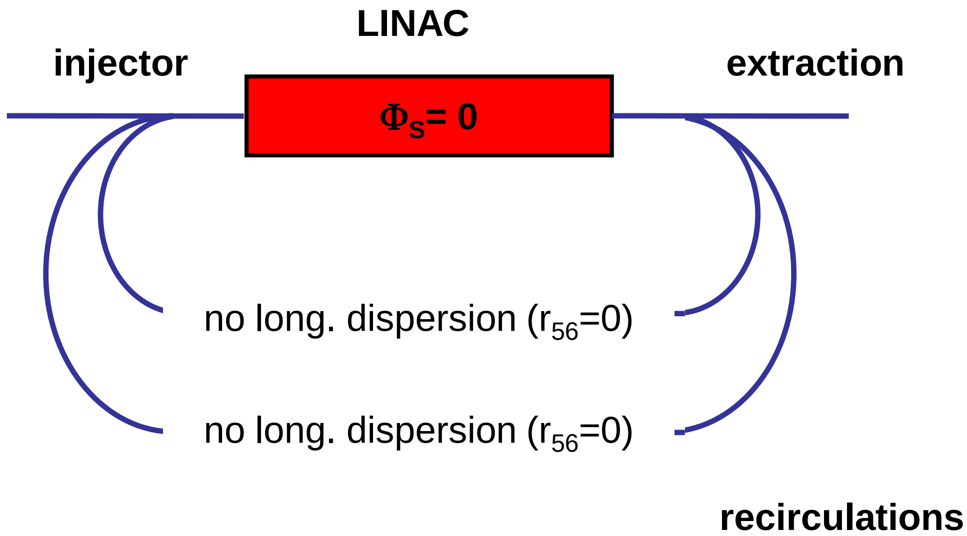


Convenient for long linacs with many cavities:

Acceleration on crest of rf field with shortest possible bunches

→ Errors scale with $\sqrt{N}$ (N = number of cavities)



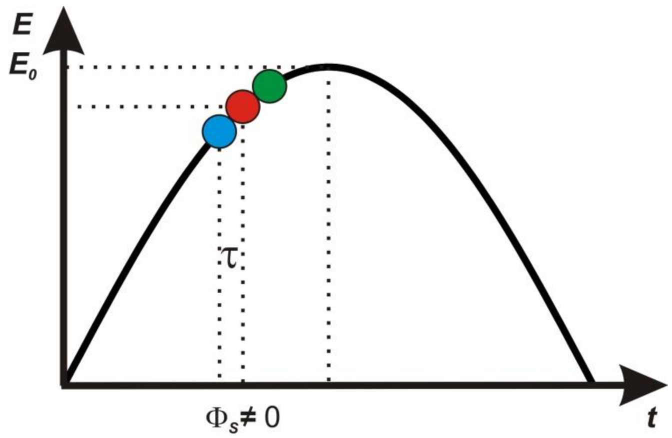

In (short) few turn recirculators:

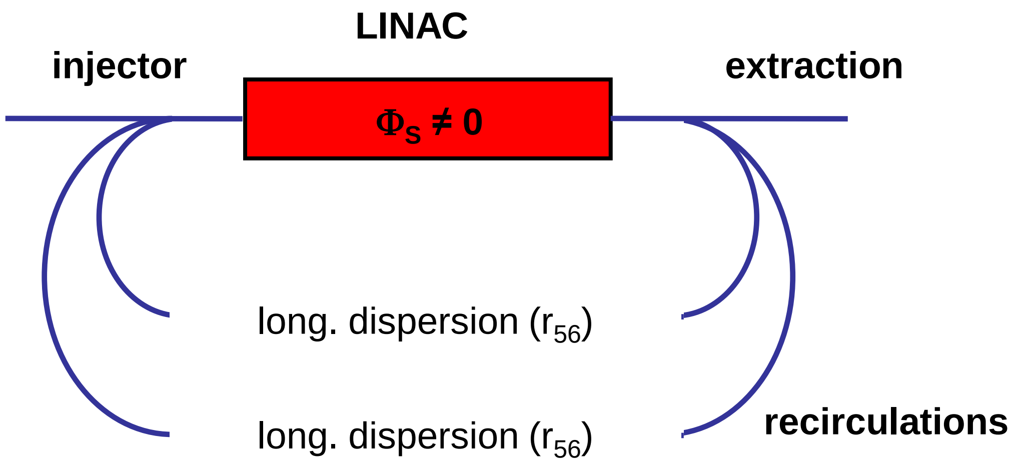
Amplitude errors of accelerating cavities can add up coherently over all turns → no averaging of errors when $t_{linac} << \tau_{cavity}$

→ Energy spread can exceed experimental requirements

# Non-isochronous recirculation scheme

- Common operation mode for microtrons and synchrotrons
- Acceleration on edge of rf field
- Different time of flight for particles having different energies




→ Particles perform synchrotron oscillations in longitudinal phase space

Half- or full integer oscillations lead to reproduction of the longitudinal phase space at injection [*Herminghaus, NIM A 305 (1991) 1*].

→ complete compensation of rf phase- and amplitude jitters possible

# MESA: External Beam Operation



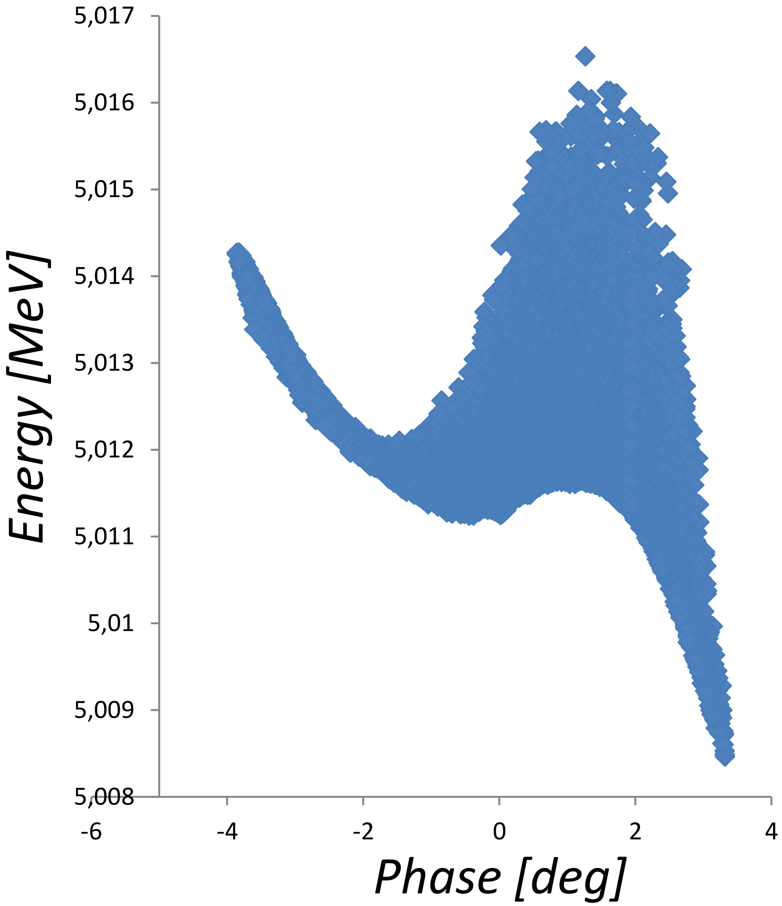
**Simulations for a new longitudinal working point**

Goal: Find optimal combination of $r_{56}$ and $\Phi_S$ for MESA 6-pass external beam mode

1. Import longitudinal phase space from MAMBO 150 µA simulation
2. Create randomized cavity parameters (4 cavities, $\Delta A_{rms} = 1 \cdot 10^{-4}$, $\Delta\phi_{rms} = 0.1°$ )
3. For each pair of $r_{56}$ and $\Phi_S$ track each particle through the accelerator

$$E_{i+1} = E_i + (A + \Delta A)\cos(\phi_S + \delta\varphi + \Delta\phi)$$
$$\varphi_{i+1} = \varphi_i + r_{56} \cdot \delta E / E_{ref} \cdot 156°$$

4. Calculate rms energy spread for each pair of $r_{56}$ and $\Phi_S$



# MESA: External Beam Operation



Results for 6-pass external beam mode:

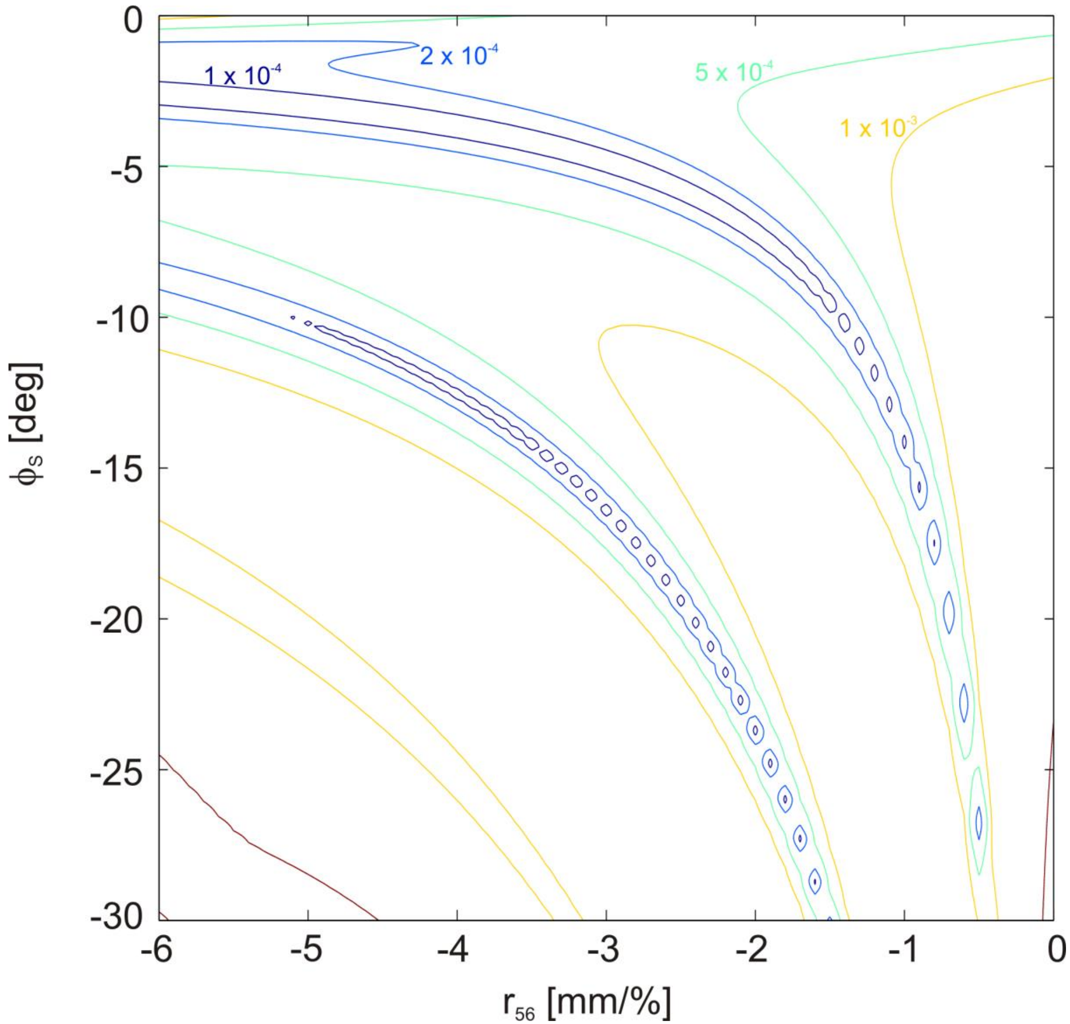
→ best energy spread at:

$r_{56}$ = -2.6 mm/% and

$\Phi_S$ = -5.8°

$\Delta E_{rms}/E = 5.5 \cdot 10^{-5}$

isochronous: $\Delta E_{rms}/E = 3.4 \cdot 10^{-4}$



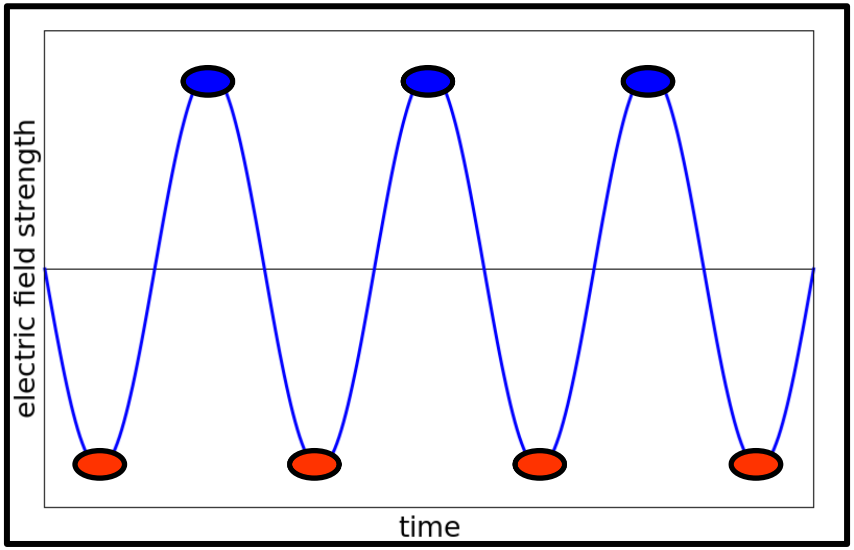
# MESA: ERL Operation



Compare the two different ERL operation modes:

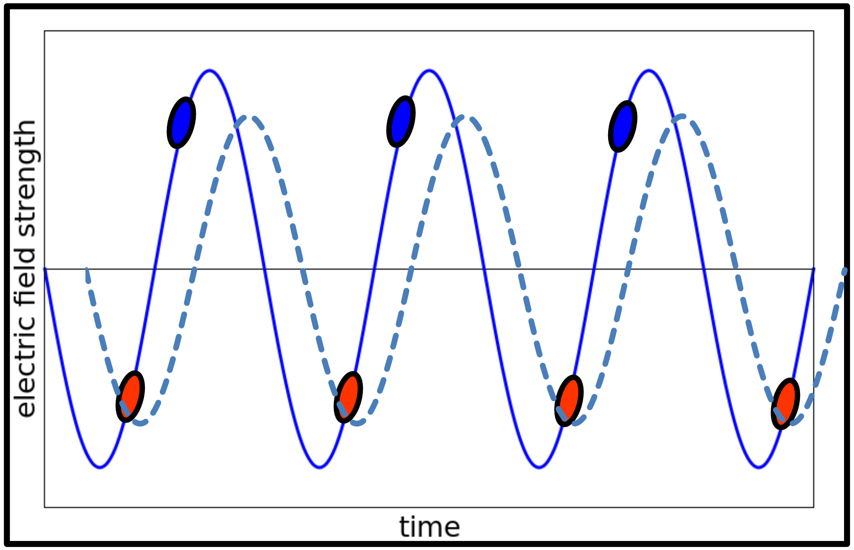
**isochronous operation**

Accelerating and decelerating bunches in phase with maximum/minimum of rf-field




**non-isochronous operation**

Decelerating bunches re-enter cavities at a different phase
→ possible disturbance on accelerating phase as well




→ On the non-isochronous working efficiency of energy recovery decreases
→ Maybe challenging for rf-control system to sustain desired accelerating field

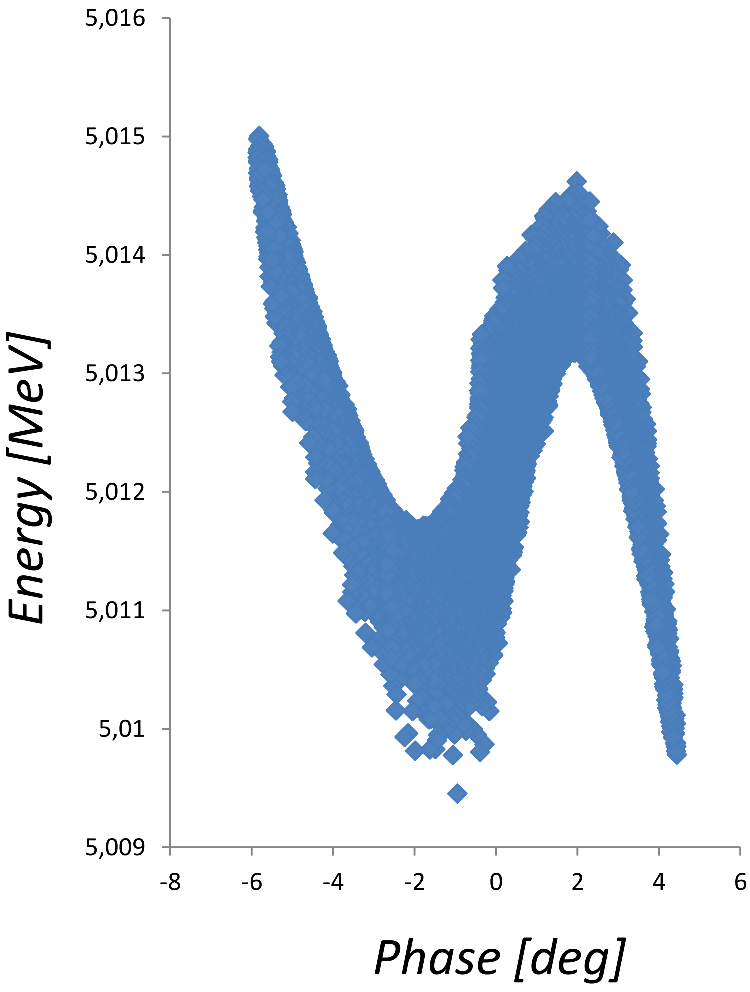
## Simulations for isochronous ERL operation

- Only 4 passes in ERL mode
- High space charge forces at maximum beam current

1. Import longitudinal phase space from MAMBO 1 mA simulation
2. Create randomized cavity parameters (4 cavities, $\Delta A_{rms} = 1 \cdot 10^{-4}$, $\Delta\phi_{rms} = 0.1°$ )
3. Track each particle through the accelerator

$$E_{i+1} = E_i + (A + \Delta A)\cos(\delta\varphi + \Delta\phi)$$

$$\varphi_{i+1} = \varphi_i$$



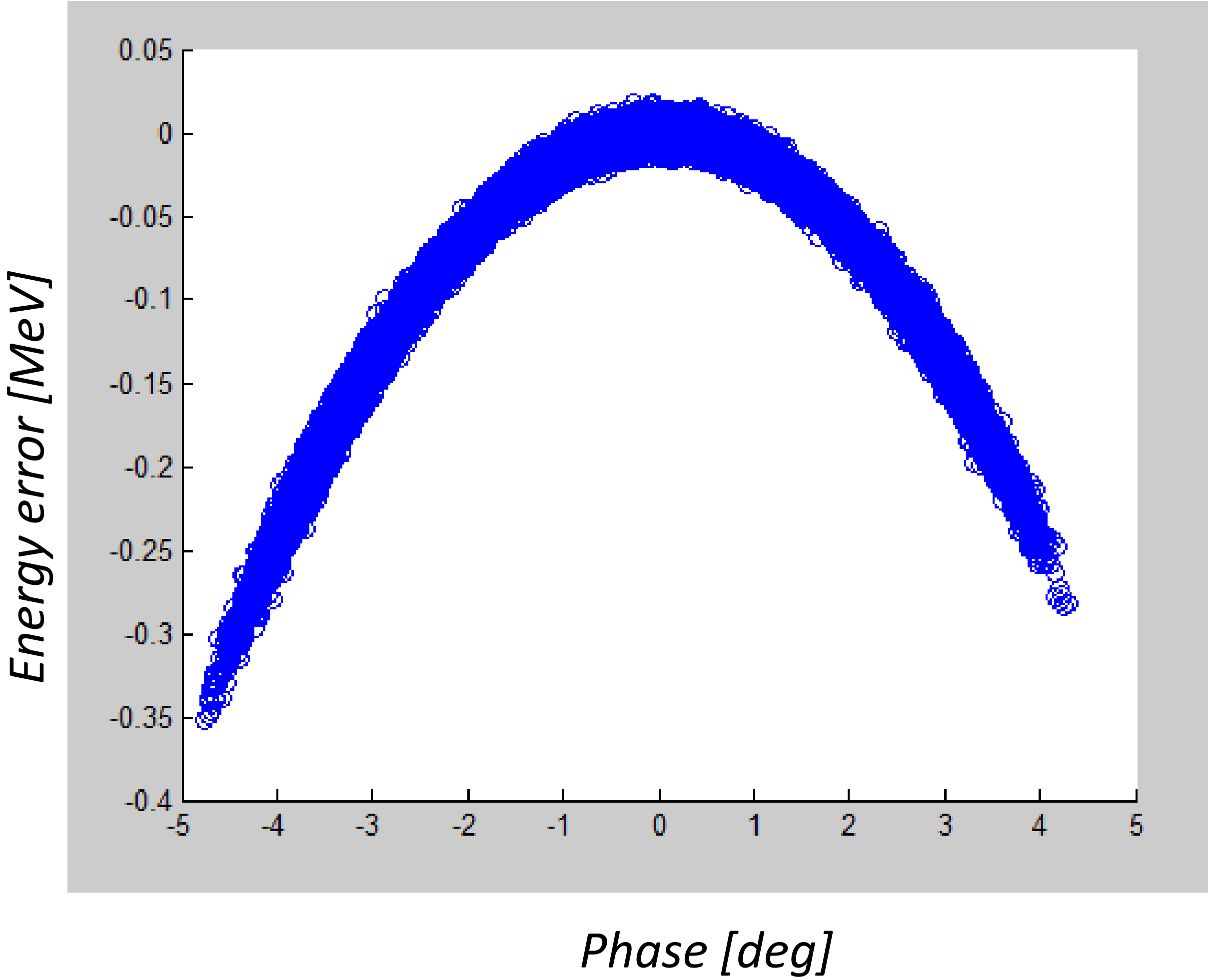

4. Calculate rms energy spread and longitudinal phase space

Results for 4-pass isochronous ERL mode:

Phase space dominated by cosine shape of accelerating field

$\Delta E_{rms}/E = 7.16 \cdot 10^{-4}$

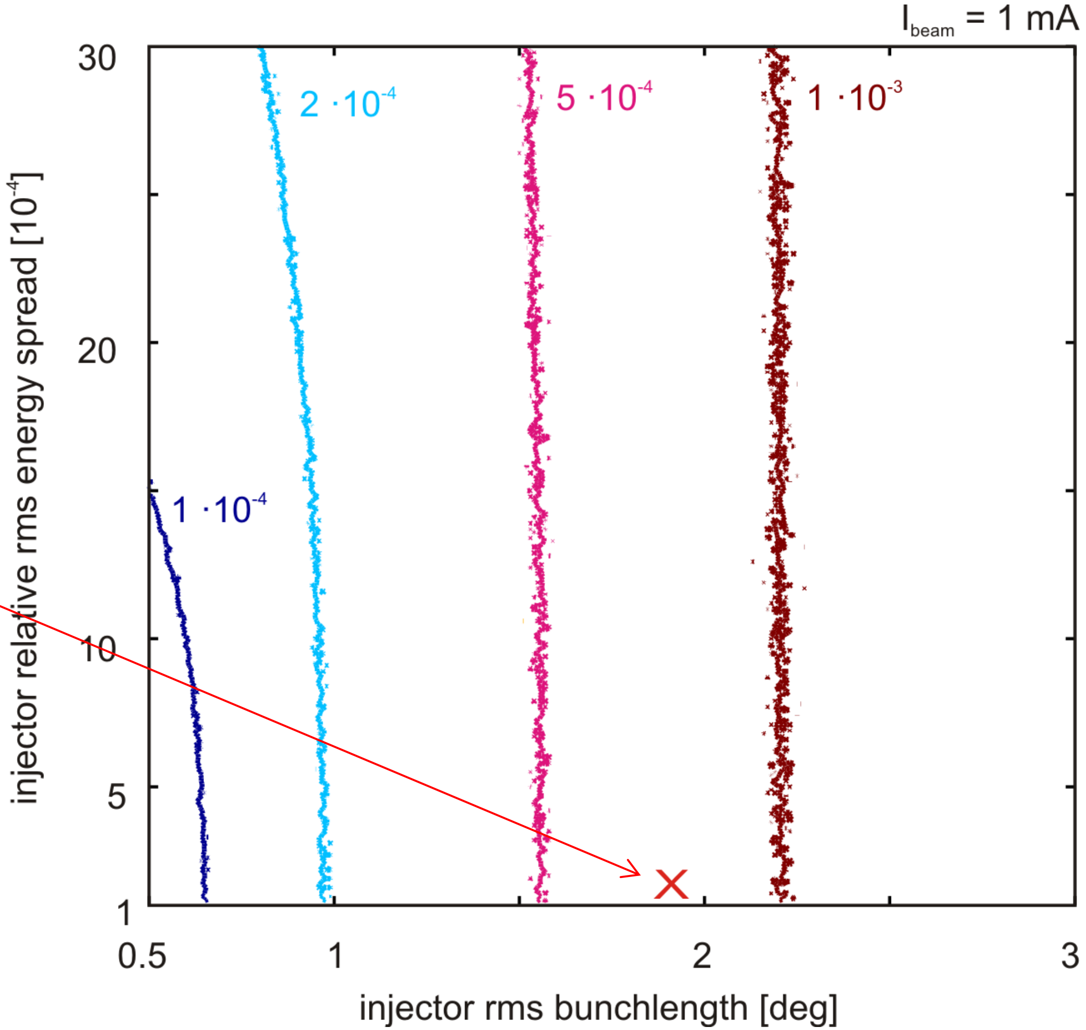
→ 75 keV @ 105 MeV



Injector properties affecting 4-pass isochronous ERL mode:

→ shorter bunches at higher energy spread can improve energy spread at experiment

→ MAMBO is optimized for best energy spread so far

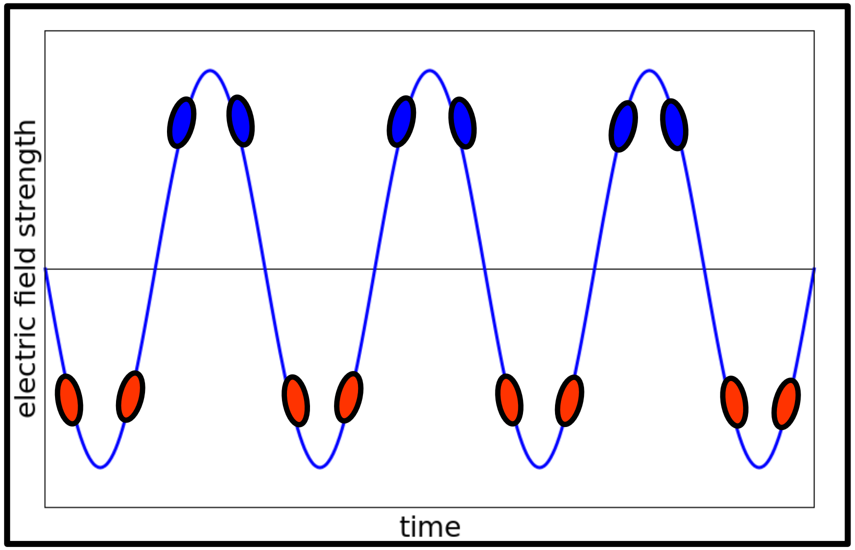


# MESA: non-iso ERL Operation



Maybe a different non-isochronous scheme in ERL operation possible?

- Use the double sided design of MESA
- First two passes acceleration on edge
- Use $r_{56}$ for a half turn in phase space
- Second two passes acceleration on **opposite** edge
- Use $r_{56}$ for a half turn in phase space (other direction)
- end up with better energy spread
- Deceleration vice-versa




$\Delta E_{rms}/E = 2.68 \cdot 10^{-4}$ (28.8 keV @ 105 MeV)

further optimization maybe possible by better matching to injector beam

# MESA: Energy variation 50-100 MeV

Going down from 105→50 Zero order:
- Varying iMAMBO probably very tedious and detrimental since Imax~pin
-Achieve 50 MeV+x by reducing energy gain per turn
(27,5, 50MeV)
- First order: But defelction angles scale liek energies 105/55=1,0909
 is not equal 50/27,5 =1,81

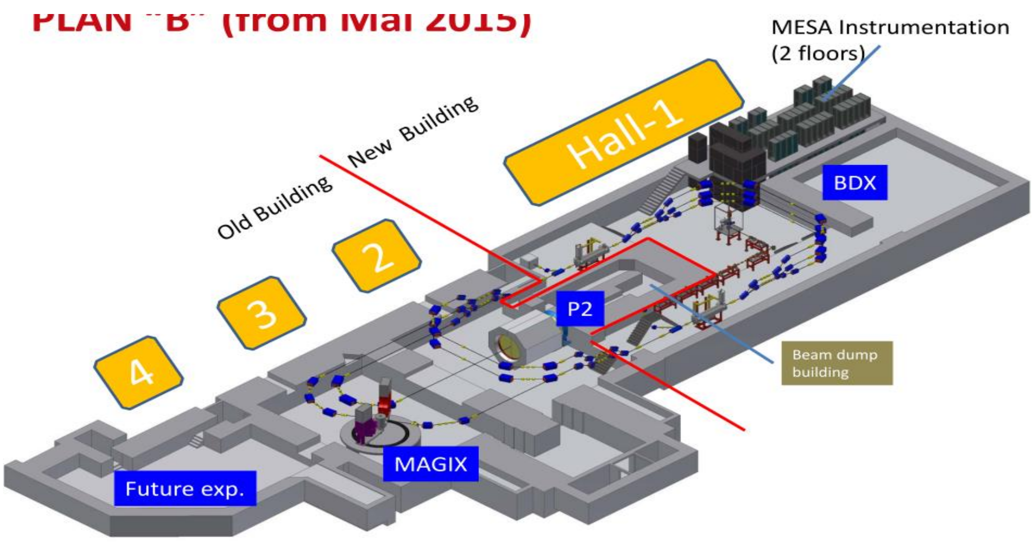
$\Delta E_{rms}/E = 2.68 \cdot 10^{-4}$ (28.8 keV @ 105 MeV)

# MESA Energy variation

Going down from 105→75 MeV Zero order:
- Varying MAMBO energy probably very tedious and detrimental since Imax~pin

-Achieve 75 MeV+x by reducing energy gain per turn
(35+5, 70+5 MeV)

- First order: But defelction angles scale liek energies 105/55=1,0909
 is not equal 75/40 =1,875 → can probably be corrected , since more space available inspreaders



# MESA: timelines

Kryomodules: delivery summer 17

→ Tested and in store summer 2018?

Kryoplant: Modifikations & purchase SAC& transfer lines (?)

,in 2018/19

MAMBO: (structures& transmitters) Order not before end 2017 , delivery until mid 2019,

→ Tested and in store beginning 2020 ?

→ Magnets: Order summer 2017, delivery end 2018

→ Vacuum, controls, etc...also feasible before 2020 (money?)

BUILDING: so far on time, finalization foreseen October 2020.

Earlier access, depends on LBB and architects.

2019-2020: Intense planning, resource allocation required → No realistic installation/commisioning schedule so far.

$\Delta E_{rms}/E = 2.68 \cdot 10^{-4}$ (28.8 keV @ 105 MeV)

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# Summary & Outlook

- a non-isochronous working point can improve the energy spread and the stability of a recirculated beam significantly, even when only few turns of recirculation are used
- a proper energy spread and a phase stabilization of the injector beam is important. Short bunchlength after injector seems to be more important than heading for best energy spread
- at MESA a non-isochronous recirculation scheme is planned for the external beam mode but further simulations still have to be done to find the optimum set of parameters
- for ERL mode at MESA further investigations are needed in order to figure out the possibility of such a system

# Thank you for your attention!

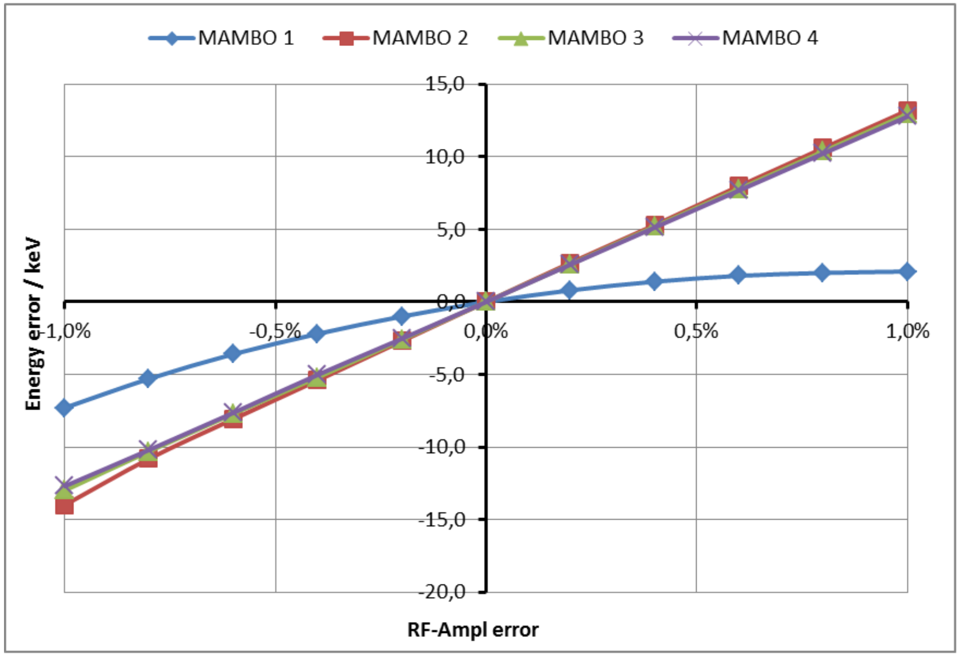
# Supplement slides

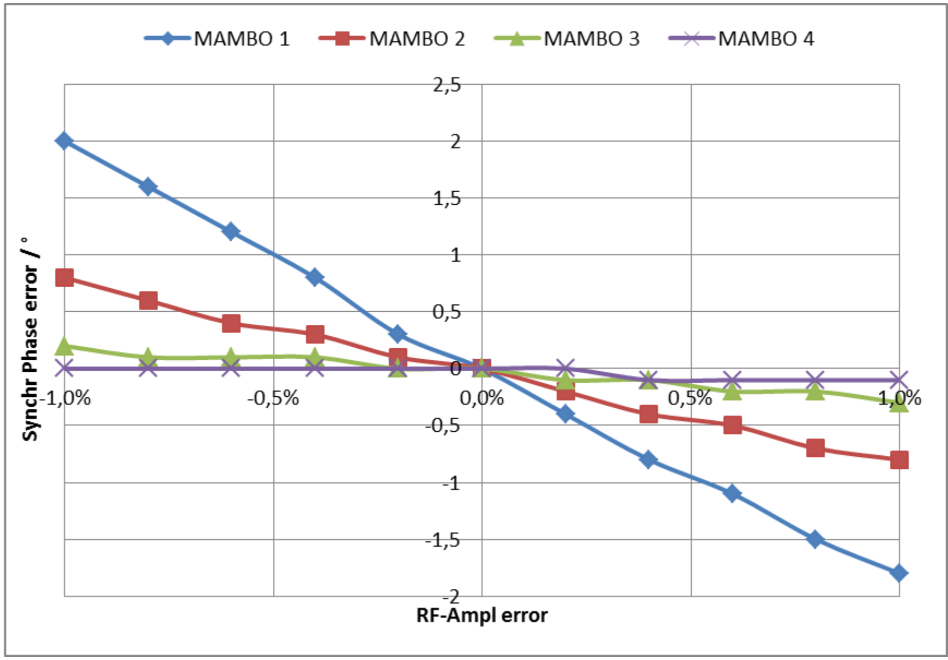
# MAMBO stability

In MAMBO rf jitters can have effects on:

- Bunchlength
- Extraction phase
- Energy spread
- Mean energy

Here: calculations for 150 µA by Robert Heine



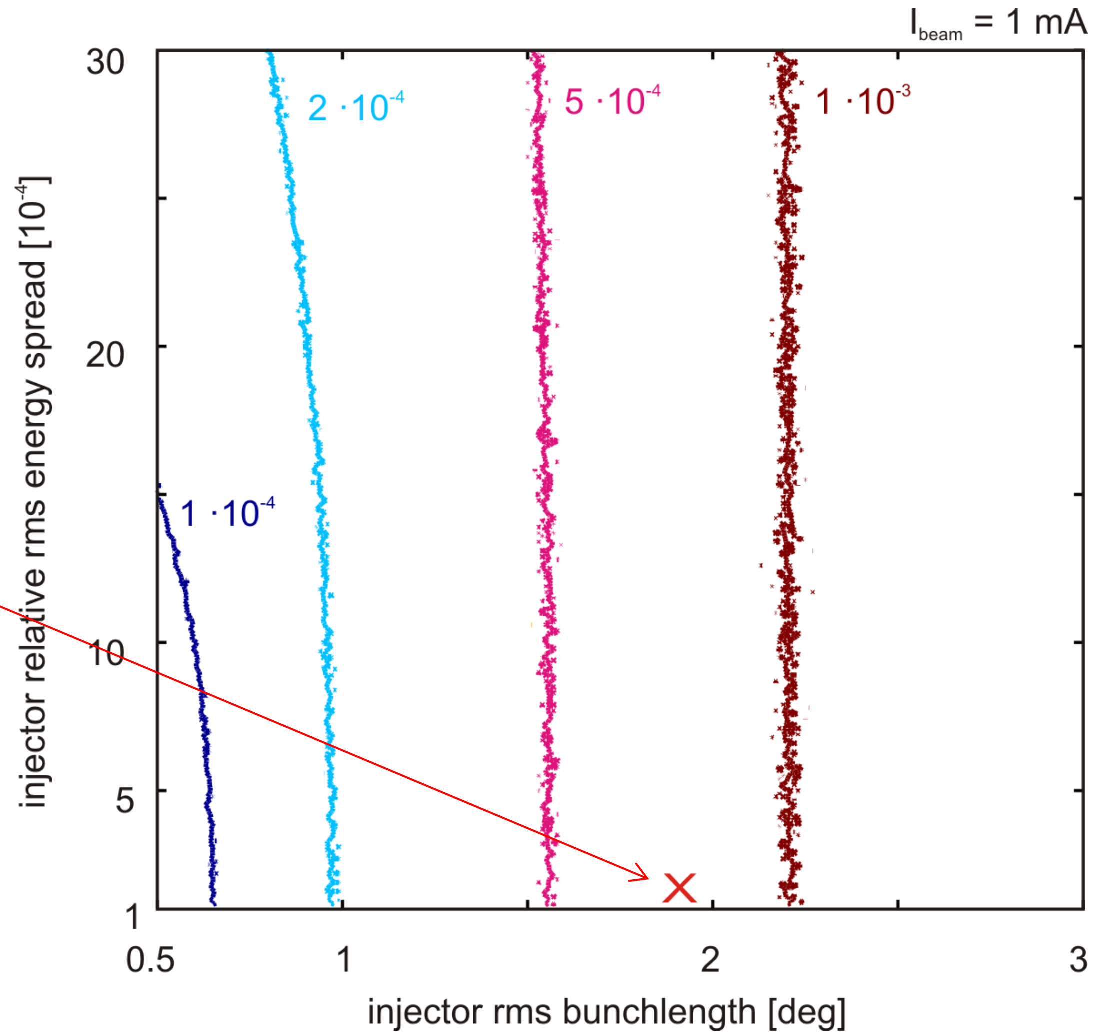

→ Investigate how EB and ERL mode are affected

# MAMBO : ERL Operation

Injector properties affecting 4-pass isochronous ERL mode:

→ shorter bunches at
higher energy spread
can improve energy spread
at experiment

→ MAMBO is optimized
for best energy spread so far



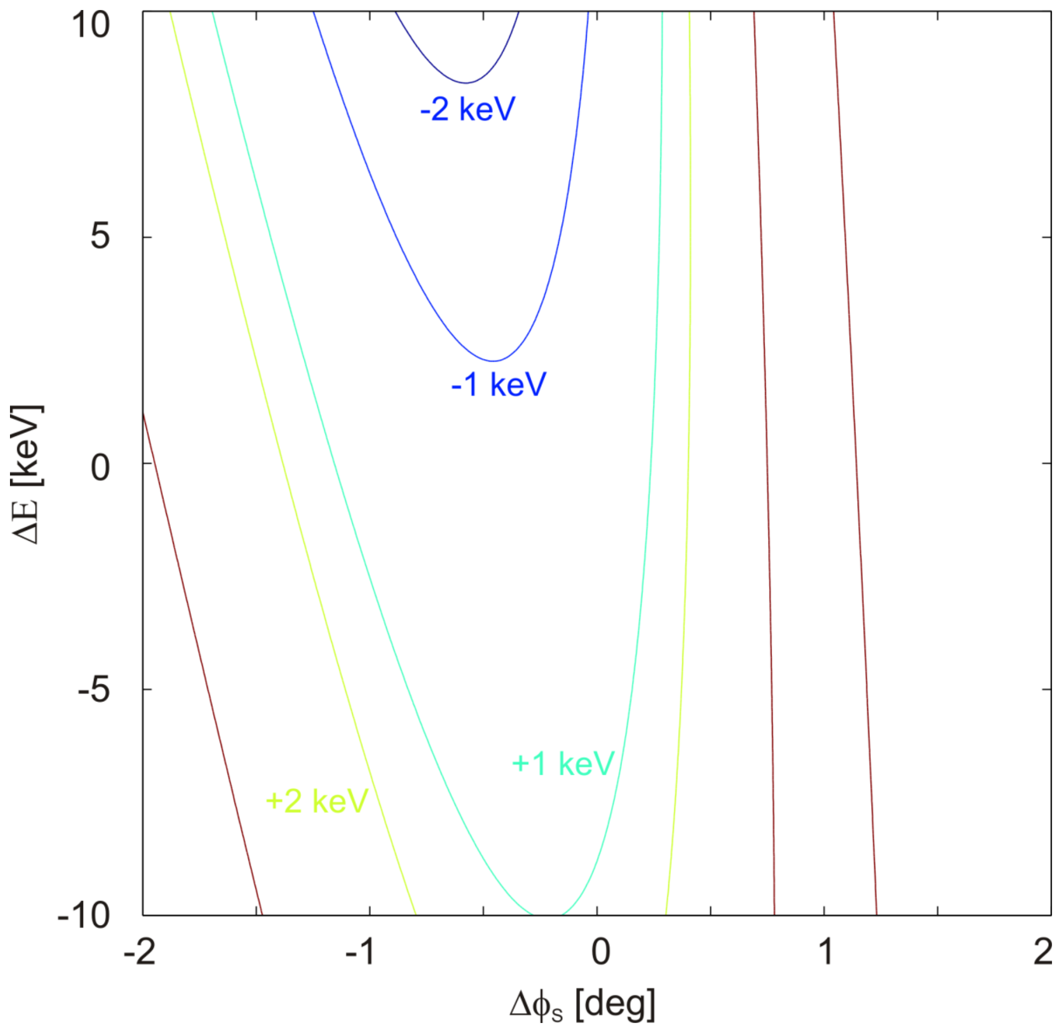
# MAMBO: EB operation

Injector properties affecting 6-pass non-isochronous ERL mode:

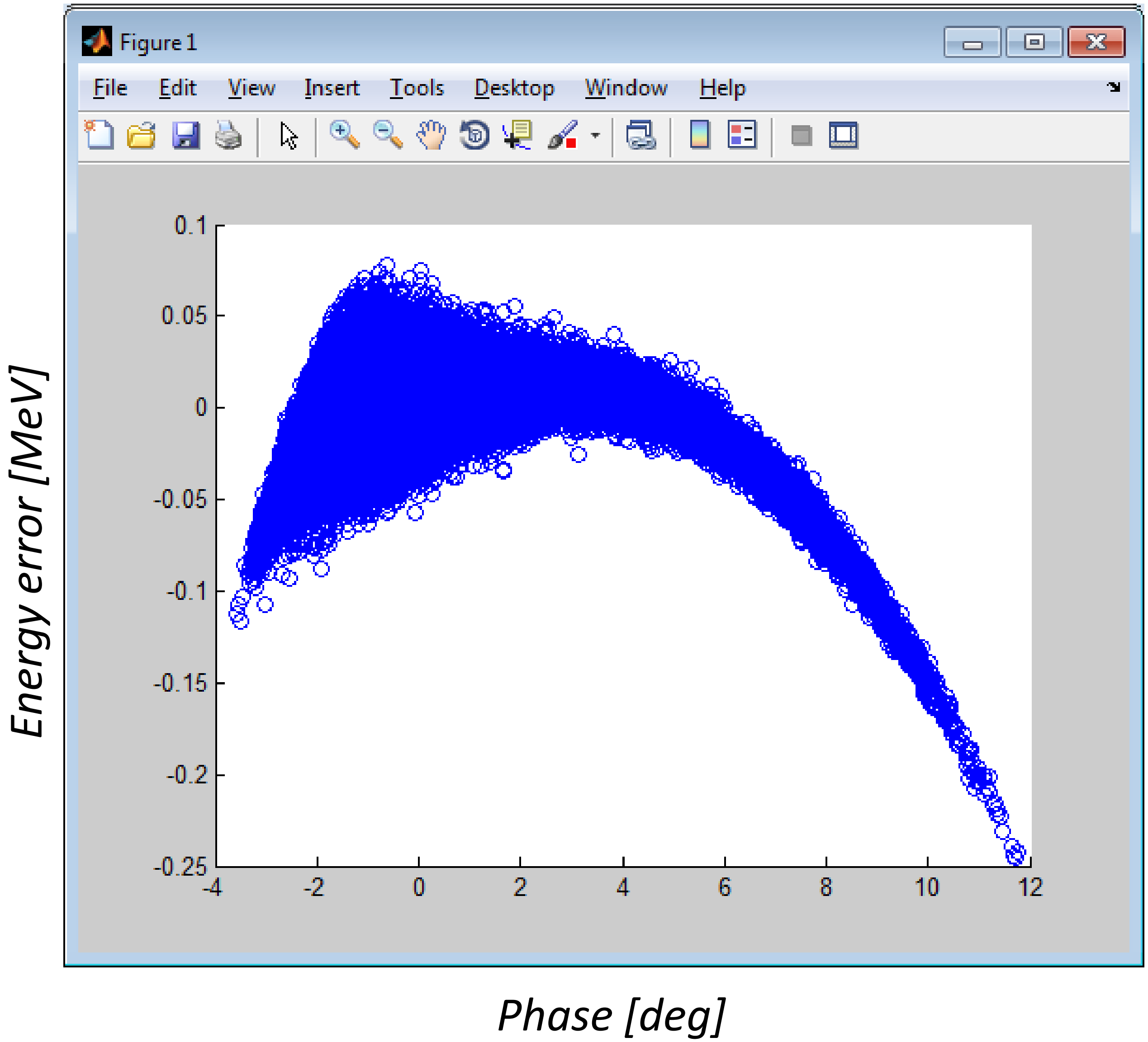
→ In EB operation energy spread stays well below 10-4

→ Mean energy can vary with respect to MAMBO properties

→ Numbers need to be cross-checked with P2 demands

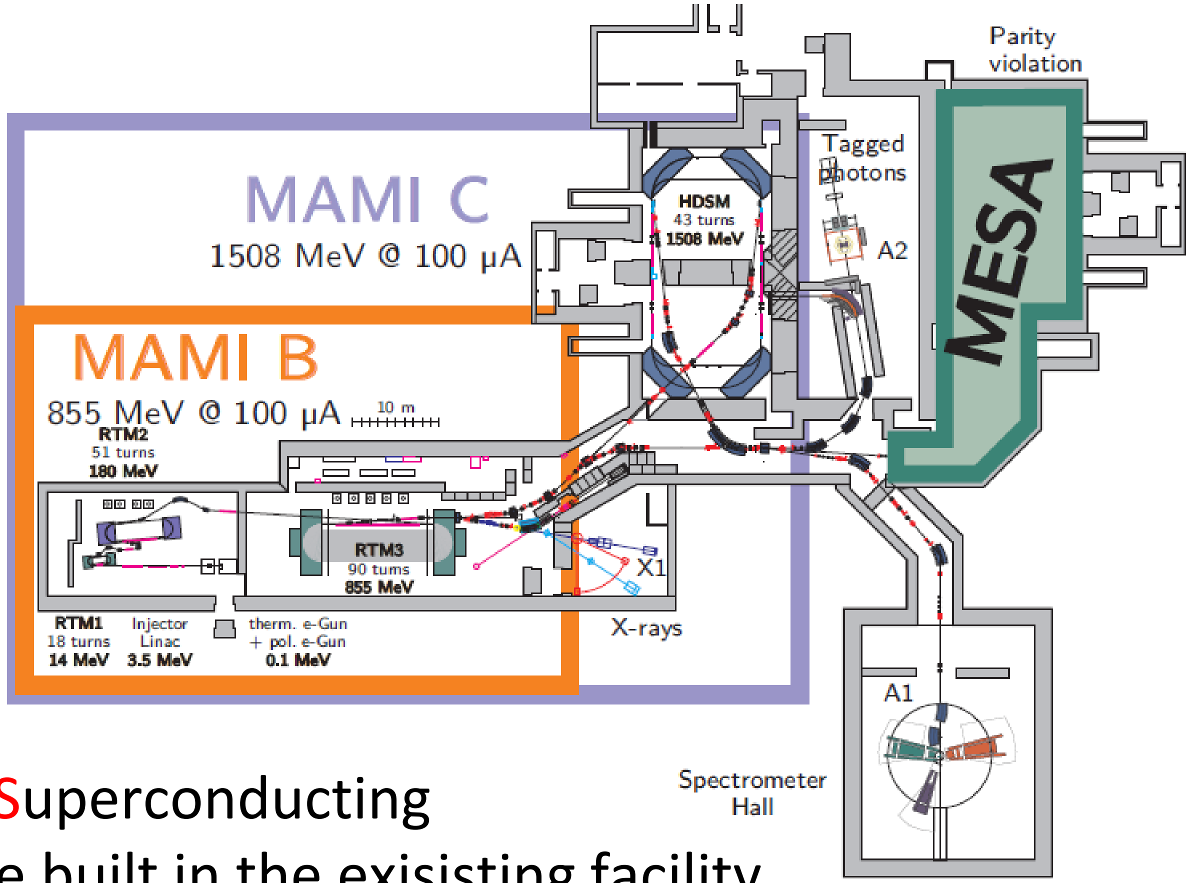


# MESA: non-iso ERL Operation



- MAMI is operating since >25 years at KPH

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

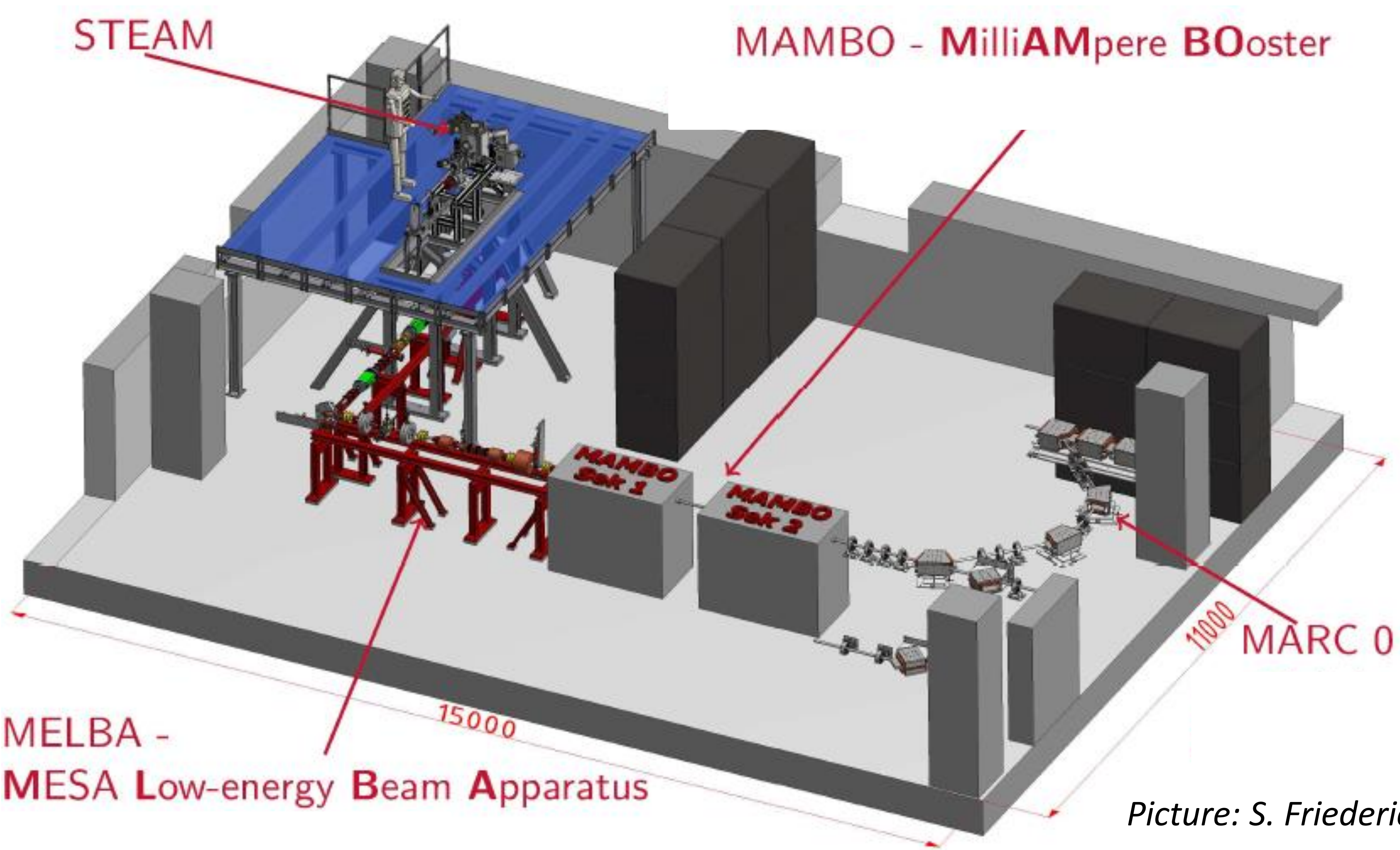



Mainz Energy Recovery Superconducting Accelerator (MESA) to be built in the exisiting facility

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

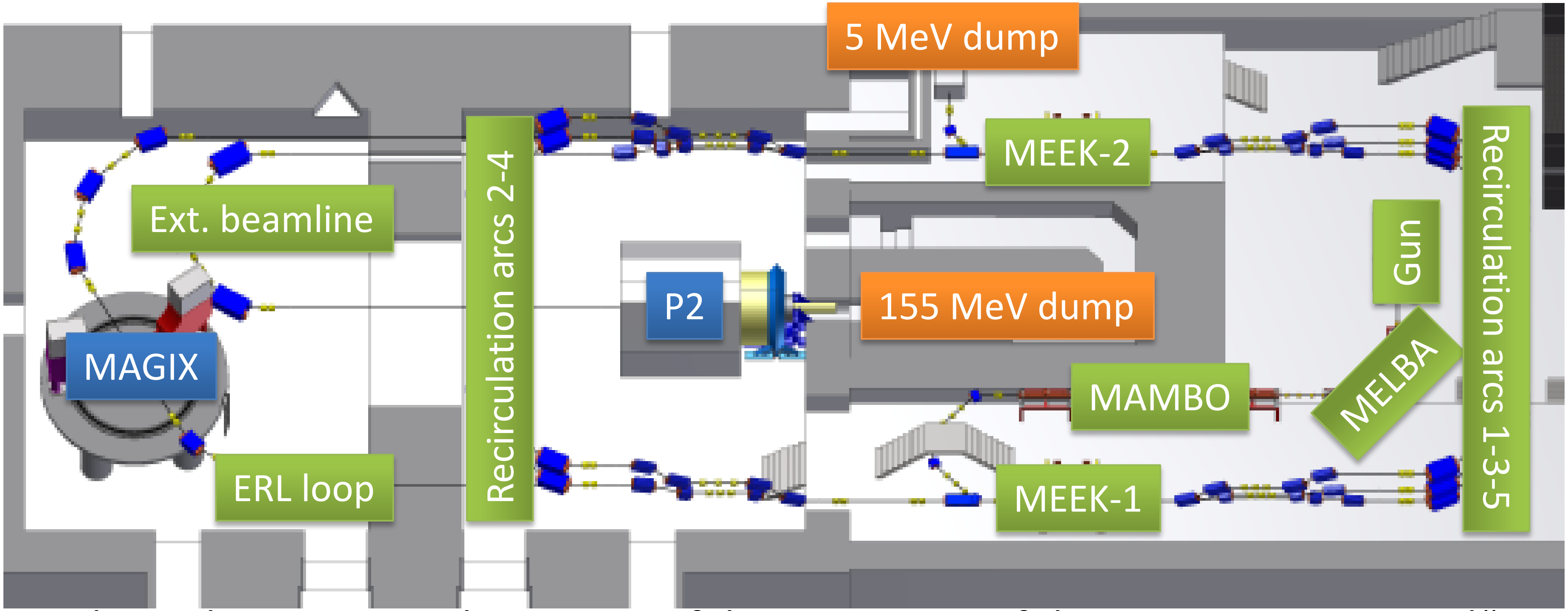
# MESA Injector Test Setup






*Picture: S. Friederich*

# MESA Accelerator Layout –optimization:




Other subsystems until 2020– careful optimization of the more „conventional“ syste

- r.f. system : Semiconductor amplifiers (of strategic importance but expensive!)
- Cryoplant (discussion with vendor for extension completed, order in ~2018)
- Recirculations arcs and experimental beamlines (magnet offers exist, expensive!)
- Cost reduction measures needed & started , e.g. Großgeräteantrag submitted (mainly Rf), in house fabrication of quadrupoles, iron pieces for deflection )

# Summary

- Construction of the extended MESA hall will delay the construction of the accelerator to at least **2020**
- But many accelerator parts have been ordered or even built already
- We will test the injector up to 2.5 MeV in a test setup in Hall 3 (old part of the buiding). Construction started **mid 2016** tests beamtimes can be run till civil construction starts
- Cryomodule tests will be performed at HIM **in 2017**
- Parts of experimental setups, detectors etc. can be tested at MAMI
- 4 PhD students funded by the new Research Training Group GRK 2128 “AccelencE” will contribute to the project from April 2016 on

# Building effects on MESA Accelerator Layout

- *The new layout provides clear advantages:*
  - The existing beam dump can be more effectively used for P2 experiment
  - In addition, it allows a new experiment: BDX (search for dark matter particles)
  - One hall (No. 4) for present stays clear,
    allowing extensions (additional experiments or instrumentation) in future
- *Disadvantages of the new layout:*
  - No accelerator setup till civil construction of the new building is finished
  - Already existing start-to-end beam dynamics calculations need to be redone
  - Nevertheless the new layout can strongly rely on the old one. Important parts like vertical spreaders and low energy beam transport will stay very close to the old layout.

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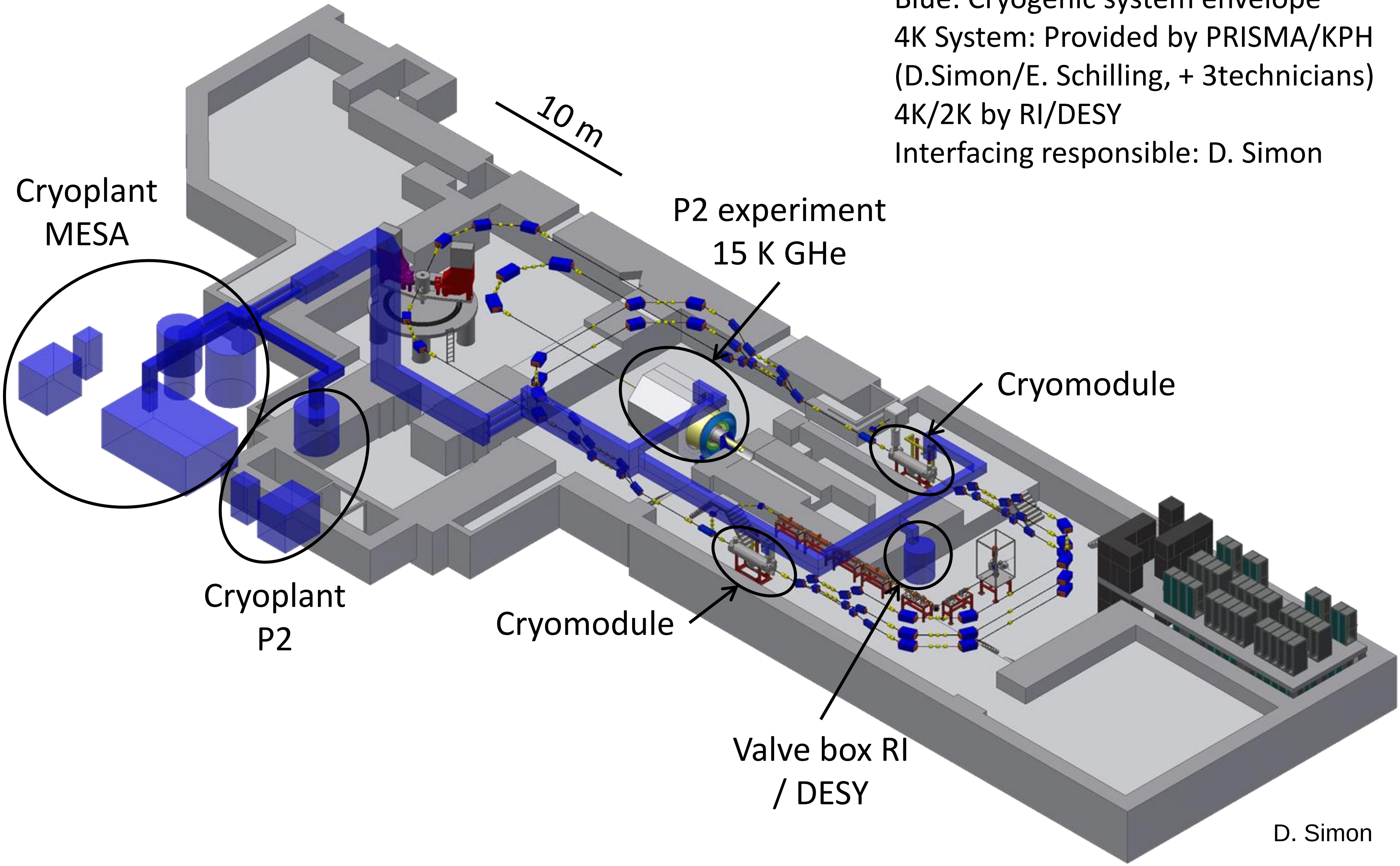
# MESA/MEEK Cryogenic system

Blue: Cryogenic system envelope
4K System: Provided by PRISMA/KPH
(D.Simon/E. Schilling, + 3technicians)
4K/2K by RI/DESY
Interfacing responsible: D. Simon




D. Simon

# Simplified P&ID for MESA