Beam dynamics layout of the MESA ERL

Florian Hug for the MESA group

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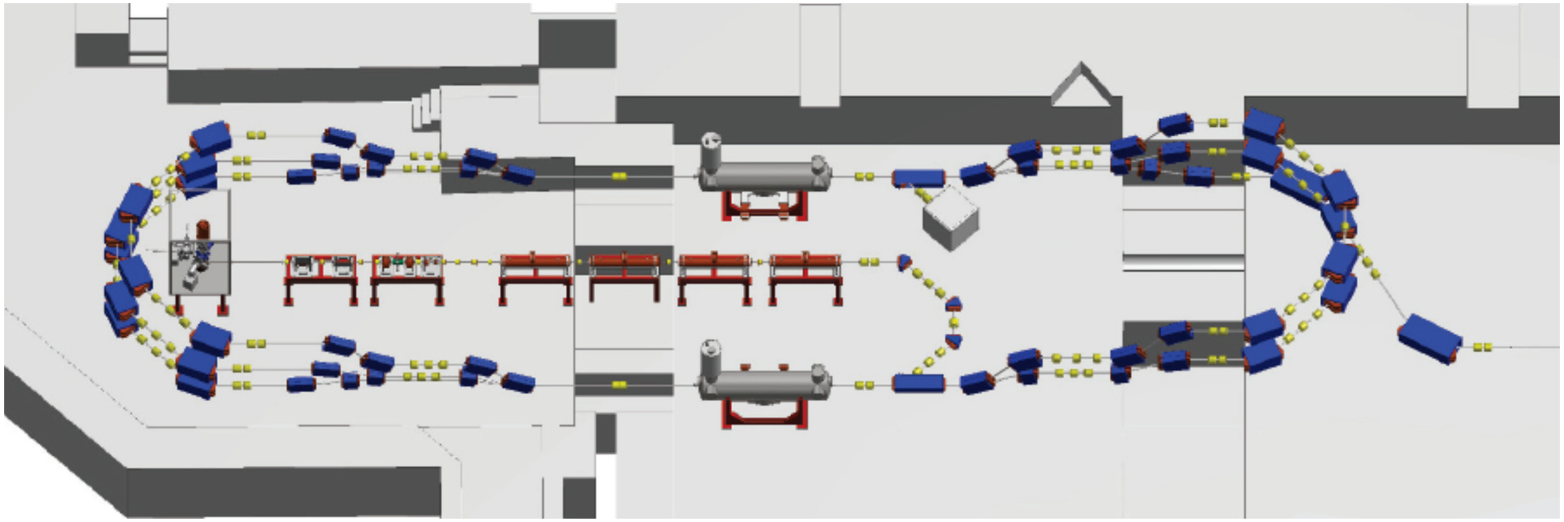
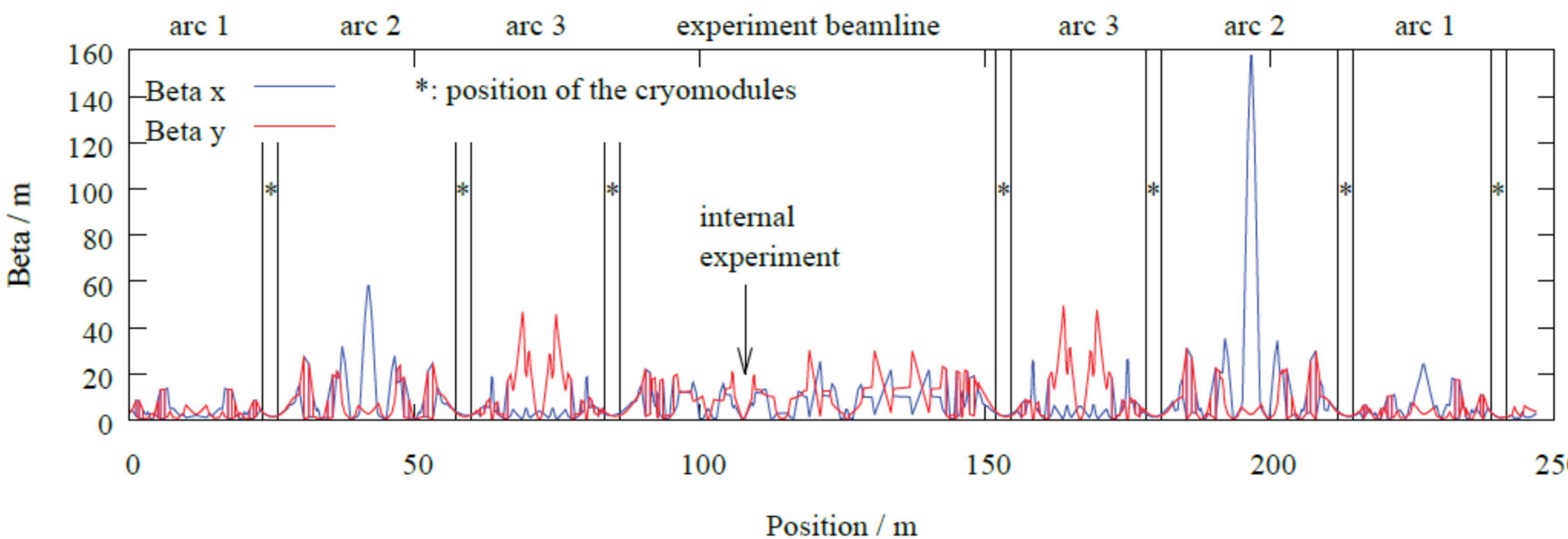
The European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871

MESA layout in 2015

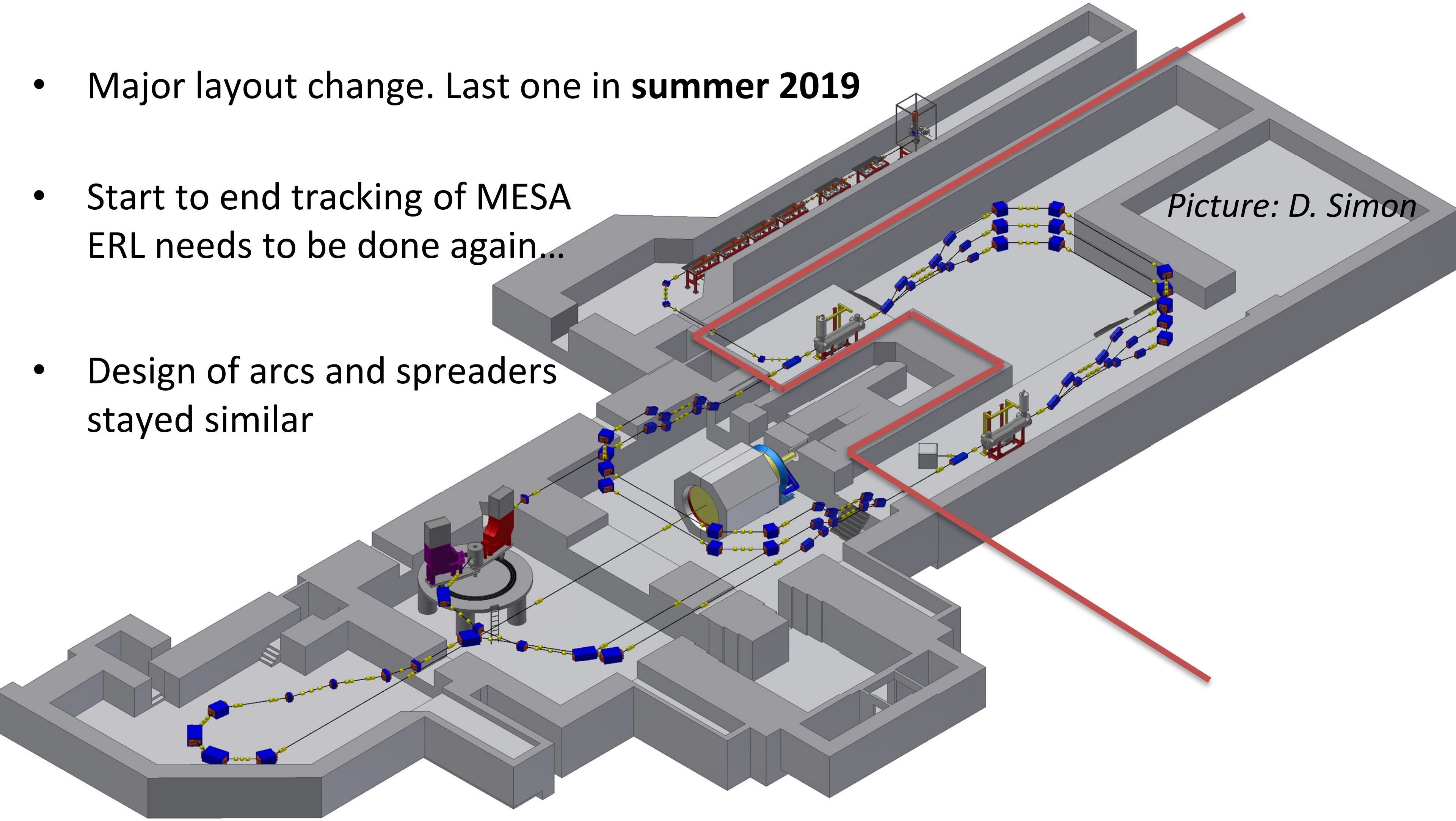




D. Simon et al., Proc. IPAC '15 (2015) 220.

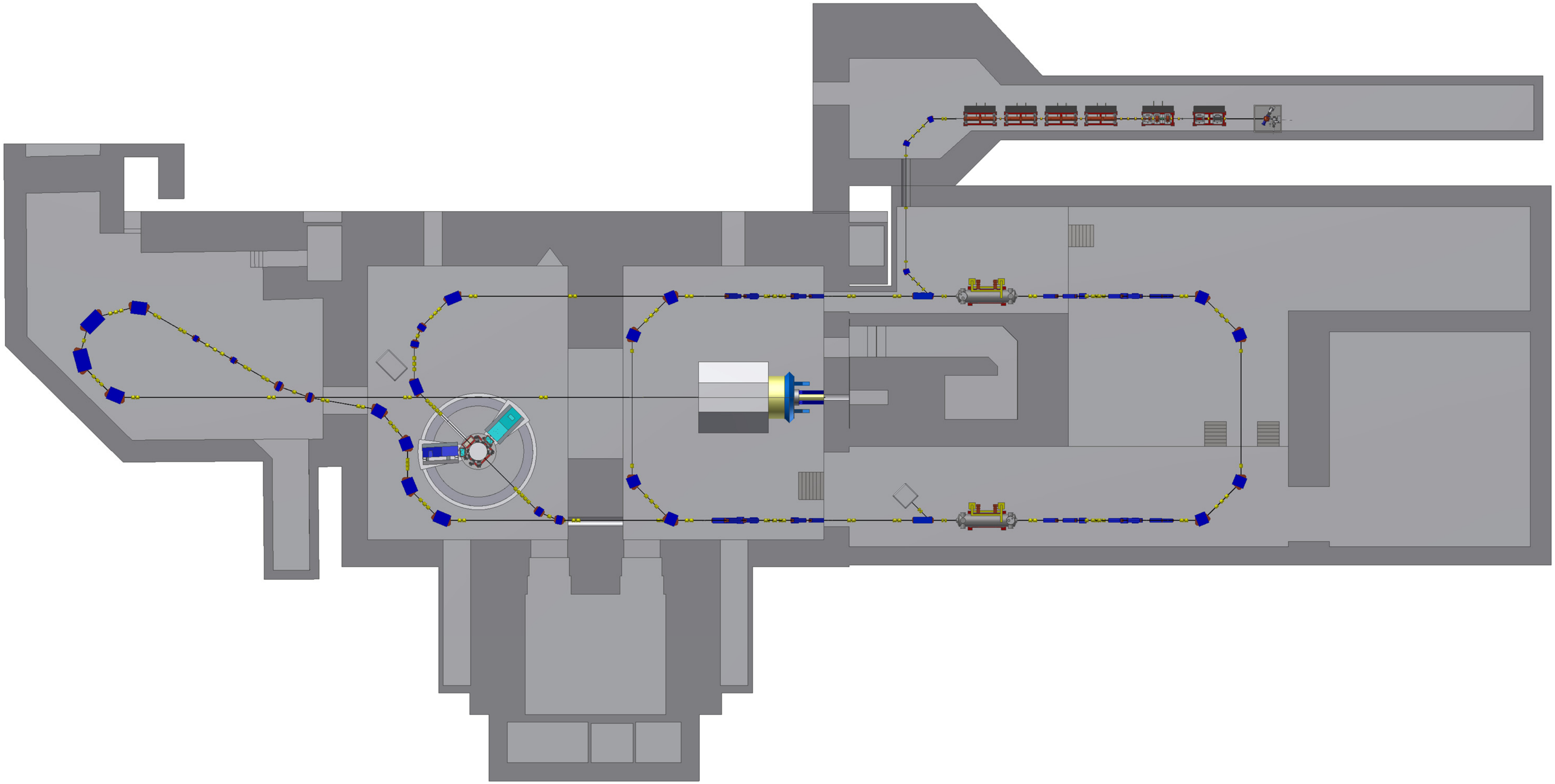
MESA layout in 2019

- Major layout change. Last one in **summer 2019**
- Start to end tracking of MESA ERL needs to be done again…
- Design of arcs and spreaders stayed similar

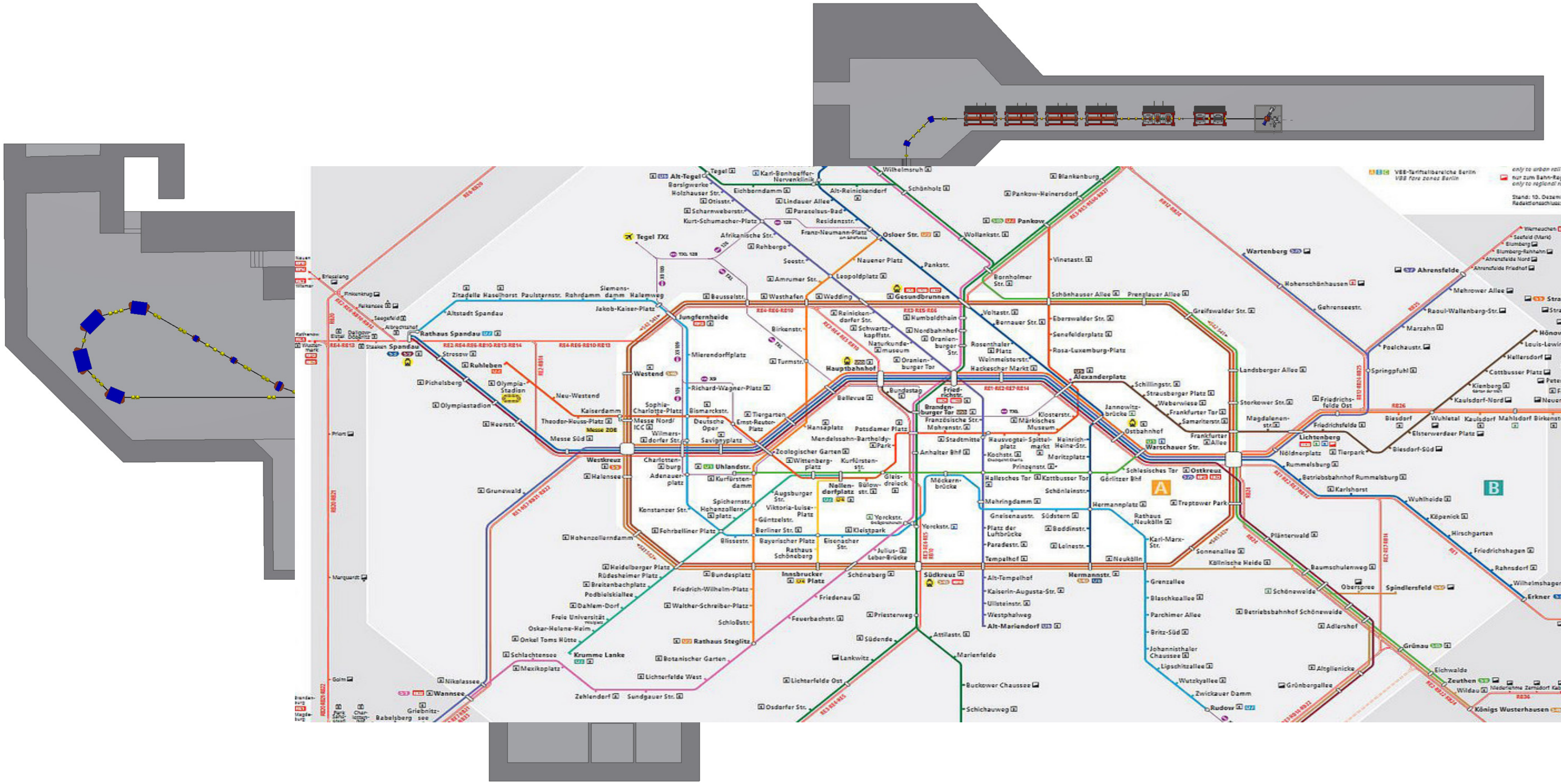


Picture: D. Simon

MESA layout in 2019, looks familiar…



MESA layout in 2019, looks familiar…



Outline

MESA recirculation optics

Acceleration in isochronous and non-isochronous operation

Injection arc for MESA

Summary and Outlook

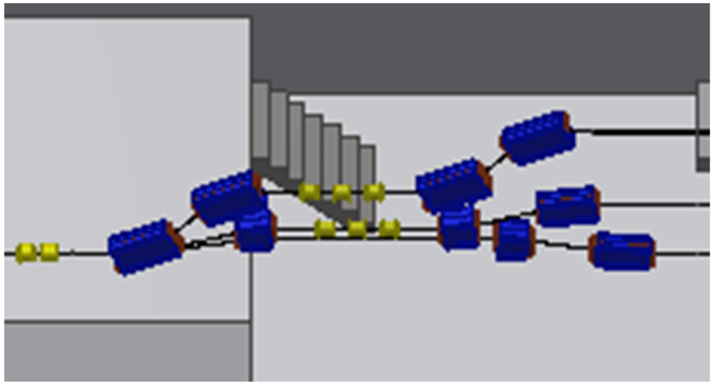
Challenges on recirculation lattice layout

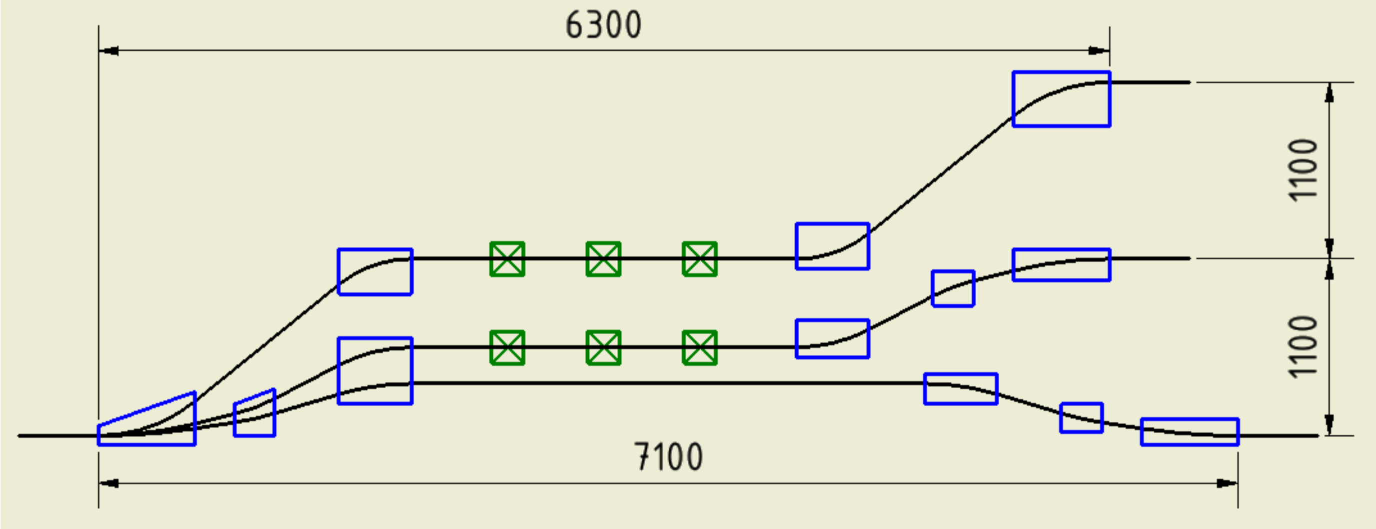
- Different operation modes require different settings of longitudinal dispersion r_{56}
  → flexibility in r_{56} without increasing transverse dispersion
- Experiments demand different beam energies, so MESA will not run on a fixed setting
  → path length adjustment needed
  → optimization of different settings during operation
- Vertical beam separation of last turn has a different focussing plane than first two turns
  → small β-functions in cryomodules in ERL mode possible
  (for reducing transverse BBU)
  → in EB mode less focussing on straight sections
- High demands on energy spread and beam stability by experiments

- Lattice is modelled with:
  - in house matrix optics program
  - MAD X
  - PARMELA for space charge and pseudo damping due to main linac modules
  - MATLAB tracking code for non-isochronous working points
  - BI code (Cornell) for BBU investigations
  - …

Vertical spreaders

- Vertical spreaders separate/combine up to three beams of different energies (here: combiner before 2nd cryomodule)
- Vertical dispersion needs to be equal zero after chicane
- Constraints on length a liitle relaxed in the new setting



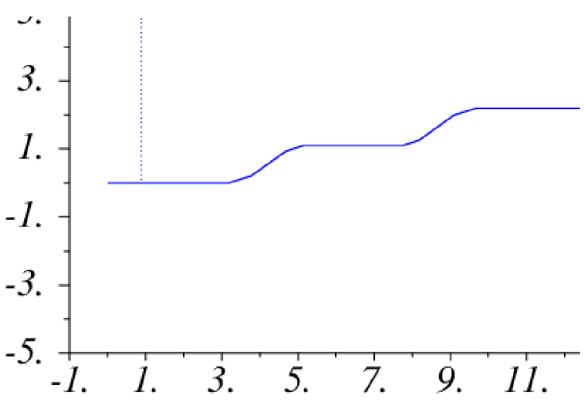


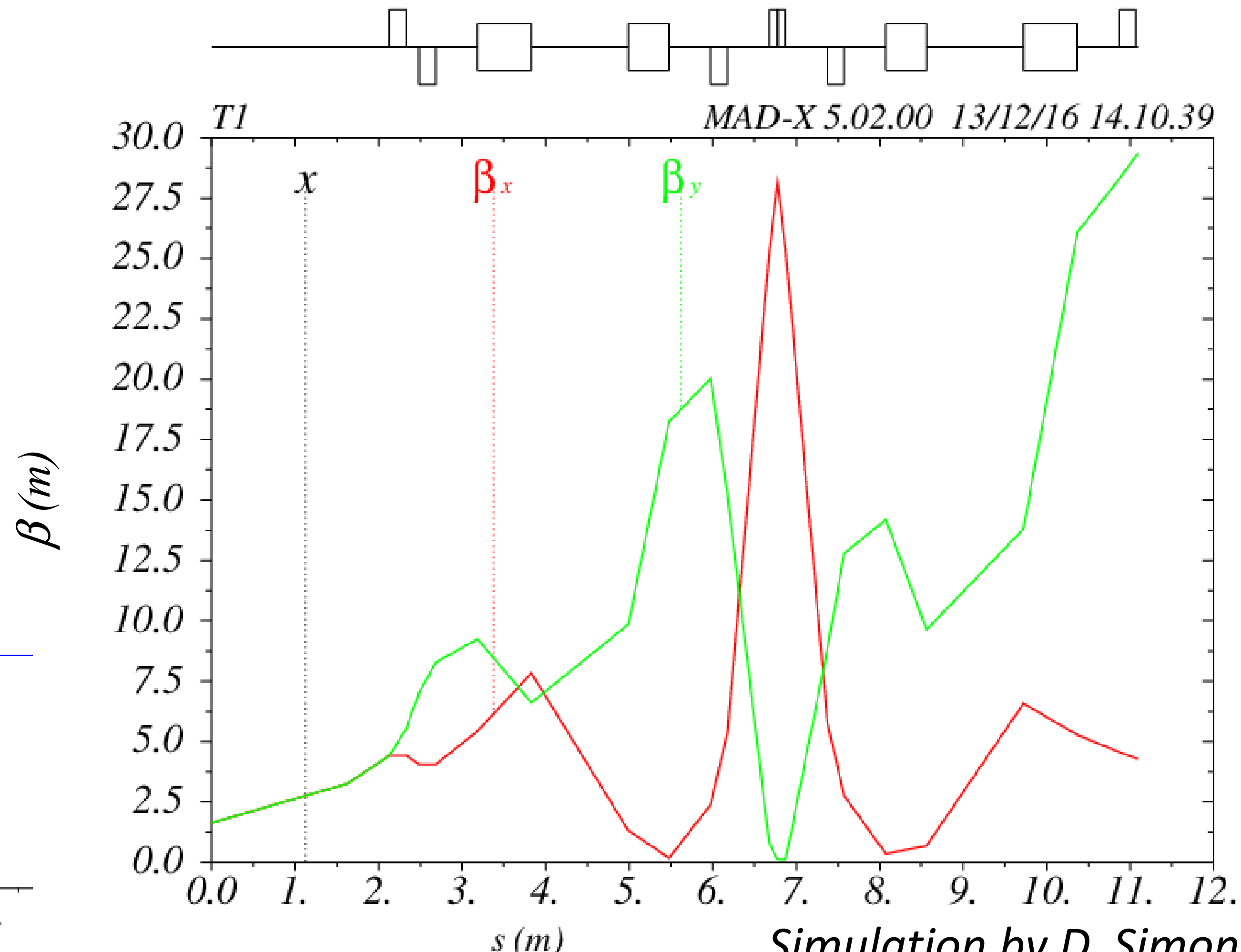
Picture: D. Simon

Spreader optics for ERL operation with low β-functions on straight section

Here: 30 MeV beam

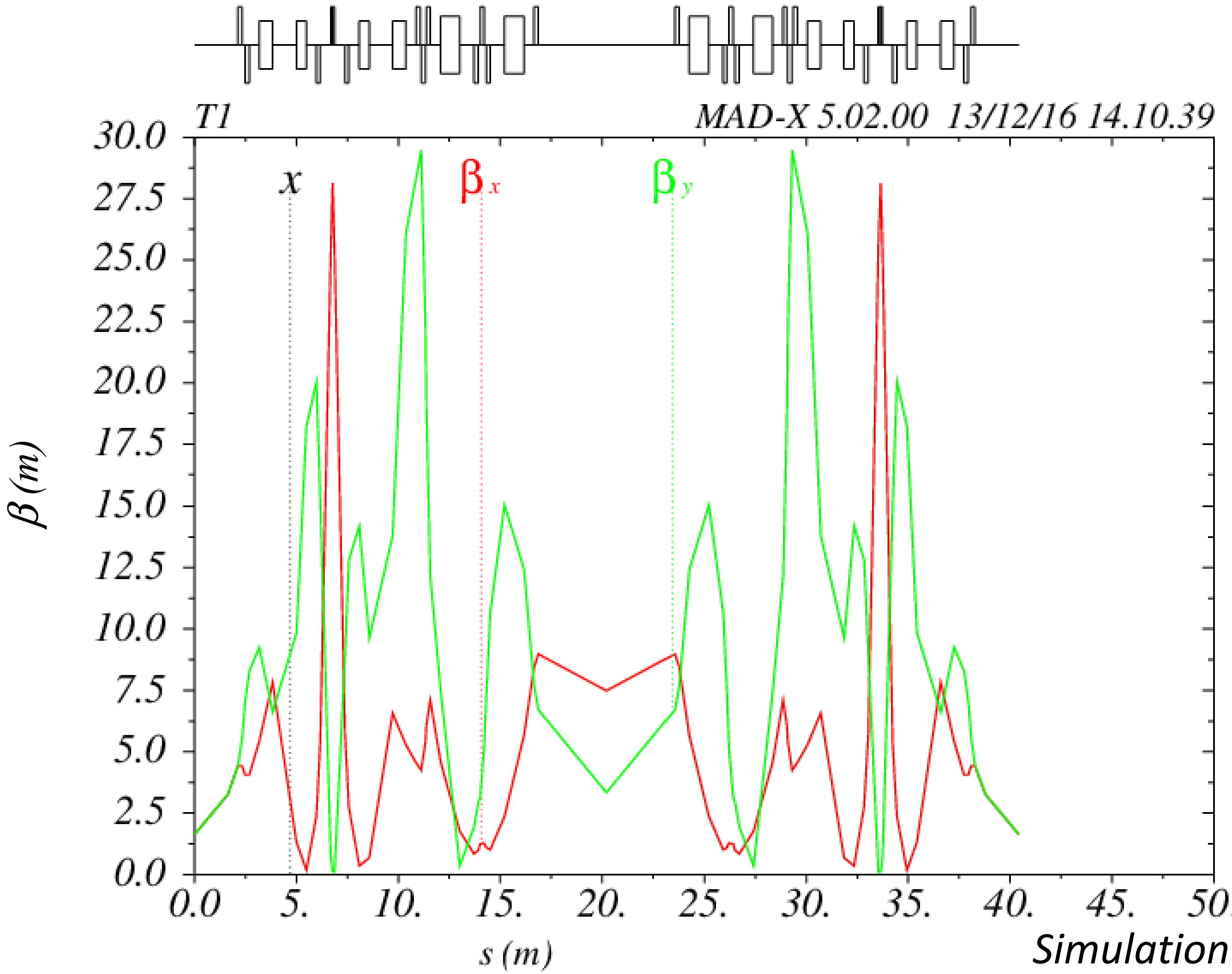
Vertical profile:





Simulation by D. Simon

Complete 1st recirculation arc lattice



Simulation by D. Simon

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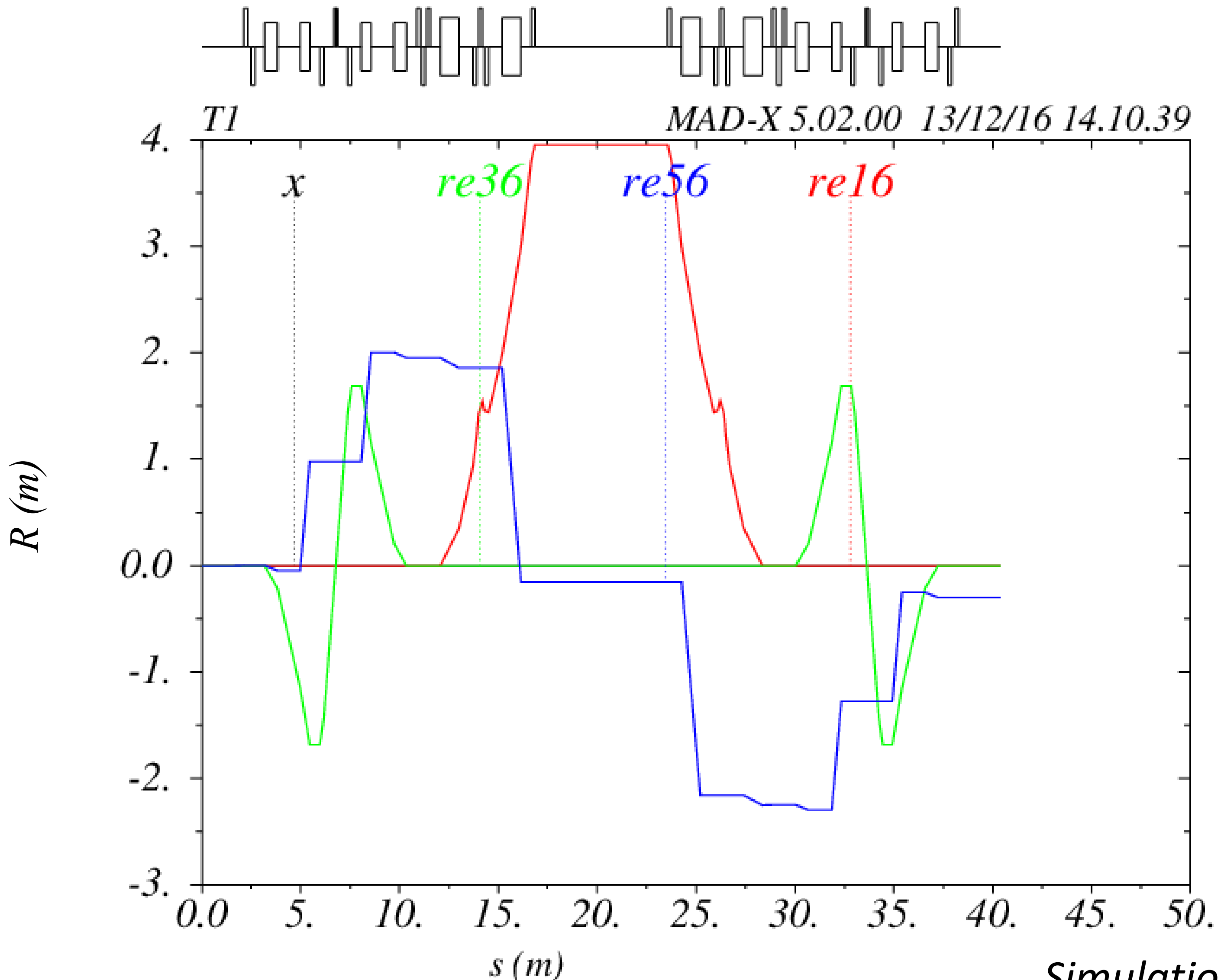
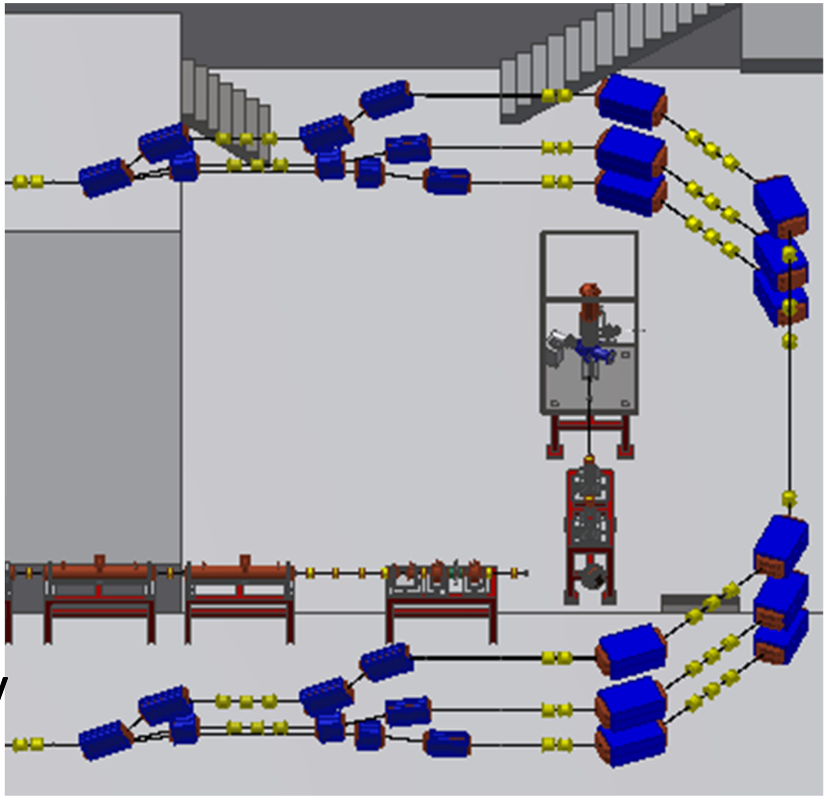


Simulation by D. Simon

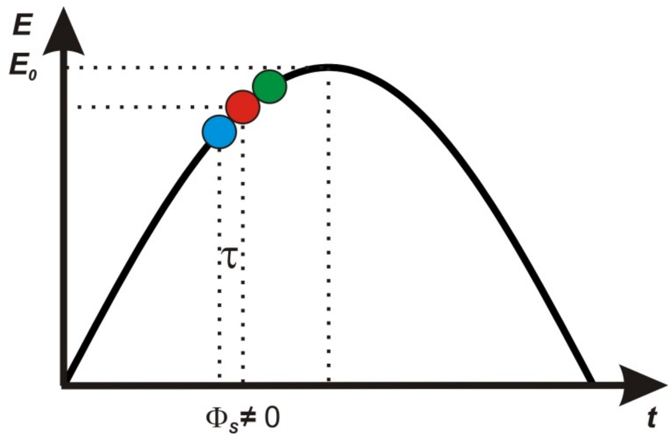
Recirculation arcs optics

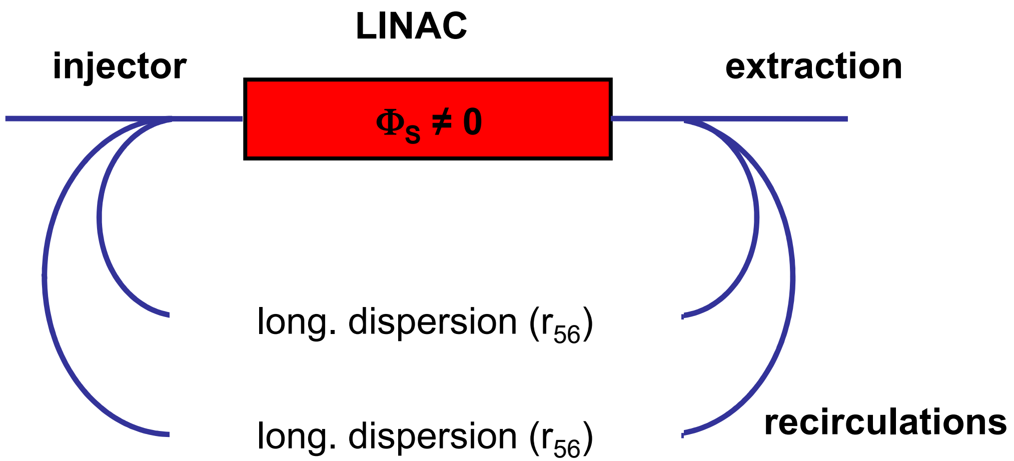
- Optics symmetric with respect to the middle of the long straight section. α=0 in the middle of the return arc
- Return arc is free of transverse and vertical dispersion
- Longitudinal dispersion r_{56} can be adjusted by changing the gradients of the middle quadrupoles in the 45° sections
- Total length 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)



Non-isochronous recirculation scheme

- Common operation mode for microtrons and synchrotrons
- Acceleration off crest of RF field
- Different time of flight for particles having different energies



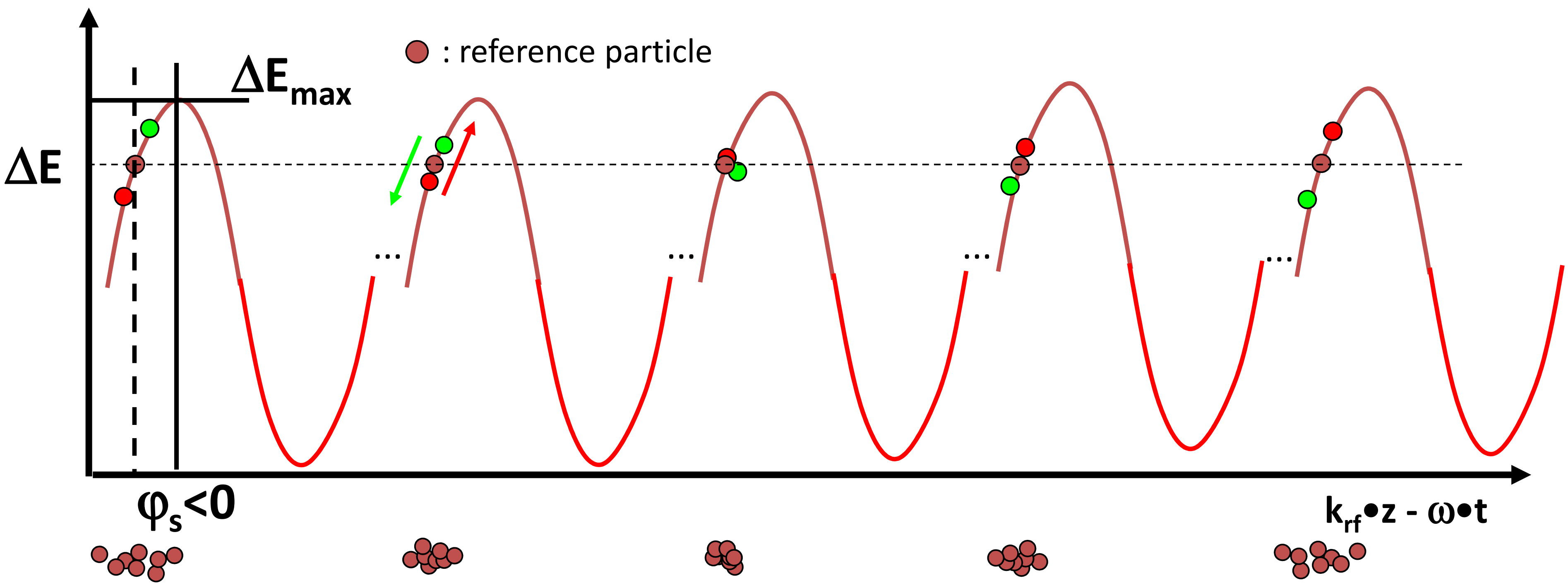


→ Particles perform synchrotron oscillations in longitudinal phase space

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

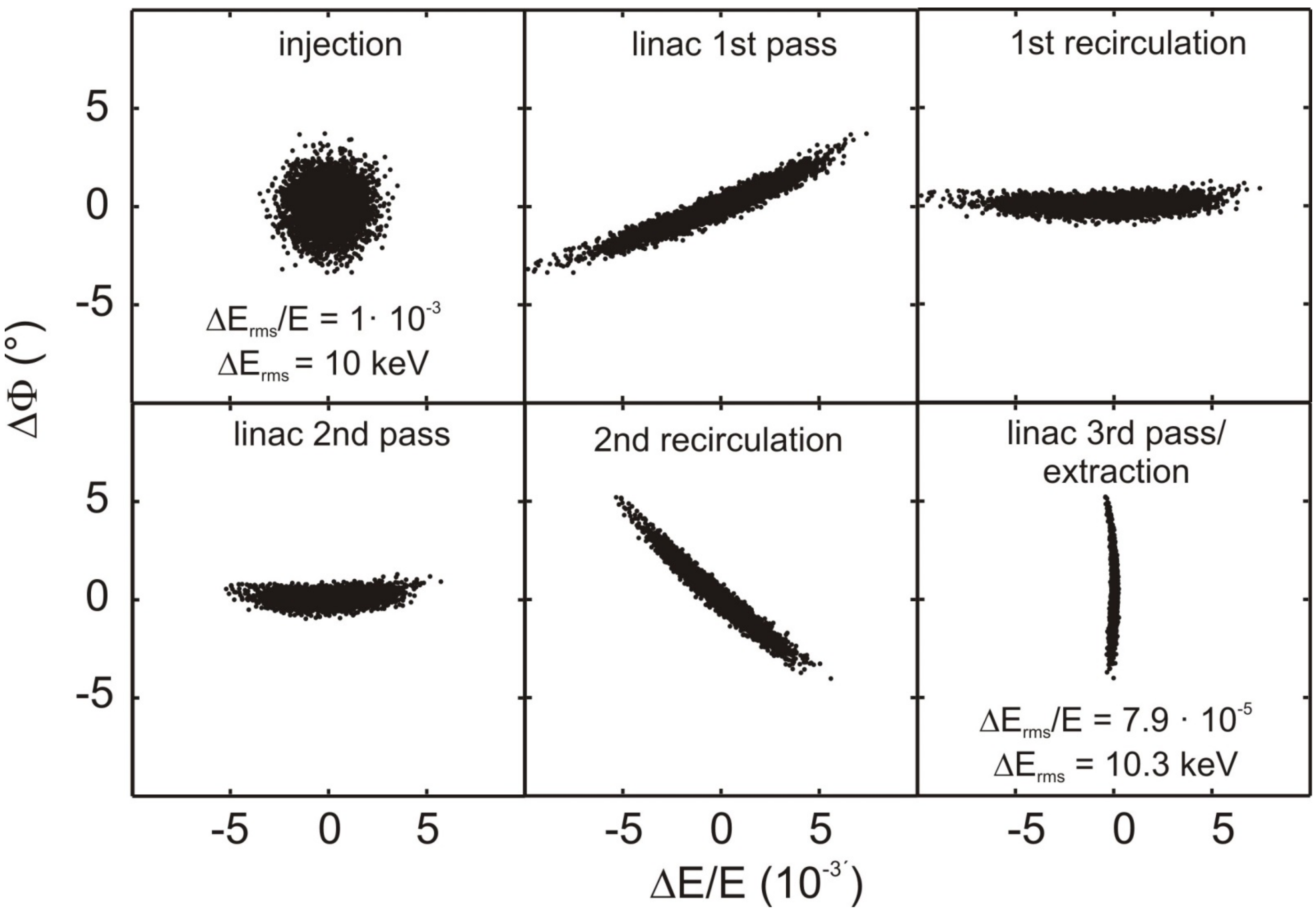
→ complete compensation of any RF phase- and amplitude jitters possible

Non-isochronous recirculation scheme



(Jankowiak/Aulenbacher, lecture on accelerator physics)

Example: non-isochronous working point of 3-pass S-DALINAC



Compare with assumption (no additional errors from linac):

Energy spread at

Injection (10 MeV):

$\Delta E_{I;rms}/E_I = 1 \cdot 10^{-3}$

$\Delta E_{I;rms} \quad = 10$ keV

After acceleration to full energy (130 MeV):

$\Delta E_{rms}/E \quad =$

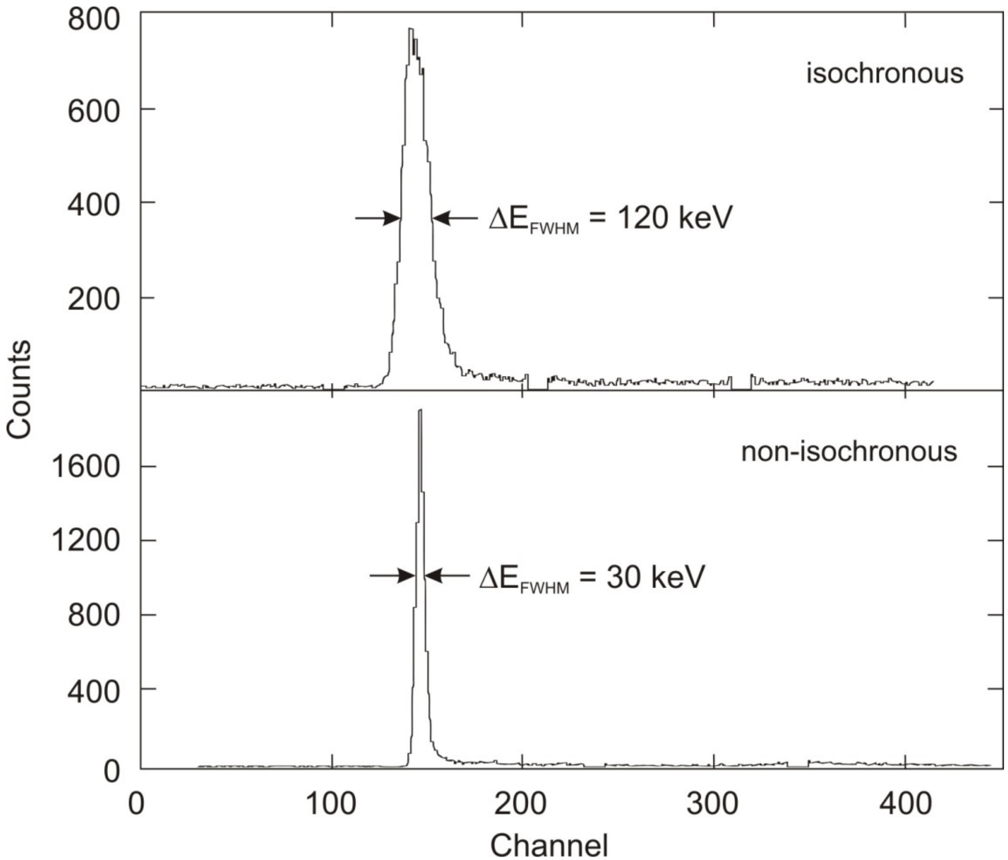
10 keV/130 MeV =

$7.7 \cdot 10^{-5}$

(F. Hug, PhD thesis, TU Darmstadt 2013)

Resulting energy spread

Elastic scattering (e,e‘) at ^{197}Au in Lintott-electron-spectrometer



→ ΔE_{FWHM} of elastic line decreased by a factor of 4

→ Energy spread of the beam decreased by a Faktor of 5.4 ($\Delta E_{rms}/E = 1.23 \cdot 10^{-4}$)

→ Highest ever achieved accuracy of a recirculated electron beam at the S-DALINAC at that moment

→ non-isochronous setting

F. Hug et al., Proc. Linac ‘12 (2012) 531.

MESA: External Beam Operation

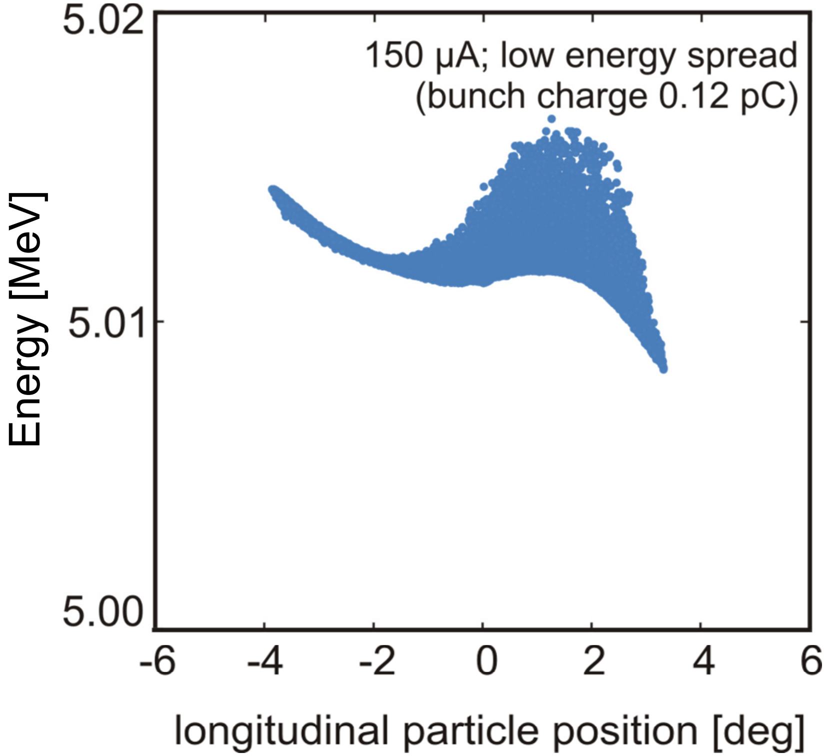
Simulations for a new longitudinal working point

Goal: Find optimal combination of r_{56} and Φ_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 Φ_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 Φ_S



F. Hug and R. Heine, (2017) J. Phys.: Conf. Ser. ***874*** *012012*

MESA: External Beam Operation

Results for 6-pass external beam mode:

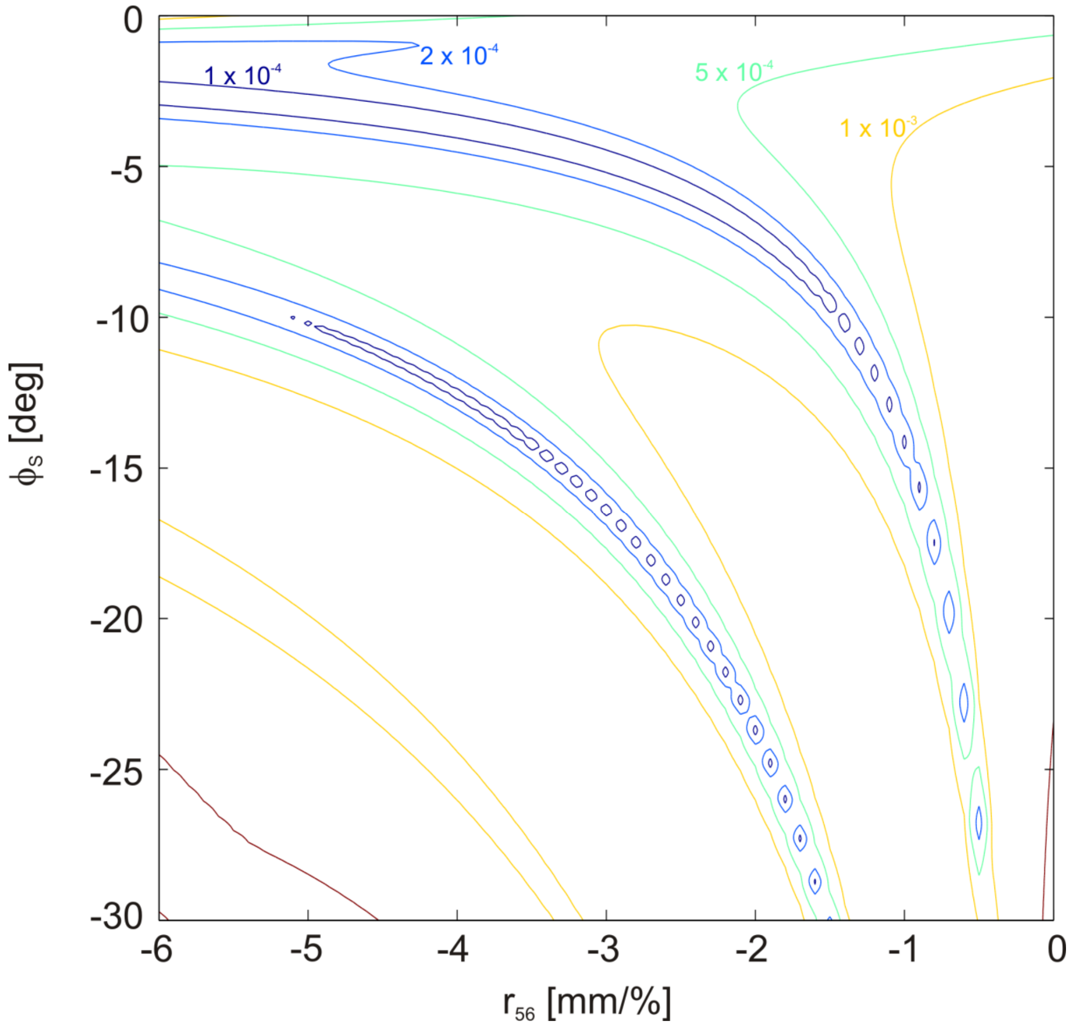
→ best energy spread at:

r_{56} = -2.6 mm/% and

Φ_S = -5.8°

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

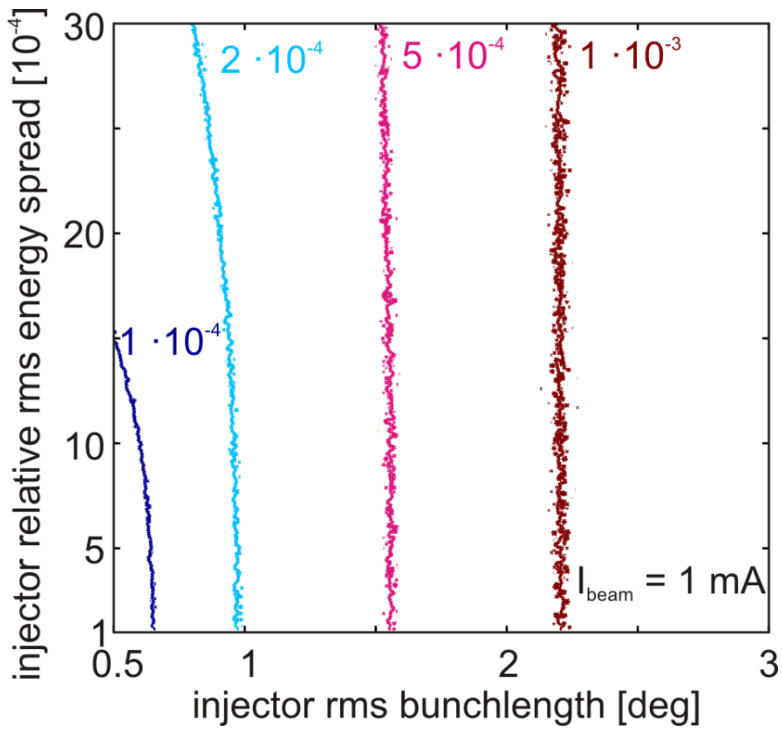
isochronous: $\Delta E_{rms}/E = 3.4 \cdot 10^{-4}$



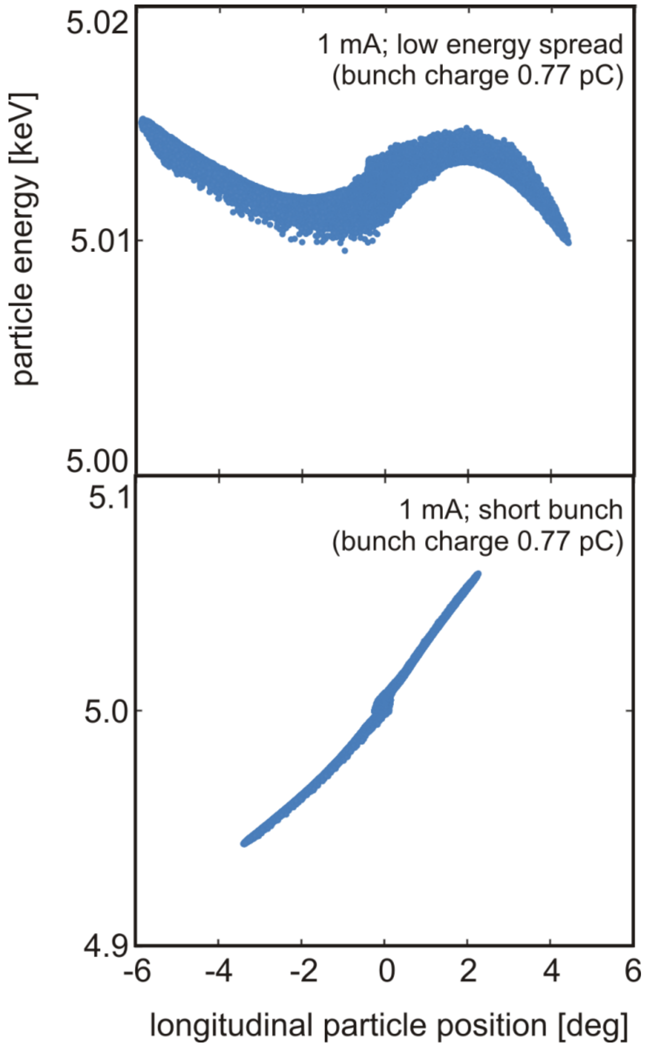
MESA: on crest isochronous ERL Operation

Simulation results for isochronous ERL operation

- High space charge forces at maximum beam current → deformed bunches
- Resulting energy spread depends mostly on bunchlength → optimize for short bunches



Injector phase space



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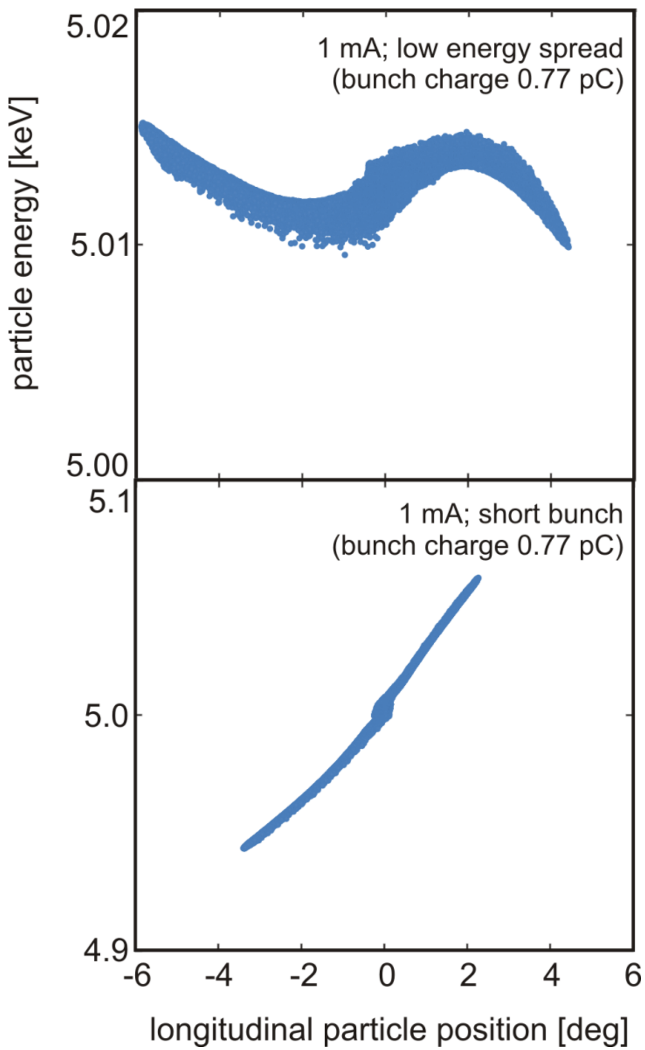


(F. Hug and R. Heine, (2017) J. Phys.: Conf. Ser. ***874*** *012012)*

MESA: on crest isochronous ERL Operation

Simulation results for isochronous ERL operation

- High space charge forces at maximum beam current → deformed bunches
- Resulting energy spread depends mostly on bunchlength → optimize for short bunches
- Bunches in the short bunch setting can be further compressed in the 180° injection arc

Resulting energy spread @ MAGIX:

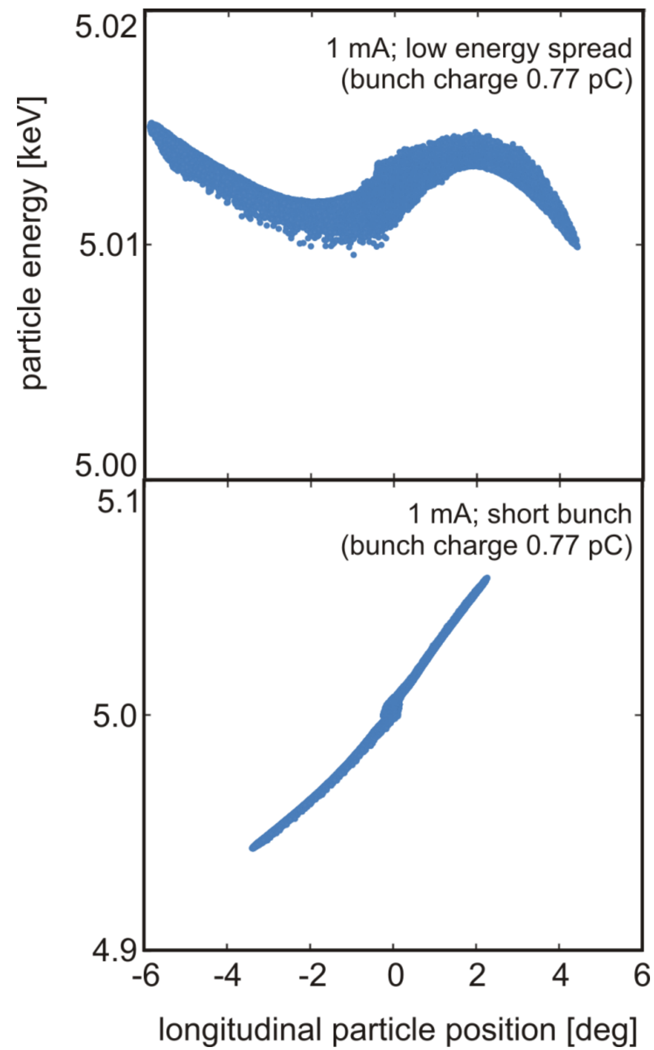
Injector optimized for best energy spread :

$\Delta E_{rms}/E = 7.2 \cdot 10^{-4}$ (75 keV @ 105 MeV)

Injector optimized for shortest bunchlength (after arc):

$\Delta E_{rms}/E = 2 \cdot 10^{-4}$ (21 keV @ 105 MeV)

Injector phase space

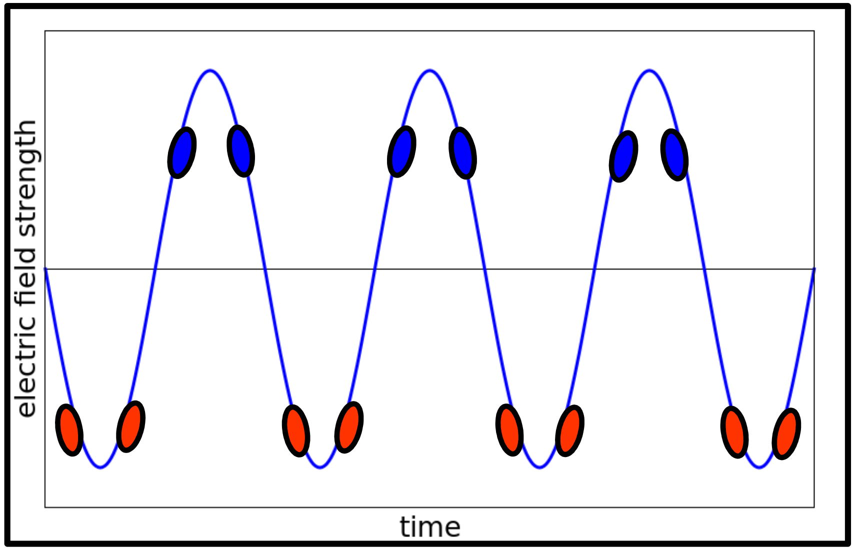


(F. Hug and R. Heine, (2017) J. Phys.: Conf. Ser. ***874*** *012012)*

MESA: non-iso ERL Operation

May be a different non-isochronous scheme in ERL operation possible?

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



First simulation results:

On crest, isochronous: $\Delta E_{rms}/E = 2 \cdot 10^{-4}$ (21 keV @ 105 MeV)
Off crest, non-isochronous: $\Delta E_{rms}/E = 8.9 \cdot 10^{-5}$ (9.3 keV @ 105 MeV)

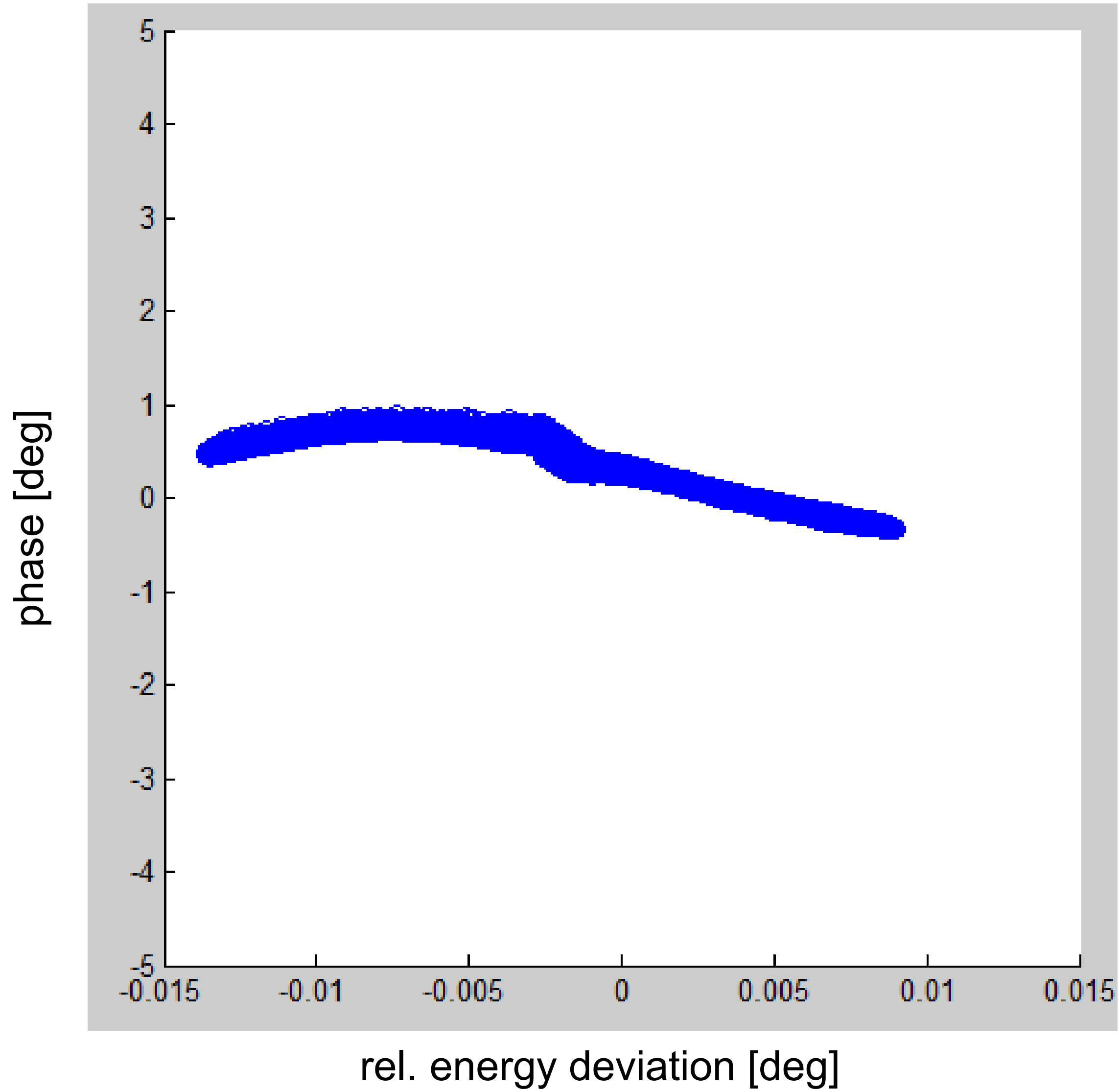
F. Hug, Proc. IPAC '17 (2017) 873.

MESA: non-iso ERL Operation

phase [deg]

rel. energy deviation [deg]

MESA: non-iso ERL Operation



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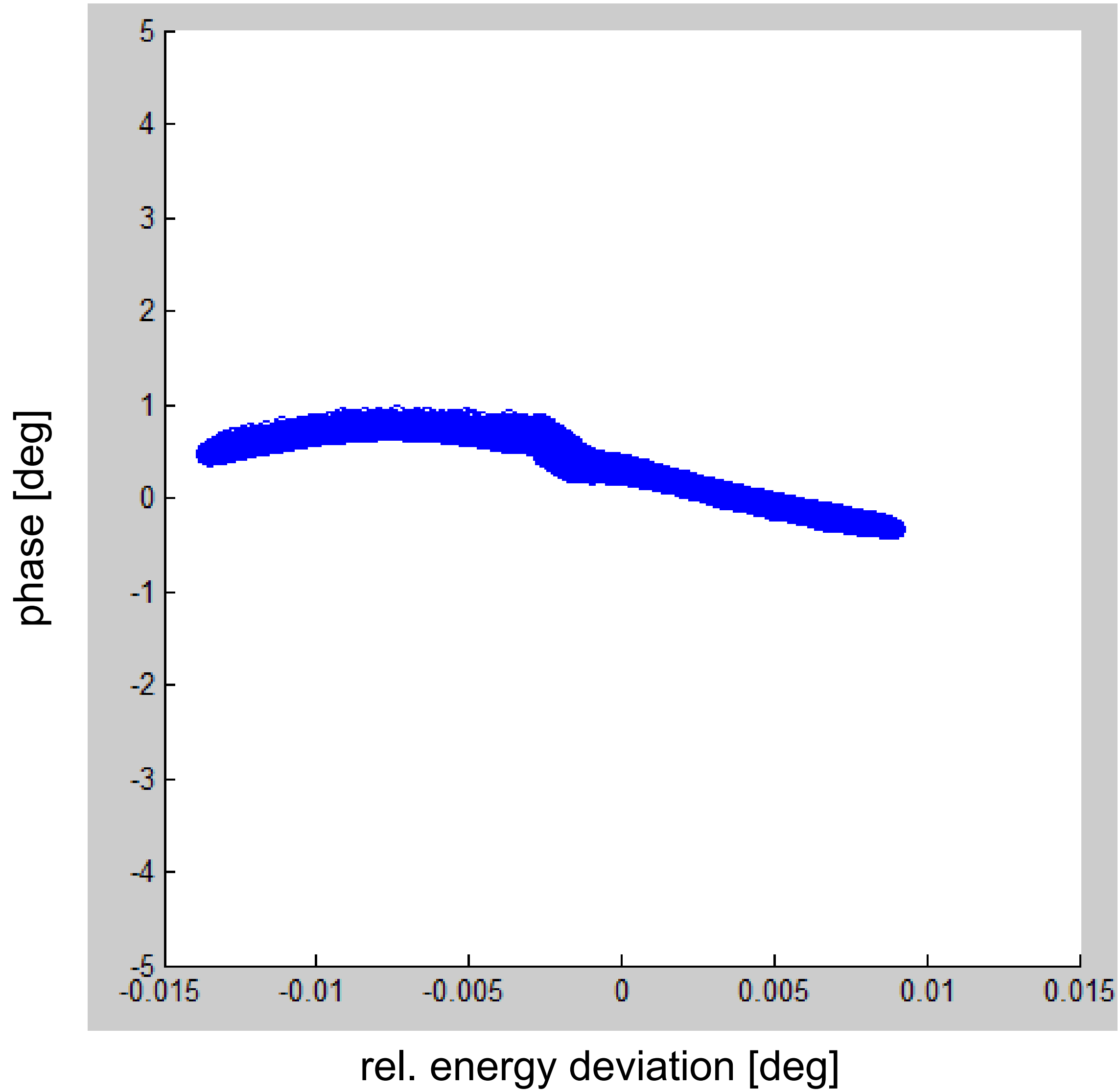

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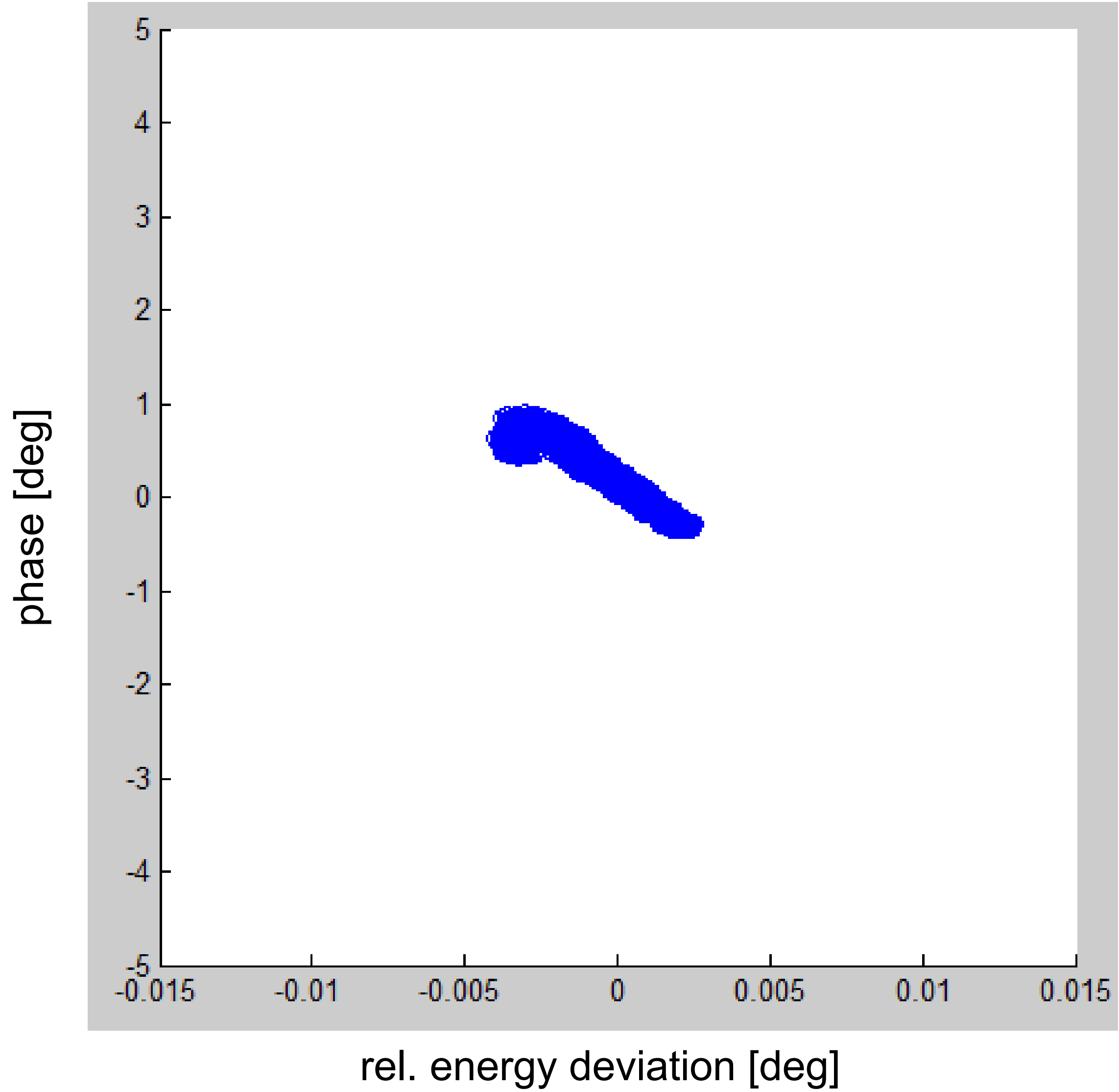

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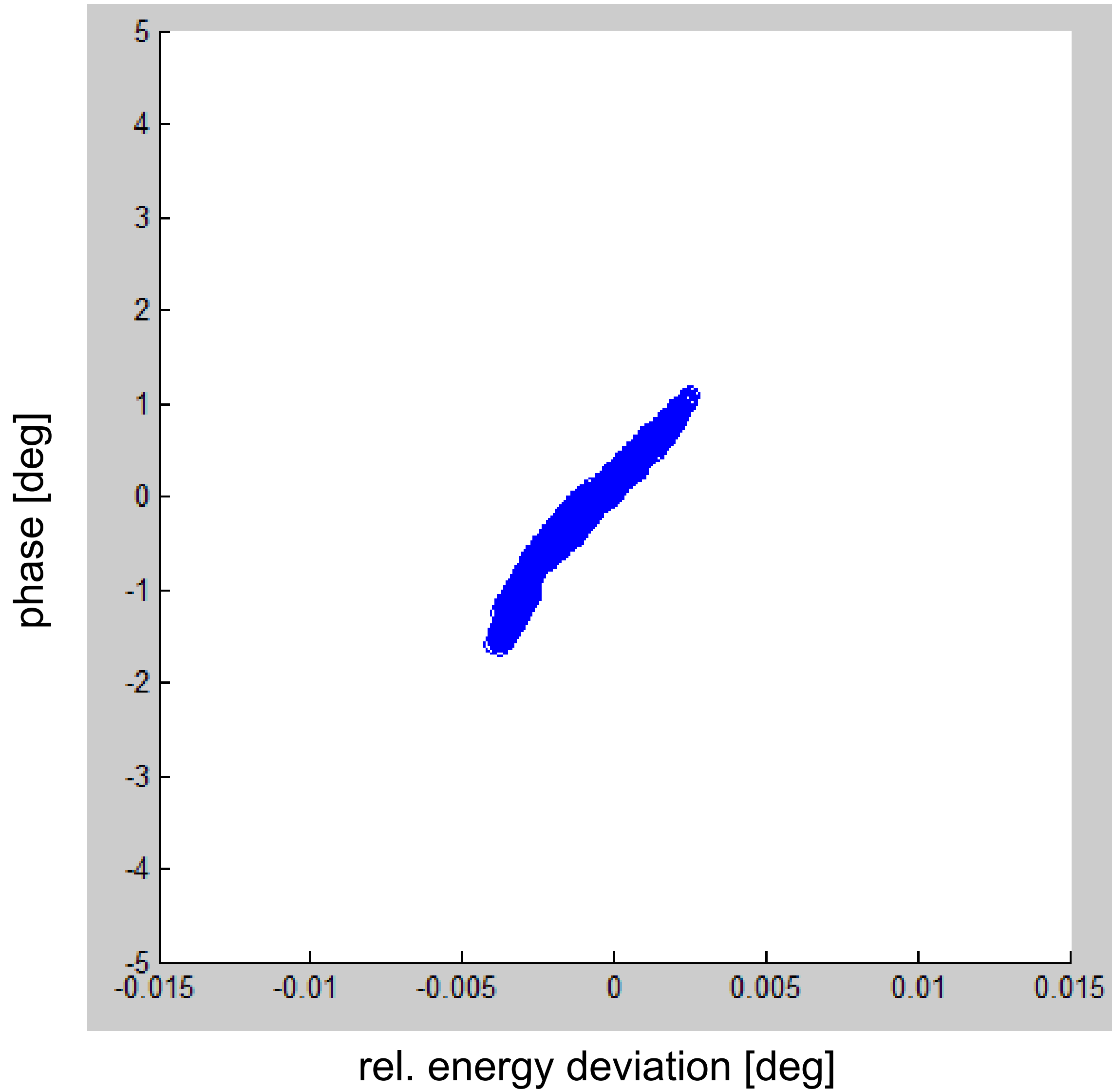

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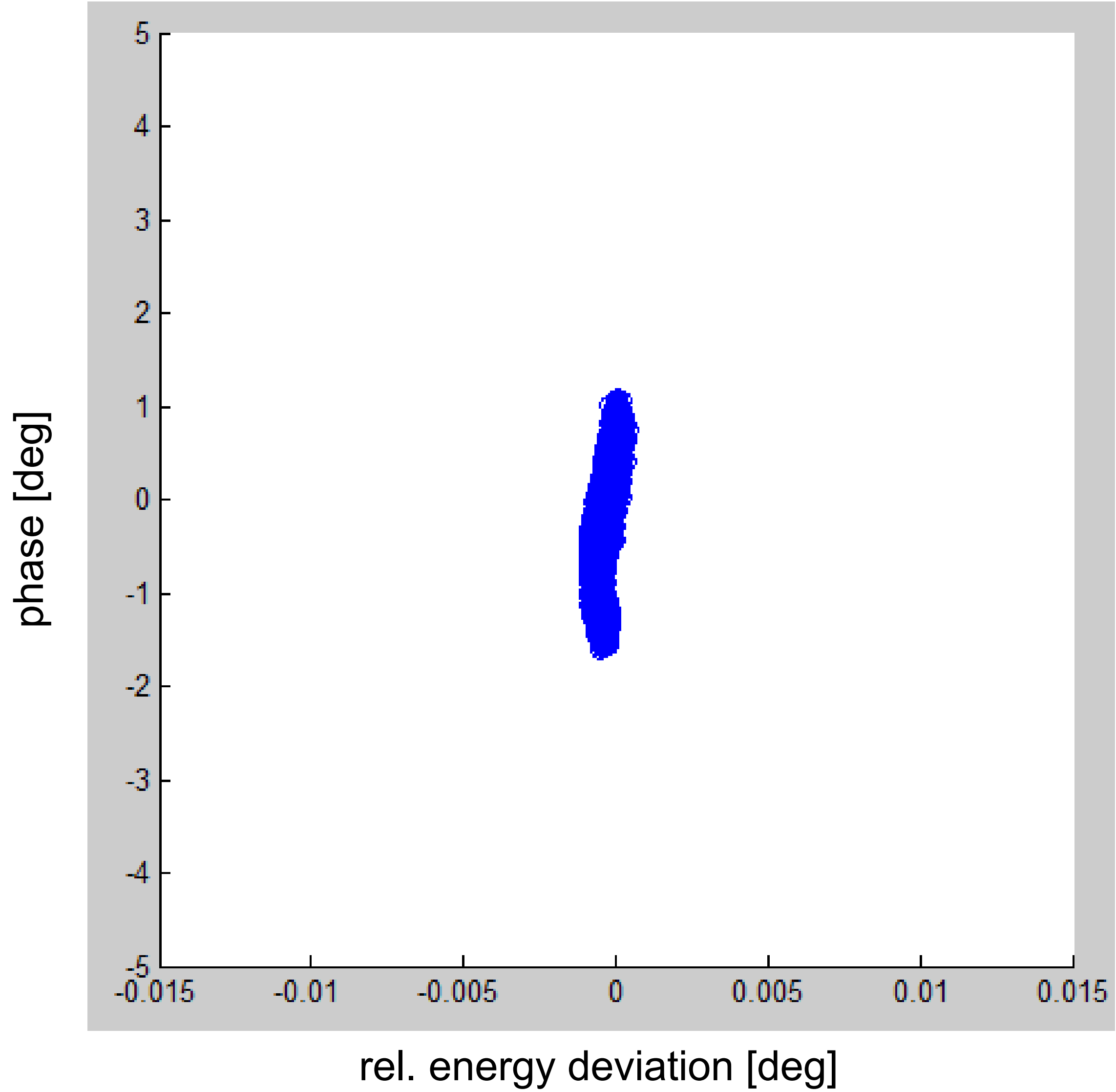

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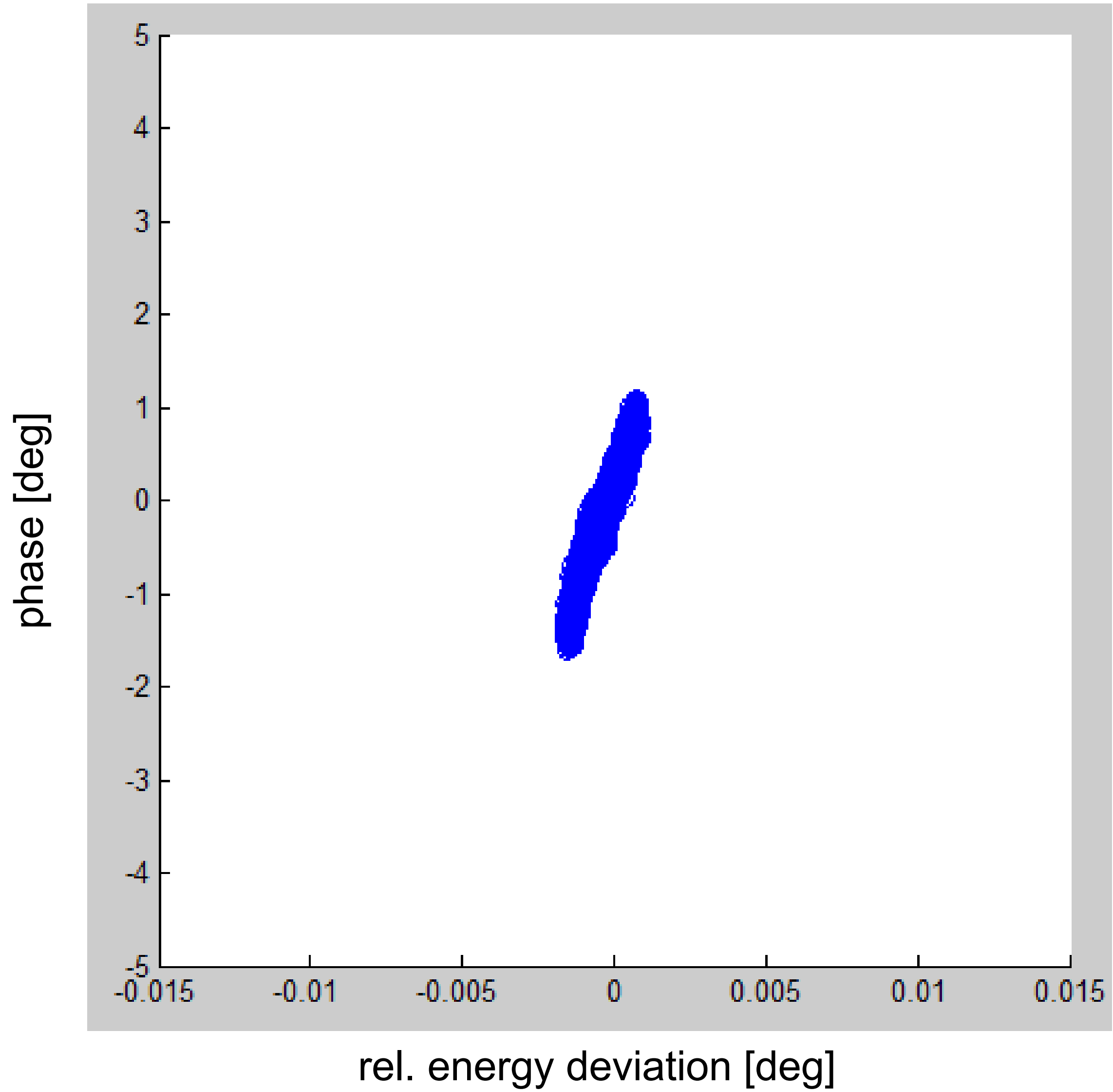

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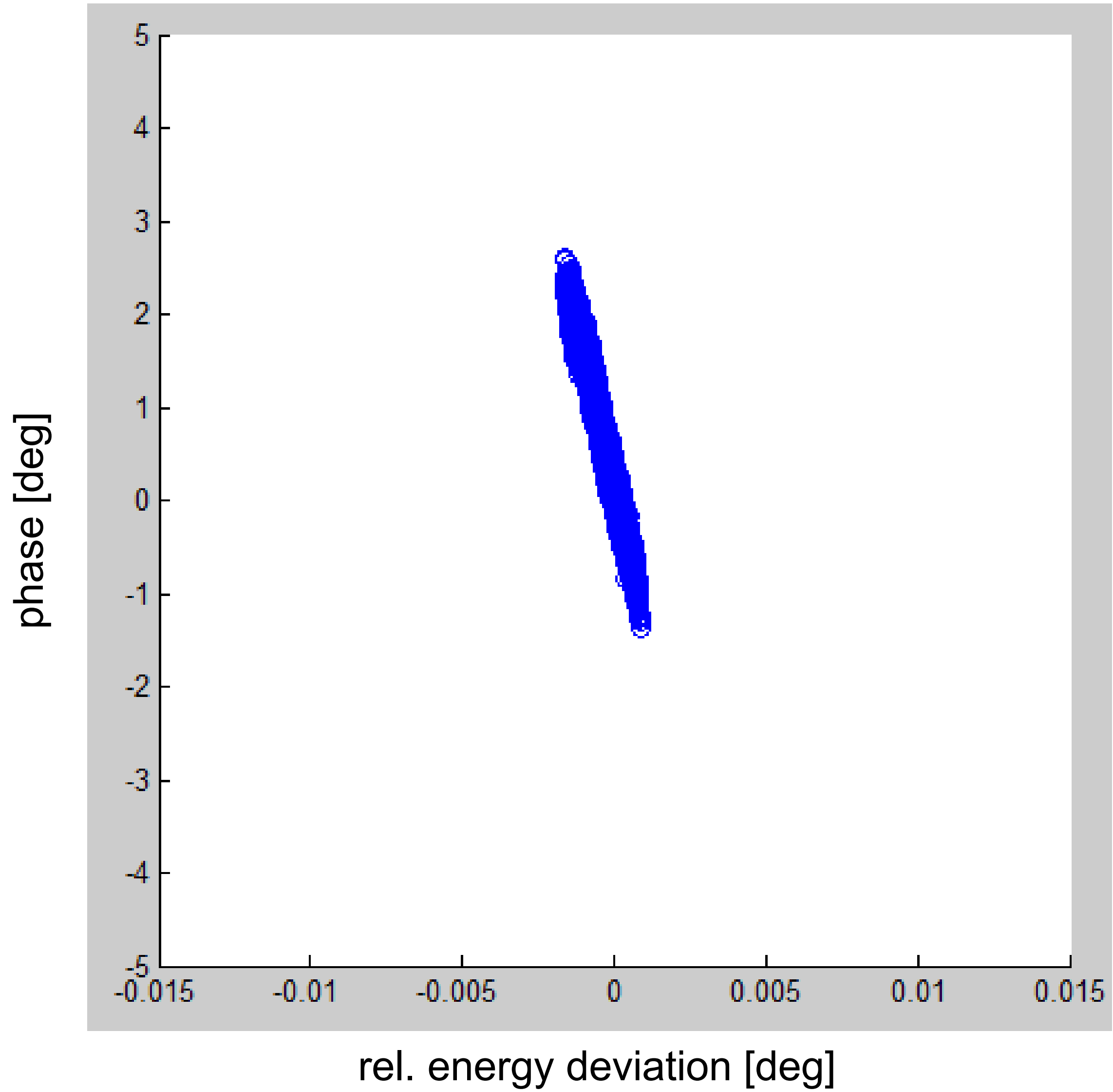

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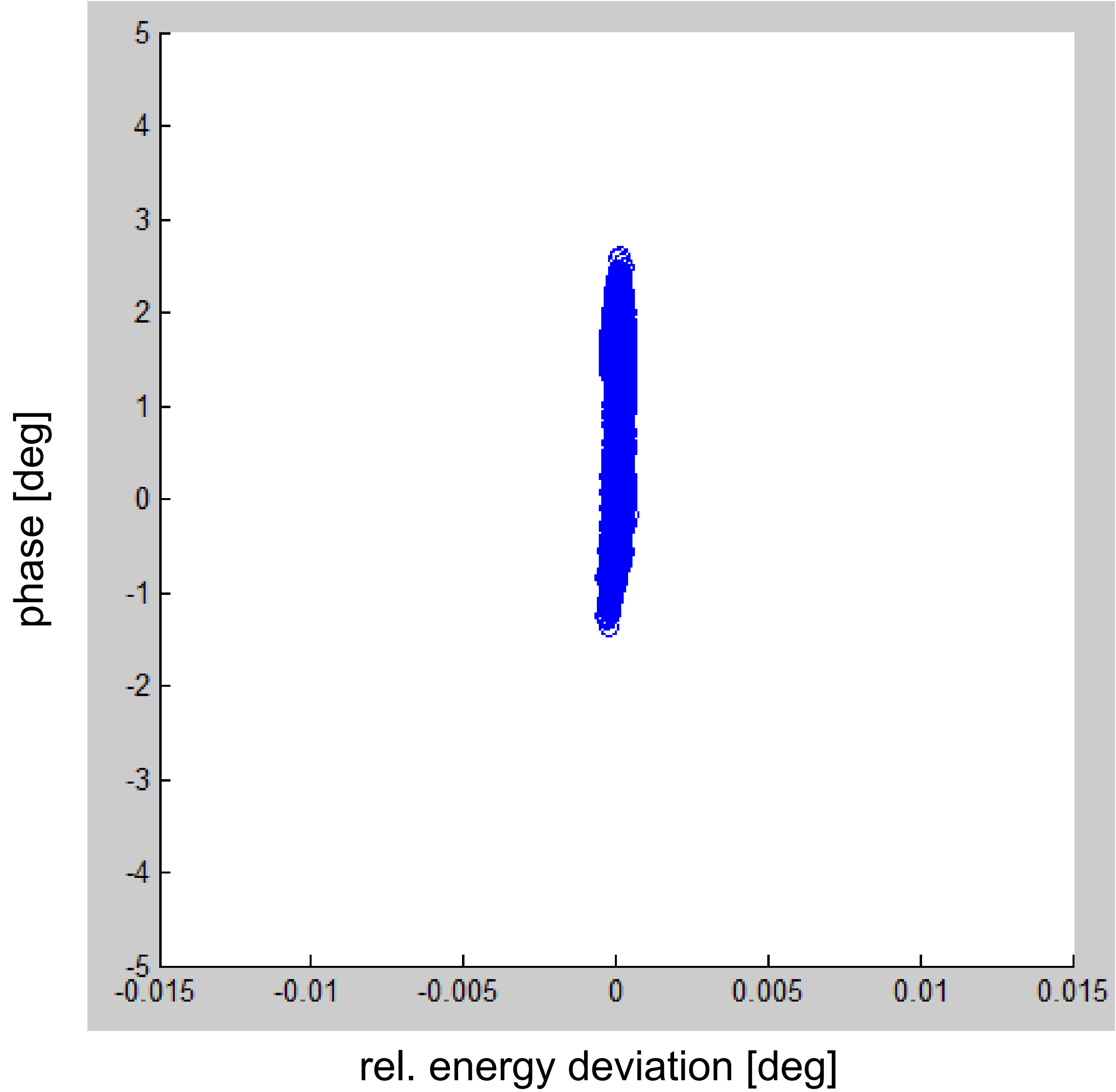
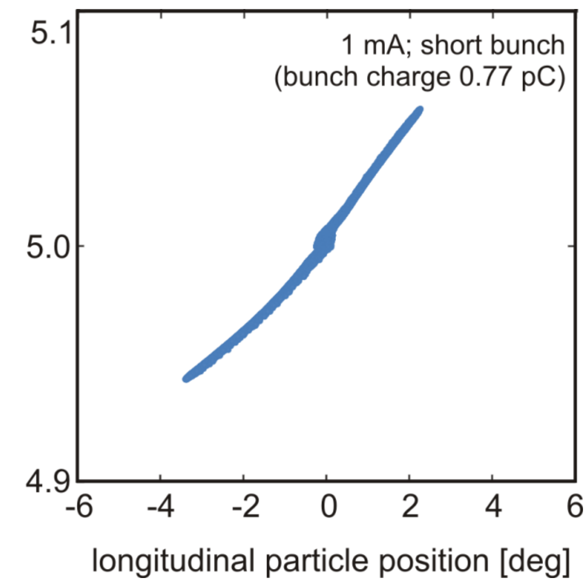
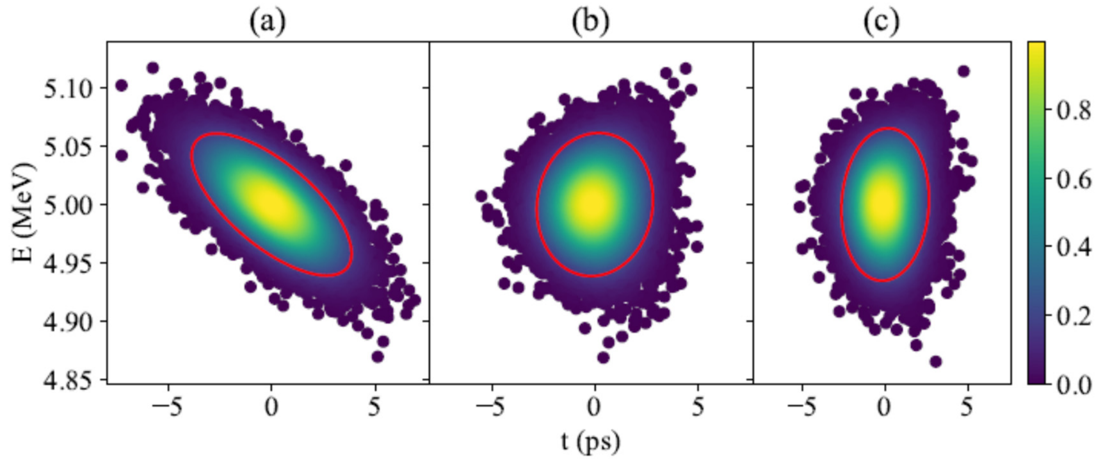


For short bunch at the position of the cryomodule we need to use the injection arc as bunch compressor

- Beam energy is low (5 MeV)
- Space charge needs to be taken into account
- Transverse dispersion set to zero at the exit
- R_{56} on a defined value for compression



→ A. Khan (poster tomorrow) developed an optimization code
→ Some corrections needed on matrix optics
→ Code works well and needs to be applied again to the newest stretched version of the arc in the (final) MESA layout…



A. Khan et al., submitted to NIM (2019)

Summary & Outlook

- MESA will be constructed in a double sided layout with vertical spreaders and vertically stacked return arcs

- two different operation modes (External Beam vs. ERL) and the requirement by the experiments for enabling every energy setting between ~20 MeV and maximum energy means a challenge for lattice design

- Lattice design is ongoing. Magnet design needs to follow. Start to end simulations for ERL mode in progress again after layout change

- at MESA a non-isochronous recirculation scheme is planned in the external beam mode for providing best energy spread @ P2

- for ERL mode at MESA further investigations are needed in order to figure out the possibility of such a system. But it can stabilize ERL operation when applied properly.