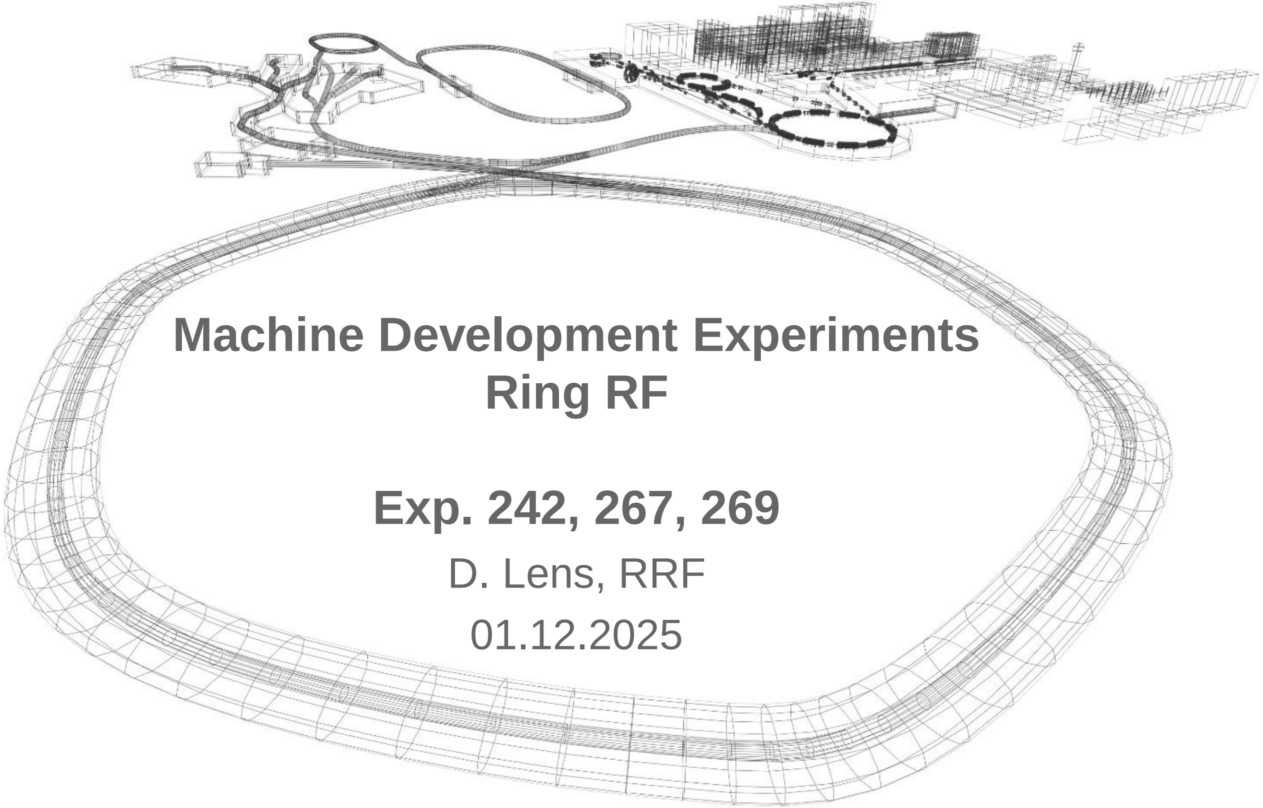


Machine Development Experiments Ring RF

Exp. 242, 267, 269

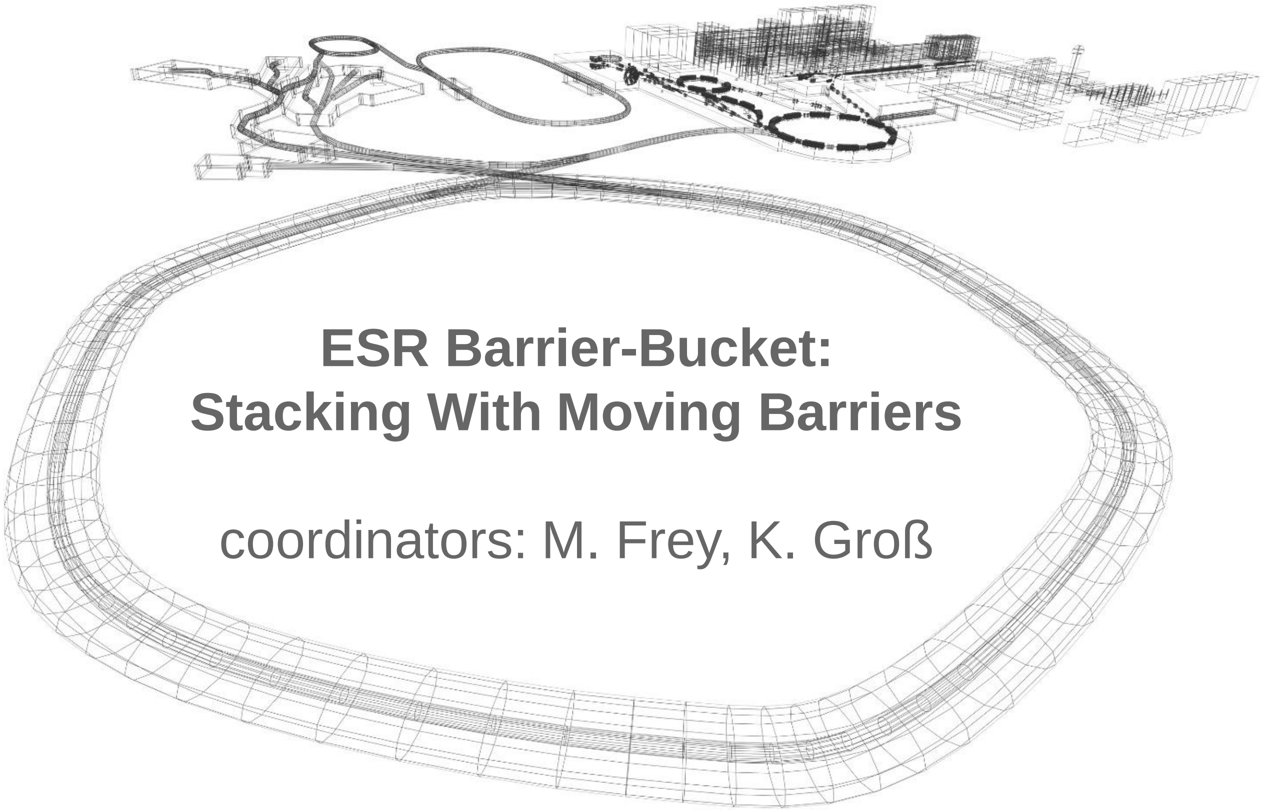
D. Lens, RRF

01.12.2025

Overview of Ring RF MDE in 2025

Nr.	Machine	Coordinator	Title
240	SIS18	K. Groß	Micro spill cavity
241	SIS18	B. Zipfel	Beam phase control
242	**SIS18**	**D. Lens**	**Bunch compression**
243	SIS18	K. Groß	Batch compression
244	SIS18	M. Hardieck	Longitudinal Feedback (PhD thesis C. Reinwald, TU Darmstadt)
267	**SIS18 & ESR**	**D. Beck**	**Phase shifting with Bunch2Bucket SIS18 → ESR**
268	ESR	B. Zipfel	Beam Phase Control
269	**ESR**	**M. Frey, K. Groß**	**Stacking with ESR Barrier Bucket**

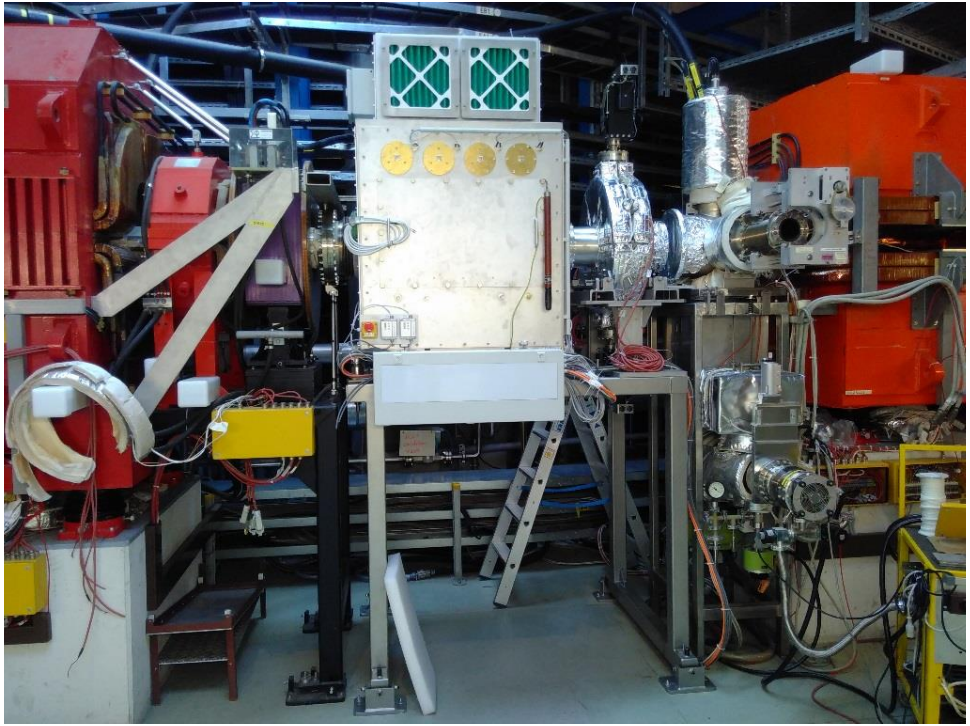
as usual: support from numerous colleagues and groups (sorry they cannot be mentioned here)



ESR Barrier-Bucket:
Stacking With Moving Barriers

coordinators: M. Frey, K. Groß

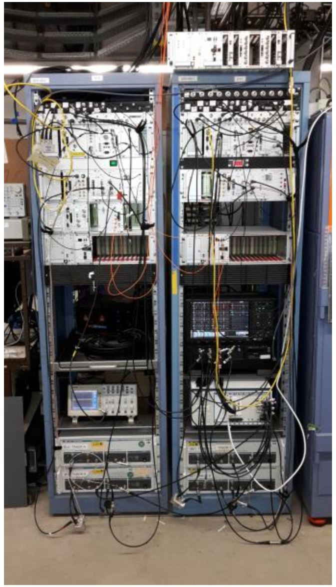
ESR Barrier Bucket cavity systems



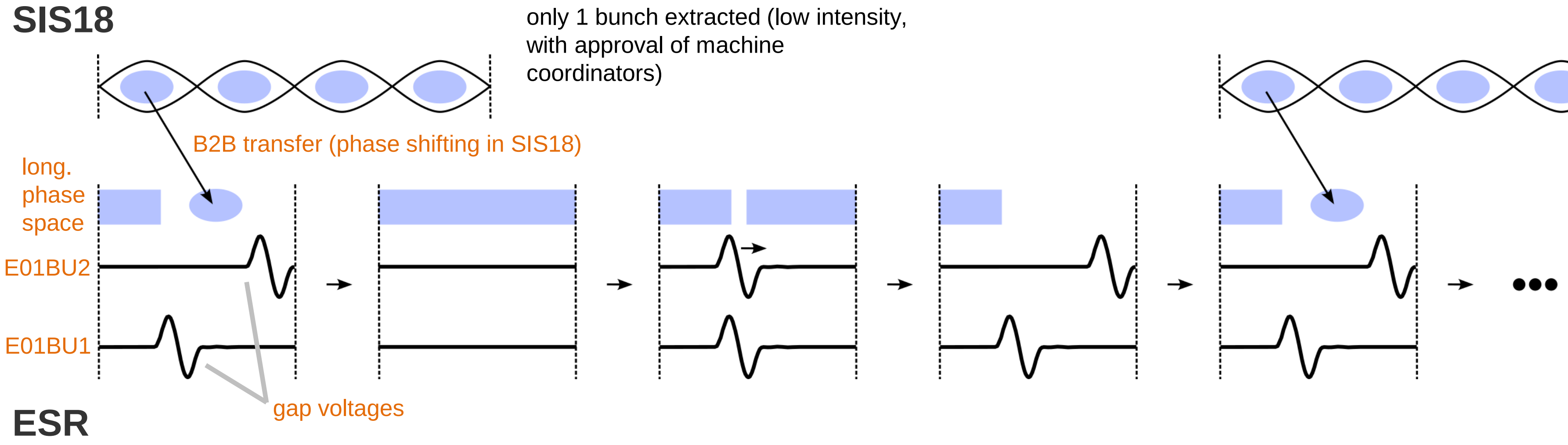
Photos: RRF/M. Frey

Barrier Bucket cavities E01BU1 and E01BU2:

- Broadband cavities combined in one housing (ESR tunnel)
- Semiconductor power amplifiers (close to the cavities)
- Low-Level Radio Frequency electronics, 5 racks (BG.1.016)



Principle of stacking with moving barriers



1) injection of new beam

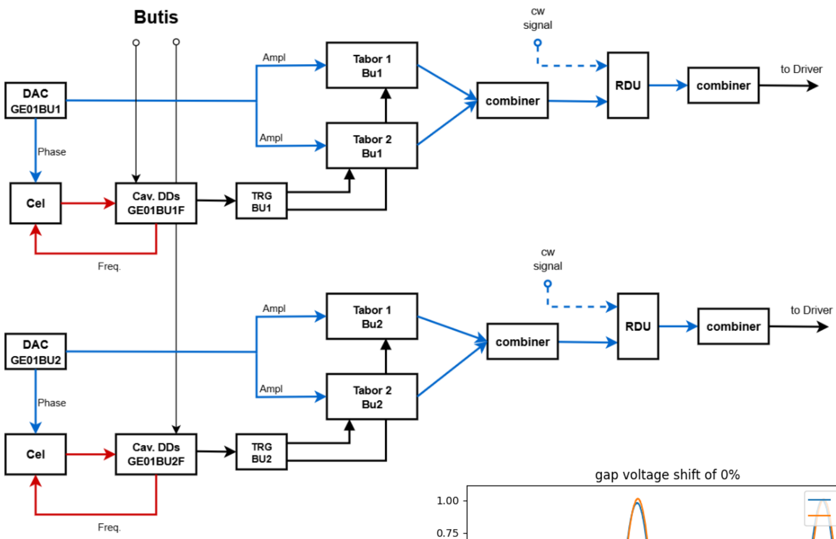
2) barriers ramped down, coasting beam (cooling on)

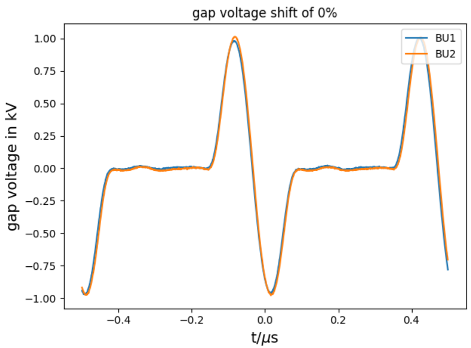
3) barriers ramped up, then shifting …

4) … 1 barrier in phase to make space for …

5) … the new injection

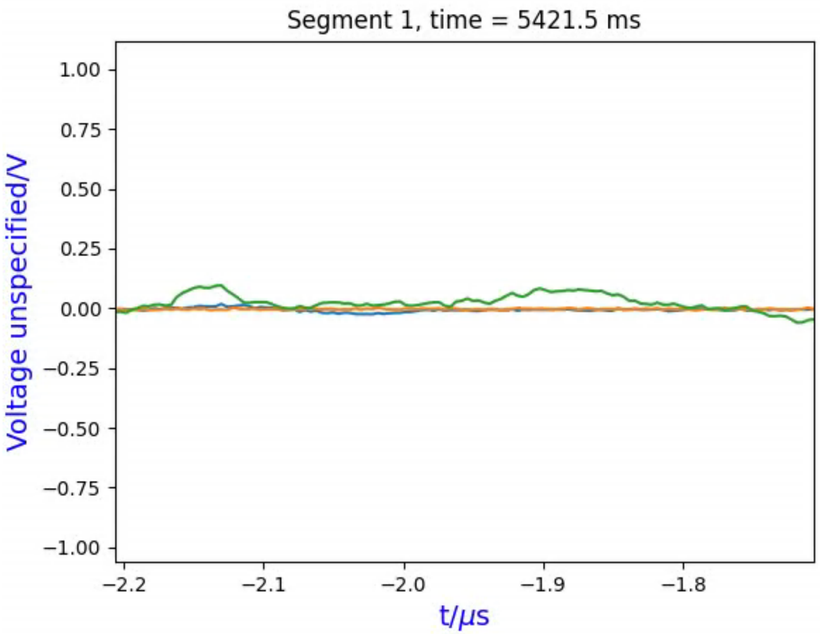
Barrier-Bucket signal generation





- ESR BB project leader: M. Frey
- each cavity has own LLRF for CW & pulsed operation
- calculation methods for pre-distorted signal generation (based on measured cavity transfer function) were developed @ TUDa (accelerator technology group, H. Klingbeil)
- software implementation: D. Penza
- phase calibration of single-sine pulses with respect to ESR Group DDS signal (h=1)
- currently fixed BB pulse (single-sine) duration of 200 ns
- up to 1 kV per cavity
- repetition frequency between 0.9 … 2 MHz

Ramping and phase shifting of barriers with beam



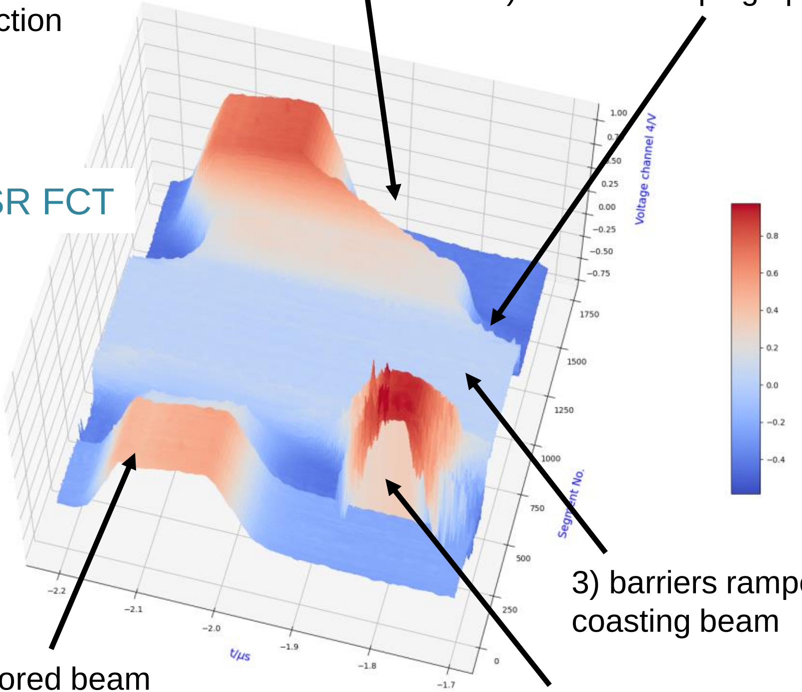
- $^{12}C^{6+}$ at 400 MeV/u (May 28th, 2025)
- Gap voltage E01BU1
- Gap voltage E01BU2
- FCT signal
- offset in phase relation between cavities and FCT due to installation (ring) positions
- preliminary analysis; observation of beam losses at each injection (not yet analyzed in detail)

Stacking with $^{12}C^{6+}$ at 400 MeV/u (May 28th, 2025)

5) one barrier moved in phase to make space for new injection

4) barriers ramping up

ESR FCT



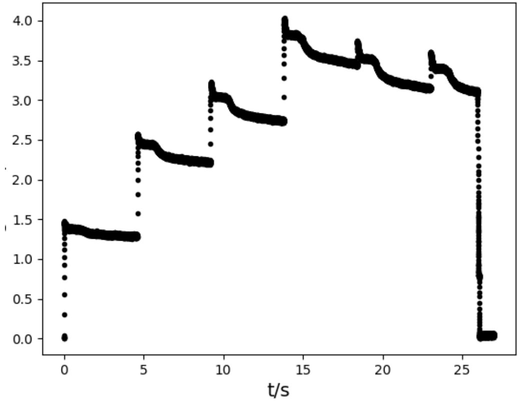
3) barriers ramped down: coasting beam

1) stored beam

2) injection of new beam

- pattern and machine settings realized by S. Litvinov, B. Lorentz, …
- stacking (proof of principle, not optimized) using B2B phase shift method in SIS18 (configured by D. Beck):

ESR DC beam current



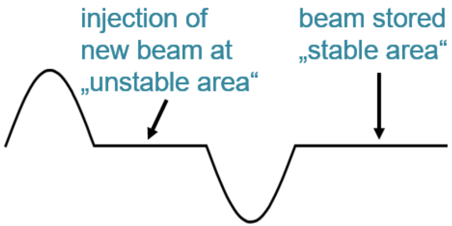
analog DC trafo signal:
Thanks to BEA (O. Chorniy)

Signal generation for stacking with fixed barriers

- Special signal preparation by RRF for subsequent MDE by T. Katayama et al., experiment with stacking:

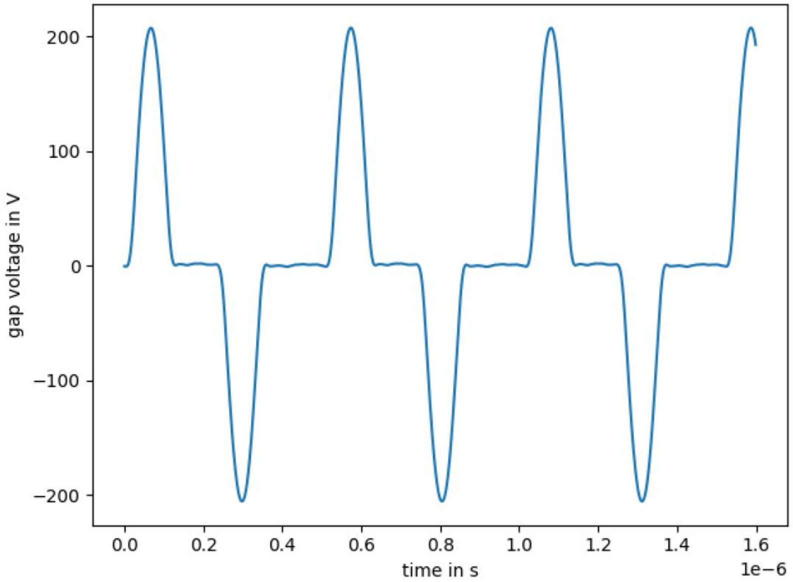
  → see talk by B. Lorentz

- Generation of two separate half-waves with one cavity, special implementation by D. Penza



- Manual setup, currently not available/planned for standard operation

Measured gap voltage of E01BU2 (averaged, n=1000)



Conclusion and outlook

Result:

- Successful stacking with moving barriers fully controlled by the central control system (target values: amplitude, phase, frequency)
- Beam losses occurred at each injection; reason not yet analyzed in detail

Special thanks to:

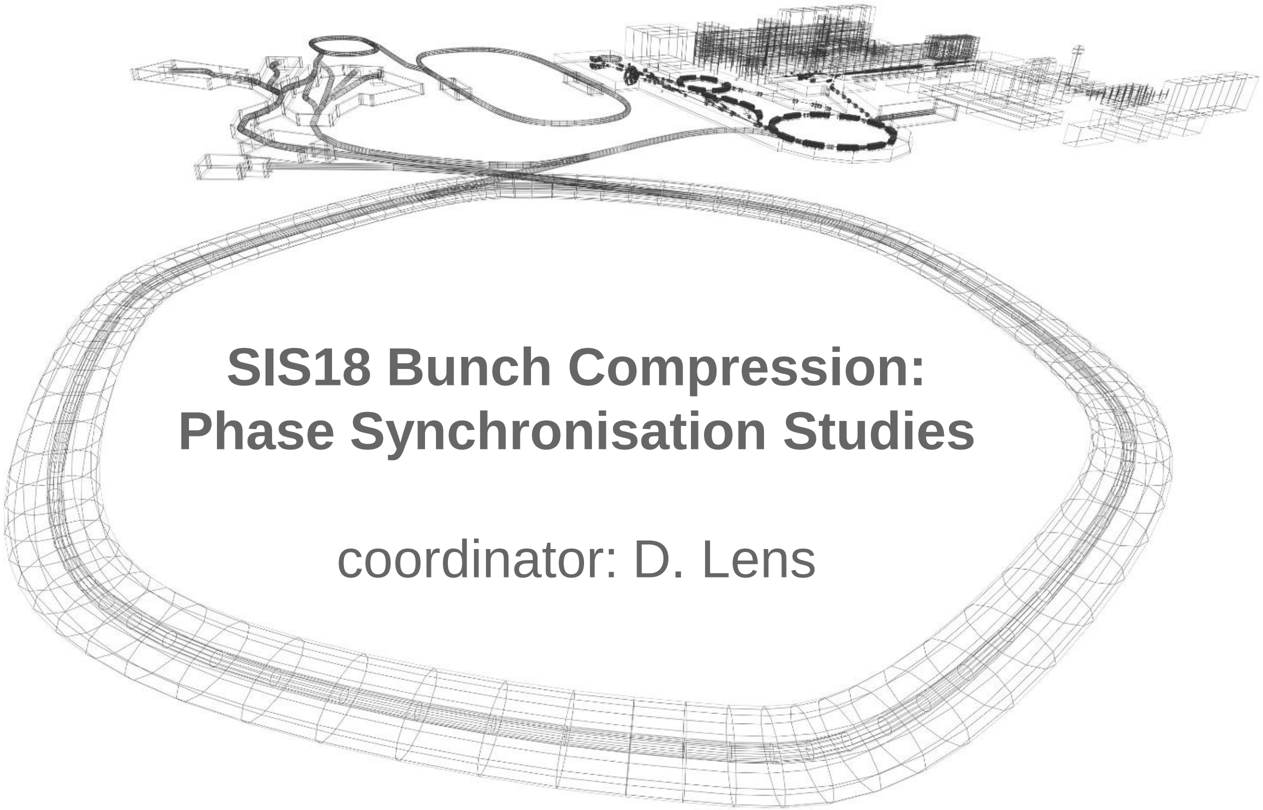
- ESR: B. Lorentz, M. Steck, S. Litvinov, T. Katayama, … (many more)
- Bunch-to-bucket transfer with phase shifting: D. Beck (see also separate talk)

Next steps:

- Remaining control system integration and LSA model implementation:

  - Switching between CW and BB mode via RF switch events (from ParamModi instead of DeviceControl)

  - Improvements for long and stable operation (e.g. automatic switching off function generators when not needed, automatic calibration procedure, …)



SIS18 Bunch Compression: Phase Synchronisation Studies

coordinator: D. Lens

SIS18 Bunch Compressor system

Cavity & amplifier

SIS18 tunnel

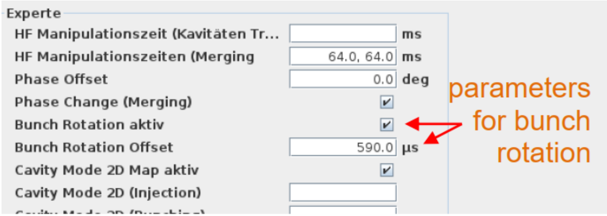
RRF supply room (BG.1.016)

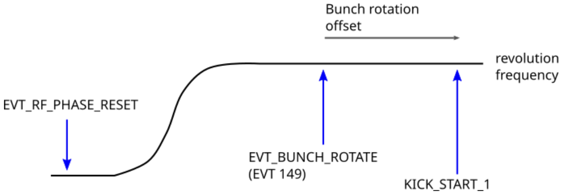
LLRF (cavity synchronization, control system interface, …)

power supply unit incl. PLC & stepper motor control

Current status of S02BB1

- status, on/off/reset from DeviceControl (PLC integrated in CCS)
- implemented data supply:
  - frequency
  - harmonic number
  - phase
  - switching on/off timing event for activation of bunch rotation for a beam cycle
  - time between start of rotation and extraction
- settings that currently have to be done with expert support (RRF):
  - changing resonance frequency: stepper motor control, via network; still needs expert knowledge
  - target amplitude
- Cavity (phase) synchronisation partly feedforward (advantage: fast; disadvantage: phase drift during pulse, needs very long delay cables)





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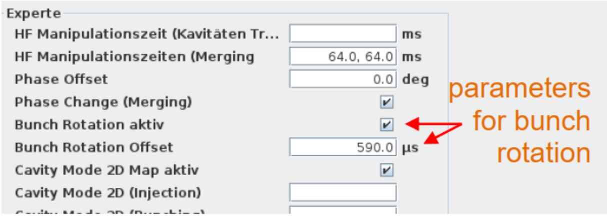
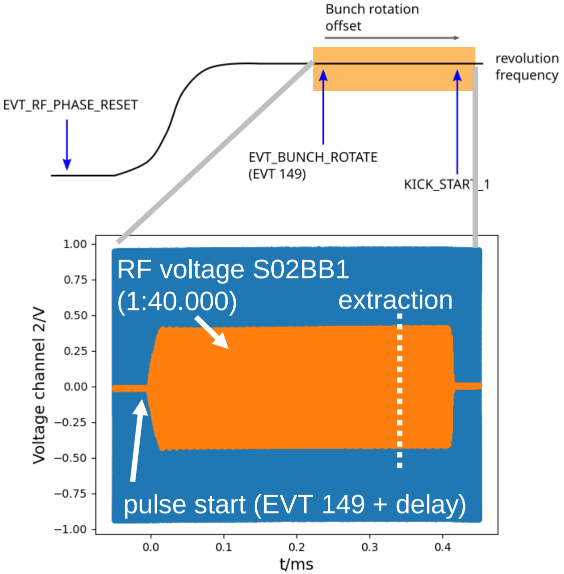
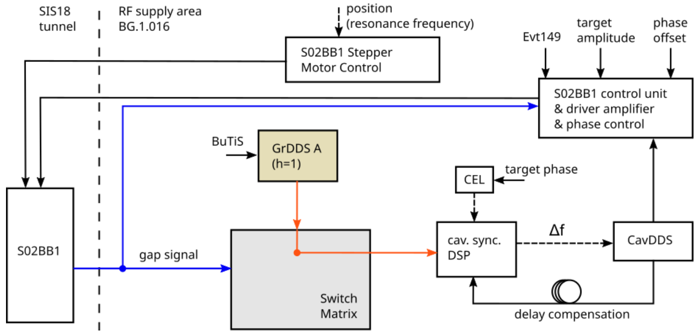




Cavity synchronization scheme



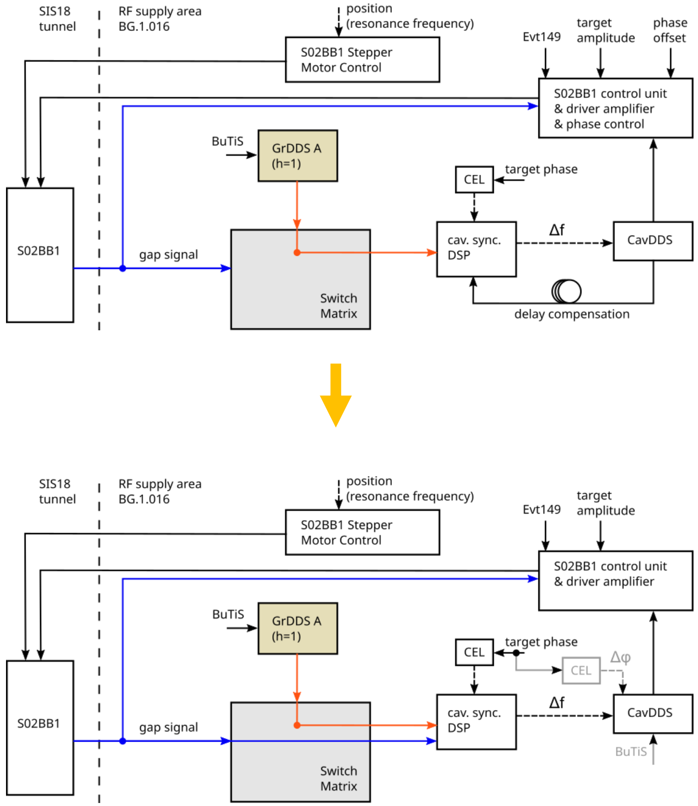
Requirements for S02BB1:

- amplitude rise time < 30 µs
- phase synchronization settling time significantly faster than for other (CW) RF systems

Synchronization scheme before MDE/beam time:

- combination of feedforward & analog phase control
- problem: phase drifts during pulse

Cavity synchronization scheme



Requirements for S02BB1:

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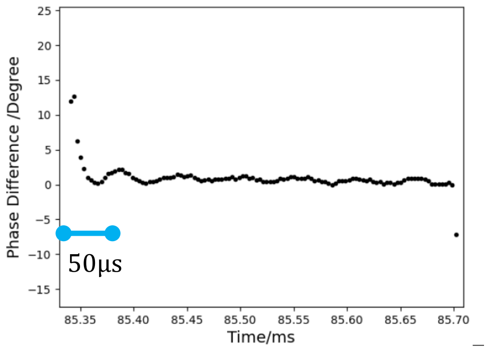
Synchronization scheme before MDE/beam time:

- combination of feedforward & analog phase control
- problem: phase drifts during pulse

Test of new scheme:

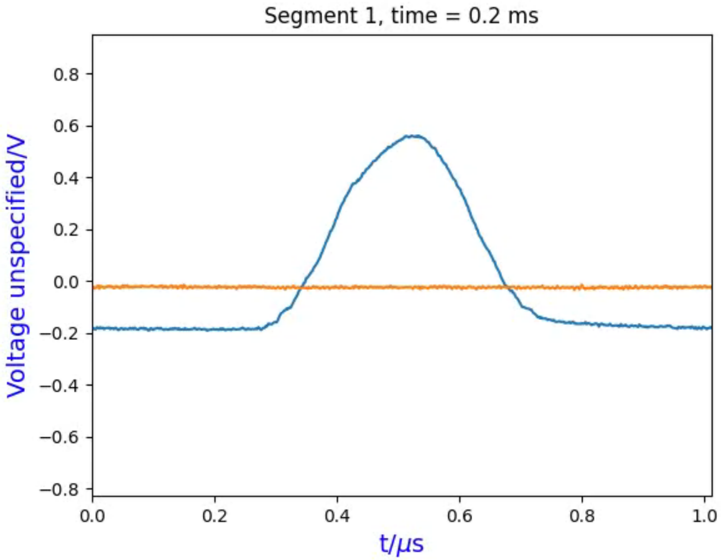
- synchronization directly on gap voltage
- new DSP hardware, PID control
- BuTiS-clocks and feedforward for Cavity DDS

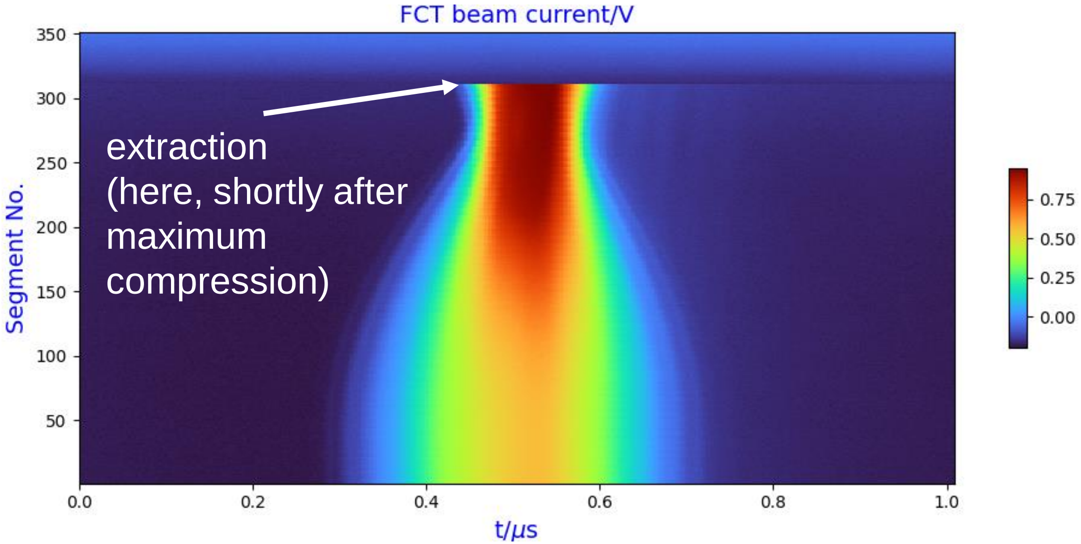
Measured gap phase (shutdown)



Compression (during PPH beam time)

compression of one SIS18 bunch (400 MeV/u, U^{73+})

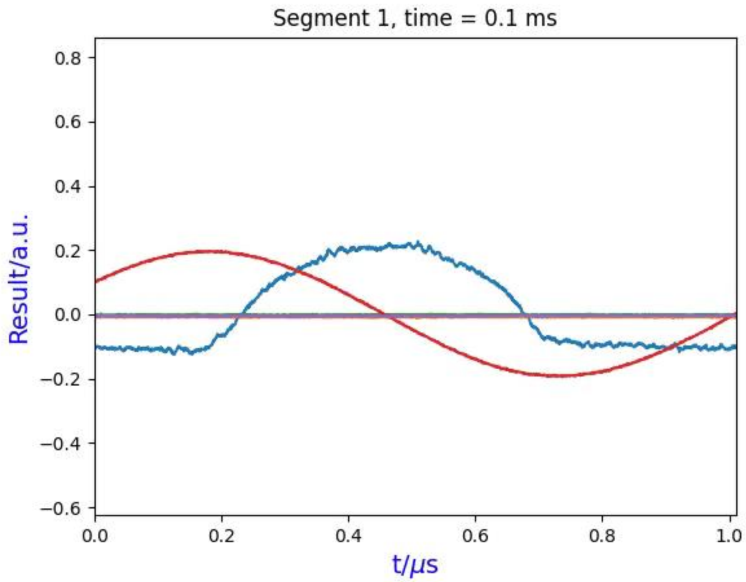




Compression with MA cavities (300 MeV/u, U^{73+})

- reduced voltage of S02BB1 (16 kV) due to problem with „remote“ operation of system (solved after MDE)
- observed FWHM: before compression: ≈ 400 ns
  highest compression: ≈ 125 ns } $\frac{1}{3.2}$
- idealized estimation: $\sqrt{\frac{(11+4+7.7+16)}{4}} \approx 3.1$
- demonstration of multi-cavity compression
- but: so far only proof-of-principle:
  - manual setup for pulsed operation of MA cavities
  - special setting of phase detection module (AGC)
  - worst case for synchronization: BE3/5 pulse starting from 0 V (phase feedback slower than amplitude feedback)
- Remaining topics if needed in standard operation:
  - partly upgrade of MA systems LLRF (incl. solution for AGC)
  - control system integration
  - choice of RF voltages before pulse (> feedback threshold)
  - momentum acceptance limits (extraction/transfer line)?

FCT signal (measured signal x 10)
Gap voltage S02BB1 (1:40.000), max. 16 kV
Gap voltage S07BE3 (1:20.000), max. 11 kV
Gap voltage S07BE4 (1:20.000), 4 kV
Gap voltage S07BE5 (1:20.000), max. 7.7 kV
(phase relations depend on installation positions)



Conclusion & outlook

Result:

- S02BB1 integrated in DeviceControl and ParamModi
- successful proof of principle of new synchronization scheme (also important for SIS100 BC), has to be further tested and optimized during shutdown

Problems during MDE and beam time:

- issue with analog amplitude feedback, limited voltage to less than 20 kV during MDE; has been solved, to be tested during shutdown
- partly unstable operation due to unacceptable high ambient temperature in BG.1.016 → insufficient cooling issue has been addressed/escalated

Outlook and tasks:

- implementation (mainly FESA) of resonance frequency tuning via CCS (without expert knowledge)
- reducing down-time due to over-heating (cooling upgrade of BG.1.016 necessary!)
- further machine development experiments needed for achieving standard operation without RRF support

Please contact RRF in advance in case SIS18 Bunch Compressor is desired for operation