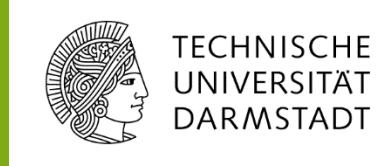
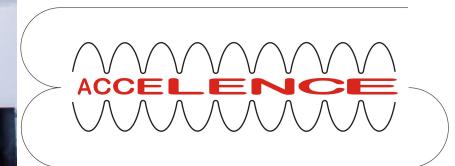


Low Level RF ERL Experience at the S-DALINAC*



Picture by Jan-
Christoph Hartung

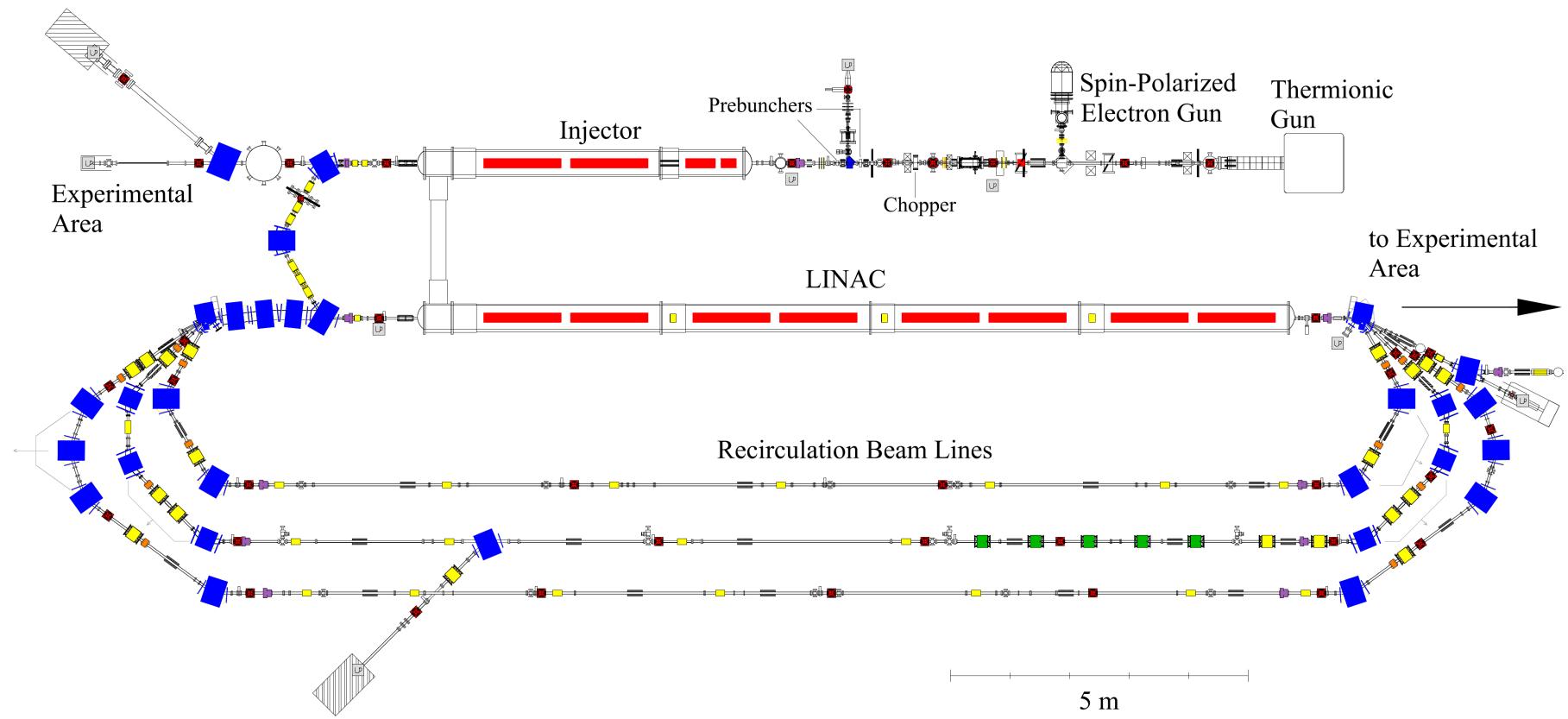


*Supported by the DFG through GRK 2128

S-DALINAC



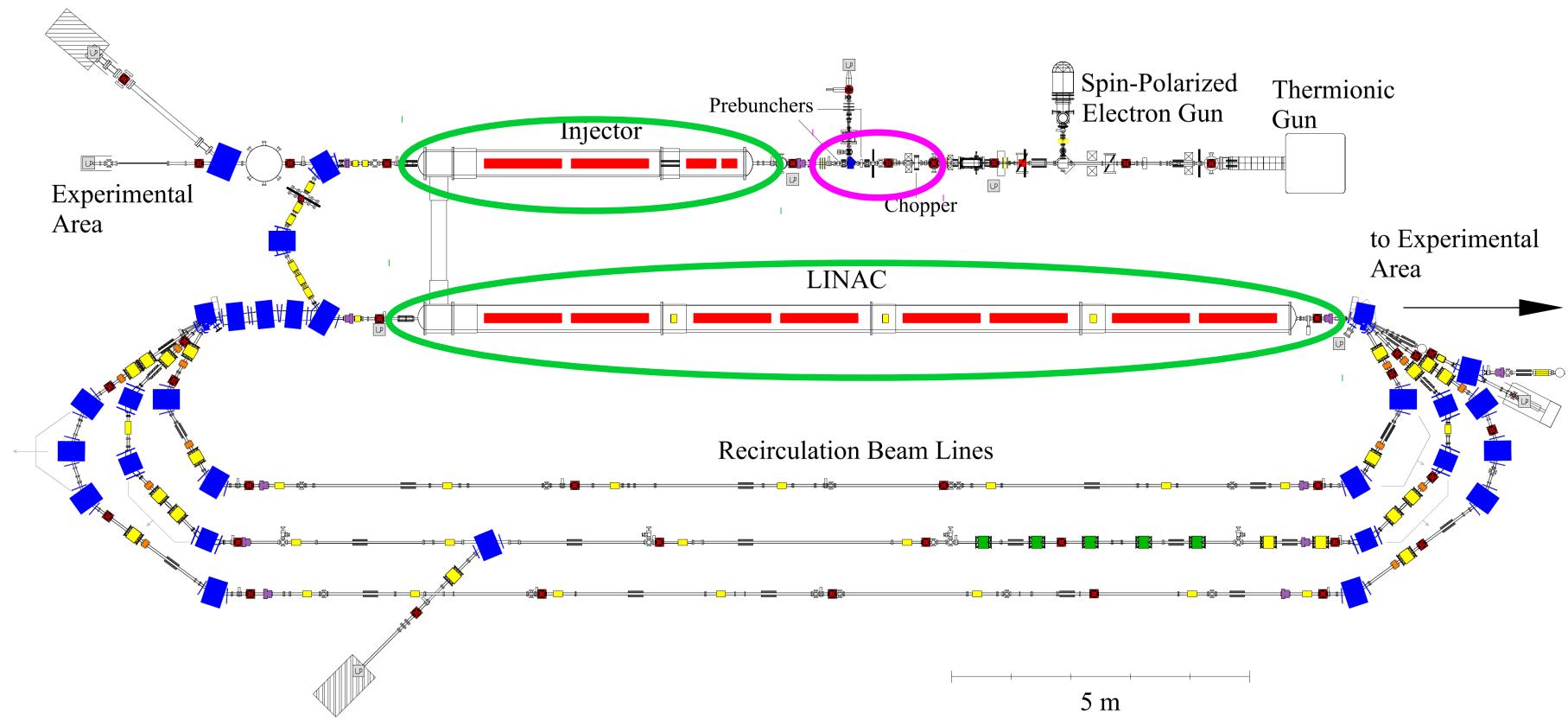
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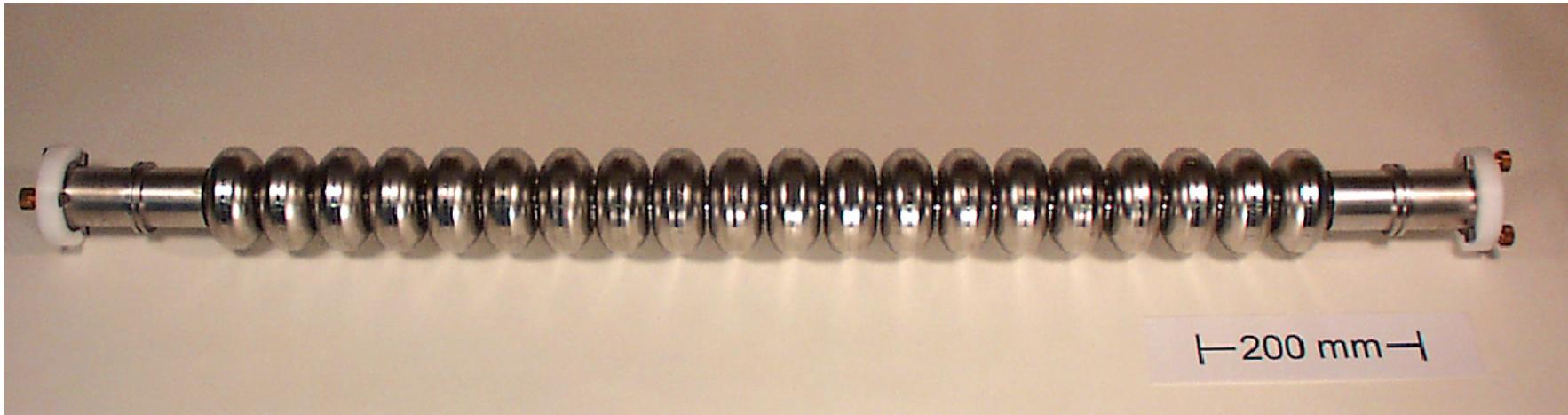
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SRF-Cavities



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Material: Niobium

(RRR=280)

Temp.: 2 K

Freq.: 2.997 GHz

Mode: TM₀₁₀

Number of cells: 20

5

Length: 1 m

0.25 m

β : 1

Q_0 : 3×10^9

3×10^9

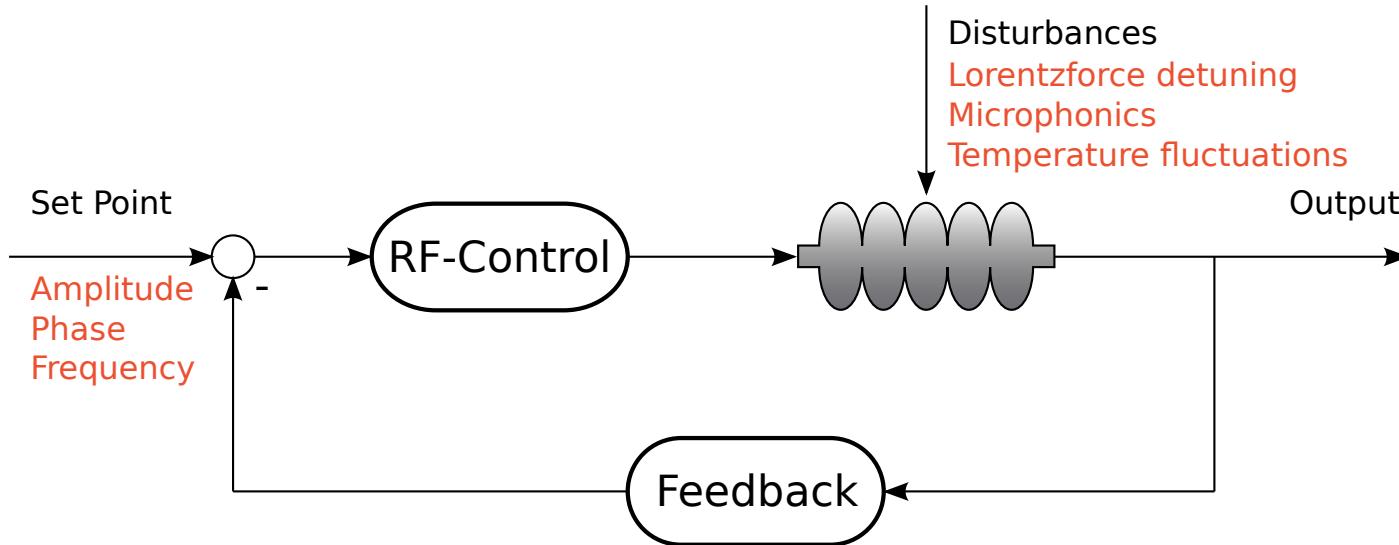
E_{acc} : 5 MV/m

5 MV/m

RF-Control Closed Loop



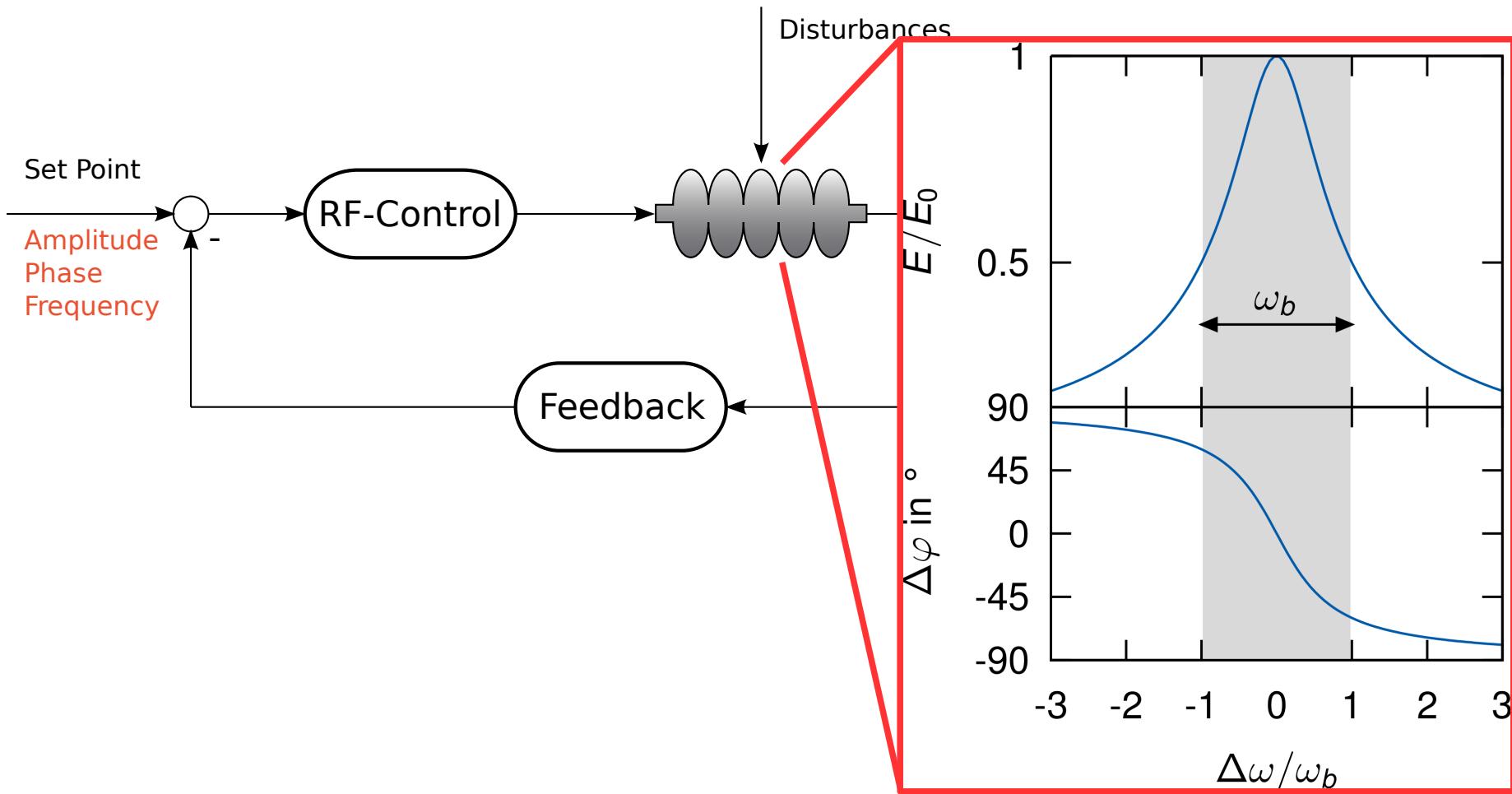
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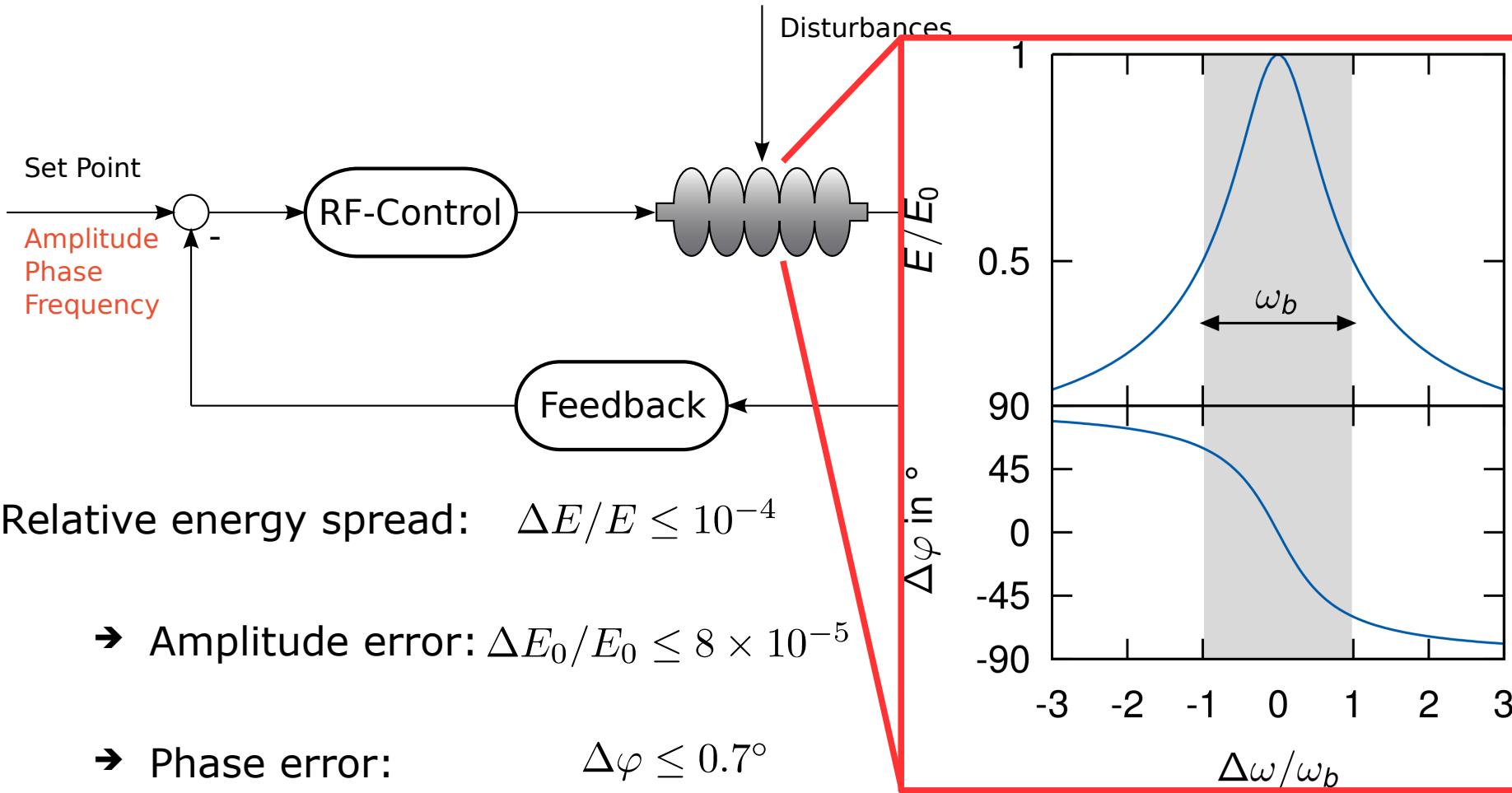
RF-Control Closed Loop



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RF-Control Closed Loop



RF-Control

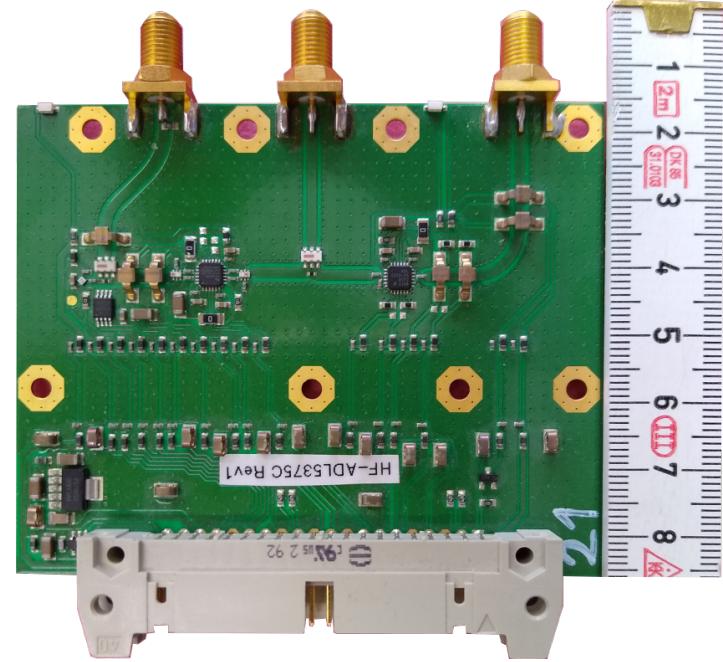
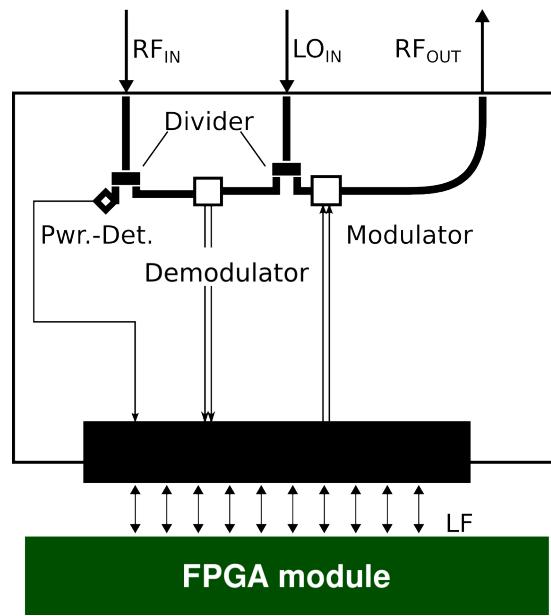
Hardware: RF-Board



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Components:

- Demodulator (Baseband)
- Modulator
- Power detector

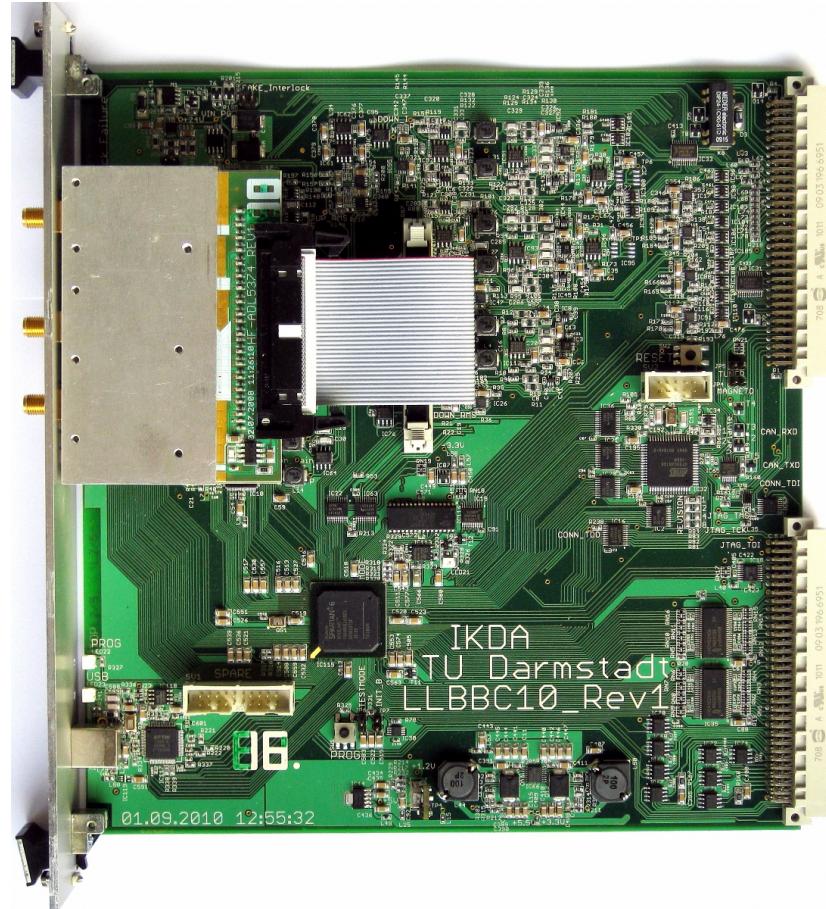


RF-Control Hardware: LLBBC-Board

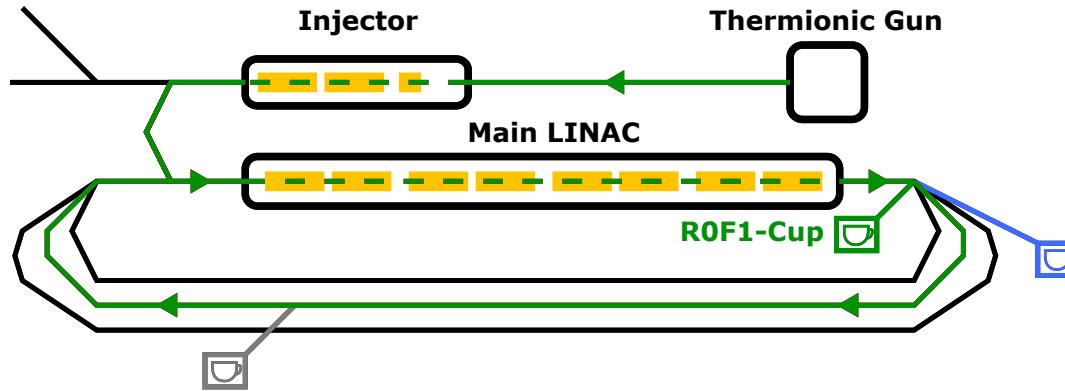


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- RF-Board (frequency-dependant)
- 18 bit ADCs with 1 MS/s
- FPGA (Xilinx Spartan-6)
- CAN-bus
- USB-2.0 (signal streaming)
- Setup developed in 2011



First ERL Operation at the S-DALINAC



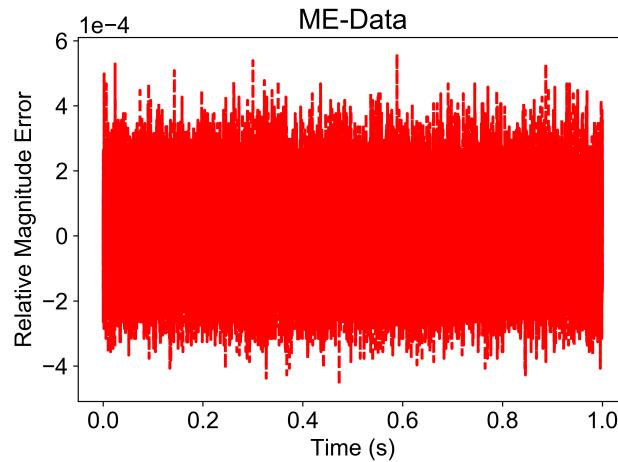
M. Arnold et al.:
First Operation of the S-DALINAC as an Energy Recovery Linac,
In Preparation

- Single turn ERL operation in August 2017
- Beam current of 1 μ A
- During ERL operation about 80-90% transmission on R0F1-Cup
- Stability of RF measured

First ERL Operation at the S-DALINAC RF Stability Measurement Steps



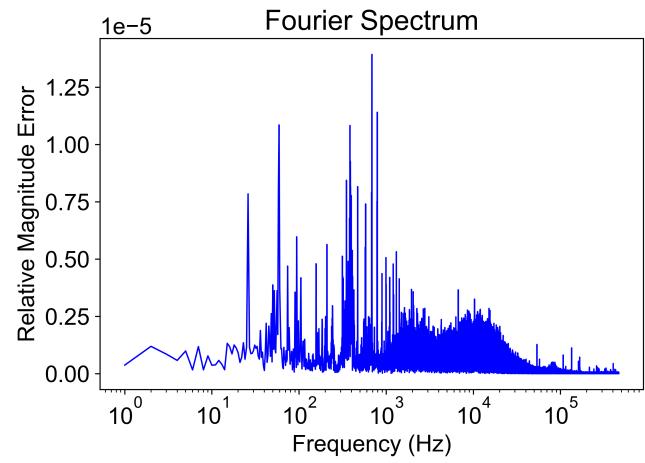
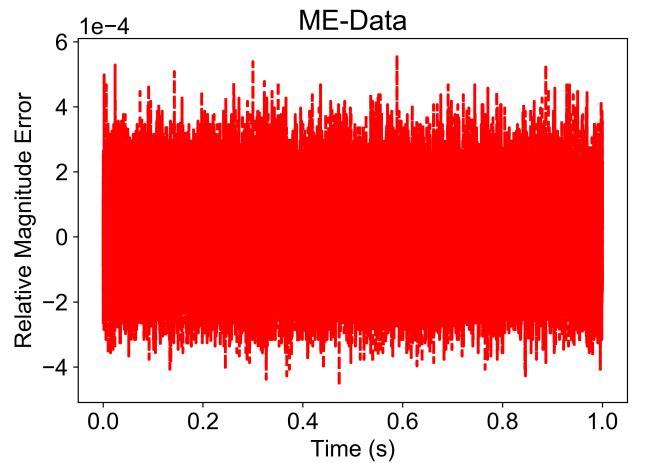
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First ERL Operation at the S-DALINAC RF Stability Measurement Steps



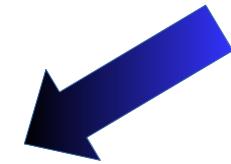
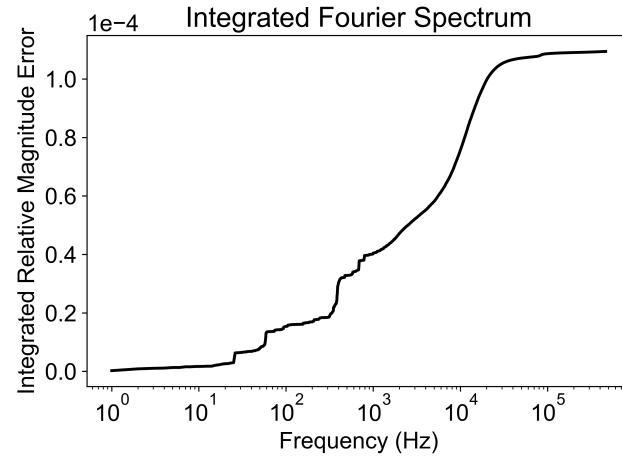
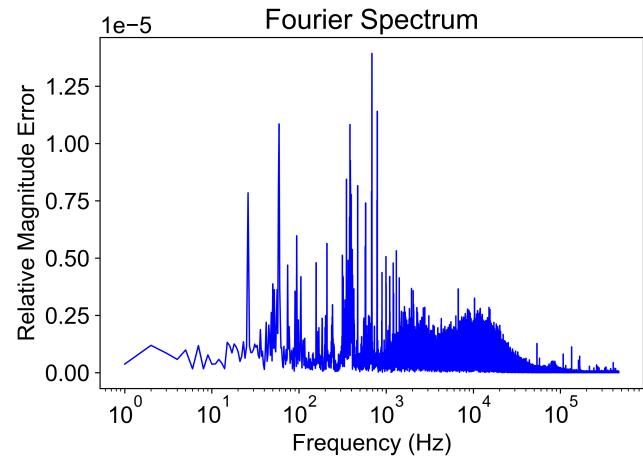
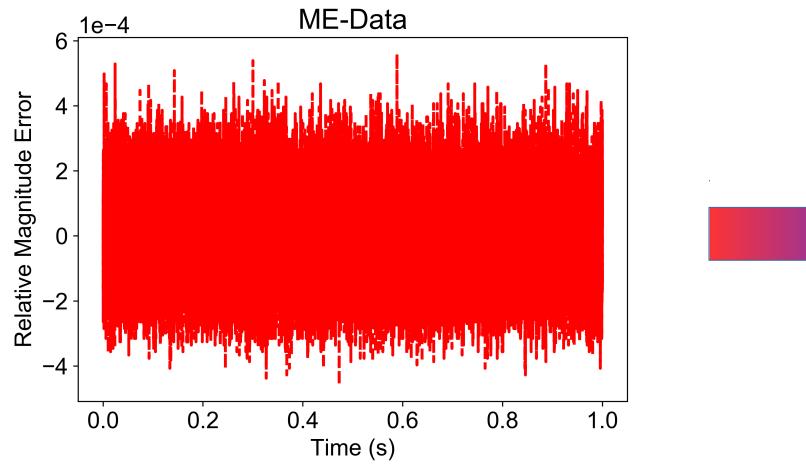
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First ERL Operation at the S-DALINAC RF Stability Measurement Steps



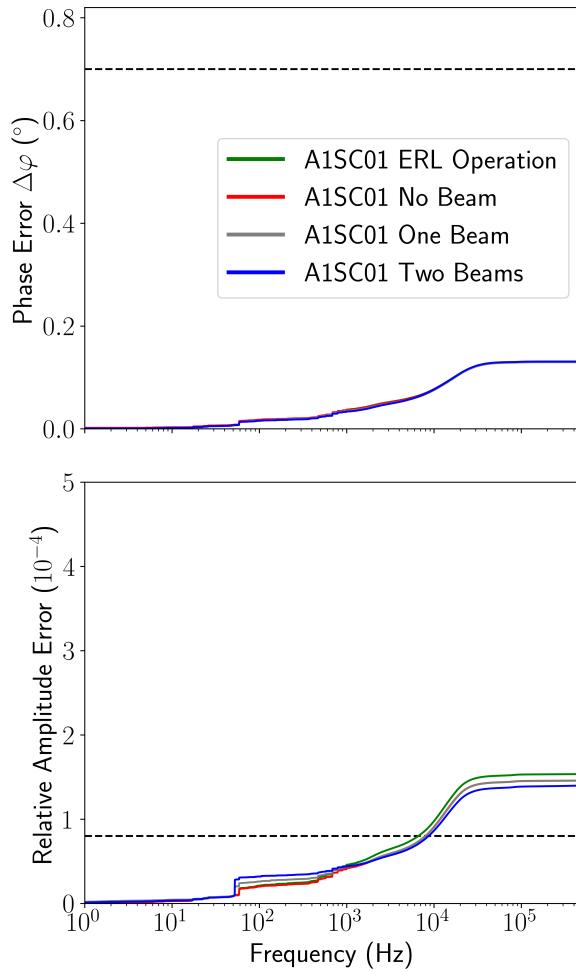
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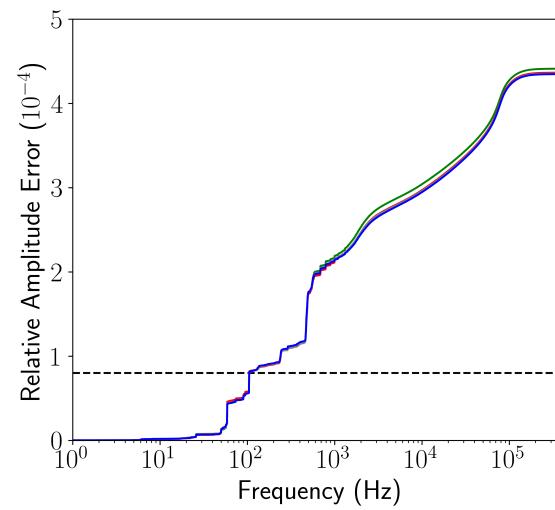
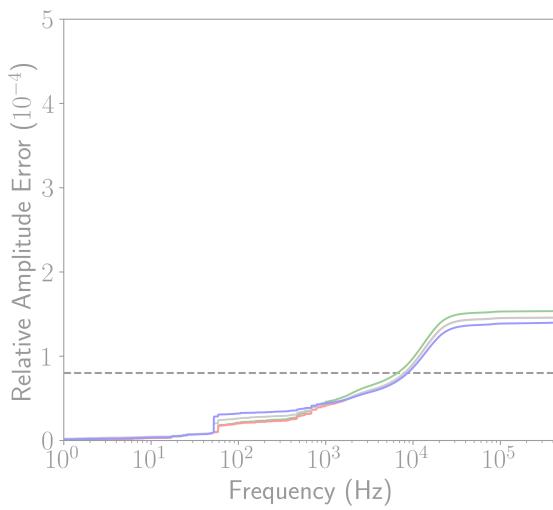
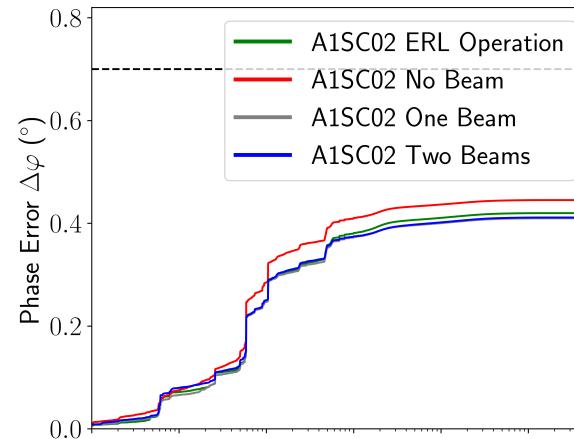
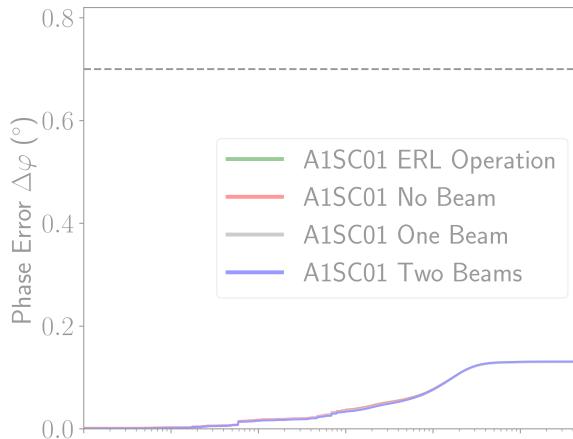
First ERL Operation at the S-DALINAC RF Stability



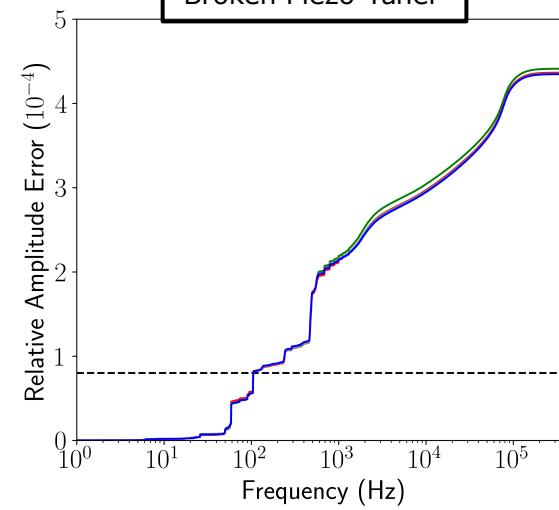
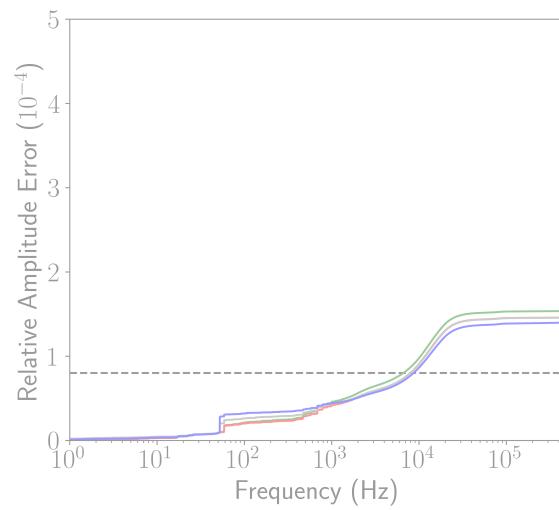
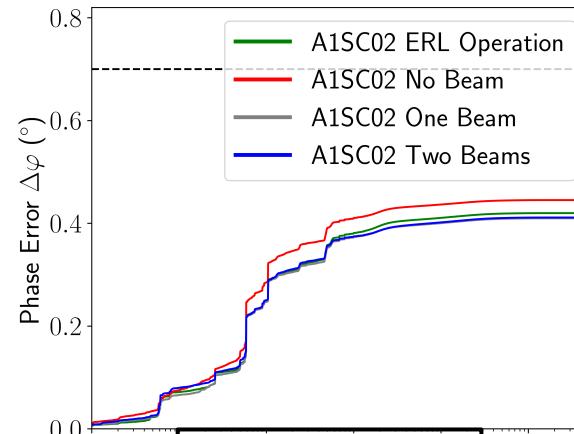
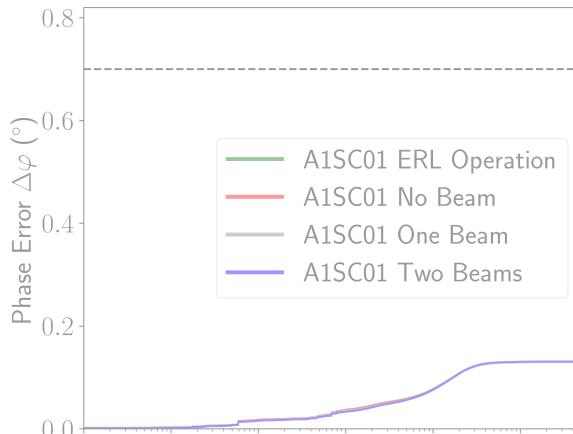
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First ERL Operation at the S-DALINAC RF Stability



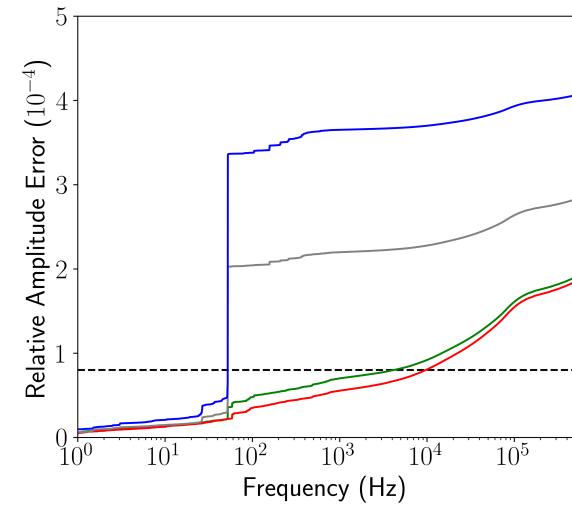
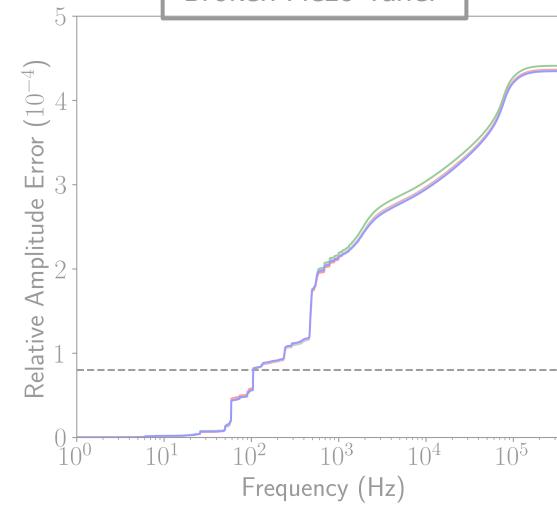
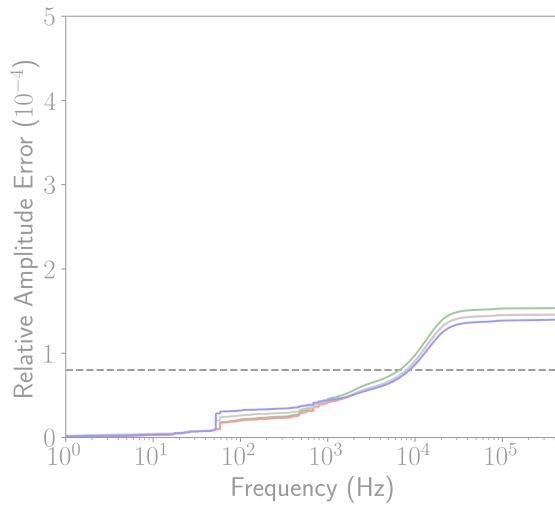
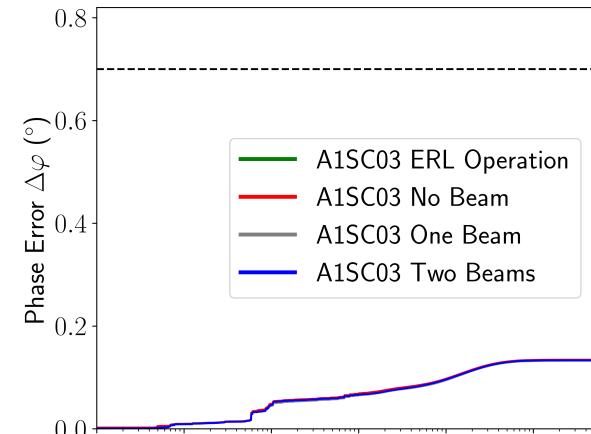
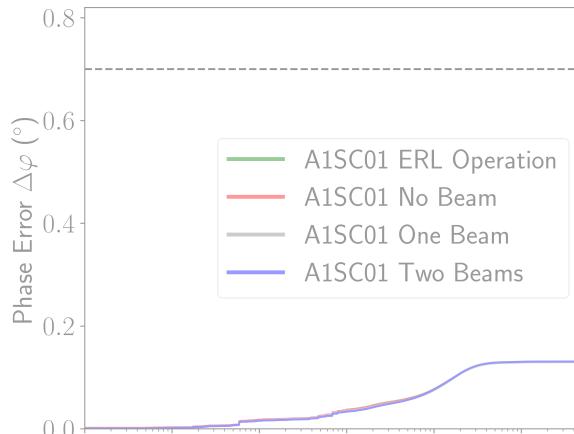
First ERL Operation at the S-DALINAC RF Stability



First ERL Operation at the S-DALINAC RF Stability



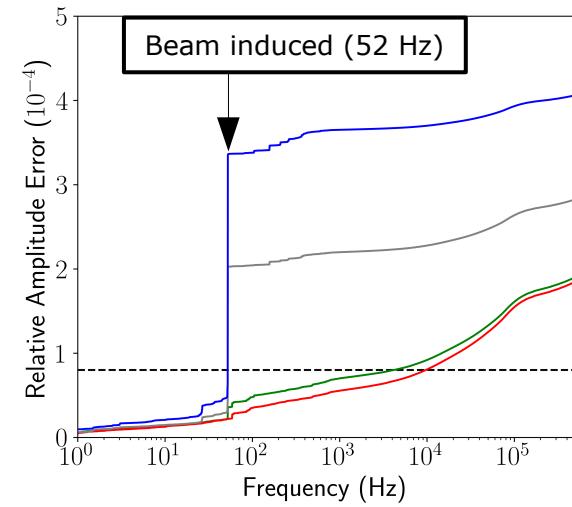
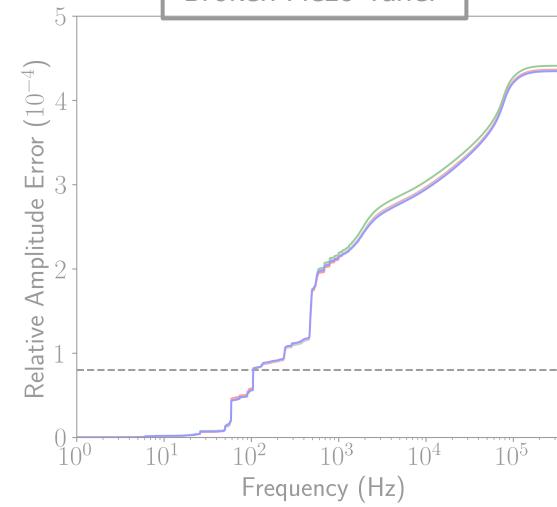
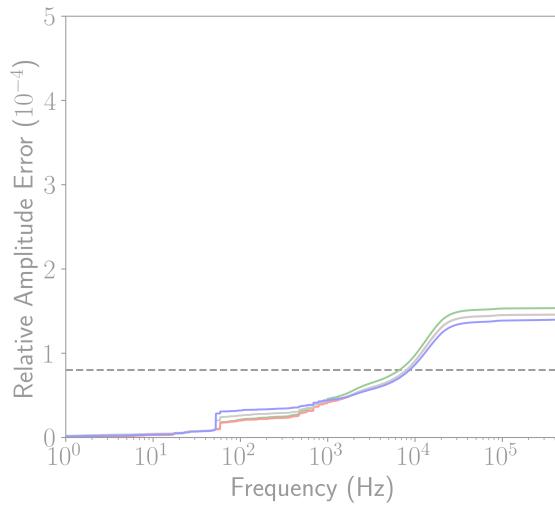
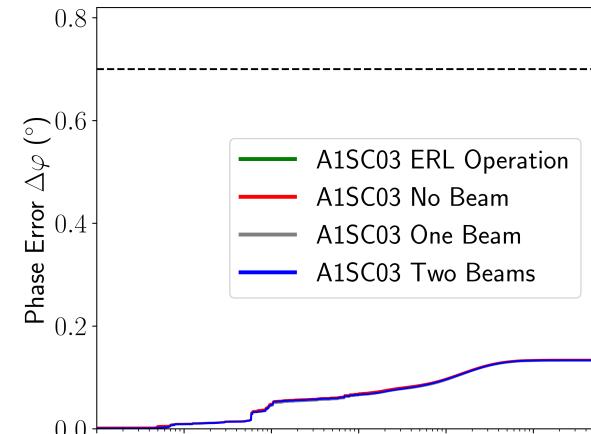
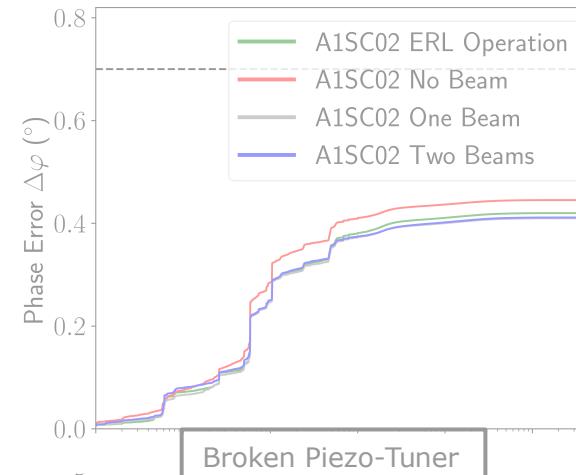
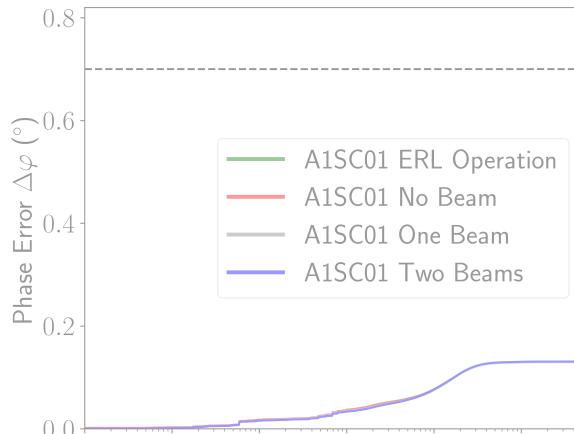
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First ERL Operation at the S-DALINAC RF Stability



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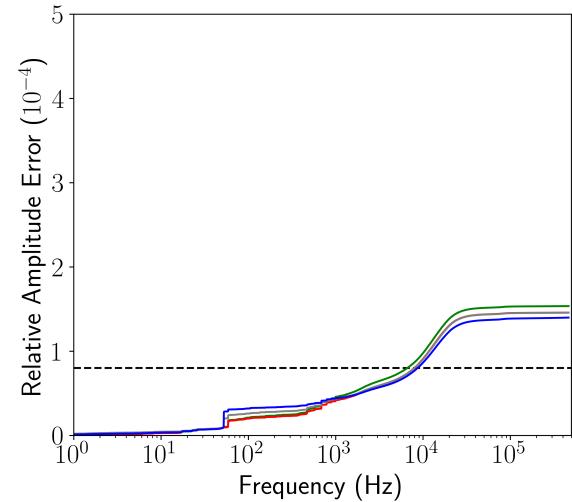
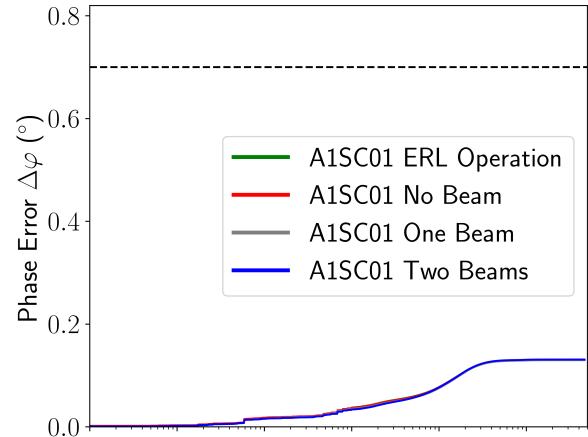


First ERL Operation at the S-DALINAC RF Control Performance



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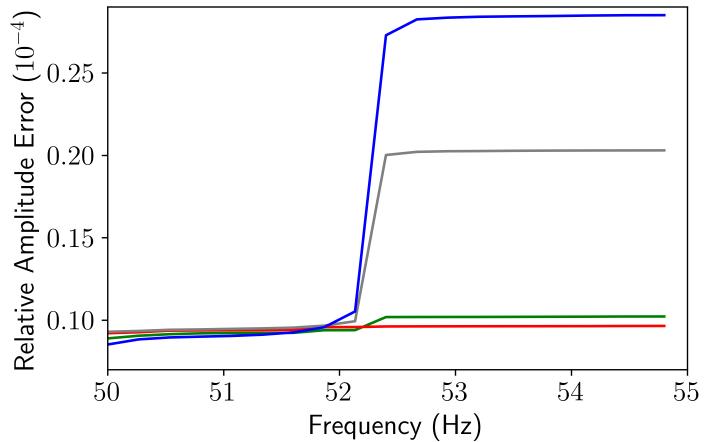
- LLRF control performance sufficient for ERL at 1 μA
- Tests for currents > 1 μA are planned
- Relative amplitude errors too big in comparison to design
- Energy spread induced by RF acceptable for once recirculated ERL



First ERL Operation at the S-DALINAC

ERL Efficiency by RF Control

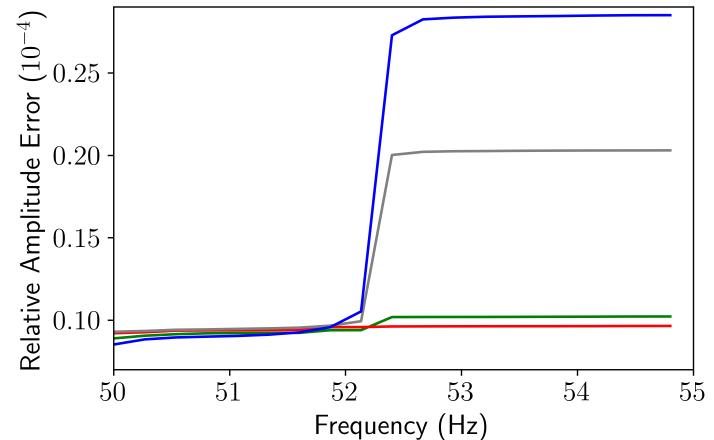
- Beam disturbance at 52 Hz
 - Modulation by netfrequency in gun?
 - Further investigation in future



First ERL Operation at the S-DALINAC

ERL Efficiency by RF Control

- Beam disturbance at 52 Hz
 - Modulation by netfrequency in gun?
 - Further investigation in future
- Nevertheless disturbance usable as first order estimate for ERL efficiency

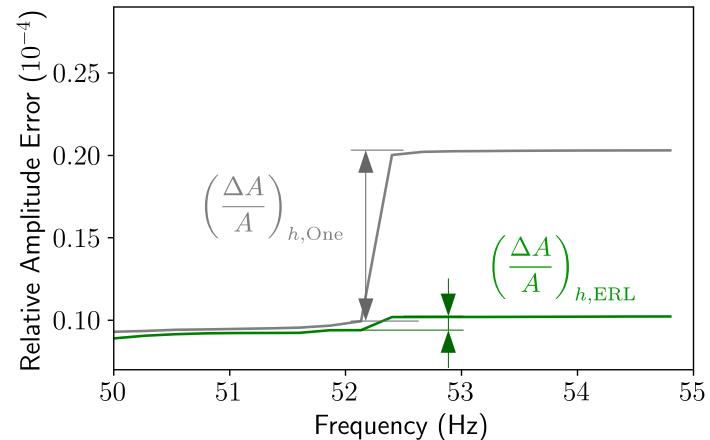


$$\mathcal{E}_{\text{RF}} = \frac{P_{b,\text{Acc}} - P_{b,\text{ERL}}}{P_{b,\text{Acc}}} = \underbrace{(90.1 \pm 0.3)\%}_{\text{A1SC01}}$$

First ERL Operation at the S-DALINAC

ERL Efficiency by RF Control

- Beam disturbance at 52 Hz
 - Modulation by netfrequency in gun?
 - Further investigation in future
- Nevertheless disturbance usable as first order estimate for ERL efficiency



$$\mathcal{E}'_{\text{RF}} = \frac{(\frac{\Delta A}{A})_{h,\text{One}} - (\frac{\Delta A}{A})_{h,\text{ERL}}}{(\frac{\Delta A}{A})_{h,\text{One}}}$$

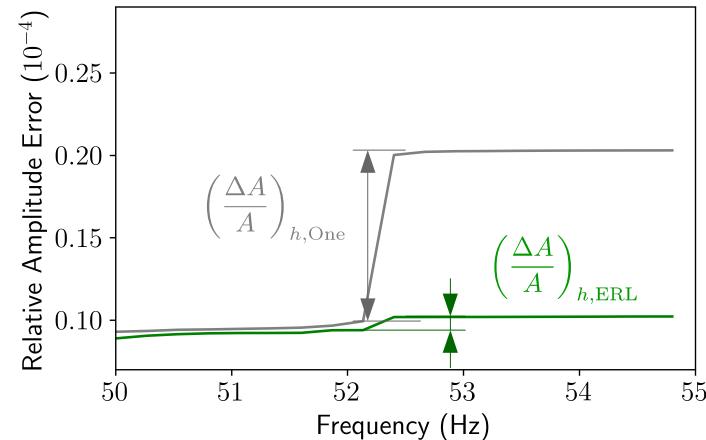
First ERL Operation at the S-DALINAC

ERL Efficiency by RF Control



- Efficiencies for ALL cavities via RF Control:

Cavity	Efficiency (+-10%)
A1SC01	92 %
A1SC02	73 %
A1SC03	92 %
A1SC04	98 %
A1SC05	96 %
A1SC06	100 %
A1SC07	100 %
A1SC08	60 %



$$\mathcal{E}'_{\text{RF}} = \frac{(\frac{\Delta A}{A})_{h,\text{One}} - (\frac{\Delta A}{A})_{h,\text{ERL}}}{(\frac{\Delta A}{A})_{h,\text{One}}}$$

Developments

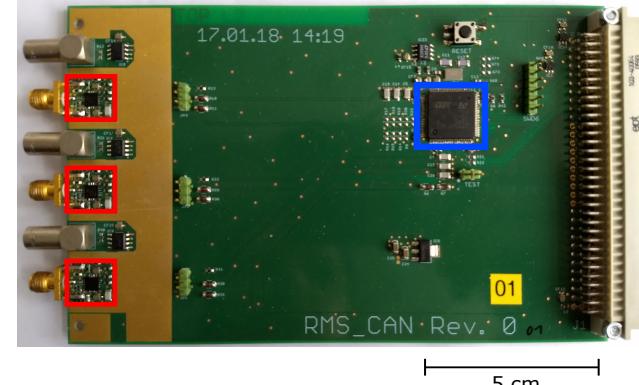
RF Power Measurement



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- Analog 65 dB true rms responding power detector (ADL 5902)
- Microcontroller (STM32) for connection with control system via CAN-bus
- 12-bit ADCs with 5 MS/s

Power Detectors Micro-Controller



- Setup actively cooled
- Radiation protected



Summary & Outlook



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- LLRF control system (RF Board, LLBBC-Board)
- Successful first ERL operation
 - Influence of the beam on RF stability negligible at 1 μ A
 - Controller gains still optimizable to reduce residual errors of RF control
 - Further investigation of beam disturbance at 52 Hz
- New RF power measurement system is ready for usage
- Extremum-seeking control as optimization algorithm for RF Control



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Thank you for your attention!