

Low Level RF ERL Experience at the S-DALINAC*



TECHNISCHE
UNIVERSITÄT
DARMSTADT

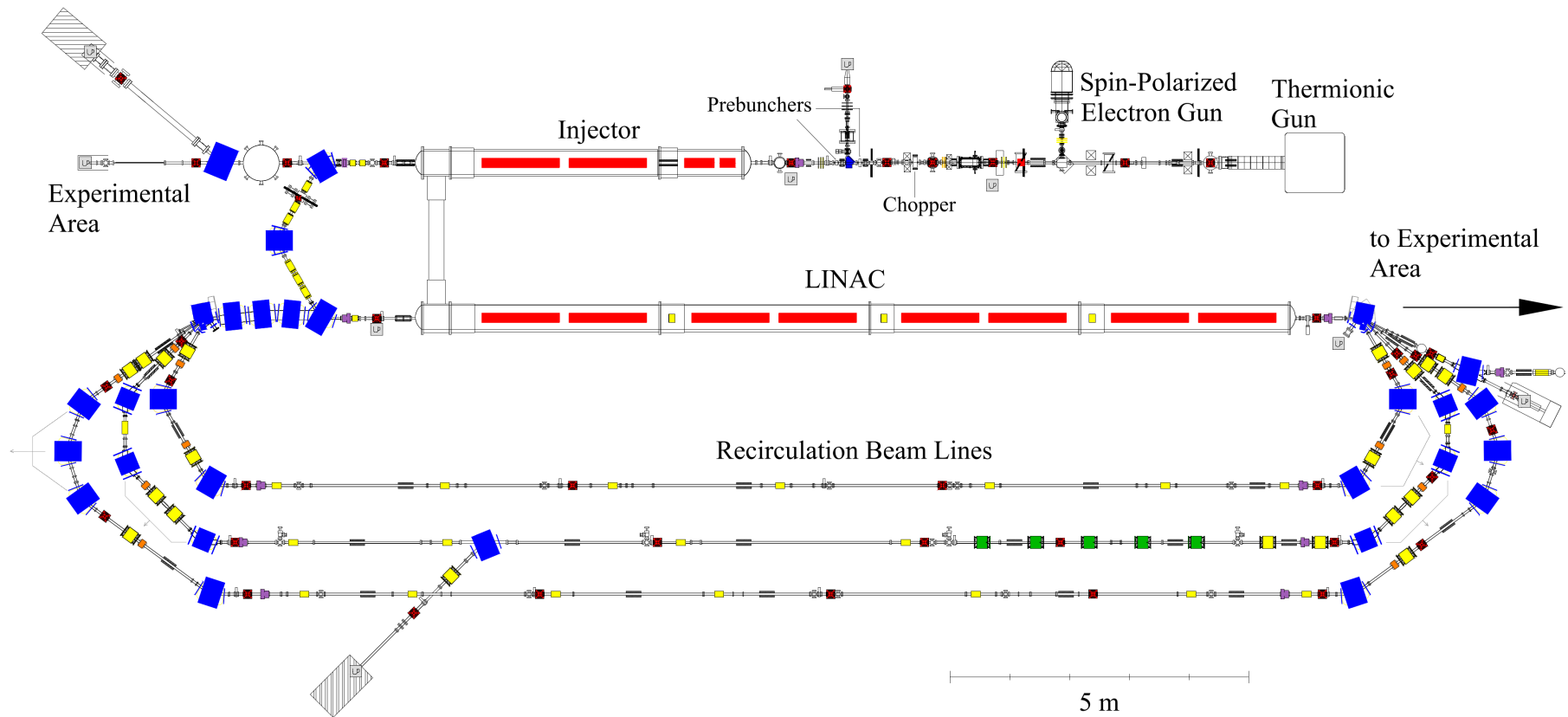


Picture by Jan-
Christoph Hartung

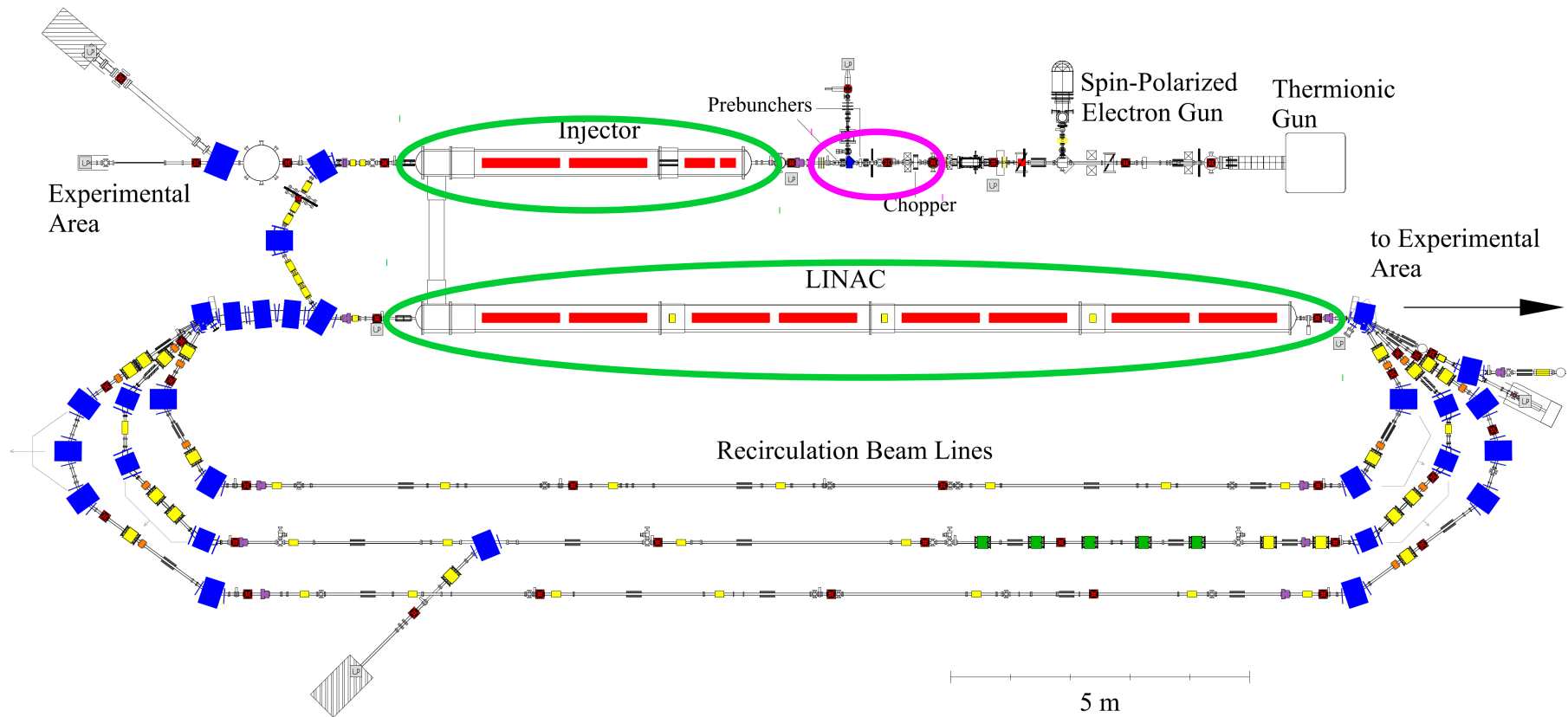


*Supported by the DFG through GRK 2128

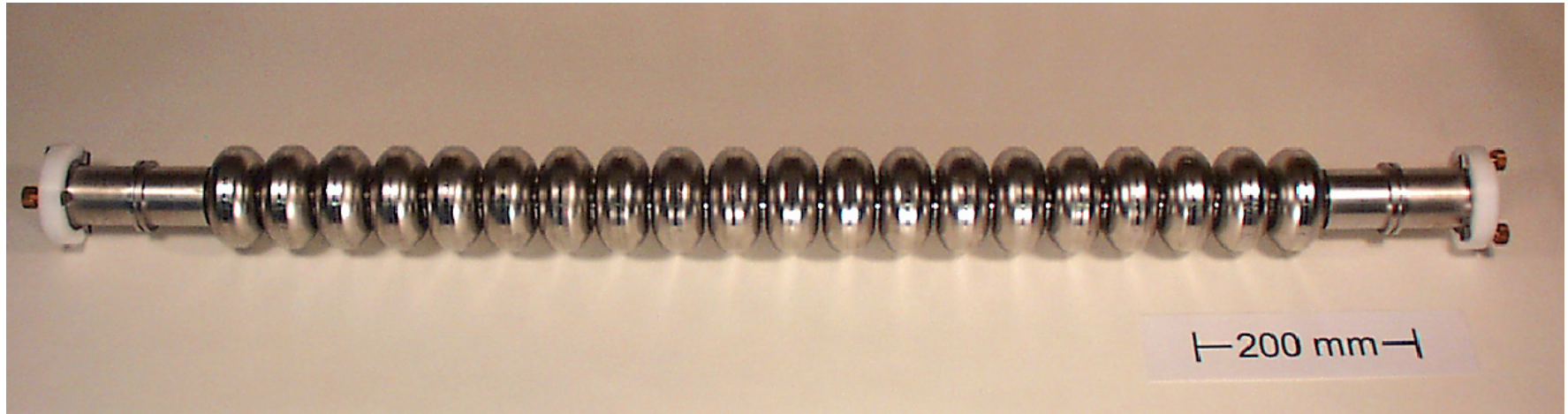
S-DALINAC



S-DALINAC



SRF-Cavities



Material: Niobium
(RRR=280)

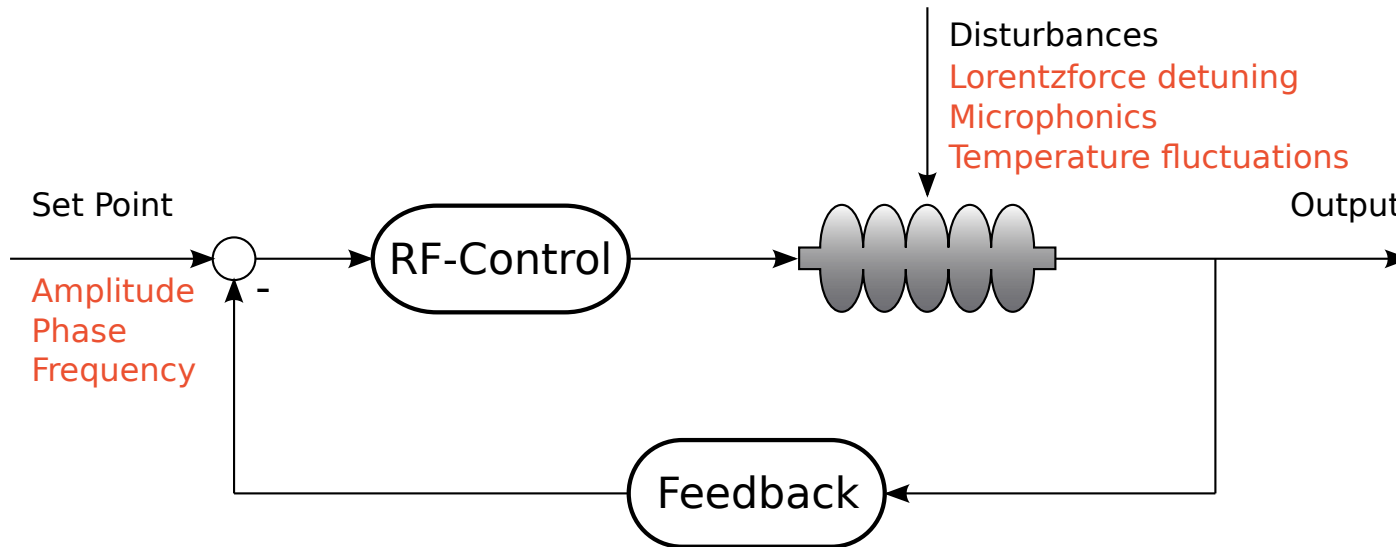
Temp.: 2 K

Freq.: 2.997 GHz

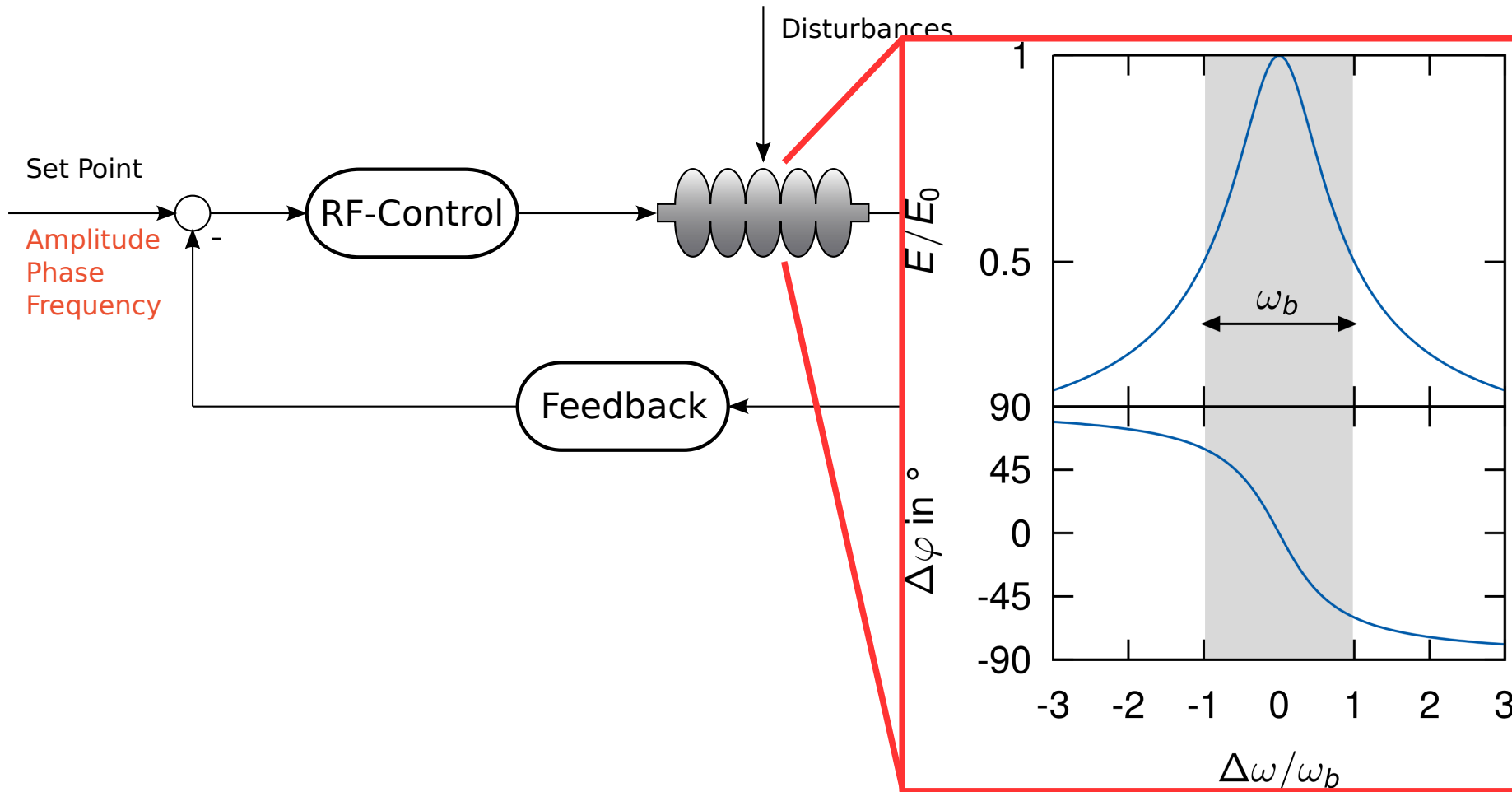
Mode: TM_{010}

Number of cells:	20	5
Length:	1 m	0.25 m
β :	1	1
Q_0 :	3×10^9	3×10^9
E_{acc} :	5 MV/m	5 MV/m

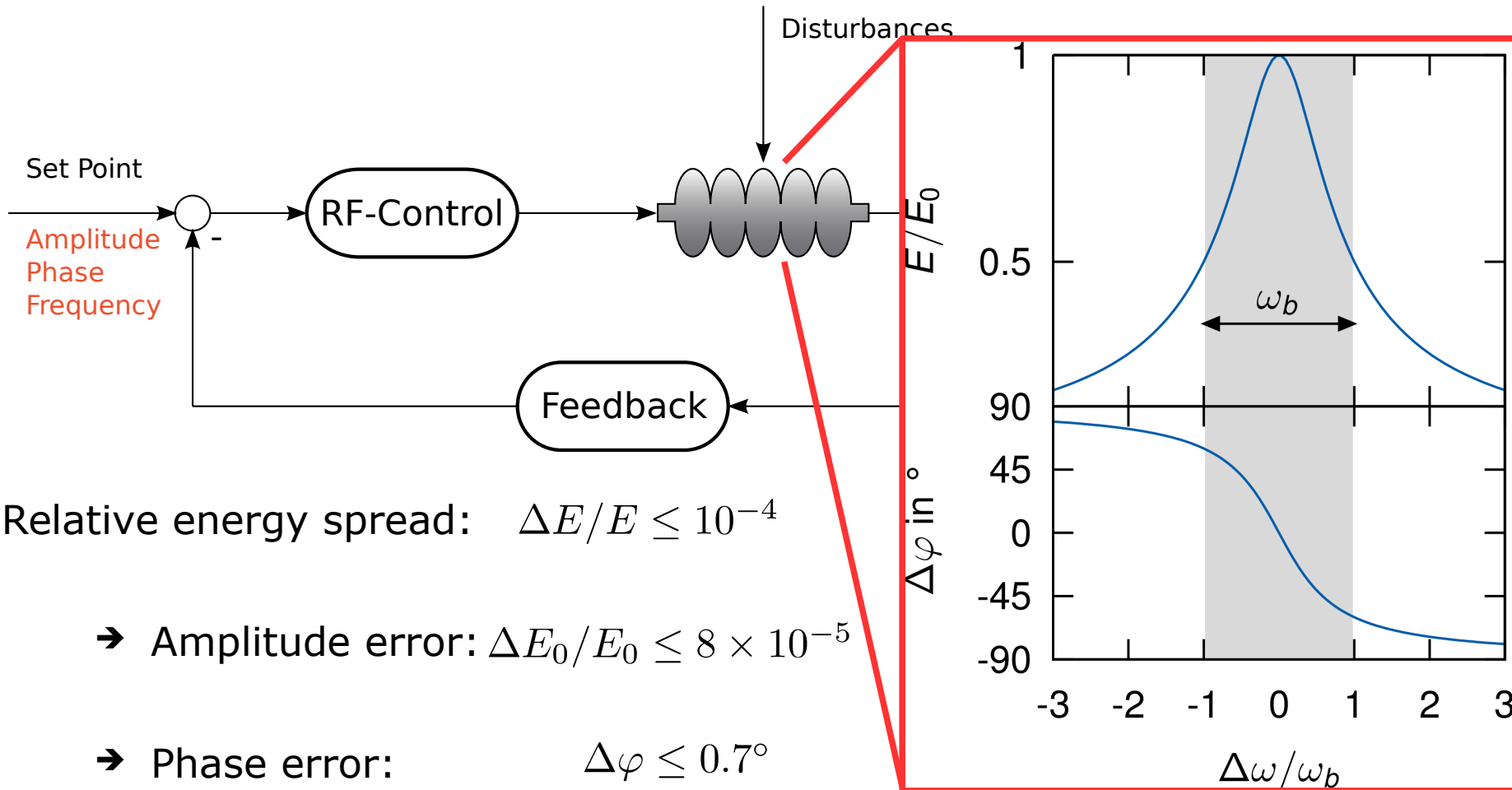
RF-Control Closed Loop



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RF-Control Closed Loop

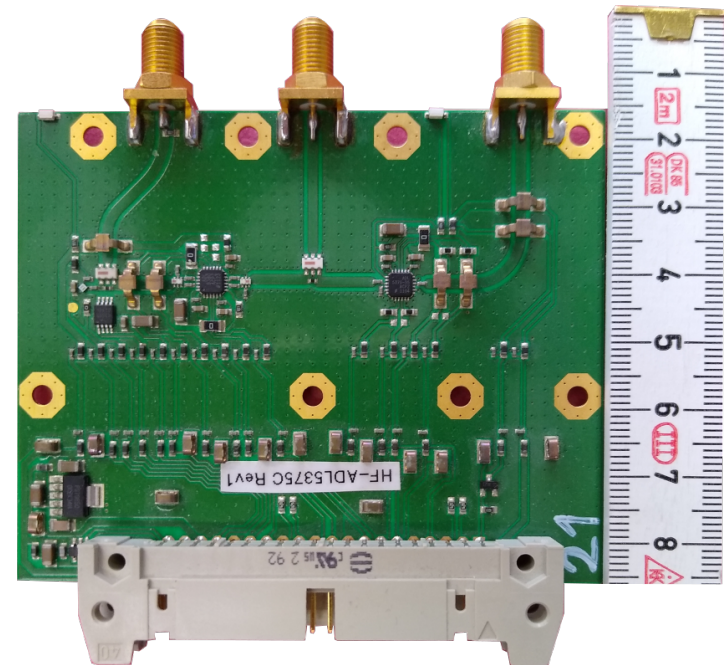
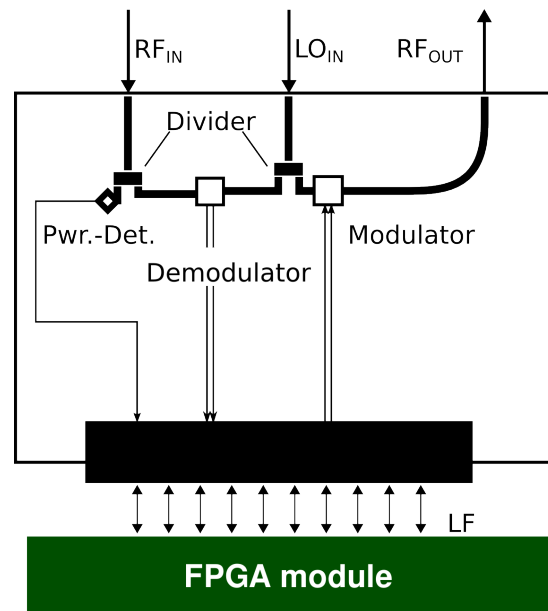


RF-Control

Hardware: RF-Board

Components:

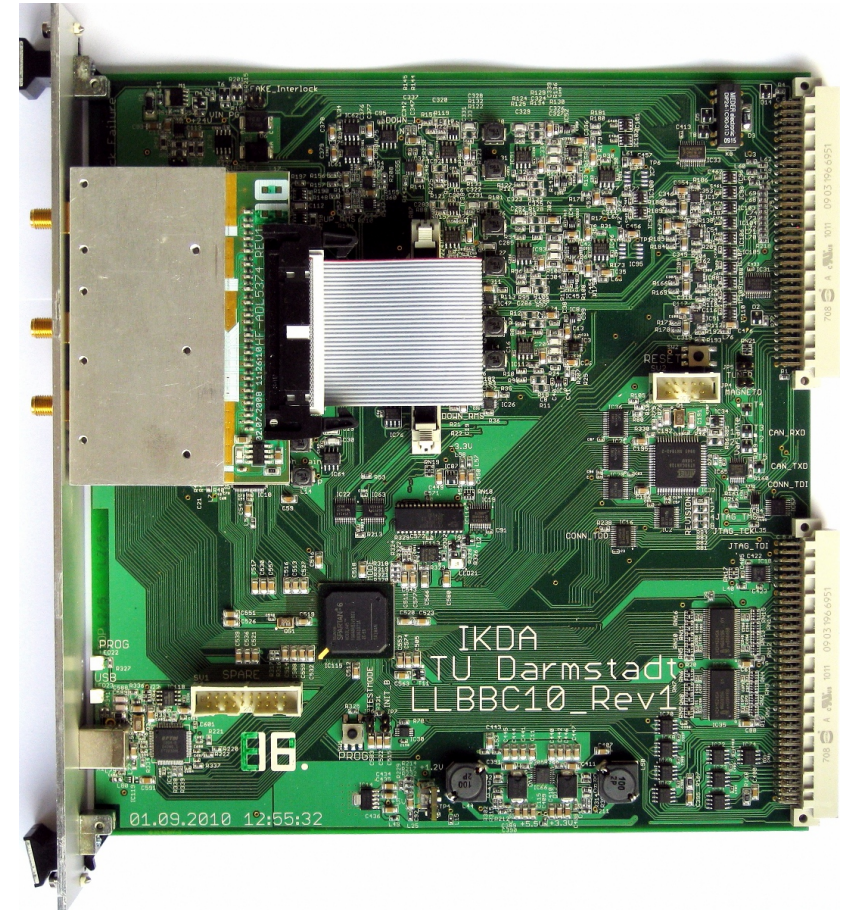
- Demodulator (Baseband)
- Modulator
- Power detector



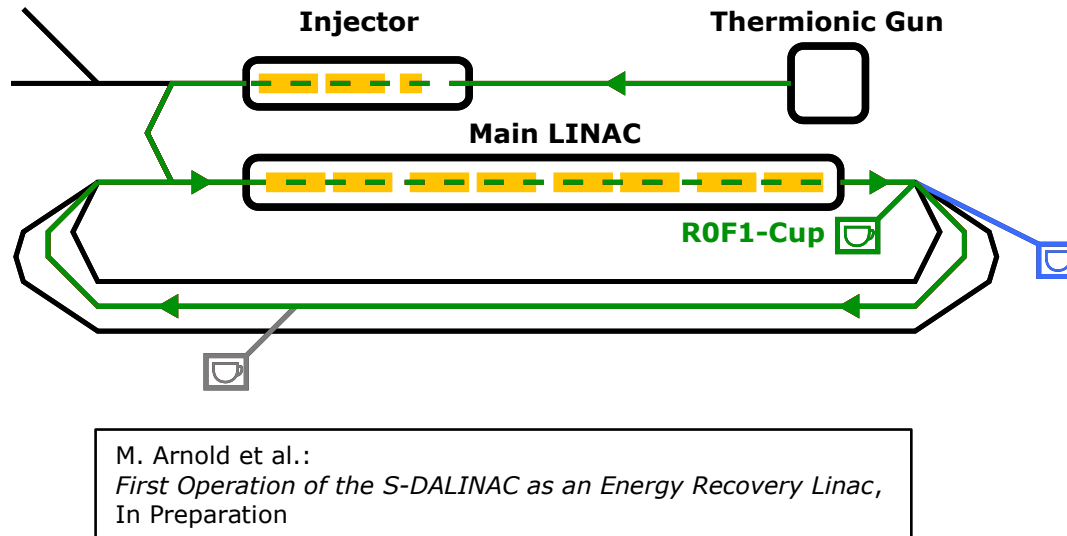
RF-Control

Hardware: LLBBC-Board

- 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



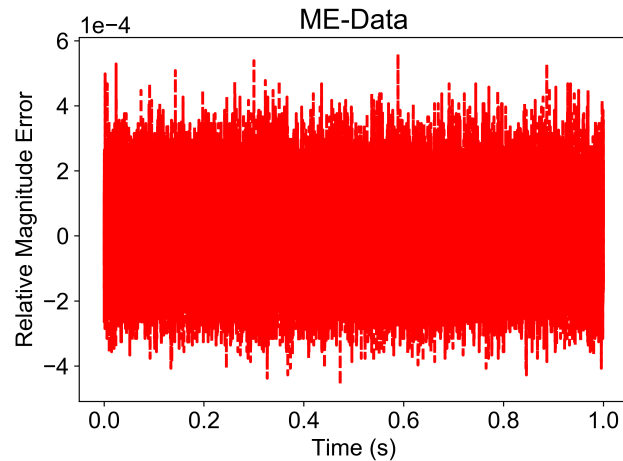
First ERL Operation at the S-DALINAC



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

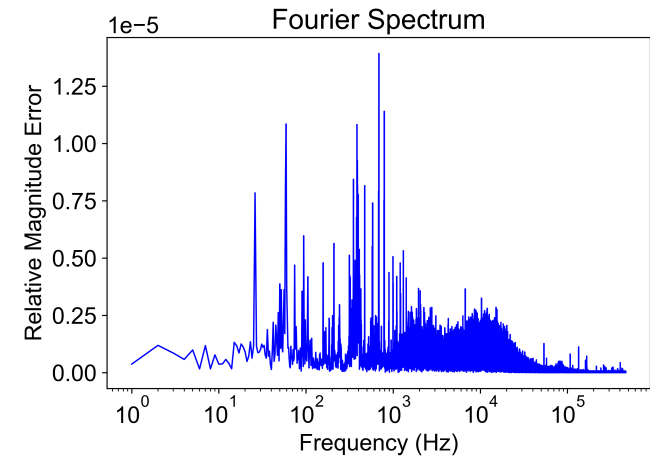
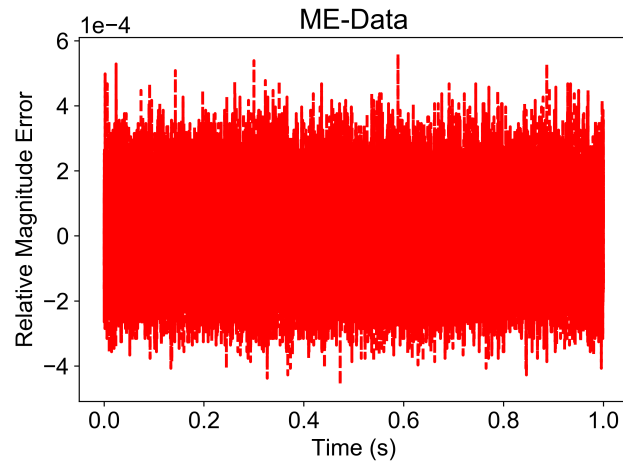
First ERL Operation at the S-DALINAC

RF Stability Measurement Steps



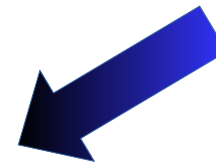
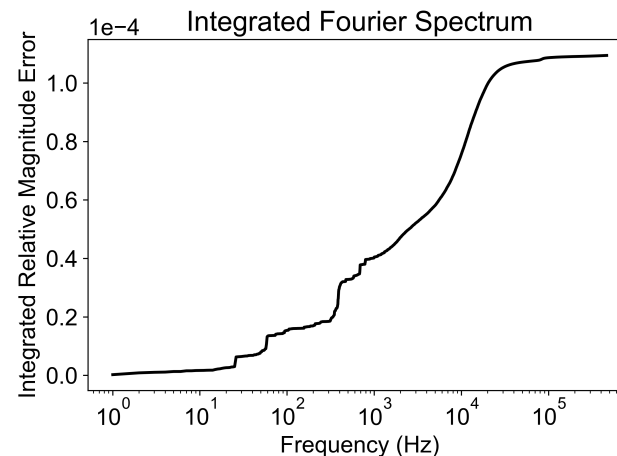
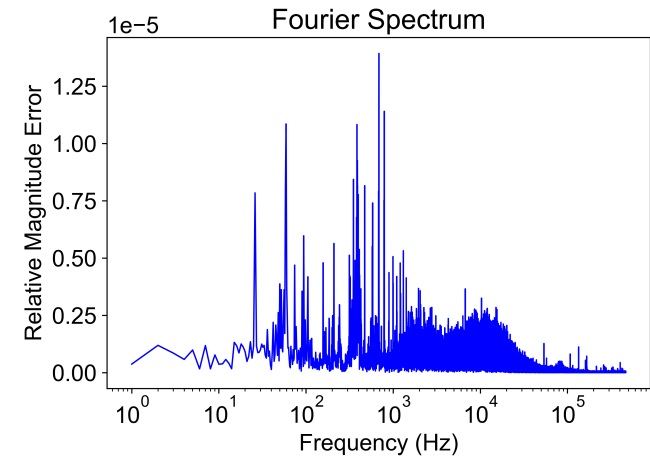
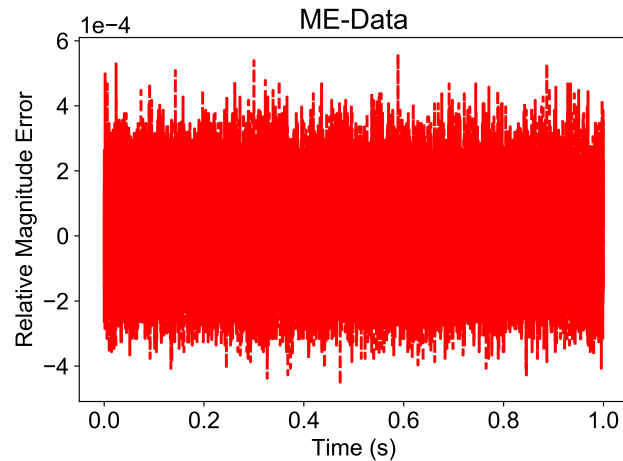
First ERL Operation at the S-DALINAC

RF Stability Measurement Steps

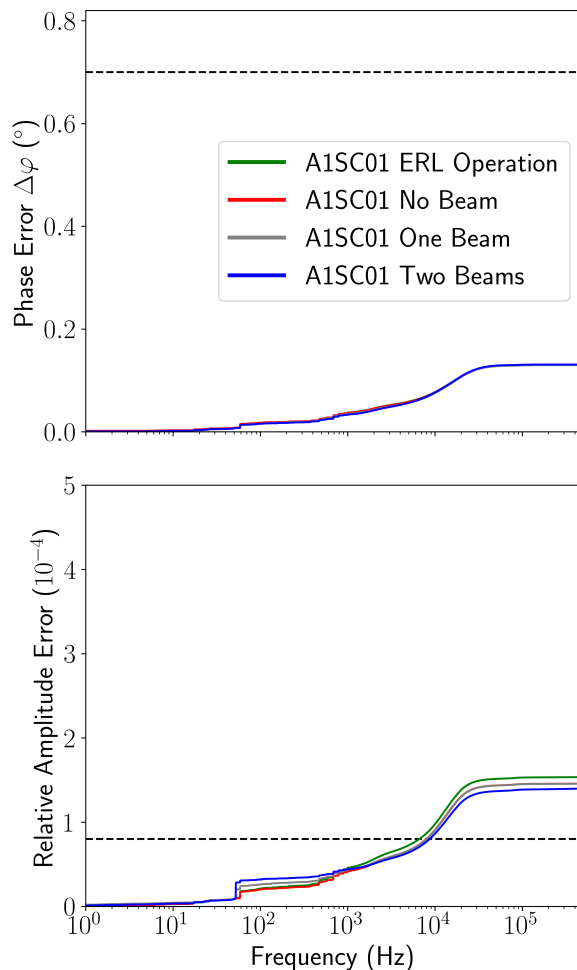


First ERL Operation at the S-DALINAC

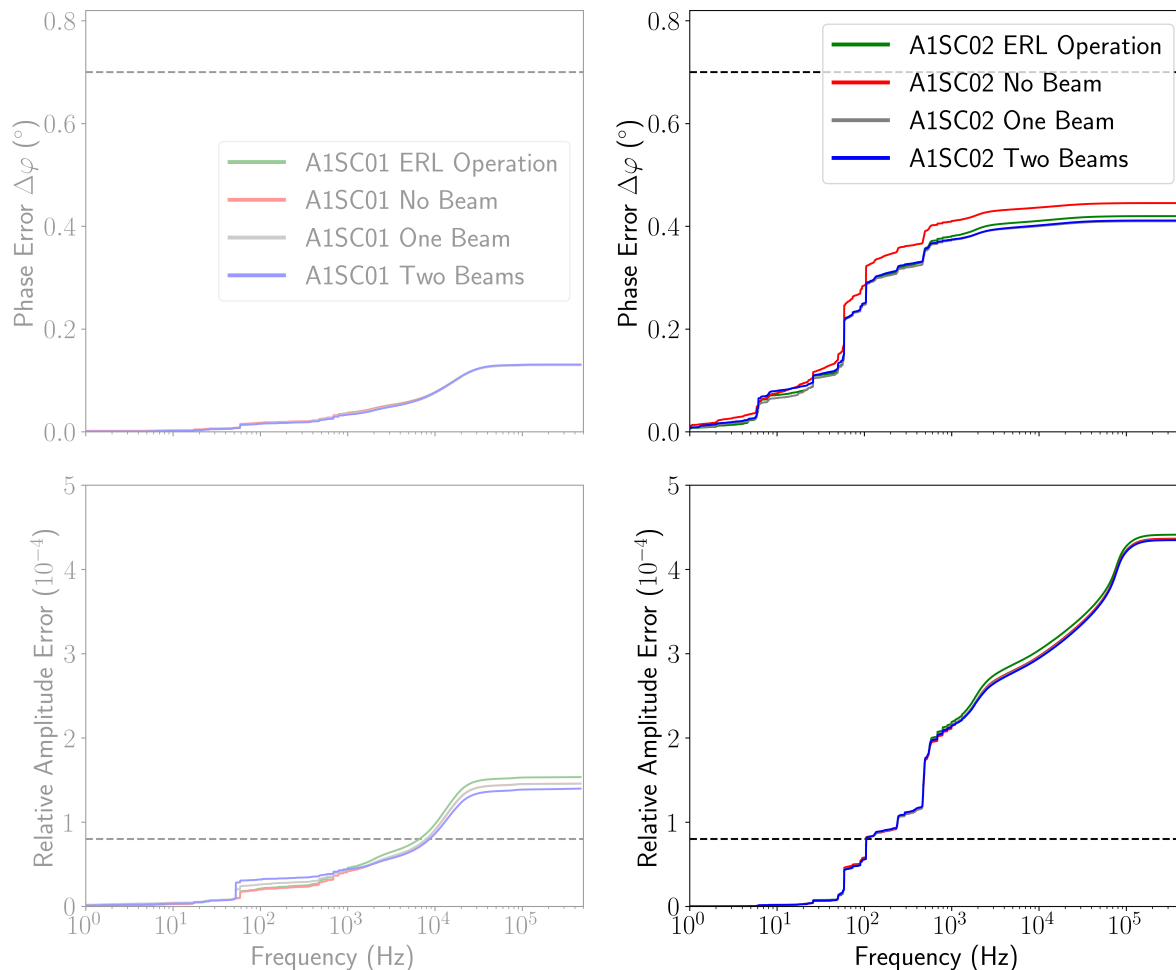
RF Stability Measurement Steps



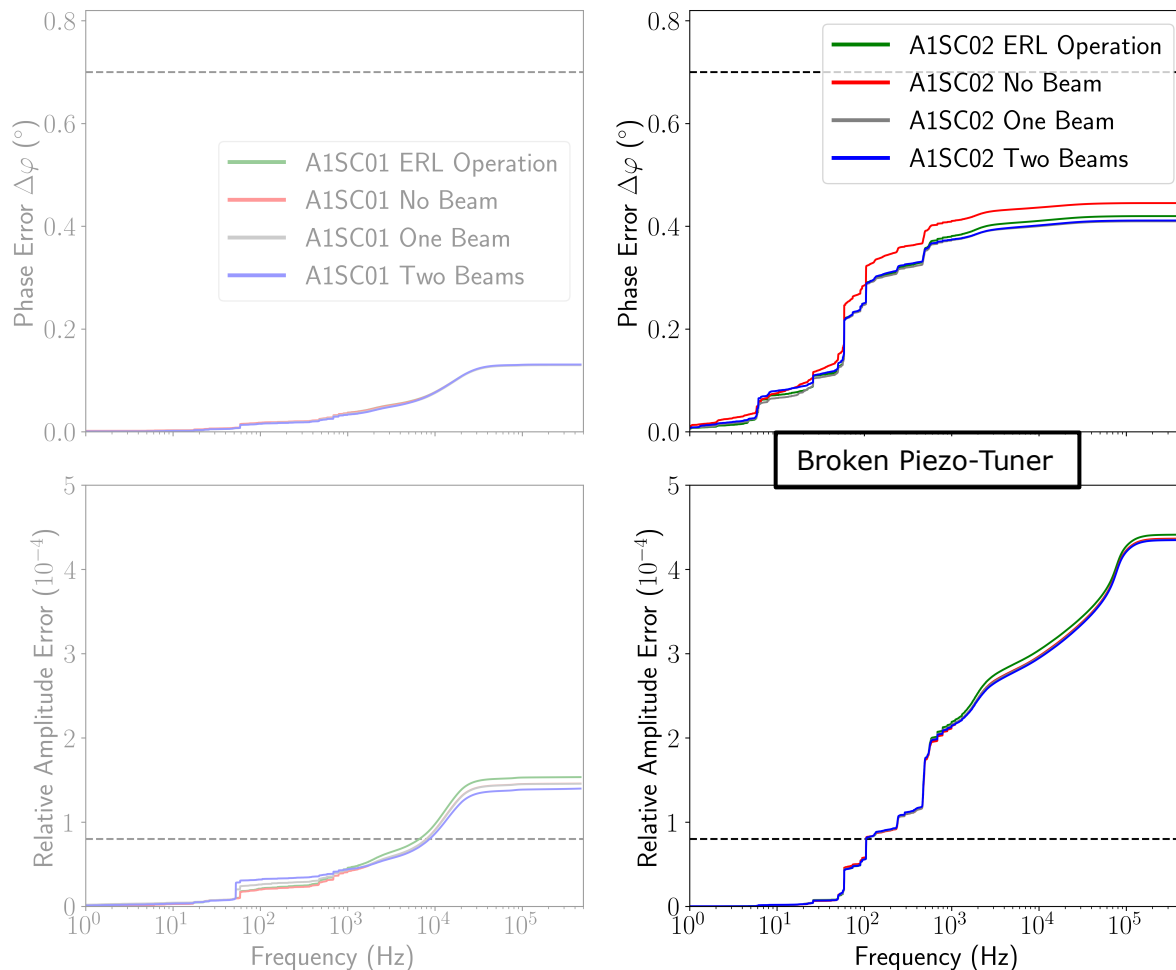
First ERL Operation at the S-DALINAC RF Stability



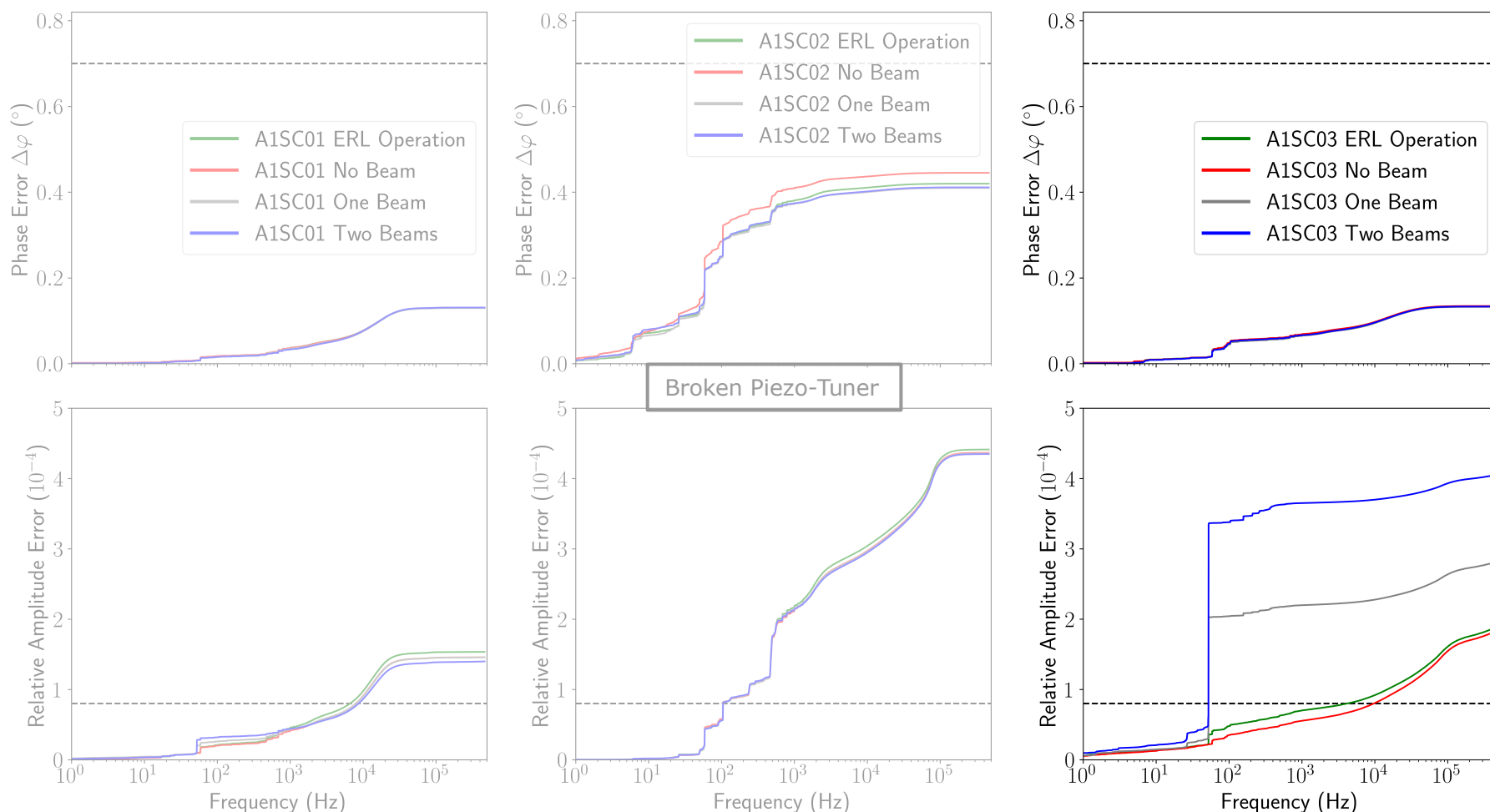
First ERL Operation at the S-DALINAC RF Stability



First ERL Operation at the S-DALINAC RF Stability

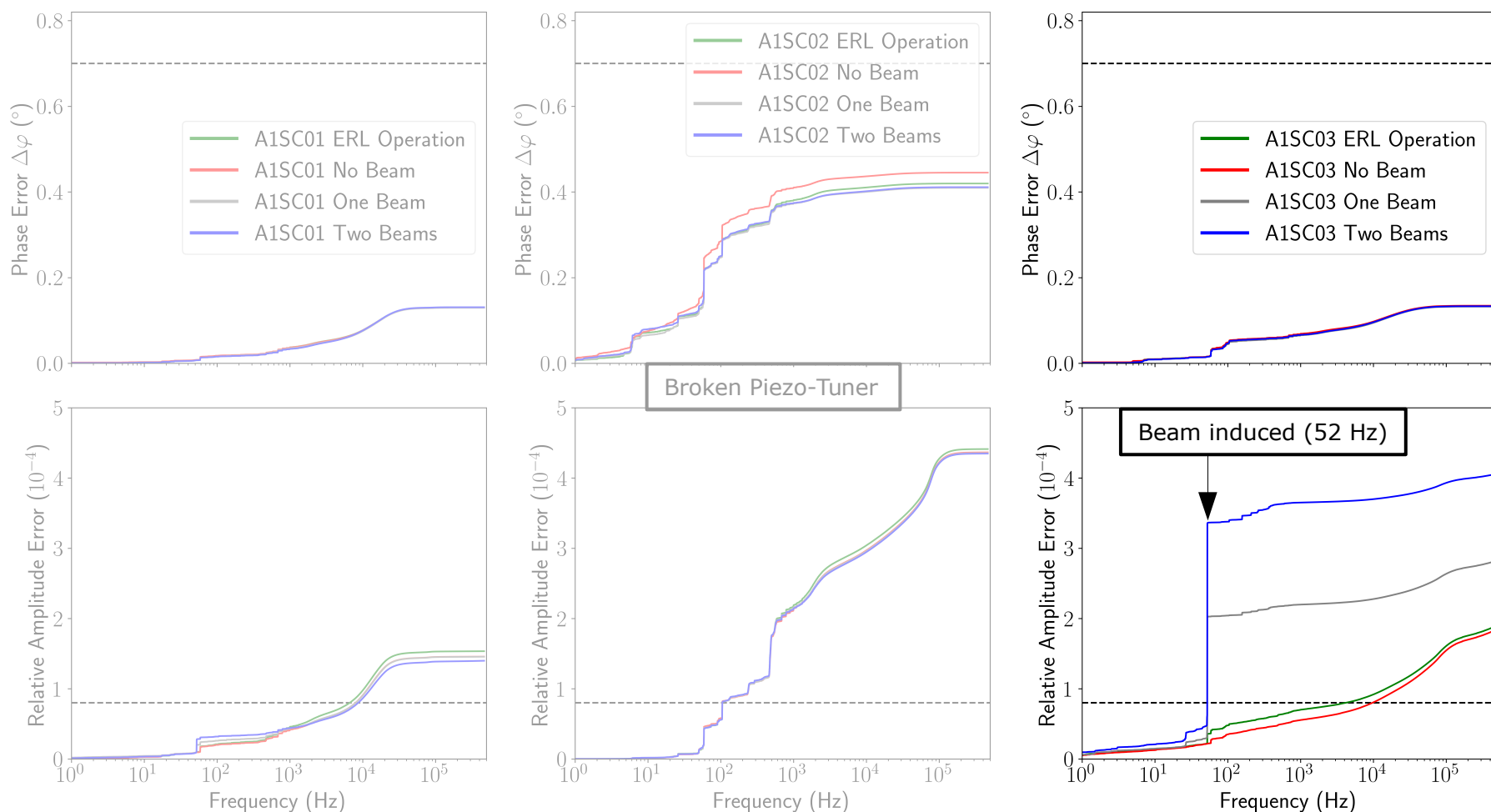


First ERL Operation at the S-DALINAC RF Stability



First ERL Operation at the S-DALINAC

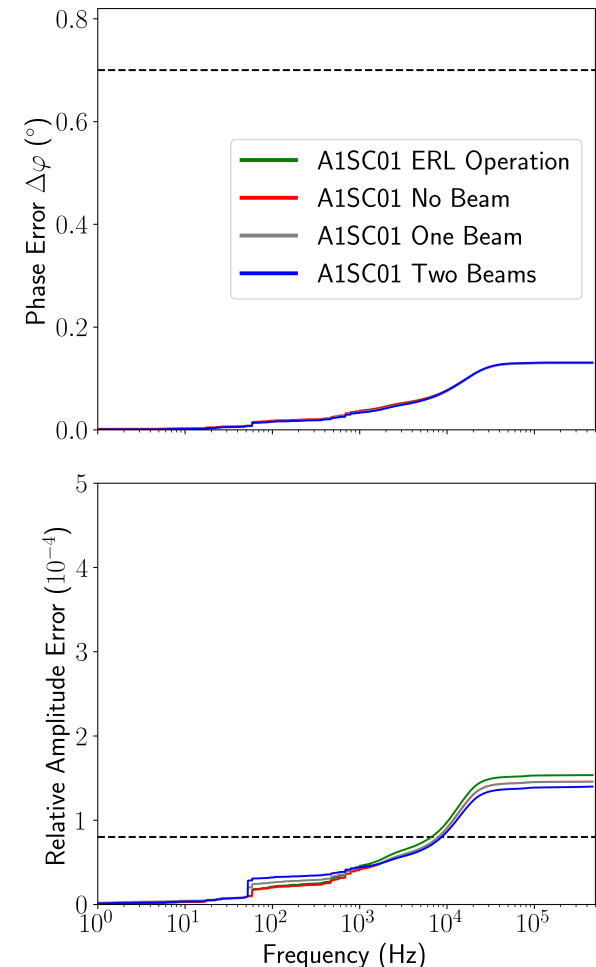
RF Stability



First ERL Operation at the S-DALINAC

RF Control Performance

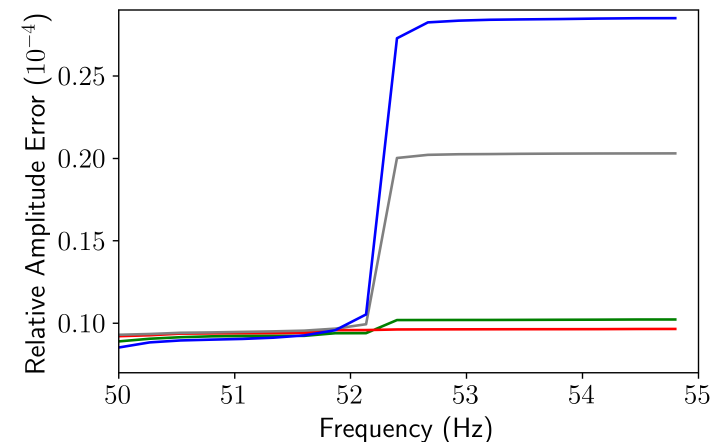
- LLRF control performance sufficient for ERL at 1 μA
- Tests for currents $> 1 \mu\text{A}$ are planned
- Relative amplitude errors too big in comparison to design
- Energy spread induced by RF acceptable for once recirculated ERL



First ERL Operation at the S-DALINAC

ERL Efficiency by RF Control

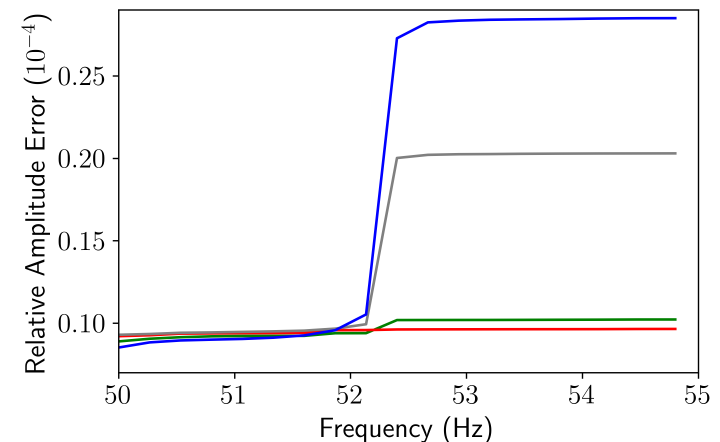
- Beam disturbance at 52 Hz
 - Modulation by netfrequency in gun?
 - Further investigation in future



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

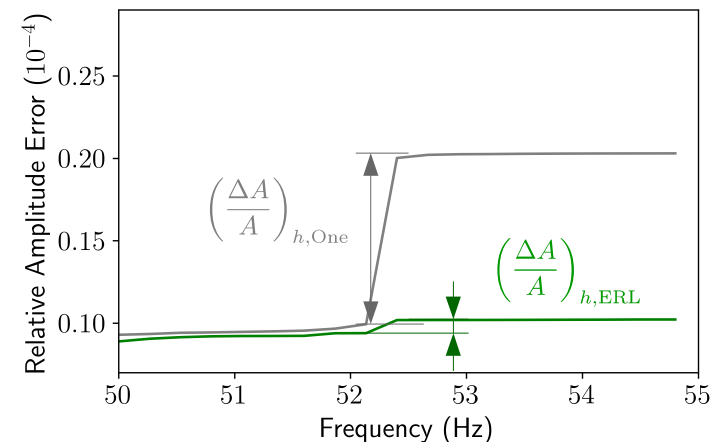


$$\mathcal{E}_{\text{RF}} = \frac{P_{b,\text{Acc}} - P_{b,\text{ERL}}}{P_{b,\text{Acc}}} = \underbrace{(90.1 \pm 0.3)\%}_{\text{A1SC01}}$$

First ERL Operation at the S-DALINAC

ERL Efficiency by RF Control

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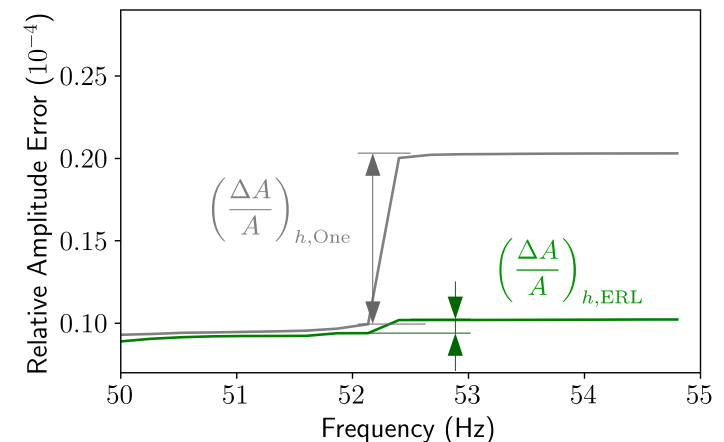
$$\mathcal{E}'_{\text{RF}} = \frac{\left(\frac{\Delta A}{A}\right)_{h, \text{One}} - \left(\frac{\Delta A}{A}\right)_{h, \text{ERL}}}{\left(\frac{\Delta A}{A}\right)_{h, \text{One}}}$$

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 %

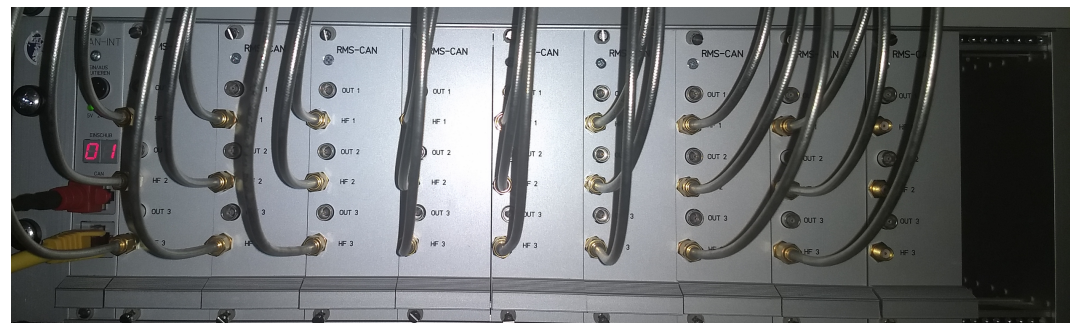
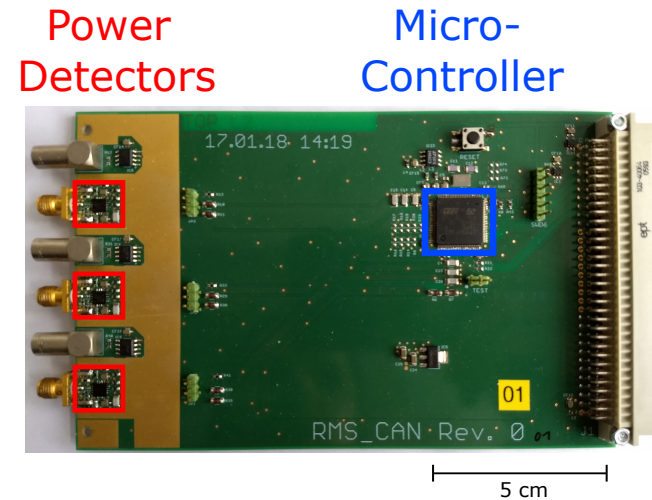


$$\mathcal{E}'_{\text{RF}} = \frac{\left(\frac{\Delta A}{A}\right)_{h, \text{One}} - \left(\frac{\Delta A}{A}\right)_{h, \text{ERL}}}{\left(\frac{\Delta A}{A}\right)_{h, \text{One}}}$$

Developments

RF Power Measurement

- 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
- Setup actively cooled
- Radiation protected



- LLRF control system (RF Board, LLBBC-Board)
- Successful first ERL operation
 - Influence of the beam on RF stability neglectible at 1 μA
 - 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

Thank you for your attention!