HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

MTCA applications at HZDR

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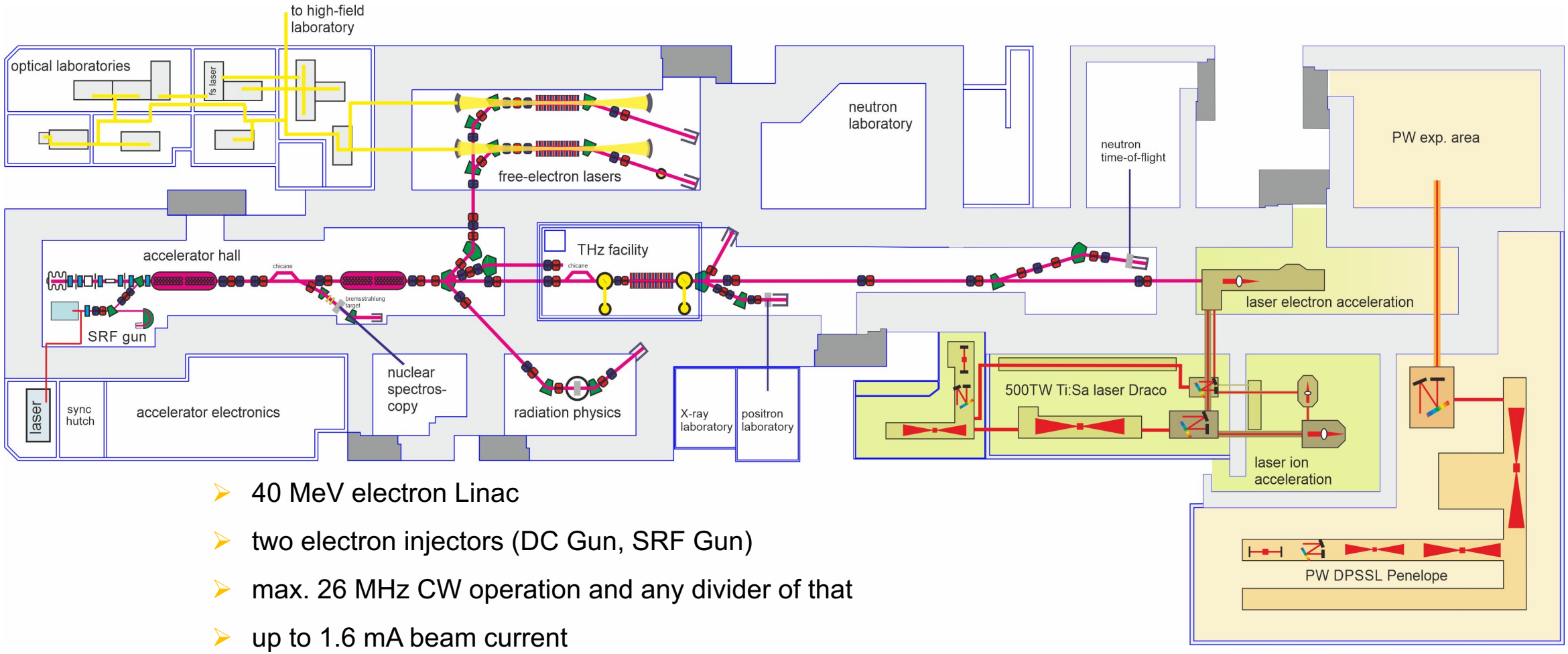
for the ELBE RF, Timing and Synchronization group

Outline

- Introduction to ELBE accelerator
- LLRF
- Bunch arrival time monitor
- Beam based Feedback
- ps-Timing System
- Outlook

Introduction ELBE

User facility since 2001

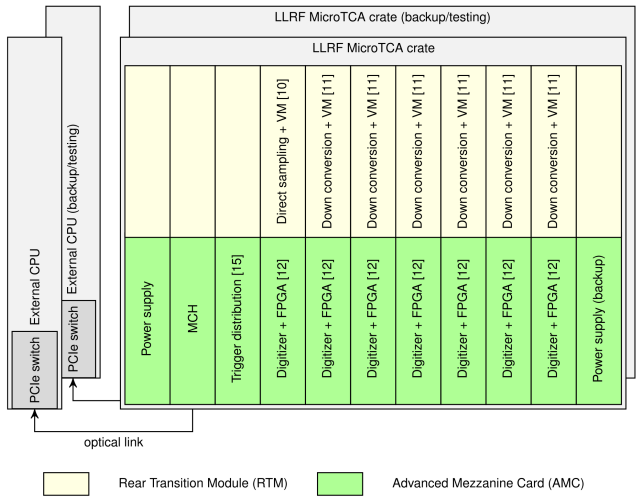


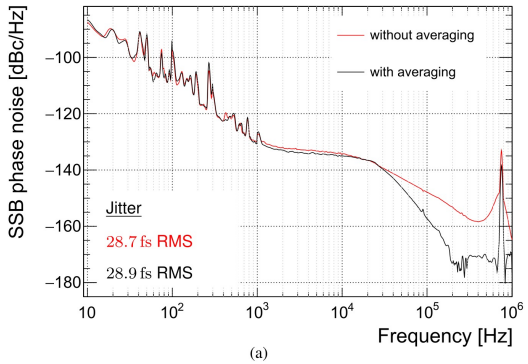
- 40 MeV electron Linac
- two electron injectors (DC Gun, SRF Gun)
- max. 26 MHz CW operation and any divider of that
- up to 1.6 mA beam current
- Macro pulsed mode for beam tuning

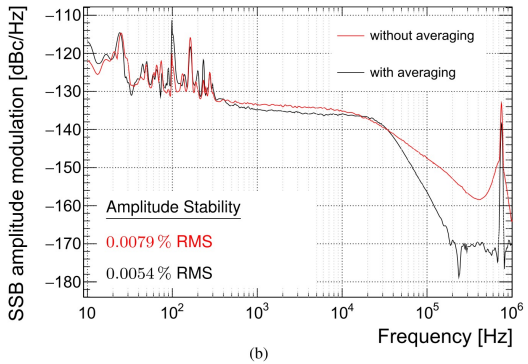
LLRF

Single cavity regulation for CW operation

- Operation of 2 NRF and 4 SRF cavities
- Adaption of DESY development and tailored for CW operation
- External CPU to run 6 LLRF server in parallel
- LLRF server based on ChimeraTK, communication through OPC/UA
- Reference implementation for other CW machines (TARLA, MESA)





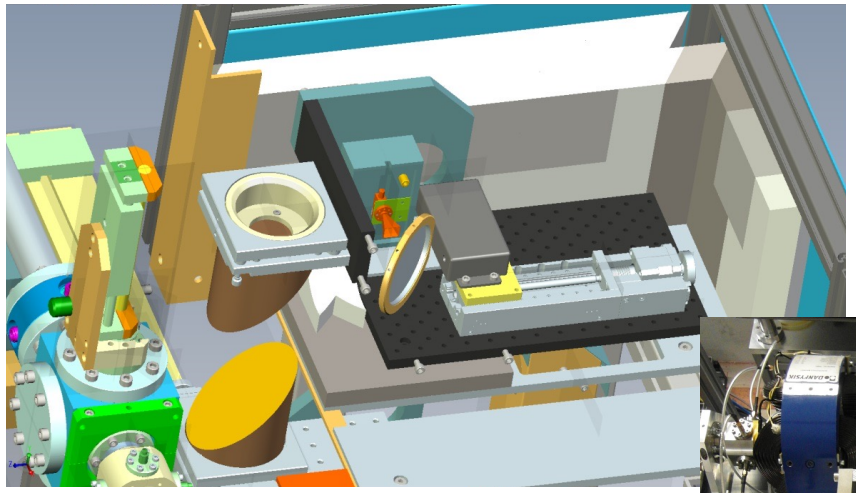


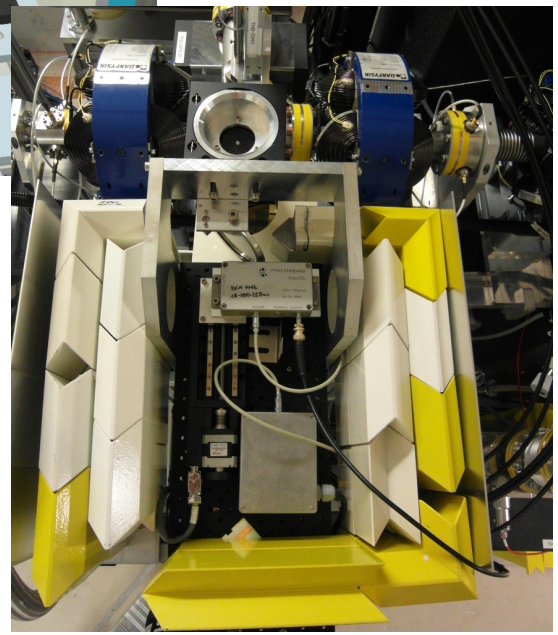
Electron Bunch Diagnostics

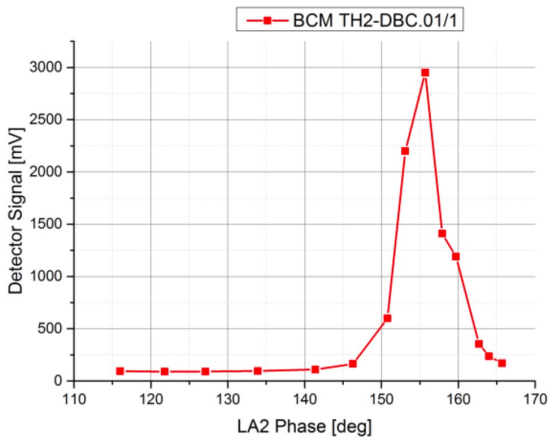
Bunch Compression Monitor - BCM

- Pyroelectric detector (movable)
- Schottky diode RF Detector (fixed)
- Wire grid as beam splitter for parallel measurements
- Silicon OTR screen / reflection of dipole radiation
- up to 13 MHz beam rate CW (usually 100 kHz)

- SIS8900 RTM and SIS8300-L2 for readout
- Electronics currently tested in lab-setup
- to be installed at ELBE in 2025

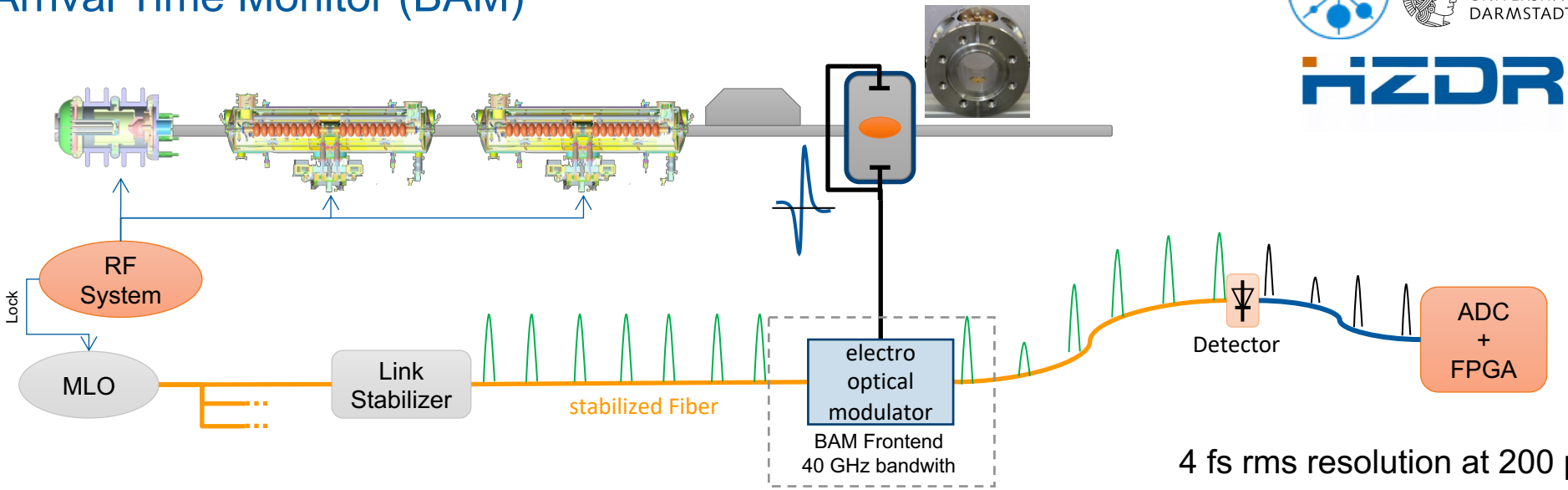




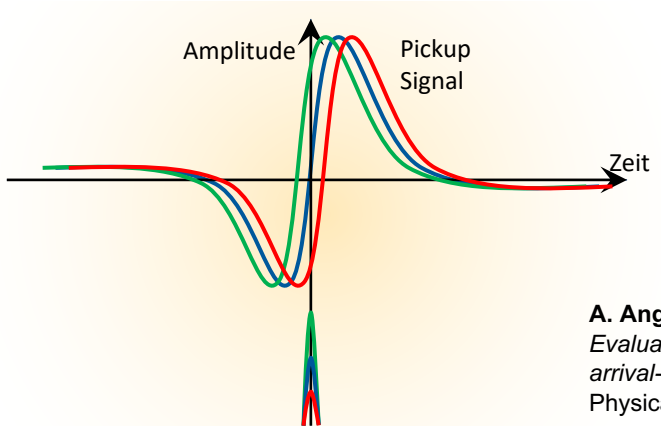


Electron Bunch Diagnostics

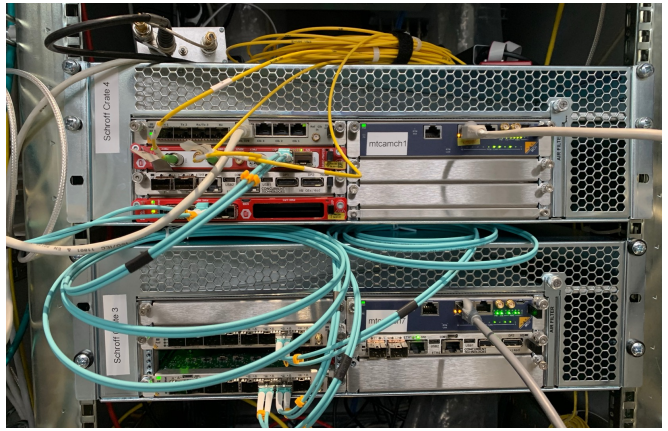
Bunch Arrival Time Monitor (BAM)



4 fs rms resolution at 200 pC bunch charge



- DSBAM on FMC25 carrier board
- FMC-MOTDRV22 for delay stages

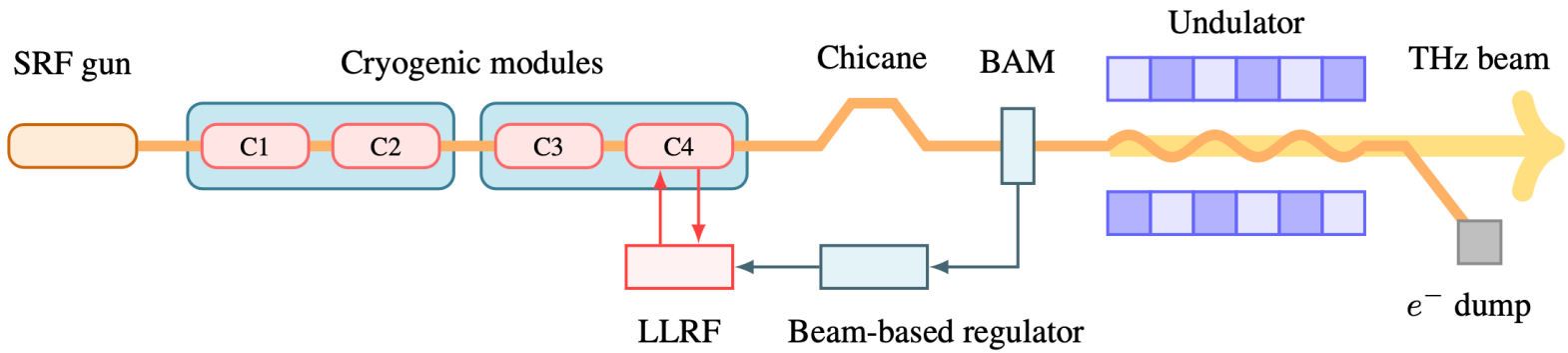


A. Angelovski, M. Kuntzsch, M.K. Czwalinna, et al.:
Evaluation of the cone-shaped pickup performance for low charge sub-10~fs arrival-time measurements at free electron laser facilities.
Physical Review Special Topics - Accelerators and Beams 18 (2015), S. 012801.

Beam Based Feedback

THz Beamline – fundamental concept

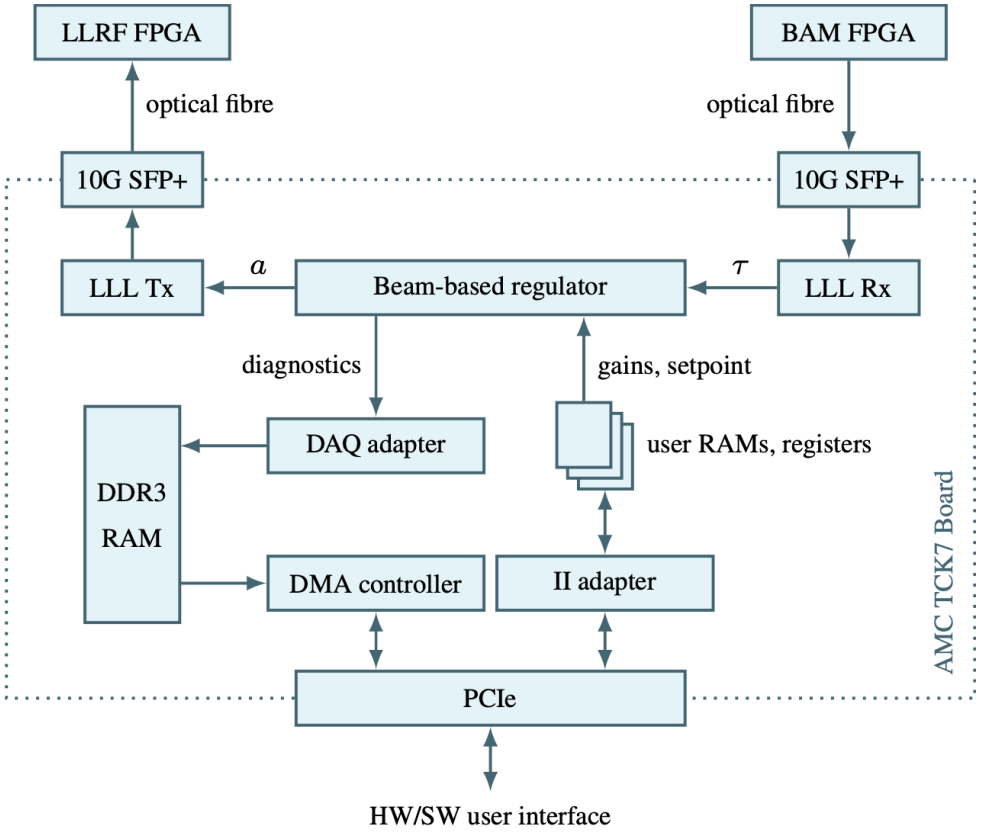
- Goal: stabilize electron bunch parameter close to THz generation
- BAM as sensor
- Error signal is send to dedicated beam-based feedback FPGA (TCK7 AMC)
- Modulates amplitude of cavity C4 in order to stabilize arrival time

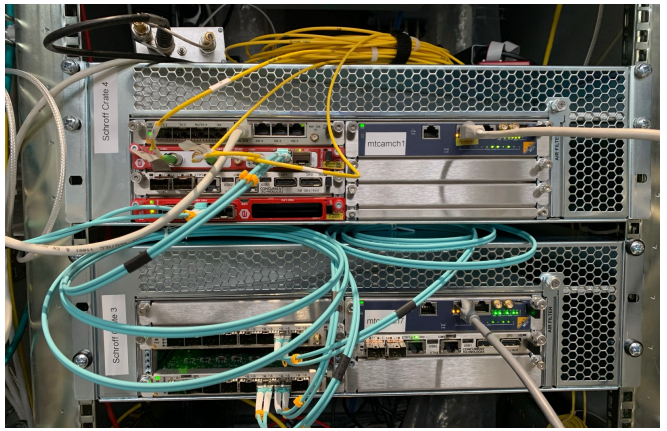


PhD Thesis Andrei Maalberg
"Improving Bam-Based Regulation for Continous-Wave Linacs with a Disturbance Model-Based Design"
Tallinn University of Technology, 2023

Beam Based Feedback

BBF integration



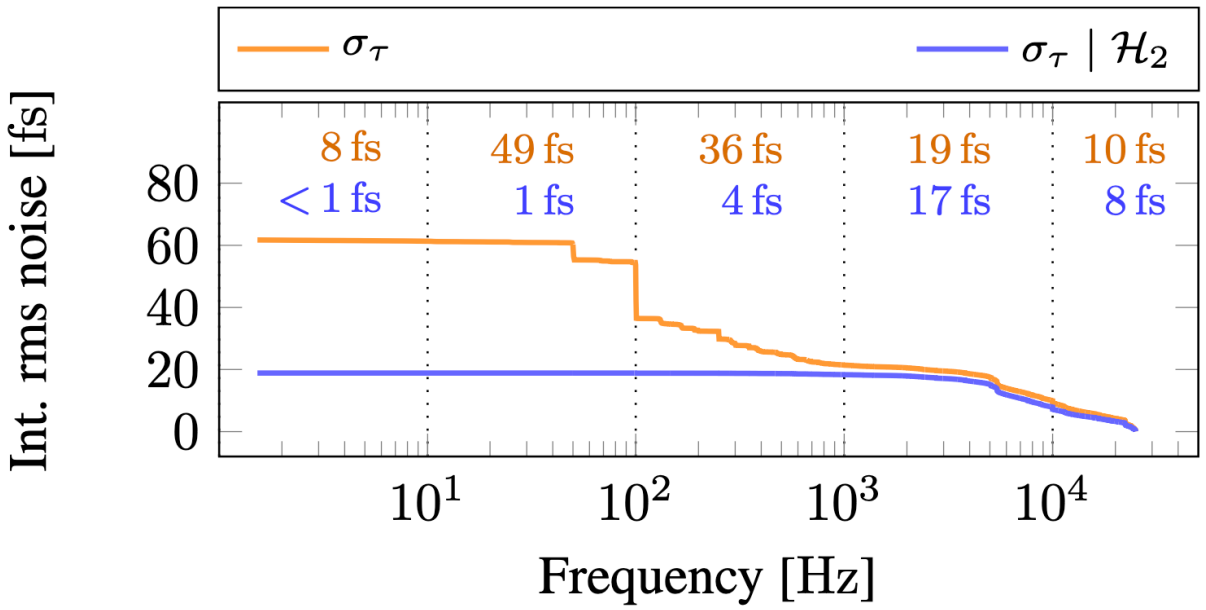


A. Maalberg, M. Kuntzsch, and E. Petlenkov,
"Real-Time Regulation of Beam-Based Feedback:
Implementing an FPGA Solution for a Continuous Wave Linear Accelerator,"
Sensors, vol. 22, no. 16, p. 6236, 2022

Beam Based Feedback

BBF – controller basics

- Jitter suppression down to 19 fs rms (from > 60 fs rms)
- almost all instabilities removed in controller bandwidth of 3.5 kHz
- System to be extended for BCM feedback as soon as readout in place

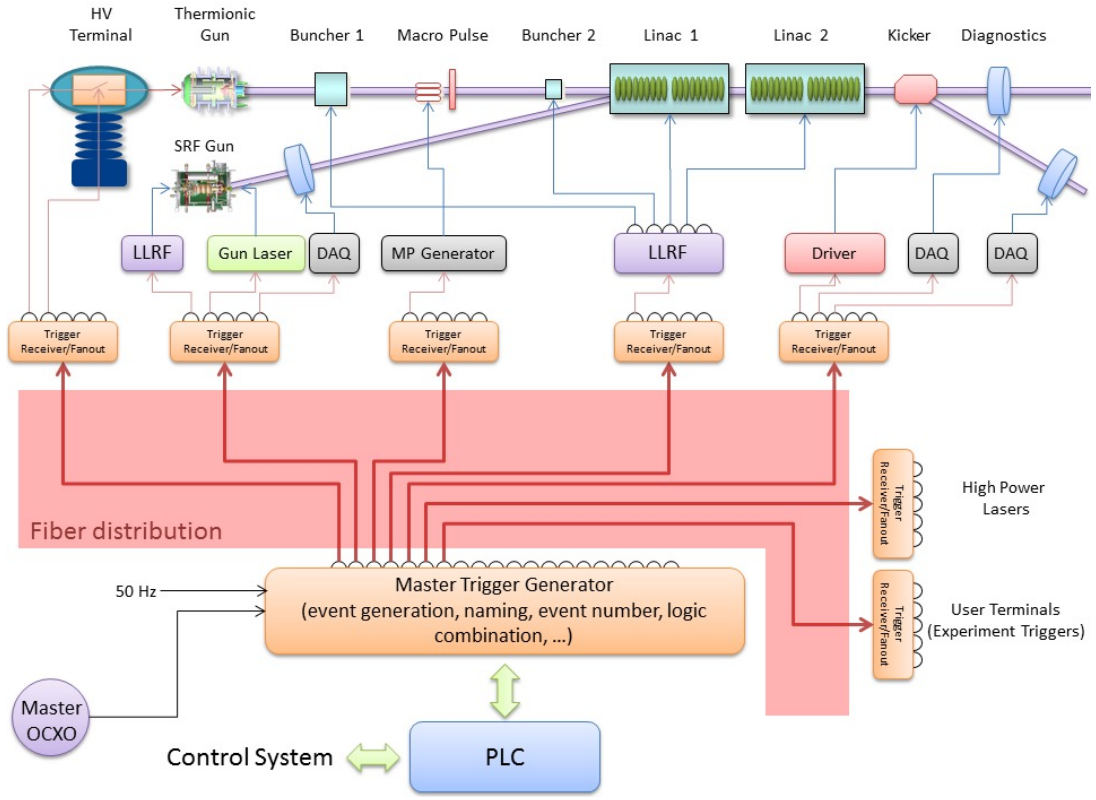


A. Maalberg, M. Kuntzsch, K. Zenker and E. Petlenkov,
"Regulation of electron bunch arrival time for a continuous-wave linac: Exploring the application of the H2 mixed-sensitivity problem",
'Phys. Rev. Accel. Beams, vol. 26, p. 072801, 2023

Timing System

Requirements for New Timing System

- Pattern generation from single shot to 26 MHz CW
- Macro pulsed patterns beam for tuning
- Highly flexible bunch patterns for biology experiments
- Parallel (and interleaved) operation of two electron guns
- Kicker control to allow multi- user operation
- Single instance for pattern generation
- Distribution to receivers galvanically isolated (no RF cables!)
- Interface to MPS system and parameter check
- Low jitter and drift compensation on picosecond level



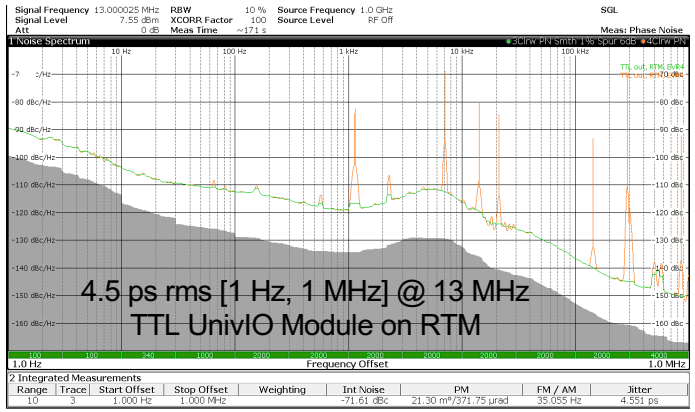
Feasibility study and European Tender → awarded to COSYLAB with Micro Research Finland hardware

Timing System

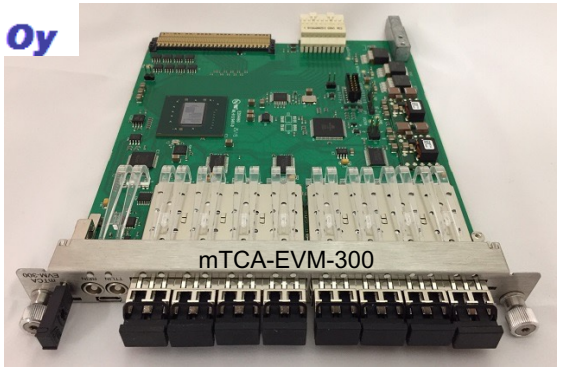
MRF MicroTCA.4 hardware

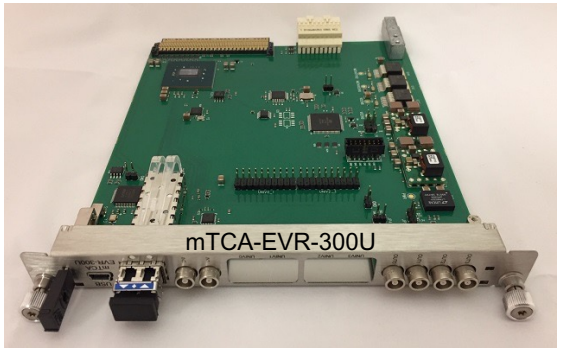
Micro-Research Finland Oy

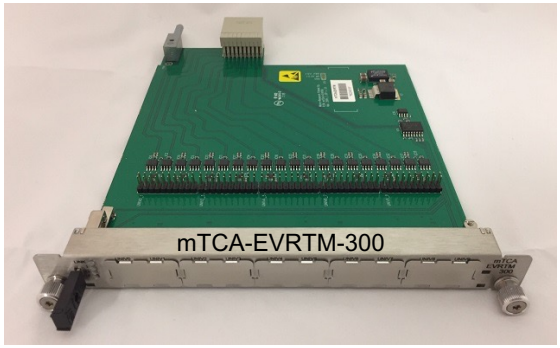
- MicroTCA based Micro Research Finland hardware (www.mrf.fi)
- MicroTCA event receivers (EVRs) for machine timing and selected users
- PCIe receiver for compact and cost effective user timing stations
- Flexible, modular topology
- Universal output modules for various logic levels
- Picosecond level jitter (< 5 ps)
- Drift compensation (< 10 ps)

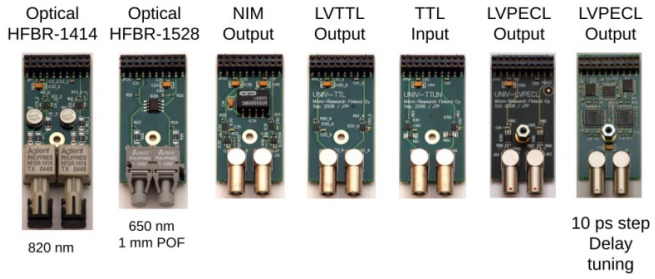


- NDA MRF - HZDR to exchange sources (hw/fw)





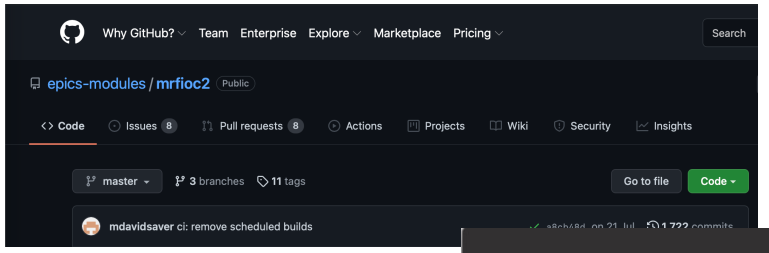


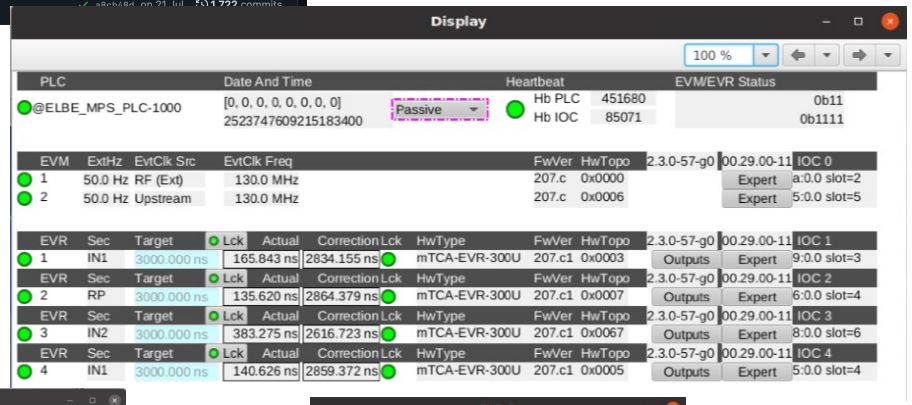


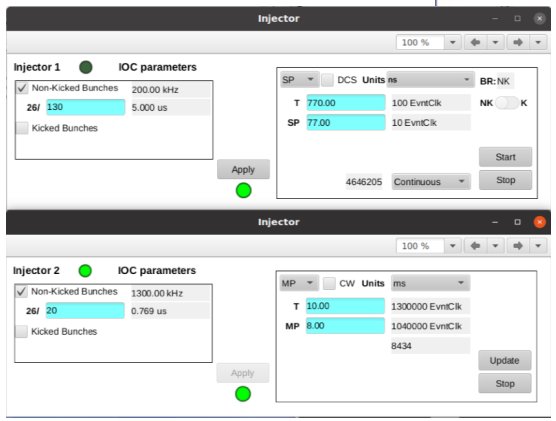
Timing System

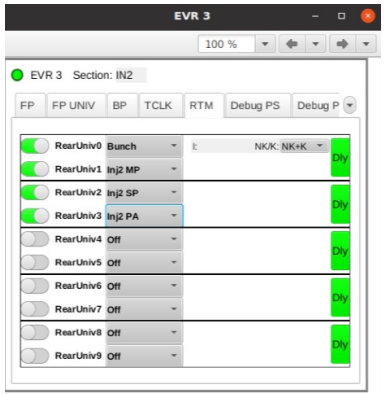
EPICS mrfioc2

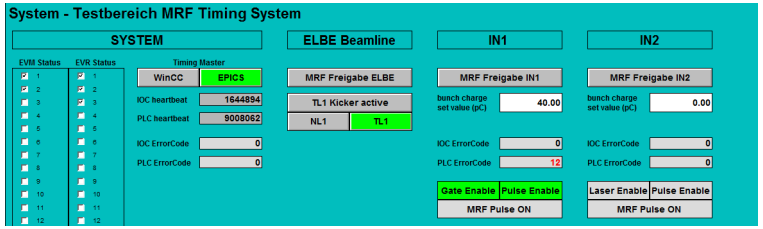
- Implementation based on EPICS mrfioc2 (https://github.com/epics-modules/mrfioc2)
- Application tailored to ELBE's requirements
  - Operation modes pre-defined
  - Parameter set, calculation and check
  - Error monitoring
- "Phoebus" GUIs for EVMs and EVRs
  - Commissioning
  - Debugging
  - Error monitoring
- WinCC GUI (ELBE SCADA)





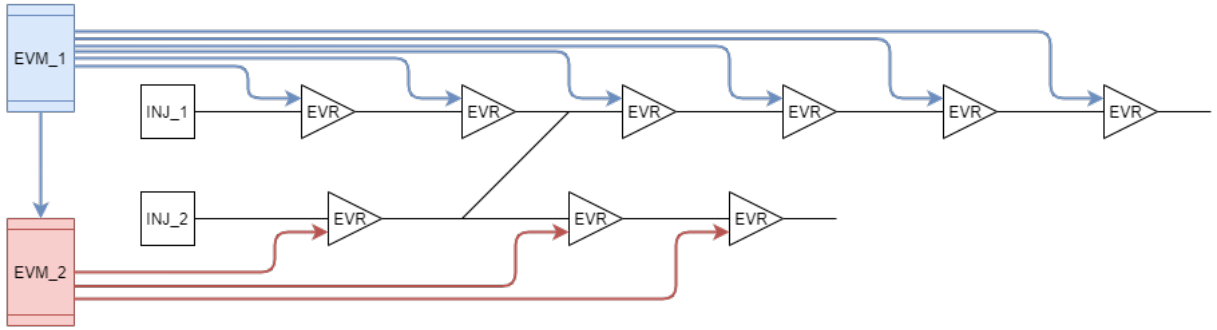




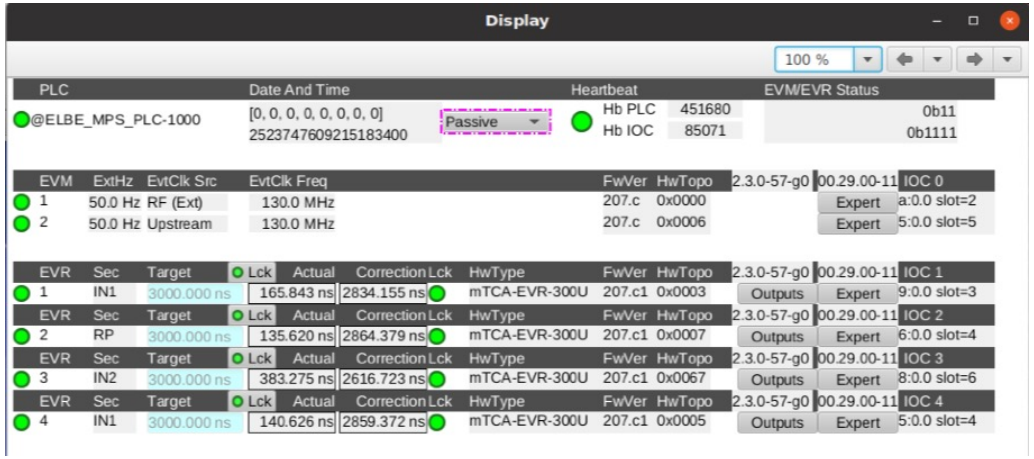


Timing System

Topology



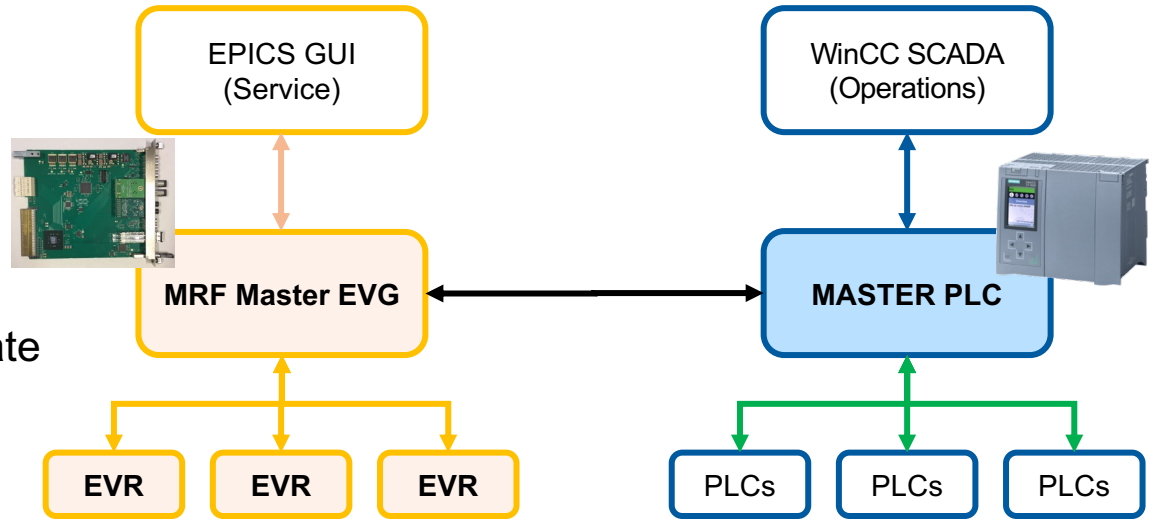
- Two EVMs
  - first to serve injector 1 and ELBE EVRs
  - second to serve injector 2 and diagnostic beamline
- SRF Gun can be operated independently in a dedicated diagnostic beamline in parallel to ELBE
- All communication to PLC through EVM1 IOC
- 130 MHz event clock (7.7 ns event rate)
- Prescalers to generate bunch clock (up to 26 MHz)

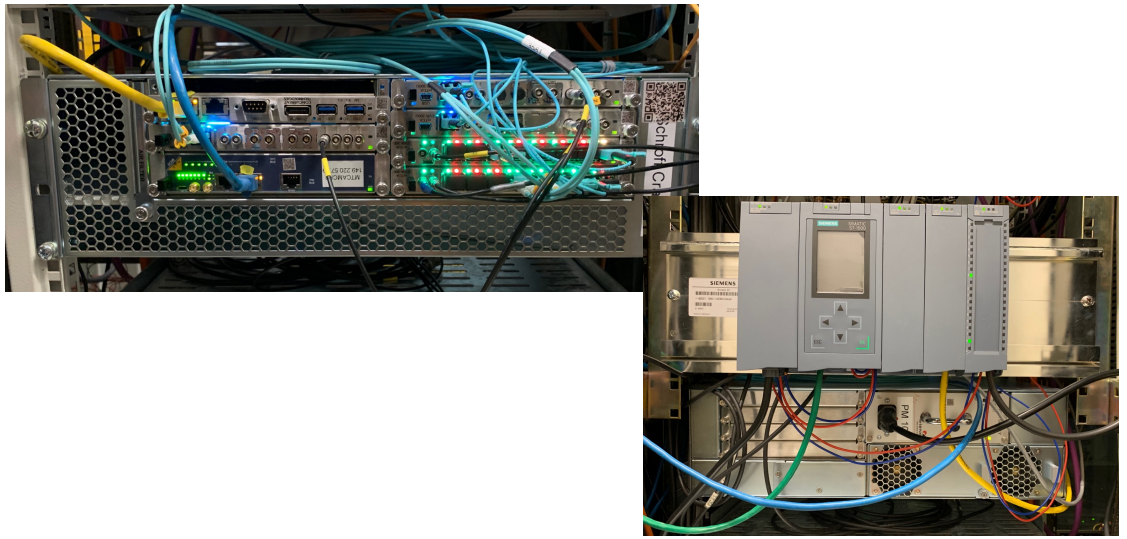


Timing System

Connection to MPS

- Machine interface through Siemens PLC
  - PLC is main instance for machine protection
  - calculates allowed beam parameters based on machine state
  - receives and issues interlocks
- heartbeat signal to monitor connection
- major change of ELBE's MPS structure



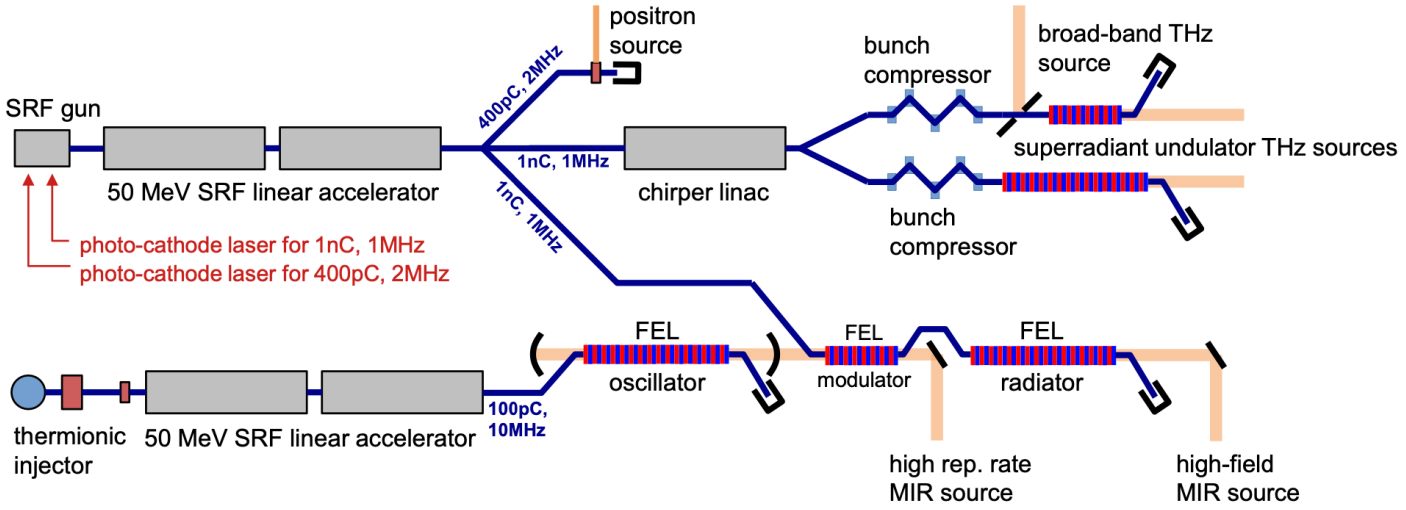


Outlook

Proposal for ELBE successor machine “DALI” (Dresden Advanced Light Infrastructure)

- 2x 50 MeV SRF Linac for THz generation
  - RF requirements: 2x 2 modules á 2 cavities with each 1x 15 kW SSPAs = 8x 15 kW SSPAs
- very positive evaluation of proposed machine by Helmholtz management
  - part of the HGF photon roadmap (together with PETRA IV and BESSY III)

- MTCA as baseline for accelerator control and diagnostics
  - goal: use as many COTS components as possible



Parameters	MIR-THz FEL-oscillator	Superradiant THz and Positrons
Electron beam energy	50 MeV	50 MeV
Bunch charge	100 pC	1 nC
Electron pulse length	Few ps	200 fs – few ps
Transverse emittance	<15 mm·mrad	<15 mm·mrad
Bunch repetition rate	10 MHz	100 kHz – 1 MHz
Average beam current	1 mA	1 mA

Table 2: *Photon beam parameters of the proposed facility available for user experiments.*

Parameter	Superradiant MIR-THz	Broadband THz	MIR-THz FEL Oscillator
Wavelength range	10 µm – 3 mm	120 µm – 3 mm	10 – 120 µm
Frequency range	0.1 – 30 THz	0.1 – 2.5 THz	2.5 – 30 THz
Pulse energy	100 – 1000 µJ	100 µJ	10 µJ
Repetition rate	0.1 – 1 MHz	0.1 – 1 MHz	10 MHz
Pulse length (RMS)	0.2 – 15 ps	0.2 ps	1 – 25 ps
Peak power	20 – 500 MW	500 MW	~1 MW
Photons per pulse	10^{16} – 10^{18}	10^{18}	10^{13}
Photon energy	0.4 – 125 meV	0.4 – 10 meV	10 – 125 meV
Bandwidth	0.5 – 15 %	100%	0.5 - 3.0 %

Table 3: *Beam parameters for positron sources.*

Parameter	Positron Annihilation Lifetime Spectroscopy	High-intensity Positron Source, microbeam	High-intensity Positron Source TRHEPD, open-beam port
Repetition rate	100 kHz – 1 MHz	100 kHz – 1 MHz	1 MHz
Positron rate	5 x 10^9 / s	1 x 10^8 / s, remoderated	1 x 10^7 / s, remoderated
Time spread	<150 ps FWHM	<500 ps FWHM	–
Beam diameter	5 mm	50 µm	1 mm, low divergence
Positron kinetic energy	500 eV – 30 keV	5 eV – 8 keV	10 keV – 20 keV

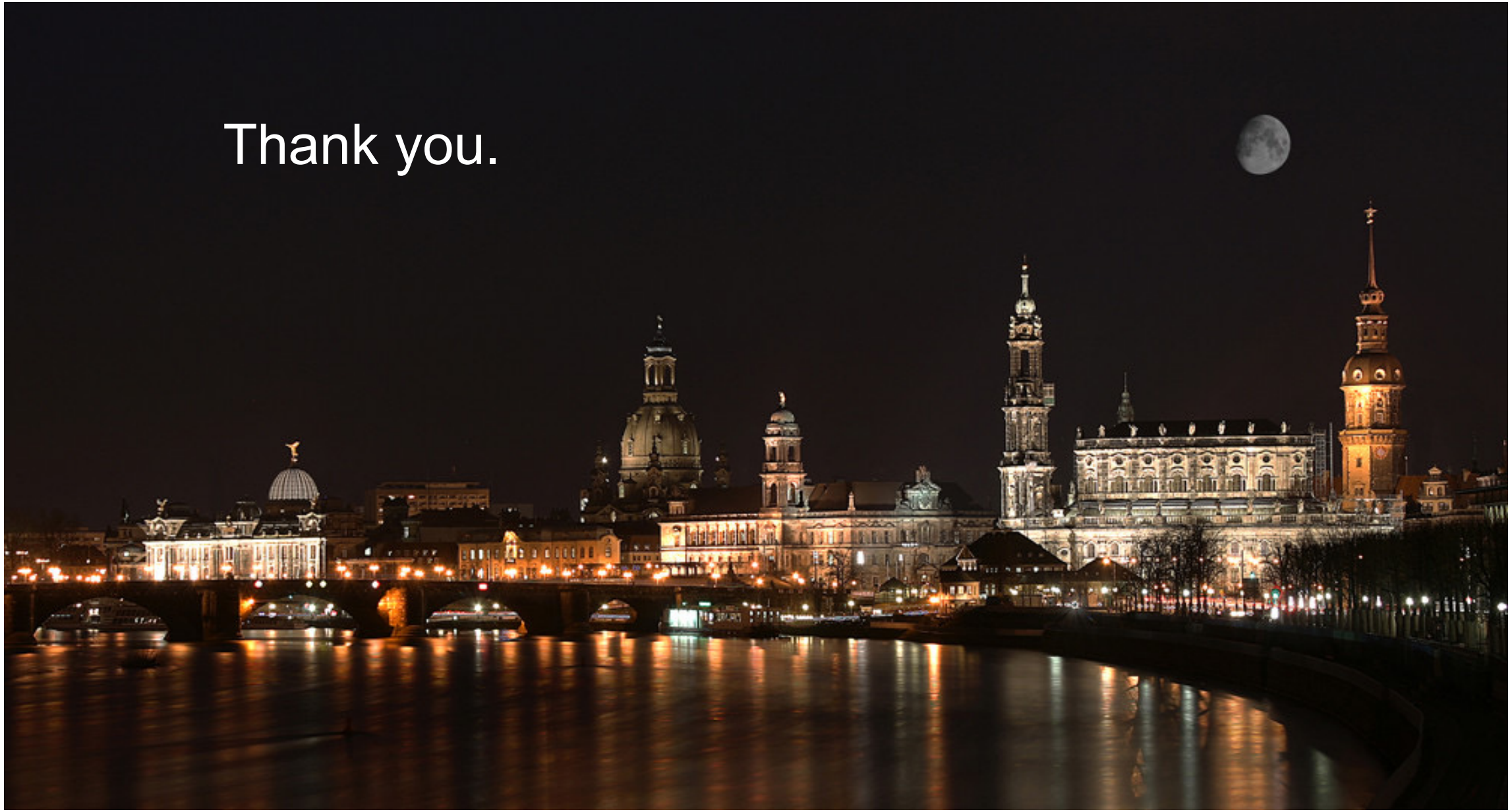
Link to conceptual design report

Conclusion

- LLRF and diagnostics implemented based on MTCA platform at ELBE
- very strong collaboration with DESY MSK (hardware, software and firmware) THANK YOU!!
- ChimeraTK is a key element to be able to integrate systems into ELBE control system

- now more than 10 years of experience with MTCA
- MTCA will be baseline for planned DALI machine

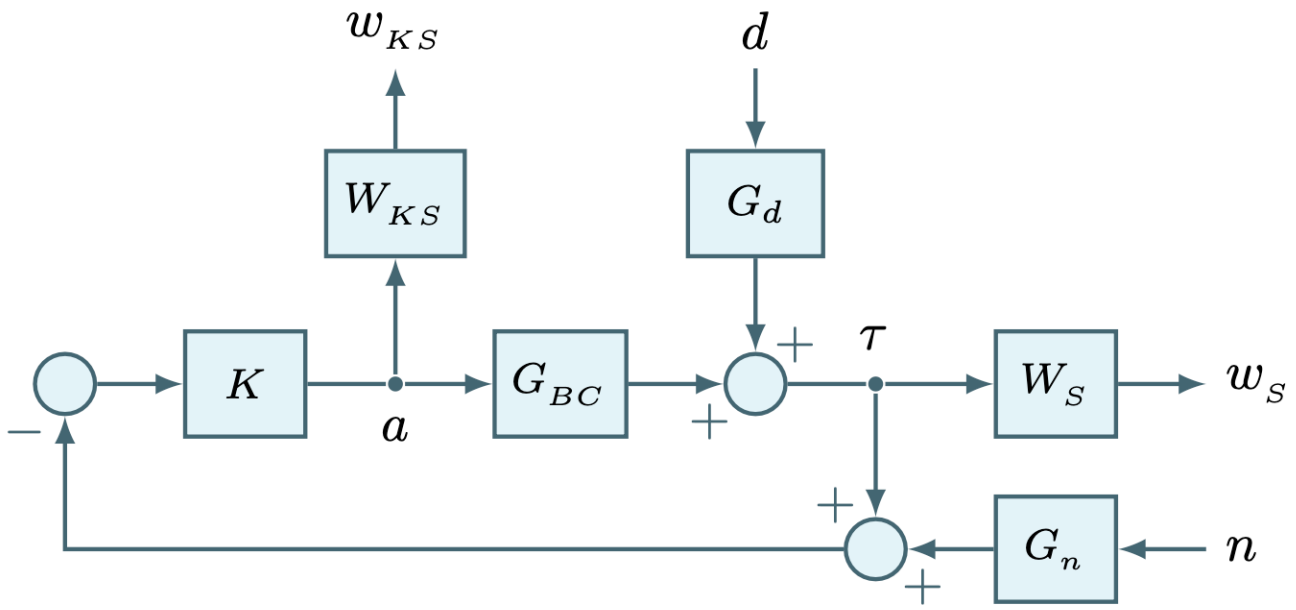
Thank you.



Beam Based Feedback

BBF – controller basics

- $\mathcal{H}_2$ regulator in mixed sensitivity configuration
- Dynamics come from external input *d*, modeled by G_d
- Bunch compressor GBC is static (a constant factor)



A. Maalberg, M. Kuntzsch, and E. Petlenkov, "Regulation of the Linear Accelerator ELBE Exploiting Continuous Wave Mode of a Superconducting RF Cavity," in Proc. 2022 Am. Control Conf., 2022, pp. 5346–5353