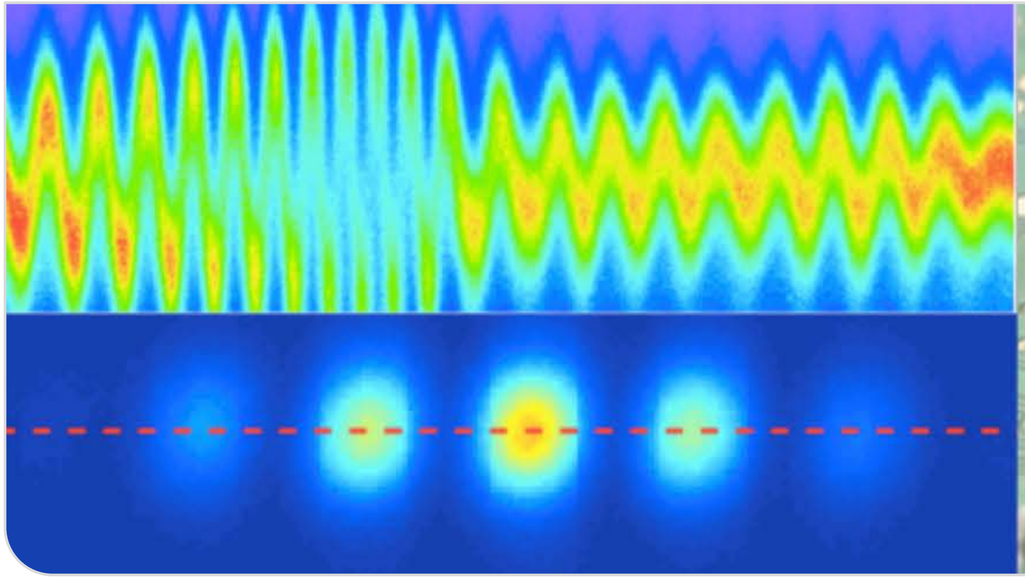
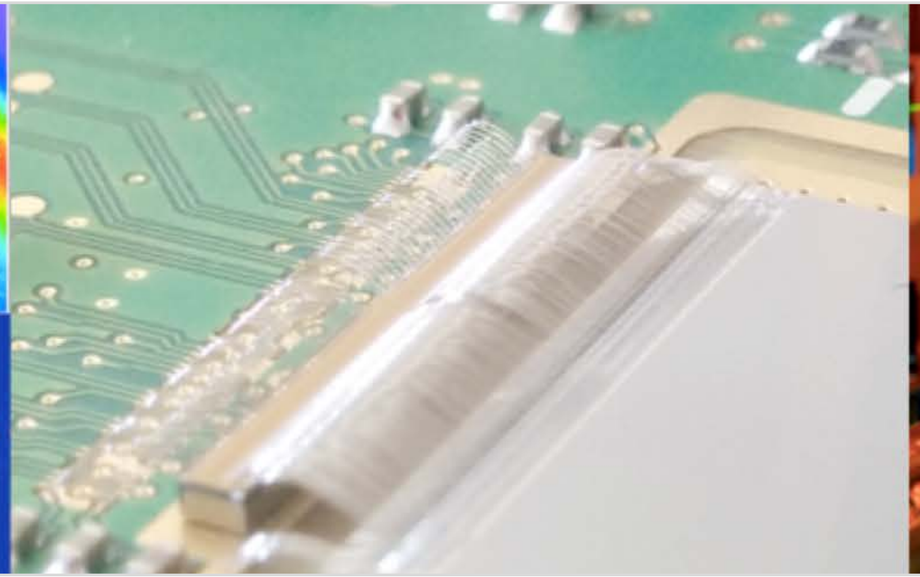
Karlsruhe Institute of Technology

Status of KIT test facilities KARA and FLUTE

28th ESLS Workshop, Grenoble, France

Marcel Schuh for the KIT team

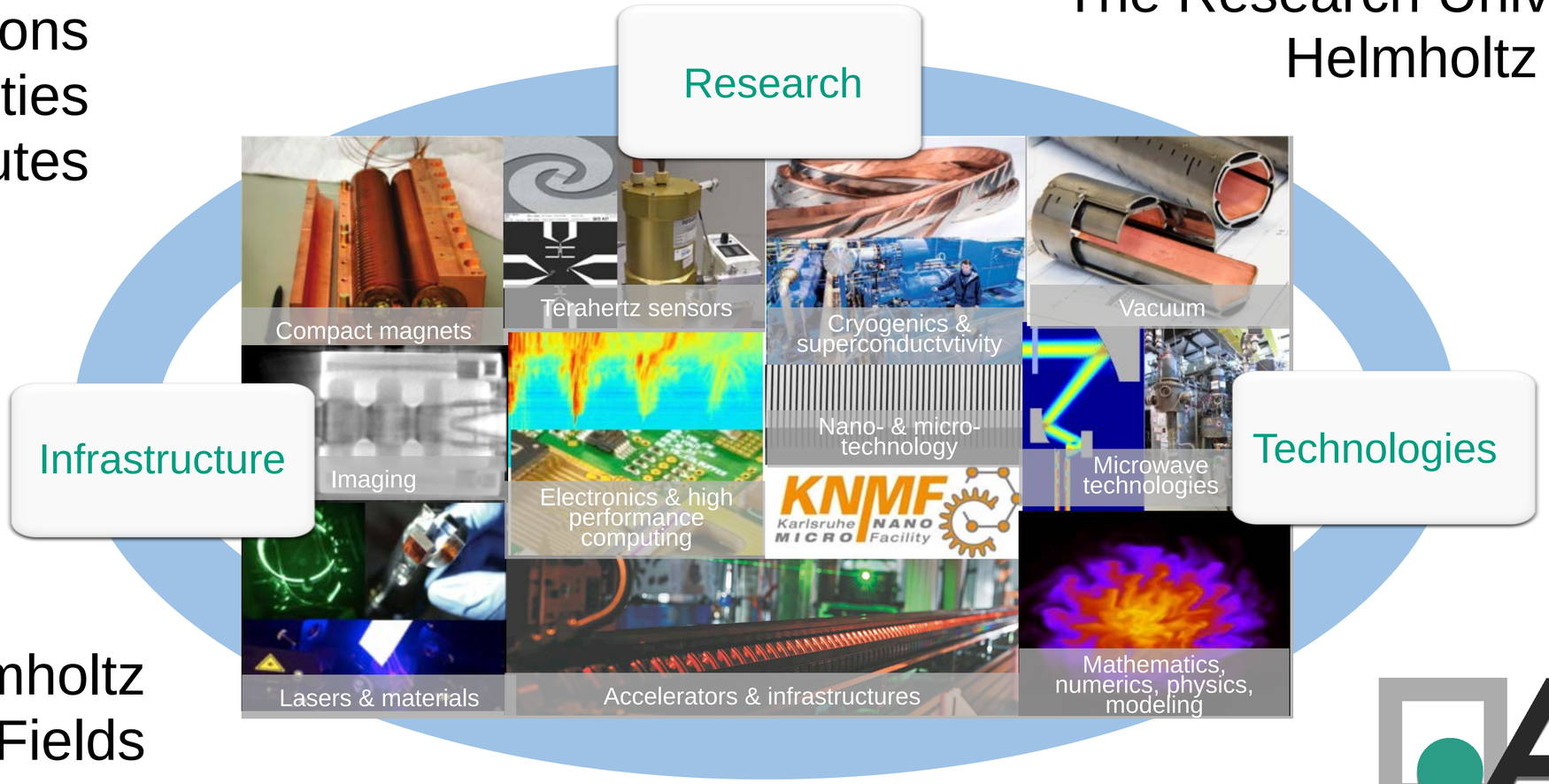




The Accelerator Technology Platform @ KIT (ATP)

5 Divisions
6 KIT-Faculties
11 Institutes

The Research University in the Helmholtz Association



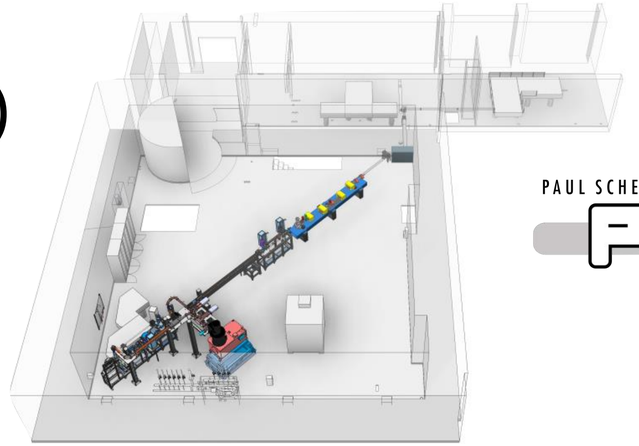
+ strong industrial partners

Helmholtz
3 Research Fields
6 Programmes

ATP
Accelerator Technology Platform @ KIT

FLUTE: Accelerator test facility at KIT

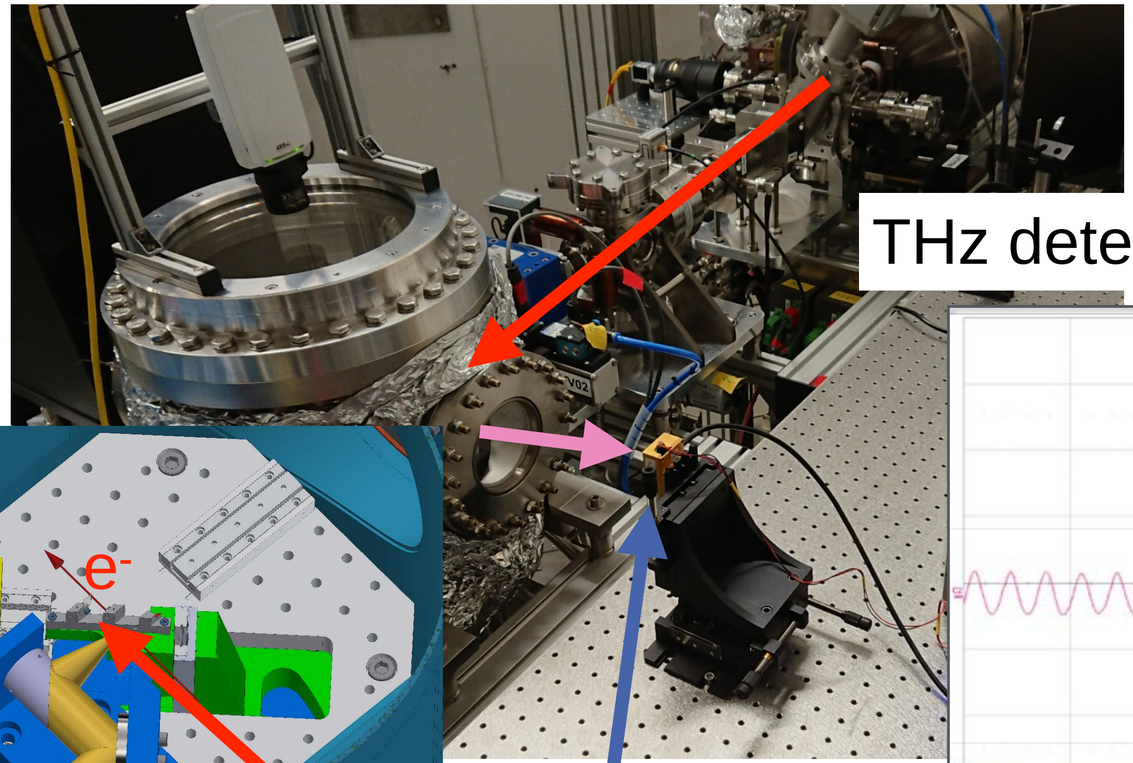
- FLUTE (Ferninfrarot Linac- Und Test-Experiment)
  - Test facility for accelerator physics within ARD
  - Experiments with THz radiation
- R&D topics
  - Serve as a test bench for new beam diagnostic methods and tools
  - Systematic bunch compression and THz generation studies
  - Develop single shot fs diagnostics
  - Synchronization on a femtosecond level

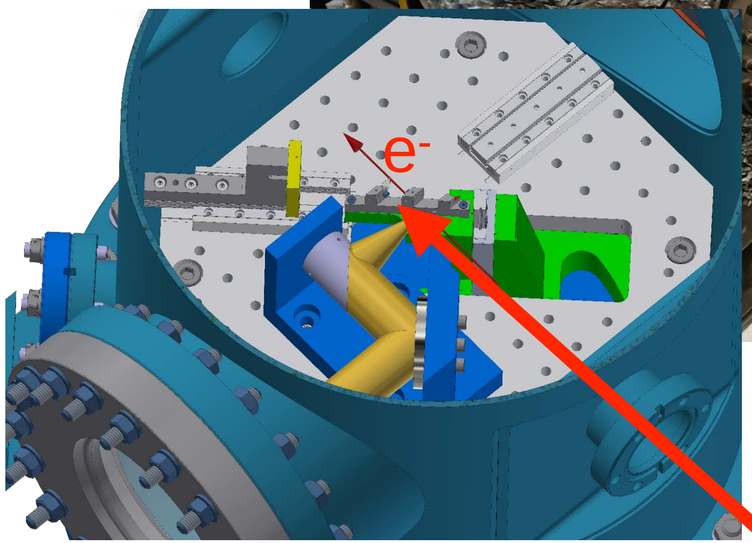


Final electron energy	~ 41	MeV
Electron bunch charge	0.001 - 3	nC
Electron bunch length	1 - 300	fs
Pulse repetition rate	10	Hz
THz E-Field strength	up to 1.2	GV/m

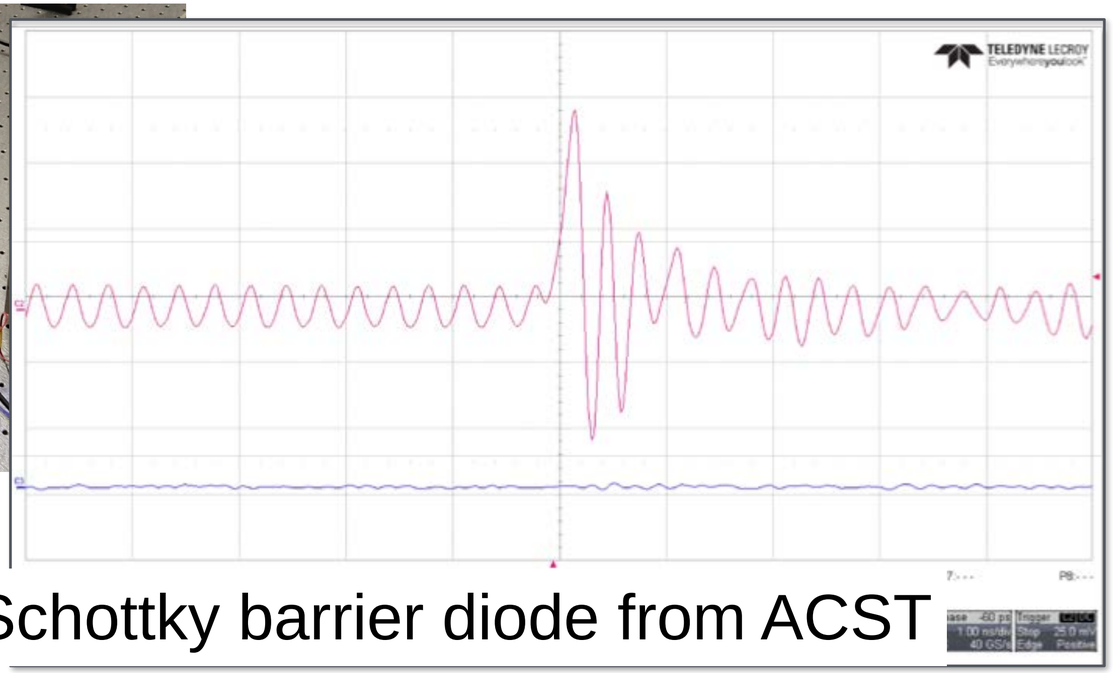
www.ibpt.kit.edu/flute

First electron generated THz signal at FLUTE in February 2020





THz detector signal from transition radiation



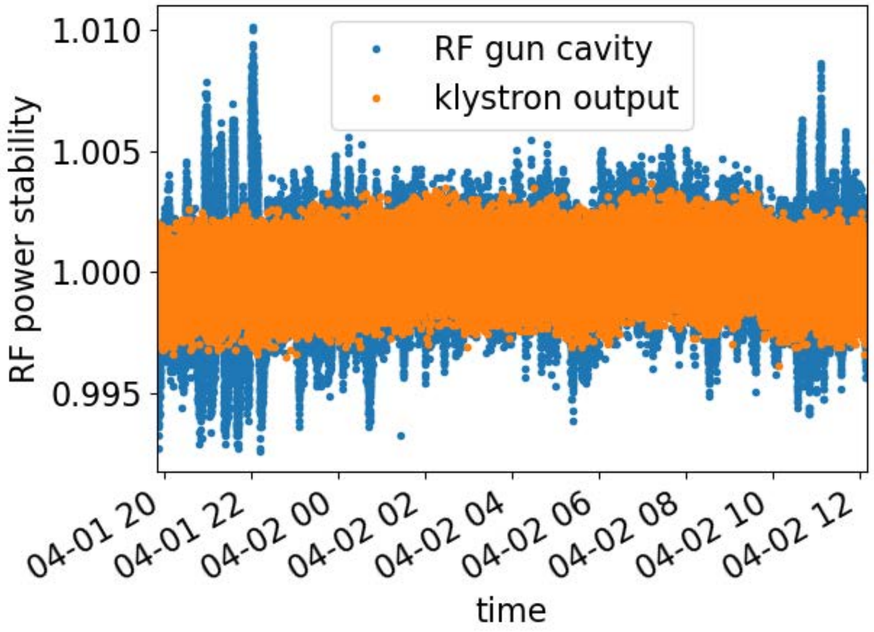
broadband Schottky barrier diode from ACST

Courtesy: M. J. Nasse, M. Nabinger

Further FLUTE progress

- Gun section fully operational
- Optimized optics setup next to gun in operation
- Longterm stability tests: 2 weeks 24/7 operation
- Closed-loop tuning of the LLRF system in collaboration with DESY
- Improvement of the AC synchronization
- Beam characterization measurements ongoing
- SRR experiment
  - Electron beam focused on SRR
  - Optics for gun & THz generation working
  - THz generation using tilted-pulse-front technique
  - Next: finding temporal and spatial overlap

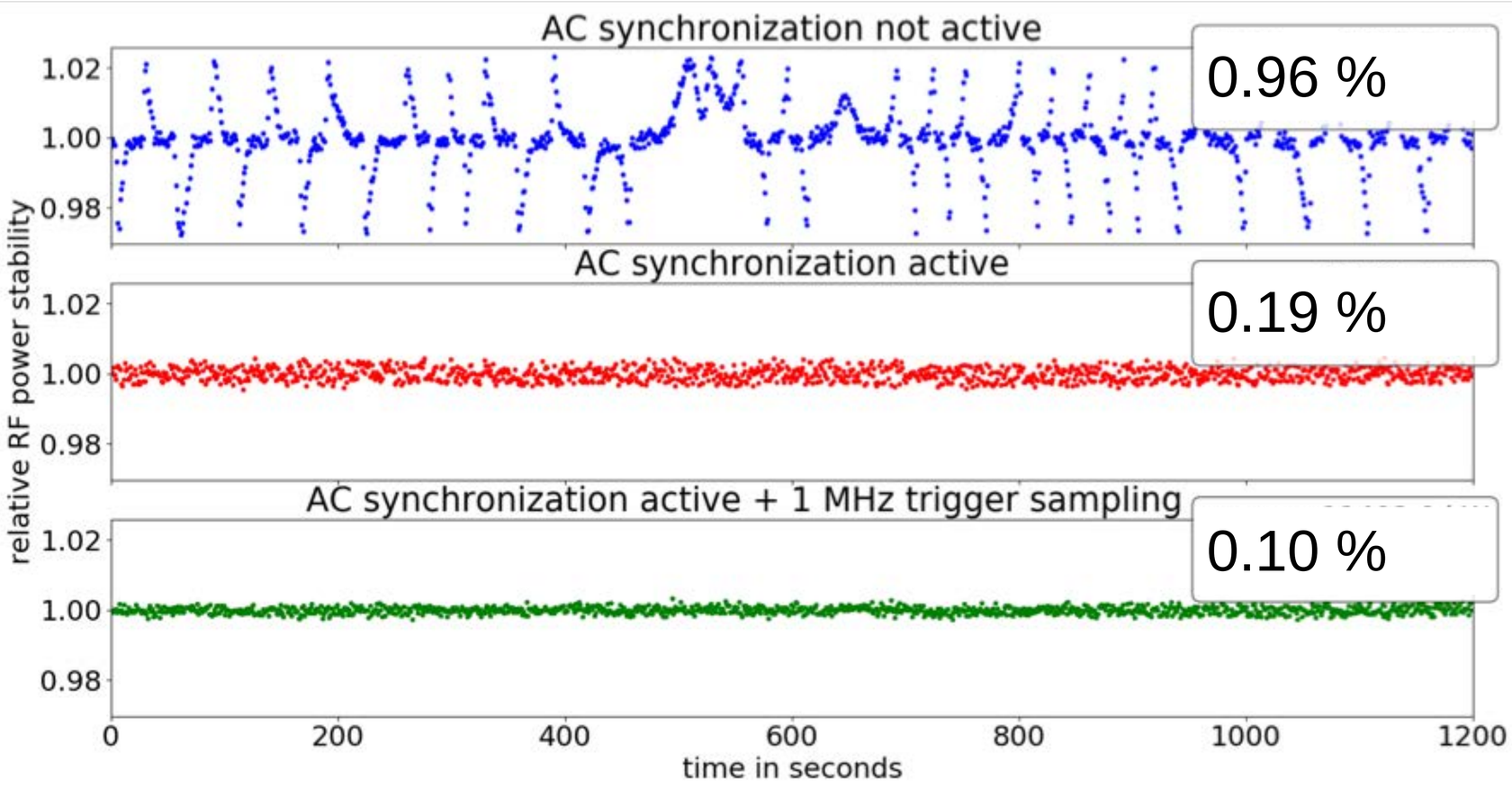
Courtesy: T. Schmelzer



Timing system - tuning of AC synchronization

- RF forward power is very sensitive to the 50Hz mains in open loop
- Issues with laser stability if the laser trigger (1kHz) is changing too fast
- Implemented a PLL which follows the 50Hz smoothly

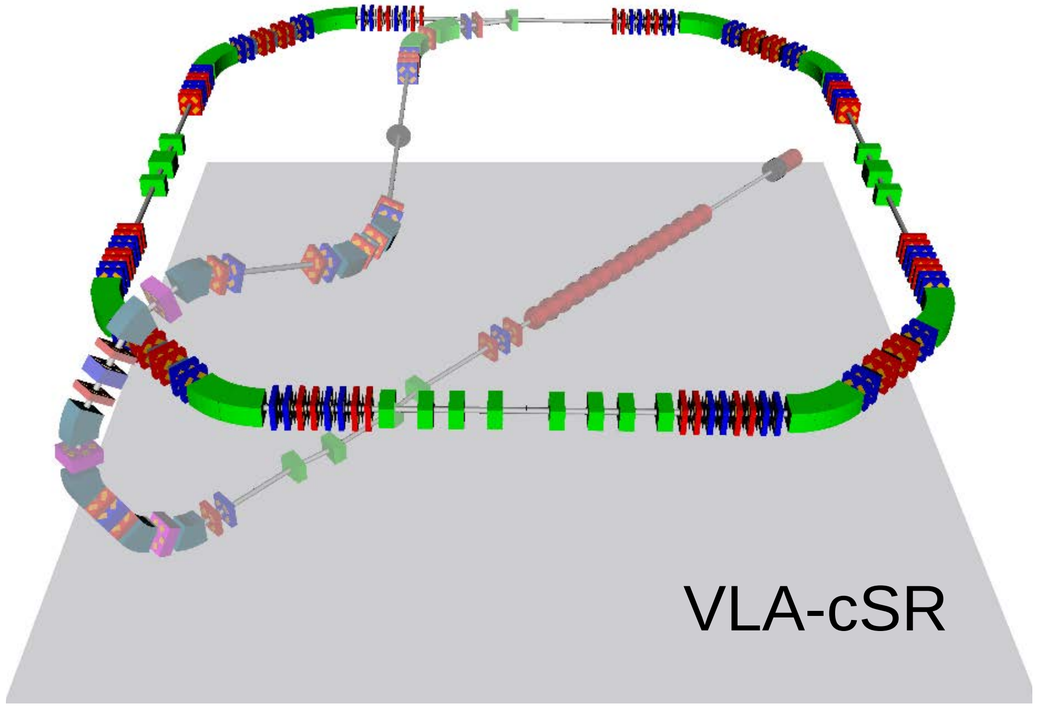
RF forward power stability



Courtesy: T. Schmelzer, N. Smale

cSTART

- Goal: Demonstration and examination of the injection and the storage of a laser wakefield accelerated (LWFA) like electron beam.
- The Very Large Acceptance compact Storage Ring (VLA-cSR)
- Utilize FLUTE with transfer line as injector
- Status
  - RF Upgrade of FLUTE in progress
  - Finalizing lattice design
  - Optimizing parameters to match with LWFA
  - Layout of diagnostics



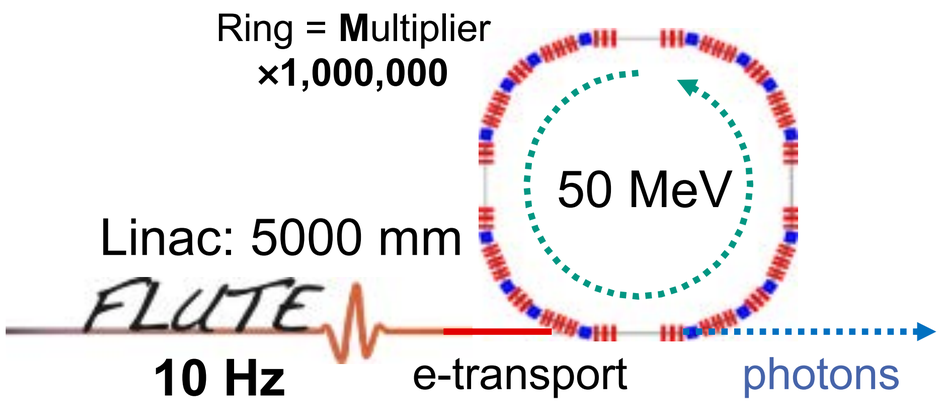
Courtesy: J. Schäfer

B. Haerer et al., proceedings of IPAC2019, TUPGW020

Compact novel accelerators and their applications

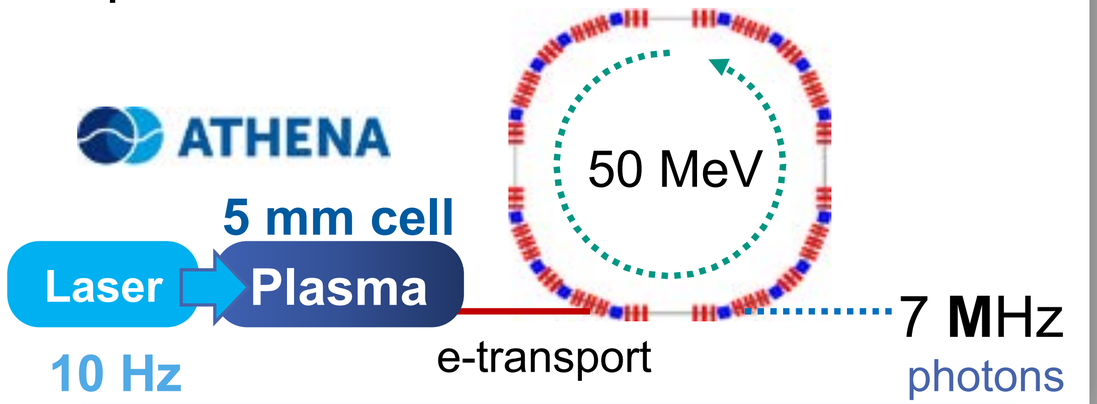
- Bring plasma acceleration to applications and compact accelerator technology
  - **„from acceleration to accelerators“**
  - Well-defined **transport of electrons originating from a plasma** to an application point

Goal: Storage of fs-long electron bunches
Solution: unique storage ring design



B. Haerer et al., proceedings of IPAC2019, TUPGW020

Goal: efficient storage of injected plasma electrons
Cooperation with DESY and HI Jena
Goal TMed: Terahertz medical imaging
Cooperation and R&D in MT-ARD-ST3 & MT-DTS

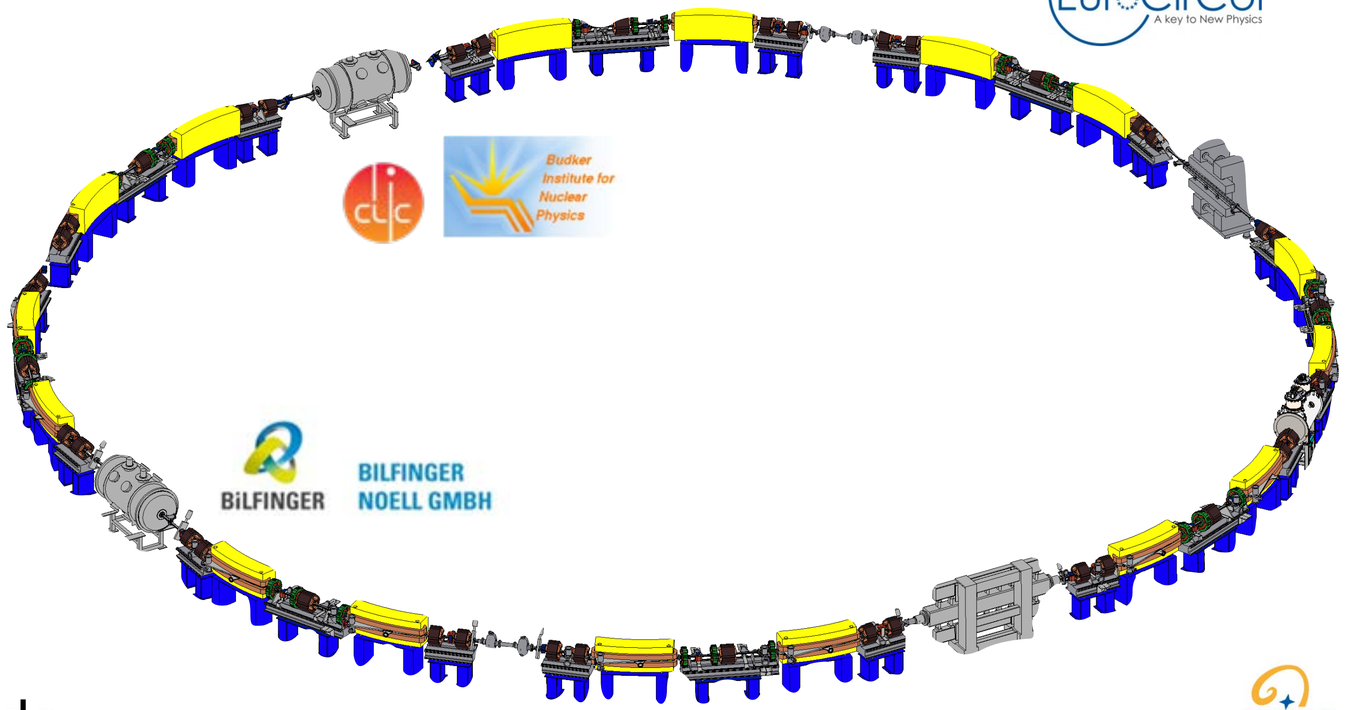


Professor for Laser-based Accelerators @ KIT

Courtesy: E. Bründermann

Karlsruhe Research Accelerator (KARA)

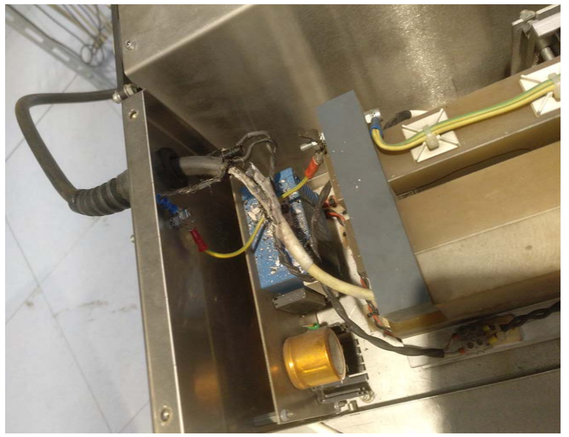
- User applications & accelerator test facility
- Key parameters
  - Circumference: 110.4 m
  - Energy range: 0.5 - 2.5 GeV
  - RF frequency: 500 MHz
  - Revolution frequency: 2.715 MHz
  - Beam current up to 200 mA
  - RMS bunch length:
    - 45 ps (for 2.5 GeV)
    - down to a few ps in short bunch mode



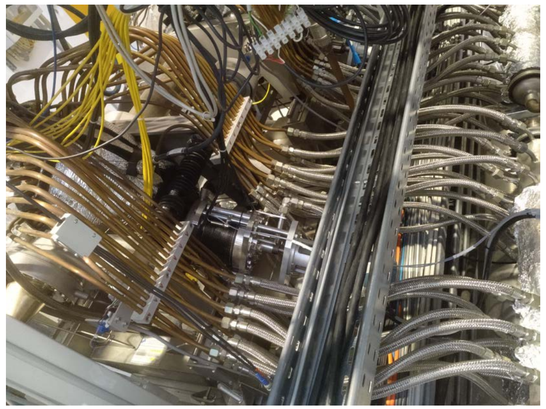
www.ibpt.kit.edu/kara

KARA operation issues 2020

- **No impact of COVID-19 on the operation schedule**, but on the power supply refurbishment program
- Start 2020 delayed by 4 weeks due to a mechanical failure in the taper of an undulator caused by a software bug
- 3 GHz modulator failures
  - Focus PS end of life
  - HV PS burned
  - Thyratron glass tube broken
- Person safety system: end switch failure
- Klystron saturation due high beam loading
  ➜ increased DC input power
- Timing issues - RF frequency moved out of acceptance

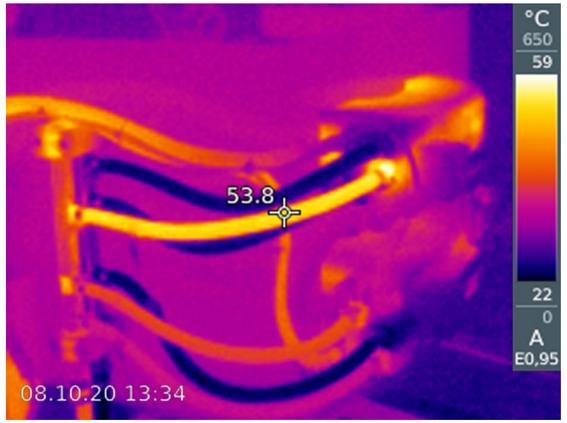


Water issues



- Cavity cooling circuits
  - Leak at a brazed copper transition joint
  - Leak at a valve due to corrosion
  - Flow degradation over time caused by the same valve type
    ➜ replacement of all valves of this type planned
- Blocked magnets cooling circuits

Courtesy: A. Mochihashi



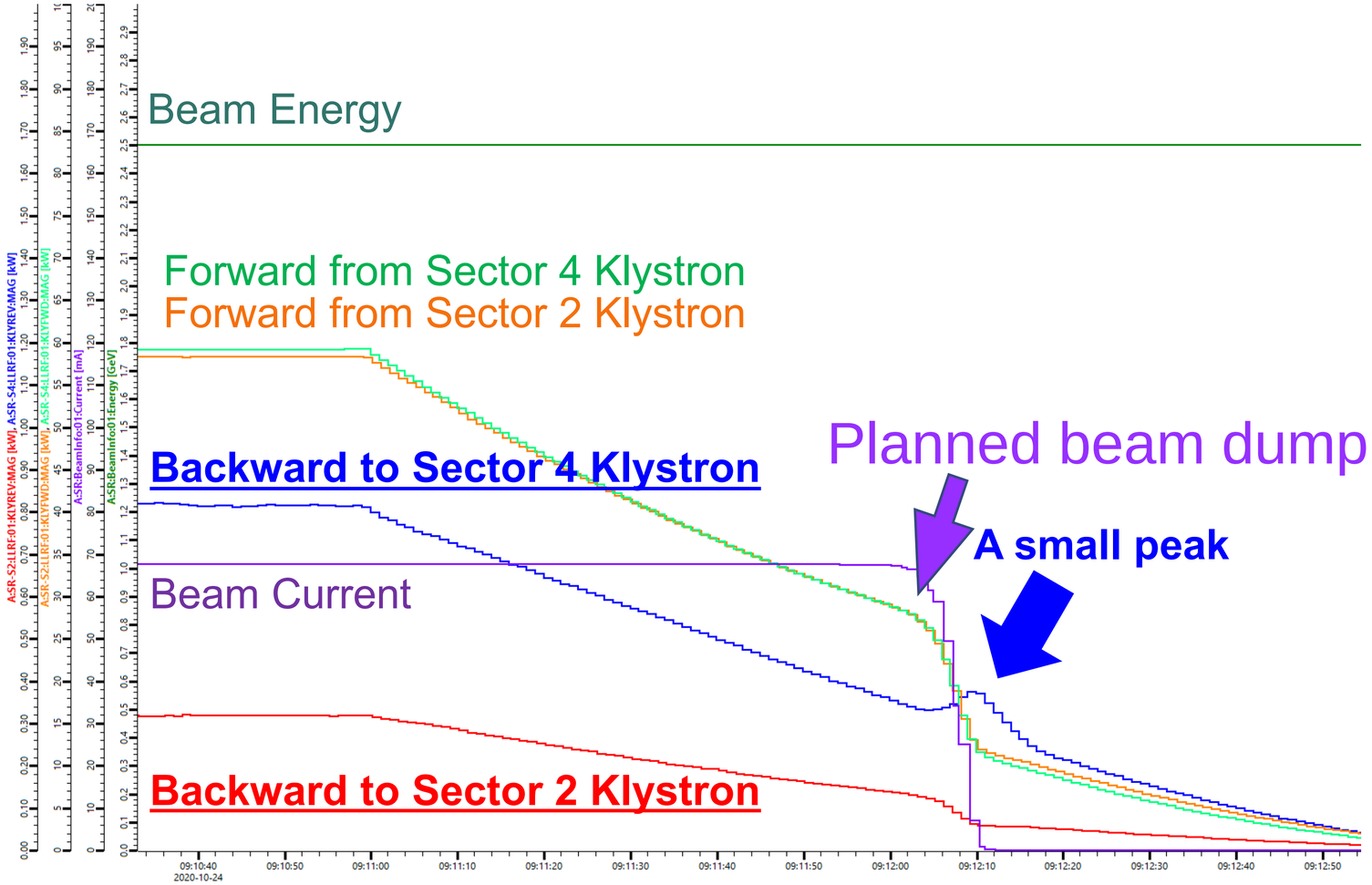
Courtesy: S. Pfeifer

Refurbishment program

- Replacement of all Kicker/Septa power supplies delayed due to COVID19
- Ordered spare septa for booster and KARA - delivery Jan 2021
- Renewal of the accelerator power distribution cabinets - add monitoring
- Replacement of main power supplies started
  - Main power supply for Microtron (DELTA SM 70-CP-450) arrived, system integration in preparation
  - Replacement of booster bend and quadrupole power supply
  - Replacement of the KARA dipole power supply
  - Split the KARA sextupoles from two to three families
  - Discussion on changing to individually powered quadrupoles in KARA

RF Circulator refurbishment

- Refurbished the two 250kW 500MHz circulators from AFT during two shutdowns in 2020
- New temperature compensation unit has a faster response time



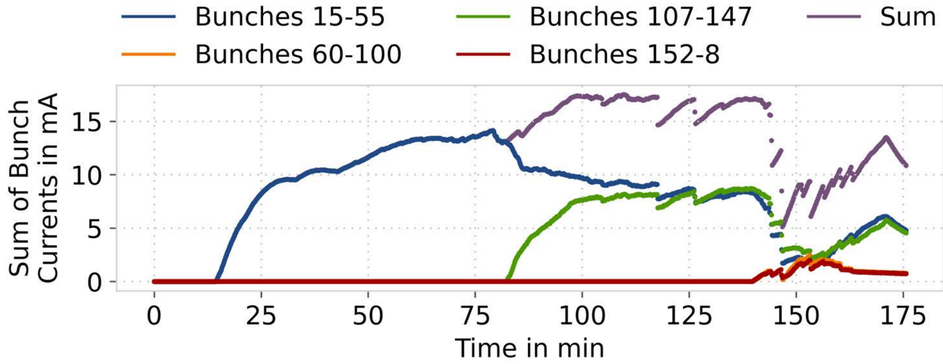
Courtesy: A. Mochihashi

Control system consolidation

- Situation in the past
  - Several control systems (ACS, WinCC OA, EPICS, LabView, Standalone Applications) used in parallel for the accelerator - beam lines uses in addition Tango and SPEC
  - Automation and high level control not possible
- Goal: Operate the accelerator with one control system (EPICS)
- Status
  - Migration process from WinCC OA to EPICS finished
  - Migration from ACS to EPICS will be finished when new power supplies are installed (only 11 devices left)
- Next steps:
  - State machine for operation
  - Machine learning based feedback systems / controls

KARA test facility activities

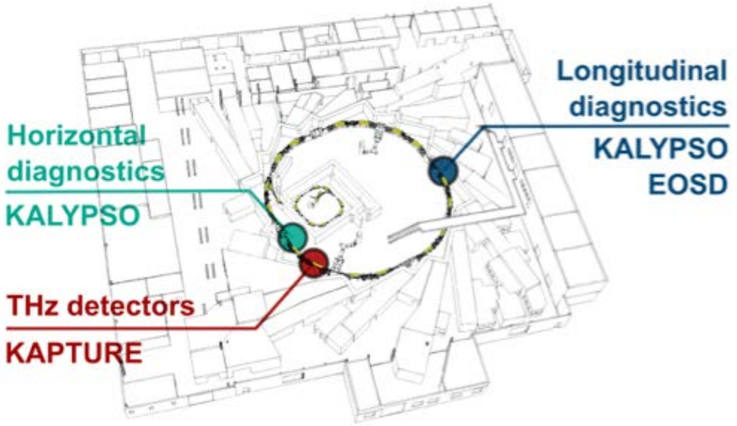
- Probing beams with low / negative momentum compaction factor
  - Momentum compaction factor α_c
  - Filling pattern
  - Energy (500 - 1300 MeV)
  - CSR measurements
  - Bunch length measurements



Courtesy: P. Schreiber

- Implementation of an impedance manipulation chamber
  - UltaSync: French-German project supported by ANR & DFG
- KARA Booster as diagnostic test bed for cSTART
  - Similar properties in terms of energy and repetition rate
  - Install new BPM, BLM and BBB electronics

KARAs distributed synchronized sensor network



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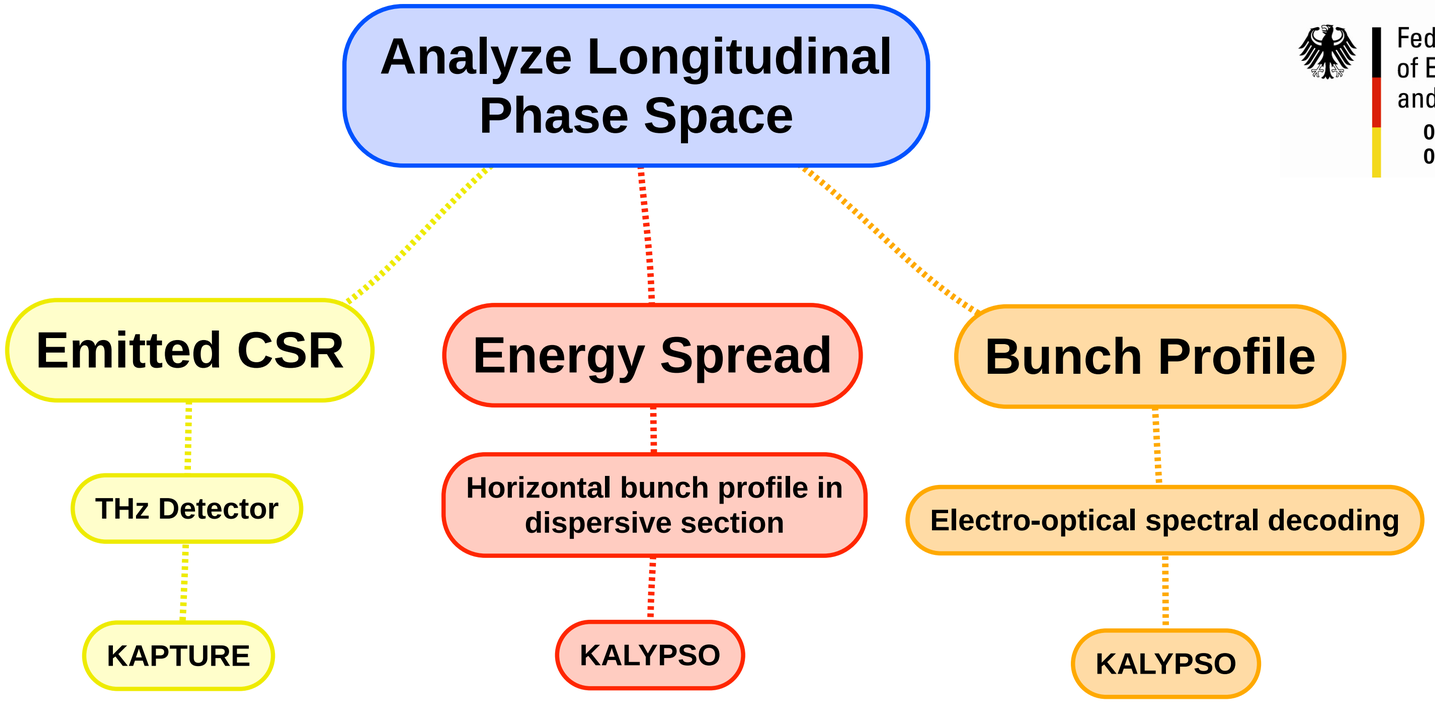
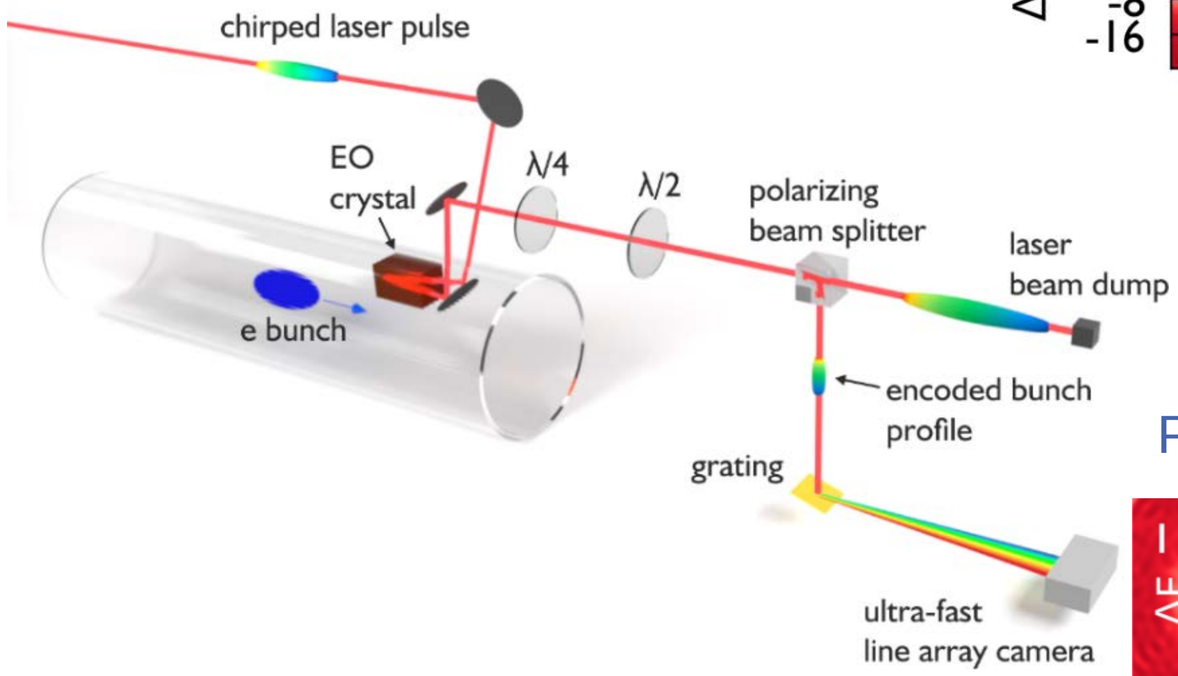


EPS-AG Frank Sacherer Prize 2020 (J.L. Steinmann)

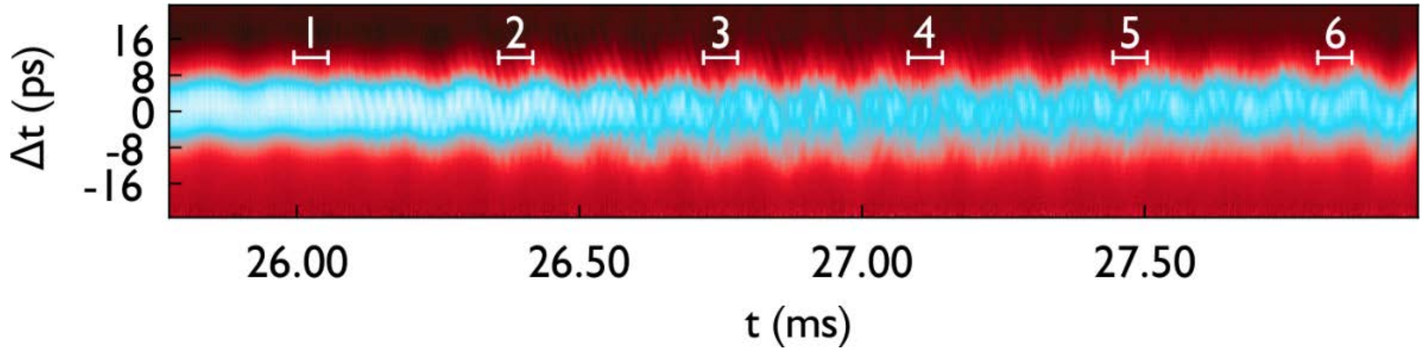
- B. Kehrer: Time-resolved studies of the micro-bunching instability at KARA, PhD dissertation, DOI: http://dx.doi.org/10.5445/IR/1000098584
- M. Brosi: In-Depth Analysis of the Micro-Bunching Characteristics in Single and Multi-Bunch Operation at KARA, PhD dissertation, DOI: https://doi.org/10.5445/IR/1000120018

Phase space tomography of electron bunches during the micro-bunching instability

EOSD experiment

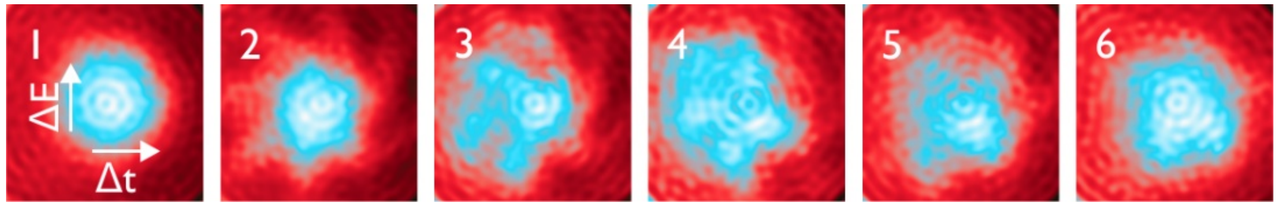


Revolution plots / sinograms



Filtered back-projection

Phase space density



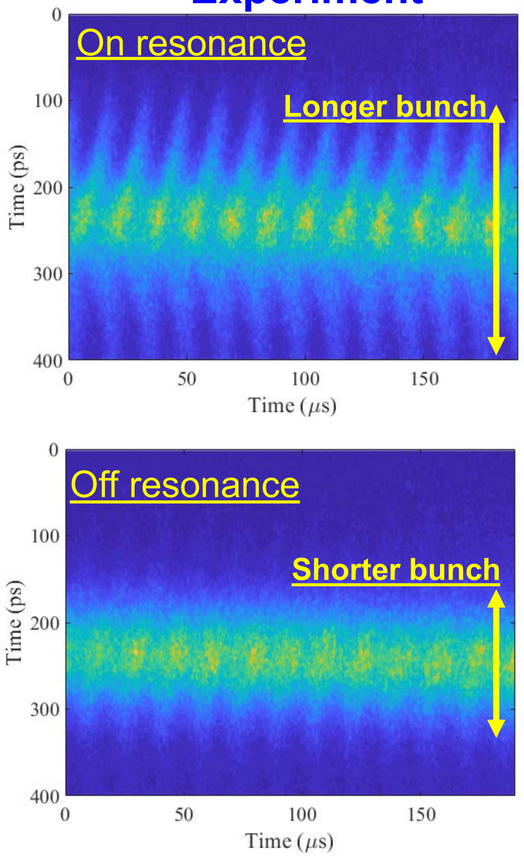
S. Funkner, et al., arXiv:1912.01323

Courtesy: S. Funkner, G. Niehues

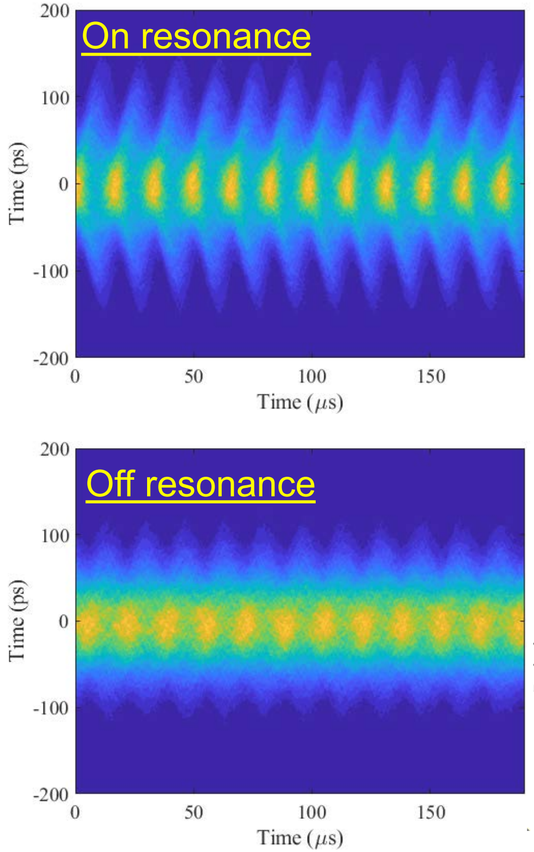
Beam manipulation on longitudinal phase space by RF phase modulation with $2f_s$

Streak Camera Image

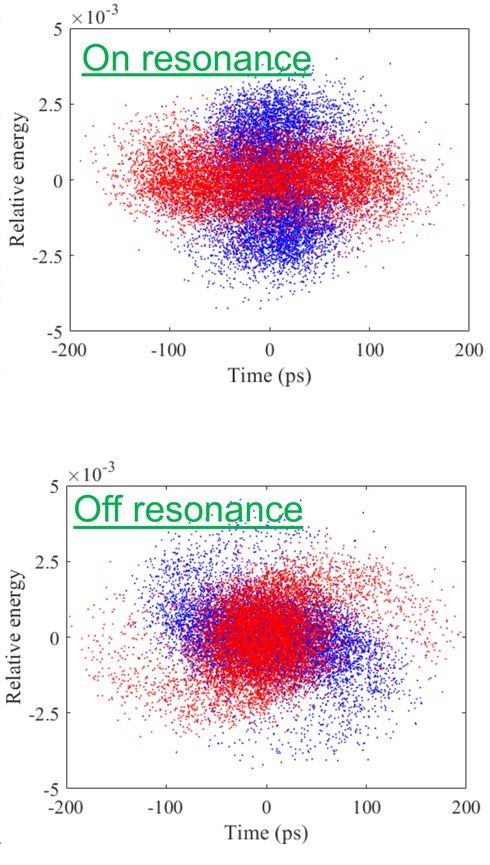
Experiment



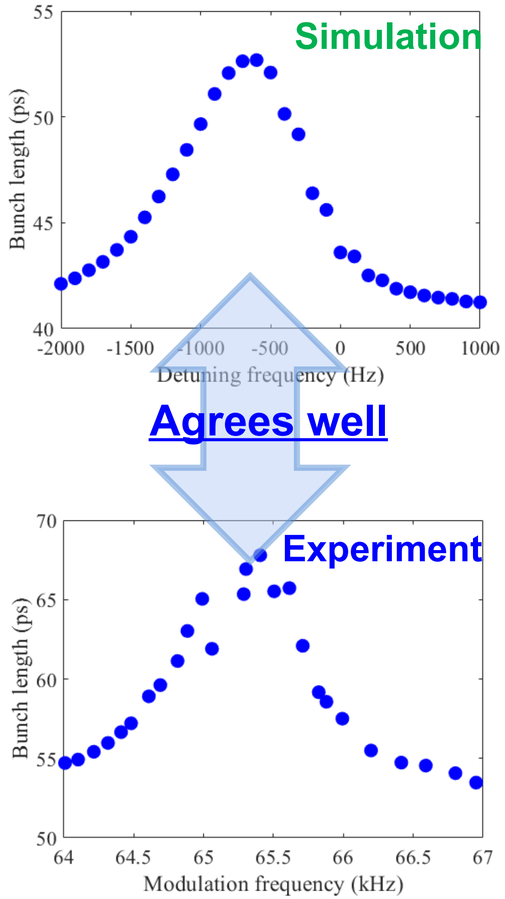
Simulation



Phase space Simulation



Detuning property



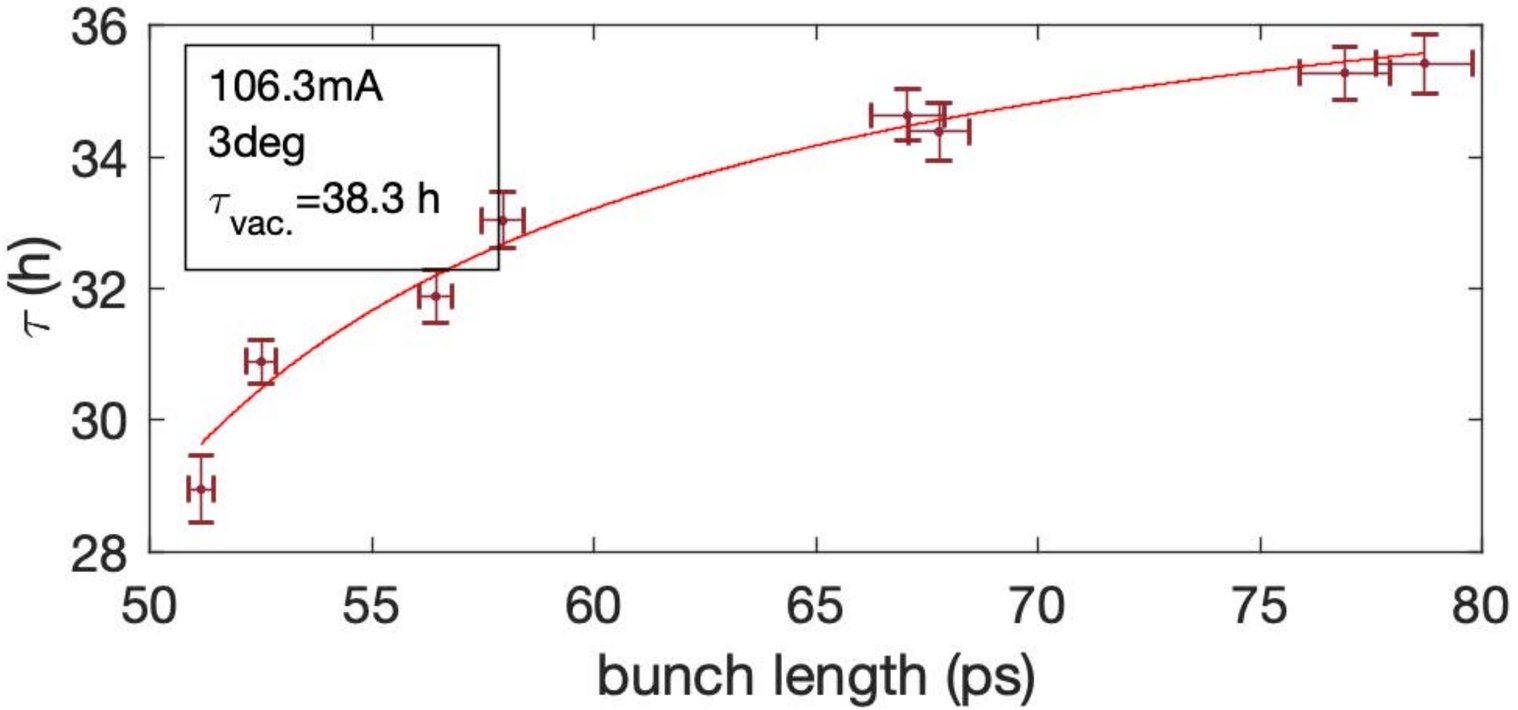
Agrees well

Article in preparation

Courtesy: A. Mochihashi, S. Maier

Systematic studies of RF phase modulation at KARA

- With the RF phase modulation the bunch length can be influenced
- Life time improvement as function of the bunch length

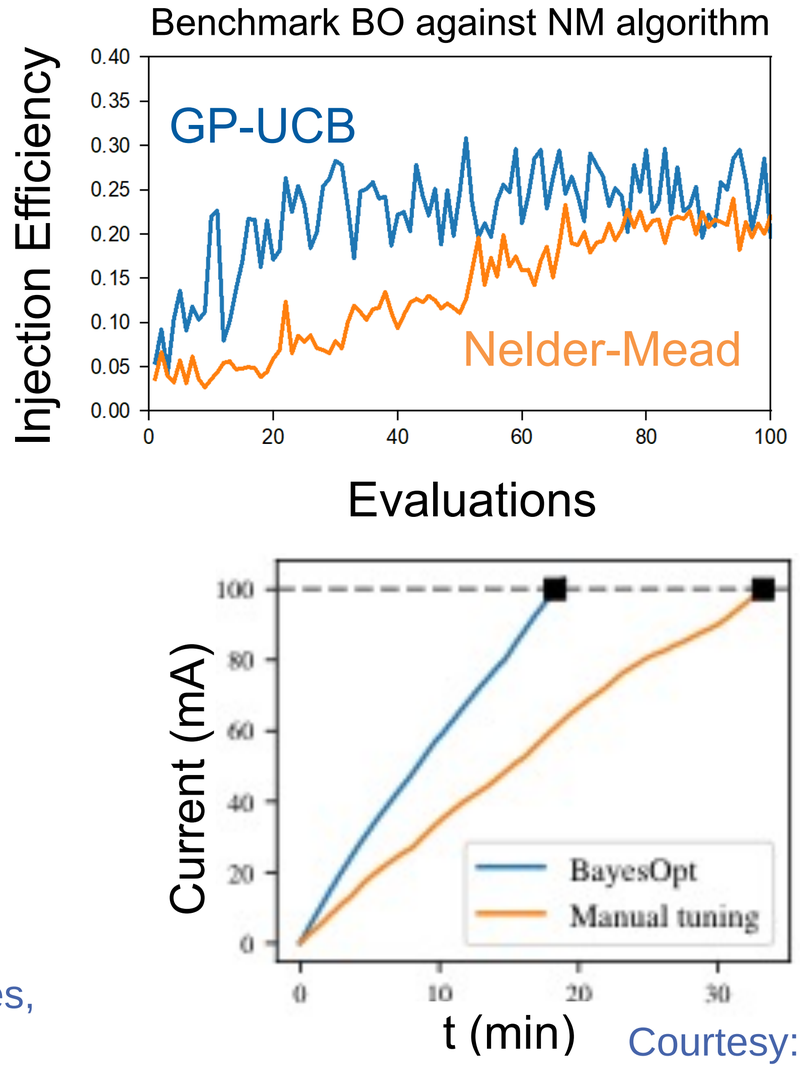


S. Maier, Systematic studies of RF phase modulation at KARA, Master thesis, DOI: 10.5445/IR/1000123900

Courtesy: S. Maier

Injection optimization using ML

- Implemented Bayesian Optimization (BO) with Gaussian Processes (GP) for the beam injection tuning at KARA
- Achieved efficient optimization for d<9 input parameters
- BO outperforms Nelder-Mead (NM) and manual tuning
- Injection tuning half-automated



C. Xu, Bayesian Optimization of Injection Efficiency at KARA using Gaussian Processes, Master thesis, to be published; article in preparation

Courtesy: C. Xu

Outlook

- Order and installation of new power supplies
- Installation and commissioning of new booster diagnostics
- Continue activities in EU projects ARIES and I.FAST in the future
- Project for energy efficient accelerators
  - Detailed power monitoring of all electric devices
  - Collaboration with other KIT facilities

Acknowledgements

- The accelerator team:
  Axel Bernhard, Edmund Blomley, Tobias Boltz, Miriam Brosi, Erik Bründermann, Hyuk Jin Cha, Kantaphon Damminsek, Samira Fatehi, Stefan Funkner, Julian Gethmann, Andreas Grau, Bastian Härer, Dima El Khechen, Michael Hagelstein, Erhard Huttel, Igor Kriznar, Benjamin Kehrer, Sebastian Maier, Anton Malygin, Sebastian Marsching, Yves-Laurent Mathis, Wolfgang Mexner, Akira Mochihashi, David Moss, Mattias Nabinger, Michael J. Nasse, Yuancun Nie, Gudrun Niehues, Meghana Patil, Alexander Papash, Micha Reißig, Robert Ruprecht, David Saez de Jauregui, Andrea Santamaria Garcia, Carl Sax, Jens Schäfer, Thiemo Schmelzer, Patrick Schreiber, Markus Schwarz, Nigel J. Smale, Johannes L. Steinmann, Pawel Wesolowski, Christina Widmann, Andreas Will, Tonia Windbichler, Chenran Xu, and Anke-Susanne Müller
- KIT Institutes (ETP, IHM, IMS, IPE, IPS, LAS, IAR, IPQ)
- Collaboration partners: