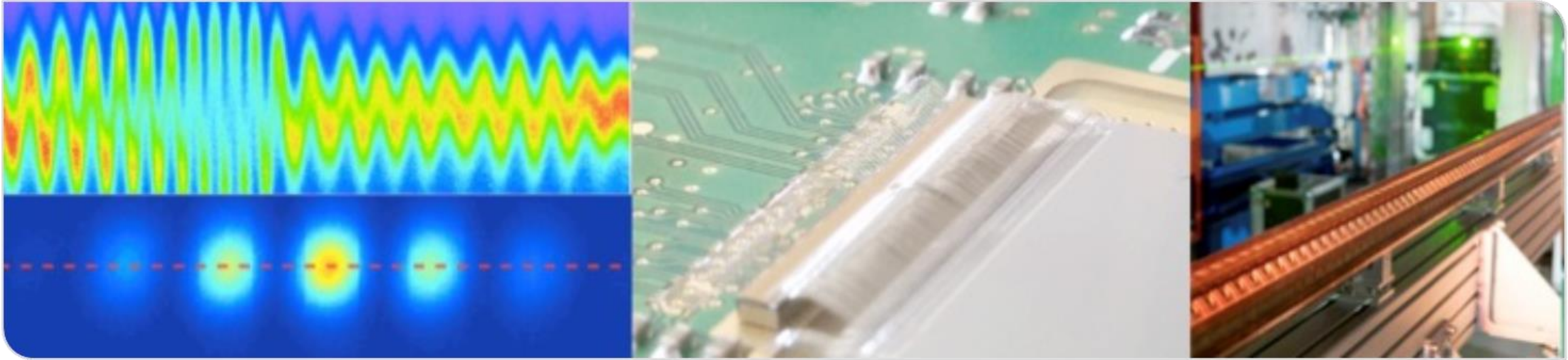
KIT - Status Test Facilities KARA & FLUTE

30th European Synchrotron Light Source Workshop 2022
Akira Mochihashi on behalf of the KIT team



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

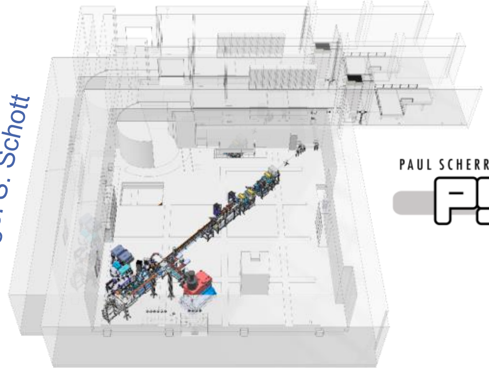


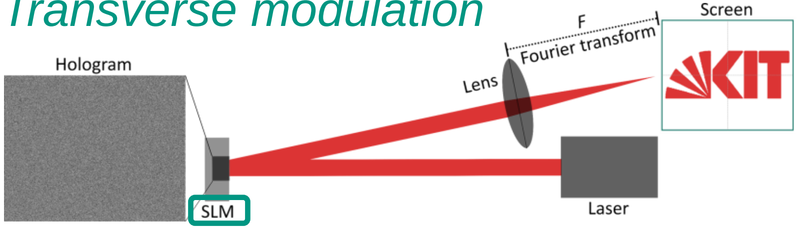
Image: S. Schott

Final electron energy	~ 41	MeV
Electron bunch charge	0.001 - 1	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

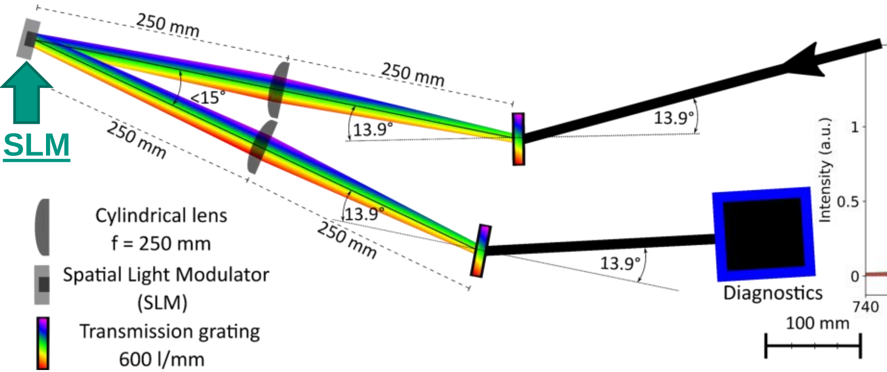
Transverse and longitudinal modulation of photoinjection pulses at FLUTE

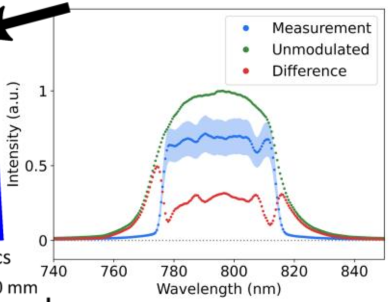
Transverse modulation



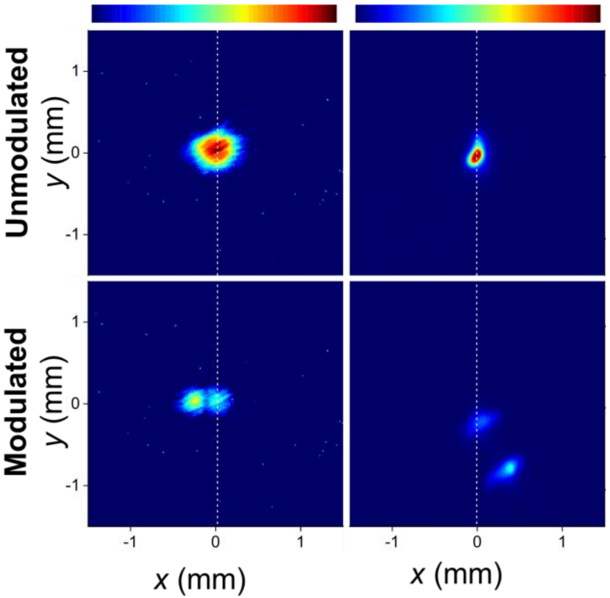
Spatial Light Modulator (SLM)

Longitudinal modulation





Photoinjection pulse modulation



M. Nabinger et al. doi: 10.18429/JACoW-IPAC2022-TUPOPT068

Optimization Studies of Simulated THz Radiation at FLUTE

- **Parallel Bayesian optimization** of machine settings for **shortest bunch** and **highest THz pulse E-field** at FLUTE
- Efficient optimization using cluster resources, single optimization run takes about 6h
- Optimized settings vs.

  design stage settings:

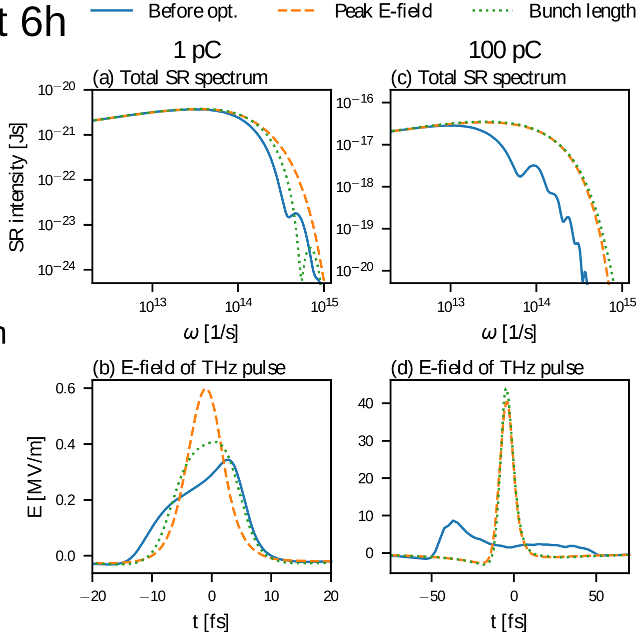
  Shortest bunch:

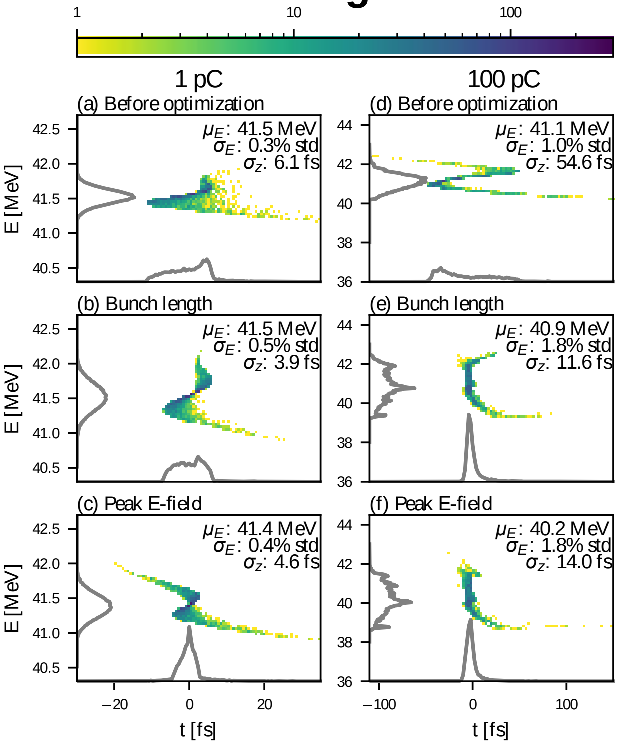
  100pC 54.6 fs → 11.6 fs

  Highest THz pulse E-field:

  1pC 350 kV/m → 600 kV/m

  100pC 8.4 MV/m → 43 MV/m

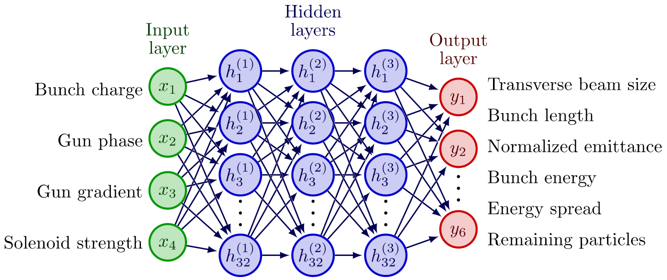




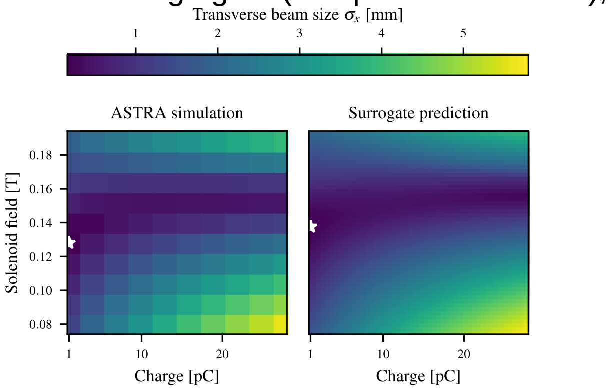
C. Xu et al. https://doi.org/10.18429/JACoW-IPAC2022-WEPOMS023

Surrogate Modelling of FLUTE Low-energy Section

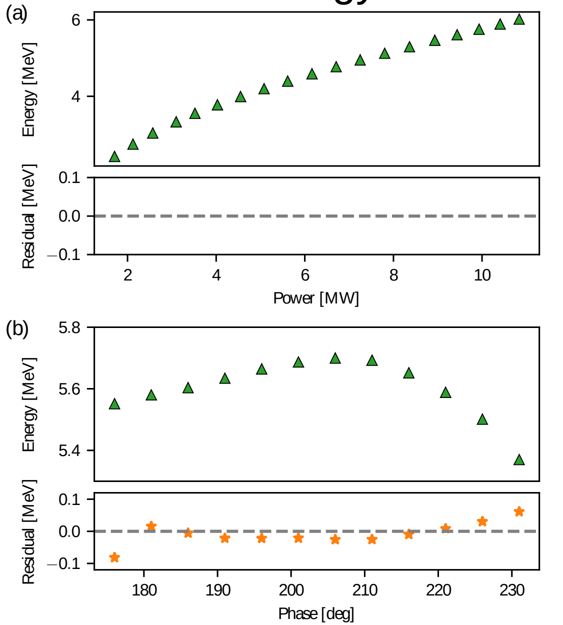
- One ASTRA space charge simulation takes ~3 min → very slow
- Use a neural network as a surrogate of the ASTRA simulations of FLUTE low-energy section.
  - Input: Charge, gun RF phase, gun RF gradient, solenoid strength
  - Output: Bunch size, length, energy, energy spread
  - Application:
    - virtual diagnostic for operation (shot-to-shot beam properties prediction)
    - training environment for reinforcement learning agent (fast prediction < 1ms);
    - speed up optimizations;



NN Structure



Comparison to ASTRA Simulation



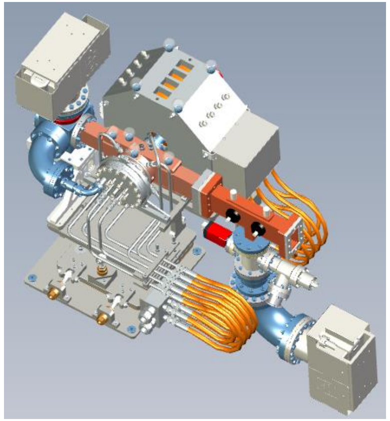
Comparison to Measurement

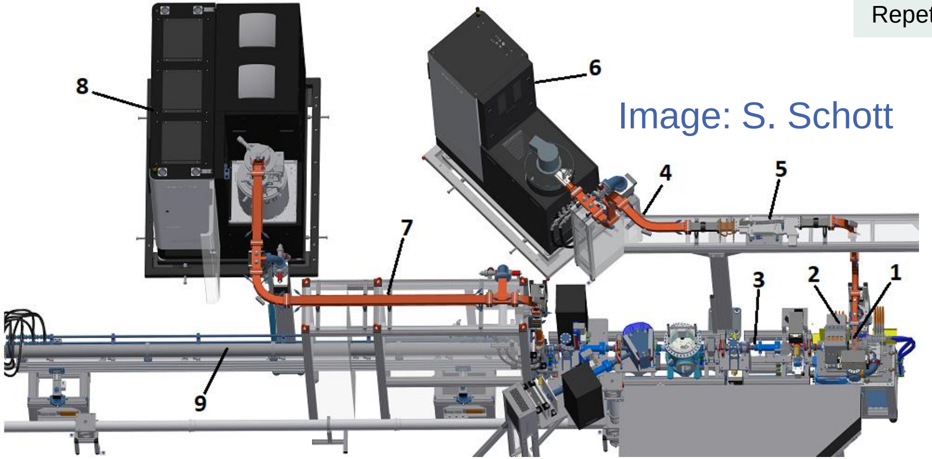
C. Xu et al. https://doi.org/10.18429/JACoW-IPAC2022-TUPOPT070

FLUTE: Upgrade status

- K100 and K300 RF units have been already installed and commissioned at FLUTE
- RF photo-injector and waveguide system has been delivered and installation will be finished by the end of 2022.
- Commissioning of the RF photo-injector is planned for the first half of 2023.
- Installation of the RF waveguide for the linac and its conditioning is planned for the second half of 2023

Parameter	K100	K300
RF power	10.6 MW	36.8 MW
Frequency	2.998 GHz	
RF pulse length	4.5 µs	
Repetition rate	50 Hz	
Pulse-to-pulse stability (V)	18 ppm	17 ppm
Repetition rate	50 Hz	





1. RF photo-injector
2. Solenoid
3. Diagnostic section
4. K100 waveguide
5. Circulator
6. K100 RF unit (10 MW)
7. K300 waveguide
8. K300 RF unit (37 MW)
9. Linac

Parameter	Value
Input RF power	9.5 MW
Output Energy	5.5 MeV
Operating Frequency	2.998 GHz
Repetition rate	50 Hz
Peak cathode field	120 MV/m
Bunch charge (max)	1 nC

A. Malygin et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOST008

Karlsruhe Research Accelerator (KARA)

- KIT synchrotron light-source & accelerator test facility

Parameters	Values
Circumference	110.4 m
Energy range	0.5 – 2.5 GeV
RF frequency / period	500 MHz / 2 ns
Revolution frequency / period	2.715 MHz / 368 ns
Beam current	Up to 200 mA
RMS bunch length	45 ps (2.5 GeV) a few ps (1.3 GeV)

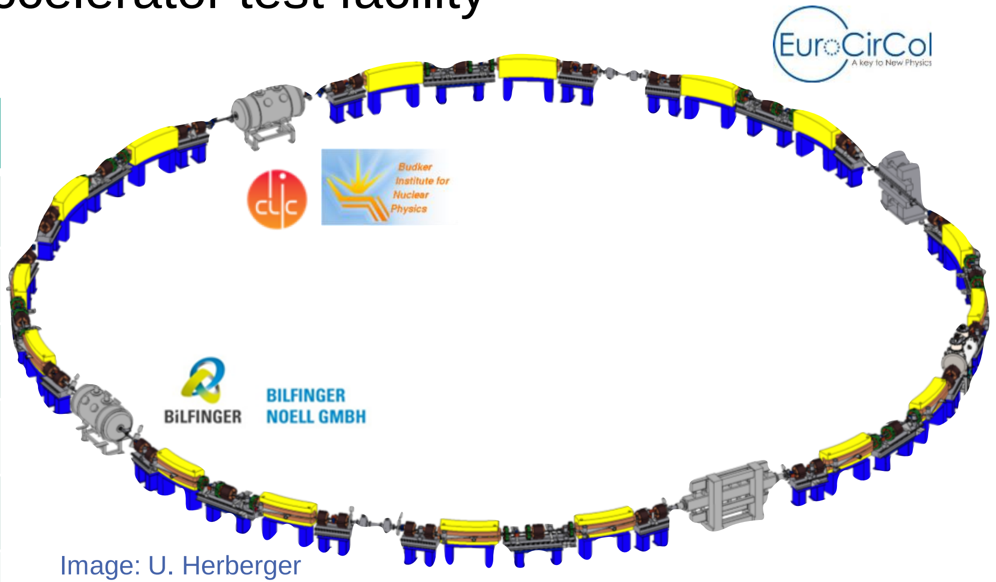


Image: U. Herberger

www.ibpt.kit.edu/kara

KARA operation 2022

- Perfect operation from January till June – delivered more beam than scheduled
- Issues with cooling plant in July and August
  - No operation for 3 weeks in July due to cooling plant failure (burned cables)
  - Limitation of cooling plant capacity: 31°C (outside) for 2.5 GeV operation mode
36°C (outside) for all machine operation mode
  - Two weeks operation with one RF Station and reduced energy to reduce heat load
- Three cavity water leaks at the input coupler circuit
- SR Dipole issues
  - Fan
  - Capacitor failure
  - Under voltage protection
- RF PLC failure

Power supply refurbishment

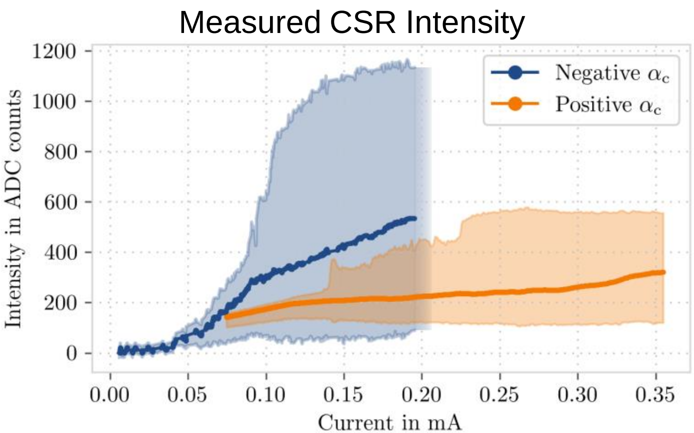
- Installed new PS for KARA sextupole magnets and split them from two into tree families in September
- FAT KARA dipole power supply
- FAT Booster dipole and quadrupole planned beginning of 2023
- Installation planned Q2 2023
- New KARA quadrupole power supplies in the ordering process
  - Start with family powering
  - Test individual powered quadrupole magnets

Power saving

- Detailed mapping of the power consumption down to the lab / device level
- Web interface for online power monitoring
- Automation to shut down and restart more systems in the injector when there is no injection
- Investigation of new operation modes at lower energy to be able to operate with one RF station to save power
- Replace old power supplies with more efficient ones
- Tests ongoing to reduce the shutdown power consumption

Beam Dynamics at Negative Momentum Compaction Factor at KARA

Longitudinal Instability

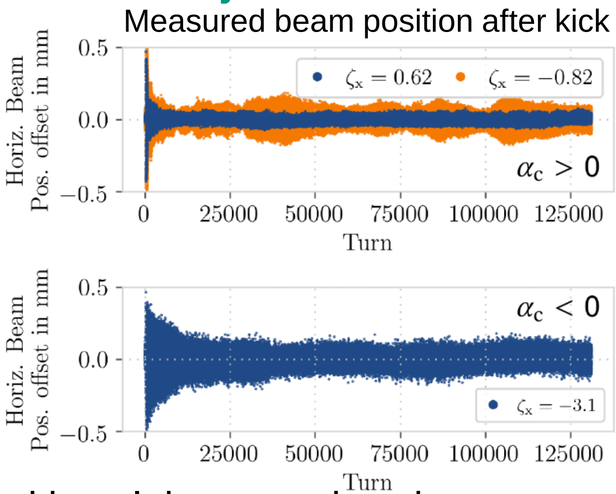


- Longitudinal instability at short bunch length
- Emission of Coherent Synchrotron Radiation (CSR)
- Comparison with positive and negative momentum compaction factor conditions

At negative compaction: higher mean- and max intensity

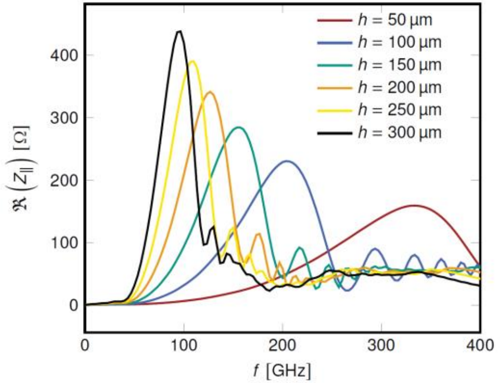
P. Schreiber et al. DOI: 10.5445/IR/1000148354
P. Schreiber et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOPT006

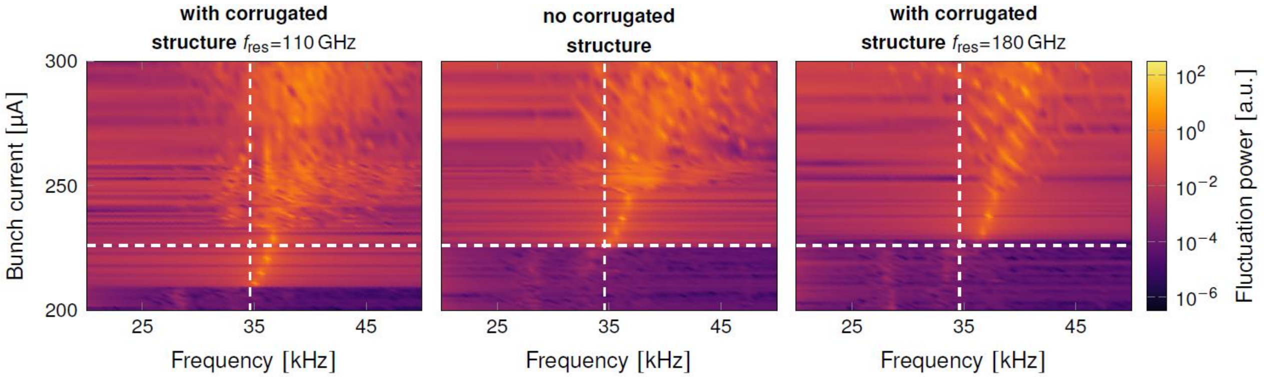
Transverse Stability

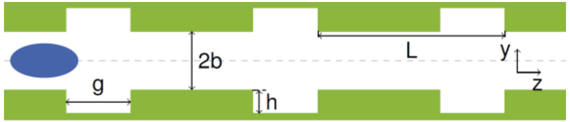


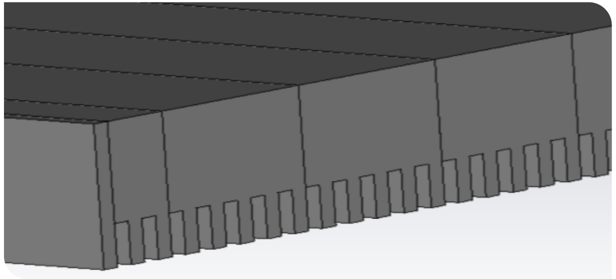
- Positive alpha, negative chroma … unstable
- Negative alpha, negative chroma … stable
  - Negative alpha operation allows sextupole field reduction
  - Enlargement of dynamic aperture
  - Benificial for future light sources

Impedance manipulation at KARA









- **Corrugated plates** will be installed into KARA
- Goal: Observe and control the microbunching instability
- Affecting threshold current and/or bursting frequency with additional impedance

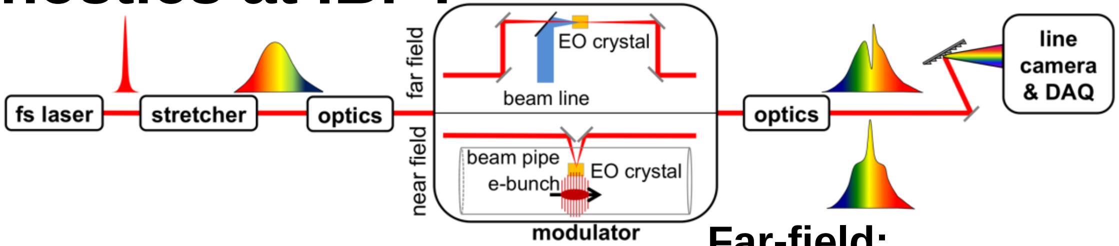
S. Maier et al., https://doi.org/10.18429/JACoW-IPAC2021-TUPAB251

S. Maier et al., https://doi.org/10.18429/JACoW-IPAC2022-WEPOMS006

S. Maier et al., MOP27, IBIC 2022 (to be published)

EO Diagnostics at IBPT

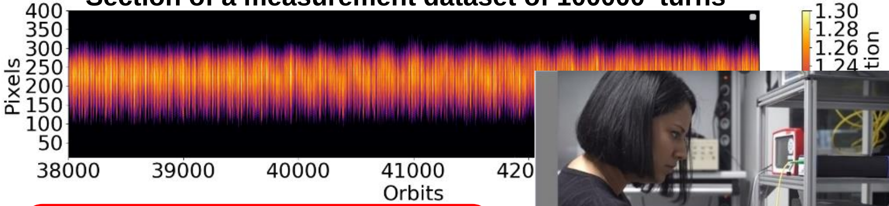
Karlsruhe Institute of Technology



Near-field:

- Resolving electron bunch profile in every turn @ 2.7 MHz
- Capable of uninterrupted data acquisition for up to several millions of turns

Section of a measurement dataset of 100000 turns



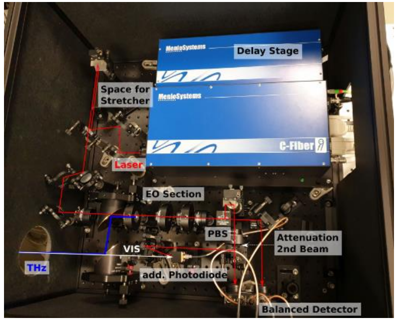
Faraday Cup Award 2021
M. M. Patil

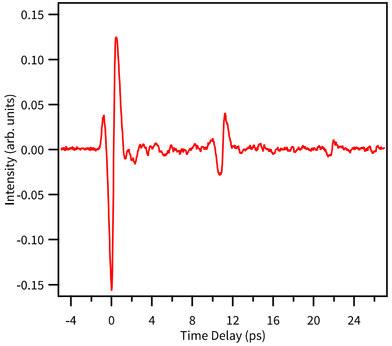
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IPAC2021-FRXC03
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IPAC2021-WEPAB33
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IBIC2021-MOOB01

Far-field:

- Experiment under commission, current status: successful EOS demonstration with off-line demonstrator using balanced detection
- Aiming to measure the complete THz pulse in single-shot

Off-line demonstrator:

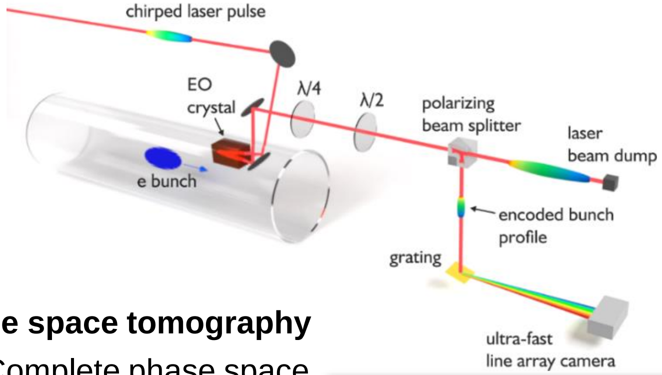




C. Widmann et al. https//:doi.org/10.18429/JACoW-IPAC2022-MOPOPT024

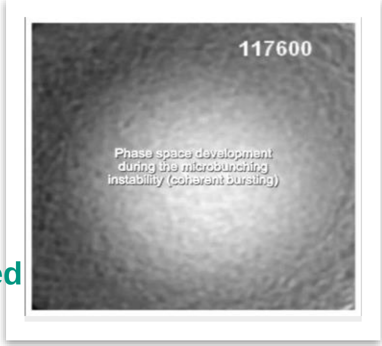
EO Diagnostics at IBPT

Near-field:



phase space tomography

- Complete phase space image reconstructed from time interval of 61 µs
- “Randon morphing“ between independent measurement



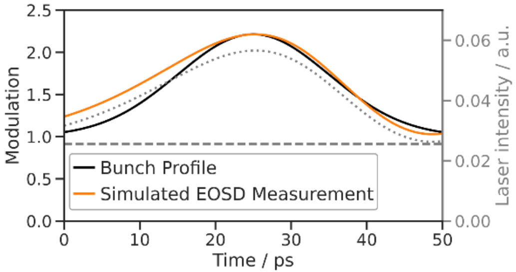
Animation reconstructed from measured data

S. Funkner et al. arXiv preprint, arXiv:1912.01323

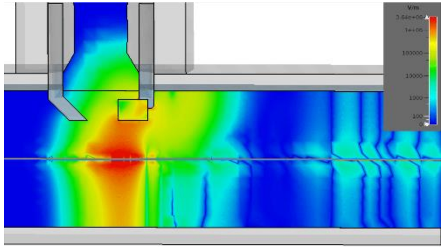
Development of an EO Bunch Profile Monitor for FCC-ee

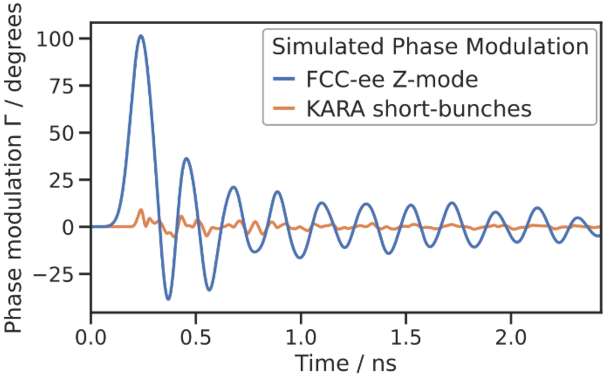
Simulations of the EO near-field measurements at KARA

FUTURE CIRCULAR COLLIDER
Innovation Study



Simulations of EO near-field monitor at KARA





M. Reißig et al. doi:10.18429/JACoW-IPAC2022-MOPOPT025
M. Reißig et al. WEP26, IBIC 2022 (to be published)

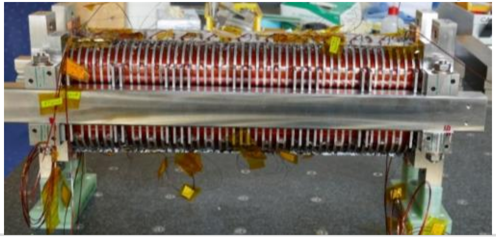
Insertion Devices R & D – Superconducting Undulators (SCUs)

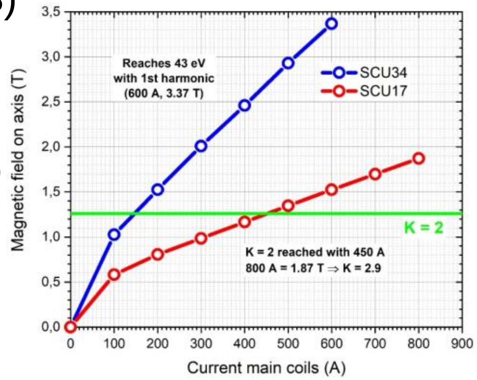
Concept

- Magnetic structure based on low temperature superconducting (LTS) wire technology (NbTi)
- Cryogen free cooling concept (cryocoolers)

SCU with switchable period length

- NbTi low temperature superconducting (LTS) wire
- Period switching 17mm/34mm
- 17mm → overlap 1st and 3rd harmonic (K>2)
- 34mm → photon energies down to 43 eV





SCU20
(20 mm period length,
~1.55 m long magnetic structure)

Photo: M. Breig, KIT

SCU20 installed and operating successfully in KARA since 2018

A. Grau et al., Applied Superconductivity Conference ASC 22 (Oct. 24-28, 2022, Honolulu, Hawaii, USA)

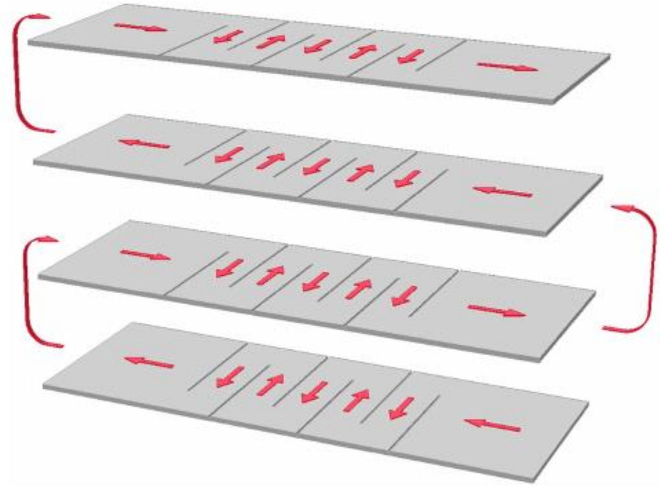
Insertion Devices R & D –
HTS Superconducting Undulators

SPONSORED BY THE Federal Ministry of Education and Research

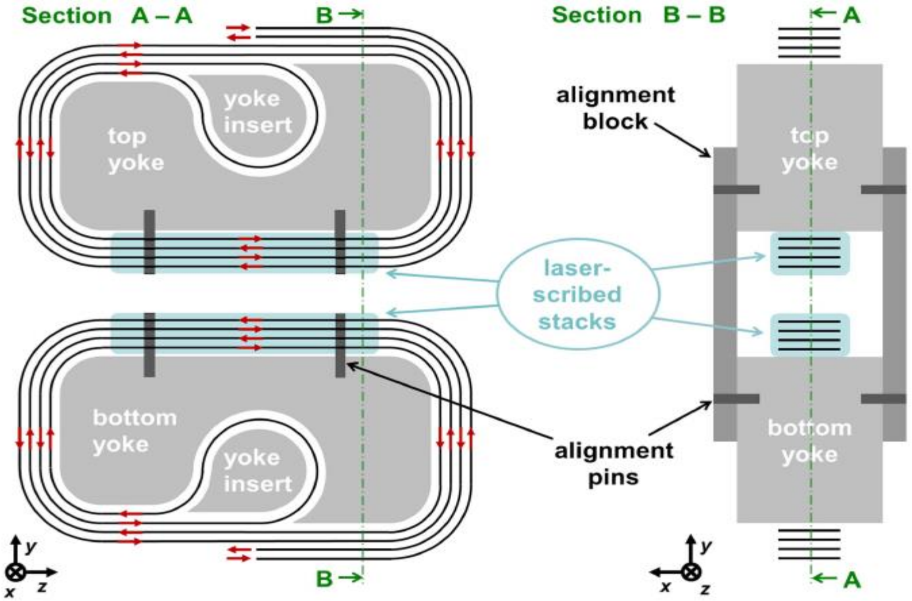
Karlsruhe Institute of Technology

Concept:

- then **stacking tapes in alternating** (current) **direction** and with phase shift between the layers
- achieved by **winding** a **two-stacked-tape** (needs one turn at the beginning, **see yoke insert**)



Courtesy: David Saez de Jauregui



Insertion devices R & D –
HTS superconducting undulators

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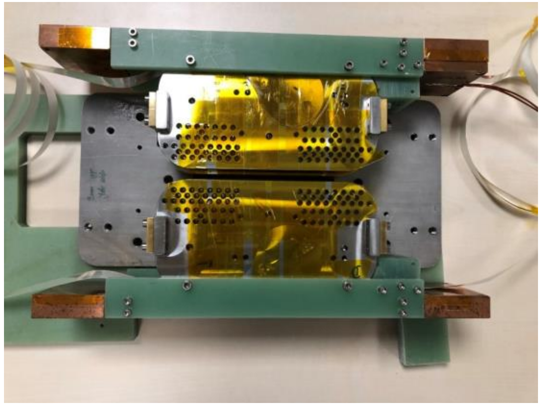
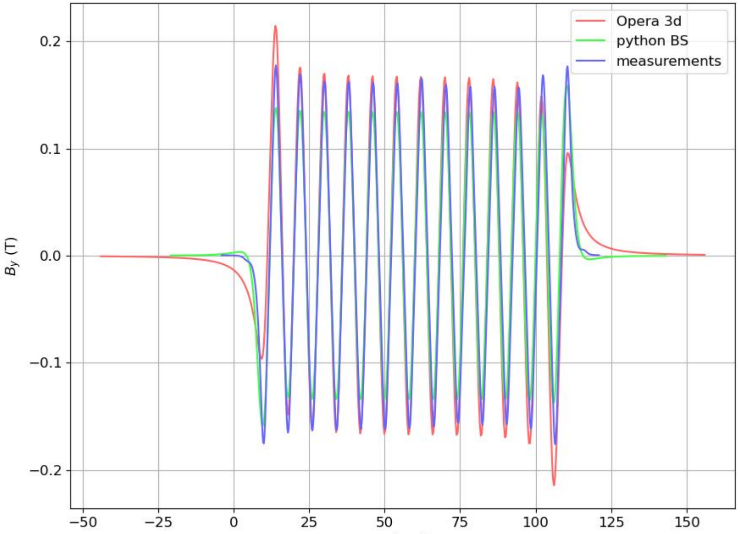
Realisation and first results:





- Undulator magnet was realized
- First measurements of a 30 stack tape undulator
- FEM model in OPERA 3D
- Promising results: simulations scale with measurements

D. Astapovych FEL2022 Proceedings (to be published)

Experience of superconducting IDs

BiLFINGER
BILFINGER NOELL GMBH
KIT Karlsruhe Institute of Technology

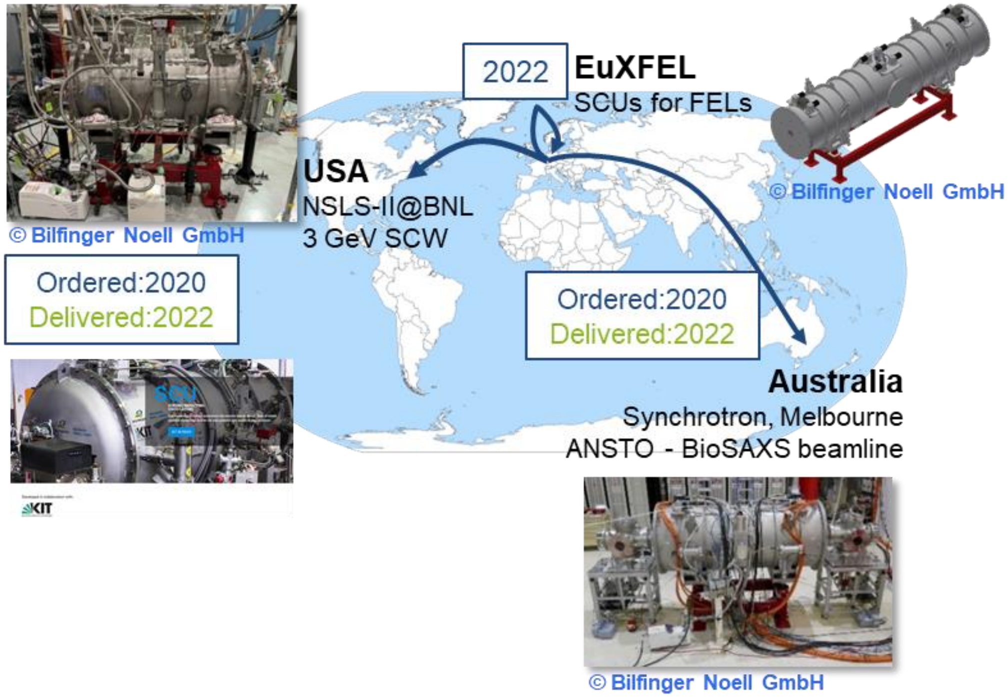
- Development of superconducting undulators in Karlsruhe started in the **early 1990s**.

- As early as **2005**, a first demonstration of a superconducting undulator, in cooperation with ACCEL Instruments GmbH, was installed in the KARA storage ring.

- In cooperation with Bilfinger Noell GmbH, SCU15 in **2014** and SCU20 in **2017** were build and installed in the KARA storage ring.

- In **2016**, a transverse gradient undulator (TGU) with ±10% energy acceptance was designed and developed to work with laser plasma electron sources.

Technology Transfer from KARA/KIT to the world



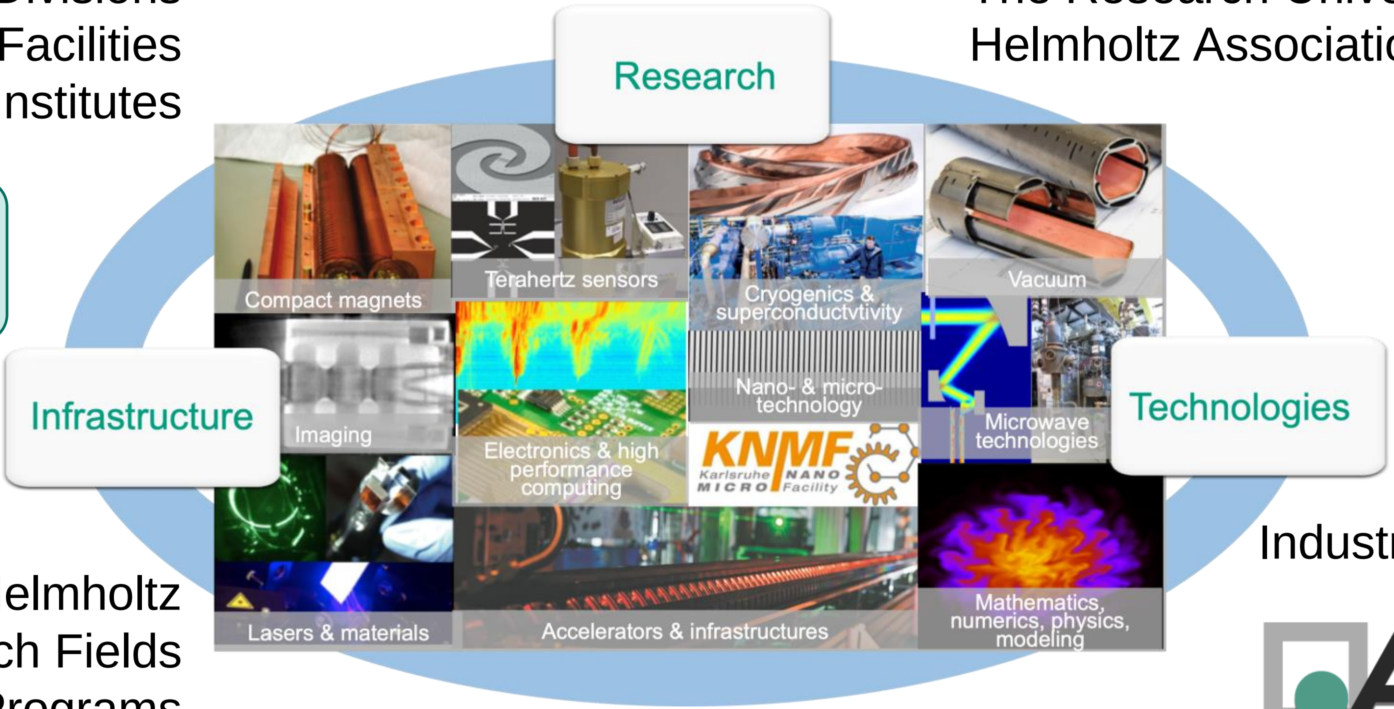
The Accelerator Technology Platform @KIT (ATP)

Karlsruhe Institute of Technology

5 Divisions
6 KIT Facilities
14 Institutes

The Research University in the Helmholtz Association

ATP in lookKIT (German)



Helmholtz
3 Research Fields
6 Programs

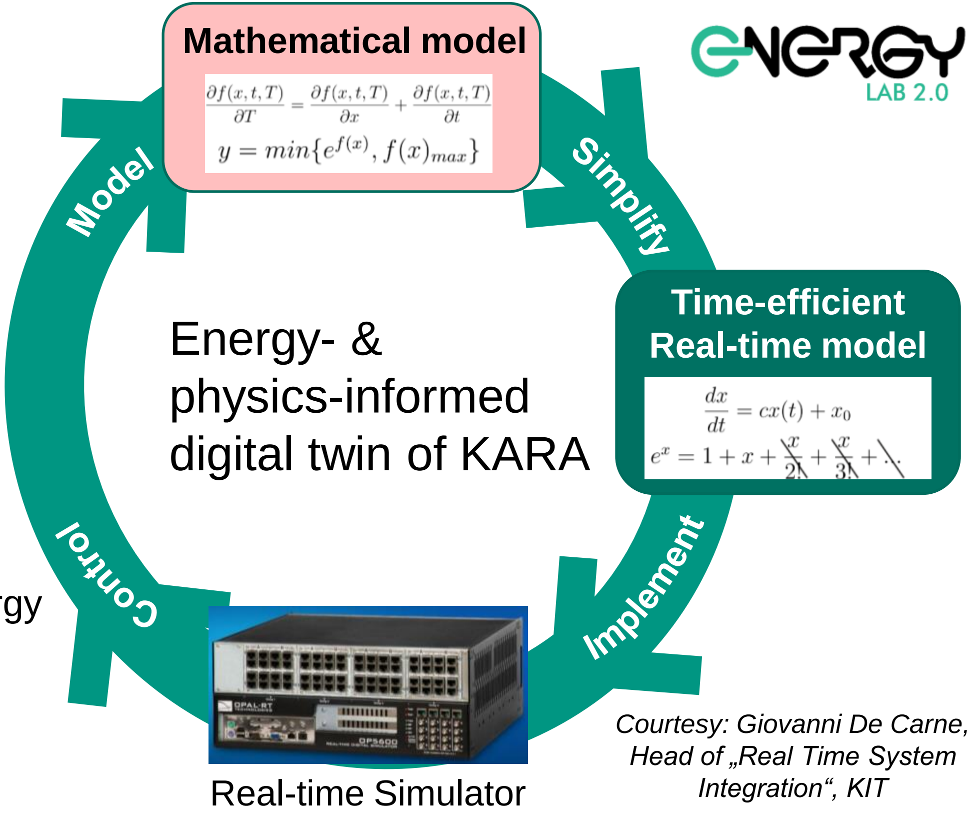
+ strong Industrial partners

Accelerator Technology Platform @ KIT

Accelerator & Energy Systems Test Field KITTEN

Accelerator Technology Platform @ KIT | Karlsruhe Institute of Technology | ENERGY LAB 2.0

- Digital twin of KARA
  - analyzing, developing and testing future energy solutions for research infrastructures
- InnovEEA
  - Load management & network stability



Courtesy: Giovanni De Carne, Head of „Real Time System Integration“, KIT

Accelerator & Energy Systems Test Field KITTEN

Accelerator Technology Platform @ KIT
Karlsruhe Institute of Technology
ENERGY LAB 2.0

KITTEN Inauguration – July 2022

With panel discussion

„Kommen große Forschungsinfrastrukturen an ihre Grenzen - Neue Energiekonzepte für die Forschung der Zukunft"

https://www.youtube.com/watch?v=-YQBtbImXA8 (in German)

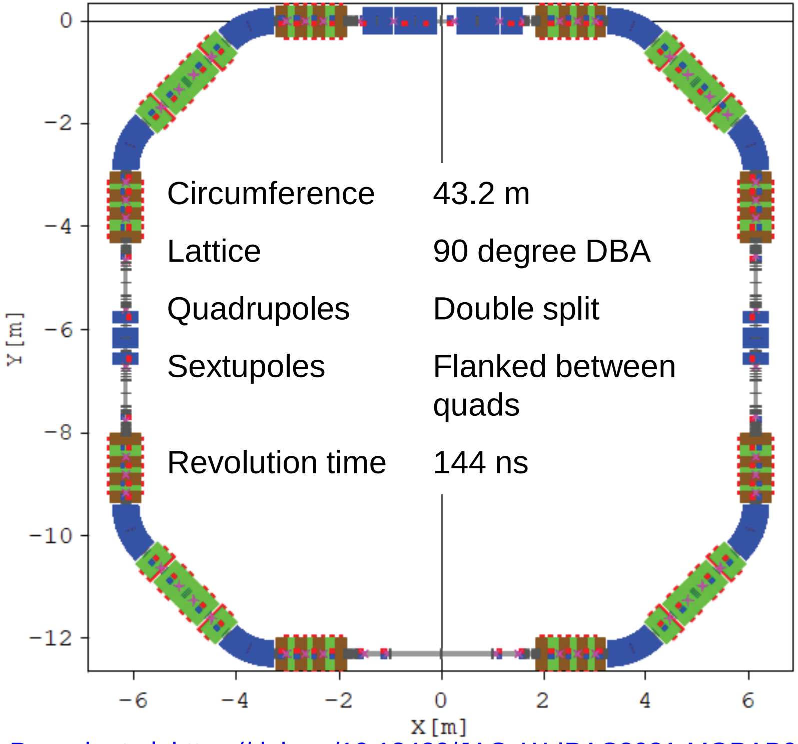
cSTART Project

- Goal: demonstration and examination of the injection and the storage of a laser wakefield accelerator (LWFA) like electron beam

- The Very Large Acceptance compact Storage Ring (VLA-cSR)

- Utilize FLUTE with transfer line as injector

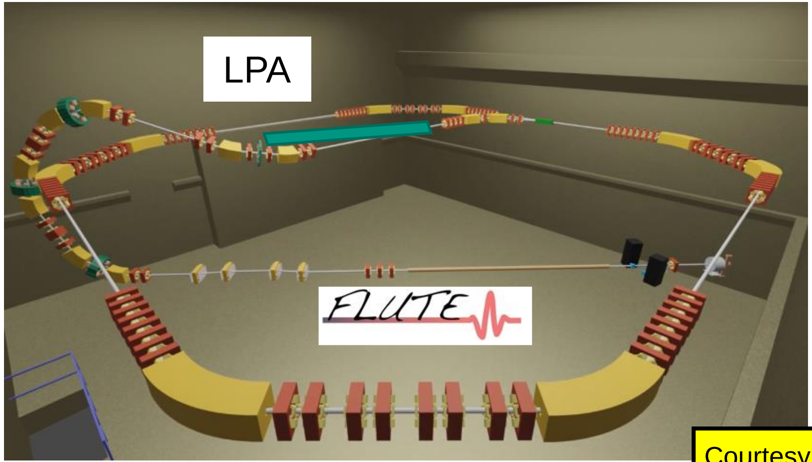
- Status
  - Conceptual design and specification: finished
  - Beam dynamics studies including coherent synchrotron radiation effects
  - Test diagnostics at KARA booster

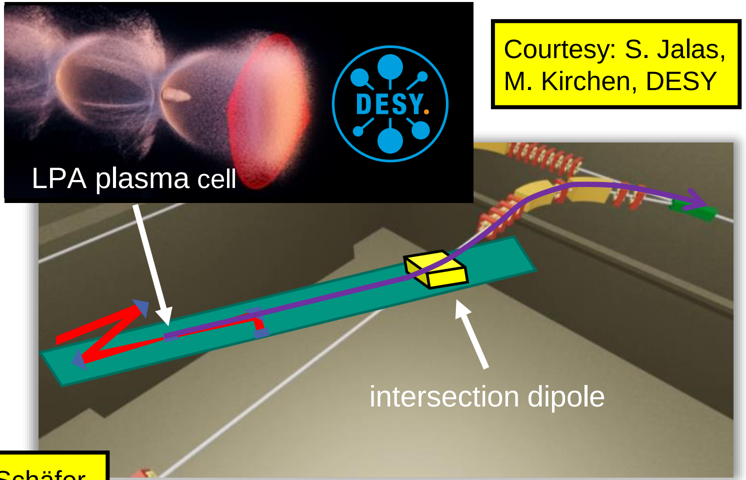


Circumference	43.2 m
Lattice	90 degree DBA
Quadrupoles	Double split
Sextupoles	Flanked between quads
Revolution time	144 ns

M. Schwarz et al. https://doi.org/10.18429/JACoW-IPAC2021-TUPAB255
D. El Khechen et al. https://doi.org/10.18429/JACoW-IPAC2022-MOPOPT026
J. Schäfer et al. https://doi.org/10.18429/JACoW-IPAC2022-MOPOST041
A. Papash et al. https://doi.org/10.18429/JACoW-IPAC2021-MOPAB035
A. Papash et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOPT023

ATHENA @KIT - Status





Courtesy: S. Jalas, M. Kirchen, DESY

Courtesy: J. Schäfer

- Clean room for laser system built ✓
- Installation of customized, commercial 75 TW laser system approaching SAT
- Conceptual design of transfer lines including diagnostics finished ✓
- Fine-tuning of optics and tracking calculations in progress

B. Haerer et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOPT059
B. Haerer et al. https://doi.org/10.18429/JACoW-IPAC2019-TUPGW020
J. Schäfer et al. https://doi.org/10.18429/JACoW-IPAC2022-MOPOST041

Acknowledgements

Thank you for your attention!

Karlsruhe Institute of Technology

- The accelerator team

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