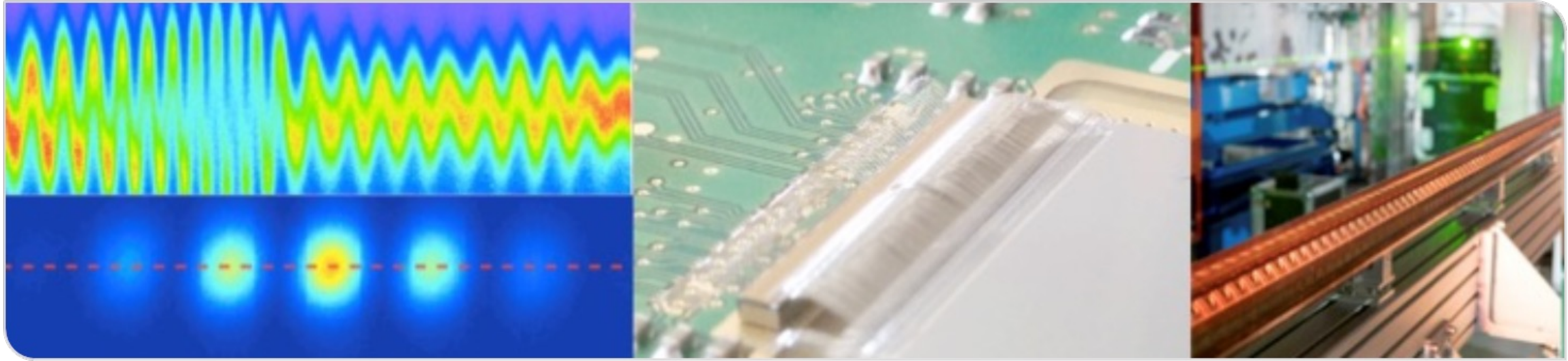
KIT Accelerators and Test Facilities

1st collaboration workshop on Reinforcement Learning for Autonomous Accelerators (RL4AA'23)
Johannes Steinmann on behalf of the KIT team

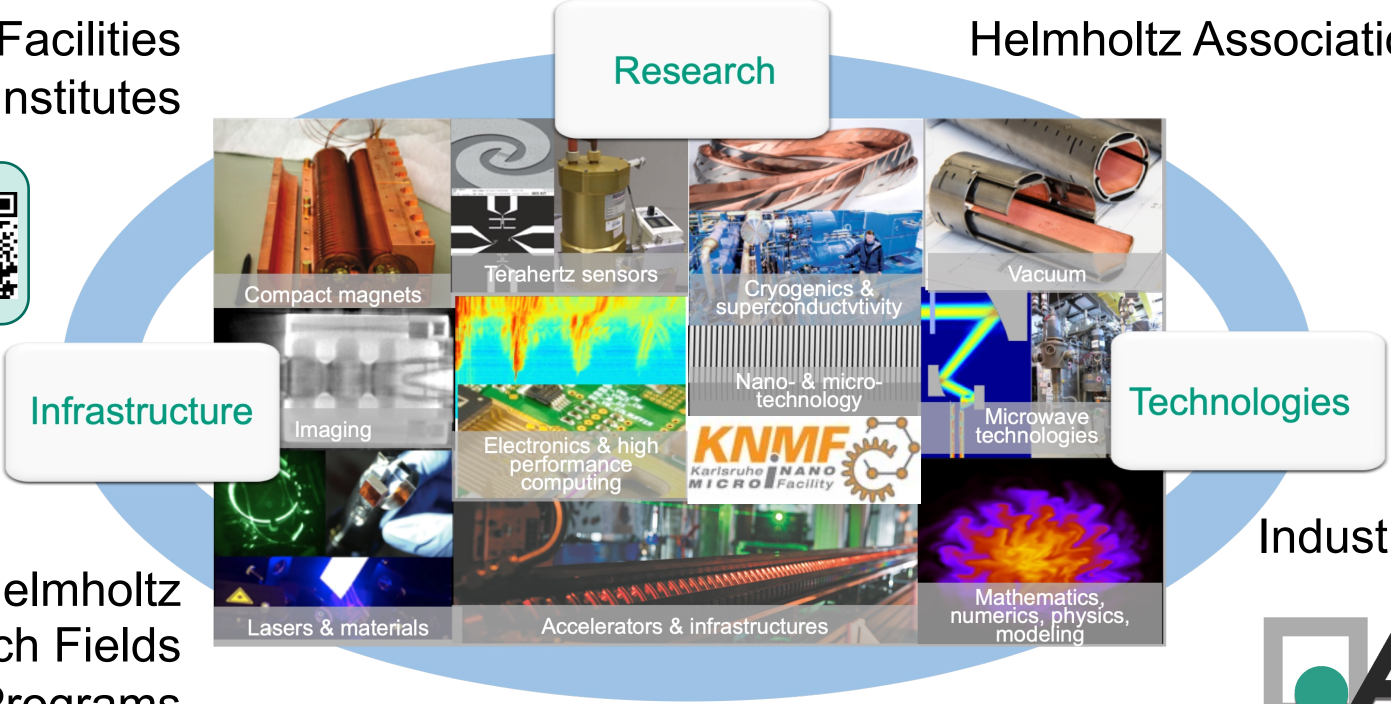


The Accelerator Technology Platform @KIT (ATP)

5 Divisions
6 KIT Facilities
14 Institutes

The Research University in the Helmholtz Association

ATP in lookKIT
(German)



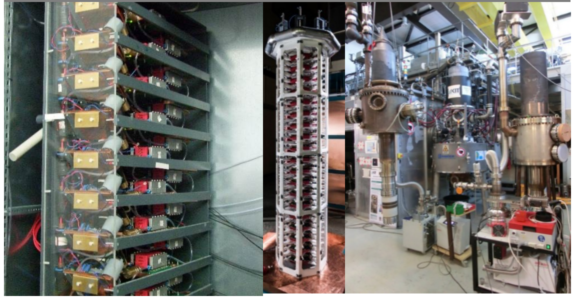
+ strong
Industrial partners

Helmholtz
3 Research Fields
6 Programs

Accelerator Technology Platform @ KIT

Test facilities & technologies - examples

Pulse power technology *Gyrotrons*



Winding technologies

Magnet test facilities

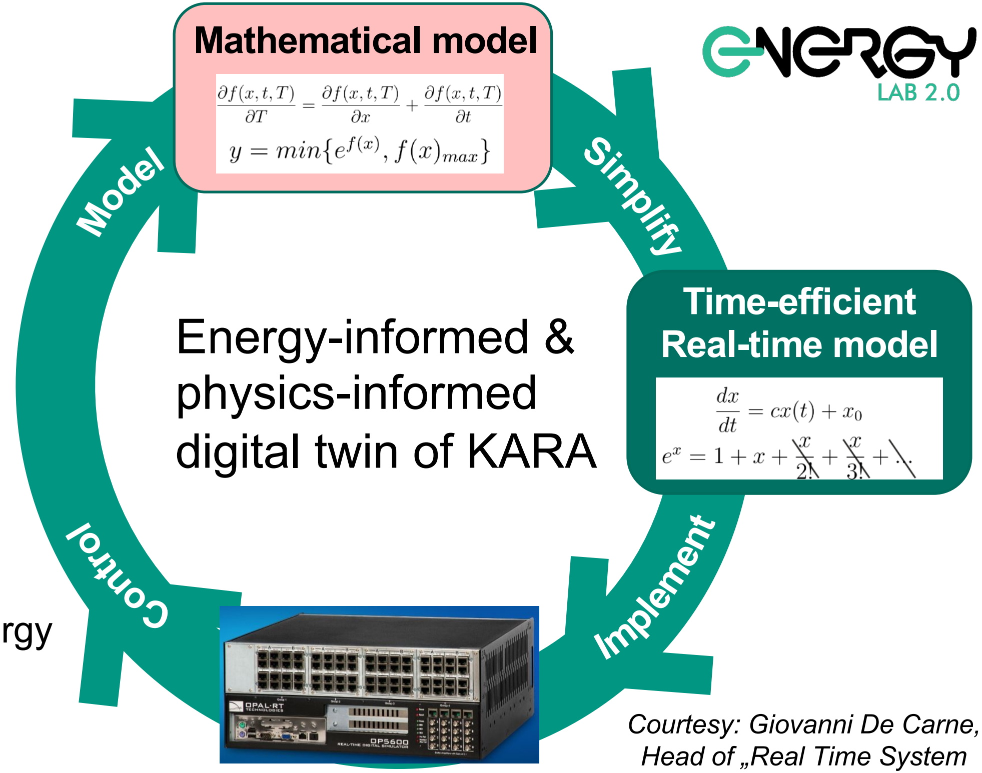
Cable technologies *High temperature superconductors*

Accelerator Technology Platform @ KIT

Accelerator & Energy Systems Test Field KITTEN

COLL AGE: ANKE-SUSANNE MÜLLER, FOTO : MARKUS BREIG

- Digital twin of KARA
  - analyzing, developing and testing future energy solutions for research infrastructures
- InnovEEA



Mathematical model

$$\frac{\partial f(x,t,T)}{\partial T} = \frac{\partial f(x,t,T)}{\partial x} + \frac{\partial f(x,t,T)}{\partial t}$$

$$y = min\{e^{f(x)}, f(x)_{max}\}$$

Simplify

Time-efficient Real-time model

$$\frac{dx}{dt} = cx(t) + x_0$$

$$e^x = 1 + x + \cancel{\frac{x}{2!}} + \cancel{\frac{x}{3!}} + \cancel{\ldots}$$

Implement

Real-time Simulator

Control

Model

Energy-informed & physics-informed digital twin of KARA

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

COLL AGE: ANKE-SUSANNE MÜLLER, FOTO : MARKUS BREIG

KITTEN Inauguration – July 2022

© Robert Fuge, KIT

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)

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
- Big upgrades in progress
  - New RF photoinjector
  - New RF system for photoinjector and linac

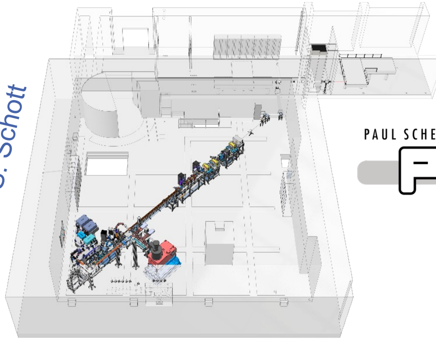
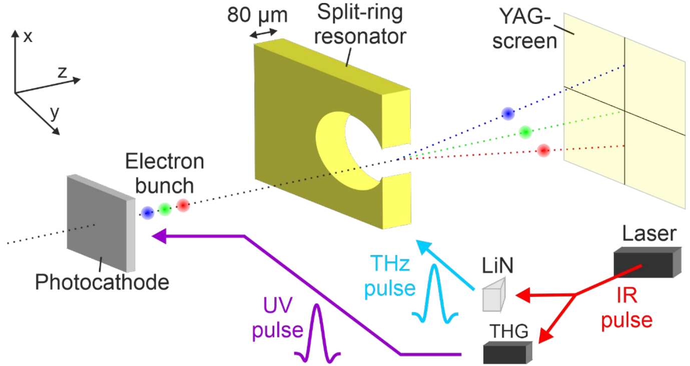


Image: S. Schott

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

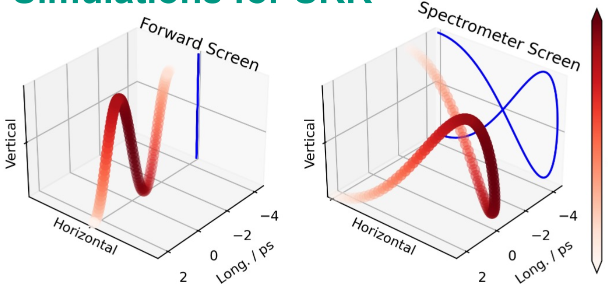
Split-ring resonator at FLUTE



Courtesy: M. Nabinger

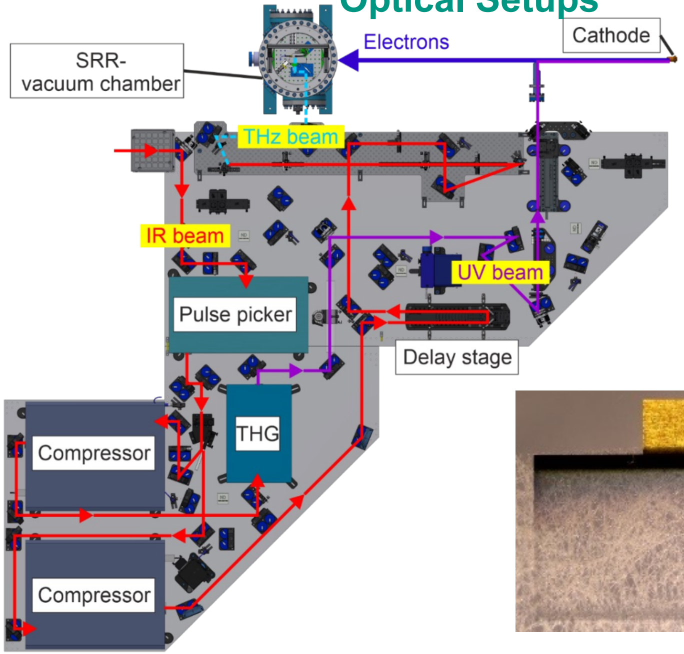
- Streaking with THz radiation and amplifying the electric field with a 20 µm gap **split-ring resonator**

Simulations for SRR

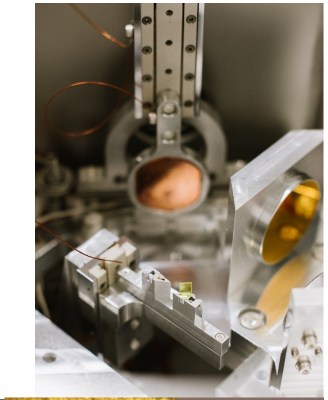


Courtesy: J. Schäfer

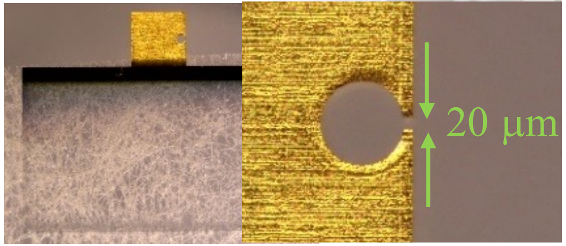
Optical Setups



Courtesy: S. Schott



Courtesy: L. Jochim



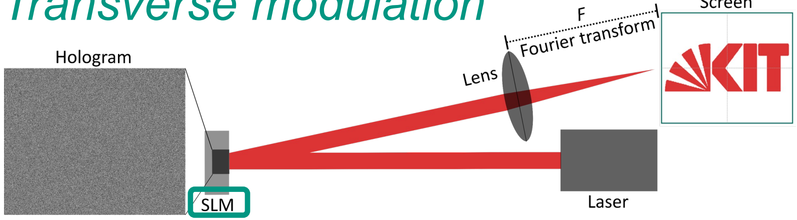
Courtesy: M. Nasse

- Setup of the split-ring resonator measurement in low energy section at FLUTE
- Experimental setup in vacuum chamber **installed**

M. Nabinger et al. https://doi.org/10.18429/JACoW-IPAC2021-MOPAB280

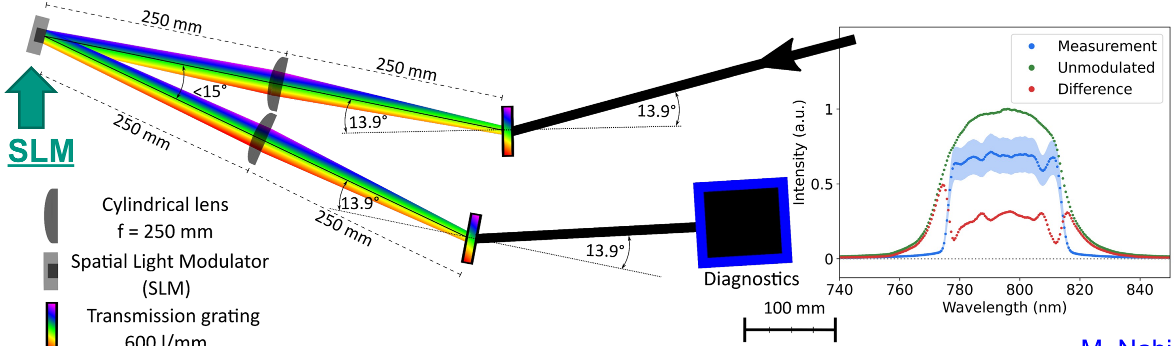
Transverse and longitudinal modulation of photoinjection pulses at FLUTE

Transverse modulation



Spatial Light Modulator (SLM)

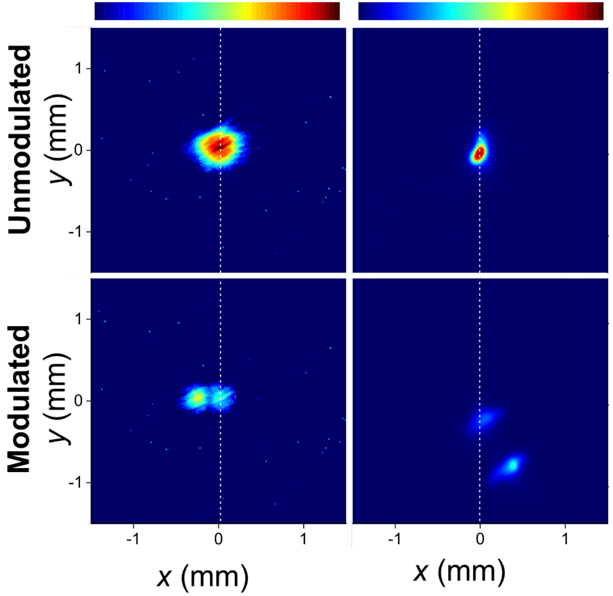
Longitudinal modulation



Photoinjection pulse modulation

Laser on cathode

Electrons on YAG screen



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

Optimization studies of simulated THz radiation

- **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:

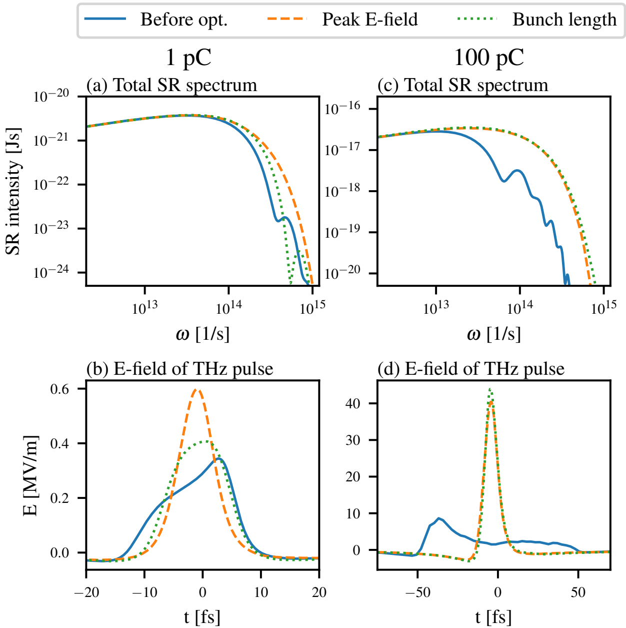
  Shortest bunch:

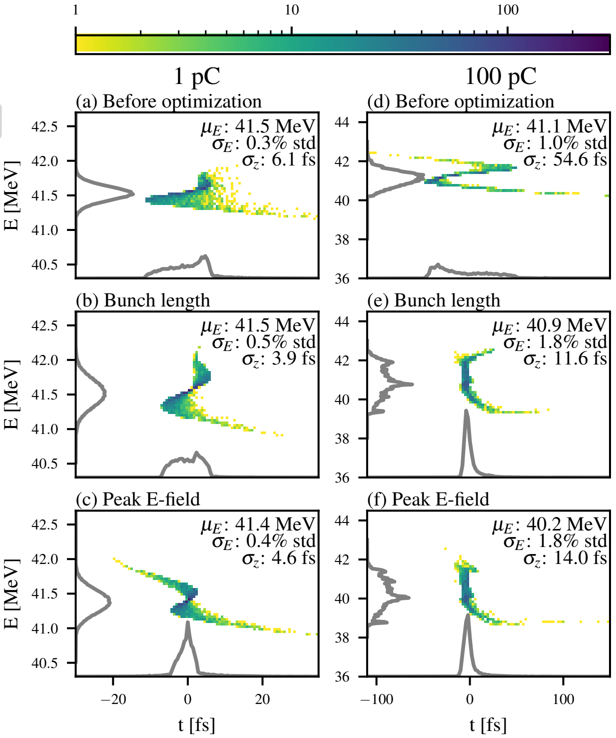
  100pC 54.6 fs → 11.6 fs

  Highest THz pulse E-field:

  1pC 350 kV/m → 600 kV/m

  100pC 8.4 MV/m → 43 MV/m

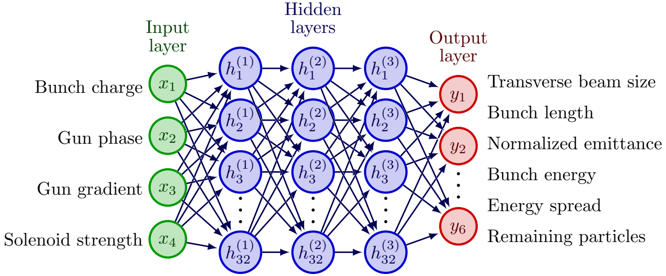




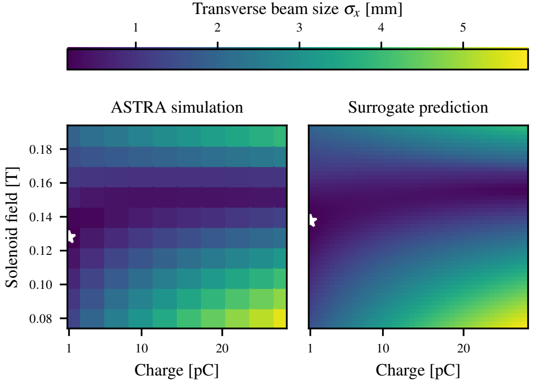
C. Xu et al. https://doi.org/10.18429/JACoW-IPAC2022-WEPOMS023

Surrogate Modelling of FLUTE Low-energy Section

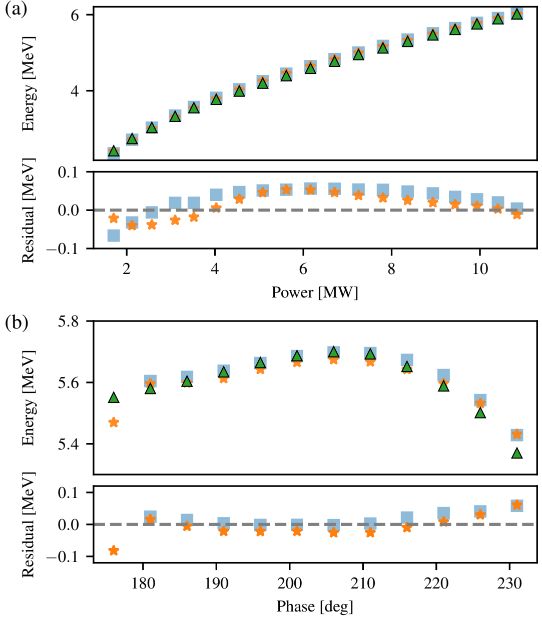
- One ASTRA space charge simulation takes ~3 min → very slow
- Use a neural network as a surrogate of the ASTRA simulations of FLUTE low-energy section.
  - Input: Charge, gun RF phase, gun RF gradient, solenoid strength
  - Output: Bunch size, length, energy, energy spread
  - Application:
    - virtual 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 el al. https://doi.org/10.18429/JACoW-IPAC2022-TUPOPT070

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)

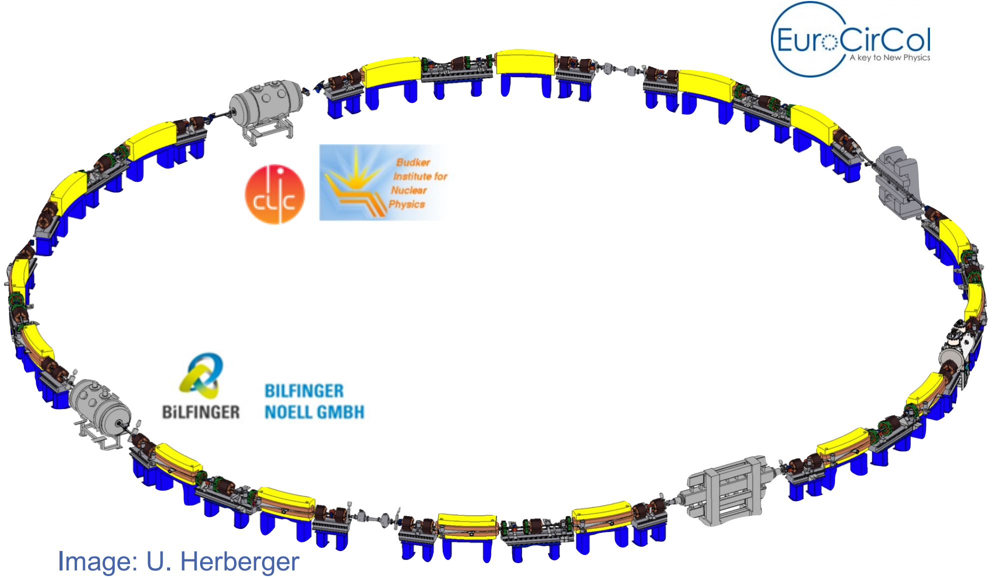


Image: U. Herberger

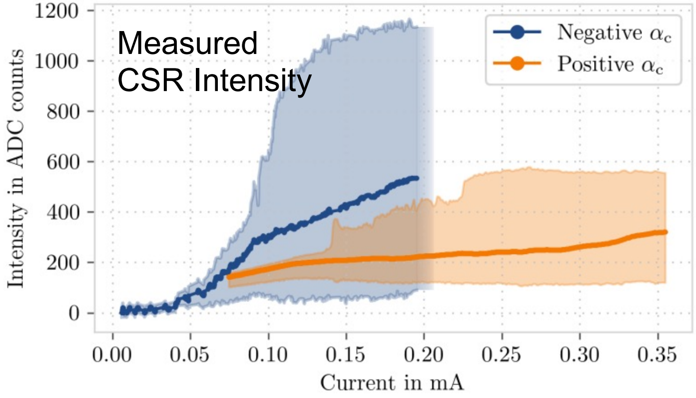
- Operation modes in 2022:
  0.5/2.3/2.5 GeV user optics, 0.5/1.3 GeV low-alpha, 0.5/1.3 GeV negative alpha

www.ibpt.kit.edu/kara

Negative Momentum Compaction Factor at KARA

- Future low emittance rings could benefit from negative momentum compaction operation
- Reduced sextupole strengths result in higher dynamic aperture
- Understanding of involved effects is necessary

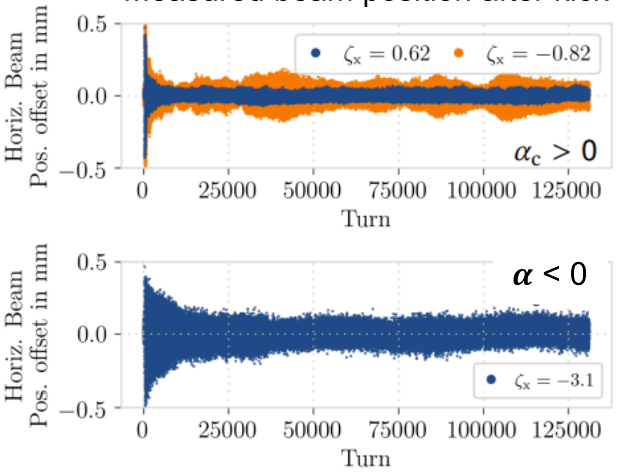
Longitudinal instability at short bunch length



At neg. mom. compaction: higher mean- and max intensity

Transverse stability

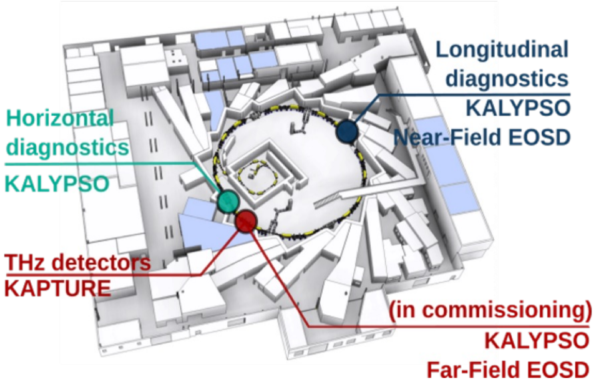
Measured beam position after kick



- Positive alpha, negative chroma … unstable
- Negative alpha, negative chroma … stable

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

KARA distributed sensor network

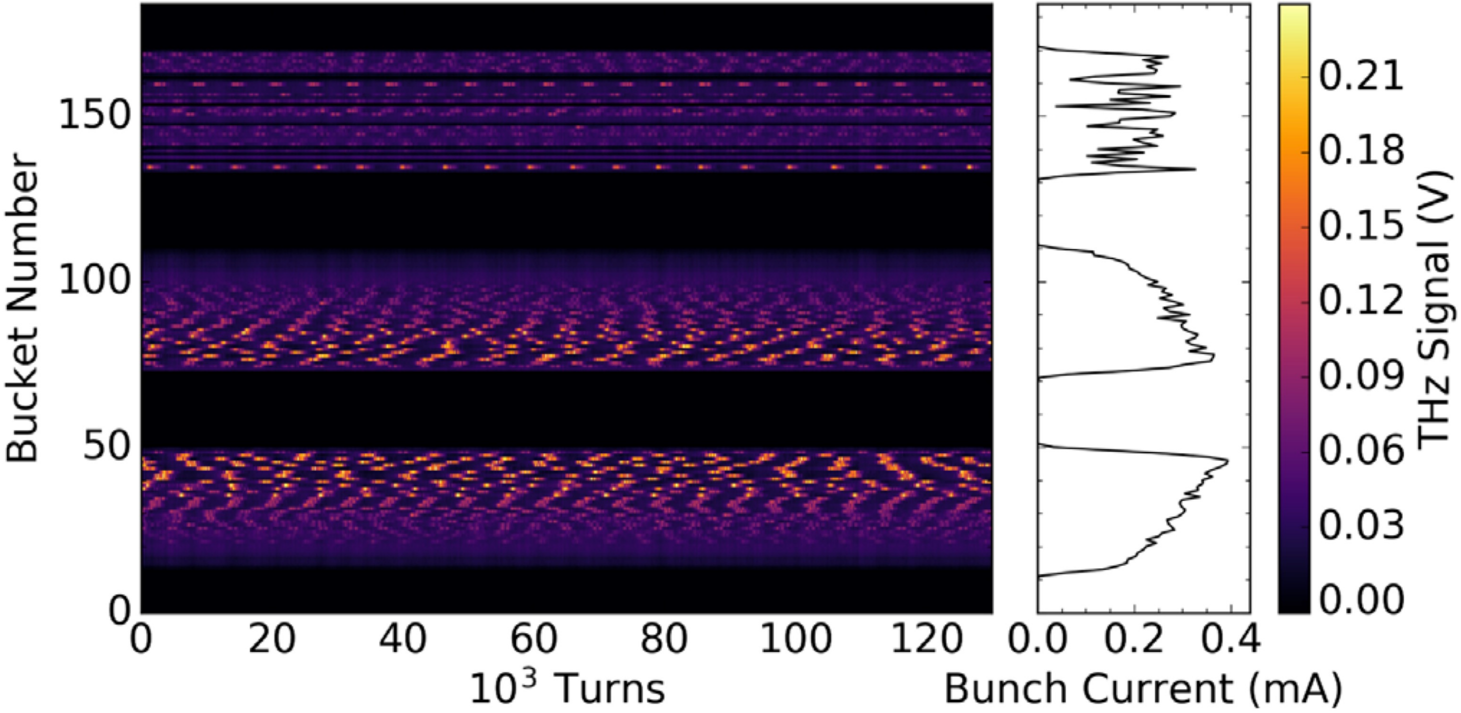


- Bunch-by-Bunch
- Turn-by-Turn
- Continuously
- Feedback

Analyze Longitudinal Phase Space

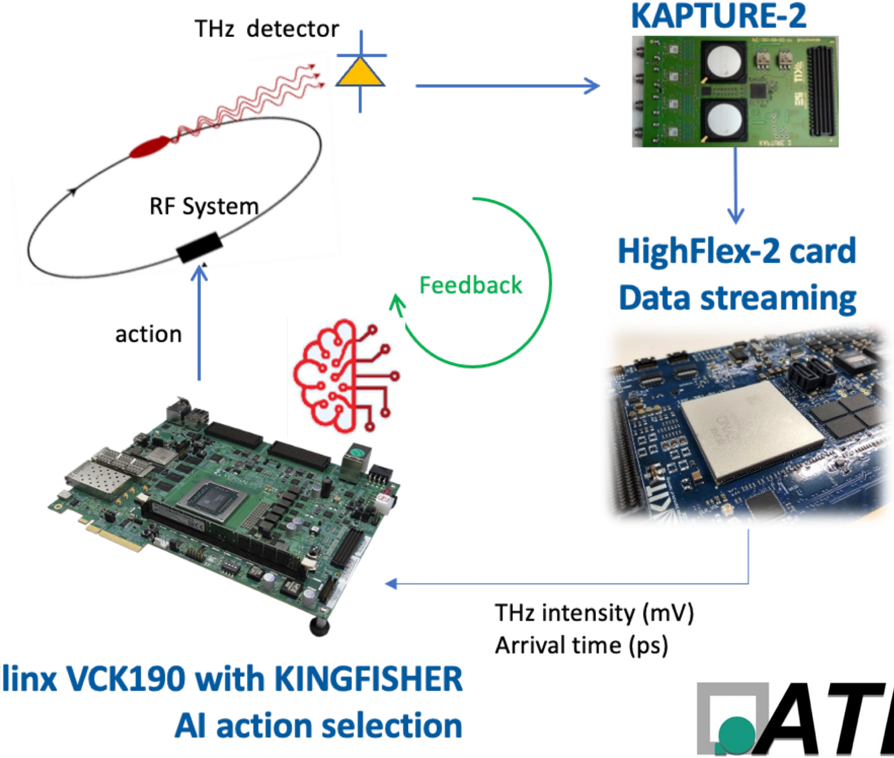
- **Emitted CSR**
  - THz Detector
    - KAPTURE
- **Energy Spread**
  - Horizontal bunch profile in dispersive section
    - KALYPSO
- **Bunch Profile**
  - Electro-optical spectral decoding
    - KALYPSO

Observing Bunch-by-Bunch Intensity



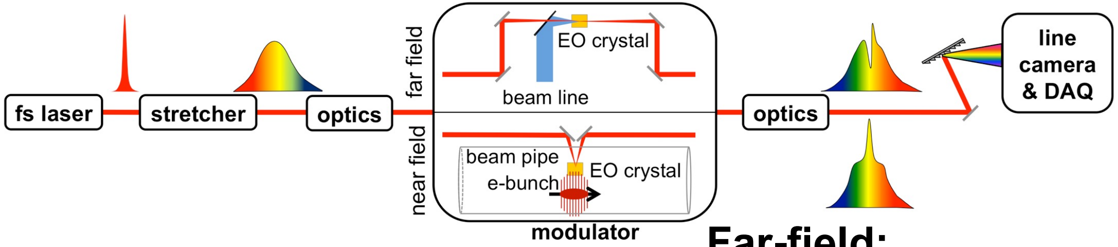
Fast adaptive Feedback on a Chip

- New Xilinx Versal Adaptive Compute Acceleration Platform:
  - AI engine array (> 1TFLOPS)
  - High speed connectivity (100 GbE, …)
- Readout tests of KINGFISHER system based on Versal completed @ KARA (April 2022)
- Looking forward to implementing action taking part



Courtesy Luca Scomparin / Michele Caselle (IPE@KIT)

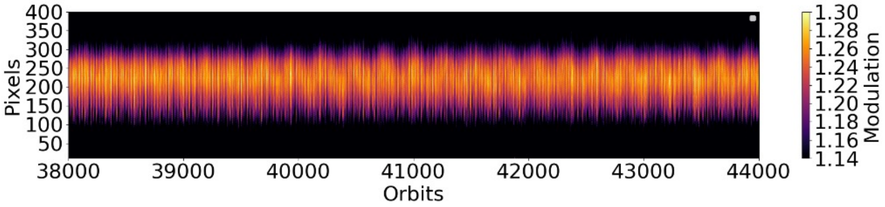
EO diagnostics at IBPT



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

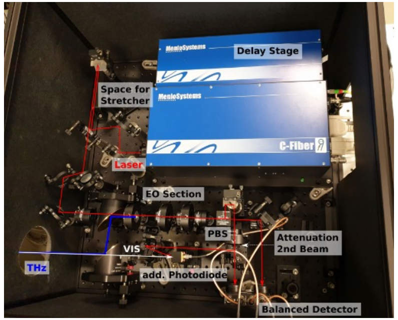


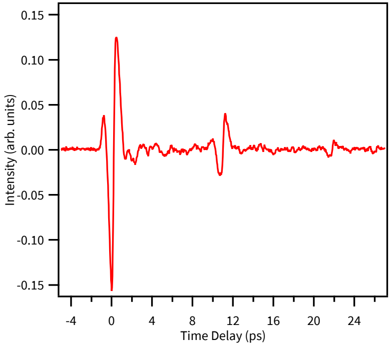
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IPAC2021-FRXC03
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IPAC2021-WEPAB33
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IBIC2021-MOOB01

Far-field:

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

Off-line demonstrator:

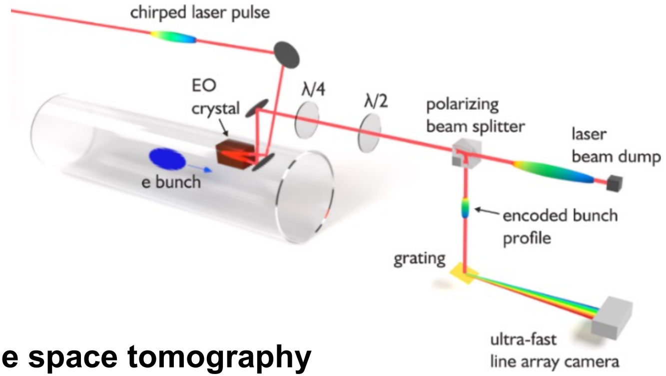




C. Widmann et al. https//:doi.org/10.18429/JACoW-IPAC2022-MOPOPT024

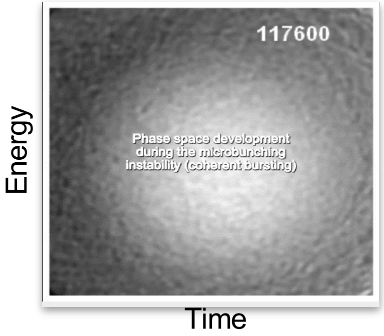
EO Diagnostics at IBPT

Near-field:



phase space tomography

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

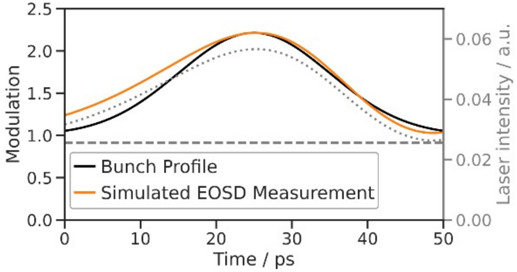


S. Funkner et al. arXiv preprint, arXiv:1912.01323

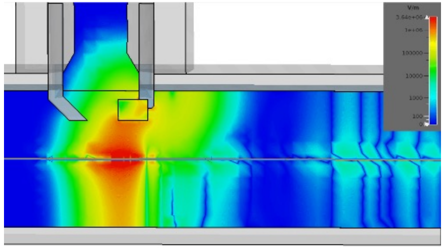
Development of an EO Bunch Profile Monitor for FCC-ee

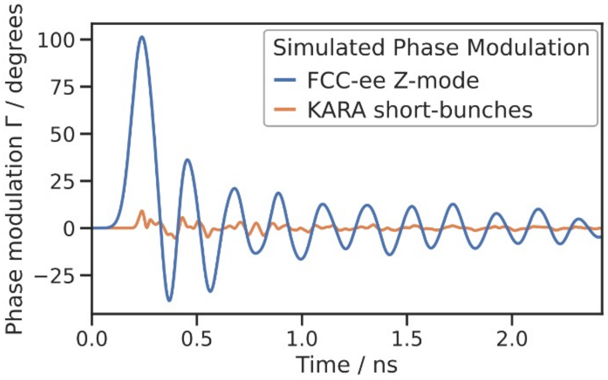
Simulations of the EO near-field measurements at KARA

FUTURE CIRCULAR COLLIDER
Innovation Study



Simulations of EO near-field monitor at KARA

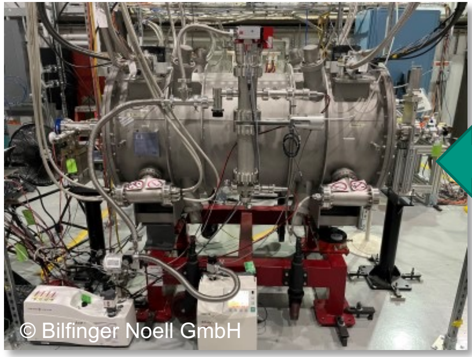




M. Reißig et al. doi:10.18429/JACoW-IPAC2022-MOPOPT025
M. Reißig et al. WEP26, IBIC 2022

Technology transfer from KARA to the world

Superconducting Undulators – **The future is now**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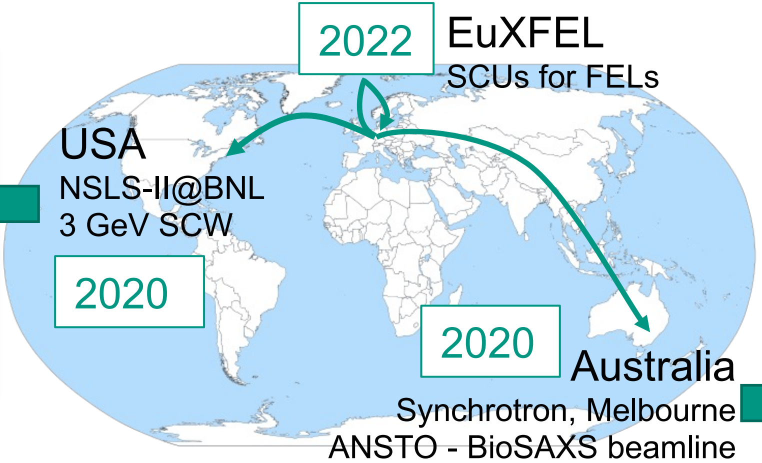

2022 EuXFEL
SCUs for FELs

USA
NSLS-II@BNL
3 GeV SCW
2020

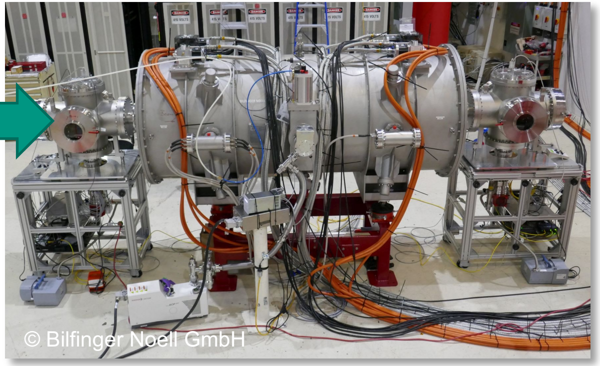
2020 Australia
Synchrotron, Melbourne
ANSTO - BioSAXS beamline


SCU

SUPERCONDUCTING UNDULATORS

Superconducing undulators revolutionize the insertion devices market. Years of reliable operation confirm that they are the most powerful light source for any experiment.

Developed in collaboration with: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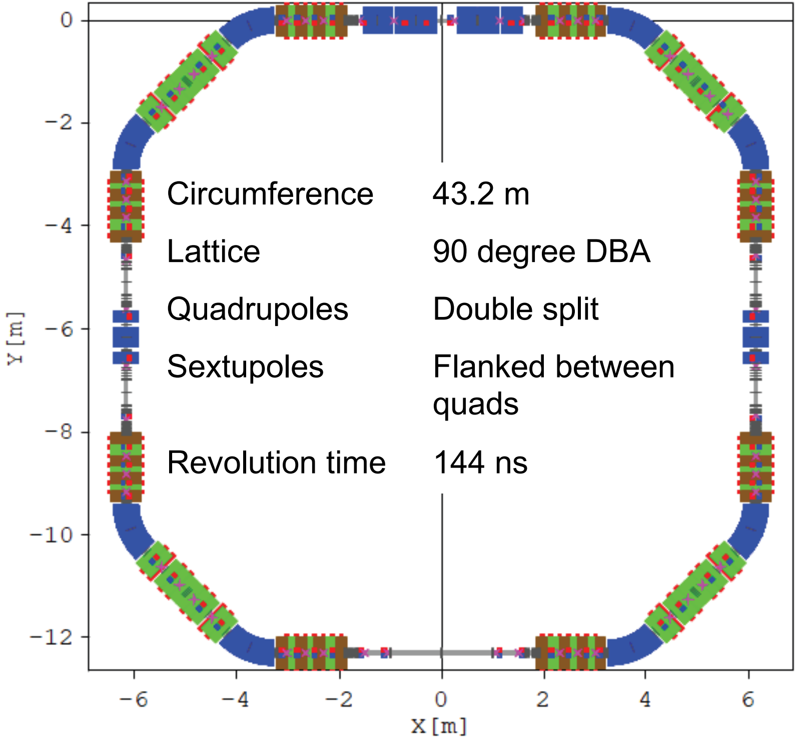
Citation: “**Superconducting undulators** …
most powerful light source for any experiment”

cSTART Project

- **Motivation:** Storage of ultra-short (fs) electron bunches with high repetition rate
- Compact storage ring with very large momentum acceptance and dynamic aperture
- FLUTE with new transfer line as injector
- Status:
  - Conceptual design and specification: finished
  - Transfer line magnets: first magnets in production
  - Test diagnostics at KARA booster: ongoing



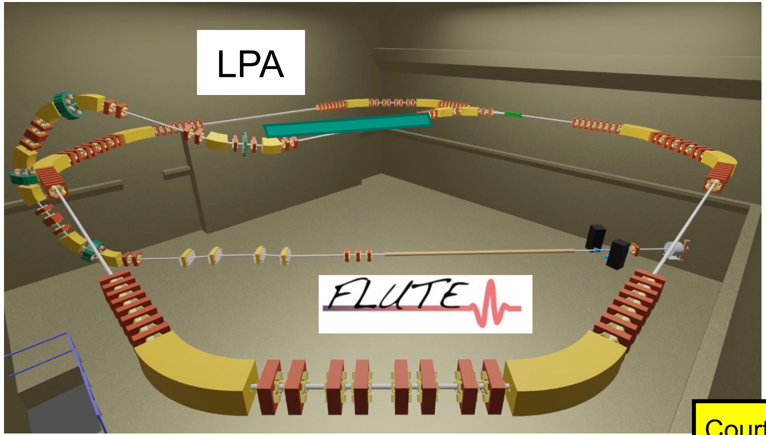
Circumference	43.2 m
Lattice	90 degree DBA
Quadrupoles	Double split
Sextupoles	Flanked between quads
Revolution time	144 ns

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

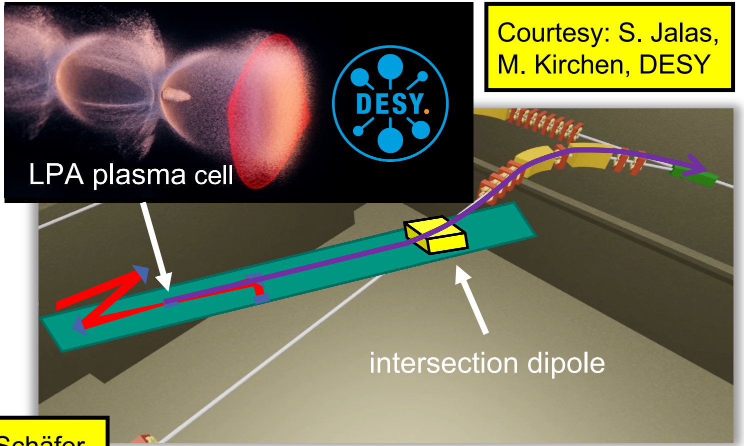
A. Papash et al. https://doi.org/10.18429/JACoW-IPAC2021-MOPAB035
A. Papash et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOPT023

ATHENA @KIT - Status

Goal: **injection & storage** of a laser plasma accelerator beam in a storage ring



Courtesy: J. Schäfer



Courtesy: S. Jalas, M. Kirchen, DESY

- Clean room for laser system built ✓
- Installation of commercial laser system in progress
- 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
E. Panofski, B. Härer et al. https://doi.org/10.18429/JACoW-IPAC2021-TUPAB163

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Thank you for your attention!

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- KIT Partner Institutes (ETP, IHM, IMS, IPE, IPS, LAS, IAR, IPQ)
- Collaboration partners: