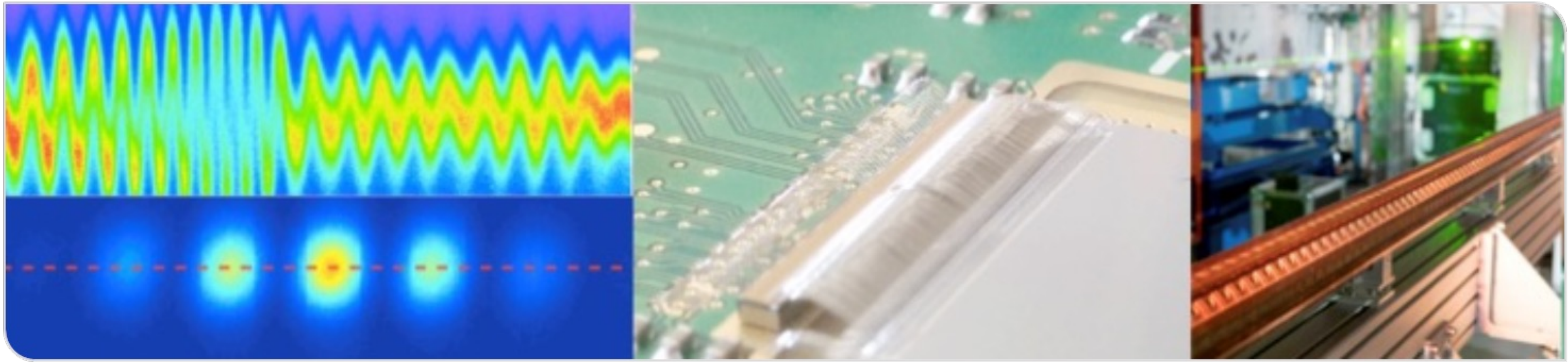
Karlsruhe Institute of Technology

# KIT Accelerators and Test Facilities

## MT ARD ST3 Meeting 2022 in Berlin
## Bastian Härer for Akira Mochihashi, on behalf of the KIT team



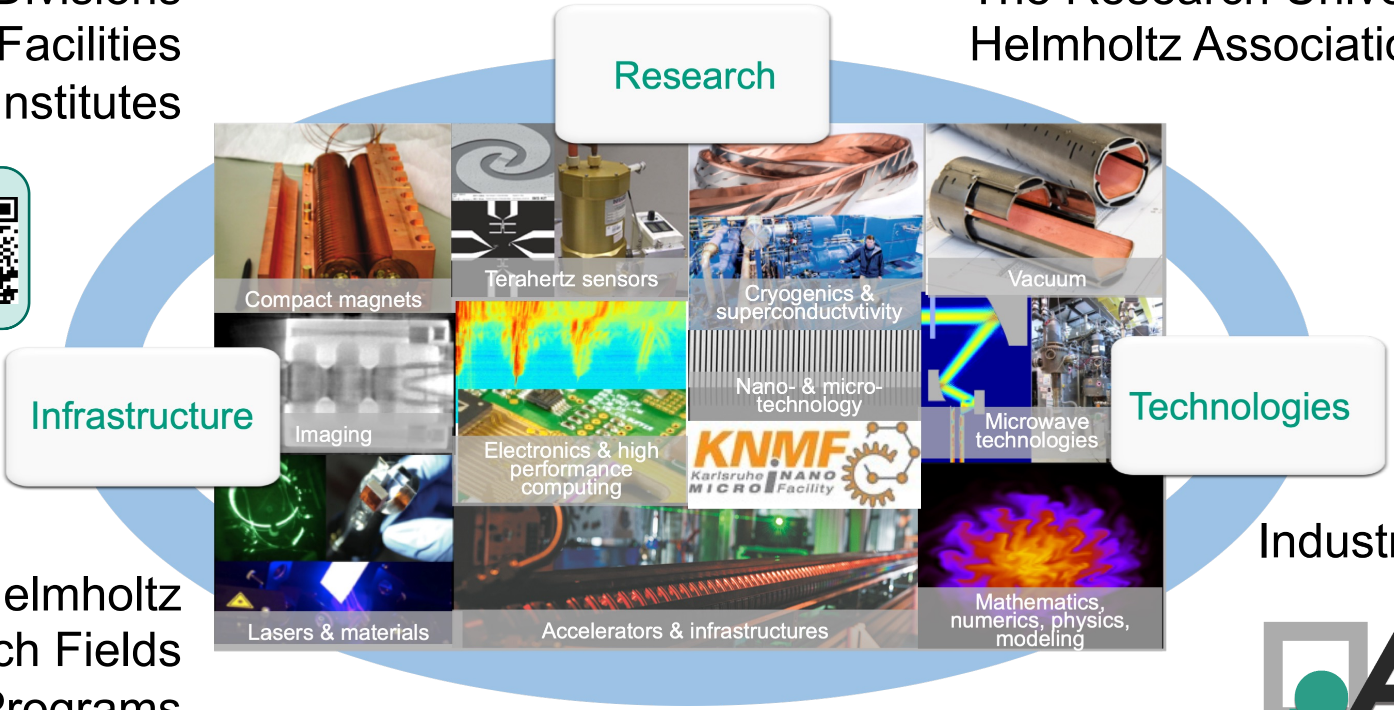
# The Accelerator Technology Platform @KIT (ATP)

Karlsruhe Institute of Technology

5 Divisions
6 KIT Facilities
14 Institutes

The Research University in the Helmholtz Association

ATP in lookKIT (German)




+ strong Industrial partners

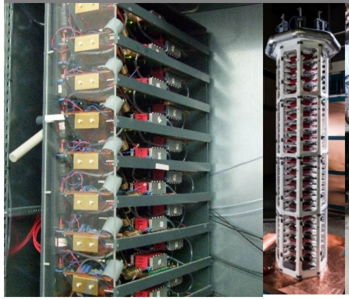
Helmholtz
3 Research Fields
6 Programs

ATP
Accelerator Technology Platform @ KIT

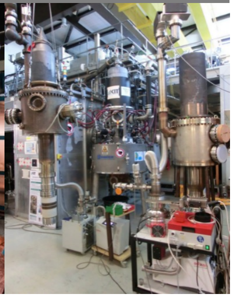
# Test facilities & technologies - examples

Karlsruhe Institute of Technology

*Pulse power technology*



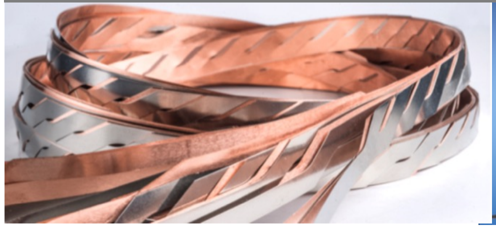
*Gyrotrons*



*Winding technologies*

*Magnet test facilities*

*Cable technologies*



*High temperature superconductors*

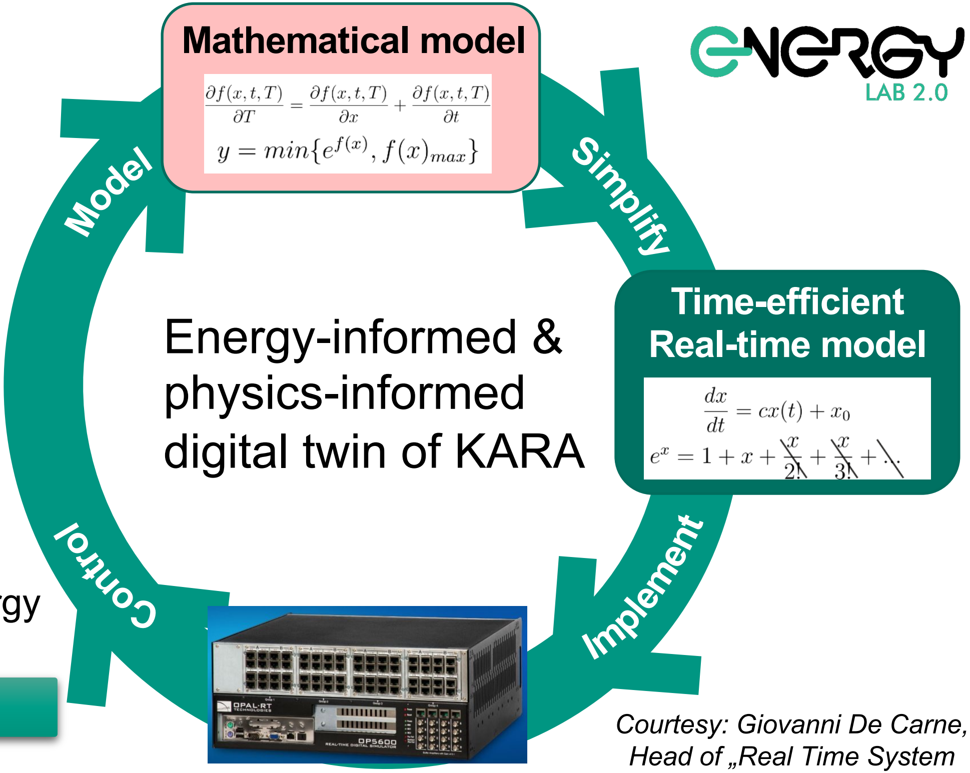
ATP
Accelerator Technology Platform @ KIT

# Accelerator & Energy Systems Test Field KITTEN


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

**@MT Annual Meeting by G. De Carne**

- InnovEEA




Real-time Simulator

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

# Accelerator & Energy Systems Test Field KITTEN


## 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)

# 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

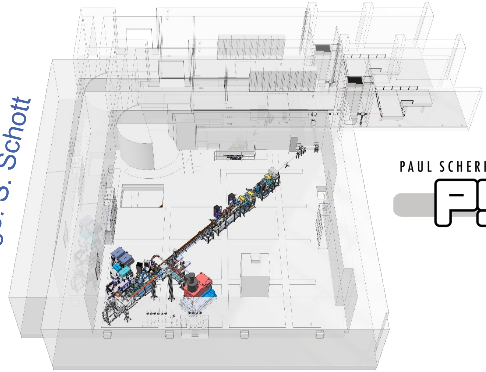


Image: S. Schott

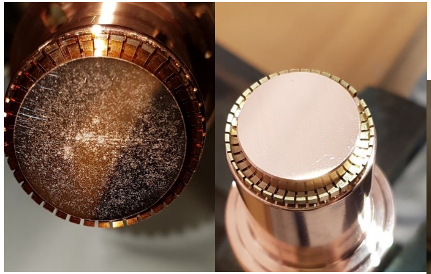
| | | |
|---|---|---|
| Final electron energy | ~ 41 | MeV |
| Electron bunch charge | 0.001 - 3 | nC |
| Electron bunch length | 1 - 300 | fs |
| Pulse repetition rate | 10 | Hz |
| THz E-Field strength | up to 1.2 | GV/m |

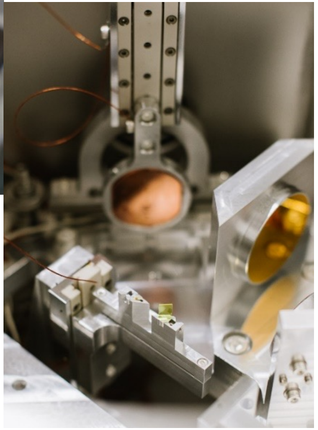
www.ibpt.kit.edu/flute

# FLUTE Status

- Ventilation of the complete machine in December 2021
  → Laser alignment of internal components
  → Exchange of cathode

Courtesy: M. Bank

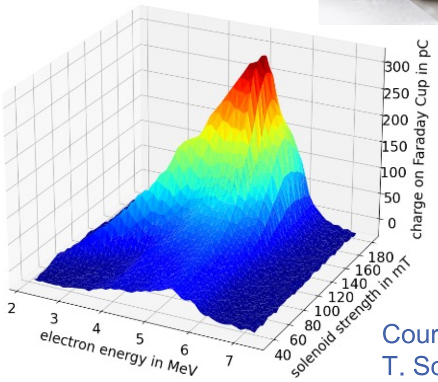




Courtesy: L. Jochim

- Split-ring resonator experiment measurement campaign in spring 2022
  → Upgrade split-ring holder and installation of pinhole aperture
  → Commissioning is under way

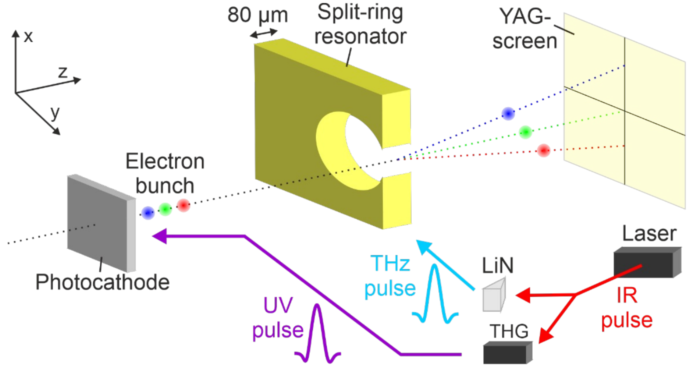
- Dark current investigation with Faraday Cup
  → Energy and charge distribution within dark current
  → Study of feasibility to use dark current for experiments




Courtesy: T. Schmelzer

- Major FLUTE upgrade coming up, planned to be finished by end of the year
  → New RF photoinjector and solenoid
  → New RF system for photoinjector and LINAC

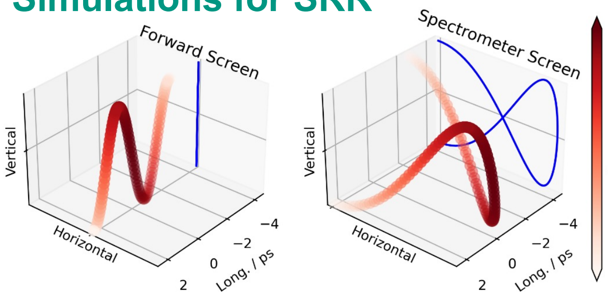
# Split-ring resonator at FLUTE




Courtesy: M. Nabinger

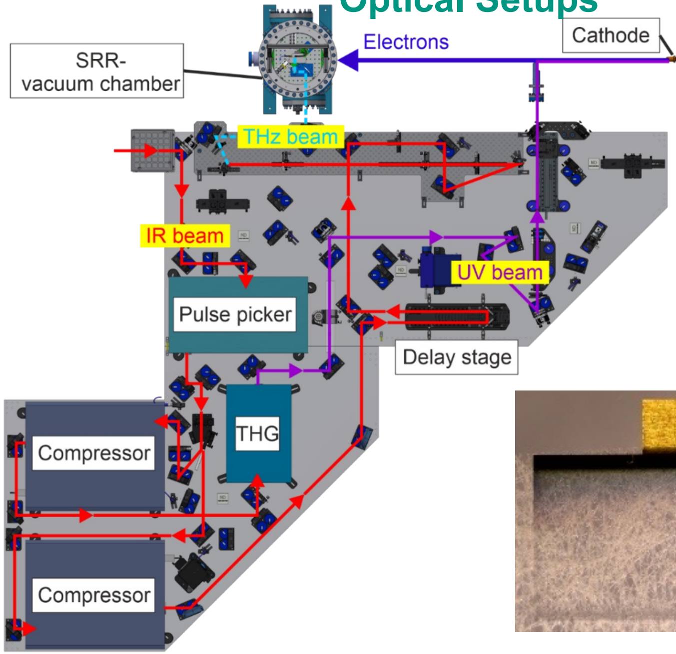
- Streaking with THz radiation and amplifying the electric field with a 20 µm gap **split-ring resonator**

## Simulations for SRR

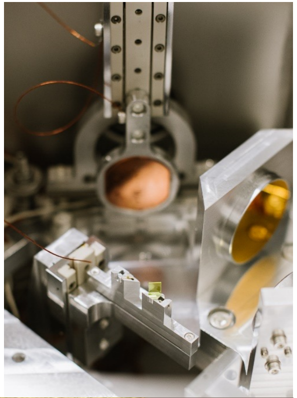



Courtesy: J. Schäfer

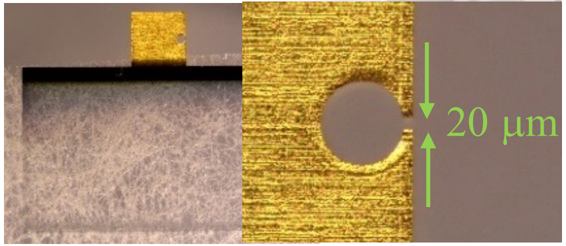
## Optical Setups




Courtesy: S. Schott



Courtesy: L. Jochim




Courtesy: M. Nasse

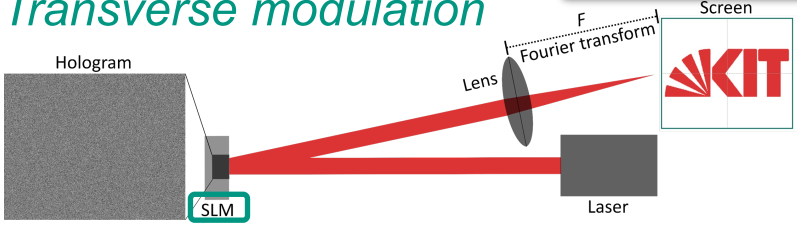
- Setup of the split-ring resonator measurement in low energy section at FLUTE
- Experimental setup in vacuum chamber **installed**

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

# Transverse and longitudinal modulation of photoinjection pulses at FLUTE

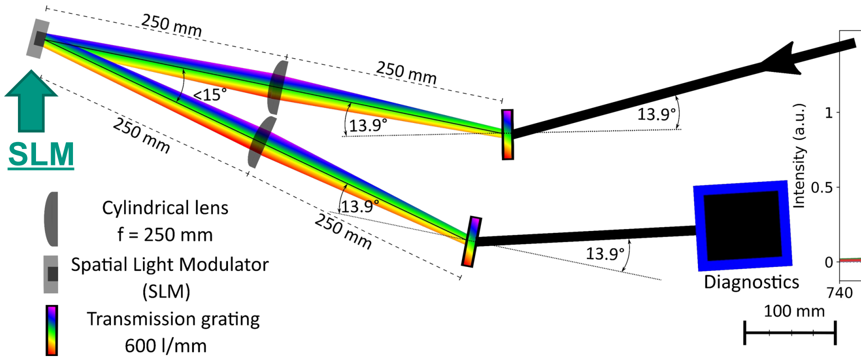
STalk + Poster by M. Nabinger

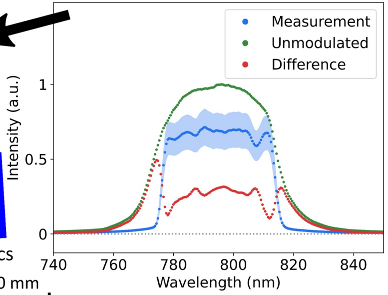
## Transverse modulation



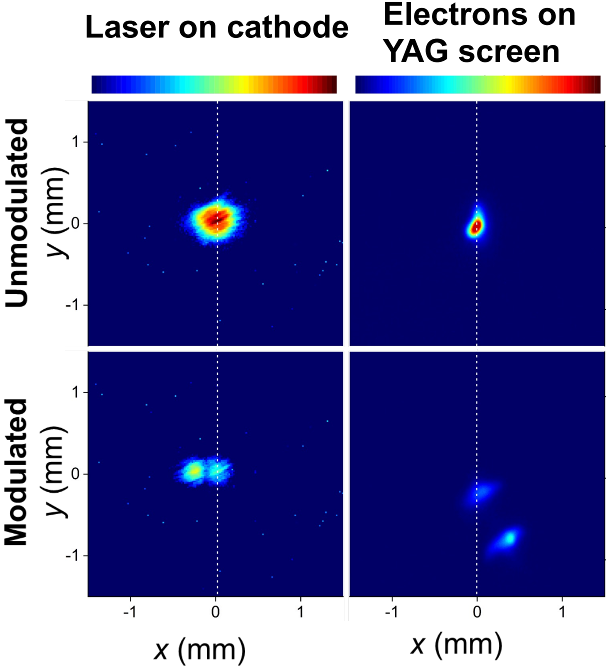

**Spatial Light Modulator (SLM)**

## Longitudinal modulation




## Photoinjection pulse modulation




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

# Optimization studies of simulated THz radiation

- **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:

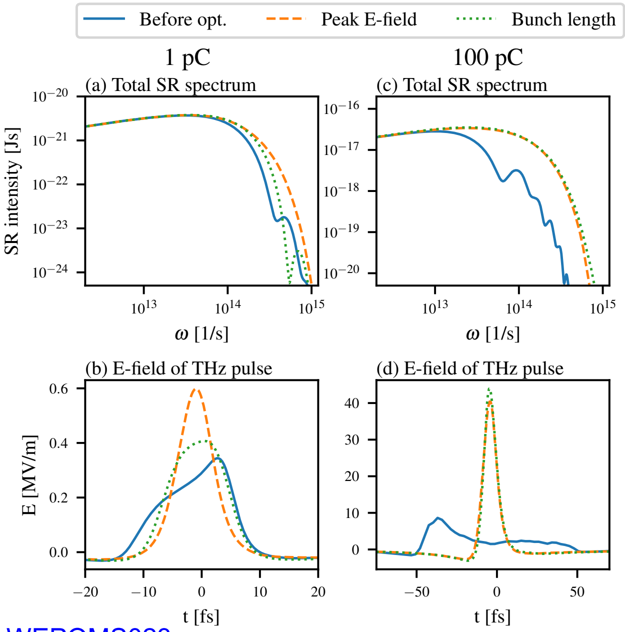
  **Shortest bunch**:

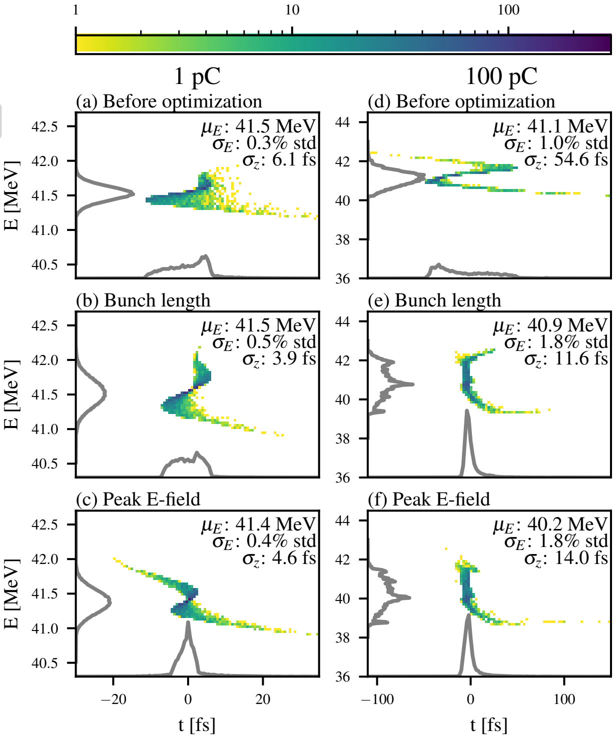
  100pC 54.6 fs → 11.6 fs

  **Highest THz pulse E-field**:

  1pC 350 kV/m → 600 kV/m

  100pC 8.4 MV/m → 43 MV/m



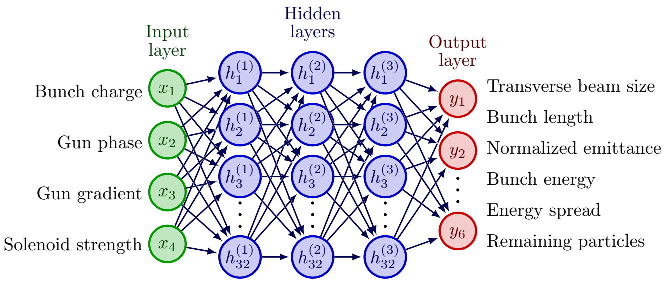




STalk + Poster by C. Xu

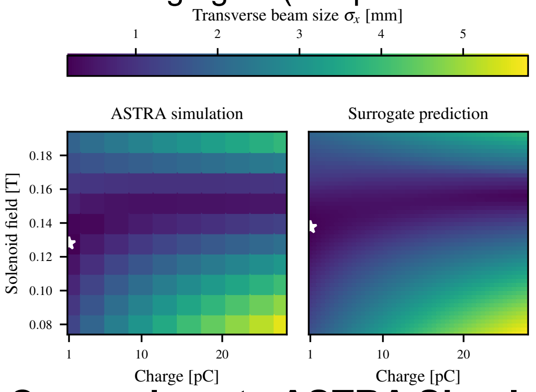
C. Xu et al. https://doi.org/10.18429/JACoW-IPAC2022-WEPOMS023

# Surrogate Modelling of FLUTE Low-energy Section

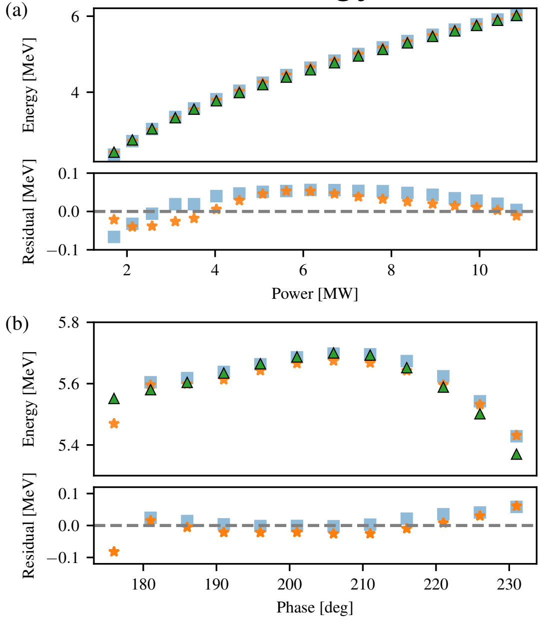
- One ASTRA space charge simulation takes ~3 min → very slow
- Use a neural network as a surrogate of the ASTRA simulations of FLUTE low-energy section.
  - Input: Charge, gun RF phase, gun RF gradient, solenoid strength
  - Output: Bunch size, length, energy, energy spread
  - Application:
    - virtual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

KIT
Karlsruhe Institute of Technology

# 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)<br>a few ps (1.3 GeV) |

EuroCirCol
A key to New Physics

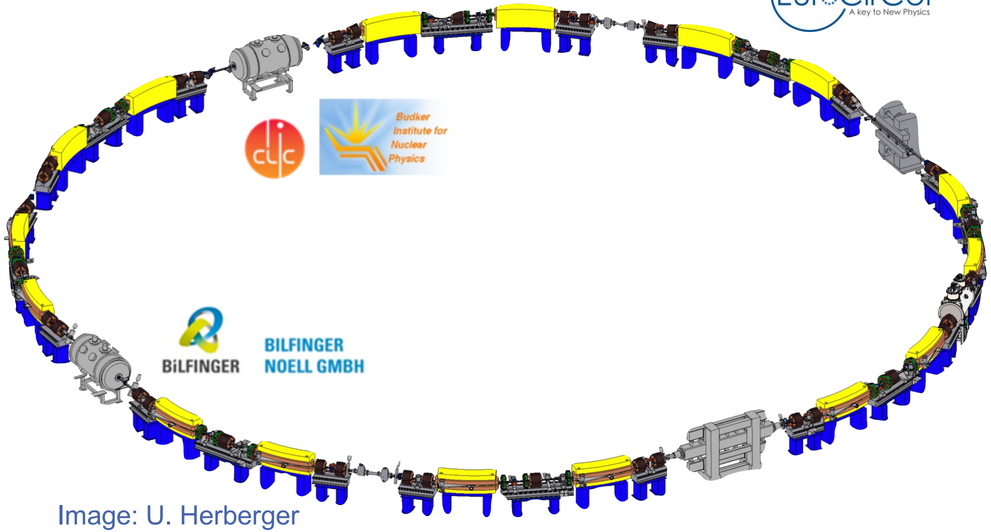
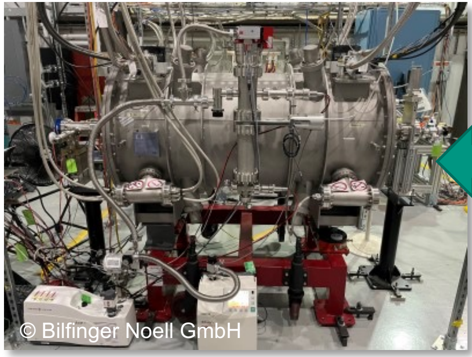


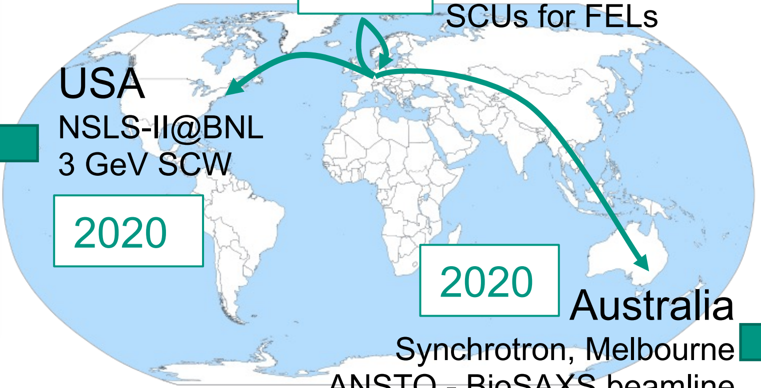
Image: U. Herberger

www.ibpt.kit.edu/kara

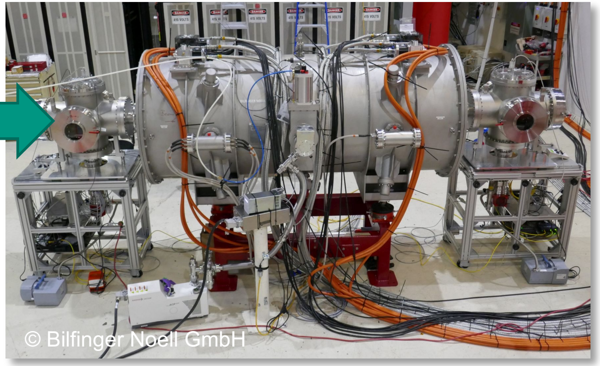
# Technology transfer from KARA to the world

[Superconducting Undulators – **The future is now**]








Citation: "**Superconducting undulators …**
**most powerful light source for any experiment**"

# KARA Operation Status

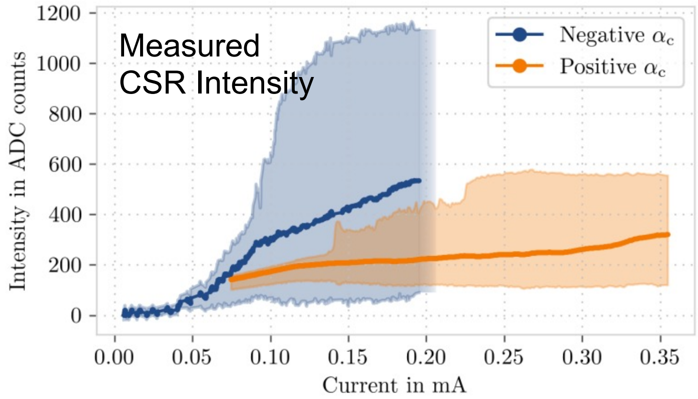
- Operation modes in 2022:
  - 0.5/2.3/2.5 GeV user optics, 0.5/1.3 GeV low-alpha, 0.5/1.3 GeV negative alpha
- Power supply refurbishment program
  - Kicker and septum magnets in booster and storage ring: **Done in 2021**
  - Storage ring sextupole magnet: **Commissioning September 2022**
  - Booster bending and quadrupole magnet: **In production**
  - Storage ring bending magnet: **In production**
- Improvement of booster beam instrumentation
  - Bunch-by-bunch feedback system
  - BPM system, beam profile monitor, beam loss monitor

    D. El Khechen et al. doi: 10.18429/JACoW-IPAC2022-MPPOPT027

# 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

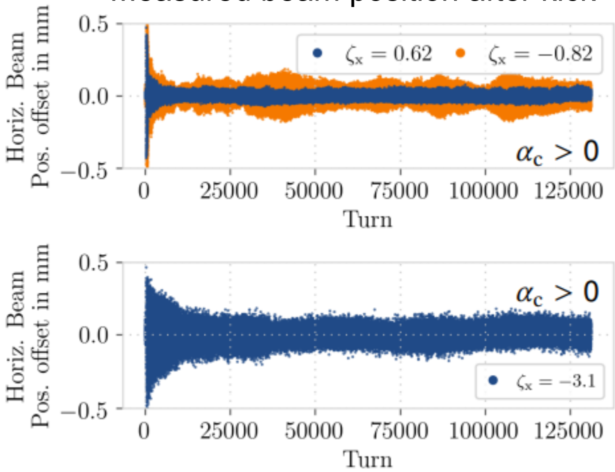



STalk + Poster by P. Schreiber

Talk @MT Annual Meeting

## Transverse stability

Measured beam position after kick

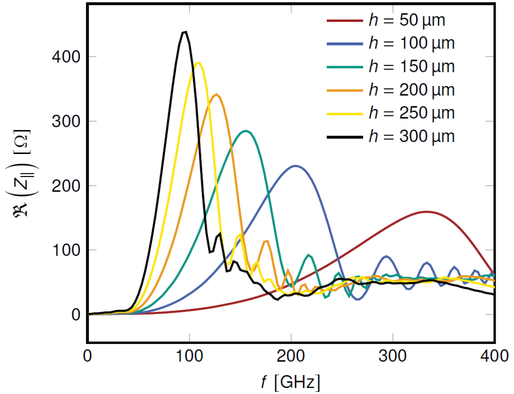


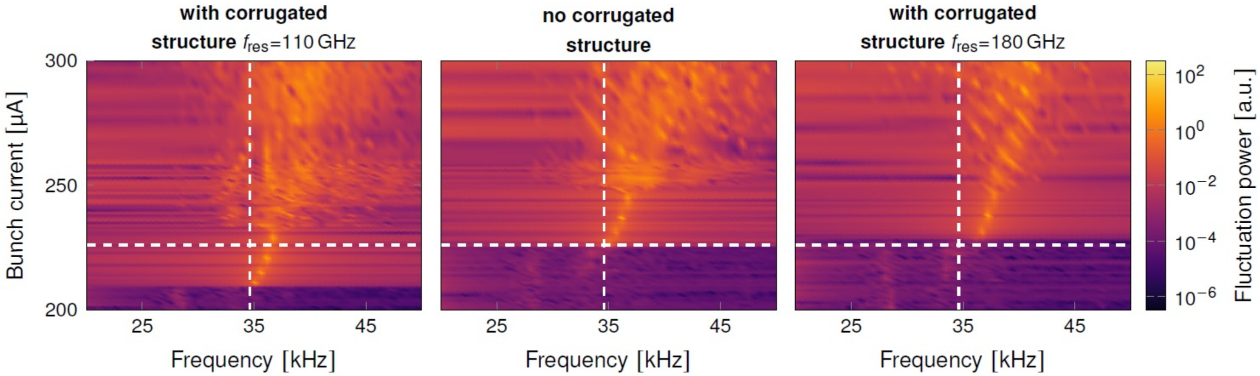

**At neg. mom. compaction: higher mean- and max intensity**

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

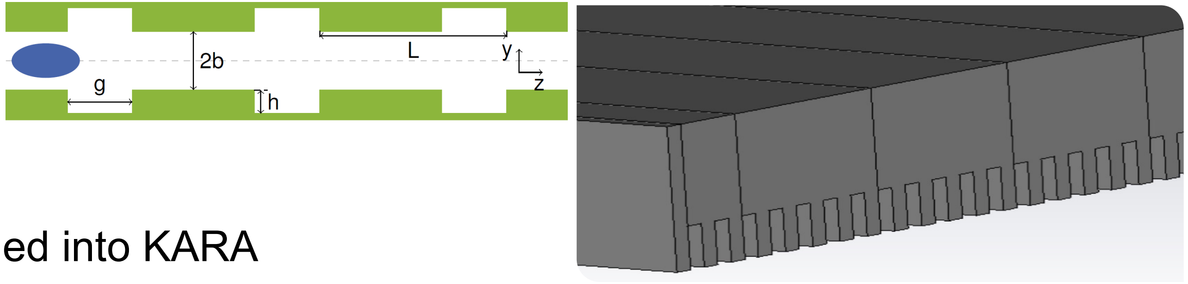
P. Schreiber et al. DOI: 10.5445/IR/1000148354 P. Schreiber et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOPT006

# Impedance manipulation at KARA




STalk + Poster by S. Maier




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

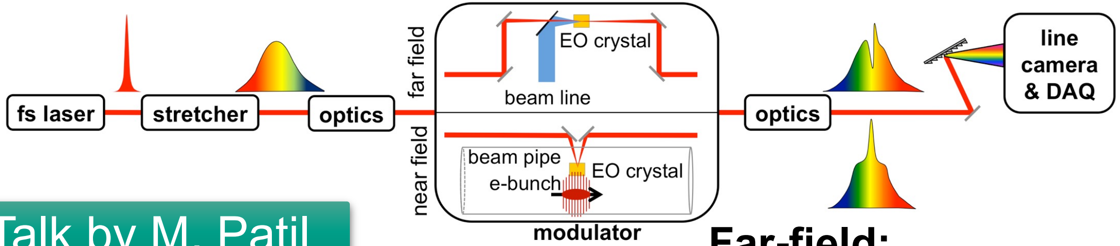
S. Maier et al. https://doi.org/10.18429/JACoW-IPAC2021-TUPAB251

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

# EO diagnostics at IBPT

STalk + Poster by G. Niehues

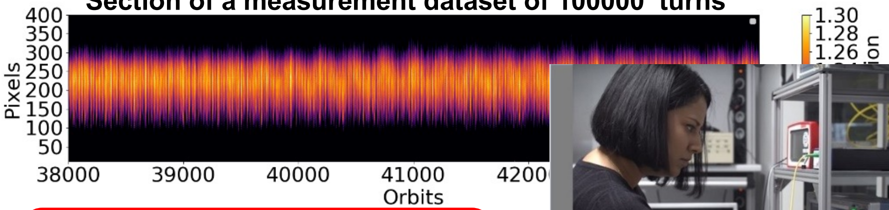
Karlsruhe Institute of Technology

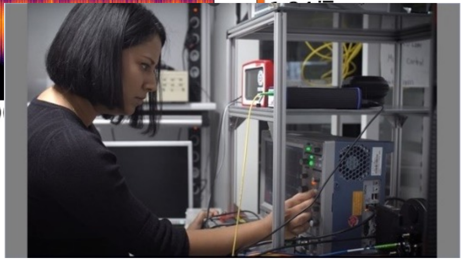



## Near-field: Talk by M. Patil

- 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**



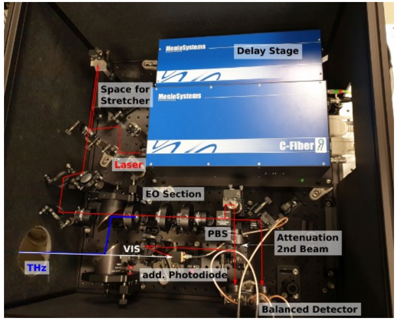
**Faraday Cup Award 2021**
**M. M. Patil**

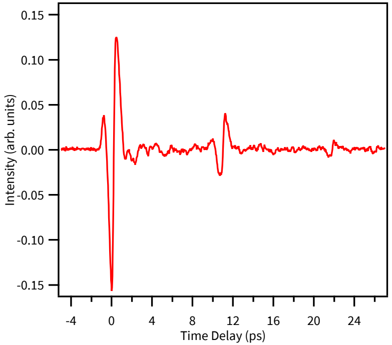
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IPAC2021-FRXC03
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IPAC2021-WEPAB33
M. M. Patil et al. https//:doi.org/10.18429/JACoW-IBIC2021-MOOB01

## Far-field:

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

**Off-line demonstrator:**



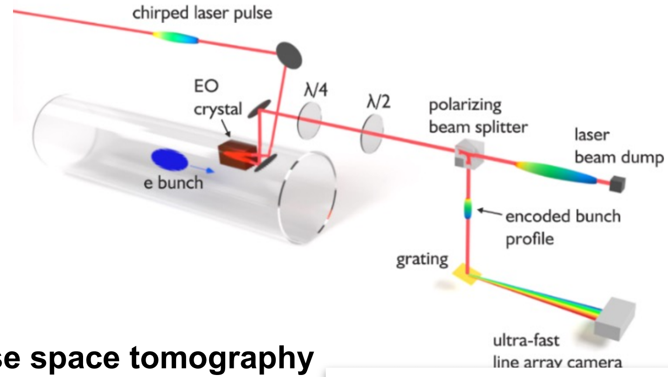




C. Widmann et al. https//:doi.org/10.18429/JACoW-IPAC2022-MOPOPT024

# EO Diagnostics at IBPT

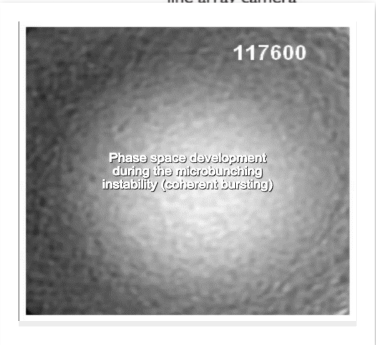
STalk + Poster by M. Reißig

## Near-field:




**phase space tomography**

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

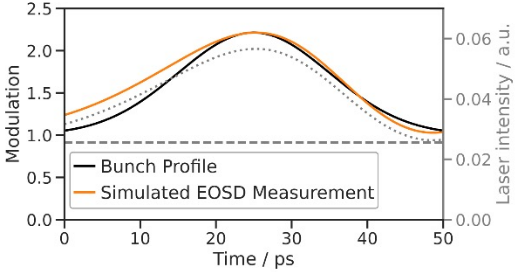



S. Funkner et al. arXiv preprint, arXiv:1912.01323

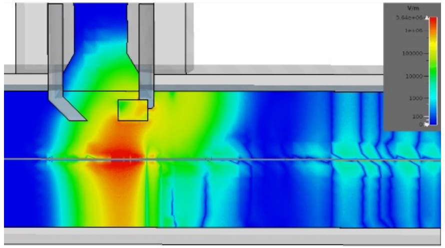
## Development of an EO Bunch Profile Monitor for FCC-ee

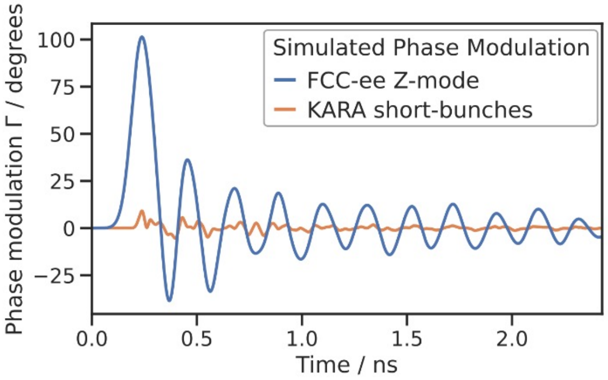
Simulations of the EO near-field measurements at KARA

FUTURE CIRCULAR COLLIDER
Innovation Study




Simulations of EO near-field monitor at KARA



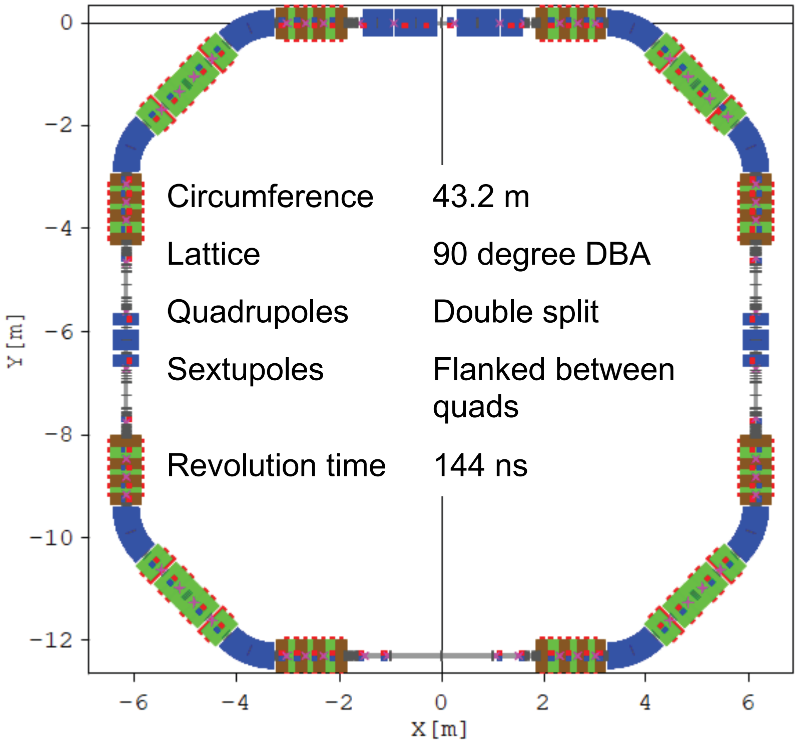



M. Reißig et al. doi:10.18429/JACoW-IPAC2022-MOPOPT025
M. Reißig et al. WEP26, IBIC 2022 (to be presented)

# 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

STalk + Poster by M. Noll

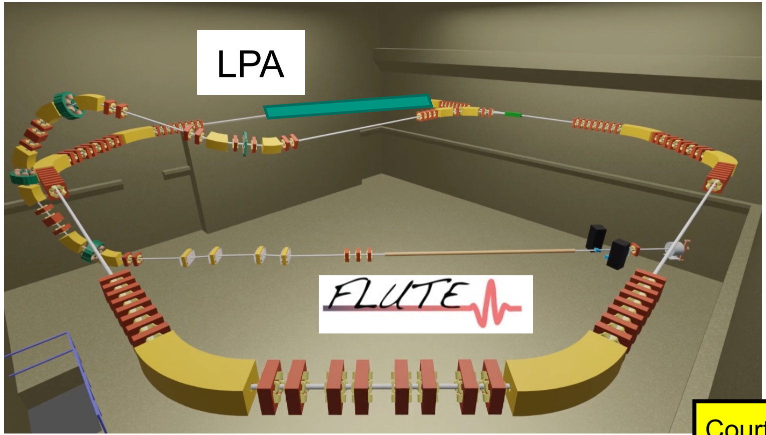



| | |
|---|---|
| Circumference | 43.2 m |
| Lattice | 90 degree DBA |
| Quadrupoles | Double split |
| Sextupoles | Flanked between quads |
| Revolution time | 144 ns |

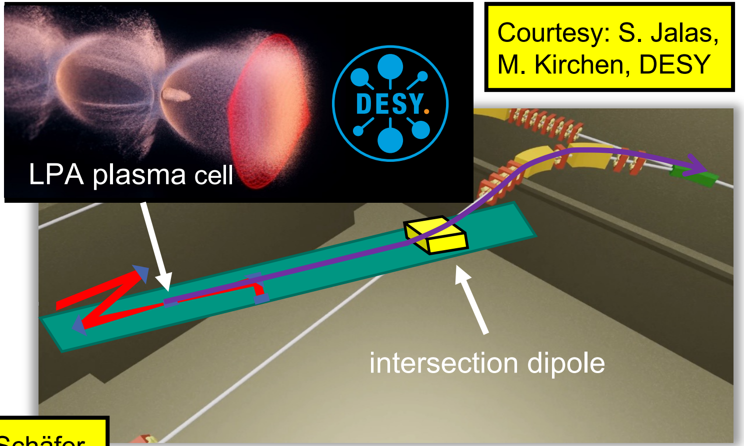

M. Schwarz et al. https://doi.org/10.18429/JACoW-IPAC2021-TUPAB255
D. El Khechen et al. https://doi.org/10.18429/JACoW-IPAC2022-MOPOPT026
J. Schäfer et al. https://doi.org/10.18429/JACoW-IPAC2022-MOPOST041
A. Papash et al. https://doi.org/10.18429/JACoW-IPAC2021-MOPAB035
A. Papash et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOPT023

# 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

**STalk + Poster by B. Härer**

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

# Acknowledgements

**Thank you for your attention!**

Karlsruhe Institute of Technology


- The accelerator team

Daria Astapovych, Alex Bernhard, Edmund Blomley, Simon Braner, Erik Bründermann, Hyuk Jin Cha, Kantaphon Damminsek, Dima El Khechen, Samira Fatehi, Stefan Funkner, Julian Gethmann, Andreas Grau, Steffen Grohmann, Bastian Härer, Michael Hagelstein, Erhard Huttel, Igor Kriznar, Stephan-Robert Kötter, Anton Malygin, Katharina Mayer, Sebastian Maier, Sebastian Marsching, Yves-Laurent Mathis, Wolfgang Mexner, Matthias Nabinger, Michael Nasse, Gudrun Niehues, Marvin Noll, Alexander Papash, Meghana Patil, Micha Reißig, Robert Ruprecht, Andrea Santamaria Garcia, Patrick Schreiber, David Seaz de Jauregui, Jens Schäfer, Thiemo Schmelzer, Marcel Schuh, Markus Schwarz, Nigel John Smale, Johannes Steinmann, Pawel Wesolowski, Christina Widmann, Chenran Xu and Anke-Susanne Müller

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