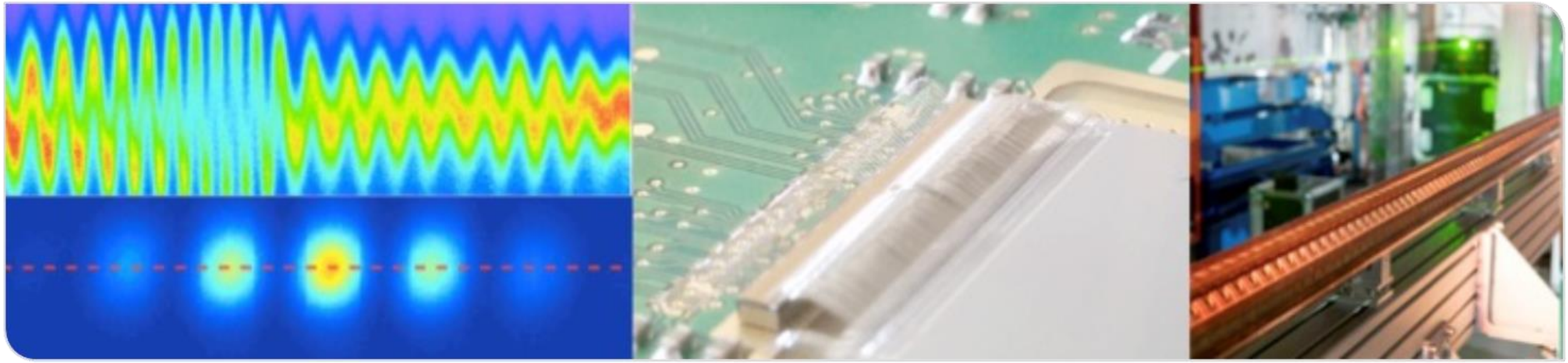
Karlsruhe Institute of Technology

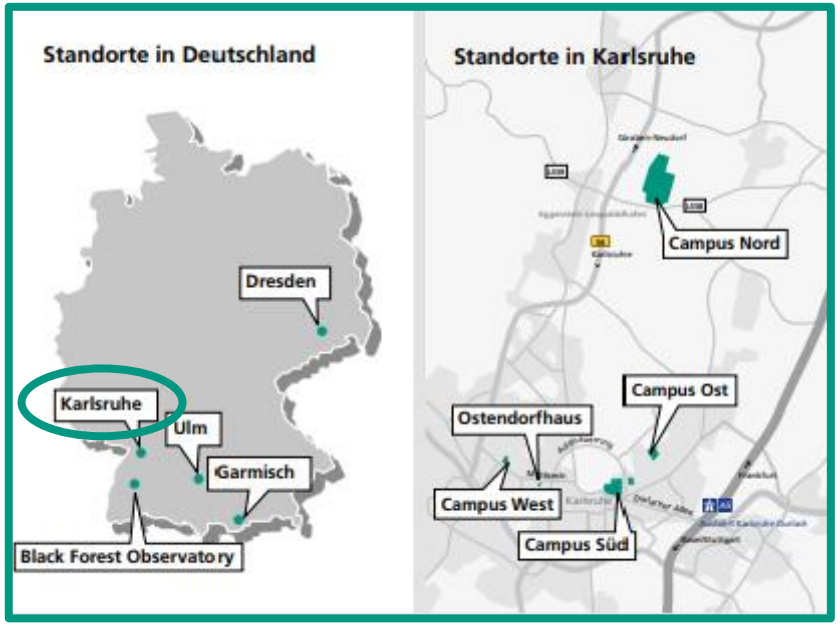
KIT – Status Test Facilities KARA and FLUTE

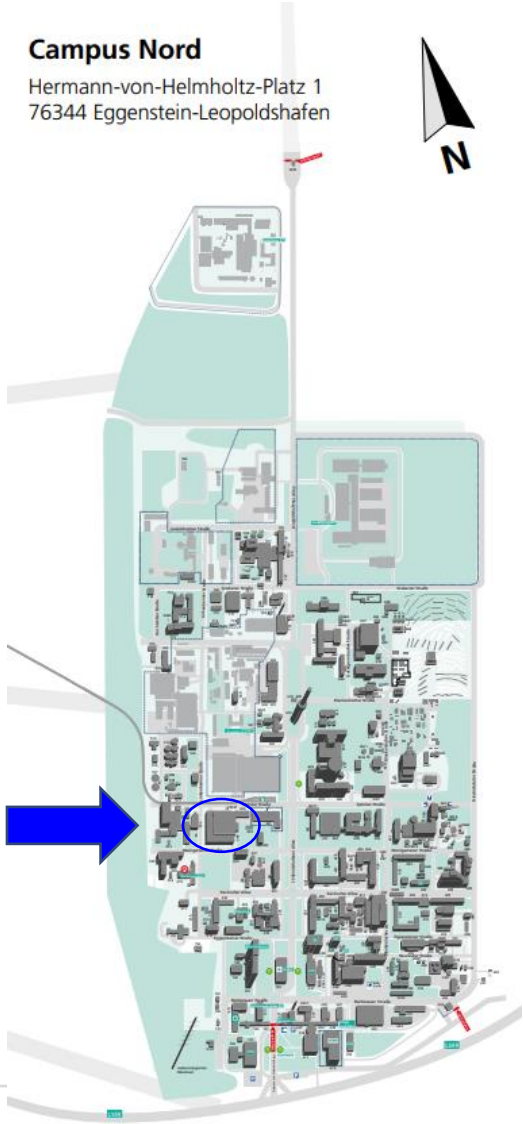
Kickoff Meeting in IFAST Workshop 2024 in KIT, Karlsruhe

Akira Mochihashi



Where is KIT?





- In the southwest of Germany
- Several campuses exist
  - Campus North: I am here
  - Campus South: near the centre of Karlsruhe city
  - Campus West, East, and more

IBPT (Institute for Beam Physics and Technology)

https://www.kit.edu/kit/lageplaene.php
https://www.kit.edu/kit/english/directions.php

Figures and Facts 2021

37 Spinoffs and Startups

5 Campuses – **200** ha area

367 Trainess

385 Professors and executive scientists

22,225 Students

300 Buildings with a usable area of **492,000 m²**

3,100 Doctoral students

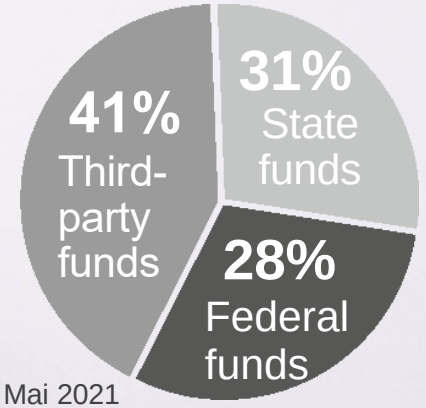
51 Patent applications

9,783 Employees

1,405 international scientists

KIT budget 2021

EUR 1090,7 million



Status: Mai 2021

Big Research Infrastructures at KIT

Acoustic Four-wheel Roller Dynamometer

KARA Synchrotron Radiation Facility

Biomass to Liquid (bioliq®)

EnergyLab 2.0

European Zebrafish Resource Center

High-perfomance Computer for Research

Grid Computing Centre Karlsruhe (GridKa)

Karlsruhe Nano Micro Facility (KNMF)

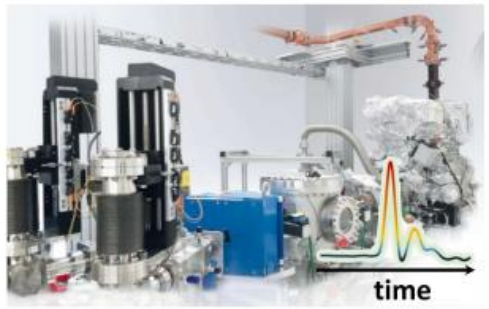
Karlsruhe Tritium Neutrino Experiment

Theodor Rehbock River Engineering Laboratory

Karlsruher Forschungsfabrik

AIDA Cloud Chamber

Accelerator Technology Platform (ATP)



Research

- Non-equilibrium physics
- Beam dynamics, ultra-short pulses
- Compact diagnostics
- Novel and compact accelerators
- R&D at superconducting insertion devices
- Particle beam tests on components
- R&D for large-scale facilities

- 230 researchers @ KIT
- R&D and consulting/QA
- Pilot projects
- Large test facilities
- Technology transfer
- Bridge for KIT R&D to Companies & to CERN

Infrastructure

- Storage ring KARA and accelerator test facility & KIT Light Source
- Linear accelerator test facility FLUTE
- Magnet Characterization Facilities (MCF)
- Test stands for superconducting and warm magnets
- SMD facility, ASIC and detector laboratories (KIT ADL)

ATP
Accelerator Technology Platform @ KIT

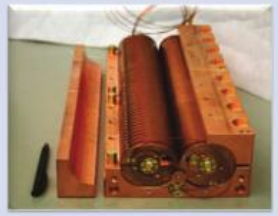
Technologies

- Cryogenics & superconductors
- Laser & materials
- Terahertz sensors
- Vacuum
- Nano- and micro-technologies
- Electronics
- HPC
- Mathematics, data science, AI
- Physics & modelling
- Imaging
- Targets & (n, γ)

https://www.ibpt.kit.edu/atp.php

Accelerator Technology Platform (ATP)

Accelerator-relevant technologies



Compact magnet technologies

Electronics and high performance computing

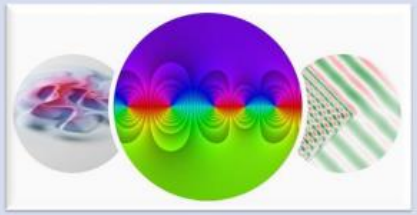
Energy R&D, KITTEN Energy Lab 2.0, KARA

Imaging, tomography

Vacuum technologies

Cryogenics, current leads

Nano- and microtechnologies



Mathematics, data science, physics, modelling, AI and machine learning

Superconducting technologies

RF, microwave & pulsed-power technologies

Terahertz sensors & particle detectors

Laser technologies & electro-optics & materials science

https://www.ibpt.kit.edu/atp.php

KARA and FLUTE at KIT IBPT

Karlsruhe Research Accelerator (KARA)

- 0.5 – 2.5 GeV electron storage ring with several operational modes and unique hardware features

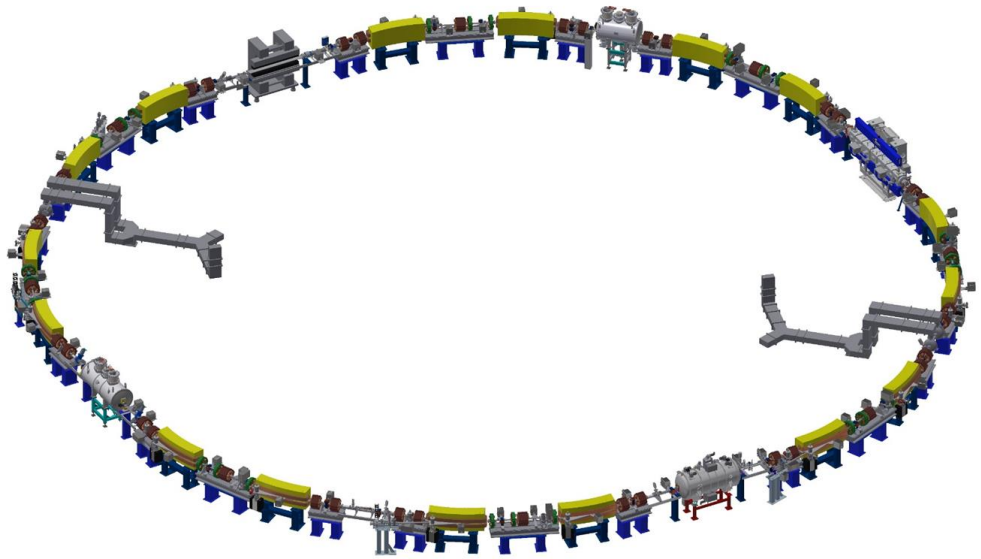


Image: U. Herberger

Far-infrared linac and test experiment (FLUTE)

- Electron linear accelerator with a test bench for new beam diagnostic methods and tools

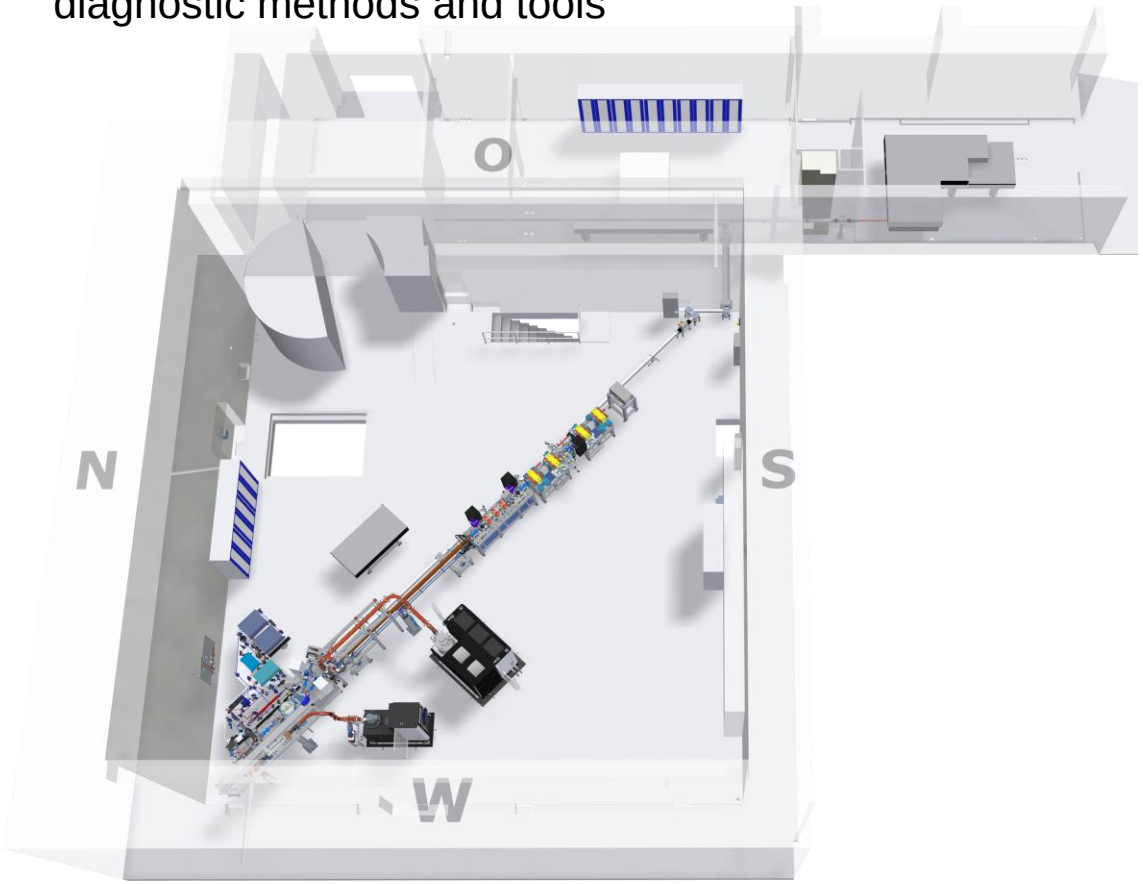


Image: S. Schott

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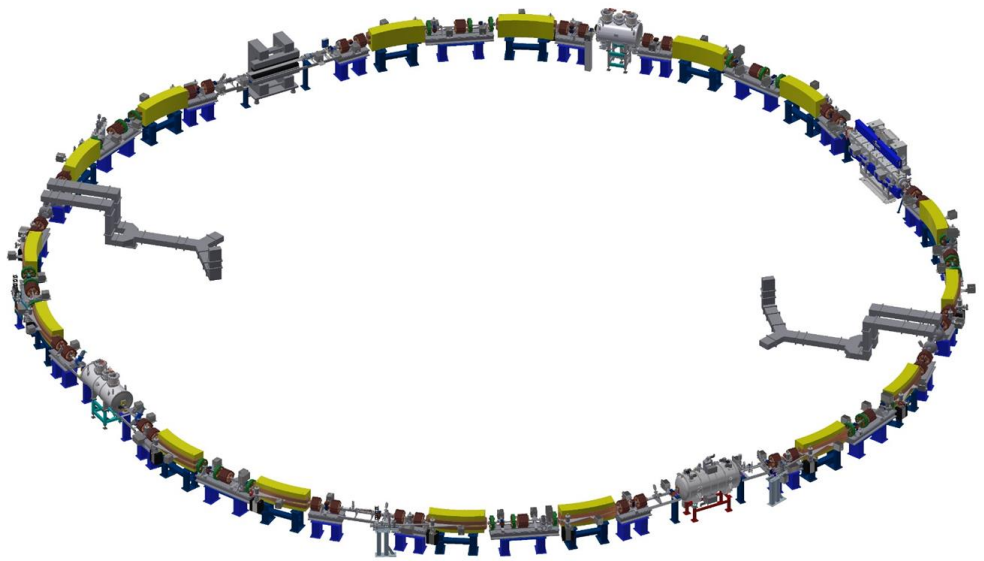

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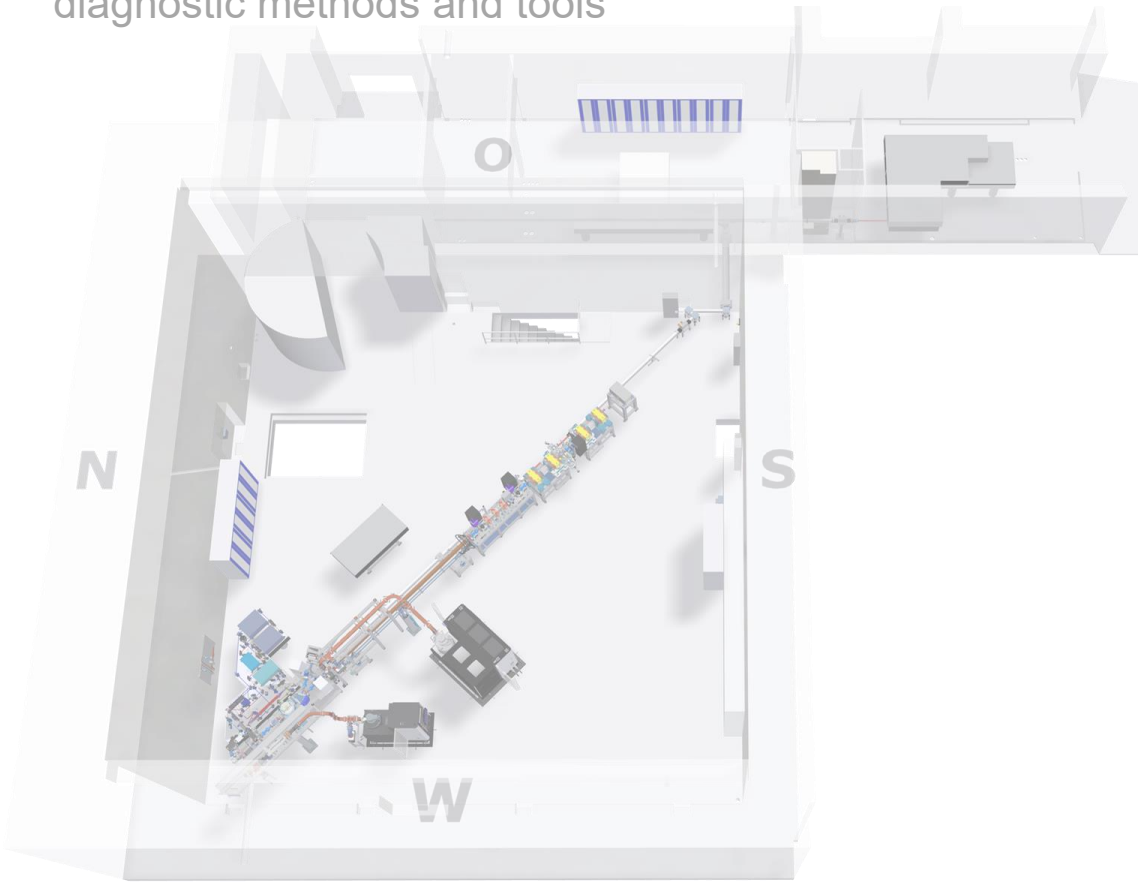
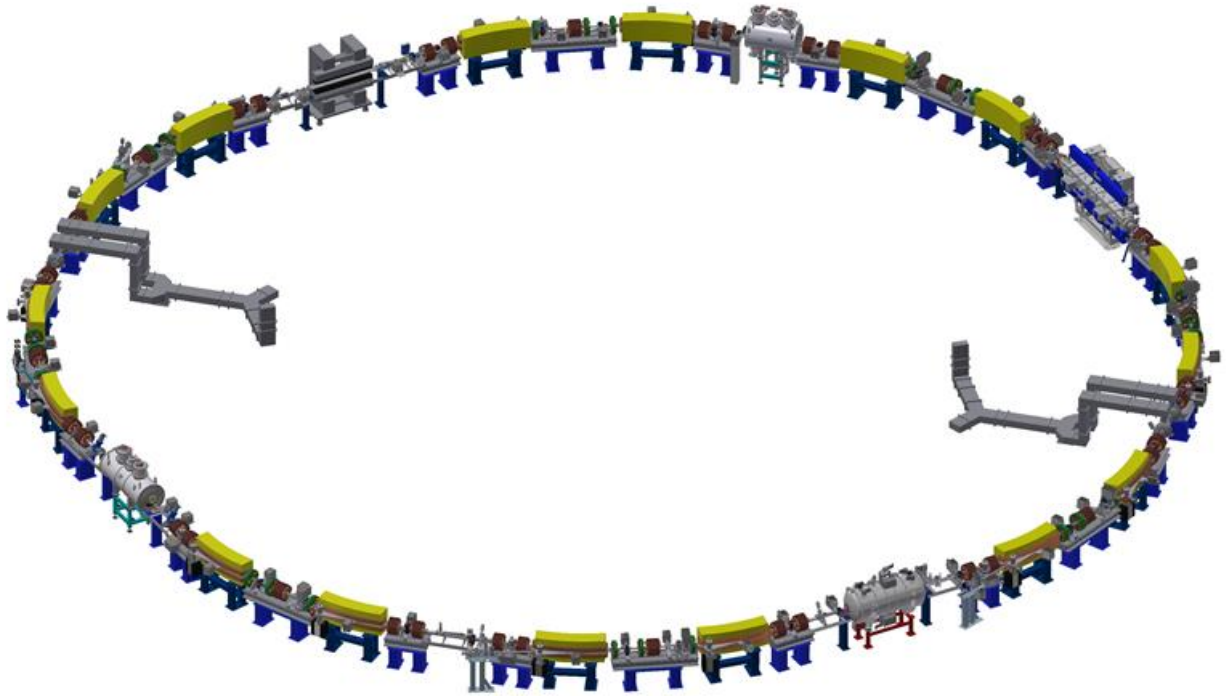


Karlsruhe Research Accelerator

KARA key parameters and features:

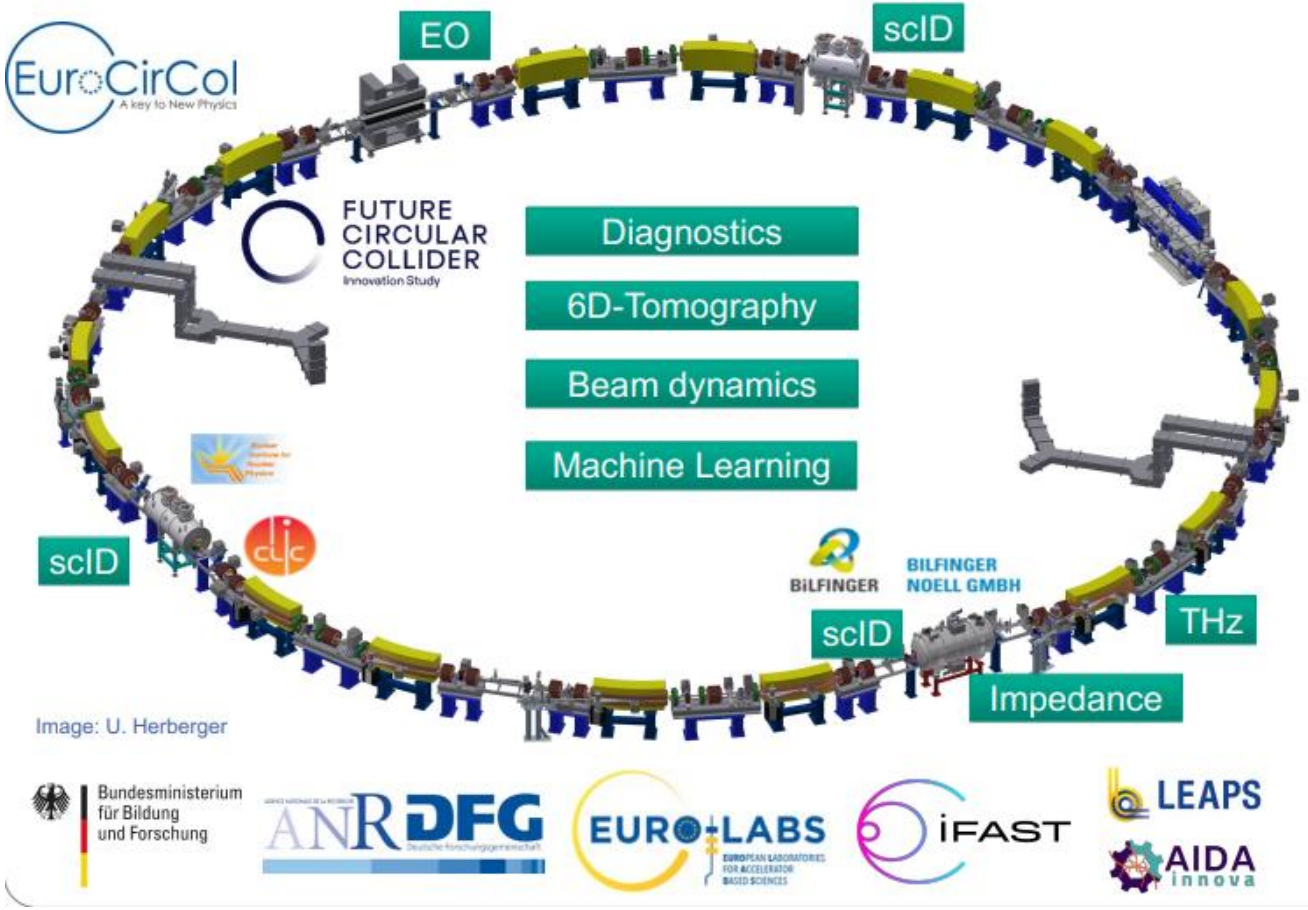
- Circumference: 110.4 m
- Energy range: 0.5 - 2.5 GeV
- RF frequency: 500 MHz
- Revolution frequency: 2.715 MHz
- Beam current up to 200 mA
- RMS bunch length:
  - 45 ps (for 2.5 GeV)
  - Down to a few ps (for 1.3 GeV)
- Different lattices for low and negative momentum compaction
- Educate and train the next scientific generation



Karlsruhe Research Accelerator

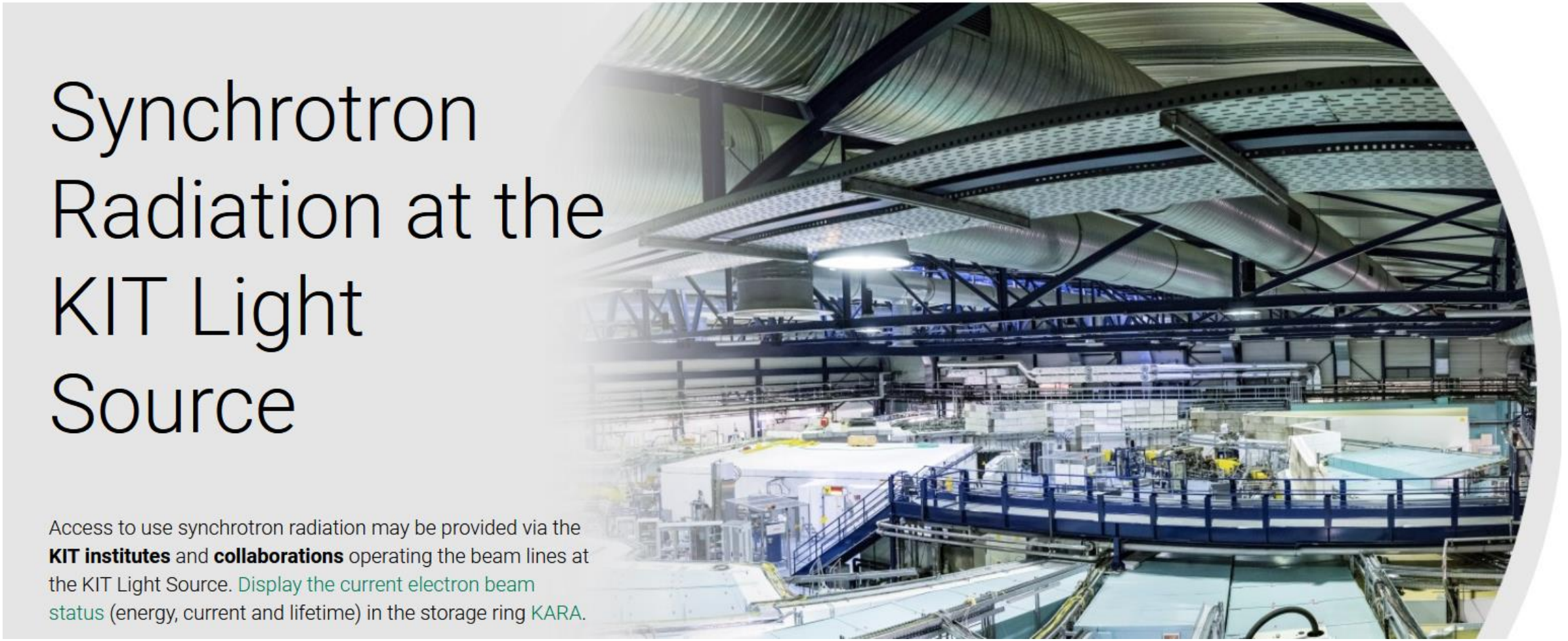
Unique hardware features:

- Distributed and synchronized sensor network
- EO-Nearfield setup
- Negative momentum compaction
- Machine learning applications in hardware
- Superconducting insertion devices
- Microbunching control



Courtesy: M. Schuh, Jan. 2023

KIT Light Source

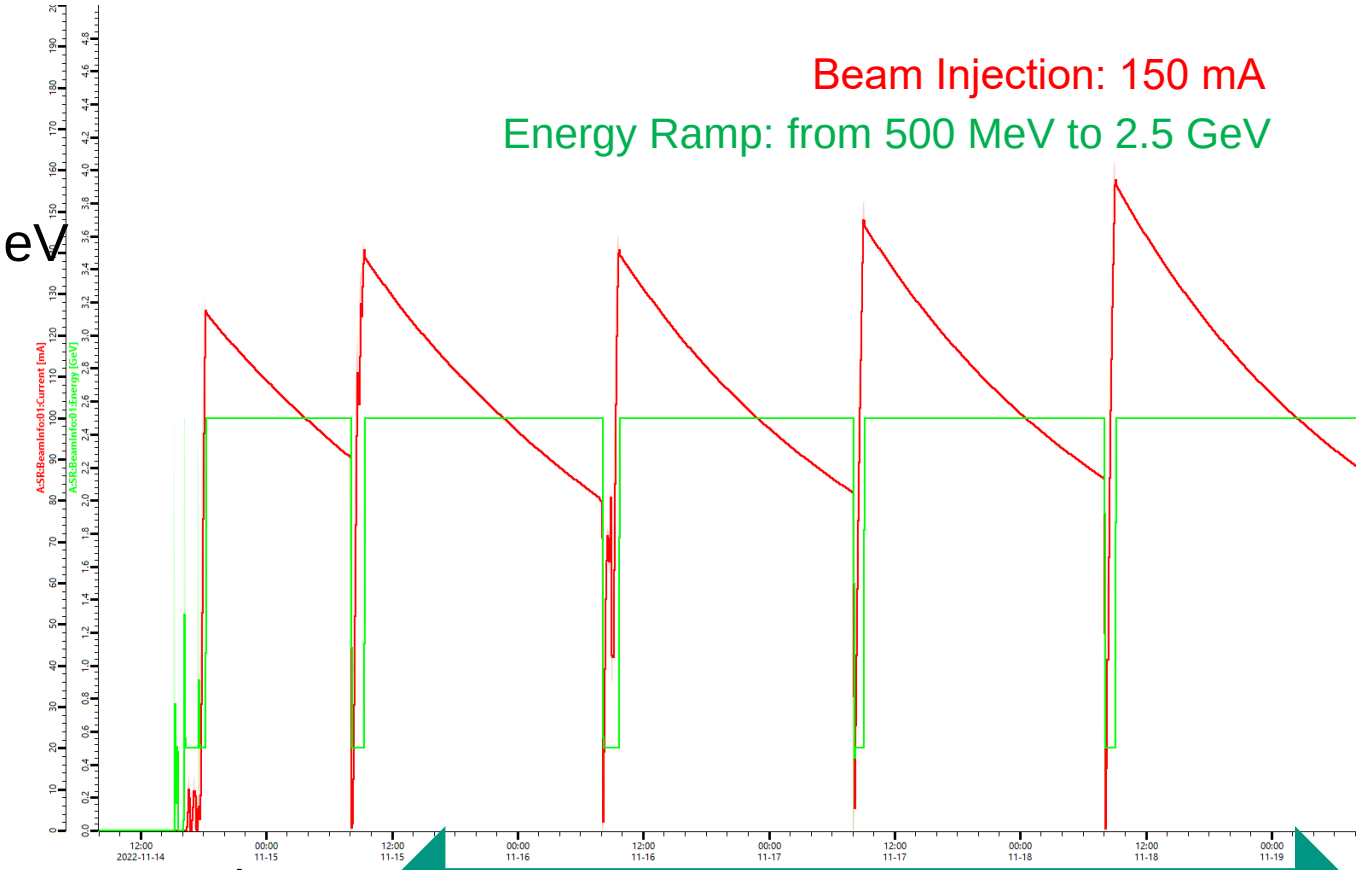


https://www.ibpt.kit.edu/KIT_Light_Source.php

KIT Light Source: Machine Operation

User operation mode:

- Monday: Startup
- Tuesday to Friday: user operation
  - Injection at 8 a.m. with 500 MeV
  - Energy ramp up to 2.5 GeV
  - Beam released to beamlines
  - Beam dump at 8 a.m.
- Saturday and Sunday: shutdown
- No full energy injection
- Decay mode operation at 2.5 GeV



https://www.ibpt.kit.edu/KARA_electron_beam_status.php

KARA and FLUTE at KIT IBPT

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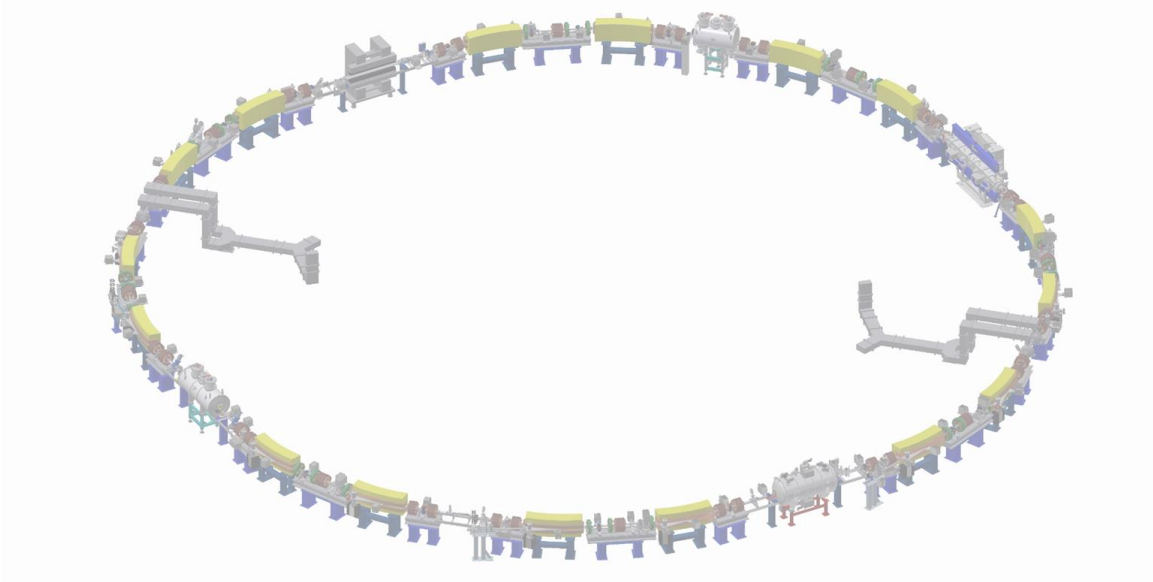

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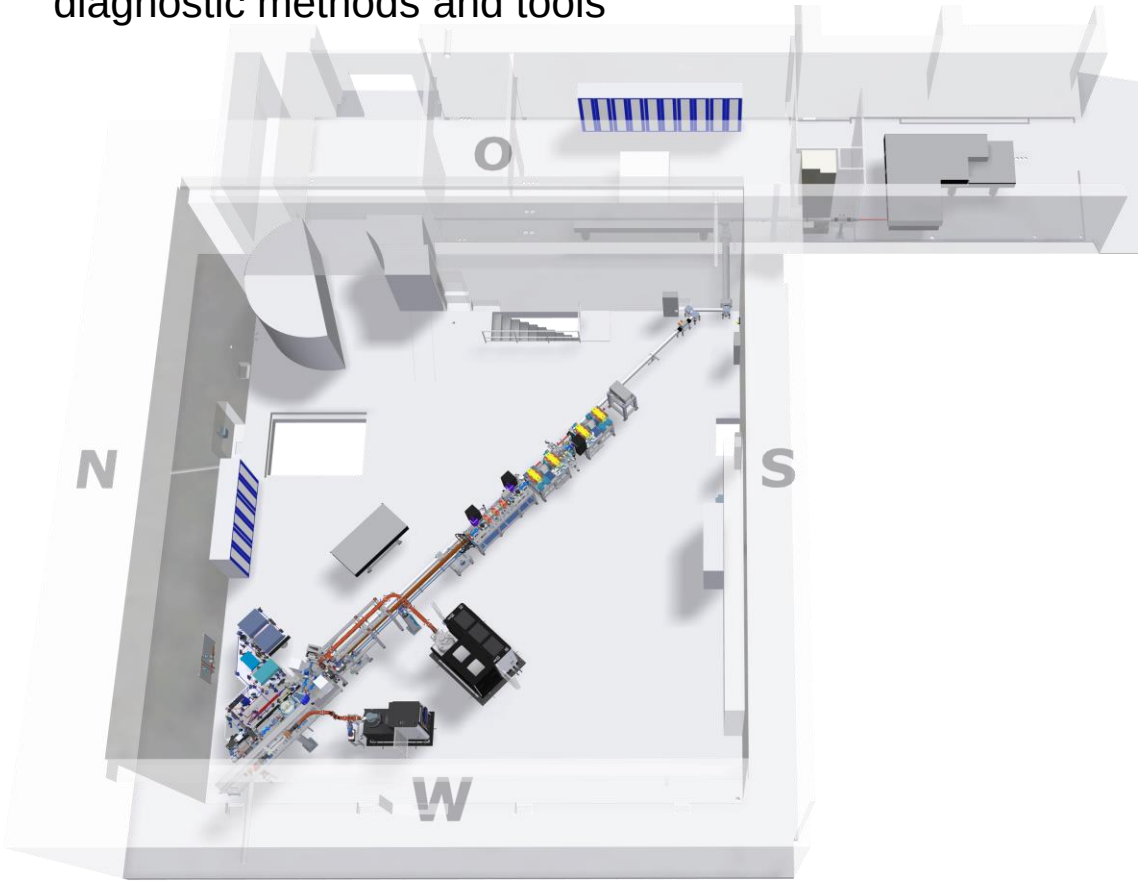
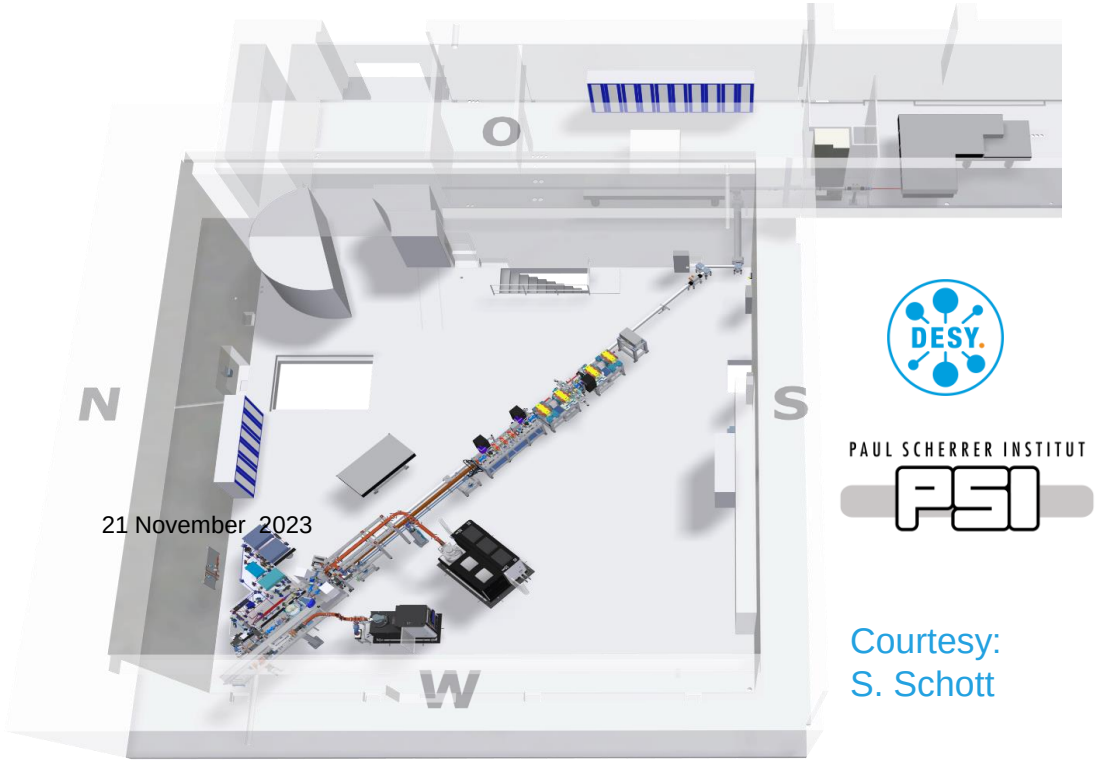


FLUTE: Accelerator Test Facility at KIT

- FLUTE (Ferninfrarot Linac- Und Test-Experiment)
  - Test facility for accelerator physics within ARD
  - Experiments with THz radiation



Courtesy:
S. Schott

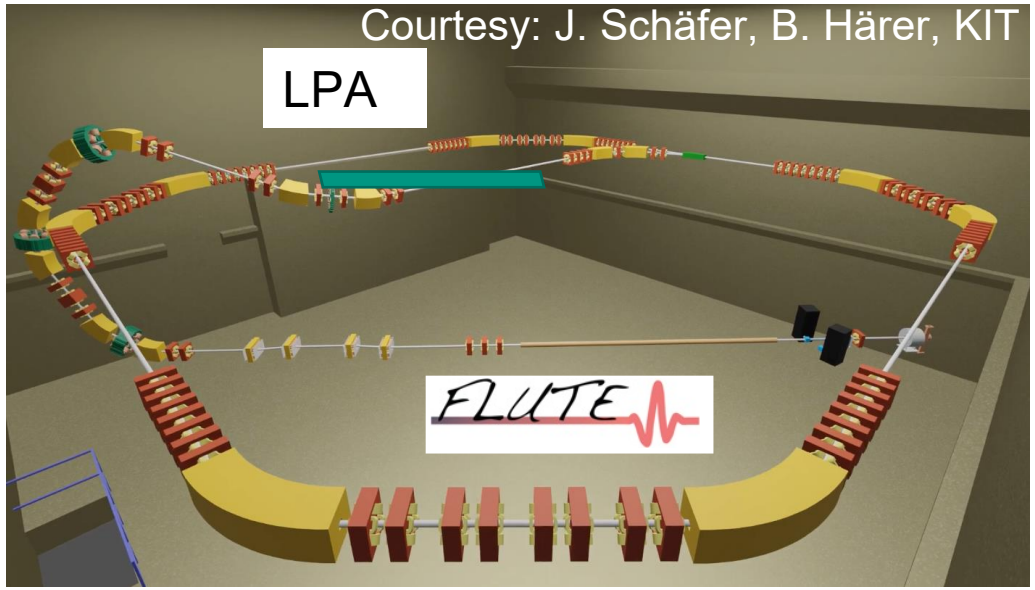
Optimal electron energy	~ 41	MeV
Electron bunch charge	0.001 - 1	nC
Electron bunch length	1 - 300	fs
Pulse repetition rate	1 - 10	Hz
THz E-Field strength	up to 1.2	GV/m

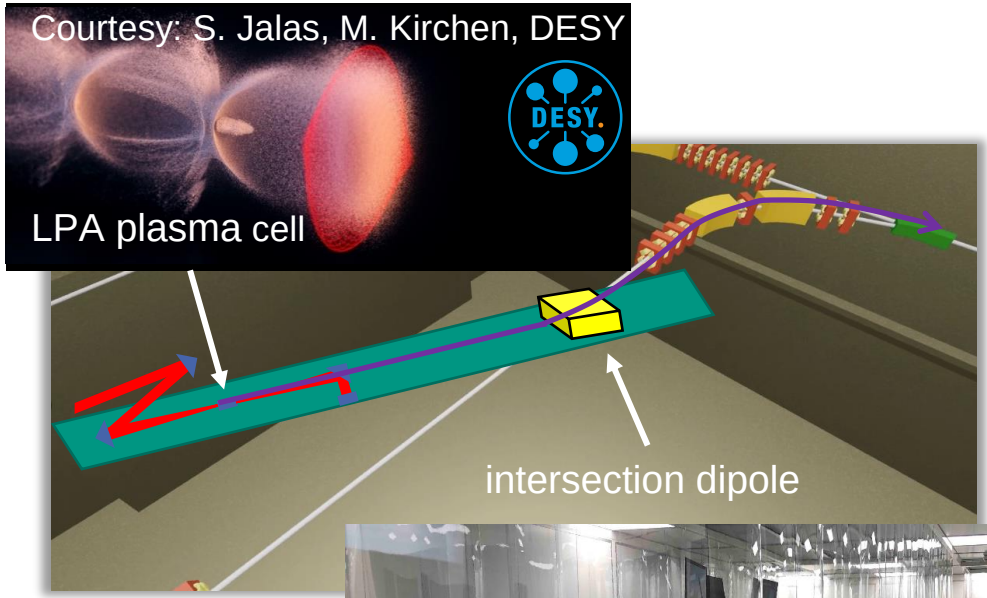
- R&D topics
  - Serve as a test bench for new beam diagnostic methods and tools
  - Systematic bunch compression and THz generation studies
  - Develop single shot fs diagnostics
  - Synchronization on a femtosecond level

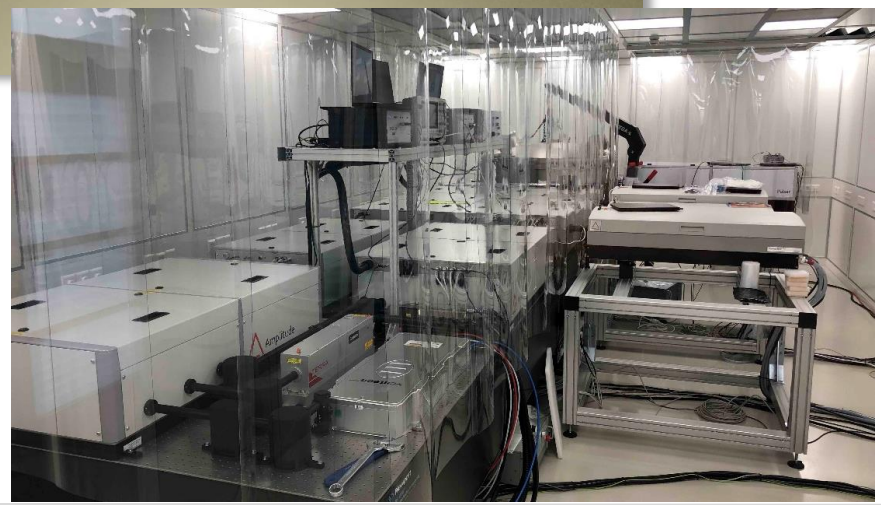
www.ibpt.kit.edu/flute

ATHENA @KIT - Status

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



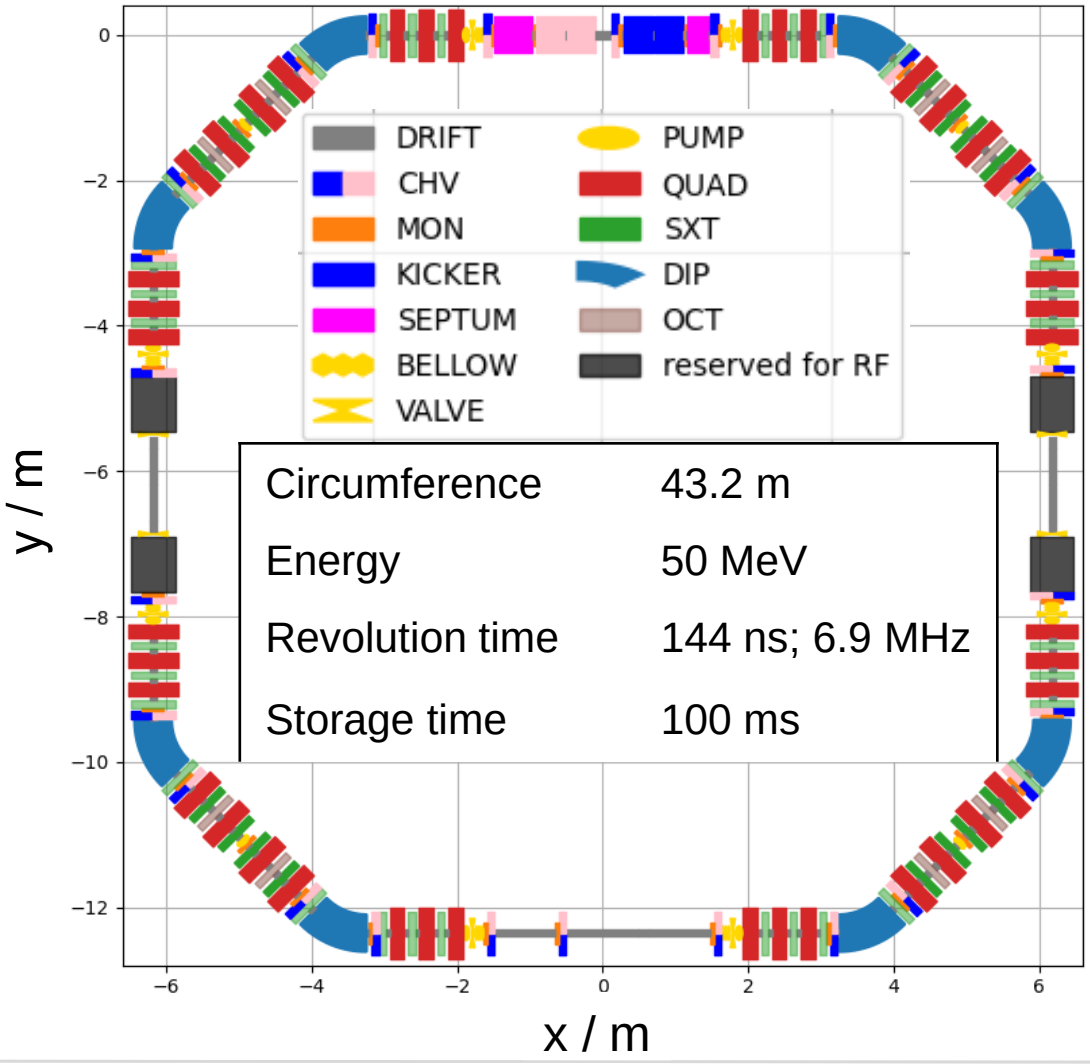




- Clean room for laser system built ✓
- Commercial 70 TW laser system in commissioning at KIT
- Conceptual design of transfer lines including diagnostics finished ✓
- Next step: Fine-tuning of optics and tracking calculations
- Prof. Matthias Fuchs at KIT since Sept. 2023 ✓

cSTART Project

- **Motivation:** Storage of LPA-like 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 delivered
  - Test diagnostics at KARA booster: ongoing
  - TDR launched in collaboration with industry

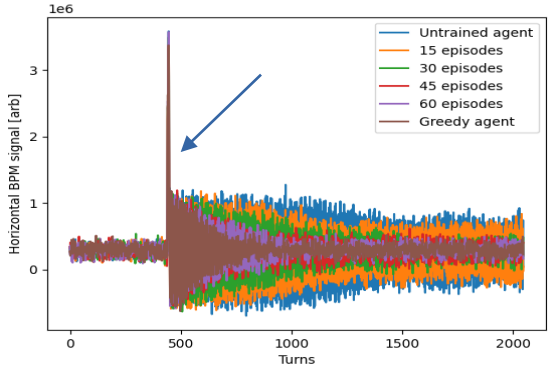


A. Papash et al. https://doi.org/10.18429/JACoW-IPAC2022-THPOPT023
M. Schwarz et al. https://doi.org/10.18429/JACoW-IPAC-23-WEPL167
D. El Khechen et al. https://doi.org/10.18429/JACoW-IPAC2022-MOPOPT026
J. Schäfer et al. https://doi.org/10.18429/JACoW-IPAC2022-MOPOST041
B. Härer et al. https://doi.org/ 10.18429/JACoW-IPAC2022-THPOPT059

AI4Accelerators team highlights

Reinforcement Learning

First successful application of RL in an accelerator with **online training** and **running on hardware in the world at KARA**!



L. Scomparin et al. The 9th annual MT meeting (Karlsruhe, 9-11 October 2023)

Lattice agnostic RL

- Code usable in different accelerators
  C. Xu et al. The 9th annual MT meeting (Karlsruhe, 9-11 October 2023)

Creation of the Collaboration on Reinforcement Learning for Autonomous Accelerators (RL4AA)!

- Kick-off with workshop organized at KIT
- Proceedings to be published
  https://rl4aa.github.io/

RL vs BO

https://arxiv.org/abs/2306.03739

[Submitted on 6 Jun 2023]

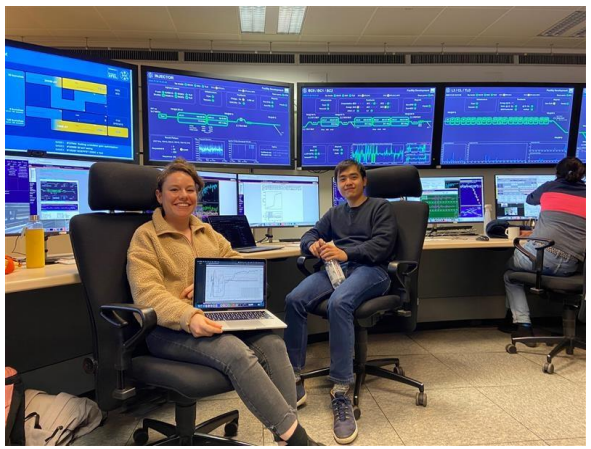
Learning to Do or Learning While Doing: Reinforcement Learning and Bayesian Optimisation for Online Continuous Tuning

Jan Kaiser, Chenran Xu, Annika Eichler, Andrea Santamaria Garcia, Oliver Stein, Erik Bründermann, Willi Kuropka, Hannes Dinter, Frank Mayet, Thomas Vinatier, Florian Burkart, Holger Schlarb

Online tuning of real-world plants is a complex optimisation problem that continues to require manual intervention by experienced human operators. Autonomous tuning is a rapidly expanding field of research, where learning-based methods, such as Reinforcement Learning-trained Optimisation (RLO) and Bayesian optimisation (BO), hold great promise for achieving outstanding plant performance and reducing tuning times.

Bayesian Optimization

- Time to inject to KARA cut in half with automated tuning by BO algorithm
  https://doi.org/10.1103/PhysRevAccelBeams.26.034601
- Emitted THz radiation at FLUTE optimized with parallel BO in simulation
  https://doi.org/10.18429/JACoW-IPAC2022-WEPOMS023
- Transfer of algorithm to EuXFEL to tune SASE emission https://www.ipac23.org/preproc/pdf/THPL028.pdf



Acknowledgements

Thank you for your attention!

- The accelerator team

Falastine Abusaif, Axel Bernhard, Edmund Blomley, Simon Braner, Erik Bründermann, Felipe Donoso Aguirre, Dima El Khechen, Samira Fatehi, Matthias Fuchs, Stefan Funkner, Julian Gethmann, Christian Goffing, Andreas Grau, Leander Grimm, Steffen Grohmann, Bastian Härer, Michael Hagelstein, Erhard Huttel, Igor Kriznar, Stephan-Robert Kötter, Bennet Krasch, Artem Kuzmin, Anton Malygin, Sebastian Maier, Sebastian Marsching, Yves-Laurent Mathis, Katharina Mayer, Wolfgang Mexner, Matthias Nabinger, Michael J. Nasse, Gudrun Niehues, Marvin Noll, Alexander Papash, Meghana Patil, Micha Reißig, Robert Ruprecht, Andrea Santamaria Garcia, David Saez de Jauregui, Jens Schäfer, Thiemo Schmelzer, André Schmidt, Marcel Schuh, Markus Schwarz, Nigel John Smale, Johannes L. Steinmann, Pawel Wesolowski, Christina Widmann, Chenran Xu and Anke-Susanne Müller

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