Welcome!

DESY. Accelerator R&D Activities

MT ARD ST3 Workshop (Virtual)

Advanced beam controls, beam diagnostics and beam dynamics

29 September 2021

Prof. Dr. Wim Leemans
Director Accelerator Division
DESY

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

MT ARD

The MT-ARD program is of central importance in POF IV

MATTER AND TECHNOLOGIES

Program *Matter and Technologies* (MT)
T. Behnke (DESY) | A.-S. Müller (KIT)

Topic *Accelerator Research and Development* (MT-ARD)
A. Jankowiak (HZB) | J. Osterhoff (DESY)
DESY, FZJ, GSI* with HIM and HI Jena, HZB, HZDR, KIT

- Subtopic 1 *Advanced CW SRF Systems*
- Subtopic 2 *New Concepts and Prototypes for Maximizing the Performance of Hadron and Electron Accelerators*
- Subtopic 3 *Advanced Beam Control, Diagnostics and Dynamics*
- Subtopic 4 *Ultra Compact, Novel Accelerators and their Applications*

Topic *Detector Technologies and Systems* (MT-DTS)
M. Weber (KIT) | S. Masciocchi (GSI)
DESY, GSI* with HIM and HI Jena, KIT

- Subtopic 1 *Detection and Measurement*
- Subtopic 2 *System Technologies*
- Subtopic 3 *Science Systems*

Topic *Data Management and Analysis* (MT-DMA)
M. Bussmann (HZDR) | V. Gülzow (DESY)
DESY, FZJ, GSI with HI Jena, HZB, HZDR, HZG

- Subtopic 1 *The Matter Information Fabric*
- Subtopic 2 *The Digital Scientific Method*
- Subtopic 3 *The Digital Experiment and Machine*

The MT-ARD program is of central importance in POF IV

Accelerator scientists push the limits of today's technology in a research network of various Helmholtz centers and institutes, eleven universities, two Max-Planck institutes, and the Max-Born institute.

ADAPTION OF ARD STRUCTURE PoF III → PoF IV

PoF III		PoF IV	
Subtopic 1	SCRF Science and Technology	Advanced cw SRF Systems	ST1
ST2	Concepts and Technologies for Hadron Accelerators	New Concepts and Prototype for Maximizing the Performance of Hadron and Electron Accelerators	ST2
ST3	Picosecond and Femtosecond Electron and Photon Beams	Advanced Concepts for Beam Control, Diagnostics and Dynamics	ST3
ST4	Novel Acceleration Concepts	Ultra Compact, Novel Accelerators and their Application	ST4

MT ARD
MATTER AND TECHNOLOGIES ACCELERATOR RESEARCH AND DEVELOPMENT

Helmholtz Centres:
DESY, FZJ, GSI, HZB, HZDR, KIT

German institutes and universities involved in the research programme:
Helmholtz-Institute Jena (HIJ) und Mainz (HIM), Humboldt Universität zu Berlin, Universität Bonn, Technische Universität Darmstadt, Technische Universität Dortmund, Universität Düsseldorf, Johann-Wolfgang-Goethe-Universität Frankfurt, Universität Hamburg, Universität Mainz, Ludwig-Maximilians-Universität München, Universität Rostock, Universität Wuppertal, Max-Planck-Institut für Quantenoptik Garching, Max-Planck-Institut für Physik München, Max-Born-Institut Berlin

A world-leading accelerator lab

DESY's mission

At DESY we have a unique combination of analytical tools

Brilliant X-rays, intense electron beams

PETRA IV. X-ray microscope for chemical, biological and physical processes

Scientific excellence in X-ray Analytics to address global challenges

Unprecedented beam parameters

- New machine 2.3 km length
- 100-times higher intensity
- 100-times faster experiments
- Experiments *in situ* und *operando*

Development of Photon Science user facilities

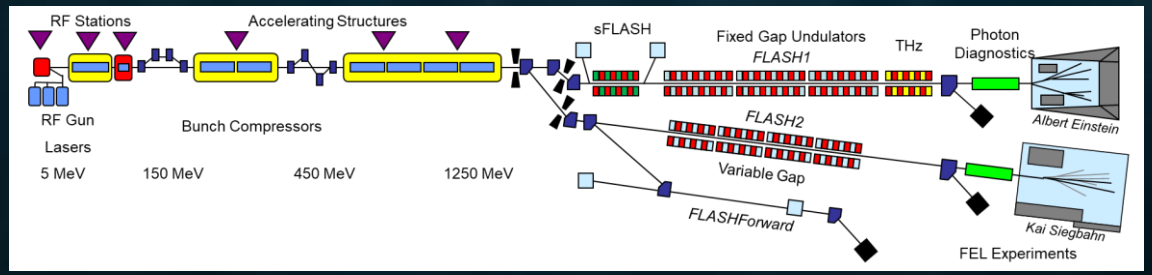
- **Sustainability as focus:**
  - **Hybrid magnets**
  - **Waste heat recuperation**
  - **High efficiency RF systems, ...**

FLASH2020+ Upgrade

FLASH will be kept at the forefront of soft X-ray FEL facilities for another decade

- Provide seeding to users
- Higher photon energies and polarization control
- Optimized operation modes in the two FLASH beamlines

Development of Photon Science user facilities



Upgrade of the European XFEL

DESY conducts R&D for XFEL, supported by operation funds of European XFEL GmbH

- **Strong link of ARD-SRF to XFEL – orientation towards strategic goal of CW upgrade of XFEL linac**

Development of Photon Science user facilities

- **Other R&D items towards improvement of the facility's performance include advanced FEL concepts, advanced beam controls, feedback systems and automatization**

We are developing technology to further strengthen and secure European XFEL's future

Upgrade:

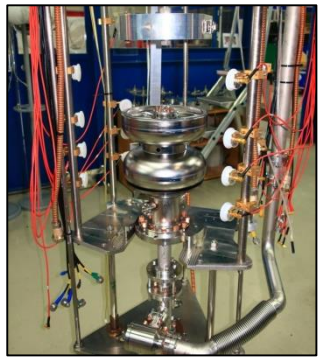
- ❑ More beamlines (2nd fan, SASE4/5)
- ❑ CW operation
- ❑ Soft x-ray ops at EuXFEL

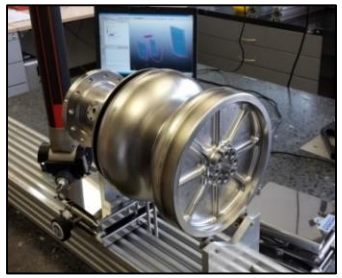
2030

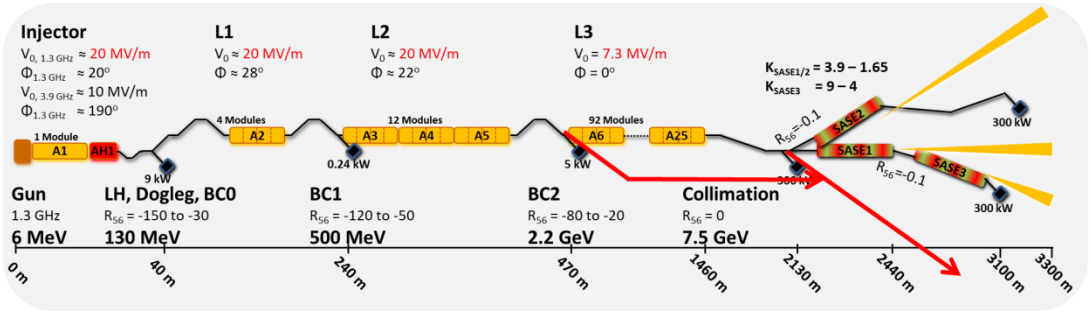
Autonomous accelerator and enhanced user ops

2025

Improve present days operation and add 'small' upgrades







2020

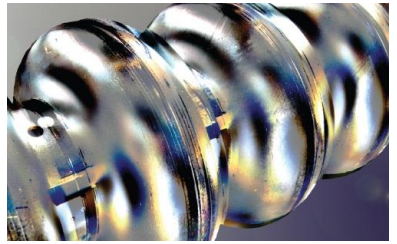
The SRF R&D community goes continuous wave

DESY SRF R&D strongly supports a further developed TESLA technology

- The **European XFEL R&D** efforts aim for technology development
- The **DESY Accelerator Research and Development (ARD)** program investigates more fundamental questions related to SRF CW performance

- **DESY activities include**
  - SRF gun development / CW injectors
  - CW linac design: Niobium material / cavities / RF power couplers / module design & operation
  - Assembly of 1+ accelerator module per year
  - We profit from our involvement in and support of CW projects under construction

several generations of SRF gun prototypes



production of Large Grain material cavities

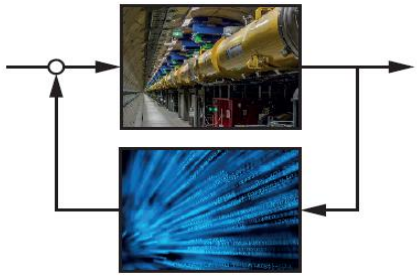
investigation of ESS and LCLS-II HE cavities

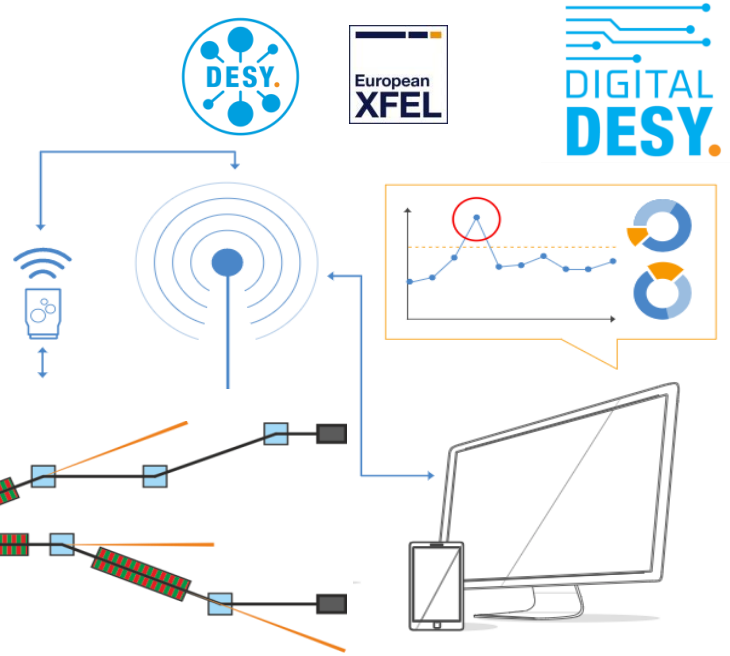
long pulse / CW operation of slightly modified XFEL type accelerator modules

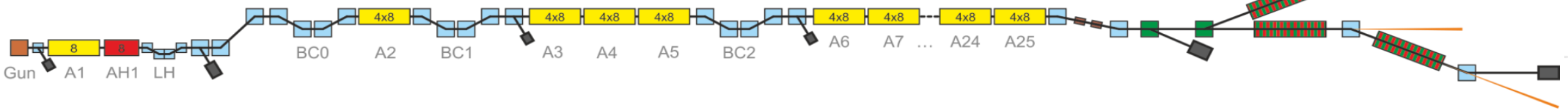
We are developing new operational modes for our accelerators

Autonomous accelerator operation: Leverage strengths of Helmholtz, partner universities and industry to provide tailored solutions

- **Data acquisition and analysis pipeline**
- **Fault diagnosis and prevention**
- **Intelligent control algorithms for accelerator operation**







Institutes, e.g.:

- Helmholtz institutes: various projects (ARD, DMA)
- SLAC: HIR^{3}X
- CERN: simulation interface for ML
- ESS: Alarms, data sharing, fault diagnosis and protection

Universities

DESY. Smaller scale facilities provide versatile platforms for accelerator development and applications

Facilities offer complementary capabilities

PITZ @DESY Zeuthen

Energy: 22 MeV

Available: starting early 2022 for high repetition rate experiments

Upgrade: towards 250 MeV foreseen in 2026-2027 time frame

Application:
Defining optimum beam parameters, tumour painting and microbeams

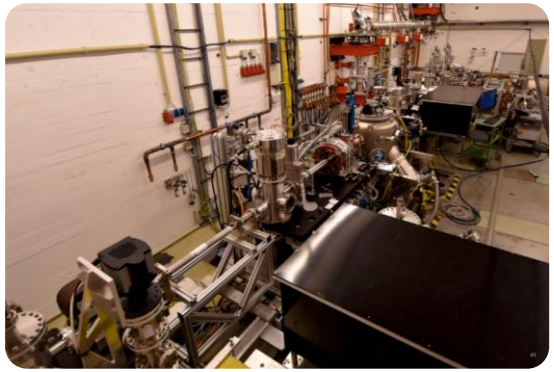
ARES

Energy: 50-160 MeV, ultra-stable, towards single digit femtosecond bunches

Available: starting mid 2022 for up to 50 Hz experiments

Application:
Radiation biology
Autonomous accelerators
Novel accelerator structure testing

REGAE

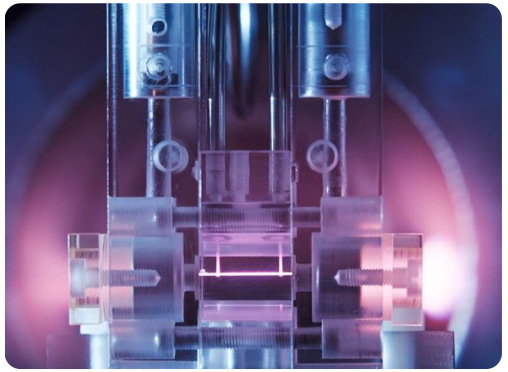


Energy: 3.6 MeV

Applications:
Ultrafast electron diffraction **(UED)**

For **low energy** radiation biology (e.g. brachytherapy)

Plasma accelerators



Energy: 1-400 MeV

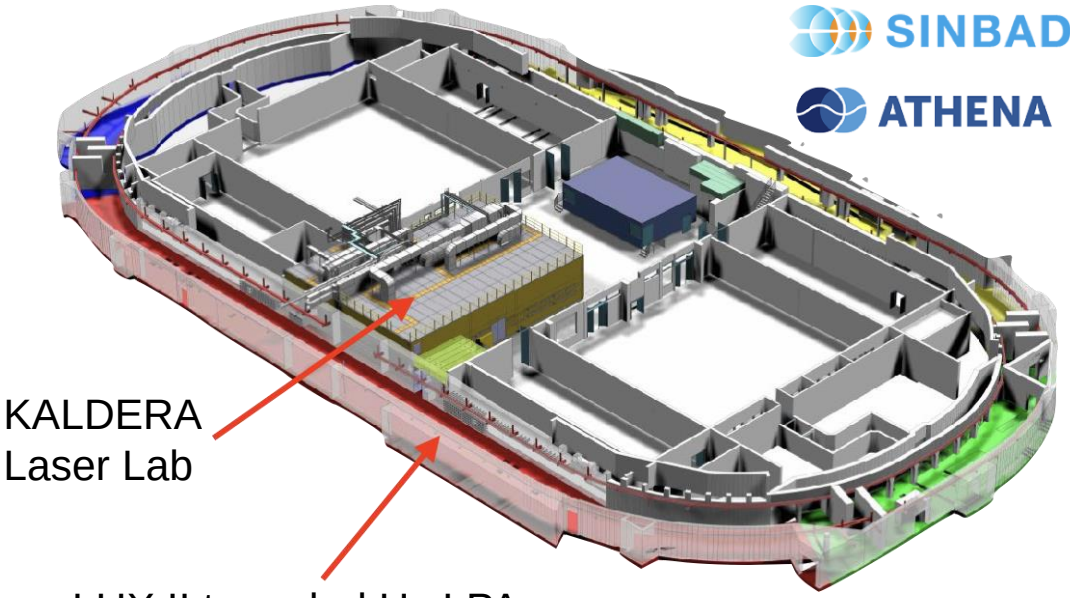
Additional information:
Offers compactness and mobility

Application:
For ultra-short bunches

DESY. focuses its R&D on high-power plasma accelerators

Our detailed technology roadmap is based on two unique infrastructures

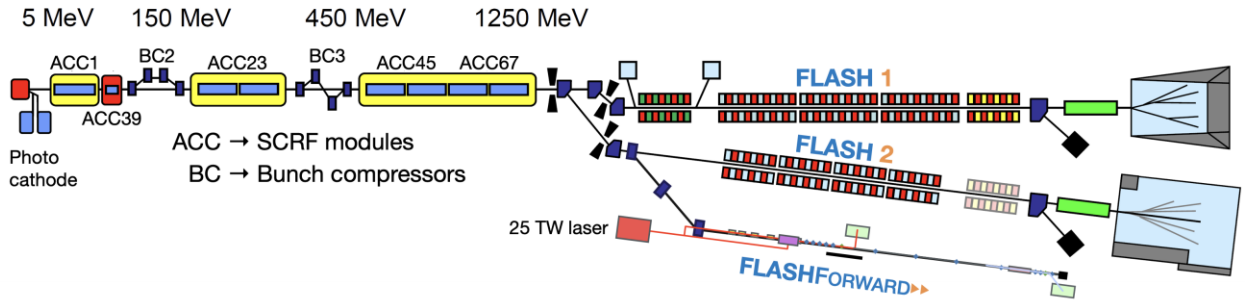
KALDERA – kW, kHz laser driver



Science case

- **100 TW**-class laser @ **kHz**-level rep-rate
- **active stabilization, feedback** and **ML/AI**
- **FEL-quality** electron beams

FLASHFORWARD ⏩ – 10 kW beam driver



- **~10 kW avg. power**, **MHz rate** acc. based on ILC/XFEL tech.
- Advanced **FEL-user facility feedback** and feedforward systems

Goal: demonstrate a self-consistent **plasma accelerator** stage with **high efficiency**, **high quality**, and **high average power**

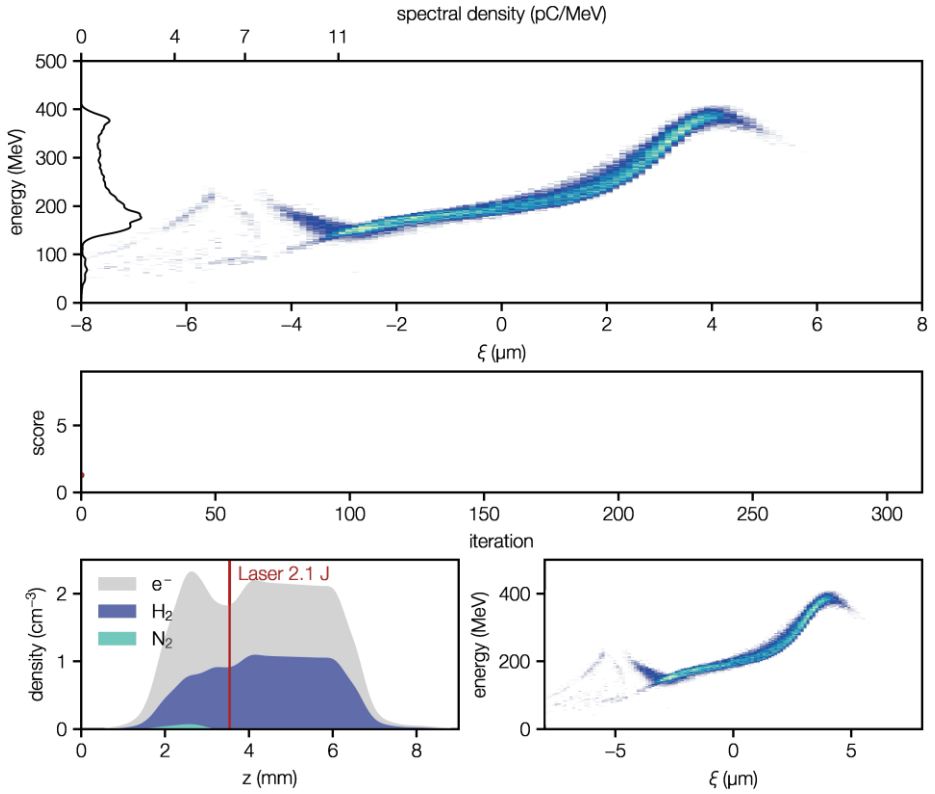
29 hours continuous operation and artificial intelligence for laser-plasma accelerator self-tuning

PHYSICAL REVIEW LETTERS **126,** 104801 (2021)

Bayesian optimization

Bayesian Optimization of a Laser-Plasma Accelerator

Sören Jalas,[1,*] Manuel Kirchen,[1] Philipp Messner,[2,1,3] Paul Winkler,[3,1] Lars Hübner,[3,1] Julian Dirkwinkel,[3] Matthias Schnepp,[1] Remi Lehe,[4] and Andreas R. Maier[3,1]

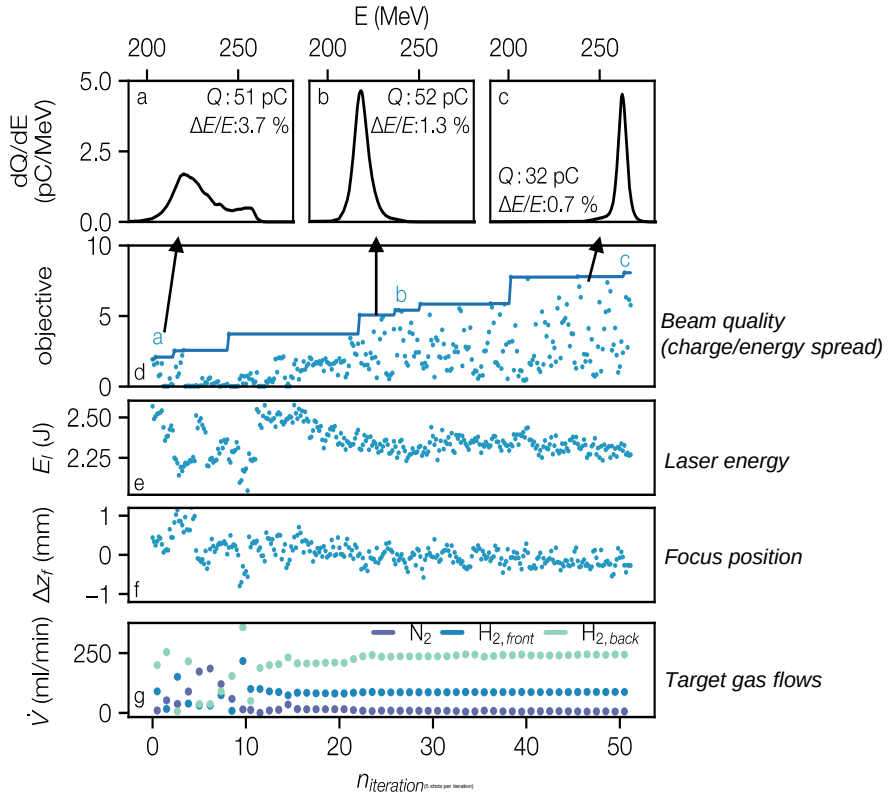


PHYSICAL REVIEW LETTERS **126,** 174801 (2021)

Optimal beam loading

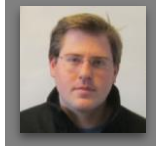
Optimal Beam Loading in a Laser-Plasma Accelerator

Manuel Kirchen,[1,*] Sören Jalas,[1] Philipp Messner,[2,1] Paul Winkler,[3,1] Timo Eichner,[1] Lars Hübner,[3,1] Thomas Hülsenbusch,[3,1] Laurids Jeppe,[1] Trupen Parikh,[3] Matthias Schnepp,[1] and Andreas R. Maier[3,1]



DESY. Is building a kW class, 100 TW laser -- KALDERA

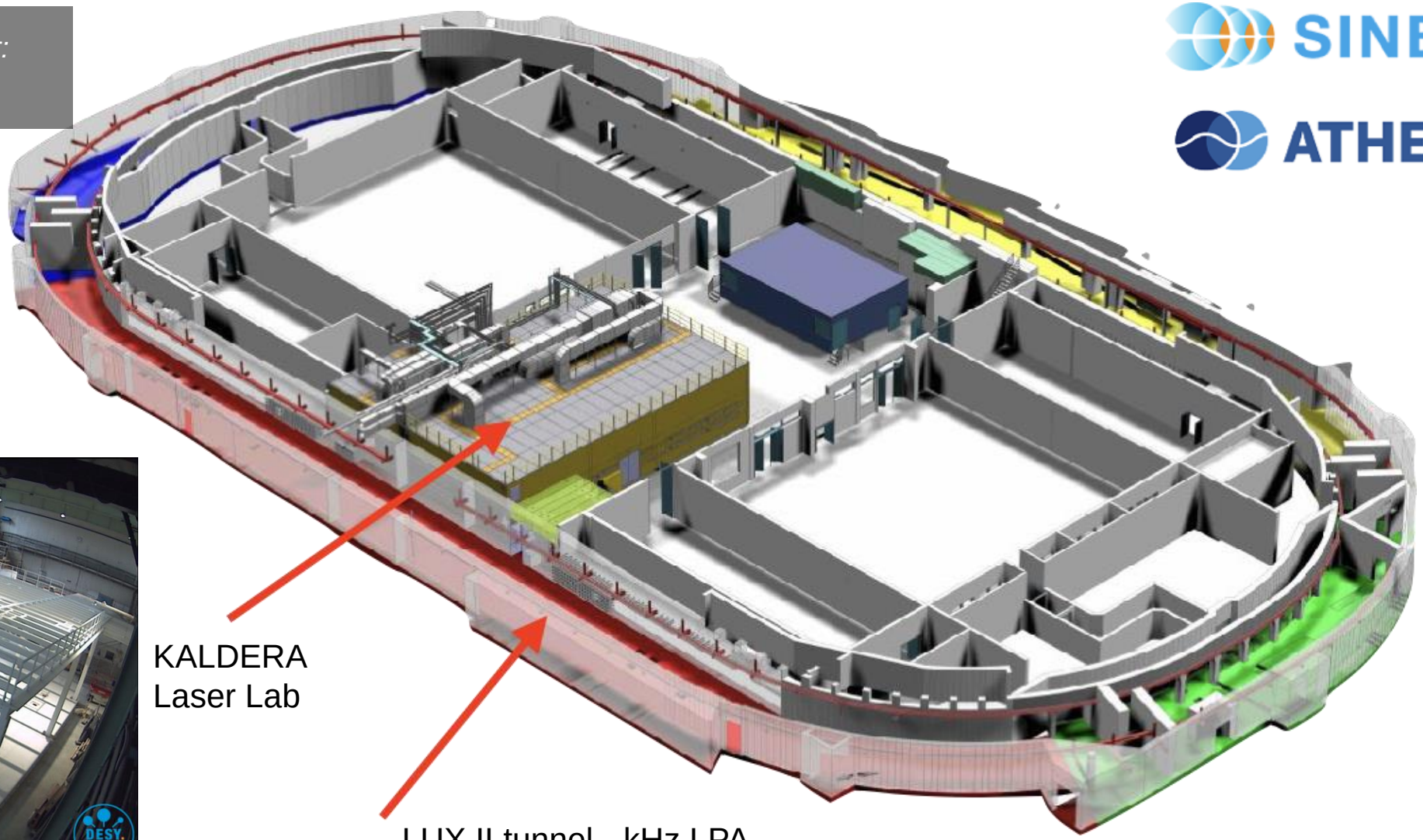
Driver for kHz, GeV class electron beams and enabling high rep rate feedback and machine learning



Project coordinator:
Andreas R. Maier

SINBAD

ATHENA



KALDERA
Laser Lab

LUX II tunnel - kHz LPA

Powering an FEL, injection into state-of-the-art storage ring, novel end-station modalities and >10 GeV plasma accelerator systems are central goals at DESY

Stable, reliable generation of high quality beams to ensure machine availability

Demo-FEL (LUX) operational

2019

2021

Simulation studies for PETRA IV injection

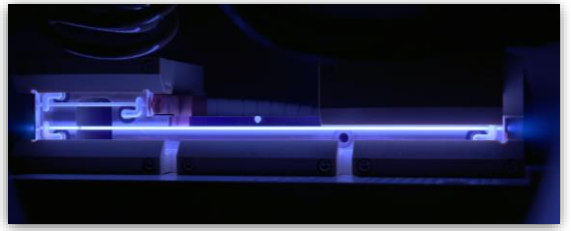
2023

High-power laser KALDERA operational

2025-2030

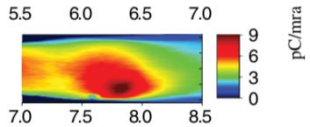
2nd Injection system development for PETRA IV: LPA-based

- **Non-linear QED**
- **Plasma building block for collider**



Laser plasma accelerators

- Up to 8 GeV
- Dechirper, plasma lenses, low emittance
- 29 hr stability run (Maier et al.)



Also: medical initiatives

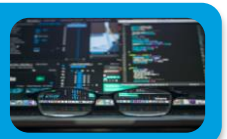
digitalDESY: We have a chance to capitalize on worldwide drive towards digitalization

With an initiative that spans all of DESY towards resilience and sustainability

Focus in the M-Dvision

Digital infrastructure monitoring
- **Safety and remote operation**

Artificial intelligence & machine learning
- **towards an Autonomous Accelerator**



Robotics and advanced human-machine interfaces

Digital LEAPS — League of European Accelerator-based Photon Sources

AIRA - Artificial Intelligence and Robotics for Accelerators

2-stage workshop: first workshop was held from **5-8 July 2021**

- Workshop to explore the landscape of technologies, scout for top talent and funding opportunities

DESY. | European XFEL | HZDR Helmholtz Zentrum Dresden Rossendorf | KIT Karlsruher Institut für Technologie | TUM | UHH

HELMHOLTZ SPITZENFORSCHUNG FÜR GROSSE HERAUSFORDERUNGEN

digitalDESY.: Can we deploy remotely controlled robot-assisted installation and user operations?

Develop a da Vinci-like robot for assisting users and technical staff

da Vinci Surgical Robot *(Intuitive Inc.*, USA)

http://Shadowrobot.com/

VR-driven controls Human Machine Interface

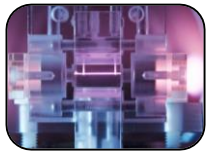
Prof. F. Steinicke et al.

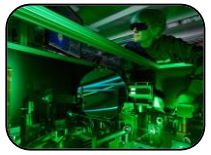
TUHH HAW HAMBURG

Summary







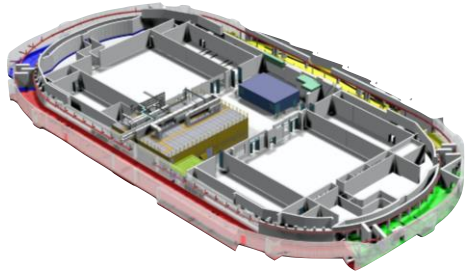



Many opportunities at DESY. in advanced beam controls, beam diagnostics and beam dynamics

- **PETRA IV.** focus on sustainability: hybrid magnets, waste heat recuperation, high efficiency RF systems
- **FLASH2020+** seeding, polarization control and optimized operation modes
- **SRF development** CW capability at EuXFEL will boost the SRF technology
- **PITZ, ARES** and **REGAE** accelerator development and applications: UED and radiation biology
- **Plasma R&D** high power plasma accelerator development
- **digitalDESY** Digital monitoring, machine learning and autonomous accelerators, advanced robotics, new human-machine interface modalities

PETRA IV. NEW DIMENSIONS

FLASH2020+




Thank you

Contact

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