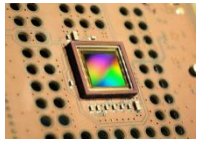
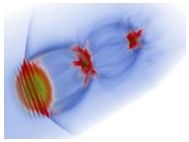
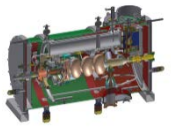
HELMHOLTZ

MT MATTER AND TECHNOLOGIES

RESEARCH FOR GRAND CHALLENGES

MT ARD

Accelerator Research and Development

Andreas Jankowiak, HZB / Jens Osterhoff, DESY
on behalf of the ARD team

June 16th, 2021
7th Annual MT Meeting
Part Two
Online

DESY. JÜLICH GSI HZB Helmholtz Zentrum Berlin HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF HI JENA HIM KIT

THE MENU

- Common ARD Milestones – Status of Plans
  “Energy Responsibility (Efficiency)” (ARD-00) and “Impact of Machine Learning” (ARD-01)

- Innovation Pool projects ACCLAIM and InnovEEA

- Highlights of ST1, ST2, ST3 and ST4

- ErUM (Exploration of the Universe and Matter) Calls 2021
  - ErUM-Data Call01 “Software & Algorithms incl. AI & ML”
  - ErUM “Research of matter with large-scale facilities (photons, neutrons, ions)”

COMMON ARD MILESTONES

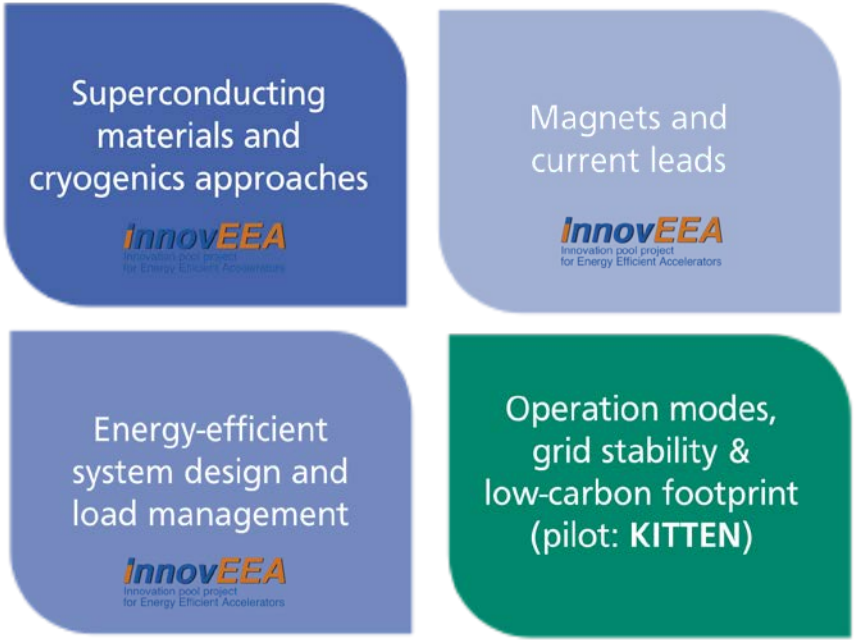
Mst	Year	Milestone + Partners	ST	Centers
ARD.00	2027	Energy Responsible (Efficient) Accelerators	common	All
ARD.01	2023	Review the usage and impact of Machine Learning on the ARD research program.	common	All
ARD.02	2024	Update evaluation of the user needs for guidance of the research program	common	All

activities to be started in 2022

ARD.00 – ENERGY-RESPONSIBLE ACCELERATORS

Coordination ARD.00: A.-S. Müller

- Prerequisite for future mid- and large-scale (accelerator-based) research infrastructures
- Model for (societal) infrastructures
- Guiding questions:
  - When is an accelerator efficient/responsible?
  - What is feasible and what is not?
  - Which compromises are thinkable?
- Helmholtz-wide consortium to investigate, develop & demonstrate new concepts from components to system solutions
- Implementation in two phases
  - Phase 1: InnovEEA *(report in 2024)*
  - Phase 2: starting from lessons learned *(formulate roadmap in 2026/2027)*



InnovEEA
Innovation pool project for Energy Efficient Accelerators

Coordination:
S. Grohmann (KIT)

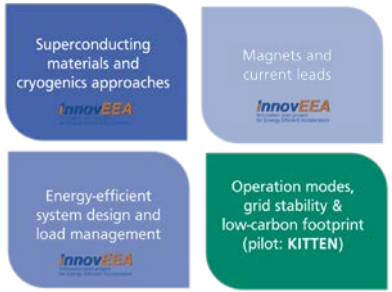
ARD.00 – ENERGY-RESPONSIBLE ACCELERATORS

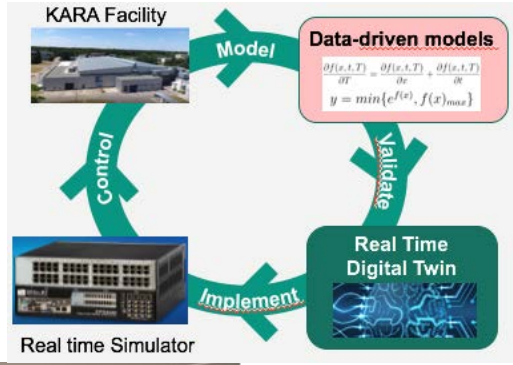
link to Research Field ENERGY

ENERGY LAB 2.0

KIT Karlsruhe Institute of Technology

Coordination: A.-S. Müller, G. De Carne (KIT)





test field

KITTEN

Courtesy: A.-S. Müller

ARD.00 – ENERGY-RESPONSIBLE ACCELERATORS

link to EU wide activities

LEAPS League of European Accelerator-based Photon Sources

PerMaLIC Collaboration

(ALBA, CLS, DESY, Diamond, ELETTRA, ESRF, HZB, IAS, MAX IV, PSI, SOLARIS, SOLEIL)

Permanent Magnets for next generation light sources

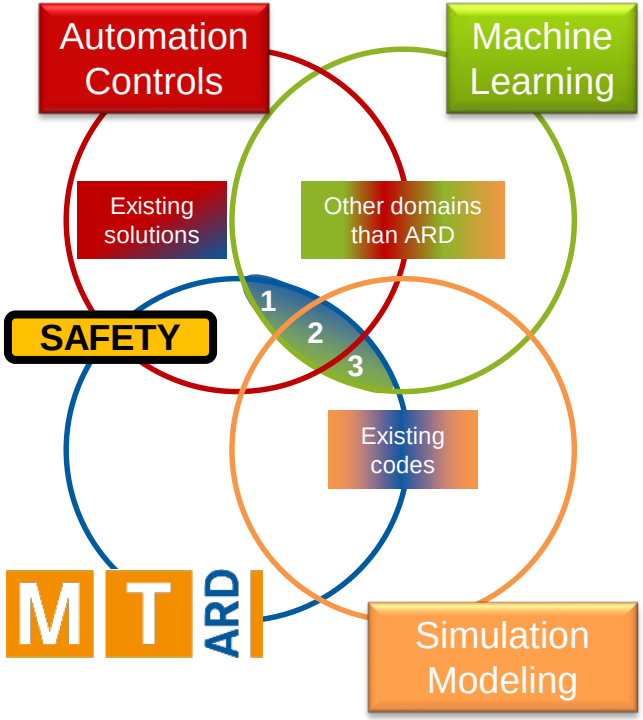
- LEAPS internal collaboration
- first workshop 22.09.2021

ARD.01 – IMPACT OF MACHINE LEARNING

Coordination ARD.01: Erik Bründermann

Focus on ARD!

Disclaimer: No attempt to be complete!



Guiding (teaser) questions

- Where does ARD profit from ML and ML-guided research?
- Where are break-even points to conventional approaches?
- Can a common understanding/language/ARD-ML-taxonomy* be found?
- Can ML improve efficiency (incl. energy) and replace tedious/cumbersome tasks?
- Are ML-algorithms transferable? Can they be standardized and easy to use?
- Is ML fast enough for fast-feedback and control tasks?
- What about safety-critical applications, if the ML-decision-process is complex?

Accelerator Operations from components (RF, magnets, lasers, …) to facility, Simulation, Modeling, Data Analysis, Physics and Engineering Experiments, …

- *Level of digitalization/automation heterogeneous (within and between facilities)*
  - Teaser Keywords (*no specific order*): remote control, industrial control systems, specialized codes, industrial and advanced diagnostics, fast feedback systems, data archiving and management, virtualized servers, network infrastructure, …
- Beam dynamics, plasma dynamics, accelerator physics codes**, accelerator and optics modelling, …

Examples:

1 - accelerator optimization (tuning, correction), autonomous operation
2 - virtual diagnostics, digital twins, anomaly detection, forecasting
3 - surrogate models, time-efficient parameter scanning, optics design

Borders blurred. For Autonomous Accelerators a confluence of it all?

* EU taxonomy for sustainable activities

** Accelerator physics codes - Wikipedia

Courtesy: E. Bründermann

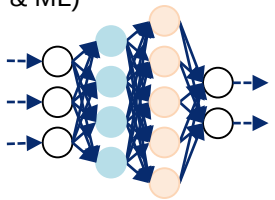
ARD.01 – IMPACT OF MACHINE LEARNING

We invite you to participate!

Task: gather information & best-practice examples with ARD-relevance from stakeholders

- **ARD Subtopics** (ST1, ST2, ST3, ST4)
- **MT-DMA**, MT-DTS
- **Center contacts**: M. Thévenet (DESY), R. J. Steinhagen (GSI), P. Schnizer (HZB), N. Hoffmann (HZDR), E. Bründermann (KIT)
- **Initiatives and Pilots** (*selection – no attempt to be complete*)
  - 2021-2023 Innovationspool **ACCLAIM** (coordinators: F. Gaede, DESY; M. Zepf, HIJ)
    - With stakeholders from ARD, DTS, DMA; centers involved: DESY, GSI, HIJ, HZB, HZDR, KIT
  - 2021-2023 Innovationspool **InnovEEA** (coordinator: S. Grohmann, KIT), ML-relevant sub-topic at KIT: load management.
    - Centers involved: DESY, GSI, HZB, KIT
  - 2020-2022 **Helmholtz AI** „**ML toward Autonomous Accelerators**“ (coordinator, PI: A. Eichler, DESY; PI: E. Bründermann, KIT)
- **Helmholtz Information & Data Science** (HAICU, HIFIS, HIDA, HIP, HMC, HDF, …)
- Research Field **Information**
- **ErUM-Data** activities (10-year BMBF-Aktionsplan published Nov 2020, 1. Call published June 4th: Software & Algorithms incl. AI & ML)

Activities: observe, collect, review & prepare evaluation of impact to complete milestone



- **Exploit synergies** – as much as possible
- Organization of & participation in workshops as needed
- Idea: establish modern collection-/link-site with one entry point for **ARD-relevant** ML usage to review
- *Toward Q4/2023*: ARD workshop “**Impact of ML on the ARD-research program**”, communicate results

Thanks for input by the center contacts, IP(s), Helmholtz AI, individuals, …

Courtesy: E. Bründermann

INNOVATION POOL – ACCLAIM

ACCELERATING SCIENCE WITH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Coordinators: M. Zepf (HIJ), F. Gaede (DESY)

Innovation Pool Project
01.01.2020 - 31.12.2023

Programs and Topics:
MT-DTS, MT-ARD, MT-DMA, MU

Participating Centers:
DESY, GSI, HIJ, HZB, HZDR, KIT

Total Budget:
551 kEUR/a + matching 197 kEUR/a

- **All WPs related to MT-ARD**
- **Work has started successfully,** hiring process concluded

WP1: AI-Methods for optimization of plasma accelerators and their laser systems (DESY, HIJ, HZDR, KIT)
- real-time feedback of laser parameter measurements
- AI assisted control of accelerator, diagnostic and detectors systems
- fast reconstruction of the governing system based on experimental diagnostics

WP2: Application of AI for the tuning and control of accelerators (DESY, GSI, HZB, KIT)
- fully automated setting of accelerator control parameters such as the injection rate
- application of ML to accelerator modelling, correction, control and startup
- RL agents for injection efficiency/orbit correction/beamline focus optimization

WP3: Machine Learning methods for anomaly detection (DESY, GSI, HZB, KIT)
- prediction and anomaly detection for accelerator measurements
- ML assisted root-cause analysis in case of accelerator failure
- AI assisted anomaly detection for failure forecasting and predictive maintenance

WP4: ML methods for efficient physics simulation (DESY, HZDR)
- application and improvement of generative networks to fast and realistic simulation of detectors responses
- simulations of laser and electron driver evolution in plasma-based accelerators by data-driven surrogate models
- explore the possibility of combining ML-simulations with Quantum computing

INNOVATION POOL – ACCLAIM - EXAMPLE

ACCELERATING SCIENCE WITH ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

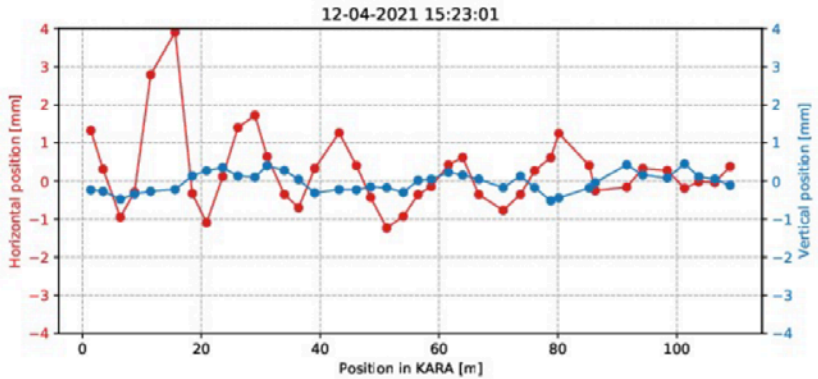
Coordinators: M. Zepf (HIJ), F. Gaede (DESY)

WP3: Machine detection and prediction of anomalies (DESY, GSI, HZB, KIT)

First efforts on BPM anomaly detection

Challenges:

- Only slow acquisition data available (1 Hz)
- Only 7 failures recorded since 2016
  - Data asymmetry



Next steps:

- Identify the different types of failures
- Build representative labeled dataset
- Simulations to complete data?
- Use supervised learning methods (forest)
- Clustering in parameter space instead of time series analysis?
- Autoencoder? (once the main patterns are identified, outliers are revealed)

Karlsruhe Institute of Technology

INNOVATION POOL – InnovEEA

INNOVATION POOL PROJECT FOR ENERGY EFFICIENT ACCELERATORS

- **Participating centers:** DESY, GSI, HZB, KIT
  - Project coordination: Steffen Grohmann, KIT
- **Goals**
  - Improve energy efficiency and environmental impact
  - Reduce effort of accelerator operation
- **Focus:** Energy-efficient cryogenics, SRF and hybrid magnet technologies, flexible load management with AI
- **Relevance**
  - Answers to societal challenges
  - Respond to MT review recommendation: energy-efficient R&D for future technical infrastructures and accelerator projects
- **Education:** Engagement of junior researchers from M.Sc. to Ph.D.
- **Duration:** 3 years
- **Total Costs:** 430 k€ p.a. (405 k€ p.a. for personnel)
  - **Funded by IP:** 345 k€ p.a. (330 k€ p.a. for personnel)

INNOVATION POOL – InnovEEA

INNOVATION POOL PROJECT FOR ENERGY EFFICIENT ACCELERATORS

Implementation and objectives

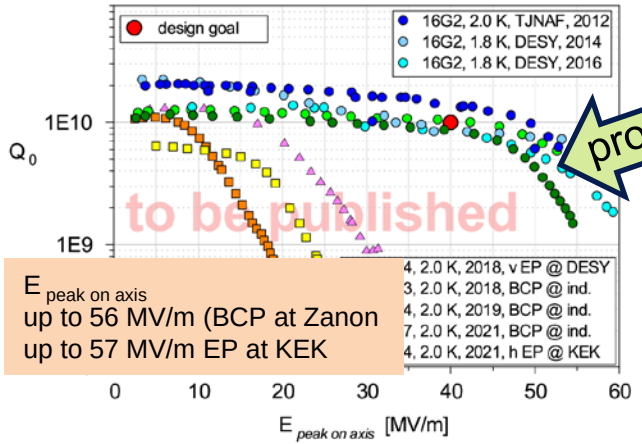
- New technical solutions, incl. mixed refrigerant cycles
- New superconductor treatments and SRF cavity cooling concepts
- Design of hybrid magnets:
  permanent magnet dipole-quadrupoles, high-gradient multipoles
- AI for new and optimized operating methods of components and acc.
  Development of synergies with FB Energie (Energy Lab 2.0 at KIT)
- Data from BESSY, FAIR and XFEL
- ARD accelerator test facility with sensor network:
  Karlsruhe Research Accelerator (KARA)
- **Vision:** Energy-efficient, “turn-key” magnet systems
  and CW SRF accelerator modules

Work packages

- Cryogenics
- SRF technology
- Magnet technology
- Load management

SRF gun development at three centers

Cavity performance progress @ DESY



$E_{peak\ on\ axis}$
up to 56 MV/m (BCP at Zanon
up to 57 MV/m EP at KEK

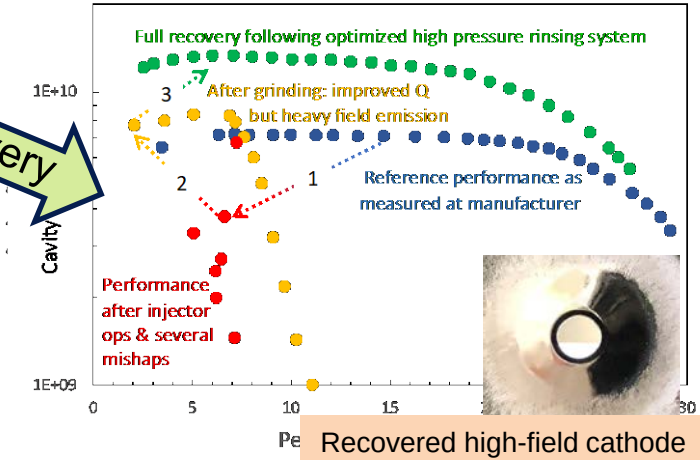
processing

SRF Gun Cavities

operation

recovery

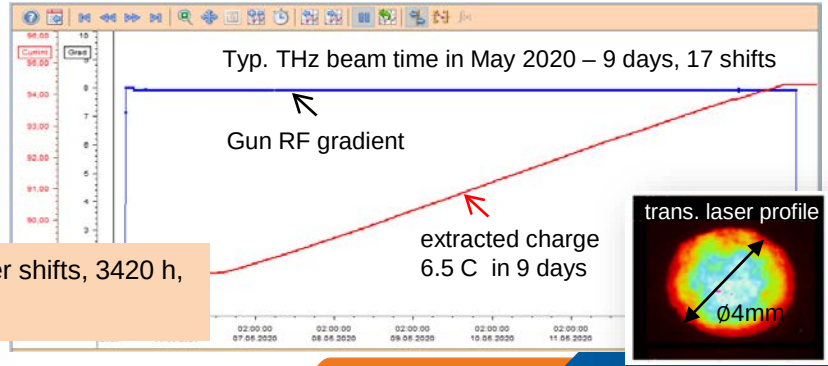
damage recovery of SRF Photoinjector @ HZB



Recovered high-field cathode region after scratch removal

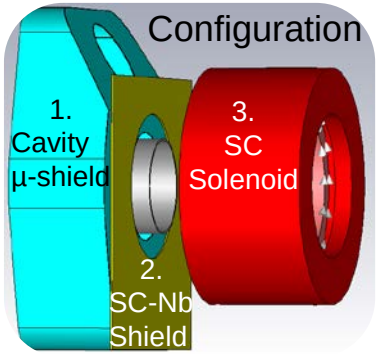
Complete gun system in operation @ HZDR

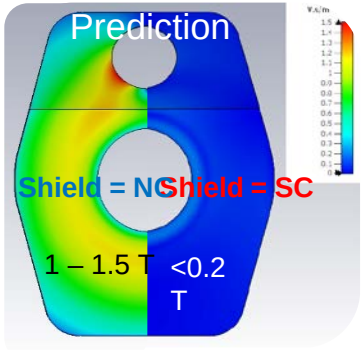
2019-05.2021: 280 user shifts, 3420 h,
25% ELBE beam time



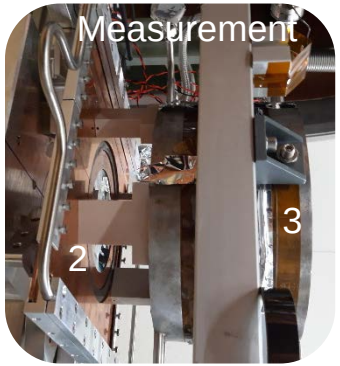
ST1 – SCIENCE

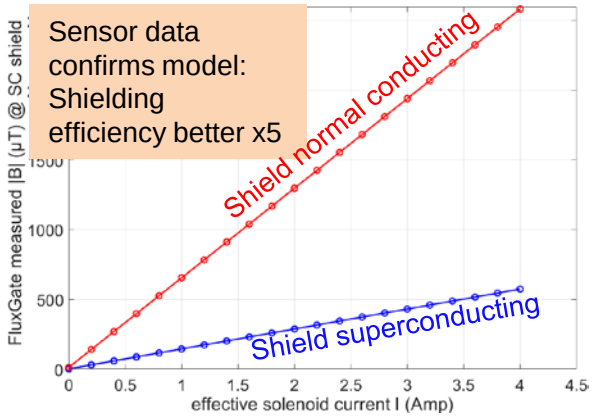
Development of new SC-Nb shield to prevent saturation of cavity µ-shield by solenoid field @ HZB



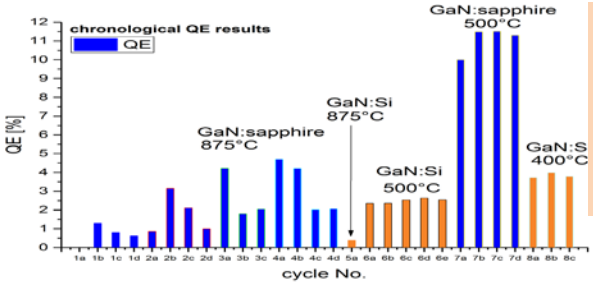


Flux density in cavity shield





Study on new photocathode: GaN(Cs)@ HZDR



GaN:sapphire reached
11% QE @310nm, life time 1 months

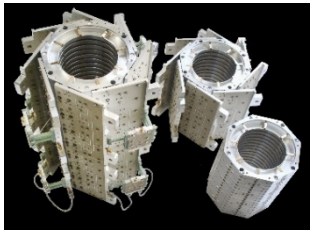
Next:
study GaN on metal cathode
(cooperation with Uni Siegen)

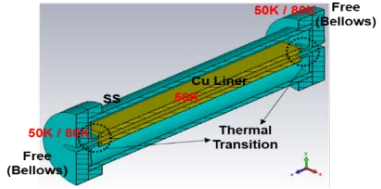
New SRF gun for LCLS-II-HE project
(cooperation SLAC-FRIB-HZDR-ANL)

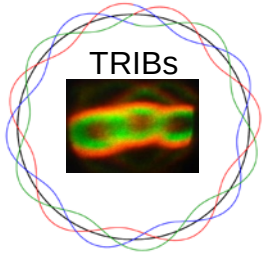
ST2 – CONCEPTS & PROTOTYPES FOR MAXIMUM PERFORMANCE

- Enhanced beam intensities, beam qualities and efficiency

World-record ramped SC magnets	Slot-ring coupler for stochastic cooling	High temperature Superconductors	Vacuum chamber and cryo-tests	Bunch separation at BESSY II/III

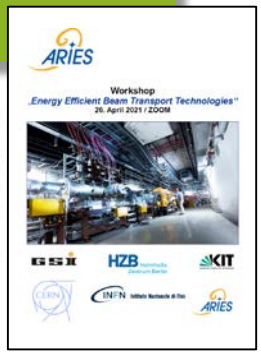






- Develop superconducting fast-ramped, low-loss magnets
  → *design review **2024***
  and cable technologies for highest efficiencies
- Push the intensity, quality and efficiency frontier with prototypes and experiments
  → *assessment of limits and options to improve **2024***
- Enable novel and efficient operation modes for storage rings
  → *summary and evaluation of progress in **2026***

Sustainable, energy efficient applications
- energy storage
- power transmission lines
- reduced environmental footprint

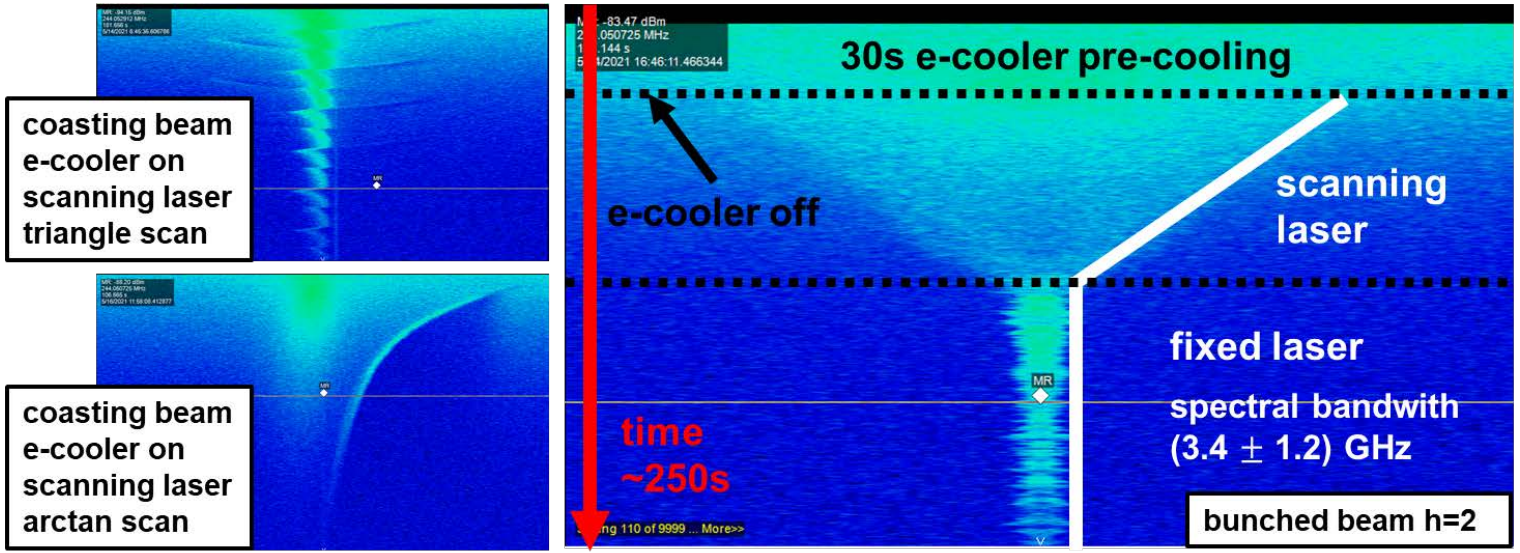


See also MS ARD.00, pilot InnovEEA
Synergy: ARIES Workshop, 26 Apr 21
https://indico.gsi.de/event/11642/

GSI, HZB, KIT

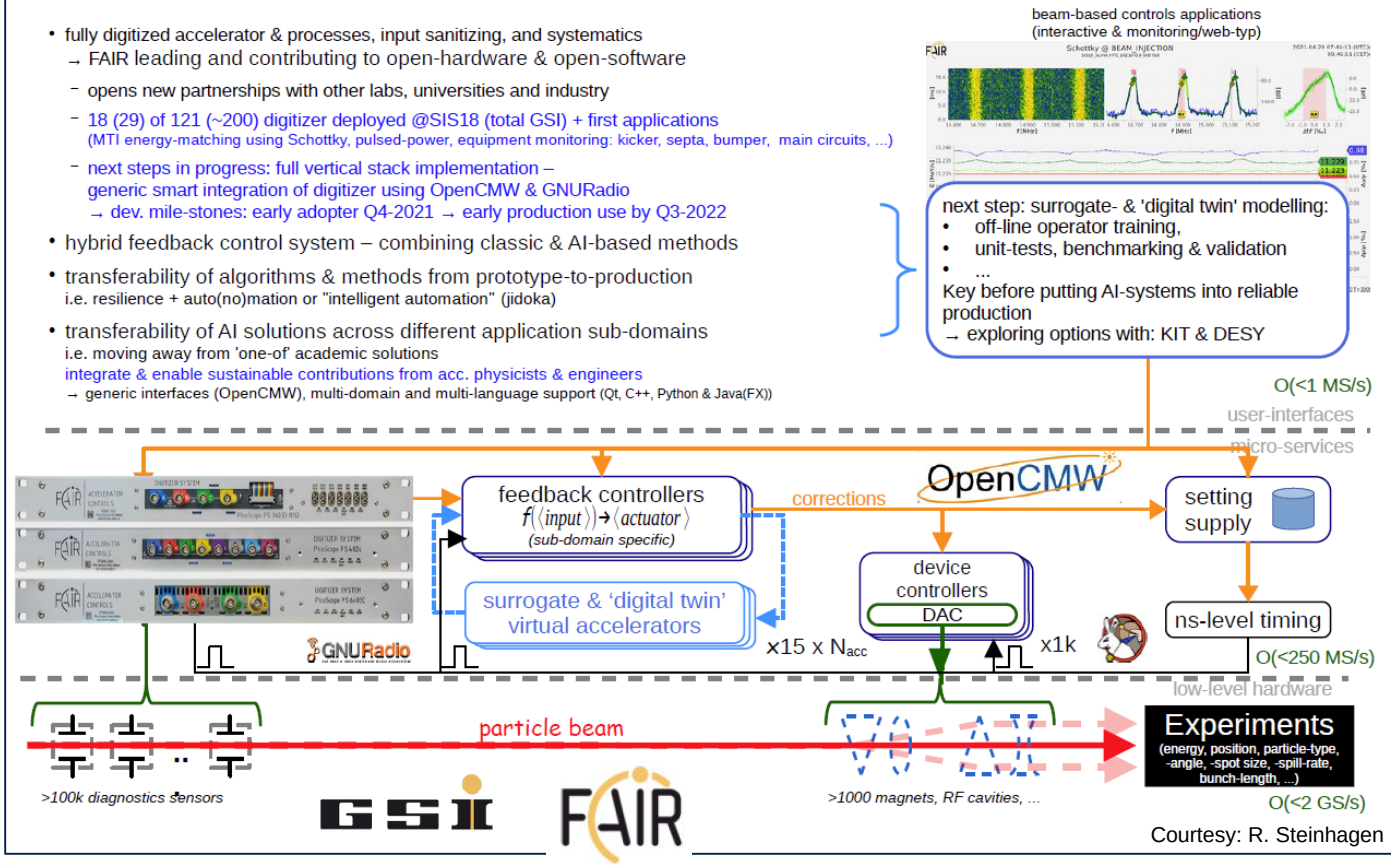
ST2 – Broadband laser cooling @ ESR 2021

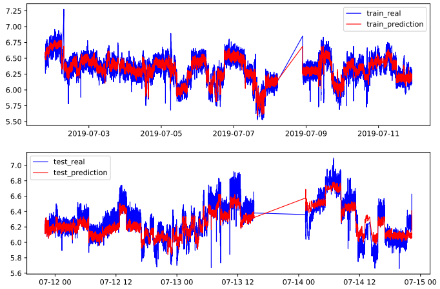
- C^{3+} test beamtime May 2021 @ ESR
  - **First broadband laser cooling** of a stored relativistic ion beam using a **novel pulsed high rep.-rate (~10 MHz) UV laser system**, tuneable **bandwith (3.4 up to 36 GHz)**



ST2 – DIGITIZATION, INTEGRATION AND ADVANCED BEAM CONTROL

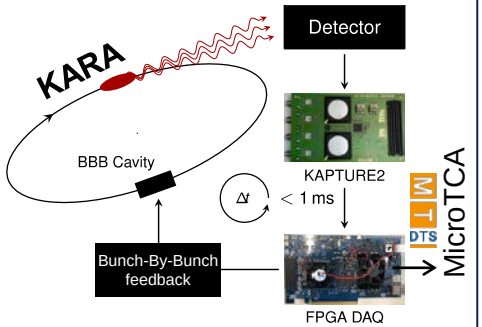
- fully digitized accelerator & processes, input sanitizing, and systematics
  → FAIR leading and contributing to open-hardware & open-software
  - opens new partnerships with other labs, universities and industry
  - 18 (29) of 121 (~200) digitizer deployed @SIS18 (total GSI) + first applications
    (MTI energy-matching using Schottky, pulsed-power, equipment monitoring: kicker, septa, bumper, main circuits, ...)
  - next steps in progress: full vertical stack implementation –
    generic smart integration of digitizer using OpenCMW & GNURadio
    → dev. mile-stones: early adopter Q4-2021 → early production use by Q3-2022
- hybrid feedback control system – combining classic & AI-based methods
- transferability of algorithms & methods from prototype-to-production
  i.e. resilience + auto(no)mation or "intelligent automation" (jidoka)
- transferability of AI solutions across different application sub-domains
  i.e. moving away from 'one-of' academic solutions
  integrate & enable sustainable contributions from acc. physicists & engineers
  → generic interfaces (OpenCMW), multi-domain and multi-language support (Qt, C++, Python & Java(FX))





Measurement Prediction (BESSY Archiver data)
See L. Vera Ramırez
ACCLAIM Kick-Off 15 Jan 21

HZB Helmholtz Zentrum Berlin

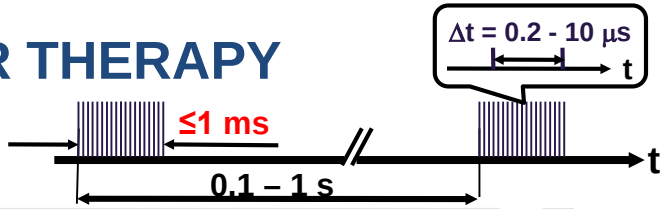


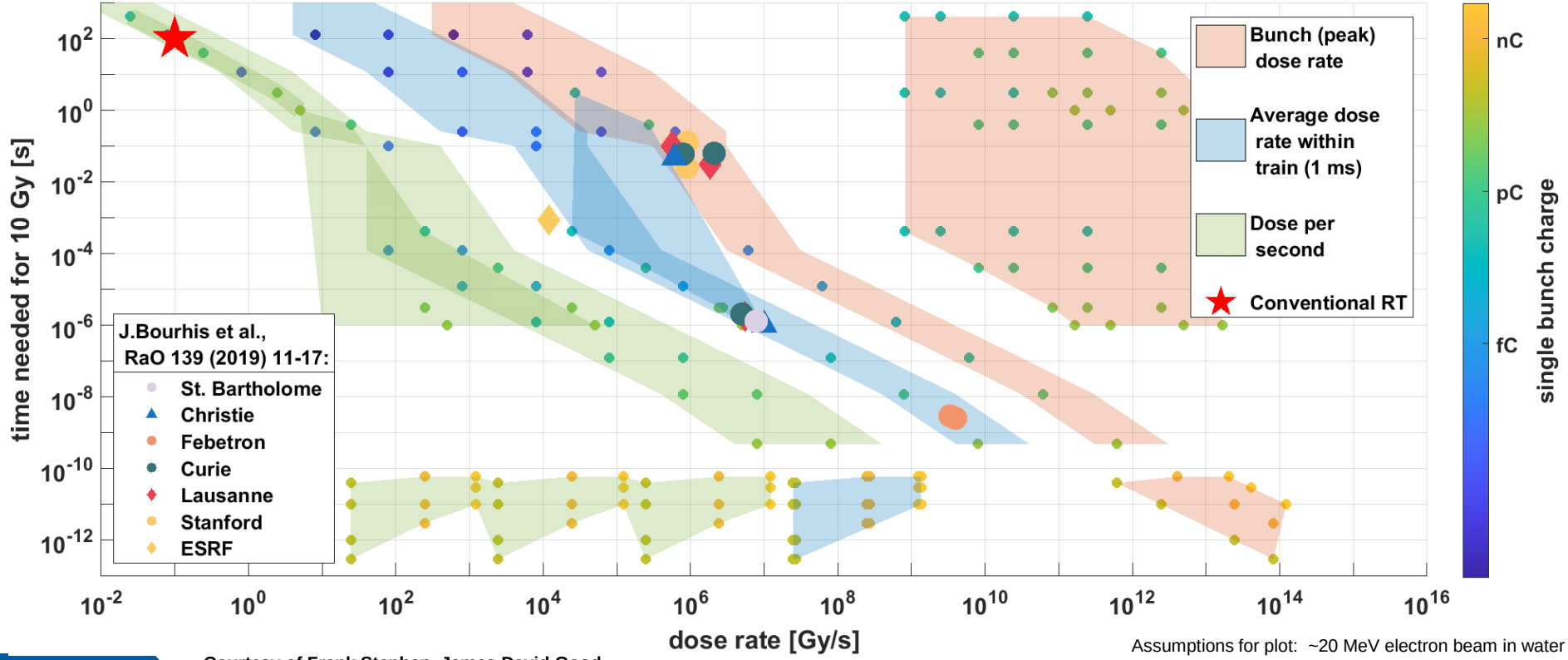
Fast feedback for real-time optimization of accelerators with Reinforcement Learning
See A. Santamaria Garcia
MT Days 3 Feb 21

KIT Karlsruhe Institute of Technology

NEWS – PITZ WILL OFFER R&D FOR CANCER THERAPY

- **Uniquely wide beam parameter space** available at PITZ, even far beyond current state-of-the-art FLASH therapy





Courtesy of Frank Stephan, James David Good, Marie-Catherine Vozenin, Jean-Francois Germond

Assumptions for plot: ~20 MeV electron beam in water with **1mm³** irradiation volume.

ST3 – SCIENCE POF-3

A hub to DTS and connecting Sub-Topics

Control of extreme beams

Dynamics code
micro-bunching instabilities

XUV seeding
nm

Diagnostic rates
Frames/second

Synchronization
in accelerators
fs

Time-resolved
fs

DESY, HZB, HZDR, KIT

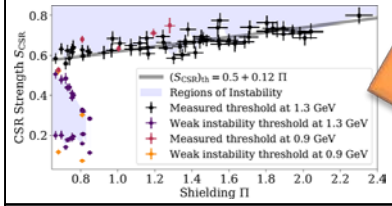
Beam Dynamics and Diagnostics

Micro-bunching instability

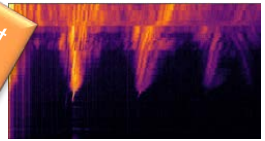
- From THz signal to MBI fingerprint in seconds

KAPTURE-1 KAPTURE-2

M. Brosi et al. IPAC'21



Snapshot Method @ KARA



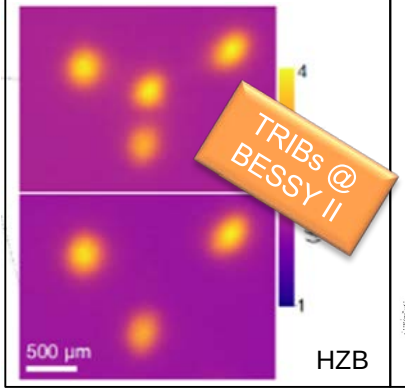
KIT

Test facilities

FLUTE @ KIT

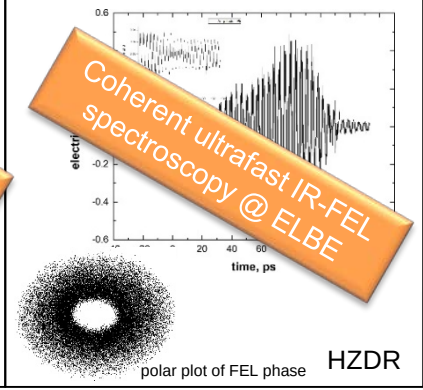
ARES @ DESY

From ST3 R&D to User Modes



TRIBs @ BESSY II

HZB



Coherent ultrafast IR-FEL spectroscopy @ ELBE

HZDR

Technology Transfer Worldwide - Controls

MicroTCA.4 – more than 70 user groups

ST3 – SCIENCE POF-4 ADVANCED BEAM CONTROL, DIAGNOSTICS & DYNAMICS

Heart beat of Matter – Faster, more throughput, at highest precision - a hub to DTS and DMA

Control of extreme beams at the forefront of technology

Helmholtz AI
Autonomous Accelerator

2021 → 2027

+ (AI) Artificial Intelligence

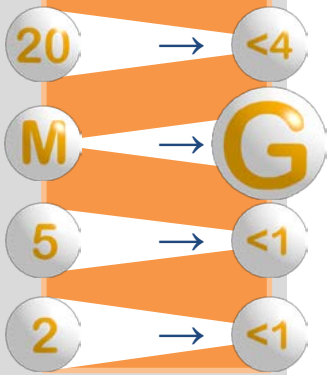
Dynamics code
micro-bunching instabilities

XUV seeding
nm

Diagnostic rates
Frames/second

Synchronization
in accelerators
fs

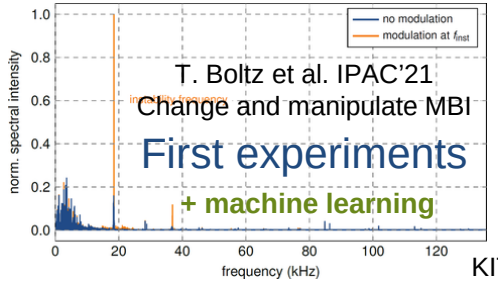
Time-resolved
fs



Attosecond metrology
Advanced beam control

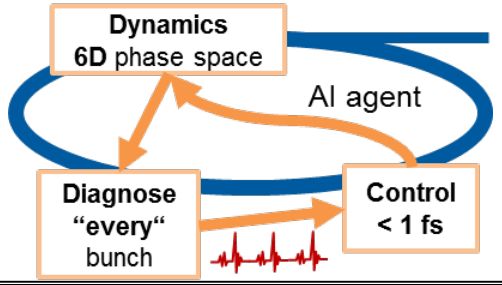
Save-the-Date

Micro-bunching instability (MBI)

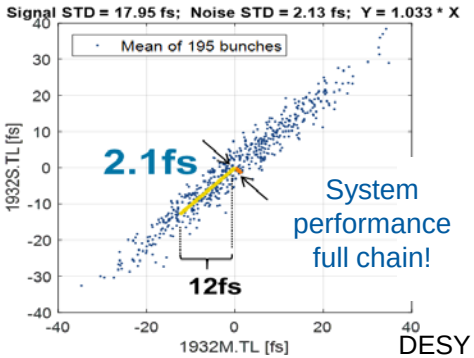


KIT

Vision: Custom & Extreme Beams

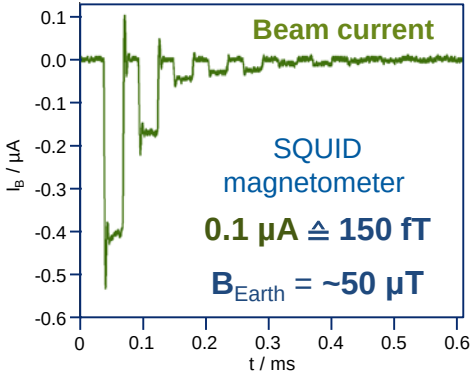


EuXFEL largest optical synchronization worldwide



DESY

Measurement of cryogenic beam current at CRYRING



GSI

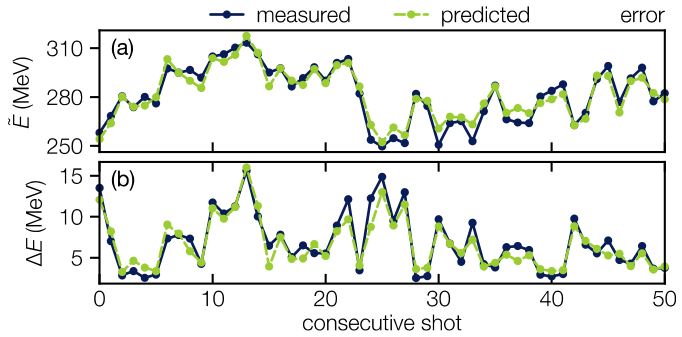
Extreme dynamic range

DESY, HZB, HZDR, GSI, KIT

ST4 – FROM PLASMA ACCELERATION TO ACCELERATORS

Advanced online diagnostics and Machine Learning improve performance

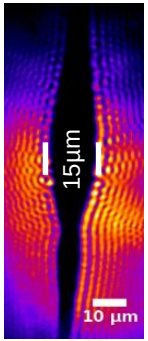
ML-based surrogate model of LPA experiment

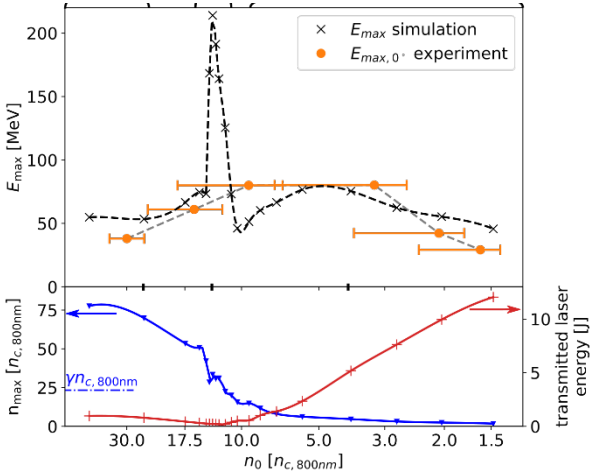


- Data from laser-plasma accelerator trains a surrogate model and enables single-shot predictive modeling
- Bayesian optimization enables sub-percent energy spread

M. Kirchen et al., PRL 126, 174801 (2021)
S. Jalas et al., PRL 126, 104801 (2021)

Density scan controlled proton acceleration





- On-shot plasma expansion monitoring and control enables quantitative modeling and identification of magnetic vortex acceleration to beyond 80 MeV proton energies with rep-rate capability

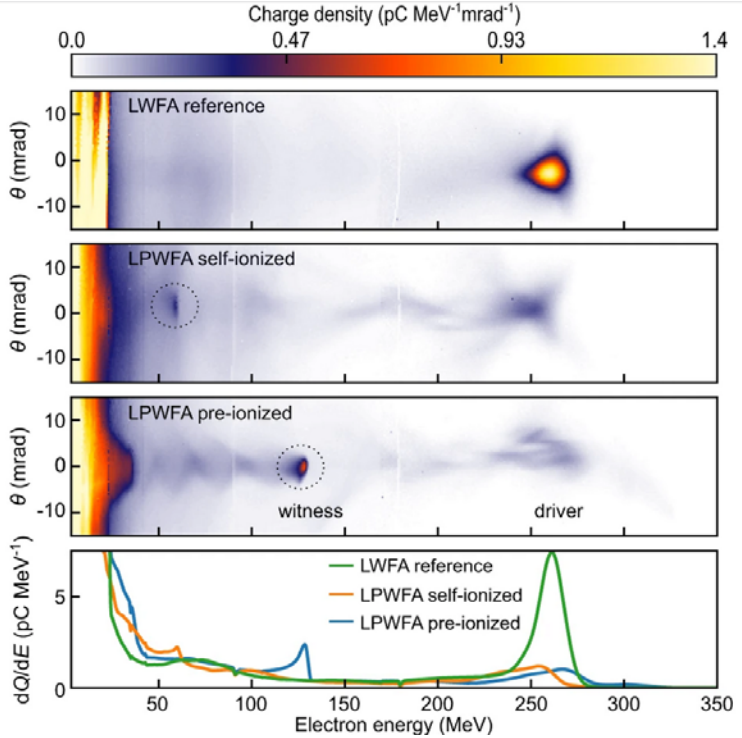
M. Rehwald et al., in submission (2021)

ST4 – APPLICATIONS OF LASER PLASMA ACCELERATORS

Compact LWFA driven PWFA development platform

- LWFA accelerated elctron bunches with extreme peak currents beyond 10 kA are employed to drive a PWFA stage
- Controlled injection (density down ramp and others, not shown) in the second stage aims for improved beam quality
- Acceleration gradients of 120 GV / m measured

T. Kurz et al., Nature Communications 12, 2895 (2021)



ErUM-DATA

- **Call for proposals – for ErUM-Data cross-community projects – published!**
- Proposal for **ErUM-Data-Hub** in preparation by editorial team of the ErUM communities.

Screenshot June 2021:
pt.desy.de/bekanntmachungen/12052021___data/index_ger.html

- ErUM-Data project proposals
- 2-step process
- Deadline: September 1, 2021

Call for proposals – published June 4th
Software & Algorithms (AI & ML)

June 24th ErUM-Data information meeting

www.beschleunigerphysik.de/de/kfb/

ErUM-DATA

- Deadline for first drafts of applications 01.09.2021
- Funding from 01.07.2022 on

- Topics “Software and Algorithms” with Focus AI & MLS

- “Verbundforschung” = Universities, Research Centres, Industry
- Collaborations between different communities (SR, HEP, Hadrons, n, Astronomy, Observatories, …)
- Development of transferable Tools – no local/isolated solutions

ErUM CALL 2021

KOMITEE FÜR BESCHLEUNIGER-PHYSIK KfB

Research of matter with large-scale facilities (photons, neutrons, ions)
Every three years, usual schedule: strategy meeting BMBF/KfB in May, call in September 2021,
KfB workshop in September 2021, deadline for proposals November 1, funding July 1 2022

Survey of hot accelerator-related topics

A) Related to existing facilities

General: superconducting RF, stabilty, energy efficiency, diagnostics, simulation, machine learning ...

Synchrotron light sources: longitudinal/transverse dynamics, short pulses, undulators (superconducting, in-vacuum) ...

Free-electron lasers: injectors with high repetition rate, seeding, synchronization, diagnostics of short bunches and pulses ...

B) Related to future "conventional" facilities

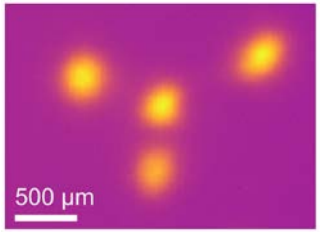
General: compact facilities (e.g. neutron sources) and components ...

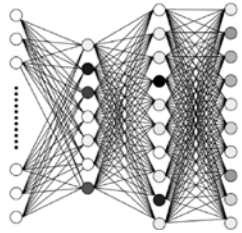
Photon sources: multi-bend achromats (BESSY III, PETRA IV), ERLs, terahertz sources (DALI) ...

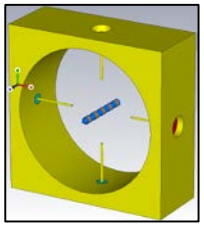
C) Related to "advanced" accelerators

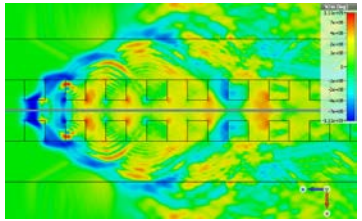
Laser-plasma: hybrid concepts, injection into conventional rings ...

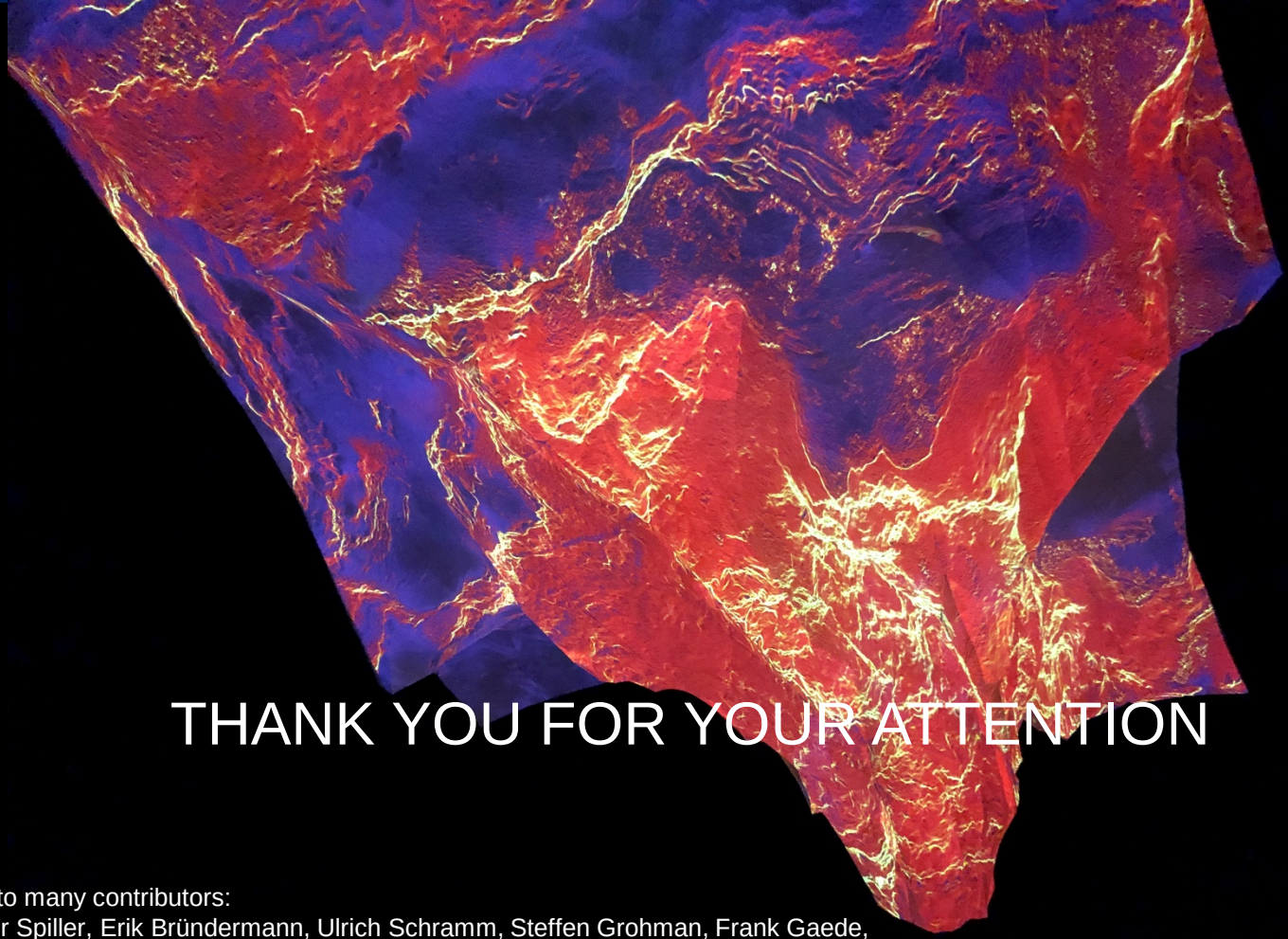
Dielectric accelerators: higher energy (MeV, GeV) ...











THANK YOU FOR YOUR ATTENTION

And many thanks to many contributors:
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