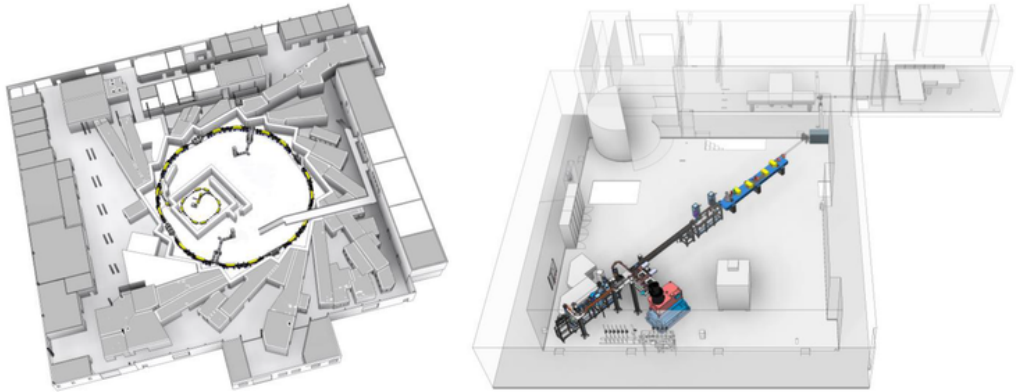
Karlsruhe Institute of Technology

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Introduction of KIT and plans for ACCLAIM

Andrea Santamaría García, Michele Caselle, Erik Bründermann, Andreas Kopmann, Anke-Susanne Müller

ACCLAIM Kick-off Meeting (15-01-2021)



Who we are

Andrea Santamaria Garcia
Research Associate
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Michele Caselle
Group leader of Beam Diagnostics
Institute of Data Processing and Electronics (IPE)

Erik Bründermann
Head of Department: Accelerator Research and Development + Operations II
Institute for Beam Physics and Technology (IBPT)

Andreas Kopmann
Head of Data Processing group
Institute of Data Processing and Electronics (IPE)

We are hiring! 1 Postdoc + 1 PhD from ACCLAIM funds

Status

Machine learning projects at KIT

Already presented in detail at the AMALEA final meeting

FINISHED

Bayesian optimization of the injection efficiency

Master thesis by Chenran Xu finished

ONGOING

Control of the micro-bunching instability with Reinforcement Learning

PhD by Weijia Wang finished
PhD by Tobias Boltz finishing this year

STARTING

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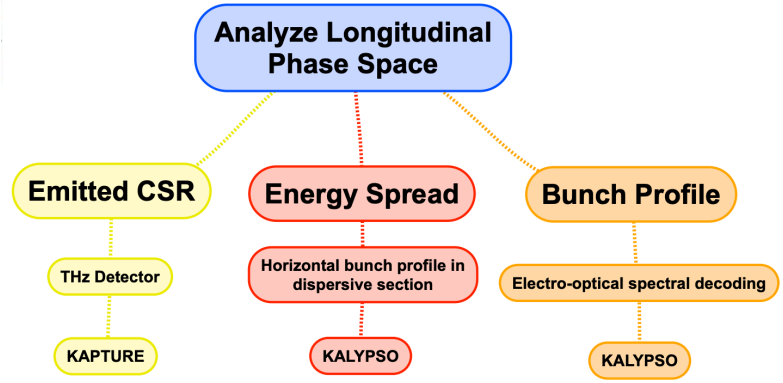
Machine Learning toward autonomous accelerators

PhD by Chenran Xu started

Karlsruhe Research Accelerator (KARA)

- **50 days of machine physics per year**
- Large database of accelerator data ready to use
- Use of the existing technology:
  - BPMs
  - Bunch-by-bunch feedback system (kicker cavity)
  - Detectors:



ACCLAIM - Plans for this year

WP1: AI methods for real-time optimization of plasma accelerators and their laser systems

Vision

- System solutions for (laser) plasma accelerators and/or its components (e.g., laser)
- Lasers toward 1 kHz, plasma accelerators overall toward 10 Hz
- From operator control to AI control

First year plan

- Define requirements with partners operating plasma laser accelerators
- Build on existing technology to progress on AI algorithms for detection, feedback and control
  - Integral signals/events from (non-)commercial detectors with fast DAQ (oscilloscope-mode e.g. KAPTURE)
  - Spectral information e.g. from driving lasers/electro-optics (spectrometer-mode e.g. KALYPSO)

What we offer/do

WP1: AI methods for real-time optimization of plasma accelerators and their laser systems

Sub-µs timescales

Diagnostics for highly repetitive signals

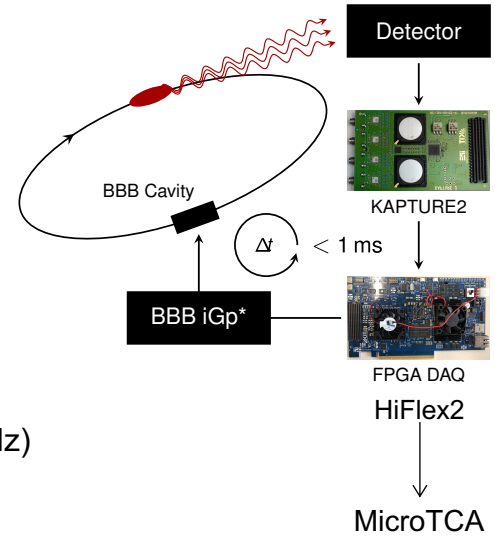
- Events/Pulses: 500 MHz
- Spectra: 2.7 MHz

Sub-ms timescales

Closed feedback loop at KARA using AI for beam control

- Detection of signals with THz detectors and KAPTURE
- FPGA + AI in progress
- First tests done in the accelerator
- Goal: total latency of control feedback loop < 1ms

More on the next slide



Sub-s timescales (overall performance)

AI-methods for accelerators being developed at FLUTE (driving lasers up to 1 kHz)

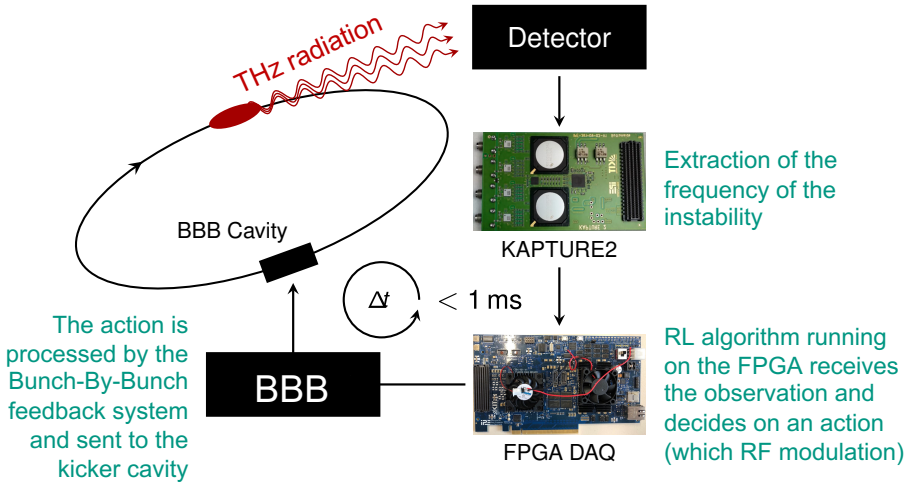
Micro-TCA environment

- e.g. laser synchronization in time to external slow signal (RF)

Collaboration with centers operating plasma accelerators

Example: Machine learning and hardware

Fast feedback for real-time optimization of accelerators applied to the control of the micro-bunching instability with Reinforcement Learning



Edmund Blomley, Tobias Boltz, Miriam Brosi, Michele Caselle, Timo Dritschler, Melvin Klein, Christoph Pohl, Weijia Wang

T. Boltz, W. Wang et al, TUCPL06, ICALEPCS 2019

Achieved:

- RL framework developed on HighFlex 2 → **easy deployment of ML algorithms on an FPGA**
- The DDPG algorithm was tested with a **very low latency of 17 µs** in the scope of a PhD thesis

New PhD position open! (2021- 2024).
Contact: Michele Caselle

First steps at real-time control of physical processes with ML

As reported in AMALEA

Example: Machine learning and hardware

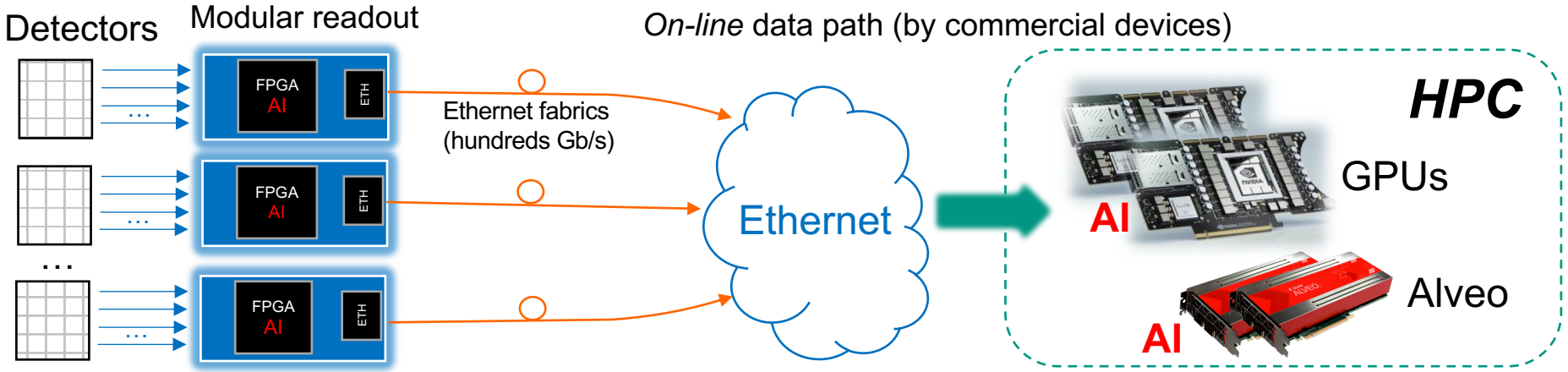
Novel heterogenous FPGA – GPU architecture
High-performance distributed ML for physics experiments

Integration of more than one sensor possible!

Contact: Michele Caselle

Key technologies:

- Development of hardware DAQ optimized for detector and AI applications
- Development of high-performance ML inference on modern programmable hardware platform (Versal)
- Novel heterogenous FPGA-GPU architecture based on emerging ethernet protocols

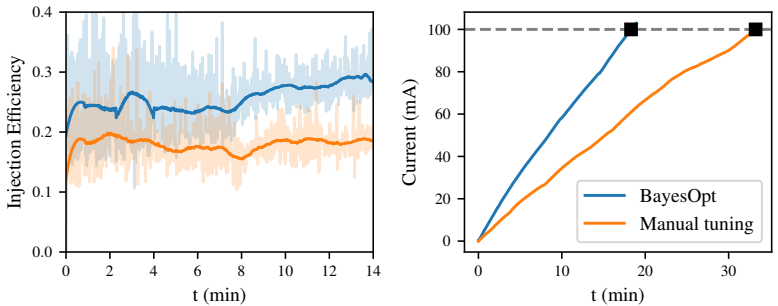


ACCLAIM - Plans for this year

WP2: Applications of AI to accelerator tuning and control (DESY, GSI, HZB, KIT)

Continuation of the injection efficiency optimization project at KARA

- Extension of the algorithm to the injectors and transfer line
- Application of other methods for this problem such as RL (like in HZB)



Courtesy of Chenran Xu

Orbit feedback

- Study of the effects of temperature on the beam orbit and replicate this correlation with a NN
- This can be extended to the effect on temperature on the RF cavities to mitigate the coupled bunch instability during injection
- Explore the feasibility of a real-time orbit correction system

ACCLAIM - Plans for this year

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

The goal is to discover correlations between parameters of the accelerator that would help to:

Detect equipment failure faster and eventually predict the failure

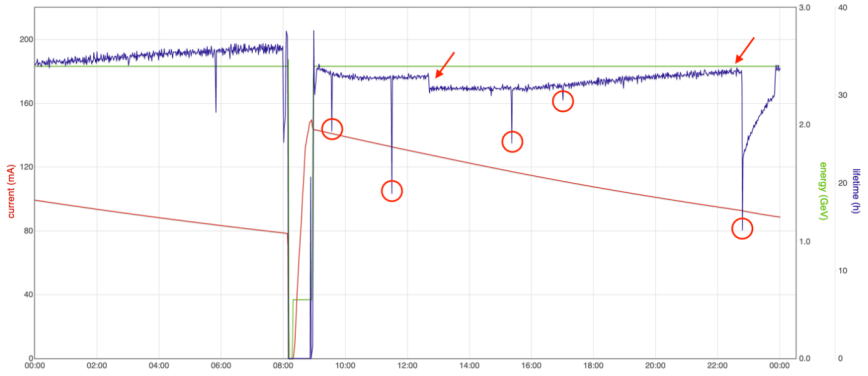
- BPM malfunction
- Magnet corrector failure

→ False orbit jumps

(HZB already worked with beam orbit + ML)

Explain beam behavior that is unaccounted for

- Lifetime drops with stable current



Methods

- Random Forest decision trees
- Orthogonal Matching Pursuit (OMP)
- Multi-layer Neural Network to classify if the orbit jump is real or false.
- Outlier detection via clustering methods (DBSCAN, etc)
- Other means of outlier detection

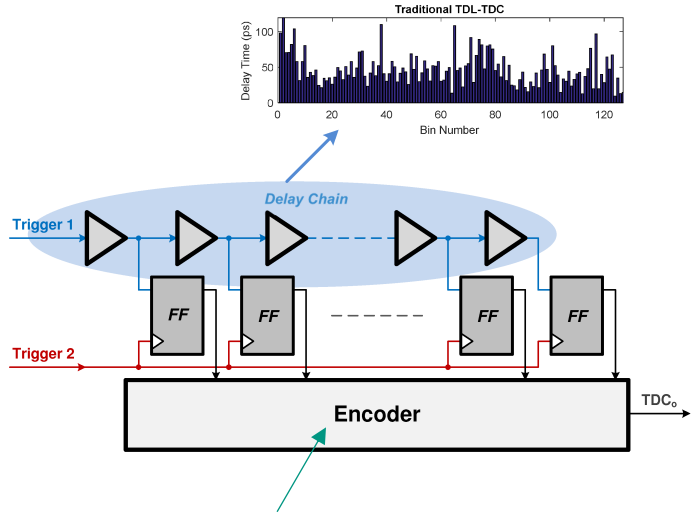
Looking forward to taking part in ACCLAIM!

Novel generation of Time-to-Digital Converter (TDC)

High precision TDC based on Machine Learning

- **Introduction:** TDCs are widely used in high-energy physics and other applications that require precise time measurements of picosecond level, typically
- **Motivation:** TDC are affected by several multi-dimensional and non-uniform size of the bins, which are strongly dominated by the internal time propagations of the signals
- **Goal**: Development a novel architecture of TDC where ML are deployed on FPGA for a real-time correction of non-linear and multi-dimensional bins size
- **Target applications**: for picosecond time measurements

Internal routing and propagation delays of the components



Replace the classical encoder and calibration stages by ML on FPGA