HELMHOLTZ AI
Artificial Intelligence Cooperation Unit

HZDR
HELMHOLTZ ZENTRUM
DRESDEN ROSSENDORF

# Virtual Pulse Reconstruction Diagnostic for Single-Shot Measurement of Free Electron Laser Radiation Power

Till Korten, Vladimir Rybnikov, Peter Steinbach, Mathias Vogt, Juliane Roensch-Schulenburg and Najmeh Mirian*
Helmholtz-Zentrum Dresden-Rossendorf HZDR, 01328 Dresden Germany
Deutsches Elektronen-Synchrotron, DESY, 22607 Hamburg, Germany

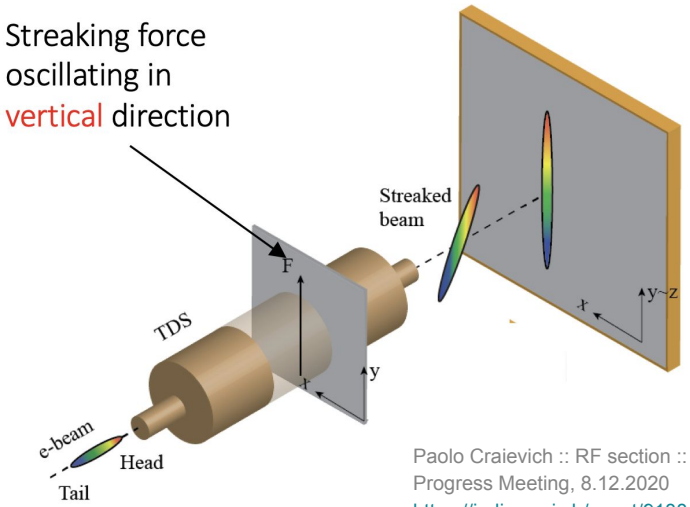
# Outline

- Transverse Deflecting Cavities and Their Applications in Accelerator Facilities
- FLASH X-Band TDS : PolariX
- FEL Pulse Power Reconstruction Tool at FLASH
- FEL Pulse Power Online Measurement
  - First-Order-Based Online Measurement
  - Machine Learning Based Online Measurement

# ❖ Transverse Deflecting Cavities

## TDS as a diagnostic tool as high-resolution time-resolved diagnostics

horizontal dimension (x)
vs z is characterized




The longitudinal distribution of the e-bunch is mapped into the transverse one, thanks to the time dependent **transversely deflecting field.**

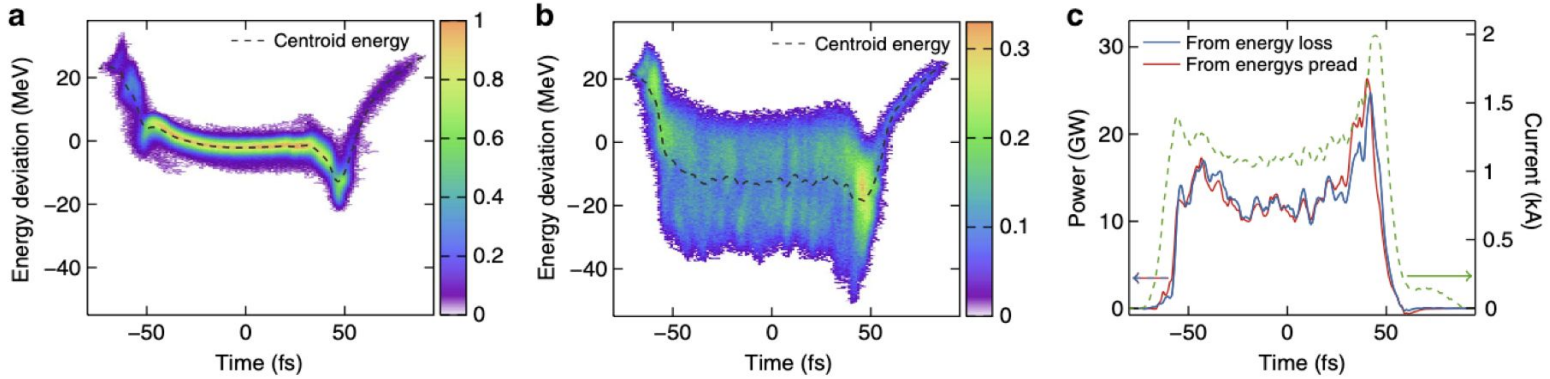
Paolo Craievich :: RF section :: Paul Scherrer Institut, SwissFEL Progress Meeting, 8.12.2020
https://indico.psi.ch/event/9188/contributions/25390/attachments/17747/26796/20201208_PolairX%20TDS%20CO84.pdf

# ❖ Transverse Deflecting Cavitie Applications in Accelerator Facilities

- ❑ Longitudinal current profile measurement
- ❑ slice emittance can be measured with Quadrupole.
- ❑ Slice energy spread measurement with Dipole
- ❑ FEL pulse reconstruction and FEL tuning

# FEL pulse reconstruction

– Measure of the FEL-induced lasing effects imprinted on the electron beam longitudinal phase space: C. Behrens et al., Nat. Communications 5, 3762 (2014)



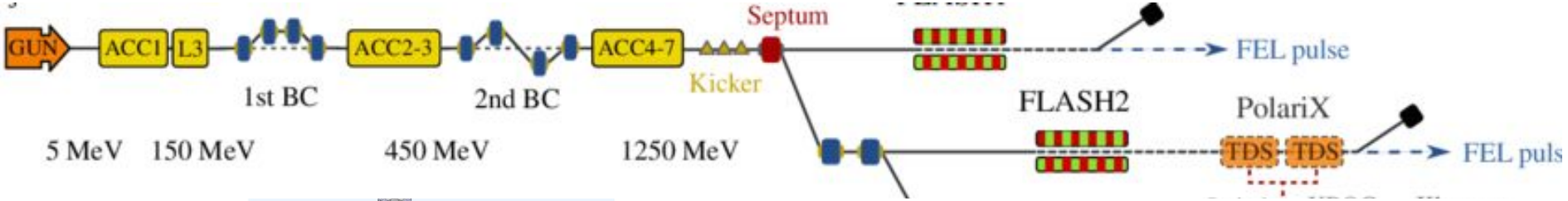

$$P(t) = \Delta E(t) I(t)/e,$$

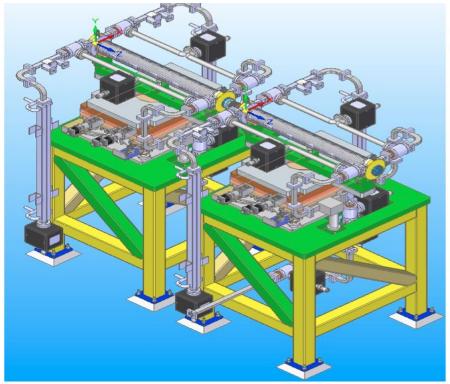
slice energy loss due to lasing

# FLASH X-Band TDS : PolariX

Variable polarization X-band structure (PolariX TDS) downstream of the FLASH2 undulatator

lators.



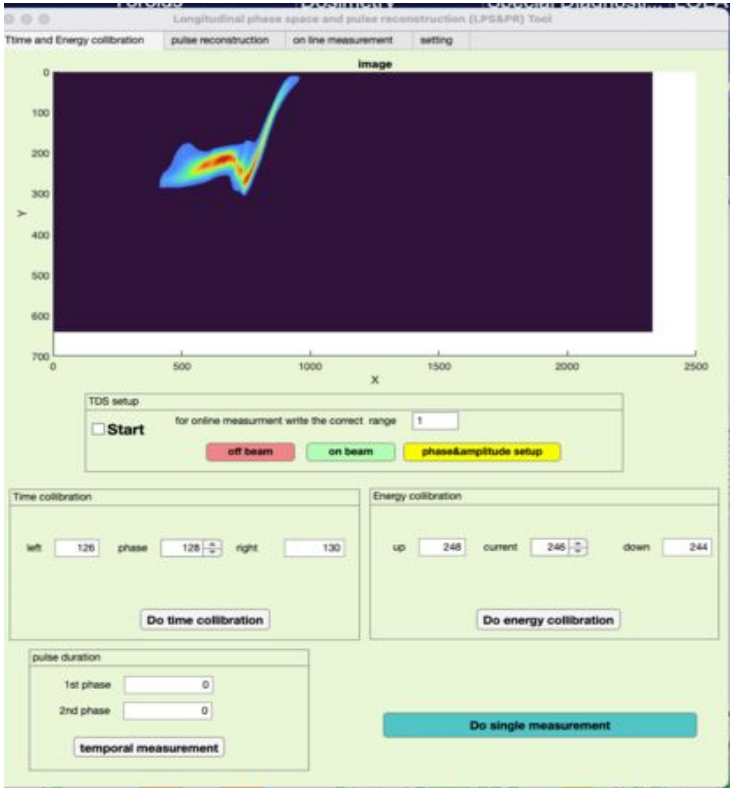



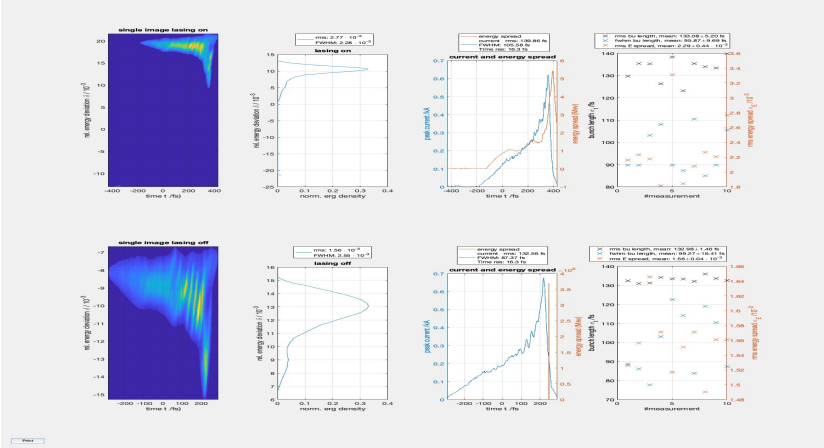
F. Christie, et al. "Apolarix TDS for the FLASH2 beamline".

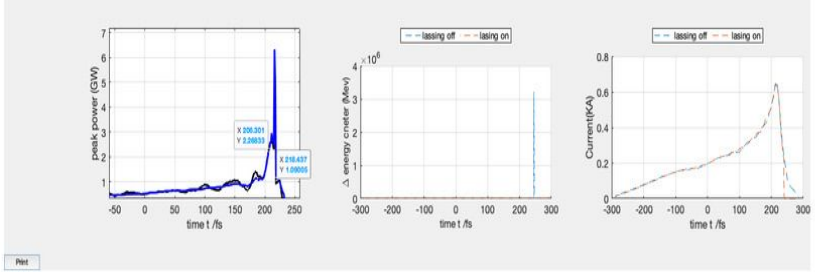
Figure 1: Technical drawing of the supports for the two PolariX TDSs at FLASH2. Courtesy of M. Föse.

# FEL Pulse Power Reconstruction Tool at FLASH

Average of a few shots lasing off and on




New measurement tool in FLASH main taskbar

# FEL Pulse Power Online Measurement

## Challenges of average method:

- It is not shot to shot
- It is not on-line measurement
- Instability is an issue in this method.
- After collecting lasing off data the machine can lose their previous status.

## Solutions:

➔ First order : Mean of several lasing-off shots

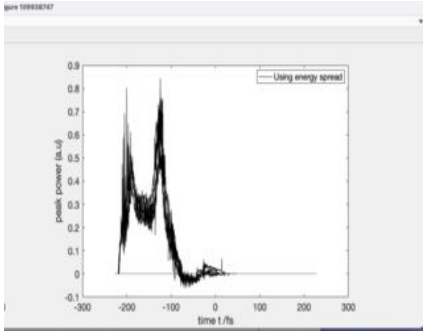
➔ Accurate model: Machine learning model

# First-Order-Based Online Measurement

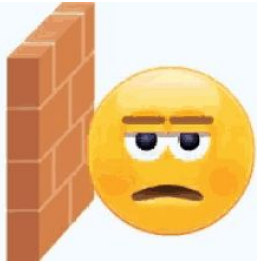
Slice analysing,
gaussian fighting for each pixel
This program is able to show

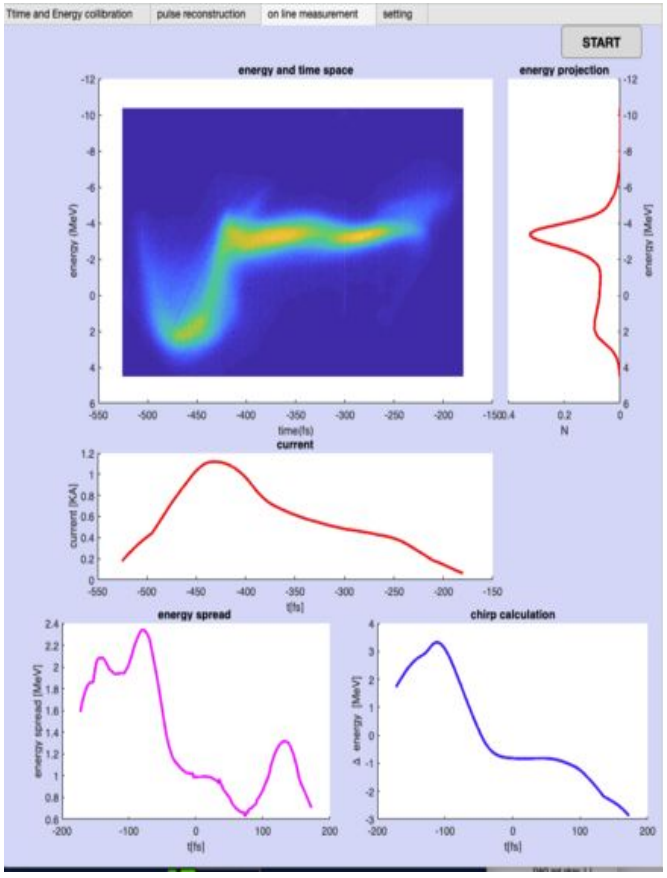
- energy spread,
- Slice energy profile
- Current profile
- Energy chirp
- FEL pulse profile

Pulse power reconstruction




This is not accurate





# Machine Learning Based Online Measurement

Providing accurate and accessible diagnoses is a fundamental challenge

- Simulation based Machine learning → low accuracy, no reproducible
- Algorithm based machine learning → required precise algorithm
- Experimental based machine learning → time consuming

>> **We are using machine learning models for stable machine**

# Machine Learning Based Online Measurement



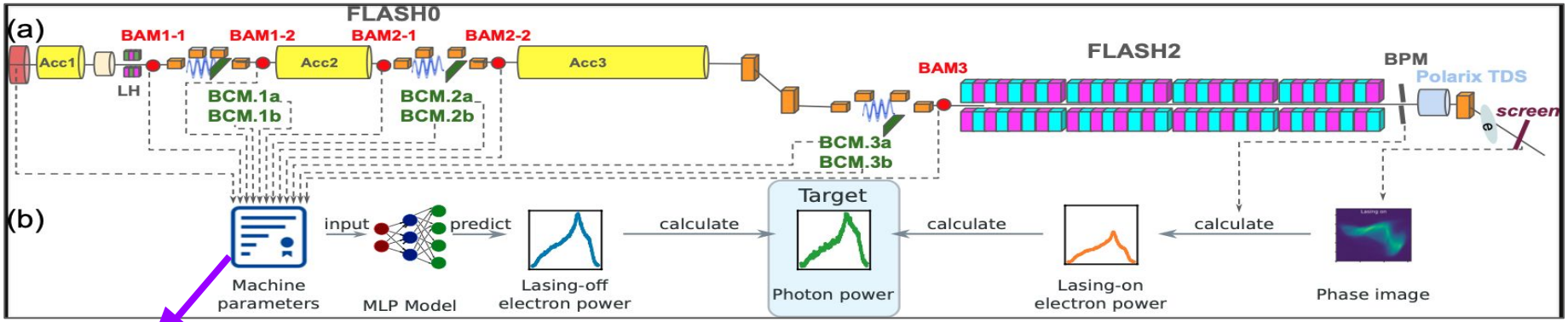
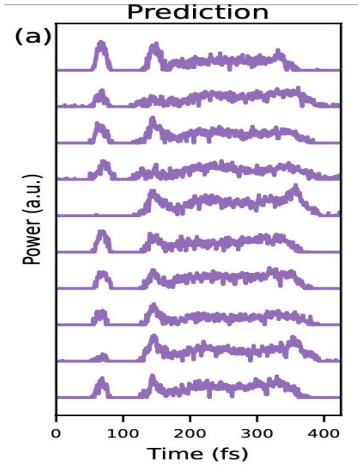


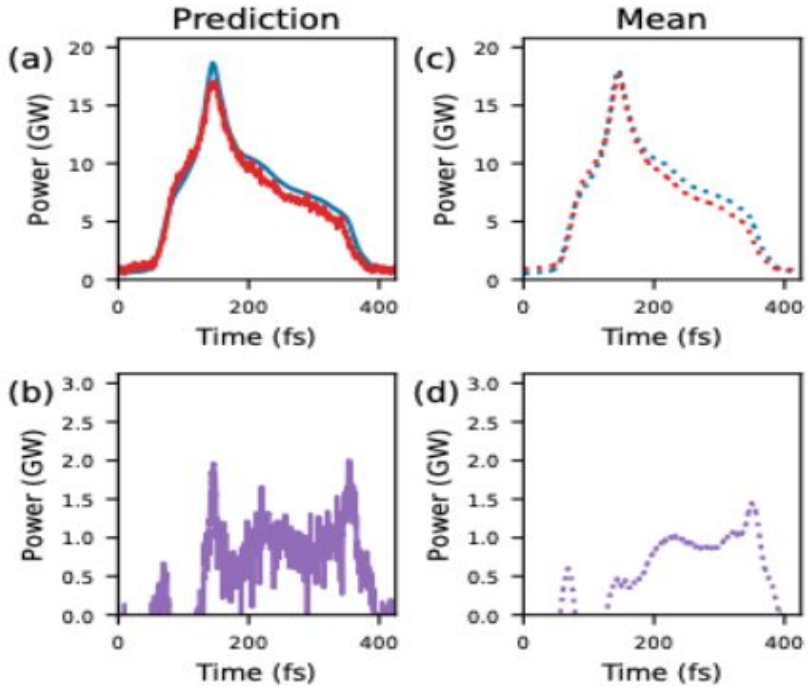

TABLE I: Machine parameters used as model input.

| Parameter name | definition |
|---|---|
| BCM.1a | measured data from more sensitive pyroelectric detector after BC1 |
| norm. BCM.1a | normalized BCM.1a to the bunch charge |
| BCM.1b | measured data from less sensitive pyroelectric detector in BC1 |
| norm. BCM.1b | normalized BCM.1b to the bunch charge |
| BCM.2a | measured data from more sensitive pyroelectric detector after BC2 |
| norm. BCM.2a | normalized BCM.2a to the bunch charge |
| BCM.2b | measured data from less sensitive pyroelectric detector after BC2 |
| norm. BCM.2b | normalized BCM.2b to the bunch charge |
| BCM.3a | measured data from more sensitive pyroelectric detector in FLASH2 after BC3 |
| norm. BCM.3a | normalized BCM.3a to the bunch charge |
| BCM.3b | measured data from less sensitive pyroelectric detector in FLASH2 after BC3 |
| norm. BCM.3b | normalized BCM.3b to the bunch charge |
| BAM1-1 | bunch arriving time before BC1 |
| BAM1-2 | bunch exciting time after BC1 |
| BAM2-1 | bunch arriving time before BC2 |
| BAM2-2 | bunch exciting time after BC2 |
| BAM3 | bunch arriving time before BC3 |
| $\Delta t$ (BAM1-2- BAM1-1) | time delay at BC1 |
| $\Delta t$ (BAM2-2 - BAM2-1) | time delay at BC2 |
| CHARGE in Gun | electron bunch charge generated at electron gun |
| CHARGE in FLASH2 | Electra bunch charge at FLASH2 beamline |
| ENERGY in FLASH2 | electron beam energy |
| BPM x, y | electron beam position before TDS in x and y directions |

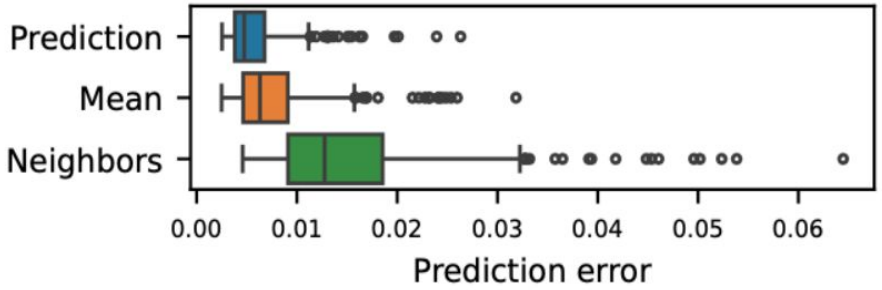
The machine is stable



# MLP Model Training Performance




Single shot photon power reconstruction




MLP model training performance.

# Thanks for your attention

This work was supported by Siegfried Schreiber

Last year, our work on virtual diagnostics was recognized with a Reproducibility Award by the AI community. I would like to dedicate this honor to Siggi Schreiber, the former head of the FLASH faculty, for the help, support, and hope he gave me when I first joined FLASH.