Virtual diagnostics for X-ray pulse characterization

Farzad Jafarinia, Simon Schnake, Christian Grech, Marc Guetg, Gianluca Geloni, Raimund Kammering, Wolfgang Freund, and Tuba Yildiz

13th MT ARD ST3 Meeting 2025
26.06.2025

Motivation

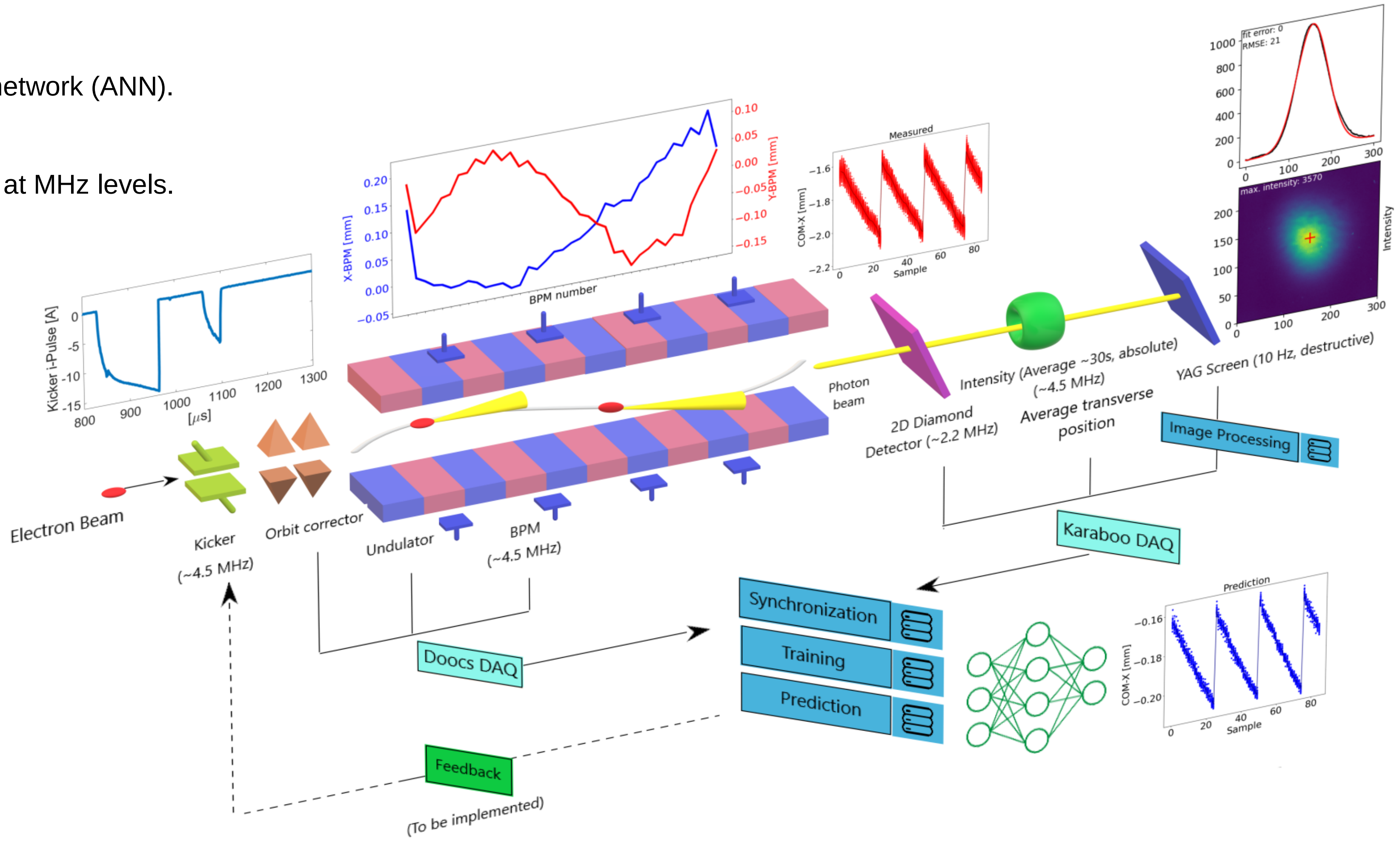
- Jitter in pointing affects intensity and sample safety.
- Conventional diagnostics are invasive and limited at high rates.
- Need for a non-invasive, high-frequency predictive model.

Goals

- Develop a virtual diagnostic tool for real-time pointing prediction at the European XFEL at MHz repetition rate.

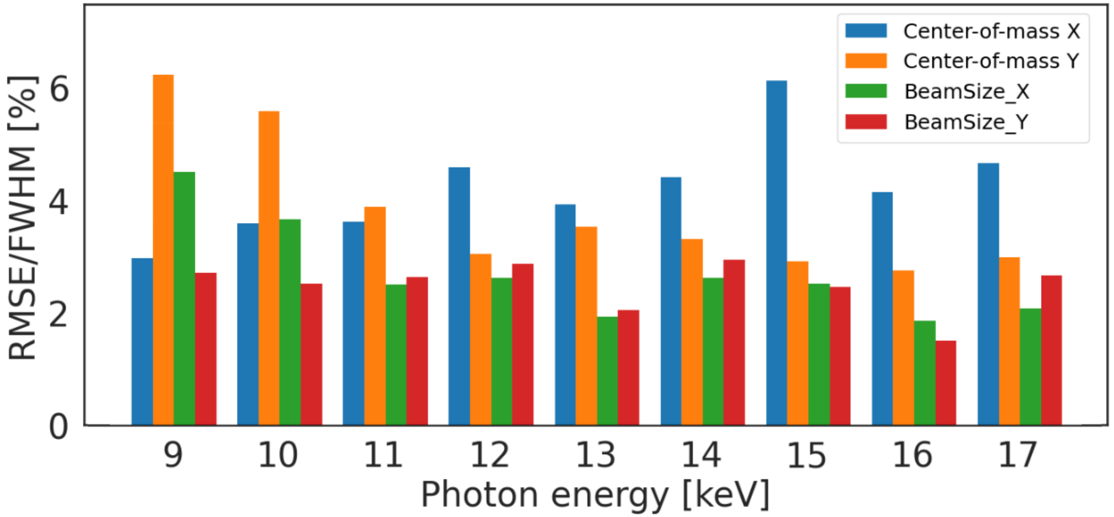
Photon Pointing Prediction Framework

- **Model**: Feed-forward artificial neural network (ANN).
- **Inputs**: Parasitic diagnostics (BPMs).
- **Outputs**: Predicted photon properties at MHz levels.

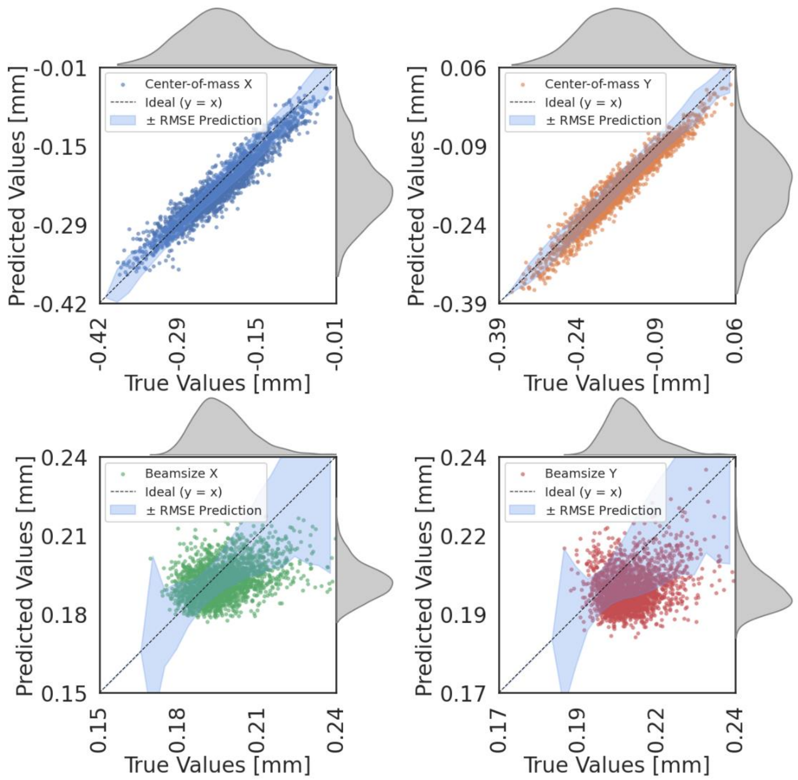


HELMHOLTZ GEMEINSCHAFT
DESY

Prediction (Single Pulse)

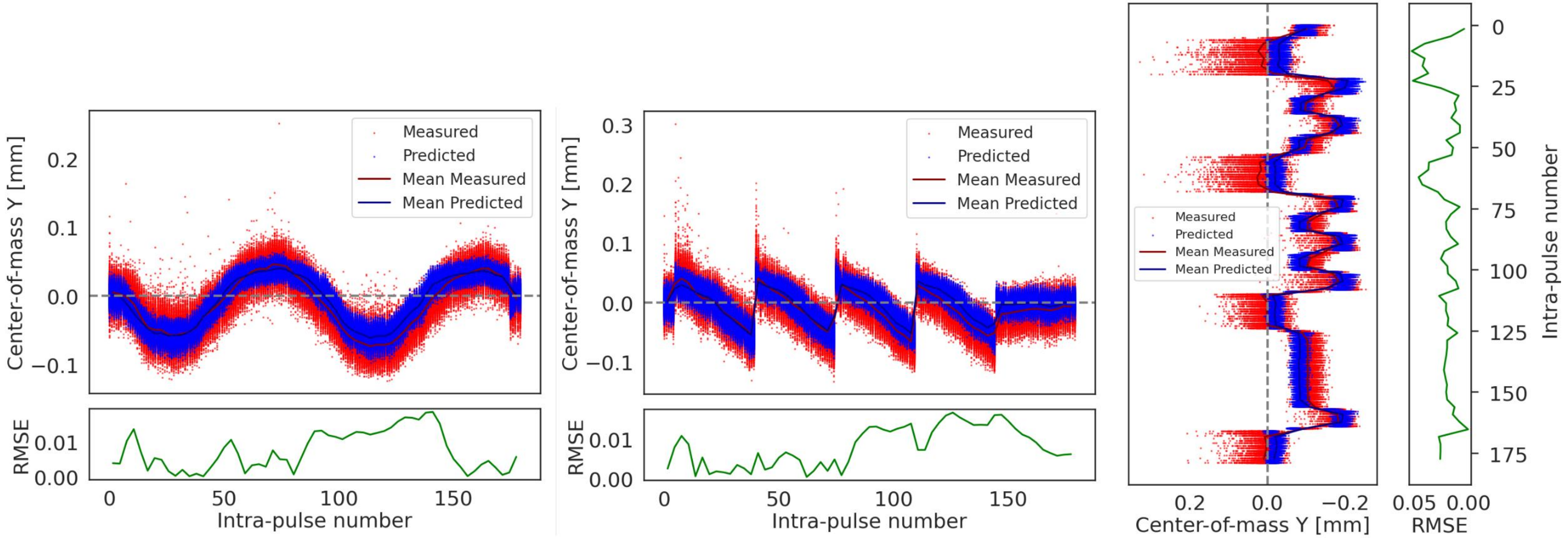


- Root-mean-square error of the predicted photon beam properties normalized by the average FWHM of the photon beam size across various photon energies, with each energy serving as the test set while others are used for training.



- 13 keV case

Prediction (Many Pulses)



- Validation with Diamond detector (17 keV, SA2)
- Intra-train X-kicks, generating distinct beam shapes
- Model ability to predict intra-train properties

Summary and Outlook

- Developed ANN-based diagnostics enable high-precision pointing prediction.
- Non-invasive solution for both hard and soft X-rays.
- Our approach enables operators to make informed decisions in real time, optimizing beam trajectories, and enhancing the efficiency of photon pulse generation without interrupting experimental operations.
- Real-time feedback and feed-forward loops with MHz kicker system.

Acknowledgments

- Special thanks to colleagues in European XFEL (Jan Grunert and Mikako Makita) for their support and helpful discussions.

Thank you for your attention!

Cryogenic Current Comparators from Lab to Beamlines

created with Gemuryou-aigazou.com

Cryogenic Current Comparators from Lab to Beamlines

Charged particle counting

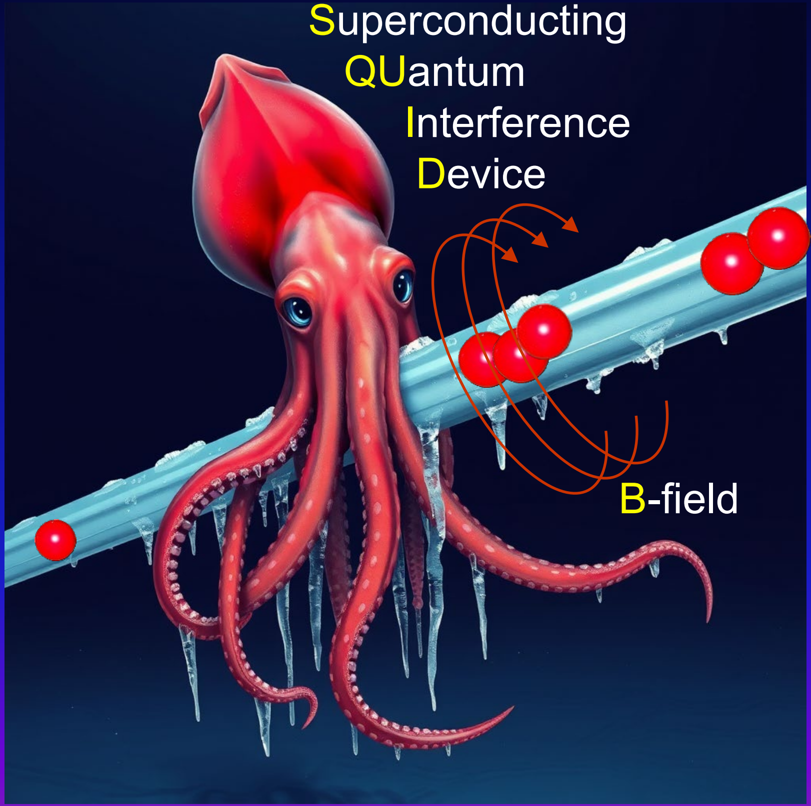
Boundary values:

- Low intensities (nA)
- Non-destructive
- Bunched / un-bunched (AC/DC)
- Direct traceable to Ampere

created with Gemuryou-aigazou.com

Cryogenic Current Comparators from Lab to Beamlines

FRIEDRICH-SCHILLER-UNIVERSITÄT JENA
GSI
HI JENA
HELMHOLTZ
Helmholtz Institute Jena



On poster:

How?

- Low temperatures
- Superconducting
- Quantum effects

Where?

- GSI / FAIR (2x2 TS, CRYRING)
- CERN (AD, SPS-NA-TT20)

created with Gemuryou-aigazou.com

Overview of THz diagnostics at PITZ

Namra Aftab

13th MT ARD ST3 Meeting

25-27.06.2025

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

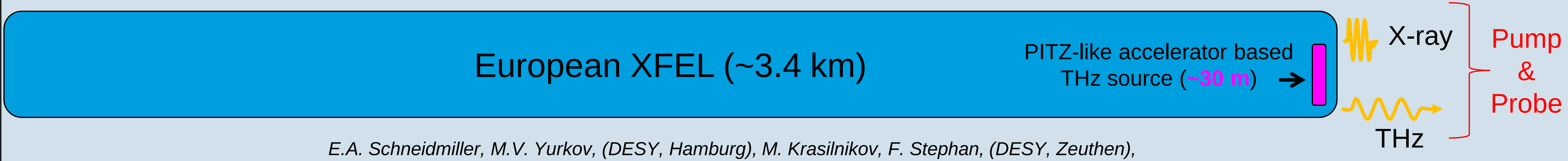
PITZ Photo Injector Test Facility Zeuthen

European XFEL

DESY.

Motivation for THz R&D at PITZ

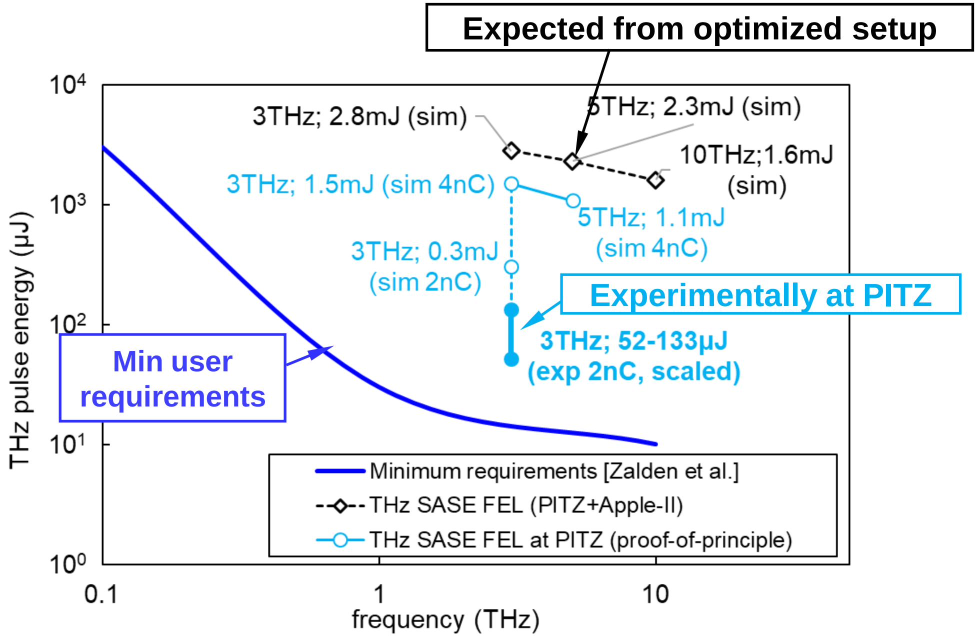
Accelerator based THz source for pump-probe experiments at the European XFEL



E.A. Schneidmiller, M.V. Yurkov, (DESY, Hamburg), M. Krasilnikov, F. Stephan, (DESY, Zeuthen), "Tunable IR/THz source for pump probe experiments at the European XFEL, Contribution to FEL 2012, Nara, Japan, August 2012

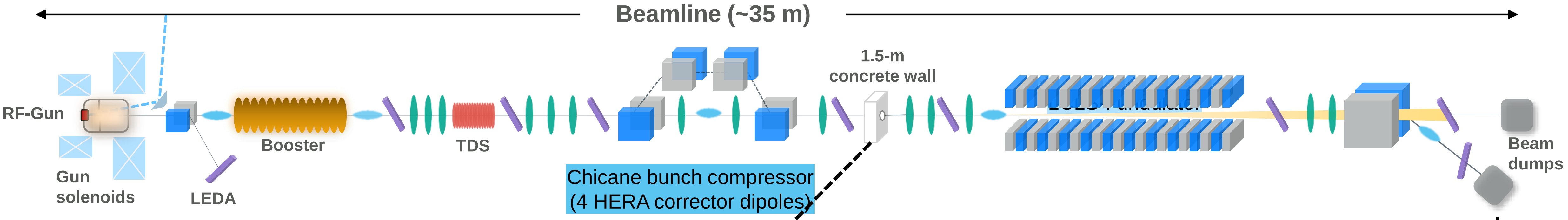
THz source requirements

- **Tunable** → $f = 0.1 \ldots 20\,THz$ $(\lambda_{rad} = 3mm \ldots 15\mu m)$
- Various temporal and *spectral* patterns, polarization - ideally **narrow-band** → $\Delta W / W \sim 0.1 \ldots 0.01$
- Time jitter → from **CEP stable** (few fs) for field driven to "intensity" driven dynamics
- **High pulse energy** $W > 10\mu J$ (μJ - hundreds of μJ - mJ , depending on f)
- **Repetition rate** to follow European XFEL → $(600\mu s \ldots 900\mu s) \times (0.1 \ldots 4.5MHz) \times 10Hz = 27000 \ldots 40500\ pulses/s$



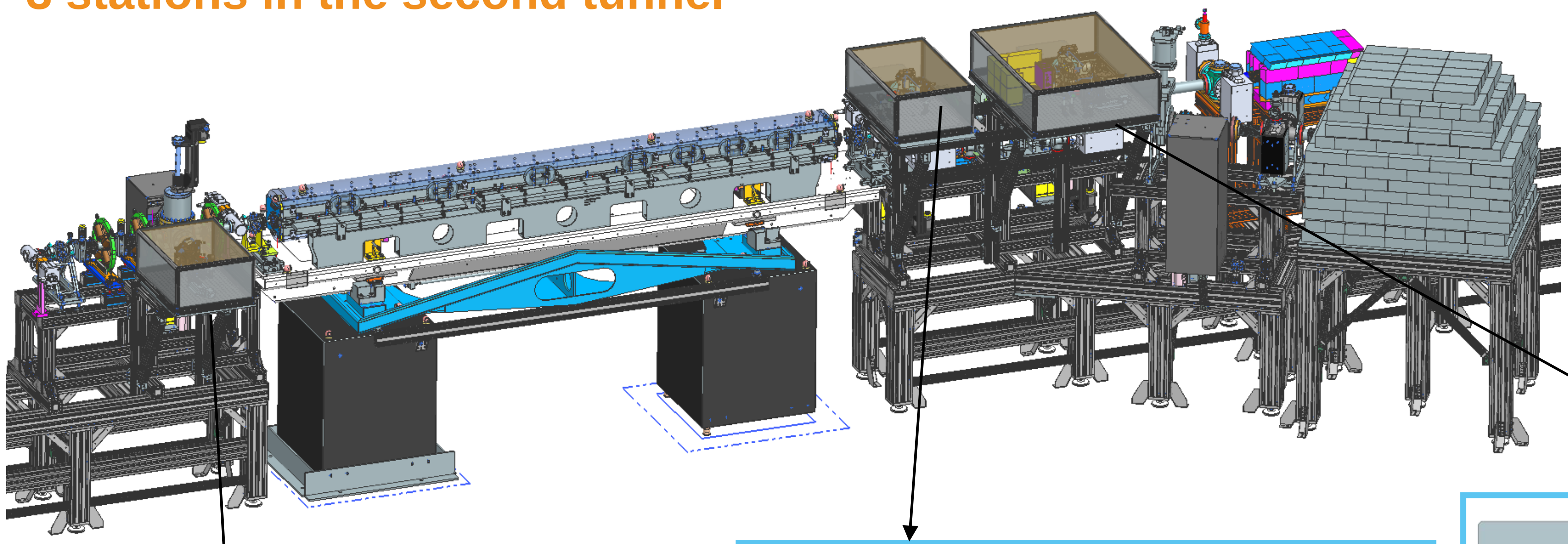
PITZ beamline schematics

Setup for the proof-of-principle experiment on THz source



THz Diagnostics at PITZ

3 stations in the second tunnel

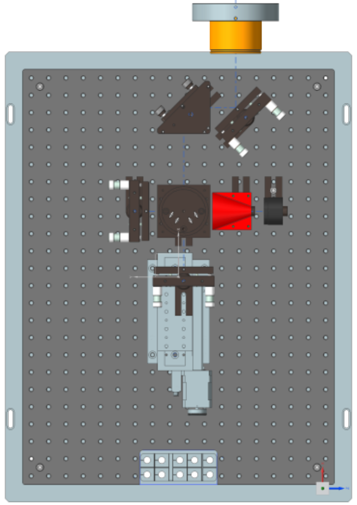


Enclosed system

Pure air circulator unit (Thorlabs) for air purification and humidity reduction.

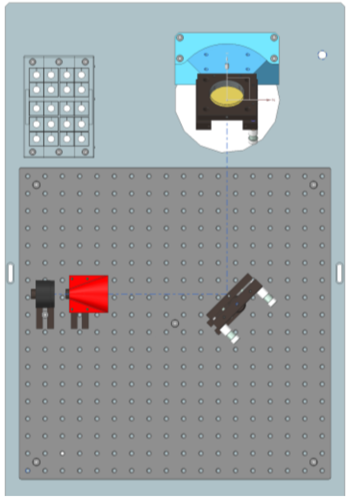
TD1:

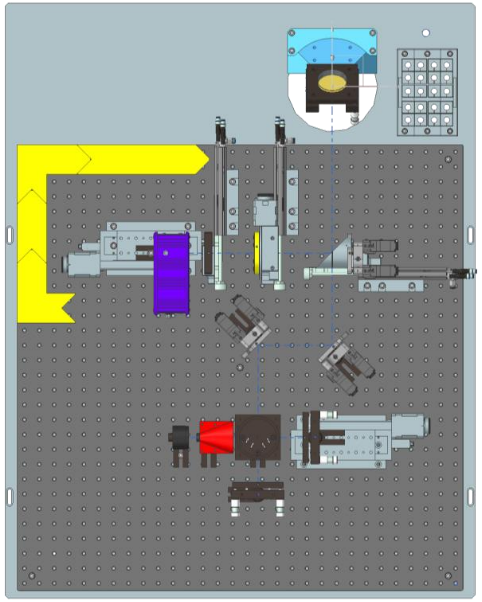
- Pulse energy using pyroelectric detector
- THz spectrum (CTR) using a Michelson interferometer
- Quartz vacuum window
- ~0.2 m transport in vacuum, ~0.5 m transport in air
- Focusing by using 90° off-axis ellipsoidal and parabolic mirrors
- 1 motorized linear stage



TD2

- Pulse energy using pyroelectric detector
- Diamond vacuum window
- ~0.8 m transport in vacuum, ~0.5 m transport in air
- Focusing by using 90° off-axis ellipsoidal mirror



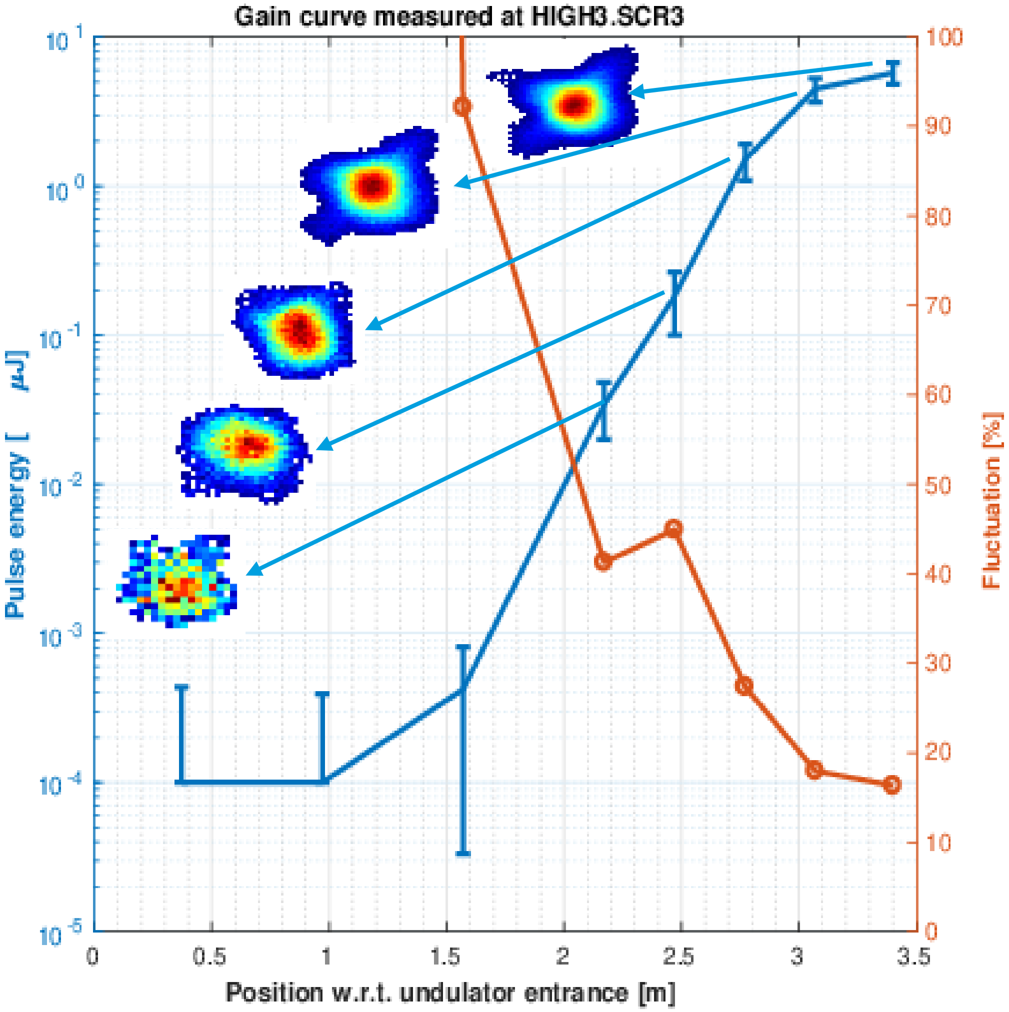


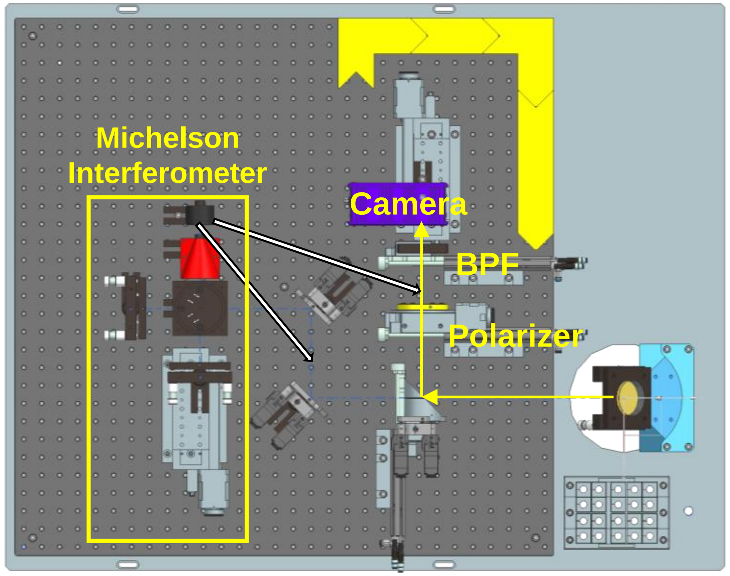
TD3:

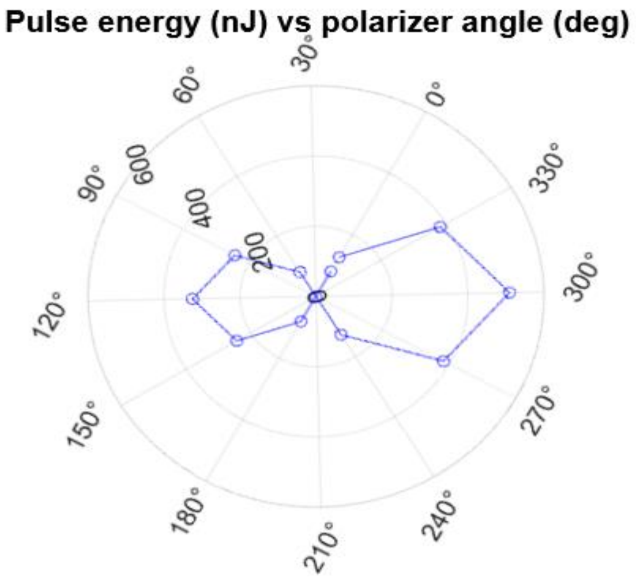
- Pulse energy using pyroelectric detectors
- Transverse profile using a THz camera
- Polarization using a THz polarizer
- THz spectrum using a Michelson interferometer
- Diamond vacuum window
- ~1.8 m transport in vacuum, 1-1.5 m transport in air
- Focusing by using 90° off-axis ellipsoidal and parabolic mirrors
- 3 pneumatic actuators, 3 motorized mirror adjusters, 2 motorized linear stages

THz diagnostic station 3

THz images along gain curve, polarizer







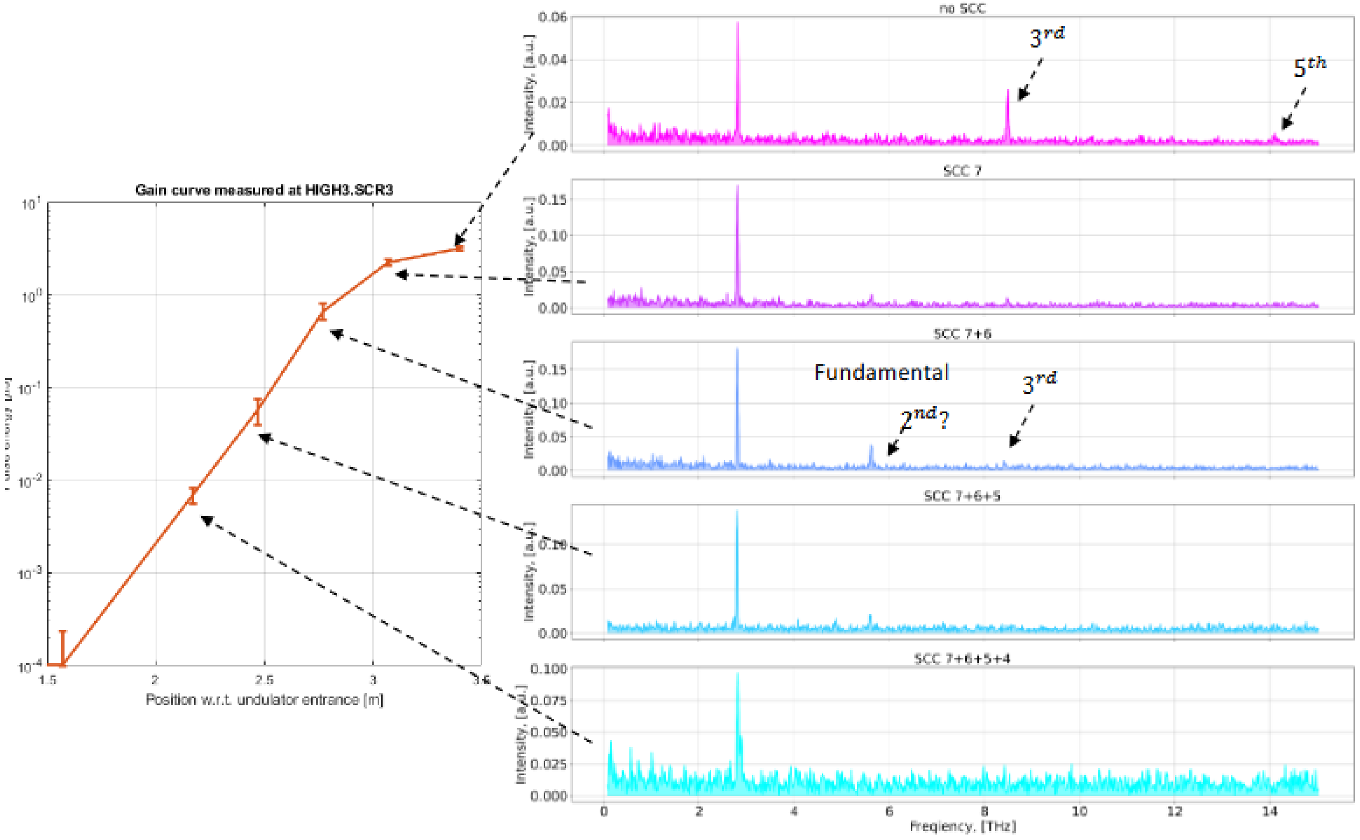
THz diagnostic station 3

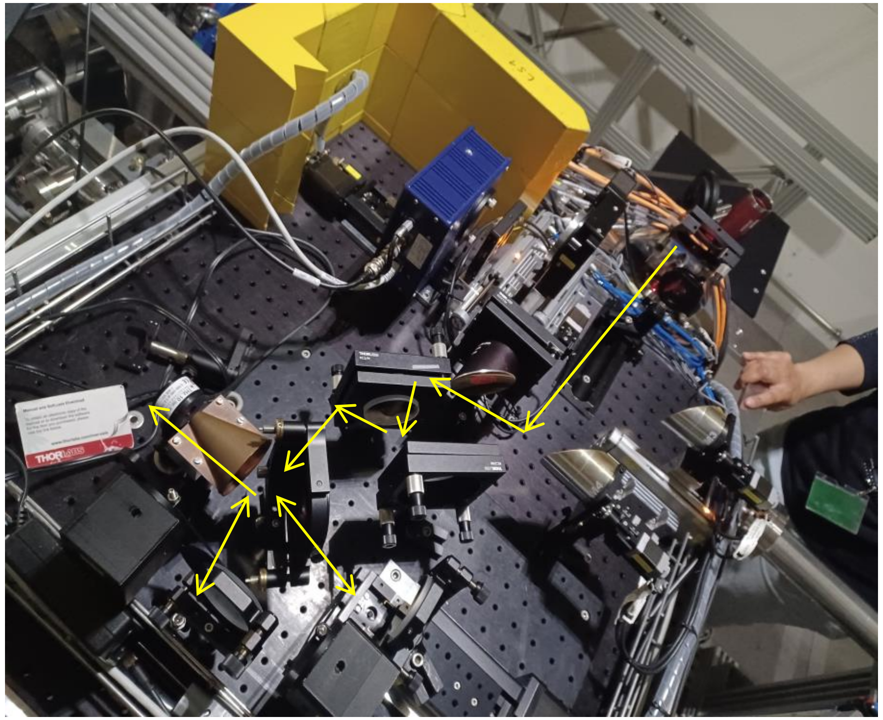
FTIR spectrometer from FLASH (E. Zapolnova, THz beamline at FLASH)

- TD3 with a compact broadband THz spectrometer based on the reflective lamellar grating
- Central wavelength ~ 2.82 THz (λrad ≈ 106.5 µm)

In-house commissioned Michelson Interferometer

- Michelson interferometer consisting of a fixed and movable arm, a beam splitter and pyrodetector with a collector cone used to measure interferogram.





More information in poster

THANK YOU.

Contact

DESY. Deutsches Elektronen-Synchrotron

www.desy.de

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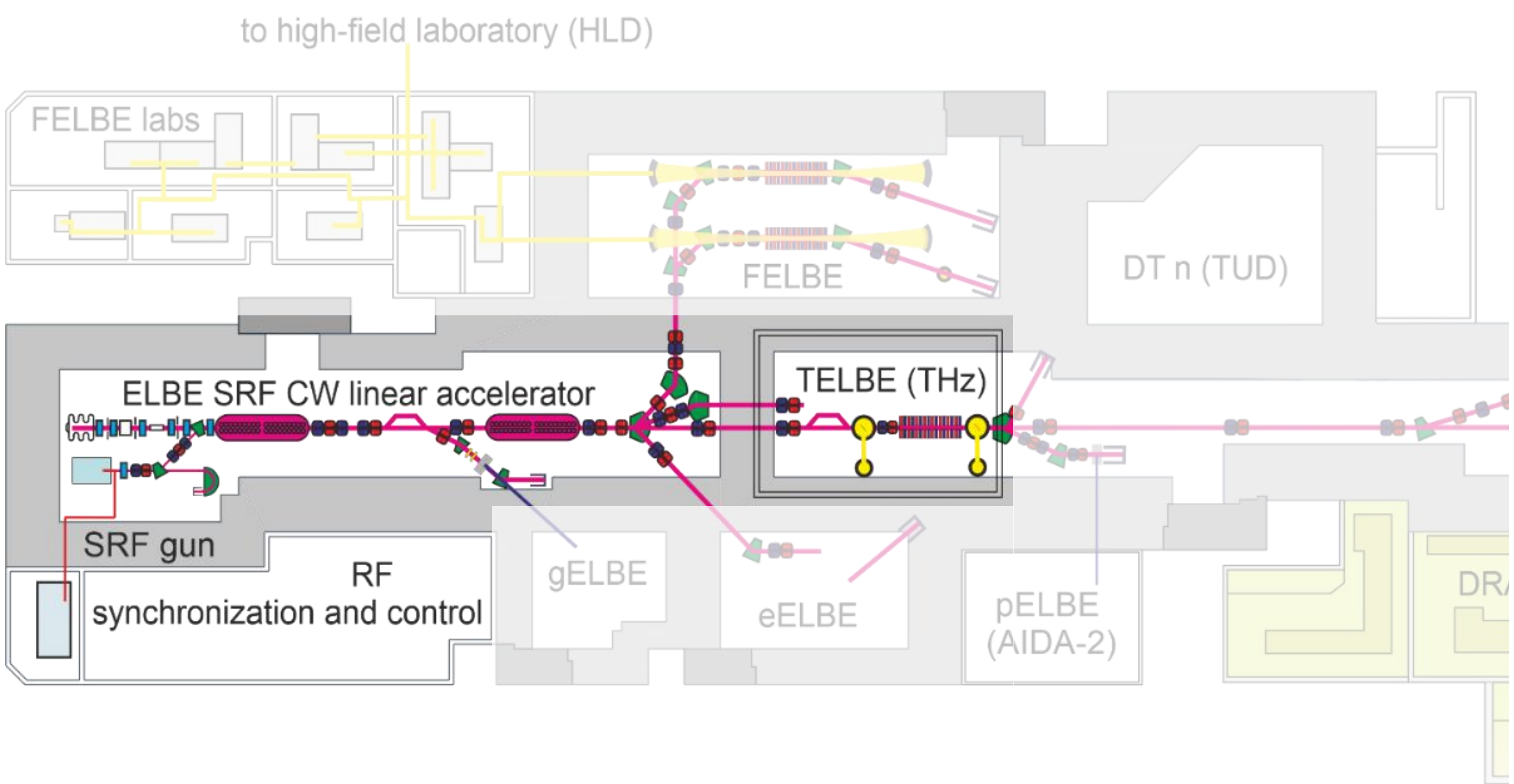
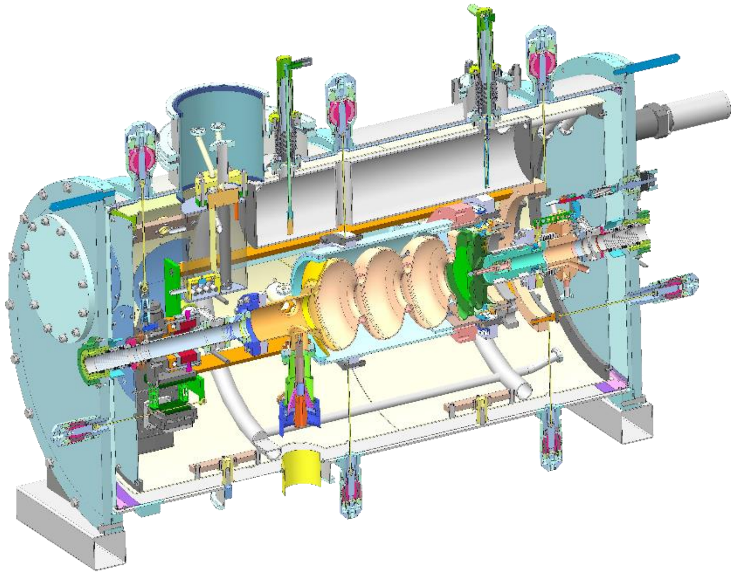
Measurements of the transverse emittance for 200 pC bunch charge at the ELBE SRF Gun

Raffael Niemczyk

ELBE Center for High-Power radiation Sources





- CW SRF gun
- 200 pC, typ. 50 kHz
- Compression phase

- THz pulse energy & beam loss

Emittance measurements

Scheme and image analysis routine

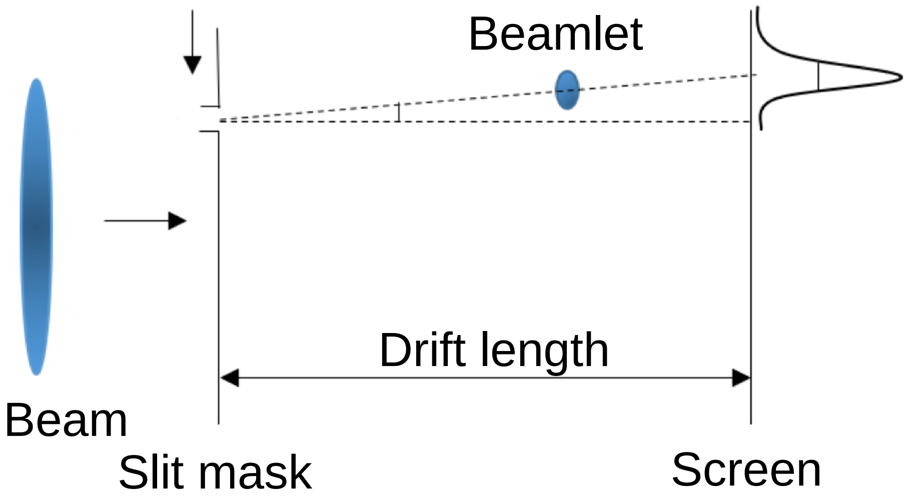
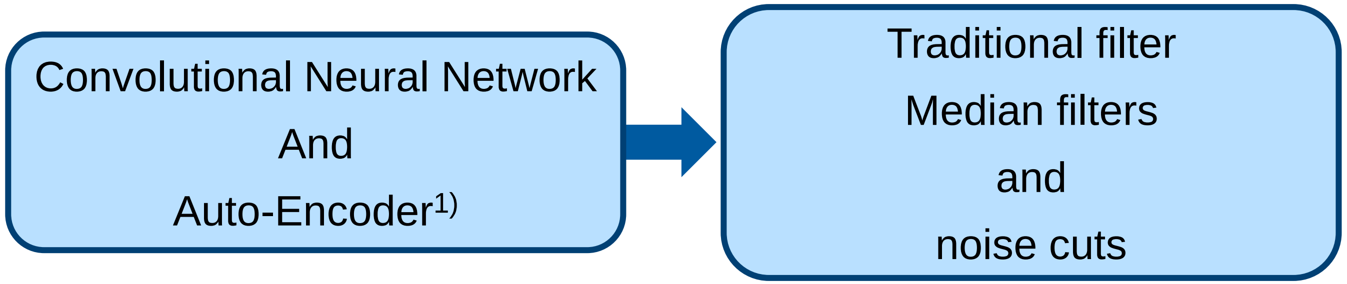


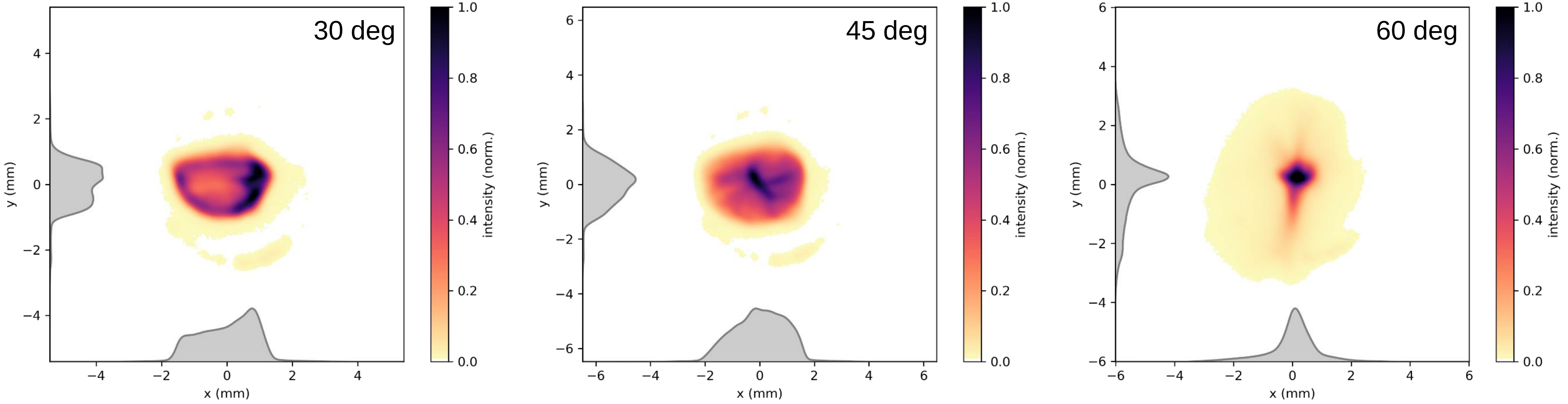
Image analysis routine



1) S.Ma, PhD thesis, University Hamburg, (2022)

Real space images

Beam distribution for different emission phases

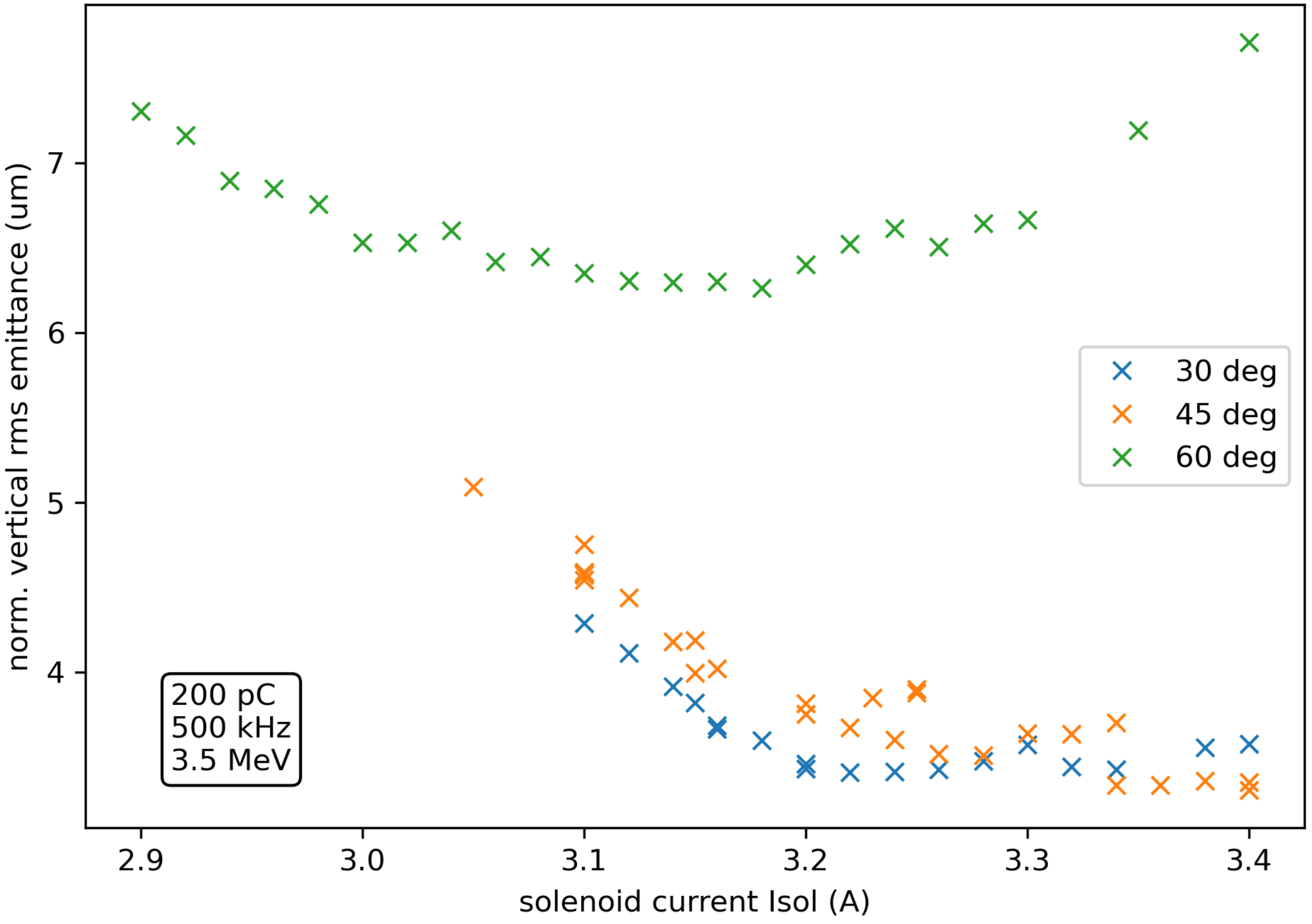


DRESDEN concept SCIENCE AND INNOVATION CAMPUS

HZDR

Emittance results

Scan of solenoid focusing and emission phase



Meet me at poster for discussion ☺

Contact

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Preparing electron diffraction at the ELBE SRF gun II

13th MT ARD ST3 Meeting 2025

Institute of Radiation Physics / Institute of Ion Beam Physics and Materials Research · Louis Stein · PhD student · l.stein@hzdr.de · www.hzdr.de

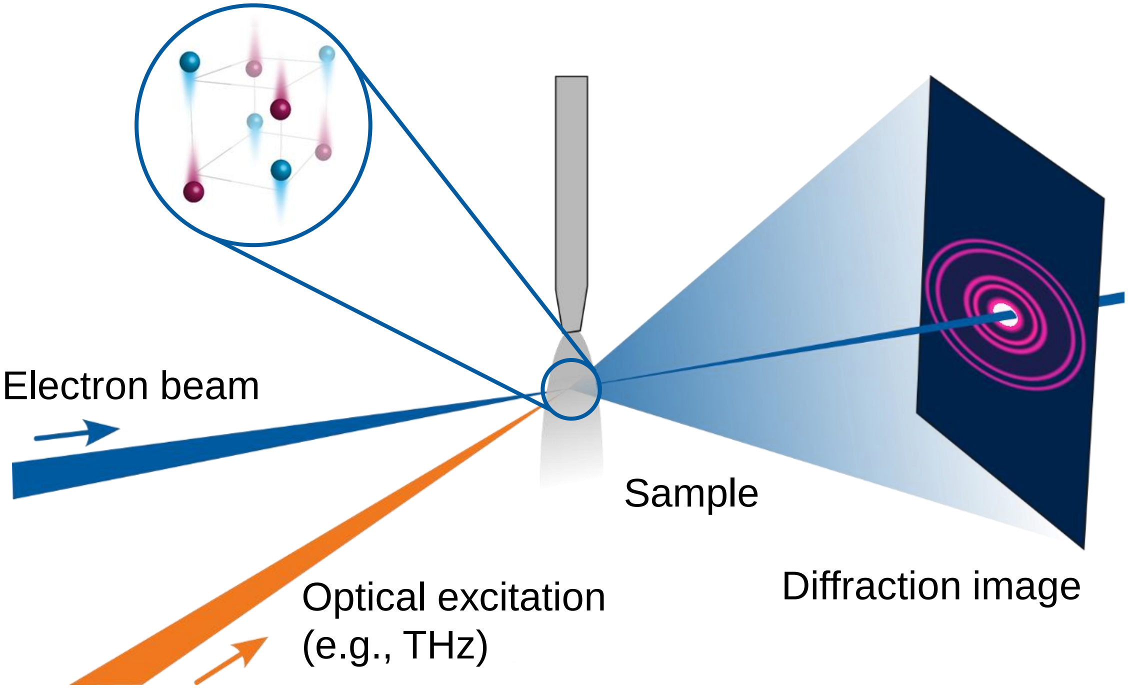
Motivation:
MeV Ultrafast Electron Diffraction (UED) and its role in DALI

- UED: observation of **structural dynamics** on the **fs timescale**

- Operates as a **pump-probe technique**:
  - Pump pulse: excitation
  - Time-delayed **probe** pulse → diffraction pattern
  - Delay variation

- **DALI (Dresden Advanced Light Infrastructure)**

→ **cutting-edge materials and life sciences research**

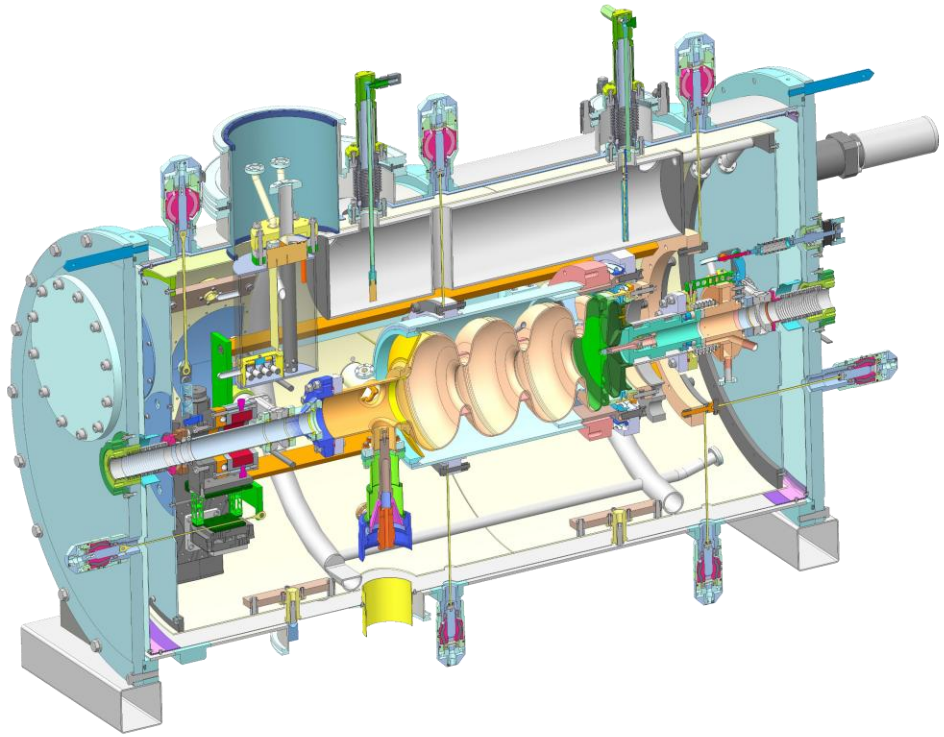


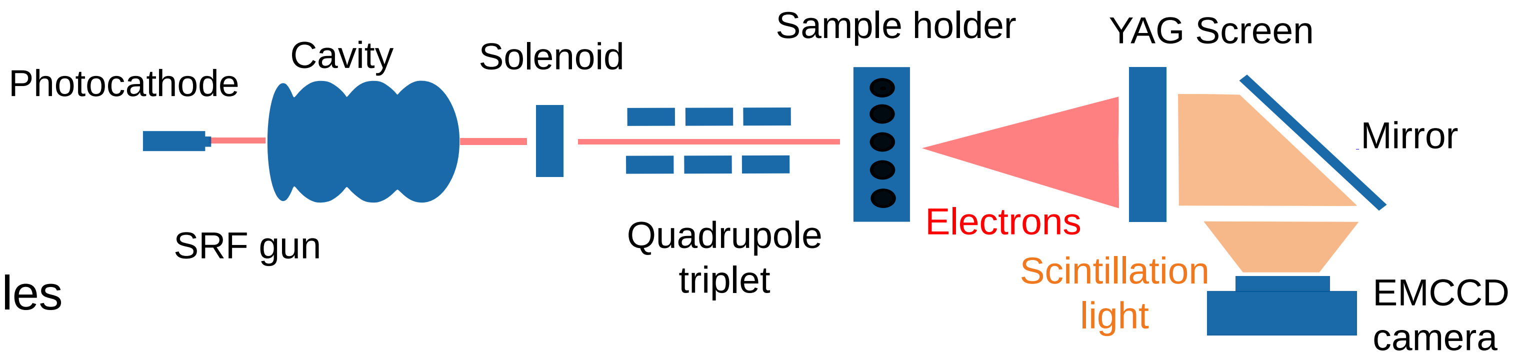
First Demonstration:
Static Electron Diffraction at ELBE

- **SRF gun** foreseen for MeV-UED:
  - MeV electron beams
  - High beam coherence
  - Short electron pulses

- First **static diffraction** experiments:
  - Adjusting cathode laser for SRF gun II
  - Sample stage
  - Screen station
  - EMCCD Camera

- Benchmark tests with known samples





Outlook:
Ultrafast Electron Diffraction at ELBE and DALI

- Static electron diffraction: beam **diagnostics**
- **Pump-probe** experiments with photocathode laser
- Gain experience in:
  - MeV electron diffraction
  - Pump-probe experiments
  - Data analysis
- Planned **DALI:** pumping with THz radiation source

  → **Worldwide unique MeV-UED setup**

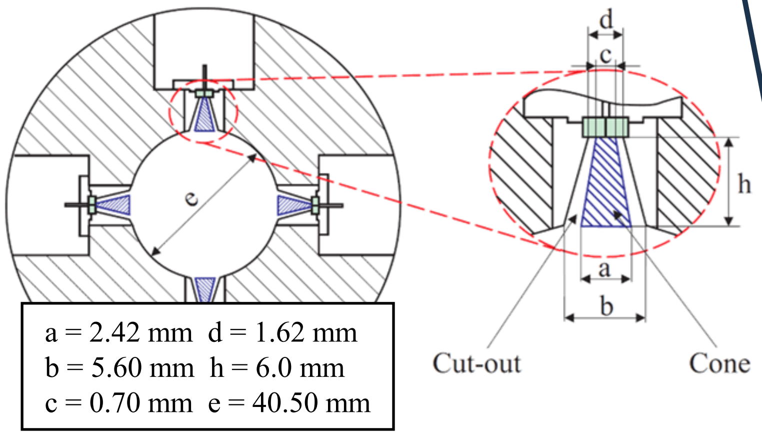
ELBE.
CENTER FOR HIGH-POWER
RADIATION SOURCES

DALi

This work is supported by the German Federal Ministry of Research, Technology and Space (BMFTR) under contract No. **05K22RO2**.
Bundesministerium für Forschung, Technologie und Raumfahrt

Design of the next PCB-based BAM Demonstrator for ELBE

Bunch Arrival-time Monitor



Pickups of the state-of-the-art BAM [1,2]

[1] A. Angelovski et al., 2012. doi:10.1103/PhysRevSTAB.15.112803 | [2] A. Angelovski, et. al, *IBIC'12*, MOPA46

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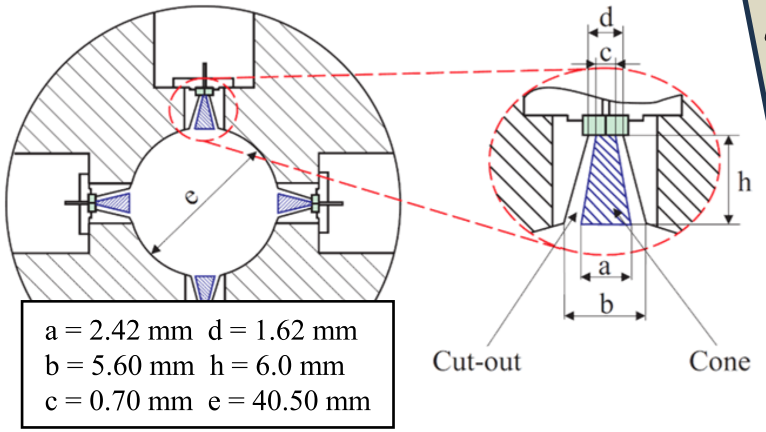

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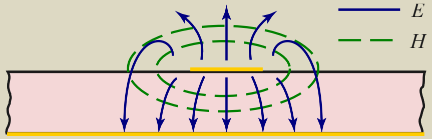
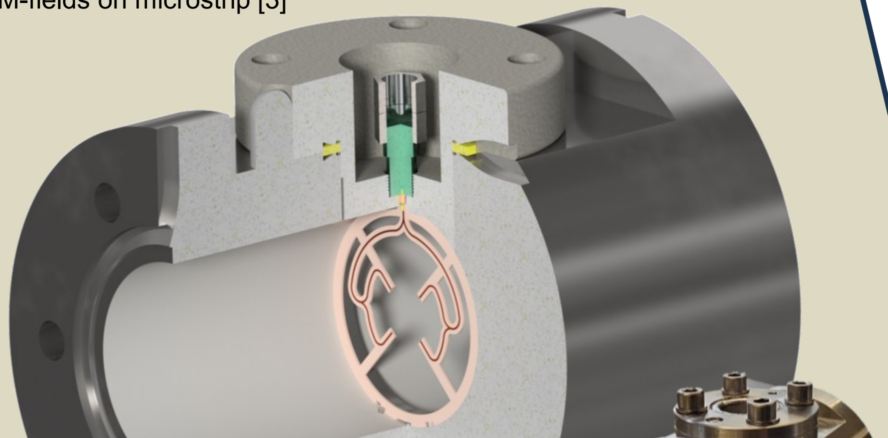
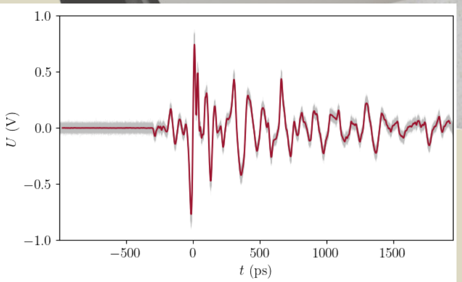


E- & M-fields on microstrip [3]

Previously on MT-ARD ST3





1024 measured pulses (gray) & average (red) [4]

Manufacturing model of the first demonstrator tested in ELBE [4]

[1] A. Angelovski et al., 2012. doi:10.1103/PhysRevSTAB.15.112803 | [2] A. Angelovski, et. al, *IBIC'12*, MOPA46 | [3] D. M. Pozar, "Microwave Engineering", 2012 | [4] B. Scheible et al., IBIC'23, doi:10.18429/JACoW-IBIC2023-TUP012

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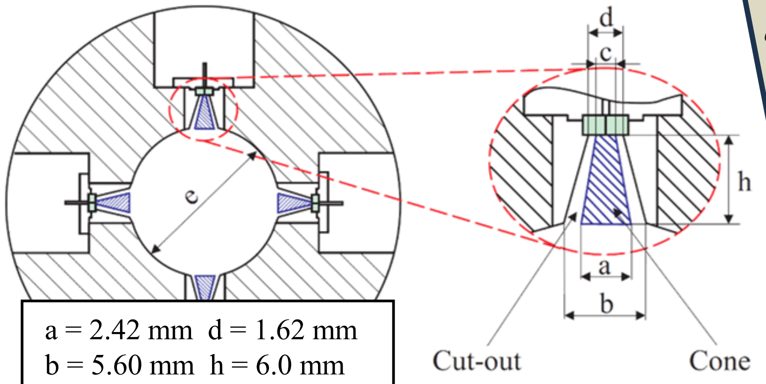
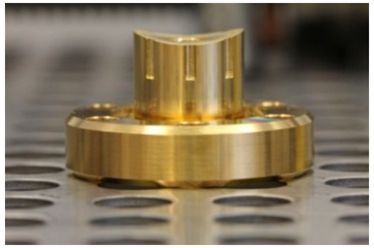
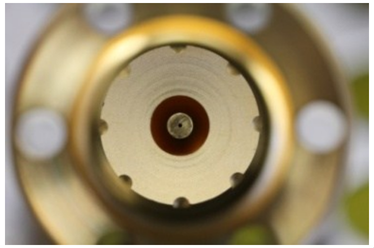


a = 2.42 mm	d = 1.62 mm
b = 5.60 mm	h = 6.0 mm
c = 0.70 mm	e = 40.50 mm

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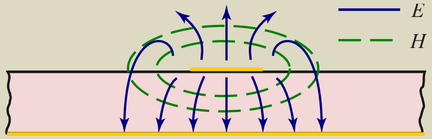
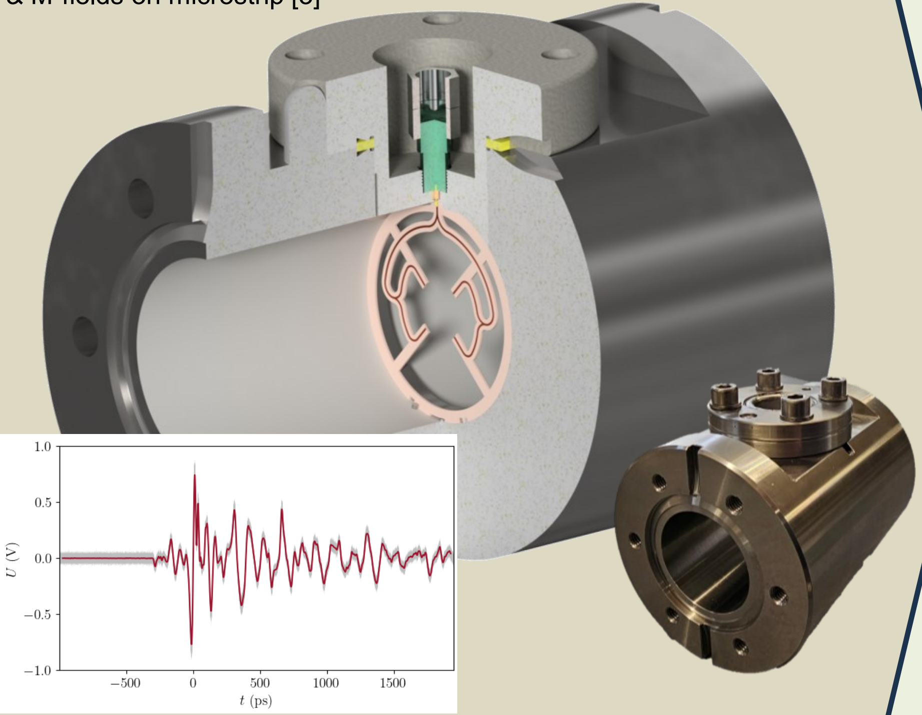


E- & M-fields on microstrip [3]

Previously on MT-ARD ST3



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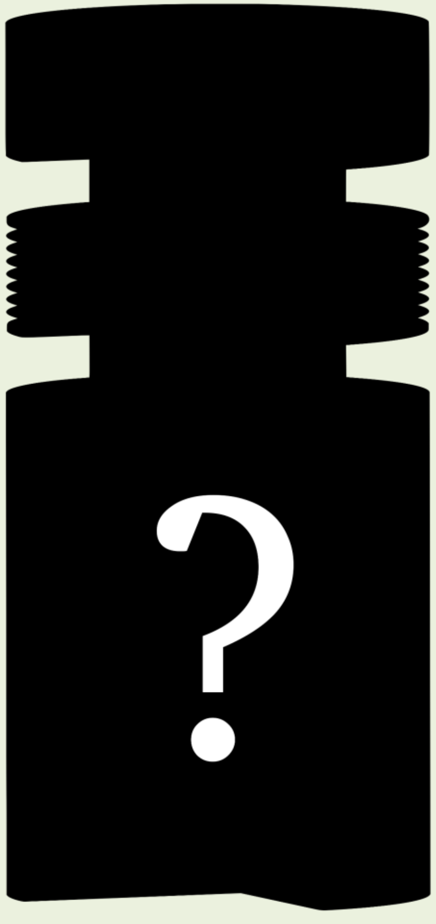
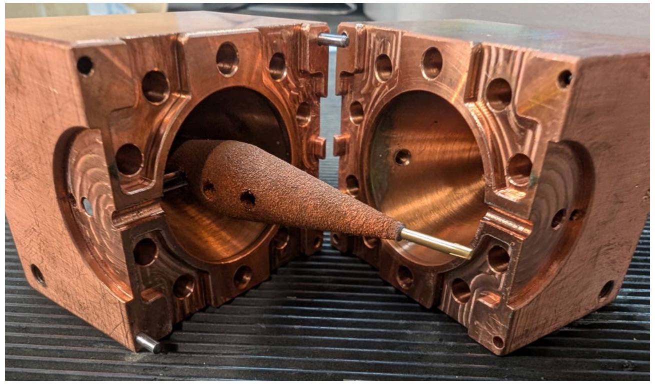


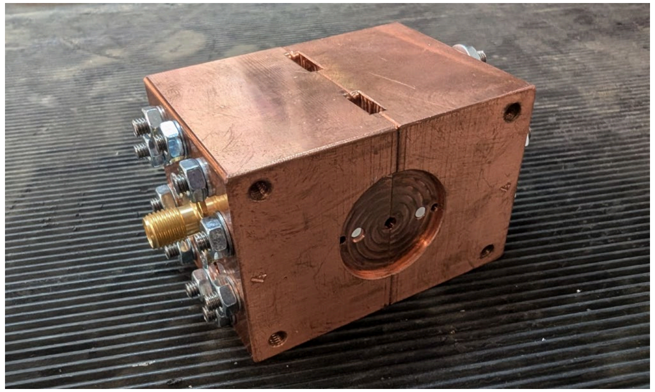
Second demonstrator for ELBE

[1] A. Angelovski et al., 2012. doi:10.1103/PhysRevSTAB.15.112803 | [2] A. Angelovski, et. al, *IBIC'12*, MOPA46 | [3] D. M. Pozar, “Microwave Engineering”, 2012 | [4] B. Scheible et al., IBIC'23, doi:10.18429/JACoW-IBIC2023-TUP012

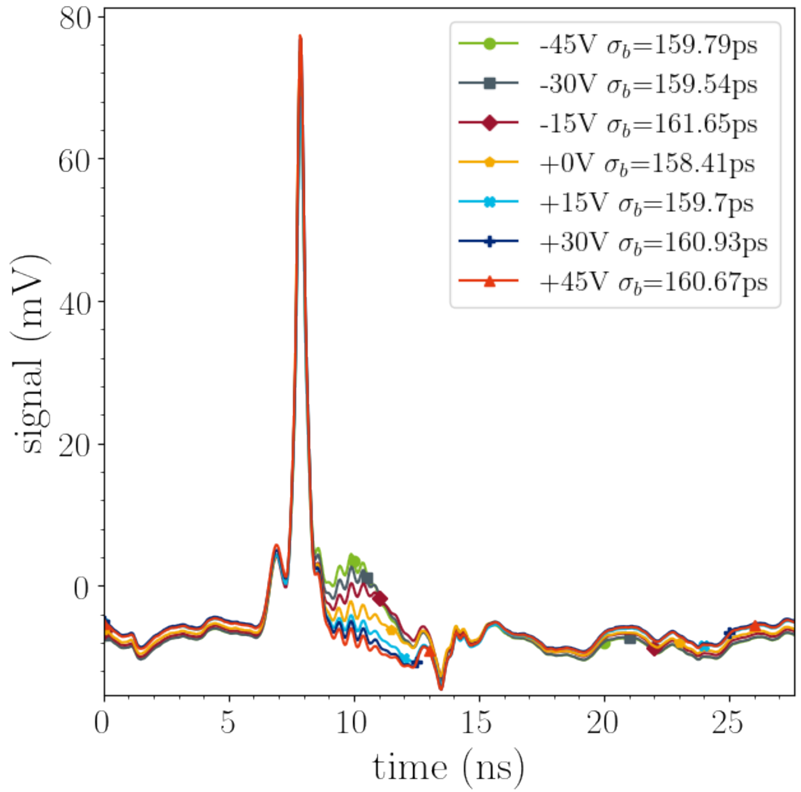
Temporal Resolution Analysis of the β-Dependency of Radially Coupled FFC Designs

- Different designs of radially coupled FFCs performed well at GSI
- Designed for heavy ions with velocities of $\beta < 20\%$
- Uses geometrical secondary electron suppression and bias to reduce impact of the secondary electrons on the signal





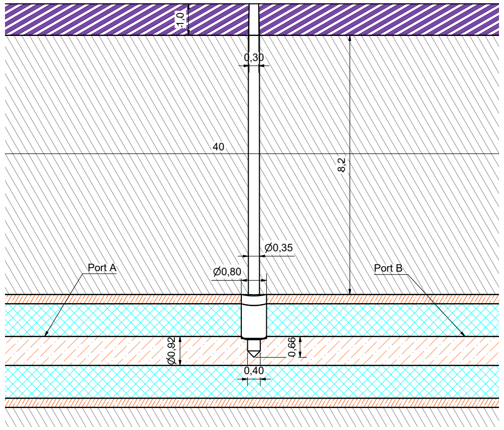
Tapered radially coupled FFC (TRCFFC) build at GSI workshop. Inner collector 3D-printed at Fraunhofer IWS Dresden.



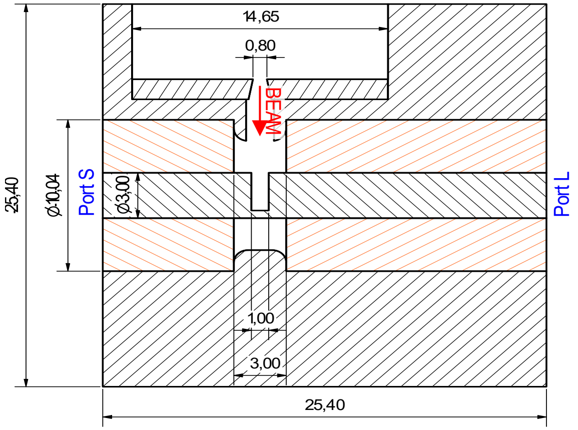
Ar^{10+} @ 11.4 MeV/u in the experimental cave X2 of GSI with different bias settings

Temporal Resolution Analysis of the β-Dependency of Radially Coupled FFC Designs

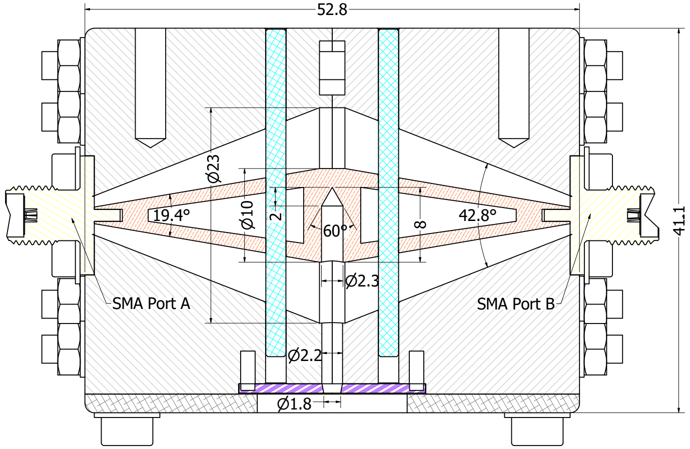
- How would these work in an electron facility based on CST simulations?
  - Bandwidth
  - Temporal resolution
- What are limitations? What would be necessary to make it work?



High Bandwidth Coaxial FFC (HBFFC)



Radially Coupled Coaxial FFC (RCFFC)



Tapered Radially Coupled Coaxial FFC (TRCFFC)

ACKNOWLEDGMENT

This work is supported by the German Federal Ministry of Education and Research (BMFTR) under contract no. 05P21RORB2.
Joint Project 05P2021 - R&D Accelerator (DIAGNOSE)

Bundesministerium für Forschung, Technologie und Raumfahrt

Latest Advancements of a Compact Electro-optical Bunch Length Detector.

B. Steffen, M. K. Czwalinna, Tomasz Kozak, Dietrich Rothe (DESY, Hamburg, Germany)

Collaboration

DESY, Hamburg B. Steffen, M. K. Czwalinna,

PhD student

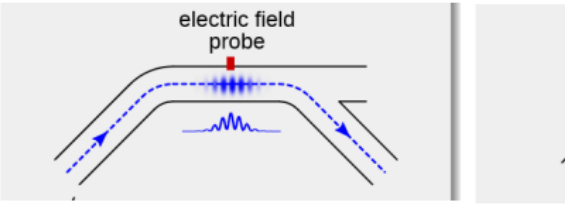
PhLAM, Lille University, France S. Bielawski, Q. Demazeux,
E. Roussel, C. Evain, Ch. Szwaj

Marie Kristin Czwalinna

13th MT ARD ST3 Meeting 2025 at DESY, Zeuthen

Electro-optic Spectral Decoding (EOSD)

From expert-only to a user-friendly measurement device



- High system complexity
  → high level of automation required
  → Supervision / fault diagnosis of all sub-components

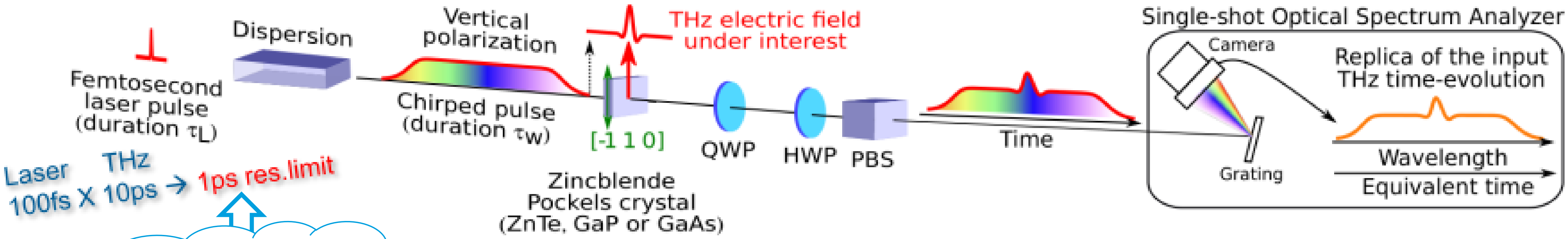
  - Automated time overlap retrieval and calibration
  - Online pulse shape monitoring

Suited for THz waveforms from different source,
- e-bunch
- FEL, CSR, ….

Longitudinal bunch shapes

u-bunch instability

THz science, e.g. spectroscopy



Limit overcome by Diversity EO (DEOS)

Frontend servers, Middle-layer server,

Control system interface
→ DOOCS backend

14th Collaboration Workshop on
Longitudinal Diagnostics

29th Sep to 1st Oct 2025
https://indico.desy.de/event/48267/overview
DESY Campus, Hamburg

For detailed discussion
On the topic & on collaboration options:

Contact

DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

MSK
Bernd Steffen
bernd.steffen@desy.de

Marie Kristin Czwalinna
marie.kristin.czwalinna@desy.de

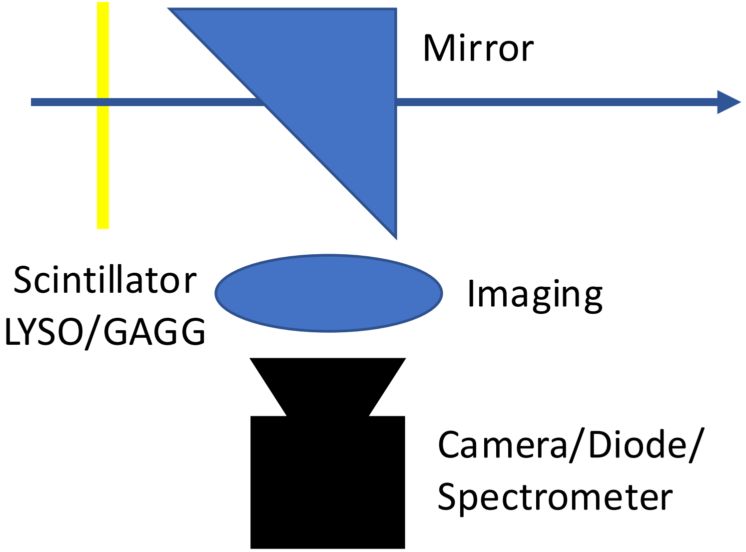
Femtosecond Radiative Longitudinal Diagnostic Techniques Employed at ARES

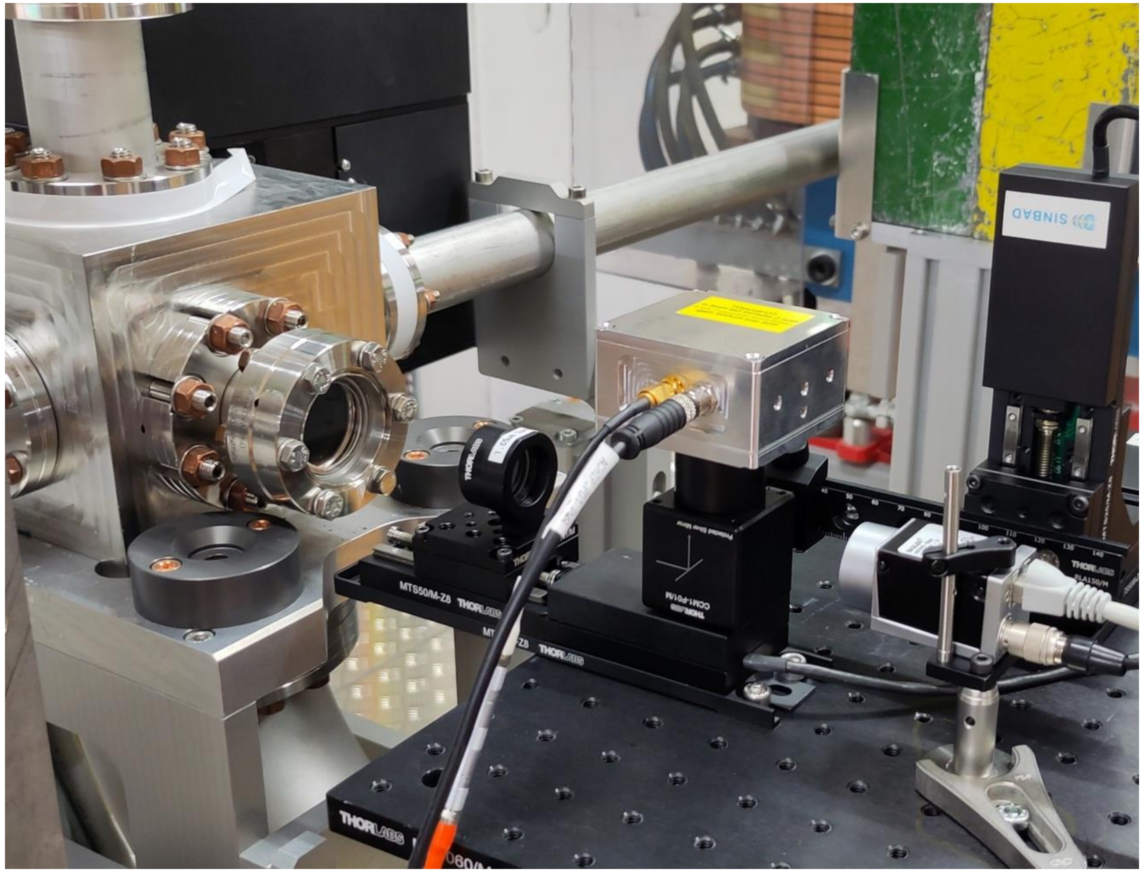
B. Stacey, W. Hillert, W. Kuropka, T. Vinatier

Deutsches Elektronen-Synchrotron DESY
Ein Forschungszentrum der Helmholtz-Gemeinschaft

TR Bunch Compression Monitor

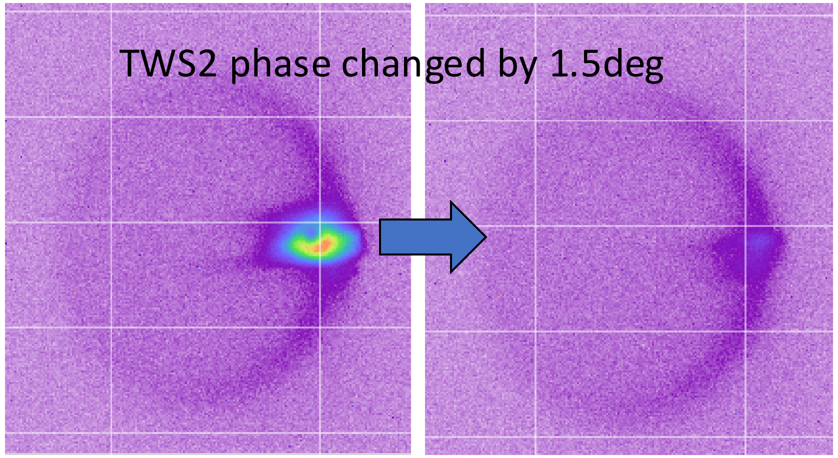
Coherent and resonant transition radiation as bunch compression monitors towards Smith-Purcell studies

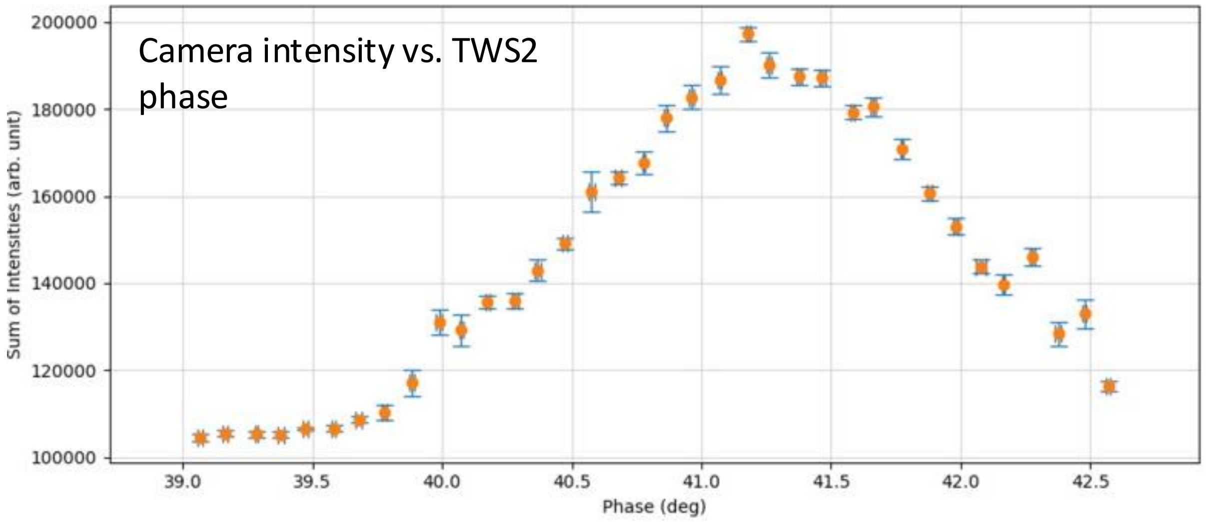


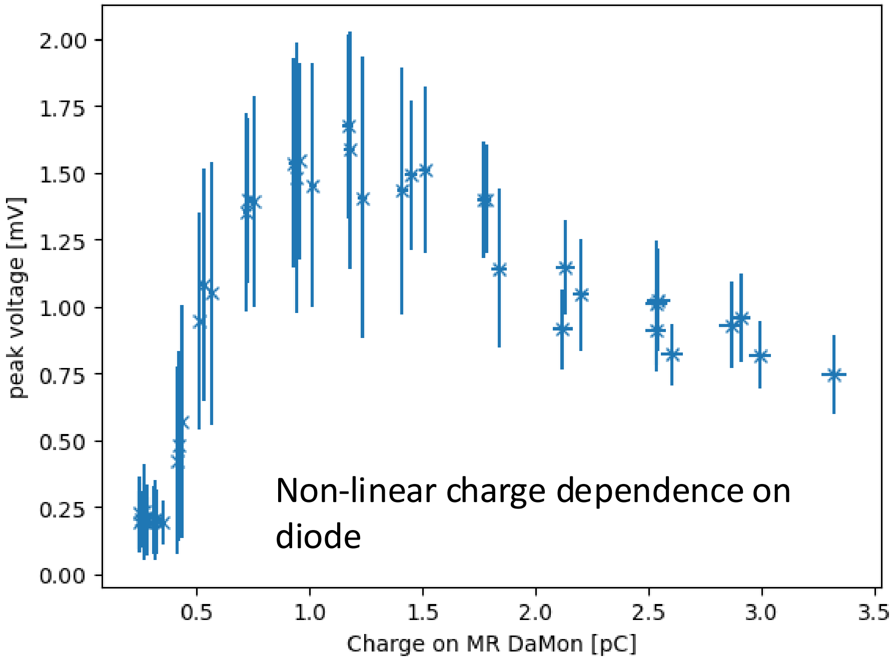


In-Vacuum TR Bunch Compression Monitor

Coherent and resonant transition radiation as bunch compression monitors towards Smith-Purcell studies

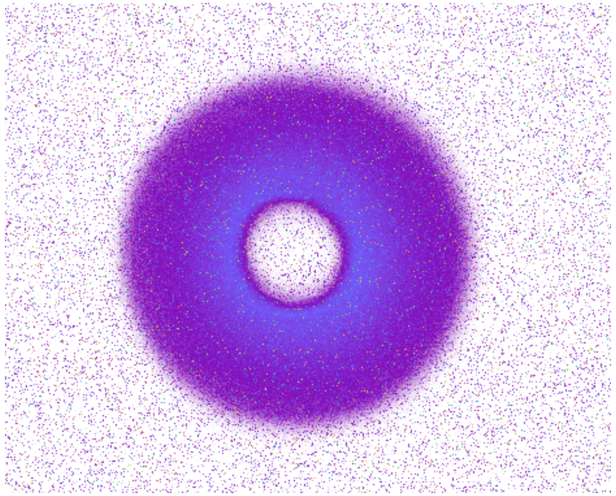




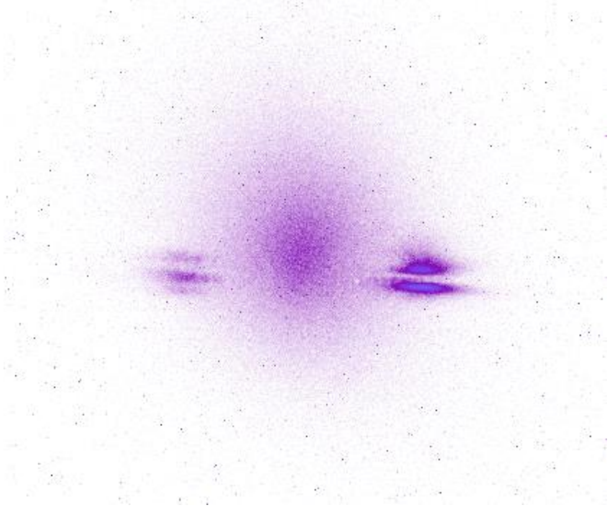


In-Air TR Bunch Compression Monitor

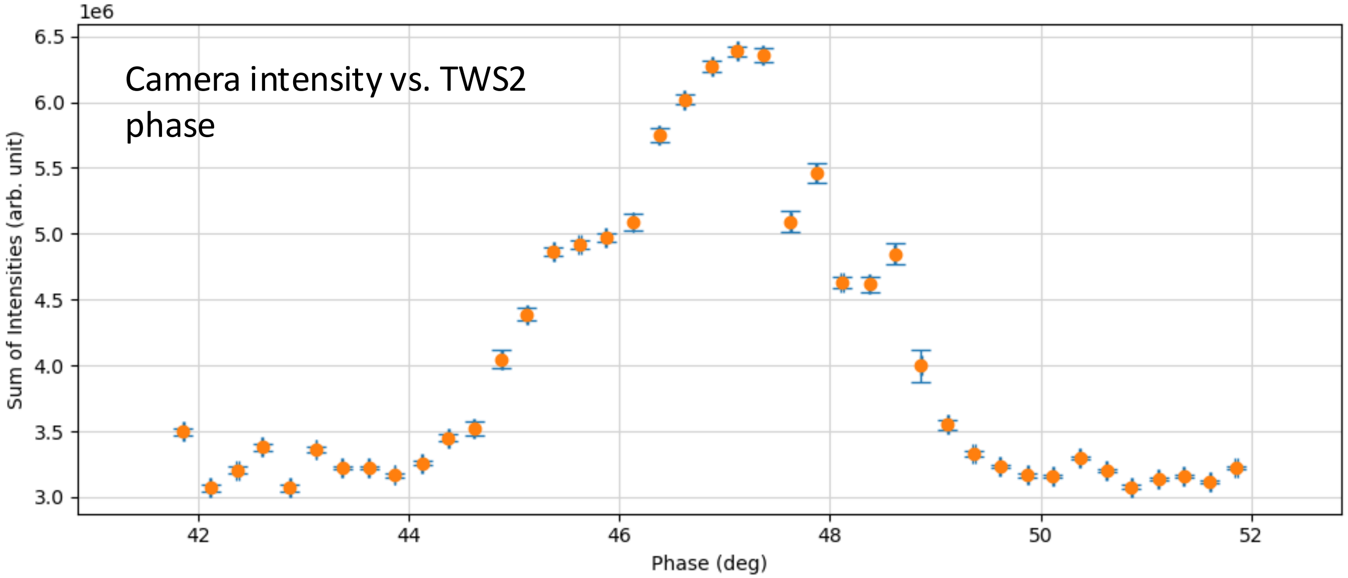
Coherent and resonant transition radiation as bunch compression monitors towards Smith-Purcell studies



- Dielectric mirror;
- TR from 50µm Ti window blocked.

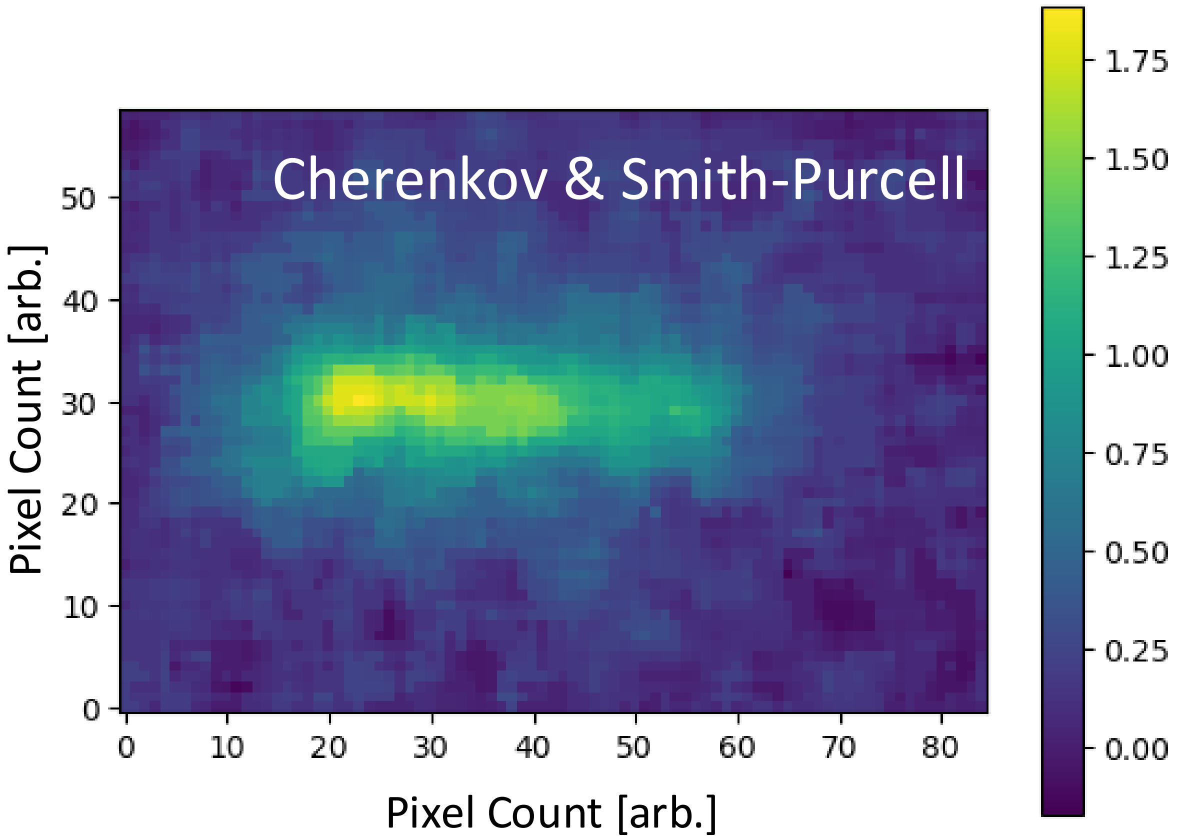


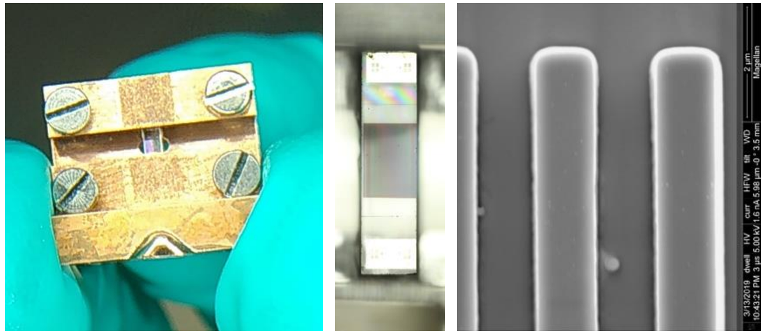
- 50µm Ti foil;
- Incoherent signal from mirror.



Smith-Purcell Longitudinal Diagnostic

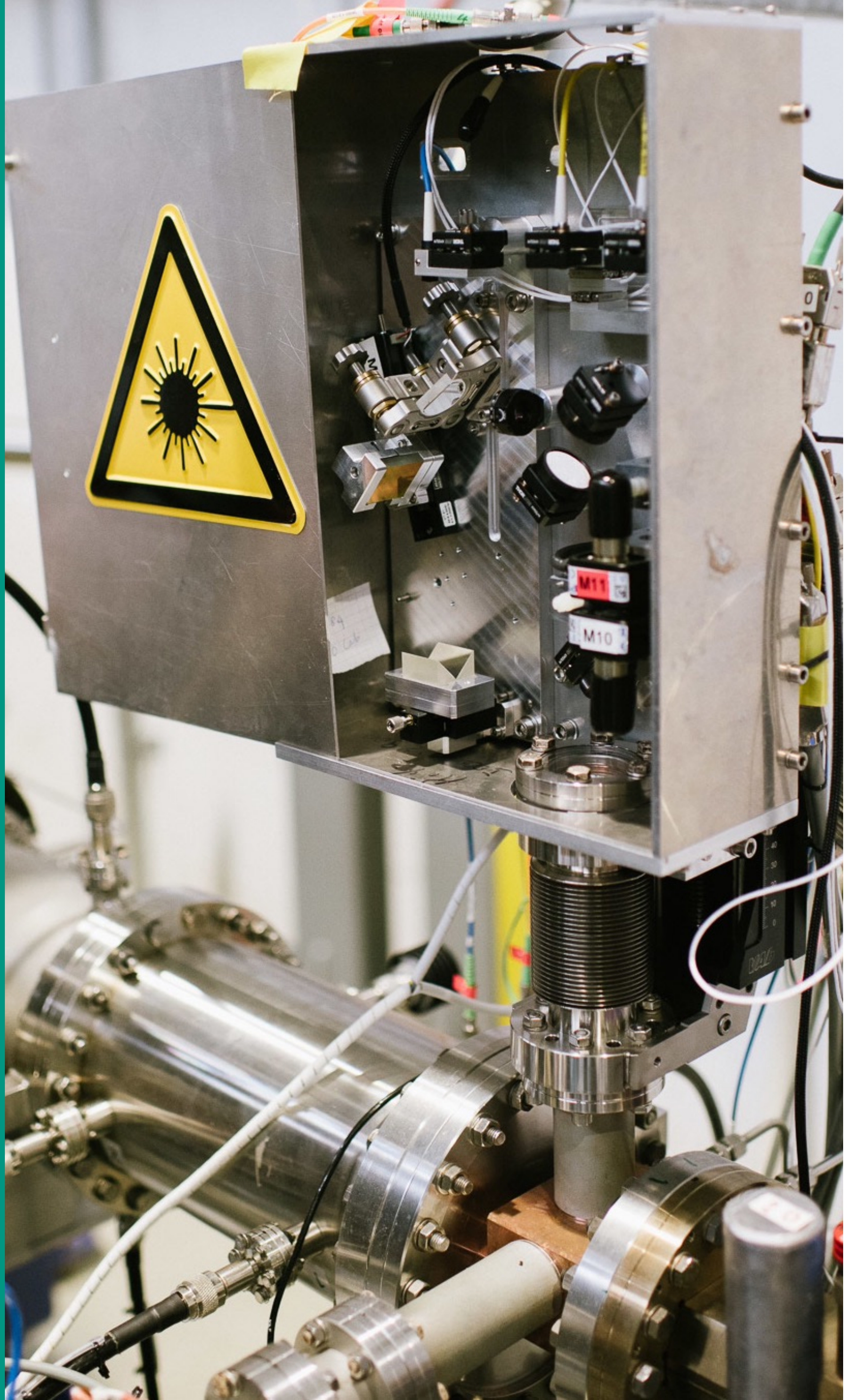
Coherent and resonant transition radiation as bunch compression monitors towards Smith-Purcell studies





2.05μm fused silica grating installed in EA chamber with 30% transmission through 1μm aperture

First prototype measurements with an electro-optical bunch profile monitor for FCC-ee



13th MT ARD ST3 Meeting, Zeuthen, 2025

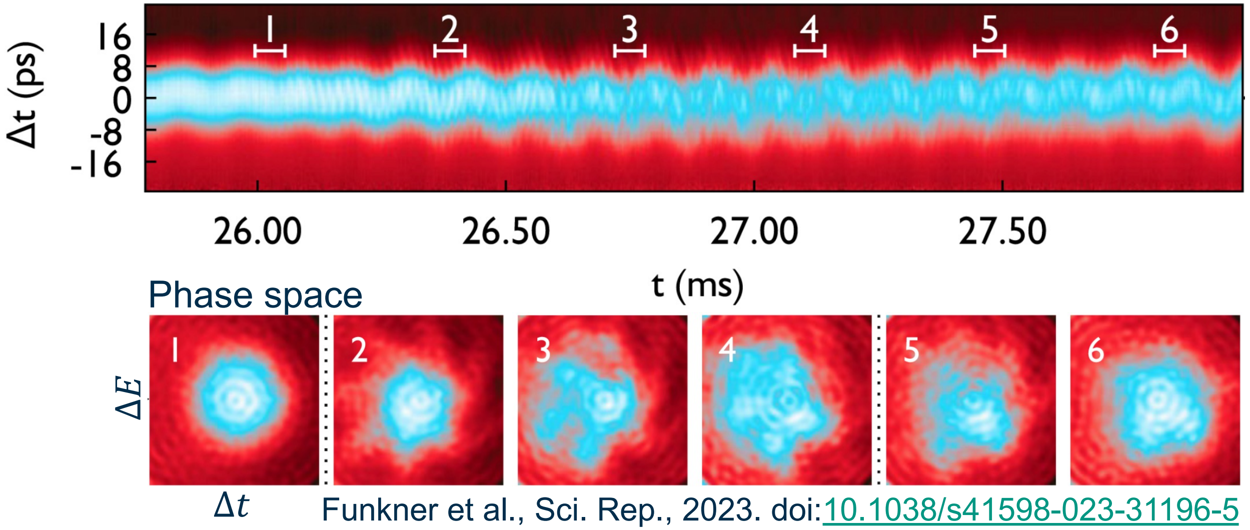
Micha Reissig et al.
KIT, Karlsruhe, Germany

Institute for Beam Physics and Technology

First prototype measurements with an electro-optical bunch profile monitor for FCC-ee

EO system at KARA:

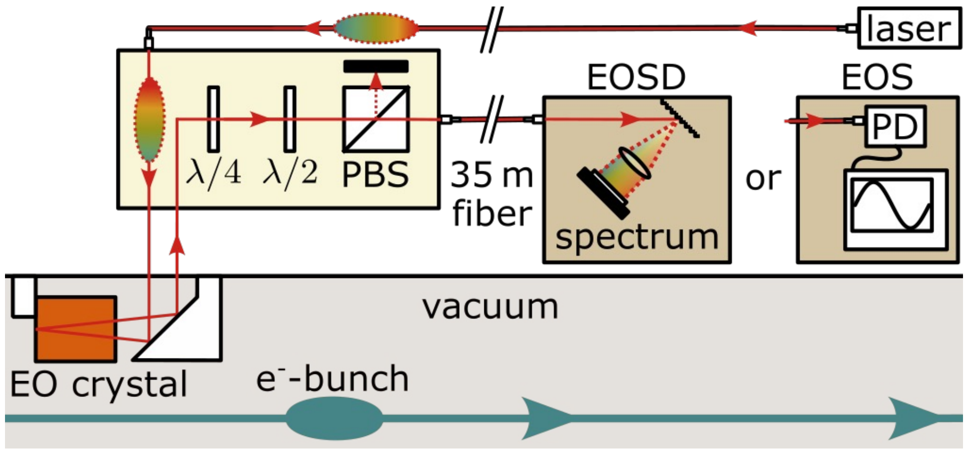
- Single-shot bunch profile measurements
- Turn-by-turn measurements at 2.7 MHz
- Designed for short bunches in the picosecond region
- Allows reconstruction of phase-space dynamics using tomography



Funkner et al., Sci. Rep., 2023. doi:10.1038/s41598-023-31196-5

Principle of Electro-optical spectral decoding (EOSD)

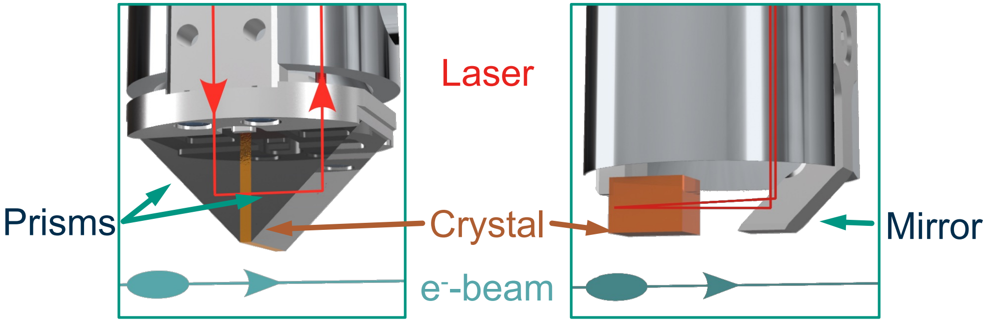
1. Pockels effect to encode bunch profile in polarization of the laser
2. Polarizer to transform into intensity modulation
3. Spectrum of the chirped laser pulse contains longitudinal bunch profile



First prototype measurements with an electro-optical bunch profile monitor for FCC-ee

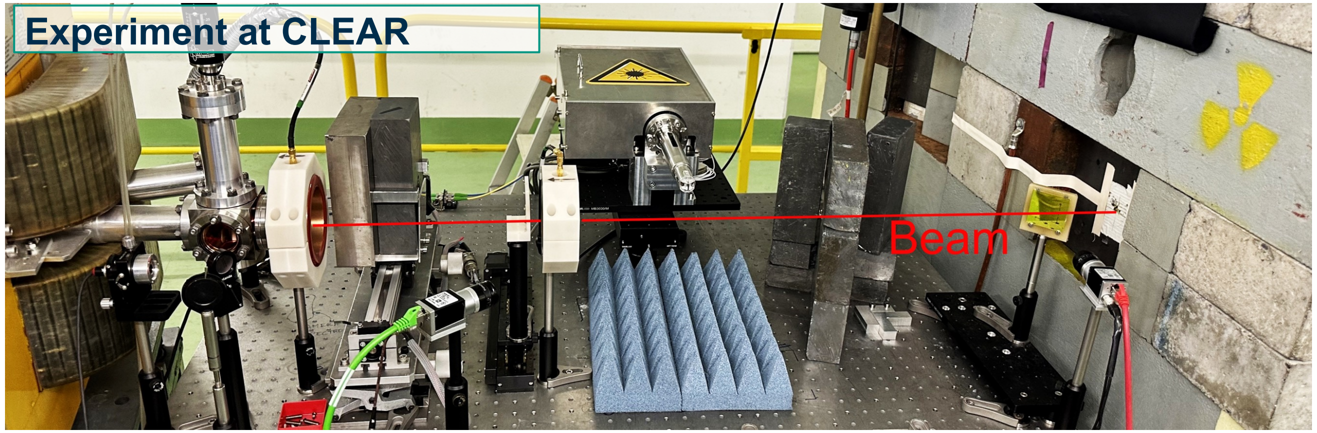
Novel crystal holder design

- Suitable for long and short e⁻-bunches
- Prisms instead of mirrors and reflective coatings
- Compact single-pass design → low impedance

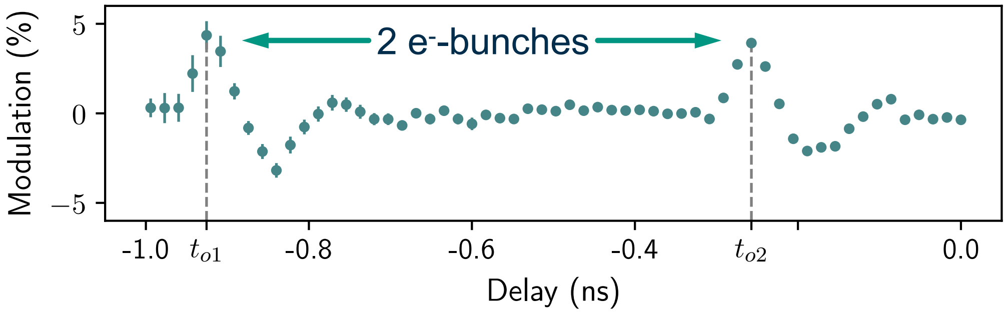


Proof-of-principle experiment at CLEAR
(CERN Linear Electron Accelerator for Research)

- Prototype built on basis of the KARA EO monitor
- Successful EO sampling of two consecutive bunches



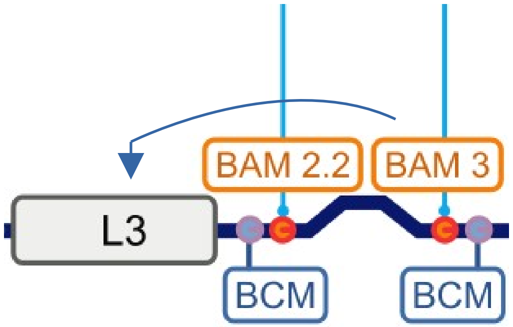
EOS prototype measurement

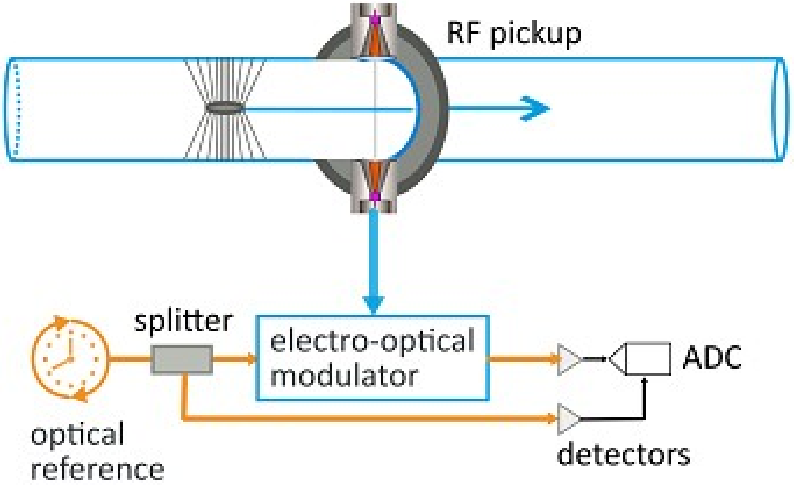


HIGH-RELIABILITY BUNCH ARRIVAL TIME MONITOR WITH FS PRECISION.

Jiri Kral, et el.
DESY, MSK

26/06/2025



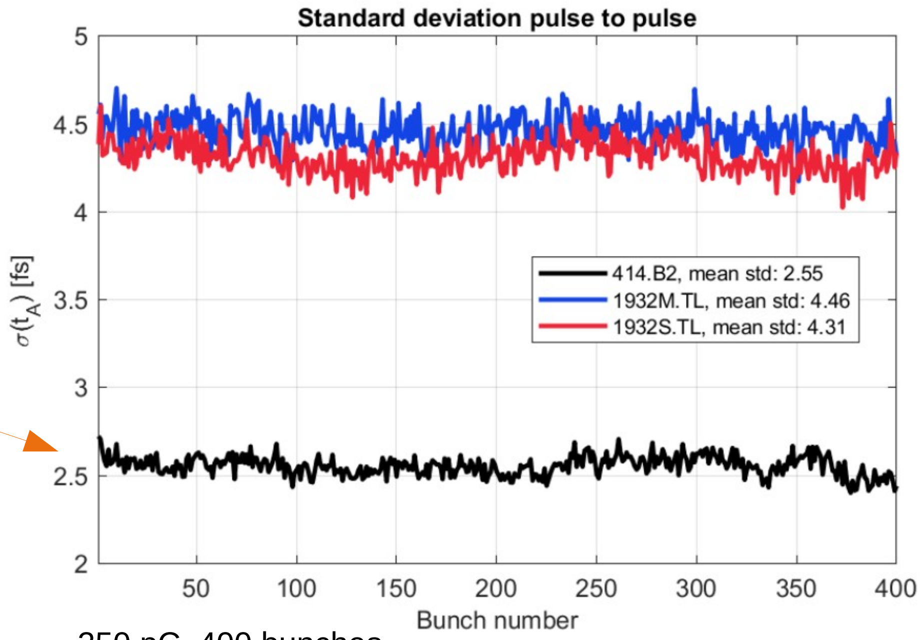


HELMHOLTZ

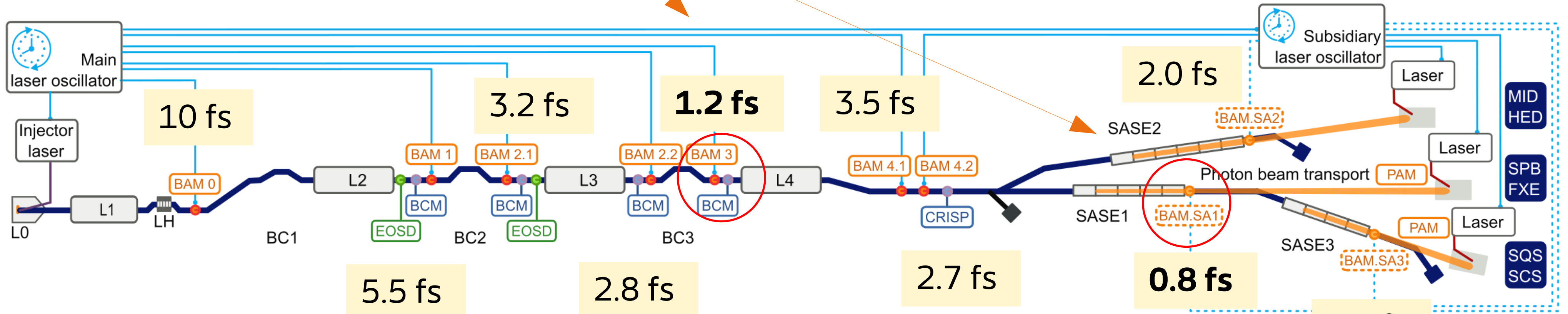
Results

Field leading:

- 24/7 measurement availability
- 2.55 fs in-loop machine synchronization
- ~ 1 fs measurement system resolution



250 pC, 400 bunches



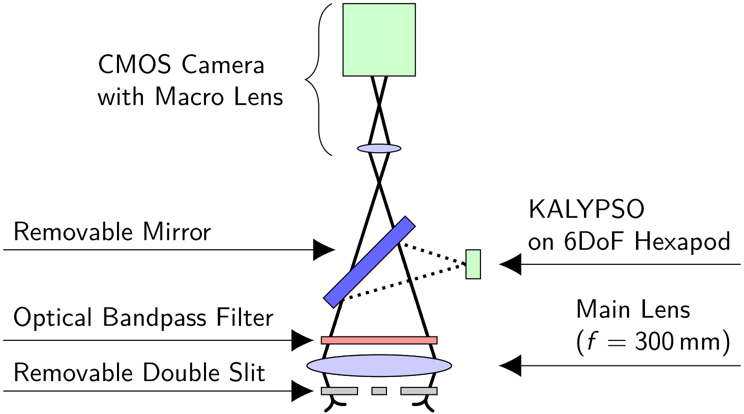
250 pC, 100 kHz – 100 MHz integrated noise

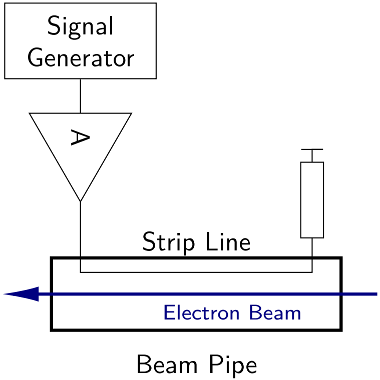
Time-Resolved Measurements of Transverse Beam Excitation in an Electron Storage Ring

13th MT ARD ST3 Meeting 2025 (DESY Zeuthen)

M.-D. Noll, E. Bründermann, M. Caselle, E. Huttel, J. L. Steinmann and A.-S. Müller | 26.06.2025

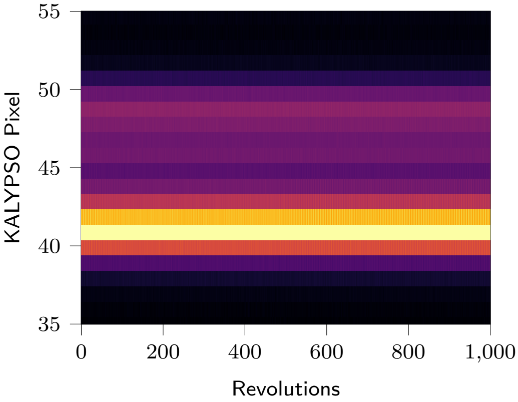
Detector and Modulation Setup



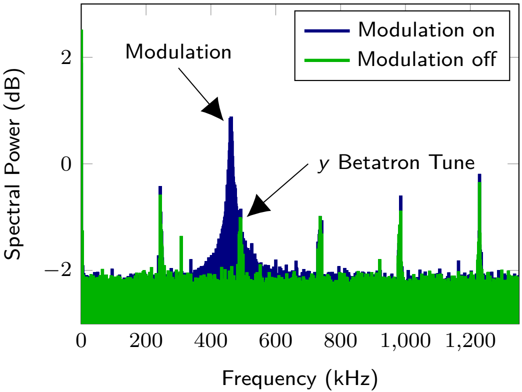


First Beam Position Results

Modulation on(t, y)



Periodogram of Modulation off and on



13th MT ARD ST3 Meeting 2025, DESY/Zeuthen

Beam Diagnostics for Measurement of longitudinal Beam Properties at UNILAC

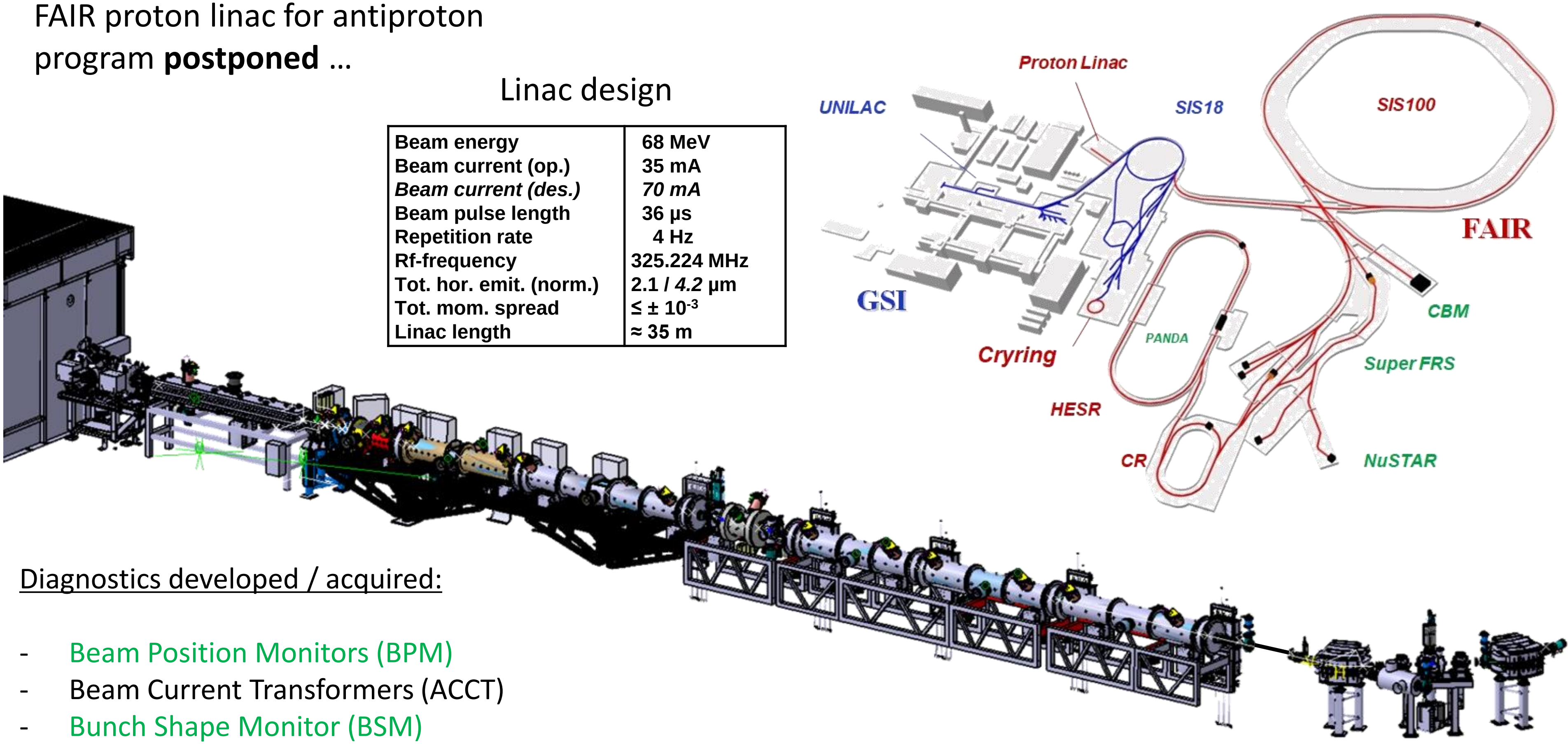
T. Sieber, P. Forck, S. Klaproth, M. Miski-Oglu, N. Schmidt, R. Singh

FAIR pLinac diagnostics development

FAIR proton linac for antiproton program **postponed** …

Linac design

Beam energy	68 MeV
Beam current (op.)	35 mA
Beam current (des.)	*70 mA*
Beam pulse length	36 µs
Repetition rate	4 Hz
Rf-frequency	325.224 MHz
Tot. hor. emit. (norm.)	2.1 / *4.2* µm
Tot. mom. spread	≤ ± 10^{-3}
Linac length	≈ 35 m

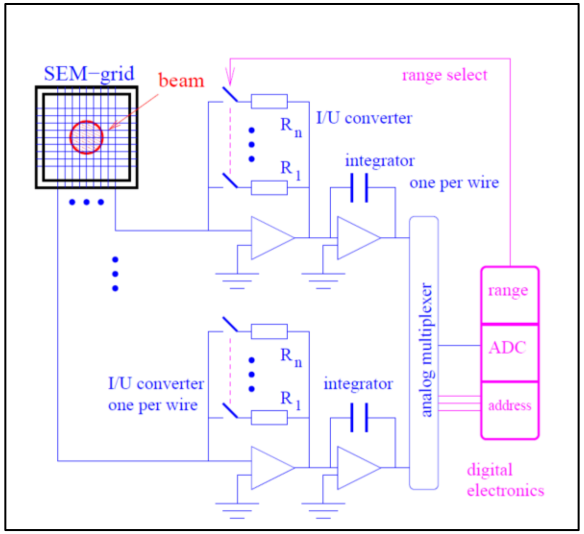


Diagnostics developed / acquired:

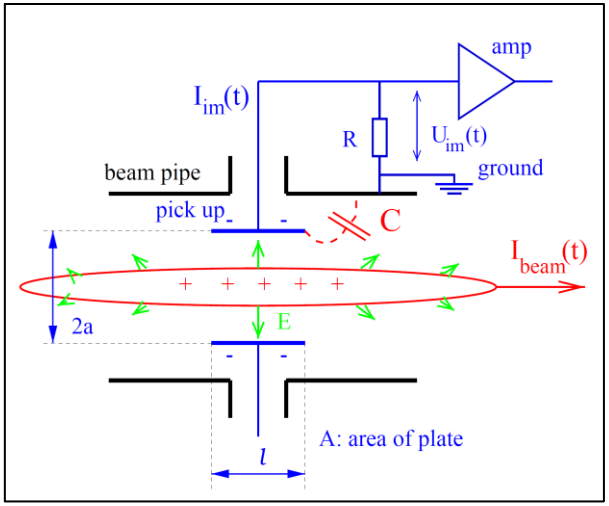
- Beam Position Monitors (BPM)
- Beam Current Transformers (ACCT)
- Bunch Shape Monitor (BSM)
- Secondary Electron Emission (SEM)- Profile Grids

→ **instruments are (in the meantime) used for beam experiments in existing GSI machines**

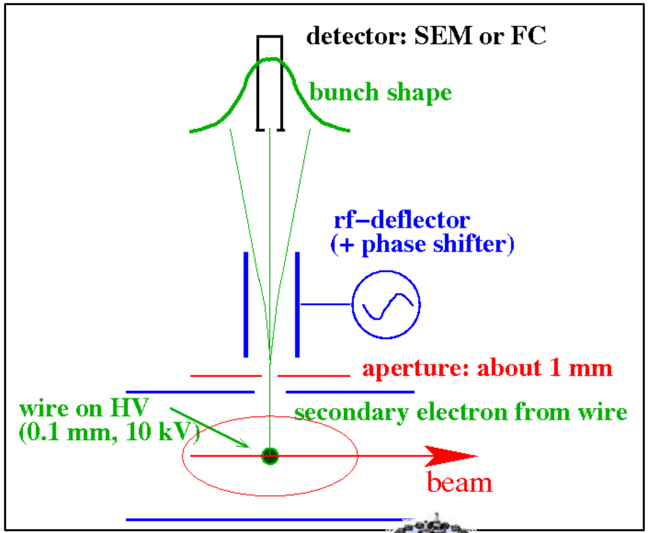
Diagnostics used for UNILAC measurements



SEM Profile Grids

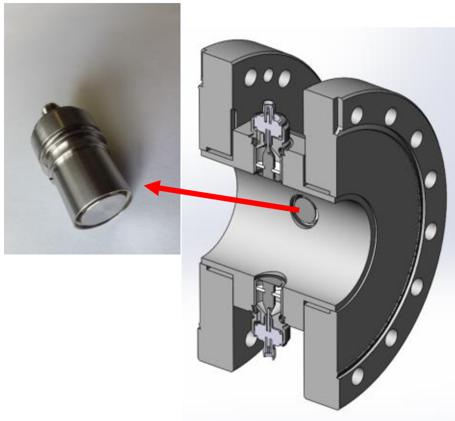


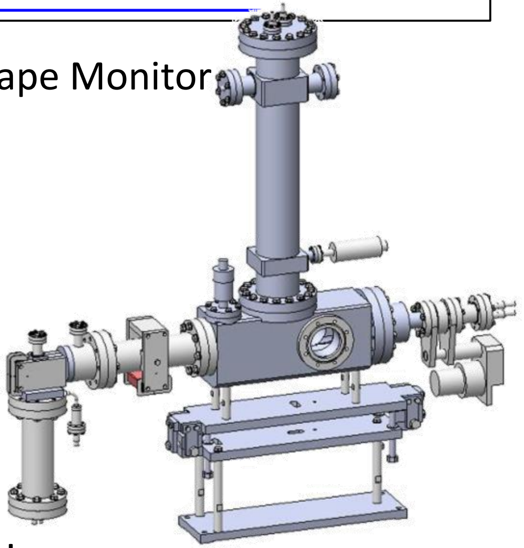
Beam Position Monitors



Bunch Shape Monitor

‘radial’ diagnostics measures longitudinal properties via dispersive elements (dipoles)

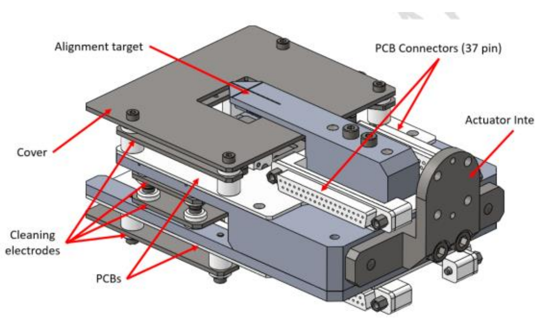


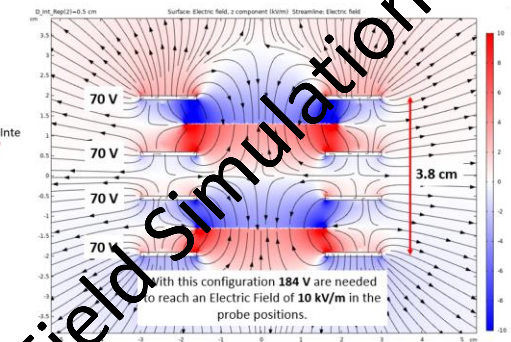


Measurement results from 2025 campaign → N. Schmidt, S. Klaproth

Some highlights ….

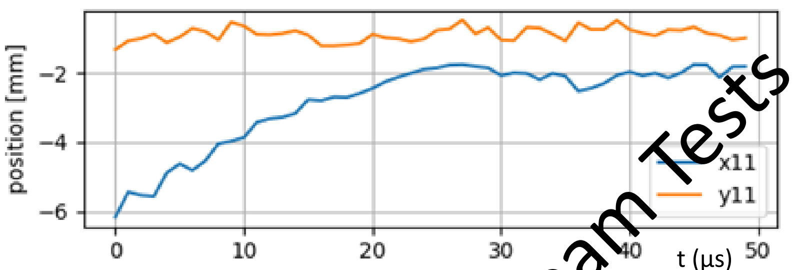
Field Simulations

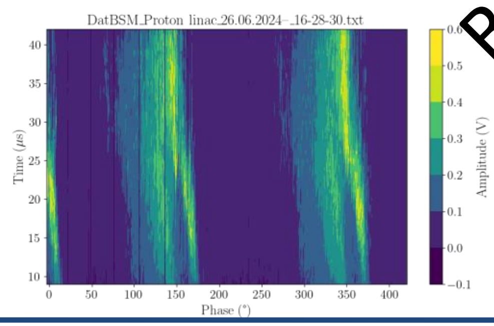




Beam Tests

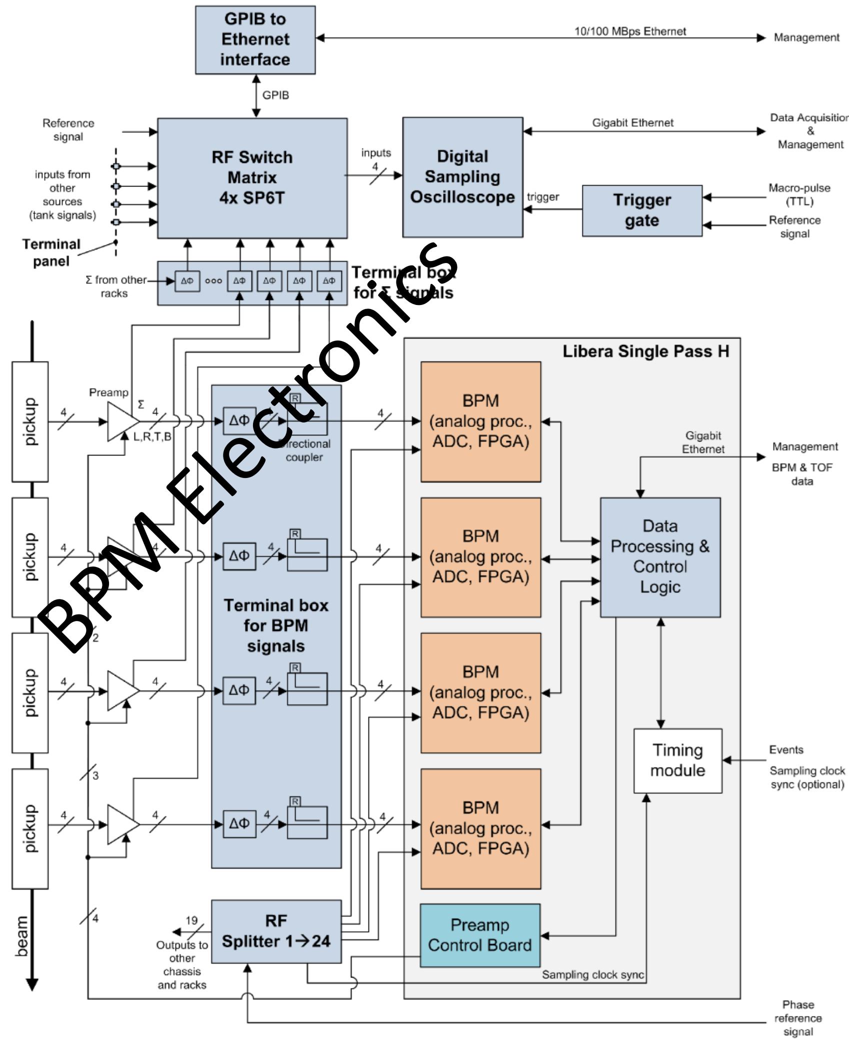
pLinac BPM test Feb. 2022 in X2 (8.6 MeV, 200µA protons)





Beam: U^{28+}, 11.4 MeV/u, 50µs, 1Hz, ~150µA

BPM Electronics



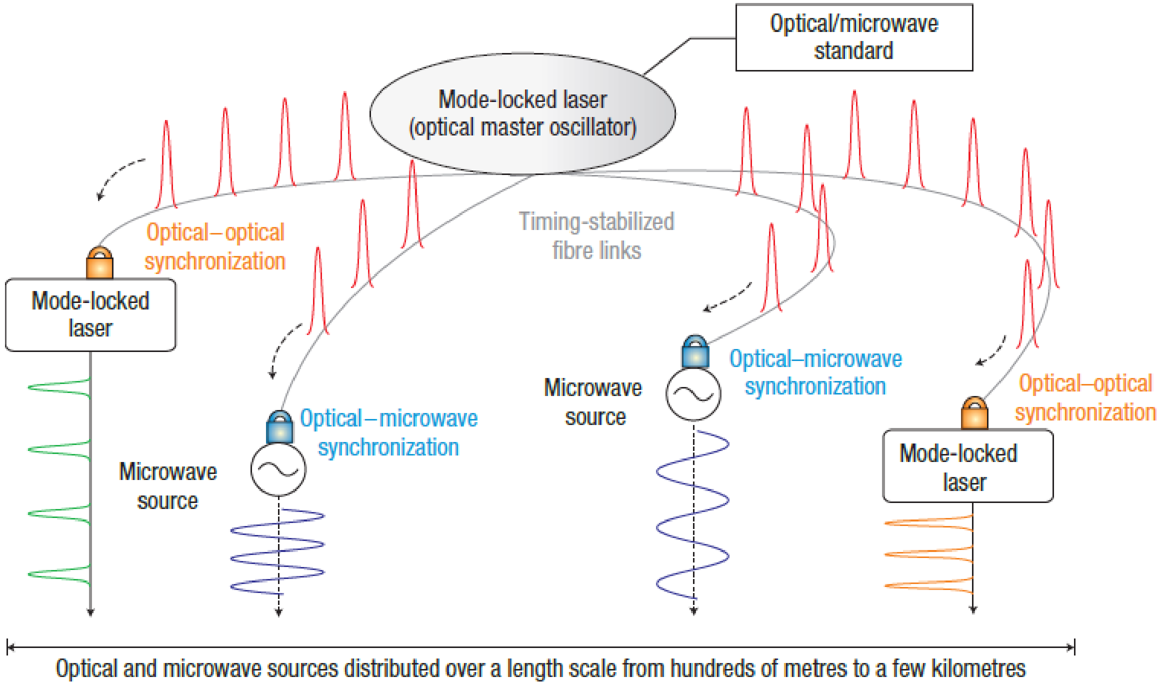
High-power Laser System Synchronization Optimization

Mohammed Salman

13th MT ARD ST3
Meeting 2025 – DESY

Introduction

- Importance of synchronization.
- Parts of the synchronization system at ELBE:
  - Reference RF oscillator
  - Optical Master Oscillator (OMO)
  - Timining-stabilized fibre links
  - Client sync- and locking
- Goal to reach < 100 fs overall jitter.



synchronization system structure [1]

[1] J.Kim, J.Cox and F.Kärtner, Drift-free femtosecond timing synchronization of remote optical and microwave sources.

Optimization work

- Upgrades and improvements
  - New Optical Master Oscillator
  - Building a client Optical-to-RF receiver
- Results, Challenges and subsequent work.

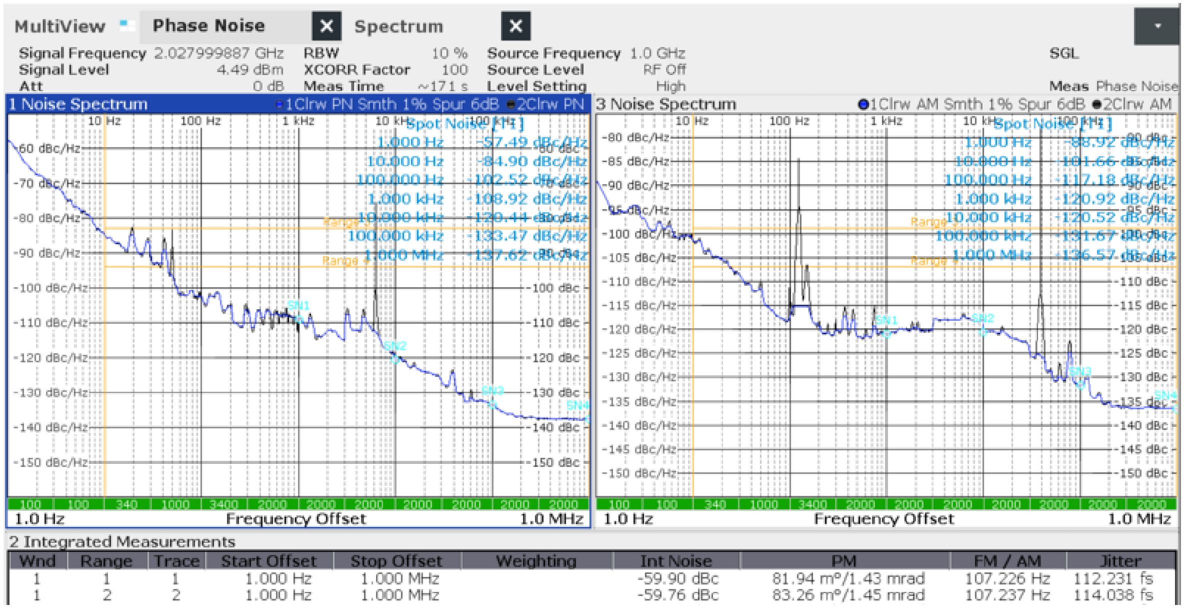


Figure1: Current Overall phase noise measurement

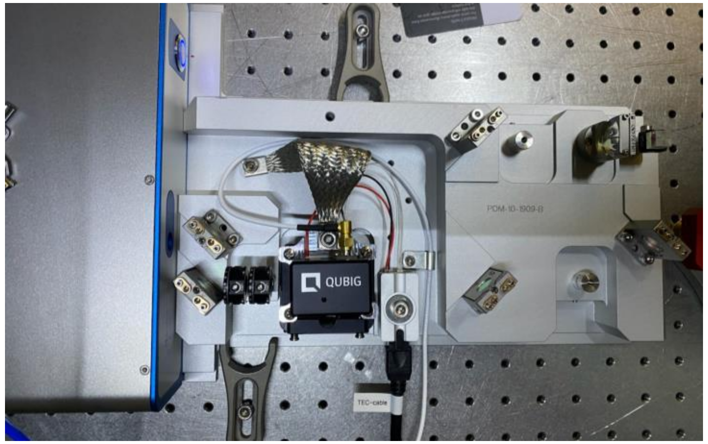


Figure2: New Optical Master oscillator + Pulse-Picker

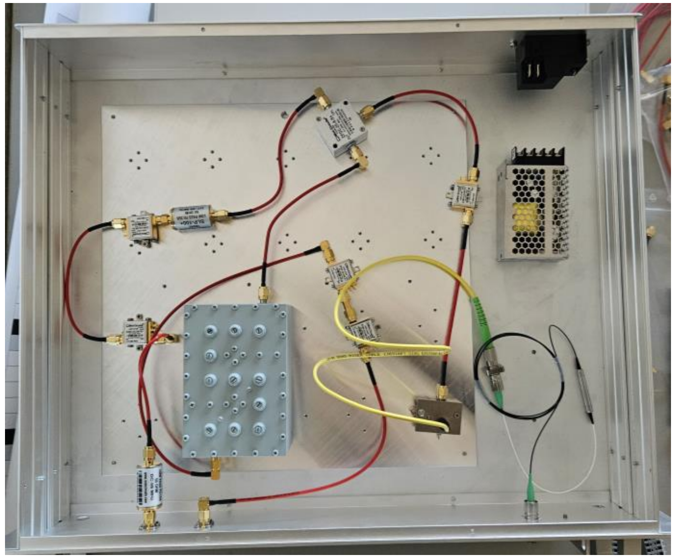


Figure3: Optical-to-RF Receiver

HELMHOLTZ

HZB Helmholtz Zentrum Berlin

Diagnostics, monitoring and analysis of high-energy proton beams

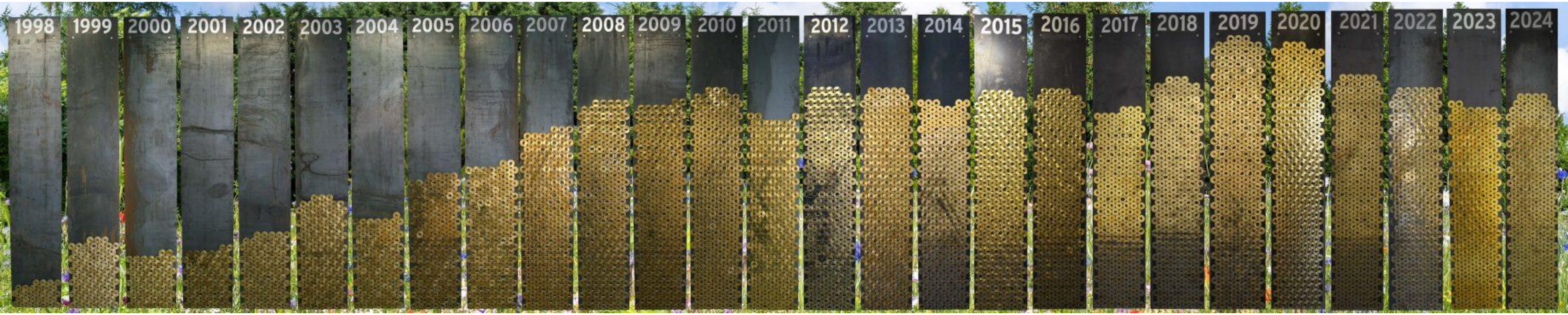
Georgios Kourkafas on behalf of Alina Dittwald
ARD ST3 Meeting 2025
DESY, Zeuthen

MT ARD

Proton Cyclotron @ HZB, Berlin Wannsee

Main application: therapy of ocular tumours with CHARITÉ university hospital Berlin. Other applications:

- accelerator research and development (ARD)
- radiation hardness tests on electronics and solar cells for space
- life sciences
- versatile user-driven irradiation campaigns

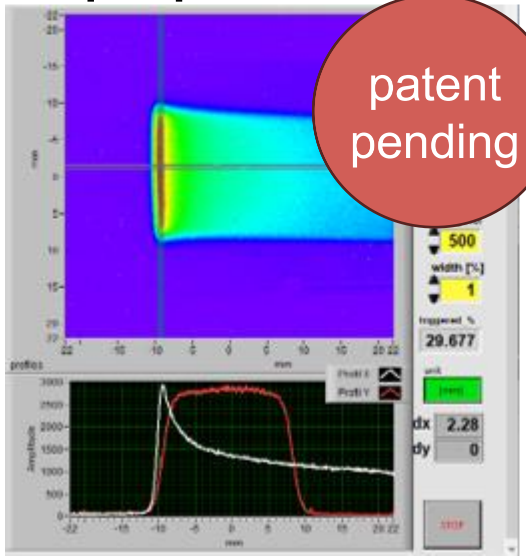


world-wide leading treatment facility
high impact papers based on experiments at HZB's proton beams

HZB Helmholtz Zentrum Berlin

Systems for beam spot analysis & depth profile visualization

Depth profile camera

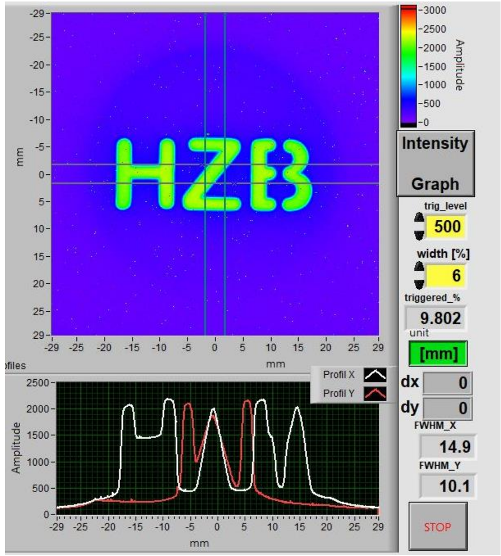


Optical system for depicting the **ion range** and Bragg peak with a 100 µm water-equivalent resolution, along with the integrated transverse beam profile

Q-eye

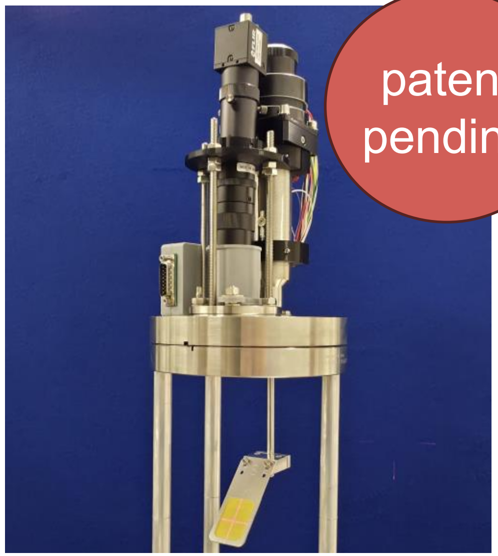
Multileaf Faraday Cup technology from HZB with a water-equivalent resolution of 120 µm transferred to industry and granted medical product verification

Field profile camera



Lightweight 3D printed camera system for the **transverse profile** in air able to measure beam currents down to 0.1 pA with a resolution of 50 µm as large as 60 mm

Optical BPM



Optical **beam profile monitor** using a thin ZnS layer on Kapton film, as a cost-effective solution with a potential of easy self-production with a resolution of 4 µm

MT ARD