Research on Ultra-short Bunch Length Measurements with Femtosecond Resolution for EuPRAXIA

EuPRAXIA Doctoral Network

Ana Guisao-Betancur, Joseph Wolfenden, Carsten Welsch.

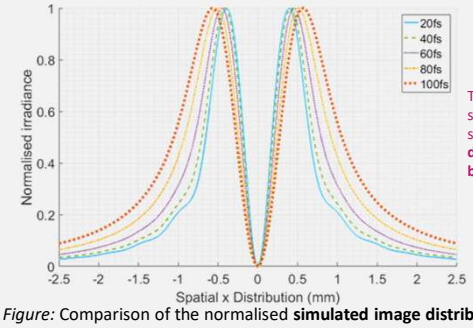
University of Liverpool and Cockcroft Institute, UK

Our approach to measuring electron bunch length

About the phenomenon of transition radiation

- It is typically **broadband**, from **microwave** to **X-ray**, depending on the particles' energy and the media's properties.
- It is **coherent** when $wavelength \geq bunch\ length$.
- For relativistic particles ($\gamma >> 1$), the radiation is **emitted in a narrow cone** ($\theta \sim 1/\gamma$) around the direction of particle propagation.
- The radiated energy is **linearly polarized** in the plane defined by the observation direction and the particle trajectory.

A THz-based imaging system has already been developed by University of Liverpool & QUASAR for **imaging** the source distribution of **coherent transition radiation** (CTR) and coherent diffraction radiation (CDR).



Theory and simulations have shown it is **dependent on bunch length**!

Figure: Comparison of the normalised **simulated image distribution** for different bunch lengths using beam parameters found in the MAX IV SPF [1].

Designing our monitor

1. **Working principle**
   - **Broadband imaging** of **coherent radiation** → Building on top of the research group's previous results.
2. **Operating conditions**
   - Shot-to-shot basis
   - Femtosecond resolution
   - Non-invasive online monitor

   → Crucial requirements for high-energy electron accelerators.
3. **Added value**
   - Design for EuPRAXIA
   - Integration to a "*Virtual diagnostics toolkit*"

   + potential to implement in other short pulse accelerator experiments

   → *New approach in particle accelerators!*

… and the virtual diagnostics toolkit

For mapping available non-invasive diagnostics into beam parameters of interest at the Interaction Point.

Input Non-invasive diagnostic* → **Machine Learning Model** → ***Prediction*** Output measurement**

- **Spectral or scalar** radiative measurements.
- **Linac** and **e-beam** parameters.

- **1D current profile.**
- **Emittance.**
- **2D LPS distribution.**

*available on a single-shot basis

**otherwise measured with invasive/destructive techniques

What are the challenges? Reliability, durability, variability, and need for redundancy of the virtual diagnostics system.

Next steps

a) Identifying the specific EuPRAXIA parameters and requirements for the monitor's design and optimization with

UK — D-Beam, Innovative Optical Diagnostic Solutions

b) Planning a secondment for testing and integration at

Italy — INFN National Institute for Nuclear Physics

References

1. Wolfenden, J., et al. (2019). Coherent Transition Radiation Spatial Imaging As a Bunch Length Monitor. 2713–2716.
2. Convery, O., et al. (2021). Uncertainty quantification for virtual diagnostic of particle accelerators. Physical Review Accelerators and Beams, 24(7), 74602.
3. Emma, C., et al. (2021). Virtual diagnostic suite for electron beam prediction and control at FACET-II. Information (Switzerland), 12(2), 1–13.
4. Cianchi, A., et al. (2018). Conceptual design of electron beam diagnostics for high brightness plasma accelerator. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 909, 350–354.

Contact Information

A.M.Guisao-Betancur@liverpool.ac.uk

The Cockcroft Institute of Accelerator Science and Technology

University of Liverpool

This project has received funding from the European Union´s Horizon Europe research and innovation programme under grant agreement no. 101073480 and the UKRI guarantee funds.