Software for Detector Design for Future Wakefield-Based Colliders

Applicant: Andrii Pauchkov (andrii.pauchkov@cern.ch).
Mentors:
Angira Rastogi (arastogi@lbl.gov);
Simone Pagan Griso (spagangriso@lbl.gov).

Abstract: This project focuses on extending the existing software pipeline for detector-design studies of future wakefield-based colliders within the Key4hep software stack. The current pipeline already supports physics event generation and detector simulation, but presently includes only a simplified smearing-based detector front-end (FE) response. The main goal of the project is to implement and validate more realistic detector FE response emulation and physics object reconstruction using native Gaudi algorithms. The developed workflow will be used to study detector occupancies, hit timing distributions, reconstruction efficiencies, and other event-level performance metrics for benchmark physics signatures. The student will gain experience with Key4hep, Gaudi, DD4hep, EDM4hep, detector simulation, reconstruction software, and detector-performance studies.

Project description and deliverables. Future wakefield-based colliders may provide very high-energy lepton collisions in compact accelerator designs. However, the optimal detector concept for such machines remains under active study. A realistic and modular software pipeline is therefore needed to evaluate detector occupancies, hit timing distributions, machine-induced backgrounds, reconstruction performance, and the impact of detector-layout choices.

The project will build on an existing Key4hep-based software setup that can already run physics event generation and DD4hep-based detector simulation. At the moment, the detector front-end response is described using a simplified smearing-based approach. The main goal of this project is to extend the pipeline by implementing more realistic detector FE response emulation and physics object reconstruction using native Gaudi algorithms. Existing approaches developed for future HEP collider studies may be adapted and validated for the wakefield-collider application.

The expected deliverables include: implementation of native Gaudi algorithms for realistic detector FE response emulation and physics object reconstruction; integration of these algorithms into the Key4hep workflow; addition of configuration options for detector and reconstruction studies; validation using DD4hep simulated events; performance studies of detector occupancies, hit timing distributions, reconstruction efficiencies, and other event-level metrics; benchmarking of selected signal models and detector-

layout choices; documentation explaining how to run, test, and extend the developed pipeline.

Project start date: June 22nd.

- **Week 1.** Onboarding: reading the main references on the 10 TeV wakefield-collider concept, the current detector-design studies, and the Key4hep software stack. Setting up the software environment and study the current workflow.

- **Week 2–3.** Implement native-Gaudi algorithms for running realistic detector FE response and physics object reconstruction, add configuration options, and validate on DD4Hep simulated events

- **Week 4–8.** Study detector occupancies, hit timing distributions, reconstruction efficiencies, and other event-level metrics. Tune the detector design for required physics performance and benchmark signal models.

- **Week 9–12.** Integrate visualization tools for creating 3D images of detector geometry. Final testing, cleanup, documentation, and preparation of the final report. Summarize the achieved software deliverables, detector performance, remaining limitations, and possible future improvements.

References:

1. Concept of 10 TeV wakefield collider, Available at: https://arxiv.org/pdf/2503.20214.

2. Key4hep documentation, Available at: https://key4hep.github.io/key4hep-doc/.

3. Gaudi documentation, Available at: https://gaudi.web.cern.ch/gaudi/.