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Project Duration: 12 Weeks
Proposed Start Date: 1st July 2026

IRIS-HEP Fellows Program Project Proposal

Charged-Particles Reconstruction at Muon Colliders: 3D Sensor Charge Digitization Model

Abstract

Muon colliders are promising candidates for future experiments due to their ability to reach multi-TeV collision energies with more compact and cheaper designs. However, muon decays produce a large beam-induced background (BIB). This project aims to successfully implement the hybrid 3D pixel sensor digitization model into the Key4Hep-based muon collider software stack. Investigation of hit timing capabilities and detector occupancy in the presence of BIB can improve "noise" rejection in the innermost layers of the detector with 3D sensor geometry.

1 Project Description and Deliverables

A muon collider can combine the strengths of hadron and electron colliders. With a bigger mass, muons emit less synchrotron radiation, so a muon collider could reach higher energies. Furthermore, muons, unlike protons, are fundamental particles that put all their energy into a collision. Thus a muon collider could be much smaller and cheaper, while still reaching multi-TeV collision energies. Muon collisions are cleaner and more likely to produce important particles like the Higgs boson. Moreover, muon collider's sensitivity to weak interactions could help detect weakly interacting massive particles.

The biggest challenge while dealing with muon colliders is the high rate of beam-induced background (BIB) produced from muon decays due ot their short lifetime. Therefore, colliders must operate quickly and efficiently before muons decay. At the same time, hits must be precisely detected so the particles from the real collision can be separated from the large multiplicity of BIB particles entering the detector concurrently. Hence we need to try for advanced technologies for high spatial and temporal resolution as well as which have high radiation tolerance in the innermost layers of the detector for good tracking performance of charged particles.

One way for a muon collider to cope with BIB would be to implement 3D sensors into the innermost layers of pixel detectors. In 3D sensors electrodes are deposited in columns, opposed to the usual planar configuration with electrodes deposited on the faces of the sensor. Therefore, 3D geometry reduces charge drift inside the detector and provides better timing precision. In addition, they are also more radiation tolerant due to the lower probability of charge trapping in the silicon defects over time. The goal of this project is to include 3D sensor charge digitization model in the muon collider software stack to study the hit occupancies and timing capabilities for better BIB mitigation techniques. This implementation will simulate timing response and pixel cluster formation in 3D pixel sensors. The main idea is to evaluate the tracker detector performance by the hit occupancy, timing and BIB rejection.

2 Project Timeline

- Weeks 1–4: study muon collider detector concepts, silicon detector digitization process and 3D sensor technology; get familiar with the muon collider software stack; run the whole pipeline from detector simulation to object reconstruction.
- Weeks 5–8: implement 3D sensor charge digitization model into the software; validate the results through hit energy and timing distributions, detector occupancy, and comparison between planar and 3D sensors.
- Weeks 9–12: study track reconstruction performance with new tracker design, analyze pixel cluster shapes for better BIB mitigation techniques; write a report detailing the development process, improvements, and analysis results.

References

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