1st Semester Report

Abdussamad Mangalasseri (samad2492@gmail.com)
Particle Physics and Astronomy
Supervisor: Dr Biplab Dey

Provisional Thesis Title: *Probing Dark Matter via Long-Lived Particles at LHCb/CODEX-b*

Introduction

The European Organization for Nuclear Research (CERN) operates the Large Hadron Collider (LHC), the world's highest-energy particle accelerator, hosting several large experiments dedicated to exploring fundamental interactions. Among them, the LHCb (Large Hadron Collider beauty) experiment is a forward spectrometer optimised for heavy-flavour physics, enabling precise studies of hadrons containing b and c quarks and providing stringent tests of the Standard Model through measurements of CP violation and rare decays.

Dark matter and its potential interaction with the Standard Model (SM) through new mediators remain one of particle physics' most compelling mysteries. The search for long-lived particles (LLPs) has emerged as a promising avenue to probe dark sector physics, particularly at the LHC experiments. The concept of LLPs has gained increasing prominence over the last decade, as evidenced by a growing body of literature [1, 2, 3], with numerous experimental efforts dedicated to their discovery. Recent theoretical developments have proposed various dark sector models that naturally give rise to LLPs [4]. The LHCb experiment has demonstrated unique capabilities in searching for LLPs, particularly in the forward region [6].

To address remaining gaps, the proposed CODEX-b (Compact Detector for Exotics at LHCb) detector extends LHCb's sensitivity to LLPs with longer decay lengths. Positioned transverse to the beamline $\sim$25 m from the interaction point in a heavily shielded volume, CODEX-b provides a nearly zero-background decay region instrumented with RPC-based tracking to identify displaced LLP decays. Its pilot demonstrator, CODEX-β, currently under commissioning, serves as a testbed for these technologies. My PhD research focuses on developing simulation and analysis tools to support LLP searches with CODEX-b, with integration into the LHCb framework.

Research Activities During the Semester

Technical Onboarding and Framework Integration

The primary focus of my first semester was establishing the integration of the CODEX-b detector within the LHCb software framework (Detector/Gauss/Boole), a critical step toward enabling realistic simulations and physics studies. This work directly supports the CODEX-b collaboration's simulation effort and ensures compatibility with LHCb's data processing pipeline. I successfully installed and validated the complete LHCb and CODEX-b software stack, providing a reliable foundation for ongoing CODEX-β data taking and physics studies.

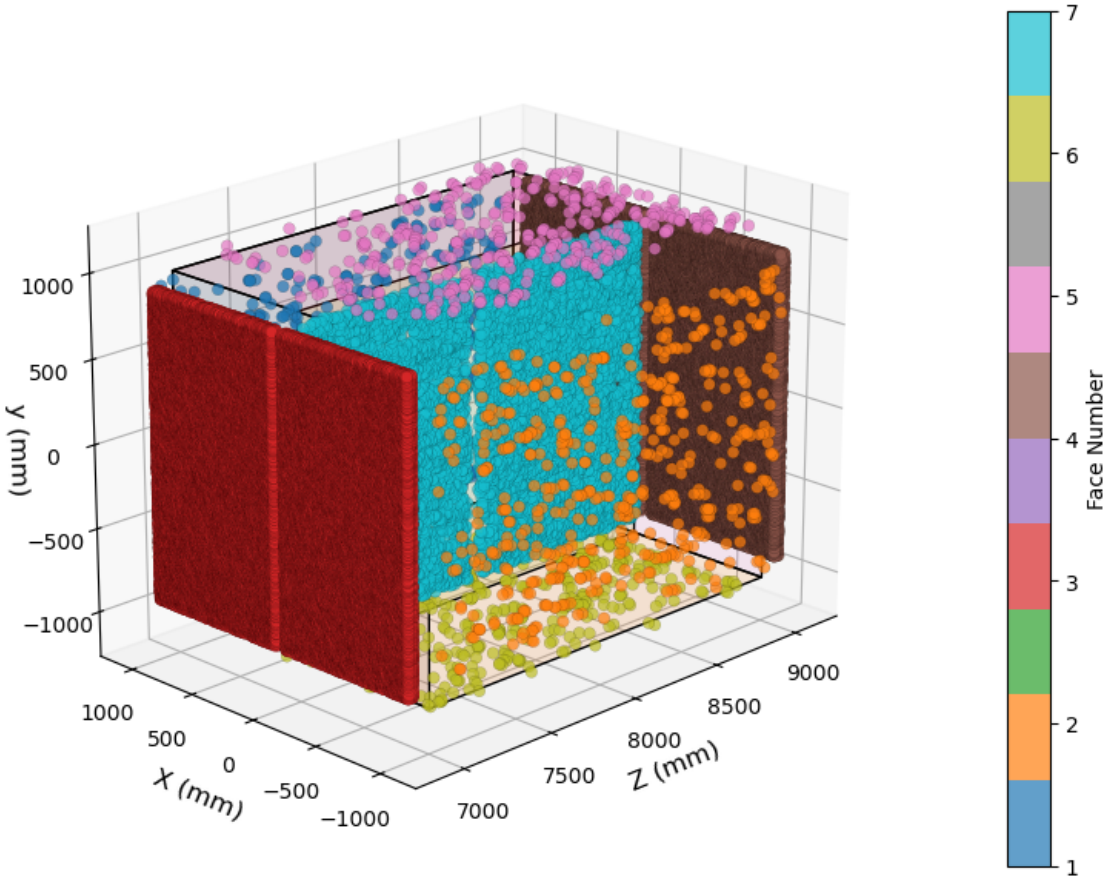

Figure 1:

Geometry Implementation

I collaborated with my colleagues to complete the CODEX-b detector geometry implementation in the LHCb framework. This involved coding the full detector description using DD4hep, including all sensitive volumes, materials, and positioning relative to the LHCb interaction point. The geometry has been thoroughly validated and is ready for merging via our submitted Merge Request (MR !692).

Hit Generation and Simulation Development

Building on the geometry, I advanced the simulation workflow by generating MC hits in CODEX-b's sensitive volumes using Gauss. Figure 1 shows successful hit deposition from Gauss-generated events, confirming proper particle propagation through the detector. A dedicated merge request (MR !1251) for Gauss has been submitted, representing a key milestone for subsequent analysis workflows.

Ongoing Simulation Optimisation

In Gauss simulations, we identified and are addressing configuration-specific issues, including volume overlapping and missing hits on the front face for certain configurations. These are being resolved through refined geometry tagging and particle propagation settings.

Boole Digitisation Development

With hits established, I initiated the digitisation phase in Boole by creating a functional skeleton for the CODEX-b digitiser (CBDigitCreator), modelling RPC response from MC hits to RawBanks compatible with LHCb's DAQ stream. A preliminary Merge Request (MR !794) has been opened, with active development underway to implement realistic RPC efficiency, clustering, and electronics effects.

These activities establish the foundation for sensitivity studies and physics analyses planned for the following semesters.

Study Activities During the Semester

Conferences and Schools

- Participation in the **CERN Starter Kit 2025** training program (1–5 December 2025), covering LHC computing, software frameworks, and experiment-specific tools.
- Completion of CERN shift training for the Data Manager role, enabling participation in LHCb/CODEX-b data operations and data-quality workflows.

PhD coursework at ELTE

- **Data Mining and Machine Learning** (FIZ/3/084)
- **Selected Chapters from Experimental High Energy Physics** (FIZ/2/117)
- **Guided Research Work 1.** (FIZ/S1/K18)

Scietific Activities

- Delivered a presentation to the CODEX-b simulation working group on simulation issues in Gauss.

References

[1] S. Alekhin et al., "A facility to search for hidden particles at the CERN SPS: the SHiP physics case," *Rep. Prog. Phys.*, vol. 79, p. 124201, 2016.

[2] J. Beacham et al., "Physics beyond colliders at CERN: beyond the Standard Model working group report," *J. Phys. G: Nucl. Part. Phys.*, vol. 47, p. 010501, 2019.

[3] C. Antel et al., "Feebly Interacting Particles: FIPs 2022 Workshop Report," arXiv:2305.01715.

[4] S. Knapen and S. Lowette, "A Guide to Hunting Long-Lived Particles at the LHC," *Annu. Rev. Nucl. Part. Sci.*, vol. 73, p. 421, 2023.

[5] L. Calefice et al., "Effect of the high-level trigger for detecting long-lived particles at LHCb," *Front. Big Data*, vol. 5, p. 1008737, 2022.

[6] G. Aielli et al., "Expression of interest for the CODEX-b detector," *Eur. Phys. J. C*, vol. 80, p. 1177, 2020.