Project Proposal: Validating Fast Analytical Tools Against the ACTS Framework

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Project Duration: 10 weeks

Introduction

Achieving precise momentum resolution ($\sigma(pT)/pT$) at future electron-positron Higgs Factories demands innovative detector designs. Currently, comprehensive Monte Carlo simulations with detailed reconstruction software, such as Geant4, provide precise performance evaluations but are computationally intensive and time-consuming, which limits their practical use during initial detector design phases [1]. To overcome this limitation, a Python-based analytical tool has been developed to provide rapid, approximate evaluations of detector performance [2]. However, the reliability of this tool must be validated against established simulations for different geometrical parameters.

This project aims to validate the analytical tool by comparing its tracking performance with that of the ACTS (A Common Tracking Software) framework [3]. By evaluating the analytical tool alongside full simulation results using consistent detector configurations, the project will demonstrate the analytical tool's capability to provide fast, accurate, and reliable feedback, which is crucial for efficient detector optimizations. Additionally, the project aims to illustrate the impact of various geometrical parameters and how changes in these parameters affect detector performance.

Project Objectives and Methodology

The validation will focus on single-muon event simulations, chosen for their simplicity and clarity in assessing intrinsic detector performance. Realistic and publicly available configurations, such as the Open Data Detector, will be utilized to ensure accuracy and reproducibility in comparisons [4].

Initially, the project involves:

- Acquiring proficiency with the ACTS reconstruction framework, particularly in performing simulations and extracting essential detector parameters (hit resolution, detector size, detector thickness).
- Inputting these parameters into the analytical Python tool to calculate performance metrics directly.

Subsequently, detailed comparative analyses will be conducted to evaluate:

- Track residue distributions.
- Transverse momentum resolution (σ(pT)/pT).
- Effects of variations in detector geometry parameters.

These metrics will be presented through performance plots, validating the analytical tool's accuracy and responsiveness to changes in detector configurations.

Plan for Summer 2025

June (Weeks 1-3)

- Familiarize thoroughly with the ACTS framework and the analytical Python tool.
- Conduct initial simulations of 10,000 single muon events with simple detector configurations to establish baseline performance metrics.
- Generate preliminary plots illustrating track residues and momentum uncertainties.

July (Weeks 4-7)

- Extract critical detector parameters (radius, hit resolution, radiation length thickness) from ACTS simulations.
- Integrate extracted parameters into the analytical tool.
- Perform detailed comparative analysis to validate the analytical tool against ACTS, documenting initial accuracy through performance plots.
- Investigate variations in detector geometry to assess their impact on track momentum resolution.

August (Weeks 8-10)

- Refine the analytical tool based on the outcomes of the July validation.
- Generate optimized performance plots that document the final validation results.
- Prepare a comprehensive technical report that summarizes validation activities, results, and provides guidelines for effectively applying the analytical tool in future detector design optimizations.

Reference

[1] S. Agostinelli et al., “Geant4—a simulation toolkit,” *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 506, no. 3, pp. 250–303, 2003. DOI:10.1016/S0168-9002(03)01368-8
[2] C. Abbamonte, V. Cairo, F. Chen, and C. Young, “Tracking Resolution Code (Version 3.0),” Zenodo, 2024. [Online]. Available: https://doi.org/10.5281/zenodo.11199209
[3] X. Ai et al., “A Common Tracking Software Project,” arXiv preprint arXiv:2106.13593, 2021. https://arxiv.org/abs/2106.13593
[4] The Open Data Detector Tracking System. CERN Document Server, 2023. https://cds.cern.ch/record/2869673