k4DetPerformance: A Framework for Tracking Performance Studies in Full Simulation Environments

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Abstract

K4DetPerformance is a framework designed to study tracking performance within full simulation environments. Initially developed for the CLD detector for FCC-ee, K4DetPerformance has now been integrated into the Key4hep software stack. Current efforts are focused on extending its applicability to other detectors. The framework requires a complete simulation and reconstruction setup. It employs Condor for running simulations and reconstructions, uses FCCAnalyses for handling RDataFrame, and matches reconstructed tracks to simulated particles. The framework supports plotting options, including the ability to superimpose plots and ratios for comparative analysis. K4DetPerformance provides a robust solution for tracking performance evaluation and has become an essential tool for detector performance studies across different detector models within the Key4hep software ecosystem.

Full Simulation

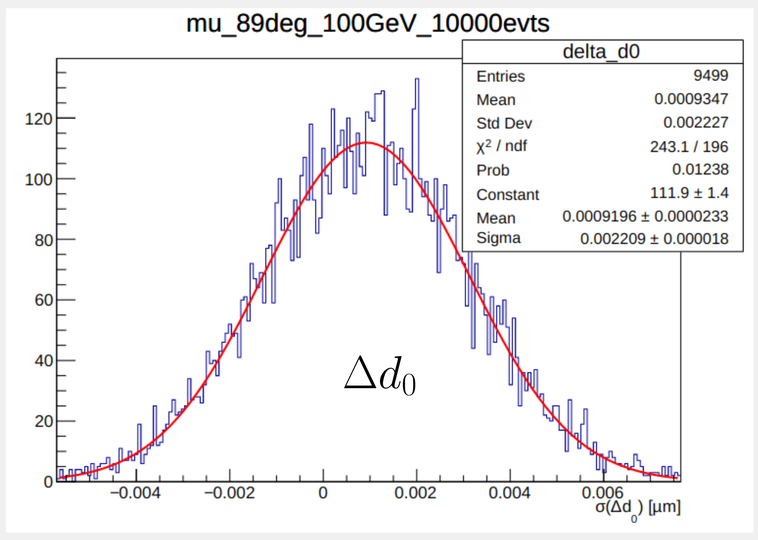
Full simulation refers to a detailed and comprehensive process using **Geant4**. The key aspects of full simulation include:

- **Realistic modeling** of particle interactions and movement.
- **Detailed detector specifications**, such as dimensions, materials, and layout.
- Simulation of the entire sequence from particle generation to their interactions with the detectors and the data capture by sensors.

Reconstruction involves interpreting the signals left in the detectors to recreate the original properties of the particles, such as their trajectory, energy, and momentum.

- Simulation with **particle gun** events
  - **Single particle** events with **fixed momentum and θ** and **flat ϕ**
  - With muons, electrons and pions
  - Simulation and reconstruction are performed using **Condor**

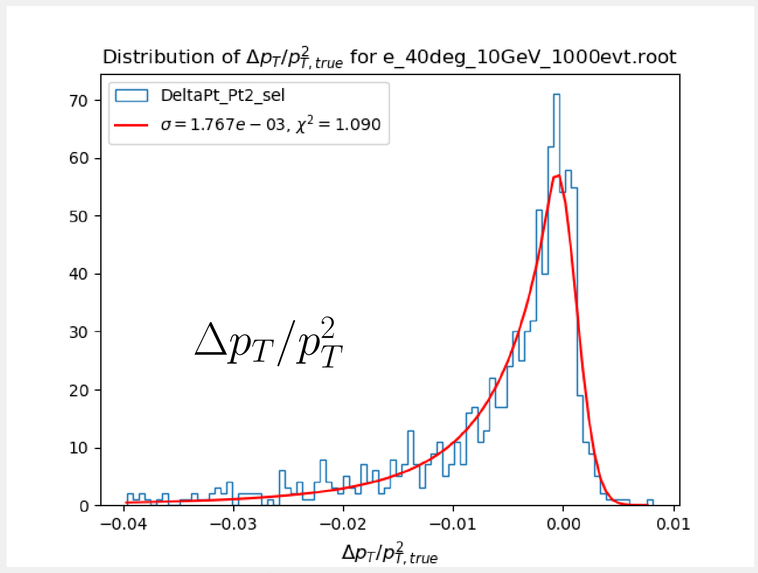
Tracking resolution



Δd_0 distribution for muons

The tracking resolution is determined by comparing reconstructed tracks to their corresponding simulated particles. This is achieved through the following steps using **FCCAnalyses** for handling **RDataFrame**:

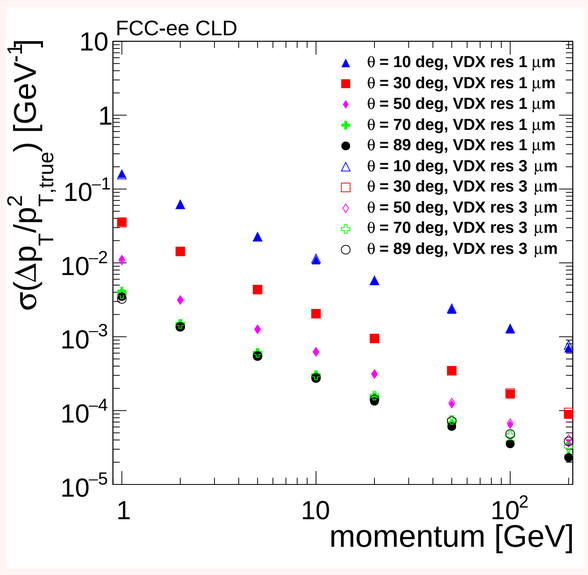
- Matching **reconstructed tracks – simulated particle**
- Calculation of resolution: $\sigma(\Delta$ = reco - true)
  - For p and pT, resolution is: $\sigma(\Delta$ = reco - true) / true^2)
  - Resolution is the width of the **gaussian fit**, or **crystal ball fit** for **electron momentum**

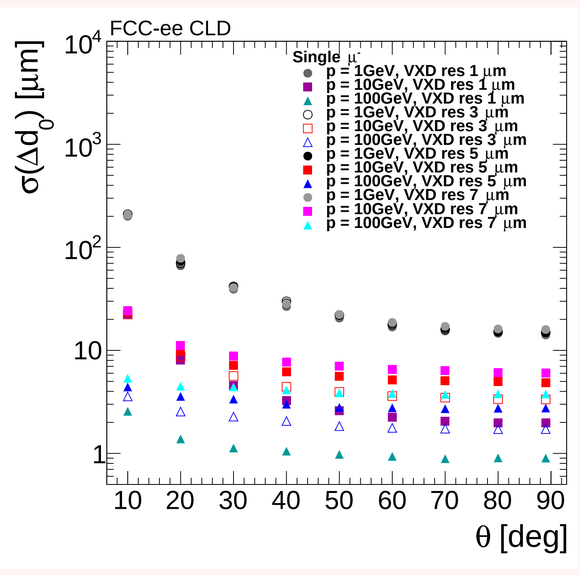


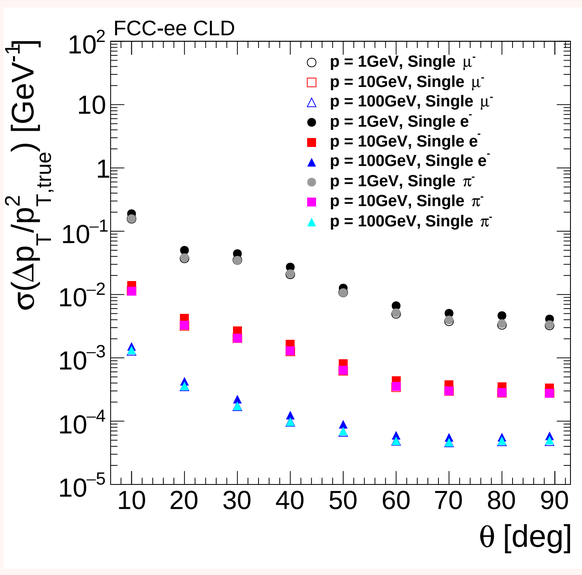
$\Delta p_T/p_T^2$ distribution for electrons

Some results for CLD detector

Superimposed plots

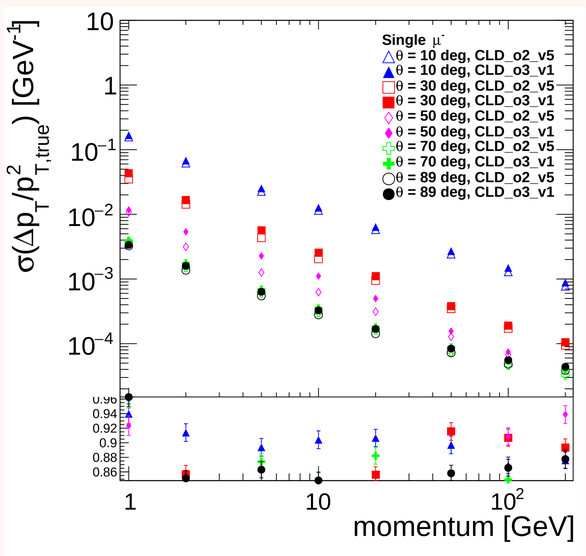






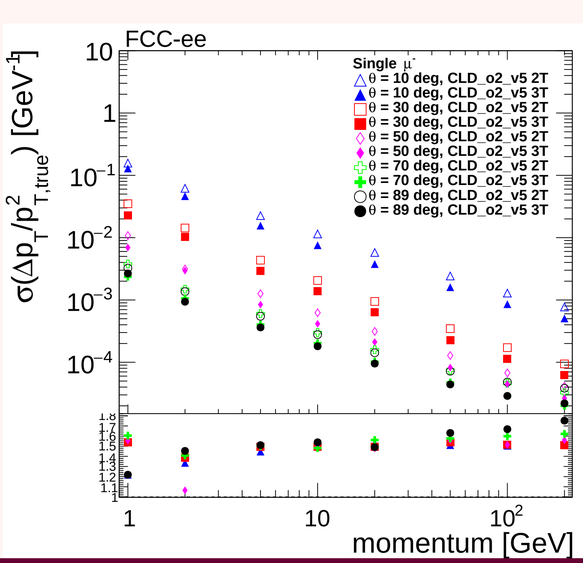
From left to right: p_T resolution as a function of momentum for different vertex spatial resolution, d_0 resolution as a function of polar angle θ for different vertex spatial resolution, p_T resolution as a function of polar angle θ for μ^-,e^- and π^-

Ratio plots



Left: p_T resolution as a function of momentum for CLD without Particle identification detector (PID) (02_v5) and CLD with PID and shrunk tracker (03_v1)

Right: p_T resolution as a function of momentum for CLD without PID with 2T (reference) and 3T magnetic field



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