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Particle Detector Simulation in C++

PHYS30762 Project Report

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Abstract

This project simulates a particle detector using object oriented design principles, and is built around a polymorphic class architecture, with an abstract `Particle` base class, concrete subclasses, and individual detector classes. The framework incorporates custom manager classes such as `DetectorManager` and `InferenceEngine` that provide methods for running batch detections, logging true versus measured energies, and inferring unseen neutrinos from missing energy. Specialised features include tau-decay branching logic, probabilistic detection efficiencies, and rule-based particle identification based on hit patterns.

1 Introduction

Modern particle physics experiments rely on sophisticated detector systems to reconstruct properties of particles produced in high-energy collisions. Among the most prominent are the ATLAS and CMS detectors at the Large Hadron Collider (LHC), designed to explore the Standard Model and search for new physics including the Higgs boson and dark matter. These detectors use layered subsystems including trackers, calorimeters, and muon chambers to capture a particle's charge, momentum, energy, and trajectory [1]. The ATLAS detector, located 100 metres underground near Meyrin, Switzerland, employs six concentric subsystems to identify and measure particles emerging from collisions by using a large magnet system to bend charged particles, ATLAS is the largest-volume particle detector constructed [2]. The CMS detector uses a superconducting solenoid generating a 4-tesla magnetic field, enabling precise momentum measurements. It shares physics goals with ATLAS but follows different engineering principles [3]. These detectors are designed to explore the Standard Model and to search for phenomena such as the Higgs boson, whose discovery was confirmed in 2012 [4].

Modern particle physics is described by the Standard Model, a quantum field theory that unifies the electromagnetic, weak, and strong interactions. It organises all known elementary particles into three generations of quarks (up, down; charm, strange; top, bottom), three generations of charged leptons (electron, muon, tau) with their corresponding neutrinos, and the gauge bosons (photon, $W^{\pm}$, Z^0, gluons) that mediate forces, additionally the Higgs boson responsible for mass generation. The Standard Model predicts

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