Z → e■e■ Decay Simulation using ROOT

Abstract

We simulate the decay of the Z boson into an electron–positron pair using ROOT. The Z boson mass distribution is modeled with a Breit–Wigner distribution, and we study the resulting electron energy spectrum in the Z boson rest frame. This project demonstrates Monte Carlo event generation and histogramming, core techniques in High Energy Physics (HEP) data analysis.

Introduction / Motivation

The Z boson is a mediator of the weak interaction with a mass around 91 GeV. Studying its decays provides insights into electroweak physics and serves as a benchmark for collider experiments such as those at CERN. ROOT, a framework developed at CERN, is widely used in High Energy Physics for data analysis and event simulation. This project demonstrates a simple toy event generator for Z → e■e■ decays, highlighting ROOT's histogramming and random number generation tools.

Methods

We approximate the Z boson mass distribution using a relativistic Breit–Wigner function: $f(m) \propto 1 / ((m^2 - M\_Z^2)^2 + (M\_Z \Gamma\_Z)^2)$ where $M\_Z \approx 91.2$ GeV is the central mass and $\Gamma\_Z \approx 2.5$ GeV is the decay width. In the Z boson rest frame, each decay produces an electron and positron of equal energy: $E\_e = m\_Z / 2$ The ROOT function `gRandom->BreitWigner(M_Z, Γ_Z)` is used to generate random Z masses. For each generated event, the electron energy is computed and filled into a histogram. Tools used: - **ROOT** (CERN's C++ analysis framework) - **C++** - **TCanvas, TH1F** classes for plotting

Results

A histogram of electron energy distribution was generated for 100,000 simulated events. The spectrum peaks around half the Z boson mass ($\approx$ 45.6 GeV) and spreads due to the natural width of the Z boson. The output histogram was saved as `ZDecay.png`. This illustrates how experimental data might look in a real collider experiment, where event counts are distributed according to the Z boson's Breit–Wigner mass distribution.

Discussion

The results confirm the expected distribution of electron energies from Z decays. While simplified (ignoring detector effects, boosts, and angular distributions), this toy model captures the essence of how invariant mass and decay width shape observed spectra. Limitations: - Simulation performed only in the Z rest frame - No background processes included - No error analysis or detector effects simulated Nevertheless, the project demonstrates the workflow of event generation, histogramming, and data visualization using ROOT, laying the groundwork for more advanced HEP simulations.

References

1. The ROOT Team, "ROOT Data Analysis Framework," CERN, https://root.cern 2. Griffiths, D., *Introduction to Elementary Particles*, Wiley-VCH, 2008 3. Thomson, M., *Modern Particle Physics*, Cambridge University Press, 2013