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PHYS 265

Lab 3 Report:
Invariant Mass Analysis of the Z Boson Decay to Leptons

Introduction

The Z boson is a fundamental particle predicted by the Standard Model and it is responsible for mediating neutral current interactions in weak nuclear processes. Utilizing precise measurement of its mass and decay width plays a crucial role in testing and justifying the Standard Model. This lab focuses on reconstructing the Z boson invariant mass distribution using simulated leptonic decay events performing a fit using the Breit-Wigner resonance model, and analyzing uncertainty through a parameter scan.

The Invariant Mass Distribution & it Fits

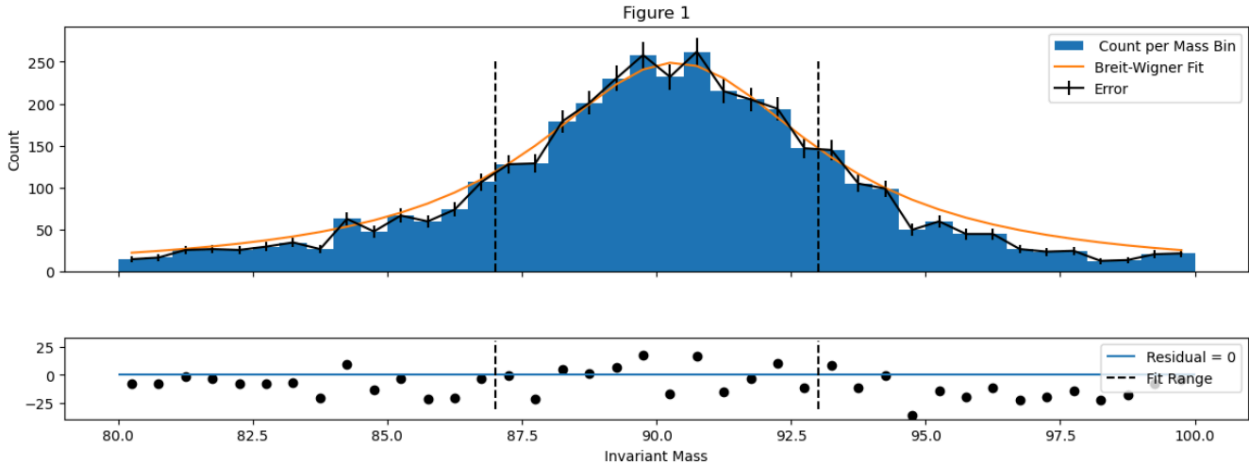
The invariant mass distribution was obtained by reconstructing the four-momentum of each lepton pair from simulated data. Using these momentum components, the invariant mass m of each lepton pair was calculated:

- $m = \sqrt{[(E + E)^2 - |p + p |^2]}$

A histogram of the invariant mass was plotted and fitted within the mass window of 87–93 GeV with a Breit-Wigner distribution defined as:

- $D(m; \text{mass}, \text{decay width}) = [2500/\pi] \times [\text{decay width}/2] / [(m - \text{mass})^2 + (\text{decay width}/2)^2$

The fitting was performed using weighted least-squares minimization and I yielded these results: Fitted mass of the Z is 91.2 GeV, Fitted uncertainty on the Z mass is 0.1 GeV, Chi-square (χ^2) is 33.2, Degrees of freedom (ν) is 30, and the P-value: 0.

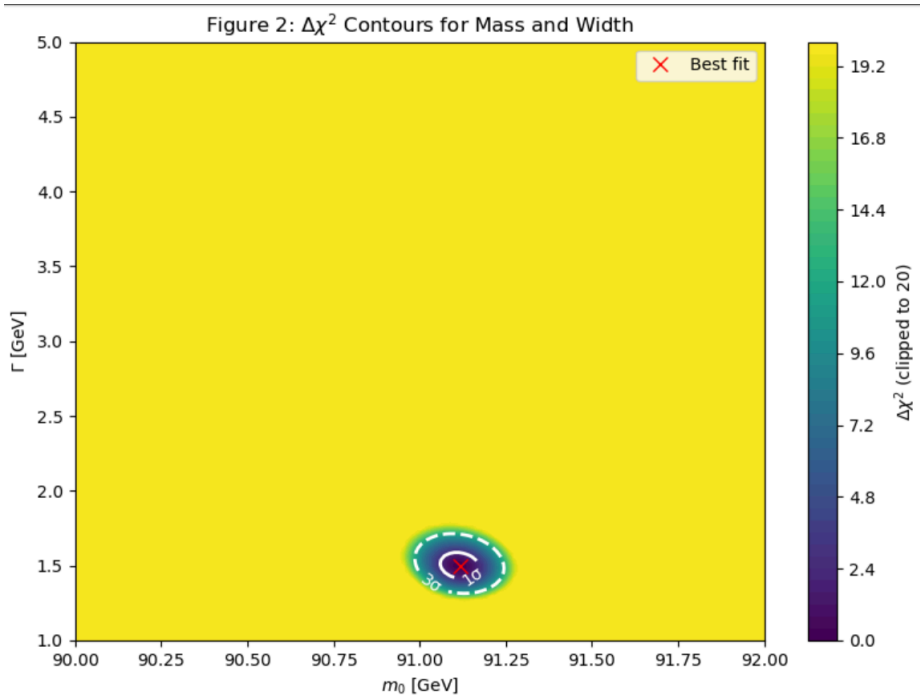


The 2D Parameter Scan

To order to understand uncertainties and correlations between mass and width decay, a two-dimensional scan of the $\Delta\chi^2$ parameter space around the best-fit parameters was conducted. The $\Delta\chi^2$ is defined as:

- $\Delta\chi^2(m, \Gamma) = \chi^2(m, \Gamma) - \chi^2$

Contours corresponding to $\Delta\chi^2$ values of 2.30 (1σ confidence level) and 11.83 (3σ confidence level) were plotted. These contours represent the statistical uncertainty and parameter correlation while indicating the range of acceptable parameter values given the data and statistical uncertainties



Discussion and Future Work

Comparison to Particle Data Group Accepted Values

Our measured mass and width of the Z boson are very close to the accepted Particle Data Group (PDG) values:

- Accepted Particle Data Group Mass: 91.1876 ± 0.0021 GeV 2
- Accepted Particle Data Group Width: 2.4952 ± 0.0023 GeV

Approximations and Limitations

- Systematic uncertainties (detector calibration, background estimation, luminosity) were not included.
- Detector energy resolution and efficiency (specific to ATLAS detector characteristics) were not considered.
- Background events that might distort the distribution were not modeled

Recommendations for Future Work

- Incorporating systematic uncertainties into the fitting procedure.

- Simulating and correcting for detector resolution effects. 3 Including realistic background modeling and subtraction.
- These improvements will significantly enhance the robustness and realism of future analyses, providing more precise measurements consistent with current experimental standards