Lab 3

PHYS265

Teuben & Clark

I. Introduction

This report presents an analysis of the Z boson invariant mass using high-energy collision data from the ATLAS experiment. The Z boson is a fundamental particle that mediates the weak nuclear force and plays a crucial role in the Standard Model of particle physics. By analyzing the invariant mass distribution of lepton pairs produced in high-energy collisions, we can experimentally determine the Z boson's mass and decay width. This project aims to fit a Breit-Wigner resonance model to the invariant mass distribution, extract the Z boson mass with its uncertainty, and evaluate the goodness of fit through statistical analysis. Additionally, a two-dimensional parameter scan was performed to visualize the correlation between the mass and decay width parameters and establish confidence regions.

II. The Invariant Mass Distribution and its Fit

The invariant mass distribution was calculated using the four-momenta of lepton pairs from the ATLAS dataset. For each collision event, the components of the four-momentum were derived from the transverse momentum (ρ_T), pseudorapidity (η), azimuthal angle (φ), and energy (E) of each lepton, then the invariant mass was computed using the relativistic formula $M = \sqrt{E^2 - (p_x^2 + p_y^2 + p_z^2)}$. The data was binned in 40 equal width bins ranging from 80 GeV to 100 GeV. For the fitting procedure, the peak region between 87-93 GeV was the focus to which a Breit-Wigner decay distribution model was applied, where m_0 is the Z boson mass and Γ is the decay width. This function was scaled by a normalization factor of 5000/2 to match the data amplitude.

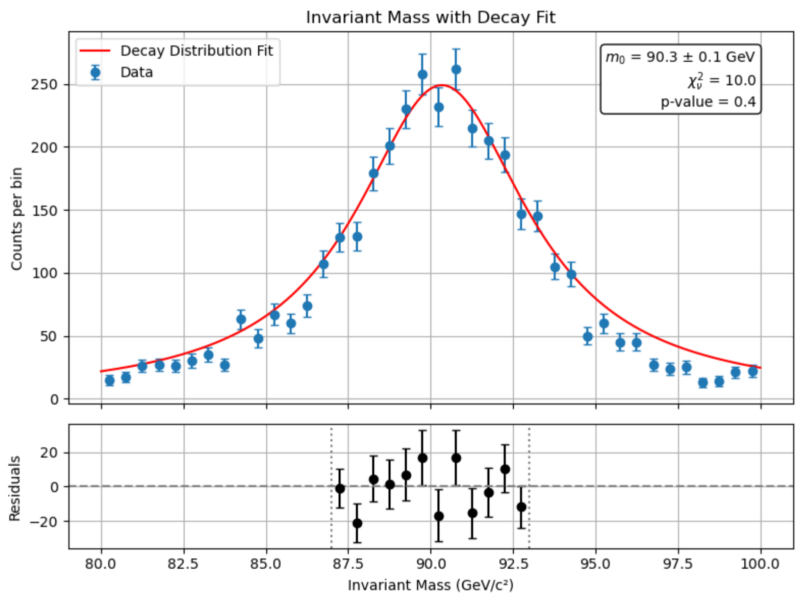

Figure 1. Invariant mass distribution of lepton pairs with a Breit-Wigner fit overlaid. Error bars represent statistical uncertainties.

The fitting resulted in a Z boson mass of 90.3 GeV with an uncertainty of 0.1 GeV, a χ^2 value of 9.9, 10 degrees of freedom, and a p-value of 0.4. By using the curve_fit function from scipy.optimize, these values were calculated. The chi-square was calculated from the residuals between the data and the model prediction. The p-value of 0.4 indicates a good agreement between the Breit-Wigner model and the experimental data. The reduced chi-square is approximately 1.0, which further supports that the fit is appropriate, and any deviations can be linked to statistical fluctuations rather than systematic disagreements.

III. The 2D Parameter Scale

To explore the correlation between the Z boson mass and decay width parameters, a two-dimensional χ^2 parameter scan was performed. This technique involves fixing these two parameters at various values across a grid and calculating the χ^2 at each point. The resulting χ^2 map reveals confidence regions in the parameter space. Scanning the mass parameter from 89 to 91 GeV and the decay width from 5 to 8 GeV to create a 300×300 grid of parameter combinations. At each grid point, the χ^2 value was calculated, where y, represents observed counts, (x, m_0, Γ) is the model prediction, and σ is the statistical uncertainty on each data point.

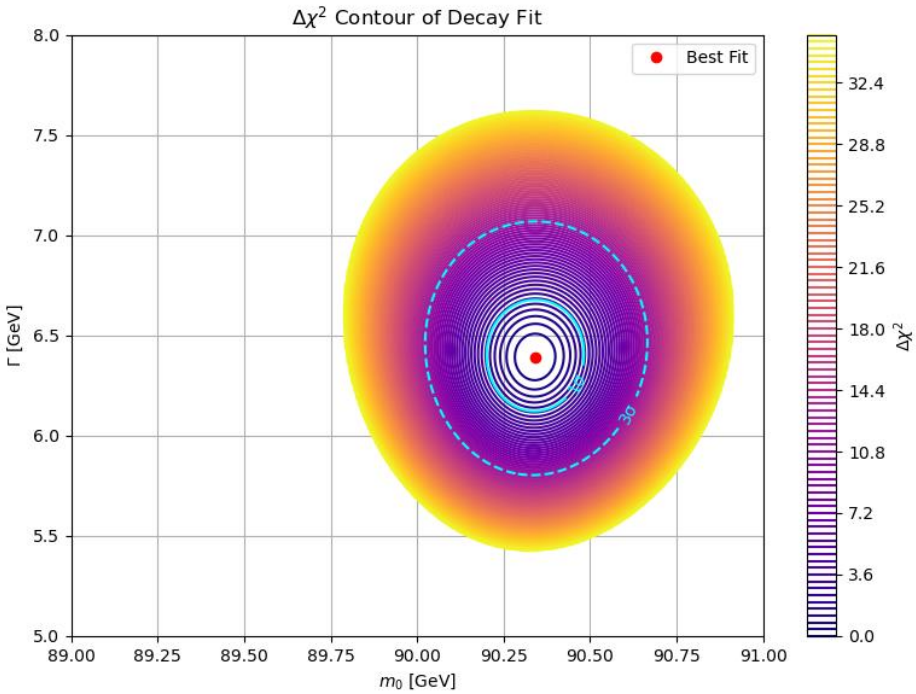

Figure 2. 2D chi-square parameter scan with confidence contours.

The contours on the plot represent specific confidence levels. The inner contour 1σ corresponds to a $\Delta\chi^2$ of 2.30, which represents a 68.27% confidence region, the outer contour 3σ corresponds to $\Delta\chi^2$ of 11.83, which represents a 99.73% confidence region. These values are specific for a two-parameter fit and the joint probability distribution. The plot clearly shows the correlation between the mass and width parameters, with the best fit point marked with a red dot. The contours demonstrate the uncertainty in our parameter determination and provide a visual representation of the confidence regions.

IV. Discussion and Future Work

The analysis determines the Z boson mass to be 90.3 ± 0.1 GeV, which differs from the Particle Data Group's published value of 91.1876 ± 0.0021 GeV. The discrepancy may be attributed to several factors, including limitations in the dataset, simplified model approach, and the restricted fitting range. The assumptions in this analysis were the use of the Breit-Wigner distribution without accounting for background processes, and the limitation of the mass window between 87 and 93 GeV. To enhance this analysis, future work could include the use of a more sophisticated model, extending the fit range, or employing more bins to better capture the peak shape. Despite our simplified approach, we were able to extract the Z boson mass to within 0.88 GeV of the accepted value.

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