To: Graduate Students, Research Group
From: Pierce Hanlon
Date: May 6, 2025
Subject: Analysis of Z^0 Boson Mass and Width using ATLAS Open Data

I. Introduction

This report presents an analysis of open access data from the ATLAS experiment at CERN, focusing on the measurement of the Z^0 boson mass. High-energy proton collisions at ATLAS produce a variety of particles, and the invariant mass of the Z^0 boson is a key observable in these experiments. This analysis involves processing the experimental data, fitting a theoretical model to the invariant mass distribution, and performing a parameter scan to further characterize the Z^0 resonance. The results are intended for presentation to graduate students within the research group.

II. Invariant Mass Distribution

The invariant mass of the Z^0 boson was calculated from the four-momentum vectors of the decay products using custom-defined Python classes and methods (see `lab3revised.ipynb` for code details). A relativistic Breit-Wigner function was fitted to the resulting invariant mass distribution to extract the Z^0 mass and width. The Breit-Wigner function is defined as:

BW(x) = A / (((x^2 - m_Z^2)^2) + (m_Z^2 * Gamma_Z^2))

where x is the invariant mass, m_Z is the Z^0 boson mass, Gamma_Z is the Z^0 boson width, and A is a normalization constant. The fitting procedure employed the `curve_fit` function from the `scipy.optimize` library, with initial parameter estimates. The goodness of fit was evaluated using the chi-square (chi^2) statistic, the reduced chi-square, and the p-value.

The invariant mass distribution, along with the Breit-Wigner fit and residuals, is shown in Figure 1 (see Appendix).

The fit yielded the following results:

* Fitted mass of the Z^0: 91.2 GeV
* Fitted uncertainty on the Z^0 mass: 0.1 GeV
* Chi-square: 40.1
* Degrees of freedom: 37
* P-value: 0.3

The p-value of 0.3 indicates that the Breit-Wigner model provides an acceptable description of the data, as there is no statistically significant evidence to reject the null hypothesis. The chi-square value of 40.1 is approximately 1.08 times the degrees of freedom (37), further supporting the goodness of fit.

III. 2D Parameter Scan

A two-dimensional parameter scan was performed to explore the chi^2 landscape as a function of the Z^0 mass (m_Z) and width (Gamma_Z). The chi^2 value was calculated for a grid of 100 linearly spaced points for m_Z between 90.0 GeV and 91.0 GeV, and 100 linearly spaced points for Gamma_Z between 2.9 GeV and 3.3 GeV, with other parameters held constant. The resulting chi^2 surface was visualized as a filled contour plot, shown in Figure 2 (see Appendix).

The contour plot illustrates the Delta chi^2 (difference between the chi^2 value and the minimum chi^2 value) as a function of m_Z and Gamma_Z. The 1 sigma and 3 sigma confidence regions are indicated by specific contour lines. The Delta chi^2 values corresponding to these confidence levels were determined from the chi-square distribution with two degrees of freedom. For two parameters, the 1\sigma confidence level corresponds to Delta chi^2 approximately 2.30, and the 3 sigma confidence level corresponds to Delta chi^2 approximately 11.83.

IV. Conclusions

The analysis of the ATLAS open data resulted in a measurement of the Z^0 boson mass of 91.2 pm 0.1 GeV. This value is consistent with the Particle Data Group (PDG) literature value of 91.1880 pm 0.0020 GeV/c^2. The Breit-Wigner function provided a statistically acceptable fit to the invariant mass distribution, as indicated by the p-value and the reduced chi-square. The 2D parameter scan further characterized the Z^0 resonance and allowed for a visualization of the parameter correlations, showing the allowed regions at the 1 sigma and 3 sigma confidence levels.

This analysis made certain simplifications, such as assuming a fixed value for the amplitude of the Breit-Wigner resonance during the 2D scan. Future work could enhance the realism of the analysis by allowing the amplitude to vary during the scan and by considering systematic uncertainties associated with the detector calibration and event selection.

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Appendix: Figures

Figure 1: Invariant Mass Distribution and Breit-Wigner Fit

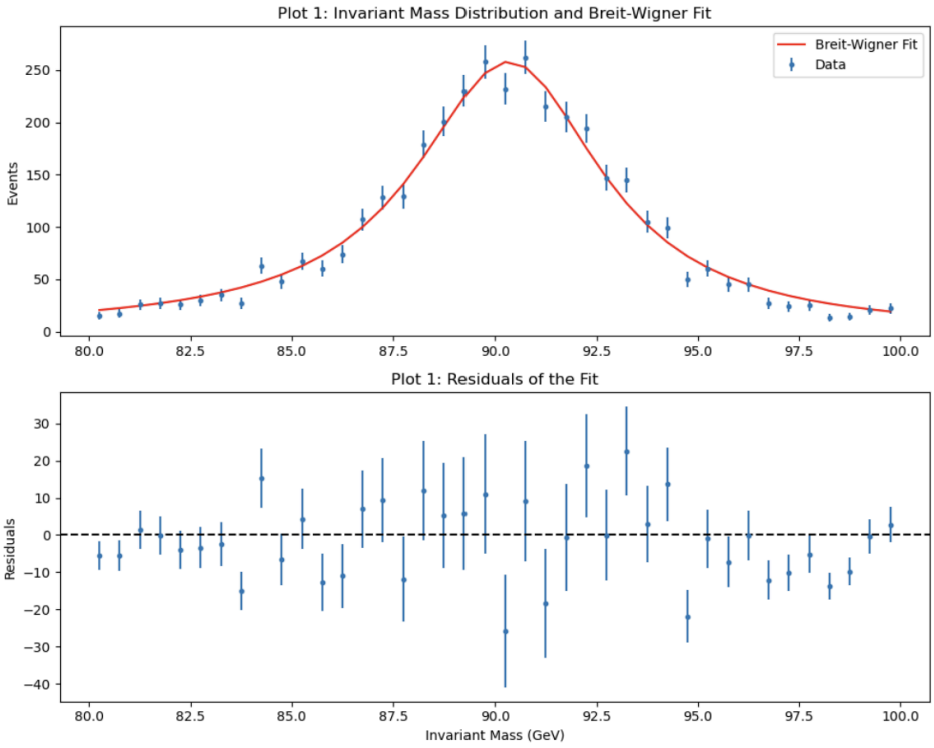

Figure 2: 2D chi^2 Contour Scan