ATLAS Data Analysis

Prepared by: Bella Pereira

Date: 05/02/2025

I. Introduction

The Z^0 boson is a fundamental neutral carrier of weak nuclear force and is central to the electroweak unification in the Standard Model of particle physics. Despite its high instability, the Z^0 boson is easy to spot in high-energy proton-proton collisions by decaying in lepton pairs. At the ATLAS detector of the LHC at CERN, physicists measure different parameters such as traverse momentum(p_T), pseudorapidity(η), azimuthal angle (ϕ), and energy E to calculate the invariant mass of decay events. In this analysis, we investigate 5000 double lepton events selected from the 2020 ATLAS open dataset. Additionally, we performed a two-dimensional chi-square parameter scan to quantify the uncertainty in the mass-width fit we found.

II. The Invariant Mass Distribution

Based on the parameters, we used standard relativistic kinematics to reconstruct the invariant mass M of each lepton pair: $M = \sqrt{E^2 - (p_x^{\ 2} + p_y^{\ 2} + p_z^{\ 2})}$ with momentum components of $p_x = p_T cos(\phi),\ p_y = p_T sin(\phi),\ p_z = p_T sinh(\eta)$. The distribution of reconstructed masses was binned into 41 intervals from 80 to 100 GeV/c^2. A Poisson standard deviation $\sigma = \sqrt{N}$, where N is the event count, was used as the error in each bin. After solving to find the invariant mass, we created a histogram of the various masses with their respective errors, then fitted the histogram to a Breit-Wigner function of the form: $D(m, m_0, \Gamma) = \frac{1}{\pi} \cdot \frac{\Gamma/2}{(m-m_0)^2+(\Gamma/2)^2}$, which models the decay distribution at a reconstructed mass m with m_0 as the mass of the Z^0boson which we are fitting and Γ is the width distribution. The fit was applied to the mashed region $87 < m < 93$ GeV using scipy.optimize.curve_fit, with normalization at 2500 events. The best-fit values for the mass of the Z^0 boson is $90.34 \pm 0.1\ GeV$. Additionally, we found the residuals between the data and theory, plotting them to help determine the agreement in the data.

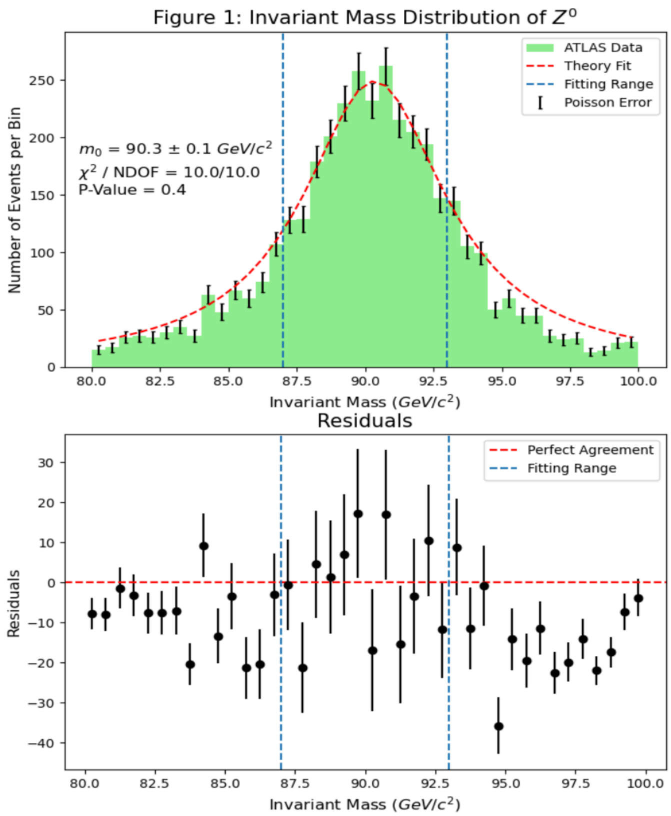

Figure 1 shows the distribution of reconstructed invariant masses of the Z^0 boson and fitted to the Breit-Wigner function. The subplot should the residuals between the data and the Breit-Wigner fit as the red dotted line shows perfect agreement while the blue dotted line should the accepted fitting range for the data. Additionally, the fit was used to perform a chi-square test analysis to determine the goodness of the fit. We found the chi-square value to be 10 and determined the number of degrees of freedom by subtracting the number of fitting parameters from the number of points tested, which we found to be 10. The p-value we found was 0.4 which is in perfect agreement with the theory as it lies between 0.95 and 0.05. This value shows that there is approximately a 40% chance of getting the experimental results.

III. 2D Parameter Scan

Finally, we aimed to determine the validity of our chi-square and p-value based on the best fit of both mass and the true width distribution. We optimized m_0 *and* Γ to preform an additional test by finding the $\Delta\chi^2$ of the two values respectively. Using a m_0 range between 89 and 91 GeV/c^2 and Γ ranging from 5 to 8 GeV/c^2, we found the differences between the values and the chi-square of 10 using the equation $\Delta\chi^2 = \chi^2 - \chi_{min}^2$.

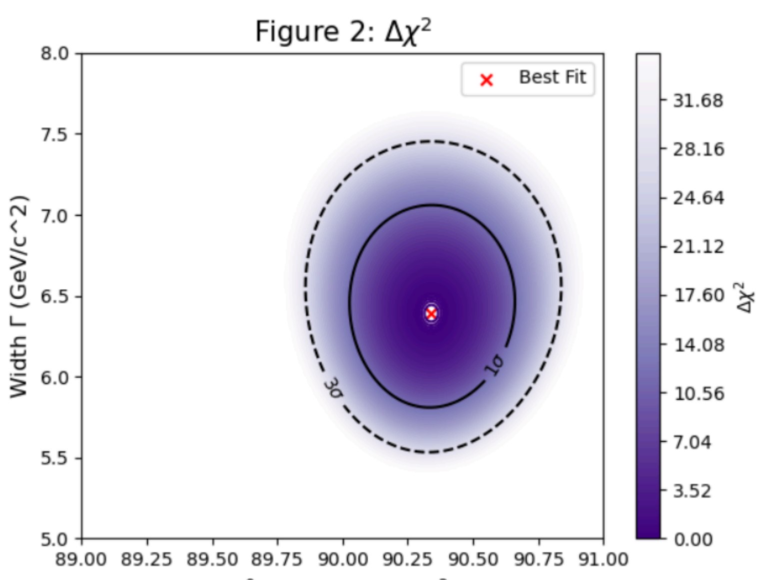

Figure 2 shows a dimensional color map of the calculated $\Delta\chi^2$, ignoring values greater than 35. The figure also contains contours associated with the 1σ and 3σ lines with the values of 2.3 and 9.21 respectively to get the minimized value of 10.

IV. Discussion and Future Work

Our measurement of the Z^0 boson was $90.34 \pm 0.1\, GeV$, however, the PDG 2024 value is 91.1880 ± 0.0020 GeV. The discrepancy of 0.9 GeV, is statistically significant which may be due to various factors. Those factors include simplified Poisson error and limited fitting range as well as coarse binning. To analyze further, we could extend the data size and reexamining fitting assumptions. Additionally, improvements in modeling detector and fininer binning can help alleviate the differences. Researching these factors is essential to the accuracy of mass extraction and alignment with accepted values.