ATLAS Data Analysis Lab Report 5/6/2025
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I. Introduction

The Large Hadron Collider, at CERN in Switzerland, is utilized to conduct particle experiments by colliding beams of protons. One of these experiments includes the ATLAS detector, which measures four properties of particles that come out of the proton-proton interactions in the collider. This lab report reflects the work that my team and I have completed studying the decay of the Z^0-boson. The study itself is based on the energy of double-lepton events that is produced through the Z^0 breakdown process. Provided with a set of data from ATLAS, we analyzed the frequency of the data, applied it to an invariant mass distribution, aligned it with a Breit-Wigner fit, and created a 2D contour to visualize the most accurate values for different parameters of the breakdown process.

II. Invarient Mass Distribution and Fit

First, we took the data provided from the ATLAS detector and applied the four components to a formula to set up an equation for the mass. My team and I analyzed these properties: the total energy E, the transverse momentum p_T, pseudorapidity η, as in the angle from the beamline, and the azimuthal angle φ from the beam, if viewed from an above perspective of the beam. Transverse momentum references the momentum that the particle has in the transverse direction. Pseudorapidity will be infinity if the particle comes straight out of the beam, and 0 if it is deflected at 90°. The azimuthal angle will be 0 if the particle comes out of the beam straight to the left or the right, and equal to π/2 if it came straight out and up. We used these values to define the four momentum of the particle, $p=(E,p_x,p_y,p_z)$ where $p_x=p_T\cos(\varphi)$, $p_y=p_T\sin(\varphi)$, and $p_z=p_T\sinh(\eta)$. As ATLAS tested on two leptons, they provided us with two sets of data for transverse momentum, pseudorapidity, azimuthal angle, and total energy, with each set respective to one of the leptons. We applied each lepton's data separately to the previous equations to have two sets of three equations each for the three dimensions of the momentum. We added the like equations, as well as the two sets of total energy, and applied all of these combined values to the equation on the left to solve for the mass.

$$M = \sqrt{E^2 - (p_x^2 + p_y^2 + p_z^2)}$$

We created a histogram to visualize this frequency of the invariant mass. We next fit the data according to the Breit-Winger peak, with the equation on the right, which determines the distribution of the decayal based on the invariant

$$\mathcal{D}(m; m_0, \Gamma) = \frac{1}{\pi}\frac{\Gamma/2}{(m-m_0)^2 + (\Gamma/2)^2}$$

mass *m*, *m0*, and a width parameter Γ. We fit half of the ATLAS data to this estimation utilizing numpy's mask feature on Python. We also completed the chi-squre, reduced chi-squre, and p-value for the data fit. We then visualized the fit and its accuracy by adding a Breit-Wigner fit to our original histogram, as well as making a second graph to portray the residuals based on the different in the fit to the original data, all visualized in Figure 1. We found the fitted mass of the Z^0 to be 90.34 ±0.0935 GeV. The chi-squre was found to be 9.99, with ten degrees of freedom, and therefore a p-value of 0.442. We also found the reduced chi-square value to be 1.0.

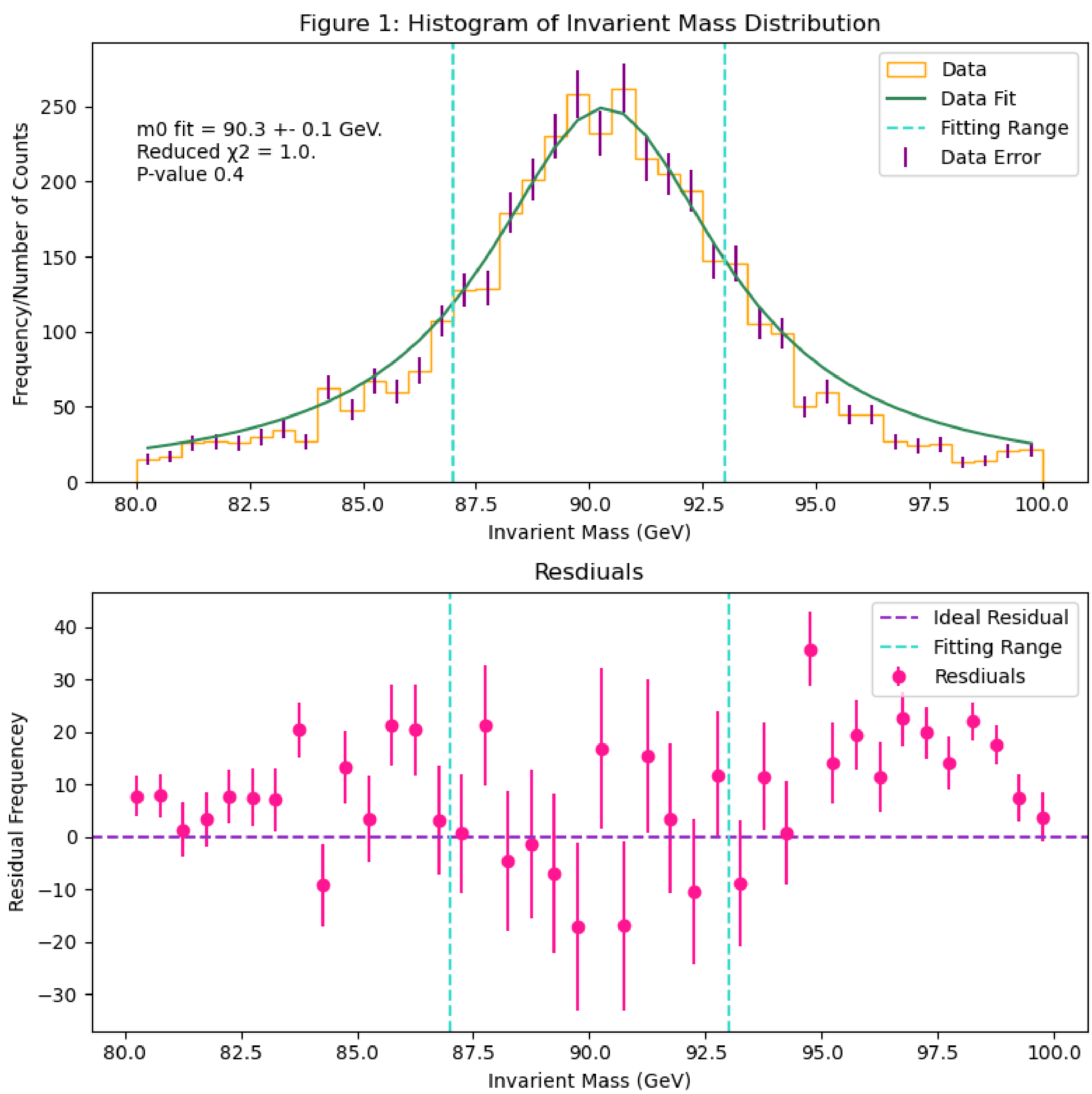

Figure 1: The first figure depicts the histogram plot of the frequency and its errors of invariant mass of the ATLAS detector, as well as the fit. It also includes a second figure which is the residuals plot, depicting between the fit and the data, again including error as well.

III. The 2D Parameter Scan

Next, my team and I worked to develop a 2D fit, as Z^0 and Γ are both independent variables and cannot be solved for individually. We first created a 2D chi-square scan of the mass-width parameter space and then created a contour plot. We utilized Python's meshgrid tool, as well as the clip ability of the program. We incorporated the 1σ and 3σ confidence levels into the plot, as well as the best fit location. This graph depicted the ideal ranges for the fitting parameters Z^0 and Γ so that the fit would best match the data.

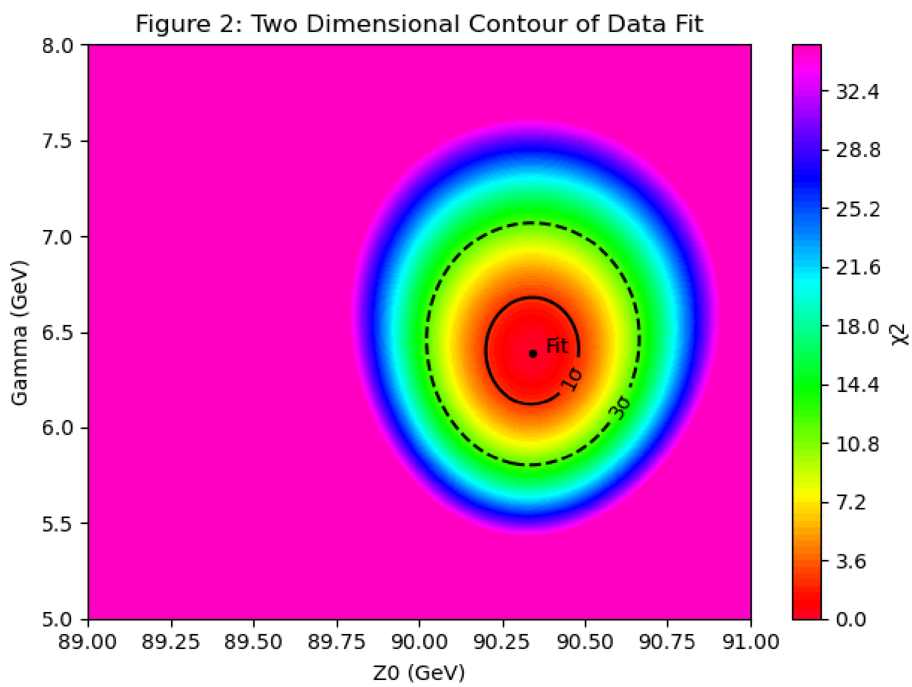

Figure 2: This figure is the the χ2 contour plot. It indicates the varying values of Z0 and Gamma, and depicts the ideal area of values for each of the parameters, in order to best fit the data.

IV. Discussion and Future Work

We calculated the value of Z^0 to be 90.34 GeV with an uncertainty of 0.0935 GeV. In comparison, the Particle Data Group's latest accepted value is is 91.1876 GeV with an uncertainty of 0.0021 GeV. Throughout our calculations we made estimations such as assuming that the lepton reaction conserves charge and mass as well as energy. We also did not account for error that the ATLAS detector may have made while detecting the information. In the future, we could account for systematic errors that the machine may have made as well as its uncertainty, which would allow our results to be more accurate.