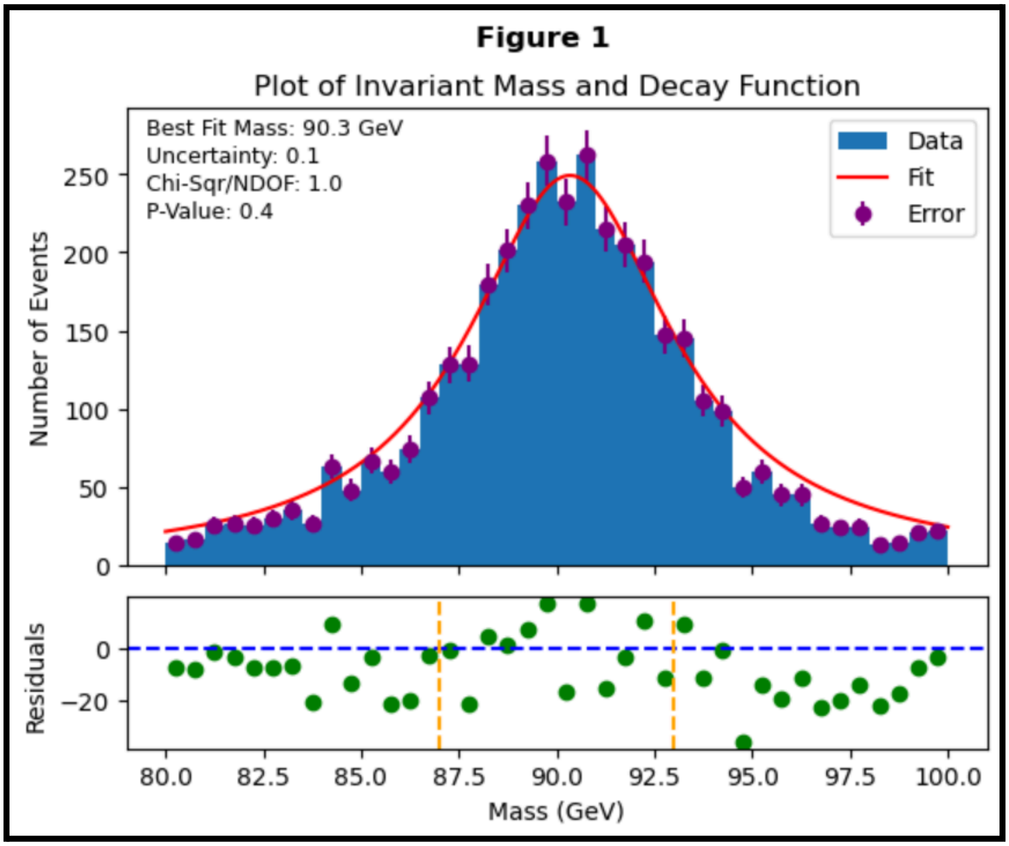
Lab 3 Report

1. Introduction

This report aims to calculate the hypothetical mass of the particle responsible for the double-lepton events in the ATLAS experiment at CERN. This calculation is done by measuring the energy of these events to find the mass of the particle which decays to produce the two leptons. Then fitting is performed to find the most likely particle mass which explains these mass measurements. In this case, the particle of interest is the Z0-boson.

2. Invariant Mass Distribution

The top plot of Figure 1 has two key elements: (1) the mass measurement calculated from the 5000 double-lepton events in the 2020 ATLAS open dataset and their associated errors; and, (2) the decay function which best fits the observed data. The bottom plot shows the residuals between the measured invariant mass and the predicted mass from the fitted decay function. The residuals demonstrate that the decay function is over-predicting compared to the masses observed on the tail ends of the mass-distribution.



The decay function follows a distribution with a Breit-Wigner peak. Thus the mass distribution at a reconstructed mass *m* depends on the true rest-mass of the Z0 and its width parameter Γ:

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

Fitting the Breit-Wigner function to the mass-distribution observed calculated from the ATLAS dataset, we find

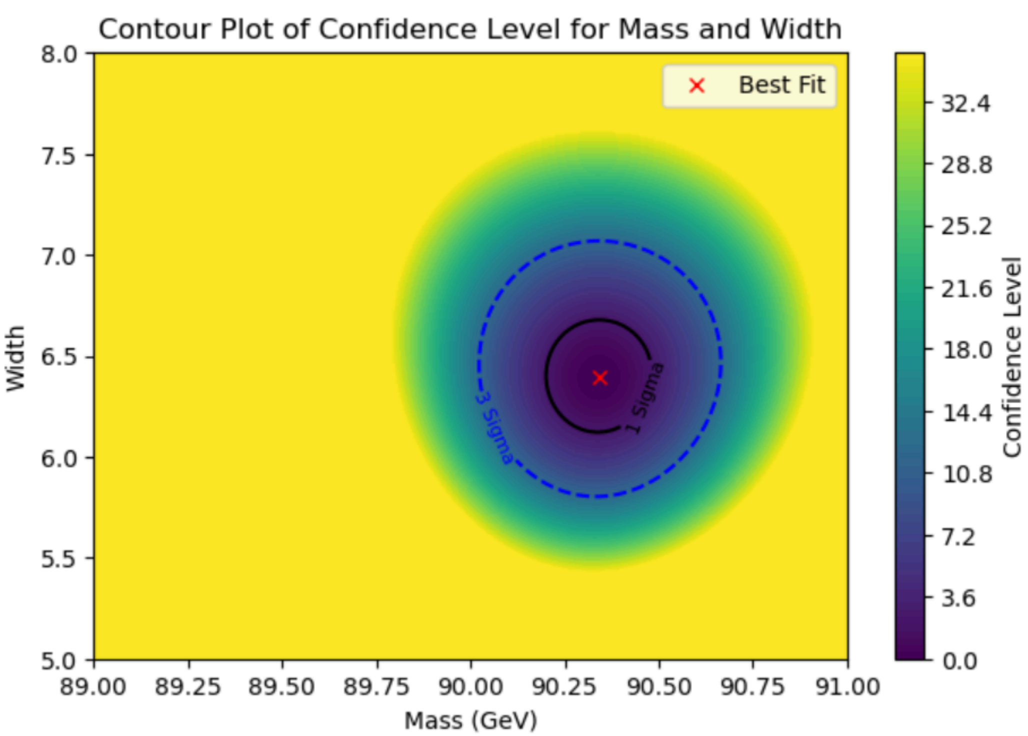
1. Fitted mass of the Z0: 90.3 GeV
2. Uncertainty on the Z0 mass: +/- 0.1
3. Chi-Square: 10.0
4. Number of degrees of freedom: 10
5. P-Value: 0.4

The null hypothesis in this experiment is that the Breit-Wigner function explains the mass-distribution observed. With a p-value of 0.4, we do not find sufficient evidence to reject the null hypothesis. The reduced chi-square was also calculated at 1.0, indicating that the model accurately predicts the observed data.

3. Two-Dimension Parameter Scan

The calculation of the best mass which explains the observed mass-distribution does have one key limitation. The Breit-Wigner function is one of two variables: mass and width. Thus, they share a joint probability distribution and we cannot determine the best-fit for the Z0 mass and experimental width parameter independently. Figure 2 plots the confidence interval corresponding to a color for a given mass and width. The solid black line indicates a region of parameters that have a 68% chance (1 sigma confidence) of explaining the observed mass-distribution. The dotted blue line indicates a region of parameters that have a 99% chance (3 sigma confidence) of explaining the observed mass-distribution. These were calculated from the difference between the chi-square at each point and the minimum chi-square, which is precisely the calculation for the confidence level.

Figure 2



4. Discussion and Future Work

The best-fit mass of 90.3 +/- 0.1 GeV found in this report does come close to the actual mass of the Z0 (91.2 +/1 0.002 GeV), but is outside the acceptable uncertainty. This is likely due to the fact that the function is only fit within 87-93 GeV. More data to fit with would produce a more accurate result in the future. Moreover, containing the overall normalization to half the number of data points worsened the fitting of the curve. Allowing this to be another parameter to fit to would require more data in and of itself, but would produce a more accurate result as well.