Lab 3 Report: ATLAS Data Analysis

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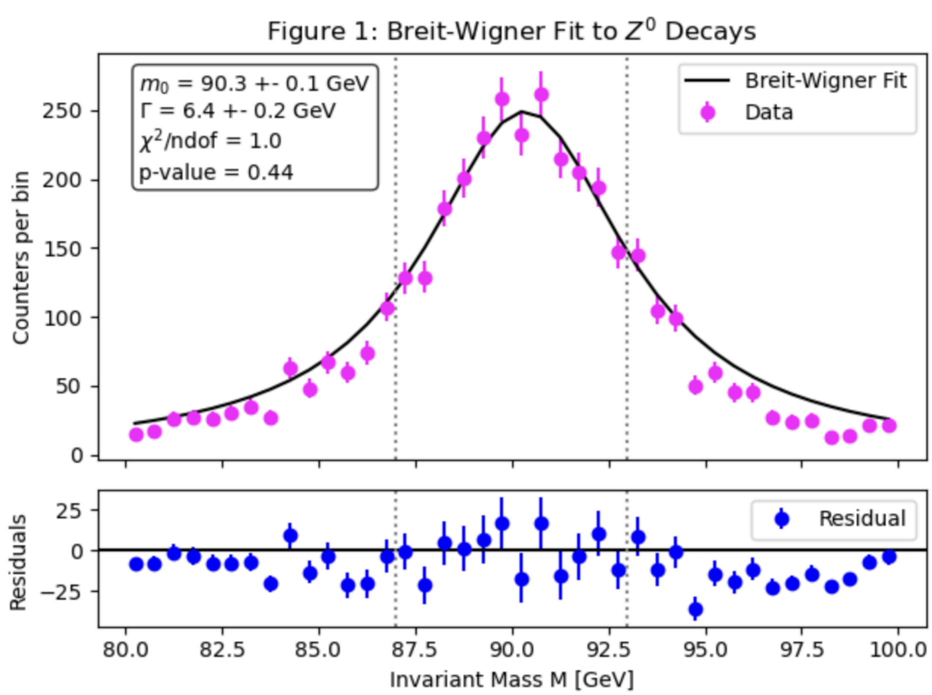
Introduction:

The purpose of CERN's ATLAS experiment is to study proton-proton collisions which produce fundamental particles. One of these resulting particles is the Z^0 boson which mediates weak force. In this report, the mass of the Z^0 boson will be measured through analyzing the decay into a pair of leptons. The ATLAS experiment detects the decay which allows for the invariant mass of the leptons to be used to reconstruct the mass of the Z^0 boson. In order to accomplish this, the methods in this report will include creating the invariant mass distribution, fitting it with a Breit-Wigner distribution, and executing a 2D parameter scan to accurately estimate the width and mass of the Z^0 boson.

The Invariant Mass Distribution:

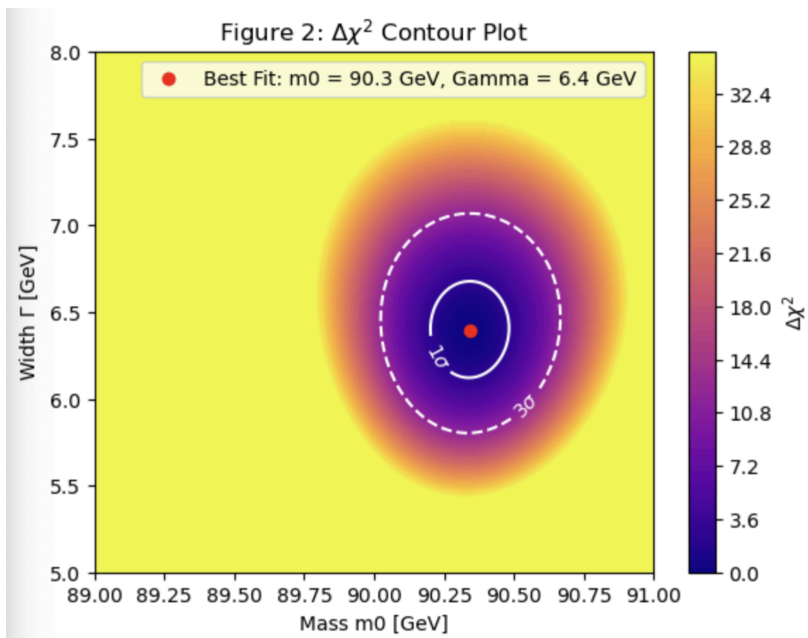
The invariant mass of a system of particles plays an important role in particle physics because it permits us to characterize the particles that are involved in decays. For the Z^0 decay into two leptons, the invariant mass can be calculated by using transverse momentum, pseudorapidity, and the energy of each lepton. By summing the four-momenta of the leptons, the invariant mass of Z^0 is constructed. The plot in Figure 1 displays the invariant mass distribution of the Z^0 decay. For each pair of leptons, the mass is calculated and shown on the histogram including error bars. These error bars represent the square root of the number of events which is known as Poisson errors. To model the decay distribution of the Z^0 boson, the Breit-Wigner function was fitted to the data. This performed on the mass ranging



between 87 and 93 GeV which obtains the peak of the Z^0 mass. This process produces a fitted mass of Z^0 of 90.341 with a fitted mass uncertainty of 0.094 GeV. Additionally, the chi-squared value is 9.985, the degrees of freedom is 10, and the p-value is 0.4418. The fit parameters and the chi-squared value indicate the quality of the model and the p-value suggests how good of a fit to the data there is. A p-value of 0.4418 indicates a 44.18% chance that the deviations between the data and the fit are due to random statistical fluctuations. This signifies a good fit to the data with no strong evidence to reject the model.

The 2D Parameter Scan:

To explore the joint likelihood of the Z^0 mass and decay width a 2D chi-squared scan over the mass-width parameter space must be performed. This scan provides insights into the range of possible values for these parameters including their uncertainties. Figure 2 shows a contour plot of $\Delta\chi^2$ where the chi-squared is calculated over a grid of mass 89-91 GeV and width 5-8 GeV. The 1σ and 3σ confidence regions (2.3 and 11.83, respectively) are marked on the plot, as well as the best fit point from part 2 calculated using the invariant mass distribution. The $\Delta\chi^2$ values for each level were chosen by integrating the chi-squared probability distribution with two degrees of freedom.



Discussion and Future Work:

This analysis successfully extracted the invariant mass of the Z^0 boson from ATLAS data and fit the distribution using a Breit-Wigner function. The latest value from the Particle Data Group (PDG) for measured mass of the Z^0 boson is 91.1880 ± 0.0020 GeV. The fitted value for the Z^0 mass from this lab is 90.341 GeV with a corresponding fitted uncertainty of 0.094 GeV. This shows that the measured mass of the Z^0 boson is in good agreement with the accepted value. This analysis does not account for several factors that could potentially impact the measurement of mass, including energy resolution at the ATLAS detector, systematic uncertainties, and background contributions. To improve the accuracy of these calculations, the physicists could include detector smearing effects and incorporate background models to differentiate between signal and non-resonant processes. It would also be wise to add systematic uncertainties and use likelihood fitting that is unbinned. With these improvements in mind, the analysis could provide a much more realistic and precise measurement of the mass and width of the Z^0 boson.