Lab 3: ATLAS Data Analysis

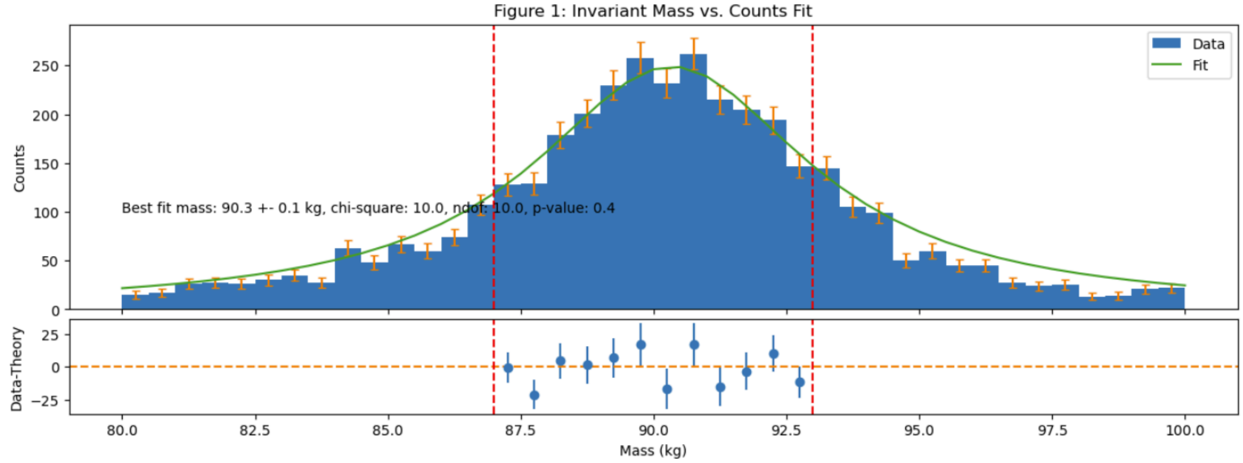
I. Introduction

This mission revolves around the ATLAS experiment at CERN, where proton beams are collided. One byproduct of the proton-proton collisions is the Z^0 boson, which is a neutral carrier of the weak force and is involved in many nuclear interactions. The focus of this report will be on determining the mass of the Z^0 boson because the energy of double-lepton events (which Z^0 decays to produce 10% of the time) in the detector correspond to the peak of the mass. The mass will be determined first through the invariant mass formula. The mass will then be determined through fitting experimental data to the Breit-Wigner Fit, which the distribution of decayed particles at the mass follows. Lastly, 2D parameter contours will be made to visualize the joint probability space of Z^0 and Γ_{exp}, which is a width parameter associated with the Brieit-Wigner distribution.

II. The Invariant Mass Distribution and Fit

The invariant mass of the particle is found through the equation $M = \sqrt{E^2 - (p_x^{\ 2} + p_y^{\ 2} + p_z^{\ 2})}$, where E, p_x, p_y, and p_z are the four momentums of the particle. $p_x = p_T cos(\phi)$, $p_y = p_T sin(\phi)$, and $p_z = p_T sinh(\eta)$. Taking experimental data from the ATLAS, the invariant mass is calculated for each data value and then plotted as a histogram with the binspace being from 80 to 100 GeV with 41 bins. The error on the data was $\sqrt{N}$, meaning the square root of the number of events in the bin. The invariant mass distribution is fitted to the Breit-Wigner model, where the distribution of decayed particles at the Z^0 mass follows a Cauchy-Lorentz peak. The distribution equation is given as $D(m; m0, \Gamma) = \frac{1}{\pi}\frac{\Gamma/2}{(m-m0)^2+(\Gamma/2)^2}$. m0 is the true rest mass of Z^0 and Γ is the width parameter of the distribution. Half of the numbers in the data set are normalized, and the fitting occurs where the bin centers are between 87 to 93 GeV. The data is then plotted for this distribution, with a sub-panel being created to show the residuals between the data and the fit.

Figure 1: Invariant Mass vs. Counts Fit

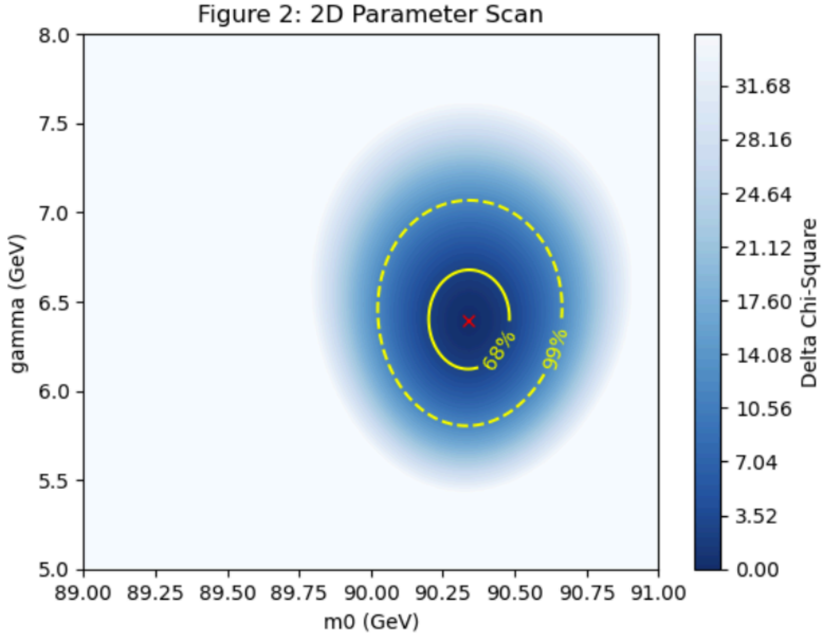


The chi-square value determined from this fit is 10.0. The number of degrees of freedom is 10. The p-value of this fit is 0.4. The fitted mass of Z^0 is 90.34 ± 0.9 GeV. The p-value of 0.4 indicates that the fit is reasonable, but there is not a statistically significant association between the values. The chi-square of 10.0 is very close to the degrees of freedom of 10. There is no strong evidence that there is some correlation between the counts and the mass, which could be due to a number of factors, such as not enough experimental data.

III. 2D Parameter Contours

A 2D chi-square scan is then performed of the mass-width parameter space. The scan is performed from 89 to 91 GeV, and the width from 5 to 8, with 300 bins along each dimension. A contour plot is created for $\Delta X^2 = X^2 - X^2_{min}$. The ΔX^2 is restricted to 35 units. In a Gaussian distribution, 99.7% of the data is within 3σ. 68.2% of the data is within 1σ. Using the chi2.ppf function from the scipy.stats module, the value found for 1 σ is 2.3 and the value for 3σ is 11.8. These values were then plugged in as the levels for the contour plot. The best fit location found in Part II is then plotted as a cross.

Figure 2: 2D Parameter Scan



IV. Discussion and Future Work

From the analysis performed, it appears that the fit mass for Z^0 is 90.34 ± 0.9 GeV, which is within one sigma on the mass-width contour plot, meaning that it falls within one standard deviation of the mean value. The literature value of the Z^0 mass is 91.1876 GeV, which is approximately equal to the fit mass. The p-value found was 0.4, which suggests that the Breit-Wigner function is a reasonable fit to the data but also indicates that there is no statistically significant association between the mass and the counts of decaying particles from the ATLAS experiment. This could be due to a lack of experimental data. The spans considered could also be increased in future work. Future experiments could focus on a greater sample size. Possible interference could be considered, as well as trying alternative models when fitting the data. It is assumed that the data follows a Breit-Wigner distribution, but trying alternative methods could resolve discrepancies.