1 Introduction

Scientists working on the ATLAS experiment at CERN use the Large Hadron Collider to collide high energy protons together with the intention of studying the byproducts of these collisions. One such byproduct is the Z^0-boson, the neutral carrier of the weak force, which decays into a pair of charged leptons. The properties of these emitted leptons can be analyzed to determine the properties of the boson from which they decayed.

In this report, we analyze data from the ATLAS experiment to determine the distribution of the invariant mass of the Z^0-bosons, then fit this distribution to a Breit-Wigner peak. This allows us to determine the best fit for the true rest mass of the particle. We then further analyze the fit by visualizing the quality of the fit across the $m_0 - \Gamma$ parameter space to show the relationship between the fit parameters.

2 The Invariant Mass Distribution

The data from the ATLAS experiment gives four properties of the particles that came out of the experiment. For each of the two leptons, it gives the energy E, the transverse-momentum p_T, the pseudorapidity η, and the azimuthal angle ϕ. The transverse-momentum describes the particles momentum in the transverse direction. The pseudorapidity describes the angle the particle makes with respect to the beamline, where $\eta = 0$ corresponds to a deflection of 90°, and $\eta \to \infty$ corresponds to no deflection.

These quantities are used to define the four-momentum $p = (E, p_x, p_y, p_z)$ of the particle, where

$$p_x = p_T \cos\phi, \quad p_y = p_T \sin\phi, \quad p_z = \sinh\eta \tag{1}$$

for each particle. The total four-momentum of the 2-particle system can be simply calculated from $p_{tot} = p_1 + p_2$. From the total four-momentum, we can calculate the invariant mass M of the Z^0-boson that preceded the leptons.

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

From the ATLAS dataset, we calculated the above quantities and obtained a distribution of invariant masses. We then fitted this distribution to a Breit-Wigner Peak, described by

$$D(M; m_0, \Gamma) = \frac{2500}{\pi} \frac{\Gamma/2}{(M - m_0)^2 + (\Gamma/2)^2} \tag{3}$$

where m_0 is the true rest mass and Γ is the width parameter of the distribution. The function above includes a normalization factor of 2500, which half the number of data points. The invariant mass distribution and Breit-Wigner fit are shown in Figure 1. The best fit of the true rest mass of Z^0 was determined to be $m_0 = 90.3 \pm 0.1$ GeV. The fit had a χ^2 of $\tilde{1}0.0$ with 10 degrees of freedom, yielding a p-value of 0.4 indicating a good quality fit.

3 The 2D Parameter Scan

Using the Breit-Wigner fit described in the previous section, we performed a 2-dimensional scan of the two fit parameters m_0 and Γ to illustrate how the χ^2 value changes in the parameter space. To calculate this, we iterated through the parameter space in the range $89.0\ GeV < m_0 < 91.0\ GeV$ and $5.0\ GeV < \Gamma < 8.0\ GeV$ and calculated the χ^2 value at each coordinate using the standard definition,

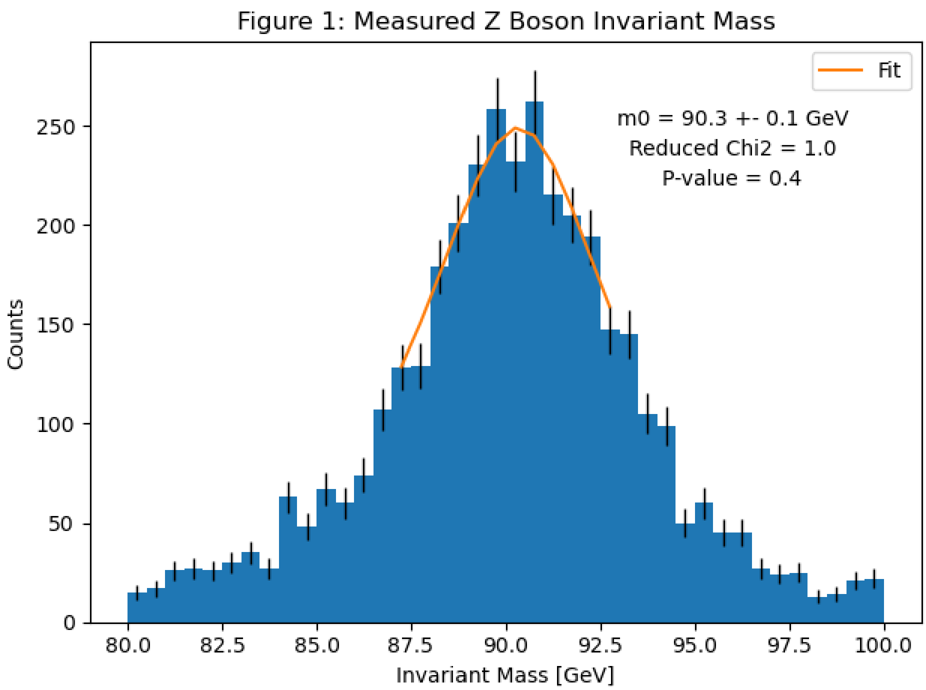
$$\chi^2 = \sum_i^N \left(\frac{x_i - o_i}{\sigma_i} \right)^2 \tag{4}$$

and plotted the difference between the χ^2 at that coordinate and the minimum χ^2 value discussed in the previous section. The plot of the parameter scan is shown in Figure 2, with the contours corresponding to a significance of 1σ and 3σ shown as well. The $\Delta\chi^2$ corresponding to each significance differs with the number of parameters, so, in this instance, where we have 2 fit parameters, the corresponding values are $\chi^2 = 2.30, 9.21$.

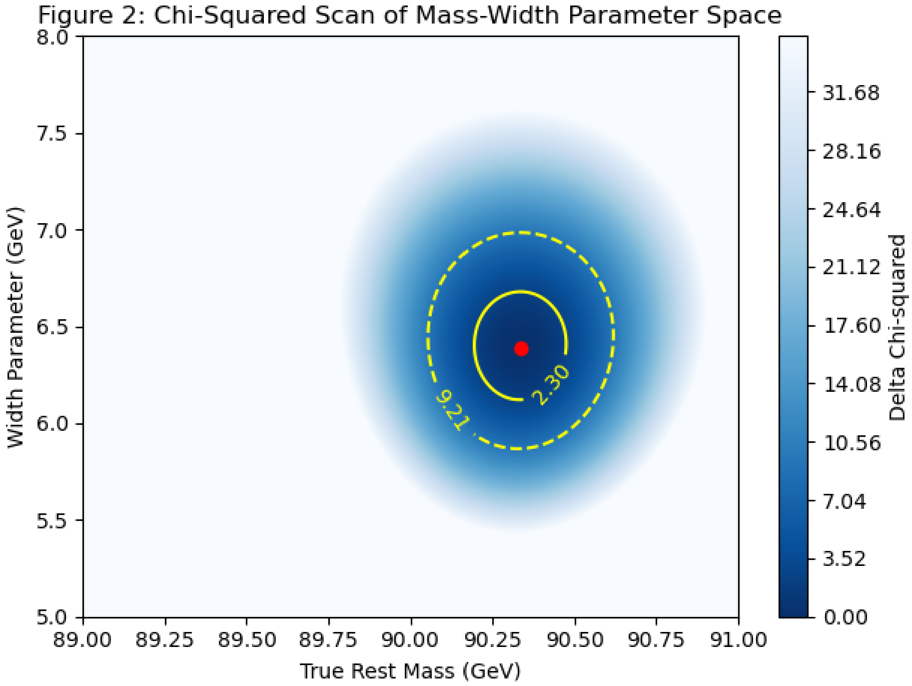
4 Discussion and Future Work

In this report, we detailed the analysis of data from the ATLAS experiment. Given a dataset of the measured properties of 5000 lepton-lepton pairs produced in the decay of Z^0-bosons, we determined the best fit rest mass to be 90.3 ± 0.1 GeV by fitting the data to a Breit-Wigner Peak. The fit was determined to have a reduced χ^2 of ~ 1 and a p-value of 0.4, indicating agreement between the data and the theory. Despite this, though, the calculated rest mass does not agree with the accepted value, $m = 91.1880 \pm 0.0020\ GeV$ within the uncertainties.

This disagreement likely comes from the lack of consideration of any systematic uncertainties present in the apparatus, as well as the finite energy resolution of the ATLAS detectors. To obtain a higher accuracy measurement and enhance the realism of the model, one must perform a more rigorous analysis that takes these into account. Systematic errors can be accounted for by calibrating the measurements as part of the data processing pipeline, and an explicit consideration of the energy resolution of the detectors would introduce more uncertainty into each measurement, broadening the invariant mass distribution and therefore, changing the best fit to the Breit-Wigner Peak.



Figur 1: The invariant mass distribution with the fitted Breit-Wigner Peak plotted over it. The errors in the counts of each bin are assumed to be $\sigma = \sqrt{N}$ The values for the fitted true rest mass m_0, the reduced χ^2 and the p-value of the fit are also displayed.



Figur 2: A 2D parameter scan of the Mass-Width (m_0 - Γ) parameter space. The z-axis shows the difference between the χ^2 at that coordinate and the minimum χ^2 value. The coordinate of the minimum χ^2 is marked with a red dot, and the 1σ and 3σ contours are marked with a solid and dashed yellow line, respectively.