Lab 3 Report: ATLAS Data Analysis

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I. Introduction

The ATLAS (A Toroidal Lhc ApparatuS) experiment at CERN in Geneva is a particle accelerator that collides beams of protons. When we collide these particles, new particles emerge from the photon-photon interaction. One of the most important fundamental particles that comes out of this interaction is the Z0-Boson. This boson decays into a lepton pair: an electron and anti-electron, a muon and anti-muon, or a tau and anti-tau.

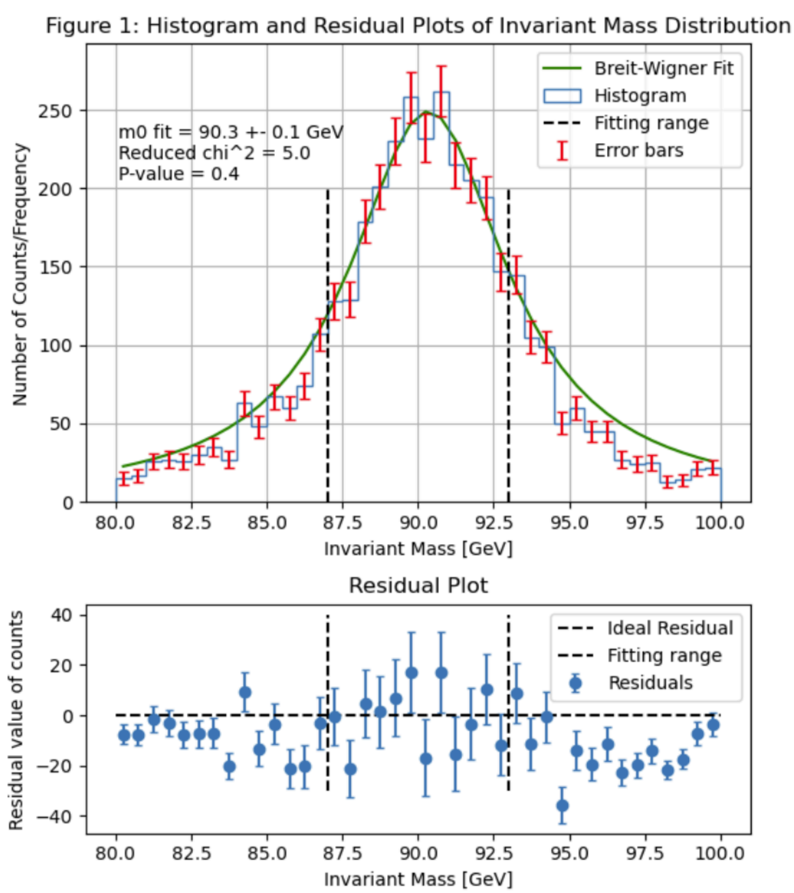
To measure the mass of the Z0-Boson, we will take the measurements of the leptons in terms of momentum, energy, pseudorapidity, and the azimuthal angle. Where pseudorapidity is determined by the angle between the beamline and the path of the lepton, and the azimuthal angle is the angle of the particle if you stare down the particle beam. Using these values will find histograms for the invariant mass of the Z0-Boson, and we will also fit these values to find the best fit mass and do a chi-square comparison for different values of the best fit mass and the Gamma (width parameter).

II. The Invariant Mass Distribution and Its Fit

From the ATLAS measurements of the lepton pairs, we will measure the x, y, z components of the momentum by using the different angles and the transverse momentum: $p_x = p_T \cos(\phi), \quad p_y = p_T \sin(\phi), \quad p_z = p_T \sinh(\eta)$, where phi is the azimuthal angle and eta is the pseudorapidity angle. We will then find the mass by using this equation $M = \sqrt{E^2 - (p_x^2 + p_y^2 + p_z^2)}$ which takes into account the energies and components of the momentum of the leptons. We will take these mass values in terms of GeV and make a histogram with a Poisson error distribution, where the uncertainty is the square root of the number of counts. From this data, we will find a fit for the mass of the Z0-Boson and the width parameter Gamma that best matches the distribution. To fit the data, we will be using the Breit-Wigner fit distribution equation:

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

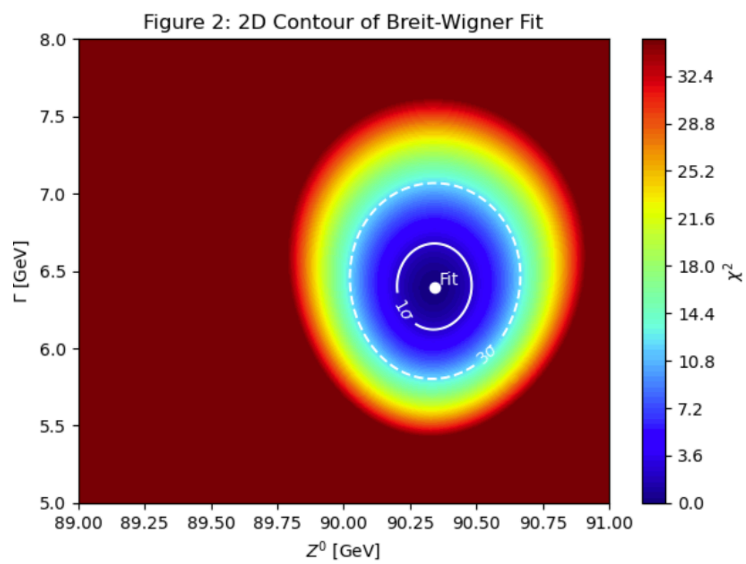
. For this lab, we will only fit across the masses bigger than 87 GeV and smaller than 93 GeV. Using the Python function curve_fit, the fitted mass of the Z0-Boson is 90.3 GeV with an uncertainty of 0.1 GeV. Figure 1 Caption: This plot shows the histogram of the mass



measurements with the error and fit data overlaid onto the histogram. We also have the residual plot for each error. In both plots, we can see the lines representing our fitting range. When we compare the chisq values of the data in the fitting range versus the Breit-Wigner Equation with our fit values, we get that chi-square is 10.0, the degrees of freedom are 10, and the P value is 0.4. Since the P value is over 0.05 and under 0.95, the fit is reasonable with the data and the uncertainties.

III. The 2D Parameter Scan

For the Breit-Wigner Equation, you can see that we are not only fitting for m0, the mass of the Z0-Boson. But we are also fitting Gamma. In our fit, we measured Gamma to be 6.4 GeV. Since the fit for m0 is also accompanied by the fit for Gamma, we will do a 2-dimensional plot showcasing the chi square comparisons for different m0 and Gammas. We will be using values for Gamma that range from 5-8 GeV, and values for m0 that range from 89-91 GeV. Both dimensions will have 300 bins each for more precise measurements. Figure 2 Caption: In this contour plot, we can see that we have two dimensions of the mass of Z0 and the Gamma. We are measuring for the chi-square relative to the minimum value from the fit, and throughout the contour plot we can see where the chi-square is the smallest by looking the the color bar. In the plot, we can see the zones that the chi-square corresponds to 1 sigma, 3 sigma, and we can also see where our fit values fit within the chi-square plot. The fit values fit in an area where the relative chi-square is the minimum, which makes sense, since when we use the Python function "curve_fit," it is taking the parameter values that will make the chi-square the smallest possible value and returning those values as parameters.



IV. Discussion and Future Work

According to the Particle Data Group, the value of the Z0-Boson is 91.1876 GeV with an uncertainty of 0.0021 GeV. For comparison, our calculated values for the mass of the Z0-Boson are 90.3 GeV with an uncertainty of 0.1 GeV. Some assumptions that we made are that the lepton to Z0-Boson interaction conserves charge, masses and energies. We also assumed that the uncertainty of the data is in poissant distribution, instead of using different models like least square fitting or Bayesian Inference uncertainties. We also don't account for any systematic error in the measurements of the particle accelerator. Systematic errors include things such as the energy resolution of the ATLAS detector. THe energy resolution is relating to how precise the detector can measure energies, for example, from low transverse momentum (20 GeV) to high energies (300 GeV), the resolution ranges from 24% to 6% respectively. These uncertainties would have an effect on the values and uncertainties that we will measure in our fits and comparisons. For future work, we should take into consideration different error analysis and utilise ATLAS's resolution uncertainties to make our results more realistic.