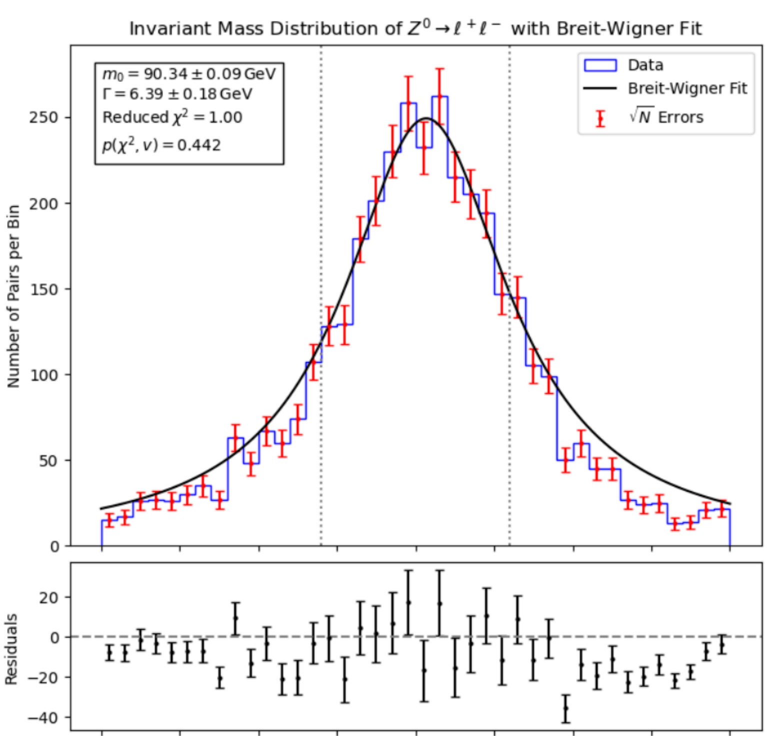
Lab 3: ATLAS Data Analysis

At CERN, in Geneva, the "A Toroidal LHC Apparatus" or ATLAS for short is located at a Large Hadron Collider or LHC. The LHC allows for collisions of protons. This allows us to study the resulting Z^0 boson particles and their properties. Z^0 boson particles are unstable and decay. About 10% of decays result in a pair of charged leptons. By studying the data resulting from the events with two charged leptons we can learn more about the Z^0 boson particles involved. In this lab our goal is to determine the invariant mass of the Z^0 boson by using data collected about the resulting lepton pairs. We will do this by using a Breit-Wigner resonance curve and fitting it to the invariant mass distribution. We will extract best fit parameters from this data. We will assess the statistical quality of the fit by doing a χ^2 analysis and computing the p-value. Finally we will look at the mass and width of the Z^0 boson across a grid of possible values to find which values have the best χ^2 fit.

In order to begin we first (1) calculated the mass associated with each resulting lepton pair. Then using the array of values we now had for the masses, (2) we created a histogram of the invariant mass values and then fitted it using a normalized Breit-Wigner distribution. Finally, we (3) scanned the values of mass and width over a surface that showed the χ^2 value to determine and show the point of best fit. For these steps we used python as our coding language with imports from NumPy, Matplotlib, and SciPy.Optimize in order to do all of the computations and fitting necessary to graph it.

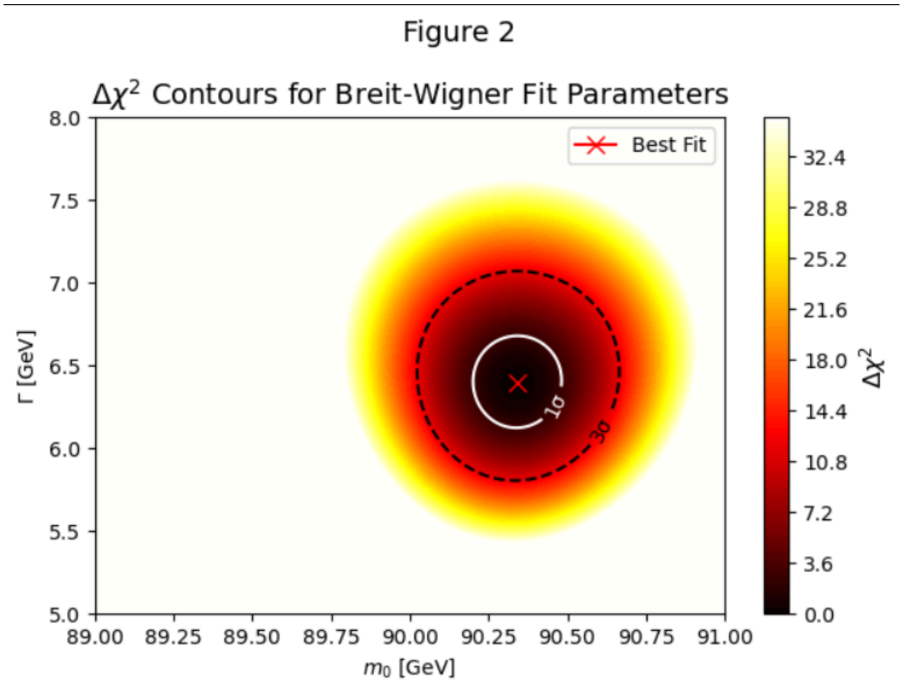
(1) When solving for the mass we were given data that include the total energy E, the momentum of two particles, pT, the azimuthal angle ϕ, and the pseudorapidity η . Using this data we constructed the component vectors of each value of moment using px = pT cos(ϕ), py = pT sin(ϕ), and pz = pT sinh(η). Then by using the given equation M = sqrt(E^2 - (px^2 + py^2 + pz^2)) we were able to solve for the mass of each Z^0 boson for each lepton pair. In order to plot the resulting data I created a histogram with 41 bins between 80-100 GeV and added error bars equal to the square root of the number of data points because of the assumed Poisson distribution.

Figure 1



(2) After this I moved onto fitting the data using a Breit-Wigner fit. Running the data through a normalized Breit-Wigner function. The function being normalized to 2500 because of the number of data points. The best-fit parameters were obtained by minimizing the χ^2 between the model and data using SciPy's curve_fit function. The result was added as a line onto the histogram that was created. The data was plotted with the best fit line being graphed as a curve through the data and the error bars on the histogram reflect the statistical uncertainty in each bin, estimated as the square root of the bin count assuming Poisson statistics.

Then I calculated the residuals and plotted them on a set of axes below the histogram resulting in Figure 1. Using the curve_fit function to solve for the best fit of the Breit-Wigner function returned the values of the m0, gamma, and the uncertainty of each.The χ^2 value was calculated as the sum of the squared differences between the observed and fitted values, each weighted by the corresponding statistical uncertainty.. The reduced χ^2 was solved by using the number of degrees of freedom which was the number of data points minus the number of fitting parameters. Finally the p-value was solved for using a chidist function. The values for each are as follows: The best fit of m0 was 90.3 ± 0.1 GeV, the best fit for the width was 6.4 ± 0.2 GeV, the value of χ^2 was 10, the value of reduced χ^2 was 1, the number of degrees of freedom was 12, and the resulting p-value was 0.442. Looking at our residual plot we can see that the data is randomly distributed around 0 which would be the ideal fit. Looking at our resulting p-value we can see that it falls between 0.05 and 0.95. A p-value of 0.4 suggests that there is a 40% probability of observing a χ^2 value as large as the one obtained, assuming the model is correct. This indicates the fit is statistically acceptable.



(3) Next we did a scan of χ^2 values across a 2D plane from 89 to 91 Gev and with the width spanning 5 to 8. By creating a meshgrid with previously stated dimensions the resulting value of χ^2 from the Breit-Wigner model was then graphed across the 2D plane. After drawing the levels for 1σ and 3σ, which were 2.30 and 11.83 because of the two fitting parameters we had, we had the resulting graph for Figure 2. The resulting contour plot shows the $\Delta\chi^2$ values across a grid of m0 and gamma, clipped at 35 for visual clarity. The color map represents how much worse each parameter pair fits the data compared to the best-fit point, which is marked by a red 'X'.

The extracted mass of the Z^0 boson from our Breit-Wigner fit was: m0 = 90.34 ± 0.09 GeV. This can be compared to the Particle Data Group world-average value: m = 91.1880 ± 0.0020 GeV. My answer falls around 0.85 GeV below the accepted value and is significantly far outside 1σ uncertainty of both the fit and the Particle Data Group reference. This suggests either experimental limitations in the analysis that I did or or that the model is missing something. This could be something such as detector effects or background contributions. I made several simplifying assumptions during the analysis that likely affected the precision and accuracy of my extracted parameters. The Breit-Wigner function assumes perfectly measured energies and momenta, but real detectors like ATLAS have finite resolution. This broadens the observed distribution and may skew the fitted mass and width. The lab also did not include any systematic errors. The analysis only considered statistical uncertainties like when I assumed the poisson distribution. Systematic errors from the devices used to take the measurements would also have an effect.This means that in practice, quantities like pT, η and ϕ carry measurement errors that would propagate into the invariant mass calculation. For future improvements it would be important to eliminate these assumptions. This would be achieved by taking note of the uncertainties in the measurements that are being taken. It would take note of the resolution of each device used to take measurements so that we could account for it in the calculations we make. We would also want to be able to consider how the data for energy and momentum is skewed by the finite resolution of the detector.

Signed,

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