Report for Graduate Students about the ATLAS Experiment

By Talya Lebson

I Introduction

At CERN, particles with high energy are sent out to hit each other to create byproducts that can be studied. This report will explore the mass of the Z^0 boson, which is one of the particles explored at CERN, created from two protons colliding. Understanding the Z^0 boson is important for understanding many nuclear reactions because the Z^0 boson decays very quickly. This report will begin with calculating the invariant mass distribution of the Z^0 boson using data from the ATLAS detector. It will then fit the data with the Breit-Wigner Fit and analyze this fit using chi-square. Lastly, it will analyze the 2D contour created based on this fit. This will help us understand the decay rate and mass of the Z^0 boson.

II Invariant Mass Distribution

In this section, the invariant mass distribution of the Z^0 boson was plotted and fit. This was done using curve_fit in python from scipy.optimize. The data used was imported from ATLAS. This is data of 5000 pairs of protons that collide and create a Z^0 boson. To begin the plotting process the mass needed to be calculated based on the total energy of each proton (E), the transverse momentum of each proton (p_T), the pseudorapidity (η) of each proton, and the azimuthal angle of the beam (**ϕ**). The transverse momentum was converted into natural units with the equations $p_x = p_T cos(\phi)$ $p_y = p_T sin(\phi)$ $p_z = p_T sinh(\eta)$. Then the transverse momenta in each direction and the total energies were summed for each pair of protons. Next, these summed values were put into the equation $M = \sqrt{E^2 - (p_x^2 + p_y^2 + p_z^2}$ to calculate the invariant mass. A histogram was then created from this data with assuming Poisson's error ($\sqrt{N}$ where N is event per bin) and 41 bins with data from 80 GeV to 100 GeV.

This data was then fit with the Breit Wigner Fit. This fit the mass distribution to the equation $D = \frac{1}{\Pi}\frac{\Gamma/2}{(m-m_0)^2+(\Gamma/2)^2}$, with fitting the width parameter (Γ) and the true mass of Z^0 (m_0).

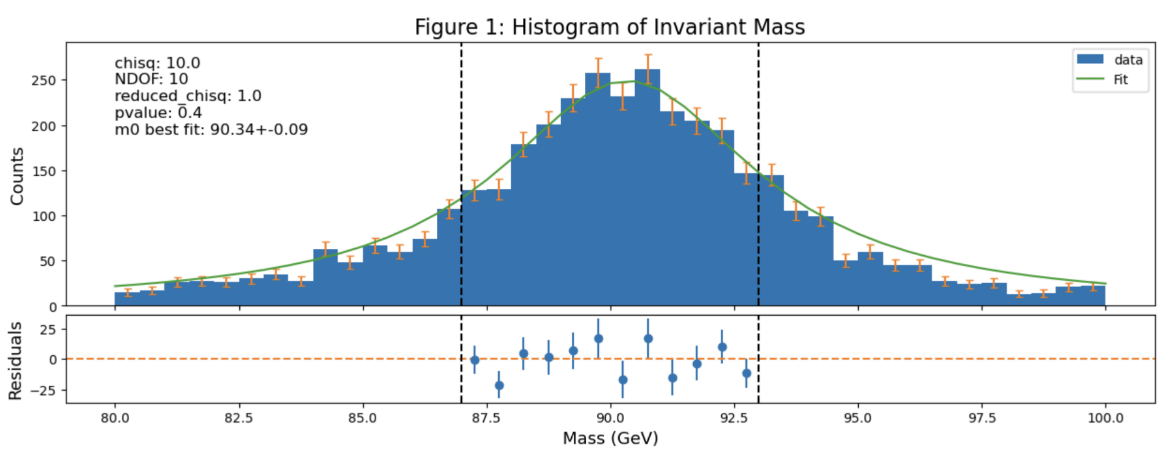

Figure 1: This graph was produced by creating a histogram of the mass calculated from

the ATLAS data. The line of best fit was calculated using the Breit-Wigner Fit. Error bars represent Poisson's uncertainty.

The fit produced a Z^0 mass of 90.3+-0.09 GeV. This fit had a chi-square of 10.0, with 10 degrees of freedom, which produced a p-value of 0.4. The degrees of freedom were calculated by taking the number of points that fell in the fitting range (12) and subtracting the number of parameters that were fit (2), this resulted in 10 degrees of freedom. Since this p-value is between 0.05 and 0.95 these results are significant. That means that the Breit-Wigner Fit aligns well with the data from ATLAS.

III 2D Parameter Scan

It is important to remember that when fitting two variables in an equation, they are not fit independently. A 2D plot shows the interaction between the fitting of the two variables and the range that they can cover. A 2D chi-square scan was created of the mass (m0) and width (Γ) parameter space. This was then used to create a contour plot of the $\Delta\chi^2$. This was calculated using the equation $\chi^2 = \Sigma((theory) - x_{data})^2/error_y$ w, hich was then used to create a contour map. A 1σ (68%)and 3σ (99%) line was created, which was calculated using the ppf function from scipy.stats, which using 2 degrees of freedom for the 2 variables calculated the levels that should be used for each confidence interval. Using this formula I found that the levels used for the 1σ are 2.3 and for the 3σ are 11.8. The chi_map was created by subtracting the minimum chi from the contour created from the m0 and gamma data. The data was also clipped at 35 for better readability.

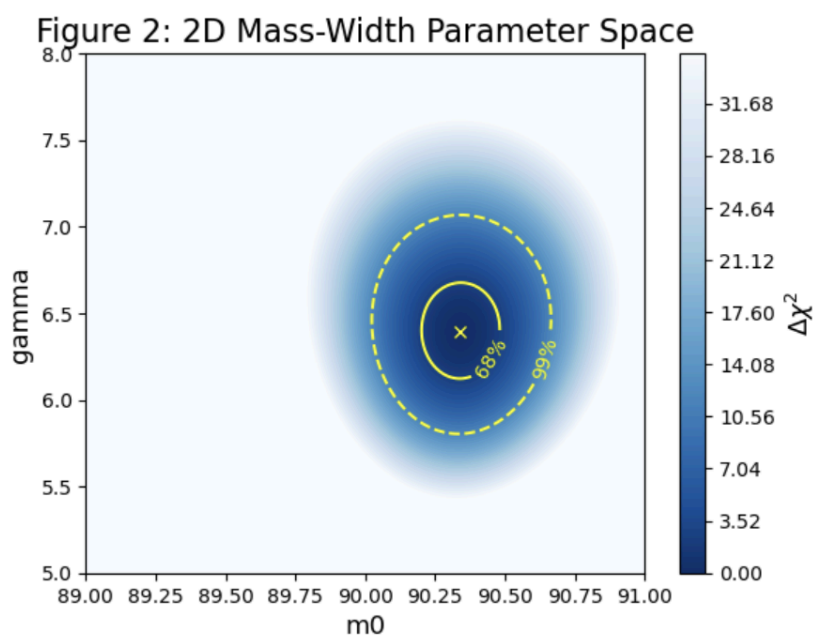

Figure 2: This is the graph created with a contour map of gamma and m0. The x in the center represents the best fit value calculated in curve fit. The circles show the 1σ (68%)and 3σ (99%) confidence intervals.

IV Conclusion

This report found that the Breit-Wigner Fit was a good fit for the data received from ATLAS of the invariant mass of the Z^0 boson. The p-value for the fit created from this data was above 0.05 and below 0.95, so the fit was significant. There were a couple of assumptions used in this report. An example of a simplification made was assuming that each proton that collided would create a Z^0 boson and nothing else. All of the calculations made based on the data from ATLAS were based on this assumption, but it is an oversimplification of the possibilities of what could occur because other particles could be created. Additionally, it assumed a perfect collision with no energy or matter lost, which will likely not occur. The next steps to enhance realism would be to include more data and attempt to replicate these calculations. Additionally, the calculation should somehow include the possibility that these collisions will not always occur perfectly to make them more accurate. The expected mass of the Z^0 boson is 91.1880+-0.0020 GeV/c^2. The mass calculated in this report was 90.34+-0.1 GeV/c^2. The value calculated was 0.848 GeV/c^2, different from the expected, which although is within an integer of the expected, is outside the range of uncertainty. Overall this analysis provided a reasonable representation of the ATLAS data, it was not perfect due to the assumptions being made and the incorrect Z^0 boson mass.