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PHYS265
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Lab 3 Report: ATLAS

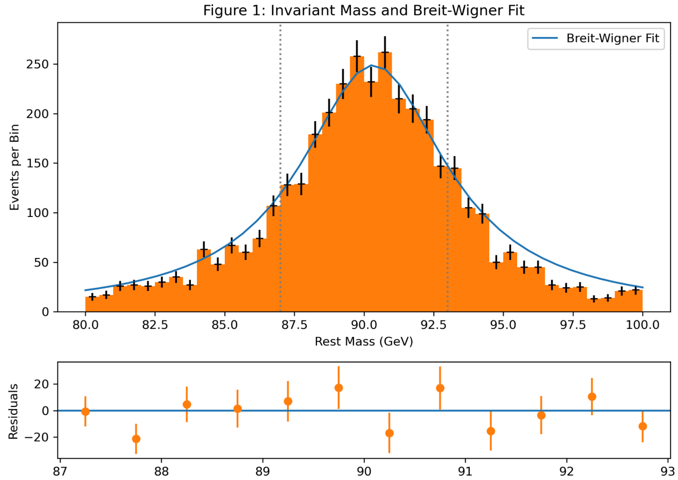
I. Introduction

I am a physicist working at the Large Hadron Collider at CERN as part of the ATLAS (A Toroidal LHC ApparatuS) experiment. We accelerate particles to very high speeds and then collide them to gain insights into even more fundamental building blocks of known particles. One of the most important particles we are investigating is the Z^0 boson, and the calculation of its mass. The Z^0 boson is an unstable particle and thus decays into a lepton pair of opposite charges. It is also possible for the Z^0 boson particle to decay to a lepton pair with no charge. Since matter and energy cannot be created or destroyed, we can measure the energy of the lepton pairs to deduce the mass of the Z^0 boson. First, I analyze the data received from the ATLAS experiment to calculate the invariant mass of the lepton pairs. I then use a Breit-Wigner fit to calculate the width (Γ) and mass of the Z^0 boson. Finally, I present a 2d chi-squared map with parameters of mass and width.

II. The Invariant Mass Distribution and its Fit

To calculate the invariant mass of the lepton pair, I used $p_x = p_T \cos(\phi), \quad p_y = p_T \sin(\phi), \quad p_z = p_T \sinh(\eta)$, $M = \sqrt{E^2 - (p_x^2 + p_y^2 + p_z^2)}$ by breaking the data into vector components and inputting them into the above equations. To make a histogram of the mass, I chose to have my bins range from 80 to 100 GeV with 41 steps. This histogram had a clear peak at 90 GeV.

Figure 1: Invariant Mass and Breit-Wigner Fit



I applied the Breit-Wigner fit to the histogram from the ranges 87 to 93 GeV. To achieve the fit I created a function within Python as follows: $\mathcal{D}(m; m_0, \Gamma) = \frac{1}{\pi}\frac{\Gamma/2}{(m-m_0)^2+(\Gamma/2)^2}$. A coefficient of 2500 was added to fix the fit to half of the points in the experimental data set.
Using curve fit from the Scipy toolbox allowed me to extract the params and covariance matrix from the curve fit, thus allowing me to define an m_fit and gamma_fit. These are the values calculated from the Breit-Wigner fit on the histogram:

1. Best-fit m_Z = 90.3 +- 0.1 GeV
2. Gamma = 6.4 +- 0.2 GeV
3. Chi-squared = 10.0
4. NDOF = 10
5. p-value = 0.4

The accepted value of the mass of the Z^0 boson is 91.1880 ± 0.0020 GeV. My model differs by .7 GeV with a larger margin of error. When dividing my Chi-squared value by the number of degrees of freedom, I get a value of 1.0. This indicates a good fit between the experimental data and the modeled function. A p-value of 0.4 is reasonable and indicates that the fit matches the data provided by the experiment.

III. The 2D Parameter Scan

Finally, this fit is inherently two-dimensional, where Z and Γ cannot be determined independently. To better visualize the fit, I performed a chi-square scan of the mass-width parameter space. The grid consisted of the mass over a range of 89 to 91 GeV with widths from 5 to 8, taking 300 data points in each respective direction.

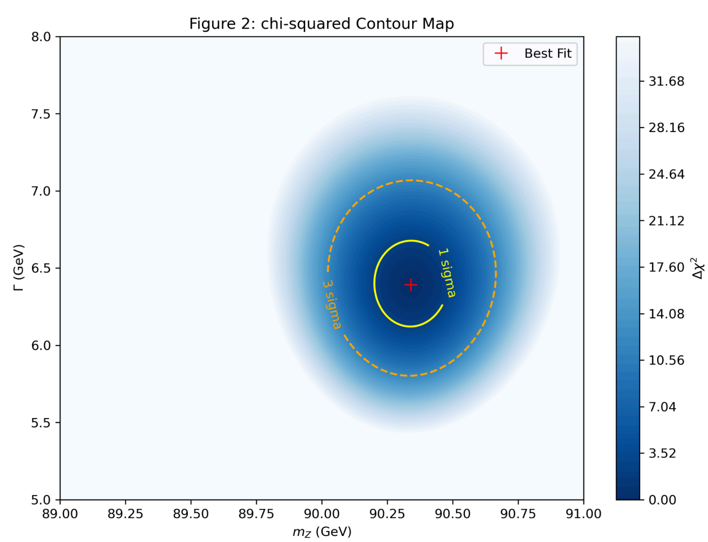


Figure 2 shows my 2D chi-squared scan with confidence levels: 1 sigma (solid) and 3 sigma (dashed). The best fit for the mass of the Z^0 Boson obtained from part 2 is indicated with the red +. Statistically insignificant data has been color-coded to focus on the best-fit location. The Chi-Squared Contour map ranges from 0 to 32, within the 1 sigma confidence level the chi-squared is less than 5.

IV. Discussion and Future Work

At the conclusion of this experiment, the best-fit value of the mass of the Z^0 Boson was 90.3 ± 0.1 GeV, being of reasonable agreement to the accepted literature value of 91.1880 ± 0.0020 GeV. Together with a p-value of 0.4 and a reduced chi-squared of 1.0, I would say that the Breit-Wigner fit modeled our experimental data well. Nonetheless, future work is always necessary. The data was not filtered or analyzed for noise and was taken at face value. In large experiments like ATLAS with many moving parts, RF noise is a constant problem that needs developed solutions. Also, we only studied one Boson, the Z^0. Obtaining data for other particles would allow the fit method to be tested more broadly and also to be improved. In the future, I definitely would like to explore the reduction of noise in complex systems like those in ATLAS using tools such as filters, FFT, and physical noise shielding such as RF shielding foil to test the effects on real data. Overall, I would say this experiment was a success, and there is fruitful ground for continuous research within the ATLAS structure.

- Justin James