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Physics 265
May 6, 2025

Lab 3: ATLAS Data Analysis

Section I: Introduction

In this report, I will discuss how I utilized JupyterLab to perform an analysis of data collected from the ATLAS experiment, which is located at CERN in Geneva, Switzerland. The ATLAS experiment is a major particle physics experiment that collides high-energy protons at near light speed in order to study the fundamental particles and interactions that arise from these collisions.

As part of the analysis, I obtained physical quantities for each particle, the transverse momentum, pseudorapidity, azimuthal angle, and total energy. Using these values, I then calculated the invariant mass of particle combinations and analyzed the resulting mass distribution. This data was visualized using a histogram. Following this, I applied a fitting procedure to the histogram data using the Breit-Wigner distribution. For this fit, I incorporated both the rest mass and a width parameter. Additionally, I included error bars to account for uncertainties in the data and plotted the residuals to assess the quality of the fit. Finally, I generated a two-dimensional contour plot based on the chi-squared values obtained during the fitting process. This plot illustrated the best-fit parameter location and the associated uncertainties, represented by error circles.

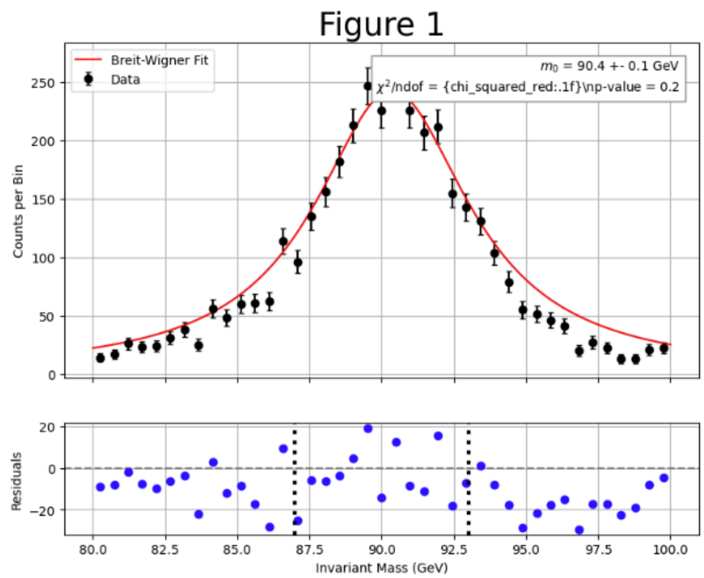
Section II: The Invariant Mass Distribution

First, I had to get the data into JupyterLab in order to begin. I accomplished this by loading a document with all of the necessary data and then storing each of the values by reading the file as a list. Once the data was stored, I computed the momenta for each particle. This was done by using the transverse-momentum values and the azimuthal angle and the pseudorapidity.

After calculating the momentum components, I calculated the invariant mass of the particle systems. This was calculated using the formula involving the square root of the total energy squared minus the sum of the squares of the momentum components in each direction. Once I had the invariant mass values for all events, I plotted these values in the form of a histogram, focusing on the mass range between 80 GeV and 100 GeV. The resulting histogram showed a clear peak around M=90 GeV, where approximately 225 masses were observed in the central bin, and about 500 masses were distributed in the neighboring bins.

To show the statistical uncertainty associated with each bin in the histogram, I added error bars. These were calculated by taking the square root of the number of events in each mass bin. Then, I fit the data using the Breit-Wigner distribution. For this fitting procedure, I employed the “curve_fit” function from the “scipy.optimize” library.

After obtaining the fit parameters, I overlaid the resulting Breit-Wigner curve onto the histogram to visually compare the model with the observed data. In addition to this, I created a separate plot where the data was shown as individual points with error bars, and the fitted curve was overlaid for clarity. I labeled this plot as “Figure 1.” In a subpanel beneath this plot, I included a graph of the residuals, which display the differences between the observed data points and the fitted values. This residual plot helped to assess the accuracy and appropriateness of the fit by highlighting any systematic deviations.



After completing all the visualizations and fit procedures, I computed several important statistical quantities. These included the fitted mass of the proton, which came out to approximately 90.4 GeV, and the associated uncertainty, which was about 0.1 GeV. Additionally, I calculated the chi-squared value for the fit, which was approximately 14.8, along with the number of degrees of freedom, which was 11. Based on these values, I determined the p-value to be around 0.2, indicating that the fit was statistically acceptable and consistent with the observed data within the expected level of uncertainty.

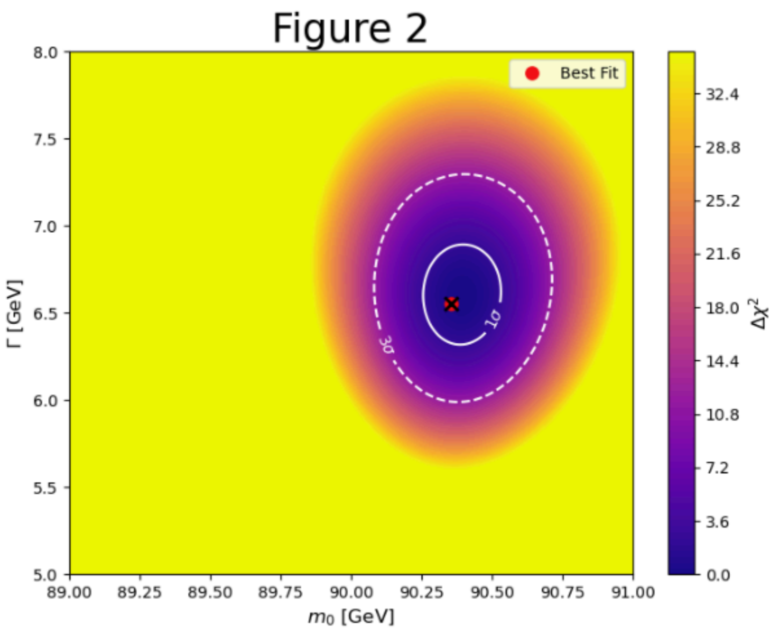
Section III: 2D Parameter Scan

Next, I moved on to creating a contour plot to visualize how the chi-squared values vary across different combinations of parameters. To begin, I constructed a two-dimensional grid that spanned a range of values for the rest mass (89 - 91 GeV) and the width parameter (5 - 8 GeV) of the Breit-Wigner distribution. These two variables were chosen as the axes of the grid because they are the primary parameters that define the shape and position of the resonance peak in the fitted distribution.

Once the grid was established, I calculated the chi-squared value at each point on the grid by evaluating how well the Breit-Wigner distribution fit the data. This process involved iterating over the entire grid and computing the chi-squared statistic by summing the squared differences between the model and the observed data, weighted by the uncertainties.

With the chi-squared values calculated, I proceeded to generate the contour plot itself. I used the rest mass values along the x-axis and the width parameter values along the y-axis. The contour lines represented regions of constant chi-squared, allowing me to identify areas where the fit quality was similar. I also included a color bar alongside the plot to provide a visual indication of the chi-squared magnitude across the grid. This made it easy to see how the chi-squared value varied and to find the region of the best fit. This plot is labeled as “Figure 2.”

I also marked the best-fit point, which corresponded to the combination of mass and width that minimized the chi-squared value, directly on the contour plot. Around this best-fit



point, I drew uncertainty contours corresponding to one sigma and three sigma regions. These were plotted as ellipses, centered on the best-fit values, and indicated the parameter ranges within which the true values are statistically likely to lie. The inclusion of the one-sigma and three-sigma contours provided a clear visual representation of the statistical uncertainty associated with the parameter estimates, and helped assess how tightly constrained the fit was based on the available data.

Section IV: Discussion and Future Work

The fitted mass of the particle I measured was approximately 90.4 GeV with an associated uncertainty of about 0.1 GeV. This value is in good agreement with the currently accepted value for the mass of the Z^0 boson, which according to the most recent data from the Particle Data Group (PDG) is 91.1876 +- 0.0021 GeV. While my result is relatively close, there is still a noticeable difference of around 0.8 GeV. This discrepancy, while not extremely large, likely arises due to several approximations and limitations in the analysis rather than any fundamental experimental difference.

Several simplifications were made during the analysis that impacted the precision and reliability of the results. One of the major approximations was the use of idealized detector data without accounting for systematic uncertainties. In a real experimental context, these systematic errors, such as biases in measurement techniques or detector calibrations, can significantly affect the results and must be carefully estimated and included in the fit. Additionally, I did not include the energy resolution of the ATLAS detector, which plays an important role in shaping the observed width of the invariant mass distribution. Ignoring resolution effects can lead to an underestimation or overestimation of the true width parameter and may shift the peak position slightly, which likely contributes to the difference between my measured mass and the PDG value. Future work would involve addressing these limitations and incorporating systematic uncertainties into the fit. This would lead to a more accurate approximation of the Z^0 mass.