An Investigation into the Invariant Mass Distribution of Z^0-boson from lepton pair decay

Introduction:

This report is a summary of my findings and calculations from the Z^0 decay data collected by ATLAS at CERN. Z^0-boson is a neutral carrier of the weak force, but it is unstable and decays. Approximately 10% of the time, however, it decays into a pair of leptons. At the ATLAS detector in CERN's LHC, 4 measurements of each decayed lepton can be taken:

1. The total Energy (E) of the lepton
2. The transverse momentum (pT) of the lepton
3. The pseudorapidity (η), or the angle of the particle with respect to the beamline
4. The azimuthal angle along the beam (ϕ)

Together, these four values can be used to calculate the four-momenta of the lepton, and ultimately its mass. The four-momenta is the particle's energy along with its momentum in the x, y and z directions.

In this report we carried out the necessary calculations to calculate the invariant masses of 5000 lepton pairs detected at the ATLAS detector. Then these masses were plotted into a histogram to analyse the decay distribution, against a theoretical model. Finally we created a contour plot of the chi-sq of a range of the fitting parameters for the theoretical model, in order to understand the fit better.

Invariant Mass Distribution:

Using the data obtained from the ATLAS detector, we can determine the four-momenta of each lepton using the following equations:

$$px = pTcos(\phi), py = pTsin(\phi), pz = pTsinh(\eta)$$

Upon determining these values, we can then find the invariant mass of the particles by applying this equation:

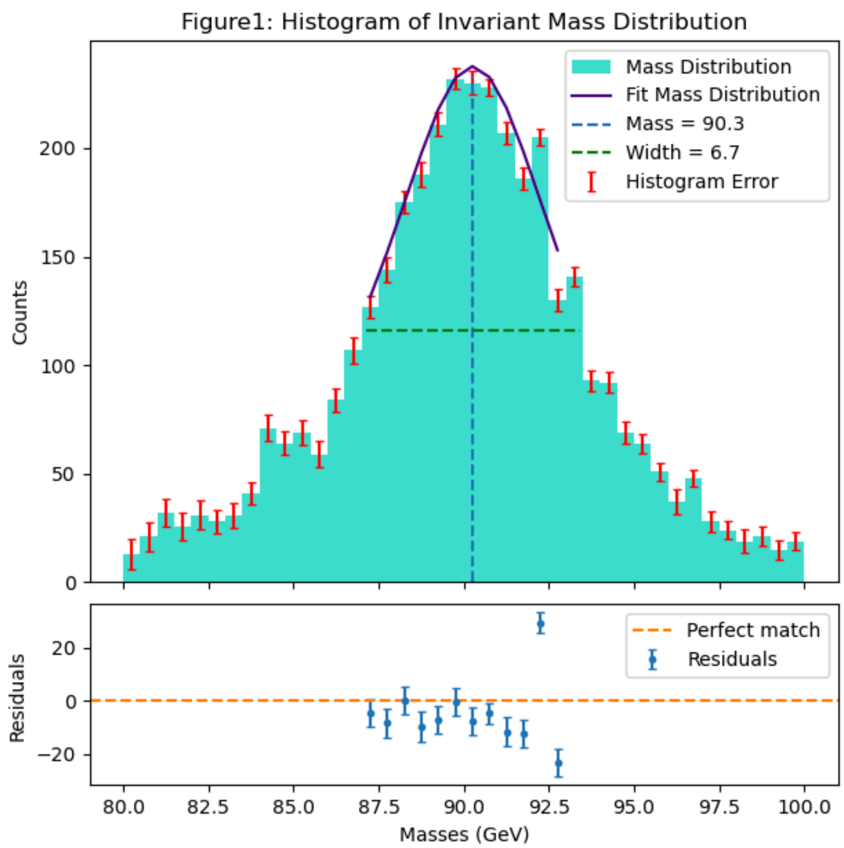
$$M = \sqrt{}(E^2 - (px^2 + py^2 + pz^2))$$

In the case that there are multiple particles we can simply sum up the four-momenta of the two particles, and this gives us the total four-momenta of the system. This four-momenta can then be inputted into the mass equation to obtain the mass of the original particle that these two leptons decayed from.

This calculation was done to each of the 5000 lepton pair data taken from the ATLAS detector. Upon calculating the invariant masses, these were then plotted as a histogram with the bins ranging from 80-100 GeV. This gives a plot of the Invariant Mass Distribution, which can be fit with a model. This distribution resembles a Poisson distribution, specifically a Breit-Wigner peak, which can be given by this equation:

$$D(m, m0, \Gamma) \;=\; \frac{1}{\pi}\frac{\Gamma/2}{(m-m0)^2+(\Gamma/2)^2}$$

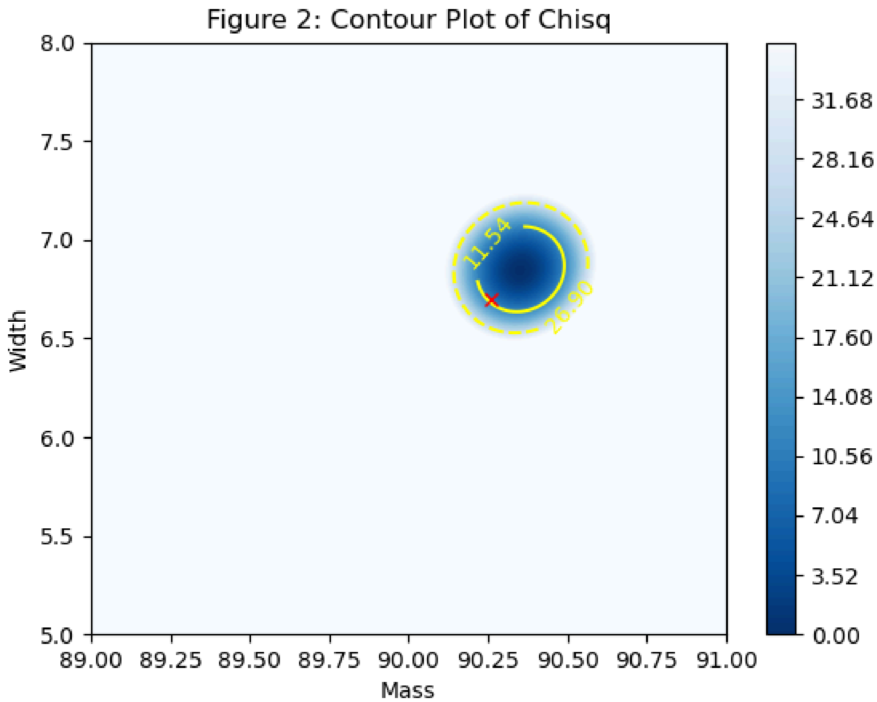
As seen by this equation, this model requires us to fit two parameters. The true rest mass of Z^0-boson (m0), and the full-width half-maximum (Γ), with m being the mass at whose probability distribution we are determining. This was fitted in python using scipy's curvefit() routine, and applied to a limited selection of the invariant masses, from 87 GeV to 93 GeV. Further, the residuals, or the difference between the data, and theory was plotted to see the variation, with 0 being perfect fit. The uncertainty for the histogram was taken to be √N with N being the count of each bin, assuming a Poisson distribution



The best fit value for the rest mass was 90.2 $\mp$0.03 GeV. The Chi-squared value for this was 98.0, with 10 degrees of freedom. The p-value of this fit was 1.4E-16. Since the p-value of this fit is so low, it shows that there is a very strong correlation between the theory and experimental data. However, it is also possible that the uncertainties were overestimated, giving such a low p-value, since this was assumed to be a simple Poisson distribution.

2D Parameter Scan:

Upon obtaining the best fit values, the next step in the analysis was to do a 2D parameter scan. To do this, the chi-sq value was calculated for a range 500 m0, and Γ values each. The m0 values were from 89 - 91 GeV, and Γ values were from 5-8. After doing this the Delta Chi-square



values were calculated, by subtracting the minimum chi-square value from each chi-square, in order to normalise it such that the minimum value would be 0. Then these values were plotted as a contour plot, with lines showing the 1 sigma, and 3 sigma confidence intervals. For 10 degrees of freedom, as we have, these values correspond to 11.54 and 26.9 chi-square values.

Using the graph it can be seen that the best fit values determined by the curve_fit() routine, denoted by the red X, are at a 1 sigma confidence level. This means that while these are not the best possible values, they still exhibit relatively good correlation.

Conclusion:

The ATLAS lepton pair decay mass distribution was analysed using the Breit-Wigner peak model, giving a true rest mass value of 90.2 ∓0.03 GeV, with reasonable confidence. This corresponds well with the literature value produced by the Particle Data Group, which put this value at around 9.2 GeV. Certain assumptions, such as the √N uncertainty can be improved upon, by taking into account the uncertainty of measurement by the ATLAS detector. Further, an increase in data points from 5000, would likely improve the fit and give a more accurate rest mass value. Another improvement could be to increase the range of values used to calibrate the fit. Currently it was assumed that the true rest mass was between 87 and 93 GeV, which it was, however, removing this assumption and allowing the fit to take all values would likely improve the quality of the fit.