ATLAS REPORT

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ABSTRACT

The purpose of this report is to analyze A Toroidal LHC Apparatus (ATLAS) Data from proton-proton interactions for the Z^0 boson's mass in GeV. When two protons collide they break open releasing fundamental particles which interact and decay, within these interactions is the Z^0 boson which is a carrier of the weak nuclear force. The Z^0 boson often decays into charged lepton pairs which must have either opposite or no charge to conserve the charge therefore we can also infer that the leptons must conserve energy, the sum of this energy is the mass of the Z^0 boson, meaning that measuring the energy in the lepton pair events we should see a peak at or near the mass of the Z^0 boson. Data received by ATLAS included the total energy E, transverse momentum p_T which is the momentum the particle has in a transverse direction, pseudorapidity η which is the angle the particle makes in respect to the beamline, and the azimuthal angle ϕ about the beam. These four properties of the particles make up the four momenta of the particle which are then used to derive the particle's invariant mass. Using scattering theory we can predict where the Z^0 boson will be located at a certain mass range from the decays. The measured mass of the Z^0 boson from the ATLAS data is approximately (90.34 ± 0.09) GeV.

I. Introduction

Within the LHC at CERN we can observe proton-proton (pp) interactions that break open protons and reveal fundamental particles such as a particle that carries the weak nuclear force known as the Z^0 boson. The Z^0 boson is unstable and eventually decays into charged lepton pairs (can also decay into photons pairs, but we are interested in the lepton pair decay) such as an electron and anti-electron, muon/anti-muon, and tau/anti-tau. They are produced with differing charges or no charge due to the fact that charge cannot be created or destroyed. Matter and energy can also not be created or destroyed, therefore, if Z^0 bosons decay into lepton pairs; they must carry energy that sums up to the mass of the boson. Measuring the energies of the double-lepton interactions we can observe an excess at the mass of the Z^0 boson.

II. Invariant Mass Distribution

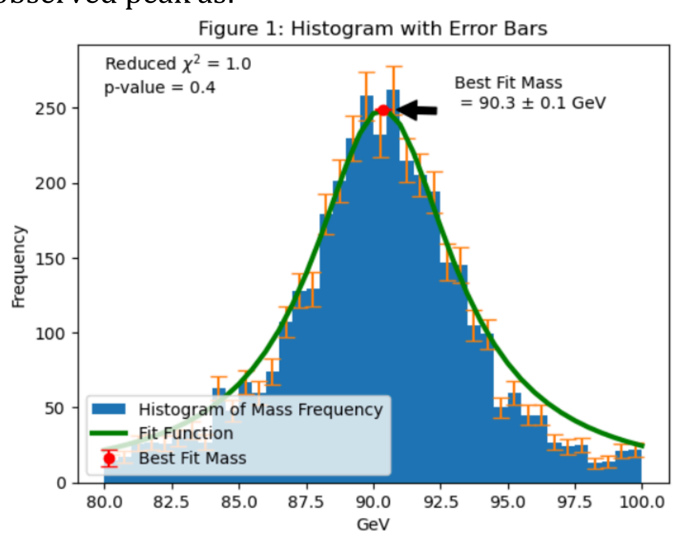
Data from A Toroidal LHC Apparatus (ATLAS) includes the four momenta of lepton pairs after a proton-proton interaction occurred, these four properties include the total energy E in Joules, transverse momentum p_T which is the momentum the particle has in a transverse direction, pseudorapidity η which is the angle the particle makes in respect to the beamline, and the azimuthal angle ϕ about the beam, both η and ϕ are in radian. To calculate the mass of the Z^0 boson from the four properties of the lepton pair we must calculate the four momenta of the particle using the following mathematical relationships:

$$p_x = p_T cos(\phi)\,, \qquad p_y = p_T sin(\phi)\,, \qquad p_z = p_T sinh(\eta) \tag{1}$$

Summing these three momenta we can take the difference from the energy and calculate the particle's invariant mass:

$$M = \sqrt{E^2 - (p_x^{\ 2} + p_y^{\ 2} + p_z^{\ 2})} \tag{2}$$

Thus, the calculated mass from the ATLAS data appears from mass ranges of 80 - 100 GeV around the observed peak as:



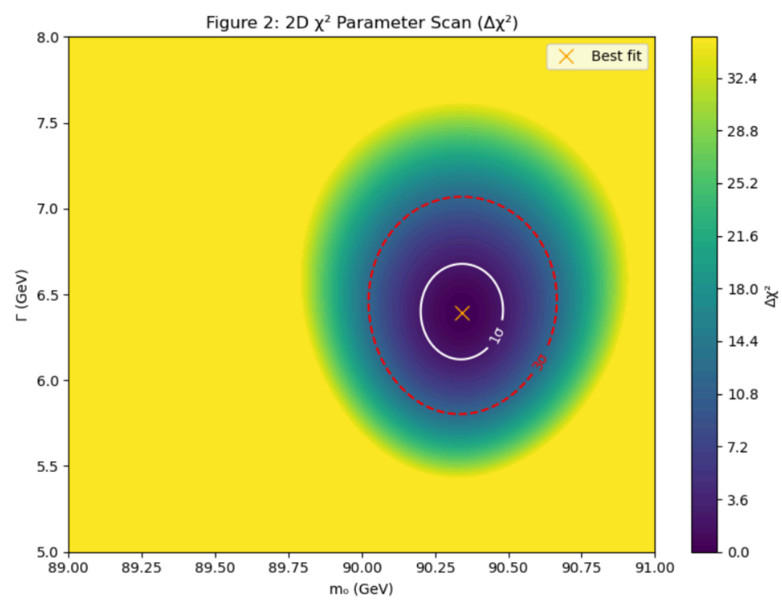
Constructed with the *matplotlib.pyplot* library in python, we observe a graph that details the frequency of the reconstructed mass from pp interactions that produced the Z^0 boson, using a binning range for the histogram (each step represents a bin) from 80 - 100, we see that the frequency peaks near 90 GeV with an uncertainty of $\sigma = \sqrt{N}$ where N is the number of counts within the bin. Using scattering theory, we can show the distribution of decays from a reconstructed mass m follows a 'Breit-Wigner' peak. The distribution depends on the rest-mass of the Z^0 boson m_0, and on the 'width' parameter Γ (related to the lifetime of a particle):

$$D(m, m_0, \Gamma) = \frac{1}{\pi}\frac{\Gamma/2}{(m-m_0)^2+(\Gamma/2)^2} \tag{3}$$

This expression creates the observed fit function by using the *scipy* function known as *curve fit* that calculates the best fitting parameters to the observed data. This yields the mass for the Z^0 boson to be (90.3 ± 0.1) GeV. The best fit mass is used to create a fit function for the data that has a χ^2 of 10.0 with 10 degrees of freedom and P value of 0.4 which is a reasonable fit as it matches the data 40% of the time.

III. 2D Parameter Scan

To evaluate that the fitted curve is correct we cannot fit the mass and width parameters independently of each other as the parameters both determine the decay distribution, therefore we must visualize the probability space for both of these parameters simultaneously:



Using a scan from 89 to 91 GeV for mass and a width from 5 to 8 for the width parameter with 300 bins for each we observe a 2D χ^2 scan for both parameters (m_0 on the x axis and Γ on the y axis) we are observing. The z axis corresponds to $\Delta\chi^2$ which is the difference in χ^2 using different values for parameters and the minimized χ^2 using the best fitted parameters, therefore the closer to 0 $\Delta\chi^2$ is the closer to the best fit. The 1σ and 3σ correspond to the level of confidence that the best fit parameter lies within this range of values where 1σ is 68.3% confidence and 3σ is 99.7% confidence for 2 degrees of freedom.

IV. Discussion and Future Work

Our calculated mass for the Z^0 boson is different from the newly reported findings by the PDG which are not widely accepted, our value is (90.3 ± 0.1) GeV while the accepted value is (91.2 ± 0.002) GeV which is a significant statistical difference between the two values by a difference of 9σ. Of course, this may be due to some simplifications made such as not accounting for the leptons radiating away energy which may decrease the reconstructed mass. It is also simplified and assumed that the fit will reflect the Breit-Wigner shape which in reality the detector has a finite resolution which affects the distribution. We also assume that the number of events are perfectly known which is not necessarily true and could affect our calculations. These calculations may be improved in the future by taking a larger data set, or taking a data set with a more defined resolution to improve the accuracy of the data. Instead of fitting to a Breit-Wigner peak we could fit it to a more reasonable function such as a gaussian curve that could give a better approximation of the mass and width parameters. The number of counts should be instead considered a parameter of its own to reduce bias in the assumption that the number of counts are fixed. Our calculations also do not take into account systematic uncertainties such as calibration of the measuring device. Another interesting finding is that the best fit for the width parameter Γ within the chosen data set is 6.39 GeV while the accepted value is closer to 2.5 GeV therefore this is an oversight within the data set. Finally, the calculated P value between the fit and data set can be improved as there is a 40% agreement between the data and the fit curve.