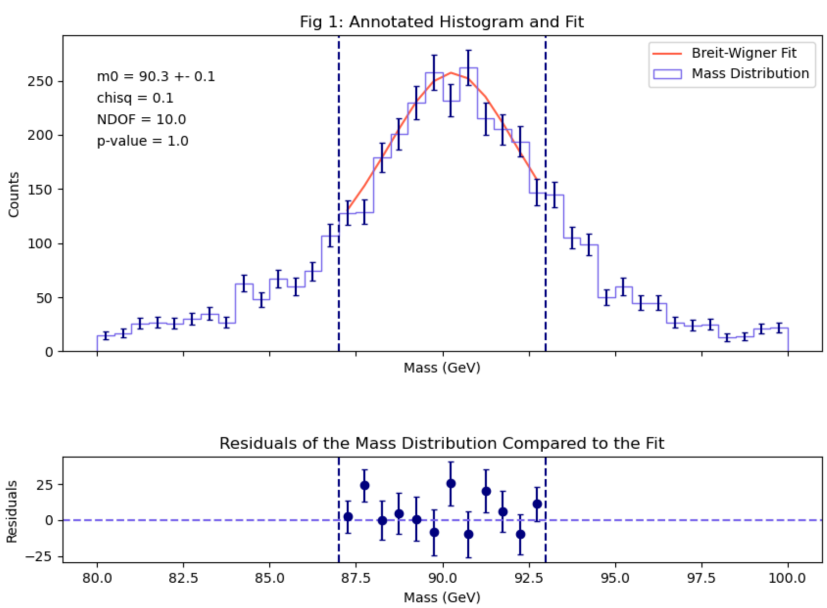
Lab Report 3

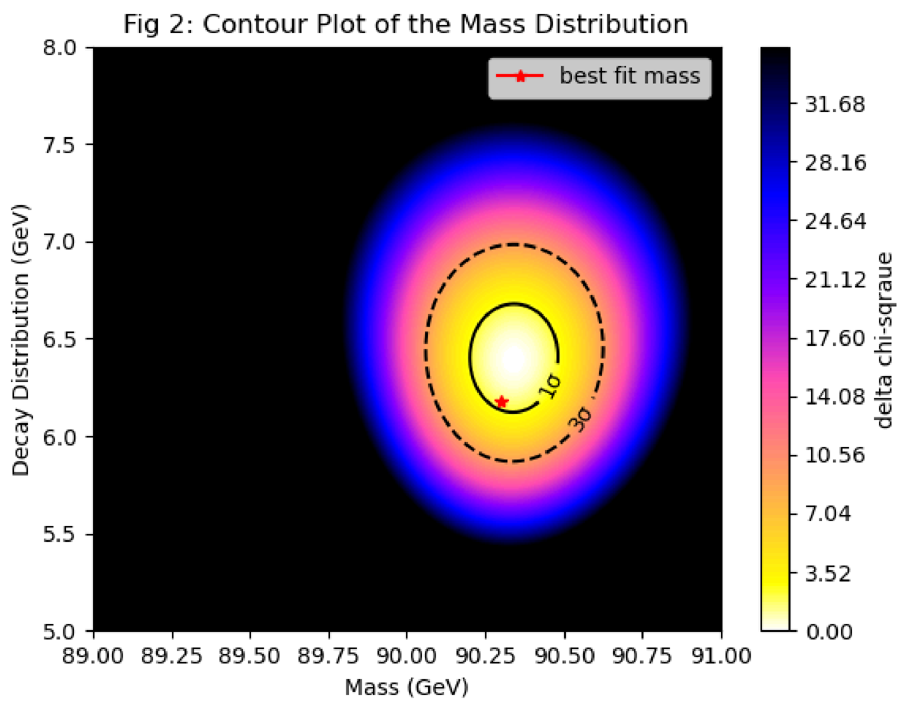
The Large Hadron Collider at CERN is used by particle physicists to measure the mass of the Z_0 boson. This boson is created from high-energy proton collisions facilitated through the collision of beams of protons and it is an important particle as it acts as an electrically neutral mediator of the weak nuclear force. In this Lab I will analyze a dataset from the ATLAS detector which is one of the four main experiments at the LHC to determine the rest or invariant mass of the boson from the lepton pairs it decays into. The mass of the Z_0 boson can be determined from this data as it gives us values for the energy and momentum components of the lepton pairs associated with each boson. This data will be analyzed with a Breit-Wigner distribution which is modeled to show the expected shape of a mass distribution made from the lepton pairs the boson decayed into. Using this fit I can extract a best fit value for the invariant mass of a Z_0 boson as well as its decay width in this data set. I will also analyze this data set by creating a 2D contour plot of the confidence levels of this distribution which will show the relationship between mass and the width in the fit. These plots can be used to determine the accuracy and quality of our measurements to see how our measurements compare with expectation.

Determining the invariant mass of each particle in this data set can be done by finding the energy in the particle as well as the three values that make up the directional momentum of the particle. The invariant mass is defined by the equation $M = \sqrt{E^2 - (p_x^2 + p_y^2 + p_z^2)}$ where E is the total energy of the particle and this value is given for each particle in the data set. The next three values determine the x, y, and z components of the particles transverse momentum where p_x is defined as, $p_x = p_T cos(\phi)$, where p_T is the transverse momentum and ϕ is the azimuthal angle about the beam, p_y is defined as $p_y = p_T sin(\phi)$, and



p_z is defined as $p_z = p_T sinh(\eta)$ where η is the pseudorapidity of the particle or the angle the particle makes with the beamline. To solve these equations in python we can load the data from the ATLAS detector into python and define functions that will take that data as inputs and output the invariant particle mass. Then to visualize and analyze the invariant masses calculated for each lepton pair we can use the matplotlib library in python to plot a histogram of the data across 41 bins from 80 GeV to 100 GeV. To further analyze this data it can fitted to a Breit-Wigner decay distribution which models the idea that we should see a peak in energy measured at the mass of the Z_0. The Breit-Wigner Fit is defined by the function $D(m;\ m0,\ \Gamma) = \frac{1}{\Pi}\frac{\Gamma/2}{(m-m0)^2+(\Gamma/2)^2}$ where m is the invariant mass measured from our data, m0 is the true rest mass of the Z_0, and Γ is a width parameter for the particle. This histogram along with its fit is shown in Fig 1 along with the residuals, or difference in the data and expectation for each mass value, and the range in which the fit was performed in From this fit I extracted a best fit m0 value of 90.3 +- 0.08 GeV as well as the chi-square which was 0.068, the number of degrees of freedom which was 10, and p value which was 1. This p value indicates that the Breit-Wigner was almost in perfect alignment with the ATLAS data.

Another method we can use to analyze this data is using a 2D parameter scan and creating a color contour plot that represents the relationship between mass and width of the fit. To do this we need to use two for loops that evaluate the chi-square of the data vs the fit at 300 different points across both m0 and gamma and from this calculating the minimum



value for each point on the chi-squared map and subtracting that from the chi-squared map. Then this can be plotted on a contour plot to visualize the relationship between mass and width in the fit. This plot can be seen in Fig 2 which also shows the 1 sigma and 3 sigma confidence levels for this distribution and the best fit mass that was calculated earlier using the Breit-Wigner fit. From this graph we can see that the best fit mass does fall within the 1 sigma confidence level meaning it is statistically consistent to the true value within a 68% confidence level. We can also see that the best fit mass is very slightly less and the width more noticeably less than what the plot indicates it should be.

The best fit mass found from the Breit-Wigner fit for this data set was 90.3 +- 0.08 GeV which is in agreement with, or within the uncertainty of, the PDG value for the Z_0 which is 91.19 +- 0.002 GeV. The distribution of the ATLAS data also fits well to its expected general shape and peak location. There is still some discrepancy between the value measured in this lab and the PDG value which is likely due to some simplifying assumptions that were made in the process of this lab. The first assumption made was that the uncertainties for the mass distribution are due entirely to statistical errors as we determined these uncertainties by taking the square root of the counts in each bin of the distribution. This method does not account for any uncertainties in the measurements in the ATLAS data that was used. We also limited our fit to a smaller mass window which meant that we only evaluated a small portion of the graph to determine our Z_0 value.