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PHYS265
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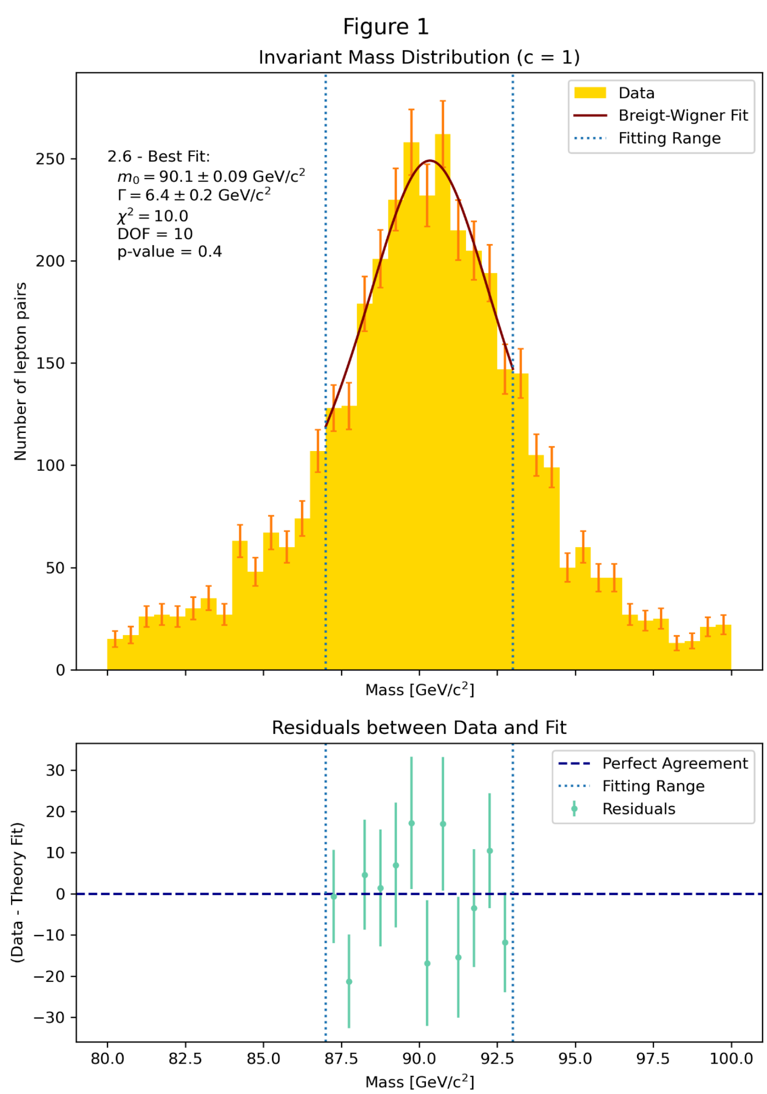
ATLAS Data Analysis

I. Introduction

The A Torodial Lhc Apparatus (ATLAS) experiment at CERN works on creating high energy proton collisions, resulting in various fundamental particles, one of which is the Z0-boson. This particle eventually delays into a pair of charged leptons, which includes a particle and its antiparticle (e.g. an electron and a positron). The purpose of this investigation is to determine the mass of the Z0 boson, which will be done by using ATLAS data that contains measurements of the properties of many lepton pairs, examining its decay distribution, utilizing the Breit-Wigner theory, and performing a chi-squared analysis.

II. The Invariant Mass Distribution and Fitting

First, we examine this ATLAS data. Row-wise, we have numerous lepton pairs, each with columns of transverse-momentum pT, pseudorapidty, azimuthal angle, and total energy. Working backwards, we're trying to determine the mass of a hypothetical particle that decayed to produce that pair. To do this, we can use a set of formulas (Eqs. 1 and 2 from the Manual), to find the hypothetical mass M for each pair. With this new array of M, we can create a histogram to see the distribution of pairs across these different masses, which resulted in the "Data" seen in Figure 1. In other words, this figure demonstrates the number of pairs that resulted a certain bin of hypothetical masses. In this



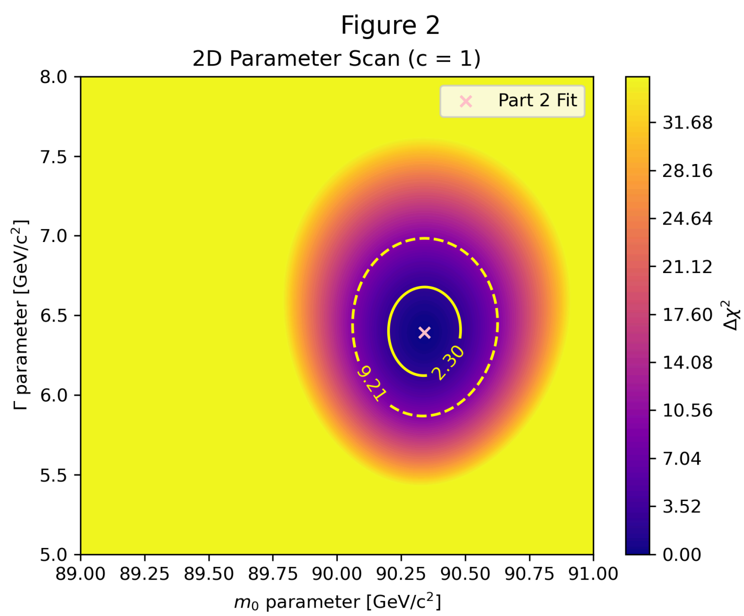
case, we used the binning range of 80 to 100 GeV with 41 bins.

Recalling our goal, which was to determine Z0, we can use this distribution to find it by curve-fitting following a theory that contains Z0. A "Breit-Wigner" fit demonstrates the theoretical distribution of decays D (which is the same as the number of pairs on the y-axis, since we know these come from decays) across the reconstructed mass m (same as the hypothetical mass bins across the x axis). This theory curve has the independent variable of m, but depends on paramters m0 (the true rest mass, which is the same as Z0), and gamma (a width parameter). By finding the best theoretical fit against the data, which is done by adjusting the fit parameters, we can determine the best value for Z0 (and gamma). This fit is seen in Figure 1 as "Breigt-Wigner Fit," which was only done within the ranges as indicated by the vertical dotted lines.

The final result of the fit was a Z0 of 90.0 +/- 0.09 GeV/c^2 (where c = 1). A chi-squared analysis gave us a chi-sq = 10.0, DOF = 10, and p-val = 0.4. This analysis was done in order to evaluate the goodness of the fit, and thus the fit parameters. The p-value tells us the percent chance that we would've gotten a chi-squared value of 10.0 or higher based on the uncertainties if we were to reproduce this analysis. Typically, a p-value between 0.05 and 0.9 are accepted. Since our p-value of 0.4 is within that range, this demonstrates that the difference between the data and the theory is not statistically significant based on the uncertainties. In other words, they agree with each other, and our fitted mass of Z0 is an acceptable value.

III. The 2D Parameter Scan

Since this fit depends on both Z0 and Gamma, we can't determine one without the other. We can visualize this in a 2D space with a contour colormap (Figure 2), each axis scans a parameter across a range of values, and the color indicates the delta chi sq. This is done by scanning through a small range of values near to what we believe is the best value for each parameter. The chi-sqs are calculated for each of those, and the delta chi-sq is determined from the chi-sq at a



specific parameter set (coordinate) minus the minimum chi-sq out of all of them. Since we have 2 fit parameters, a 1sig and 3sig confidence level corresponds with a delta chi-sq of 2.3 and 9.21, respectively, which were derived from the properties of multi-dimensional Gaussian distributions.

IV. Discussion and Future Work

As a result of this investigation, the true rest-mass of the Z0 Boson is 90.0 +/- 0.09 GeV/c^2, where c = 1 (with a Gamma of 6.39 +/- 0.2 GeV/c^2). Compared to the latest accepted value from the Particle Data Group group (91.1880 +/- 0.0020 GeV/c^2), this value is slightly higher than the fit value by about 0.8 GeV/c^2. However, it's important to note the assumptions and simplifcations used to come to these conclusions.

This investigation relied on data taken from ATLAS, which used various instruments to create these high energy particle collisions as well as take the measurements we used. This fit doesn't consider any systematic uncertainties that could've traced from flaws in the equipment they used. Besides the possible flaws, we also don't consider the resolution of the ATLAS instruments used to detect things like energy (how well it can distinguish the various energies). This resolution can affect the accuracy of the instrument, and relates to the intrinsic uncertainty of the instrument.

In order to give a more realistic value of Z0, we could first test for systematic errors in the instruments by having them take multiple measurements of the same thing, and comparing it to a known set of values. If there appears to be a consistent pattern of deviation from the expected values, rather than following a random distribution of deviation, then it's likely that systematic errors exist. The instruments would need to be adjusted accordingly. Once we know which instruments are cleared to the best of our knowledge, we'd need to test the accuracy of the instruments through various experiments and determine an uncertainty to each of the array of data points we use. This could improve our calculations for the hypothetical mass M, which affects our distribution, and ultimately the curve fit.

Signed,

- *Jamie Vásquez-Rojas*