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I: INTRODUCTION

This season's research intensive with the ATLAS group at CERN yields reliable results regarding invariant mass measurements of the Z boson (Z^0). Drawing from a best-run dataset of five thousand measurements, reliable, repeatable samples display agreement with existing models for Z^0 in terms of invariant mass, decay and full width at half maximum of its statistical curve. Data taken during this session sets a standard for further research in this field.

II: MODELING INVARIANT MASS DISTRIBUTION

Due to the extremely short shelf life of Z^0, data is collected in the form of decays from Z^0 to its respective leptons. Upon decay, detectors return a signature mass of Z^0 from the combined masses of the lepton pair. The four momentum of the particle decays are calculated, subtracted from the energy of both decay particles, and square rooted to find invariant mass expressed as a histogram of 40 bins for visualization purposes:

$$p_x = p_T\cos(\phi)\,, p_y = p_T\sin(\phi)\,, P_z = p_T\sinh(\eta)\,;$$

$$p_T = p_1 + p_2, \qquad \phi = \phi_1 + \phi_2, \qquad \eta = \eta_1 + \eta_2, \qquad E = E_1 + E_2$$

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

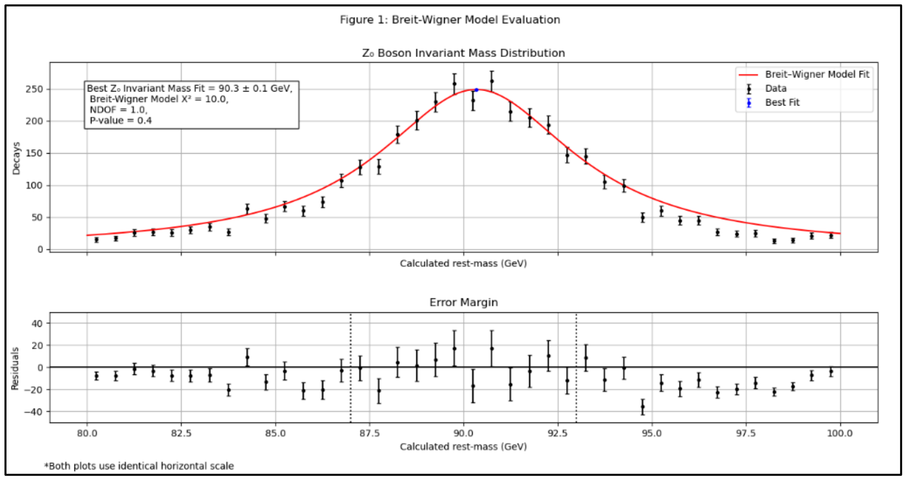
where p is transverse momentum, ϕ is azimuthal angle about the particle beam, and η is particle angle to the beamline (pseudorapidity). Poisson statistics are used to calculate error across the range of decay measurements:

$$\sigma_M = \sqrt{decays}$$

Using scattering theory, decay distribution of Z^0 is modeled using a Breit-Widner/Cauchy-Lorentz (BW) peak:

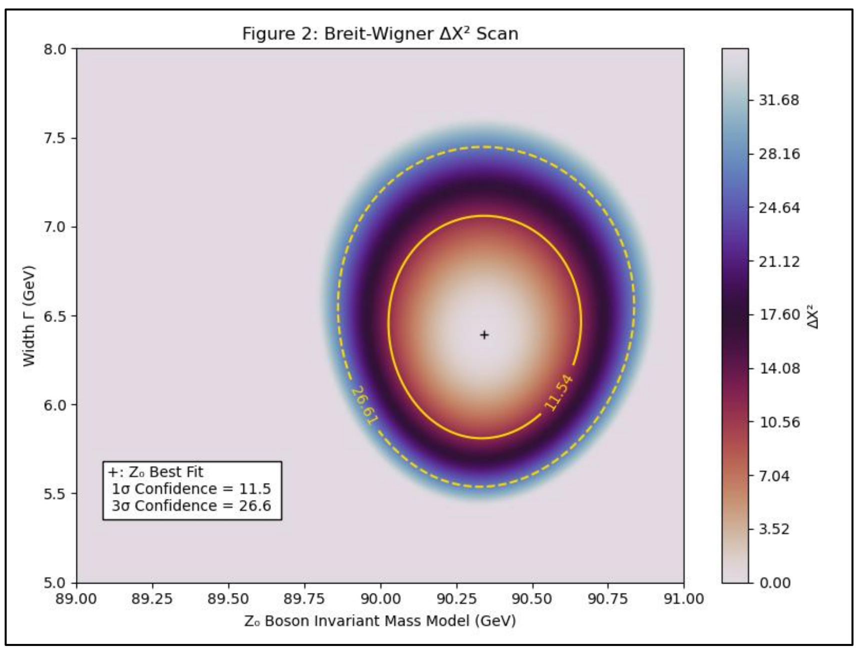
$$D(m,\Gamma) = \frac{2500}{\pi}\left(\frac{\frac{\Gamma}{2}}{(m - m_{Z^0})^2 + \left(\frac{\Gamma}{2}\right)^2}\right)$$

where m is invariant mass of Z^0, Γ is the width parameter based on the particle's lifetime by the Heisenberg uncertainty principle, and 2500 is the data normalization factor for the range of analysis for the model.



Data is loaded into Python and plot as points over the full collection range with Poisson error. A dummy array is created to generate the BW model over the full range of data, and a NumPy mask is applied to the model for further analysis over the full width half maximum of the model curve. Complete data and model are shown together. Residuals are taken between the masked data values and the model, and plot with respect to invariant mass with hatched vertical indicator lines showing analysis area. Using SciPy's curve_fit module, the best fit for the mass of Z^0 is 90.3 ± 0.1 GeV, with its covariant matrix evaluated about its diagonals to find uncertainty. A X^2 analysis over the area of interest returns a X^2 value of 10.0, reduced X^2 of 1.0, and P-value of 0.4 using 10 degrees of freedom and two fitting parameters (m, Γ), showing promise for reproducibility and reliability of the BW model in this capacity.

III: 2D PARAMETER SCAN



Due to the nature of multiple fitting parameters, a 2D X^2 map is required to generate a full, graphical analysis of reliability. Across 300 bins and within the optimal range for both m and Γ, a X^2 map is generated by looping model data and X^2 numbers over 2D space, and projecting it over an (X, Y) mesh grid. X^2 is clipped at 35, eliminating values of negligible confidence. A heat map is added to delineate X^2 range for both invariant mass and width. Contours are added to delineate 1δ and 3δ confidence levels, calculated using SciPy.stats cumulative distribution function for 68.3% and 99.7% with 10 degrees of freedom, showing 11.5 and 26.6, respectively.

IV: DISCUSSION

The accuracy and precision of the BW model against recorded data from trials at CERN set an exciting precedent for the future of particle physics, proving that existing models describe behavior that may apply to the search for other elusive elementary particles. While more testing must be done to ensure this model's reliability, this first step shows definitive promise in a field offering mystery after mystery, often producing more questions with each answer.

This study, however, is a rough draft regarding the applicability of such methods. Several assumptions are made, the least of which held the speed of light equal to zero but include omission of the energy resolution and overall systematic uncertainty of the ATLAS device. Where this study ultimately measured 90.3 ± 0.1 GeV for Z^0, the current accepted value set by the Particle Data Group (PDG) is 91.1880 ± 0.0020 GeV: well outside our range of uncertainty and measured at a much finer capacity. Our study must therefore consider other factors which may affect the model used herein for practical future use.

V: REFERENCES

https://pdglive.lbl.gov/DataBlock.action?node=S044M