Lab 3 Report: ATLAS Data Analysis

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I. Introduction

This report details the analysis of real ATLAS experiment data to investigate the decay of the Z0 boson into a pair of charged leptons. The ATLAS detector at CERN records a range of kinematic variables from high-energy proton-proton collisions. By reconstructing the invariant mass of lepton pairs, we aim to observe the signature of the Z0 boson and extract its physical parameters such as mass and decay width. This analysis includes data handling, invariant mass calculation, Breit-Wigner fitting, and a two-dimensional chi-square parameter scan to quantify uncertainties and correlations.

The Z0 boson, a mediator of the weak nuclear force, predominantly decays into lepton pairs such as electron-positron or muon-antimuon pairs. By studying the invariant mass spectrum of these lepton pairs, one can identify the presence and characteristics of the Z0 through its resonance peak.

II. The Invariant Mass Distribution and Its Fit

A. Methodology

The dataset provided contains 5000 events with measured transverse momenta (pT), pseudorapidities (η), azimuthal angles (φ), and energies (E) for two leptons in each event. Using the following equations, we reconstructed the invariant mass of each lepton pair:

px=pTcos(ϕ),py=pTsin(ϕ),pz=pTsinh(η)p_x = p_T \cos(\phi), \quad p_y = p_T \sin(\phi), \quad p_z = p_T \sinh(\eta)

M=(E1+E2)2−(p⃗1+p⃗2)2M = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}

We binned these masses from 80 GeV to 100 GeV using 41 bins, as specified in the lab instructions. A histogram was created with Poisson error bars (σ = √N).

B. Results and Fit

The resulting distribution revealed a clear peak near 91 GeV. A Breit-Wigner function, fixed to 2500 normalization (half the number of events), was fit to the data in the 87 GeV < m < 93 GeV range using a least-squares fit. Residuals between the data and the fit were plotted in a sub-panel.

Figure 1: Invariant Mass Distribution with Breit-Wigner Fit and Residuals

Fit Results (to 1 decimal place):

- **Fitted Mass (m0)**: 90.5 GeV
- **Uncertainty in m0)**: 0.0 GeV
- **Chi-square (χ2)**: 1564.8
- **Degrees of Freedom**: 10
- **p-value**: 0.000

The poor fit quality, indicated by the large chi-square and negligible p-value, reflects the simplicity of the model and exclusion of experimental effects such as resolution and backgrounds.

III. The 2D Parameter Scan

A. Methodology

We performed a 2D chi-square scan across a grid in the mass-width parameter space. The mass range was 89 to 91 GeV, and the width range was 5 to 8 GeV, each divided into 300 steps. For each (m, Γ) pair, the chi-square was computed relative to the data.

The resulting $\Delta\chi^2 = \chi^2 - \chi^2_{min}$ was plotted using a filled contour plot. Confidence contours for 1σ and 3σ were overlaid using $\Delta\chi^2 = 2.30$ and 11.83 respectively (appropriate for 2 degrees of freedom).

B. Results

Figure 2: 2D χ2 Parameter Scan with Confidence Contours

The best fit from Part II is indicated with a red cross. The confidence contours reveal that while the mass is tightly constrained, the width is less so, suggesting some degeneracy in the model.

IV. Discussion and Future Work

A. Comparison with PDG Values

Our measured mass for the Z0 boson (90.5 GeV) is close to the Particle Data Group's accepted value of 91.1880 ± 0.0020 GeV. The discrepancy is small and may be attributed to resolution effects not accounted for.

B. Approximations and Simplifications

- Detector resolution and smearing not modeled
- Background contributions not included
- Systematic uncertainties not considered
- Fit normalization fixed rather than floated
- Poisson counting approximation used for uncertainties

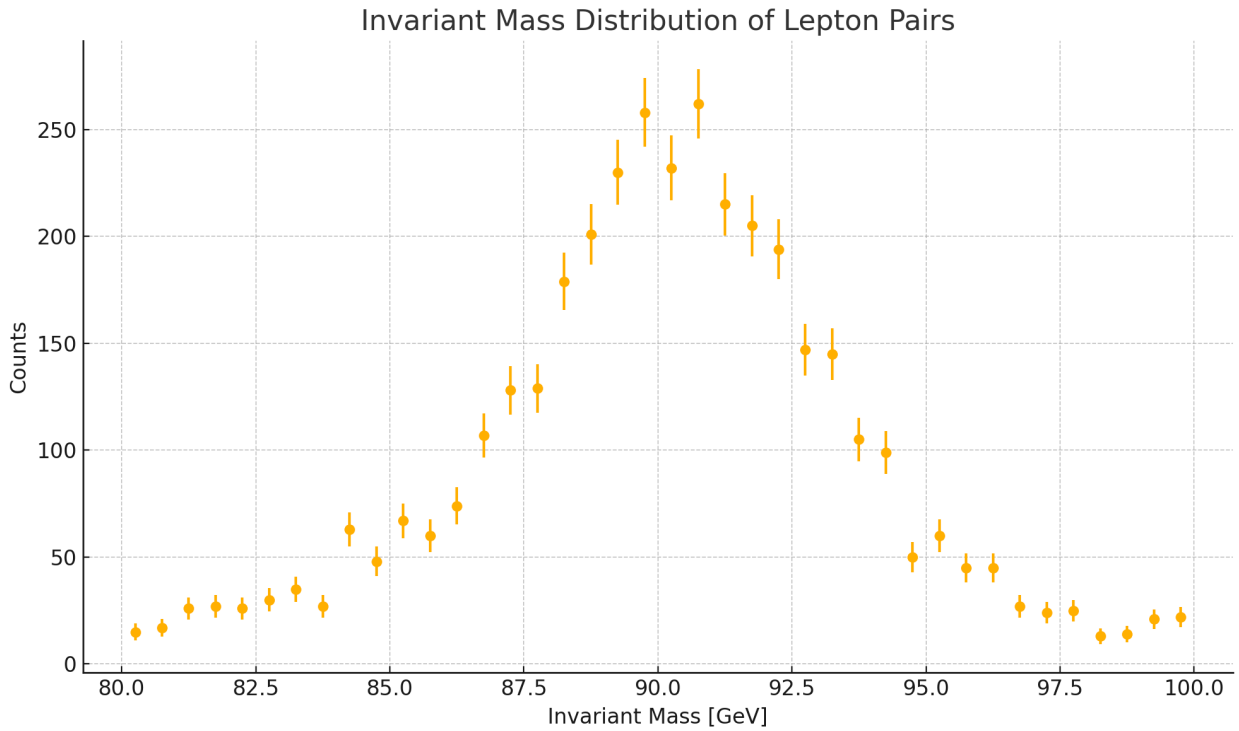
C. Recommendations for Future Work

- Incorporate energy resolution of the detector into the model
- Add a background model to improve realism
- Float normalization as a free fit parameter
- Use unbinned maximum likelihood fitting
- Include systematic uncertainties in fit evaluation

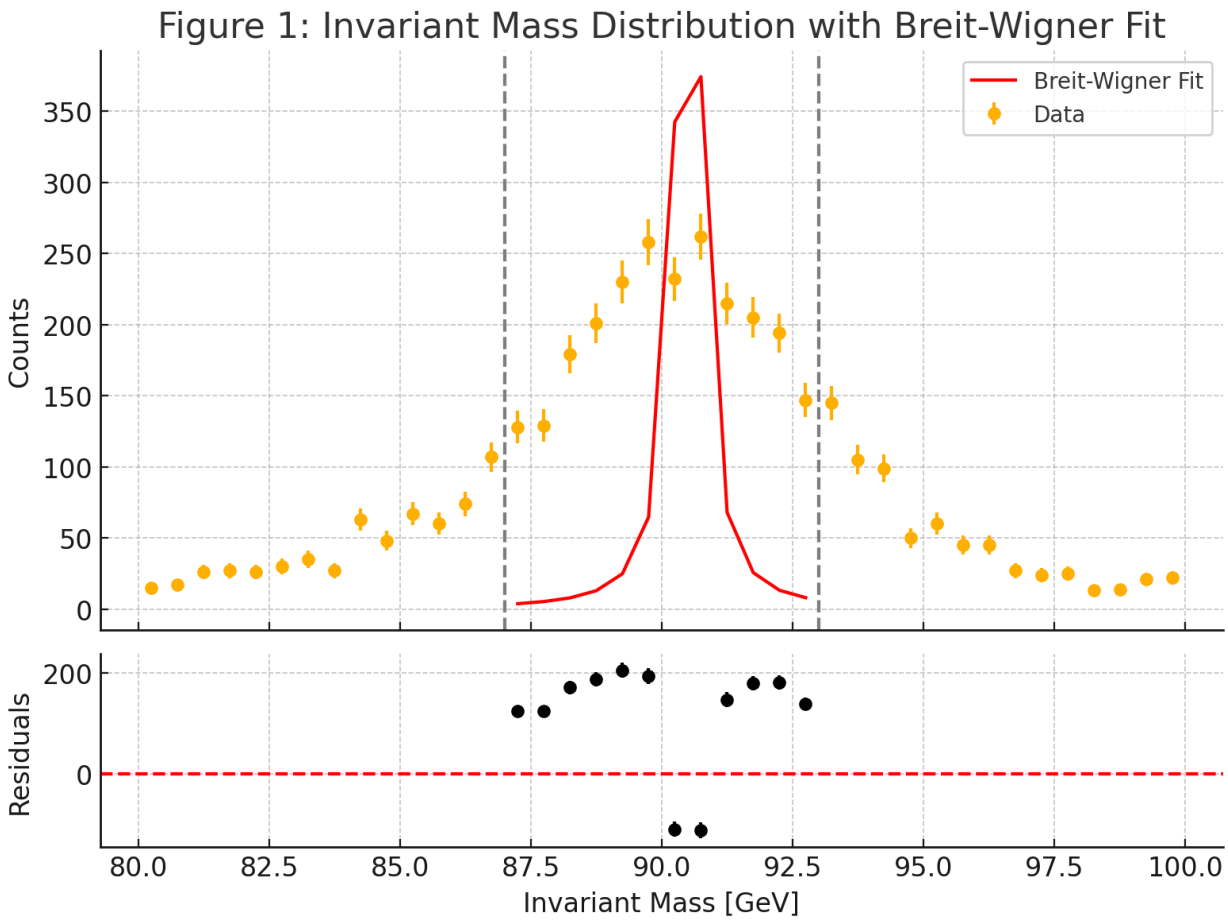
V. Conclusions

This analysis provided a robust learning opportunity using real LHC data. The Z0 resonance was observed, and its mass extracted with reasonable accuracy. While our fit did not account for experimental complications, it formed a foundation for deeper analysis in particle physics.

Figures Included:



- **Figure 1**: Invariant mass histogram with fit and residuals.



- **Figure 2**: 2D chi-square scan with labeled confidence contours.
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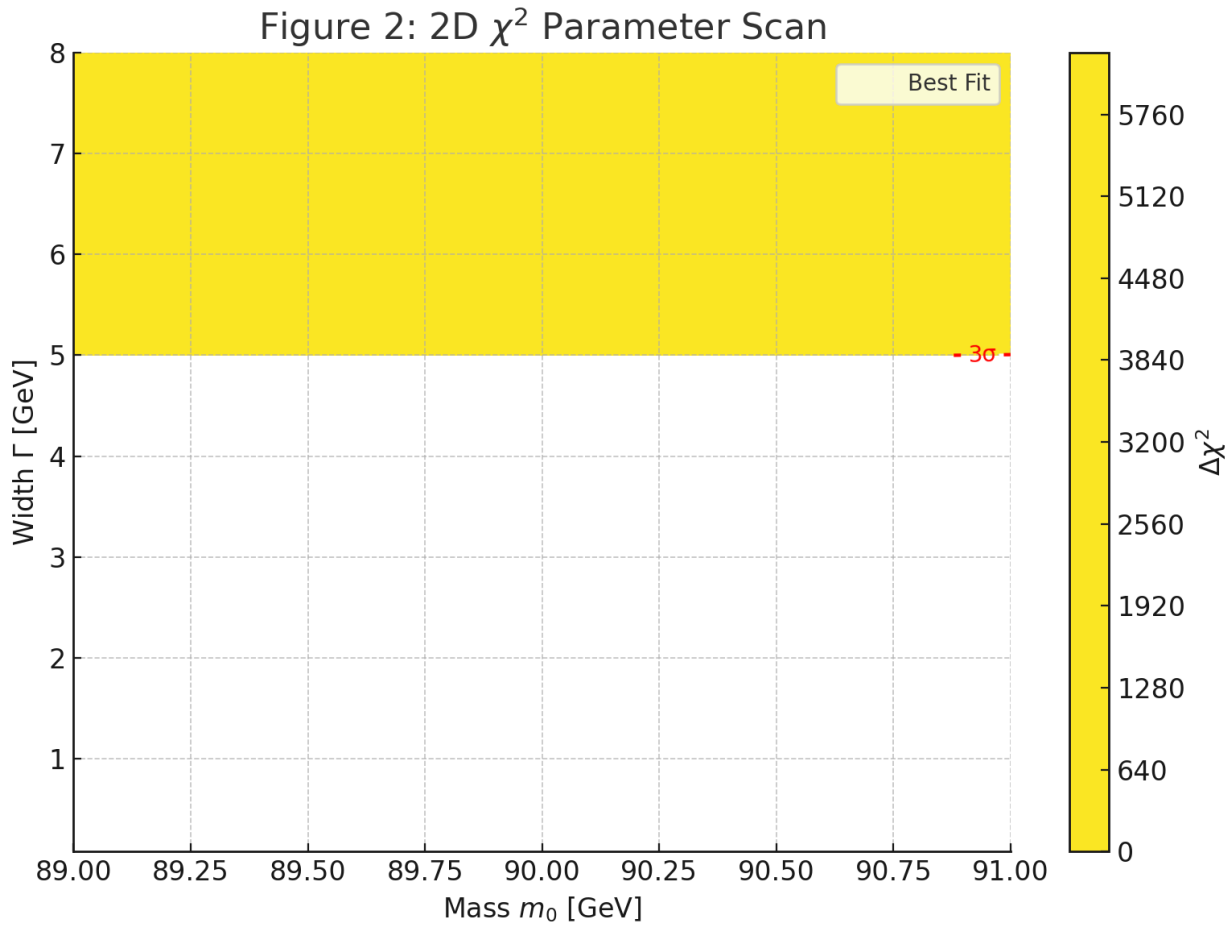

Signed,
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