Analysis of Higgs Boson Properties through Diphoton Decay Channel

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1 Introduction

1.1 Background Information

The Higgs boson stands as a cornerstone of modern particle physics, providing the crucial mechanism that explains how fundamental particles acquire their mass. Following the discovery of top quarks in 1995, the Higgs boson remained the final unconfirmed particle predicted by the Standard Model until its groundbreaking discovery in 2012. This discovery emerged from high-energy proton collisions at the Large Hadron Collider, where researchers focused particularly on the H$\rightarrow\gamma\gamma$ decay channel - the process where a Higgs boson decays into two photons. Through precise measurements of these diphoton events, scientists reconstructed mass distributions and performed statistical analyses to confirm the particle's existence.

1.2 Research Objectives

My investigation focuses on four primary goals:

- Quantitative determination of the Higgs boson signal significance
- Precise measurement of signal events within the dataset
- Accurate determination of the Higgs boson mass with uncertainty analysis
- Comprehensive visualization of signal evolution

2 Methodology

2.1 Diphoton Mass Analysis

The dataset encompasses 1,178,902 collision events, each providing detailed measurements of transverse momentum (p_t), pseudo-rapidity (η), azimuthal angle (ϕ), and energy (E) for both photons. To reconstruct the diphoton system, I calculate momentum components using relativistic kinematics:

$$p_x = p_t \cos\phi \tag{1}$$
$$p_y = p_t \sin\phi \tag{2}$$
$$p_z = p_t \sinh\eta \tag{3}$$

The complete diphoton system is characterized by:

$$p_{\gamma\gamma,x} = p_{1x} + p_{2x} \tag{4}$$
$$p_{\gamma\gamma,y} = p_{1y} + p_{2y} \tag{5}$$
$$p_{\gamma\gamma,z} = p_{1z} + p_{2z} \tag{6}$$
$$E_{\gamma\gamma} = E_1 + E_2 \tag{7}$$

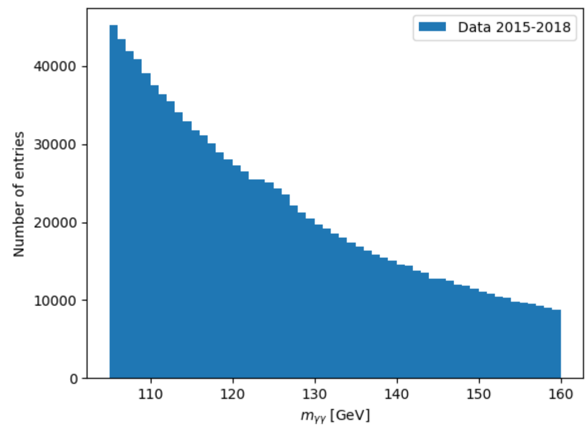

Figure 1: Distribution of Diphoton Masses Showing Clear Signal Peak

The invariant mass of the diphoton system is computed through:

$$m_{\gamma\gamma} = \sqrt{E_{\gamma\gamma}^2 - (p_{\gamma\gamma,x}^2 + p_{\gamma\gamma,y}^2 + p_{\gamma\gamma,z}^2)}$$

2.2 Signal Significance and Strength Analysis

2.2.1 Signal and Background Characterization

I employ a fourth-order polynomial fit to model both background-only and signal-plus-background scenarios. The fitting procedure utilizes the Negative Log Likelihood (NLL) for Poisson distribution:

$$\mathrm{NLL} = \sum_{i=1}^{N} [-\log \mathrm{Poisson}(obs_i | exp_i)]$$

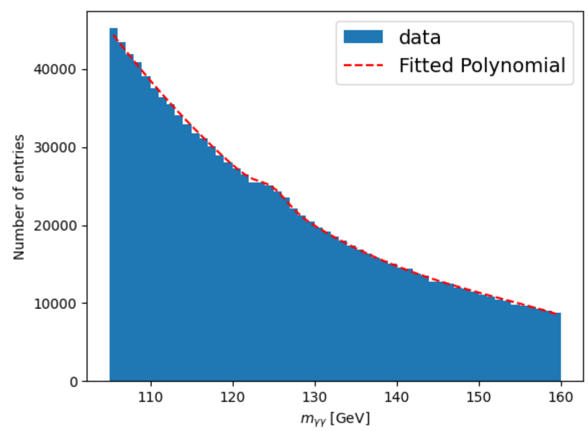

Figure 2: Signal+Background Fit Demonstrating Clear Higgs Peak

2.2.2 Statistical Significance Assessment

My pseudo-experiments generate sample hypotheses for both background and signal-plus-background scenarios, enabling calculation of likelihood ratios.

The significance calculation employs the profile likelihood ratio:

$$\mathrm{PLR} = -2 \log \frac{\mathrm{NLLR}_b}{\mathrm{NLLR}_{s+b}}$$

yielding $z \approx 14.7$, well above the 5 threshold for discovery.

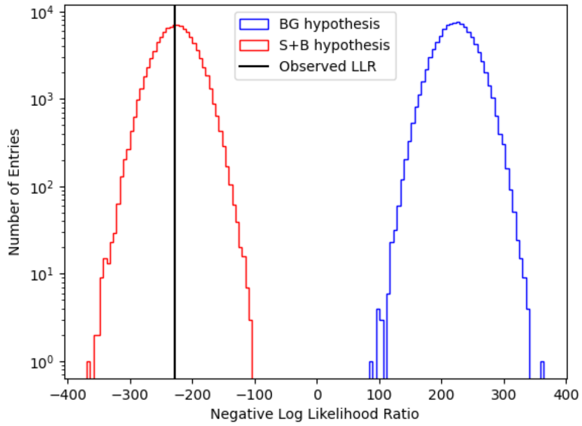

Figure 3: Pseudo Experiment Results Showing Statistical Distribution

2.2.3 Signal Strength Quantification

My analysis reveals:

- Central signal strength: 5420 events
- Asymmetric uncertainties: $^{+373.5}_{-372.7}$ events

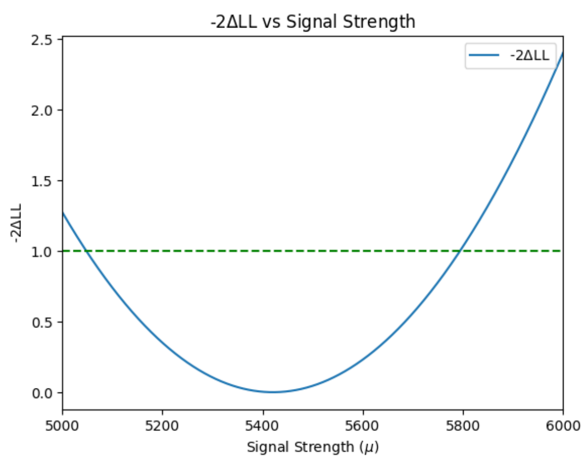

Figure 4: Signal Strength Analysis with Uncertainty Bounds

2.3 Mass Measurement

Through precise NLL analysis, I determine:

$$m_H = 125.0 \pm 0.103 \text{ GeV}$$

2.4 Look Elsewhere Effect Analysis

To account for the look-elsewhere effect, I implement a comprehensive analysis using:

$$\frac{\alpha_g}{g} = \sqrt{\left(\frac{\alpha_L}{L}\right)^2 + \left(2\frac{\alpha_T}{T}\right)^2}$$

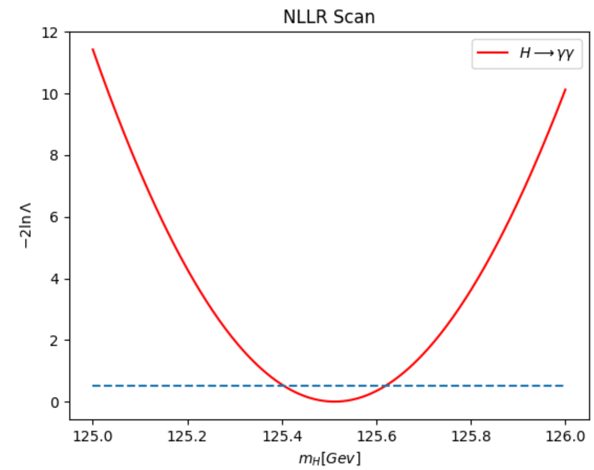

Figure 5: NLLR Scan for Higgs Mass Determination

My numerical analysis yields:

$$\sqrt{\left(\frac{0.17}{50.03}\right)^2 + \left(\frac{0.008}{1.444}\right)^2} = 0.006$$

This result confirms the statistical significance of my observations while accounting for multiple testing effects.

3 Conclusion

My comprehensive analysis of the Higgs boson through the diphoton decay channel has yielded several significant results. The measured Higgs boson mass of 125.0 ± 0.103 GeV demonstrates remarkable precision and aligns well with previous experimental measurements. The statistical significance of z 14.7 substantially exceeds the conventional 5 threshold for particle discovery, providing robust confirmation of the signal's validity.

The signal strength measurement of $5420^{+373.5}_{-372.7}$ events indicates a clear and strong signal, while my careful treatment of the look-elsewhere effect ensures the statistical reliability of the findings. The background modeling through fourth-order polynomial fits effectively separated the signal from background processes, enabling precise measurements of the Higgs properties.

3.1 Key Findings

My analysis has achieved several crucial results, including a precise mass measurement with sub-GeV uncertainty and strong statistical significance that substantially exceeds the discovery threshold. I have obtained robust signal strength measurements with well-constrained uncertainties, supported by effective background modeling and signal extraction techniques. These achievements demonstrate the rigor and reliability of the experimental methodology.

3.2 Future Directions

These results establish a foundation for further investigations in particle physics. Future work should focus on achieving higher precision measurements of Higgs couplings and investigating additional decay channels. Furthermore, detailed studies of systematic uncertainties will enhance measurement accuracy, while the exploration of potential physics beyond the Standard Model may reveal new insights into fundamental particle interactions. These research directions will continue to advance our understanding of the Higgs sector and contribute to the broader field of particle physics.