Search for a Mini Higgs-like Resonance
Likelihood Analysis and the Look-Elsewhere Effect

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Abstract

A toy Monte Carlo search for a narrow Higgs-like resonance is performed in the invariant-mass range $110\ \text{GeV} \leq m \leq 150\ \text{GeV}$. An unbinned profile-likelihood method is used to test for the presence of a localized signal over a smooth exponential background. A mass hypothesis scan is carried out to compute the local significance as a function of the assumed signal mass. The Look-Elsewhere Effect is estimated to obtain a global significance.

1 Introduction

Searches for new particles in high-energy physics often involve testing for localized excesses over smooth backgrounds in invariant-mass spectra. When the particle mass is unknown *a priori*, the data must be scanned over a range of mass hypotheses, leading to the so-called Look-Elsewhere Effect (LEE), which reduces the global statistical significance of any observed excess.

In this report, a simplified Higgs-like search is performed using a toy dataset consisting of an exponential background and a possible narrow Gaussian signal. The goal is to quantify the local and global statistical significance of an observed excess using likelihood-based hypothesis testing.

2 Physics and Statistical Setup

The dataset consists of reconstructed invariant masses m in the range

$$110\ \text{GeV} \leq m \leq 150\ \text{GeV}.$$

Two components are considered:

- A smooth background modeled by an exponential probability density function.

```
samples = np.random.exponential(scale=30, size=N_bkg_obs) + 100
```

- A narrow signal modeled by a Gaussian resonance.

```
        signal = np.random.normal(mH_true, sigma, N_sig_obs)
```

The signal width is fixed to

$$\sigma = 1.5\ \text{GeV}.$$

```
    sigma = 1.5
```

The signal mass m_H and signal strength $\mu \geq 0$ are treated as unknown parameters to be inferred from the data.

3 Likelihood Construction

An unbinned likelihood function is constructed for the signal-plus-background hypothesis. For a dataset $\{m_i\}_{i=1}^{N}$, the likelihood is

$$\mathcal{L}(\mu) = e^{-(\mu S + B)} \prod_{i=1}^{N} \left[\mu\, S\, s(m_i; m_H, \sigma) + B\, b(m_i)\right], \tag{1}$$

where $s(m)$ and $b(m)$ are normalized signal and background probability density functions, S and B are the expected signal and background yields, and $\mu \geq 0$ is the signal strength parameter.

The signal PDF is given by

$$f_{\text{sig}}(m \mid m_H) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left[-\frac{(m - m_H)^2}{2\sigma^2}\right]. \tag{2}$$

The background PDF is modeled as

$$f_{\text{bkg}}(m \mid \lambda) = \frac{\lambda e^{-\lambda m}}{e^{-\lambda m_{\min}} - e^{-\lambda m_{\max}}}. \tag{3}$$

Parameters

- **Parameters of interest:** μ, m_H
- **Nuisance parameters:** background slope λ

```python
def nll(params, mH_fixed, data):
    mu, B, slope = params
    if mu < 0 or B < 0 or slope <= 0: return 1e12

    fS = signal_pdf(data, mH_fixed)
    fB = background_pdf(data, slope)


    return (mu + B) - np.sum(np.log(mu * fS + B * fB + 1e-12))
```

4 Local Significance Scan

To search for a possible signal at an unknown mass, a mass hypothesis scan is performed over the range

$$110\ \text{GeV} \leq m_H \leq 150\ \text{GeV}$$

in steps of $\Delta m = 0.5$ GeV.

At each mass hypothesis m_H, the profile-likelihood-ratio test statistic is defined as

$$q_0(m_H) = -2 \ln \frac{L(\mu = 0, \hat{\hat{\nu}})}{L(\hat{\mu}, \hat{\nu})}, \tag{4}$$

where:

- $\hat{\mu}, \hat{\nu}$ maximize the likelihood without constraints,
- $\hat{\hat{\nu}}$ maximizes the likelihood under the background-only hypothesis.

Using asymptotic approximations (Wilks' theorem), the local significance is approximated by

$$Z_{\text{local}}(m_H) \simeq \sqrt{q_0(m_H)}. \tag{5}$$

5 Observed Excess

The local significance scan reveals a maximum local significance of

$$Z_{\text{local}}^{\text{max}} = 6.68.$$

The mass corresponding to this maximum significance is found to be

$$m_H^{\text{best}} = 125.0 \text{ GeV}.$$

This indicates a strong localized excess consistent with a narrow resonance at this mass, prior to accounting for the Look-Elsewhere Effect.

6 Look-Elsewhere Effect

Since multiple mass hypotheses are tested, the global significance must be corrected for the Look-Elsewhere Effect.

The effective number of independent trials is estimated as

$$N_{\text{eff}} \approx \frac{m_{\max} - m_{\min}}{\sigma} = \frac{40 \text{ GeV}}{1.5 \text{ GeV}} \approx 27. \tag{6}$$

The global p-value is approximated by

$$p_{\text{global}} \approx N_{\text{eff}}\, p_{\text{local}}^{\text{min}}. \tag{7}$$

This corresponds to a global significance of

$$Z_{\text{global}} = 6.19.$$

```
    N_eff = (m_max - m_min) / sigma
p_local = 1 - norm.cdf(Z_max_local)
p_global = N_eff * p_local
Z_global = norm.ppf(1 - p_global)
```

7 Discussion and Interpretation

The global significance is smaller than the local significance due to the multiple testing inherent in scanning over many mass hypotheses. Nevertheless, the reduction is modest because the signal is narrow and well-localized, resulting in a limited number of effectively independent trials.

With a global significance exceeding 5σ, the observed excess satisfies the conventional particle-physics criterion for a discovery.

It should be noted that the dataset analyzed here is a toy Monte Carlo sample with an injected signal at a fixed mass. The analysis itself does not make use of this information and treats the signal mass as unknown.

8 Plots

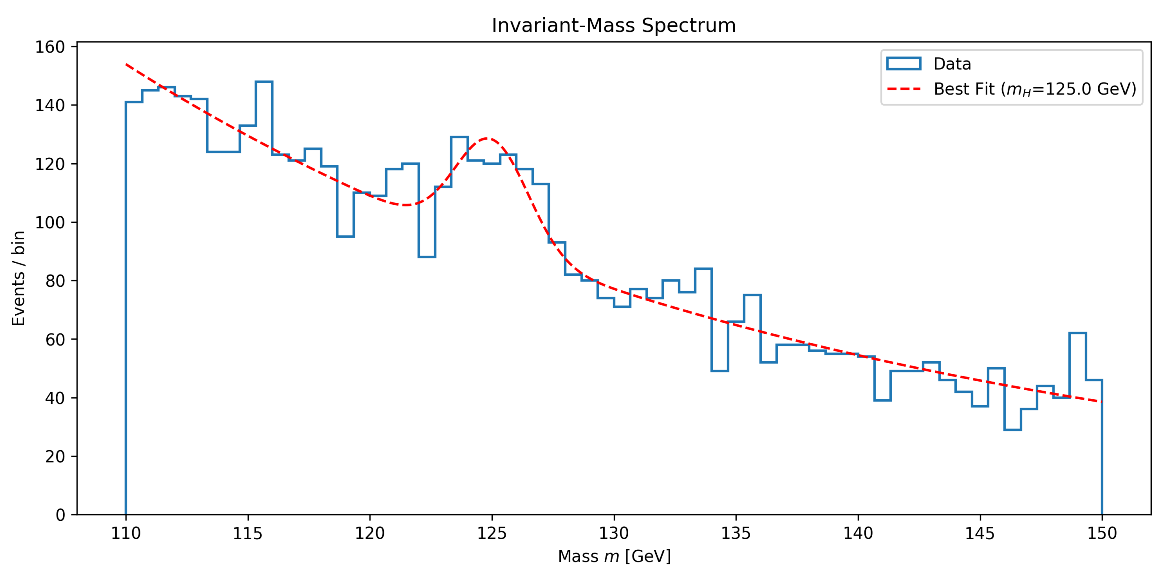

Figure 1: Invariant-mass spectrum with the best-fit signal-plus-background model.

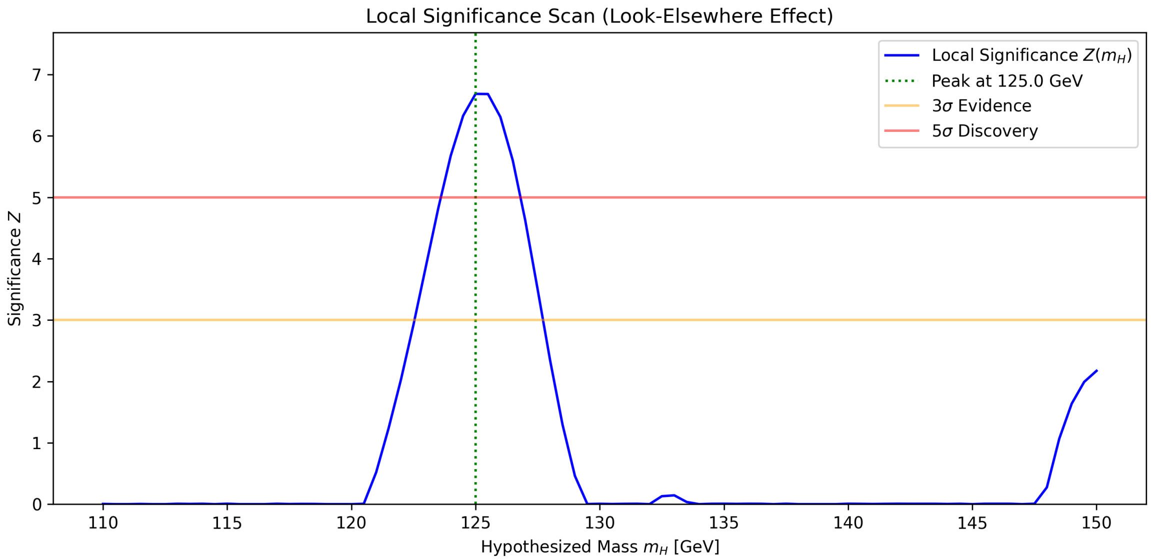

Figure 2: Local significance $Z_{\text{local}}(m_H)$ as a function of the hypothesized signal mass. Horizontal lines indicate the 3σ and 5σ thresholds.

9 Conclusion

A simplified Higgs-like search was performed using an unbinned likelihood approach. A significant excess was observed near $125\ \text{GeV}$. After accounting for the Look-Elsewhere Effect, the excess remains significant at the discovery level. This analysis illustrates the role of likelihood-based methods and multiple-testing corrections in particle physics searches.