Searching for di-Higgs Production in the 4 b-jet Channel using the ATLAS Detector at the LHC

Paper in preparation

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Motivation

Higgs pair (HH) production allows for the direct measurement of the Higgs potential and thus serves as a useful probe for both Standard Model (SM) and Beyond the Standard Model physics scenarios.

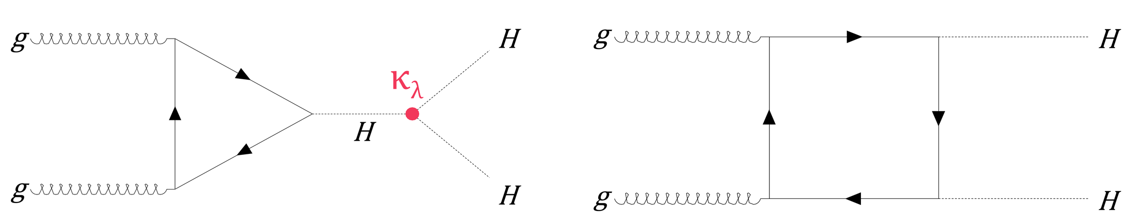
The Higgs potential is of great theoretical interest due to the central role it could play in answering several open physics questions. For example, alterations to the SM Higgs potential could explain matter-anti-matter asymmetry [1].

$$\frac{1}{2}m_H^2 h^2 + \frac{\lambda_{3,\mathrm{SM}}}{3}\kappa_\lambda h^3 + \frac{1}{4}\lambda_4 h^4$$

Higgs potential after Electroweak Symmetry Breaking, parameterized in terms of κ_λ

These alterations typically modify the tri-linear Higgs coupling (κ_λ), which enters one of two leading diagrams for HH production. Thus, HH production is a prime location for addressing these questions.

Results will be shown here for the dominant 4 b-jet final state, where both Higgs decay to two *b* quarks. This channel has the most signal, but difficult backgrounds.



Leading HH production diagrams. Interference effects between these diagrams leads to enhanced sensitivity to κ_λ

Reconstruction and Event Selection

Selection focused on removing dominant QCD multi-jets and ttbar backgrounds, without sculpting

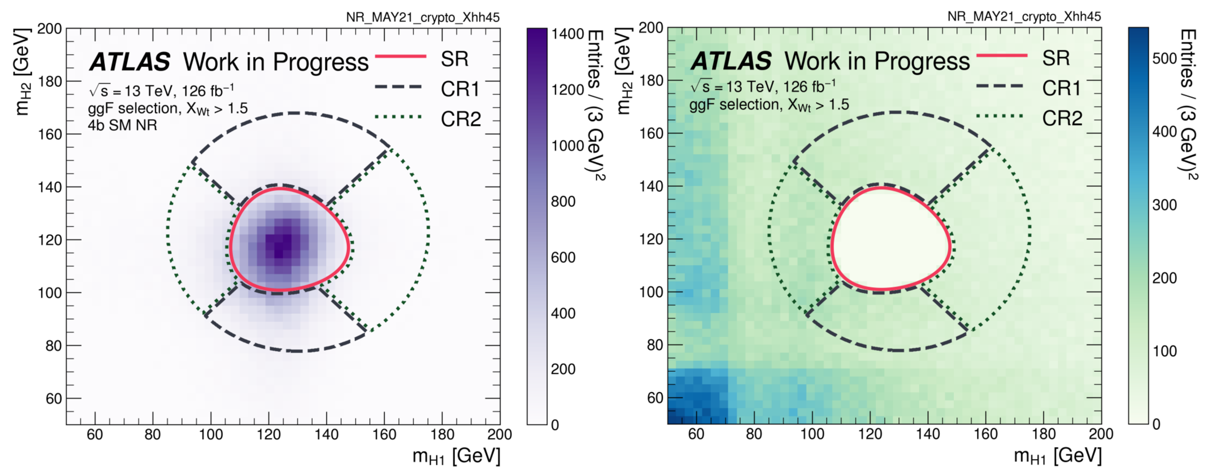
- 2 complementary b-jet triggers per year
- Apply kinematic cuts on p_T and jet angular positions, plus targeted top-veto
- ≥4 jets, pair jets by minimum angular distance (ΔR) to form Higgs Candidates

Analysis Region Definitions

Sets of kinematic regions for different # of b-tags:

- Kinematic regions: 2 control (CR1, CR2), 1 signal (SR)
- # of b-tags: 2 (control), 3+0 loose (validation), 3+1 loose and ≥4 (signal)

From these, the analysis signal regions are: SR 3b+1l, SR 4b



Kinematic regions plotted over 4b data (blinded) and MC signal

Signal Model

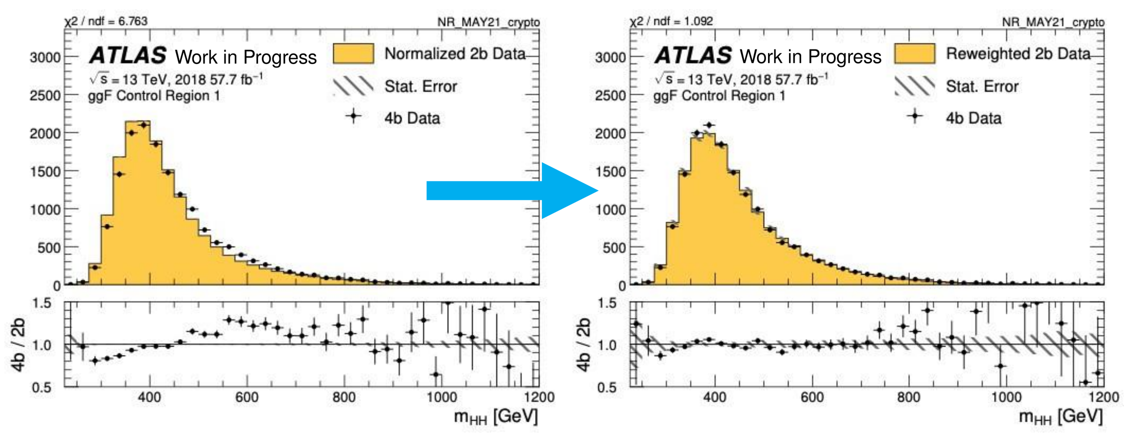
Monte Carlo (MC) samples are used to model the SM and $\kappa_\lambda=10$ HH signal. Other values of κ_λ are obtained by reweighting the SM sample. This reweighting is derived at truth level, as a function of the invariant mass of the HH system (m_{HH})

Background Estimation

Background is mostly QCD multi-jets which is difficult to model accurately with simulation, so a data driven method is used.

Method:

- Make use of similarity between 2b and 4b (3b1l) kinematics. Correct further with reweighting.
- Use a neural network to estimate the density ratio $w(x) = \frac{p_{4\mathrm{b}}(x)}{p_{2\mathrm{b}}(x)}$ by optimizing $\mathcal{L}(R(x)) = \mathbb{E}_{x\sim p_{2b}}[\sqrt{R(x)}] + \mathbb{E}_{x\sim p_{4b}}[\frac{1}{\sqrt{R(x)}}]$
- Fit a model in background rich CR1/CR2
- Use CR1 model prediction to estimate background in blinded SR 4b from SR 2b data
- Two uncertainties:
  - Extrapolation: difference in CR1/CR2 models
  - Model instability: IQR of 100 bootstrap predictions



Comparison of normalized/reweighted 2b vs 4b CR1 m_{HH} distributions, showing improved modeling after reweighting

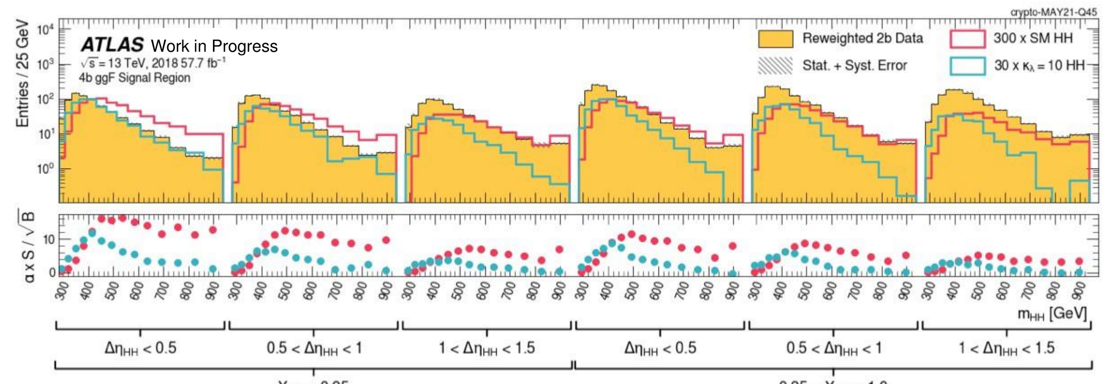
Background Validation

This background model is validated by repeating the procedure in 8 different sets of background rich validation regions, where the pseudo-signal region is unblinded for comparison. Namely:

- 5 regions shifted to different center points
- Nominal regions, but estimating 3b0l data instead of 4b/3b1l
- Nominal regions but with an angular cut reversed

HH Cross-Section Upper Limits

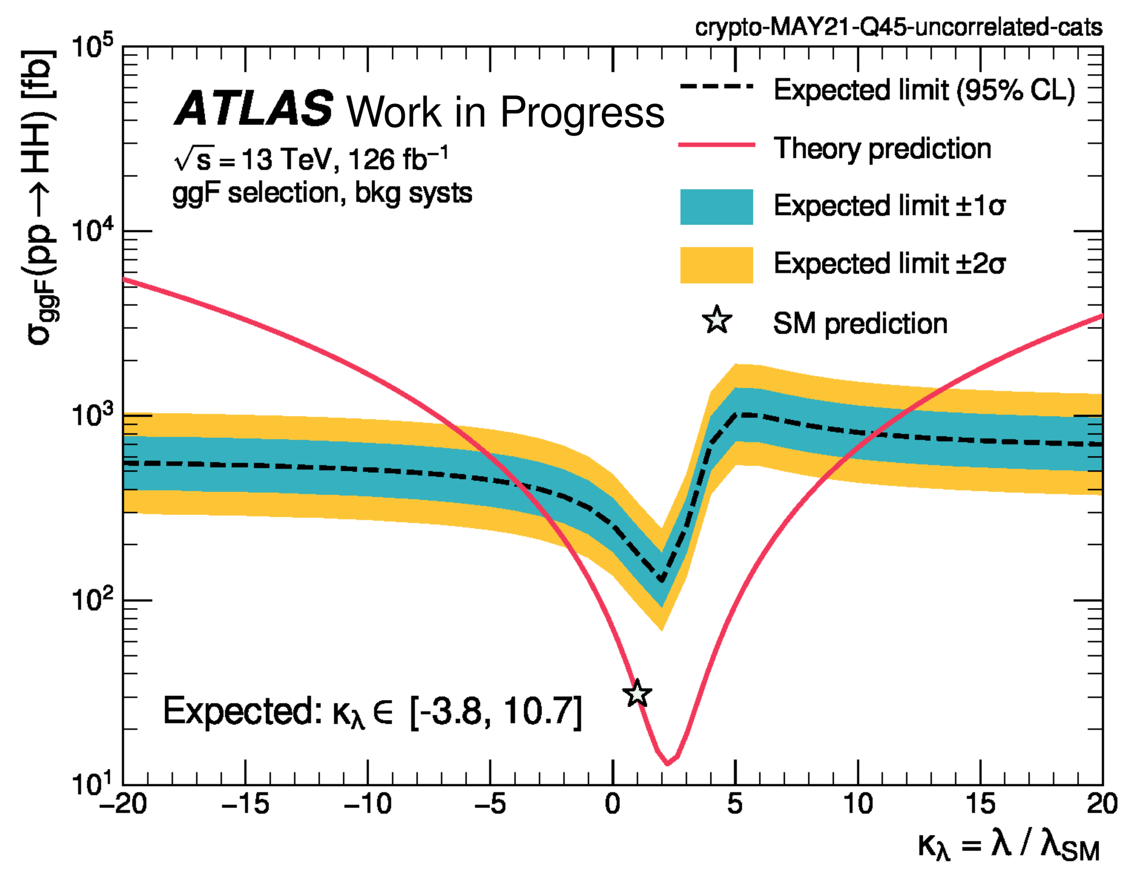
Likelihood fits are performed to SR 4b and 3b1l data binned by m_{HH}, Higgsness (X_{HH}), angular info ($\Delta\eta_{HH}$), and year.



Signal and background models for 2018 SR 4b in bins of m_{HH}, X_{HH}, and $\Delta\eta_{HH}$

A test statistic based on the profile likelihood ratio is used to test signal strength hypotheses for a range of κ_λ values. The CL_s method is then used to obtain upper cross-section limits. Comparing these limits to theory predictions gives an **expected 95% CL limit of -3.8 ≤ κ_λ ≤ 10.7**.

Similarly, for the Standard Model value, $\kappa_\lambda=1$, an **expected limit of 5.78 times the SM** is obtained. More than 2x stronger limit than previous result.



Di-Higgs cross-section limits obtained for a range of κ_λ values.

References

[1] Kanemura, S., Okada, Y., & Senaha, E. (2005). Electroweak baryogenesis and quantum corrections to the triple Higgs boson coupling. Physics Letters B, 606(3-4), 361-366.

Discovery, accelerated