Search for non-resonant di-Higgs production in the $\boldsymbol{HH \rightarrow bb\gamma\gamma}$ decay channel in pp collisions at $\sqrt{\boldsymbol{s}} = \mathbf{13}$ TeV with the ATLAS detector

Alex Wang

University of Wisconsin

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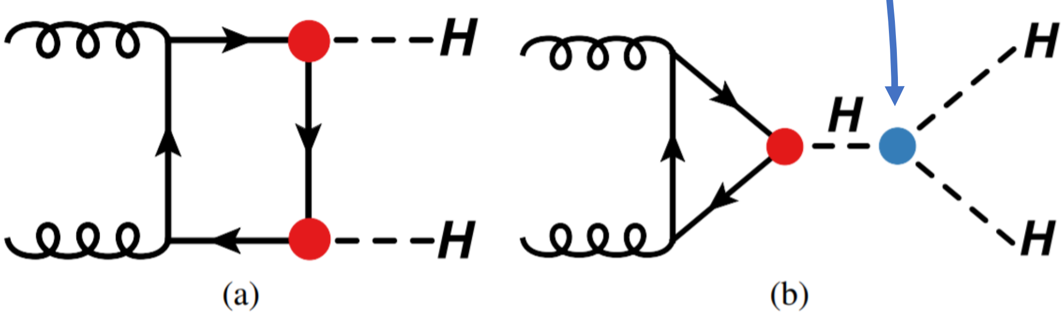
Outline

- **Analysis introduction**
- Event selection and categorization
- Results
- Summary

Introduction

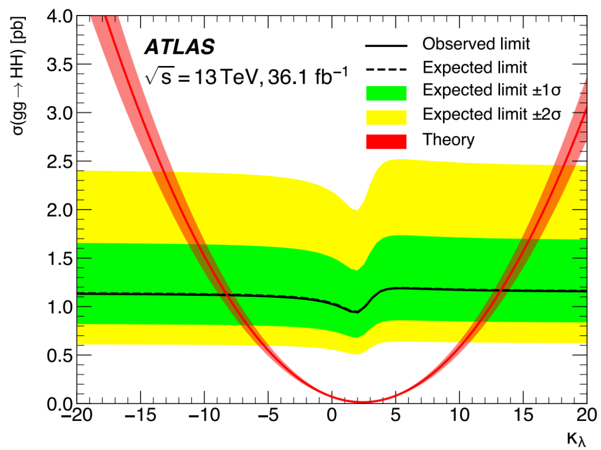
- One of the goals of LHC physics is to observe di-Higgs (HH) production as a probe of the Higgs boson self-coupling
- **Non-resonant di-Higgs** production proceeds mainly through **gluon-fusion (ggF)** from two leading order diagrams

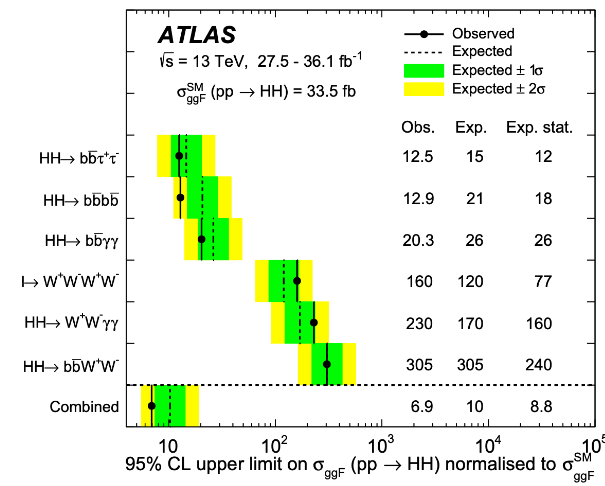


- In the SM, these diagrams interfere destructively and lead to a small production cross-section of 31 fb
- BSM modifications to the self-coupling $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$ can result in much higher cross-sections
- The next largest production mode is from **vector-boson fusion (VBF)** but with a much smaller cross-section (1.7 fb in the SM)

Introduction

- $bb\gamma\gamma$ is one of the top three HH channels in sensitivity: combine large $H \rightarrow bb$ branching ratio with excellent ATLAS photon resolution
- Reminder of 36 fb^{-1} $bb\gamma\gamma$ search: JHEP 11 (2018) 040
  - **95% CL upper limit on SM cross section: 22 * SM**
  - $\boldsymbol{\kappa_\lambda \in [-8.2, 13.2]}$





- Today: show the latest $HH \rightarrow bb\gamma\gamma$ result with the full ATLAS Run 2 dataset of 139 fb^{-1} (ATLAS-CONF-2021-016)
- Highlight: reoptimized event selection w.r.t. previous result

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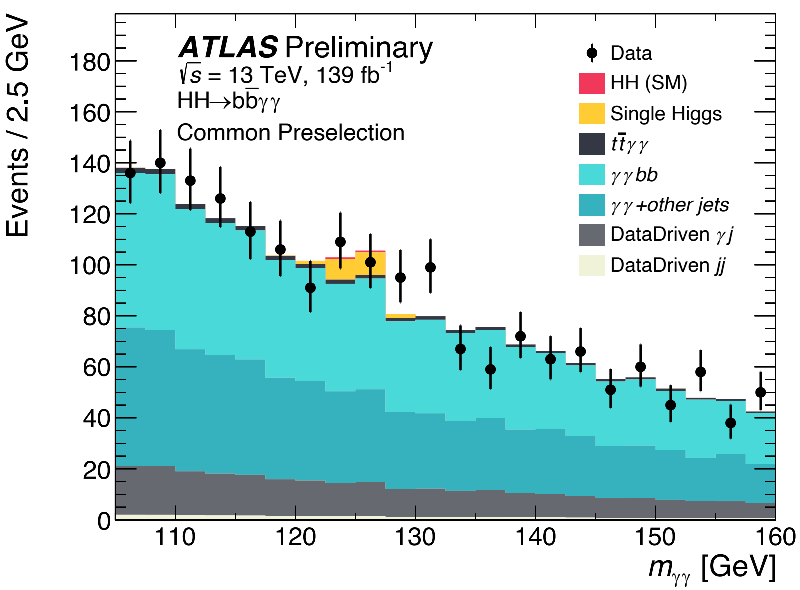
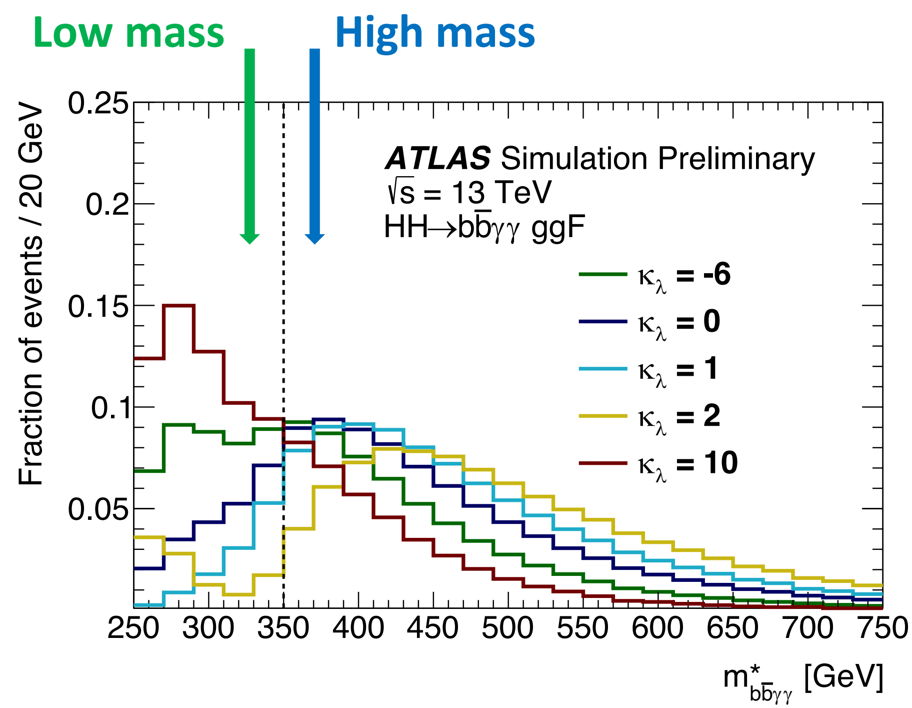
Event selection strategy (1)

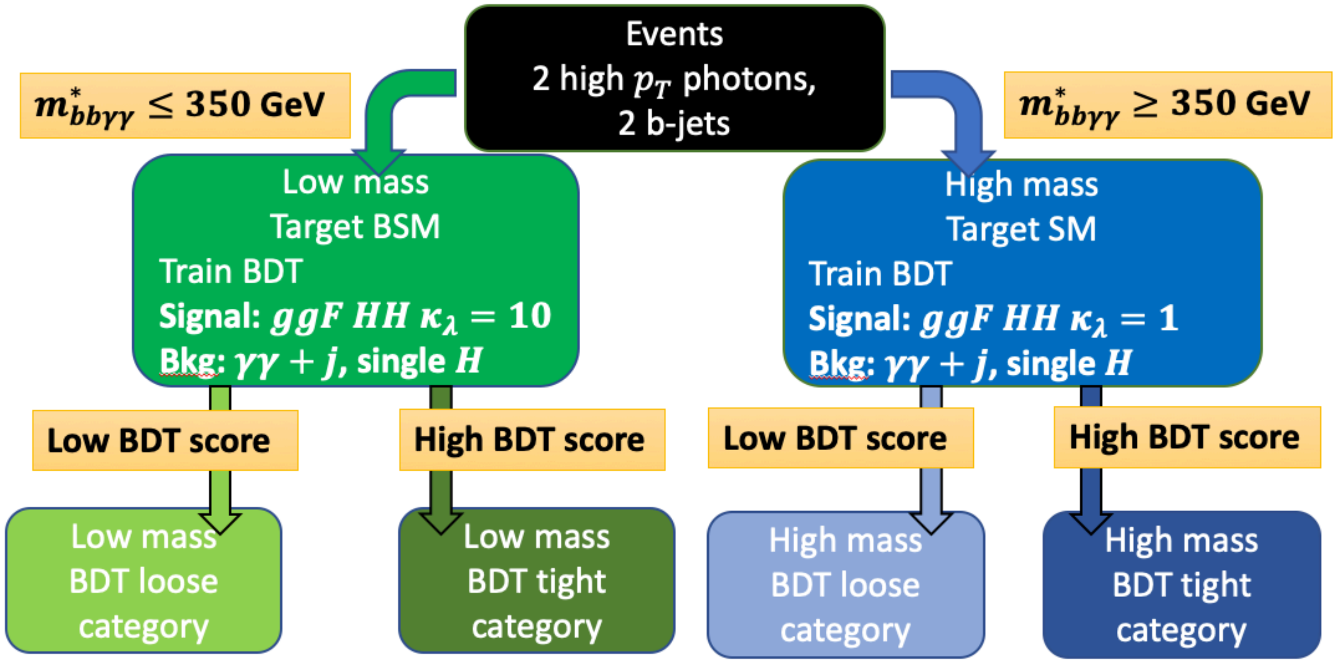
- Events with **two photons** and **two b-jets** are selected
- Events are divided into a **high mass** (targeting SM-like signals) and **low mass** region (targeting non SM-like signals) using the modified 4-body mass to improve resolution

$$m^*_{bb\gamma\gamma} = m_{bb\gamma\gamma} - (m_{bb} - 125\text{ GeV}) - (m_{\gamma\gamma} - 125\text{ GeV})$$





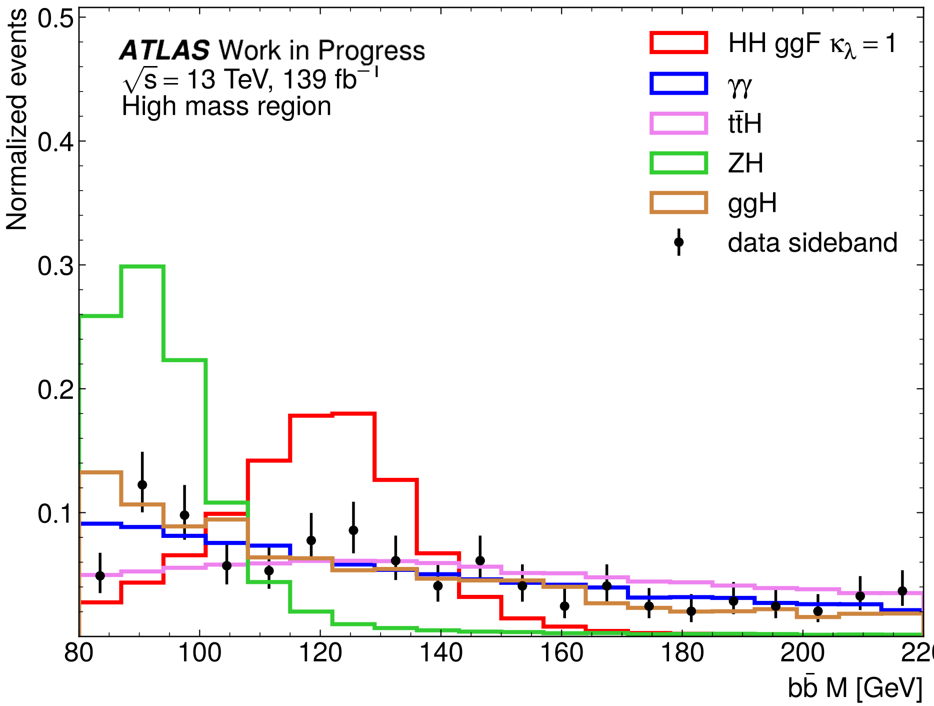
Event selection strategy (2)

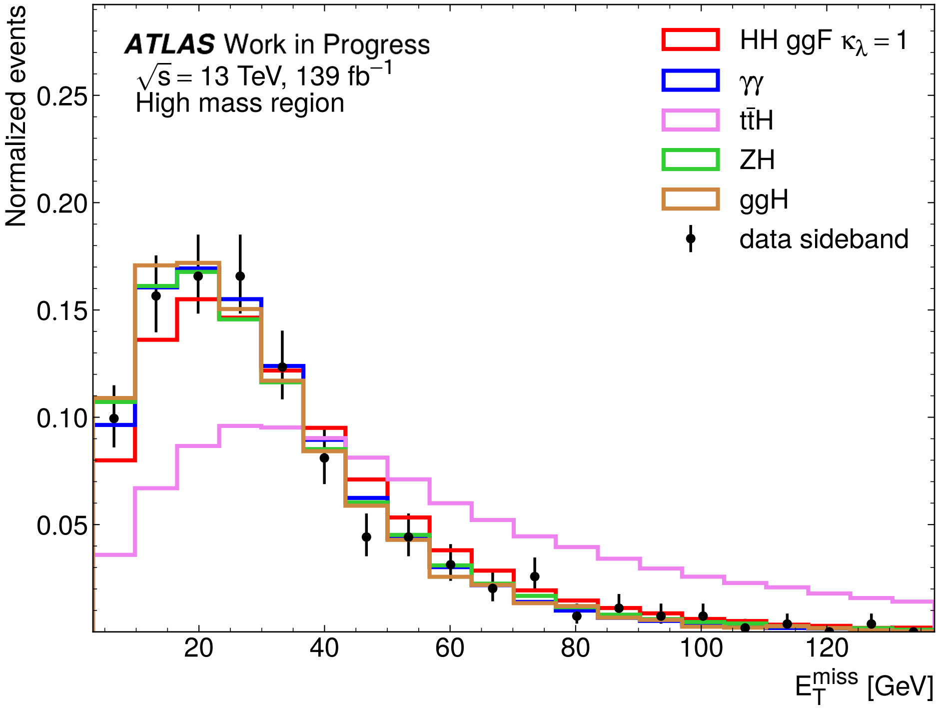


- In each region a **Boosted Decision Tree** (BDT) is trained on MC to separate HH signals from continuum $\gamma\gamma$ + single H background to obtain **four signal-sensitive categories**
- For various signal hypotheses, obtain final results from a signal + background fit to $m_{\gamma\gamma}$ in data in **all four** categories

BDT input variables

- Plots for shape comparison only
- **data sideband** used to validate $\gamma\gamma$ **MC**

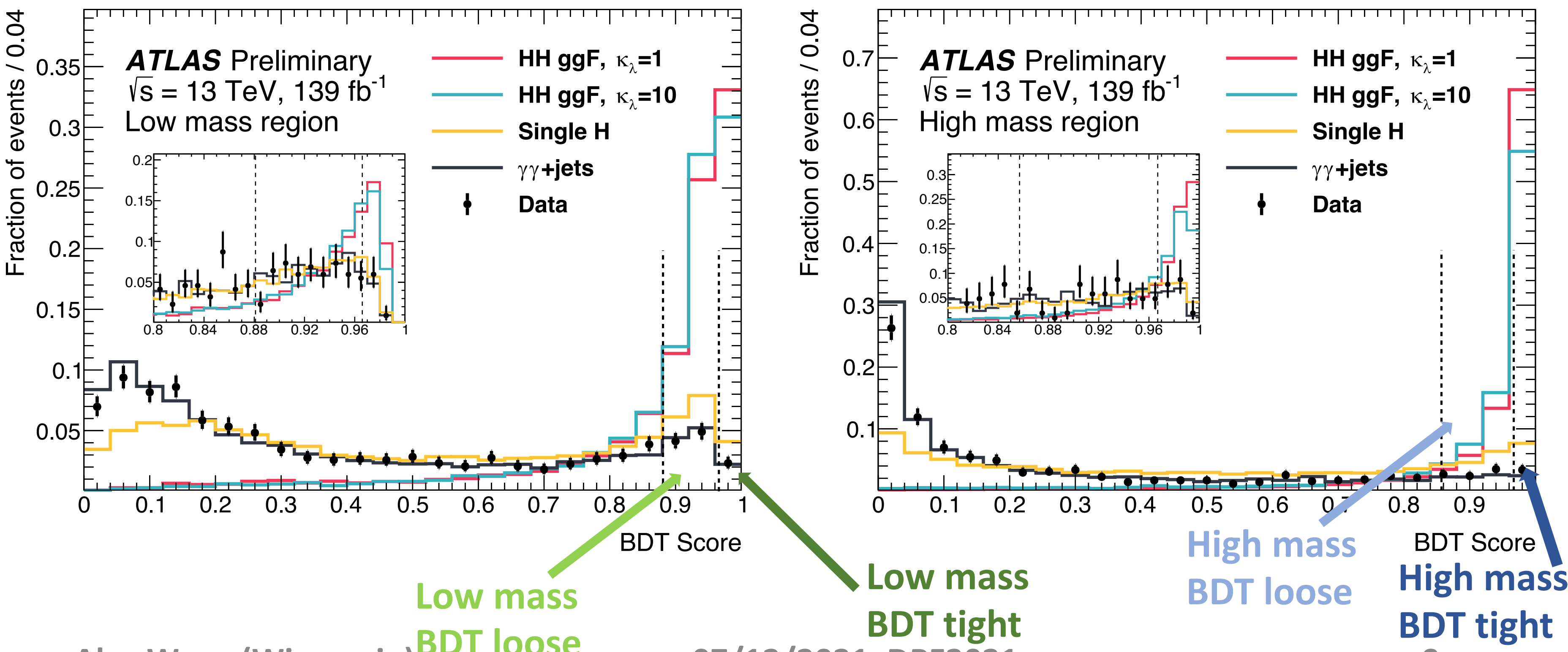




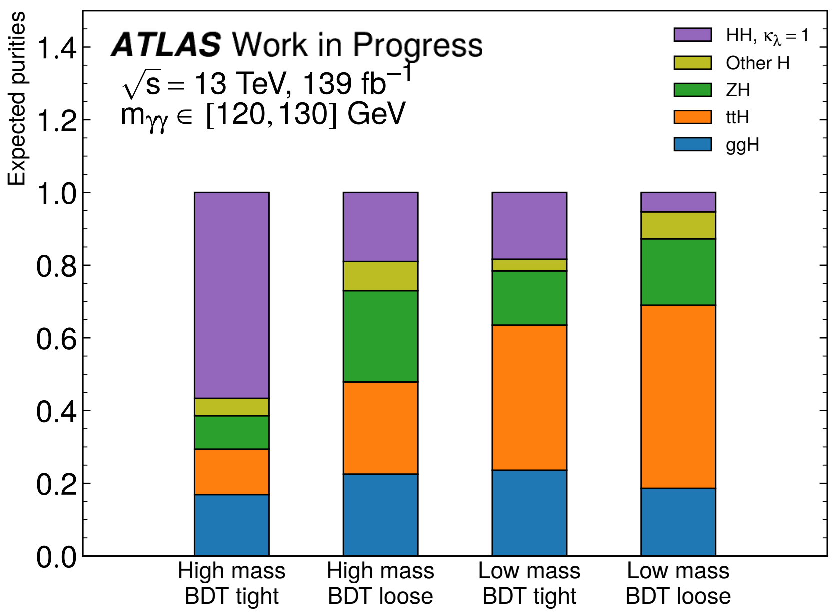
- BDT is trained using a variety of photon and jet-related input variables to reject the different types of backgrounds
- Some of the most powerful variables in the **high mass** region:
- Left: Mass of the bb system is very powerful – see sharp peaks for HH and ZH
- Right: Missing E_T is good against ttH

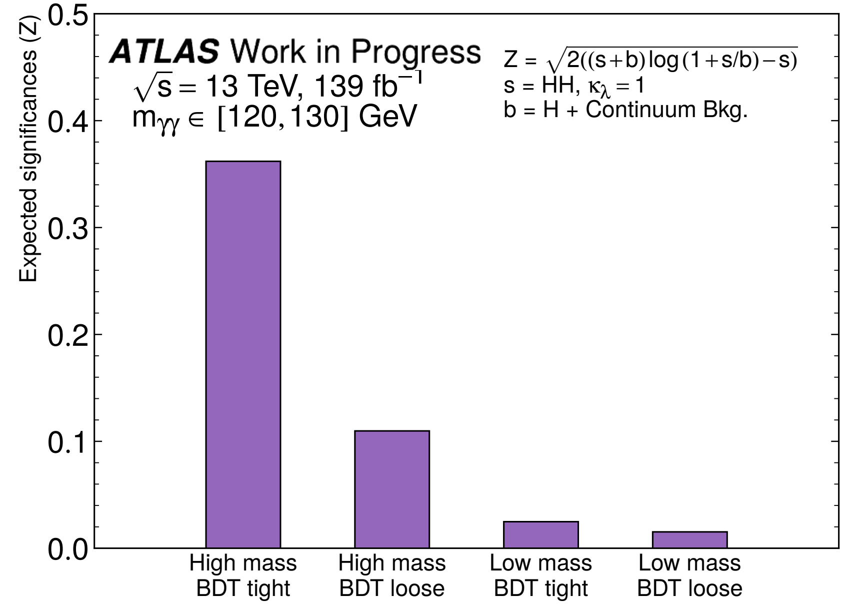
BDT output

- Good separation between HH signal and backgrounds
- Data sideband agrees well with $\gamma\gamma$ MC used for training
- Both $\kappa_\lambda = 1$ and $\kappa_\lambda = 10$ HH samples are signal like, since BDT is not designed to distinguish between different signals



Category purity & significance





- Largest single Higgs backgrounds are from ttH, ggH, ZH
- For the SM signal, the sensitivity is mainly due to the High mass BDT tight category

- Next: the results with the categories

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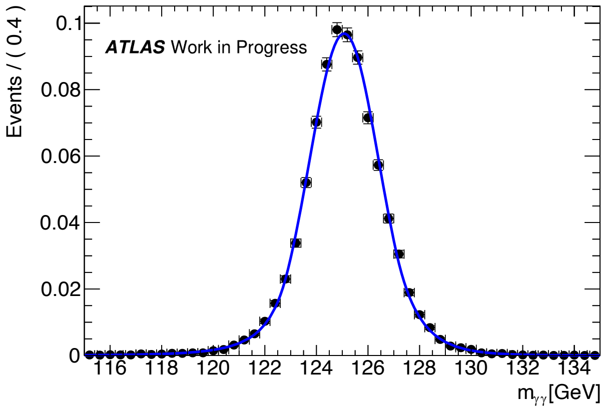
Signal + background modeling

- Modeling is done independently in each of the four analysis categories

- **HH signal + H background**: normalization and shape determined from a double sided crystal ball (DSCB) fit to MC

Size of smallest mass window containing 68% of the signal → σ_{68}

Category	σ_{68} [GeV]
High mass BDT tight	1.46 ± 0.01
High mass BDT loose	1.61 ± 0.02
Low mass BDT tight	1.72 ± 0.06
Low mass BDT loose	1.81 ± 0.03



- **Non-resonant $\gamma\gamma$ background**: normalization and shape determined from a fit to $m_{\gamma\gamma}$ using an analytical (exponential) function
- This is completely data-driven, except for potential bias resulting from specific choice of function: **spurious signal**

Systematic uncertainties

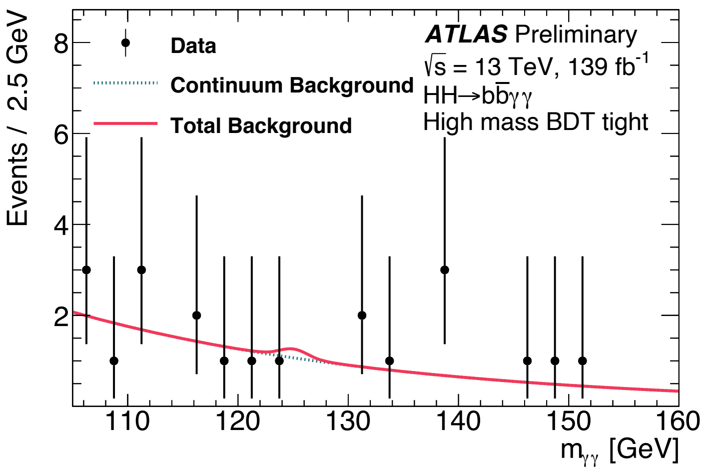
- **Spurious signal** is estimated from a signal + background fit to a background-only MC template
- This test also confirms that the BDT selection does not create any "bump" in the $m_{\gamma\gamma}$ spectrum due to choice of input variables
- In general the analysis is almost completely statistically dominated with the Run 2 dataset

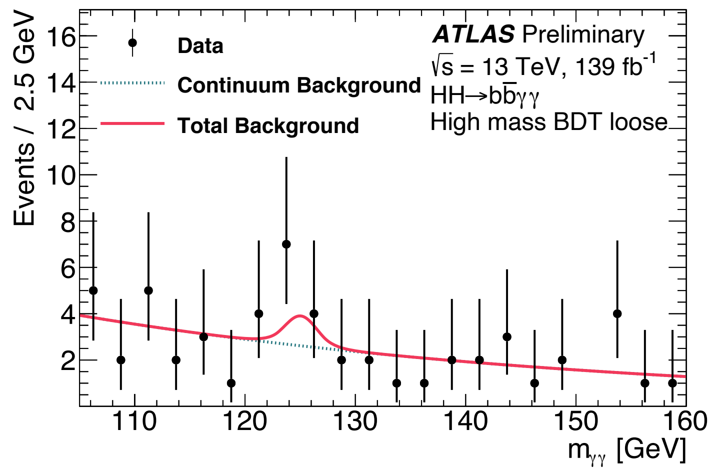
Source	Type	Non-resonant analysis HH
Experimental		
Photon energy scale	Norm. + Shape	5.2
Photon energy resolution	Norm. + Shape	1.8
Flavor tagging	Normalization	0.5
Theoretical		
Heavy flavor content	Normalization	1.5
Higgs boson mass	Norm. + Shape	1.8
PDF+α_s	Normalization	0.7
Spurious signal	Normalization	5.5

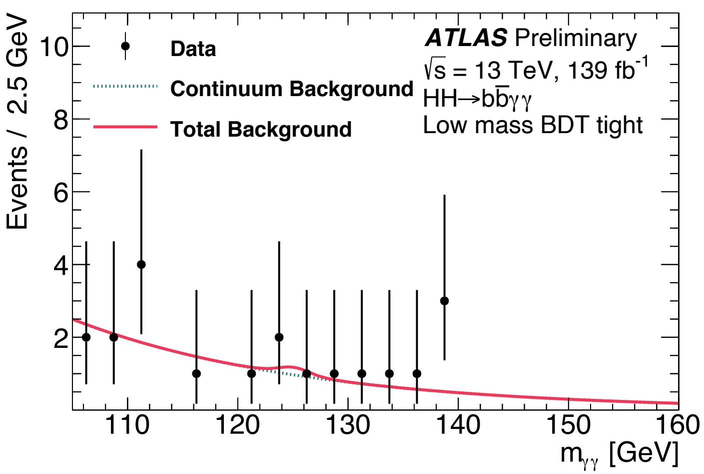
Relative impact of systematics on upper limit [%]

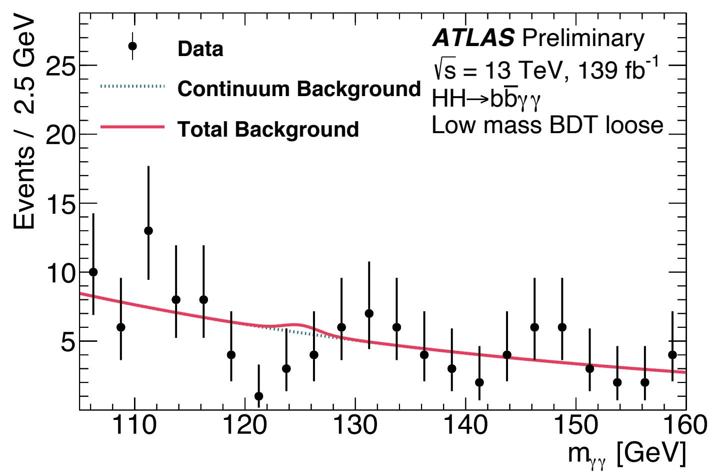
$m_{\gamma\gamma}$ distribution

- The HH signal is obtained from a **simultaneous fit to $m_{\gamma\gamma}$** across all categories
- **No significant excess is observed** and upper limits are set at 95% CL







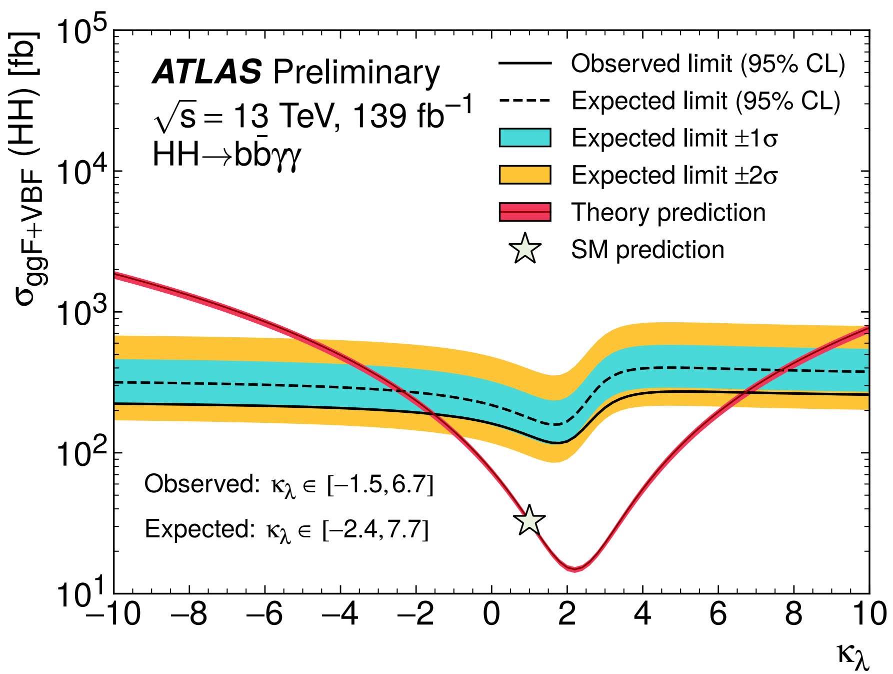


Analysis results

- The observed (expected) **limit on the HH non-resonant production cross-section** is **130fb (180fb)**, corresponding to **4.1 (5.5)** times the SM cross-section
- The observed (expected) **constraint on the Higgs boson self-coupling** is $\mathbf{-1.5 < \kappa_\lambda < 6.7\ (-2.4 < \kappa_\lambda < 7.7)}$

- XS limits improved by a factor of ~4 compared to the 36 fb^{-1} result

- κ_λ constraint improved by a factor of ~2



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- The new 139 fb^{-1} ATLAS non-resonant $bb\gamma\gamma$ result improves significantly on the 36 fb^{-1} search
- Use a combination of $m_{bb\gamma\gamma}$ cuts and BDTs to define signal-sensitive categories
- Obtain good sensitivity for both the SM HH signal and the BSM κ_λ variations
- Looking forward to further improvements from Run 3 data and beyond!

CONF note link:

[ATLAS-CONF-2021-016]

To be submitted soon as a paper