Search for di-Higgs production in the $HH \rightarrow bb\gamma\gamma$ decay channel with the ATLAS detector

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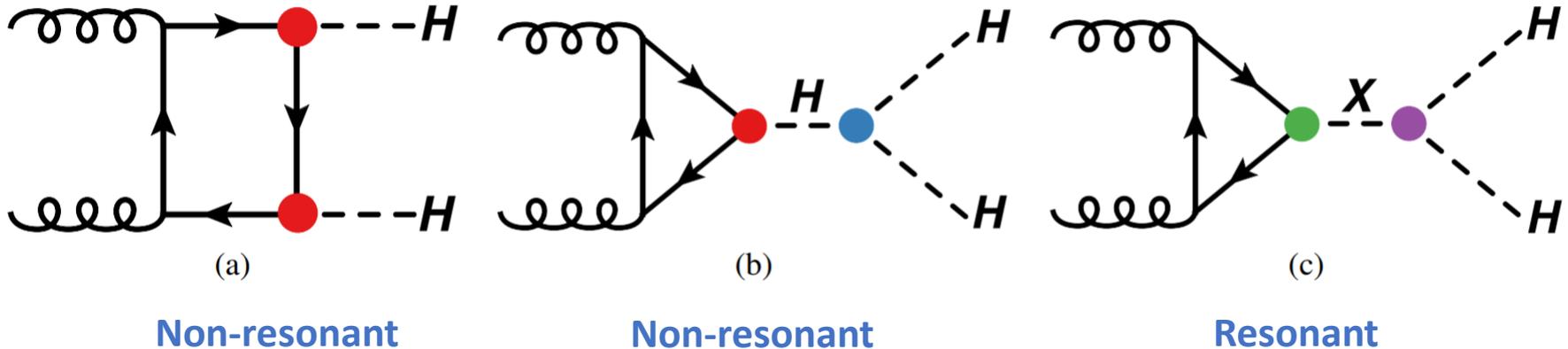
DPF 2019

July 31, 2019

Outline

1. **Analysis overview**
2. Event selection and categorization
3. Expected results
4. Summary

Analysis overview

|		
(a) **Non-resonant**	(b) **Non-resonant**	(c) **Resonant**

- Measuring Di-Higgs production at ATLAS

- $HH \to \gamma\gamma bb$ decay channel: combine large $H \to bb$ branching ratio with excellent ATLAS photon resolution

- **Non-resonant**: search for SM HH production, with possible modifications of the Higgs self coupling

- **Resonant**: search for BSM $X \to HH$, where $m_X \in$ [250,3000] GeV

$36fb^{-1}$ publication

- A brief reminder of the latest results ...

- Two high p_T **photons**

- Cut based approach: selections using jet p_T, m_{bb}

- **Loose selection**: for low resonance masses and limit on Higgs self-coupling

- **Tight selection**: for high resonance masses and limit on SM cross section

- Further sort into **2 b-tag** category and **1 b-tag** category
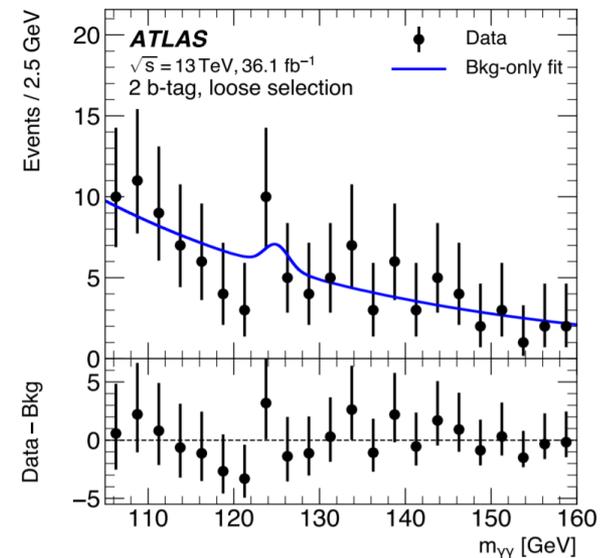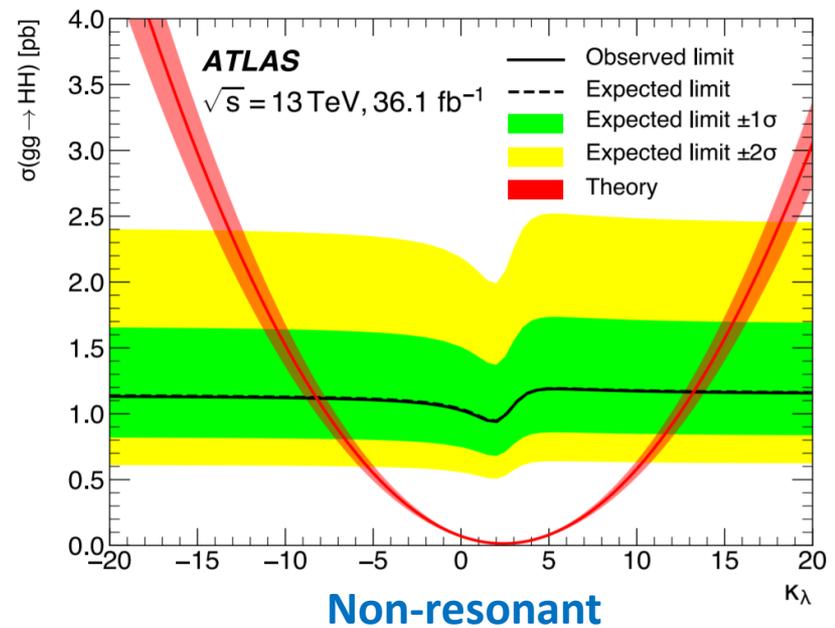

Non-resonant
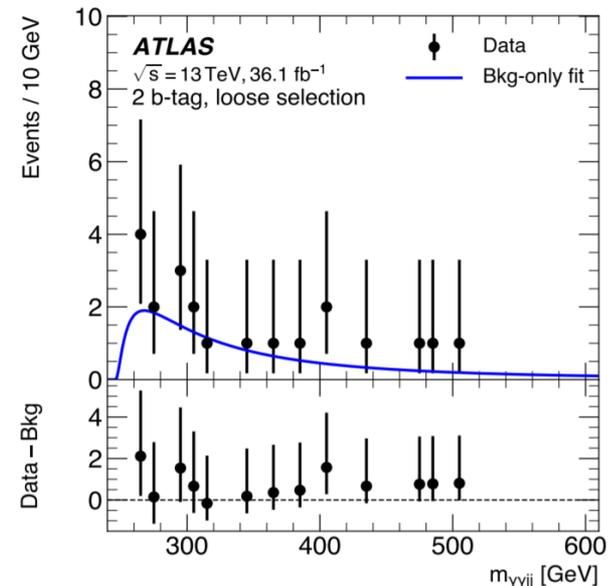
Resonant

$36fb^{-1}$ **paper: JHEP 11 (2018) 040**

$36fb^{-1}$ publication

- HH and H from simulation

- Continuum $\gamma\gamma$ background from analytic function fitted on data sideband

- Perform S + B fit on $m_{\gamma\gamma}$ for non-resonant, on $m_{\gamma\gamma bb}$ for resonant

- No excess observed

- Observed limit on non-resonant $\kappa_\lambda = 1$ model:
  - **Cross section < 22 * SM**
  - $\boldsymbol{\kappa_\lambda \in [-8.2, 13.2]}$

- Observed limits on cross sections of resonant model vary from
  - **1.1pb - 0.12pb**

$36fb^{-1}$ **paper: JHEP 11 (2018) 040**
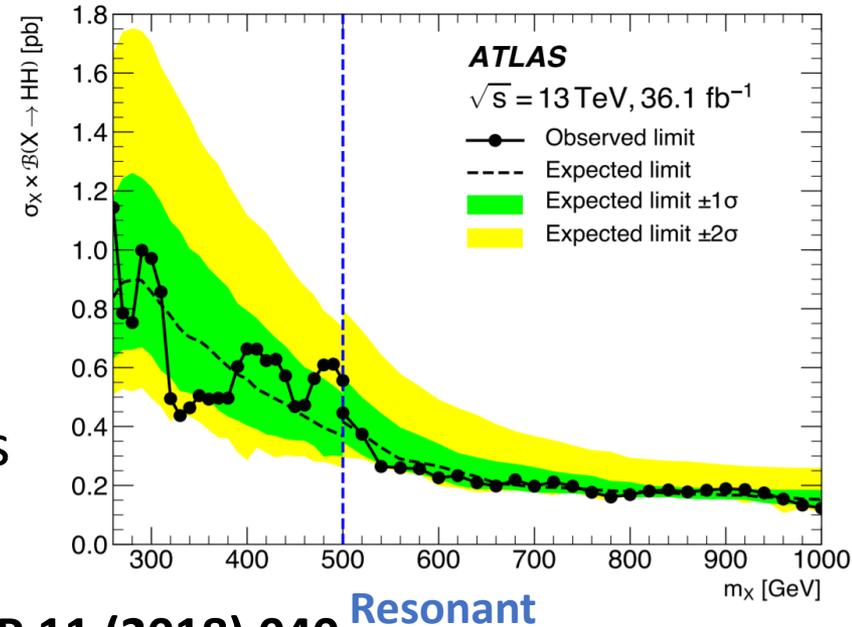
Non-resonant

Resonant

Contents of this presentation

- This presentation:

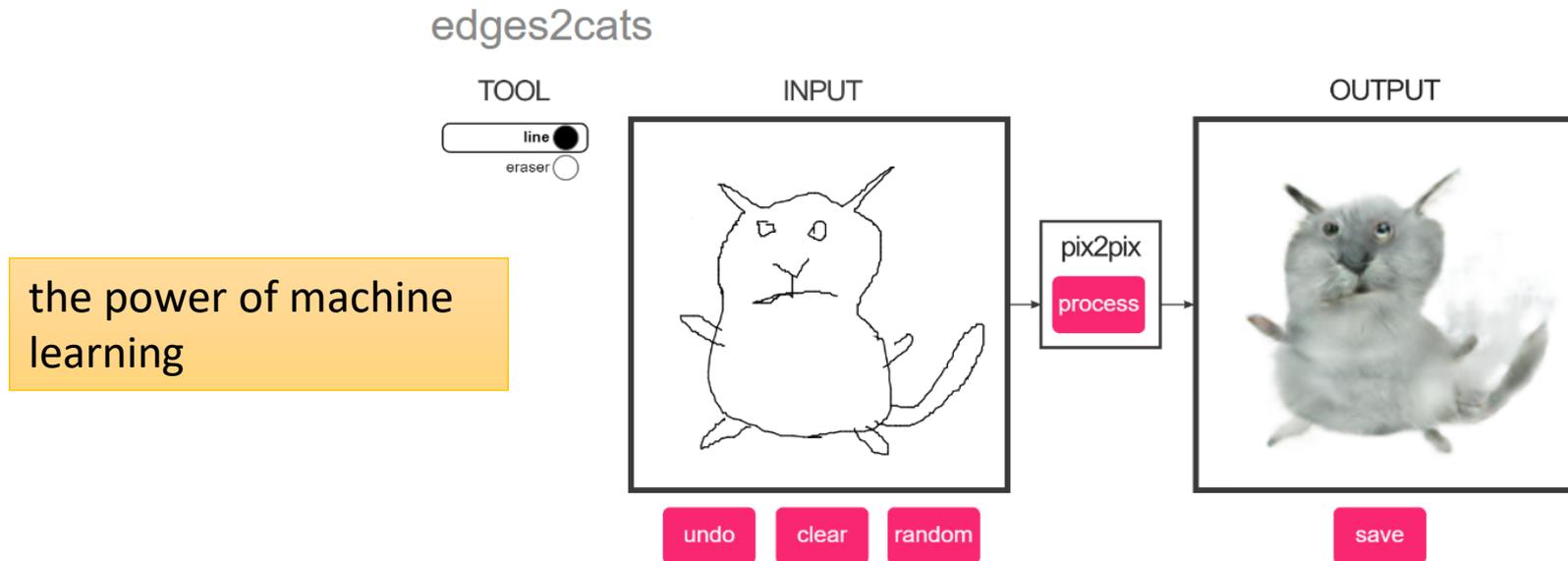- Focus on **non-resonant Di-Higgs production** from **ggF**, with possible modifications of the Higgs self-couplings ($\boldsymbol{\kappa_\lambda}$)
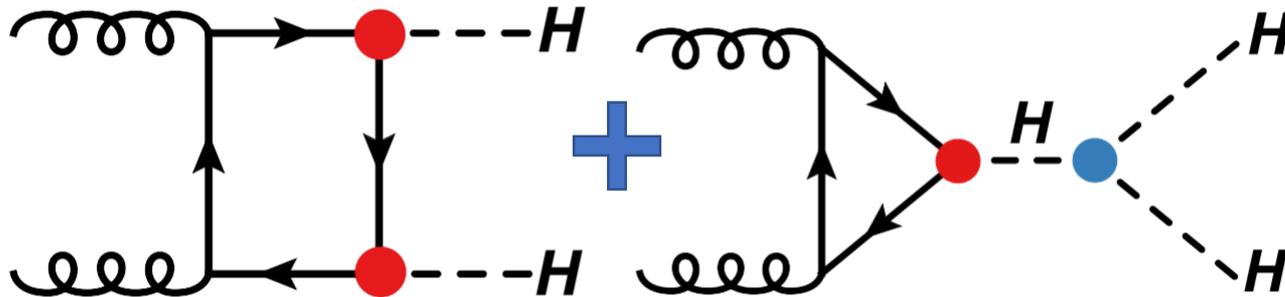
- Try to improve on the $36 fb^{-1}$ analysis

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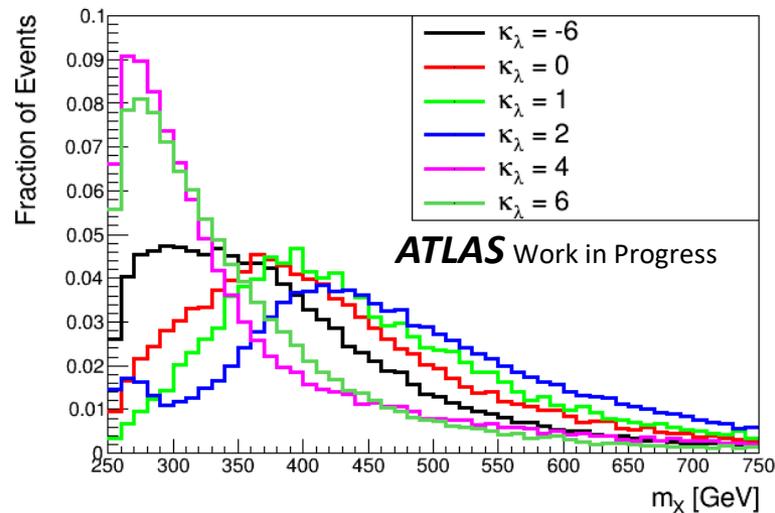3. Expected results
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Improving on the $36 fb^{-1}$ analysis

- One possibility for improvement:
- Use a BDT to categorize events instead of the cut based selection
- Multiple signal models, with $\kappa_\lambda \in [-10, 10]$
- Aim for good sensitivity for both SM and BSM values of κ_λ
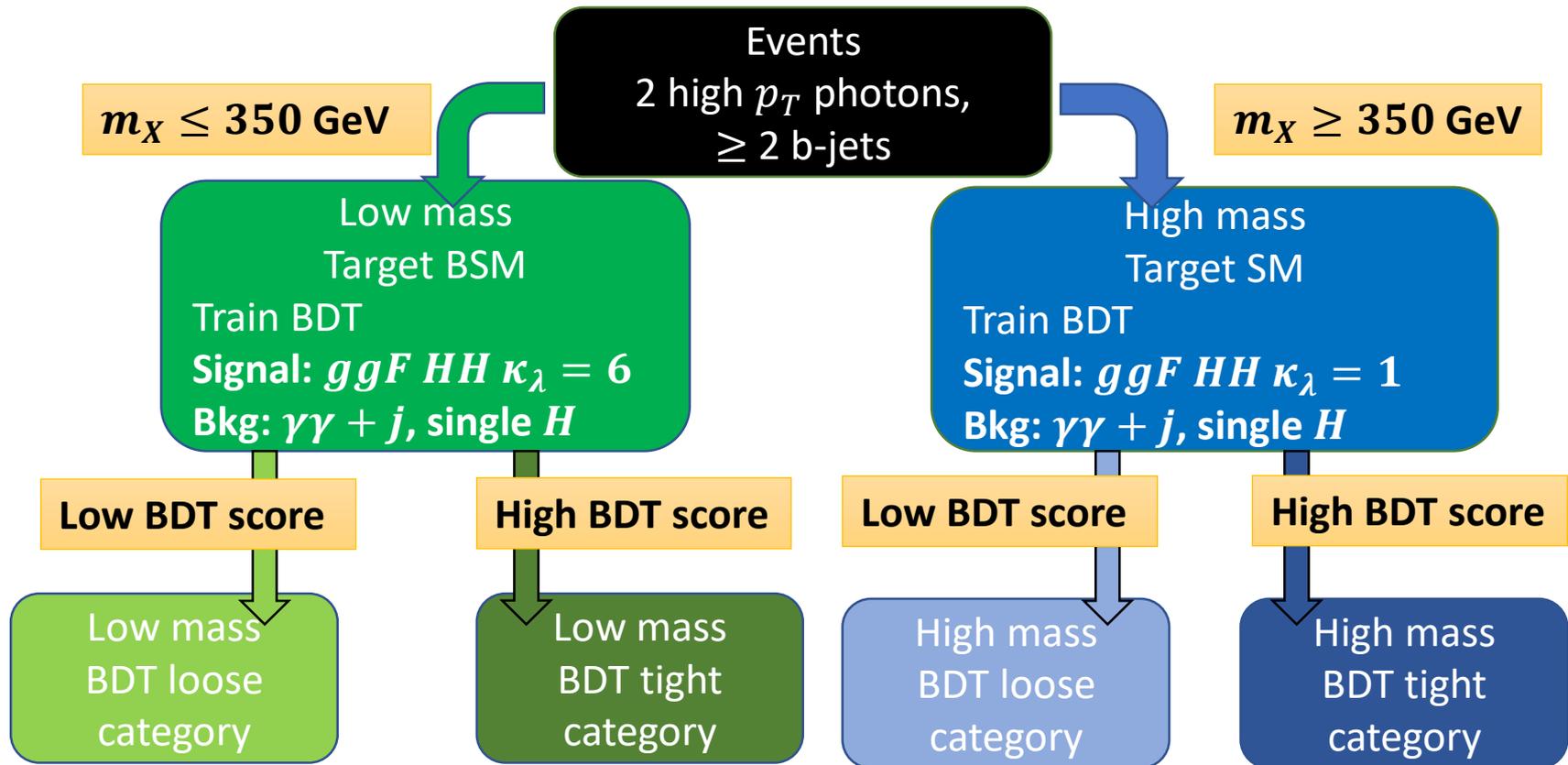
the power of machine learning

edges2cats

TOOL

line
eraser

INPUT

pix2pix
process

OUTPUT

undo clear random

save

Defining regions with $m_{\gamma\gamma bb}$

- $m_{\gamma\gamma bb}$ is sensitive to κ_λ and can be used as a discriminating variable

- In practice, use $m_X = m_{\gamma\gamma bb} - m_{\gamma\gamma} - m_{bb} + 250$ in place of $m_{\gamma\gamma bb}$ for better peak resolution

- Define two regions:
  - "High mass" with $m_X \geq 350$ GeV, targeting SM κ_λ
  - "Low mass" with $m_X < 350$ GeV, targeting BSM κ_λ

Basic strategy

Events
2 high p_T photons,
$\geq$ 2 b-jets

$m_X \leq 350$ GeV

$m_X \geq 350$ GeV

Low mass
Target BSM
Train BDT
Signal: $ggF\ HH\ \kappa_\lambda = 6$
Bkg: $\gamma\gamma + j$, single H

High mass
Target SM
Train BDT
Signal: $ggF\ HH\ \kappa_\lambda = 1$
Bkg: $\gamma\gamma + j$, single H

Low BDT score

High BDT score

Low BDT score

High BDT score

Low mass
BDT loose
category

Low mass
BDT tight
category

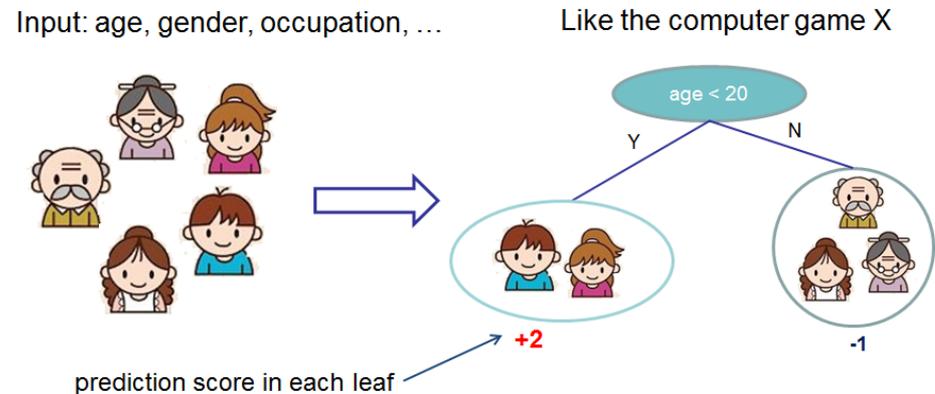High mass
BDT loose
category

High mass
BDT tight
category

- Evaluate the sensitivity for **all signal models**, using the combined performance in **all four High mass** and **Low mass** categories
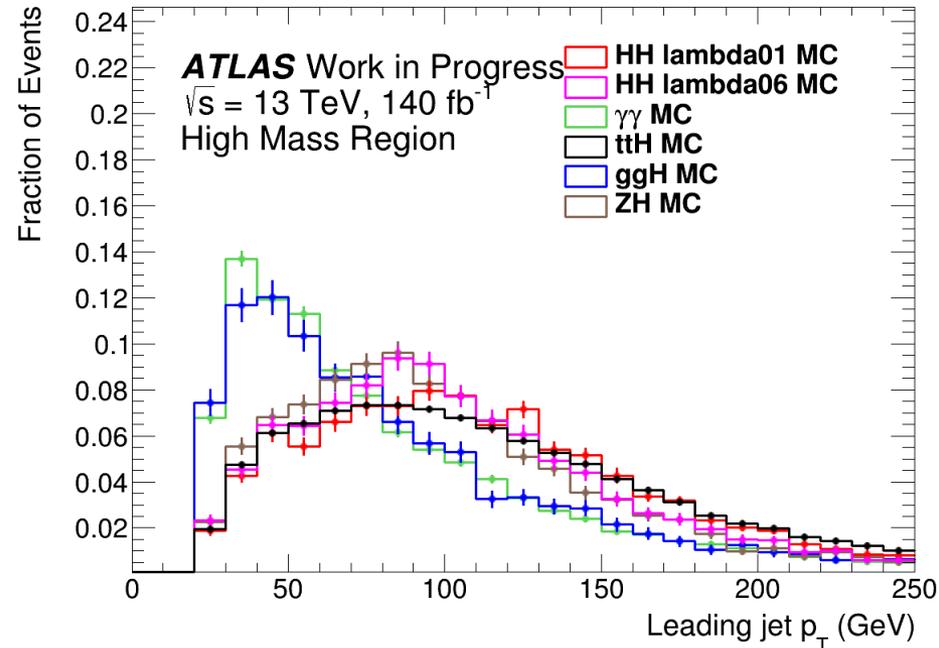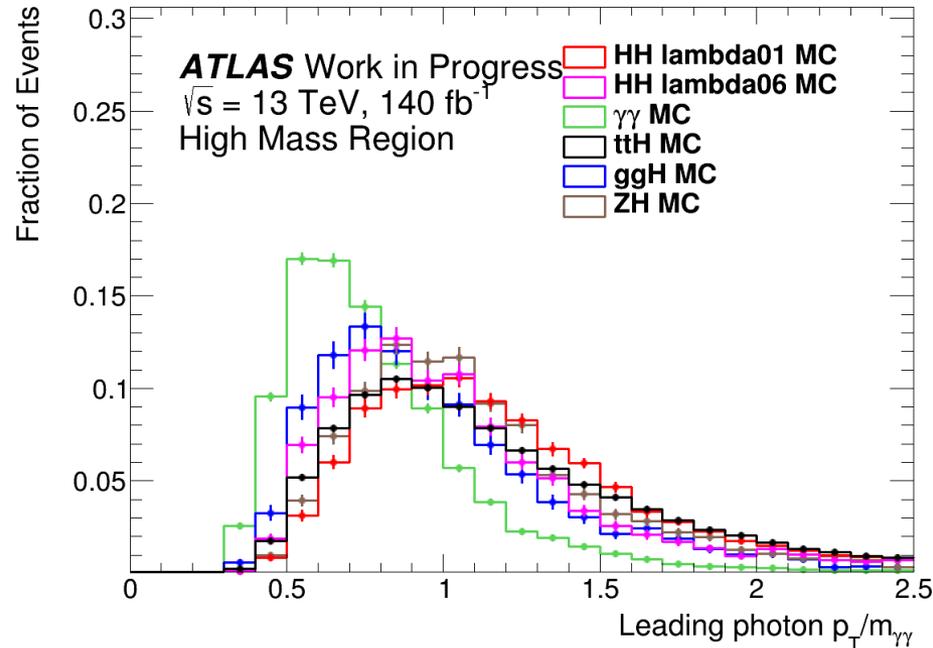
What is a BDT?

- A BDT (Boosted Decision Tree) is a type of supervised machine learning algorithm

- Given a set of input variables, decide whether an event is signal or background

- Conceptually, nothing more than a complicated sequence of cuts

- Here use XGBoost → fast, robust performance without much hyperparameter tuning needed

Kinematic variables (high mass region)

- In both **high** and **low** mass regions, use a mixture of variables defined by the photon and jet kinematics

- In the **high mass** region, photon (left) and jet (right) variables offer good separation between the SM HH signal and $ggH + \gamma\gamma$ backgrounds

Kinematic variables (high mass region)
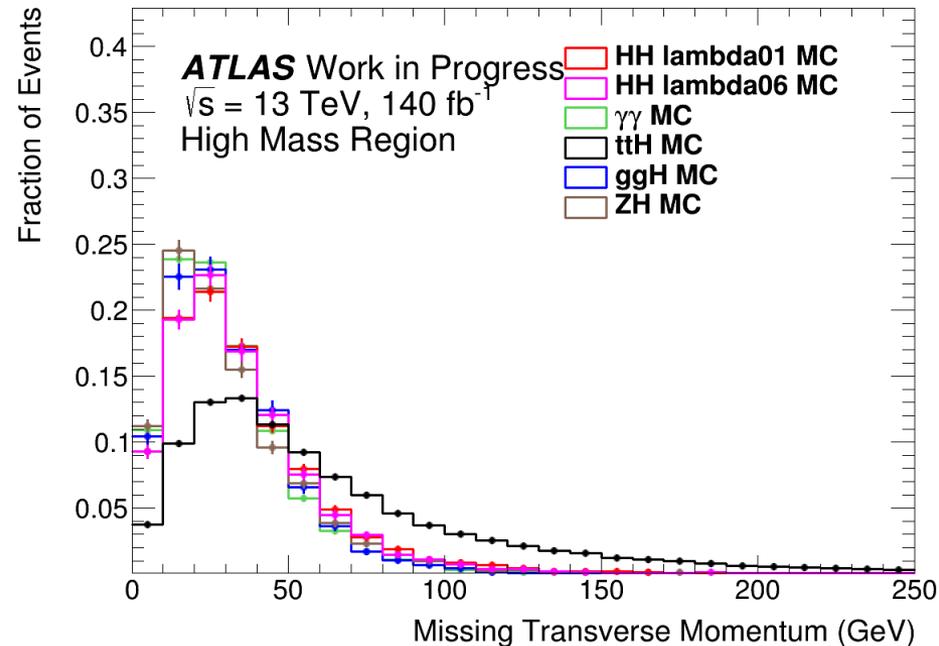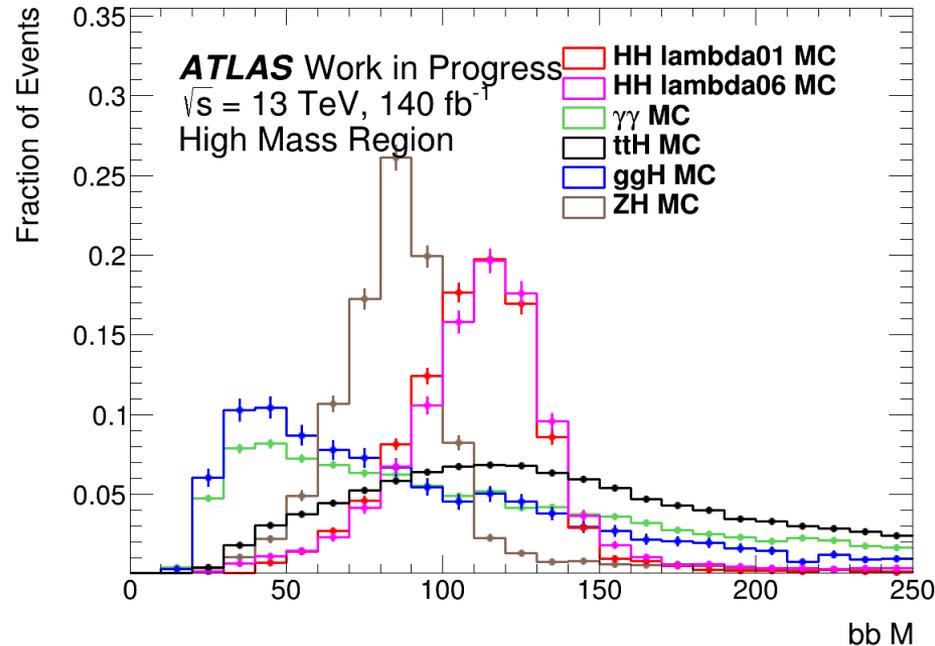
- Some additional plots in the **high mass** region

- Left: Mass of the bb system is very powerful – see sharp peaks for HH and ZH

- Right: Missing E_T is good against ttH

Kinematic variables (low mass region)
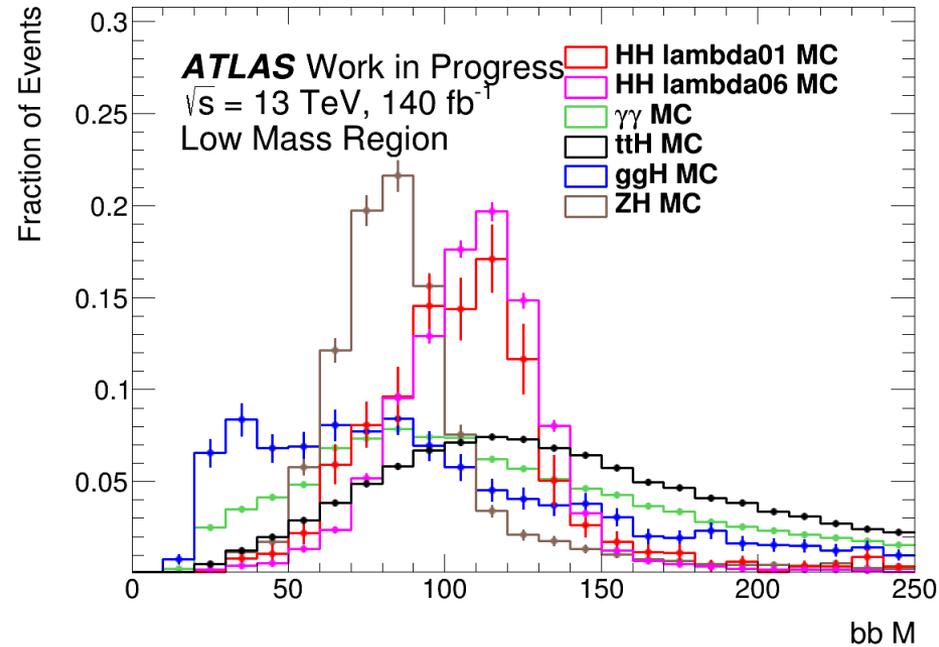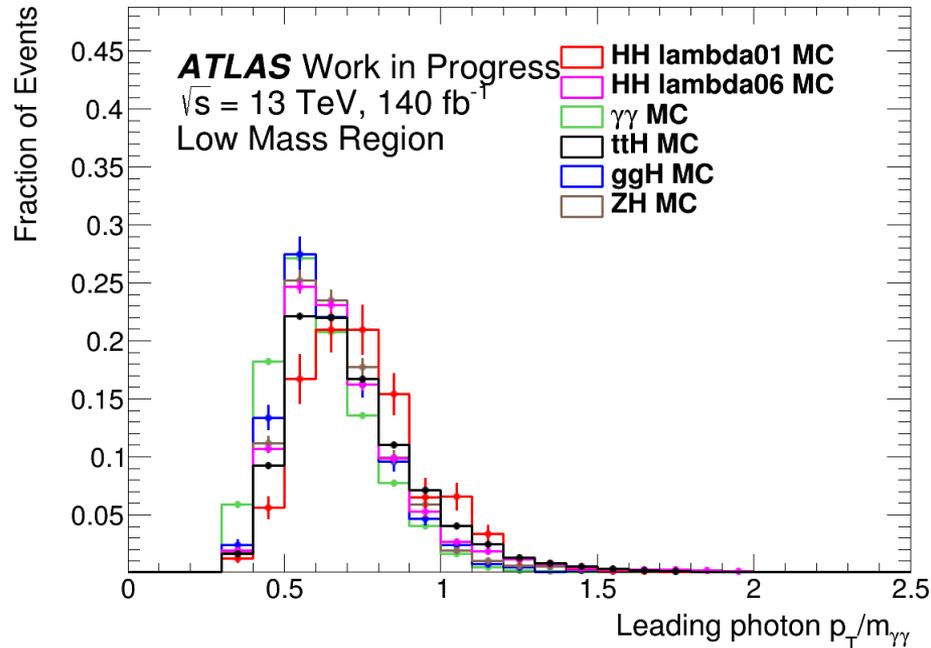
- Some more plots in the **low mass** region

- Left: Photon and jet variables not as powerful as in high mass region due to softer p_T

- Right: But m_{bb} is quite good

BDT output

- Good separation between signal ($\gamma\gamma bb$) and backgrounds ($\gamma\gamma + ZH + ggH + ttH$)

- Data sideband agrees well with $\gamma\gamma$ MC used for training

- Both $\kappa_\lambda = 1$ and $\kappa_\lambda = 6$ HH samples are signal like – good since sensitivity is evaluated using all four categories
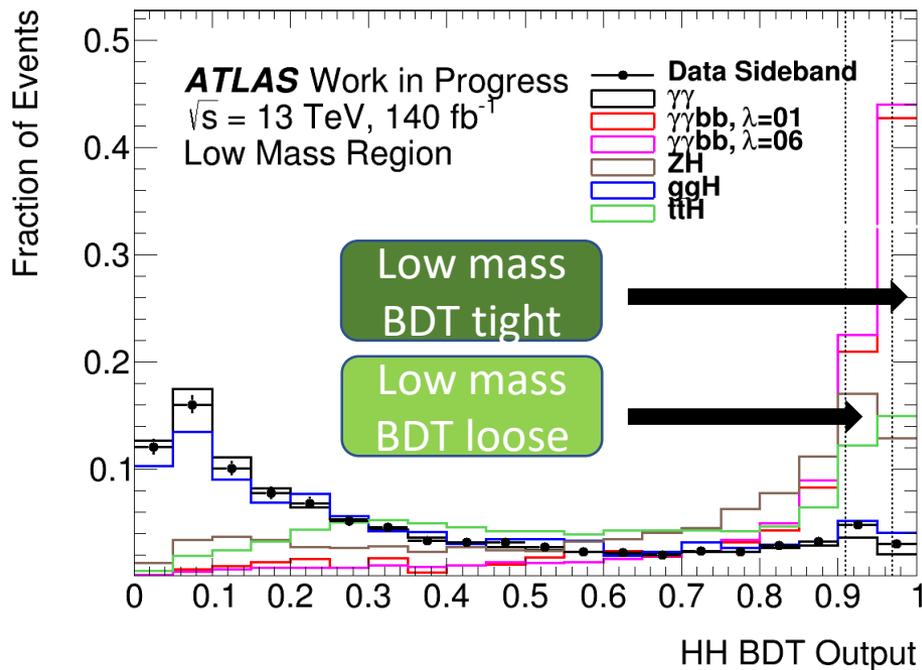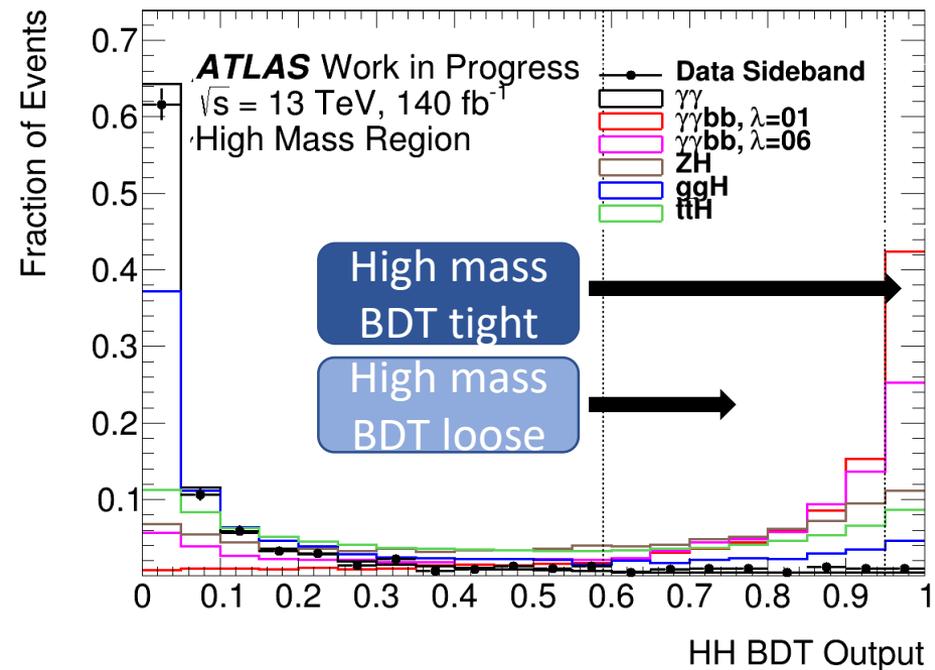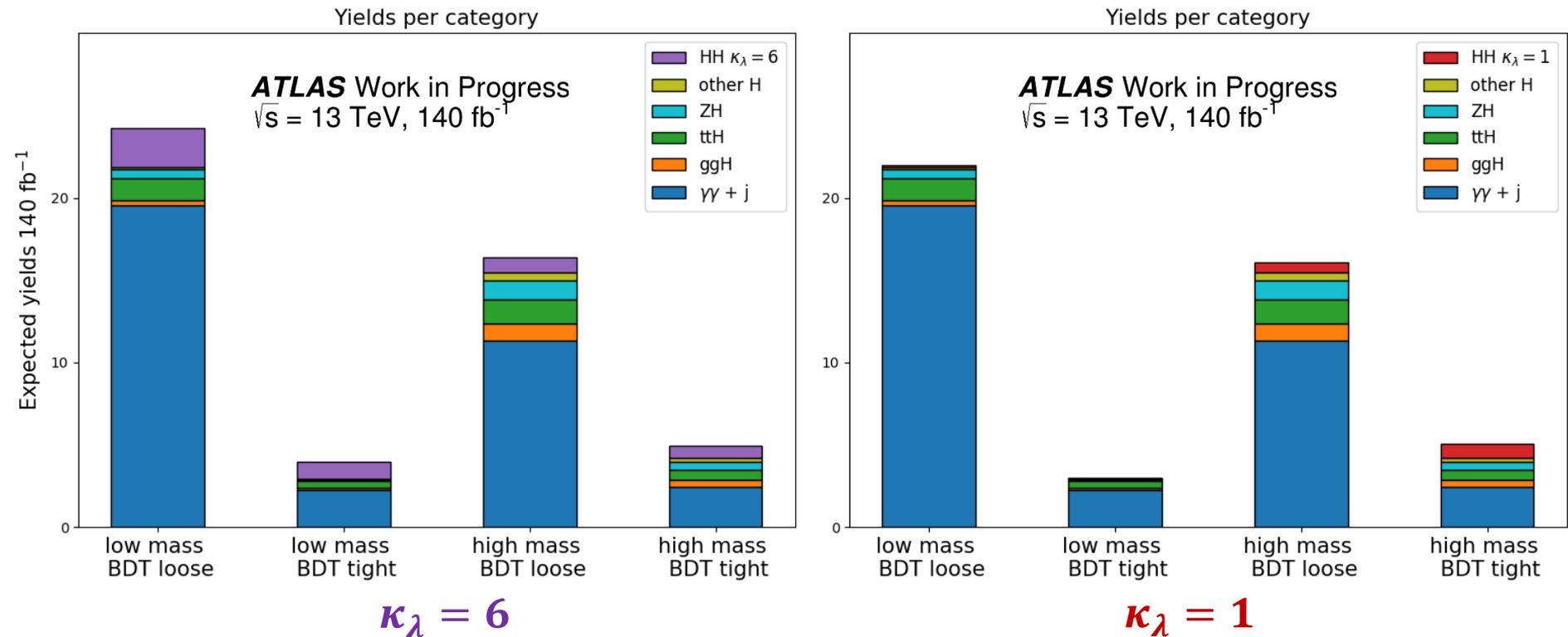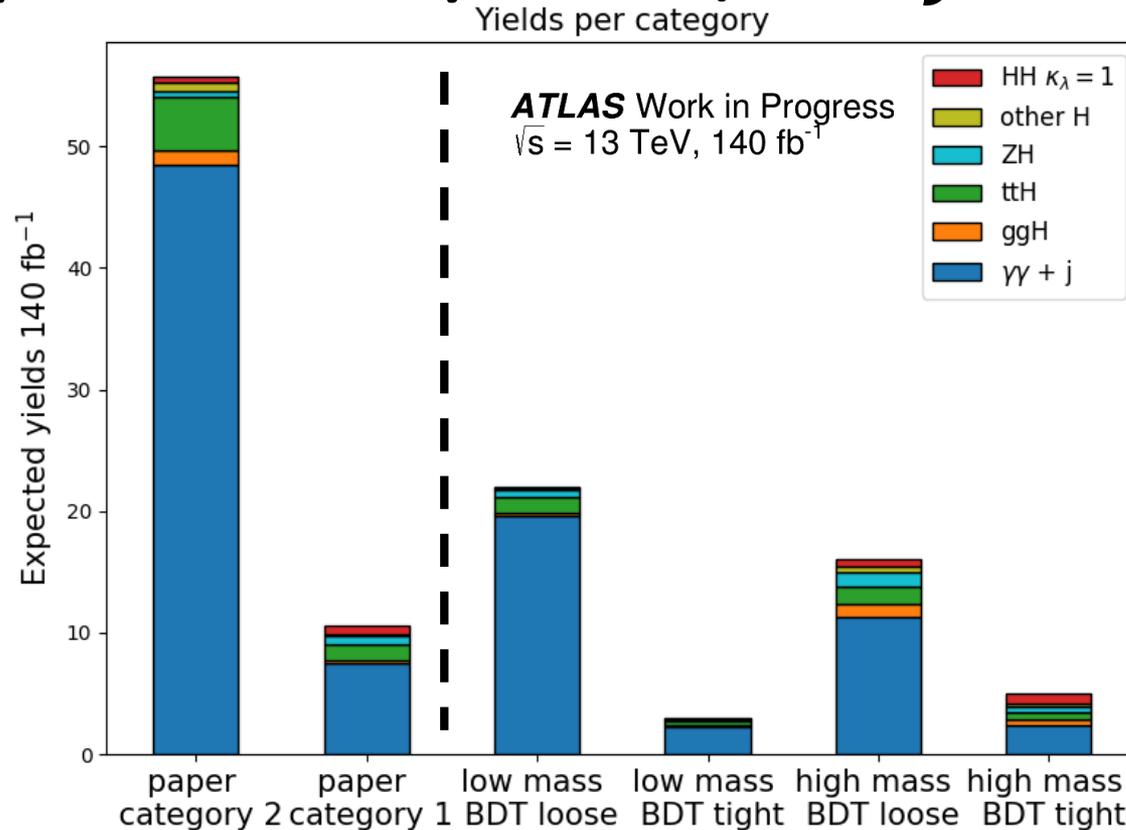
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Comparison of yields ($140fb^{-1}$)

$\boldsymbol{\kappa_\lambda = 6}$ $\boldsymbol{\kappa_\lambda = 1}$

- Main background is from continuum $\gamma\gamma$, but with also significant ggH, ttH, ZH in high mass region and significant ttH in low mass region

Comparison of yields ($140 fb^{-1}$)

- Example for $\kappa_\lambda = 1$

- For similar signal efficiency, BDT based approach has much better rejection of $\gamma\gamma + j$, ttH, and ZH compared to the previous paper selections

Expected significance ($\mathbf{140fb^{-1}}$)

$\mathbf{140fb^{-1}}$	Paper cut based	(NEW) BDT
Significance ($\kappa_\lambda = 1$)	0.23σ	0.42σ
Significance ($\kappa_\lambda = 6$)	0.66σ	0.88σ

- Compare expected significance, evaluated using (stat. only) number counting formula

- $$Z_0 = \sqrt{2\left((s+b)\ln\left(1+\frac{s}{b}\right) - s\right)}$$

- Noticeable improvement over cut based selection for both $\kappa_\lambda = 1$ and $\kappa_\lambda = 6$ models

- How does it perform on other models which were not used for training?

Significance for different κ_λs
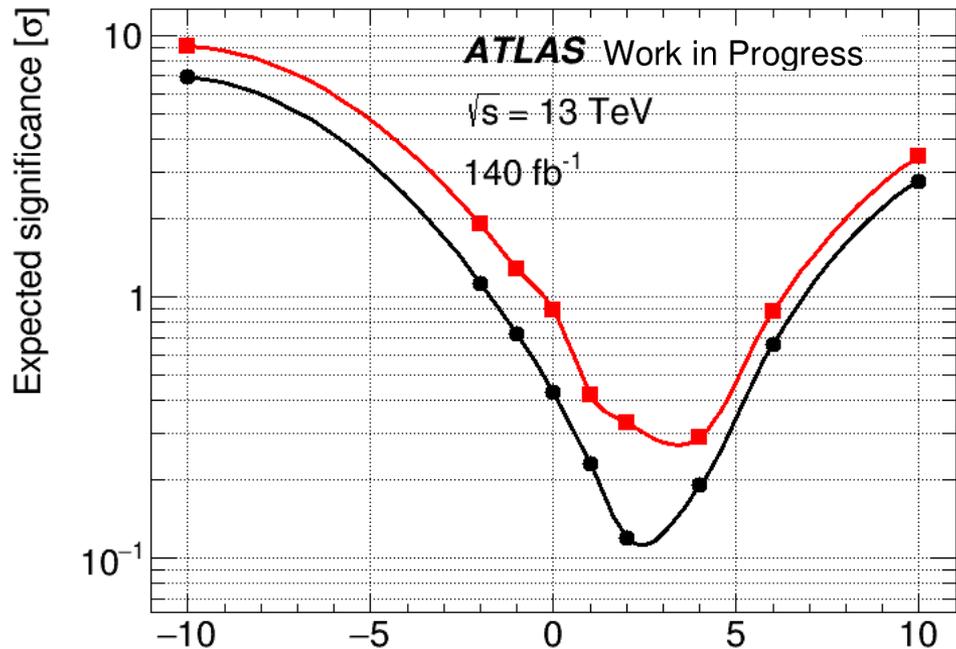
New BDT

Paper cut based

- Using the same **unchanged** "high mass" and "low mass" categories optimized on the SM and $\kappa_\lambda = 6$ signal gives improvement over paper cut based selections of **30 - 100%** for **all values of** κ_λ

- Demonstrates robustness of approach!

Bonus: BDT score vs $m_{\gamma\gamma}$

- Final result will be from a fit to $m_{\gamma\gamma}$ modeled by analytical function

- Check that BDT will not create any difficult to model peaks in the mass distribution

- No such problems seen in $\gamma\gamma +$ j sample
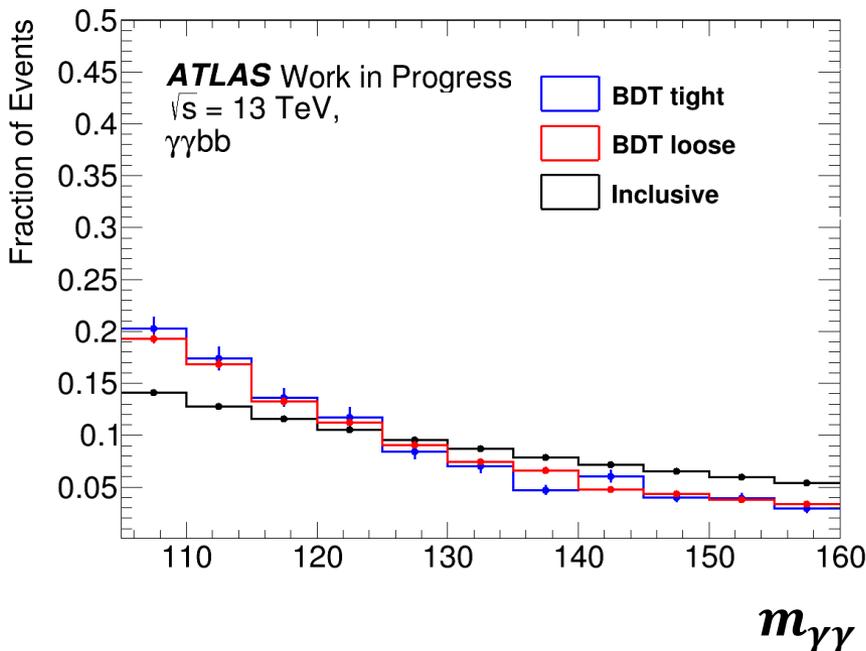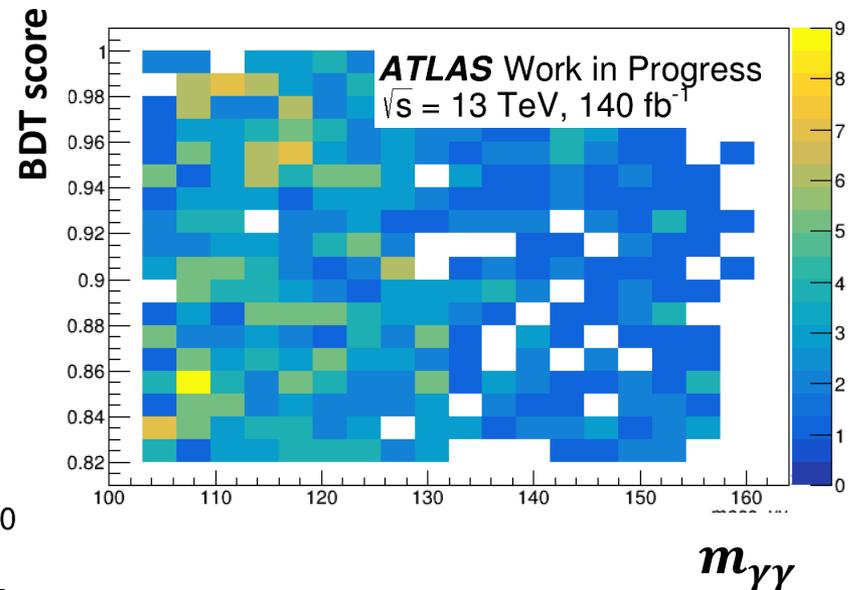
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Summary

- Presented a BDT based strategy for reoptimizing the ATLAS non-resonant $HH \to \gamma\gamma bb$ analysis

- Define two regions based on $m_{\gamma\gamma bb}$ to target either SM or BSM values of κ_λ

- In each region, use a BDT to create signal enhanced categories

- **Large improvement in expected significance over previous cut based approach for all values of κ_λ, of order ~ 30 – 100%**

- Looking forward to new results on SM HH cross sections and Higgs self couplings with $140 fb^{-1}$!