ICHEP 2022
BOLOGNA

Searches for resonances decaying to pairs of Higgs boson in ATLAS

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on behalf of the ATLAS collaboration

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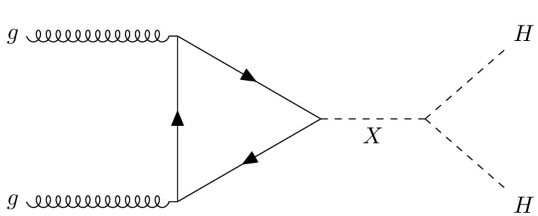
Introduction

- Di-Higgs production is a key process to probe Beyond Standard Model (BSM) physics. Several BSM physics scenarios predict new resonances decaying to standard-model-like Higgs pairs.
- Some representative benchmark models:
  - Generic spin-0 resonance (e.g. 2HDM and MSSM) with negligible width.
  - Spin-2 gravitons (Randall-Sundrum models) with model dependent width.
- Today we will go through some latest ATLAS results on searches for resonances decaying to HH.

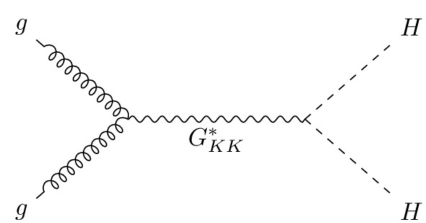
Large branching ratio ⟷ Clean signature

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

Branching ratio of HH decay channels



Spin-0

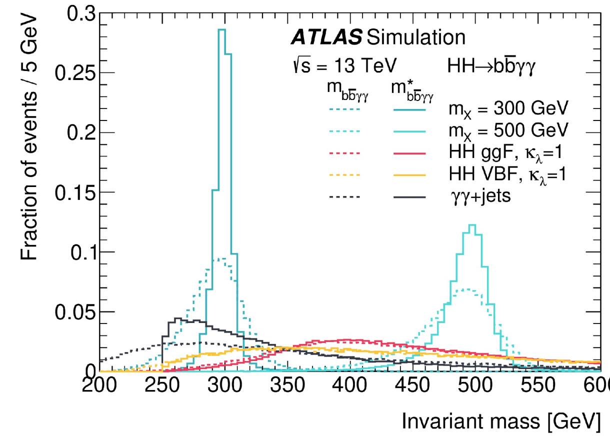


Spin-2

HH→bbγγ

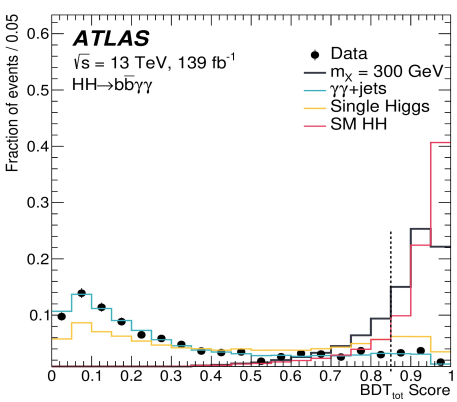
HDBS-2018-34

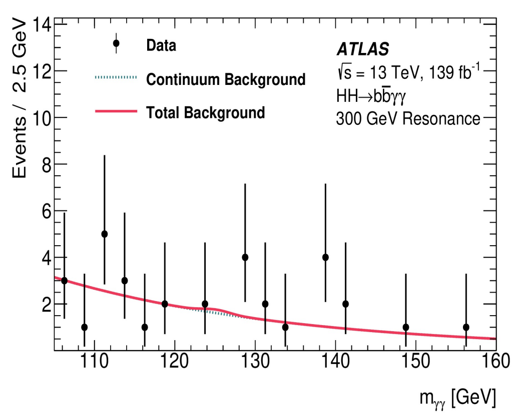
- Small branching ratio (0.26%). Clean signature. Di-photon triggers provide good sensitivity to low m_X domain.
- Combined two BDTs:
  - One against continuous backgrounds (γγ, ttγγ);
  - One against resonant backgrounds (ZH, ttH).
  - Cut on BDT_{tot} score optimized for each m_X.
- Mass window cut on $m^*_{bb\gamma\gamma}$, which improves the mass resolution comparing to $m_{bb\gamma\gamma}$.
- Fit on diphoton mass.

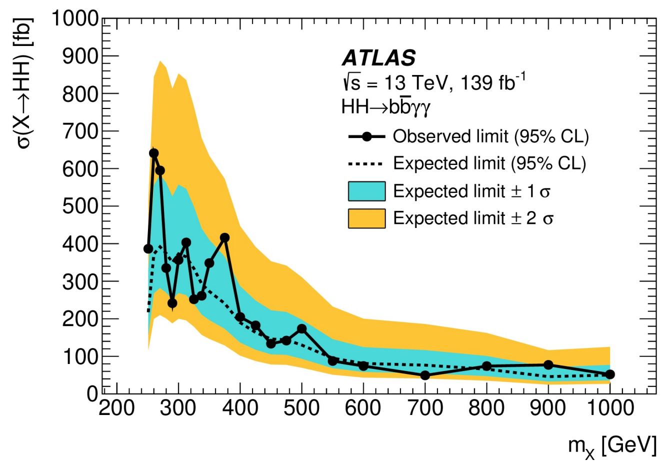


$$m^*_{bb\gamma\gamma} = m_{bb\gamma\gamma} - m_{bb} - m_{\gamma\gamma} + 250\ \text{GeV}$$

- Obs (exp) limits 610 – 47 fb (360 – 43) over $251 < m_X < 1000$ GeV. Very strong constraints on low mass narrow-width resonance pp→X→HH.





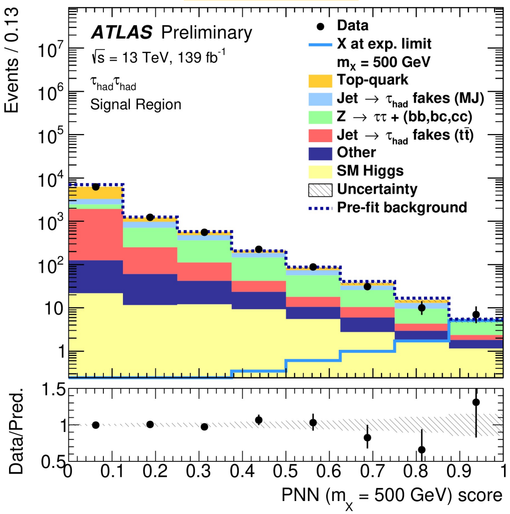


HH→bbττ

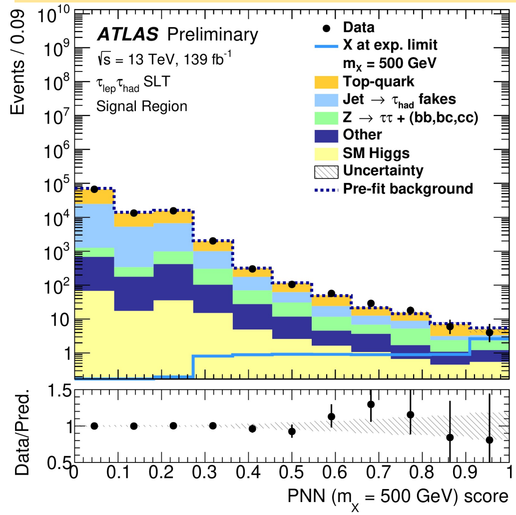
ATLAS-CONF-2021-030

- Relative clean final state with low background.

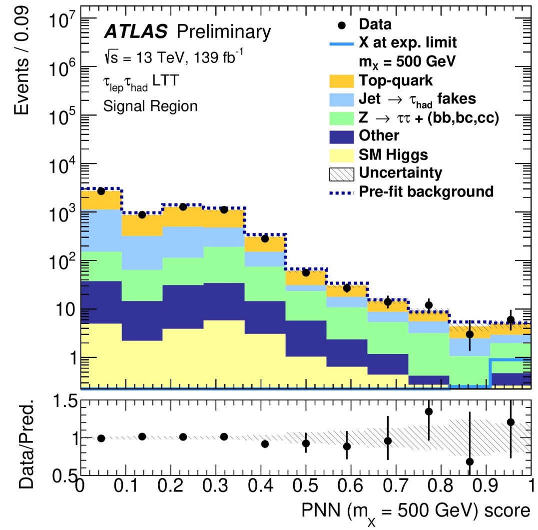
$\tau_{had}\tau_{had}$



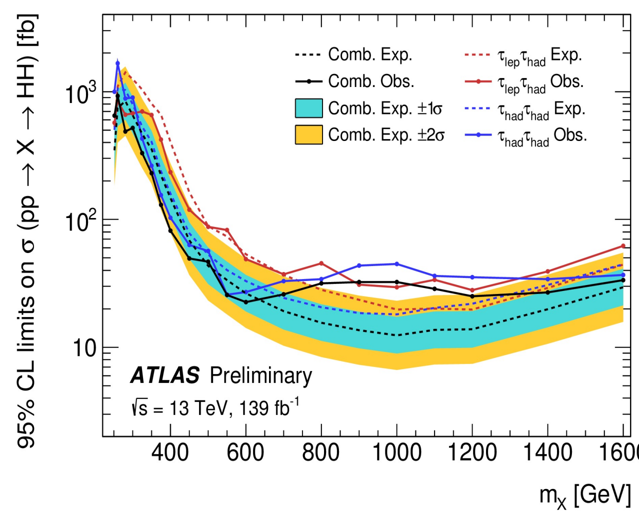
$\tau_{lep}\tau_{had}$, single e/μ trigger



$\tau_{lep}\tau_{had}$, e/μ + τ trigger



- Parametrized neural networks (PNN) trained per category on signal against all backgrounds.
- Fit on PNN output scores.
- Obs (exp) limits 23 – 920 fb (12 – 840 fb).
  - A broad excess between 700 – 1200 GeV.
  - Largest deviation from SM at 1 TeV: local (global) significance 3.0 (2.0) σ.

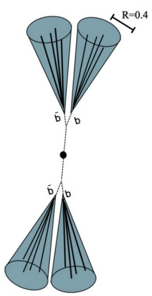


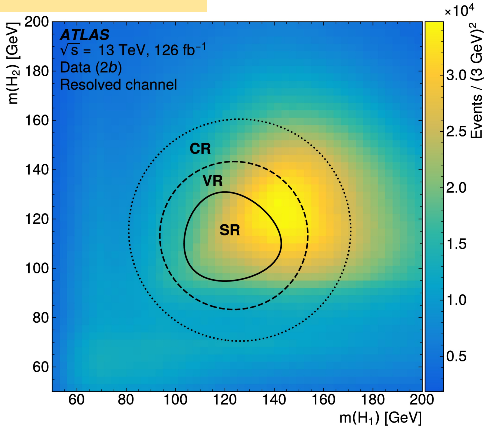
HH→bbbb

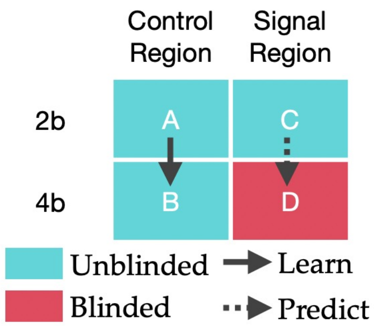
- Largest branching ratio (34%). Multi-jet background estimation is challenging.
- Background estimated from control region data with less b-tag jets.
- Fit on di-Higgs mass.

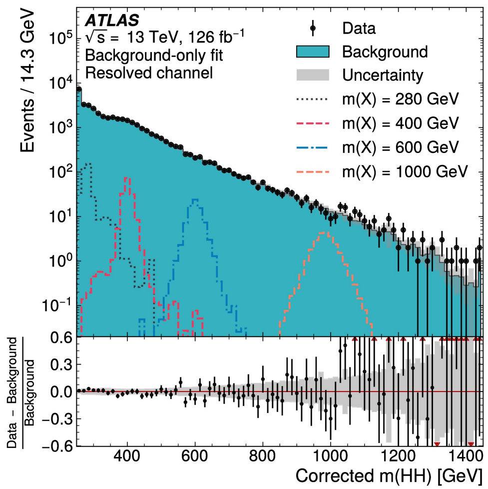
HDBS-2018-41

Resolved channel

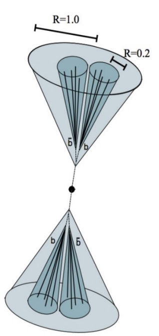


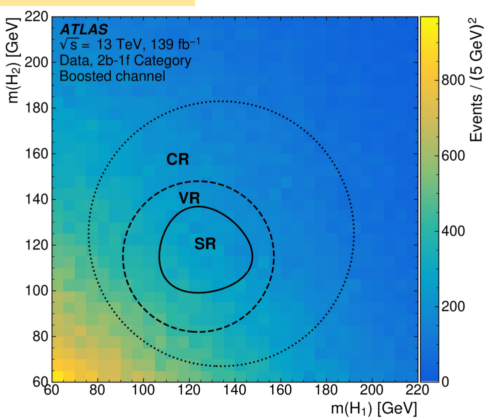


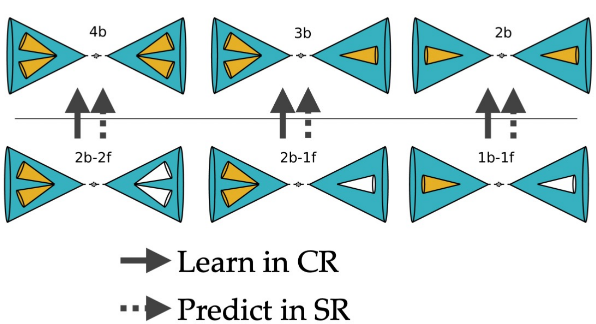


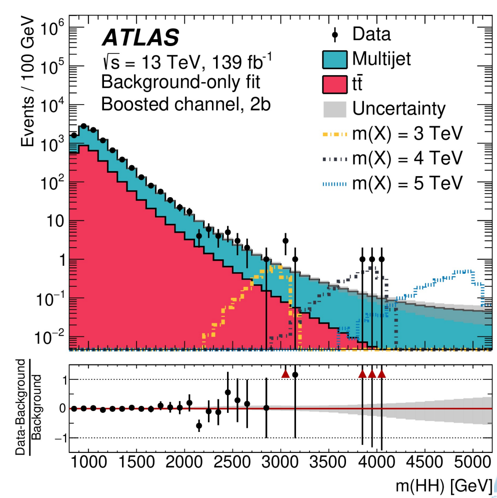


Boosted channel





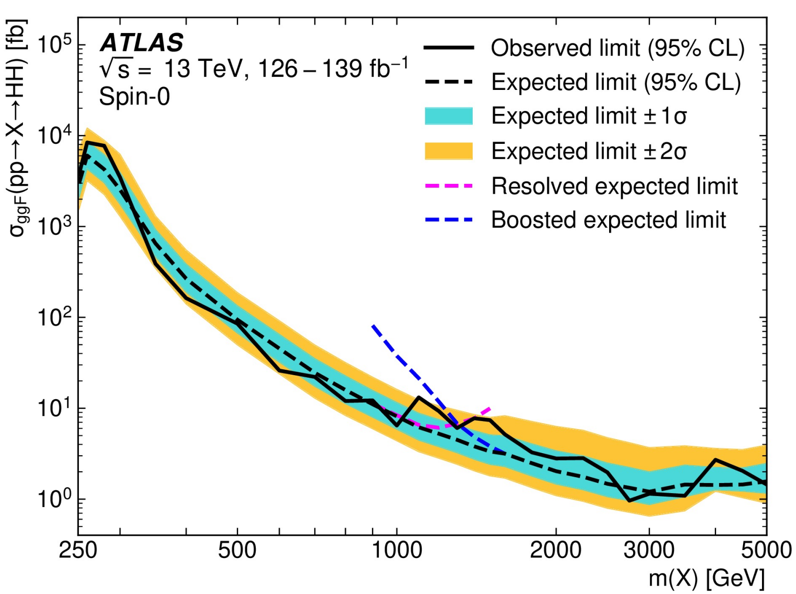


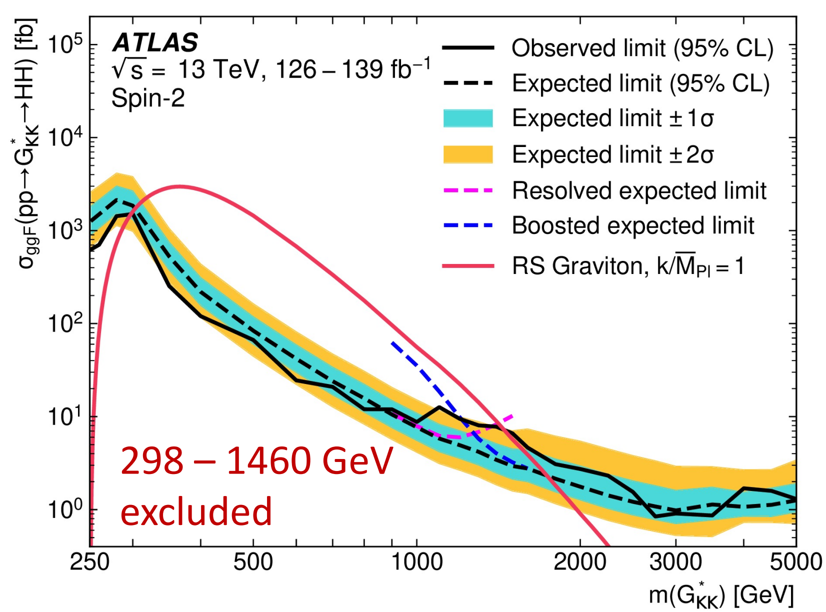


HH→bbbb

HDBS-2018-41

- No significant excess.
  - Largest deviation at 1.1 TeV: Local (global) significance 2.6 (1.0) σ.
- Constraints on narrow spin-0 resonance, and spin-2 graviton with non-negligible width (3% – 20%).
- 3 – 5 TeV covered for the first time.



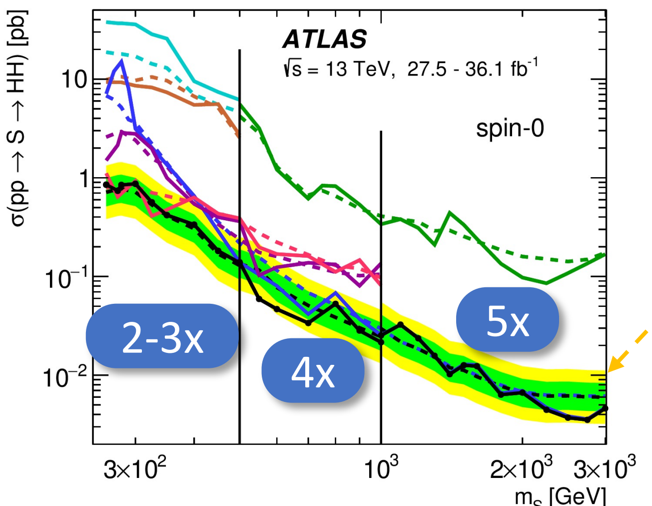


Combination

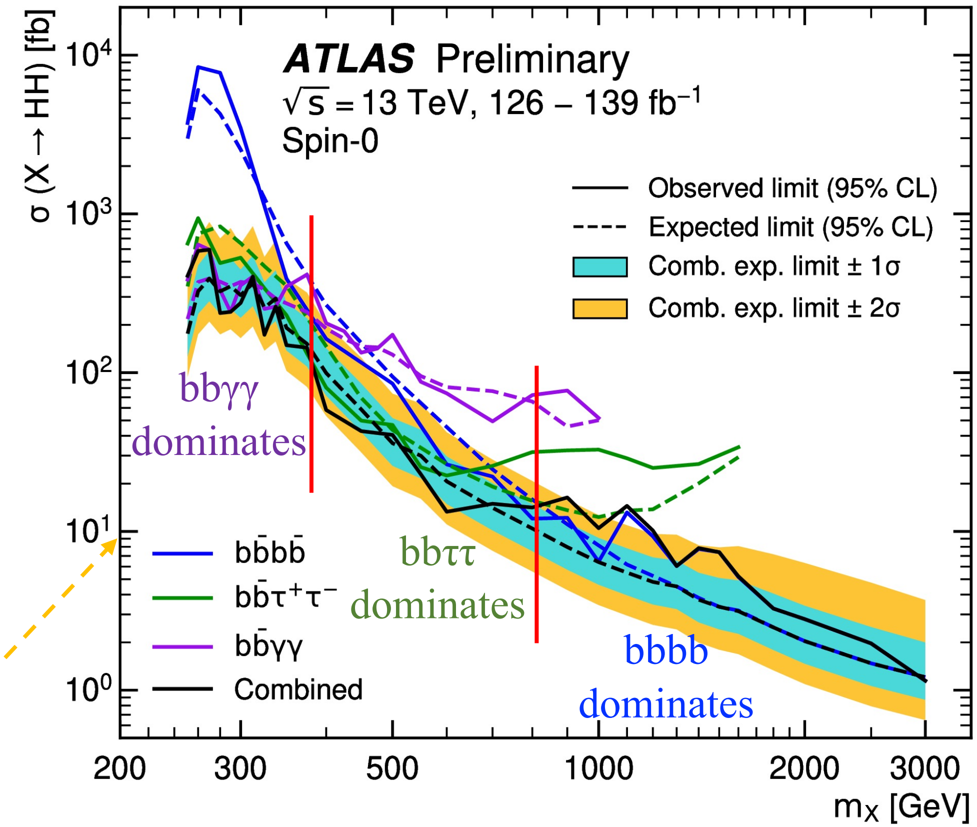
ATLAS-CONF-2021-052

- Combining three channels.
- Complementarity between channels allows to obtain optimal exclusion limits on ggF X→HH cross section across m_X.

Improvements comparing to previous analysis



HDBS-2018-58



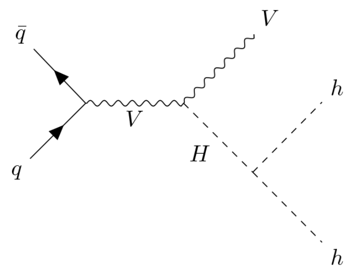
Largest deviation at 1.1 TeV:
local (global) significance 3.2 (2.1) σ.

Vhh

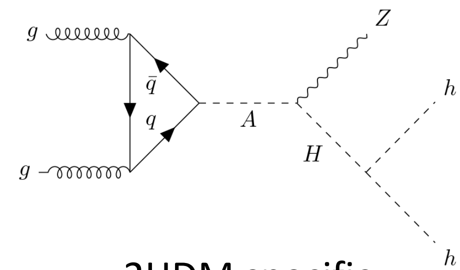
ATLAS-CONF-2022-043

- First analysis targeting Vhh final state. Two signal scenarios are considered.
- 0L, 1L, 2L channels targeting vvbbbb, lvbbbb, llbbbb final states.
- Fit on BDT output.
- See Nicholas Kyriacou's poster.

H – heavy scalar Higgs
h – standard model Higgs
A – neutral, heavy, CP-odd pseudo-scalar

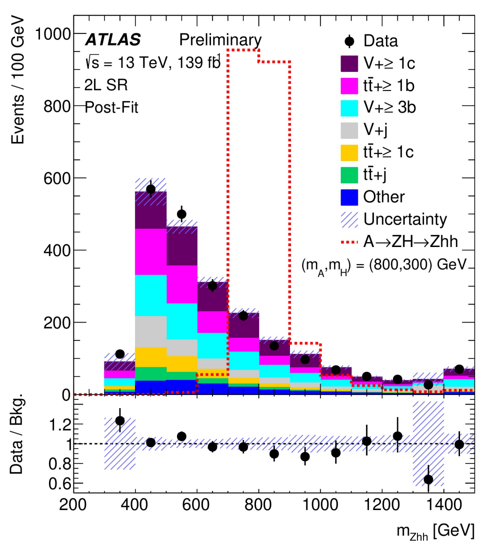


generic Higgstrahlung
VH, H→hh

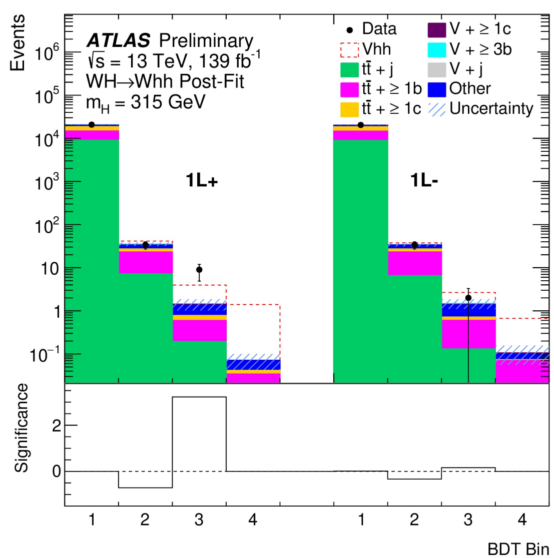


2HDM specific
A→ZH, H→hh

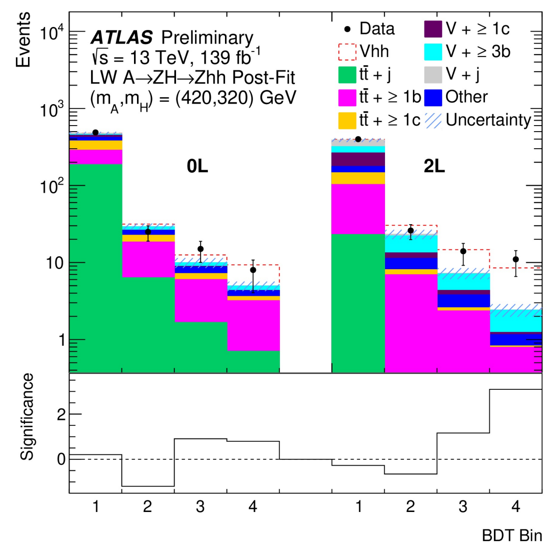
2L SR m_{Zhh}



1L BDT



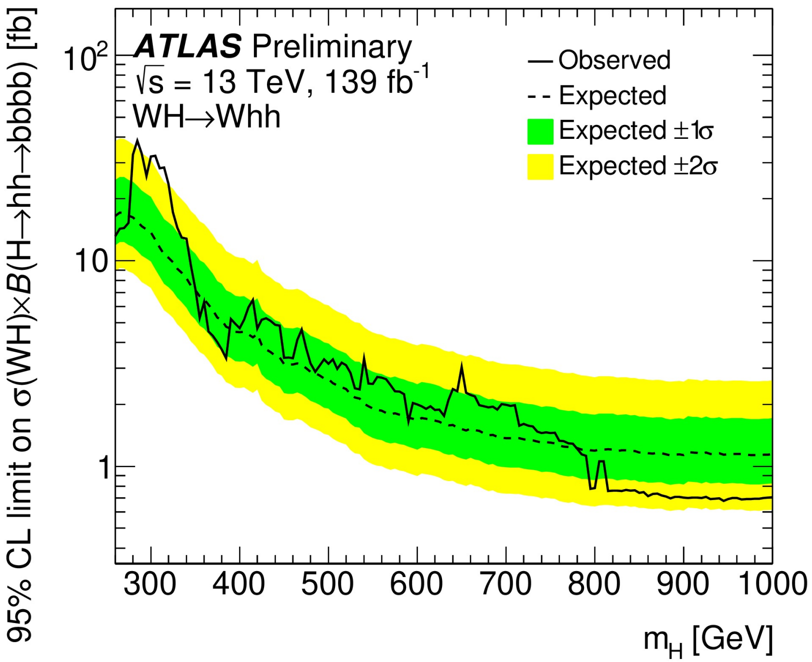
0L & 2L BDT

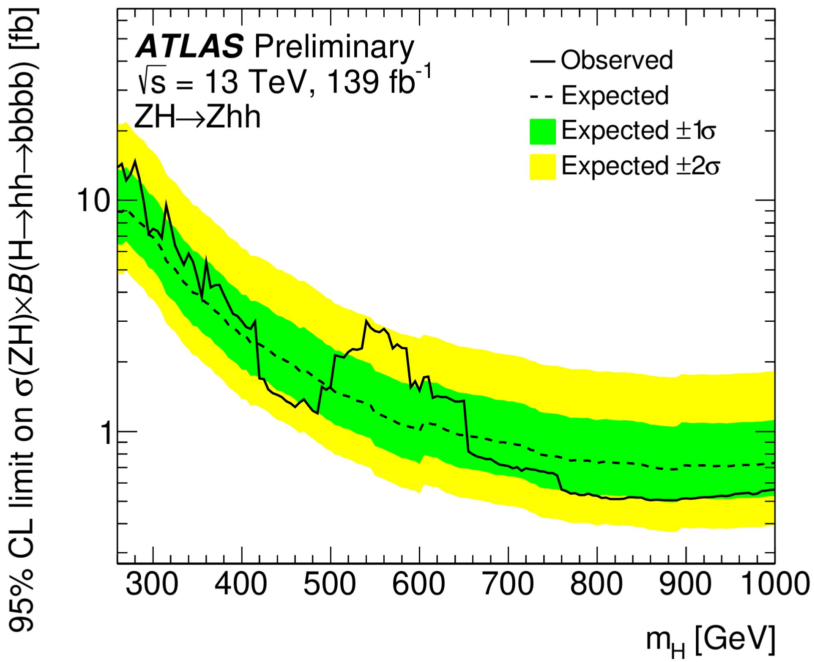


VH, H→hh results

ATLAS-CONF-2022-043

- No significant excess.
- Largest deviation
  - WH at 315 GeV: local (global) significance 2.5 (1.3) σ.
  - ZH at 550 GeV: local (global) significance 2.7 (1.3) σ.





A→ZH, H→hh results

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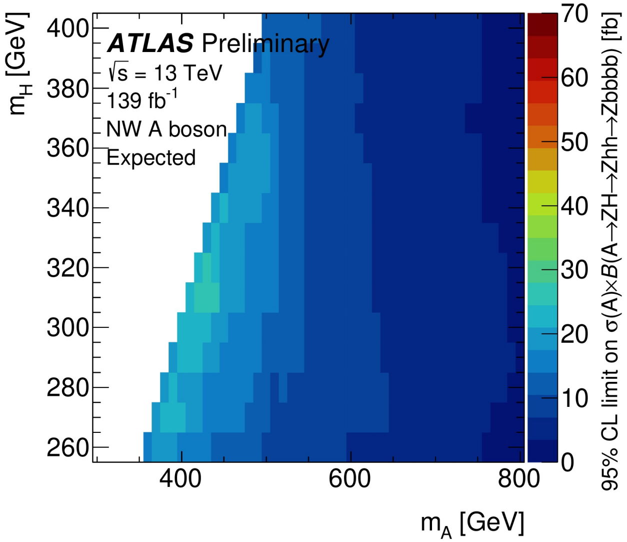
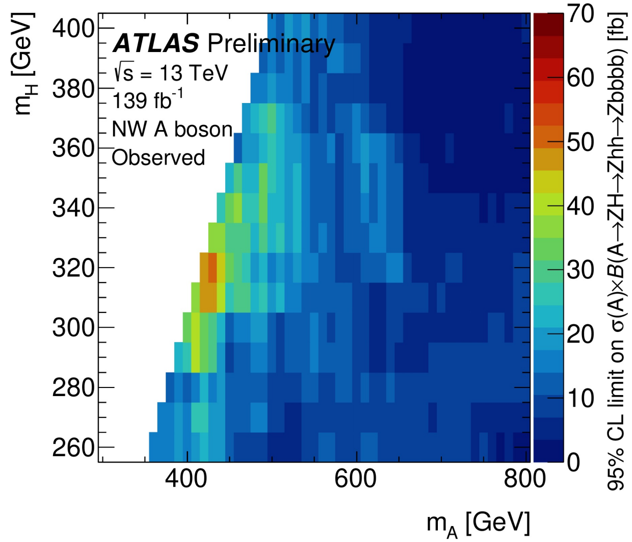
Expected

Observed





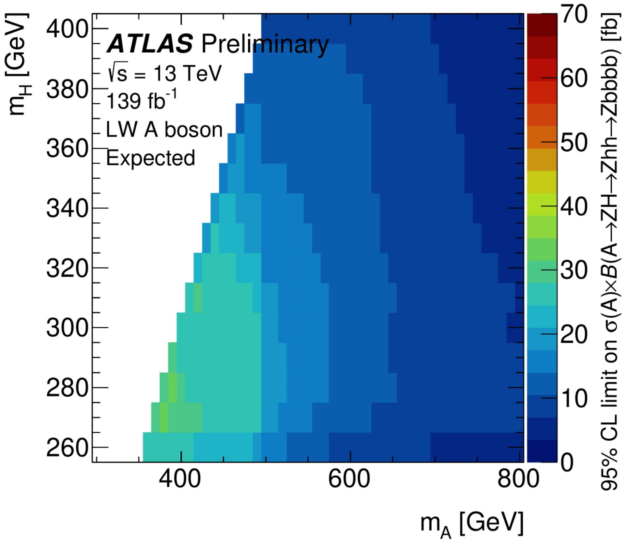
Narrow-width A boson

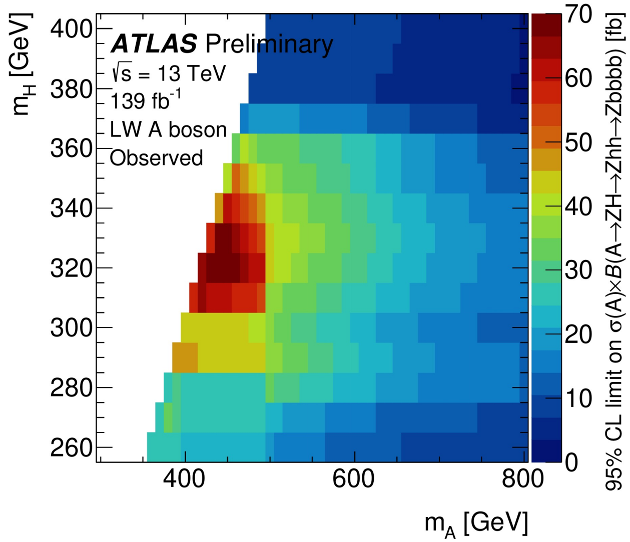
Largest deviation:

$(m_A, m_H) = (800, 300)$

Local: 3.6 σ

Global: 1.6 σ





Large-width (20%) A boson

Largest deviation:

$(m_A, m_H) = (420, 320)$

Local: 3.8 σ

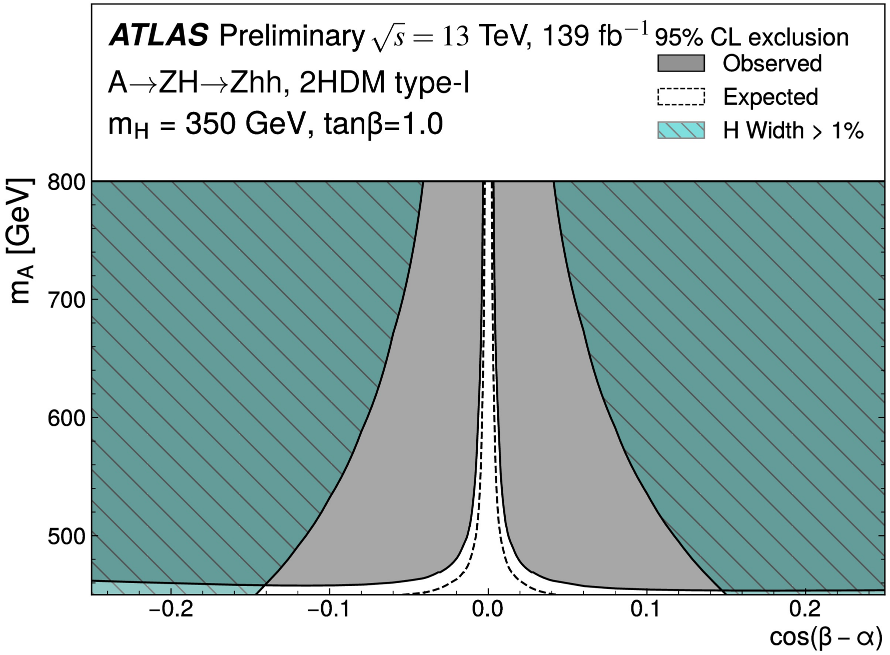
Global: 2.8 σ

2HDM interpretation of A→ZH limits

NEW

ATLAS-CONF-2022-043

- The A→ZH results are interpreted as constraints in the 2HDM parameter space.
  - m_A – mass of the A boson.
  - m_H – mass of the heavy H boson.
  - tanβ – ratio of the vacuum expectation values of the two doublets.
  - cos(β−α) – with α as the mixing angle of H and h.



- The limits are only valid for the parameter space where H width < 1%.
- In the limiting case of cos(β−α) → 0, the h boson has SM-like coupling and the Hhh coupling vanishes, reflected by the inability to exclude this region.

2HDM interpretation of A→ZH limits

NEW

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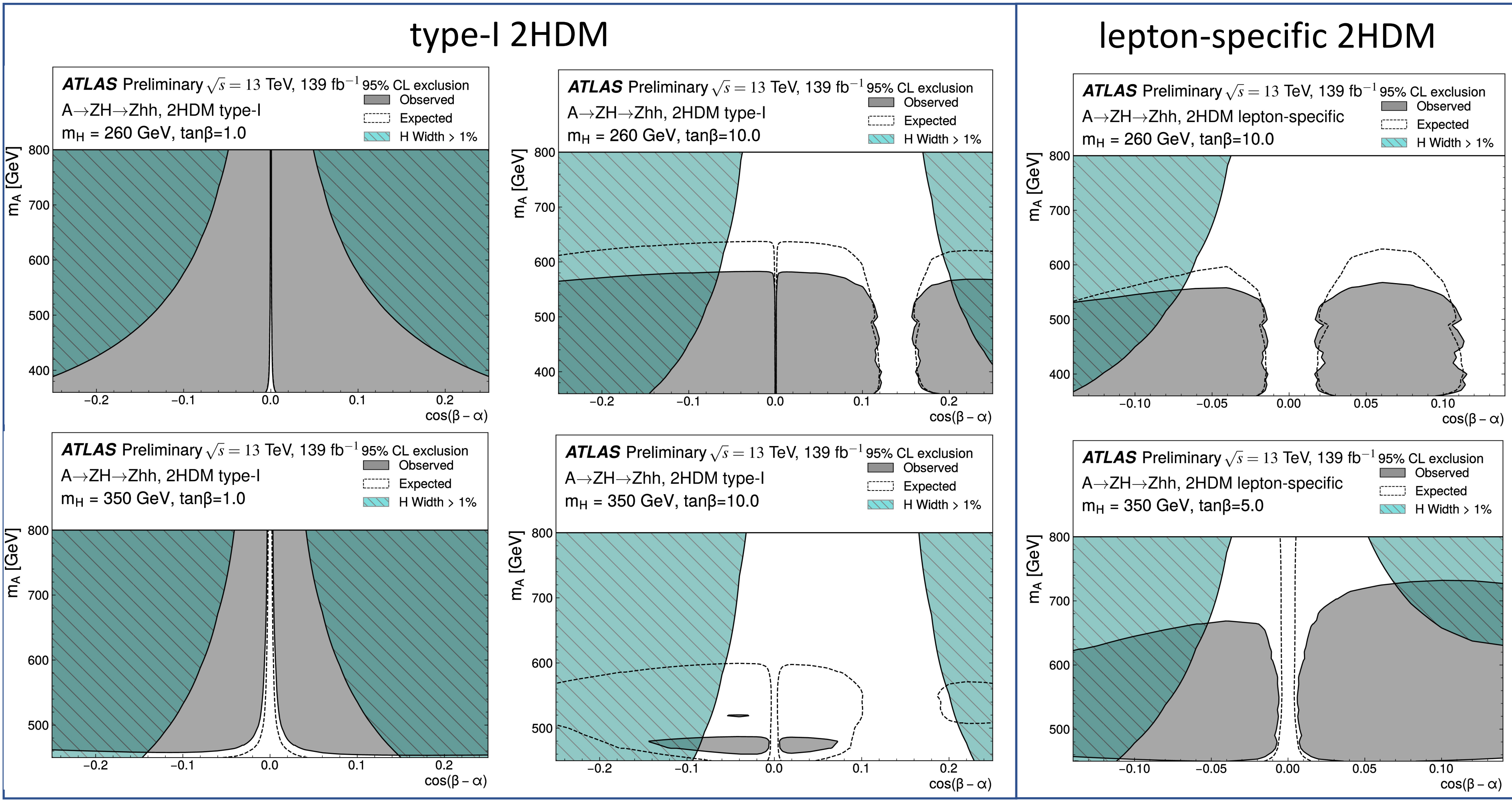
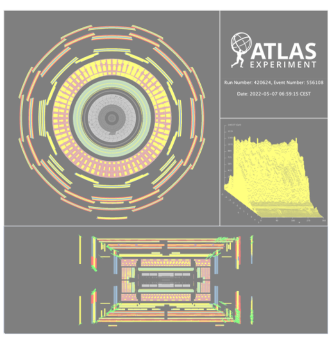


- Limits are interpreted on the cos(β−α) – m_A plane for different m_H and tanβ.
- For tanβ=1 the sensitivity is the same for both scenarios.

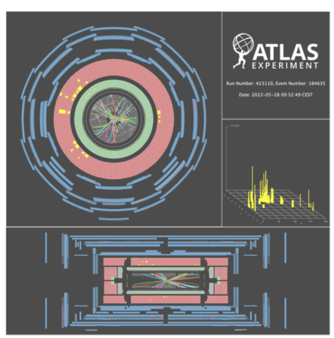
Summary and outlook

- Searches for new resonances decaying to di-Higgs are performed with full Run2 dataset in ATLAS, exploiting various final states:
  - bbγγ, bbττ and bbbb channels are combined to provide full coverage of constraints over mass range 251 GeV – 3 TeV on spin-0 scalar X.
  - Vhh channel is explored for the first time, setting limits on generic VH(hh) and 2HDM specific A→ZH(hh) productions
- In general, the data are found to be in good agreement with SM. Strong constraints are established.
  - More data is needed to pin down the nature of a few excess.

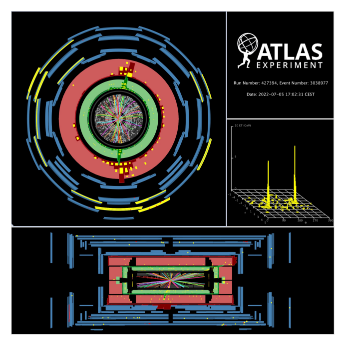
Run3 physics data is around the corner:
Stay tunned for more data and more existing results!



Run3 beam splashes
(07 May 2022)



Run3 900 GeV test collisions
(28 May 2022)



Run3 13.6 TeV collisions
(05 July 2022)