Prague in 1835 by Vincenc Morstadt

Searches for resonances decaying to pairs of Higgs bosons in ATLAS

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Introduction

Zoology of Higgs-pair resonance search program at ATLAS

- New particles in many BSM theories
  - no fine tuning of model choice and its parameters
  - generic spin-0 scalar in narrow-width approximation
  - Kaluza-Klein spin-2 graviton in Randall-Sundrum model
- Two Higgs Doublet Model; $X \to HH$
  - second Higgs doublet introduced in the theory
  - a total of 5 Higgs bosons is hence predicted
  - coupling $H \to hh$ allowed with h corresponding to the Higgs boson at 125 GeV
- Two Real Singlet Model; $X \to SH$
  - SM extension with two real scalar singlets
  - a total of 3 Higgs bosons
  - masses not predicted, typical searches focus on $X \to SH$ decay

Outline

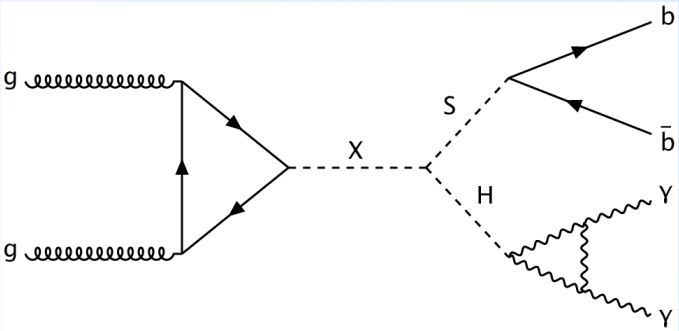
1. $X \to S(\to bb)H(\to \gamma\gamma)$ [submitted to JHEP, arXiv:2404.12915]
2. $X \to S(\to WW/ZZ)H(\to \gamma\gamma)$ [submitted to JHEP, arXiv:2405.20926]
3. $X \to S(\to WW/ZZ)H(\to \tau\tau)$ [JHEP 10 (2023) 009]
4. VBF HH $\to$ 4b [submitted to Phys. Lett. B, arXiv:2404.17193]
5. $X \to HH$ combination [Phys. Rev. Lett. 132 (2024) 231801]

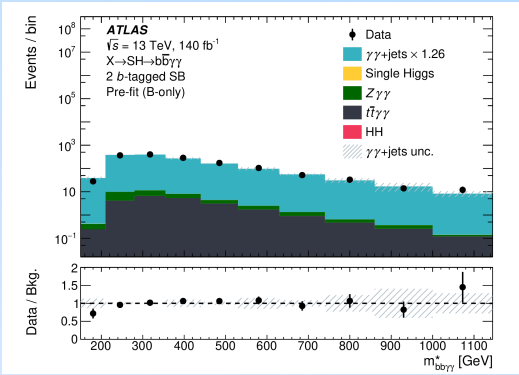
$$\underline{X \to S(\to bb)H(\to \gamma\gamma)}$$

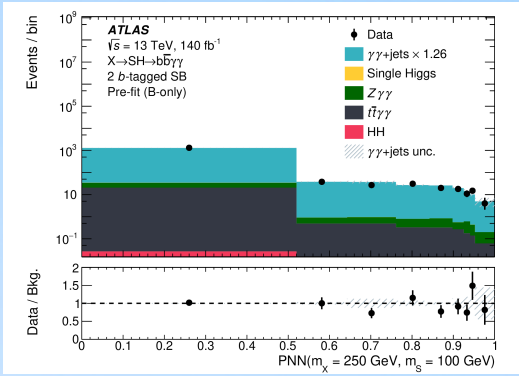
[submitted to JHEP, arXiv:2404.12915]

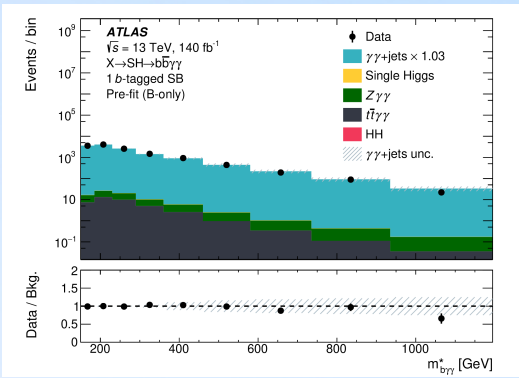
$X \to S(\to bb)H(\to \gamma\gamma)$

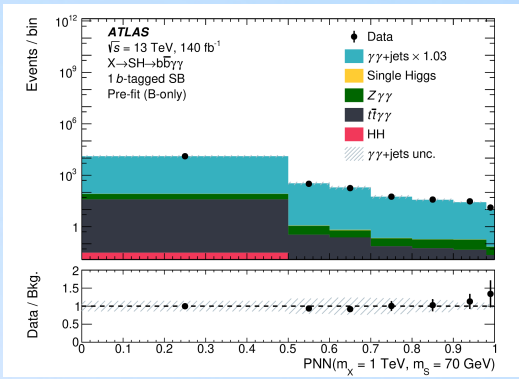
- resonant production of heavy scalar X
- number of b-tagged jets to categorise events into two SRs
- events in the SRs also required to satisfy $120 < m_{\gamma\gamma} < 130$ GeV
- parametrised neural networks to provide continuous sensitivity in the (m_X, m_S) plane
- maximum likelihood fit on the binned PNN output distribution







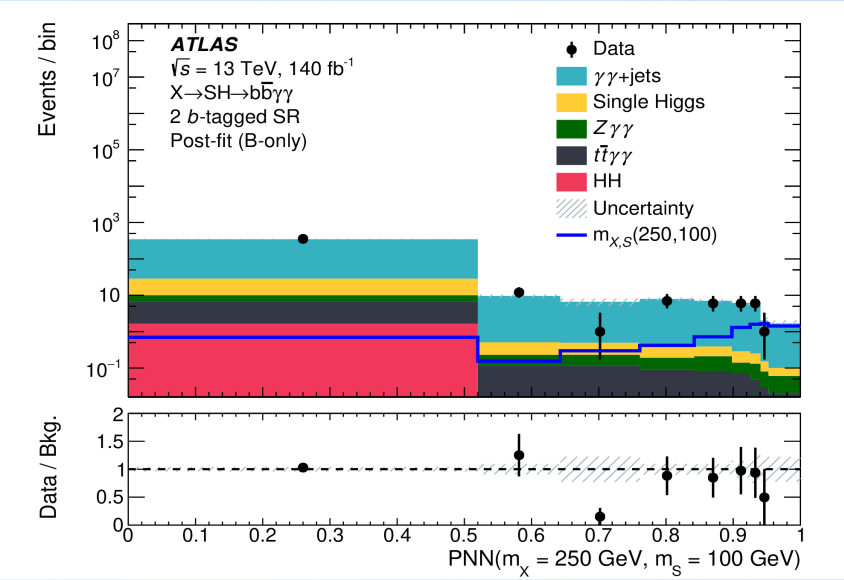


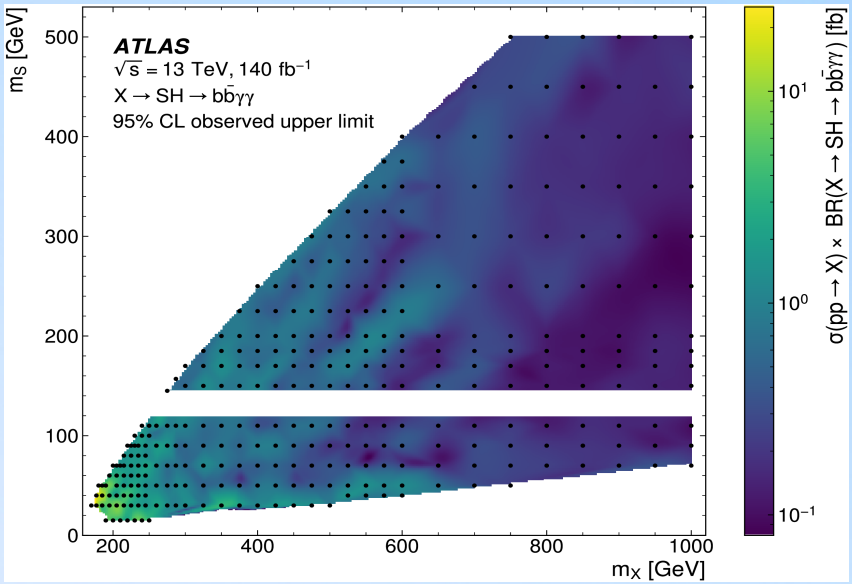


$$m^*_{bb\gamma\gamma} = m_{bb\gamma\gamma} - (m_{\gamma\gamma} - 125\ \text{GeV})$$

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

Results





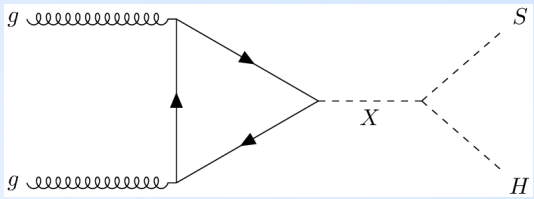
- 95% CL upper limits on $\sigma(pp \to X) \times \mathcal{B}(X \to SH \to bb\gamma\gamma)$
- limits ranging from 38 fb to 0.09 fb

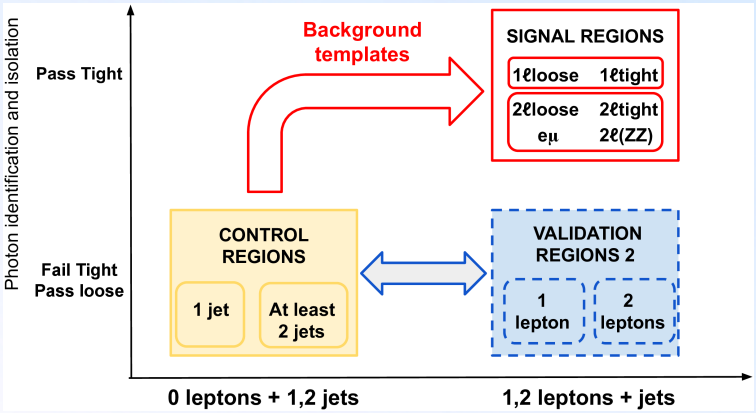
$$\underline{X \to S(\to WW/ZZ)H(\to \gamma\gamma)}$$

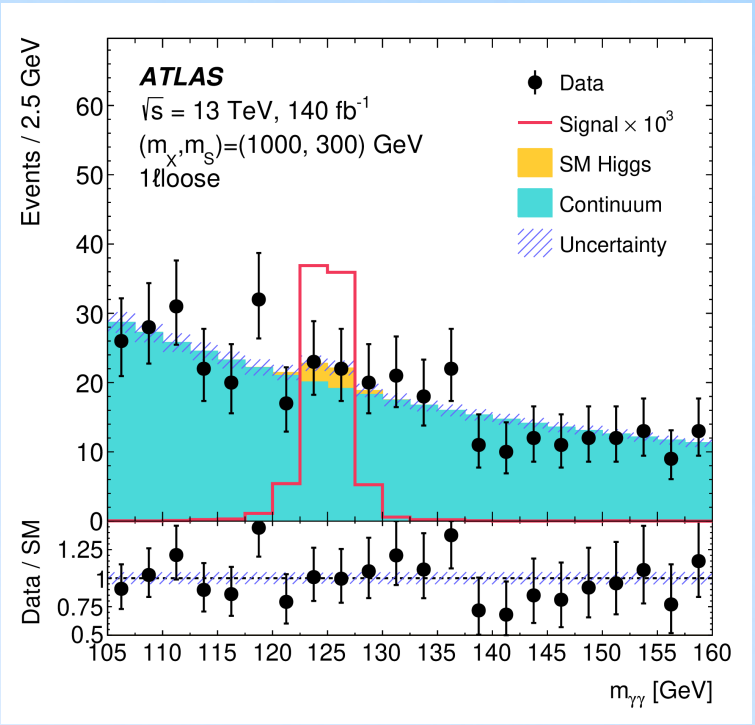
[submitted to JHEP, arXiv:2405.20926]

$X \to S(\to WW/ZZ)H(\to \gamma\gamma)$

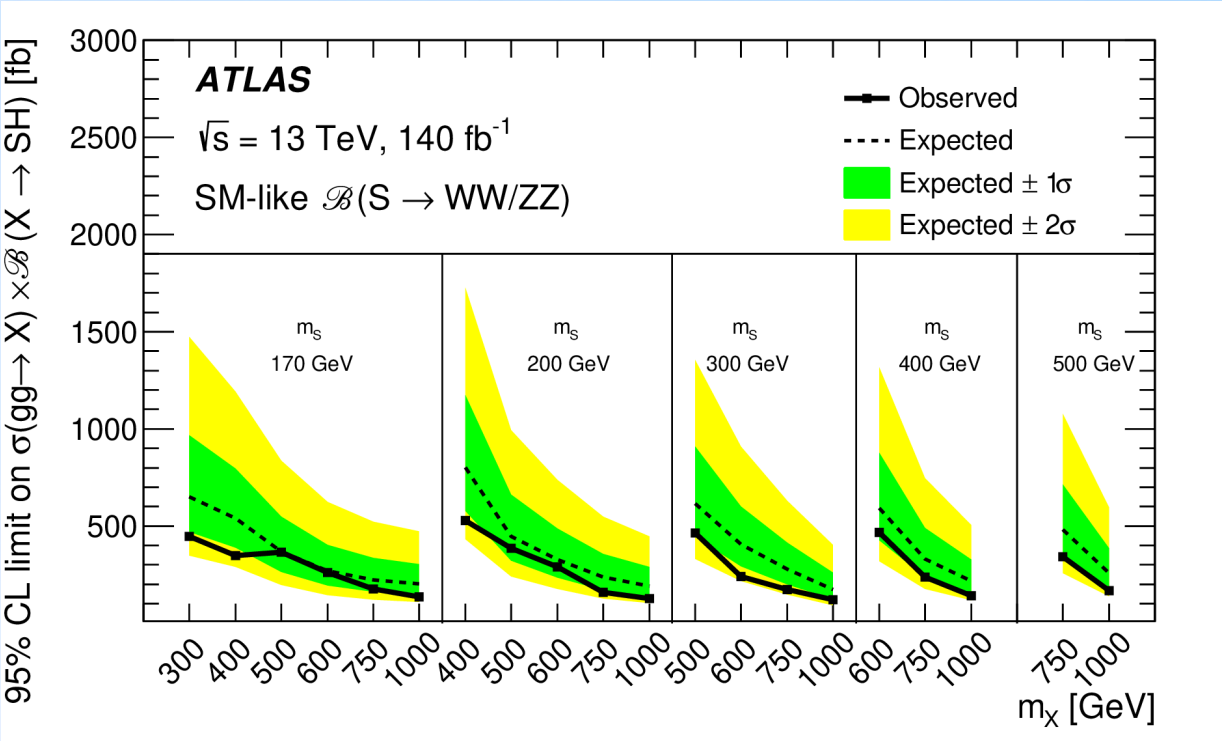
- signature 1 or 2 leptons, e or μ, and photons
- binned likelihood fit in six $m_{\gamma\gamma}$ SRs defined with 1 ℓ tight, 1 ℓ loose, 2 ℓ tight, 2 ℓ loose, $e\mu$, 2ℓ







Results



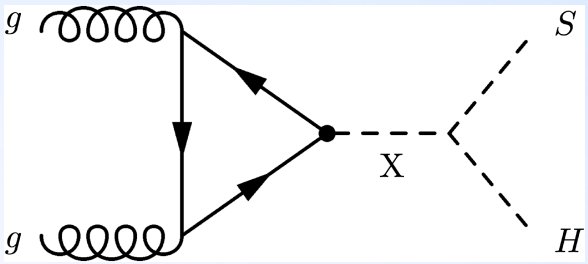
- 95% CL upper limits on $\sigma(gg \to X) \times \mathcal{B}(X \to SH)$ under the assumption of SM-like branching ratios for $S \to WW/ZZ$
- limits also presented under the assumptions of $\mathcal{B}(S \to WW) = 100\%$ and $\mathcal{B}(S \to ZZ) = 100\%$

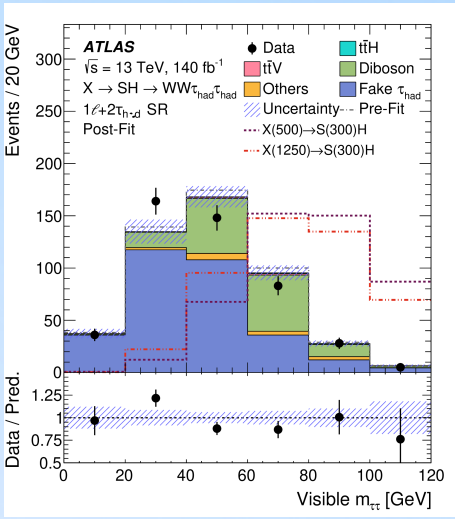
$$\underline{X \to S(\to WW/ZZ)H(\to \tau\tau)}$$

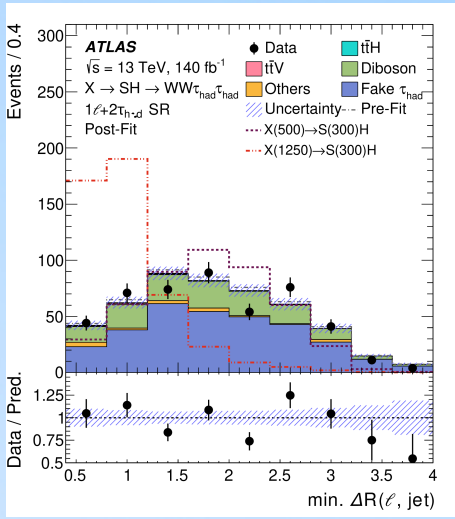
[JHEP 10 (2023) 009]

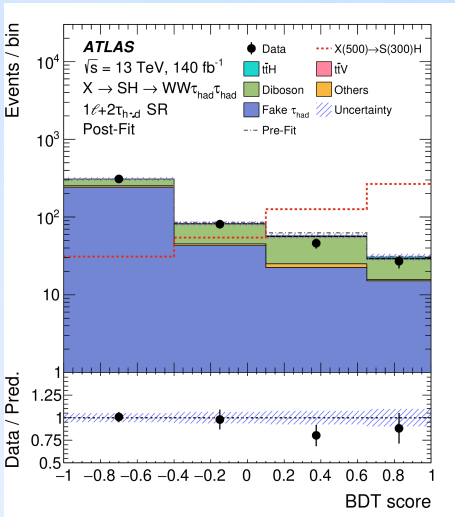
$X \to S(\to WW/ZZ)H(\to \tau\tau)$

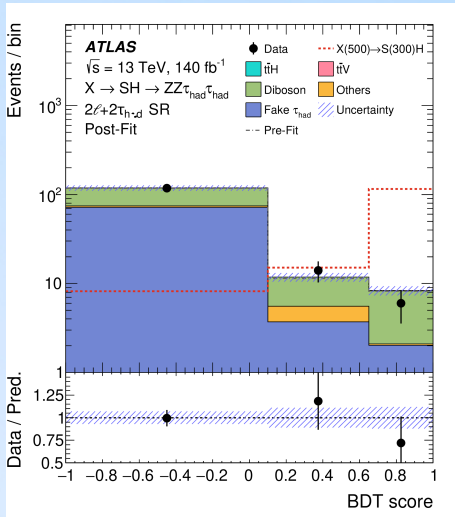
- two hadronically-decaying tau leptons and one or two light leptons
- three signal regions according to number of light leptons and m_{ll}, $WW1\ell2\tau_{had}$, $WW2\ell2\tau_{had}$, $ZZ2\ell2\tau_{had}$
- BDTs to separate signal and background with m_X provided as input parameter and assigned randomly for background
- binned likelihood fit on a BDT score trained on 14 event-based observables





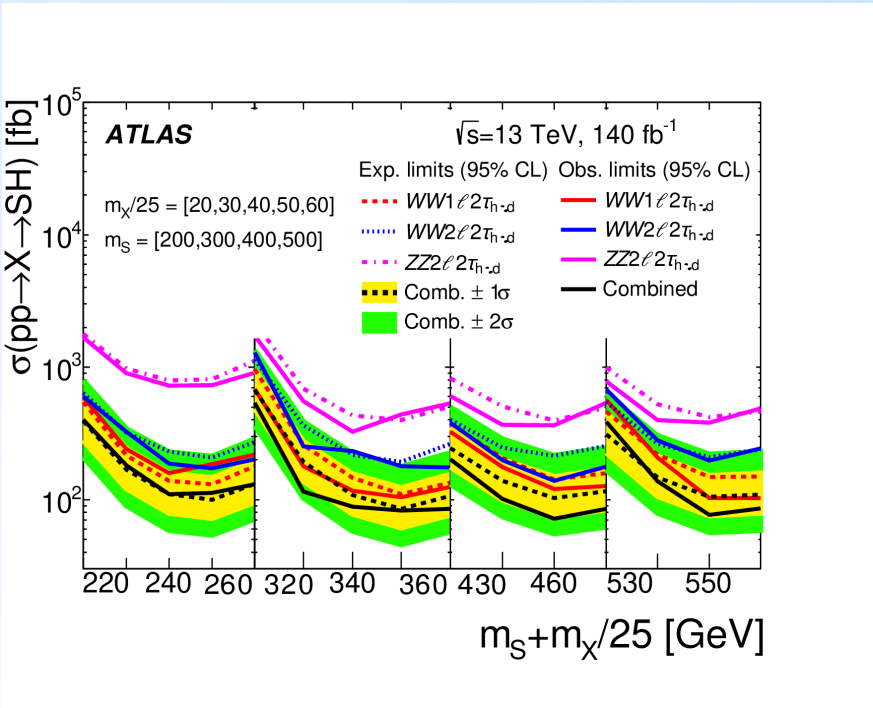


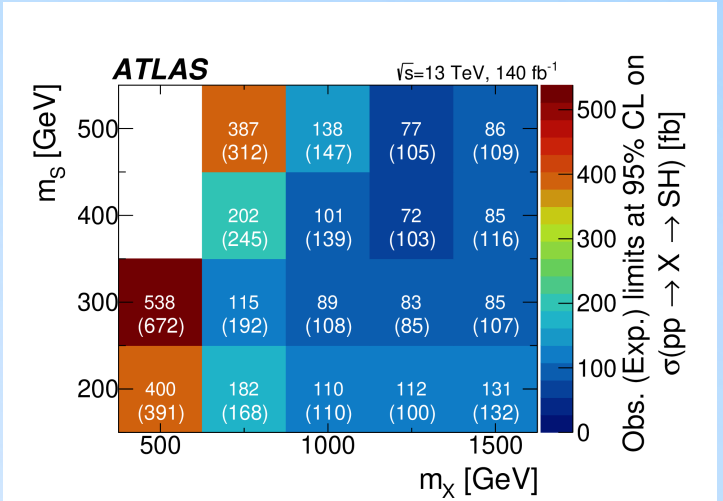


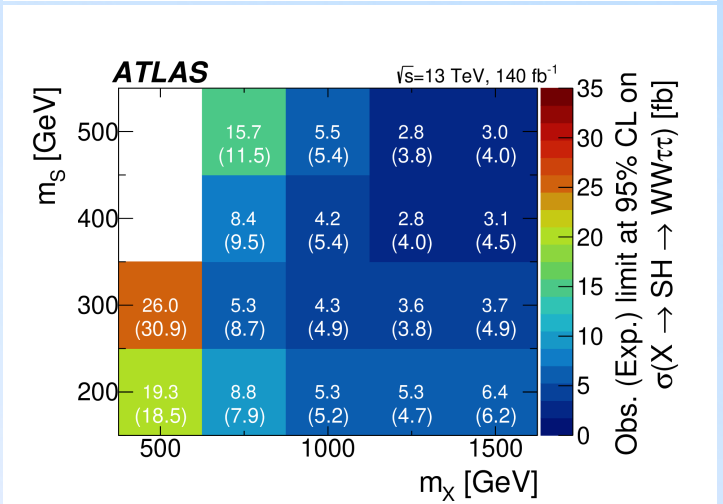


Results

- 95% CL upper limits on $\sigma(pp \to X \to SH)$ for the three channels and their statistical combination
- limits in the 72 – 542 fb range





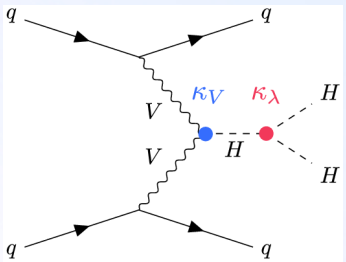


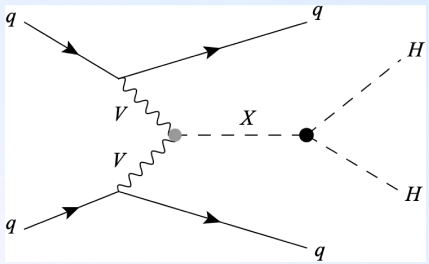
VBF HH $\rightarrow$ 4b

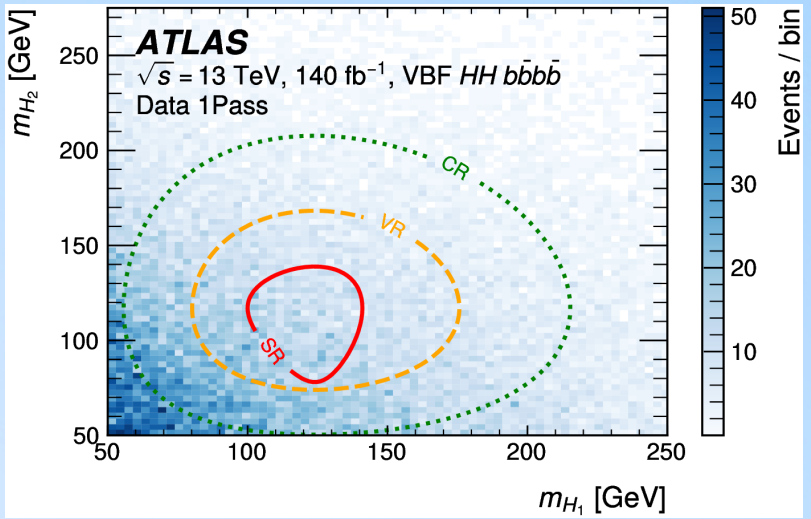
[submitted to Phys. Lett. B, arXiv:2404.17193]

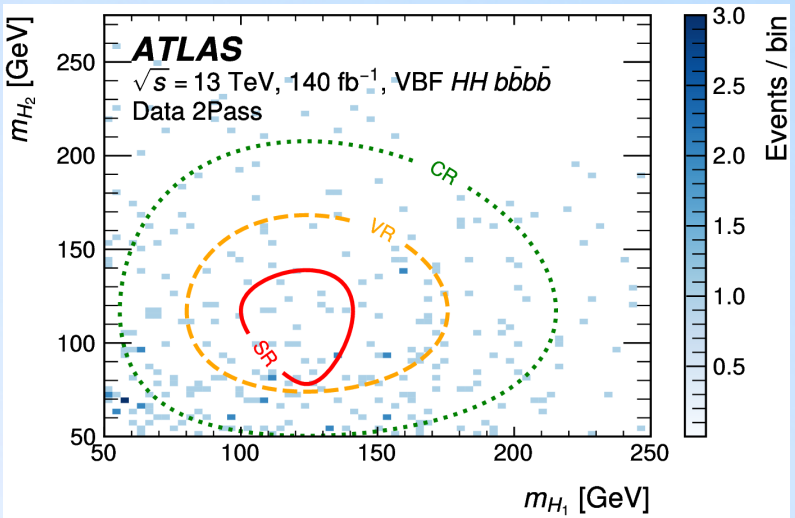
VBF HH $\rightarrow$ 4b

- various non-resonant diagrams considered in addition, and for the first time, to the resonant production mode
- analyses targeting the boosted regime
- CRs, VRs and SRs defined in the 2D Higgs boson mass planes
- 1Pass and 2Pass selections based on one or two of the leading large-R jets tagged as containing two b-jets
- binned maximum likelihood fit on a mass-parametrised BDT output that discriminates signal events from background









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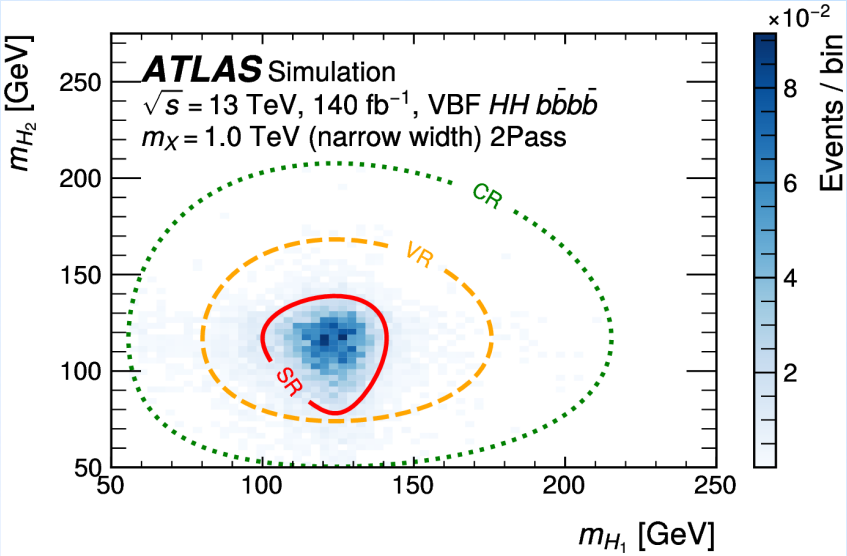
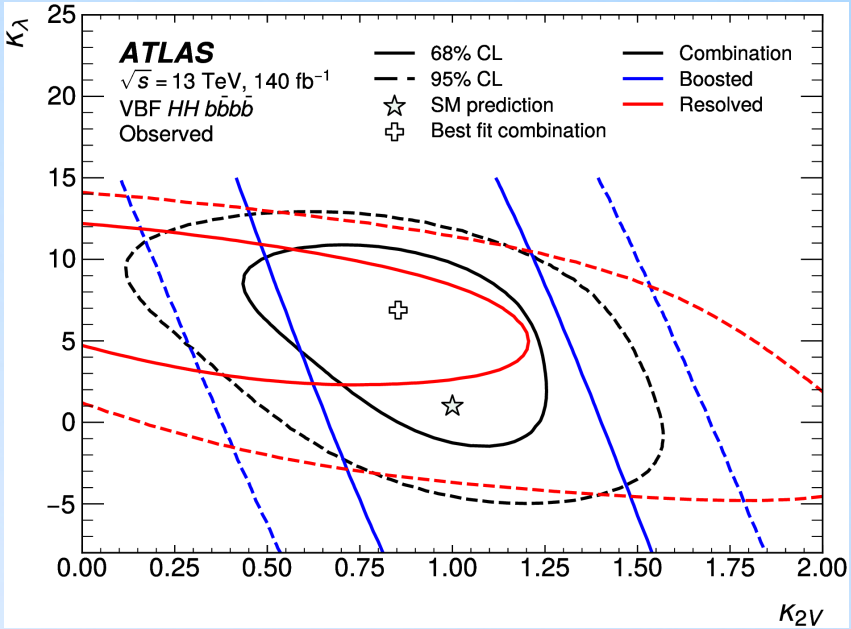
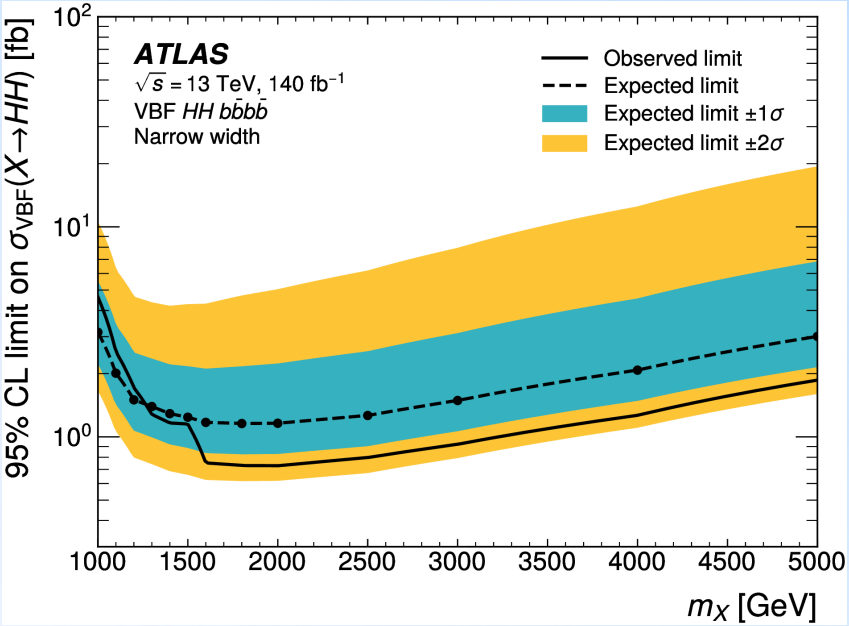
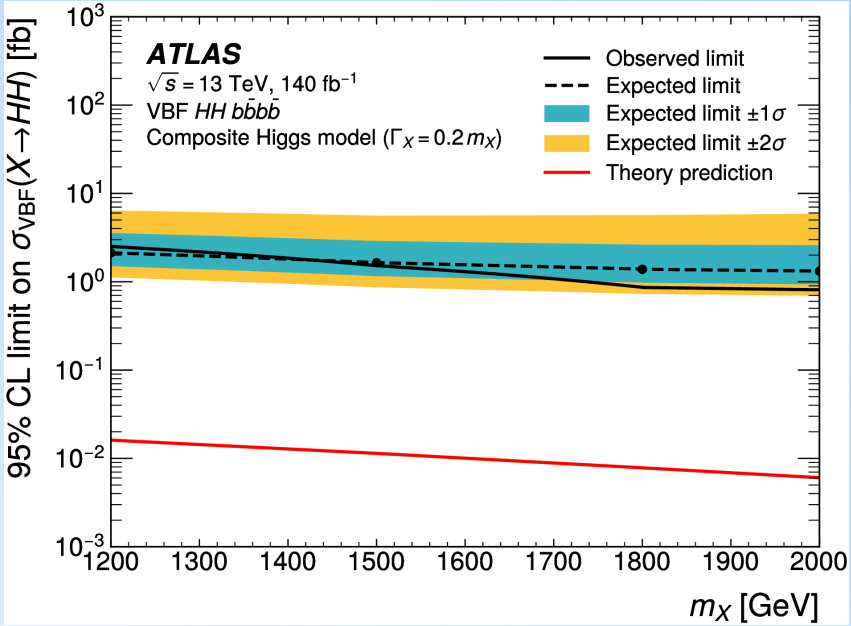




- Likelihood contours at 68% and 95% CL in the $k_\lambda - k_{2V}$ plane
- resolved, boosted and combined all shown

Results



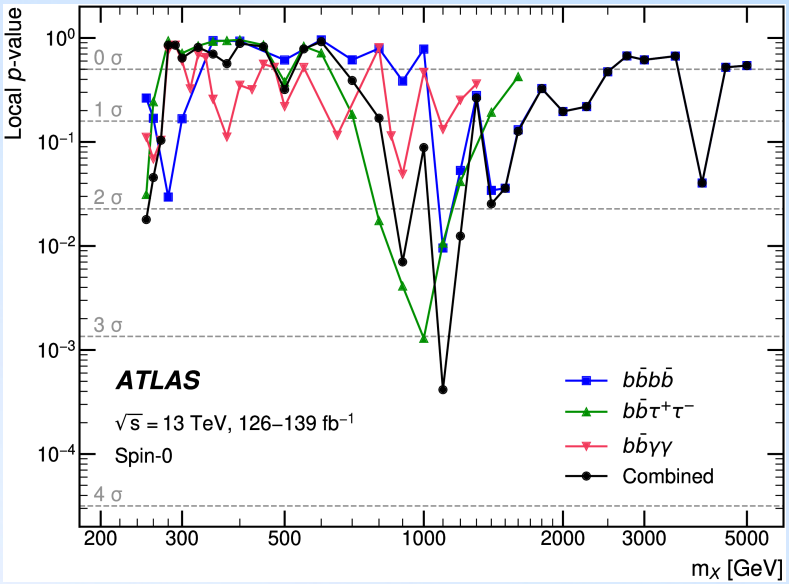


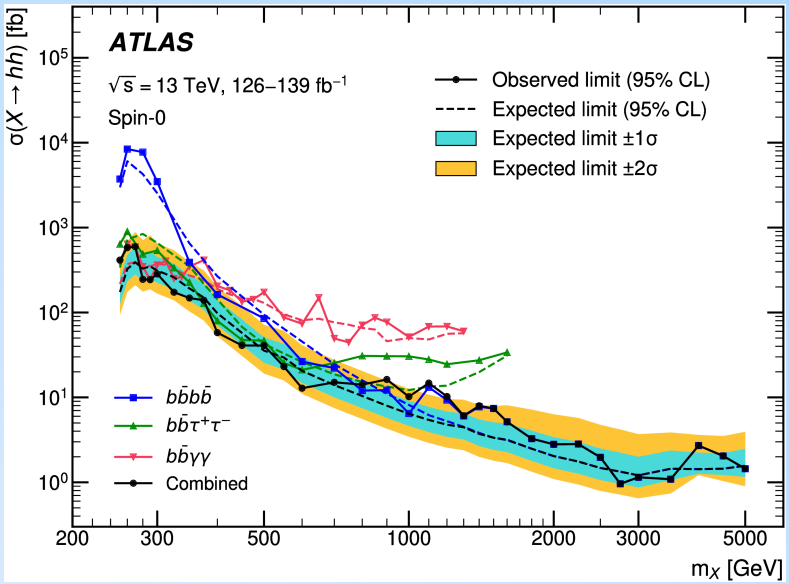
- 95% CL upper limits on spin-0 heavy resonance cross-section with narrow-width and broad-width approximations and assuming the SM $H \to bb$ branching ratio
- theoretical prediction is for the Composite Higgs Model at leading order

$X \to HH$ combination

[Phys. Rev. Lett. 132 (2024) 231801]

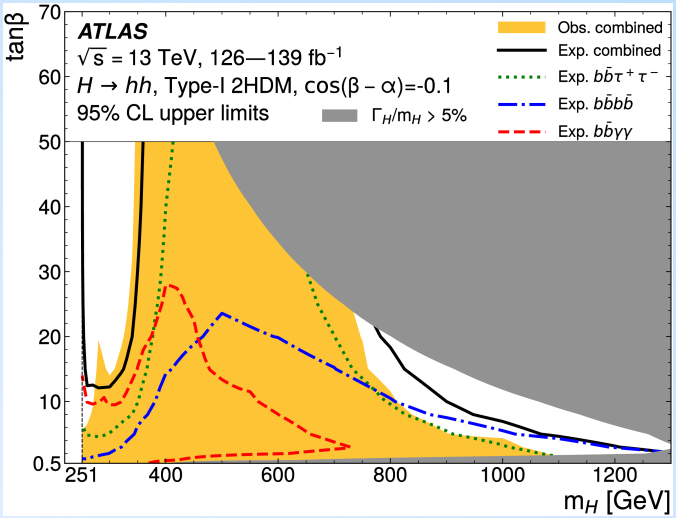
$X \to HH$ combination

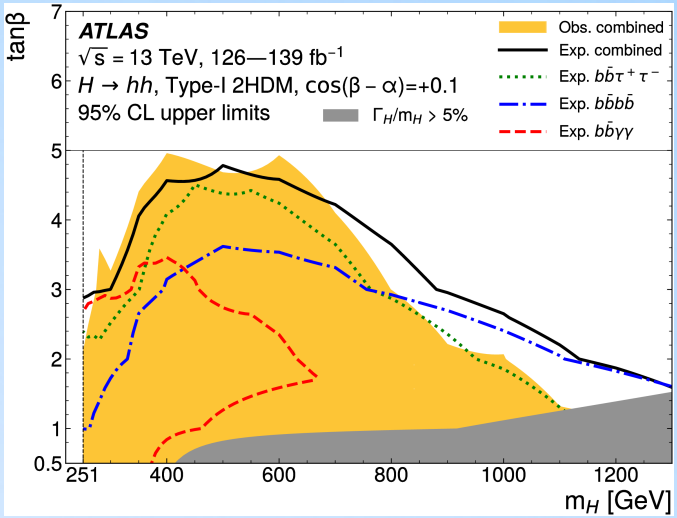


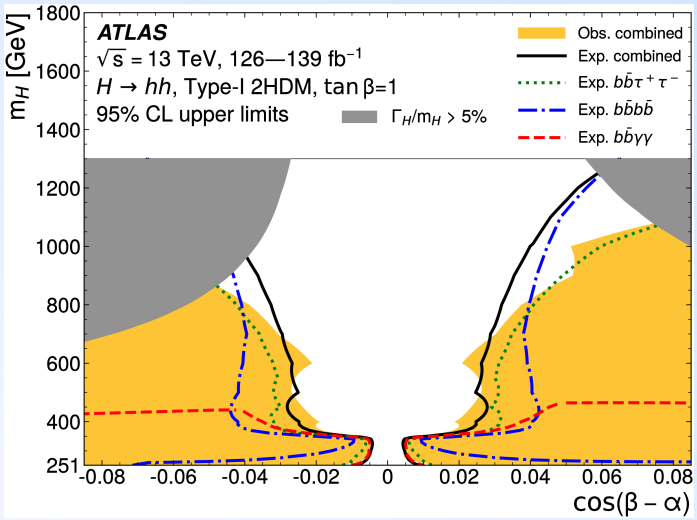


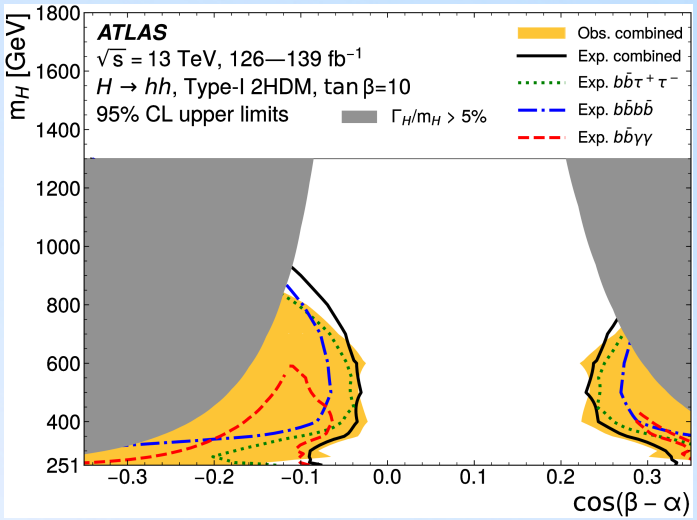
- combination of $bb\gamma\gamma$, $bb\tau\tau$ and $4b$ channels with full Run-2 data
- each channel contributing the most at different resonance masses
  - $bb\gamma\gamma$ until $m_X \lesssim 350$ GeV, $bb\tau\tau$ in $350 \lesssim m_X \lesssim 800$ GeV, $4b$ for $m_X \gtrsim 800$ GeV

Exclusion in the 2HDM parameter space









- 95% CL limit on the Type-I 2HDM parameter space

Conclusions

Wide experimental program targeting Higgs boson pairs

- both resonant and non-resonant
- improvements in object reconstruction and identification is as important as getting more data
- many decay channels being investigated with the full Run-2 dataset
- individual analysis on full Run-2 dataset yields better results compared to combined analyses with partial Run-2 dataset

Run-2 search program keeps going together with first analyses on Run-2 + Run-3 data!

THANK YOU FOR YOUR ATTENTION !

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