Search for a resonance decaying into a scalar particle and a Higgs boson in the final state with two bottom quarks and two photons in proton-proton collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

Maxime Fernoux on behalf of the ATLAS Collaboration
Aix-Marseille University / CNRS / CPPM

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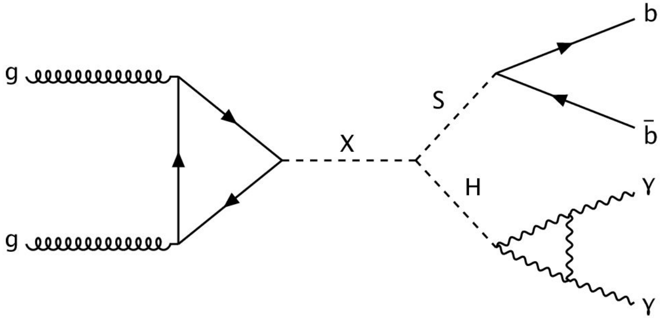
Theory context

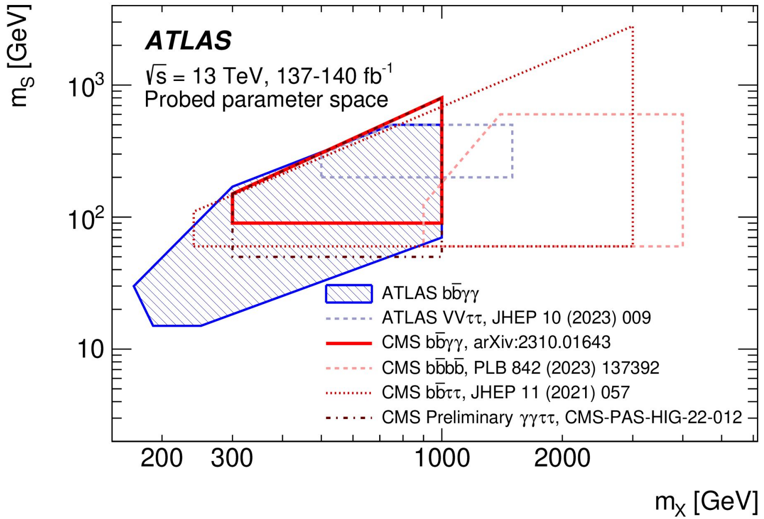
- The Higgs sector is a hot spot to find Beyond Standard Model physics
  It could be extended by additional scalar bosons

- In this analysis, we look for an asymmetric $X \to SH$ decay (where H is the SM Higgs boson) with $S \to bb$ and $H \to \gamma\gamma$
  Some models predict this phenomenology
  → SM extension with two real or a complex singlet
  → Complex 2HDM, NMSSM, 2HDM+S …



- Model-independent research
  → set limits on production cross-section times BR
  Use the narrow width approximation
  (Γ_S , Γ_X << m_{bb}, $m_{bb\gamma\gamma}$ experimental resolutions)

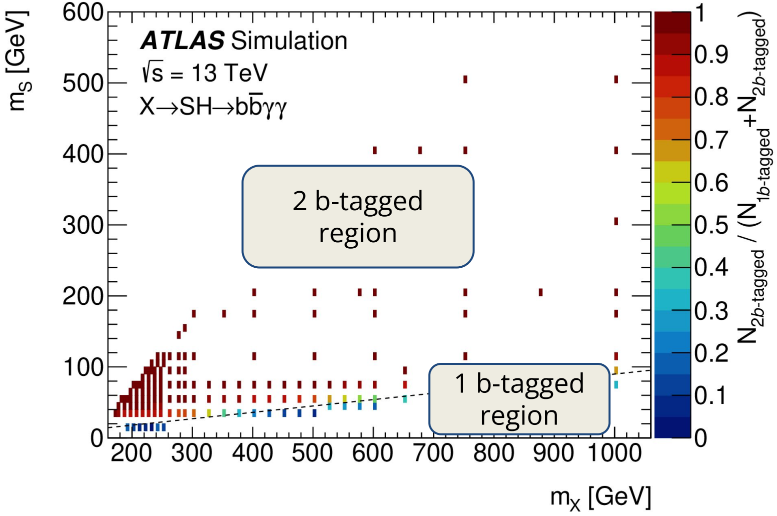
- Experimentally probed region :
  $170 \leq m_X \leq 1000$ GeV and $15 \leq m_S \leq 500$ GeV



Event selection

- Full ATLAS Run-2 dataset with 140 fb^{-1} of *p-p* collisions at 13 TeV is used
  Main trigger : diphoton trigger - events with E_T > 35 (25) GeV for the leading (subleading) photon

- Event selection :
  - Two '*Tight*' reconstructed and isolated photons with 105 < $m_{\gamma\gamma}$ < 160 GeV and p_T > 0.35 (0.25) $m_{\gamma\gamma}$ for the leading (subleading) photon → target $H \rightarrow \gamma\gamma$ decay
  - No lepton and between 2 and 5 jets with |η| < 2.5 → reduce *ttH* background
  - One or two *b*-tagged jets at the 77% *b*-tagging efficiency working point



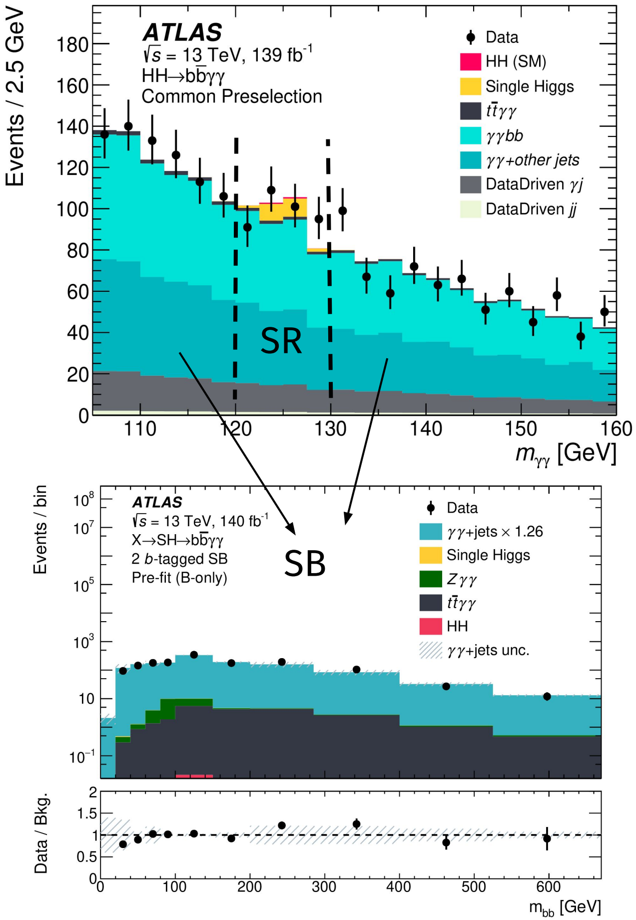
- When $m_S << m_X$, the *b*-jets from $S \rightarrow bb$ decay will be reconstructed as only one jet
  → Two signal regions are defined
  - 'Merged' region with **exactly one *b*-tagged jet**
  - 'Resolved' region with **exactly two *b*-tagged jets**

Analysis strategy

- Main backgrounds :
  Non resonant $\gamma\gamma$+jets (including photons misidentified as jets)
  Resonant single or di-Higgs - same $H \rightarrow \gamma\gamma$ decay as signal : *ttH*, ggF *H*, *ZH* and also VBF *H* in the 1 *b*-tagged jet region

- $m_{\gamma\gamma}$ distribution defines :
  - A signal region (SR) between $120 < m_{\gamma\gamma} < 130$ GeV
  - Control region sidebands (SB)
    $\rightarrow$ used to correct the $\gamma\gamma$+jets normalization and check data - Monte-Carlo agreement

- Theoretical and $\gamma\gamma$+jets modelisation systematic uncertainties are taken into account on top of experimental ones



Signal - background discrimination

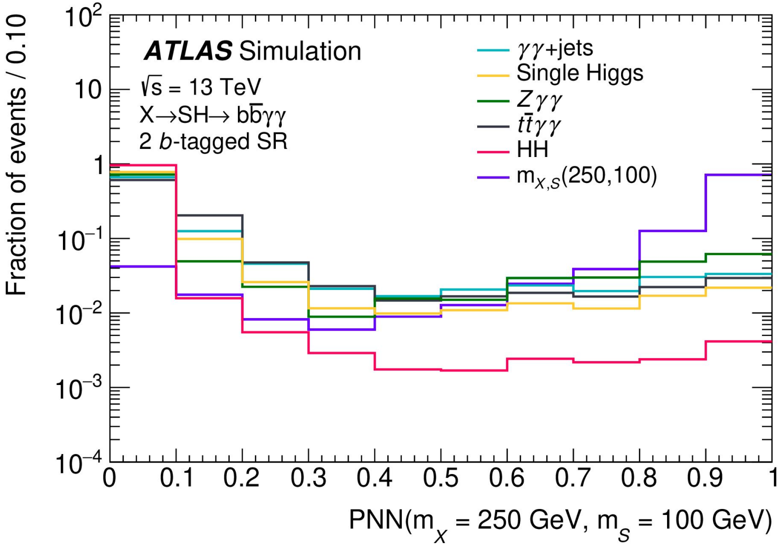
- Parameterized neural networks (PNN) are used to discriminate signal from background in the SR
They take a vector of parameters θ as input in addition to the event features x and allow a smooth coverage of the mass space

- One PNN for each search region :
  - 2 *b*-tagged region : $\theta = (m_S, m_X)$, $x = (m_{bb}, m_{bb\gamma\gamma}^*)$
  - 1 *b*-tagged region : $\theta = (m_X)$, $x = (p_T^b, m_{b\gamma\gamma}^*)$

- Training samples :
$\gamma\gamma$+jets, *ttH*, ggF *H*, *ZH* and corresponding region signals. VBF *H* and *HH* are also used in the 1 *b*-tagged region. Training is performed on SR and SB events

- Results are obtained with a binned log-likelihood fit of the PNN distribution

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



NB : different binning used during the fit

Results (1)

- **Local signal observed significance**
  Probed mass points chosen to achieve a good resolution

- Largest excess with respect to the background only hypothesis at (m_X, m_S) = (575, 200) GeV
  Local (global) significance of 3.5 (2.0) standard deviation

- No deviation from background only hypothesis observed for the excess reported by CMS at (m_X, m_S) = (650, 90) GeV
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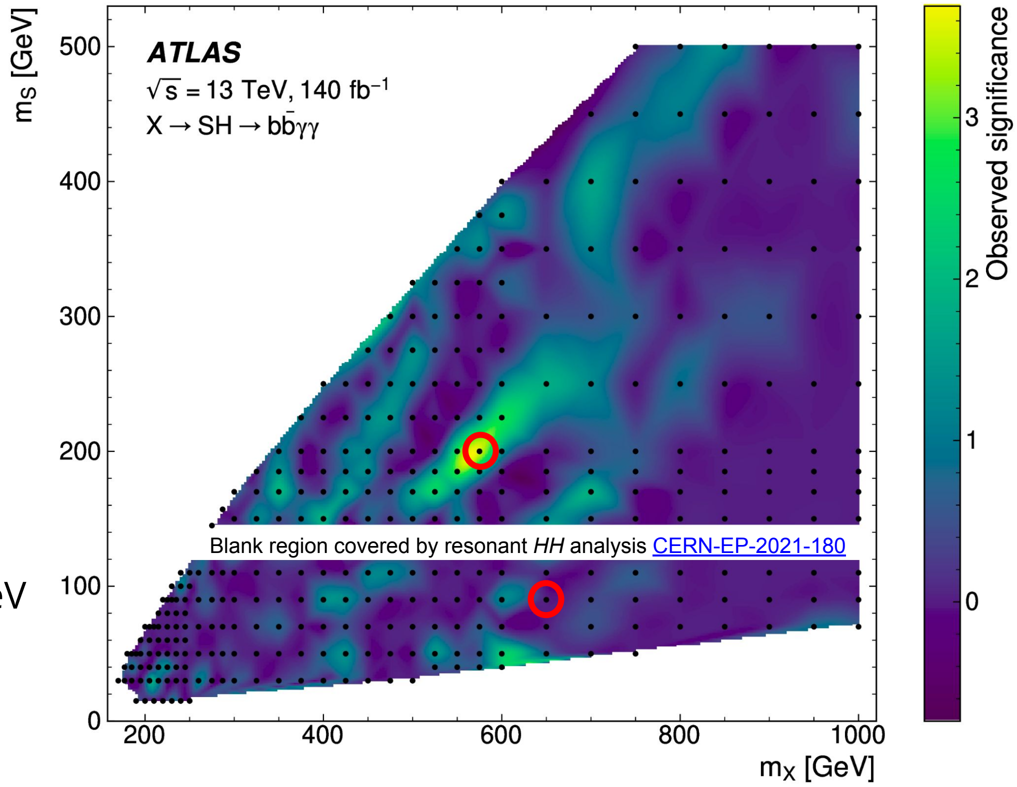
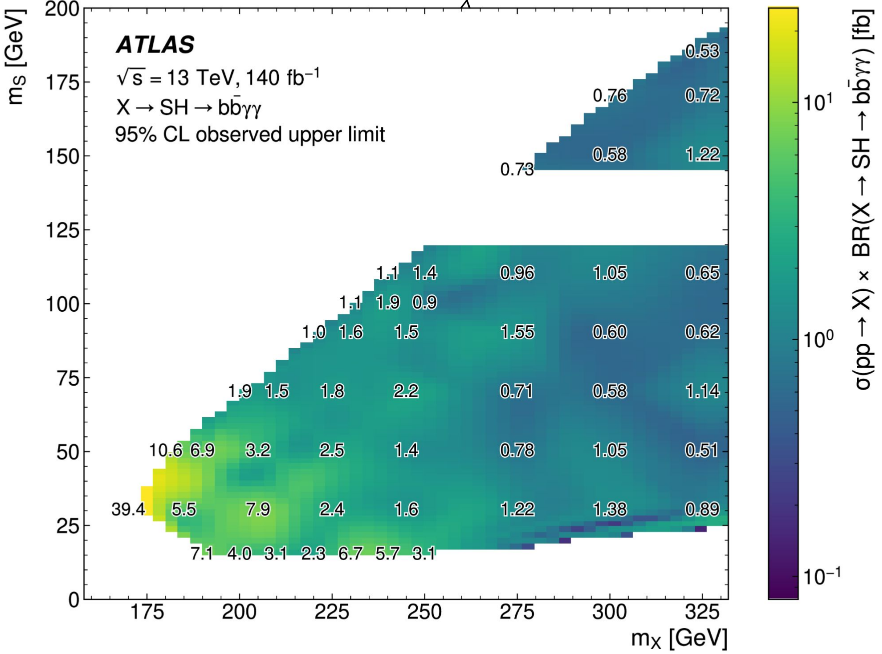


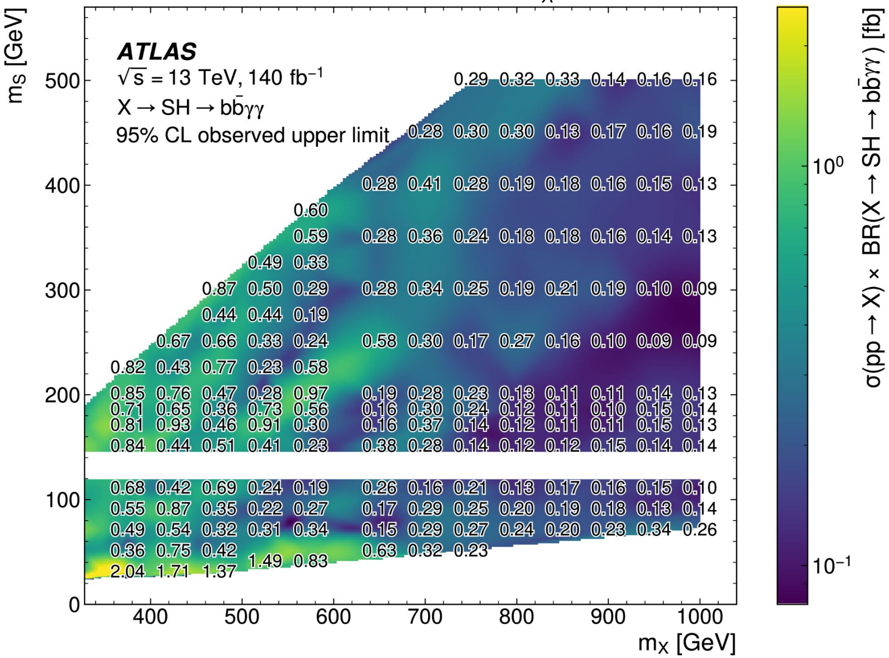
Results (2)

- **Observed limits** on the production cross section times branching ratio to $bb\gamma\gamma$

Limits at low m_X



Limits at high m_X



- Limits range from 0.09 to 39 fb
  Best sensitivity in the high mass region due to a better signal efficiency

Conclusion

- This analysis looks for two potential new scalar bosons in the $X \to SH \to bb\gamma\gamma$ channel
  - The search region is $170 \le m_X \le 1000$ GeV and $15 \le m_S \le 500$ GeV
    $\to$ First analysis to probe low m_S and m_X values thanks to diphoton trigger
  - First usage of PNNs to probe the $bb\gamma\gamma$ final state

- Results show a small deviation from the background only hypothesis for (m_X, m_S) = (575, 200) GeV with a local (global) significance of 3.5 (2.0) standard deviations
  - We report no deviation for the (m_X, m_S) = (650, 90) GeV mass point where CMS observed an excess
- Limits are set on the signal production cross section and decay in the $bb\gamma\gamma$ final state and range from 0.09 to 39 fb
- Analysis submitted to JHEP
  Preprint available : arXiv:2404.12915

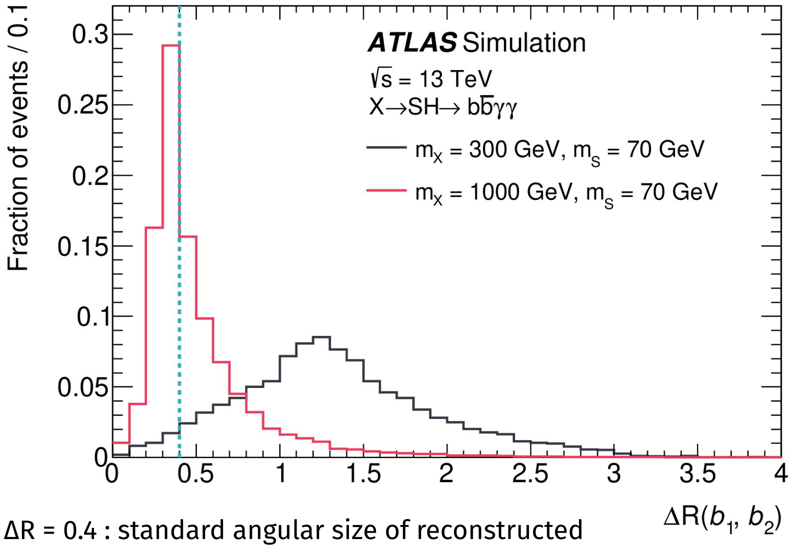
Back-up

Event selection

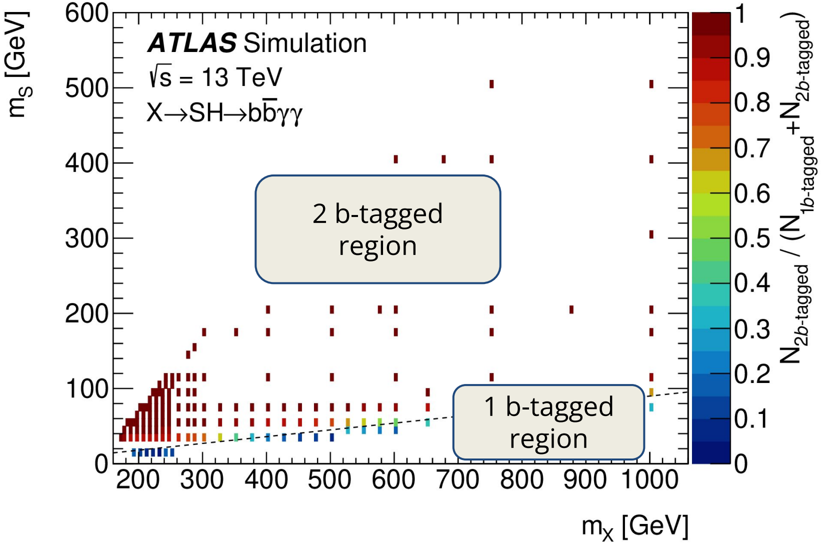
- Photons *Tight* identification and isolation criteria defined here : arXiv:1908.00005
- Flavour tagging algorithm used for *b*-jet tagging is DL1r arXiv:2211.16345

Merged region

- The angular distance between *b*-jets becomes smaller than the jet reconstruction size when $m_S \ll m_X$ (*S* is boosted)

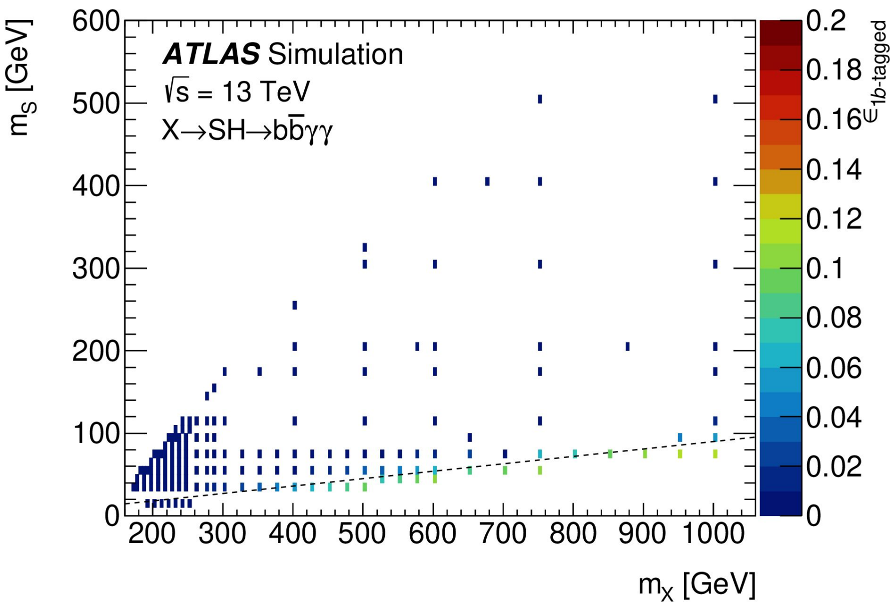


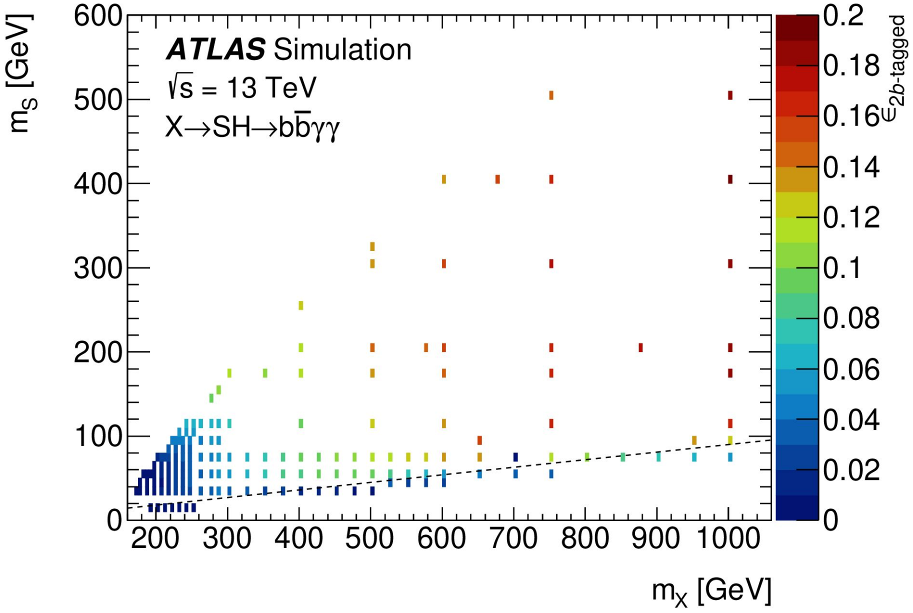
ΔR = 0.4 : standard angular size of reconstructed jets in ATLAS



Signal efficiency

- Signal efficiency in the 1 *b*-tagged (left) and 2 *b*-tagged jet region (right)

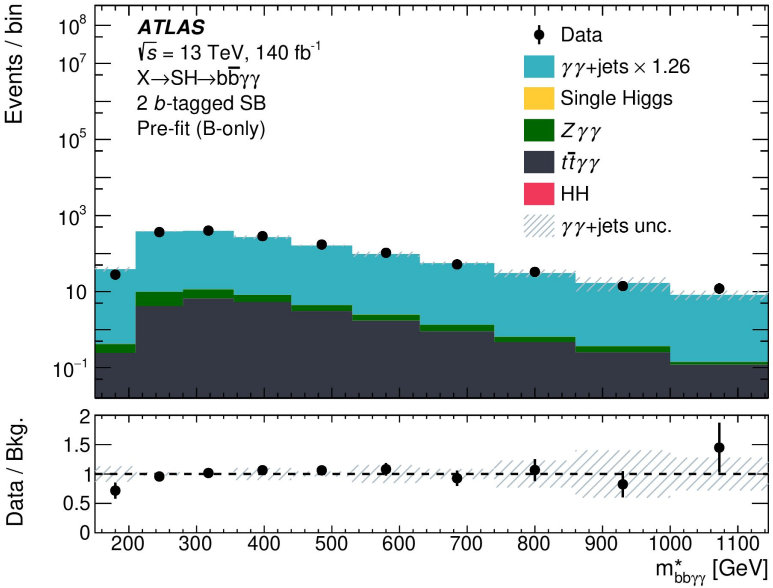




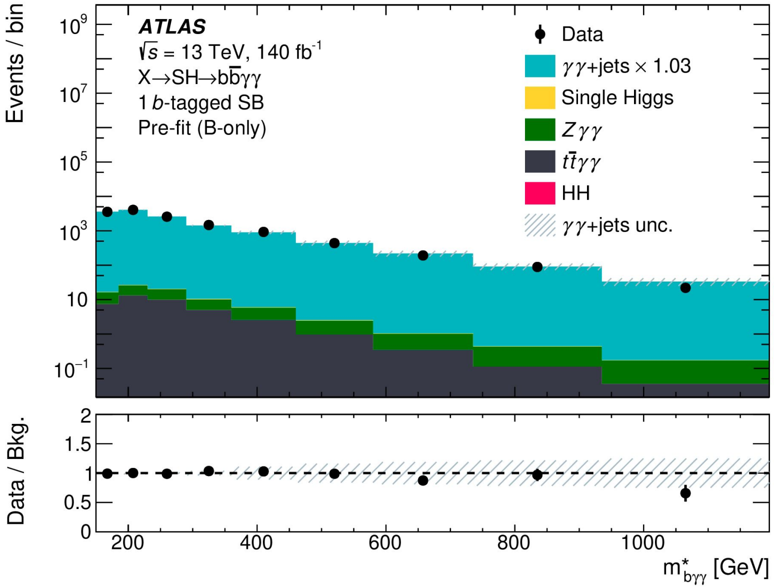
Data - MC agreement

- PNN inputs distribution in sidebands

- m_{bbyy}*



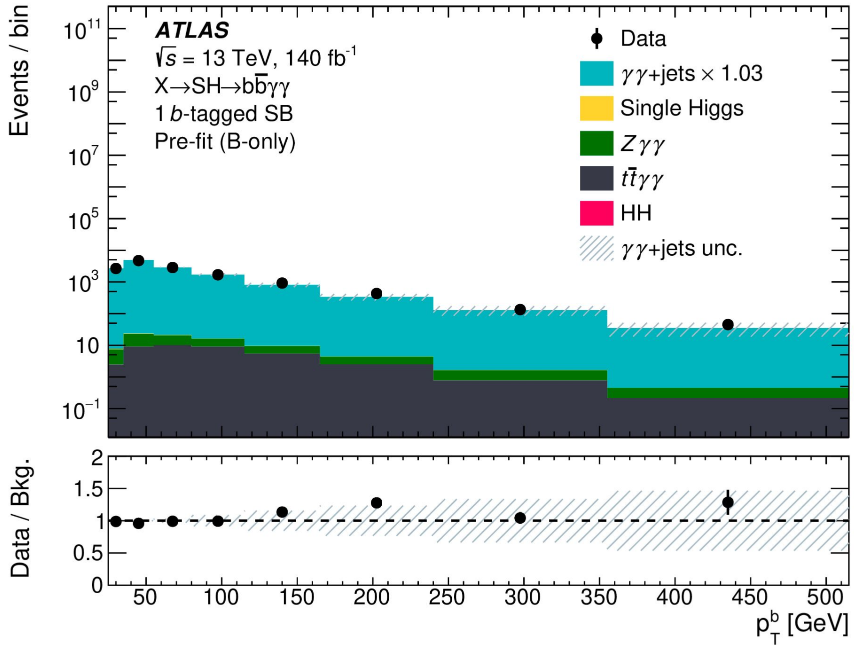
- m_{byy}*



Data - MC agreement

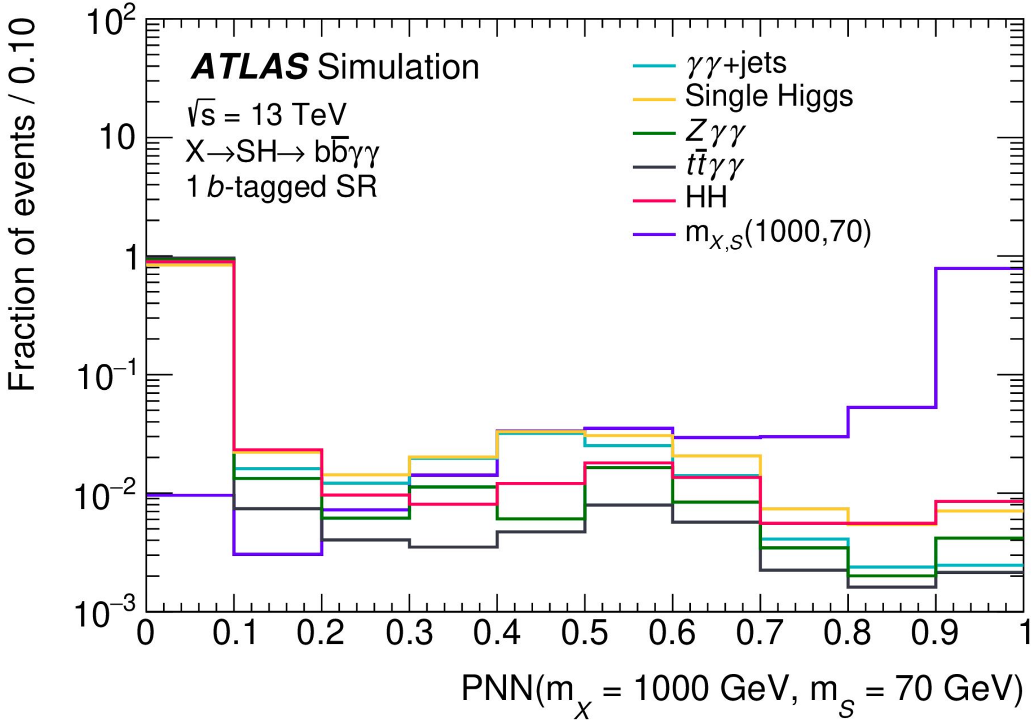
- PNN inputs distribution in sidebands

- p_T^b



PNN distribution in 1 b-tagged region

- PNN score distribution for the (m_X, m_S) = (1000, 70) GeV mass point in the 1 *b*-tagged jet region



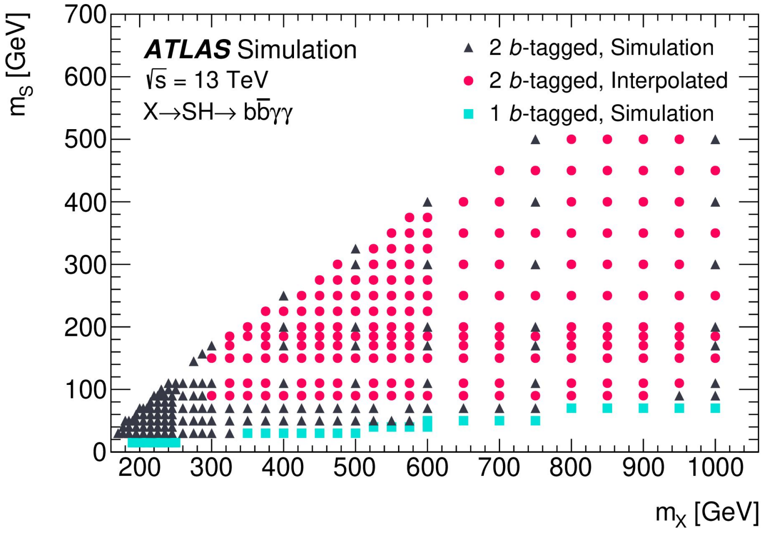
Systematic uncertainties

- Summary table of experimental and theoretical systematics
  Major ones are surrounded in red

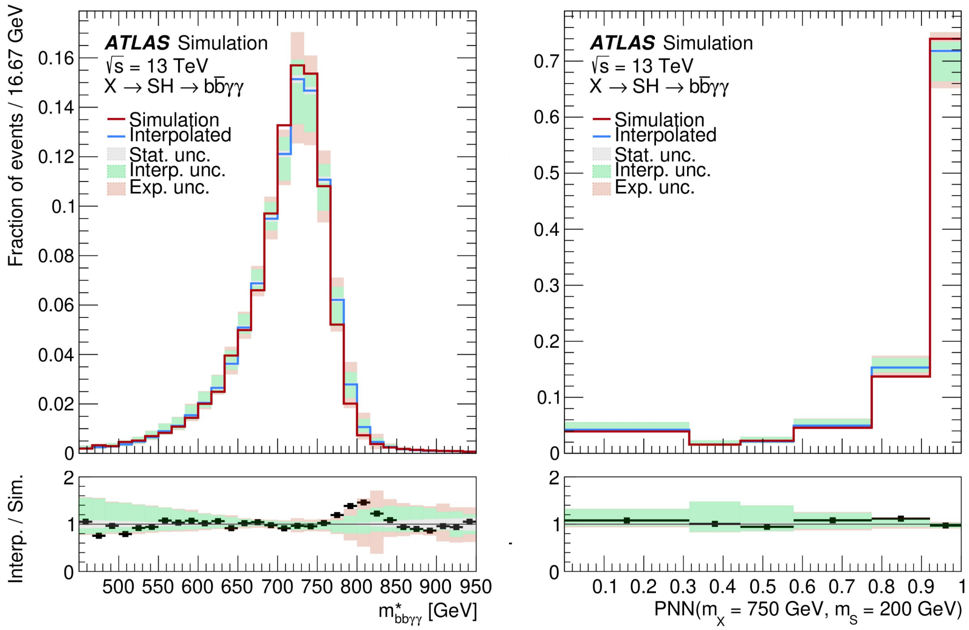
		Signal	HH ggF	HH VBF	ttH & ZH	Other Single Higgs	Continuum $\gamma\gamma$+jets
Theory	Normalisation	$BR(H \to \gamma\gamma)$	$BR(H \to \gamma\gamma)$ $BR(H \to b\bar{b})$ PDF+α_S Scales + m_t	$BR(H \to \gamma\gamma)$ $BR(H \to b\bar{b})$ PDF+α_S Scales	$BR(H \to \gamma\gamma)$	$BR(H \to \gamma\gamma)$ PDF+α_S Scales	$\gamma\gamma$ transfer factor
	Shape+Norm.	Scales, PDF+α_S Parton shower Interpolation	Parton Shower		Scales, PDF+α_S Parton Shower		Scales, PDF+α_S Modelling
Exp.	Shape+Norm.	Pile-up modelling Diphoton trigger efficiency Photon identification and isolation efficiency Photon energy scale and resolution Jet energy scale and resolution Jet vertex tagger efficiency Flavour tagging efficiency (all exp. systematics are neglected for bbH, tH and $VBF\ H$)					

Mass space granularity

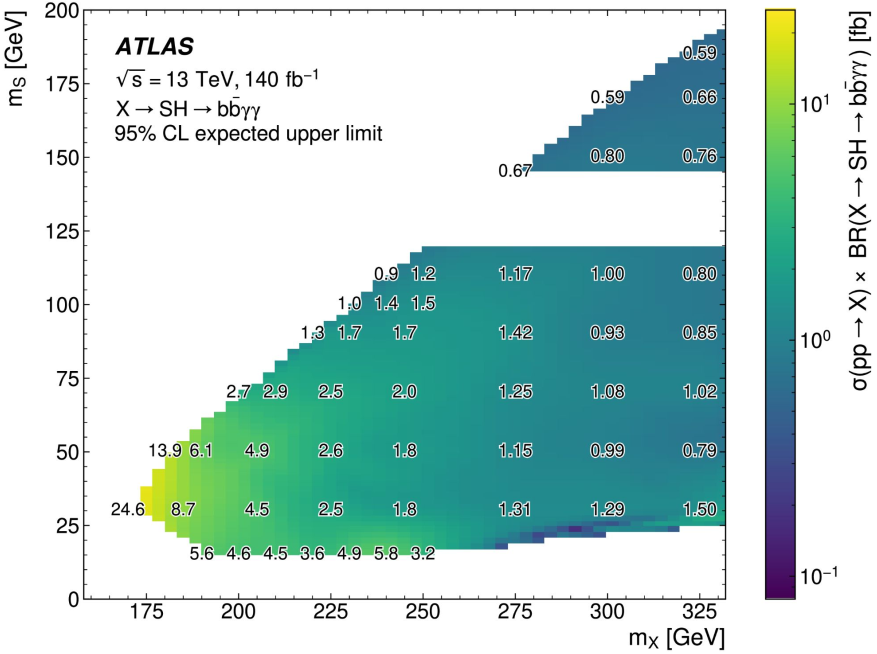
- Required granularity is assessed with signal injection tests to be sure not to miss any signal

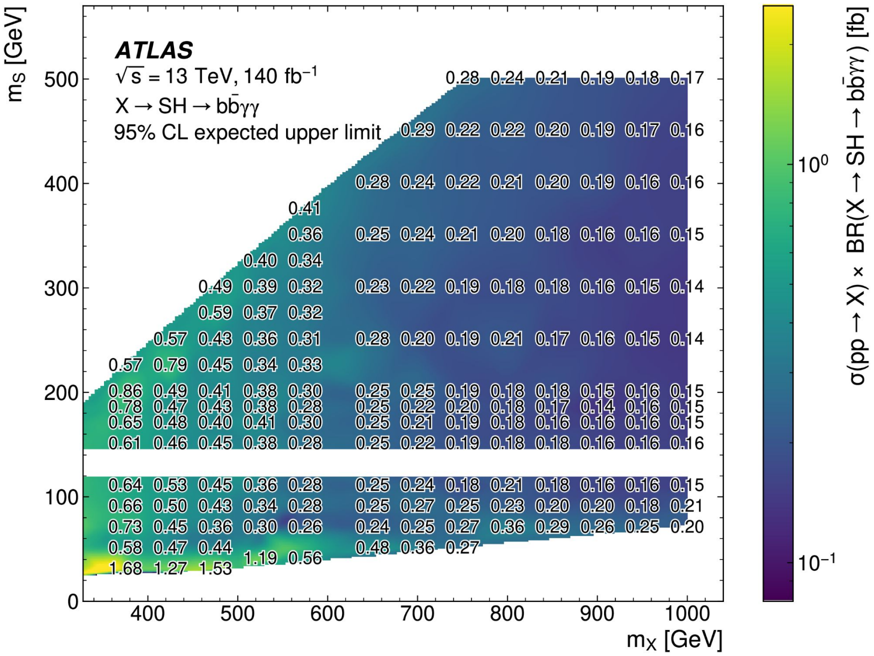


- For the red points, kinematic distributions are interpolated and used to compute PNN scores



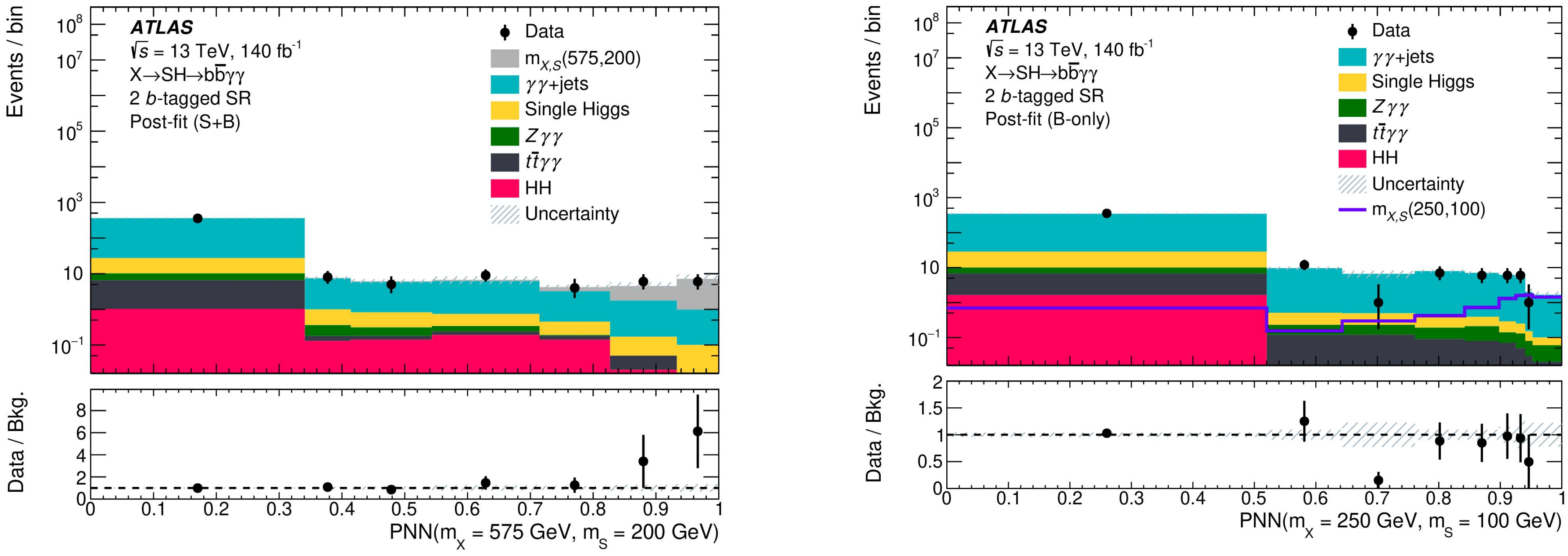
Expected limits





Post fit PNN distribution

- Post fit PNN distribution in SR for the point with the largest excess (m_X, m_S) = (575, 200) GeV and another point in the 2 *b*-tagged jet region (m_X, m_S) = (250, 100) GeV



Excess reported by CMS

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  We perform a signal injection at $(m_X, m_S) = (650, 90)$ GeV with a signal cross section of 0.35 fb (CMS best fit value)

  This signal injection gives an expected local excess of 2.7 standard deviation whereas we do not see any excess with respect to the background only hypothesis ($p_0 > 0.5$)