Beyond the Standard Model in the Higgs Sector at ATLAS

Tong Qiu

On behalf of the ATLAS Collaboration

10 Jun 2024

THE UNIVERSITY *of* EDINBURGH

Introduction

- A 125 GeV Higgs boson was discovered by the ATLAS and CMS experiments in 2012. Its observed properties are compatible with the Standard-Model predictions.

- The observed SM-like Higgs boson could be part of an extended Higgs sector.

- BSM extensions to the SM Higgs sector:
  - New Higgs bosons
  - Higgs coupling to new particles
  - Modifying Higgs coupling to Standard Model particles

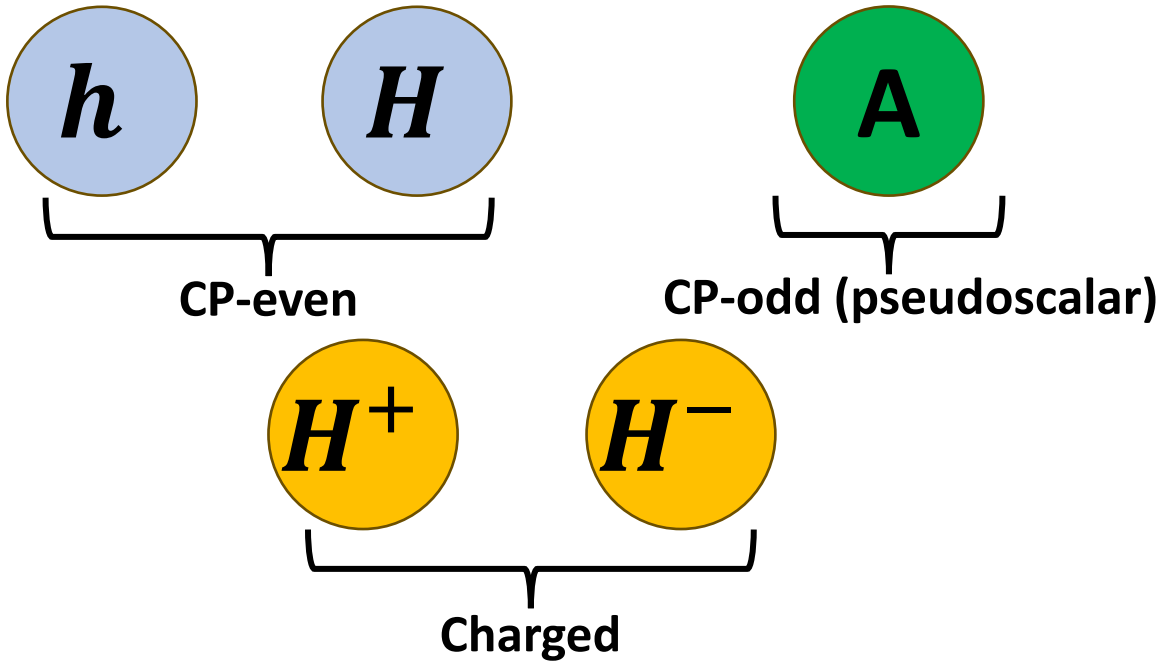
- Discuss a few recent ATLAS Run 2 searches for BSM Higgs sectors.

Search for $H^+ \to t\bar{b}$

JHEP06(2021)145

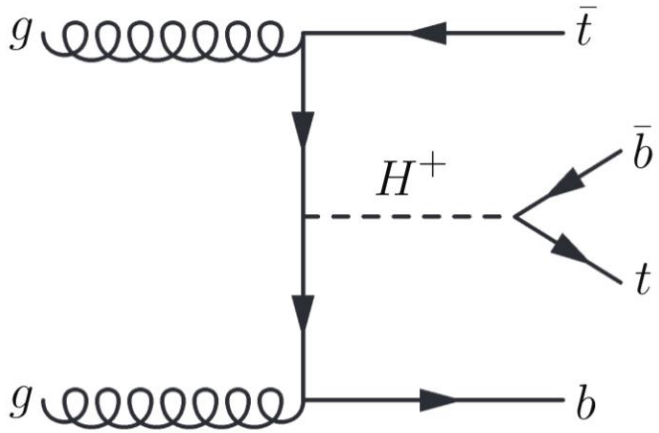
Motivation

- Two-Higgs-Doublet Model (2HDM): extend the SM by adding an additional Higgs doublet, resulting in five Higgs bosons:



- The second Higgs doublet is required by many BSM theories, such as SUSY, axion theories.
- Free parameters: tanβ (vacuum expectation energy ratio), cos(β-α) (α is the mixing angle between two CP-even Higgs) and Higgs masses.

Signal



- Search for $pp \to tbH^+ \to tbtb$ in the H^+ mass range from 200 GeV to 2000 GeV using the full Run 2 ATLAS data.

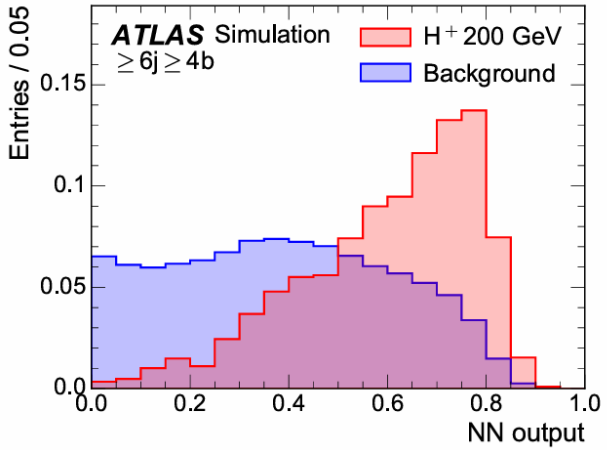
- The $H^+ \to t\bar{b}$ decay has the highest branching ratio when the mass of H^+ is above the top mass.

Search for $H^+ \to t\bar{b}$

JHEP06(2021)145

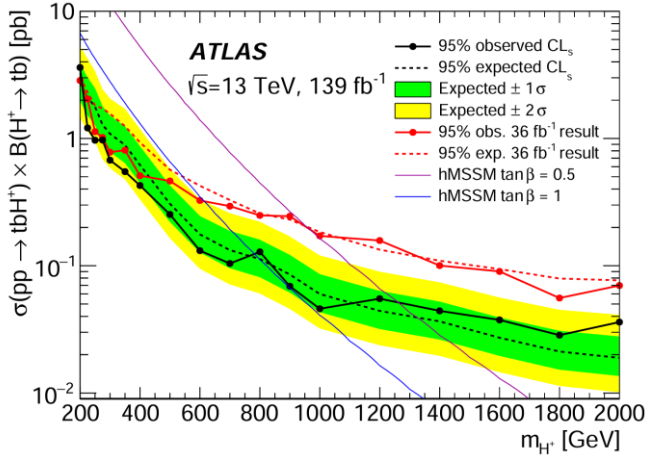
Analysis Strategy

- Event selection:
  - At least one charged lepton (electrons or muons)
  - At least 5 jets
  - At least 2 b-tagged jets
- Four signal regions:
  - 5 jets, 4 b-tagged; 5 jets, ≥4 b-tagged; ≥ 6 jets, 3 b-tagged; ≥ 6 jets, ≥4 b-tagged
- Events with 2 b-tagged jets as control region.
- A neural network used to separate signals from the background, and the score is the fit variables.

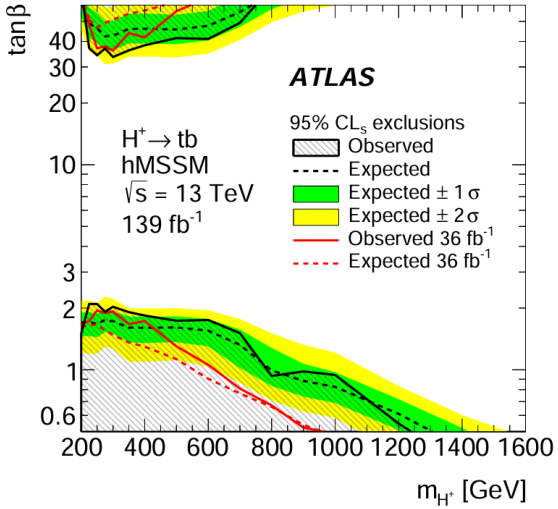


Results

- Upper limit at 95% CL on XSxBR.



- Interpret the results using different benchmark scenarios.
- Exclusion on m_{H^+}-tanβ space.

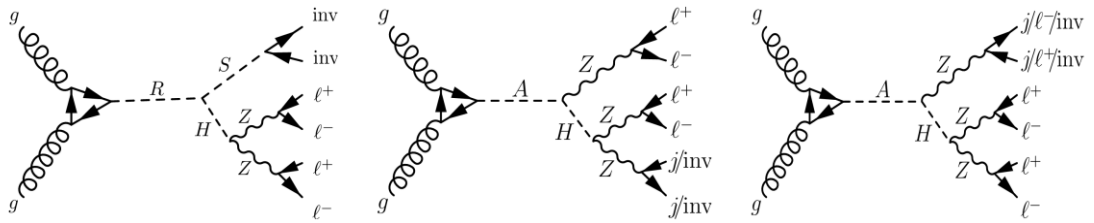


Heavy resonance in leptons and met/jets final states

arXiv:2401.04742

Motivation

- Targeting both 2HDM model (A → ZH) and 2HDM+S model (R → SH) where S is a scalar boson.
- S is assumed to be a dark matter portal (X→ $\chi\bar{\chi}$).

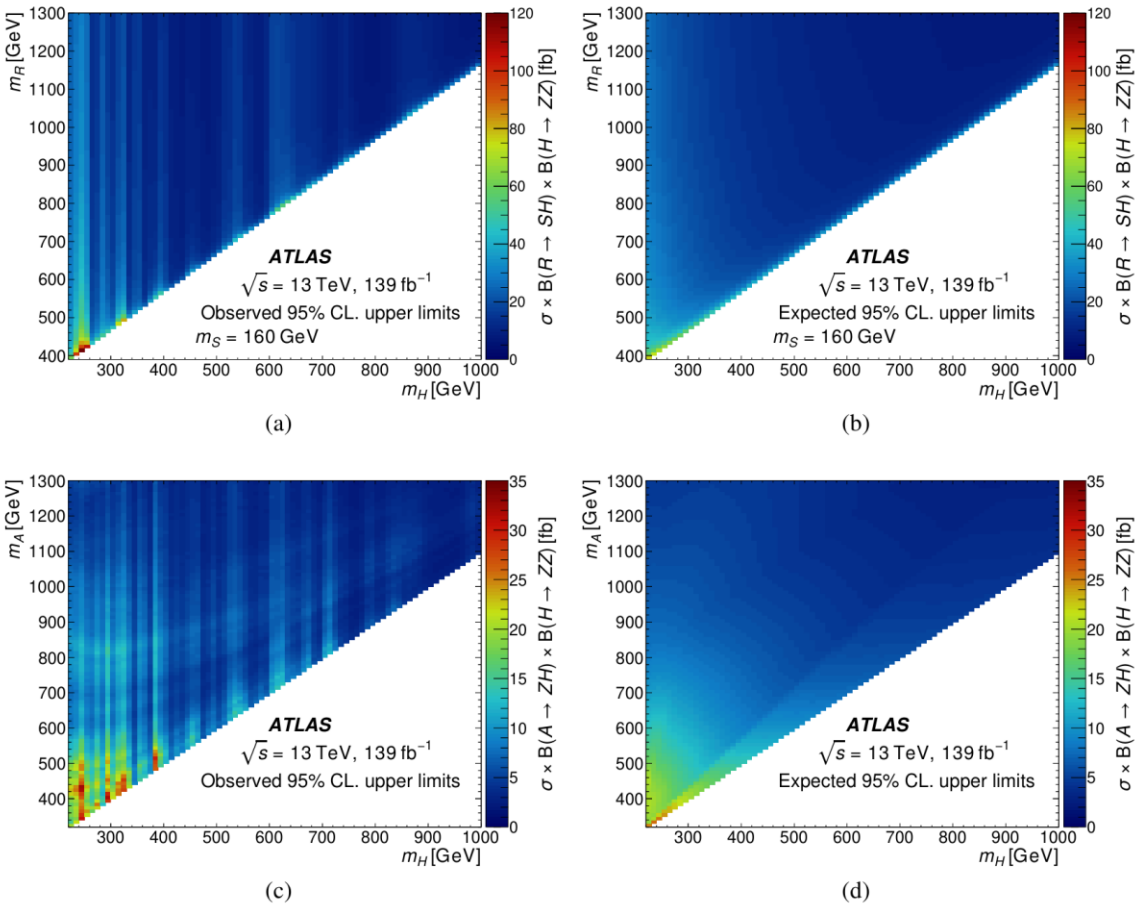


Analysis Strategy

- Reconstruct Z bosons using two same-flavour and opposite-sign lepton pairs closest to the Z mass.
- Seven signal regions targeting topologies.
  - Signal regions defined using variables like number of jets, di-jets mass, missing transverse energy significance and transverse momentum of the 4 leptons.

Results

- Set limit on the (m_R, m_H) space and the (m_A, m_H) space.

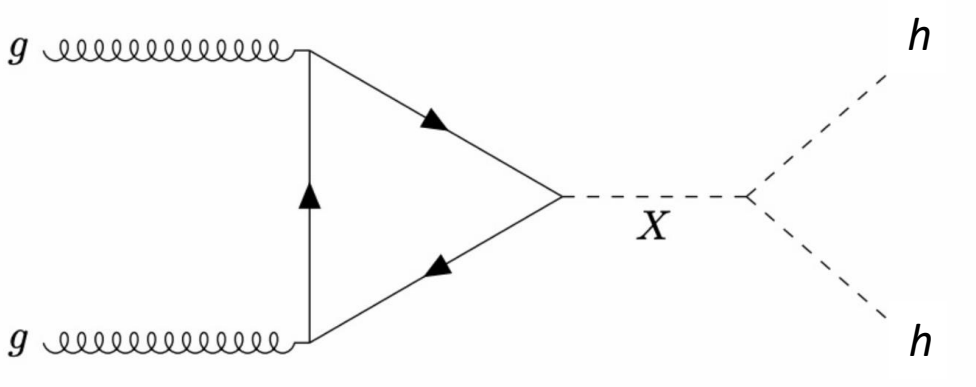


Combined search for di-Higgs resonance

arXiv:2311.15956

Motivation

- Search for a spin-0 narrow-width heavy resonance X decaying into two 125 GeV Higgs bosons.
- X could be the heavy CP-even or the CP-odd Higgs in 2HDM.

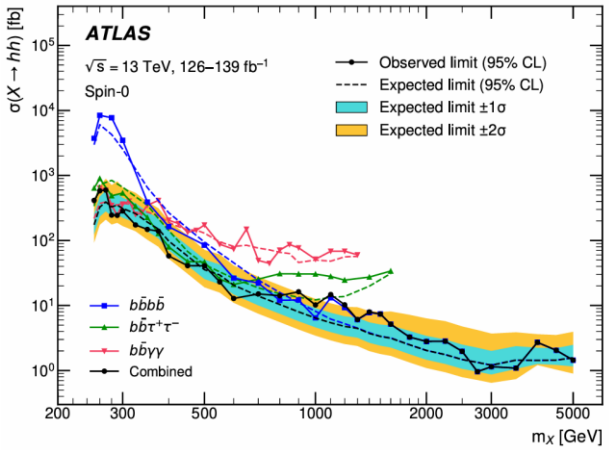


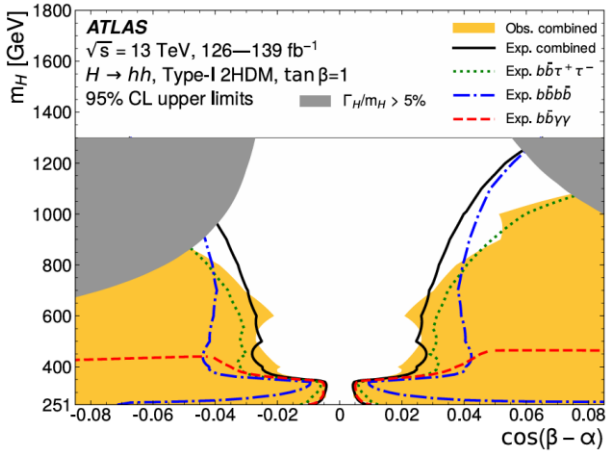
Combining three searches: bbbb, bbττ, bb$\gamma\gamma$

- bbbb search PhysRevD.105.092002
  - Resolved channel: 4 small-R jets. Use a BDT to pair jets. Covering 251 GeV < m_X< 1.5 TeV.
  - Merged channel: 2 large-R jets. Covering the mass range of 900 GeV < m_X< 5 TeV.
- bb$\gamma\gamma$ search PhysRevD.106.052001
  - Require two b-tagged small-R jets and two photons.
  - Probing 251 GeV < m_X< 1.3 TeV
- bbττ search JHEP07(2023)040
  - Two channels depending on the τ decay: $\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$, $\tau_{\mathrm{had}}\,\tau_{\mathrm{had}}$. Requiring two b-tagged small-R jets.
  - Probe 251 GeV < m_X< 1.6 TeV.

Results

- Exclusion on masses (m_A, m_H) and 2HDM parameters (tanβ, cos(β-α))

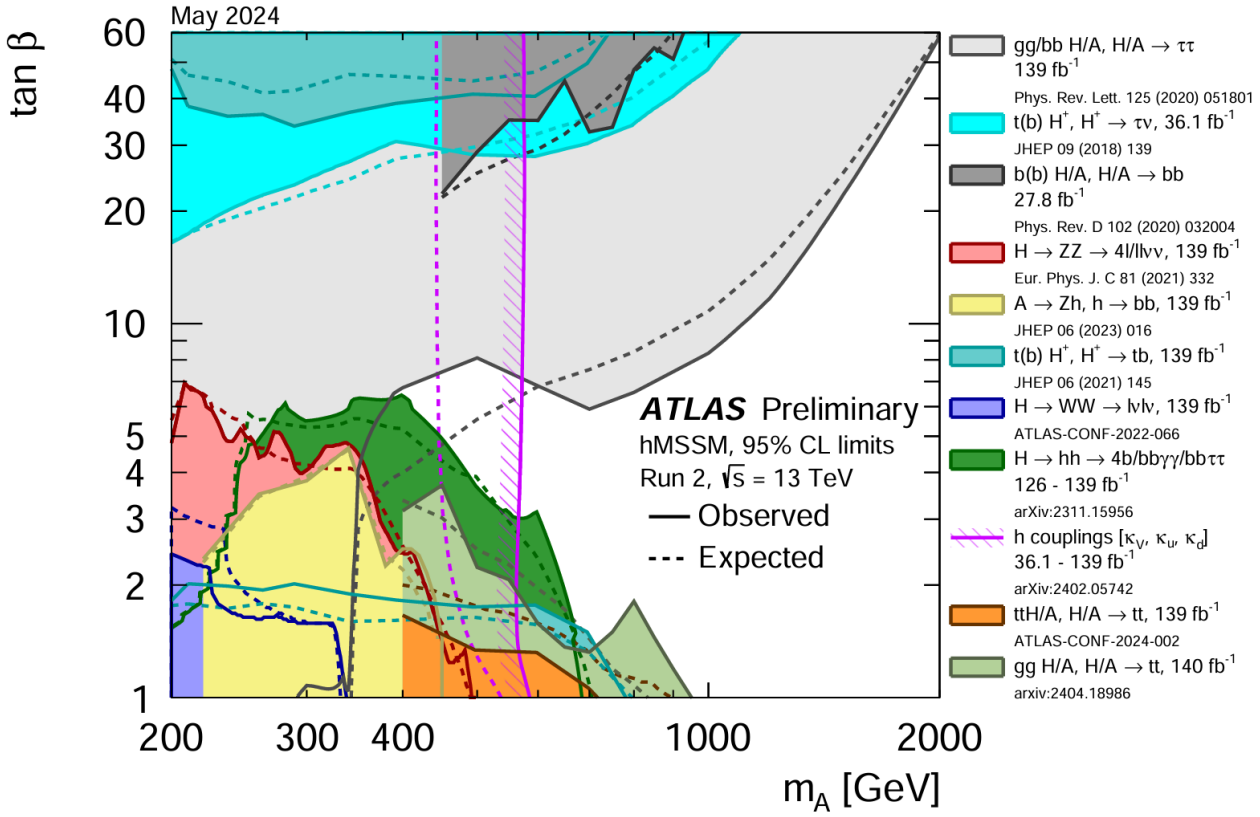


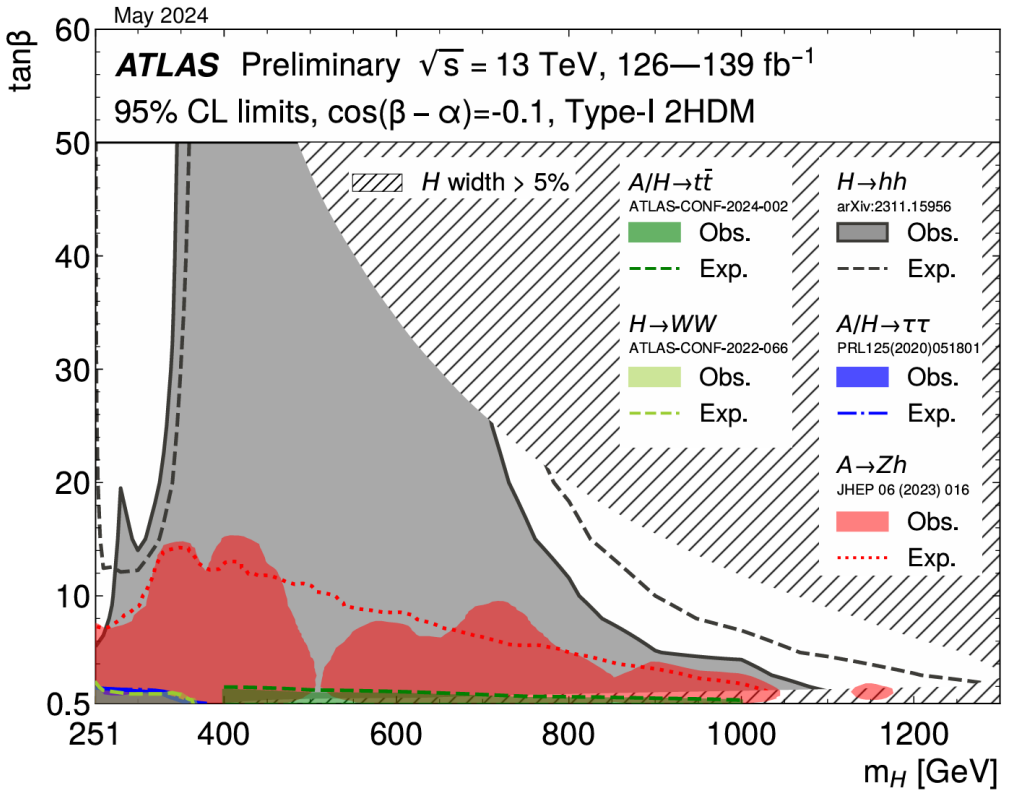


Interpretation for BSM Higgs

ATL-PHYS-PUB-2024-008

- Interpretations combining direct searches for BSM Higgs bosons and measurement of the 125 GeV SM-like Higgs boson.
- Constrain parameters in the hMSSM benchmark scenario of MSSM Higgs sector and the type-I 2HDM.
- Exclusion on the masses of the BSM heavy Higgs and tanβ.



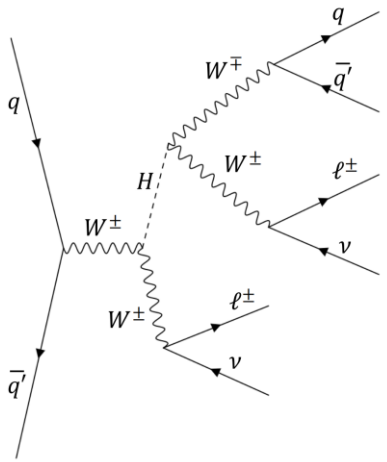


Search for a generic heavy Higgs decaying into WW

JHEP07(2023)200

Motivation

- Higher dimensional interactions between heavy Higgs bosons and SM gauge bosons.
- Dim-6 operators enhance the VH production.
- Search for WH->lvlvjj (from WWW decay, 2 same-sign leptons).

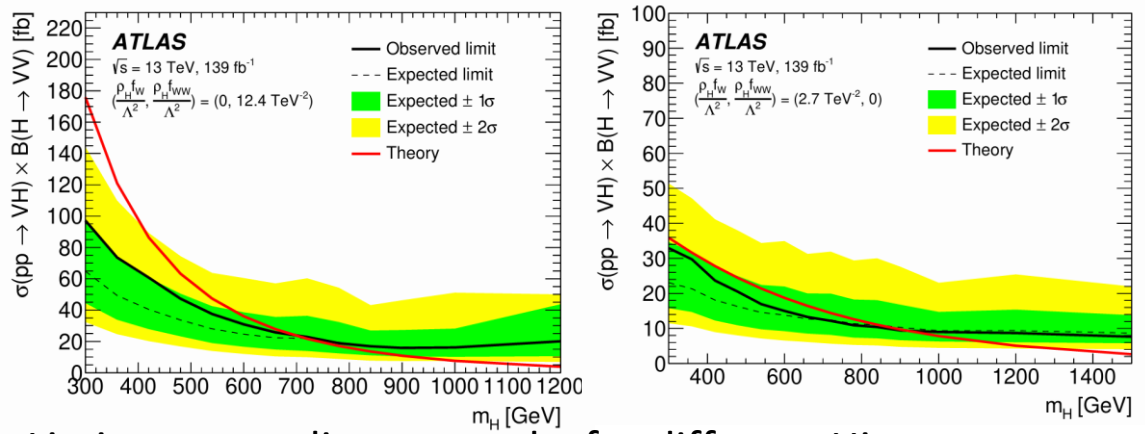


Analysis Strategy

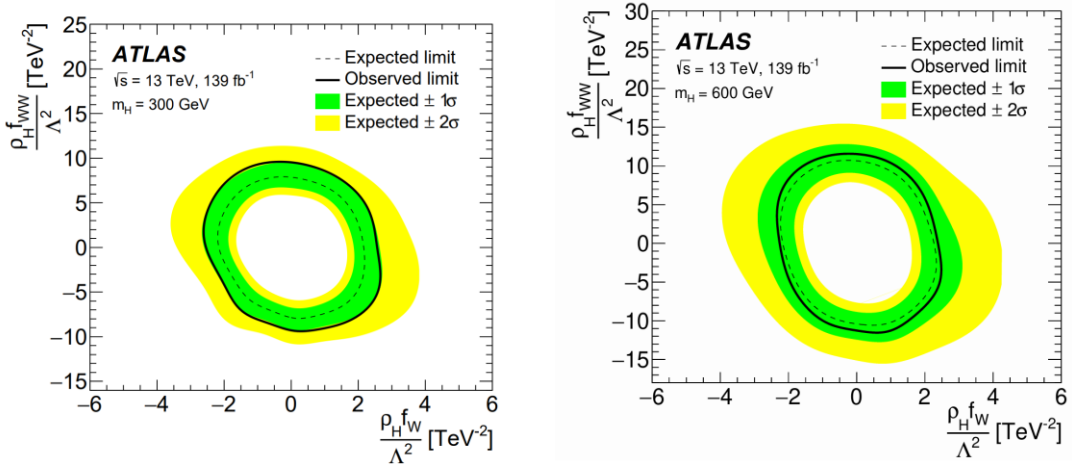
- Events are required to have two same-signed leptons (electrons or muons).
- The W → $q\bar{q}$ is reconstructed using either two small-R jets or one large-R jets.
  - Resolved: the di-jet invariant mass is required to be close to the W mass.
  - Merged: use a boson tagger to select hadronically decaying W bosons.

Results

- The coupling strengths affect the momentum of the Higgs boson. Limits on XSxBR calculated for different coupling strengths.



- Limits on coupling strengths for different Higgs masses.

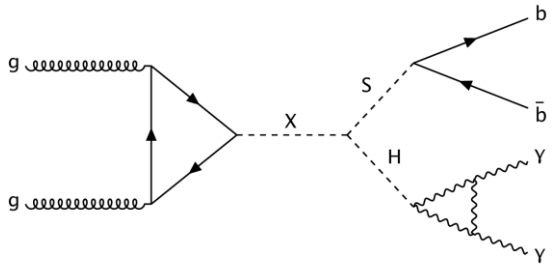


Search for $X \to S(\to bb)h(\to \gamma\gamma)$

arXiv:2404.12915

Motivation

- Search for two scalar bosons X and S where X decays into a 125 GeV Higgs boson and an S boson.
- Motivated by:
  - Extends SM Higgs sector with a complex singlet
  - Extends SM Higgs sector with or two real singlets
  - 2HDM+a real scalar singlet.

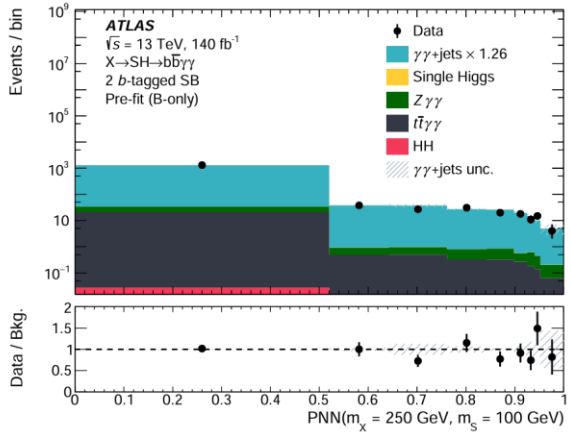


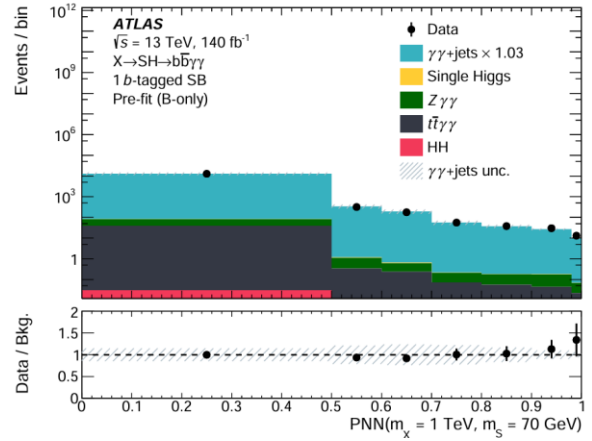
Analysis strategy

- Select events with one or two b-tagged small-R jets and two photons.
- Two signal region: 1 b-tagged and 2 b-tagged
- Requiring 120 GeV < $m_{\gamma\gamma}$< 130 GeV. Events not in the mass window are in the control region.

Parametrized neural networks

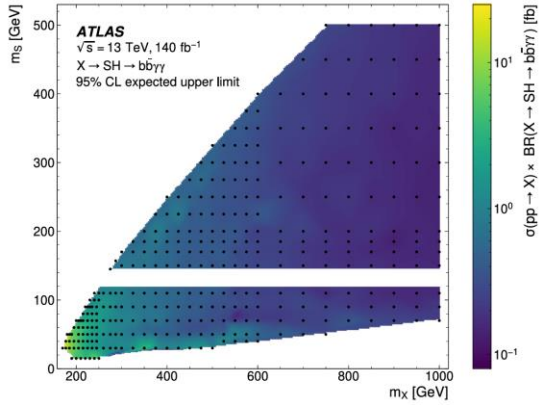
- The final discriminant is the output of parametrized neural networks (PNN) whose input features include mass of the resonances.

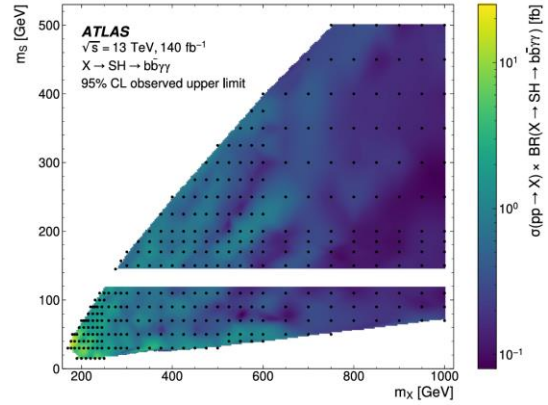




Results

- Upper limit on XSxBR at 95% CL on the (m_X, m_S) space.





Very low-mass di-photon resonance searches

JHEP 07 (2023) 155

Motivation

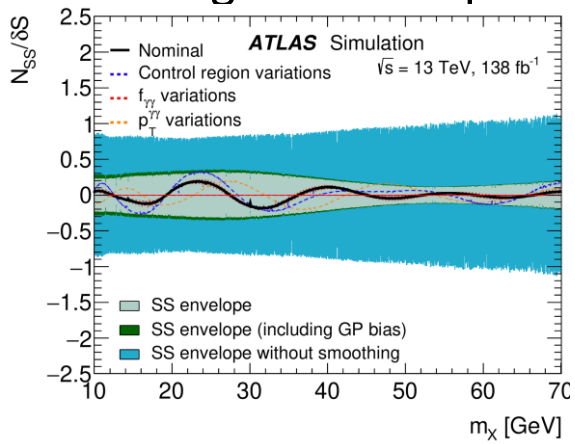
- Search for a light resonance (10 GeV < m_X < 70 GeV) decaying into two photons.
- A natural target of this search are light axion-like particles (heavy QCD axion models, R-axion in SUSY breaking models and composite Higgs models).

Event selection

- Two photons with $E_T > 20$ GeV.
- Di-photon objects with $P_T^{\gamma\gamma} > 50$ GeV.

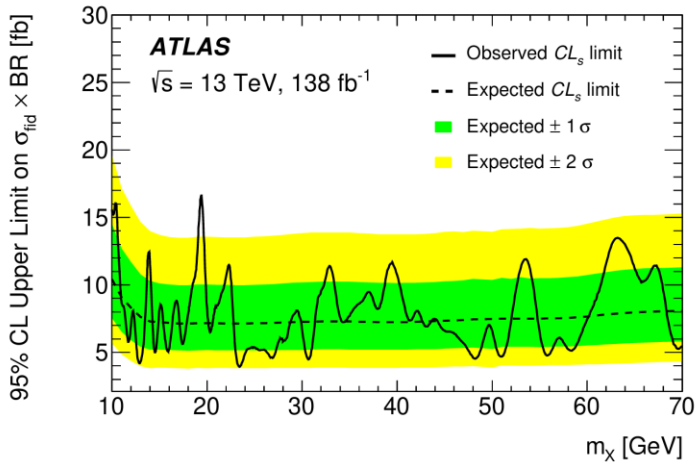
Background modelling

- Irreducible background ($\gamma\gamma$) template built from Monte Carlo.
- Reducible background (jj, γj) template built using a data-driven method.
- Total background modelled by analytical functions.
- Bias of the analytical functions estimated by the signal yield when fitting to background template.
- Gaussian Processes used to mitigate statistical fluctuations in background templates.



Results

- Limits on XSxBR in a fiducial region.



Conclusion

- Searched for BSM Higgs sectors using the full Run 2 data collected by the ATLAS detector.
- All observations agree with the Standard Model.
- Stronger limits on XSxBR and BSM model parameters.
- Awaiting more exciting results from the ongoing LHC Run 3.