Searching for New Symmetries in the Higgs Sector at ATLAS

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On behalf of the ATLAS Collaboration

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Physics Motivation

- The discovery of the Higgs boson confirmed the mass generation mechanism via spontaneous electroweak symmetry breaking and completed the SM
- However, additional scalar fields can explain phenomena that SM fails to answer, like new sources of CP violation, dark matter candidates, etc
  - 2 Higgs doublet model (2HDM): h, H, A, $H^{\pm}$
  - 3HDM: 2 additional Higgs doublet; Georgi-Machacek (GM) Model: 1 Higgs doublet + 2 triplets
- This talk will present recent searches for additional low-/high-mass Higgs bosons, as well as decays of the SM Higgs boson to new light scalar particles, using full Run 2 data collected by the ATLAS detector at 13 TeV

Analysis Topics Covered Today

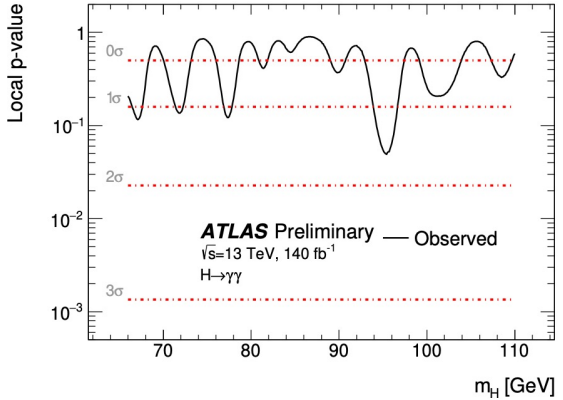
- Search for additional neutral Higgs boson
  - Low mass H→$\gamma\gamma$
  - ttH→4top
  - WH→WWW
  - H→hh
- Search for additional charged Higgs boson
  - $H^{++}\rightarrow l^{+}l^{+}$
  - $H^{+}\rightarrow WZ$
  - $t\rightarrow H^{+}b$, H+→cb
- Search for exotic decay of the SM Higgs boson
  - h→aa→4γ
  - h→aa→bbμμ

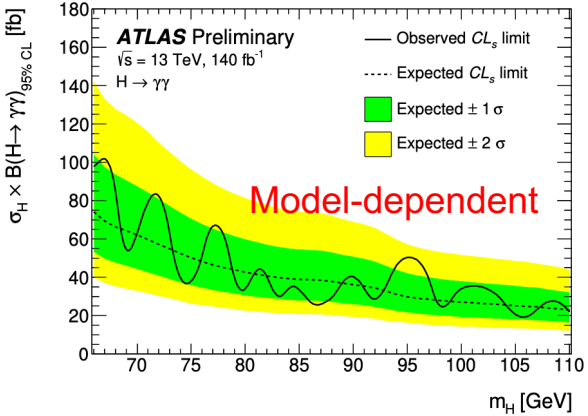
Caveat: SM Higgs boson denoted as “h” in this talk
”l” refers to electron or muon

Search for Additional Neutral Higgs Boson

Search for Low-mass H→$\gamma\gamma$

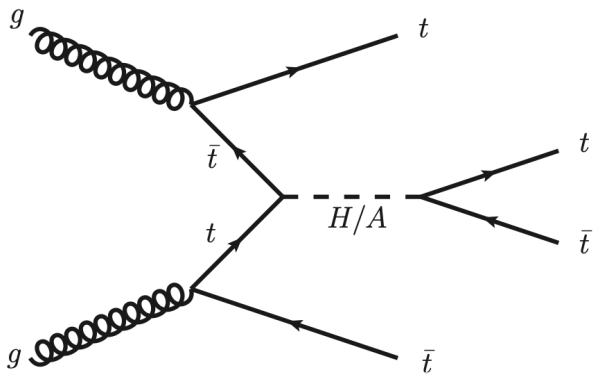
- Searching for low mass resonance within 66 - 110 GeV
- $\gamma\gamma$ selected with E_T > 22 GeV and $E_T/m_{\gamma\gamma}$> 0.38; Z->ee bkg. largely reduced via object BDT
- Events sorted into 9 categories based on photon conversion and BDTs
- Analytic function fit to the observed $m_{\gamma\gamma}$ spectra (62 – 120 GeV)
  - Allow data on either side of hypothetical signal peak to constrain bkg.





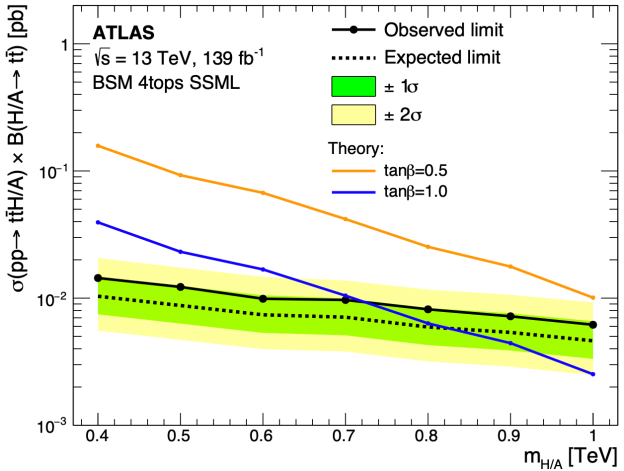
ATLAS-CONF-2023-035

Search for Heavy Higgs in 4 Top Events



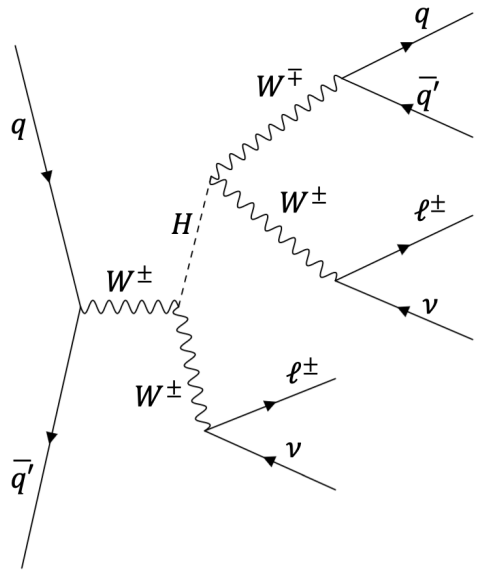
Predicted by 2HDM, heavy Higgs mass assumed to be 400 – 1000 GeV

- Events selected with 2 same-sign leptons or ≥3 leptons; ≥6 jets (≥2 of which are b-jets)
- Major bkg. coming from SM 4-top, ttW/Z/H
- BDT trained to separate sig. and bkg., used for final fitting



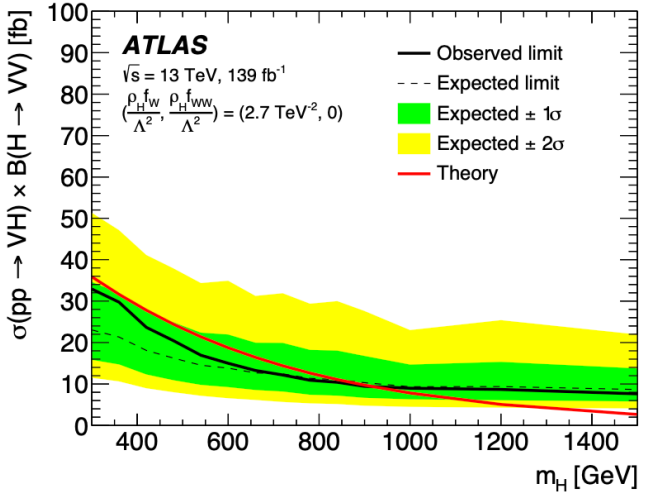
arXiv:2211.01136

Search for Heavy Higgs via WH Mode



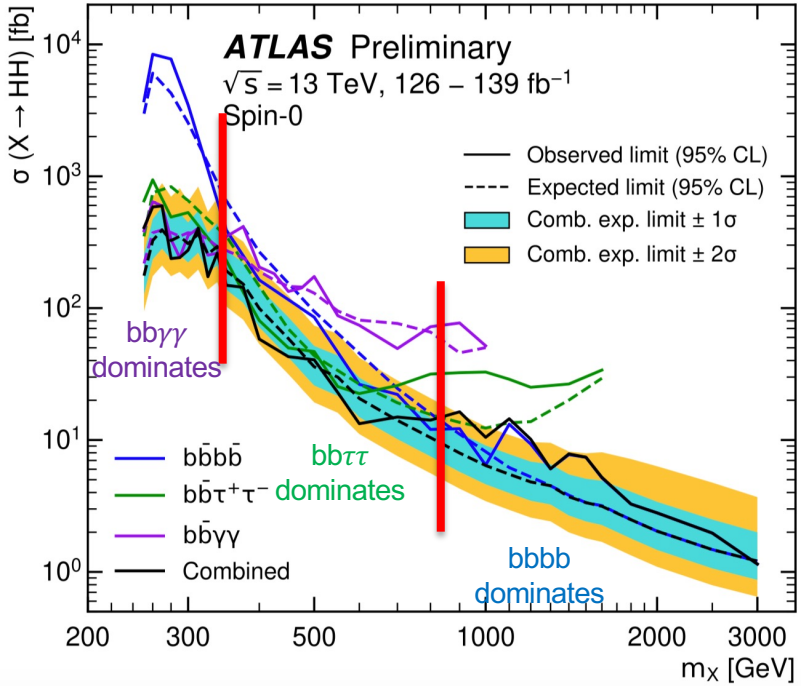
A generic search for heavy H→WW→lvqq in the model where H is fermiophobic

- Single lepton un-prescaled trigger used
- Selected two same-sign leptons plus MET together with 2 small-R jets (resolved SR) or 1 large-R jet (boosted SR)
- No deviation from SM seen



arXiv:2211.02617

Search for Heavy Scalar with hh Events



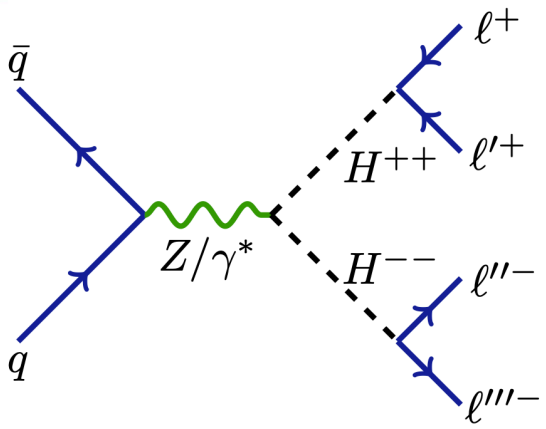
- Many BSM theories predicted a heavy scalar decaying into two SM Higgs bosons
- Three major sensitive channels for hh: bb$\tau\tau$, 4b and bb$\gamma\gamma$
- Performed statistical combination for these three channels to maximize the sensitivity to heavy scalar resonance production

ATLAS-CONF-2021-052

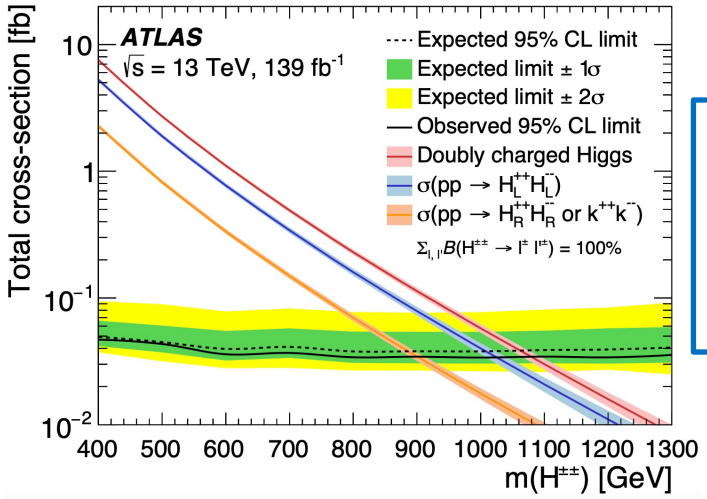
No statistically significant excess found, largest excess at 1.1 TeV: local (global) significance is 3.2σ (2.1σ)

Search for Additional Charged Higgs Boson

Search for Doubly Charged Higgs



- ≥ 2 tight leptons (e/μ, leptonic τ decays)
- Lepton-flavor-violating decays allowed
- 3 SRs: $l^{\pm}l^{\pm}$, $l^{\pm}l^{\pm}l^{\mp}$, $l^{+}l^{+}l^{-}l^{-}$, $m(l^{\pm}, l^{\pm})_{lead}$ > 300 GeV

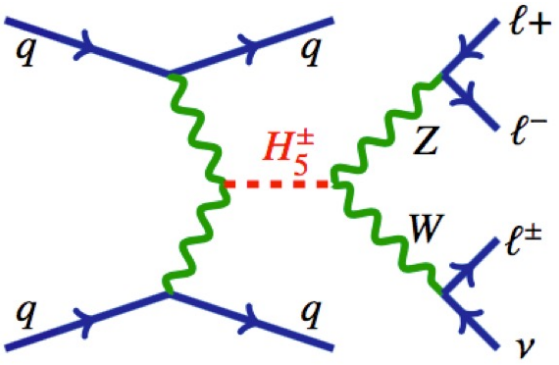


Predicted by various BSM models such as LRSMs, type-II seesaw models, Zee–Babu neutrino mass model, etc

Mass below 1080 (900) GeV excluded for LRSMs (Zee-Babu model)

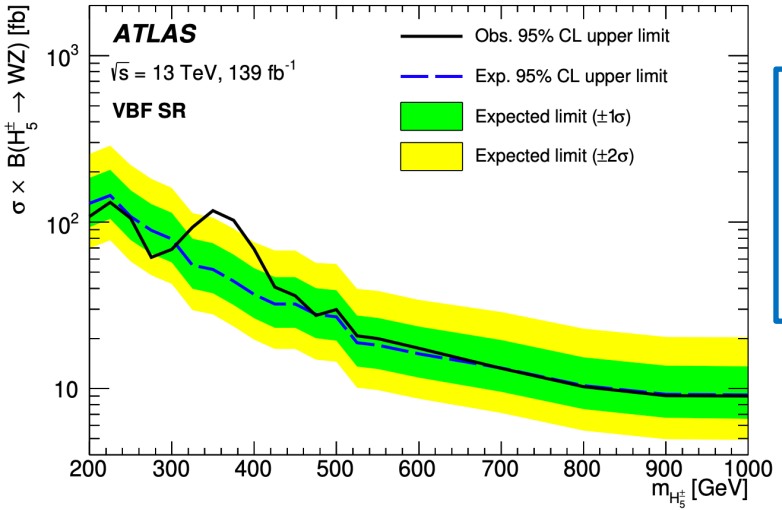
arXiv:2211.07505

Search for Charged Higgs Decaying into WZ



Predicted by Georgi–Machacek (GM) model
Produced in VBF mode

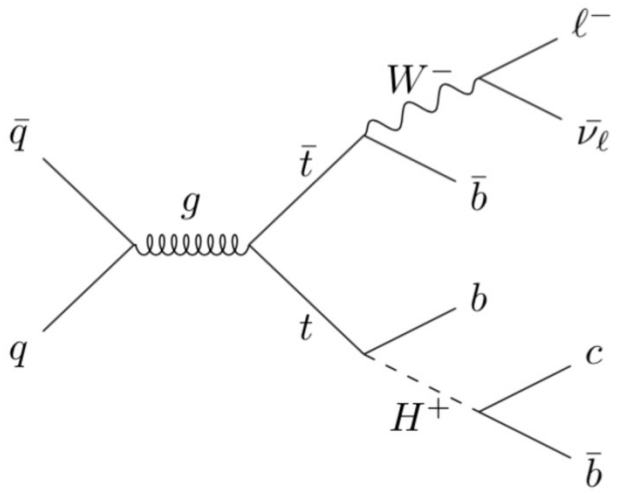
- Events selected with 3 leptons and 2 forward jets
- ANN used for sig. and bkg. (WZ, ZZ, etc) classification
- WZ invariant mass used for final fitting



Local (global) significance for 375 GeV is 2.8 (1.6)σ

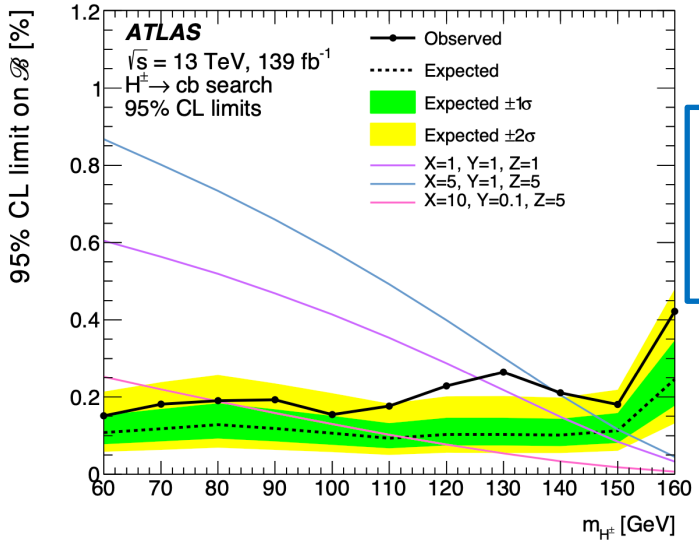
arXiv:2207.03925

Search for Charged Higgs in Top Decays



Predicted by 3HDM, where the lightest charged Higgs can be lighter than top quark

- Events selected with 1 e/μ and ≥4 jets
- NN trained to separate sig. vs bkg. (mainly from ttbar+jets) and used for fitting
- No significant data excess seen



Local (global) significance for 130 GeV is 3.0 (2.5)σ

arXiv:2302.11739

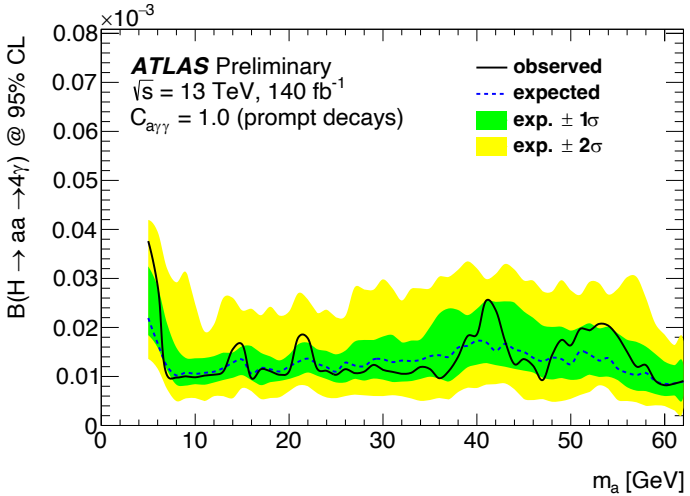
Search for Exotic Decay of the SM Higgs Boson

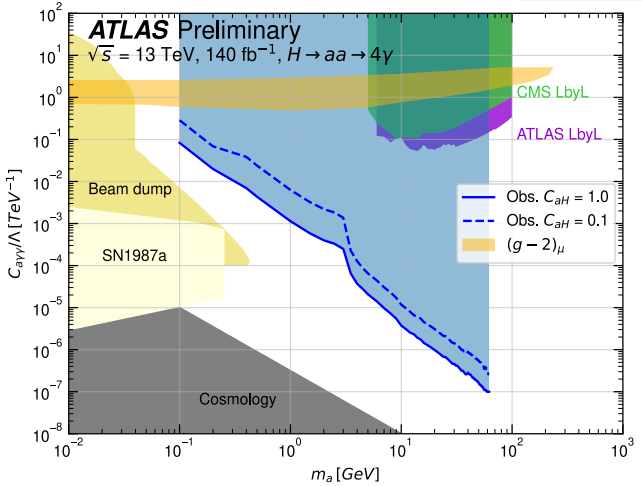
Search for h→aa→4γ

New!

- Axion-like particles (ALPs) decaying into $\gamma\gamma$ is sensitive to various models that could explain $(g\text{-}2)_\mu$ discrepancy
- Signal signature depending on the axion mass (collimated/resolved photons) and $C_{a\gamma\gamma}$ (long-lived/promptly decaying)
- m_{inv}^{reco} (invariant mass of all photon candidates) used for final fitting

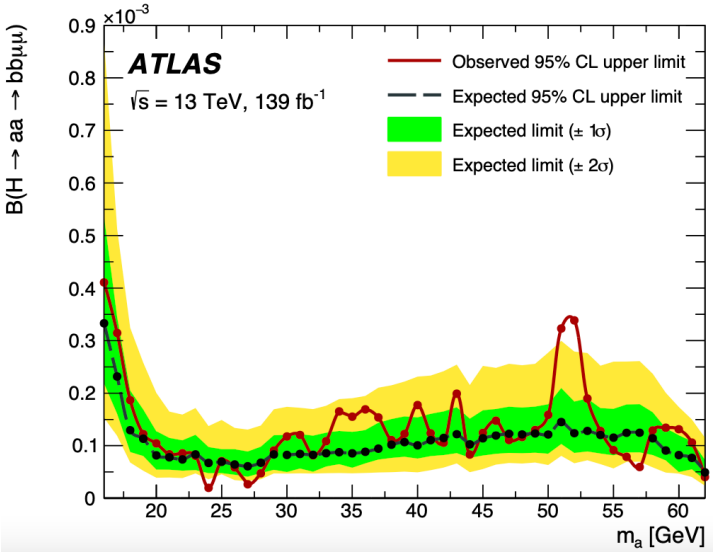
ATLAS-CONF-2023-040





Search for h→aa→bbμμ

- Events selected with single/di-muon triggers, $m_{\mu\mu}$ in 15 – 65 GeV
- Performed kinematic likelihood fit exploiting equal m_{bb} and $m_{\mu\mu}$ to improve mass resolution and reduce bkg.
- BDT further trained to separate signal from SM bkg. (DY+jets, ttbar)



No significant excesses seen
Local (global) significance for 52 GeV is 3.3 (1.7)σ

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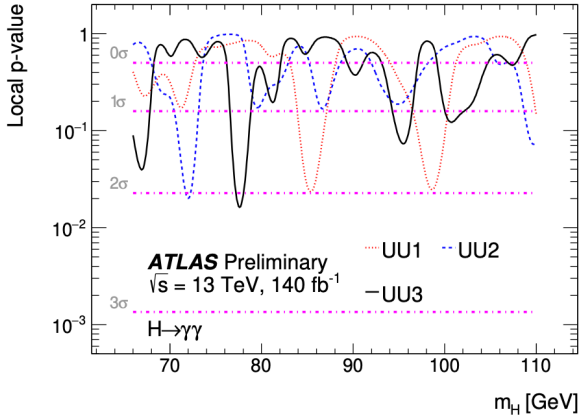
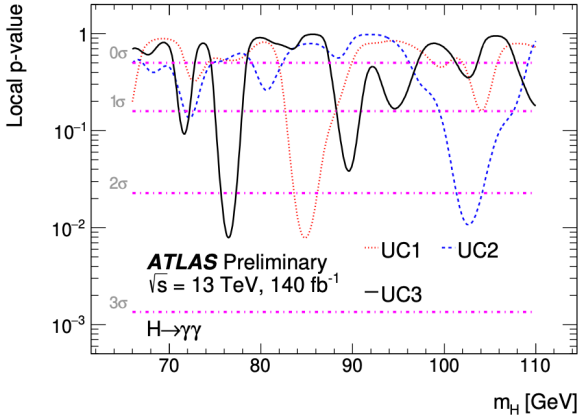
Summary

- Presented the latest searches for additional low/high-mass Higgs bosons, as well as decays of the SM Higgs boson based on the full Run 2 data
- Many other related searches not covered for today due to time constraint
  - ATLAS-CONF-2022-039, JHEP 01 (2022) 063, JHEP 03 (2022) 041, arXiv:2301.03902, etc
- No sign of new symmetries in the Higgs sector at the current precision level, stringent limits have been set according to relevant models
- Large amount for Run 3 data can provide us room for more precise probe, stay tuned!

Backup



(a)



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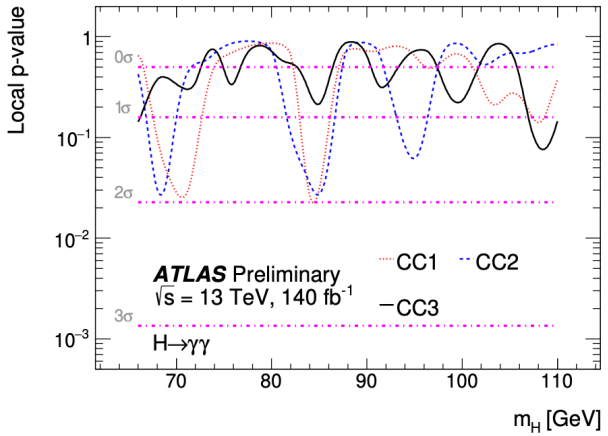
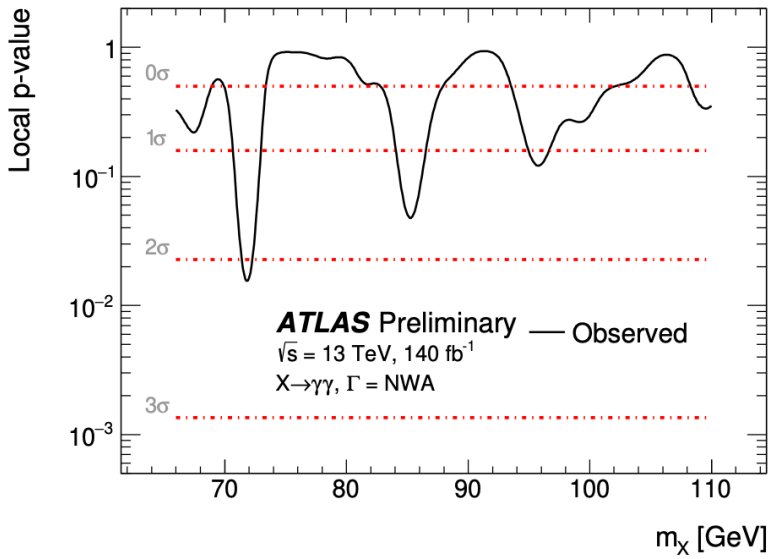
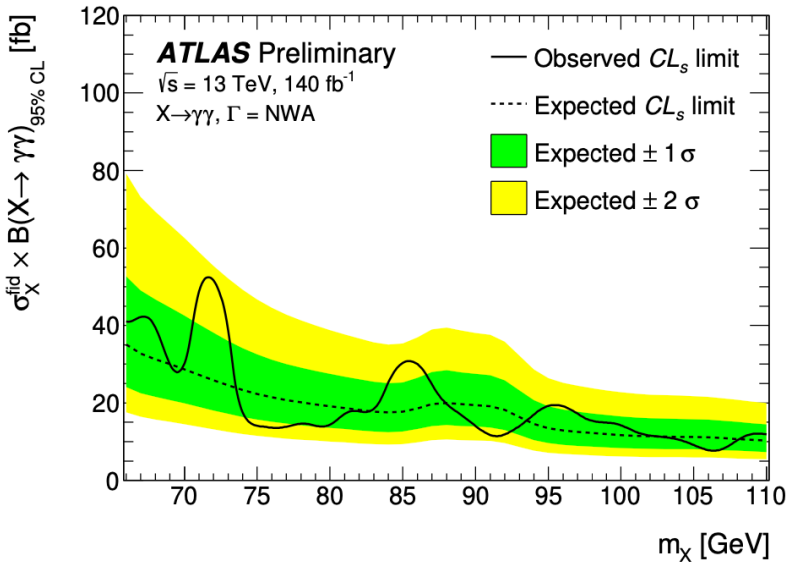


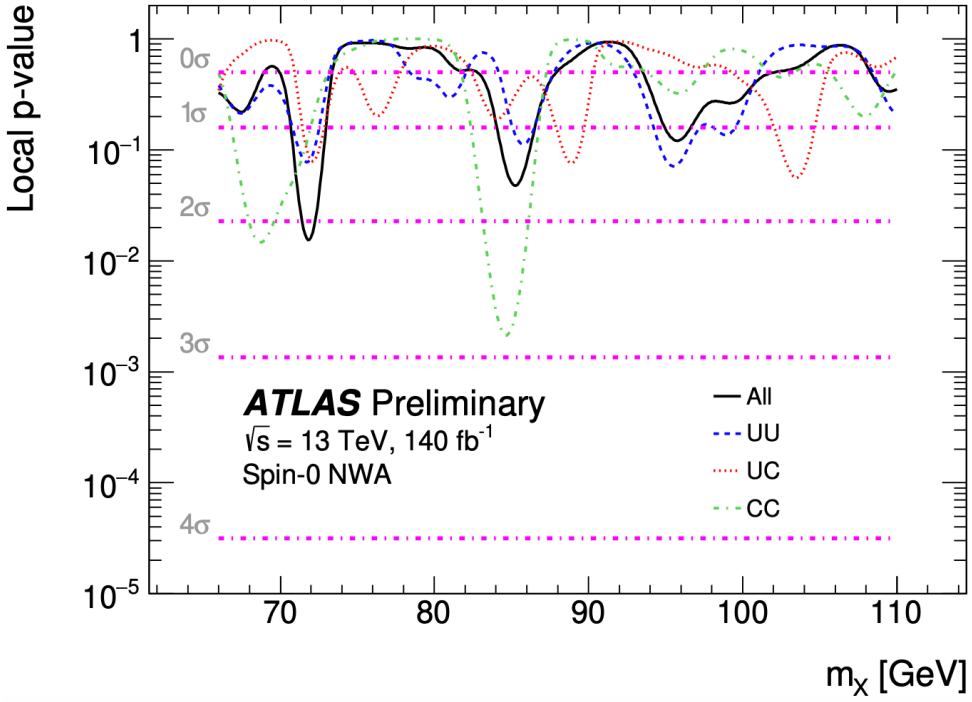
(c)

Model-dependent

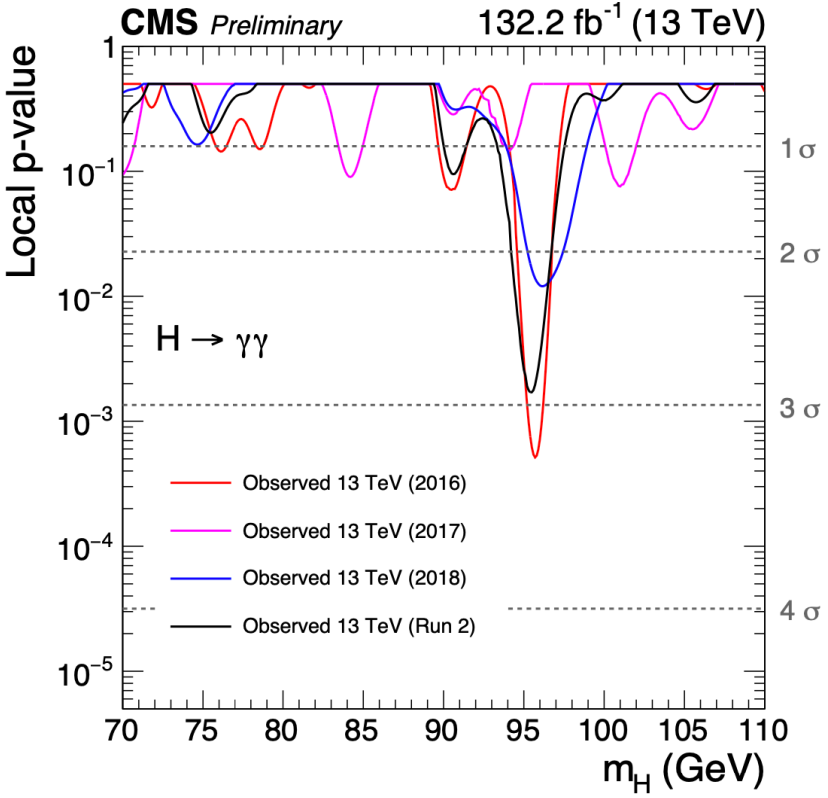




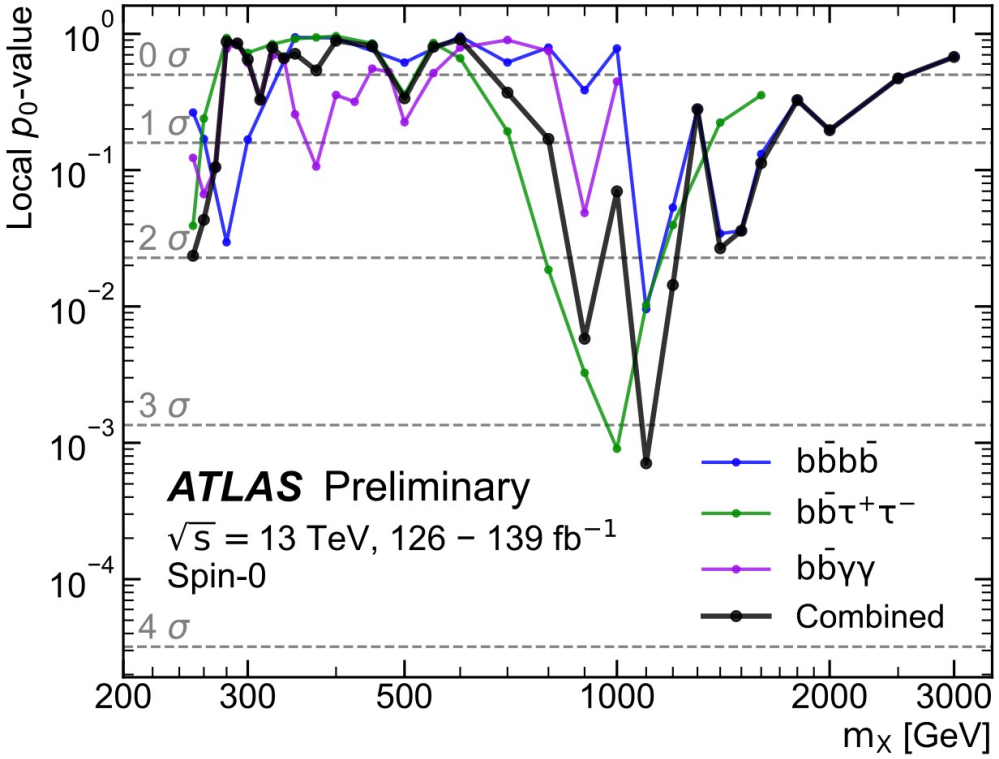
Model-independent

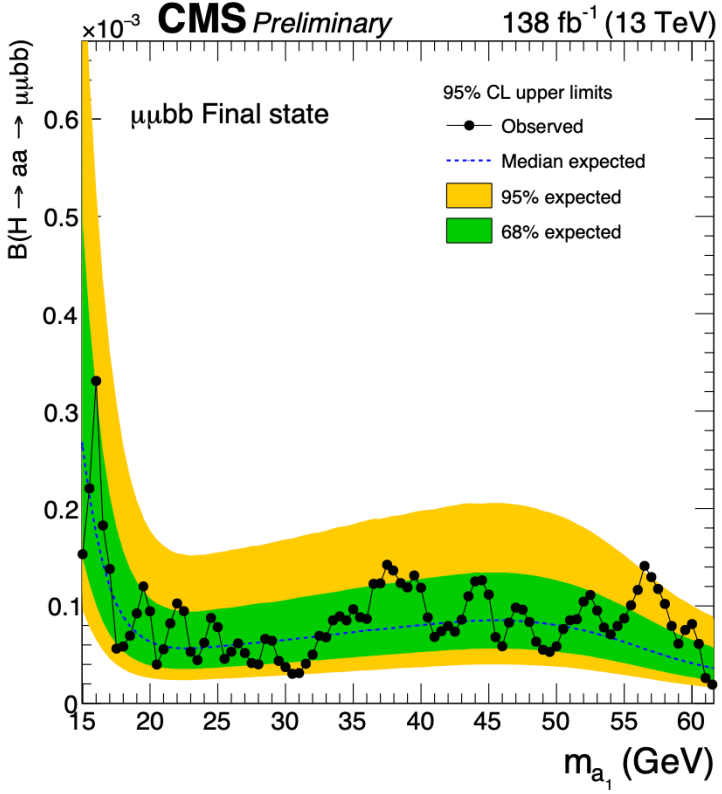


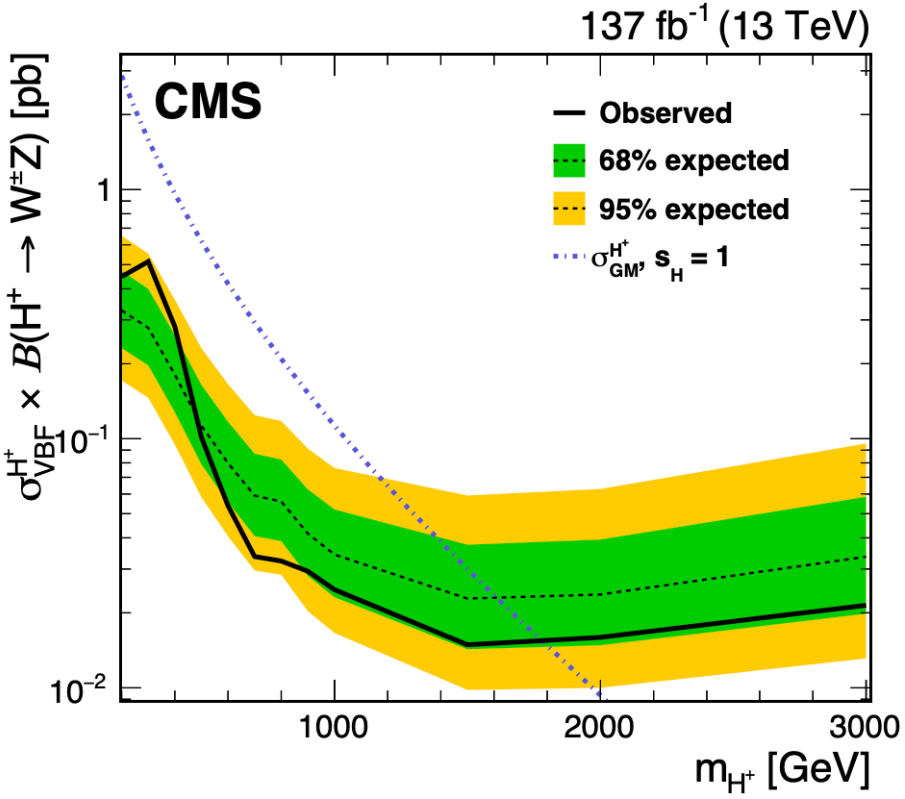
Model-independent



CMS-PAS-HIG-20-002


Local p_0-value
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0 σ
1 σ
2 σ
3 σ
4 σ
ATLAS Preliminary
$\sqrt{s}$ = 13 TeV, 126 − 139 fb^{-1}
Spin-0
$b\bar{b}b\bar{b}$
$b\bar{b}\tau^+\tau^-$
$b\bar{b}\gamma\gamma$
Combined
200
300
500
1000
2000
3000
m_X [GeV]


CMS Preliminary
138 fb-1 (13 TeV)
×10-3
μμbb Final state
95% CL upper limits
Observed
Median expected
95% expected
68% expected
B(H → aa → μμbb)
0.6
0.5
0.4
0.3
0.2
0.1
0
15
20
25
30
35
40
45
50
55
60
ma1 (GeV)


137 fb^{-1} (13 TeV)
CMS
Observed
68% expected
95% expected
$\sigma^{H^+}_{GM}$, $s_H = 1$
$\sigma^{H^+}_{VBF} \times B(H^+ \to W^{\pm}Z)$ [pb]
1
10^{-1}
10^{-2}
1000
2000
3000
m_{H^+} [GeV]