Searches for additional Higgs bosons in ATLAS

Higgs 2021 (Oct 18 -22)

Yanjun Tu (University of Hong Kong)
on behalf of the ATLAS Collaboration

香 港 大 學
THE UNIVERSITY OF HONG KONG

Outline

- Introduction
- Latest Run II results of searching for additional Higgs Bosons in ATLAS
  - Heavy Neutral Higgs
  - Charged Higgs
  - Doubly Charged Higgs
- Summary

Introduction

- EWSB is still not well understood. Many new physics models predict extended Higgs sector (2HDM, 3 HDM, hMSSM etc.)
- Additional Higgs bosons have been extensively searched in ATLAS. The latest results with full Run II 139 fb^{-1} data are:

Heavy Neutral Higgs	
$A \to Zh(125)$	ATLAS-CONF-2020-043
$A \to ZH$	EPJC 81 (2021) 396
$H \to ZZ$	EPJC 81 (2021) 332
$A/H \to \gamma\gamma$	PLB (2021) 136651
$A/H \to \tau\tau$	PRL 125 (2020) 051801

Charged Higgs	
$H^{\pm} \to cb$	ATLAS-CONF-2021-037
$H^{\pm} \to tb$	JHEP 06 (2021) 145
$H^{\pm} \to W^{\pm}A$	ATLAS-CONF-2021-047
Doubly Charged Higgs	
$H^{\pm\pm} \to W^{\pm}W^{\pm}$ $H^{\pm\pm} \to W^{\pm}Z$	JHEP 06 (2021) 146

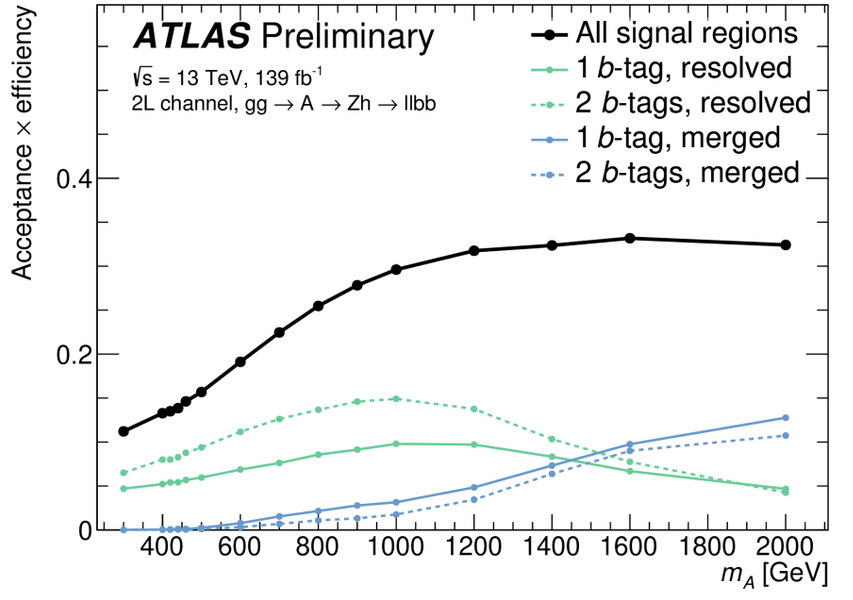
- Some heavy resonance searches could be interpreted in heavy Higgs (backup slides)

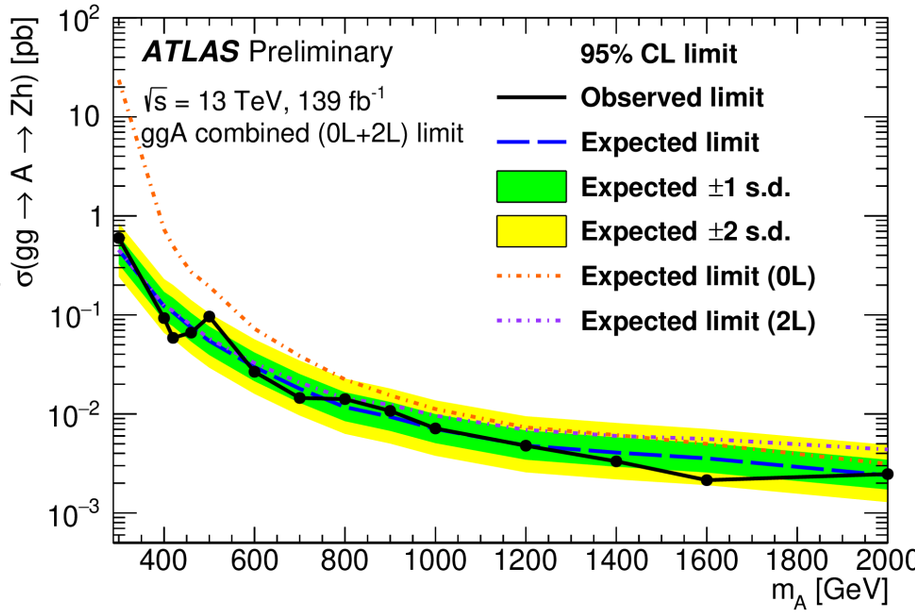
$X \to V\gamma$	ATLAS-CONF-2021-041
$W' \to WH$	ATLAS-CONF-2021-026
$X \to VV$	EPJC 80 (2020) 1165

- The previous results with partial Run II data are not presented.

Heavy neutral Higgs $A \to Zh$

- CP-odd A (ggF production), decays into a Z boson and the $h(125)$ already known.
  - $Z \to \ell^+\ell^-, h \to bb$ 2-Lepton channel
  - $Z \to \nu\nu, h \to bb$ 0-Lepton channel
- $h \to bb$ could be resolved (two small-R jets ΔR = 0.4) or merged (one large-R jet ΔR = 1.0).
- dominant backgrounds $t\bar{t}$ and Z+jets.
- dominant systematic uncertainties related to JES and JER.
- fit to the reconstructed resonance candidate mass.
- the most significant excess: local 1.6σ at 500 GeV in the 2-Lepton channel.

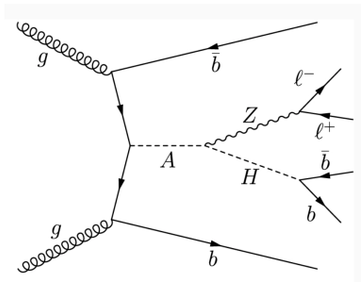


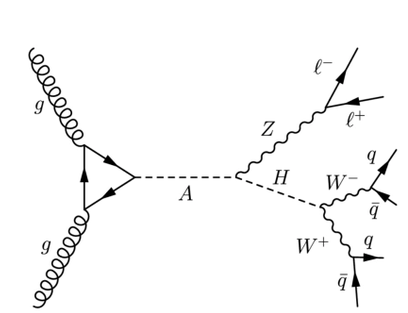


ATLAS-CONF-2020-043

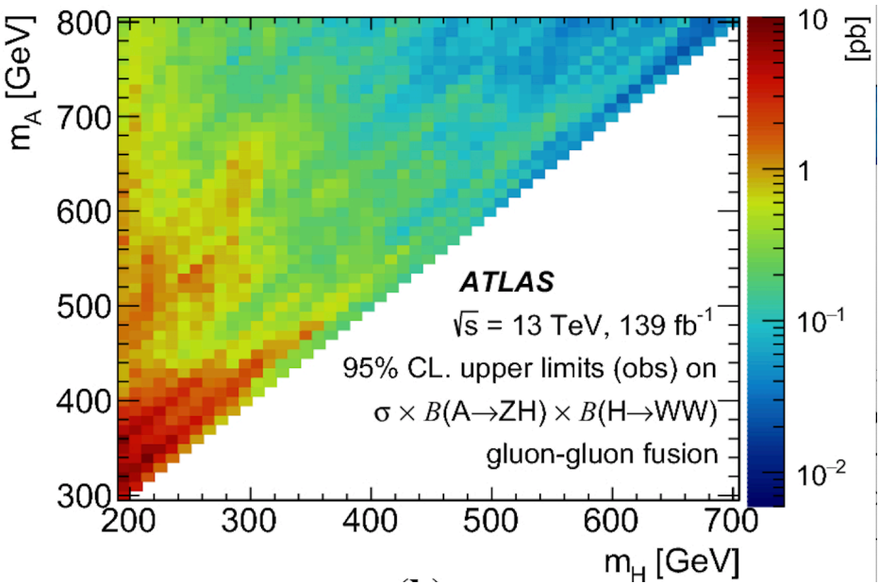
Heavy neutral Higgs $A \to ZH$

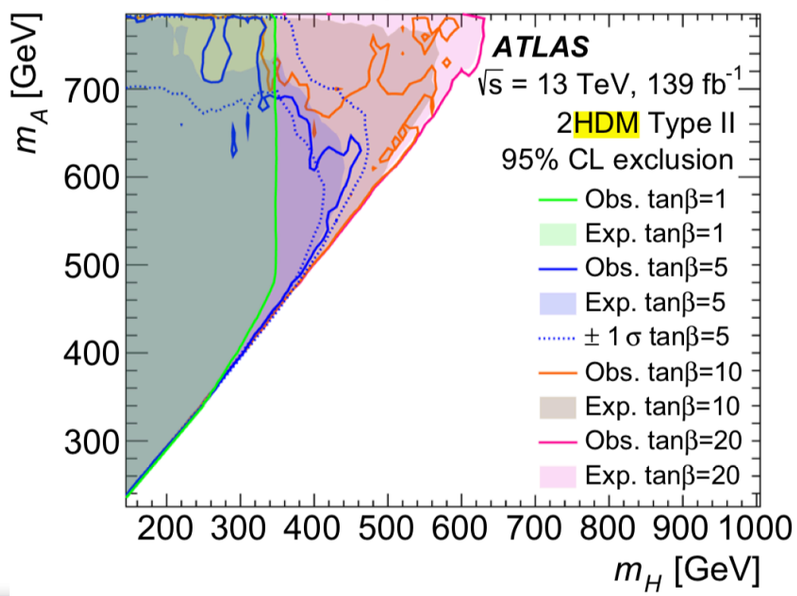
- when $m_A > m_H$, motivated by EWK baryogengesis in the 2HDM, CP-odd A decays into a Z boson and the CP-even H
  - $Z \to \ell^+\ell^-, H \to bb$ 2 b-jets (ggF) or >= 3 b-jets (bbA)
    - dominant backgrounds Z+jets and $t\bar{t}$, constrained from data
    - dominant systematics related to background modelling, the signal interpolation, and the JES and JER.
  - $Z \to \ell^+\ell^-, H \to WW \to \ell\ell 4q$ >=4 jets (ggF)
    - dominant backgrounds Z+jets, constrained from data
    - dominant systematics related to the JES and JER.
- the most significant excess:
  - local 3.1σ at $(m_A, m_H) = (610,290)$ GeV (ggF $\ell\ell bb$), or at $(m_A, m_H) = (440,220)$ GeV (bbA $\ell\ell bb$)
  - local 2.9σ at $(m_A, m_H) = (440,310)$ GeV (ggF $\ell\ell WW$)





EPJC 81 (2021) 396

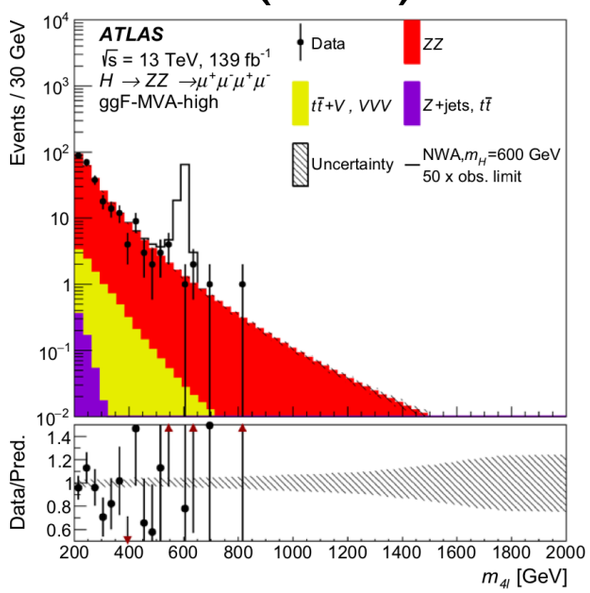


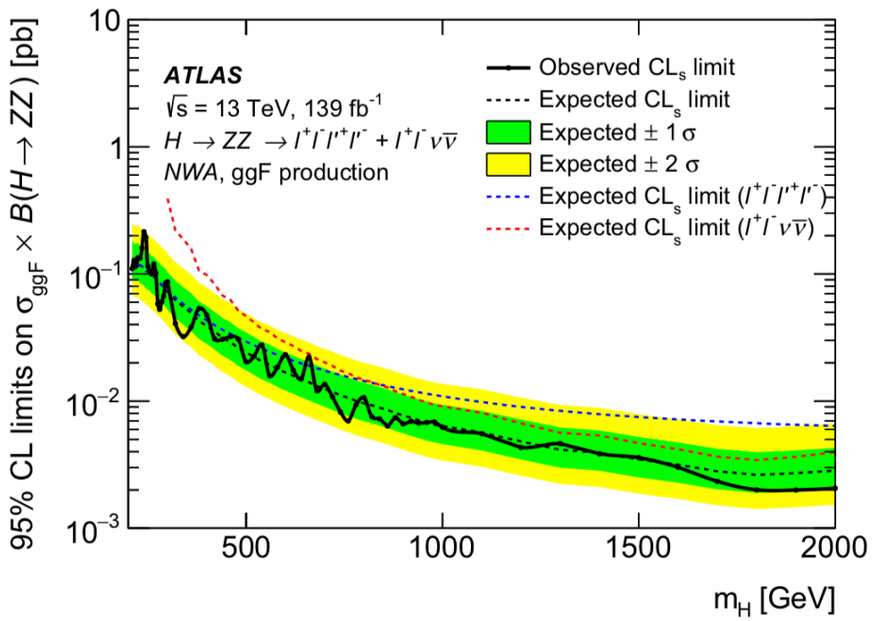


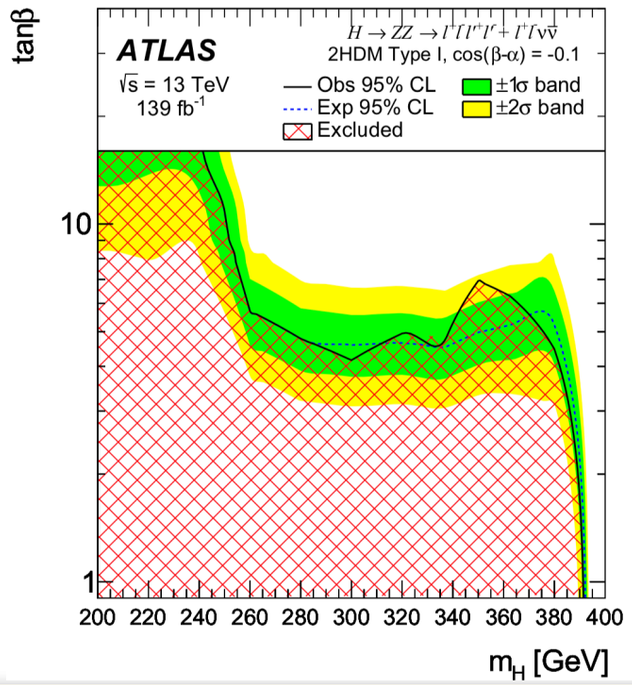
Heavy neutral Higgs $H \to ZZ$

EPJC 81 (2021) 332

- heavy neutral H decays into ZZ (ggF and VBF).
  - $\ell\ell\ell\ell$ dominant backgrounds non resonance ZZ, constrained from data
  - $\ell\ell\nu\nu$ dominant backgrounds ZZ, and WZ (in ggF enriched signal region).
- dominant systematics depend on production modes and mass hypothesis .
  - ggF: ZZ parameterisation, Z+jets, the NLO EW correction and parton shower
  - VBF: theoretical modelling of the discriminating variables the ZZ events, JES
- two DNNs (ggF and VBF), cut based (VBF).
- the most significant excess for narrow width: local 2.0σ at 240 GeV (ggF), 2.4σ at 620 GeV (VBF).

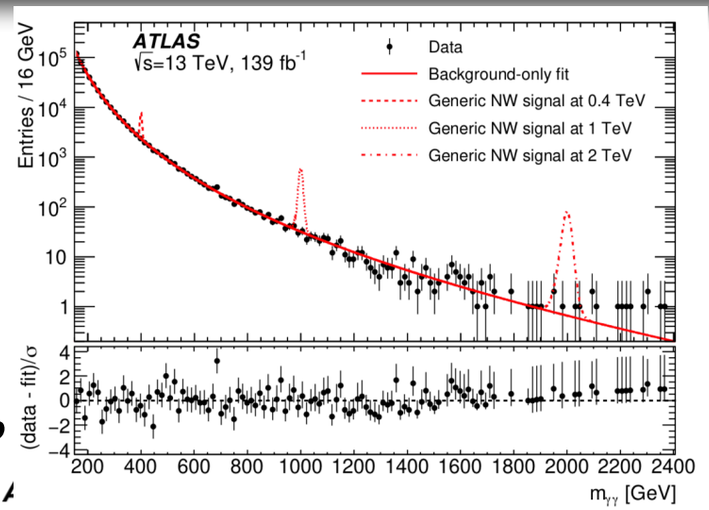


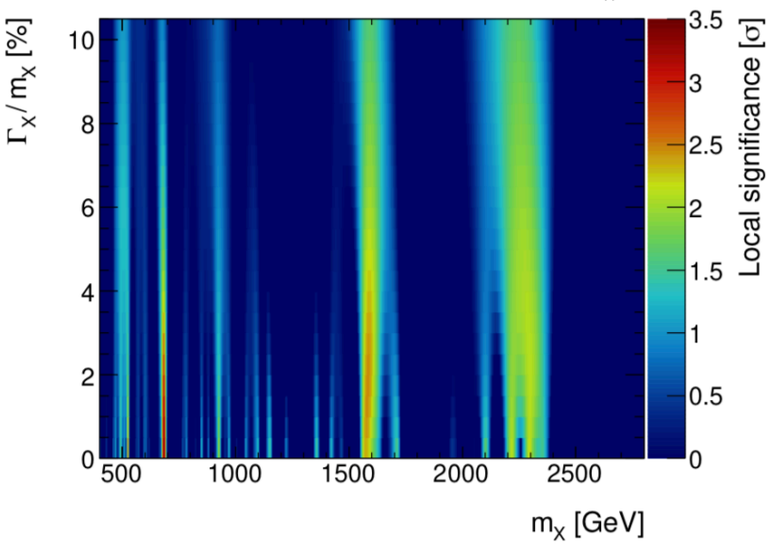


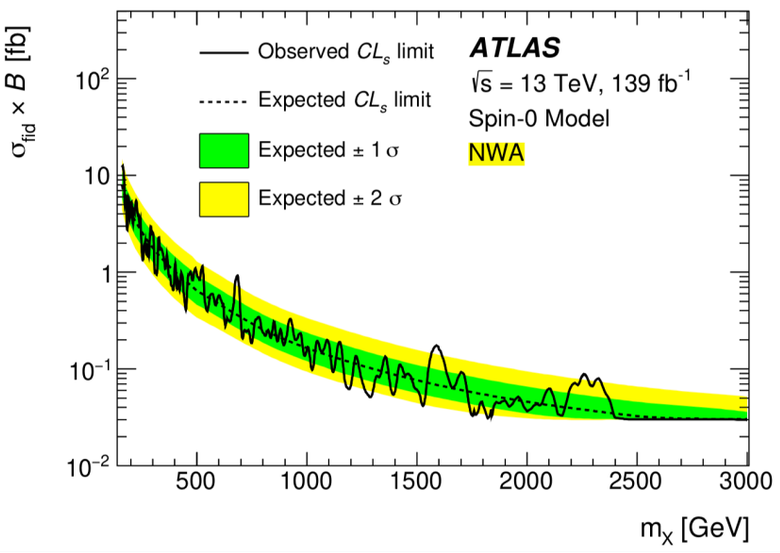


Heavy neutral Higgs $A/H \to \gamma\gamma$

- high-mass resonance decays into two photons.
- dominant backgrounds: non-resonant $\gamma\gamma$, γj, jj.
- improved object reconstruction, energy calibration, and description of the spurious-signal uncertainty
- additional kinematic cuts: $E_T/m_{\gamma\gamma}$> 0.3 (leading γ), $E_T/m_{\gamma\gamma}$> 0.25 (sub-leading γ).
- fit signal and background components using analytical functions.
  - background: from Sherpa $\gamma\gamma$ MC and data-driven γj
  - data: double-sided crystal ball convolved with BW
- the most significant excess for narrow width:
  - local 3.29σ at 684 GeV

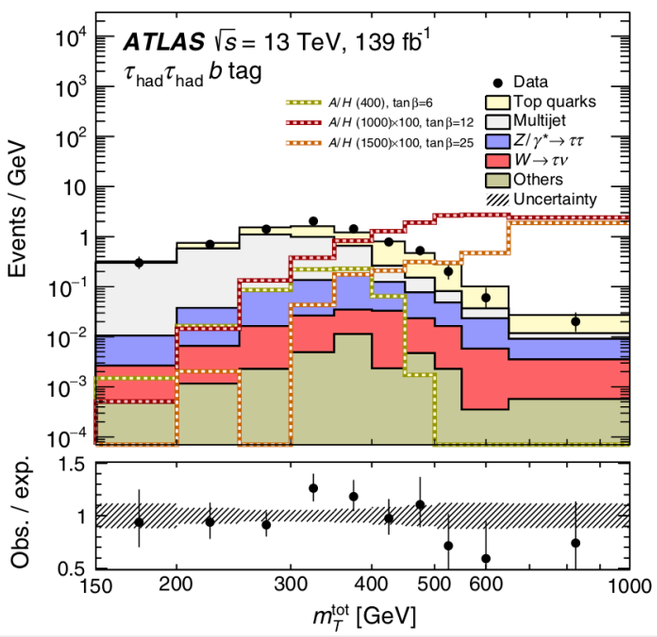


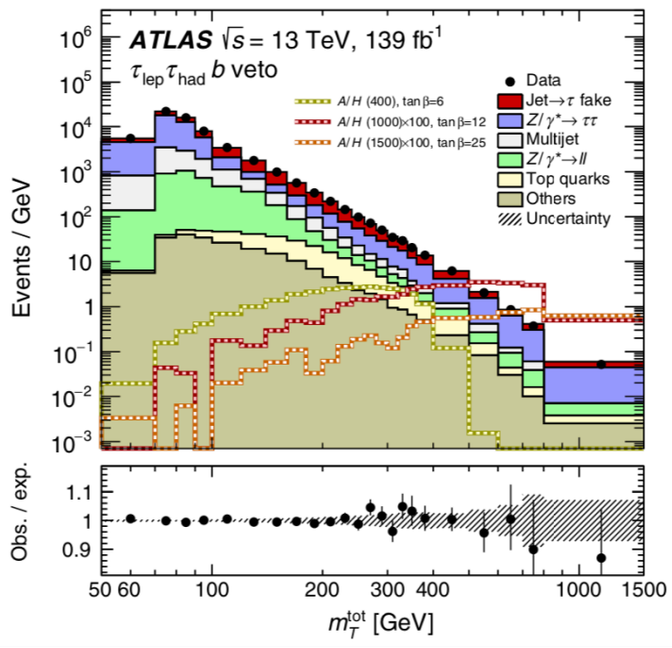


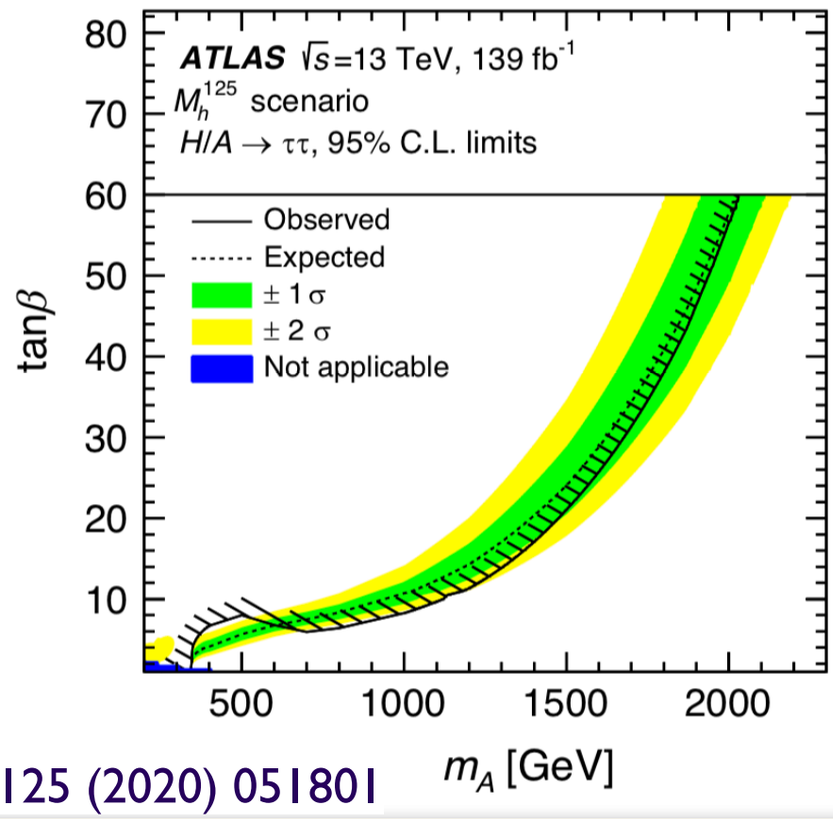


Heavy neutral Higgs $A/H \to \tau\tau$

- two channels $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ with *b* tag and *b*-veto categories (ggF, bbA)
- improved modelling of the top-quark background, the backgrounds estimated from data, the reconstruction of high-P_T τ
- dominant backgrounds from jet fake τ or lepton, data-driven estimation.
- major systematic uncertainties related the τ_{had} identification efficiency and energy scale etc.
- the most significant excess: local 2.2 σ at 400 GeV (ggF), 2.7 σ at 400 GeV (bbA)
- strongest MSSM limits, especially at high tanβ.



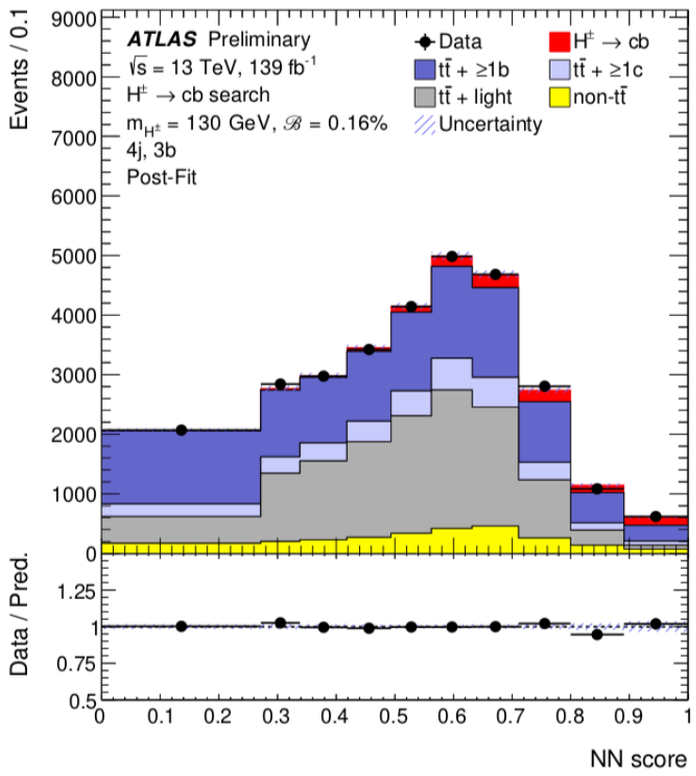


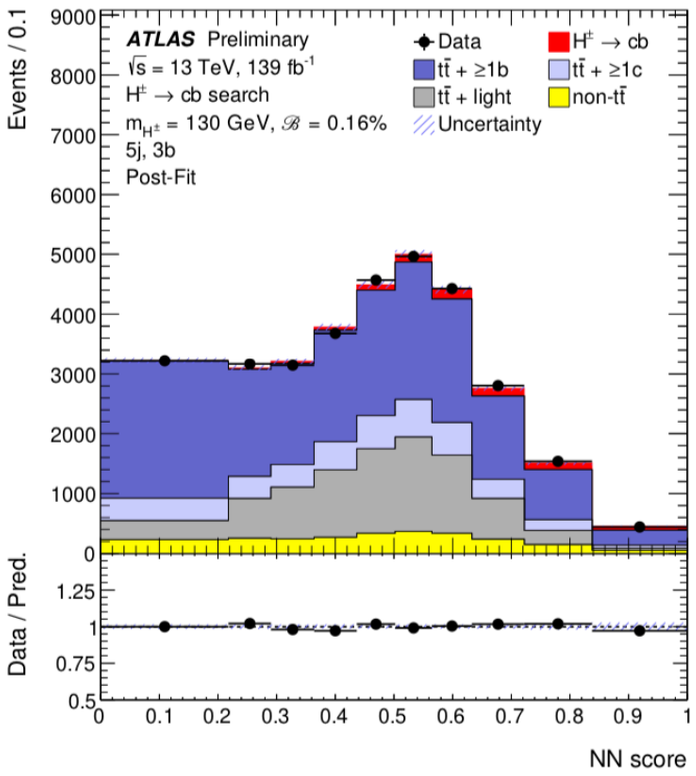


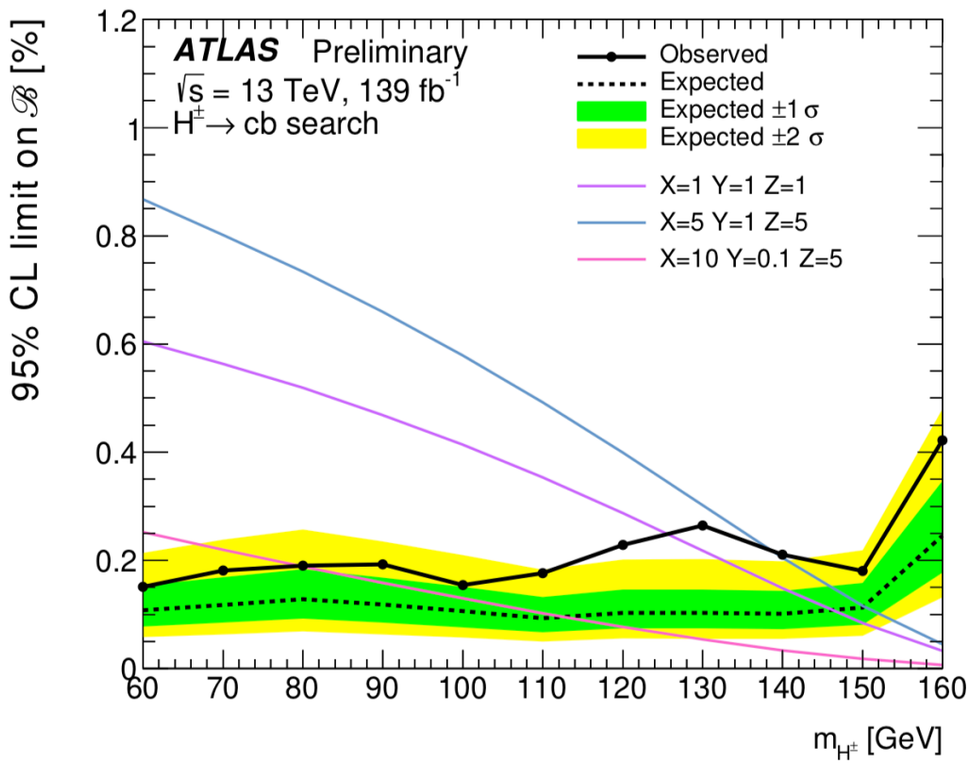
PRL 125 (2020) 051801

Light Charged Higgs $H^{\pm} \to cb$

- search for light charged Higgs $m_{H^{\pm}}$ 60 GeV to 160 GeV ATLAS-CONF-2021-037
- $pp \to t\bar{t} \to W^{\pm}bH^{\pm}b$ ($H^{\pm} \to cb$, $W \to \ell\nu$), one lepton ℓ + ≥ 4jets (≥ 3b-jets)
- low SM background from $t\bar{t}$ production compared to $H^{\pm} \to cs$ and $H^{\pm} \to \tau\nu$ channels, due to the *Vcb* suppression.
- dominant backgrounds SM $t\bar{t}$+jets, corrected and constrained from data.
- fit on the NN output distributions under the signal-plus-background hypothesis
- the most significant excess: local 3.0σ at 130 GeV



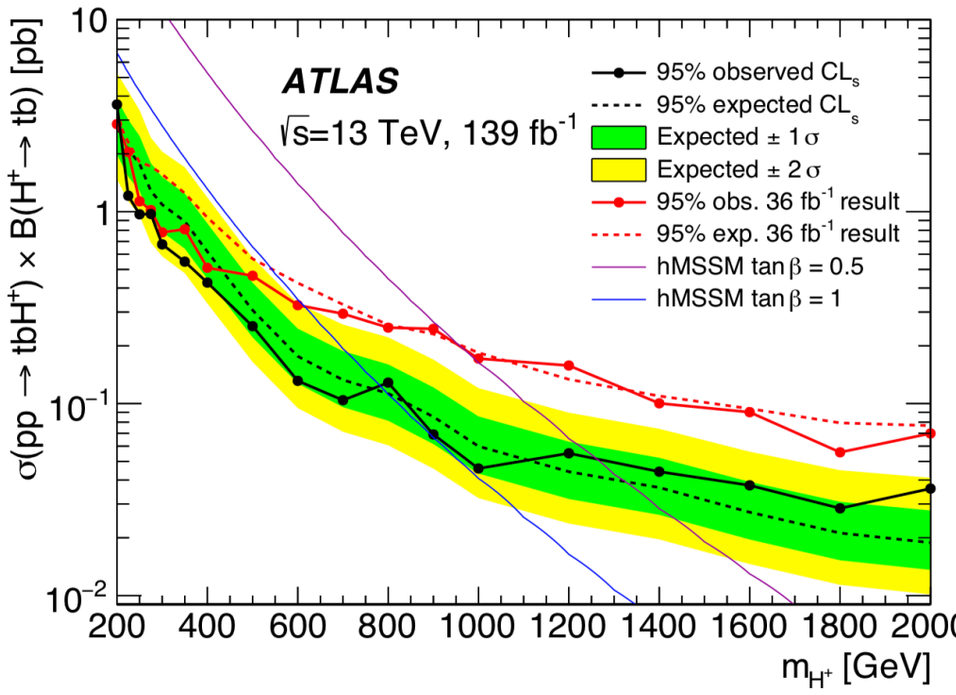


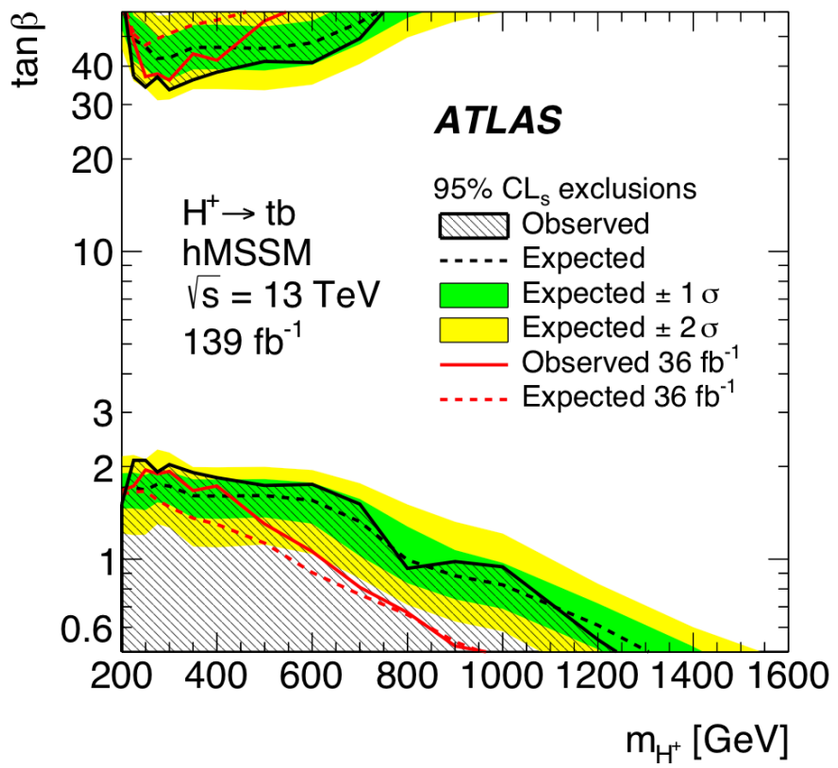


Heavy Charged Higgs $H^{\pm} \to tb$

- search for heavy charged Higgs in tb associated production: $pp \to tbH^{\pm} \to tbtb$, exact one lepton, 5jets ($\geq 3b$-jet).
- dominant background $t\bar{t}$+jets, constrained from data.
- fit to the data on the NN output distributions, and each mass hypothesis is tested separately.
- dominant systematics related to the $t\bar{t}$ modelling,.
- compared to previous ATLAS search with 36 pb^{-1}
  - the observed σ × Branching ratio limits improved by 5% to 70%, depending on the $H^{\pm}$ mass
- sensitive in low tanβ, complementary to $H/A \to \tau\tau$

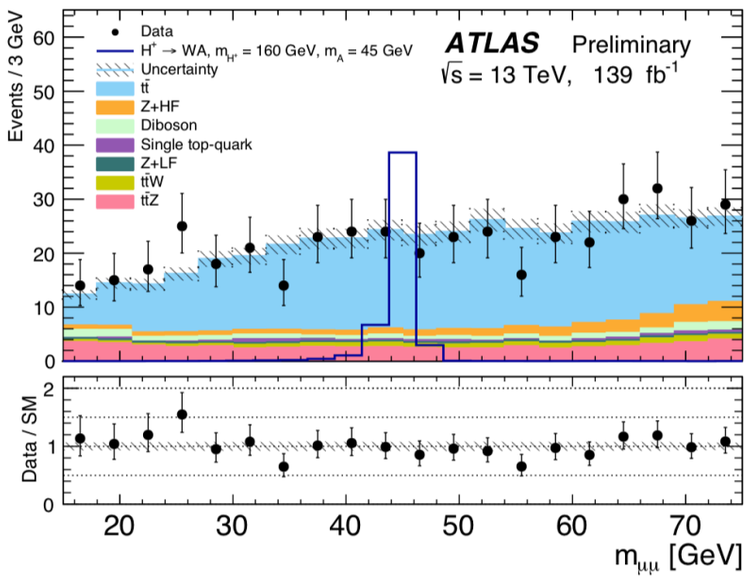
JHEP 06 (2021) 145

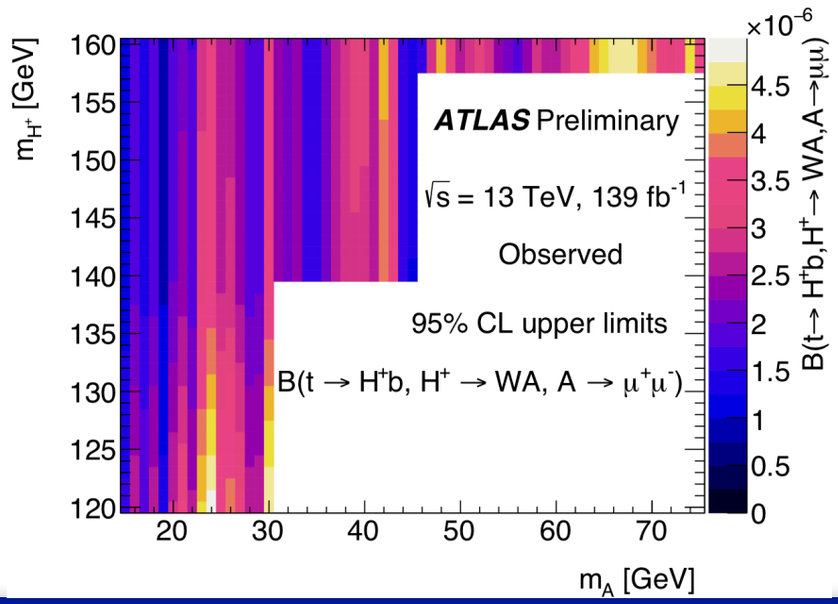


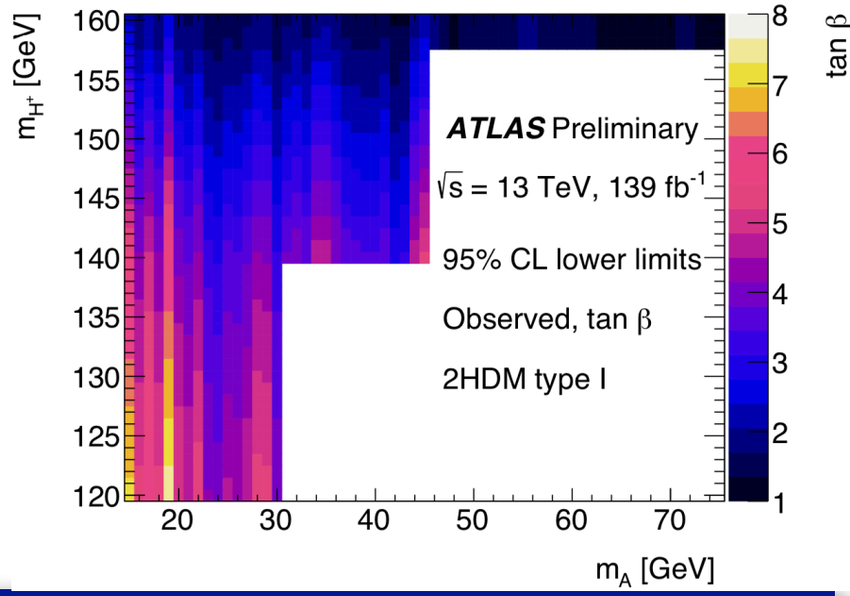


Light Charged Higgs $H^{\pm} \to W^{\pm}A$

- search for light charged Higgs $m_{H^{\pm}}$ 100 GeV to 160 GeV ATLAS-CONF-2021-047
- $pp \to t\bar{t} \to W^{\pm}bH^{\pm}b$ ($H^{\pm} \to W^{\pm}A$, $A \to \mu\mu$), one electron, two muons, ≥ 3 jets ($\geq 1b$-jet), m_A 15 GeV to 75 GeV.
- dominant backgrounds $t\bar{t}(fake), ttZ, Z$+heavy flavor jets, constrained from data
- search for an excess in the opposite-sign $m_{\mu\mu}$ spectrum in 15 to 75 GeV range, with counting experiments in multiple mass windows.
- dominant systematics from the $t\bar{t}$, ttZ normalisation, the $t\bar{t}$ modelling(hard-scatter and parton shower) and the limited statistics of MC samples.
- the most significant excess: local 1.24σ at 24 GeV

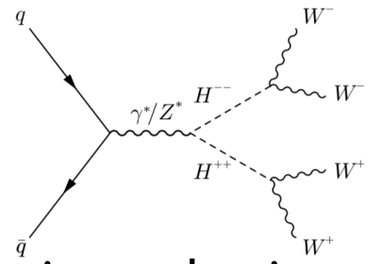




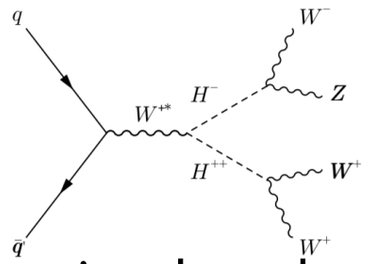


Doubly Charged Higgs $H^{\pm\pm} \to W^{\pm}W^{\pm}/W^{\pm}Z$

- search for doubly charged Higgs $H^{\pm\pm}$ and singly charged $H^{\pm}$ in two scenarios of a type-II seesaw model.
- 3 channels: $2\ell(SS), 3\ell, 4\ell$
- backgrounds with prompt lepton from the MC simulation (WZ constrained by data), with non-prompt lepton from the data-based method.
- the model is excluded for $M_{H^{\pm\pm}} < 350$ GeV (pair production), for $M_{H^{\pm\pm}} < 230$ GeV (associated production)

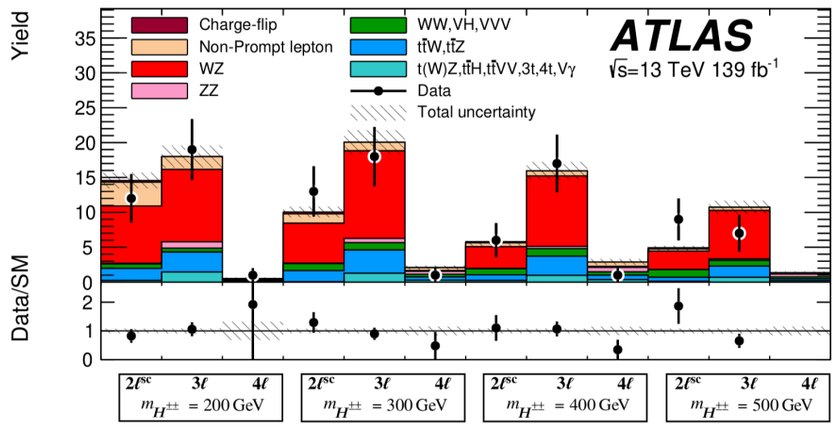


pair production

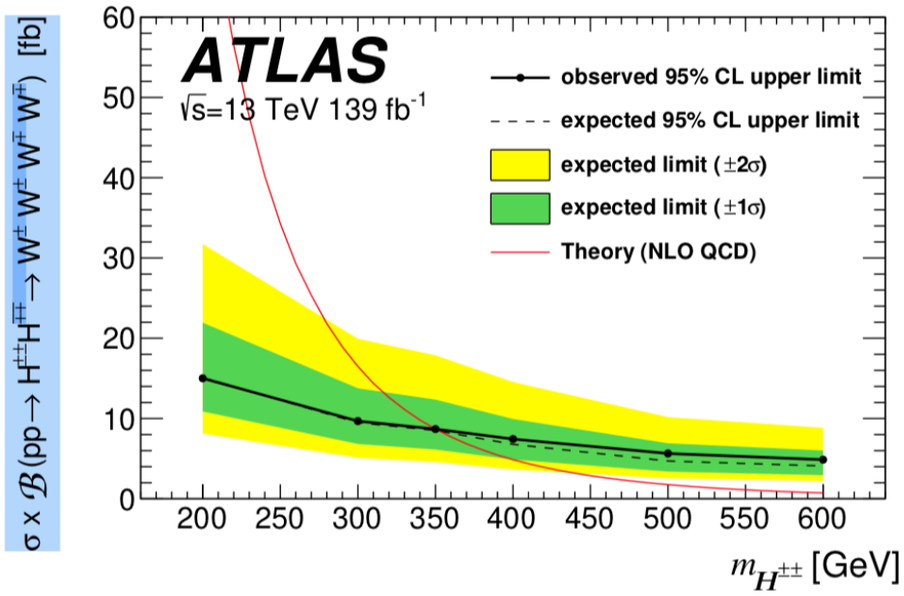


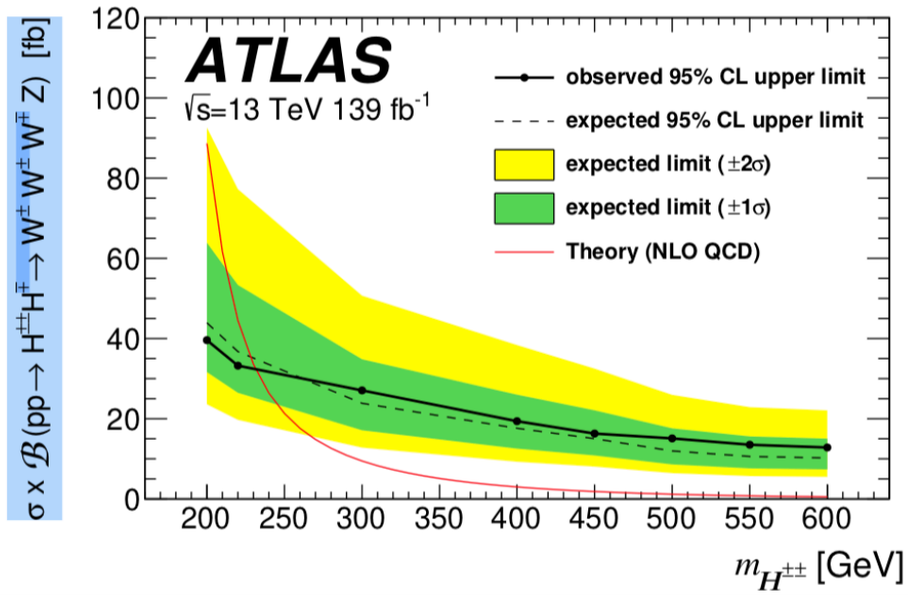
associated production

$m_{H^{\pm}} - m_{H^{\pm\pm}} \geq 100$ GeV $|m_{H^{\pm}} - m_{H^{\pm\pm}}| \leq 5$ GeV



JHEP 06 (2021) 146

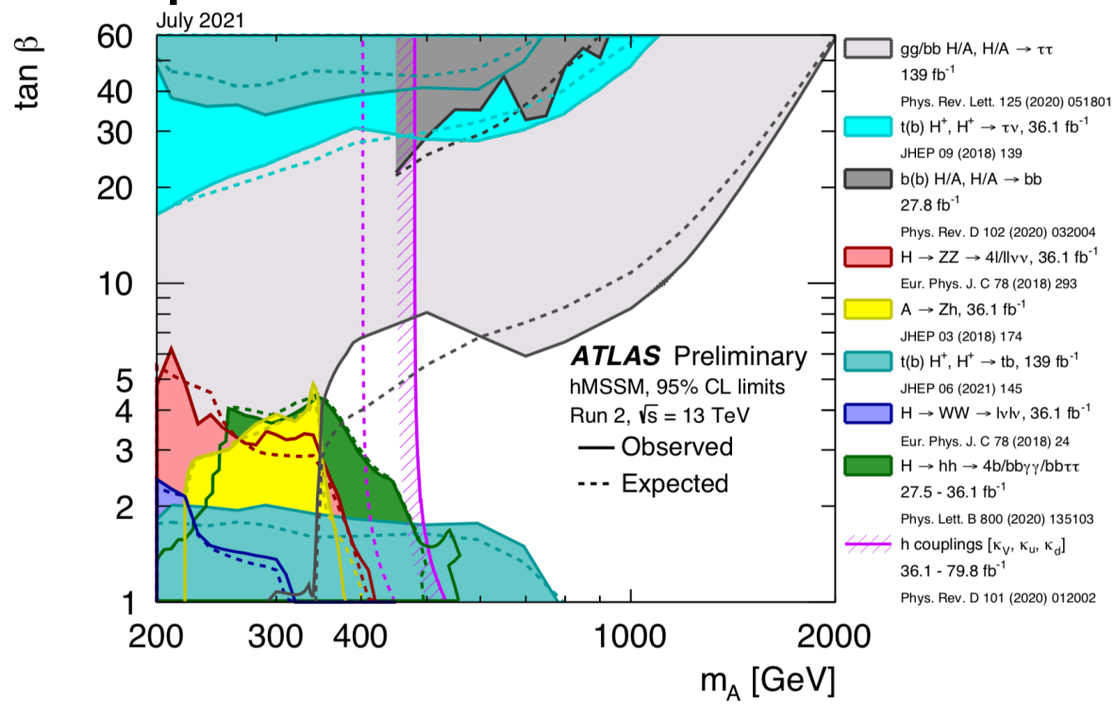




Summary

- additional Higgs bosons have been extensively searched in many channels in ATLAS.
- the latest results with full Run II data are presented. Significant improvements are made compared to the previous searches.
- no significant excess from the SM prediction has been observed. Individual analyses have local 3σ excess, but this is expected.
- more analyses results will be delivered with full Run II data
- more uncovered phase space will be explored.

hMSSM summary plot from direct and indirect searches
ATL-PHYS-PUB-2021-030

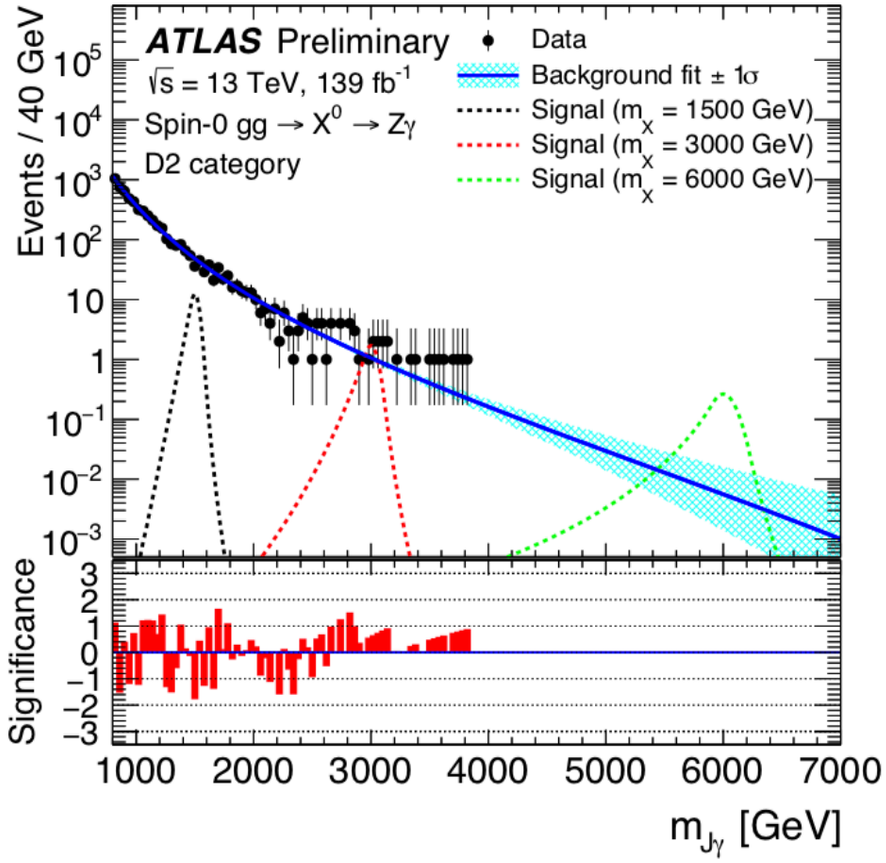


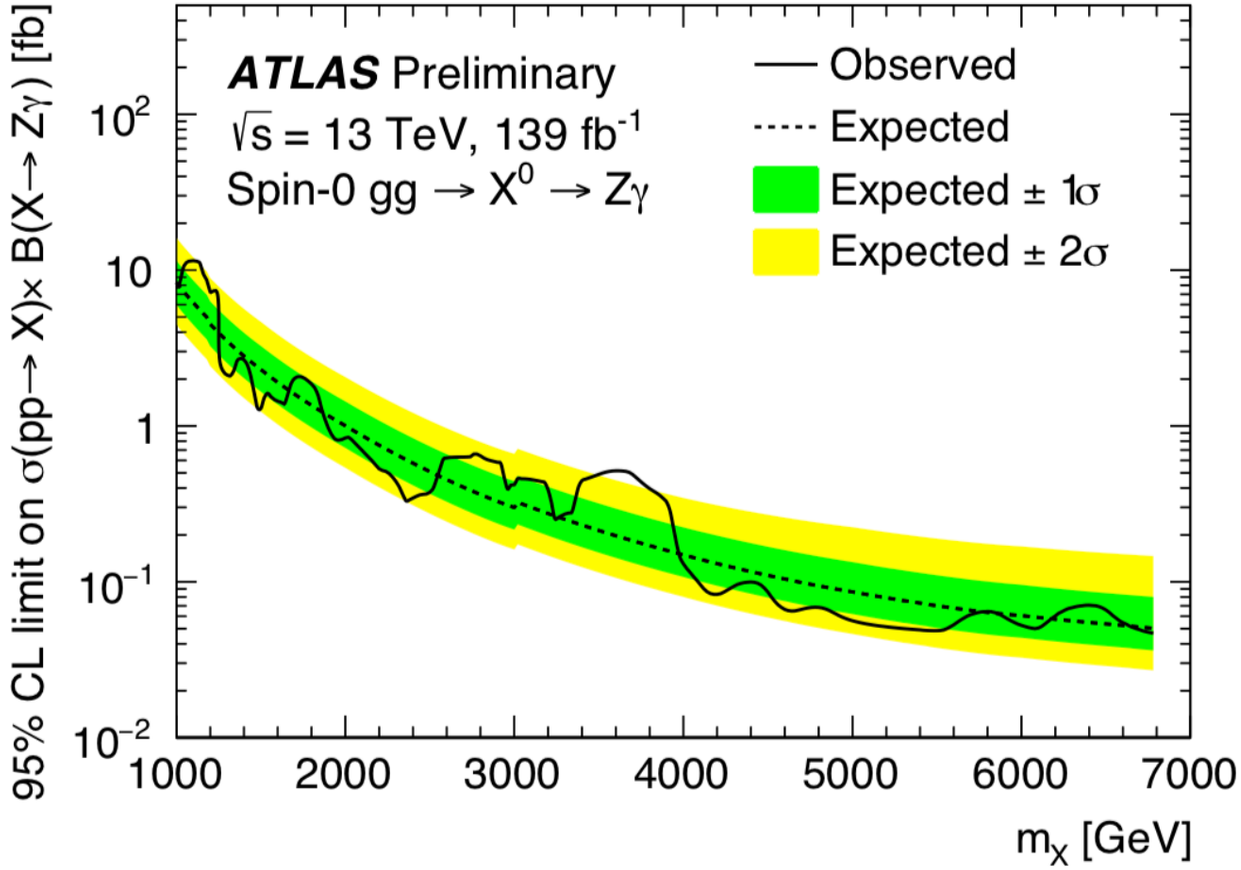
Thanks for your attention!

Backup

Heavy resonance $X \to V\gamma$

- heavy resonance X (>1 TeV) decays into $Z\gamma$ or $W\gamma$, leading to one photon and a large ΔR = 1.0 jet
- dominant backgrounds γj
- optimised the identification of the hadronic decays of highly boosted Z bosons (and *W in spin-1 particle search*).
- the most significant excess : local 2.5σ at 3640 GeV ATLAS-CONF-2021-041

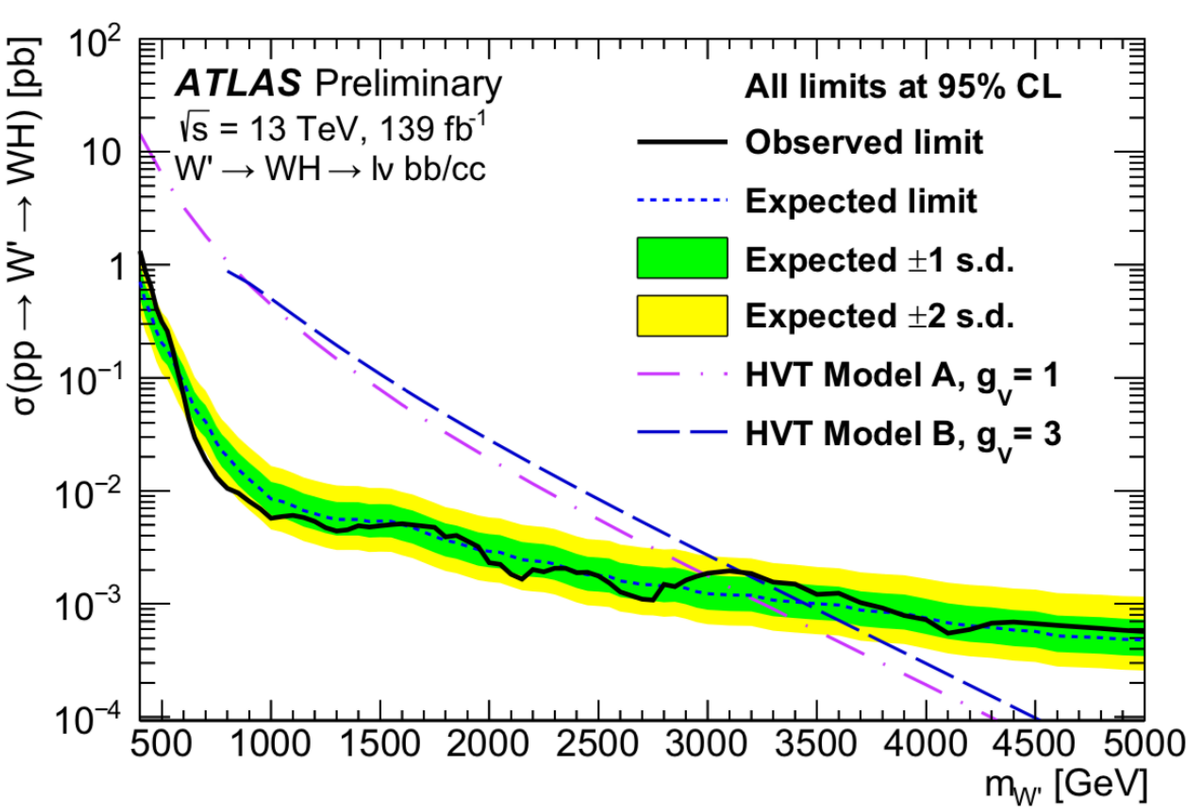


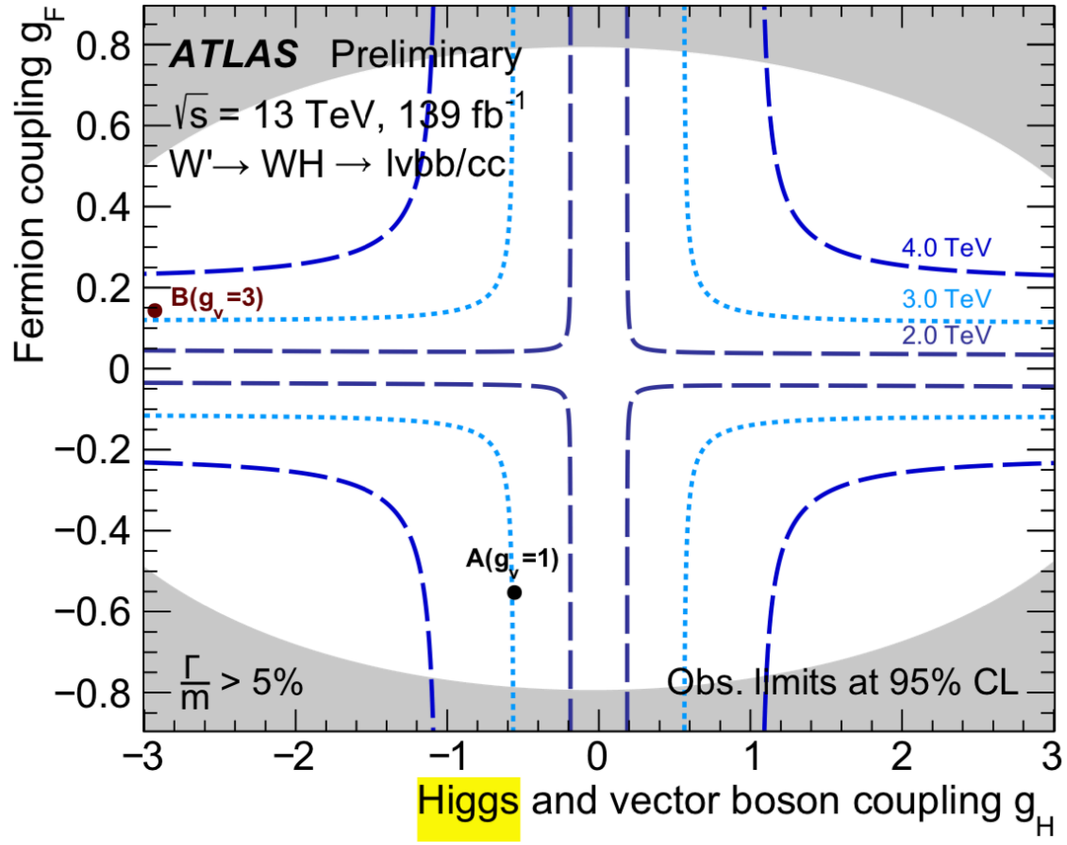


Heavy resonance $W' \to WH$

- heavy resonance W' decays into WH, $W \to \ell\nu, H \to bb/cc$, HVT benchmark models
- dominant backgrounds $W + jets$, $t\bar{t}$, and $Z + jets$
- improved b-tagging, lepton isolation and jet reconstruction
- the cross-section limits improve by at least 200% on the search results from the analysis on the partial Run II data

ATLAS-CONF-2021-026





Heavy resonance $X \to VV$

- heavy resonance X decays into VV, $W \to \ell\nu, H \to bb/cc$, interpreted as radions, heavy bosons, gravitons
- 0-lepton ($\nu\nu qq$), 1-lepton ($\ell\nu qq$), 2-leptons ($\ell\ell qq$)
- dominant backgrounds $V + jets, t\bar{t}$
- MVA for distinguishing production processes, using tracking information in the large-*R* jet, and introducing *b*-tagging for large-*R* jets.

EPJC 80 (2020) 1165