Current ATLAS Results and HL-LHC Prospects for New Scalar Searches

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On behalf of the ATLAS Collaboration

Outline

- Introduction

- ATLAS Searches for BSM Additional New Scalars
  - Heavy Scalar Resonances
  - New Neutral Scalar Resonances
  - Charged Higgs

- ATLAS Searches for BSM (Exotic) Higgs Decays into New Pseudo-scalars (a)

- ATLAS Searches for New Heavy Resonances decaying to HH
- HL-LHC Prospects

- Conclusions

Introduction

- After the discovery in 2012 of the Higgs boson at 125 GeV studies of Higgs properties and Higgs sector nature continue
- SM leaves some phenomena unexplained e.g. hierarchy problem, baryon asymmetry, dark matter/ energy, flavor problem etc.
- Extended Higgs sectors predicted by many theories of BSM physics, especially theories with naturalness, axions, SUSY, or dark matter.
- Additional scalars (neutral or charged) are predicted in modified/extended Higgs models and can be probed in low/high-mass resonance searches.
- Searches for rare and exotic decays of the Higgs boson are an important component of the “precision” Higgs program.
- Some recent ATLAS results highlighted in this talk (Run-2 data results)

ATLAS Searches for Heavy Resonances

- $H \rightarrow$ ZZ high mass
- Generic Heavy Higgs search VH, V:Z,W **New!**
  - $W^{\pm}H \rightarrow W^{\pm}W^{\pm}W^{\mp} \rightarrow \ell^{\pm}\nu\ell^{\pm}\nu jj$

- In additional slides:
  - H → γγ high-mass resonance
  - A/H → ττ
  - A→Zh, Z→2e/2μ or 2ν, h →bb
  - A→ZH, Z→2e/2μ, H →bb, WW
  - W/Z +γ, $X^{\pm} \rightarrow W^{\pm}\gamma$, $X^{0} \rightarrow Z\gamma$

ATLAS Summary Plots
- ATLAS-CONF-2022-028 New!
- ATL-PHYS-PUB-2022-008
- ATL-PHYS-PUB-2021-018
- ATL-PHYS-PUB-2021-030

Search BSM H→ZZ→4ℓ+ℓℓνν - Analysis

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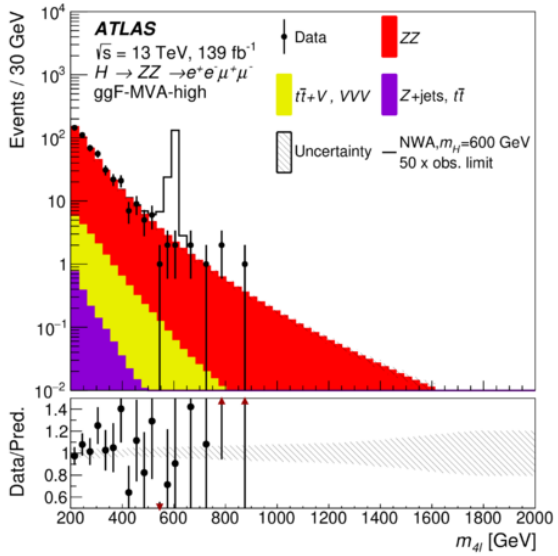
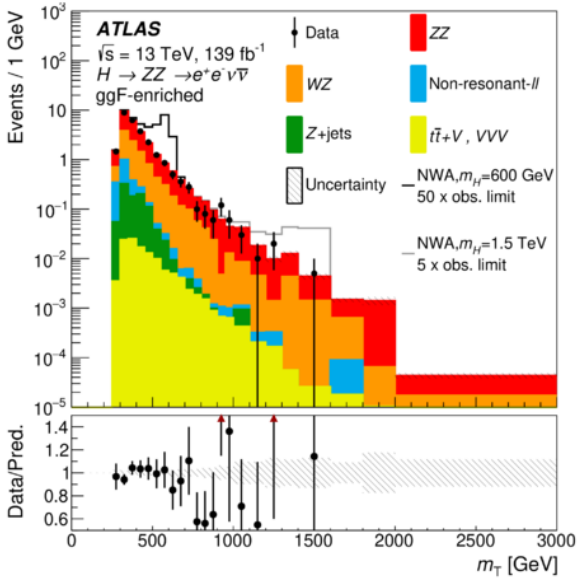
- Heavy ZZ resonances (spin-0 or spin-2) appear in many BSM models like:
  - Additional Higgs boson in two-Higgs-doublet model (2HDM)
  - Graviton in Randall-Sundrum (RS) model
- Searches for heavy resonances in combination of 4ℓ and ℓℓνν final states improve overall sensitivity due to:
  - good mass resolution of 4ℓ and large BR of ℓℓνν
- Mass range 200 GeV to 2 TeV (for heavy Higgs)
- Narrow widths (NW) and large widths (LW) considered, VBF included for NW only
- LW search includes interference effects with background

- Machine Learning (DNN) used in the NW analysis
- Lepton and jet reconstruction, isolation improved
- Cross section limits for:
  - Spin 0 resonance: ggF+VBF - Narrow Width (NW) and ggF Large Width (LW) heavy Higgs
- Interpretations of:
  - Spin-0 resonance: 2HDM (Type-I, -II)
  - Spin 2 resonance: Graviton RS

Distribution of $m_{4\ell}$ (4ℓ) invariant mass & transverse mass m_T (2ℓ2ν)





- No significant excess with respect to the background predictions found

$$m_{\mathrm{T}} \equiv \sqrt{\left[\sqrt{m_Z^2 + \left(p_{\mathrm{T}}^{\ell\ell}\right)^2} + \sqrt{m_Z^2 + \left(E_{\mathrm{T}}^{\mathrm{miss}}\right)^2}\right]^2 - \left|\vec{p}_{\mathrm{T}}^{\,\ell\ell} + \vec{E}_{\mathrm{T}}^{\mathrm{miss}}\right|^2}$$

Search BSM H→ZZ→4ℓ+ℓℓνν - Limits

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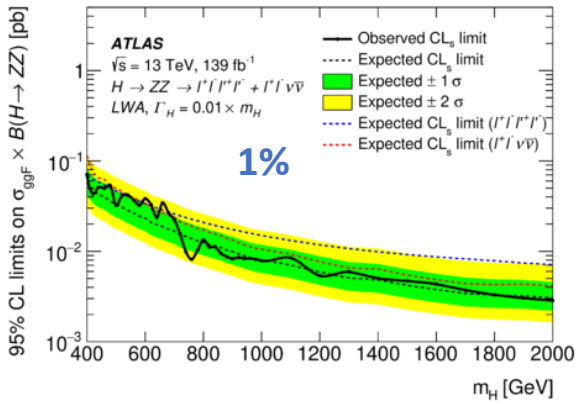
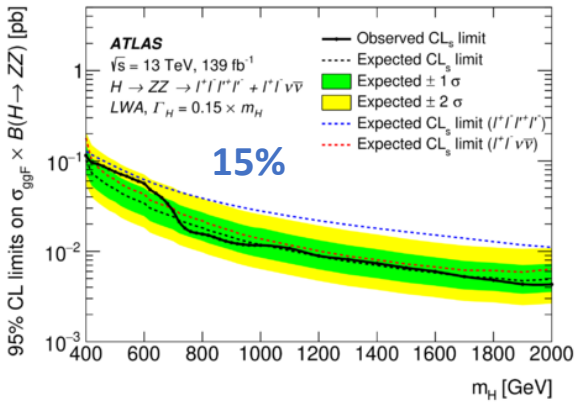
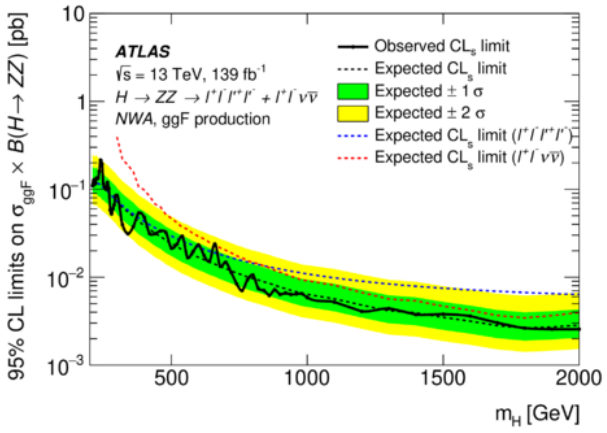
- Upper limits (95% CL) on production cross section
- For NW study
  - Both ggF and VBF signals included
  - MVA-based analysis used as baseline for NWA
- For LW study only ggF production and Cut-based analysis
  - Search mass range above 400 GeV
  - Interpretation at 4 widths: 1, 5, 10, 15% of signal mass
  - Interference of H-B and H-h taken into account (up to ~10%)
- For Graviton excitation search in the context of the bulk RS model:
  - NW Cut-based study for mass above 600 GeV

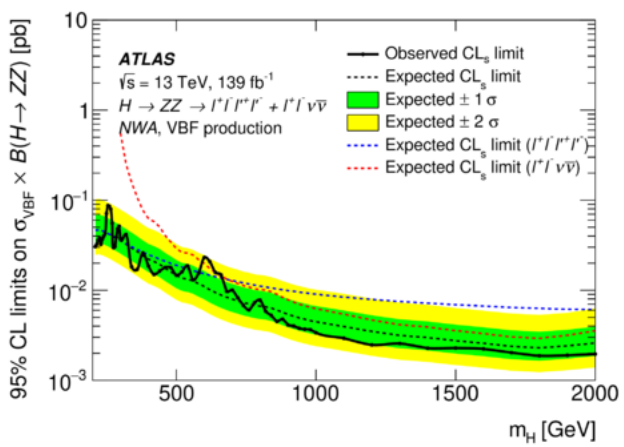
Large Width Combined 4ℓ + 2ℓ2ν





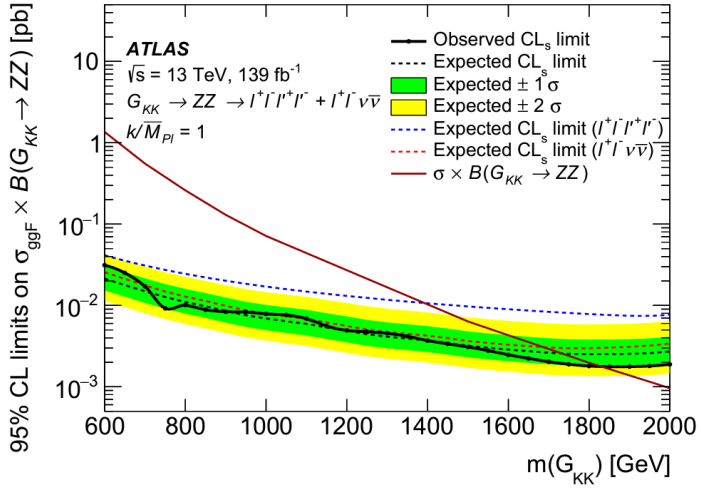
Narrow Width Combined 4ℓ + 2ℓ2ν





- ggF: 200 pb (240 GeV) - 2.6 fb (2000 GeV)
- VBF: 87 fb (255 GeV) - 1.9 fb (1800 GeV)

'Graviton' Combined 4l + 2l2ν



- Compared to theoretical prediction, mass < 1830 GeV excluded

Upper limits improved ~60% (wrt 36 fb^{-1} publication) on σ of spin-0 and spin-2 resonances

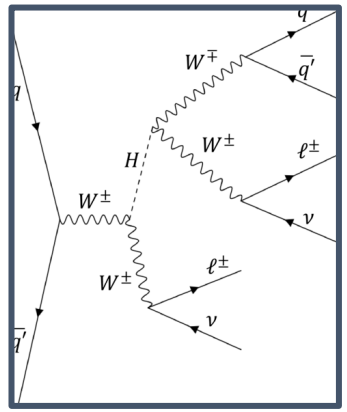
Generic Heavy Higgs search VH - Analysis

New!

ATLAS-CONF-2022-033

- Target searches for model-independent heavy Higgs boson produced in VH channel in same-sign di-lepton final state

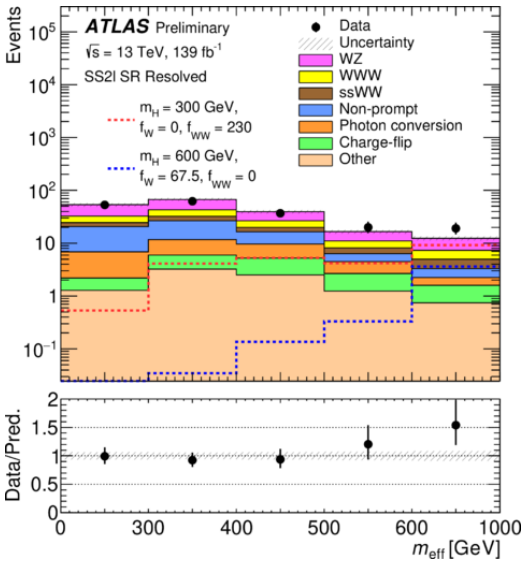
- Search for heavy Higgs bosons (mass: 300 GeV -1.5 TeV) decaying into a pair of vector bosons
- Analysis concentrates on associated production with a vector boson (VH, $V = W, Z$)



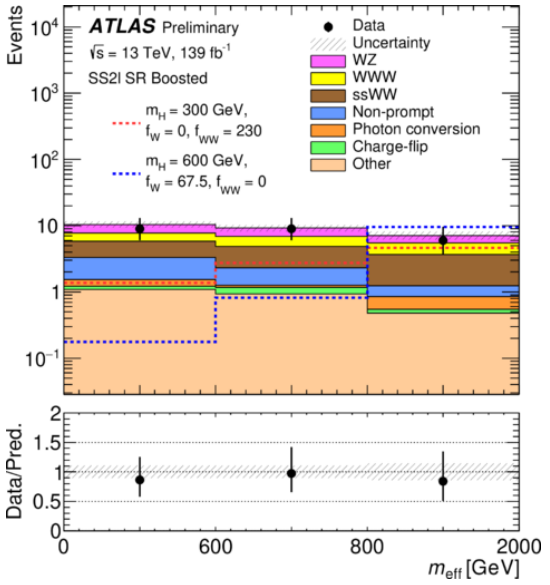
- $W^{\pm}H \rightarrow W^{\pm}W^{\pm}W^{\mp} \rightarrow \ell^{\pm}\nu\ell^{\pm}\nu jj$

- Final states ($\ell^{\pm}\nu\ell^{\pm}\nu qq$) with 2 leptons of the same electric charge (ℓ: e or μ) (SS2L), missing transverse momentum and jets
  - Veto: used for 3rd lepton at event selection level
  - 2 categories for reconstruction of $W \rightarrow qq$ with mass around 80 GeV:
    - Resolved: two small-R jets or
    - Boosted: one large-R jet

- Resolved SR



- Boosted SR



- Dominant SM backgrounds: WZ + jets, SS WW + jets
  - Control regions (WZ CRs, ssWW CR)
- Electron-charge flip background (suppressed by BDT and other cuts)
- Non-prompt background (CR) and photon conversion (CR Wγ)

- Observable "effective mass"- $M_{eff} = \sum P_T^{Lepton} + \sum P_T^{V\text{-jets}} + E_T^{miss}$

- Observed data in agreement with SM background

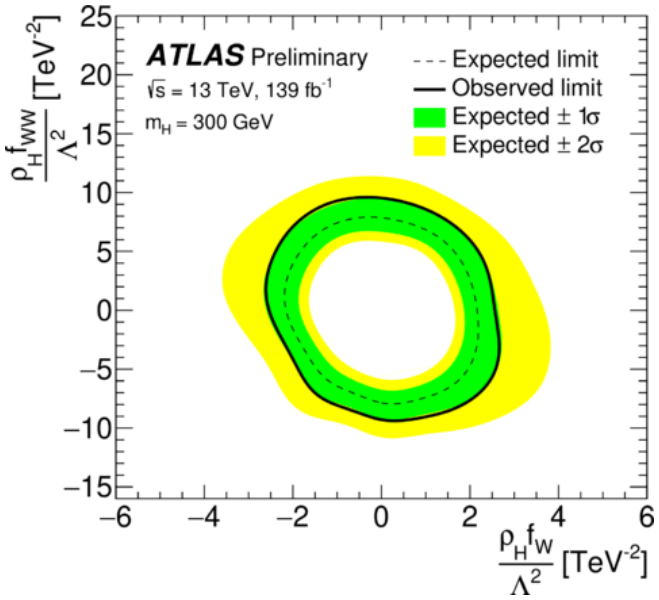
Generic Heavy Higgs search VH - Limits

New!

- Results are interpreted using higher dimensional operators in an EFT
- 95% CL cross-section limits as a function of heavy m_H and coupling strengths to vector bosons

ATLAS-CONF-2022-033

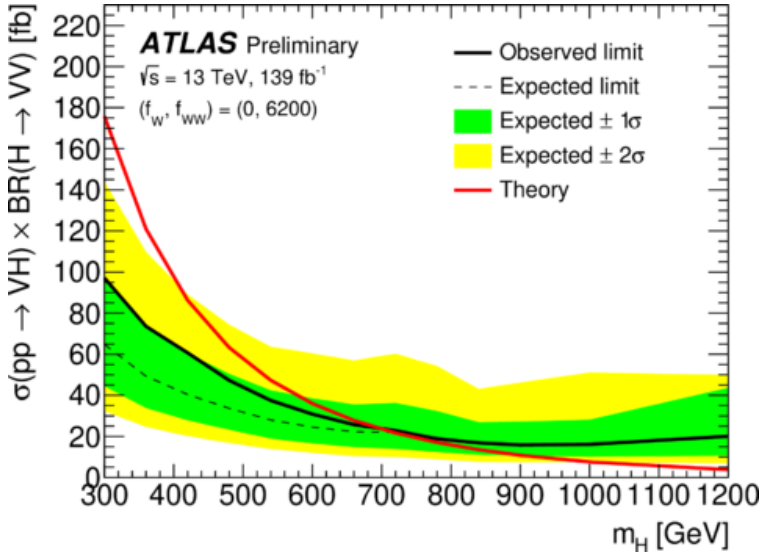
- 95% CL observed, expected upper limits on production of heavy Higgs as function of BSM HVV coupling strengths: $\rho_H f_W/\Lambda^2$ and $\rho_H f_{WW}/\Lambda^2$ with mass 300 GeV (also studied 600, 900 GeV)



- f_W, f_{WW}, anomalous couplings to W fields
- $\rho_H = \sin(\beta - \alpha)$ scaling factor set to 0.05
- Λ scale set to 5 TeV

- Coupling strengths of $|(\rho_H f_{WW})/\Lambda^2| > 2.7$ TeV^{-2} and $|(\rho_H f_{WW})/\Lambda^2| > 10$ TeV^{-2} excluded at 95% CL for the production of heavy m_H = 300 GeV

- 95% CL observed, expected upper limits on production of heavy Higgs boson as function of mass with (f_W, f_{WW}) fixed at (0, 6200)



- Limits are set in m_H region 300 to 1500 GeV, and depend upon the assumed couplings

- Heavy Higgs bosons are excluded at 95% CL up to 700 GeV and 900 GeV with anomalous couplings to vector bosons (f_W , f_{WW}) fixed at (0,6200) and (1350,0)

New!

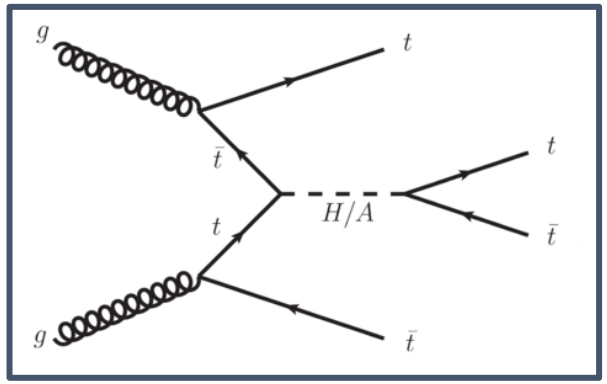
ATLAS Searches for New Neutral Resonances

- $t\bar{t}H/A \rightarrow t\bar{t}t\bar{t}$
- $WZ \rightarrow \ell\nu\ell'\ell'$ resonance
- FCNC $t \rightarrow qX$ (q=u,c), $X \rightarrow b\bar{b}$

$t\bar{t}H/A \rightarrow t\bar{t}t\bar{t}$ - Analysis

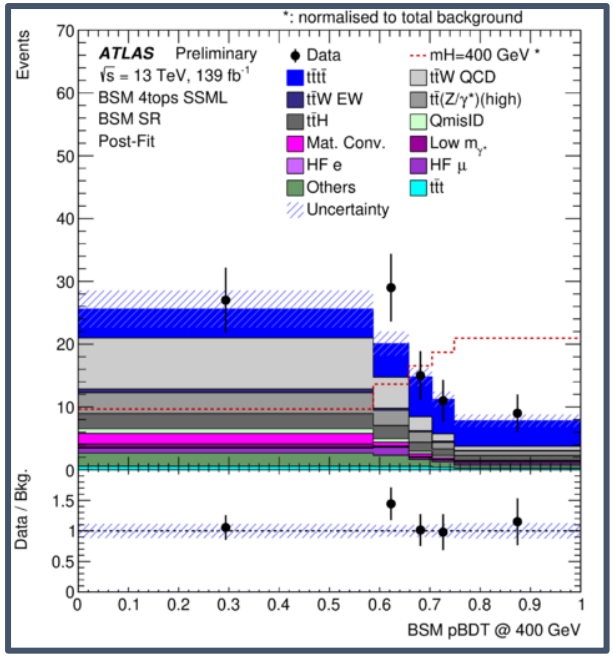
ATLAS-CONF-2022-008

- Search for a new heavy scalar Higgs boson (H) or pseudo-scalar (A) (mass > $2m_{top}$: 400 GeV -1 TeV) produced in association with a pair of top quarks, with the Higgs boson decaying into a pair of top quarks ($H/A \rightarrow t\bar{t}$)



- Analysis targets 2HDM type-II model, $t\bar{t}H \rightarrow t\bar{t}t\bar{t}$ signal, interpretation on low tanβ region in the alignment limit $\sin(\beta - \alpha) \rightarrow 1$
- $A \rightarrow t\bar{t}$ decay mode dominates at the low tanβ region

- Search targets a final state with exactly 2 leptons with the same-sign electric charge or at least 3 leptons (SSML)
- 4-top-quarks enriched SR: $N_{jets} \geq 6$, $N_{b\text{-}jets} \geq 2$ and $\Sigma p^{l}_{T} + \Sigma p^{j}_{T} > 500$GeV
- 2 BDT classifiers:
  - SM BDT: separate SM $t\bar{t}t\bar{t}$ events from other SM backgrounds
  - BSM pBDT (final discriminant): BSM mass parametrized BTD, separate BSM $t\bar{t}t\bar{t}$ SR from all backgrounds
- Irreducible backgrounds: prompt leptons ($t\bar{t}t\bar{t}$, $t\bar{t}W/Z$+jets) (MC+Data CR)
- Reducible backgrounds: fake/non-prompt leptons (CRs)



*5 CRs: CR Conv. (Mat. Conv., , Low $m_{\gamma*}$), CR HF e/μ, CR $tt\bar{}W$+j, CR lowBDT

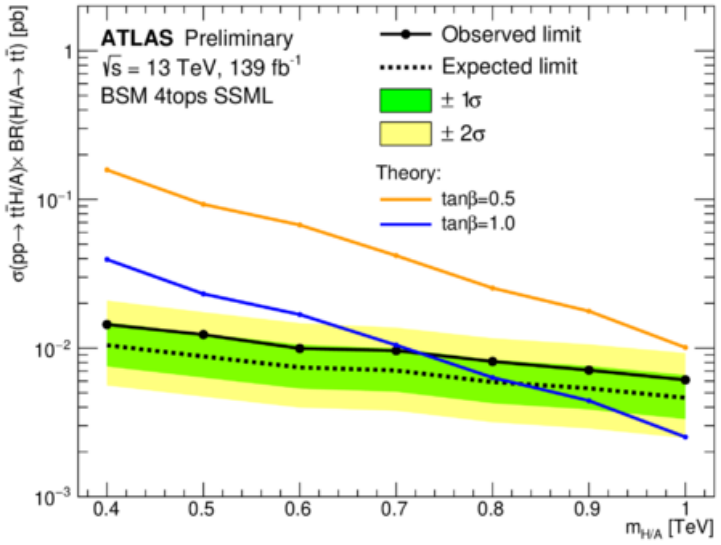
- Data and post-fit background comparison with background-only* fit in BSM SR for BSM pBDT distribution with m_H=400 GeV

$t\bar{t}H/A \rightarrow t\bar{t}t\bar{t}$ - Limits

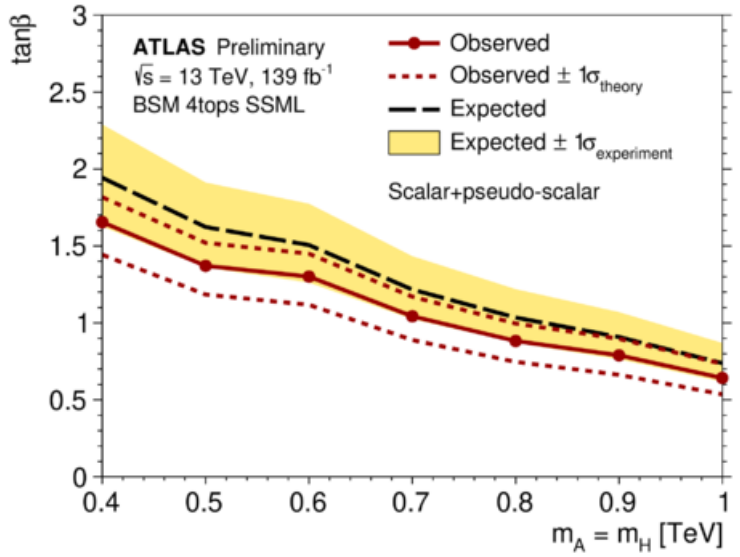
ATLAS-CONF-2022-008

- No significant excess of events over the SM expectation observed
- Results interpreted in the context of the two-Higgs-doublet model of type II

- 95% CL exclusion limits on cross-section of 2HDM type II scalar (H) and pseudo-scalar (A) Higgs boson



- 95% CL exclusion regions in tanβ versus mass plane, assuming that both, a heavy scalar H and pseudo-scalar A, contribute to the $t\bar{t}t\bar{t}$ final state and have the same mass $m_H=m_A$



- Best fit signal cross-section ranges between $4\ ^{+6}_{-5}$ fb and $2\ ^{+2}_{-2}$ fb across 400 GeV to 1000 GeV
- Observed (expected) upper limits range between 14 (10) fb and 6 (5) fb

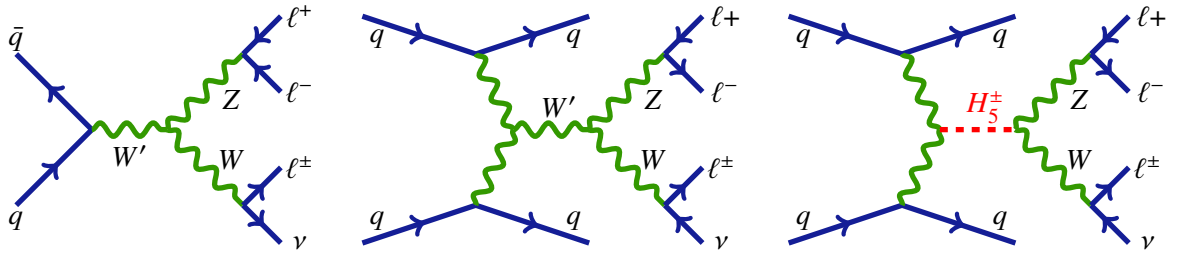
- Excluded values of tan β range between 1.2 (1.6) and 0.5 (0.6), where only one particle (both particles) contribute to the $t\bar{t}t\bar{t}$ final state

- Improved expected sensitivity wrt previous search with 36 fb^{-1} by x ~4

W Z → ℓνℓ′ℓ′ - Analysis

ATLAS-CONF-2022-005

- Search for WZ fully leptonic heavy resonance (mass: 200 GeV-5 TeV)
  - WZ-fusion or DY process



$qq' \to W' \xrightarrow{(a)} WZ \to l\nu ll$ (b) $pp \to H^{\pm}_5\, j\, j \xrightarrow{(c)} W^{\pm}Z\, j\, j \to l^{\pm}\nu l^{+}l^{-}\, j\, j$

(a) HVT W' production via DY, (b) HVT W' production via VBF (c) GM $H^{\pm}_5$ production via VBF

- 3 Resonance benchmark models:
  - Heavy Vector Triplets (HVT) produced by Drell-Yan (DY) production (HVT Model A: g_V = 1 and Model B: g_V = 3)
  - Heavy Vector Triplets produced by VBF production (HVT Model C: c_F = 0)
  - Georgi - Machacek (GM) Higgs Triplet Model produced via VBF production ($H^{\pm}_5$ GM)

- Experimental signature
  - 3 high p_T leptons
  - Missing transverse energy
  - 2 Jets (in case of VBF)
- Backgrounds
  - Irreducible: SM WZ (QCD, EWK), ZZ (CRs)
  - Reducible: non-prompt leptons (Z+jets, Zγ, $t\bar{t}$) (DD)

- Cut-based selection used to build DY signal region (SR)
- Artificial Neural Network (ANN) used for the VBF
- WZ invariant mass used as discriminating variable

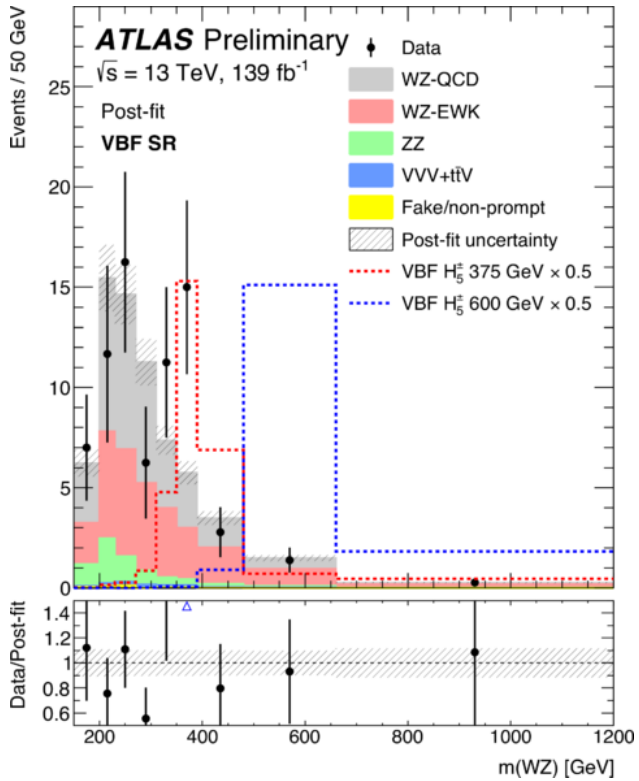
- SR, DY
- $p_T(V)/m(WZ) > 0.35$

- SR, VBF
- ≥ 2 VBF jets
- m_{jj} >100GeV
- Veto events with b-tagged jets
- ANN Output > 0.82

W Z → ℓνℓ′ℓ′ - Limits

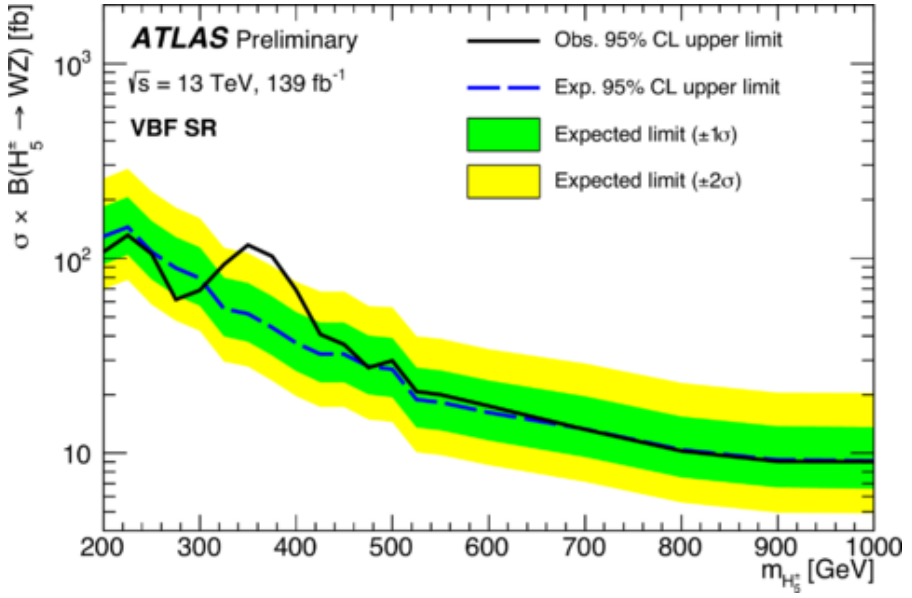
ATLAS-CONF-2022-005

- Comparisons of data and expected backgrounds of the WZ invariant mass VBF signal regions



- VBF: no significant excess observed over SM predictions
- DY: data consistent with SM predictions

- 95% CL upper limits on σ × B($H^{\pm}_5 \rightarrow$ WZ) of GM model as a function of $m_{H^{\pm}_5}$



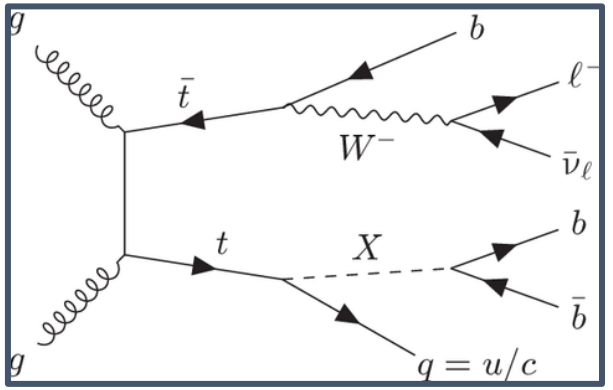
- VBF category: Observed excess around 375 GeV
  - Local significance 2.8σ (2.5σ for W' HVT)
  - Global significance 1.6σ (1.7σ for W' HVT

- HVT DY model, W'mass < 2.4 TeV excluded for Model A (g_V = 1) and < 2.5 TeV for Model B (g_V = 3)
- HVT VBF model, W'mass < 340 GeV, 500 GeV and 700 GeV excluded (c_F = 0 and $g_V c_H$ = 1.0, 1.5 and 2.0) respectively

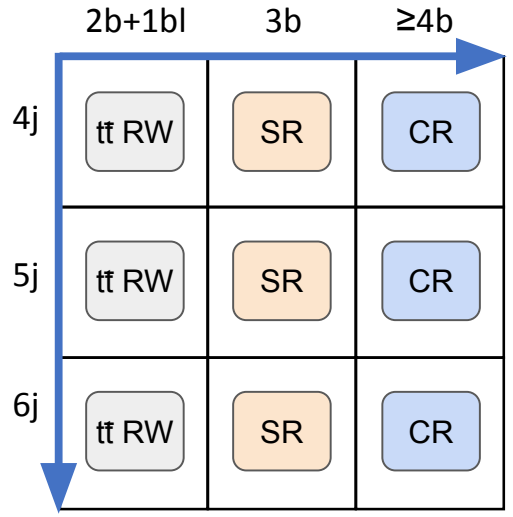
Search for t → qX($b\bar{b}$) - Analysis

ATLAS-CONF-2022-027

- Search for FCNC decay of top-quark into BSM particle lighter than the top quark
- Channel: lepton+jets $t\bar{t}\rightarrow(qX)(b\ell\nu)$ with scalar $X\rightarrow b\bar{b}$ and $q=u/c$
- Analysis description
  - Studied m_X [20, 160] GeV ($m_X < m_{top}$) for both $t\rightarrow cX$ and $t\rightarrow uX$ channels
  - Final state characterised by an isolated electron or muon and at least 4 jets
  - Events are categorised according to the multiplicity of jets and b-tagged jets
  - Backgrounds mainly $t\bar{t}$ +jets
  - For signal-background discriminant: implemented a mass-parameterised neural network (NN output - final discriminant)
  - Fitted individual mass hypothesis for each channel individually



- Event selection: region definitions
  - For the fit:
    - Sg: 3 b-tags regions: 4j3b, 5j3b, 6j3b
    - CRs: ≥4 b-tags regions: 4j4b, 5j≥4b, 6j≥4b
  - To derive $t\bar{t}$ correction:
    - 2b-tag + 1b-tag loose(bl): 4j2b+1bl,5j2b+1bl,6j2b+1bl

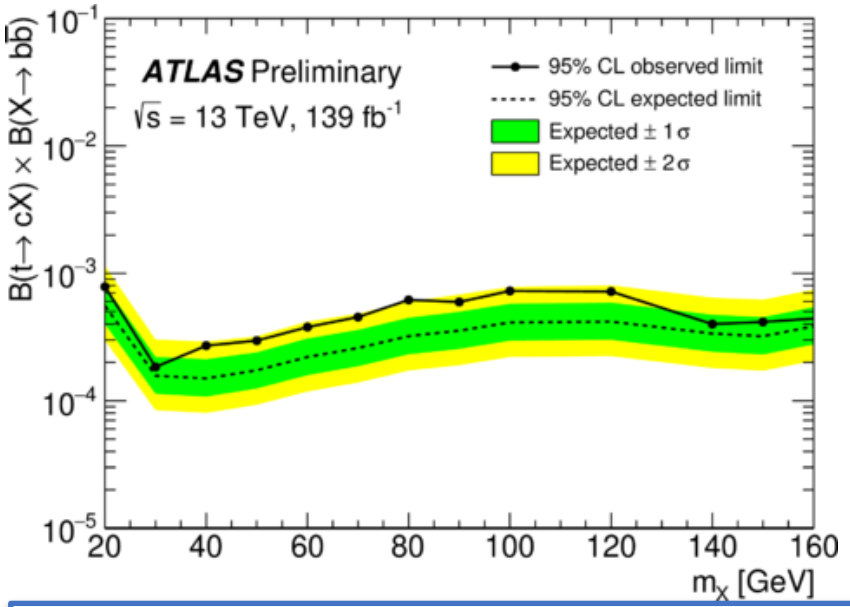


Search for t → qX($b\bar{b}$) - Limits

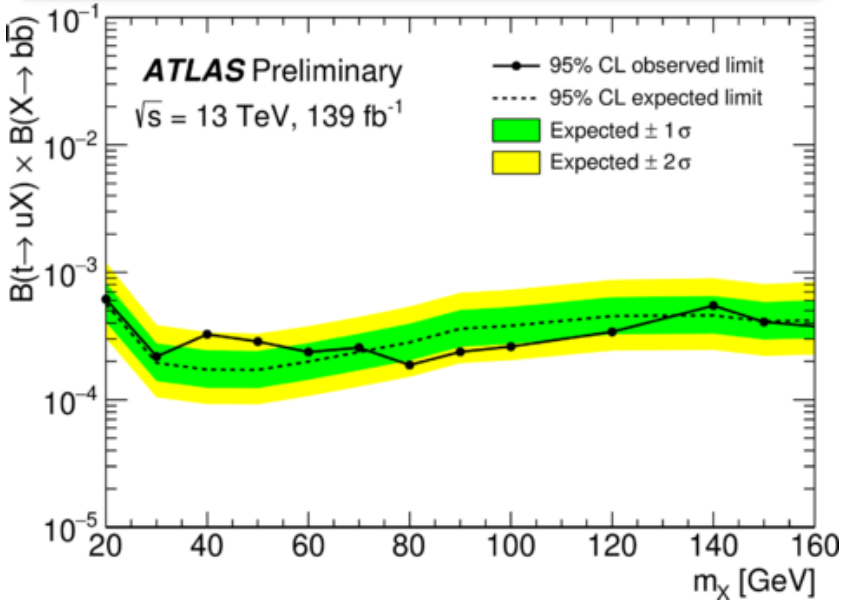
ATLAS-CONF-2022-027

- Channel: lepton+jets $t\bar{t} \to (qX)(b\ell\nu)$ with scalar $X \to b\bar{b}$ and q=u/c
  - No significant excess above the expected SM background observed
  - Expected and observed 95% CL upper limits set

95% CL upper limits for B(t → cX) × B(X→ $b\bar{b}$)



95% CL upper limits for B(t → uX) × B(X→ $b\bar{b}$)



- Upper limits range from:
  - 0.018% to 0.078% (0.015% to 0.056%) obs (exp) limits for t→cX
  - 0.019% to 0.062% (0.017% to 0.057%) obs (exp) limits for t→uX
- t→cX slightly higher upper limits (~2σ)
- t→uX excess at 40 GeV of ~1.8σ

- Expected limits are x ~3 better wrt previous ATLAS 36 fb^{-1} results ($t \to qH(b\bar{b})$)

ATLAS searches for Charged Higgs

- $t \to H^{\pm} b$, $H^{\pm} \to cb$
- $H^{\pm} \to W^{\pm} A \to W^{\pm} \mu\mu$
- $H^{++}/H^{--} \to \ell^{+}\ell^{+}/\ell^{-}\ell^{-}$ **New!**

In additional slides:
- $H^{+} \to tb$
- $H^{++} \to W^{+}W^{+}$

Search for $H^{\pm} \rightarrow cb$ - Analysis

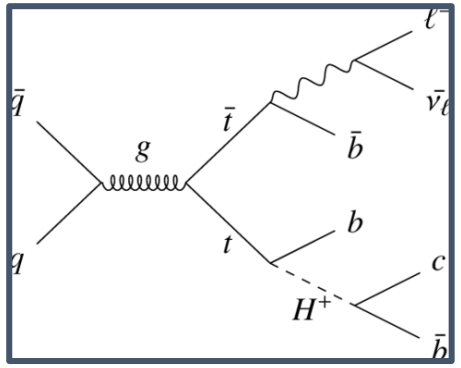
ATLAS-CONF-2021-037

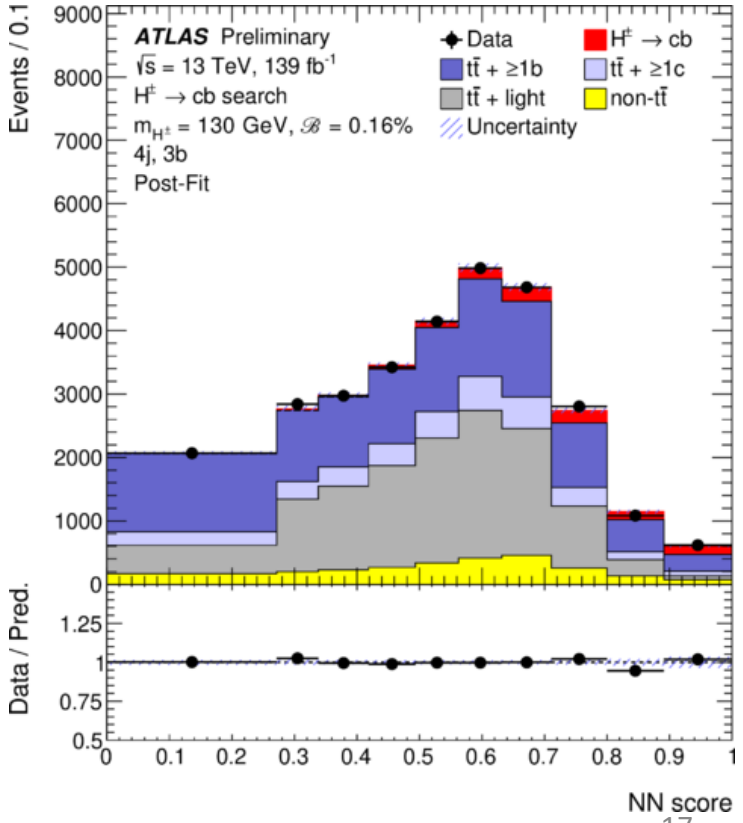
- Search targets the production of a charged Higgs boson, $H^{\pm}$ via top-quark decays, $t\bar{t} \rightarrow WbH^{\pm}b$, followed by the decays $H^{\pm} \rightarrow cb$ and $W \rightarrow \ell\nu$

- BSM scenarios such as 3HDM (3 Higgs Doublets Model) at low H^{+} mass (60-160 GeV)
- Lightest charged Higgs boson can be lighter than the top quark

- Final states lepton-plus-jets, 1-e/μ (trigger), ≥ 4-jets (≥3 b-jets)
- Categories based on number of jets (4, 5 and 6) & b-jets (3 and ≥4), main signal regions are (4j, 3b) and (5j, 3b)
- Main SM background: $t\bar{t}$ + jets; $t\bar{t}$ + ≥ 1b, $t\bar{t}$ + ≥ 1c, $t\bar{t}$ + light jets (DD approach to correct simulation)
- Parameterized Neural Network as final discriminant

- No significant excess above the background-only hypothesis

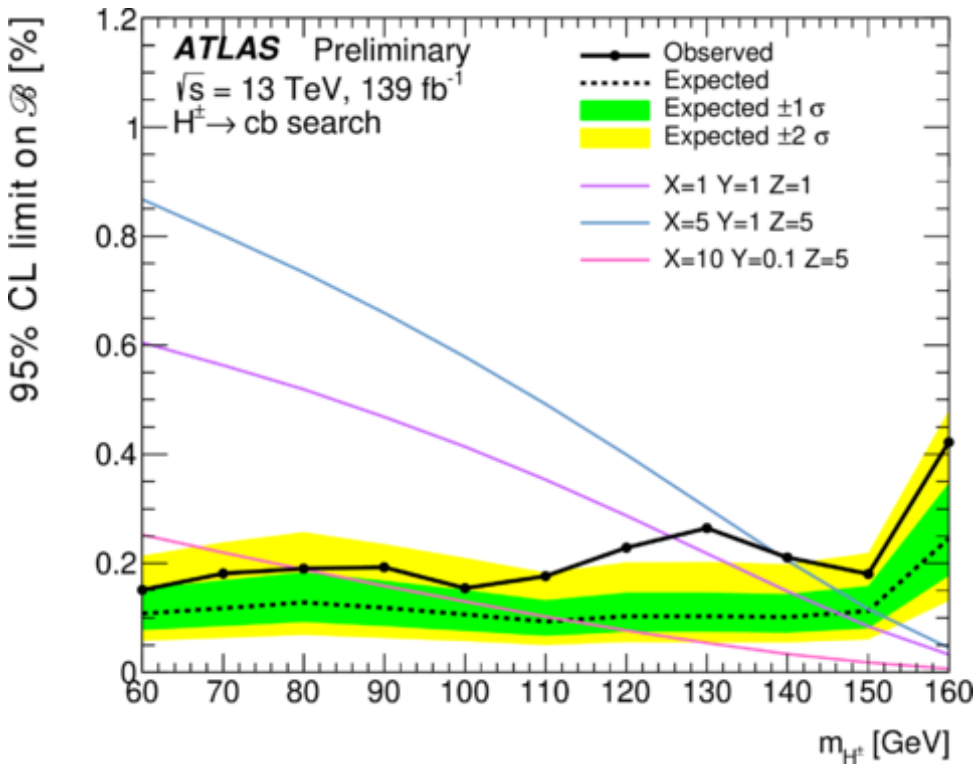




Search for $H^{\pm} \rightarrow cb$ - Limits

ATLAS-CONF-2021-037

- 95% CL observed (expected) limits for $B(t \rightarrow H^{\pm}b) \times B(H^{\pm} \rightarrow cb)$



- The largest excess in data corresponds to ~3σ for $m_{H\pm}$ =130 GeV and a global p-value ~1.6σ in the considered $m_{H\pm}$ range

- 3HDM predicted limits corresponding to 3 benchmark values for parameters X, Y and Z

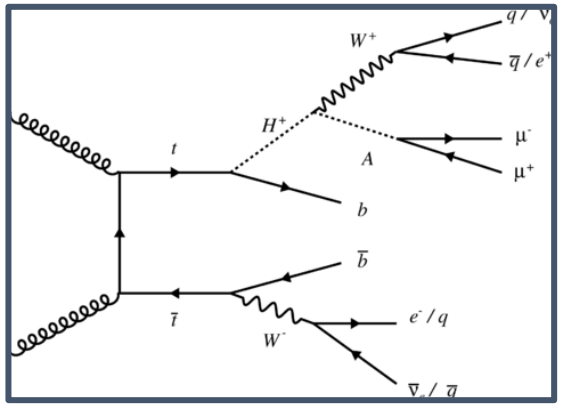
- Upper BR limits between 0.15% (0.09%) and 0.42% (0.25%) for $m_{H\pm}$ between 60 and 160 GeV

- Improved expected sensitivity by x 5 wrt previous studies and extended $m_{H\pm}$ range

Search for $t \to bH^{\pm}$, $H^{\pm} \to W^{\pm}A$, $A \to \mu^{+}\mu^{-}$ - Analysis

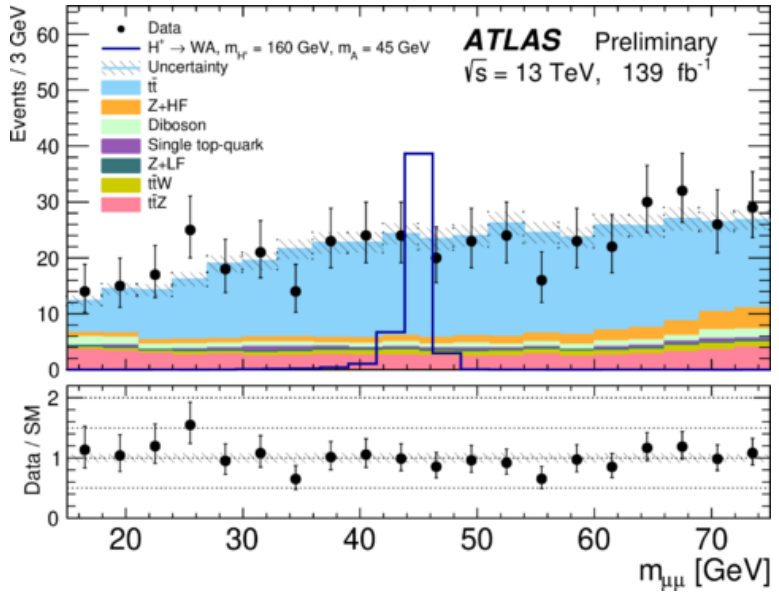
ATLAS-CONF-2021-047

- Search for a charged Higgs boson $H^{\pm}$ decaying to a pseudoscalar particle A and a W boson in top-quark pair events



- Events selected with one electron and two muons in the final state (eμμ) and three or more jets, at least one b-tagged
- Main backgrounds ($t\bar{t}$, $t\bar{t}Z$, Z+HF) are estimated using a semi-data-driven approach

- Scenario with different m_{H+} and m_A, low m_{H+} (100-160 GeV) and m_A (15-75 GeV) in $t\bar{t}$ decay
- Scanning m_A with $A \to 2\mu$ for different m_{H+} windows in the eμμ final state
- Sensitive to any A produced in association with top-quarks



- No significant excess above the background-only hypothesis

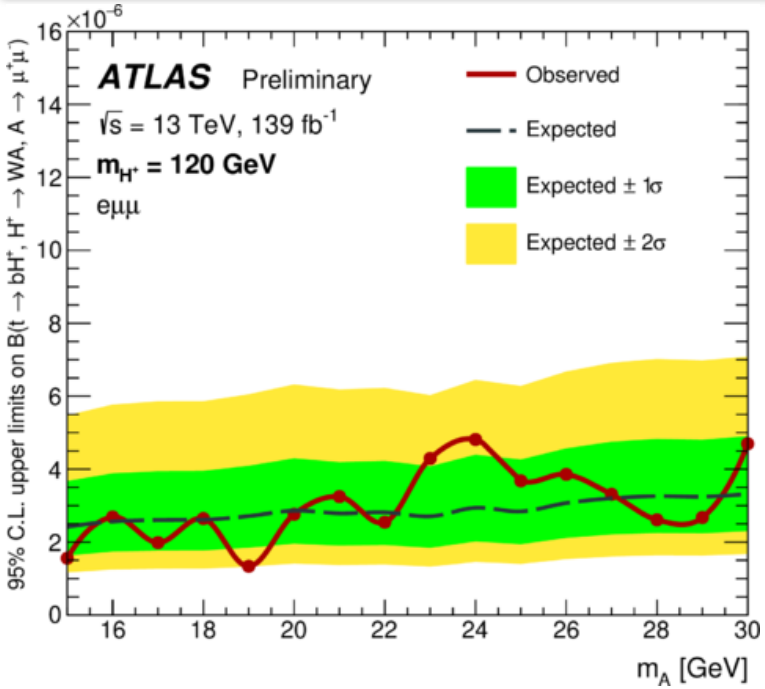
- Post-fit plot of observed di-muon mass spectrum in inclusive SR using CR-only fit

Search for t→bH±, H± → W±A, A →μ⁺μ⁻ - Limits

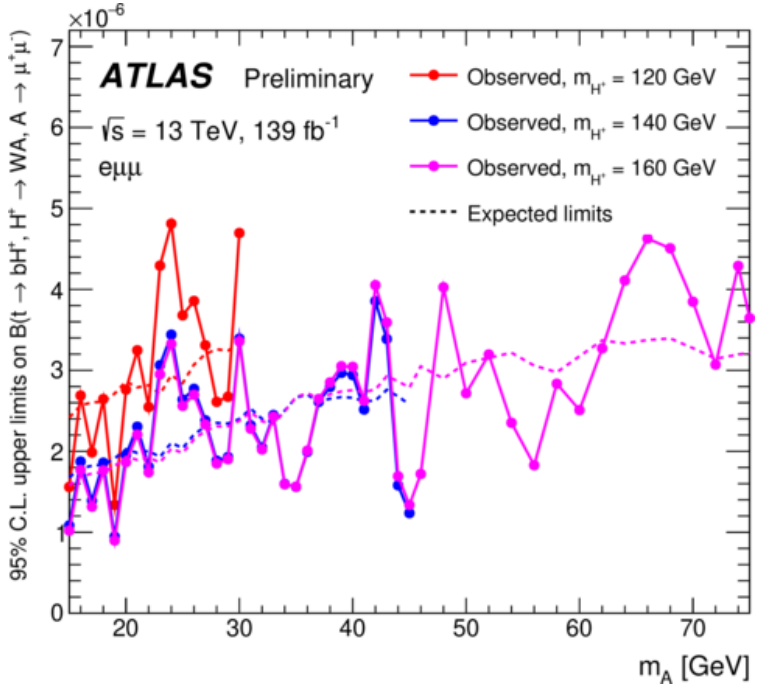
ATLAS-CONF-2021-047

- Interpretations in the context of 2HDM vs m_A, m_{H^+}

- Expected and observed upper limits on BR (t → bH±, H± → W±A, A → μ⁺μ⁻)



- Overlay of limits for different values of m_{H^+}



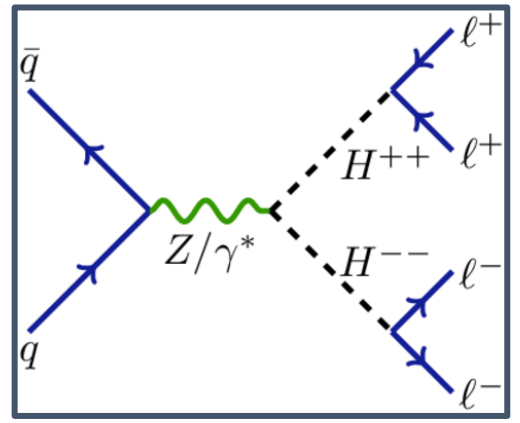
- Observed (expected) BR limits vary from 0.9 (1.6)×10⁻⁶ to 6.9 (9.9)×10⁻⁶ depending on m_{H^+} and m_A

- Also set the first lower limits on tanβ in a 2HDM type-I model in the $m_{H^\pm}$, m_A parameter space
- Observed (expected) lower limits range from 1.1 (1.4) to 7.7 (5.7)

Search for $H^{++}/H^{--} \to \ell^+\ell^+/\ell'^-\ell'^-$ - Analysis

ATLAS-CONF-2022-010

- Search for pair production of doubly charged Higgs $H^{\pm\pm}$ bosons, each decaying into a pair of prompt, isolated, and highly energetic leptons with the same electric charge
- BSM left-right symmetric (LRS) model ($H_L^{\pm\pm}$ and $H_R^{\pm\pm}$)



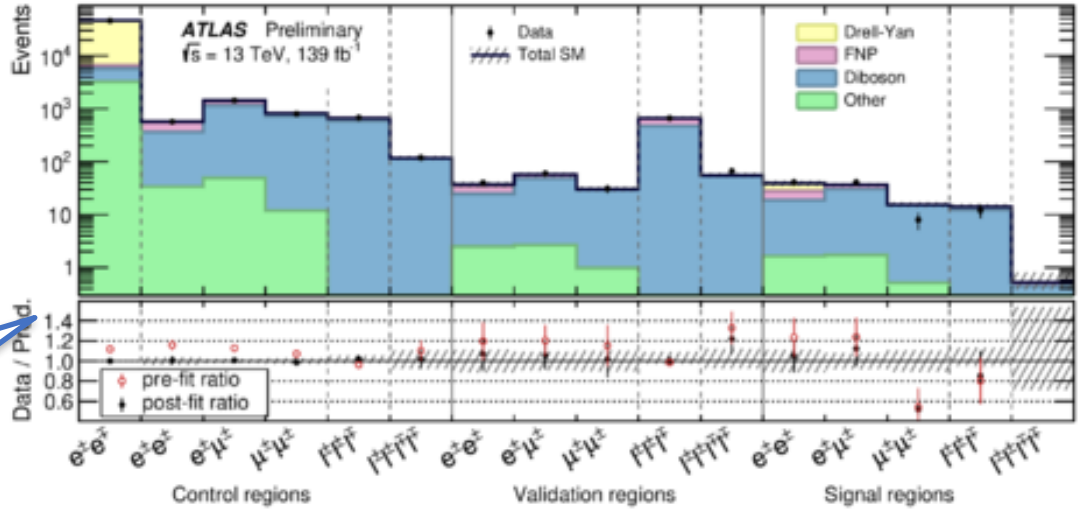
New!

- Drell–Yan pair production

- Final states same-charge leptonic decays, $H^{\pm\pm} \to \ell^\pm\ell'^\pm$, $\ell,\ell' = e,\mu$ in 2-, 3-, and 4-lepton channels
- Main variable $m(\ell^\pm, \ell'^\pm)_{lead,}$ 4-leptons single-bin event yield
- SR: $300 < m(\ell^\pm, \ell'^\pm)_{lead} < 1300$ GeV

- Veto on b-jets to suppresses top quark background
- Irreducible background, prompt leptons from dibosons (CRs)
- Reducible background, non-prompt lepton, charge mis-id (DD)

- Numbers of observed and expected events in control (DYCR, DBCR2L, DBCR3L, CR4L) validation (VR2L, VR3L, VR4L) and signal regions (SR2L, SR3L, SR4L) for all channels
- Split by lepton flavour and electric charge combination



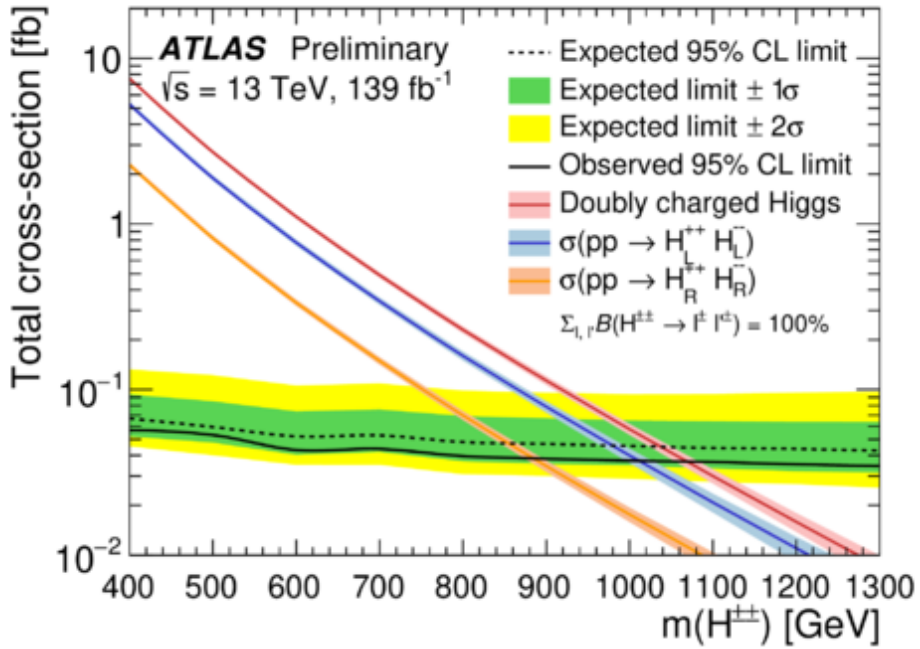
- No significant excess above the background-only hypothesis

Search for $H^{++}/H^{--} \rightarrow \ell^+\ell^+/\ell'^-\ell'^-$ - Limits

New!

- Observed and expected 95% CL upper limits on the $H^{\pm\pm}$ pair production cross-section as a function of $m(H^{\pm\pm})$ for combination of all channels

ATLAS-CONF-2022-010



- $\Sigma_{\ell\ell'} B(H^{\pm\pm} \rightarrow \ell^\pm\ell'^\pm)$ a 100% assumed

- Blue, Orange and Red lines ⇒ theoretical signal cross-section predictions given by NLO calculation
- Correspond to left-handed $H^{\pm\pm}_L$, right-handed $H^{\pm\pm}_R$ and a sum of both

- Observed lower limit on the mass of a doubly charged Higgs is 1080 GeV
- Improved limit (300 GeV higher) wrt previous results

- The limit obtained from the four-lepton final state is the most sensitive and drives the combined result

ATLAS Searches for New Pseudo-Scalar Resonances In Exotic Higgs Boson Decays

- $H \rightarrow XX/ZX \rightarrow 4\ell$

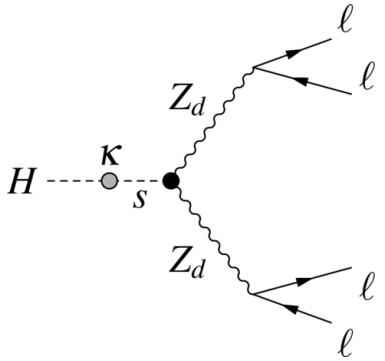
- In additional slides:
  - $H \rightarrow \chi_1\chi_2 \rightarrow b\bar{b}$ + MET
  - $H \rightarrow aa \rightarrow b\bar{b}\mu\mu$

ATLAS Summary Plots
ATL-PHYS-PUB-2021-008

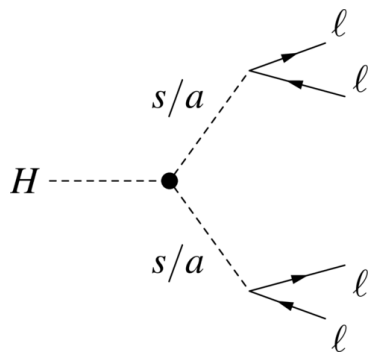
h → Z_dZ_d/aa → 4ℓ - Analysis

JHEP 03 (2022) 041

- Search for exotic decays of the Higgs in lepton final states, 4e, 2e2μ, 4μ
  - High-mass (HM): H→XX→4ℓ, 15 GeV< m_X < 60 GeV
  - Low-mass (LM): H →XX →4μ, 1 GeV< m_X < 15 GeV
  - ZX channel: (ZX) H→ZX→4ℓ, 15 GeV< m_X < 55 GeV
- Select two pairs of prompt Same Flavor Opposite Sign (SFOS) leptons
- Define pairs m_{12} and m_{34} such that $|m_{12} - m_Z| < |m_{34} - m_Z|$
- Four-lepton mass: 115 $GeV < m_{4\ell} <$ 130 GeV compatible with Higgs mass

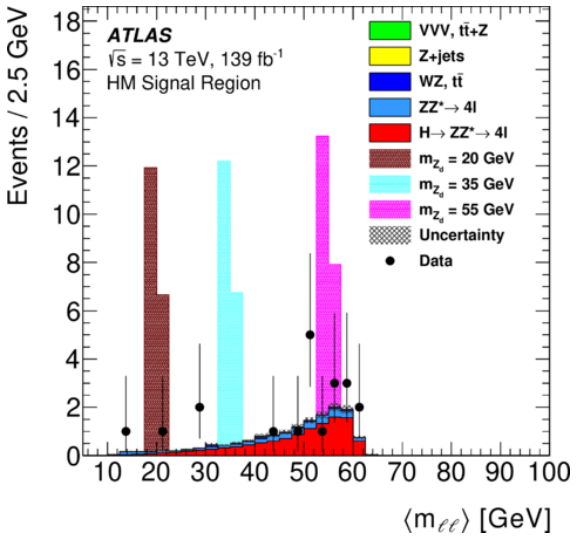


Dark Higgs S, coupling κ (controls coupling between *s* and H)

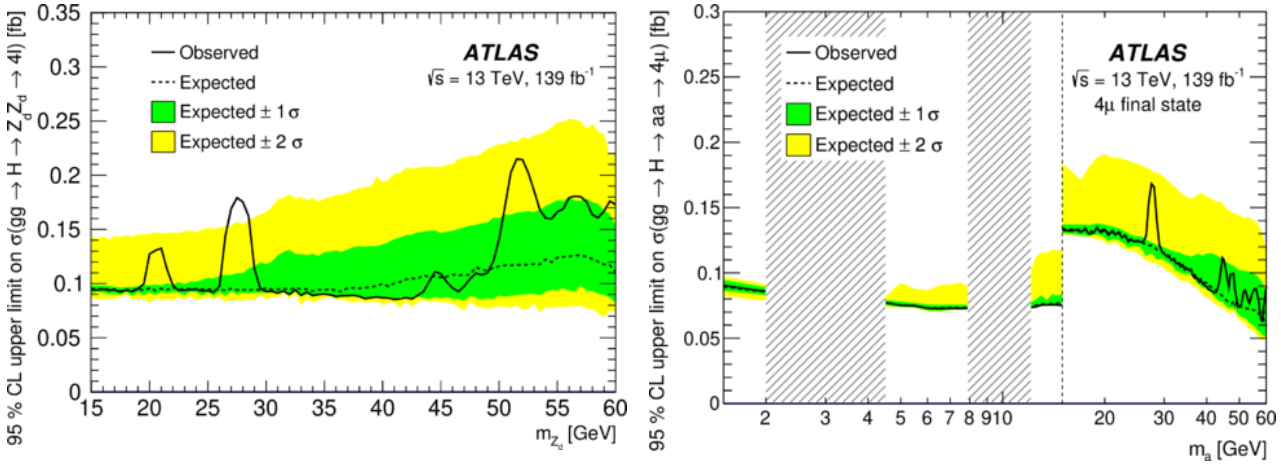


2HDM+S model allow Higgs to couple to new low mass (pseudo)scalar *s* (α)

⟨ $m_{\ell\ell}$ ⟩ distribution for HM



Upper limits at 95% CL on (left) $\sigma(H \to Z_dZ_d \to 4\ell)$ and (right) on $\sigma(H \to \alpha\alpha \to 4\mu)$



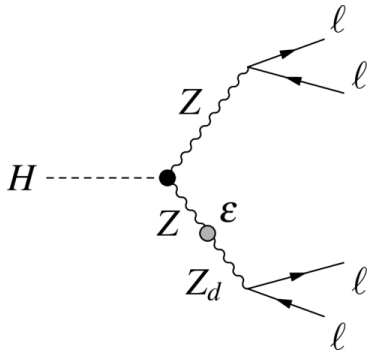
- Upper limits also set on Higgs mixing parameter: $\kappa' = \kappa\, m_H^2/|m_H^2 - m_S^2|$

h → ZZ$_d$/Za → 4ℓ - Analysis

JHEP 03 (2022) 041

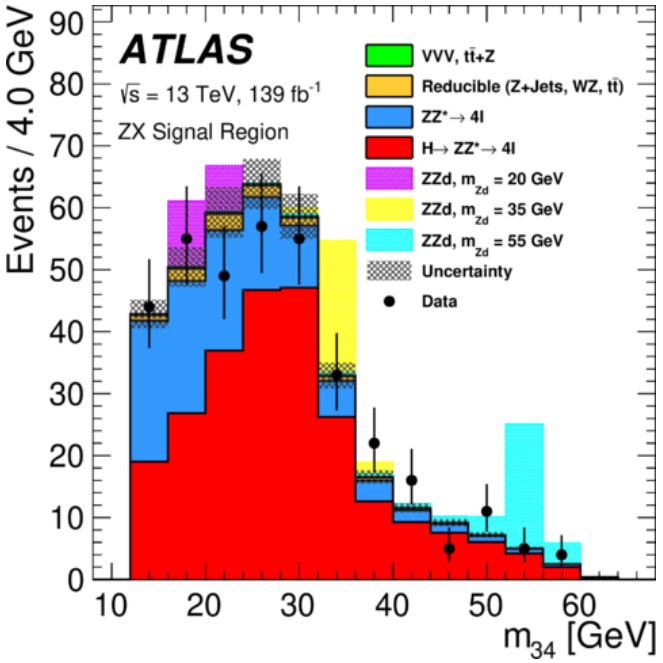
- Quadruplet selection similar to SM $H \to ZZ^* \to 4\ell$

Kinetic mixing parameter ϵ (controls coupling between Z_d and SM Z)

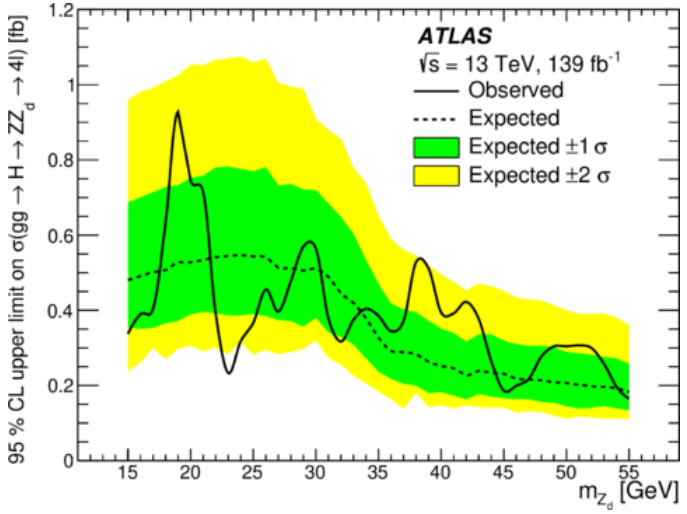


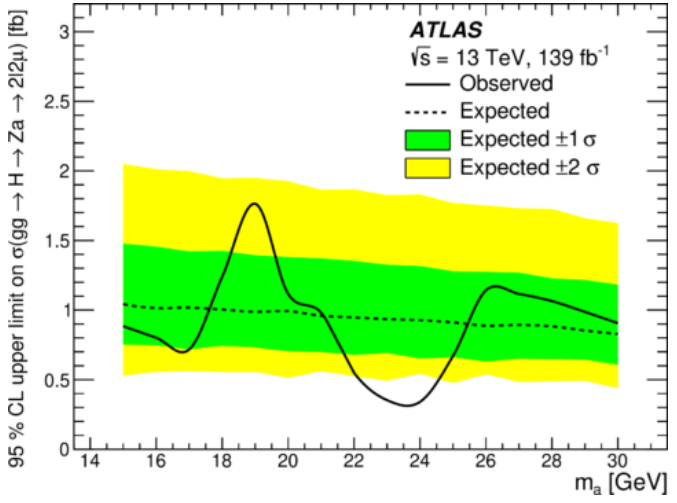
m$_{34}$ distribution for ZX

Backgrounds
- H→ ZZ* → 4ℓ
- ZZ* → 4ℓ
- Z + jets, tt̄



Upper limits at 95% CL on (a) $\sigma(H \to ZZ_d \to 4\ell)$ and (b) on $\sigma(H \to Z\alpha \to 2\ell 2\mu)$





- Upper limits also set on mixing parameters: Z_d mixing parameter ε, Z-Z_d mass mixing parameter δ

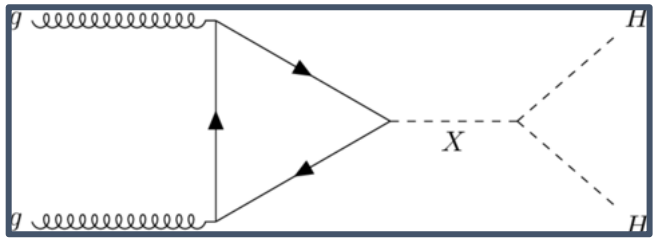
- Limits x ~2-4 better wrt previous ATLAS 36 fb^{-1} results

ATLAS Searches for Resonant Higgs Boson Pair Production

Di-Higgs HH combination - Analysis

ATLAS-CONF-2021-052

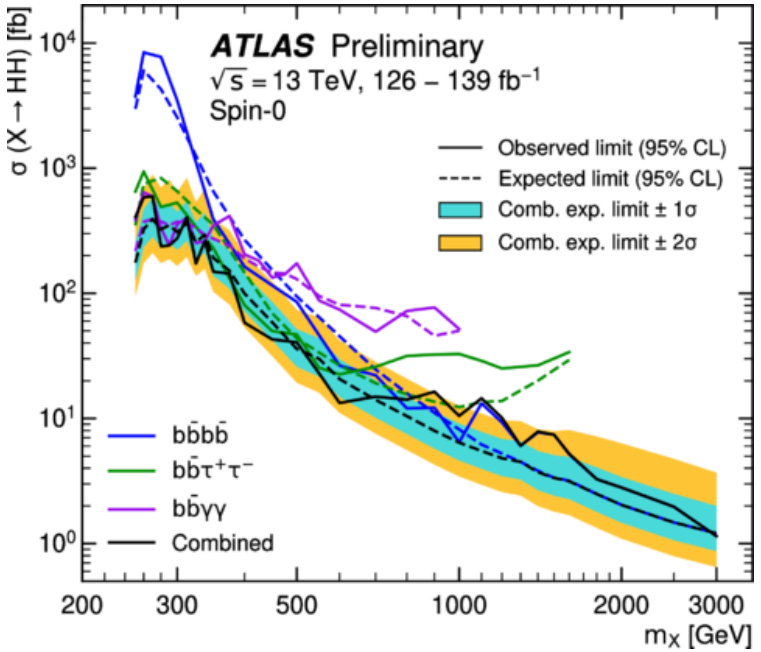
- Heavy scalar (spin-0) NW resonance X (250 GeV - 3 TeV)
- Predicted by BSM models such as hMSSM
- In this search, only ggF process



- Search for new heavy scalar decaying to higgs pairs includes three channels: $b\bar{b}\gamma\gamma$, $b\bar{b}\tau\tau$ and $b\bar{b}b\bar{b}$
- Limits on cross-section pp → X → HH as a function of m_X

- Expected, observed 95% CL upper limits on σ(X →HH) for spin-0 resonance as a function of m_X in $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^+\tau^-$ and $b\bar{b}b\bar{b}$, and their statistical combination

- Different channels contribute to complementary mass ranges
  - $b\bar{b}\gamma\gamma$ in low mass ranges (< 400 GeV) ; discriminant: $m_{\gamma\gamma}$
    - Backgrounds: γγ + jets, H → γγ
    - arXiv:2112.11876
  - $b\bar{b}\tau\tau$ in intermediate mass range (400-800 GeV); ($\tau_{had}\tau_{had}$ & $\tau_{lep}\tau_{had}$), discriminant: MVA
    - Backgrounds: $t\bar{t}$, Z + HF
    - ATLAS-CONF-2021-030
  - $b\bar{b}b\bar{b}$ at the highest mass (> 800 GeV); resolved: 4 small-R (R=0.4) jets (m_X < ~1 TeV), boosted: 2 large-R (R=1.0) jets, discriminant: m_{HH}
    - Background: QCD multi-jets
    - Phys. Rev. D 105 (2022) 092002



- The largest excess found at m_X = 1.1 TeV, it corresponds to a global (local) significance of 2.1σ (3.2σ)

- 95% CL observed (expected) upper limits 1.1-595 fb (1.2-392 fb) in 251 GeV≤ m_X≤3 TeV

HL-LHC

ATLAS Searches for New Scalars

- $X \rightarrow HH \rightarrow 4b$
- $H/A \rightarrow \tau\tau$

ATLAS Snowmass White paper
ATL-PHYS-PUB-2022-018

Prospects of HH → 4b Resonance Search - Analysis

ATL-PHYS-PUB-2018-028

- HL-LHC sensitivity study for high-mass resonance production with decay into HH → $b\bar{b}b\bar{b}$ at the HL-LHC
  - Use bulk Randall-Sundrum model as benchmark

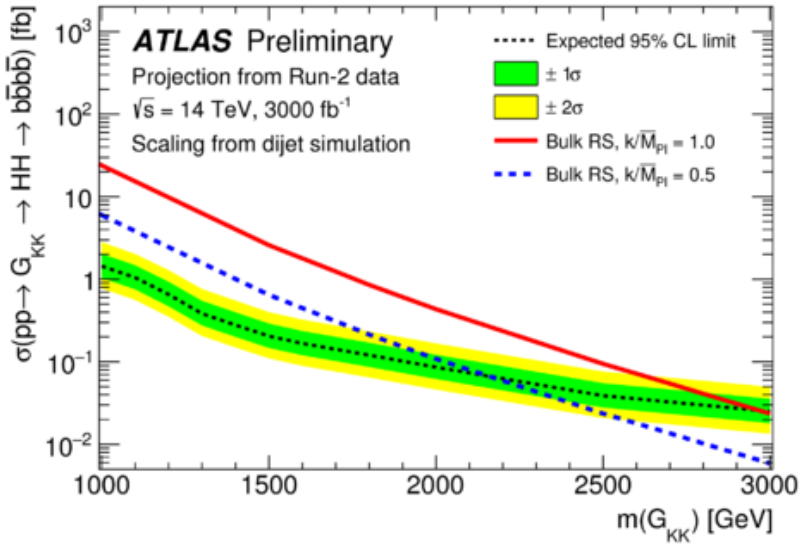
- Basis for projection to HL-LHC
  - 2015+2016 data analysis with 36.1 fb^{-1} at $\sqrt{s}$ = 13 TeV
- Scaling to 3000 fb^{-1}
  - Scaling from $\sqrt{s}$ = 13 TeV with Run 2 detector to $\sqrt{s}$ = 14 TeV with Phase-II detector
  - Scaling for analysis improvements:
    - use variable-radius track jets
    - requirement of a maximum number of charged particles associated with large-R jets

- Systematic uncertainties:
  - b-tagging efficiency uncertainties reduced by x 3
  - large-R jet mass resolution reduced by x 2
  - data-driven background uncertainties scale as $1/\sqrt{N}$

- Reconstruction of highly boosted Higgs bosons with large-radius jets and b-tagged track sub-jets to discriminate the signal from the dominant multijet background

- Expected upper limits on σ (pp→ G_{KK}→HH→ $b\bar{b}b\bar{b}$)

- 95% expected upper limits for HL-LHC analysis (with analysis improvements included) using the dijet MC



- 95% CL upper limits estimated to be 1.44-0.025 fb for resonance mass of 1.0-3.0 TeV

H/A → ττ prospects at HL-LHC - Analysis

ATL-PHYS-PUB-2018-050

- Prospects extrapolated by Run-2 MSSM Higgs → ττ 36.1 fb^{-1} analysis

- MSSM Higgs boson masses of 0.2-2.25 TeV and tan β of 1-58 searched for in the $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ decay modes

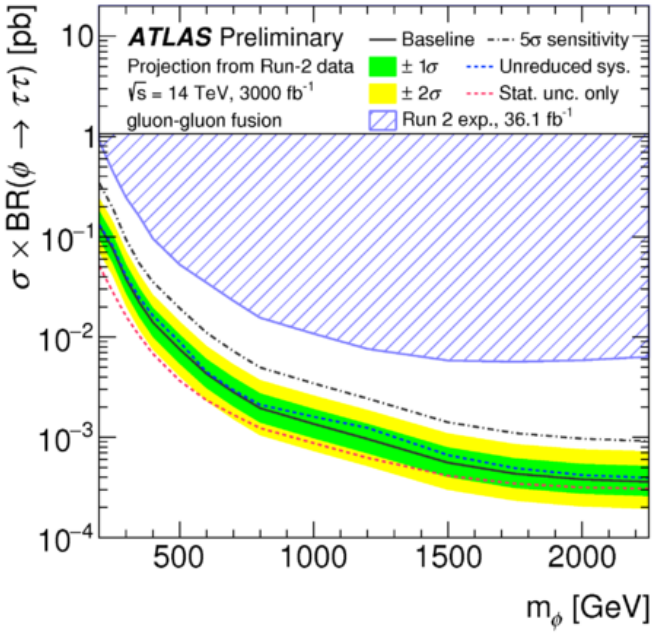
- Scaling of input:
  - luminosity: 36.1 → 3000 fb^{-1}
  - background cross section: 13 → 14 TeV, assume 1.18x
- Systematics
  - high p_T τ systematics are reduced by a factor of 2
  - other systematics are kept the same

- Limits are calculated from a statistical combination of the $\tau_e\tau_{had}$, $\tau_\mu\tau_{had}$ and $\tau_{had}\tau_{had}$ channels
- Observable: total transverse mass (m_{tot})

- Expected limits 130-0.4 fb (130-0.3 fb) for gluon-gluon fusion (b-associated) production for masses 0.2-2.25 TeV
- Increase in sensitivity x 2-3 compared to searches with full Run 2 data

- Expected upper limits on σ x BR (pp → ϕ →ττ)

- Projected 95% CL upper limits on σ x BR (pp → ϕ →ττ) for ggF production as a function of mass



- If no signal emerges, results are interpreted in the context of MSSM benchmark scenarios
- In hMSSM scenario tanβ > 1 is expected to be excluded in 250 < m_A < 350 GeV & tanβ > 10 for m_A = 1.5 TeV

Conclusions

- **ATLAS Run-2** searches for additional new scalars performed in various channels with improved reconstruction and analysis methods
- No evidence found so far, therefore, exclusion limits were set
- Many BSM Exotic Higgs analyses with Run-2 13 TeV data still on-going
- **Run-3** will enhance discovery potential of BSM Higgs-like and other (pseudo)/scalars also in Exotics Higgs boson decays with new challenges
- ATLAS searches for BSM phenomena in Extended Higgs Sector aim to cover maximum topologies
- **Looking forward to analyse Run-3 data!**

- **HL-LHC** will provide us the opportunity to probe a large parameter space of new physics through dedicated direct searches in extended Higgs sectors
- Searches for additional Higgs-like bosons at higher and lower masses considering decays into a pair of vector bosons or fermions, charged and neutral Higgs bosons, is an important part of the HL-LHC Higgs physics program.
- The detector upgrades will open up currently inaccessible parameter spaces of BSM models.
- The HL-LHC searches will benefit from the increased statistics and improvements of the reconstruction methods and allow us to study very small branching ratios and rare decays.
- The sensitivity of the searches for heavy resonances decaying to Higgs bosons will be similarly enhanced, with the potential to study unexplored production modes and decays.

ATLAS Public Results

Additional Slides

ATLAS Analyses Covered

- **New Heavy Scalar Resonances:**
  - HZZ high mass (Eur. Phys. J. C 81 (2021) 332)
  - Generic Heavy Higgs search VH, V:Z,W [$W^{\pm}H \to W^{\pm}W^{\pm}W^{\mp} \to \ell^{\pm}\nu\ell^{\pm}\nu jj$ (ATLAS-CONF-2022-033) **New!**
- **New Neutral Scalar Resonances: New!**
  - $t\bar{t}$H/A → $t\bar{t}t\bar{t}$ (ATLAS-CONF-2022-008)
  - WZ → ℓνℓ′ℓ′ resonance (ATLAS-CONF-2022-005)
    - also interpretation as $H^{\pm}_5$ GM (singly-charged Higgs boson in the Georgi-Machacek model)
  - FCNC t → qX (q=u,c), X → $b\bar{b}$ (ATLAS-CONF-2022-027)
- **Charged Higgs-like Scalars:**
  - $H^{\pm}$ → $W^{\pm}$ A→$W^{\pm}\mu\mu$ (ATLAS-CONF-2021-047)
  - t→$H^{\pm}$b, $H^{\pm}$→cb (ATLAS-CONF-2021-037)
  - H^{++} /H^{--} → $\ell^{+}\ell^{+}/\ell^{-}\ell^{-}$ (ATLAS-CONF-2022-010) **New!**
- **Exotic Higgs Decays (pesudo-scalars):**
  - H → XX/ZX → 4ℓ (JHEP 03 (2022) 041)
- **New Heavy Resonances decaying to HH**
  - $b\bar{b}b\bar{b}$, $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^{+}\tau^{-}$ (ATLAS-CONF-2021-052)
    - $b\bar{b}b\bar{b}$ (Phys. Rev. D 105 (2022) 092002), $b\bar{b}\gamma\gamma$ (arXiv:2112.11876)
- **HL-LHC Heavy Higgs-like resonances**
  - ATL-PHYS-PUB-2018-050 - *H/A → ττ*
  - ATL-PHYS-PUB-2018-028 - *X → HH → 4b*

ATLAS Extra Analyses (not covered)

- **New Heavy Scalar Resonances:**
  - H → γγ high-mass resonance (Phys. Lett. B 822 (2021) 136651)
  - A/H → ττ (PRL 125 (2020) 051801)
  - A→Zh, Z→2e/2μ or 2ν, h →bb (ATLAS-CONF-2020-043)
  - A→ZH, Z→2e/2μ, H →bb, WW (Eur. Phys. J. C. 81 (2021) 396)
  - $X^{\pm} \to W^{\pm}\gamma$, $X^{0} \to Z\gamma$ (ATLAS-CONF-2021-041)

- **Charged Higgs-like Scalars**:
  - $H^{+} \to$ tb (JHEP 06 (2021) 145)
  - H++-> $W^{+}W^{+}$ (JHEP 06 (2021) 146)

- **Exotic Higgs Decays (pesudo-scalars):**
  - H → $\chi_1\chi_2 \to b\bar{b}$ +MET (JHEP 01 (2022) 063)
  - H → aa → $b\bar{b}\mu\mu$ (Phys. Rev. D 105 (2022) 012006)

ATLAS Summary Plots

- ***ATLAS Summary Plots***
  - ATL-PHYS-PUB-2021-008 - Exotic Higgs boson decay summary plots (April 2021)
  - ATL-PHYS-PUB-2022-008 - Georgi-Machacek summary plots (March 2022)
  - ATL-PHYS-PUB-2021-030 - hMSSM summary plot (July 2021)

  - ATL-PHYS-PUB-2021-018 - Summary of Diboson Resonance Searches
  - ATLAS-CONF-2022-028 - New! Combination of searches for heavy resonances using 139 fb^{-1}

  - ATL-PHYS-PUB-2022-018 - Snowmass white paper

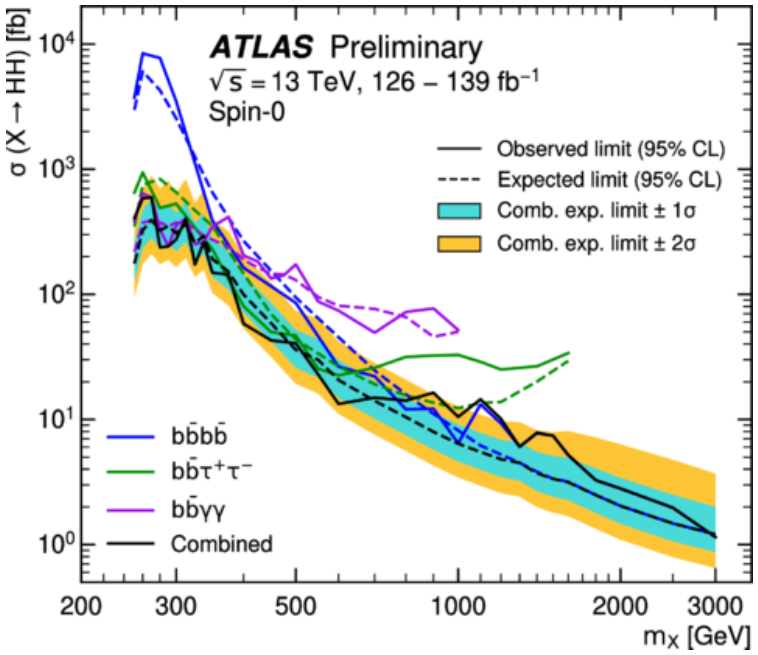
- ATLAS Public Results

Di-Higgs HH combination - Results - Limits

- No statistically significant excess above the SM expectation has been found
- Upper limits on the production cross-section of a heavy scalar resonance decaying to two SM Higgs bosons are set

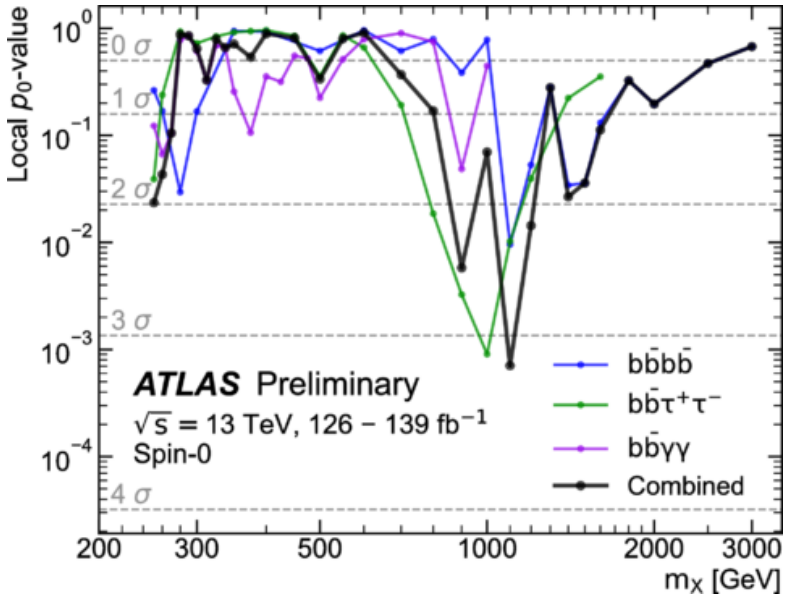
ATLAS-CONF-2021-052

- Expected and observed 95% CL upper limits on σ(X →HH) for a spin-0 resonance as a function of m_X in $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^+\tau^-$ and $b\bar{b}b\bar{b}$, and their statistical combination



- 95% CL upper limits set 1.1-595 fb (1.2-392 fb) in observation (expectation) in mass range 251GeV≤ m_X≤3TeV

- Local p_0-value as a function of m_X for spin-0 resonance.
- Each curve represents p_0-value corresponding to $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^+\tau^-$, $b\bar{b}b\bar{b}$ and p_0-value resulting from their statistical combination



- The largest excess in the combined limit is found at m_X = 1.1 TeV and it corresponds to a local (global) significance of 3.2σ (2.1σ)

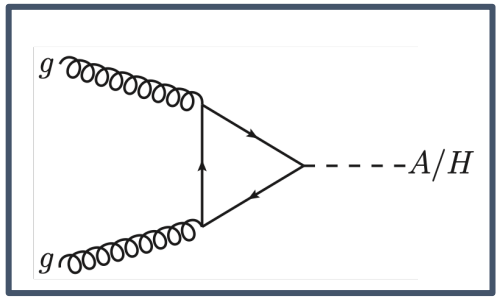
ATLAS Searches for Heavy Resonances

- $H \rightarrow \gamma\gamma$ high-mass resonance
- $A/H \rightarrow \tau\tau$
- $A \rightarrow Zh$: $Z \rightarrow 2e/2\mu$ or 2ν, $h \rightarrow bb$
- $A \rightarrow ZH$: $Z \rightarrow 2e/2\mu$, $H \rightarrow bb$, WW
- $W/Z + \gamma$: $X^{\pm} \rightarrow W^{\pm}\gamma$, $X^{0} \rightarrow Z\gamma$

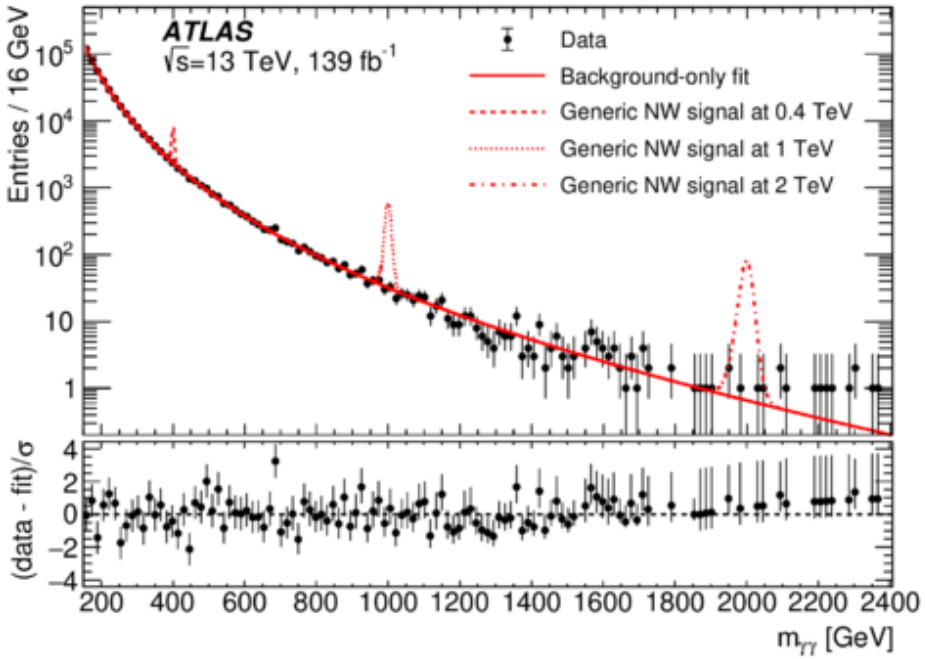
Search BSM H → γγ - Analysis

Phys. Lett. B 822 (2021) 136651

- Search for a di-photon resonance in the high mass spectrum ($m_{\gamma\gamma}$>160 GeV)
  - Spin-0 search for a narrow width (NW) (160 GeV-3 TeV), large width (LW) (400-2.8 TeV) resonance up to Γ_X/m_X=10%
  - Spin-2 search (NW) (500 GeV-2.8 TeV) for the RS graviton with couplings 0.01<k/M_{Pl}<0.1



- Analysis strategy common for both searches:
  - main background: non-resonant γ pairs ($\gamma\gamma$); smaller: γ + jet (γj) and 2 jets (jj), with jets misidentified as photons; relative contribution from 2D sideband method
  - fit data with analytical functions: model background and signal shape
  - $m_{\gamma\gamma}$ as final discriminant



- Fiducial selection: 2 γ with $|\eta|$ < 2.37, $E_T/m_{\gamma\gamma}$ > 0.3, $E_T/m_{\gamma\gamma}$ > 0.25 for leading and subleading γ
- γ isolation, scalar sum of p_T of stable particles in ΔR = 0.4 around γ < 0.05E_T + 6 GeV

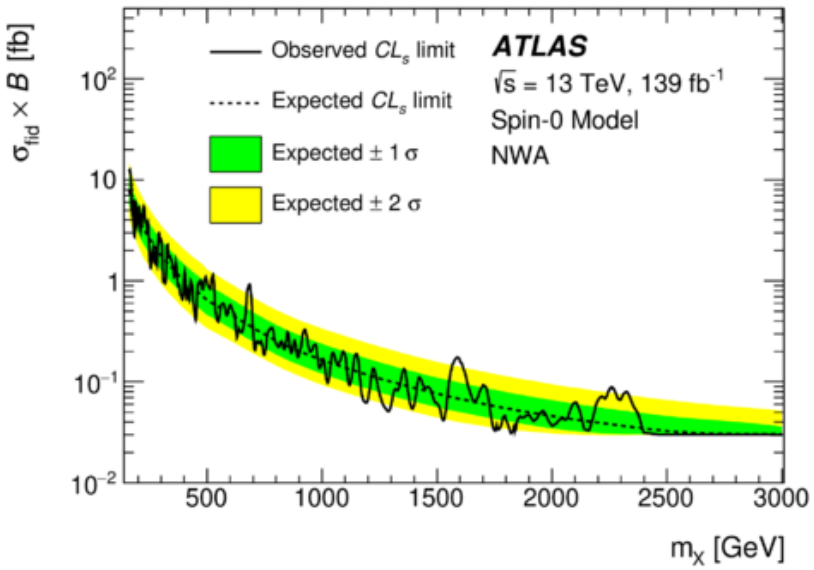
- Background-only fit to the data as a function of the di-photon invariant mass $m_{\gamma\gamma}$
  - Several generic NW signal shapes overlaid

Search BSM H → γγ - Limits

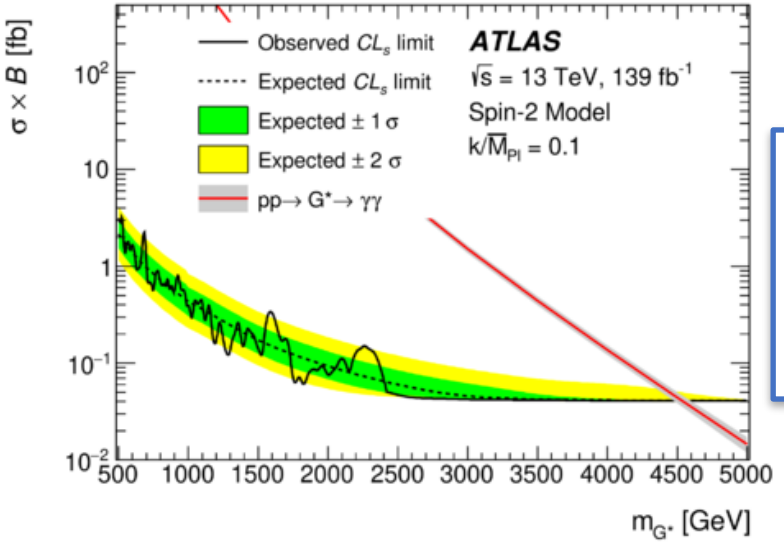
Phys. Lett. B 822 (2021) 136651

- No significant excess of events over the SM expectation is observed
- Extraction of limits:
  - on fiducial cross-section for spin-0 resonances (model-independent)
  - on total cross-section for the RS-graviton (as a benchmark spin-2 model)

- 95% CL expected and observed upper limits on (left) the fiducial and (right) the total production $\sigma \times B(X \to \gamma\gamma)$ of the lightest KK graviton as a function of its mass m_{G^*} for $k/\bar{M}_{Pl} = 0.1$



- 95% CL observed upper limits range from 12.5 fb at 160 GeV to about 0.03 fb at 2800 GeV



- Observed excess for mass of ≃ 684 GeV, for spin-0 NWA and for spin-2 $k/M_{Pl} = 0.01$: 3.29σ local (1.30σ, 1.36σ global) significance

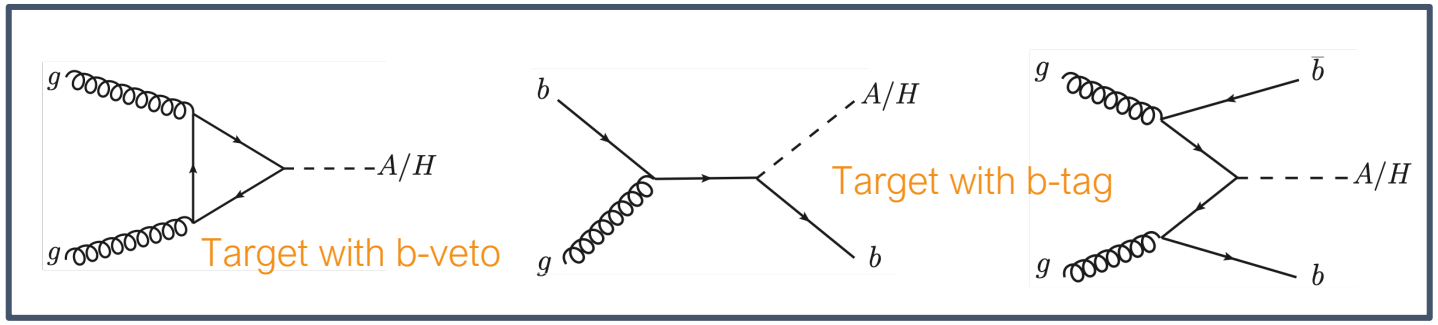
- 95% CL observed limits range from 3.2 fb - 0.04 fb for a graviton mass 500 - 5000 GeV, for $k/M_{Pl} = 0.1$
- RS1 graviton excluded for masses < 4.5 (2.2, 3.9) TeV for k/M_{Pl} = 0.1 (0.01, 0.05)

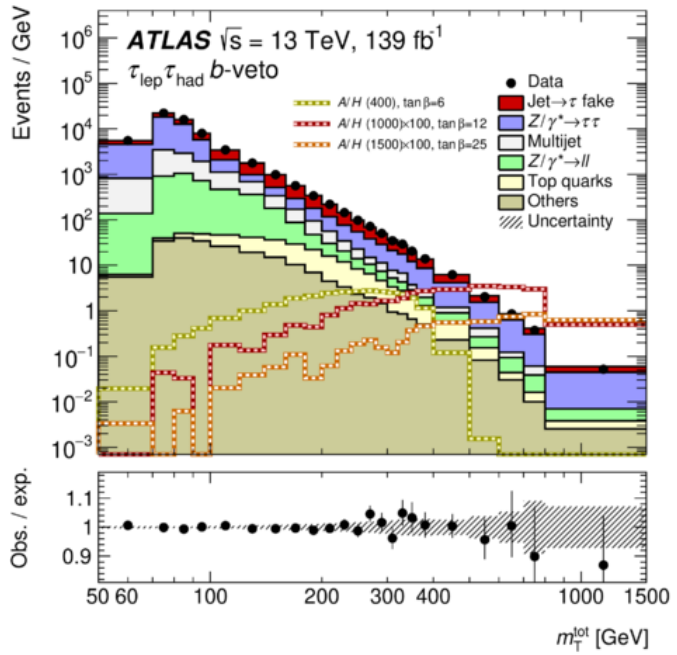
Search BSM A/H → ττ - Analysis

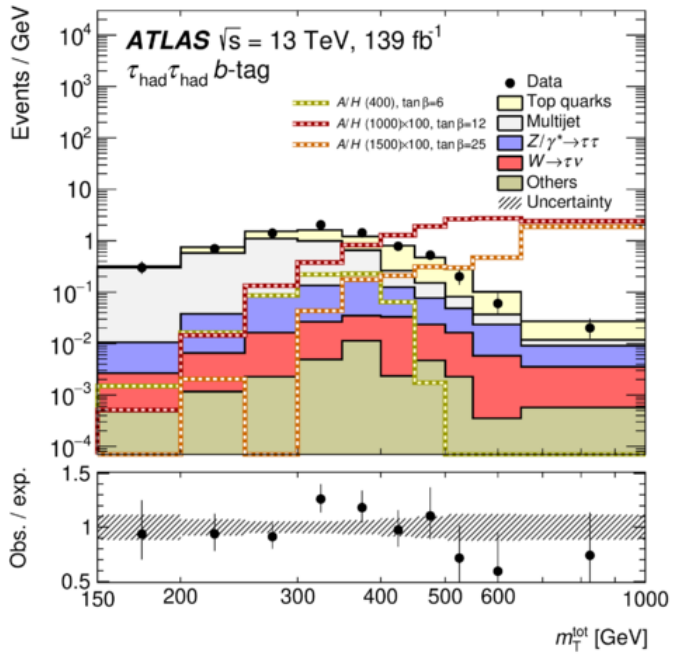
Phys. Rev. Lett. 125 (2020) 051801

- Search for heavy resonances A/H
- 2 HDM (MSSM), introduce 5 Higgs Bosons at tree level described by:
  - m_A and tanβ,
  - at large tanβ coupling to τ-lepton enhanced

- Search in mass range 0.2-2.5 TeV
- At least one τ-lepton decaying into final states with hadrons
  - $\tau_{lep}\tau_{had}$ ~46%
  - $\tau_{had}\tau_{had}$ ~42%







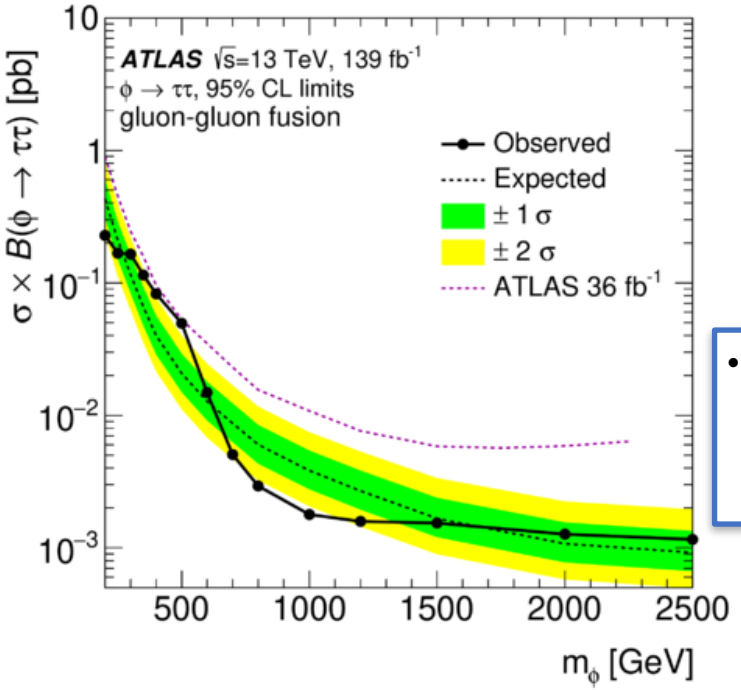
No signal excess

Search BSM A/H → ττ - Limits

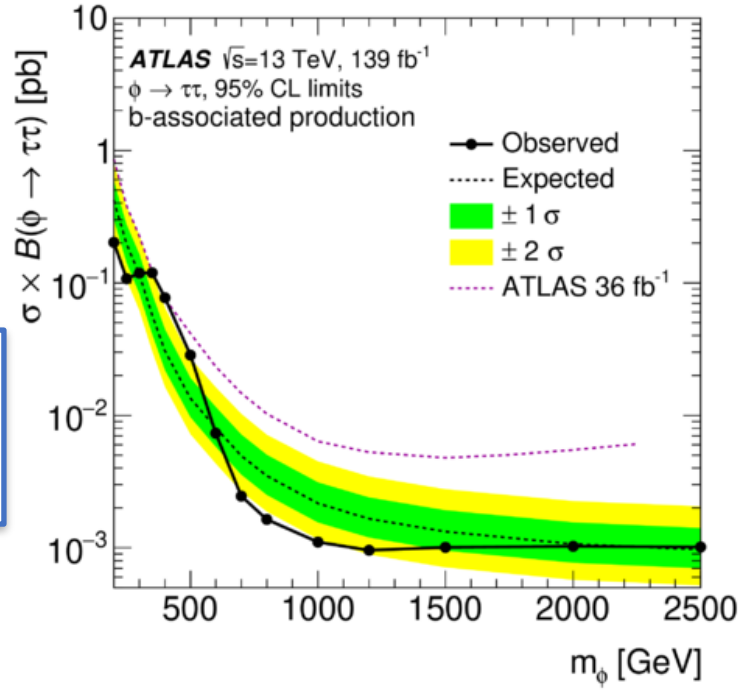
Phys. Rev. Lett. 125 (2020) 051801

- No significant excess of events over the SM expectation observed
- Cross section limits set for the 2HDM MSSM scenario

- Observed and expected 95% CL upper limits on σ x BR (pp → ϕ →ττ) for a scalar boson (φ) produced via (left) ggF and (right) b-associated production
- Limits calculated from a statistical combination of $\tau_{lep}\tau_{had}$ and $\tau_{had}\tau_{had}$ channels



- Higher sensitivity (x4-5) due to increased luminosity, improved τ ID and analysis optimization



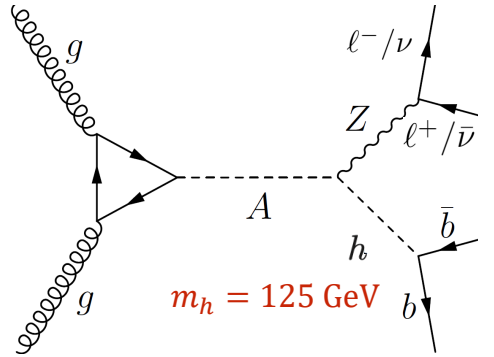
- Upper limits in the range 240–1.2 fb (230–1.0 fb) for gluon–gluon fusion (b-associated) production of scalar bosons with masses of 0.2–2.5 TeV

A→Zh, Z→2e/2μ or 2ν, h →bb - Analysis

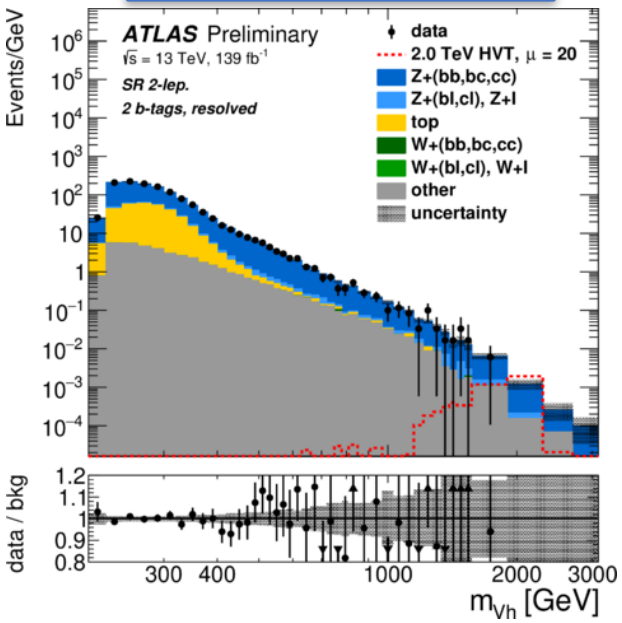
ATLAS-CONF-2020-043

- Search for new heavy resonances (300 Ge - 5 TeV) decaying into Z and 125 GeV Higgs boson in vvbb and ℓℓbb final states, where ℓ= e± or μ±
- Z′ resonances in heavy-vector-triplet models (HVT) and the CP-odd scalar boson A in two-Higgs-doublet models (2HDM)

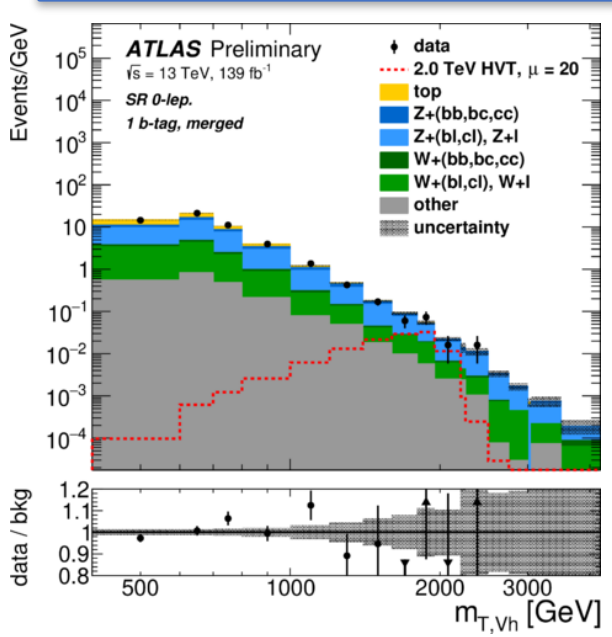
- Two channels:
  - Zh → 2e/2μ bb (2ℓ) - single lepton trigger & two identified leptons
  - Zh →vv bb (0ℓ) - E_T^{miss} trigger and E_T^{miss} > 150 GeV
- Categorization: Resolved or merged bb system with 1 or 2 b-tags



- Mass m_{Vh} (2ℓ) (resolved)

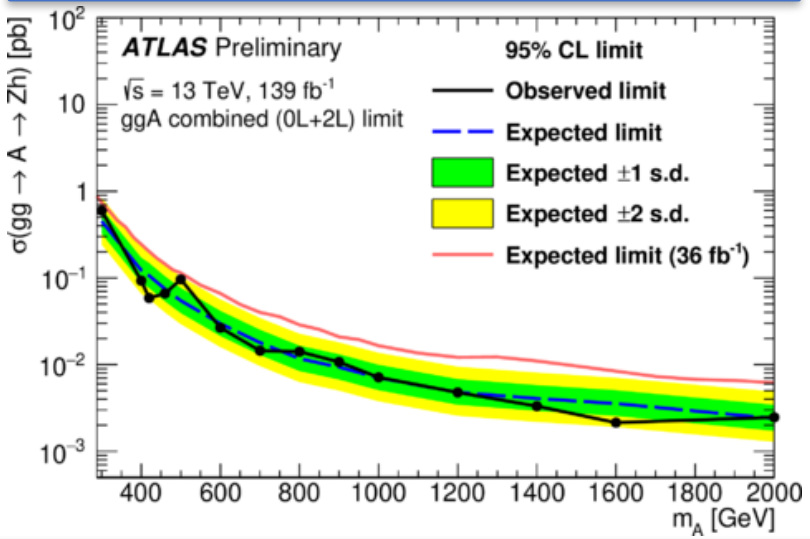


- Transverse mass $m_{T,Vh}$ (0ℓ) (merged)



- Observed data in agreement with SM background

- 95% CL U.L. on σ(gg → A) x BR(A → Zh) (0ℓ) + 2ℓ)



- Limits improved wrt 36 fb^{-1} ~50% at 300 GeV to ~500% at 5 TeV

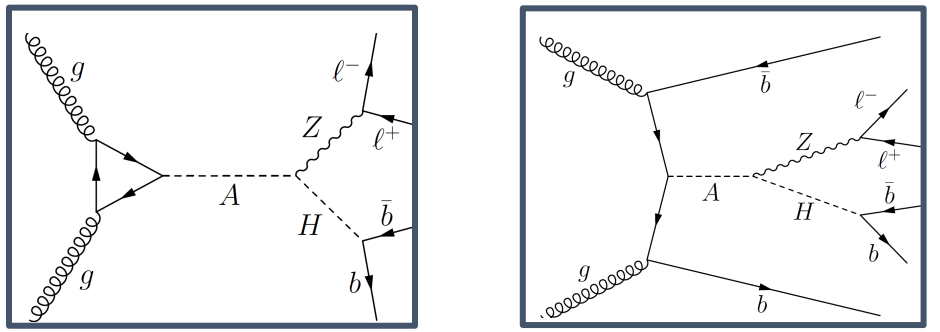
- Z': 95% CL U.L.: 1 pb - 0.4 fb, $m_{Z'}$ =300GeV - 5 TeV
- Excluded $m_{Z'}$ < 2.9 TeV (3.2 TeV) for HVT Model A (B)
- A: 95% CL U.L. 0.6 pb - 3 fb m_A =300GeV - 2 TeV

A→ZH, Z→2e/2μ, H →bb - Analysis

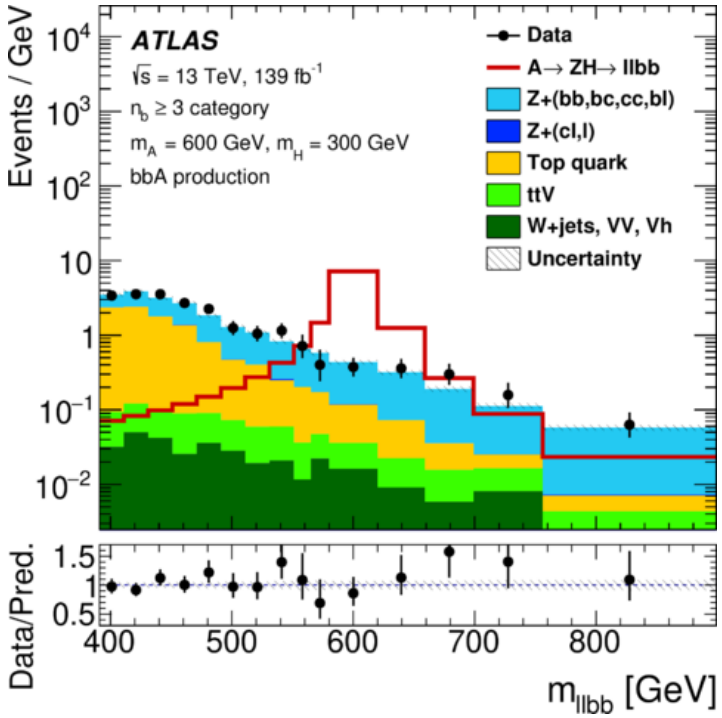
Eur. Phys. J. C. 81 (2021) 396

- Search for a heavy neutral Higgs boson, A, decaying into Z boson and another heavy Higgs boson, H
- Z decaying into electrons or muons and H into a pair of b-quarks (or W bosons)

- Mass range considered for A: 230-800 GeV and H: 130-700 GeV for H
- Scenario with different m_H and m_A, motivated by 2HDM
- Scanning m_A (widths up to 20%) for different m_H windows with Z → 2e/2μ, H→bb

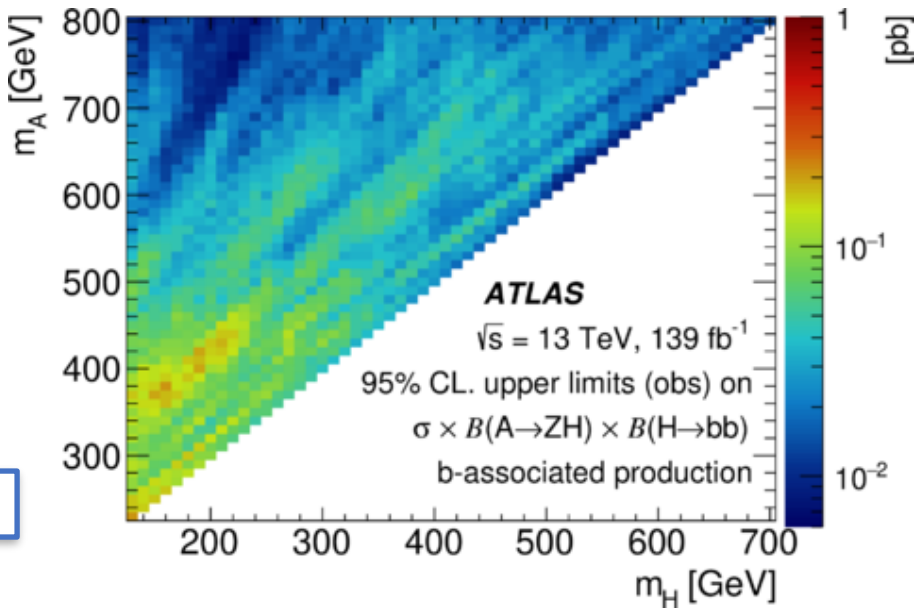


- (Left) gluon-gluon fusion and (right) b-associated production



- Mass m_{llbb} distribution for $n_b \geq 3$ and b-associated production

- 95 % CL upper limits for σ×B(A→ZH)×B(H→bb)



- Also interpretation in 2HDM

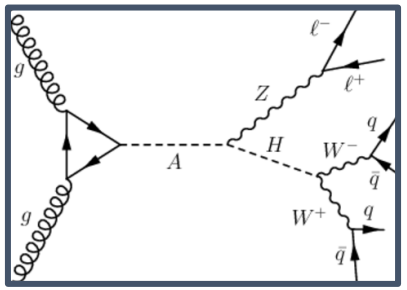
- Observed data in agreement with SM background

- 95% CL upper limits 0.0062-0.380 pb for H→bb

A→ZH, Z→2e/2μ, H →WW - Analysis

Eur. Phys. J. C. 81 (2021) 396

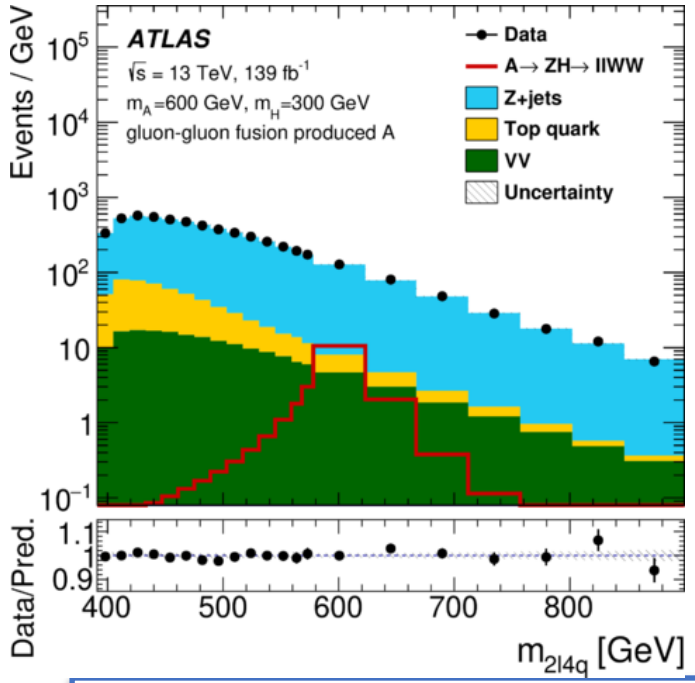
- Search for a heavy neutral Higgs boson, A, decaying into Z boson and another heavy Higgs boson, H
- Z decaying into electrons or muons and H into a pair (of b-quarks or) W bosons

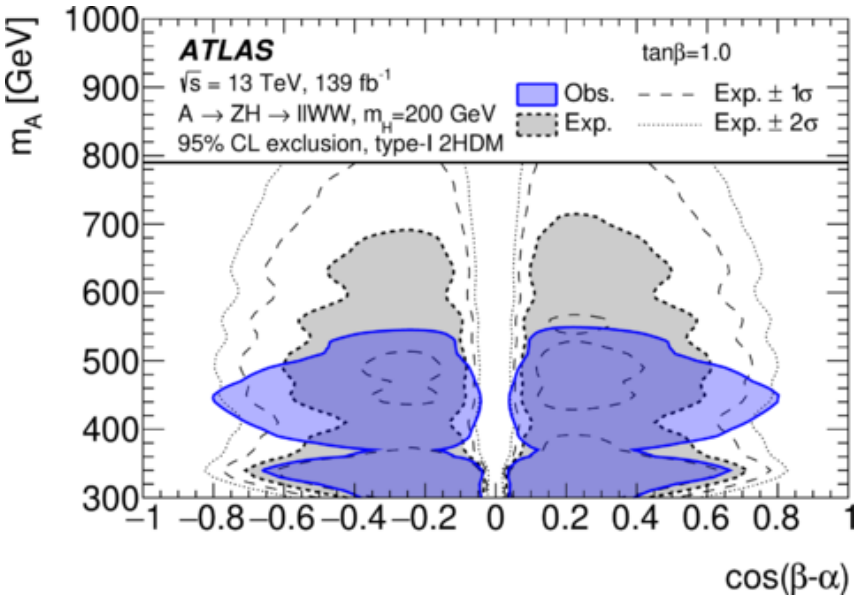


- Mass range considered for A: 230-800 GeV and H: 130-700 GeV for H
- Scenario with different m_H and m_A, motivated by 2HDM
- Scanning m_A (widths up to 20%) for different m_H windows with Z → 2e/2μ, H→WW

- Interpretations in 2HDM vs m_A, m_H and tanβ

- Mass m_{2l4q} distribution for ggF





95% CL exclusion regions in (cos(β-α), m_A) plane, tanβ=1.0, m_H=200 GeV in type-I 2HDM

- Observed data in agreement with SM background

- 95 % CL upper limits for σ×B(A→ZH)×B(H→WW): 0.023-8.9 pb

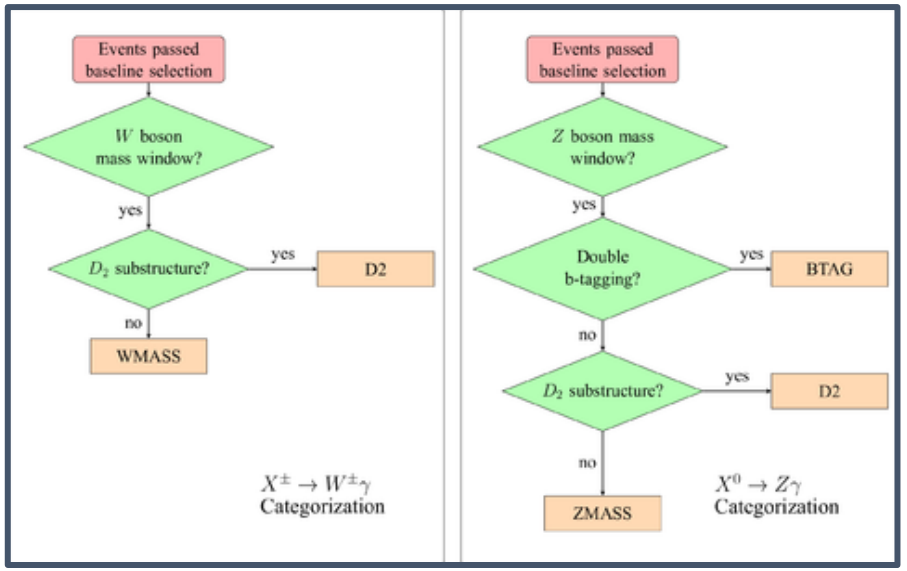
Search for high-mass W/Z+γ resonance - Analysis

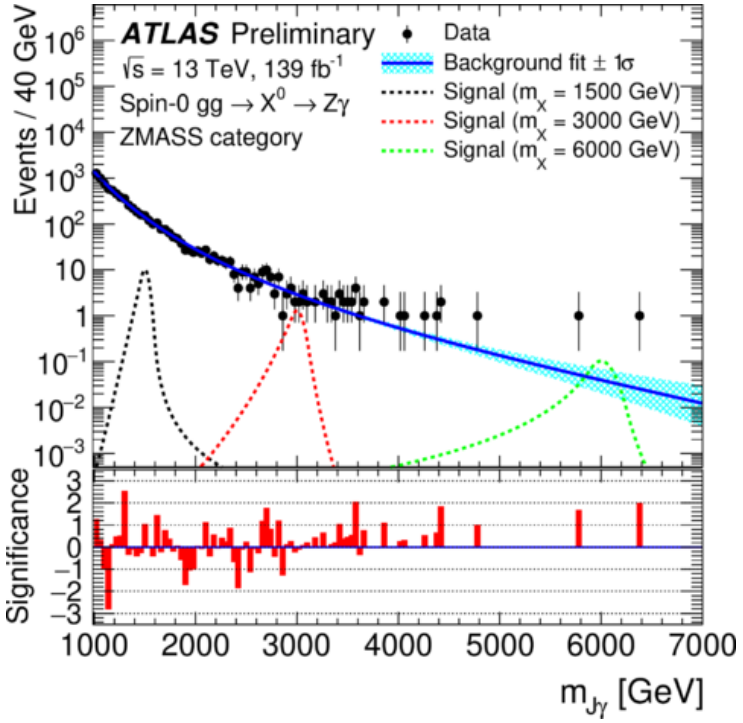
ATLAS-CONF-2021-041

- Search for high-mass *charged and neutral* bosons decaying to Wγ and Zγ
- The sensitivity of the search is determined using models of the production and decay of spin-1 charged bosons and spin-0/2 neutral bosons.
- The range in resonance masses studied from 1.0 TeV to 6.8 TeV

- Analysis target the boosted hadronic decays of the W or Z boson reconstructed as a large radius jet in association with a photon and
- The boson tagging to improve the sensitivity
- Final discriminant $m_{J\gamma}$

- Event categorization of $X^{\pm} \rightarrow W^{\pm}\gamma$ and $X^{0} \rightarrow Z\gamma$



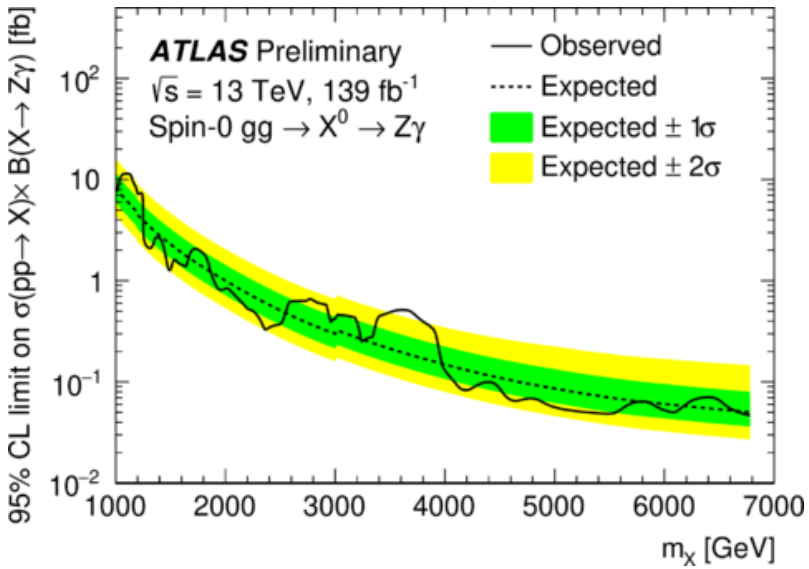


- The $m_{J\gamma}$ distributions of data events selected for the spin-0 $gg \rightarrow X^{0} \rightarrow Z\gamma$ search in the ZMASS category.
- No significant excess above the background-only hypothesis

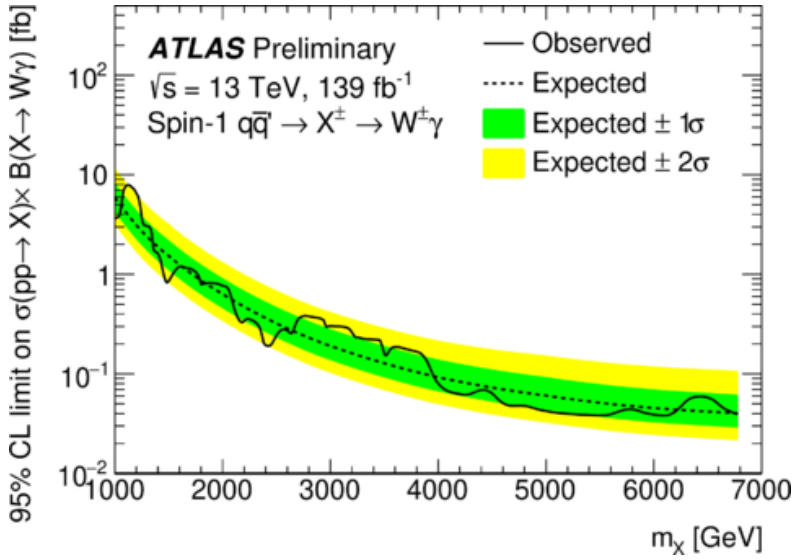
Search for high-mass W/Z+γ resonance -Limits

- 95% CL upper limits set on σ(pp→ X)× B(X→ W/Zγ) as a function of m_X for spin-0 gg→ X^0 → Zγ, spin-2 gg→ X^0 → Zγ, spin-2 qq̄→ X^0 → Zγ and spin-1 qq̄'→ $X^\pm$ → $W^\pm$γ

- 95% CL upper limits set on σ(pp→ X)× B(X→ W/Zγ) for spin-0 gg→ X^0 → Zγ



- 95% CL upper limits set on σ(pp→ X)× B(X→ W/Zγ) for spin-1 qq̄'→ $X^\pm$ → $W^\pm$γ



- Limits from 10 to 0.05 fb as m_x increases from 1TeV to 6.8TeV

ATLAS-CONF-2021-041

- Limits include ggF and qq production modes

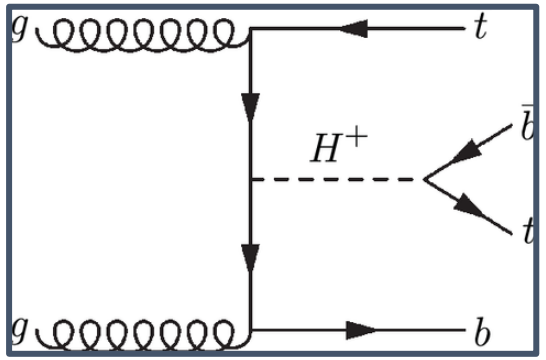
ATLAS Searches for Charged Higgs

- $H^+ \rightarrow tb$
- $H^{++} \rightarrow W^+W^+$

Search for heavy $H^+ \rightarrow tb$ - Analysis

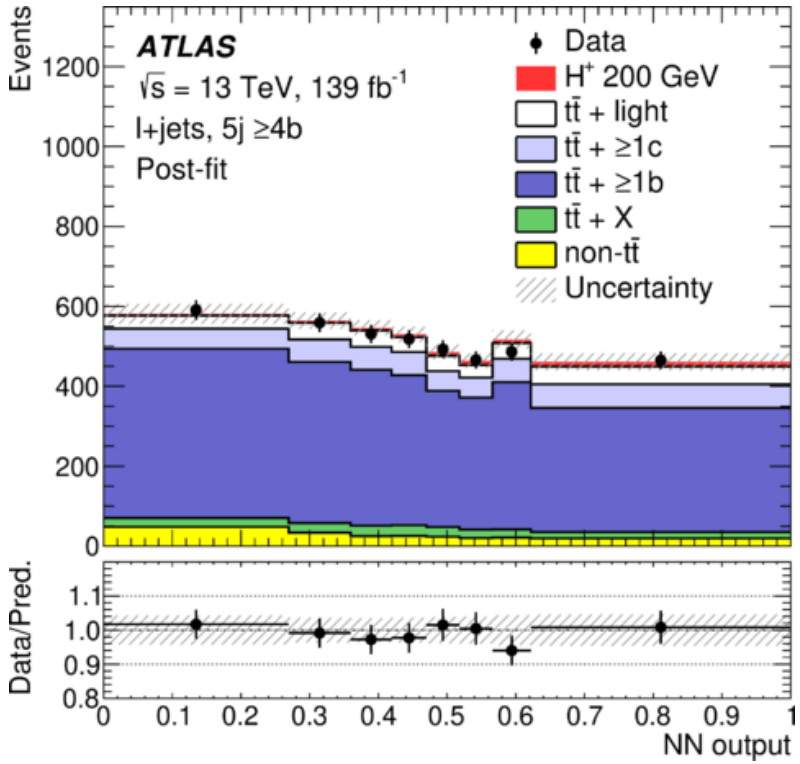
JHEP 06 (2021) 145

- Search for heavy charged Higgs bosons (200-2000 GeV) decaying into a top quark and a bottom quark



- Key channel in several new physics scenarios such as 2HDM (MSSM) at high H^+ mass

- Final states with jets and one electron or muon (trigger)
- Events are categorised according to the multiplicity of jets and b-tagged jets
- Multivariate analysis techniques are used to discriminate between signal and background events

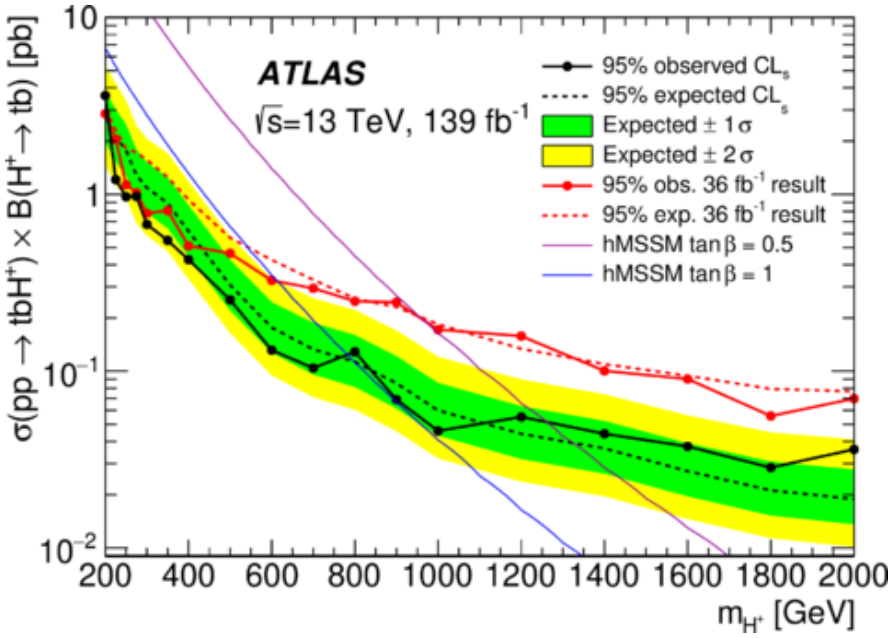


- No significant excess above the background-only hypothesis

Search for heavy $H^+ \rightarrow tb$ - Limits

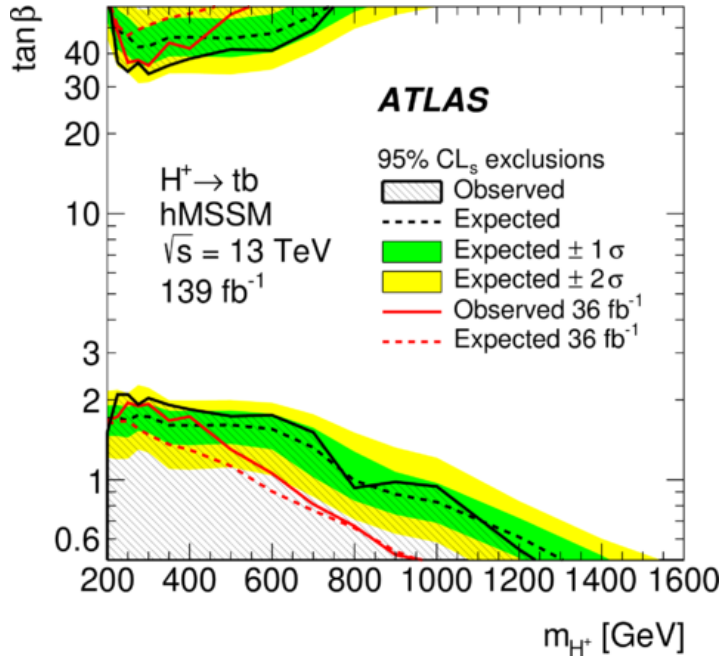
JHEP 06 (2021) 145

- Observed and expected upper limits for the production of $H^+ \rightarrow tb$ in association with a top quark and a bottom quark.



- 95% CL limits range from 3.6 pb at 200 GeV to 0.035 pb at 2000 GeV

- Observed and expected limits on tanβ as a function of m_{H+} in the hMSSM scenario.



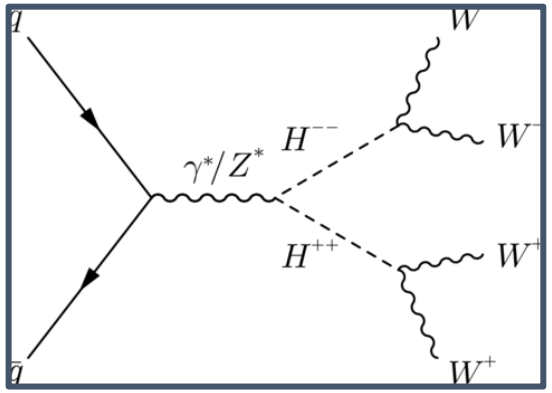
- Exclusions in the tan β vs m(H^+) plane performed for various benchmark scenarios

- Higher sensitivity wrt 36 fb^{-1} due to larger dataset and improved analysis

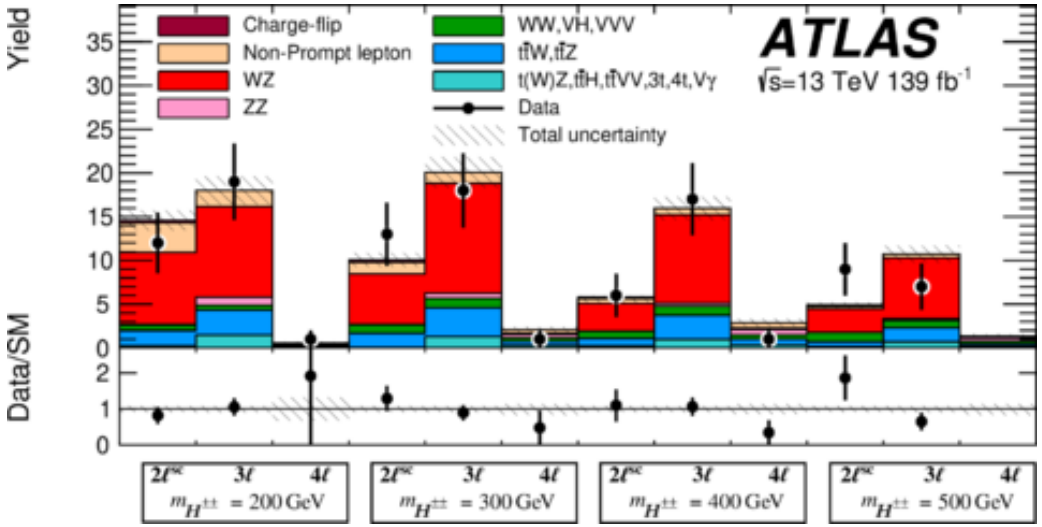
Search for $H^{++} \rightarrow W^+W^+$ - Analysis

JHEP 06 (2021) 146

- Pair production of double charged Higgs bosons (Type-II Seesaw Model)
- Focus on the bosonic decay mode studied $m(H^{\pm\pm}) \in [200,600]$ GeV
- Pair production: $m(H^{\pm}) > m(H^{\pm\pm})$ (> 100 GeV)
- Multivariate analysis in three channels: 2 same-sign charge, 3 or 4 leptons
- Prompt lepton backgrounds from MC, non-prompt leptons from data

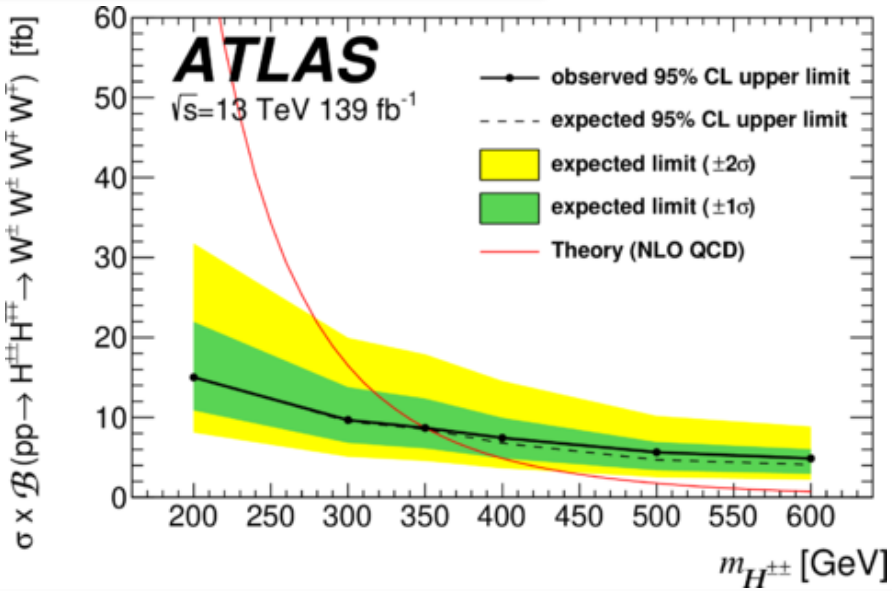


- Data event yields compared with the expected contributions from relevant background sources, for the combination of the individual channels of the $2\ell^{sc}$, 3ℓ and 4ℓ SRs



- No significant excess in any of the signal regions

- Sensitive to triplet vev υ_t~ 100 MeV



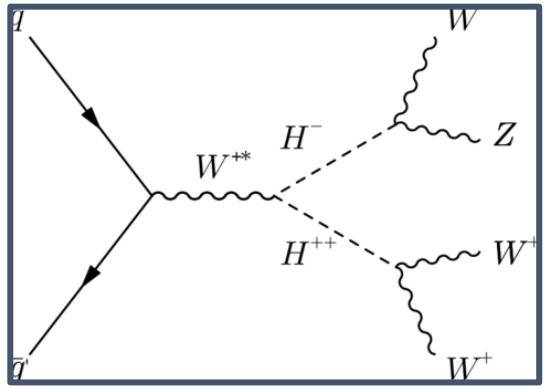
- Observed and expected 95% CL upper limits on $H^{\pm\pm}$ σ x BR obtained from the combination of $2\ell^{sc}$, 3ℓ and 4ℓ channels

- $H^{\pm\pm}$ masses excluded below 350 GeV for the pair production

Search for $H^{++} \rightarrow W^+W^+$ and $H^- \rightarrow W^-Z$ - Analysis

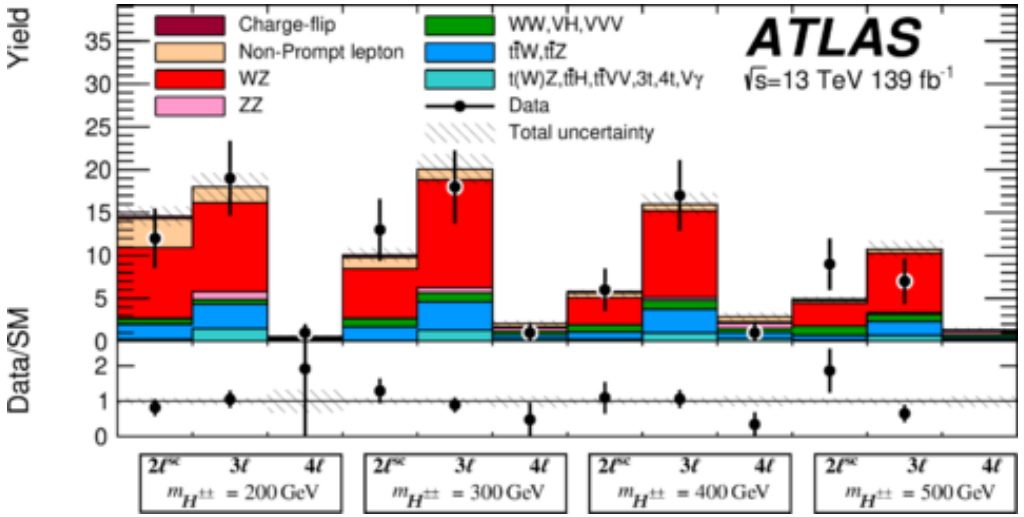
JHEP 06 (2021) 146

- Associated production of single charged and double charged Higgs bosons
- Multivariate analysis in three channels: 2 same-sign charge, 3 or 4 leptons
- Prompt lepton backgrounds from MC, non-prompt leptons from data



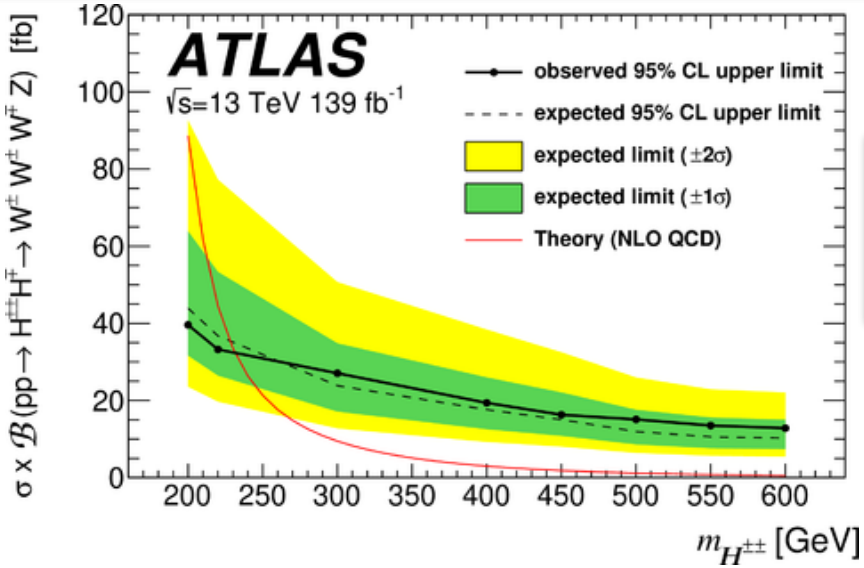
- Data event yields compared with the expected contributions from relevant background sources, for the combination of the individual channels of the $2\ell^{sc}$, 3ℓ and 4ℓ SRs

- Sensitive to triplet vev v_t~ 100 MeV
- Targets range $|m_{H^{\pm\pm}} - m_{H^{\pm}}| < 5$ GeV



- No significant excess in any of the signal regions

- Observed and expected 95% CL upper limits on $H^{\pm\pm}$ and $H^{\pm}$ associated σ x BR obtained from the combination of $2\ell^{sc}$, 3ℓ and 4ℓ channels



- Upper limits on the pair (associated) σxBR:
- 15 fb-5 fb (40 fb-10 fb) for $H^{\pm\pm}$ mass 200 GeV-600 GeV

- $H^{\pm\pm}$ masses excluded below 230 GeV for the associated production

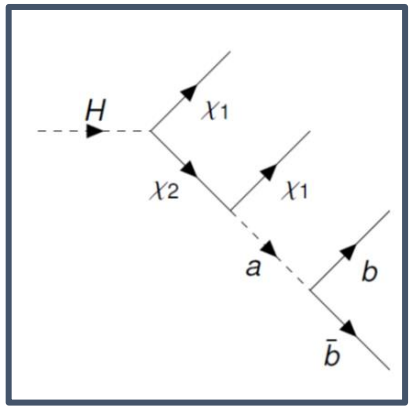
ATLAS Searches for New Pseudo-Scalar Resonances In Exotic Higgs Boson Decays

- $H \rightarrow \chi_1\chi_2 \rightarrow b\bar{b}$ + MET
- $H \rightarrow aa \rightarrow b\bar{b}\mu\mu$

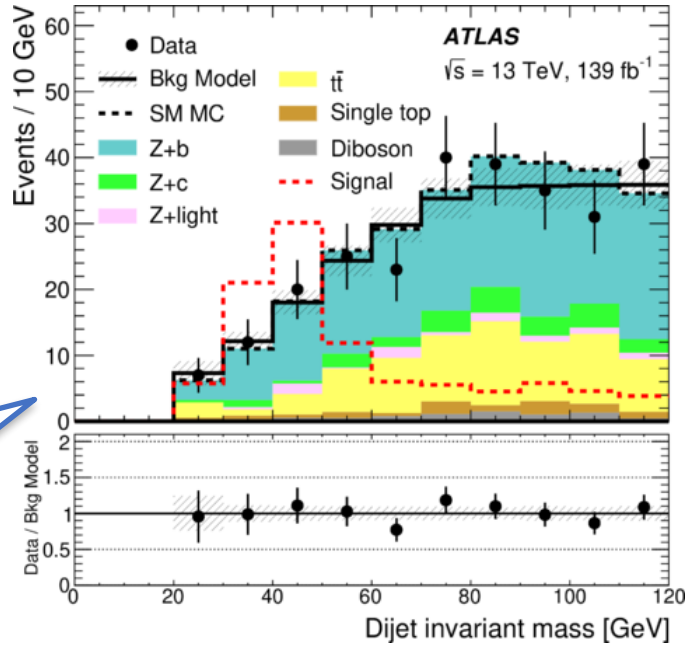
Search Zh → ℓℓbb̄ + MET - Analysis

JHEP 01 (2022) 063

- The search targets events from $ZH(125)$ production in an NMSSM scenario (near the PQ symmetry limit) into the ($\ell\ell$) bb̄+MET final states
- Production scenario $H \rightarrow \tilde{\chi}_2^0\tilde{\chi}_1^0$ *with* $\tilde{\chi}_2^0 \rightarrow a\tilde{\chi}_1^0$
  - $\tilde{\chi}^0_{1,2}$ the two lightest neutralinos
  - *a,* the light pseudoscalar Higgs boson decays to a pair of b-quarks
- Search for peak in the dijet invariant mass (20-65 GeV) from *a* decays



- Final state: pair of 2 SFOS leptons (Z), 2 b-jets and missing transverse momentum (E_T^{miss}) from the two $\tilde{\chi}_1^0$ neutralinos
- Main backgrounds are Z+HF and $t\bar{t}$ (CRs)
- Signal Region (SR): 81 < $m_{\ell\ell}$ < 101 GeV, $p_T^{\ell\ell}$> 40 GeV, ≥ 2 jets, ≥ 1 b-jet, p_T^j > 20 GeV, 20 < m_{jj} < 120 GeV, E_T^{miss} > 100 GeV
- Suppress top background using: p_T fraction: 0.8 ≤ (p_T^{jj} +E_T^{miss}) / $p_T^{\ell\ell}$ ≤ 1.2



- Distribution of the dijet invariant mass in SR
- The distribution labelled `Signal' is for the model with (m_a, $m\tilde{\chi}_1^0$, $m\tilde{\chi}_2^0$) = (45 GeV, 10 GeV, 80 GeV), setting all branching ratios to 100% in the decay chain H → $\tilde{\chi}_2^0\tilde{\chi}_1^0$ → a $\tilde{\chi}_1^0\tilde{\chi}_1^0$ → bb̄ $\tilde{\chi}_1^0\tilde{\chi}_1^0$

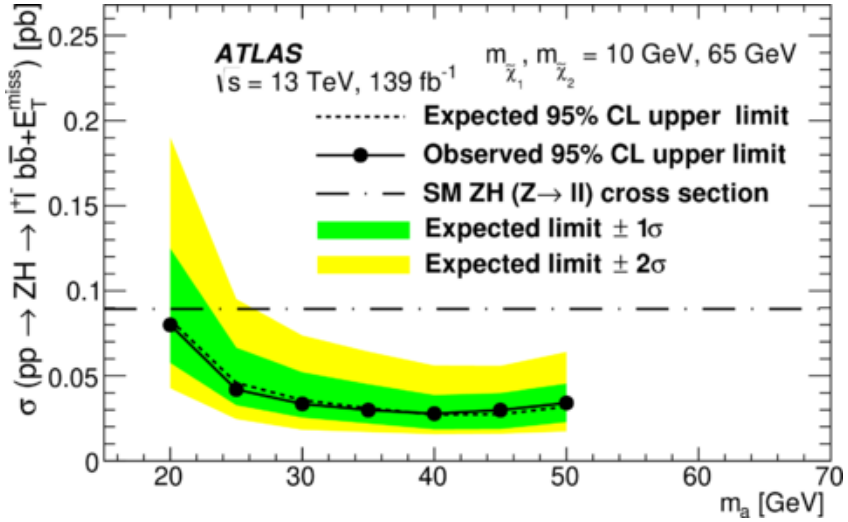
No signal excess over SM background

Search Zh → ℓℓbb̄ + MET - Limits

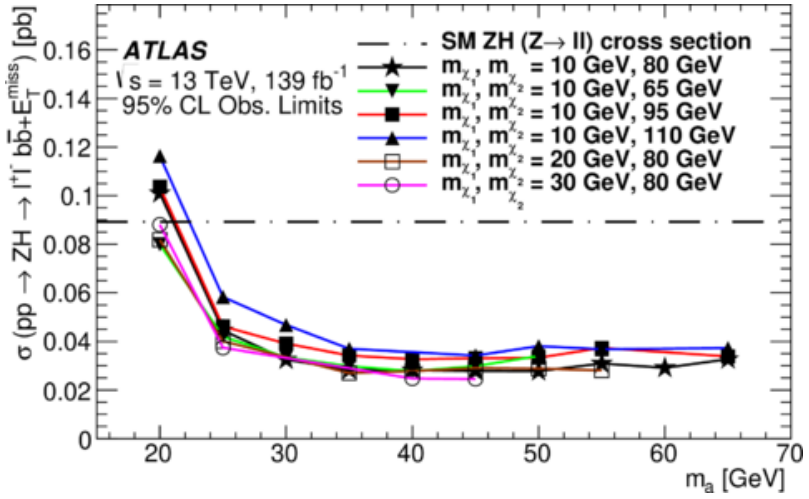
JHEP 01 (2022) 063

- No significant excess of events over the SM expectation observed
- Cross section limits set for the NMSSM scenario

- 95% CL upper limits on σ(pp → ZH) x BR for Z → ℓ⁺ℓ⁻ (ℓ = e, μ, τ) and H → $\tilde{\chi}_2^0\tilde{\chi}_1^0$ → a $\tilde{\chi}_1^0\tilde{\chi}_1^0$ → bb̄ $\tilde{\chi}_1^0\tilde{\chi}_1^0$ as a function of m_a ($m_{\tilde{\chi}_1^0}$ = 10 GeV and $m_{\tilde{\chi}_2^0}$ = 65 GeV)



- 95% CL user limits, 6 together, without the uncertainty bands



- All branching ratios in the decay chain are set to 100%
- SM value used for σ(pp → ZH) × BR(Z → ℓ⁺ℓ⁻)

- Upper limit on BR (H → $\tilde{\chi}_2^0\tilde{\chi}_1^0$) of 31% in the region of highest sensitivity
  - m_a: 35 - 55 GeV for fixed $m_{\tilde{\chi}_1^0}$ = 10 GeV, $m_{\tilde{\chi}_2^0}$ = 80 GeV

Search BSM H(125) → aa →bb̄μμ - Analysis

- Search for exotic decays of the H(125) into a pair of new light pseudoscalar particles *a*, H→*aa*, where one *a*-boson decays into a b-quark pair and the other into a muon pair

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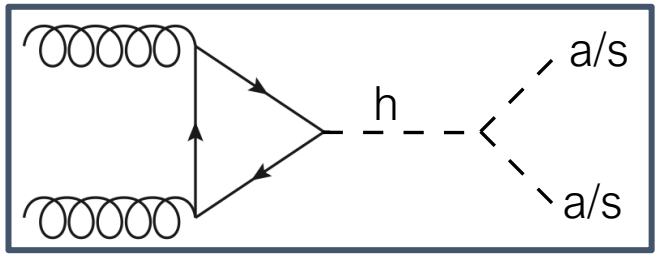
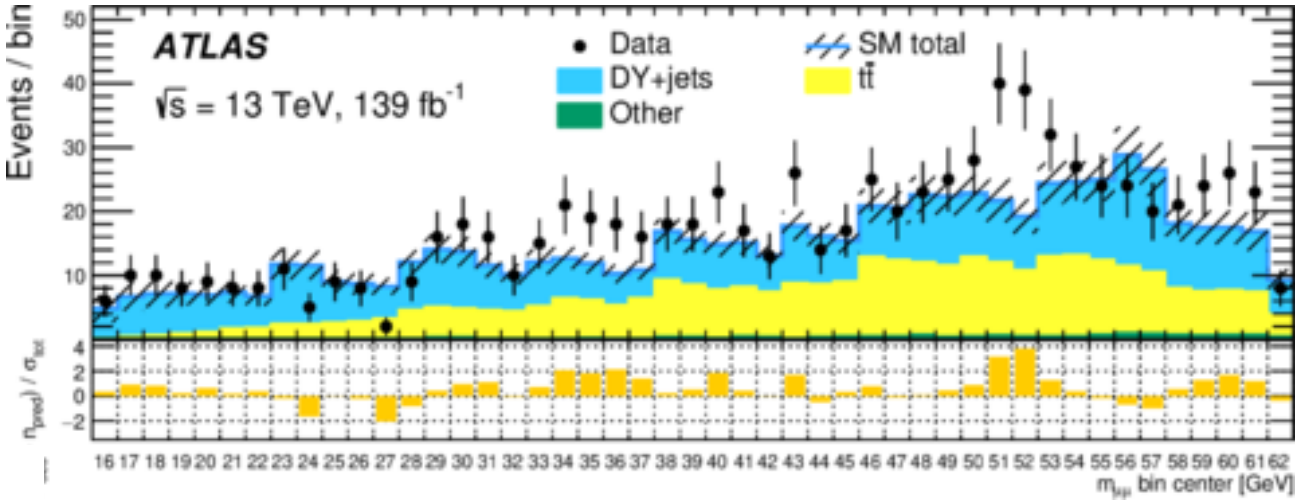
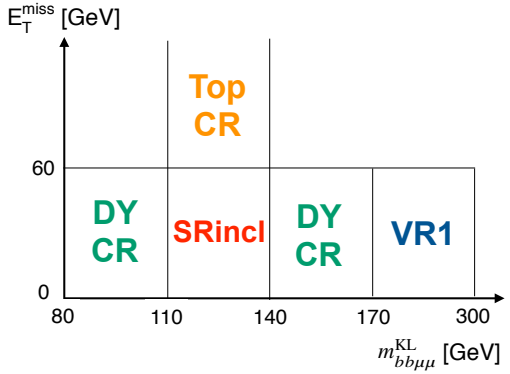


- Search for narrow di-muon resonance, $m_{\mu\mu}$ in [15 − 65] GeV
- 2 b-tagged jets with p_T > 20 GeV,
- Requiring $m_{bb} \simeq m_{\mu\mu}$ - kinematic likelihood (KL) fit → (ln(L^{max}))
- Signal events 110 < $m^{KL}_{bb\mu\mu}$ < 140 GeV and ln(L^{max}) > −8
- E_T^{miss} < 60 GeV to suppress tt̄
- Sensitivity increased by using BDT (BDTm_a > 0.2)



- Dominant backgrounds (96%)
  - DY di-muon in association with b-quarks
  - tt̄ with each W decay into a muon and a neutrino
- 2 control regions constrain tt̄ and DY backgrounds

- Signal, control, and validation regions



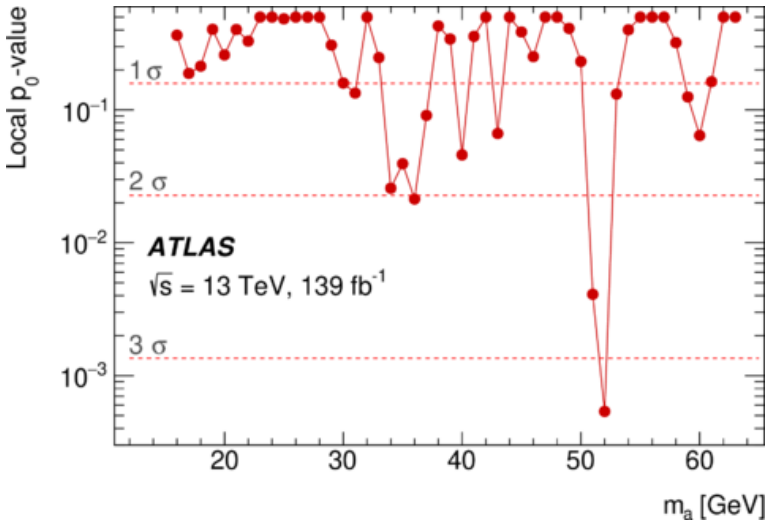
- Post-background-validation-fit number of events in all SR bins (after applying the BDT selection)

Search BSM H(125) → aa →bb̄μμ - Limits

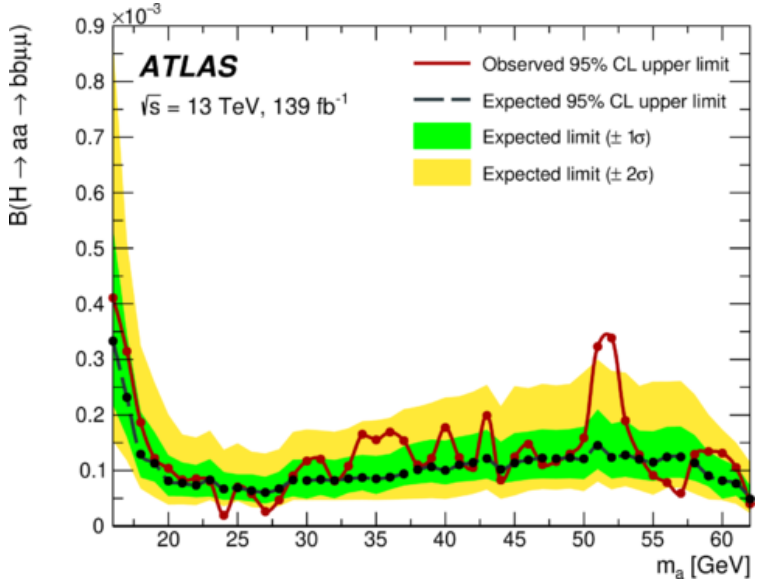
- No significant excess of events over the SM expectation is observed

Phys. Rev. D 105 (2022) 012006

- Local p0-values in standard deviations (σ) as a function of the signal mass hypothesis



- Upper limits on B(H → aa → bb̄μμ) at 95% CL, with the BDT selection, as a function of the signal mass hypothesis



- Largest excess for $m_{\mu\mu}$ = 52 GeV ⇒ 3.3σ local and 1.7σ global p_0

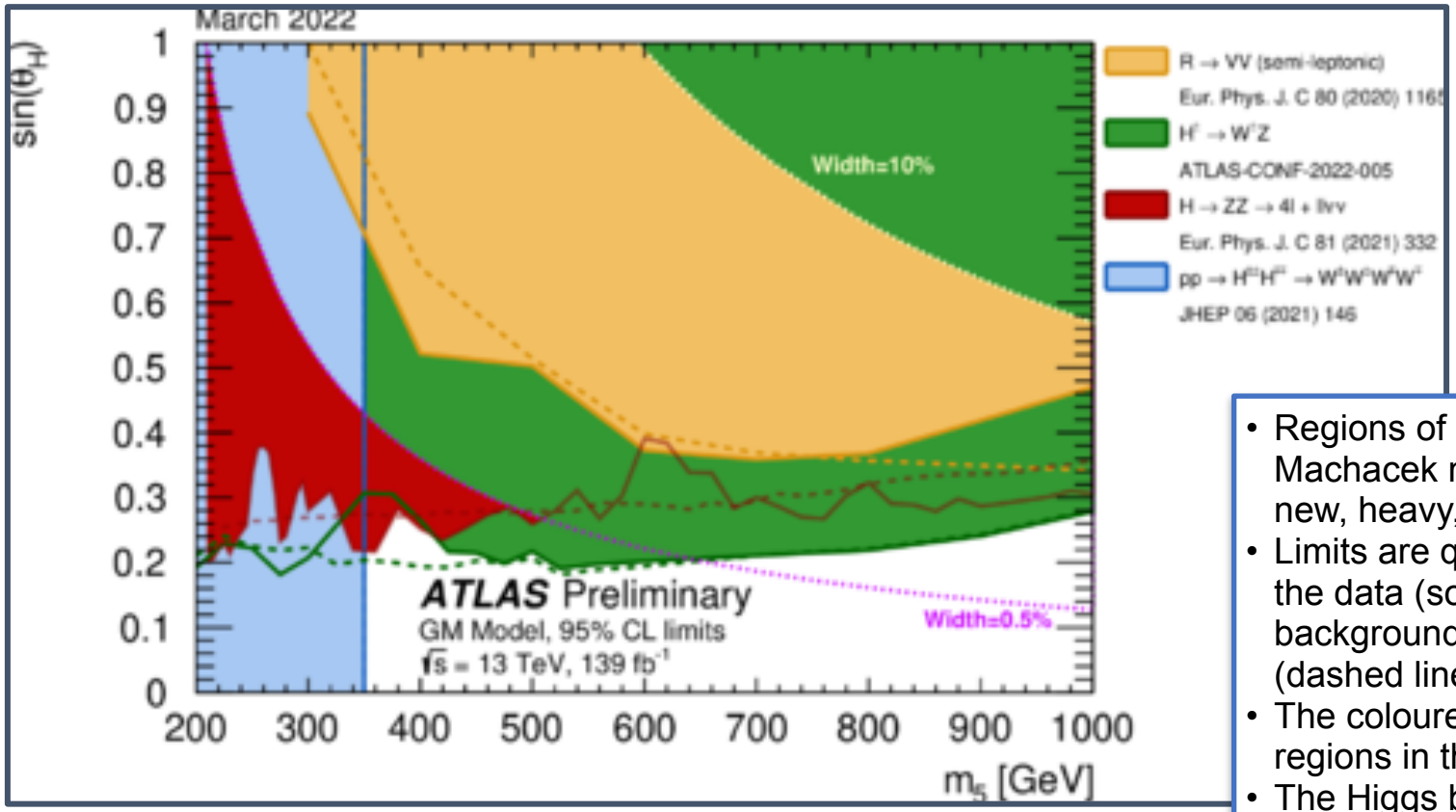
Upper limits at 95% CL in the range (0.2-4.0)×10^{-4}

- The limits improve upon the ATLAS 36 fb^{-1} result by a factor of 2–5 over the full $m_{\mu\mu}$ range

ATLAS Summary Plots

ATLAS Summary Plots

Interpretation of heavy Higgs boson searches in the ATLAS experiment in the Georgi-Machacek model

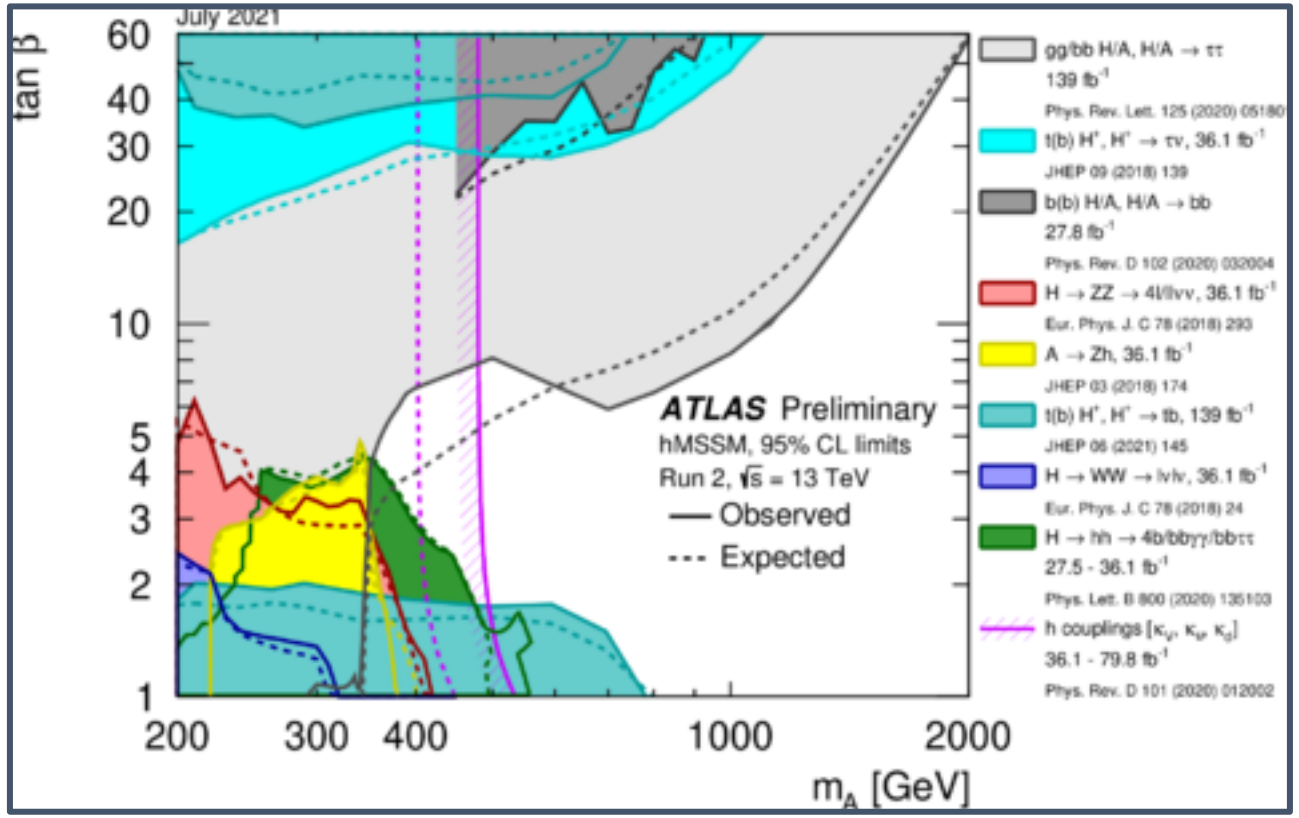


[ATL-PHYS-PUB-2022-008]

- Regions of the H5 plane benchmark of the Georgi-Machacek model excluded via direct searches for new, heavy, neutral or charged Higgs bosons.
- Limits are quoted at 95% CL and are indicated for the data (solid lines) and the expectation from the background model assuming only SM processes (dashed lines).
- The coloured areas indicate the observed excluded regions in this parameter space.
- The Higgs bosons that are searched for are produced via VBF for all searches shown here apart from pp → $H^{\pm\pm}H^{\mp\mp}$ production that proceeds via the Drell-Yan mechanism.

ATLAS Summary Plots

hMSSM summary plots from direct and indirect searches

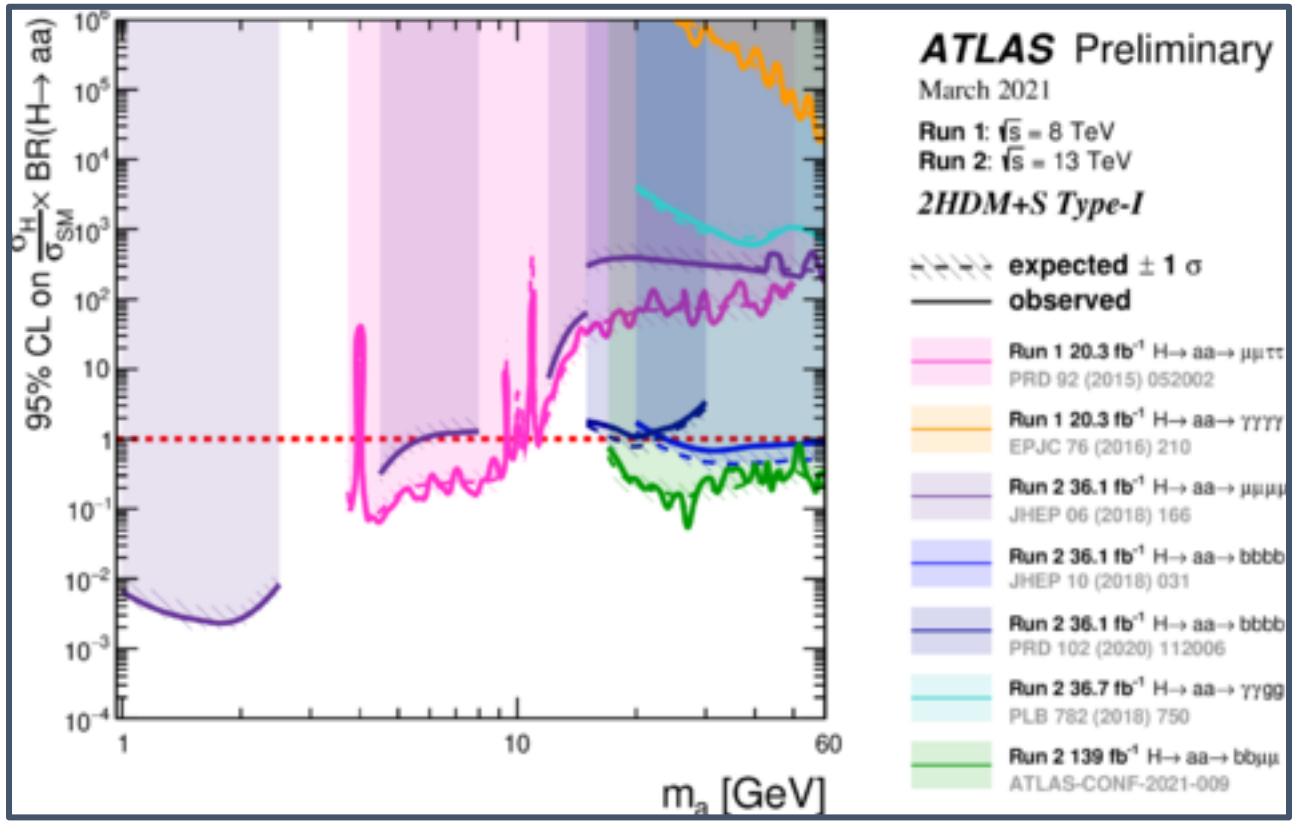


ATL-PHYS-PUB-2021-030

- Regions of the [m_A, tanβ] plane excluded in the hMSSM via direct searches for heavy Higgs bosons and fits to the measured rates of observed Higgs boson production and decays.
- Limits are quoted at 95% CL and are indicated for the data (solid lines) and the expectation for the SM Higgs sector (dashed lines).
- The light shaded or hatched regions indicate the observed exclusions.
- Unless otherwise specified, only gluon-gluon fusion (gg) is considered for the production mode.

ATLAS Summary Plots

Summary of Exotic Higgs Boson Decays from the ATLAS Experiment



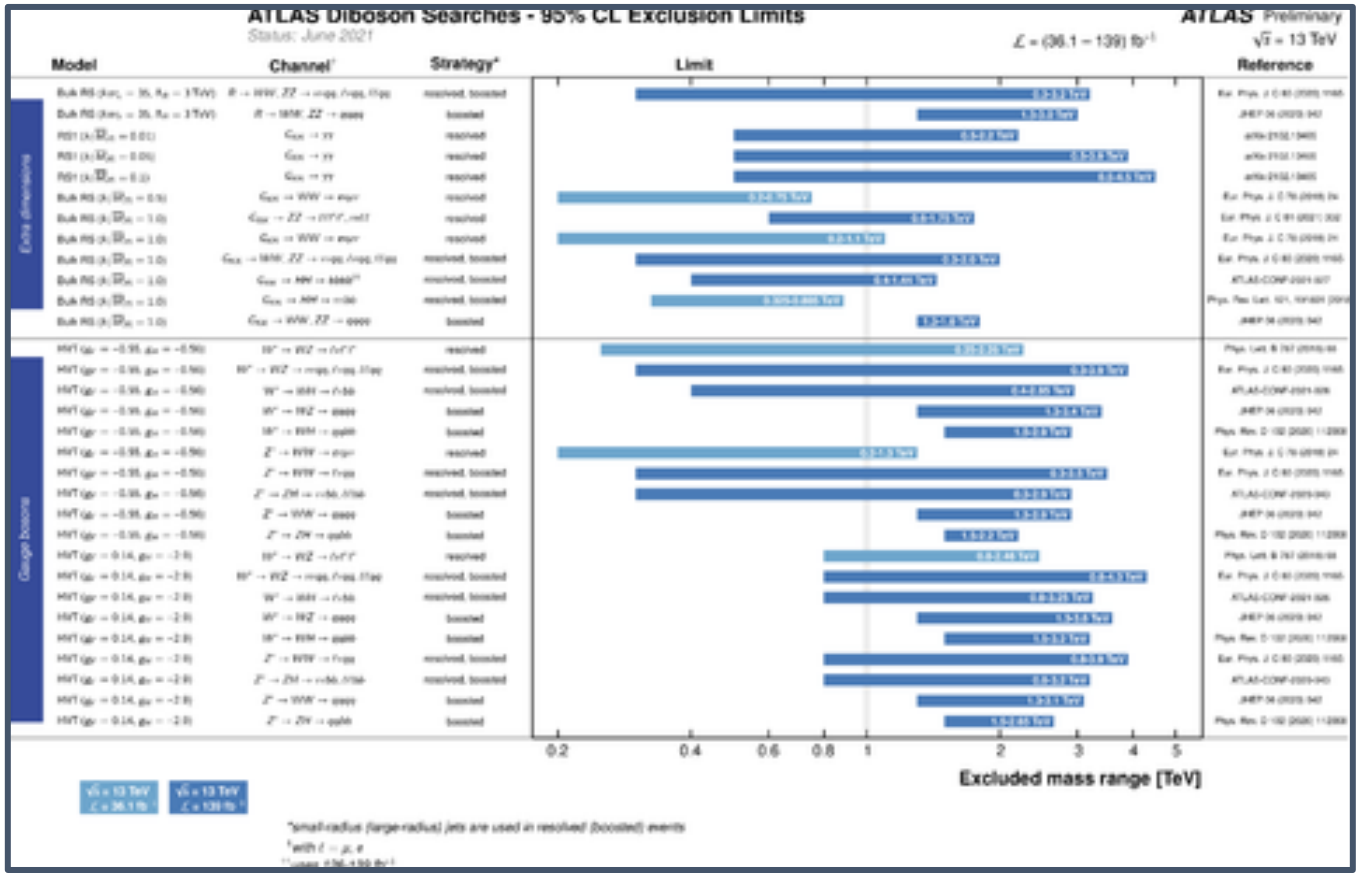
ATL-PHYS-PUB-2021-008

- Observed and expected 95% CL upper limits on σ_H/σ_{SM} x B(H→aa) in the 2HDM+S type-I scenario

ATLAS Summary Plots

Summary of ATLAS diboson searches

ATL-PHYS-PUB-2021-018

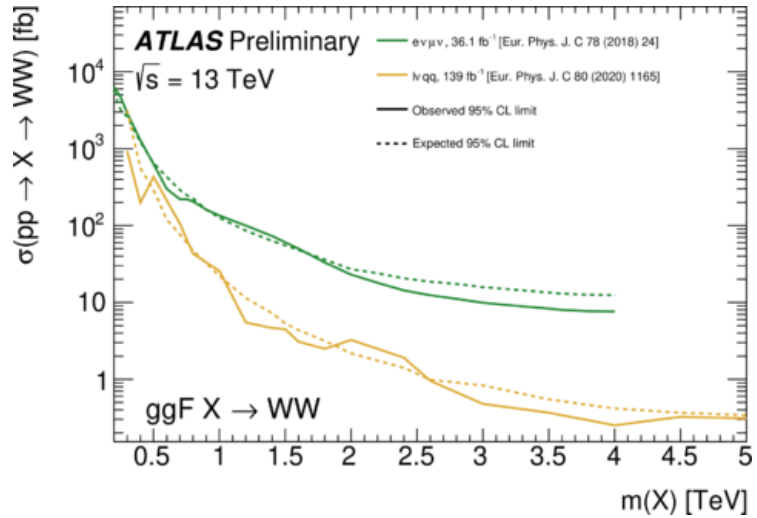


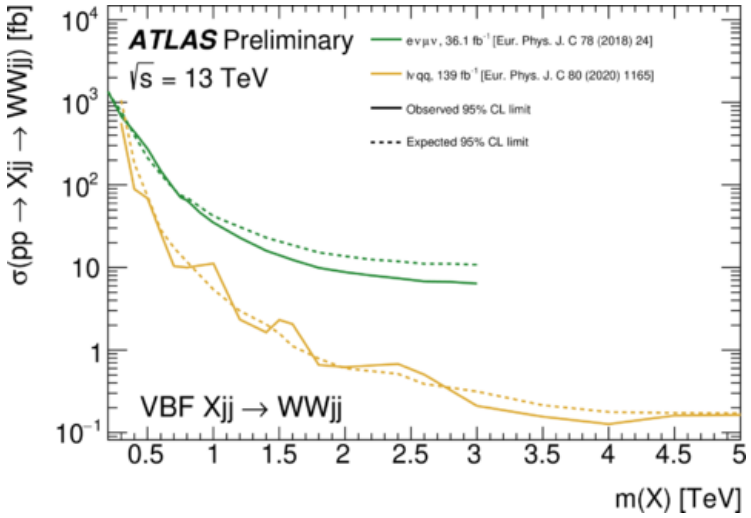
- The inputs to these summary figures are obtained from searches for new heavy particles decaying to a pair of bosons (WW, WZ, ZZ, WH, ZH, γγ in p-p collisions at √s=13 TeV, with both partial and full Run 2 datasets

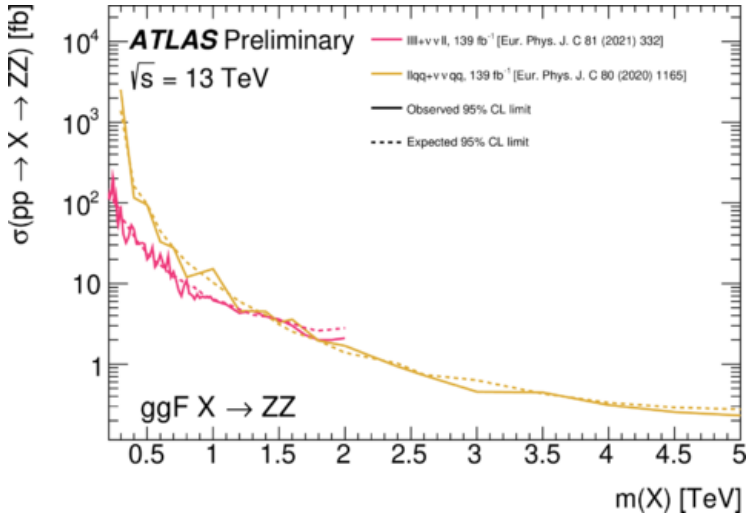
Summary of Diboson Resonance Searches

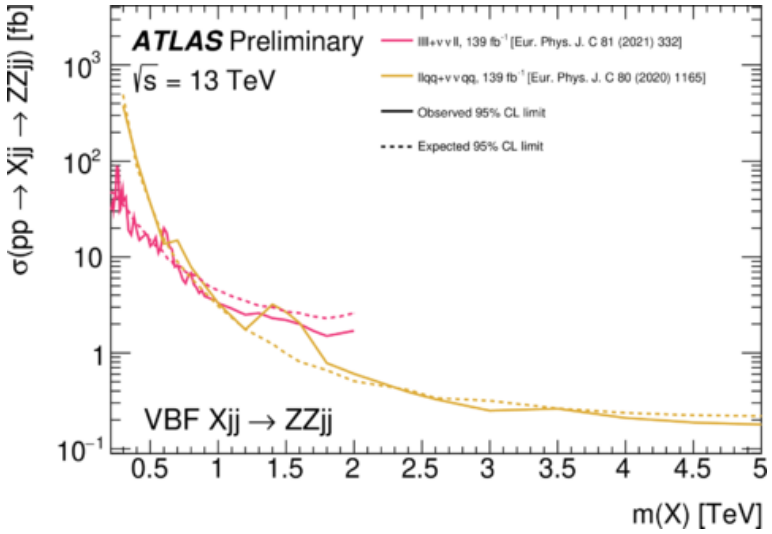
ATL-PHYS-PUB-2021-018

- Searches for new heavy scalar decaying to ZZ and WW - leptonic and hadronic decays









- Higher mass range, above 2 TeV, covered by ZZ→ℓℓqq/vvqq and WW → ℓvqq channels

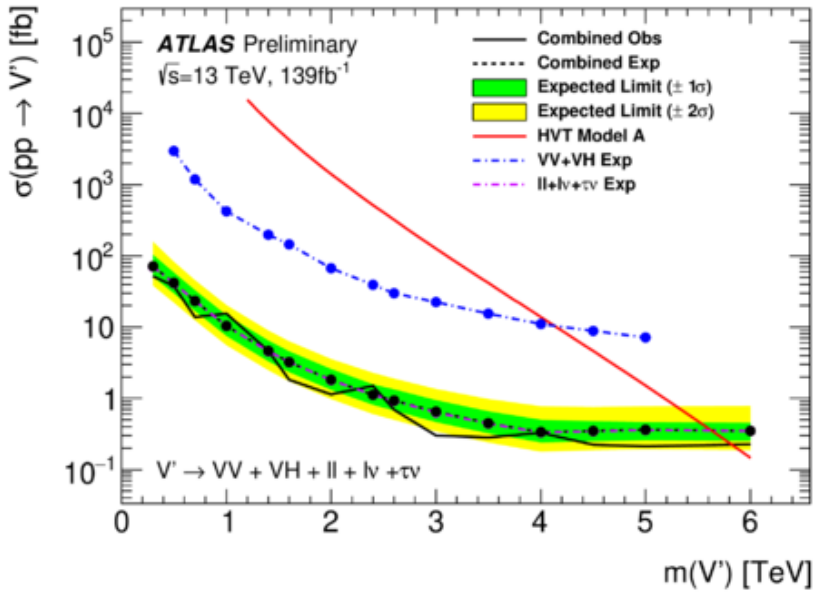
ATLAS Summary Plots

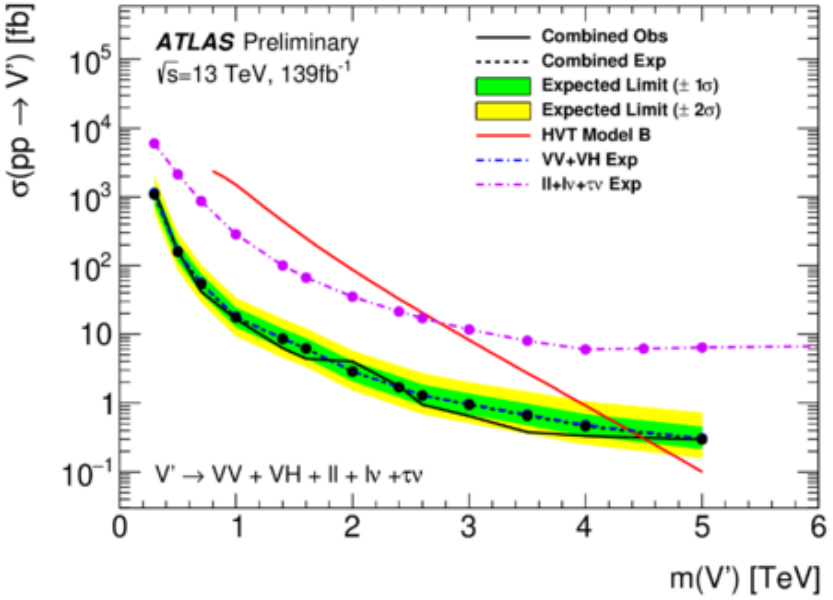
ATLAS-CONF-2022-028

Summary of ATLAS diboson searches (New!)

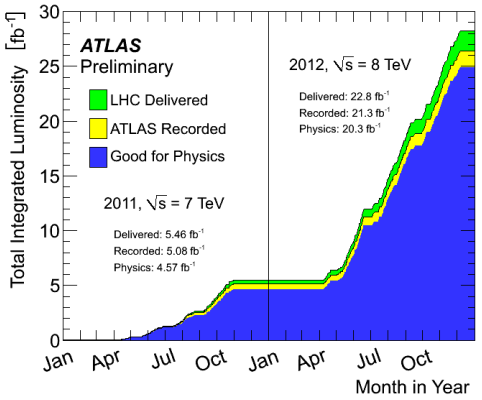
- Analyses selecting bosonic decays in VV: $qqqq$, $\nu\nu qq$, $\ell\nu qq$, $\ell\ell qq$, $\ell\nu\ell\ell$, and VH: $qqbb$, $\nu\nu bb$, $\ell\nu bb$, and $\ell\ell bb$ final states combined, searching for a narrow-width resonance.
- Analyses selecting leptonic $\ell\nu$ and $\ell\ell$ final states combined.
- Sets of analyses further combined with each other.
- A simplified model predicting a spin-1 HVT investigated

- No significant deviation from the SM prediction observed
- 95% CL cross-section limits are set
- Limits are also expressed in terms of constraints on couplings of the HVT to quarks, leptons, and Higgs boson.
- Data exclude a HVT with mass below 5.8 TeV in a weakly coupled scenario (left, HVT model A) and 4.5 TeV in a strongly coupled scenario (right, HVT model B).

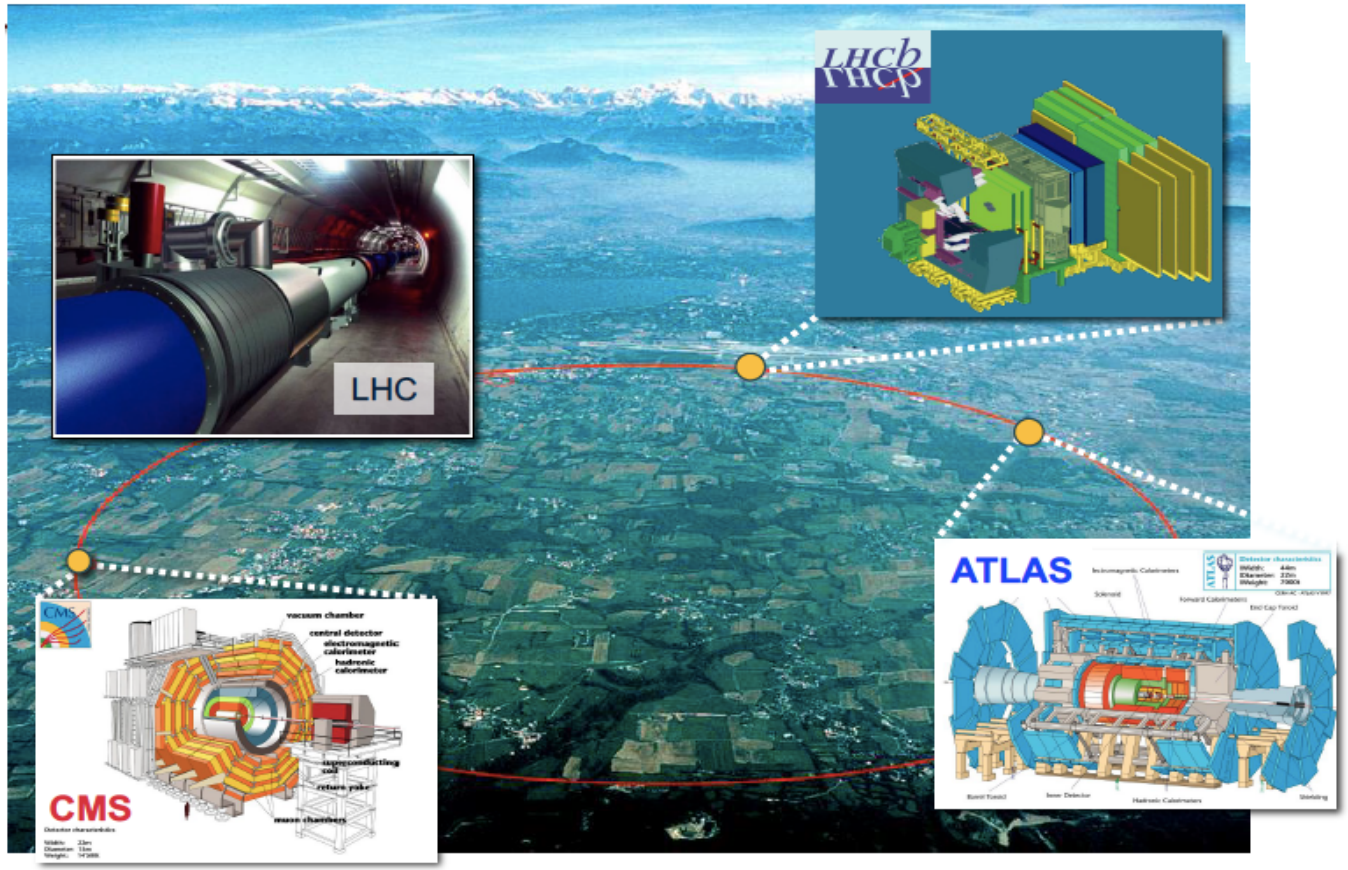


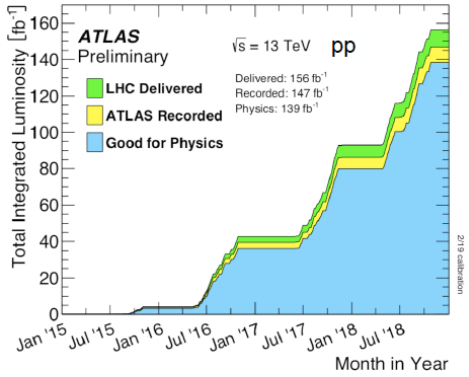


ATLAS Experiment at LHC at CERN



Run-1 (2011-2012)
~25 fb^{-1}





Run-2 (2015-2018)
~140 fb^{-1}