Brookhaven National Laboratory

ATLAS EXPERIMENT

Intersection of Particle and Nuclear Physics, CIPANP 2022

Search for exotic decays of the Higgs boson and additional scalar particles in ATLAS

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on behalf of the ATLAS collaboration

Overview

- With the Higgs we found the first fundamental scalar particle ten years ago

- Many proposed extensions of the Standard Model feature additional scalars or pseudo scalar particles
  - E.g. Two-Higgs Doublet Model (2HDM) feature $h^0, A^0, H^0, H^\pm$

- Mixing between Higgs and additional scalars could provide access to dark sectors
  - $\mathrm{BR}(H \rightarrow \mathrm{BSM}) < 12\%$ (*Nature* **607**, 52–59 (2022))

- Robust program in ATLAS searching for new scalars and exotic Higgs decays

Charged Higgs

$t \rightarrow H^\pm b, H^\pm \rightarrow cb$

$H^\pm \rightarrow ZW \rightarrow 3\ell + \nu$

$H^{\pm\pm} H^{\mp\mp} \rightarrow 4\ell$

New scalar / pseudoscalar

$t\bar{t}H \,/\, t\bar{t}A \rightarrow 4t$

$X \rightarrow \gamma\gamma$, low mass X

$X \rightarrow \gamma\gamma$, high mass X

$t \rightarrow qX, X \rightarrow b\bar{b}, q = u, c$

$H \rightarrow$ leptons + b-jets

Heavy $H \rightarrow WW$

Exotic Higgs Decays

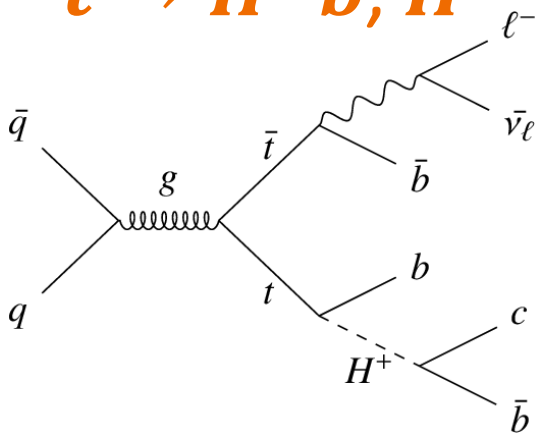
$H \rightarrow \chi_1\chi_2,\ \chi_2 \rightarrow a\chi_1,\ a \rightarrow b\bar{b}$

$H \rightarrow Z_d Z_d \rightarrow 4\ell, H \rightarrow Z Z_d \rightarrow 4\ell$

$H \rightarrow aa \rightarrow b\bar{b}\mu\mu$

$t \to H^{\pm} b,\ H^{\pm} \to cb$

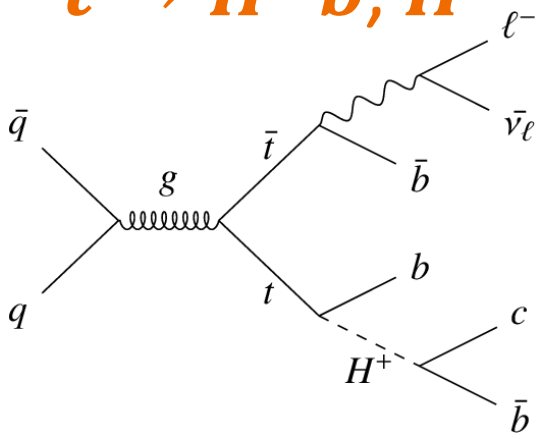
ATLAS-CONF-2021-037



- Search for charged Higgs $H^{\pm}$ in jet final state
- Dataset enriched in $t\bar{t}$ production
- Exploit high multiplicity of jets with b-hadrons
- Signal signature: 3 b-jets, 1 c-jet (+initial- or final-state radiation)
- Nine regions: $(4j, 5j, 6j) \times$ nBtags $(3, \geq 4)$ + $(4j, 5j, 6j) \times (2\ \text{bTags} + 1\ \text{loose bTag})$

nJet \ bTags	3	≥ 4	$2 + 1$ loose
4	main signal	Signal, mis-ided c-jet (only exactly 4 bTags)	$t\bar{t}$ background
5	main signal	$t\bar{t} + \geq 1b$ background	$t\bar{t}$ background
6	signal	$t\bar{t} + \geq 1b$ background	$t\bar{t}$ background

$t \to H^{\pm} b,\ H^{\pm} \to cb$



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- Nine regions: $(4j, 5j, 6j) \times$ nBtags $(3, \geq 4)$ + $(4j, 5j, 6j) \times (2\ \text{bTags} + 1\ \text{loose bTag})$
- Mass- parametrized Neural Network classifier for signal selection
- Larger dataset, improved analysis technique ⇒ 5x improvement on expected limited w.r.t. prior publication (JHEP 11 (2018) 115)

Joint fit to neural network score over all regions to extract branching ratio limits

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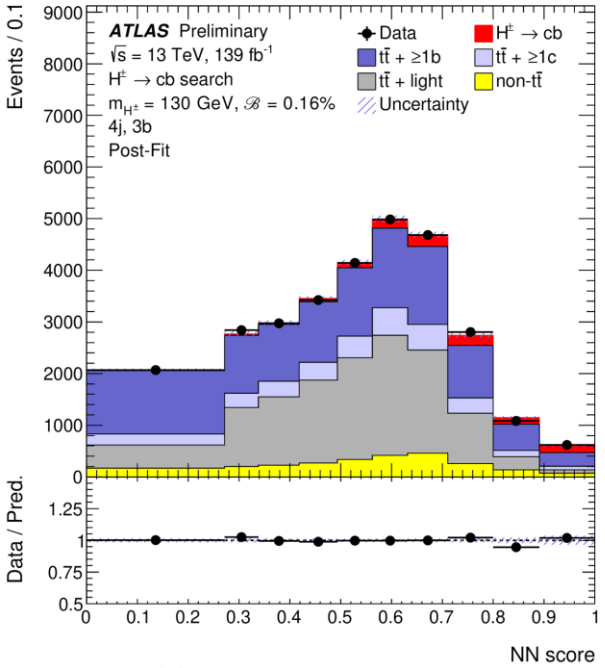
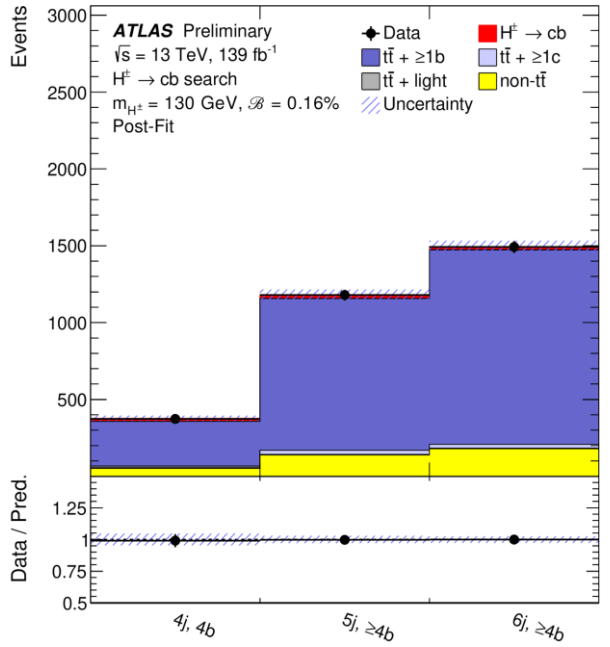
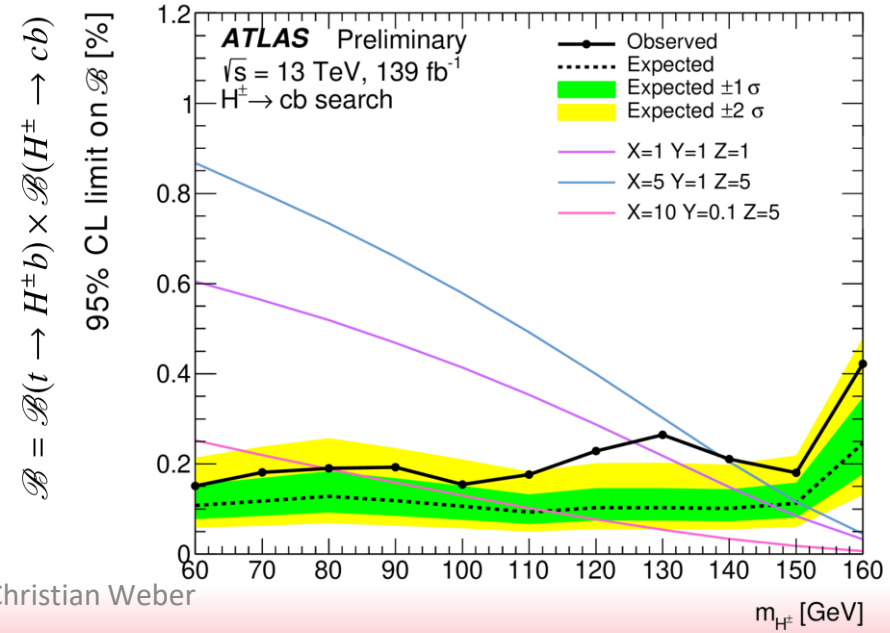


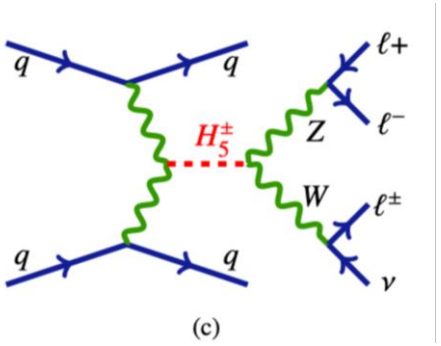




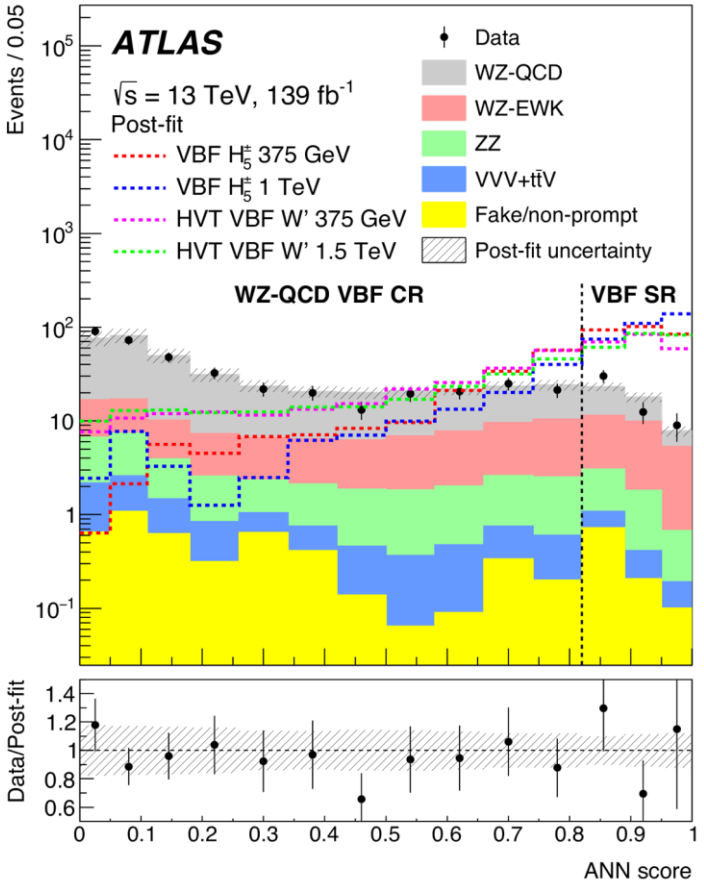
largest excess:
3σ local significance
1.6σ global significance

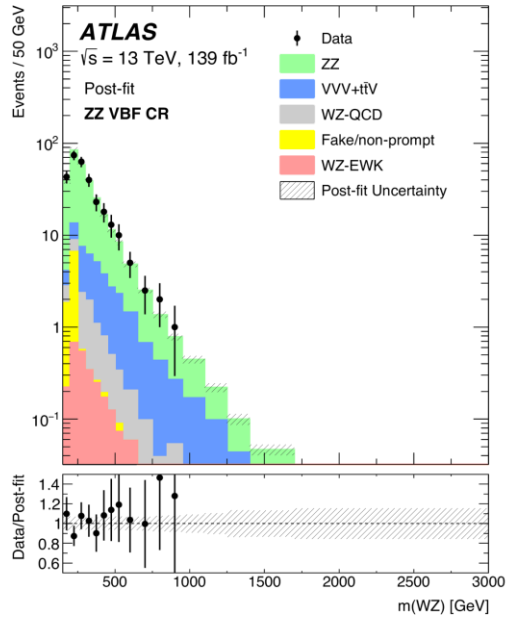
$H^{\pm} \rightarrow ZW \rightarrow 3\ell + \nu$

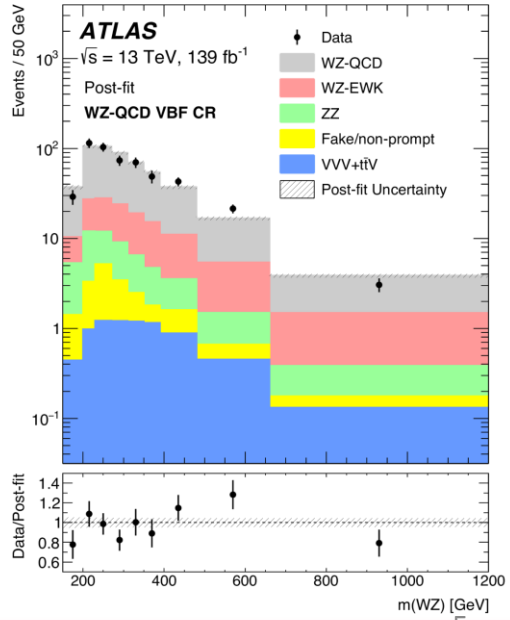
arXiv:2207.03925



- Search for $H^{\pm} \rightarrow$ ZW in $3\ell + \nu$ final
- Require exactly 3ℓ + $E_T^{\text{miss}} > 25$ GeV
  Drell-Yan: $p_T^V \,/\, m_{WZ} > 0.35$
  VBF: 2+ VBF jets, no b-jets, $m_{jj} > 500$ GeV
- minimum neural network score
  8 input variables, trained on all $H^{\pm}$ together







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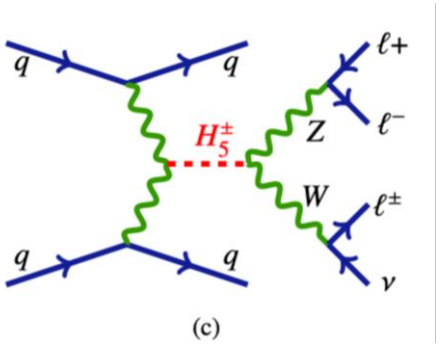

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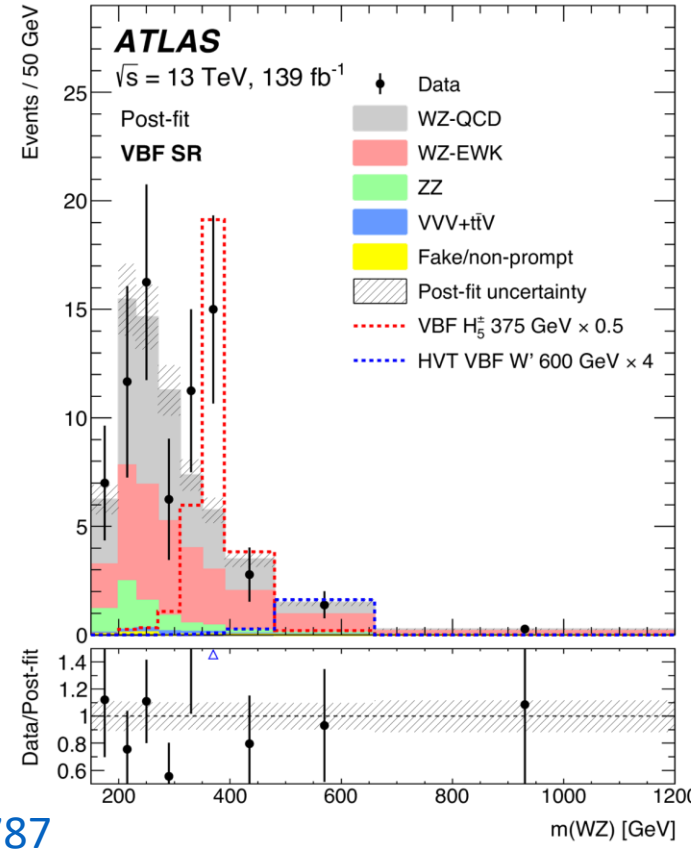
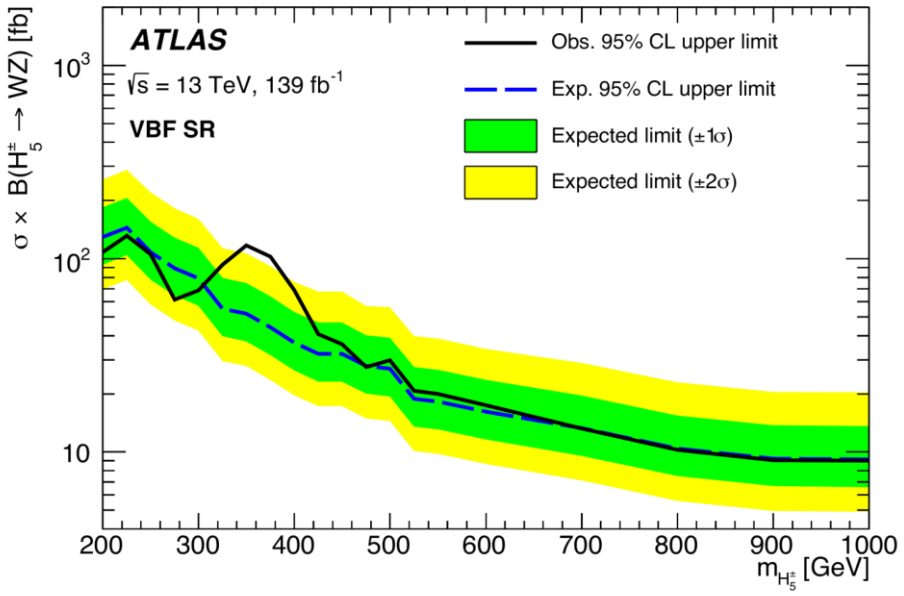
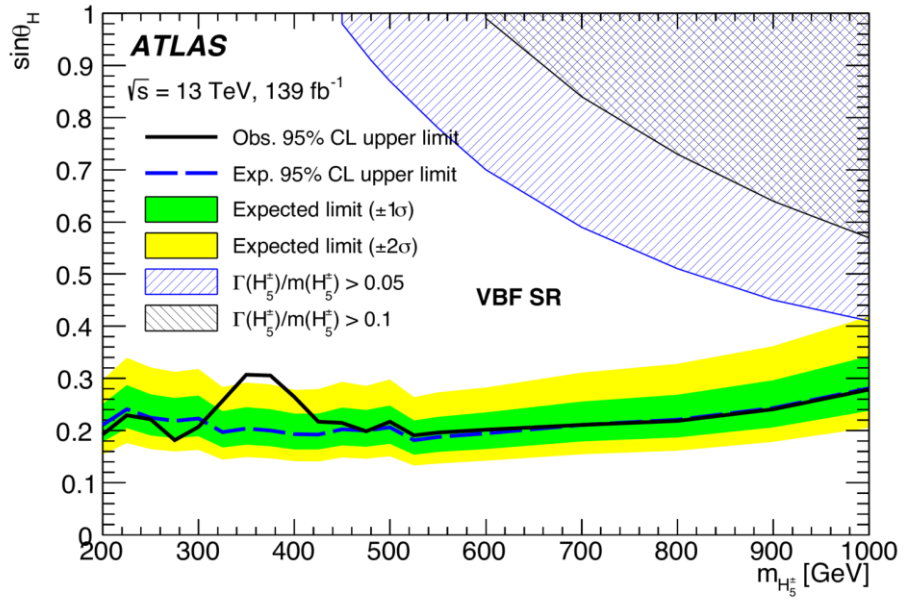
  VBF: 2+ VBF jets, no b-jets, $m_{jj} > 500$ GeV
- minimum neural network score
  8 input variables, trained on all $H^{\pm}$ together
- Limit via profile-likelihood test in m_{WZ} distribution with signal templates
- WZ ZZ estimated via concurrent fit to dedicated control regions
- Previous iteration form ATLAS Phys. Lett. B 787 (2018) 68, 35% improvement
- Moderate excess at around $m_{H^{\pm}} = 375$ GeV
  2.8σ local significance, 1.6σ global







$H^{\pm\pm}H^{\mp\mp} \rightarrow 4\ell$

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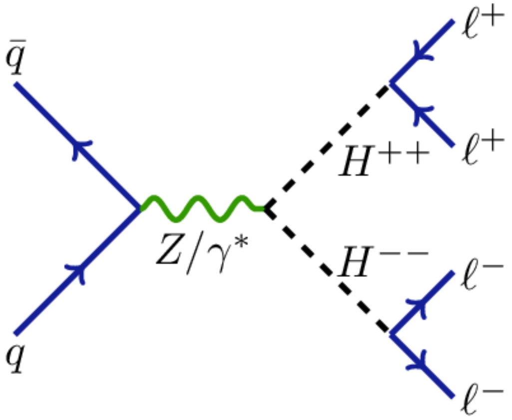

	control regions				signal regions			validation regions		
	DYCR	DBCR2L	DBCR3L	CR4L	SR2L	SR3L	SR4L	VR2L	VR3L	VR4L
Channel	e^+e^-	$e^\pm e^\pm$ $e^\pm\mu^\pm$ $\mu^\pm\mu^\pm$	$\ell^\pm\ell^\pm\ell^\mp$	$\ell^+\ell^+\ell^-\ell^-$	$e^\pm e^\pm$ $e^\pm\mu^\pm$ $\mu^\pm\mu^\pm$	$\ell^\pm\ell^\pm\ell^\mp$	$\ell^+\ell^+\ell^-\ell^-$	$e^\pm e^\pm$ $e^\pm\mu^\pm$ $\mu^\pm\mu^\pm$	$\ell^\pm\ell^\pm\ell^\mp$	$\ell^+\ell^+\ell^-\ell^-$
Nr. Leptons	2	2	3	4	2	3	4	2	3	4
$m(\ell^\pm,\ell'^\mp)_{\mathrm{lead}}$ [GeV]	≥ 300	-	-	-	-	-	-	-	-	-
$m(\ell^\pm,\ell'^\pm)_{\mathrm{lead}}$ [GeV]	-	[200, 300)	≥ 300	[100, 200)	≥ 300	≥ 300	≥ 300	≥ 300	[100, 300)	[200, 300)
$p_{\mathrm{T}}(\ell^\pm,\ell'^\pm)_{\mathrm{lead}}$ [GeV]	-	-	-	-	≥ 300	≥ 300	-	[200, 300)	-	-
$\Delta R(\ell^\pm,\ell'^\pm)_{\mathrm{lead}}$	-	-	-	-	< 3.5	-	-	< 3.5	-	-
$\overline{M}$ [GeV]	-	-	-	-	-	-	≥ 300	-	-	-
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	-	> 30 -	-	-	-	-	-	> 30 -	-	-
$\lvert\eta(\ell,\ell')\rvert$	-	< 3.0 -	-	-	-	-	-	< 3.0 -	-	-
Z-veto	-	-	inverted	-	-	✓	✓	-	✓	-

- Search for pair production of double charged Higgs $H^{\pm\pm}\,H^{\mp\mp}$, $H^{\pm\pm} \rightarrow \ell^\pm\ell^\pm$
  $\ell = e, \mu$ and leptonic τ decays
- e, μ final states ⇒ 3 signal regions
  same sign 2ℓ, 3ℓ, and 4ℓ final state

$H^{\pm\pm}H^{\mp\mp} \rightarrow 4\ell$

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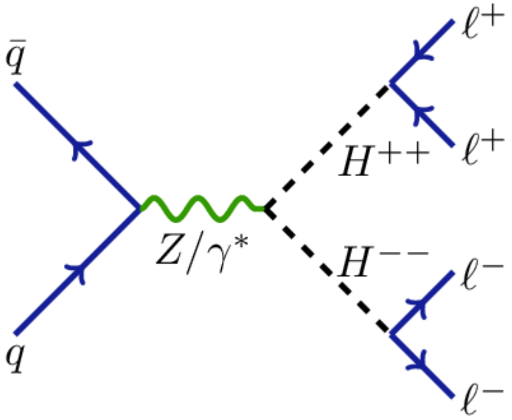
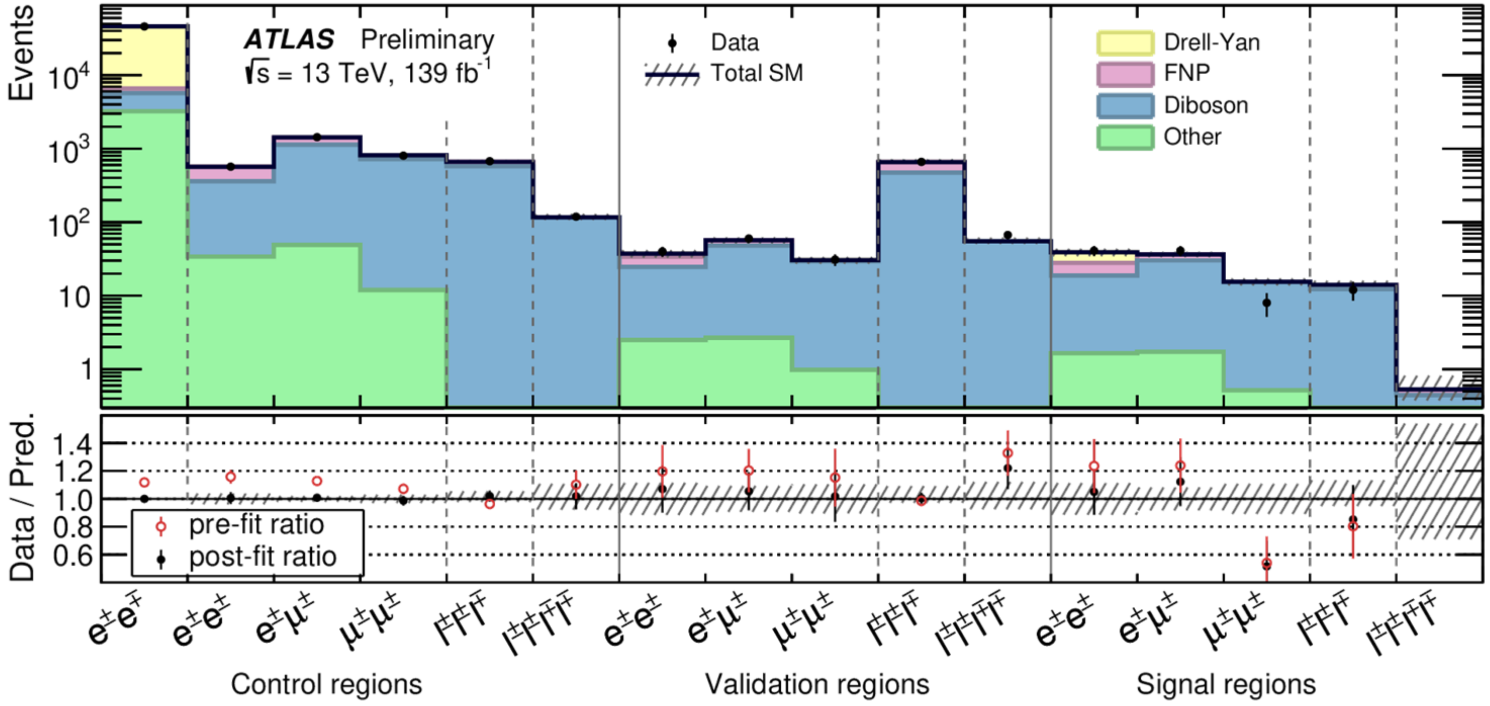


- Search for pair production of double charged Higgs $H^{\pm\pm}\ H^{\mp\mp}$, $H^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$ $\ell = e, \mu$ and leptonic τ decays
- e, μ final states $\Rightarrow$ 3 signal regions same sign 2ℓ, 3ℓ, and 4ℓ final state
- Fit over leading di-lepton invariant mass distribution $m_{\ell_1^{\pm}\ell_2^{\pm}}$, ($2\ell$, 3ℓ regions), single bin event yields in 4ℓ region
- concurrent fits in CR for Drell-Yan and di-boson backgrounds

	control regions				signal regions			validation regions		
	DYCR	DBCR2L	DBCR3L	CR4L	SR2L	SR3L	SR4L	VR2L	VR3L	VR4L
Channel	e^+e^-	$e^{\pm}e^{\pm}$; $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$	$\ell^{\pm}\ell^{\pm}\ell^{\mp}$	$\ell^+\ell^+\ell^-\ell^-$	$e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$	$\ell^{\pm}\ell^{\pm}\ell^{\mp}$	$\ell^+\ell^+\ell^-\ell^-$	$e^{\pm}e^{\pm}$; $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$	$\ell^{\pm}\ell^{\pm}\ell^{\mp}$	$\ell^+\ell^+\ell^-\ell^-$
Nr. Leptons	2	2	3	4	2	3	4	2	3	4
$m(\ell^{\pm},\ell'^{\mp})_{\text{lead}}$ [GeV]	≥ 300	-	-	-	-	-	-	-	-	-
$m(\ell^{\pm},\ell'^{\pm})_{\text{lead}}$ [GeV]	-	[200, 300)	≥ 300	[100, 200)	≥ 300	≥ 300	≥ 300	≥ 300	[100, 300)	[200, 300)
$p_{\text{T}}(\ell^{\pm},\ell'^{\pm})_{\text{lead}}$ [GeV]	-	-	-	-	≥ 300	≥ 300	-	[200, 300)	-	-
$\Delta R(\ell^{\pm},\ell'^{\pm})_{\text{lead}}$	-	-	-	-	< 3.5	-	-	< 3.5	-	-
$\overline{M}$ [GeV]	-	-	-	-	-	-	≥ 300	-	-	-
$E_{\text{T}}^{\text{miss}}$ [GeV]	-	> 30; -	-	-	-	-	-	> 30; -	-	-
$\lvert\eta(\ell,\ell')\rvert$	-	< 3.0; -	-	-	-	-	-	< 3.0; -	-	-
Z-veto	-	-	inverted	-	-	✓	✓	-	✓	-



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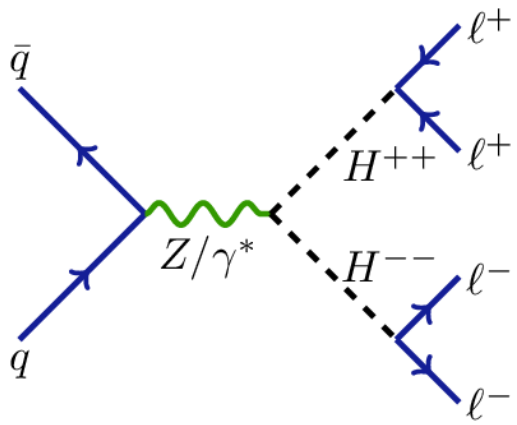

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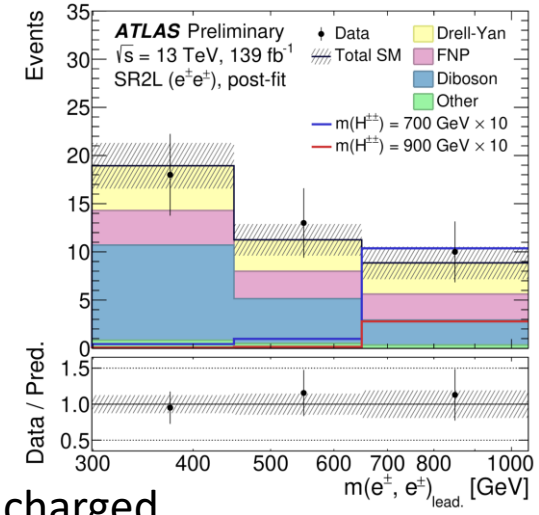
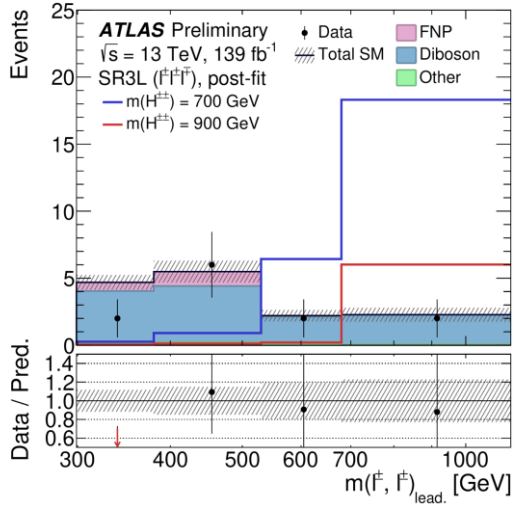
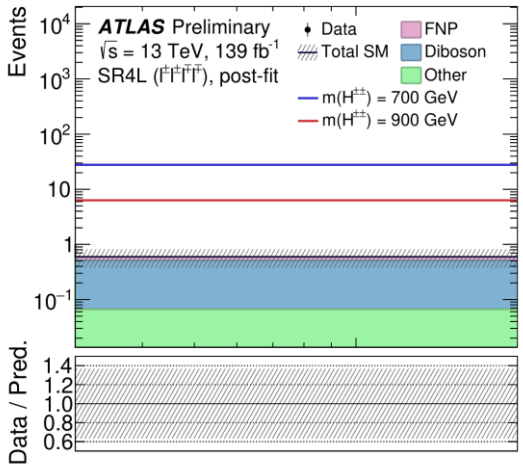
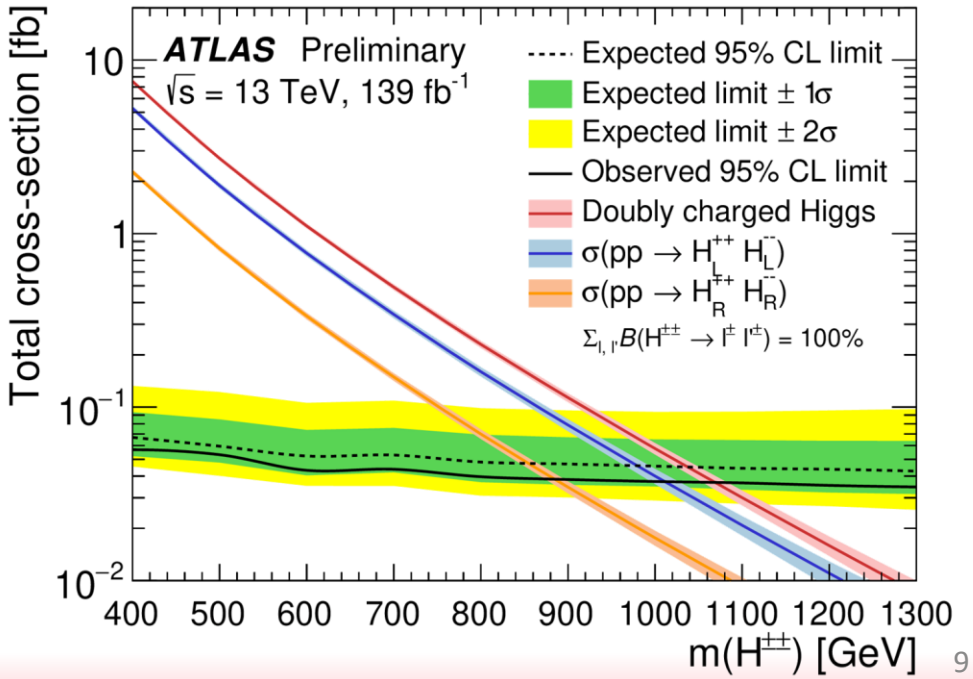






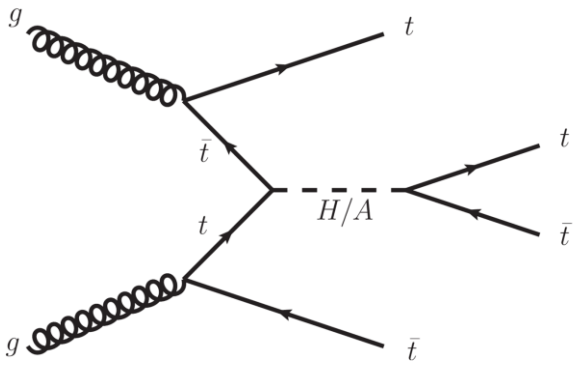
- Search for pair production of double charged Higgs $H^{\pm\pm}\,H^{\mp\mp}$, $H^{\pm\pm} \rightarrow \ell^{\pm}\ell^{\pm}$
  $\ell = e, \mu$ and leptonic τ decays
- e, μ final states ⇒ 3 signal regions
  same sign 2ℓ, 3ℓ, and 4ℓ final state
- Fit over leading di-lepton invariant mass distribution $m_{\ell_1^{\pm}\ell_2^{\pm}}$, ($2\ell$, 3ℓ regions), single bin event yields in 4ℓ region
- concurrent fits in CR for Drell-Yan and di-boson backgrounds
- ~2x improvement w.r.t. prior result
  Eur. Phys. J. C 78 (2018) 199

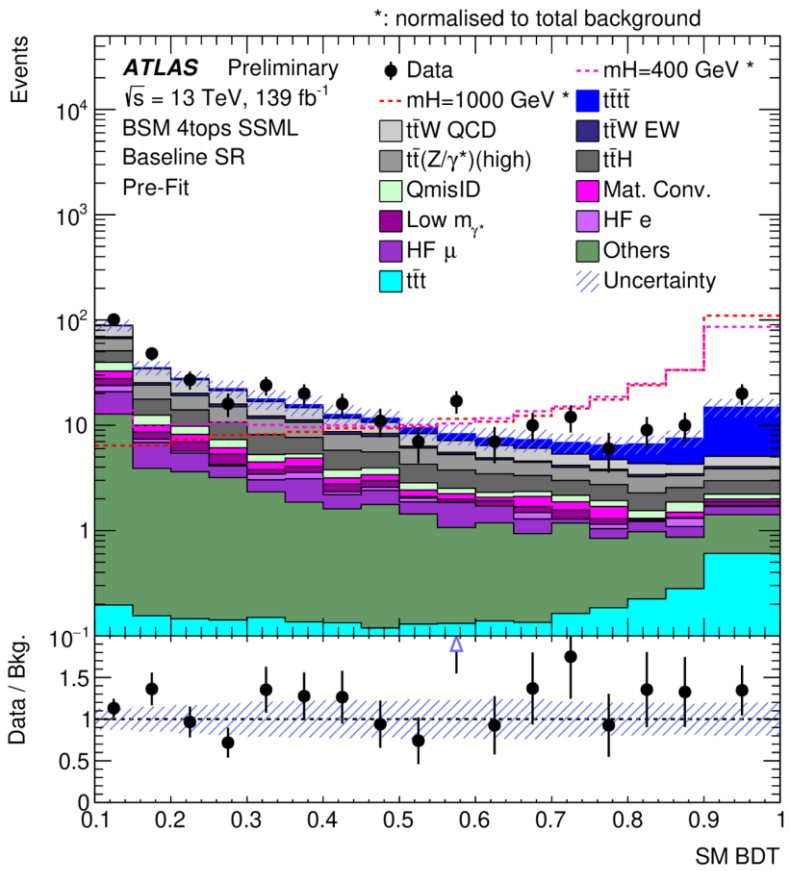
No excesses, consistent with Standard Model

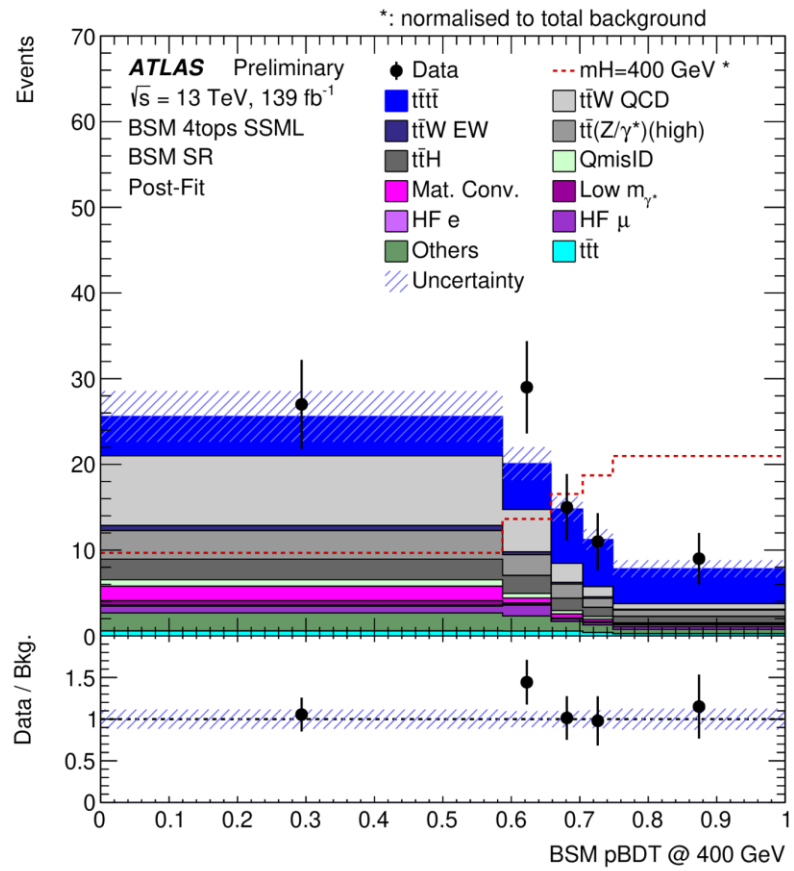


$t\bar{t}H$ / $t\bar{t}A \rightarrow 4t$

ATLAS-CONF-2022-008



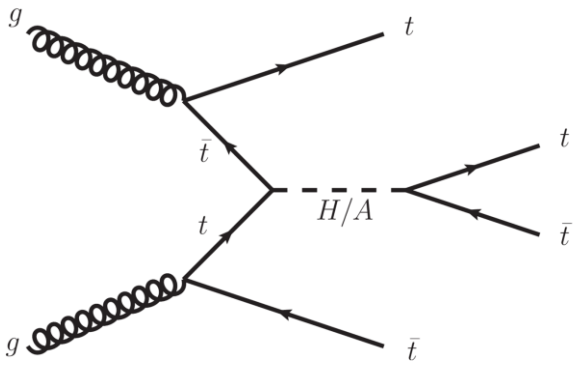


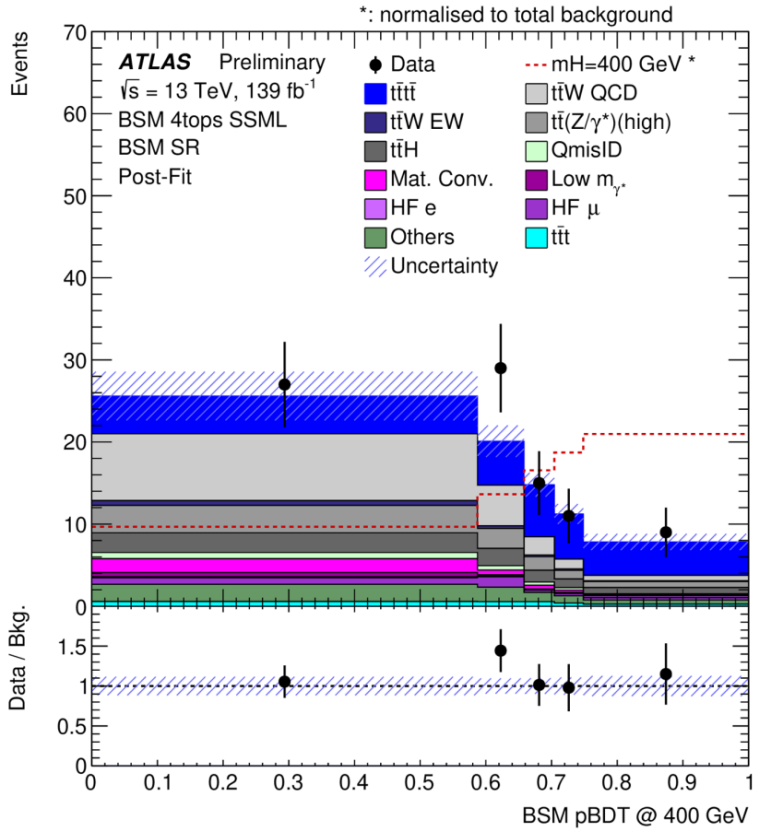


- Search for heavy scalar H, pseudoscalar A in $4t$ processes
- Avoids large negative interference from SM $t\bar{t}$ in $gg \rightarrow H/A \rightarrow t\bar{t}$
- $\ell^{\pm}\ell^{\mp}$ or $\geq 3\ell$, but Z-vetoed
  6+ jets, 2+ of those b-tagged
  $H_T > 500$ GeV
- Signal selection via two sequential BDTs
  1. Discriminate $t\bar{t}t\bar{t}$ from other backgrounds (SM BDT)
  2. Select signal from $t\bar{t}t\bar{t}$ events, signal mass-parametrized (BMS pBDT)

H_T: scalar sum of pT of all leptons and jets in the event

$t\bar{t}H$ / $t\bar{t}A \rightarrow 4t$





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- Fit to BSM pBDT score distribution for signal, concurrent fit in control regions to fix backgrounds

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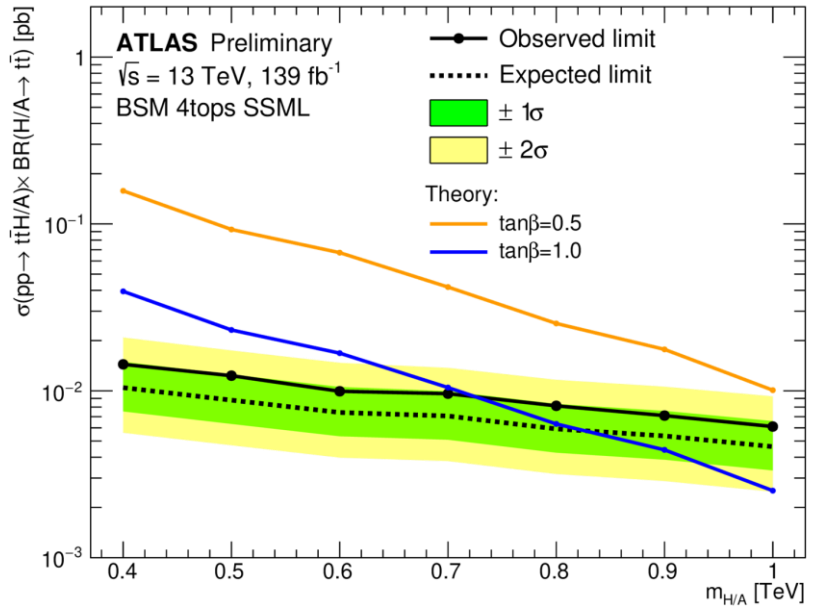
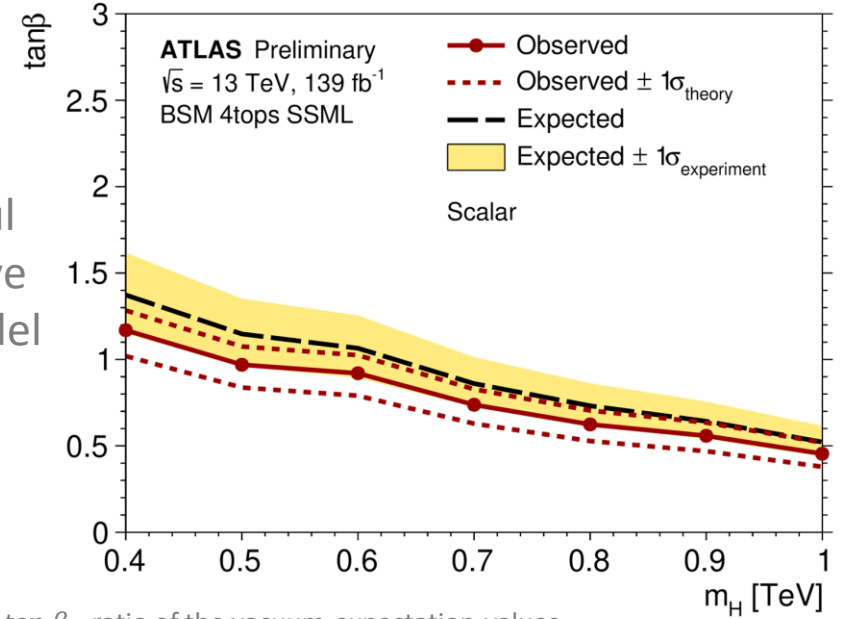
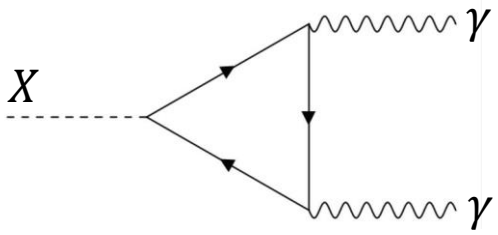




No meaningful excesses above Standard Model expectations

$\tan\beta$ - ratio of the vacuum-expectation-values of the two Higgs doublets in the 2HDM model

$X \to \gamma\gamma$, low mass X



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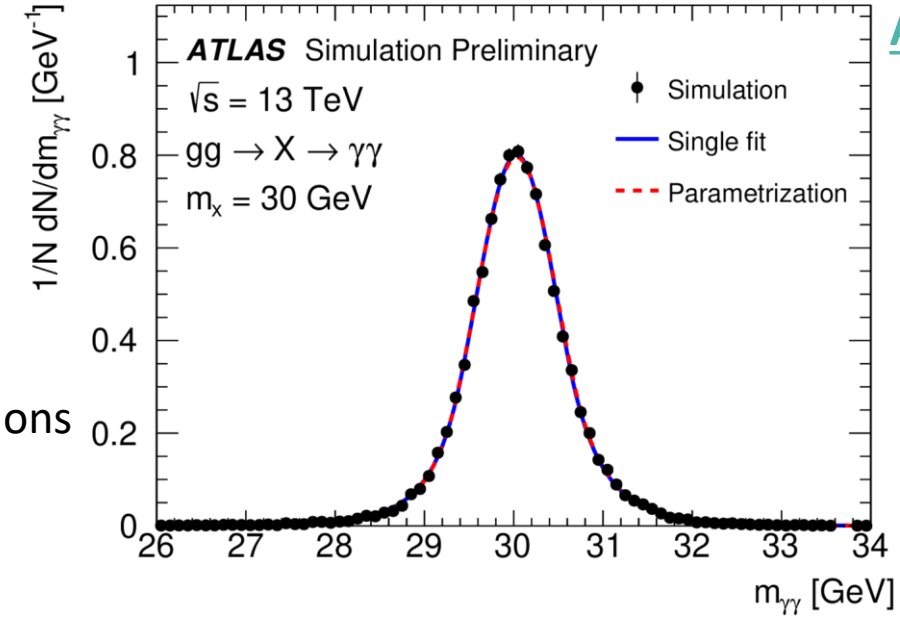
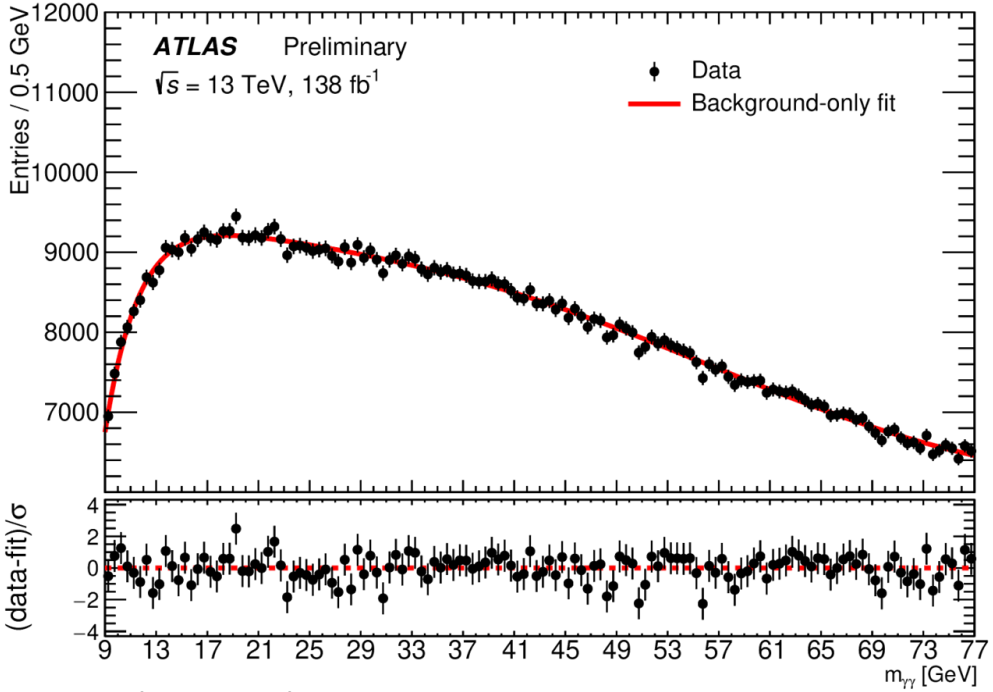


- Search for light axion-like particle X, coupling to gluons
- First LHC result with
  $10\ \text{GeV} < m_{\gamma\gamma} < 70\ \text{GeV}$
- Two isolated photons,
  $E_T^{\gamma} > 22\ \text{GeV}$, $p_T^{\gamma\gamma} > 50\ \text{GeV}$
  mitigate trigger turn-on,
  optimize background shape
- Signal shape modelled by double-sided Crystal Ball
- Background modelled by analytical function



$X \to \gamma\gamma$, low mass X

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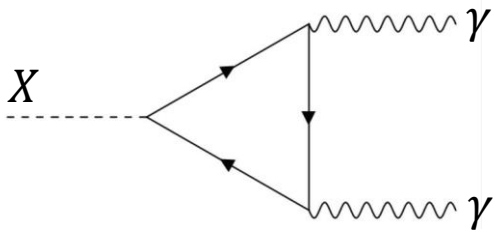

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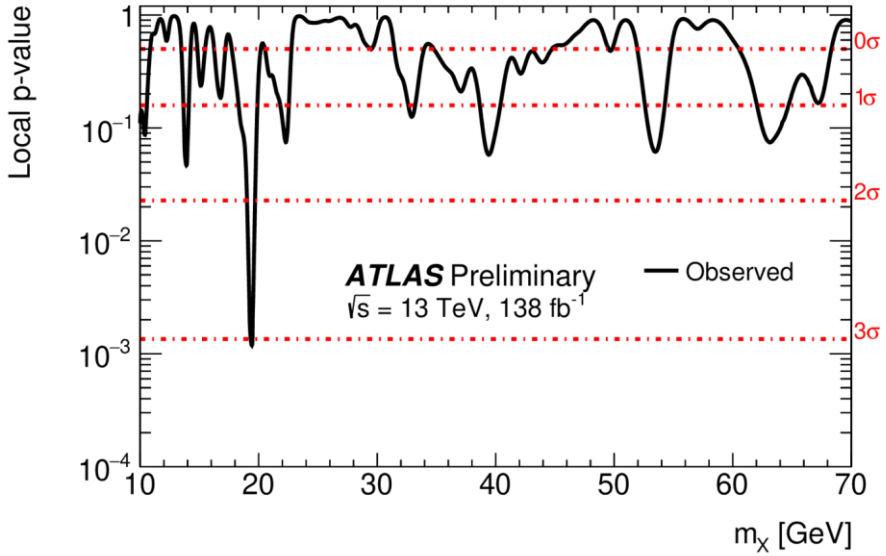
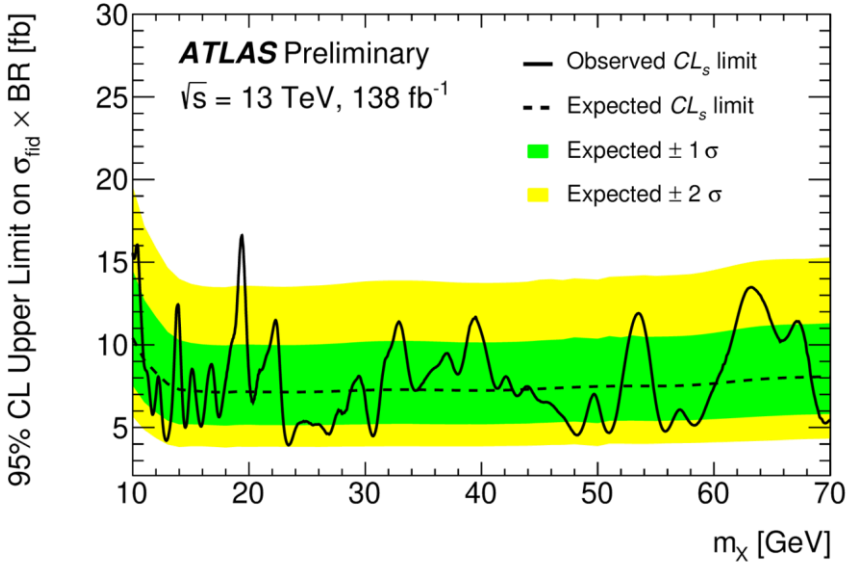
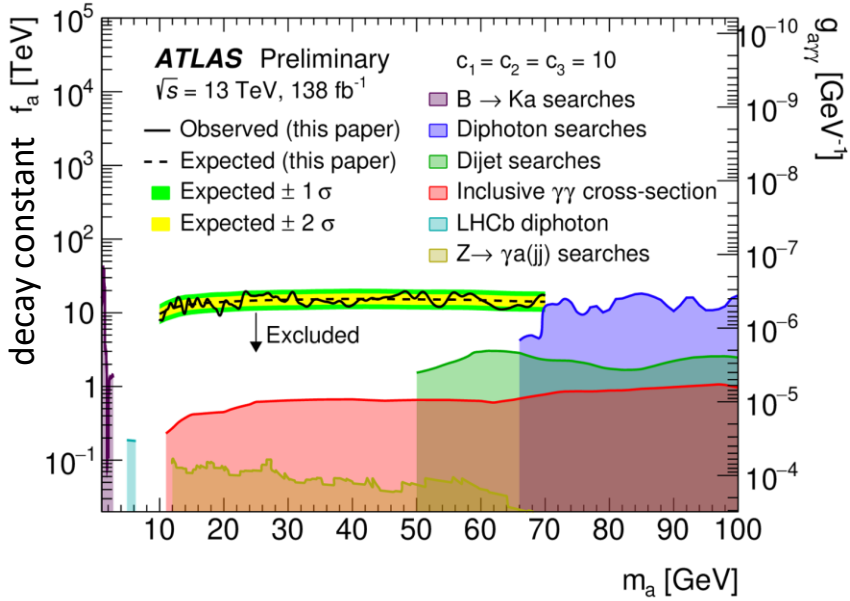
  mitigate trigger turn-on,
  optimize background shape
- Signal shape modelled by double-sided Crystal Ball
- Background modelled by analytical function
- Limit down to $m_X = 10\ \text{GeV}$
- 3.0 σ local, 1.5 σ global excess around $m_X = 19.4\ \text{GeV}$







$X \to \gamma\gamma$, high mass X

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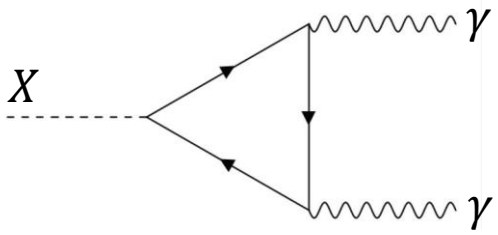
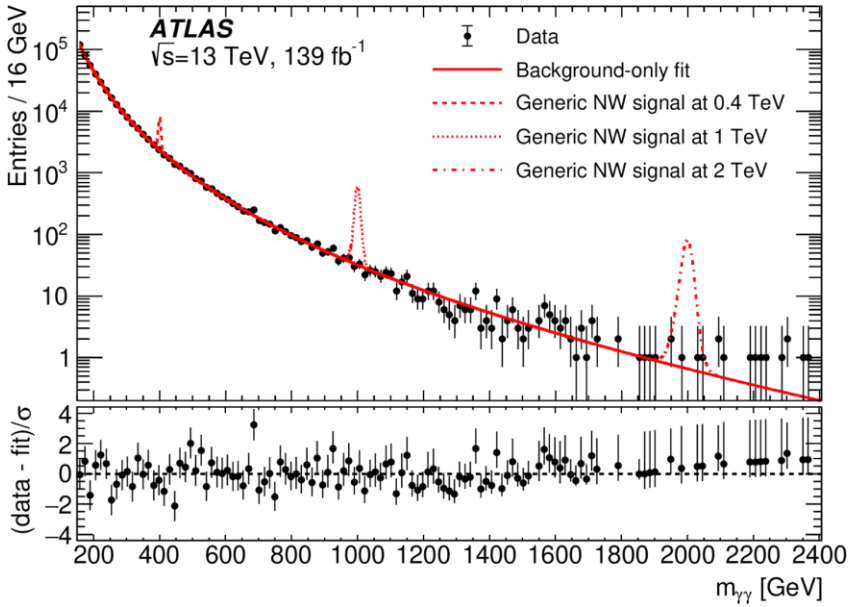
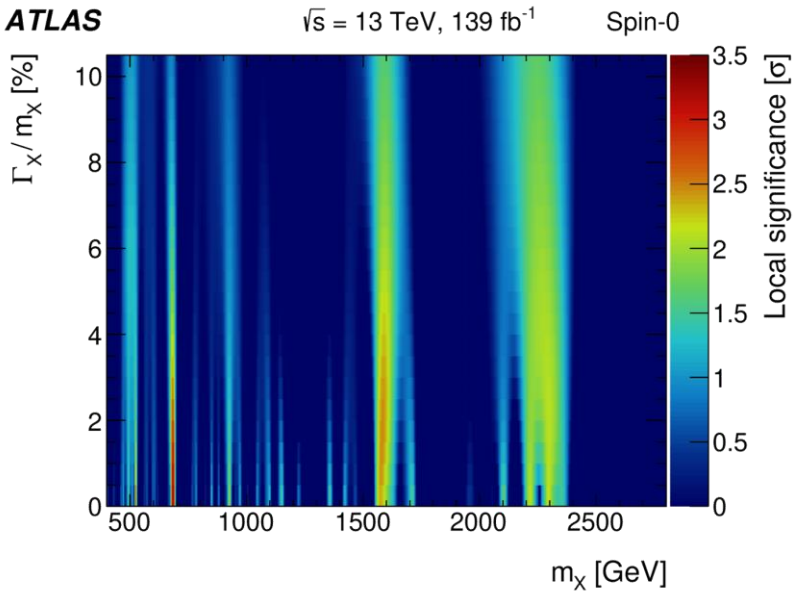
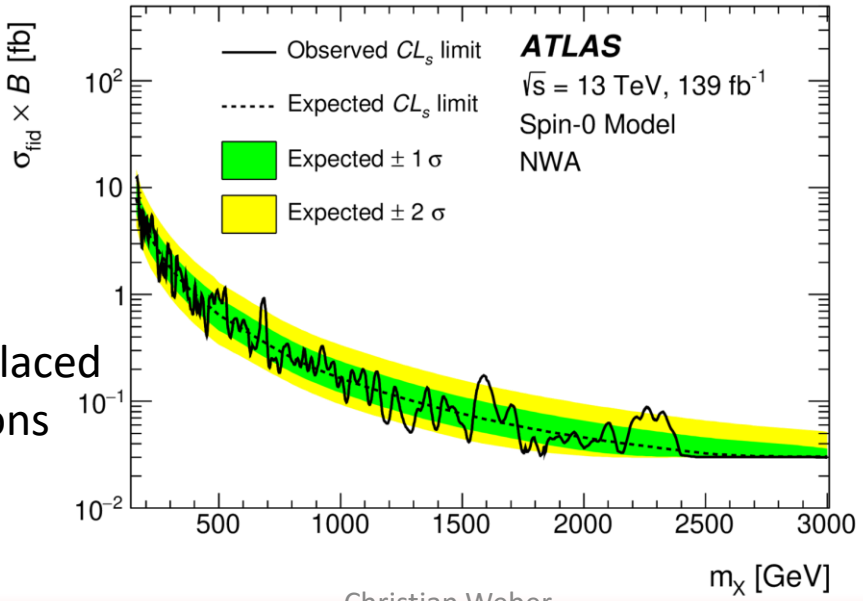
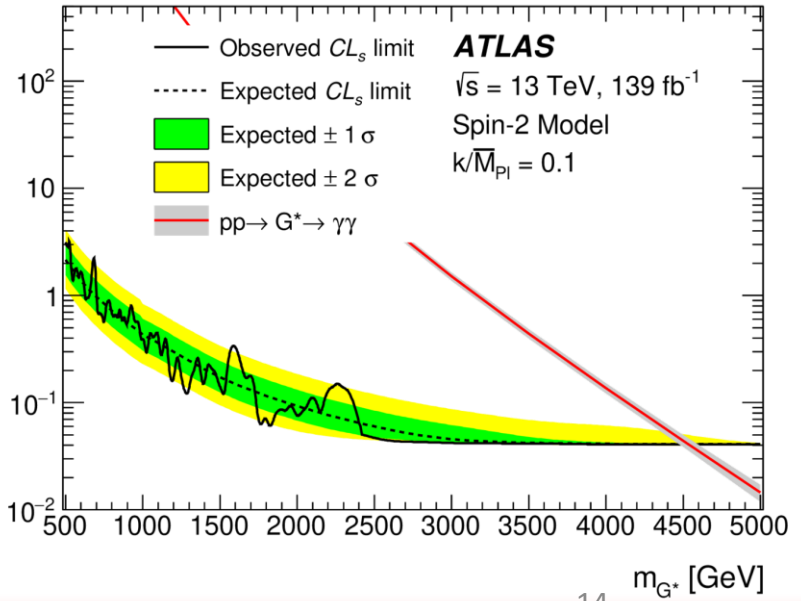


- Search for heavy scalar X in $\gamma\gamma$ final state
- Two isolated photons
  $\frac{E_T^{\gamma 1}}{m_{\gamma\gamma}} > 0.3, \frac{E_T^{\gamma 2}}{m_{\gamma\gamma}} > 0.25, m_{\gamma\gamma} > 150$ GeV
- Signal $m_{\gamma\gamma}$ distribution
  Double-sided crystal ball
- Main backgrounds: non-resonant $\gamma\gamma$, γ+jet, di-jet with jet misidentified as photon
- Background modelled by analytical function
- Template fit to $m_{\gamma\gamma}$ distribution
- No significant excesses found, limits placed on scalar and Randal-Sundrum gravitons production cross section









$t \to qX, X \to b\bar{b}, q = u, c$

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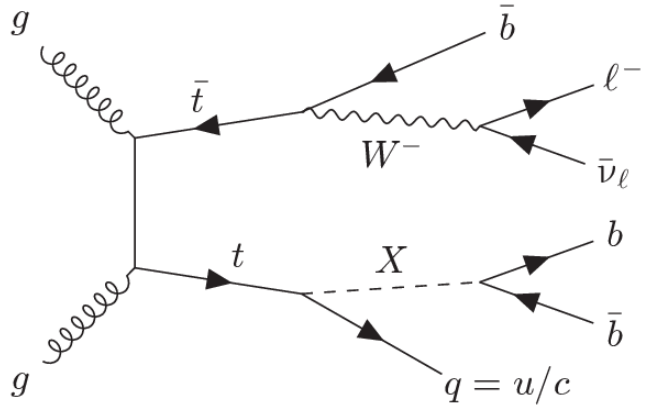
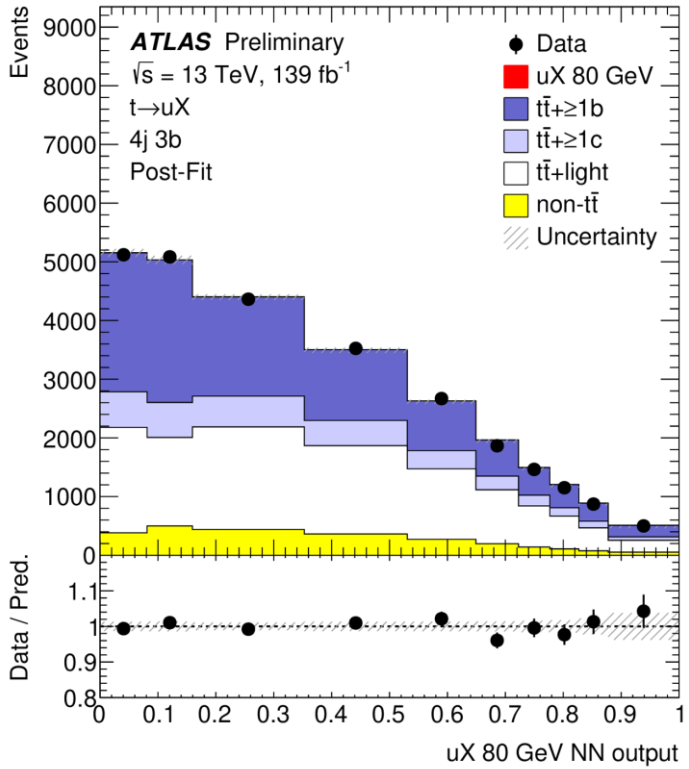
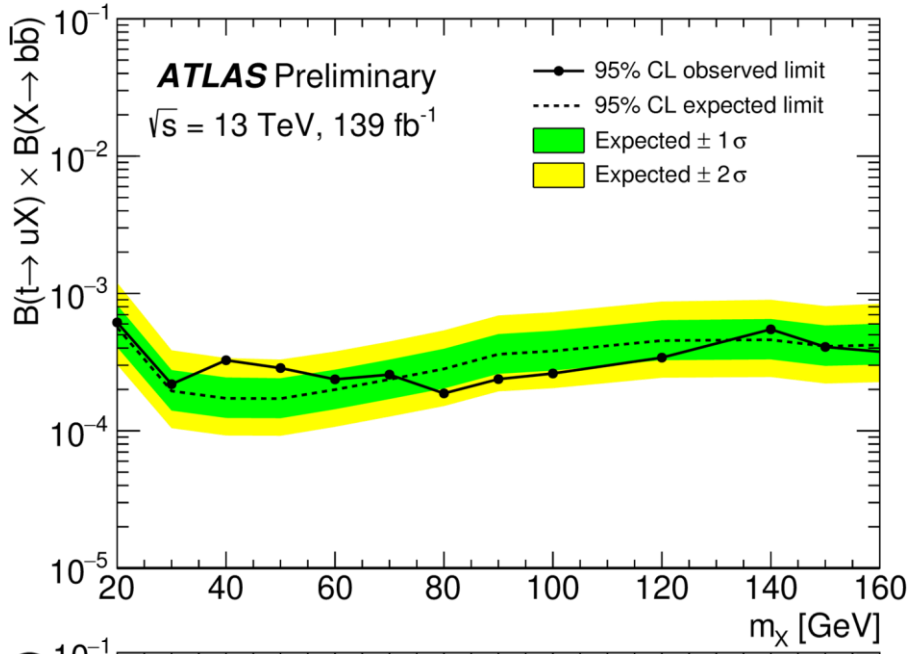
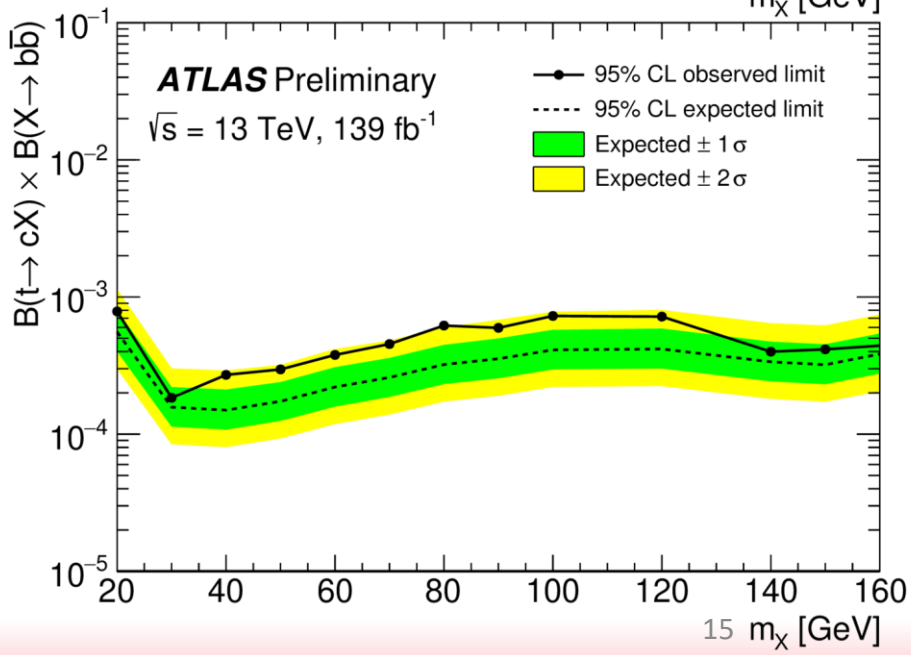




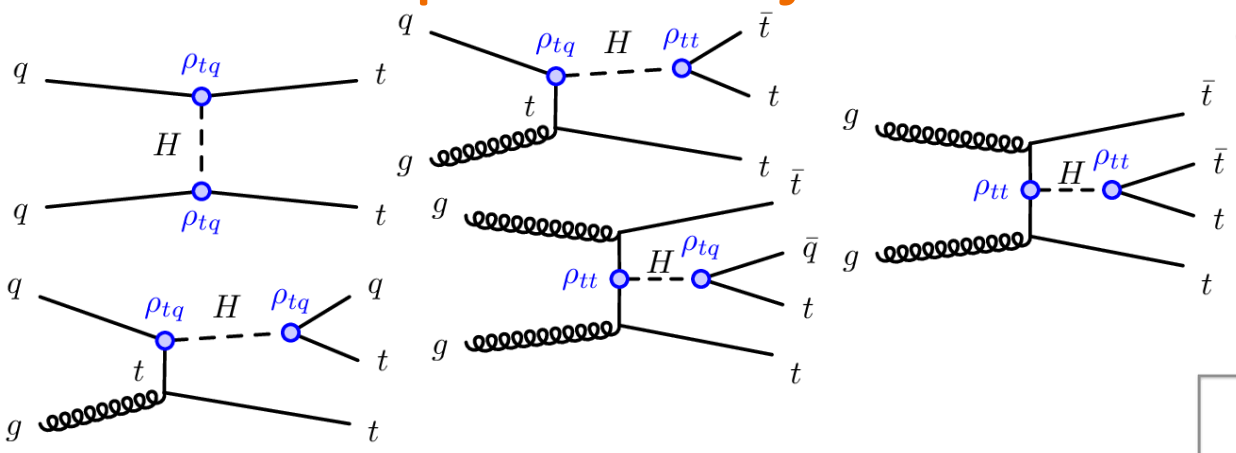




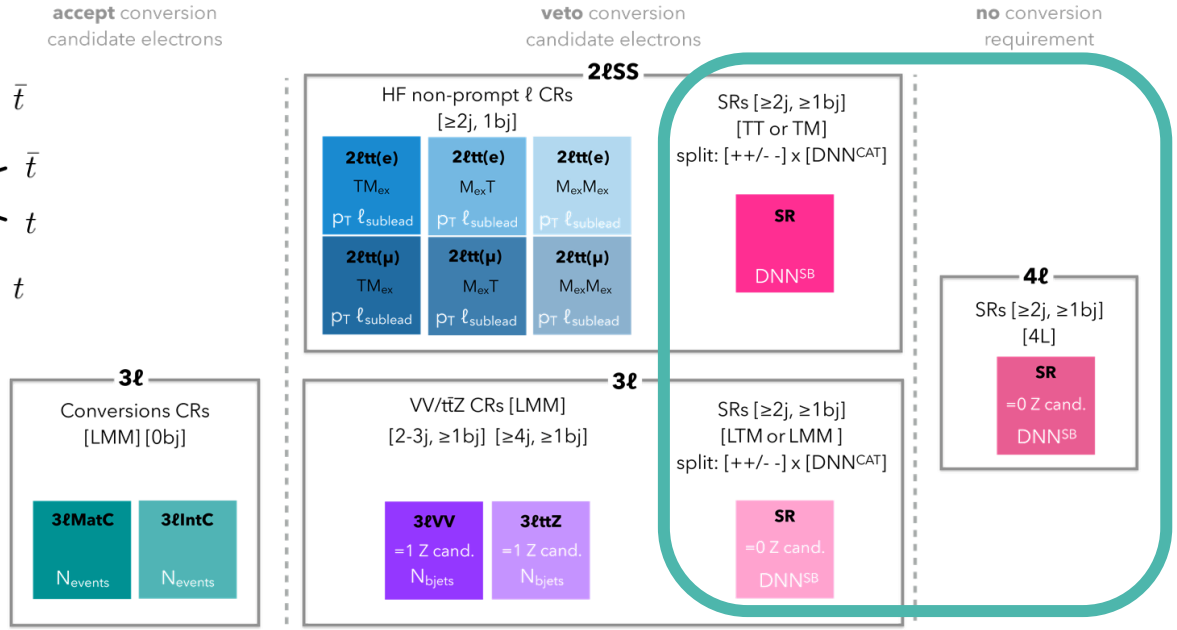
- Search flavor changing neutral current decay $t \to qX, X \to b\bar{b}$ in $t\bar{t}$ events, X light scalar with flavor charge
- signature: exactly 1ℓ, $E_T^{\text{miss}} \geq 20$ GeV, ≥ 4 jets at least three b-tagged,
- Neural Network for signal selection
- Three signal regions $(4j, 5j, 6j) \times 3b$
  Three control regions $(4j, 5j, 6j) \times \geq 4b$
  Regions with $2b$ to improve $t\bar{t}$ background modelling
- Concurrent fit to signal and control regions on Neural Network score
- Results generally consistent with Standard Model

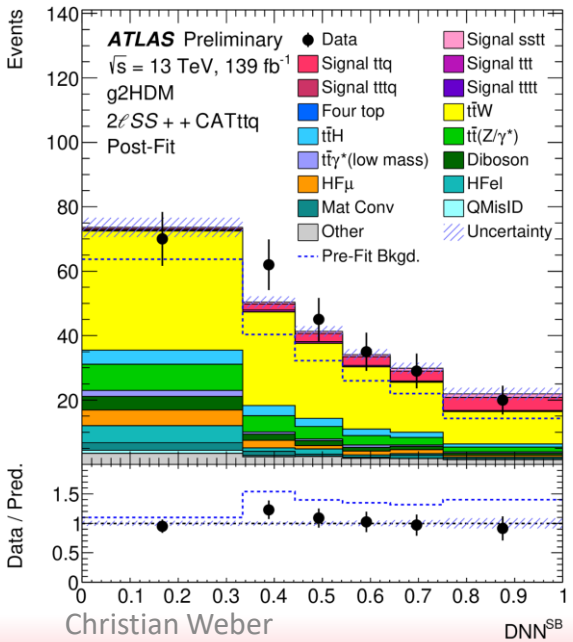
$H \rightarrow$ leptons + b-jets

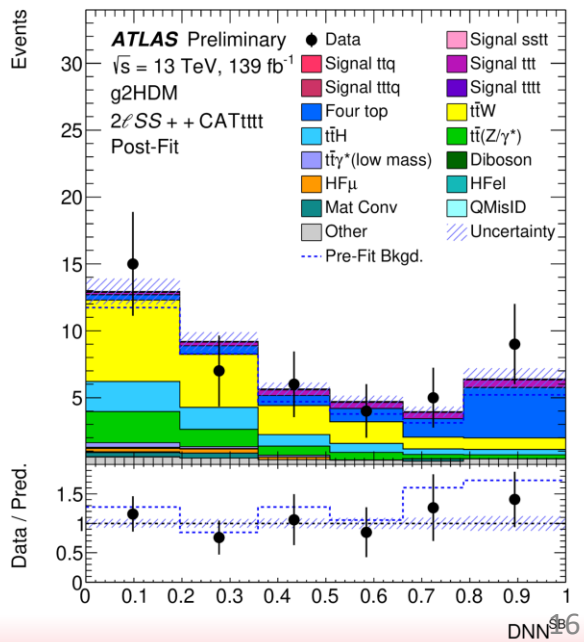
ATLAS-CONF-2022-039



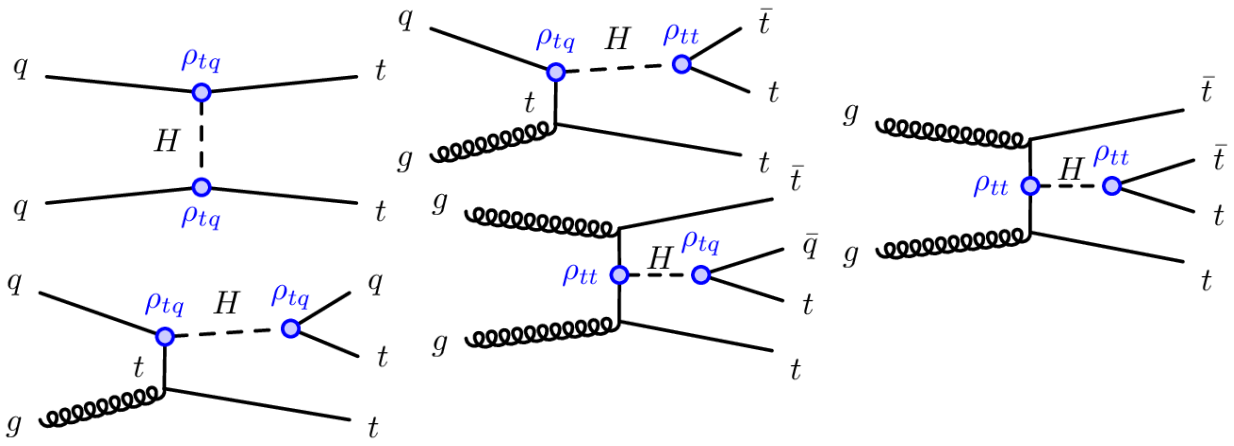
- Search for new scalar H with flavor-violating decays
- Signal: 2, 3, or 4 t-quark final states
  $\ell^{\pm}\ell^{\pm}$, 3ℓ or 4ℓ
- Signal regions by lepton multiplicity, total lepton charge, multi-output DNN (DNN^{cat}) (17 signal regions total)
- Second DNN for signal-background discrimination (DNN^{SB})



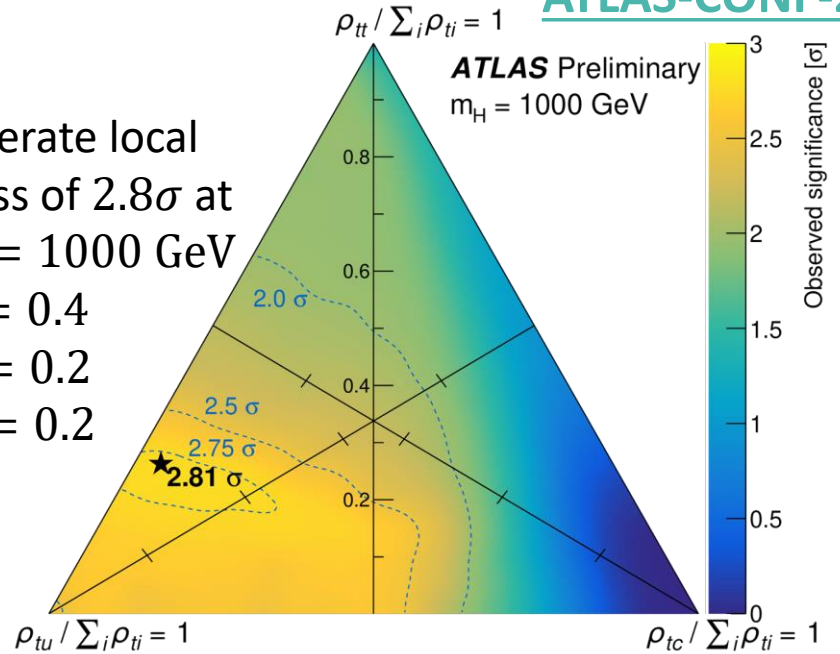




$H \rightarrow$ leptons + b-jets

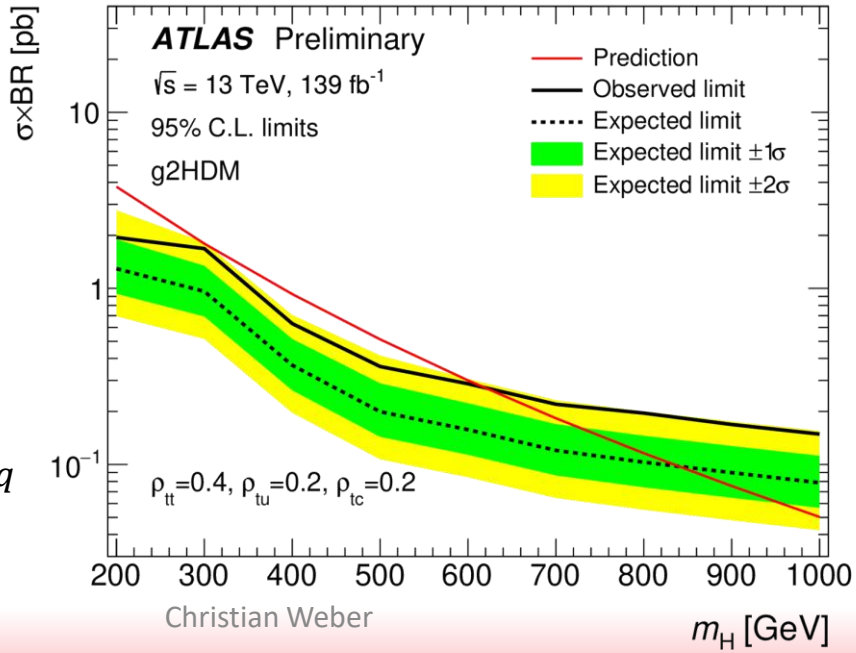


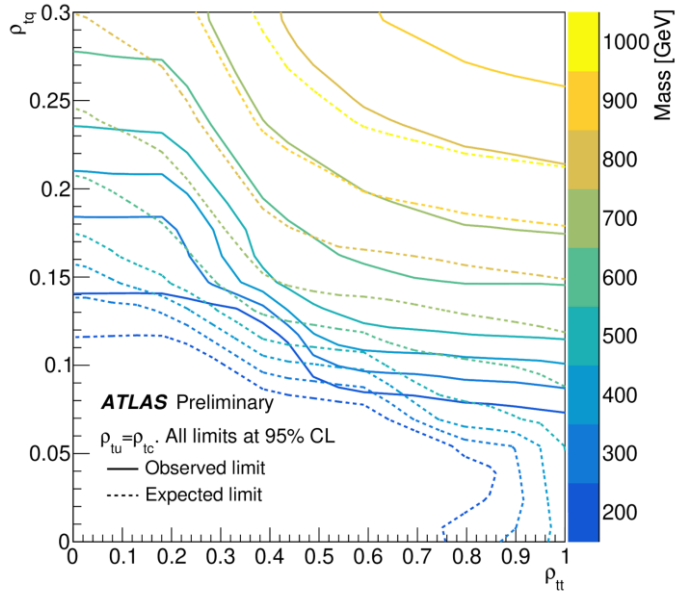
ATLAS-CONF-2022-039



Moderate local excess of 2.8σ at
$m_H = 1000$ GeV
$\rho_{tt} = 0.4$
$\rho_{tc} = 0.2$
$\rho_{tu} = 0.2$

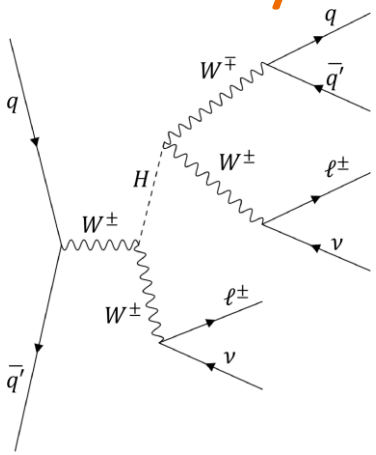
- Search for new scalar H with flavor-violating decays
- Signal: 2, 3, or 4 t-quark final states
  $\ell^{\pm}\ell^{\pm}$, 3ℓ or 4ℓ
- Signal regions by lepton multiplicity, total lepton charge, multi-output DNN (DNN^{cat}) (17 signal regions total)
- Second DNN for signal-background discrimination (DNN^{SB})
- Fit on DNN^{SB} concurrently with control regions
- Extract limit on new scalar production cross section as a function of m_H, H-tq couplings ρ_{tq}



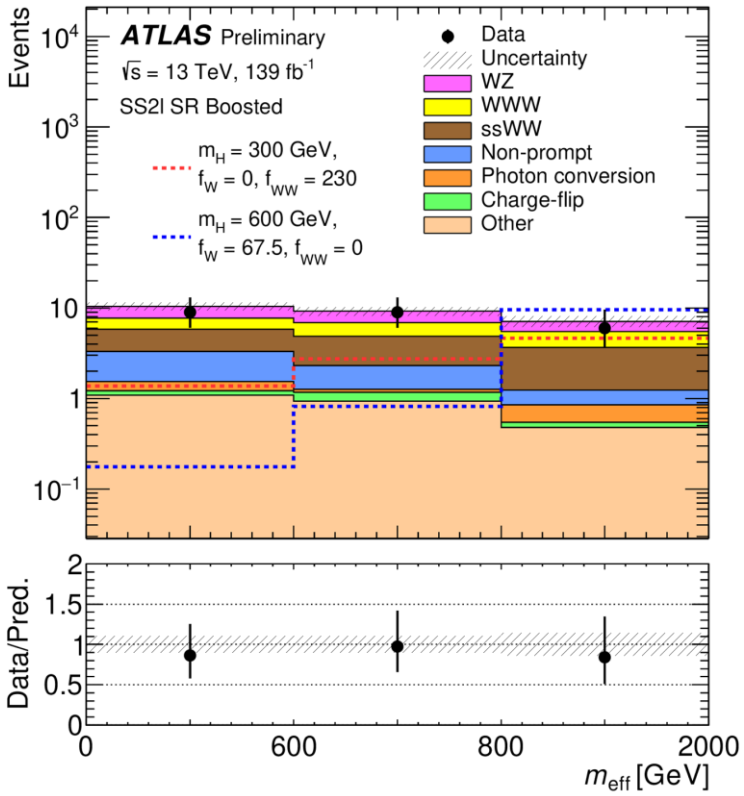


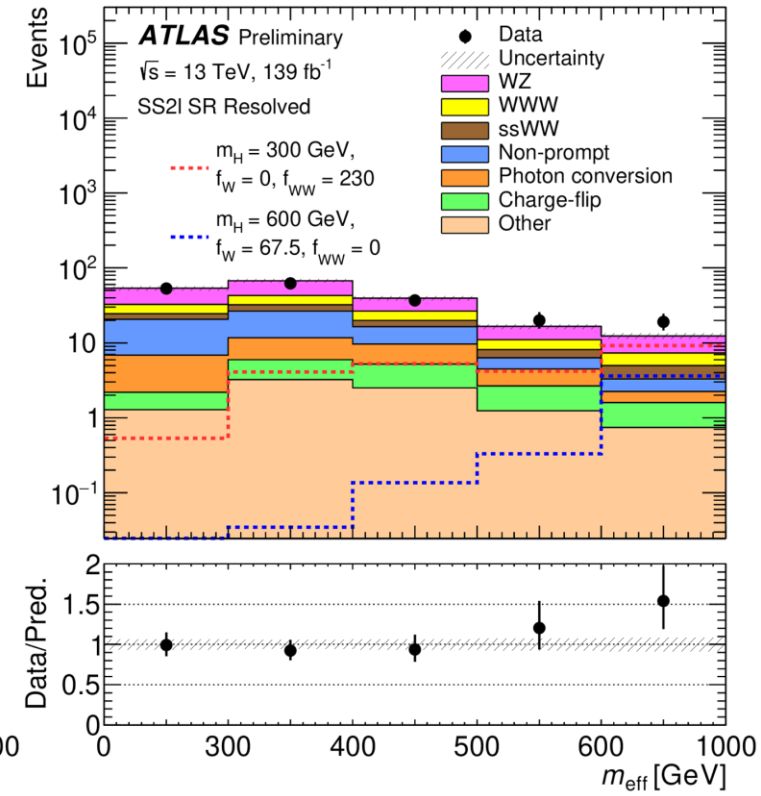
Heavy $H \to WW$

ATLAS-CONF-2022-033

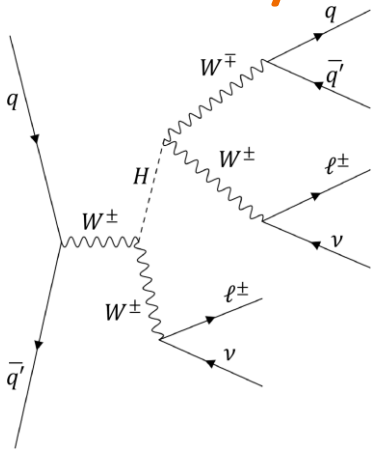


- Search for heavy Higgs to WW in associated production with W
- $\ell^{\pm}\nu\ell^{\pm}\nu qq$ final state
  veto events with additional leptons
  veto events with b-tagged small radius jets
- Two signal regions, depending on qq jet overlap
  Resolved SR: two small radius jets
  Boosted SR: one large radius jet
- Fit over effective mass m_{eff} distribution:
  m_{eff} =scalar sum of p_T for leptons, jet(s) + E_t^{miss}

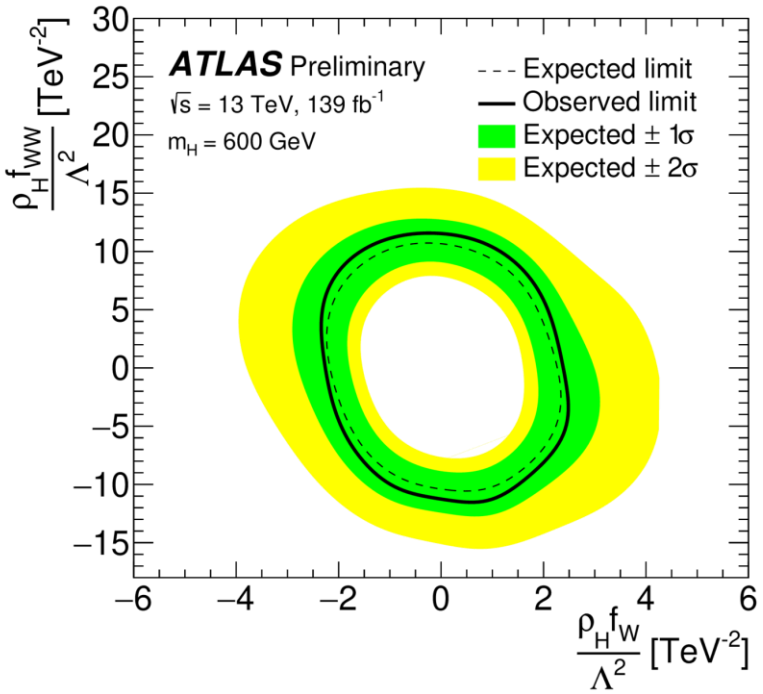




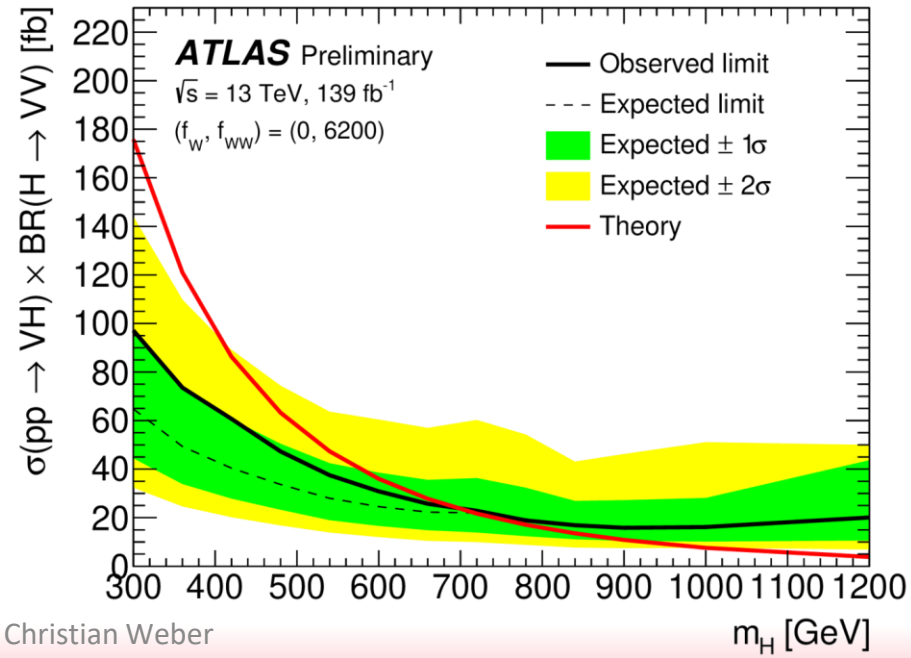
Heavy $H \to WW$



- Search for heavy Higgs to WW in associated production with W
- $\ell^{\pm}\nu\ell^{\pm}\nu qq$ final state
  veto events with additional leptons
  veto events with b-tagged small radius jets
- Two signal regions, depending on qq jet overlap
  Resolved SR: two small radius jets
  Boosted SR: one large radius jet
- Fit over effective mass m_{eff} distribution: :
  scalar sum of p_T for leptons, jet(s) + E_t^{miss}
- Limits on effective field theory BSM HVV coupling
  - $\rho_H = \sin(\beta - \alpha)$ in 2HDM models
  - f_W , f_{WW} = anomalous coupling to W



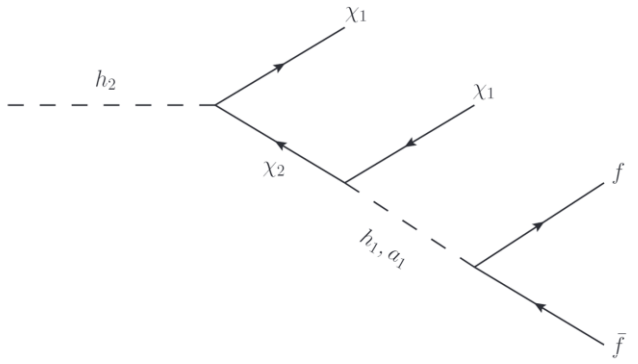
[ATLAS-CONF-2022-033]



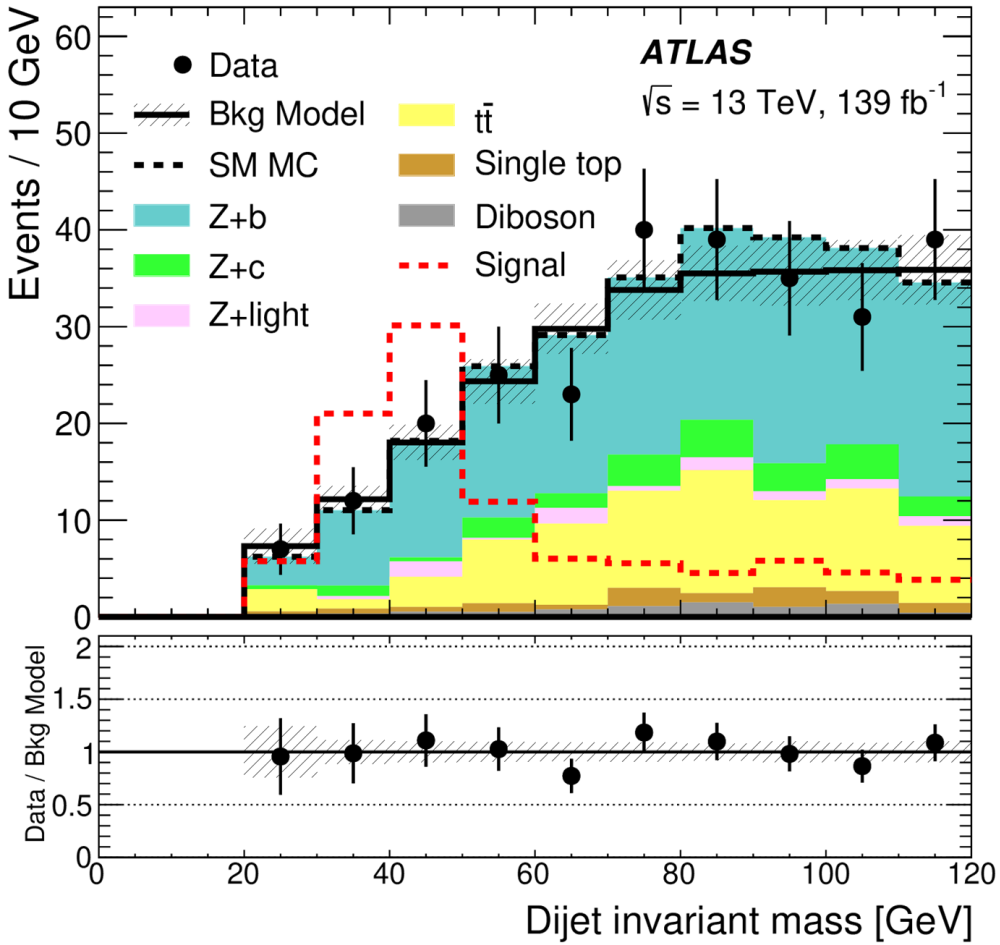
Results consistent with Standard Model expectations

$H \to \chi_1\chi_2,\ \chi_2 \to a\chi_1,\ a \to b\bar{b}$

JHEP 01 (2022) 063

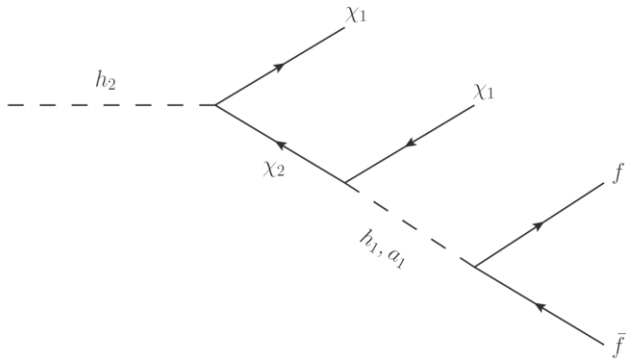


- Search for cascade $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0, a \to bb$ Higgs from ZH production
- NMSSM scenario: $\tilde{\chi}_1^0, \tilde{\chi}_2^0$ two lightest neutralinos, a - light pseudoscalar
- Select on $Z \to \ell\ell, \ell = e, \mu$ to reduce backgrounds
- Model of background distribution constructed from fits in Control Regions
- Limits via fits of signal distribution and background model to m_{jj} distribution

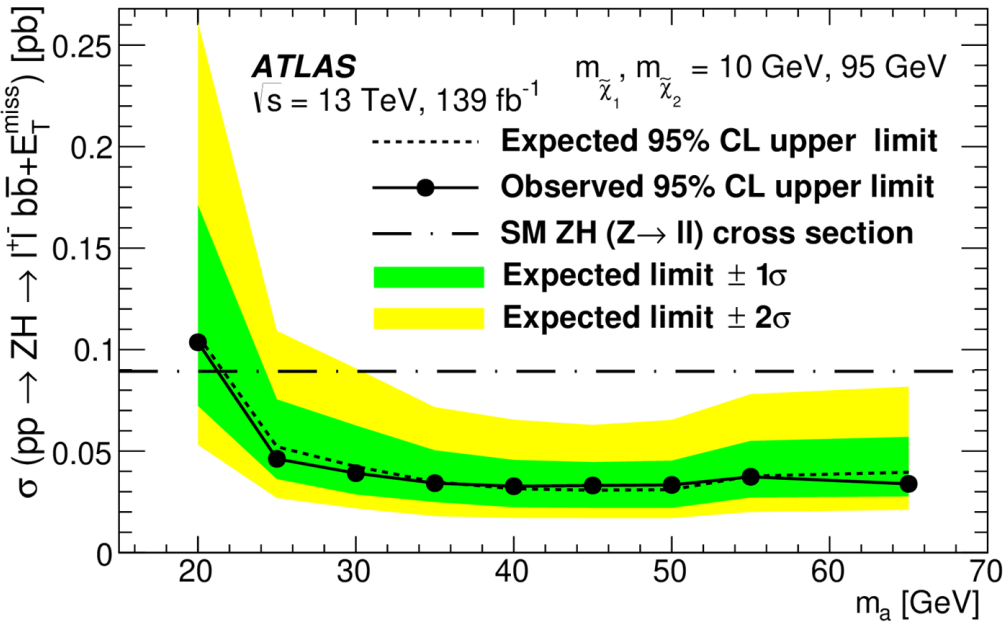


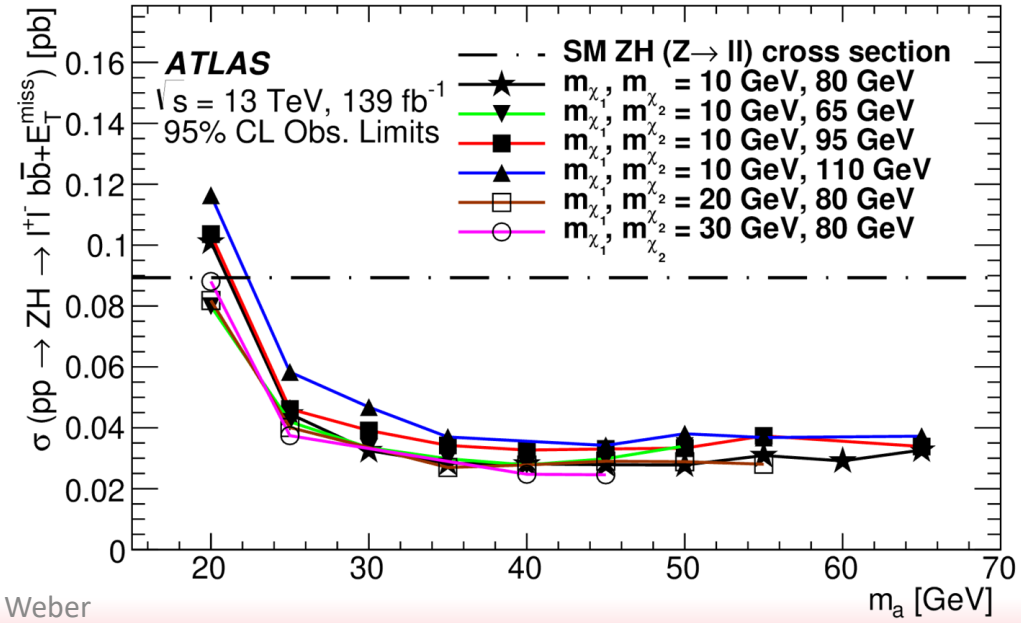
$H \to \chi_1\chi_2,\ \chi_2 \to a\chi_1,\ a \to b\bar{b}$

JHEP 01 (2022) 063



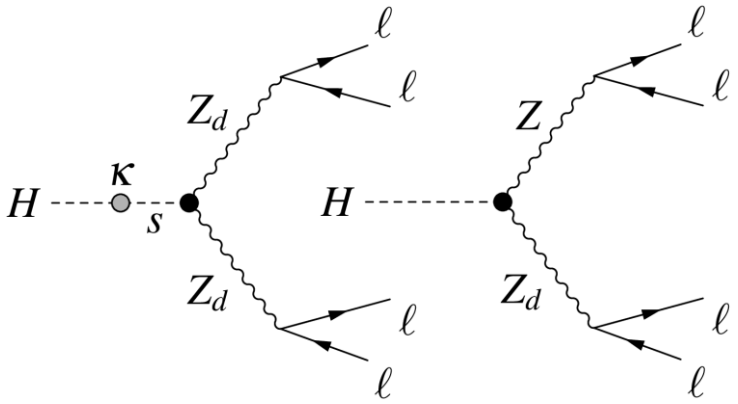
- Search for cascade $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0, a \to bb$ Higgs from ZH production
- NMSSM scenario: $\tilde{\chi}_1^0, \tilde{\chi}_2^0$ two lightest neutralinos, a - light pseudoscalar
- Select on $Z \to \ell\ell, \ell = e, \mu$ to reduce backgrounds
- Model of background distribution constructed from fits in Control Regions
- Limits via fits of signal distribution and background model to m_{jj} distribution
- 3d limit as a function of $m_a, m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}$
- Results are consistent with Standard Model





$H \to Z_d Z_d \to 4\ell$, $H \to Z Z_d \to 4\ell$

JHEP 03 (2022) 041

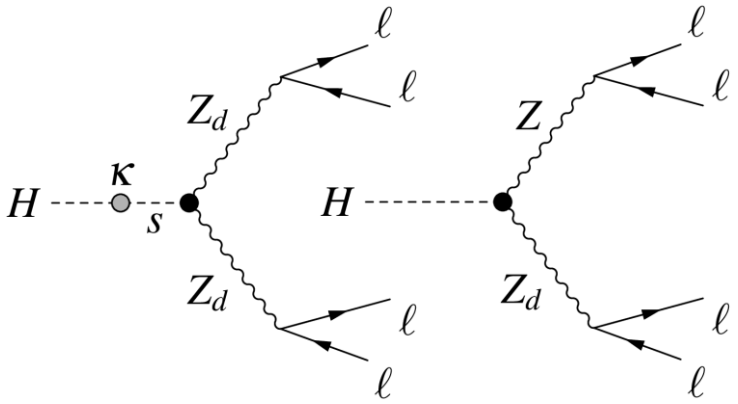


High-mass Z_d (HM):	$\mathrm{H} \to Z_d Z_d \to 4\ell$	$15\ \mathrm{GeV} < m_{Z_d} < 60\ \mathrm{GeV}$	$\ell = \mathrm{e}, \mu$
Low-mass Z_d (LM):	$\mathrm{H} \to Z_d Z_d \to 4\mu$	$1\ \mathrm{GeV} < m_{Z_d} < 15\ \mathrm{GeV}$	
Single Z_d channel:	$\mathrm{H} \to Z Z_d \to 4\ell$	$15\ \mathrm{GeV} < m_{Z_d} < 55\ \mathrm{GeV}$	$\ell = e, \mu$

- Search for Higgs to one or two BSM vector bosons in 4ℓ final state, $\ell = e, \mu$
- Higgs from gluon-gluon fusion production
- $ZZ^* \to 4\ell$ main background for all channels

$H \to Z_d Z_d \to 4\ell$, $H \to Z Z_d \to 4\ell$

JHEP 03 (2022) 041

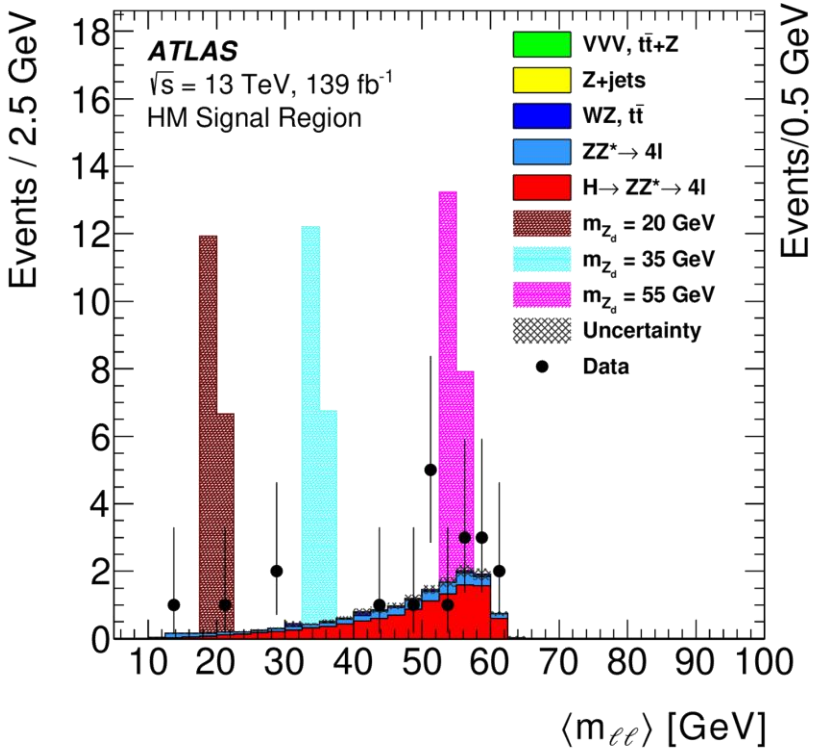


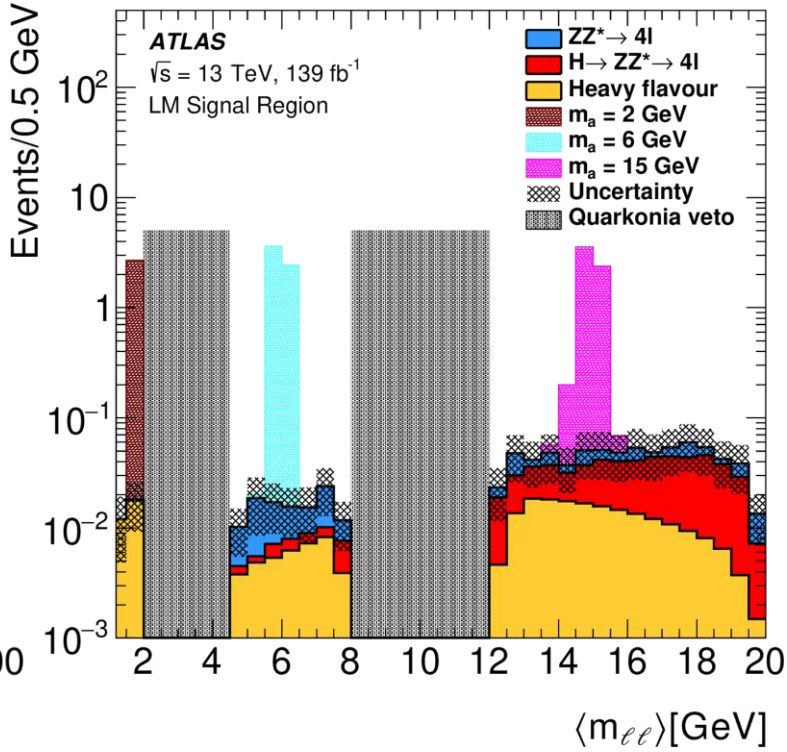
High-mass Z_d (HM):	$H \to Z_d Z_d \to 4\ell$	$15\ \text{GeV} < m_{Z_d} < 60\ \text{GeV}$	$\ell = e, \mu$
Low-mass Z_d (LM):	$H \to Z_d Z_d \to 4\mu$	$1\ \text{GeV} < m_{Z_d} < 15\ \text{GeV}$	
Single Z_d channel:	$H \to Z Z_d \to 4\ell$	$15\ \text{GeV} < m_{Z_d} < 55\ \text{GeV}$	$\ell = e, \mu$

$Z_d Z_d$

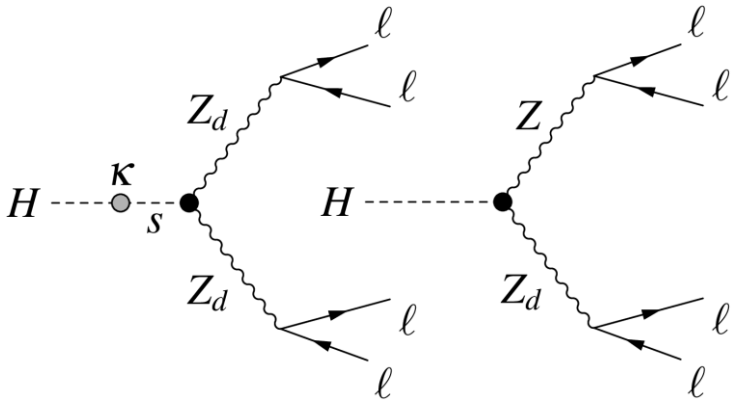
- Select leptons so that $\Delta_{m\ell\ell} = |m_{12} - m_{34}|$ minimal
- $m_{4\ell}$ compatible with Higgs
  Veto Z-bosons and quarkonia
  $m_{12} \,/\, m_{34} > 0.85$
  LM $1.2\ \text{GeV} < m_{12}, m_{34} < 20\ \text{GeV}$
- fits to $\langle m_{\ell\ell} \rangle = \frac{1}{2}(m_{12} + m_{34})$ for limits

0 data events after selection





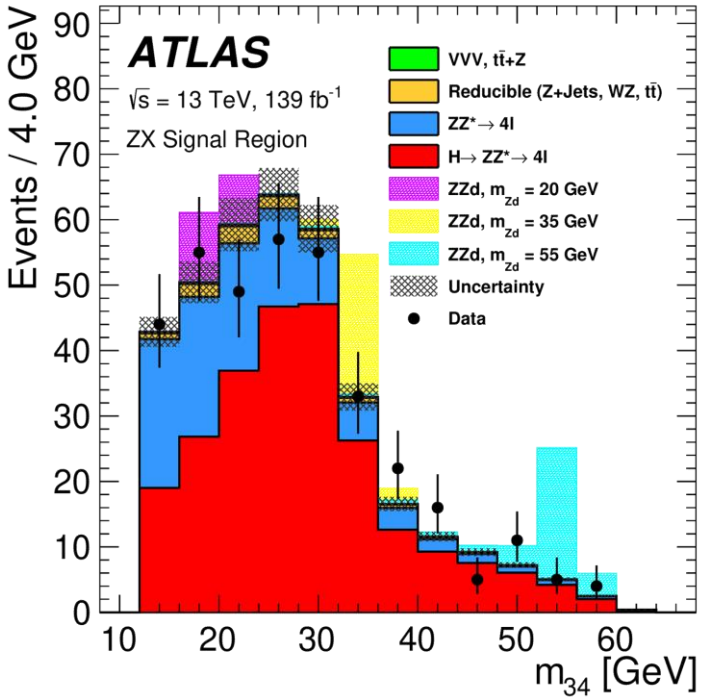
$H \to Z_d Z_d \to 4\ell, H \to Z Z_d \to 4\ell$

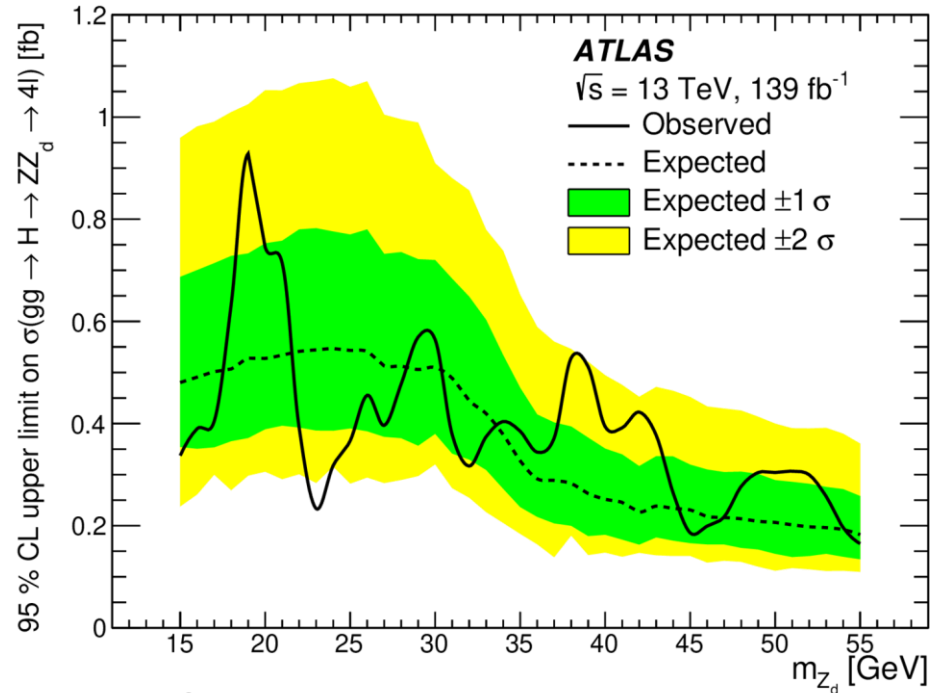


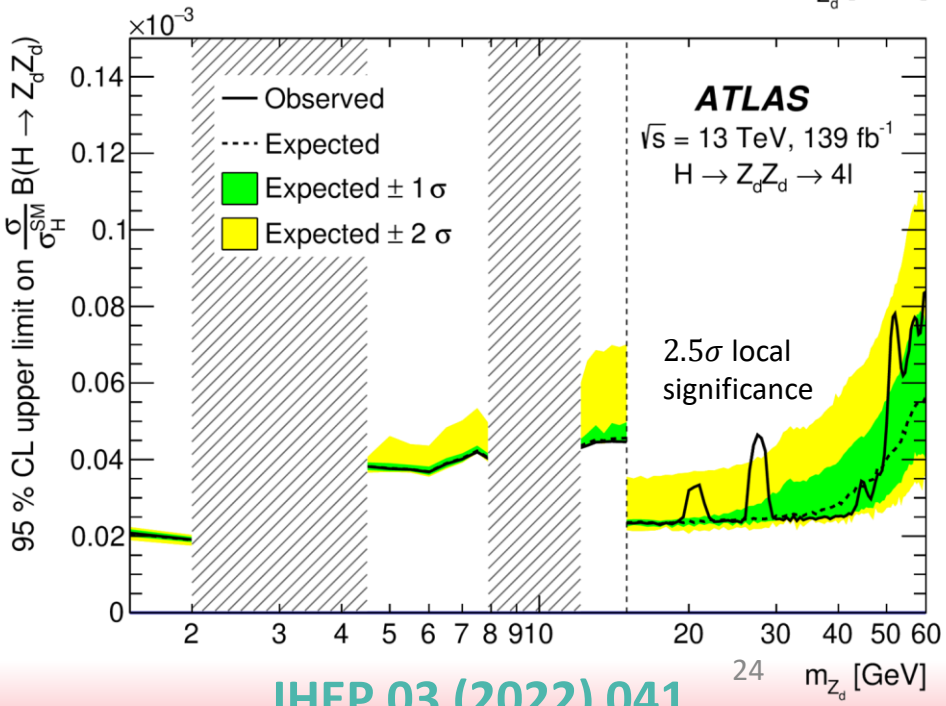
Single Z_d

- Select leptons flavor, $m_{\ell\ell}$:
  $4\mu, 2e2\mu, 2\mu 2e, 4e,$
  $\min(|m_Z - m_{12}|),\ \min(|m_Z - m_{34}|)$
- $m_{4\ell}$ compatible with Higgs
  m_{12} compatible with Z
- Template fits to m_{34}

- Slight excess in High-Mass $Z_d Z_d$ channel around $m_{Z_d} = 28$ GeV with 2.5σ local significance

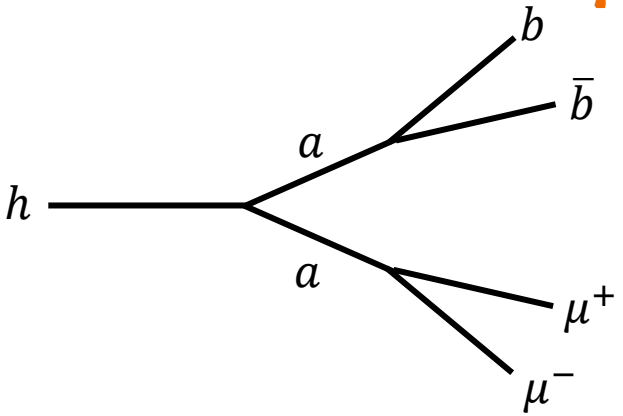




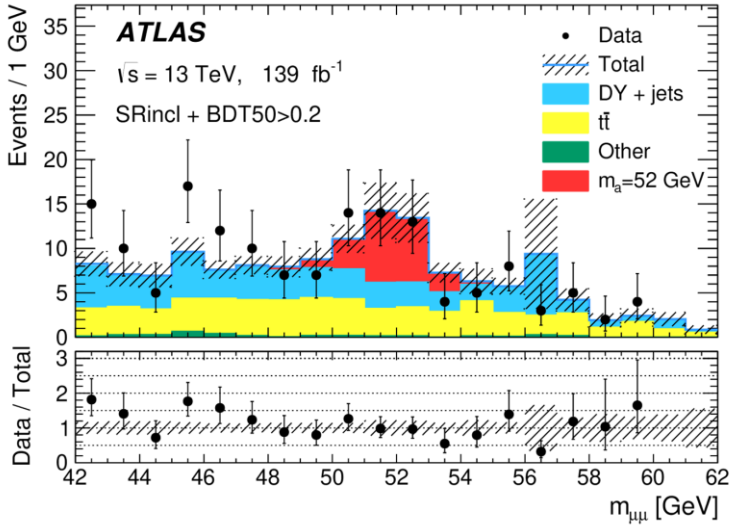


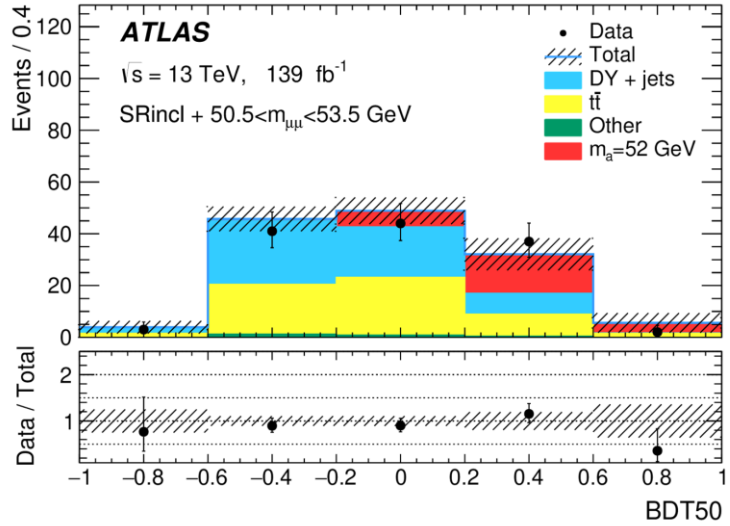
[JHEP 03 (2022) 041]

$H \to aa \to b\bar{b}\mu\mu$



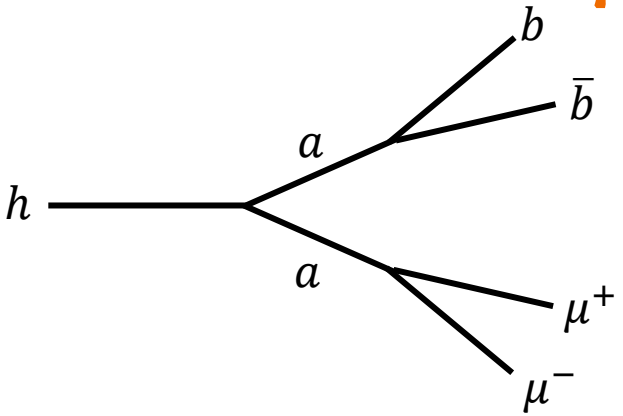
Phys. Rev. D 105 (2022) 012006





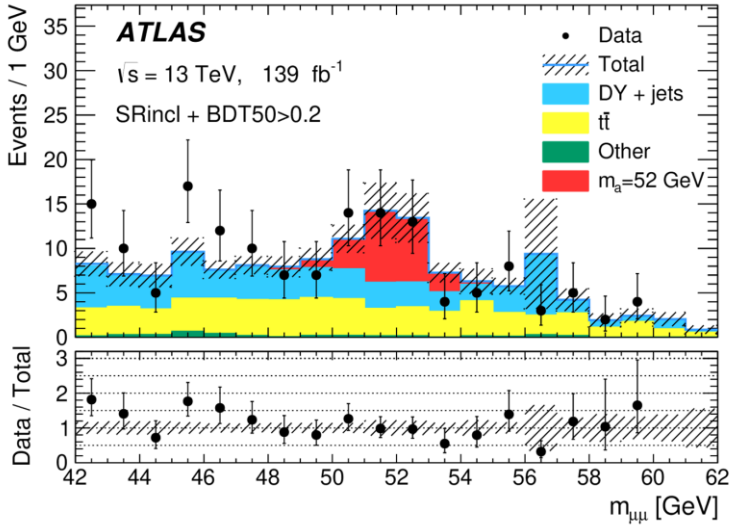
- $H \to aa \to \mu\mu\, bb$, gluon-gluon fusion production
- $a \to bb$ large branching fraction
  $a \to \mu\mu$ clean, high-resolution signal for trigger
- 2μ, exactly 2 b-tagged jets, $E_T^{\text{miss}} < 60$ GeV
  $15\ \text{GeV} < m_{\mu\mu} < 65\ \text{GeV}$, $m_{\mu\mu bb} < 140$ GeV
  kinematic fit to improve $m_{\mu\mu bb}$
- BDT to improve signal selection, trained individually for multiple signal mass points

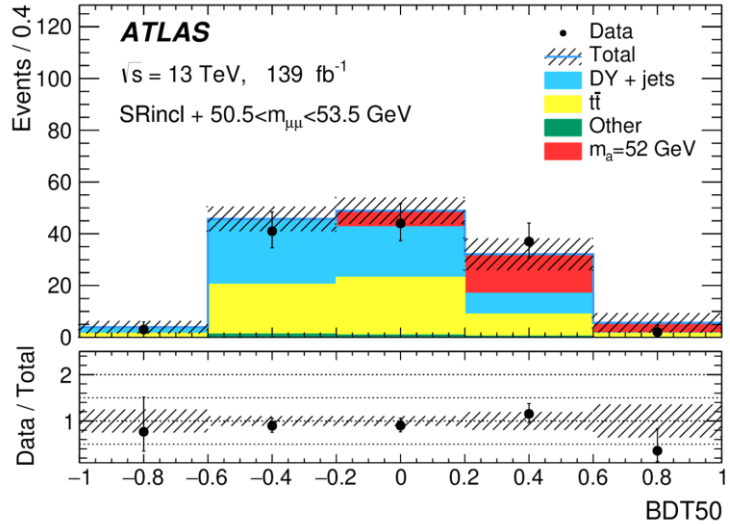
$H \to aa \to b\bar{b}\mu\mu$

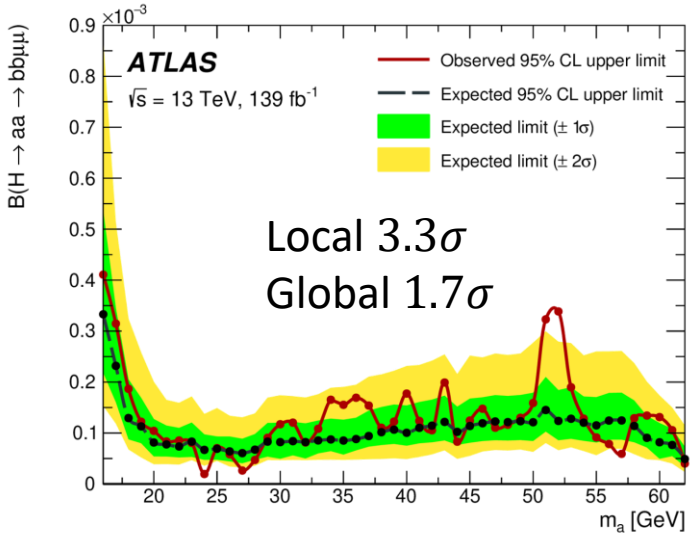


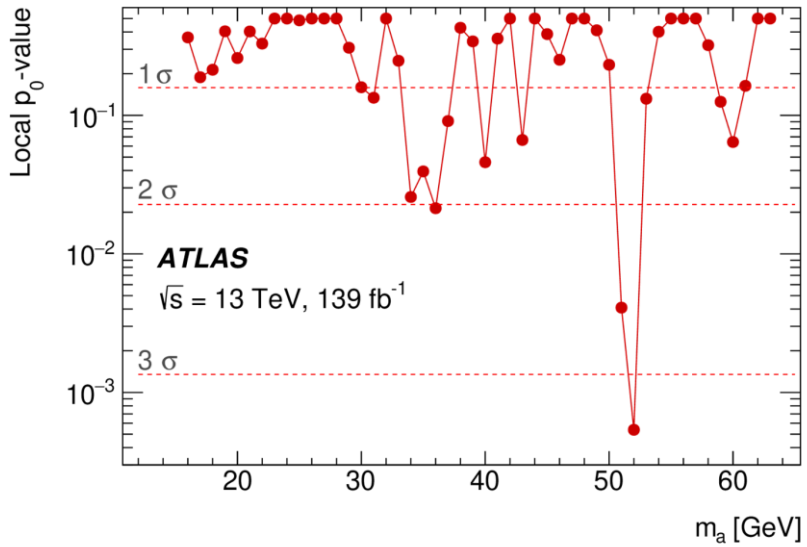
Phys. Rev. D 105 (2022) 012006

- $H \to aa \to \mu\mu\, bb$, gluon-gluon fusion production
- $a \to bb$ large branching fraction
  $a \to \mu\mu$ clean, high-resolution signal for trigger
- 2μ, exactly 2 b-tagged jets, $E_T^{\text{miss}} < 60$ GeV
  $15\ \text{GeV} < m_{\mu\mu} < 65\ \text{GeV}$, $m_{\mu\mu bb} < 140\ \text{GeV}$
  kinematic fit to improve $m_{\mu\mu bb}$
- BDT to improve signal selection, trained individually for multiple signal mass points
- Fit to $m_{\mu\mu}$ in 2 to 3 GeV wide windows around presumed m_a
- 4x improvement on limit due to larger dataset and BDT w.r.t prior ATLAS result
  Phys. Lett. B 790 (2019) 1









Conclusion

- Comprehensive program targeting signatures of new scalars, pseudoscalars and beyond Standard Model Higgs decays

- Results generally consistent with Standard Model expectations
  - Though few local hints of excesses

- LHC Run 3 just started, but Run 2 analysis still being released
  - More to come with Run 3 data

Charged Higgs

$t \to H^{\pm} b, H^{\pm} \to cb$

$H^{\pm} \to ZW \to 3\ell + \nu$

$H^{\pm\pm} H^{\mp\mp} \to 4\ell$

New scalar / pseudoscalar

$t\bar{t}H \,/\, t\bar{t}A \to 4t$

$X \to \gamma\gamma$, low mass X

$X \to \gamma\gamma$, high mass X

$t \to qX, X \to b\bar{b}, q = u, c$

$H \to$ leptons $+ b$-jets

Heavy $H \to WW$

Exotic Higgs Decays

$H \to \chi_1\chi_2, \ \chi_2 \to a\chi_1, \ a \to b\bar{b}$

$H \to Z_d Z_d \to 4\ell, H \to Z Z_d \to 4\ell$

$H \to aa \to b\bar{b}\mu\mu$

See all public ATLAS results here

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Thank you!

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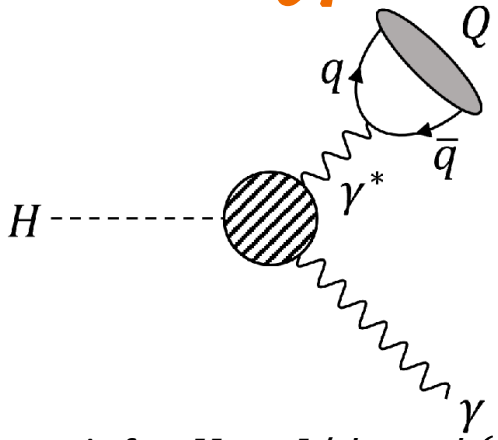
See all public ATLAS results here

Backup

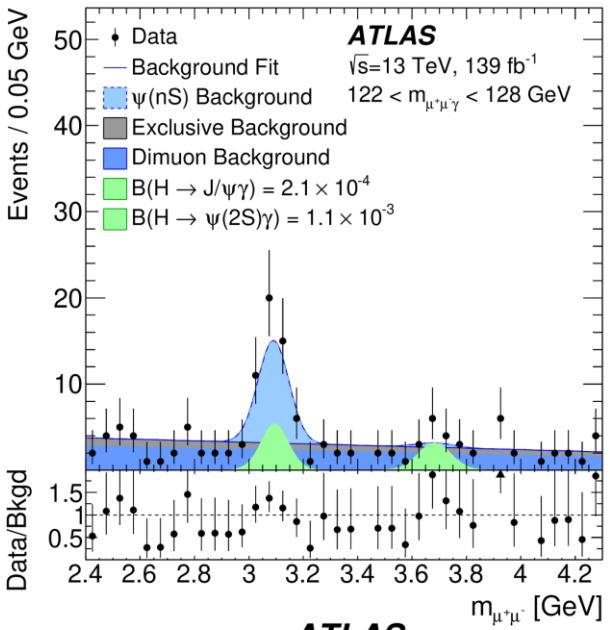


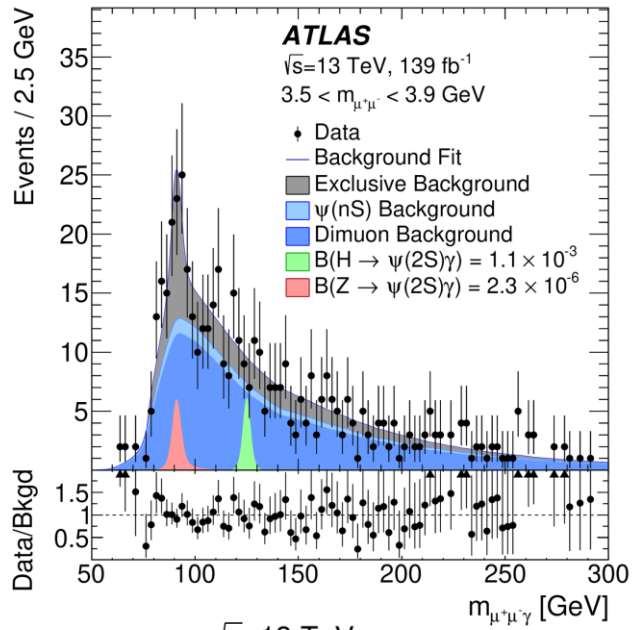
$H \to Q\gamma$

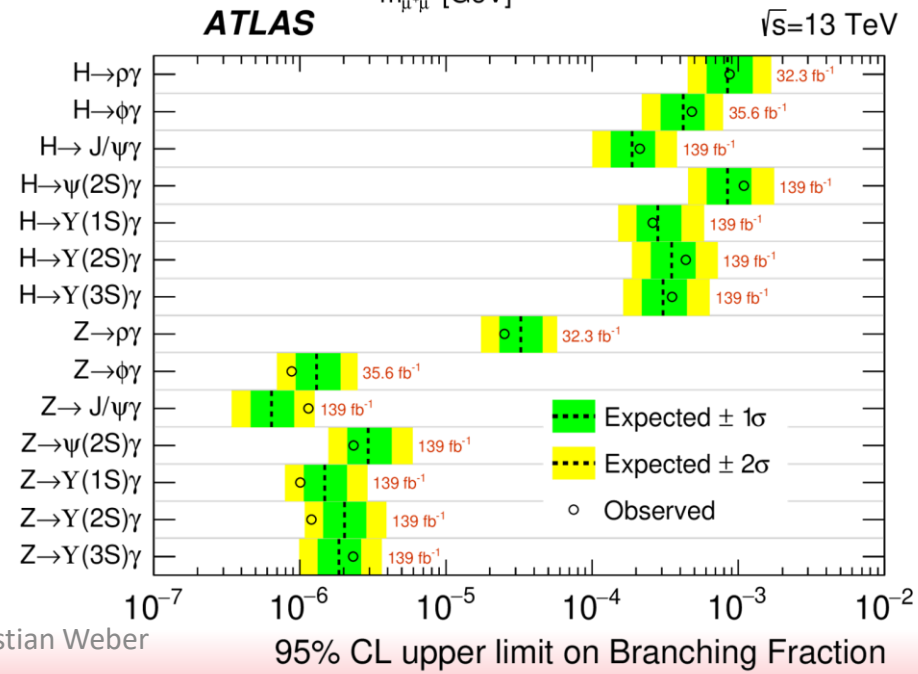


- Search for $H \to J/\psi\,\gamma$, $\psi(2S)\gamma$, $\Upsilon(1S, 2S, 3S)\,\gamma$ in $\mu^-\mu^+\gamma$ final state
- $p_T^\mu > 3.0$ GeV, one μ: $p_T^\mu > 18$ GeV, $p_T^\gamma > 35$ GeV
  $m_{\mu\mu}$ cut consistent with $m_{\psi(nS)}$ or $m_{\Upsilon(nS)}$, $p_T^{\mu\mu}$, $m_{\mu\mu\gamma}$ cuts
- 3 signal regions: $\psi(nS)$, $\Upsilon(nS)$ barrel (high resolution), $\Upsilon(nS)$ endcap (lower resolution)
- Signal and background $m_{\mu\mu}$, $m_{\mu\mu\gamma}$ distributions described by analytical model

arXiv:2208.03122

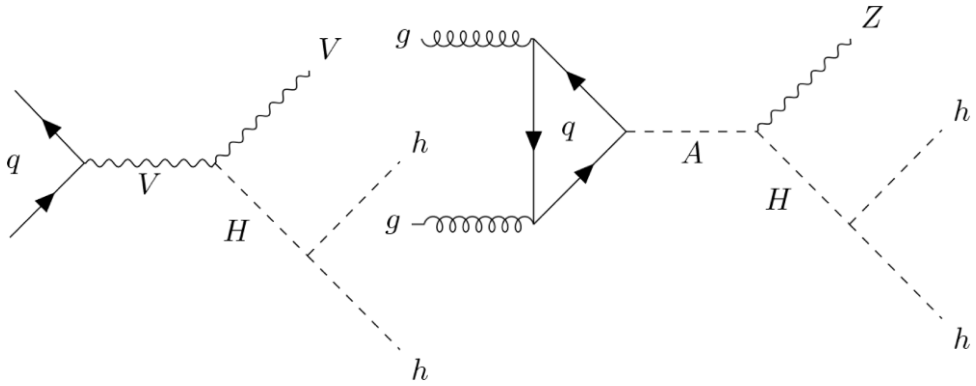






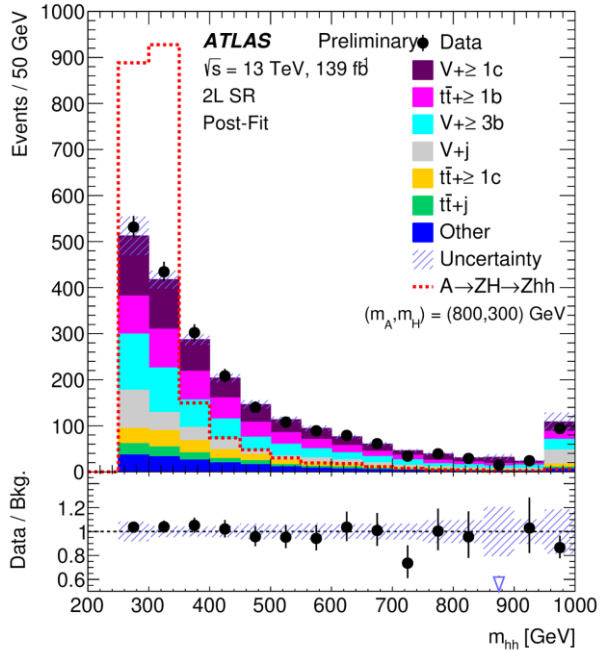
limits on
H(Z) → φ γ and
H(Z) → ρ γ
are taken from
JHEP 07 (2018) 127

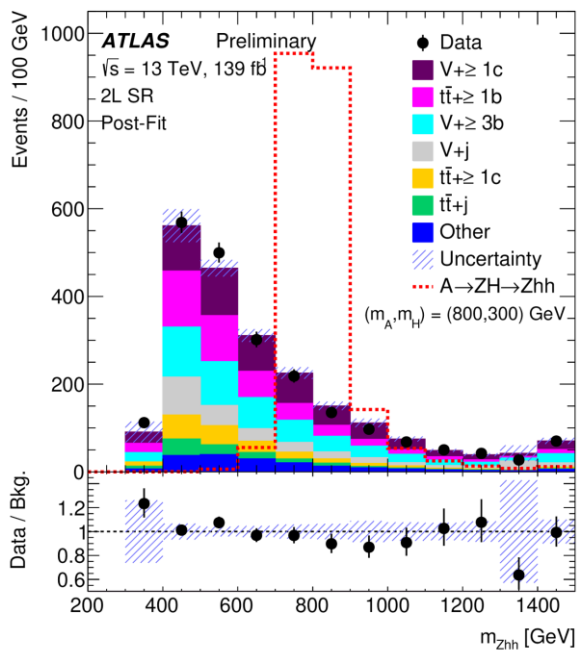
$HH + V \rightarrow 4b + V$

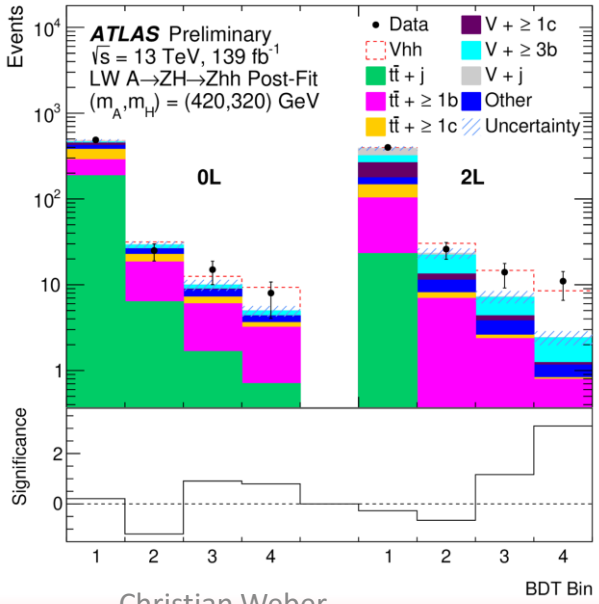


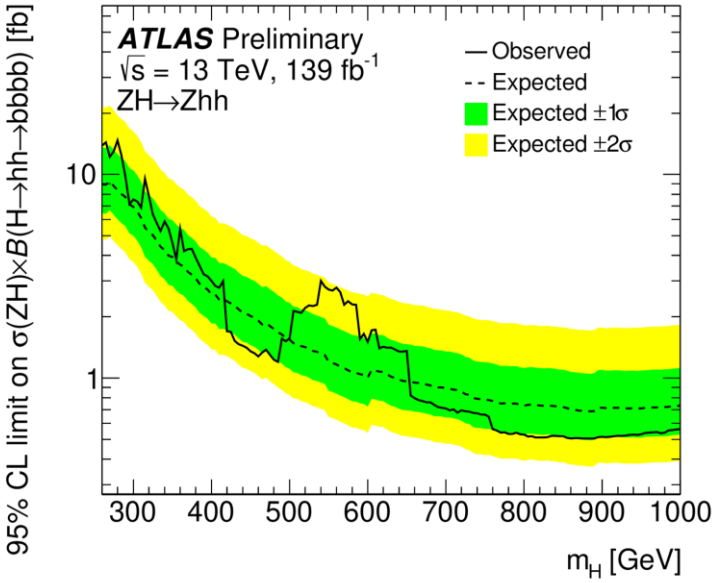
- Search for Heavy Higgs $H \rightarrow hh$ in association with V-boson, $hh \rightarrow b\bar{b}b\bar{b}$, $Z \rightarrow \ell\ell, \nu\nu$
- signal regions: 0ℓ, 1ℓ $2\ell \times \mathrm{V} \rightarrow VH$; 0ℓ, $2\ell \times A \rightarrow ZH$ $\geq 4b$-jets,
- Control Regions for $t\bar{t}$, V+jets
- one BDT for signal discrimination per signal region
- Fit to BDT score

ATLAS-CONF-2022-043









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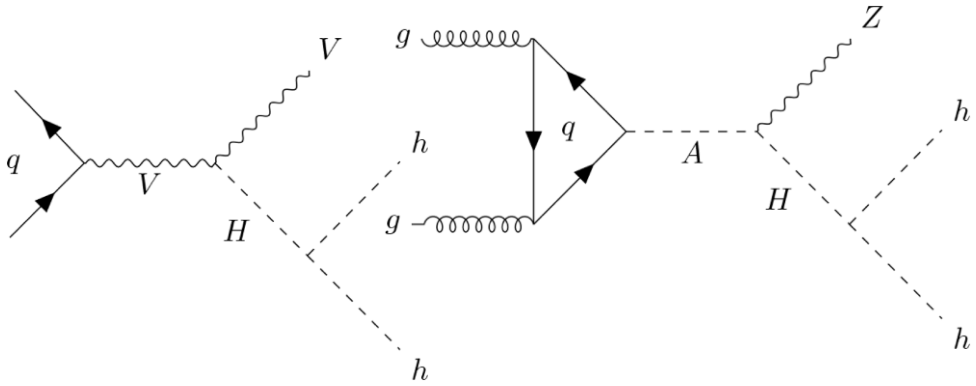

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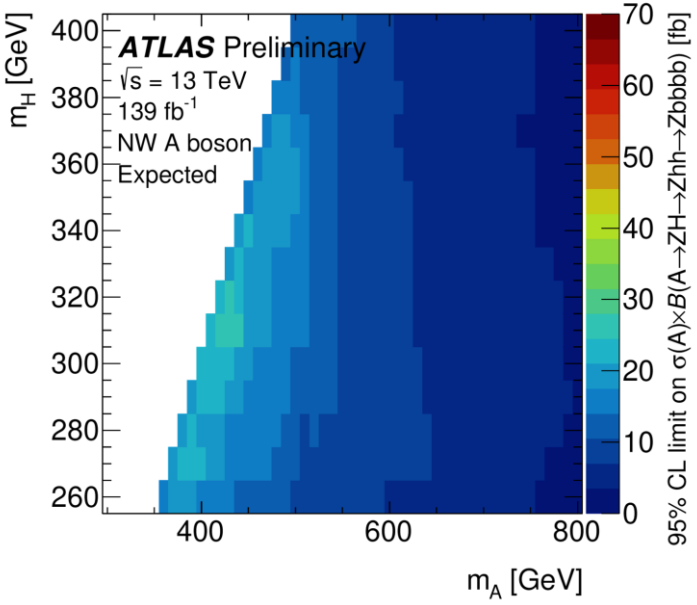
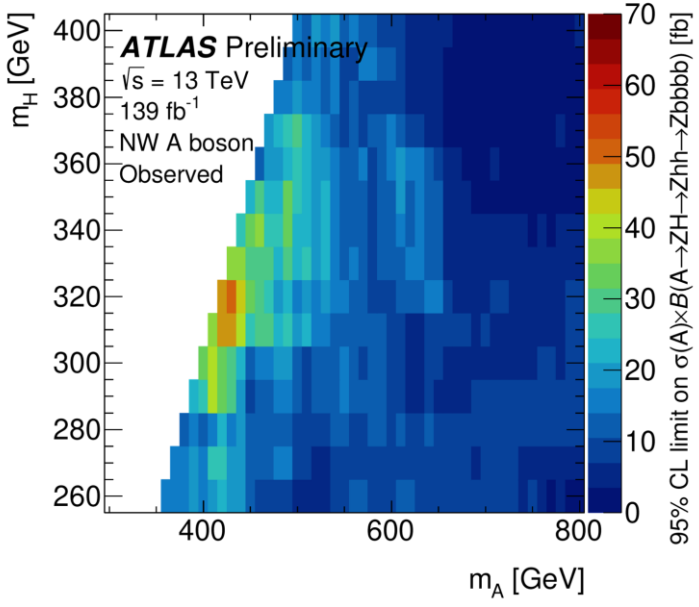
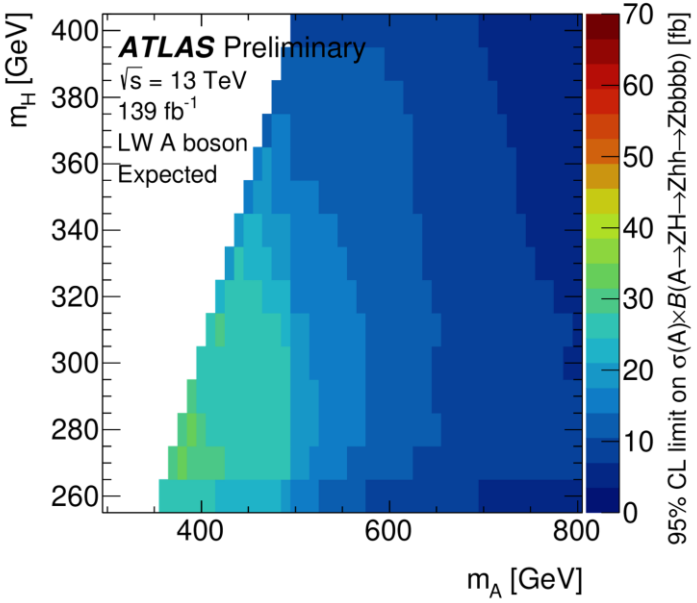
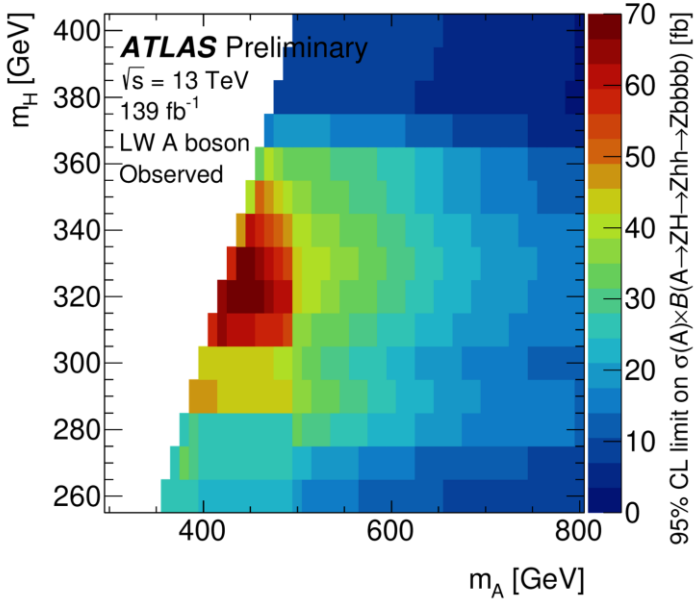
ATLAS-CONF-2022-043

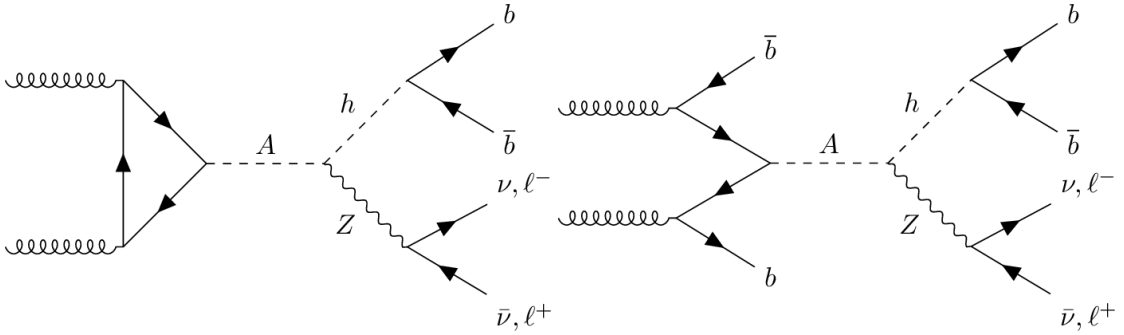




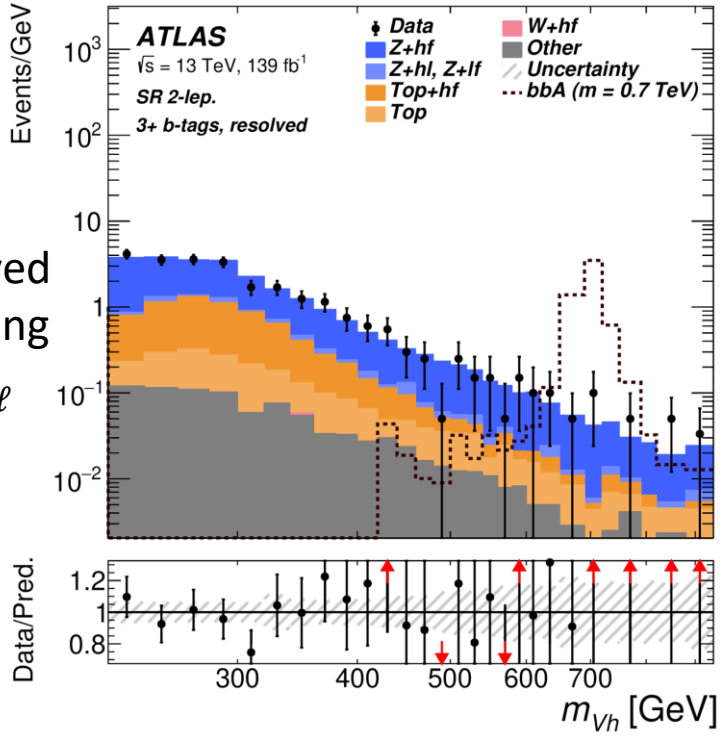




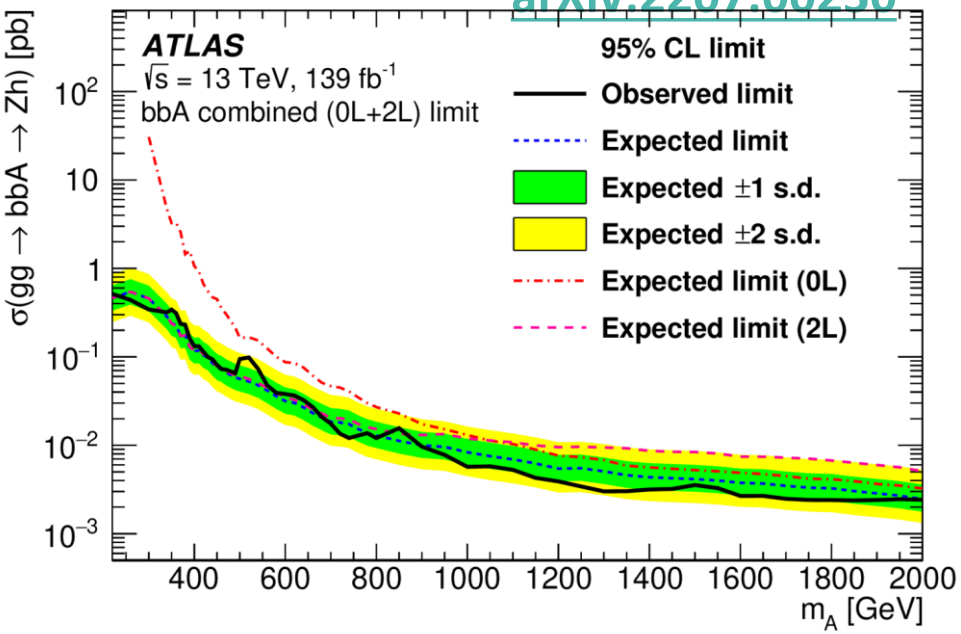
$A \to Zh, h \to b\bar{b}, Z \to \ell\ell, \nu\nu$

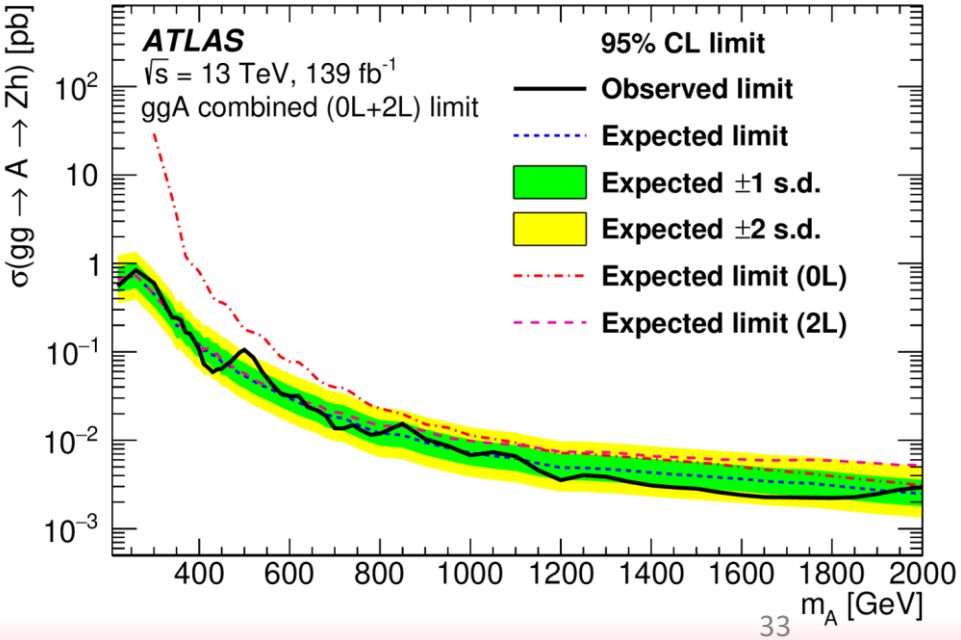


- Search for pseudoscalar A in ggF or b-associated production; decaying to Z and SM Higgs boson
- $A \to Zh$, $h \to b\bar{b}$, $Z \to \ell\ell$ or $\nu\nu$
  4 signal regions
  $Z \to \ell\ell$ or $\nu\nu \times b\bar{b}$ merged or resolved
- All defined by kinematic cuts, including E_T^{miss}, p_T, angular variables, $m_h, m_{\ell\ell}$

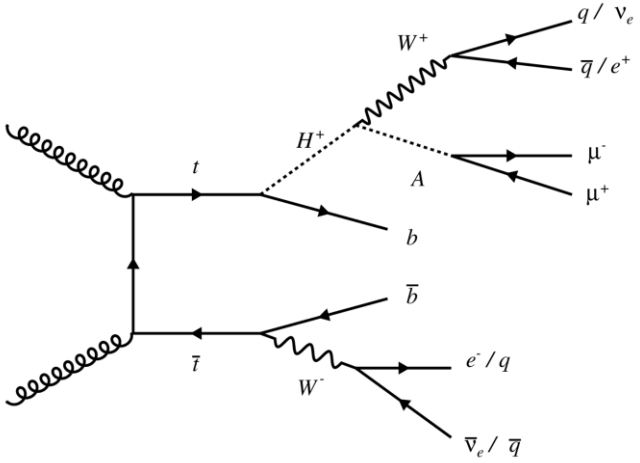


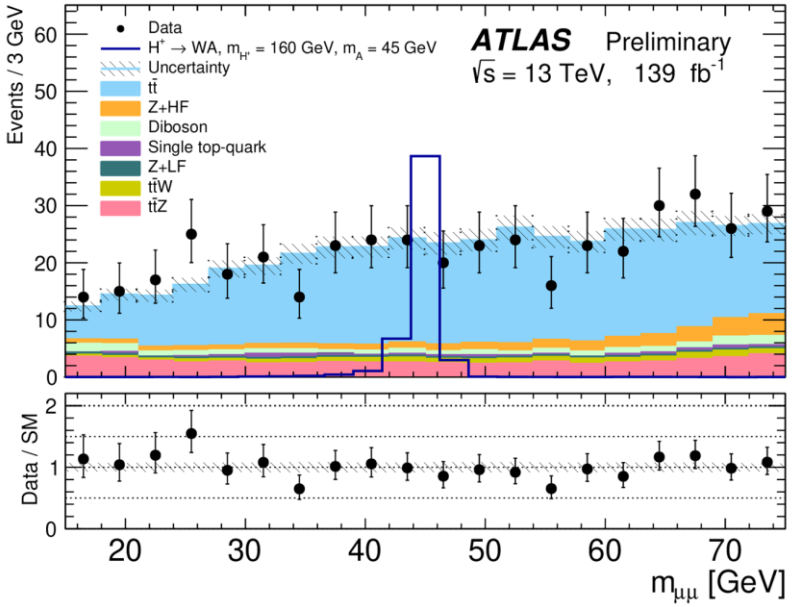
arXiv:2207.00230





$H^{\pm} \rightarrow W^{\pm}A \rightarrow W^{\pm}\mu\mu$

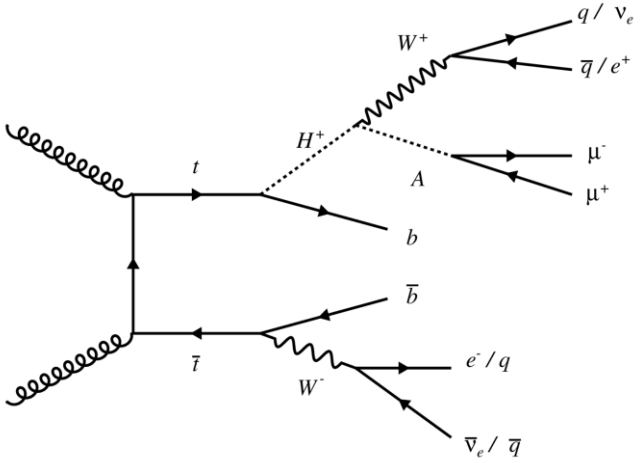


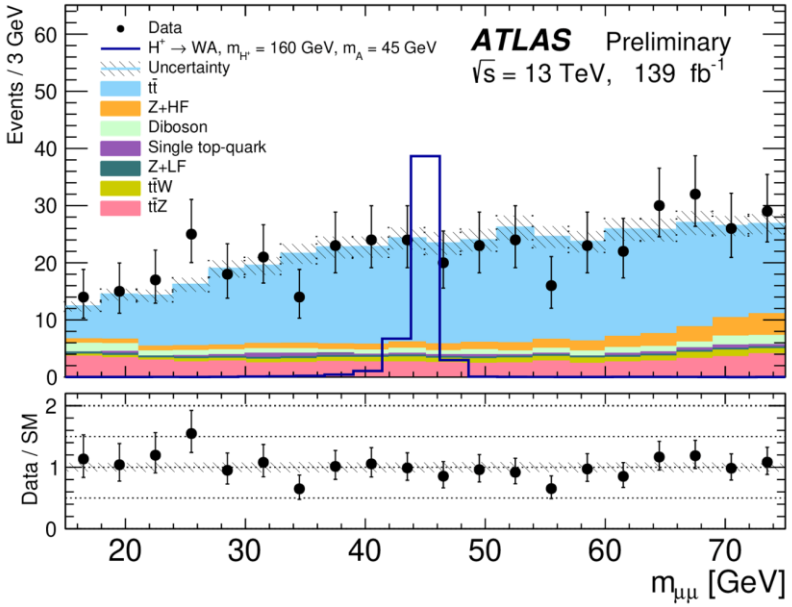


[ATLAS-CONF-2021-047]

- Search for charged Higgs $H^{\pm}$ in $\mu\mu$ final state via intermediate $W^{\pm}A$, A CP odd pseudoscalar
- Require $\mu^+\mu^-$, $1e$, ≥ 3 jets, at least one b-tagged
- Look for resonance in $m_{\mu\mu}$ spectrum
  $H^{\pm}$ spectrum not used in due poor resolution

$H^{\pm} \rightarrow W^{\pm}A \rightarrow W^{\pm}\mu\mu$





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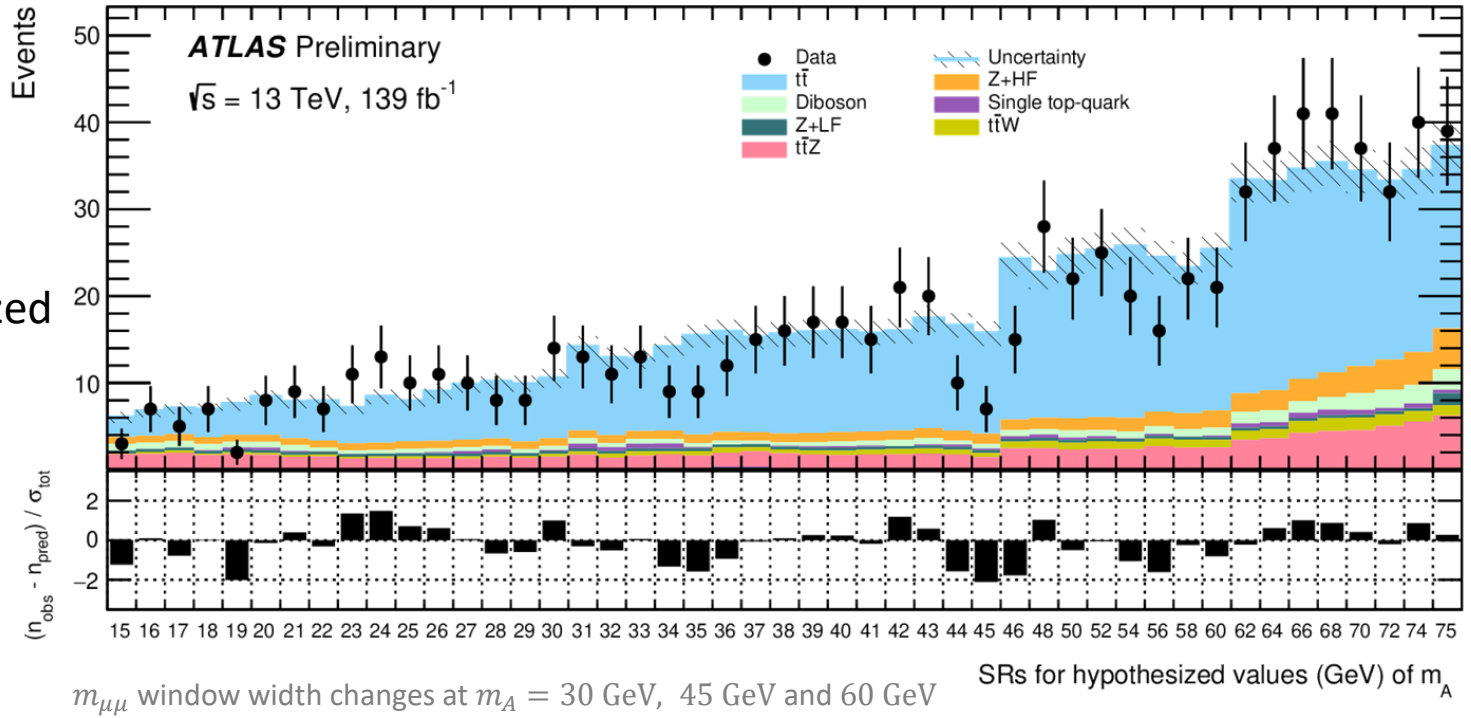
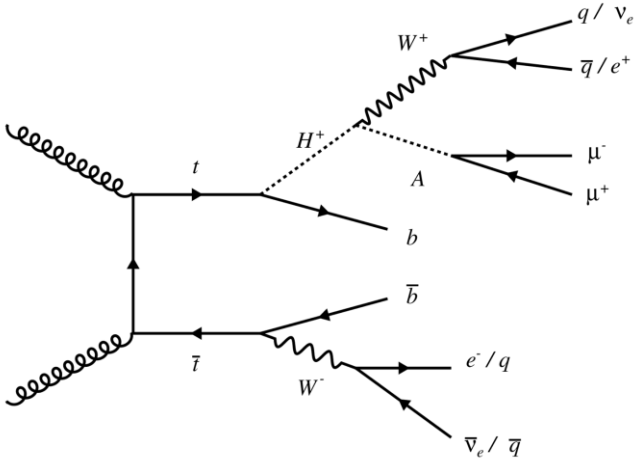
  Advantage: Reduced dependence on $m_{H^{\pm}}$, only enters via selection efficiency



$m_{\mu\mu}$ window width changes at $m_A = 30$ GeV, 45 GeV and 60 GeV

$H^{\pm} \rightarrow W^{\pm}A \rightarrow W^{\pm}\mu\mu$



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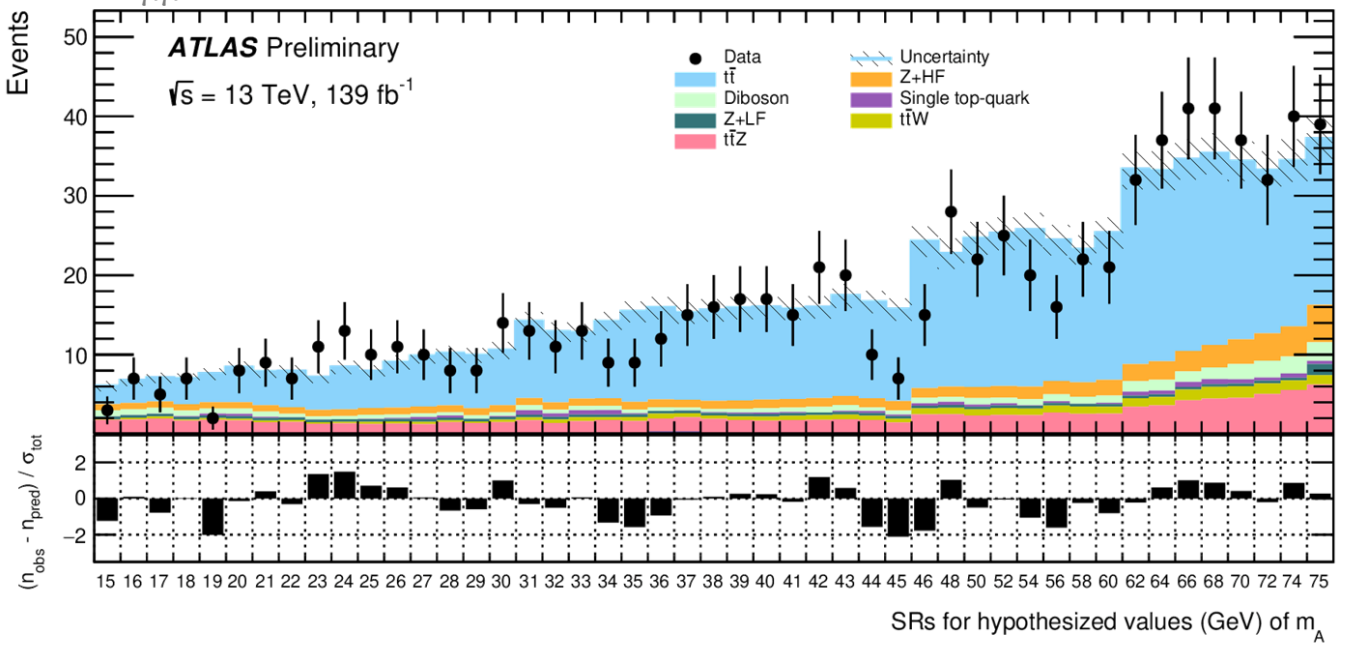
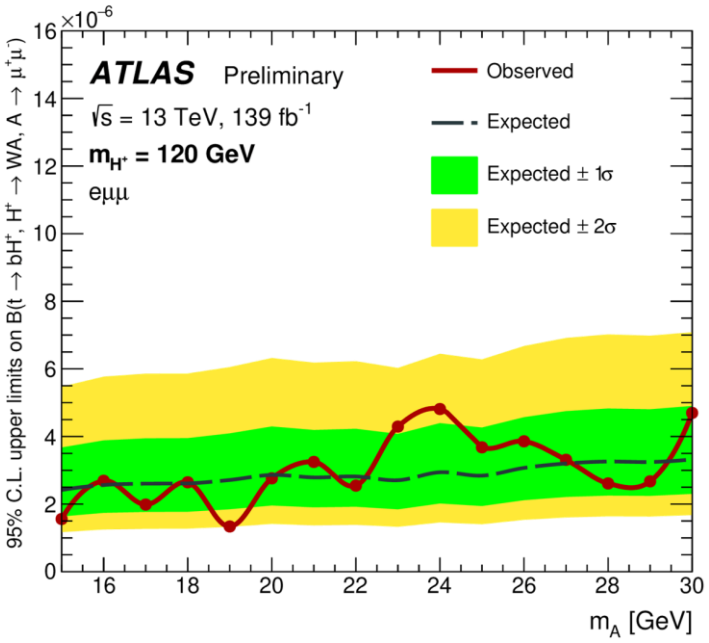
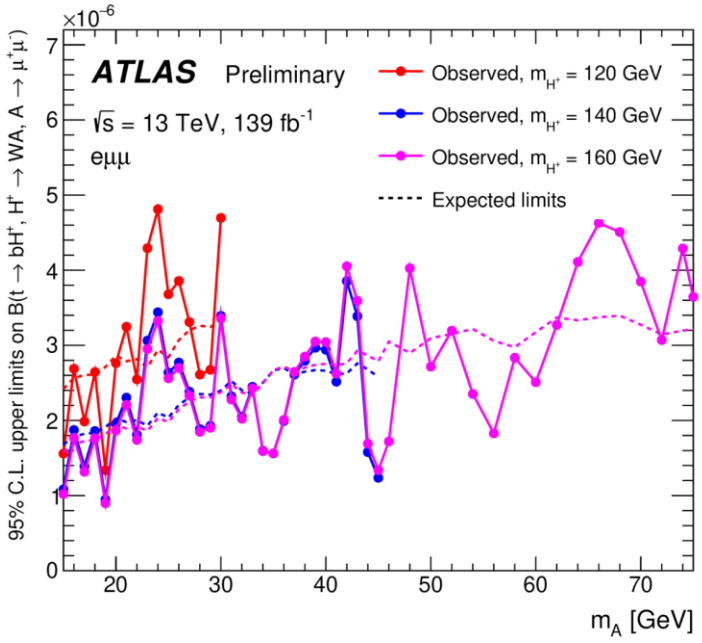
  Advantage: Reduced dependence on $m_{H^{\pm}}$, only enters via selection efficiency
- $\sim$2x improvement over prior CMS results
  Phys. Rev. Lett. **123**, 131802

$m_{\mu\mu}$ window width changes at $m_A = 30$ GeV, 45 GeV and 60 GeV



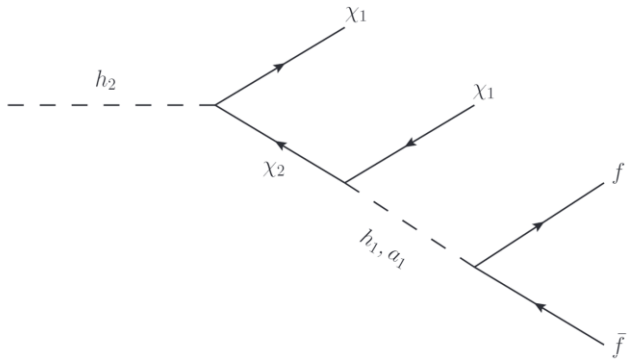




ATLAS-CONF-2021-047

$H \to \chi_1\chi_2,\ \chi_2 \to a\chi_1,\ a \to b\bar{b}$

JHEP 01 (2022) 063



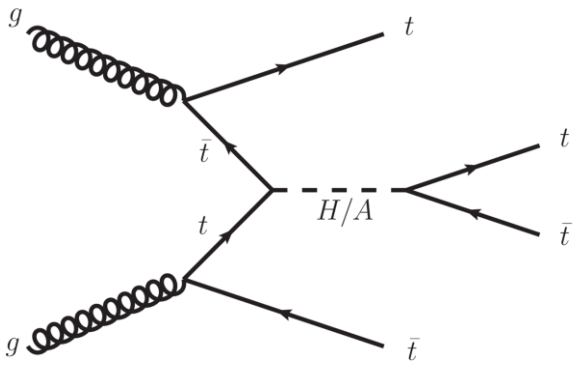
- Search for cascade $H \to \tilde{\chi}_2^0\tilde{\chi}_1^0 \to a\tilde{\chi}_1^0\tilde{\chi}_1^0, a \to bb$ Higgs from ZH production
- NMSSM scenario: $\tilde{\chi}_1^0, \tilde{\chi}_2^0$ two lightest neutralinos, a - light pseudoscalar
- Select on $Z \to \ell\ell, \ell = e, \mu$ to reduce backgrounds
- Model of background distribution constructed from fits in Control Regions
- Limits via fits of signal distribution and background model to m_{jj} distribution
- 3d limit as a function of $m_a, m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}$

	SR	CRZ	CRTop	VRMET
Number of leptons			2	
Number of jets			≥ 2	
Number of b-tagged jets			≥ 1	
Dilepton p_{T} [GeV]			> 40	
p_{T} fraction			[0.8, 1.2]	
Dilepton mass [GeV]	[81, 101]	[81, 101]	[50, 81] or > 101	[81, 101]
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 100	[60, 100]	> 100	> 50
Dijet mass [GeV]	[20, 120]	[20, 120]	[20, 120]	> 150

p_T fraction: $\frac{p_T^{jj} + E_T^{\mathrm{miss}}}{p_T^{ll}}$

$t\bar{t}H$ / $t\bar{t}A \rightarrow 4t$

ATLAS-CONF-2022-008

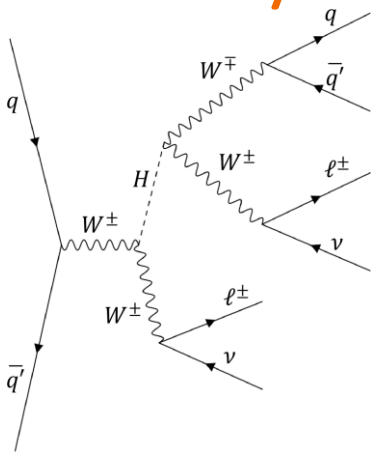


- Search for heavy scalar H, pseudoscalar A in $4t$ processes
- $\ell^+\ell^+$ or $\ell^-\ell^-$, Z-vetoed
  6+ jets, 2+ of those b-tagged
  $H_T > 500$ GeV

Region	Channel	N_j	N_b	Other selection cuts	Fitted variable
CR Conv	$e^\pm e^\pm \,\|\|\, e^\pm \mu^\pm$	$4 \leq N_j < 6$	≥ 1	$m_{ee}^{CV} \in [0, 0.1]$ GeV $200 < H_T < 500$ GeV	m_{ee}^{PV}
CR HF e	$eee \,\|\|\, ee\mu$		$= 1$	$100 < H_T < 250$ GeV	Yield
CR HF μ	$e\mu\mu \,\|\|\, \mu\mu\mu$		$= 1$	$100 < H_T < 250$ GeV	Yield
CR $t\bar{t}W$	$e^\pm \mu^\pm \,\|\|\, \mu^\pm \mu^\pm$	≥ 4	≥ 2	$m_{ee}^{CV} \notin [0, 0.1]$ GeV, $\|\eta(e)\| < 1.5$ for $N_b = 2$, $H_T < 500$ GeV or $N_j < 6$; for $N_b \geq 3$, $H_T < 500$ GeV	$\sum p_T^\ell$
CR lowBDT	SS+3L	≥ 6	≥ 2	$H_T > 500$ GeV, SM BDT < 0.55	SM BDT
BSM SR	SS+3L	≥ 6	≥ 2	$H_T > 500$ GeV, SM BDT ≥ 0.55	BSM pBDT

Heavy $H \to WW$

ATLAS-CONF-2022-033



- Search for heavy Higgs to WW in associated production with W
- $\ell^{\pm}\nu\ell^{\pm}\nu qq$ final state
  veto events with additional leptons
  veto events with b-tagged small radius jets
- Two signal regions, depending on qq jet overlap
  Resolved SR: two small radius jets
  Boosted SR: one large radius jet

Selections	Boosted SR	Resolved SR	*ssWW* CR	Boosted *WZ* CR	Resolved *WZ* CR
Trigger	Single lepton				
Leptons	two same-sign leptons with $p_{\mathrm{T}} > 27, 20$ GeV zero additional veto leptons			three leptons with $p_{\mathrm{T}} > 27, 20, 20$ GeV at least one SFOS lepton pair	
$m_{\ell\ell}$	> 100 GeV			-	
$m_{\ell\ell\ell}$	-			> 100 GeV	
b-jets	zero b-tagged small-R jets				
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 80 GeV	> 60 GeV	> 40 GeV		
Large-R jets	at least one large-R jet with $p_{\mathrm{T}} > 200$ GeV, $\lvert\eta\rvert < 2.0$ 50 GeV $< m_J < 200$ GeV and pass 80% W-tagger WP	zero large-R jets with $p_{\mathrm{T}} > 200$ GeV, $\lvert\eta\rvert < 2.0$ 50 GeV $< m_J < 200$ GeV		at least one large-R jet with $p_{\mathrm{T}} > 200$ GeV, $\lvert\eta\rvert < 2.0$ 50 GeV $< m_J < 200$ GeV and pass 80% W-tagger WP	zero large-R jets with $p_{\mathrm{T}} > 200$ GeV, $\lvert\eta\rvert < 2.0$ 50 GeV $< m_J < 200$ GeV
Small-R jets	-	at least two small-R jets with $p_{\mathrm{T}} > 20$ GeV and $\lvert\eta\rvert < 2.5$		-	at least two small-R jets with $p_{\mathrm{T}} > 20$ GeV and $\lvert\eta\rvert < 2.5$
m_{jj}	-	50 GeV $< m_{jj} < 110$ GeV	> 200 GeV	-	-