

Searches for low- and high-mass resonances with the ATLAS detector

On behalf of the ATLAS collaboration

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Higgs 2021



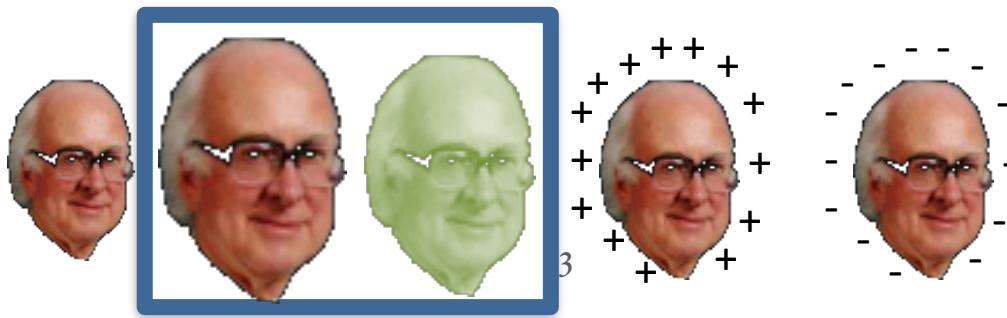
Outline

- Beyond the Standard Model
 - 139 fb⁻¹ results
 - High mass ZZ
 - High mass $\gamma\gamma$
 - 80 fb⁻¹ results
 - Low mass $\gamma\gamma$
 - 36 fb⁻¹ results
 - High mass WW
- Summary



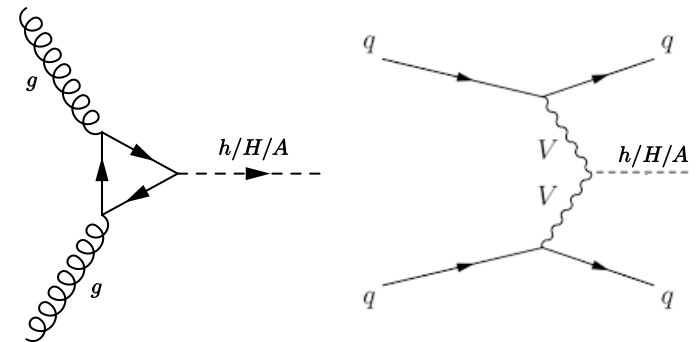
Beyond the SM

- **Standard Model (SM):**
One doublet of Higgs, only one neutral Higgs boson.
- SM needs to be **extended**:
 ν mass, dark matter...
- Fermions (leptons and quarks) come in **three generations**, why only one Higgs doublet?
- In many extensions of the SM:
Prediction of two complex Higgs doublets (**2HDM**).
- Five physical states: H^+ , H^- , h^0 , H^0 , A^0 .



- **Search for heavy resonances decaying into a pair of Z bosons in the $llll$ and $llvv$ final states using 139 fb^{-1} at 13 TeV.**
- Many channels:
 - Productions: gluon-gluon fusion and vector-boson-fusion.
 - Decays: $llll$ and $llvv$.
 - Width assumptions: narrow-width approximation and large-width assumption (only for the ggF channel).
 - Spins: 0 (two-Higgs-doublet model) and 2 (Randall–Sundrum).
- Mass range: 200-2000 GeV.
- Discriminating variable:
 - $llll$: m_{4l} (four-lepton invariant mass).
 - $llvv$:

$$m_T \equiv \sqrt{\left[\sqrt{m_Z^2 + (p_T^{\ell\ell})^2} + \sqrt{m_Z^2 + (E_T^{\text{miss}})^2} \right]^2 - \left| \vec{p}_T^{\ell\ell} + \vec{E}_T^{\text{miss}} \right|^2}.$$



III

- Require two same-flavour, opposite-sign lepton pairs and have invariant masses cuts.
- For the NWA events are classified based on NN to separate the ggF and VBF production mechanisms.
- Signal modelling:
 - NWA: Crystal Ball and Gaussian function.
 - LWA and graviton: convolved also with the parton-level lineshape of m_{4l} .

IIvv

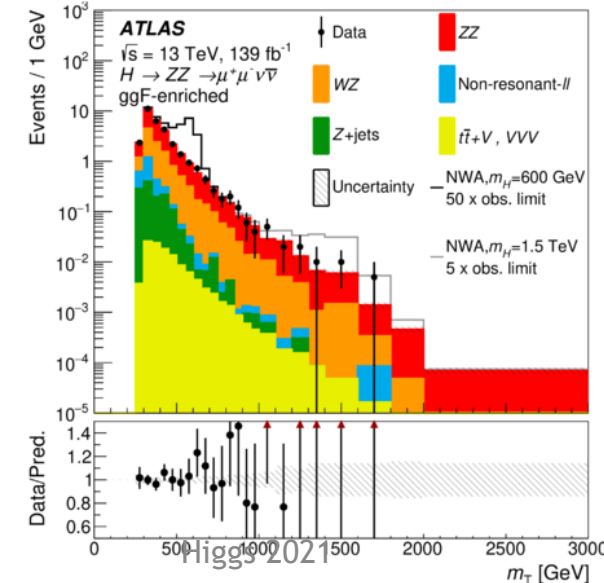
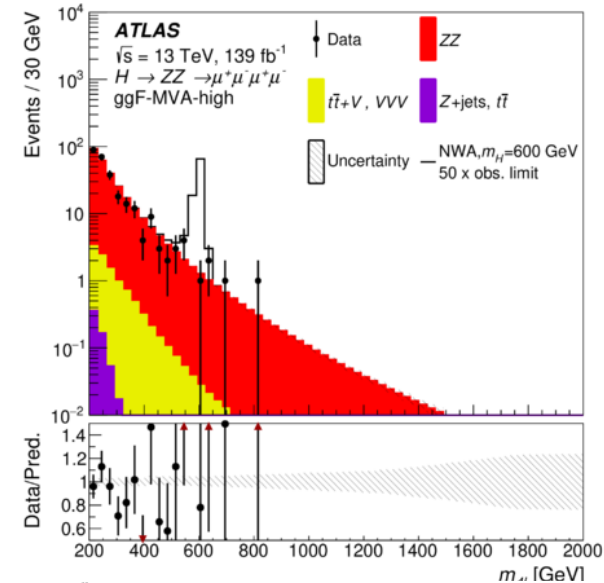
- Require a same-flavour, opposite-sign lepton pair and have additional missing E_T related and angular cuts.
- Separate ggF from VBF based on jets related selections.
- Signal modeling:
 - M_T - transverse mass template derived from simulations and fit to data.

H → ZZ

New

Eur. Phys. J. C 81 (2021) 332

- Background estimation:
 - Minor backgrounds - simulated from MC.
 - Major backgrounds - shape from MC and normalization from data.
 - llll: dominant non resonant ZZ - using functional form.
- LWA
 - H-h interference: reweighting the the particle-level lineshape of generated signal events.
 - H-B interference: generating Inclusive sample of signal+background+interference.

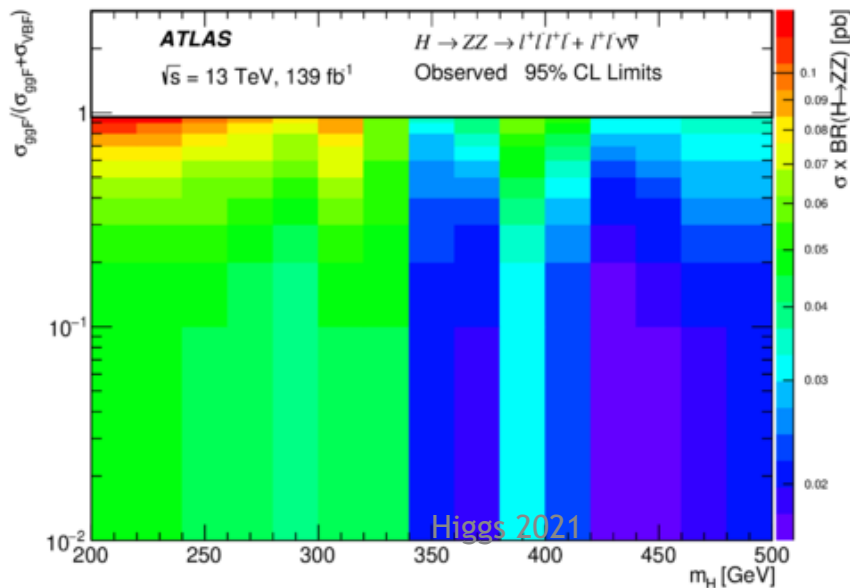
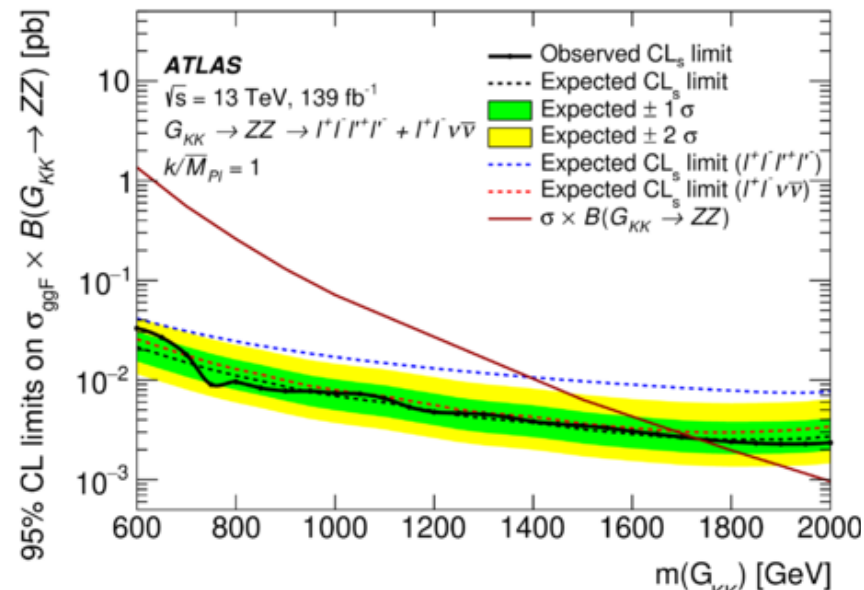
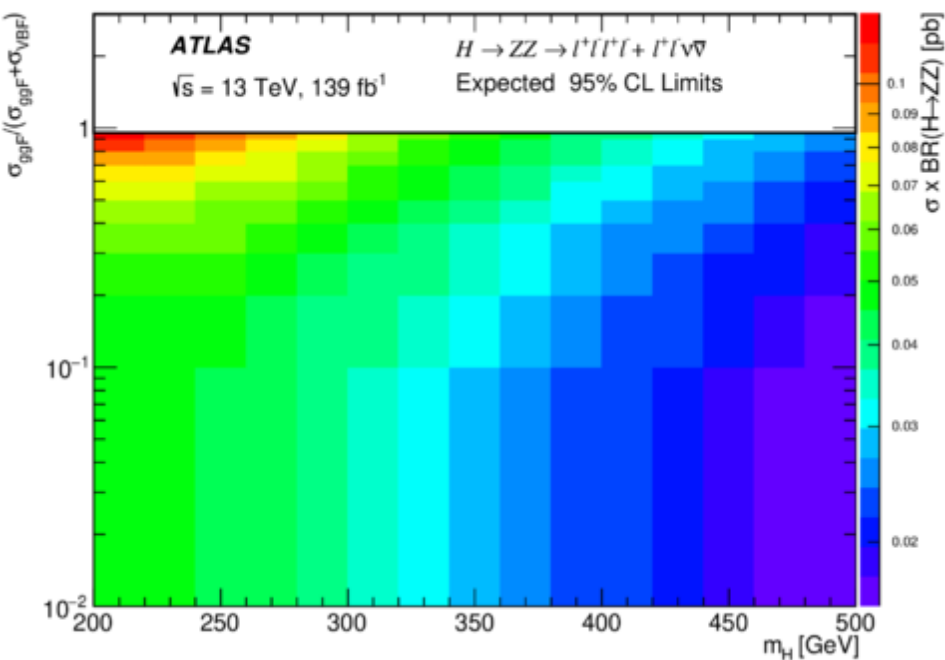


H → ZZ

New

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- Upper limits on $\sigma \times \text{BR}$ are set at the 95% CLs:
 - NWA (improvement of up to ~40% wrt previous results due to **improvements** in object performances and in the analysis):
 - 200–2.6 fb for ggF.
 - 87–1.9 fb for VBF.



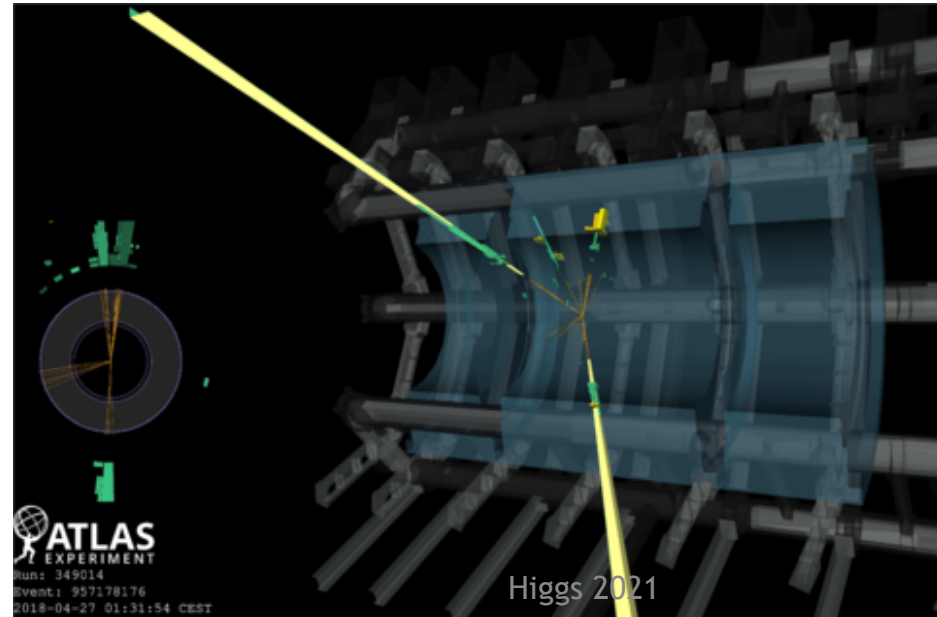
Higgs 2021

$$H \rightarrow \gamma\gamma$$

New

Phys. Lett. B 822 (2021) 136651

- Search for heavy **resonances** decaying into photon pairs using 139 fb^{-1} at 13 TeV.
- Motivation:
 - Spin 0 - extended Higgs sector.
 - Spin 2 - warped extra-dimension model.
- Require at least two photons with $E_T > 22 \text{ GeV}$ and additional $E_T/m_{\gamma\gamma} > 0.3$ (0.25) for leading (subleading) γ .
- The signal is modeled using
 - Double Sided Crystal Ball
 - Convolved with the truth line shape.
 - Breit-Wigner.



$H \rightarrow \gamma\gamma$

New

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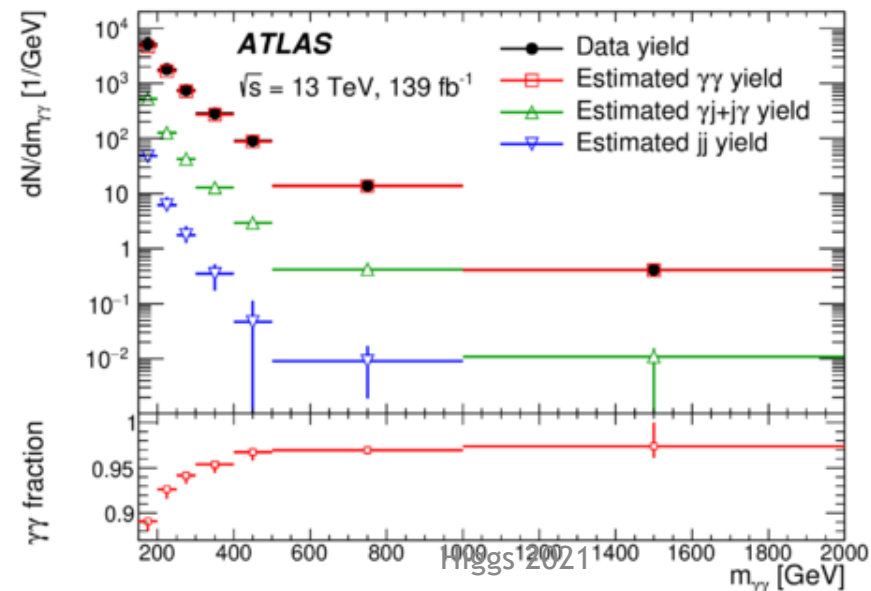
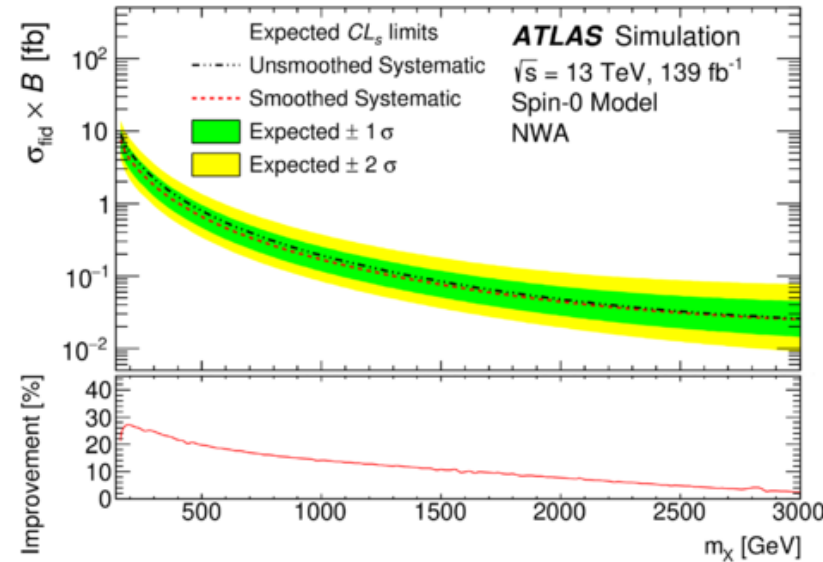
- Background estimation:
 - Irreducible ($\gamma\gamma$) from MC.
 - Reducible ($\gamma j, j\gamma, jj$) from data driven methods.
 - Mixed according to data-driven purities.
 - Fluctuations suppressed using the functional decomposition method.
- Up to 25% gain on the limit wrt using the default MC.

- Background modeling:
 - Fit range: 160-3000 GeV (spin dependent).

- Functional form:

$$f(x; b, a_0, a_1) = N(1 - x^{1/3})^b x^{a_0 + a_1 \log(x)}$$

- Uncertainty obtained using the spurious signal method.

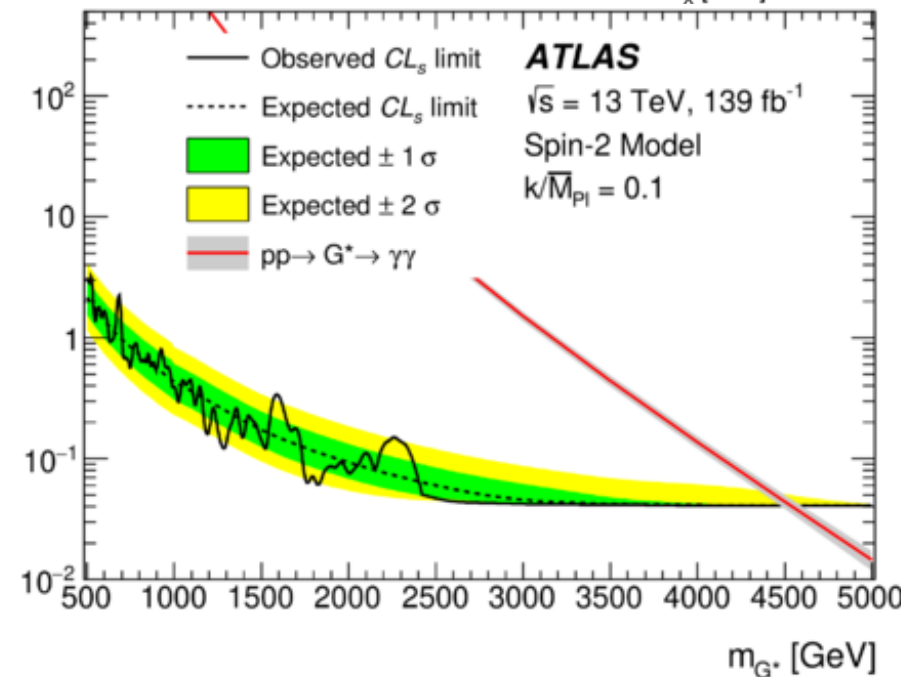
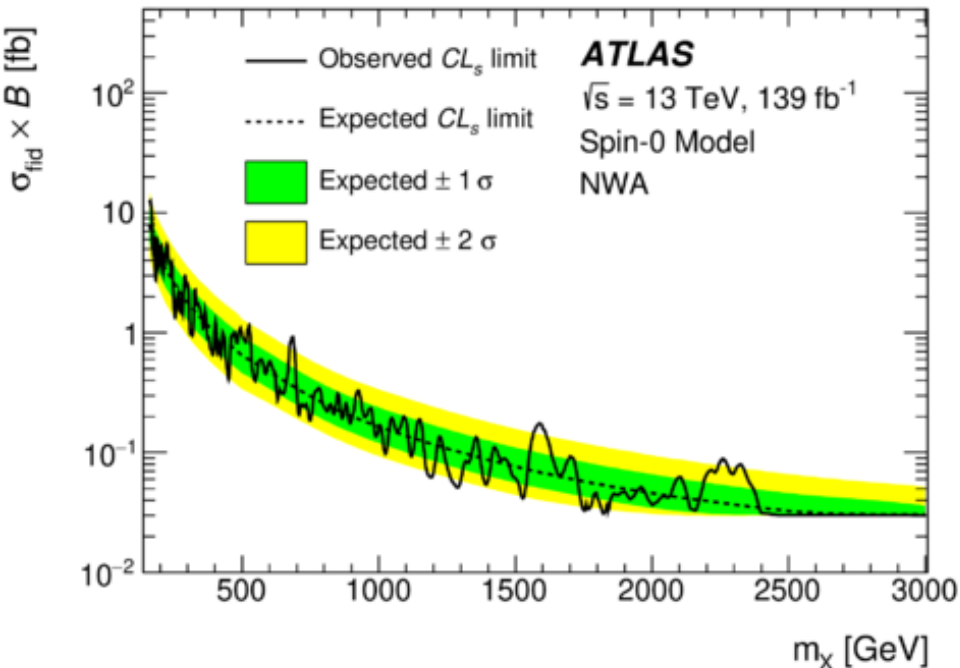
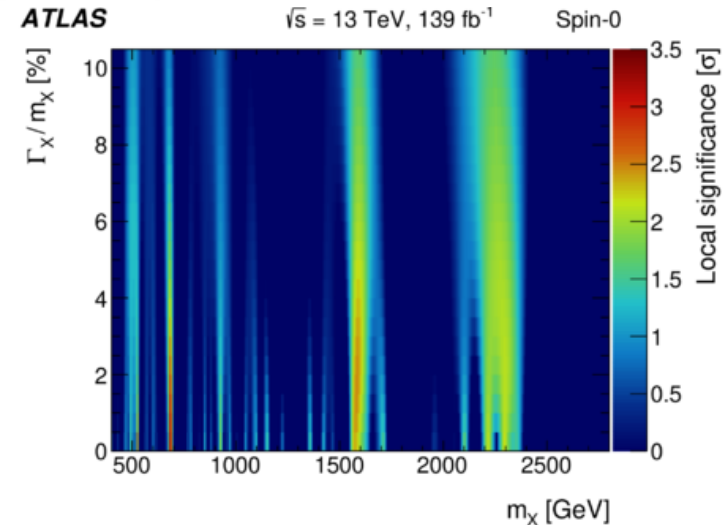


$$H \rightarrow \gamma\gamma$$

New

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- Upper limits on the fiducial $XS \cdot BR$ are set at the 95% CLs:
 - Spin 0: 12.5–0.03 fb.
 - Spin 2: 3.2–0.04 fb.
- Highest local (global) is 3.29σ (1.36) at $m = 684$ GeV.



$$H \rightarrow \gamma\gamma$$

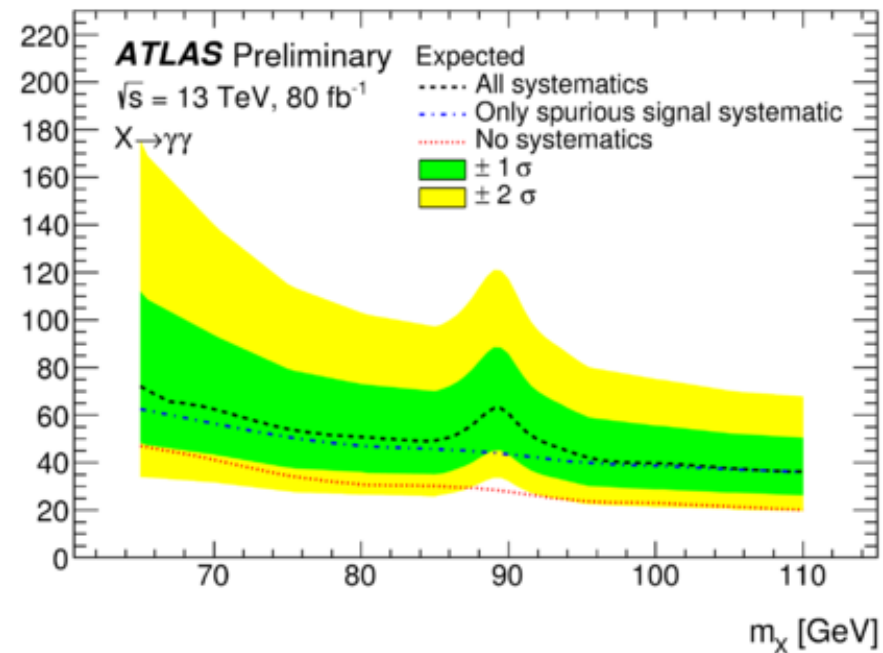
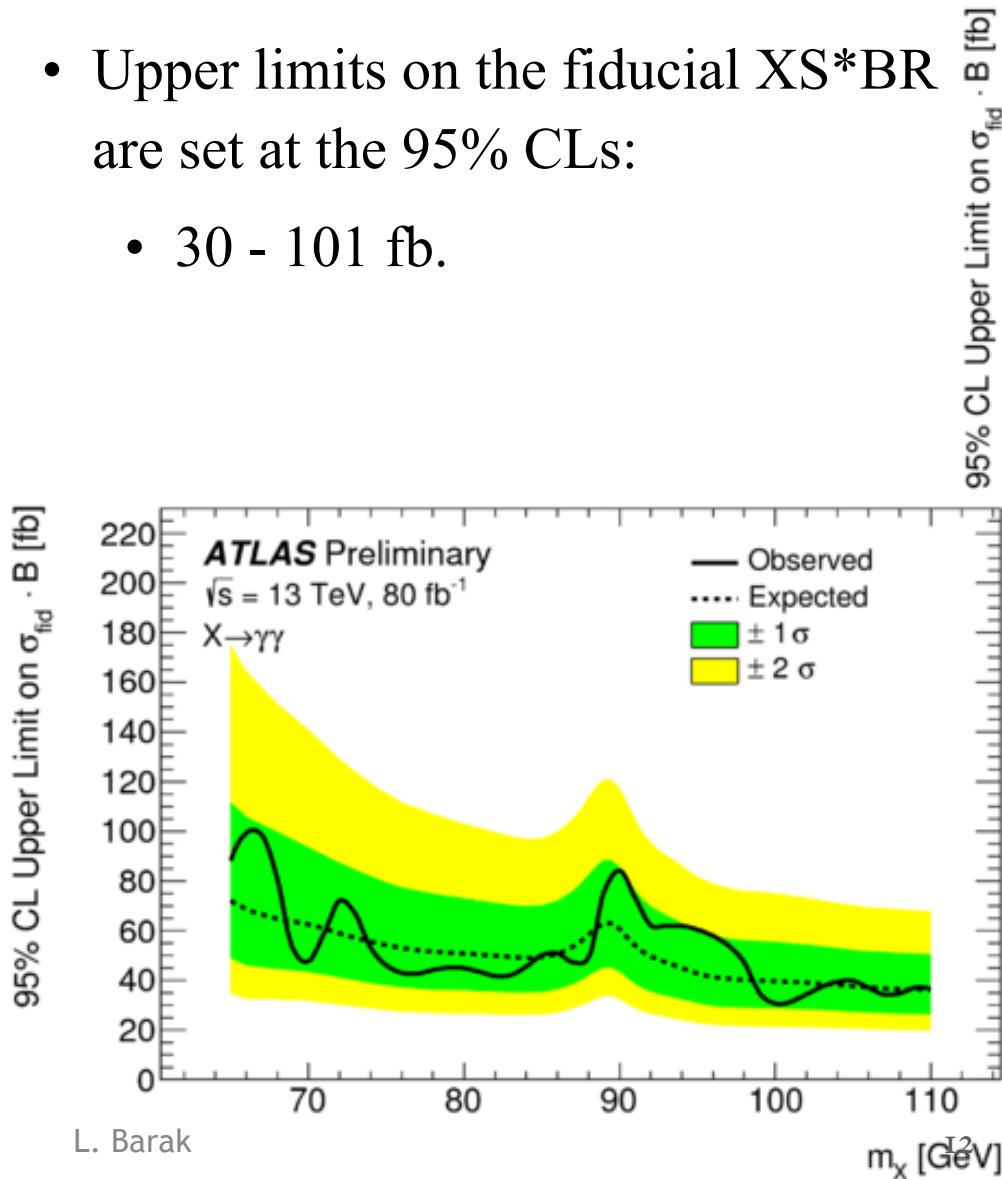
ATLAS-CONF-2018-025

- **Search for low-mass resonance decaying into photon pairs using 80 fb⁻¹ at 13 TeV.**
- Mass range: 65 - 110 GeV.
- Additional features:
 - Another background: Drell-Yan originates from $Z/\gamma^* \rightarrow e^+e^-$ with electrons faking photons.
 - Shape and normalization constrained using a data-driven measurement of $e \rightarrow \gamma$ events in $Z \rightarrow ee$ decays.
 - Categories based on the photon reconstruction: both unconverted (UU), one converted and one unconverted (CU) or both converted (CC).
- Background estimation:
 - Both the non-resonant continuum and the resonant DY are estimated separately in each category.
 - The continuum is fitted on data, with the normalization and function parameters free, while for the DY both shape and normalization are fitted but constrained by control regions.

$H \rightarrow \gamma\gamma$

ATLAS-CONF-2018-025

- Upper limits on the fiducial $XS \cdot BR$ are set at the 95% CLs:
 - 30 - 101 fb.



H → WW

Eur. Phys. J. C 78 (2018) 24

- **Search for heavy resonances decaying into WW in the $e\nu\mu\nu$ final state using 36.1 fb^{-1} at 13 TeV.**
- Many channels:
 - Productions: gluon-gluon fusion and vector-boson-fusion.
 - Width assumptions: narrow-width approximation and large-width assumption.
 - Spins: 0 (2HDM, GM), 1 (HVT) and 2 (Randall–Sundrum, ELM).
- Mass range: 200-5000 GeV.
- Discriminating variable:

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{\text{miss}}|^2},$$

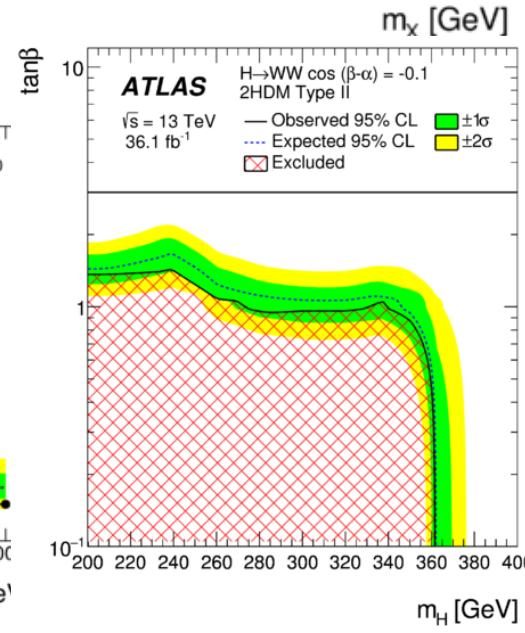
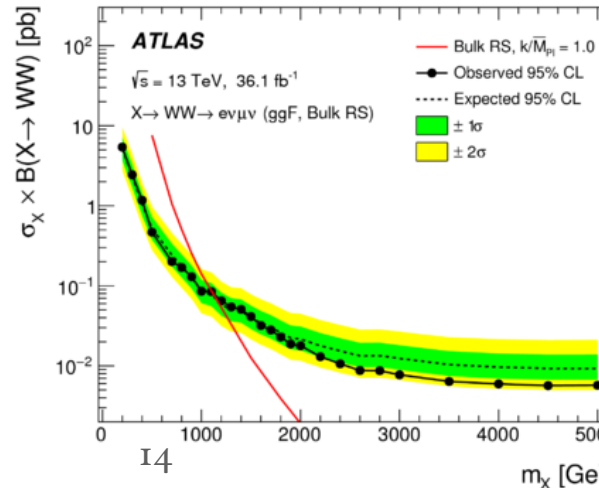
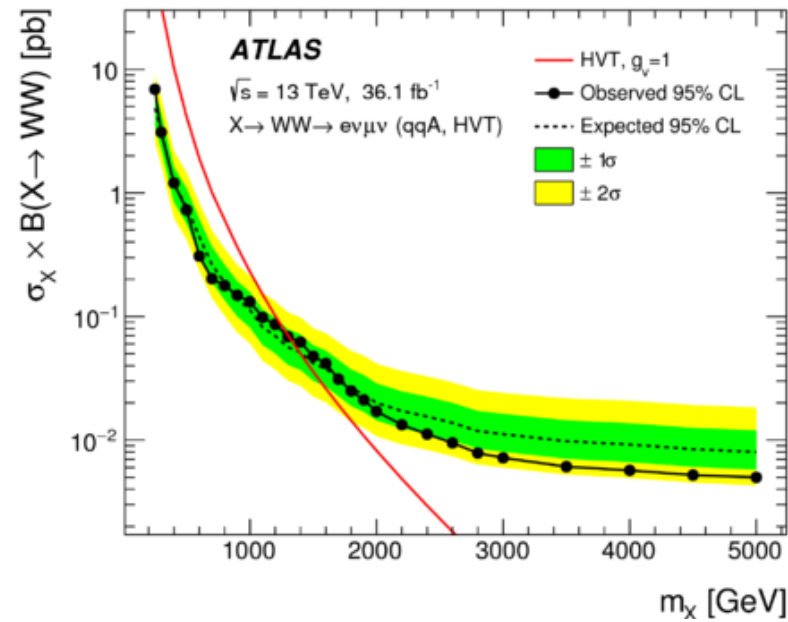
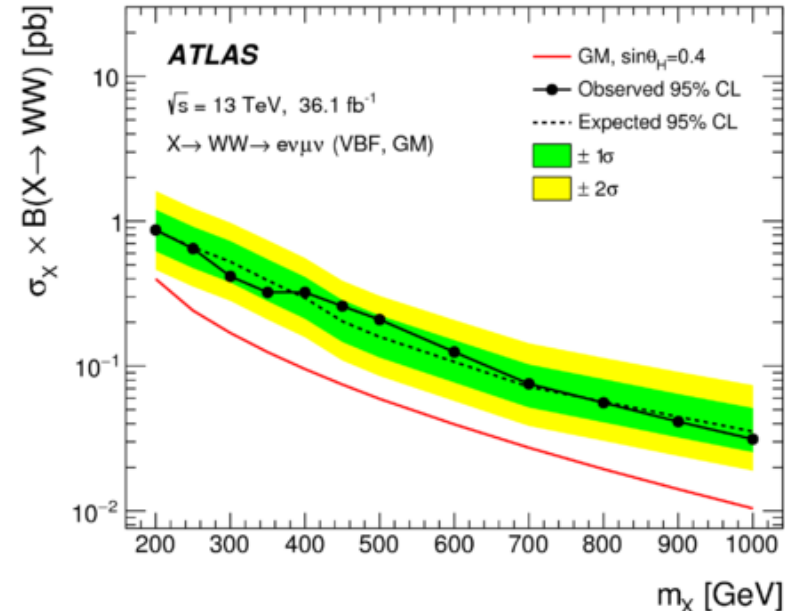
Where $E_T^{\ell\ell} = \sqrt{|\mathbf{p}_T^{\ell\ell}|^2 + m_{\ell\ell}^2}$

Model	Resonance spin	Production mode		
		ggF	qqA	VBF
NWA	Spin-0	x		x
2HDM		x		x
LWA		x		x
GM				x
HVT	Spin-1		x	x
Bulk RS	Spin-2	x		
ELM				x

H → WW

Eur. Phys. J. C 78 (2018) 24

- Dominant BGs: non resonant VV and V+jets.
- Upper limits on $\sigma_X \times \text{BR}$ are set at the 95% CLs:
 - NWA:
 - 6.4–0.008 pb for ggF.
 - 1.3–0.006 pb for VBF.



Summary

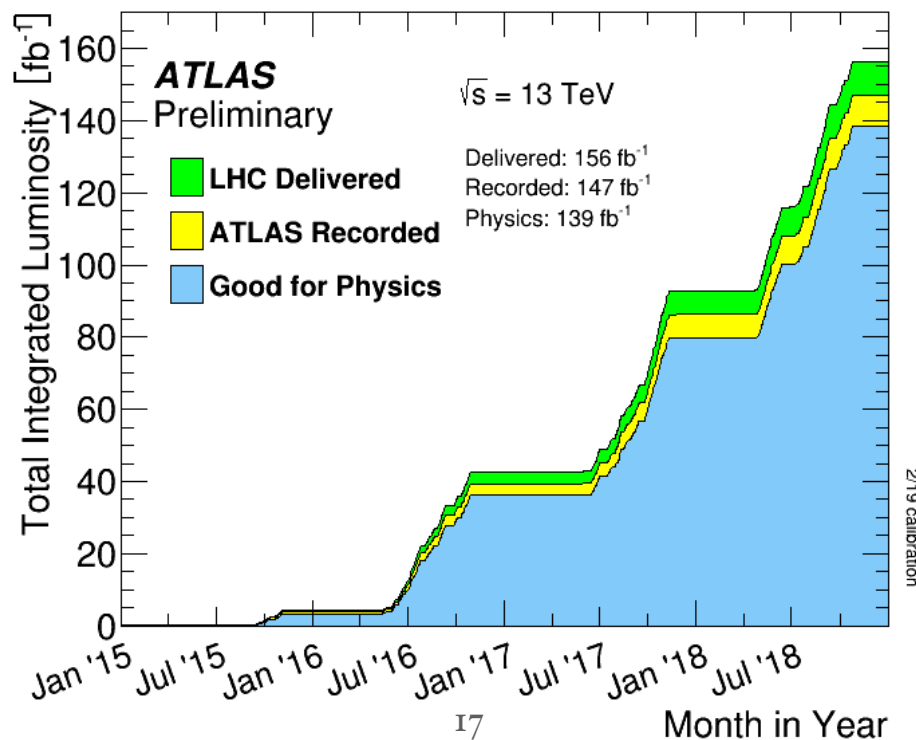
- ATLAS is searching for a new physics in various production and decay modes, under different spin assumptions.
- Unfortunately, no significant deviation from the SM prediction has been observed.
- Many more exciting results to come using the full Run 2 dataset.



**THANK YOU
FOR YOUR ATTENTION**

The LHC

- Run 2 is over with more than 150 fb⁻¹ of data delivered during 2015-2018.
 - Almost 140 fb⁻¹ are good for physics.



H → WW

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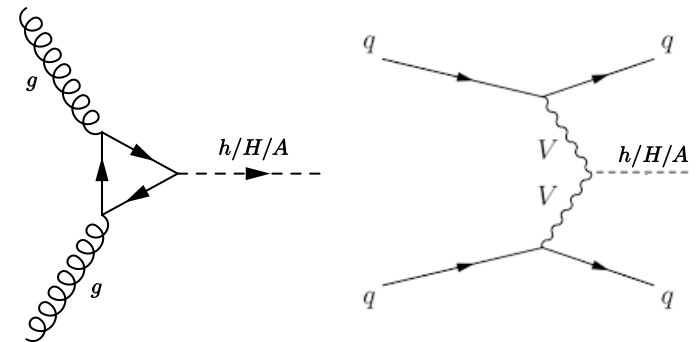
- **Search for heavy resonances decaying into WW in the $e\nu\mu\nu$ final state using 36.1 fb^{-1} at 13 TeV.**

SR _{ggF}	SR _{VBF1J}	SR _{VBF2J}
Common selections		
$N_{b\text{-tag}} = 0$ $ \Delta\eta_{\ell\ell} < 1.8$ $m_{\ell\ell} > 55 \text{ GeV}$ $p_{\text{T}}^{\ell,\text{lead}} > 45 \text{ GeV}$ $p_{\text{T}}^{\ell,\text{sublead}} > 30 \text{ GeV}$ veto if $p_{\text{T}}^{\ell,\text{other}} > 15 \text{ GeV}$ $\max(m_{\text{T}}^{\text{W}}) > 50 \text{ GeV}$		
ggF phase space	VBF1J phase space	VBF2J phase space
Inclusive in N_{jet} but excluding VBF1J and VBF2J phase space	$N_{\text{jet}} = 1$ and $ \eta_j > 2.4, \min(\Delta\eta_{j\ell}) > 1.75$	$N_{\text{jet}} \geq 2$ and $m_{jj} > 500 \text{ GeV}, \Delta y_{jj} > 4$

SUMMARY SLIDES

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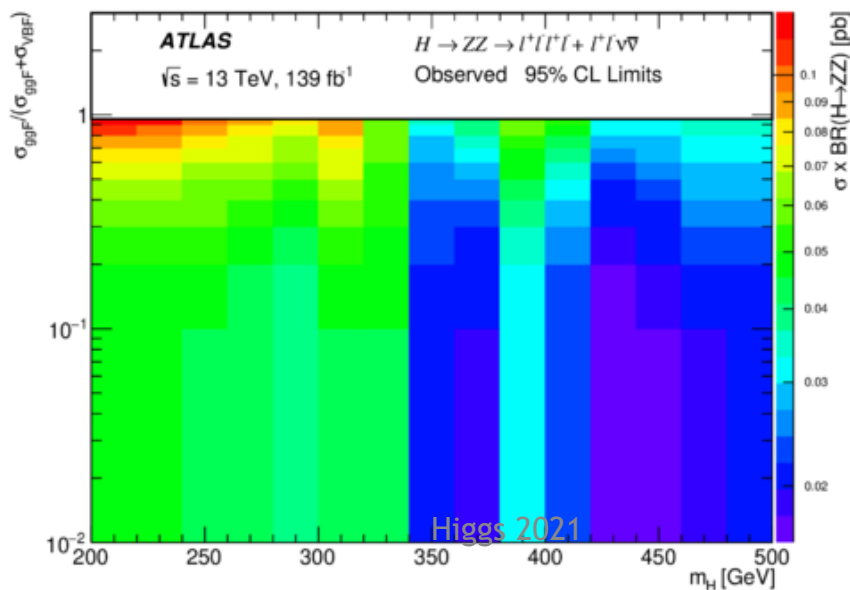
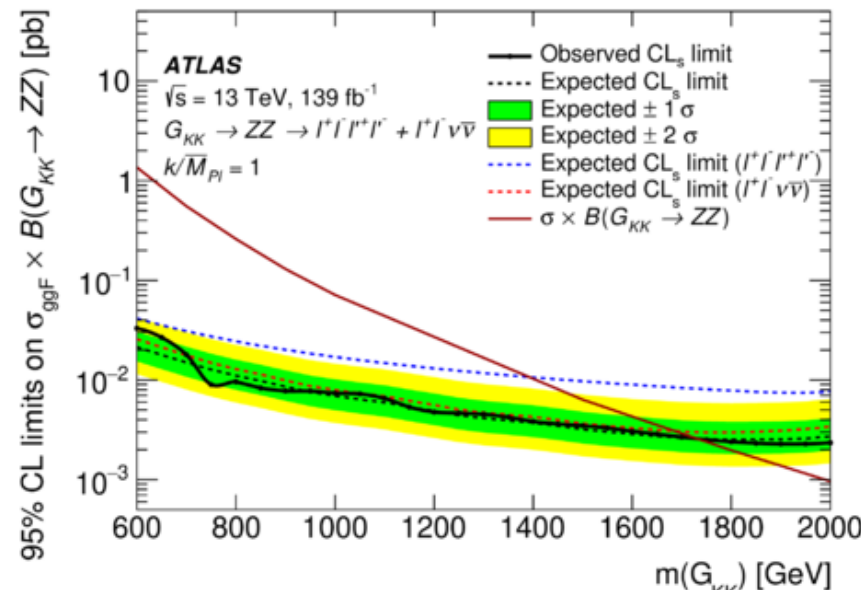
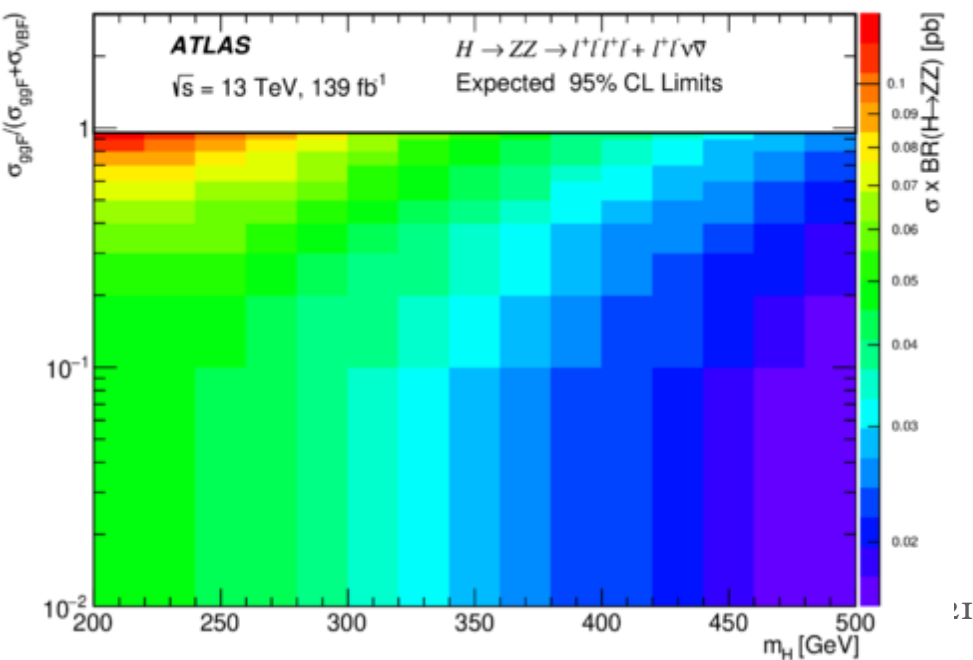


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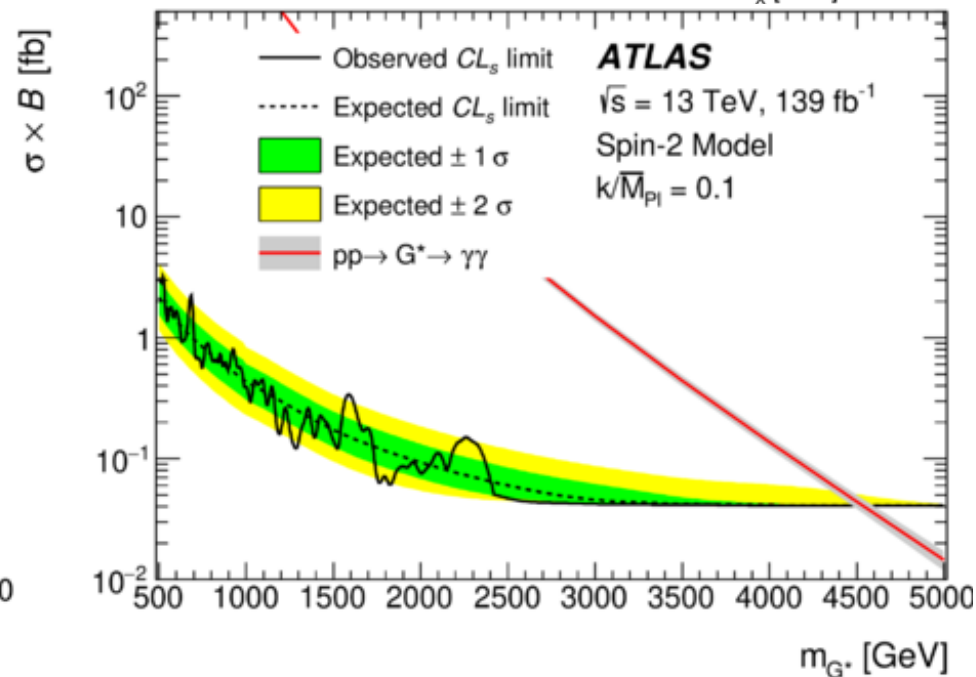
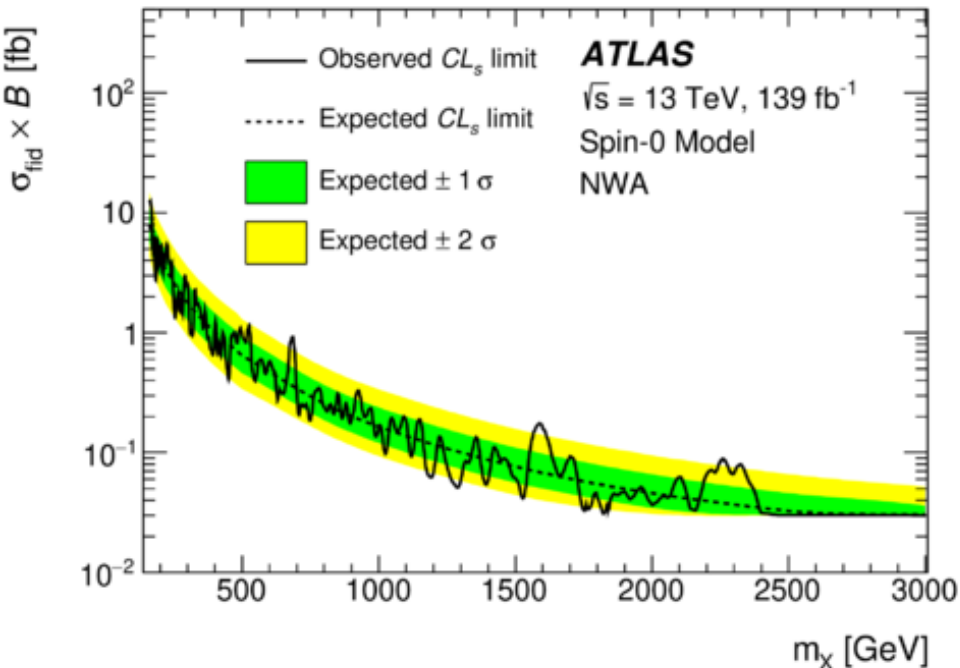
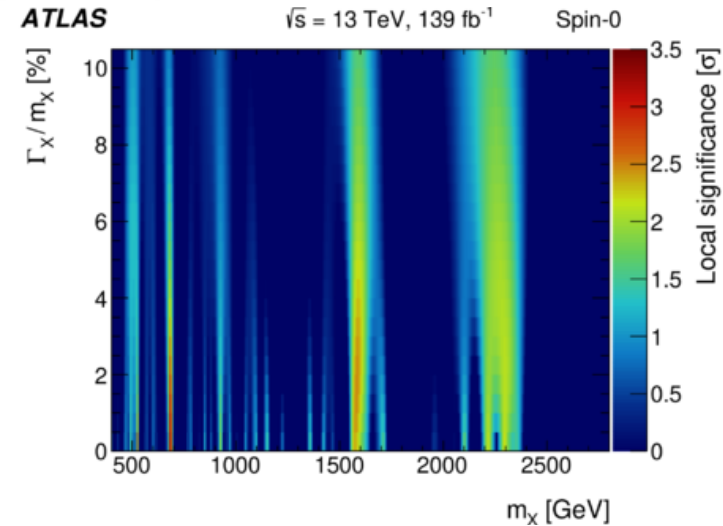
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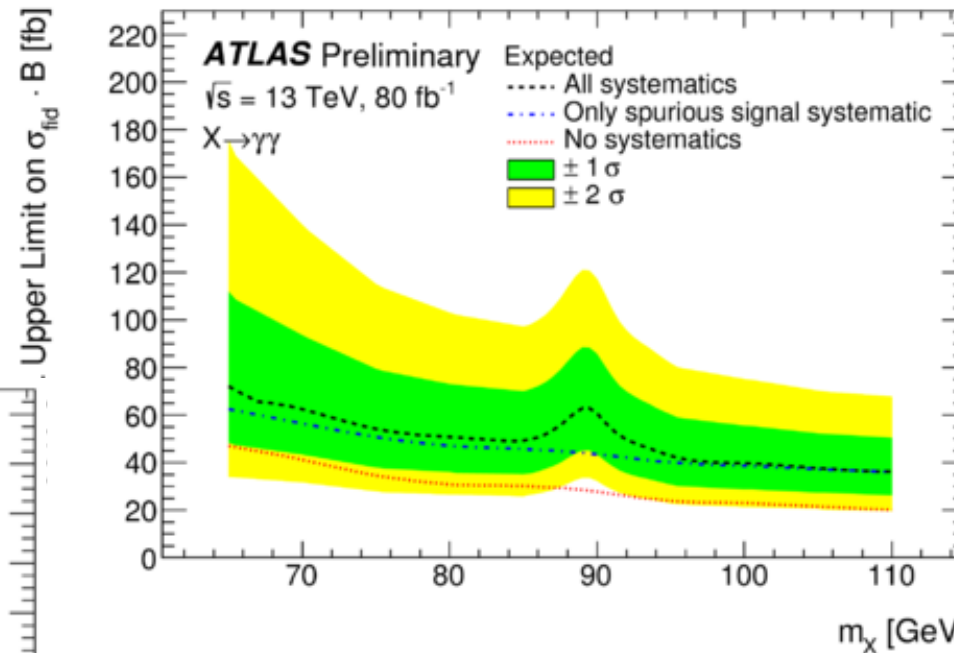
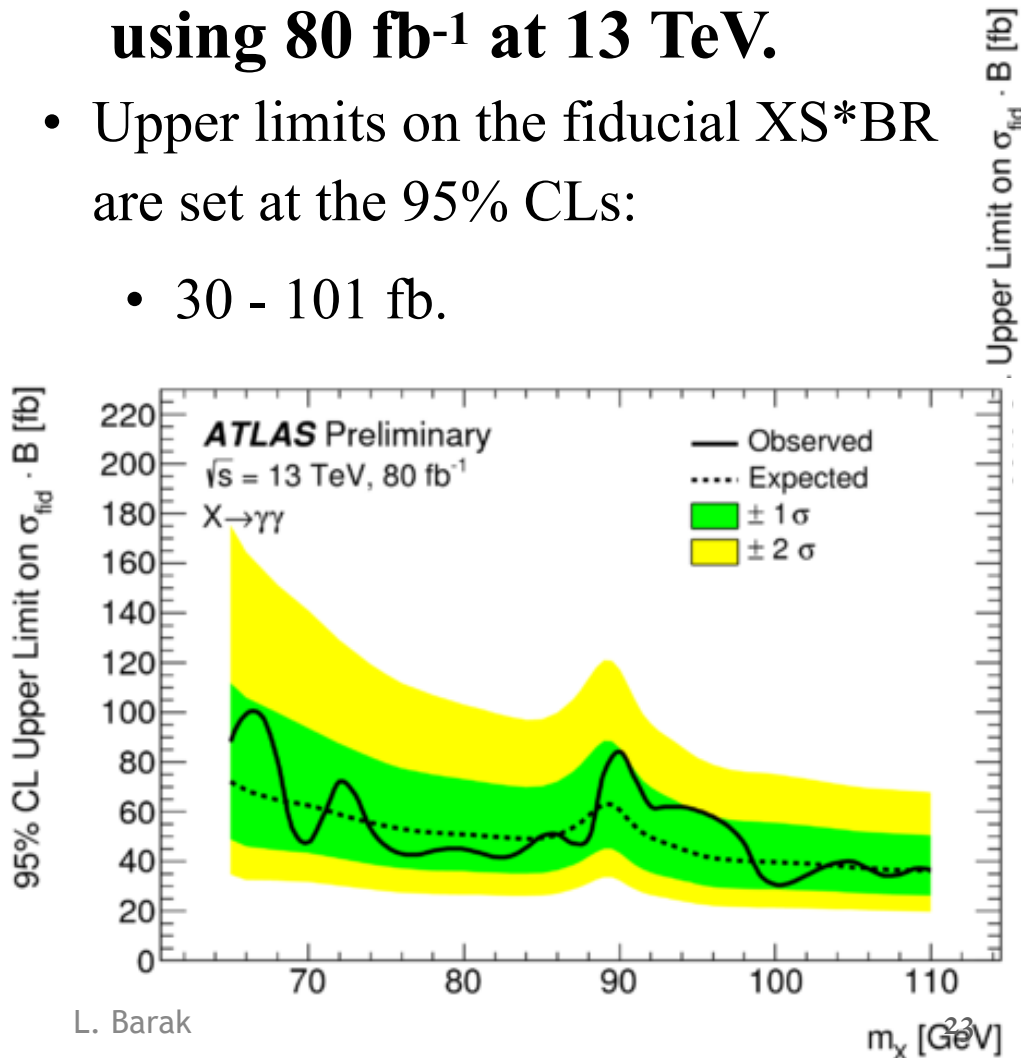
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		x		x
				x
HVT	Spin-1		x	x
Bulk RS ELM	Spin-2	x		
				x

