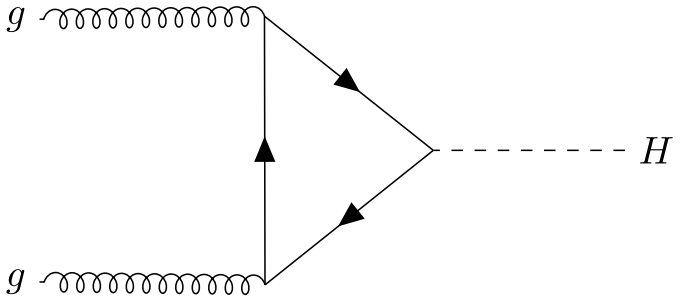
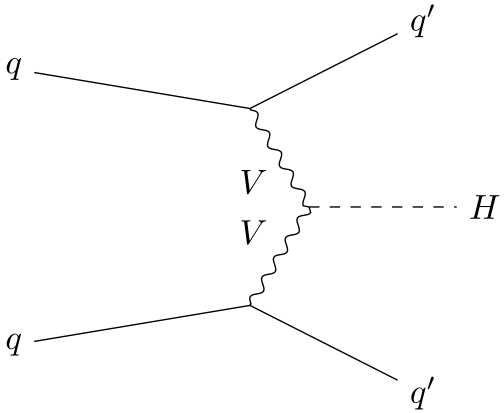
Measurements of Higgs boson production by gluon–gluon fusion and vector-boson fusion using $H \to WW^* \to e\nu\mu\nu$ decays in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

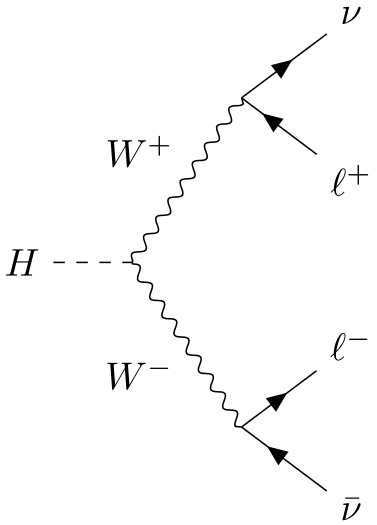
Alexander Gavrilyuk

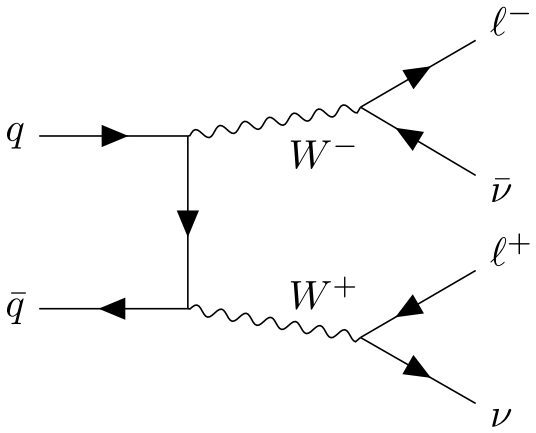
arXiv:2207.00338v1, submitted to: Phys. Rev. D

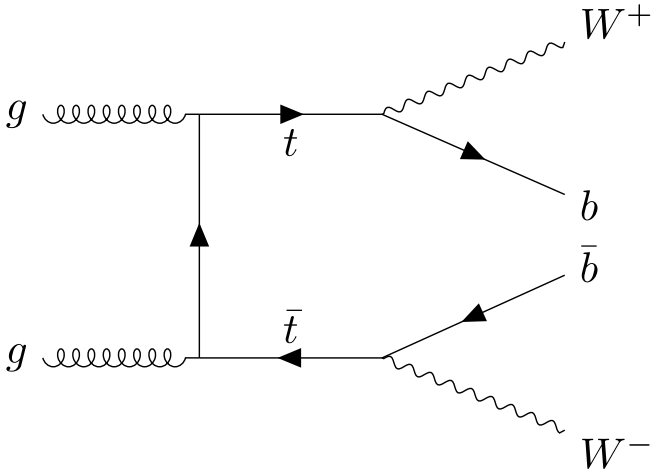
Signal and main background processes

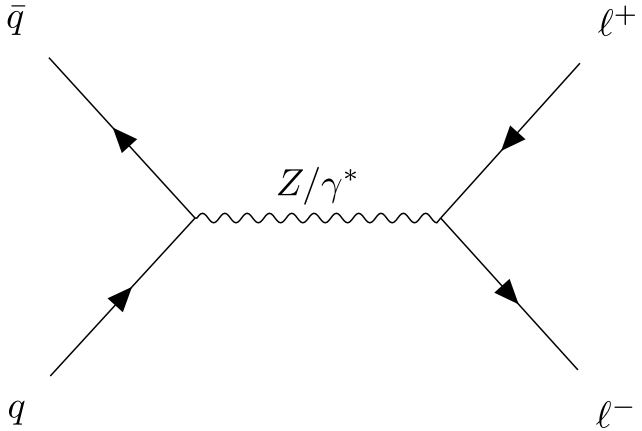








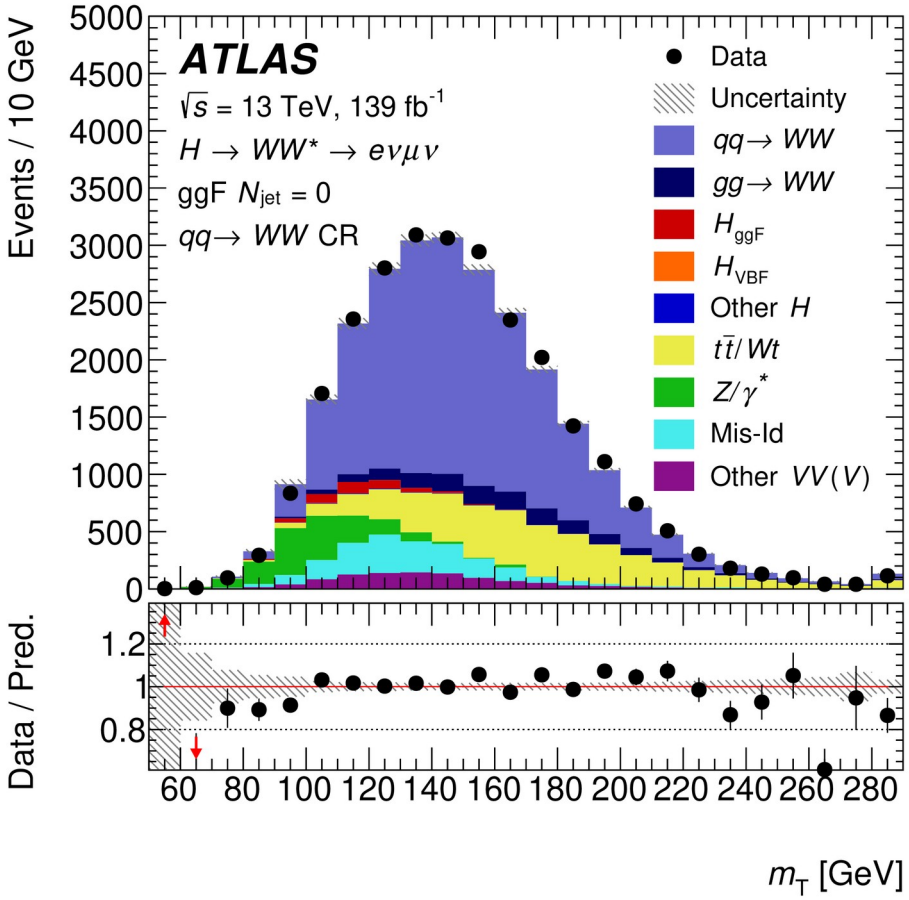


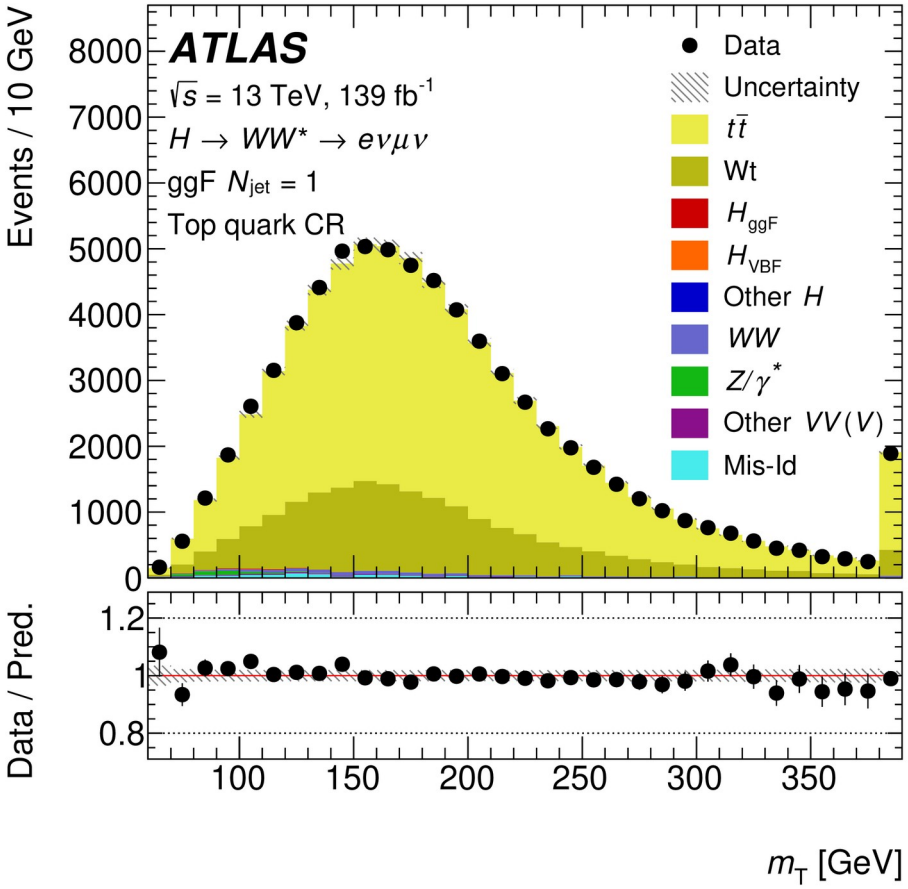


Event selection

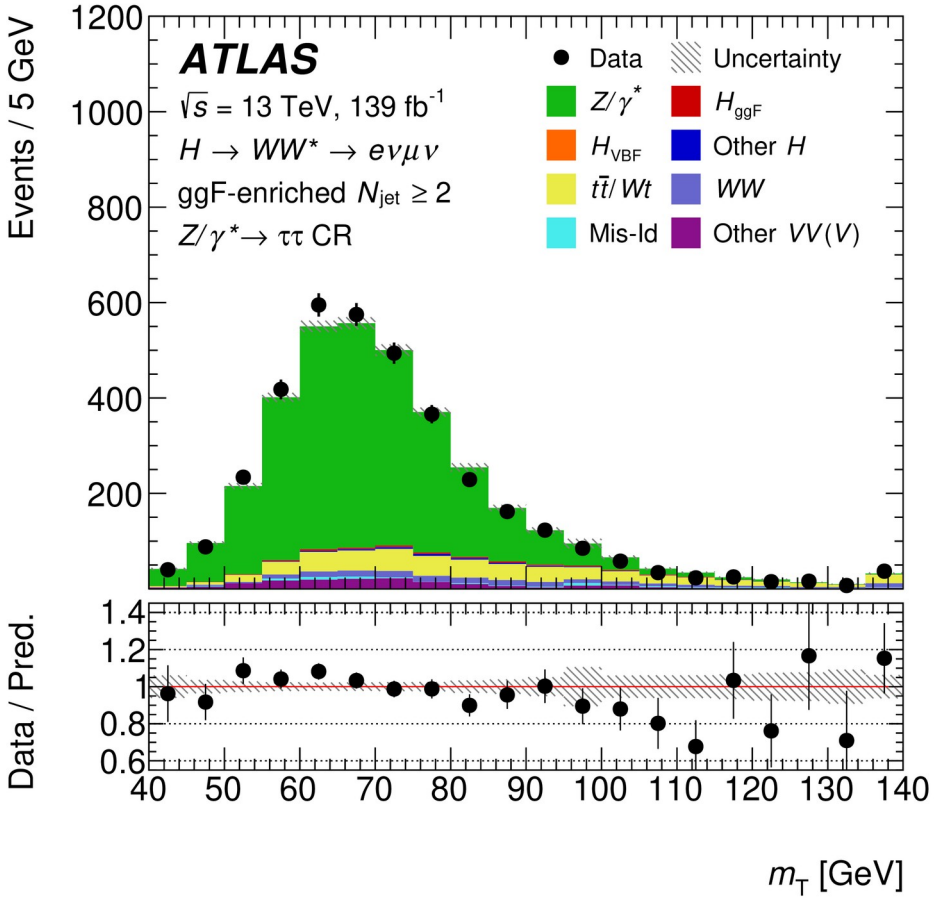
<table>
<tr><th>Category</th><th>$N_{\text{jet},(p_T>30\text{ GeV})} = 0$ ggF</th><th>$N_{\text{jet},(p_T>30\text{ GeV})} = 1$ ggF</th><th>$N_{\text{jet},(p_T>30\text{ GeV})} \geq 2$ ggF</th><th>$N_{\text{jet},(p_T>30\text{ GeV})} \geq 2$ VBF</th></tr>
<tr><td rowspan="2">Preselection</td><td colspan="3">Two isolated, different-flavor leptons ($\ell = e, \mu$) with opposite charge
$p_T^{\text{lead}} > 22$ GeV , $p_T^{\text{sublead}} > 15$ GeV
$m_{\ell\ell} > 10$ GeV</td><td></td></tr>
<tr><td colspan="3">$p_T^{\text{miss}} > 20$ GeV</td><td></td></tr>
<tr><td rowspan="3">Background rejection</td><td colspan="4">$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$</td></tr>
<tr><td rowspan="2">$\Delta\phi_{\ell\ell,E_T^{\text{miss}}} > \pi/2$
$p_T^{\ell\ell} > 30$ GeV</td><td colspan="3">$m_{\tau\tau} < m_Z - 25$ GeV</td></tr>
<tr><td>max $(m_T^{\ell}) > 50$ GeV</td><td></td></tr>
<tr><td rowspan="3">$H \to WW^* \to e\nu\mu\nu$
topology</td><td colspan="3">$m_{\ell\ell} < 55$ GeV
$\Delta\phi_{\ell\ell} < 1.8$</td><td rowspan="3">central jet veto
outside lepton veto
$m_{jj} > 120$ GeV</td></tr>
<tr><td colspan="2"></td><td>fail central jet veto
or
fail outside lepton veto</td></tr>
<tr><td colspan="2"></td><td>$|m_{jj} - 85| > 15$ GeV
or
$\Delta y_{jj} > 1.2$</td></tr>
<tr><td>Discriminating fit variable</td><td colspan="3">m_T</td><td>DNN</td></tr>
</table>

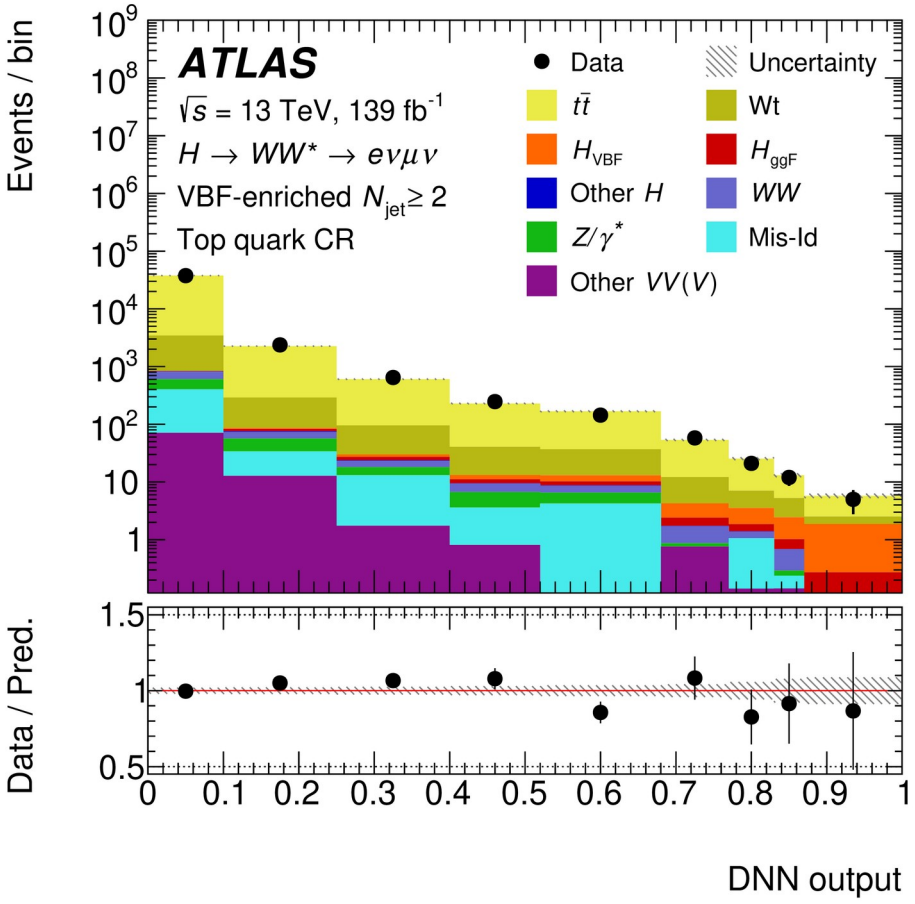
Control Regions for the most interesting background, 0/1 jet



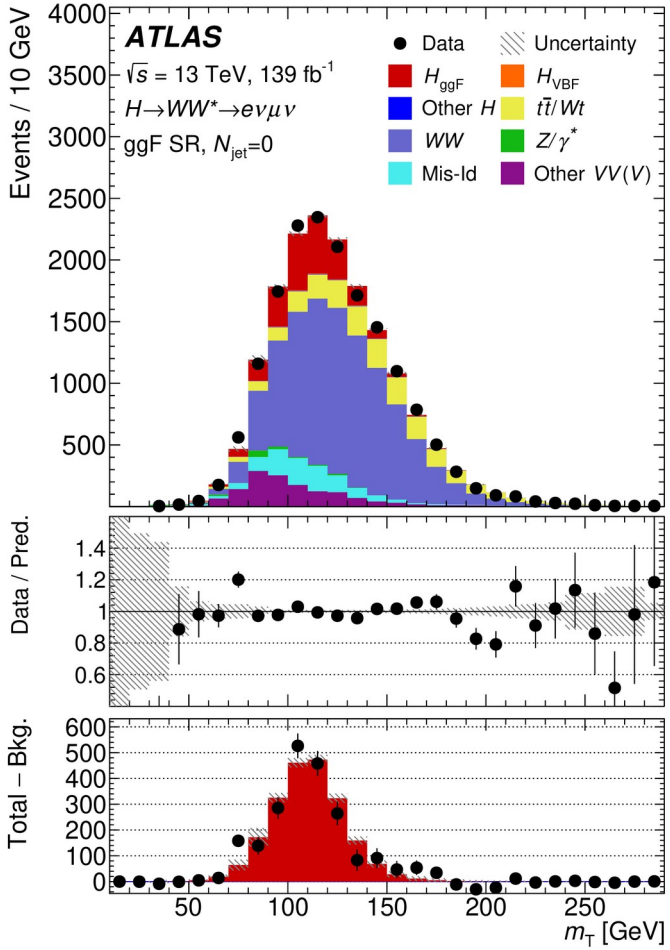


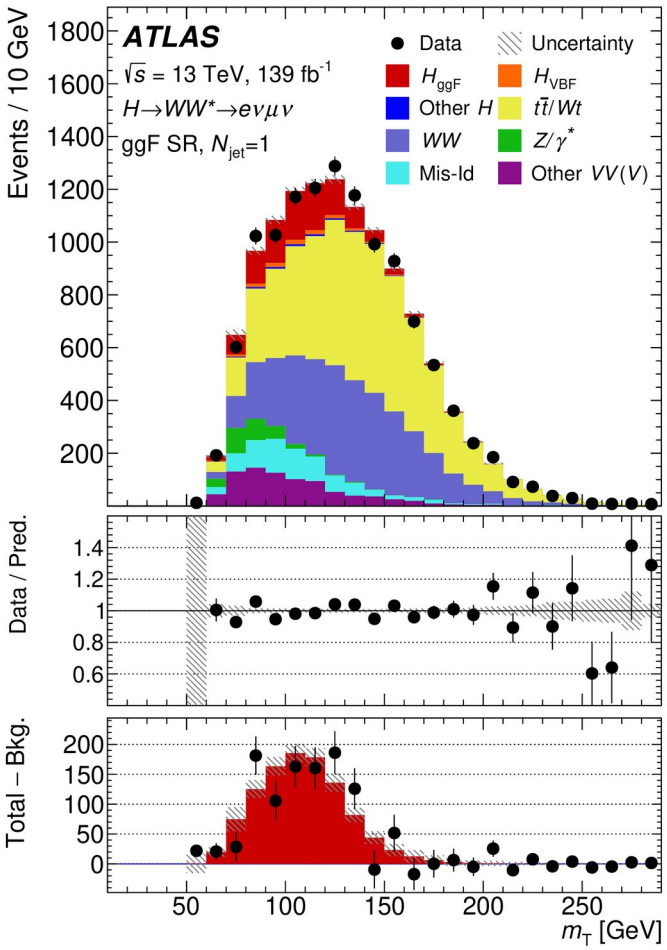
Control Regions for the most interesting background, 2 jets



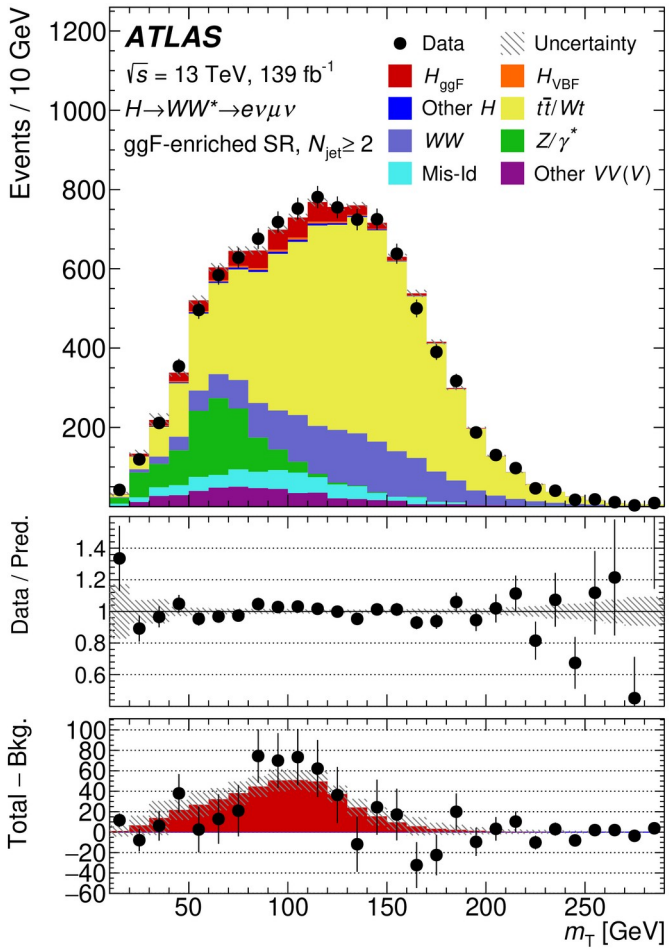


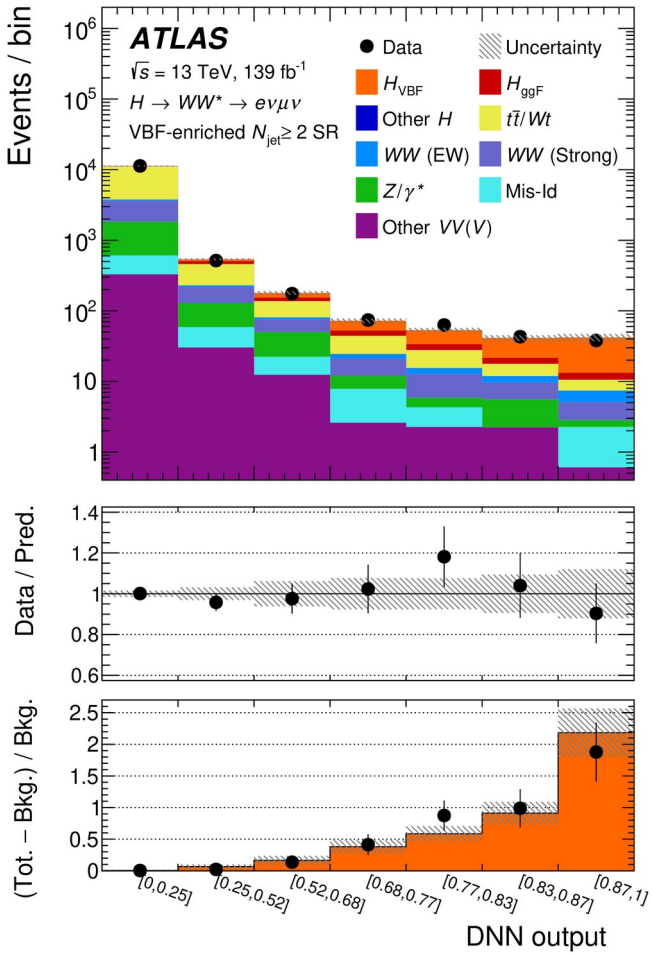
Ggf 0Jet, 1 Jet Signal Regions



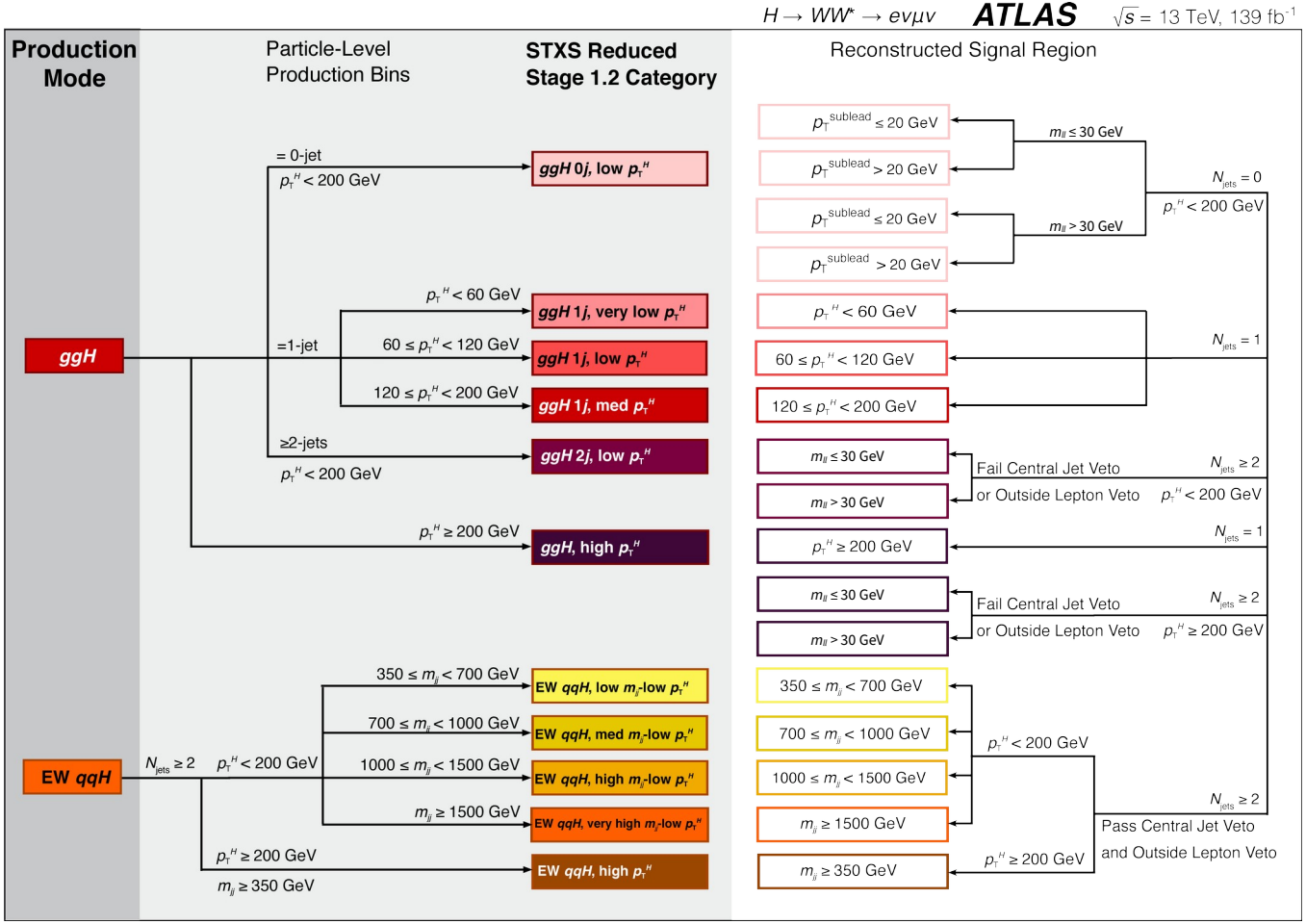


2jet ggF, VBF Signal Regions



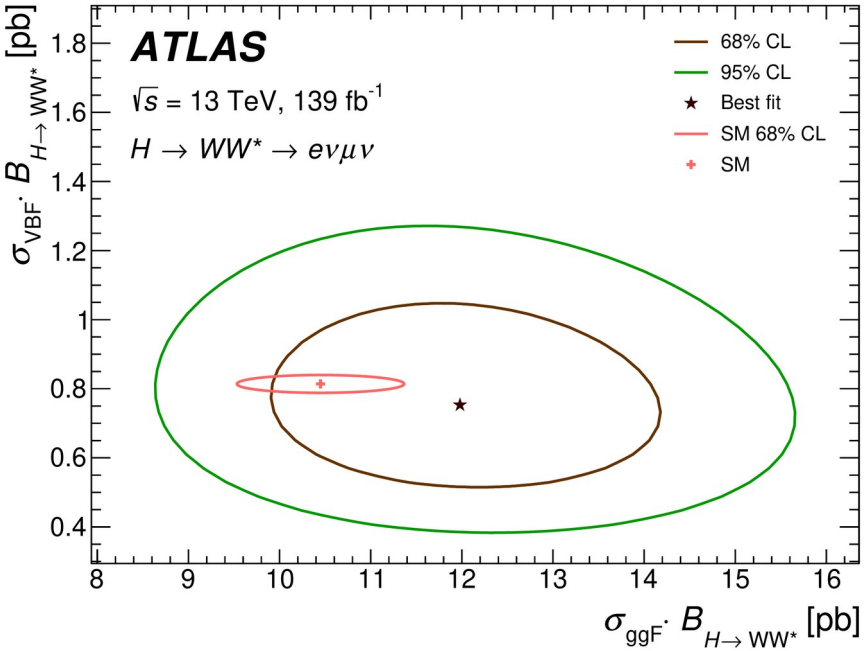


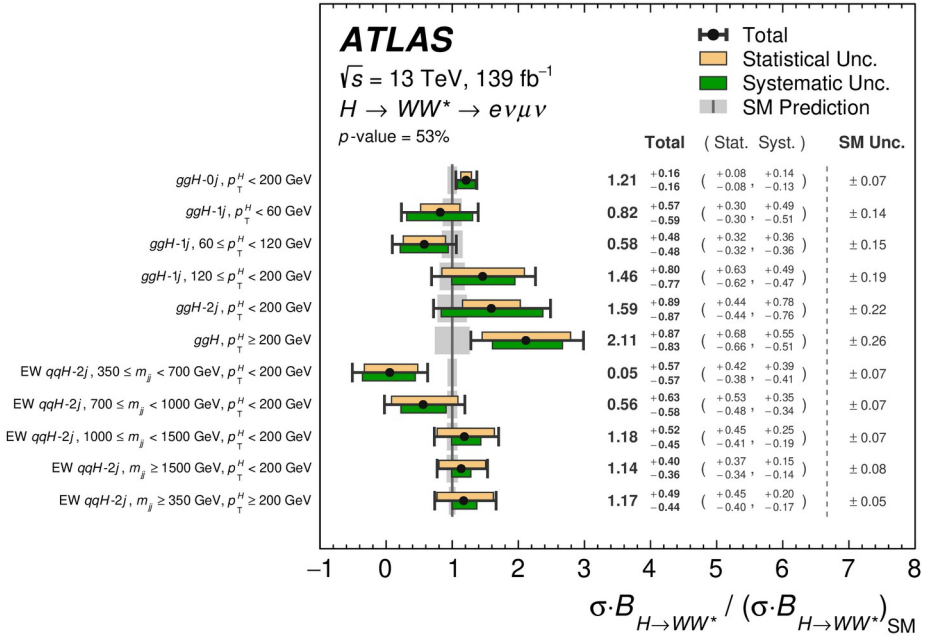
(Reduced) STXS Stage 1.2



Each SR and corresponding CR is further divided providing independent XS measurements in kinematically different sub-regions

Measured ggF and VBF cross-sections, total and STXS





$$\sigma_{\text{ggF+VBF}} \cdot \mathcal{B}_{H\to WW^*} = 12.3 \pm 1.3 \text{ pb}$$

$$= 12.3 \pm 0.6\ (\text{stat.})\ ^{+0.8}_{-0.7}\ (\text{exp. syst.})\ \pm 0.6\ (\text{sig. theo.})\ \pm 0.7\ (\text{bkg. theo.})\ \text{pb},$$

compared to the SM predicted value of 11.3 ± 0.5 pb.

Result summary

- **ATLAS 36 fb^{-1}** $\mu_{ggF} = 1.10^{+0.21}_{-0.20}$ $\mu_{VBF} = 0.62^{+0.36}_{-0.35}$

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- **ATLAS 139 fb^{-1}** $\mu_{ggF} = 1.15^{+0.14}_{-0.13}$ $\mu_{VBF} = 0.93^{+0.23}_{-0.20}$

  Current

- **CMS 138 fb^{-1}** $\mu_{ggF} = 0.92^{+0.11}_{-0.10}$ $\mu_{VBF} = 0.71^{+0.28}_{-0.25}$

  arXiv:2206.09466, JHEP03(2021)003

backup

Event selections for Control Regions

CR	$N_{\text{jet},(p_T>30\text{ GeV})} = 0$ ggF	$N_{\text{jet},(p_T>30\text{ GeV})} = 1$ ggF	$N_{\text{jet},(p_T>30\text{ GeV})} \geq 2$ ggF	$N_{\text{jet},(p_T>30\text{ GeV})} \geq 2$ VBF
$qq \to WW$	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$			
	$\Delta\phi_{\ell\ell,E_T^{miss}} > \pi/2$ $p_T^{\ell\ell} > 30$ GeV $55 < m_{\ell\ell} < 110$ GeV $\Delta\phi_{\ell\ell} < 2.6$	$m_{\ell\ell} > 80$ GeV		
		$\lvert m_{\tau\tau} - m_Z \rvert > 25$ GeV $\max(m_T^{\ell}) > 50$ GeV	$m_{\tau\tau} < m_Z - 25$ GeV $m_{T2} > 165$ GeV	
			fail central jet veto or fail outside lepton veto	
			$\lvert m_{jj} - 85 \rvert > 15$ GeV or $\Delta y_{jj} > 1.2$	
$t\bar{t}/Wt$	$N_{b\text{-jet},(20<p_T<30\text{ GeV})} > 0$ $\Delta\phi_{\ell\ell,E_T^{miss}} > \pi/2$ $p_T^{\ell\ell} > 30$ GeV $\Delta\phi_{\ell\ell} < 2.8$	$N_{b\text{-jet},(p_T>30\text{ GeV})} = 1$ $N_{b\text{-jet},(20<p_T<30\text{ GeV})} = 0$	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 1$
		$m_{\tau\tau} < m_Z - 25$ GeV		
		$\max(m_T^{\ell}) > 50$ GeV	$m_{\ell\ell} > 80$ GeV $\Delta\phi_{\ell\ell} < 1.8$ $m_{T2} < 165$ GeV	
			fail central jet veto or fail outside lepton veto	central jet veto outside lepton veto
			$\lvert m_{jj} - 85 \rvert > 15$ GeV or $\Delta y_{jj} > 1.2$	
Z/γ^*	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$			
	$m_{\ell\ell} < 80$ GeV no p_T^{miss} requirement		$m_{\ell\ell} < 55$ GeV	$m_{\ell\ell} < 70$ GeV
	$\Delta\phi_{\ell\ell} > 2.8$	$m_{\tau\tau} > m_Z - 25$ GeV		$\lvert m_{\tau\tau} - m_Z \rvert \leq 25$ GeV central jet veto outside lepton veto
		$\max(m_T^{\ell}) > 50$ GeV	fail central jet veto or fail outside lepton veto	
			$\lvert m_{jj} - 85 \rvert > 15$ GeV or $\Delta y_{jj} > 1.2$	

MT2 definition

$$m_{\mathrm{T2}}^2 = \min_{\not{p}_1+\not{p}_2=\not{p}_{\mathrm{T}}} \left[\max\{m_{\mathrm{T}}^2(p_{\mathrm{T}}^a, \not{p}_1), m_{\mathrm{T}}^2(p_{\mathrm{T}}^b, \not{p}_2)\}\right]$$

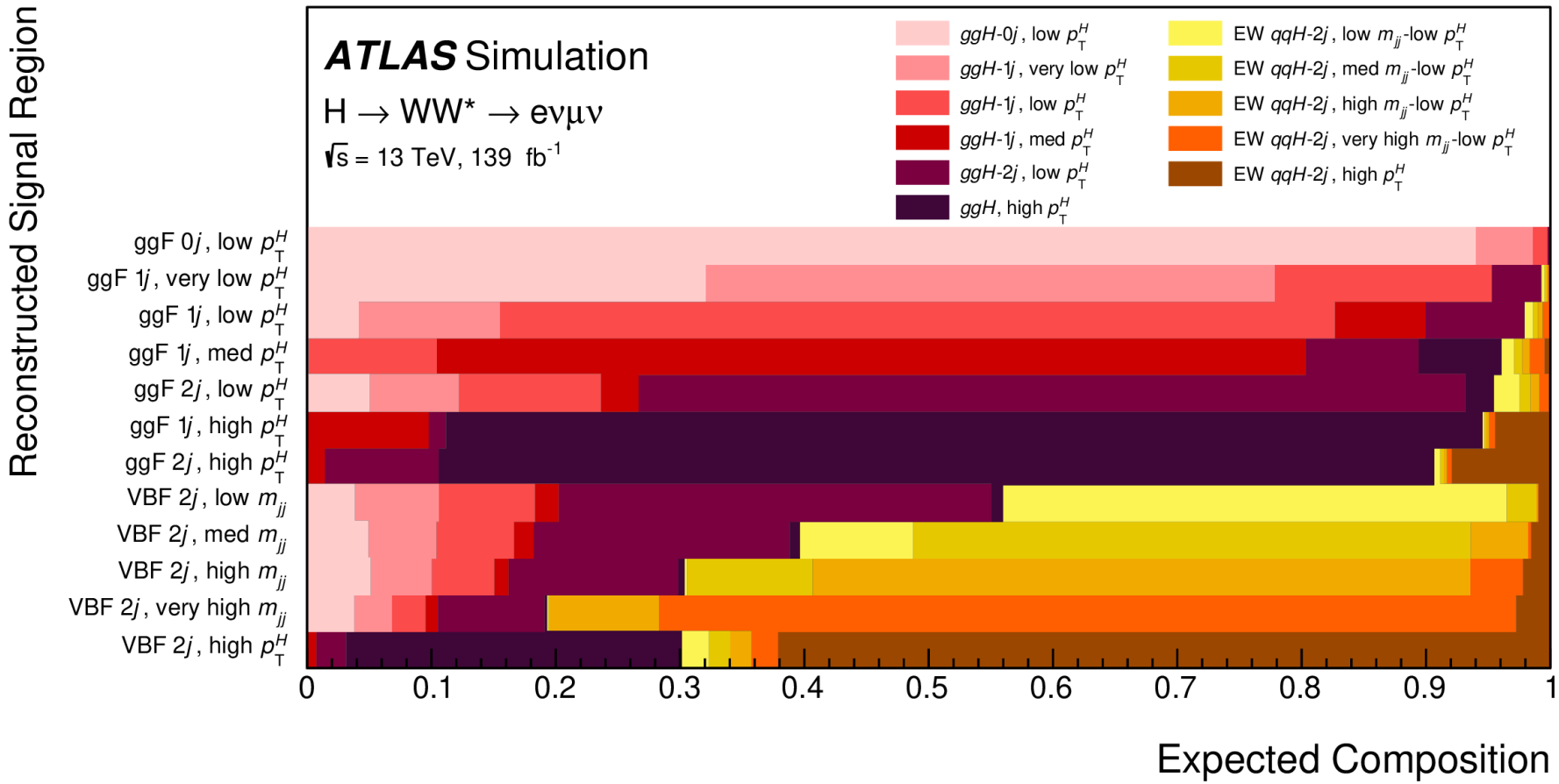
where the minimization is over all possible two-momenta, $\bar{p}_{1,2}$, such that their sum gives the observed missing transverse momentum $\bar{p}_T$, and where each of p_T^a and p_T^b is the combined transverse momentum of a charged lepton and a jet.

- $m^2_{T2} \leq m^2_W$ (decay of a pair of W each with a single invisible particle)
- $m^2_T \leq m^2_W$ (decay with single invisible particle)

Yields in SRs

Process	$N_{jet} = 0$ ggF	$N_{jet} = 1$ ggF	$N_{jet} \geq 2$ ggF	$N_{jet} \geq 2$ VBF Inclusive	$N_{jet} \geq 2$ VBF DNN: [0.87, 1.0]
H_{ggF}	2100 ± 220	1100 ± 130	440 ± 90	209 ± 40	2.6 ± 0.9
H_{VBF}	23 ± 9	103 ± 30	46 ± 12	180 ± 40	28.8 ± 5.5
Other Higgs	40 ± 20	55 ± 28	55 ± 27	29 ± 15	0.04 ± 0.02
WW	9700 ± 350	3500 ± 410	1500 ± 470	2100 ± 340	4.6 ± 1.2
$t\bar{t}/Wt$	2200 ± 210	5300 ± 340	6100 ± 500	7600 ± 370	2.6 ± 0.8
Z/γ^*	140 ± 50	280 ± 40	930 ± 70	1300 ± 300	0.6 ± 0.1
Other VV	1400 ± 130	840 ± 100	470 ± 90	380 ± 80	0.6 ± 0.1
Mis-Id	1200 ± 130	720 ± 90	470 ± 50	330 ± 40	1.7 ± 0.2
Total	$16\,770 \pm 130$	$11\,940 \pm 110$	$10\,030 \pm 100$	$12\,200 \pm 180$	42.0 ± 5.1
Observed	16 726	11 917	9 982	12 189	38

STXS Composition



Breakdown of the main contributions to the total uncertainty

Source	$\frac{\Delta\sigma_{\text{ggF+VBF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{ggF+VBF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%]	$\frac{\Delta\sigma_{\text{ggF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{ggF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%]	$\frac{\Delta\sigma_{\text{VBF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{VBF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%]
Data statistical uncertainties	4.6	5.1	15
Total systematic uncertainties	9.5	11	18
MC statistical uncertainties	3.0	3.8	4.9
Experimental uncertainties	5.2	6.3	6.7
Flavor tagging	2.3	2.7	1.0
Jet energy scale	0.9	1.1	3.7
Jet energy resolution	2.0	2.4	2.1
$E_{\text{T}}^{\text{miss}}$	0.7	2.2	4.9
Muons	1.8	2.1	0.8
Electrons	1.3	1.6	0.4
Fake factors	2.1	2.4	0.8
Pileup	2.4	2.5	1.3
Luminosity	2.1	2.0	2.2
Theoretical uncertainties	6.8	7.8	16
ggF	3.8	4.3	4.6
VBF	3.2	0.7	12
WW	3.5	4.2	5.5
Top	2.9	3.8	6.4
$Z\tau\tau$	1.8	2.3	1.0
Other VV	2.3	2.9	1.5
Other Higgs	0.9	0.4	0.4
Background normalizations	3.6	4.5	4.9
WW	2.2	2.8	0.6
Top	1.9	2.3	3.4
$Z\tau\tau$	2.7	3.1	3.4
Total	10	12	23