ATLAS-CONF-2021-014

Measurement of the ggF, H→WW* with full Run2 data at ATLAS

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Outline

- Overview and introduction
- Signal region (SR) definition
- Background estimation
- Systematic uncertainties
- Simplified Template Cross Sections and fit results
- Summary

Overview and Introduction

The results with 36.1 fb^{-1} dataset

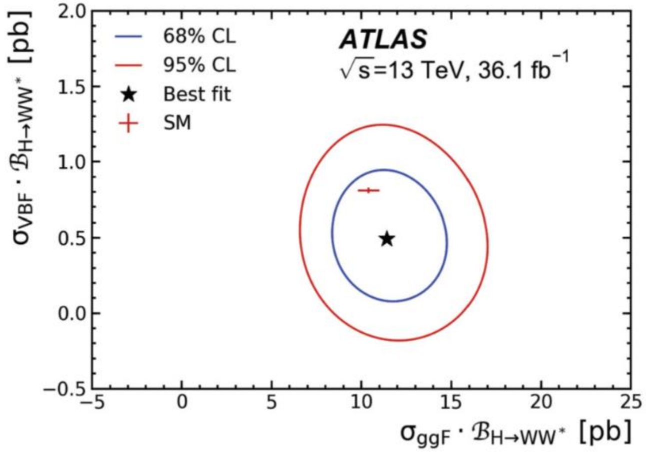
Precision:

$$\mu_{\text{ggF}} = 1.10^{+0.10}_{-0.09}(\text{stat.})^{+0.13}_{-0.11}(\text{theo syst.})^{+0.14}_{-0.13}(\text{exp syst.})$$
$$= 1.10^{+0.21}_{-0.20}$$
$$\mu_{\text{VBF}} = 0.62^{+0.29}_{-0.27}(\text{stat.})^{+0.12}_{-0.13}(\text{theo syst.}) \pm 0.15(\text{exp syst.})$$
$$= 0.62^{+0.36}_{-0.35}.$$

$$\sigma_{\text{ggF}} \cdot \mathcal{B}_{H\to WW^*}$$
$$= 11.4^{+1.2}_{-1.1}(\text{stat.})^{+1.2}_{-1.1}(\text{theo syst.})^{+1.4}_{-1.3}(\text{exp syst.})\ \text{pb}$$
$$= 11.4^{+2.2}_{-2.1}\ \text{pb}$$

$$\sigma_{\text{VBF}} \cdot \mathcal{B}_{H\to WW^*}$$
$$= 0.50^{+0.24}_{-0.22}(\text{stat.}) \pm 0.10(\text{theo syst.})^{+0.12}_{-0.13}(\text{exp syst.})\ \text{pb}$$
$$= 0.50^{+0.29}_{-0.28}\ \text{pb}.$$

	Syst. uncert. dominant	Stat. uncert. dominant
Source	$\Delta\sigma_{\text{ggF}} \cdot \mathcal{B}_{H\to WW^*}$ [%]	$\Delta\sigma_{\text{VBF}} \cdot \mathcal{B}_{H\to WW^*}$ [%]
Data statistics	10	46
CR statistics	7	9
MC statistics	6	21
Theoretical uncertainties	10	19
ggF signal	5	13
VBF signal	<1	4
WW	6	12
Top-quark	5	5
Experimental uncertainties	8	9
b-tagging	4	6
Modelling of pile-up	5	2
Jet	2	2
Lepton	3	<1
Misidentified leptons	6	9
Luminosity	3	3
TOTAL	18	57



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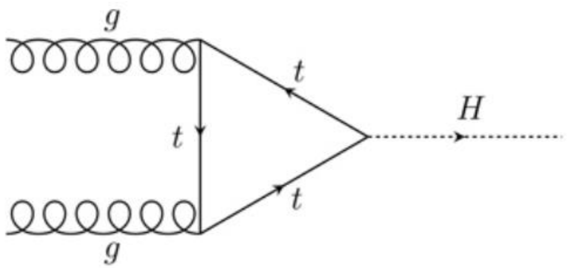
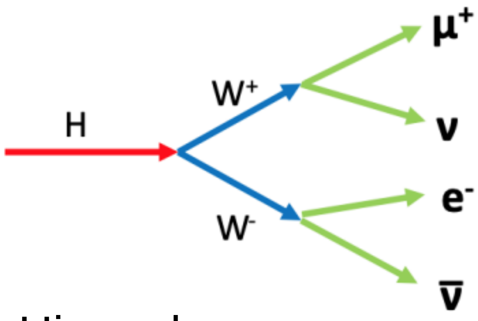
Overview and Introduction



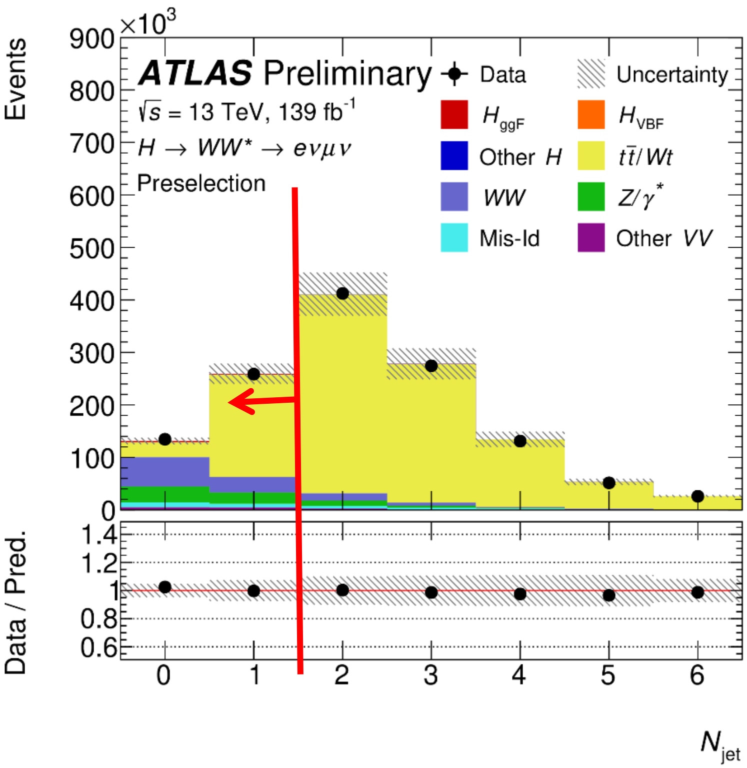
ggF production



Higgs decay

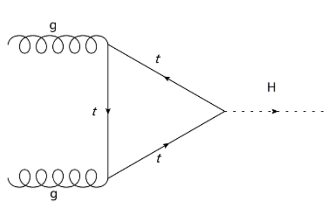
- Only select different flavour (eμ+μe) opposite charge leptons in the final states.
- Classified by the number of jets (0/1).
- Main backgrounds:
  - WW
  - NonWW diboson
  - top
  - Ztautau
  - Wjets

Channel	$qqWW$	Top	Z/γ^*	VV other than $qqWW$	W + jets
$N_{\text{jet}} = 0$	CR	CR	CR	MC+VR	Data
$N_{\text{jet}} = 1$	CR	CR	CR	MC+VR	Data

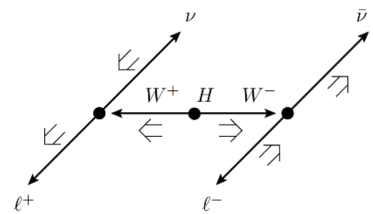


Signal selection and background estimation

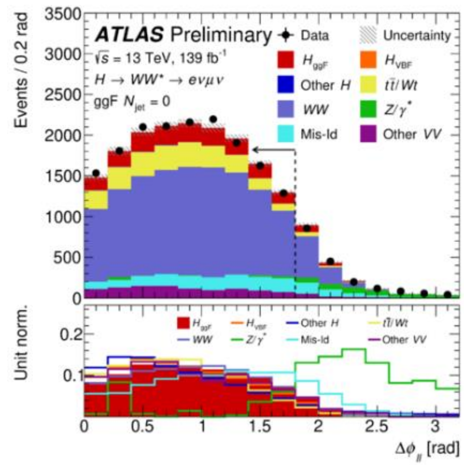
Signal Selection

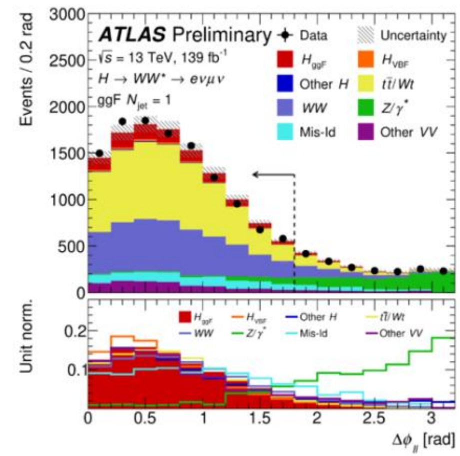


ggF production



H→WW decay.





Signal region

Category	$N_{\text{jet}} = 0$	$N_{\text{jet}} = 1$
Preselection	Two isolated leptons ($\ell = e, \mu$) with opposite charge	
	$p_T^{\text{lead}} > 22\text{GeV}$, $p_T^{\text{sublead}} > 15\text{GeV}$	
	$m_{\ell\ell} > 10\text{GeV}$	
	$E_T^{\text{miss, track}} > 20\text{GeV}$	
Background rejection	$N_{b\text{-jet}} = 0$	
	$\Delta\phi(\ell\ell, E_T^{\text{miss}}) > \pi/2$	$\max(m_T^{\ell}) > 50\text{GeV}$
	$p_T^{\ell\ell} > 30\text{GeV}$	$m_{\tau\tau} < m_Z - 25\text{GeV}$
$H \to WW^* \to \ell\nu\ell\nu$ topology	$m_{\ell\ell} < 55\text{GeV}$	
	$\Delta\phi_{\ell\ell} < 1.8$	

Reduce fake Bkg

Reduce DY Bkg/QCD Bkg

Reduce top Bkg

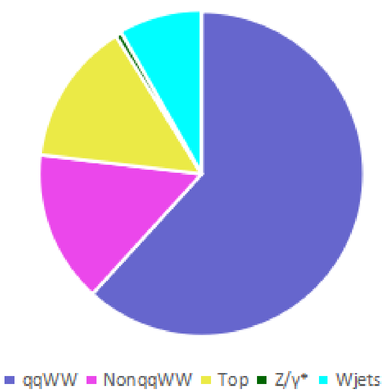
Reduce DY Bkg

Reduce WW Bkg

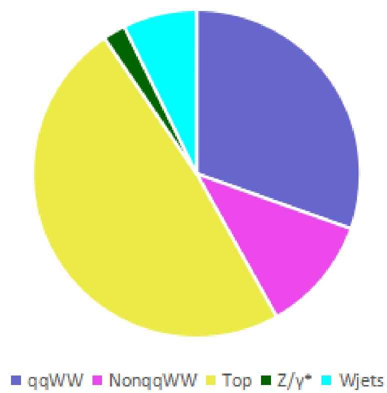
Reduce DY Bkg

Backgrounds Estimation

Contribution to total background in the signal region



0jet SR

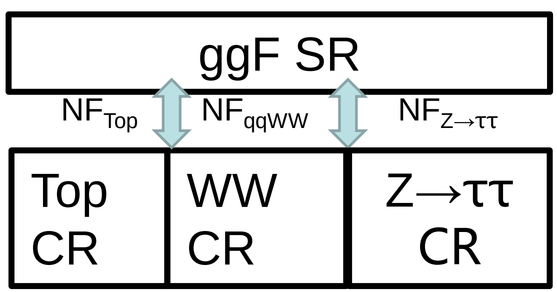


1jet SR

Channel	$qqWW$	Top	Z/γ^*	VV other than $qqWW$	W + jets
$N_{\text{jet}}=0$	CR	CR	CR	MC+VR	Data
$N_{\text{jet}}=1$	CR	CR	CR	MC+VR	Data

Orthogonalize SRs to CRs

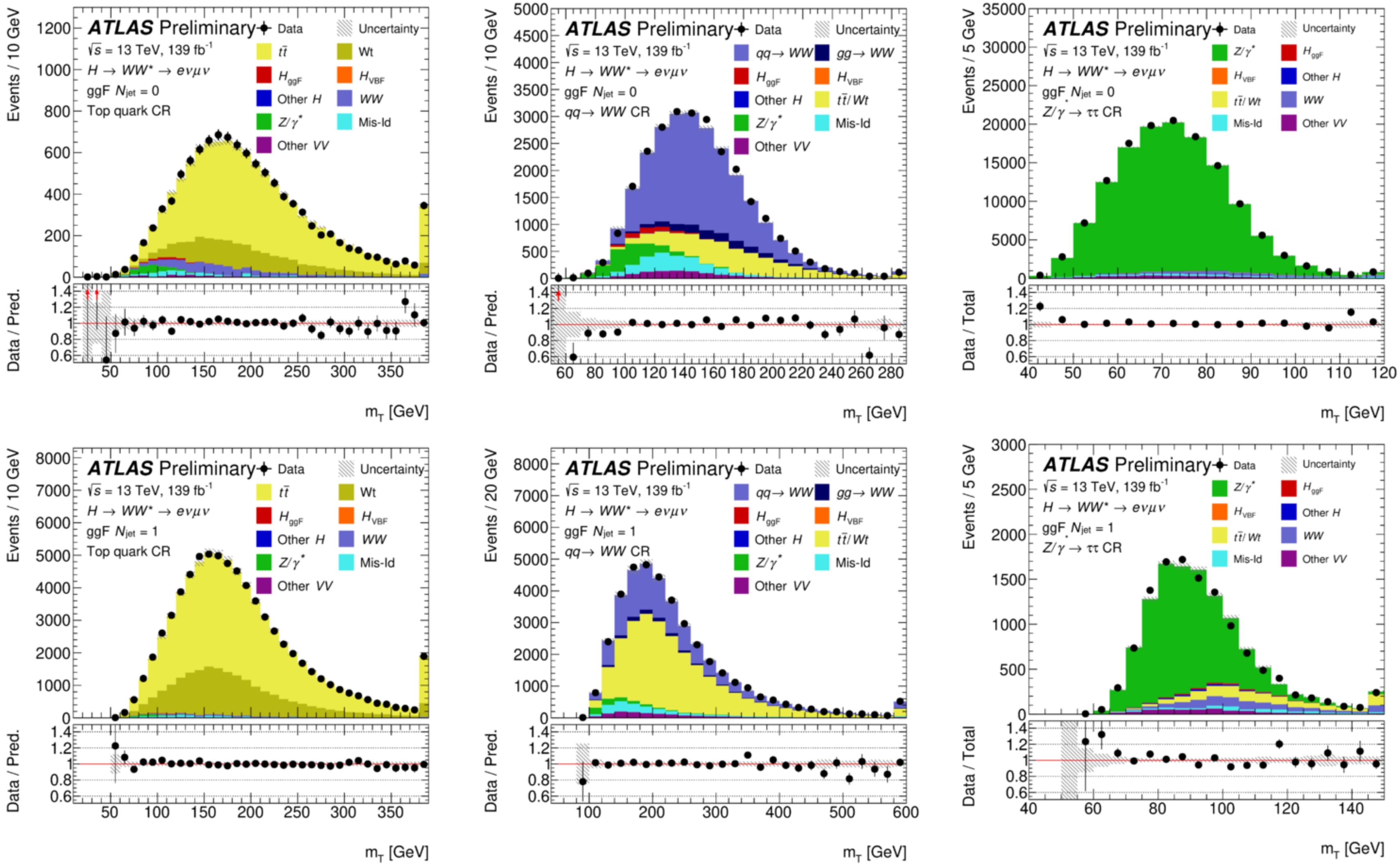
CR	$N_{\text{jet}}=0$	$N_{\text{jet}}=1$
WW	$\boxed{55 < m_{\ell\ell} < 110\text{GeV}}$ $\Delta\phi_{\ell\ell} < 2.6$	$\boxed{m_{\ell\ell} > 80\text{GeV}}$ $\lvert m_{\tau\tau} - m_Z \rvert > 25\text{GeV}$
	b-jet veto	
		$\max(m_{\text{T}}^{\ell}) > 50\text{GeV}$
top quark	$\boxed{N_{b\text{-jet},(20\text{GeV}<p_{\text{T}}<30\text{GeV})} > 0}$ $\Delta\phi(\ell\ell, E_{\text{T}}^{\text{miss}}) > \pi/2$ $p_{\text{T}}^{\ell\ell} > 30\text{GeV}$ $\Delta\phi_{\ell\ell} < 2.8$	$\boxed{N_{b\text{-jet},(p_{\text{T}}>30\text{GeV})} = 1}$ $N_{b\text{-jet},(20\text{GeV}<p_{\text{T}}<30\text{GeV})} = 0$ $\max(m_{\text{T}}^{\ell}) > 50\text{GeV}$ $m_{\tau\tau} < m_Z - 25\text{GeV}$
$Z \to \tau\tau$	no $E_{\text{T}}^{\text{miss, track}}$ requirement	
	$m_{\ell\ell} < 80\text{GeV}$ $\boxed{\Delta\phi_{\ell\ell} > 2.8}$	$m_{\ell\ell} < 80\text{GeV}$ $\boxed{m_{\tau\tau} > m_Z - 25\text{GeV}}$
	b-jet veto	
VV	same-sign leptons all SR cuts	same-sign leptons all SR cuts



The m_T Distribution in the CRs

0jet

1jet



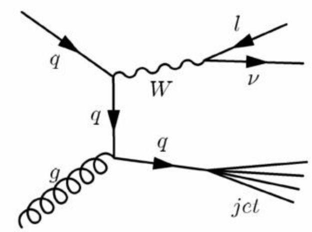
Top CR

WW CR

Ztt CR

W+jets: Fake factor method

- Due to poor MC modeling, W+jets background estimated in a data driven way using fake factor method.



- Three ingredients: W+jets control sample, fake factor and flavour correction.

$$N^{W+\text{jets}}_{\text{id+id}} = \boxed{N^{W+\text{jets}}_{\text{id+anti-id}}} \times \boxed{FF} \times \boxed{CF} = \boxed{(N_{\text{id+anti-id}} - N^{EW}_{\text{id+anti-id}})} \times \boxed{FF} \times \boxed{CF}$$

where the fake factor and the flavour correction factors defined as

$$\boxed{FF(\mathrm{p}_T,\eta) = \frac{N_{\text{id}}(\mathrm{p}_T,\eta)}{N_{\text{anti-id}}(\mathrm{p}_T,\eta)}} ; \boxed{CF = [\frac{FF(W+jets)}{FF(Z+jets)}]_{MC}}$$

  - Fake factor derived in Z+jets control sample with dedicated "3-lepton" selection in which 2 leptons are "Z-tagged" and an additional "fake candidate" lepton.

  - CF corrects for the different flavour compositions in W+jet (CR) and Z+jets (FF).

Electron		Muon	
identified	anti-identified	identified	anti-identified
$p_T > 15$ GeV		$p_T > 15$ GeV	
$\lvert\eta\rvert < 2.47$,excluding $1.37 < \lvert\eta\rvert < 1.52$		$\lvert\eta\rvert < 2.5$	
$\lvert z_0 \sin\theta\rvert < 0.5$ mm		$\lvert z_0 \sin\theta\rvert < 0.5$ mm	
$\lvert d_0\rvert/\sigma(d_0) < 5$		$\lvert d_0\rvert/\sigma(d_0) < 3$	$\lvert d_0\rvert/\sigma(d_0) < 15$
Pass LHTight if $p_T < 25$ GeV Pass LHMedium if $p_T > 25$ GeV	Pass LHLoose	Pass Quality Tight	Pass Quality Medium
Pass FCTight isolation		Pass FCTight isolation	
AUTHOR = 1			
	Veto against identified electron		Veto against identified muon

Statistical analysis

Fit Setup

- Perform binned profile likelihood fit to extract signal strength μ_{ggF} :

$$\mathcal{L}(\mu,\boldsymbol{\theta}) = \underbrace{\prod_{i\in\text{bins}} \text{Pois}(N|\mu s_i(\boldsymbol{\theta}) + \gamma_i b_i(\boldsymbol{\theta}))}_{\text{SR bins + CRs likelihood}} \underbrace{\prod_{i\in\text{bins}} \text{Pois}(m_i|\gamma_i\tau_i)}_{\text{Constraint on MC stat. unc.}} \underbrace{\prod_{\theta\in\boldsymbol{\theta}} \text{Gaus}\left(\tilde{\theta}\middle|\theta\right)}_{\text{Constraint on syst. unc.}}$$

- m_T used as discriminant variable in the final fit.
  - [80-130] GeV considered, outside as over/under-flow.

- 8 signal regions:

N_j	$m_{\ell\ell}$	p_T^{sublead}
$N_{\text{jet}} = 0$	[10-30, 30-55]	[15-20, 20-∞]
$N_{\text{jet}} = 1$	[10-30, 30-55]	[15-20, 20-∞]

- Optimize the sensitivity by re-mapping the m_T distribution
  - [<90, 90–100, 100–110, 110–120, 120–130, >130] GeV for both 0 and 1jet

Systematics uncertainties

- Theory uncertainties:
  - ggF signal: ggF jet bin migration, α_S, shower
  - VBF: scale, shower, pdf, matching
  - WW: α_S, pdf, scale, QSF,CSSKIN , ckkw (truth level),ggWW scale
  - Top: Interference (Wt only), matching, shower, scale, ISR, FSR, pdf
  - Z$\tau\tau$: generator, pdf, scale, α_S

- Experimental uncertainties follow the ATLAS recommendation:
  - Trigger
  - Pileup reweighting
  - MET
  - Electron and muon related
  - Jet
  - Flavour tagging
  - Luminosity

➢The dominant experimental uncertainties originate from b-jet identification, the pile-up modelling, the jet energy resolution, and the Mis-Id background estimate.

Combined fit results (ggF+VBF)

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- Perform ggF + VBF combined fit.
- Sensitivity:

$$\mu_{\text{ggF}} = 1.20\,^{+0.16}_{-0.15}$$

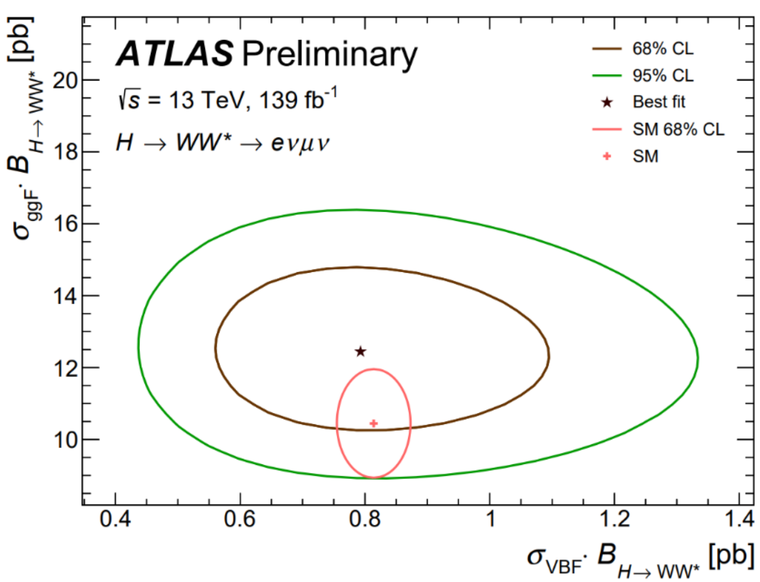
To date, It's the most precise result

$$= 1.20 \pm 0.05\ (\text{stat.})\ ^{+0.09}_{-0.08}\ (\text{exp syst.})\ ^{+0.10}_{-0.08}\ (\text{sig theo.})\ ^{+0.12}_{-0.11}\ (\text{bkg theo.})$$

$$\mu_{\text{VBF}} = 0.99\,^{+0.24}_{-0.20}$$

$$= 0.99\,^{+0.13}_{-0.12}\ (\text{stat.})\ ^{+0.07}_{-0.06}\ (\text{exp syst.})\ ^{+0.17}_{-0.12}\ (\text{sig theo.})\ ^{+0.10}_{-0.08}\ (\text{bkg theo.}).$$

- Significance is 6.6 for VBF



Source	$\frac{\Delta\sigma_{\text{ggF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{ggF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%]	$\frac{\Delta\sigma_{\text{VBF}}\cdot\mathcal{B}_{H\to WW^*}}{\sigma_{\text{VBF}}\cdot\mathcal{B}_{H\to WW^*}}$ [%]
Data statistical uncertainties	5	13
Total systematic uncertainties	11	18
MC statistical uncertainties	4	3.2
Experimental uncertainties	6	7
Flavour Tagging	2.4	0.9
Jet energy scale	1.4	3.3
Jet energy resolution	2.3	1.9
$E_{\text{T}}^{\text{miss}}$	1.9	5
Muons	2.1	0.7
Electrons	1.5	0.3
Fake factors	2.4	1.0
Pile-up	2.4	1.3
Luminosity	2.0	2.1
Theoretical uncertainties	8	16
ggF	5	4
VBF	0.7	13
Top	4	5
$Z\tau\tau$	2.0	2.1
WW	4	5
Other VV	3	1.2
Background normalisations	5	5
WW	3.1	0.5
Top	2.4	2.2
$Z\tau\tau$	3.1	4
TOTAL	12	22

Simplified Template Cross Sections

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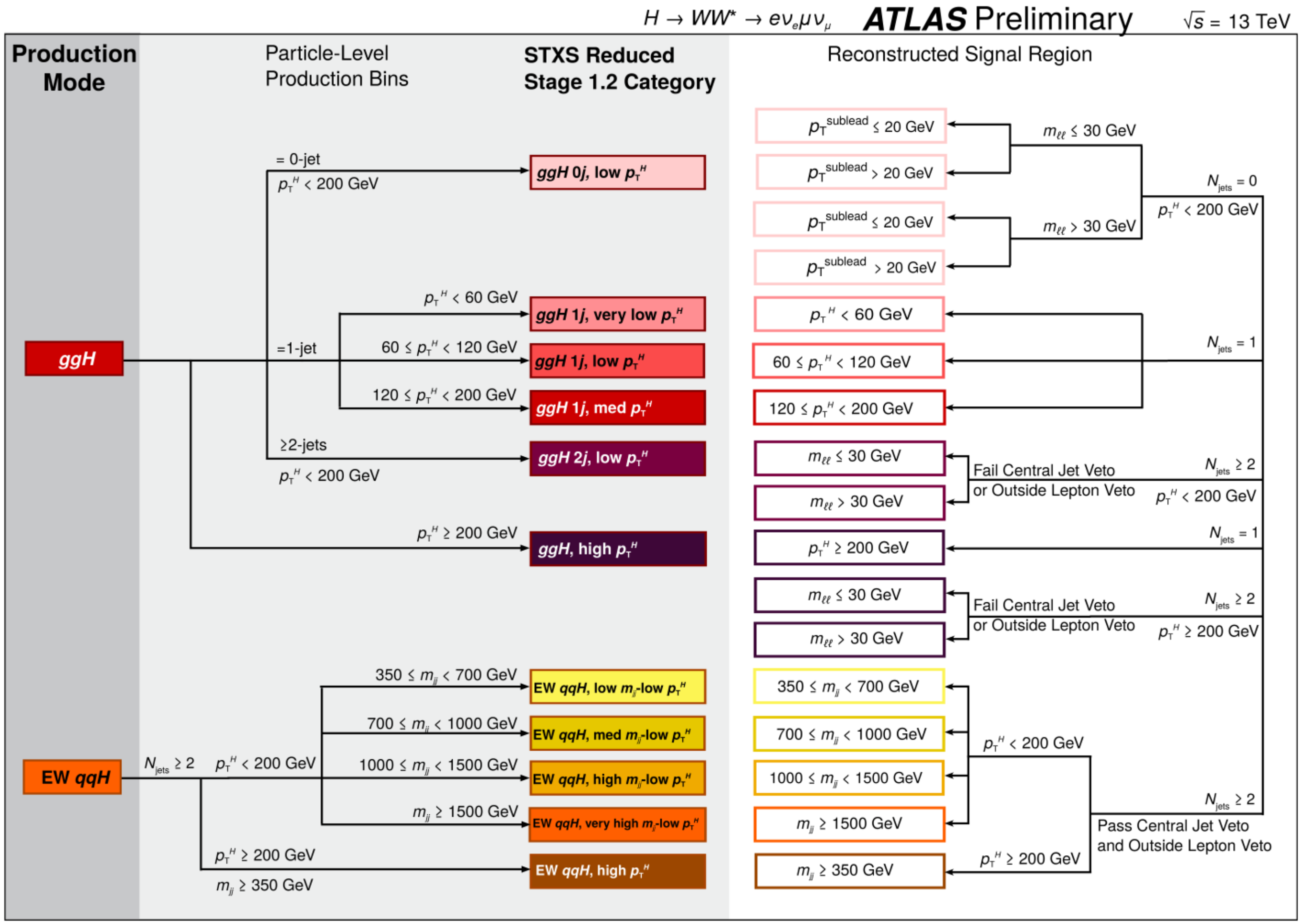

- ➢ Split by p_T^H, N_{jets}, m_{jj} into 11 categories

$$p_T^H = |\boldsymbol{p}_T^{\ell\ell} + \boldsymbol{E}_T^{\text{miss}}|$$

- ➢ 17 signal regions (SR)
- ➢ 27 control regions (CR)

- ➢ This analysis based on the reduced stage 1.2 category to ensure sensitivity for all measurements.
- ➢ CRs split similar to SRs where statistics allow

STXS Results

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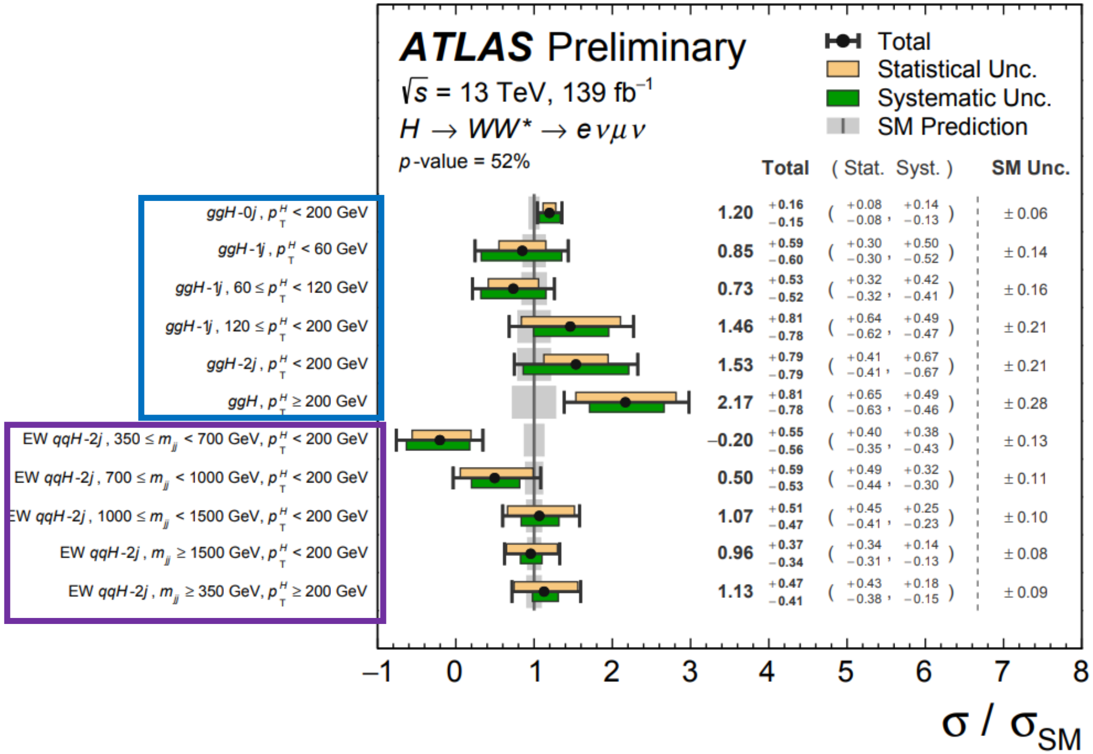
ggH

qqH



- Extracted by profile likelihood fit: 17 SRs (m_T/DNN) + 27 CRs
- ggH uncertainties limited by both stat. + syst. uncertainty
- qqH uncertainties limited by statistical uncertainty at high m_{jj} / p_T^H
- Compatible with the SM predictions with a p-value of 52%

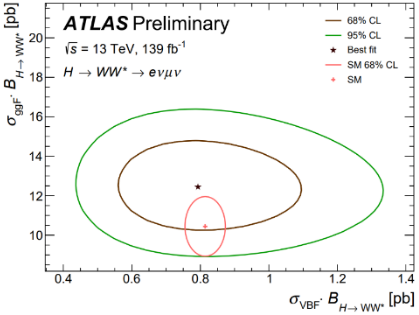
Summary

- Presented the full Run2 H→WW* analysis.

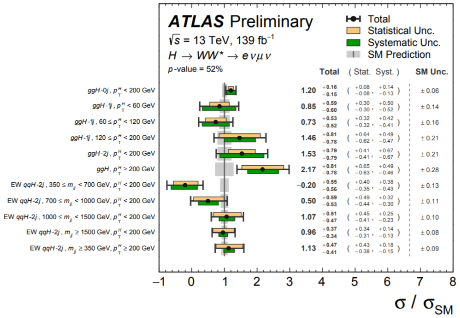
- ggF+VBF combined fit results:

$$
\begin{aligned}
\mu_{\text{ggF}} &= 1.20\,^{+0.16}_{-0.15} \\
&= 1.20 \pm 0.05\ (\text{stat.})\ ^{+0.09}_{-0.08}\ (\text{exp syst.})\ ^{+0.10}_{-0.08}\ (\text{sig theo.})\ ^{+0.12}_{-0.11}\ (\text{bkg theo.}) \\
\mu_{\text{VBF}} &= 0.99\,^{+0.24}_{-0.20} \\
&= 0.99\,^{+0.13}_{-0.12}\ (\text{stat.})\ ^{+0.07}_{-0.06}\ (\text{exp syst.})\ ^{+0.17}_{-0.12}\ (\text{sig theo.})\ ^{+0.10}_{-0.08}\ (\text{bkg theo.}).
\end{aligned}
$$

To date, It's the most precise result



- The STXS fit results are compatible with the SM predictions with a p-value of 52%



Thank you for your attention

Back-up

Event preselection

- Preselection:
  - Exactly two opposite-charge , different-flavour (e,μ) leptons.
  - $p_T^{Lead} > 22GeV, p_T^{Sublead} > 15GeV$
  - $m_{ll} > 10GeV$
  - $p_T^{miss} > 20GeV$
- The definition of Signal regions and control regions are based on the preselection

Triggers used in this analysis:

An OR combination of unprescaled single lepton and dilepton triggers.

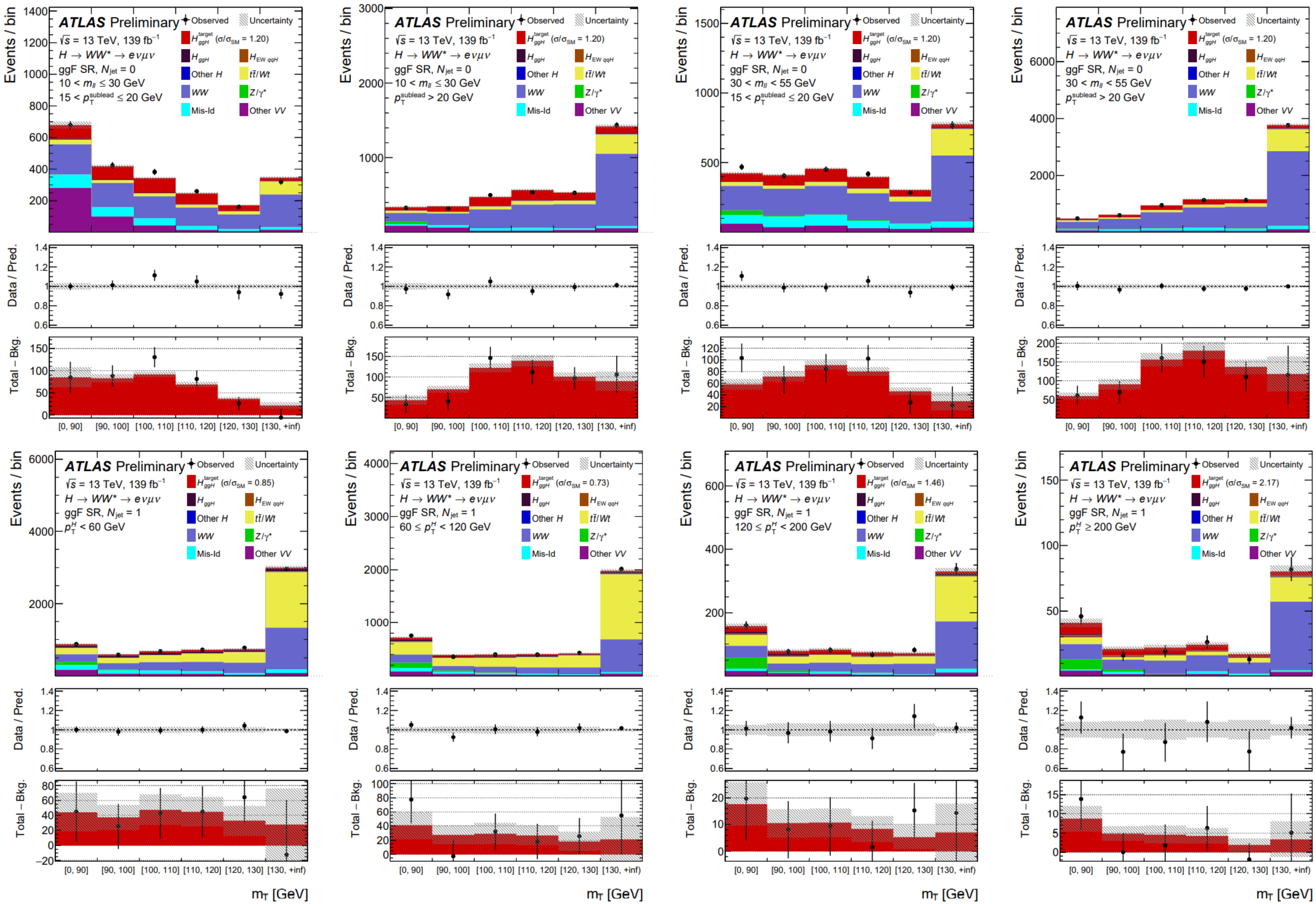
Lepton	Level-1 Trigger	High Level Trigger
2015		
e	L1_EM20VH	HLT_e24_lhmedium_L1EM20VH
	L1_EM22VHI	HLT_e60_lhmedium
	L1_EM22VHI	HLT_e120_lhloose
μ	L1_MU15	HLT_mu20_iloose_L1MU15
	L1_MU20	HLT_mu50
$e\mu$	L1_EM15VH_MU10	HLT_e17_lhloose_mu14
2016–2018		
e	L1_EM22VHI	HLT_e26_lhtight_nod0_ivarloose
	L1_EM22VHI	HLT_e60_lhmedium_nod0
	L1_EM22VHI	HLT_e140_lhloose_nod0
μ	L1_MU20, L1_MU21	HLT_mu26_ivarmedium
	L1_MU20, L1_MU21	HLT_mu50
$e\mu$	L1_EM15VH_MU10	HLT_e17_lhloose_nod0_mu14

Using the direction and magnitude of the measured missing transverse momentum and projecting it along the directions defined by the two reconstructed charged leptons, the mass of the *tau*-lepton pair, m_{tautau}, can be reconstructed using the so-called collinear approximation

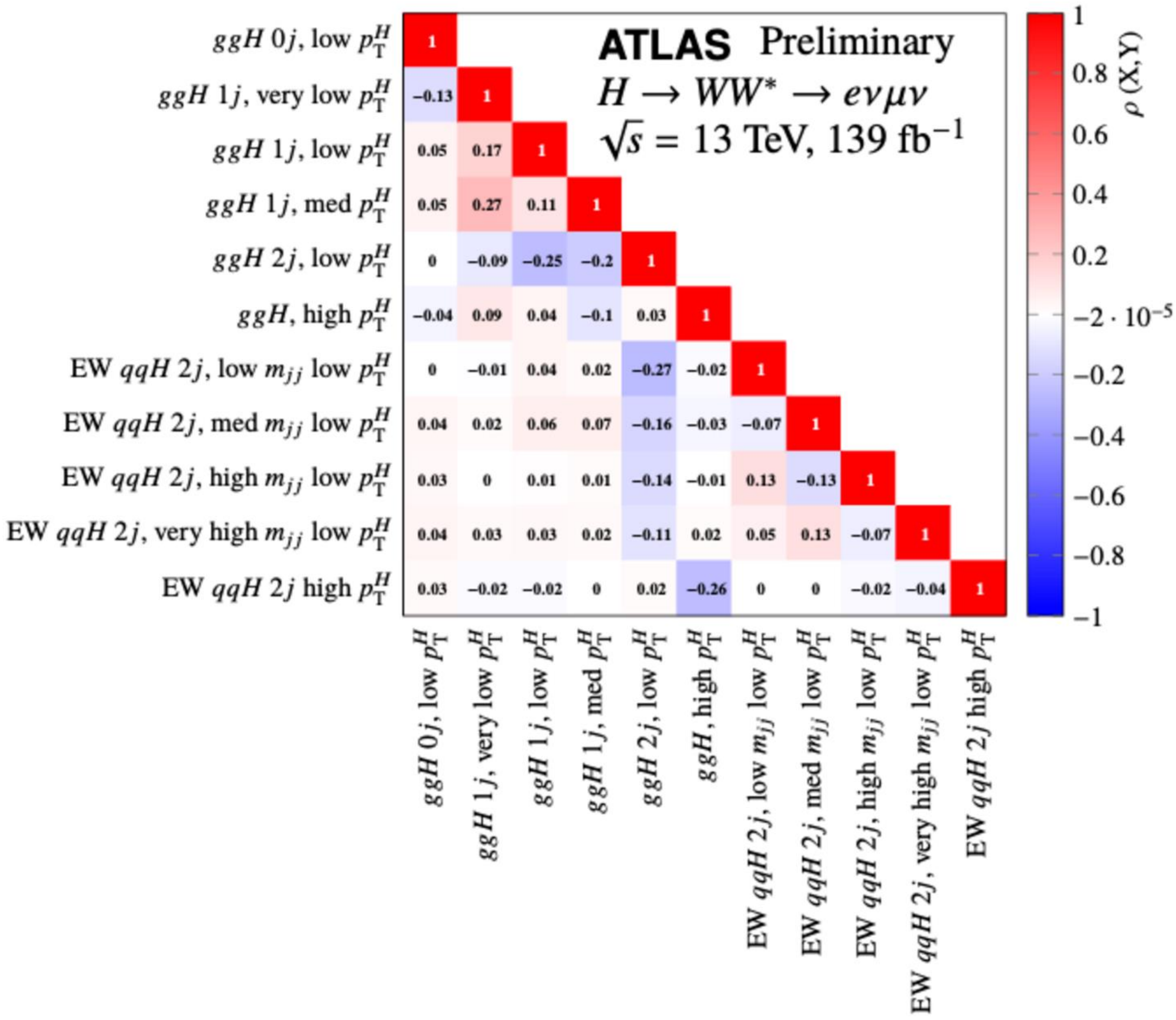
MC samples

Process	Matrix element (alternative)	PDF set	UEPS model (alternative model)	Prediction order for total cross section
ggF H	POWHEG-BOX v2 [33–37] NNLOPS [36, 40, 53] (MG5_AMC@NLO) [59, 89]	PDF4LHC15 NNLO [92]	PYTHIA 8 [38] (Herwig 7) [58]	N^3LO QCD + NLO EW [11, 43–52]
VBF H	POWHEG-BOX v2 [33–35, 53] (MG5_AMC@NLO)	PDF4LHC15 NLO	PYTHIA 8 (Herwig 7)	NNLO QCD + NLO EW [55, 93, 94]
VH excl. $gg \to ZH$	POWHEG-BOX v2	PDF4LHC15 NLO	PYTHIA 8	NNLO QCD + NLO EW [62–66]
$gg \to ZH$	POWHEG-BOX v2	PDF4LHC15 NLO	PYTHIA 8	NNLL [95, 96]
$qq \to WW$	SHERPA 2.2.2 [75]	NNPDF3.0NNLO [97]	SHERPA 2.2.2 [76–81]	NLO [82, 83, 98]
$qq \to WWqq$	SHERPA 2.1.1 [99]	CT10 [100]	SHERPA 2.2.1	LO
$gg \to WW$	SHERPA 2.2.2	NNPDF3.0NNLO	SHERPA 2.2.2	NLO [101]
$WZ/V\gamma^*/ZZ \to \ell\ell\ell\ell/\ell\ell\ell\nu$	SHERPA 2.2.2	NNPDF3.0NNLO	SHERPA 2.2.2	NLO [99]
Other $WZ/V\gamma^*/ZZ$	POWHEG-BOX v2	CT10	PYTHIA 8	NLO [99]
$V\gamma$	SHERPA 2.2.8 [75]	NNPDF3.0NNLO	SHERPA 2.2.8	NLO [99]
$t\bar{t}$	POWHEG-BOX v2 (MG5_AMC@NLO)	NNPDF3.0NLO	PYTHIA 8 (Herwig 7)	NNLO+NNLL [102–108]
Wt	POWHEG-BOX v2 (MG5_AMC@NLO)	NNPDF3.0NLO	PYTHIA 8 (Herwig 7)	NNLO [109, 110]
Z/γ^*	SHERPA 2.2.1 (MG5_AMC@NLO)	NNPDF3.0NNLO	SHERPA 2.2.1	NNLO [84]

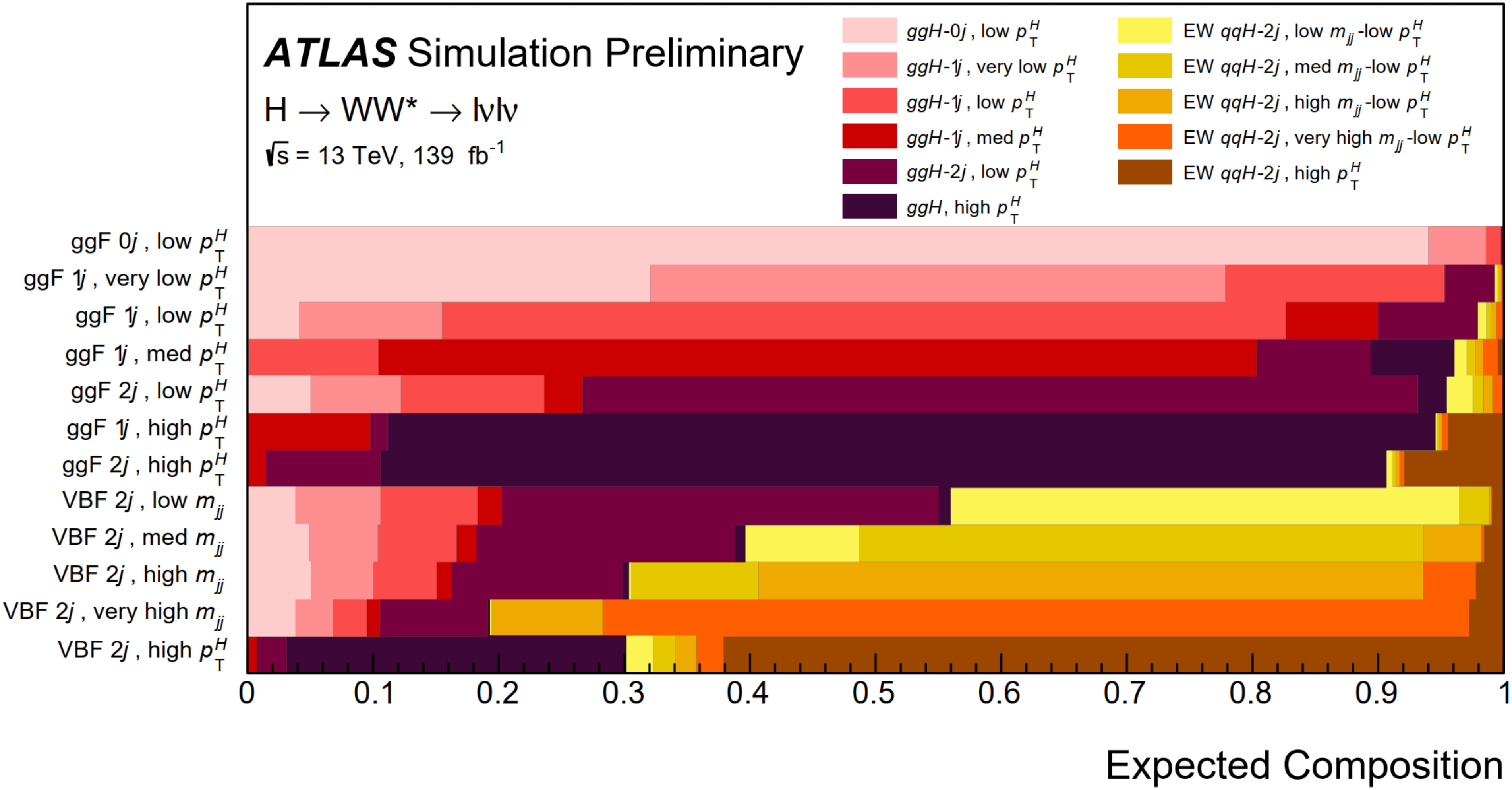
The m_T distribution in 0/1jet SRs after remapping



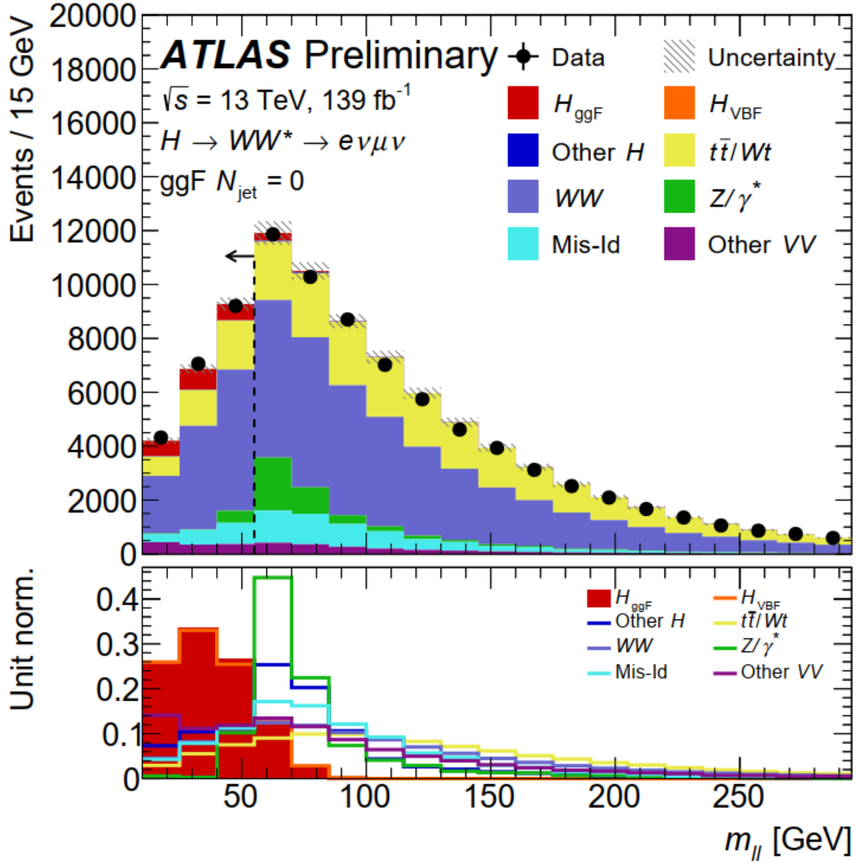
Correlation plot

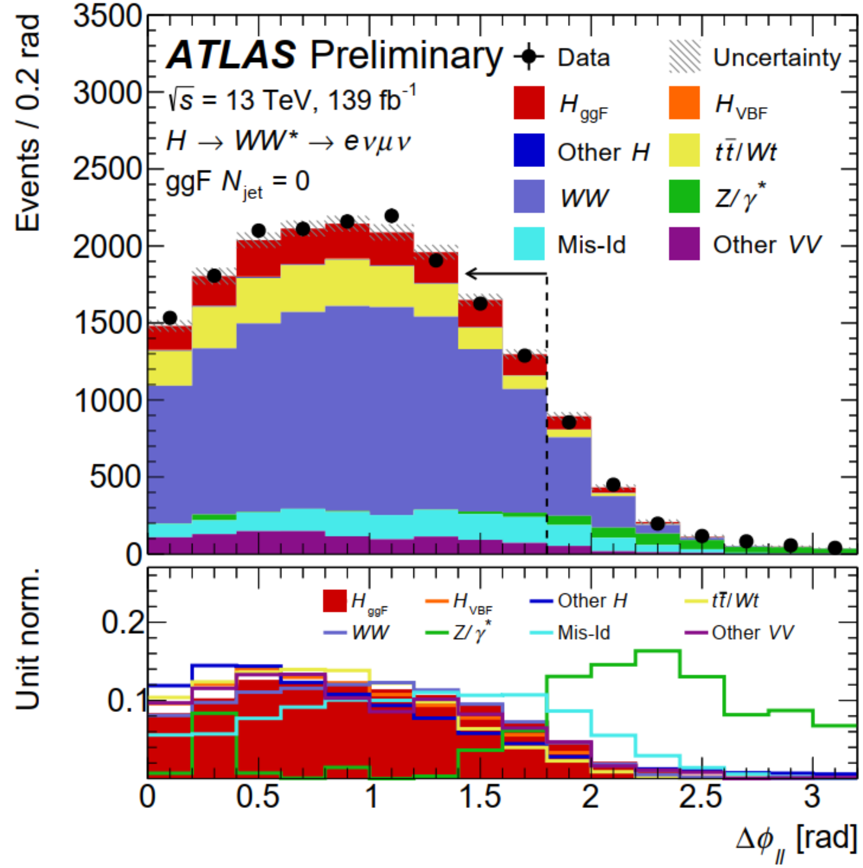


The signal composition



The variables distribution before applying corresponding cuts





The variables distribution before applying corresponding cuts