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Measurement of $H \to \tau\tau$ at $\sqrt{s} = 13\,\text{TeV}$ with the ATLAS Experiment

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on behalf of the ATLAS collaboration

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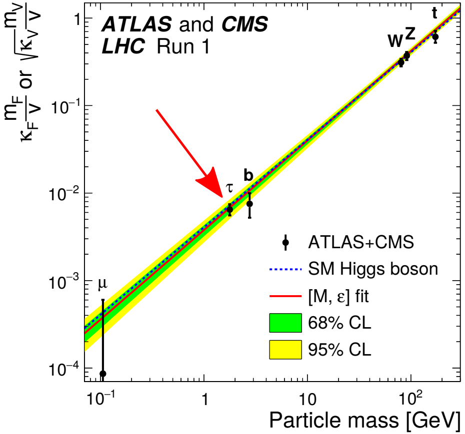
Bundesministerium
für Bildung
und Forschung

ATLAS
EXPERIMENT

Motivation



JHEP 1608 (2016) 045

Measurements in $H \to \tau\tau$

- $\sigma \times BR$ (Yukawa coupling)
- CP from final state
  - Spin-correlations of tau decay products
- CP from VBF production
  - Event kinematics of final state particles

Analysis Strategy

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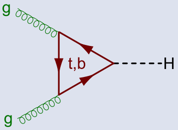
Analysis Overview

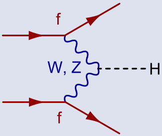
- '15 + '16 data ($36.1\,\text{fb}^{-1}$)
- Cut based analysis
- Focus on boosted and VBF topologies
- 3 sub-channels
  - 4-5 signal regions each
  - Different background models
- Likelihood fit in $m_{\tau\tau}^{MMC}$
  $\Rightarrow \sigma_H \times BR_{H\to\tau\tau}$

Publication

- Published as:
  PRD **99** (2019) 072001

Dominant Production Modes





$\sigma_{ggF}^{SM} = 49\,\text{pb}$ $\sigma_{VBF}^{SM} = 3.8\,\text{pb}$

arXiv:1610.07922

$H \to \tau\tau$ Sub-Channels

- $\tau_{\text{lep}}\tau_{\text{lep}}$ (12 %)
- $\tau_{\text{lep}}\tau_{\text{had}}$ (46 %)
- $\tau_{\text{had}}\tau_{\text{had}}$ (42 %)

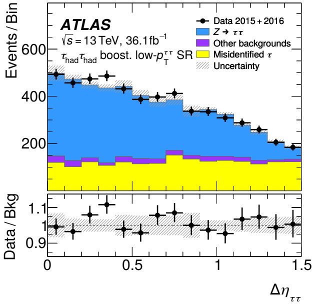
Background Estimation

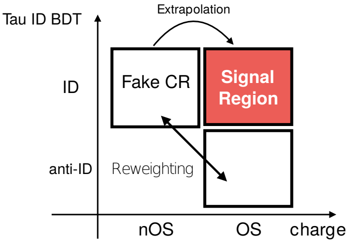
- $Z \to \tau\tau \Rightarrow$ MC with free normalisation (validated in $Z \to \ell\ell$ VR)
- Misidentified τ (Fakes) $\Rightarrow$ data-driven techniques
- Other Backgrounds $\Rightarrow$ Directly from MC (Top, W+Jets, Diboson)

Fakes Estimation for $H \to \tau_{\text{had}}\tau_{\text{had}}$

- From not-opposite-sign region (nOS)
- Real-tau backgrounds subtracted via MC

	$q(\tau_1) \cdot q(\tau_2)$	nTracks(τ)
SR	$= -1$	$\in \{1, 3\}$
nOS	$\neq -1$	$\in \{1, 2, 3\}$





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$H \to \tau\tau$ Fit Regions

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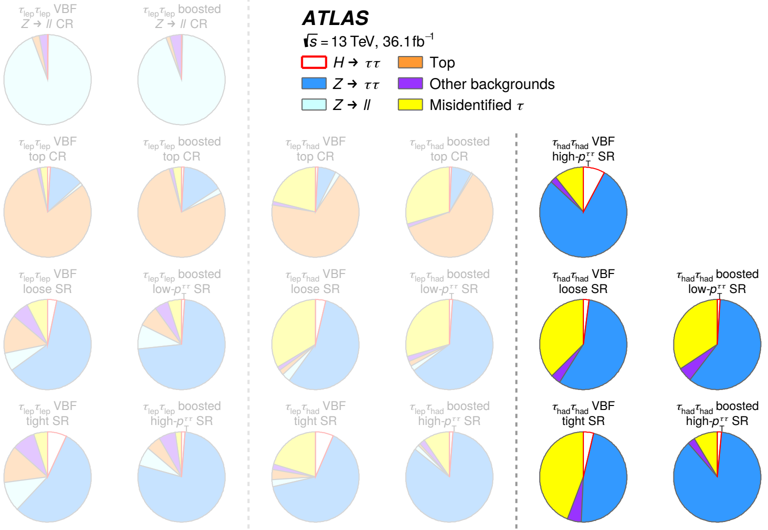

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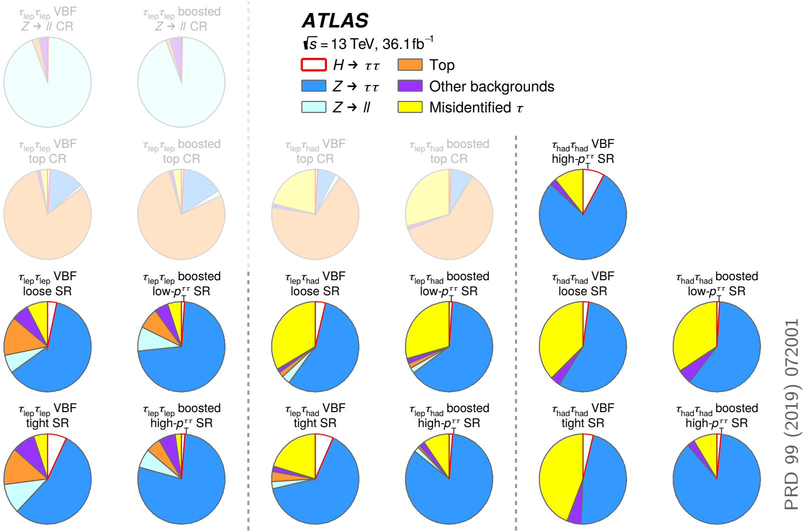
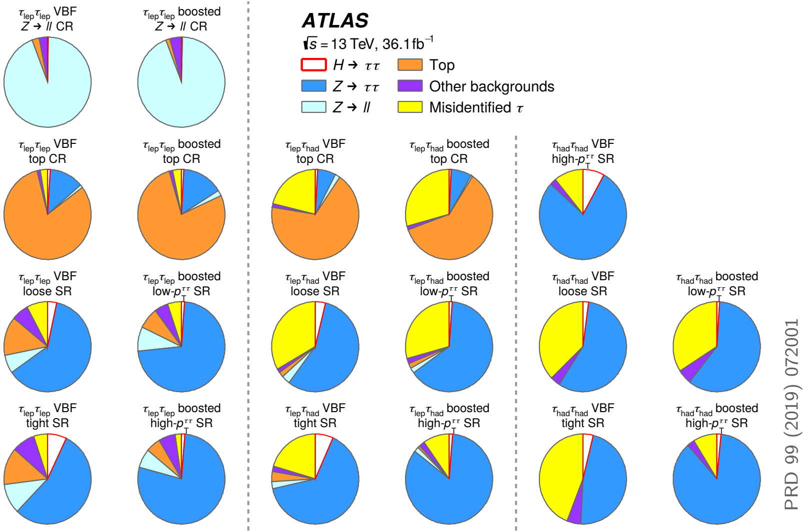
lep lep | lep had | had had

$H \to \tau\tau$ Fit Regions



lep lep | lep had | had had

$H \to \tau\tau$ Fit Regions



lep lep — lep had — had had

Final $m_{\tau\tau}^{\text{MMC}}$ Distributions

High-p_T Boosted and Tight VBF SRs

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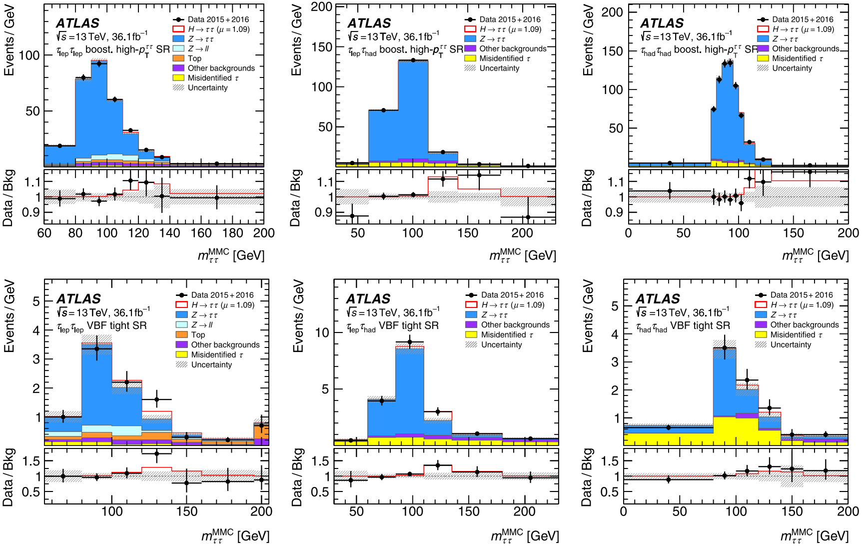

$\tau_{lep}\tau_{lep}$ $\tau_{lep}\tau_{had}$ $\tau_{had}\tau_{had}$

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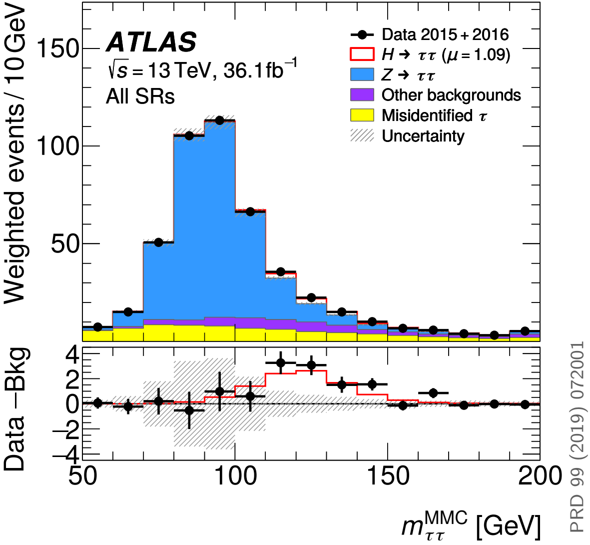
Final $m_{\tau\tau}^{MMC}$ Distribution



Cross-Section Results

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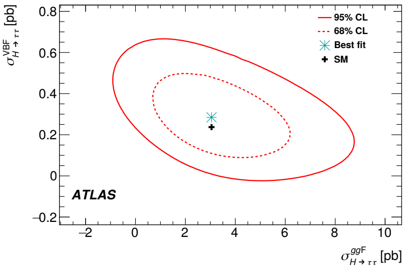
	Measured	SM
$\sigma^{tot}_{H\to\tau\tau}$	$3.77\,^{+0.60}_{-0.59}\,(\text{stat.})\,^{+0.87}_{-0.74}\,(\text{syst.})$ pb	3.46 ± 0.13 pb
$\sigma^{ggF}_{H\to\tau\tau}$	$3.1 \pm 1.0\,(\text{stat.})\,^{+1.6}_{-1.3}\,(\text{syst.})$ pb	3.05 ± 0.13 pb
$\sigma^{VBF}_{H\to\tau\tau}$	$0.28 \pm 0.09\,(\text{stat.})\,^{+0.11}_{-0.09}\,(\text{syst.})$ pb	0.237 ± 0.006 pb



Process	Particle-level selection	σ [pb]	σ^{SM} [pb]
ggF	$N_{jets} \geq 1$, $60 < p_T^H < 120$ GeV, $\|y_H\| < 2.5$	1.79 ± 0.53 (stat.) $\pm\, 0.74$ (syst.)	0.40 ± 0.05
ggF	$N_{jets} \geq 1$, $p_T^H > 120$ GeV, $\|y_H\| < 2.5$	0.12 ± 0.05 (stat.) $\pm\, 0.05$ (syst.)	0.14 ± 0.03
VBF	$\|y_H\| < 2.5$	0.25 ± 0.08 (stat.) $\pm\, 0.08$ (syst.)	0.22 ± 0.01

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Conclusion

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Summary

- ATLAS measurement of $\sigma_{H \to \tau\tau}$ with $\int \mathscr{L} \mathrm{dt} = 36.1\,\mathrm{fb}^{-1}$ at $\sqrt{s} = 13\,\mathrm{TeV}$
- Measured cross-sections in good agreement with SM

Outlook

- Full Run 2 dataset is about factor 4 larger
- Reduce uncertainties on total cross section
- Explore fiducial measurements with finer granularity

Additional Material

$H \to \tau\tau$ MC Samples

Process	Monte Carlo generator	PDF	UEPS	Cross-section order
ggF	Powheg-Box v2	PDF4LHC15 NNLO	Pythia 8.212	N^{3}LO QCD + NLO EW
VBF	Powheg-Box v2	PDF4LHC15 NLO	Pythia 8.212	~NNLO QCD + NLO EWF
VH	Powheg-Box v2	PDF4LHC15 NLO	Pythia 8.212	NNLO QCD + NLO EW
$t\bar{t}H$	MG5_aMC@NLO v2.2.2	NNPDF30LO	Pythia 8.212	NLO QCD + NLO EW
W/Z + jets	Sherpa 2.2.1	NNPDF30NNLO	Sherpa 2.2.1	NNLO
$VV/V\gamma^*$	Sherpa 2.2.1	NNPDF30NNLO	Sherpa 2.2.1	NLO
$t\bar{t}$	Powheg-Box v2	CT10	Pythia 6.428	NNLO + NNLL
Wt	Powheg-Box v1	CT10F4	Pythia 6.428	NLO

$H \to \tau\tau$ Trigger-Selection

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Analysis channel	Trigger	Analysis p_T requirement [GeV] 2015	2016
$\tau_{lep}\tau_{lep}$ & $\tau_{lep}\tau_{had}$	Single electron	25	27
	Single muon	21	27
$\tau_{lep}\tau_{lep}$	Di-electron	15 / 15	18 / 18
	Di-muon	19 / 10	24 / 10
	Electron+muon	18 / 15	18 / 15
$\tau_{had}\tau_{had}$	Di-$\tau_{\text{had-vis}}$	40 / 30	40 / 30

$H \to \tau\tau$ Pre-Selection

$\tau_{\text{lep}}\tau_{\text{lep}}$ $ee/\mu\mu$	$\tau_{\text{lep}}\tau_{\text{lep}}$ $e\mu$	$\tau_{\text{lep}}\tau_{\text{had}}$	$\tau_{\text{had}}\tau_{\text{had}}$
$N_{e/\mu}^{\text{loose}} = 2$, $N_{\tau_{\text{had-vis}}}^{\text{loose}} = 0$		$N_{e/\mu}^{\text{loose}} = 1$, $N_{\tau_{\text{had-vis}}}^{\text{loose}} = 1$	$N_{e/\mu}^{\text{loose}} = 0$, $N_{\tau_{\text{had-vis}}}^{\text{loose}} = 2$
e/μ : Medium, gradient iso.		e/μ : Medium, gradient iso.	
		$\tau_{\text{had-vis}}$: Medium	$\tau_{\text{had-vis}}$: Tight
Opposite charge		Opposite charge	Opposite charge
$m_{\tau\tau}^{\text{coll}} > m_Z - 25\,\text{GeV}$		$m_{\text{T}} < 70\,\text{GeV}$	
$30 < m_{\ell\ell} < 75\,\text{GeV}$	$30 < m_{\ell\ell} < 100\,\text{GeV}$		
$E_{\text{T}}^{\text{miss}} > 55\,\text{GeV}$	$E_{\text{T}}^{\text{miss}} > 20\,\text{GeV}$	$E_{\text{T}}^{\text{miss}} > 20\,\text{GeV}$	$E_{\text{T}}^{\text{miss}} > 20\,\text{GeV}$
$E_{\text{T}}^{\text{miss, hard}} > 55\,\text{GeV}$			
$\Delta R_{\tau\tau} < 2.0$		$\Delta R_{\tau\tau} < 2.5$	$0.8 < \Delta R_{\tau\tau} < 2.5$
$\lvert\Delta\eta_{\tau\tau}\rvert < 1.5$		$\lvert\Delta\eta_{\tau\tau}\rvert < 1.5$	$\lvert\Delta\eta_{\tau\tau}\rvert < 1.5$
$0.1 < x_1 < 1.0$		$0.1 < x_1 < 1.4$	$0.1 < x_1 < 1.4$
$0.1 < x_2 < 1.0$		$0.1 < x_2 < 1.2$	$0.1 < x_2 < 1.4$
$p_{\text{T}}^{j_1} > 40\,\text{GeV}$		$p_{\text{T}}^{j_1} > 40\,\text{GeV}$	$p_{\text{T}}^{j_1} > 70\,\text{GeV}$, $\lvert\eta_{j_1}\rvert < 3.2$
$N_{b\text{-jets}} = 0$		$N_{b\text{-jets}} = 0$	

$H \to \tau\tau$ Selection

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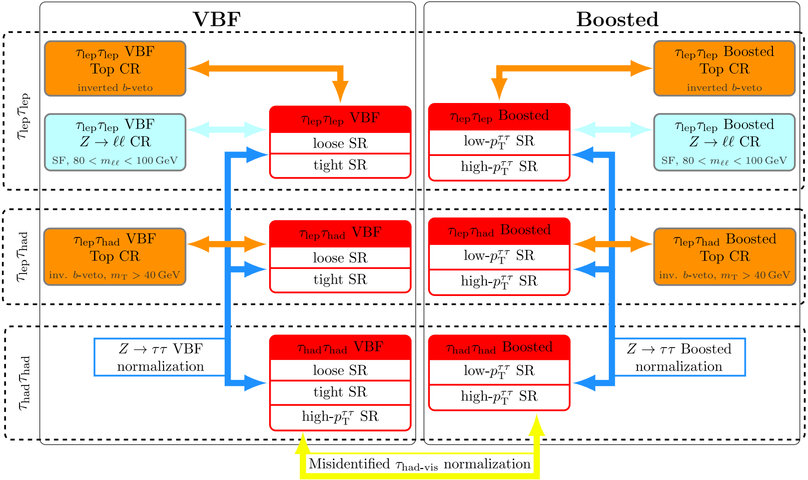
Signal Region		Inclusive	$\tau_{lep}\tau_{lep}$	$\tau_{lep}\tau_{had}$	$\tau_{had}\tau_{had}$
VBF	High-$p_T^{\tau\tau}$	$p_T^{j_2} > 30$ GeV $\lvert\Delta\eta_{jj}\rvert > 3$ $m_{jj} > 400$ GeV $\eta_{j_1} \cdot \eta_{j_2} < 0$ Central leptons	—		$p_T^{\tau\tau} > 140$ GeV $\Delta R_{\tau\tau} < 1.5$
	Tight		$m_{jj} > 800$ GeV	$m_{jj} > 500$ GeV $p_T^{\tau\tau} > 100$ GeV	Not VBF high-p_T $m_{jj} > (1550 - 250 \cdot \Delta\eta_{jj})$ GeV
	Loose		Otherwise		
Boosted	High-$p_T^{\tau\tau}$	Not VBF $p_T^{\tau\tau} > 100$ GeV	$p_T^{\tau\tau} > 140$ GeV $\Delta R_{\tau\tau} < 1.5$		
	Low-$p_T^{\tau\tau}$		Otherwise		

$H \to \tau\tau$ Fit Model



Final $m_{\tau\tau}^{\mathrm{MMC}}$ Distributions

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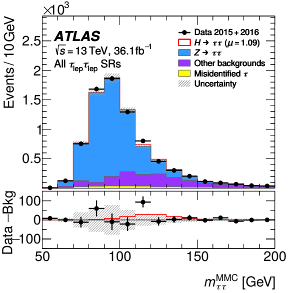
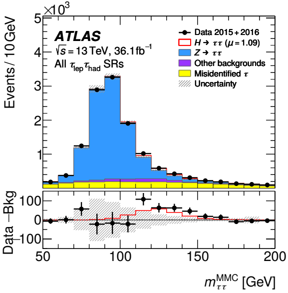
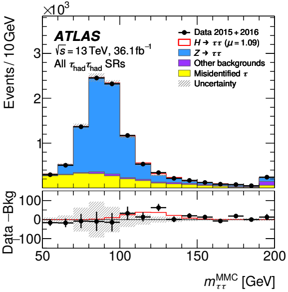


$\tau_{\mathrm{lep}}\tau_{\mathrm{lep}}$ Sub-Channel



$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ Sub-Channel



$\tau_{\mathrm{had}}\tau_{\mathrm{had}}$ Sub-Channel

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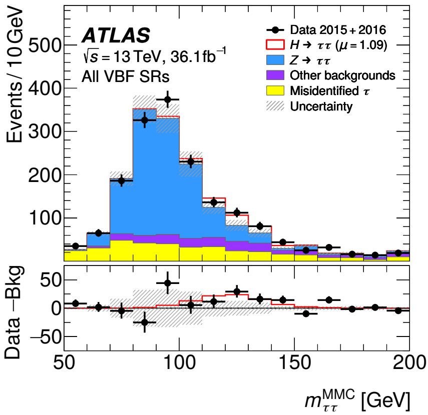
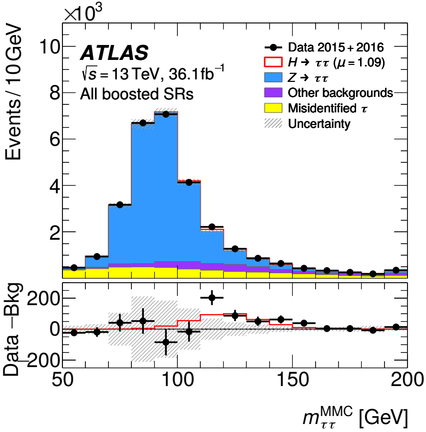
Final $m_{\tau\tau}^{MMC}$ Distributions



All VBF SRs



All boosted SRs

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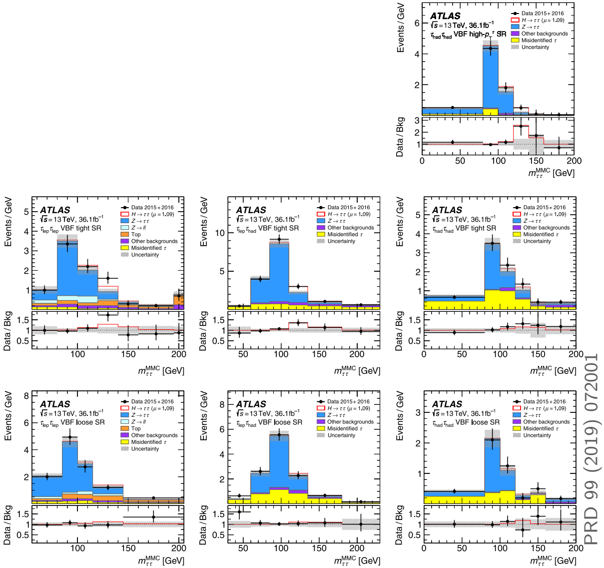

ATLAS
√s = 13 TeV, 36.1 fb⁻¹
τhad τhad VBF high-pT τ SR
τlep τlep VBF tight SR
τlep τhad VBF tight SR
τhad τhad VBF tight SR
τlep τlep VBF loose SR
τlep τhad VBF loose SR
τhad τhad VBF loose SR
Data 2015+2016
H → ττ (μ = 1.09)
Z → ττ
Z → ll
Top
Other backgrounds
Misidentified τ
Uncertainty
Events / GeV
Data / Bkg
m_ττ^MMC [GeV]
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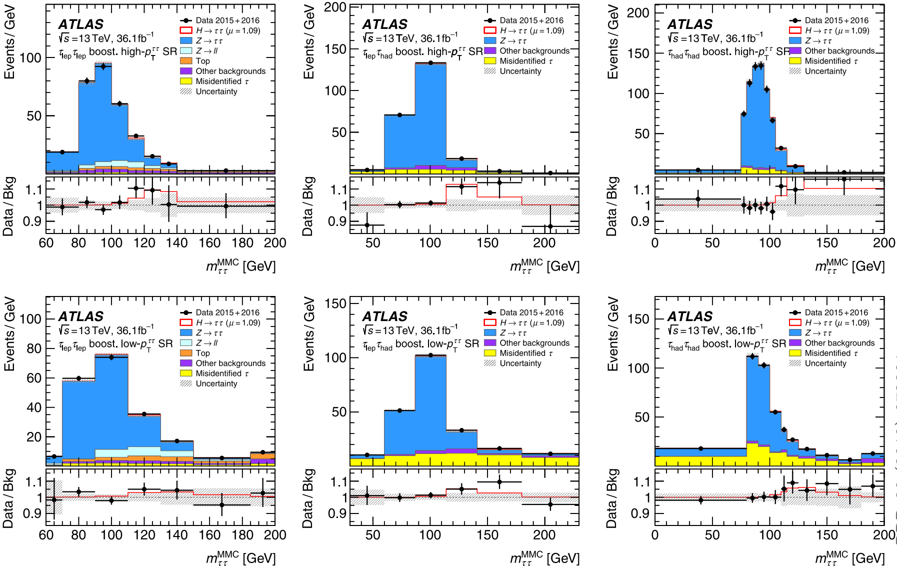
Final $m_{\tau\tau}^{\mathrm{MMC}}$ Distributions
In the Boosted Signal Regions



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$Z \to \ell\ell$ Controll Regions

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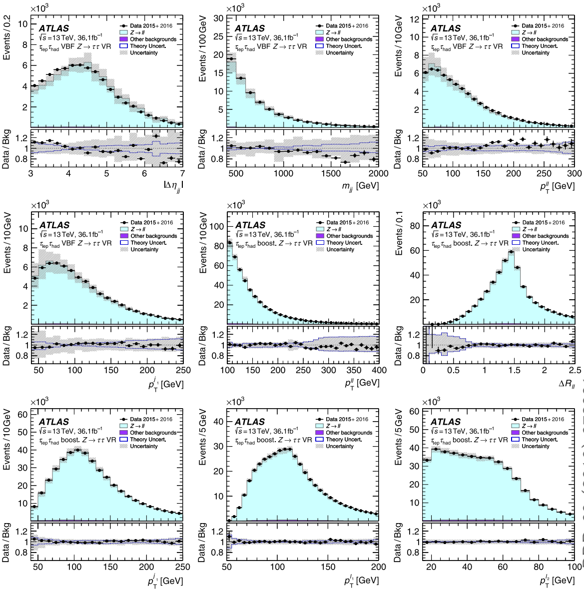

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	$\tau_{\text{lep}}\tau_{\text{lep}}$ VBF		$\tau_{\text{lep}}\tau_{\text{lep}}$ boosted	
	Loose	Tight	Low-$p_T^{\tau\tau}$	High-$p_T^{\tau\tau}$
$Z \to \tau\tau$	151 ± 13	107 ± 12	2977 ± 90	2687 ± 64
$Z \to \ell\ell$	15.1 ± 4.9	20.3 ± 6.6	360 ± 54	236 ± 31
Top	33.0 ± 6.4	25.1 ± 4.5	321 ± 50	189 ± 29
VV	11.8 ± 2.2	10.7 ± 1.5	194.1 ± 8.5	195.3 ± 8.8
Misidentified τ	18.3 ± 9.6	9.6 ± 4.8	209 ± 92	80 ± 35
ggF, $H \to WW^*$	1.2 ± 0.2	1.4 ± 0.3	11.8 ± 2.6	16.4 ± 1.7
VBF, $H \to WW^*$	1.7 ± 0.2	4.1 ± 0.5	2.9 ± 0.3	2.9 ± 0.3
ggF, $H \to \tau\tau$	2.6 ± 0.9	1.8 ± 0.9	34.4 ± 9.2	33.8 ± 9.5
VBF, $H \to \tau\tau$	5.3 ± 1.5	11.3 ± 3.0	7.7 ± 2.1	8.2 ± 2.3
WH, $H \to \tau\tau$	< 0.1	< 0.1	2.5 ± 0.7	3.1 ± 0.9
ZH, $H \to \tau\tau$	< 0.1	< 0.1	1.3 ± 0.4	1.6 ± 0.4
$t\bar{t}H$, $H \to \tau\tau$	< 0.1	0.1 ± 0.1	1.5 ± 0.5	1.2 ± 0.4
Total background	232 ± 13	178 ± 12	4075 ± 61	3408 ± 54
Total signal	8.0 ± 2.2	13.2 ± 3.5	47 ± 12	48 ± 12
Data	237	188	4124	3444

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	$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ VBF		$\tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ boosted	
	Loose	Tight	Low-$p_{\mathrm{T}}^{\tau\tau}$	High-$p_{\mathrm{T}}^{\tau\tau}$
$Z \to \tau\tau$	178 ± 18	323 ± 21	4187 ± 92	5347 ± 82
$Z \to \ell\ell$	10.0 ± 3.0	12.7 ± 3.1	130 ± 37	115 ± 16
Top	5.8 ± 1.6	17.9 ± 4.6	121 ± 20	57 ± 10
Misidentified τ	103 ± 16	101 ± 15	1895 ± 80	605 ± 29
Other backgrounds	4.0 ± 1.6	9.3 ± 1.9	115.0 ± 7.8	129.0 ± 8.8
ggF, $H \to \tau\tau$	3.8 ± 1.1	7.1 ± 1.9	62 ± 16	66 ± 22
VBF, $H \to \tau\tau$	7.6 ± 2.2	24.7 ± 6.8	11.9 ± 3.4	14.0 ± 4.0
WH, $H \to \tau\tau$	< 0.1	0.1 ± 0.0	3.9 ± 1.1	5.4 ± 1.4
ZH, $H \to \tau\tau$	< 0.1	< 0.1	1.8 ± 0.5	2.8 ± 0.7
$t\bar{t}H$, $H \to \tau\tau$	< 0.1	< 0.1	0.1 ± 0.0	0.2 ± 0.1
Total background	301 ± 17	463 ± 21	6448 ± 81	6253 ± 80
Total signal	11.5 ± 3.2	32.0 ± 8.2	80 ± 20	89 ± 26
Data	318	496	6556	6347

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$H \to \tau_{\text{had}}\tau_{\text{had}}$ Yields

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	$\tau_{\text{had}}\tau_{\text{had}}$ VBF			$\tau_{\text{had}}\tau_{\text{had}}$ boosted	
	Loose	Tight	High-$p_T^{\tau\tau}$	Low-$p_T^{\tau\tau}$	High-$p_T^{\tau\tau}$
$Z \to \tau\tau$	67.3 ± 9.2	100 ± 12	141 ± 12	3250 ± 130	3582 ± 82
Misidentified τ	45.0 ± 5.4	96.4 ± 9.2	20.0 ± 2.9	1870 ± 140	364 ± 53
Other backgrounds	4.4 ± 1.4	11.6 ± 1.7	4.4 ± 0.7	281 ± 21	109.9 ± 9.2
ggF, $H \to \tau\tau$	1.1 ± 0.4	2.0 ± 0.7	3.5 ± 1.0	41 ± 11	48 ± 14
VBF, $H \to \tau\tau$	1.4 ± 0.5	6.4 ± 1.8	11.2 ± 3.0	9.0 ± 3.4	10.7 ± 2.9
WH, $H \to \tau\tau$	< 0.1	< 0.1	< 0.1	3.3 ± 0.9	4.4 ± 1.2
ZH, $H \to \tau\tau$	< 0.1	< 0.1	< 0.1	2.4 ± 0.7	2.9 ± 0.8
$t\bar{t}H$, $H \to \tau\tau$	< 0.1	< 0.1	< 0.1	1.6 ± 0.5	1.9 ± 0.5
Total background	116.7 ± 9.4	208 ± 12	165 ± 12	5401 ± 78	4057 ± 64
Total signal	2.6 ± 0.8	8.6 ± 2.4	14.9 ± 3.8	57 ± 15	68 ± 18
Data	121	220	179	5455	4103

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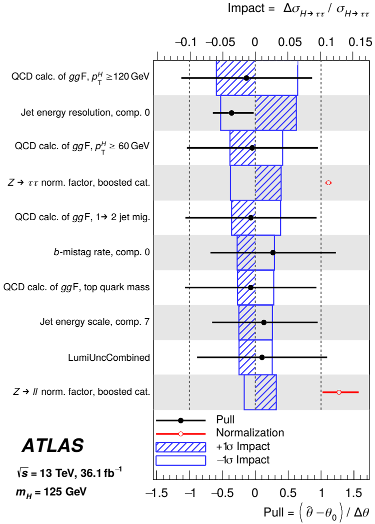
$H \to \tau\tau$ Uncertainties

Source of uncertainty	Impact $\Delta\sigma/\sigma_{H\to\tau\tau}$ [%] Observed	Impact $\Delta\sigma/\sigma_{H\to\tau\tau}$ [%] Expected
Theoretical uncert. in signal	+13.4 / −8.7	+12.0 / −7.8
Background statistics	+10.8 / −9.9	+10.1 / −9.7
Jets and $E_{\mathrm{T}}^{\mathrm{miss}}$	+11.2 / −9.1	+10.4 / −8.4
Background normalization	+6.3 / −4.4	+6.3 / −4.4
Misidentified τ	+4.5 / −4.2	+3.4 / −3.2
Theoretical uncert. in background	+4.6 / −3.6	+5.0 / −4.0
Hadronic τ decays	+4.4 / −2.9	+5.5 / −4.0
Flavor tagging	+3.4 / −3.4	+3.0 / −2.3
Luminosity	+3.3 / −2.4	+3.1 / −2.2
Electrons and muons	+1.2 / −0.9	+1.1 / −0.8
Total systematic uncert.	+23 / −20	+22 / −19
Data statistics	±16	±15
Total	+28 / −25	+27 / −24



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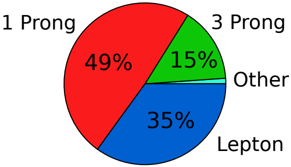
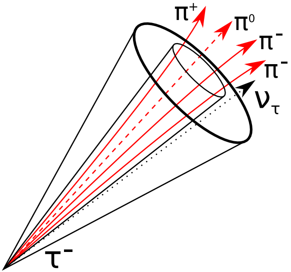
General

- Heaviest lepton in the SM (1.78 GeV)
  $\Rightarrow$ Important for Higgs and BSM physics
- Decays either to lighter leptons or hadrons



Decay modes of tau leptons



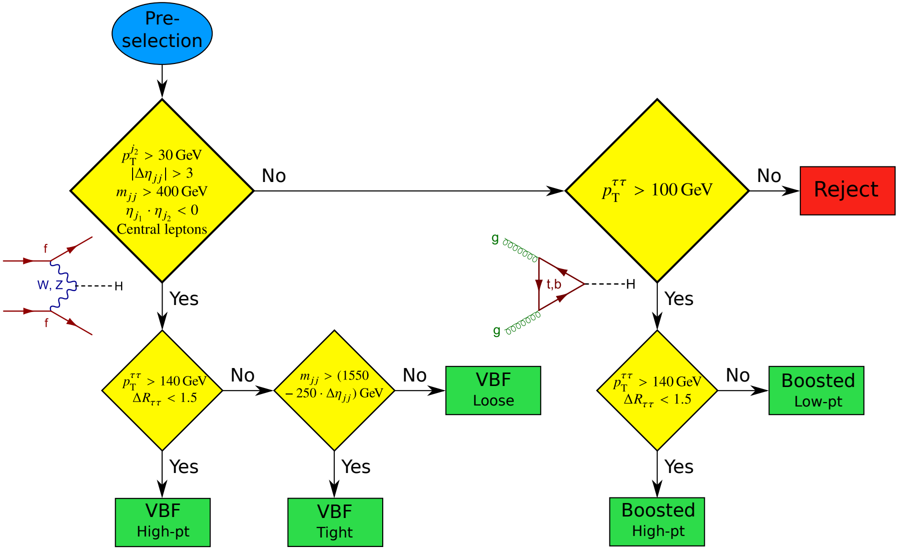
Scheme for a 3 prong tau decay

Hadronic Decays

- Categorised by number of charged tracks ("prong")
  - 1 prong: e.g. $\tau^{\pm} \rightarrow \nu_{\tau}\, \pi^{\pm}\, (n\, \pi^{0})$
  - 3 prong: e.g. $\tau^{\pm} \rightarrow \nu_{\tau}\, \pi^{\pm}\, \pi^{\pm}\, \pi^{\mp}\, (n\, \pi^{0})$
- Forming narrow jets ($\tau_{\text{had-vis}}$)
- Displaced secondary vertex
- Identified with MVA techniques

Signal Regions

In the $H \rightarrow \tau_{\text{had}}\tau_{\text{had}}$ Channel



$H \to \tau\tau$ Backgrounds

In the $H \to \tau_{had}\tau_{had}$ Channel

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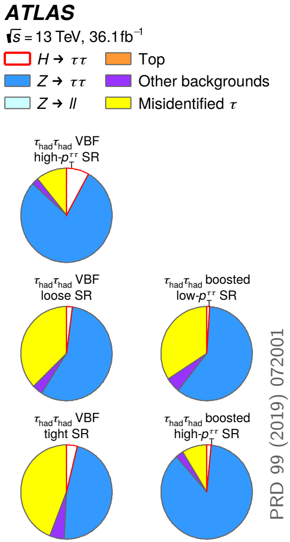


Dominant Backgrounds

- $Z \to \tau\tau$
  $\Rightarrow$ MC with free normalisation
- Misidentified τ (Fakes)
  $\Rightarrow$ Template from control region

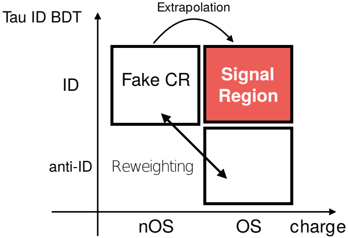
Other Backgrounds

At least one real tau:

- Top
- W+Jet
- Diboson

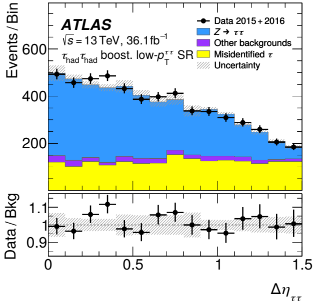
$\Rightarrow$ Estimated by MC

	$q(\tau_1) \cdot q(\tau_2)$	nTracks(τ)	τ_2-ID
SR	$= -1$	$\in \{1, 3\}$	tight
nOS	$\neq -1$	$\in \{1, 2, 3\}$	tight
anti-ID	$= -1$	$\in \{1, 3\}$	medium, not tight



Template

- From not-opposite-sign (nOS)
- Real-tau backgrounds subtracted via MC



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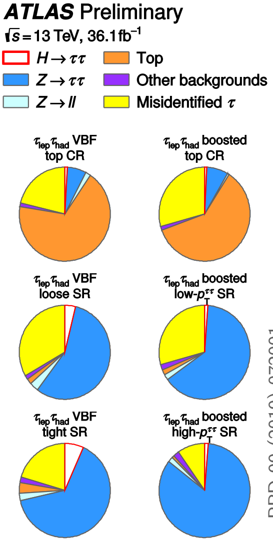
$\Delta\Phi_{\tau\tau}$-Reweighting

- Anti-ID is kinematically closer to SR
- Reweighting of events in $\Delta\Phi_{\tau\tau}$



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Dominant Backgrounds

- $Z \to \tau\tau$
  $\Rightarrow$ MC with free normalisation
- Jet faking τ_{had}
  $\Rightarrow$ Fake factor method
- $t\bar{t}$, single-top
  $\Rightarrow$ MC with CR for fit

Other Backgrounds

- $Z \to \ell\ell$
- W+Jet
- Diboson

$\Rightarrow$ Estimated by MC

Idea: Take data from anti-τ region and scale it with fake factor (FF):

$$N_{\text{fakes}}^{\text{SR}} = \left(N_{\text{data}} - N_{\text{MC}}^{\text{not } j \rightarrow \tau}\right)^{\text{anti-}\tau} \cdot FF$$

Fake factor is combined for all processes with jets faking τ_{had}:

$$FF = R_W \cdot FF_W + R_Z \cdot FF_Z + R_{Top} \cdot FF_{Top} + R_{QCD} \cdot FF_{QCD}, \qquad \sum_i R_i = 1$$

Z+jets and Top backgrounds can be merged with W+jets, since

$$R_Z, R_{Top} \lesssim 1\%, \qquad FF_Z \approx FF_{Top} \approx FF_W \text{ (quark-jet dominated)}$$

$$\Rightarrow \mathbf{FF} = (\mathbf{1} - \mathbf{R_{QCD}}) \cdot \mathbf{FF_W} + \mathbf{R_{QCD}} \cdot \mathbf{FF_{QCD}}$$

(for each SR, binned in p_T and N_{tracks})

$$\mathbf{FF} = (\mathbf{1} - \mathbf{R_{QCD}}) \cdot \mathbf{FF_W} + \mathbf{R_{QCD}} \cdot \mathbf{FF_{QCD}}$$

Caclulating fake factors and R_{QCD} in anti-τ region:

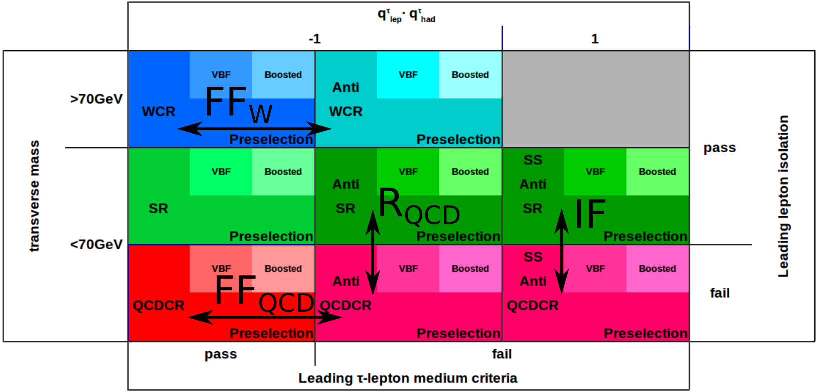
$$\mathbf{FF_i} = \frac{\left(N_{\text{data}} - N_{\text{MC}}^{\text{not } j \rightarrow \tau}\right)^{\text{pass-}\tau}}{\left(N_{\text{data}} - N_{\text{MC}}^{\text{not } j \rightarrow \tau}\right)^{\text{anti-}\tau}}, \text{ in } CR_i \qquad \mathbf{R_{QCD}} = \left(\frac{N_{\text{QCD, data}}}{N_{\text{data}} - N_{\text{MC}}^{\text{not } j \rightarrow \tau}}\right)^{\text{anti-}\tau}$$

$$N_{\text{QCD, data}}^{\text{anti-}\tau} = \left(N_{\text{data}} - N_{\text{MC, true lepton}}\right)_{\text{QCD-CR}}^{\text{anti-}\tau} \cdot IF$$

With a correction factor for the anti-isolation cut in the QCD CR:

$$IF = \left(\frac{\left(N_{\text{data}} - N_{\text{MC, true lepton}}\right)^{\text{iso}}}{\left(N_{\text{data}} - N_{\text{MC, true lepton}}\right)^{\text{non-iso}}}\right)^{\text{same-sign}}$$

$H \to \tau_{\text{lep}}\tau_{\text{had}}$ Fake Factor

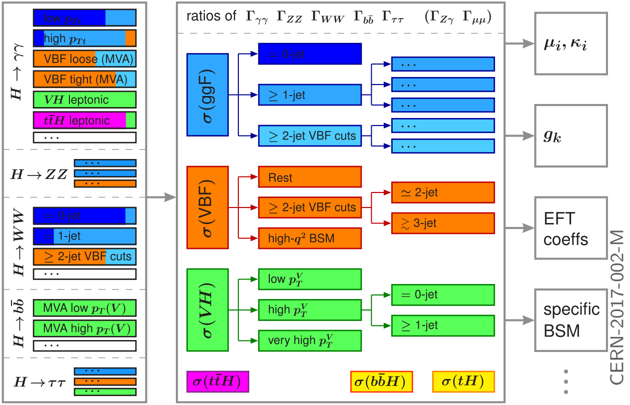


(Caveat: isolation factor derived in “pass-τ”)

In addition, a *simplified template cross-section* (STXS) fit is performed.

Idea

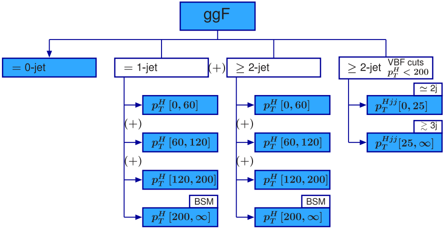
- Step between:
  - total xsec
  - diff. fid. xsec
- Decay channel combination
- Split by production mode
- Exclusive phase space bins
- see also: CERN-2017-002-M



STXS scheme

STXS Result

Simplified Template Cross Sections



Fit to Data

- Signal templates from STXS bins
- Fixed cross-section in some ggH bins:
  - 0-jet
  - ≥1-jet $p_T(\mathrm{H}) < 60$ GeV
  - VBF like
- VH and ttH Bins fixed to SM

Results

Three STXS bins left free in fit:

Process	Particle-level selection	σ [pb]	σ^{SM} [pb]
ggF	$N_{\mathrm{jets}} \geq 1, 60 < p_T^H < 120\,\mathrm{GeV}, \lvert y_H \rvert < 2.5$	$1.79 \pm 0.53\,(\mathrm{stat.}) \pm 0.74\,(\mathrm{syst.})$	0.40 ± 0.05
ggF	$N_{\mathrm{jets}} \geq 1, p_T^H > 120\,\mathrm{GeV}, \lvert y_H \rvert < 2.5$	$0.12 \pm 0.05\,(\mathrm{stat.}) \pm 0.05\,(\mathrm{syst.})$	0.14 ± 0.03
VBF	$\lvert y_H \rvert < 2.5$	$0.25 \pm 0.08\,(\mathrm{stat.}) \pm 0.08\,(\mathrm{syst.})$	0.22 ± 0.01

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