ATLAS results on rare H(125) and BSM decays

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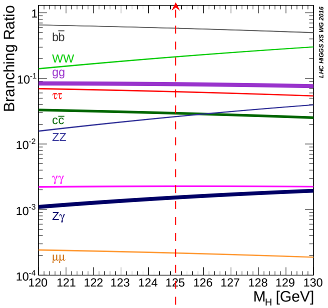
On behalf of the ATLAS collaboration

Where rare and BSM Higgs decay stand



- Need to consolidate the $1^{st}/2^{nd}$ gen. fermions' Yukawa couplings with the Higgs boson.
- Small masses → Tiny $BR(H \to 1^{st}/2^{nd}\ gen.\ f\bar{f}) < 0.1\%$ → Sensitive to possible BSM physics enhancement.
- Higgs portal to Dark Sector.

Ranking in BR:

- Rare: $c\bar{c}$, $Z\gamma$, 4ν (invisible), $\mu^+\mu^-$(M.Zgubic's talk)
- Very rare: X+γ, X: Quarkonia or vector mesons
- BSM: lepton flavour violation (LFV) $e\tau/\mu\tau$

Analysis	$\sqrt{s}, \mathcal{L}[fb^{-1}]$	BR_{SM}	Reference
$\mu^+\mu^-$	13TeV, 139	$\sim 10^{-4}$	ATLAS-CONF-2019-028
$J/\psi\gamma, \Upsilon\gamma$	13TeV, 36.1	$\sim 10^{-9} - 10^{-6}$	PLB 786 (2018)134
$\Phi\gamma, \rho\gamma$	13TeV, 35.6	$\sim 10^{-6} - 10^{-5}$	JHEP 07 (2018) 127
$Z\gamma$	13TeV, 36.1	$\sim 10^{-3}$	JHEP 10 (2017) 112
$c\bar{c}$	13TeV, 36.1	2.9%	PRL 120 (2018) 211802
invisible	(2015+2016) + Run 1	$\sim 10^{-3}$	PRL 122 (2019) 231801
$e\tau/\mu\tau$	13TeV, 36.1	0	HIGG-2017-08

What to be presented

- Quick summaries of rare decays:
  - Higgs $\rightarrow$ X+γ:
    - $J/\psi\gamma, \psi(2S)\gamma, \Upsilon\gamma$. X: Quarkonia (Q) $c\bar{c}$, $\bar{b}b$
    - $\Phi\gamma, \rho\gamma$. X: $s\bar{s}$, (u,d) mesons
    - $Z\gamma$. X: Z boson
  - Higgs decay $\rightarrow \mu^{+}\mu^{-}$.

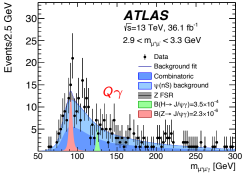
- Details into:
  - Rare decay $H \rightarrow c\bar{c}$
  - BSM LFV $H \rightarrow \ell\tau$
  - BSM Higgs $\rightarrow$ invisible.

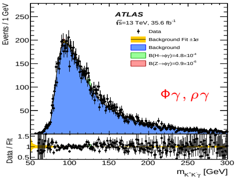
Higgs rare decays: X+γ, $\mu^+\mu^-$

Analysis	Final states	13 TeV, $\mathcal{L}[\text{fb}^{-1}]$	SM prediction	Results	Reference
			BR(H decays)	$\sigma_H \times$ BR(H decays)	
$Z\gamma$	$ee/\mu\mu + \gamma$	36.1	10^{-4}	6.6 (5.2) $\times$ SM	JHEP 10 (2017) 112
$\mu^+\mu^-$		139		1.7 $\times$ SM	ATLAS-CONF-2019-028, Miha's talk
				BR(H decays)	
$\rho\gamma$	$\pi^+\pi^-\gamma$	35.6	10^{-6}	$(8.8) \times \mathbf{10}^{-4}$	JHEP 07 (2018) 127
$\Phi\gamma$	$K^+K^-\gamma$			$4.8 \times \mathbf{10}^{-4}$	
$J/\psi\gamma$			10^{-8}	$3.5 \times \mathbf{10}^{-4}$	
$\psi(2S)\gamma$	$\mu^+\mu^-\gamma$	36.1		$2.0 \times \mathbf{10}^{-3}$	PLB 786 (2018)134
$\Upsilon\gamma$ (n=1, 2, 3)				$(4.9, 5.9, 5.7) \times \mathbf{10}^{-4}$	

- No significant excess.
- Maxinum likelihood fit to reconstructed Higgs mass.
- 95% CL limit on BR(H decays) or $\sigma_H \times$ BR(H decays).

PLB 786 (2018)134





JHEP 07 (2018) 127

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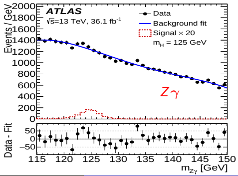
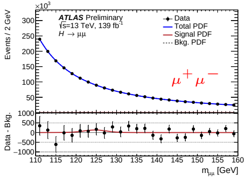


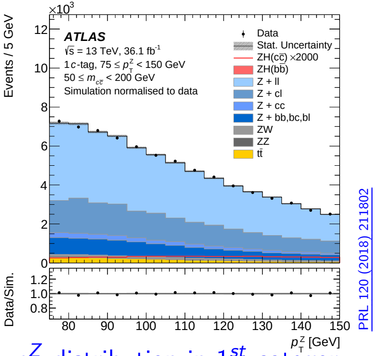


ATLAS-CONF-2019-028

$H \to c\bar{c}$ PRL 120 (2018) 211802, 36.1 fb^{-1}, 13TeV

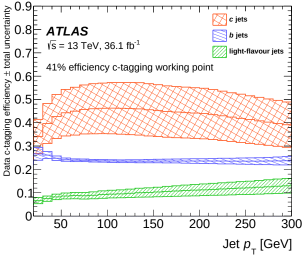
- **Motivation**: investigate Higgs coupling to c-quarks.
- **Challenges**: small BRs, large bkgs, challenging jet flavor identification $\to$ direct search $ZH \to \ell\ell c\bar{c}$, ($\ell = e, \mu$).
- Harder p_{T}^{Z} distribution in ZH compared to Z+jets.
- **Select**: single-lepton triggers
  - $=$ 2 same flavour opposite sign (SFOS) $\mu\bar{\mu}$ or 2 SF ee, $|m_{\ell\ell} - m_Z| \leq 10$ GeV.
  - $\geq$ 2 jets, in which ≥ 1 c-tagged (using c-tagging algorithm)
- **Reject bkgs**: $\Delta R(c, \bar{c}) < 2.2$, 1.5, 1.3 for events $p_{\mathrm{T}}^{Z} \in [75, 150], [150, 200], [200, \infty)$ GeV.

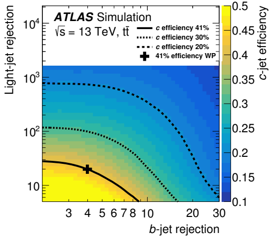
- 4 categories: p_{T}^{Z}: [75, 150], $>$ 150 GeV. c-tags: 1, 2.
- **Validation:** measuring ZW & ZZ yields (samples enriched in W $\to$ cs, cd & Z $\to c\bar{c}$ decays).



p_{T}^{Z} distribution in 1st category

$H \to c\bar{c}$ c-tagging algorithm





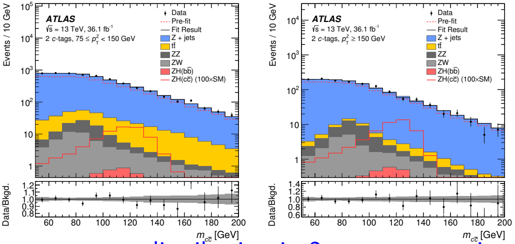
PRL 120 (2018) 211802

Chosen: c-jets 41% efficiency, rejection factors of 4.0(20) for b-jets(l-jets).

- Different lifetimes of b-, c- and light-flavor hadrons $\to$ Flavor-tagging.
- Train BDT $\to$ 2 multivariate discriminants: c-jets vs l-jets, c-jets vs b-jets separation
- Calibrate the efficiencies to data using b-quarks from $t \to Wb$, c-quarks from $W \to cs, cd$
- Reducing stat. uncert. in the simulation by weighting events based on jets' tagging efficiencies = $f(\text{jet-flavor}, p_{\mathrm{T}}, \eta, \Delta R(j,j))$

$H \to c\bar{c}$ Fit

- Discriminating variable: $m_{c\bar{c}}$ from 2 highest-p_{T} jets.
- Joint profile-likelihood fit to $m_{c\bar{c}}$ in 4 categories: extract the signal yield & Z+jets bkg normalization.
- 15 bins in each category, $m_{c\bar{c}} \in [50, 200]$ GeV, 10 GeV width.



PRL 120 (2018) 211802

$m_{c\bar{c}}$ distribution in 2 c-tag categories

- Separate norm. factors for Z+jets, same for the rest.
- Systematic uncertainties: on shape/normalization.

Source	$\sigma/\sigma_{\mathrm{tot}}$
Statistical	**49%**
Floating Z + jets normalization	31%
Systematic	**87%**
Flavor tagging	73%
Background modeling	47%
Lepton, jet and luminosity	28%
Signal modeling	28%
MC statistical	6%

- Signal strengh $\mu_{ZH} = \dfrac{\text{measured Signal}}{\text{SM prediction}}$

$H \to c\bar{c}$ Results

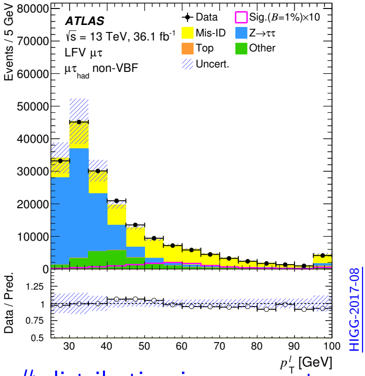
Sample	Yield, 50 $GeV < m_{c\bar{c}} <$ 200 GeV			
	1 c-tag		2 c-tags	
	$75 \leq p_T^Z < 150\,GeV$	$p_T^Z \geq 150\,GeV$	$75 \leq p_T^Z < 150\,GeV$	$p_T^Z \geq 150\,GeV$
Z + jets	69400 ± 500	15650 ± 180	5320 ± 100	1280 ± 40
ZW	750 ± 130	290 ± 50	53 ± 13	20 ± 5
ZZ	490 ± 70	180 ± 28	55 ± 18	26 ± 8
$t\bar{t}$	2020 ± 280	130 ± 50	240 ± 40	13 ± 6
$ZH(b\bar{b})$	32 ± 2	19.5 ± 1.5	4.1 ± 0.4	2.7 ± 0.2
$ZH(c\bar{c})$ (SM)	-143 $\pm$ 170 (2.4)	-84 $\pm$ 100 (1.4)	-30 $\pm$ 40 (0.7)	-20 $\pm$ 29 (0.5)
Total	72500 ± 320	16180 ± 140	5650 ± 80	1320 ± 40
Data	72504	16181	5648	1320

- No excess on observed data over the expected backgrounds.
- Best fit value of $\mu_{ZH} = -69 \pm 101 \to$ negative post-fit signal.
- Observed (expected) upper limit at 95% CL:
  - on $\sigma(pp \to ZH) \times BR(H \to c\bar{c})$: 2.7 ($3.9^{+2.1}_{-1.1}$) pb. (SM value is 26 fb).
  - or on signal strength: 110 (150^{+80}_{-40})

LFV $H \to \ell\tau$ HIGG-2017-08, 36.1 fb^{-1}, 13TeV

- **Motivation**: BSM theories such as extensions of the Higgs sector or warped extra dimension models
- 4 categories:
  - **Production channels:** VBF; non-VBF: ggF, WH/ZH.
  - **Decay channels**: leptonic, hadronic.
- **Select:** Single-lepton triggers
  - $=1e$ and $=1\mu$ **opposite sign (OS)** in dilepton final states $\ell\tau_{\ell'}$.
  - $=1\ell$ and $=1\tau_{had-vis}$ of OS in the τ_{had} channel.
  - b-veto

- Leading-p_{T} lepton's flavour determines $e\tau$ or $\mu\tau$ channel.
- 1st Search $H \to e\tau$: $e\tau_{\mu}$, $e\tau_{had}$
- 2nd Search $H \to \mu\tau$: $\mu\tau_{e}$, $\mu\tau_{had}$



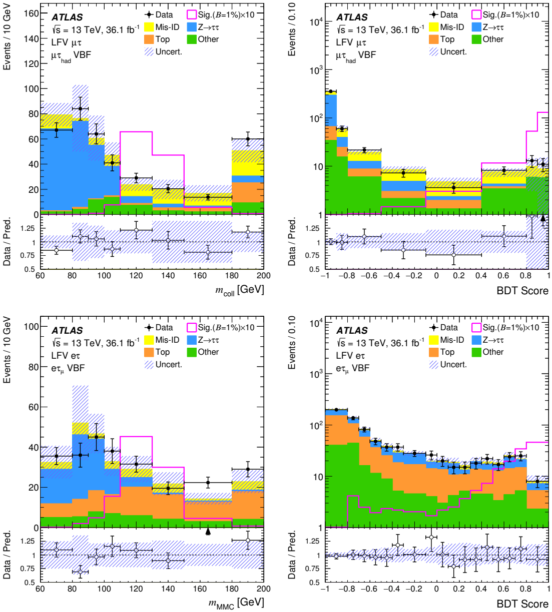
$p_{\mathrm{T}}{}^{\mu}$ distribution in $\mu\tau_{had}$ category

LFV $H \to \ell\tau$ Background Modelling

- Top control regions (CRs): inverted b-veto cut.
- $Z \to \tau\tau$ CRs: inverted $p_{\mathrm{T}}^{\ell_1}$ cut.
- Exploits BDT algorithms to enhance the signal separation from the background.

Bkgs/Channels	Leptonic		Hadronic	
	VBF	non-VBF	VBF	non-VBF
	From simultaneous fit including CRs			
$Z \to \tau\tau$	Normalization: from the fit. Separate factors for VBF, non-VBF.			
top (single-t, $t\bar{t}$)	Shape: from simulation.			
	Normalization: from the fit with 1 common factor.		Normalization: from MC, fixed in the fit.	
	Data driven method			
W+jets, t, multijet	Jets misidentified as leptons Inverted isolation from OS data events		Jets misidentified as $\tau_{had-vis}$ Fake factor method	
$Z \to ee$			electrons misidentified as $\tau_{had-vis}$	
	Cuts which reduce bkgs			
	$m_{\ell\ell'}(=m_{vis}) \in [30,100]$ GeV $\downarrow t-quarks$		$\sum_{i=\ell,\tau_{had-vis}} \Delta\Phi(i, E_{\mathrm{T}}^{\mathrm{miss}}) \downarrow$ W+jets	
	$\frac{p_{\mathrm{T}}^{e}(track)}{p_{\mathrm{T}}^{e}(cluster)} < 1.2(\mu\tau_e\ only) \downarrow Z \to \mu\mu$		$\Delta\eta(\ell, \tau_{had-vis}) \downarrow$ misidentified $\tau_{had-vis}$	
	Best BDT variable as "reconstructed" Higgs invariant mass $\downarrow H \to \tau\tau$, HWW			
	m_{MMC} by MMC algorithm		m_{coll} with collinear approximation	

LFV $H \to \ell\tau$ fit

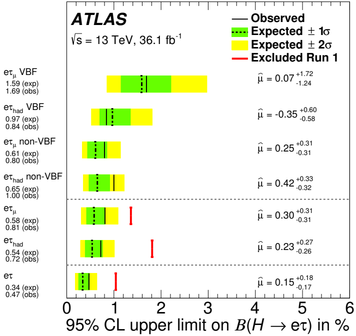


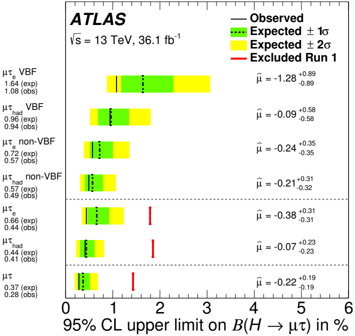
- **Fit**: Maxinum binned likelihood fit made from BDT score distributions of all signal regions and event yields in CRs.
- **Systematic uncertainties** affect the normalization and/or the shape.
- Correlations across processes, channels, categories and regions.
- **Main systematic sources**: from estimation of mis-identified leptons/jets bkgs and jet energy scale

LFV $H \to \ell\tau$ results

	$\mu\tau_e$ non-VBF	$\mu\tau_e$ VBF	$\mu\tau_{\rm had}$ non-VBF	$\mu\tau_{\rm had}$ VBF
Signal	287 ± 23	14.6 ± 1.9	1200 ± 120	25 ± 5
$Z \to \tau\tau$	1860 ± 130	144 ± 26	96100 ± 2000	274 ± 33
Top-quark	1260 ± 130	390 ± 34	1620 ± 210	51 ± 10
Mis-identified	1340 ± 210	41 ± 21	63900 ± 1600	149 ± 33
Other	1180 ± 140	168 ± 18	23000 ± 1000	104 ± 15
Total Bkg.	5640 ± 100	743 ± 29	184500 ± 1200	580 ± 30
Data	5664	723	184508	583

- Observed data agrees with expected background.
- The observed (median) 95% CL limit: 0.47% ($0.34^{+0.13}_{-0.10}$%) and 0.28% ($0.37^{+0.14}_{-0.10}$%) for $H \to e\tau$ and $H \to \mu\tau$

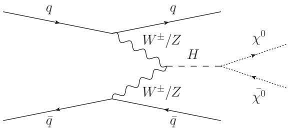




Combination of Higgs to invisible, 36.1 fb^{-1}+ Run1, 13 TeV + 7,8 TeV

- **Motivation:** Higgs Portal to Dark Matter with $m_{DM} < \frac{m_H}{2}$
- Assuming productions & acceptance as in the SM: $BR(H \to ZZ^* \to 4\nu) \sim 10^{-3}$ $\Rightarrow$ result not sensitive to this but to BSM enhancement

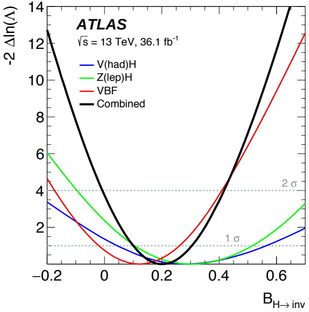
- VBF H $\to$ inv, the most sensitive channel



- Combination of direct searches for H $\to$ invisible (E_T^{miss}) from different Higgs production channels: association with Z($\ell\ell$), W/Z(jj) & VBF (jj). PRL 122 (2019) 231801
  - Signatures: large E_T^{miss}+ particles produced in association with the Higgs boson
  - Combination of Run 2 + combination of Run 1
  - Setting 95% CL limit on BR(H$\to$inv)

Techniques

- Statistical combination of individual Run 2 analyses
  - Maximize the combined binned likelihood ratio.
- Combined Run 2 result is then combined with Run 1 one.
- Correlation scheme:
  - Correlating most of the experimental uncertainties.
  - Except flavor tagging and the JES due to different parametrizations (impact found to be small).
  - Correlating most of the theoretical uncertainties,
  - Not correlating uncertainties which are tightly constrained.

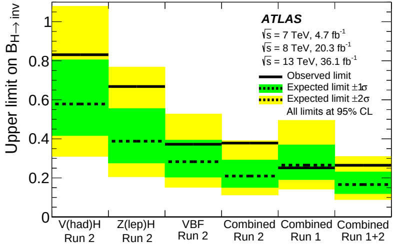


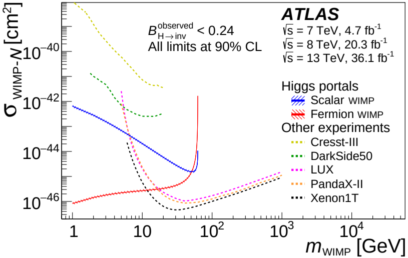
- Observed negative log likelihood ratios Run 2.

Results No significant excess

Analysis		ATLAS	
		VBF	Combo
Limit obs(exp)	Run2	0.37 (0.28)	0.38 (0.21)
	Run1+Run2		0.26 (0.17)
Reference		PLB 793 (2019) 499	PRL 122 (2019) 231801

- Results driven by VBF channel (most sensitive)
- Model-dependent additional constraints from visible H-coupling measurements: ATLAS-CONF-2019-005 (check slide 23).





- Upper limit at 95% CL on BR(H→inv) obs(exp) 0.26(0.17)
- Upper limit at 90% CL on WIMP-nucleon scattering XS.

Conclusion

- Presented summaries of the rare decays of the Higgs boson to Quarkonia/vector mesons in association with γ; Zγ.

- Direct search for $H \to c\bar{c}$, LFV $H \to \ell\tau$ decays are shown in details.

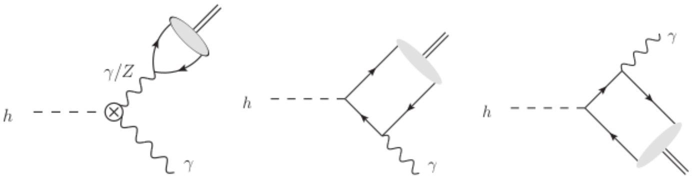
- No significant excess anywhere. Limits are 1 to 5 order of magnitude far from the SM, so there is still room for BSM physics.
  - The searches are statistically limited.
  - At HL-LHC, much larger dataset will allow substantial improvements to a much closer limit at the level of SM prediction or even observation ($Z\gamma$) (see Murray's slides).

- Combination of the direct searches for invisible decays put tight constraint on Higgs portal Dark Matter decays. Much more stringent limit is expected at the HL-LHC.

BACK UP

Higgs to X+γ

From J. Broughton



- Distinctive topology of a pair of high-p_{T} isolated muons, recoiling against a high-p_{T} isolated photon
- **Higgs decays:** Sensitive to Higgs boson quark couplings for c and b quarks

Higgs rare decays

Analysis	13 TeV, $\mathcal{L}[\mathrm{fb}^{-1}]$	SM prediction	Results	Reference
		BR(H decays)		
$J/\psi\gamma$	36.1	$(2.99^{+0.16}_{-0.15}) \times \mathbf{10^{-6}}$	$3.5 \times \mathbf{10^{-4}}$	PLB 786 (2018)134
$\psi(2S)\gamma$		$(1.03 \pm 0.06) \times \mathbf{10^{-6}}$	$2.0 \times \mathbf{10^{-3}}$	
$\Upsilon\gamma$ n=1, 2, 3		$(5.22^{+2.02}_{-1.70}, 1.42^{+0.72}_{-0.57}, 0.91^{+0.48}_{-0.38}) \times \mathbf{10^{-9}}$	$(4.9, 5.9, 5.7) \times \mathbf{10^{-4}}$	
$\Phi\gamma$	35.6	$(2.31 \pm 0.11) \times \mathbf{10^{-6}}$	$4.8 \times \mathbf{10^{-4}}$	JHEP 07 (2018) 127
$\rho\gamma$		$(1.68 \pm 0.08) \times \mathbf{10^{-5}}$	$(8.8) \times \mathbf{10^{-4}}$	
		BR(H decays)	$\sigma_H \times BR(H\ decays)$	
$Z\gamma$	36.1	$(1.54 \pm 0.09) \times \mathbf{10^{-3}}$	6.6 (5.2) $\times$ SM	JHEP 10 (2017) 112
$\mu^+\mu^-$	139	$2.17 \times \mathbf{10^{-4}}$	1.7 $\times$ SM	ATLAS-CONF-2019-028, K.Becker's talk

$H \to c\bar{c}$

Process	Event Generator (alternative)	Parton Shower (alternative)	PDF (alternative)	Tune	Cross-section
$q\bar{q} \to ZH$	POWHEG-BOX v2 [28] +GOSAM [35] +MINLO [45,46]	PYTHIA 8 (HERWIG 7 [47])	PDF4LHC15NLO [33] /CTEQ6L1 [36,37]	AZNLO [34] (A14 [48])	NNLO (QCD)* +NLO (EW) [38,39,40,41,42,43,44]
$gg \to ZH$	POWHEG-BOX v2	PYTHIA 8 (HERWIG 7)	PDF4LHC15NLO /CTEQ6L1	AZNLO (A14)	NLO+NLL (QCD) [49,50,51,15]
$t\bar{t}$	POWHEG-BOX v2	PYTHIA 8 (HERWIG 7)	NNPDF3.0NLO [52] /NNPDF2.3LO	A14	NNLO+NNLL [53]
ZW, ZZ	SHERPA 2.2.1 [29] (POWHEG-BOX)	SHERPA (PYTHIA 8)	NNPDF3.0NNLO	SHERPA	NLO
Z+jets	SHERPA 2.2.1 (MG5_AMC)	SHERPA (PYTHIA 8)	NNPDF3.0NNLO (NNPDF2.3LO)	SHERPA (A14)	NNLO [54]

Flavour-labelling on from simulated events

$p_T > 5$ GeV, $\Delta R(j, jet\ axis) \leq 0.3$

b-hadron	~~b-hadron~~	~~b-hadron~~
	c-hadron	~~c-hadron~~
↓	↓	↓
b-jets	c-jets	light-jets (l-jets)

$H \to \ell\tau$ Event selections

Selection	$\ell\tau_{\ell'}$	$\ell\tau_{\text{had}}$
Baseline	exactly $1e$ and 1μ, OS $p_T^{\ell_1} > 45$ GeV $p_T^{\ell_2} > 15$ GeV $30\,\text{GeV} < m_{\text{vis}} < 150\,\text{GeV}$ $p_T^e(\text{track})/p_T^e(\text{cluster}) < 1.2$ ($\mu\tau_e$ only)	exactly 1ℓ and $1\tau_{\text{had-vis}}$, OS $p_T^{\ell} > 27.3$ GeV $p_T^{\tau_{\text{had-vis}}} > 25$ GeV, $\lvert\eta^{\tau_{\text{had-vis}}}\rvert < 2.4$ $\sum_{i=\ell,\tau_{\text{had-vis}}} \cos\Delta\phi(i, E_T^{\text{miss}}) > -0.35$ $\lvert\Delta\eta(\ell, \tau_{\text{had-vis}})\rvert < 2$
	b-veto (for jets with $p_T > 25$ GeV and $\lvert\eta\rvert < 2.4$)	
VBF	Baseline ≥ 2 jets, $p_T^{j_1} > 40$ GeV, $p_T^{j_2} > 30$ GeV $\lvert\Delta\eta(j_1, j_2)\rvert > 3$, $m(j_1, j_2) > 400$ GeV	
	–	$p_T^{\tau_{\text{had-vis}}} > 45$ GeV
Non-VBF	Baseline plus fail VBF categorization	
	$m_T(\ell_1, E_T^{\text{miss}}) > 50$ GeV	–
	$m_T(\ell_2, E_T^{\text{miss}}) < 40$ GeV	–
	$\lvert\Delta\phi(\ell_2, E_T^{\text{miss}})\rvert < 1.0$	–
	$p_T^{\tau}/p_T^{\ell_1} > 0.5$	–
Top-quark CR VBF and non-VBF	inverted b-veto: ≥ 1 b-tagged jet ($p_T > 25$ GeV and $\lvert\eta\rvert < 2.4$)	
$Z \to \tau\tau$ CR VBF and non-VBF	inverted $p_T^{\ell_1}$ requirement: $35\,\text{GeV} < p_T^{\ell_1} < 45\,\text{GeV}$	

$H \to \ell\tau$ BDT variables

$\ell\tau_{\ell'}$ Variable	VBF	non-VBF	$\ell\tau_{\text{had}}$ Variable	VBF	non-VBF
m_{MMC}	HR	HR	m_{coll}	HR	HR
$p_{\text{T}}^{\ell_1}$	•	•	p_{T}^{ℓ}	•	HR
$p_{\text{T}}^{\ell_2}$	HR	HR	$p_{\text{T}}^{\tau_{\text{had-vis}}}$	•	HR
$\Delta R(\ell_1, \ell_2)$	HR	•	$\Delta R(\ell, \tau_{\text{had-vis}})$	•	•
$m_{\text{T}}(\ell_1, E_{\text{T}}^{\text{miss}})$	•	HR	$m_{\text{T}}(\ell, E_{\text{T}}^{\text{miss}})$	HR	•
$m_{\text{T}}(\ell_2, E_{\text{T}}^{\text{miss}})$	HR	•	$m_{\text{T}}(\tau_{\text{had-vis}}, E_{\text{T}}^{\text{miss}})$	HR	HR
$\Delta\phi(\ell_1, E_{\text{T}}^{\text{miss}})$	•	•	$\Delta\phi(\ell, E_{\text{T}}^{\text{miss}})$	HR	•
$\Delta\phi(\ell_2, E_{\text{T}}^{\text{miss}})$		HR	$\Delta\phi(\tau_{\text{had-vis}}, E_{\text{T}}^{\text{miss}})$	•	
$m(\text{j}_1, \text{j}_2)$	•		$m(\text{j}_1, \text{j}_2)$	•	
$\Delta\eta(\text{j}_1, \text{j}_2)$	HR		$\Delta\eta(\text{j}_1, \text{j}_2)$	•	
$p_{\text{T}}^{\tau}/p_{\text{T}}^{\ell_1}$		HR	$\sum_{i=\ell,\tau_{\text{had-vis}}} \cos\Delta\phi(i, E_{\text{T}}^{\text{miss}})$	•	•
			$E_{\text{T}}^{\text{miss}}$	HR	•
			m_{vis}		HR
			$\Delta\eta(\ell, \tau_{\text{had-vis}})$		•
			η^{ℓ}		•
			$\eta^{\tau_{\text{had-vis}}}$		•
			ϕ^{ℓ}		•
			$\phi^{\tau_{\text{had-vis}}}$		•
			$\phi(E_{\text{T}}^{\text{miss}})$		•

Combination of Higgs to invisible decays

Analysis	$\sqrt{s}$	Int. luminosity	Observed	Expected	p_{SM}-value	Reference
Run 2 VBF	13 TeV	36.1 fb^{-1}	0.37	$0.28^{+0.11}_{-0.08}$	0.19	[36]
Run 2 $Z(\text{lep})H$	13 TeV	36.1 fb^{-1}	0.67	$0.39^{+0.17}_{-0.11}$	0.06	[37]
Run 2 $V(\text{had})H$	13 TeV	36.1 fb^{-1}	0.83	$0.58^{+0.23}_{-0.16}$	0.12	[38]
Run 2 Comb.	13 TeV	36.1 fb^{-1}	0.38	$0.21^{+0.08}_{-0.06}$	0.03	this Letter
Run 1 Comb.	7, 8 TeV	4.7, 20.3 fb^{-1}	0.25	$0.27^{+0.10}_{-0.08}$	—	[35]
Run 1+2 Comb.	7, 8, 13 TeV	4.7, 20.3, 36.1 fb^{-1}	0.26	$0.17^{+0.07}_{-0.05}$	0.10	this Letter

Parameter	(a) $B_{inv} = B_{undet} = 0$	(b) B_{inv} free, $B_{undet} \geq 0$, $\kappa_{W,Z} \leq 1$	(c) $B_{BSM} \geq 0$, $\kappa_{off} = \kappa_{on}$
κ_Z	1.11 ± 0.08	> 0.87 at 95% CL	$1.16^{+0.18}_{-0.13}$
κ_W	1.05 ± 0.09	> 0.85 at 95% CL	$1.12^{+0.18}_{-0.15}$
κ_b	$1.03^{+0.19}_{-0.17}$	0.88 ± 0.13	$1.08^{+0.25}_{-0.20}$
κ_t	$1.09^{+0.15}_{-0.14}$	$[-1.03, -0.79] \cup [0.93, 1.24]$ at 68% CL	$1.14^{+0.19}_{-0.18}$
κ_τ	$1.05^{+0.16}_{-0.15}$	0.97 ± 0.13	$1.12^{+0.23}_{-0.21}$
κ_γ	1.05 ± 0.09	0.98 ± 0.07	$1.10^{+0.19}_{-0.13}$
κ_g	$0.99^{+0.11}_{-0.10}$	$1.01^{+0.13}_{-0.11}$	$1.02^{+0.22}_{-0.13}$
B_{inv}	-	< 0.30 at 95% CL	-
B_{undet}	-	< 0.22 at 95% CL	-
B_{BSM}	-	-	< 0.47 at 95% CL

Fit results for Higgs boson coupling modifiers ATLAS-CONF-2019-005