Higgs boson measurements in the $H \to WW \to l\nu l\nu$ decay channel

ICHEP,
30th July, 2020

Anamika Aggarwal, on behalf of
HWW ATLAS analysis group

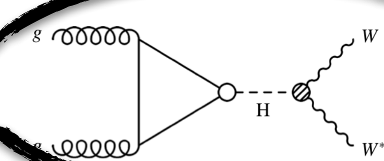
https://doi.org/10.1016/j.physletb.2018.11.064

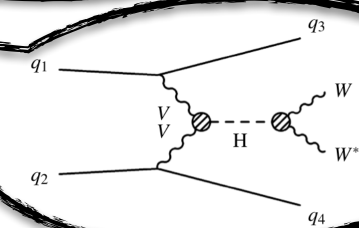
HWW couplings analysis

36.1 fb^{-1}

Why $H \to WW$?

- Large Branching ratio
- Distinguishable signal in leptonic decay mode
- Highest sensitivity to total signal strength





- 36.1 fb^{-1} data is analysed.
- Results derived with simultaneous maximum likelihood fit.
- Observables used in the fit:
  - ☞ for ggF m_T $\left(m_T = \sqrt{(E_T^{\ell\ell} + E_T^{miss})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{miss}|^2}\right)$
  - ☞ for VBF BDT with input variables m_{jj}, Δy_{jj}, $m_{\ell\ell}$, $\Delta\phi_{\ell\ell}$, m_T, $\sum_\ell C_\ell$, $\sum_{\ell,j} m_{\ell j}$, p_T^{tot}

m_{ll} (m_{jj}) {m_{lj}}: invariant mass of 2 leading leptons (2 leading jets) {lepton-jet pair}

Δy_{jj}: difference between the two jet rapidities

$\Delta\Phi_{ll}$: difference between the azimuthal angles of the two leptons

$C_l = |2\eta_l - \sum\eta_j| / \eta_{jj}|$, where η: pseudorapidity

p_T^{tot}: total transverse momentum

Signal Region

Event selection criteria to get signal dominated region

Category	$N_{jet,(p_T>30\ GeV)} = 0$ ggF	$N_{jet,(p_T>30\ GeV)} = 1$ ggF	$N_{jet,(p_T>30\ GeV)} \geq 2$ VBF
Preselection	Two isolated, different-flavour leptons ($\ell = e, \mu$) with opposite charge $p_T^{lead} > 22$ GeV, $p_T^{sublead} > 15$ GeV $m_{\ell\ell} > 10$ GeV		
	$p_T^{miss} > 20$ GeV		
Background rejection	$N_{b\text{-}jet,(p_T>20\ GeV)} = 0$		
	$\Delta\phi(\ell\ell, E_T^{miss}) > \pi/2$ $p_T^{\ell\ell} > 30$ GeV	max $(m_T^\ell) > 50$ GeV	
		$m_{\tau\tau} < m_Z - 25$ GeV	
$H \to WW^* \to e\nu\mu\nu$ topology	$m_{\ell\ell} < 55$ GeV $\Delta\phi_{\ell\ell} < 1.8$		central jet veto outside lepton veto
Discriminant variable BDT input variables	m_T		BDT m_{jj}, Δy_{jj}, $m_{\ell\ell}$, $\Delta\phi_{\ell\ell}$, m_T, $\sum_\ell C_\ell$, $\sum_{\ell,j} m_{\ell j}$, p_T^{tot}

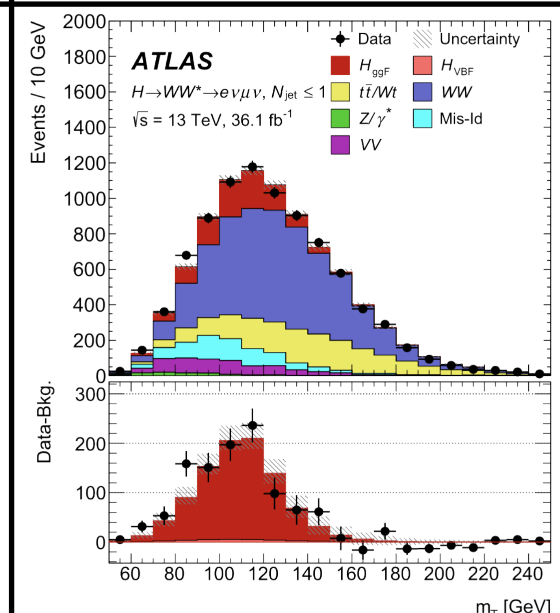
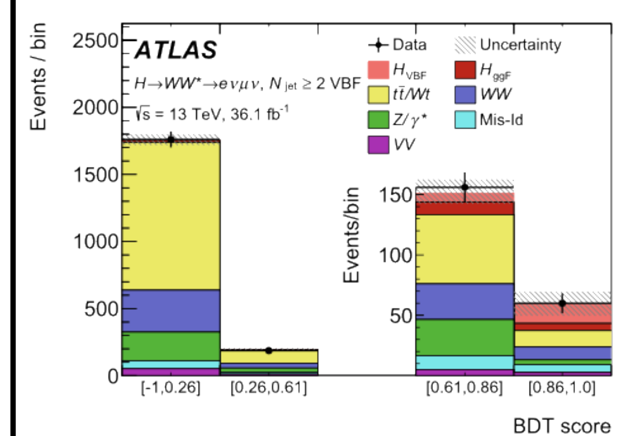
Control Regions

- Used to normalise the predictions of some of the background processes.
- Defined for the main background processes:
  - WW ☞ high m_{ll} region
  - $t\bar{t}$/Wt ☞ events with b-tag jets
  - Z/γ^* ☞ m_{ll} within m_Z window
- Misidentified leptons background is estimated using a data-driven technique.

Uncertainty

- Sources of systematic uncertainty:
  - Experimental (8% ggF, 9% VBF)
  - Theoretical (10% ggF, 19% VBF)
- Dominant experimental uncertainties:
  - Misidentified leptons (6% ggF, 9% VBF)
  - b-tagging efficiency (4% ggF, 6% VBF)
- Dominant theoretical uncertainties:
  - ggF: WW background (6%)
  - VBF: ggF background (13%)

Results

Signal	ggF	VBF
Post-fit distributions		
Signal Strength	$\mu_{ggF} = 1.10^{+0.10}_{-0.09}(\text{stat.})^{+0.13}_{-0.11}(\text{theo syst.})^{+0.14}_{-0.13}(\text{exp syst.})$ $= 1.10^{+0.21}_{-0.20}$	$\mu_{VBF} = 0.62^{+0.29}_{-0.27}(\text{stat.})^{+0.12}_{-0.13}(\text{theo syst.}) \pm 0.15(\text{exp syst.})$ $= 0.62^{+0.36}_{-0.35}$.
Cross section * branching ratio	$\sigma_{ggF} \cdot \mathcal{B}_{H \to WW^*}$ $= 11.4^{+1.2}_{-1.1}(\text{stat.})^{+1.2}_{-1.1}(\text{theo syst.})^{+1.4}_{-1.3}(\text{exp syst.})$ pb $= 11.4^{+2.2}_{-2.1}$ pb	$\sigma_{VBF} \cdot \mathcal{B}_{H \to WW^*}$ $= 0.50^{+0.24}_{-0.22}(\text{stat.}) \pm 0.10(\text{theo syst.})^{+0.12}_{-0.13}(\text{exp syst.})$ pb $= 0.50^{+0.29}_{-0.28}$ pb.
Observed (Expected) significance	$Z_0^{ggF} = 6.0(5.3)$	$Z_0^{VBF} = 1.8(2.6)$

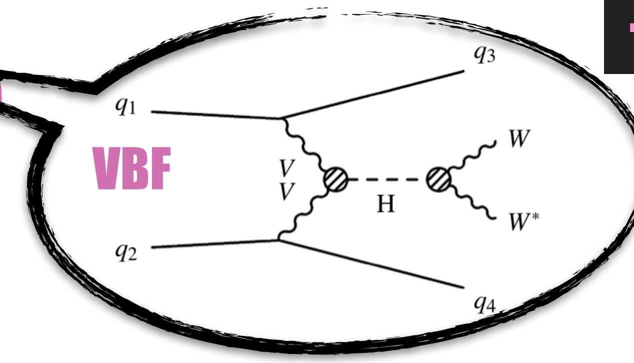
Anamika Aggarwal

ATLAS EXPERIMENT Nikhef Radboud Universiteit Nijmegen

139 fb^{-1}

NEW RESULTS

HWW couplings analysis



- 139 fb^{-1} data is analysed.
- Results derived with simultaneous maximum likelihood fit.
- Most notable improvements with respect to previous Run 2 analysis:
  - ☞ Refinements in object selection together with an increased number of Monte Carlo (MC) simulated events.
  - ☞ A new multi-variate discriminant using a Deep Neural Network (DNN)

Signal Region

Event selection criterion to get signal dominated region

Pre-selection	Two isolated, different-flavour leptons ($\ell = e, \mu$) with opposite charge $p_T^{lead} > 22$ GeV , $p_T^{sublead} > 15$ GeV $m_{\ell\ell} > 10$ GeV, $N_{jet} \geq 2$ $N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$
Selection	$\lvert m_{\tau\tau} - m_Z \rvert < 25$ GeV $m_{jj} > 120$ GeV central jet veto outside lepton veto

A DNN is applied in the SR that uses 15 discriminant variables:
$\Delta\phi_{\ell\ell}$, $m_{\ell\ell}$, m_T, Δy_{jj}, m_{jj}, p_T^{tot}, $\sum_\ell C_\ell$, $m_{\ell 1 j1}$, $m_{\ell 1 j2}$, $m_{\ell 2 j1}$, $m_{\ell 2 j2}$, $p_T^{jet_1}$, $p_T^{jet_2}$, $p_T^{jet_3}$, and MET significance

Control Regions

- Two Control regions.
- CR yields normalise top-quark and Z+jets backgrounds in the SR

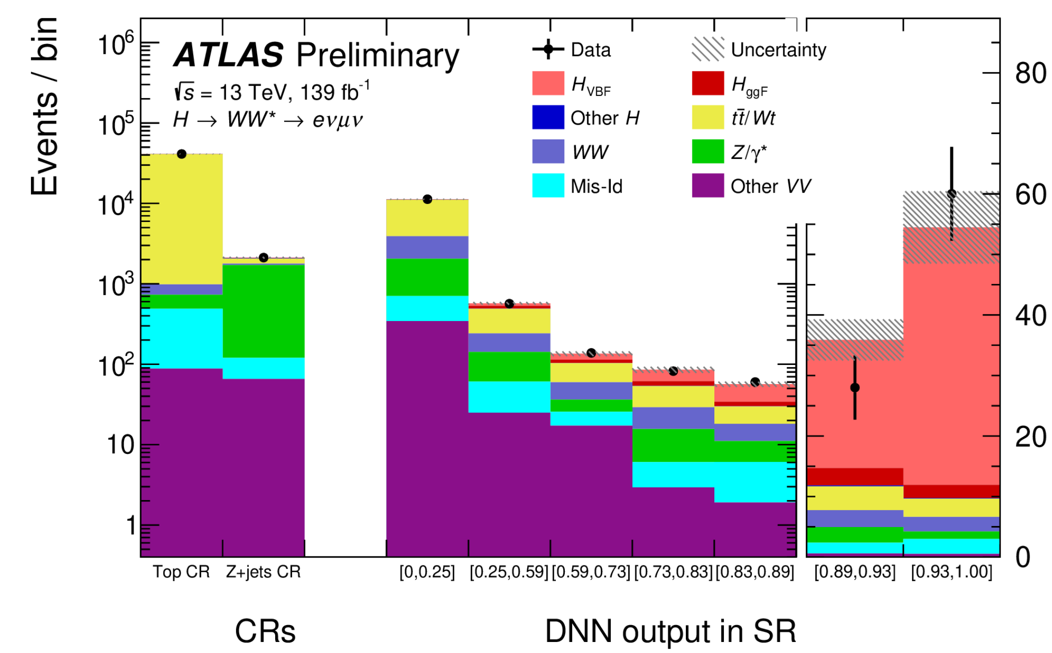
$Z \to \tau\tau$ CR	Top-quark CR
Two isolated, different-flavour leptons ($\ell = e, \mu$) with opposite charge $p_T^{lead} > 22$ GeV , $p_T^{sublead} > 15$ GeV $m_{\ell\ell} > 10$ GeV, $N_{jet} \geq 2$	
$N_{b\text{-jet},(p_T>20\text{ GeV})} = 0$	$N_{b\text{-jet},(p_T>20\text{ GeV})} = 1$
$\lvert m_{\tau\tau} - m_Z \rvert < 25$ GeV – $m_{\ell\ell} < 70$ GeV central jet veto outside lepton veto	$\lvert m_{\tau\tau} - m_Z \rvert < 25$ GeV – –

Uncertainty

- Sources of systematic uncertainty:
  - Experimental (8.8%)
  - Theoretical (signal 14.4%, background 7.7%)
- Dominant experimental uncertainty:
  - missing transverse momentum measurement (4.7%)
- Dominant background theoretical uncertainty:
  - ggF background(5.2%)

Results

Post-fit distributions



Signal Strength

$$\mu_{VBF} = 1.04\,^{+0.24}_{-0.20}$$
$$= 1.04\,^{+0.13}_{-0.12}\,(\text{stat.})\,^{+0.09}_{-0.08}\,(\text{exp syst.})\,^{+0.17}_{-0.12}\,(\text{sig. theo.})\,^{+0.08}_{-0.07}\,(\text{bkg. theo.})$$

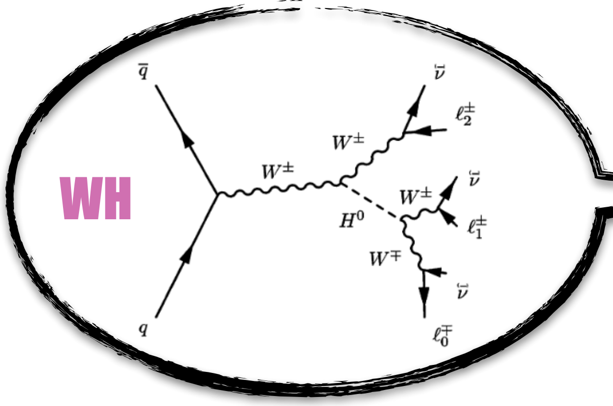
Cross section * branching ratio

$$\sigma_{VBF} \cdot \mathcal{B}_{H\to WW^*} = 0.85\,^{+0.20}_{-0.17}\text{ pb}$$
$$= 0.85 \pm 0.10\,(\text{stat.})\,^{+0.08}_{-0.07}\,(\text{exp syst.})\,^{+0.13}_{-0.10}\,(\text{sig. theo.})\,^{+0.07}_{-0.06}\,(\text{bkg. theo.})\text{ pb}$$

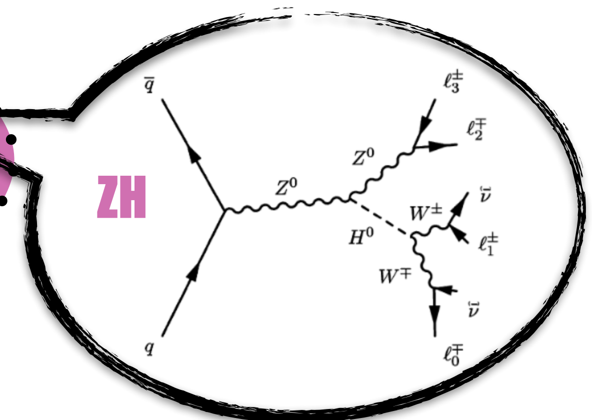
Observed (Expected) significance

$Z_0^{VBF} = 7.0(6.2)$

FIRST OBSERVATION



HWW couplings analysis



$36.1\ fb^{-1}$

- $36.1\ fb^{-1}$ data is analysed.
- In the WH, H→WW* production, the Higgs boson couples only to W bosons, at both the production and decay vertices.
- This measurement is the most precise measurement of this channel to date.

SFOS: same-flavour opposite-sign charge (lepton pair)

Signal Region

Event selection criterion to get signal dominated region

	WH		ZH	
Preselection	3 isolated leptons ($p_T > 15$ GeV) total lepton charge ± 1		4 isolated leptons ($p_T > 10$ GeV) total lepton charge 0	
Category	Z-dominated	Z-depleted	2-SFOS	1-SFOS
Number of SFOS	2 or 1	0	2	1
Number of jets	≤ 1	–	≤ 1	≤ 2
Number of b-jets	0	0	0	0
E_T^{miss} [GeV]	> 30	–	> 45	–
$p_T^{4\ell}$ [GeV]	–	–	> 45	–
$m_{\ell\ell}$ [GeV]	> 12 (min. SFOS)	–	> 10	> 10
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	> 25 (SFOS)	–	< 10 ($m_{\ell_2\ell_3}$)	< 10 ($m_{\ell_2\ell_3}$)
$m_{\ell_0\ell_1}$ [GeV]	–	–	< 55	< 60
$\Delta\phi^{boost}_{\ell_0\ell_1}$	–	–	< 2.3	< 1.9
$m_{\tau\tau}$ [GeV]	–	–	–	< 50
$\Delta\phi_{\ell_0\ell_1, \vec{p}_T^{miss}}$ [rad]	–	–	–	> 0.4
$m_{4\ell}$ [GeV]	–	–	> 140	–
BDT	$BDT_{Zdom} > 0.3$	$BDT_{t\bar{t}} > 0.2$ & $BDT_{WZ} > 0.15$	–	–

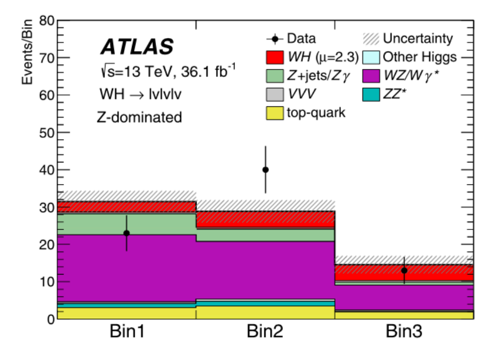
Control Regions

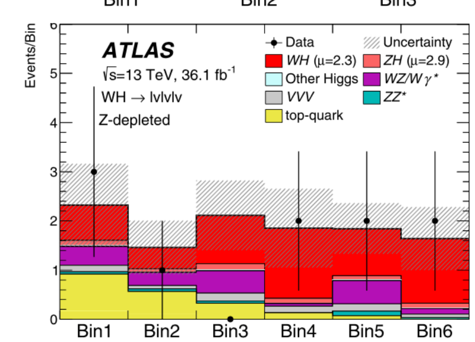
- CRs normalise the main background processes.
- $WZ/W\gamma_*$ and top-quark processes for the WH channel
- ZZ_* for the ZH channel in the 2-SFOS SR.
- In the 1-SFOS SR, ZZ_* is estimated purely from simulation.

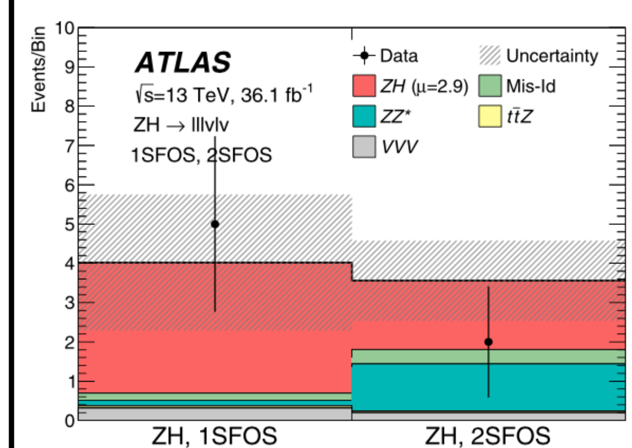
Uncertainty

- Sources of systematic uncertainty:
  - Experimental (12% WH, 7% ZH)
  - Theoretical (16% WH, 15% ZH)
- Dominant experimental uncertainties:
  - misidentification of leptons (8% WH, 3% ZH)
- Dominant theoretical uncertainty:
  - WH: $WZ/W\gamma_*$ background (12%)
  - ZH: ZH signal (14%)

Results

<table>
<tr><th>Signal</th><th>WH</th><th>ZH</th></tr>
<tr><td>Post-fit distributions</td><td>




</td><td>


</td></tr>
<tr><td>Signal Strength</td><td>$\mu_{WH} = 2.3^{+1.1}_{-0.9}(\text{stat.})^{+0.49}_{-0.36}(\text{exp syst.})^{+0.41}_{-0.33}(\text{theo syst.}) = 2.3^{+1.2}_{-1.0}$</td><td>$\mu_{ZH} = 2.9^{+1.7}_{-1.3}(\text{stat.})^{+0.54}_{-0.28}(\text{exp syst.})^{+0.66}_{-0.27}(\text{theo syst.}) = 2.9^{+1.9}_{-1.3}$</td></tr>
<tr><td>Cross section * branching ratio</td><td>$\sigma_{WH} \cdot \mathcal{B}_{H \to WW^*} = 0.67^{+0.31}_{-0.27}(\text{stat.})^{+0.14}_{-0.11}(\text{exp syst.})^{+0.11}_{-0.09}(\text{theo syst.})$ pb</td><td>$\sigma_{ZH} \cdot \mathcal{B}_{H \to WW^*} = 0.54^{+0.31}_{-0.24}(\text{stat.})^{+0.10}_{-0.05}(\text{exp syst.})^{+0.11}_{-0.05}(\text{theo syst.})$ pb</td></tr>
<tr><td>Observed (Expected) significance</td><td>$Z_0^{WH} = 2.6\ (1.3)$</td><td>$Z_0^{ZH} = 2.8(1.2)$</td></tr>
</table>