Search for a high mass Higgs boson in the $H \to WW \to e\nu\mu\nu$ channel in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

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Yongke Zhao

Shandong University & LAL

On behalf of the ATLAS collaboration

Abstract

A search for a high-mass Higgs boson is performed in the $H \to WW \to \ell\nu\ell\nu$ decay channel using pp collision data corresponding to an integrated luminosity of 13.2 fb^{-1}, collected at a centre-of-mass energy of 13 TeV by the ATLAS detector at the Large Hadron Collider. Different hypotheses are tested, including heavy Higgs with a narrow width approximation (NWA) and a large width assumption (LWA). Three orthogonal event categories are defined for the search: one ggF quasi-inclusive category where the VBF phase spaces are excluded and two VBF categories where the VBF signals are dominant. No evidence of a high-mass Higgs boson is found. Upper limits on $\sigma_H \times \mathrm{BR}(H \to WW)$ as a function of the Higgs boson mass and width are obtained in the mass range between 300 GeV and 3 TeV.

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Motivation

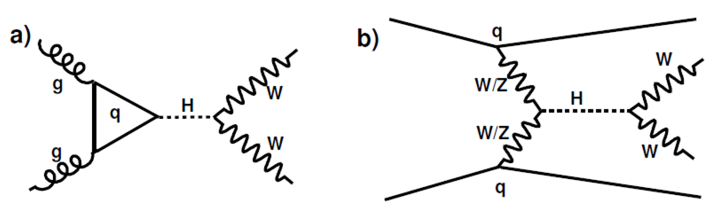
We are searching for a heavy Higgs beyond the Standard Model

Data: LHC Run 2 (year 2015 + 2016) data with $\int$L dt = 13.2 fb^{-1} at 13 TeV

Signal hypotheses: a heavy Higgs with a narrow width approximation (NWA) or large width assumption (LWA)

Mass range: 300 GeV — 3 TeV

Heavy Higgs production modes targeted: a) ggF b) VBF



Event Selection

VBF 1J phase space: $N_{\text{jet}} = 1$, $|\eta_j| > 2.4$ and $\min(|\Delta\eta_{j\ell}|) > 1.75$

VBF 2J phase space: $N_{\text{jet}} \geq 2$, $m_{jj} > 500\,\text{GeV}$ and $|\Delta y_{jj}| > 4$

Signal Regions (SRs)

SR$_{\text{ggF}}$	SR$_{\text{VBF1J}}$	SR$_{\text{VBF2J}}$
Preselection cuts: $p_T^{\text{lead}} > 25\,\text{GeV}$, $p_T^{\text{sublead}} > 15\,\text{GeV}$, 3rd lepton veto, $m_{\ell\ell} > 10\,\text{GeV}$		
$N_{b\text{-jet}} = 0$ $|\Delta\eta_{\ell\ell}| < 1.8$ $m_{\ell\ell} > 55\,\text{GeV}$ $p_T^{\text{lead}} > 45\,\text{GeV}$ $p_T^{\text{sublead}} > 30\,\text{GeV}$ $\max(m_T^W) > 50\,\text{GeV}$		
Inclusive in N_{jet} but excluding VBF1J and VBF2J phase space	$N_{\text{jet}} = 1$ $|\eta_j| > 2.4$ $\min(|\Delta\eta_{j\ell}|) > 1.75$	$N_{\text{jet}} \geq 2$ $m_{jj} > 500\,\text{GeV}$ $|\Delta y_{jj}| > 4$

$$m_T^W = \sqrt{2p_T^{\ell} E_T^{\text{miss}}(1 - \cos(\phi^{\ell} - \phi^{E_T^{\text{miss}}}))}$$

Control Regions (CRs)

WW CR$_{\text{ggF}}$	Top CR$_{\text{ggF}}$	WW CR$_{\text{VBF1J}}$	Top CR$_{\text{VBF}}$
Preselection cuts: $p_T^{\text{lead}} > 25\,\text{GeV}$, $p_T^{\text{sublead}} > 15\,\text{GeV}$, 3rd lepton veto, $m_{\ell\ell} > 10\,\text{GeV}$			
$N_{b\text{-jet}} = 0$ $|\Delta\eta_{\ell\ell}| > 1.8$	$N_{b\text{-jet}} = 1$ $|\Delta\eta_{\ell\ell}| < 1.8$	$N_{b\text{-jet}} = 0$ $(|\Delta\eta_{\ell\ell}| > 1.8$ or $m_{\ell\ell} < 55\,\text{GeV})$	$N_{b\text{-jet}} \geq 1$ – –
$m_{\ell\ell} > 55\,\text{GeV}$ $p_T^{\text{lead}} > 45\,\text{GeV}$ $p_T^{\text{sublead}} > 30\,\text{GeV}$ $\max(m_T^W) > 50\,\text{GeV}$		$p_T^{\text{lead}} > 25\,\text{GeV}$ $p_T^{\text{sublead}} > 25\,\text{GeV}$ –	$p_T^{\text{lead}} > 25\,\text{GeV}$ $p_T^{\text{sublead}} > 15\,\text{GeV}$ –
Excluding VBF VBF1J and VBF2J		VBF1J phase space	VBF1J or VBF2J phase space

How SRs and CRs defined:

- Most cuts are optimized to have the maximum sensitivity, i.e. $|\Delta\eta_{\ell\ell}|$, $m_{\ell\ell}$, p_T^{lead}, etc.
- Cut on $\max(m_T^W)$ (also p_T^{sublead}) is used to reduce W+jets and Z+jets contributions
- Cuts in VBF1J phase space are mainly used to gain VBF sensitivity
- Some cuts are inversed / changed / removed from SRs to define CRs, i.e. $|\Delta\eta\ell\ell|$ ($m_{\ell\ell}$), $N_{b\text{-jet}}$, etc.
- p_T^{sublead} mainly used to improve WW purity in WW CRs

Discriminating Variable

The **transverse mass** is defined as

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - |\mathbf{p}_T^{\ell\ell} + \boldsymbol{E}_T^{\text{miss}}|^2}, \quad (1)$$

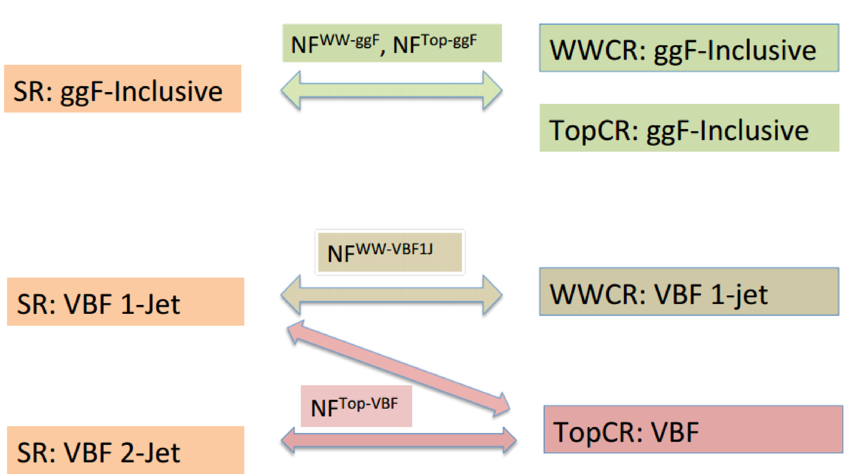
where

$$E_T^{\ell\ell} = \sqrt{|\mathbf{p}_T^{\ell\ell}|^2 + m_{\ell\ell}^2}. \quad (2)$$

Background Estimation

Top, WW: dominant backgrounds. Four normalization scale factors (NFs) are used for the main backgrounds (Top and WW)

- NFs are determined from final fit using SRs and CRs
- WW background in VBF 2J SR is estimated using MC prediction



W+jets: small contribution. Derived from data using "fake-factor" method (same as $H \to WW$ coupling analysis). Fake-factors (FFs) derived using di-jets samples

$$N_{\text{id+id}}^{\text{W+jets}} = N_{\text{id+anti-id}}^{\text{W+jets}} \times \text{FF} = (N_{\text{id+anti-id}} - N_{\text{id+anti-id}}^{\text{EW}}) \times \frac{N_{\text{id}}}{N_{\text{anti-id}}}$$

- id / anti-id: leptons required to pass / veto the lepton identification
- Anti-id leptons have looser requirements to improve the statistics

Z+jets, non-WW diboson, H125: small contribution. Predicted from simulation (ggF component interference with WW also considered)

Dominant Systematics

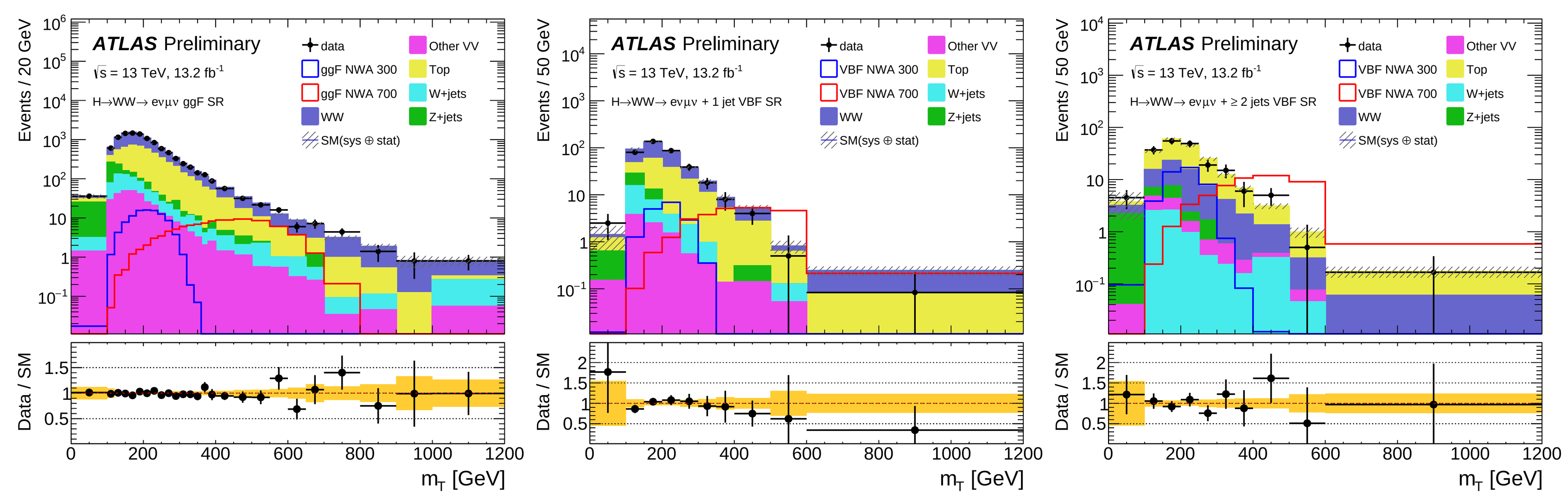
- Signal QCD scale uncertainties on category migration: 30% (m_H = 300 GeV) — 90% (m_H = 3 TeV) for VBF 1J and 25% — 40% for VBF 2J
- Top (WW) background jet energy scale and resolution uncertainty: 9.8% (16%) and 12% (23%) in VBF 1J and 2J SRs
- Top (WW) background generator uncertainty: 17% (35%), 48% (48%) in VBF 1J, 2J SRs

Similar in CRs ⟶ Extrapolation uncertainties from CRs to SRs remain small

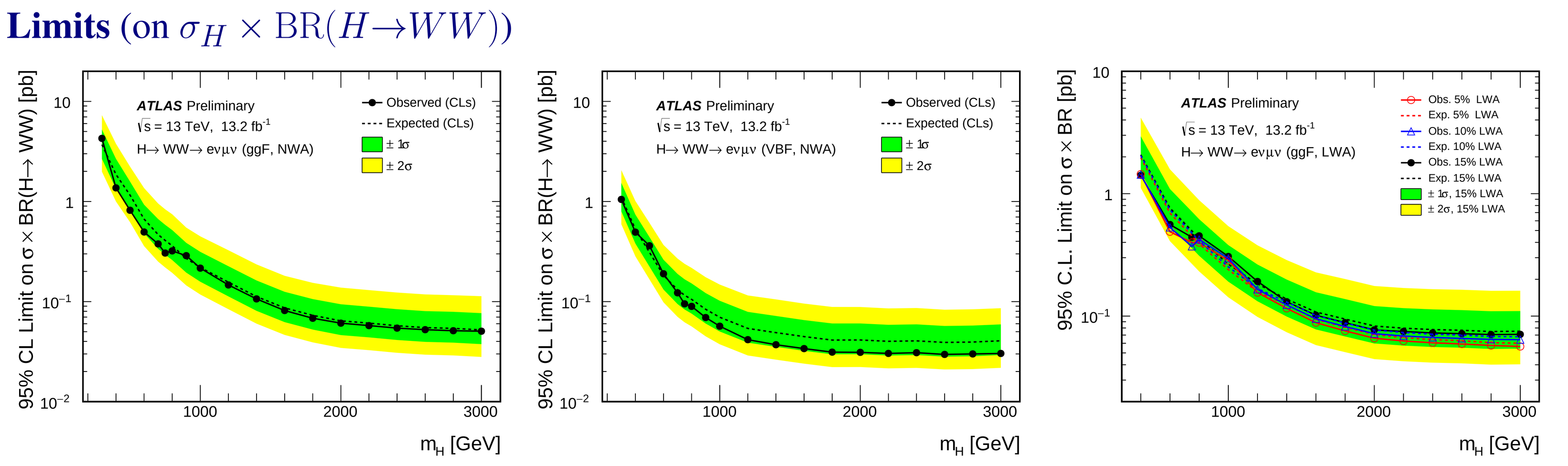
Results

Event yields (from final fit): see table 1

Plots (in SRs)



Limits (on $\sigma_H \times \mathrm{BR}(H \to WW)$)



	SR$_{\text{ggF}}$	Top CR$_{\text{ggF}}$	WW CR$_{\text{ggF}}$
WW	5300 ± 400	430 ± 90	1430 ± 120
Top-quark	4200 ± 400	20560 ± 210	900 ± 100
Z/γ*	557 ± 25	46 ± 12	10.7 ± 1.0
W+jets	450 ± 120	260 ± 80	105 ± 30
VV	323 ± 12	37 ± 4	88.5 ± 3.4
Backgrounds	10790 ± 110	21330 ± 180	2530 ± 40
Data	10718	21333	2589

Table 1: Event yields

Conclusion

- Luminosity is improved and mass range extended with respect to previous results.
- **No evidence of a heavy Higgs boson is found** in the mass range between 300 GeV and 3 TeV.
- Upper limits are set on $\sigma_H \times \mathrm{BR}(H \to WW)$ in two scenarios: NWA and LWA.
- Aim at paper publication with Run 2 (full year 2015 + 2016) data ($\sim$ 36 fb^{-1}) soon.