Search for Higgs to WW ($\ell\nu\ell\nu$, $\ell\nu qq$) in ATLAS

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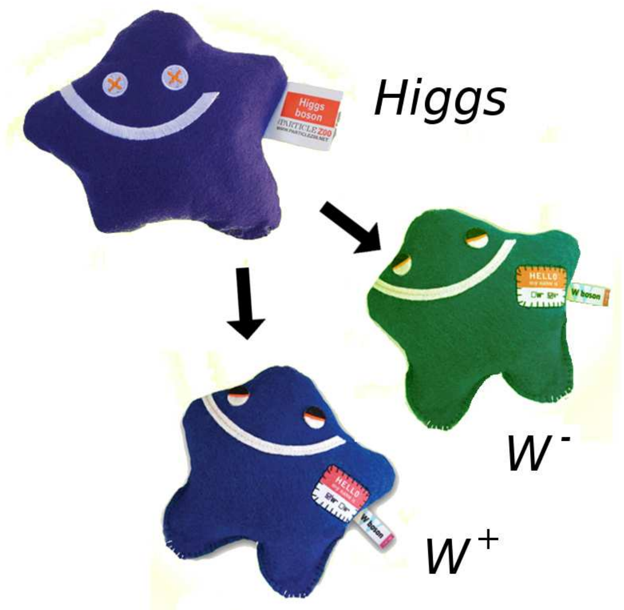
on behalf of the
ATLAS Collaboration



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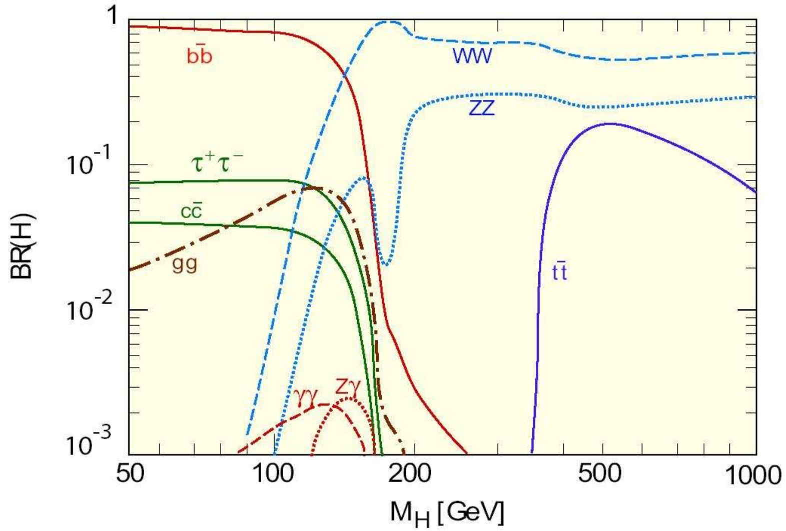
Introduction

- The direct search for the Higgs boson responsible for EWSB in the Standard Model is well underway at the LHC.
  - With 1 fb^{-1} of data collected, ATLAS has sensitivity near or at SM Higgs production over a wide range of masses.
- The $H \to WW$ channels take advantage of the large branching fraction for Higgs bosons to decay to WW for $m_H \geq 130$ GeV.
- The $H \to WW^{(*)} \to \ell\nu\ell\nu$ channels (ee, $e\mu$ and $\mu\mu$):
  - **ATLAS-CONF-2011-111**
- The $H \to WW \to \ell\nu qq$ channels (e and μ):
  - **ATLAS-HIGG-2011-09**

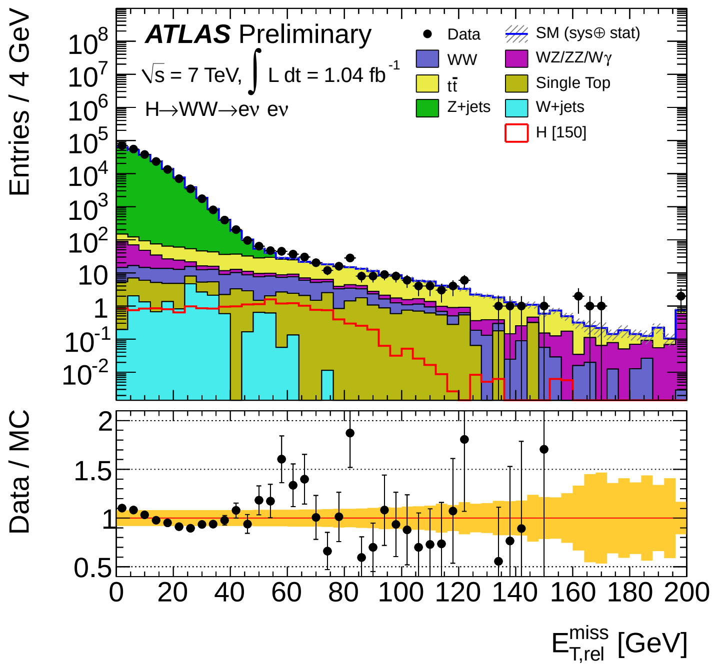


The $H \to WW^{(*)} \to \ell\nu\ell\nu$ Analysis

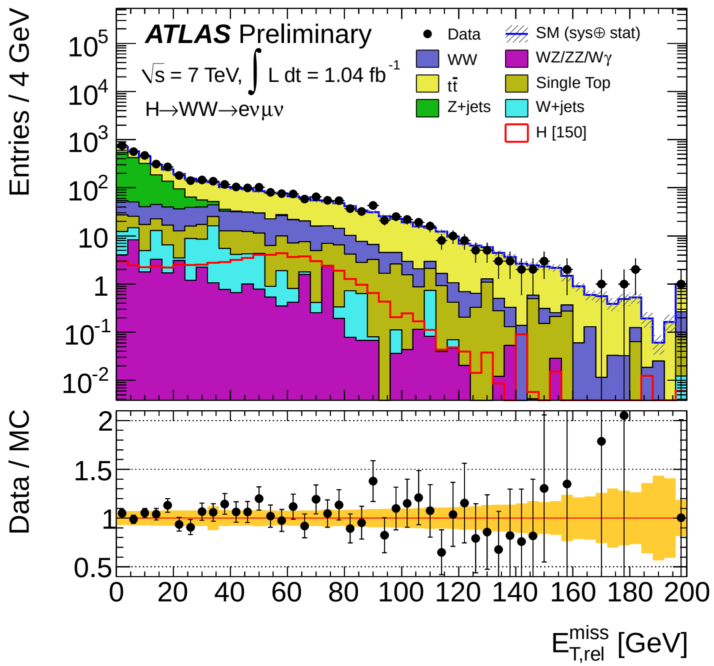
- Combines the large BR for $H \to WW$ with a clean final state.
  - Analysis performed for $110 < m_H < 240$ GeV. Reference mass shown in plots and tables at $m_H = 150$ GeV.
  - Largest sensitivity of any Higgs channel at $m_H \approx 165$ GeV.
- The events are selected requiring two leptons and large $E_{\mathrm{T}}^{\mathrm{miss}}$:
  - Exactly two opposite sign leptons (e or μ). The leading lepton $p_{\mathrm{T}} > 25$ GeV. Sub-leading muon (electron) $p_{\mathrm{T}} > 15\ (20)$ GeV.
  - For same flavor leptons, require $m_{\ell\ell} > 15$ GeV and $|m_{\ell\ell} - m_Z| > 15$ GeV. For $e\mu$ channel, just require $m_{\ell\ell} > 10$ GeV.
  - Require $E_{\mathrm{T,rel}}^{\mathrm{miss}} > 40$ GeV (ee, $\mu\mu$) or $E_{\mathrm{T,rel}}^{\mathrm{miss}} > 25$ GeV ($e\mu$).

$$E_{\mathrm{T,rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \cdot \sin\Delta\phi & \text{if } \Delta\phi < \pi/2 \\ & \quad \Delta\phi = \min(\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \ell),\ \Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, j)) \end{cases}$$

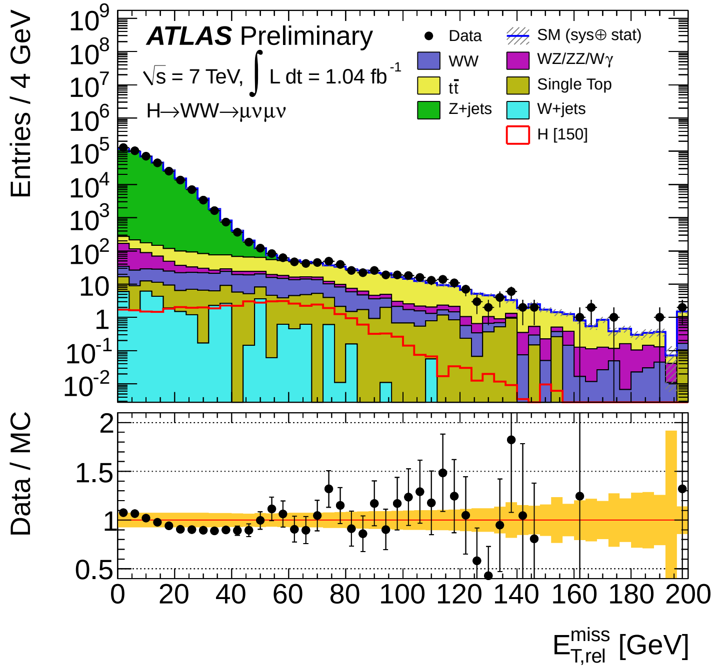
Selecting Two Leptons and Large $E_{\mathrm{T,rel}}^{\mathrm{miss}}$



ee channel



$e\mu$ channel



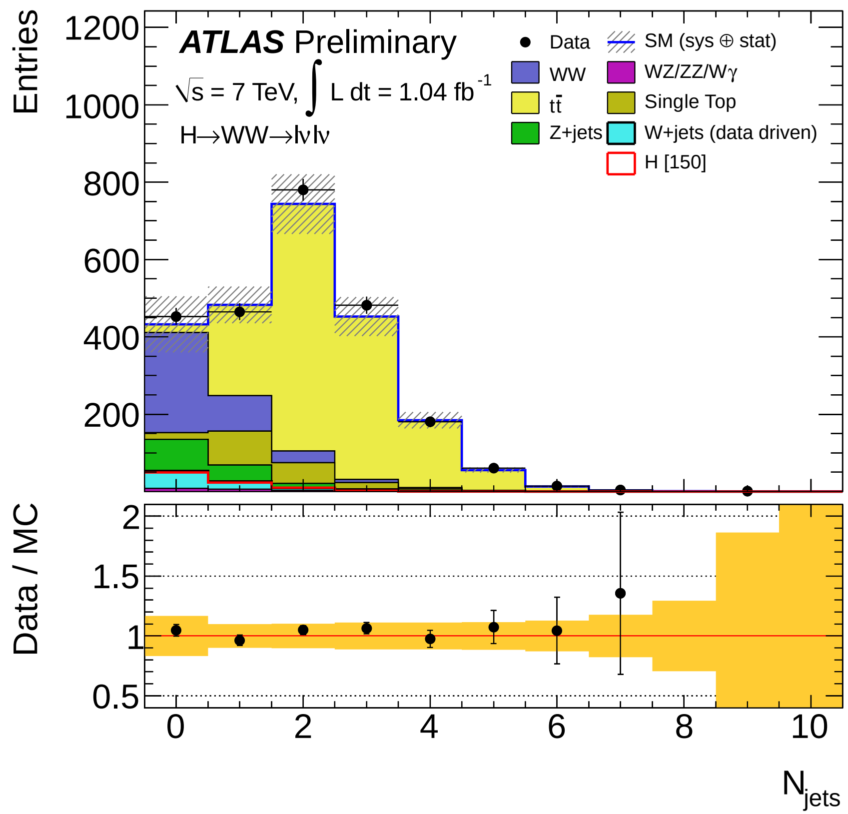
$\mu\mu$ channel

Selection	WW	Z/γ^*+jets	$t\bar{t}$	Total Bkg.	Observed
$m_{\ell\ell} > 15$ GeV	820 ± 60	$590,000 \pm 40,000$	$3,600 \pm 400$	$590,000 \pm 40,000$	614,855
$\lvert m_Z - m_{\ell\ell}\rvert > 15$ GeV	720 ± 50	$55,000 \pm 4,000$	$3,200 \pm 300$	$60,000 \pm 4,000$	63,978
$E_{\mathrm{T,rel}}^{\mathrm{miss}}$	390 ± 30	140 ± 120	$1,570 \pm 190$	$2,400 \pm 300$	2,438

- Dominated by Z/γ^*+jets and $t\bar{t}$ at this stage of the event selections.

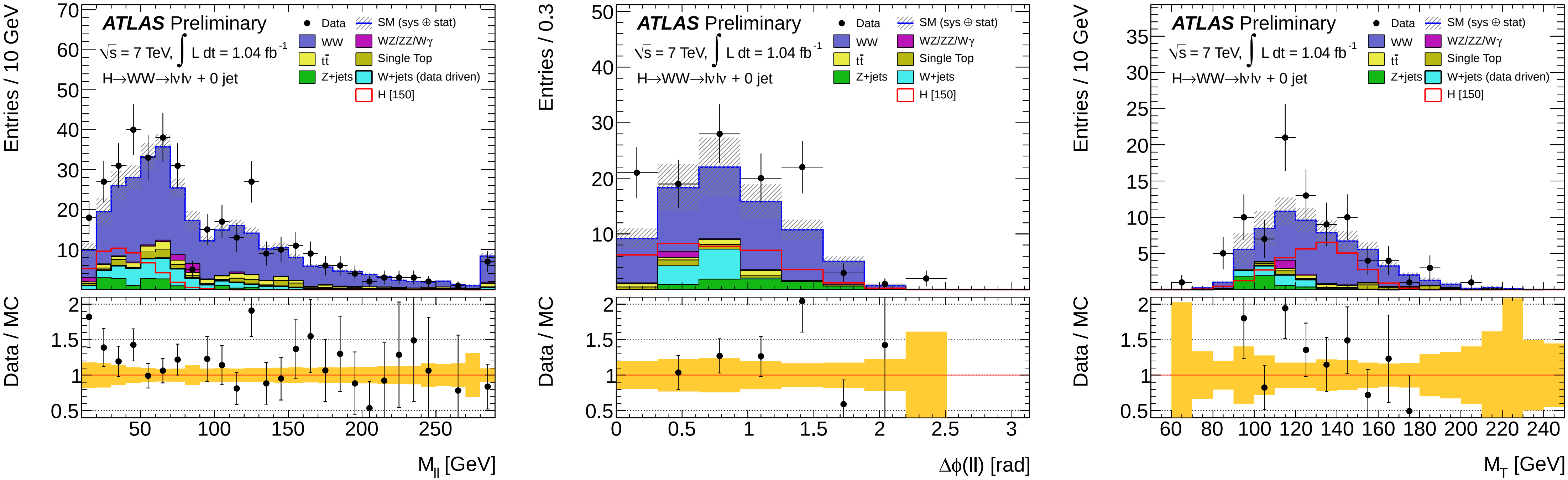
Jet Multiplicity and Topological Selections

- After the $E_{\mathrm{T,rel}}^{\mathrm{miss}}$ selection, divide the events into:
  - Events with no jets with $p_{\mathrm{T}} > 25$ GeV and $|\eta| < 4.5$.
  - Events with exactly one jet. Apply b-tag veto.
- Apply topological selections:
  - Require the dilepton mass $m_{\ell\ell} < 50$ GeV ($m_H < 170$ GeV), $m_{\ell\ell} < 65$ GeV ($m_H \geq 170$ GeV).
  - The dilepton opening angle $\Delta\phi_{\ell\ell} < 1.3$ ($m_H < 170$ GeV), $\Delta\phi_{\ell\ell} < 1.8$ ($m_H \geq 170$ GeV).
  - $0.75 \times m_H < m_{\mathrm{T}} < m_H$ GeV.



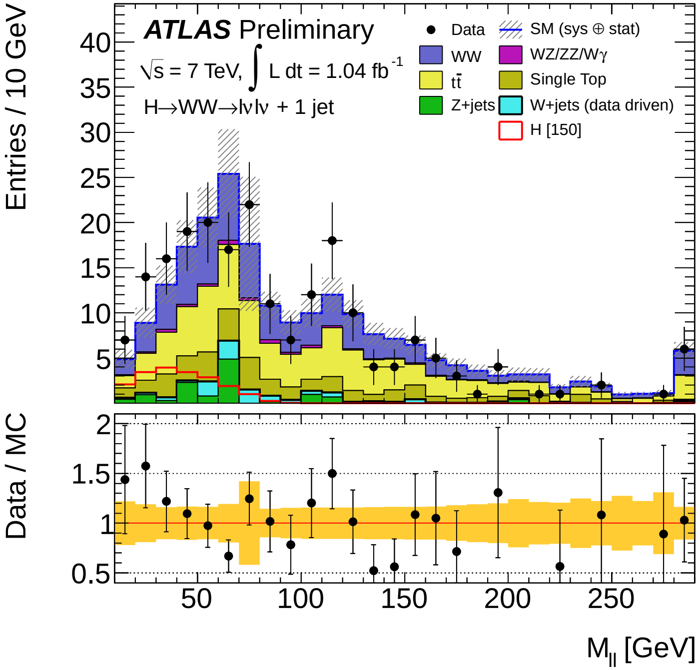
$$m_{\mathrm{T}} = \sqrt{(E_{\mathrm{T}}^{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\mathbf{P}_{\mathrm{T}}^{\ell\ell} + \mathbf{P}_{\mathrm{T}}^{\mathrm{miss}})^2}$$

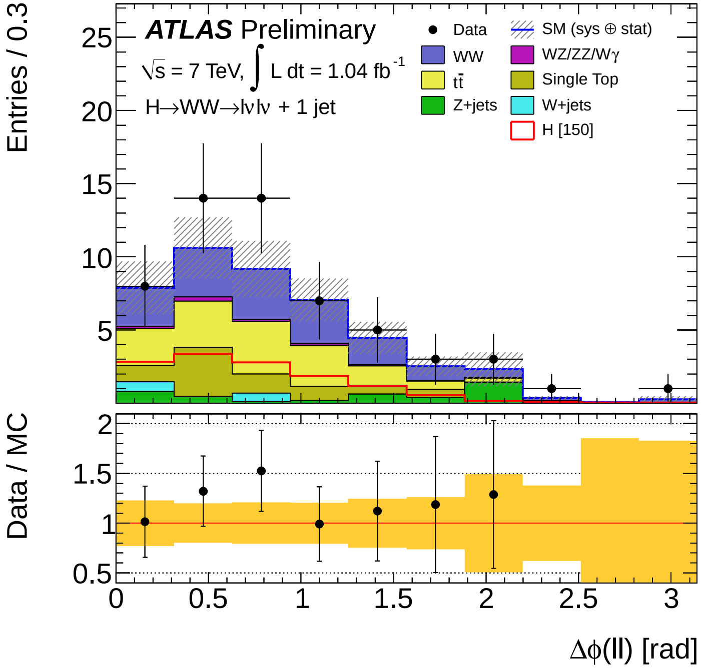
The $H \to WW^{(*)} \to \ell\nu\ell\nu$ + 0 Jet Channel

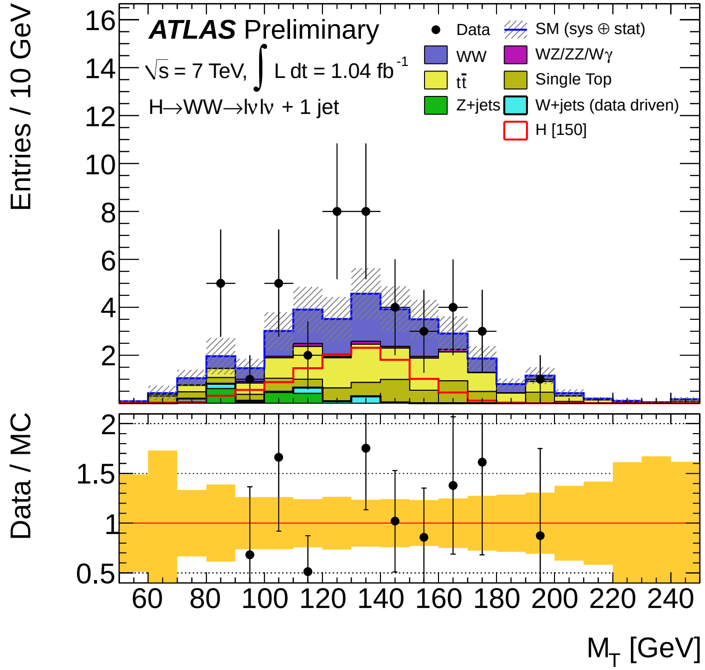


m_H = 150 GeV	Signal	WW	W+jets	Z/γ^*+jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
Jet Veto	50 ± 11	260 ± 30	46 ± 17	80 ± 70	22 ± 8	17 ± 4	7.8 ± 1.5	430 ± 100	453
$\lvert\mathbf{P}_{\mathrm{T}}^{\ell\ell}\rvert > 30$ GeV	48 ± 10	230 ± 20	38 ± 14	15 ± 6	19 ± 7	16 ± 4	7.3 ± 1.4	330 ± 50	371
$m_{\ell\ell} < 50$ GeV	34 ± 7	59 ± 8	11 ± 3	7 ± 4	2.7 ± 1.8	2.8 ± 0.8	0.9 ± 0.3	83 ± 11	116
$\Delta\phi_{\ell\ell} < 1.3$	30 ± 7	46 ± 6	5.8 ± 1.8	5 ± 3	2.7 ± 1.7	2.8 ± 0.8	0.8 ± 0.2	63 ± 9	89
m_{T}	21 ± 4	26 ± 3	2.9 ± 0.9	1 ± 2	1.6 ± 1.2	0.7 ± 0.4	0.6 ± 0.2	33 ± 5	49
ee	3.1 ± 0.7	3.7 ± 0.7	0.5 ± 0.2	0.4 ± 0.6	0.0 ± 0.6	0.0 ± 0.2	0.05 ± 0.19	4.7 ± 1.2	7
$e\mu$	11 ± 2	13.4 ± 1.9	1.7 ± 0.7	0 ± 0	1.1 ± 0.8	0.4 ± 0.3	0.4 ± 0.3	17 ± 2	21
$\mu\mu$	6.9 ± 1.5	8.8 ± 1.3	0.7 ± 0.5	0.5 ± 2.0	0.4 ± 0.8	0.3 ± 0.3	0.18 ± 0.19	11 ± 3	21

The $H \to WW^{(*)} \to \ell\nu\ell\nu$ + 1 Jet Channel







m_H = 150 GeV	Signal	WW	W+jets	Z/γ^*+jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
1 jet	23 ± 4	92 ± 9	20 ± 10	40 ± 30	240 ± 60	88 ± 13	6.2 ± 0.8	490 ± 70	465
b-jet veto	23 ± 4	91 ± 9	19 ± 10	40 ± 30	140 ± 40	45 ± 7	6.1 ± 0.8	340 ± 50	333
$\lvert\mathbf{P}_T^{\rm tot}\rvert < 30$ GeV	19 ± 3	76 ± 8	9 ± 5	25 ± 19	80 ± 20	35 ± 6	4.1 ± 0.5	230 ± 40	221
$m_{\ell\ell} < 50$ GeV	13 ± 3	16 ± 3	1.2 ± 0.5	3.4 ± 1.6	12 ± 4	7.2 ± 1.7	0.9 ± 0.2	41 ± 5	56
$\Delta\phi_{\ell\ell} < 1.3$	11 ± 2	13 ± 2	1.0 ± 0.5	1.5 ± 1.2	11 ± 4	6.3 ± 1.5	0.74 ± 0.20	33 ± 5	44
$m_{\rm T}$	7.2 ± 1.6	6.2 ± 1.3	0.5 ± 0.9	0.4 ± 0.6	4.9 ± 1.7	2.3 ± 0.7	0.34 ± 0.16	15 ± 3	21
ee	0.9 ± 0.3	0.8 ± 0.3	0.08 ± 0.04	0.0 ± 0.4	0.8 ± 1.0	0.2 ± 0.4	0.06 ± 0.08	2.0 ± 1.2	4
$e\mu$	4.0 ± 0.9	3.5 ± 0.8	0.4 ± 0.2	0.4 ± 0.7	3.1 ± 1.3	1.2 ± 0.6	0.24 ± 0.13	8.8 ± 1.9	8
$\mu\mu$	2.3 ± 0.5	1.9 ± 0.4	0.0 ± 0.8	0.0 ± 0.4	1.1 ± 1.1	0.8 ± 0.7	0.04 ± 0.07	3.9 ± 1.7	9

Background Estimates and Control Regions

- The two largest backgrounds, SM WW production and top production, normalized using dedicated control regions in data.

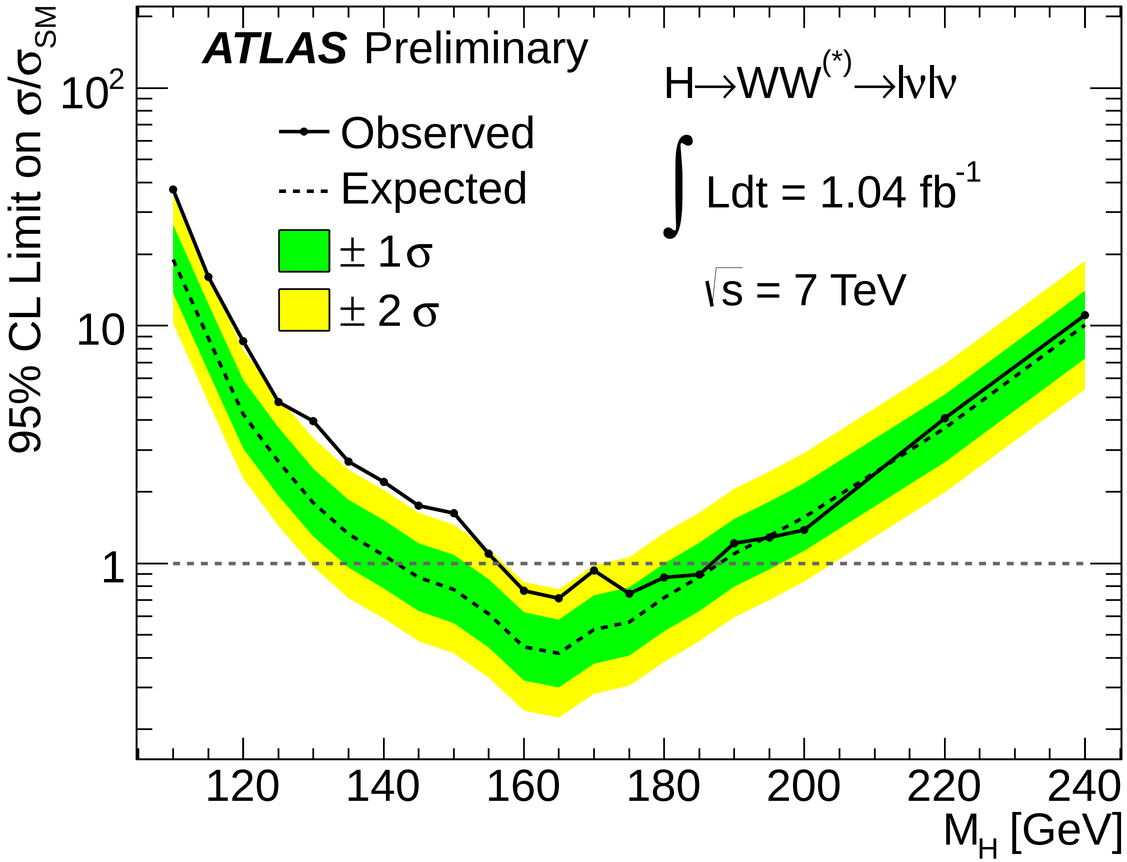
$$N_{data}^{S.R.} = \alpha \times N_{data}^{C.R.}, \qquad \alpha = \frac{N_{MC}^{S.R.}}{N_{MC}^{C.R.}}$$

- W+jets background entirely determined from data, other (smaller) backgrounds are taken from Monte Carlo.
  - Apply scale factor to Z/γ^*+jets for potential $E_{\mathrm{T}}^{\mathrm{miss}}$ mis-modeling.

Control Region	Estimate	Obs
WW 0-jet	150 ± 30	153
WW 1-jet	109 ± 14	97
top 1-jet	130 ± 40	136

	α_{WW}^{0j}	α_{WW}^{1j}	α_{top}^{1j}	β_{top}^{1j}
Q^2 Scale	3%	4%	9%	–
MC Modeling	4%	4%	4%	–
PDF	3%	3%	3%	–
Jet E Scale + Resolution	1%	3%	$^{-26}_{+58}$%	$^{-30}_{+52}$%
b-tagging Efficiency	–	0.2%	$^{-21}_{+17}$%	$^{-22}_{+18}$%
MC Statistics	4.3%	12.9%	6%	–

The $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$ Exclusion Limit

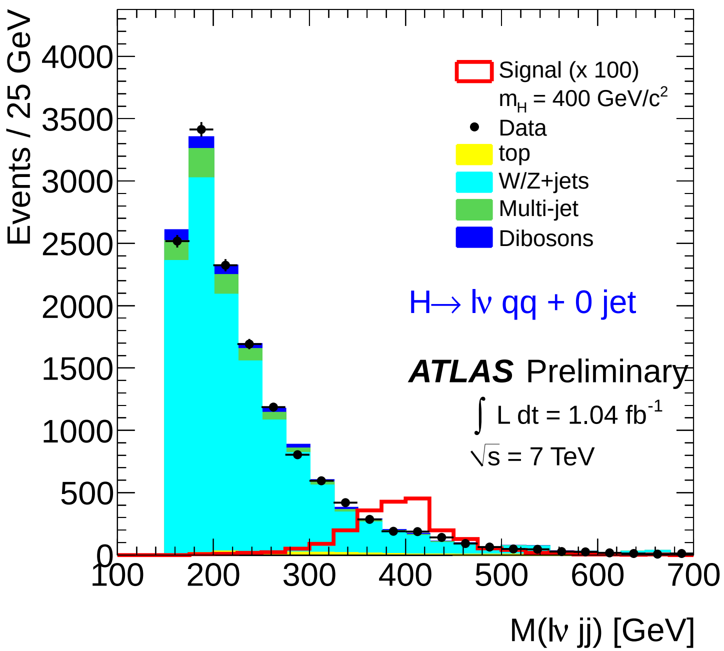


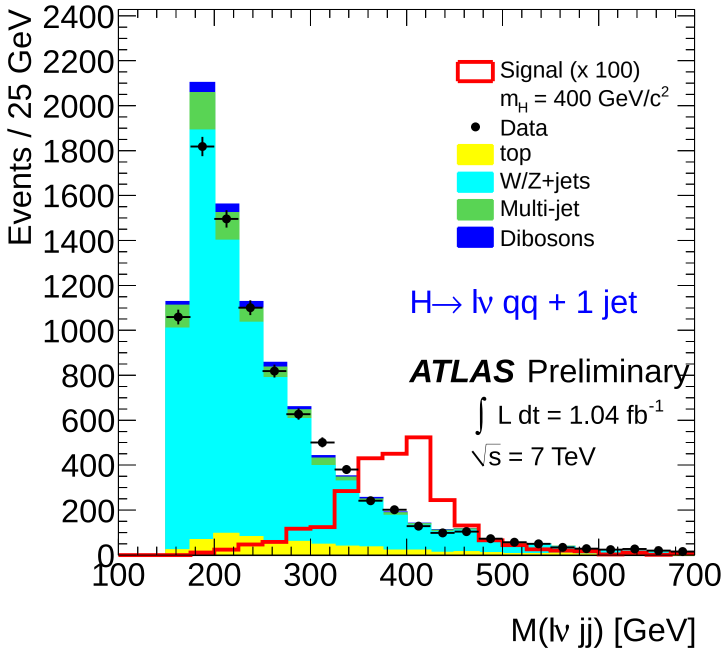
- A SM Higgs boson with $158 < m_H < 186$ GeV is excluded at 95% CL.
  - Expected exclusion mass range is $142 \leq m_H \leq 186$ GeV. The observed limit is at least 2σ higher than expected for $126 \leq m_H \leq 154$ GeV.

The $H \to WW \to \ell\nu qq$ Analysis

- At large Higgs boson masses, it is possible to start using the $H \to WW \to \ell\nu qq$ decay channel. Has large branching ratio.
  - Analysis performed for $240 < m_H < 600$ GeV. Reference mass shown in plots and tables at $m_H = 400$ GeV.
  - Large sensitivity for all m_H, especially for $m_H \approx 350$ GeV.
- Events are selected requiring one lepton, large $E_{\mathrm{T}}^{\mathrm{miss}}$ and jets:
  - Require exactly one lepton (e or μ) with $p_{\mathrm{T}} > 30$ GeV.
  - Require $E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV.
  - Events are required to have exactly two or exactly three jets. Require one pair of jets fulfill $71 < M_{jj} < 91$ GeV.
  - Using the constraints $M(\ell\nu) = M(W)$ and $M(qq) = M(W)$, the Higgs boson mass $M(\ell\nu qq)$ can be reconstructed.
- Search for a peak in $M(\ell\nu qq)$ over the continous background.

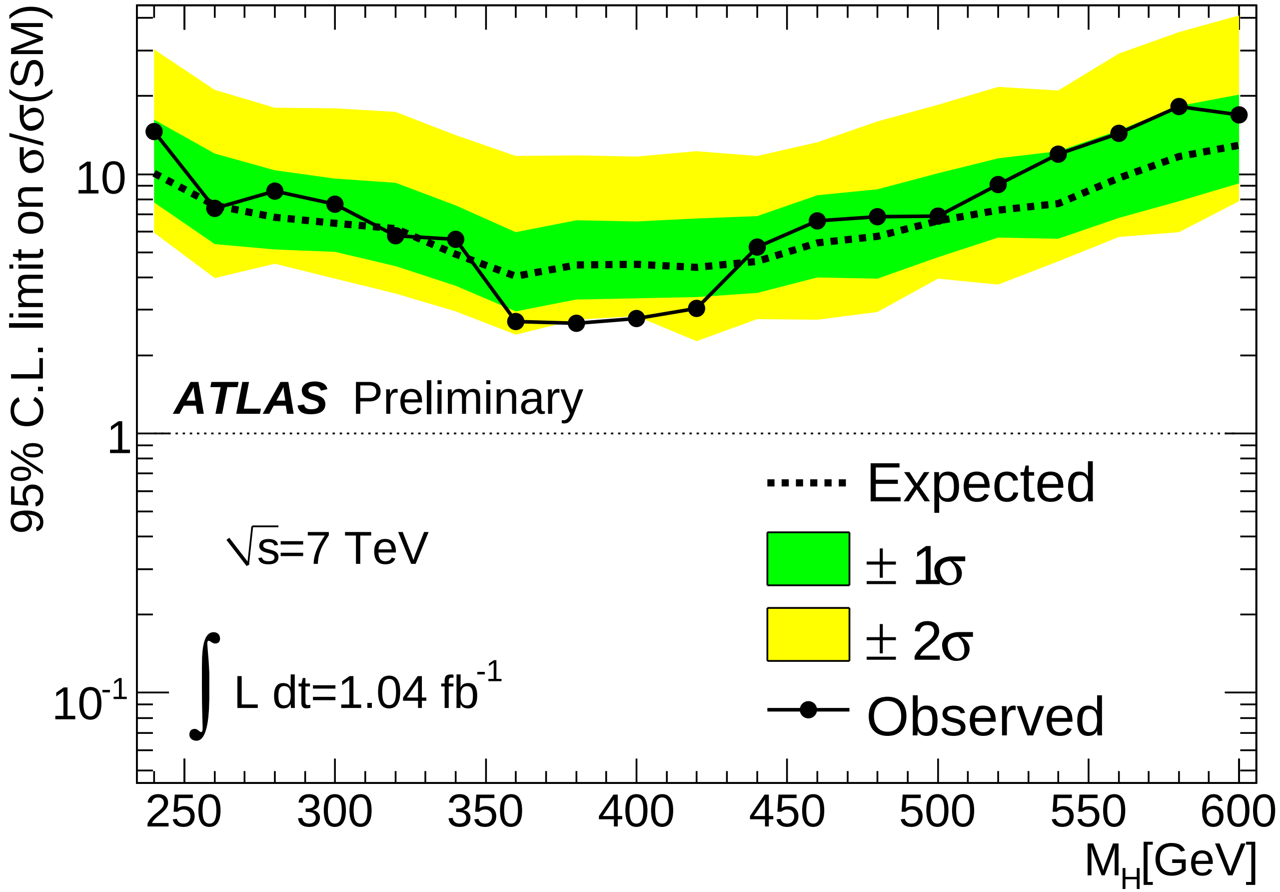
Sample Composition and Mass Plots





m_H = 400 GeV	H($e\nu qq$) + 0j	H($\mu\nu qq$) + 0j	H($e\nu qq$) + 1j	H($\mu\nu qq$) + 1j	H + 0j or 1j
V+jets	10782 ± 291	13375 ± 869	6513 ± 247	7412 ± 674	38082 ± 1170
Multi-jet	890 ± 24	256 ± 17	669 ± 25	212 ± 19	2027 ± 43
Top	170 ± 34	164 ± 33	489 ± 98	503 ± 101	1326 ± 265
Dibosons	397 ± 79	414 ± 83	161 ± 32	204 ± 41	1176 ± 235
Expected Background	12239 ± 304	14209 ± 874	7832 ± 269	8331 ± 683	42611 ± 1223
Observed	11988	13906	7543	8250	41687
Expected Signal (m_H = 400 GeV)	14 ± 3.6	12 ± 3.1	18 ± 4.7	14 ± 3.6	58 ± 15

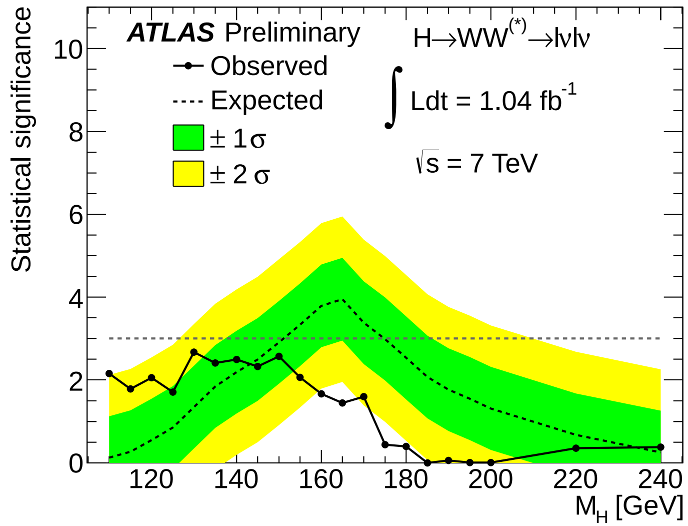
The $H \to WW \to \ell\nu qq$ Exclusion Limit



- The upper limit at $m_H = 400$ GeV is 2.5 times the SM cross section.
  - Expected limit for $m_H = 400$ is ~ 5 times the SM cross section.

Conclusions

- The $H \to WW^{(*)} \to \ell\nu\ell\nu$ and the $H \to WW \to \ell\nu qq$ channels have been analyzed using 1 fb^{-1} of data collected with the ATLAS detector.
  - No convincing evidence for a Higgs boson has been observed.
  - At intermediate masses, the $H \to WW^{(*)} \to \ell\nu\ell\nu$ analysis excludes a Higgs boson in the mass range $158 < m_H < 186$ GeV.
  - At high masses, the $H \to WW \to \ell\nu qq$ analysis sets an upper limit on the cross section between 2.5 to 10 times the SM cross section.
- An excess of events can be observed for low masses.
  - Corresponding to $\approx 2.5\sigma$ in the range $130 < m_H < 150$ GeV.



- Time will tell whether:
  - It is a fluctuation.
  - It is a background.
  - It is something exciting. ☺