

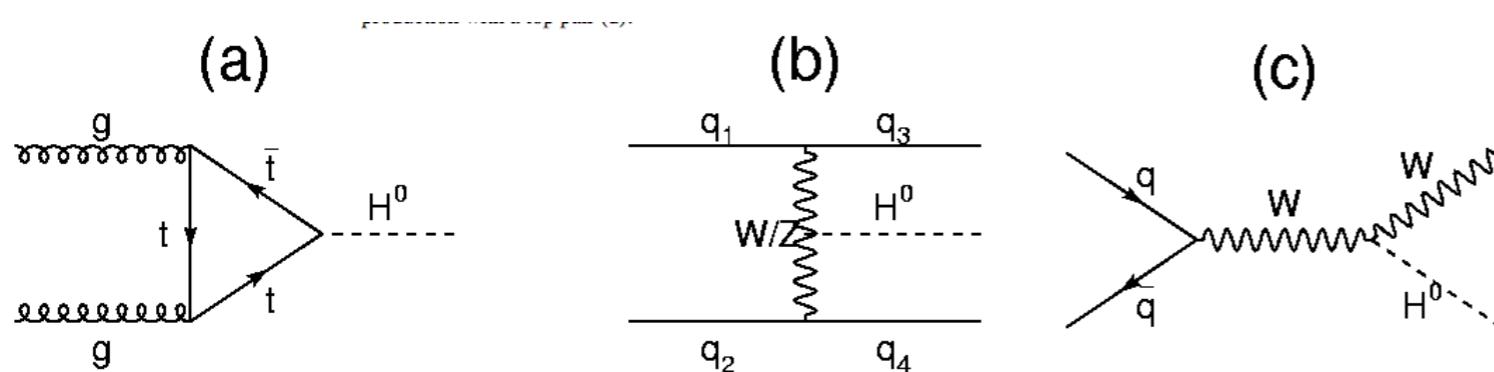
# Search for the Higgs boson in the $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ channel in ATLAS

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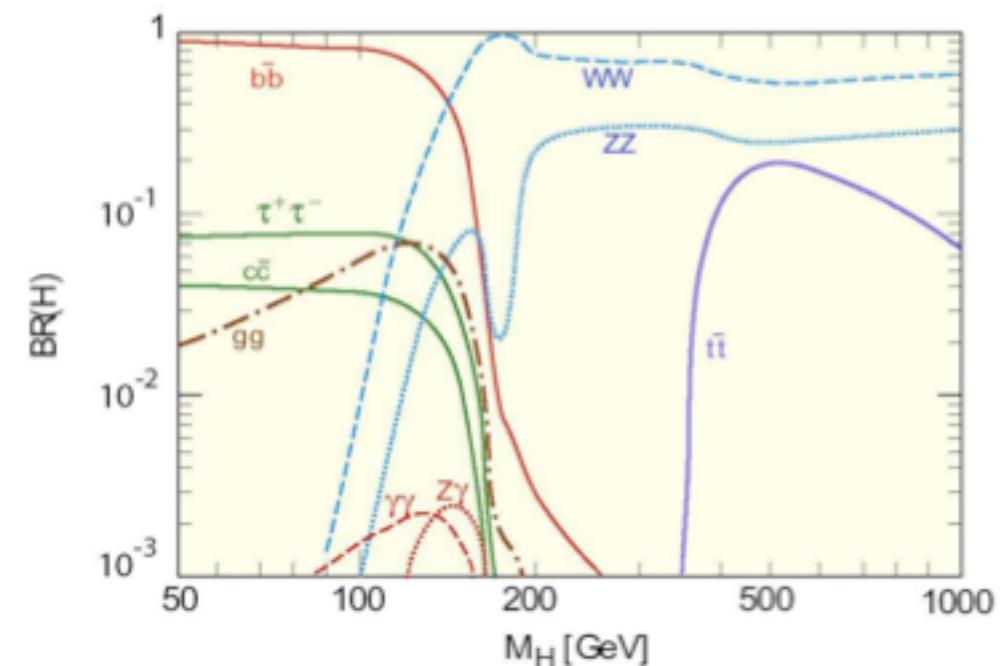
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# Introduction

- The  $H \rightarrow WW$  channels take advantage of the large branching ratio for Higgs bosons decaying to  $WW$  when  $m_H \geq 130$  GeV
- The **ggF** (gluon fusion,  $gg \rightarrow H$ ) production process, the **VBF** (vector boson fusion,  $qq' \rightarrow qq'H$ ) and the **WH/ZH** ( $\underline{qq'} \rightarrow WH, ZH$ ) production processes where the vector boson decays to a  $q\bar{q}$  pair are considered
- signature : high pT lepton pair and large missing transverse momentum , background is an issue
- Analysis uses **2.1 fb<sup>-1</sup>** data taken from 7TeV LHC in summer
- Search range is **110-300 GeV**



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# $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ selection

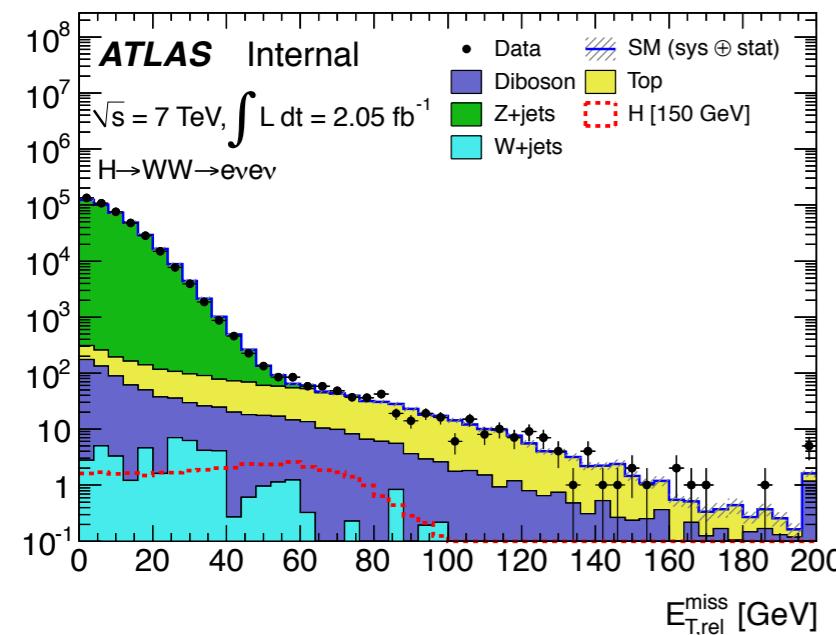
## Trigger and object definition

- Trigger
  - Electron with  $E_T$  of at least 20 GeV, 22 GeV toward end of considered data period
  - Or muon with  $p_T$  of at least 18 GeV, identification criteria tightened toward end of considered data period
- Electron
  - Clustered energy deposits in the EM calorimeter with an associated track
  - Energy measurement is taken from the EM calorimeter, the pseudorapidity  $\eta$  and azimuthal angle  $\varphi$  are taken from the associated track
  - $|\eta| < 2.47$ , outside  $1.37 < |\eta| < 1.52$
  - A tight set of identification cuts with an efficiency of 71% for electrons with  $E_T > 20$  GeV.
- Muon
  - Combined tracks in the inner detector and muon spectrometer, efficiency of this reconstruction is 92% for muons with  $p_T > 20$  GeV
  - Quality cuts on the number and type of hits in the inner detector
  - $|\eta| < 2.4$
- Common on muon and electron
  - transverse impact parameter significance  $\leq 10\sigma$
  - Impact parameter along the beam direction  $\leq 10$  mm
  - Scalar sum of energy of tracks nearby  $\Delta R = 0.2$ ,  $p_T^{\text{track}} < 0.1 * p_T$ ,  $E_T^{\text{calo}} < 0.15 * p_T$

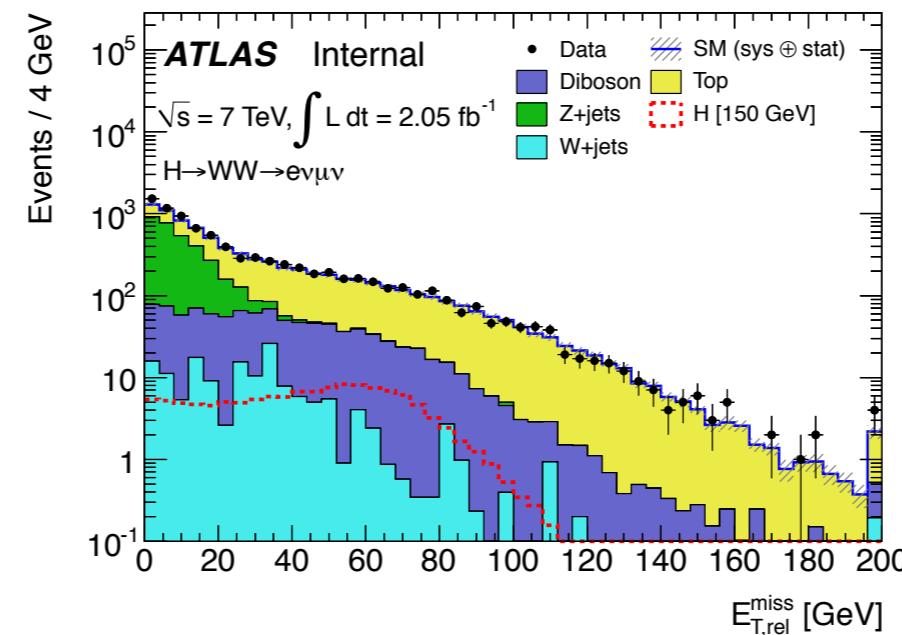
# $H \rightarrow WW^{(*)} \rightarrow l\nu/l\nu$ selection

## Dilepton and $E_T^{\text{miss}}$

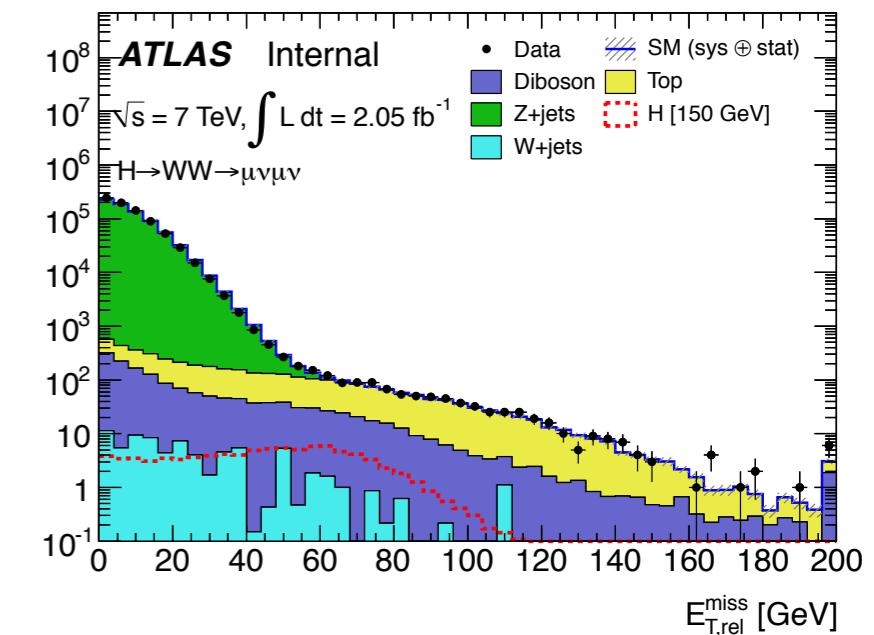
- The events are selected requiring two leptons and large  $E_T^{\text{miss}}$  (missing transverse momentum)
  - Exactly two opposite sign leptons (e or  $\mu$ ). The leading lepton  $p_T > 25$  GeV. Sub-leading muon (electron)  $p_T > 15$  (20) GeV.
  - For same flavor leptons, require  $m_{ll}$  (invariant mass of 2 leptons)  $> 15$  GeV and  $|m_{ll} - m_Z| > 15$  GeV. For  $e\mu$  channel, just require  $m_{ll} > 10$  GeV.
  - Require  $E_{T,\text{rel}}^{\text{miss}} > 40$  GeV ( $ee, \mu\mu$ ) or  $E_{T,\text{rel}}^{\text{miss}} > 25$  GeV ( $e\mu$ ).
  - $E_{T,\text{rel}}^{\text{miss}} = E_T^{\text{miss}}$ , if  $\Delta\varphi \geq \pi/2$
  - $E_{T,\text{rel}}^{\text{miss}} = E_T^{\text{miss}} \cdot \sin \Delta\varphi$ , if  $\Delta\varphi < \pi/2$   $\Delta\varphi = \min(\Delta\varphi(E_T^{\text{miss}}, l), \Delta\varphi(E_T^{\text{miss}}, j))$



ee channel



eμ channel



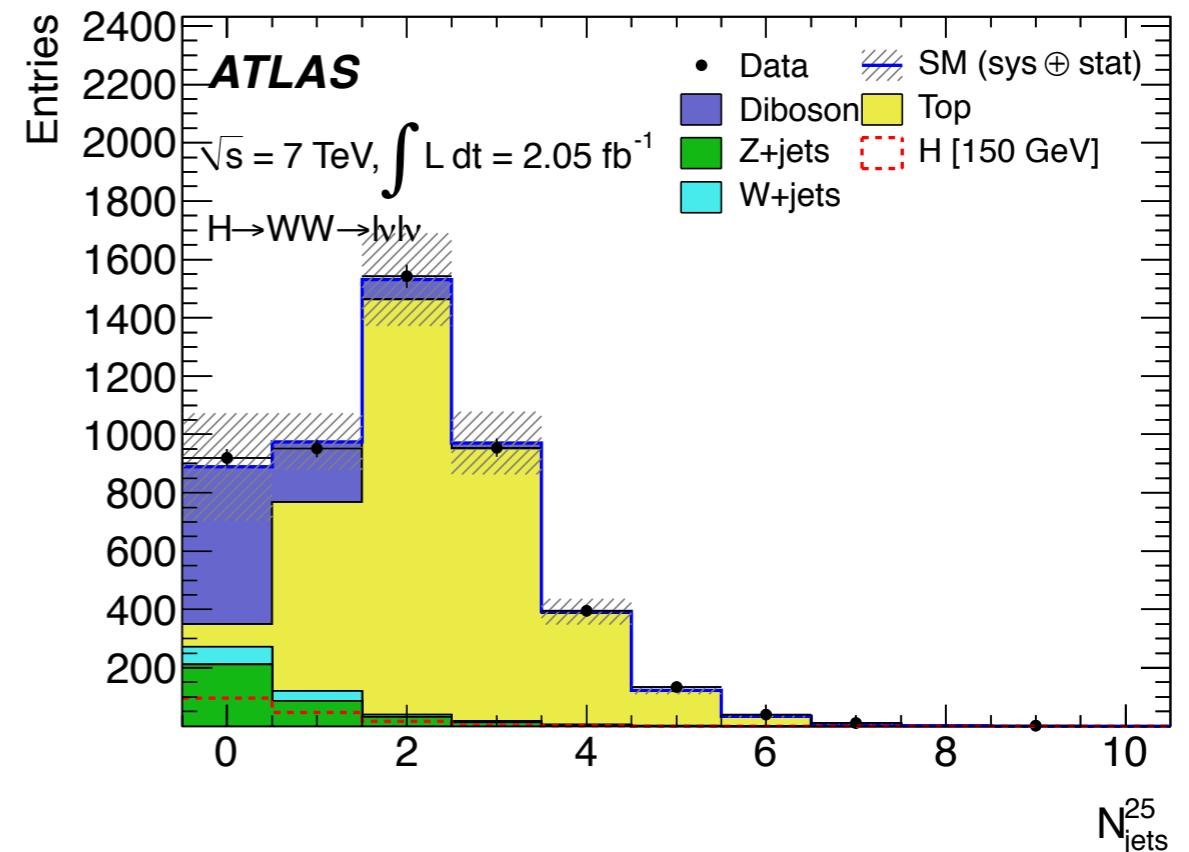
μμ channel

$E_{T,\text{rel}}^{\text{miss}}$  distribution before cut applied in 3 channels

# $H \rightarrow WW^{(*)} \rightarrow l\nu/\nu$ selection

## Separate jet bins

- Jet selection:  $p_T > 25$  GeV,  $||\eta| < 4.5$
- Analysis separate in 0 jet, exactly 1 jet and at least 2 jets cases after  $E_T^{\text{miss}}$  cut defined previously
- Common topological cuts applied to all jet bins
  - $m_H < 170$  GeV
    - $m_{\parallel} < 50$  GeV
    - $\Delta\phi_{\parallel} < 1.3$
    - $0.75 * m_H < m_T < m_H$
  - $220 \text{ GeV} > m_H \geq 170 \text{ GeV}$ 
    - $m_{\parallel} < 65$  GeV
    - $\Delta\phi_{\parallel} < 1.8$
    - $0.75 * m_H < m_T < m_H$
  - $m_H > 220$  GeV
    - $50 < m_{\parallel} < 180$  GeV
    - $0.6 * m_H < m_T < m_H$



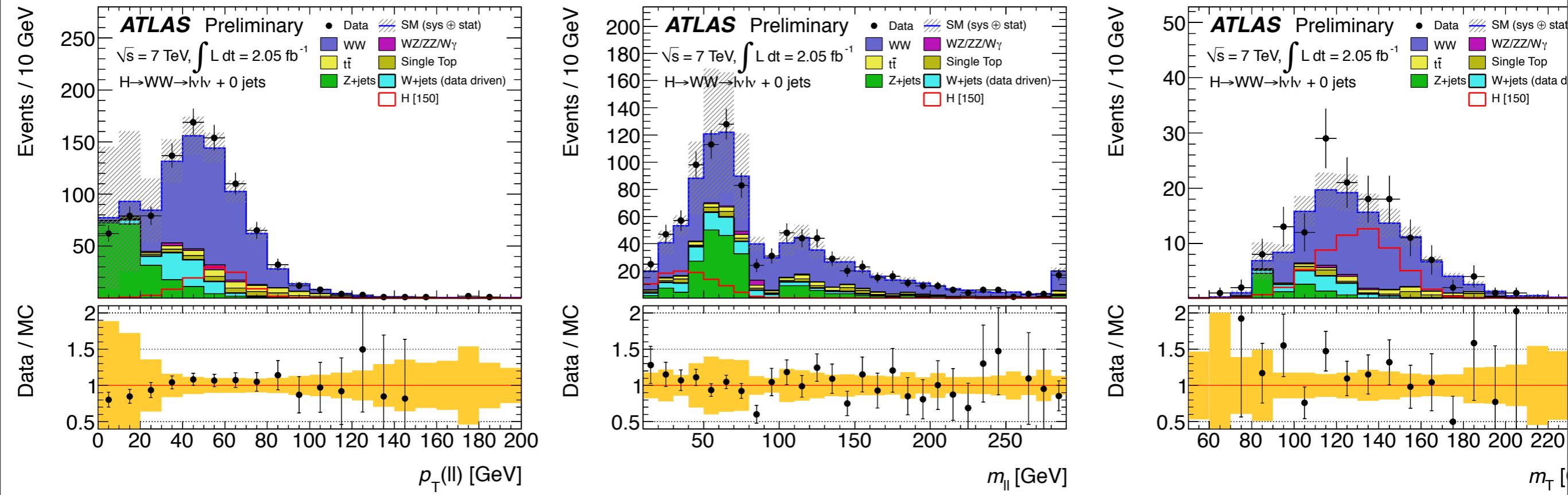
Jet multiplicity before separating into different bins

$$m_T = \sqrt{(E_{\parallel} + E_{\text{miss}}^T)^2 - (P_{\parallel} + P_{\text{miss}})^2}$$

# $H \rightarrow WW^{(*)} \rightarrow l\nu/l\nu$ selection

## 0 jet bin selection

- $p_T^{\text{ll}} > 30 \text{ GeV}$
- common topological selection defined previously



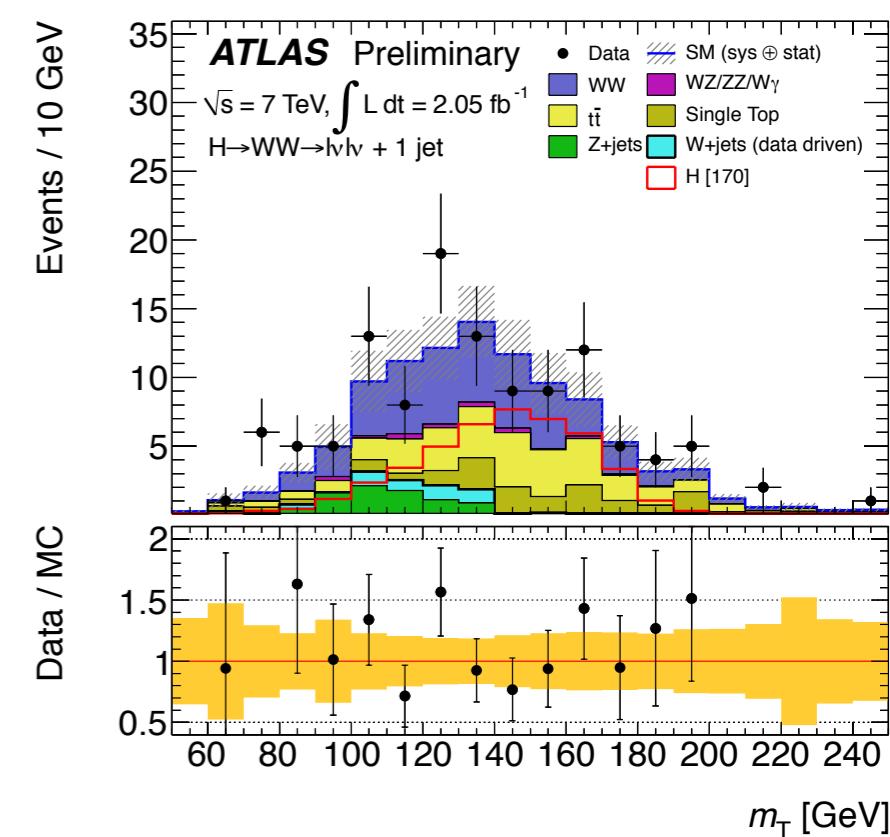
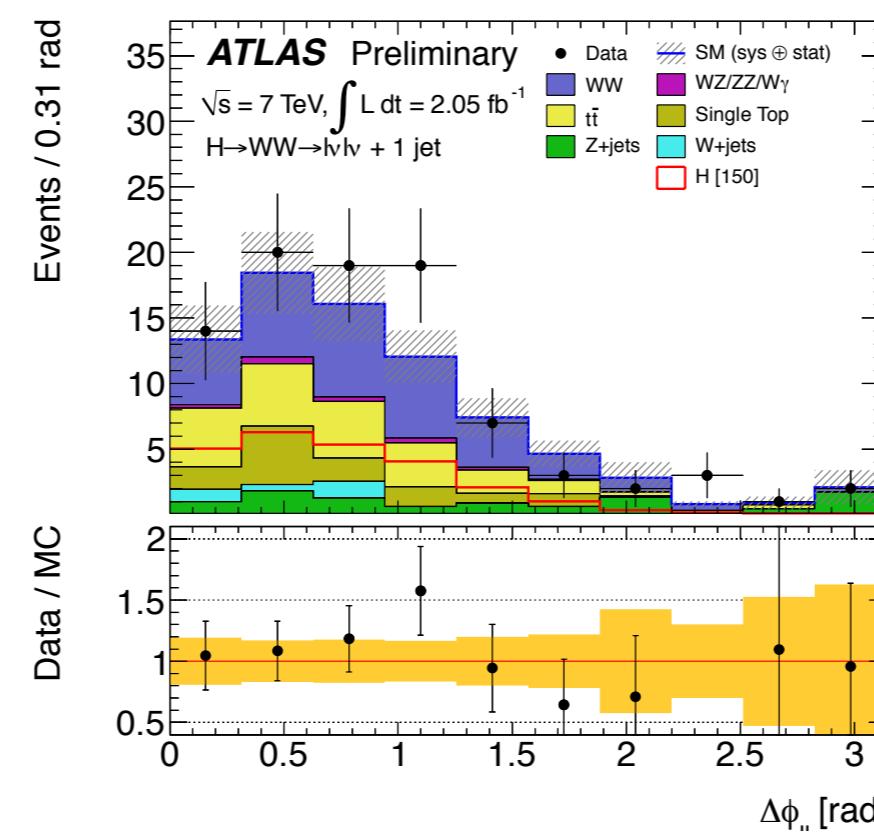
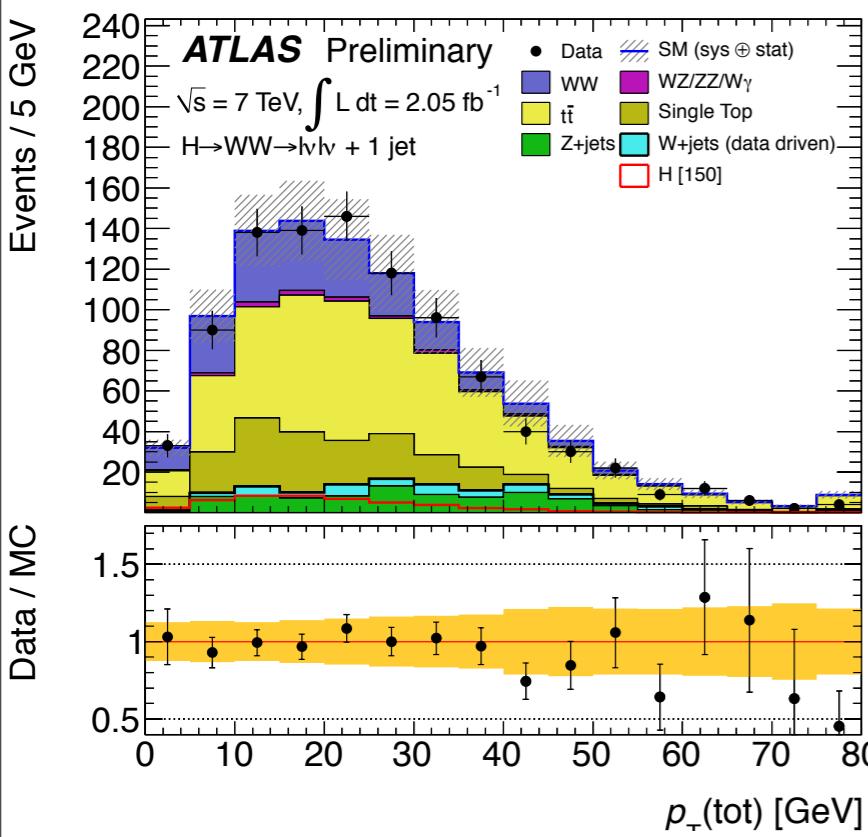
	Signal	WW	W + jets	Z/ $\gamma^*$ + jets	$t\bar{t}$	$tW/tb/tqb$	WZ/ZZ/W $\gamma$	Total Bkg.	Observed
Jet Veto	$100 \pm 20$	$520 \pm 50$	$80 \pm 40$	$170 \pm 170$	$42 \pm 14$	$32 \pm 8$	$15 \pm 4$	$870 \pm 170$	920
$ \mathbf{P}_T^{\ell\ell}  > 30 \text{ GeV}$	$100 \pm 20$	$470 \pm 50$	$70 \pm 30$	$30 \pm 12$	$39 \pm 14$	$29 \pm 8$	$13 \pm 4$	$650 \pm 100$	700
$m_{\ell\ell} < 50 \text{ GeV}$	$68 \pm 15$	$118 \pm 15$	$21 \pm 8$	$13 \pm 8$	$7 \pm 4$	$5.8 \pm 1.8$	$1.9 \pm 0.6$	$170 \pm 20$	199
$\Delta\phi_{\ell\ell} < 1.3$	$58 \pm 13$	$91 \pm 12$	$12 \pm 5$	$9 \pm 6$	$6 \pm 3$	$5.8 \pm 1.8$	$1.7 \pm 0.6$	$125 \pm 19$	149
$0.75 m_H < m_T < m_H$	$40 \pm 9$	$52 \pm 7$	$5 \pm 2$	$2 \pm 4$	$2.4 \pm 1.6$	$1.5 \pm 1.0$	$1.1 \pm 0.5$	$63 \pm 10$	81
$ee$	$6.2 \pm 1.4$	$7.5 \pm 1.1$	$1.0 \pm 0.4$	$0.9 \pm 1.5$	$0.3 \pm 0.4$	$0 \pm 0$	$0.08 \pm 0.06$	$9.7 \pm 1.7$	10
$e\mu$	$21 \pm 5$	$27 \pm 4$	$3.2 \pm 1.4$	$0 \pm 0$	$1.3 \pm 0.6$	$1.0 \pm 0.7$	$0.6 \pm 0.4$	$33 \pm 5$	38
$\mu\mu$	$13 \pm 3$	$17 \pm 2$	$1.1 \pm 0.7$	$1 \pm 3$	$0.8 \pm 1.2$	$0.5 \pm 0.5$	$0.37 \pm 0.10$	$21 \pm 5$	33

0 jet final cut flow result

# $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$ selection

## | jet bin selection

- reject b-jet
- $p_T(\text{total}) < 30 \text{ GeV}$  (including lepton, jet and MET)
- common topological selection
- $Z \rightarrow \tau\tau$  rejection
- assume invisible and visible products of  $\tau$  are collinear, energy fraction of visible product  $x^1 > 0, x^2 > 0, |\mathcal{M}_{\tau\tau} - M_Z| > 25 \text{ GeV}$



	Signal	WW	W + jets	Z/ $\gamma^*$ + jets	t <bar>t</bar>	tW/tb/tqb	WZ/ZZ/W $\gamma$	Total Bkg.	Observed
1 jet	$50 \pm 9$	$193 \pm 20$	$40 \pm 20$	$70 \pm 70$	$470 \pm 120$	$170 \pm 30$	$14 \pm 2$	$970 \pm 140$	952
b-jet veto	$48 \pm 9$	$188 \pm 19$	$35 \pm 19$	$70 \pm 60$	$170 \pm 50$	$66 \pm 11$	$14.0 \pm 2.0$	$550 \pm 80$	564
$P_T^{\text{tot}} < 30 \text{ GeV}$	$39 \pm 7$	$154 \pm 16$	$18 \pm 9$	$40 \pm 30$	$110 \pm 30$	$50 \pm 9$	$9.7 \pm 1.5$	$380 \pm 60$	405
$Z \rightarrow \tau\tau$ veto	$39 \pm 7$	$150 \pm 17$	$18 \pm 8$	$30 \pm 20$	$100 \pm 20$	$48 \pm 8$	$9 \pm 2$	$360 \pm 30$	388
$m_{\ell\ell} < 50 \text{ GeV}$	$26 \pm 6$	$33 \pm 5$	$3.3 \pm 1.4$	$8 \pm 7$	$20 \pm 7$	$11 \pm 3$	$1.8 \pm 0.5$	$77 \pm 11$	90
$\Delta\phi_{\ell\ell} < 1.3$	$23 \pm 5$	$25 \pm 4$	$2.1 \pm 1.0$	$4 \pm 6$	$17 \pm 6$	$9 \pm 3$	$1.5 \pm 0.4$	$60 \pm 10$	72
$0.75 m_H < m_T < m_H$	$14 \pm 3$	$12 \pm 3$	$0.9 \pm 0.4$	$1.3 \pm 1.9$	$8 \pm 2$	$4.0 \pm 1.6$	$0.7 \pm 0.3$	$28 \pm 5$	29
$ee$	$2.0 \pm 0.5$	$1.7 \pm 0.5$	$0.17 \pm 0.08$	$0.1 \pm 0.2$	$0.8 \pm 0.4$	$0.6 \pm 0.3$	$0.12 \pm 0.11$	$3.5 \pm 0.9$	5
$e\mu$	$7.6 \pm 1.8$	$6.7 \pm 1.5$	$0.6 \pm 0.3$	$0.6 \pm 1.1$	$4.5 \pm 1.5$	$2.3 \pm 1.1$	$0.5 \pm 0.2$	$15 \pm 3$	14
$\mu\mu$	$4.7 \pm 1.1$	$4.0 \pm 0.8$	$0.1 \pm 0.2$	$0.6 \pm 0.5$	$3.1 \pm 1.9$	$1.2 \pm 1.0$	$0.10 \pm 0.07$	$9 \pm 2$	10

# Background estimation

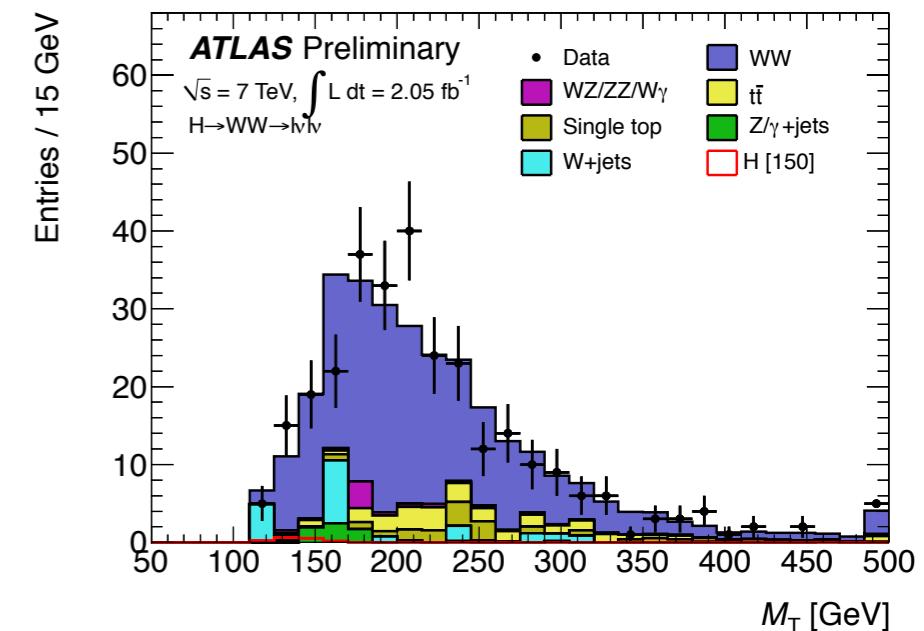
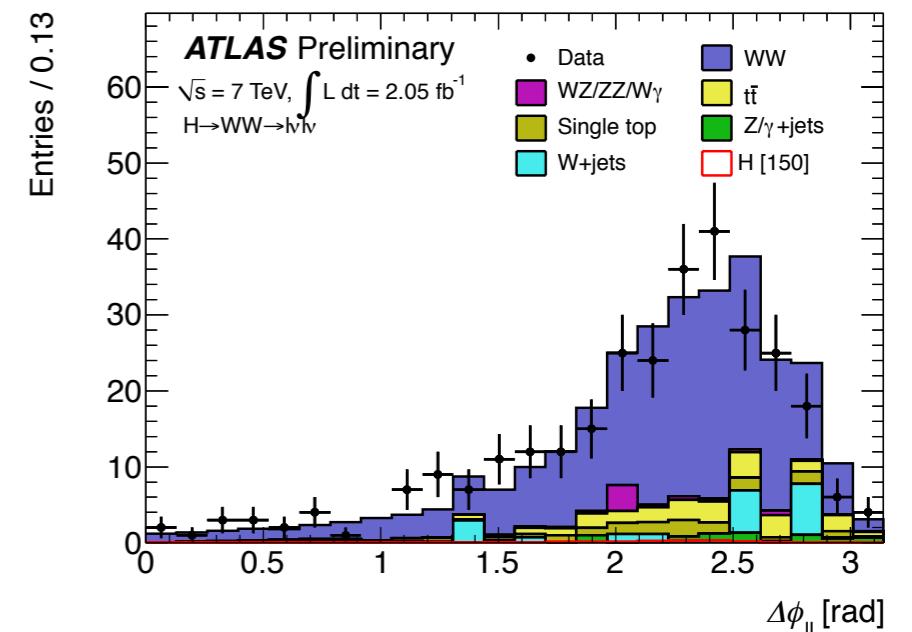
- $WW$ 
  - Irreducible
  - Normalized using control region in data
- $Top$ 
  - Arising from losing jets
  - Normalized using control region in data
- $W+jet$ 
  - Misidentified leptons from jets
  - Scaling control region in data using jets enriched lepton selection
- $Z+jet$ 
  - Fake missing  $E_T$
  - Apply scale factors for potential Missing  $E_T$  mis-modeling

# WW estimation

- MC prediction is normalized to data using control region
- Control region
  - Remove  $\Delta\phi_{ll}$  and  $m_T$  cuts
  - $m_{ll} > 80 \text{ GeV}$  ( $m_H < 220 \text{ GeV}$ )
  - $m_{ll} > 180 \text{ GeV}$  or  $m_{ll} < 50 \text{ GeV}$  ( $m_H \geq 220 \text{ GeV}$ )

	Signal	WW	$W + \text{jets}$	$Z/\gamma^* + \text{jets}$	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
for low $m_H < 220 \text{ GeV}$									
$ee + e\mu + \mu\mu$	$1.7 \pm 0.4$	$220 \pm 30$	$20 \pm 15$	$6 \pm 8$	$25 \pm 10$	$15 \pm 4$	$8 \pm 3$	$300 \pm 60$	296
$ee$	$0.030 \pm 0.012$	$27 \pm 4$	$3 \pm 3$	$1 \pm 7$	$4 \pm 2$	$1.3 \pm 1.2$	$0.35 \pm 0.11$	$36 \pm 6$	52
$e\mu$	$1.7 \pm 0.4$	$150 \pm 20$	$16 \pm 11$	$1.0 \pm 0.8$	$15 \pm 6$	$9 \pm 3$	$6 \pm 3$	$200 \pm 40$	184
$\mu\mu$	$0.030 \pm 0.012$	$45 \pm 6$	$1.7 \pm 1.4$	$4 \pm 3$	$5 \pm 2$	$4.4 \pm 1.6$	$1.3 \pm 0.3$	$62 \pm 10$	60
for low $m_H \geq 220 \text{ GeV}$									
$ee + e\mu + \mu\mu$	$10 \pm 2$	$170 \pm 20$	$24 \pm 12$	$13 \pm 19$	$15 \pm 6$	$8 \pm 3$	$3.3 \pm 0.6$	$240 \pm 40$	258
$ee$	$1.6 \pm 0.4$	$24 \pm 3$	$4 \pm 2$	$0 \pm 30$	$2.7 \pm 1.4$	$0.5 \pm 0.5$	$0.24 \pm 0.09$	$35.0 \pm 2.0$	33
$e\mu$	$5.4 \pm 1.2$	$96 \pm 13$	$14 \pm 7$	$0.2 \pm 0.2$	$9 \pm 4$	$5.9 \pm 1.8$	$1.8 \pm 0.4$	$130 \pm 30$	132
$\mu\mu$	$3.5 \pm 0.7$	$53 \pm 7$	$6 \pm 2$	$9 \pm 6$	$3.4 \pm 1.5$	$2.0 \pm 0.8$	$1.3 \pm 0.3$	$75 \pm 11$	93

Control region cut flow result



# Top estimation

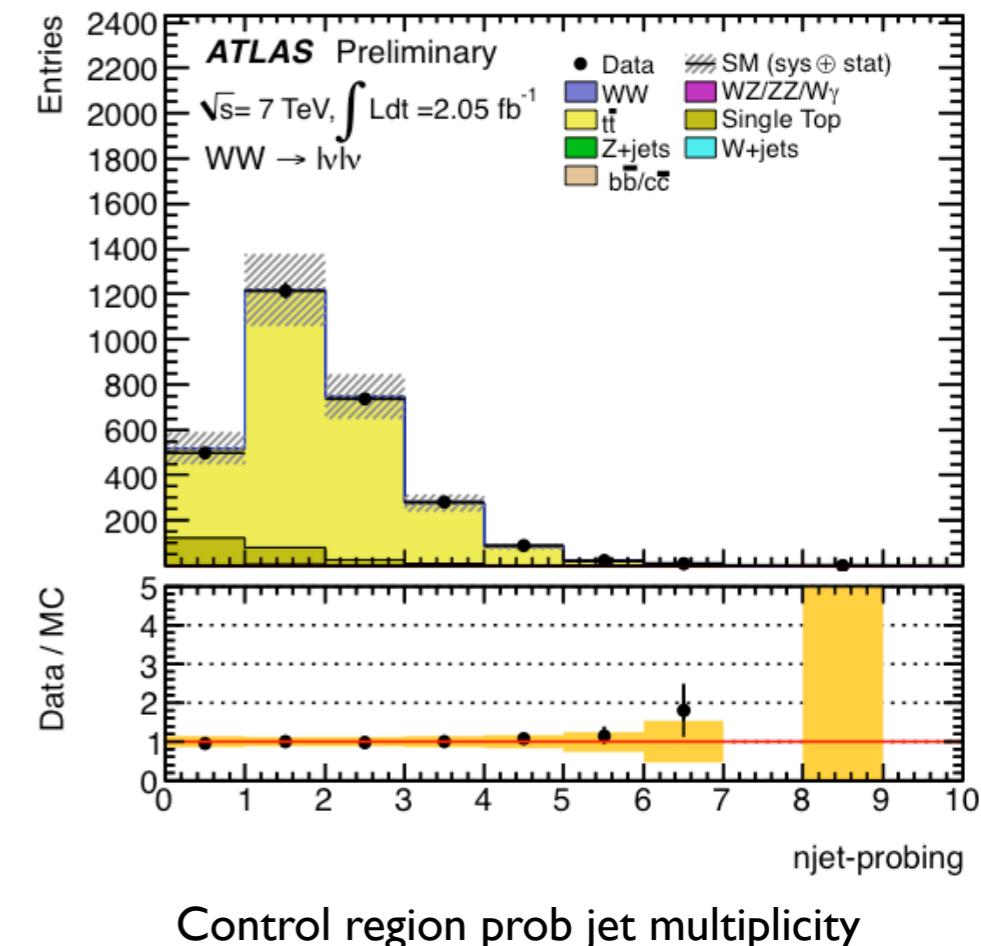
- 0 jet analysis

$$N_{\text{Top}}^{\text{Bkg}}(\text{0-jet}) = N_{\text{Top}}^{\text{Data}} \times \text{SF} \times \frac{N_{\text{Top}}^{\text{MC}}(\text{0-jet})}{N_{\text{Top}}^{\text{MC}}}$$

- $N_{\text{Data}}$  is top events from data after preselection, other background contribution is extracted using MC
- SF is from control sample, asking b-tag jets.
  - prob jet defined as jet with  $dR > 0.1$  to the b-jet
  - $\text{SF} = (\text{P}_{\text{btag,data}} / \text{P}_{\text{btag,MC}})^2$ ,  $\text{P}_{\text{btag}}$  is the fraction of events with no prob jet in data or simulation

- 1 jet analysis

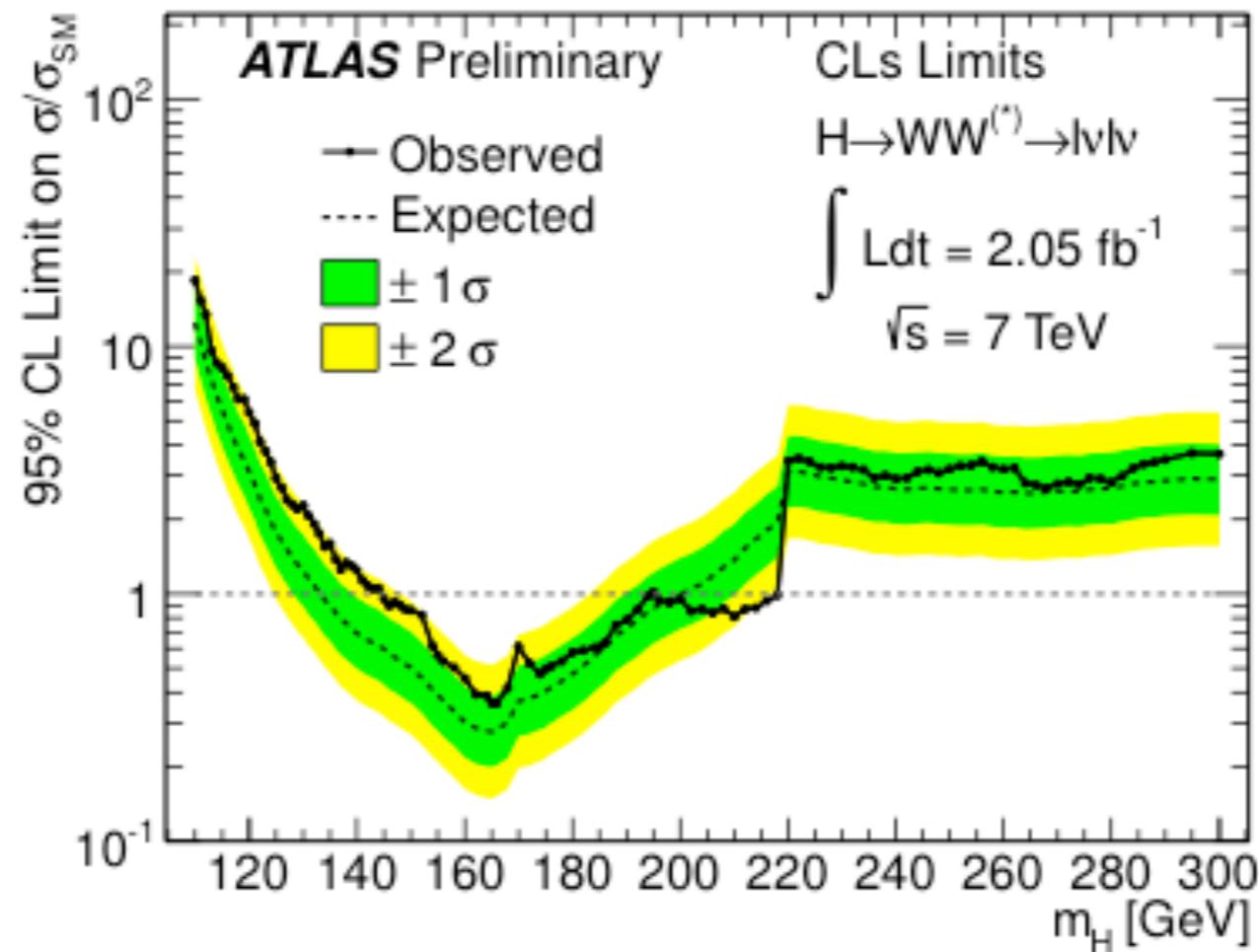
- The top background MC prediction is normalized to the data using a control sample defined by reversing the b-jet veto cut and removing the cuts on  $\Delta\phi_{\text{ll}}$ ,  $m_{\text{ll}}$ , and  $m_{\text{T}}$



	Signal	$WW$	$Z/\gamma^* + \text{jets}$	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
$ee + e\mu + \mu\mu$	$0.9 \pm 0.3$	$3.9 \pm 1.0$	$1 \pm 17$	$180 \pm 60$	$80 \pm 19$	$0.2 \pm 0.9$	$270 \pm 80$	249
$ee$	$0.09 \pm 0.04$	$0.26 \pm 0.13$	$0.9 \pm 0.9$	$24 \pm 7$	$10 \pm 3$	$0.02 \pm 0.02$	$35 \pm 9$	32
$e\mu$	$0.6 \pm 0.2$	$2.6 \pm 0.7$	$0.0 \pm 0.7$	$110 \pm 40$	$53 \pm 12$	$0.2 \pm 0.8$	$170 \pm 50$	153
$\mu\mu$	$0.29 \pm 0.11$	$1.0 \pm 0.4$	$0.04 \pm 0.04$	$46 \pm 19$	$17 \pm 5$	$0.0 \pm 0.2$	$60 \pm 20$	64

Control region cut flow result

# Standard Model Limit



- The jump in the expected and observed limits at 220 GeV is due to the change in the selection at that point.
- Observed 95% CL exclusion with CLs: **154-186** GeV
- Expected exclusion: **135-196** GeV

# Summary

- $H \rightarrow WW \rightarrow l\bar{v}l\bar{v}$  analysis done with  $2.1 \text{ fb}^{-1}$
- 95% CL exclusion region between 154-186 GeV
- Slight excess above background observed in low mass region
- Corresponding to  $\approx 2\sigma$

# My contributions since April 2011

- Cut flow with baseline selection
- Optimization of the track and calorimeter isolations as a function of different cone size as well as in presence of different pile-up conditions
- Study of muon-jet overlap which results in bin migration in the analyses 0-jet, 1-jet, 2-jets
- Optimization of the muon term in  $E_T^{\text{miss}}$  calculation:
  - adding tagged muons
  - quality cuts on standalone muons
  - For combined muons, select muons with the best ID/MS resolutions