Standard Model Higgs Searches at ATLAS H->ZZ/WW

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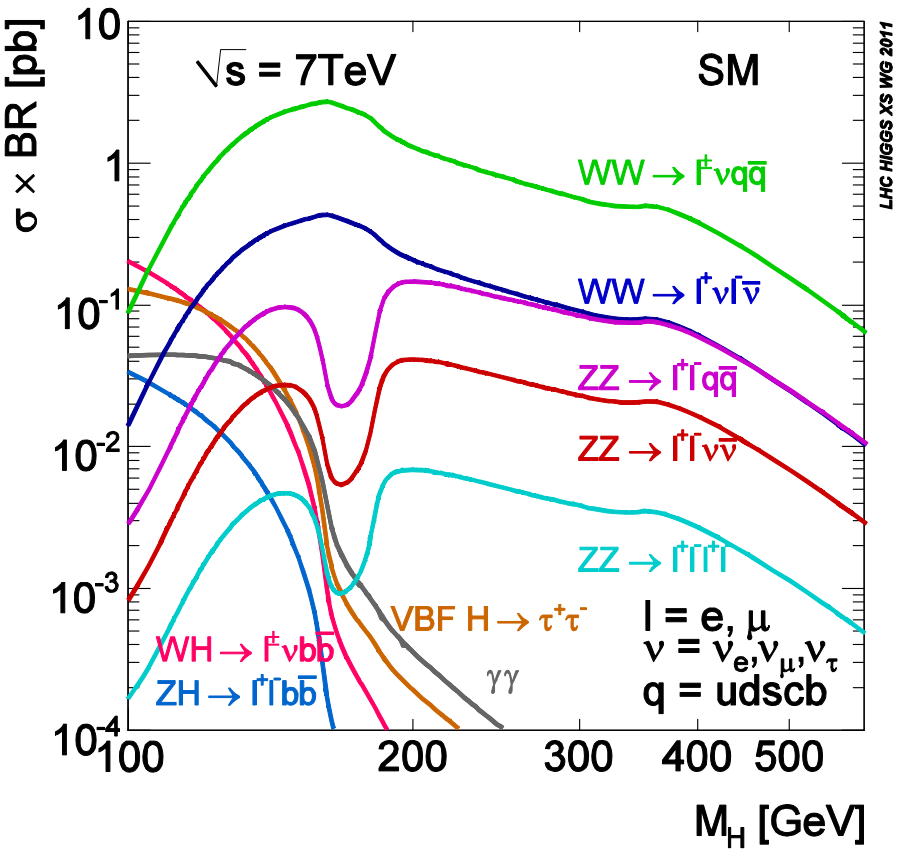
for the ATLAS Collaboration

Higgs Hunting 2011, Orsay, France, July 27th-29th, 2011

- H->ZZ (llqq,llvv,llll)
- H->WW (lvlv,lvqq)

  (ATLAS-CONF-2011-111)

Higgs Production at the ATLAS



SM H->ZZ:

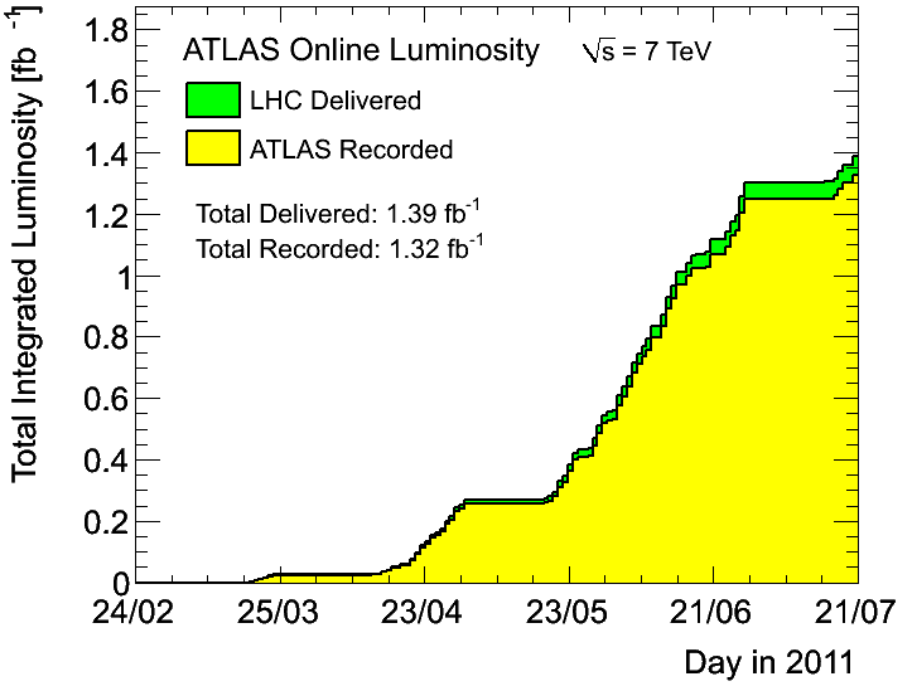
- Sizeable branching ratio, especially for llqq and llvv
- Presence of at least 1 on shell Z, clean final states

SM H->WW:

- Take advantage of high decay fraction and high branching fraction especially for lvqq(e,μ) and lvlv($ee,\mu\mu,e\mu$) – clean dilepton signature

Update for Summer 2011:

- Published 2010 data for 35pb^{-1}
- Excellent LHC performance in 2011, delivered 1.3fb^{-1} peak lumi 1.5×10^{33}cm^{-2}s^{-1} (already out of date!)
- Analyses presented here use >1fb^{-1}



H->ZZ->llqq

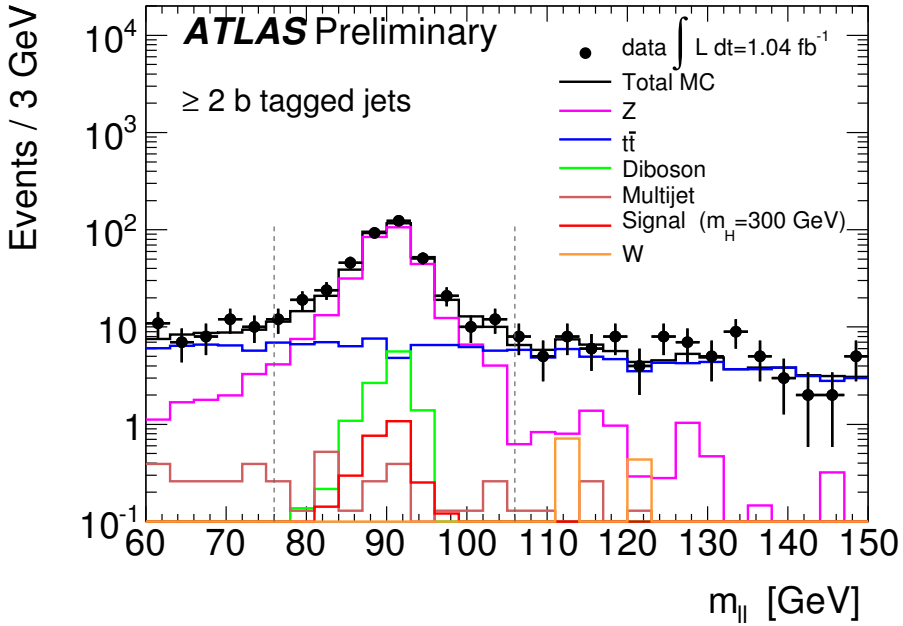
Signature lepton pair(ee,μμ)+2 jets:

- Main background Z+jets

Search in 200 < m_H < 600 GeV:

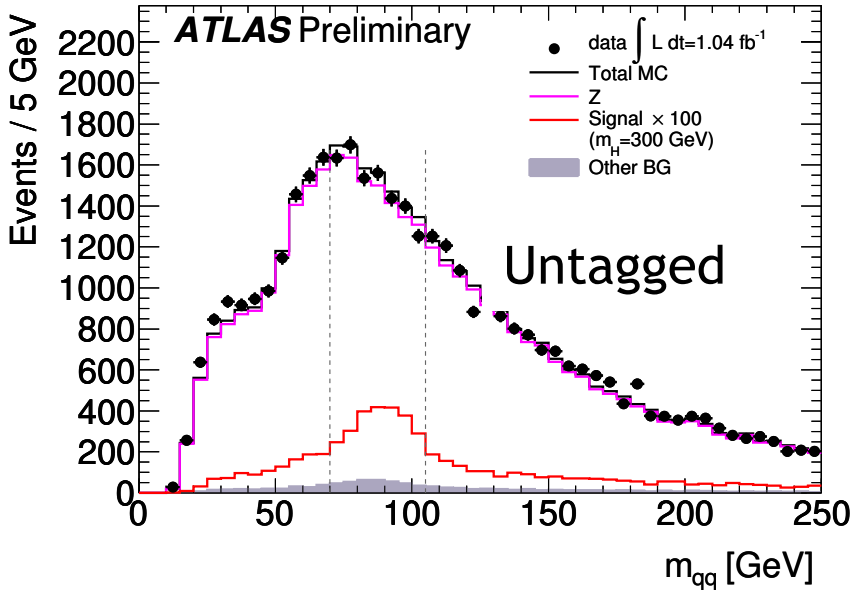
- Optimised high/low mass region m_H>300 GeV
- "Tagged" 2 b tags, "Untagged" 0/1 b tag
- High mass: p_T>45 GeV, $\Delta\phi_{ll}<\pi/2$, $\Delta\phi_{jj}<\pi/2$

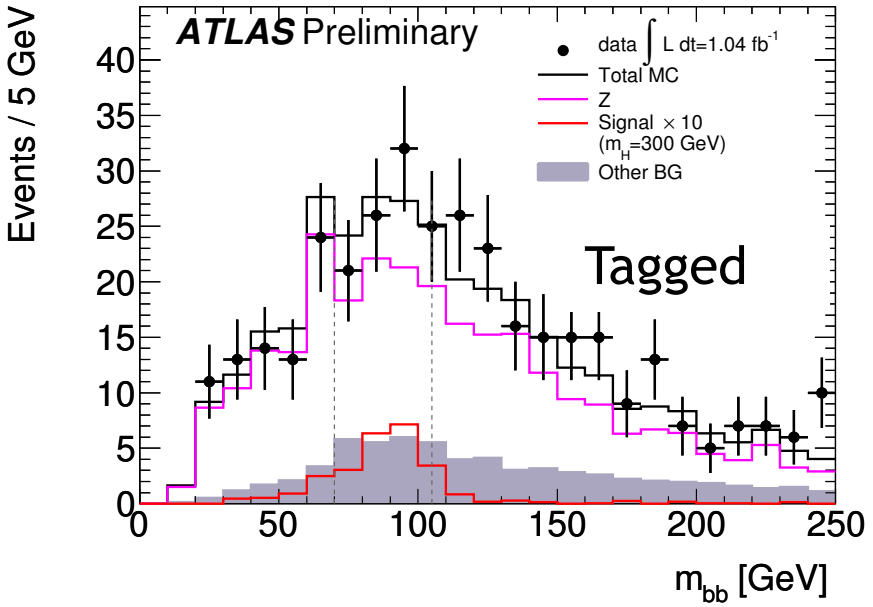
More details in talk from Carl Gwilliam



p_T^l>20 GeV, 67 < m_{ll} < 105 GeV, MET<50 GeV

Two p_T>25 GeV , |η|<2.5 jets , 70<m_{jj}<105 GeV



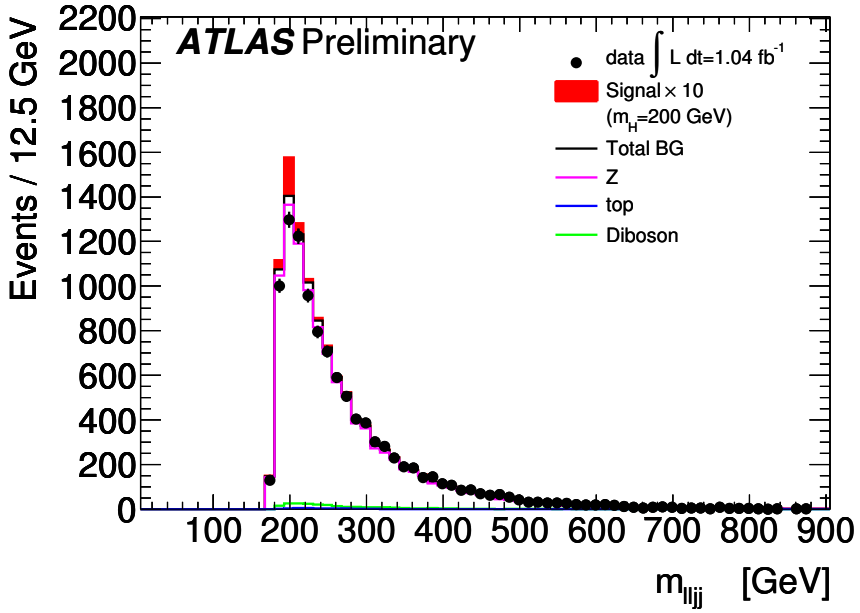


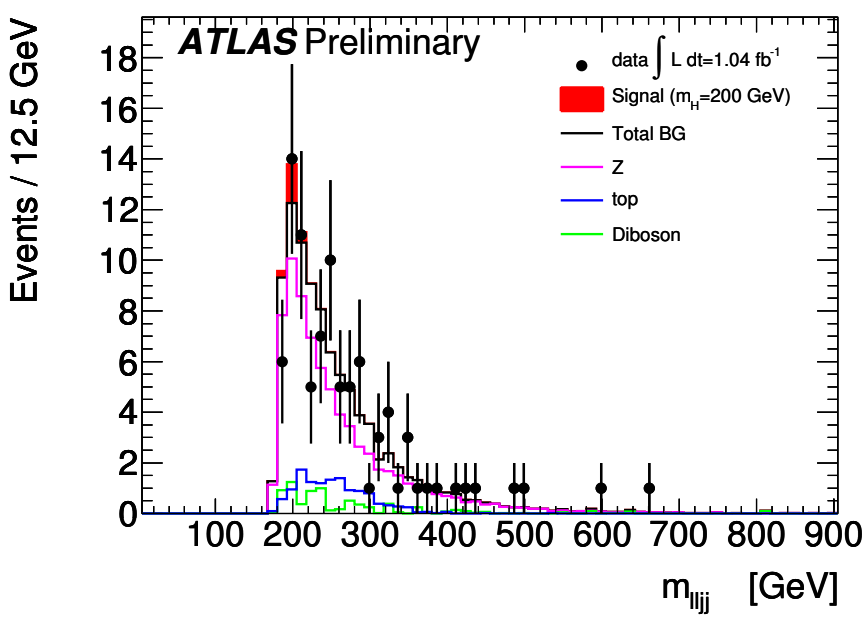
H->ZZ->llqq : Results

Untagged

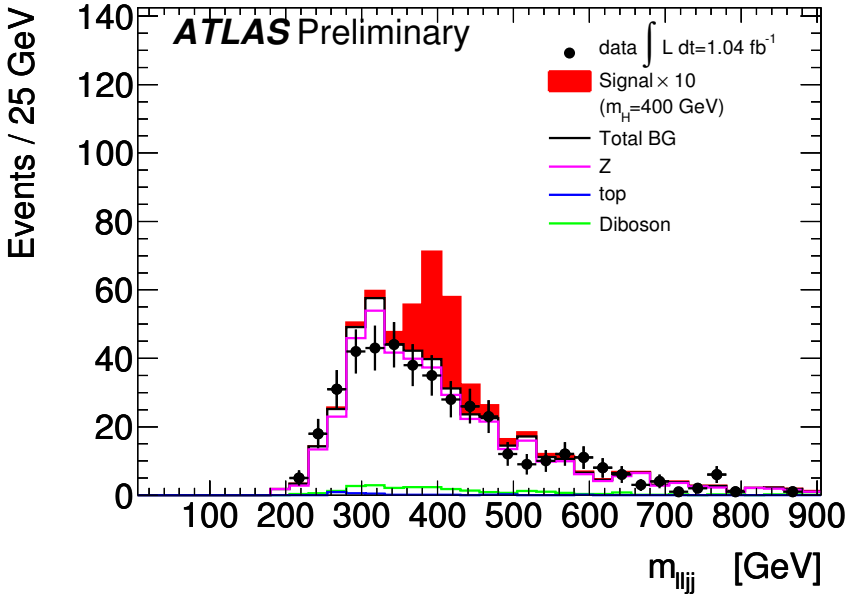
Final discriminant: m_{lljj}

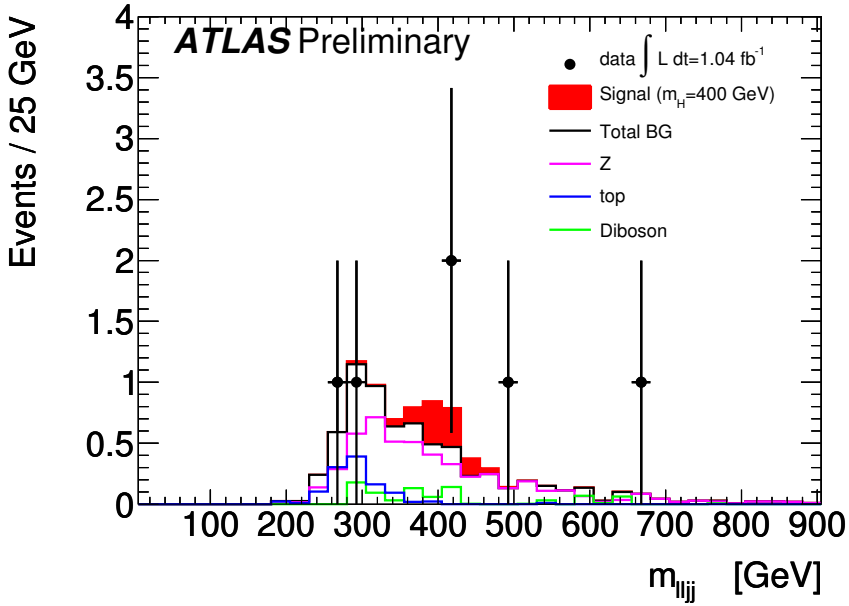
Tagged





m_H=200 GeV

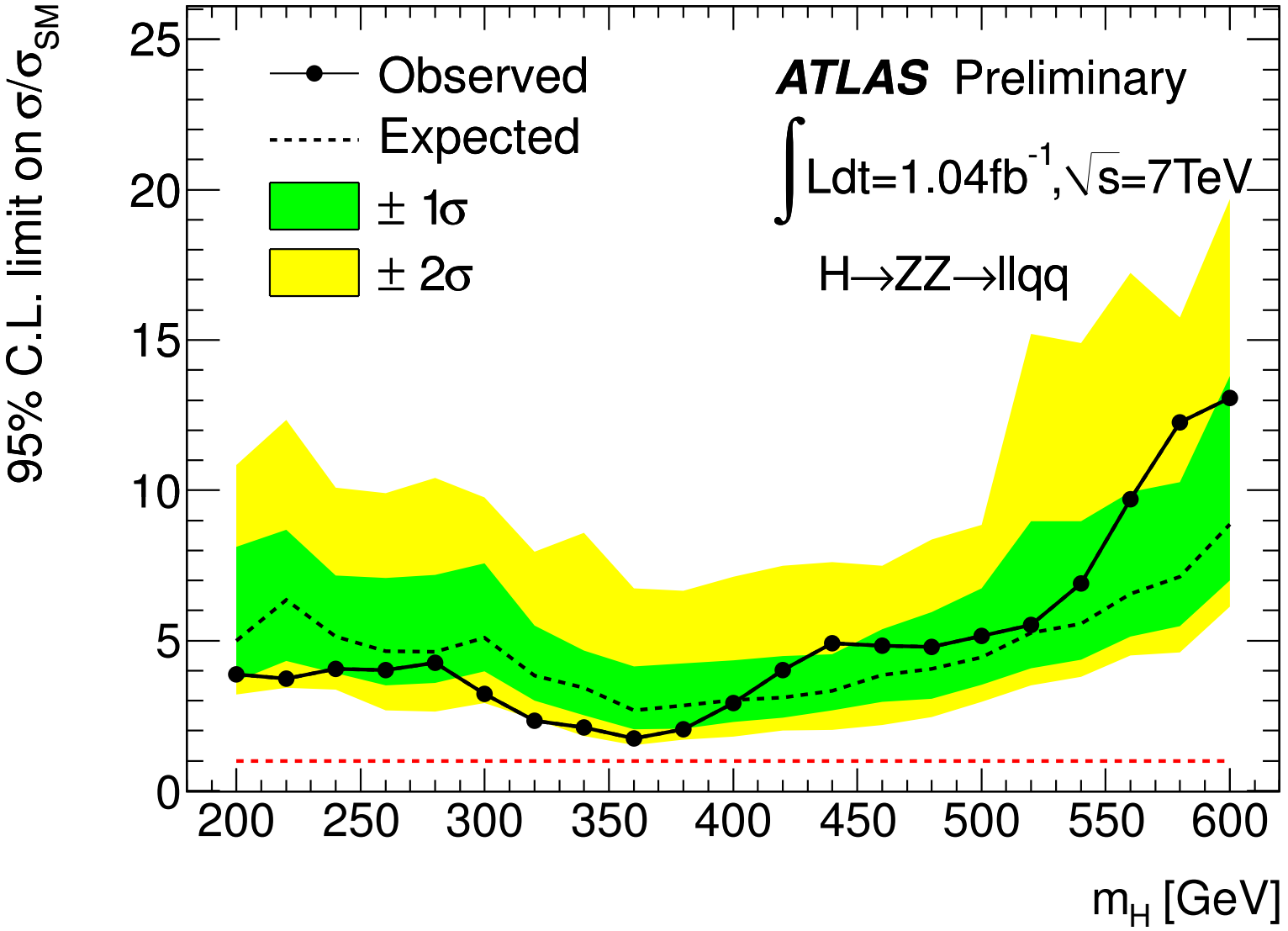




m_H=400 GeV

H->ZZ->llqq : Exclusion Limits

- Combined exclusion limit from tagged and untagged samples
- Standard ATLAS: CLs modified frequentist formalism with profile likelihood test statistic
- Good sensitivity across mass range



- Expected limit 2.7-9 xSM cross section, observed 1.7 xSM @mH=360 GeV
- These channels approaching σ_{SM} with 1fb^{-1}

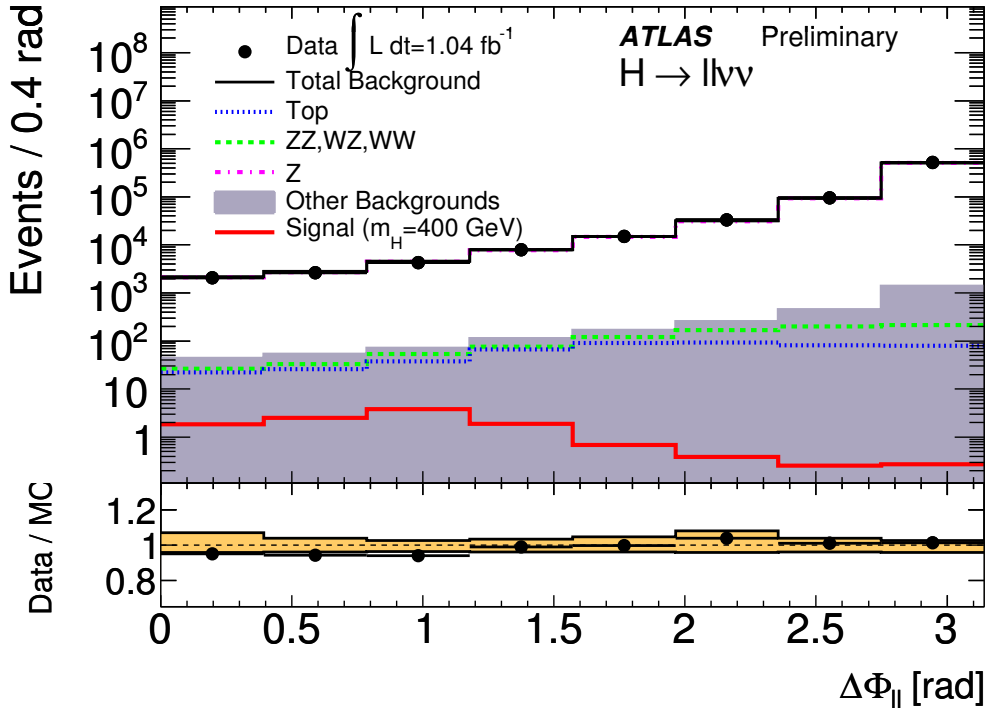
H->ZZ->llνν

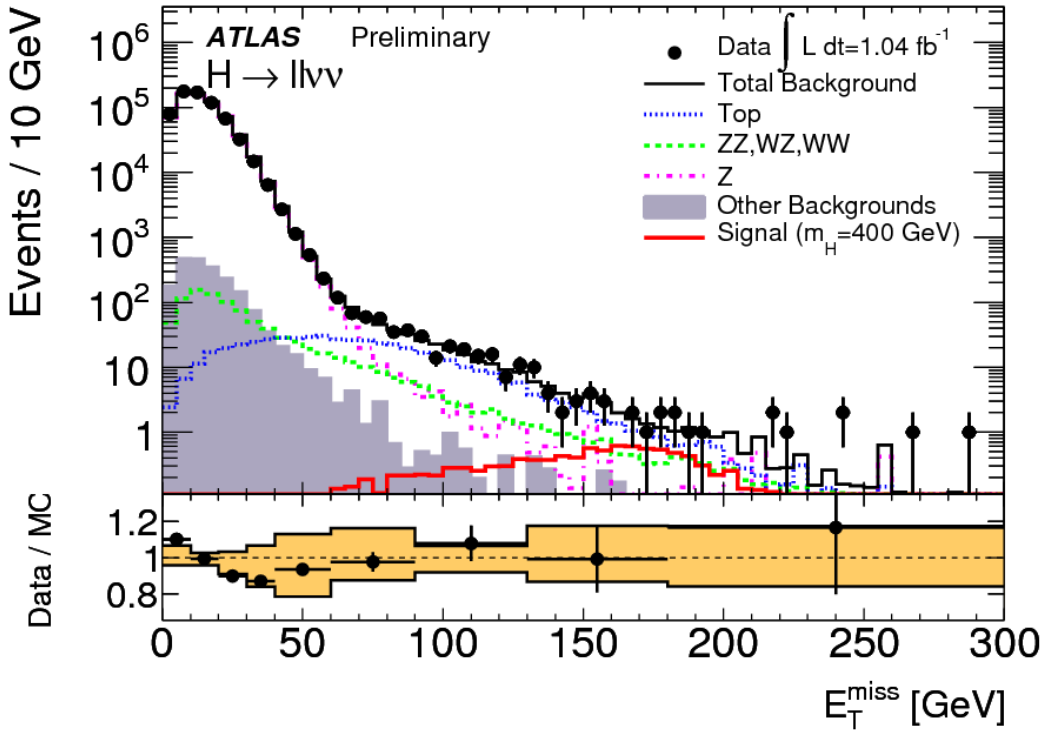
Signature lepton pair(ee,$\mu\mu$)+MET:

- Main backgrounds top and diboson
- Signal contributions from H->WW->lνlν

Search in 200 < m_H < 600 GeV:

- Optimised "high"/"low" mass region m_H>280 GeV

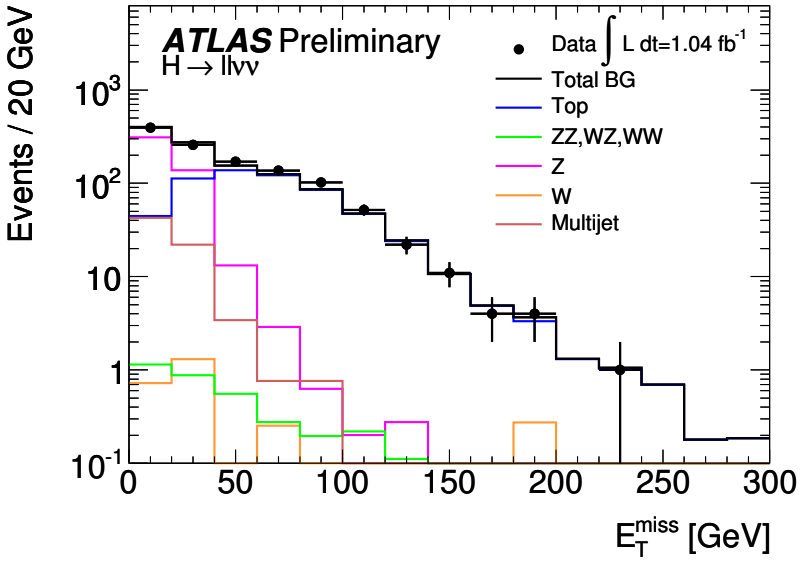




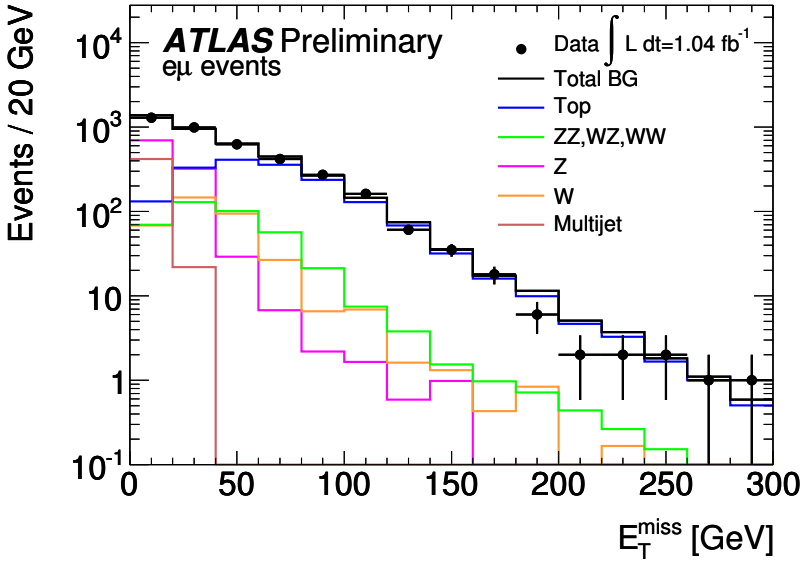
- Two high p_T isolated leptons
- 3rd lepton and b-jet vetoes
- MET>66 GeV (high mass MET>82 GeV)
- $\Delta\phi$(jet,MET)>0.3, high mass also $\Delta\phi$(Z,MET)>1
- $1<\Delta\phi_{ll}<2.64$, high mass $\Delta\phi<2.25$
- Final discriminant is transverse mass

ZZ->llvv : Backgrounds

Top m_{ll} sidebands and b-tag

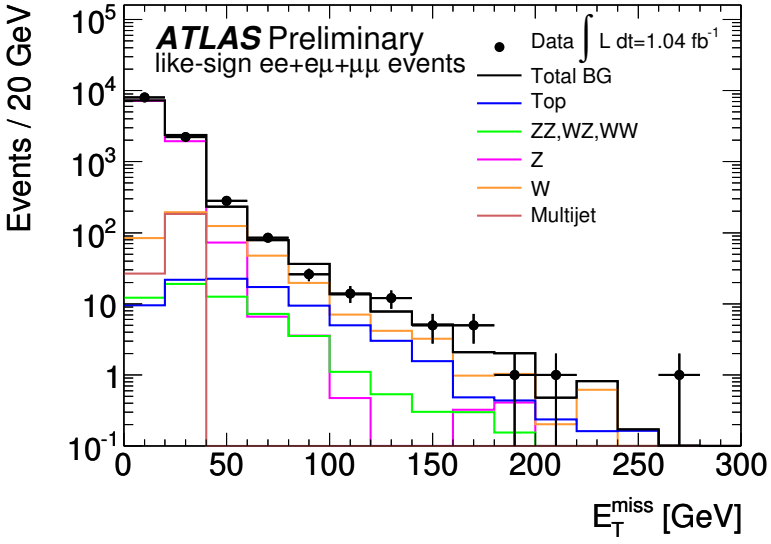


Top: eμ events

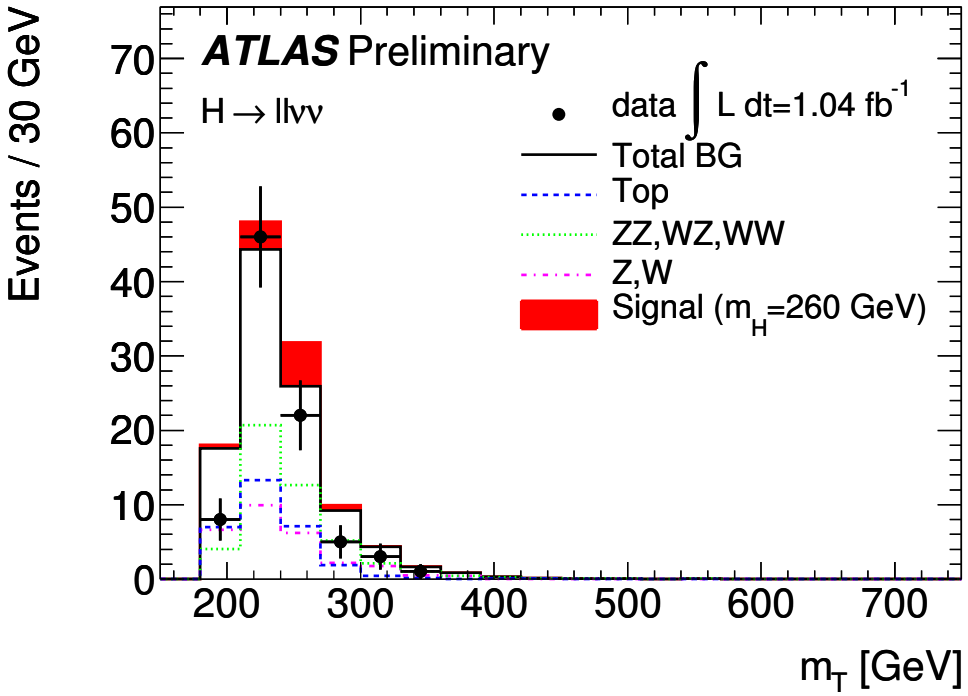


- Top background. MC expectation verified with data
- W+jets background, MC normalized in control region
- Diboson backgrounds from theory ~10%
- Data driven QCD background 'Multijet' (small)

W+jets: same sign lepton pairs



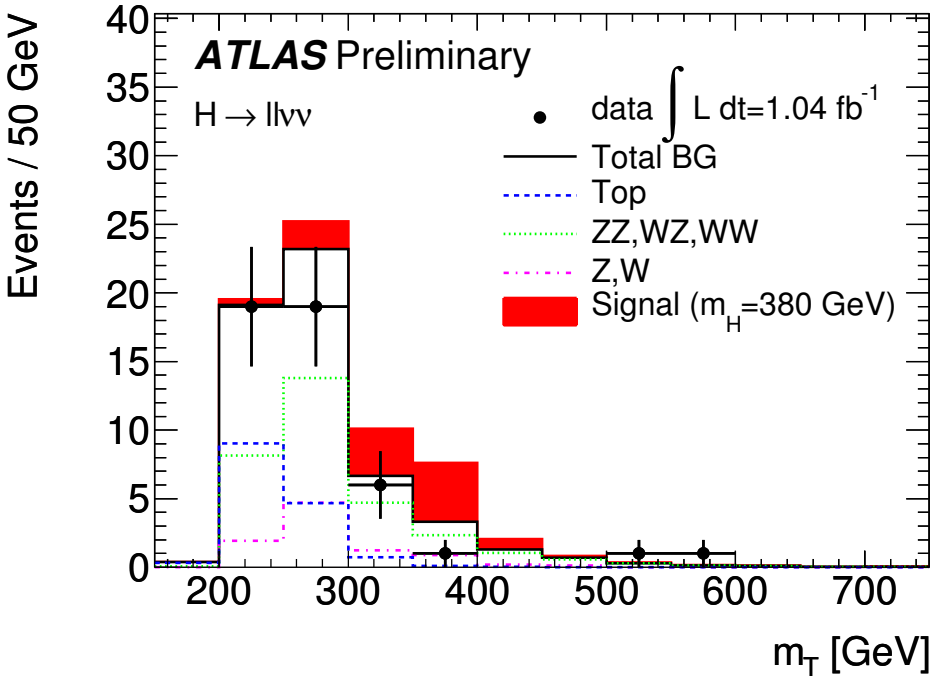
H->ZZ->>llvv : Results



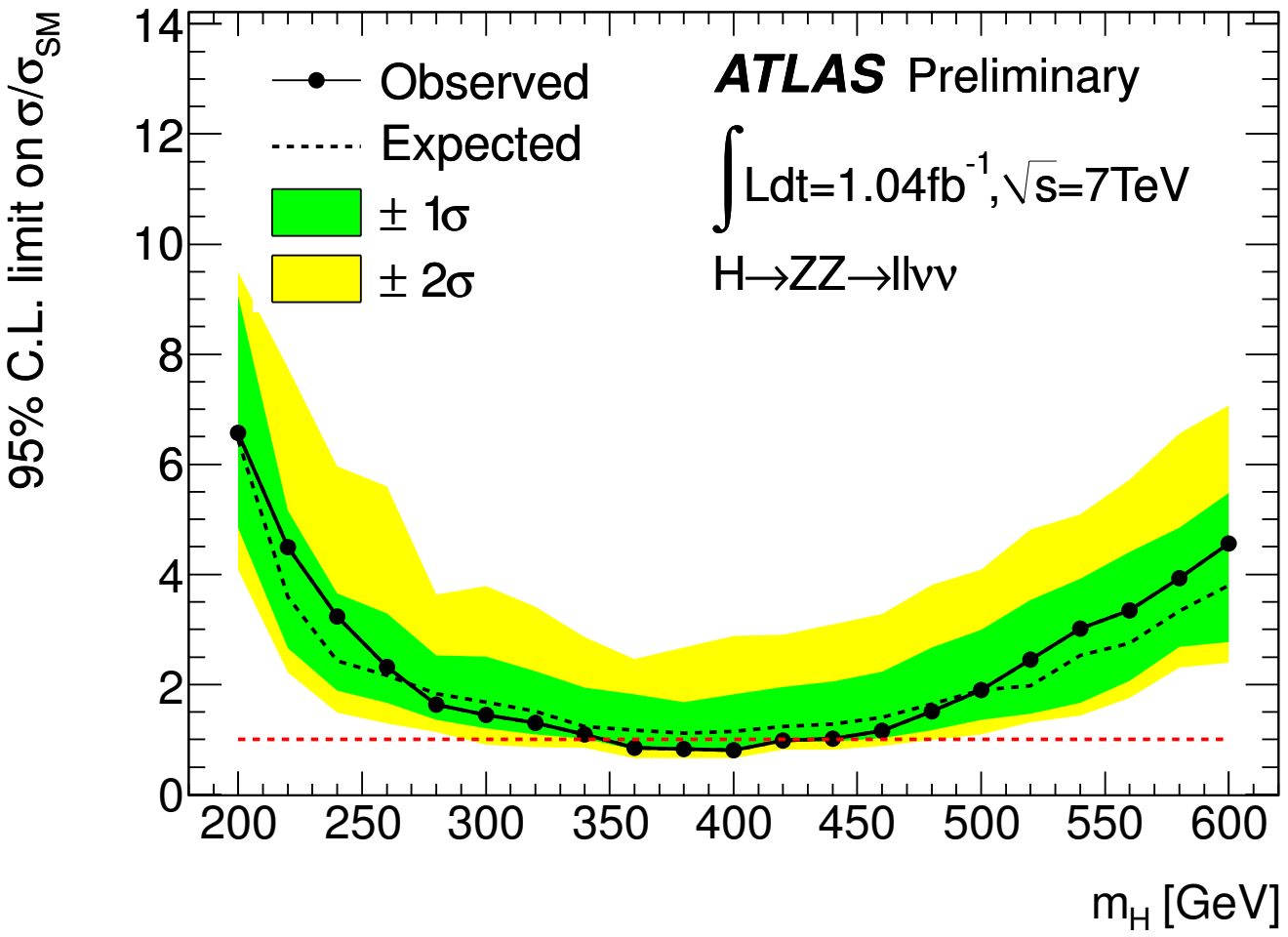
Top background at low M_T

Diboson background at higher M_T

No sign of SM Higgs



H->ZZ->llqq : Exclusion Limit



- Sensitivity across mass range
- Expected limit 1.2-7 x SM cross section
- Exclude SM Higgs between $360 < m_H < 420$ GeV

H->ZZ*->llll

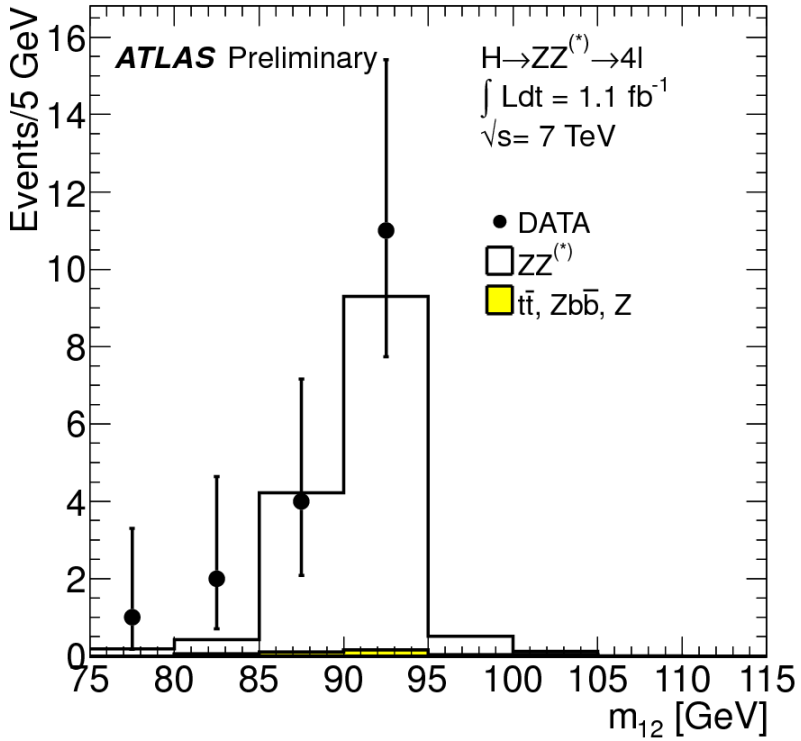
Very clean signature but low rate

- Main background is ZZ production, Z+jets, top suppressed by isolation/impact parameter
- $110 < m_H < 600$ GeV, sensitivity best 200-400 GeV

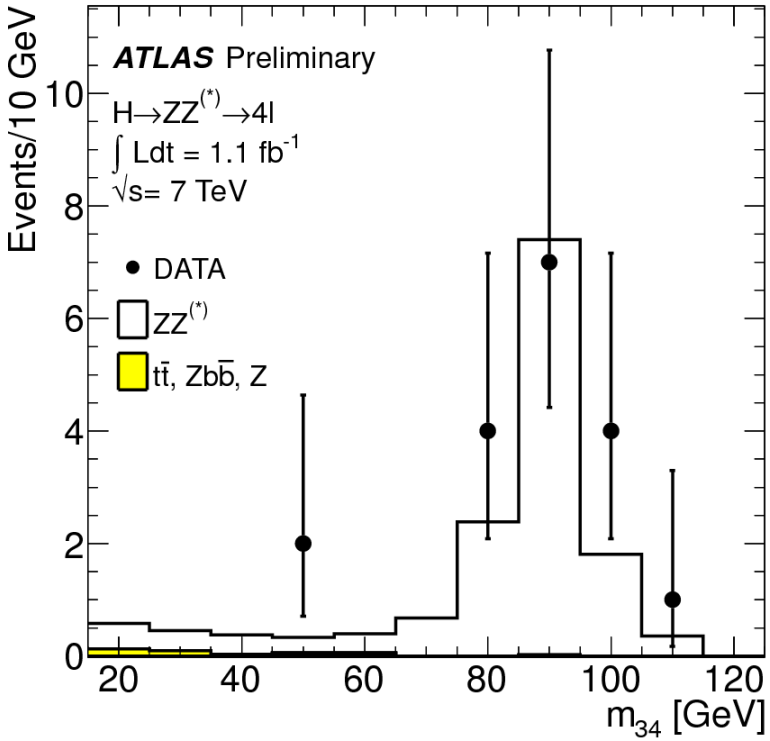
Event Selection:

- 2 pairs of same flavour, opposite charge leptons (4e,4μ,2e2μ)
- Lepton mass selection: $|m_{12}-m_Z|<15$ GeV and $m_{34}<115$ GeV and $m_{34}>m_{Threshold}(m_{4l})$

Primary Lepton pair (closest to Z) mass distribution



Secondary Lepton pair



H->ZZ->llll : Backgrounds

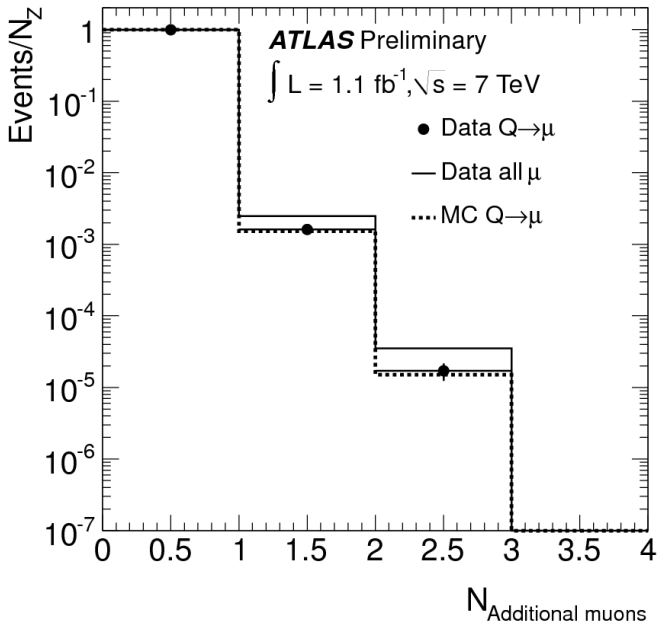
Dominant ZZ* production normalized to MC prediction

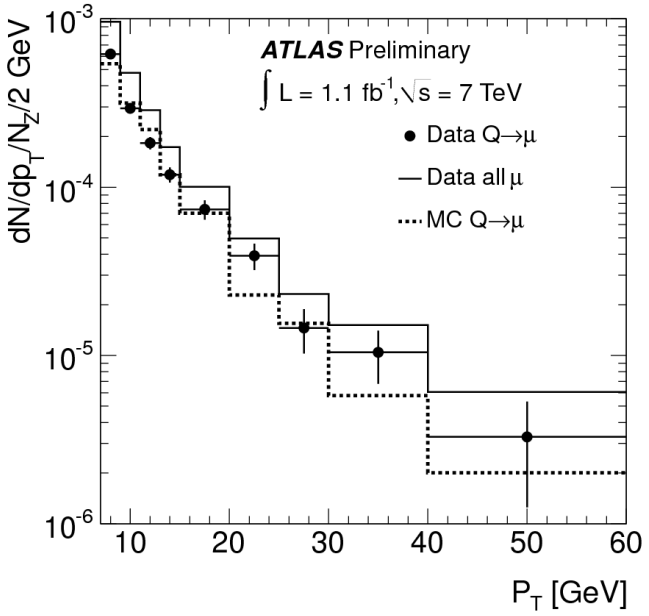
- Theory uncertainty 15%
- Luminosity error 3.7%

tt background using MC, verified in control region

Z+jets normalized on data control sample

- Select Z(->ll), and no isolation, impact parameter cuts on second
- Separate into different components(heavy flavour, electroweak, fakes)
- μμ dominated by Zbb
- ee: Z+light
- Uncertainties 20-40%

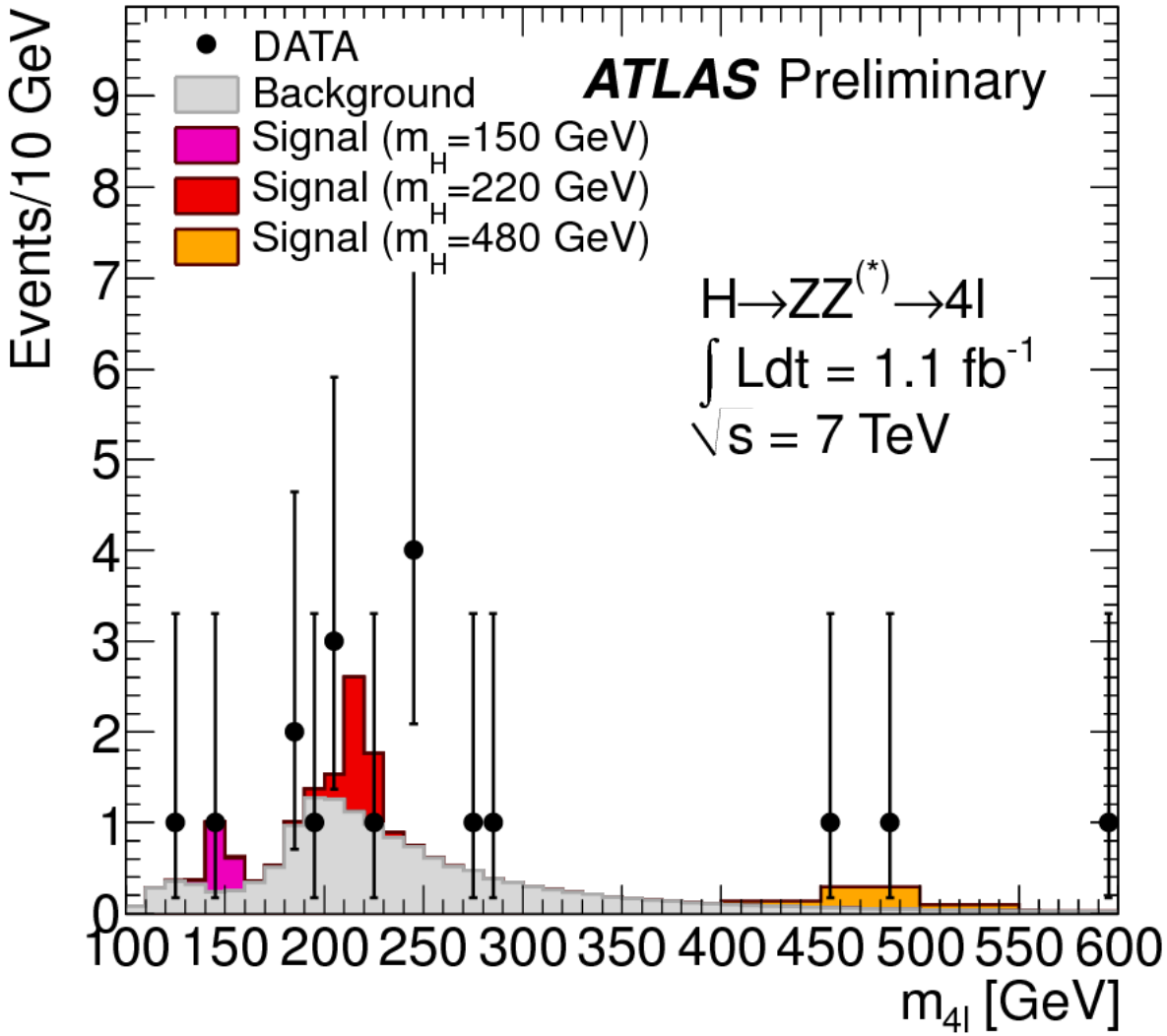




H->ZZ->4l : Results

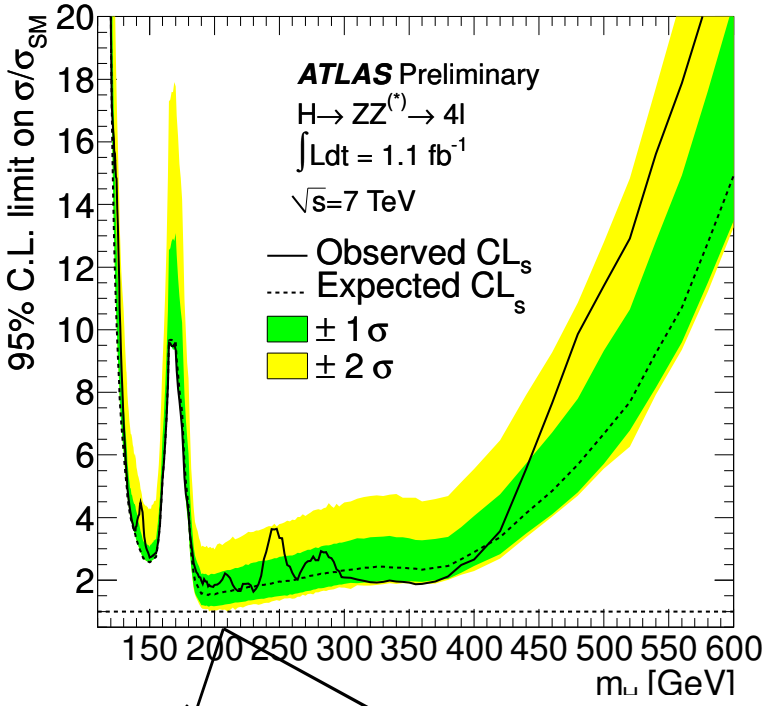
Summary of event yield in 4l invariant mass:

- Signal shown for three values of m_H (150, 220, 480 GeV)
- Sum of background expectation shown
- Shape follows expectation, local fluctuations observed

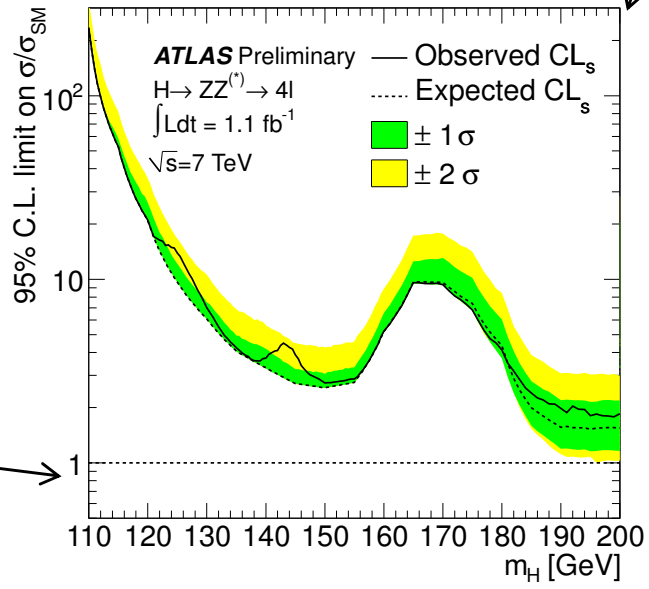


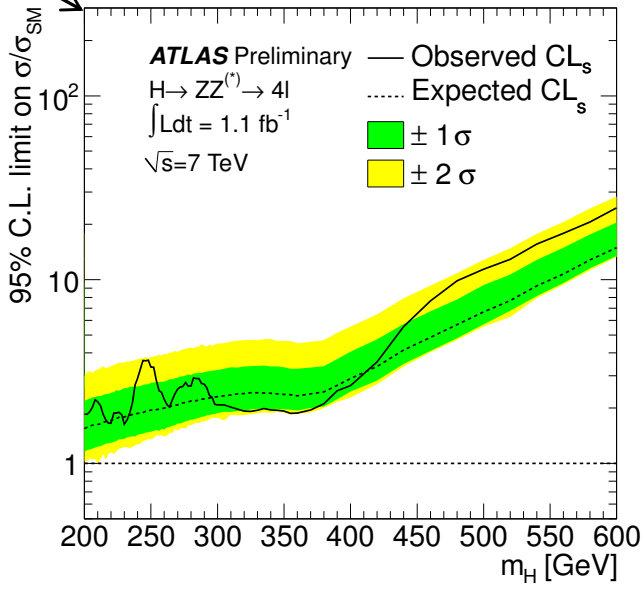
H->ZZ->4l : Exclusion Limits

- Expectation approaching SM
- Observed limits: 1.8 x SM @m_H=200 GeV
- Fluctuations observed, mostly due to single events



SM Expectation →





H->WW->lvlv

Search in range 110 < m_H < 240 GeV. Two isolated leptons and large MET:

See talk by Aaron Armbruster

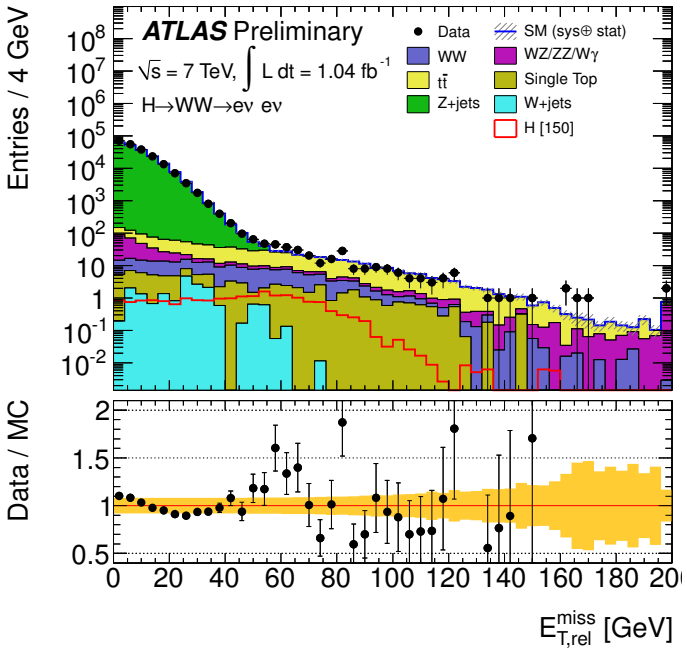
- Opposite sign dilepton events: leading lepton (e or μ) p_T>25 GeV, subleading p_T>20(15) for e(μ)
- Same flavour: m_{ll}>15 GeV, $|m_{ll}-m_Z|$>15 GeV. For eμ channel just require m_{ll}>10 GeV
- Require $E_{T,rel}$>40 GeV for ee,μμ and $E_{T,rel}$ >25 GeV for eμ

Dominated by Z+jets before cut

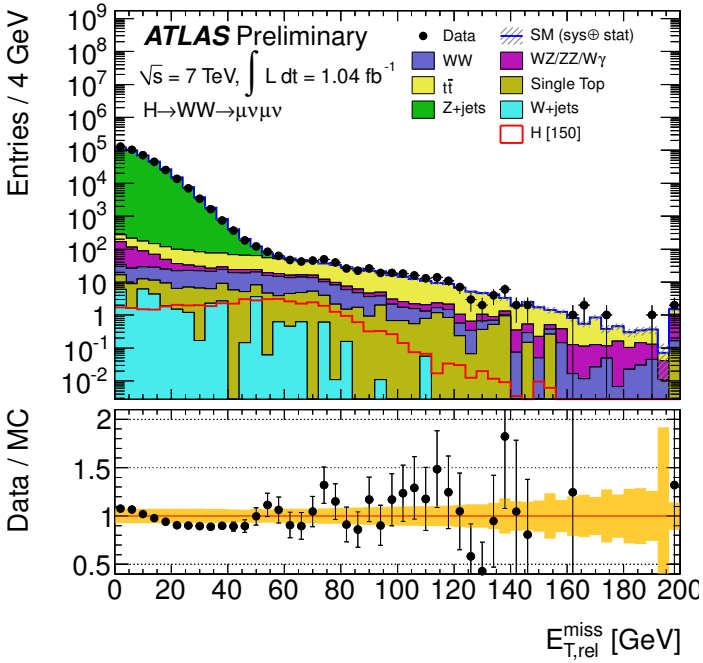
$$E_{\mathrm{T,rel}}^{\mathrm{miss}} = \begin{cases} E_{\mathrm{T}}^{\mathrm{miss}} & \text{if } \Delta\phi \geq \pi/2 \\ E_{\mathrm{T}}^{\mathrm{miss}} \cdot \sin\Delta\phi & \text{if } \Delta\phi < \pi/2 \end{cases}$$

$$\Delta\phi = \min(\Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, \ell),\ \Delta\phi(E_{\mathrm{T}}^{\mathrm{miss}}, j))$$

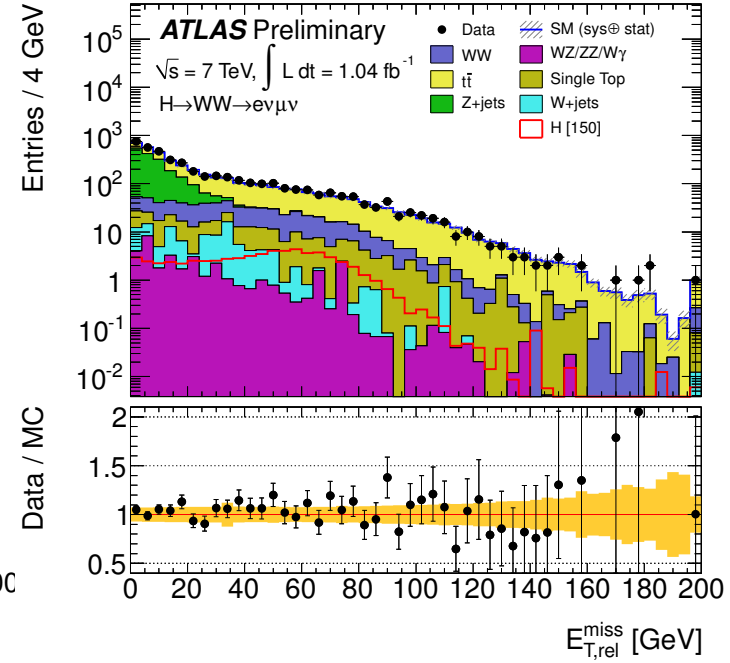
ee channel



μμ channel



eμ channel



H->WW->lvlv

Jet Multiplicity division of events:

- Events with no jets with p_T>25 GeV and $|\eta|$< 4.5. Apply p_T^{ll}>30 GeV to reduce Drell-Yan
- Events with exacly 1 jet. Apply b-tag veto to reduce top. Vector sum of H+j p_T <30 GeV and Z->ττ rejection

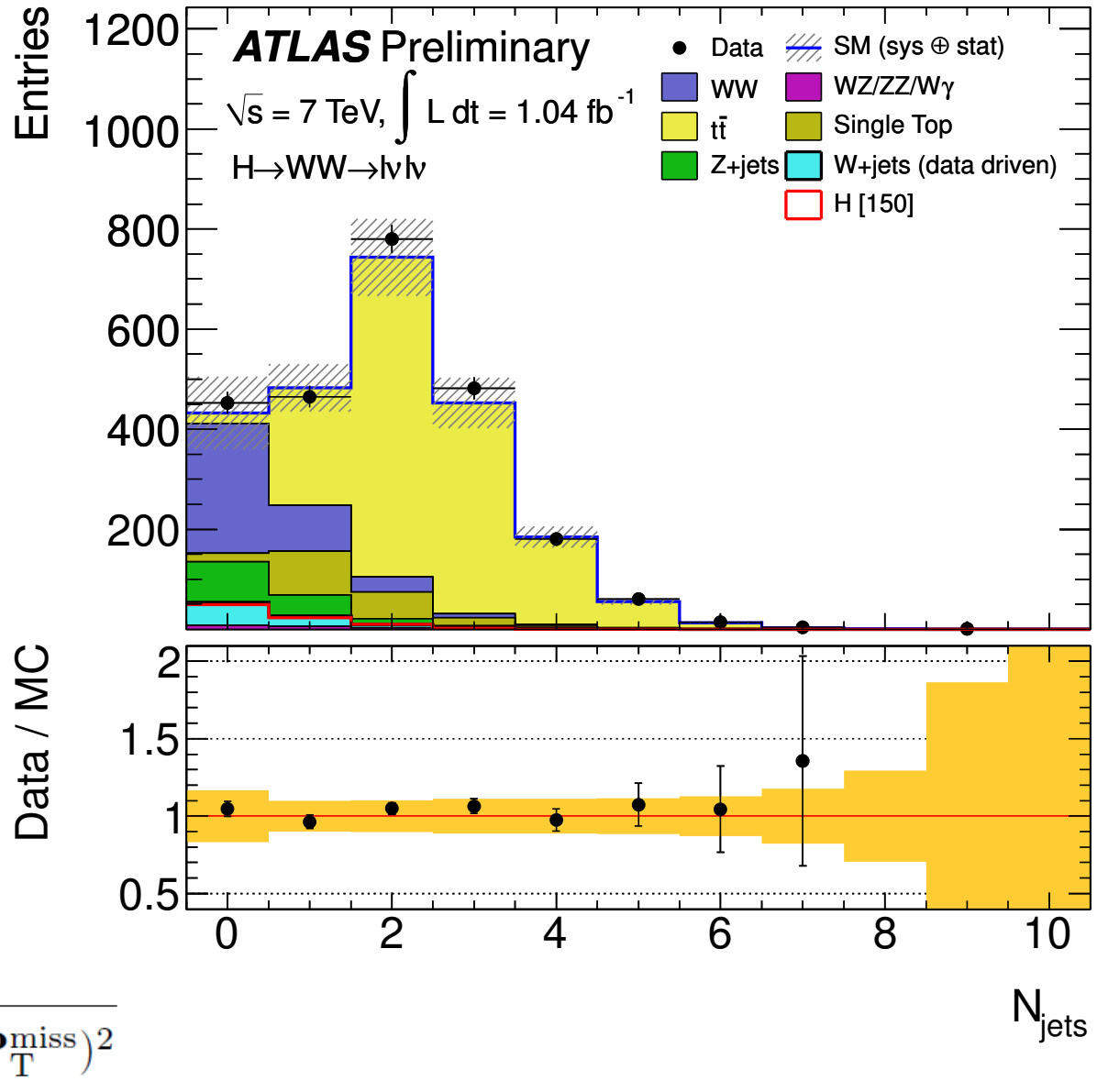
Topological dilepton selections, optimised for low and high mass around 170 GeV:

- m_{ll}<50 (60) GeV for low(high) mass
- $\Delta\phi_{ll}$<1.3(1.8) for low(high) mass

Sliding mass cut for final selection:

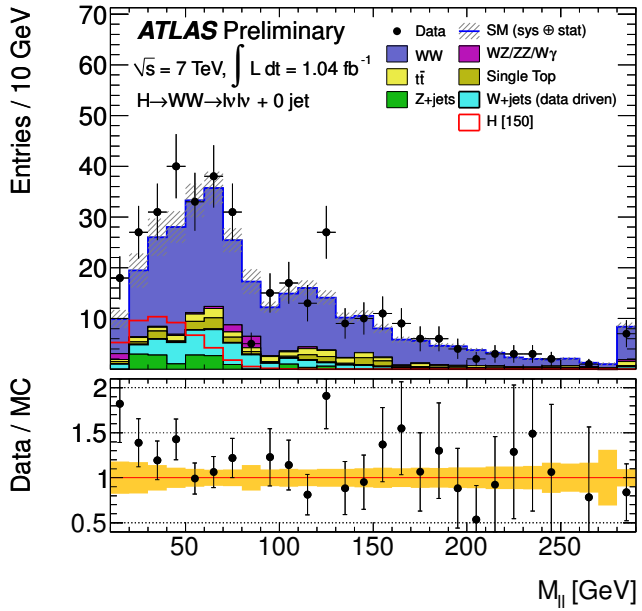
- 0.75 x m_H < m_T < m_H

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

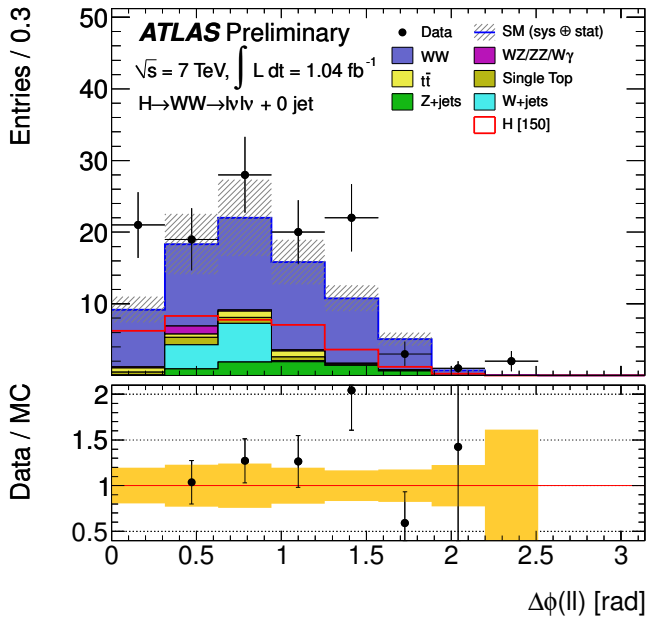


H->WW->lvlv : 0-jet channel

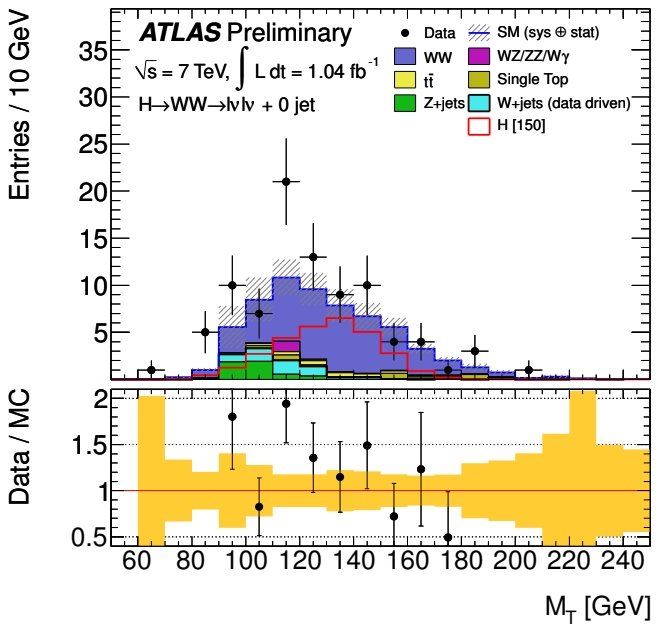
M_{ll} after p_T^{ll} cut:



$\Delta\phi_{ll}$ after m_{ll} cut:



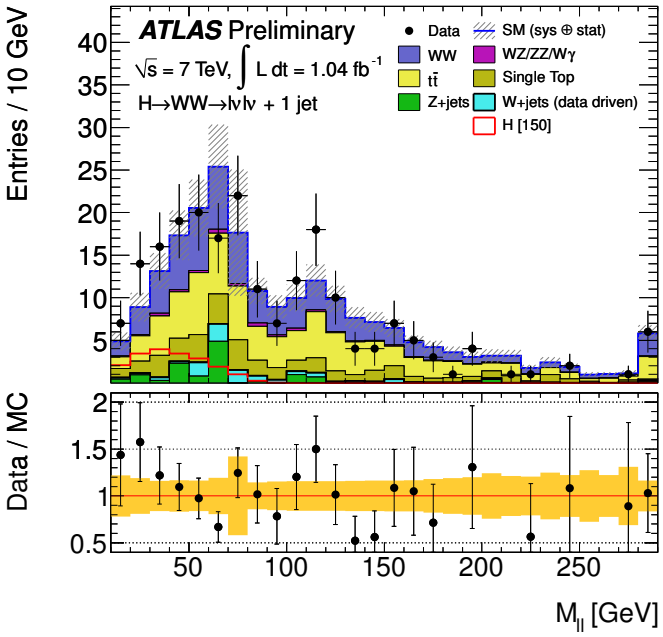
M_T after all cuts:



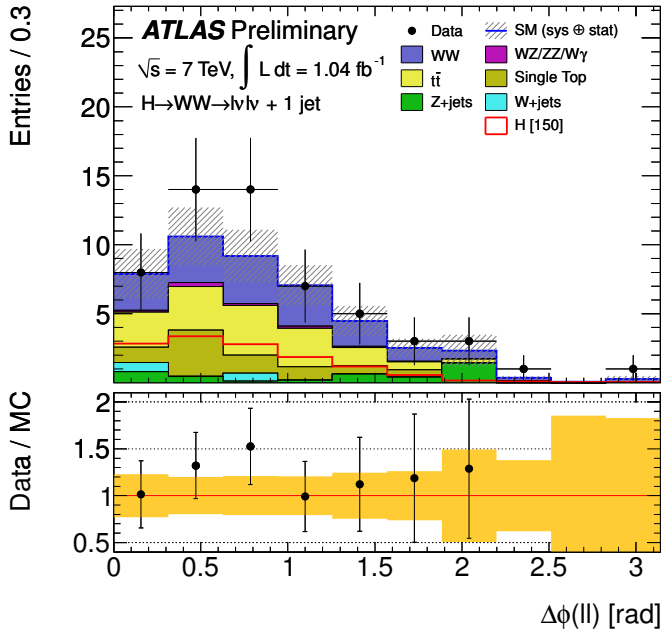
Selection	Signal	WW	W+jets	Z/γ^*+jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
Jet Veto	50 ± 11	260 ± 30	46 ± 17	80 ± 70	22 ± 8	17 ± 4	7.8 ± 1.5	430 ± 100	453
$\lvert\mathbf{P}_T^{\ell\ell}\rvert > 30$ GeV	48 ± 10	230 ± 20	38 ± 14	15 ± 6	19 ± 7	16 ± 4	7.3 ± 1.4	330 ± 50	371
$m_{\ell\ell} < 50$ 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	2.8 ± 1.7	2.8 ± 0.8	0.8 ± 0.2	63 ± 9	89
$0.75 \times m_H < m_T < m_H$	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

H->WW->lvlv : 1-jet channel

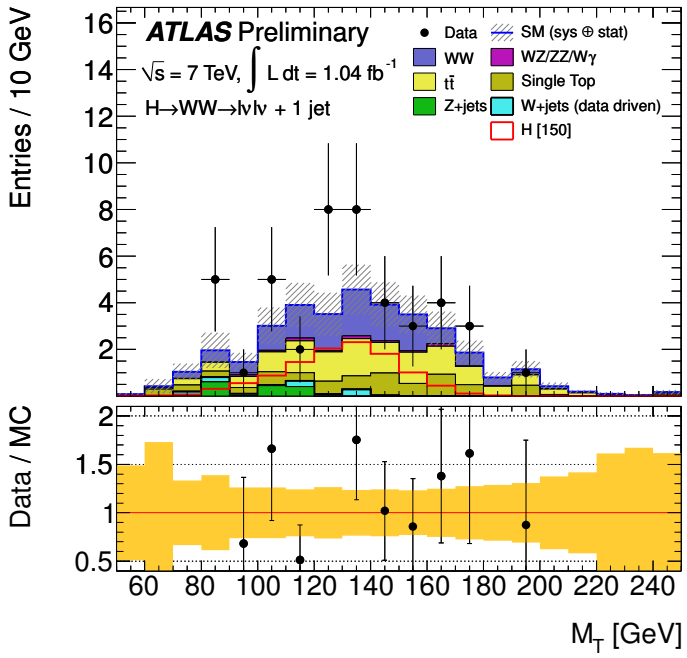
M_{ll} after Z->ττ veto:



$\Delta\phi_{ll}$ after m_{ll} cut:



M_T after all cuts:



Selection	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
$\lvert\mathbf{P}_T^{\text{tot}}\rvert < 30$ GeV	19 ± 3	76 ± 8	9 ± 5	25 ± 19	80 ± 20	35 ± 6	4.1 ± 0.5	230 ± 40	221
$Z \to \tau\tau$ veto	19 ± 4	74 ± 8	10 ± 5	20 ± 10	80 ± 19	33 ± 5	4.0 ± 0.7	220 ± 17	212
$m_{\ell\ell} < 50$ 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
$0.75 \times m_H < m_T < m_H$	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

H->WW->lvlv : Backgrounds and Control Regions

- Two largest backgrounds SM WW and top normalized using 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 from data template, other smaller backgrounds from, MC

Control regions in data:

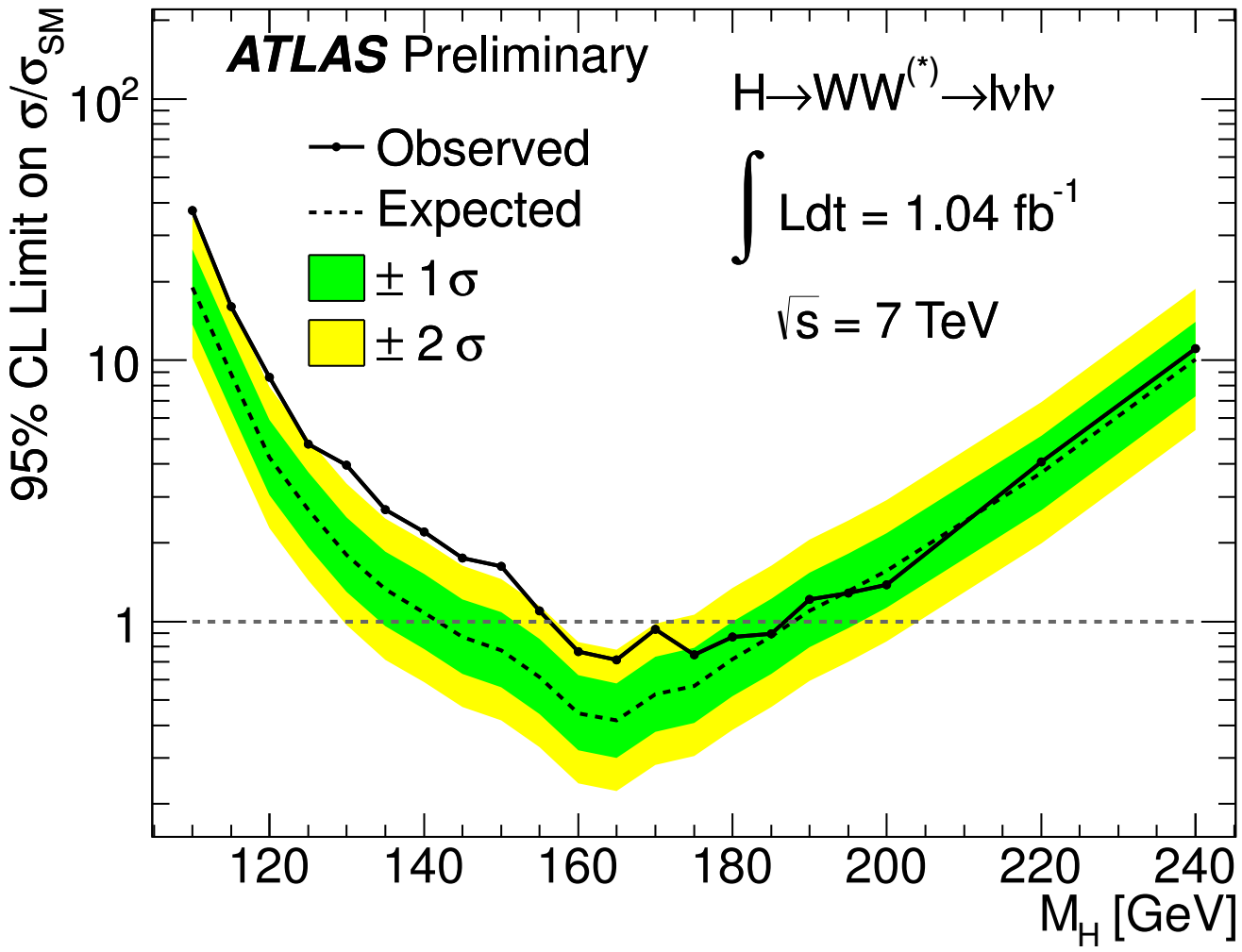
Control Region	Estimate	Obs
WW 0-jet	150 ± 30	153
WW 1-jet	109 ± 14	97
top 1-jet	130 ± 40	136

Uncertainties on extrapolation factors:

	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%	–

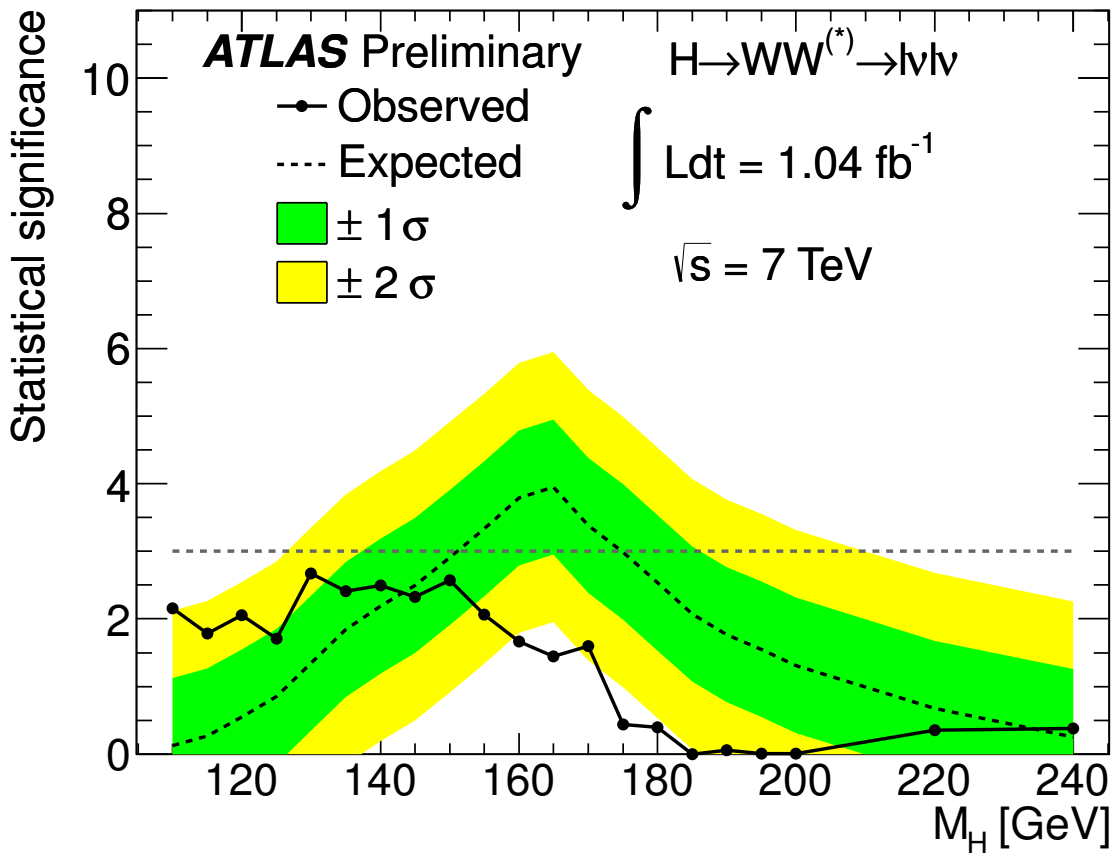
- Likelihood formed from signal region, 2 control regions for ee,μμ,eμ and 2 jet bins

H->WW->lvlv : Exclusion Limit



- Exclude SM Higgs between $158 < m_H < 186$ GeV at 95% CL
- Expected exclusion 142-186 GeV

H->WW->lvlv : Significance



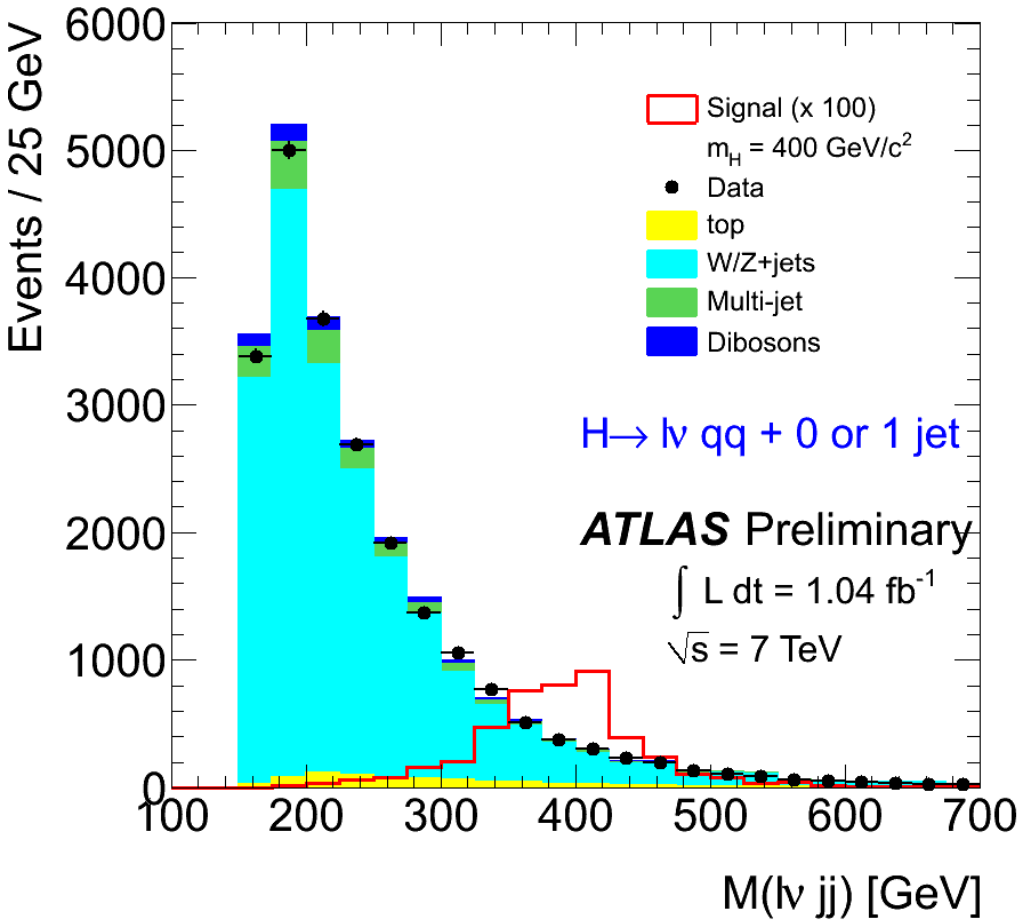
Statistical significance assuming SM Higgs hypothesis

- >2σ excess 126 < m_H < 158 GeV
- Largest 2.7σ at 130 GeV

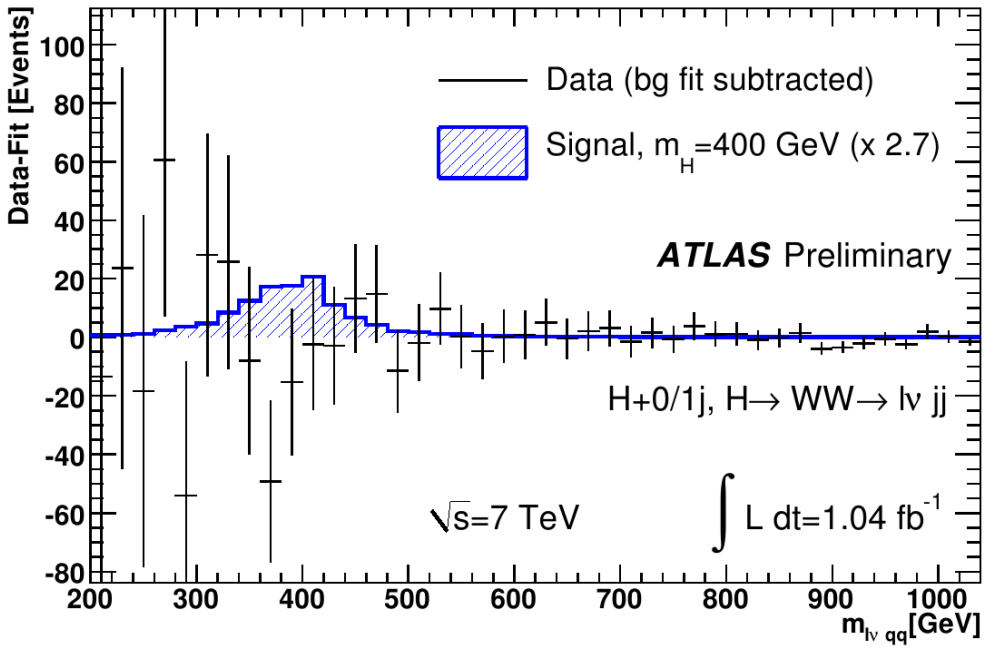
H->WW->lvqq

Search in 240 < m_H < 600 GeV range:

- Single high p_T lepton p_T>30 GeV, MET>30 GeV, b-tag veto
- Require 2 or 3 jets with 1 combination consistent with M_W [E_T>30GeV, $|\eta|$<2.8(4.5)]
- Constraint M(lν)=M(jj)=M_W can reconstruct m_H=M(lνjj)



Data background fit using 2 exponentials:



H->WW-lvqq : Backgrounds

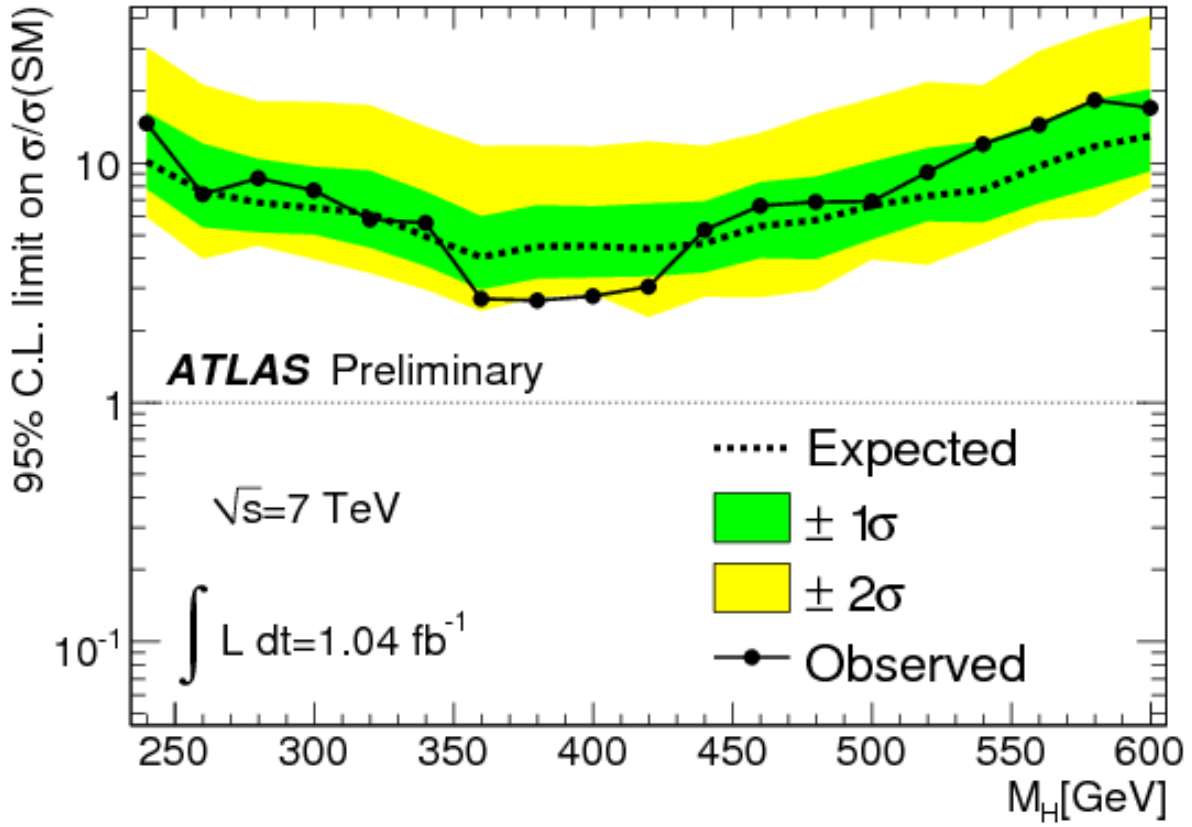
	H($e\nu jj$) + 0j	H($\mu\nu jj$) + 0j	H($e\nu jj$) + 1j	H($\mu\nu jj$) + 1j	H + 0j or 1j
V+jets	10782 ± 291	13375 ± 869	6513 ± 247	7412 ± 674	38082 ± 1170
Multi-jet	890 ± 24	256 ± 17	669 ± 25	212 ± 19	2027 ± 43
Top	170 ± 34	164 ± 33	489 ± 98	503 ± 101	1326 ± 265
Dibosons	397 ± 79	414 ± 83	161 ± 32	204 ± 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

- V+jets shape modelled by MC
- Multi-jet obtained from data templates with loose/anti-lepton selection. Normalization of Multi-jet and V+jets from fit to MET distribution (errors from fit).
- Top and dibosons from MC (errors from energy scale, cross-section, luminosity)

Likelihood fit:

- Non-resonant background from fit with 2 exponentials
- Signal shape from MC
- Fit per jet channel, lepton flavour categories, including systematic effects of detector and theory uncertainties on signal

H->WW->lvqq : Exclusion Limit



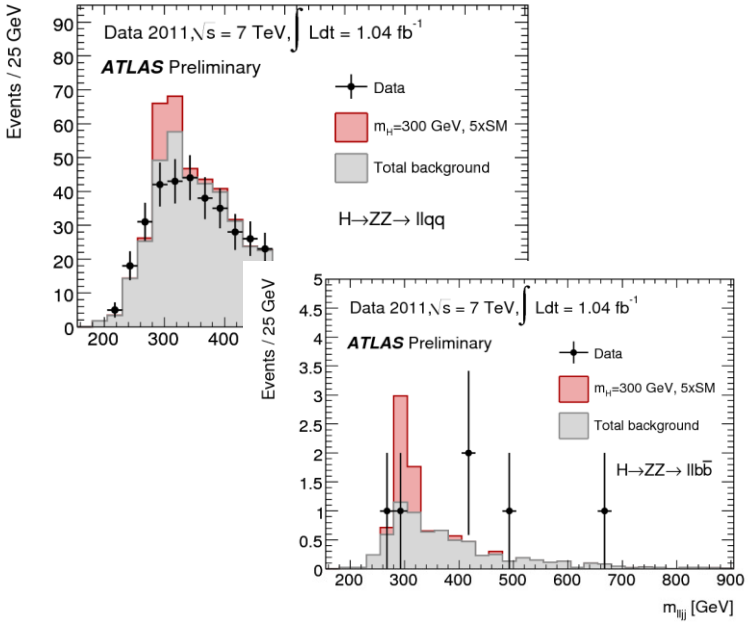
- The upper limit at m_H=400 GeV is 2.5 times the SM cross-section
- Expected limit is around 5 times the SM cross-section

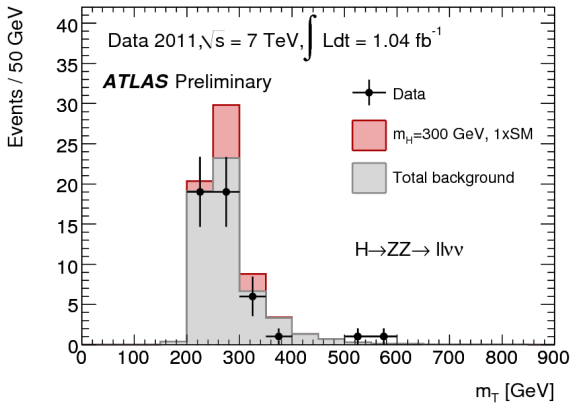
Conclusions

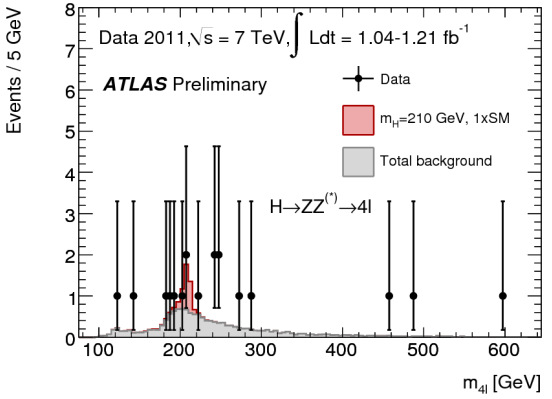
- ATLAS analysed data samples with 1fb-1 of data for H->ZZ/WW production in a number of decay channels
- Large data sample means that sensitive to the Higgs Boson across wide mass range: $110 < m_H < 600$ GeV
- H->ZZ->llvv exclude SM Higgs between $360 < m_H < 420$ GeV
- H->WW->lvlv exclude SM Higgs between $158 < m_H < 186$ GeV
- Slight excess of events at low mass with around 2.5σ significance
- More data required to see if it a fluctuation or something more interesting
- The H->ZZ/WW channels will continue to play crucial role in SM Higgs searches at LHC

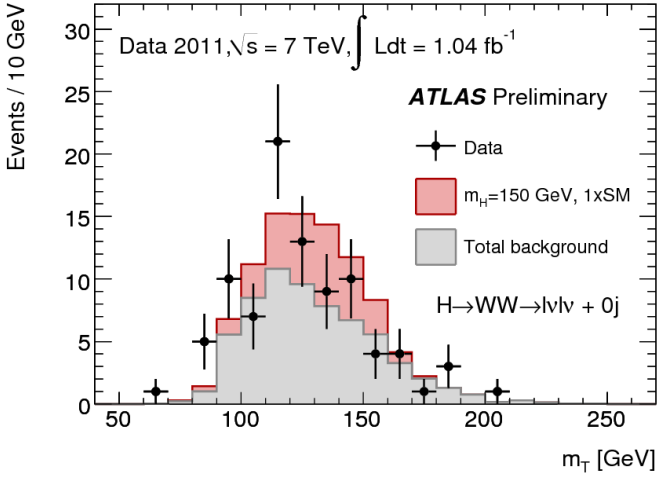
Extra Slides

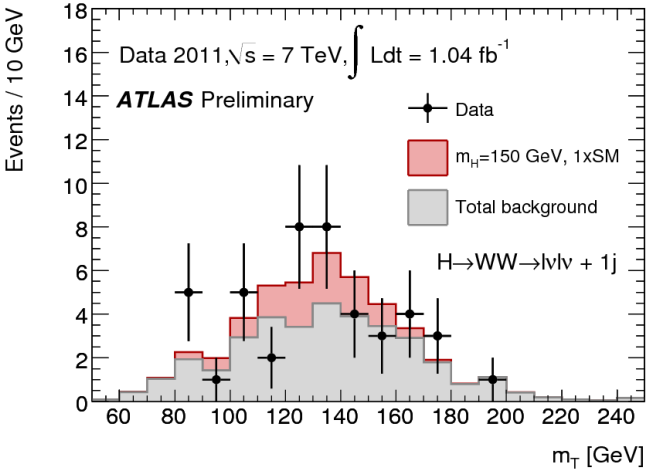
H->ZZ/WW signal/bkg

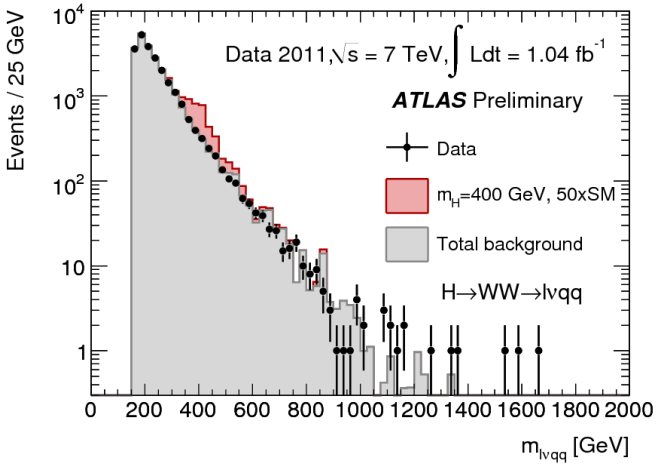




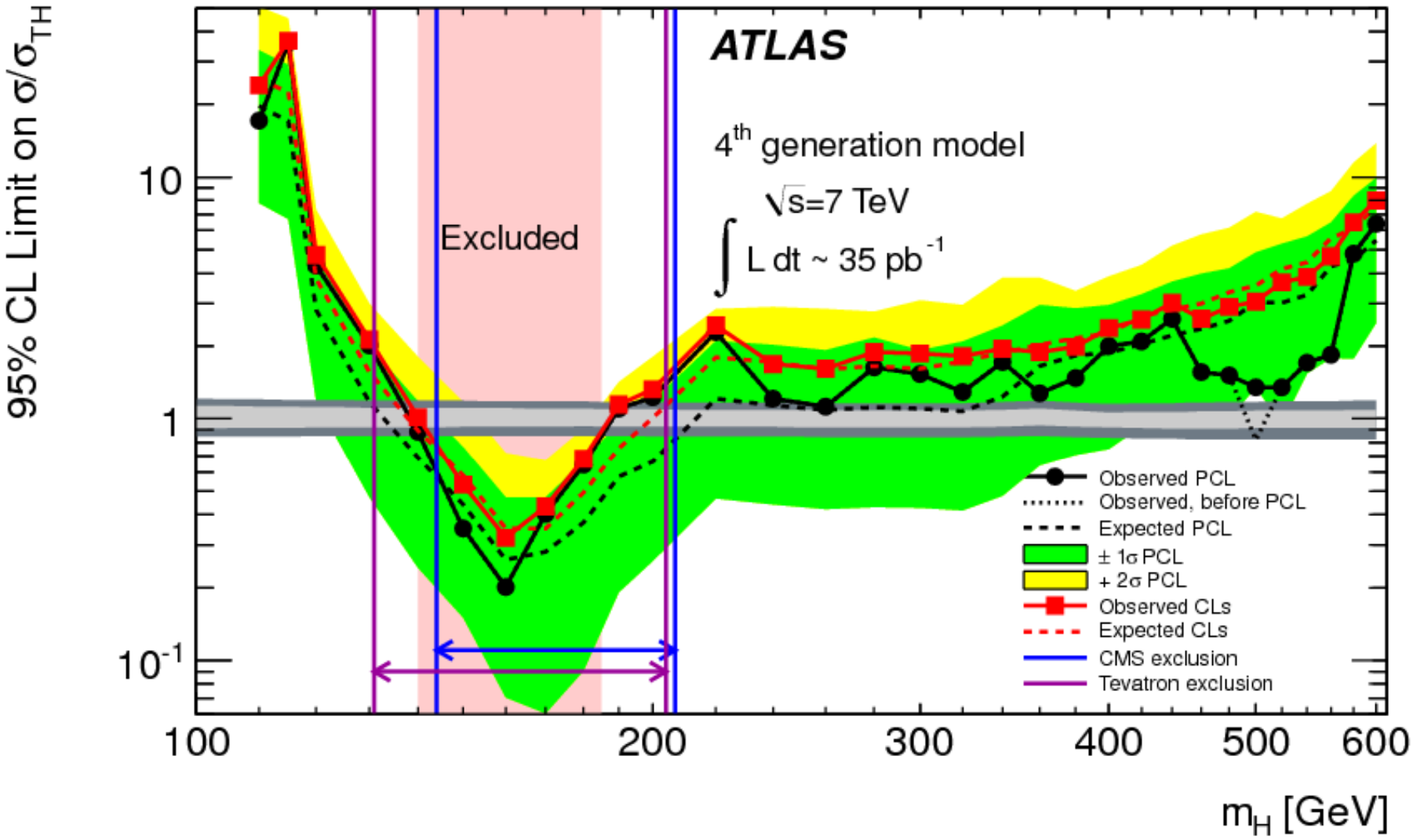








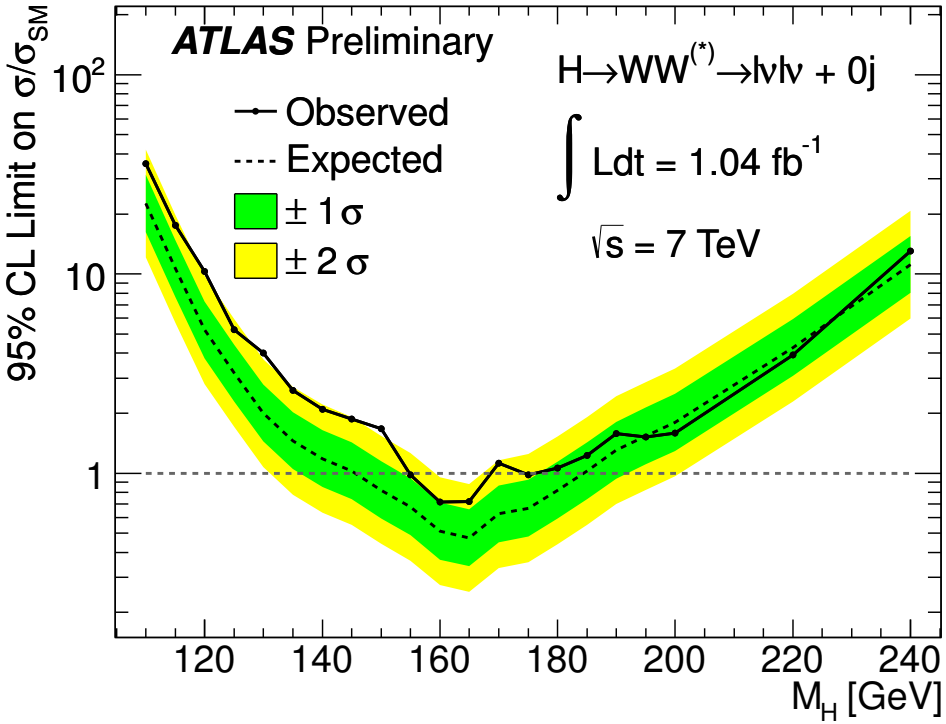
Fourth Generation Limits : 2010

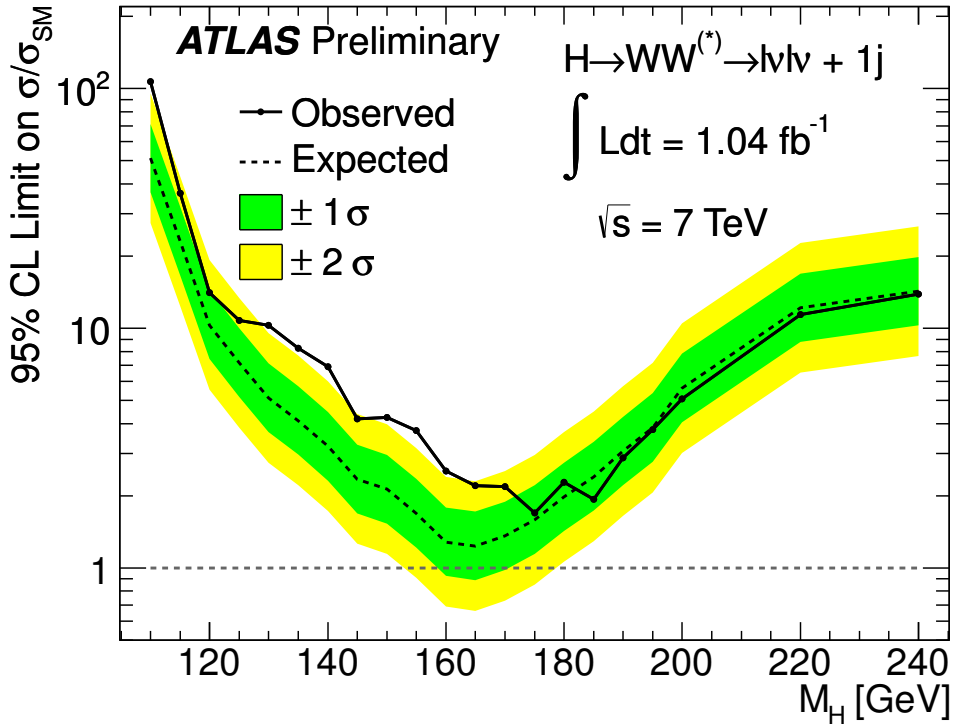


Excluded cross section to the expected one when a fourth generation of high mass quarks and leptons with Standard Model-like couplings to the Higgs boson are included in the cross section calculations

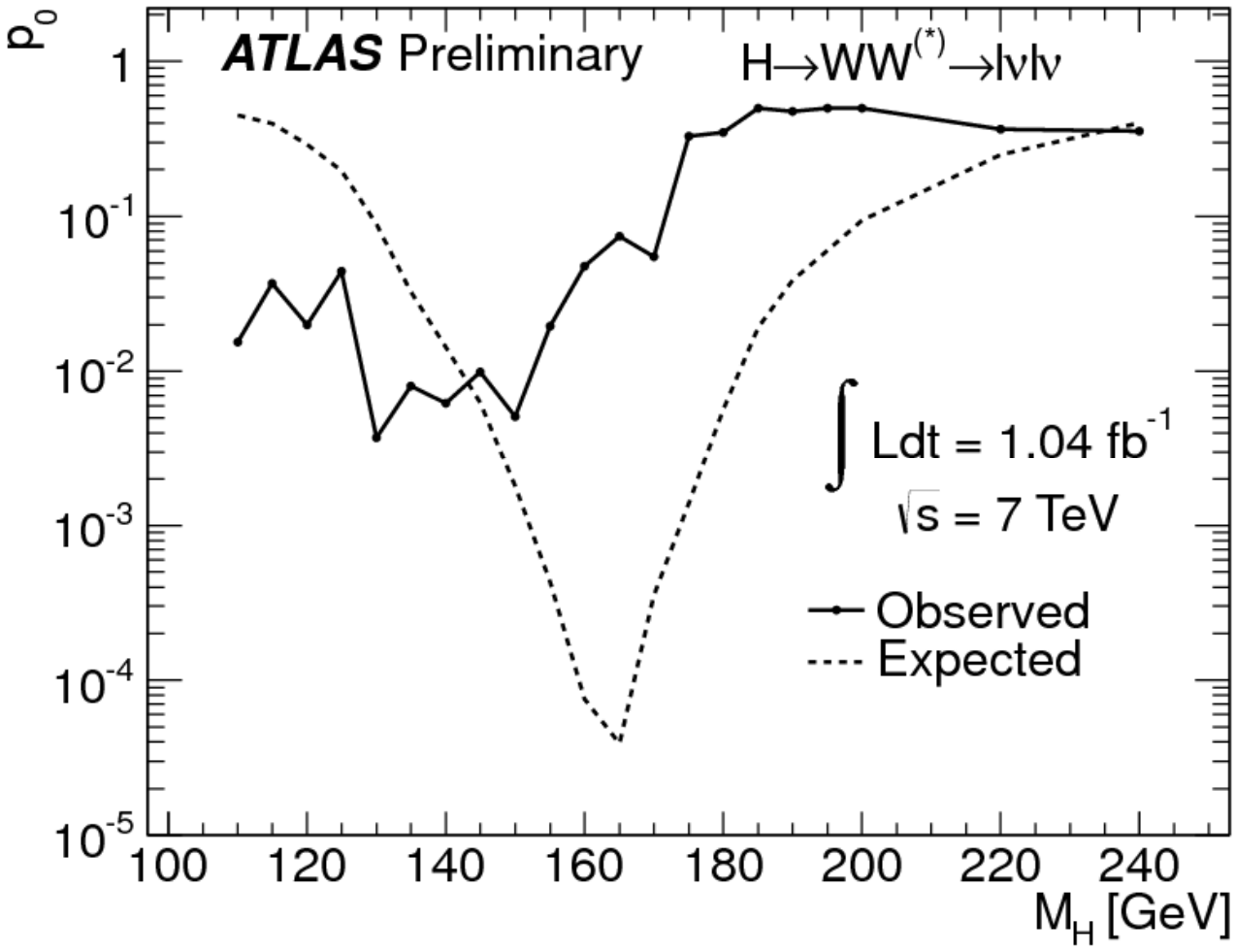
H->WW->lvlv

Exclusion for 0 and 1 jet



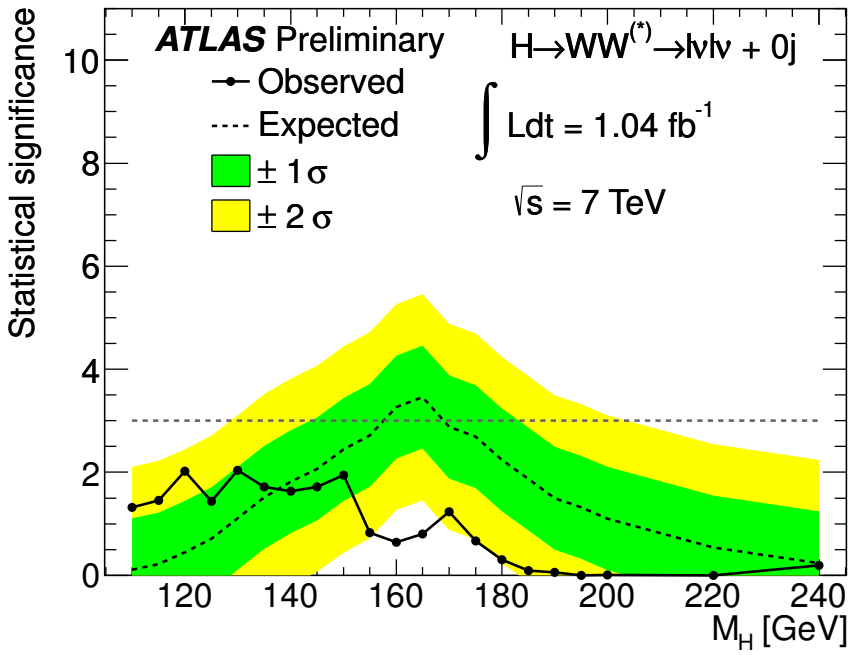


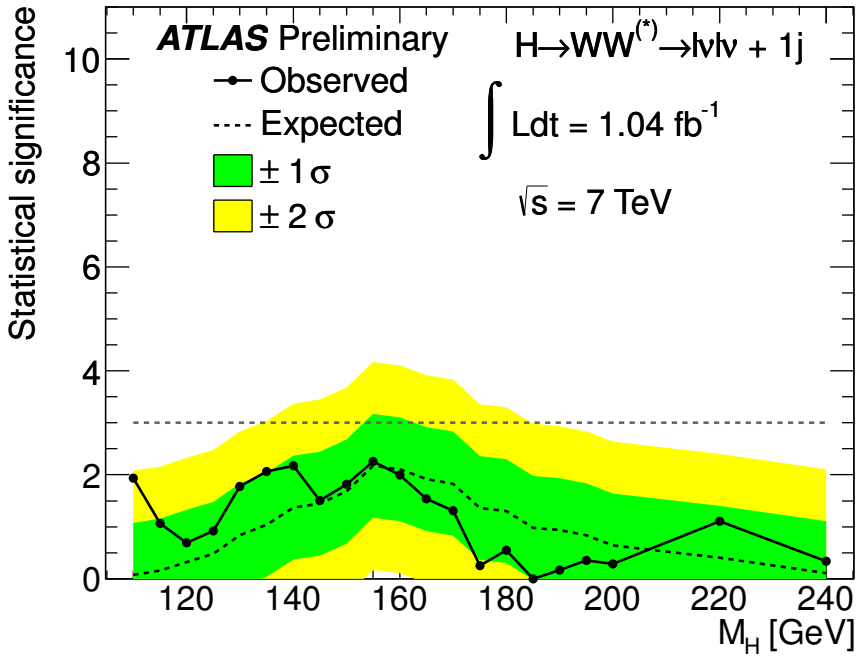
H->WW->lvlv : background only p-value



H->WW->lvlv

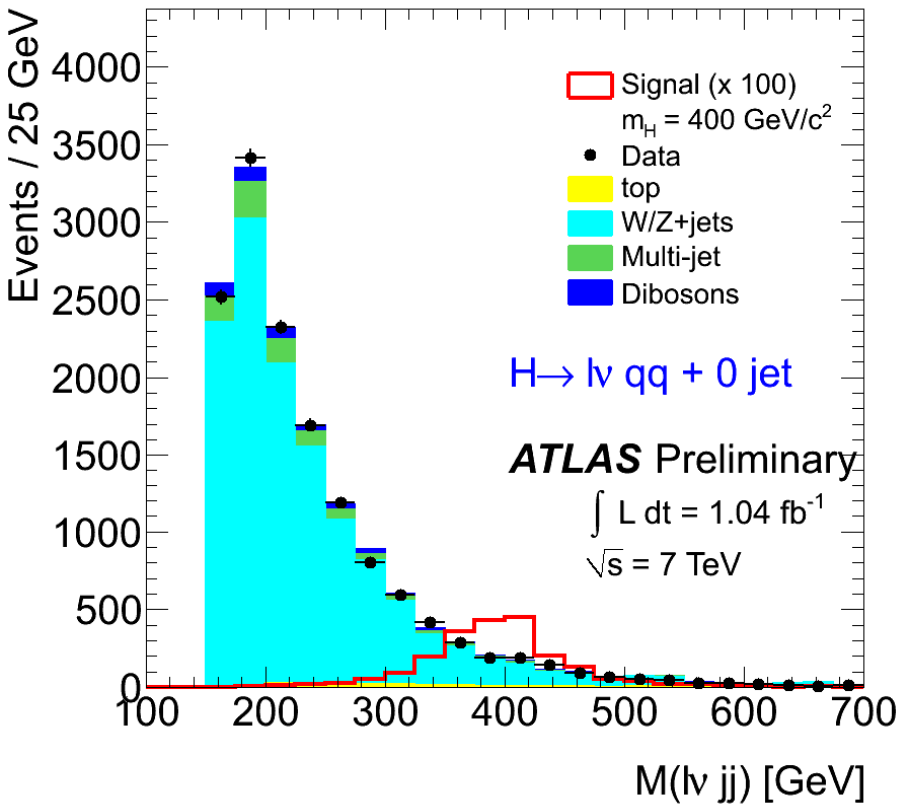
Significance 0 and 1 -jet

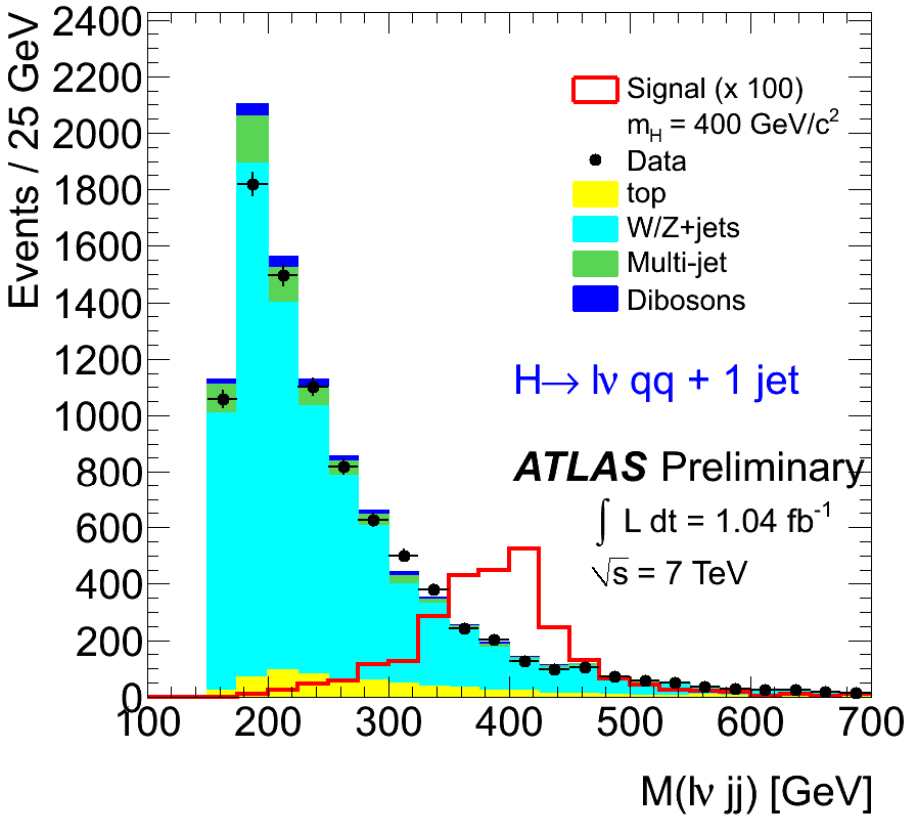




H->WW->lvqq

M(lvjj) 0 and 1 jet





H->WW->lvjj

M(lvjj) subtracted 0 and 1 jet