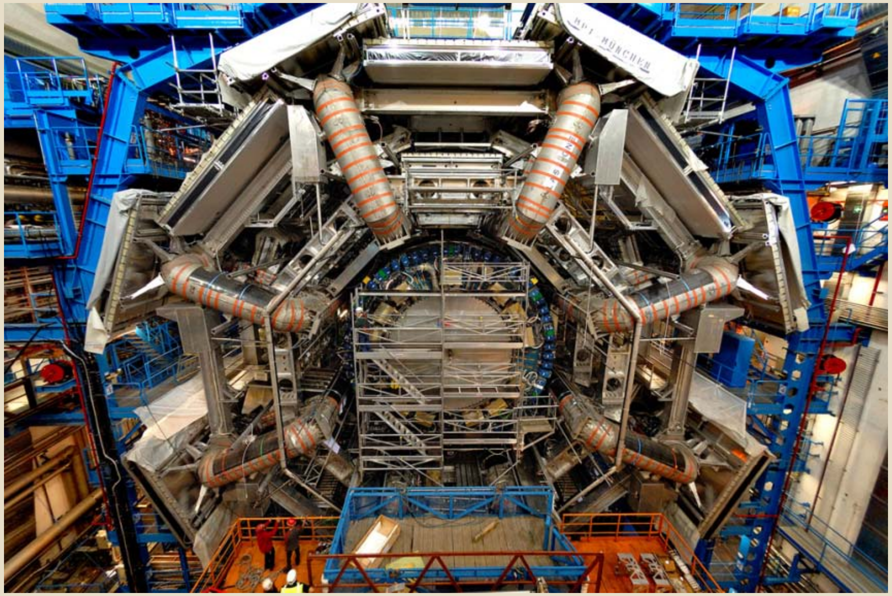
ATLAS Higgs searches in WW and ZZ channels

LYDIA ICONOMIDOU-FAYARD (LAL-ORSAY)
ON BEHALF OF THE ATLAS COLLABORATION



The ATLAS Detector

Multi-purpose detector at LHC

Details in JINST 3 (2008) S08003

→Inner tracking system with silicon pixels , silicon microstrips and transition radiation detectors, immersed in a 2T field made by a solenoid SC magnet.

→Liquid Argon EM Calorimetry, projectively segmented in 3 layers and hermetic in φ.

→ Hadronic Calorimetry (Scintillating tiles or Larg)

→ Muon spectrometer operating in a large SC toroid magnet system.

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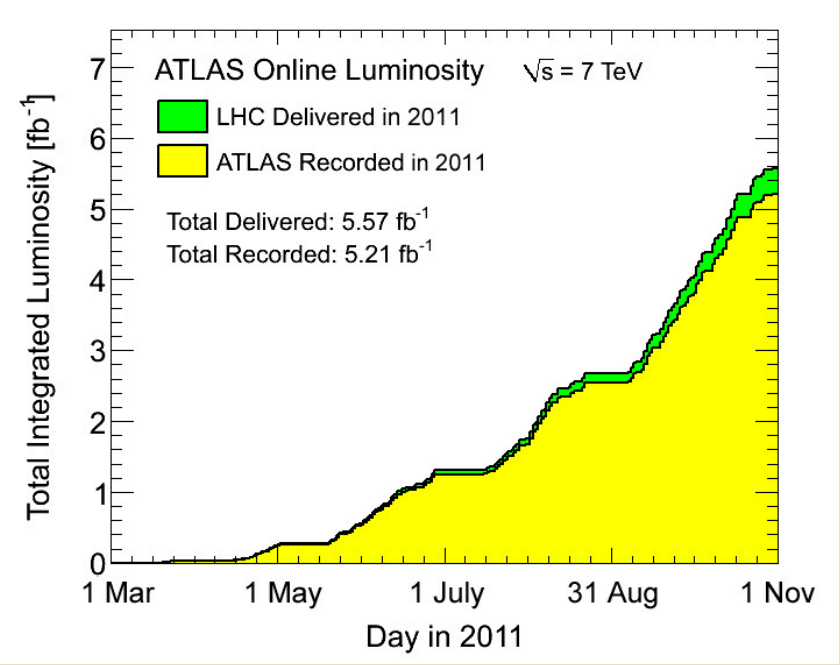
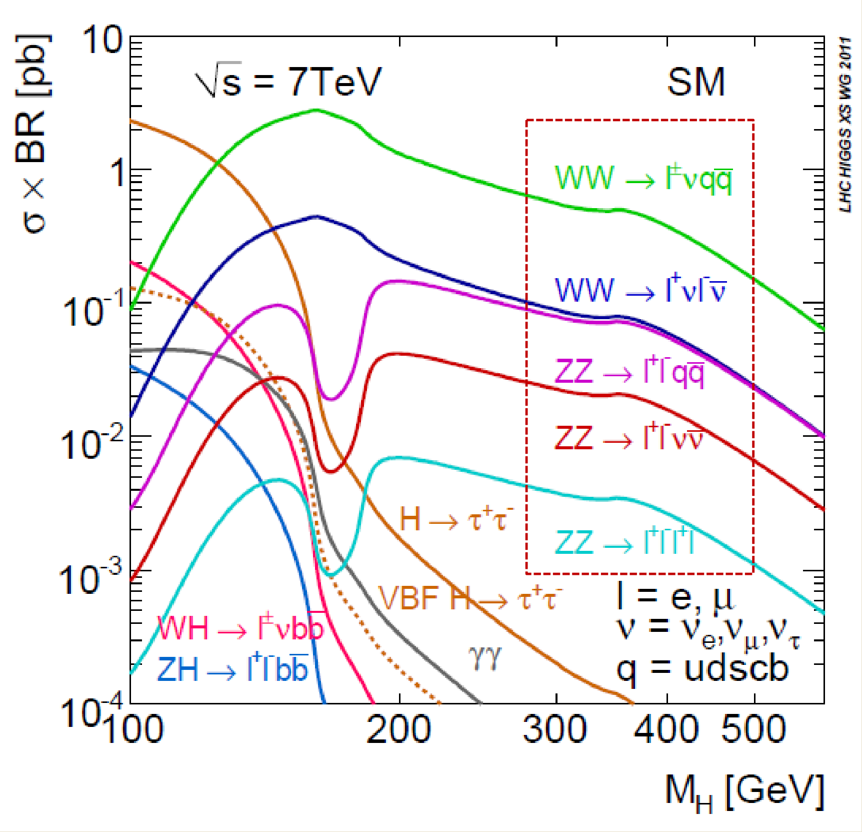
→ATLAS collected 5.2 fb^{-1} by the end of the proton-proton run at $\sqrt{s}$=7TeV .
→Average efficiency over 2011 : ~93%

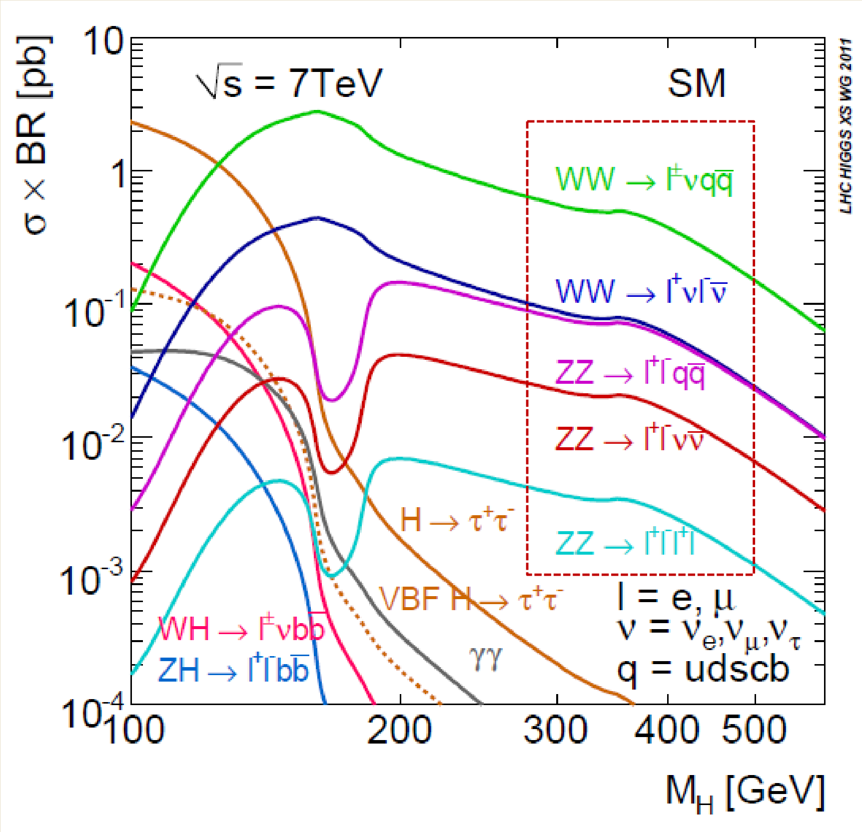


The Higgs decays through Diboson channels



The Higgs decays through Diboson channels

➔Span a large M_H range



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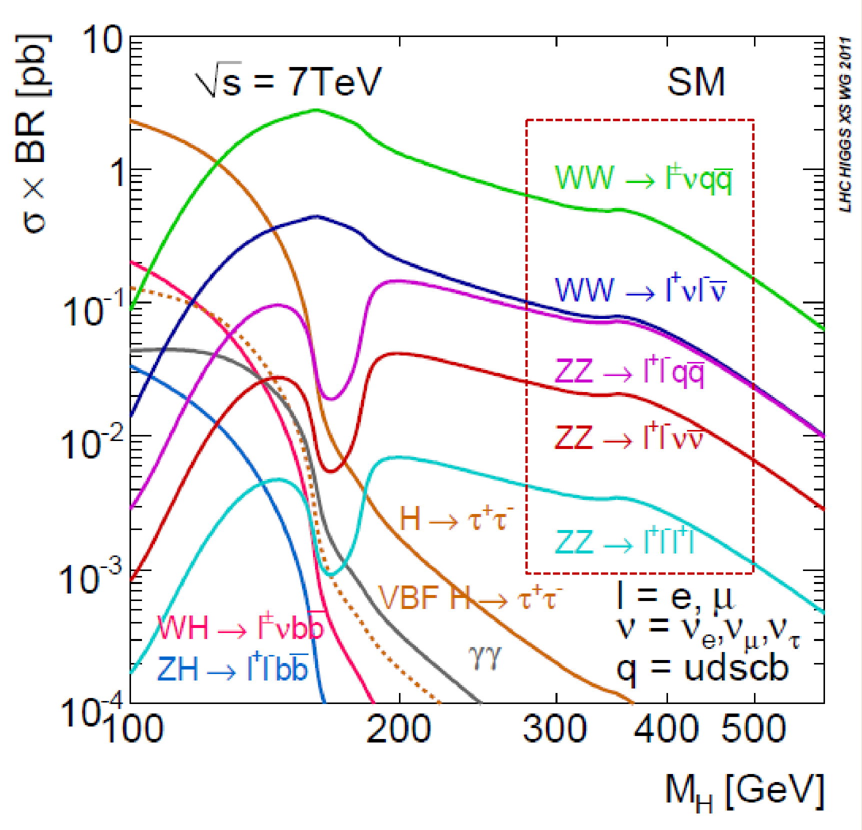
➔WW are the most abundant channels for M_H>~135GeV. Not all final state particles are fully measured



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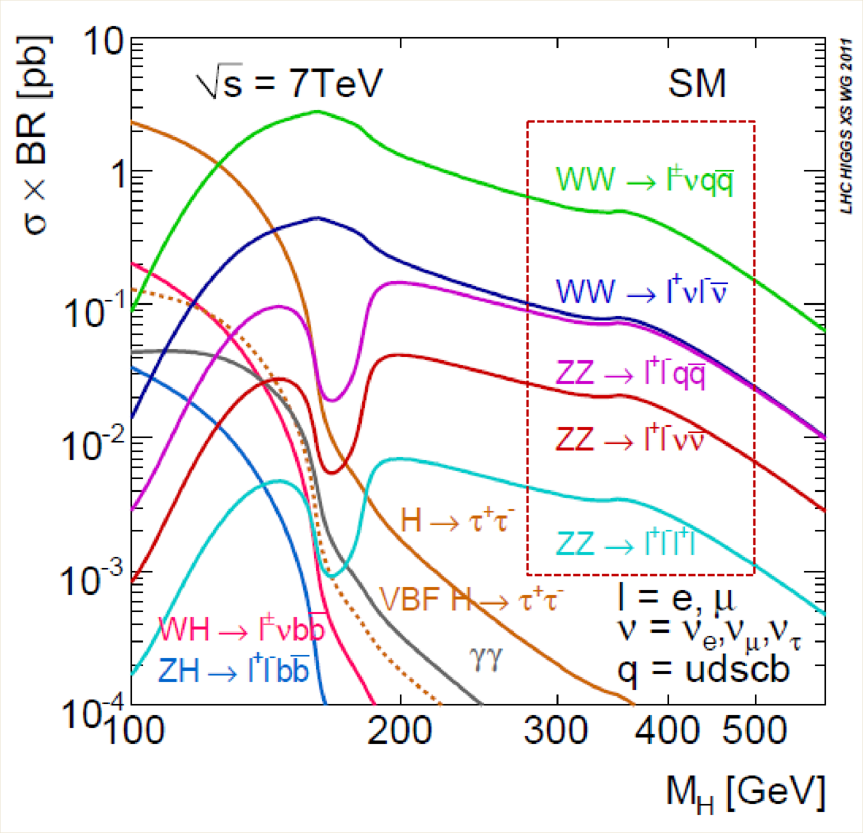
➔ZZ smaller rate but advantage from the full reconstruction of at least one on-shell Z.
Sharp peak for ZZ→4l .



Signal and background yields

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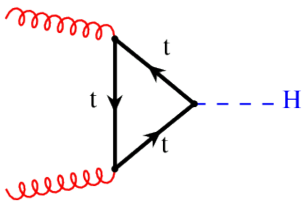
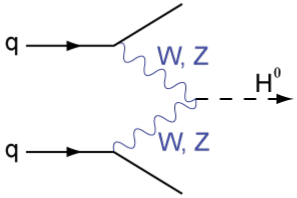
CROSS-SECTIONS



gg->H : NNLO QCD
NNLL for soft gluon
NLO for EW



qq->Hqq (VBF):
NNLO QCD
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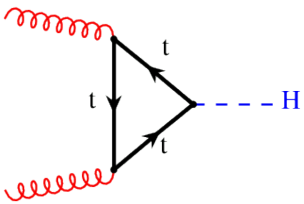
Signal and background yields

CROSS-SECTIONS



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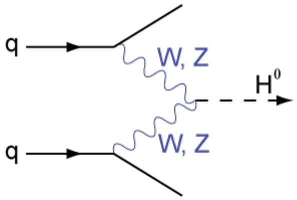

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LHC Higgs Cross-Section Working Group arXiv:1101.0593 [hep-ph]

Signal and background yields

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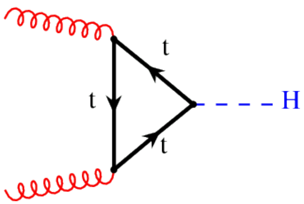

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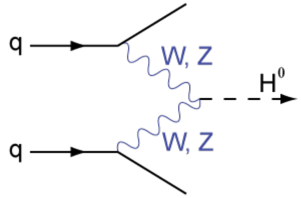

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SIGNAL

POWHEG –Pythia
Reweight of the H PT spectrum
PhoTOS for FS QED radiative corrections
TAUOLA
MC@NLO
H->ZZ->4l PROPHECY4F for BR

BACKGROUNDS

PYTHIA
ALPGEN
HERWIG for parton showering and hadronization
MC@NLO
JIMMY for the underlying event
MCFM

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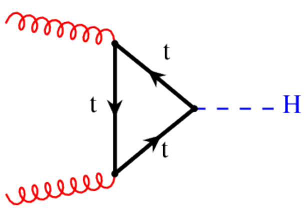

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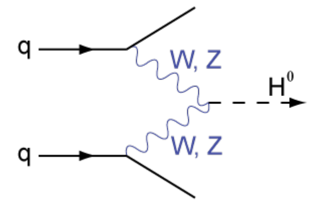

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GEANT4

Higgs→WW$^{(*)}$

Two channels :

➔ $H \rightarrow WW^{(*)} \rightarrow \ell^+\nu\ell^-\overline{\nu}$ with l=μ, e (in 110-300GeV)

(with 1.7 fb^{-1} of data ATLAS-CONF-2011-134)

➔ $H \rightarrow W\ W^{(*)} \rightarrow\ l\,\nu\,j\,j$ with l = e, μ (in 240-600GeV)

(with 1.04fb^{-1} of data arXiv:1109.3615v1 [hep-ex])

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Common feature:
Isolated lepton(s) and
missing transverse momentum

H→W W$^{(*)}$ → lν jj : analysis and results

➔One single lepton P_T>30GeV, well identified and isolated

➔ ETmiss> 30 GeV

➔2 (H+0) or 3 (H+1) jets with one 71<M (jj)<91 GeV

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Backgrounds :
→W+Jets, Z+Jets and Top modelled by MC.
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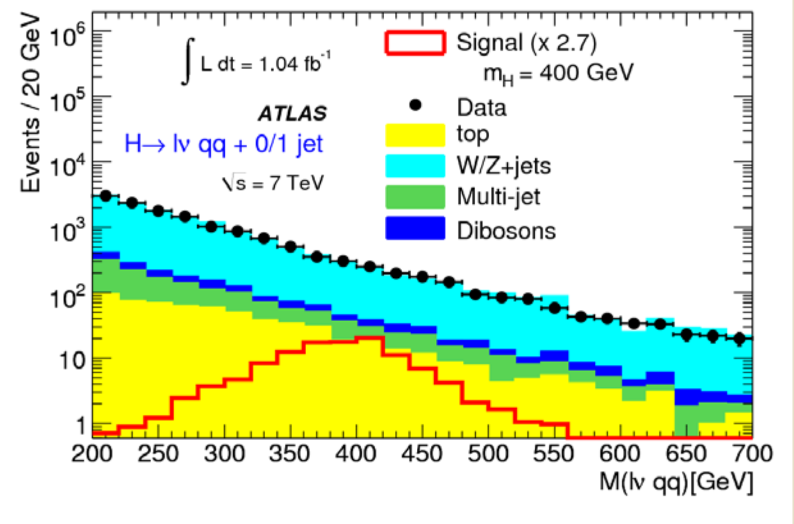

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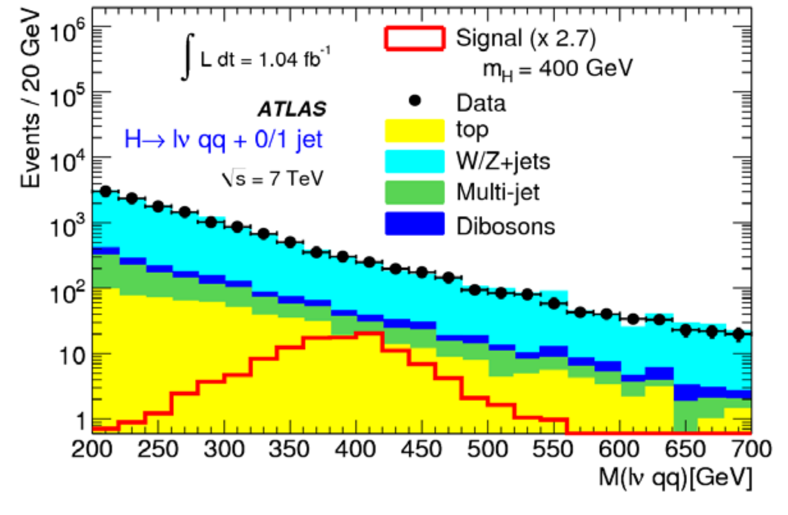
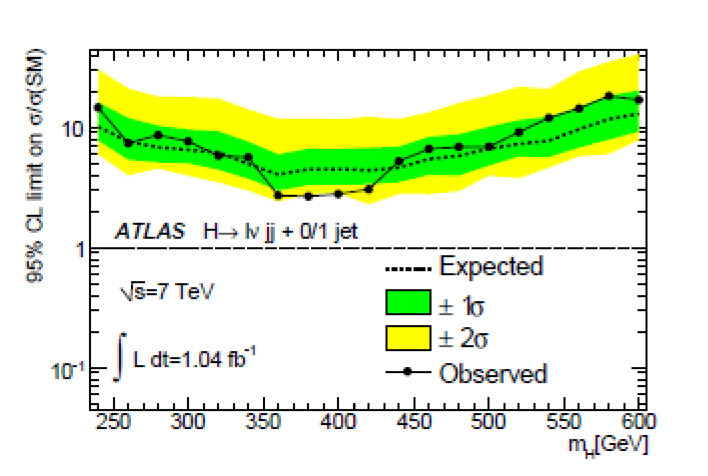




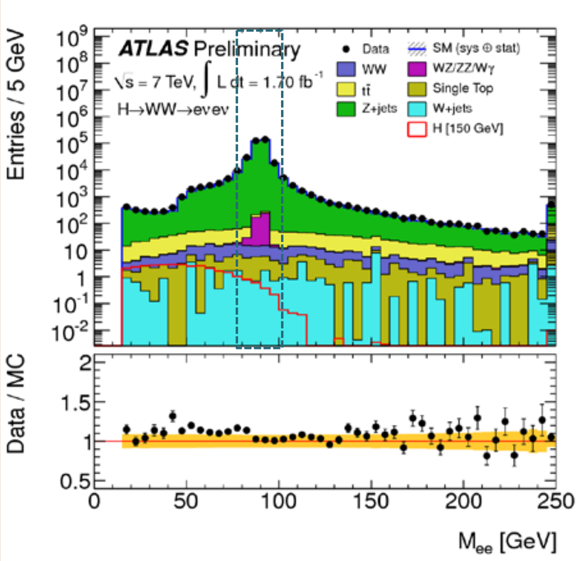
$H \rightarrow W W^{(*)} \rightarrow l^+\nu\, l^-\nu$: selection

Require

➔Opposite charge leptons

➔Apply ϒ and Z veto in m(ll)

(m_{ll}>15GeV, | M_Z-M_{ll} |>15GeV)



$H \rightarrow W W^{(*)} \rightarrow l^{+}\nu\, l^{-}\nu$: selection

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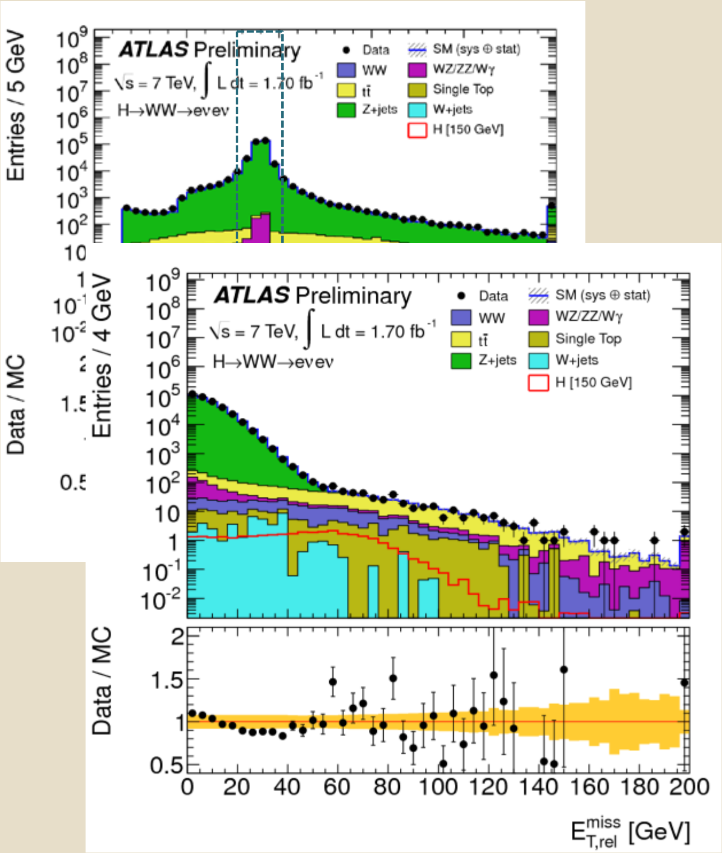

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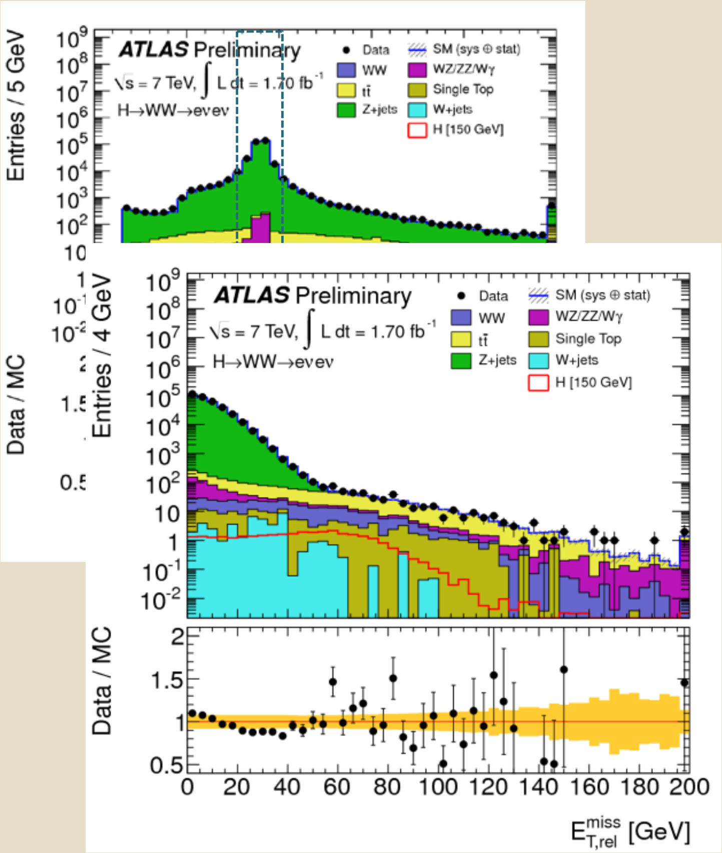

Major Backgrounds:
top, W+j, Z+j, SM WW
Estimated from data driven methods

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Different cuts for H+0, H+1 jet:

➔O-Jet : P_T (ll)>30GeV

➔1-Jet : Reject b-jet, P_T>25GeV, (P_T (l1)+ P_T (l2)+P_T(jet)+Etmiss)<30GeV, Z->ττ veto

Major Backgrounds: top, W+j, Z+j, SM WW

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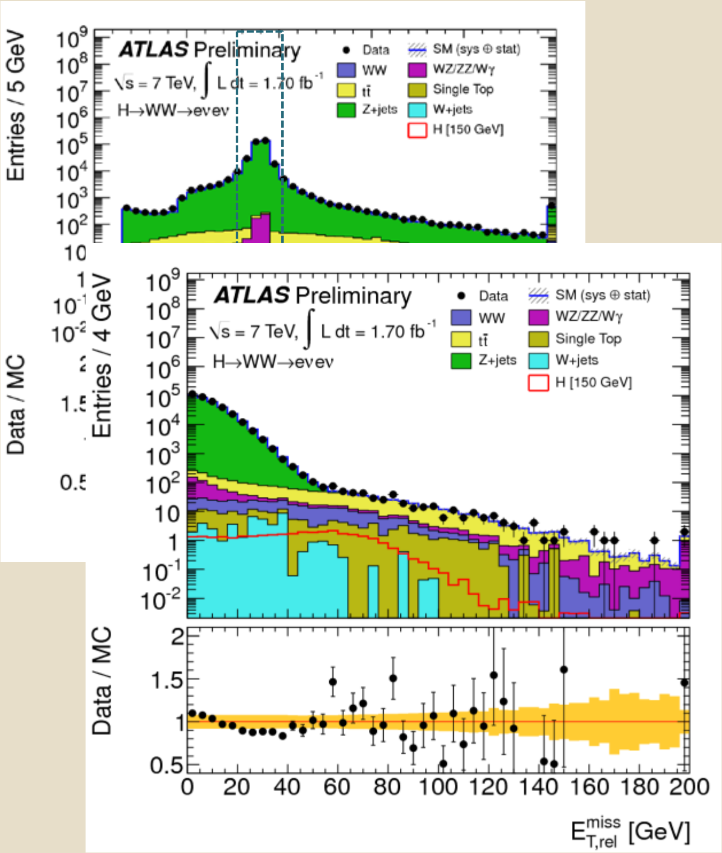

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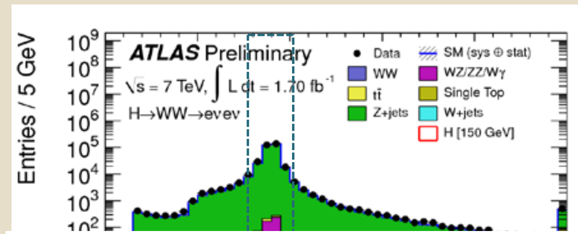

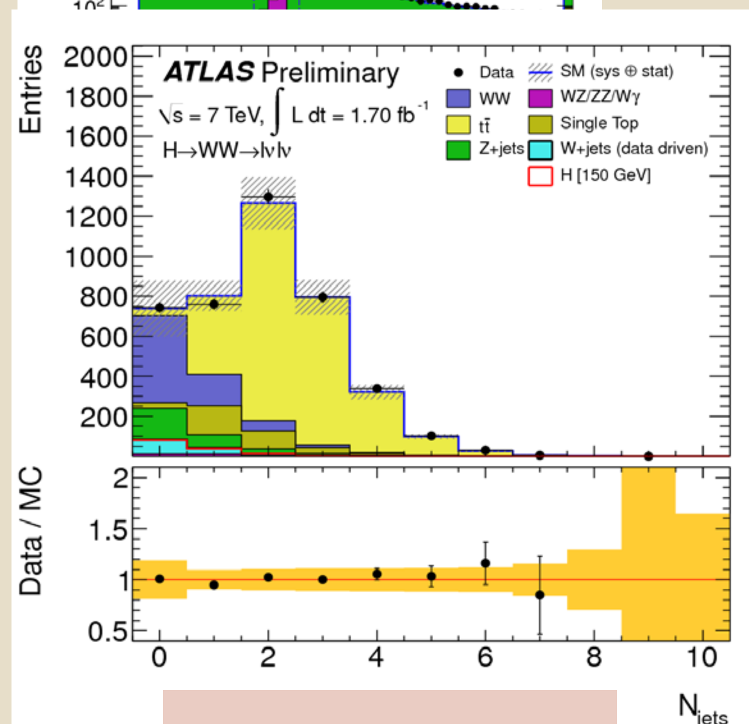

P_T + m(ll)+ETmiss

$H \to W W^{(*)} \to l^+\nu\, l^-\nu$: selection (2)

Other cuts M_H dependent

Cut on the transverse mass

$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - (\mathbf{p}_T^{\ell\ell} + \mathbf{p}_T^{\text{miss}})^2}$$

$0.75*M_H<M_T< M_H$ for $M_H<220$GeV
$0.6*M_H<M_T<M_H$ otherwise

Rejection of top and WW backgrounds:
Cuts on m(ll) and $\Delta\Phi$ (ll)

m (ll) <50 (65) for M_H <170 (220)GeV
50<m (ll)<180 for M_H >220 GeV
$\Delta\Phi$ (ll)<1.3 (1.8) for M_H <170 (220) GeV

$H \rightarrow W W^{(*)} \rightarrow l^+ \nu \, l^- \nu$: selection (2)

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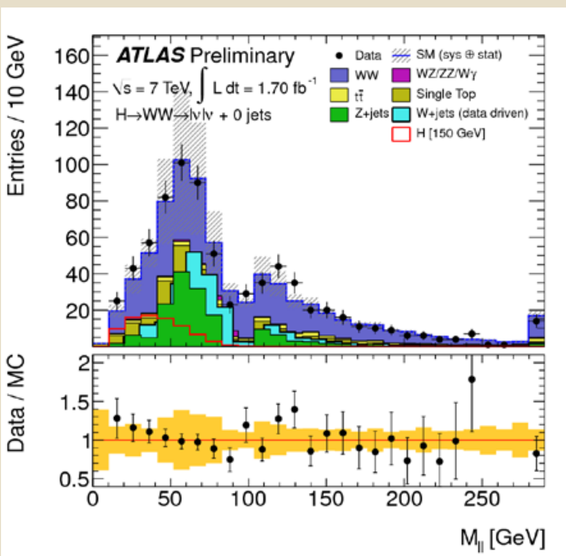
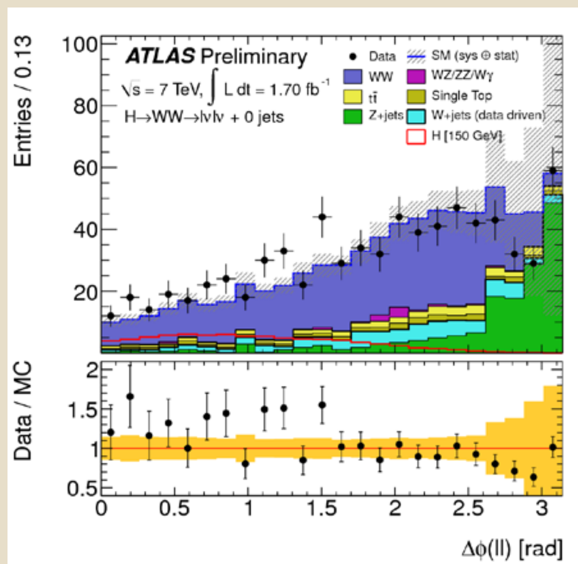
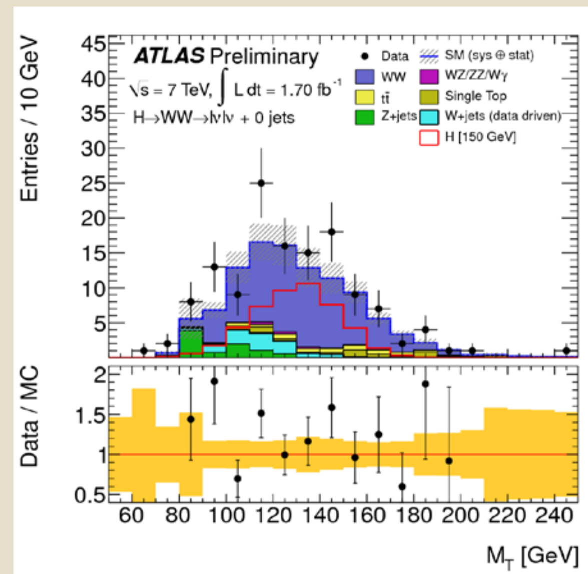
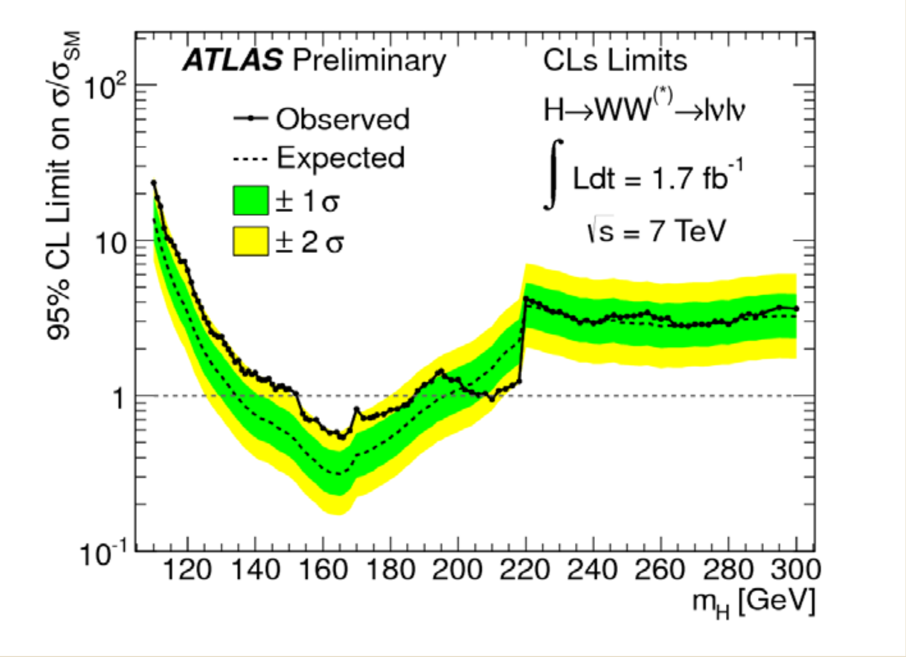






$H \to W W^{(*)} \to l^+\nu\, l^-\nu$: Results



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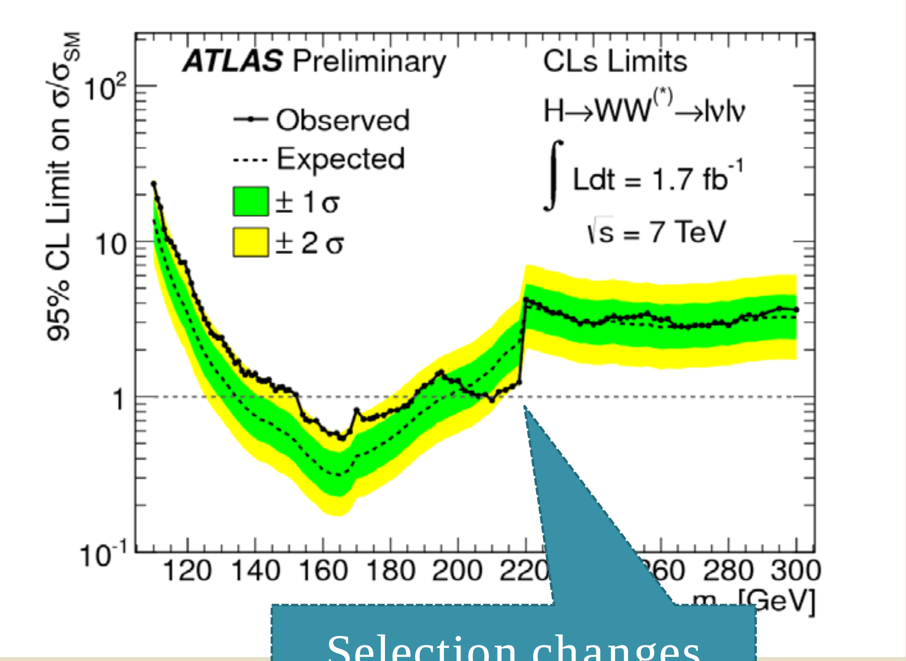
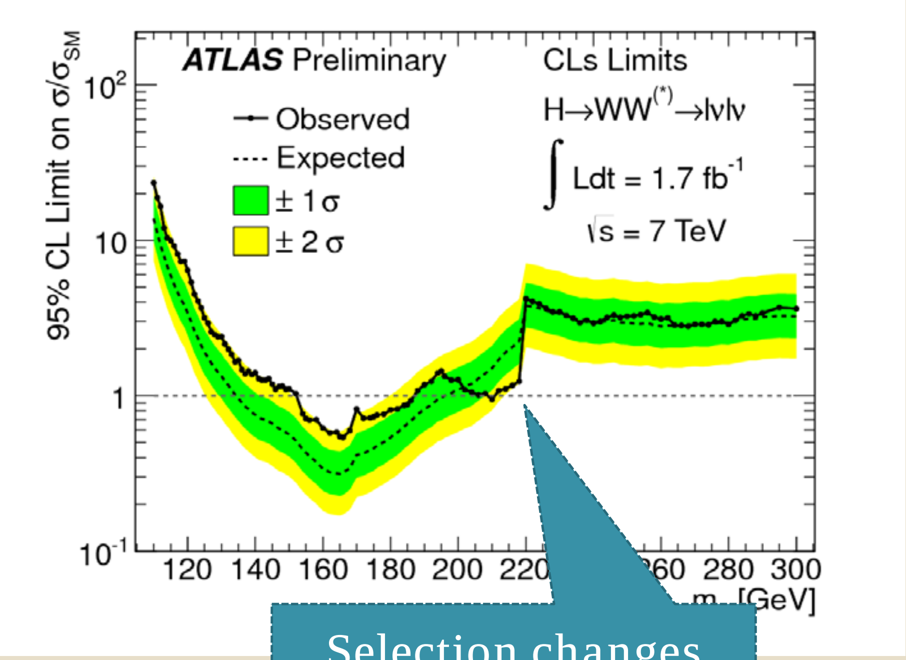


Selection changes

H→ W W $^{(*)}$ → $l^+\nu\, l^-\nu$: Results

Largest deviation from expectation : ~2σ



Selection changes

Excluded : 154GeV<M_H <186GeV

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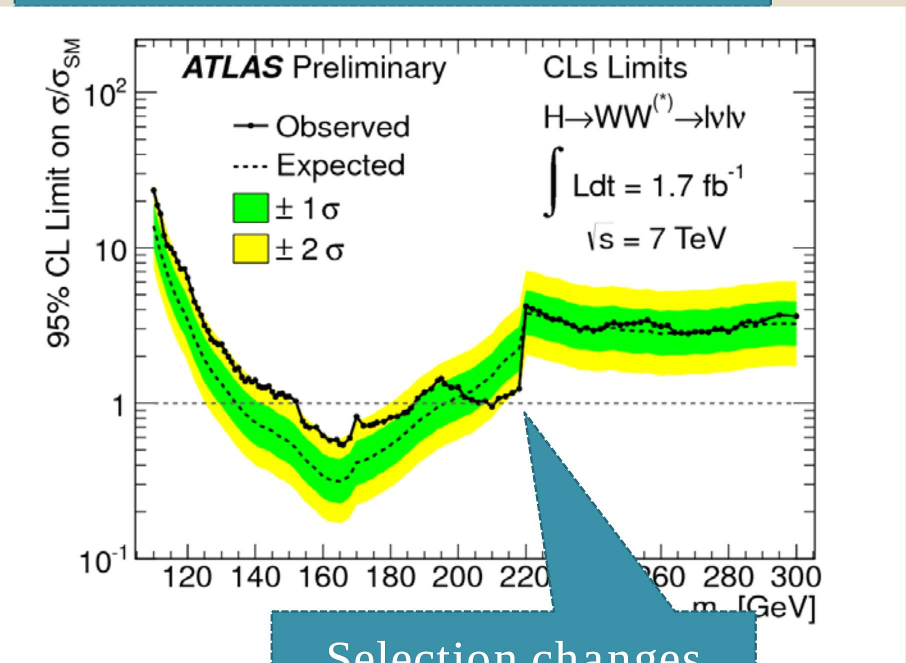
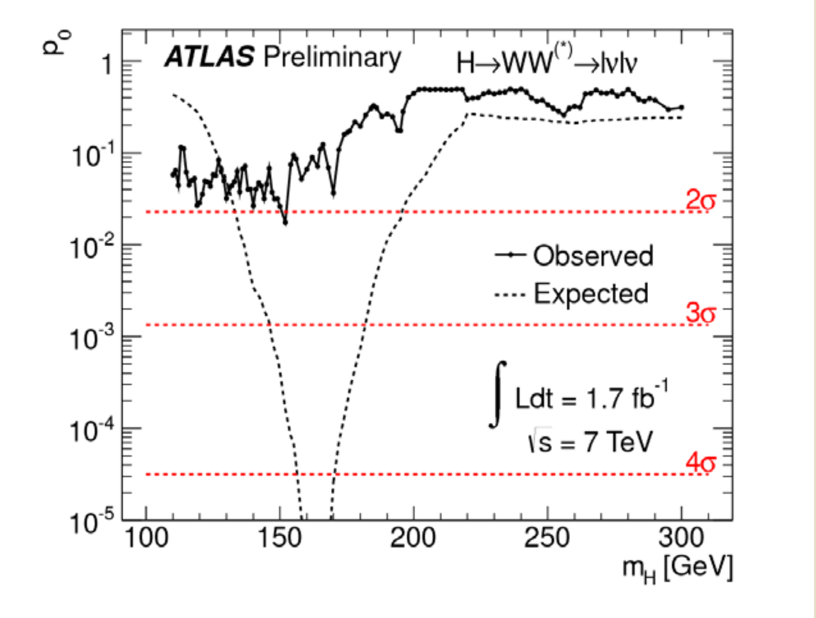


Selection changes

p0 value= probability for the background to fluctuate



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Higgs→ZZ$^{(*)}$

Three channels :

- ➔ H→ZZ → l^+l^- νν with l=μ, e (200-600 GeV)
  (with 2.05fb^{-1} of data NEW ATLAS-CONF-2011-148)
- ➔ H→ZZ → l^+l^- qq with l=μ, e (200-600 GeV)
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- ➔ H→ZZ$^{(*)}$ → 4l with with l=μ, e (120-600 GeV)
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Common feature:
Isolated leptons and
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$H \to ZZ \to l^+ l^- q\bar{q}$ (l=e or μ) selection

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Two leptons with P_T>20GeV,well identified , with isolated tracks and $M_{ll} \in [M_Z \pm 15]$ GeV

➔Z->qq: jets reconstructed using anti-Kt algorithm with P_T>25 GeV and Mjj ϵ [70,105]GeV

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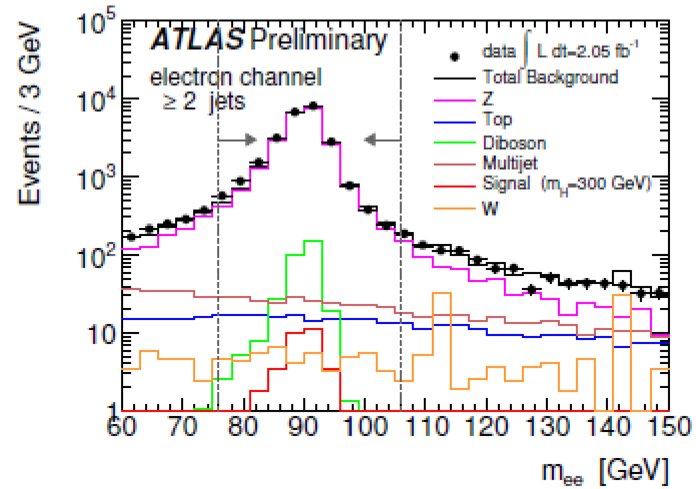

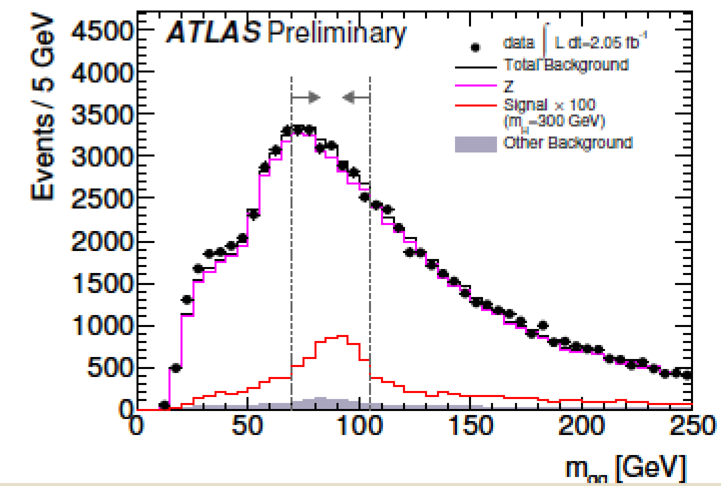

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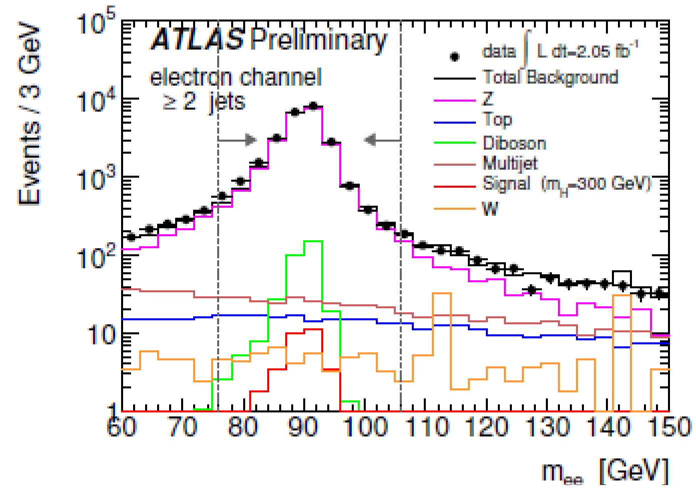
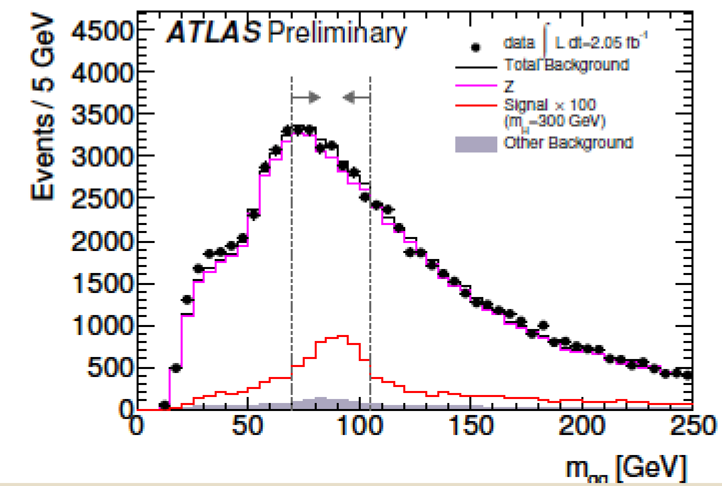
➔20% of signal contain 2 b-jets. Divide sample into Z+2 b-tagged jets and into Z+<2 tagged jets
➔tagging: 70% efficiency for a light jet rejection of 100





$H \rightarrow ZZ \rightarrow l^+l^-q\bar{q}$ ($l=e$ or μ) background

→Main backgrounds : Z+jets and $t\bar{t}$

→Assessed with data-driven studies

using Mjj or M_{ll} sidebands respectively

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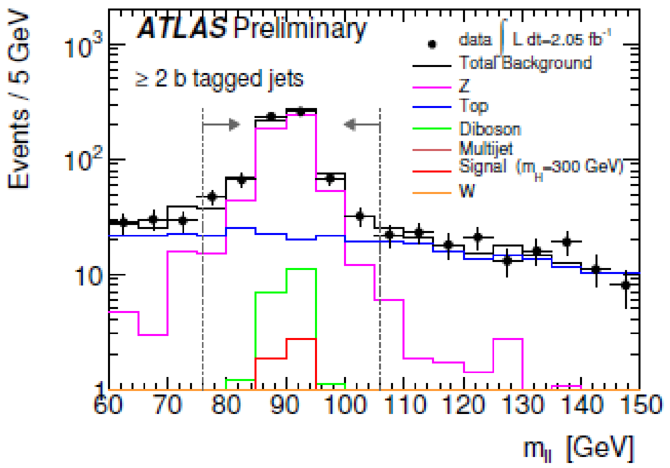
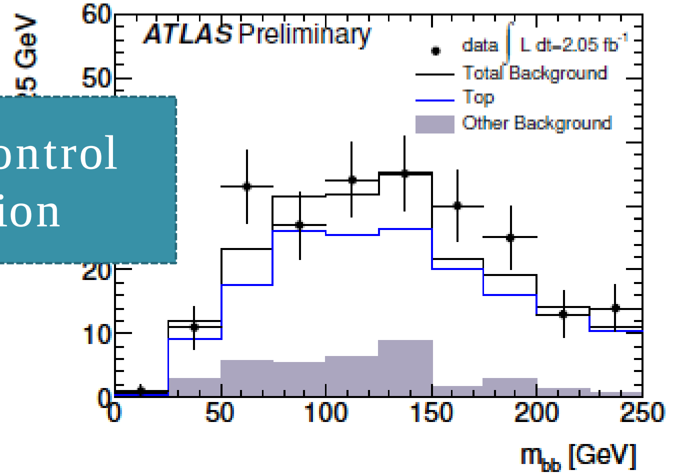




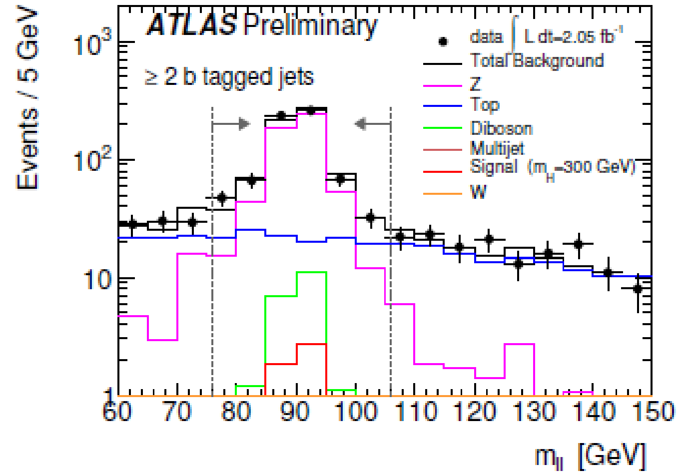
Top control region

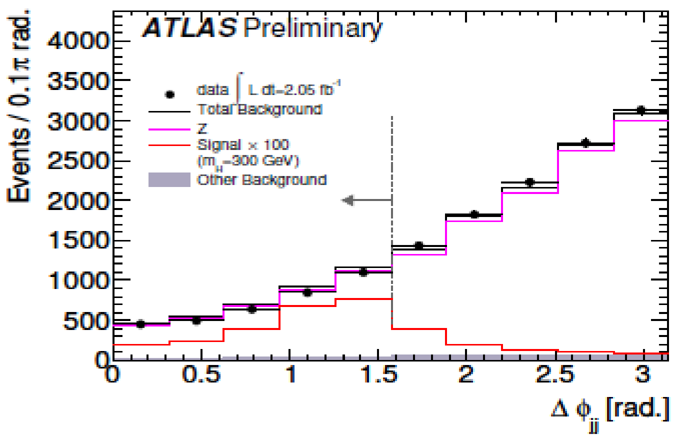
H→ZZ→ $l^+l^-q\bar{q}$ (l=e or μ) background

→Main backgrounds : Z+jets and $t\bar{t}$

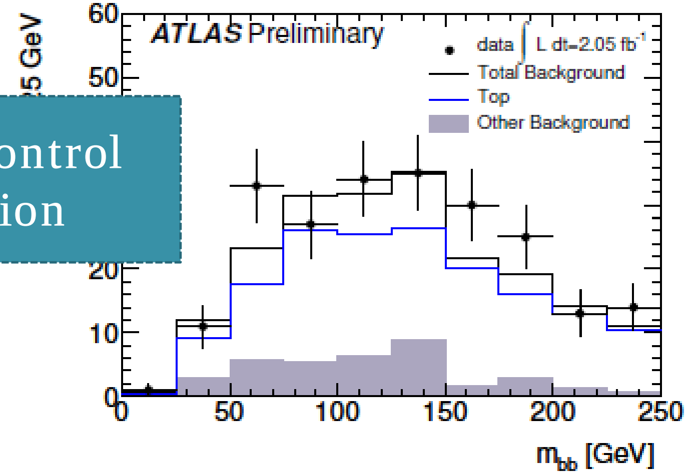
→Assessed with data-driven studies using Mjj or M_{ll} sidebands respectively

→For M_H>300GeV, angular kinematical cuts allow better rejection against Z+jets
$\Delta\Phi(jj)<90^o$,$\Delta\Phi(ll)<90^o$, P_T>45GeV



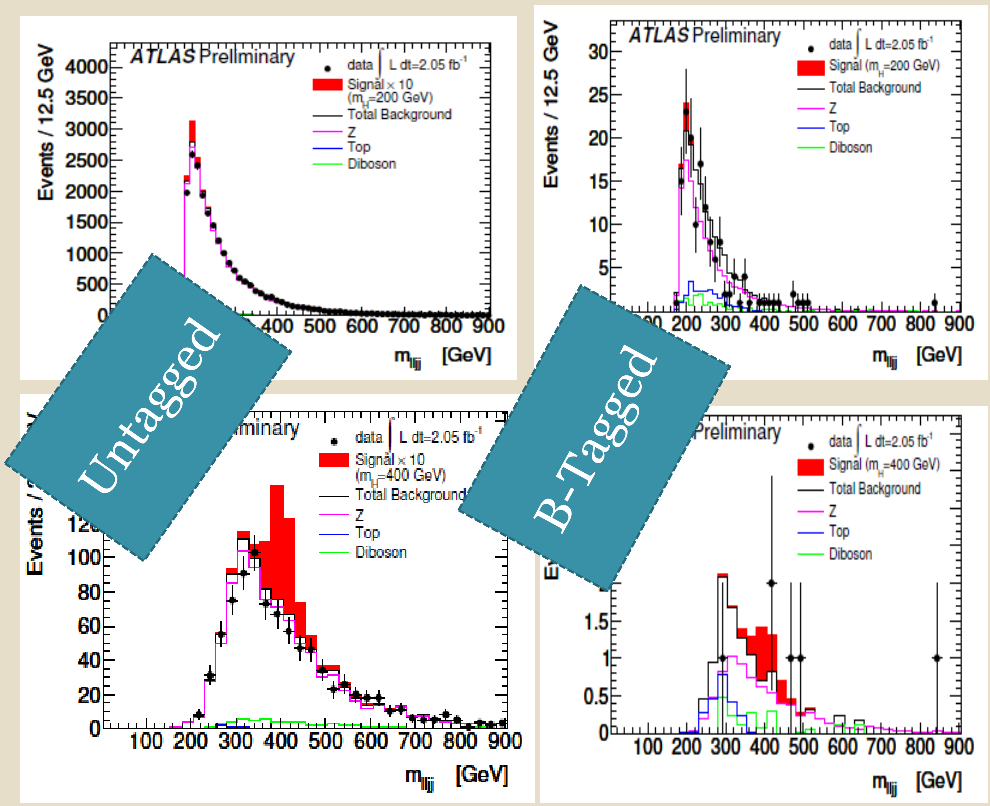


Top control region



H→ZZ→ $l^+l^-q\bar{q}$ (l=e or μ): Results

Final discriminant M (lljj)

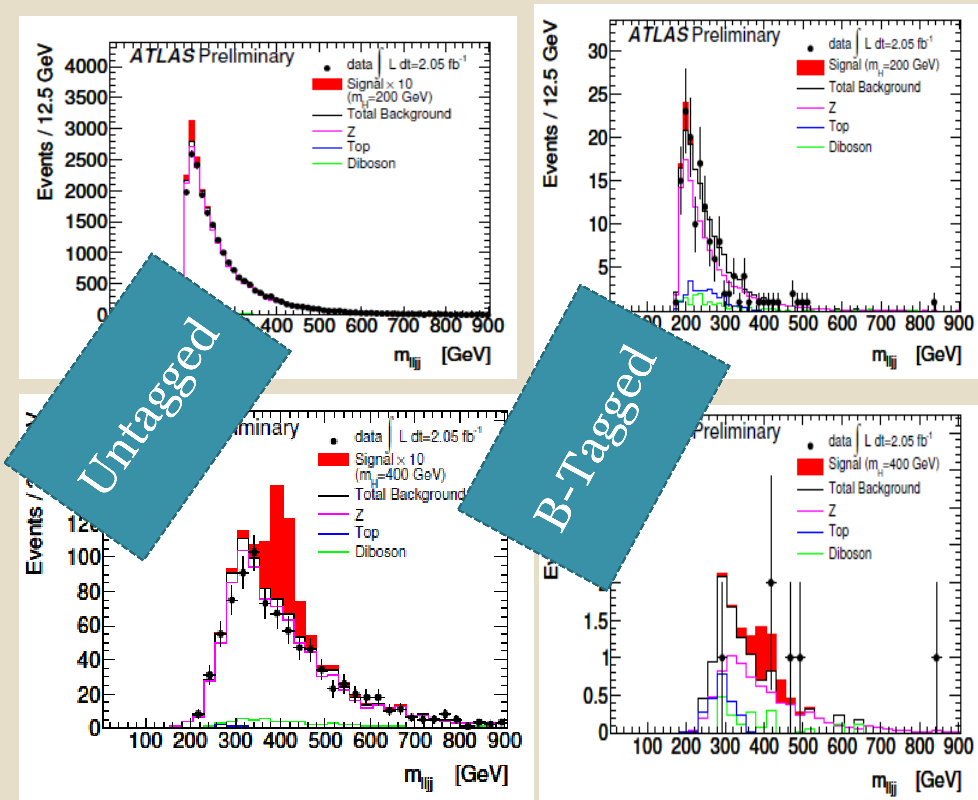


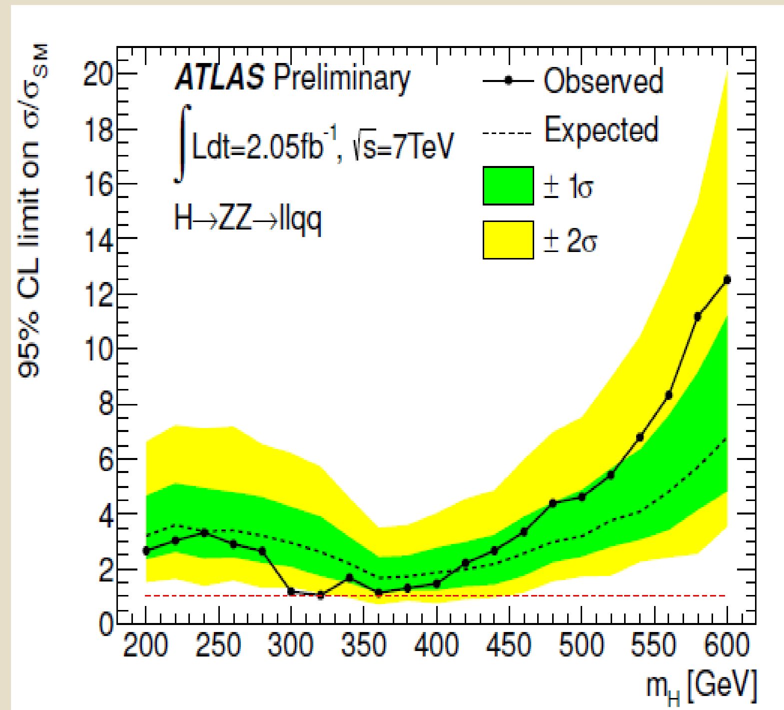
H→ZZ→ $l^+l^-q\bar{q}$ (l=e or μ): Results

Final discriminant M (lljj)

Untagged

B-Tagged





No SM exclusion yet

$H \to ZZ \to l^+l^-\nu\bar{\nu}$ (l=e or μ): Selection

- ➔Require isolated leptons with P_T>20GeV
- ➔$M_{ll} \in [M_Z \pm 15]$
- ➔ETmiss
- ➔If jets require to be far from ETmiss

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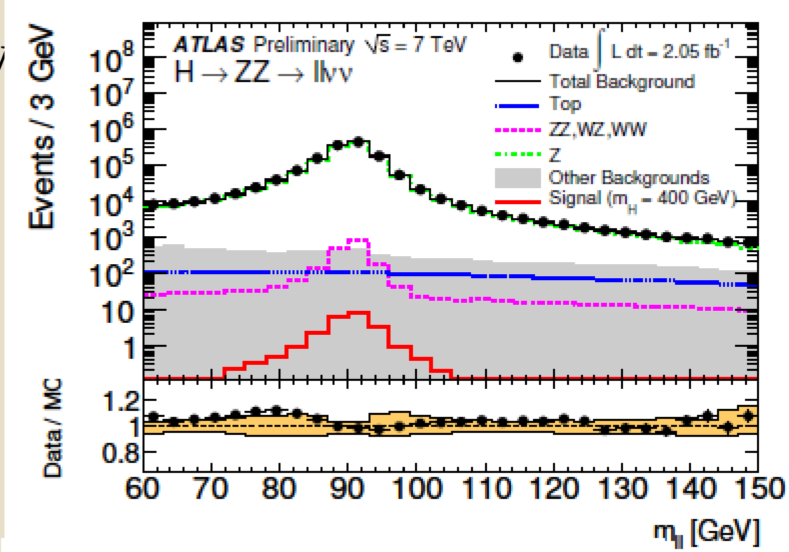

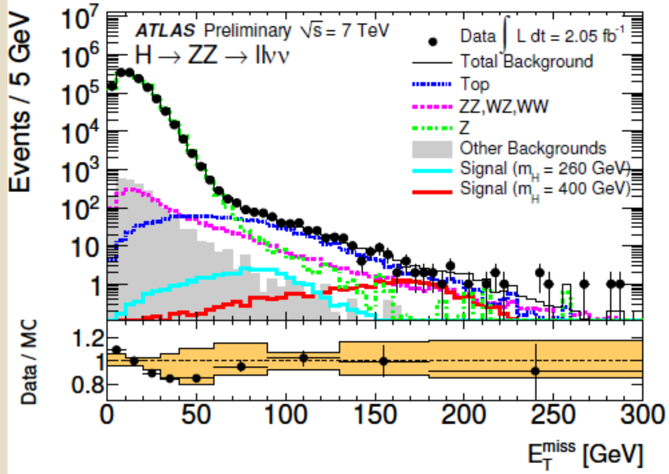

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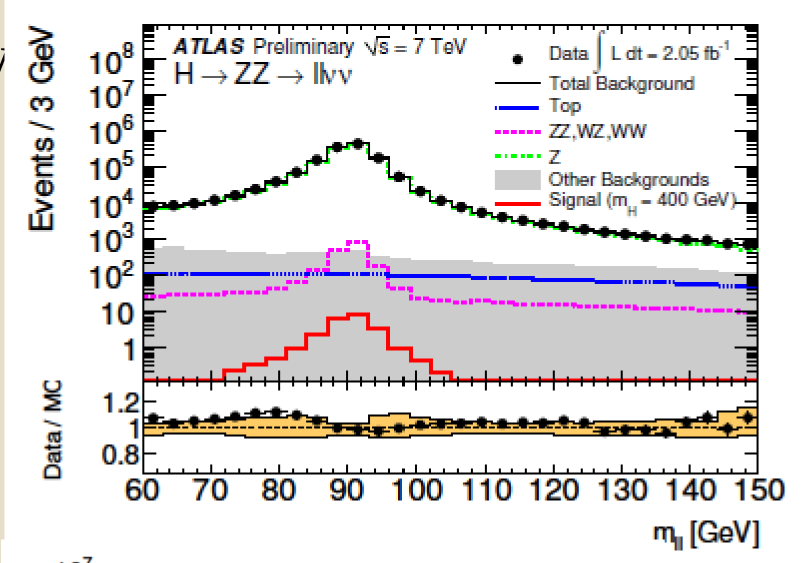
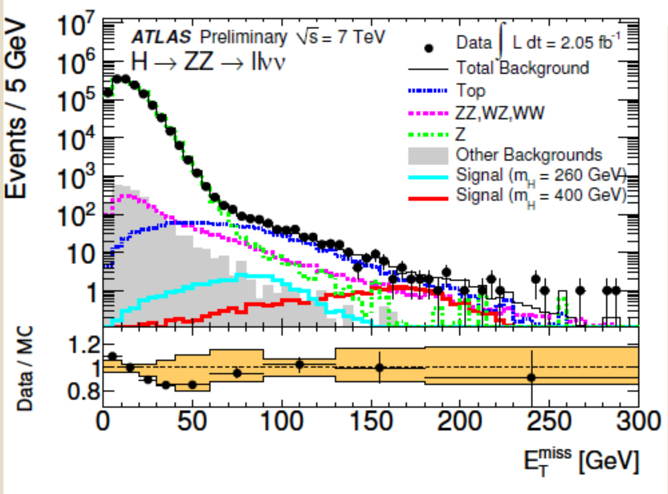


Backgrounds

➔Main reducible: Z+jets and $t\bar{t}$ from data driven methods

➔ ZZ, WW from MC



$H \to ZZ \to l^+l^-\nu\bar{\nu}$ (l=e or μ): Backgrounds

- ➔ High M_H hypothesis (>280GeV):
  - Etmiss>82GeV
  - $\Delta\Phi(ll)<2.25$
  - $\Delta\Phi$ (Etmiss, P_T (ll)) > 1
- ➔ Low M_H hypothesis (<280GeV):
  - Etmiss>66GeV and
  - $1<\Delta\Phi(ll)<2.64$

$H \rightarrow ZZ \rightarrow l^+l^-\nu\bar{\nu}$ (l=e or μ): Backgrounds

Discriminant variable : $m_T^2 \equiv \left[\sqrt{m_Z^2 + |\vec{p}_T^{\,\ell\ell}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\,\mathrm{miss}}|^2}\right]^2 - \left[\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,\mathrm{miss}}\right]^2$

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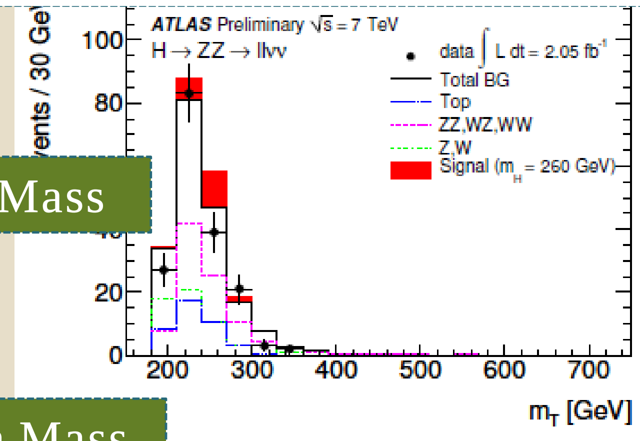
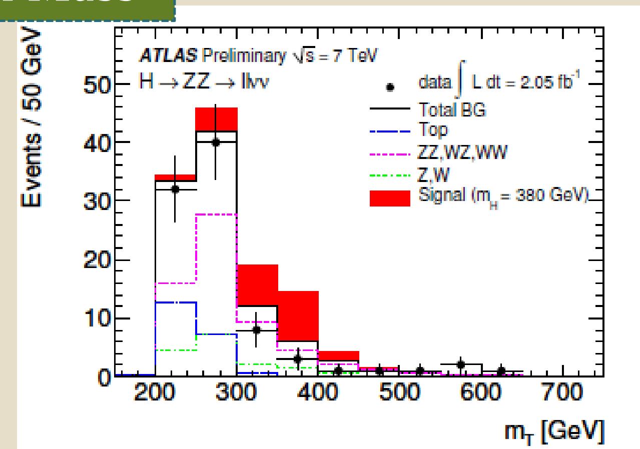
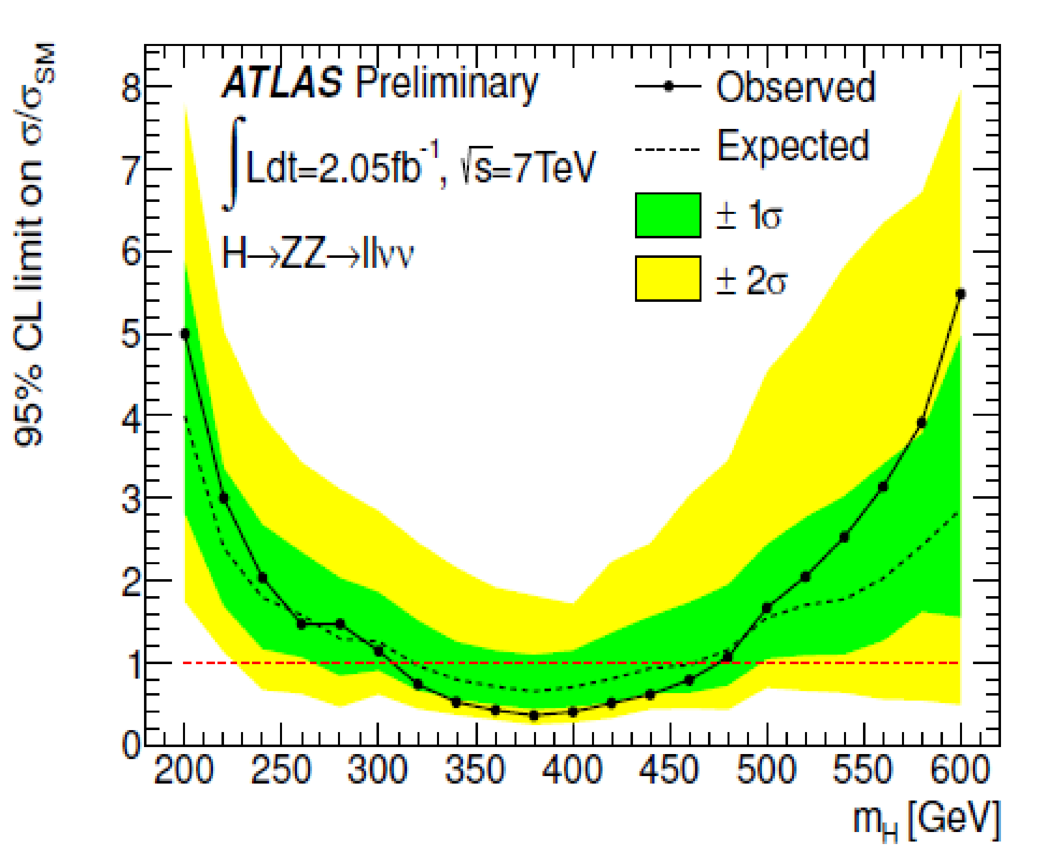
Low Mass



High Mass



$H \rightarrow ZZ \rightarrow l^+l^-\nu\bar{\nu}$ (l=e or μ): Results



Exclusion:
310 -470GeV at 95%CL

$H \rightarrow ZZ^* \rightarrow 4l$ ($l=e$ or μ): selection

➔The "GOLDEN" channel

➔Allows M_H reconstruction with fwhm~5(35)GeV at M_H=130(400)GeV

➔Allows to probe low M_H through Z* (performances at low P_T crucial!).

➔All leptons P_T>7 GeV well identified and isolated .

➔ Require one $M_{ll} \in [M_Z \pm 15 GeV]$

➔ Constraints on impact parameter

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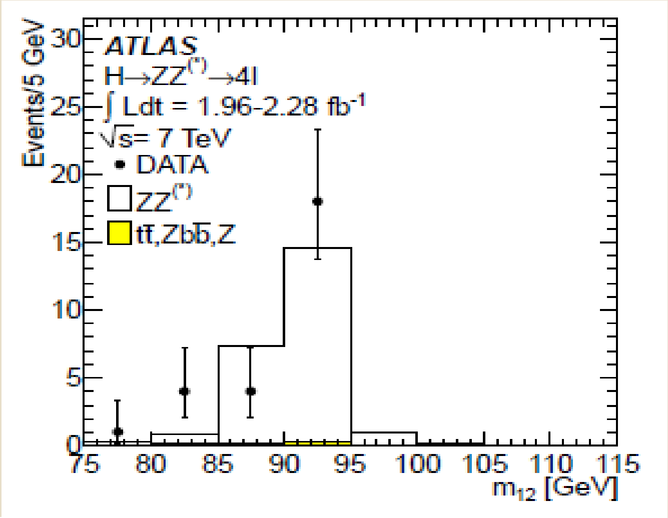

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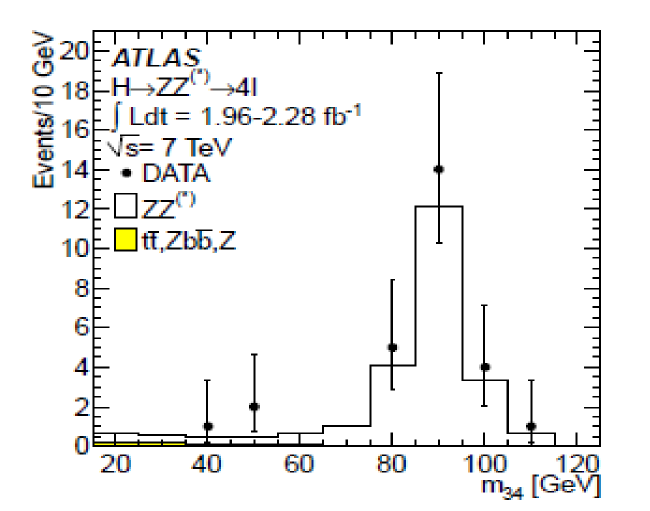
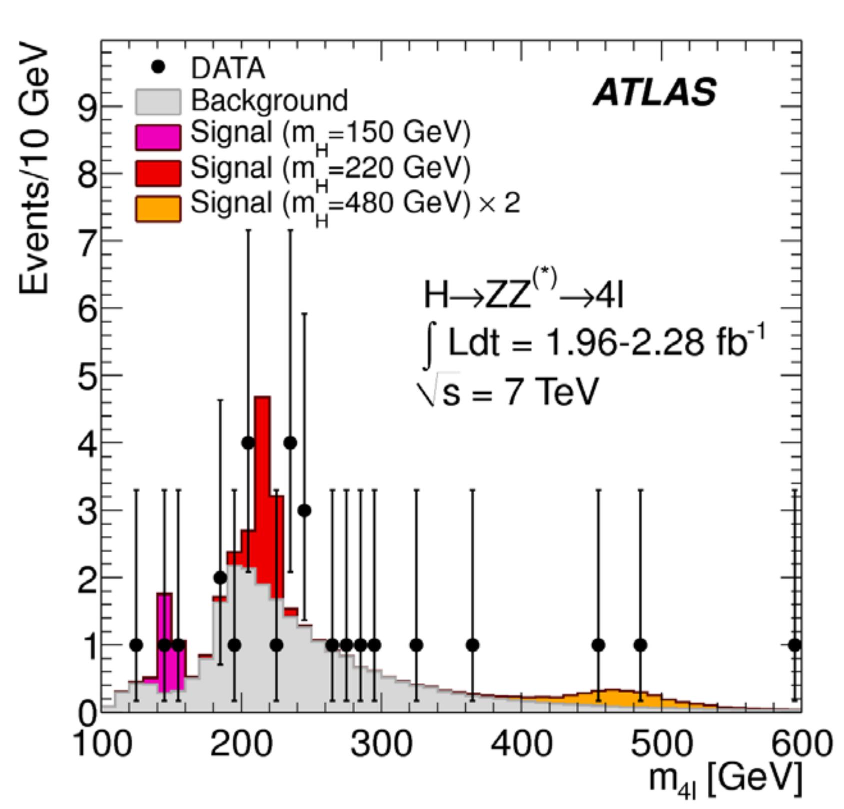


H→ZZ*→4l (l=e or μ): Results

Final discriminant: M (4l)



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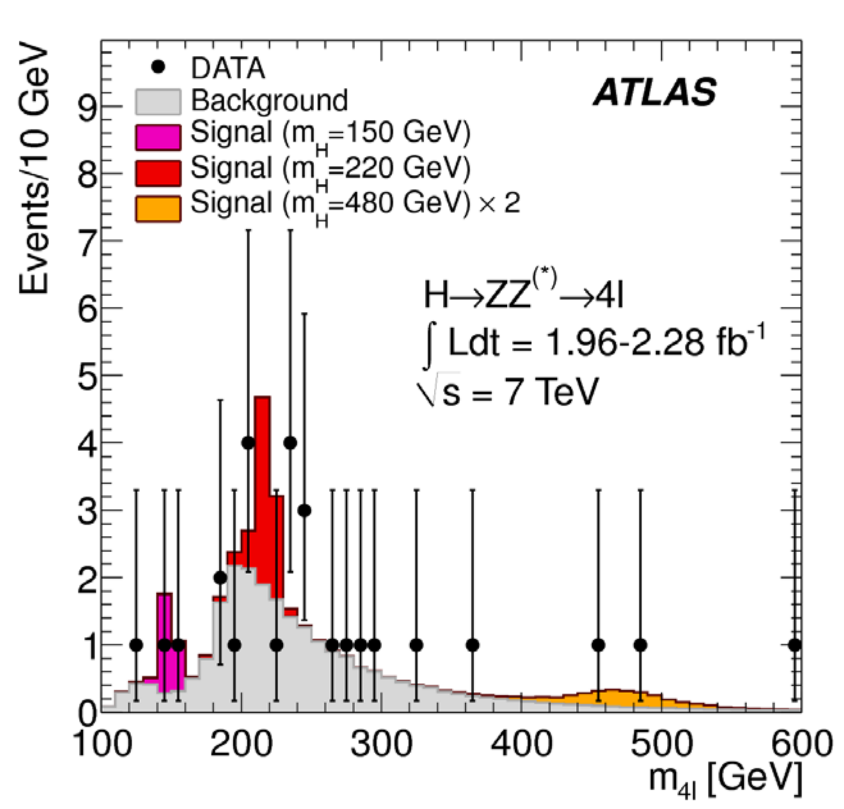

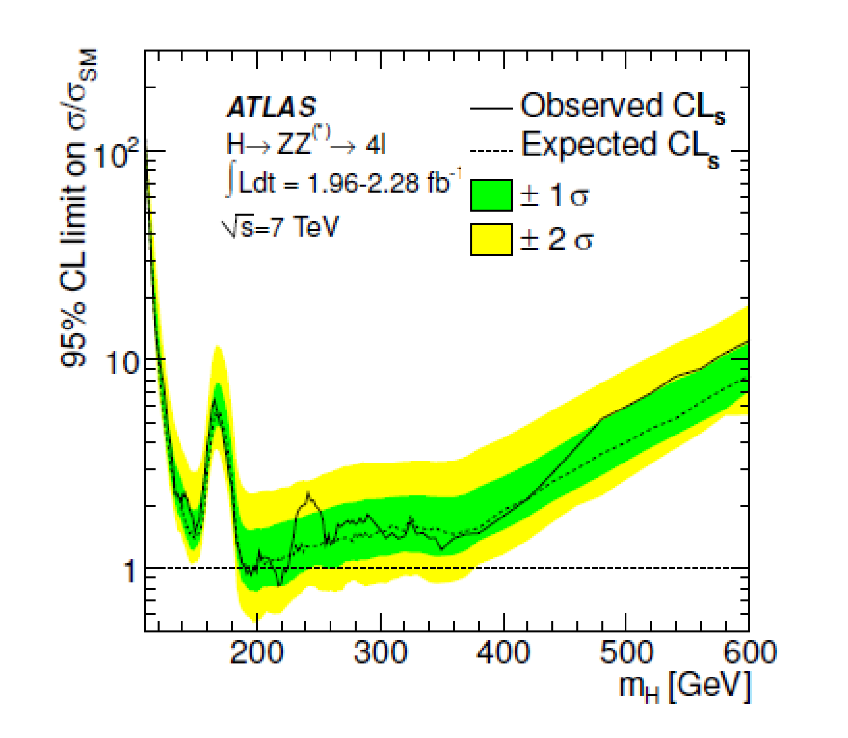

M_H (GeV) excluded in 95%CL : 191-197, 199-200 and 214-224

Conclusions and Prospects

➔ATLAS collaboration has provided updated exclusion limits for SM Higgs decays in diboson channels. No excess has been observed.

Other results:

➔ Searches at low M_H : see talk by Michael Duehrssen-Debling

➔ Combined ATLAS result : see talk by Fabien Tarrade.

➔ Next milestones:

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➔ Winter conferences : Update with optimised object performances and analyses.

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Thank you !

BACKUP

Systematics of Z→ ll qq

Source of Uncertainty	Treatment in analysis
Jet Energy Scale (JES)	$2-7\%$ as a function of p_T and η
Jet Pile-up Uncertainty	$3-7\%$ as a function of p_T and η
b-quark Energy Scale	2.5%
Jet Energy Resolution	1-4%
Electron Selection Efficiency	$0.7-3\%$ as a function of p_T, $0.4-6\%$ as a function of η
Electron Reconstruction Efficiency	$0.7-1.8\%$ as a function of η
Electron Energy Scale	0.1-6% as a function of η, pileup, material effects etc.
Electron Energy Resolution	Sampling term 20%, a small constant term has a large variation with η
Muon Selection Efficiency	0.2-3% as a function of p_T
Muon Trigger Efficiency	$< 1\%$
Muon Momentum Scale	2-16% η dependent systematic on scale
Muon Momentum Resolution	p_T and η dependent resolution smearing functions, systematic $\lesssim 1\%$
b-tagging Efficiency	5-15% as a function of p_T
b-tagging Mis-tag Rate	10-22% as a function of p_T and η
Missing Transverse Energy	Propagate object uncertainties to E_T^{miss}

Number of events in H→ZZ→llqq (2.05fb^{-1})

	Untagged		Tagged	
	Low-m_H	High-m_H	Low-m_H	High-m_H
Z+jets	$20672 \pm 110 \pm 310$	$858 \pm 20 \pm 61$	$126 \pm 1 \pm 26$	$7.6 \pm 0.2 \pm 1.6$
W+jets	$20 \pm 4 \pm 10$	$0.8 \pm 0.5 \pm 0.4$	< 0.1	< 0.1
Top	$85 \pm 2 \pm 11$	$6.4 \pm 0.5 \pm 1.1$	$24 \pm 1 \pm 5$	$2.2 \pm 0.4 \pm 0.5$
Multijet	$87 \pm 3 \pm 87$	$2.1 \pm 0.5 \pm 2.1$	$0.1 \pm 0.1 \pm 0.1$	< 0.1
ZZ	$214 \pm 7 \pm 28$	$17.2 \pm 1.8 \pm 2.8$	$14.0 \pm 1.5 \pm 3.8$	$1.7 \pm 0.5 \pm 0.5$
WZ	$292 \pm 6 \pm 56$	$34 \pm 2 \pm 6$	$0.6 \pm 0.3 \pm 0.3$	< 0.1
Total background	$21369 \pm 110 \pm 332$	$919 \pm 20 \pm 62$	$165 \pm 2 \pm 27$	$11.6 \pm 0.6 \pm 1.8$
Data	21032	851	145	6
Signal				
$m_H = 200$ GeV	$64 \pm 1 \pm 12$		$4.4 \pm 0.4 \pm 1.1$	
$m_H = 300$ GeV		$14.0 \pm 0.5 \pm 2.9$		$1.2 \pm 0.1 \pm 0.3$
$m_H = 400$ GeV		$21.1 \pm 0.5 \pm 3.8$		$2.1 \pm 0.2 \pm 0.6$
$m_H = 500$ GeV		$11.5 \pm 0.2 \pm 2.1$		$1.3 \pm 0.1 \pm 0.4$
$m_H = 600$ GeV		$5.4 \pm 0.1 \pm 1.0$		$0.5 \pm 0.0 \pm 0.2$

Event yields for H→ZZ→llνν (2.05fb^{-1})

Source	low m_H search	high m_H search	
Z + jets	$40.5 \pm 4.1 \pm 3.1$	$9.9 \pm 2.1 \pm 3.6$	
W + jets	$17 \pm 4 \pm 17$	$6.1 \pm 1.7 \pm 6.1$	
top	$40 \pm 1 \pm 12$	$20.9 \pm 1.0 \pm 6.2$	
Multijet	$1.2 \pm 0.7 \pm 0.6$	$0.4 \pm 0.4 \pm 0.2$	
ZZ	$35.1 \pm 0.7 \pm 4.1$	$29.6 \pm 0.6 \pm 3.5$	
WZ	$32.4 \pm 1.0 \pm 3.8$	$23.2 \pm 0.8 \pm 2.7$	
WW	$25.4 \pm 0.7 \pm 3.1$	$9.4 \pm 0.4 \pm 1.1$	
Total BG	$192 \pm 6 \pm 35$	$100 \pm 3 \pm 17$	
Data	175	89	
m_H [GeV]	Signal expectation		s/b
200	$9.9 \pm 0.2 \pm 1.8$		8%
300		$19.9 \pm 0.3 \pm 3.5$	24%
400		$19.6 \pm 0.3 \pm 3.4$	57%
500		$8.8 \pm 0.1 \pm 1.5$	60%
600		$3.6 \pm 0.0 \pm 0.6$	60%

Experimental systematics in H→WW*→lνlν

Table 2: Experimental sources of systematic uncertainty per object or event.

Source of Uncertainty	Treatment in the analysis
Jet Energy Resolution (JER)	$\sim$ 14%, see Ref. [69]
Jet Energy Scale (JES)	Takes into account close-by jets effect, jet flavor composition uncertainty and event pile-up uncertainty in addition to global JES uncertainty Global JES < 10% for $p_{\mathrm{T}} > 15$ GeV and $\lvert\eta\rvert < 4.5$, see Ref. [70] Pile-up uncertainty 2-5% for $\lvert\eta\rvert < 2.1$ and 3-7% for $2.1 < \lvert\eta\rvert < 4.5$ These are summed in quadrature before application.
Electron Selection Efficiency	Separate systematics for electron identification, reconstruction and isolation, added in quadrature Total uncertainty of 2-5% depending on η and E_T
Electron Energy Scale	Uncertainty smaller than 1%, depending on η and E_T
Electron Energy Resolution	Energy varied within its uncertainty, 0.6% of the energy at most
Muon Selection Efficiency	0.3-1% as a function of η and p_{T}
Muon Momentum Scale	η dependent scale offset in p_{T}, up to $\sim$ 0.13%
Muon Momentum Resolution	p_{T} and η dependent resolution smearing functions, $\leq$ 5%
b-tagging Efficiency	p_{T} dependent scale factor uncertainties, 5.6-15%, see Ref. [68]
b-tagging Mis-tag Rate	up to 21% as a function of p_{T}, see Ref. [68]
Missing Transverse Energy	13.2% uncertainty on topological cluster energy Electron and muon p_{T} changes from smearing propagated to MET Effect of out-of-time pileup: MET smeared by 5 GeV in 1/3 of MC events
Luminosity	3.7% [25]

Number of events of H+0 jet→WW*→lνlν (1.7fb-1)

	Signal	WW	W + jets	Z/γ^* + jets	$t\bar{t}$	$tW/tb/tqb$	$WZ/ZZ/W\gamma$	Total Bkg.	Observed
Jet Veto	82 ± 17	430 ± 40	70 ± 40	160 ± 150	37 ± 13	28 ± 7	11 ± 3	740 ± 160	738
$\lvert P_T^{\ell\ell} \rvert > 30$ GeV	79 ± 17	390 ± 40	60 ± 30	28 ± 11	35 ± 12	25 ± 7	10 ± 3	540 ± 80	574
$m_{\ell\ell} < 50$ GeV	56 ± 12	98 ± 13	17 ± 7	12 ± 7	6 ± 3	4.8 ± 1.5	1.2 ± 0.4	139 ± 20	175
$\Delta\phi_{\ell\ell} < 1.3$	48 ± 11	76 ± 10	9 ± 4	8 ± 6	5 ± 2	4.8 ± 1.5	1.1 ± 0.3	105 ± 16	131
$0.75\, m_H < m_T < m_H$	34 ± 7	43 ± 6	5 ± 2	2 ± 4	2.2 ± 1.4	1.2 ± 0.8	0.7 ± 0.3	53 ± 9	70
ee	5.2 ± 1.2	6.2 ± 0.9	0.9 ± 0.4	0.8 ± 1.4	0.3 ± 0.3	0 ± 0.3	0.07 ± 0.05	8.2 ± 1.7	9
$e\mu$	17 ± 4	22 ± 3	2.8 ± 1.3	0 ± 1.3	1.1 ± 0.5	0.8 ± 0.6	0.31 ± 0.19	27 ± 4	32
$\mu\mu$	11 ± 2	14 ± 2	1.0 ± 0.6	1 ± 3	0.8 ± 1.1	0.4 ± 0.4	0.31 ± 0.09	18 ± 5	29

Event yields for H→ZZ*→4l (2.1fb^{-1})

	$\mu\mu\mu\mu$		$ee\mu\mu$		$eeee$	
	Low mass	High mass	Low mass	High mass	Low mass	High mass
Integrated Luminosity	2.28 fb^{-1}		1.96 fb^{-1}		1.98 fb^{-1}	
$ZZ^{(*)}$	1.02±0.15	7.7±1.2	0.99±0.16	9.6±1.4	0.39±0.09	3.6±0.5
Z, $Zb\bar{b}$, $t\bar{t}$	0.06±0.01	0.01±0.01	0.29±0.11	0.15±0.06	0.23±0.09	0.12±0.05
Total Background	1.08±0.15	7.7±1.2	1.28±0.19	9.8±1.4	0.62±0.13	3.7±0.5
Data	1	11	1	8	1	5
$m_H = 130$ GeV	0.42 ± 0.07		0.40 ± 0.06		0.14 ± 0.03	
$m_H = 150$ GeV	0.98 ± 0.15		0.97 ± 0.15		0.34 ± 0.06	
$m_H = 200$ GeV		2.26 ± 0.33		2.64 ± 0.38		0.98 ± 0.14
$m_H = 240$ GeV		1.74 ± 0.25		2.24 ± 0.32		0.88 ± 0.13
$m_H = 300$ GeV		1.18 ± 0.17		1.64 ± 0.23		0.64 ± 0.09
$m_H = 400$ GeV		0.86 ± 0.13		1.23 ± 0.18		0.52 ± 0.08
$m_H = 600$ GeV		0.15 ± 0.02		0.23 ± 0.04		0.10 ± 0.02

H→WW*→lν j j

	H($e\nu jj$) + 0j	H($\mu\nu jj$) + 0j	H($e\nu jj$) + 1j	H($\mu\nu jj$) + 1j	H + 0j or 1j
W/Z+jets	10780 ± 290	13380 ± 870	6510 ± 250	7410 ± 670	38080 ± 1160
Multi-jet	890 ± 24	256 ± 17	669 ± 25	212 ± 19	2027 ± 43
Top	170 ± 34	164 ± 33	489 ± 98	500 ± 100	1320 ± 270
Dibosons	397 ± 79	414 ± 83	161 ± 32	204 ± 41	1180 ± 240
Expected Background	12240 ± 300	14210 ± 870	7830 ± 270	8330 ± 680	42600 ± 1200
Data	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

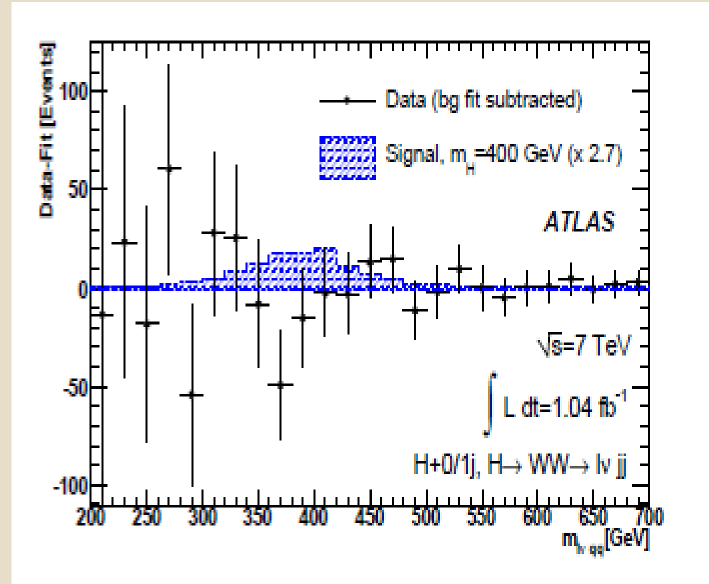

TABLE II: Expected and observed numbers of events for an integrated luminosity of 1.04 fb^{-1} after all selection cuts (except for the requirement that $m(\ell\nu) = m(W)$ has a real solution) for the signal and the main backgrounds. For the W/Z+jets and MJ backgrounds, the uncertainties are taken from the fit to the $\not{E}_T$ distribution used to normalize these backgrounds.