Search for the Standard Model Higgs Boson in ATLAS

XX International Workshop on Deep-Inelastic Scattering and Related Subjects

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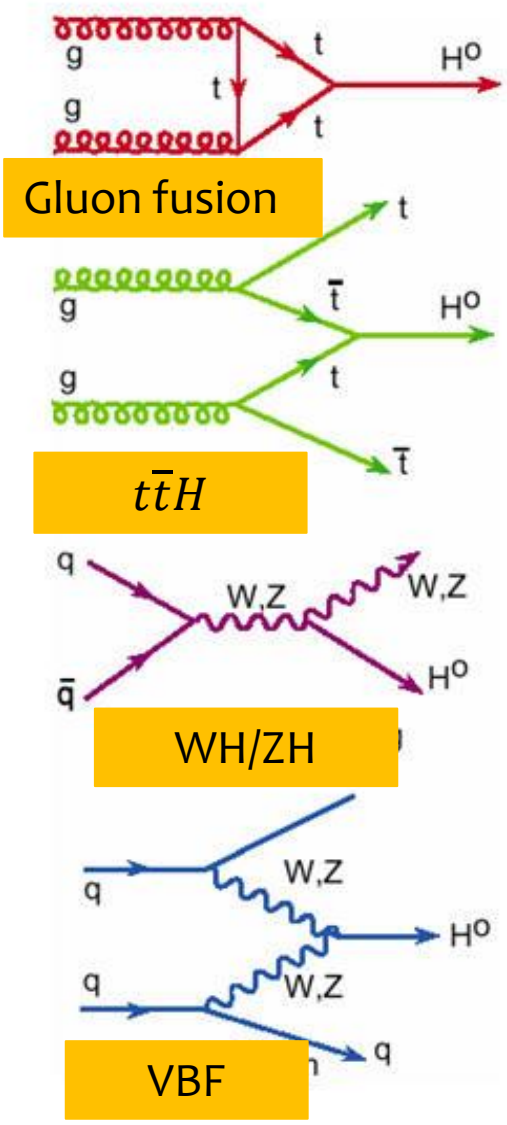
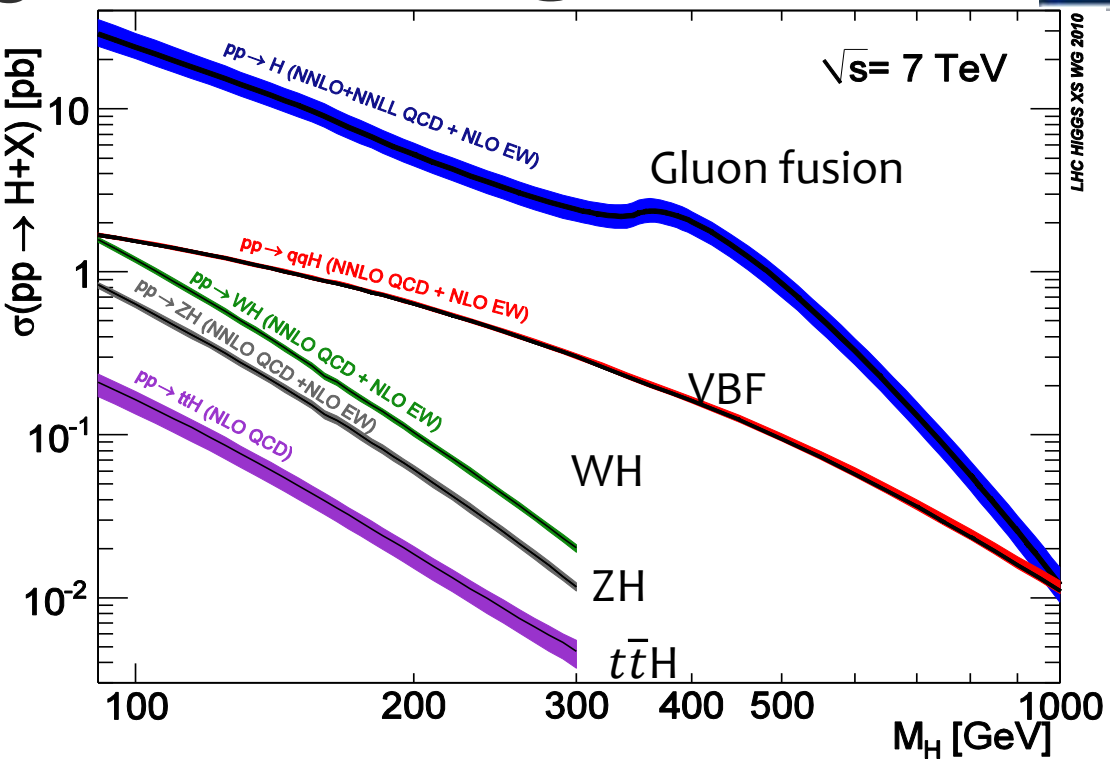
(for ATLAS collaboration)

Outline

- SM Higgs Production & decay modes
- LHC performance & ATLAS data-taking in 2011
- SM Higgs Search Strategies in ATLAS
  - Production rate ($\sigma \times BR$) depending on the Higgs boson mass (m_H)
  - Higgs boson mass resolution
- Results with all channels combined
- Summary & Conclusions

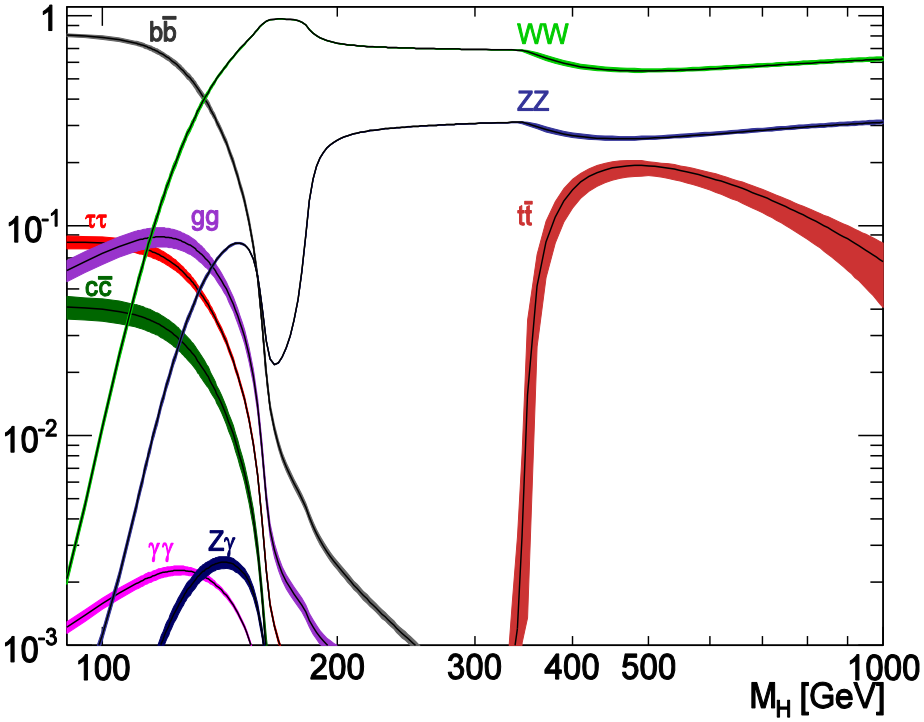
SM Higgs Production @ LHC

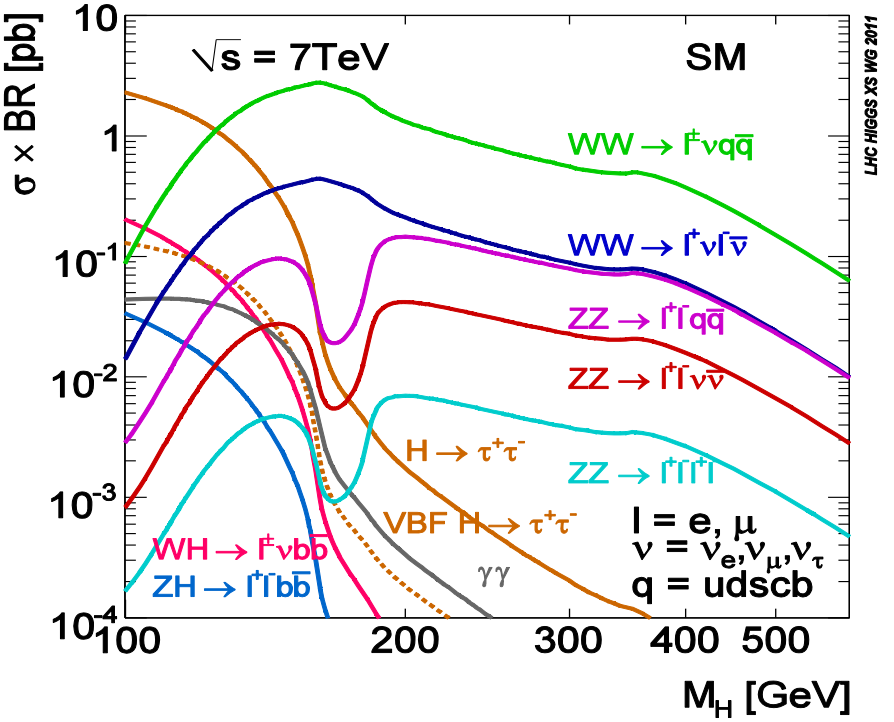




- PowHeg+Pythia generators for gluon fusion and VBF mechanisms
- Pythia for associated production (WH, ZH and $t\bar{t}H$)
- Cross-section & the uncertainties from LHC Higgs cross section Working group
  - arXiv:1101.0593 & arXiv:1201.3084

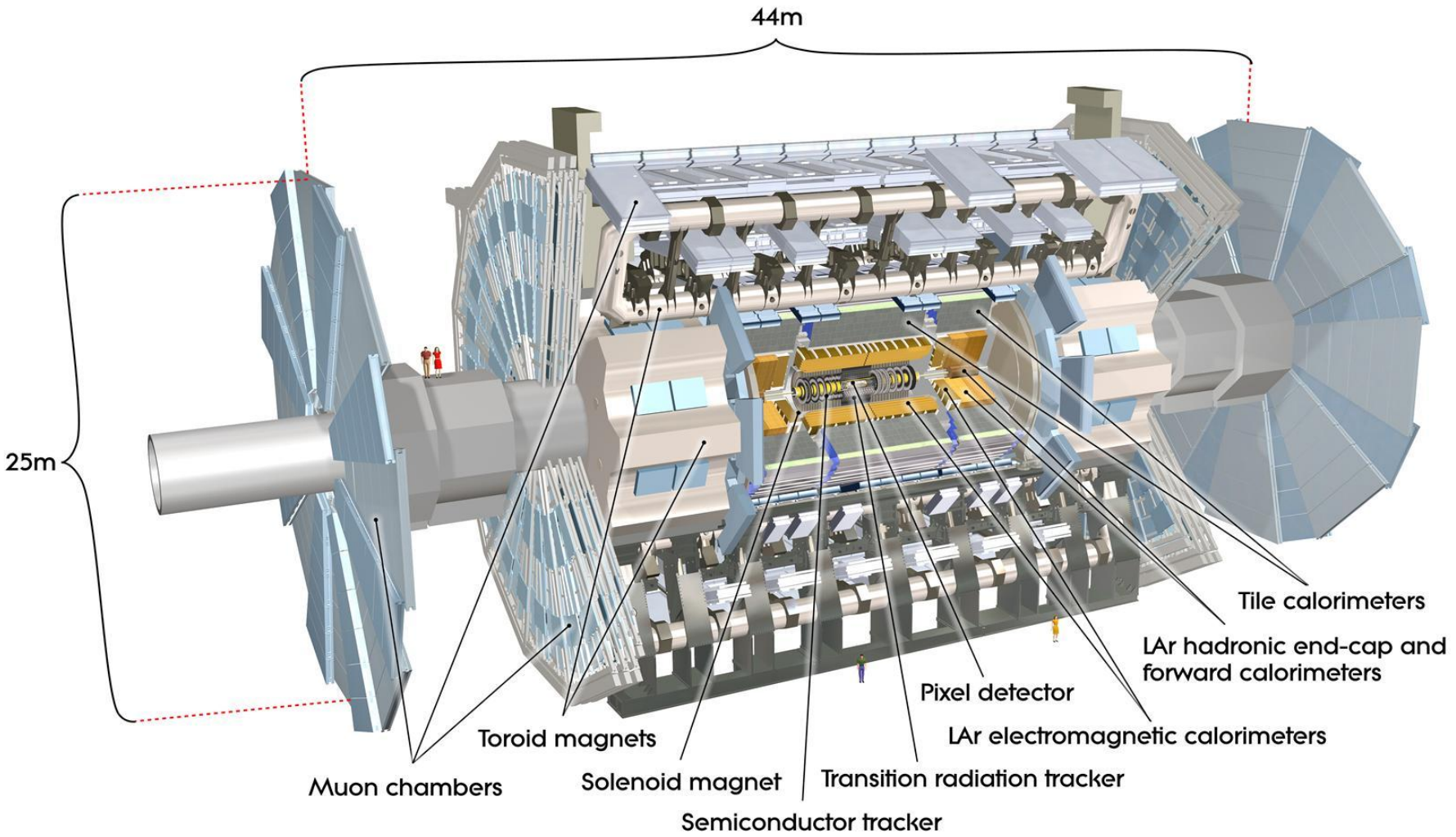
Higgs Boson Decays





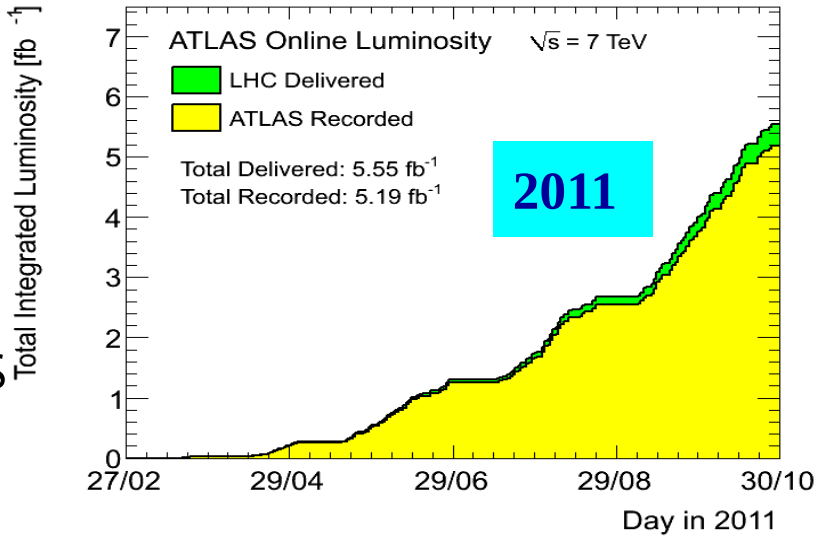
- m_H>135 GeV:
  - $H \rightarrow ZZ$ and $H \rightarrow WW$ are dominant decay modes
- m_H<135 GeV:
  - $H \rightarrow b\bar{b}$ and $H \rightarrow \tau\tau$ are the dominant modes
  - $H \rightarrow \gamma\gamma$ has small branching ratio but with clean signature

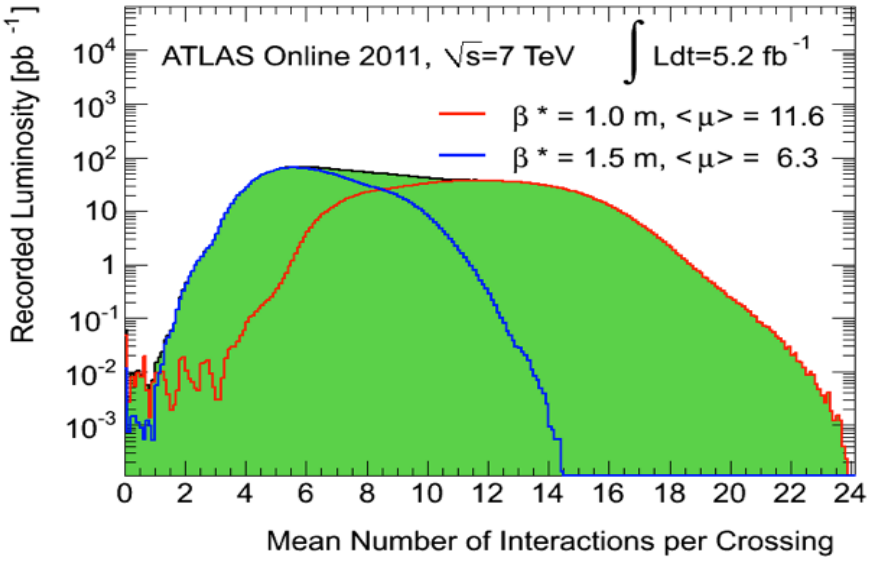
A Toroidal LHC ApparatuS

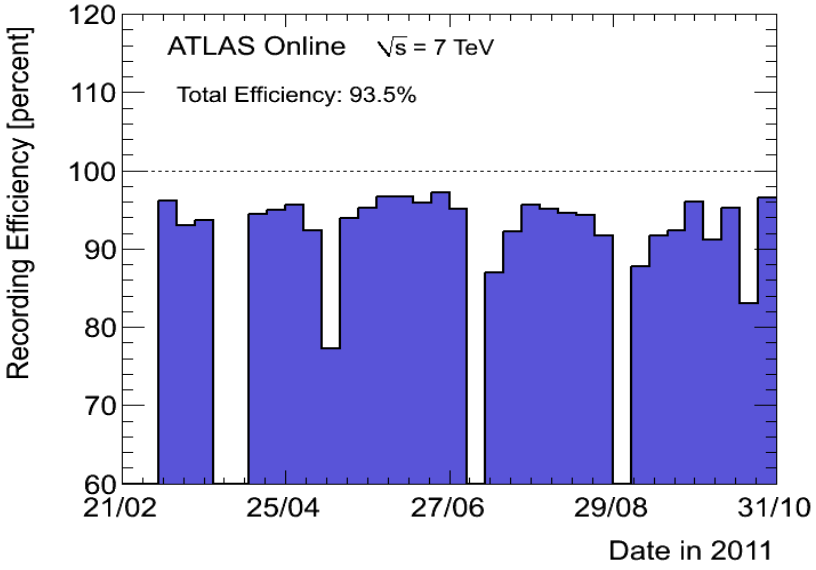


LHC performance & ATLAS data-taking

- The SM Higgs searches presented here are with full 2011 dataset i.e., 4.6-4.9 fb^{-1} (depending on search channel).
- Excellent performance of the ATLAS detectors with over all >93% data-taking efficiency.







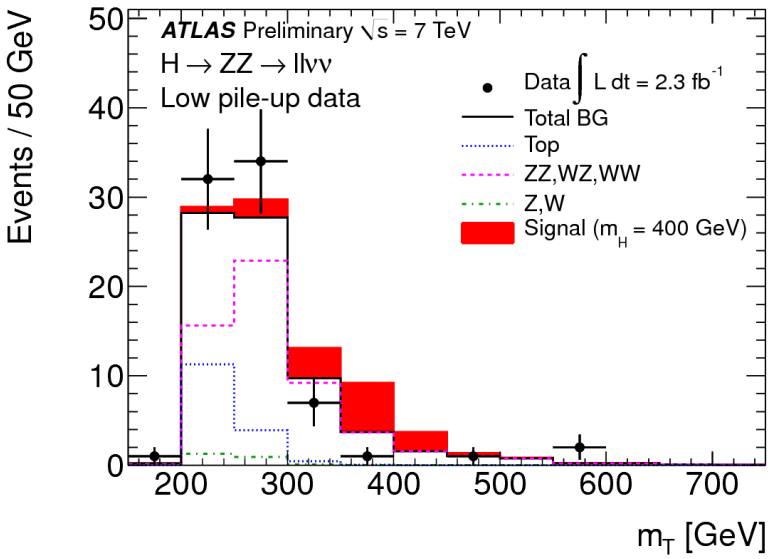
ATLAS Search Strategies for SM Higgs

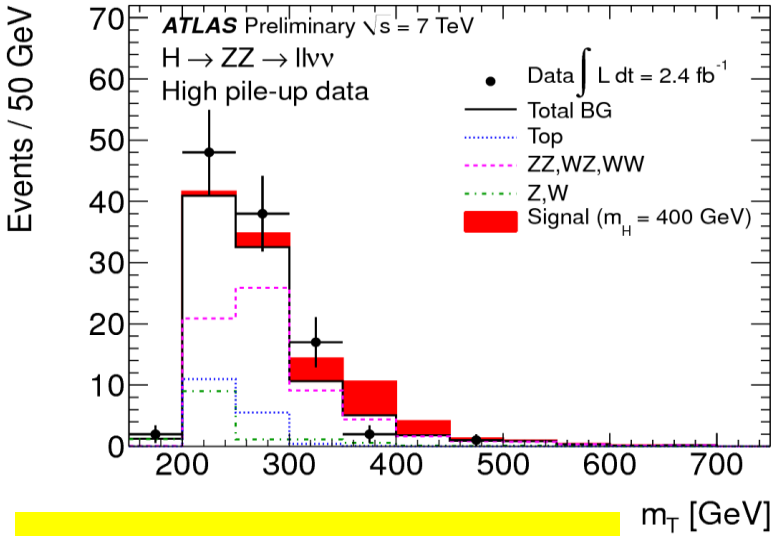
Searches in the following channels have been pursued with 2011 data

Channel	Higgs mass range (GeV)	$\int \mathcal{L}dt$ (fb^{-1})	Reference
Low m_H, good mass resolution			
$H \to \gamma\gamma$	110-150	4.9	arXiv:1202:1414
$H \to ZZ^{(*)} \to 4l$	110-600	4.8	arXiv:1202:1415
Low m_H, limited mass resolution			
$H \to WW^{(*)} \to lvlv$	110-600	4.7	CONF-2012-012
$H \to \tau\tau(\mathrm{ll}, \mathrm{lh}, \mathrm{hh})$	100-150	4.7	CONF-2012-014
$VH, H \to b\bar{b}$	110-130	4.7	CONF-2012-015
High m_H			
$H \to ZZ \to llvv$	200-600	4.7	CONF-2012-016
$H \to ZZ \to llqq$	200-600	4.7	CONF-2012-017
$H \to WW \to lvqq$	300-600	4.7	CONF-2012-018

Exclusion limits on $\mu=\sigma/\sigma_{SM}$ @ 95% confidence level using CL_s method [J Phys G28(2002) 2693-2704]

$H \rightarrow ZZ \rightarrow llνν$





- For high mass searches the most sensitive channel
- Limits are based on

$$m_T = \sqrt{\left(\left(E_T^{ll}\right) + \left(E_T^{miss}\right)\right)^2 - \left(\left|p_T^{ll} + p_T^{miss}\right|\right)^2}$$

  - Missing E_T is sensitive to the Pileup
- 4 sub-channels : (ee,μμ)⊗(low-,high-Pileup)
- Different selection criteria depending on the mass range.
- Observed exclusion: 320-560 GeV

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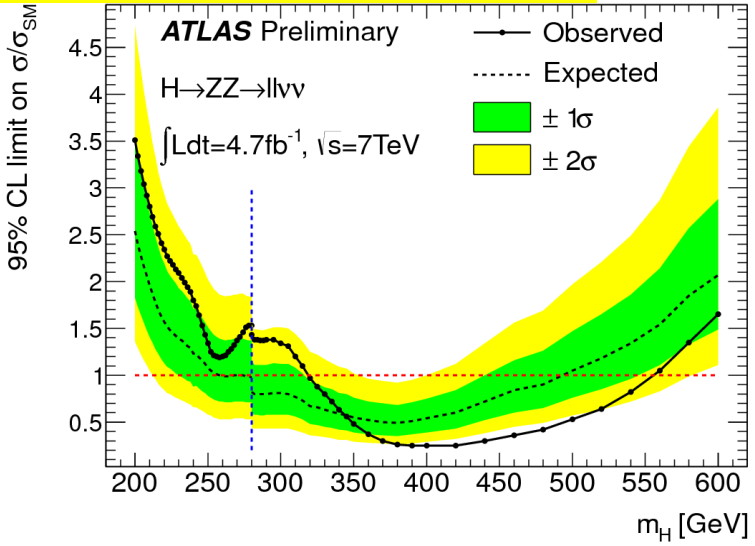
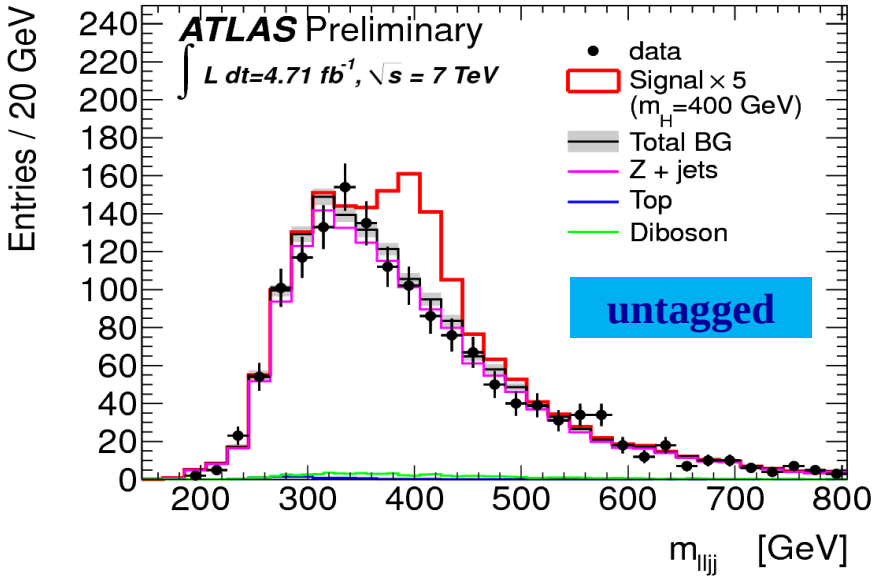
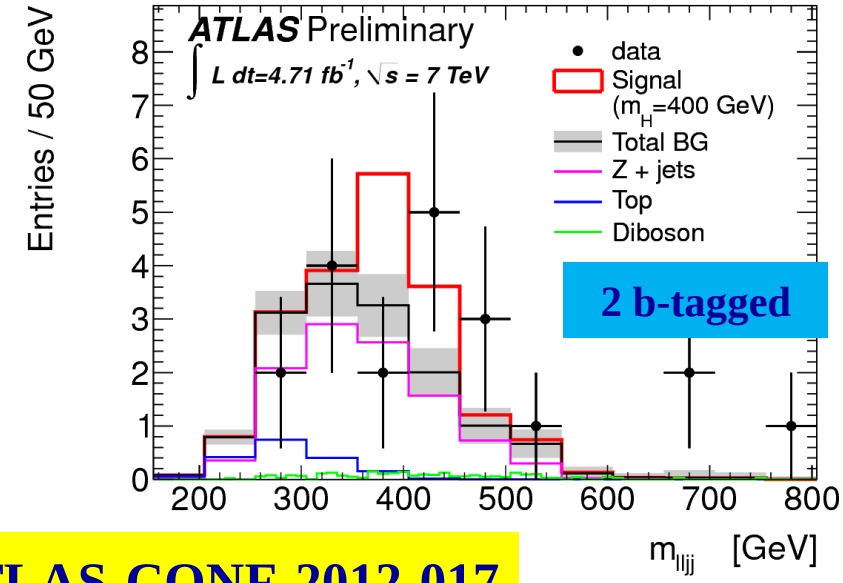
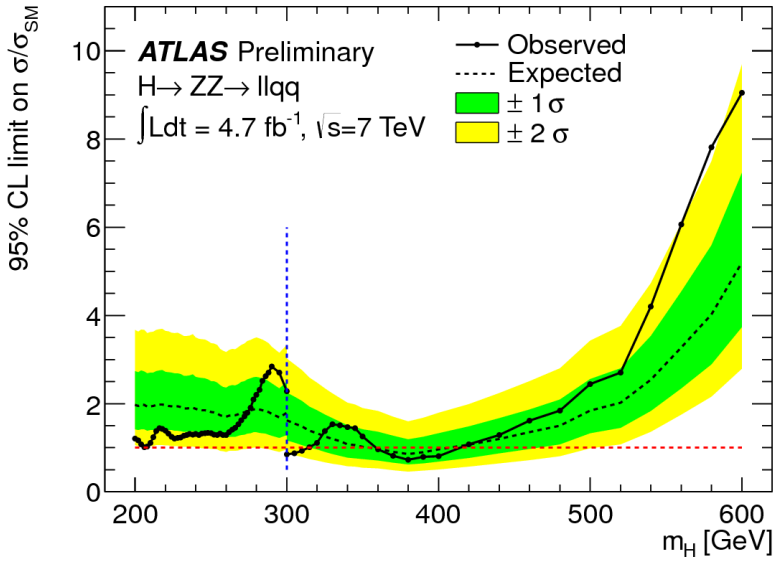


$H \rightarrow ZZ \rightarrow llqq$







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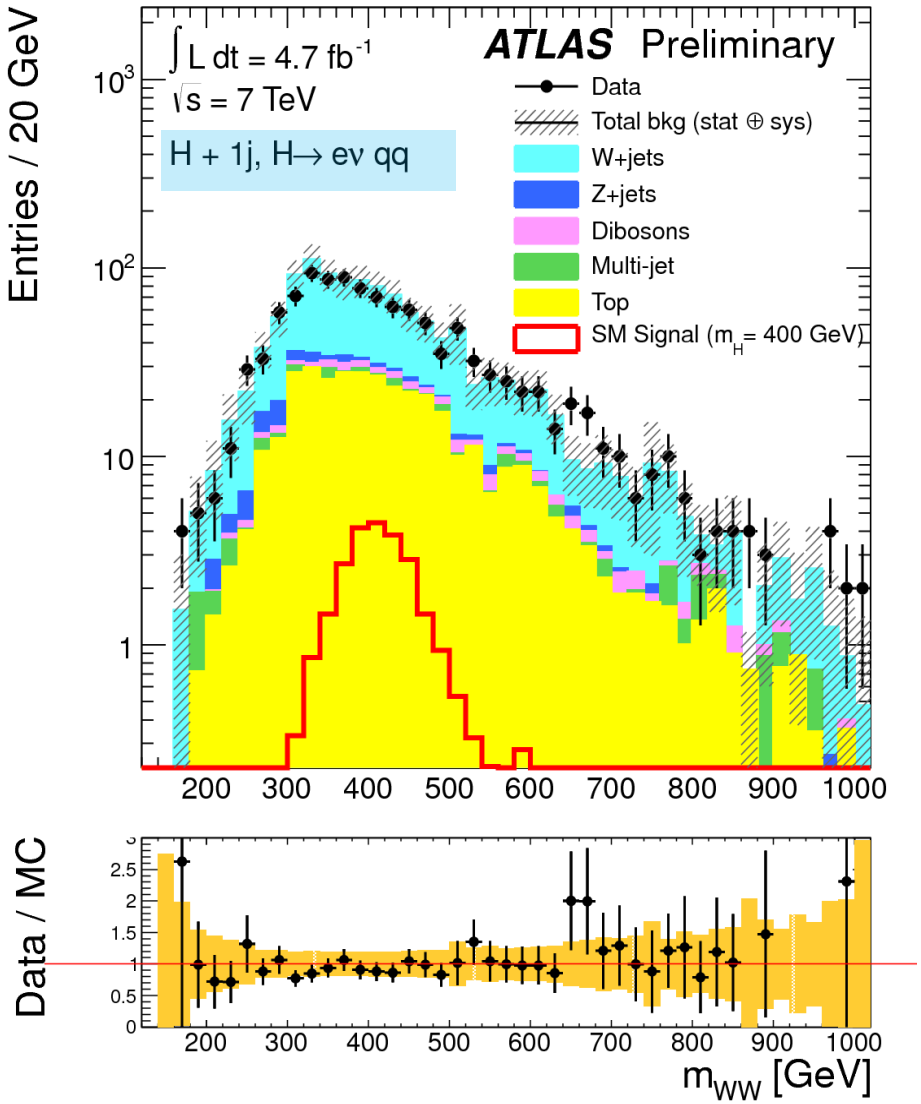
- 2 Sub-channels: "untagged jets" and "2 b-tagged jets"
- Limits based on m_{lljj}
- Different selection criteria depending on the mass range.
- Observed exclusion: 300-310 and 360-400 GeV

$H \to WW \to l\nu qq$



- Higgs mass reconstruction through $m_{qq}=m_W$ and $m_{l\nu}=m_W$
- 3 Sub-channels: 0, 1 and 2 jets (VBF contribution)
- Background modeling: fitting $m_{l\nu qq}$ spectrum from data

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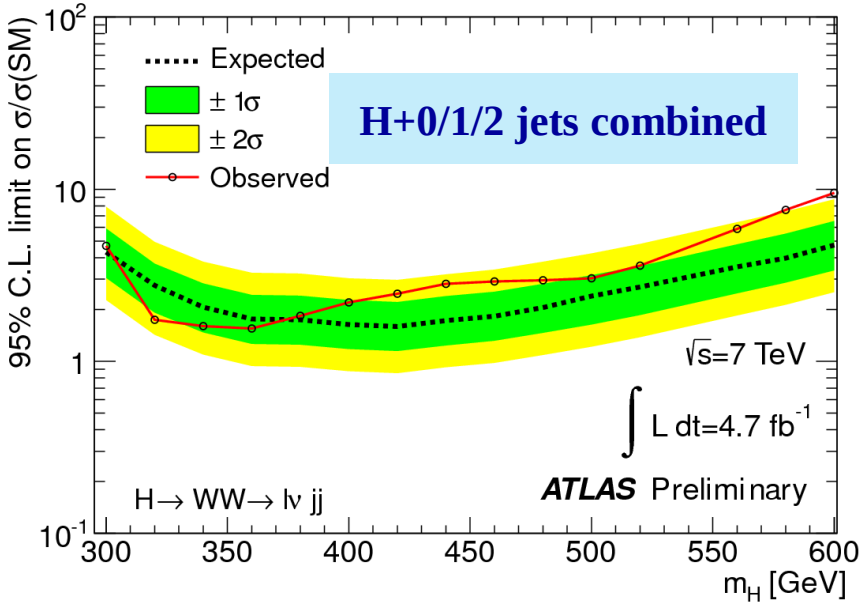
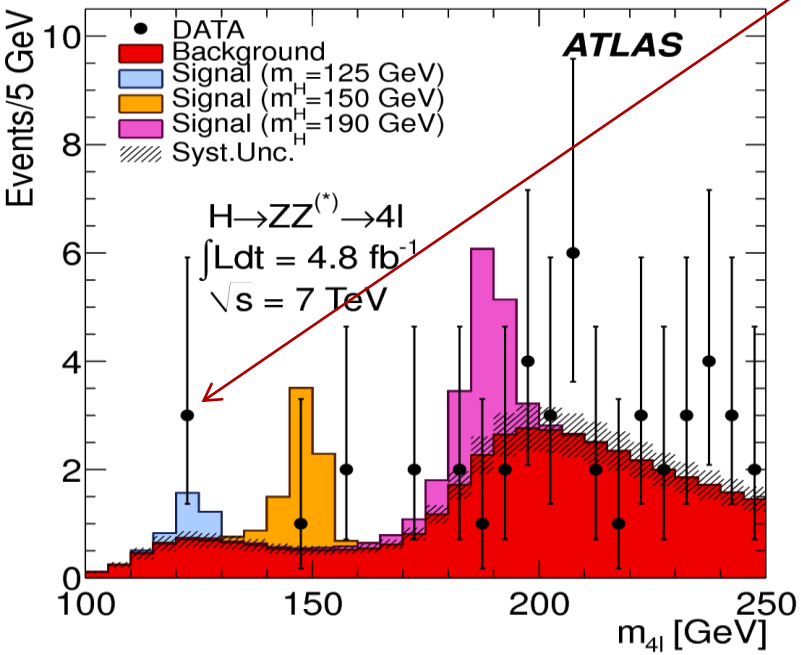


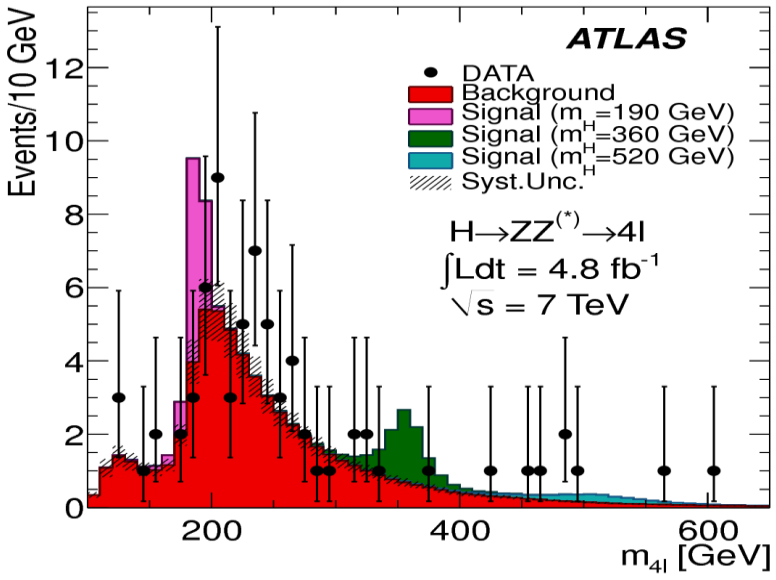
$H \rightarrow ZZ^{(*)} \rightarrow 4l$: The Golden channel

- Very clean signal with excellent mass resolution (1.5-2% for $m_H \approx 130$ GeV) from 4 well reconstructed leptons (e,μ)
  - For $m_H > 350$ GeV , natural width dominates
- SM $ZZ^{(*)}$ production is the irreducible background
- Lepton identification well modeled in MC; not affected by the event pileup
- Different selection criteria are applied for $m_{4l} > 180$ GeV and $m_{4l} < 180$ GeV

arXiv:1202.1415

Two 2e2μ candidates with m_{4l}=123.6, 124.3 GeV
One 4μ candidate with m_{4l}=124.6 GeV





$H \rightarrow ZZ^{(*)} \rightarrow 4l$: The Golden channel

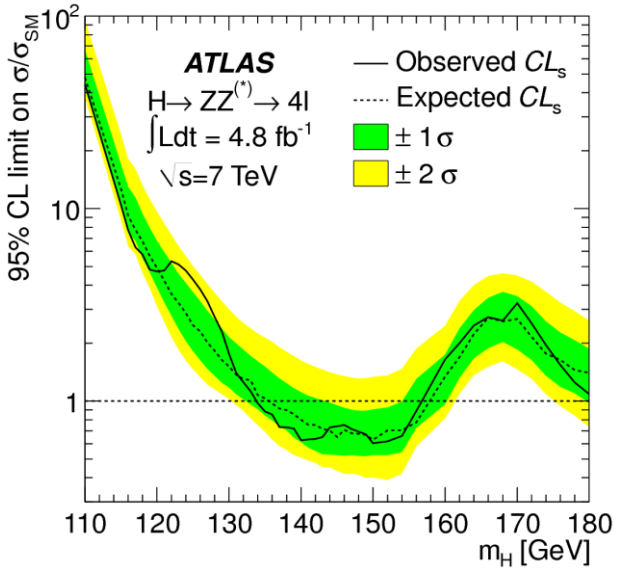
- $ZZ^{(*)}$ and $t\bar{t}$ are estimated from MC
- Z+jets kinematics from MC while normalized to data control region
- Limits are based on m_{4l} distribution
- Event Yields:

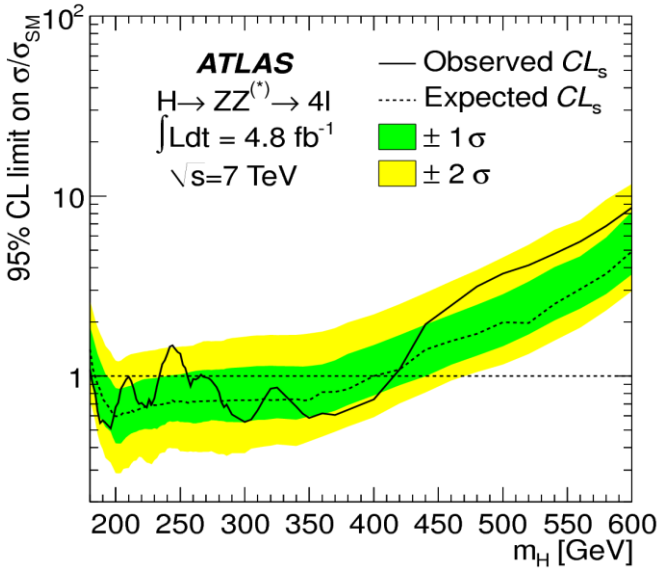
	4μ	2e2μ	4e
Expected	18.6±2.8	29.7±4.5	13.4±2.0
Observed	24	30	17

Expected limit:
137-157, 184-400 GeV

Observed limit:
134-156, 182-233, 256-265, 268-415 GeV

arXiv:1202.1415

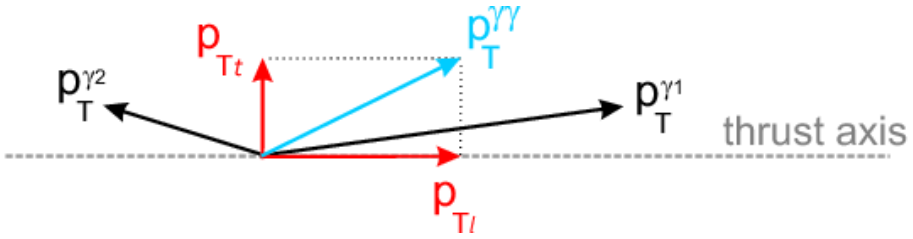




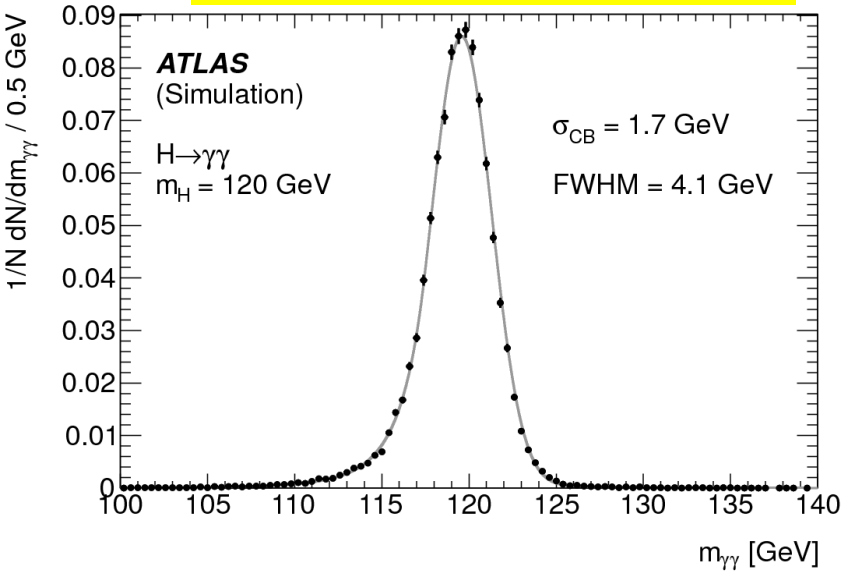
Small excesses observed with local significance values of 2.1σ, 2.2σ and 2.1σ for m_H of 125, 244 and 500 GeV respectively

$H \rightarrow \gamma\gamma$

- Br($H \rightarrow \gamma\gamma$) is very small (0.2%) but with distinct signatures
- Good γγ mass resolution is crucial for identifying signal peak over the continuous background distribution (γγ, γ+jet and dijet).
- Search consists of 9 orthogonal categories having different $m_{\gamma\gamma}$ resolutions [photon η ⊗conversion status ⊗$p_T^{\gamma\gamma(\text{Thrust})}$]
  - Signal extraction by fitting $m_{\gamma\gamma}$ simultaneously.
- Background modeling:
  - Exponential function with free slope and normalization
- Signal $m_{\gamma\gamma}$ modeling:
  - Sum of Crystal Ball (core) and Gaussian (tail) functions.

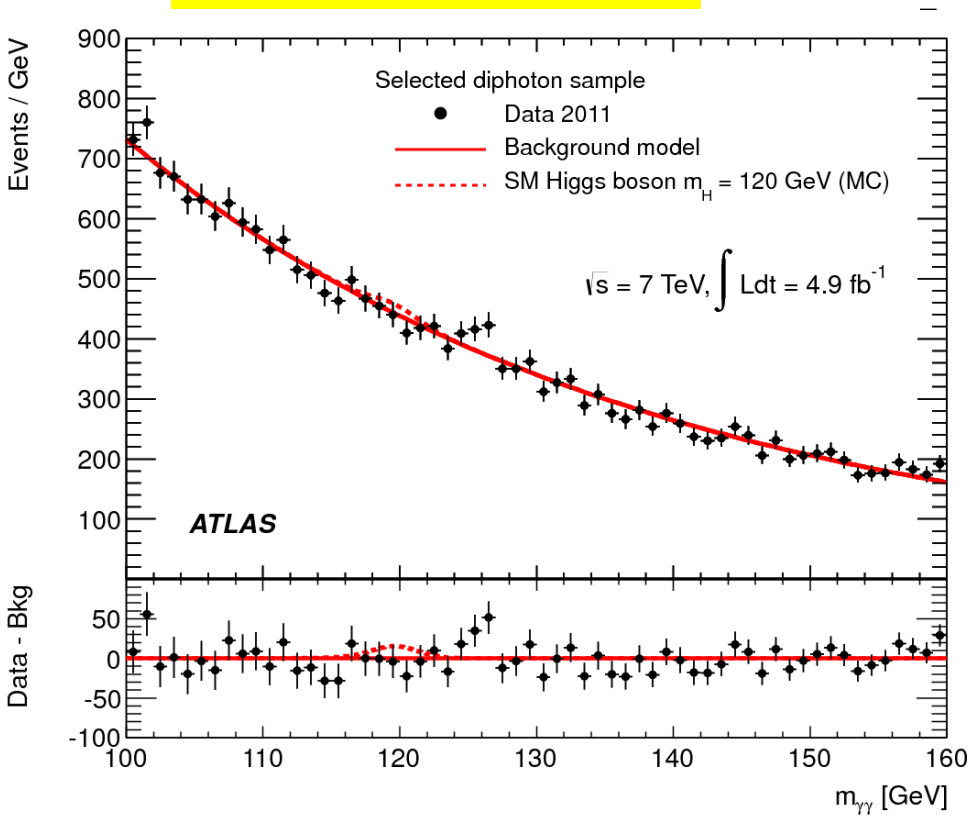


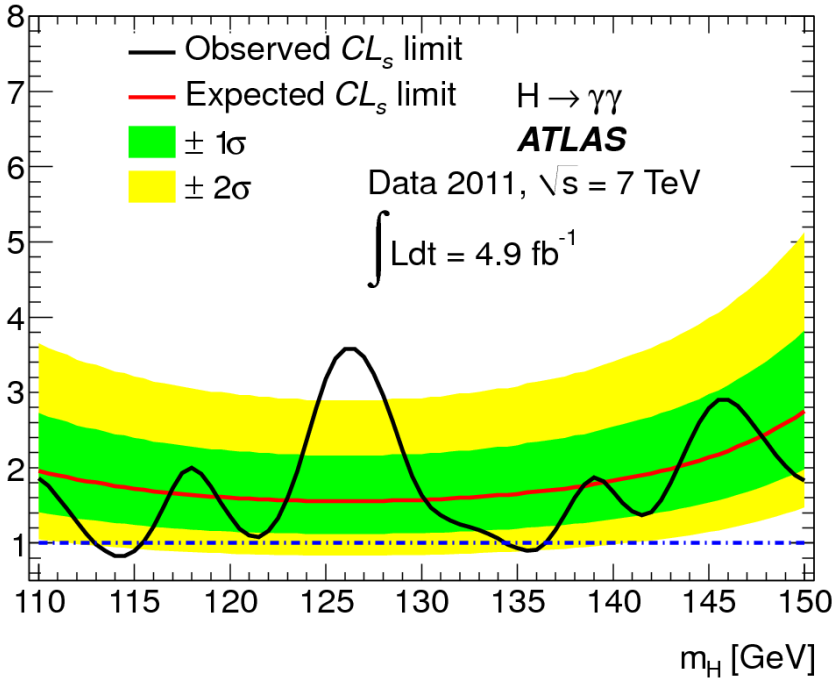
arXiv:1202.1414



$H \rightarrow \gamma\gamma$

arXiv:1202.1414





Observed exclusion:
113-115 GeV and, 134.5-136 GeV

- An excess of events observed around 126.5 GeV
  - Local significance: 2.8σ
  - Global significance: 1.5σ (Look-Elsewhere-Effect for m_H range of 110-150 GeV)

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

- Most sensitive channel over a broad range of Higgs mass (120-180 GeV)
- Limits derived using $m_T = \sqrt{\left(\left(E_T^{ll}\right) + \left(E_T^{miss}\right)\right)^2 - \left(\left|p_T^{ll} + p_T^{miss}\right|\right)^2}$ owing to the presence of two neutrinos
- 9 sub-channels (ee, eμ, μμ)⊗ (0, 1, 2 jets[VBF])
- Background processes: Drell-Yan/Z+jets, WW, $t\bar{t}$, QCD, W+jets

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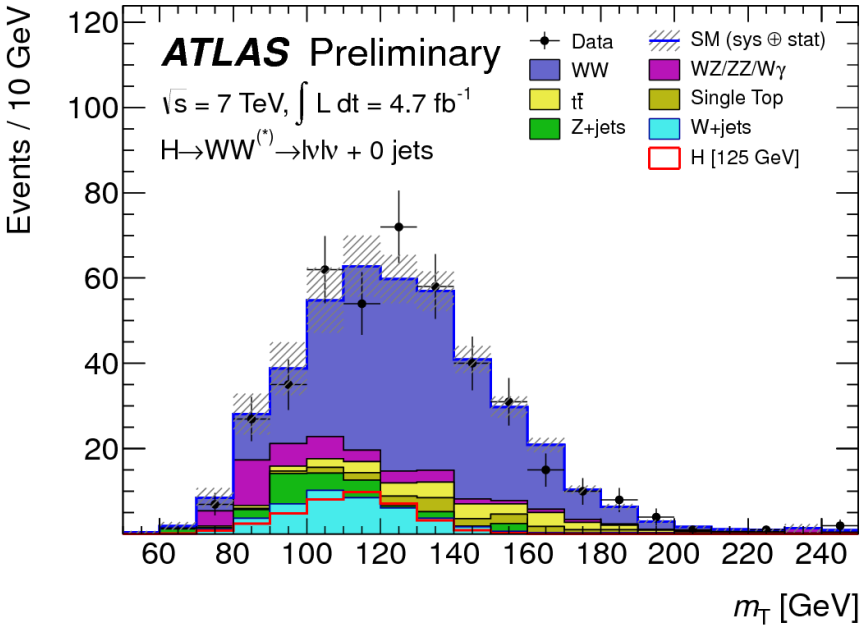
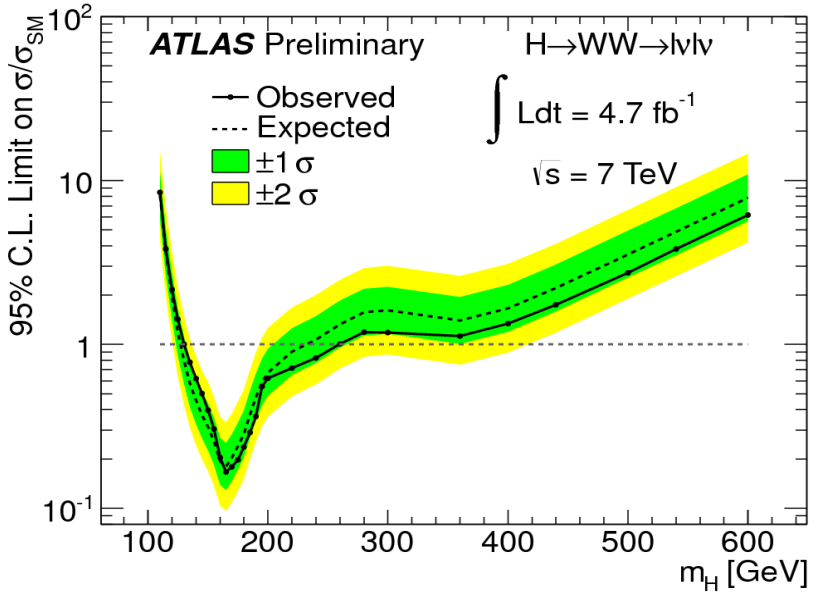
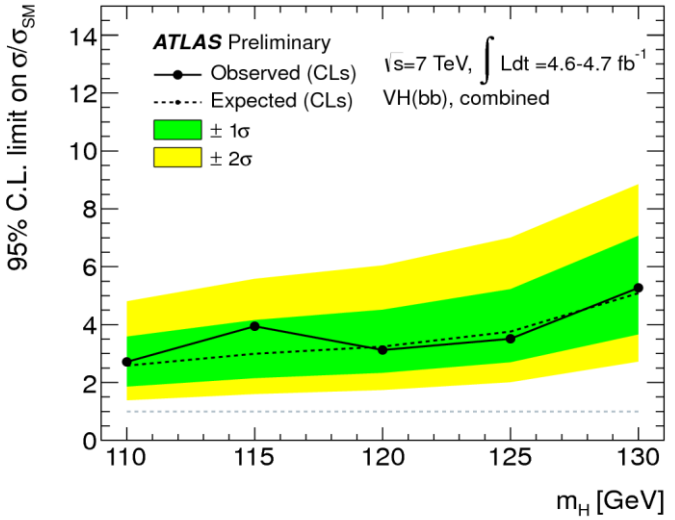
- Expected Exclusion limits: 127-234 GeV
- Observed Exclusion limits: 130-260 GeV





$(W/Z)\mathrm{H} \rightarrow (\mathrm{l}\nu/\mathrm{ll},\nu\nu)\, b\bar{b}$

- Requirement of exactly 2 b-tagged jets
- W/Z and Higgs boson recoil away with significant p_T
  - Event classification depending on p_T^W, p_T^Z and E_T^{miss} for $WH \rightarrow l\nu b\bar{b}$, $ZH \rightarrow llb\bar{b}$ and $ZH \rightarrow \nu\nu b\bar{b}$ respectively.
- Major background processes: W/Z+b-jets, QCD, top
- Systematics on background processes are crucial
  - 20%, 26% and 27% for $WH \rightarrow l\nu b\bar{b}$, $ZH \rightarrow llb\bar{b}$ and $ZH \rightarrow \nu\nu b\bar{b}$ respectively.



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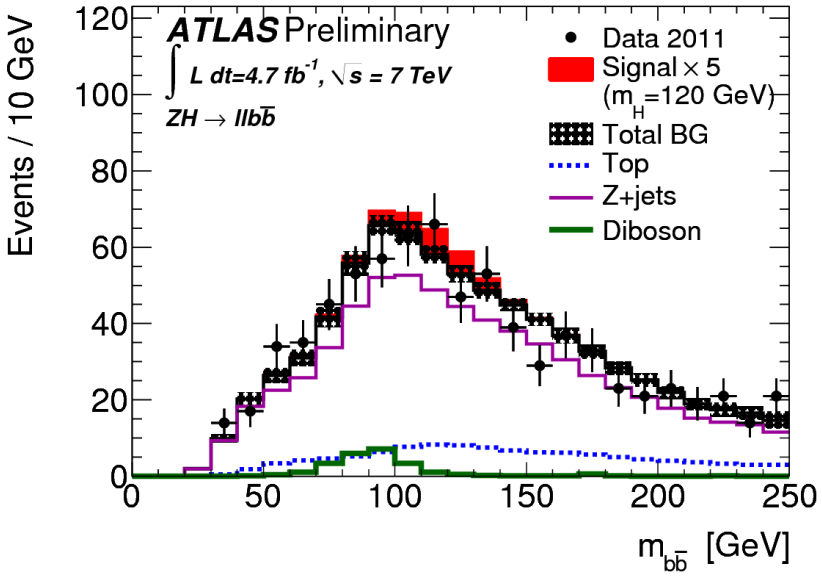
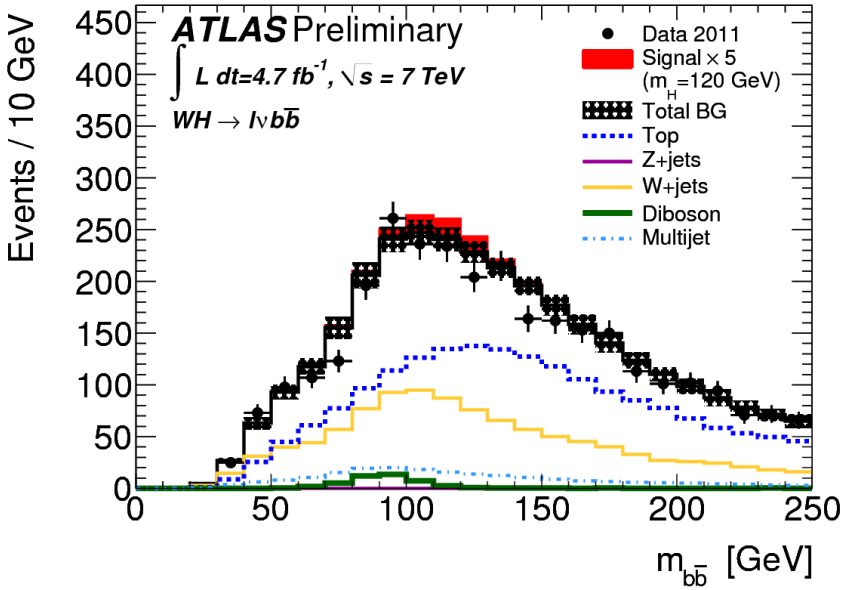
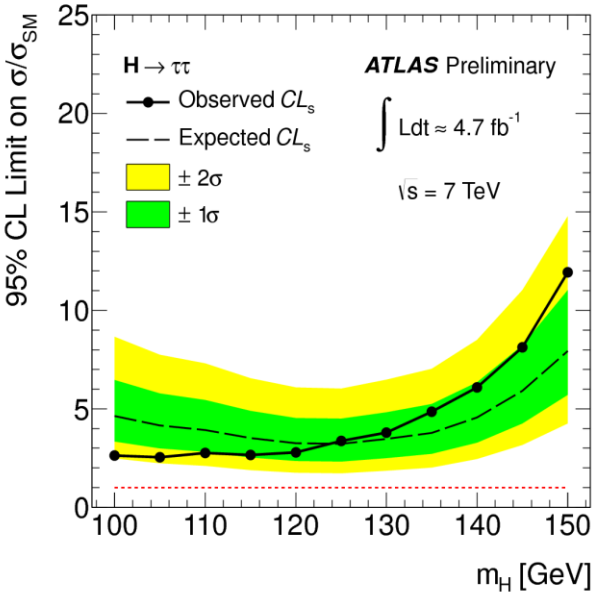




$H \rightarrow \tau\tau \rightarrow (ll4\upsilon, l\tau_{had}3\upsilon, \tau_{had}\tau_{had}2\upsilon)$

- Mass reconstruction using collinear approximation
  - Missing Mass calculator (MMC) for $H \rightarrow \tau\tau \rightarrow l\tau_{had}3\upsilon$
- Sub-channels with different number of jets [0, 1 jets, 2-jets - VH/VBF]
- Major background processes
  - Irreducible $Z \rightarrow \tau\tau$: normalization from MC; shape from $Z \rightarrow \mu\mu$ data through embedding simulated τ-leptons (replacing the muons).
  - Instrumental effects: fake leptons and fake τ-jets from data



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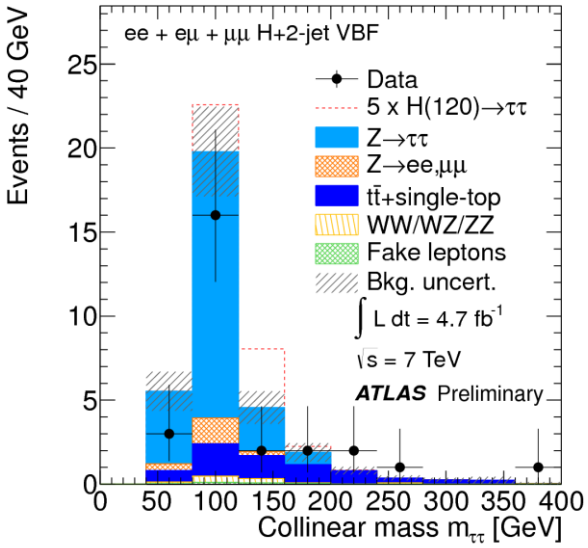

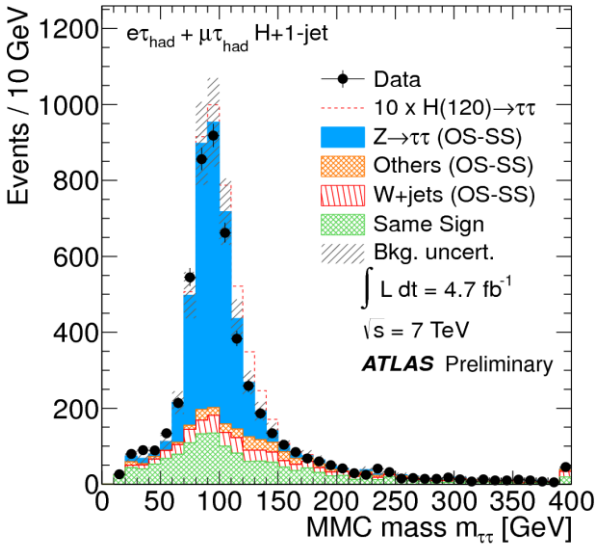

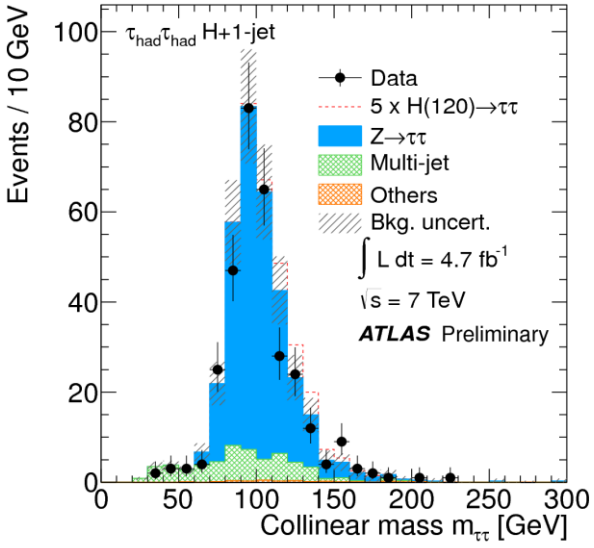

SM Higgs Combination

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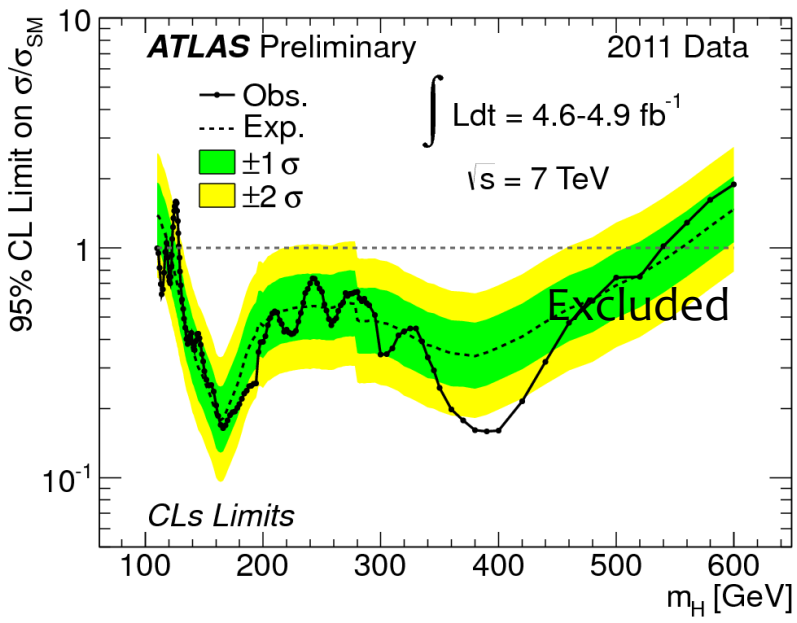
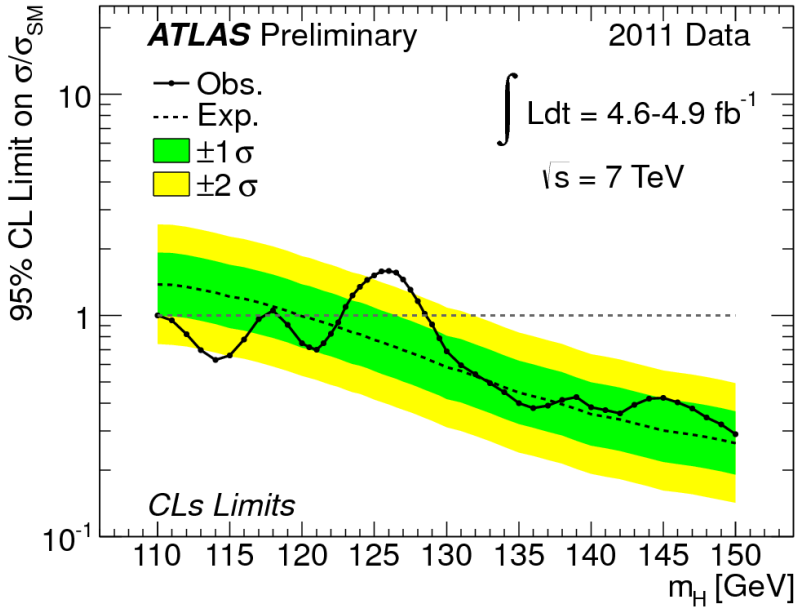




Expected Exclusion @ 95% CL: 120-555 GeV

Observed exclusion @95% CL: 110-117.5, 118.5-122.5, 129-539 GeV

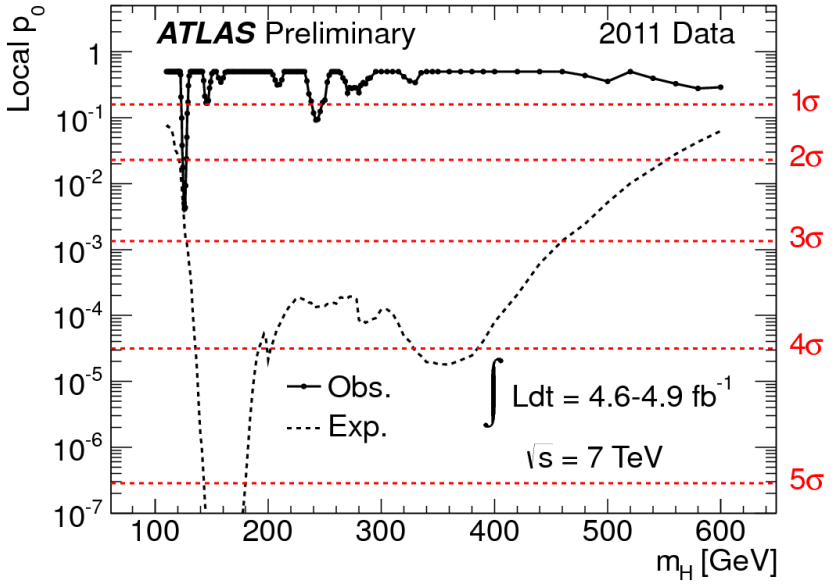
Observed exclusion @ 99% CL: 130-486 GeV

Diagnostics of Observed Excess

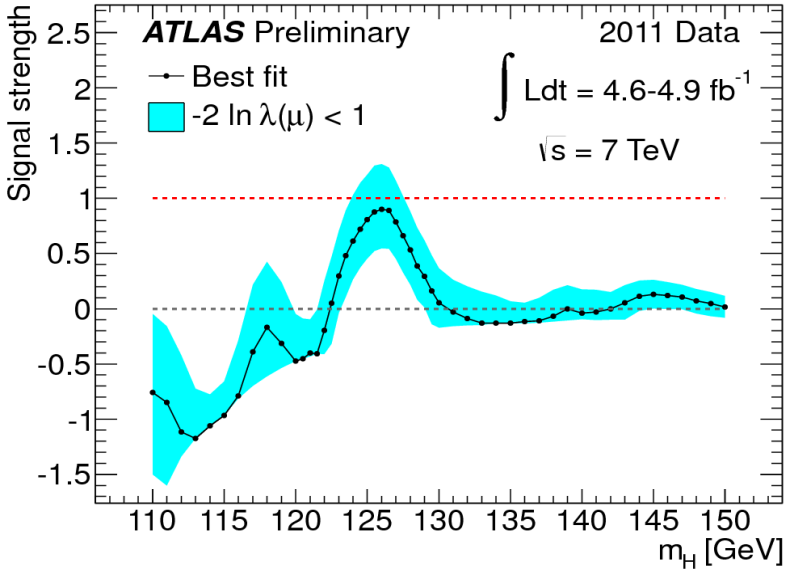
An excess of observed events at $m_H \approx 126$ GeV | **ATLAS-CONF-2012-019**

- Observed local significance for m_H=126 GeV: 2.5σ
- Expected local significance assuming SM Higgs mass of 126 GeV: 2.8σ
- Best-fit for signal strength at m_H=126 GeV: $\hat{\mu} = 0.9^{+0.4}_{-0.3}$
- Look-Elswhere-Effect: Global probability for such observation is 30% for 110<m_H<600 GeV

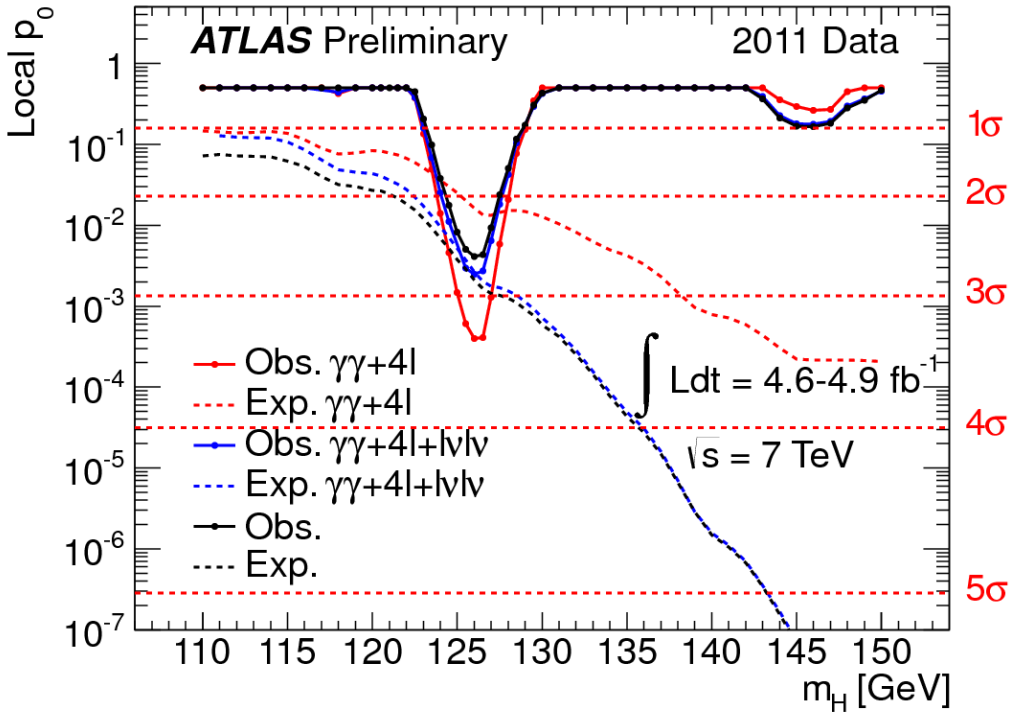
Background fluctuation Probability



Best fit of $\mu=\sigma/\sigma_{SM}$



Diagnostics of Observed Excess



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An excess of observed events at $m_H \approx 126$ GeV

- Contribution from high resolution channels:
  - $H \to \gamma\gamma$ & $H \to ZZ^{(*)} \to 4l$ combined local significance at m_H=126 GeV : 3.5σ
- Not observed in any other channels: $H \to WW^{(*)} \to l\nu l\nu$, $H \to \tau\tau$, $H \to b\bar{b}$
  - Considering all channels the local significance for m_H=126 GeV: 2.5σ

Summary & Conclusions

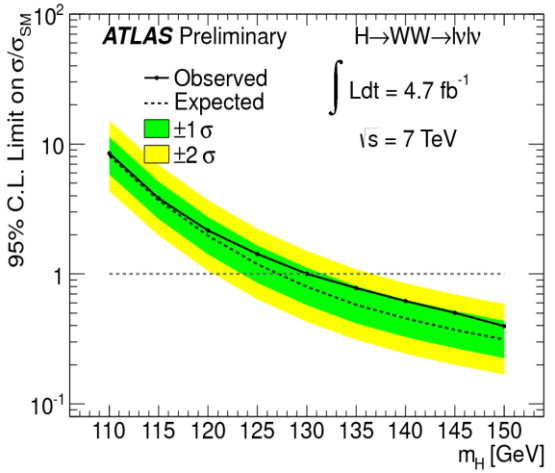
- Excellent LHC & ATLAS performance during 2011 operation
- ATLAS has performed extensive searches for the SM Higgs boson using the full dataset from 2011 LHC operation.
  - Combined ATLAS results exclude wide range of SM Higgs boson masses
    - 110-117.5, 118.5-122.5, 129-539 GeV @ 95% CL
    - 130-486 GeV @ 99% CL
    - The observed excess in the low-m_H range has the maximum local significance of 2.5 σ
  - The excess of events near 126 GeV is compatible with the SM Higgs
    - Statistical significance is not yet large enough to claim either evidence or discovery.
- 2012 LHC operation with pp collisions at 8 TeV is about to start and larger dataset is expected -- stay tuned.

Extras

$H \to WW^{(*)} \to l\nu l\nu$

m_H=125 GeV

Lepton Channels	0-jet ee	0-jet $\mu\mu$	0-jet $e\mu$	1-jet ee	1-jet $\mu\mu$	1-jet $e\mu$
Total bkg.	58 ± 5	114 ± 10	257 ± 13	21 ± 3	37 ± 5	76 ± 6
Signal	3.8 ± 0.1	9.0 ± 0.1	25 ± 0.2	1.1 ± 0.1	2.3 ± 0.1	6.0 ± 0.1
Observed	52	138	237	19	36	90



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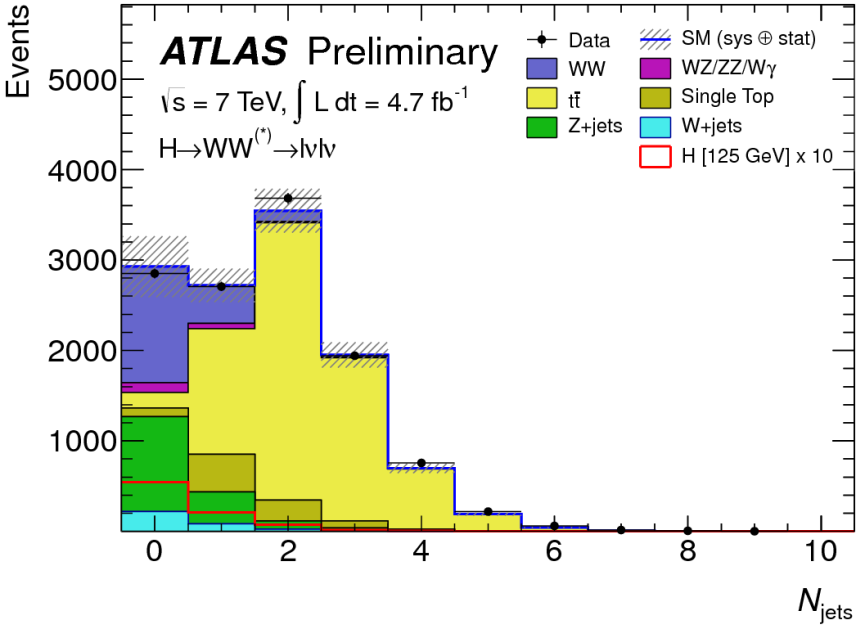

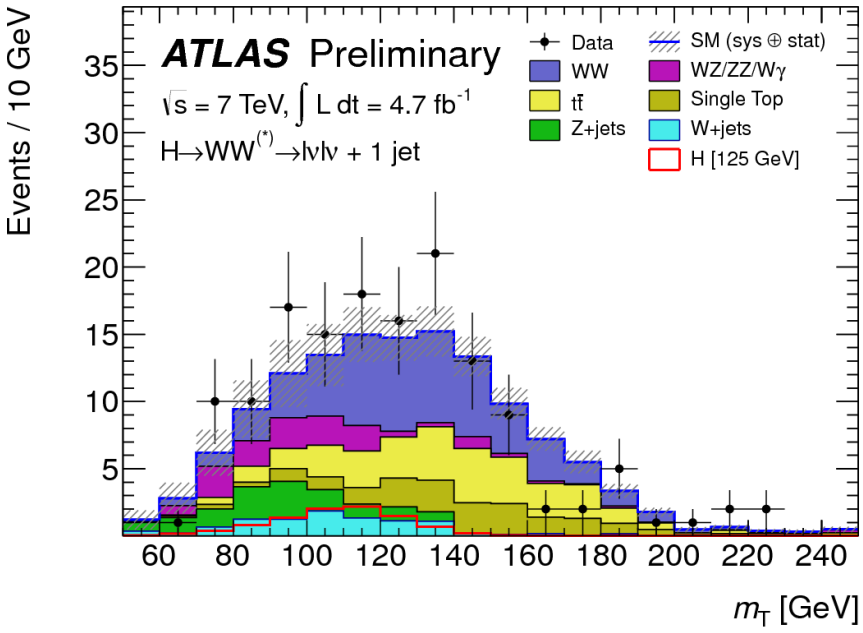

$(W/Z)\mathrm{H} \rightarrow (\mathrm{l}\nu/\,\mathrm{ll},\nu\nu)\, b\bar{b}$

Bin	$ZH \rightarrow \ell^+\ell^- b\bar{b}$ p_{T}^{Z}[GeV]				$WH \rightarrow \ell\nu b\bar{b}$ p_{T}^{W}[GeV]				$ZH \rightarrow \nu\bar{\nu} b\bar{b}$ $E_{\mathrm{T}}^{\mathrm{miss}}$[GeV]		
	0-50	50-100	100-200	>200	0-50	50-100	100-200	>200	120-160	160-200	>200
Number of events for $80 < m_{b\bar{b}} < 150$ [GeV]											
Data	139	164	62	13	622	597	276	15	103	22	24
Signal	1.4 ± 0.2	2.0 ± 0.3	1.7 ± 0.3	0.4 ± 0.1	4.7 ± 0.9	5.2 ± 1.0	4.1 ± 0.9	1.4 ± 0.3	2.3 ± 0.5	1.3 ± 0.3	1.8 ± 0.5
Top	18	25	7	0	260	383	219	8.6	42	9	4
W+jets	-	-	-	-	285	181	72	12	13	7	4
Z+jets	132	126	58	5.6	0.4	0.3	0.1	0.0	33	12	7
Diboson	8	6	4	1	13	13	8	1	5	5	4
Multijet	-	-	-	-	64	42	4	1	1.2	0.2	0.4
Total Bkg	157 ± 15	157 ± 11	70 ± 7	6 ± 2	625 ± 36	620 ± 24	303 ± 13	23 ± 4	94 ± 10	33 ± 5	20 ± 5

m_H=120 GeV

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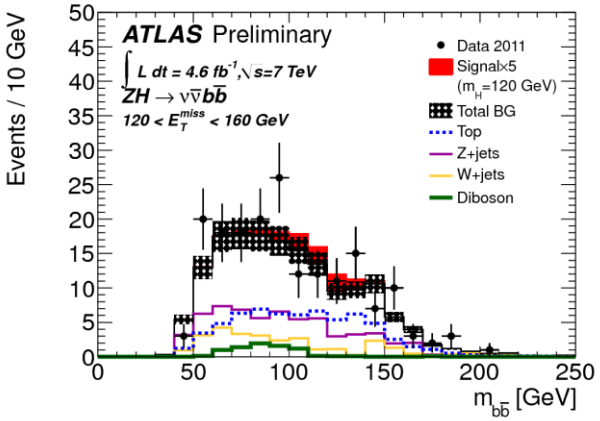
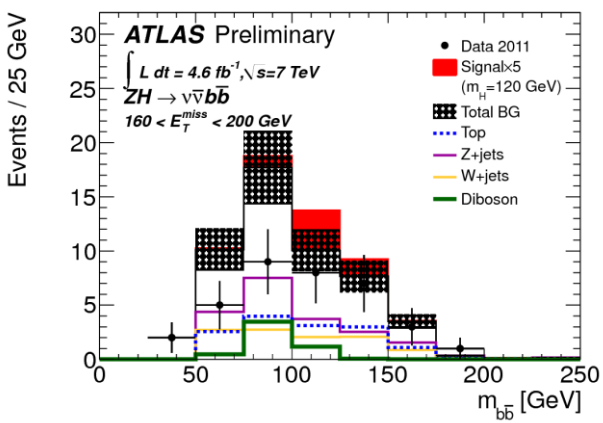
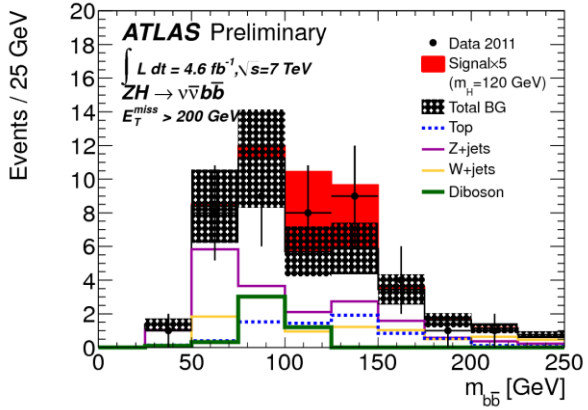
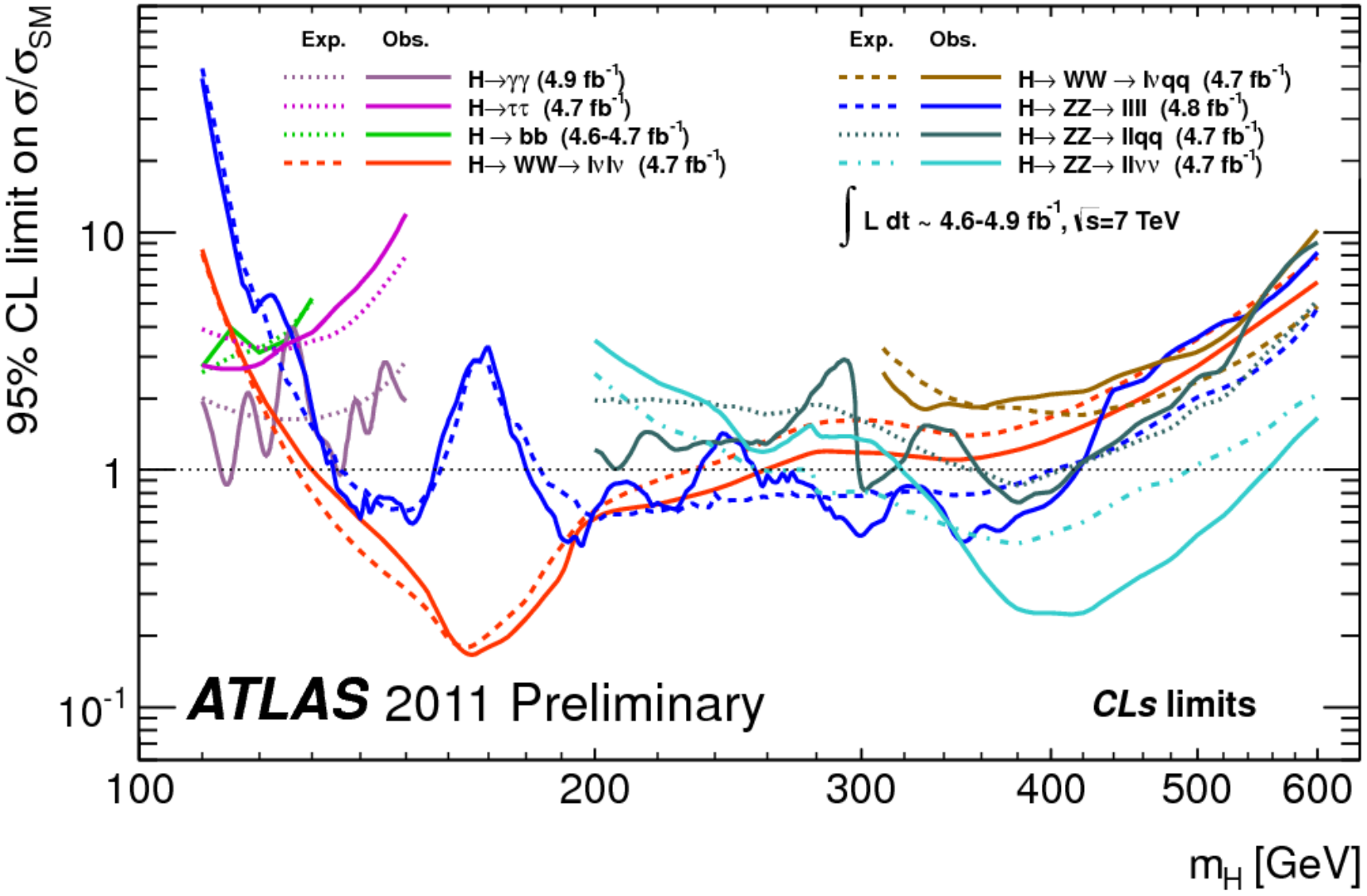






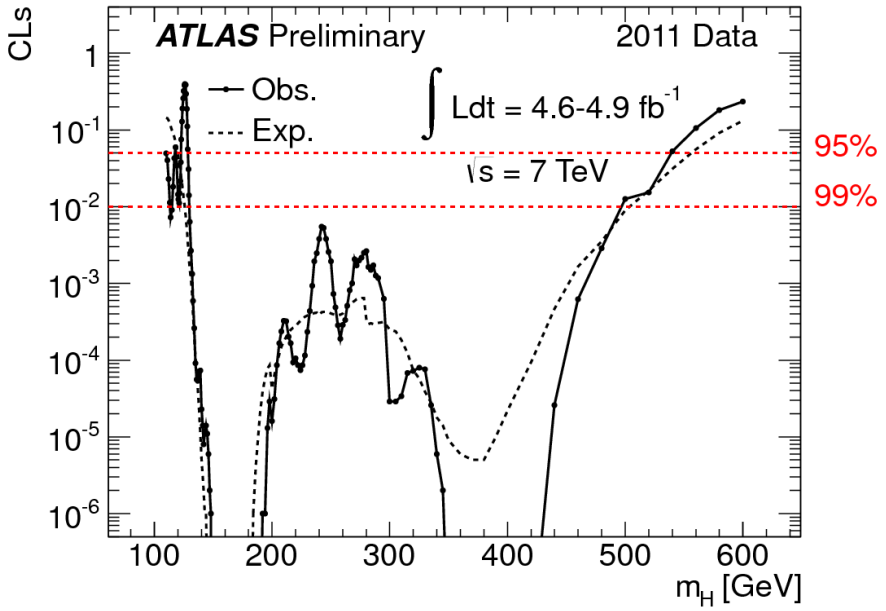
SM Higgs Combination

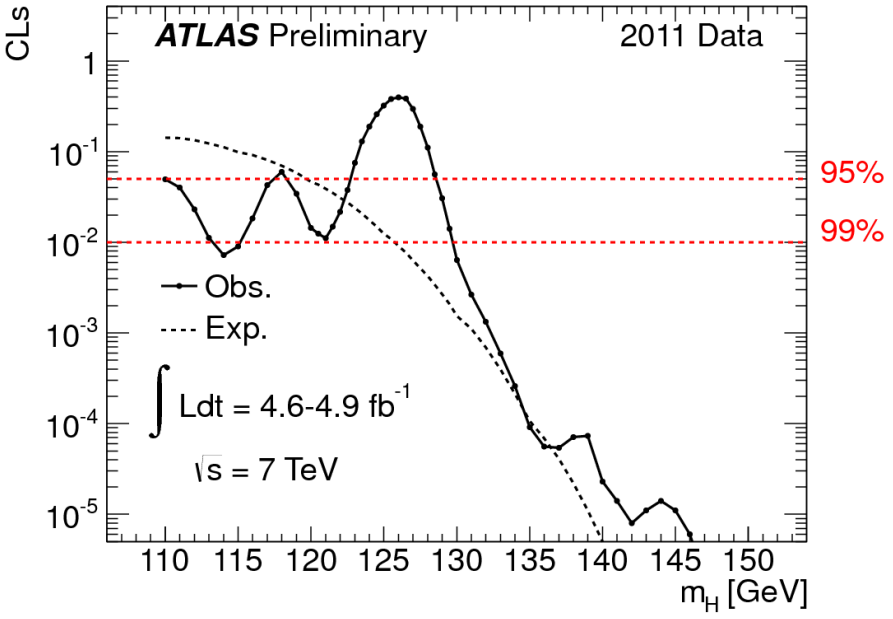
ATLAS-CONF-2012-019



SM Higgs Combination

ATLAS-CONF-2012-019





Expected Exclusion @ 95% CL: 120-555 GeV

Observed exclusion @95% CL: 110-117.5, 118.5-122.5, 129-539 GeV

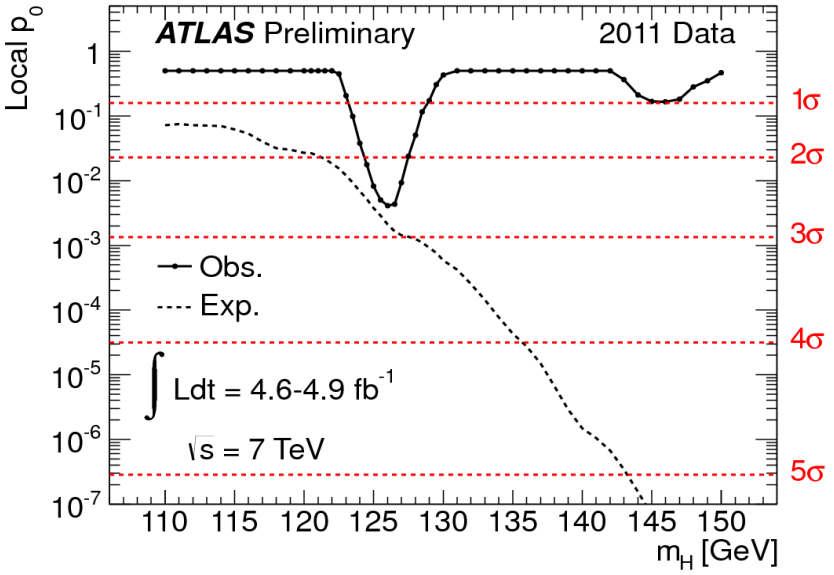
Observed exclusion @ 99% CL: 130-486 GeV

Diagnostics of Observed Excess

An excess of observed events at $m_H \approx 126$ GeV | **ATLAS-CONF-2012-019**

- Observed local significance for m_H=126 GeV: 2.5σ
- Expected local significance assuming SM Higgs mass of 126 GeV: 2.8σ
- Best-fit for signal strength at m_H=126 GeV: $\hat{\mu} = 0.9^{+0.4}_{-0.3}$
- Look-Elswhere-Effect: Global probability for such observation is 30% for 110<m_H<600 GeV

Background fluctuation Probability



Best fit of $\mu=\sigma/\sigma_{SM}$