Searches for the Higgs Boson with ATLAS

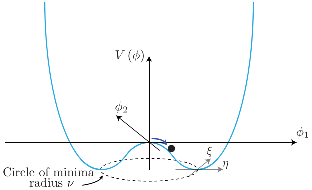
PHENO2012: 7-9th May, University of Pittsburgh

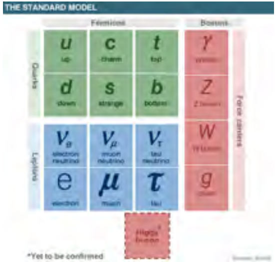
Alex Martyniuk, University of Victoria
On behalf of
the ATLAS collaboration

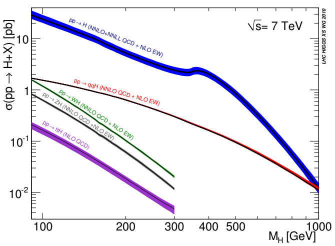
07/05/2012

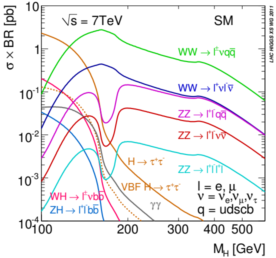
The Higgs Boson

- Higgs mechanism is a proposed method for electroweak symmetry breaking
- Provides mass to the vector bosons
- The Higgs boson is a physical manifestation of the scalar field
- The Higgs is the missing piece of the SM
- Many production and decay channels to explore



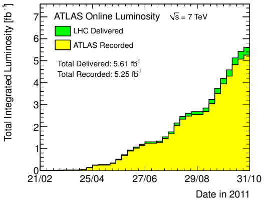


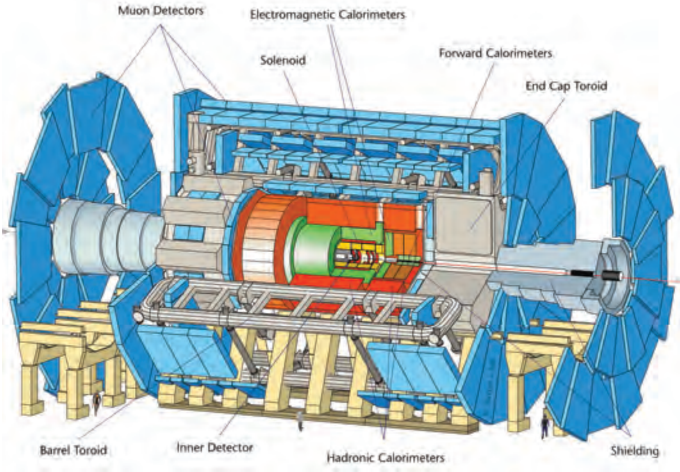




ATLAS

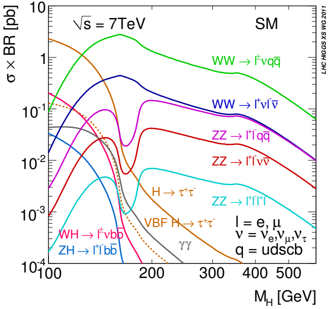
- ATLAS is a general purpose detector
- Almost full 4π layered coverage
- 2011 data taking efficiency at $\approx 93.5\%$
- Good quality data $\approx 90 - 96\%$
- Peak $\mathcal{L} = 10^{33}\text{cm}^{-2}\text{s}^{-1}$





The pieces of the puzzle

Higgs Decay	Subsequent Decay	Additional Sub-Channels	m_H Range	L [fb^{-1}]
$H \to \gamma\gamma$	–	9 sub-channels ($p_{T_t} \otimes \eta_\gamma \otimes$ conversion)	110-150	4.9
$H \to ZZ$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110-600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low pile-up, high pile-up}	200-280-600	4.7
	$\ell\ell q\bar{q}$	{b-tagged, untagged}	200-300-600	4.7
$H \to WW$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes$ {0-jet, 1-jet, VBF}	110-300-600	4.7
	$\ell\nu q q'$	$\{e, \mu\} \otimes$ {0-jet, 1-jet}	300-600	4.7
$H \to \tau^+\tau^-$	$\ell\ell 4\nu$	$\{e\mu\} \otimes$ {0-jet} $\oplus$ {1-jet, VBF, VH}	110-150	4.7
	$\ell\tau_{had} 3\nu$	$\{e, \mu\} \otimes$ {0-jet} $\otimes$ {$E_T^{miss} \gtrsim 20$ GeV} $\oplus$ $\{e, \mu\} \otimes$ {1-jet, VBF}	110-150	4.7
	$\tau_{had}\tau_{had} 2\nu$	{1-jet}	110-150	4.7
$VH \to b\bar{b}$	$Z \to \nu\bar{\nu}$	$E_T^{miss} \in \{120-160, 160-200, \geq 200$ GeV$\}$	110-130	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7

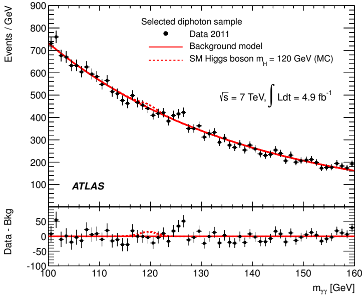


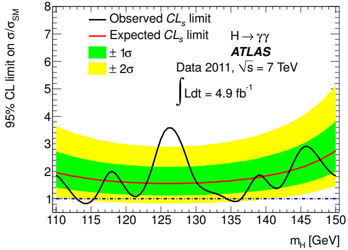
- LHC Higgs x-sec pages

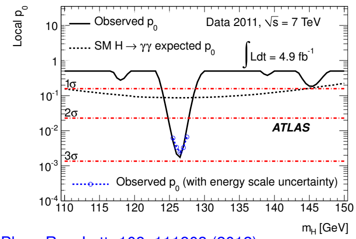
- ATLAS analyses make use of the various Higgs production and decay modes
- Combined they form a complete search in the range $m_H = 110 - 600$ GeV

$H \to \gamma\gamma$

- Analysis uses 9 separate photon categories
- Categories distinguished by the photons η, (un)converted status and the momentum component of the diphoton system transverse to the thrust axis
- $m_{\gamma\gamma}$ spectrum fitted with an exponential per category
- Mass resolution $\approx$ 1.7% for $m_H = 120$ GeV
- Maximum deviation from the background expectation is observed at 126 GeV
- Local significance of 2.8σ (1.5σ with look-elsewhere effect)



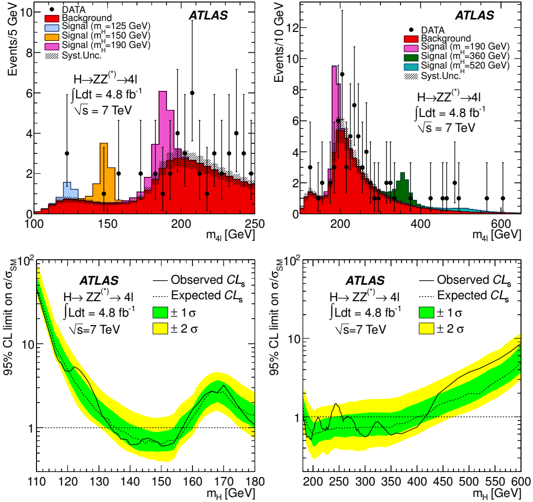




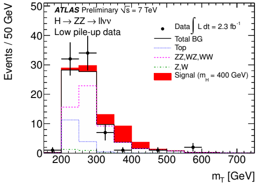
- Phys. Rev. Lett. 108, 111803 (2012)

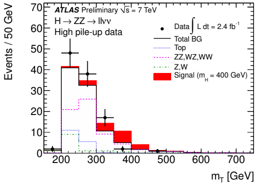
$H \to ZZ \to llll$

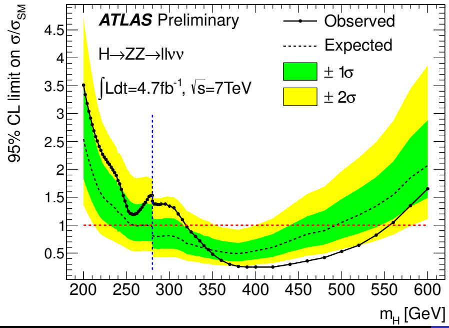
- Analysis uses m_{4l} distribution as the discriminating variable
- Three separate channels combined: 4μ, $2e2\mu$, $4e$
- Clean signature with a low background
- Provides good sensitivity over large mass range
- Mass resolution $\approx$ 1.5%(2%) in $4\mu(e)$ channel at $m_H = 120$ GeV
- Deviations from the background expectation are observed at 125 GeV, 244 GeV and 500 GeV
- Local significances of 2.1σ, 2.3σ and 2.2σ respectively
- None remain significant when the look-elsewhere effect is taken into account
- Phys. Lett. B710 383-402 (2012)



$H \to ZZ \to ll\nu\bar{\nu}$



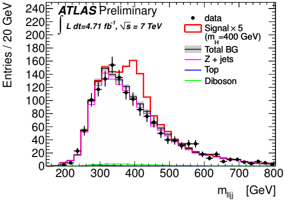


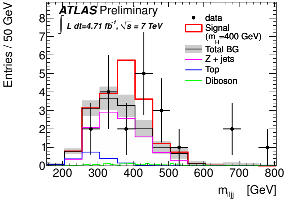


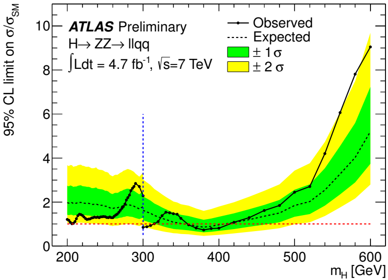
- Analysis uses m_T distribution as the discriminating variable
- Two channels are combined: $2\mu 2\nu_\mu$, $2e2\nu_e$
- Provides significant decay branching fraction combined with distinct signature of a high p_T lepton pair with large E_T^{miss}
- Separate selections are made in the low ($m_H < 280$ GeV) and high ($m_H > 280$ GeV) mass regions
- Data sample of 4.7fb^{-1} split into low (2.3fb^{-1}) and high (2.4fb^{-1}) pileup regions
- No significant excesses are seen in the full mass range
- The channel by itself excludes a SM Higgs mass in the range $320 < m_H < 560$ GeV
- ATLAS-CONF-2012-016

$H \to ZZ \to llq\bar{q}$

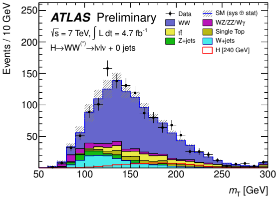
- Analysis uses m_{lljj} distribution as the discriminating variable
- Two channels are combined: $2\mu q\bar{q}$, $2eq\bar{q}$
- Separate selections are made in the low ($m_H < 300$ GeV) and high ($m_H > 300$ GeV) mass regions
- Analysis is further split into tagged (2 b-tags) and untagged selections ($<$ 2 b-tags)
- The tagged selection offers greater rejection of the dominant Z+jets background
- No significant excesses are seen in the full mass range
- The channel by itself excludes a SM Higgs mass in the ranges $300 < m_H < 310$ GeV and $360 < m_H < 400$
- ATLAS-CONF-2012-017

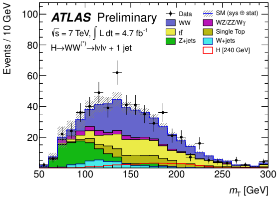


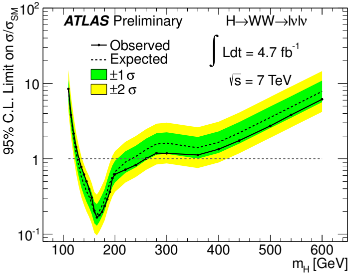




$H \to WW \to l\nu l\nu$



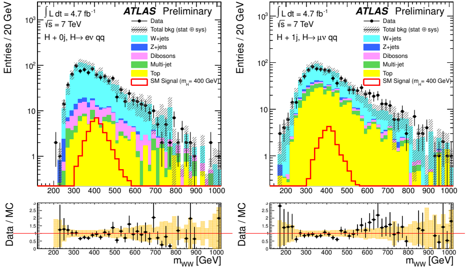


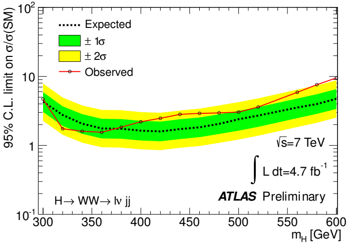


- Analysis uses m_T distribution as the discriminating variable
- Three channels are combined: $2\mu 2\nu_\mu$, $e\mu\nu_e\nu_\mu$, $2e2\nu_e$
- Channel covers the full mass range but suffers from poor mass resolution
- Analysis is split into 0, 1 and ≥ 2 jet categories
- $W+$jets background is derived from data, WW, top and D-Y backgrounds are normalised in control regions
- No significant excesses are seen in the full mass range
- The channel by itself excludes a SM Higgs mass in the ranges $130 < m_H < 260$ GeV
- The expected exclusion was $127 < m_H < 234$
- ATLAS-CONF-2012-012

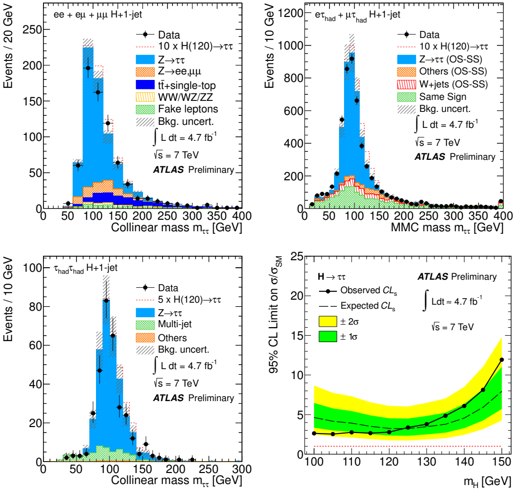
$H \to WW \to l\nu q\bar{q}'$

- Analysis uses m_{WW} distribution as the discriminating variable
- Two channels are combined: $\mu\nu_{\mu}q\bar{q}$, $e\nu_{e}q\bar{q}$
- Analysis is split into 0, 1 and 2 additional jet categories
- Monte Carlo studies performed to provide a background parameterisation
- No significant excesses are seen in the full mass range
- The best sensitivity in this channel occurs at 400 GeV
- Here an upper limit on the $H \to WW$ cross section of 2.6pb is set
- This corresponds to 2.2 times the SM prediction
- ATLAS-CONF-2012-018





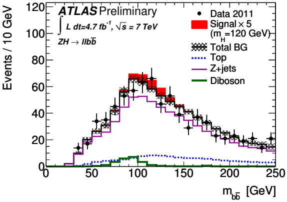
$H \rightarrow \tau\tau$

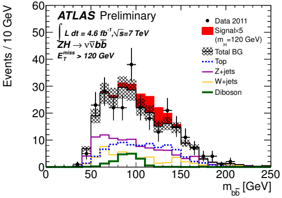


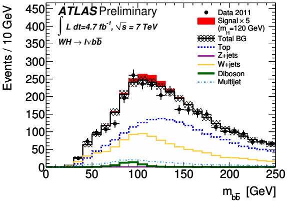
- Analysis of three separate channels which use various methods to reconstruct the mass of the system
- $H \rightarrow \tau\tau \rightarrow ll4\nu$
- An effective mass distribution is used in the 0-jet channel
- A collinear mass approximation is used in the 1 and 2 jet channels
- $H \rightarrow \tau\tau \rightarrow l\tau_{\mathrm{had}}3\nu$
- Uses a missing mass calculator to reconstruct the $m_{\tau\tau}$
- Reconstructs with 99% efficiency and 13 – 20% $m_{\tau\tau}$ resolution
- $H \rightarrow \tau\tau \rightarrow \tau_{\mathrm{had}}\tau_{\mathrm{had}}2\nu$
- A collinear mass approximation is again used
- No significant excesses are seen in the combined full mass range
- Upper limits are set on the $H \rightarrow \tau\tau$ cross section between 2.5 and 11.9 times the SM prediction
- ATLAS-CONF-2012-014

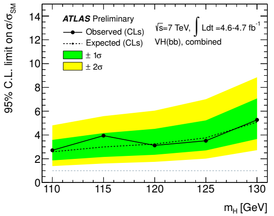
$VH \to b\bar{b}$

- Again three separate channels
  - $ZH \to l^+ l^- b\bar{b}$
  - $ZH \to \nu\bar{\nu} b\bar{b}$
  - $WH \to l\nu b\bar{b}$
- Higgs production channel in association with a leptonically decaying vector boson used
- Provides a high p_T lepton or large E_T^{miss} to trigger on and reduces QCD backgrounds
- $m_{b\bar{b}}$ used as the discriminating variable
- No excess seen over the background expectation in any channel
- The combined upper limits are between 2.7 and 5.3 times the SM $H \to b\bar{b}$ cross section
- ATLAS-CONF-2012-015



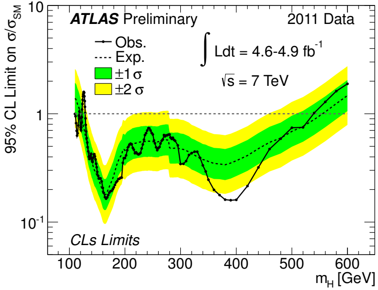


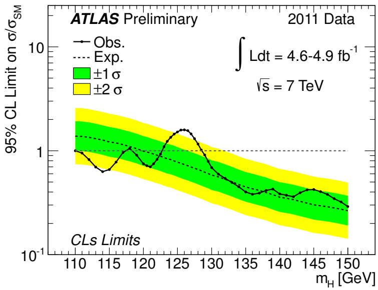




Combination result

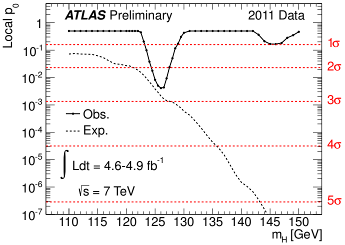
- The channels shown have been combined to give the overall ATLAS Higgs search result
- Systematics in the combination are taken to be either 100% correlated or 100% uncorrelated between channels
- In the absence of a signal expect to exclude the Standard Model Higgs boson at 95% C.L. between: $120 < m_H < 555$ GeV
- Observed exclusion at 95% C.L.: $110 < m_H < 117.5$, $118.5 < m_H < 122.5$, $129 < m_H < 539$ GeV
- Observed exclusion at 99% C.L.: $130 < m_H < 486$ GeV
- Observe an excess in the low mass region at $m_H \approx 126$ GeV
- ATLAS-CONF-2012-019

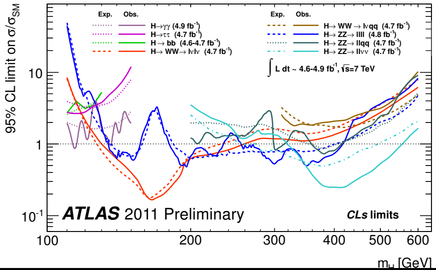


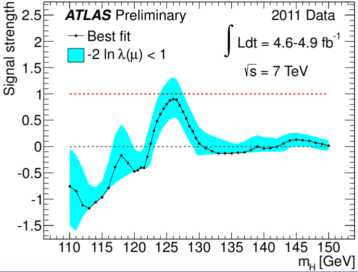


A closer look

- The excess at ≈126 GeV is dominated by the $H \to \gamma\gamma$ and $H \to ZZ \to llll$ contributions
- $H \to WW \to l\nu l\nu$ contribution shows a weaker than expected limit but no significant excess
- The m_H ≈126 GeV excess has a combined local significance of 2.5σ (2.9σ expected in the presence of a SM signal)
- Within errors the strength of the combined $m_H = 126$ GeV excess is compatible with a SM Higgs boson ($\mu = \sigma/\sigma_{SM} = 0.9^{+0.3}_{-0.4}$)
- Global probability of a fluctuation of this magnitude occurring across the full mass range of $110 < m_H < 600$ GeV is 30% or 10% in the range $110 < m_H < 146$ GeV



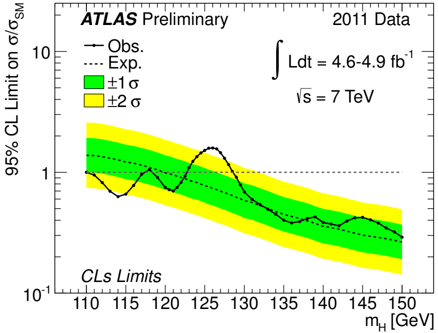




Summary and Outlook

- Searches for the Higgs boson have been undertaken in a wide range of channels using the full ATLAS 2011 dataset of up to 4.9fb^{-1}
- The allowed SM Higgs mass range has been severely restricted by the limits set by ATLAS
- The remaining allowed regions are $117.5 < m_H < 118.5$ GeV, $122.5 < m_H < 129$GeV or $m_H > 539$ GeV
- In the low mass region an excess of events over the background expectation has been observed at a $m_H \approx 126$ GeV

- The excess has a local significance of 2.5σ
- Signal strength is compatible with a SM Higgs boson
- Global probability of a fluctuation of this magnitude occurring across the full mass range is 30% or 10% in the range $110 < m_H < 146$ GeV
- More data is required to comment further on the nature of this excess
- The LHC is back up and running well at 8 TeV
- Expect in the region of 15-20 fb^{-1} of data delivered this year
- The Higgs has run out of places to hide
- Will this excess turn to a 5σ discovery with more data?

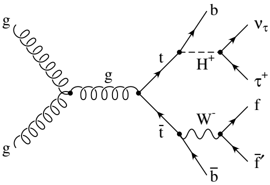


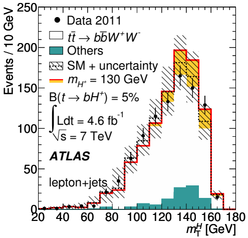
BACKUP

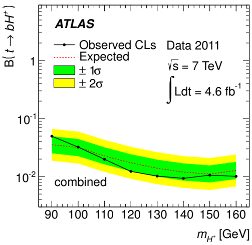
$H^+ \to \tau\nu$

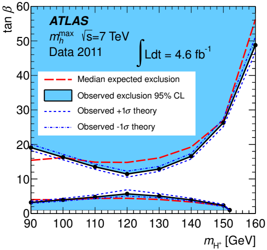
- In models containing two Higgs doublets, e.g. the MSSM, five Higgs Bosons are present h, H, A, $H^\pm$
- If light enough the $H^\pm$ can replace a W boson in a top decay
- Searches made in $t\bar{t}$ decays with the dominant MSSM decay channel $H^+ \to \tau\nu$
- Search performed in three channels defined

  by the decays $t\bar{t} \to b\bar{b}WH^+ \to$
  - $b\bar{b}\,(q\bar{q})\,(\tau_{\text{lep}}\nu)$
  - $b\bar{b}\,(l\nu)\,(\tau_{\text{had}}\nu)$
  - $b\bar{b}\,(q\bar{q})\,(\tau_{\text{had}}\nu)$
- No excess is seen in any channel
- Upper limits set on the branching ratio of $t \to H^+ b$ assuming 100% $Br(H^+ \to \tau\nu)$
- Limits also set on the possible values of tan β as a function of m_{H^+}
- arXiv e-print









Typical Systematics

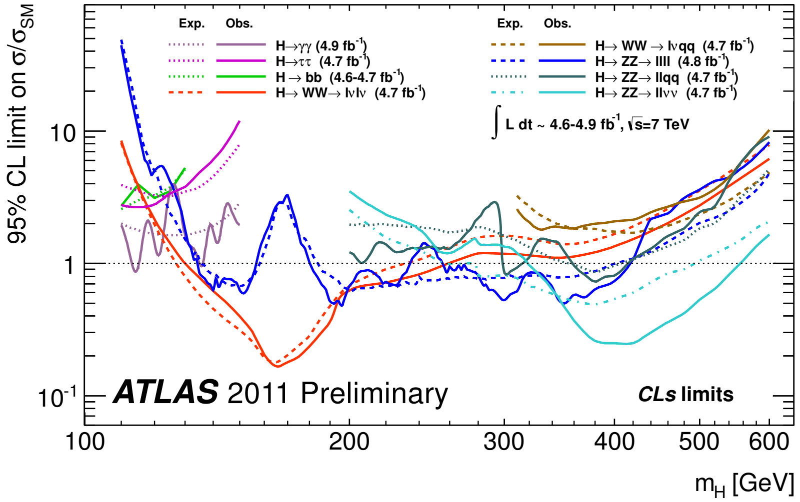
- Systematics in the combination are taken to be either 100% correlated or 100% uncorrelated between channels

Object	Source	Uncertainty on signal yield	Channel(s) most affected
-	Luminosity	3.9%	All
Photons	Efficiency	11%	$H \to \gamma\gamma$
Electrons	Efficiency	$< 3\%$	$H \to ZZ \to 4\ell$
	Energy scale	$< 1\%$	
	Energy resolution	$< 0.5\%$	
Muons	Efficiency	$< 1\%$	$H \to ZZ \to 4\ell$
	Momentum resolution	$< 1\%$	
Jets	Energy scale	Up to 12%	$H \to \tau\tau$, $b\bar{b}$, $ZZ \to \ell\ell qq$, $WW \to \ell\nu qq$
	Resolution	Up to 20%	$H \to WW \to \ell\nu qq$
b-jets	Efficiency	Up to 15%	$H \to b\bar{b}$
τ-jets	Efficiency	Up to 8%	$H \to \tau\tau$

- Selected theoretical uncertainties

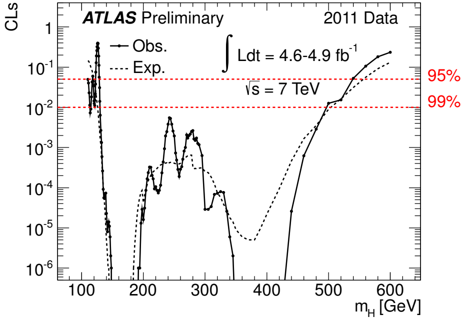
	ggF	VBF	WH/ZH
QCD scale	$\pm 12\%$ $\pm 8\%$	$\pm$ 1%	$\pm$ 1%
PDF + α_S	$\pm$ 8%	$\pm$ 4%	$\pm$ 4%
Mass lineshape	$150\% \times \left(\frac{m_H}{\mathrm{TeV}}\right)^3$		

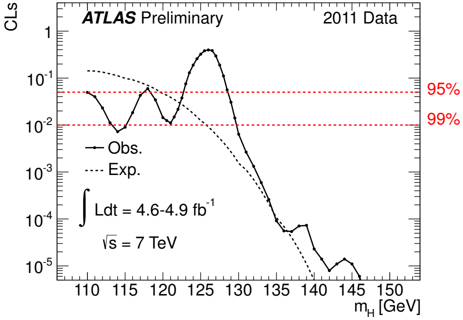
Breaking down the combination



Breaking down the combination

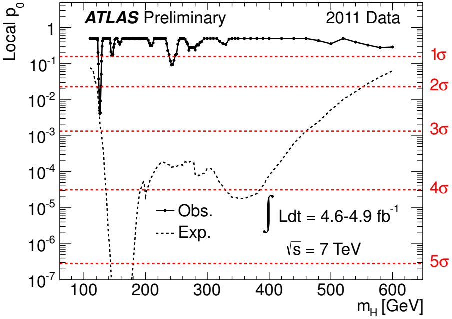
- $CL_S(\mu) = \frac{p_\mu}{1-p_b}$

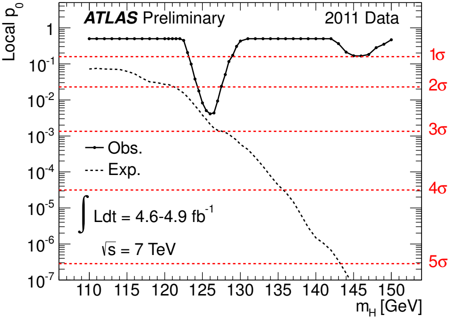




Breaking down the combination

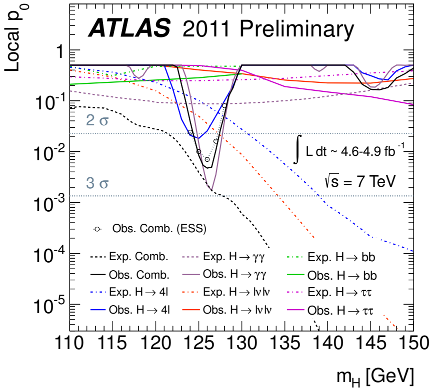
- Investigate local p_0 - the probability for the background to fluctuate and give an excess of events as large or larger than that observed

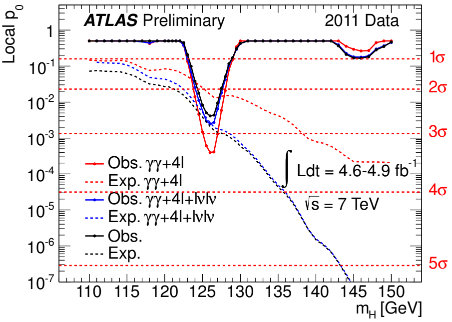




Breaking down the combination

- Investigate local p_0 - the probability for the background to fluctuate and give an excess of events as large or larger than that observed





Breaking down the combination

- Blue band plots - Show the best fit of the signal strength w.r.t. the SM expectation $\mu = \frac{\sigma}{\sigma_{SM}}$