

Searches for the Higgs Boson with ATLAS

PHENO2012: 7-9th May, University of Pittsburgh

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On behalf of
the ATLAS collaboration

07/05/2012

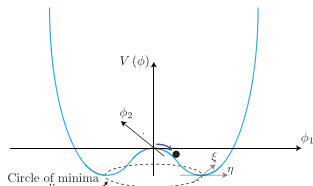


**University
of Victoria**



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

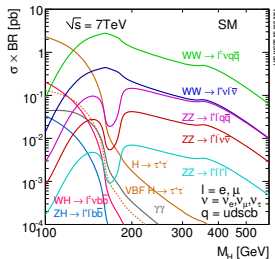
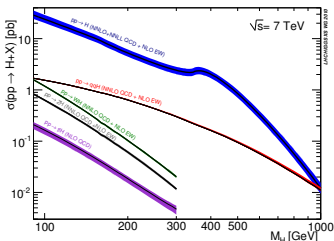


THE STANDARD MODEL

| | Fermions | | | Bosons | |
|---------|------------------------------|----------------------------|----------------------------|--------------------|----------------|
| Quarks | u up | c charm | t top | γ photon | Force carriers |
| | d down | s strange | b bottom | Z Z boson | |
| Leptons | ν_e electron neutrino | ν_μ muon neutrino | ν_τ tau neutrino | W W boson | |
| | e electron | μ muon | τ tau | g gluon | |
| | | | | Higgs boson | |

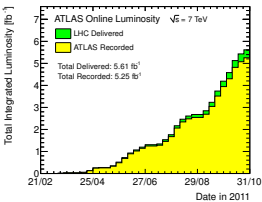
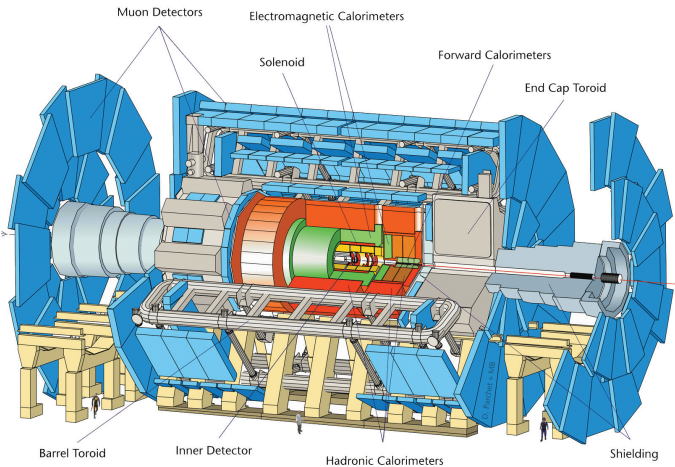
*Yet to be confirmed

Source: AAAS



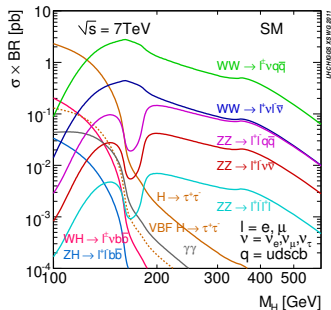
ATLAS

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

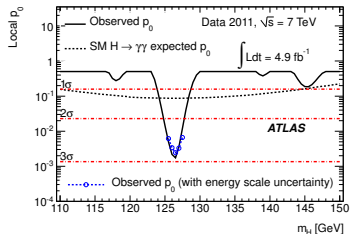
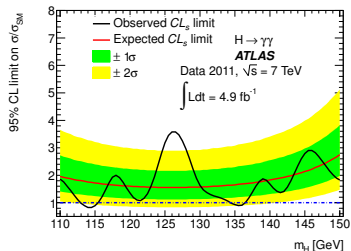
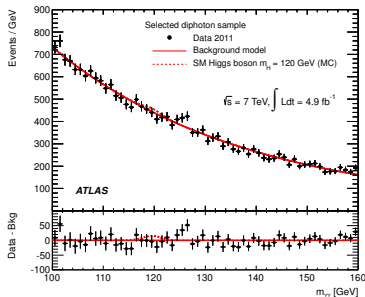


● [LHC Higgs x-sec pages](#)

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

$H \rightarrow \gamma\gamma$

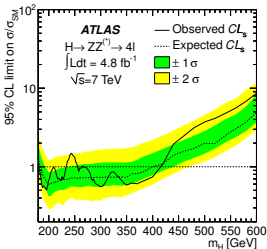
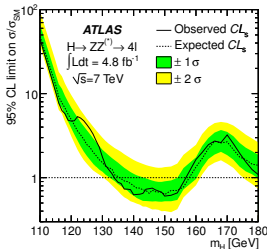
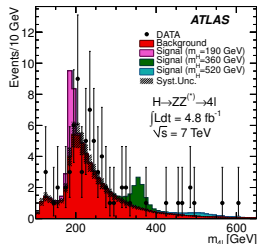
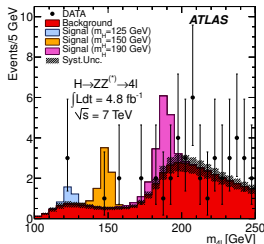
- Analysis uses 9 separate photon categories
- Categories distinguished by the photons η , (un)converted status and the momentum component of the diphoton system transverse to the thrust axis
- $m_{\gamma\gamma}$ spectrum fitted with an exponential per category
- Mass resolution $\approx 1.7\%$ for $m_H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



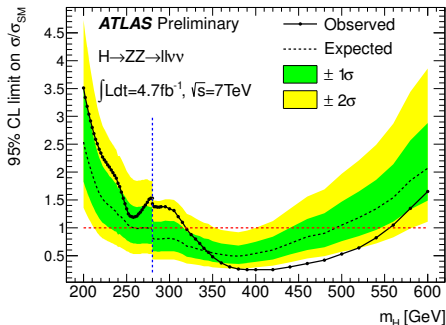
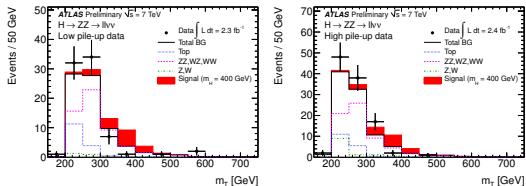
Phys. Rev. Lett. 108, 111803 (2012)

$H \rightarrow ZZ \rightarrow 4\ell$

- Analysis uses $m_{4\ell}$ 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 \(2012\)](#)



$H \rightarrow ZZ \rightarrow \ell\ell\nu\bar{\nu}$

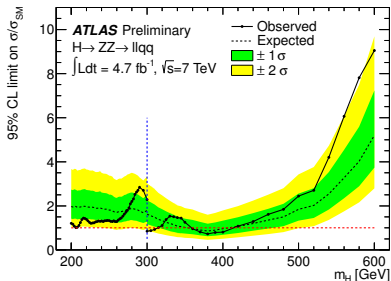
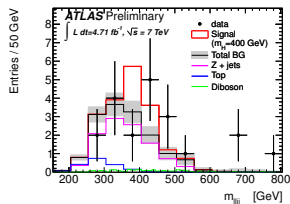
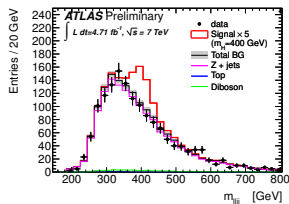


- Analysis uses m_T distribution as the discriminating variable
- Two channels are combined: $2\mu 2\nu_\mu, 2e 2\nu_e$
- Provides significant decay branching fraction combined with distinct signature of a high p_T lepton pair with large E_T^{miss}
- Separate selections are made in the low ($m_H < 280$ 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](#)

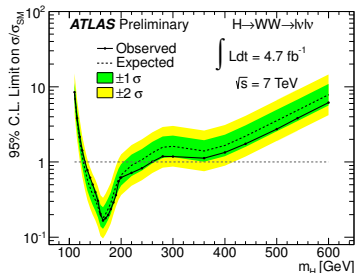
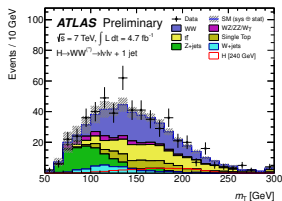
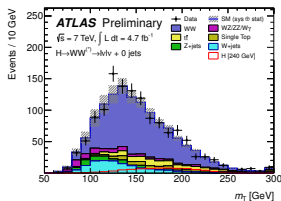
$H \rightarrow ZZ \rightarrow llq\bar{q}$

- Analysis uses m_{lljj} distribution as the discriminating variable
- Two channels are combined: $2\mu q\bar{q}$, $2e q\bar{q}$
- 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](#)



$H \rightarrow WW \rightarrow l\nu l\nu$

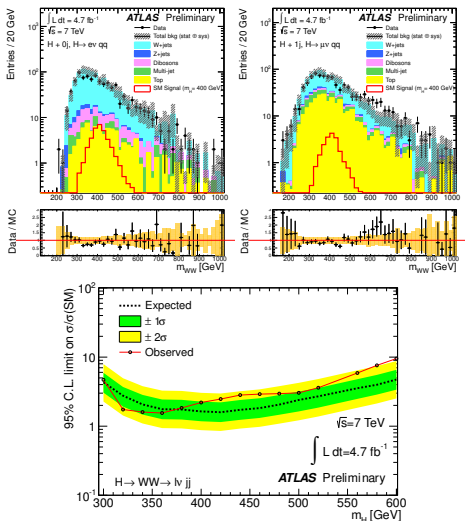


- Analysis uses m_T distribution as the discriminating variable
- Three channels are combined: $2\mu 2\nu\mu\mu$, $e\mu\nu e\nu\mu$, $2e2\nu e$
- Channel covers the full mass range but suffers from poor mass resolution
- Analysis is split into 0, 1 and ≥ 2 jet categories
- W +jets background is derived 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 $127 < m_H < 234$

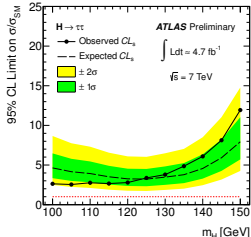
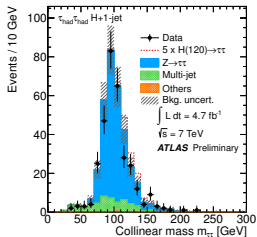
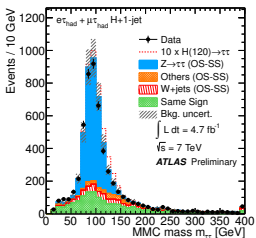
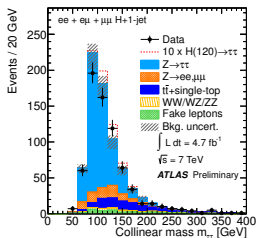
• [ATLAS-CONF-2012-012](#)

$H \rightarrow WW \rightarrow l\nu qq'$

- 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 $H \rightarrow WW$ cross section of 2.6pb is set
- This corresponds to 2.2 times the SM prediction
- [ATLAS-CONF-2012-018](#)



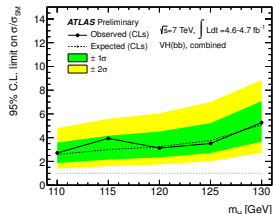
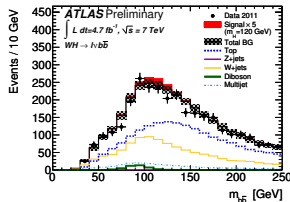
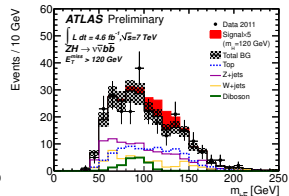
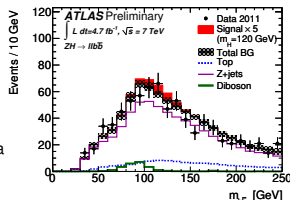
$H \rightarrow \tau\tau$



- 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
- $H \rightarrow \tau\tau \rightarrow l\tau_{had}3\nu$
- Uses a missing mass calculator to reconstruct the $m_{\tau\tau}$
- Reconstructs with 99% efficiency and 13 – 20% $m_{\tau\tau}$ resolution
- $H \rightarrow \tau\tau \rightarrow \tau_{had}\tau_{had}2\nu$
- 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](#)

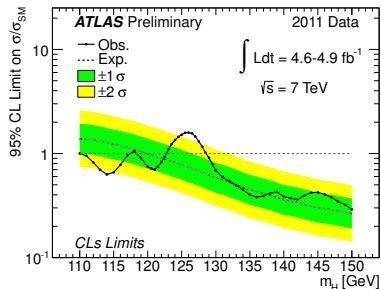
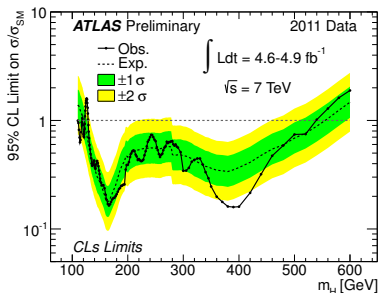
$VH \rightarrow b\bar{b}$

- Again three separate channels
 - $ZH \rightarrow l^+l^-b\bar{b}$
 - $ZH \rightarrow \nu\bar{\nu}b\bar{b}$
 - $WH \rightarrow l\nu b\bar{b}$
- 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 $H \rightarrow b\bar{b}$ cross section
- [ATLAS-CONF-2012-015](#)



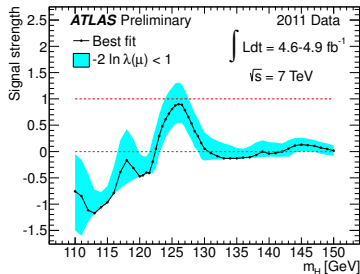
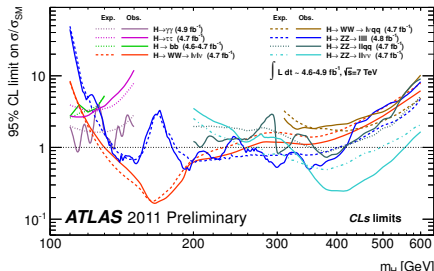
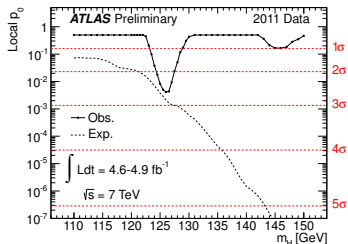
Combination result

- 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](#)



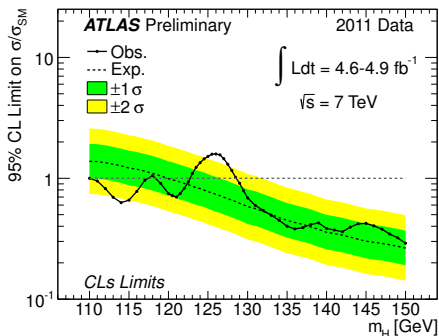
A closer look

- The excess at ≈ 126 GeV is dominated by the $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ \rightarrow llll$ contributions
- $H \rightarrow WW \rightarrow l\nu l\nu$ contribution shows a weaker than expected limit but no significant excess
- The $m_H \approx 126$ 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

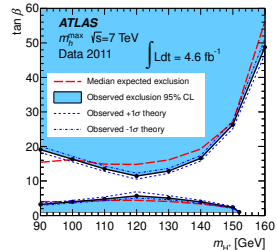
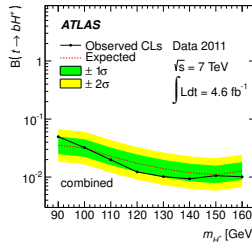
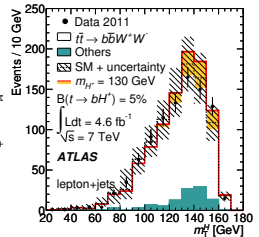
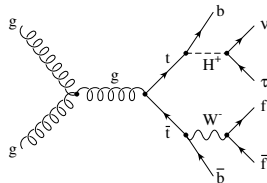
- Searches for the Higgs boson have been undertaken in a wide range of channels using the full ATLAS 2011 dataset of up to 4.9fb^{-1}
 - The allowed SM Higgs mass range has been severely restricted by the limits set by ATLAS
 - The remaining allowed regions are $117.5 < m_H < 118.5 \text{ GeV}$, $122.5 < m_H < 129\text{GeV}$ or $m_H > 539 \text{ GeV}$
 - In the low mass region an excess of events over the background expectation has been observed at $m_H \approx 126 \text{ GeV}$
- 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 $110 < m_H < 146 \text{ GeV}$
 - 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 $15\text{-}20 \text{ fb}^{-1}$ 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

$H^+ \rightarrow \tau\nu$

- 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 $H^+ \rightarrow \tau\nu$
- Search performed in three channels defined by the decays $t\bar{t} \rightarrow b\bar{b}WH^+ \rightarrow$
 - $b\bar{b} (q\bar{q}) (\tau_{lep}\nu)$
 - $b\bar{b} (l\nu) (\tau_{had}\nu)$
 - $b\bar{b} (q\bar{q}) (\tau_{had}\nu)$
- No excess is seen in any channel
- Upper limits set on the branching ratio of $t \rightarrow H^+ b$ assuming 100% $Br(H^+ \rightarrow \tau\nu)$
- Limits also set on the possible values of $\tan\beta$ as a function of m_{H^+}



[arXiv e-print](#)

Typical Systematics

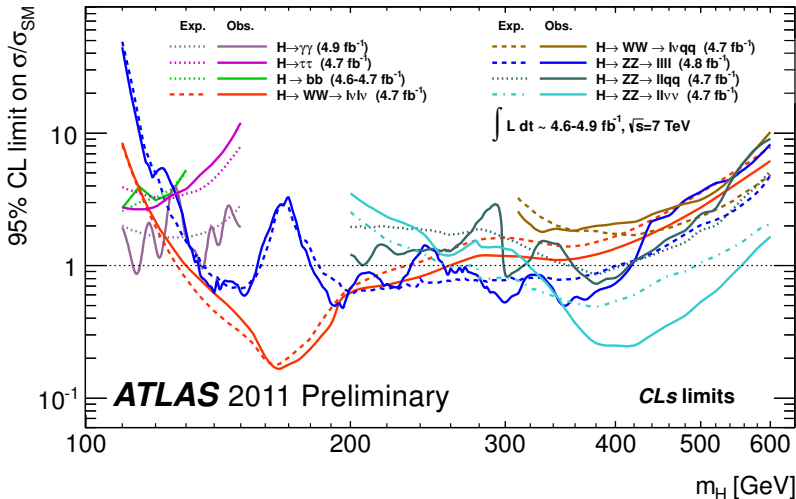
- Systematics in the combination are taken to be either 100% correlated or 100% uncorrelated between channels

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

- Selected theoretical uncertainties

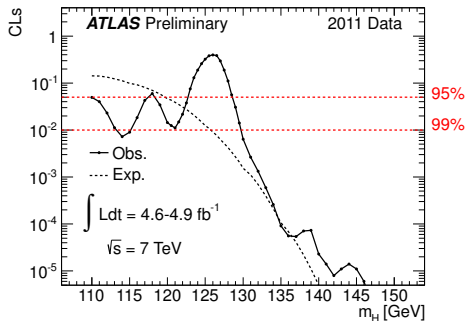
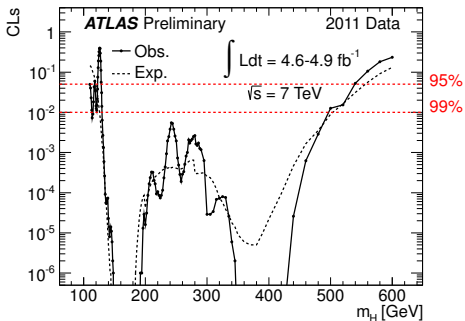
| | ggF | VBF | WH/ZH |
|------------------|--|-----------|-----------|
| QCD scale | $\pm 12\%$ | $\pm 1\%$ | $\pm 1\%$ |
| PDF + α_S | $\pm 8\%$ | $\pm 4\%$ | $\pm 4\%$ |
| Mass lineshape | $150\% \times \left(\frac{m_H}{\text{TeV}}\right)^3$ | | |

Breaking down the combination



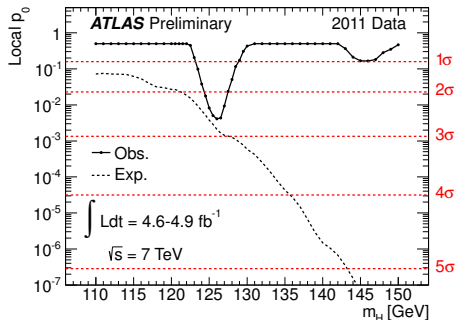
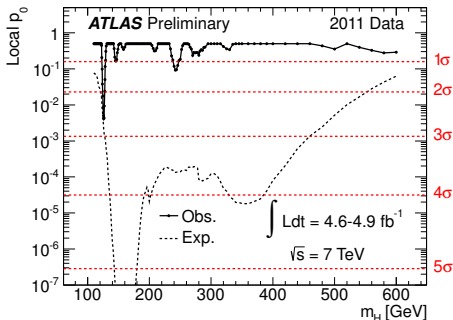
Breaking down the combination

• $CL_S(\mu) = \frac{p_{\mu}}{1-p_b}$



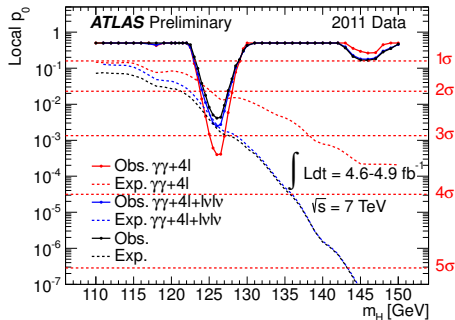
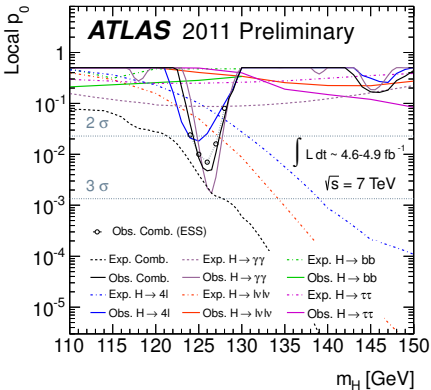
Breaking down the combination

- 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 $\mu = \frac{\sigma}{\sigma_{SM}}$

