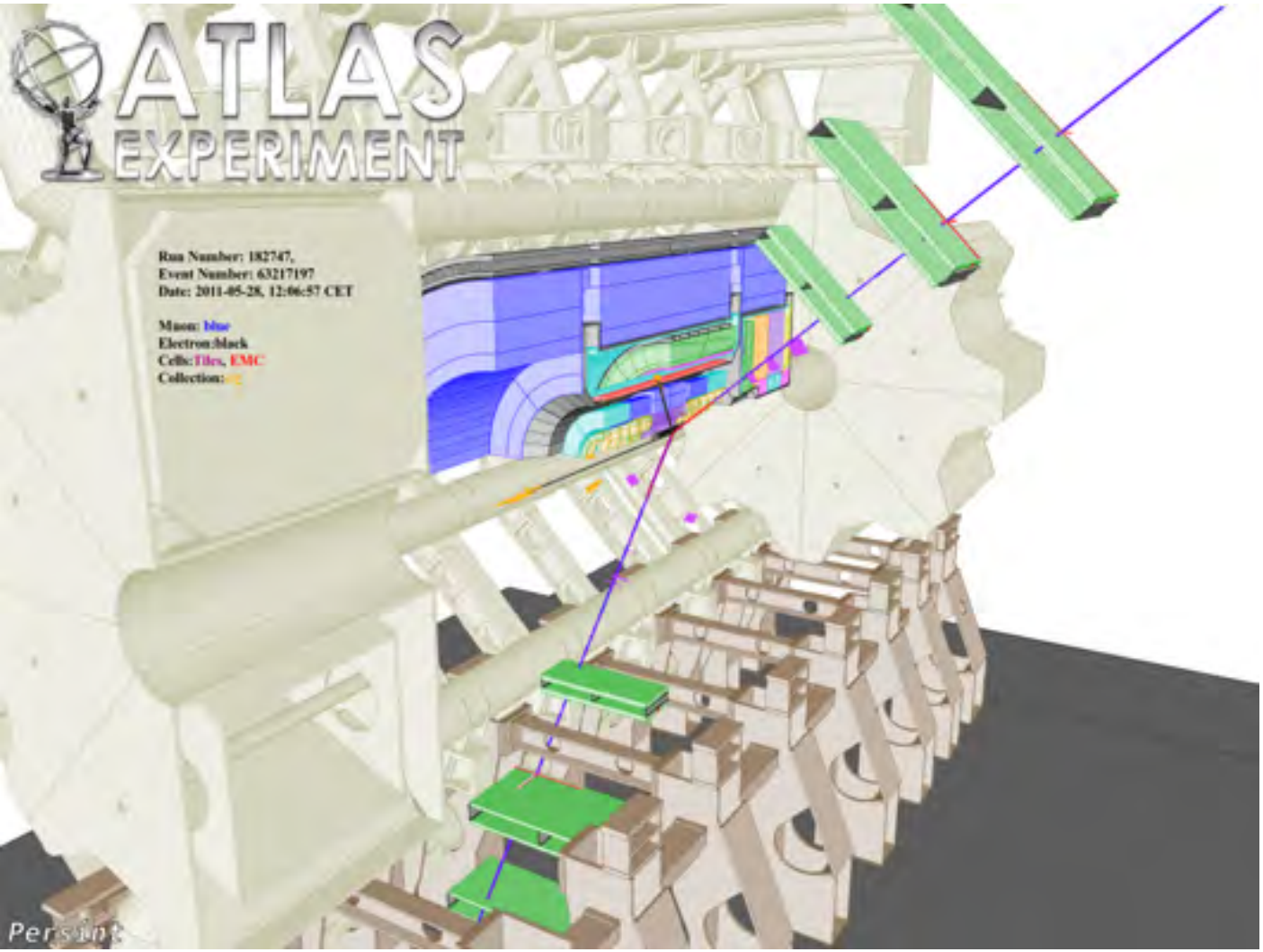
Searches for a heavy Higgs boson at ATLAS

PLHC 2012: 4-9th June, Vancouver

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

08/06/2012

Outline

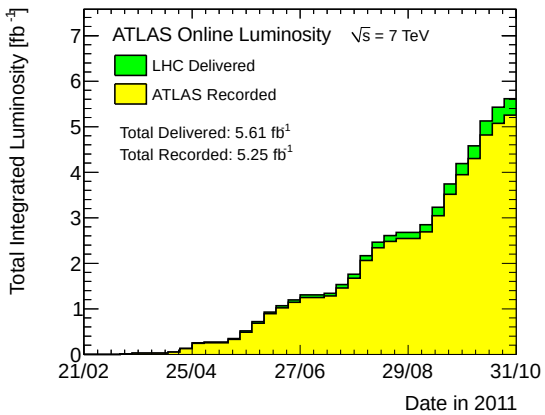


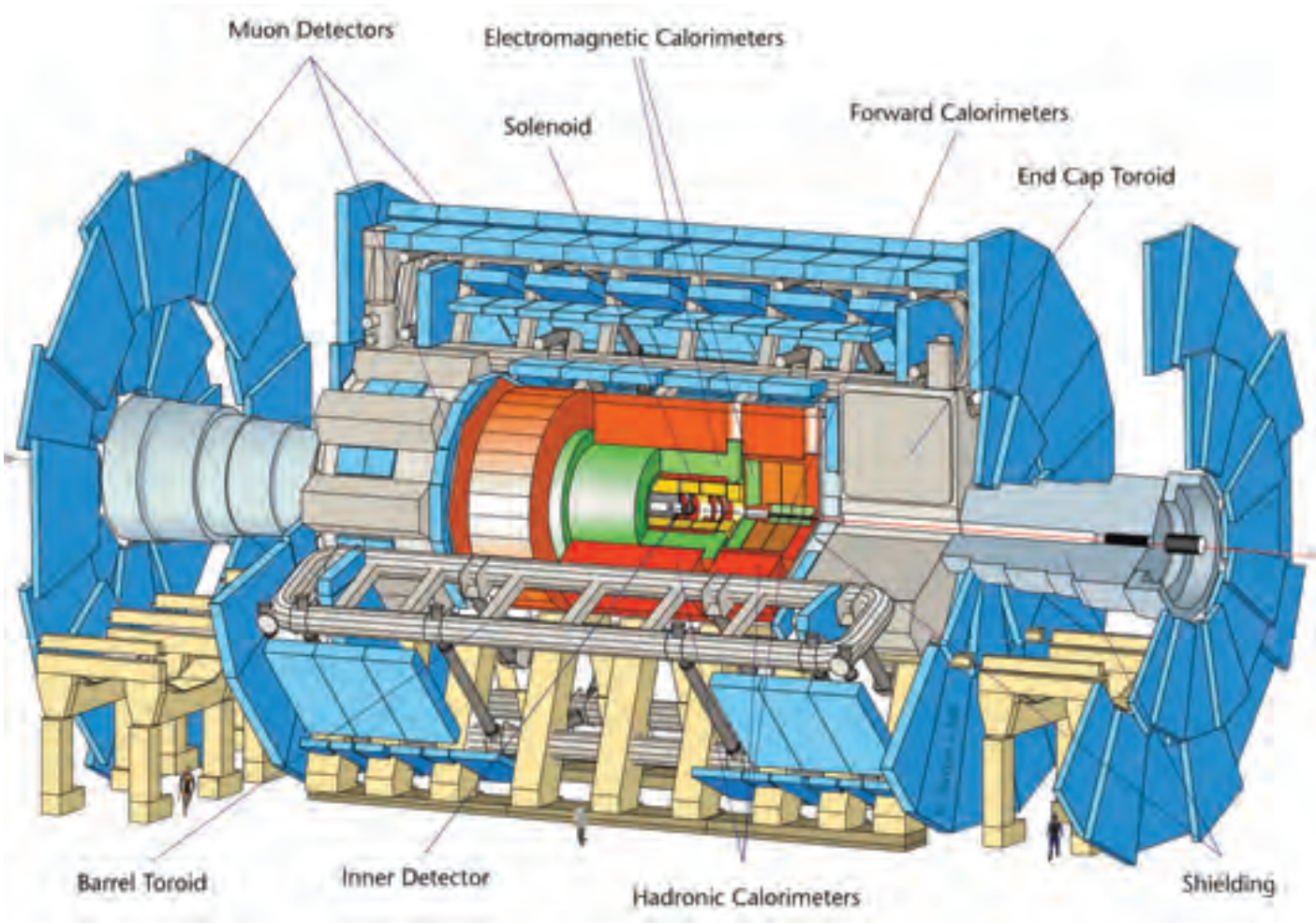
Event display of a $ee\mu\mu$ candidate event with $m_{4l} = 209.7$ GeV.

- ATLAS & LHC
- The Higgs
- Search strategy and channels
- Limit combination
- Conclusions

ATLAS & LHC

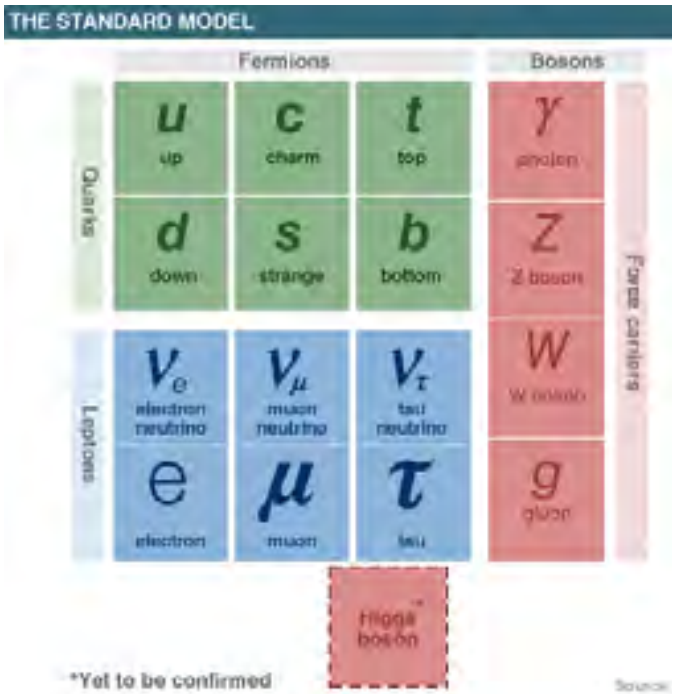
- ATLAS is a general purpose detector
- Almost full 4π layered coverage
- 2011 data taking efficiency at $\approx 93.5\%$
- Recorded 5.25fb^{-1}
- Runs with good data quality $\approx 90 - 96\%$
- Peak $\mathcal{L} = 3.6 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$

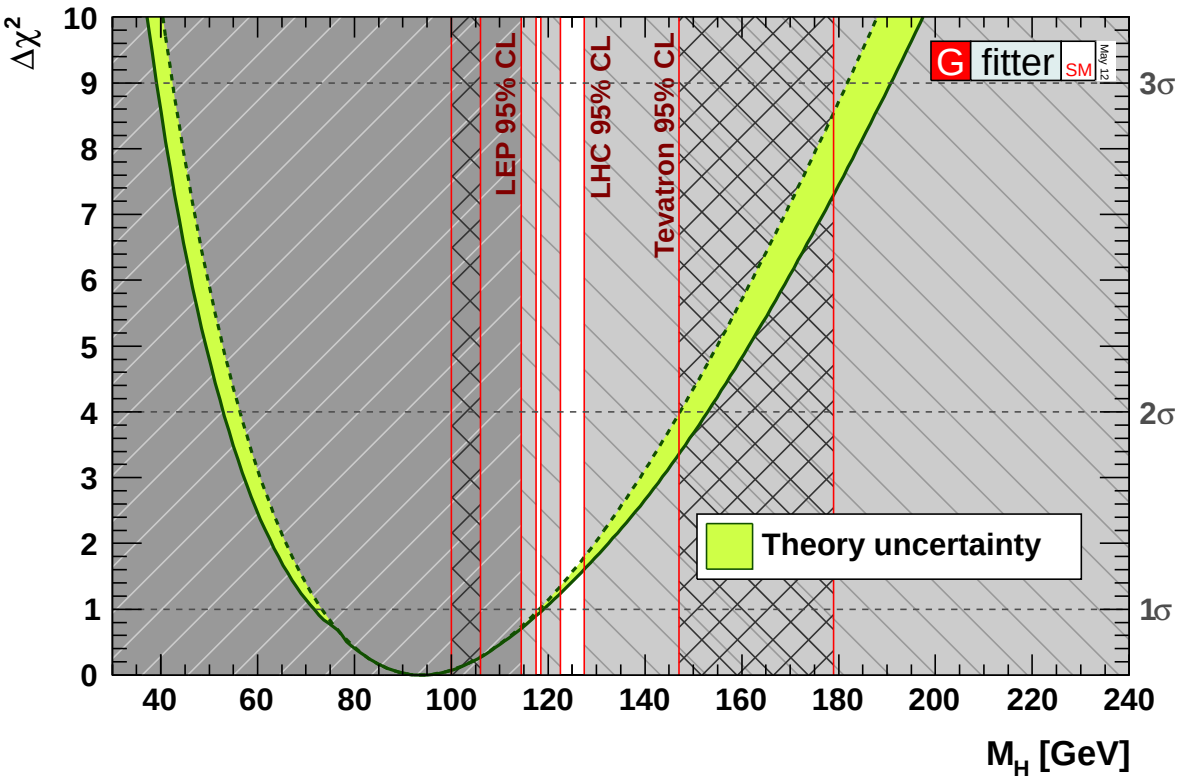




The Higgs Boson

- Higgs mechanism is the source of electroweak symmetry breaking in the SM
- Provides mass to the vector bosons and the fermions
- The Higgs boson is a physical manifestation of the scalar field
- Electroweak data along with measurements of the top and W mass strongly favour a light SM Higgs
- Models beyond the SM can contain a high mass Higgs
- Important to complement indirect exclusions with a direct search in the region
- In the remainder of the talk a heavy Higgs is assumed to have $m_H \geq 200\text{GeV}$

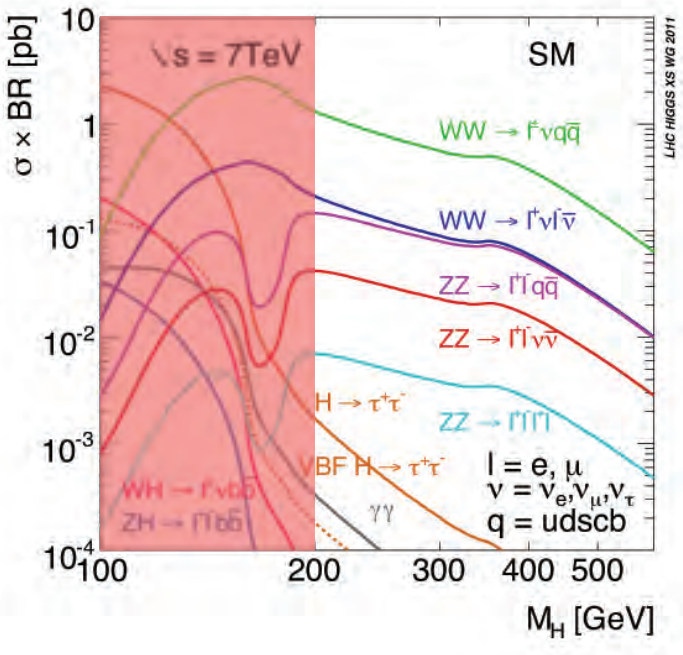




GFitter: $\Delta\chi^2$ as a function of m_H

The pieces of the puzzle

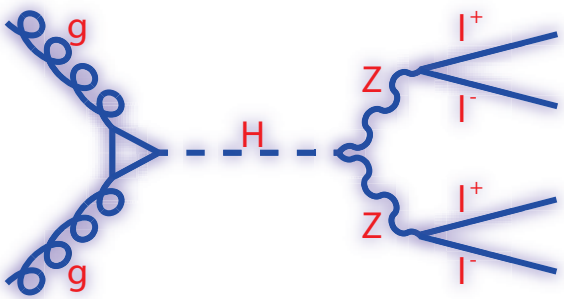
Higgs Decay	Subsequent Decay	Additional Sub-Channels	m_H Range	L [fb^{-1}]
$H \to \gamma\gamma$	–	9 sub-channels ($p_{T_t} \otimes \eta_\gamma \otimes$ conversion)	110-150	4.9
$H \to ZZ$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110-600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low 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
	$\ell\nu q\bar{q}'$	$\{e, \mu\} \otimes$ {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



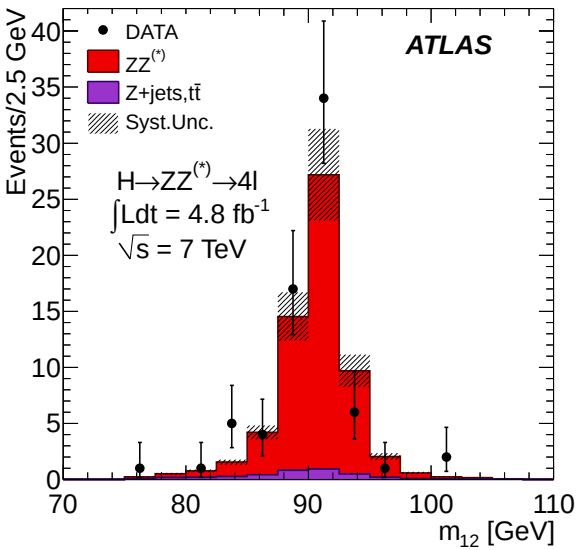
- LHC Higgs x-sec pages

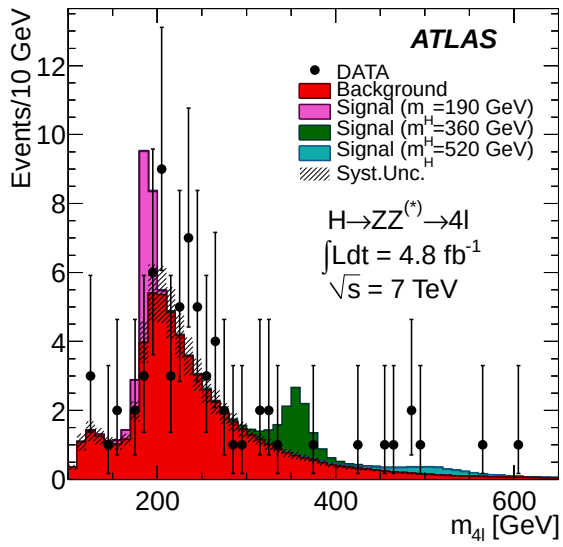
- ATLAS analyses make use of the various Higgs production and decay modes
- The low mass channels were covered in the previous session by Tatsuya
- Beyond $m_H \geq 2m_V$ the Higgs is expected to predominantly decay to two on-shell vector bosons
- Therefore in the range $m_H = 200 - 600$ GeV the ATLAS searches are dominated by the diboson channels

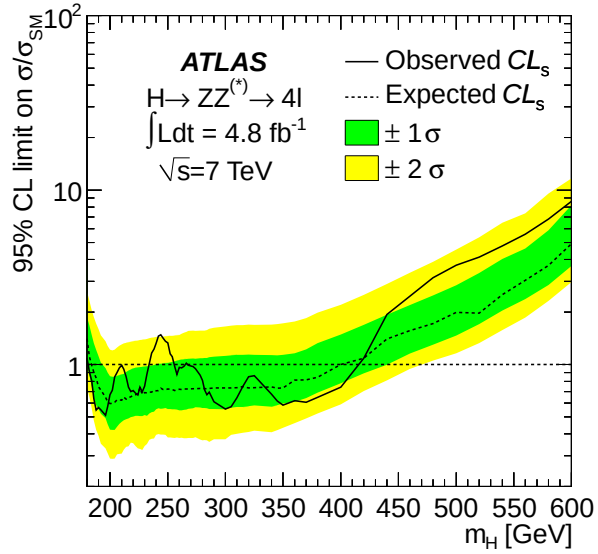
$H \to ZZ \to llll$



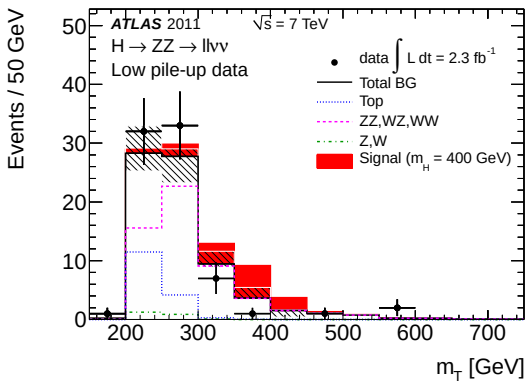
- Analysis uses m_{4l} distribution as the discriminating variable
- Three separate channels combined: 4μ, $2e2\mu$, $4e$
- Clean signature with a low background
- Provides good sensitivity over large mass range
- Mass resolution $\approx$ 1.5%(2%) in $4\mu(e)$ channel at $m_H = 120$ GeV
- Deviations from the background expectation are observed at 125, 244 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
- In high mass regions this channel excludes a SM Higgs mass in three ranges 182 − 233 GeV, 256 − 265 GeV and 268 − 415 GeV
- Phys. Lett. B710 383-402 (2012)

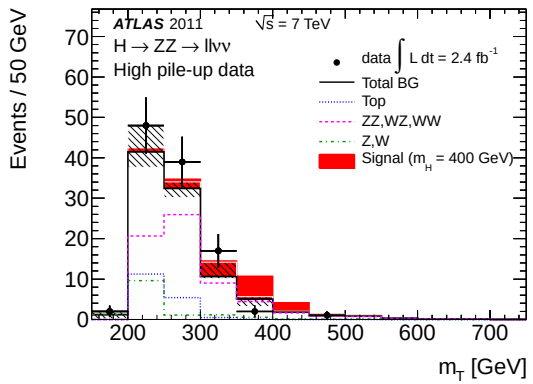


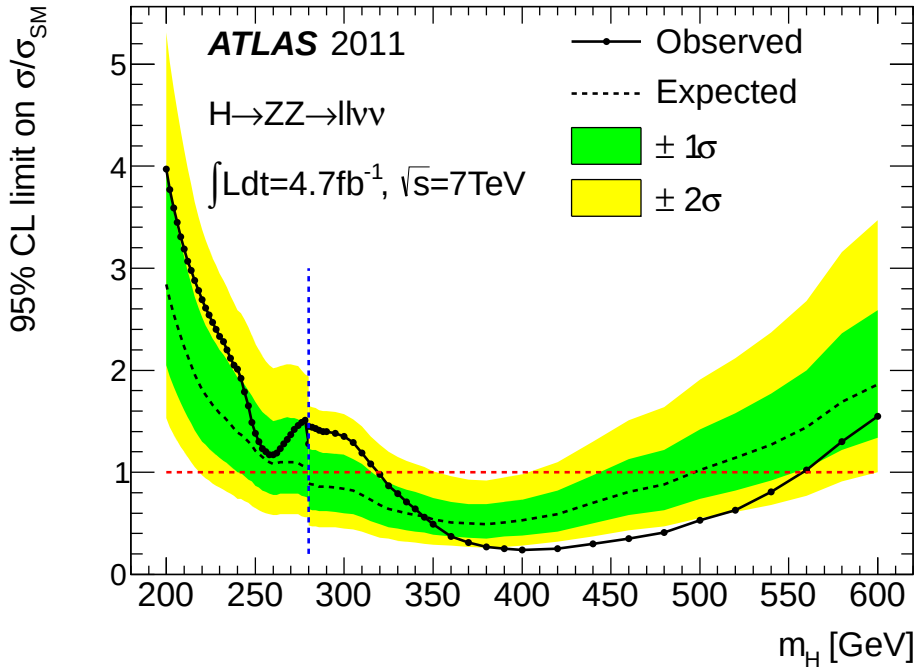


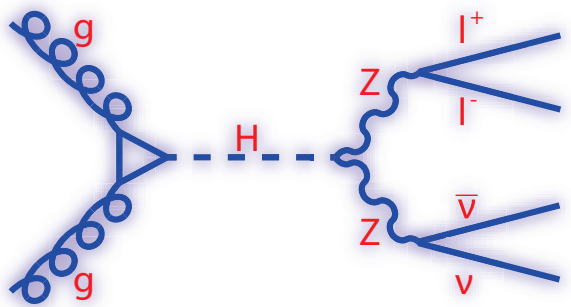


$H \to ZZ \to ll\nu\bar{\nu}$



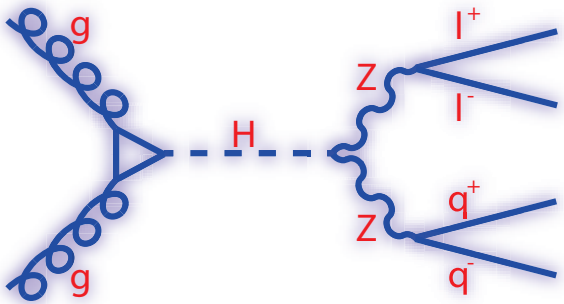




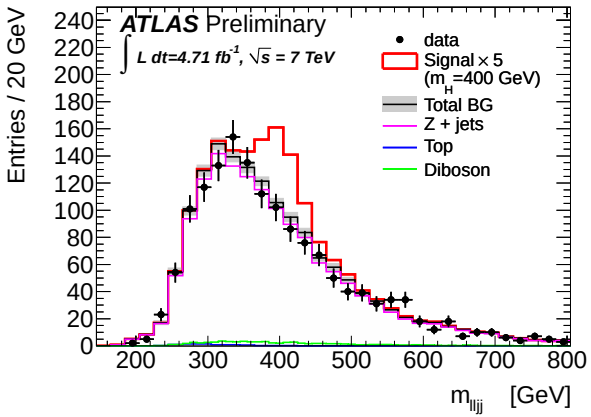


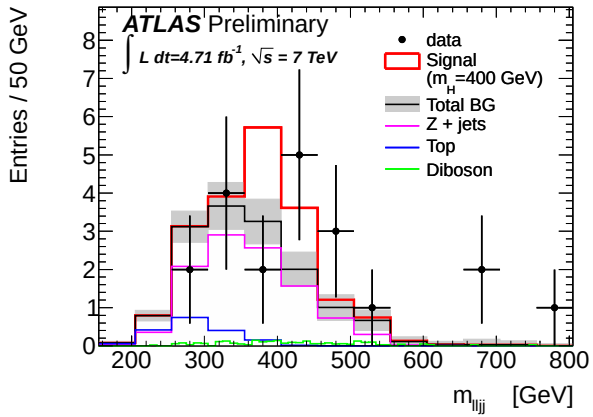
- Analysis uses m_T distribution as the discriminating variable
- Two channels are combined: $2\mu 2\nu$, $2e2\nu$
- Provides significant decay branching fraction combined with distinct signature of a high p_T lepton pair with large E_T^{miss}
- Separate selections are made in the low ($m_H < 280$ GeV) 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
- arXiv:1205.6744 Submitted to PLB

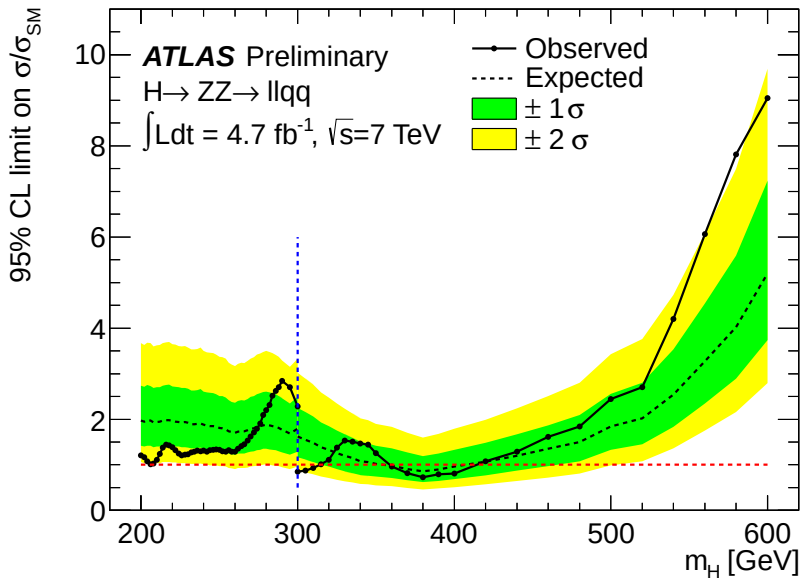
$H \to ZZ \to llq\bar{q}$



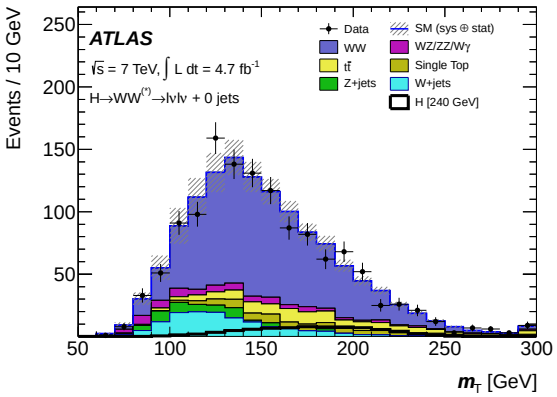
- Analysis uses m_{lljj} distribution as the discriminating variable
- Two channels are combined: $2\mu q\bar{q}$, $2eq\bar{q}$
- Separate selections are made in the low ($m_H < 300$ GeV) and high ($m_H > 300$ GeV) mass regions
- Analysis is further split into tagged (2 b-tags) and untagged selections (< 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 $360 < m_H < 400$ GeV
- ATLAS-CONF-2012-017

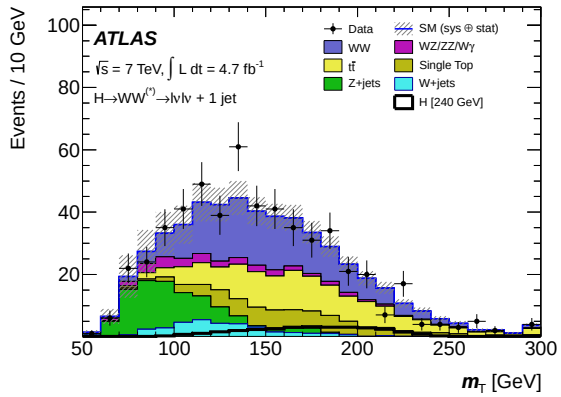


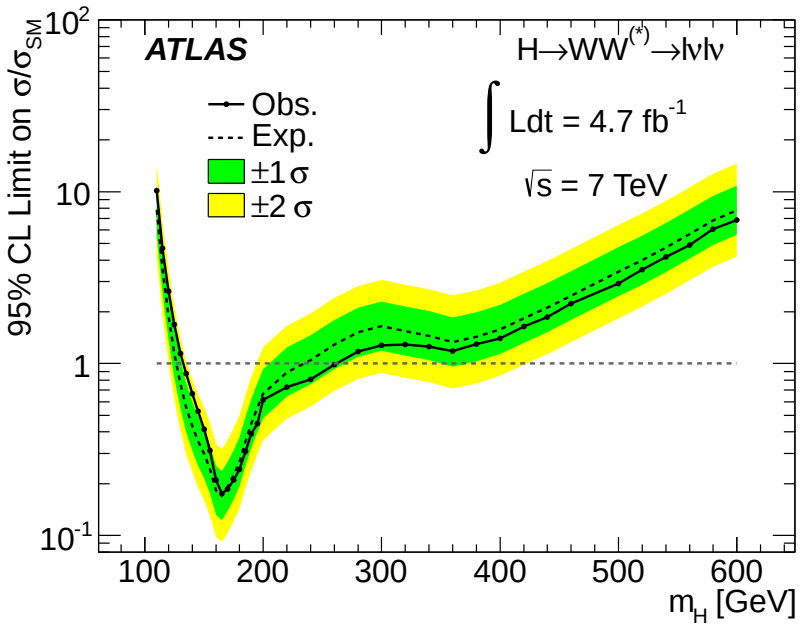


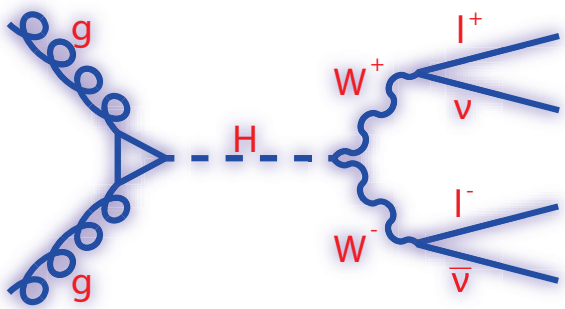


$H \to WW \to l\nu l\nu$



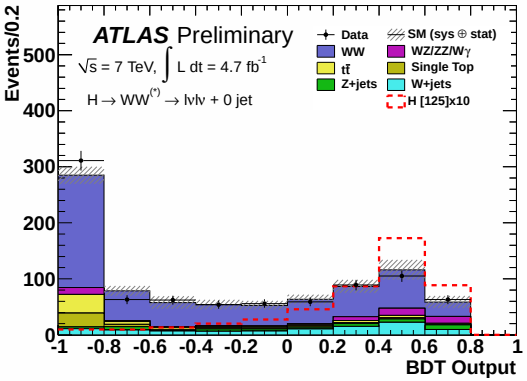


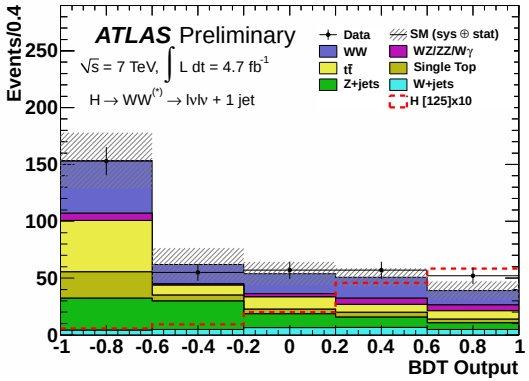


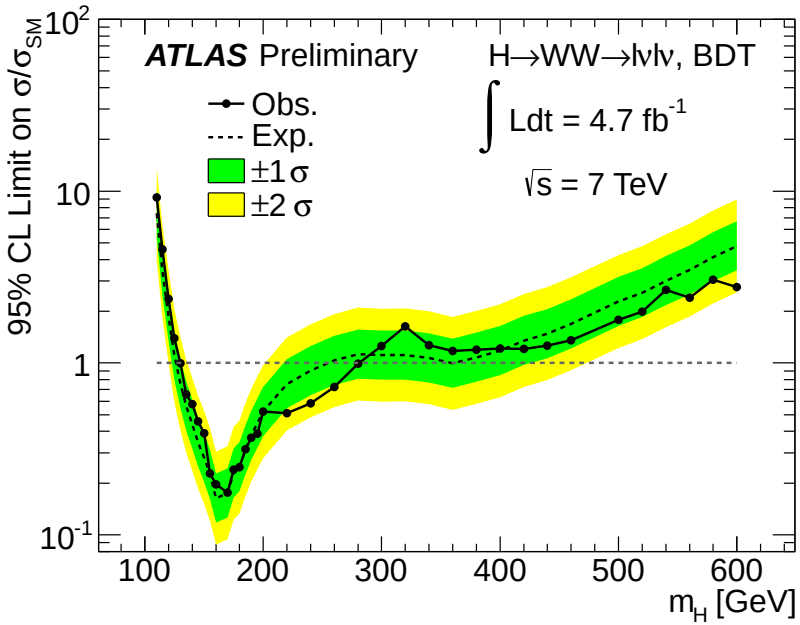


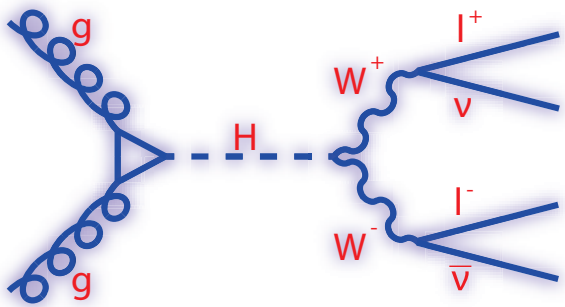
- Analysis uses m_T distribution as the discriminating variable
- Three channels are combined: $2\mu 2\nu_\mu$, $e\mu\nu_e\nu_\mu$, $2e2\nu_e$
- Channel covers the full mass range but suffers from poor mass resolution
- Analysis is split into 0, 1 and $\geq$2 jet categories
- W+jets background is derived from data, WW, top and D-Y backgrounds are normalised in control regions
- The channel by itself excludes a SM Higgs mass in the ranges $130 < m_H < 261$ GeV
- The expected exclusion was $127 < m_H < 234$ GeV
- arXiv:1206.0756 Submitted to PLB
- ATLAS-CONF-2012-060 ←New MVA results

$H \to WW \to l\nu l\nu$: MVA Results



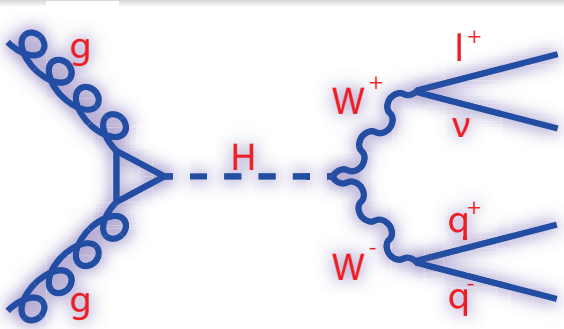




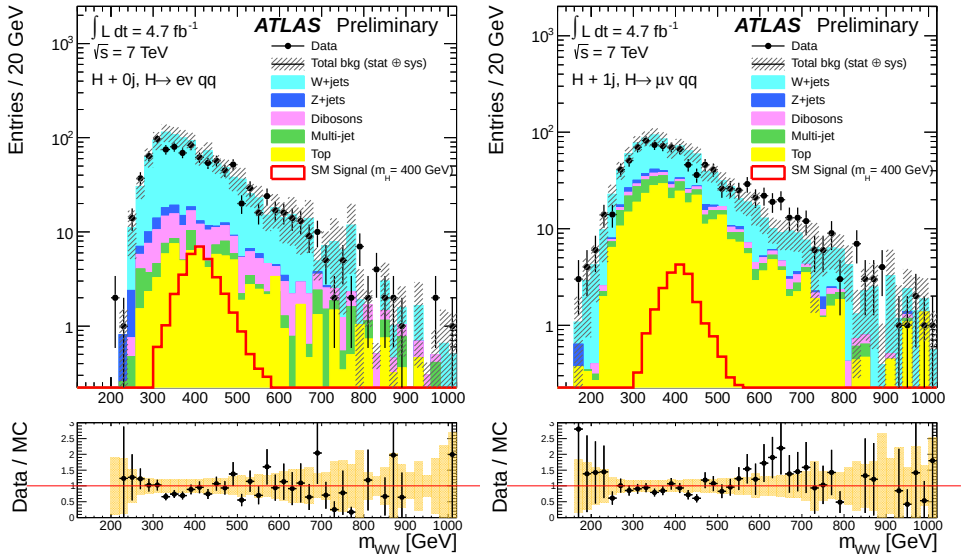


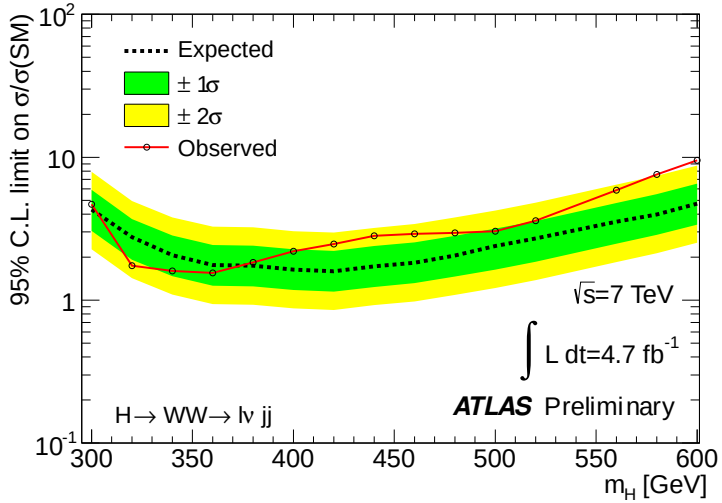
- Analysis uses BDT distribution as the discriminating variable
- Three channels are combined: $2\mu 2\nu_\mu$, $e\mu\nu_e\nu_\mu$, $2e2\nu_e$
- Channel covers the full mass range but suffers from poor mass resolution
- Analysis is split into 0, 1 jet categories
- W+jets background is derived from data, WW, top and D-Y backgrounds are normalised in control regions
- The channel by itself excludes a SM Higgs mass in the ranges $130 < m_H < 281$ GeV
- The expected exclusion was $127 < m_H < 255$ GeV
- arXiv:1206.0756 Submitted to PLB
- ATLAS-CONF-2012-060 ←New MVA results

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



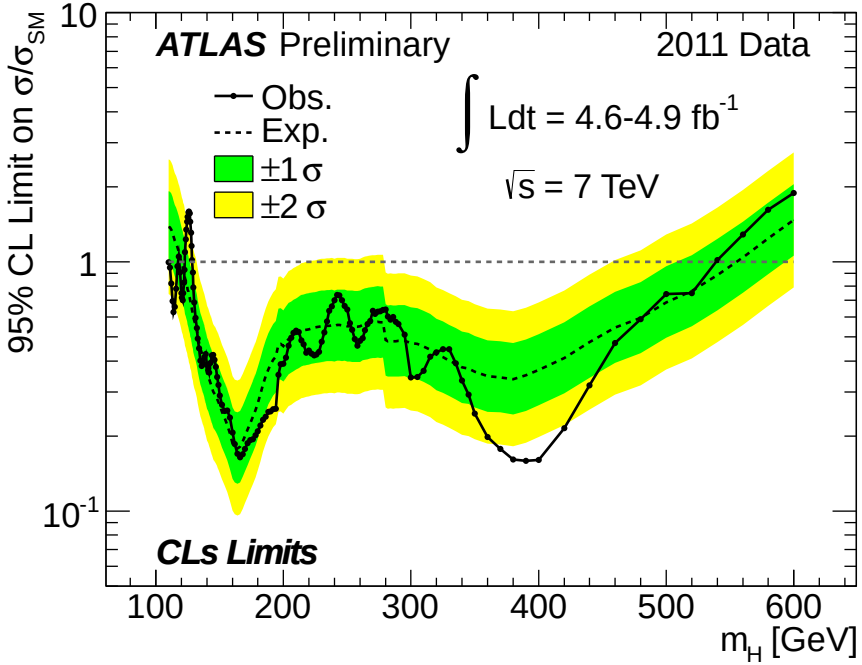
- Analysis uses m_{WW} distribution as the discriminating variable
- Two channels are combined: $\mu\nu_\mu q\bar{q}$, $e\nu_e q\bar{q}$
- Analysis is split into 0, 1 and 2 additional jet categories
- Monte Carlo studies performed to provide a background parameterisation which is validated in M_{jj} sidebands
- 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 2.6 pb is set
- This corresponds to 2.2 times the SM prediction
- ATLAS-CONF-2012-018

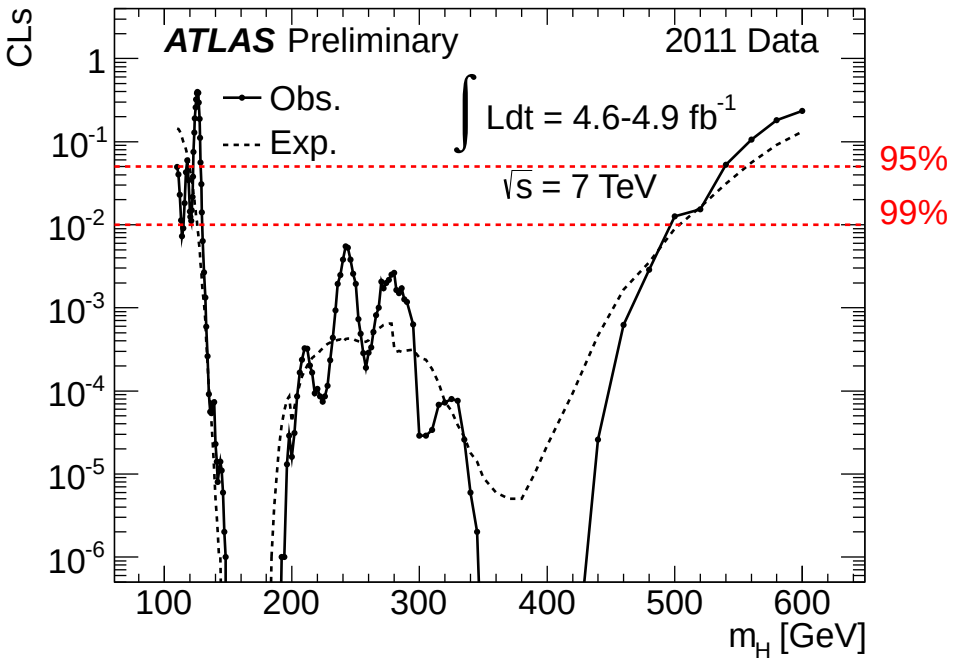




Combination result

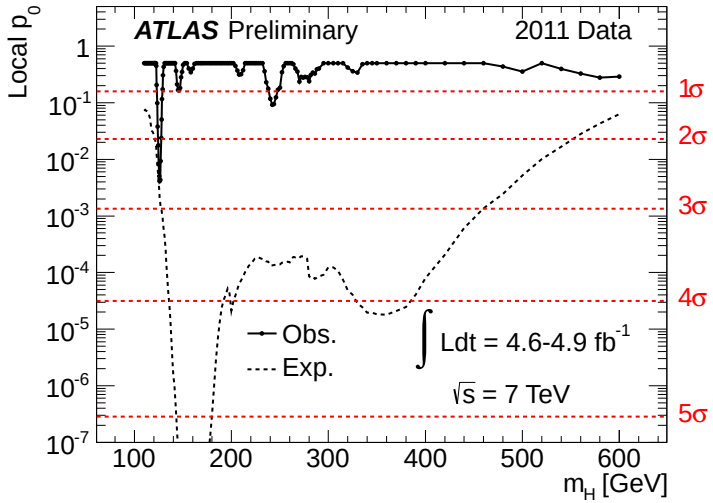
- The channels shown have been combined to give the overall ATLAS Higgs search result
- Systematics in the combination are taken to be either 100% correlated or 100% uncorrelated between channels
- In the absence of a signal expect to exclude the Standard Model Higgs boson at 95% C.L. between: $120 < m_H < 555$ 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
- A SM high mass Higgs is therefore excluded by this combination below $m_H < 539$ GeV
- ATLAS-CONF-2012-019

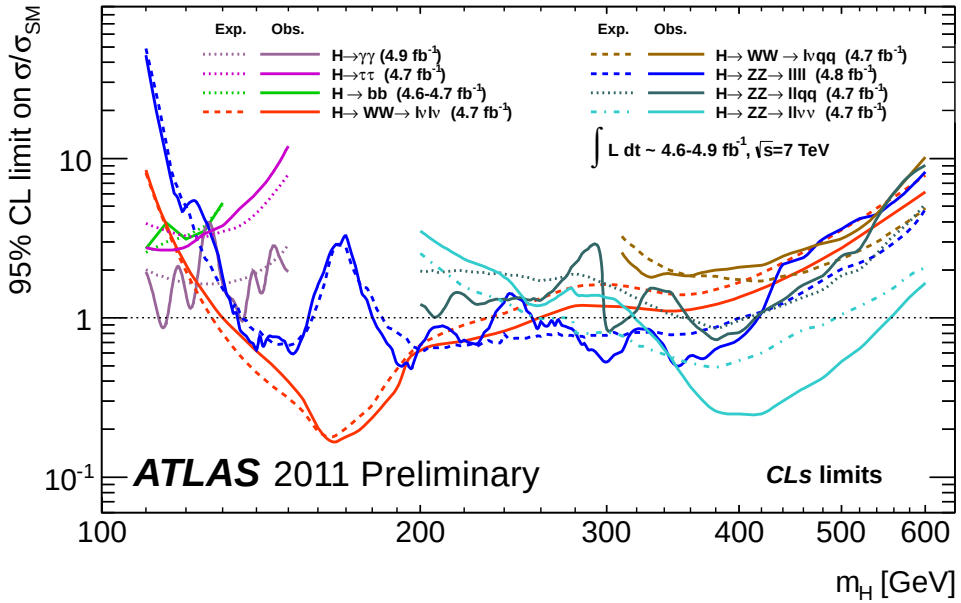


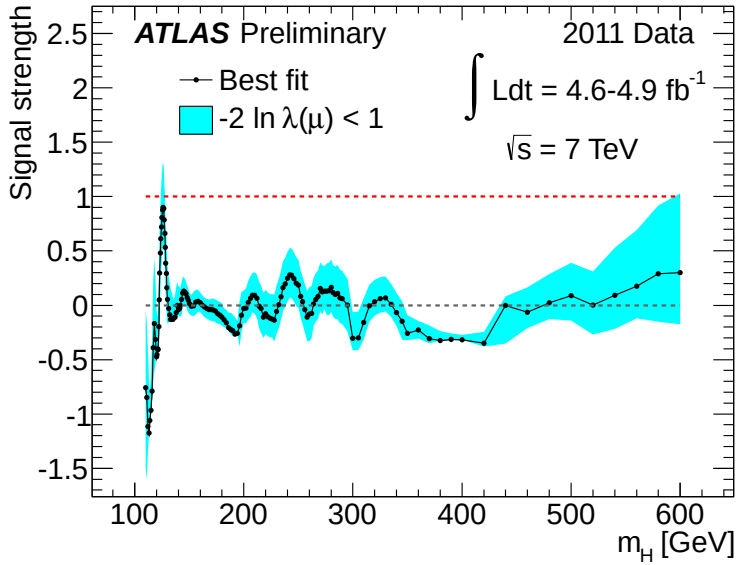


A closer look

- The exclusion in the high mass region is dominated by the *ZZ* contributions
- The *WW* channels also contribute, but require more data to exclude on their own
- The two high mass fluctuations observed in the $ZZ \rightarrow llll$ channel are not significant in the combination
- A far larger fluctuation would be expected for a SM signal in these regions
- Throughout the excluded range the signal strength is fully consistent with the background only hypothesis

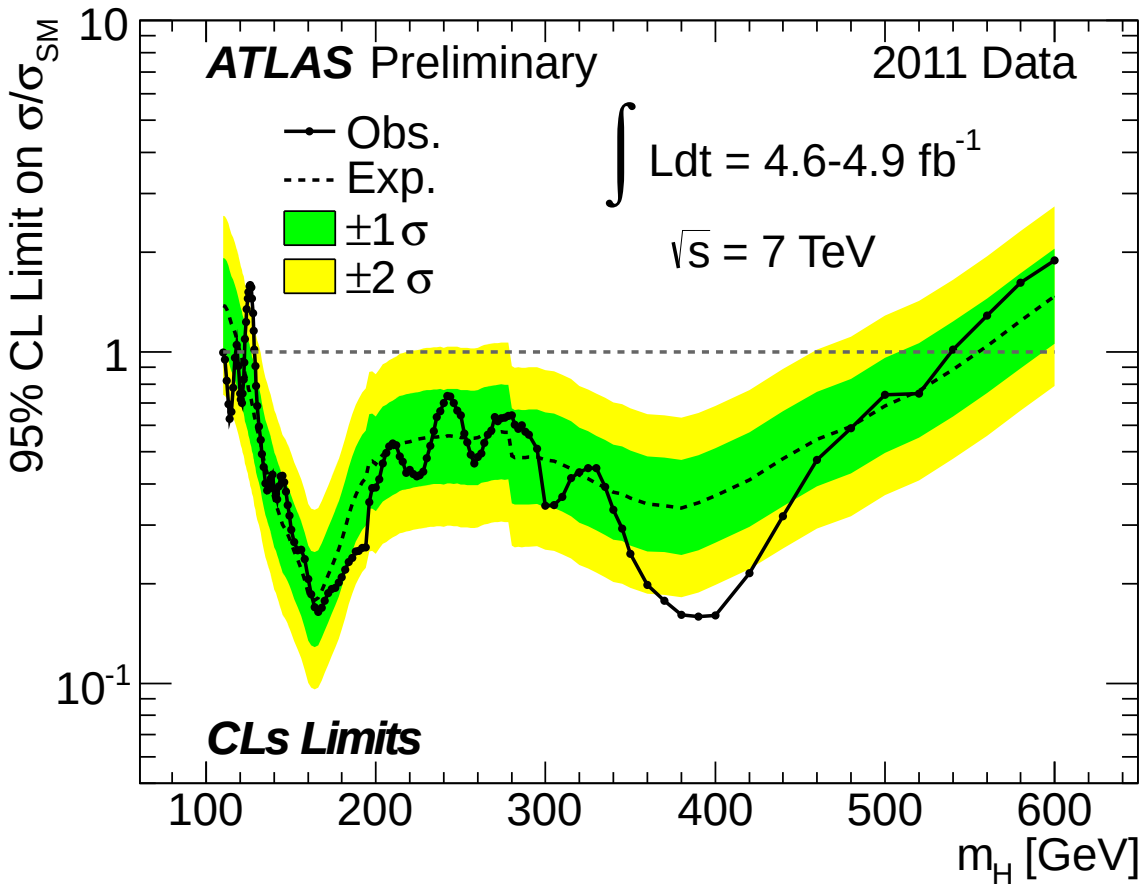






Summary and Outlook

- 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
- At a 99% C.L. the exclusion is still strong excluding a range of $130 \leq m_H \leq 486$ GeV
- 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
- Focus now turns to extending the searches to higher masses and probing further for none SM strength signals



BACKUP

Typical Systematics

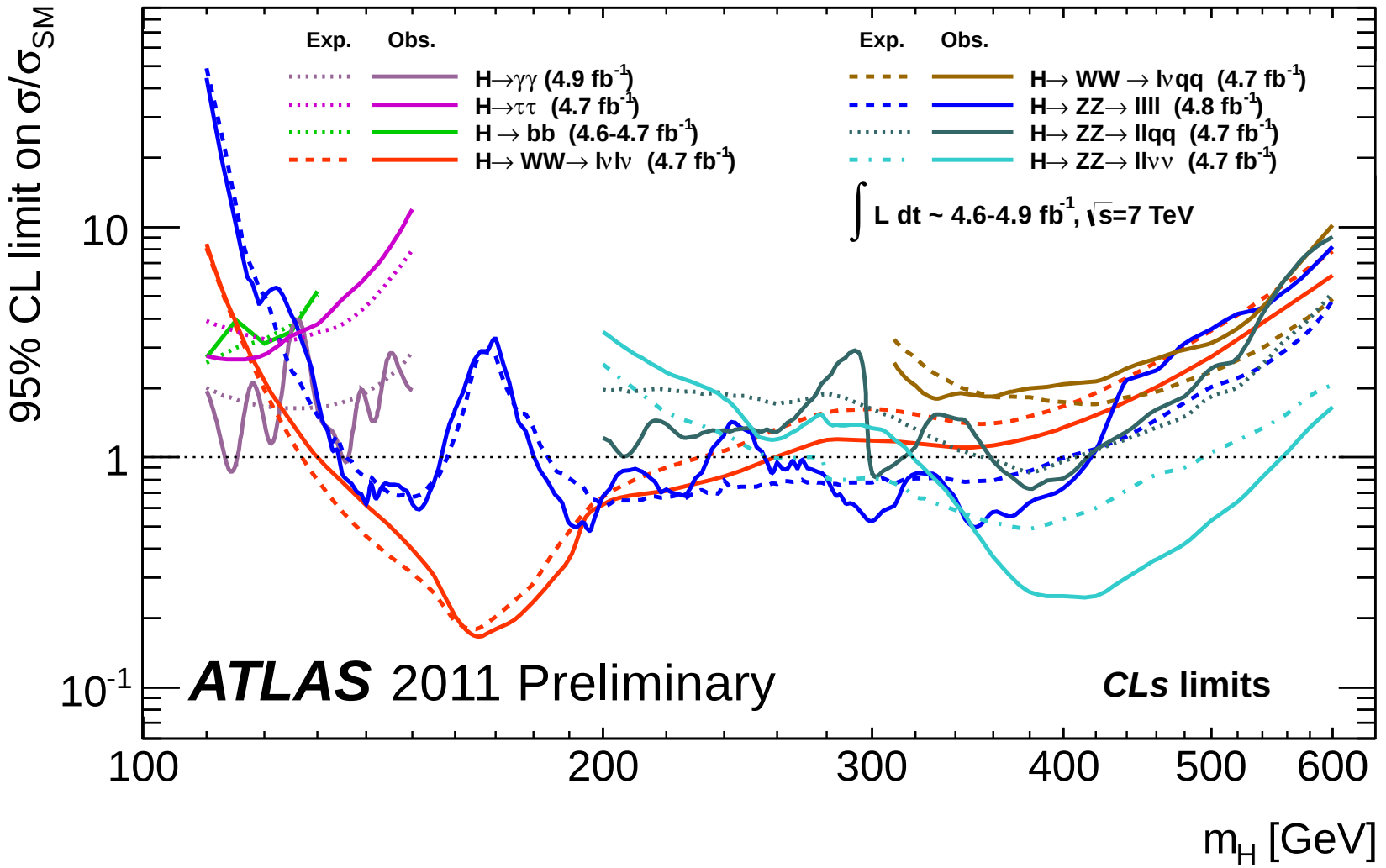
- Systematics in the combination are taken to be either 100% correlated or 100% uncorrelated between channels

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

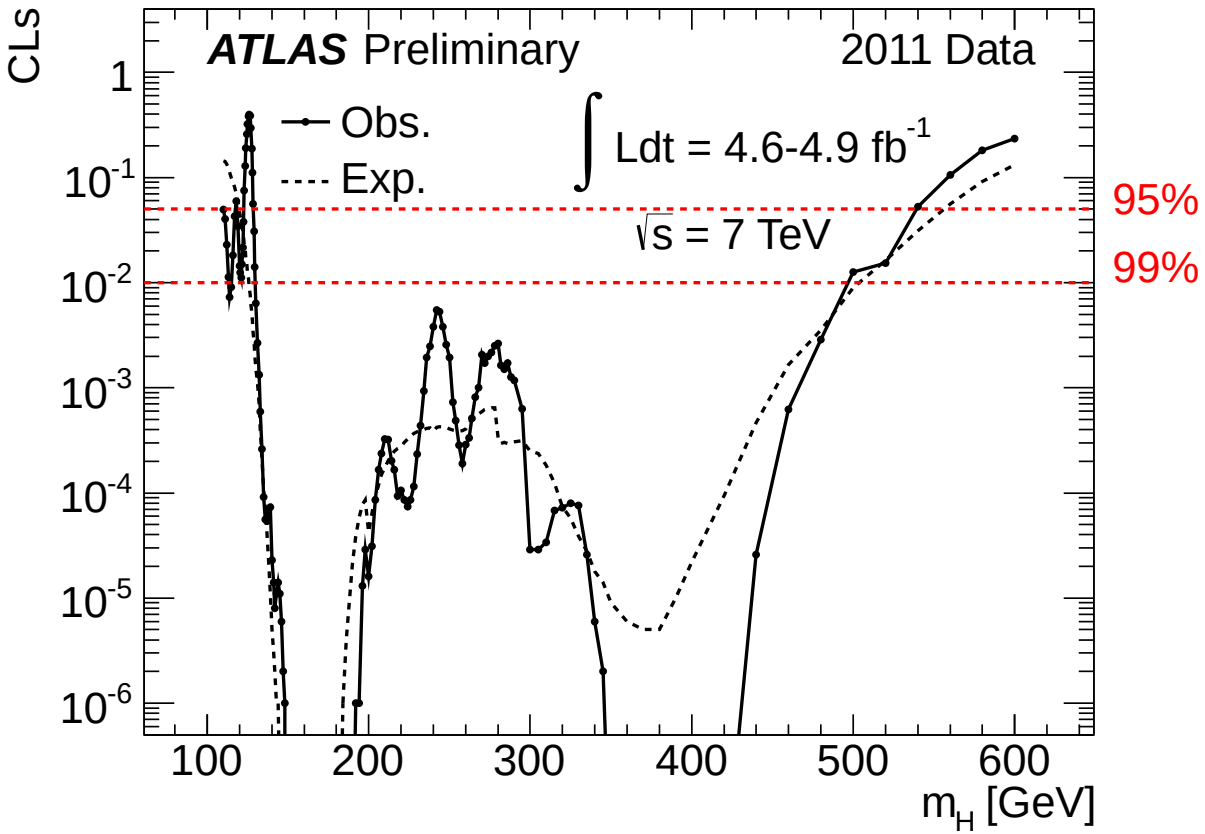
	ggF	VBF	WH/ZH
QCD scale	$\pm^{12\%}_{8\%}$	$\pm$ 1%	$\pm$ 1%
PDF + α_S	$\pm$ 8%	$\pm$ 4%	$\pm$ 4%
Mass lineshape	$150\% \times \left(\frac{m_H}{\text{TeV}}\right)^3$		

Breaking down the combination



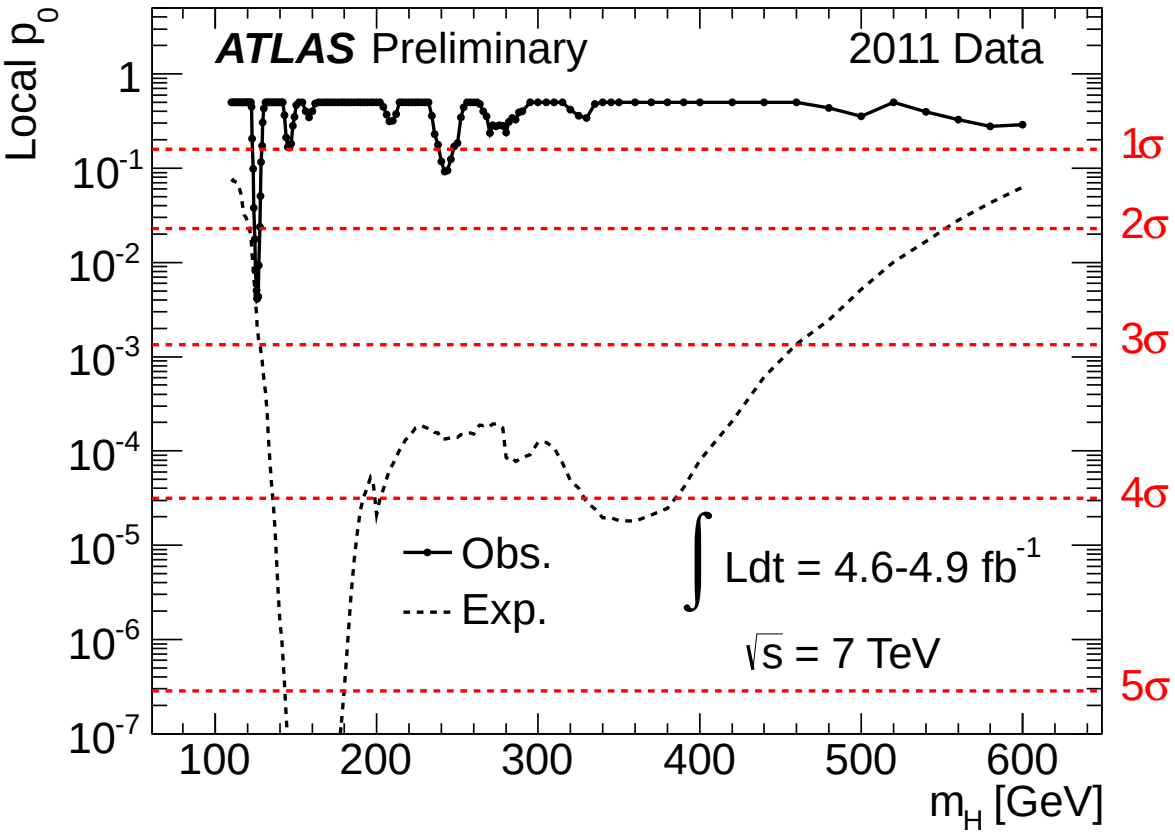
Breaking down the combination

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



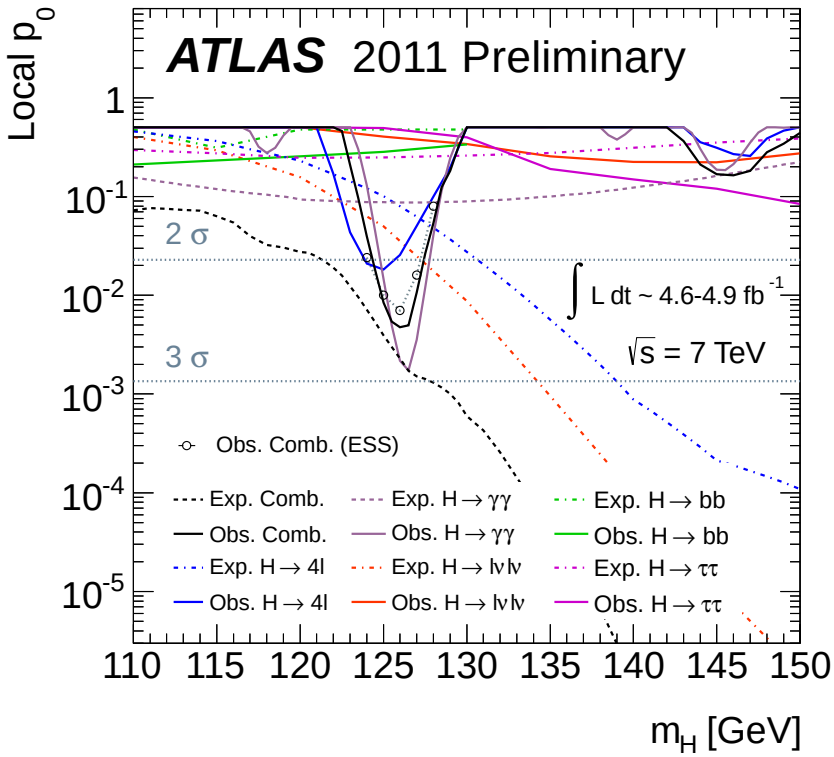
Breaking down the combination

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