Higgs searches with ATLAS

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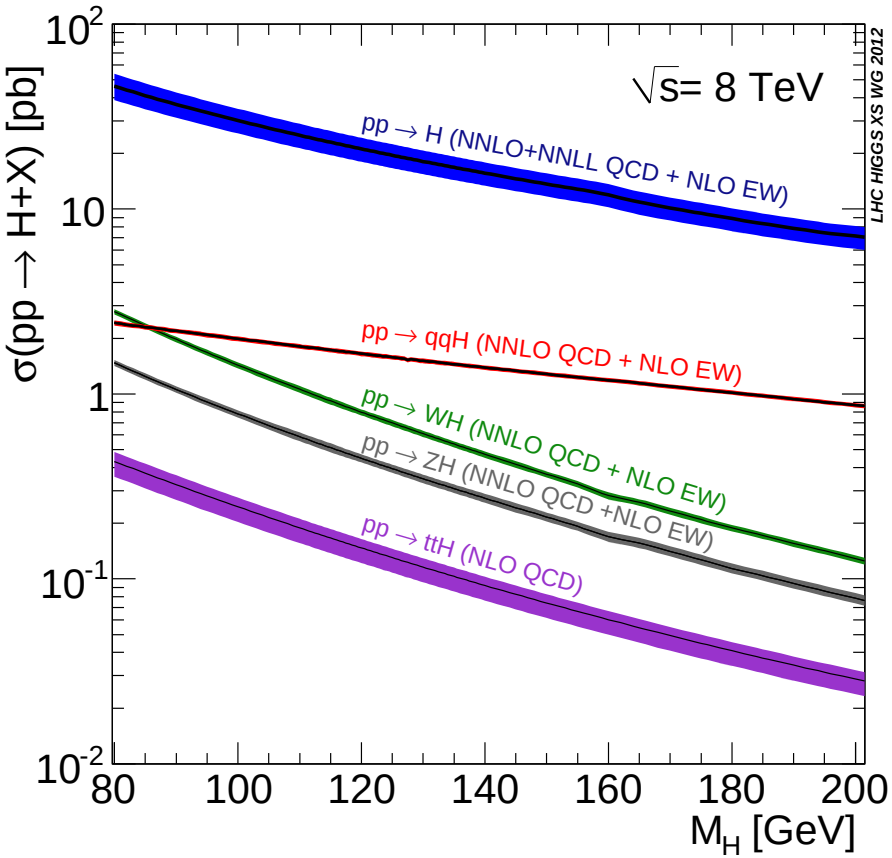
UNIVERSITY OF LIVERPOOL

27th Aug 2013

Lomonosov Conference

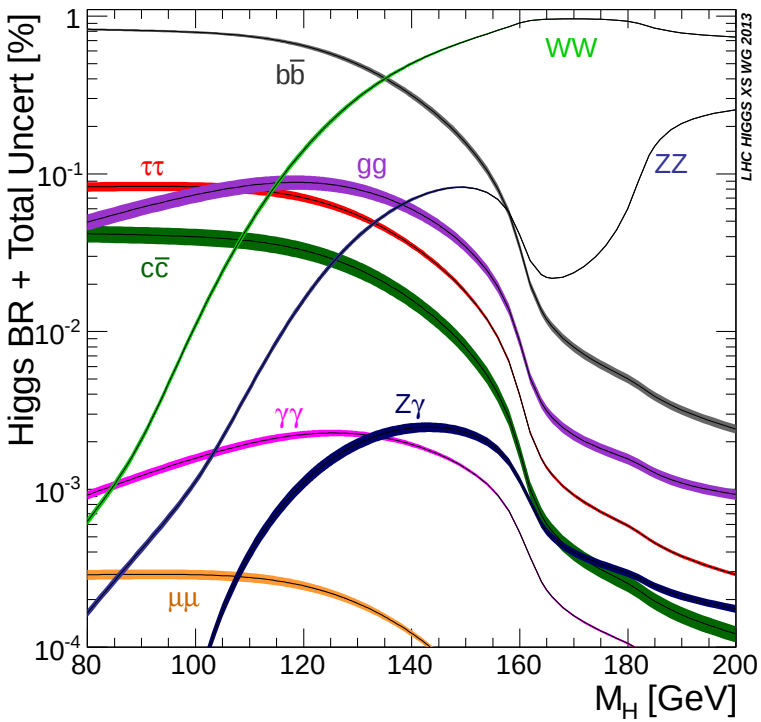
Introduction

- ATLAS results from $H \to \gamma\gamma$, $H \to ZZ^{(*)} \to llll$ and $H \to WW^*$ channels already presented in earlier talk by Richard St. Denis.
- Focus on more challenging SM Higgs decays and BR limits on inv. decay of Higgs boson.



- SM x-sec (pb) for $m_H = 125.5$ GeV

ggF	*VBF*	*WH*	*ZH*	*ttH*
19	1.6	0.7	0.41	0.13



- BR(%) for $m_H = 125.5$ GeV

bb	*WW*	$\tau\tau$	*ZZ*	$\gamma\gamma$	$Z\gamma$	$\mu\mu$
57	22	6.2	2.8	0.23	0.16	0.02

Bibliography used in this talk

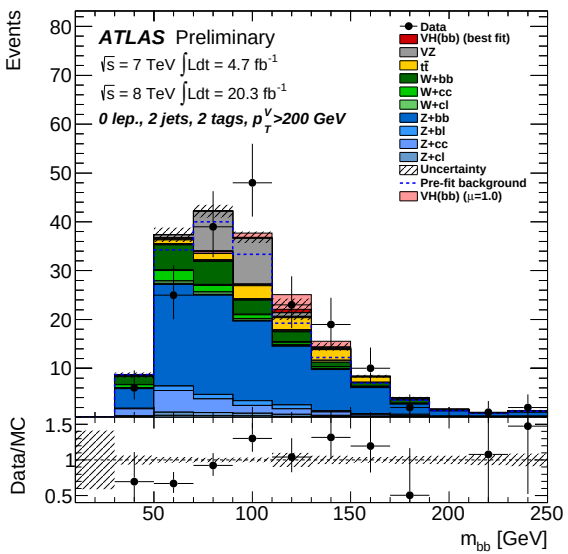
- ATLAS Higgs results : https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults
- LHC Higgs cross section working group : https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

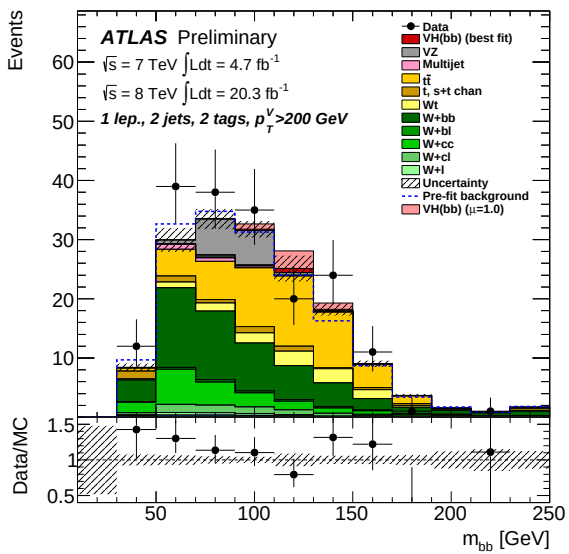
Channel	Reference	Luminosity (fb^{-1})	
		$\sqrt{s} = 7$ TeV	$\sqrt{s} = 8$ TeV
$VH \to Vb\bar{b}$	ATLAS-CONF-2013-079	4.7	20.3
$H \to \tau\tau$	ATLAS-CONF-2012-160	4.6	13.0
$VH \to VWW^*$	ATLAS-CONF-2013-075	4.7	20.7
$H \to Z\gamma$	ATLAS-CONF-2013-009	4.6	20.7
$t\bar{t}H \to t\bar{t}\gamma\gamma$	ATLAS-CONF-2013-080	-	20.3
$H \to \mu\bar{\mu}$	ATLAS-CONF-2013-010	-	20.7
$ZH \to l\bar{l} + inv$	ATLAS-CONF-2013-011	4.7	13.0

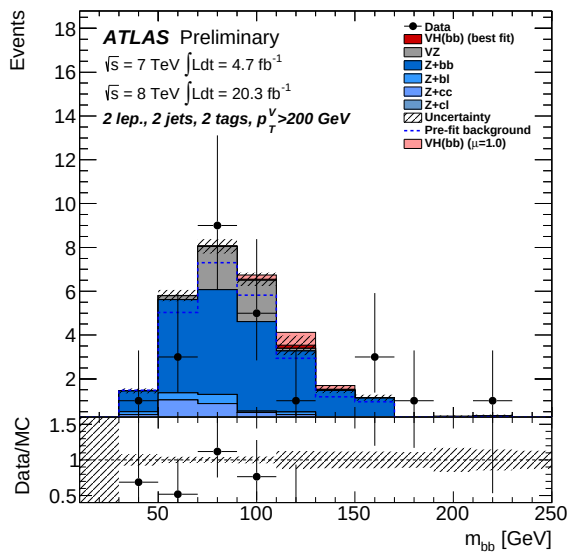
$VH \to Vb\bar{b}$

- Associated $(W/Z)H$ production, with $W \to l\nu$, $Z \to ll$ and $Z \to \nu\nu$, and with $H \to bb$.
- Each channel is further divided up into 2/3 jets $\otimes$ 5$p_T^{W/Z}$ bins $(p_T^{W/Z}) = [< 90], [90 - 120], [120 - 160], [160 - 200], [> 200]$ GeV.
- Flavour composition of main backgrounds is determined from data.

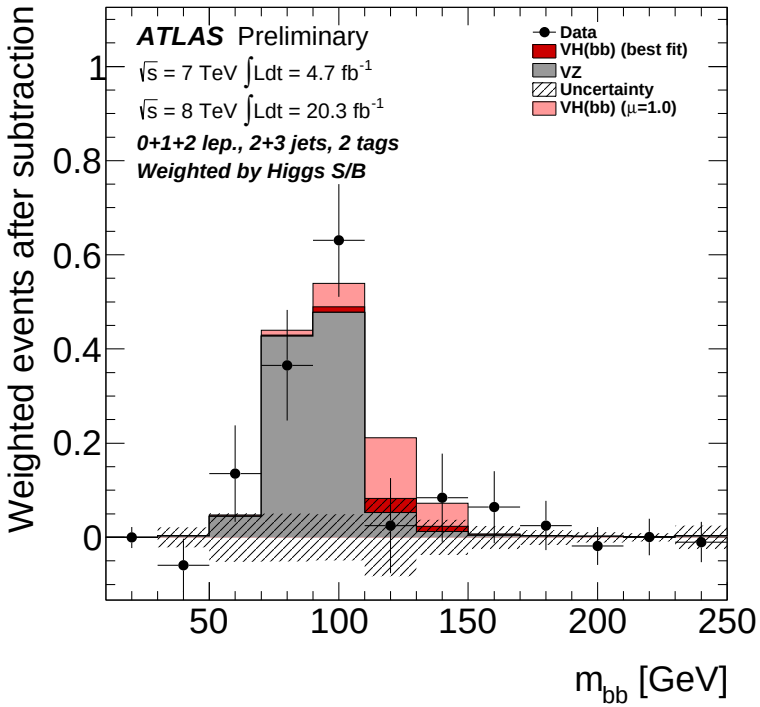
0 lepton ($ZH \to \nu\nu bb$) 1 lepton ($WH \to l\nu bb$) 2 lepton ($ZH \to llbb$)





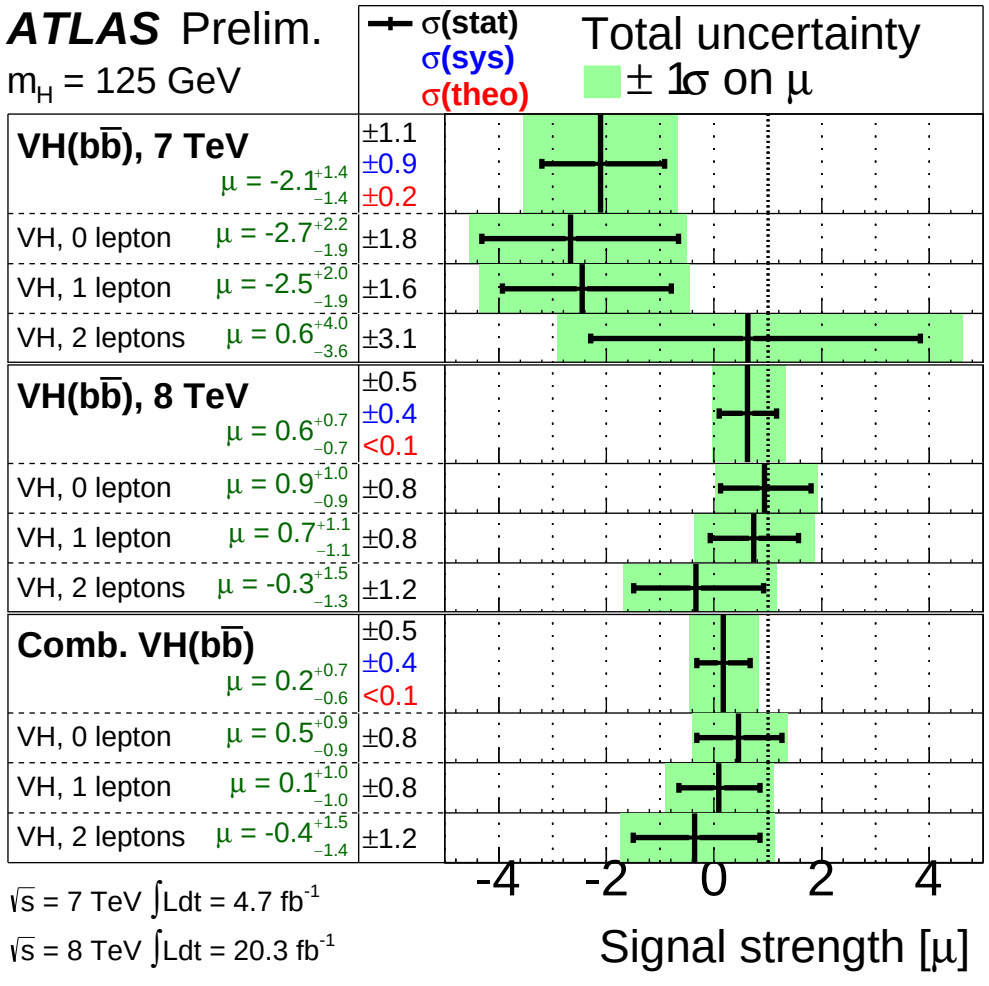


$VH \to Vb\bar{b}$ Results



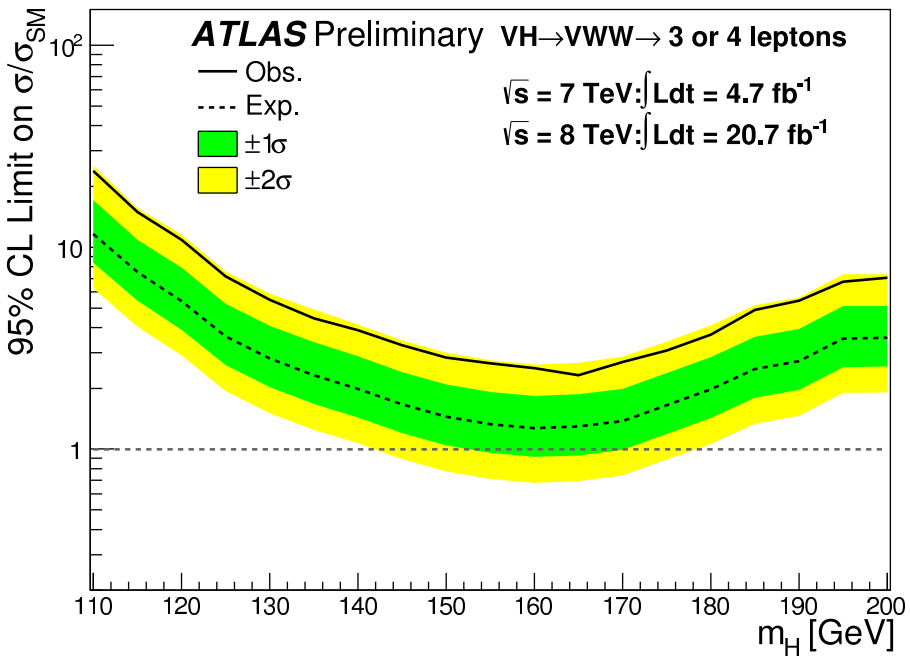
$\mu = 0.2^{+0.7}_{-0.6}$ for $m_H = 125$ GeV

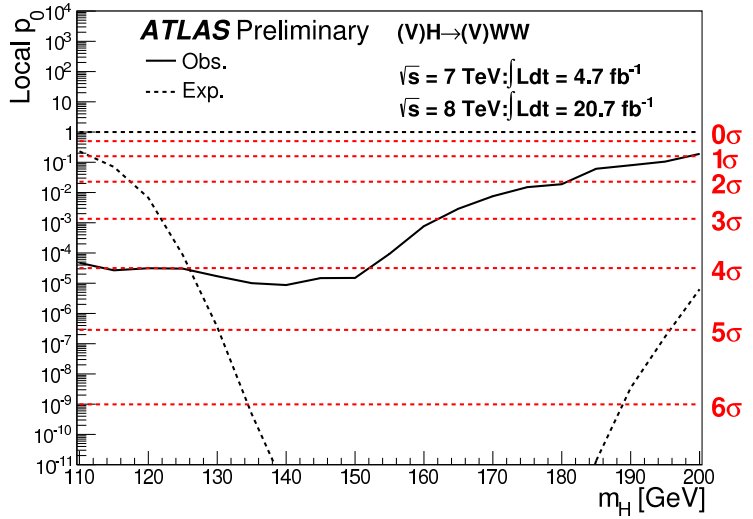
Background subtracted m_{bb} distribution, combining all regions with S/B weighting



$VH \to VWW^*$, $H \to WW^* \to l\nu l\nu$

- Complementary to the $H \to WW^*$ channel with ggF and VBF production.
- Search only for leptonic decays of W and Z bosons.
- Two separate channels: $WH \to WWW^* \to l\nu l\nu l\nu$ and $ZH \to ZWW^* \to lll\nu l\nu$.

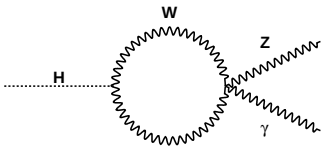




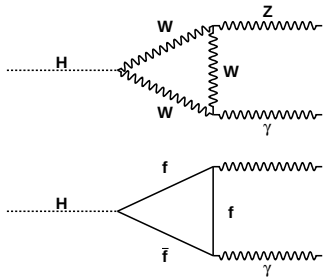
7.2 (3.2 expected) $\times$ SM prediction for $m_H = 125$ GeV at 95% CL

- 4σ (3.8σ exp.) excess when combined with $H \to WW^*$ analysis.

$H \to Z\gamma$, $Z \to l\bar{l}$

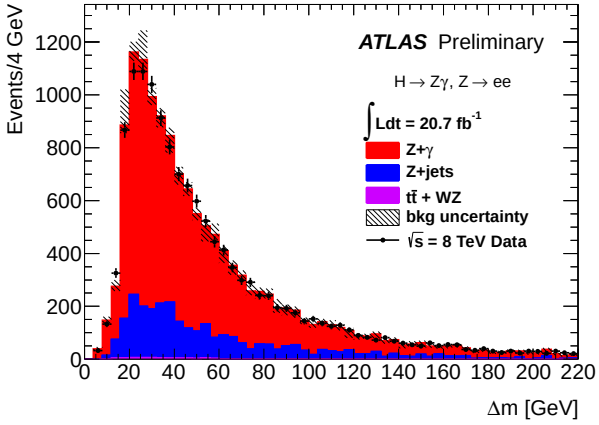


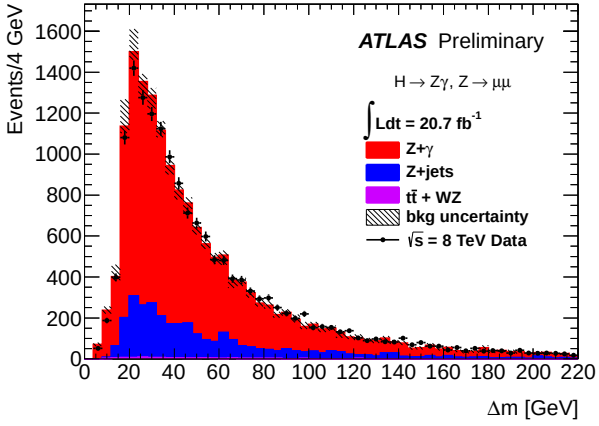
- $H \to Z\gamma$ proceeds via electro-weak loops.
- Much smaller BR than $H \to \gamma\gamma$ but can constrain BSM physics independently.



EVENT SELECTION

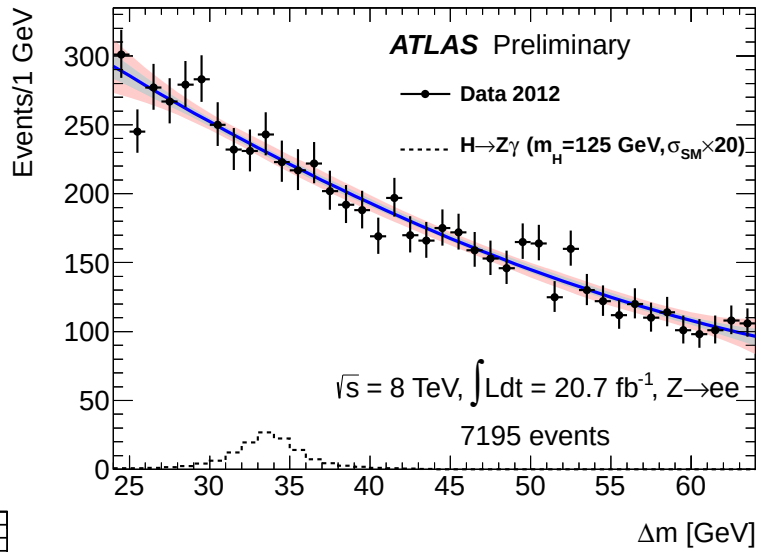
- At least 2 isolated high p_T electrons or muons.
- At least 1 high p_T isolated photon.
- $\Delta R(\gamma, l) > 0.3$.
- $m_{ll\gamma} > (m_Z - 10)$ GeV.
- Use $\Delta m = m_{ll\gamma} - m_{ll}$ as the discriminating variable.

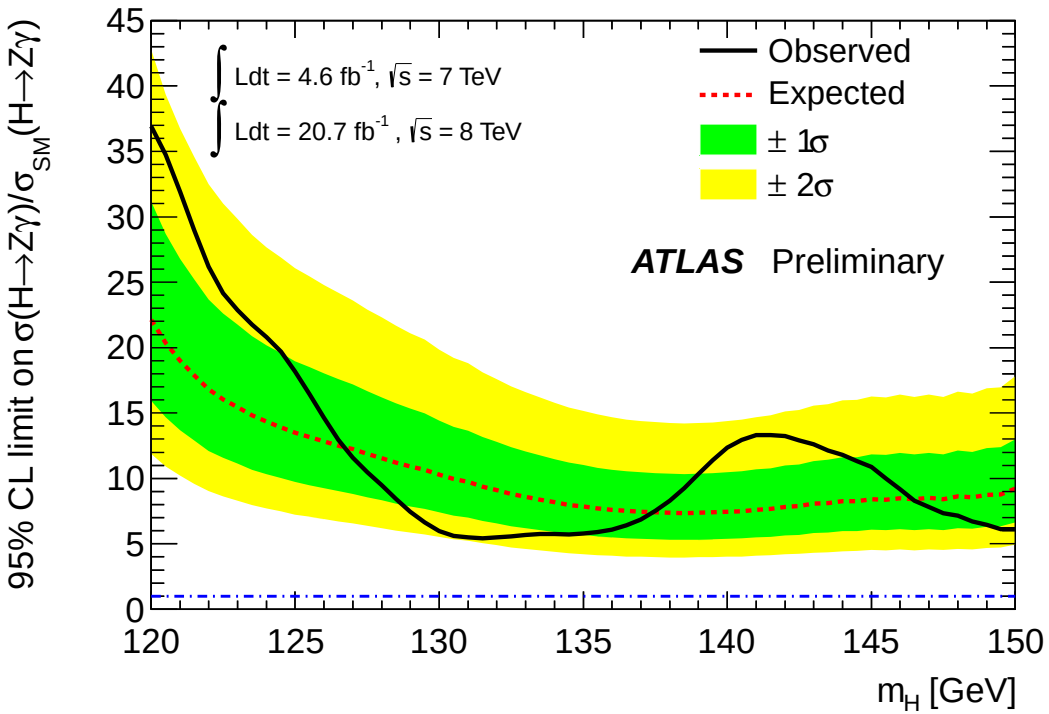




$H \to Z\gamma,\ Z \to l\bar{l}$

- Background determined from data driven method.
- More statistics required before this channel becomes sensitive to SM Higgs boson.

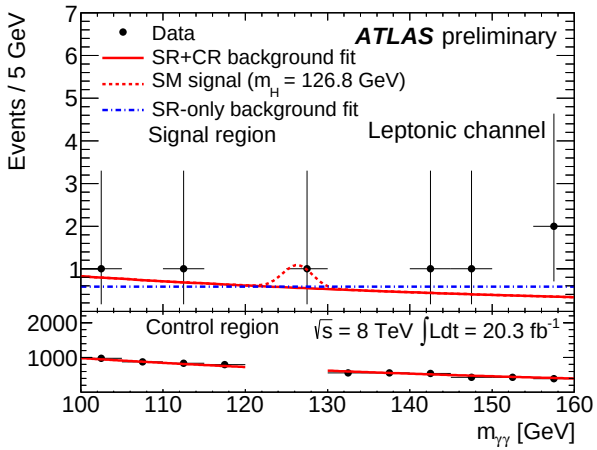


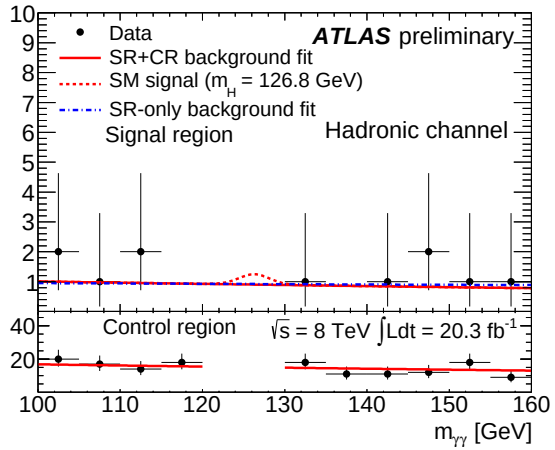


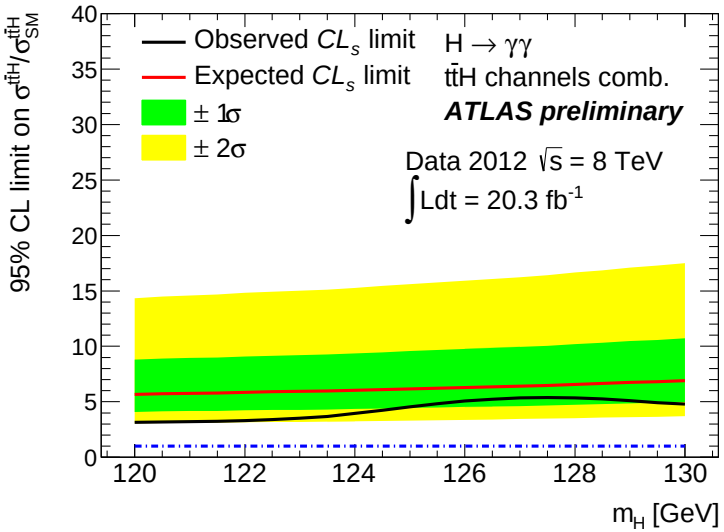
18.2 (13.5 expected) $\times$ SM prediction for $m_H = 125$ GeV at 95% CL

$t\bar{t}H \rightarrow t\bar{t}\gamma\gamma$

- Search includes di-lepton, single lepton and fully hadronic $t\bar{t}$ decays.
- 2 isolated photons, 1 with $p_T > 40$ GeV, the other with $p_T > 30$ GeV.
- Leptonic:
  - At least one electron or muon
  - At least one b-tagged jet.
  - $E_T^{miss} > 20$ GeV.
- Hadronic:
  - 6 jets, at least 2 b-tagged.
  - Lepton veto.





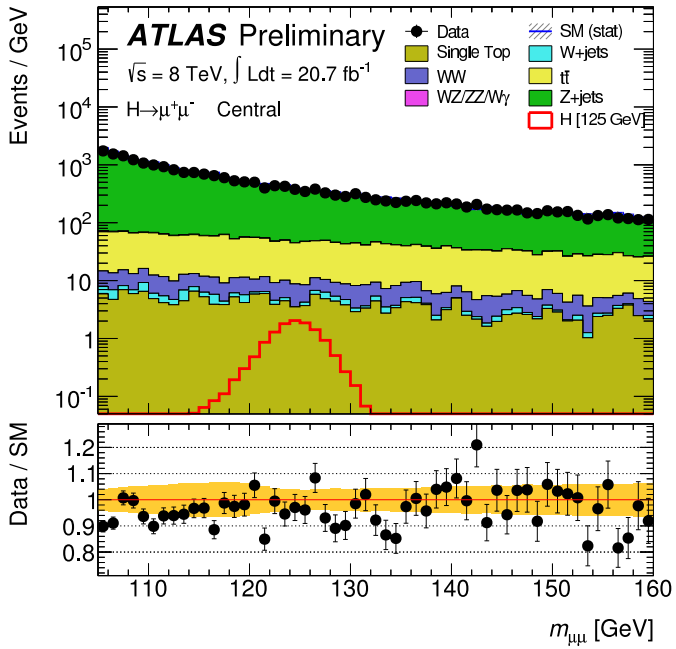


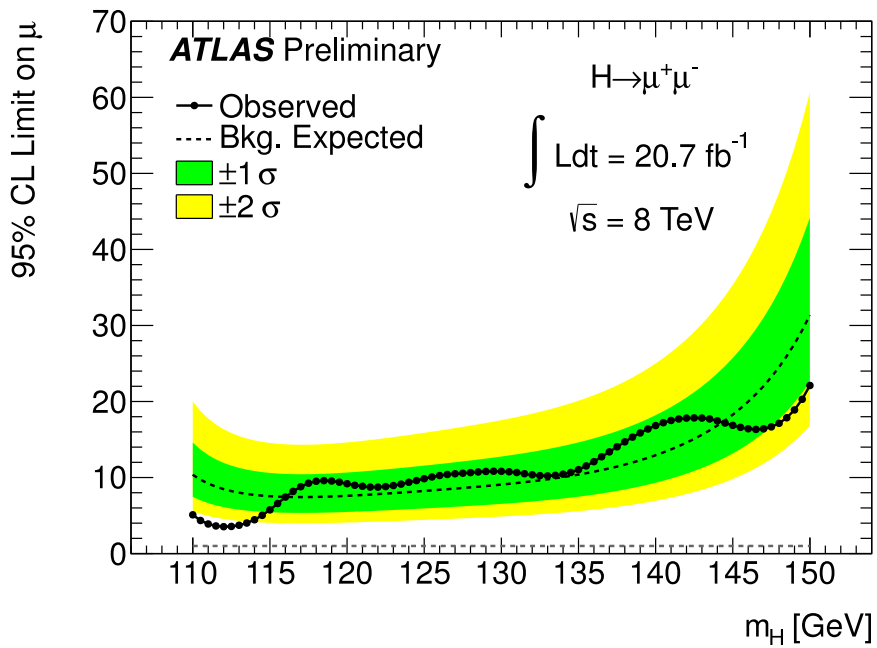
5.3 (6.4 expected) $\times$ SM prediction at $m_H = 126.8$ GeV at 95% CL

$H \to \mu\mu$

- Only channel where coupling to second generation can be measured.
- Large dataset required.

- 2 oppositely charged muons, one with $p_T > 25$ GeV another with $p_T > 15$ GeV.
- Divided into 2 categories, $|\eta(\mu_1, \mu_2)| < 1$ and $1 < |\eta(\mu_1, \mu_2)| < 2.5$ to take advantage of narrower signal width in central region.
- Background modelled by sum of Breit-Wigner and exp.



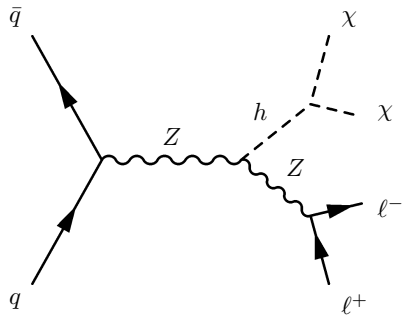


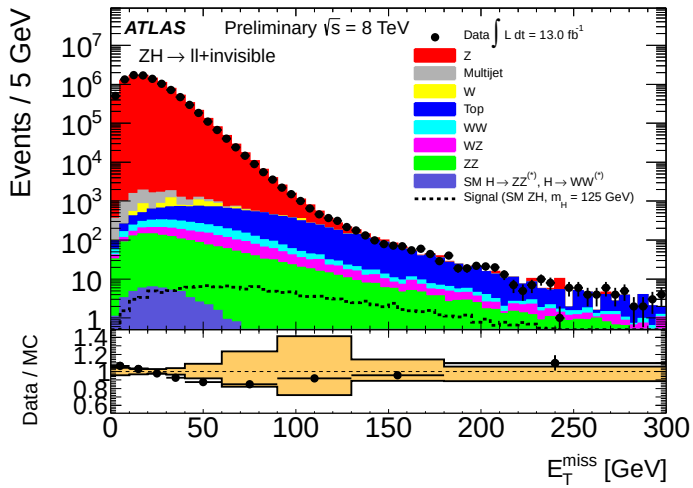
9.8 (8.2 expected) $\times$ SM prediction for $m_H = 125$ GeV at 95% CL

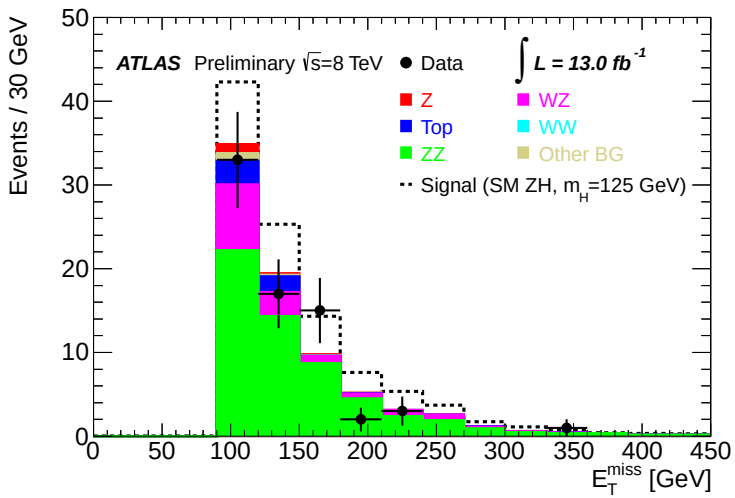
$ZH \rightarrow ll + inv$

- SM Higgs decay to invisible particles via $H \rightarrow ZZ^{(*)} \rightarrow \nu\bar{\nu}\nu'\bar{\nu}'$ is very small.
- Search for enhancements in the inv. decay fraction due to BSM physics from SM Higgs candidate at $m_H = 125$ GeV and for additional Higgs decaying invisibly.
- Assume SM production rate and 100% BR to invisible particles for additional Higgs.

- 2 OS leptons ($p_T > 20$ GeV) with $|m_Z - m_{ll}| < 15$ GeV.
- Third lepton veto ($p_T > 7$ GeV).
- $E_T^{miss} > 90$ GeV.
- $\Delta\phi(l, l) < 1.7$.
- $\Delta\phi(Z, E_T^{miss}) > 2.6$.
- $|E_T^{miss} - p_T^Z|/p_T^Z < 0.2$.
- $\Delta\phi(E_T^{miss}, p_T^{miss} < 0.2)$.
- Jet veto (jets with $p_T > 20$ GeV and $|\eta| < 2.5$).
- E_T^{miss} distribution after all cuts is used as final discriminator.

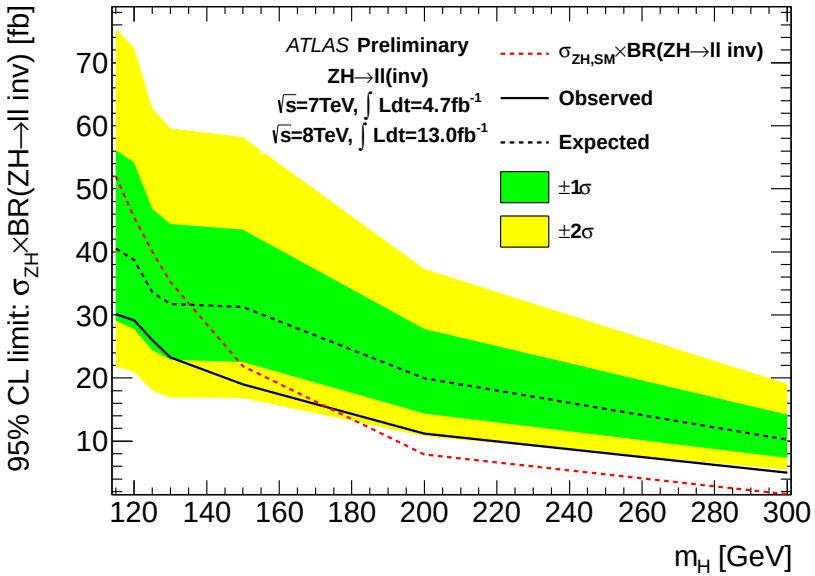


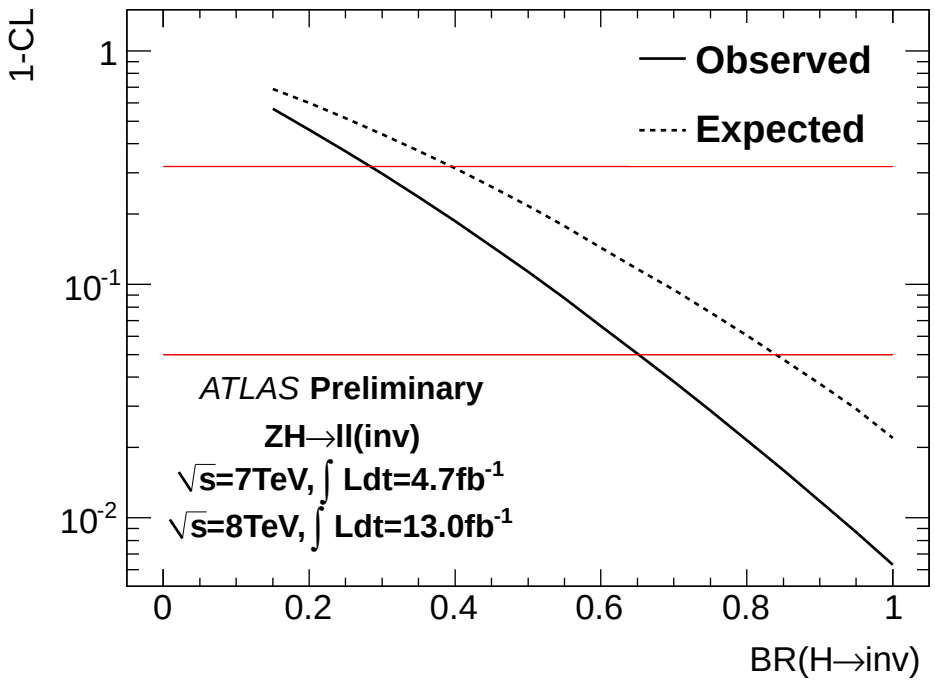




$ZH \rightarrow ll + inv$

- No excess in search for additional Higgs bosons.
- Set limits on $\sigma \times BR$ in range $115 < m_H < 300$ GeV.





- Limit on invisible BR of SM Higgs candidate at $m_H = 125$ GeV.
- Red lines indicate 68% and 95% CL.

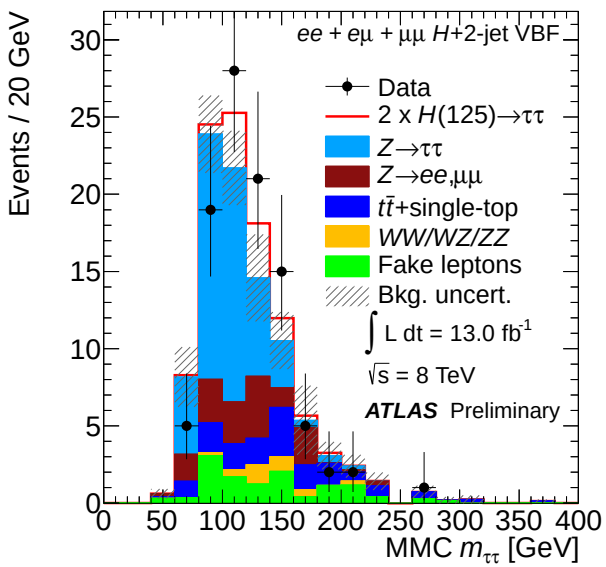
$BR(H \rightarrow inv) <$ 65% (84% expected) for $m_H = 125$ GeV at 95% CL

$H \to \tau\tau$

- Analysis yet to be updated to full 2012 statistics.
- Search includes di-lepton ($\tau_{lep}\tau_{lep}$), single lepton ($\tau_{lep}\tau_{had}$) and fully hadronic ($\tau_{had}\tau_{had}$) channels.

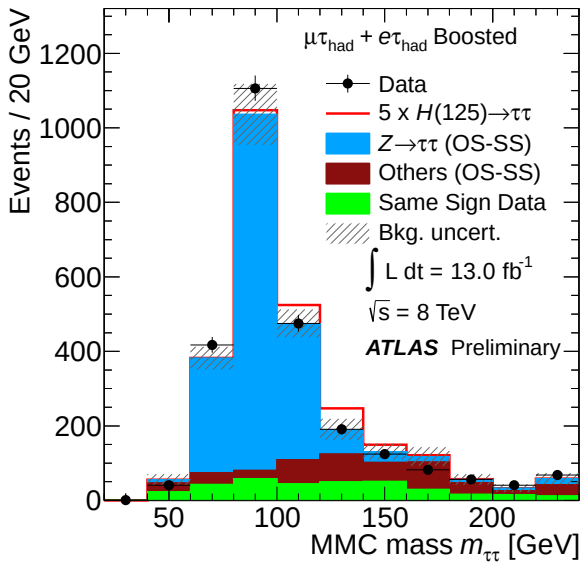
$\tau_{lep}\tau_{lep}$

- 2-jet VBF, Boosted, 2-jet VH, 1-jet and 0-jet



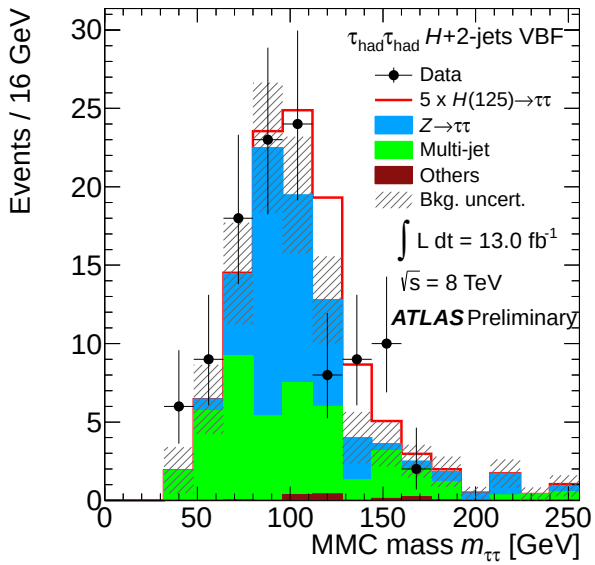
$\tau_{lep}\tau_{had}$

- VBF, Boosted, 1-jet and 0-jet



$\tau_{had}\tau_{had}$

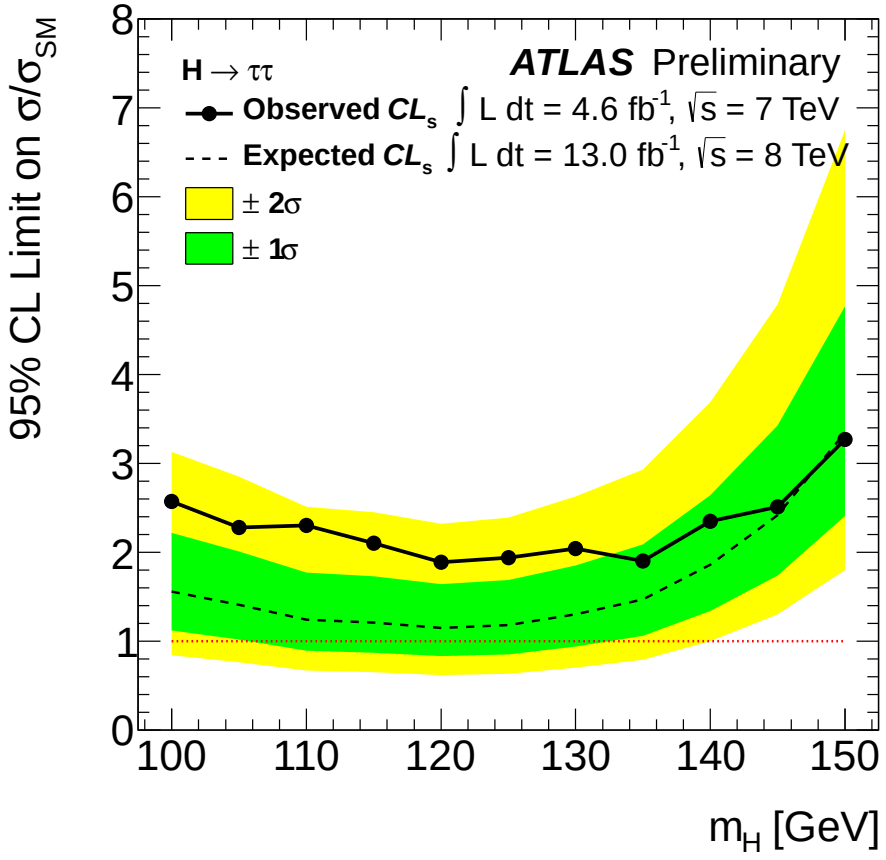
- VBF, Boosted

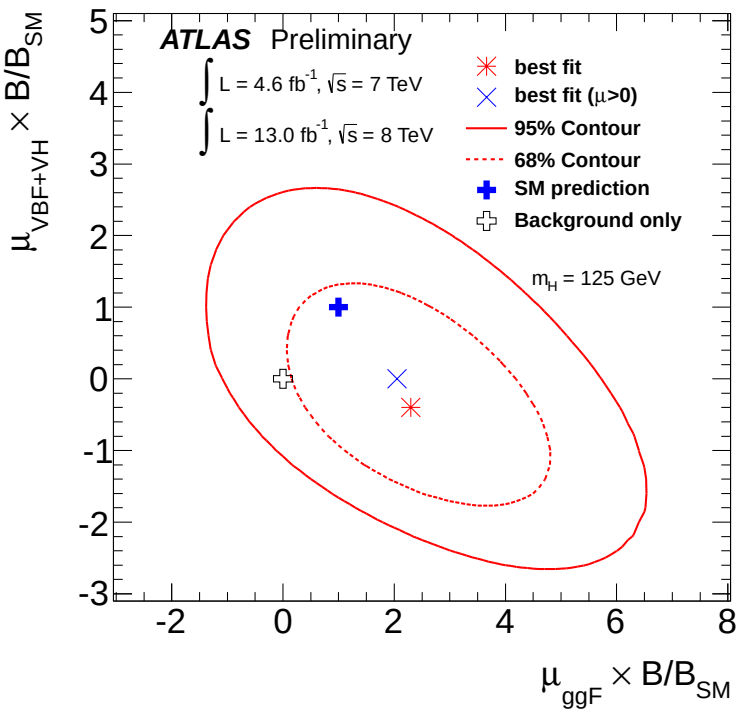


$H \to \tau\tau$

- Combined 2011 + 2012 data has 1.1σ excess above SM background only expectation.
- The observed upper limit on $\sigma \times BR$ at 95% CL on the $H \to \tau\tau$ decay is 1.9 $\times$ SM prediction, 1.2 expected.

best fit $\mu = 0.7 \pm 0.7$ using $m_H = 125$ GeV

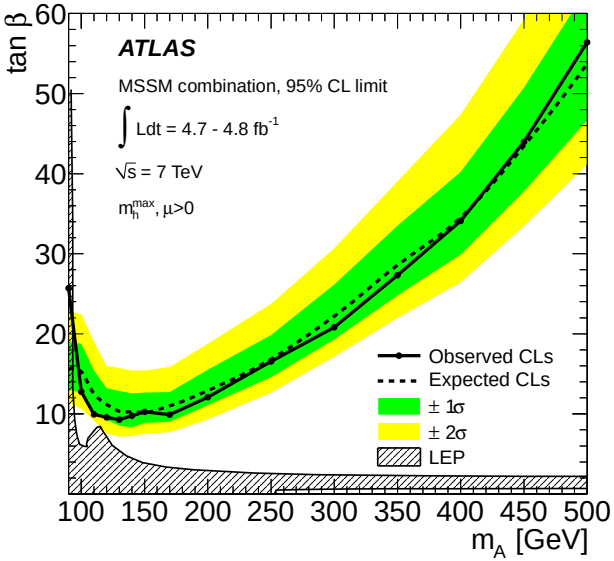




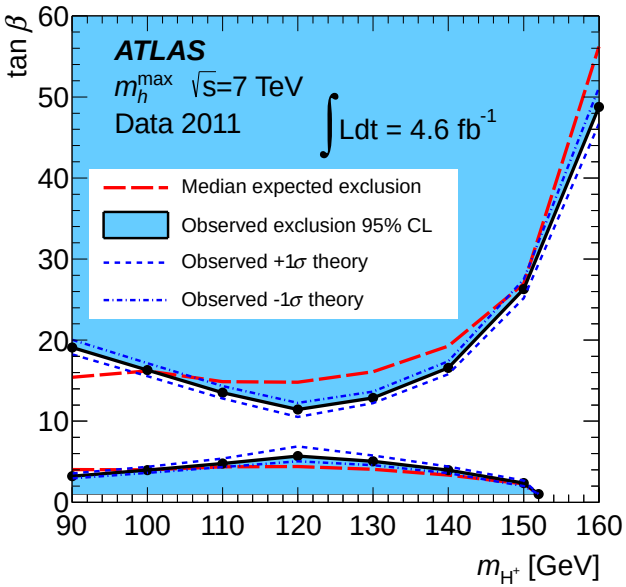
Reminder of BSM Higgs analyses

- 2011 analyses on BSM Higgs searches using 4.7 fb^{-1} at 7 TeV.
- MSSM:
  - $H \to \tau\tau$ and $H \to \mu\mu$ - JHEP02 2013 095
- Charged Higgs:
  - $H^+ \to \tau\nu$ - JHEP 2013 076
  - $H^+ \to c\bar{s}$ - Eur.Phys.J C 73 (2013) 2465
- Doubly charged Higgs:
  - $H \to l^{\pm}l^{\pm}$ - Eur.Phys.J. C72 (2012) 2244

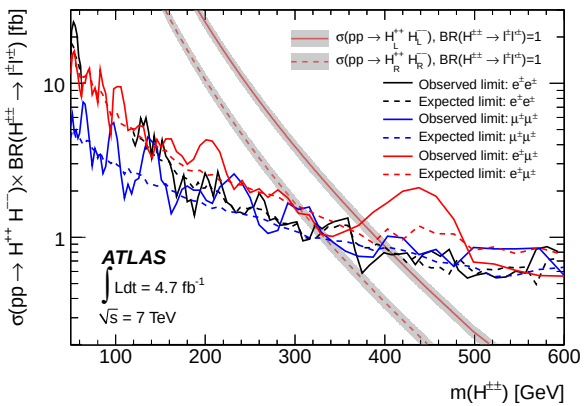
MSSM $H \to \tau\tau$



$H^+ \to \tau\nu$



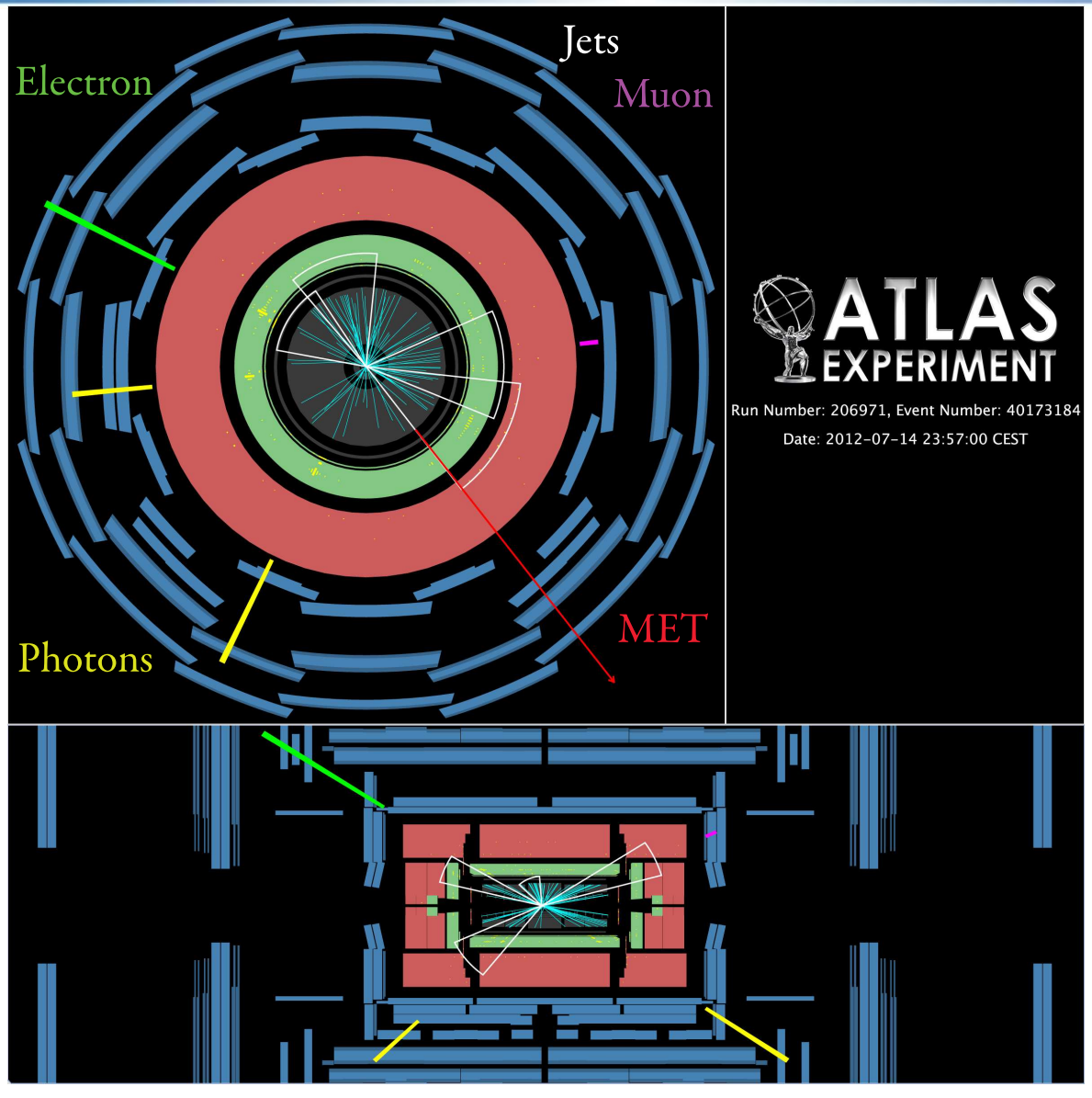
$H \to l^{\pm}l^{\pm}$



Conclusions and Outlook

- Searches for SM Higgs in ATLAS in low-rate final states has been presented.
- $VH \rightarrow Vbb$ and $H \rightarrow \tau\tau$ starting to become sensitive to SM Higgs.
  - Still compatible with both background only and signal plus background expectations.
- $VH \rightarrow VWW^*$ channel gives additional sensitivity to $H \rightarrow WW^*$ analysis.
- $H \rightarrow Z + \gamma$, $t\bar{t}H$ and $H \rightarrow \mu\bar{\mu}$ not yet sensitive to SM Higgs signal.
- $ZH \rightarrow ll + inv$ sets limit on possible BSM physics in the Higgs sector.
  - No excess seen in final E_T^{miss} distribution.
  - Direct(indirect) limit of $BR(H \rightarrow inv)$ at $< 0.65(0.6)$ at 95%CL.
- $H \rightarrow \tau\tau$ and $ZH \rightarrow l\bar{l} + inv$ still to be updated with full 2012 dataset.

Leptonic $t\bar{t}H \rightarrow t\bar{t}\gamma\gamma$ candidate event



Backups

- backups...

$WH \rightarrow WWW^* \rightarrow l\nu l\nu l\nu$

- Exactly 3 isolated leptons, with $p_T > 15$ GeV and total charge ± 1
- One lepton must have $p_T > 25$ GeV
- Split into Z-enriched (one SFOS lepton pair) and Z-depleted (no such pair)

Cut	Z-enriched	Z-depleted
Jet multiplicity	$N_{jet} \leq 1$	
b-veto	$N_{b-tag} = 0$	
$E_{T,Rel}^{miss}$	$E_{T,Rel}^{miss} > 40$ GeV	$E_{T,Rel}^{miss} > 25$ GeV
Dilepton mass cut	$\lvert m_{ll} - m_Z \rvert < 25$ GeV and $m_{ll} > 12$ GeV	$m_{ll} > 12$ GeV
Angular cut	$\Delta\phi_{l_0 l_1} < 2.0$	
overlap	Remove events selected by $H \rightarrow WW^*$	

$ZH \rightarrow ZWW^* \rightarrow l\bar{l}l\nu l\nu$

Cut		
E_T^{miss}	$E_T^{miss} > 30$ GeV	
p_T^l	highest p_T lepton: $p_T > 25$ GeV second highest p_T lepton: $p_T > 20$ GeV third highest p_T lepton: $p_T > 15$ GeV fourth highest p_T lepton: $p_T > 10$ GeV	
Jet multiplicity	$N_{jet} \leq 1$	
b-veto	$N_{b-tag} = 0$	
Mass cuts	$\lvert m_{l_2 l_3} - m_Z \rvert < 10$ GeV $10 < \lvert m_{l_0 l_1} \rvert < 65$ GeV	
Angular cut	$\Delta\phi_{01} < 2.5$	
Channel separation	2SFOS	1SFOS
p_{T4l}	$p_{T4l} > 30$ GeV	-
m_{4l}	$m_{4l} > 130$ GeV	-
overlap	Remove events selected by $H \rightarrow WW^*$	

$VH \rightarrow Vbb$ selection

Object	0-lepton	1-lepton	2-lepton
Leptons	0 loose lept	1 tight + 0 loose lept	1 med. + 1 loose lept
Jets	$2\ b-tagged$ jets $p_T^{jet_1} > 45$ GeV $p_T^{jet_2} > 20$ GeV $2\ b-tagged$ jets ≤ 1 extra jets		
E_T^{miss}	$E_T^{miss} > 120$ GeV $p_T^{miss} > 30$ GeV $\Delta\phi(E_T^{miss}, p_T^{miss}) < \pi/2$ $\min[\Delta\phi(E_T^{miss}, jet)] > 1.5$ $\Delta\phi(E_T^{miss}, bb) > 2.8$	$E_T^{miss} > 25$ GeV	$E_T^{miss} < 60$ GeV
Vector boson	-	$m_T^W < 120$ GeV	$83 < m_{ll} < 99$ GeV