Higgs boson searches at ATLAS

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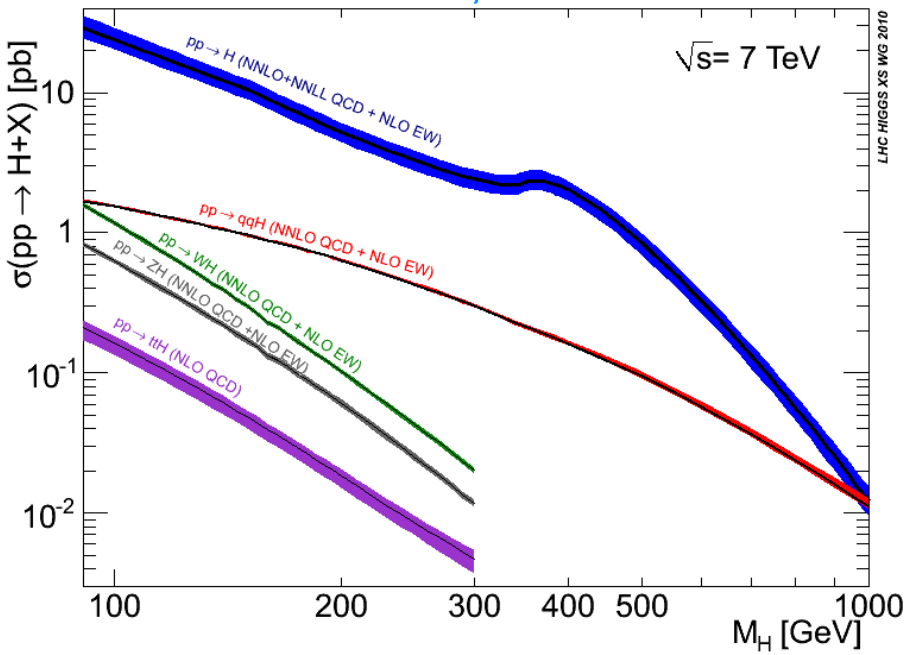
on behalf of the ATLAS collaboration

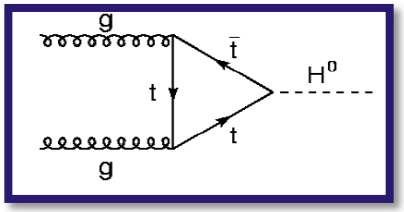
Outline

- Higgs at the LHC
- ATLAS data taking in 2011
- Searches for SM Higgs
  - Intermediate and high mass searches with WW
  - Intermediate and high mass searches with ZZ
  - Low mass searches
  - ATLAS SM Higgs combination
- Searches for MSSM + BSM Higgs
- Conclusions and prospects

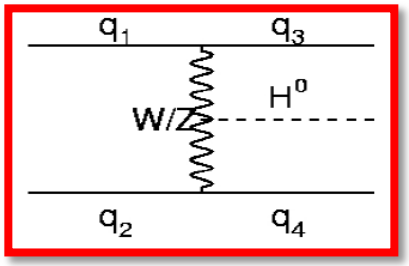
Higgs production at the LHC

CERN-2011-002; arXiv:1101.0593

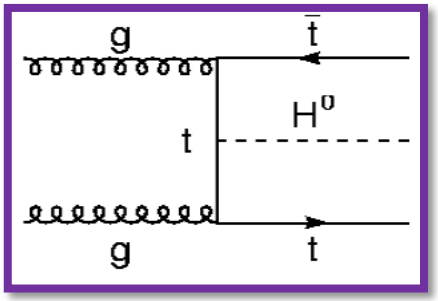


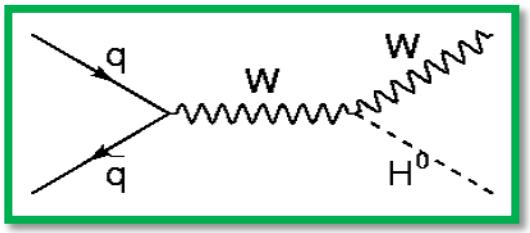


Gluon fusion is dominant at LHC



Vector Boson Fusion is very distinctive (2 forward jets)



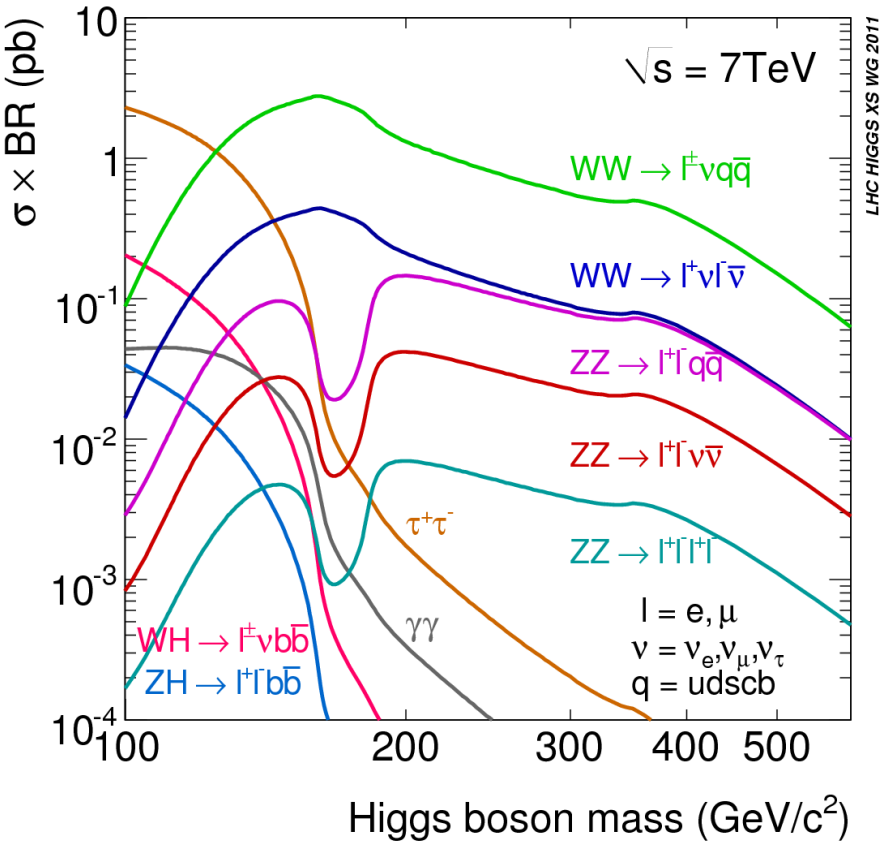


Associated production with W/Z provides improved trigger signature for H → bb over QCD background. Important at low mass.

Higgs decay channels

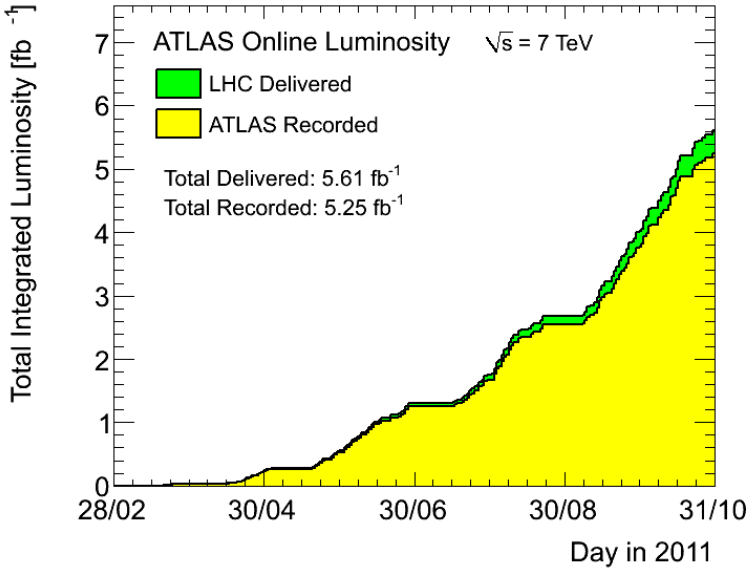
- $H \rightarrow WW^{(*)}$
  - $WW \rightarrow l\nu qq$ very large rate; important at high mass
  - **$WW \rightarrow l\nu l\nu$ most sensitive**
- $H \rightarrow ZZ^{(*)}$
  - $ZZ \rightarrow llqq$ good for high mass
  - **$ZZ \rightarrow llvv$ best for high mass**
  - **$ZZ \rightarrow llll$ "golden" channel**
- **$H \rightarrow \gamma\gamma$**
  - **Rare; best for low mass**
- $H \rightarrow \tau\tau$
  - Rare, but good s/b; low mass
- $H \rightarrow bb$
  - Associated production with W/Z
  - Useful but difficult

CERN-2011-002; arXiv:1101.0593



ATLAS data taking in 2011

- ATLAS recorded 5.25 fb^{-1} in 2011
  - Data taking efficiency 93.5%
- Higgs boson searches performed with 1.0-2.3 fb^{-1}



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ATLAS EXPERIMENT

Intermediate and high mass searches with WW

- $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$: highest sensitivity
- $H \rightarrow WW^{(*)} \rightarrow l\nu qq$

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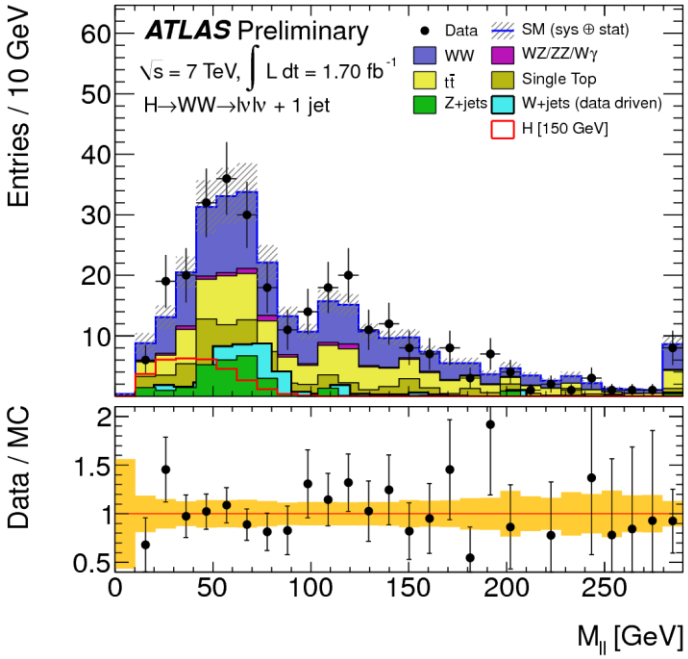
ATLAS EXPERIMENT

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

- 1.7 fb^{-1} of data; ATLAS-CONF-2011-134
- Most sensitive process for $120 < m_H < 200$ GeV
  - Challenging because reconstruction of invariant mass not possible due to two neutrinos
- Event selection
  - 2 opposite sign, high p_T, isolated leptons
  - Cuts on m_{ll} to veto dileptons from Υ, γ^*, Z
  - Large E_T^{miss} separated from the nearest lepton/jet
  - 0 or 1 high p_T light jet
- Event counting analysis
  - Topological cuts on dilepton (m, p_T, $\Delta\phi$)
  - Cut on transverse mass



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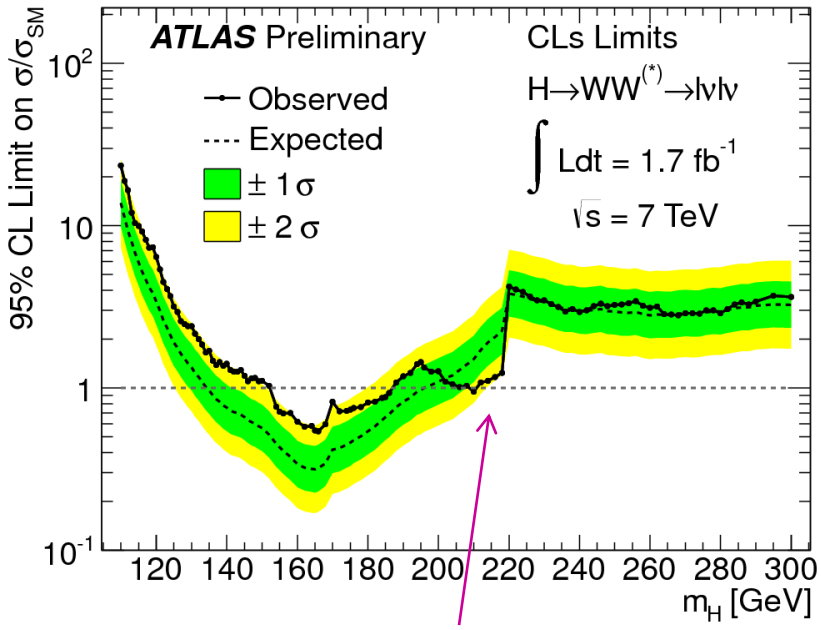
ATLAS EXPERIMENT

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

- Main backgrounds
  - WW, top, W+jets, Z+jets estimated from data-driven methods
- Dominant systematics
  - JES, E_T^{miss} measurement (6.1%)
- No significant excess observed
  - Largest deviation from expectation is 2σ at m_H = 130 GeV
  - SM Higgs excluded at 95% CL between 154-186 GeV

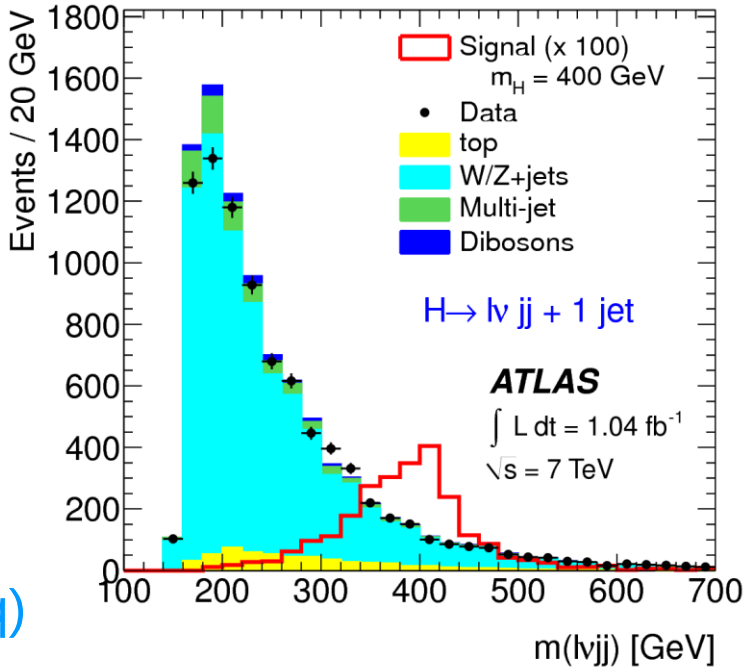
σ/σ_{SM}	Higgs production cross section we exclude, divided by the expected Higgs cross section in Standard Model
	Higgs excluded at 95% CL below this line
	Observed
	Expected without Higgs
	Expected region at 68% Confidence Level
	Expected region at 95% Confidence Level



Change in cuts

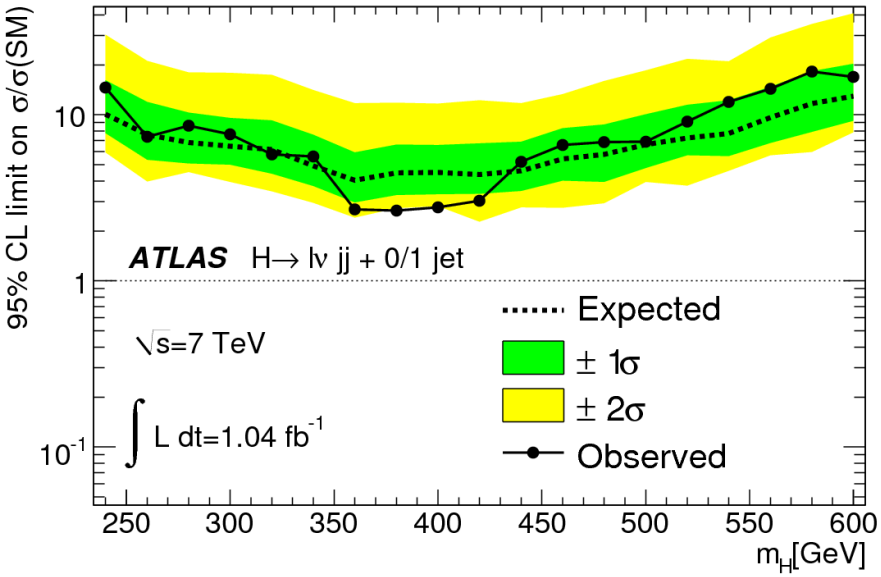
$H \rightarrow WW^{(*)} \rightarrow l\nu qq$

- 1.04 fb^{-1} of data; arXiv:1109.3615
- Acceptable s/b at high mass
  - $m_H > 2m_W$ if both W's are on-shell
  - Search in $240 < m_H < 600$ GeV
- Event selection
  - Exactly 1 high p_T, isolated lepton
  - Large E_t^{miss}
  - 2 or 3 high p_T jets with one pair coming from W decay
- Shape analysis of invariant mass m(lνqq)
  - Impose $m_{l\nu} = m_W$



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

- Main backgrounds
  - Z+jets dominates
  - Z+jets, W+jets, top shape predicted from MC, fitted to data
  - QCD multjets estimated from data-driven methods
- Dominant systematics
  - Jet energy scale (17%)
  - Theory (19.4%)
  - Jet energy resolution (8.6%)
- No significant excess observed
  - Upper limit at m_H = 400 GeV is 2.7 × SM prediction



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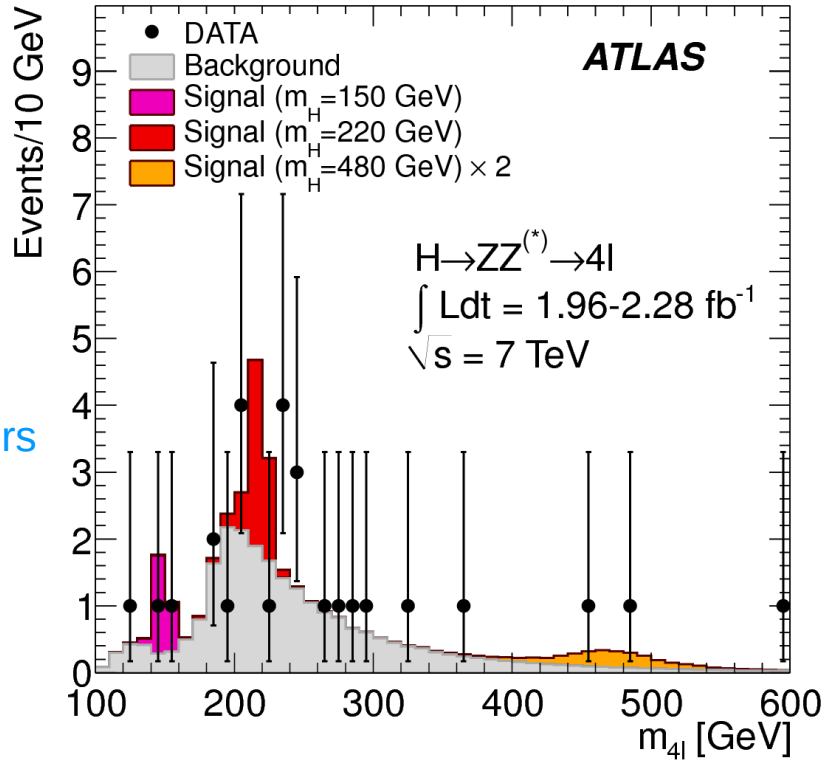
ATLAS EXPERIMENT

Intermediate and high mass searches with ZZ

- $H \rightarrow ZZ^{(*)} \rightarrow llll$: golden channel
- $H \rightarrow ZZ^{(*)} \rightarrow ll\nu\nu$: most sensitive for high mass
- $H \rightarrow ZZ^{(*)} \rightarrow llqq$

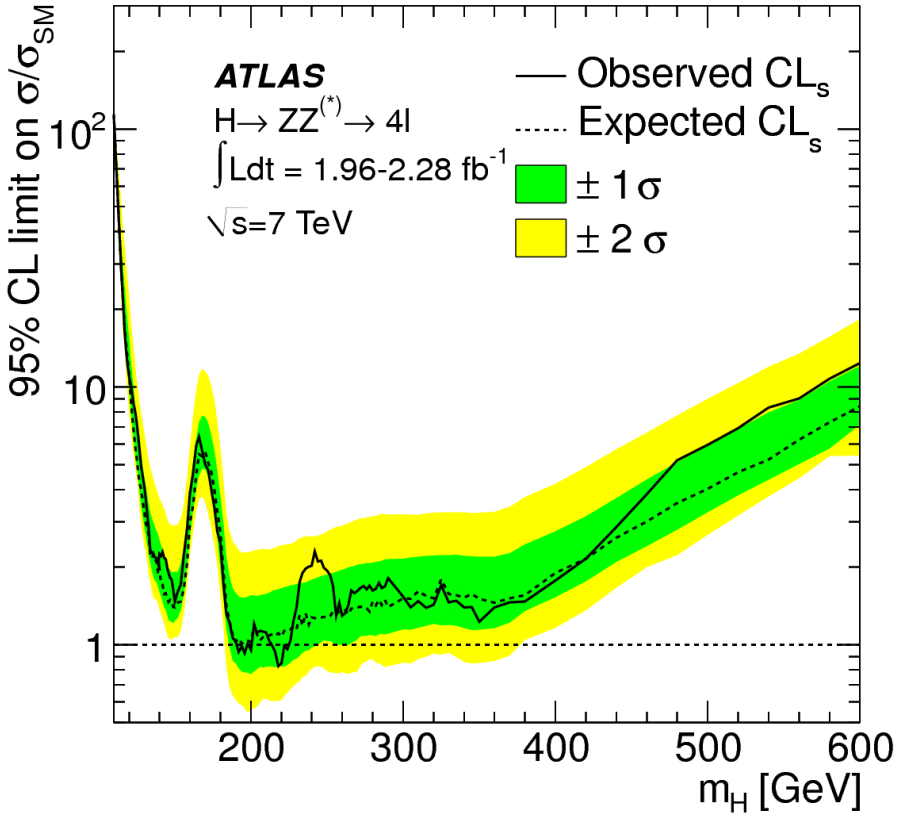
$H \rightarrow ZZ^{(*)} \rightarrow 4l$

- 2.1 fb^{-1} of data;
  Phys. Lett. B 705 (2011) 435-451
- "Golden" channel
  - Very clean (narrow resonance over continuum), but low rates
  - Search in $110 < m_H < 600$ GeV
- Event selection
  - 2 same-flavour, opposite sign dilepton pairs
  - At least one pair from Z
  - All leptons are isolated
  - Constraint on impact parameter for $m_{4l} < 2m_Z$
- Shape analysis of invariant mass m_{4l}



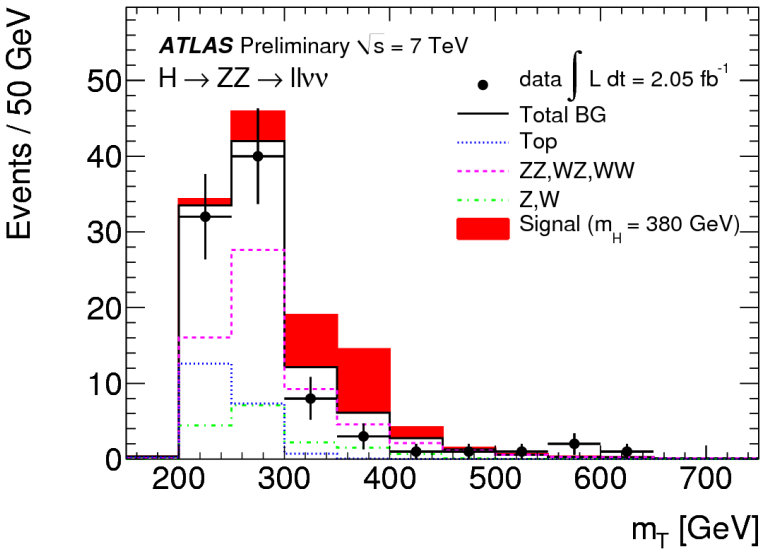
$H \rightarrow ZZ^{(*)} \rightarrow 4l$

- Main backgrounds
  - ZZ from MC (irreducible)
  - ttbar also from MC
  - Z+jets, Z+bb shape from MC, normalised using data
- Dominant systematics
  - e/γ efficiency (3.3%)
  - μ efficiency (1.2%)
- Follows SM prediction quite well
  - Some fluctuations due to single events
  - SM Higgs excluded at 95% CL in mass ranges 191-197, 199-200 and 214-224 GeV



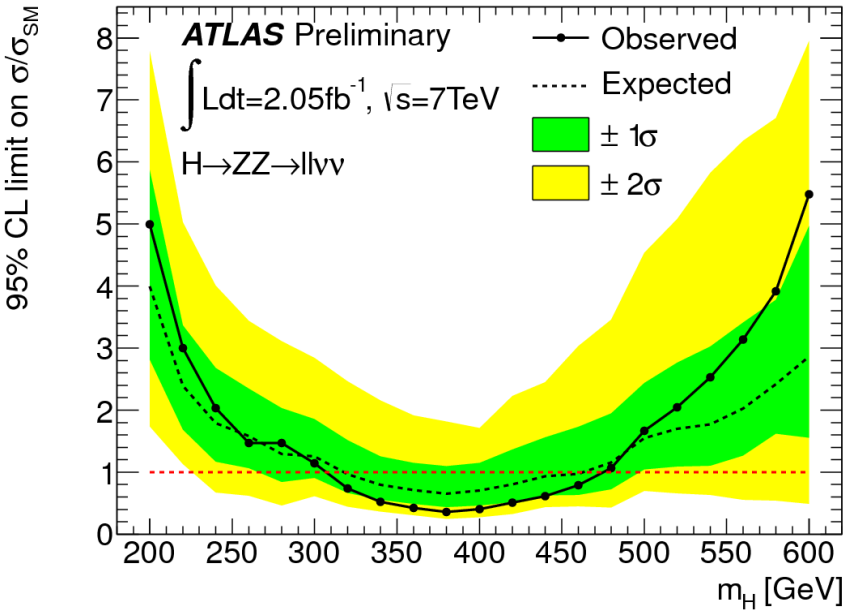
$H \rightarrow ZZ^{(*)} \rightarrow llνν$

- 2.05 fb^{-1} of data; ATLAS-CONF-2011-148
- Significant s/b for $200 < m_H < 600$ GeV
  - Same final state as $WW^{(*)} \rightarrow lνlν$
- Event selection
  - Z selection with 2 opposite sign, high p_T, isolated leptons
  - Large E_T^{miss}
  - Jets well separated from E_T^{miss}
  - Veto events with b-tags
  - Topological cuts for Z(νν)
- Shape analysis of transverse mass m_T
  - All E_T^{miss} assumed to be from Z



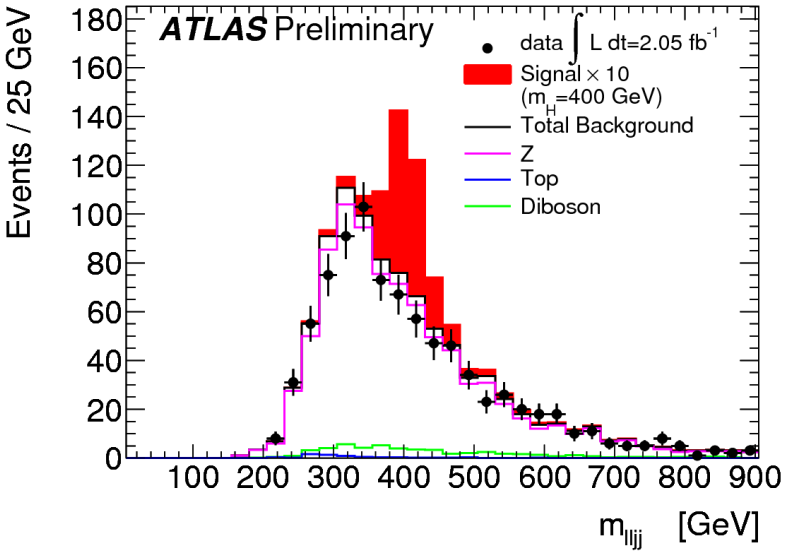
$H \rightarrow ZZ^{(*)} \rightarrow llνν$

- Main backgrounds
  - Dibosons from MC (irreducible)
  - Z+jets, ttbar, QCD multijets estimated from data-driven methods
- Dominant systematics
  - E_T^{miss} measurement (+6.6%/-4.2%)
- No significant excess observed
  - SM Higgs excluded at 95% CL between 310-470 GeV



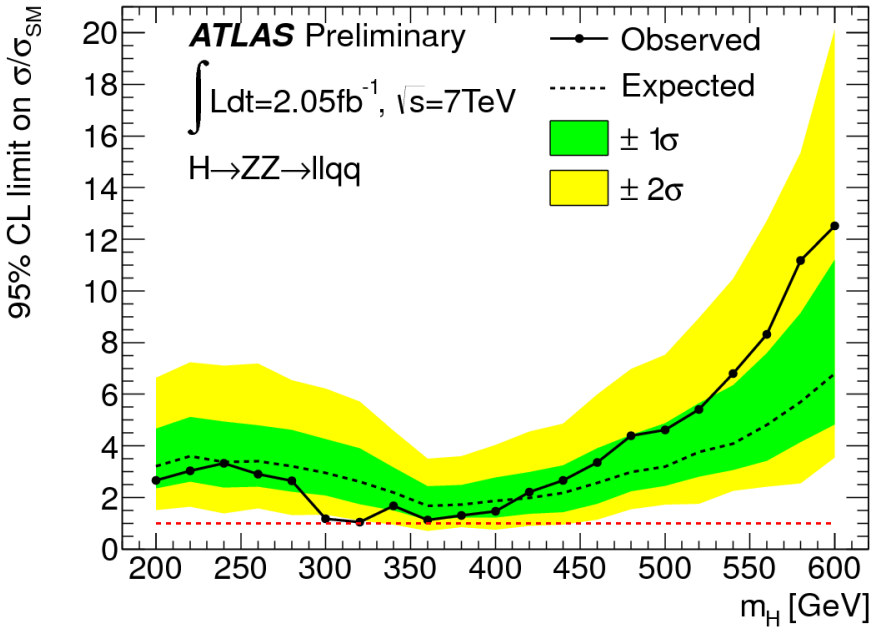
$H \rightarrow ZZ^{(*)} \rightarrow llqq$

- 2.05 fb^{-1} of data; ATLAS-CONF-2011-150
- Acceptable s/b for $m_H > 2m_Z$
  - Both Z's are on shell
- Event selection
  - Z selection with 2 opposite sign, high p_T, isolated leptons
  - Veto additional leptons
  - Z selection with 2 high p_T jets
  - Low E_t^{miss}
- Shape analysis of invariant mass m_{lljj}
  - Angular kinematic cuts for $m_H > 300$ GeV



$H \rightarrow ZZ^{(*)} \rightarrow llqq$

- Main backgrounds
  - Z+jets, ttbar estimated from data-driven methods
- Dominant systematics
  - Jet energy scale (+3.7%/-10.4%)
- Good sensitivity in a large mass range
  - No SM exclusion yet



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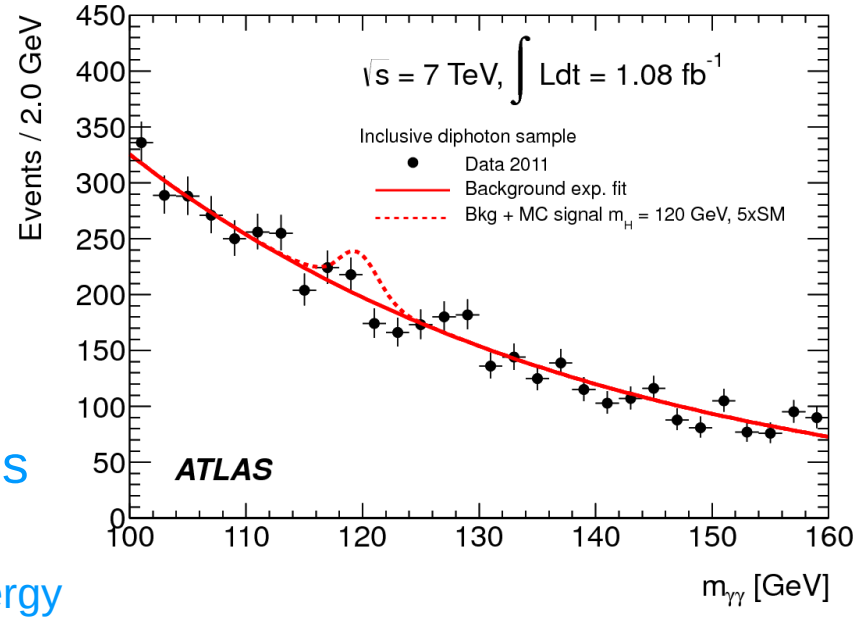
ATLAS EXPERIMENT

Low mass searches

- $H \rightarrow \gamma\gamma$: most sensitive
- $H \rightarrow \tau\tau$
- $W/Z + H \rightarrow l\nu/ll + bb$

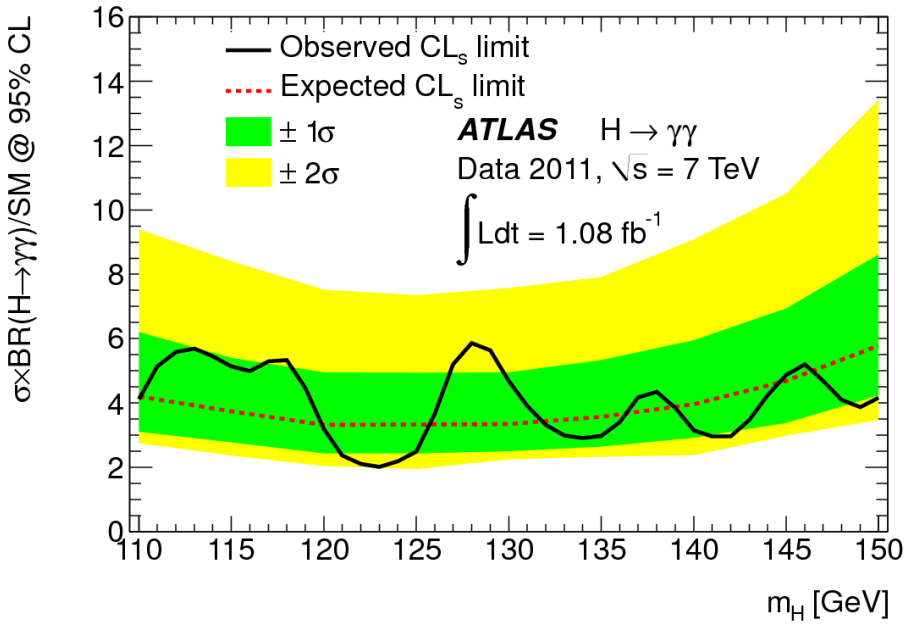
$H \rightarrow \gamma\gamma$

- 1.08 fb^{-1} of data;
  Phys. Lett. B 705 (2011) 452-470
- Rare decay from W/t loop
  - Clean signature
  - Best for low mass
  - Shape analysis of invariant mass $m_{\gamma\gamma}$
- Event selection
  - 2 high p_T, isolated photons
- Analysis separated into 5 categories
  - η bins and converted/unconverted
  - Data-driven methods for estimating energy resolution and pointing resolution



H → γγ

- Main backgrounds
  - γγ + X estimated from data-driven methods (irreducible)
  - γj, jj + X estimated from data-driven methods
- Dominant systematics
  - γ efficiency (+11.6%/-10.4%)
- No significant excess observed
  - Still statistics limited



$H \rightarrow \tau\tau$

- Promising channel for $110 < m_H < 150$ GeV
  - VBF production offers small background, but low signal production rate
- Three classes of final states depending on τ decay
  - Lepton-lepton (ll)
  - Lepton-hadron (lh)
  - Hadron-hadron (hh) : not studied at ATLAS
- Main backgrounds
  - Z(ll)+jets, W(lν)+jets, QCD multijet estimated using data-driven methods
  - Z(ττ) irreducible
- Dominant systematics
  - Jet energy scale (+3.3%/-10.0% for ll, +19%/-16% for lh)

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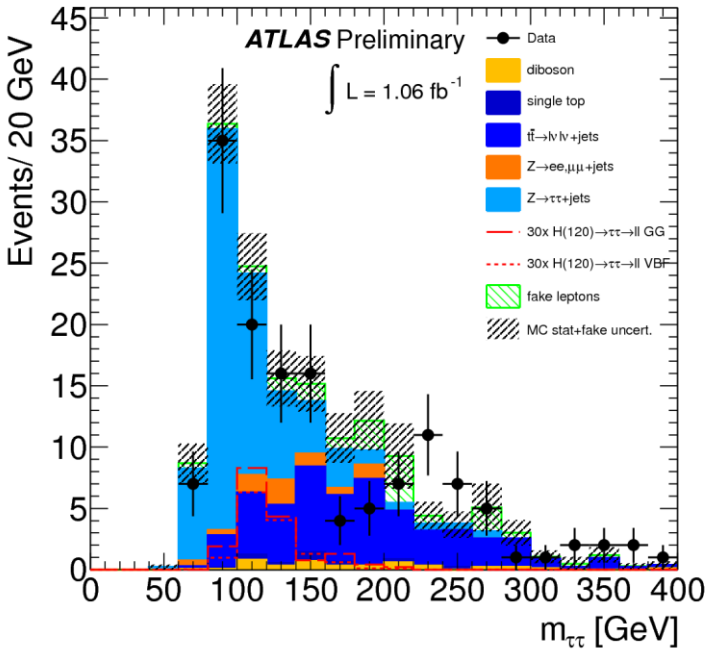
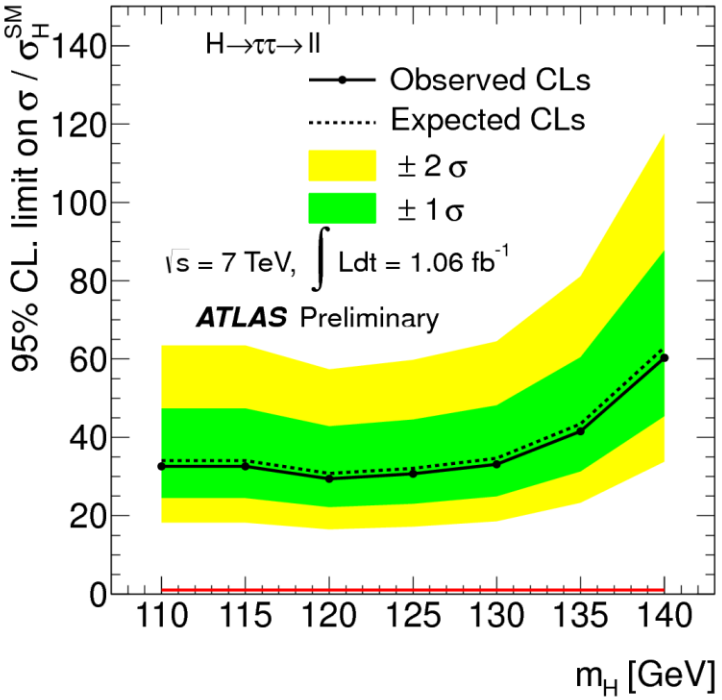
$H \rightarrow \tau\tau \rightarrow ll + 4\nu$

- 1.06 fb^{-1} of data; ATLAS-CONF-2011-133
- Event selection
  - 2 opposite sign, high p_T, isolated leptons
  - Cuts on m_{ll} to veto dileptons from Υ, γ^*, Z
  - At least 1 high p_T jet
  - Large E_T^{miss}
- Event counting analysis
  - Reconstruct $m_{\tau\tau}^{effective}$ using collinear approximation
  - Apply mass window cut





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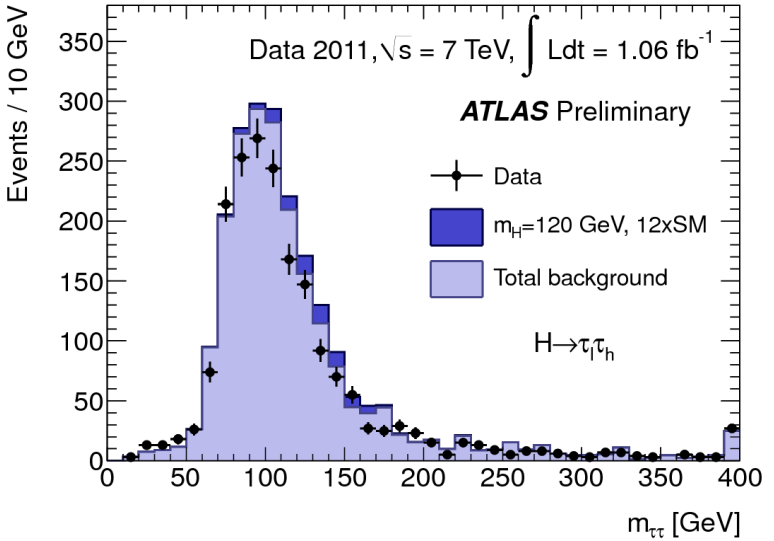
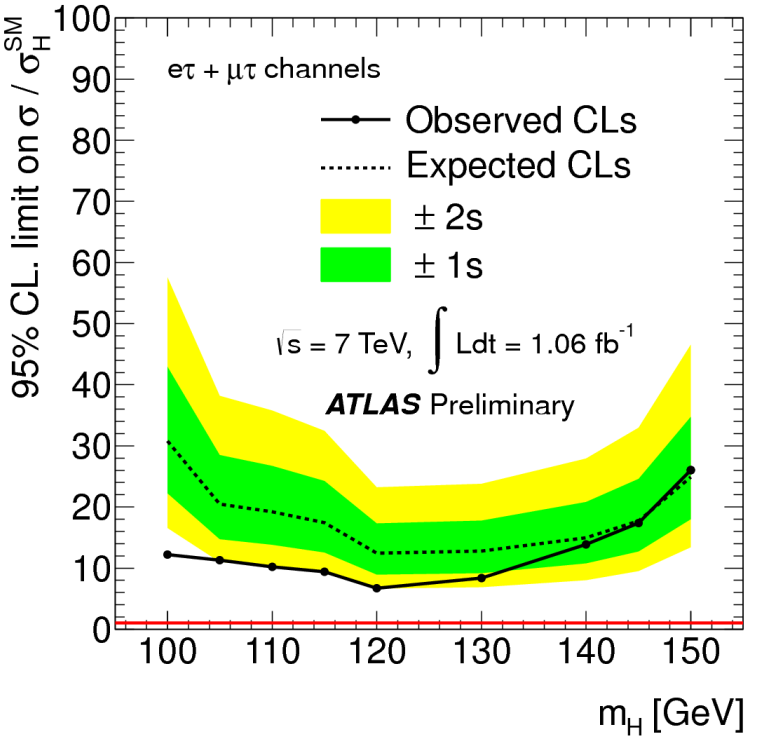
$H \rightarrow \tau\tau \rightarrow l\tau_{had} + 3\nu$

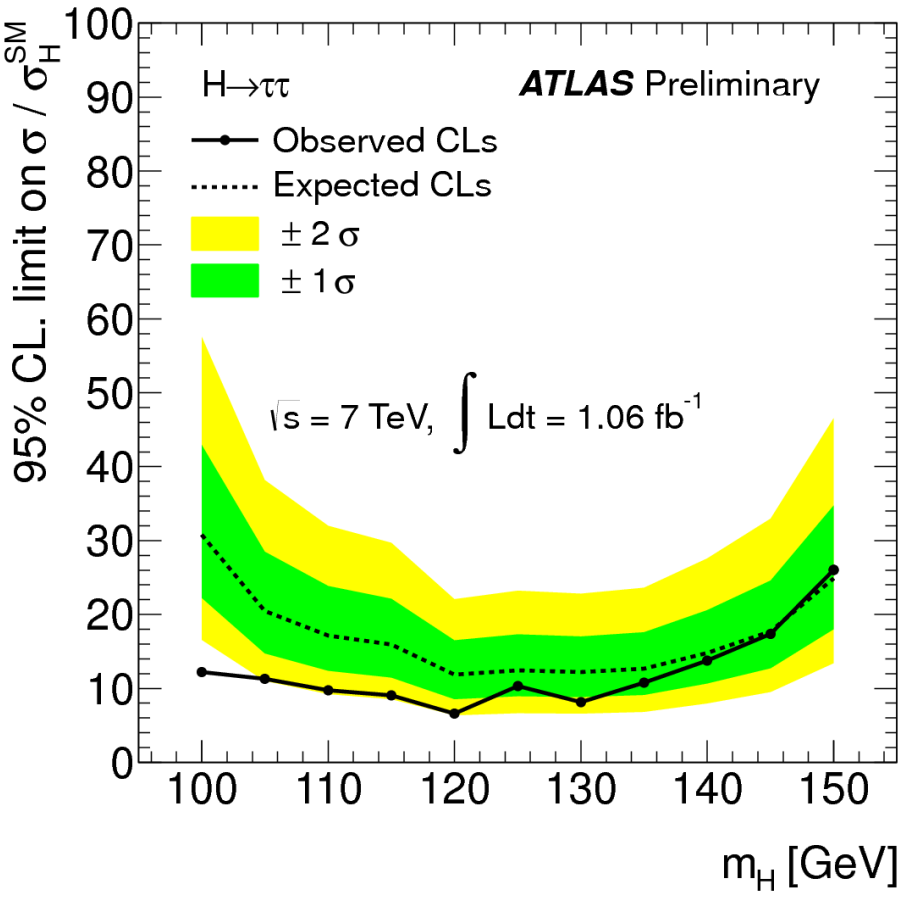
- 1.06 fb^{-1} of data; ATLAS-CONF-2011-132
- Event selection
  - 1 high p_T, isolated lepton
  - 1 high p_T τ_{had}
  - Large E_T^{miss}
  - Cut on transverse mass
- Shape analysis using Missing Mass Calculator (MMC)
  - New mass reconstruction technique





$H \rightarrow \tau\tau$

- Combined limit is dominated by lepton-hadron limit



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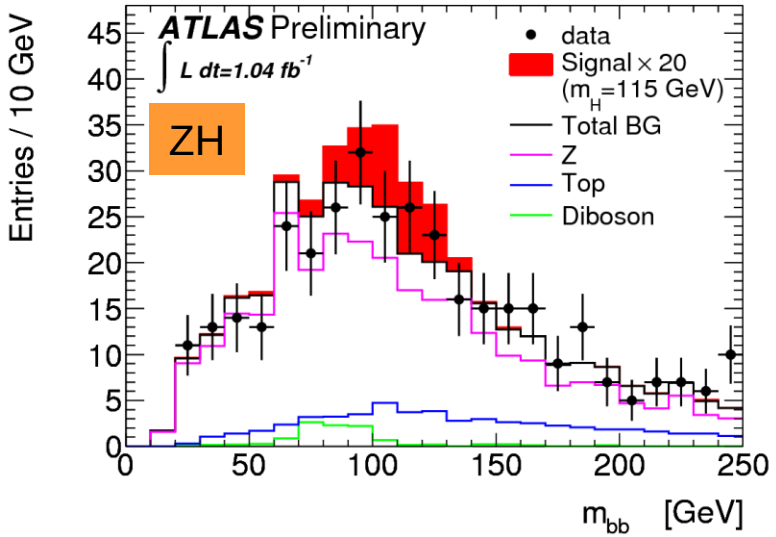
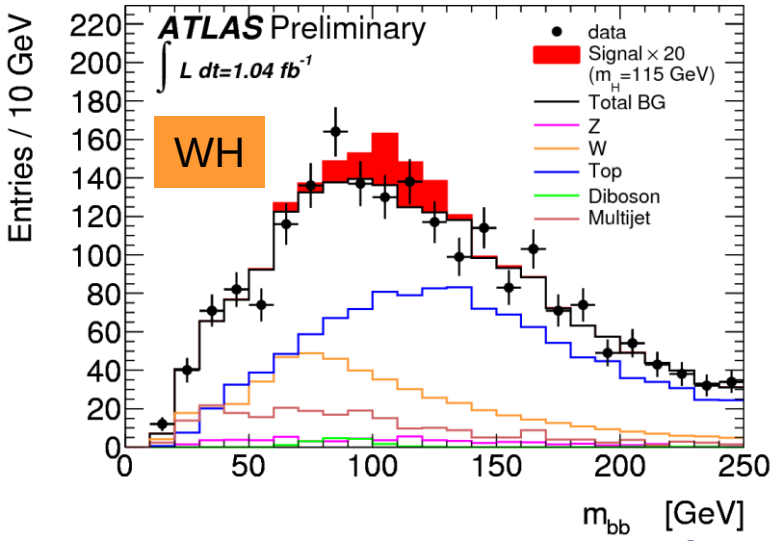
ATLAS EXPERIMENT

W/Z + H → lν/ll + bb

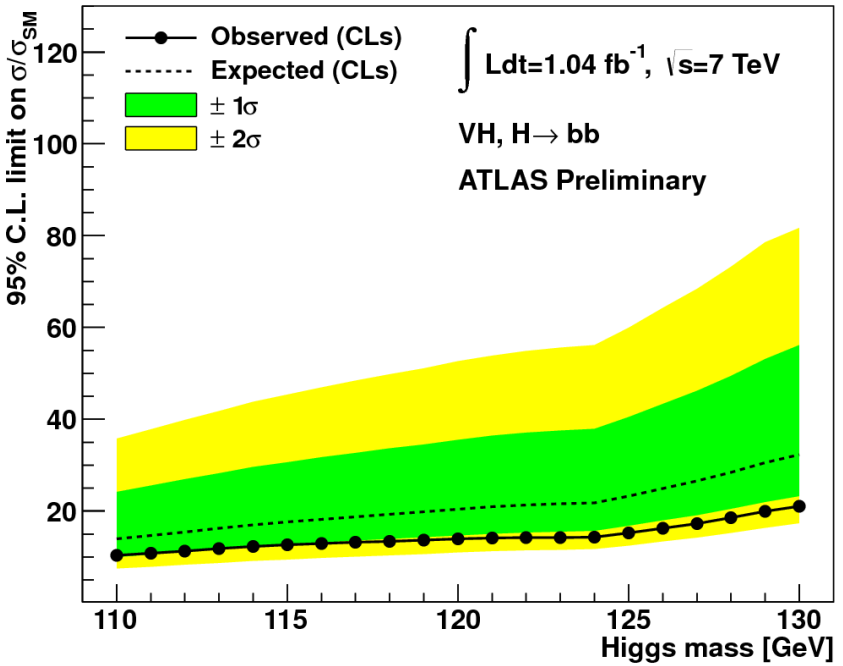
- 1.04 fb^{-1} of data; ATLAS-CONF-2011-103
- H → bb is dominant decay channel for $110 < m_H < 130$ GeV
  - QCD jet background renders an inclusive search impossible and a search in association with W/Z and ttbar challenging
  - Possibility of directly measuring Higgs to quark couplings
- Event selection
  - Identify W/Z leptonic decay
  - Exactly 2 b-tagged, high p_T jets
  - WH cuts to veto ttbar
  - ZH cuts to veto E_T^{miss}
- Shape analysis of invariant mass m_{bb}





W/Z + H → lν/ll + bb

- Main backgrounds
  - W+jets, Z+jets, top, QCD multijets estimated from data-driven methods
  - Diboson from MC
- Dominant systematics
  - b-tag efficiency (17%)
- No significant excess observed



ATLAS Standard Model Higgs combination

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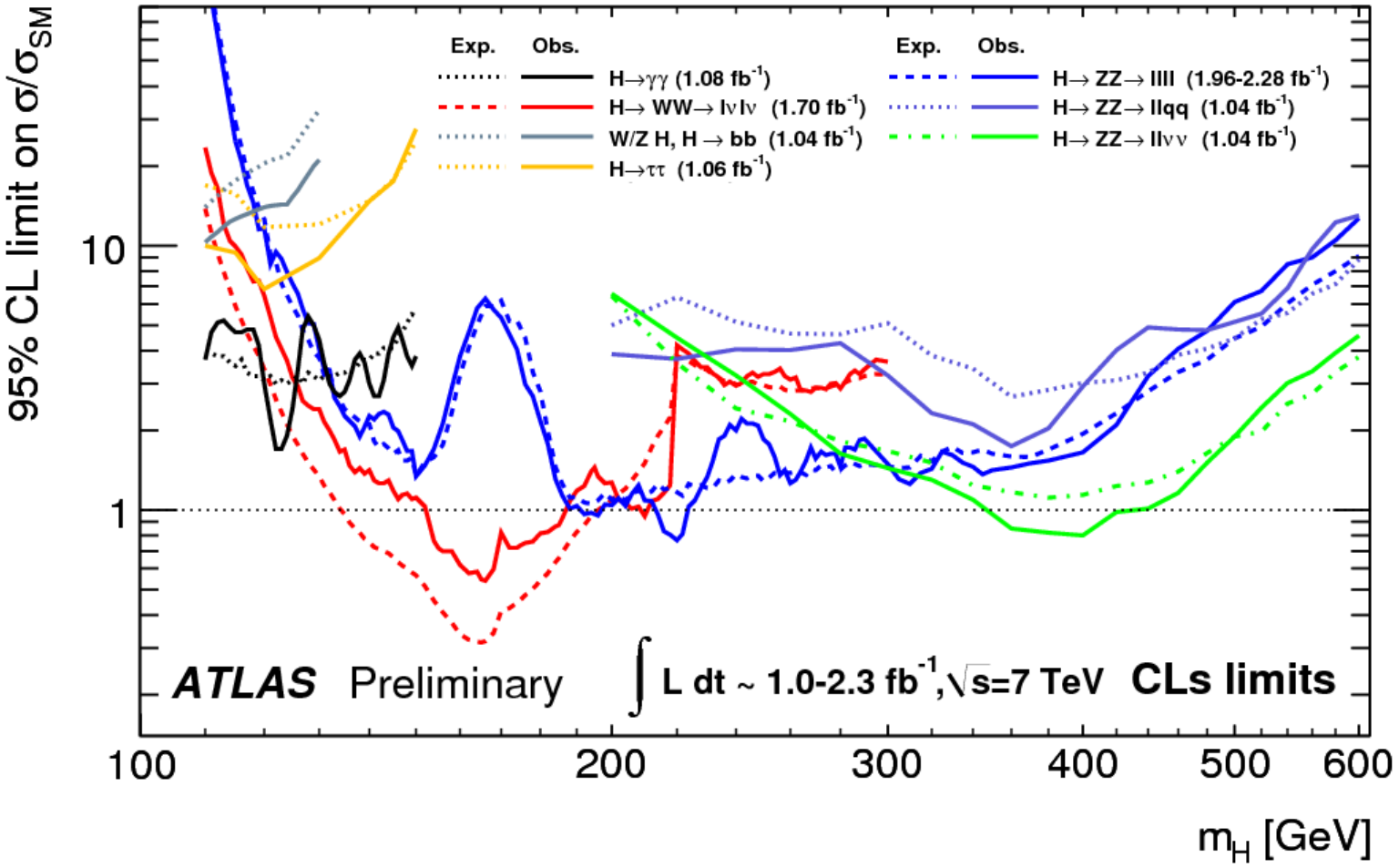
ATLAS EXPERIMENT

ATLAS SM Higgs search



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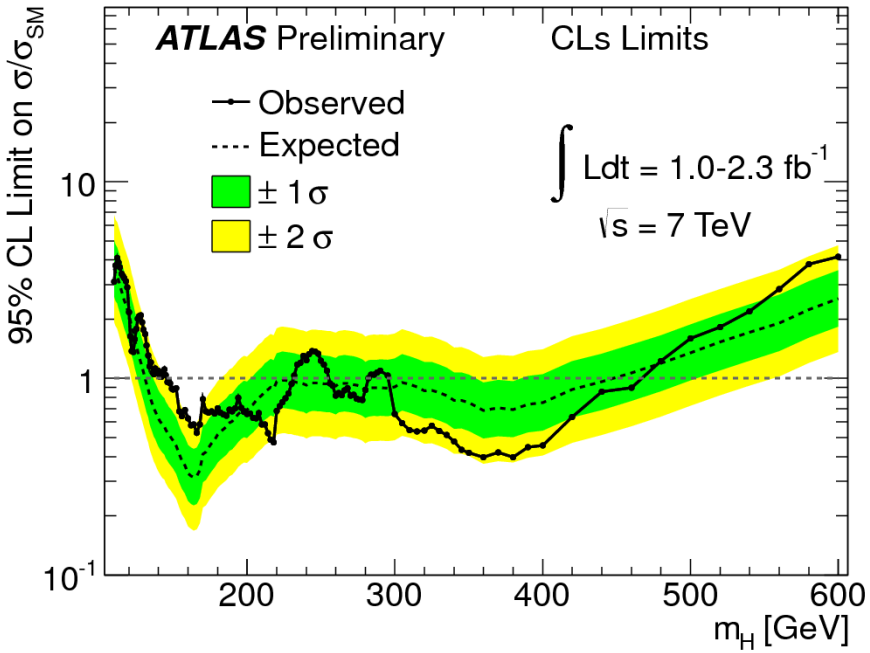
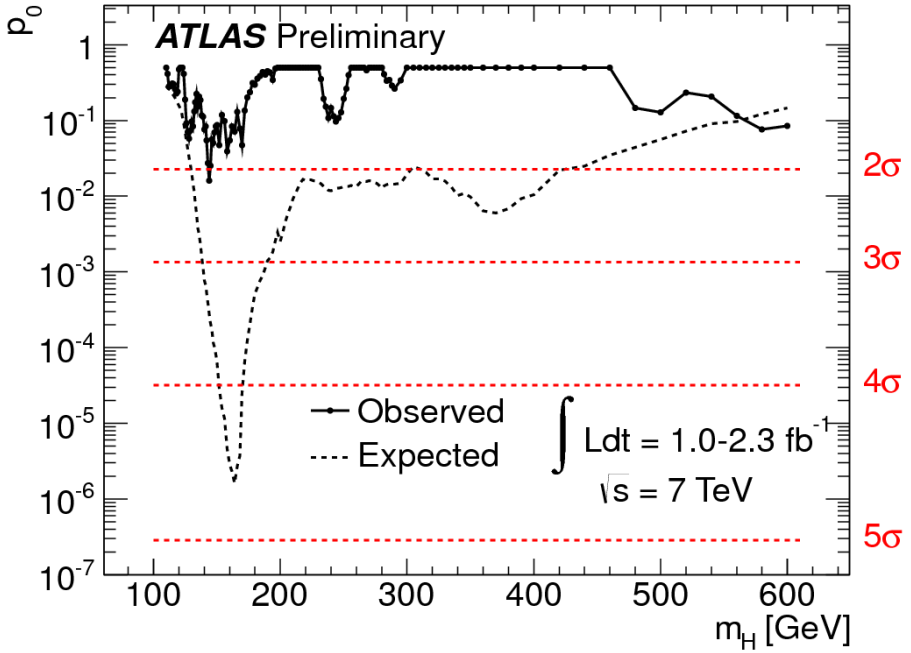
ATLAS EXPERIMENT

ATLAS SM Higgs combination

- Standard Model Higgs excluded at 95% CL in mass ranges 146-230, 256-282, 296-459 GeV
- p-value is probability that the predicted background will fluctuate as high as the observed excess
  - No combined excess beyond 2.1σ is observed

ATLAS-CONF-2011-135





Searches for MSSM + BSM Higgs

- MSSM $H/A/h \rightarrow \tau\tau$
- MSSM $H^+ \rightarrow \tau\nu$
- $H^+ \rightarrow cs$
- $H^{++} \rightarrow \mu^+\mu^+$
- Fermiophobic Higgs

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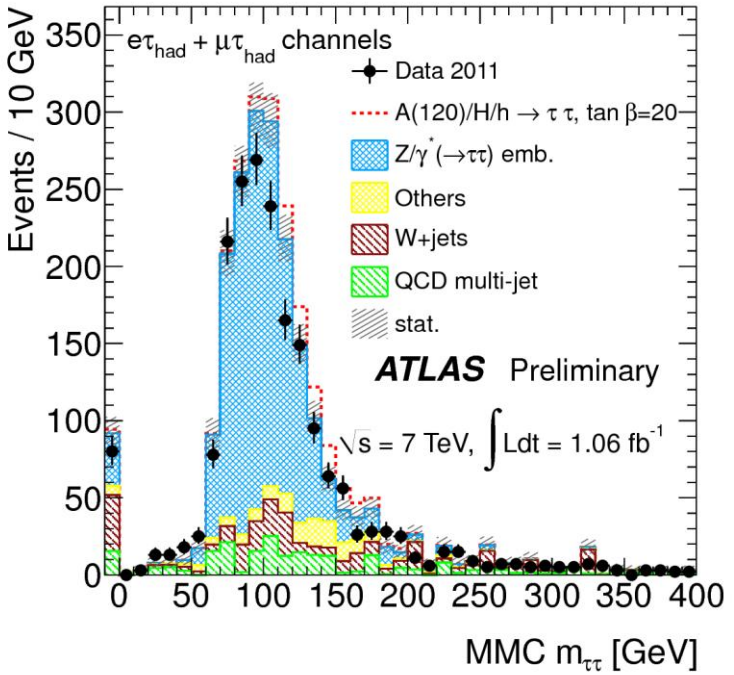
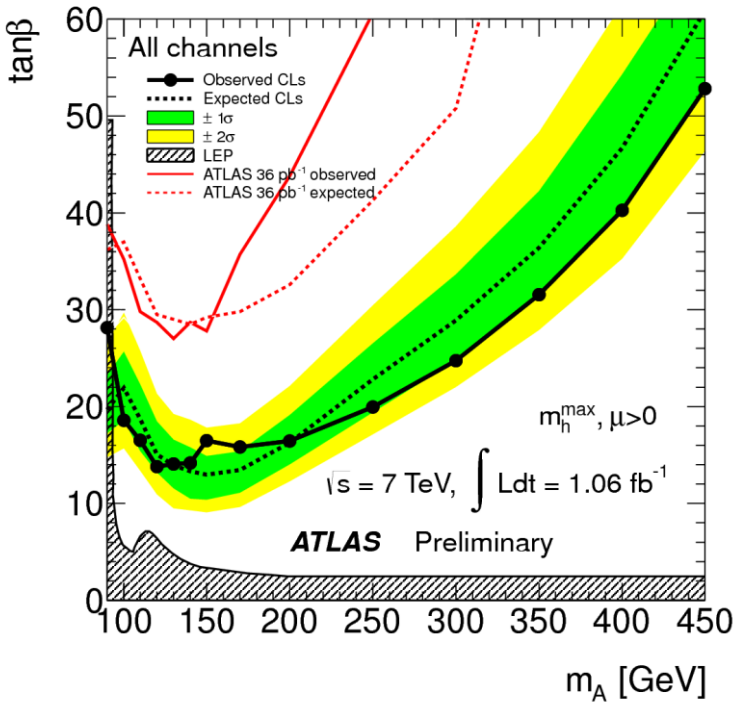
MSSM H/A/h → ττ

- 1.06 fb^{-1} of data; ATLAS-CONF-2011-132
- One of the most promising channels
  - gg → H/A/h and associated b production
- Mass reconstruction depends on τ decay channels
  - eμ + 4ν : reconstruct $m_{\tau\tau}^{effective}$
  - lτ_{had} + 3ν : Missing Mass Calculator $m_{\tau\tau}$
  - τ_{had} τ_{had} + 2ν : reconstruct $m_{\tau\tau}^{visible}$
- Main backgrounds
  - Z/W+jets, top, diboson
  - QCD for eμ and lτ_{had}
- lτ_{had} provides most stringent limit





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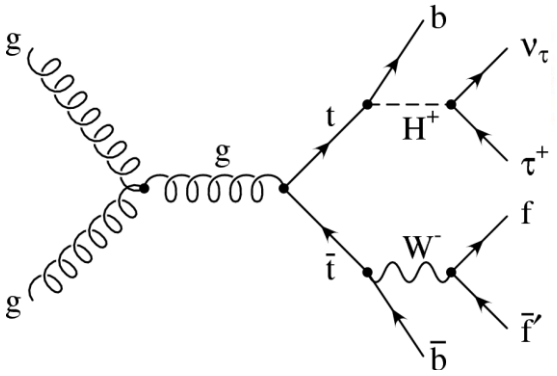
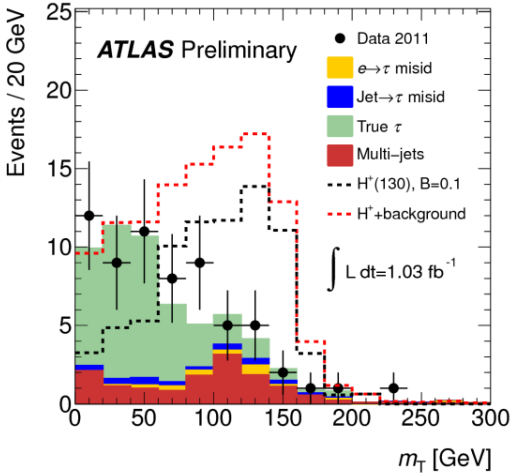
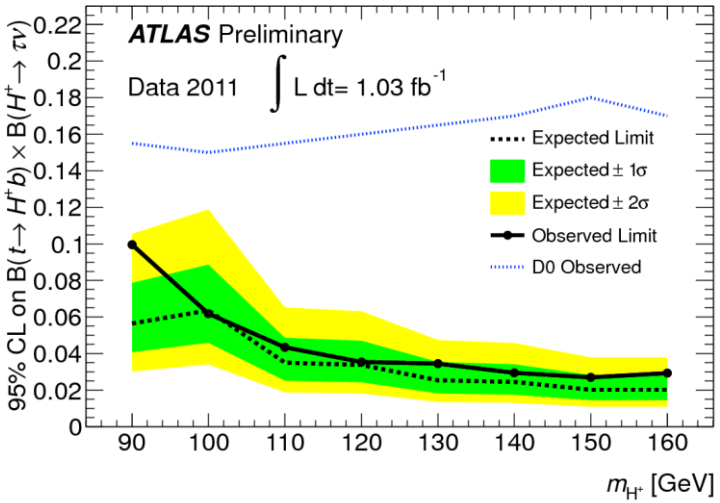
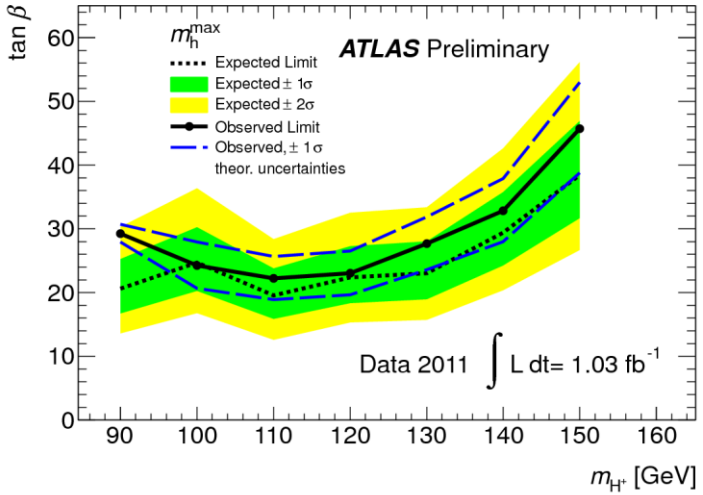


$H^+ \rightarrow \tau\nu \rightarrow \tau_{had} + 2\nu$

- 1.03 fb^{-1} of data; ATLAS-CONF-2011-138
- A light H^+ produced in top decay
  - For ttbar topology, H^+ replaces one W
  - For tanβ > 3, decays to τν
- For τ_{had} + 2ν, reconstruct transverse mass
- No signal seen
  - Upper limits on branching ratios and MSSM parameter space







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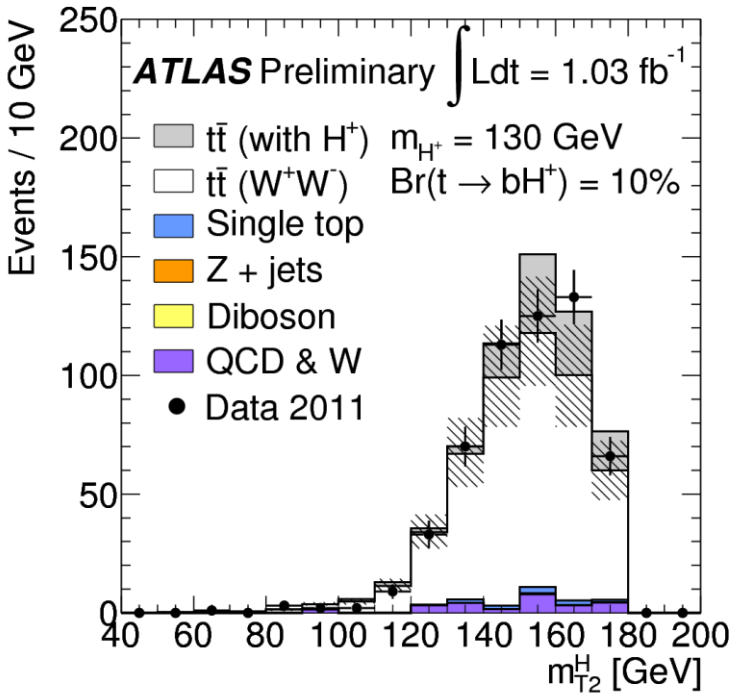
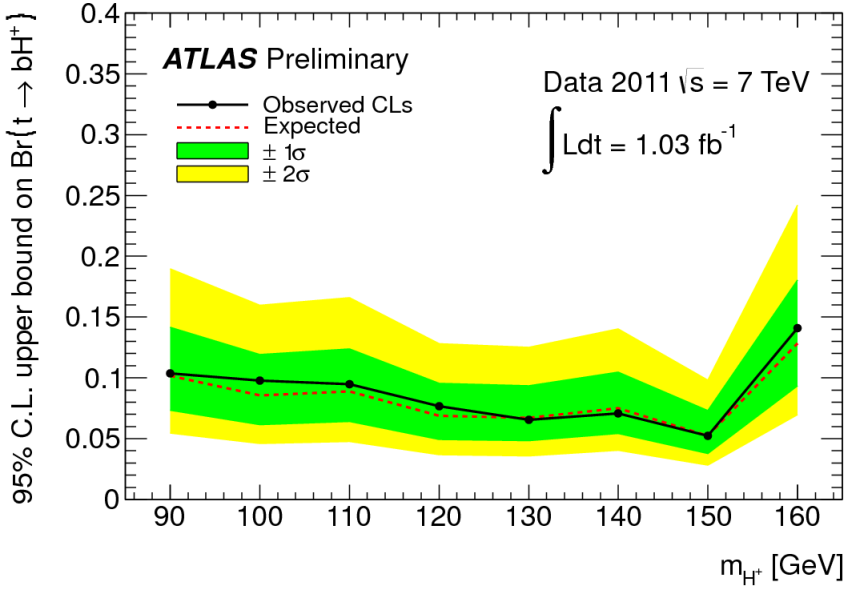
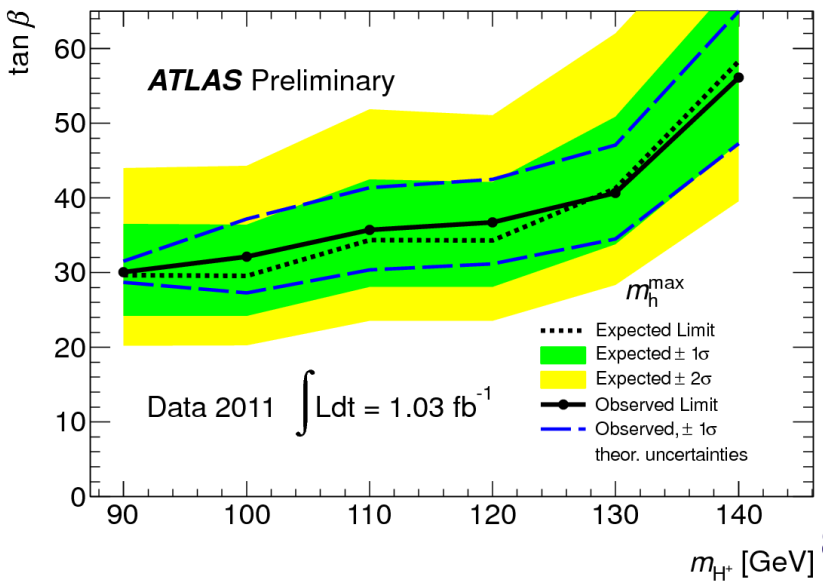
$H^+ \rightarrow \tau\nu \rightarrow e/\mu + 3\nu$

- 1.03 fb^{-1} of data; ATLAS-CONF-2011-151
- For e/μ + 3ν, solve event kinematics
  - Maximise transverse Higgs mass
- No signal seen
  - Upper limits on branching ratios and MSSM parameter space







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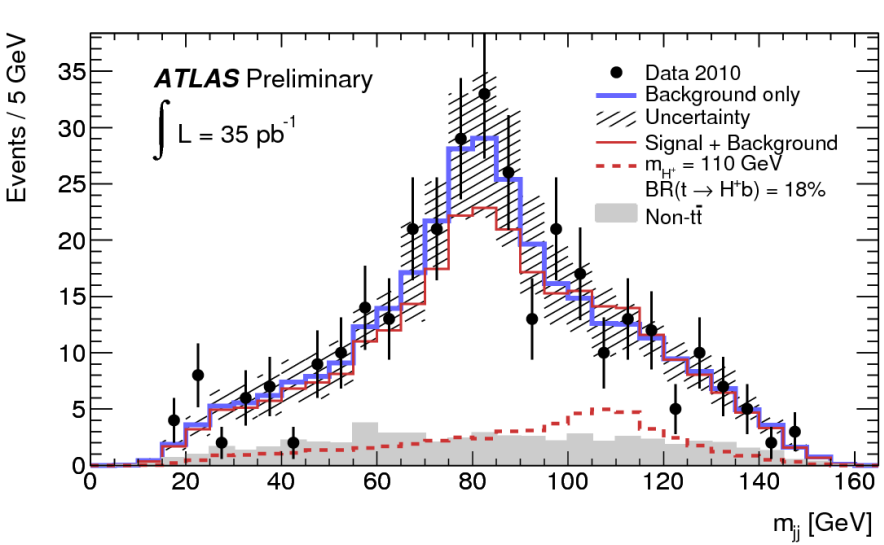
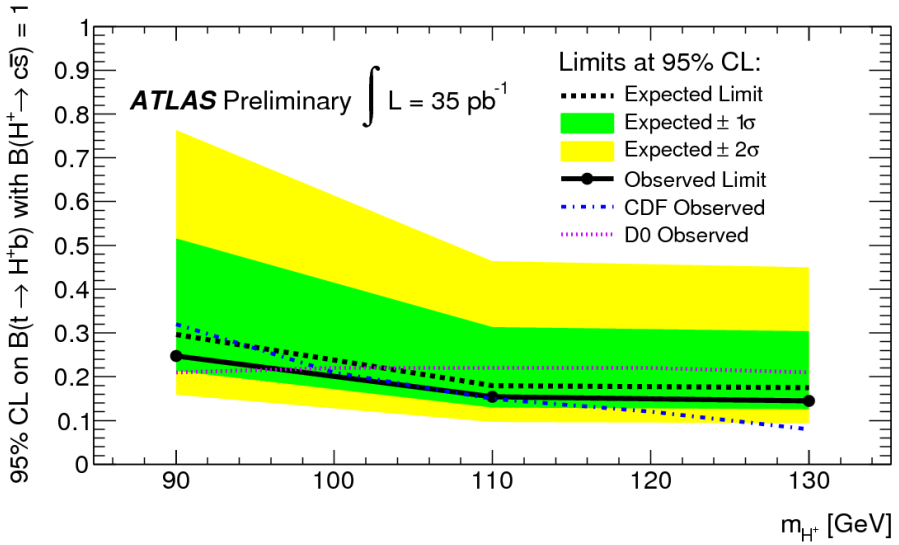
ATLAS EXPERIMENT

$H^+ \rightarrow cs$

- 35 pb^{-1} of data; ATLAS-CONF-2011-094
- Same ttbar topology as for $H^+ \rightarrow \tau\nu$
  - H^+ decays to 2 jets; dominates at $\tan\beta < 1$
  - Kinematic fit of ttbar with top mass constrained to latest measured value
  - H^+ appears as a heavy W in m_{jj} distribution
- No signal seen
  - Upper limit set on branching ratio $Br(t \rightarrow H^+b) \times Br(H^+ \rightarrow cs)$





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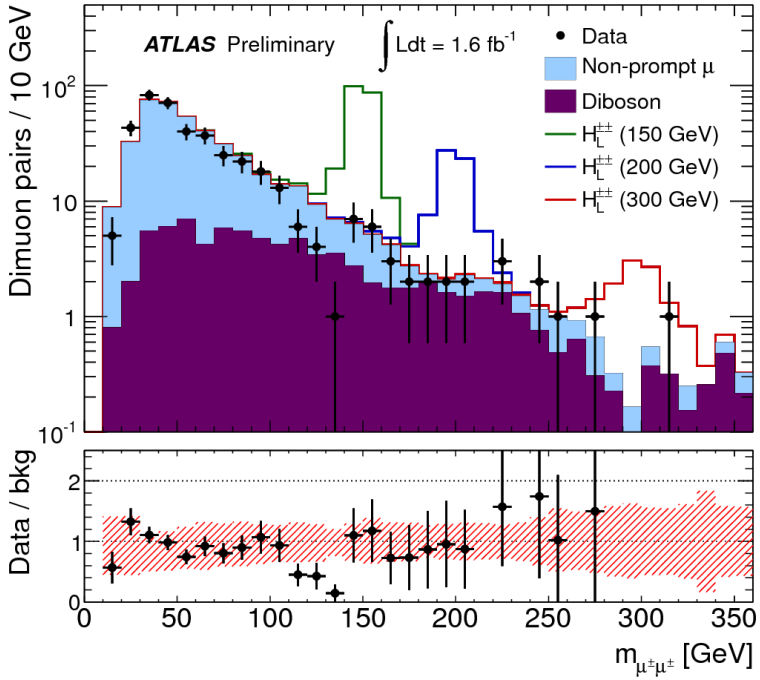
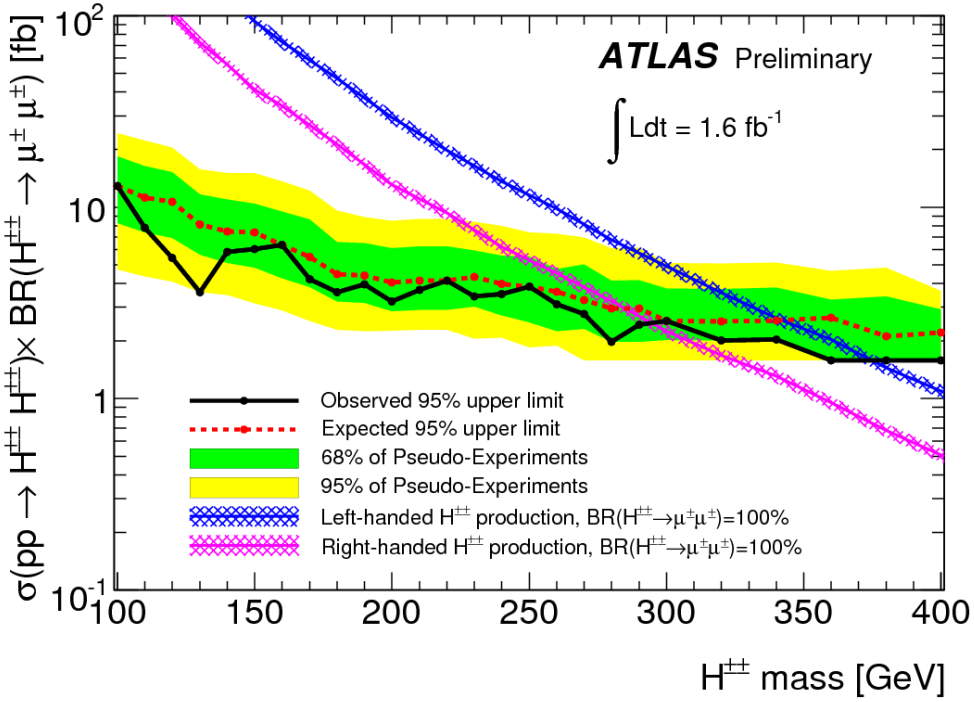
ATLAS EXPERIMENT

$H^{++} \rightarrow \mu^+\mu^+$

- 1.6 fb^{-1} of data; ATLAS-CONF-2011-127
- Predicted in little Higgs, Higgs triplet and left-right symmetric models
- Look for dimuon resonance
- Upper limit set on branching ratio





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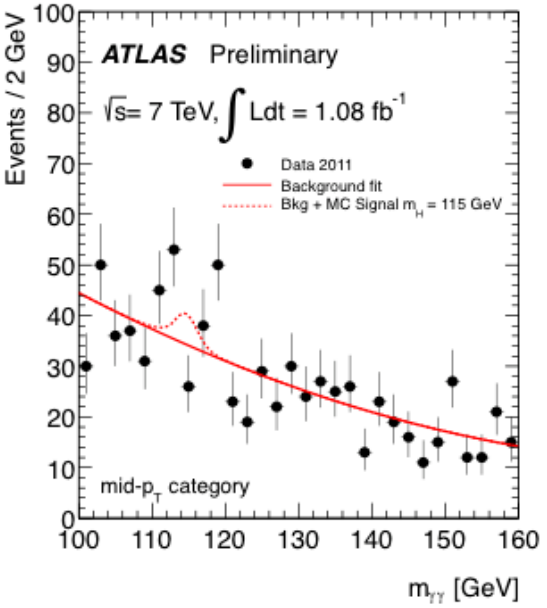
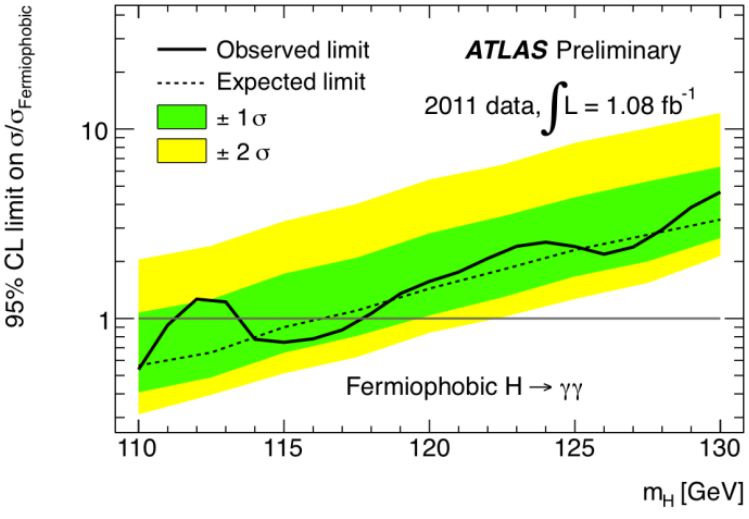
ATLAS EXPERIMENT

Fermiophobic Higgs

- 1.08 fb^{-1} of data; ATLAS-CONF-2011-149
- Extension of SM Higgs which does not couple to fermions
  - Vector Boson Fusion and associated VH production only
  - Decays to γγ, WW, ZZ, Zγ
- Focused on γγ channel
  - Reconstruct $m_{\gamma\gamma}$
- Upper limits on simplistic fermiophobic Higgs extension of SM
  - Limits on SM Higgs also constrain the limits on fermiophobic Higgs
  - Excluded in mass ranges 110-112 and 113-118 GeV at 95% CL





Conclusions and prospects

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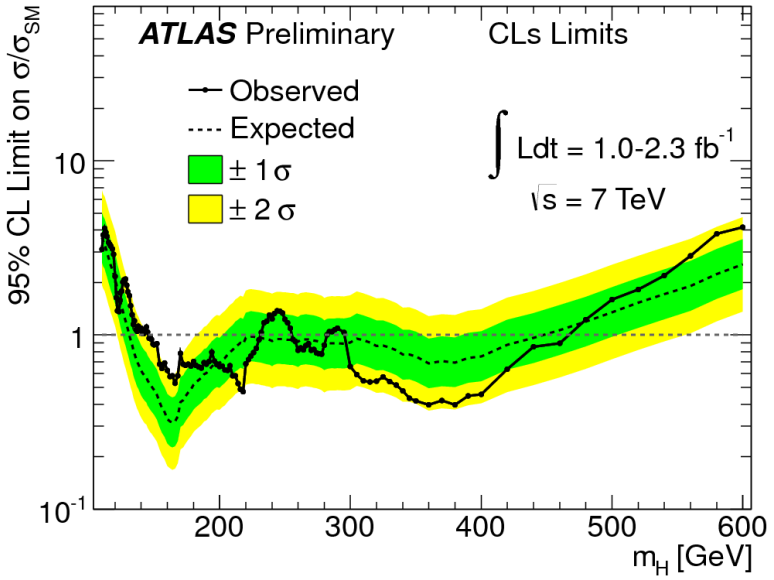
ATLAS EXPERIMENT

Conclusions

Standard Model Higgs

- Searches performed in several channels with luminosity 1.0-2.3 fb^{-1}
- Statistical combination shows no significant excess in 110-600 GeV
- SM-like Higgs is excluded at 95% CL in mass ranges 146-230, 256-282, 296-459 GeV



MSSM + BSM Higgs

- Also probed a wide variety of non-Standard Model
  - MSSM Higgs
  - Singly and doubly charged Higgs
  - Fermiophobic Higgs
- No excess observed in the channels studied

Prospects

- Analysis of full 2011 dataset to be announced 13 December @ CERN
  - More than 2σ sensitivity in entire mass range expected
- Work underway to optimise object performances, reduce systematics and optimise selections
- Additional 5-10 fb^{-1} in 2012
  - Discovery possible over most of mass range
  - Conclusive answer on the Standard Model Higgs should be achievable
- Very exciting times ahead!

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