Higgs Searches at ATLAS

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for the ATLAS collaboration

Berkeley Workshop on SUSY at LHC

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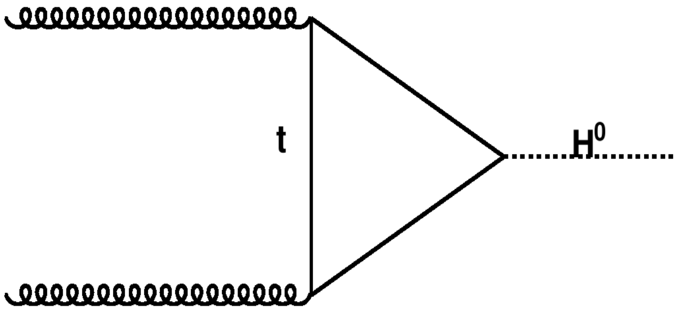
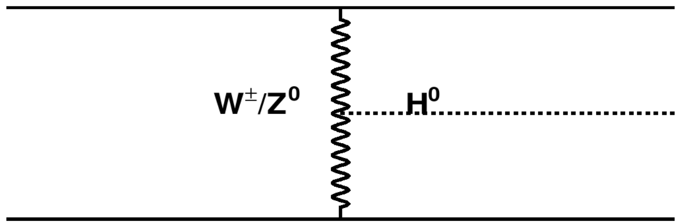
Higgs Production & Decays (1)

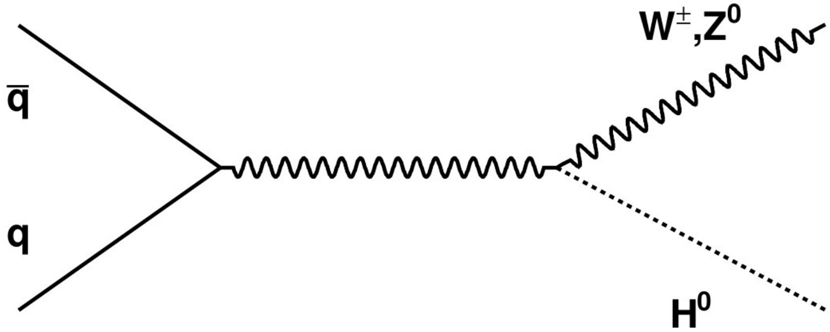
gluon Fusion

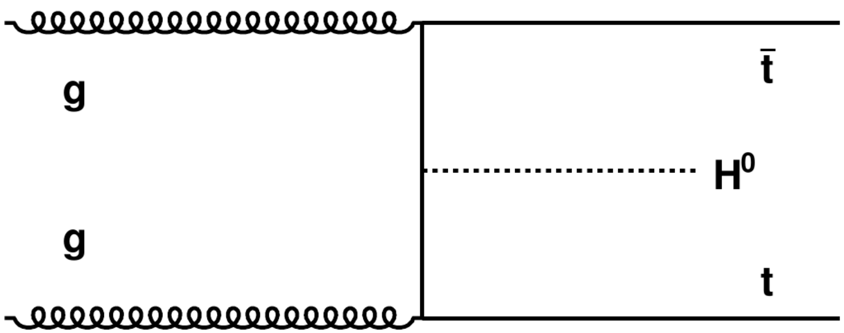


Weak Boson Fusion



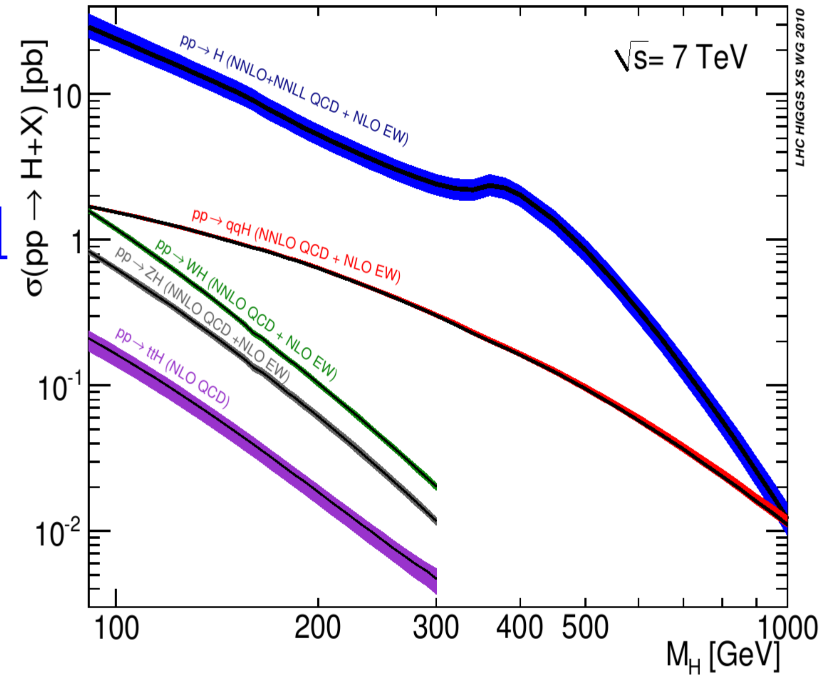
- In the Standard Model, Higgs boson production primarily through gluon fusion and Weak Boson Fusion (WBF)
  - Typical Feynman diagrams for ggH and WBF are shown above
- In some searches (e.g. $H\rightarrow\gamma\gamma$, bb), WH/ZH/ttH are important too
  - Typical Feynman diagrams for WH/ZH and ttH are shown below

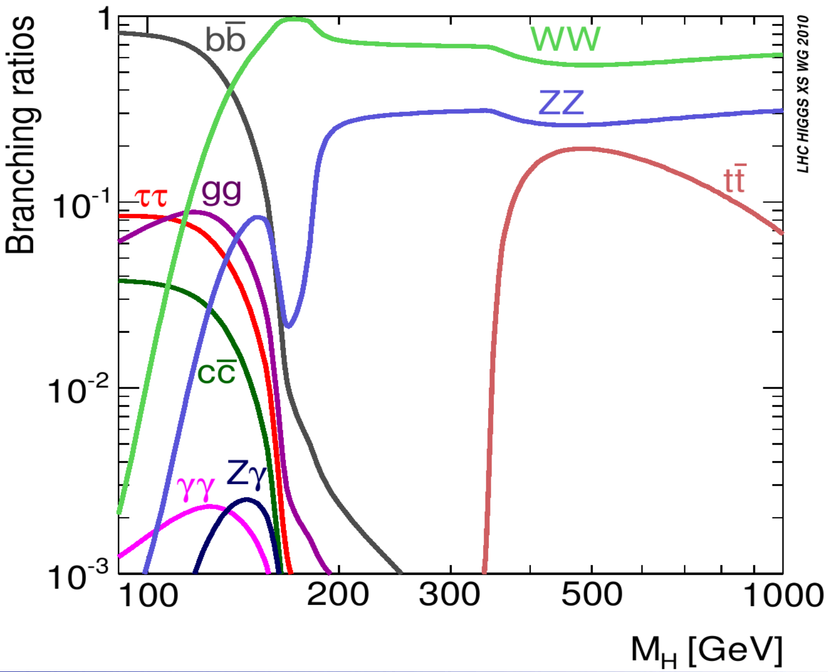




Higgs Production & Decays (2)

- Right: cross-sections (top) and branching ratios (bottom) in the Standard Model (SM)
- Decay modes which have been analyzed in data:
  - $H \to WW$, $H \to ZZ$ at high mass
  - $H \to bb$, $H \to \tau\tau$, and $H \to \gamma\gamma$ at low m_H
- Cross-sections are taken from "Handbook of LHC Higgs Cross-sections," arXiv:1101.0593





arXiv:1101.0593

H→WW→lνlν (1)

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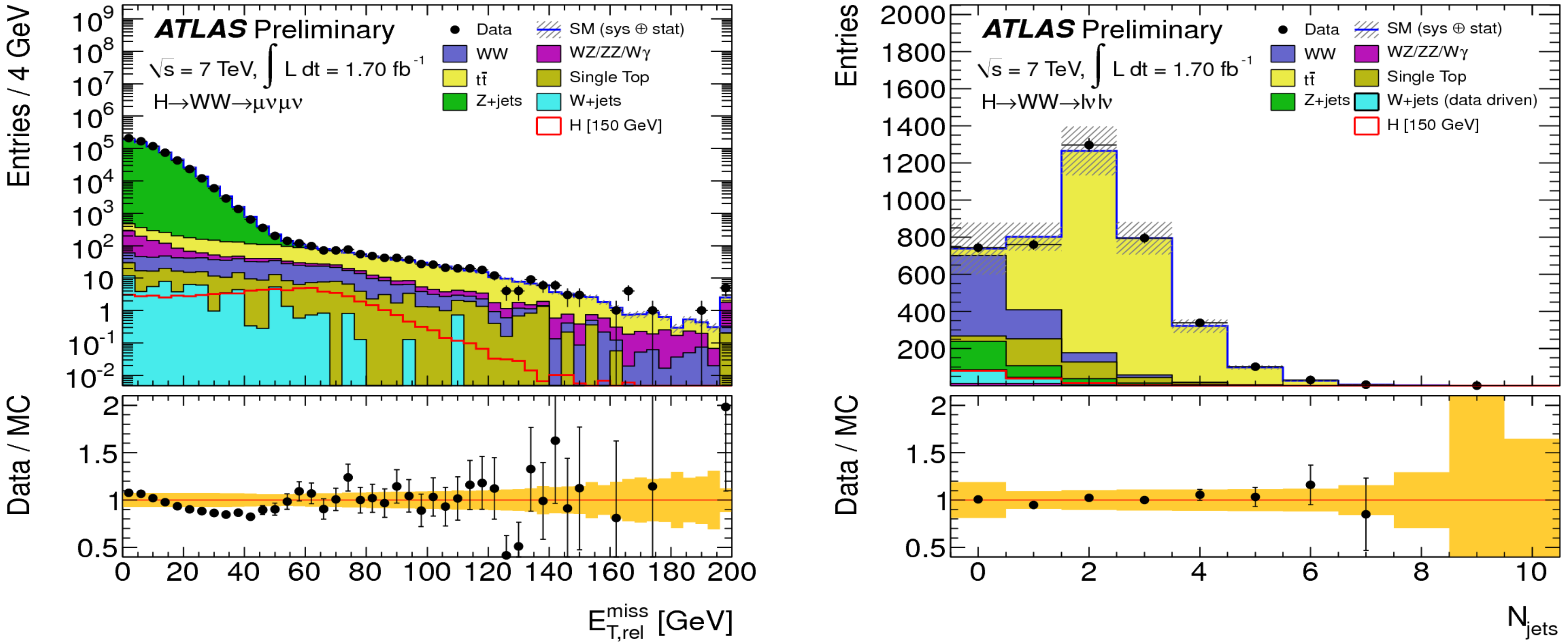

- Requiring two leptons suppresses QCD multijet background to negligible levels
- Large background from Z is suppressed by requiring large E_T^{miss} in same-flavor events (left)
- Top events are rejected by cut on jet multiplicity (right).
  - Presently, only N_{jet}=0 and N_{jet}=1 considered

$H \to WW \to l\nu l\nu$ (2)

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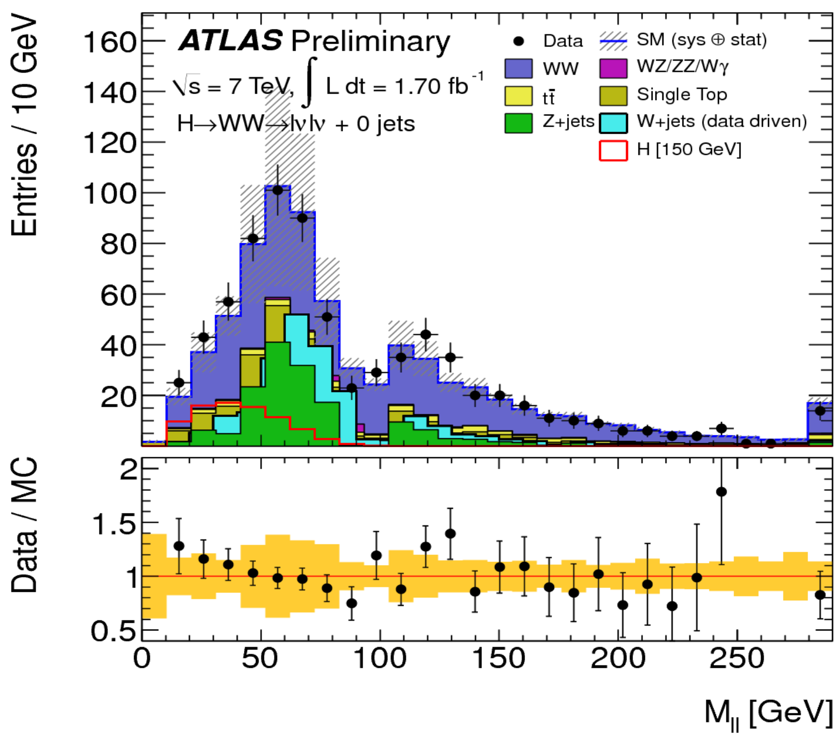

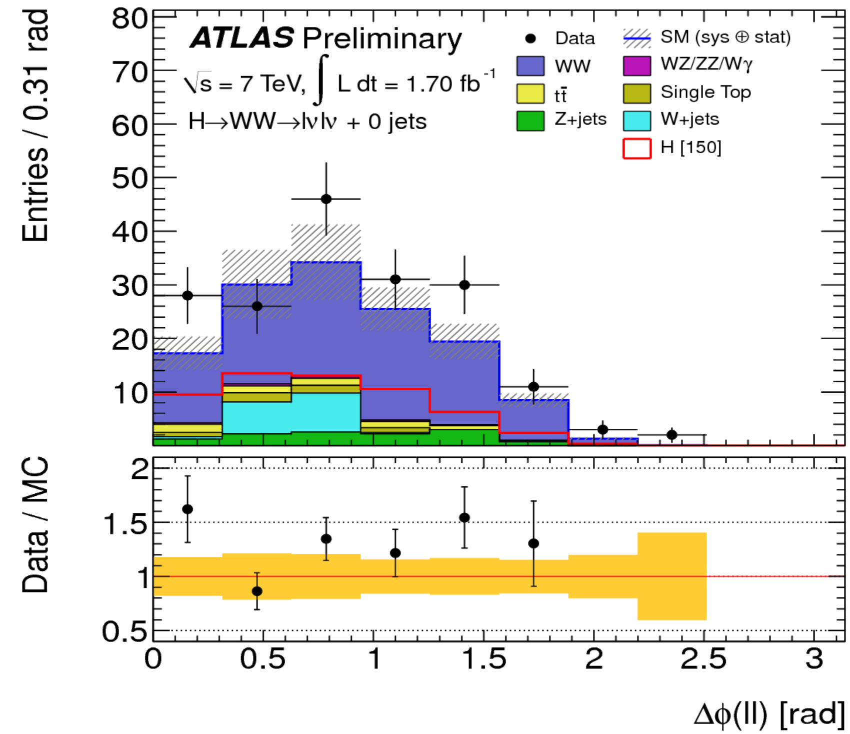

- Event selection exploits different angular distributions caused by kinematics and by spin correlations. Above: M_{ll} (left) and $\Delta\phi_{ll}$ (right) in events with no jets
- Backgrounds are estimated with control samples:
  - Diboson: count events in a region with altered M_{ll} and $\Delta\phi_{ll}$ cuts
  - Top (in H+1j): reverse b-veto and drop cuts on M_{ll}, M_T, and $\Delta\phi_{ll}$

Control Region	Expected BG	Observed
WW+0j	250±50	238
WW+1j	139±18	144
tt+1j	350±100	316

H→WW→lνlν (3)

ATLAS-CONF-2011-134

Source	WW+0j	WW+1j	tt+1j (SR)	tt+1j (CR)
Q^2 scale	3%	4%	9%	-
MC Modeling	4%	4%	4%	-
PDF	3%	3%	3%	-
Jet E scale/res	<1%	+2.3/-1%	-35/+32%	-36/+32%
b-tagging	-	-	23%	-19/+20%
MC stats	4.3%	12.9%	6%	-

- For major backgrounds (WW+0/1j and tt+1j), control samples are modeled in fit using ratio of cross-sections in signal region over control region taken from MC
  - WW+1j control region has significant contamination from top, so use tt+1j control region to normalize it as well

- Above: uncertainties on the ratio of cross-sections in the signal region over the listed control region.
  - The last column shows the uncertainty in the ratio of top backgrounds in the WW+1j control sample and the top control region for H+1j.

H→WW→lνlν (4)

ATLAS-CONF-2011-134

- Backgrounds which are small after cuts (ttbar in H+0j, W+jets, Z+jets) are also measured using control regions, but only the final estimate is modeled in the Likelihood, not the control sample itself:
  - W+jets: loosened lepton selection. Derive a p_T-dependent extrapolation factor from dijet data to get estimate in signal region, accounting for contamination from real leptons
  - Top in H+0j uses two control samples:
    - Two leptons and E_T^{miss} w/non-top backgrounds removed using MC
    - Two leptons and E_T^{miss}, w/ ≥1 b-tagged jet; used to estimate an efficiency for the jet veto
    - Efficiency from second control sample and corrections from MC are applied to first control sample to estimate top in signal region
  - Z+jets: use events on Z peak to derive a correction factor for the ratio of high-E_T^{miss} to low-E_T^{miss}; apply it to events with small m_{ll}.

H→WW→lνlν (5)

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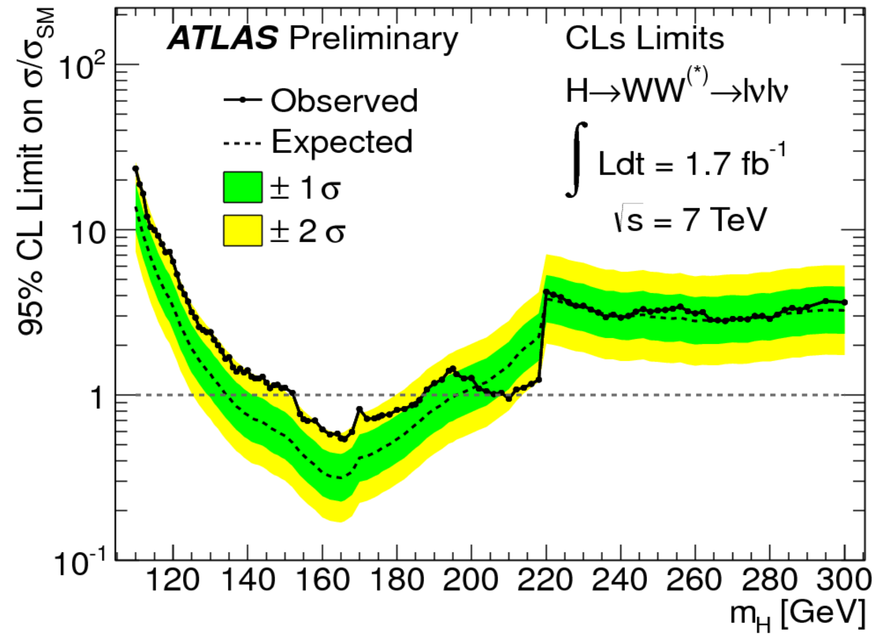
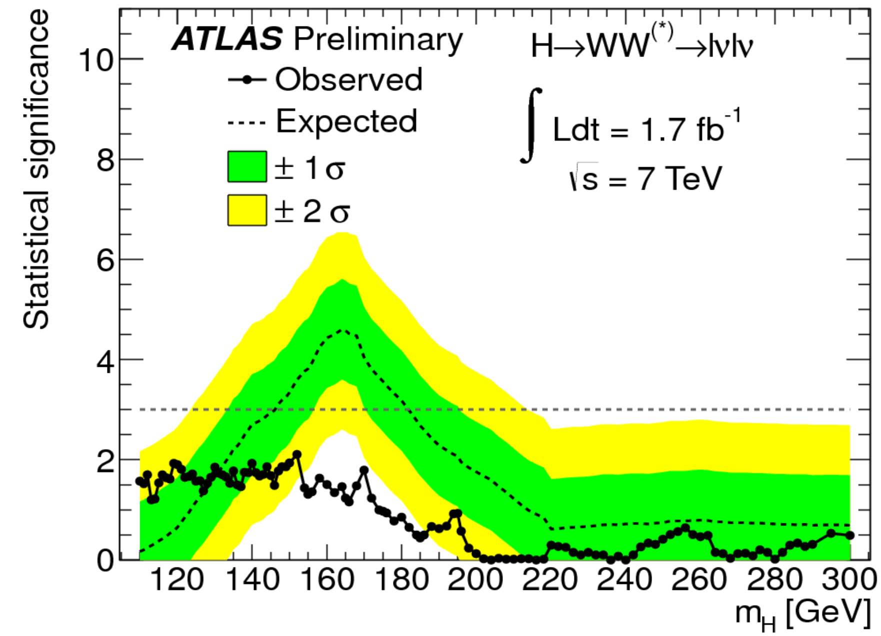
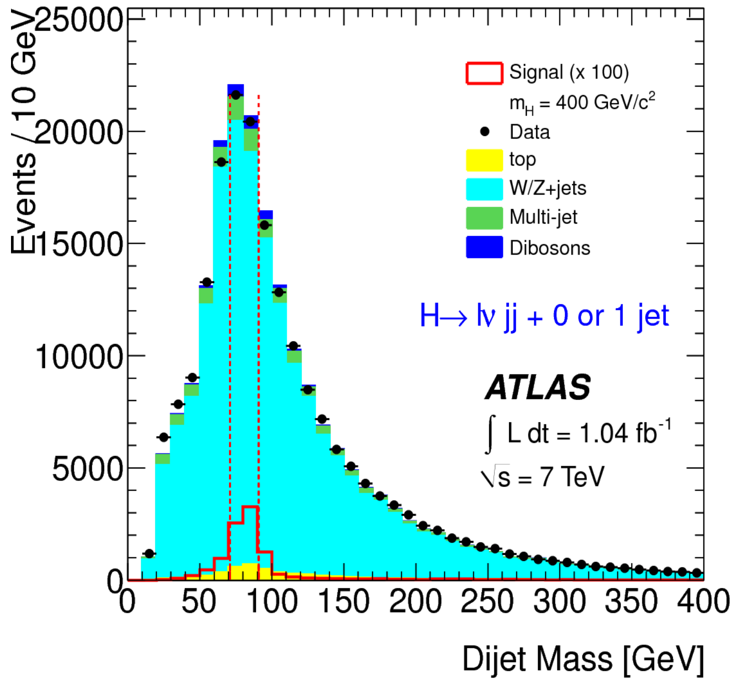


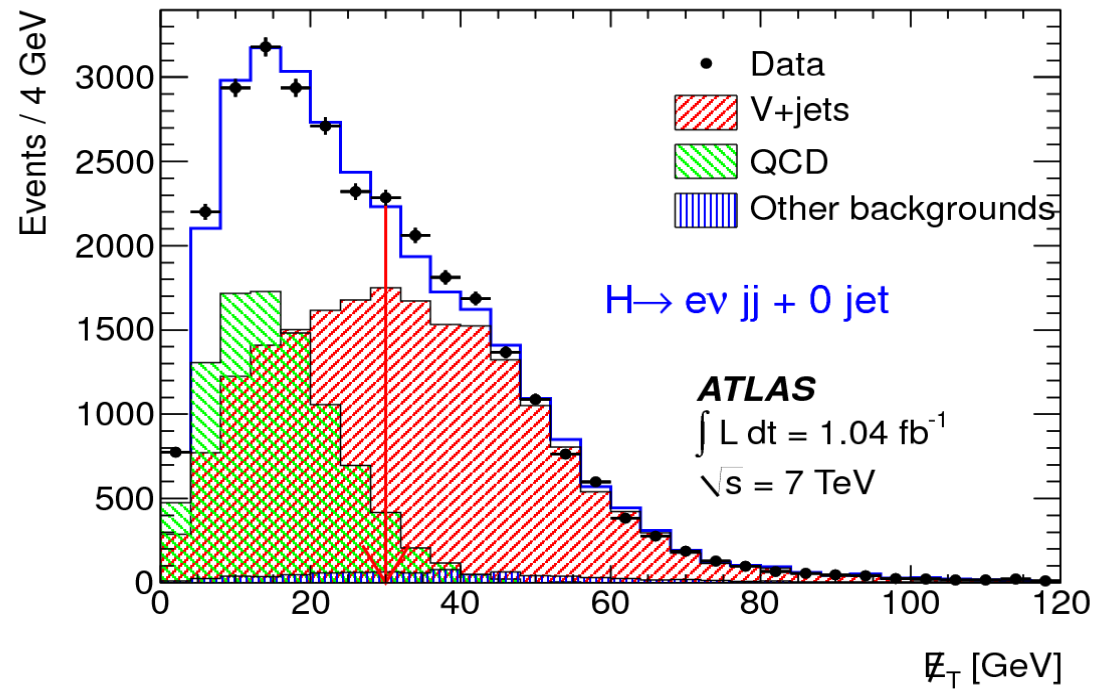


- Upper bounds on production cross-section (left) and significance of excess over background (right).
  - No significant excess, always less than about 2σ
  - Upper limit is set as a function of m_H, in units of the Standard Model prediction. ATLAS excludes $154<m_H<186$ GeV ($135<m_H<196$ GeV expected)

H→WW→lνqq (1)

arXiv:1109.3615

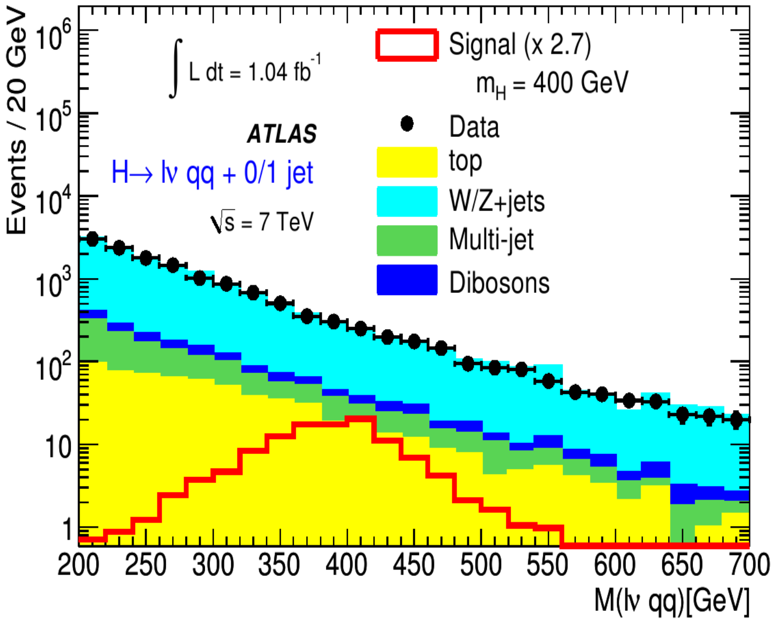


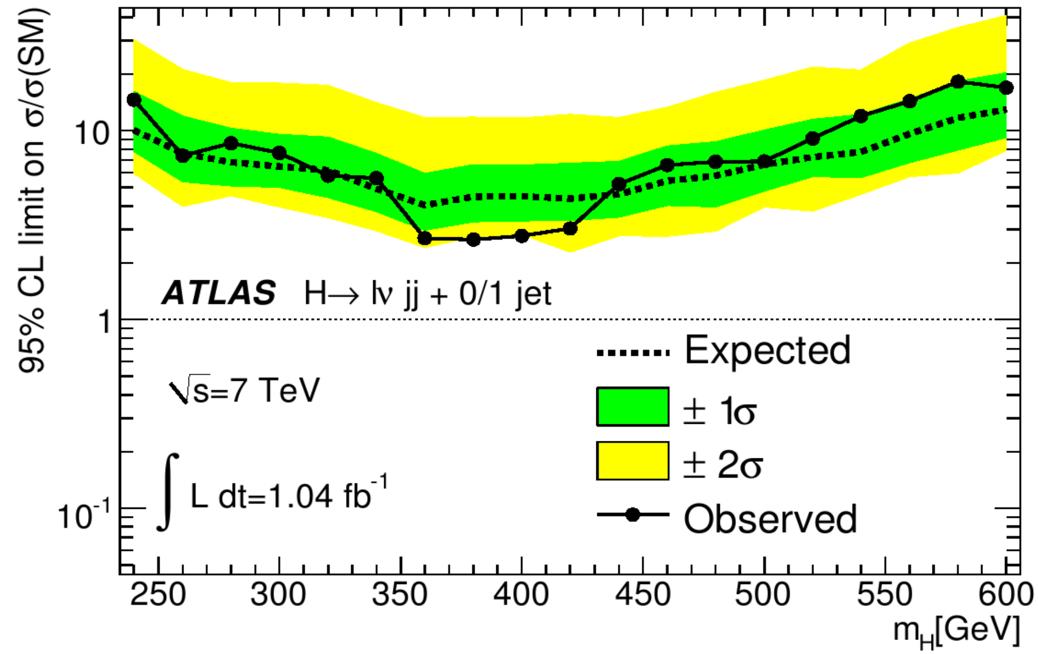


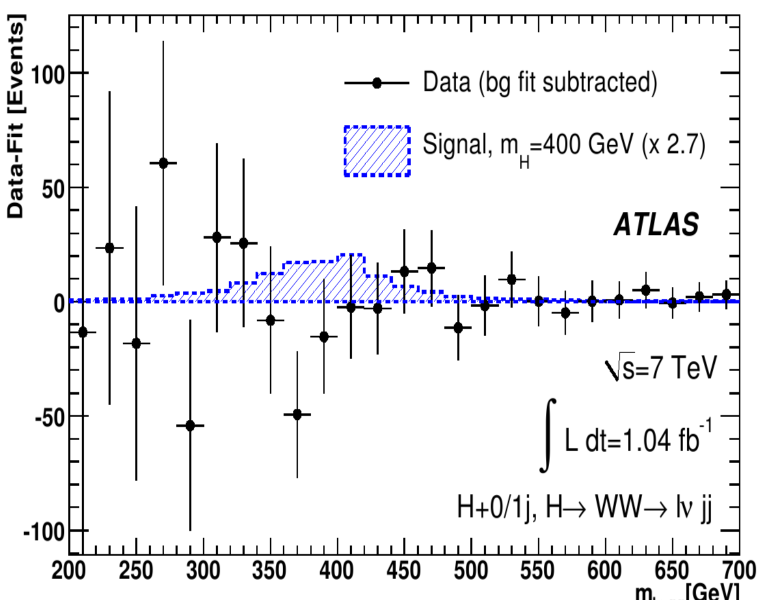
- Select events with one lepton, two or three jets, and E_T^{miss}.
- Two jets must have m_{jj} close to m_W (left)
  - Contributes to large systematic from the jet E scale uncertainty
- Estimate background from jets misidentified as leptons using a sample of events in data with lepton isolation cut reversed.
  - Can estimate the shapes of most kinematic variables by just plotting. See, for example, green region in upper right plot
  - A normalization factor is estimated with a template fit to the E_T^{miss} distribution (right). Shape of V+jets taken from MC, but it floats in the fit too and both contributions are rescaled for the final plots.

H→WW→lνqq (2)

arXiv:1109.3615



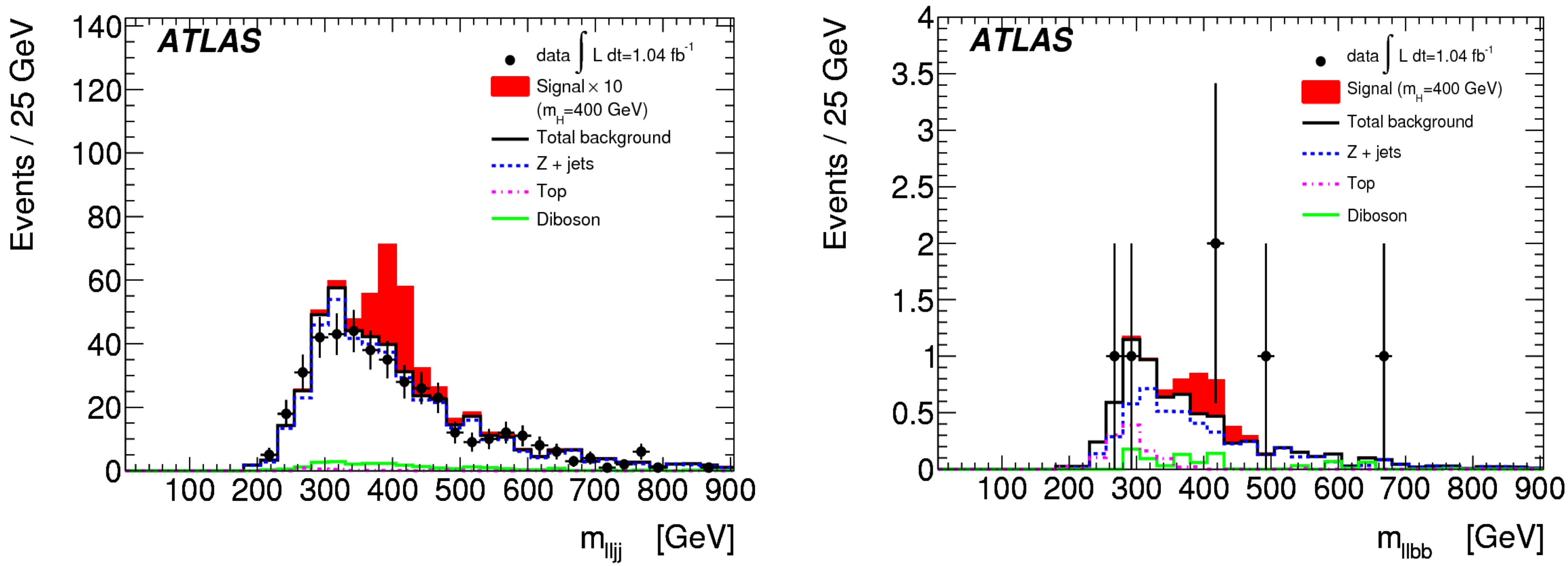




- Estimate P_Z^{ν} and M_{WW} by solving $M_W = M_{l\nu}$. Require two real solutions; take one with smaller $|P_Z^{\nu}|$
- Fit $M_{l\nu qq}$ distribution with a double exponential for background, hist PDF for signal)
- Exclude 2.7xSM for m_H=400 GeV

H→ZZ→llqq (1)

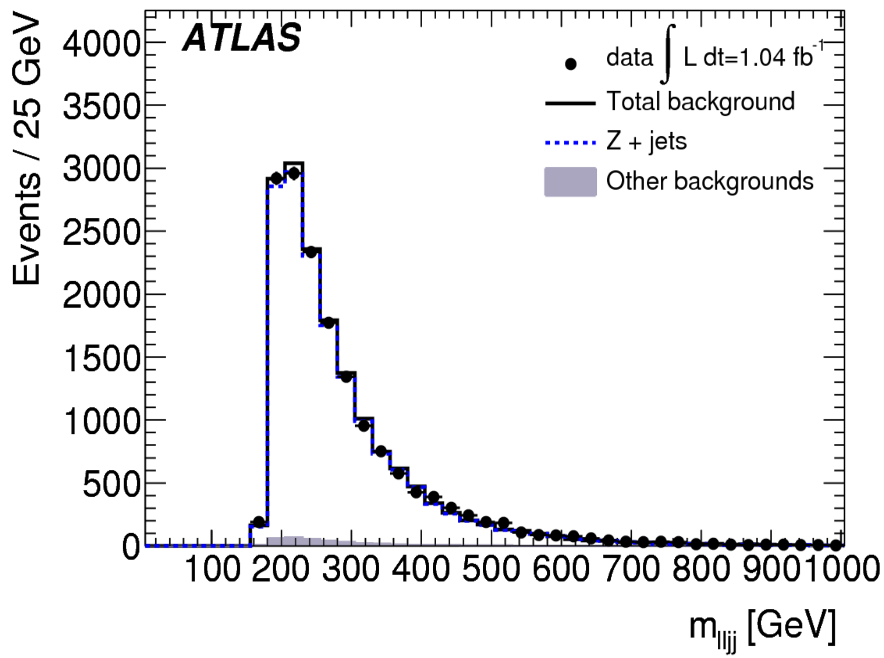
arXiv:1108.5064

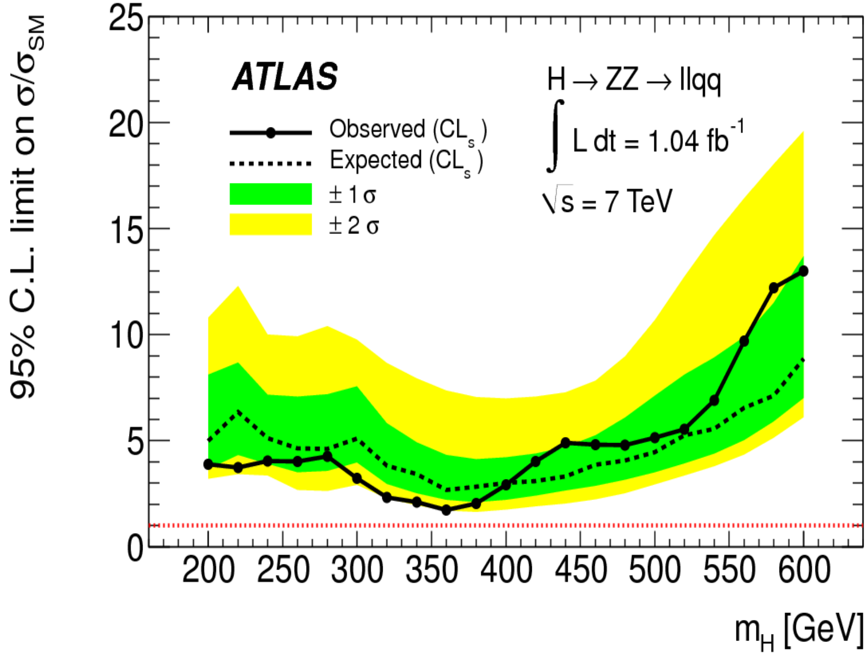


- Signature is two leptons and two jets, with small MET, and with M_{ll} and M_{qq} near M_Z.
- Divide the signal into events with fewer than two b-tagged jets (left) and events with two (right)
- For $m_H \geq 300$ GeV, also use angular information about the jets and leptons to suppress background.
  - Require $\Delta\phi_{ll} > \pi/2$ and $\Delta\phi_{jj} > \pi/2$

H→ZZ→llqq (2)

arXiv:1108.5064

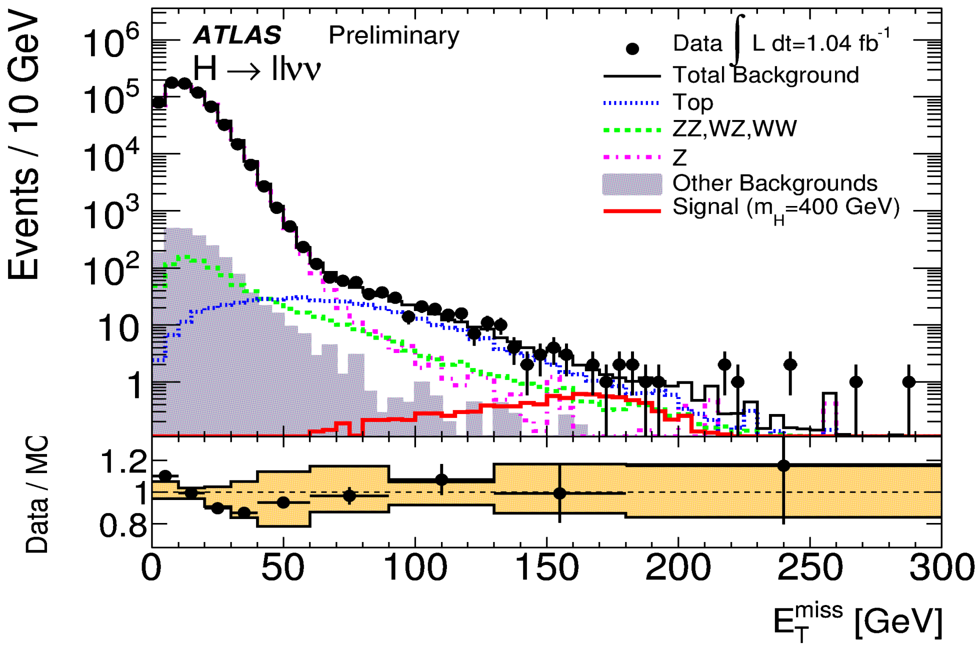


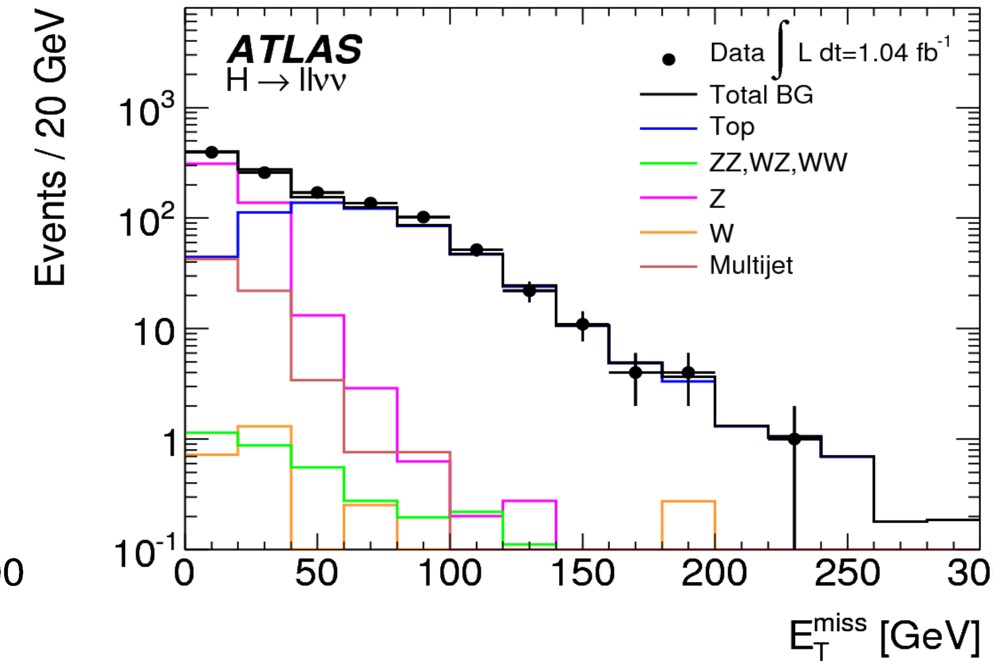


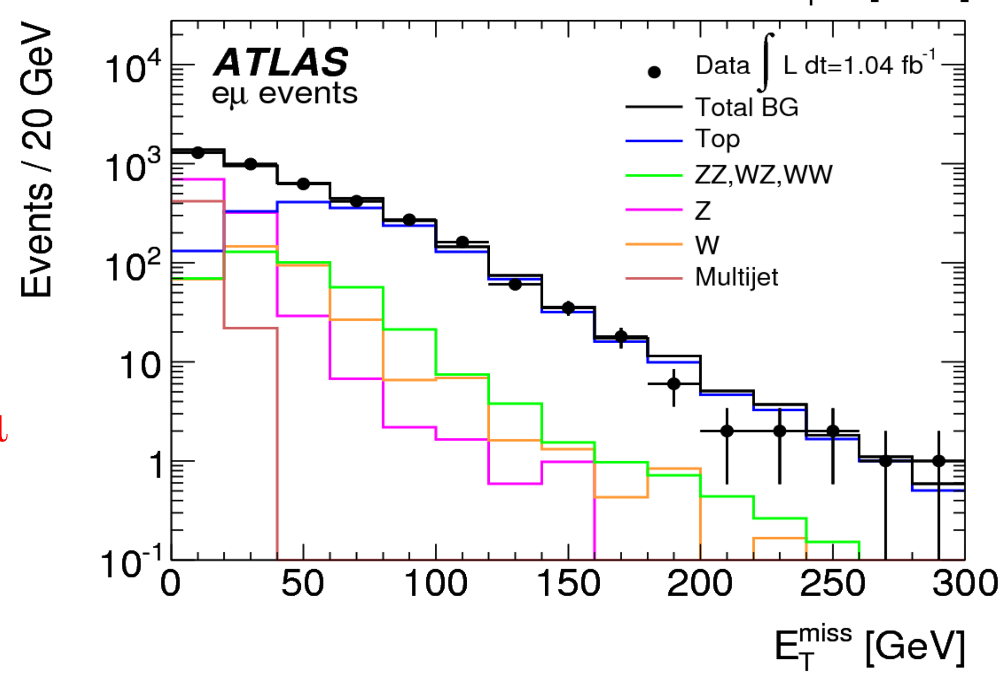
- Background shape and normalization in MC is validated by data/MC comparisons in m_{jj} sidebands (left) and m_{ll} sidebands (not shown)
  - Systematic error on the Z+jets normalization comes from comparisons of these sidebands, and ranges from 1.4% for low-m_H untagged selection to 18% for high-m_H b-tagged selection. Shape uncertainty comes from comparisons between Pythia and Alpgen
- Observed limits are approaching the Standard Model prediction for m_H near ~300-400 GeV

H→ZZ→llνν (1)

arXiv:1109.3357



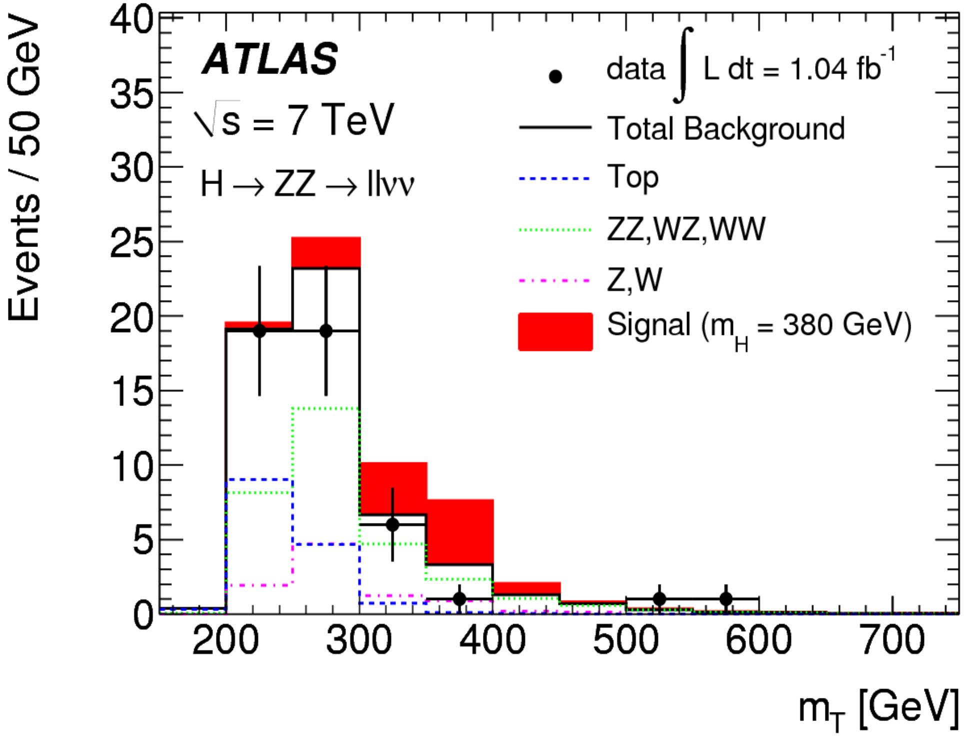


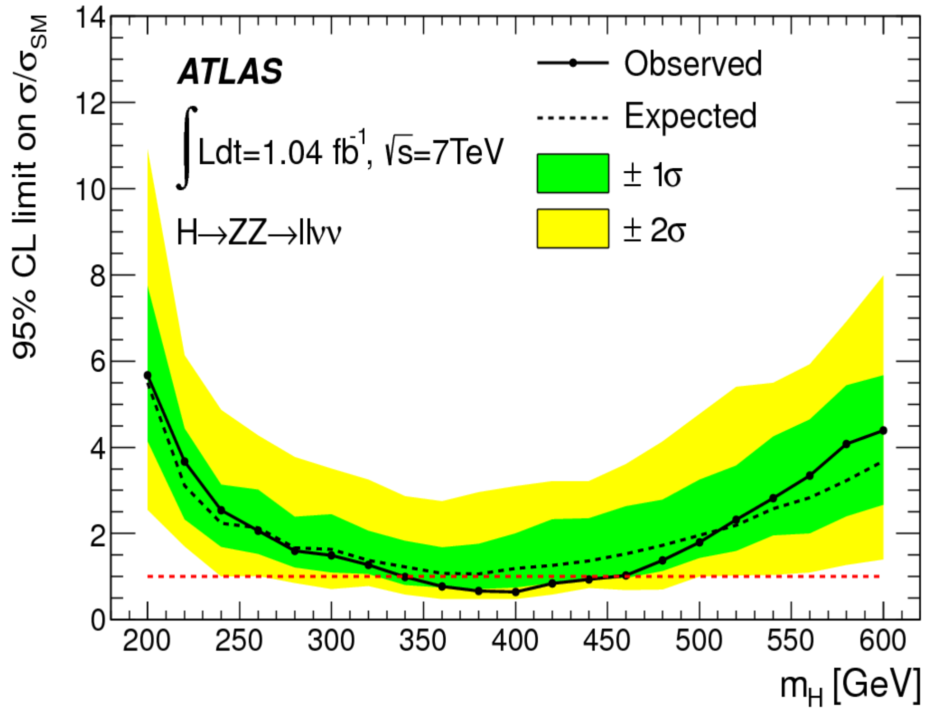


- Two leptons with $m_{ll}=m_Z$ and very large MET (left)
- Diboson BG is from MC
- E_T^{miss} performance in top BG checked using events with m_{ll} outside Z peak (top right) and eμ events (bottom right)
- Z and W+jets evaluated from MC with data/MC comparisons

H→ZZ→llνν (3)

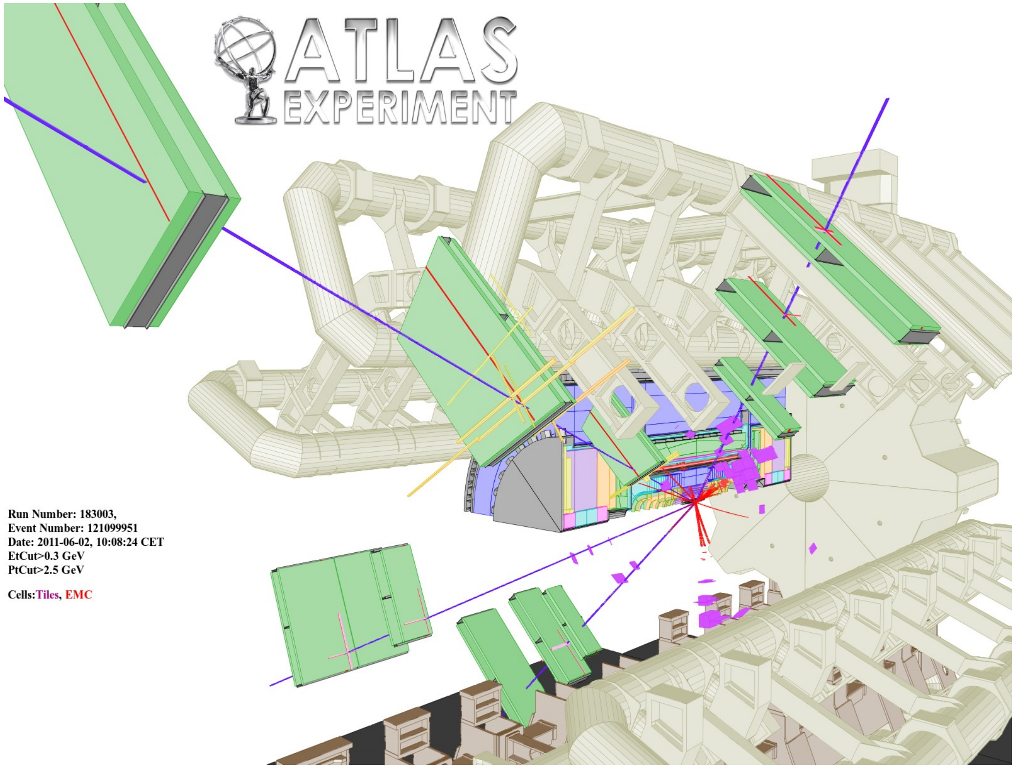
arXiv:1109.3357

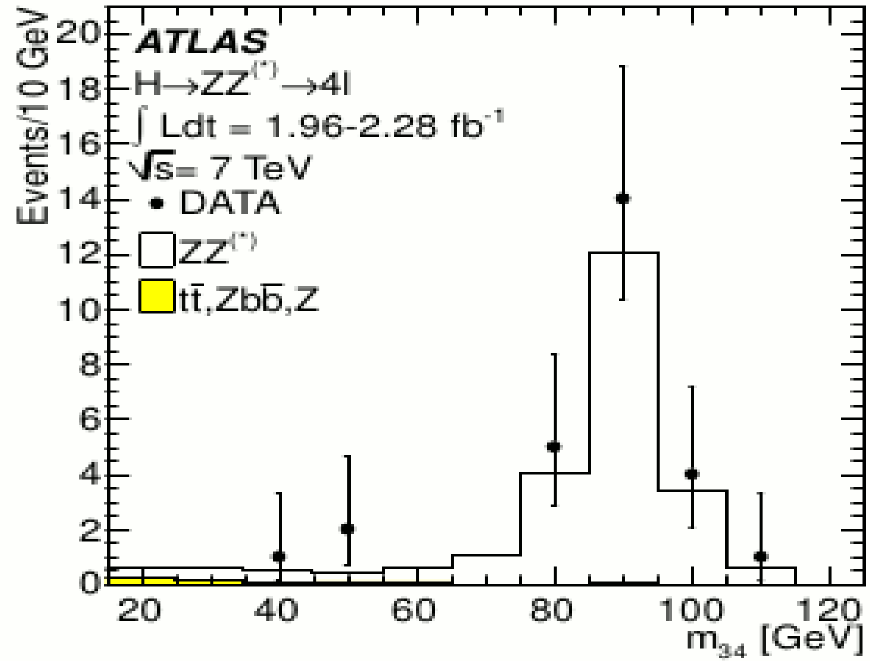




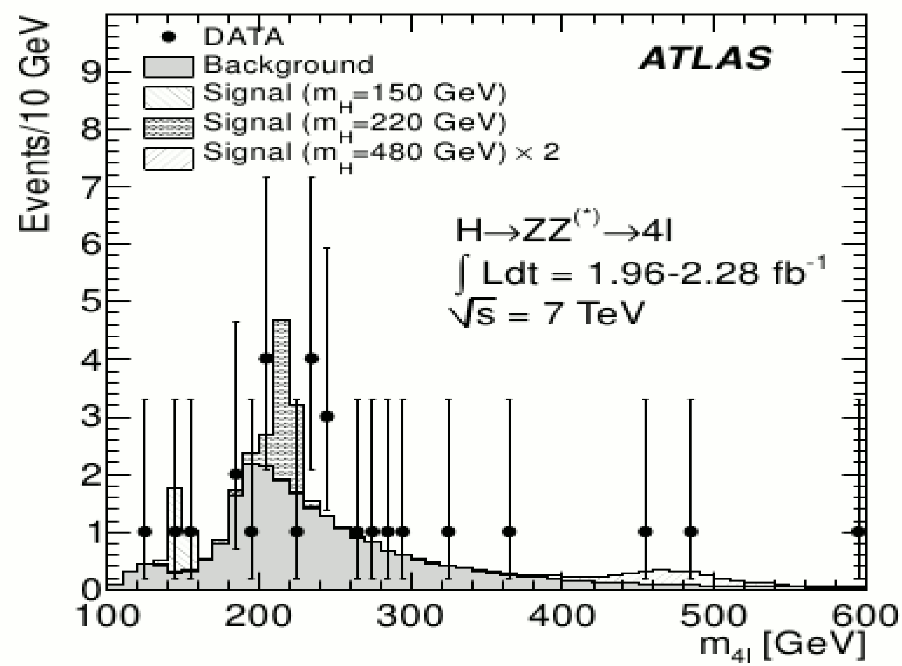
- Left: set limits based on the transverse mass distribution
  - Systematic errors on BG normalization: gluon fusion signal (+14/-10%), VBF signal (4%) and diboson background taken from theory; top quark production (9%), W+jets (100%), and QCD multijet (50%) are estimated from data
- Right: we are just starting to exclude a Standard Model Higgs boson around $360<m_H<420$ GeV

H→ZZ→4l (1)





arXiv:1109.5945

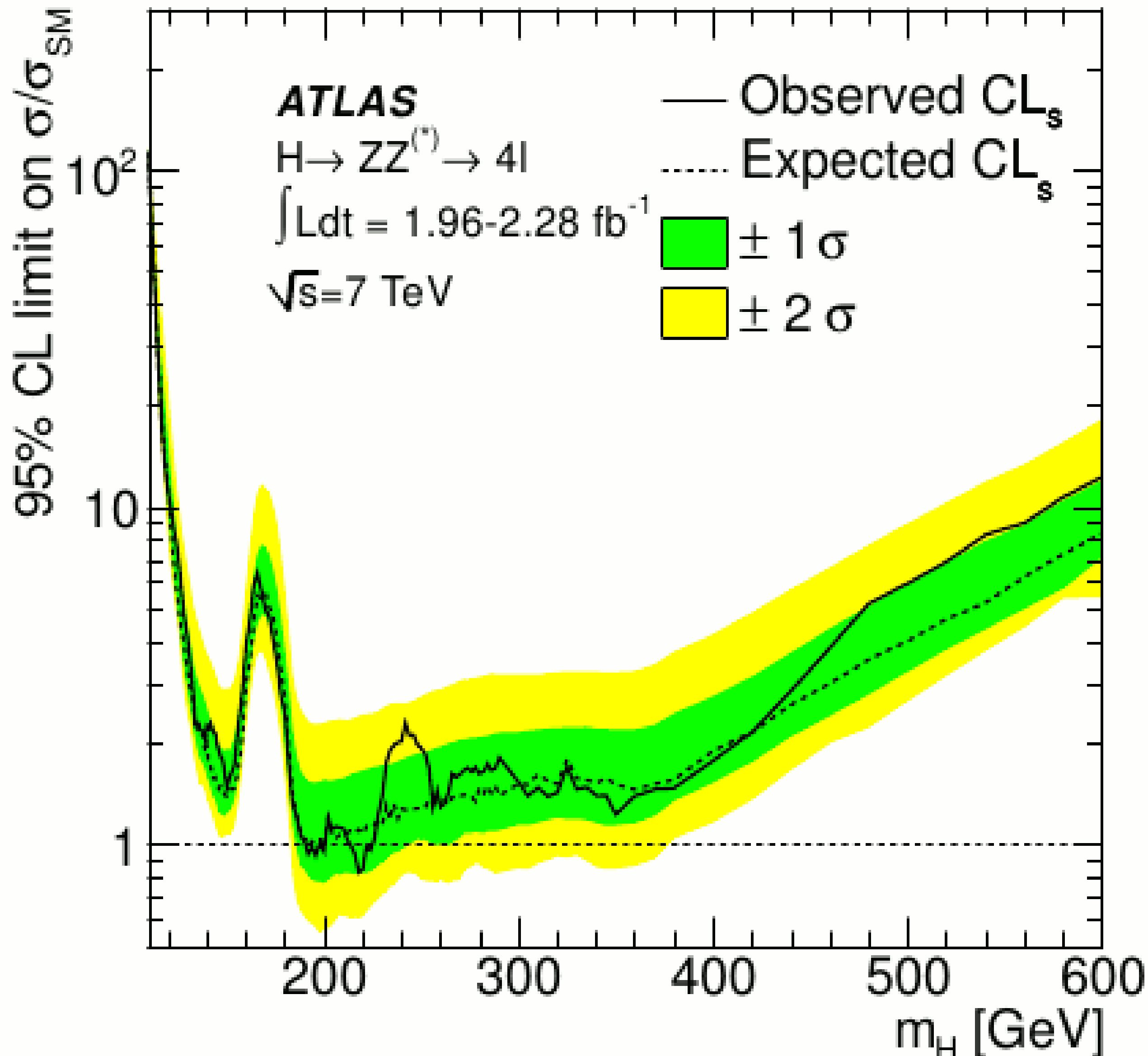


- Very clean: four leptons (e or μ)
- Dilepton mass, lepton isolation, and impact parameter cuts suppress top and Z+jets
- Good four-lepton mass resolution helps separate signal from otherwise irreducible continuum ZZ background

H→ZZ→4l (2)

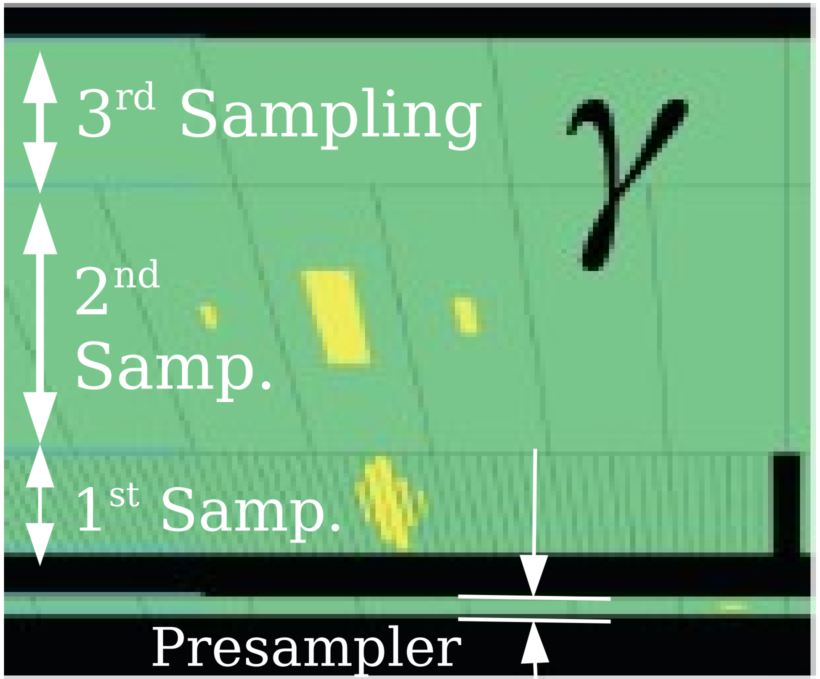
arXiv:1109.5945

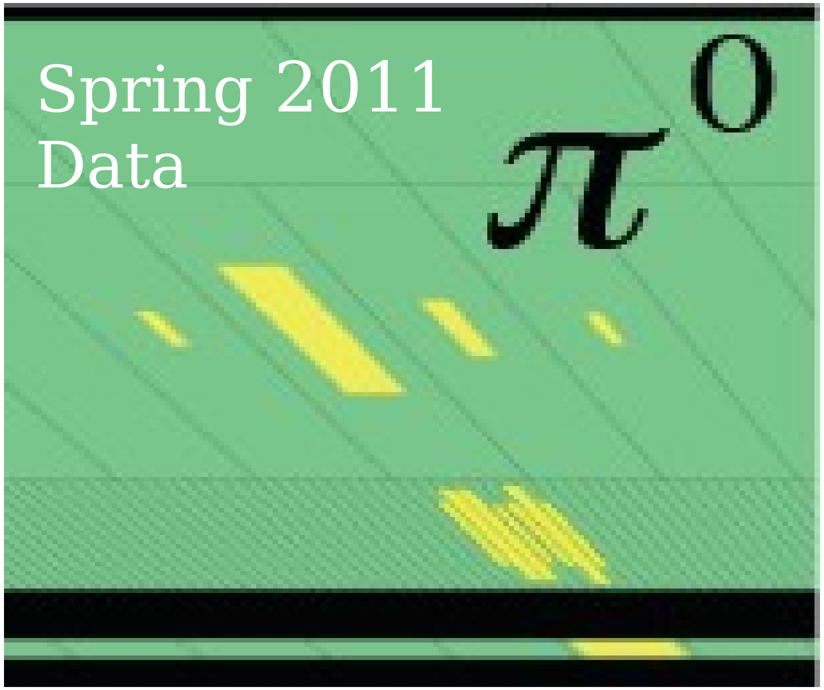
- Background estimates:
  - ZZ from MC prediction
  - top also from MC prediction, but validated in control region
  - Z+jets normalized to data using control region based on loosened isolation cuts for second lepton pair
- Very close to excluding a broad region of Standard Model parameter space
- Some values of m_H near 200 GeV are already excluded



H→γγ (1)

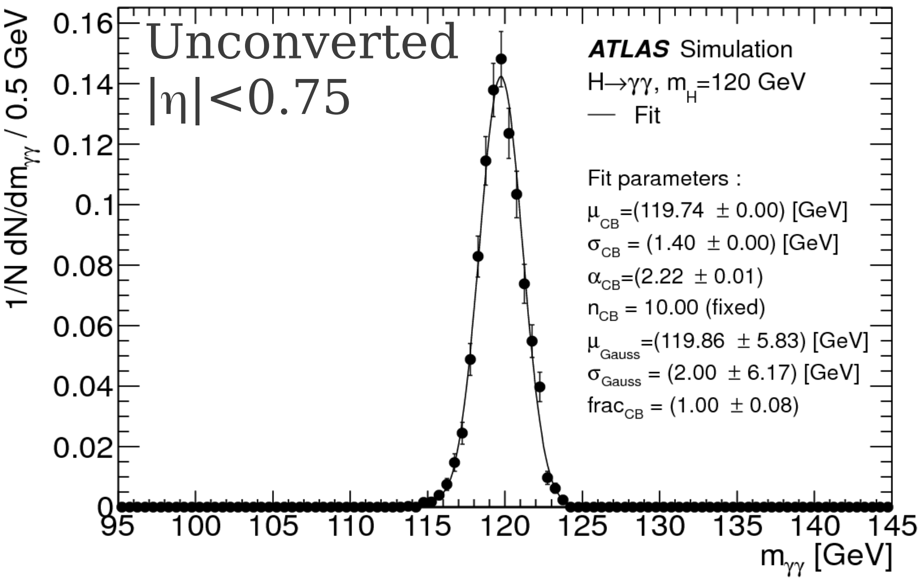
- H→γγ decay proceeds only via top and W loops, so BR(H→γγ) is small (~0.002). However, no subsequent decay as in the case of H→ZZ→4l.
- H→γγ signal is 0.04 pb, but background from continuum γγ is very large
  - Cross-section for qq→γγ is ~21 pb; for qg→γγ it's about 8 pb.
  - Background from γ+jet (before photon ID cuts) is ~$1.8\text{x}10^5$ pb
  - Background from dijets is ~$5\text{x}10^8$ pb.
  - Need large rejection, esp. against π^0 decays.
- Photon ID is based on lateral and longitudinal segmentation of the electromagnetic calorimeter.

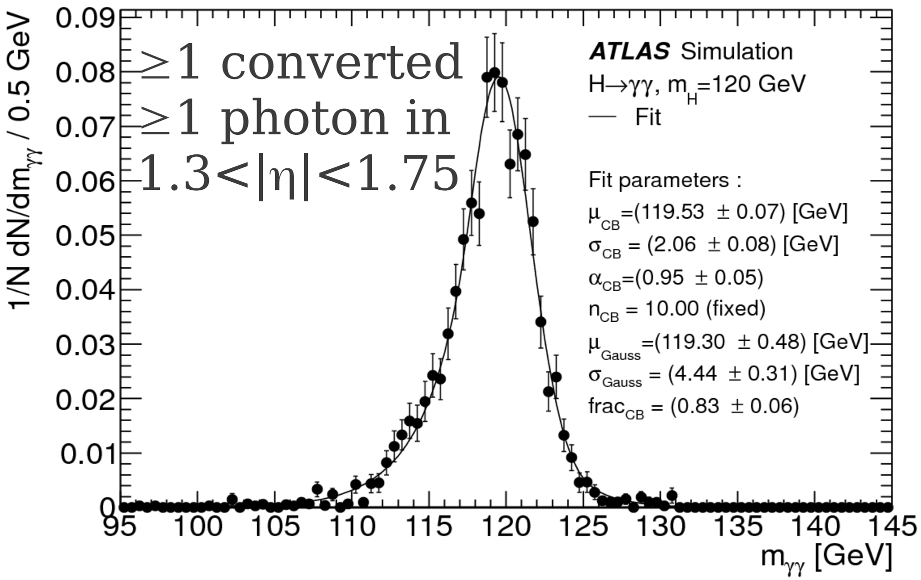




H→γγ (2)

arXiv:1108.5895

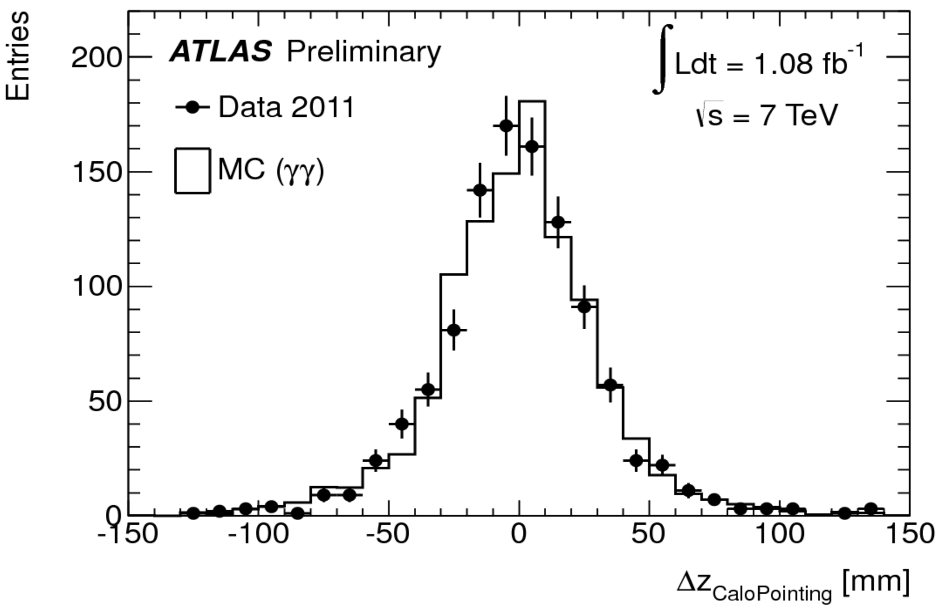


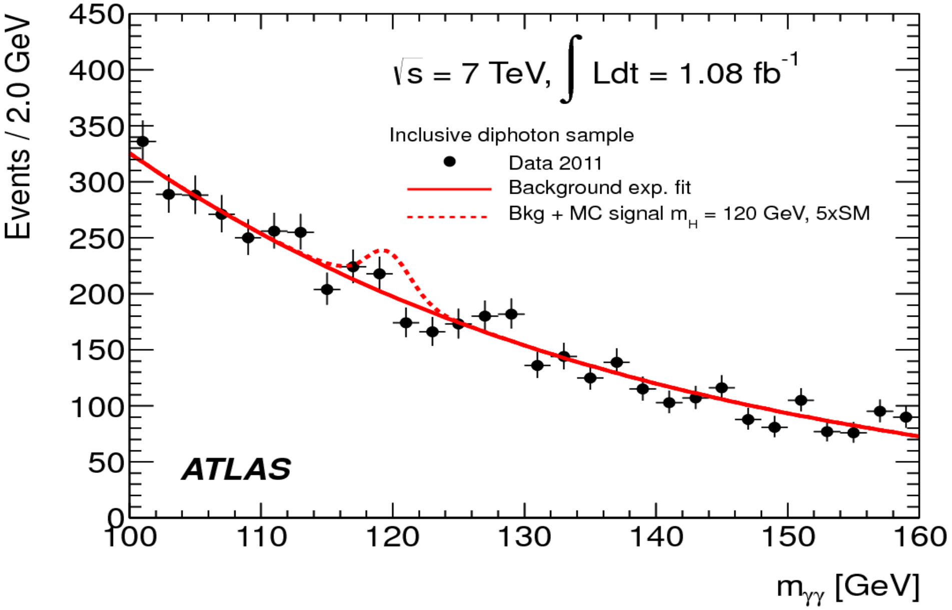


- Very good mass resolution of ~1.7 GeV helps distinguish between Higgs signal and continuum background
- Events are separated into categories based on the quality of photon reconstruction and location of photon candidates.
- Resolution ranges from ~1.4 GeV for unconverted photons in the central region of the detector (left) to ~2 GeV with asymmetric tails for photons which land in the region between the barrel and endcap and also show signs of having converted to an e^+e^- pair before reaching the calorimeter (right)

H→γγ (3)

arXiv:1108.5895



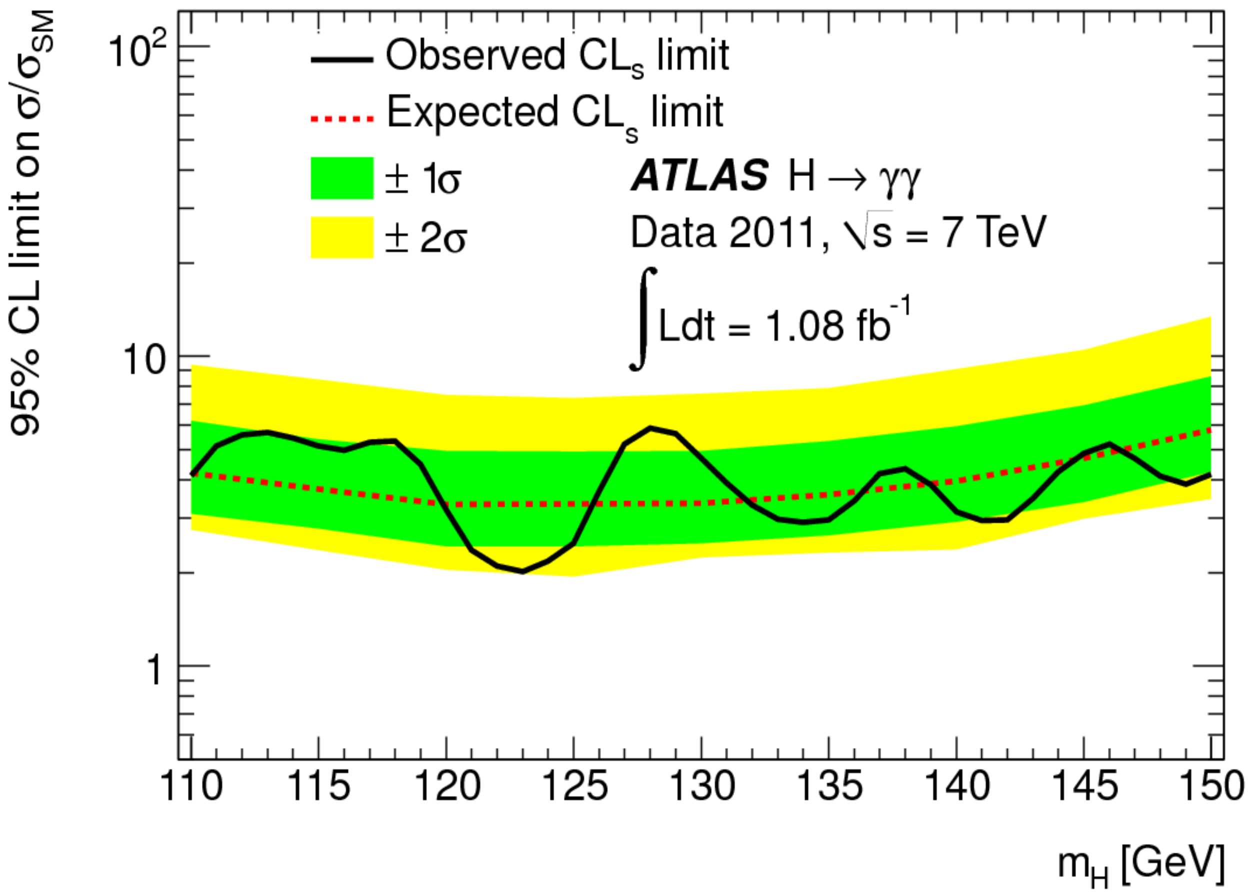


- Improve mass resolution by using "pointing" information: positions of clusters in the different calorimeter layers can give an estimate of the photon's direction of flight, and identifies the primary vertex with a resolution of ~20-30 mm (left).
- Signal is extracted using a fit to $M_{\gamma\gamma}$ (right). Plot shown above is inclusive, but fit treats pseudorapidity/conversion categories separately
- Normalization of background from jets is checked using loosened photon ID cuts.
  - Measured background is compatible with predictions

H→γγ (4)

arXiv:1108.5895

- Systematic Uncertainties:
  - Signal Yield (±12%)
  - Invariant Mass Resolution (±14%)
  - Background modeling (depends on m_H; ±5 events for m_H=110 GeV, ±3 events for m_H=150 GeV.)



- ATLAS currently excludes ~2-6 times the Standard Model prediction, depending on m_H.

WH/ZH, H→bb (1)

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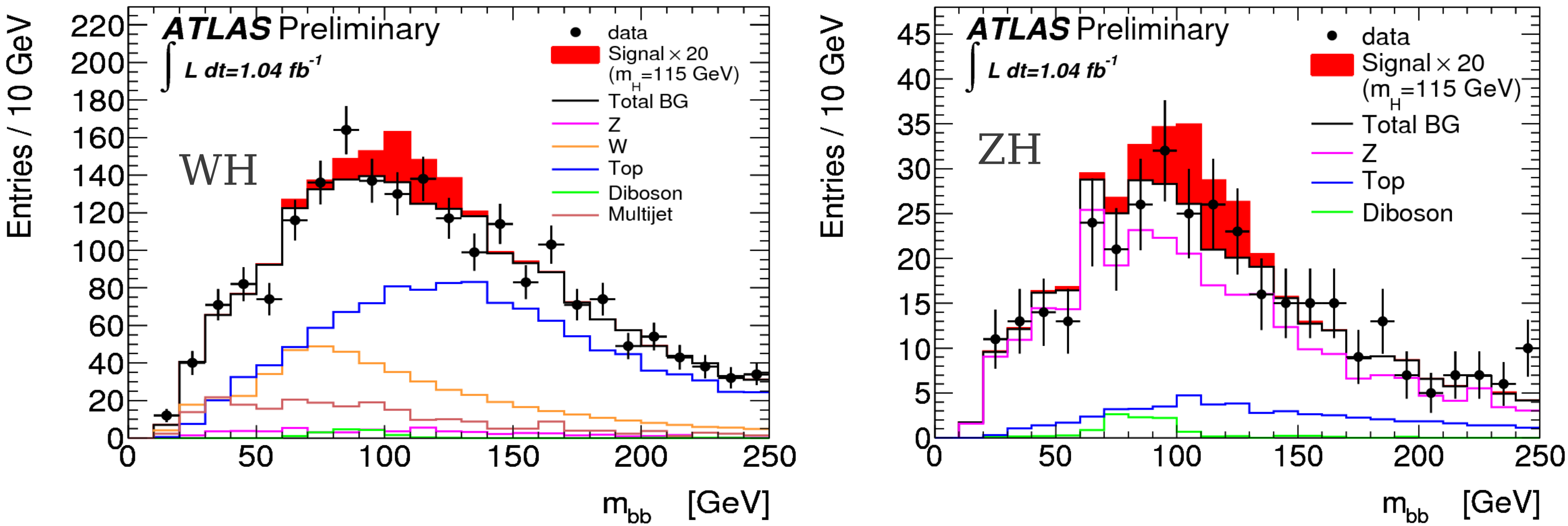
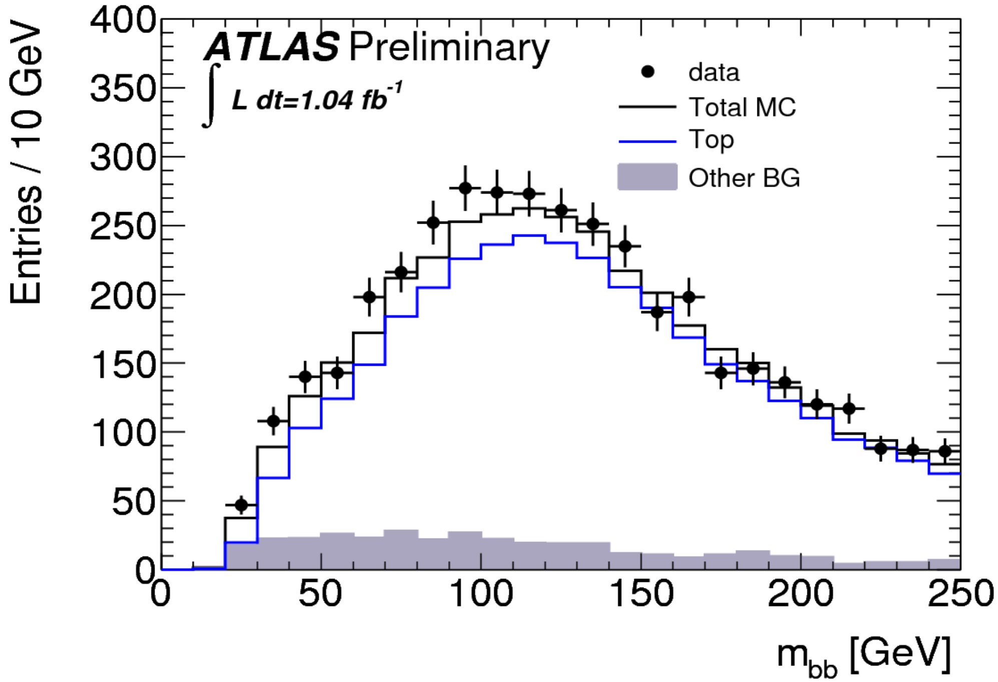
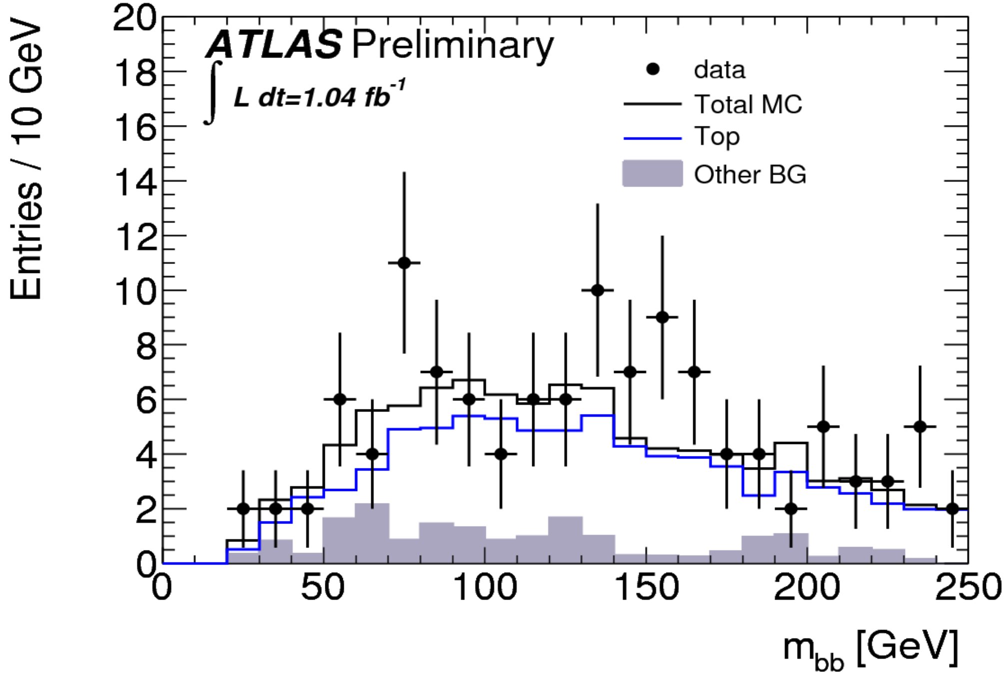


- ggH and WBF are dominant Higgs production mechanisms, but for H→bb these modes are overwhelmed by background. WH/ZH (H→bb) is best for this decay mode
- Select W→lν and Z→ll decays by requiring two leptons or one lepton and E_T^{miss}.
- Select two b-tagged jets with p_T>25 GeV
- Dominant backgrounds for both are W+jets, Z+jets, top

WH/ZH, H→bb (2)

ATLAS-CONF-2011-103





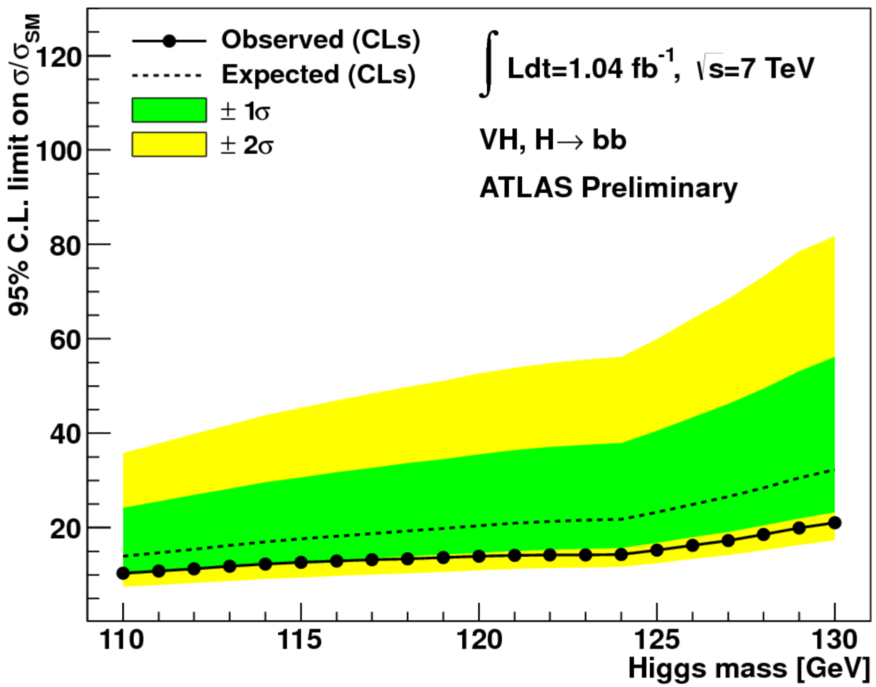
- Top quark backgrounds are checked with control samples.
- Left: control sample for WH consists of events with three jets (in the signal region only two are allowed)
  - Top normalization in signal region comes from fit to sidebands in m_{bb}
- Right: control sample for ZH consists of events with m_{ll} outside the Z peak
- Assign 9% uncertainty to top in ZH based on this comparison; 6% for top in WH based on the fit to m_{bb}

WH/ZH, H→bb (3)

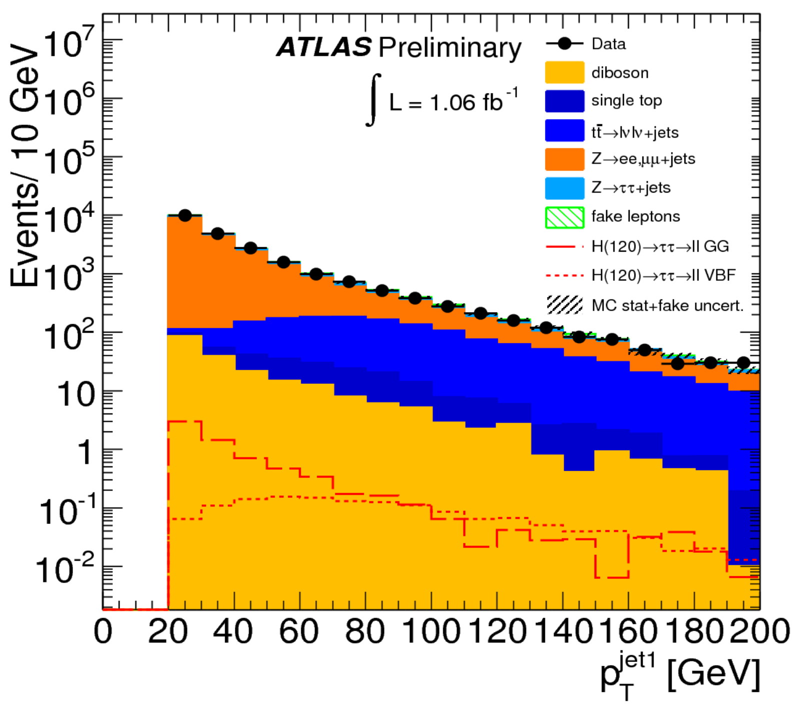
ATLAS-CONF-2011-103

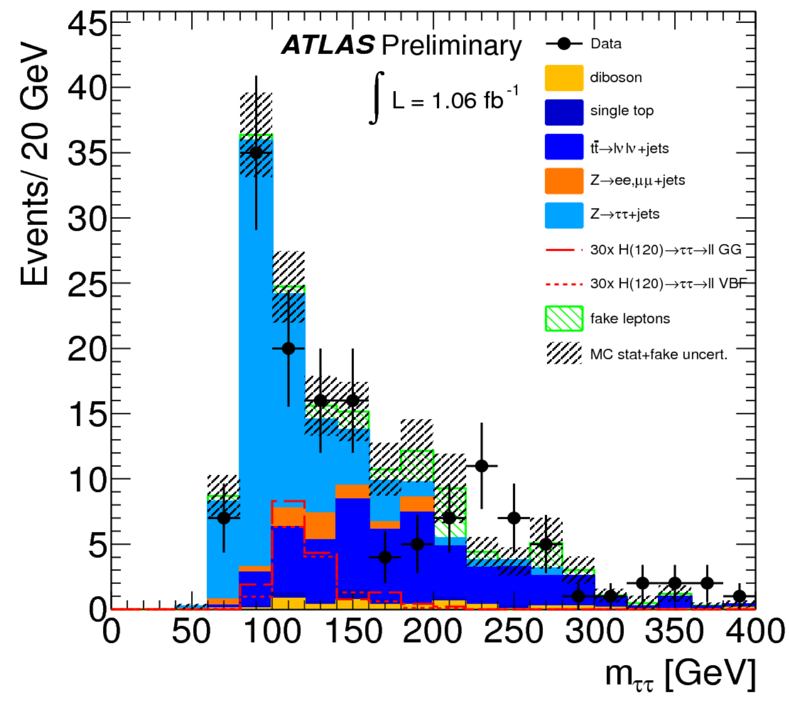
Uncertainty	ZH, 115 GeV	ZH, 130 GeV	WH, 115 GeV	WH, 130 GeV
Muon Res.	1%	4%	3%	1%
Jet E scale	9%	7%	1%	3%
E_T^{miss} Res.	2%	2%	2%	3%
b-tagging eff.	16%	17%	16%	17%
b-tag mistag	<1%	<1%	3%	3%
Luminosity	4%	4%	4%	4%
Higgs x-sec	5%	5%	5%	5%

- Above: major sources of background uncertainty. Several other sources contribute at the level of 1% or less
  - Electron E scale & resolution, Jet E res., electron and muon efficiency
- Exclude Higgs production with cross-section ~10-20 times the Standard Model prediction



H→ττ (1)



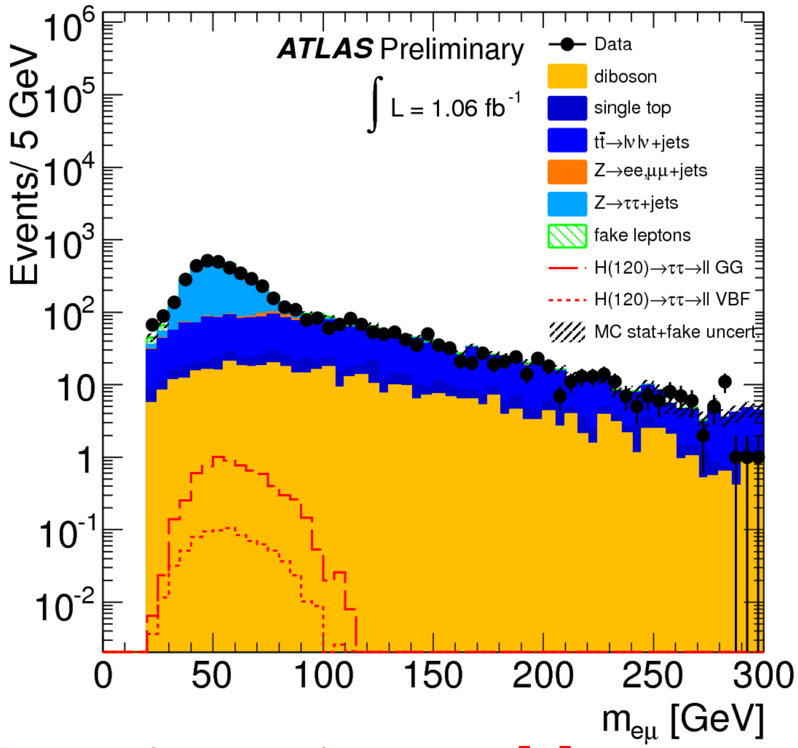


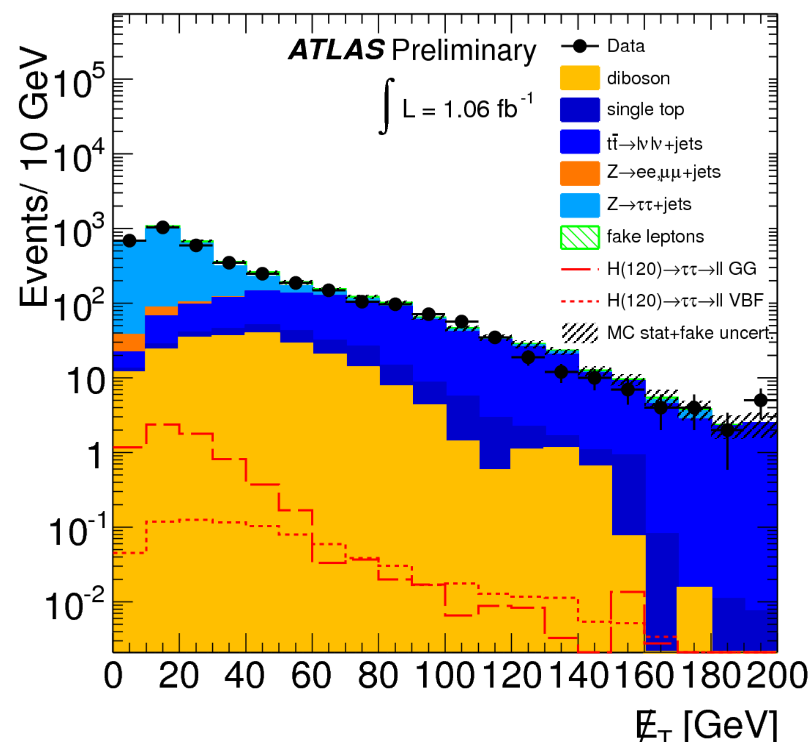
ATLAS-CONF-2011-133

- Promising channel for $110<m_H<140$ GeV
  - In the H+1j final state considered here, both ggH and WBF contribute
- Require two leptons and at least one hard jet ($p_T>40$ GeV). Analysis is based on $m_{\tau\tau}$ assuming τ decay products are collinear with parent τ lepton (left)

H→ττ (2)

ATLAS-CONF-2011-133



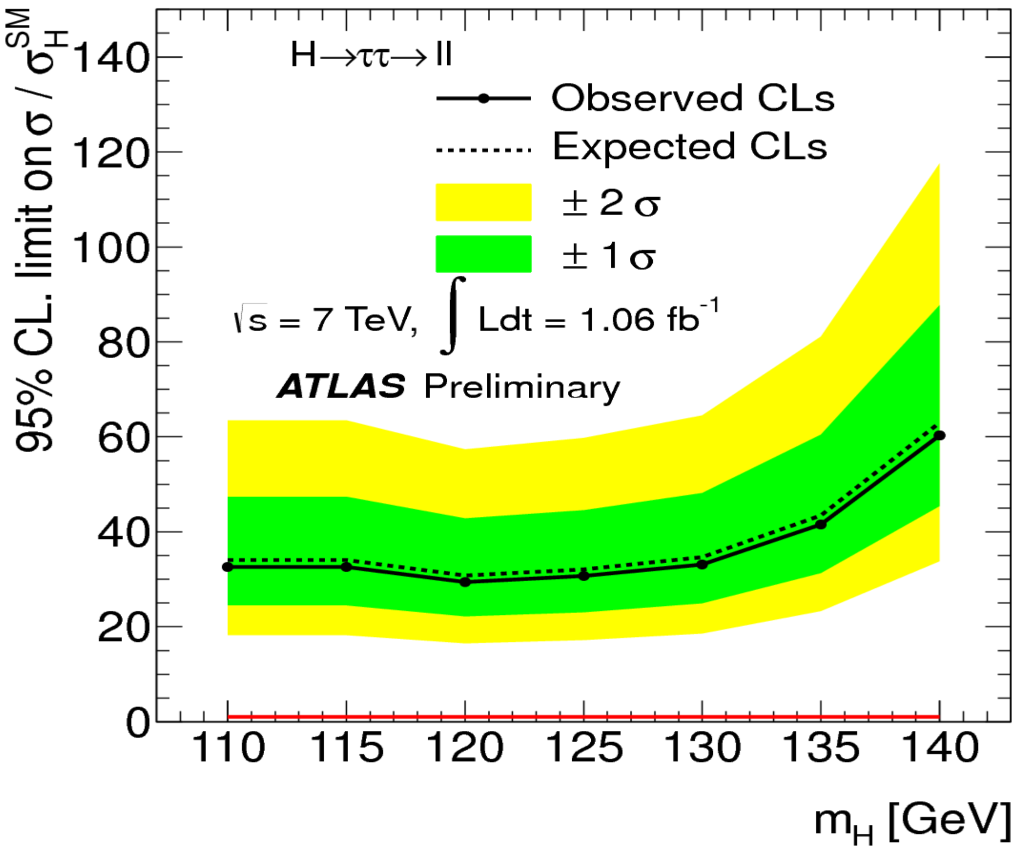


- Z→ττ is estimated by τ embedding (select Z→μμ in data and replace the reconstructed muons by simulated tau leptons)
- Top, Z→ee/μμ, and diboson backgrounds are taken from MC
- Backgrounds from jets misidentified as leptons are taken from control sample with reversed isolation, normalized by a template fit in the signal region
- Overall agreement is good. Example plots above: dilepton invariant mass (left) and E_T^{miss} (right)

H→ττ (3)

ATLAS-CONF-2011-133

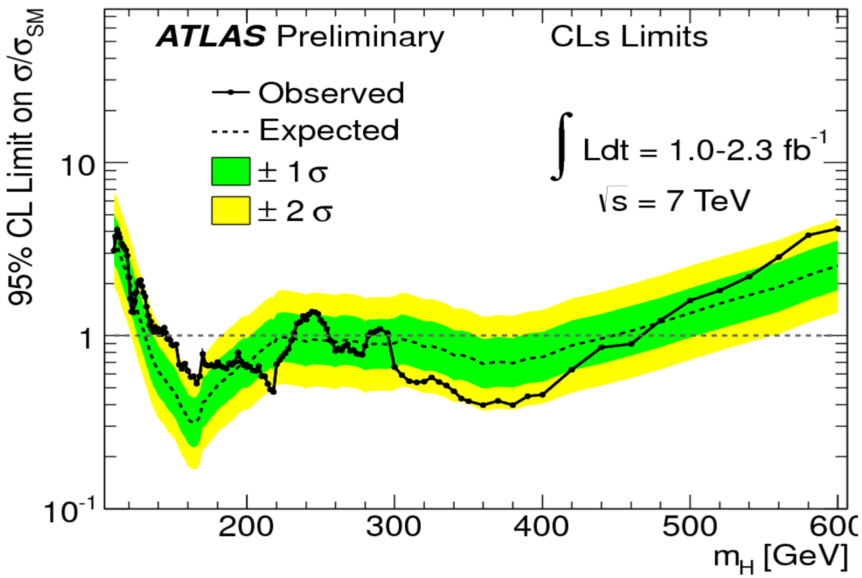
- Dominant sources of systematic error on background are the jet energy scale uncertainty (-9.8/+7.0%) and MC statistics (8%)

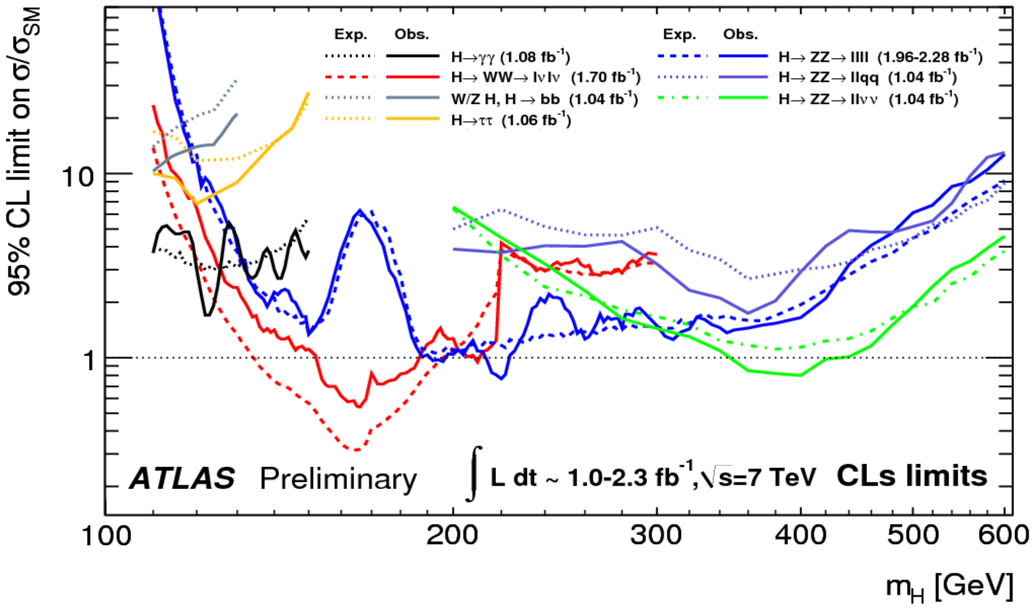


- No significant excess. Upper limits on cross-section are about 30x the Standard Model prediction (above)

Combined Limits

ATLAS-CONF-2011-135





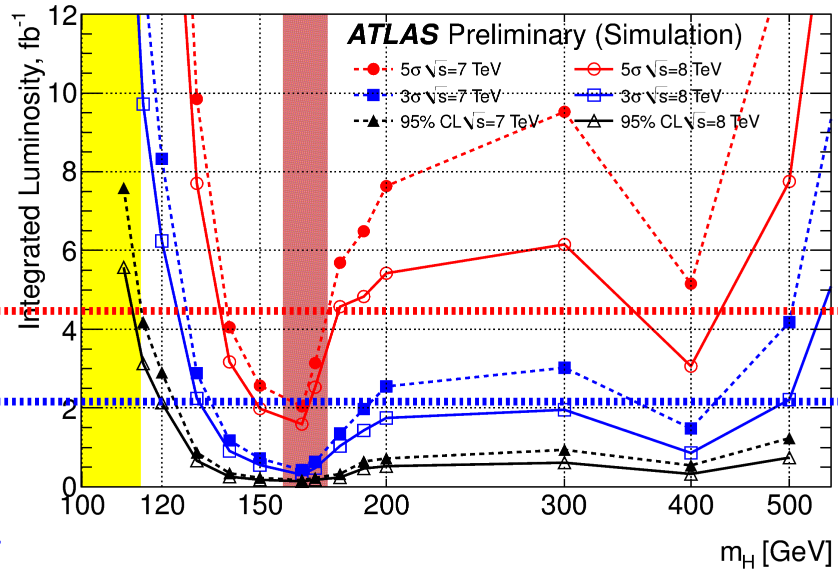
- Exclude a Standard Model Higgs boson with m_H in the ranges 146-232 GeV, 256-282 GeV, or 296-466 GeV.
  - Includes $H\rightarrow\gamma\gamma$, $H\rightarrow bb$, $H\rightarrow\tau\tau$, $H\rightarrow WW\rightarrow l\nu l\nu$, $H\rightarrow ZZ\rightarrow 4l$, $H\rightarrow ZZ\rightarrow ll\nu\nu$, and $H\rightarrow ZZ\rightarrow llqq$

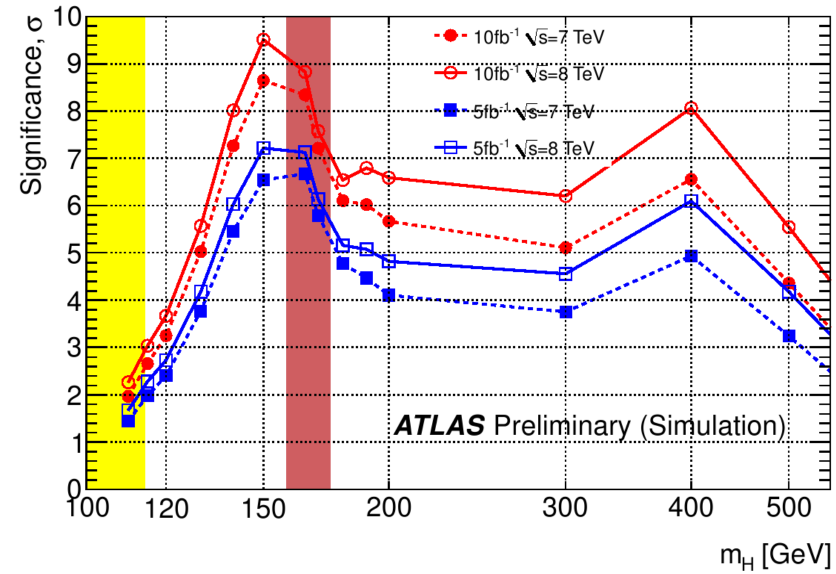
Prospects for Future Running

ATL-PHYS-PUB-2011-001

Recorded so far

Analyzed so far





- With this year's data, expect only a small window of allowed Standard Model Higgs masses to remain near the LEP limit.
- With another 5-10 fb^{-1} next year, we should have a much stronger statement
- ...but a Higgs discovery in 114-130 GeV is challenging at this center-of-mass energy

Summary

- Using the $H \rightarrow WW \rightarrow l\nu l\nu$ channel, ATLAS excludes the presence of a Higgs boson in the ranges 154-186 GeV
- The $H \rightarrow WW \rightarrow l\nu qq$ search excludes about 2.7 times the Standard Model cross-section at m_H=400 GeV
- With $H \rightarrow ZZ \rightarrow ll\nu\nu$, exclude 360-420 GeV. Independent limits from $H \rightarrow ZZ \rightarrow llqq$ and $H \rightarrow ZZ \rightarrow 4l$ are approaching exclusion of the Standard Model for some masses.
- $H \rightarrow \gamma\gamma$ search excludes ~2-6xSM
- $H \rightarrow \tau\tau$ search currently excludes ~30x the SM prediction
- $WH/ZH \rightarrow bb$ search excludes ~10-20 times SM prediction
- Except for two holes (232-256 GeV and 282-296 GeV), the SM Higgs is excluded for $146 < m_H < 466$ GeV with current analyzed luminosity