Higgs Searches at CMS & ATLAS

W. Quayle

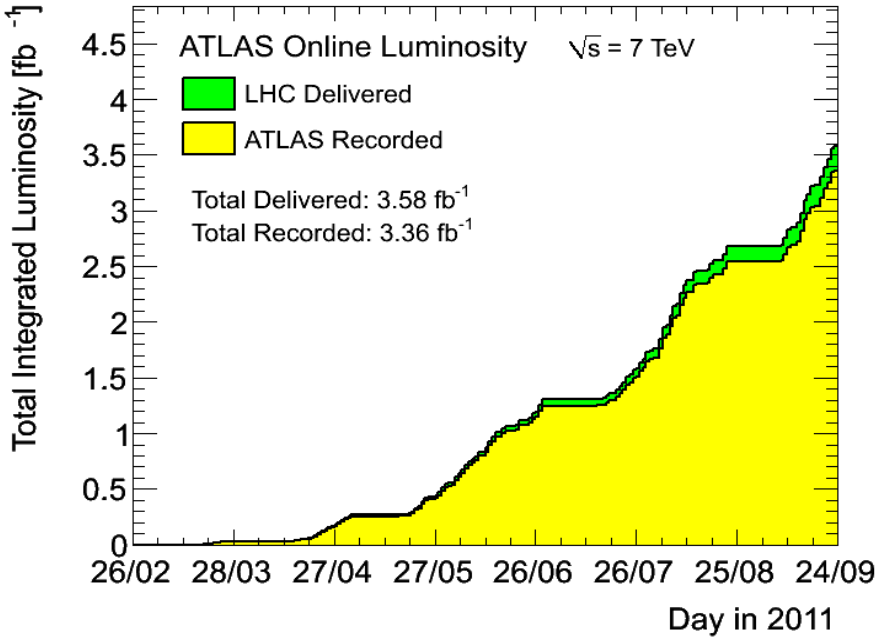
for the CMS and ATLAS collaborations

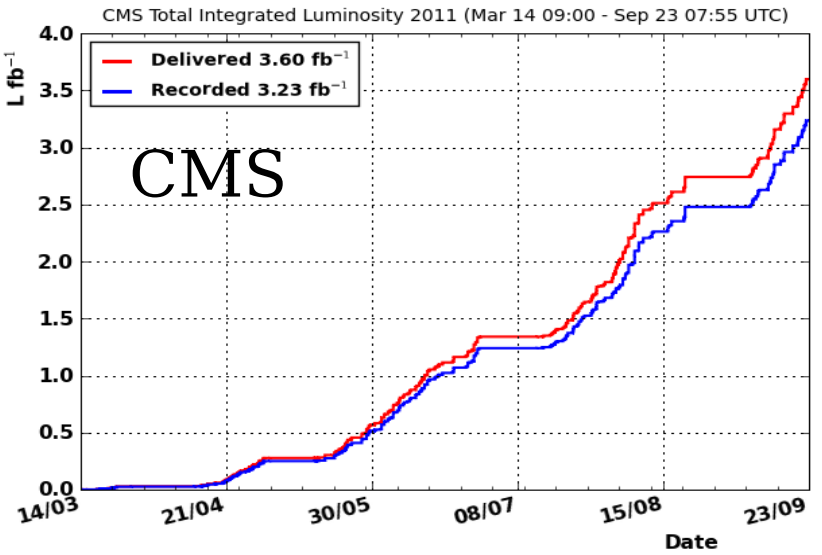
LCWS2011

27 September, 2011

LHC Operation

- ~3.2-3.4 fb^{-1} of $\sqrt{s}$=7 TeV pp collision data recorded so far in 2011. Data-taking efficiency for ATLAS and CMS is ~90-95%
  - Up to 2.2 fb^{-1} analyzed so far
  - Still have several weeks of pp collisions before heavy ion run starts
  - At the beginning of the year, the goal was to have 1 fb^{-1} or more of integrated luminosity before the end of the year.
- Future plans:
  - Run in 2012, at $\sqrt{s}$=7 TeV or possibly at $\sqrt{s}$=8 TeV
  - Long shutdown, then run at higher energy

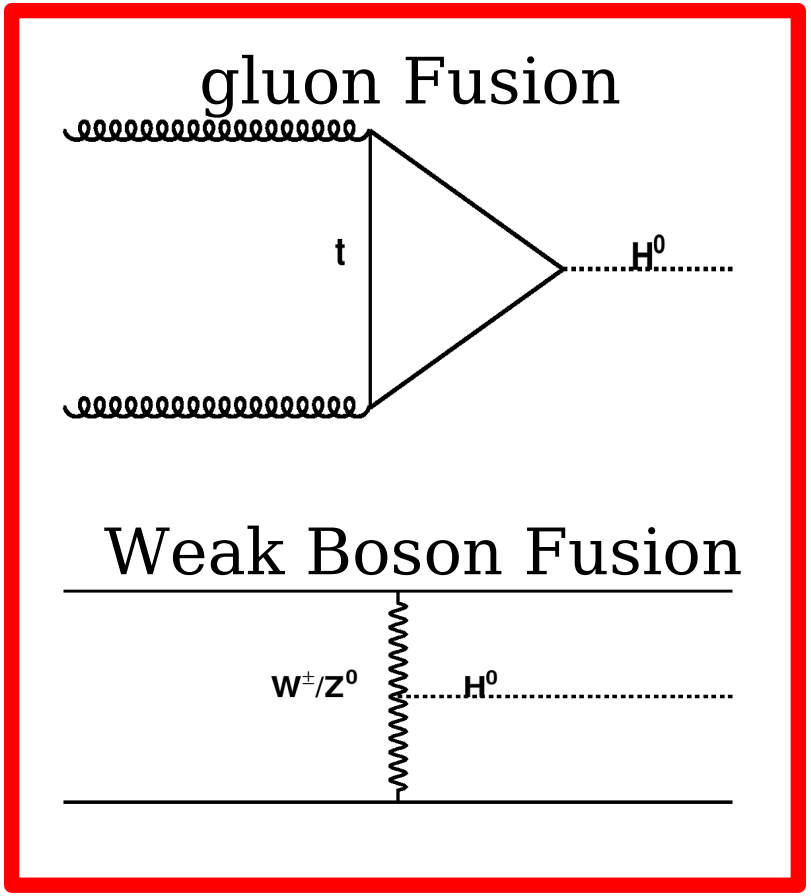




Higgs Production & Decays (1)

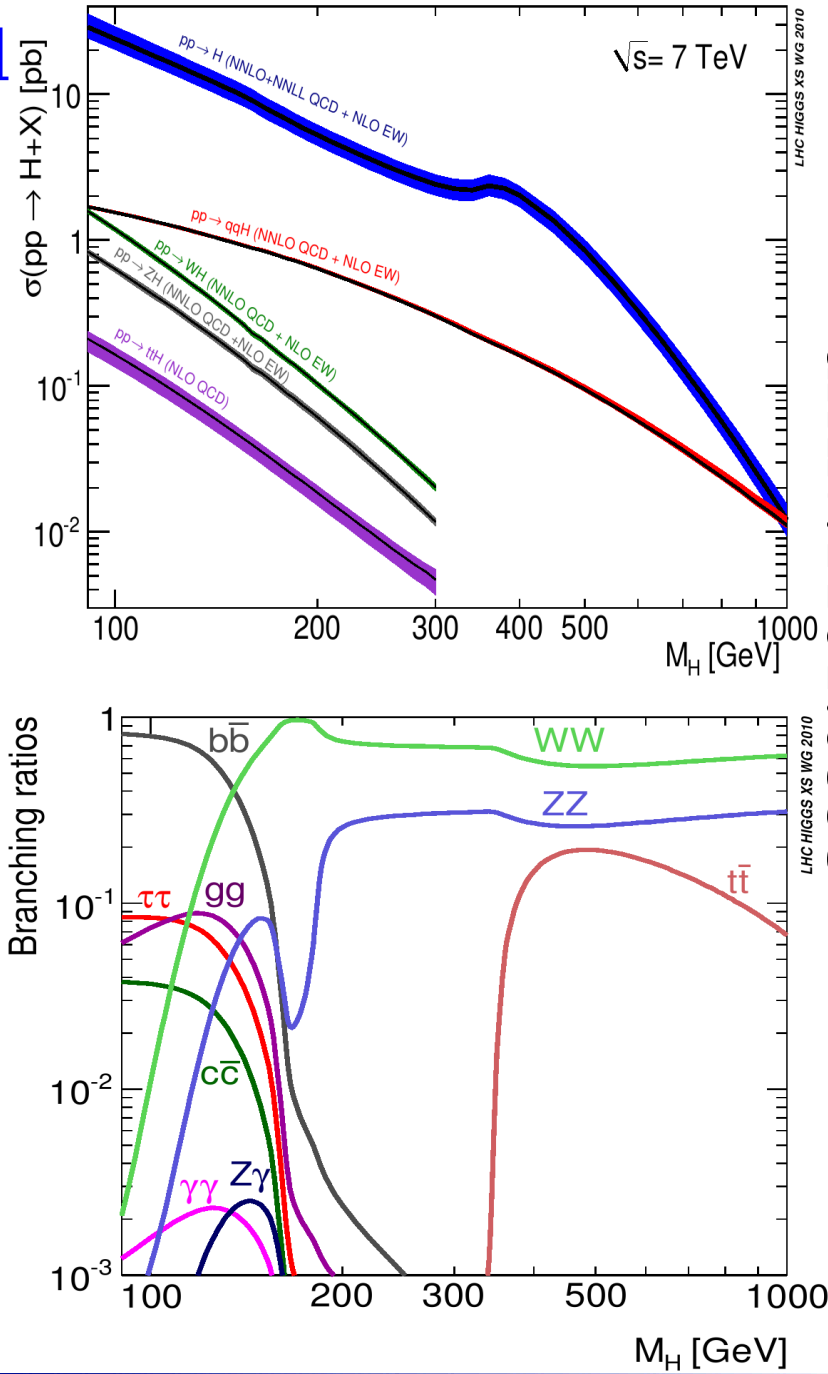
- In the Standard Model, Higgs boson production primarily through gluon fusion and Weak Boson Fusion (WBF)
  - In some searches (e.g. H→$\gamma\gamma$, bb), WH/ZH/ttH are important too

- In MSSM/2HDM, $h^0/A^0/H^0$ is also produced in with two b quarks (if tan β is large). $H^{\pm}$ is produced in top decays if $M_{H+} < M_{top}$, or in association with top (gb fusion) if $M_{H+} > M_{top}$



Higgs Production & Decays (2)

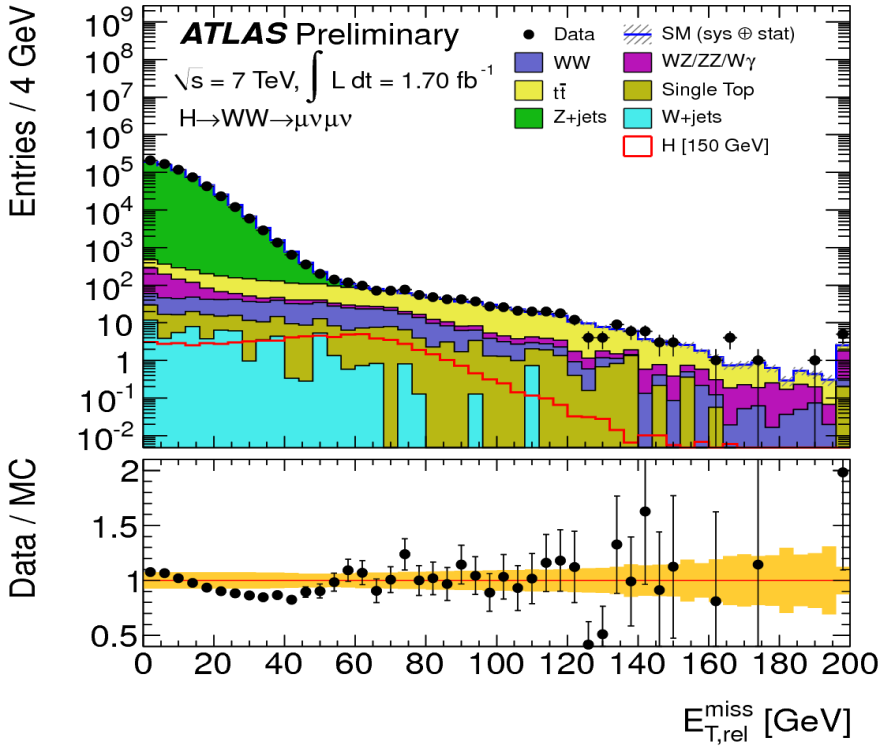
- Right: cross-sections (top) and branching ratios (bottom) in the Standard Model (SM)
- Standard Model decay modes which have been analyzed in data:
  - H→WW, H→ZZ at high mass
  - H→bb, H→$\tau\tau$, and H→$\gamma\gamma$ at low m_H
- MSSM decay modes which have been analyzed in data:
  - $H^+ \rightarrow \tau\nu$
  - $A/H^0 \rightarrow \tau\tau$
- Cross-sections are taken from "Handbook of LHC Higgs Cross-sections," arXiv:1101.0593

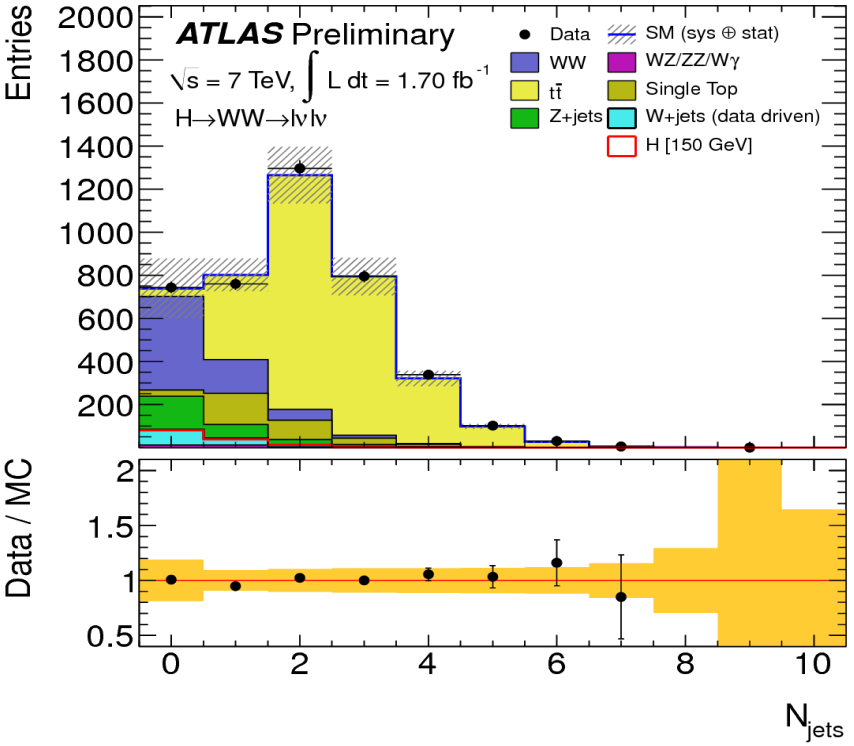


arXiv:1101.0593

H→WW→lνlν (1)

ATLAS-CONF-2011-134

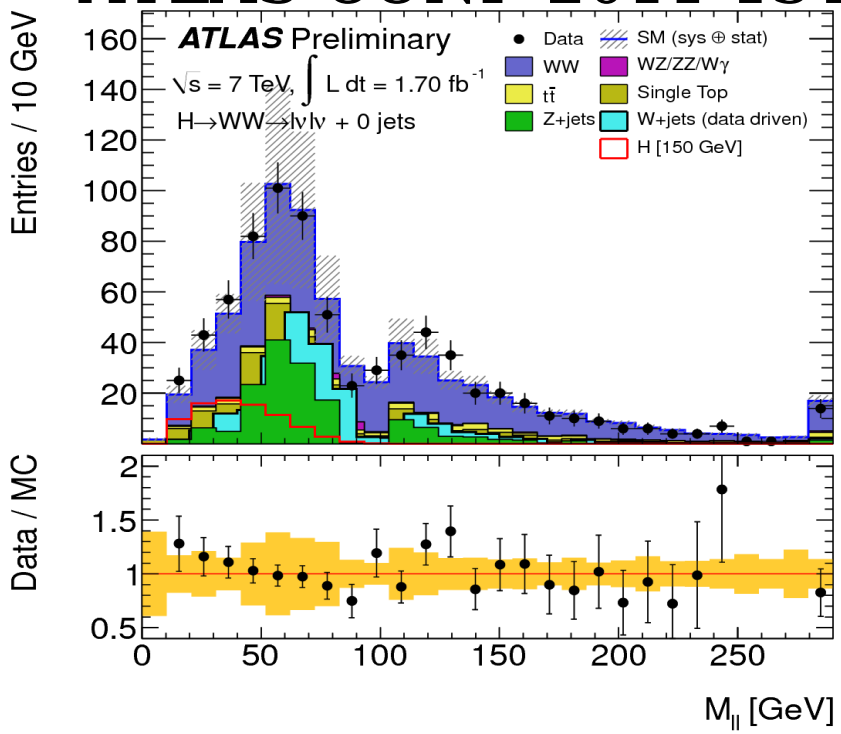




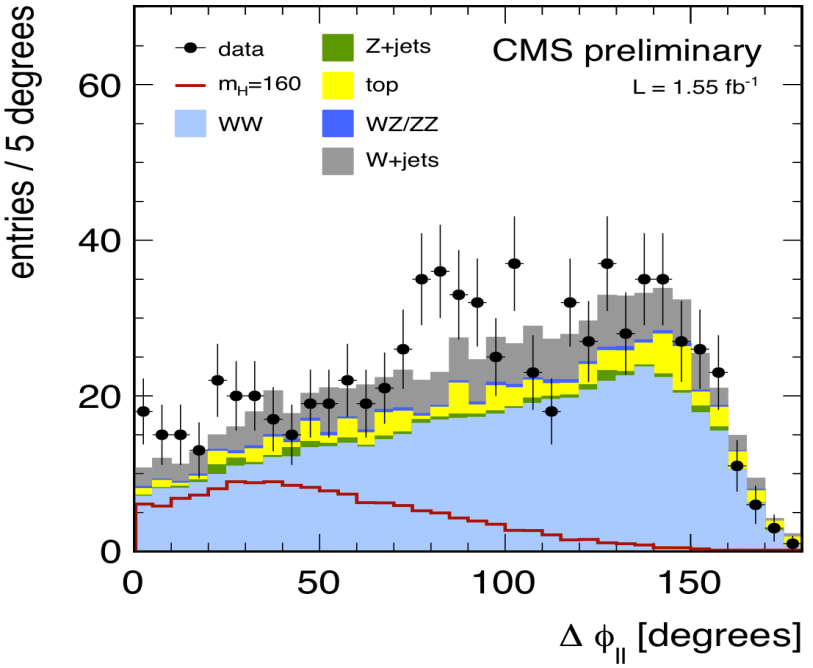
- Requiring two leptons suppresses QCD multijet background to negligible levels
- Large background from Z is suppressed by requiring large E_T^{miss} in same-flavor events (left)
- Top events are rejected by cut on jet multiplicity (right).
  - N_{jet}=0 and N_{jet}=1 considered in ATLAS analysis
  - N_{jet}=2 also included in CMS analysis

H→WW→lνlν (2)

ATLAS-CONF-2011-134



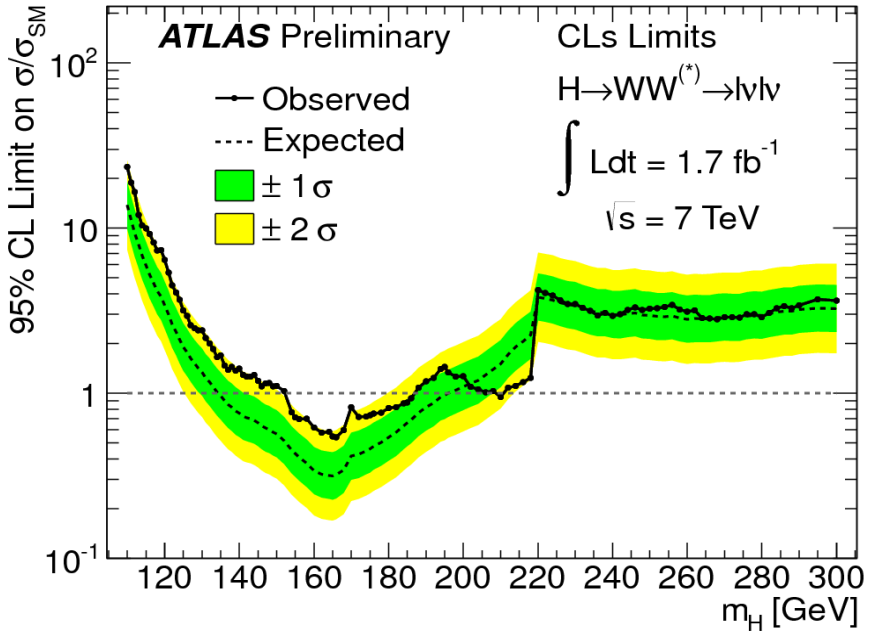
CMS-HIG-11-014



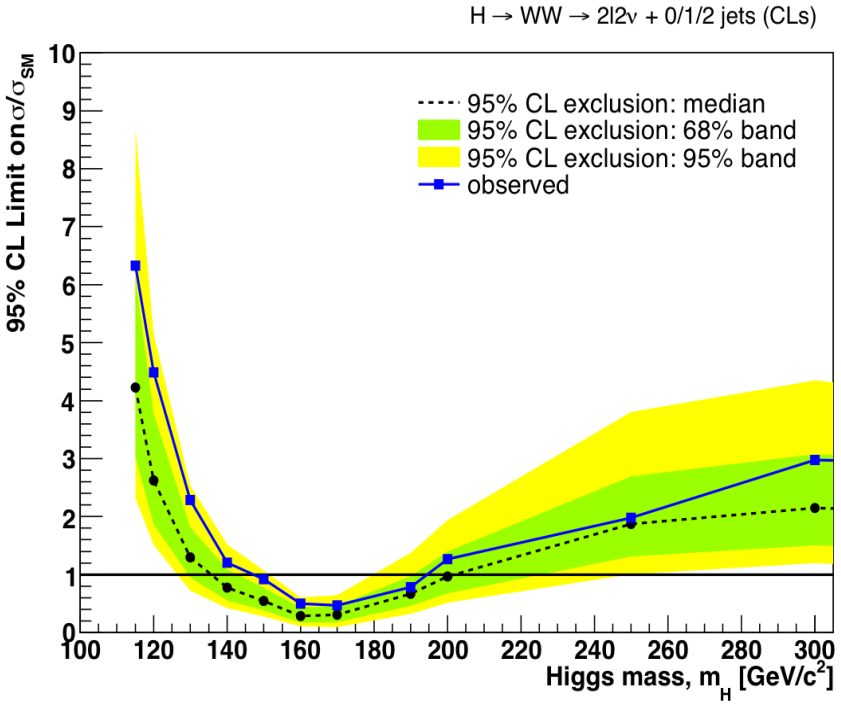
- Event selection exploits different angular distributions caused by kinematics and by spin correlations. Above: M_{ll} (left) and $\Delta\phi_{ll}$ (right) in events with no jets
- Backgrounds are estimated with control samples:
  - W+jets based on loosened lepton selection
  - ttbar based on altered jet cuts, b-tagging, or MC simulation
  - Z+jets based on altered M_{ll} and P_T^{miss} cuts
  - Diboson based on altered M_{ll} and $\Delta\phi_{ll}$ cuts

H→WW→lνlν (3)

ATLAS-CONF-2011-134

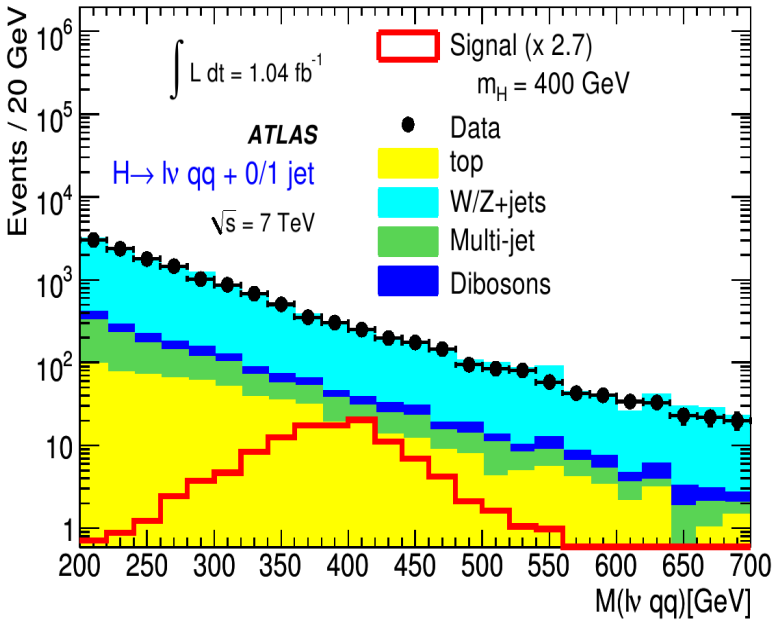


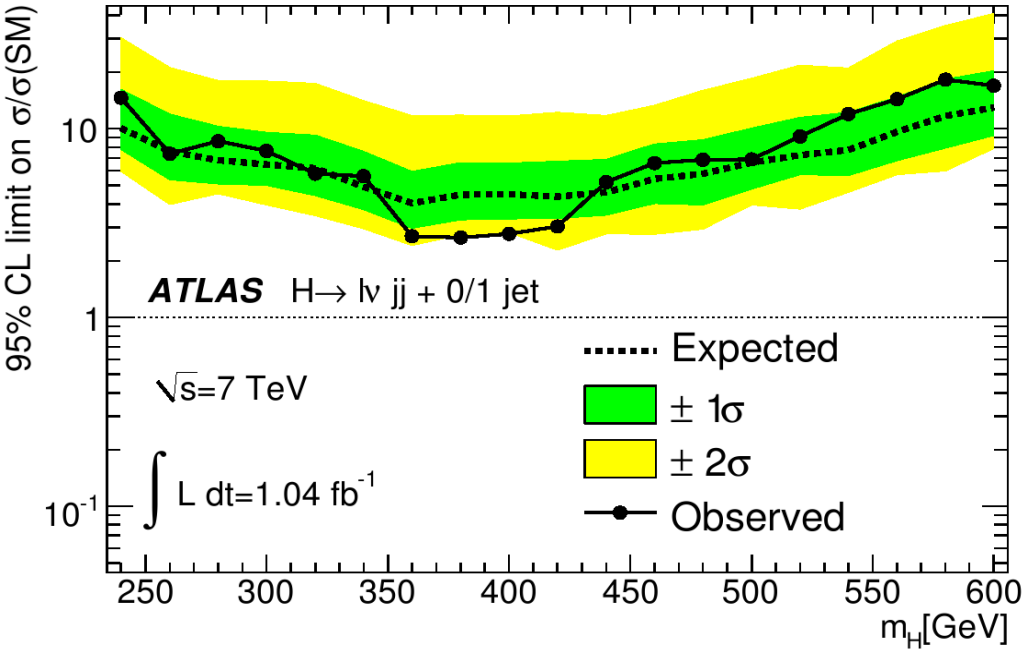
CMS-HIG-11-014

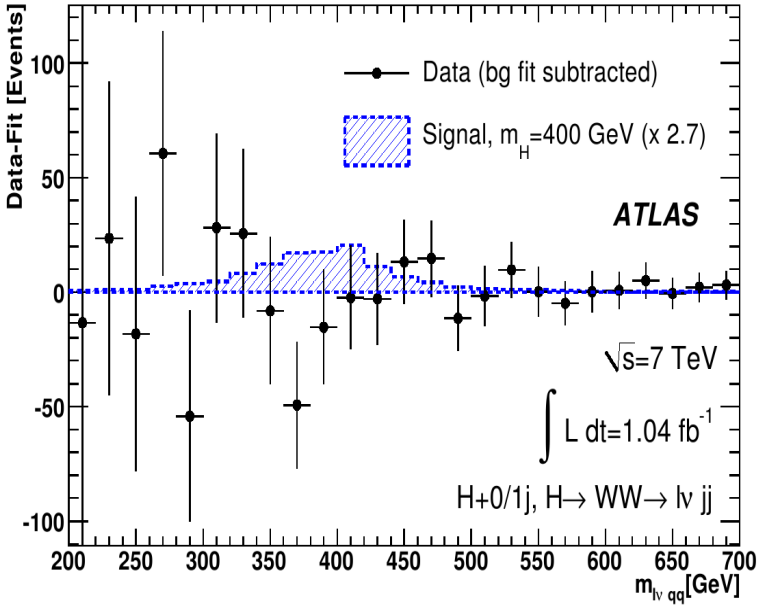


- ATLAS analysis is cut-based and includes contributions from H+0/1j events.
- CMS analysis also includes contributions from H+2j
- Neither experiment sees a significant excess, so an upper limit is set as a function of m_H, in units of the Standard Model prediction. ATLAS excludes $154<m_H<186$ GeV ($135<m_H<196$ GeV expected), while CMS excludes $147<m_H<194$ GeV ($135<m_H<200$ GeV expected)

H→WW→lνqq





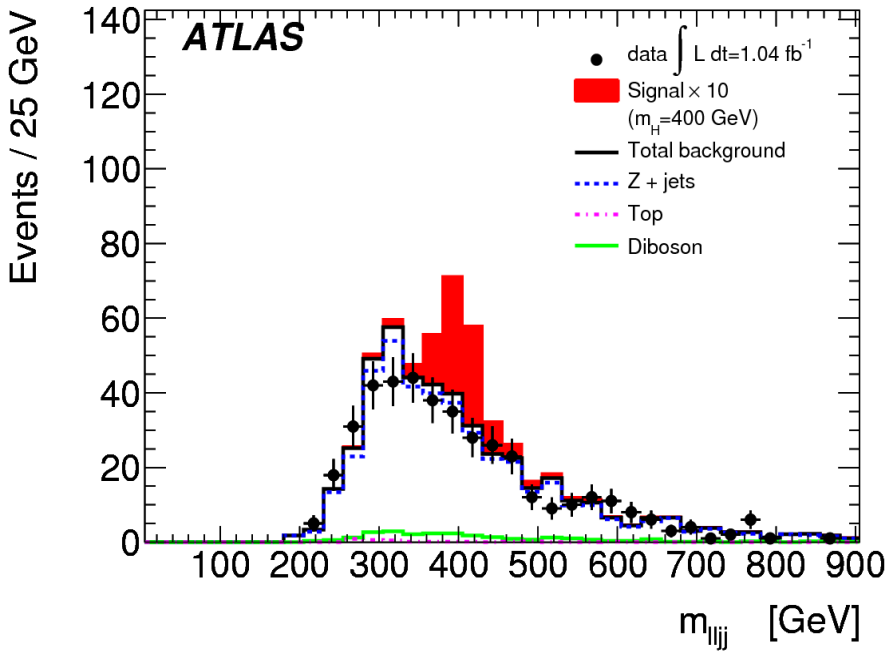


arXiv:1109.3615

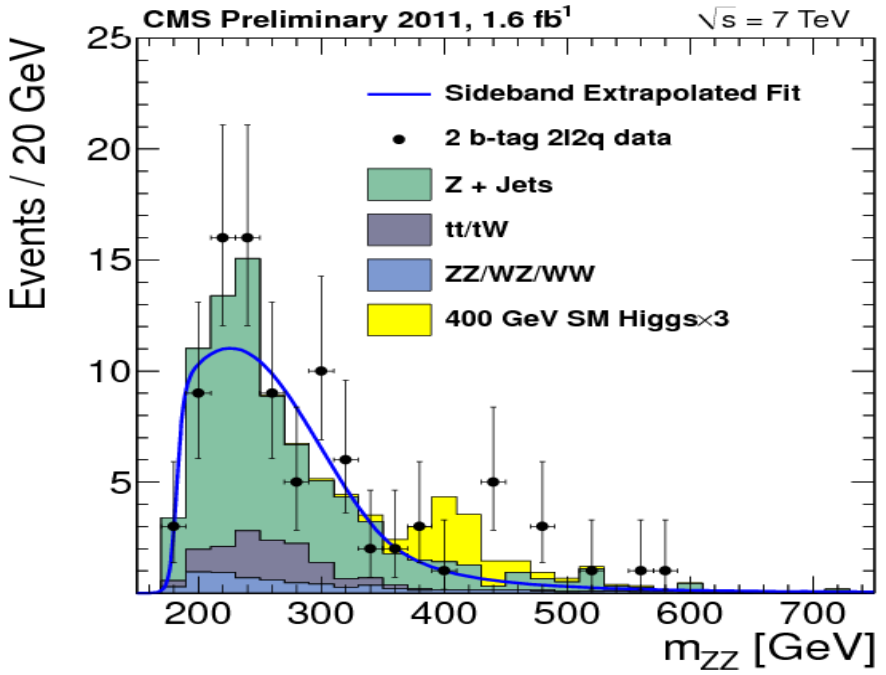
- Estimate P_Z^{ν} and M_{WW} by solving $M_W=M_{l\nu}$. Require two real solutions; take one with smaller $|P_Z^{\nu}|$
- Check QCD background with anti-isolated lepton sample, but take final normalizations from fit (double exponential for background, hist PDF for signal)
- Exclude 2.7xSM for m_H=400 GeV

H→ZZ→llqq (1)

arXiv:1108.5064



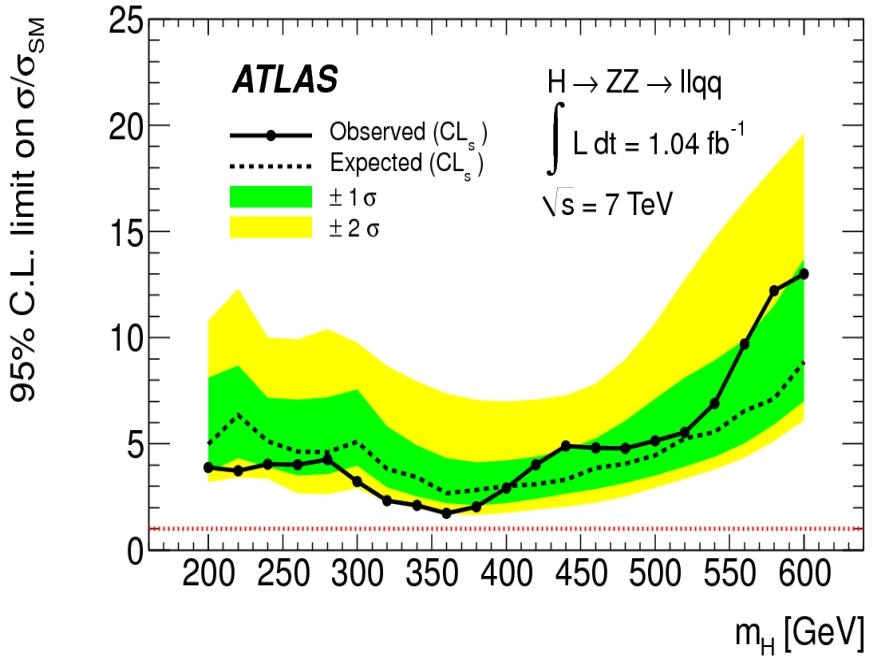
CMS-HIG-11-017



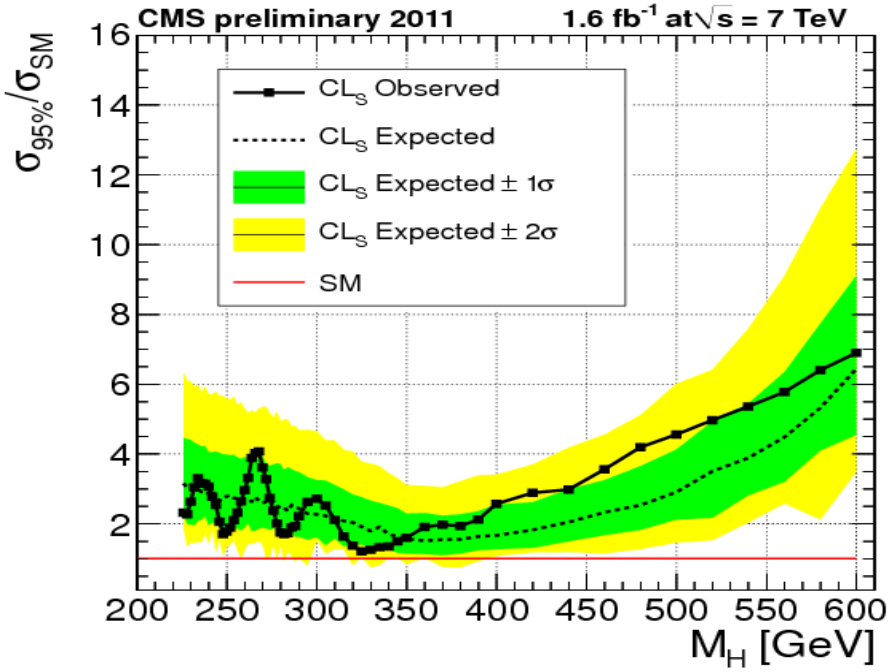
- Signature is two leptons and two jets, with small MET, and with M_{ll} and M_{qq} near M_Z.
- Divide the signal into events with fewer than two b-tagged jets (left) and events with two (right)
- Also use angular information about the jets and leptons to suppress background.
  - $\Delta\phi_{ll}>\pi/2$ and $\Delta\phi_{jj}>\pi/2$ for ATLAS
  - Likelihood discriminant for CMS

H→ZZ→llqq (2)

arXiv:1108.5064



CMS-HIG-11-017

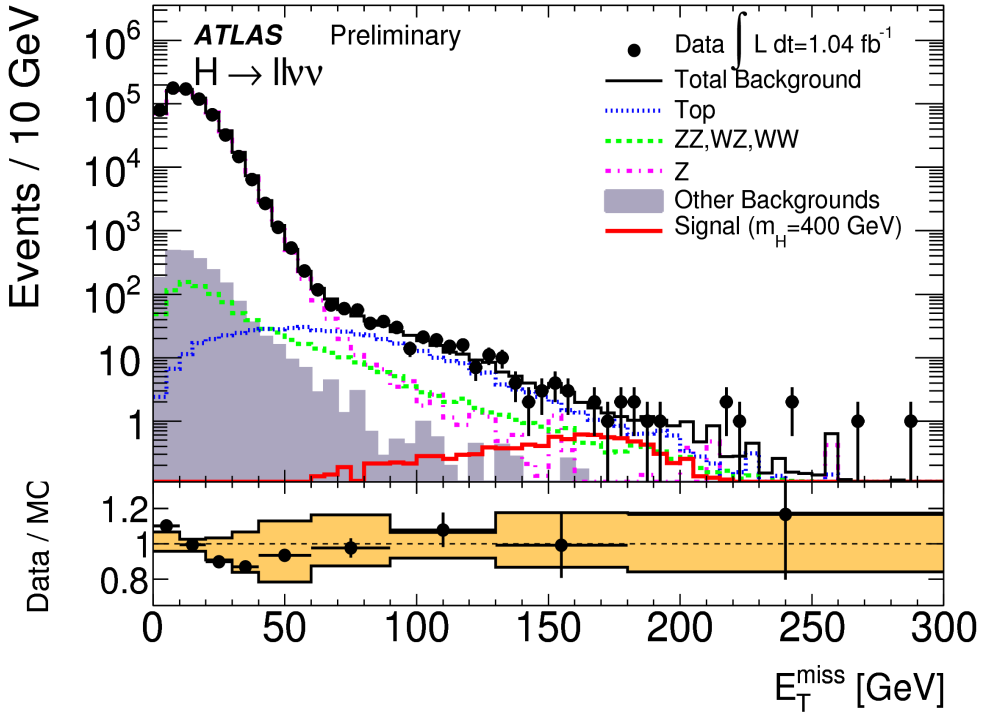


- Background shape & normalization comes from MC (validated by comparison with data) in ATLAS analysis and from a fit in the CMS analysis.

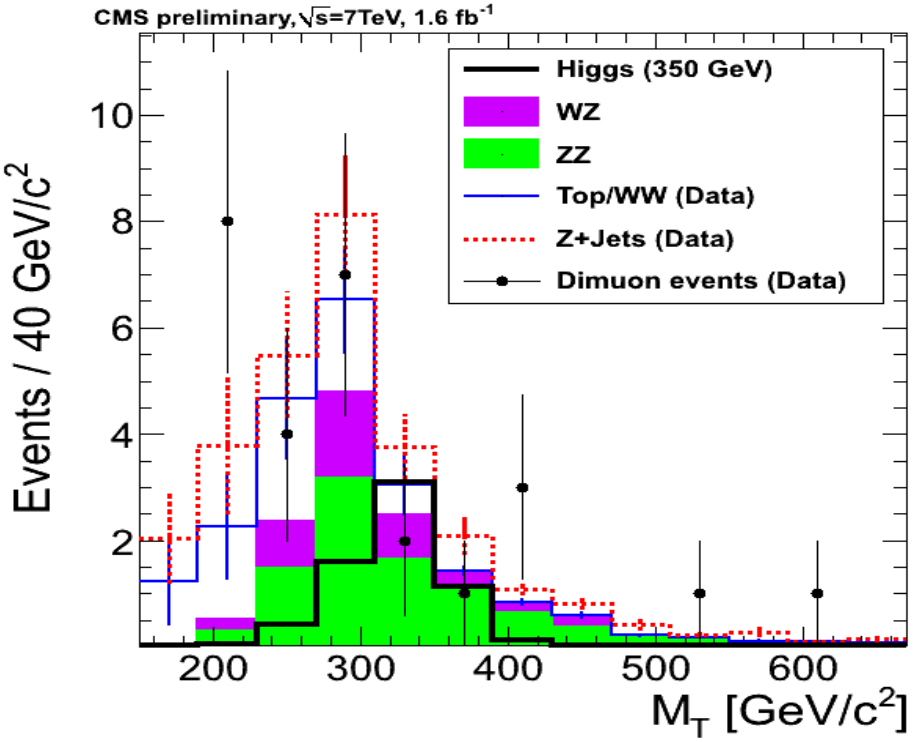
- Observed limits for ATLAS and CMS are approaching the Standard Model prediction for m_H near ~300-400 GeV

H→ZZ→llνν (1)

arXiv:1109.3357



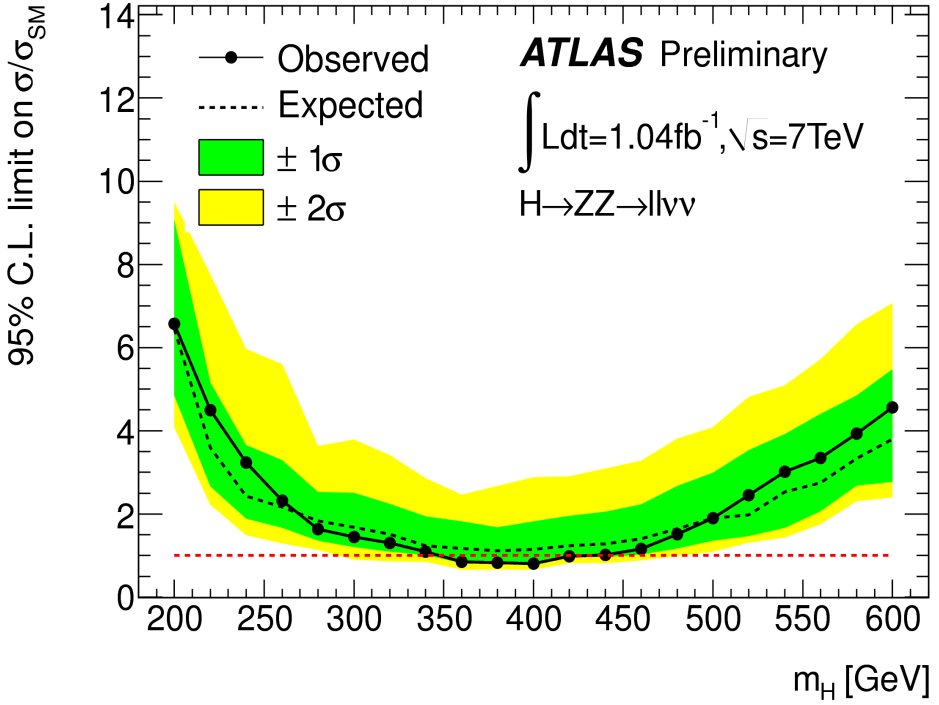
CMS-HIG-11-016



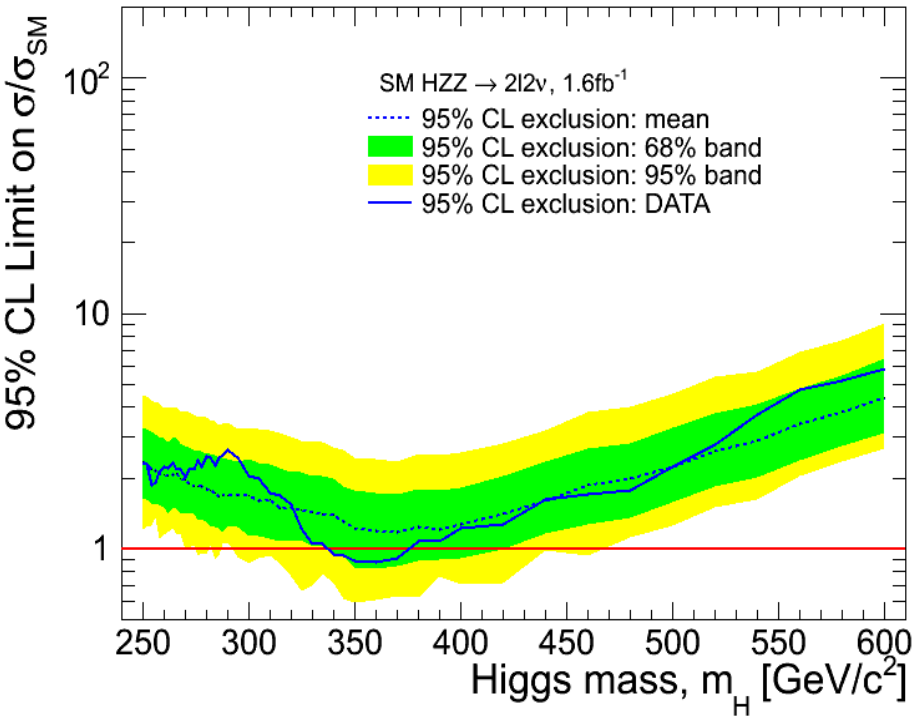
- Two leptons with $m_{ll}=m_Z$ and very large MET (left)
- Set limits based on transverse mass distribution (right)
- WW, WZ, ZZ backgrounds estimated from MC
- top background evaluated from data ($e\mu$ sample)
- Z and W+jets backgrounds evaluated from MC with data/MC comparisons (including γ+jets in CMS analysis)

H→ZZ→llνν (2)

arXiv:1109.3357

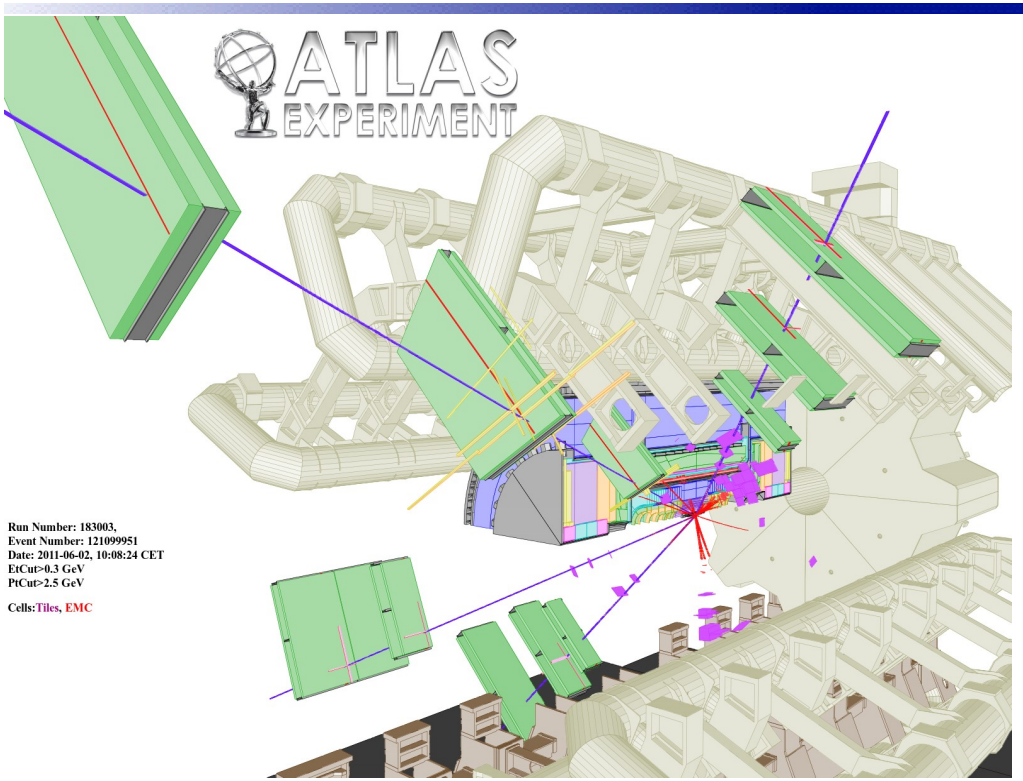


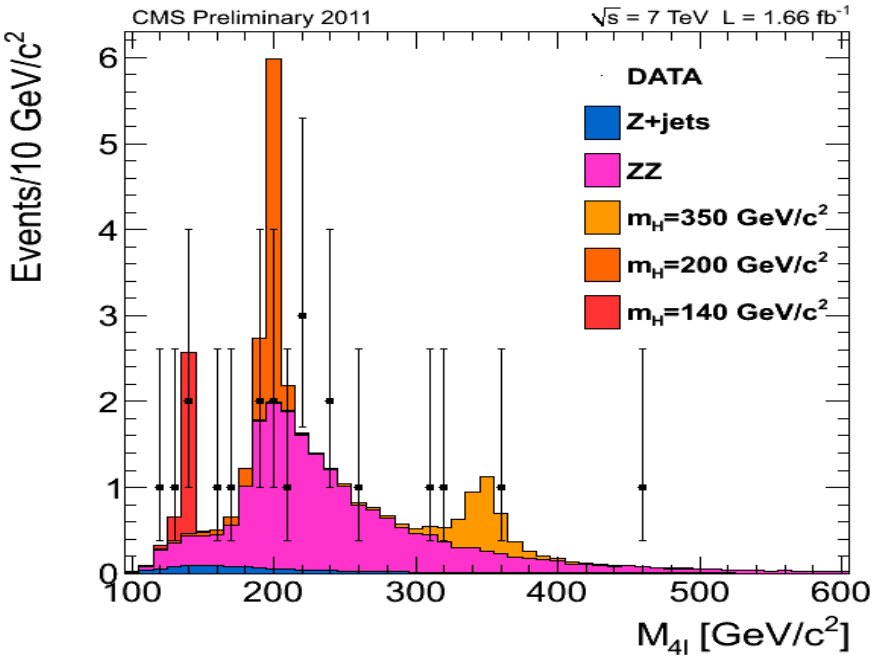
CMS-HIG-11-016



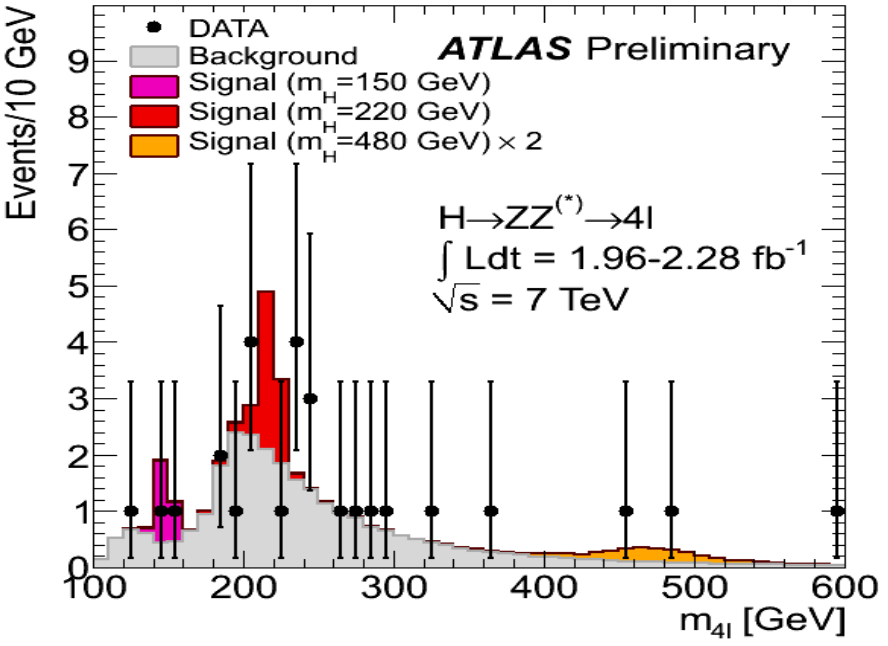
- The limits from both experiments are just starting to exclude a Standard Model Higgs boson
  - $360 < m_H < 420$ GeV excluded by ATLAS
  - $340 < m_H < 380$ GeV excluded by CMS

H→ZZ→4l (1)





CMS-HIG-11-015

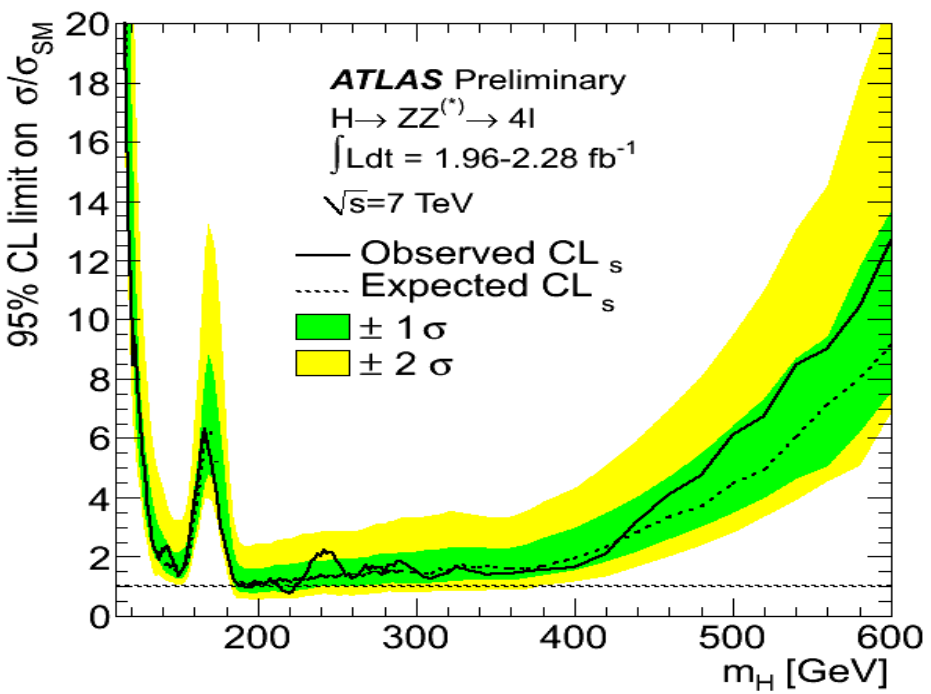


ATLAS-HIGG-2011-05

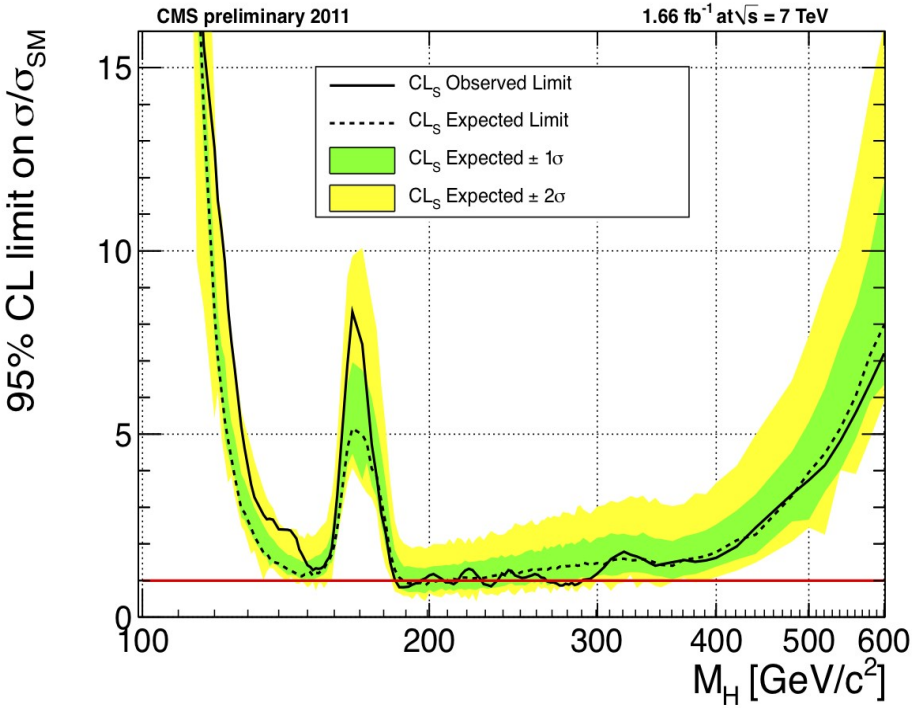
- Very clean: four leptons (e or μ)
- Dilepton mass, lepton isolation, and impact parameter cuts suppress top and Z+jets
- Good four-lepton mass resolution helps separate signal from otherwise irreducible continuum ZZ background

H→ZZ→4l (2)

ATLAS-HIGG-2011-05



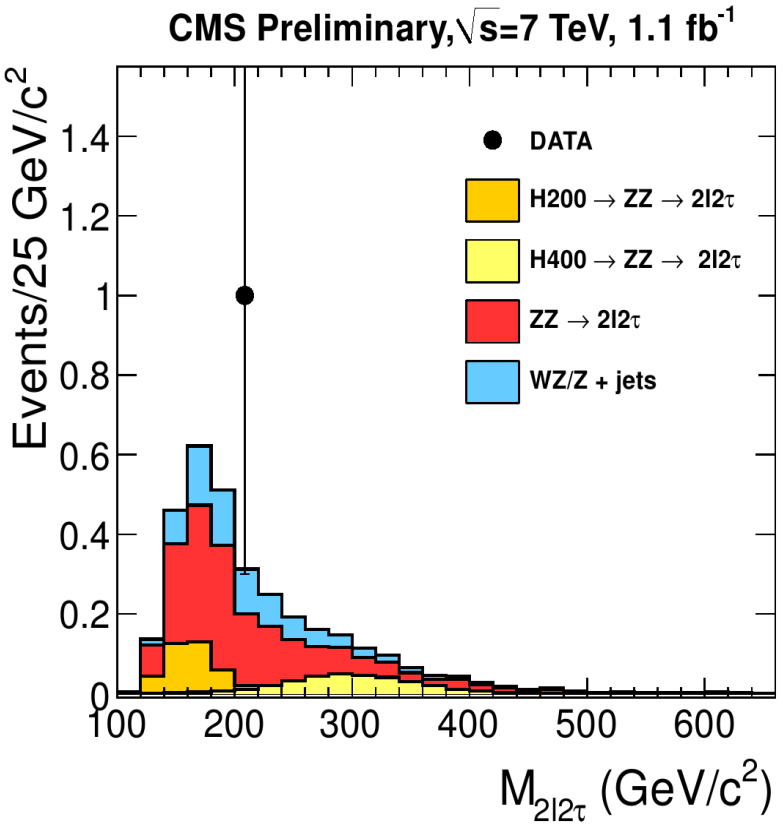
CMS-HIG-11-015

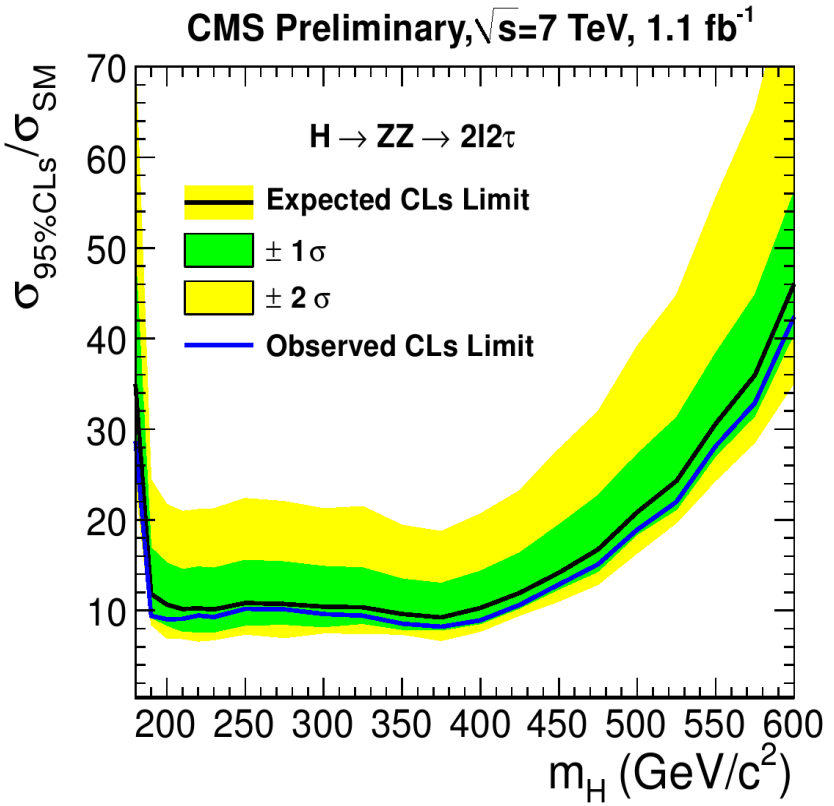


- Background estimates:
  - ZZ from MC prediction
  - top also from MC prediction, but validated in control region
  - Z+jets normalized to data using control region based on loosened isolation cuts for second lepton pair

- Very close to excluding Standard Model
- Some values of m_H near 200 GeV are already excluded

H→ZZ→4l (3)

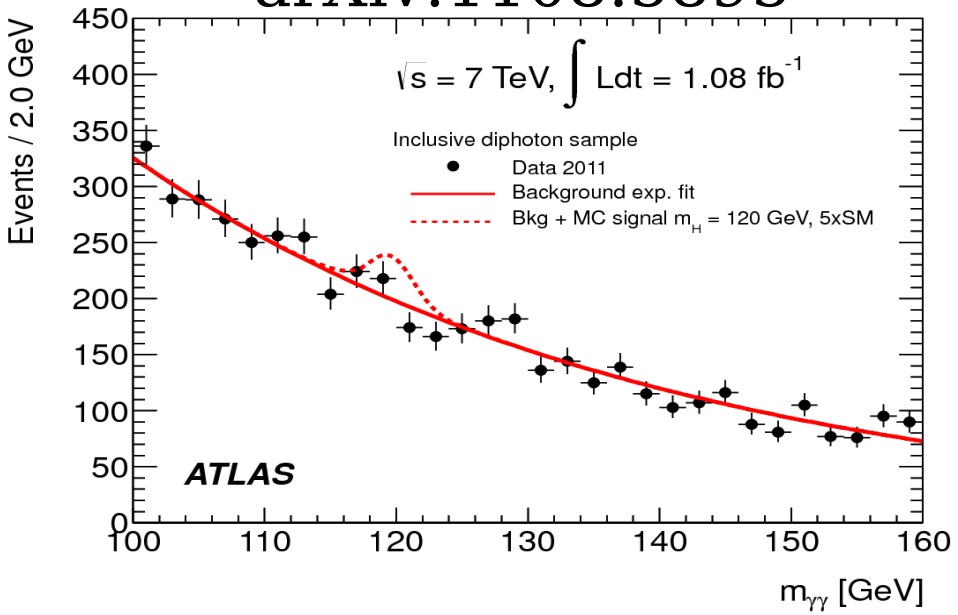




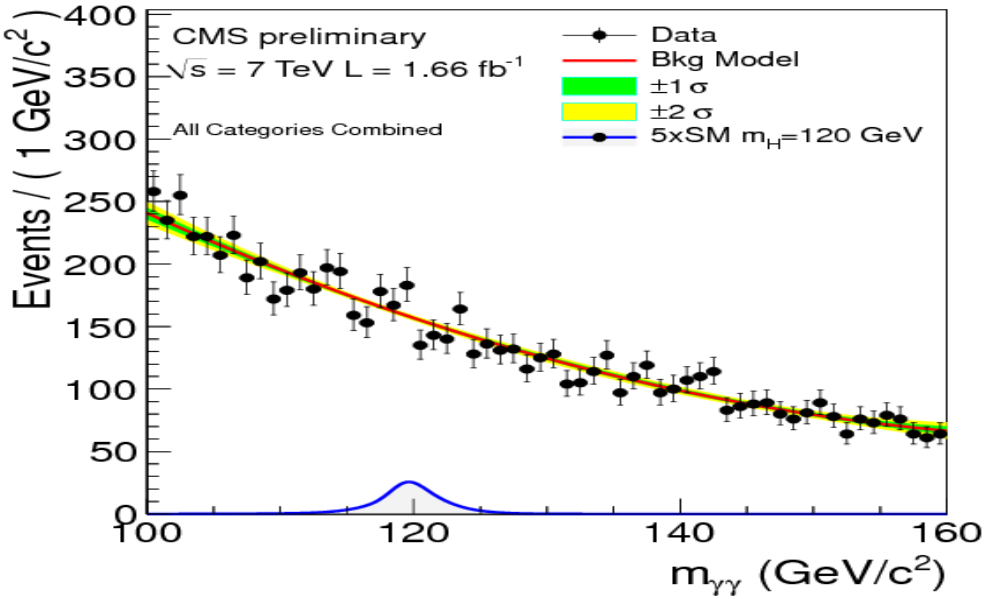
- CMS also includes H→ZZ→ll$\tau\tau$ (τ→e/μ/j) channel.
- Only the visible decay products of the τ leptons are used in the Higgs boson mass reconstruction
- Limits on the Higgs production cross-section are at the level of ~10x the Standard Model.

H→$\gamma\gamma$ (1)

arXiv:1108.5895



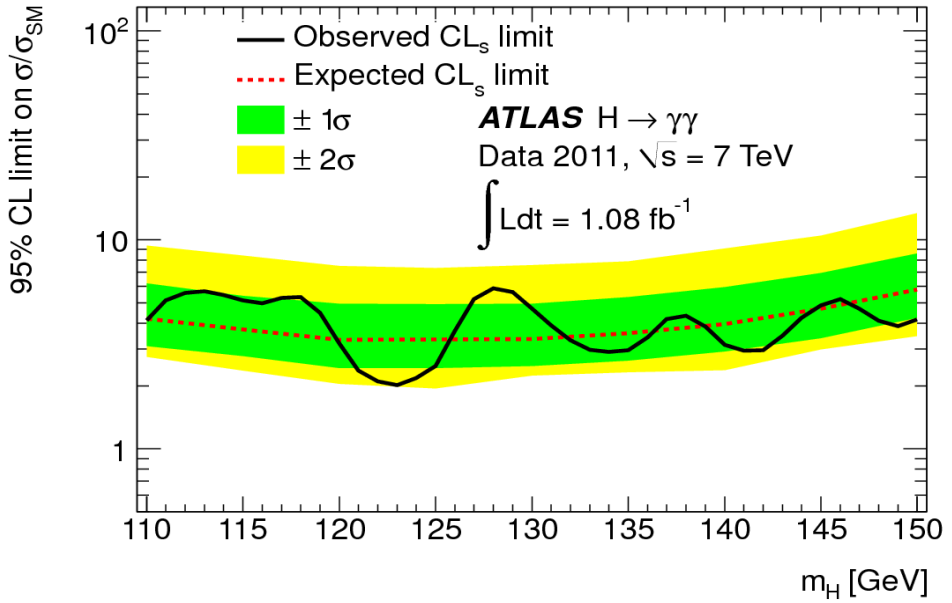
CMS-HIG-11-021



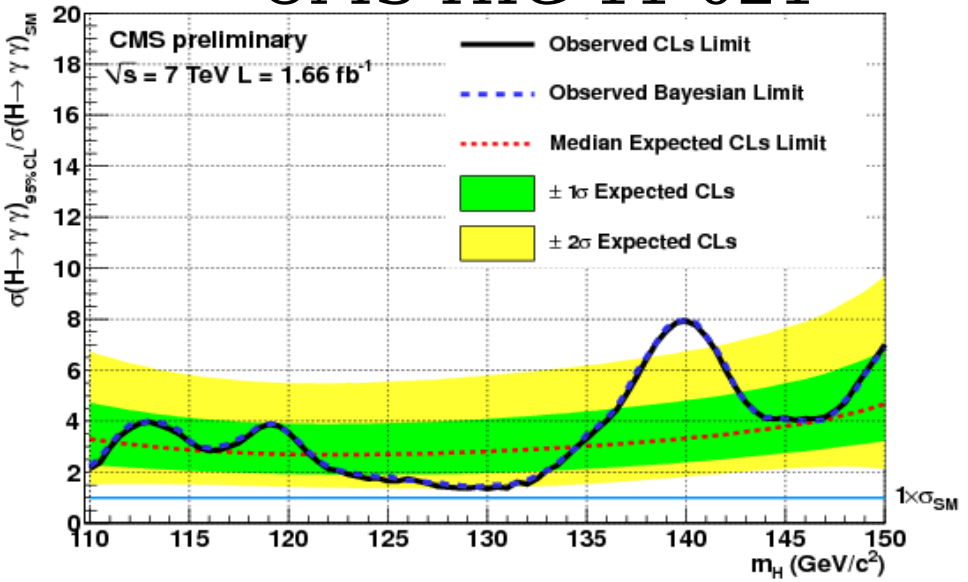
- BR(H→$\gamma\gamma$) is small (~0.002), but no subsequent decay as in the case of H→ZZ→4l. Good mass resolution helps distinguish signal from continuum background.
- Signal is extracted using a fit to $M_{\gamma\gamma}$. Plots shown above are inclusive, but fit separates events into several categories based on pseudorapidity and either isolation (CMS) or signs that a photon has converted (ATLAS)
- Normalization of background from jets is checked using loosened photon ID cuts.
  - Measured background is compatible with predictions

H→γγ (2)

arXiv:1108.5895



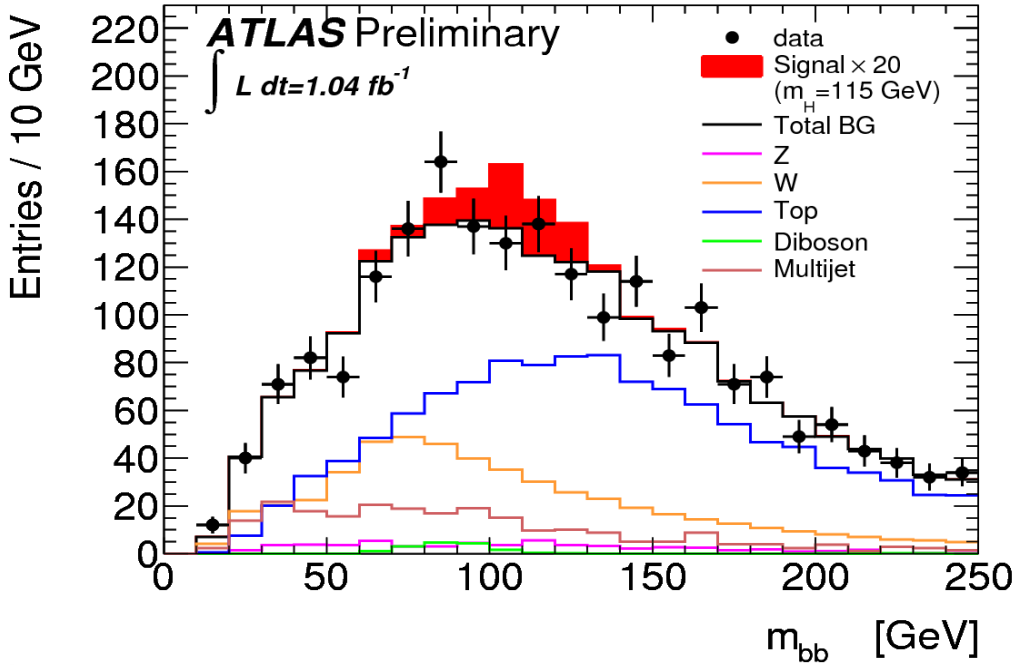
CMS-HIG-11-021



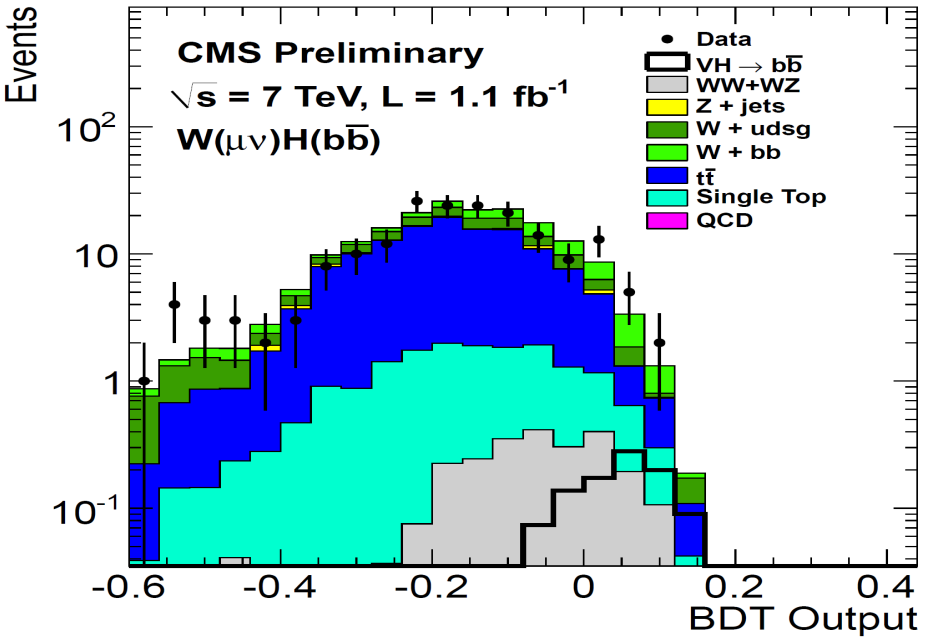
- ATLAS and CMS both exclude ~2-6 times the Standard Model prediction

WH/ZH, H→bb (1)

ATLAS-CONF-2011-103



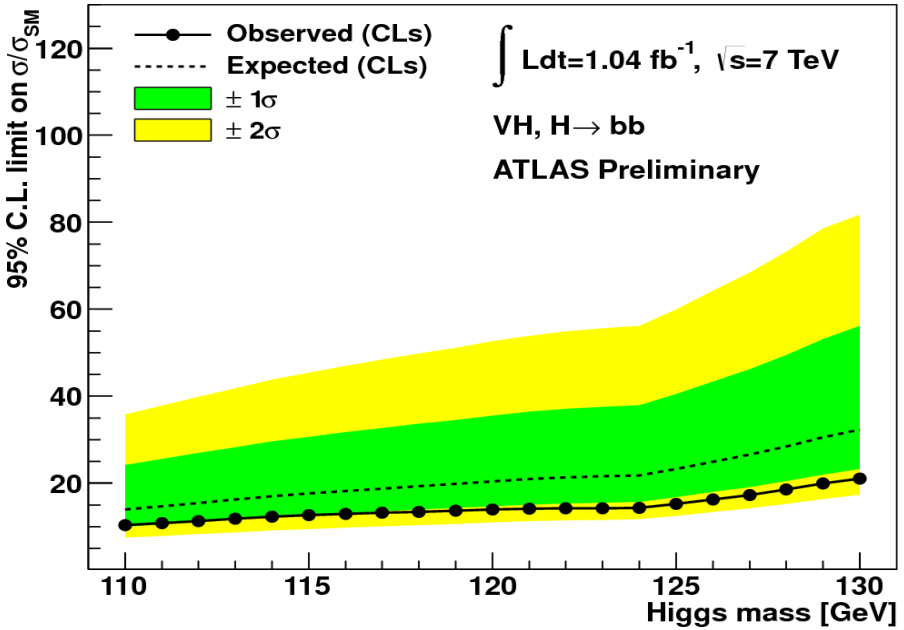
CMS-HIG-11-012



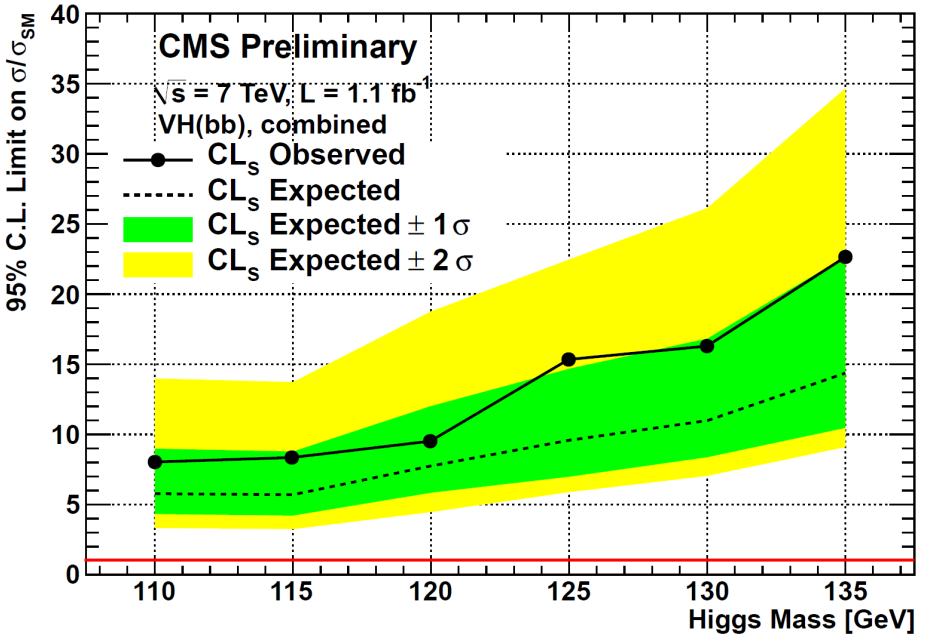
- ggH and WBF are dominant Higgs production mechanisms, but for H→bb these modes are overwhelmed by background. WH/ZH (H→bb) is best for this decay mode
- W→lν and Z→ll decays (also Z→$\nu\nu$ in CMS analysis) are considered.
- ATLAS analysis is cut-based; CMS uses Boosted Decision Tree analysis
- Dominant backgrounds for both are W+jets, Z+jets, top

WH/ZH, H→bb (2)

ATLAS-CONF-2011-103

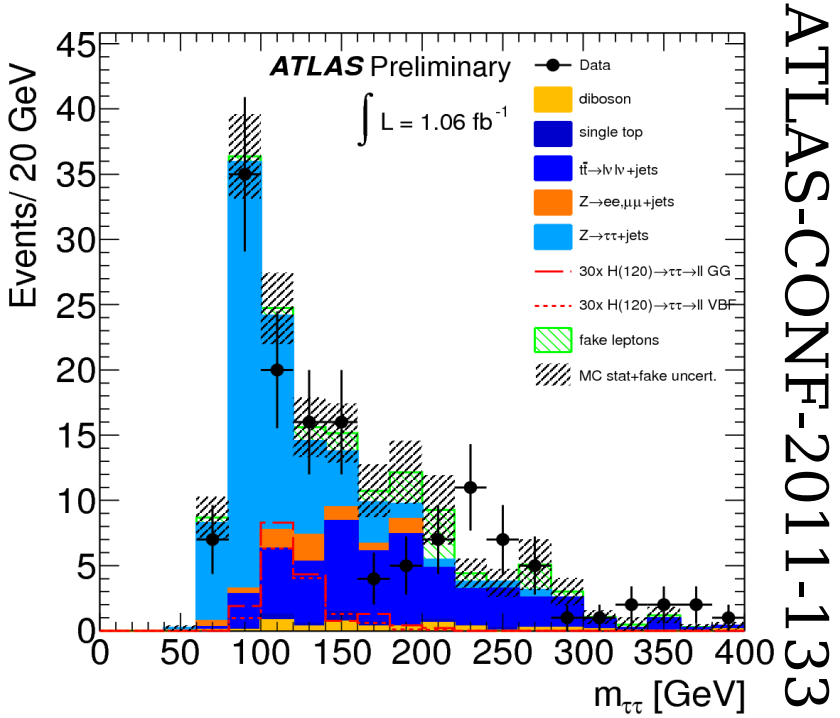


CMS-HIG-11-012

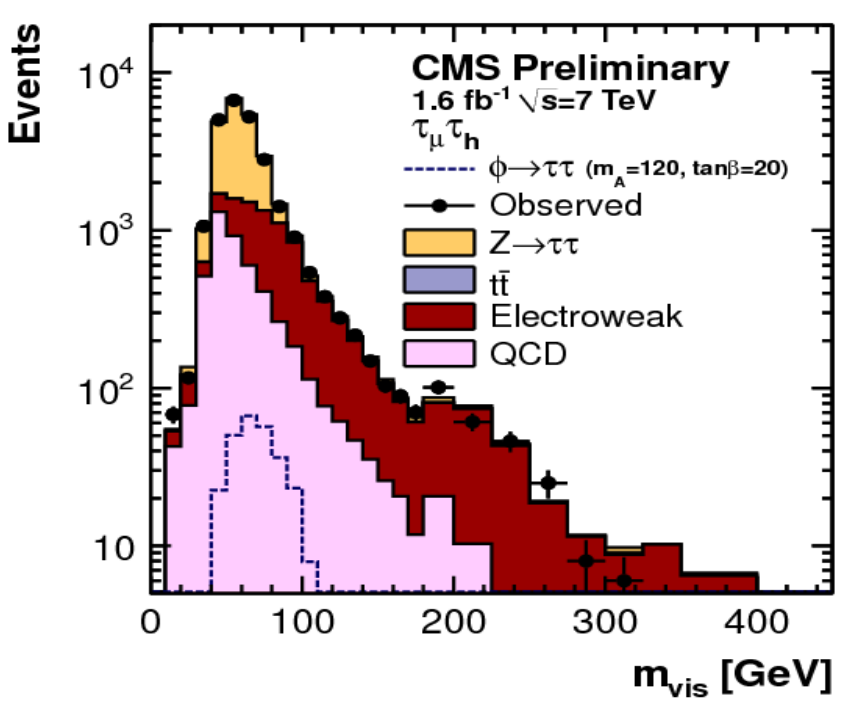


- Both experiments exclude ~10-20 times Standard Model
  - CMS result is slightly stronger due to use of multivariate techniques and boosted jet pairs

H/A→ττ (1)



ATLAS-CONF-2011-133

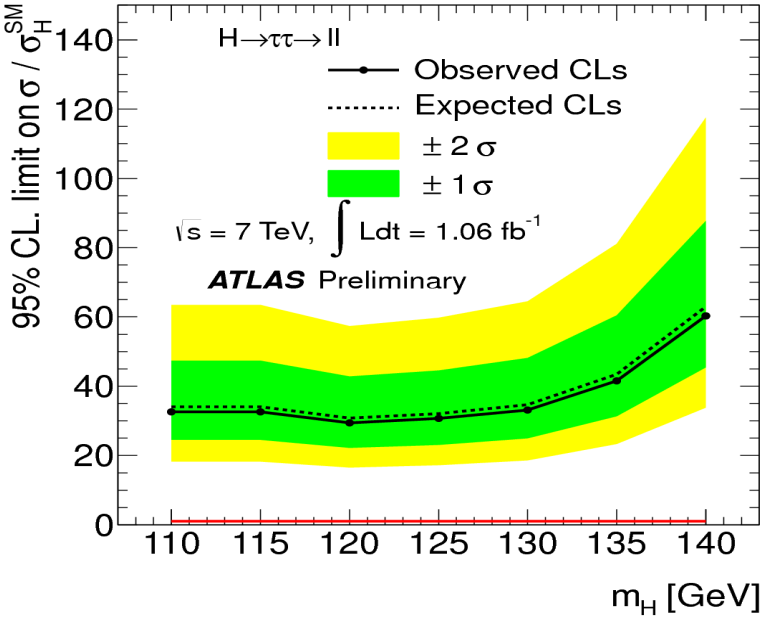


CMS-PAS-HIG-11-020

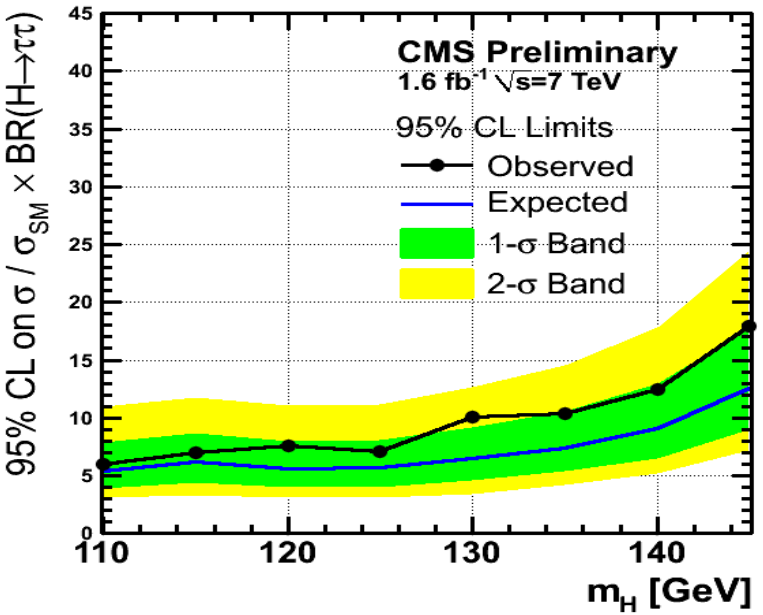
- Promising channel for Standard Model with $110<m_H<140$ GeV, or for MSSM Higgs in a broad mass range
  - In Standard Model, production is via ggH (H+0/1j) WBF (H+2j, well separated in η, and suppressed central jet activity)
  - In MSSM, production is via ggH or bbH.
- Analysis is based on $m_{\tau\tau}$ assuming τ decay products are collinear with parent τ lepton (ATLAS) or mass of visible τ decay products (CMS)

H/A→ττ (2)

ATLAS-CONF-2011-133



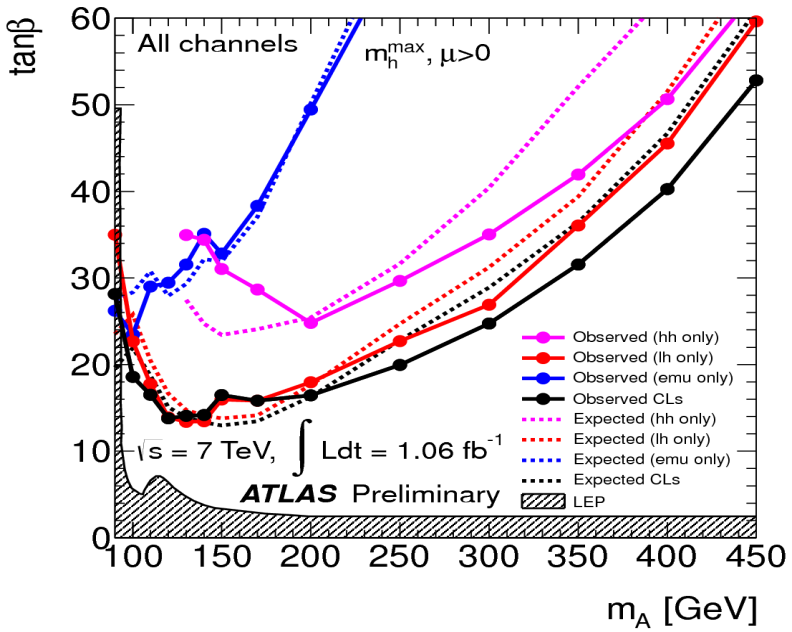
CMS-PAS-HIG-11-020



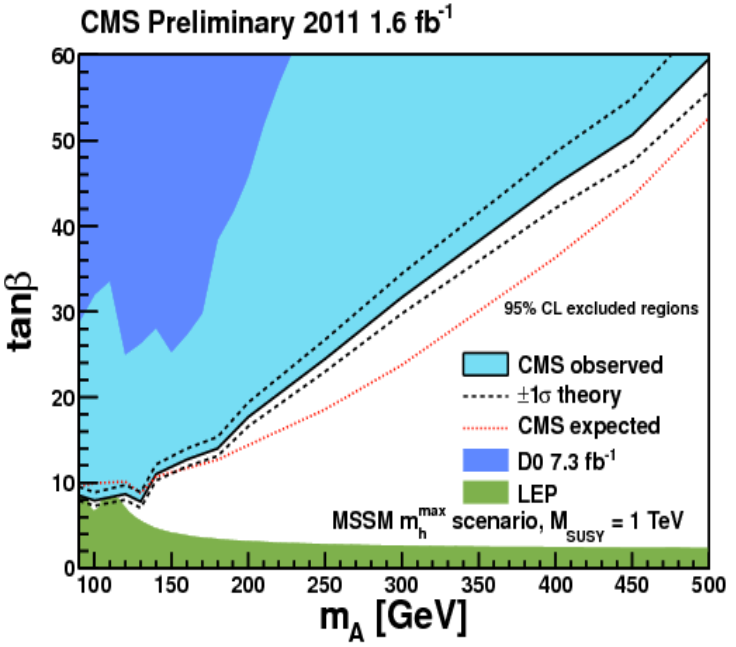
- For Standard Model, ATLAS analysis of 1 fb^{-1} includes only H→ττ→ll in association with at least one jet; CMS analysis of 1.6 fb^{-1} also includes H→ττ→lh and separate categories of events which pass/fail the WBF jet tagging cuts
- No significant excess in either experiment, so quote upper limits on signal in Standard Model (above)

H/A→ττ (3)

ATLAS-CONF-2011-132



CMS-PAS-HIG-11-020

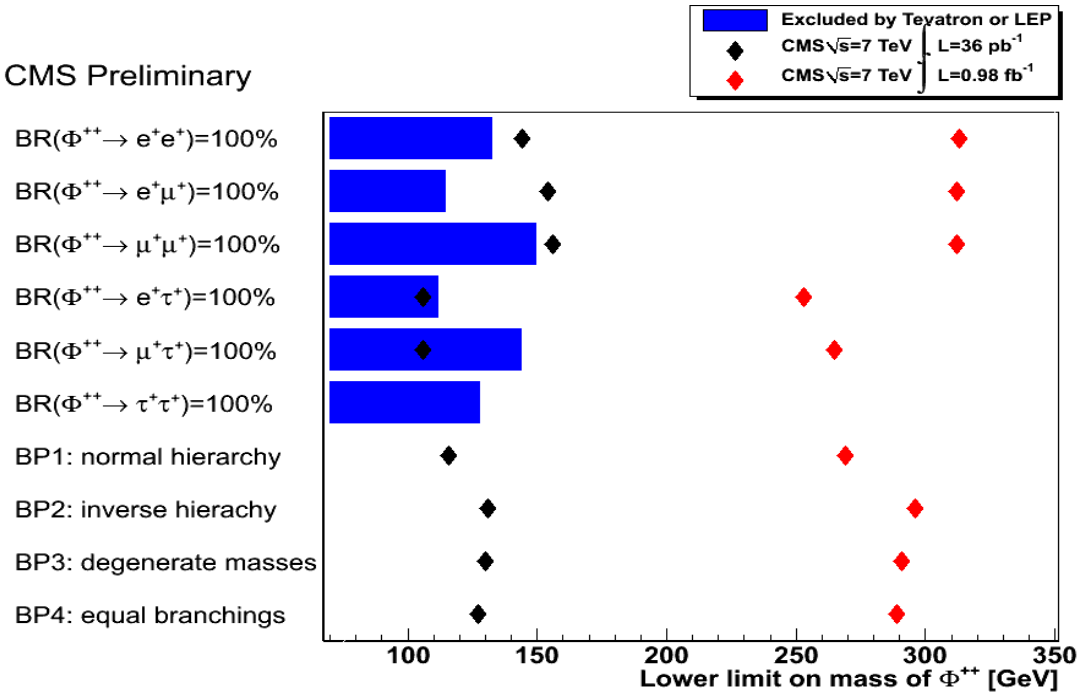


- Both ATLAS and CMS include H→ττ→ll and H→ττ→lh in MSSM Higgs search. ATLAS also includes H→ττ→hh.
- The two experiments exclude similar regions of the m_A/tan(β) plane

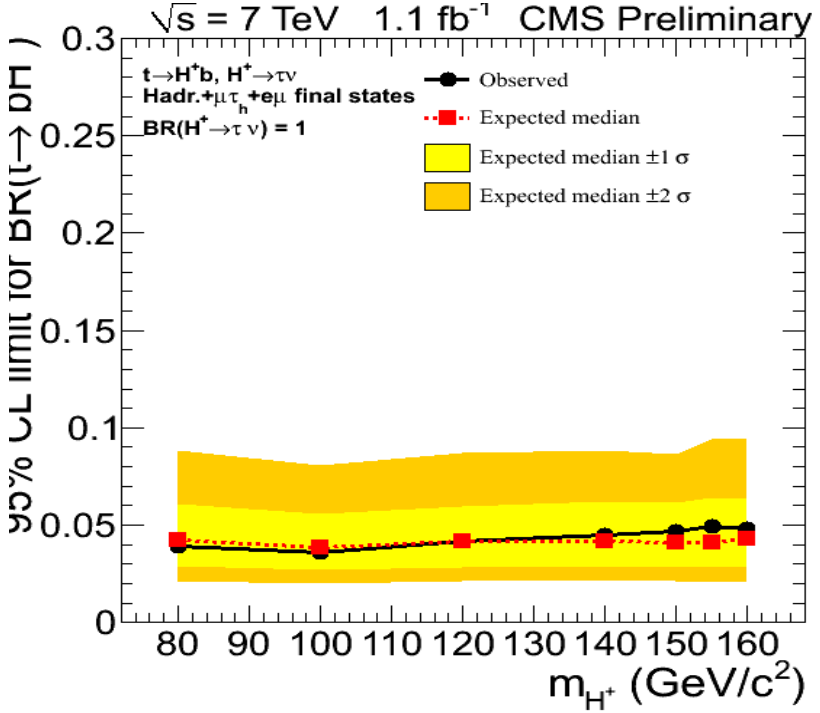
SUSY H^+ & Exotic Higgs

CMS-PAS-HIG-11-007

$\phi^{++} \rightarrow l^+l^+$



$H^+ \rightarrow \tau\nu$

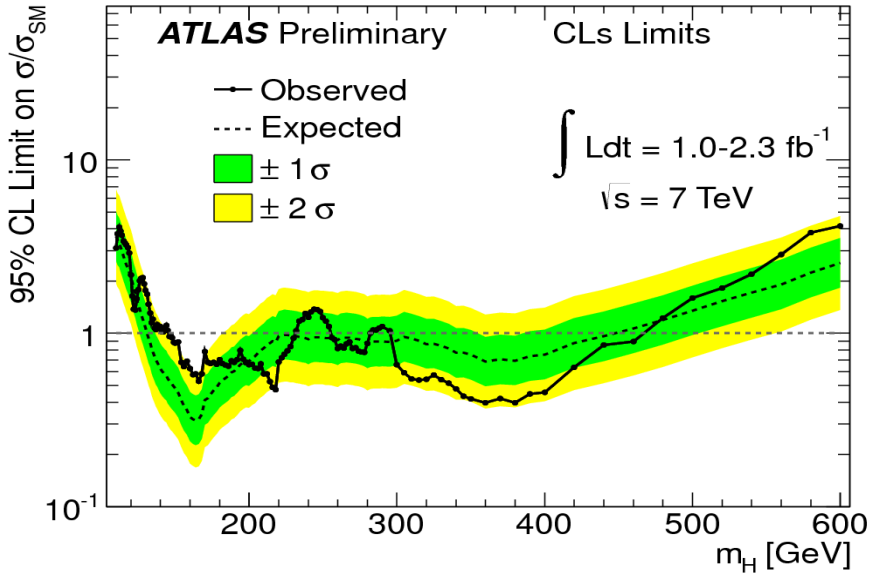


CMS-PAS-HIG-11-008

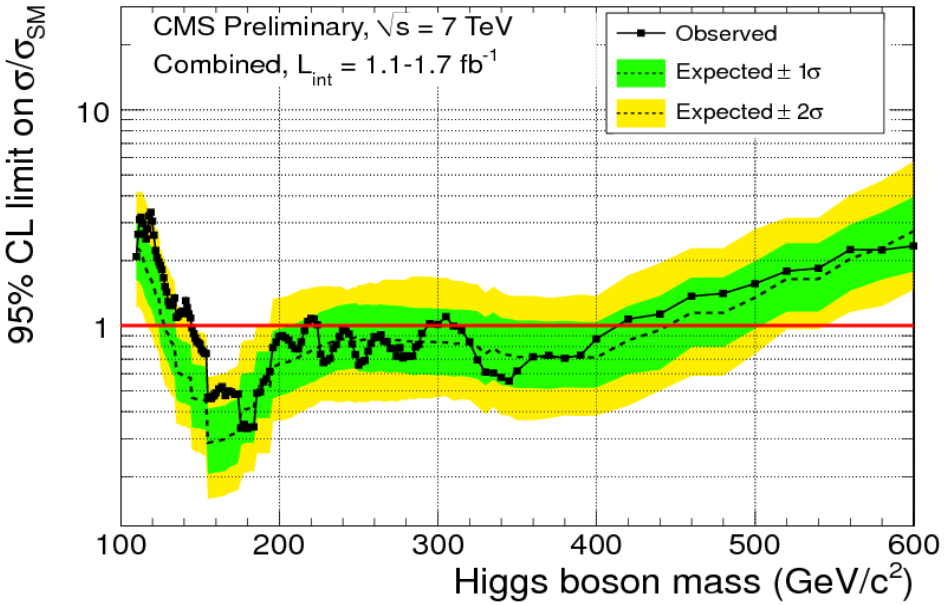
- ϕ^{++}, ϕ^+, and ϕ^0 arise in models with extra Higgs triplets. H^+ also shows up in models with an extra Higgs doublet
- Triplet responsible for small ν mass, but unknown ν mass matrix means unknown branching ratios, broad search, but below ~$2M_W$ only leptonic decays
- Above: CMS limits on $\phi^{++} \rightarrow l^+l^+$ and $H^+ \rightarrow \tau\nu$

Standard Model Combination

ATLAS-CONF-2011-135



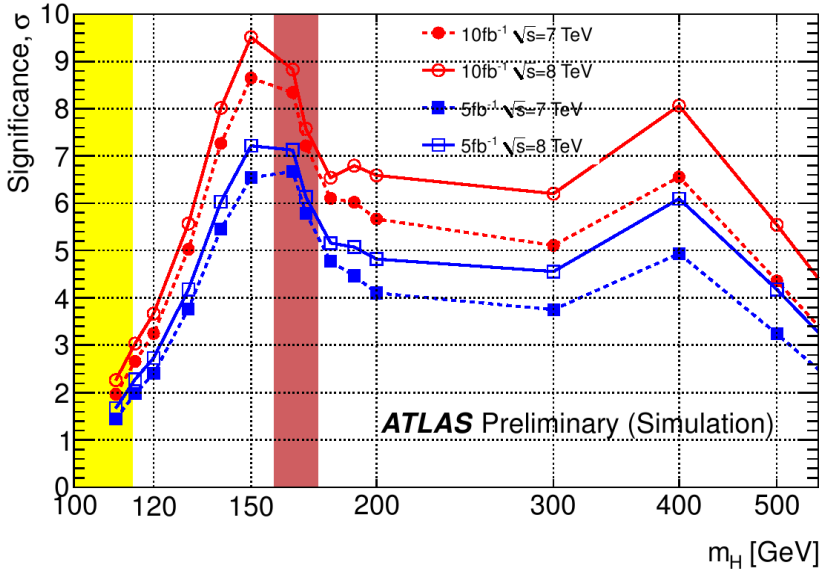
CMS-HIG-11-022



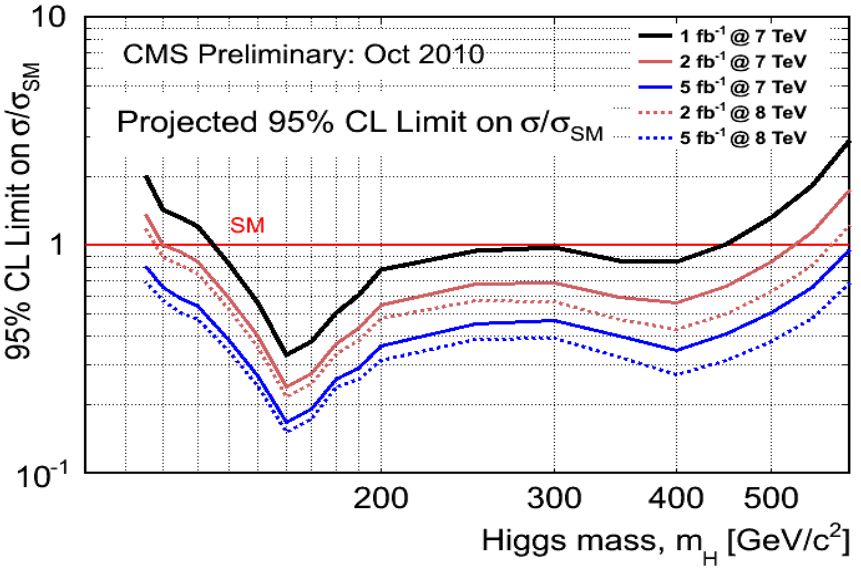
- ATLAS excludes a Standard Model Higgs boson with m_H in the ranges 146-232 GeV, 256-282 GeV, or 296-466 GeV.
  - Includes H→$\gamma\gamma$, H→bb, H→$\tau\tau$, H→WW→lνlν, H→ZZ→4l, H→ZZ→ll$\nu\nu$, and H→ZZ→llqq
- CMS excludes a Standard Model Higgs boson with m_H in the ranges 145-216 GeV, 226-288 GeV, or 310-400 GeV.
  - Includes H→$\gamma\gamma$, H→$\tau\tau$, H→bb, H→WW→lνlν, H→ZZ→4l, H→ZZ→ll$\tau\tau$, H→ZZ→ll$\nu\nu$, and H→ZZ→llqq
- Work to combine the two limits is ongoing

Prospects for Future Running

ATL-PHYS-PUB-2010-015



CMS NOTE 2010/008



- With 5-10 fb^{-1} at 8 TeV, exclude all m_H up to 600 GeV
- Higgs discovery in 114-130 GeV is challenging at this center-of-mass energy

Summary

- Using the H→WW→lνlν channel, ATLAS and CMS have independently excluded the presence of a Higgs boson in the ranges 154-186 GeV and 147-194 GeV, respectively
- The ATLAS H→WW→lνqq search excludes about 2.7 times the Standard Model cross-section at m_H=400 GeV
- With H→ZZ→ll$\nu\nu$, ATLAS excludes 360-420 GeV, and CMS excludes 340-380 GeV. Independent limits from H→ZZ→llqq and H→ZZ→4l are approaching exclusion of the Standard Model for some masses.
- ATLAS and CMS H→$\gamma\gamma$ searches exclude ~2-6xSM
- ATLAS and CMS H/A→$\tau\tau$ searches have extended the excluded region of MSSM plane
- WH/ZH→bb searches exclude ~10-20 times SM prediction
- CMS excludes ϕ^{++} up to ~300 GeV and H^+ with BR(H^+→$\tau\nu$)>~5% if m_{H+}<160 GeV
- Except for a small hole (288-296 GeV), the SM Higgs is excluded by at least one experiment for 145<m_H<466 GeV.