Standard Model Measurements at ATLAS and CMS

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Joint HEPP/APP Meeting

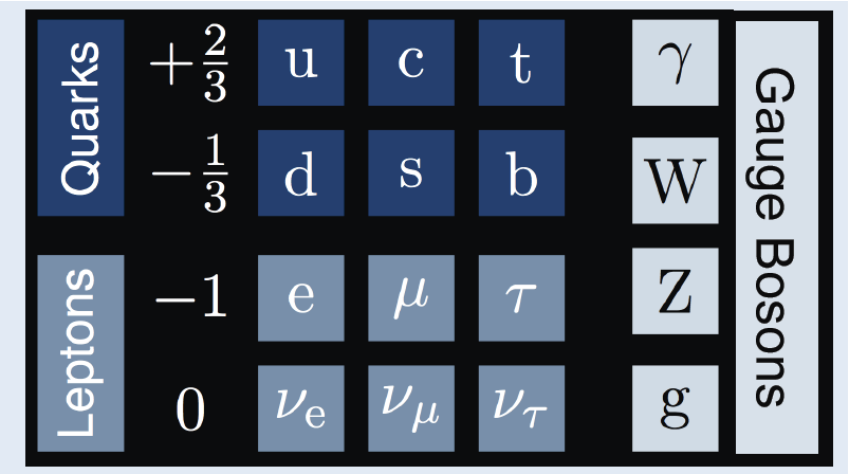
Imperial College London

Overview

Introduction

SM Measurements with:

- Jets and photons
- W and Z bosons
- Heavy flavour



SM Higgs Searches

Overview

Introduction

SM Measurements with:

- Jets and photons
- W and Z bosons
- Heavy flavour

Benchmarks
Precision tests
Improved modelling
Proton structure
Searches

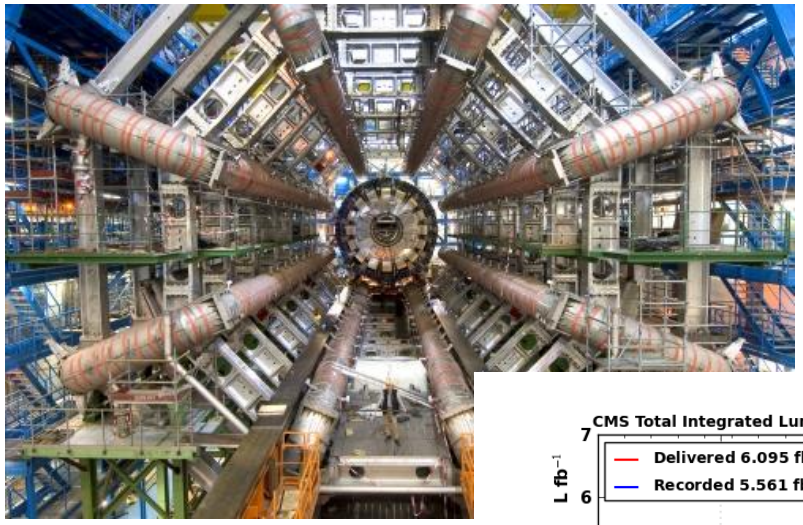
SM Higgs Searches

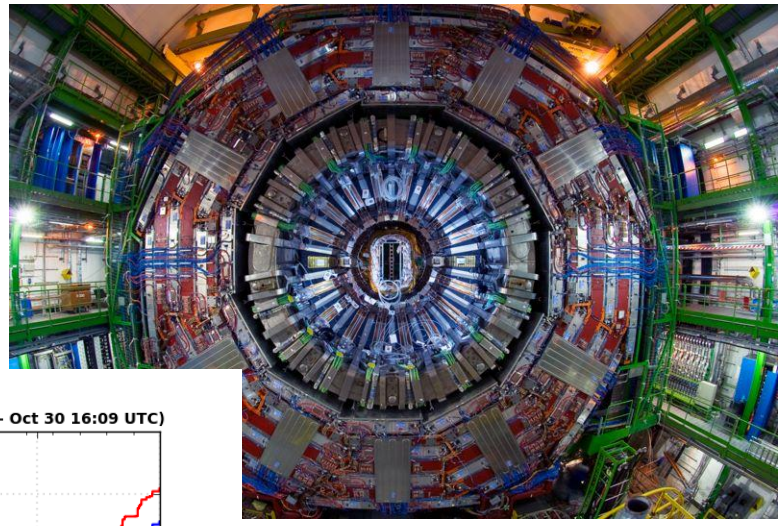
EWSB and origin of mass

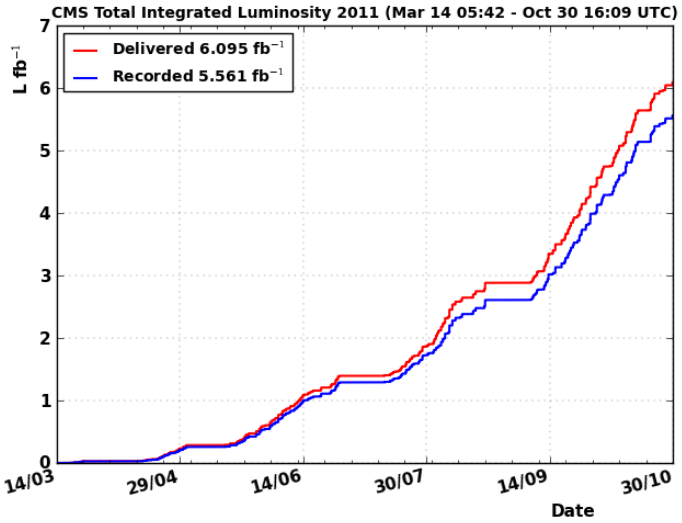
Impossible to cover the full program at ATLAS and CMS
Picked a few highlights! Apologies if I miss one you'd like to see!

Introduction

ATLAS and CMS “General purpose” detectors at the LHC



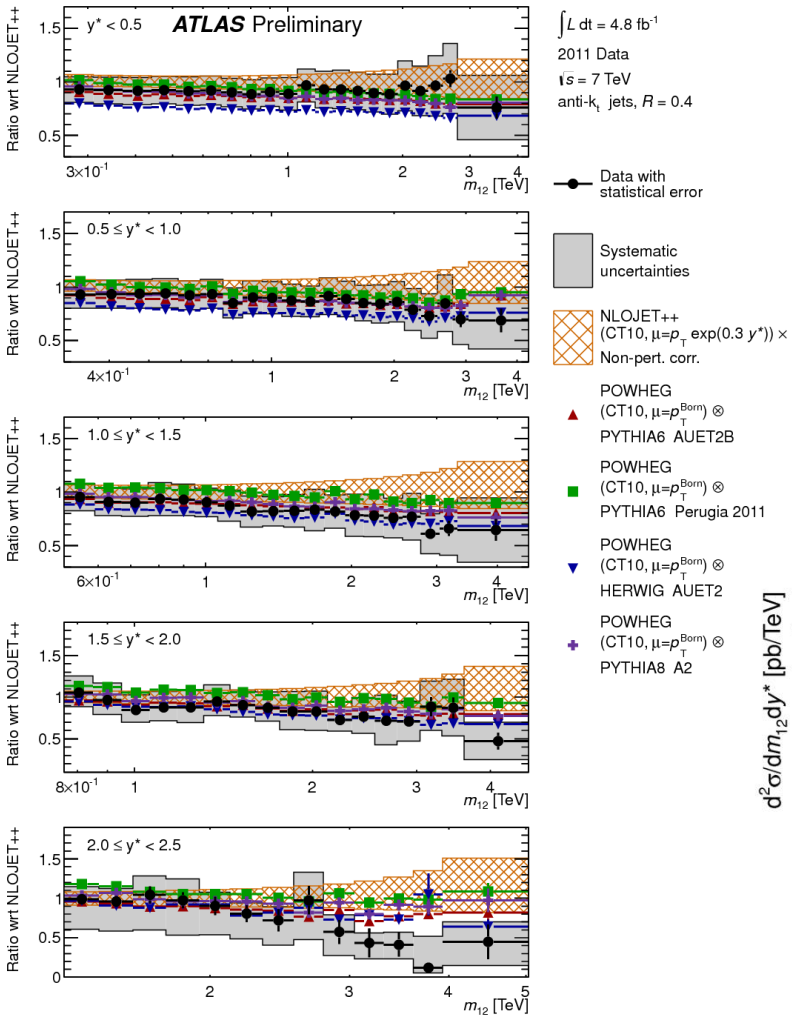




Detectors and accelerator performed extremely well in 2011

Around $5fb^{-1}$ recorded per experiment at $\sqrt{s}=7TeV$

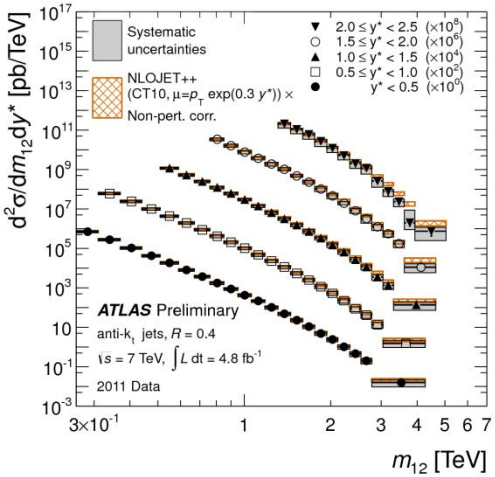
Jet cross sections

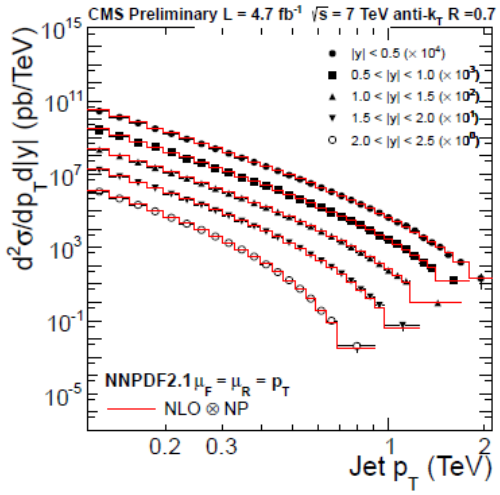


New inclusive jet cross section measurements with 2011 data

Generally good agreement with theoretical models within errors

Some visible variation between models



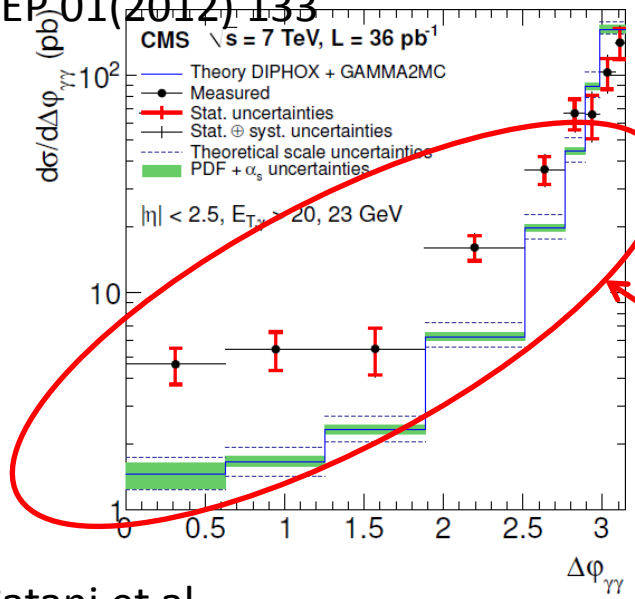


CMS-QCD-11-004

ATLAS-CONF-2012-021

Photon cross sections

JHEP 01(2012) 133

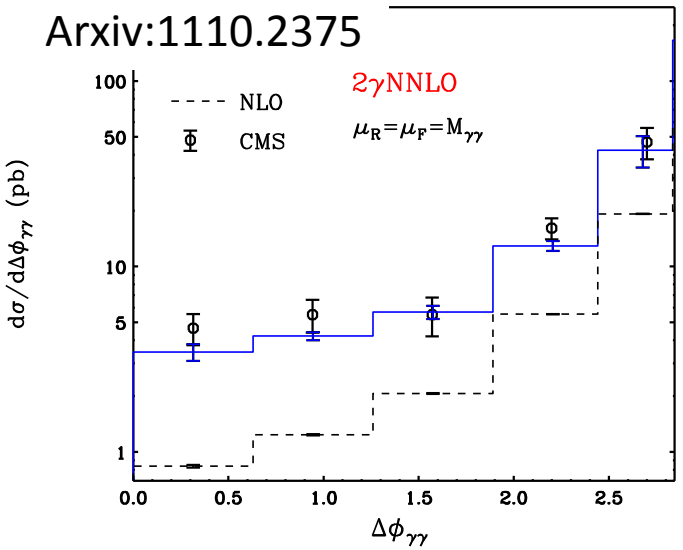


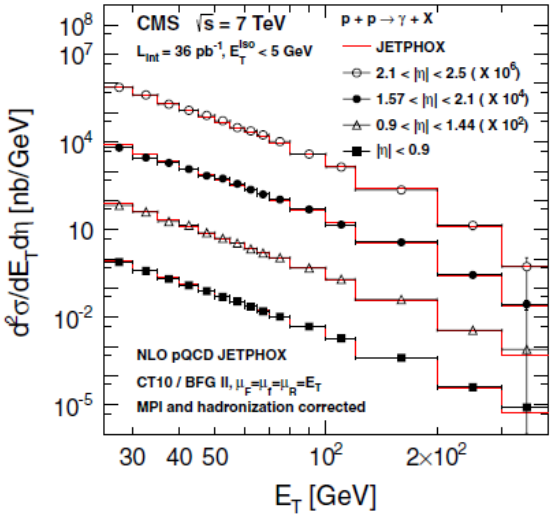
New results with photon + jets, diphotons on their way

Generally good agreement between data and models

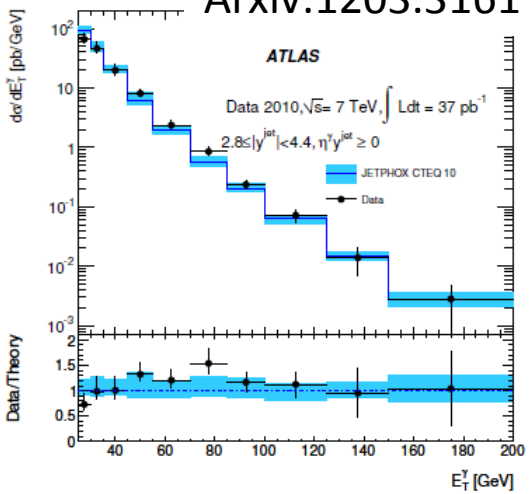
Not always though!
Sensitivity to higher order effects

Catani et al.
Arxiv:1110.2375



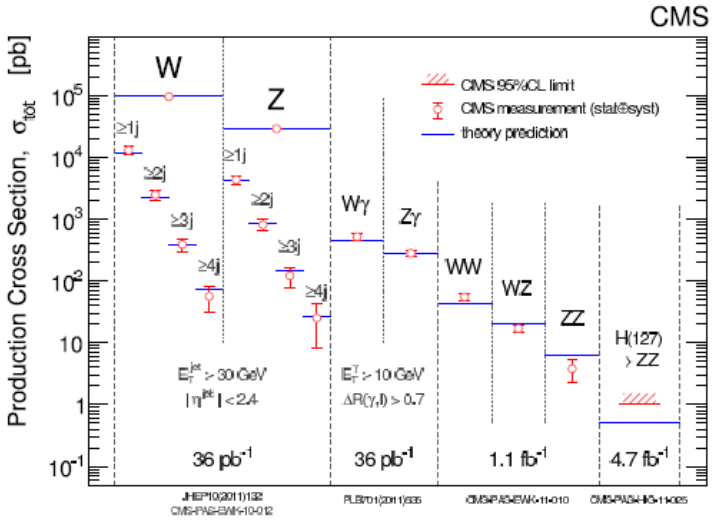


Arxiv:1203.3161



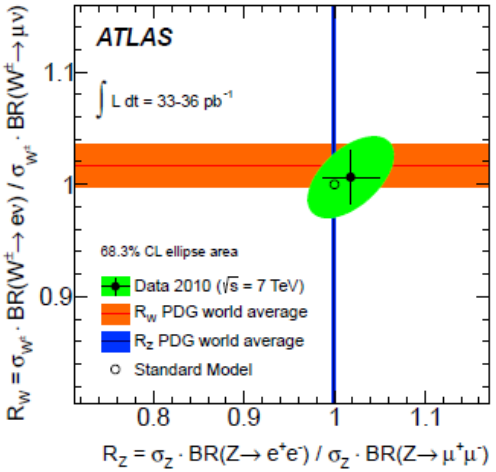
Phys.Rev.D 84,052011

SM with W and Z bosons

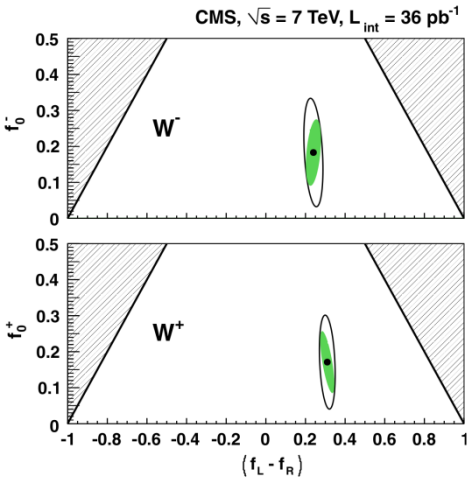


Huge range of measurements involving W and Z

Arxiv:1109.5141

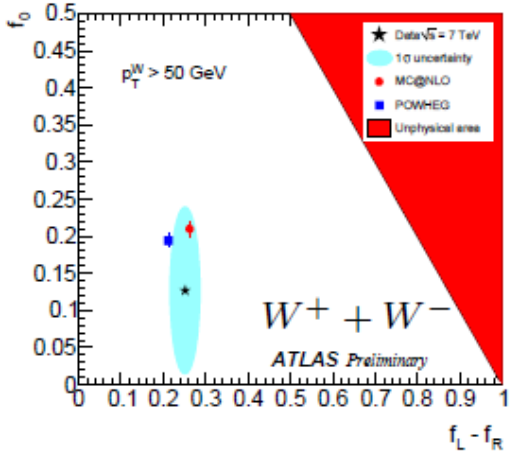


W polarisation – 3 states: f_0, f_L, f_R



Tests of pQCD

Arxiv:1203.2165

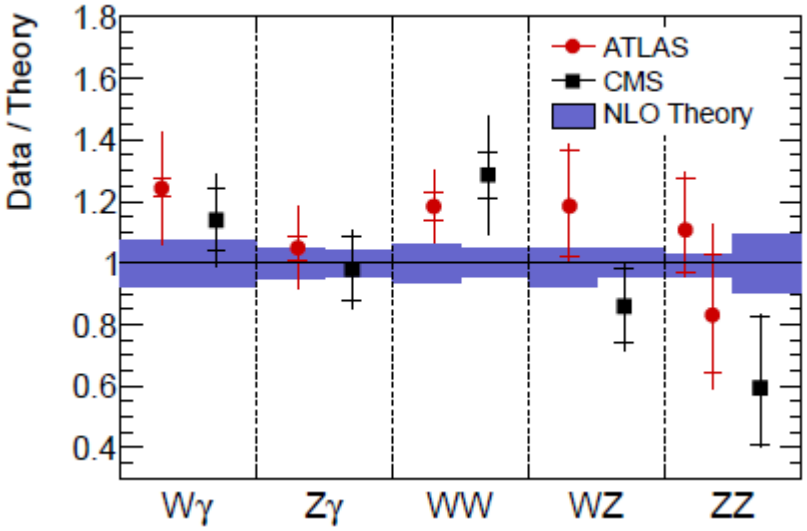


Ratio of Z decays to e and μ and ratio of W decays to e and μ – lepton universality in W and Z decay

Phys. Rev. Lett. 107 (2011) 021802

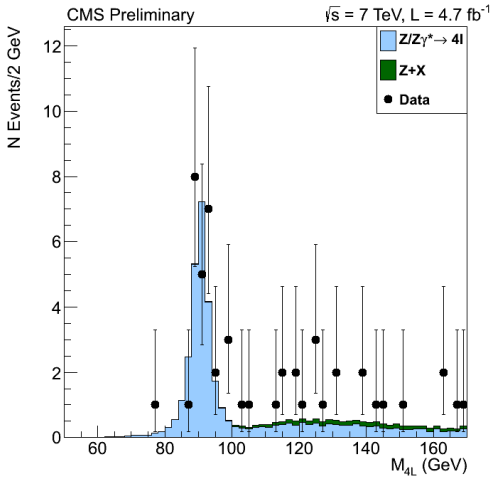
SM with W and Z bosons

Diboson measurements
past the “discovery” era



Important backgrounds
for NP searches

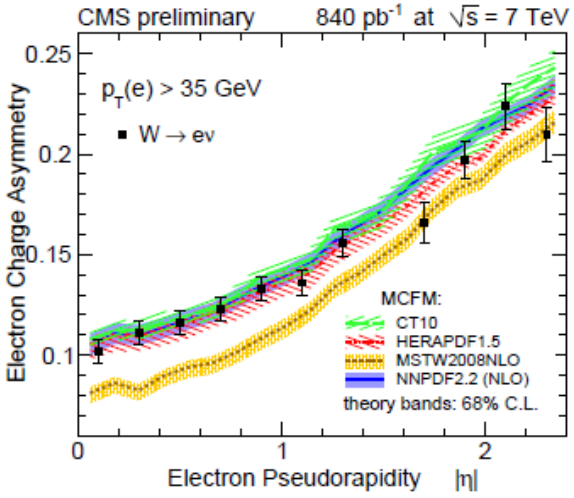
Precision tests of EWK



CMS-SMP-12-009

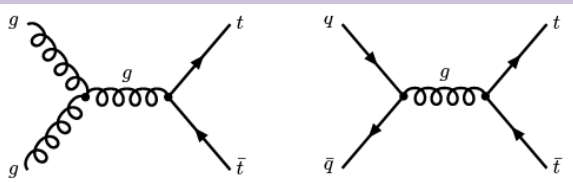
Z→4l
Standard Candle for
Higgs Search

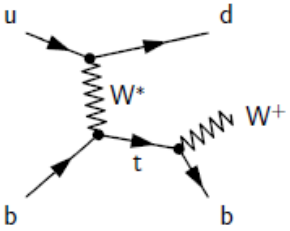
Constraints on u/d
PDFs from lepton
charge asymmetry

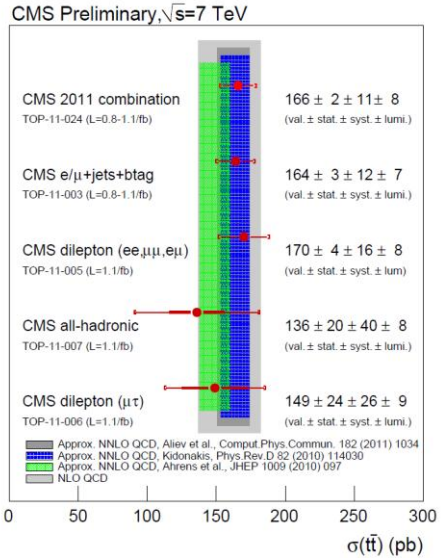


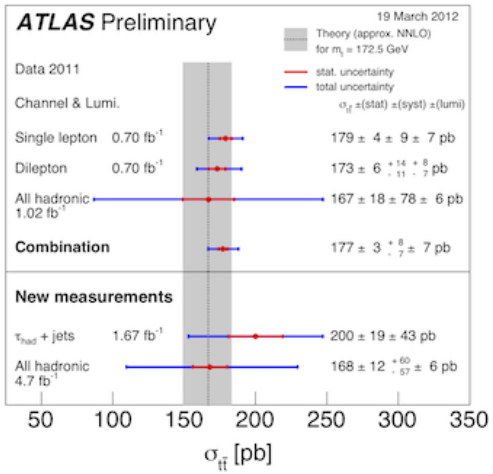
CMS-SMP-12-001

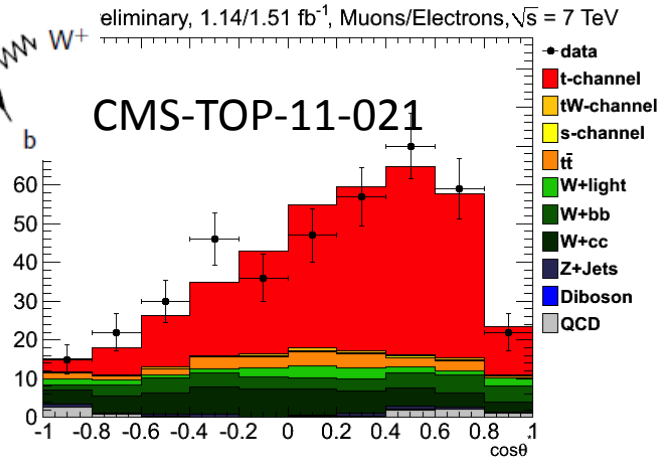
Top cross sections



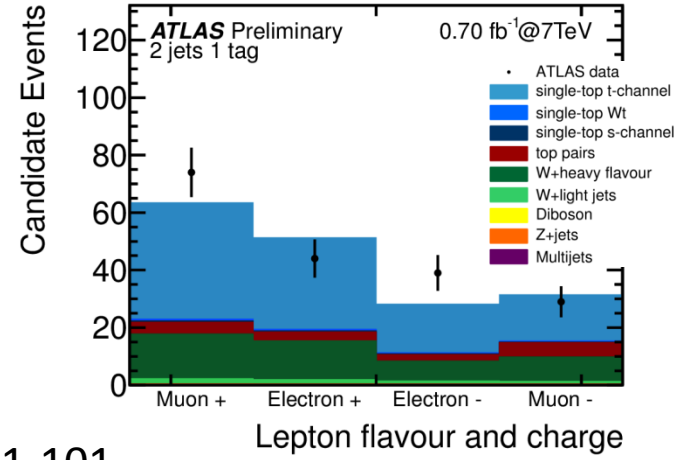








$$70.2 \pm 5.2(\text{stat}) \pm 10.4(\text{syst}) \pm 3.4(\text{lumi})\ \text{pb}$$



New measurements from ATLAS and CMS

Excellent agreement across channels

Uncertainties:
Experimental ~6-8%,
Theory ~8%

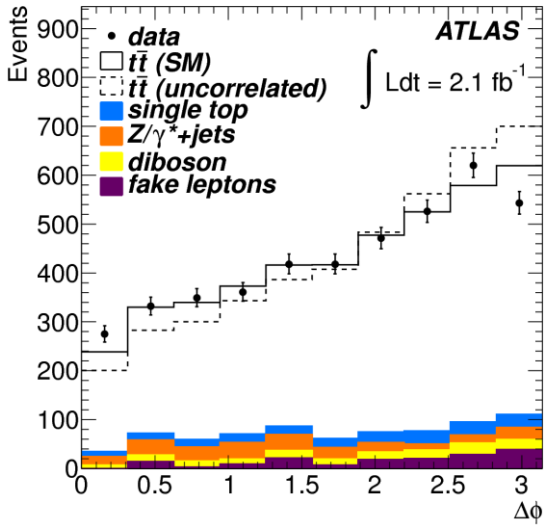
ATLAS-CONF-2011-101

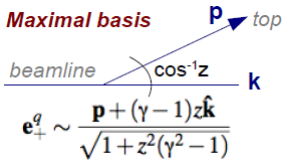
$$90 \pm 9(\text{stat})^{+31}_{-20}(\text{syst})\ \text{pb}$$

SM with top

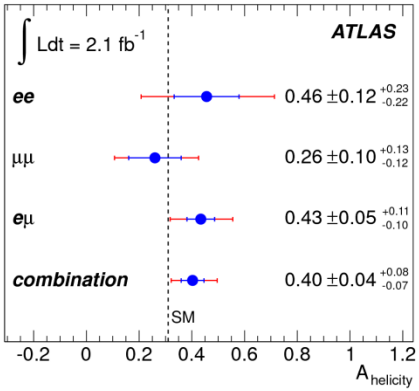
Observation of spin correlations

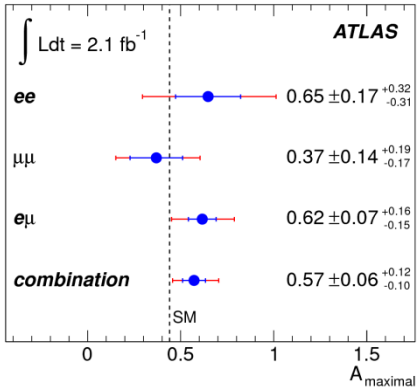
$$A' = \frac{\sigma_{tt}(\uparrow\uparrow)+\sigma_{tt}(\downarrow\downarrow)-\sigma_{tt}(\uparrow\downarrow)-\sigma_{tt}(\uparrow\downarrow)}{\sigma_{tt}(\uparrow\uparrow)+\sigma_{tt}(\downarrow\downarrow)+\sigma_{tt}(\uparrow\downarrow)+\sigma_{tt}(\uparrow\downarrow)}$$





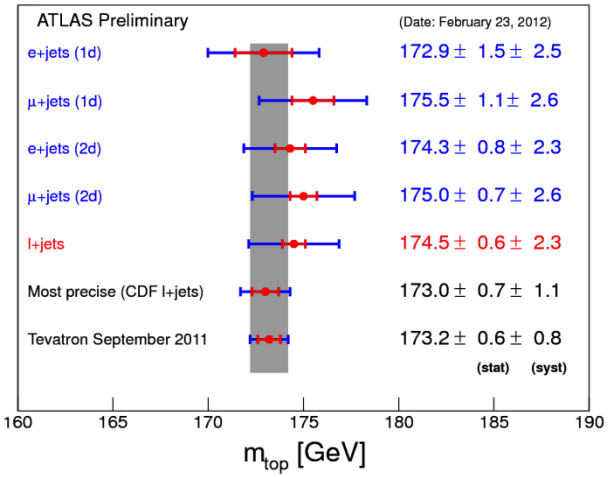
$$e_{\pm}^{q} \sim \frac{\mathbf{p}+(\gamma-1)z\hat{\mathbf{k}}}{\sqrt{1+z^2(\gamma^2-1)}}$$



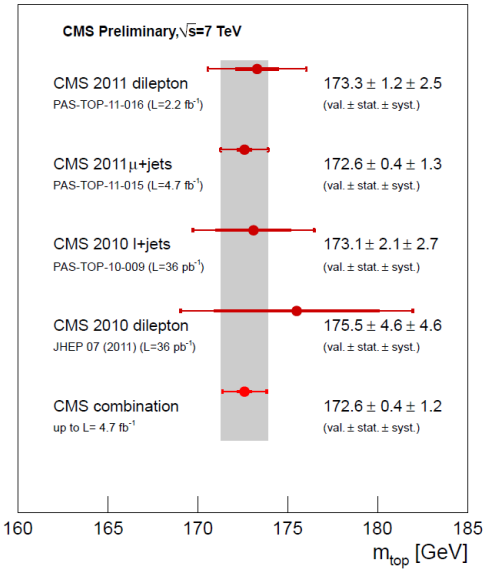


Arxiv:1203.4081

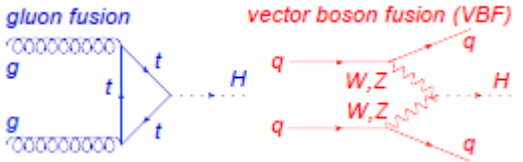
Top mass

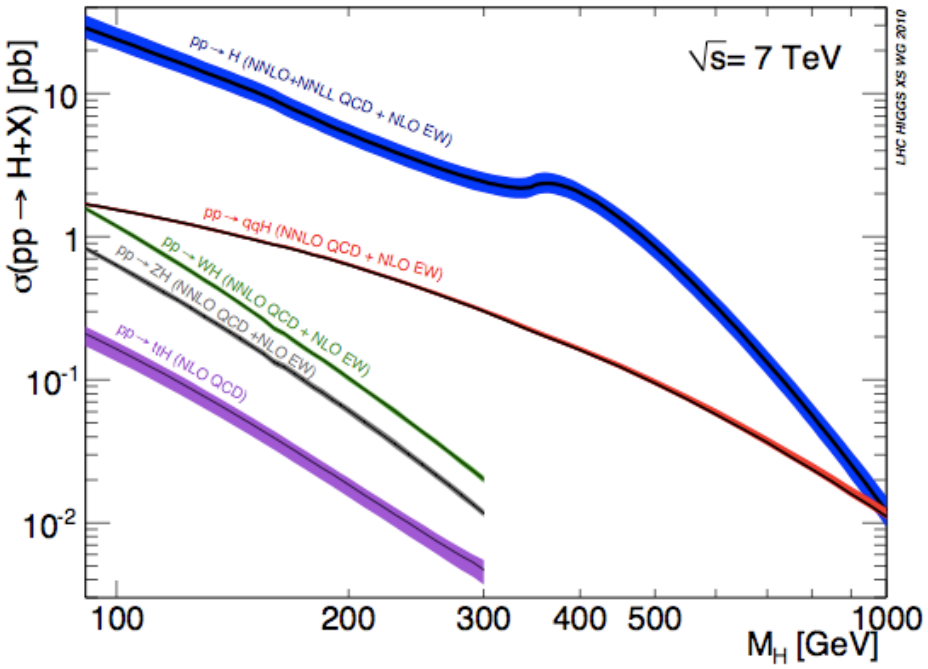


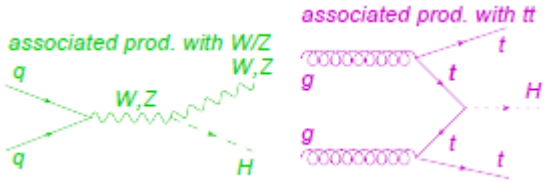
New measurements approaching Tevatron precision

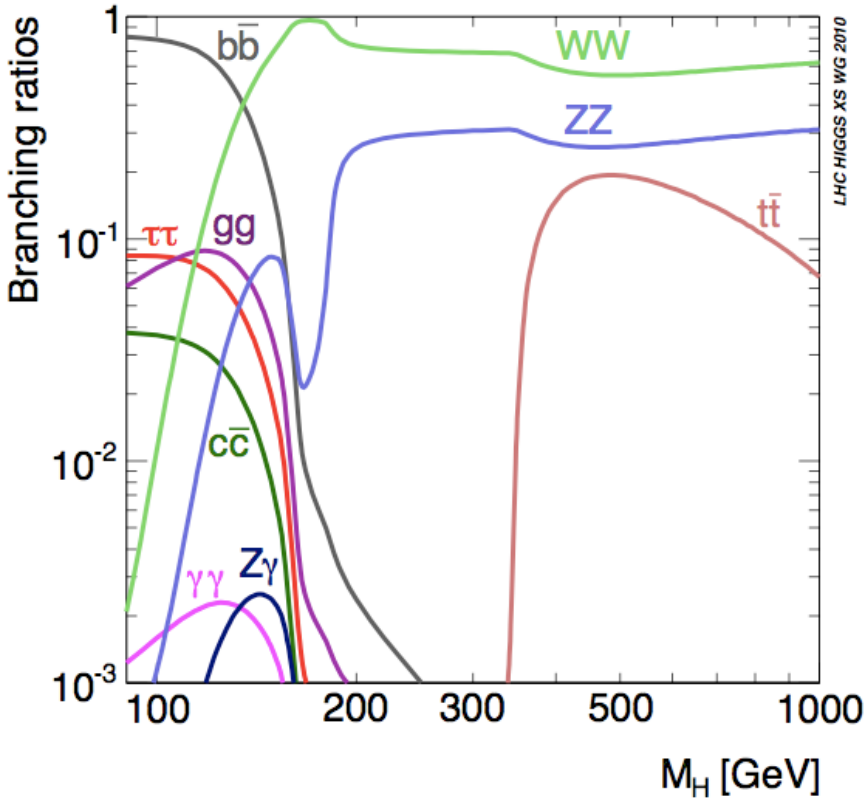


SM Higgs: Production and Decay









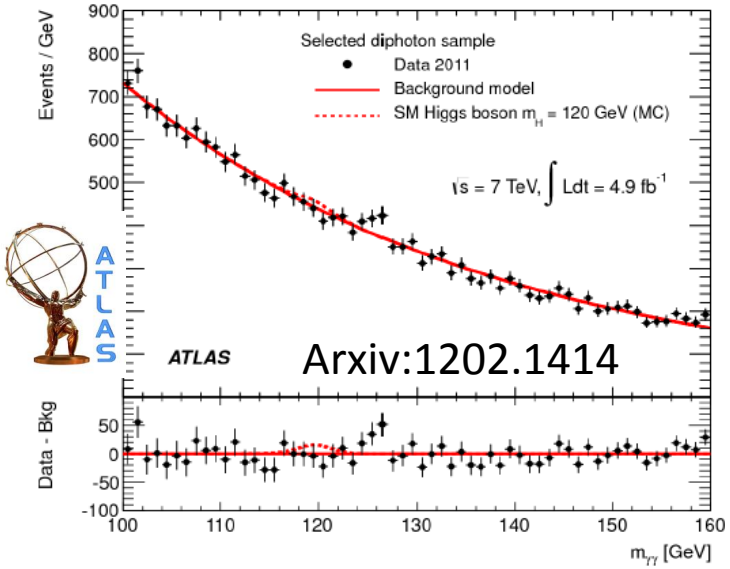
Channels

Large number of channels covering mass range from, 110-600 GeV

	Channel	m_H range (GeV)	Luminosity (fb^{-1})	Sub-channels	m_H resolution
new	$H \to \gamma\gamma$	110–150	4.8	2	1–2%
	$H \to \tau\tau \to e\tau_h/\mu\tau_h/e\mu + X$	110–145	4.6	9	20%
new	$H \to \tau\tau \to \mu\mu + X$	110–140	4.5	3	20%
new	$WH \to e\mu\tau_h/\mu\mu\tau_h + \nu$'s	100–140	4.7	2	20%
	$(W/Z)H \to (e\nu/\mu\nu/ee/\mu\mu/\nu\nu)(bb)$	110–135	4.7	5	10%
	$H \to WW^* \to 2\ell 2\nu$	110–600	4.6	5	20%
new	$WH \to W(WW^*) \to 3\ell 3\nu$	110–200	4.6	1	20%
	$H \to ZZ^{(*)} \to 4\ell$	110–600	4.7	3	1–2%
	$H \to ZZ^{(*)} \to 2\ell 2q$	130–164 200–600	4.6	6	3% 3%
	$H \to ZZ \to 2\ell 2\tau$	190–600	4.7	8	10–15%
	$H \to ZZ \to 2\ell 2\nu$	250–600	4.6	2	7%

Channel	m_H range (GeV)	Backgrounds	$\mathcal{L}$ (fb^{-1})	Reference
low-m_H, good mass resolution				
$H \to \gamma\gamma$	110-150	$\gamma\gamma$, γj, jj	4.9	arXiv:1202.1414
$H \to ZZ^{(*)} \to 4\ell$	110-600	$ZZ^{(*)}$, $Z + jets$, $t\bar{t}$	4.8	arXiv:1202.1415
low-m_H, limited mass resolution				
$H \to WW^{(*)} \to \ell\nu\ell\nu$	110-600	WW, $t\bar{t}$, $W/Z + jet$	4.7	CONF-2012-012
$H \to \tau\tau(ll, lh, hh)$	100-150	$Z \to \tau\tau$, $t\bar{t}$	4.7	CONF-2012-014
$VH, H \to bb$	110-130	$W/Z + jets$, $t\bar{t}$	4.7	CONF-2012-015
high-m_H				
$H \to ZZ \to \ell\ell\nu\nu$	200-600	diboson, $t\bar{t}$, $Z + jets$	4.7	CONF-2012-016
$H \to ZZ \to \ell\ell jj$	200-600	$Z + jets$, $t\bar{t}$, diboson	4.7	CONF-2012-017
$H \to WW \to \ell\nu jj$	300-600	$W + jets$, $t\bar{t}$, multijets	4.7	CONF-2012-018

H→γγ

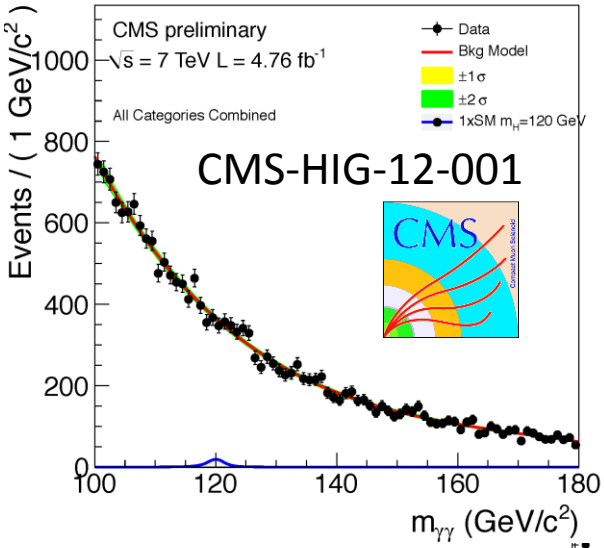


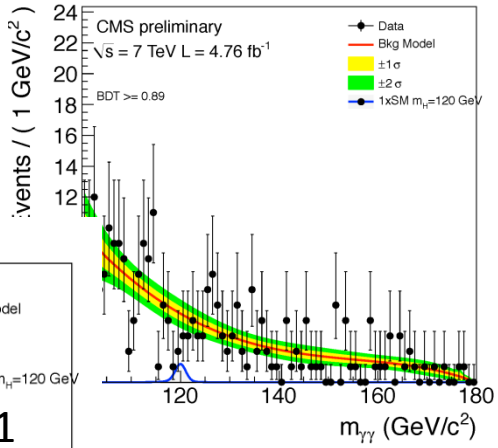
Split into 9 categories varying in mass resolution and S/B

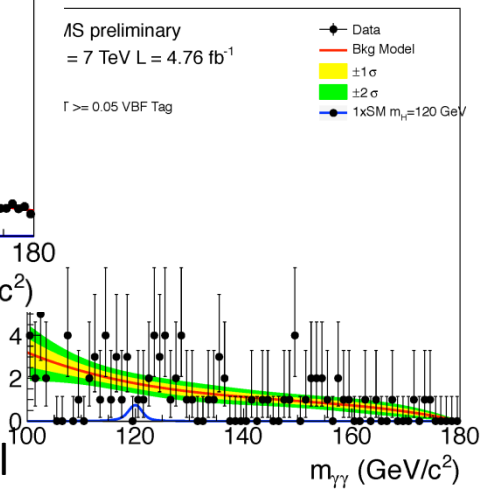
Signal: CB + Gaussian
Background: exponential

Background model validated with high stats MC
Additional small uncertainty covers choice of model

5 categories:
4 from MVA classifier
1 optimised for VBF





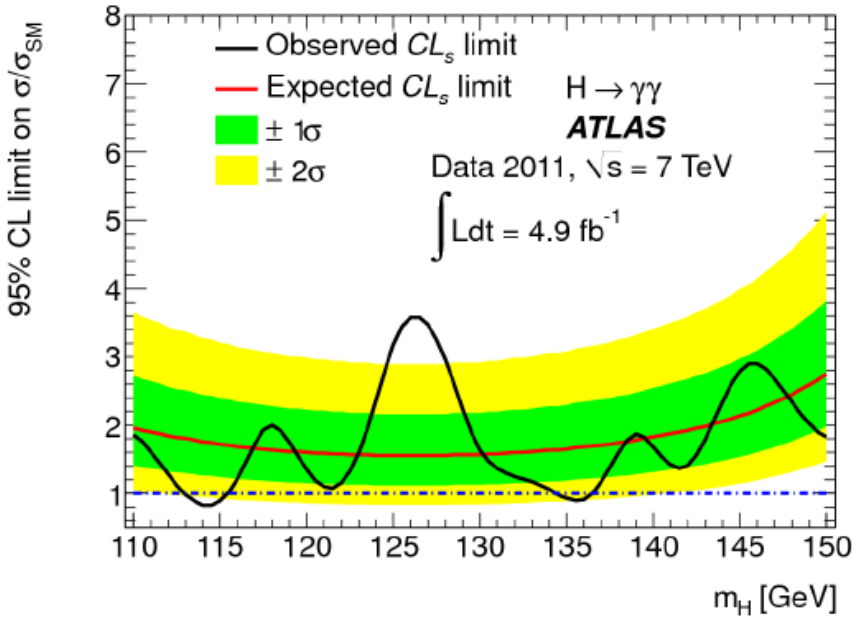


Signal: sum of gaussians

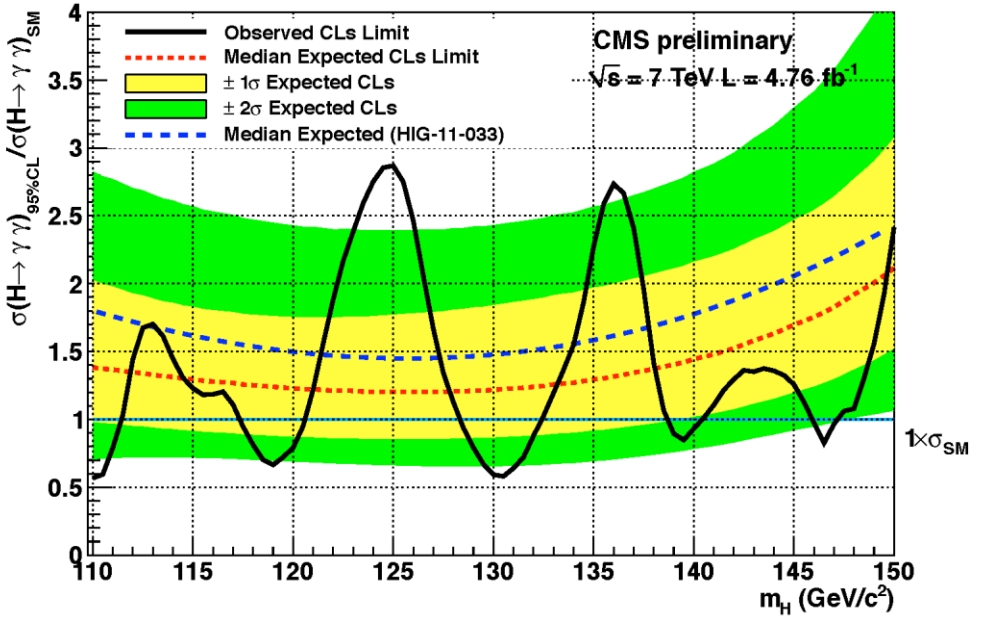
Polynomial background model chosen to ensure minimal bias

Alternate background model less sensitive to model choice

H→γγ



Largest excess ~126 GeV with 2.8σ
(1.5σ after LEE for mH=110->150 GeV)

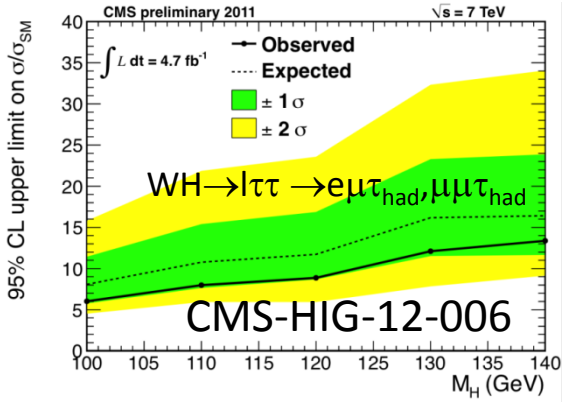


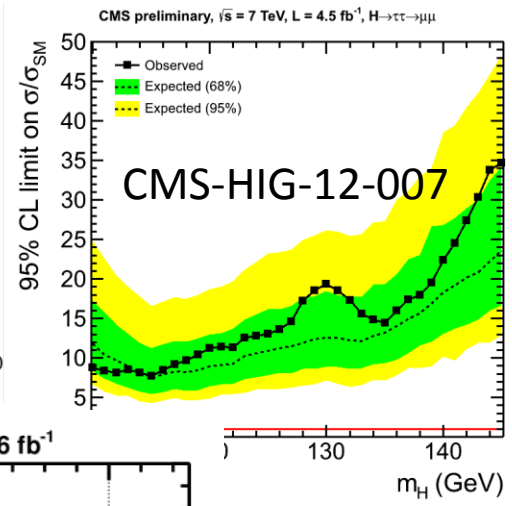
Largest excess ~125 GeV with 2.9σ
(1.6σ after LEE for mH=110->150 GeV)

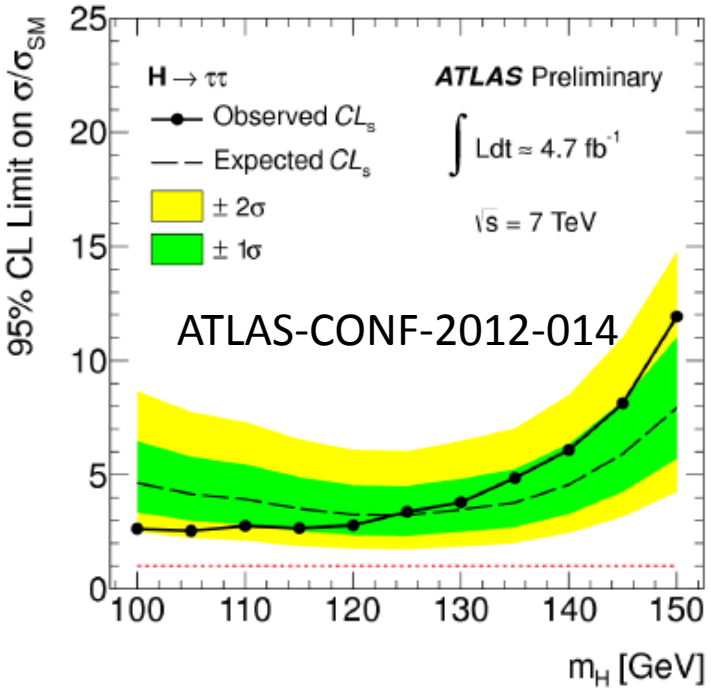
H→ττ

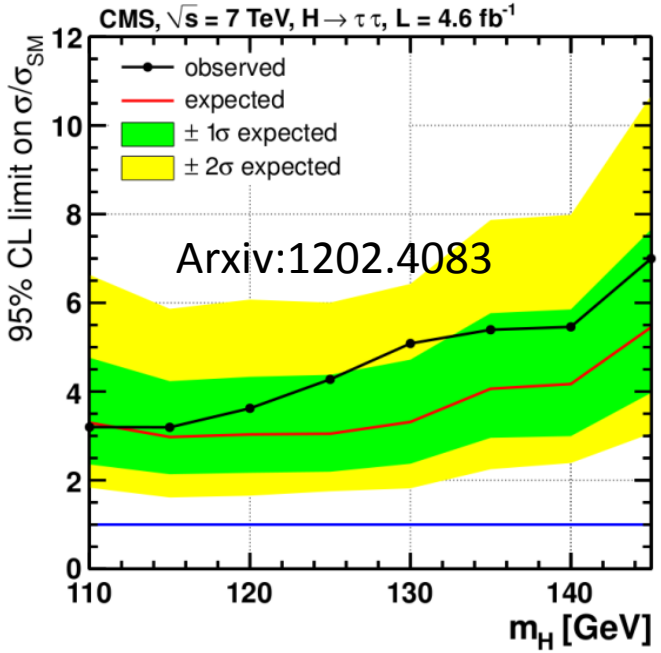
Important channel in low mass region despite broad mass peak

2l4ν, lτ_{had}3ν, $\tau_{had}\tau_{had}$2ν
Split into many subcategories based on jets multiplicity, kinematics , MET and VBF









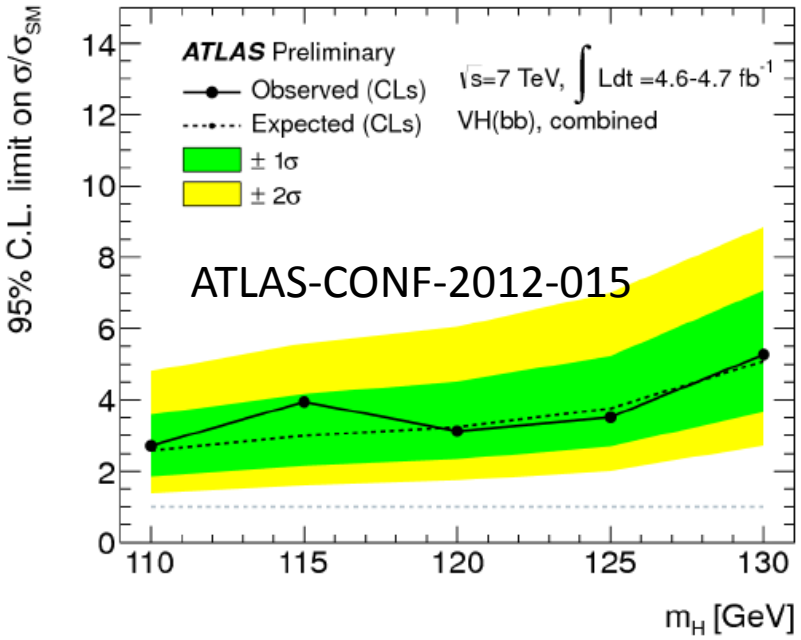
Dominant irreducible background: Z→ττ

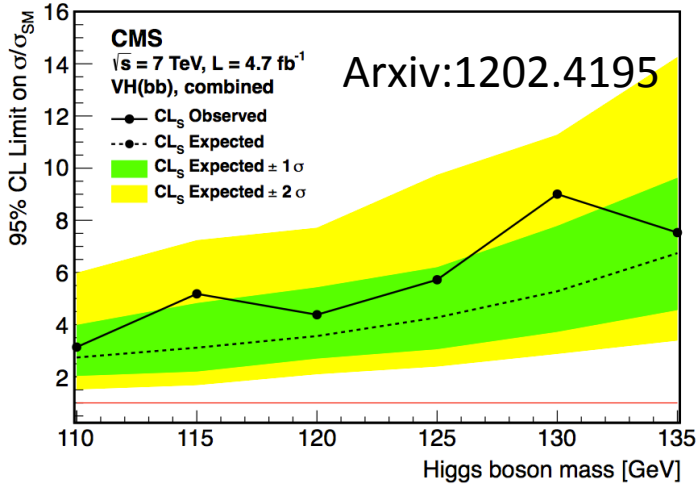
(also v. important in MSSM Higgs searches)

VH,H→bb

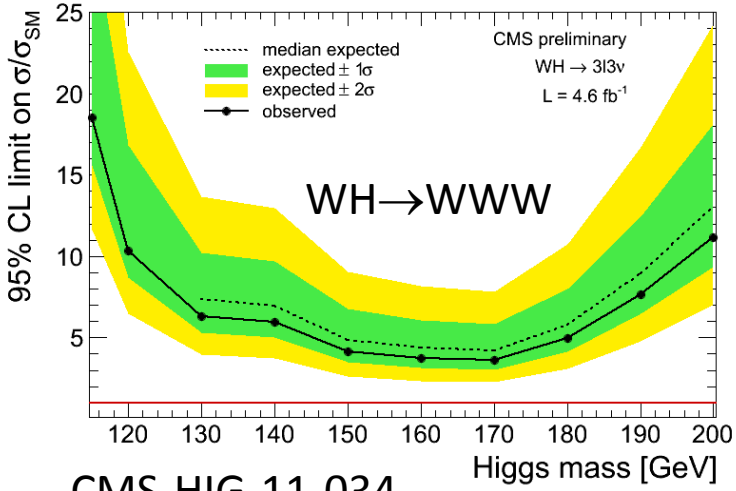
Large backgrounds - need lepton tag from associated production

Additionally split into boosted/non-boosted to gain sensitivity





New low mass channel…

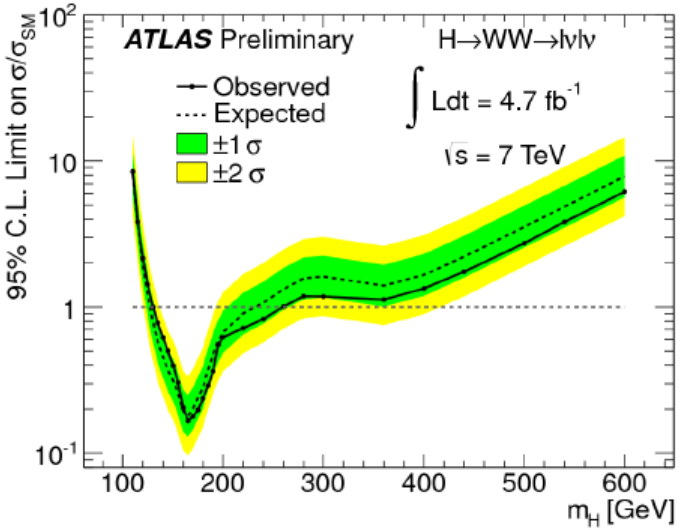


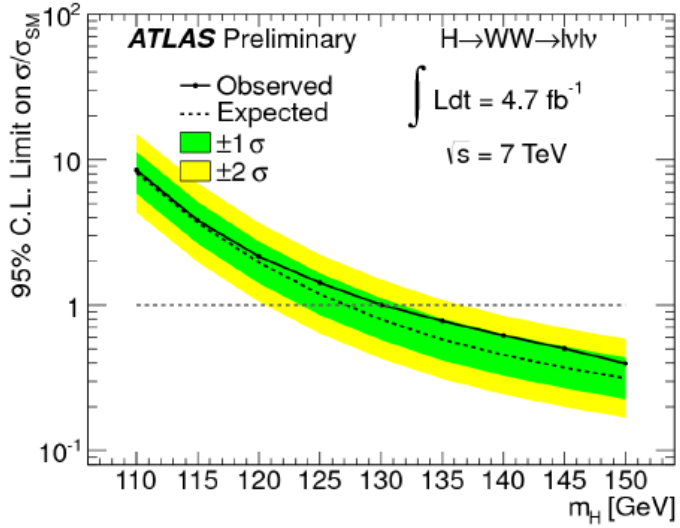
CMS-HIG-11-034

Search for broad bb mass peak

Sensitivity between 3-5 x SM

H→WW





H→WW→lυjj

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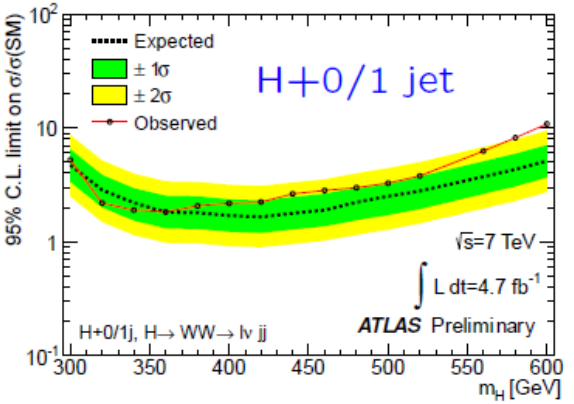
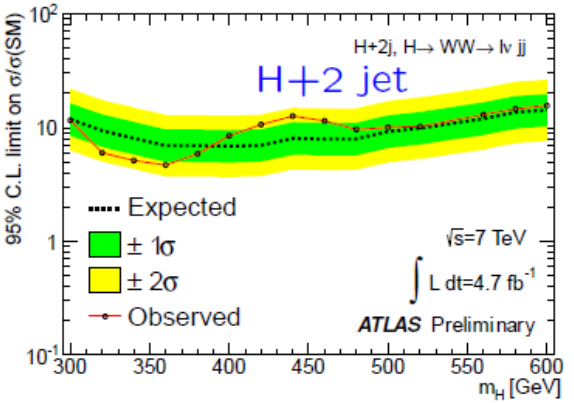
Divided into jet categories 0,1 and 2 (VBF) jets





H→WW→lυlυ

Most sensitive channel across broad mass range 125-180

Expected exclusion: 127-234 GeV
Observed exclusion: 130-260 GeV

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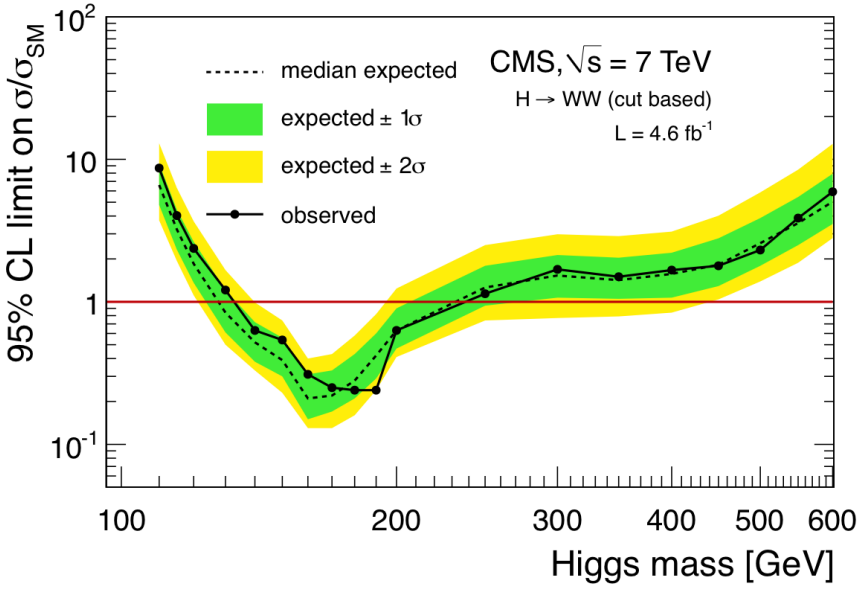
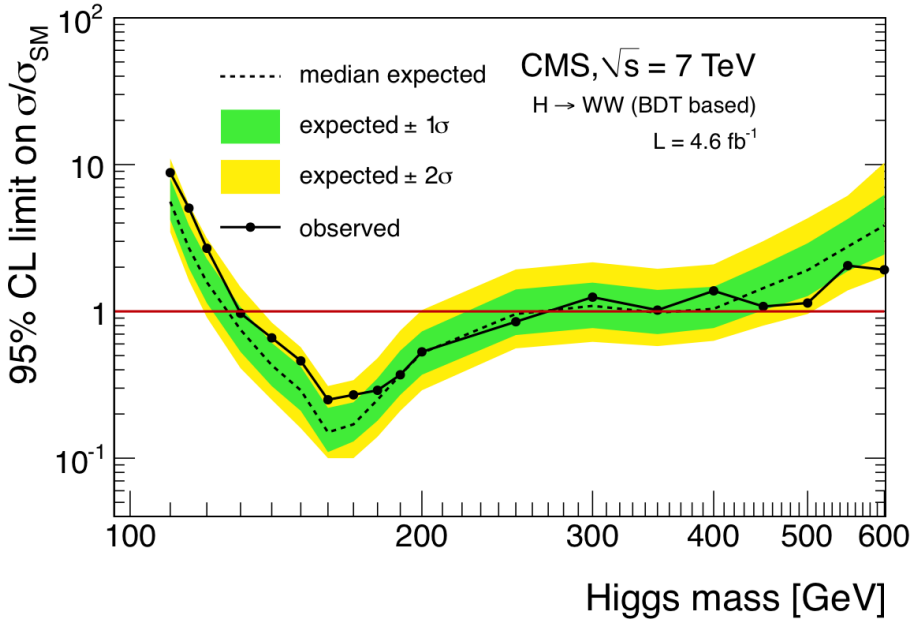
H→WW

Events split into 3 jet multiplicity bins: 0,1 and 2 (VBF)



Arxiv:1202.1489

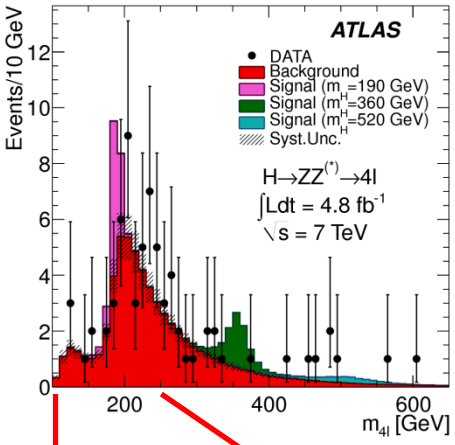


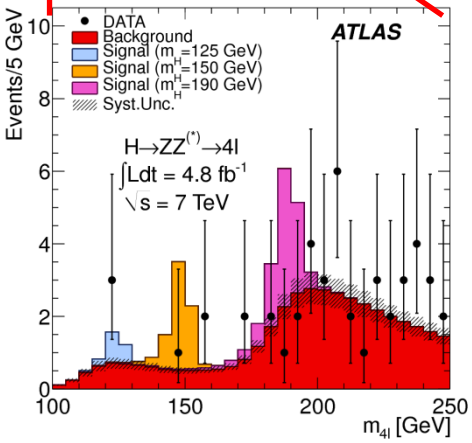
Two parallel approaches:
- cut-based analysis
- MVA shape based analysis

Observed exclusion:
- 132-238 GeV (cuts)
- 129-270 GeV (MVA)

H→ZZ→4l

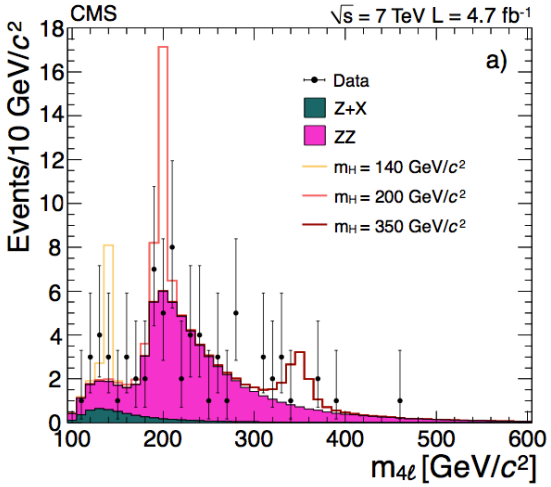
Arxiv:1202.1415

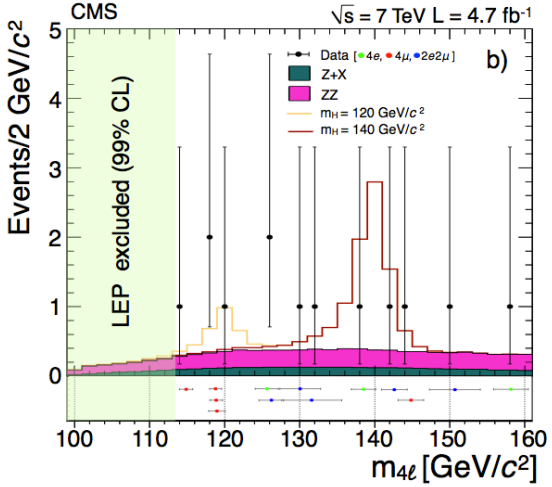




The "golden" channel : very clean with v. good resolution

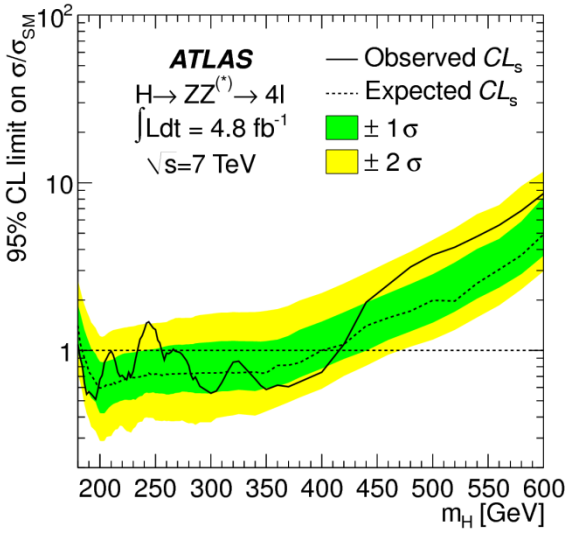
Important high mass channel but with significant sensitivity at low mass

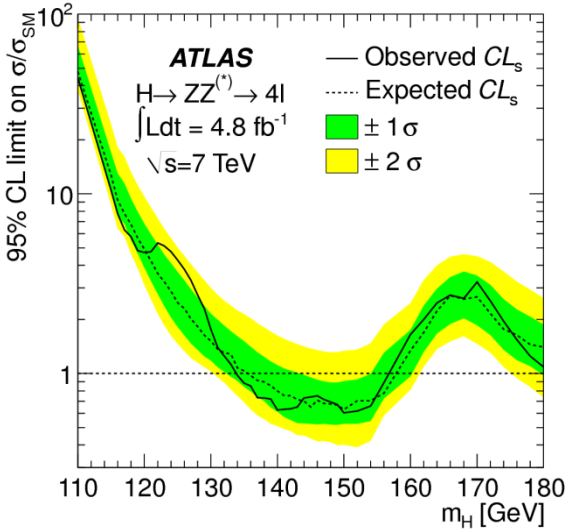


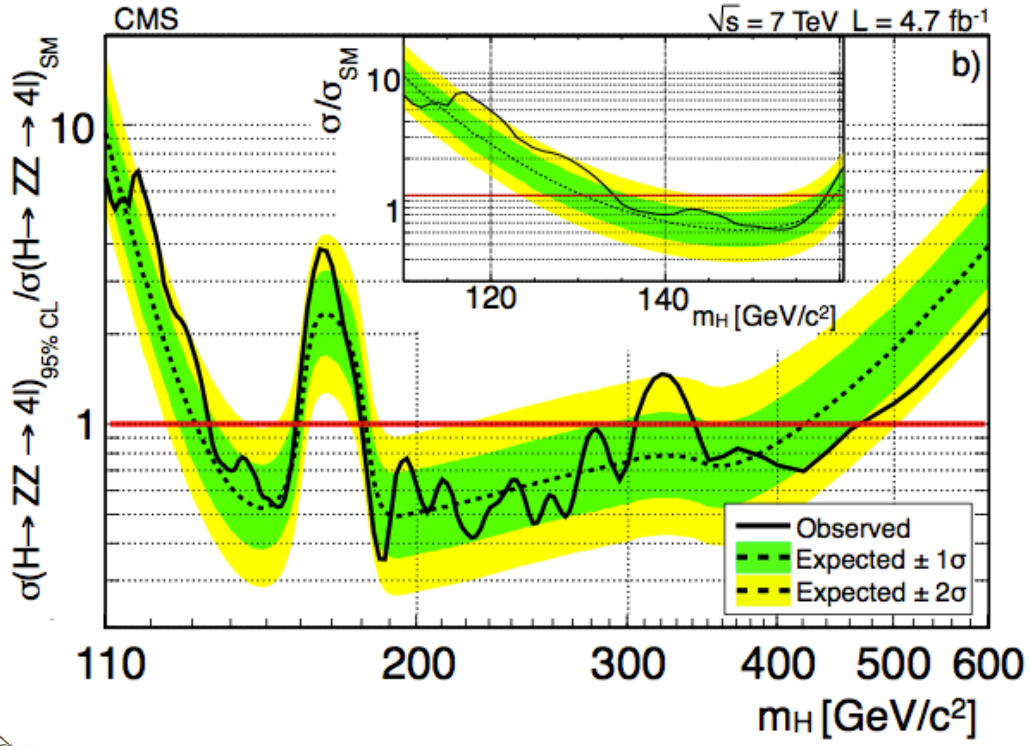


Arxiv:1202.1997

H→ZZ→4l







Observed limits:
134-156, 182-233, 256-265, 268-415 GeV

Observed limits:
134-158,180-305, 340-465 GeV

H→ZZ→2l2υ and 2l2j

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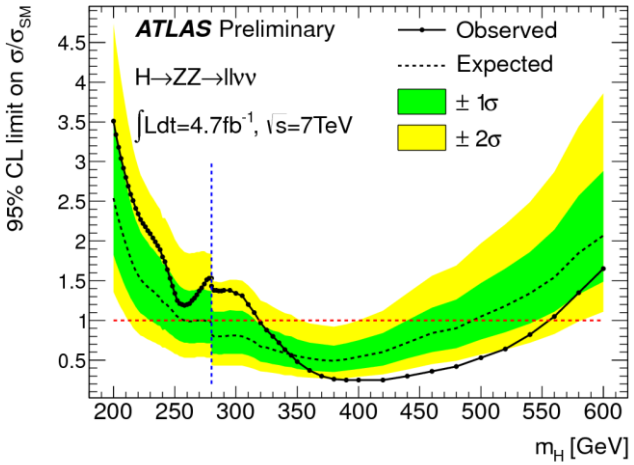
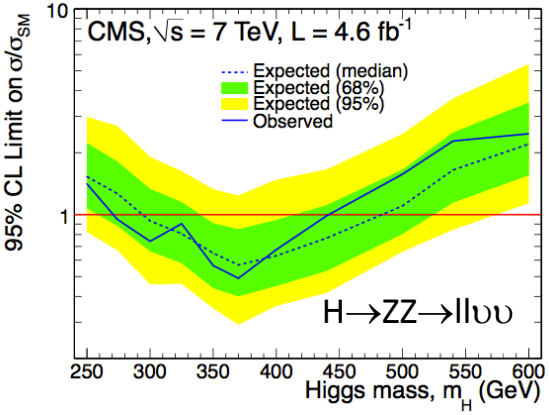
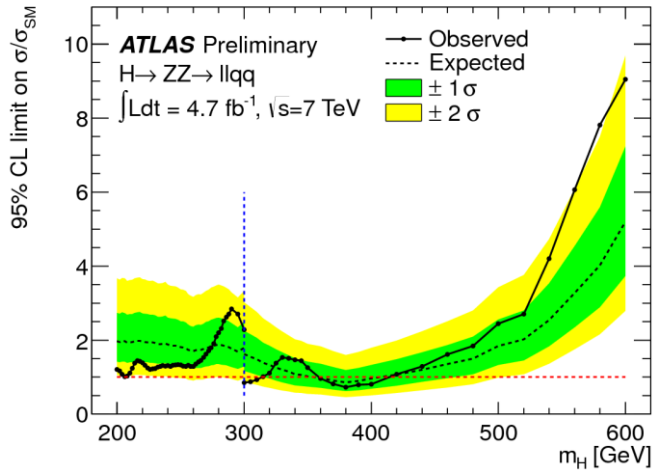


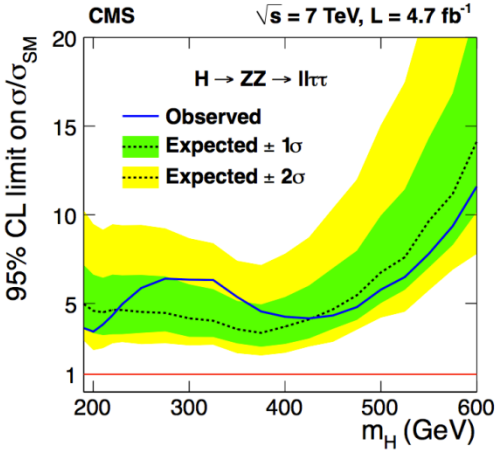
H→ZZ→llυυ
Most sensitive channel in high mass range

Arxiv:1202.3478

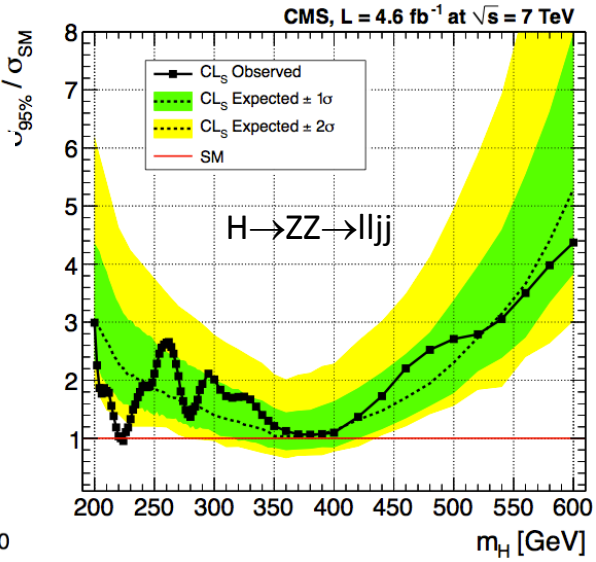




ATLAS-CONF-2012-017



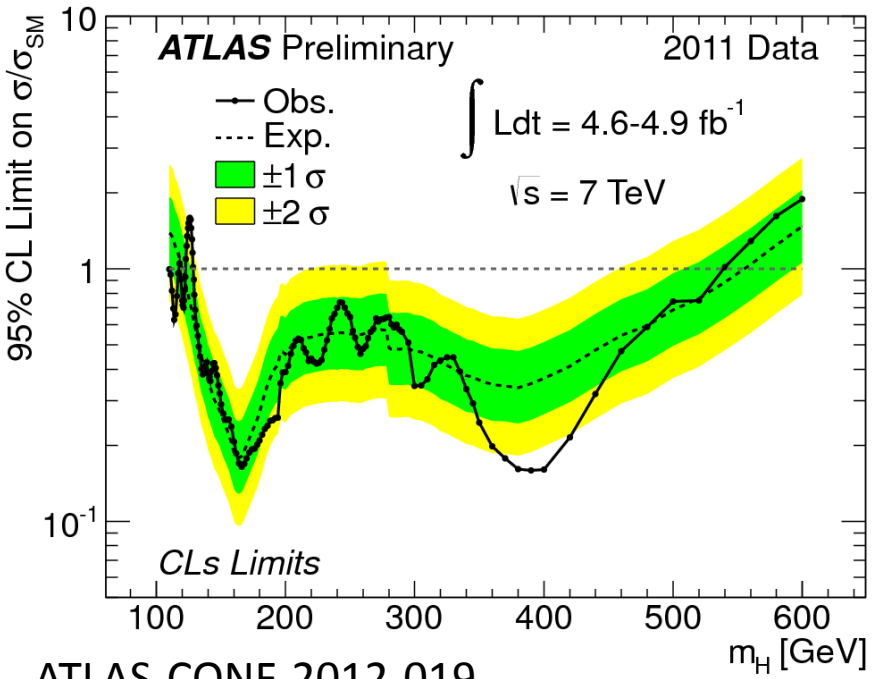
Arxiv:1202.3617



Arxiv:1202.1416

Combinations: limits

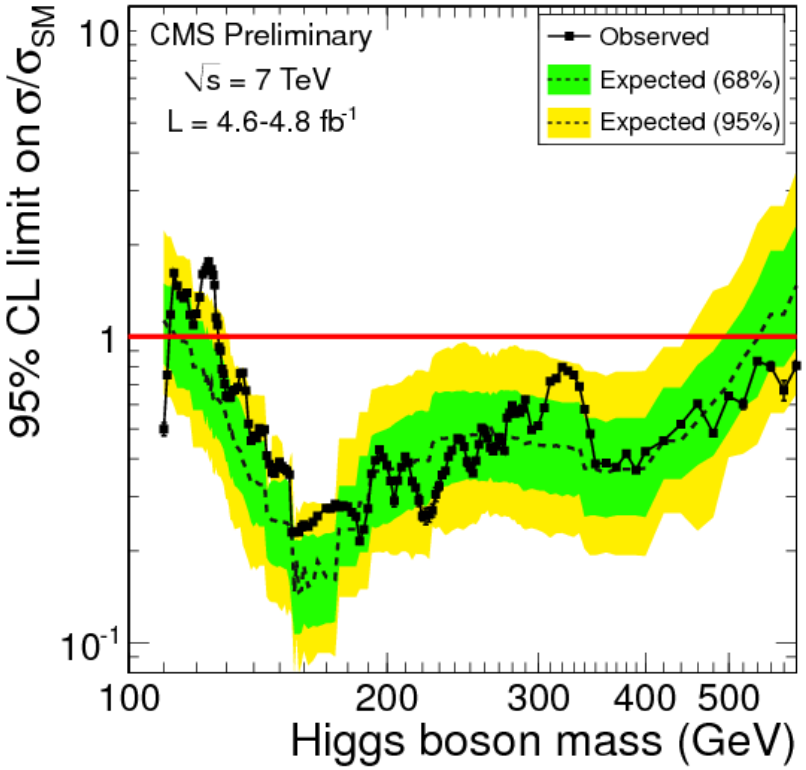
Not much room left for a SM Higgs!



ATLAS-CONF-2012-019

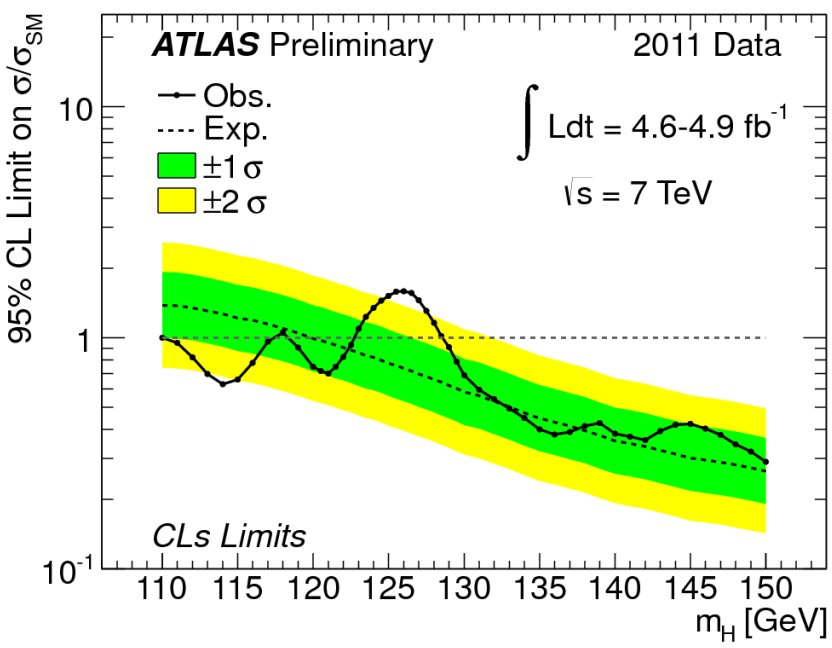
Observed exclusion: (@95%)
110-117.5, 118.5-122.5, 129-539 GeV
(@99% - 130-486 GeV)

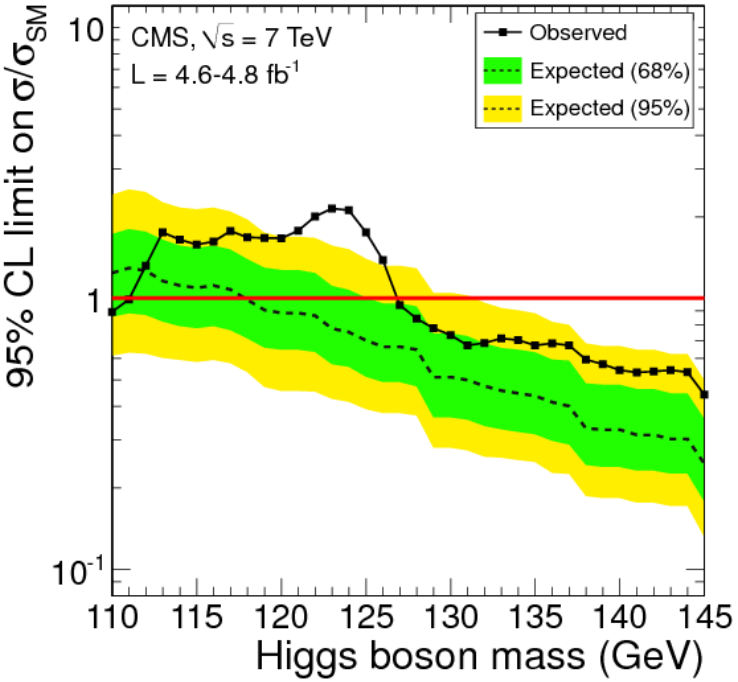
CMS-HIG-12-008



Observed exclusion: (@95%) 127-600 GeV
(@99% - 129-525 GeV)

Combinations: low mass limits

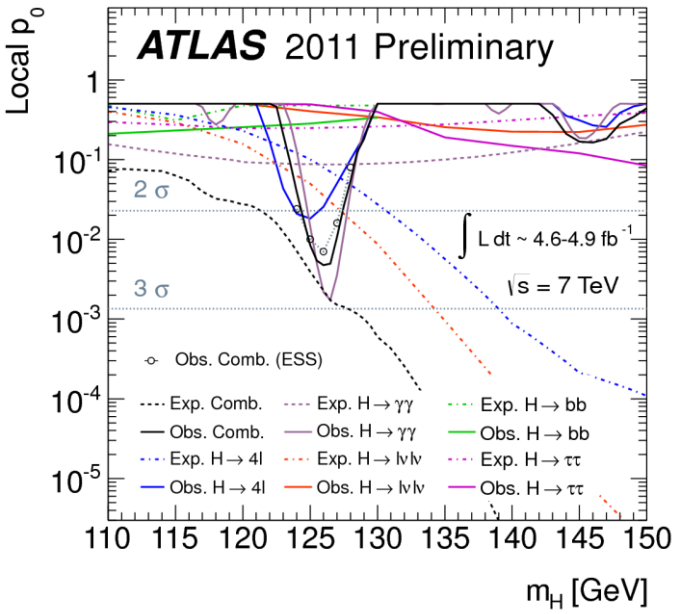




Exclusion not as tight as expected due to low mass excesses in both experiments

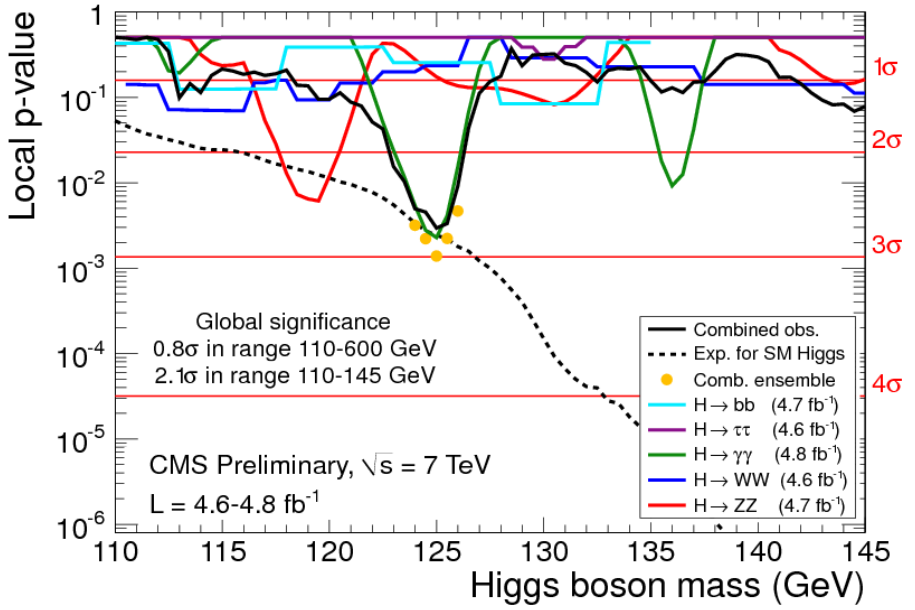
Combinations: p-values

Local probabilities for a background fluctuation as large as observed excess



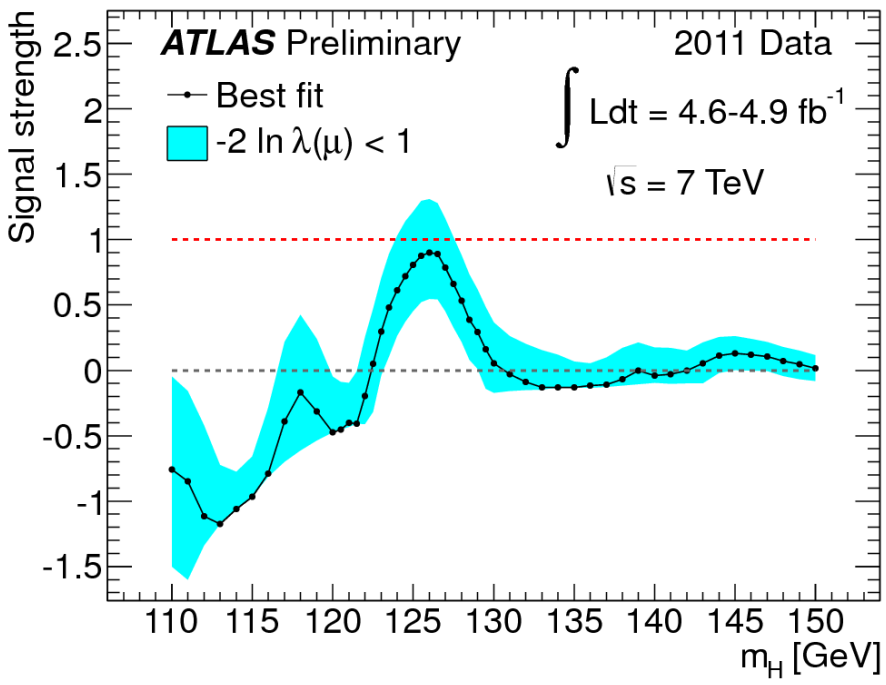
Local significance: 2.5 σ
p ~ 30% (110-600)
P ~ 10% (110-146)

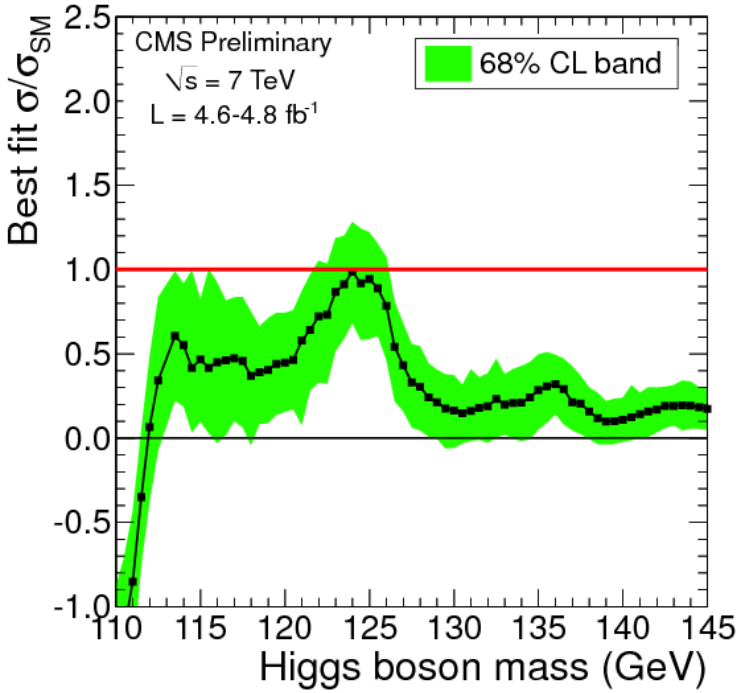
Be careful of look elsewhere effect!



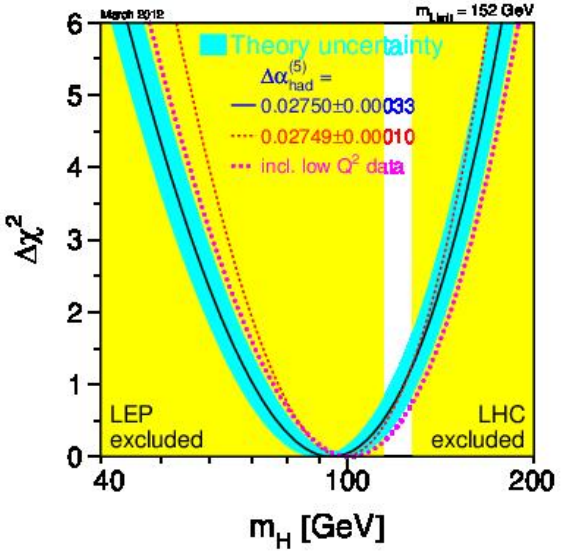
Local significance: 3.1 σ
1.5σ (110-600)
2.1σ ~ 10% (110-146)

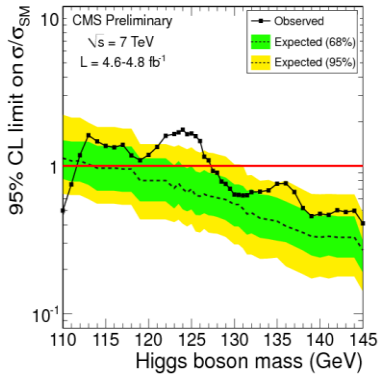
Combinations: best fit signal

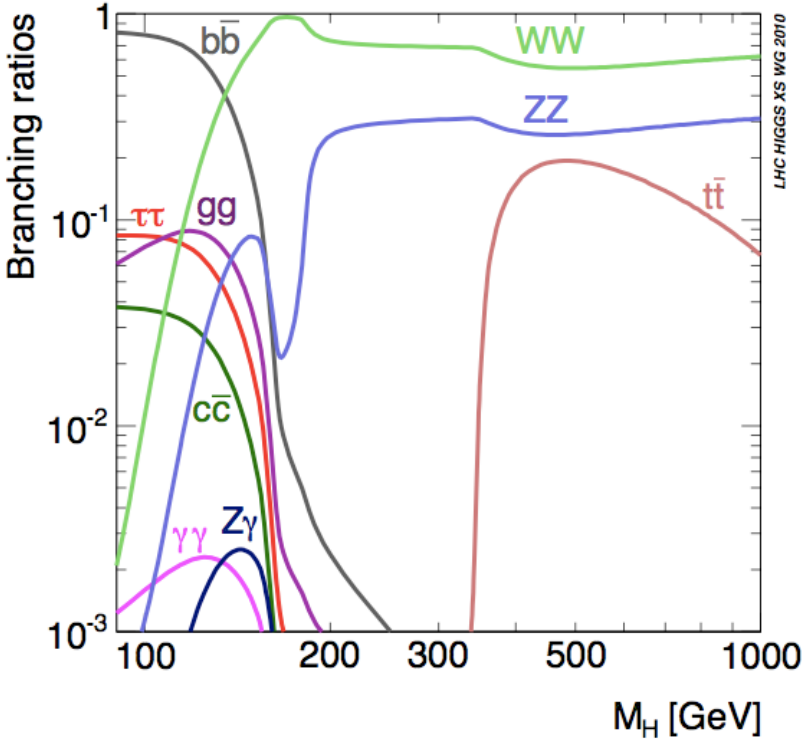


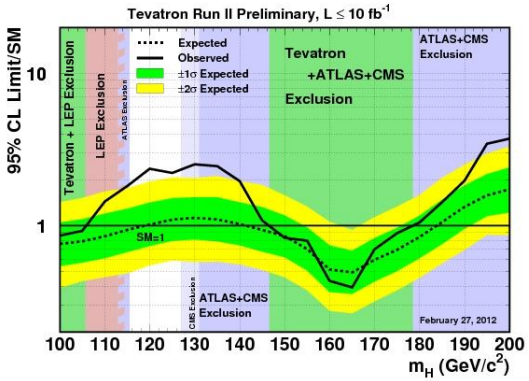


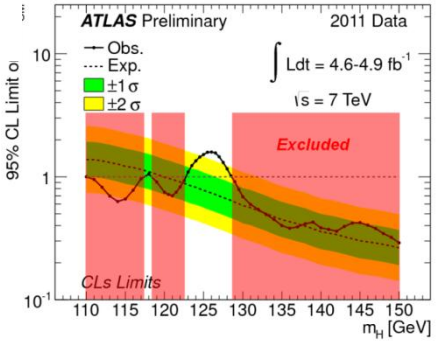
Higgs: end of the beginning?











Around 125 GeV – great place to be if there is a signal. Lots of channels accessible!

Conclusions

Huge program of standard model measurements

Precision probes of EWK and pQCD

Improved modelling of backgrounds for searches

Standard Model Higgs search

End is nigh! – at least for SM Higgs

This years data should see discovery or exclusion

Bottom line on current results: Wait and see!