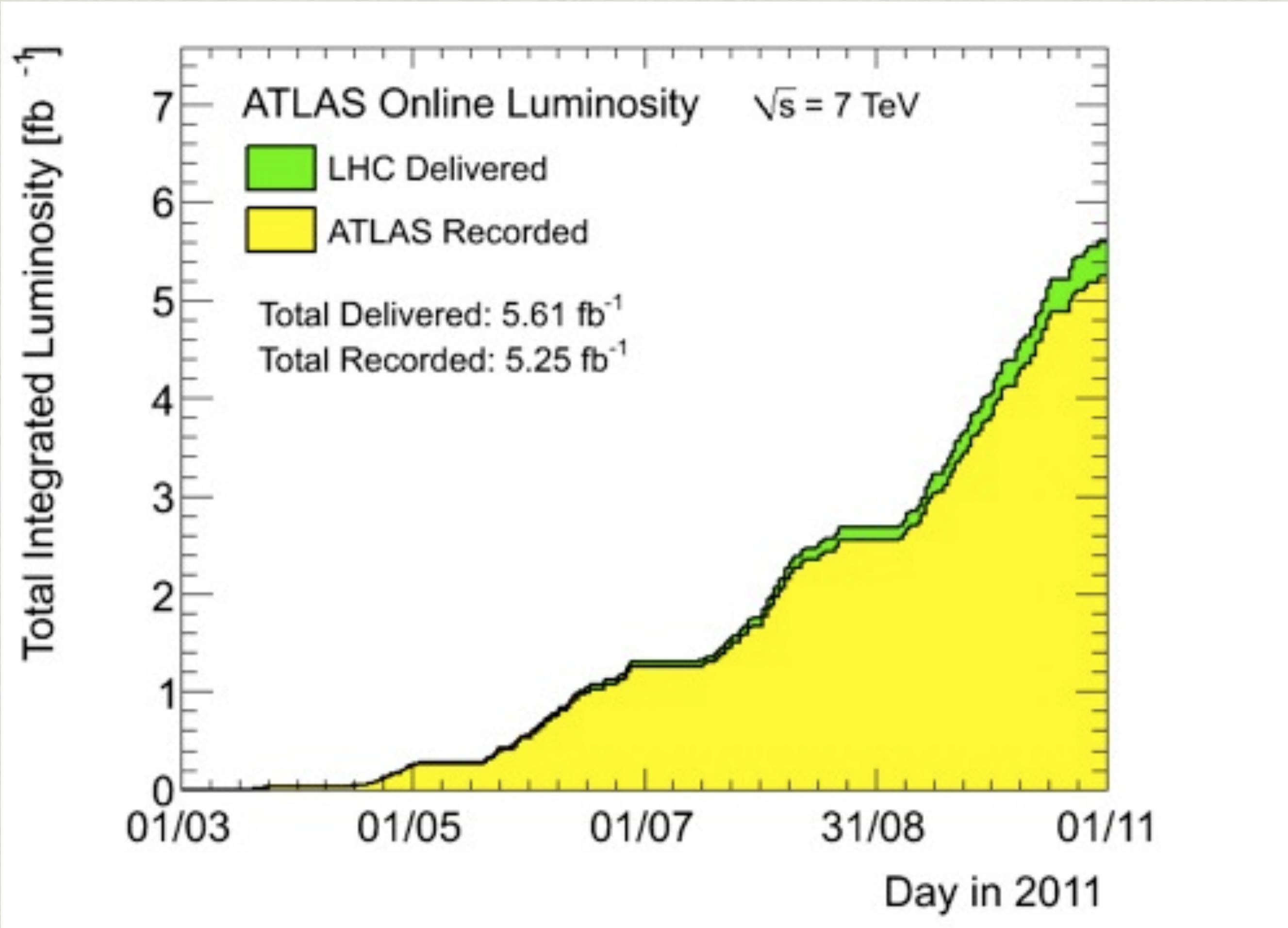
APPS 2011

Higgs  at LHC

Pamela Ferrari NIKHEF

Wednesday, 30 November 2011

Integrated luminosity



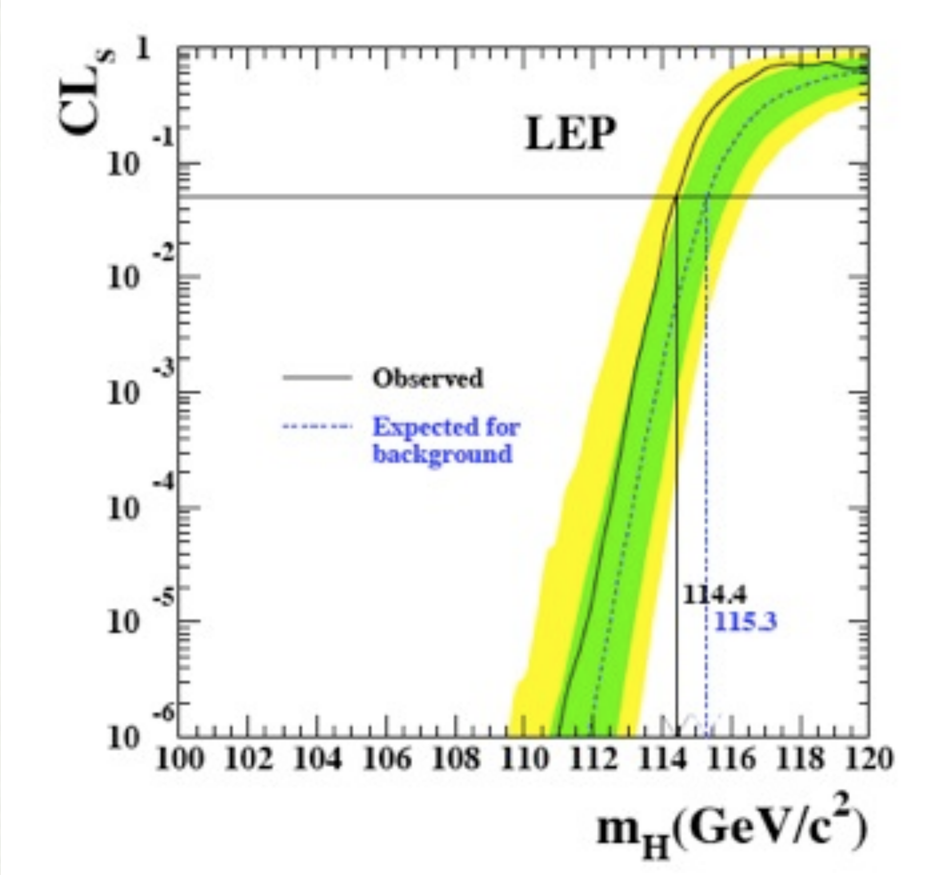
5.61 fb-1 delivered

analyses use <2.3 fb^{-1}

SM Higgs

Cannot show all results, a selection from ATLAS and CMS is shown

LEP & Tevatron

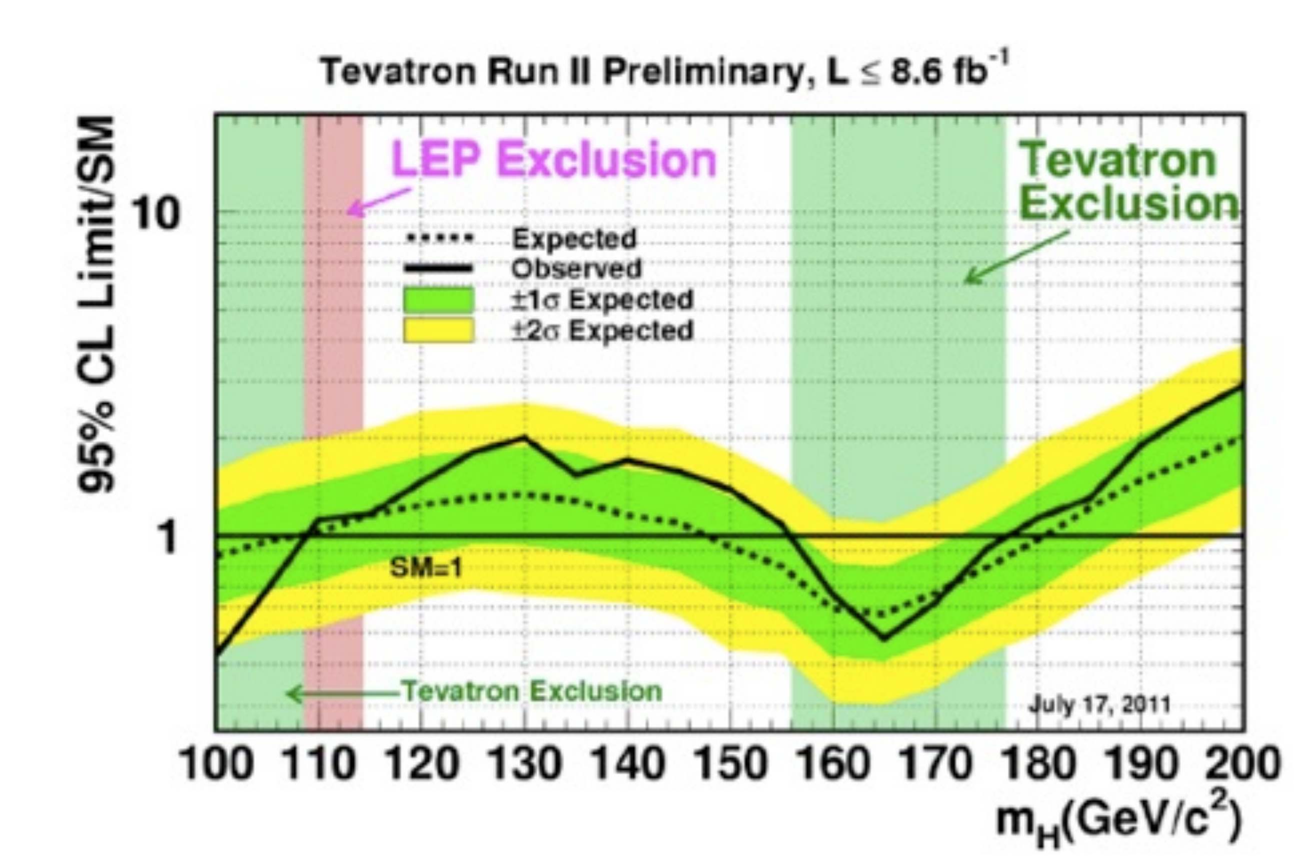


Observed exclusion @ 95%CL

< 114.4 GeV

Expected exclusion @95% CL

< 115.3 GeV



Observed exclusion @ 95%CL

100-109 156-177 GeV

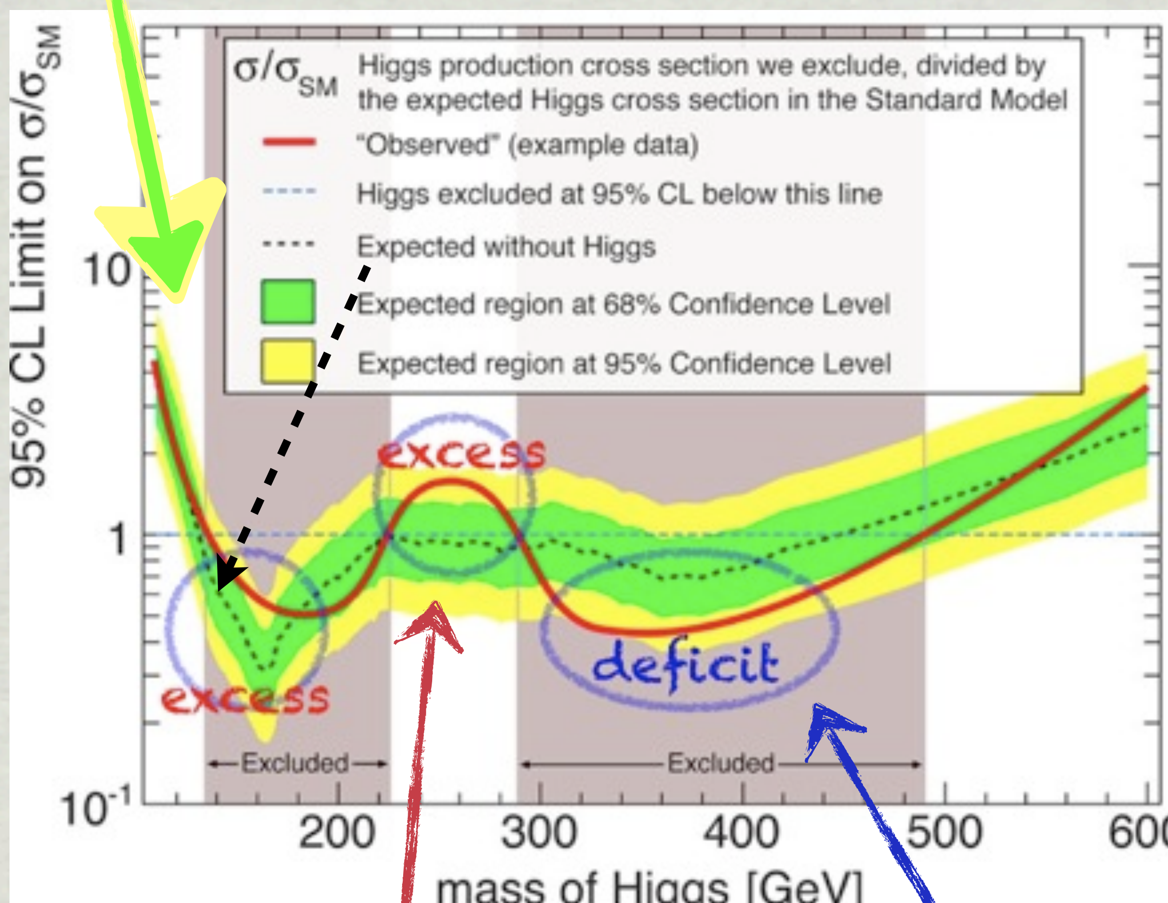
Expected exclusion

100-108 148-181 GeV

Statistical combination: few hints

What are all those curves?

1σ and 2 σ bands around expectation



observed limit in data

95% limits on σ/σ_{SM} using CL_S

excess in data wrt background only expectation

deficit in data wrt background only expectation

Much more in Wouter's talk!

Statistical combination: few hints

That can't be the whole story.. what else?

- The p-value is the measure of the probability to observe of an excess in data just due to background.

- The Look Elsewhere Effect (LEE): what is the probability that such a fluctuation appears anywhere on the plot?
  - what is the probability that you get a high bin in a 100 bins plot?
  - what is the probability that you get a high bin in a 1000 bins plot?

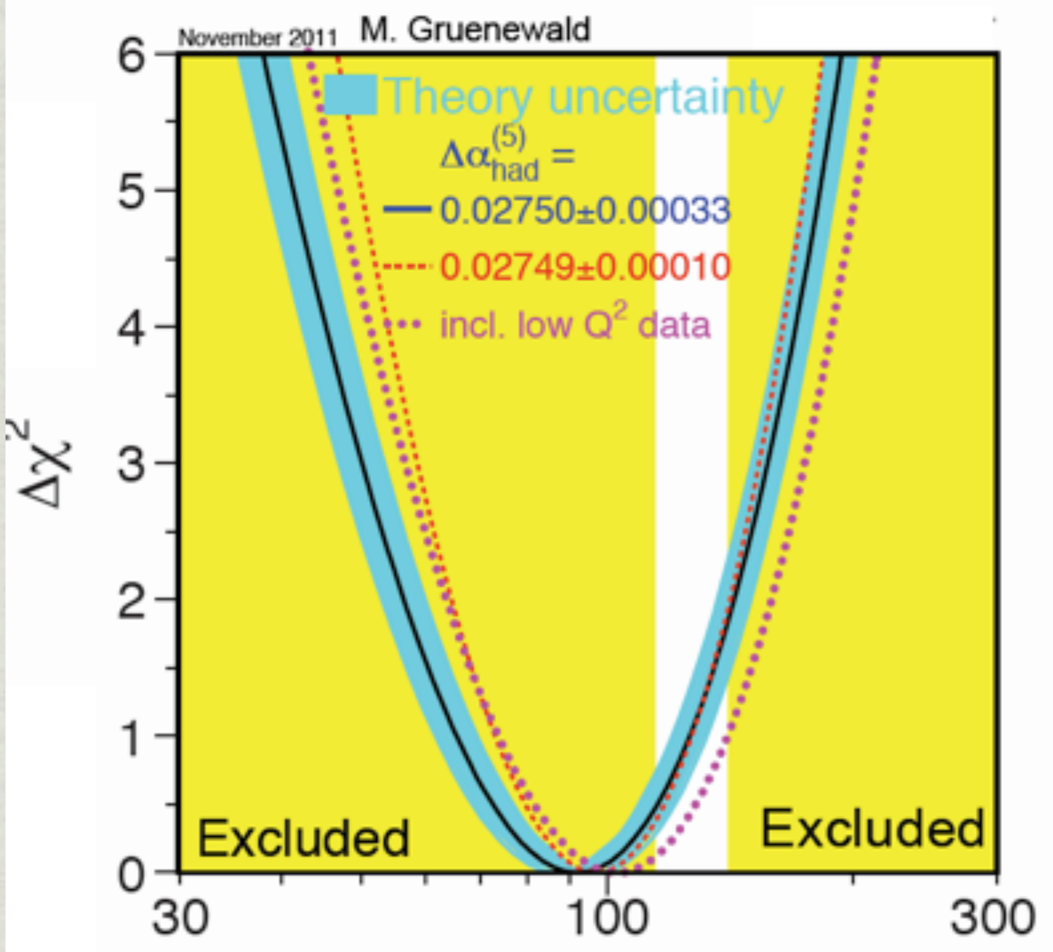
EW Fit constraints

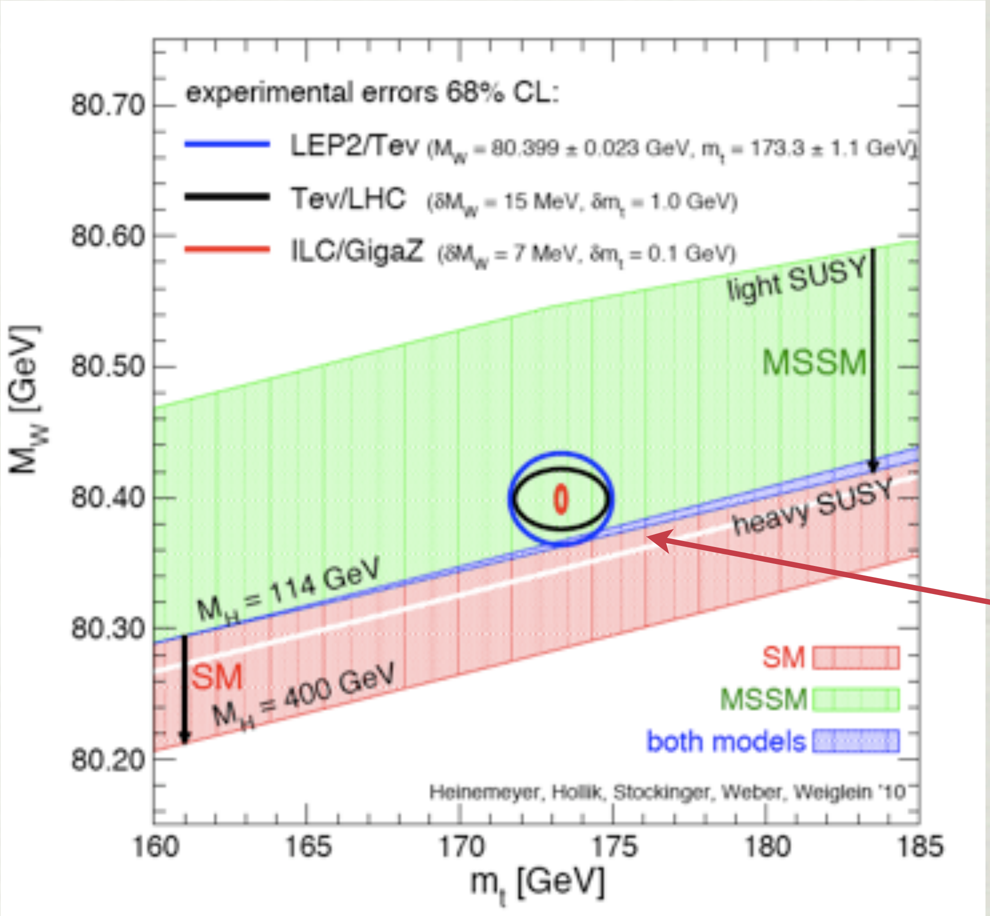
From present EW fit the preferred value for m_H is

$m_H = 92^{+34}_{-26}$ GeV @68% CL

$m_H <$ 161 GeV @95% CL

This limit increases to 185 GeV when including the LEP-2 direct limit of 114 GeV (in yellow).

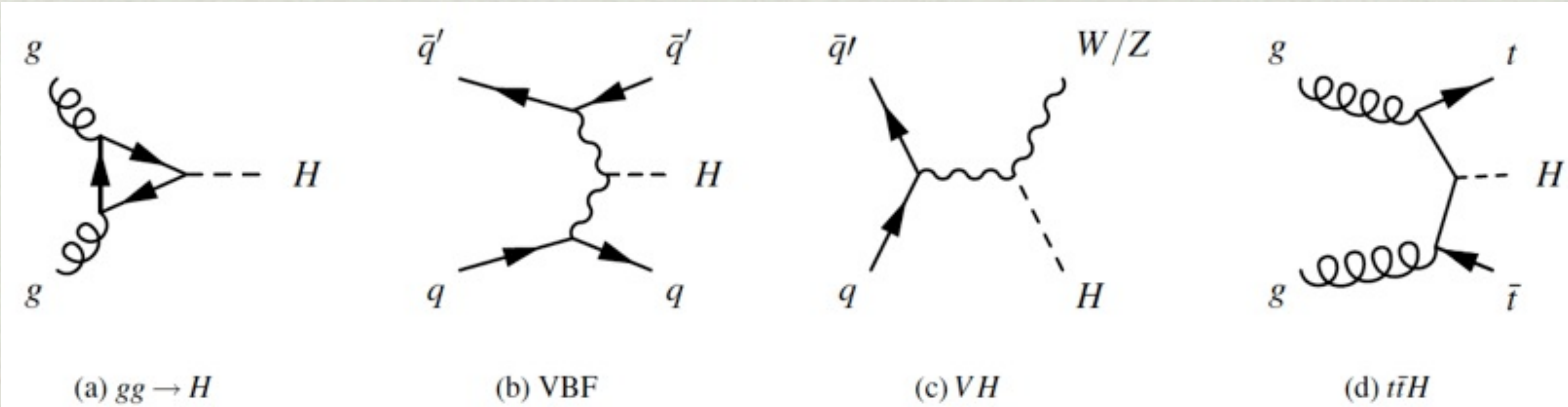




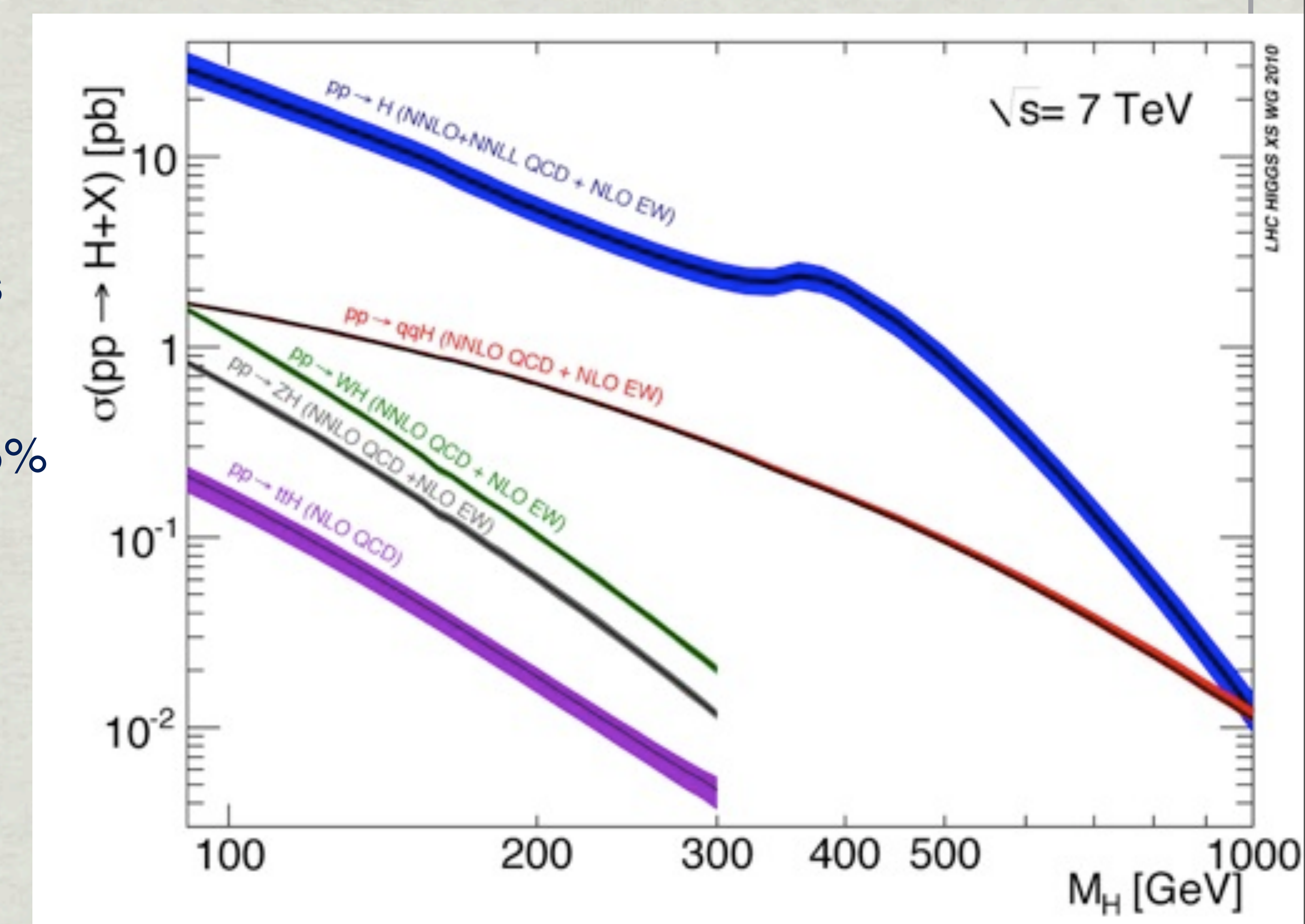
This is in the context of the SM. But please remember that the SM doesn't explain everything.

Are the Higgs constraints more compatible with MSSM?

Production x-sections

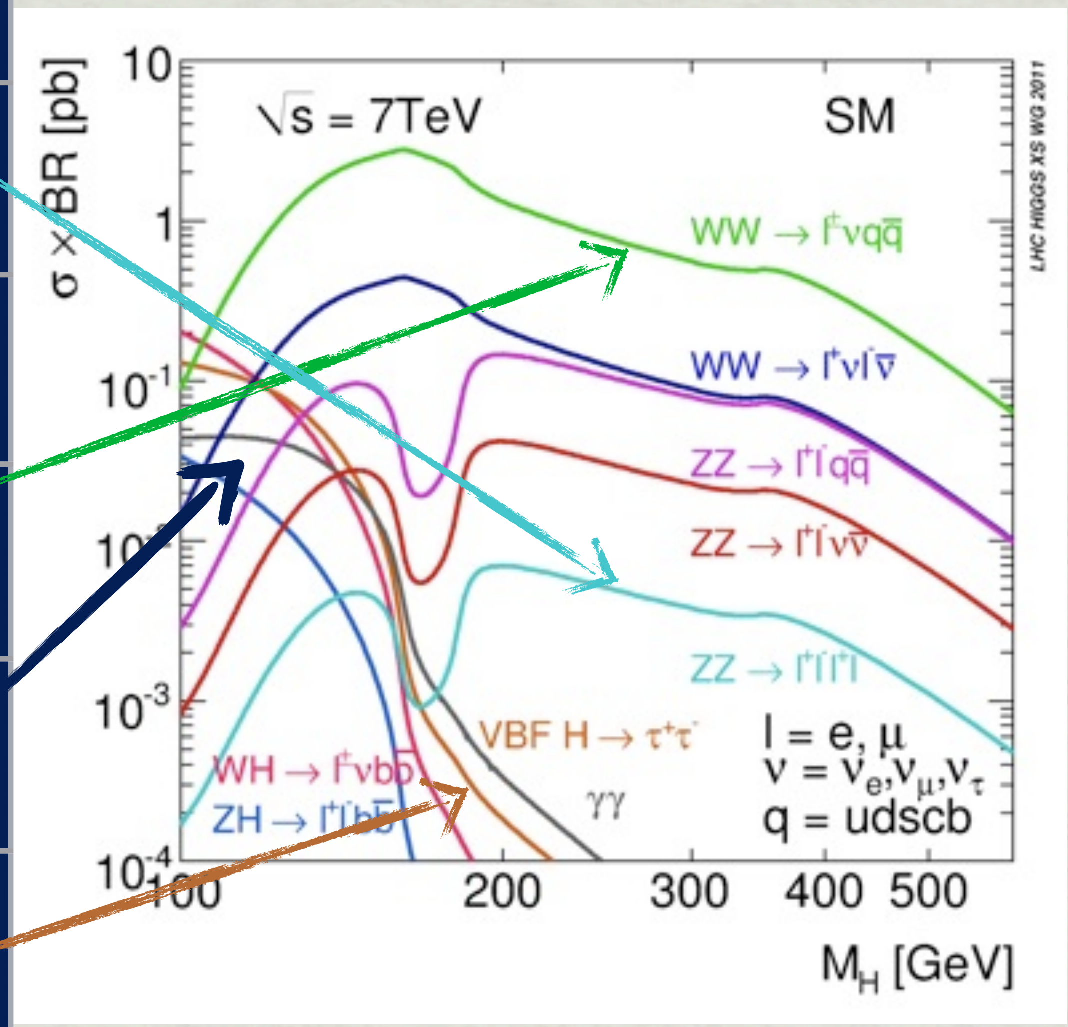


- Gluon fusion: Dominant process at LHC, but the cross-section theoretical uncertainty is at the 15% level (even if is known at NNLO)
- VBF: process known at the 5% (N)NLO. Forwards jets and a rapidity gap
- Associated W,Z production: known at (N)NLO at 5%
- Associated ttbar production: known at NLO (15%)



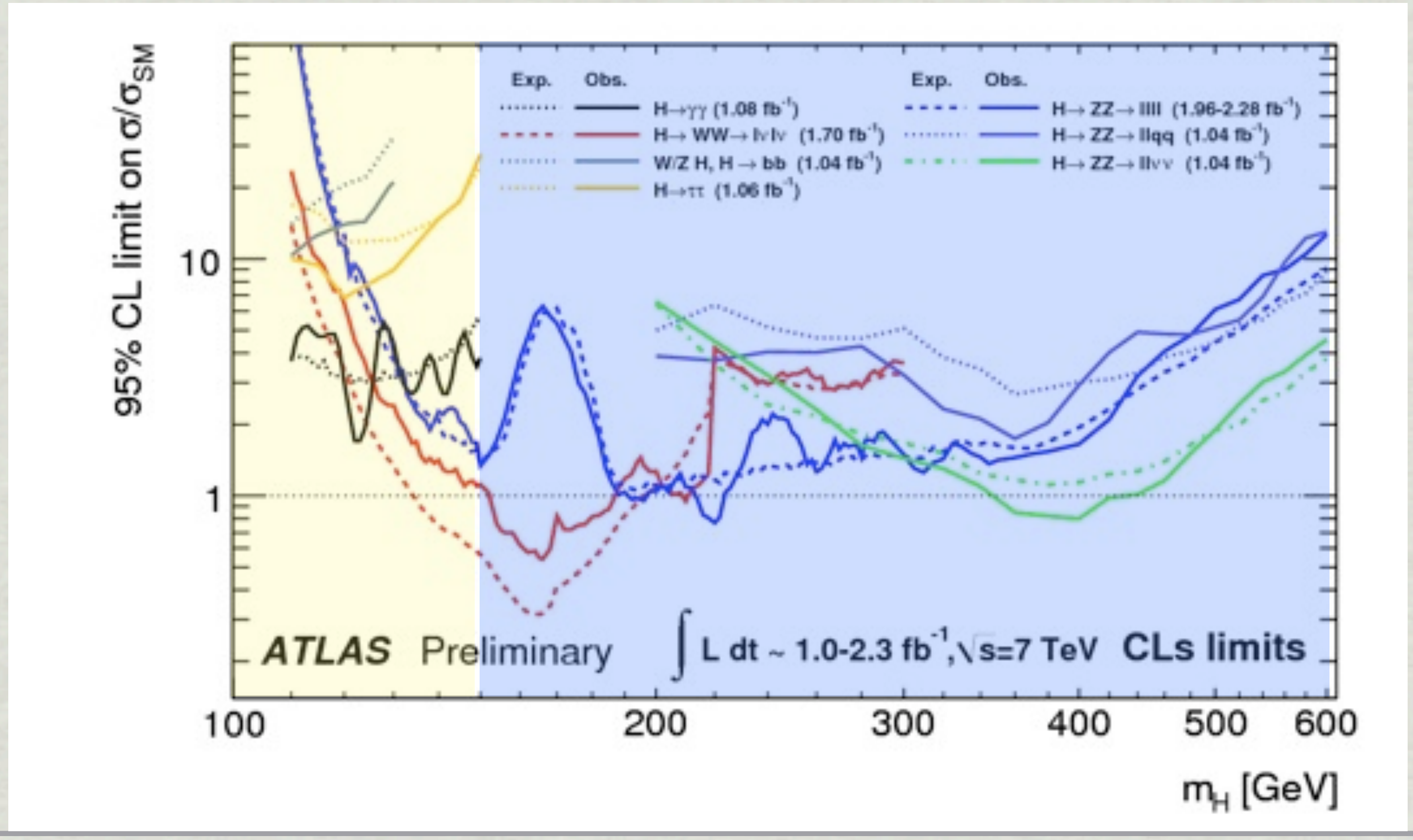
What is the best channel?

H→ZZ→llll	golden channel
H→ZZ→llνν/llbb	good @ high mass
H→WW→lνlν	most sensitive
H→WW→lνqq	highest rate
H→γγ	rare but good @ low mass
H→ττ	good s/b, rare, but good @ low mass
H→bb (ttH,WH/ZH)	useful but difficult due to large backgrounds



Channels used

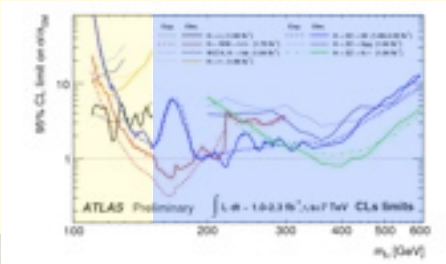
channel	region	CMS method	ATLAS method	CMS Lumi	ATLAS Lumi
H→bb	low	Cut&Count	m_{bb}	1.1 fb-1	1.0 fb-1
H→ττ	low	$m_{\tau\tau}$ shape (binned)	$m_{\tau\tau}$ shape (binned)	1.6 fb-1	1.1 fb-1
H→γγ	low	$m_{\gamma\gamma}$ shape (unbinned)	$m_{\gamma\gamma}$ shape (unbinned)	1.7 fb-1	1.1 fb-1
H→WW→lνlν	low/high	cut & count	cut & count	1.5 fb-1	1.7 fb-1
H→ZZ→4l	low/high	m_{ZZ} (unbinned)	m_{ZZ} (binned)	1.7 fb-1	2.3 fb-1
H→ZZ→2l2τ	high	-	m_{ZZ} (binned)	-	1.1 fb-1
H→ZZ→2l2q	high	m_{ZZ} (unbinned)	m_{ZZ} (unbinned)	1.6 fb-1	1.0 fb-1
H→ZZ→2l2ν	high	cut & count	m_T shape (binned)	1.6 fb-1	2.0 fb-1



low m_H region:
m_H<150 GeV

ATLAS-CONF-2011-103

H→bb (low m_H)



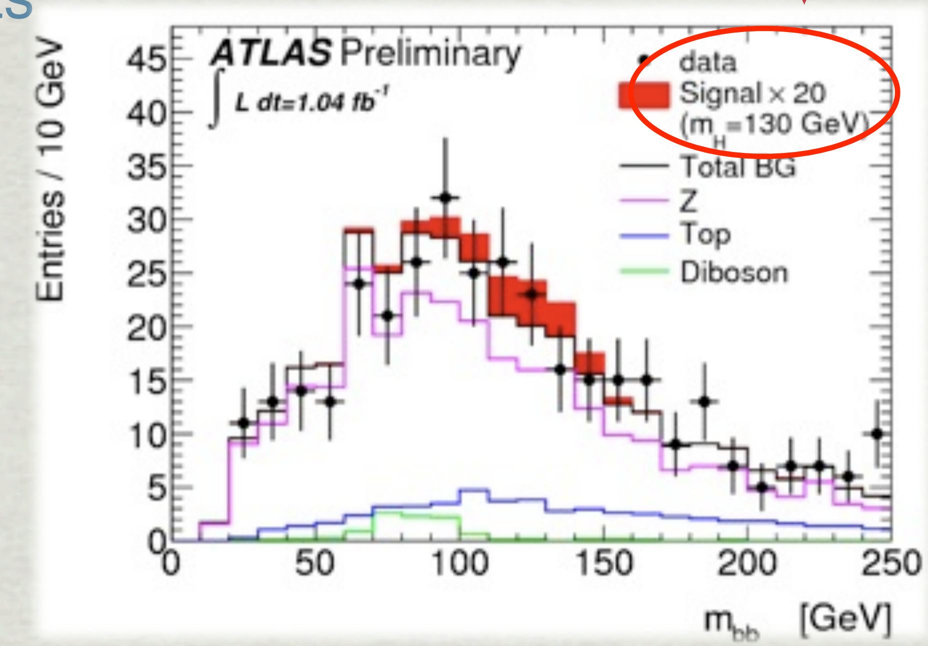
Affected by large bb backgrounds

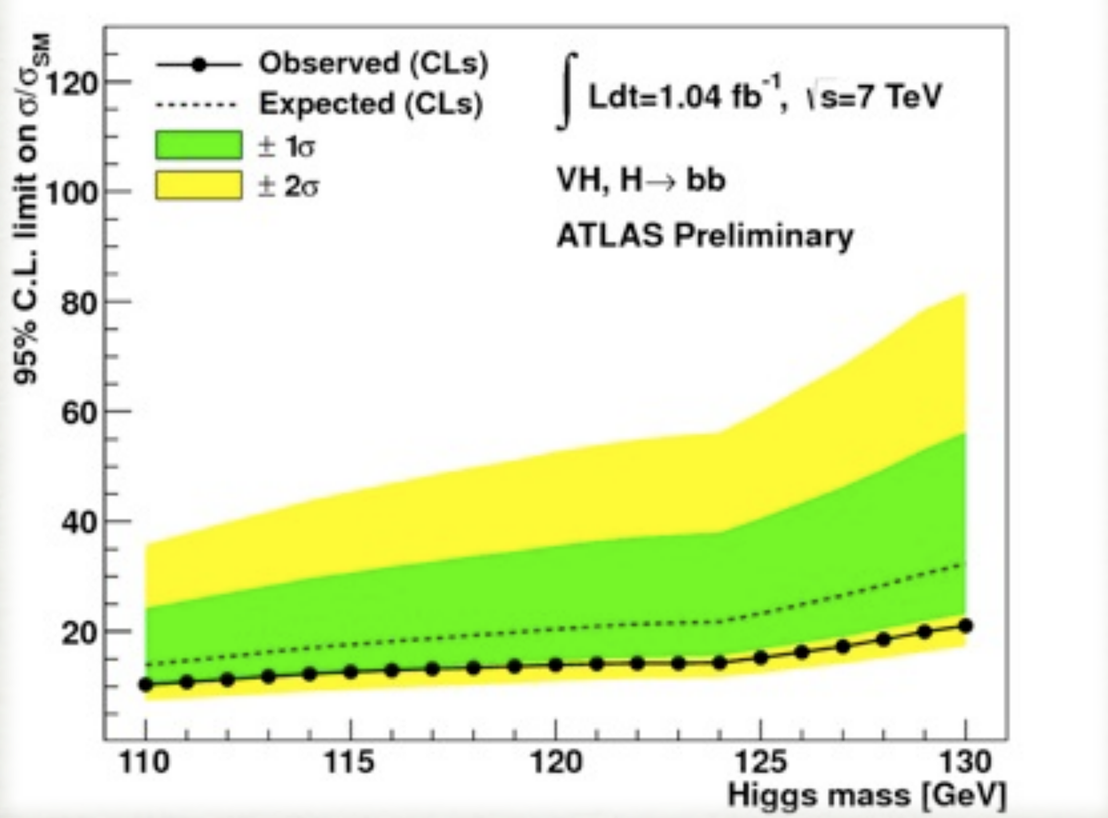
- ZH associated production: 2 leptons (pT>25 GeV),76<m_{ll}<106 GeV, E_{Tmiss} <50GeV, 2 b-jets

  from data: Zjets bkg normalization from mbb sidebands, where Z+jets dominates.

- WH: 1 lepton, M_{ljT} >40 GeV, E_{Tmiss} >25 GeV, =2 b-tag jets

  - top, Wjj, QCD bkg normalization from simultaneous fit of data control regions
  - Wjj bkg shape from untagged m_{jj} distribution

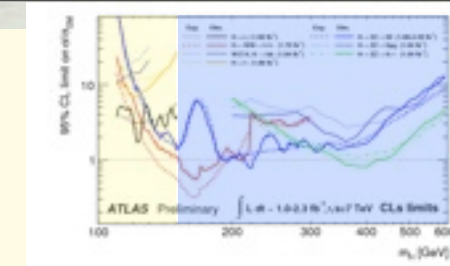




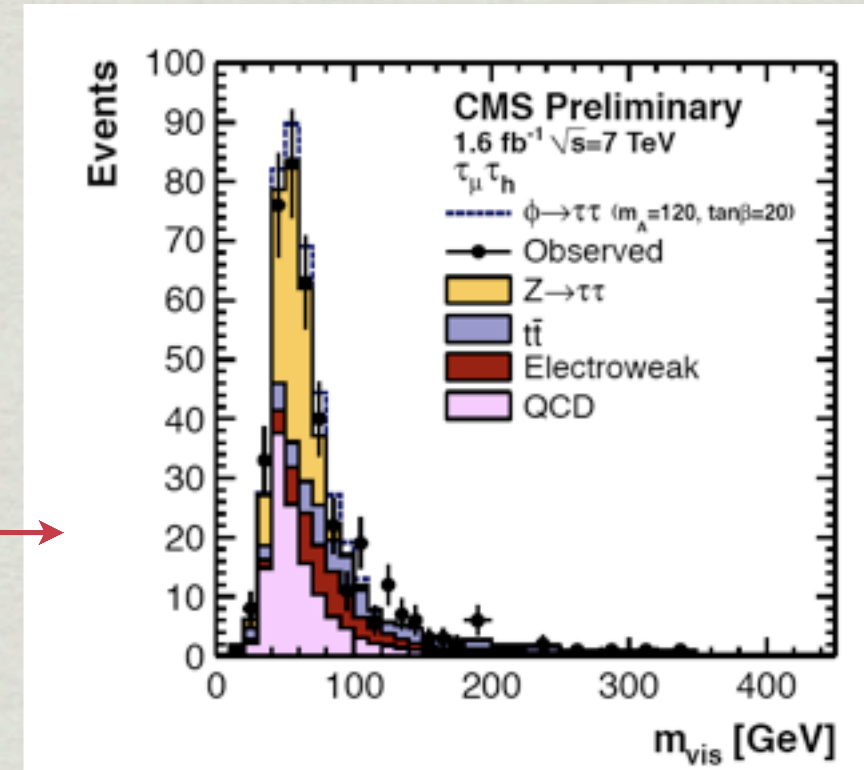
The combined (WH+ZH) exclusion ranges between 10 to 20 times the SM cross section → No Excess is observed

CMS-HIG-11-020

H→ττ (low m_H)



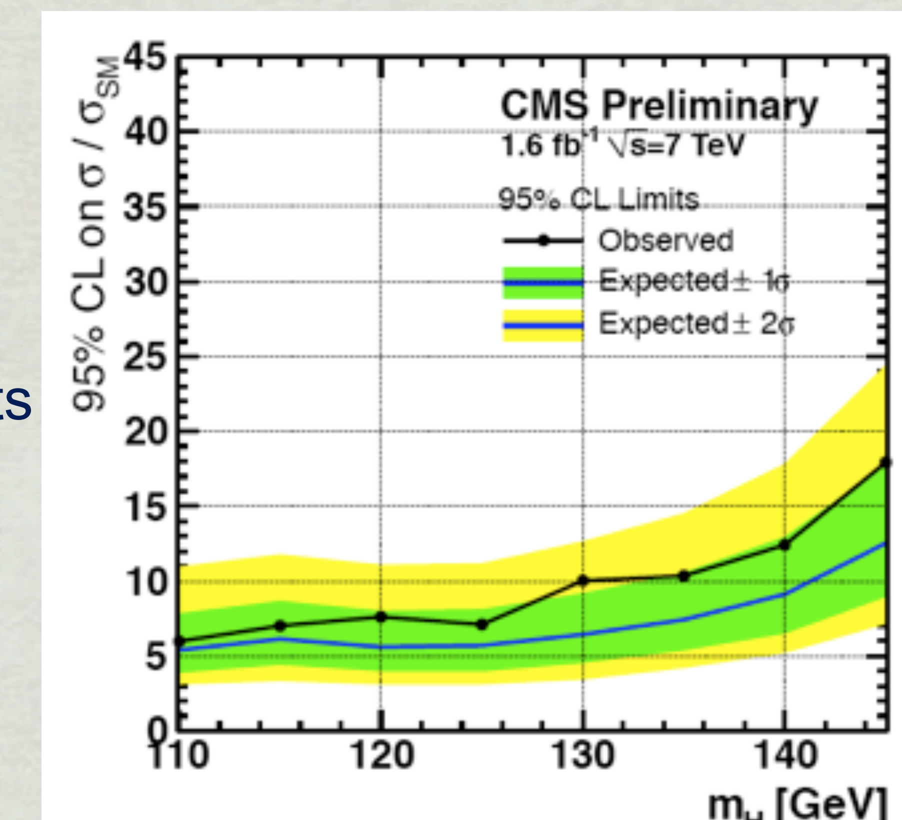
- Look for Higgs produced in association with
  - a b-quark jet (MSSM search)
  - two forward jets from VBF Higgs production (SM search).
- Channels used:
  - $\tau_{e/\mu}\tau_{had}$ high BR, golden channel with & wo 2 VFB jets
  - $\tau_e\tau_\mu$ clean (eμ easier than 2e, 2μ) with & wo 2 VFB jets
- Look for peak in $m_{\tau\tau}$



Backgrounds:
Z+jets (Z→ττ~irreducible), W+jets, QCD, dibosons, top.

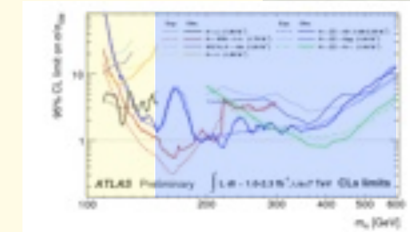
- QCD and W+jets normalization from Same Sign events.
- Z(ll)+jets, ttbar, dibosons normalisation from control sample without τ's, scaled for probabilities of e,μ, jets to fake τ's (taken from data).
- Z→ττ normalisation constrained by Z→ee/μμ measurements & fit on m_{vis}

limits at 9 x SM

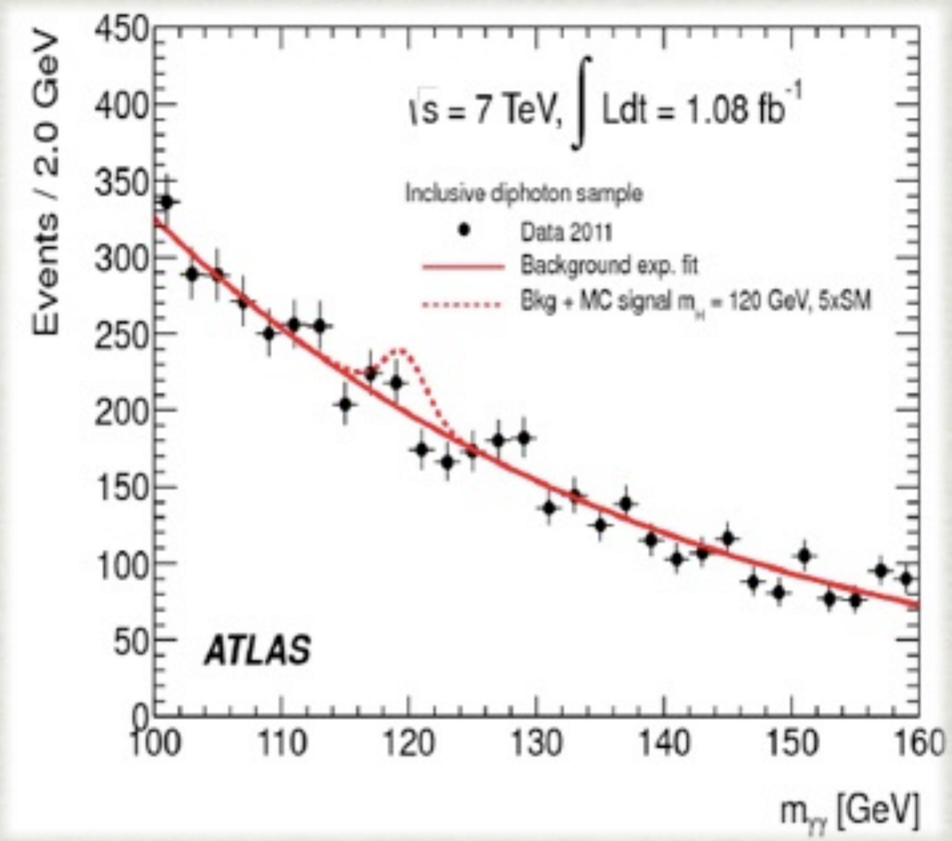


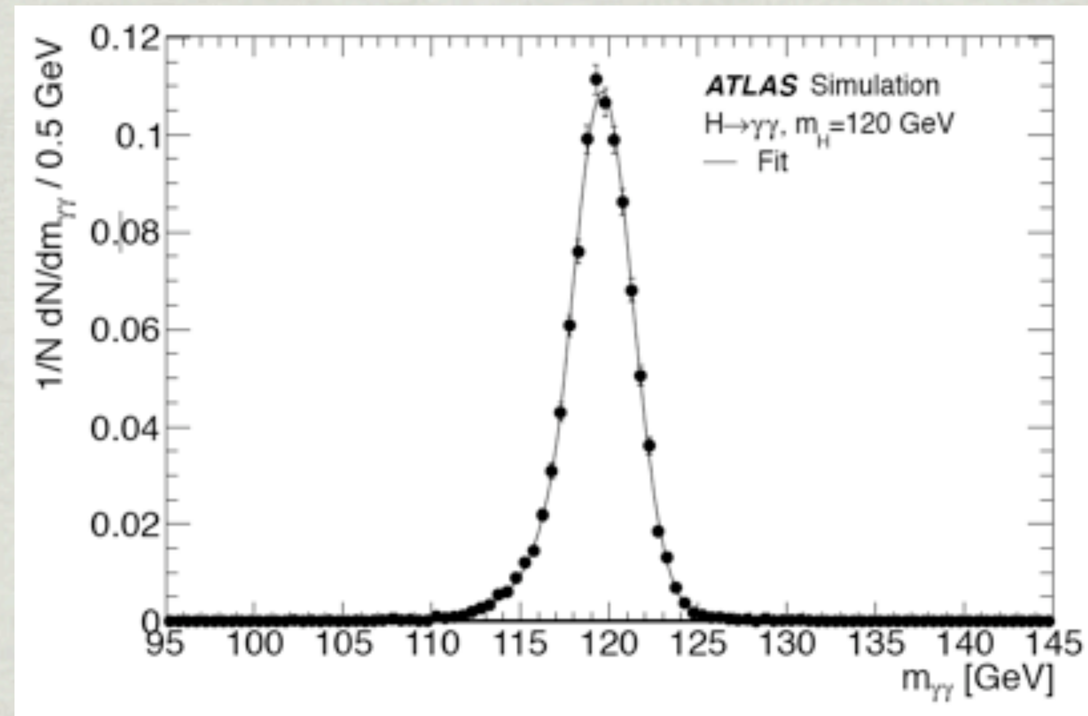
CMS-PAS-HIG-11-021
ATLAS arXiv:1108.5895v1 [hep-ex]

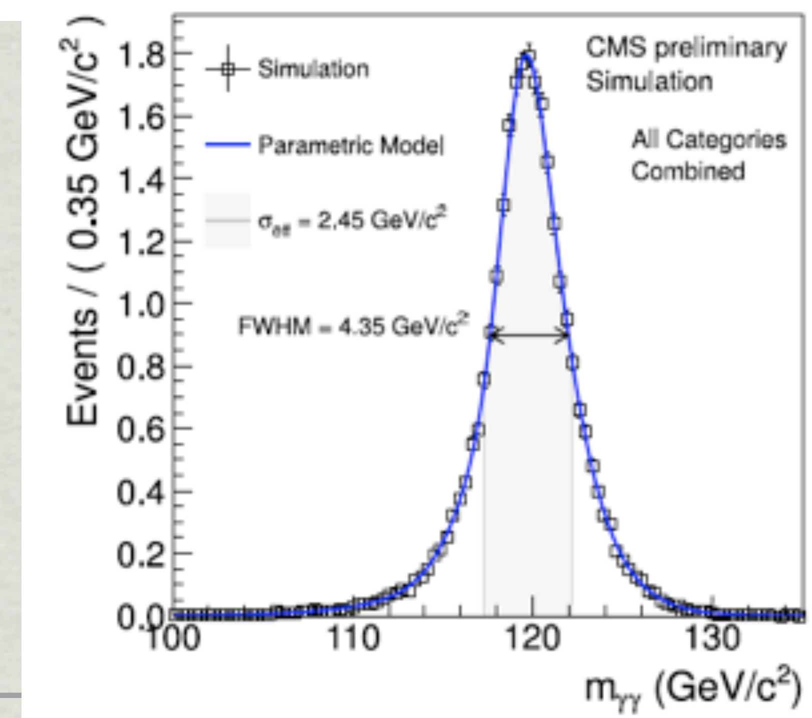
$H \rightarrow \gamma\gamma$ (low m_H)



- Trigger on di-photons at low p_T: 2 photons and $p_T(\gamma1)>40$ GeV & $p_T(\gamma2)>25(/30)$ GeV ATLAS(/CMS).
- Isolation and tight photon requirements are the key to reduce backgrounds.
- Events are split in different bins/categories depending on expected mass resolution: e.g. η bins, converted/uncoverted photons.



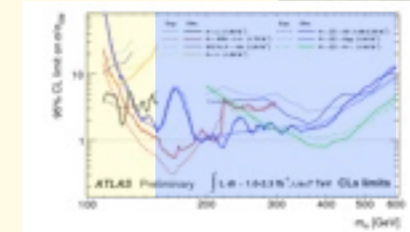




- $m_{\gamma\gamma}$ spectrum is dominated by real photons for both experiments.
- The background is estimated from unbinned fit to the observed $m_{\gamma\gamma}$ spectrum, therefore the errors on the background are just to due functional shape modelling and statistical.

CMS-PAS-HIG-11-021
ATLAS arXiv:1108.5895v1 [hep-ex]

$H \rightarrow \gamma\gamma$ (low m_H)



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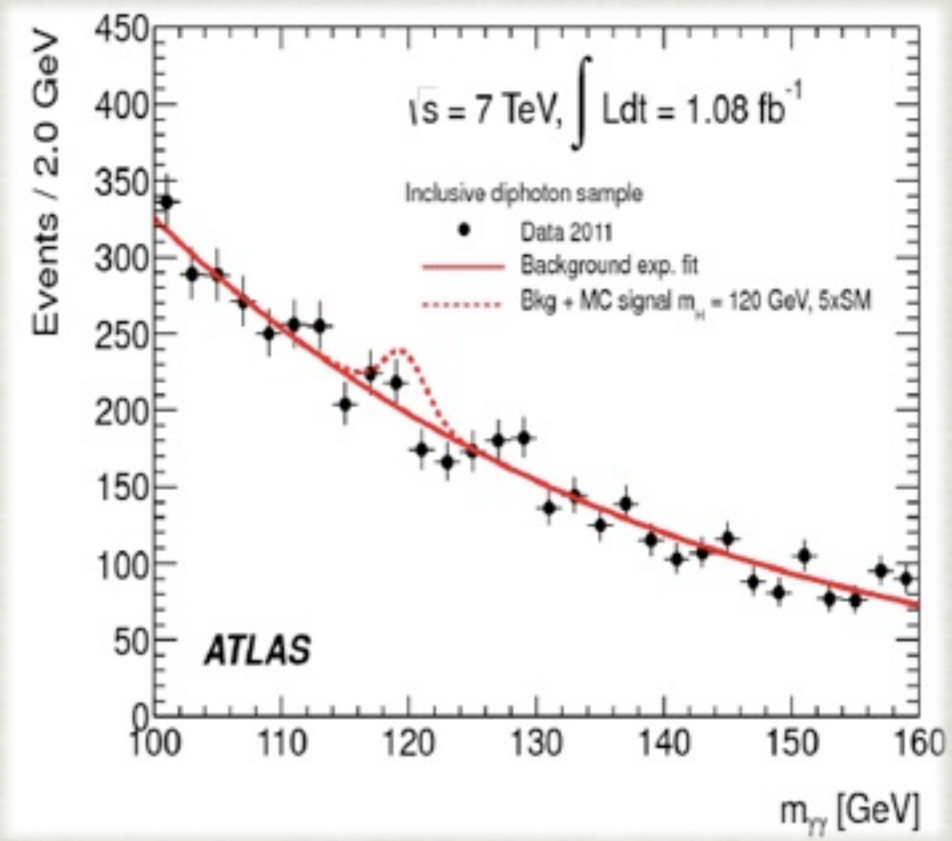
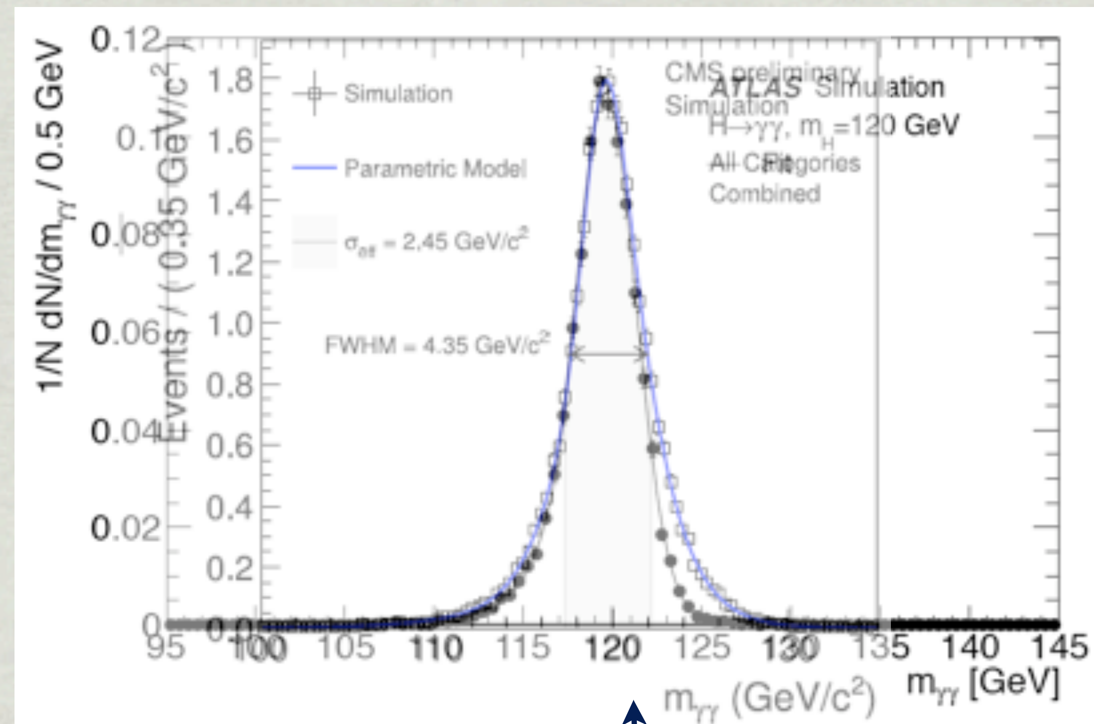
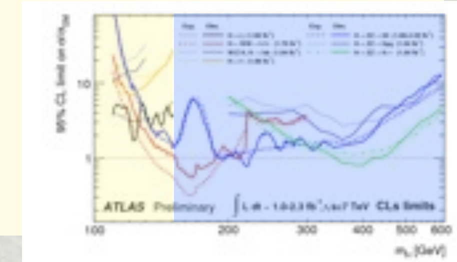


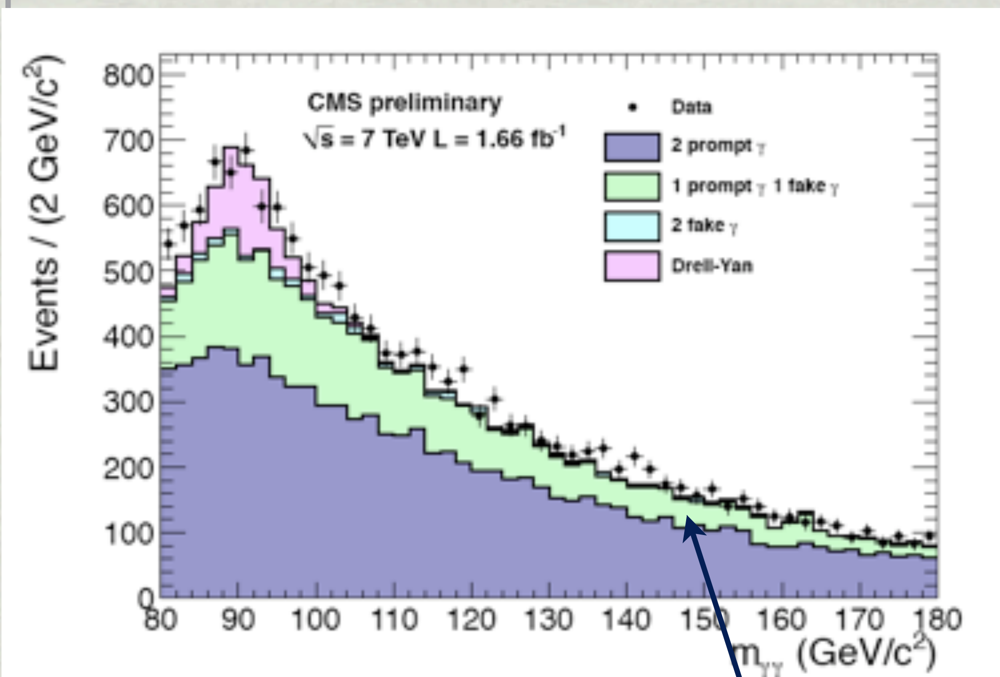


- $m_{\gamma\gamma}$ spectrum is dominated by real photons for both experiments.
- The background is estimated from unbinned fit to the observed $m_{\gamma\gamma}$ spectrum, therefore the errors on the background are just to due functional shape modelling and statistical.

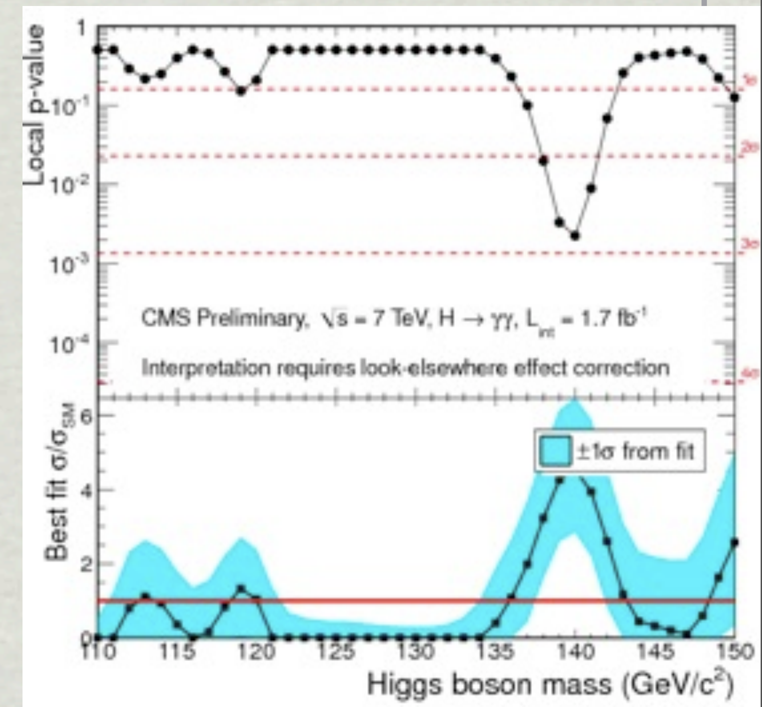
The mass resolution is similar for both experiments (blue CMS/black ATLAS)

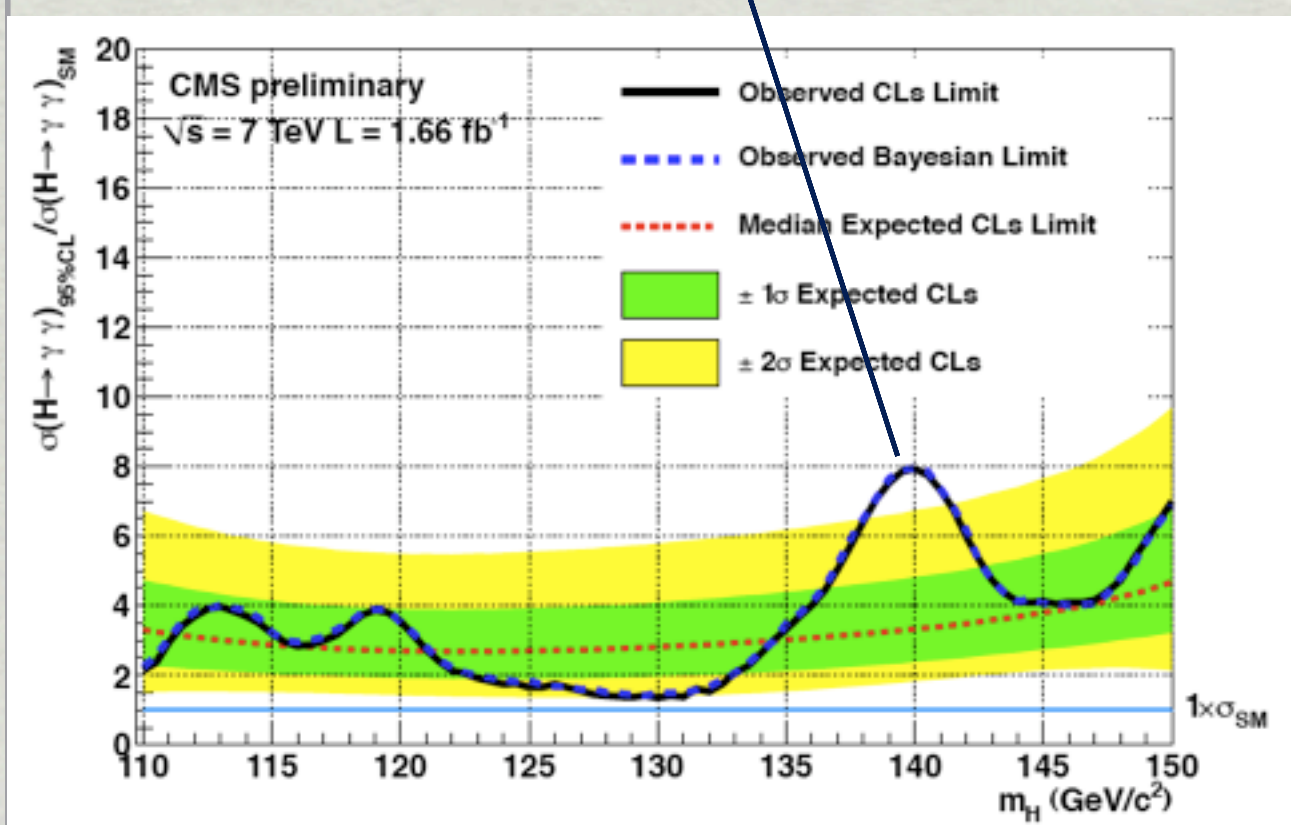
H→ γγ (low m_H)

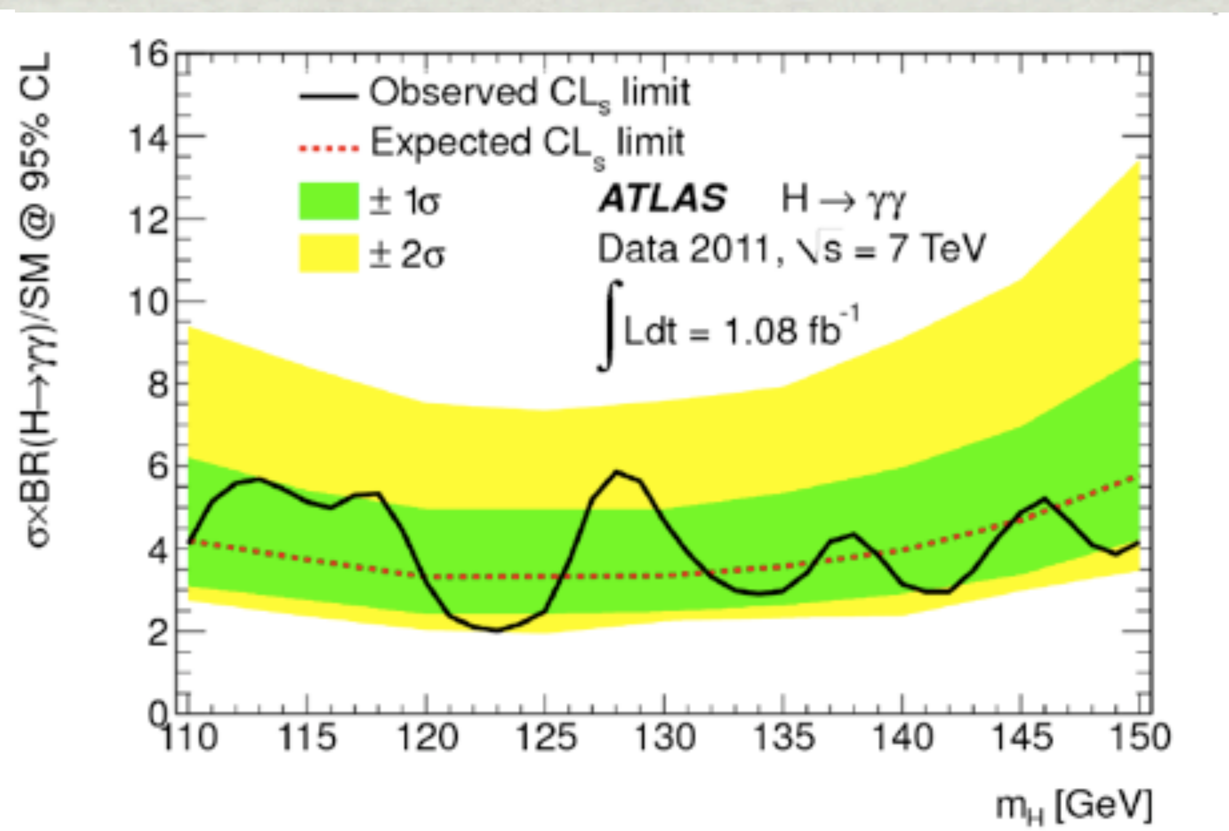




- ATLAS and CMS have similar signal & background shapes
- CMS sees an excess at m_H~140 GeV excess reduced to 1.7σ by LEE effect
- ATLAS doesn't see any significant excess







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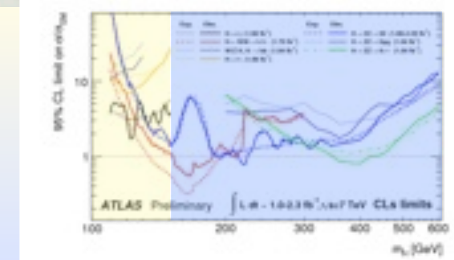
CMS-PAS-HIG-11-014
ATLAS-CONF-2011-134

$H \rightarrow WW \rightarrow l\nu l\nu$

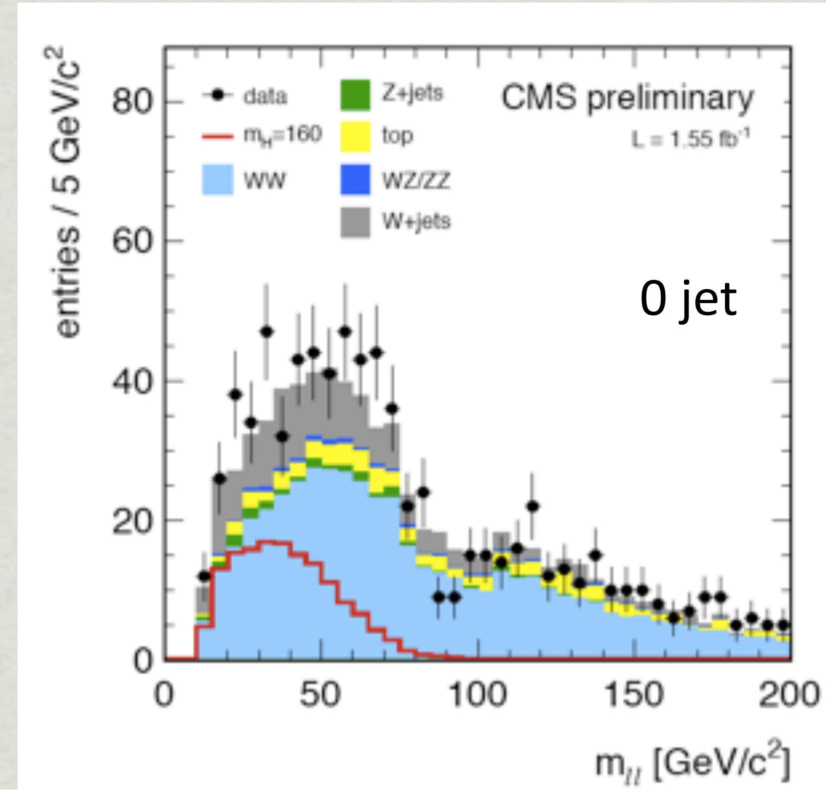


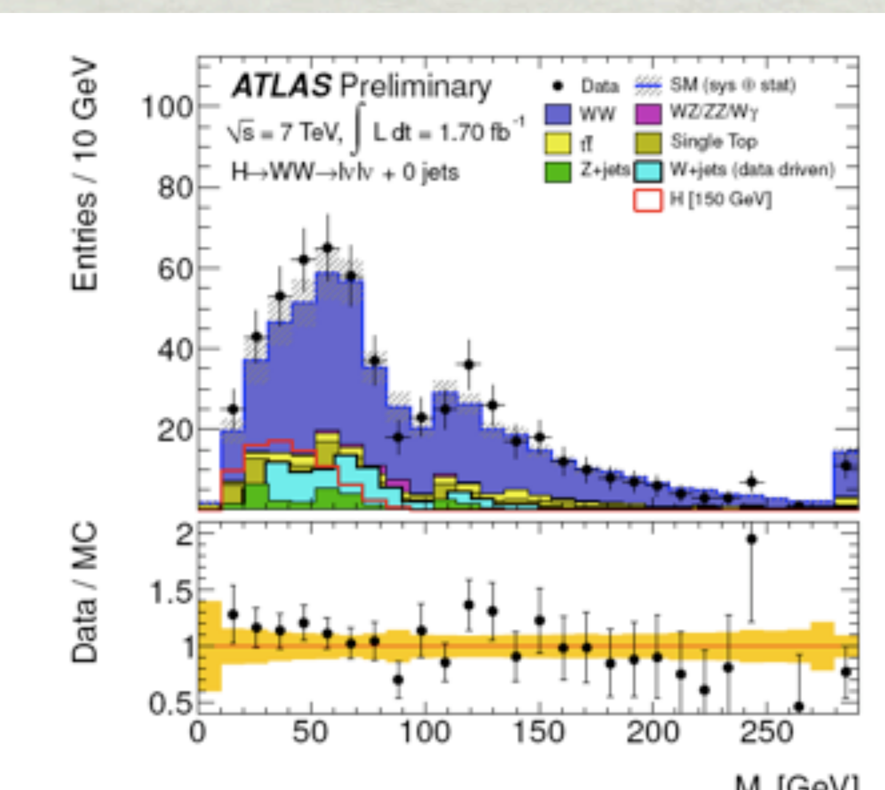
Most sensitive channel for 130< m_H <200 GeV.
Analysis in 0 and 1 jet bin (ATLAS+CMS) and 2 jet bin (CMS)
Cut based (ATLAS+CMS)

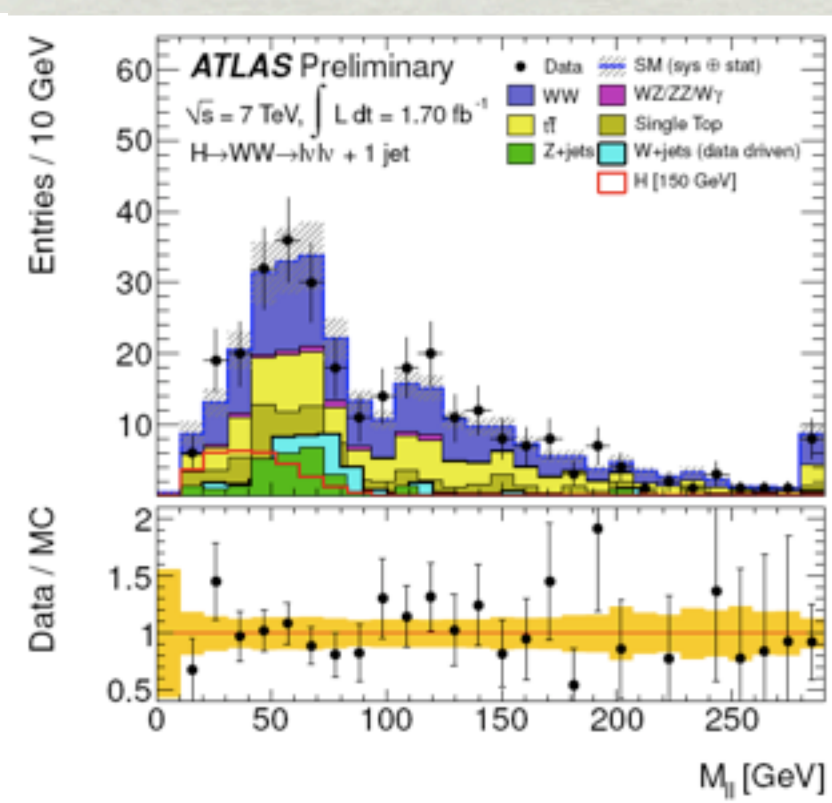
Major backgrounds depend on jet bin:
WW (0,1 jet bin), top(1,2 jet), W+j (0 jet), Z+j, estimated from data.

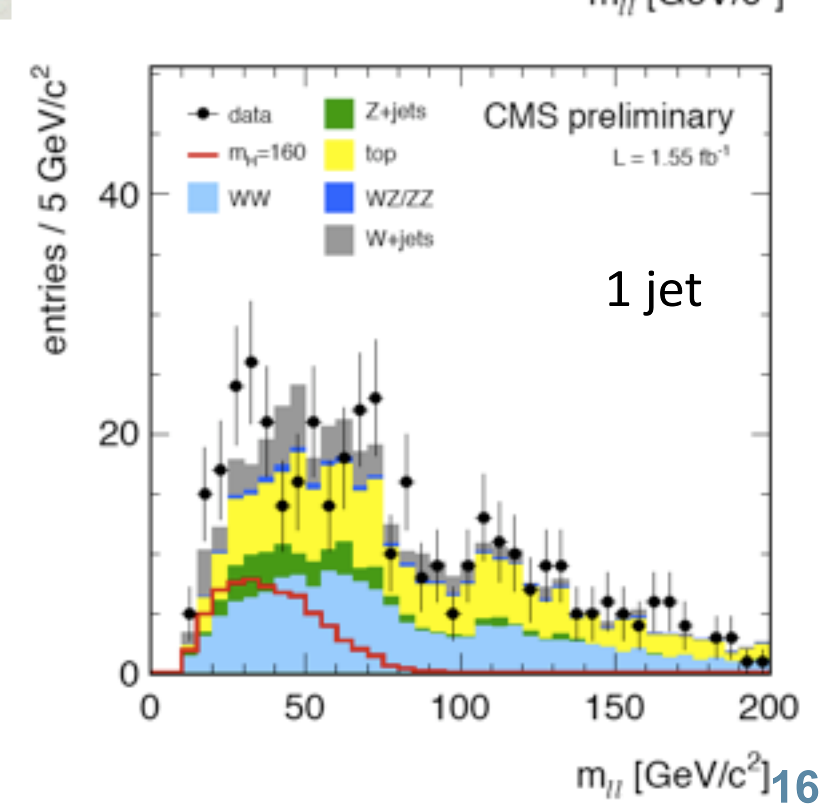
Selection similar for both experiments:

- 2 opposite sign leptons (ATLAS $p_{T2/1}$>15 (20 for e)/25 GeV, CMS $p_{T1/2}$>10-25 GeV)
- E_{Tmiss}, p_{Tll}, small $\Delta\phi_{ll}$ (against WW), reject b-tag in >0jet (against top), reject Z mass window, mass dependent m_{ll} cut

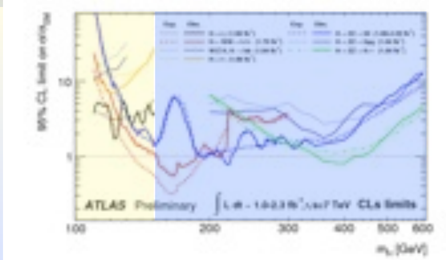








H→WW→ lνlν

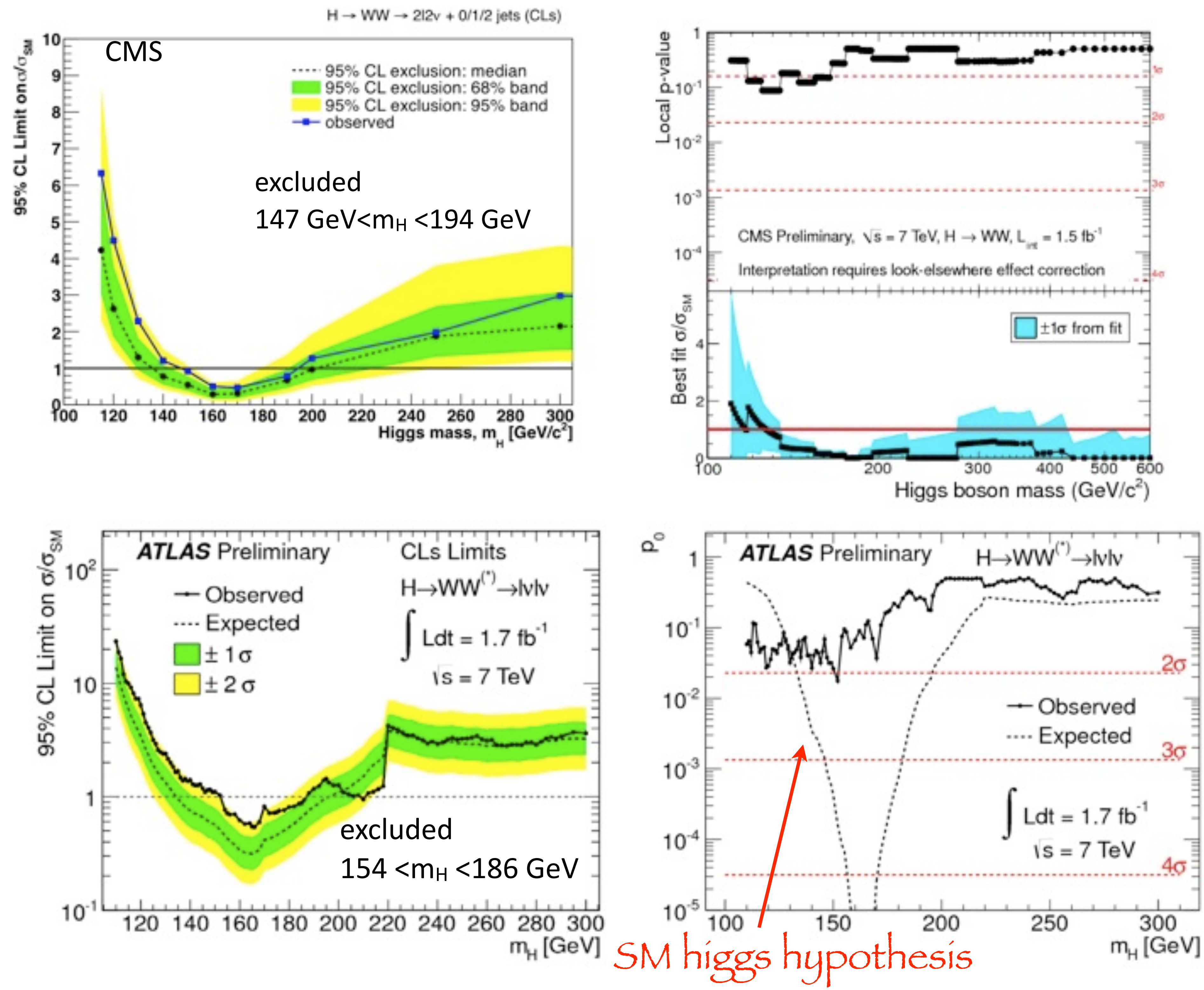


ATLAS:

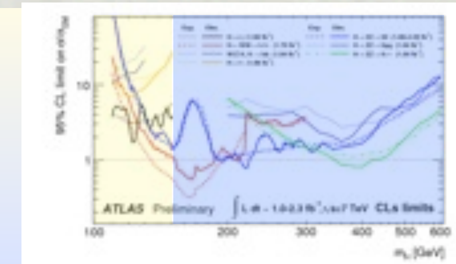
93 observed evt
76±10 expected evt

CMS:

141 observed evt
120±11 expected evt



H→WW→ lνlν



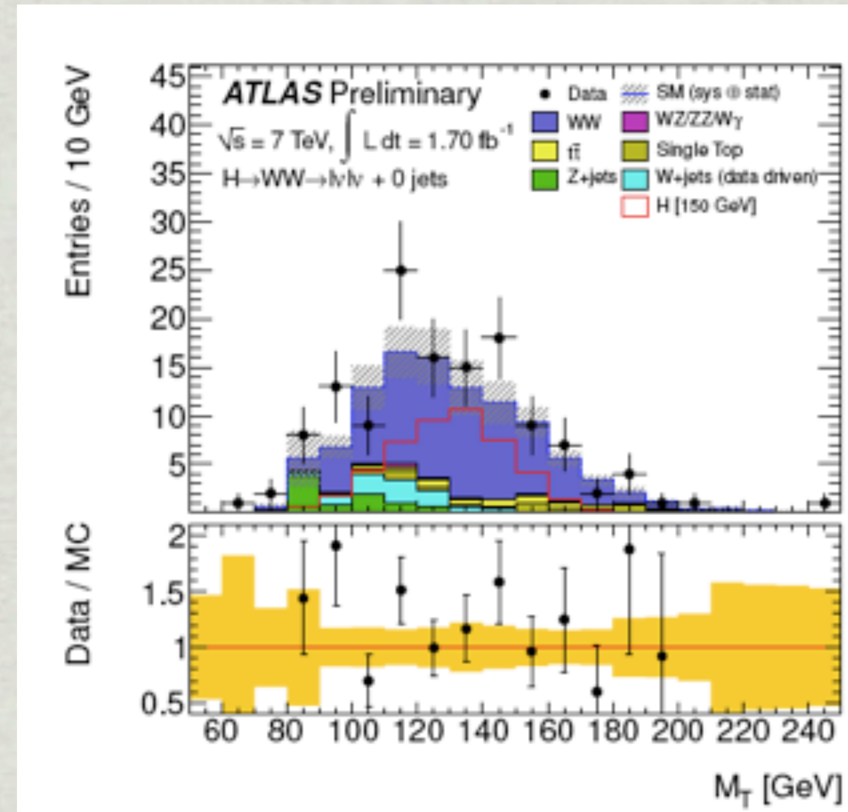
“excess”:

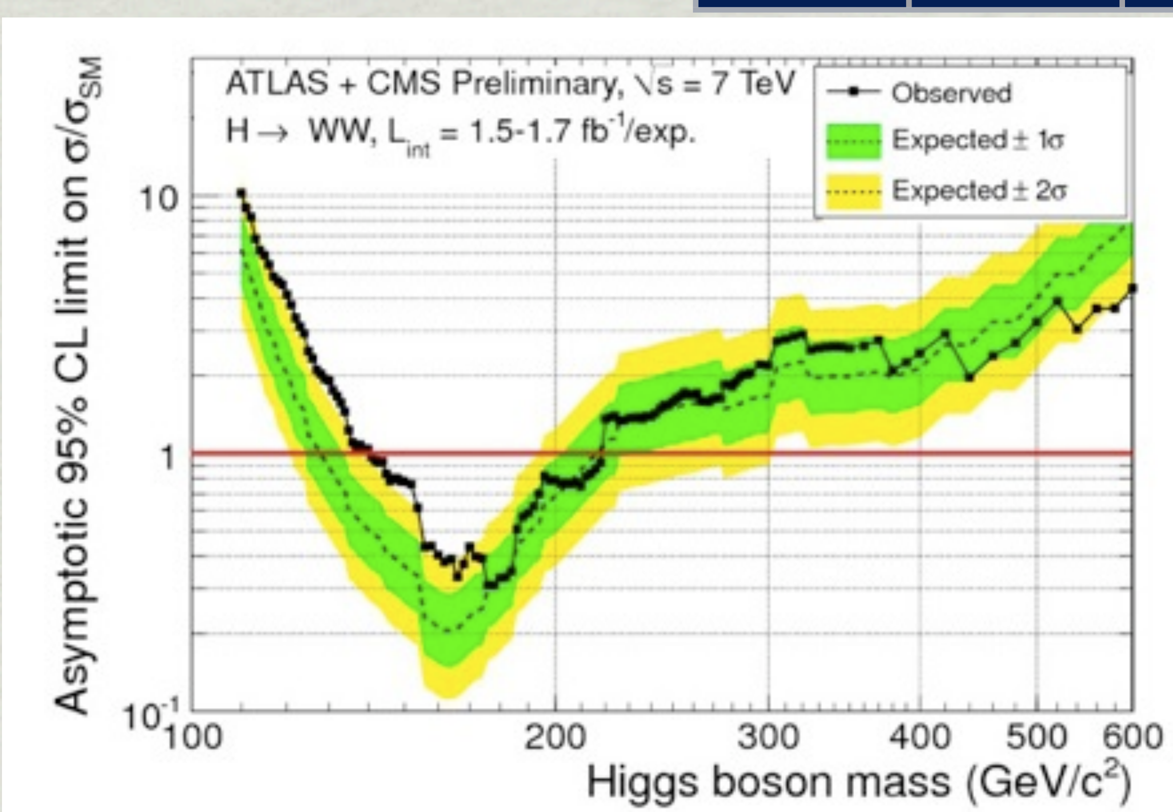
mainly 0 jet channel in ATLAS

mainly in 1 jet channel in CMS

ATLAS 0 jet channel	m_H=150 GeV	Bkg	Data
ee	5.2±1.2	8.2±1.7	9
eμ	17±4	27±4	32
μμ	11±2	18±5	29

CMS 1 jet channel	m_H=140 GeV	Bkg	Data
ee/μμ	6.6±2.2	17.8±3.5	23
eμ	4.6±1.5	12.6±3.7	23



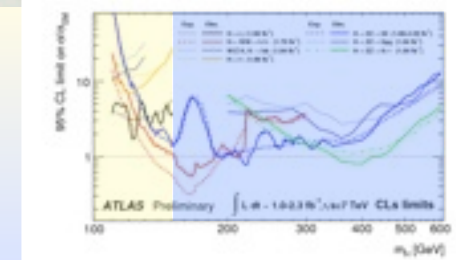


ATLAS + CMS see < 2σ fluctuation.

Due to low mass resolution, excess is broad.

CMS-PAS-HIG-11-015
arXiv:1109.5945v1 [hep-ex]

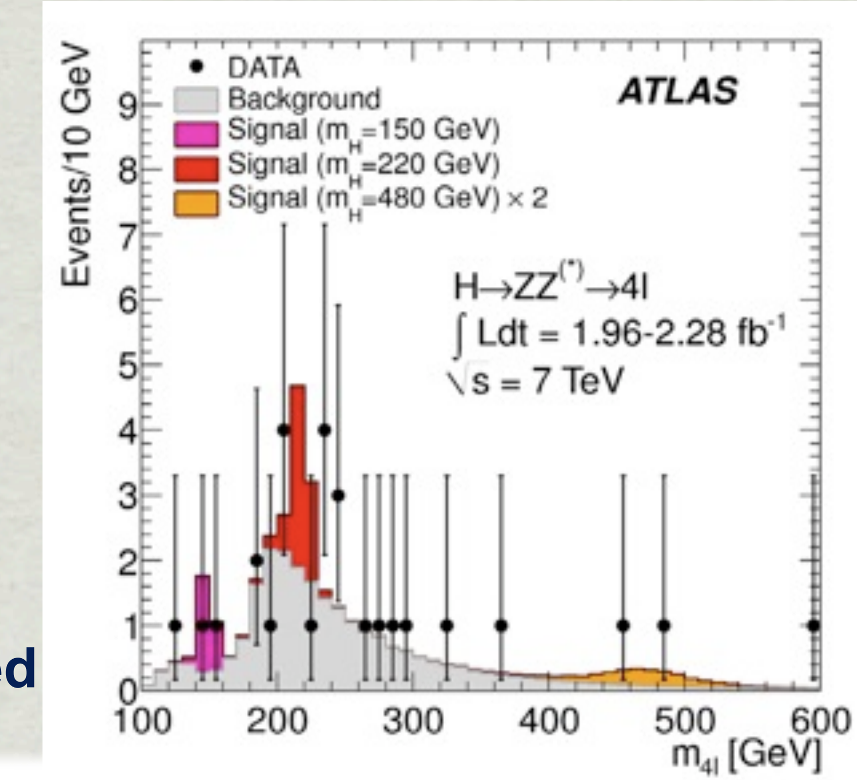
H→ZZ→ 4l



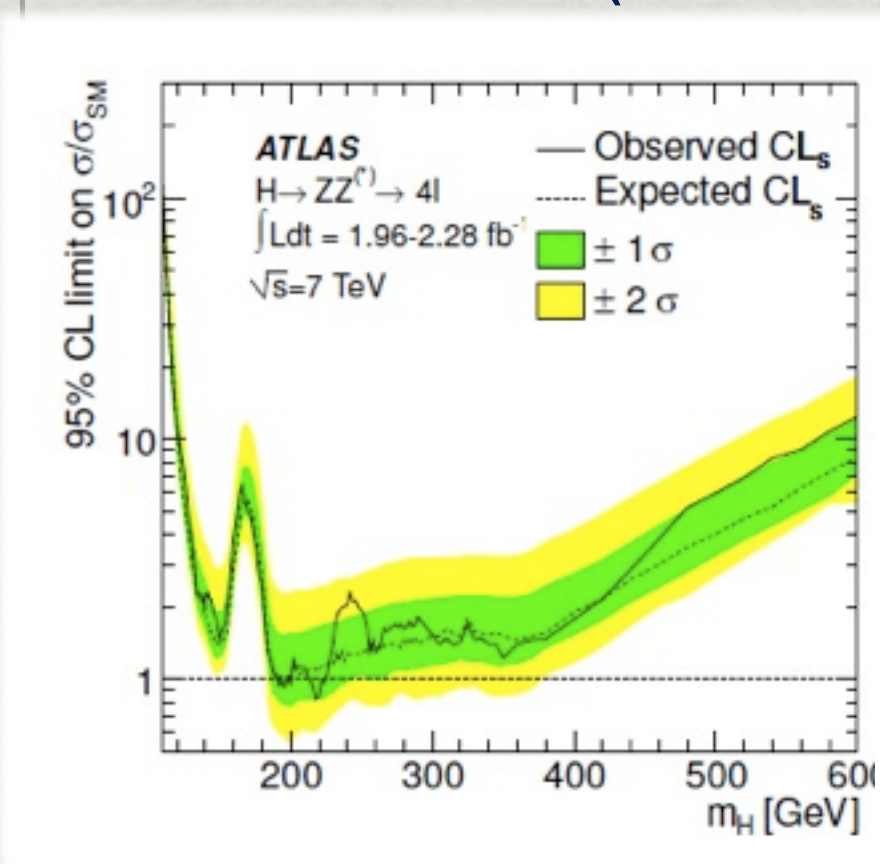
<u>The golden channel:</u> low bgk & good mass reco. 5(35) GeV at m_H=130(400)GeV. Analysis in 4e, 4μ, 2e2μ channels.

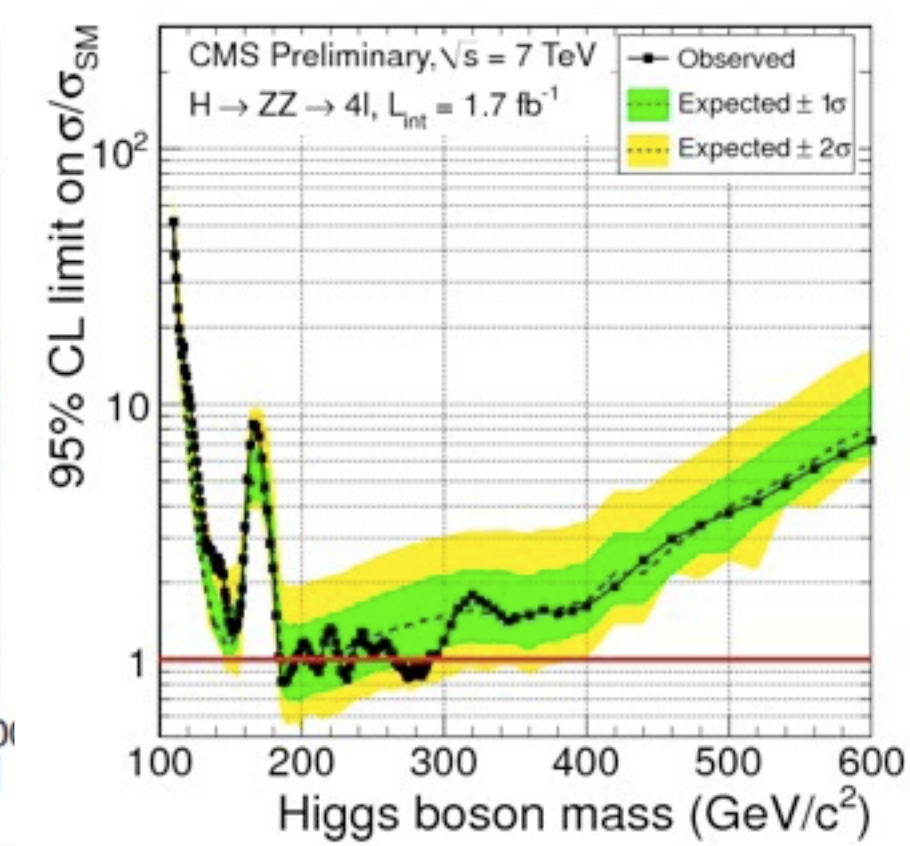
<u>Data Driven backgrounds:</u>
ttbar→lνblνb and Zbb give 2 leptons from b: use b-tag veto
Z+jets and top backgrounds estimated from data.

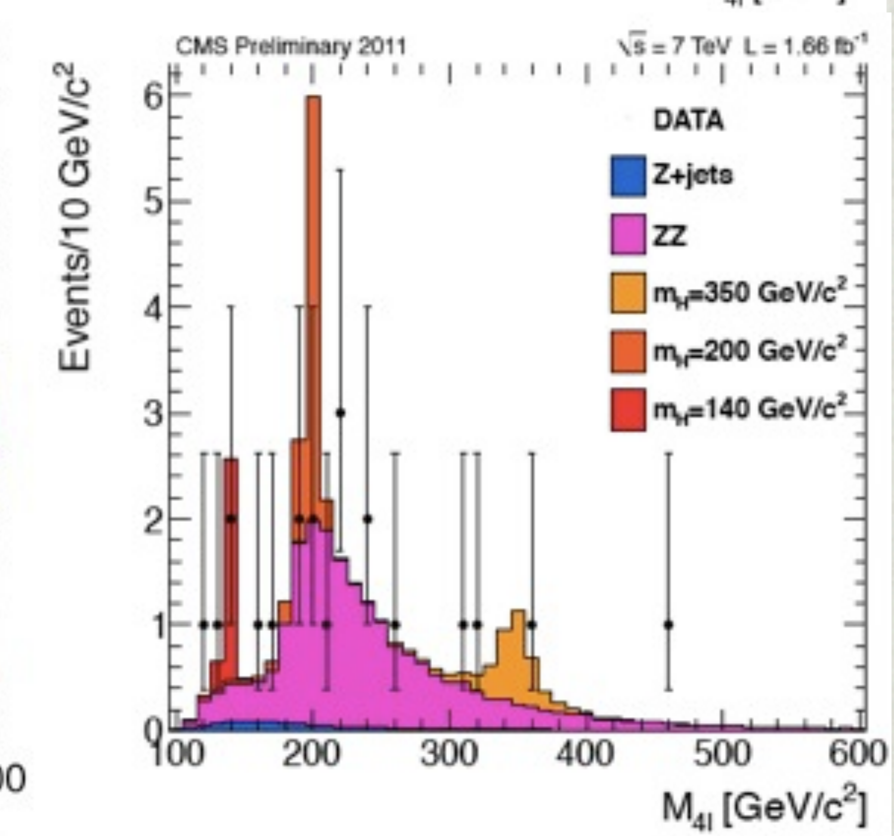
<u>Remaining background:</u>
ZZ* from MC (CMS uses normalization from Z→ll event with theoretical correction σ_{ZZ}/σ_Z)



CMS small excess m_h<180 GeV: 6 evt observed / 3 expected
(ATLAS expects 3 and sees 3)

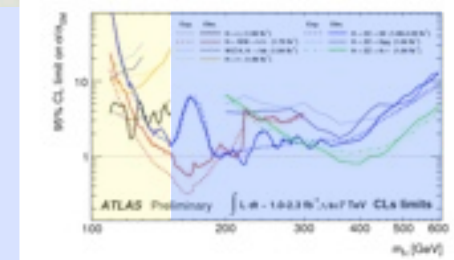






CMS-PAS-HIG-11-016
ATLAS-CONF-2011-148

$H \to ZZ \to 2l2\nu$

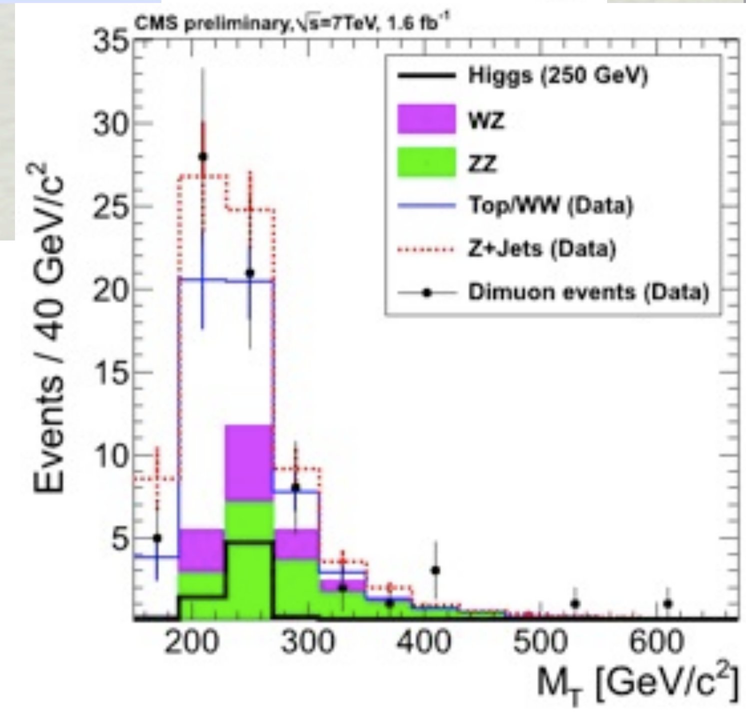


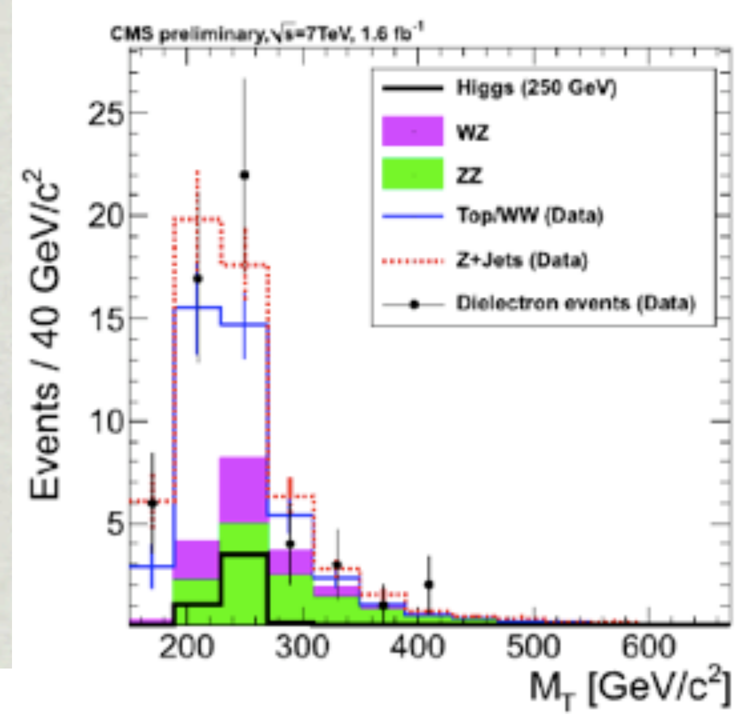
Higher statistics than 4l ($2e2\nu$, $2\mu2\nu$).

Both experiments perform a mass dependent analysis:
  cuts depend on m_H

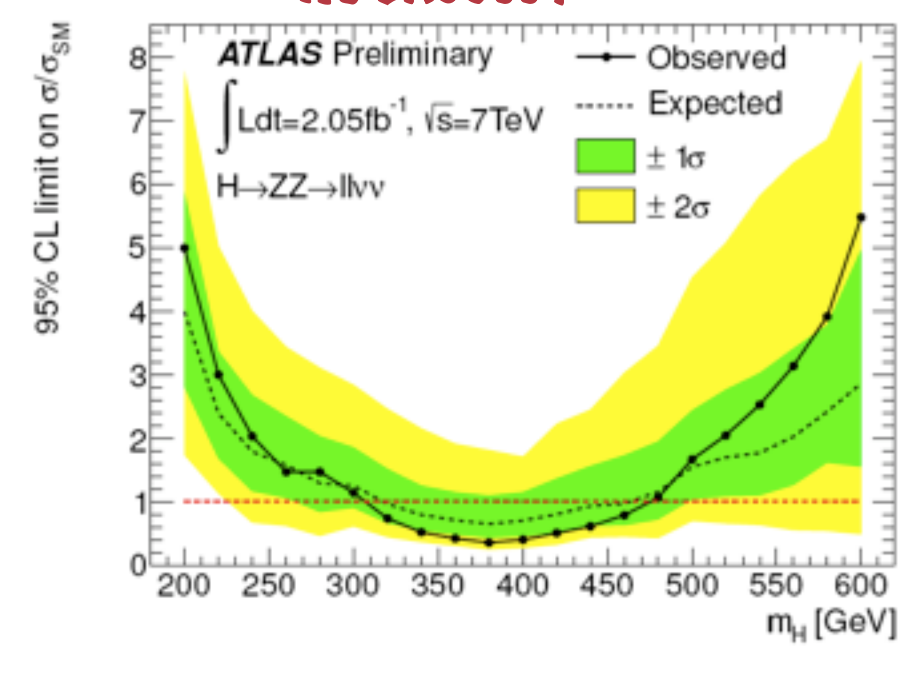
Large E_{TMiss} if m_H>200 GeV.

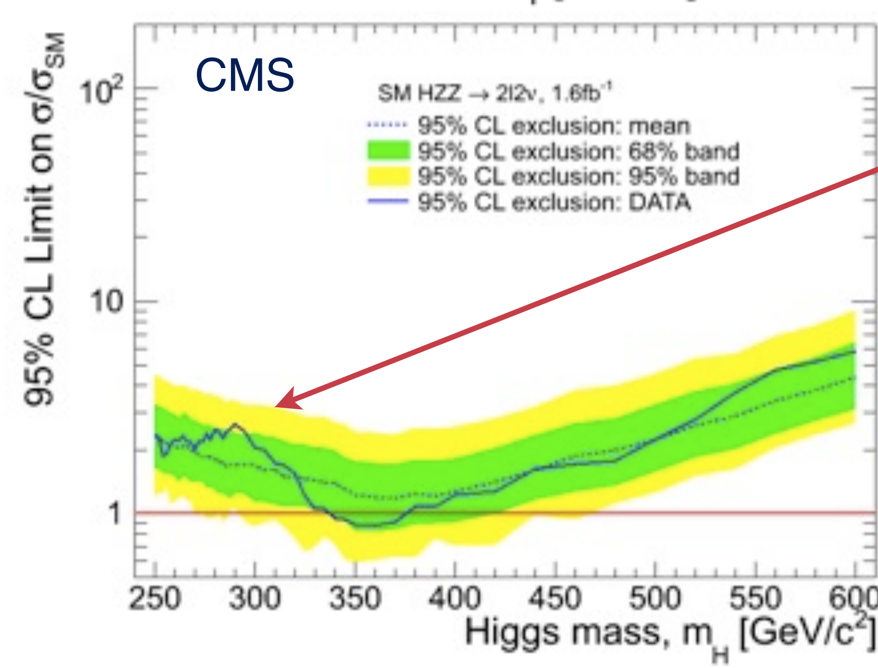
Bkg:
  Diboson background from MC.
  Z/W+jets, top, WW(CMS),
  QCD normalization from data.





No Excess !

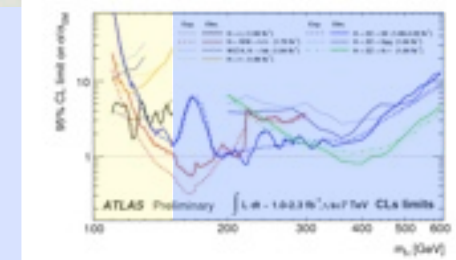


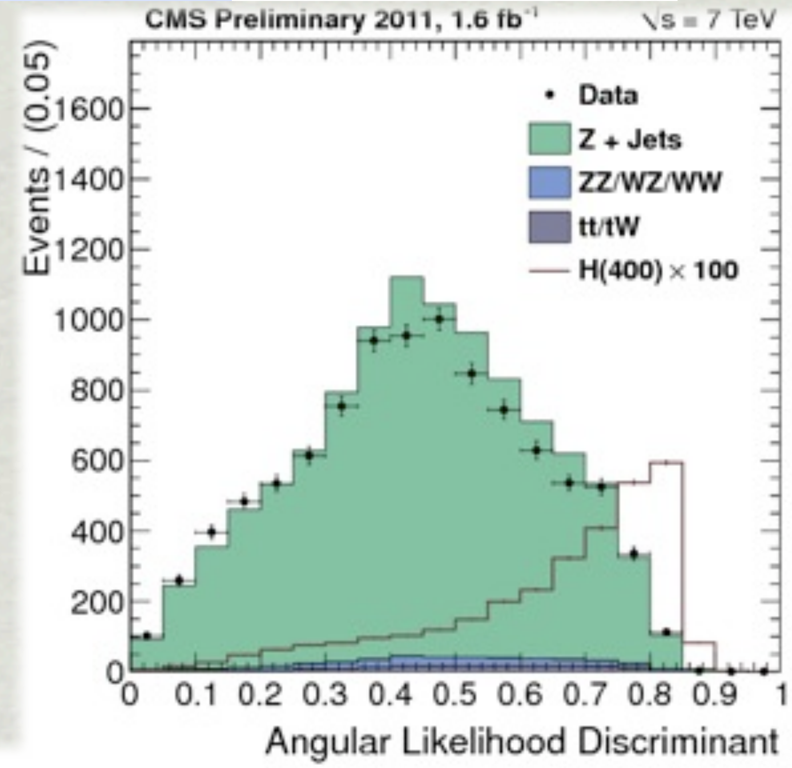


	Total	mH(300)	Data
μμ	21 ± 2.4	5.4 ± 0.72	18
ee	15 ± 1.9	4.2 ± 0.59	22

CMS-PAS-HIG-11-017
ATLAS-CONF-2011-150

$H \to ZZ \to 2l2q$





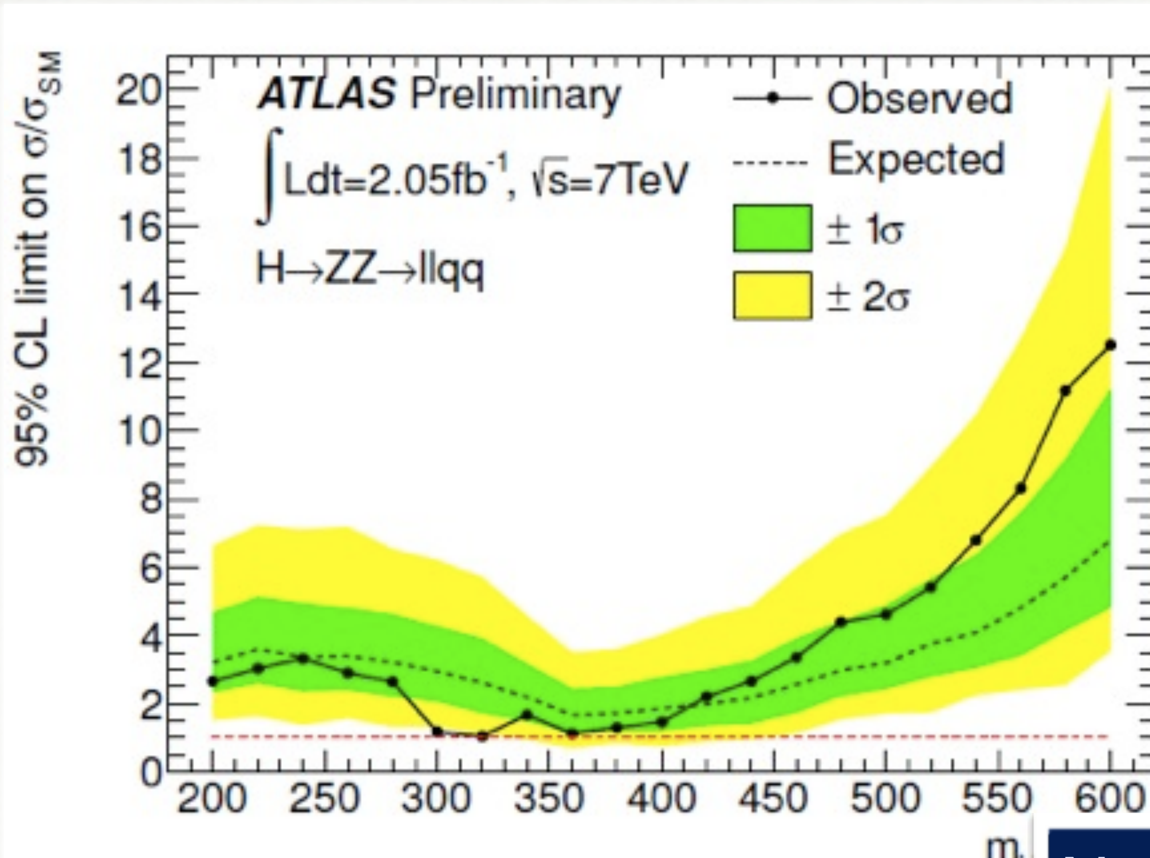
Highest rate among ZZ processes. Fully reconstructed final state:

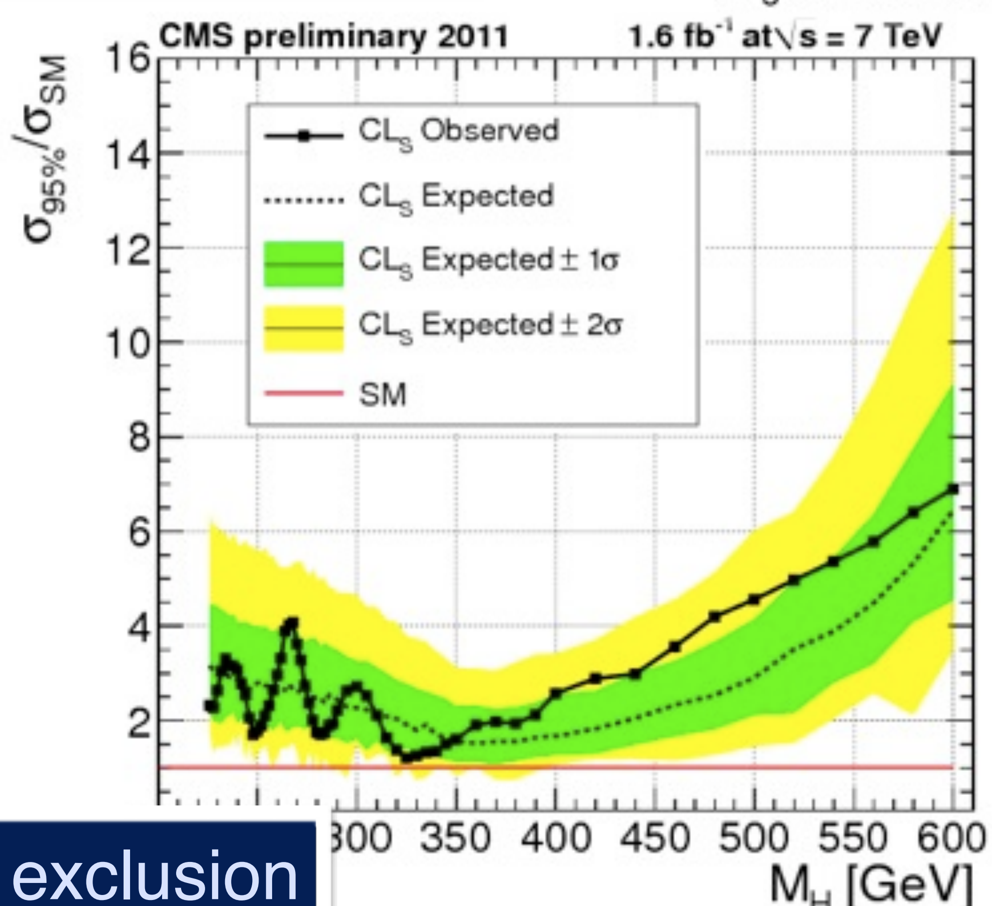
Search for a peak in m_{2l2j}.

Different categories depending on the number of b-tagged jets.

CMS: backgrounds from sidebands $60<m_{jj}<75$ GeV& $105<m_{jj}<130$ GeV uses decay angles distributions to discriminate.

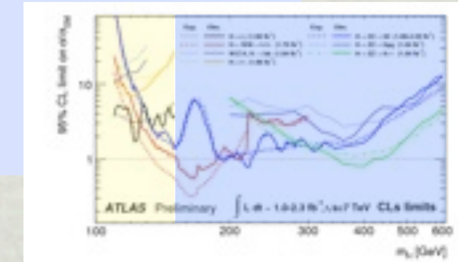
ATLAS: Z+jets normalized with mjj sidebands distribution, other backgrounds from simulation (top checked with data).



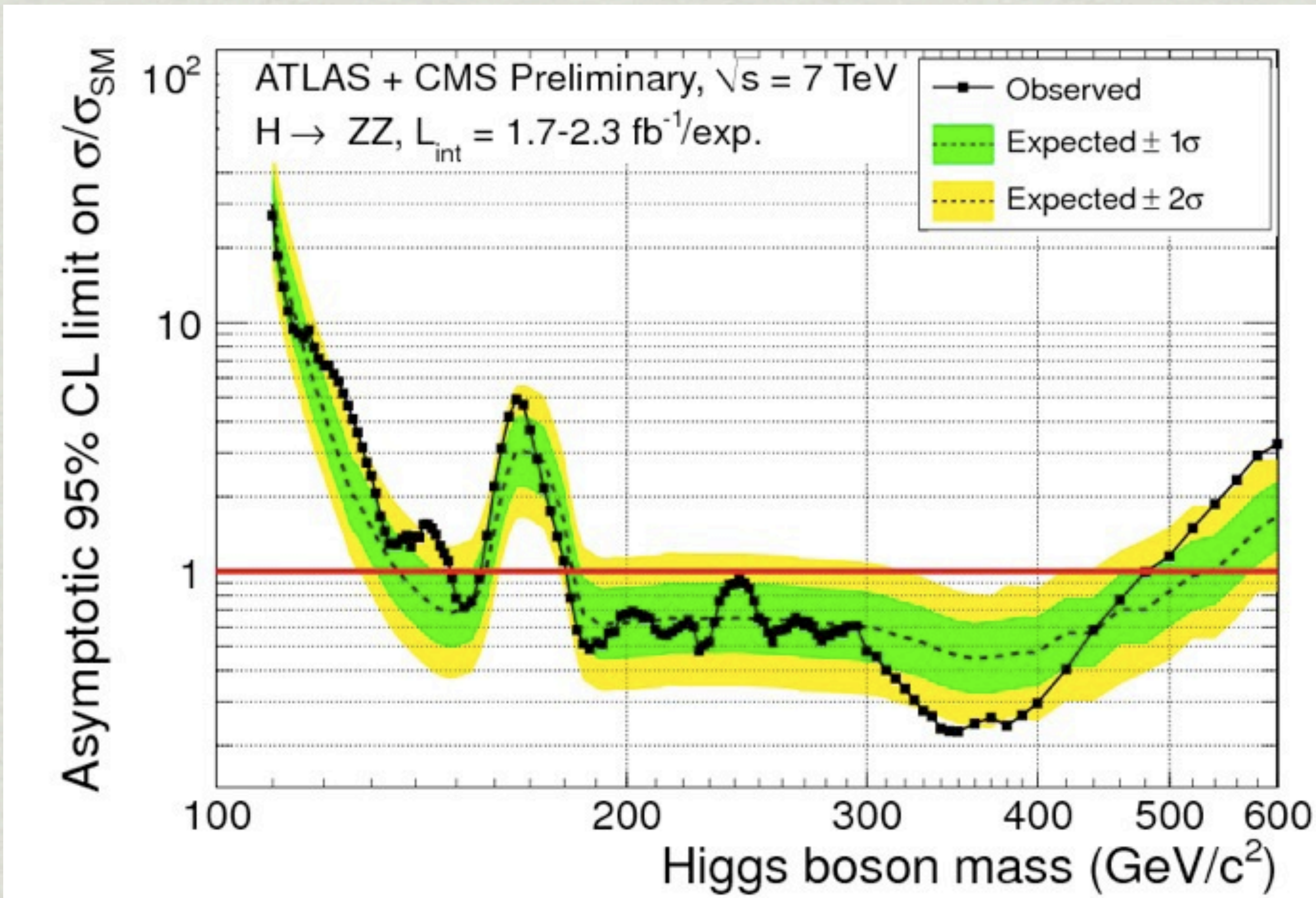


No SM exclusion

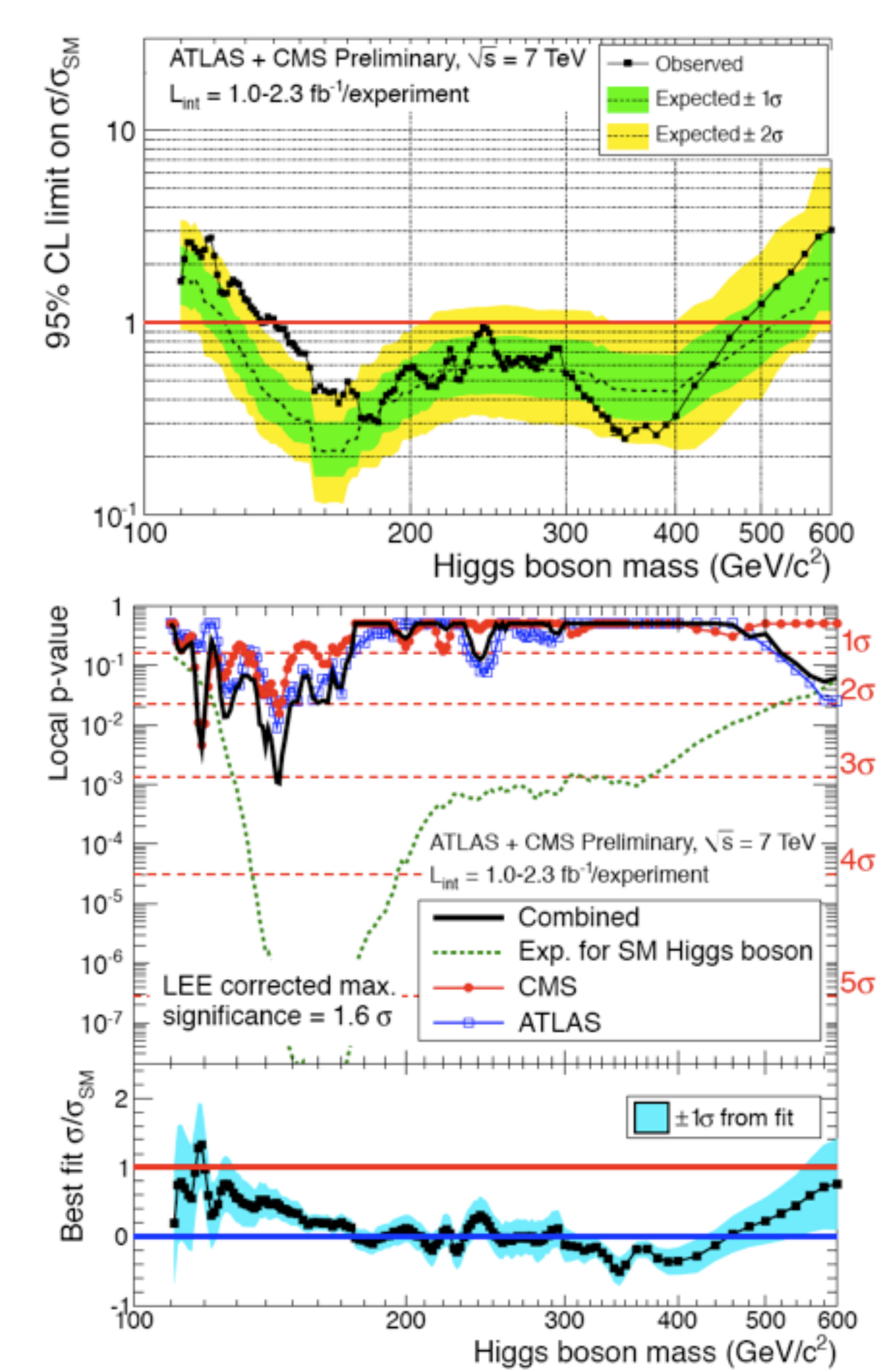
H→ZZ→ combined



Excludes alone from 180<M_H<480 GeV



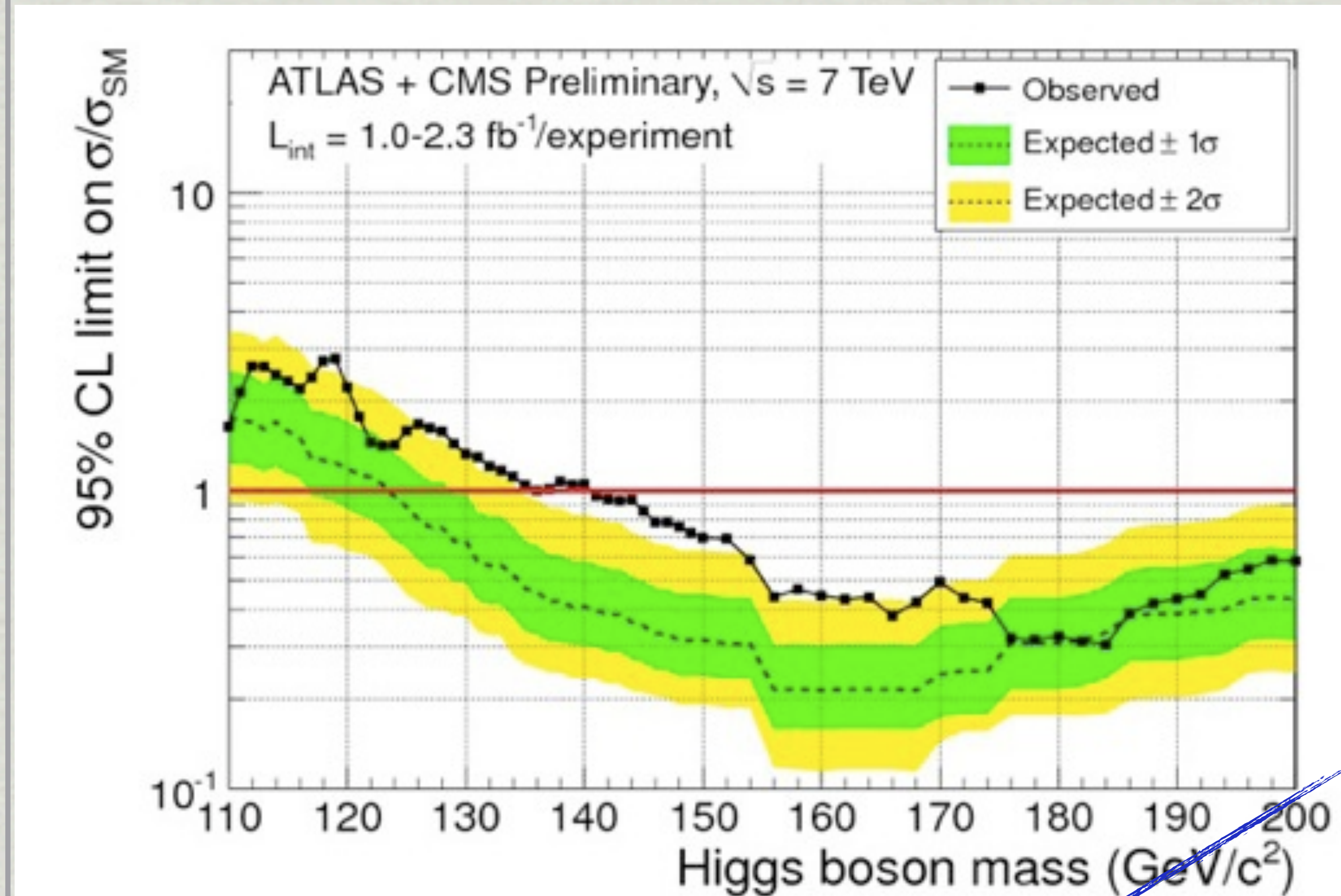
Overall combination

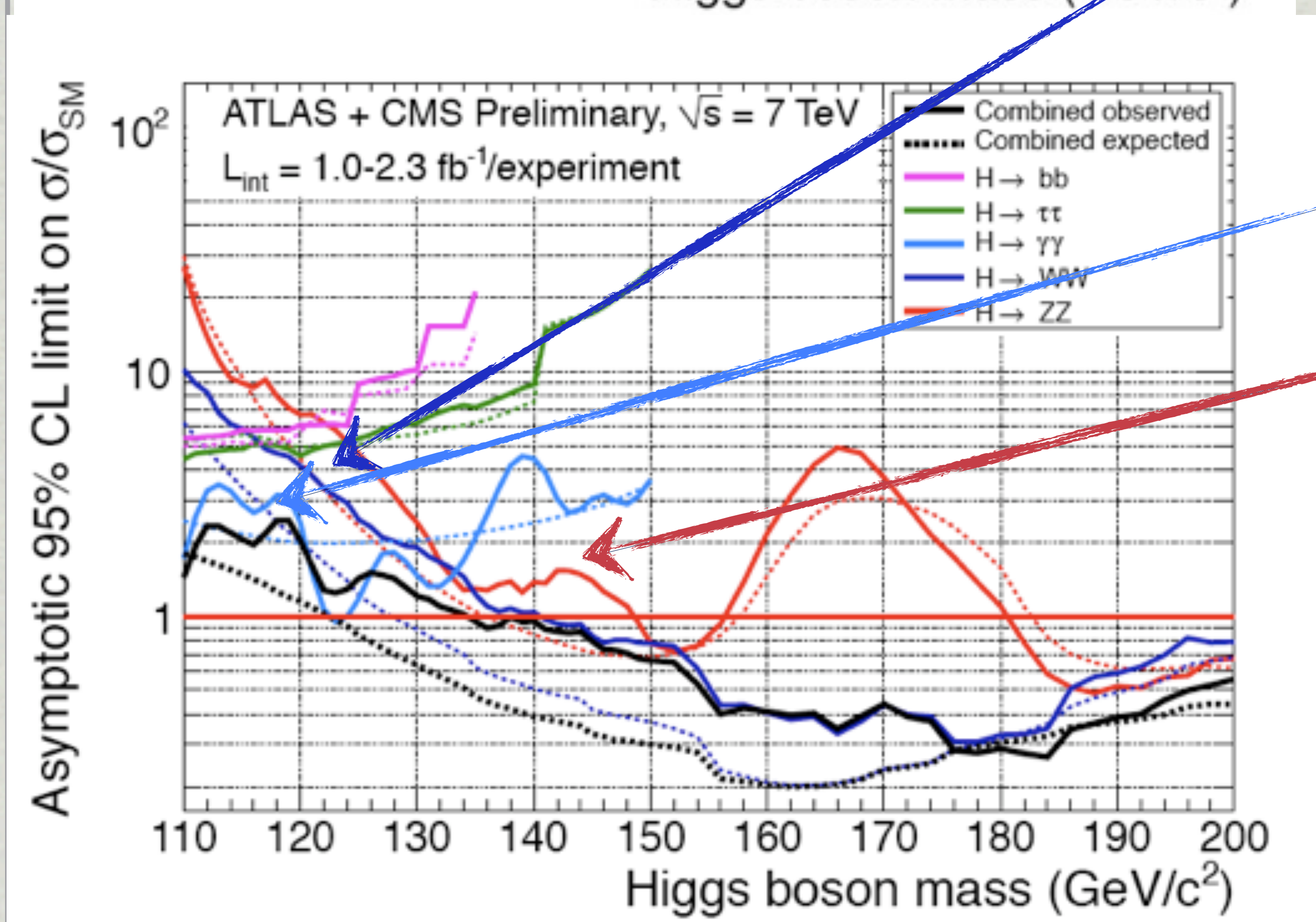


Observed exclusion 95% CL
141-476 GeV
Expected exclusion 95% CL
124-520 GeV

Both experiments have excess at low mass

Low mass Higgs





The largest contribution is due to the WW channel

Some excess also from
- the γγ channel
- the ZZ channel

1.6σ after LEE is far from being a significant excess, but it shows some disagreement. Definitely something that should be understood.
More data and more channels becoming more competitive, will give us the answer

MSSM Higgs

Cannot show all results, a selection from ATLAS and CMS is shown

MSSM Higgs: H→ττ

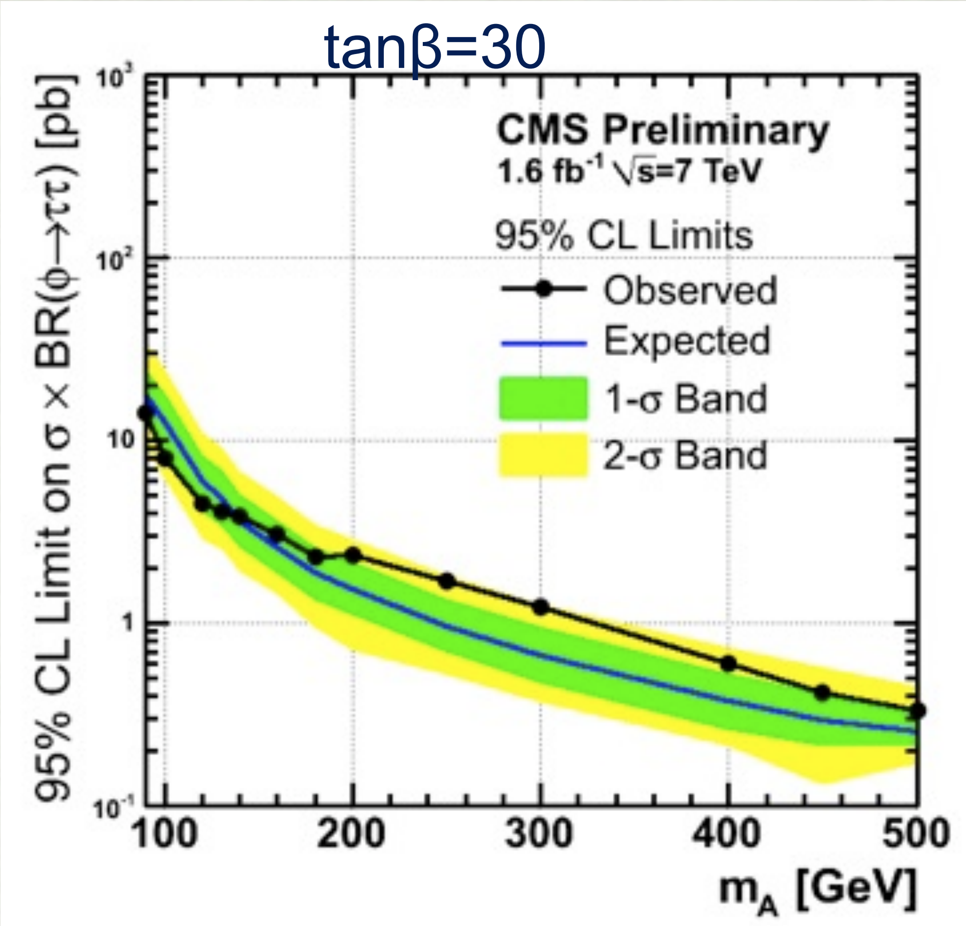
CMS-HIG-11-020
ATLAS Phys.Lett.B705(2011)174

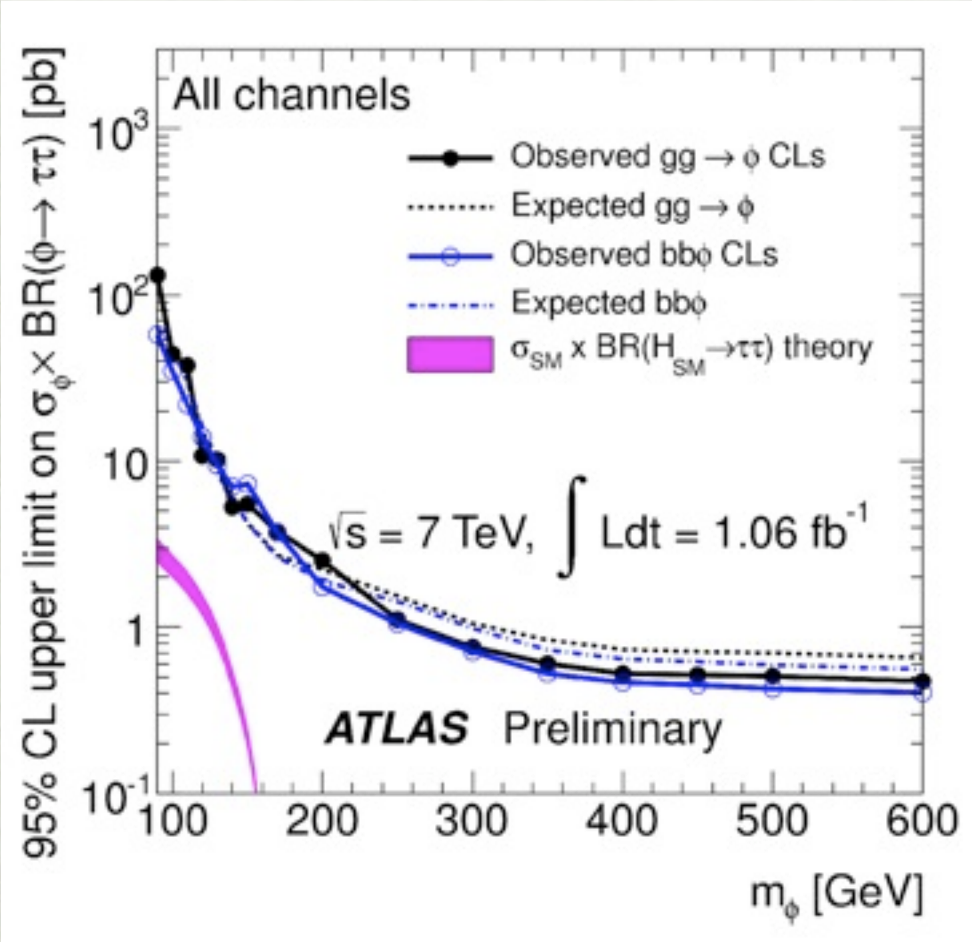
The MSSM has 5 Higgs bosons ($h^0, A^0, H, H^\pm$).
The production goes via gluon fusion or in association with b-quark.
Higgs decays via WW, ZZ are suppressed or absent. The couplings to 3rd generation down-type fermions are strongly enhanced in wide regions (large tanβ) of the MSSM space, making H→ττ a very appealing
(H→bb has large backgrounds)

Visible mass is used as discriminant.

ATLAS	CMS (see this talk page 12)
eμ4ν	eμ
$e/\mu+\tau_{had}3\nu$	$e/\mu+\tau_{had}$
$2\tau_{had}2\nu$	-

tanβ=30

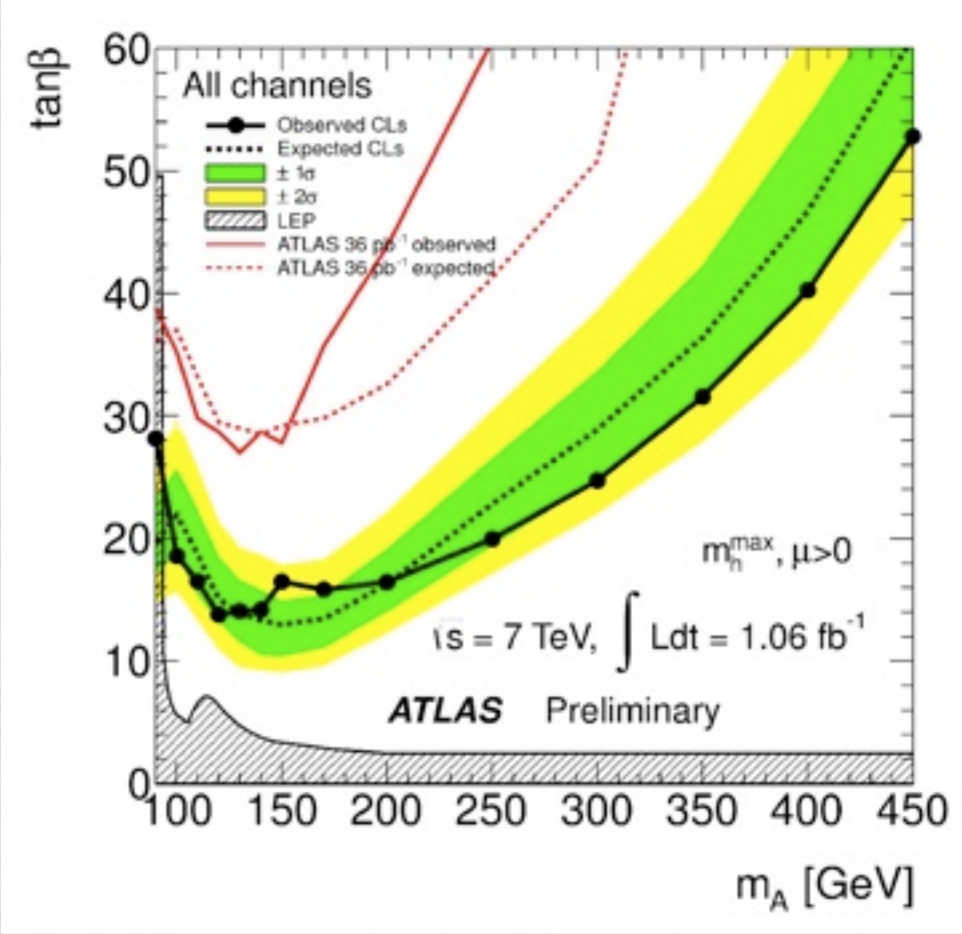


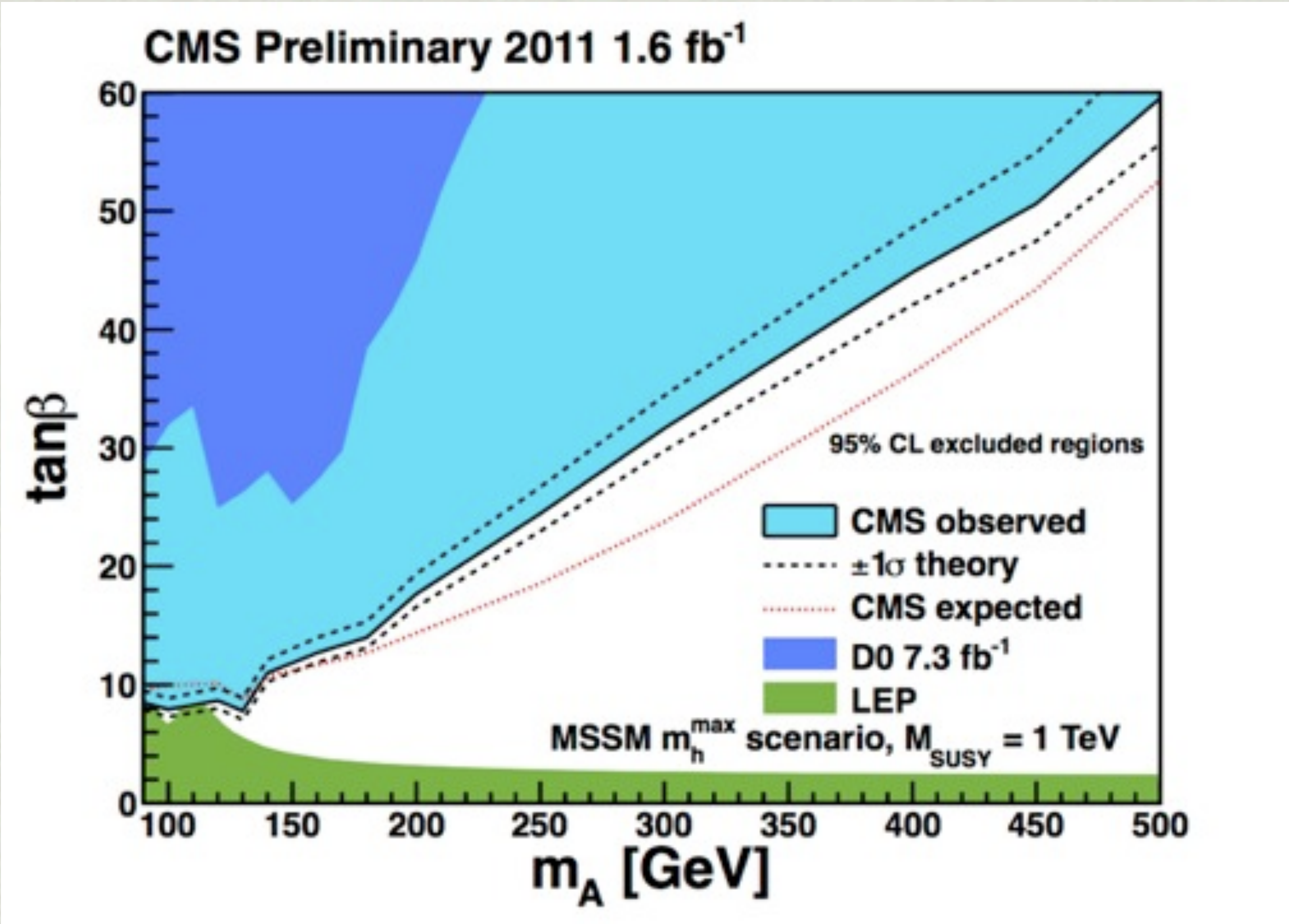


No significant excess observed.

MSSM H→ττ

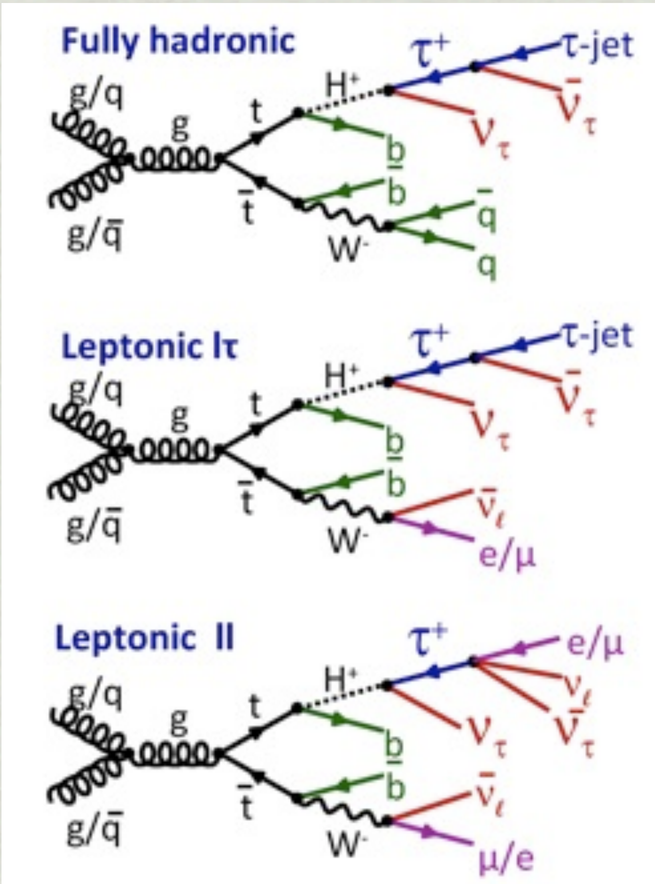
Most of the MSSM mh-max scenario is excluded up to mA<120 GeV by CMS! More data will come.





Charged Higgs

CMS-HIG-11-008
ATLAS-CONF-2011-138
ATLAS-CONF-2011-151



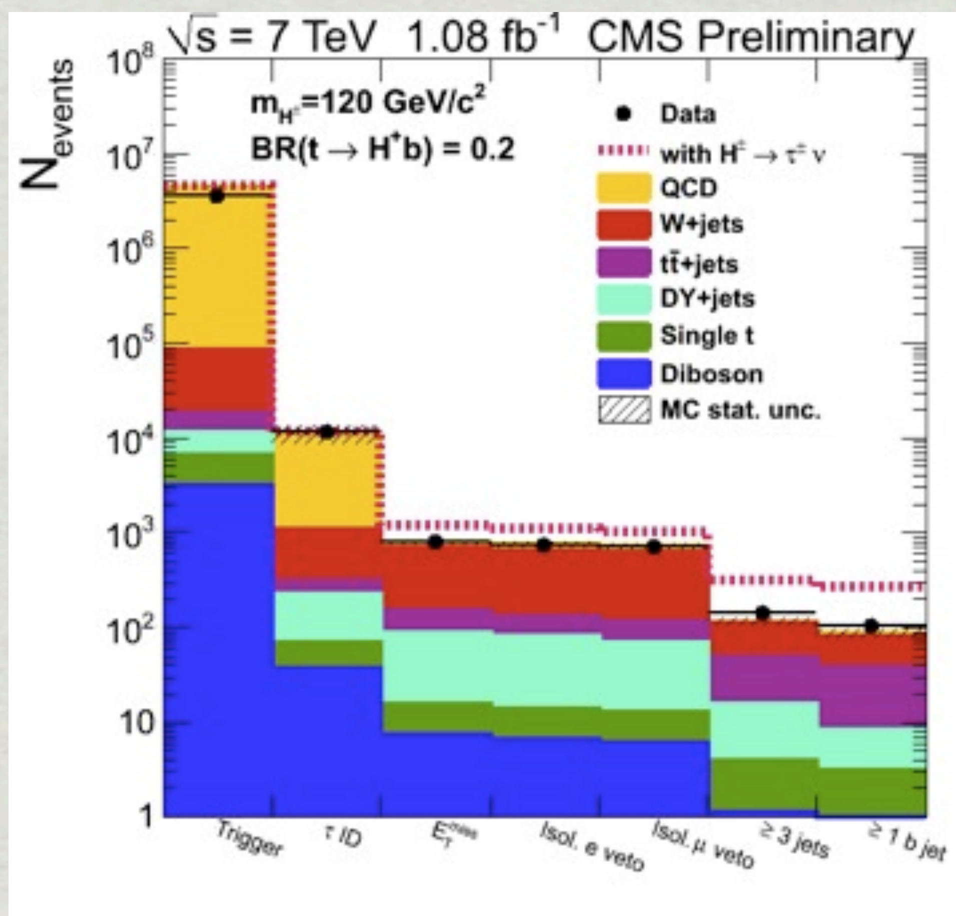
The selections are similar in ATLAS and CMS.

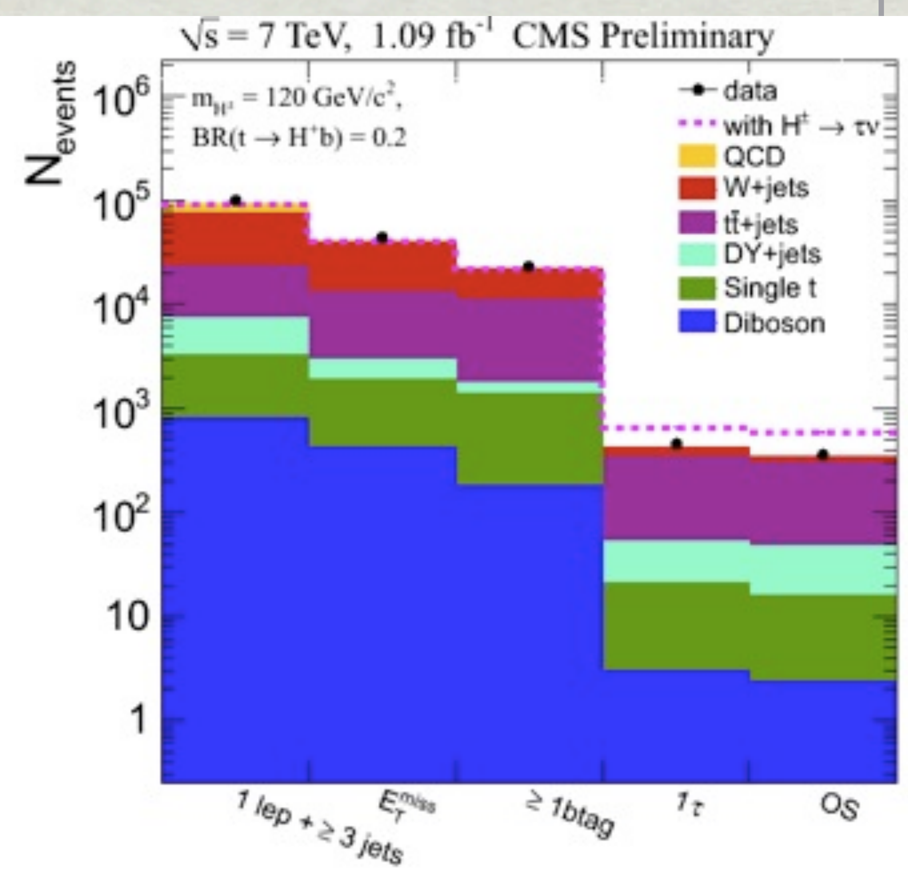
Selection in the Fully Hadronic channel is based on 1 tau jet,≥4 jets (≥1 b-tag), large MET.

1/2 Lepton channel:
1/2 leptons, ≥3 jets (≥1 b-tag), MET

QCD multijet background Data Driven.

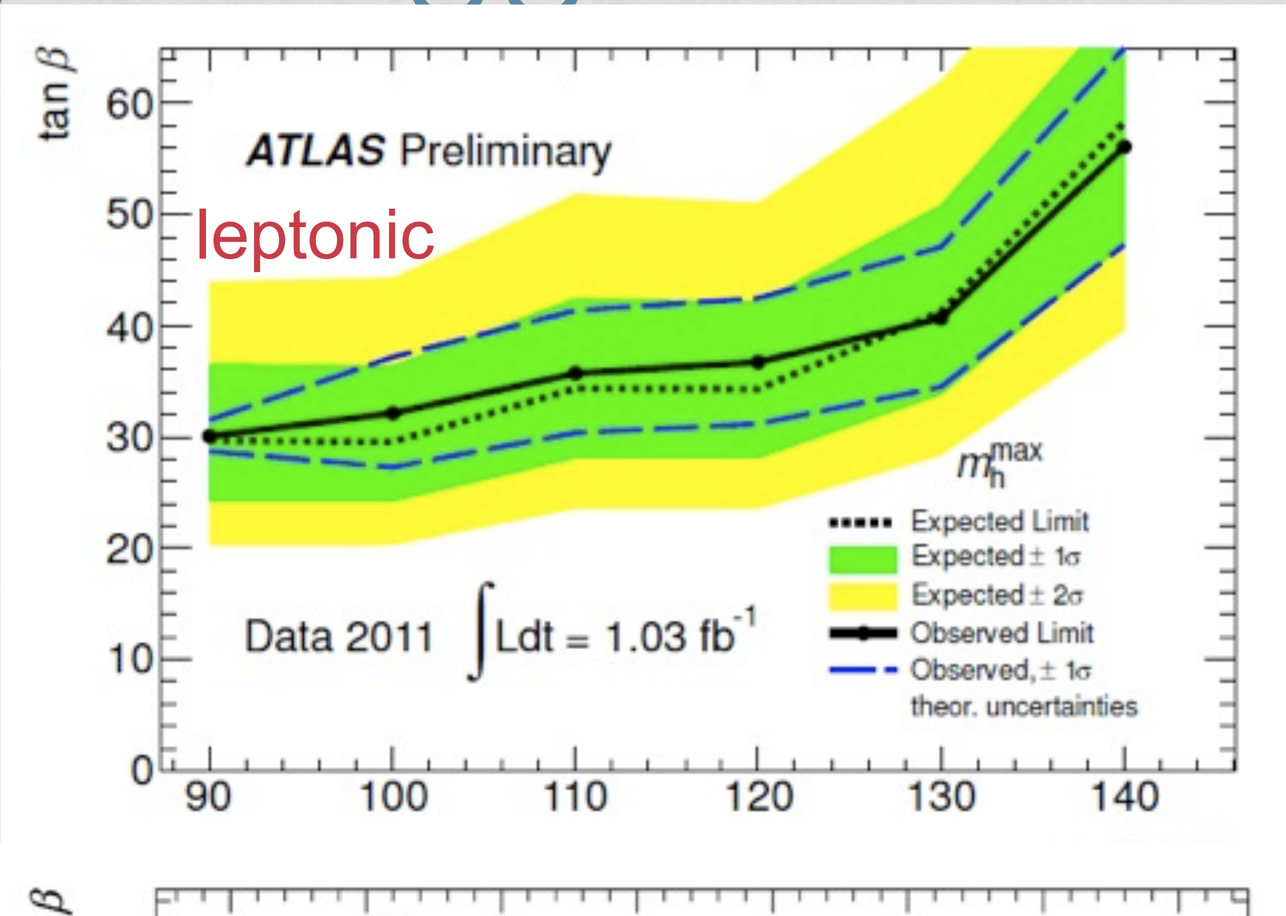
No excess observed.

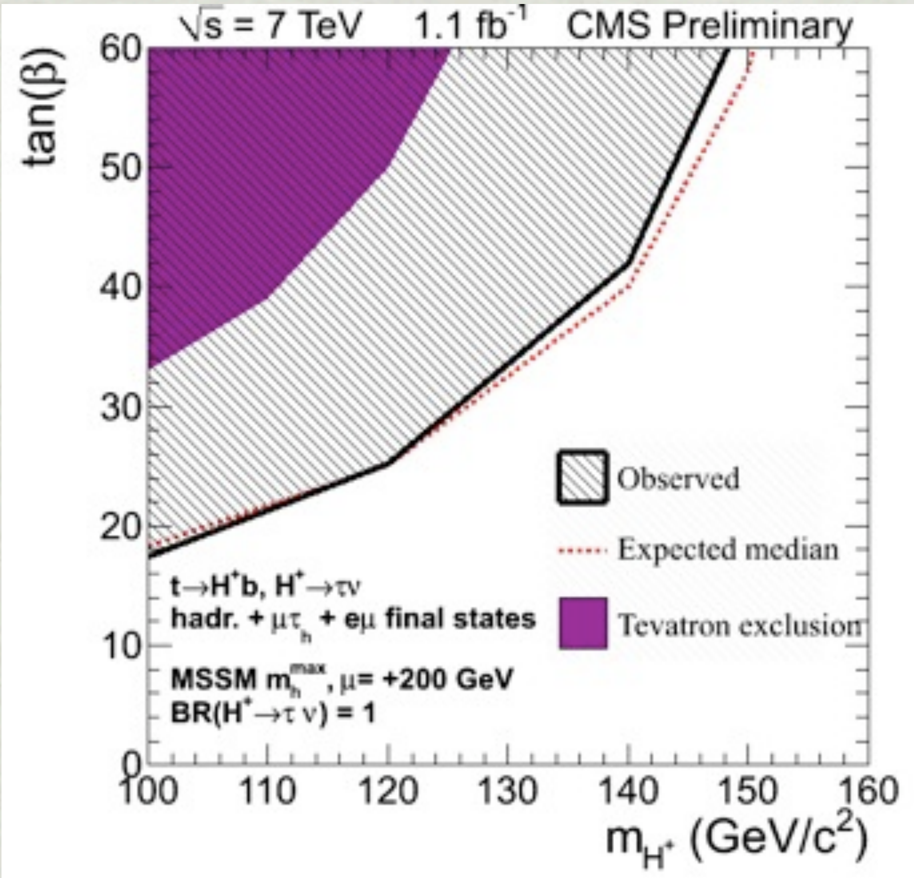


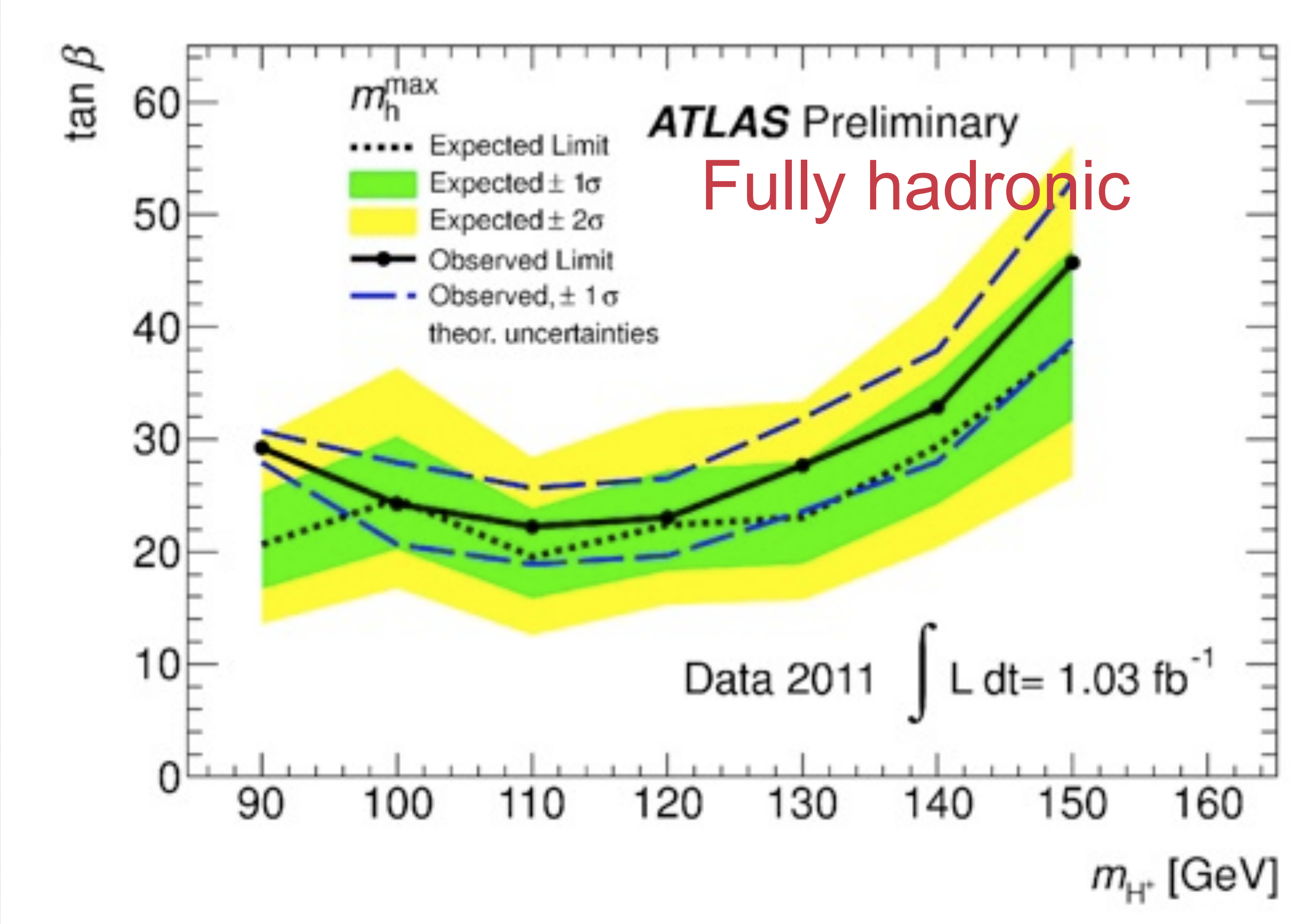


Charged Higgs

Limits in m_h-max scenario superseed previous experiments







Conclusions

We have excluded a wide range of SM Higgs masses

We haven't observed any significant excess, not only in the SM but also in the MSSM until now.

We are frantically working to do "better" than this, which might sadly mean we are going to fully exclude a low mass SM Higgs very soon.

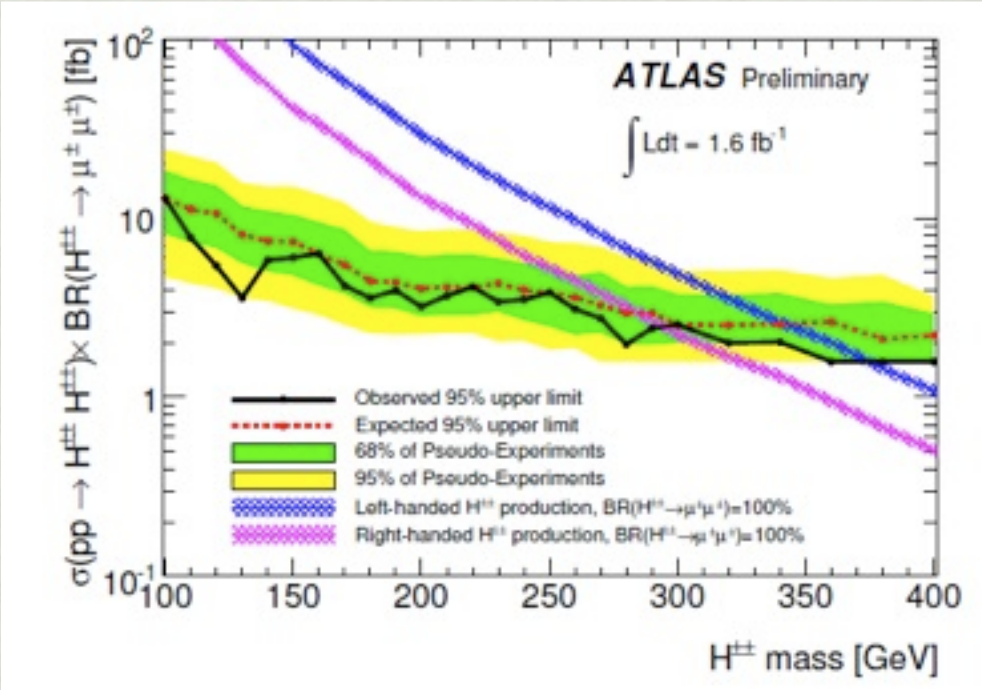
But we have hints and hope that much is still behind the corner and that we will finally find something!
Even if totally unexpected (to quote Paris last sentence),

But most likely in order to find something totally unexpected I agree that we would need to sit down and ask ourselves: aren't we searching only for the obvious?

Back-up

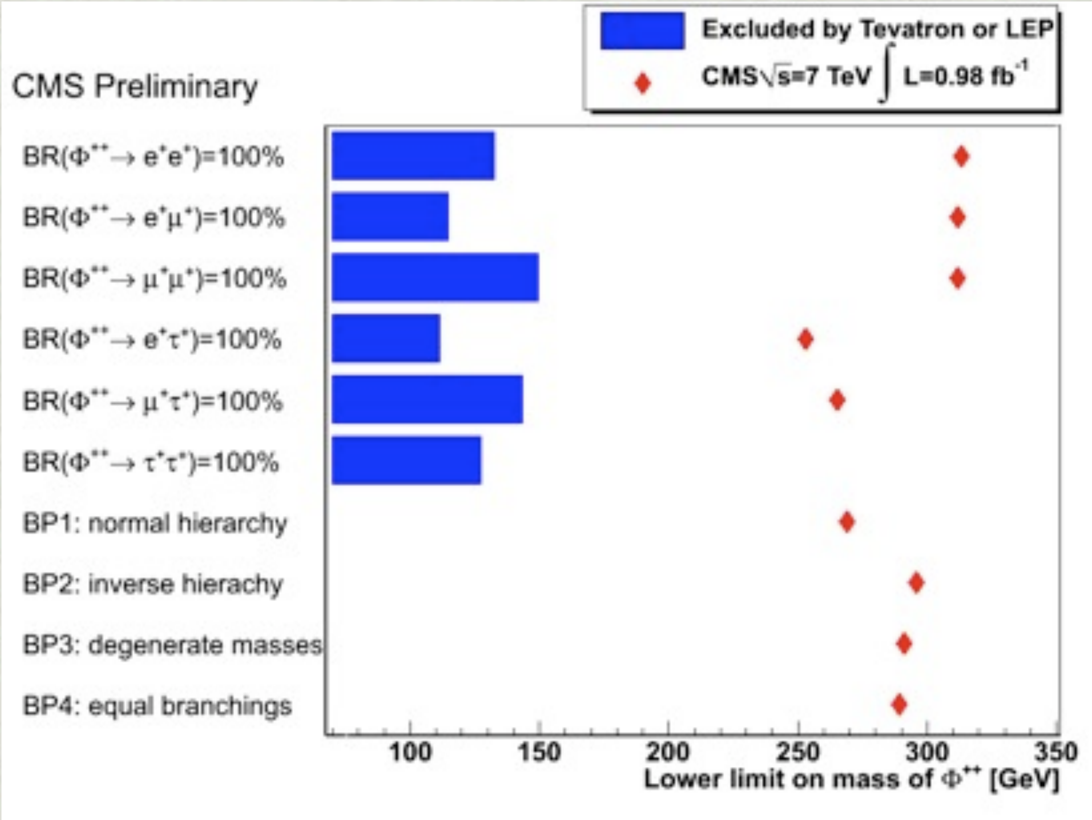
Doubly charged Higgs

CMS-PAS-HIG-11-007
ATLAS arXiv:1108.5895v1 [hep-ex]

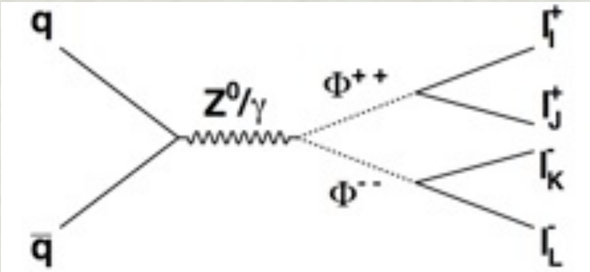


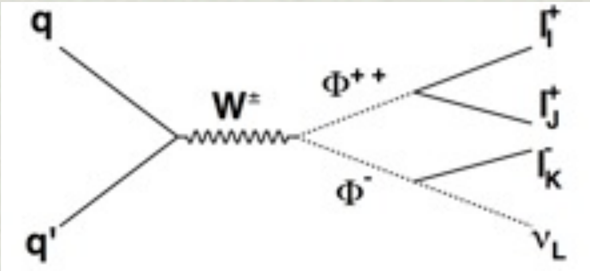
Predicted in little Higgs, Higgs triplet and leftright symmetric models
ATLAS Look for same sign muons

CMS



Predicted in little Higgs, Higgs triplet and leftright symmetric models
ATLAS Look for same sign muons





ATLAS & CMS correlated systematics

Source	Affected Processes	Typical uncertainty
PDFs+α_s (cross sections)	$gg \to H$, $t\bar{t}H$, $gg \to VV$	$\pm 8\,\%$
	VBF H, VH, VV@NLO	$\pm 4\,\%$
Higher-order uncertainties on cross sections	total inclusive $gg \to H$	$^{+12\,\%}_{-7\,\%}$
	inclusive "gg" $\to H + \geq 1$ jets	$\pm 20\,\%$
	inclusive "gg" $\to H + \geq 2$ jets	$\pm 20\%$ (NLO), $\pm 70\%$ (LO)
	VBF H	$\pm 1\,\%$
	associated VH	$\pm 1\,\%$
	$t\bar{t}H$	$^{+4\,\%}_{-10\,\%}$
	uncertainties specific to high mass Higgs boson, see Section 2.1	$\pm 30\%$
	V	$\pm 1\,\%$
	VV up to NLO	$\pm 5\,\%$
	$gg \to VV$	$\pm 30\,\%$
	$t\bar{t}$, incl. single top productions for simplicity	$\pm 6\,\%$
acceptance	acceptance for $H \to WW \to \ell\nu\ell\nu$ events	$\pm 2\%$
phenomenology	modelling of underlying event and parton showering	$\pm 10\,\%$
	fake lepton probability (W + jets $\to \ell\ell^{fake}$)	$\pm 40\%$
luminosities	ATLAS and CMS uncertainties on their luminosity measurements	$\pm 3.7\,\%$, $\pm 4.5\,\%$

ATLAS systematics on signal uncorr with CMS

Systematic uncertainties		Higgs boson decay channels (mass in GeV/c^2)						
source	type	$\gamma\gamma$ (120)	bb (120)	$\tau\tau$ (120)	WW $\ell\nu\ell\nu$ (150)	ZZ $\ell\ell\ell\ell$ (200)	ZZ $\ell\ell\nu\nu$ (400)	ZZ $\ell\ell qq$ (400)
luminosity	lumi	3.7%						
reconstruction efficiencies	μ		1%	1.1%	0.6%	1.2%	0.7%	0.5%
	e		1%	3.4%	2%	1.9%	1.2%	1.1%
	γ	11%						
	τ_{had}			8.3%				
	b-tag		16%				0.7%	4.9%
p_T scale (event yield)	jets/E_T^{miss}		2-8%	16%	6%		1.4%	1.3 %
	e		1%	${}^{+1.2}_{-0.1}$%	0.2%	0.1%	0.2%	0.3%
p_T resolution	μ		2%		1.5%	0.1%	1%	1.2%
	e		1%		0.1%	0.1%	0.2%	0.2%
	γ							
	jets		1%	0.2%	2%		0.2%	2.2%
	E_T^{miss}		2%	0.4%	0.6%			

CMS systematics on signal uncorr with ATLAS

Systematic Uncertainties		Higgs boson decay channels (mass in GeV/c^2)							
					WW	ZZ			
source	type	$\gamma\gamma$ (120)	bb (120)	$\tau\tau$ (120)	$\ell\nu\ell\nu$ (150)	$\ell\ell\ell\ell$ (200)	$\ell\ell\tau\tau$ (400)	$\ell\ell\nu\nu$ (400)	$\ell\ell qq$ (400)
luminosity	lumi	4.5%							
trigger efficiencies	μ		2%			2%	1%	2%	1%
	e		2%			2%	1%	1%	1%
	γ	1%							
	E_T^{miss}		2%						
reconstruction efficiencies	μ		4%	1%	3%	3%	2%	2%	1%
	e		4%	2%	4%	3%	6%	2%	2%
	γ	1-3%							
	τ_{had}			6%			10%		
	b-tag		20%						20%
p_T scale (event yield)	μ				2%	1%	1%	2%	1%
	e				2%	2%	2%	5%	2%
	jets/E_T^{miss}		2%	4%	2-10%			2%	0.2%
p_T scale (shape)	μ					0.3%			
	e					0.3%			
	γ	0.1-0.3%							
	τ_{had}			3%					
p_T resolution (event yield)	jets/E_T^{miss}		10%						
	jets/E_T^{miss}		2%	4%	2-10%			2%	0.2%
p_T resolution (shape)	μ					10%			
	e					10%			
	γ	20%							