Standard Model Higgs searches in ATLAS and CMS

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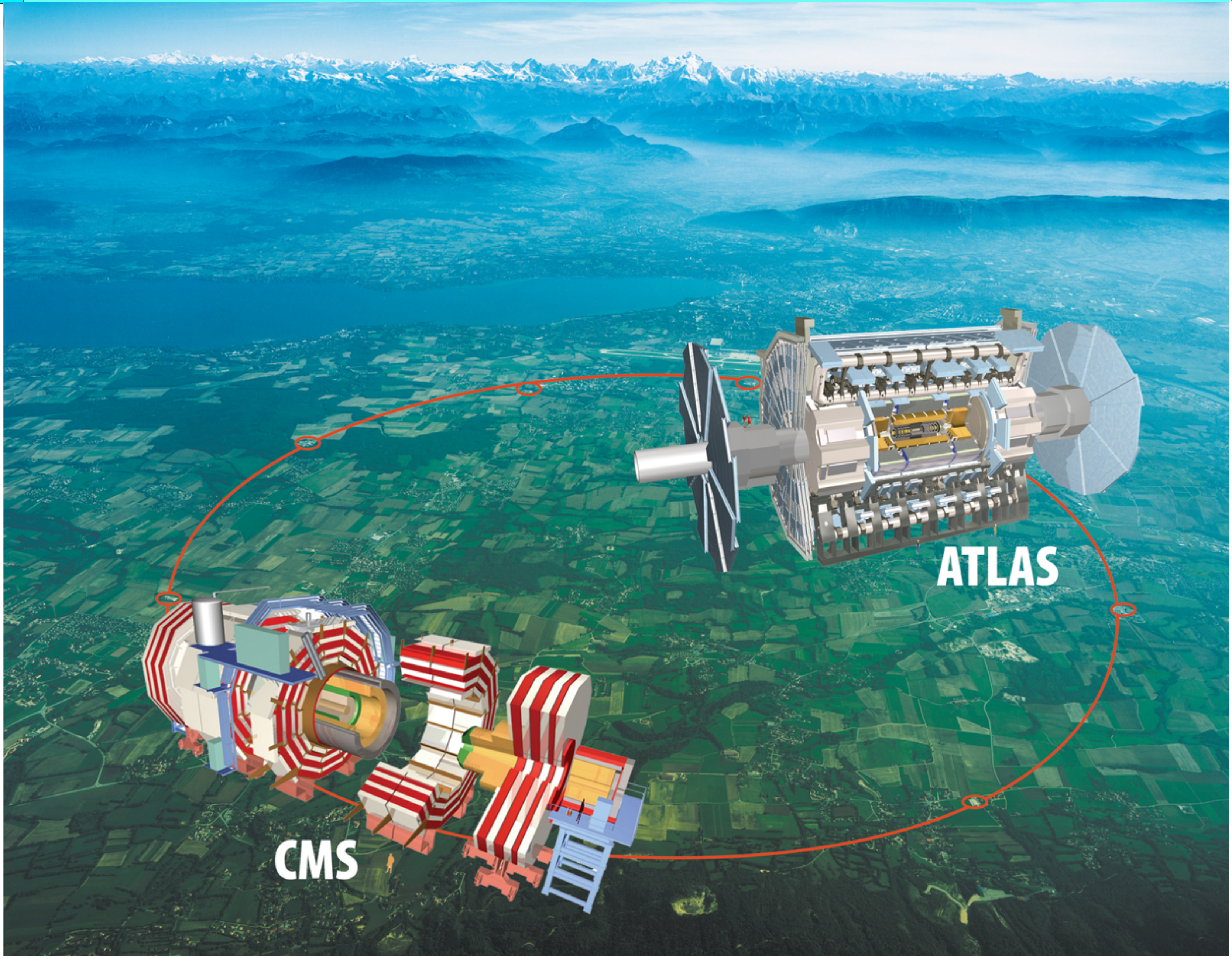
Outline

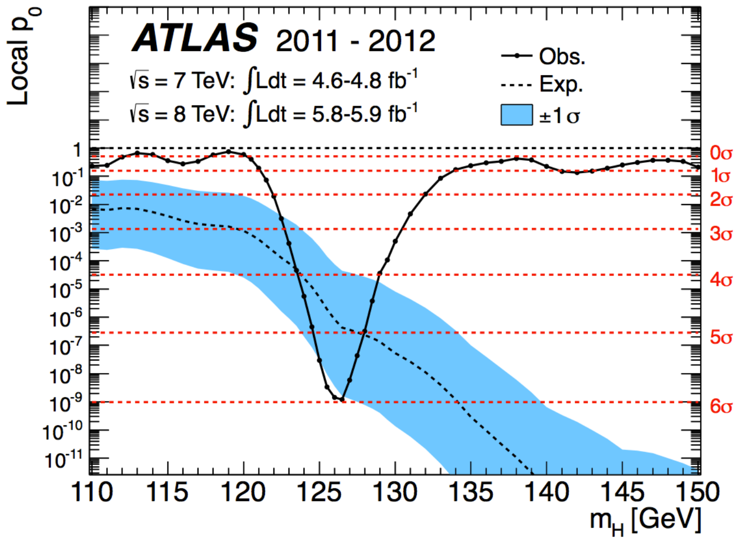
- Introduction
- The discovery of the new boson
- Analysis in the various channels
- Measurement of the properties of the new boson
  - Mass
  - Couplings
  - Spin-parity
- Summary and outlook

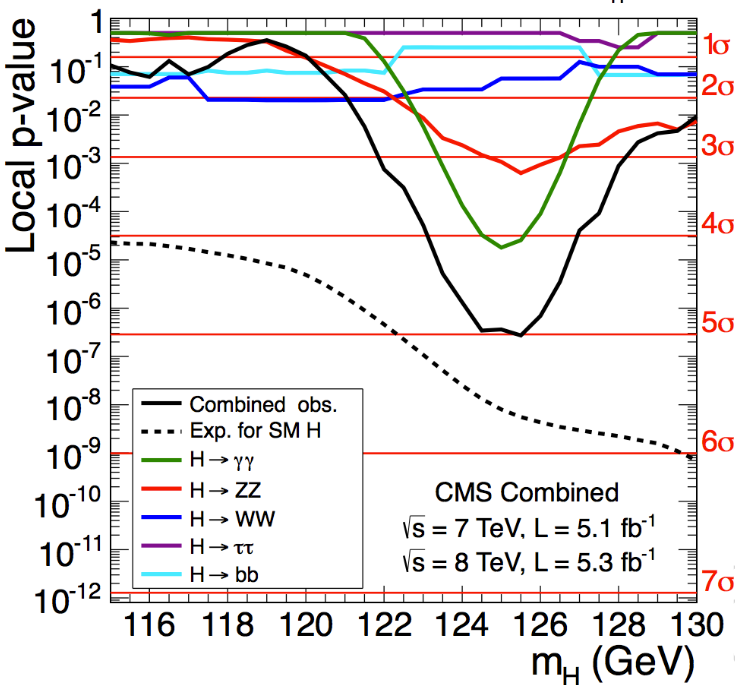
LHC and detectors



The discovery of the new Higgs-like boson

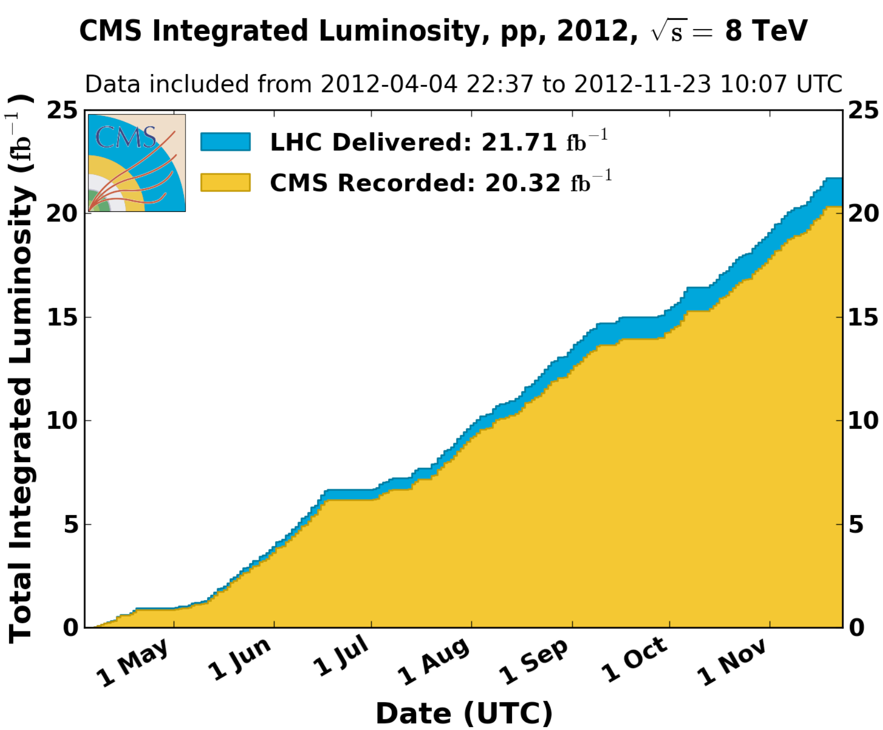
- In March 2012 ATLAS and CMS presented some excess at ~125 GeV
- On July 4th 2012 CMS and ATLAS reported the observation of a new boson with mass about 125 GeV that is consistent with the SM Higgs boson
- 5 main channels in CMS:
  - $H \to \gamma\gamma$
  - $H \to ZZ \to 4l$
  - $H \to WW \to 2l2\nu$
  - $H \to \tau\tau$
  - $H \to bb$



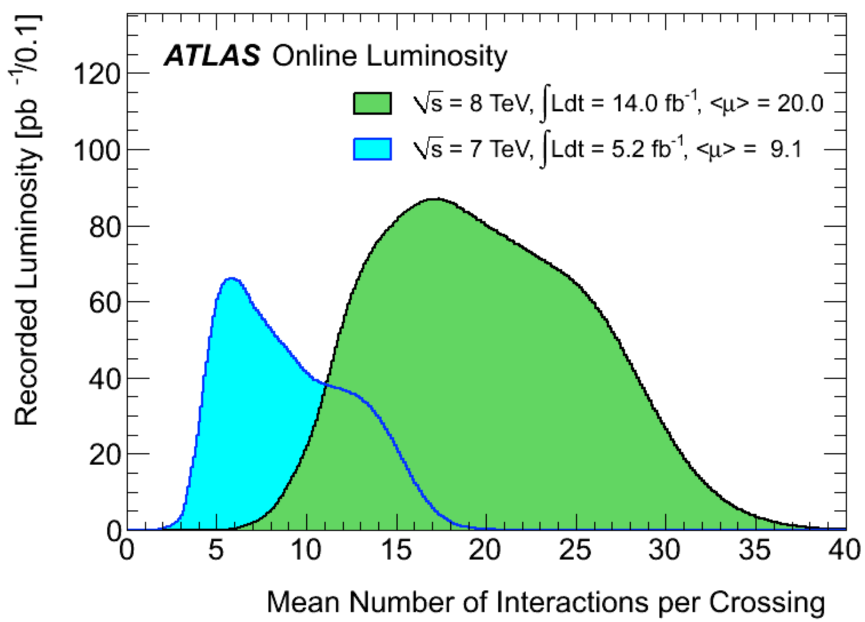


2012 data taking

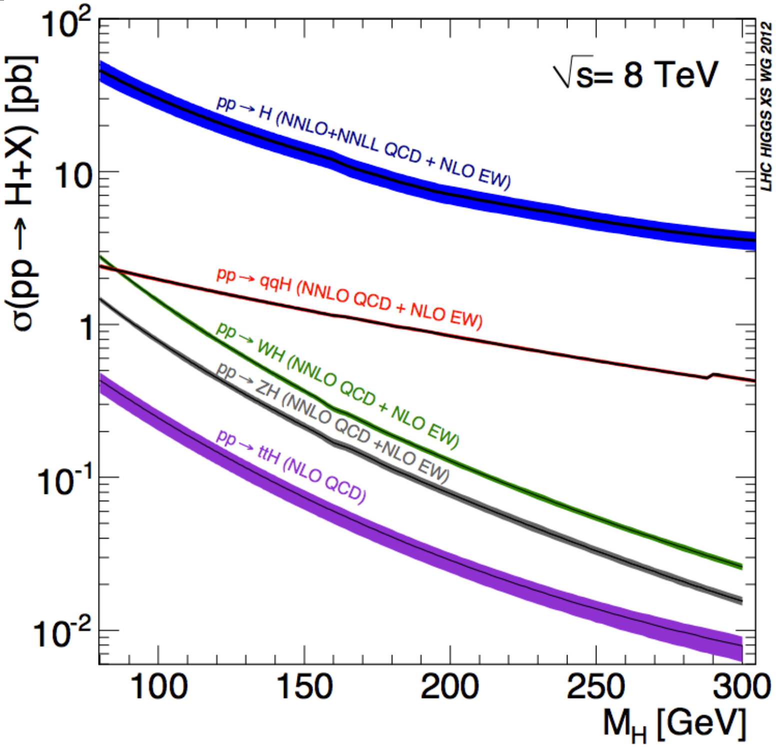
- LHC is running at 8 TeV since beginning of April
- Already exceeded 20 fb^{-1} per experiment of collected data
- Maximum luminosity 7.5 x 10^{33} $cm^{-2}s^{-1}$

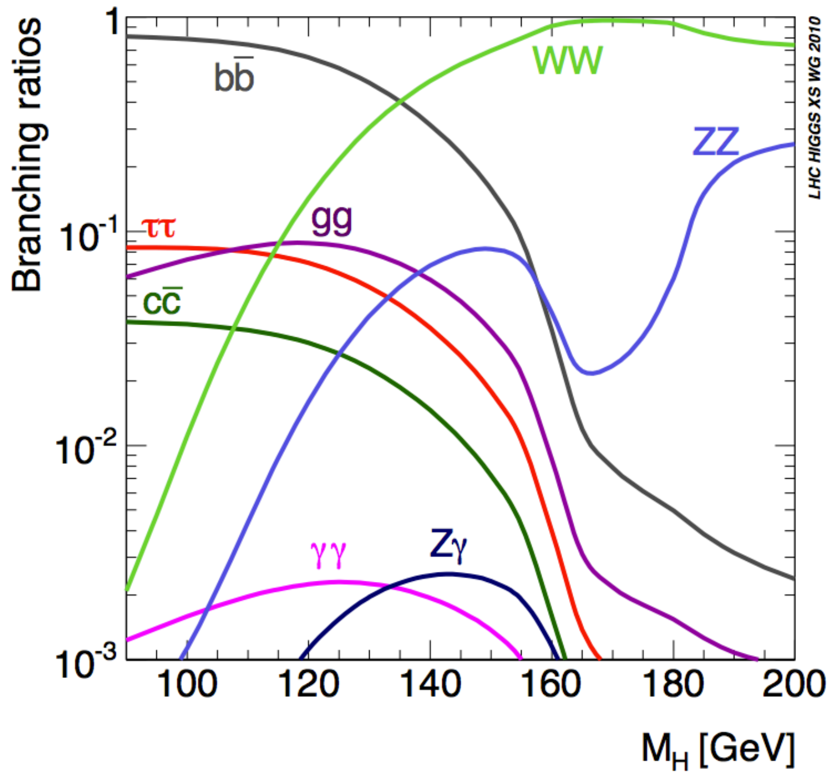


- Multiple interactions occur for each bunch crossing (in-time and out-of-time pileup)
- Mean PU ~10 events in 2011 and ~20 events in 2012

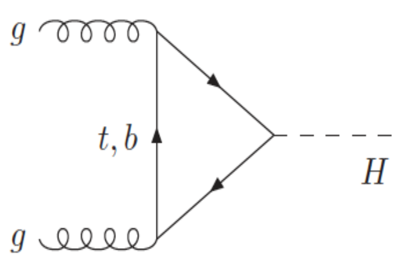


SM Higgs production and decay

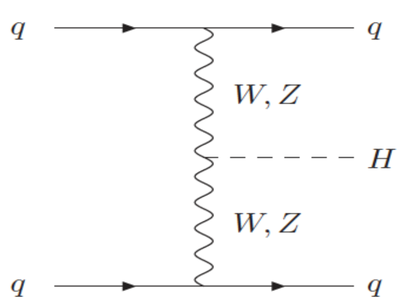




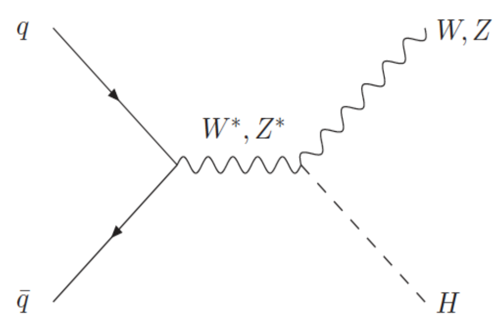
ggH



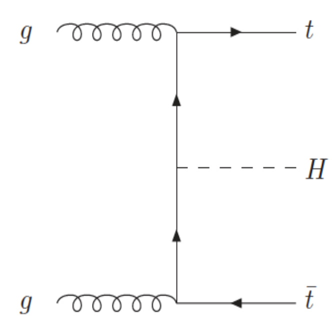
VBF



VH



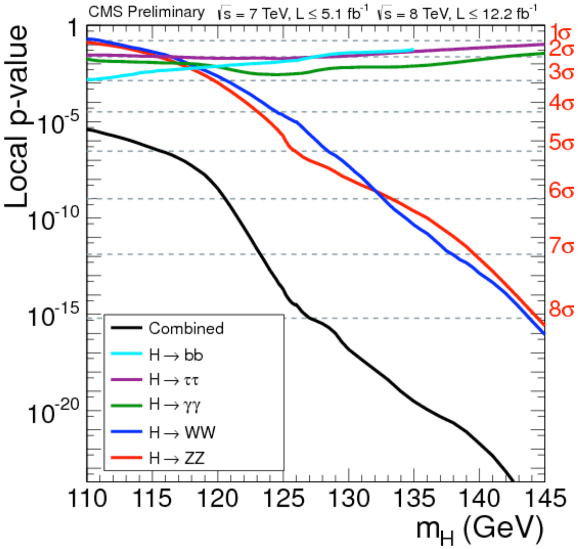
ttH



Exploit all four production modes

Most sensitive search channels at 125 GeV

- 2 channels with excellent mass resolution (1-2%)
  - γγ and ZZ -> 4l
  - Search for mass peak over the BG
- 3 channels with worse mass resolution (10-20%)
  - WW -> 2l2ν, ττ and bb
  - Search for excess above estimated BG



Illustrative CMS for ICHEP dataset 5 + 5 fb-1

Channel	σ x BR (7-8 TeV) (pb)	Mean Efficiency	Number of signal events	Average s/b	Mass resolution
γγ untagged	0.045	40%	180	3.5%	1%
γγ VBF	0.003	20%	6	20%	1%
ZZ->4l untagged	0.002	30%	8	150%	1.5%
WW->2l2ν untagged	0.2	5%	100	15%	20%
WW VBF	0.015	3%	4	25%	20%
ττ untagged	1.3	2.5%	300	1%	15%
ττ VBF	0.088	2%	15	10%	15%
bb VH	0.13	4%	50	3%	9%

M_H = 125 GeV

Approximate values, only for illustration

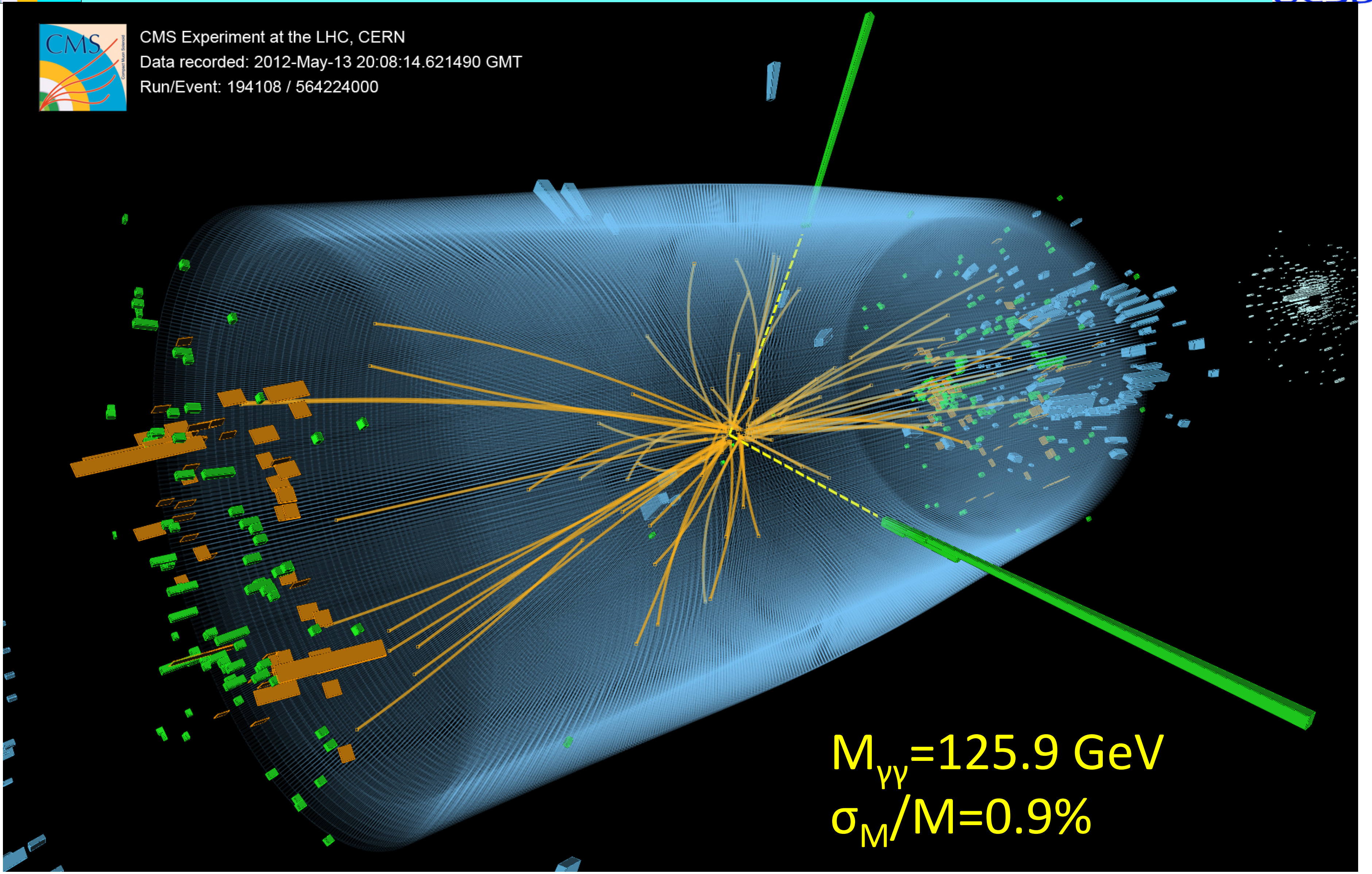
Updates of the analysis

Channel	Int Lumi CMS (fb^{-1})	Int Lumi ATLAS (fb^{-1})
γγ (untagged, VBF tag)	5 + 5	5 + 5
ZZ->4l (untagged)	**5 + 12**	5 + 5
WW->2l2ν (0-1 jet)	**5 + 12**	**13**
WW->2l2ν (VBF tag)	**5 + 12**	5 + 5
ττ (untagged, VBF tag, VH tag)	**5 + 12**	**5 + 13**
bb (VH tag)	**5 + 12**	**5 + 13**

Results that have been updated for the HCP conference in November are indicated in red

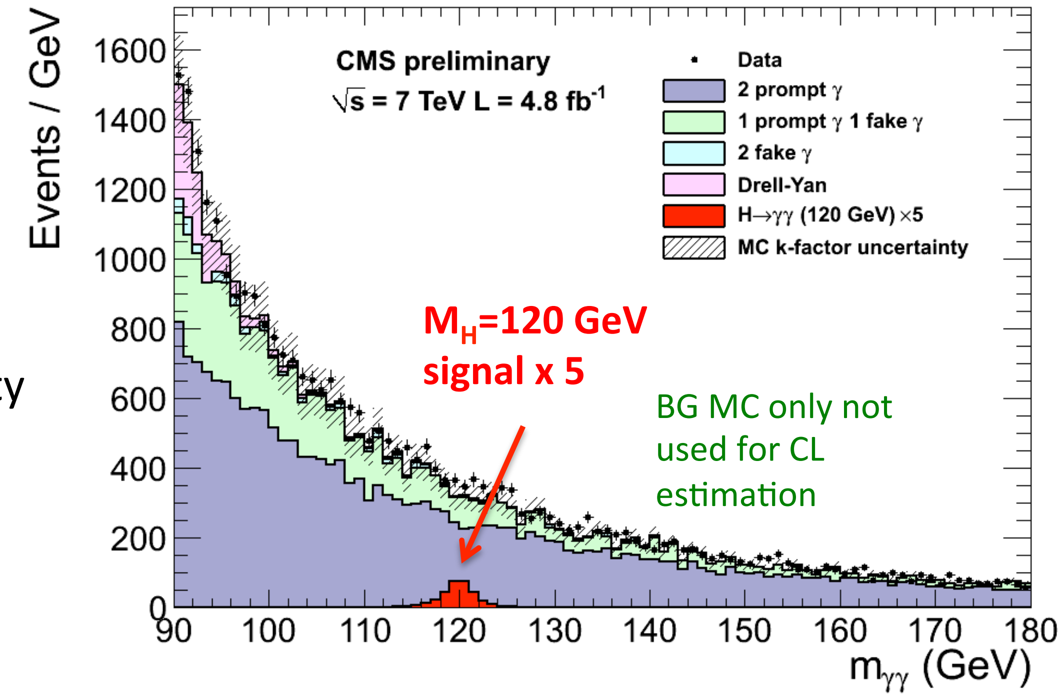
- **2012 analyses have been 'blind'**
  - All analyses have been developed before looking at the signal region
  - This avoids possible experimental bias

H→γγ


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
$M_{\gamma\gamma}$=125.9 GeV
σ_M/M=0.9%

H→γγ analysis strategy

- Search for a small mass peak over large and smooth background
  - Irreducible: 2γ QCD production
  - Reducible: γ+jet with 1 additional fake photon, QCD with 2 fake photons, DY with electrons faking photons
- **Narrow mass peak**
  - mass resolution 1-2%
- Studied mass range: 110-150 GeV
- Split into event classes to enhance the sensitivity



- ATLAS
  - Split into 9 categories
  - Diphoton P_{Tt}, η, converted/unconverted
- CMS
  - Cut based and MVA based analyses
  - Split into 4 categories + VBF analysis

CMS H→γγ analysis

- 4 non-VBF event classes split based on a diphoton Boosted Decision Tree (BDT) classifier output + dijet tag classes
- BG is estimated by fitting to a polynomial in the full mass range (3rd to 5th order)
  - Possible BG bias is always less than 20% of the statistical error
  - Different BG estimation in cross check analysis gives consistent results

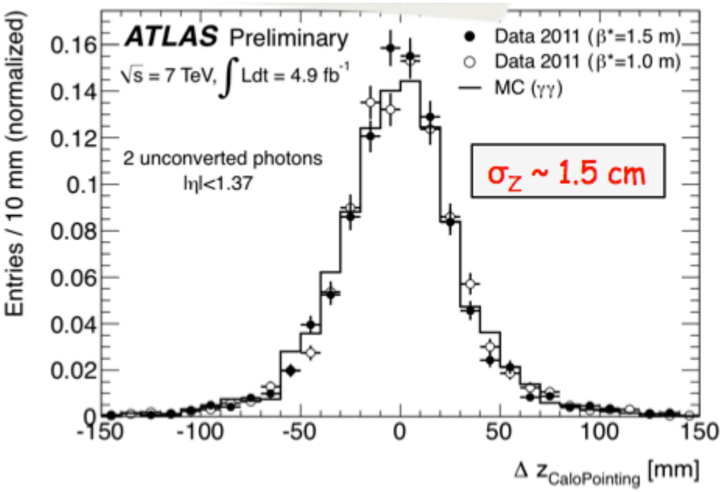
Event categories		SM Higgs boson expected signal ($m_H = 125$ GeV)							Background $m_{\gamma\gamma} = 125$ GeV (events/GeV)
		Events	ggH	VBF	VH	ttH	σ_{eff} (GeV)	FWHM/2.35 (GeV)	
7 TeV, 5.1 fb^{-1}	BDT 0	3.2	61%	17%	19%	3%	1.21	1.14	3.3 ± 0.4
	BDT 1	16.3	88%	6%	6%	–	1.26	1.08	37.5 ± 1.3
	BDT 2	21.5	92%	4%	4%	–	1.59	1.32	74.8 ± 1.9
	BDT 3	32.8	92%	4%	4%	–	2.47	2.07	193.6 ± 3.0
	Dijet tag	2.9	27%	72%	1%	–	1.73	1.37	1.7 ± 0.2
8 TeV, 5.3 fb^{-1}	BDT 0	6.1	68%	12%	16%	4%	1.38	1.23	7.4 ± 0.6
	BDT 1	21.0	87%	6%	6%	1%	1.53	1.31	54.7 ± 1.5
	BDT 2	30.2	92%	4%	4%	–	1.94	1.55	115.2 ± 2.3
	BDT 3	40.0	92%	4%	4%	–	2.86	2.35	256.5 ± 3.4
	Dijet tight	2.6	23%	77%	–	–	2.06	1.57	1.3 ± 0.2
	Dijet loose	3.0	53%	45%	2%	–	1.95	1.48	3.7 ± 0.4

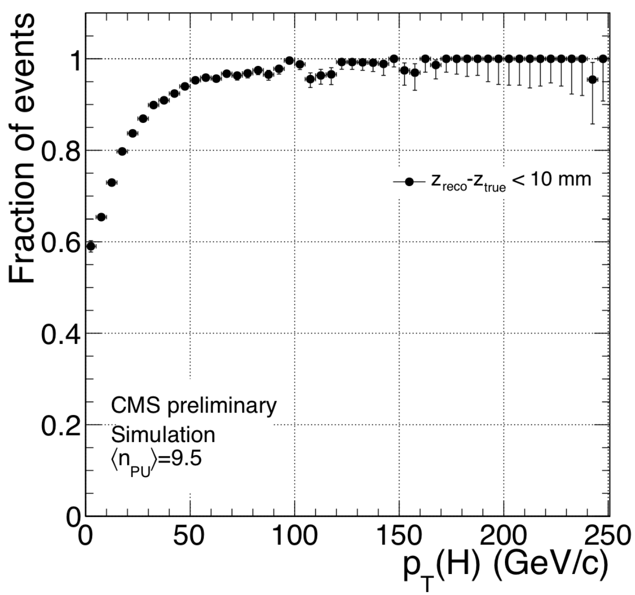
Resolution in 2012 somewhat worse that 2011 because for now used prompt-reco

H→γγ vertex determination

Primary vertex Z position

- ATLAS has pointing calorimetry
  - Z resolution 1.5 cm for two unconverted photons, good enough to have negligible contribution to mass resolution
- CMS uses underlying event and recoil jets,
  - Affected by pileup
  - checked with Z->μμ
  - Overall efficiency >80%
- Both also exploit tracks from converted photons

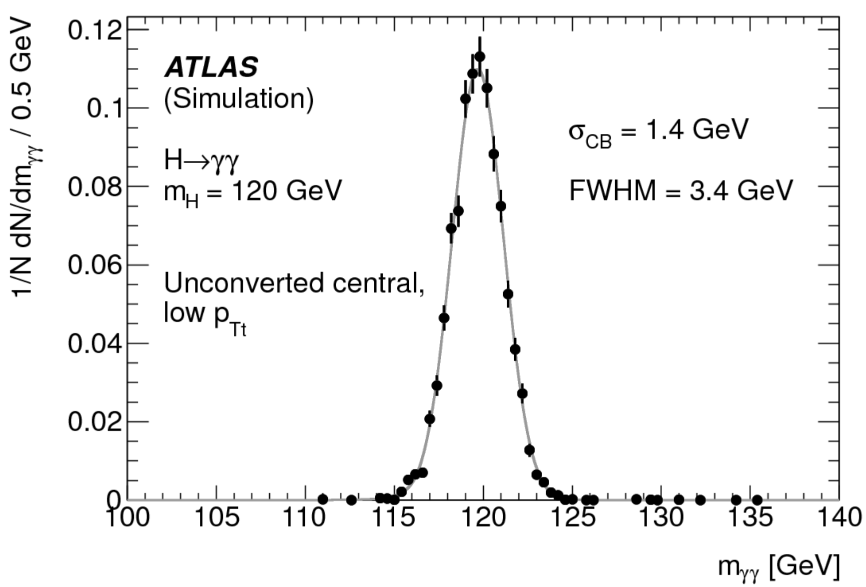


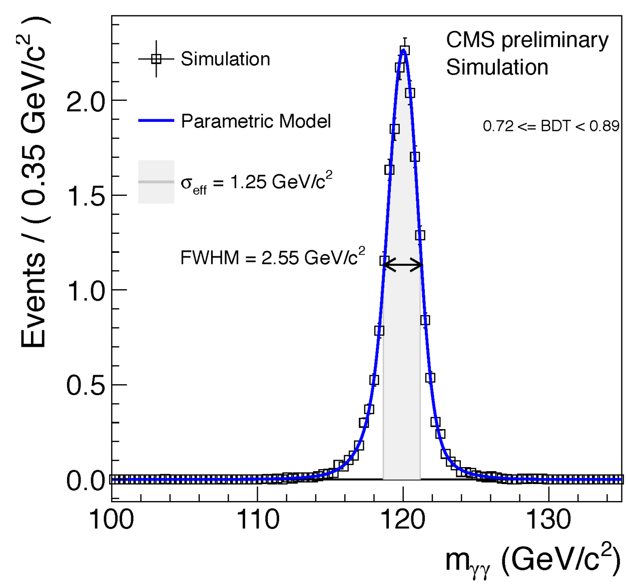


H→γγ energy resolution

- Energy resolution extremely important
  - Need precise ECAL calibration
  - CMS uses MVA energy regression
- Energy scale and resolution measured with Z->ee
  - Exploit similarities between electron and photons
  - Precision from tagged photons from Z->μμγ would be smaller

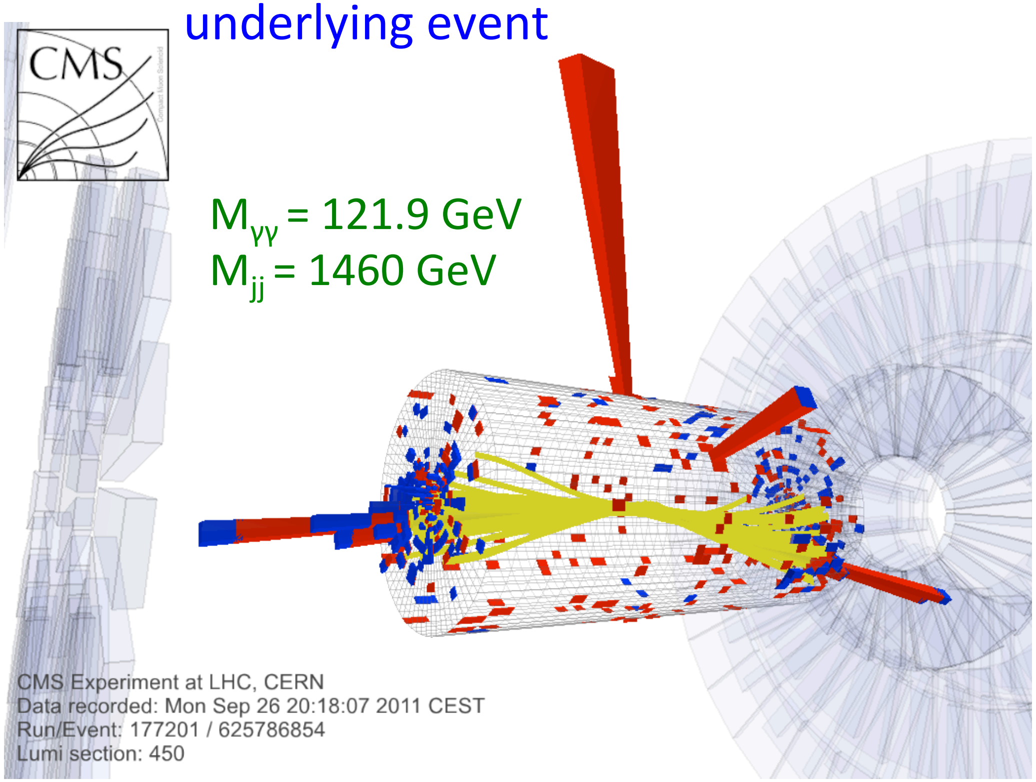
Examples of high resolution event classes



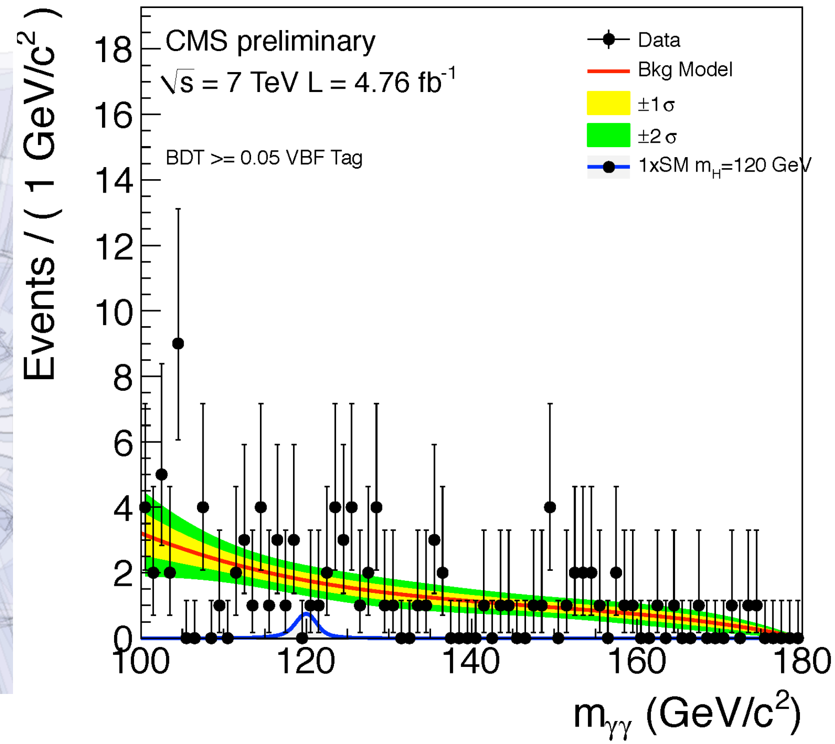


H→γγ VBF analysis

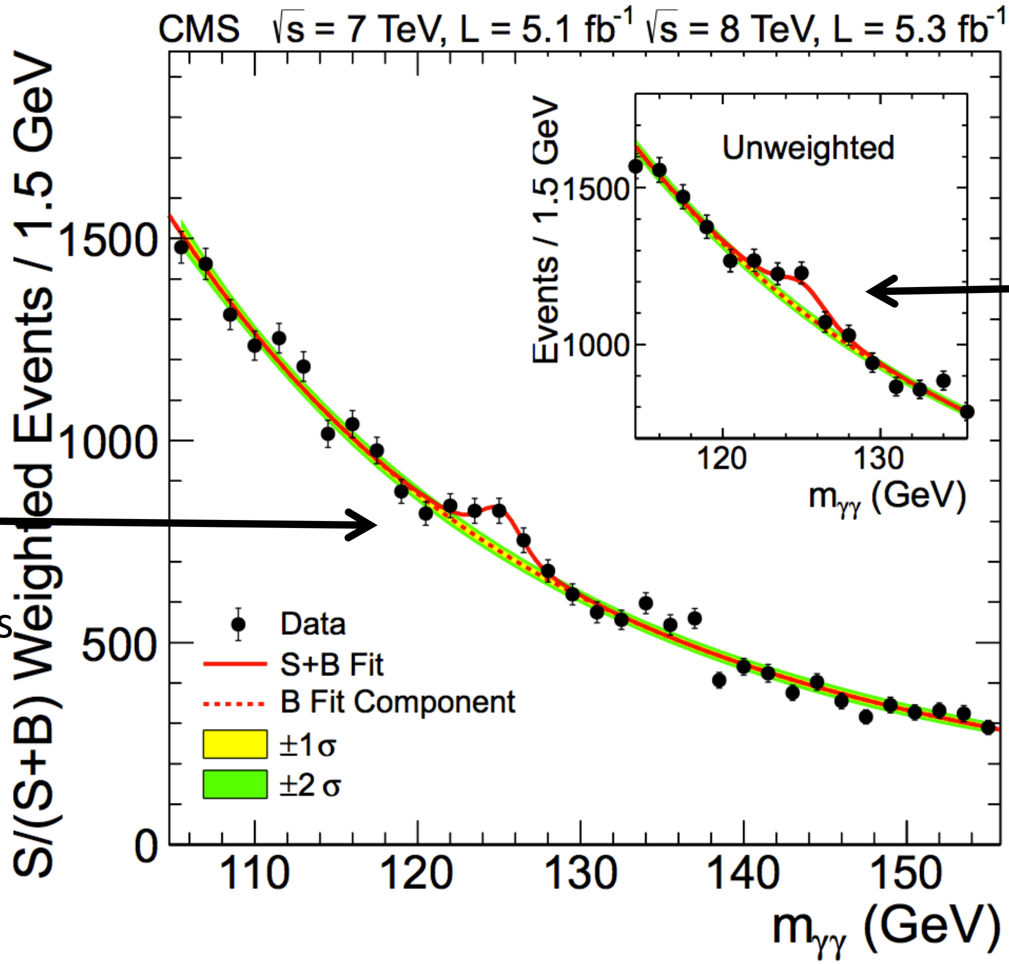
- Exclusive dijet tag improves sensitivity by ~10%
- Photon identification is the same
  - tighter lead photon E_t cut (E_t lead/$M_{\gamma\gamma}$ > 55/120)
- Dijet tag selection on dijet variables
  - exploits two additional VBF high p_T jets at large rapidity
- Contamination of gg-fusion ~25%, syst. error 50-70% dominated by underlying event



Dijet tag selection has high s/b, ~1/3



H→γγ combined mass spectrum



Weighed data events and BG model parametrizations

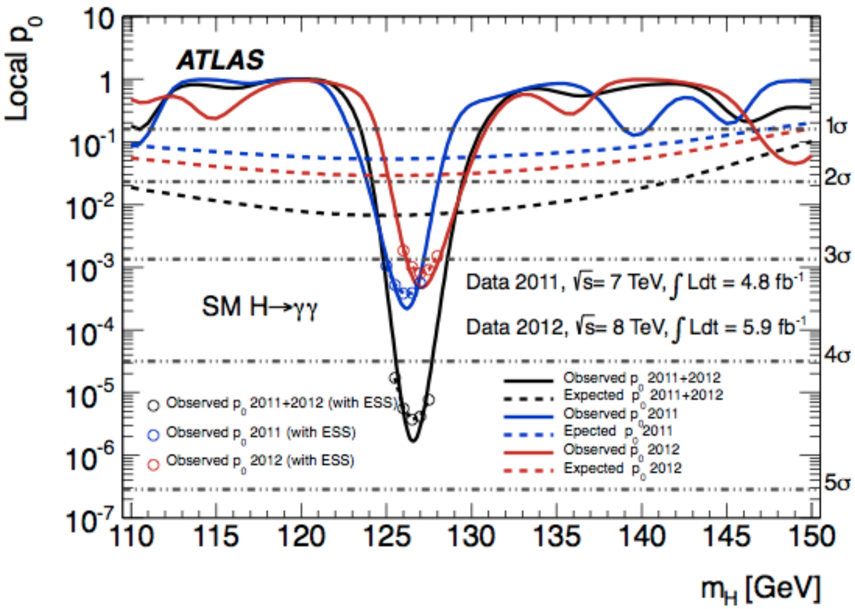
Unweighed data events and BG model parametrizations

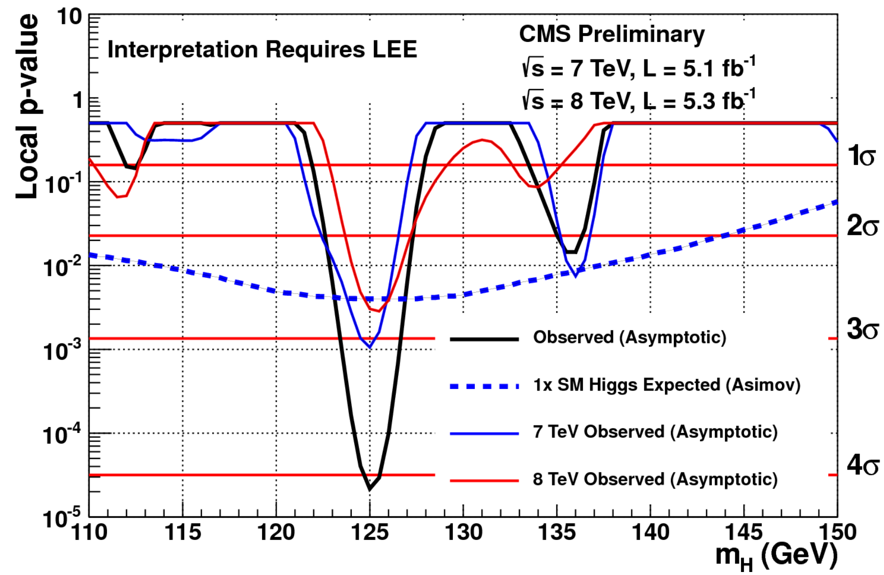
- Sum of mass distributions for each event class, weighted by S/(S+B)
- B is integral of background model over a constant signal fraction interval

- This plot is not used in the analysis and it is for illustration only, it adds all event classes together

H→γγ results: p-values

- P-value: probability that a BG only fluctuation is more signal-like than observation





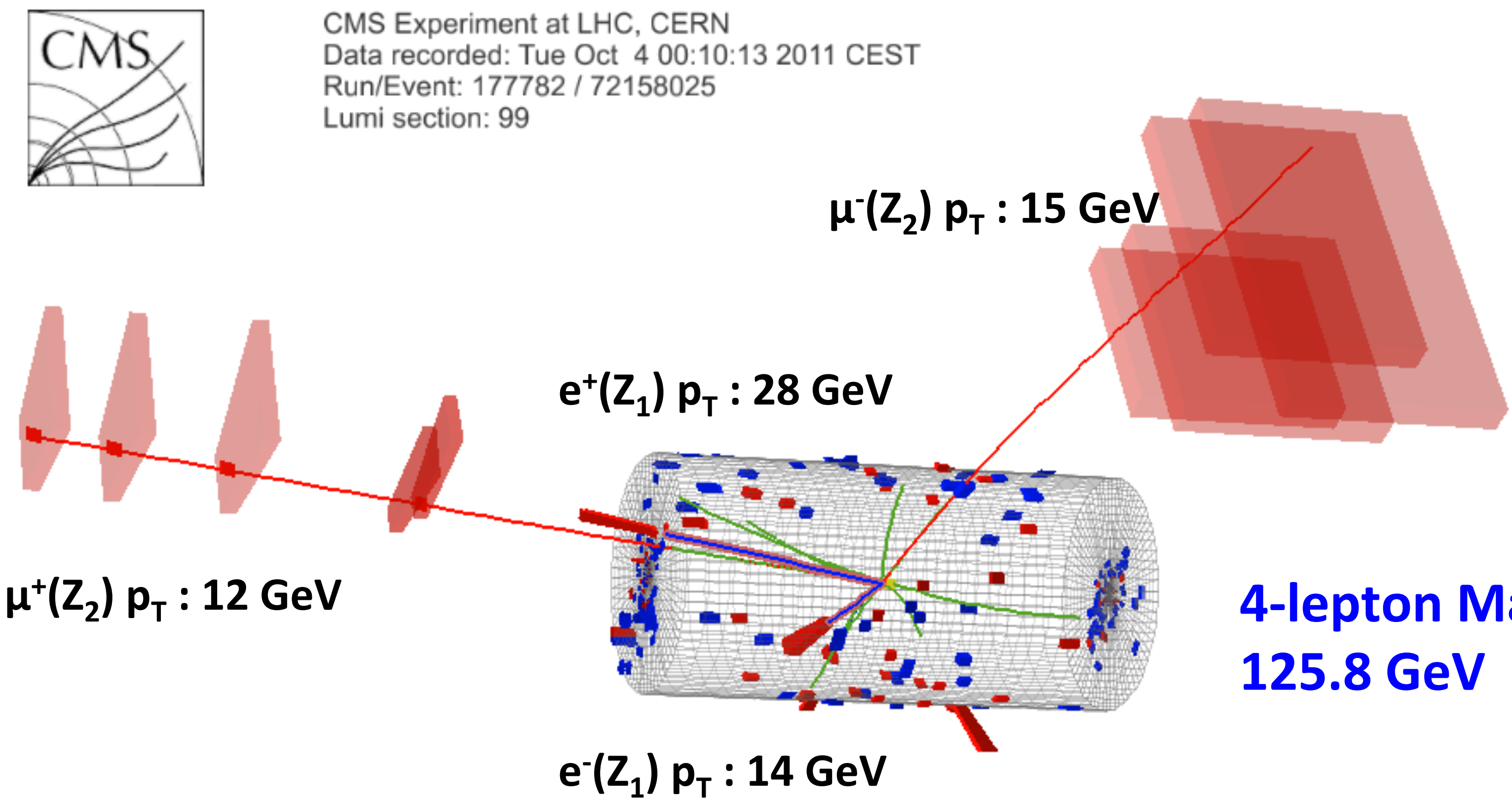
Similar results from cut based and cross Check MVA analysis (3.7 and 4.6 σ)

	ATLAS	CMS
Mass position of minimum local p-value	126.5 GeV	125 GeV
Local significance at minimum	4.5 σ	4.1 σ
Fitted value of μ	1.8 ± 0.5	1.56 ± 0.43

μ is the signal strength modifier $\mu = \sigma/\sigma_{SM}$

$H \rightarrow ZZ \rightarrow 4l$ (4μ, $4e$, $2e2\mu$)

- Clean channel: 2 high mass pairs of opposite sign isolated electrons or muons coming from PV
- **Narrow mass peak**
  - Very good mass resolution 1-2 %
- Background
  - irreducible: ZZ
  - reducible: Z+jets, Zbb, tt, WZ
- Very small BR ~10^{-4} at 125 GeV



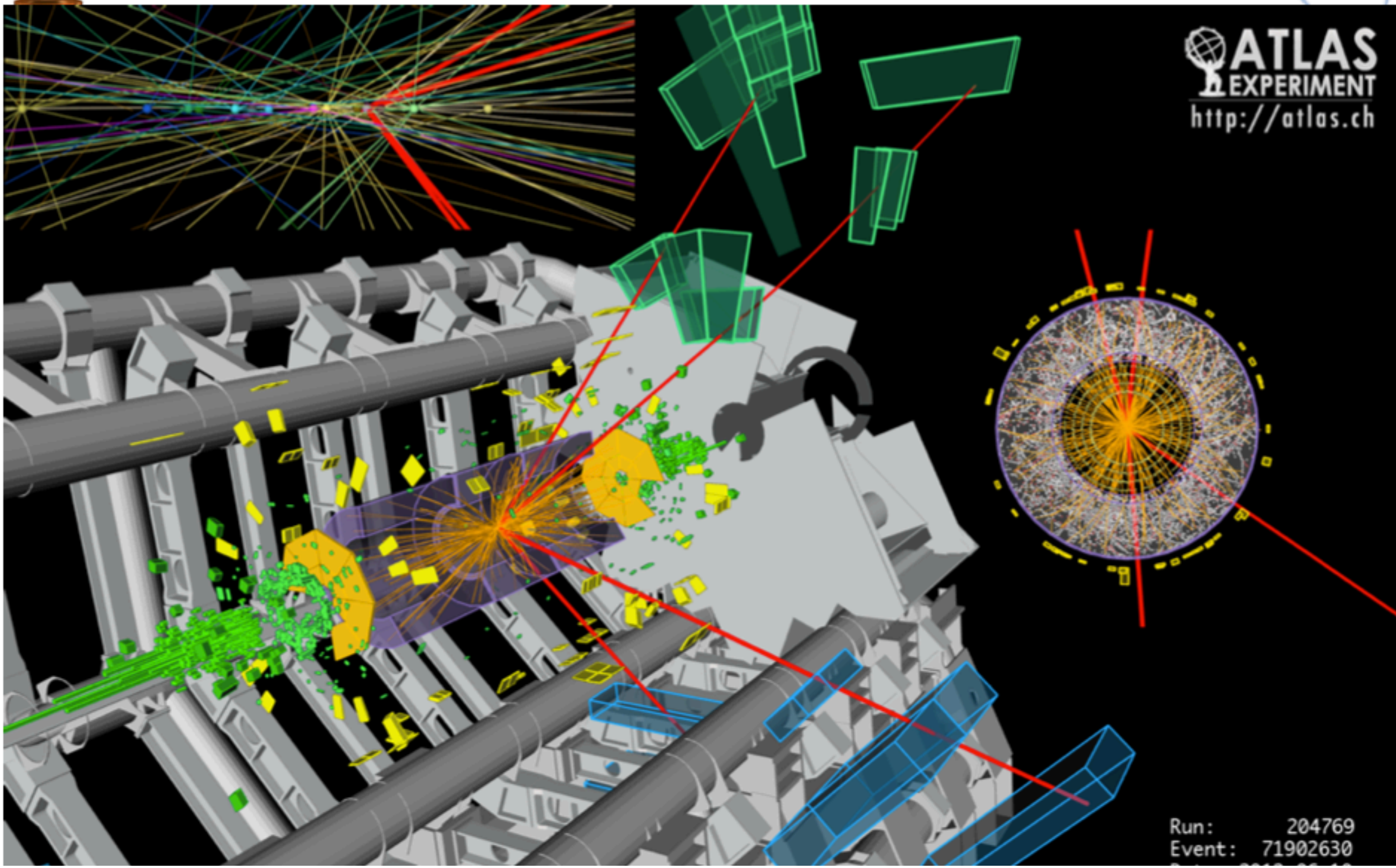
4-lepton Mass : 125.8 GeV

$m_{4\mu} = 125.1$ GeV

p_T (muons)= 36.1, 47.5, 26.4, 71 .7 [GeV]

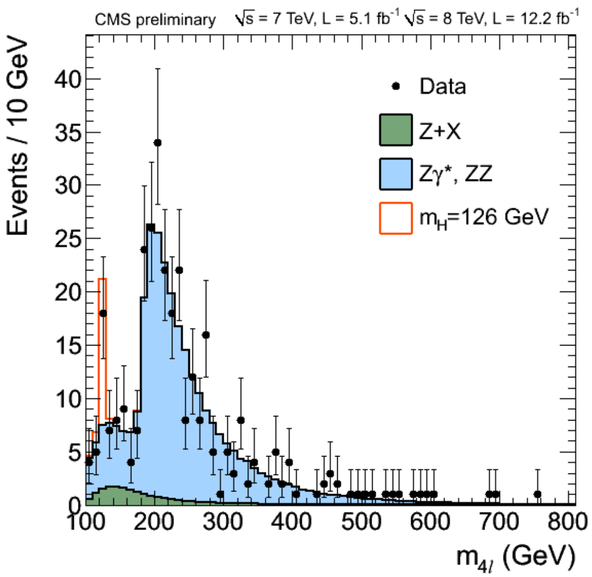
m_{12}= 86.3 GeV, m_{34}= 31.6 GeV

15 reconstructed vertices!

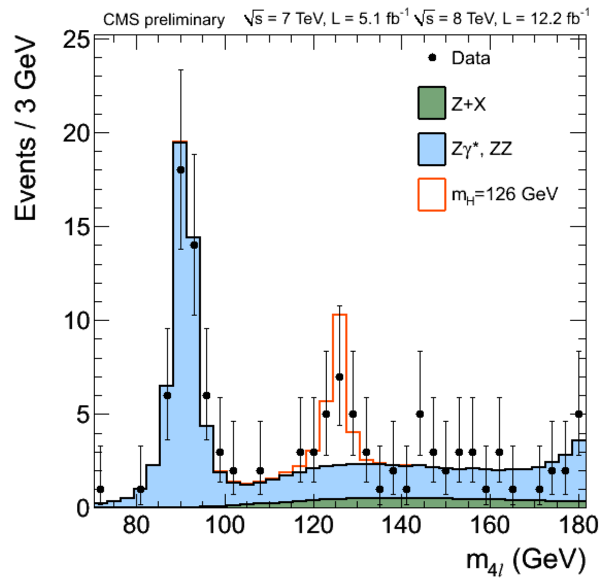


H→ZZ→4l: invariant mass spectrum

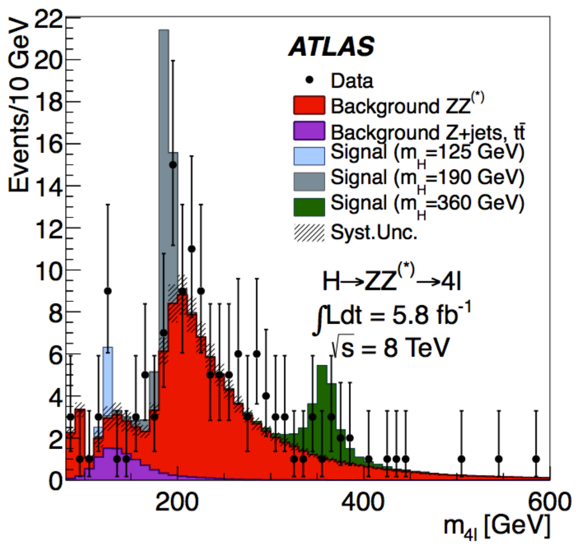
Full mass range

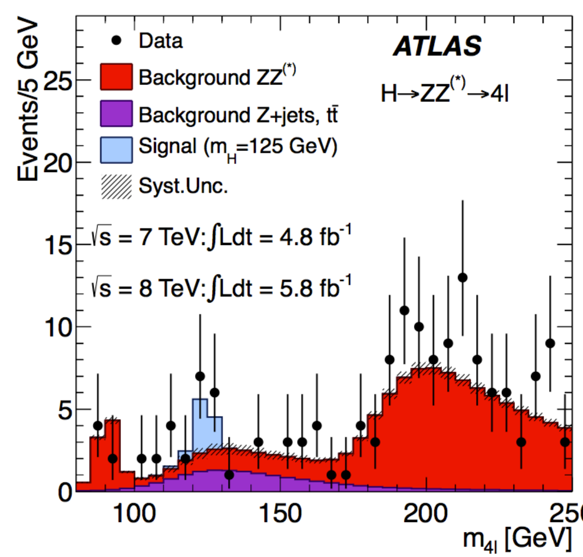


Low mass

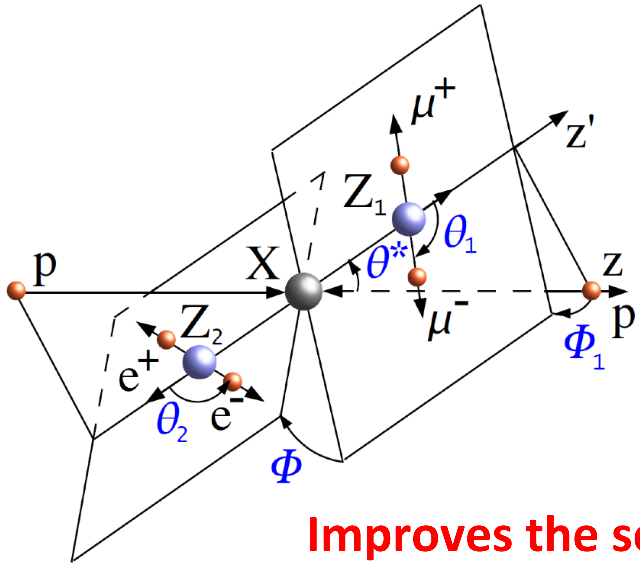


Only 8 TeV





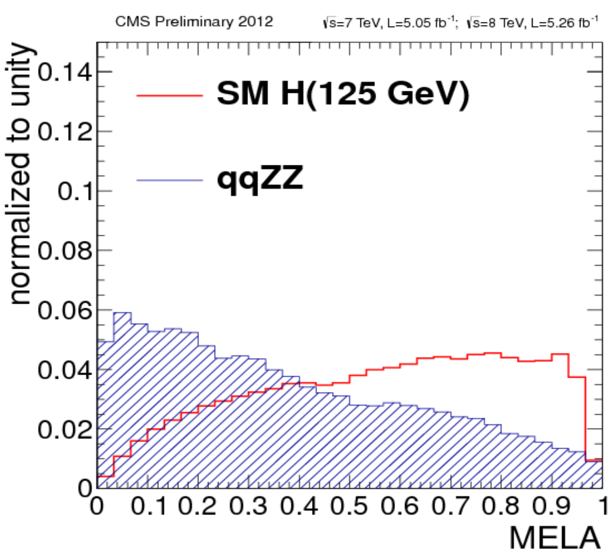
CMS: use other kinematical variables



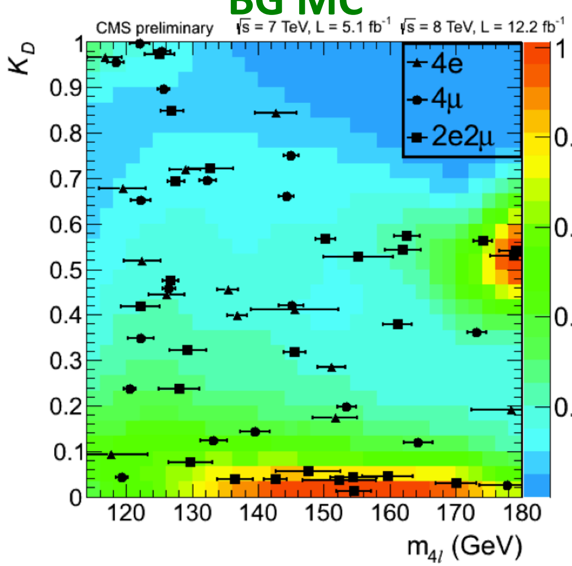
MELA: Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to ZZ background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

$$\text{MELA} = \left[1 + \frac{\mathcal{P}_{\text{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\text{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

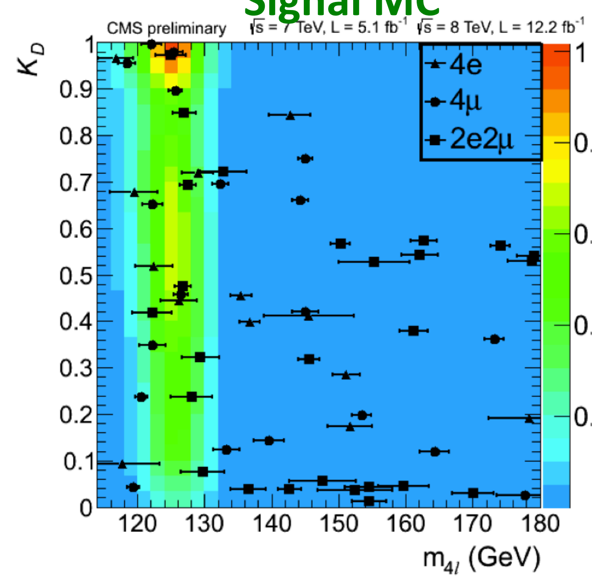
Improves the sensitivity by ~20% compared to using the mass alone



BG MC

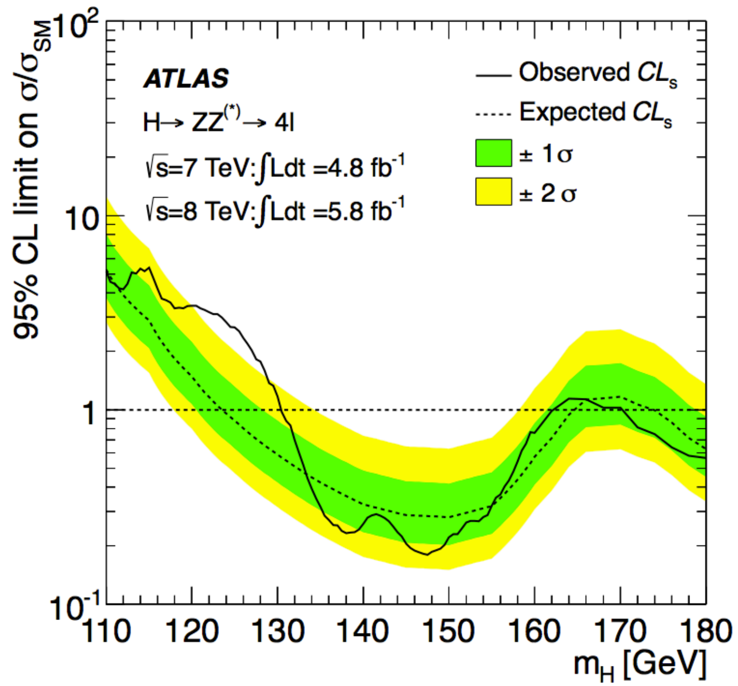


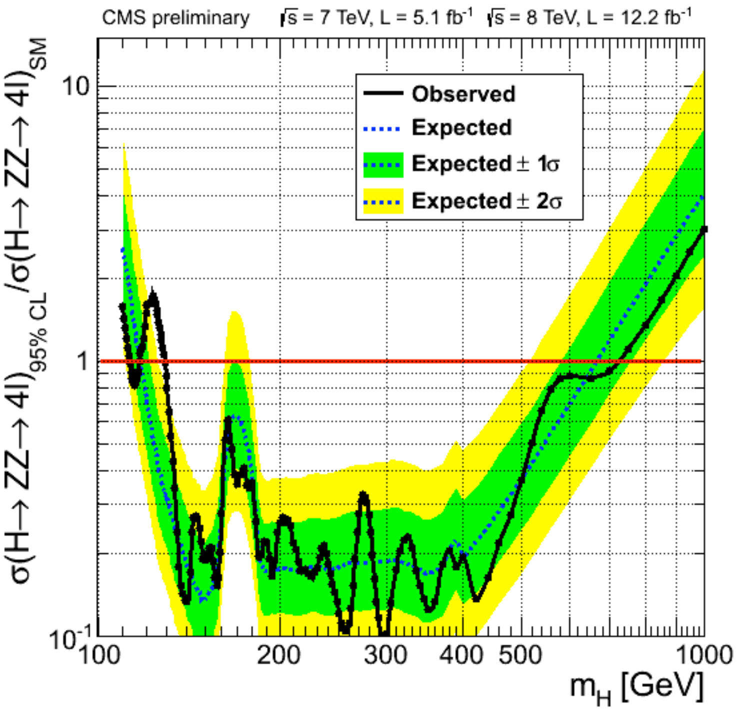
Signal MC



H→ZZ→4l exclusion

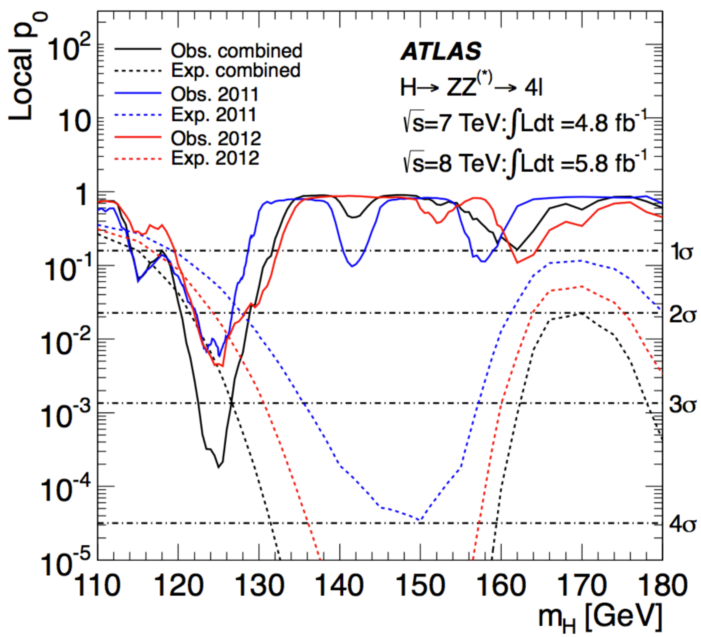
ATLAS: Not updated after discovery papers in July

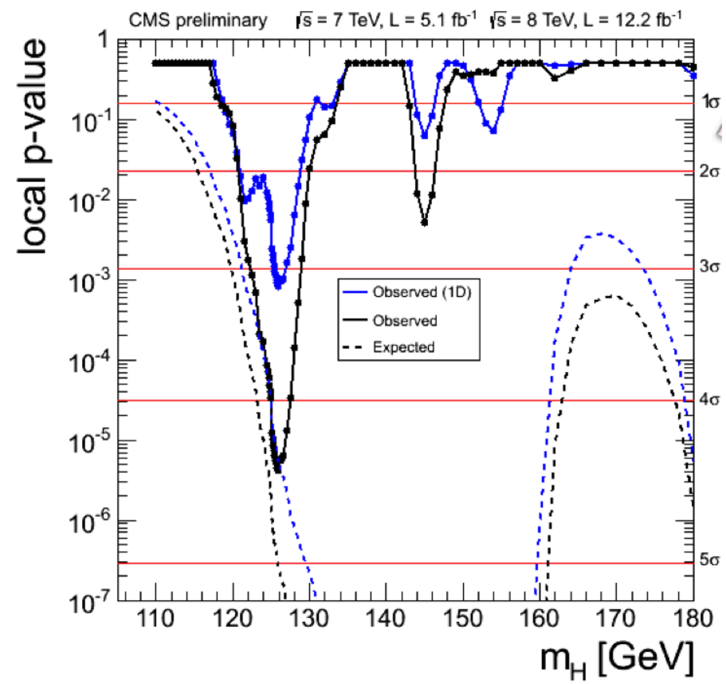




	ATLAS	CMS
Expected exclusion 95% CL	124 - 164 and 176 - 500 GeV	120 - 680 GeV
Observed exclusion 95% CL	131 - 162 and 170 - 460 GeV	113 – 116 and 129 - 720 GeV

H→ZZ→4l p-value



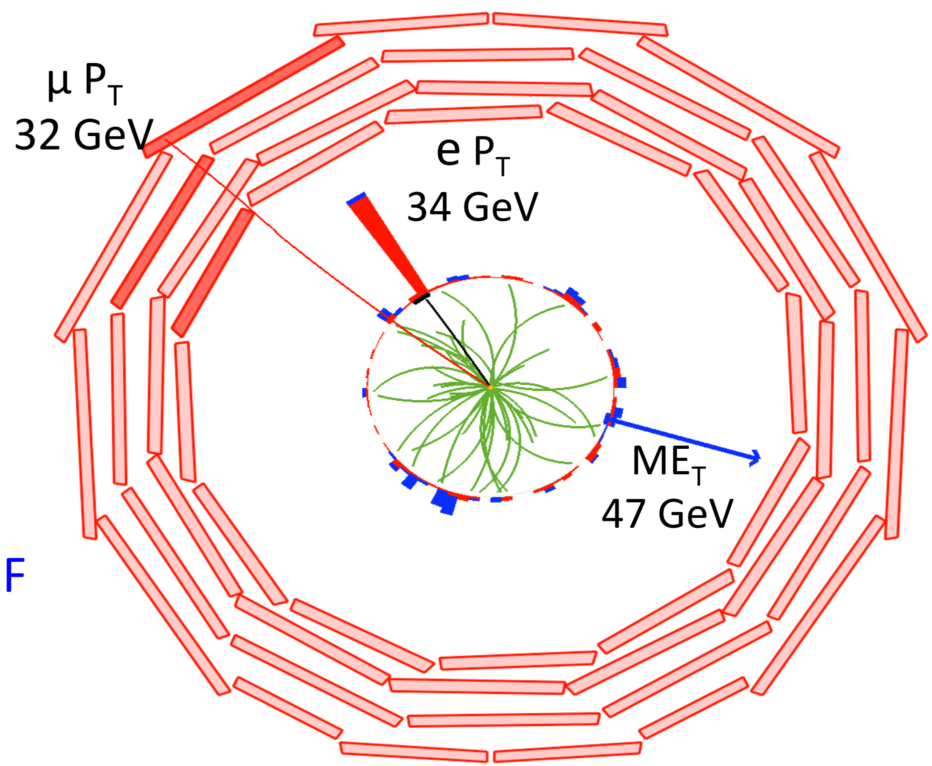


	ATLAS	CMS
Mass position of minimum local p-value	125 GeV	126.0 GeV
Local significance at minimum	3.6 σ	4.5 σ
Expected	2.7 σ	5.0 σ
Fitted μ	1.4 ± 0.6	0.8 ± 0.3

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

- Most sensitive channel around 2 x M_W (125 <~ M_H <~ 200 GeV)
- **No narrow mass peak (mass resolution ~20%)**
- Main backgrounds
  - WW (irreducible but signal tends to have smaller angle between leptons)
  - Z+jets, WZ, ZZ, tt, W + jets

H->WW->eμνν candidate in CMS



- Analysis can be performed in exclusive jet multiplicities (0, 1, 2-jet bins) and flavour (ee, μμ, eμ)
  - Different BG
  - 2 jet bin mainly corresponds to VBF dijet tag

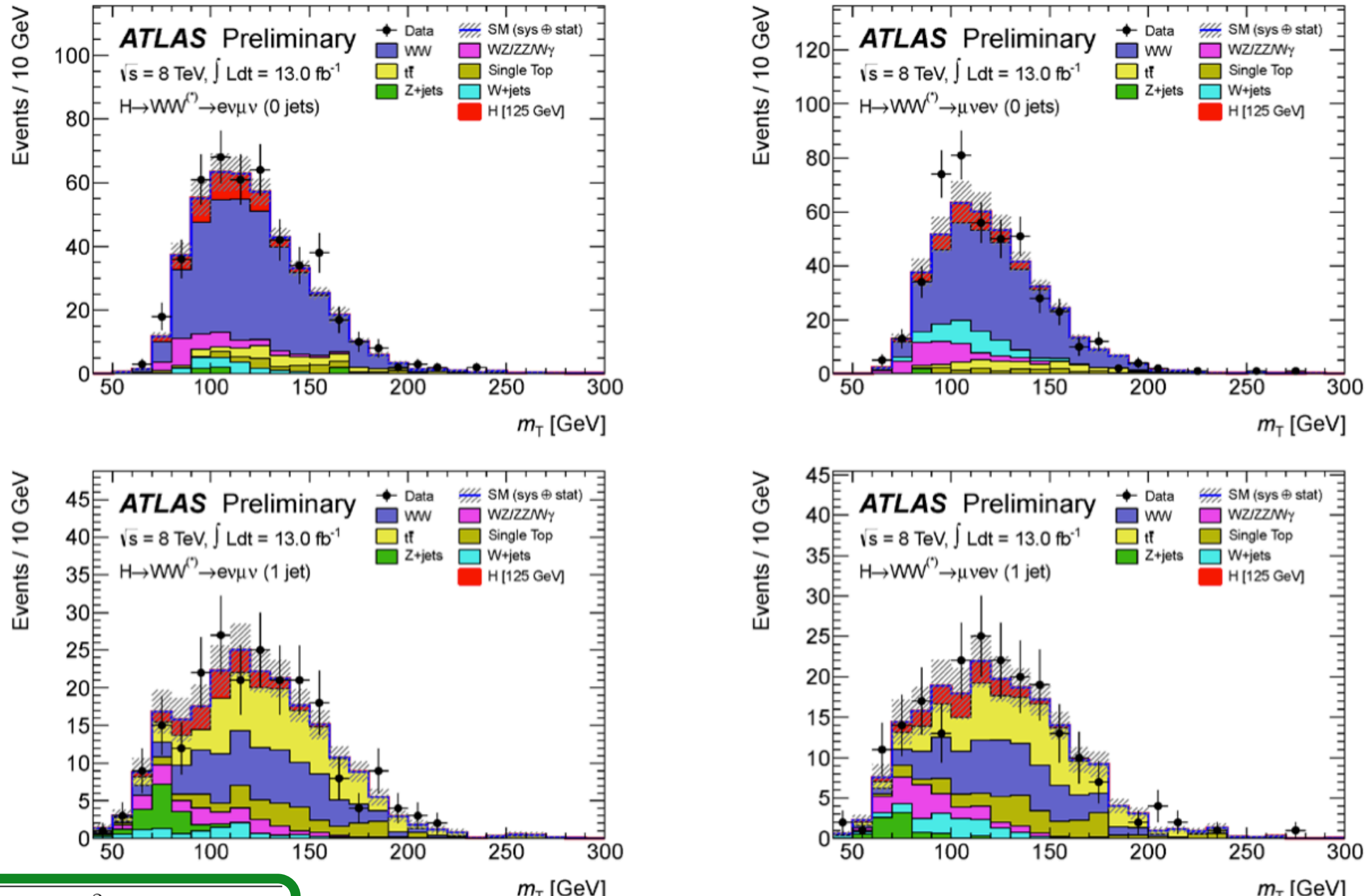
$WW \rightarrow l\nu l\nu$ analysis strategy

CMS

0 Jets (SHAPE)	1 Jet (SHAPE)	2 Jets (Cuts)	Different flavour (eμ)
0 Jets (Cuts)	1 Jet (Cuts)	2 Jets (Cuts)	Same flavour (ee, μμ)

- Same flavour has much larger BG and larger systematic errors (cut based analysis used)
- ATLAS only uses different flavour signature
  - Due to PU effect on MET resolution
  - Define 4 categories: eμ and μe (first is highest PT) and 0-jet and 1-jet categories
- New for CMS: 2D shape analysis in M_{ll}, M_T variables

ATLAS 4 categories at 8 TeV

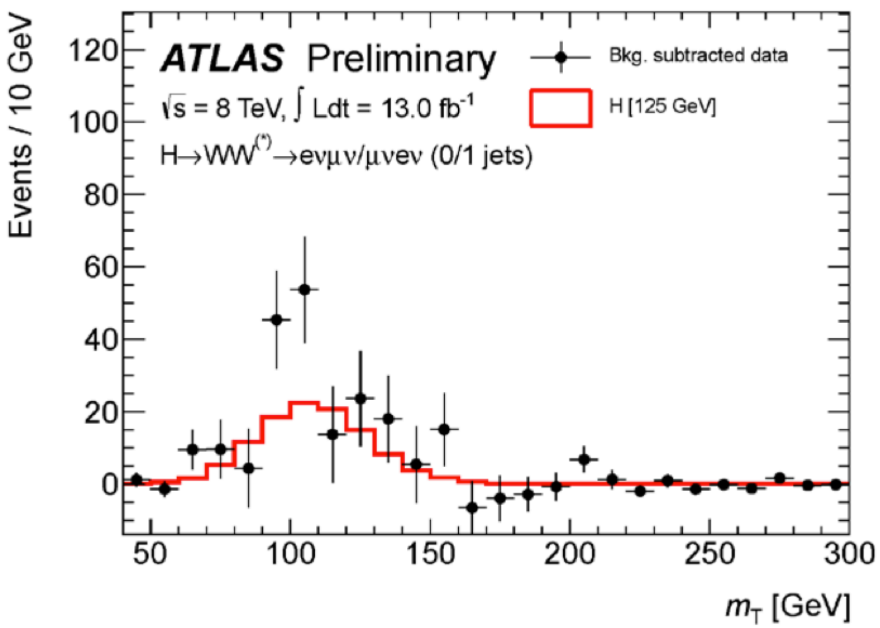


$$m_T \equiv \sqrt{\left(\sqrt{p_T^{\ell\ell 2} + m_{\ell\ell}^2} + \not{E}_T\right)^2 - |\vec{\mathbf{p}}_T^{\ell\ell} + \vec{\not{\mathbf{E}}}_T|^2}$$

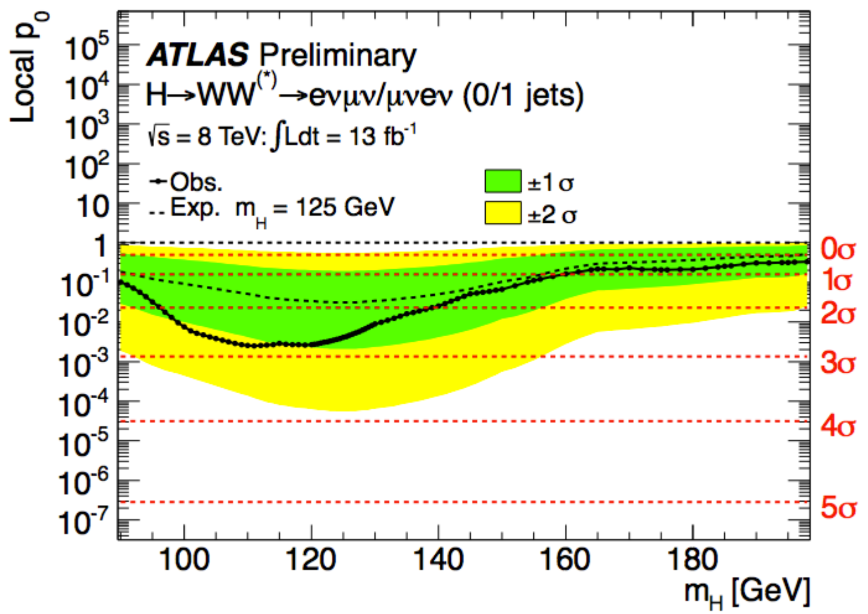
	Signal	WW	$WZ/ZZ/W\gamma$	$t\bar{t}$	$tW/tb/tqb$	$Z/\gamma^* +$ jets	$W +$ jets	Total Bkg.	Obs.
$H+$ 0-jet	45 ± 9	242 ± 32	26 ± 4	16 ± 2	11 ± 2	4 ± 3	34 ± 17	334 ± 28	423
$H+$ 1-jet	18 ± 6	40 ± 22	10 ± 2	37 ± 13	13 ± 7	2 ± 1	11 ± 6	114 ± 18	141

ATLAS WW 4 channels combined

Background subtracted data for the 4 channels combined



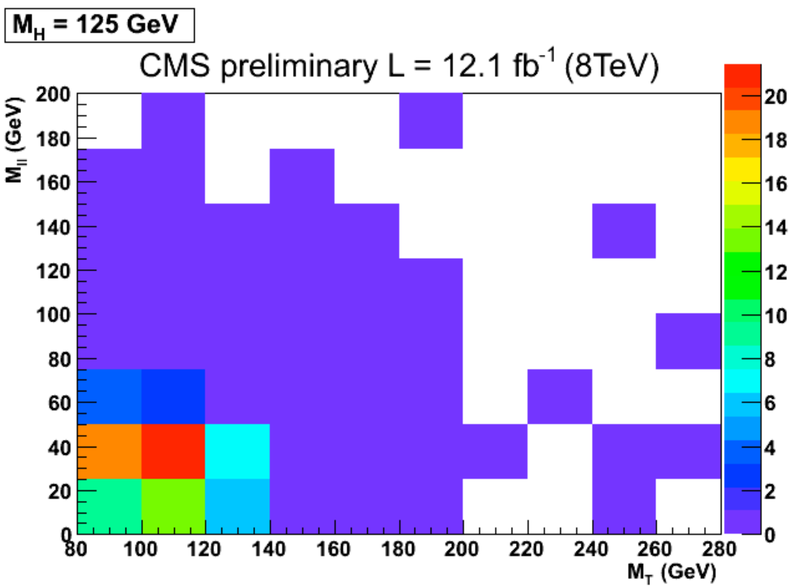
Only 8 TeV data, tot yet combined with 2011 7 TeV data

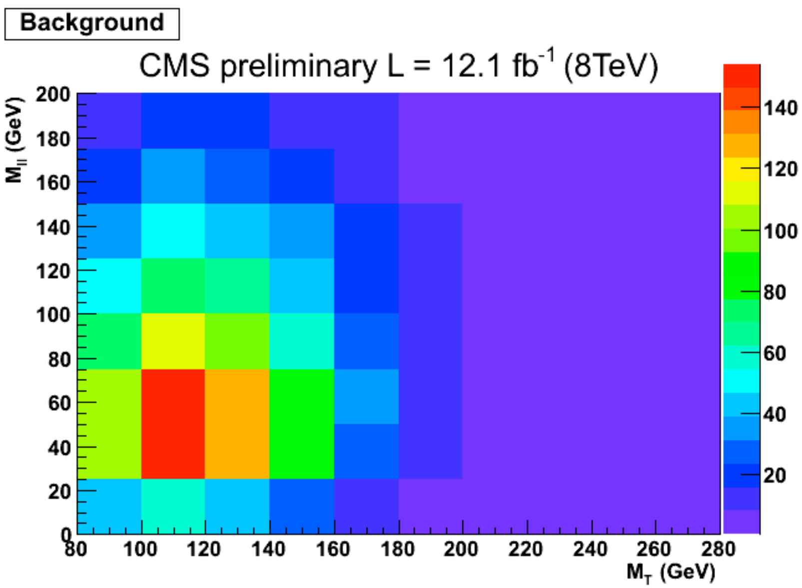


- Observed 2.6 σ at 125 GeV (1.9 σ expected)
- Fitted μ =1.5 ± 0.6

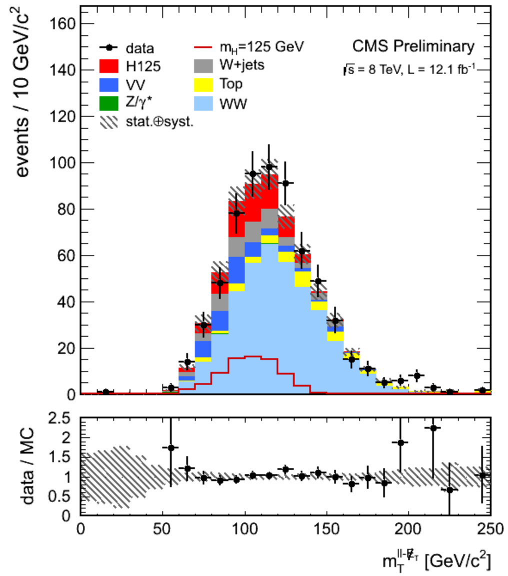
CMS: 2D shape analysis

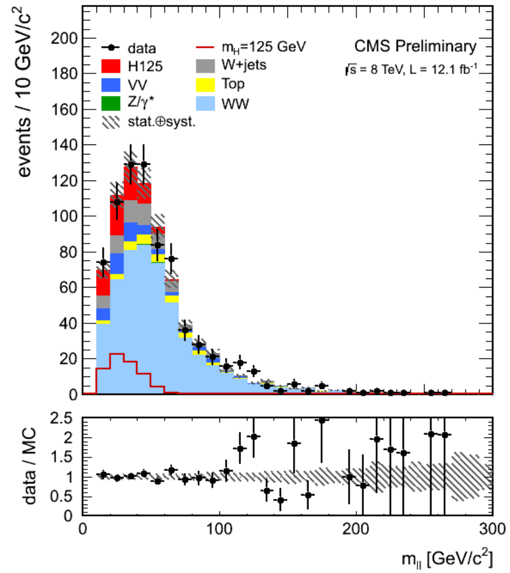
- Only for most sensitive channels
- Use M_{ll} vs M_T
- Different types of BG have different distributions
- 2D fit is able to constrain the BG in different regions
- Simpler than previous MVA analysis because it is the same for all masses



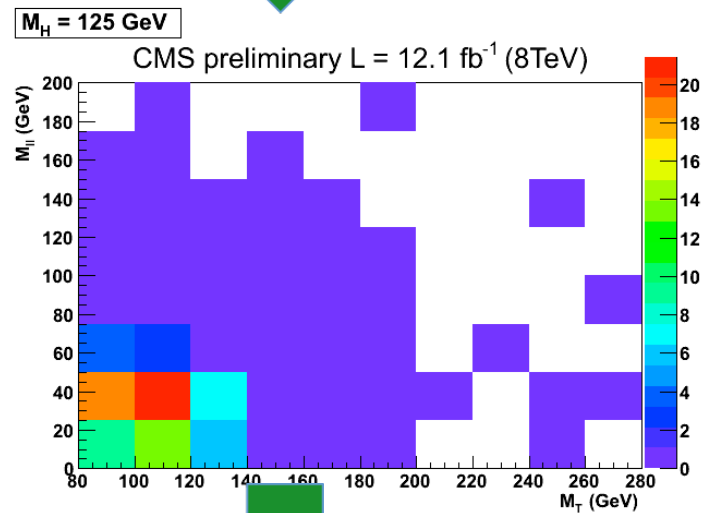


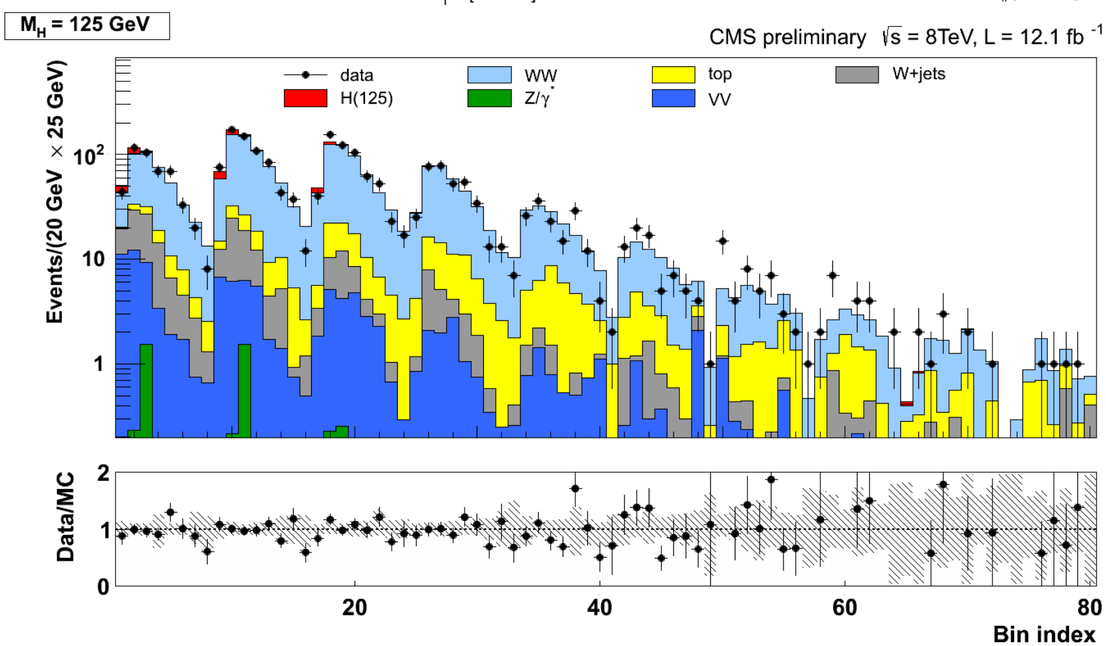
2D analysis





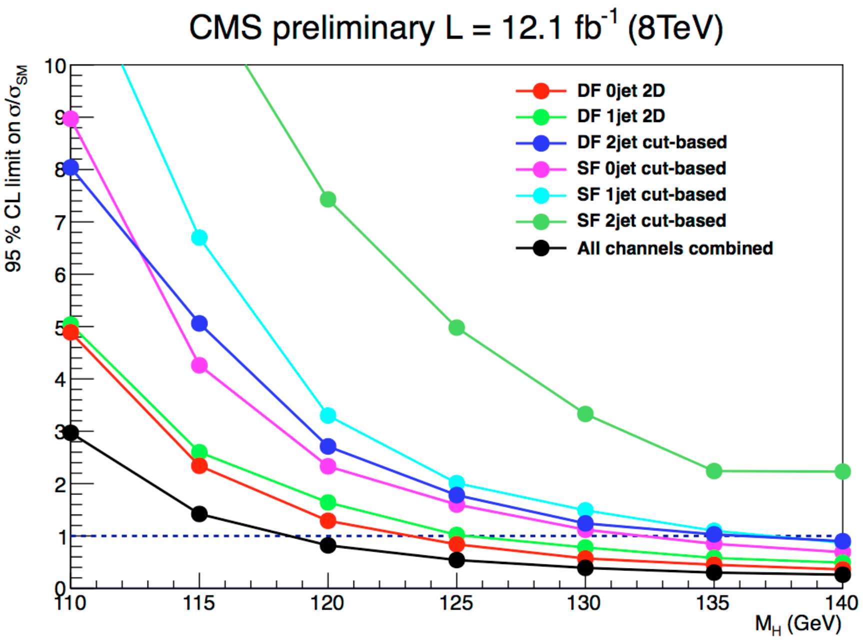
Combine the two variables

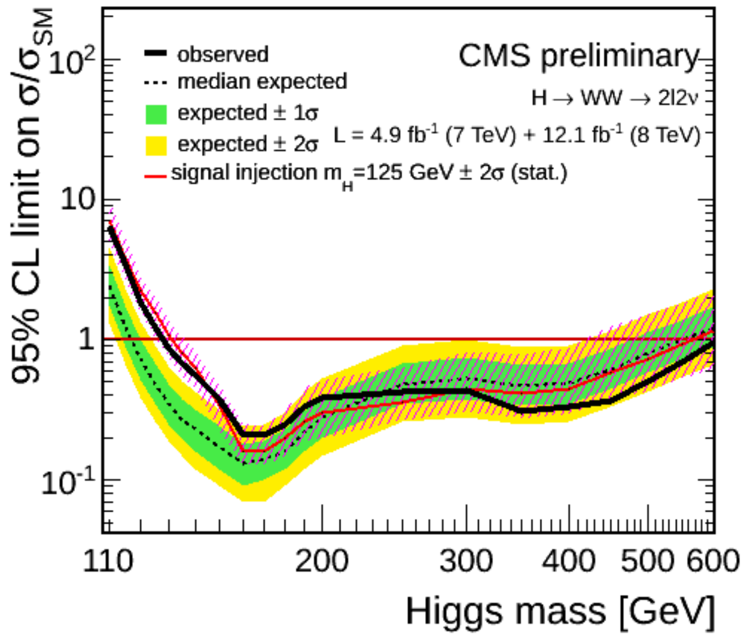




Unfold to visualize
In 1 dimension

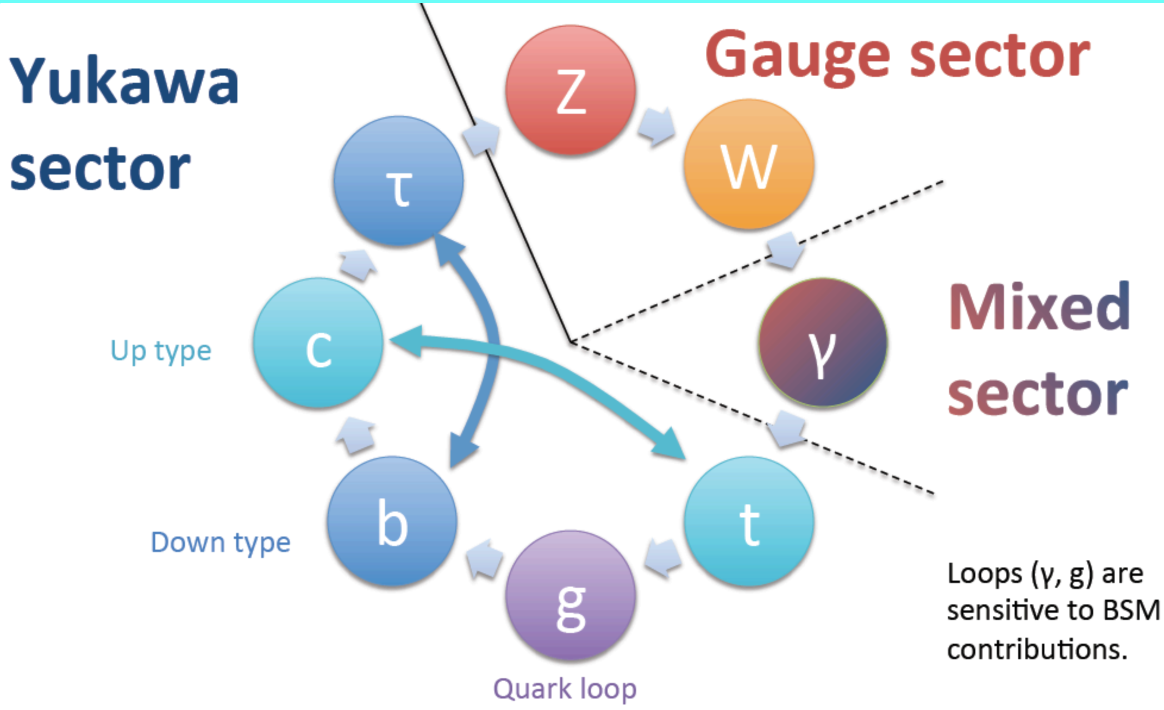
CMS WW results





- Combine published 7 TeV cut based with 8 TeV 2D shape analysis
- Observed: 3.1 σ at 125 GeV (expected: 4.1 σ)
  - Evidence of H->WW->lνlν decay
- Signal strength μ = 0.74 ± 0.25 at 125 GeV

New boson's decays to fermions



- Couplings of the new boson in the Yukawa sector are not yet directly observed
- H(125) presumably couples to quarks, indicated by presence of gg-fusion
- H->ττ decay not yet established

H→ττ analysis

- Complicated analysis, combination of many different sub-channels

Decay

$$H \rightarrow \tau\tau \rightarrow \ell\ell + 4\nu \ (12\%)$$
$$H \rightarrow \tau\tau \rightarrow \ell\tau_h + 3\nu \ (46\%)$$
$$H \rightarrow \tau\tau \rightarrow \tau_h\tau_h + 2\nu \ (42\%)$$

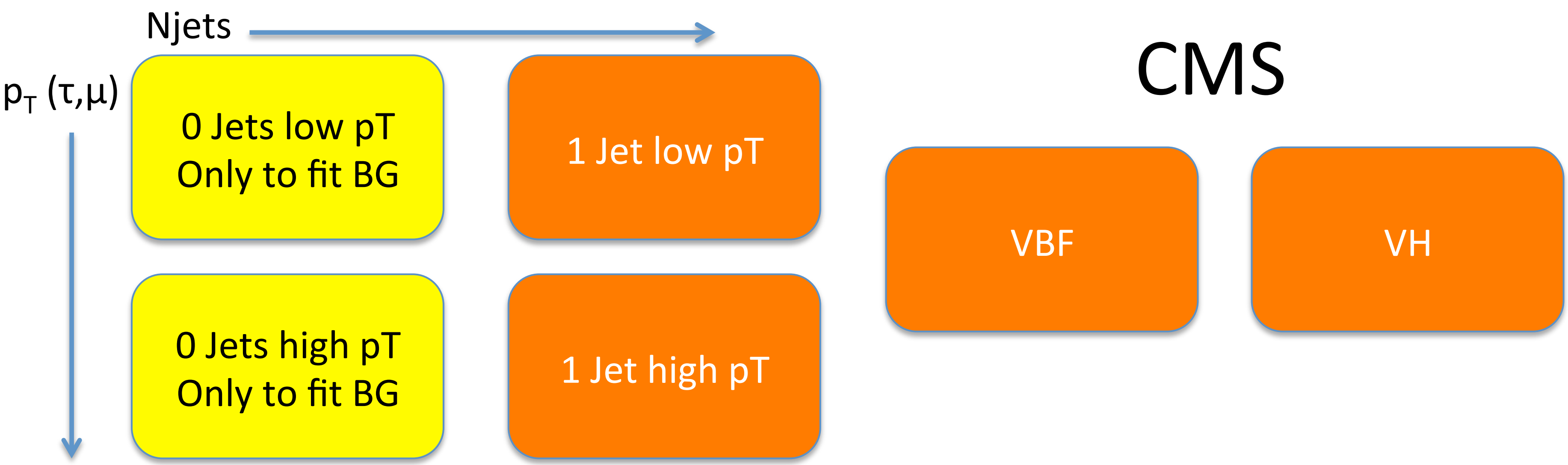
$\otimes$

Also split e and μ in the analysis

Production/signature

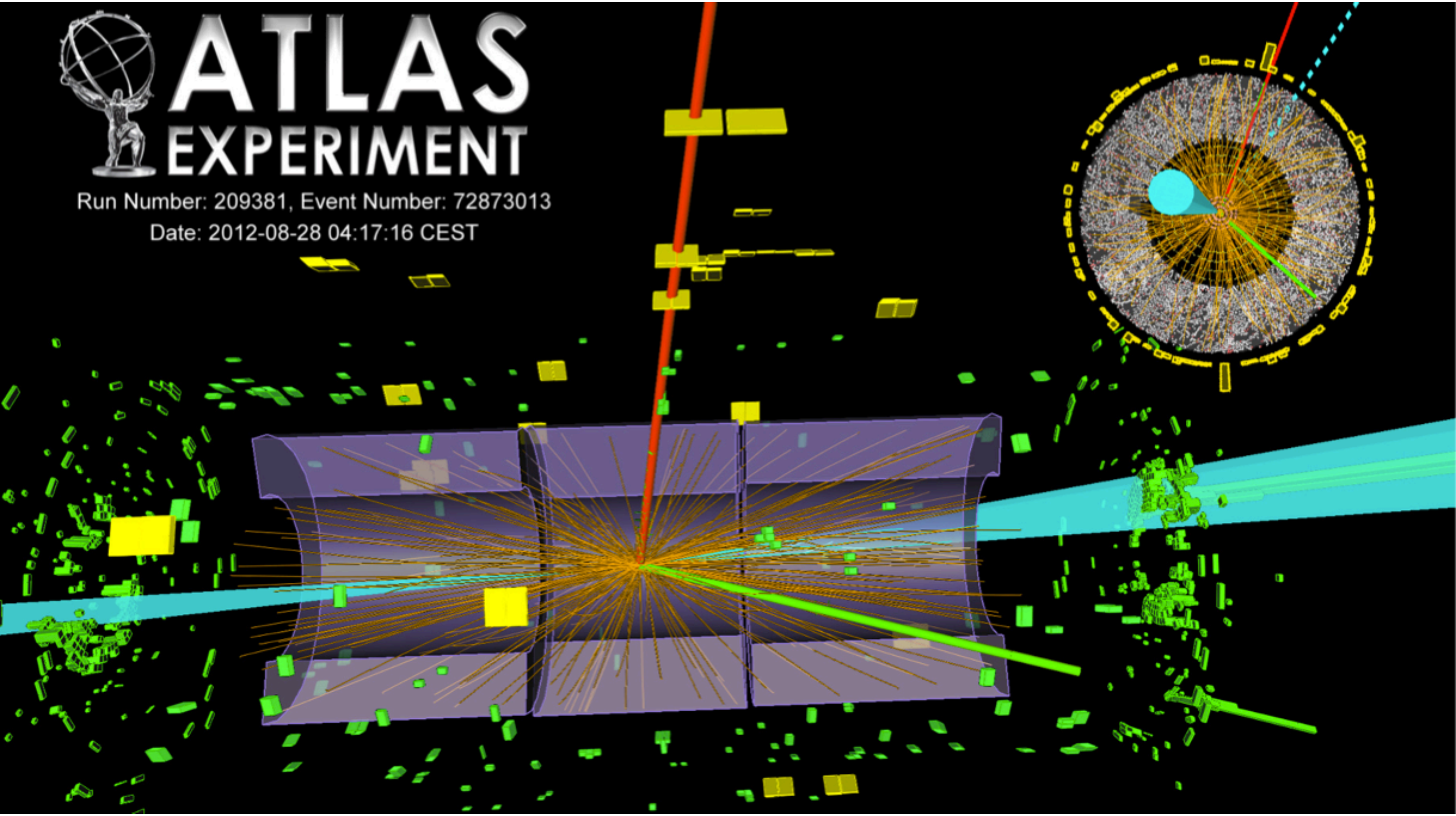
0-jet (ATLAS only)
1-jet boosted
2-jet VBF
VH (ATLAS 2-jet, CMS leptonic decays of V)

- More than 10 sub-channels for each of the experiments



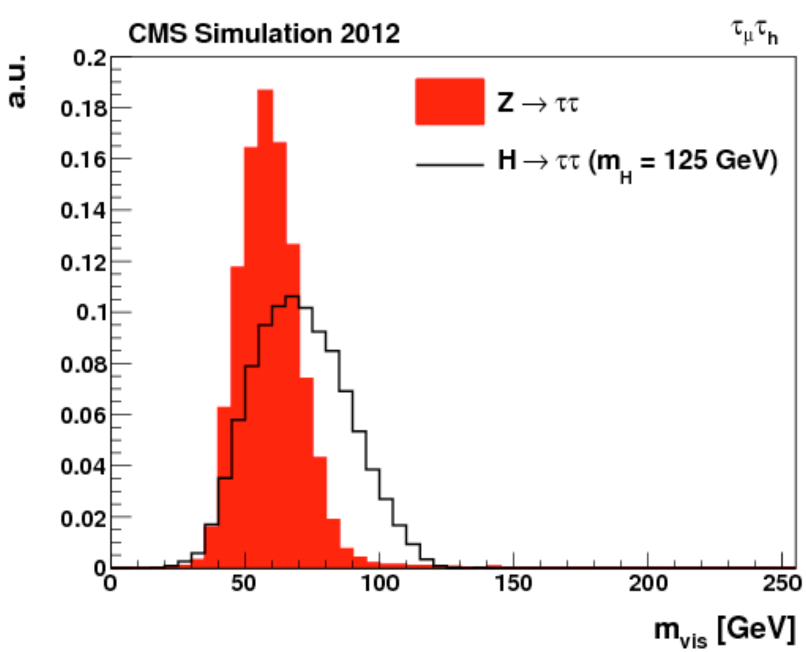
- Z->ττ main BG
- Stopped using 0-jet category in CMS
  - Only kept to fit BG normalization

H→ττ VBF candidate

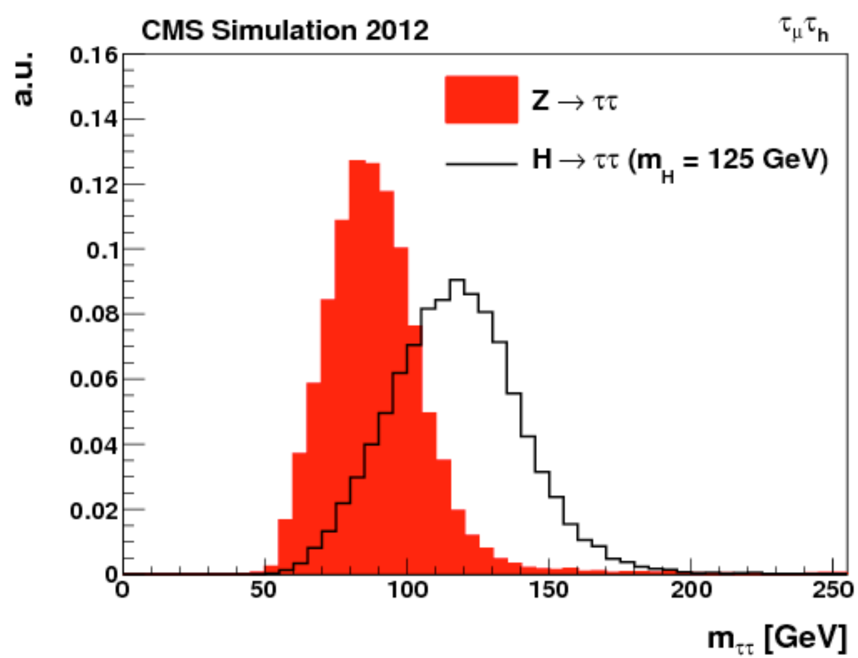


- Invariant mass calculation
  - Use full kinematical fit
  - Mass resolution: 15-20%

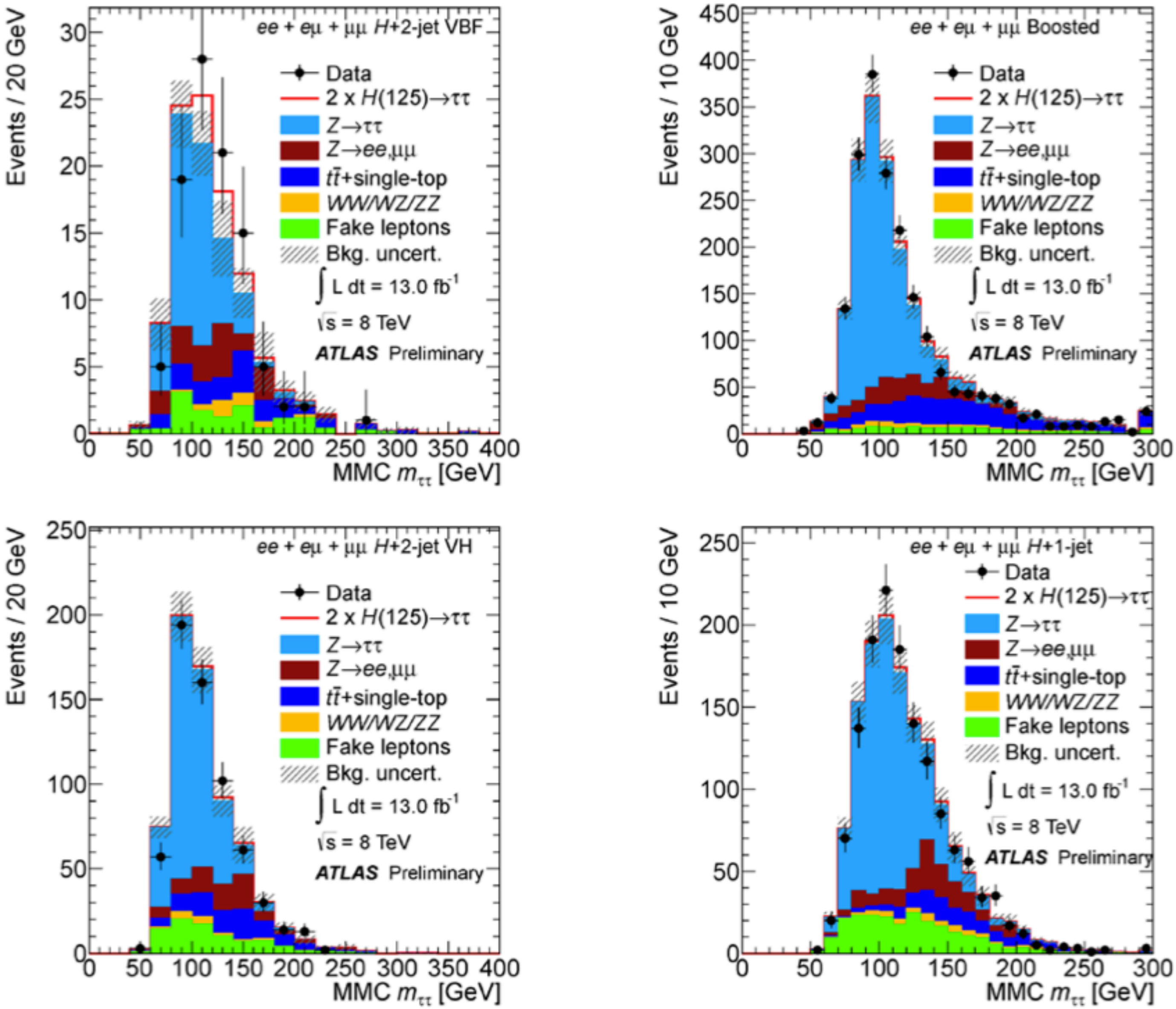
Visible mass



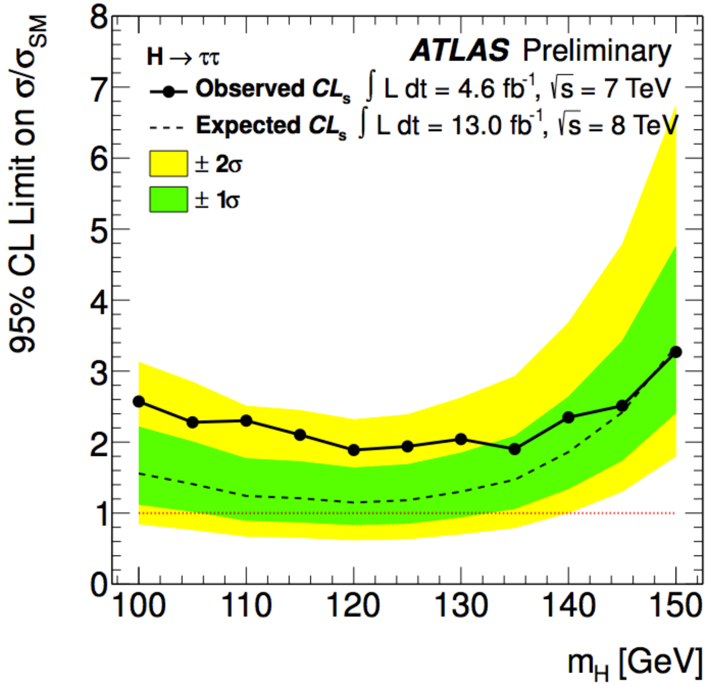
Fitted mass

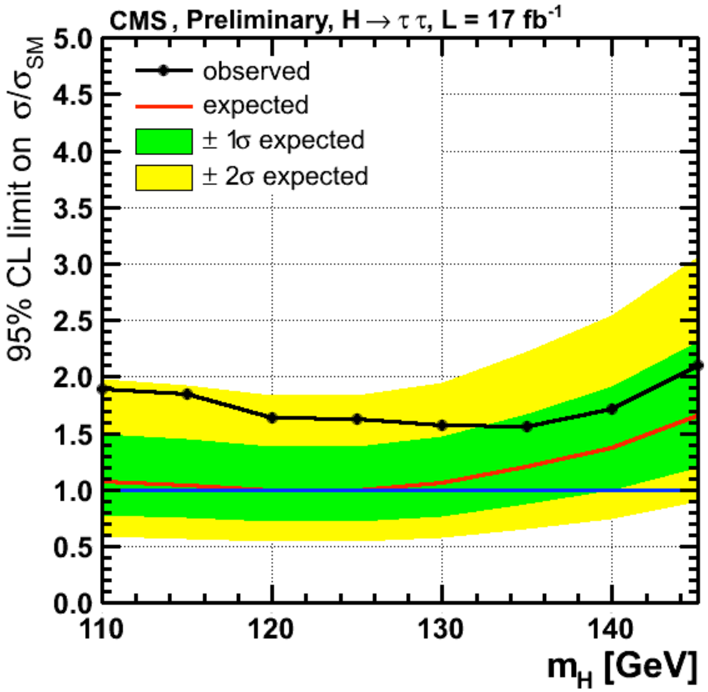


Reconstructed ττ mass spectrum



H→ττ results

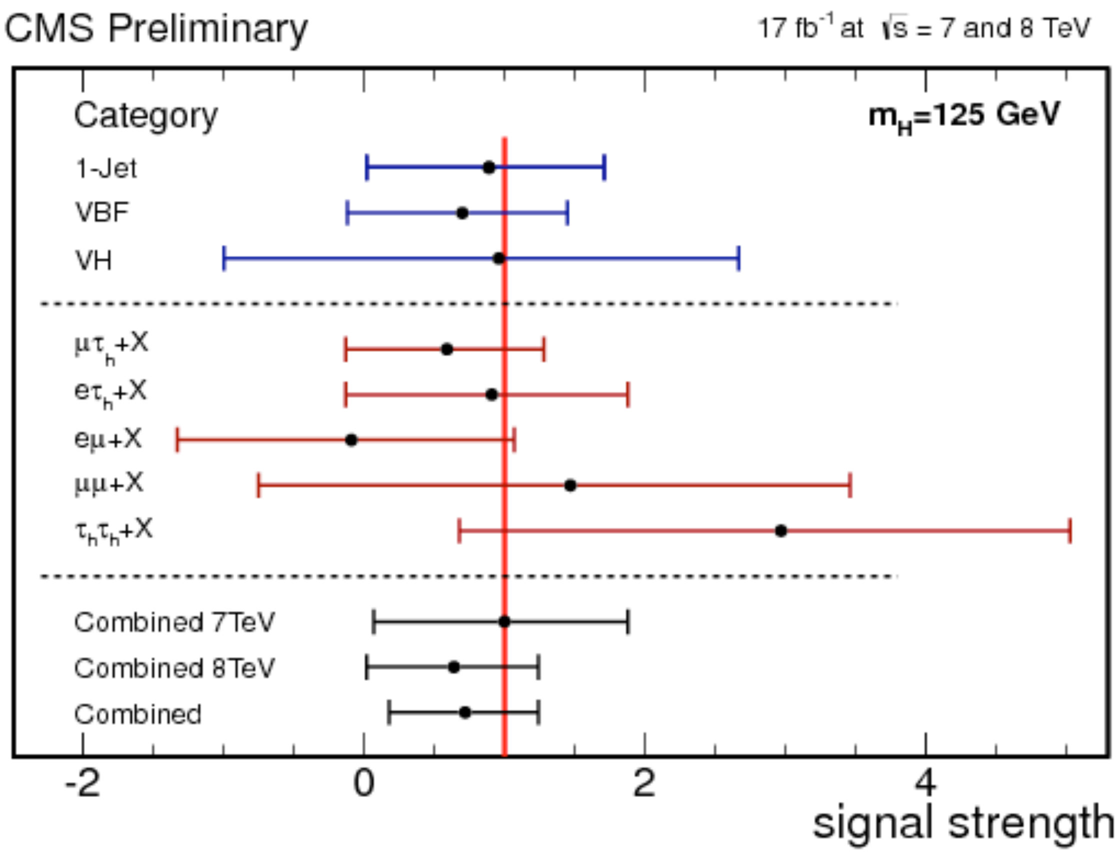




	ATLAS	CMS
Expected 95% CL exclusion	1.2	1.0
Observed exclusion 95% CL	1.9	1.6
Fitted μ	0.7 ± 0.7	0.72 ± 0.52

Three views of channel compatibility plots

- Fitted signal strength in different categories/channels/run periods



By production tag

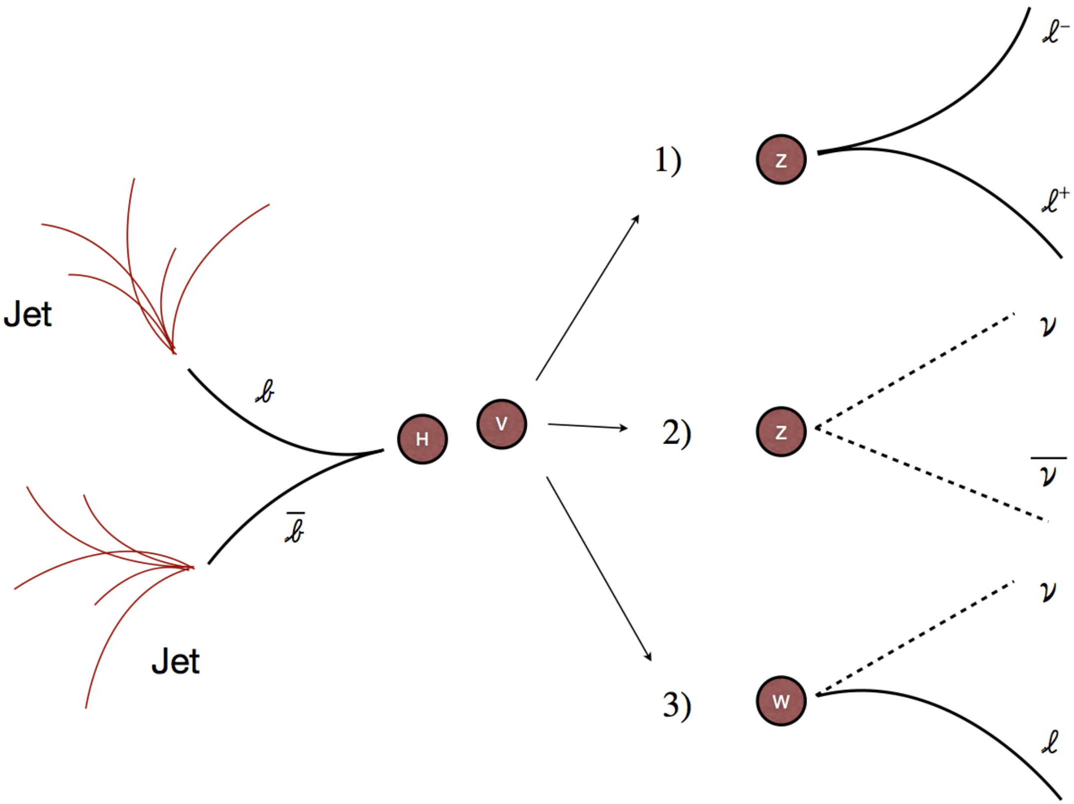
By decay channel

By year/CM energy

Not yet evidence of ττ decay

H→bb channel

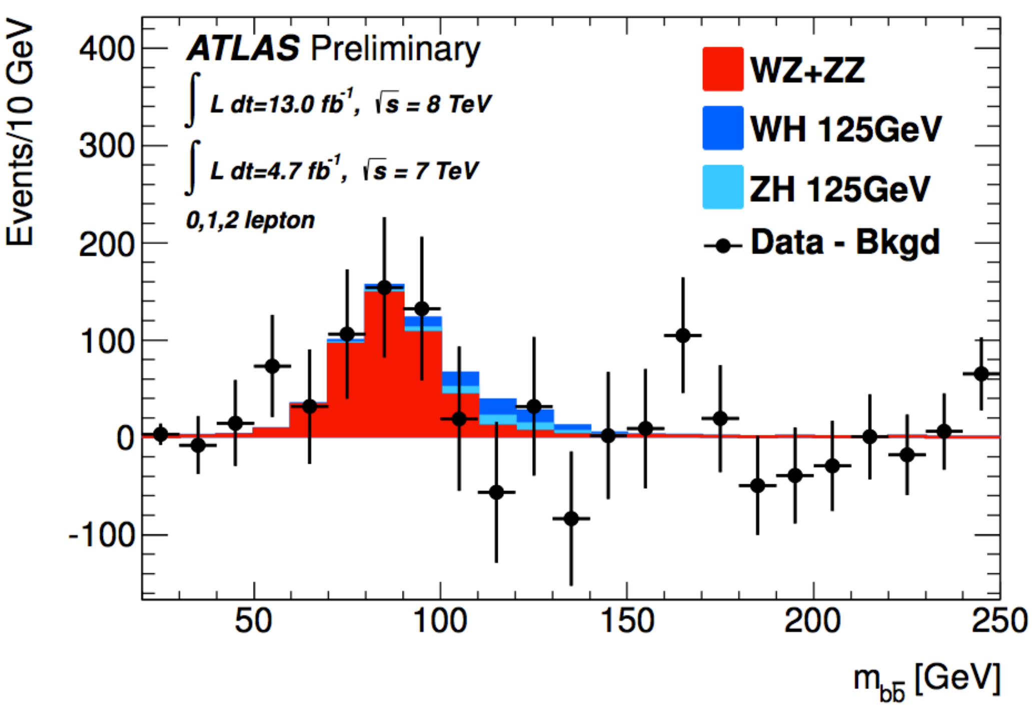
- BR in SM at 125 GeV ~60%
- BG too large (7-8 orders of magnitude larger, needs additional tag
- Both ATLAS and CMS use VH associated production
  - Z->ee, μμ, νν
  - W->e,μ
- Mass resolution ~10%
- Also start exploiting ttH production
  - Much less sensitive and for now only 2011 data analyzed



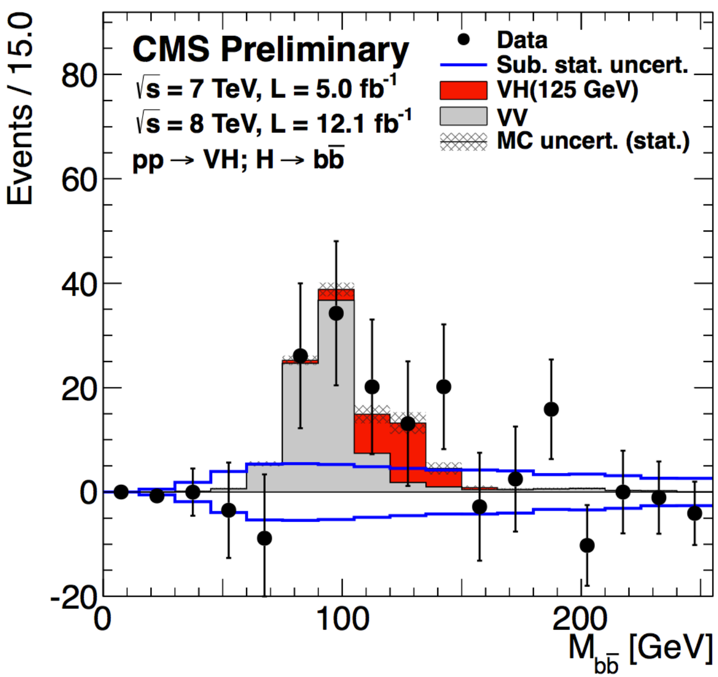
H→bb all channels combined

- Both experiment observe ZV with Z->bb
  - ~5 times larger cross section
  - All BG except diboson 'signal' subtracted in the plots
- CMS sees larger excess than ATLAS at 125 GeV

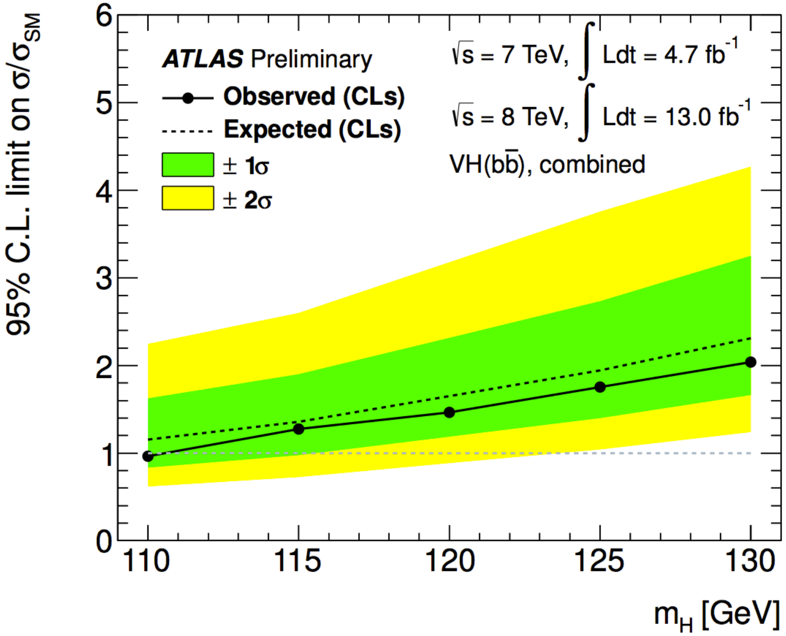
4 sigma significance of ZV

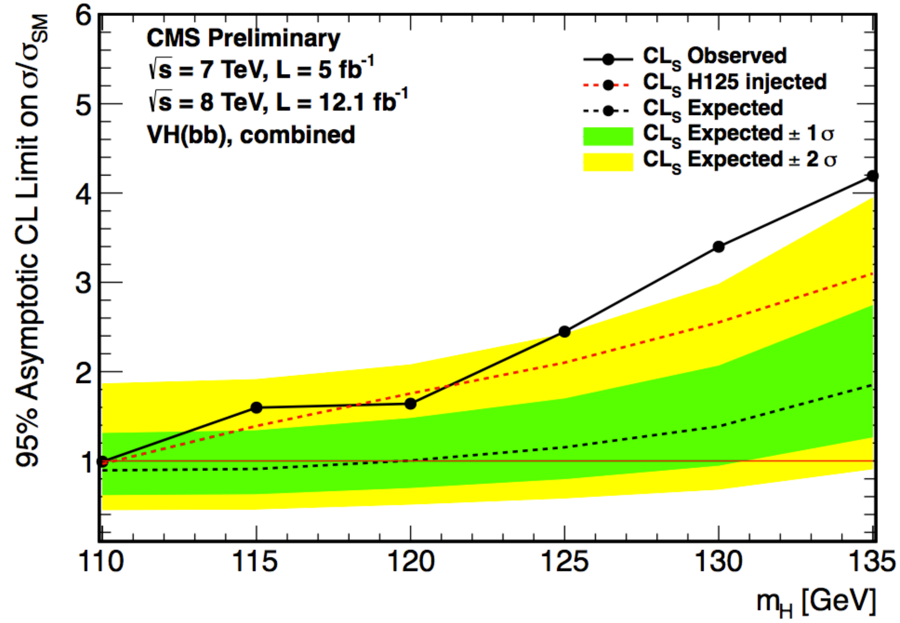


Tighter cut based selection



H→bb results





	ATLAS	CMS
Expected 95% CL exclusion	1.9	1.1
Observed exclusion 95% CL	1.8	2.4
Observed significance	0.64	2.2 σ
Expected significance	0.15	2.1 σ
Fitted μ	-0.4 ± 0.7 ± 0.8	1.3 ± 0.7

Some excess observed in CMS

Combination of channels

- Method for CL calculation is LHC-type CLs
  - Frequentist CLs with profiled likelihood test statistics and log-normal treatment of nuisance parameters
  - ATL-PHYS-PUB/CMS NOTE 2011-11, 2011/005, (2011)
- To extract the values of the parameters, we scan the profile likelihood ratio:

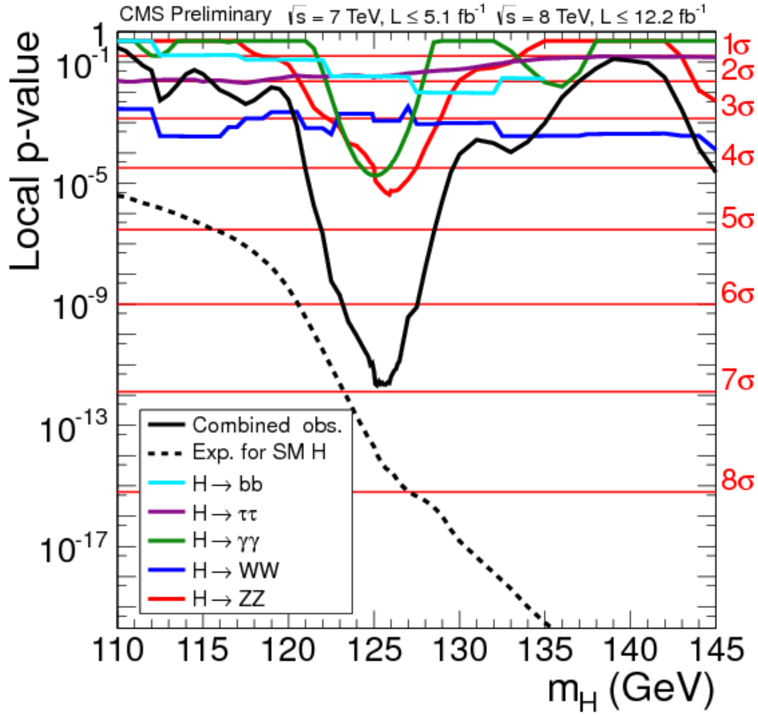
$$q(a) = -2 \ln \frac{\mathcal{L}(\text{obs} \mid s(a) + b, \hat{\theta}_a)}{\mathcal{L}(\text{obs} \mid s(\hat{a}) + b, \hat{\theta})}$$

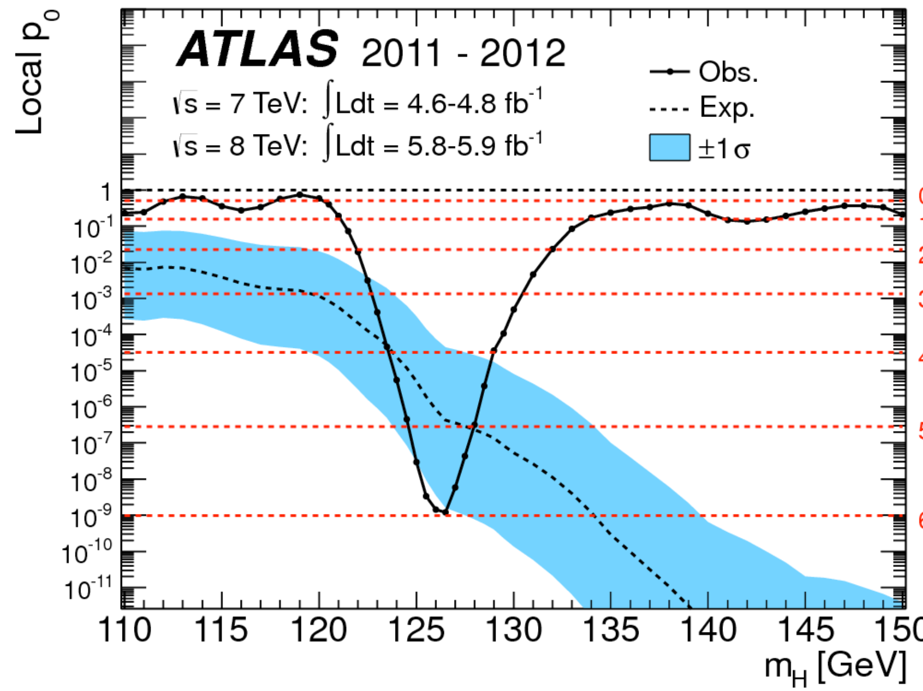
  where $\hat{a}$ and $\hat{\theta}$ are the values of the parameters and the nuisances that maximize the likelihood

- To parametrize the couplings, follow LHC working group prescription (arXiv:1209.0040)
  - SM dependent models, search for small deviations

Observation of a new boson at ~126 GeV

No new combination after the observation paper

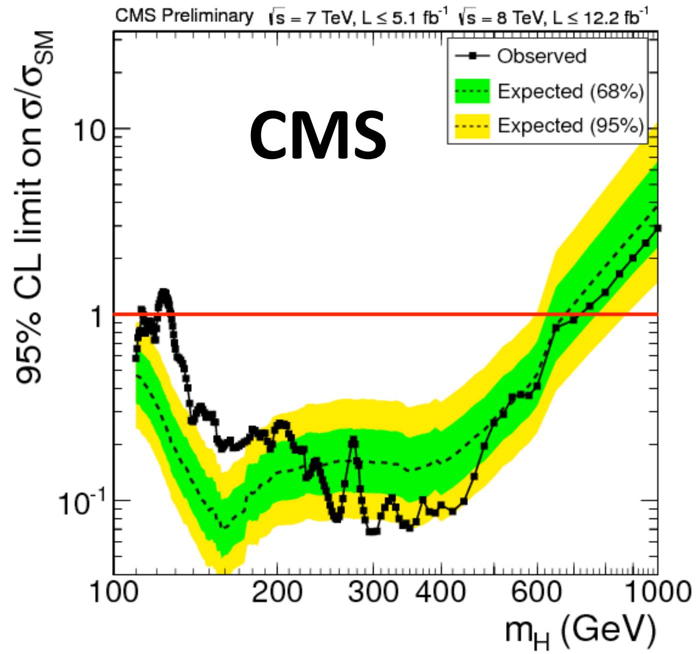


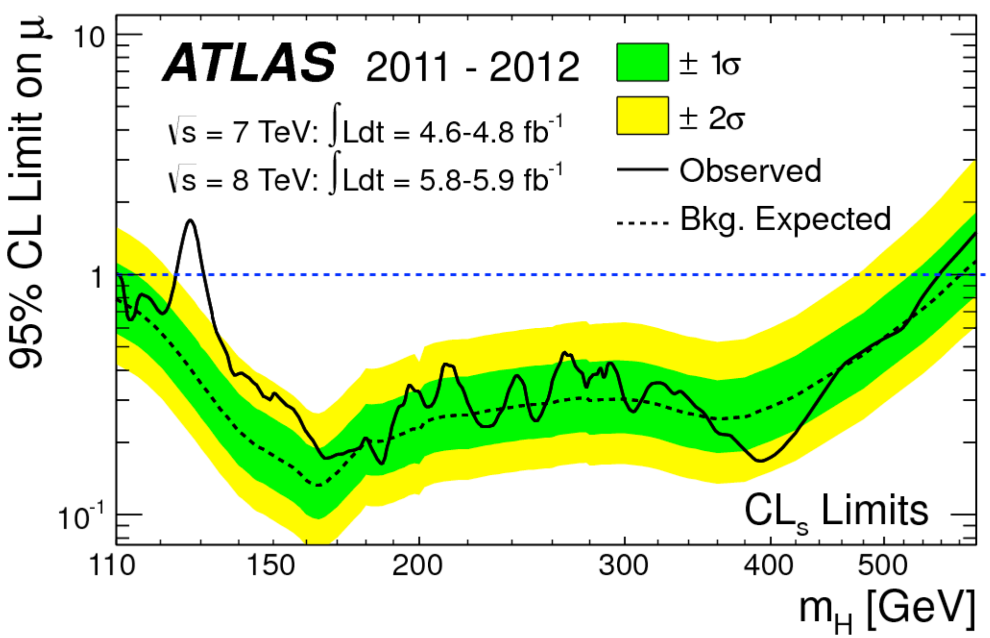


- Observation is confirmed with excesses of 6 - 7 σ in the 2 experiments at a mass near 126 GeV

Exclusion in the rest of the mass range

- At high mass most sensitive channels are WW and ZZ decays





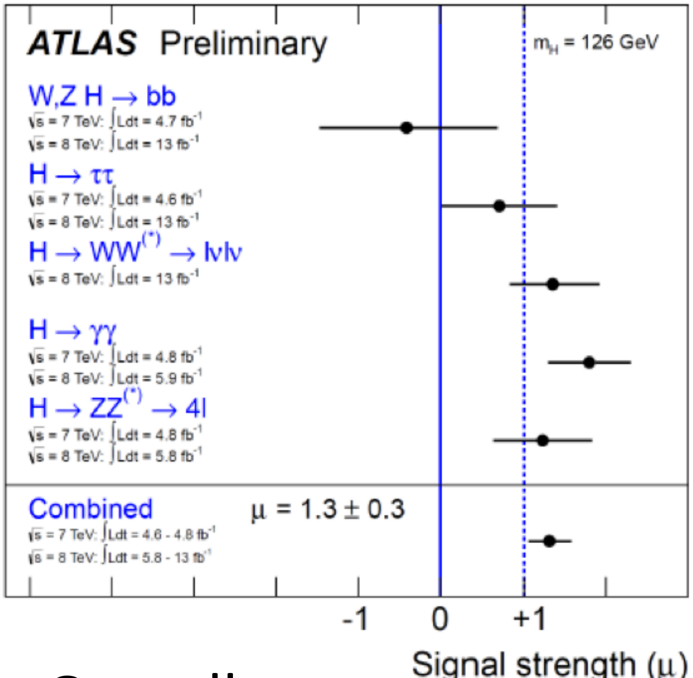
	ATLAS	CMS
Expected exclusion 95% CL	110 – 580 GeV	110 - 680 GeV
Observed exclusion 95% CL	130 - 560 GeV	129 - 720 GeV

New boson's properties

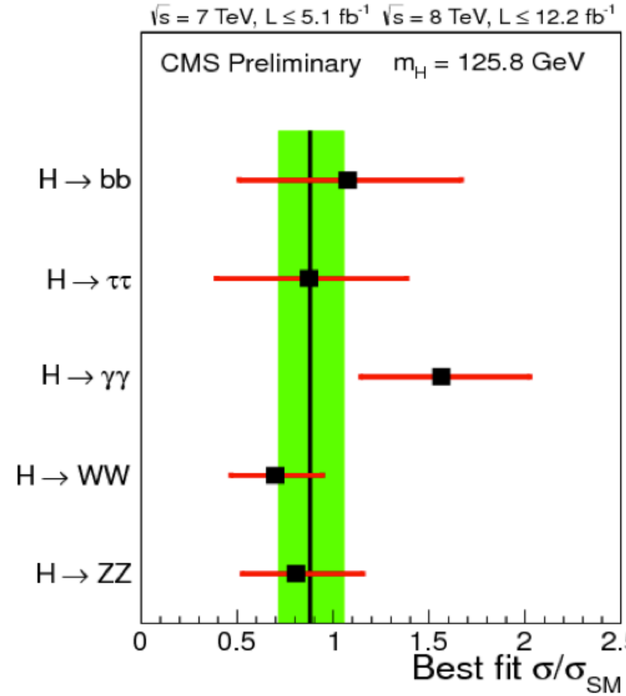
- After the discovery the questions we ask are:
  - What is the mass?
  - Is this particle a Higgs boson?
  - Is it consistent with the SM Higgs boson?
- To answer these we should:
  - Measure the production cross sections and BR
  - Measure the couplings
  - Measure spin and parity
    - Spin 1 excluded by the observation of the diphoton decay
- Both ATLAS and CMS are now starting to address all these questions

Signal strength μ in different channels

ATLAS



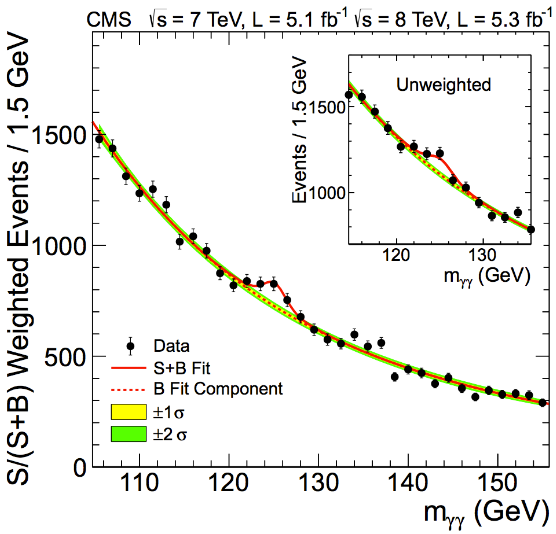
CMS

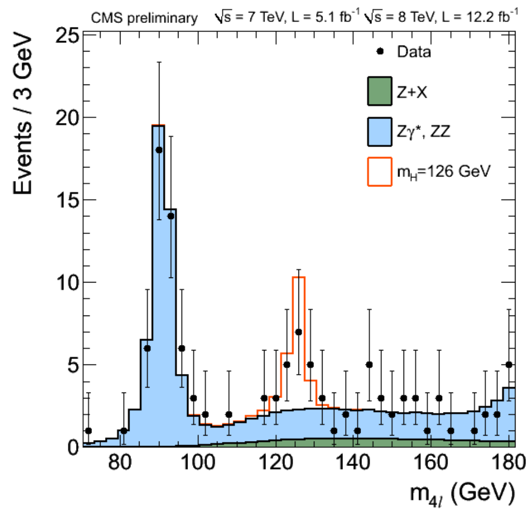


- Overall μ
  - ATLAS: 1.3 ± 0.3
  - CMS: 0.9 ± 0.2
- Everything consistent with SM within errors, no large deviations observed
- χ^2 probability of channel compatibility with SM ~50%

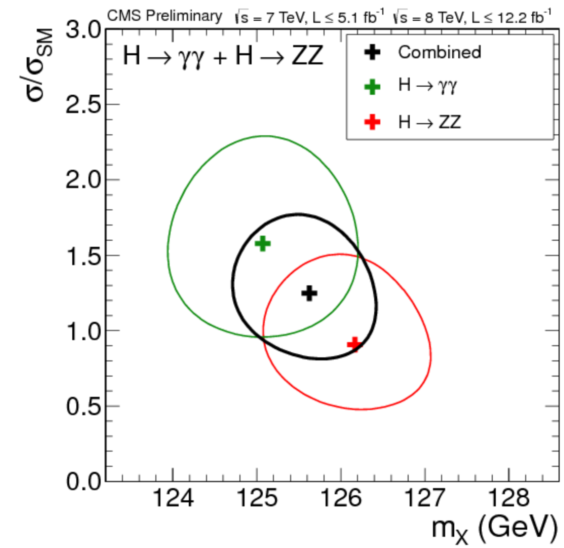
Mass measurement

From γγ and ZZ -> 4l mass spectra

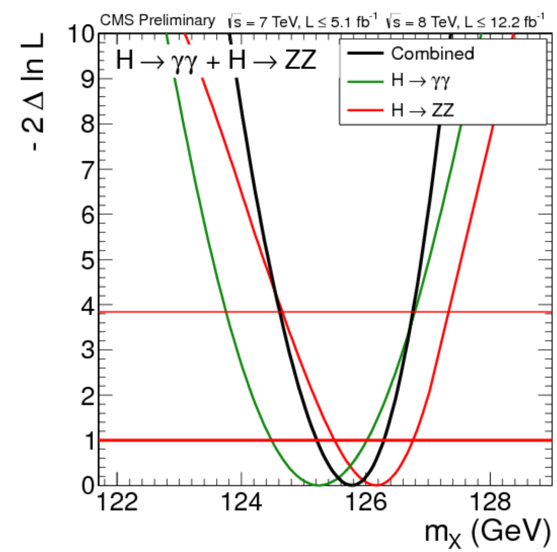




2D scan μ vs mass



1D scan: mass

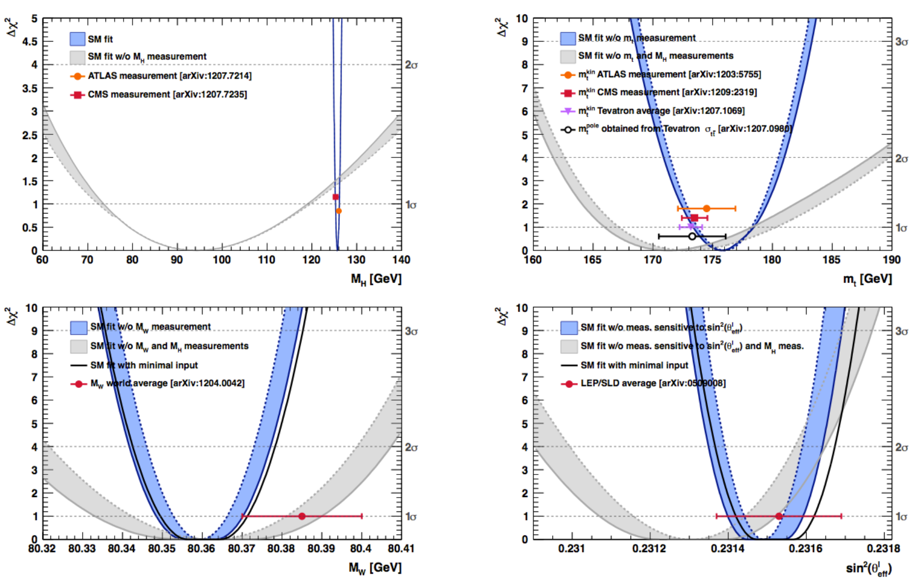


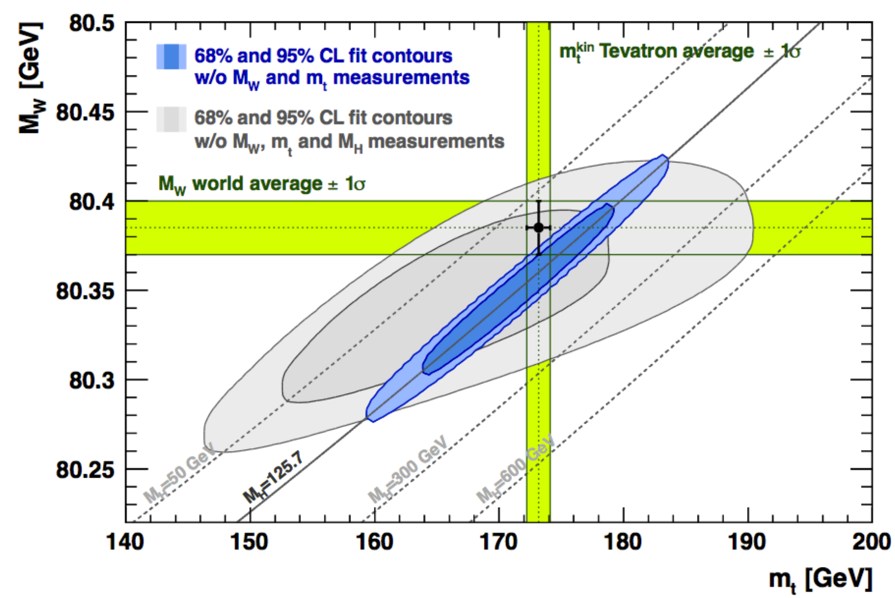
- Results
  - ATLAS 126.0 ± 0.4(stat.) ± 0.4 (syst.)
  - CMS 125.8 ± 0.4(stat.) ± 0.4 (syst.)
- Dominant systematic error is the absolute energy scale
  - largely uncorrelated between CMS and ATLAS

Global Fits – gfitter results

- M_H was the last SM parameter to be directly measured
- Important for EW precision test
- SM p-value of global fit 7%
  - Was 9% without direct measurement of MH
- Including M_H in the SM M_W and $\sin^2\theta_{eff}$ are predicted with a precision superior to the direct measurements and are compatible with them

arXiv:1209.2716

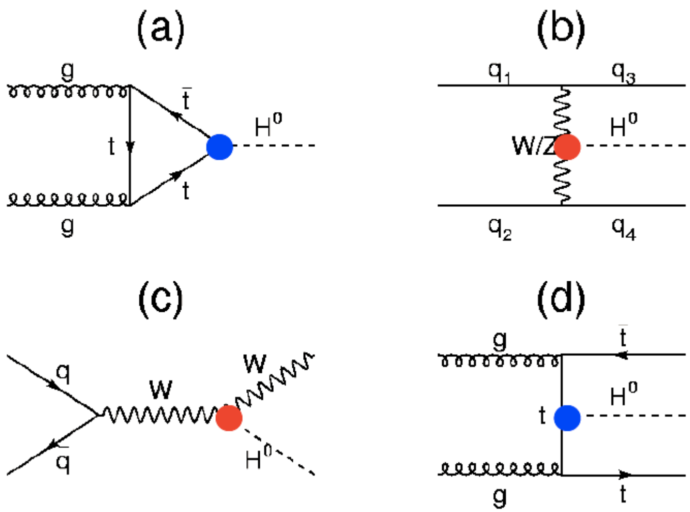


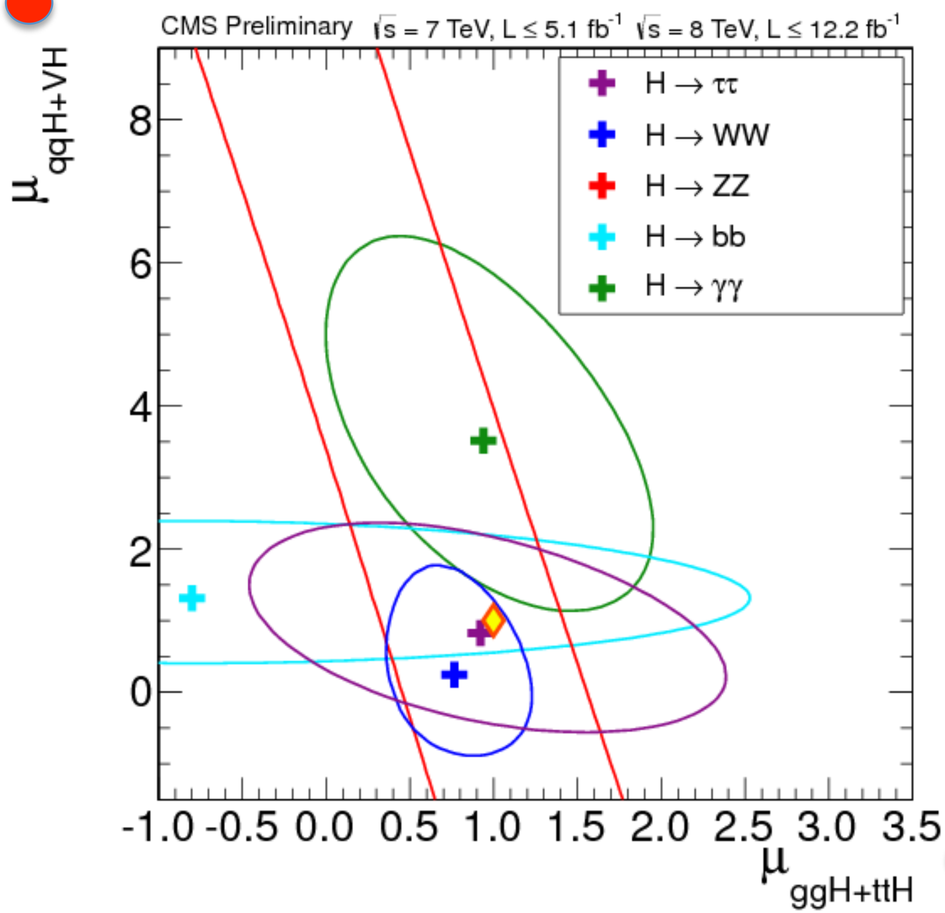


Production cross sections

- Measurement of production cross sections in the different channels
  - Decay BRs are fixed to the SM

ttH, WH and ZH couplings

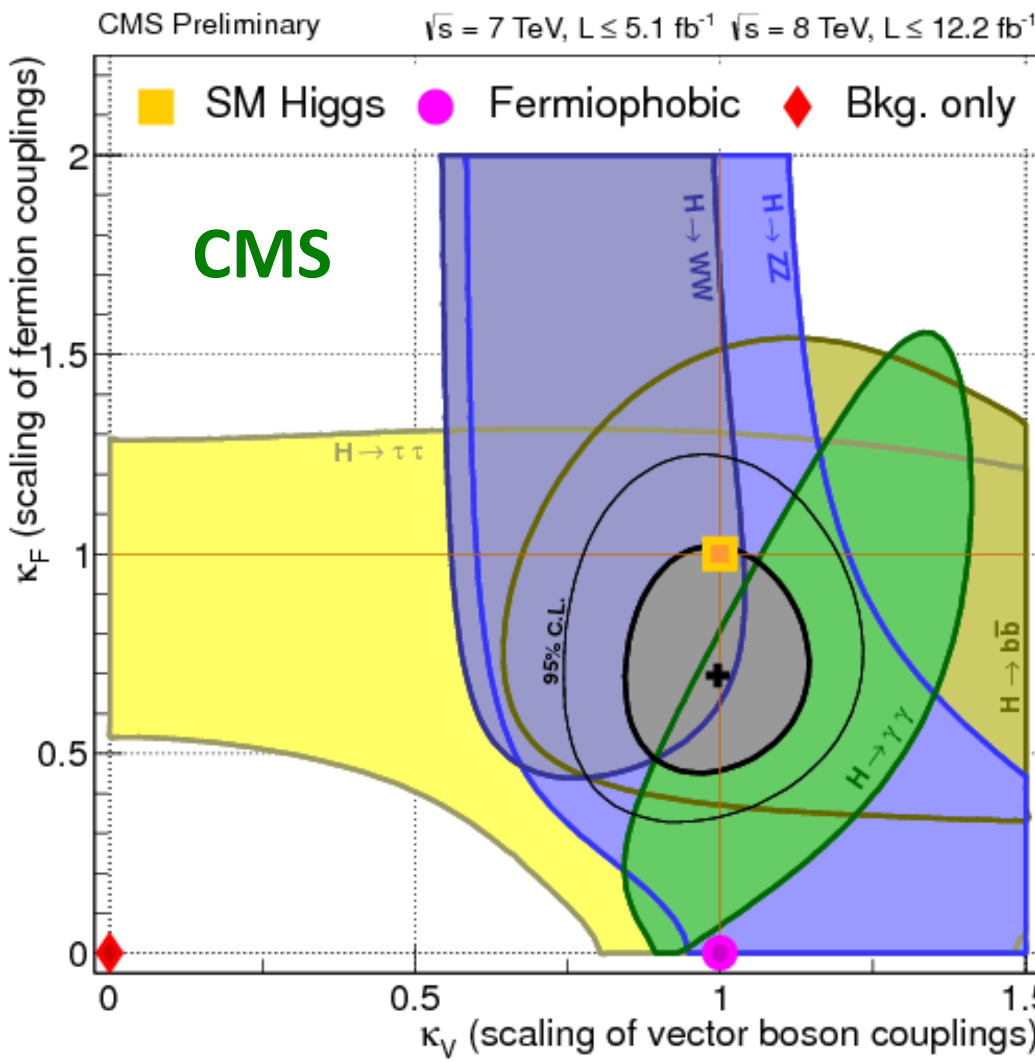




- ZZ has no tagged channel
- All decay modes are within ~1σ of SM.

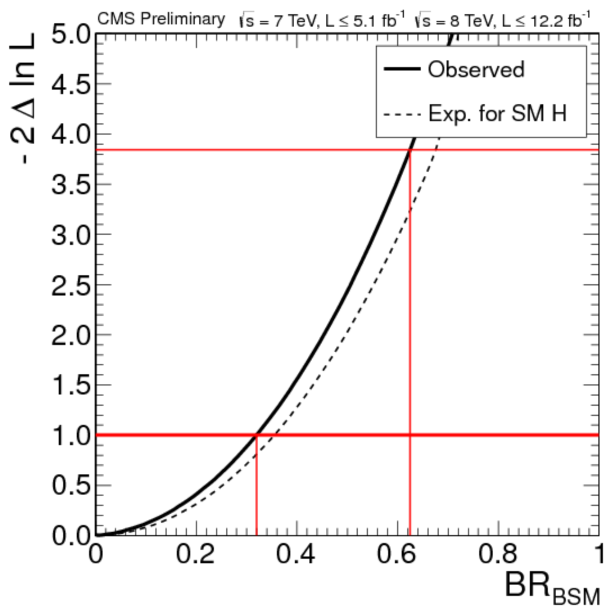
κ_V, κ_F limits

- Vector and fermion couplings are scaled by two scale, κ_V and κ_F
- Agree with SM at ~ 1 σ
- Fermiophobic scenario excluded at >4σ level
- Similar conclusions from ATLAS



Invisible width

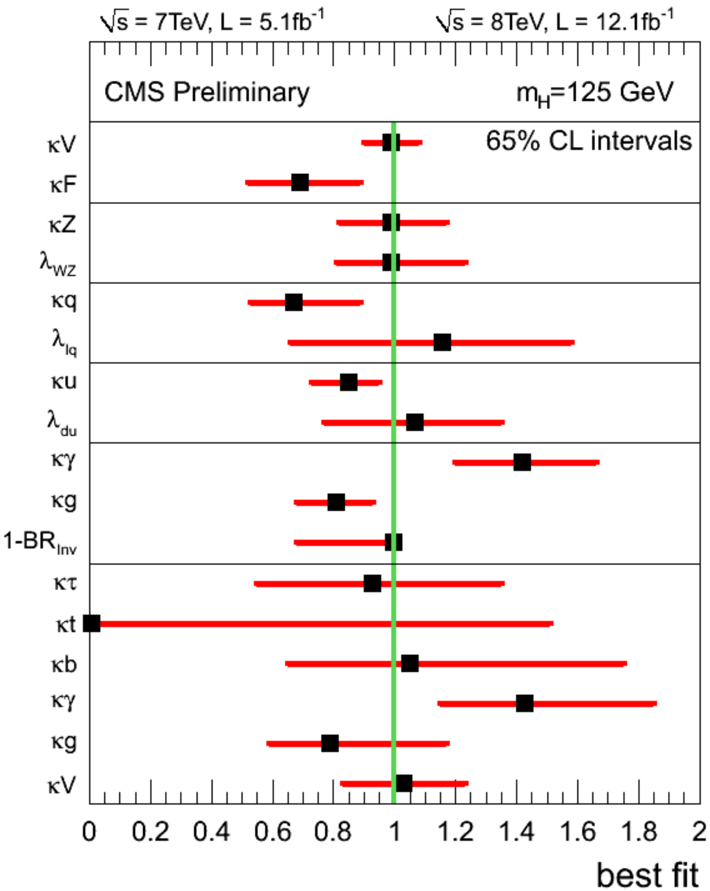
- Allow for new particles in the loops: parameterize the photon and the gluon loops with effective scale factors (κ_γ, κ_g)
- Allow contribution of invisible decays to the total width
- Other couplings are fixed to the SM



- CMS obtains limit $BR_{Inv} < 0.62$ at 95% CL
- Similar results from ATLAS

All fitted couplings

CMS



CMS

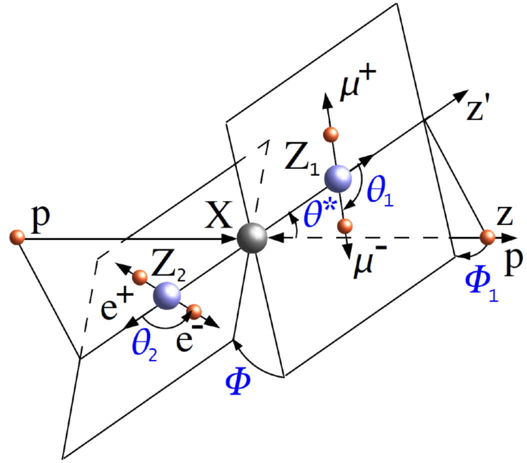
Model parameters	Assessed scaling factors (95% CL intervals)	
λ_{wz}, κ_z	λ_{wz}	[0.57,1.65]
$\lambda_{wz}, \kappa_z, \kappa_f$	λ_{wz}	[0.67,1.55]
κ_v	κ_v	[0.78,1.19]
κ_f	κ_f	[0.40,1.12]
κ_γ, κ_g	κ_γ	[0.98,1.92]
	κ_g	[0.55,1.07]
$\mathcal{B}(H \to BSM), \kappa_\gamma, \kappa_g$	$\mathcal{B}(H \to BSM)$	[0.00,0.62]
$\lambda_{du}, \kappa_v, \kappa_u$	λ_{du}	[0.45,1.66]
$\lambda_{\ell q}, \kappa_v, \kappa_q$	$\lambda_{\ell q}$	[0.00,2.11]
$\kappa_v, \kappa_b, \kappa_\tau, \kappa_t, \kappa_g, \kappa_\gamma$	κ_v	[0.58,1.41]
	κ_b	not constrained
	κ_τ	[0.00,1.80]
	κ_t	not constrained
	κ_g	[0.43,1.92]
	κ_γ	[0.81,2.27]

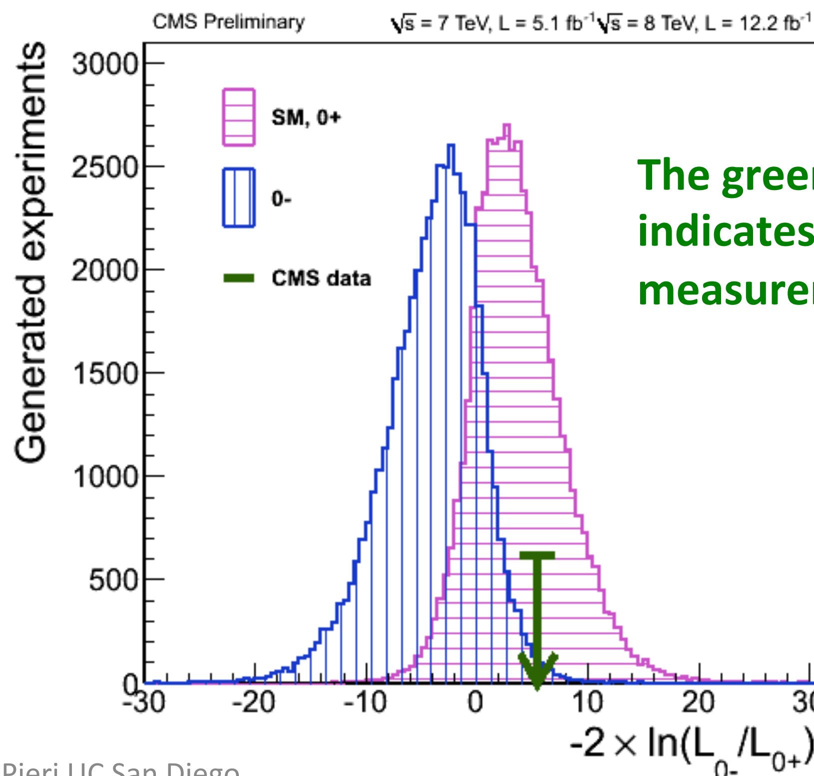
First measurement of the parity

- CMS use the ZZ to 4 leptons channel where all decay angles are measured
- Carry out 2D analysis with versus s/b discriminant combined with mass versus parity discriminant :

$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\rm SM}}{\mathcal{P}_{\rm SM} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_1, m_2, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{\rm SM}(m_1, m_2, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

- Plot shows log-likelihood ratio between the signal models for 0^+ and 0^-
- CMS excludes pseudo-scalar hypothesis at 2.5 σ level (CL_S for 0^- is 3%)
- Also possible to use WW, γγ and VBF, analyses are in progress





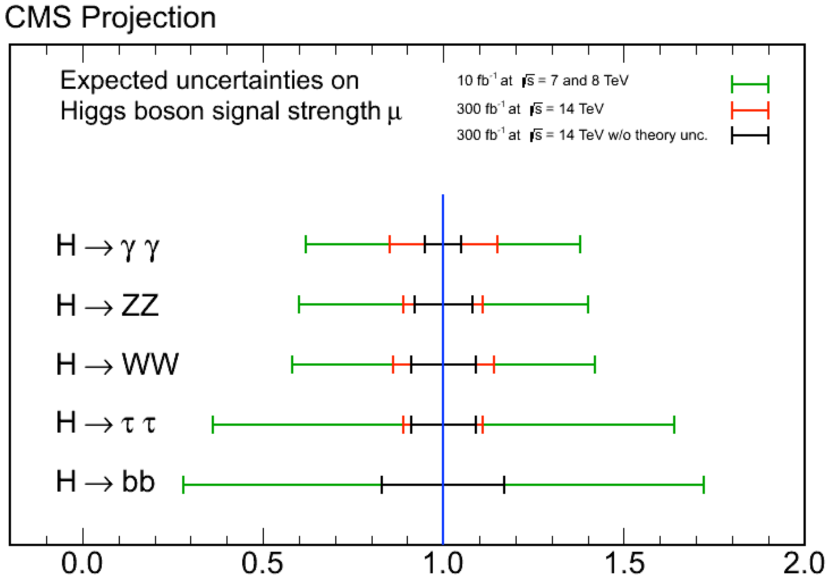
The green arrow indicates the measurement

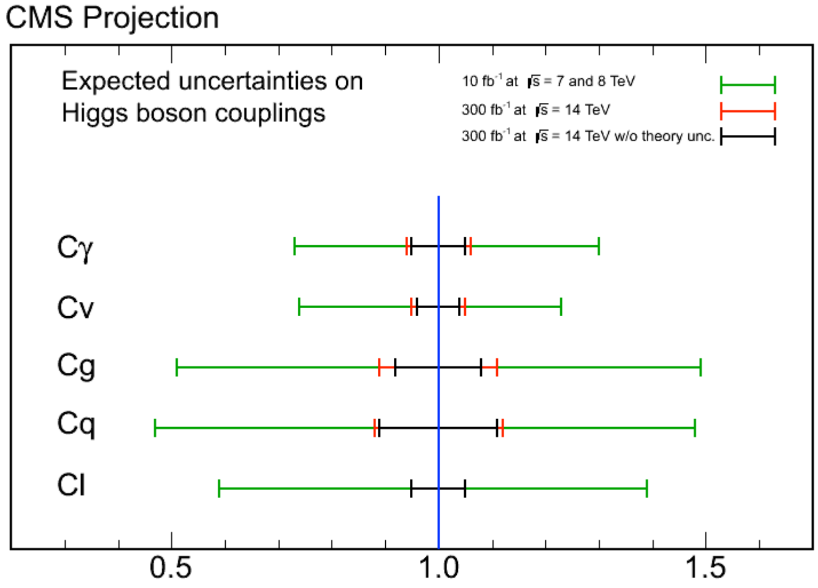
Summary

- After the discovery of the new boson ATLAS and CMS have started to measure its properties
- Branching ratios, couplings and mass have been measured and (unfortunately) they all agree quite well with the SM
- First measurement of the parity disfavours the 0^- hypothesis

Outlook

- A few weeks left of running LHC at 8 TeV
- Followed by two years of LHC shutdown to prepare the higher energy, resume data taking in 2015:
  - CM energy should be between 13 and 14 TeV
- Expect most final results on SM Higgs physics at 8 TeV by next summer
- Current projections for 300 fb^{-1} at 14 TeV indicate a precision of O(10%) on the couplings and BRs

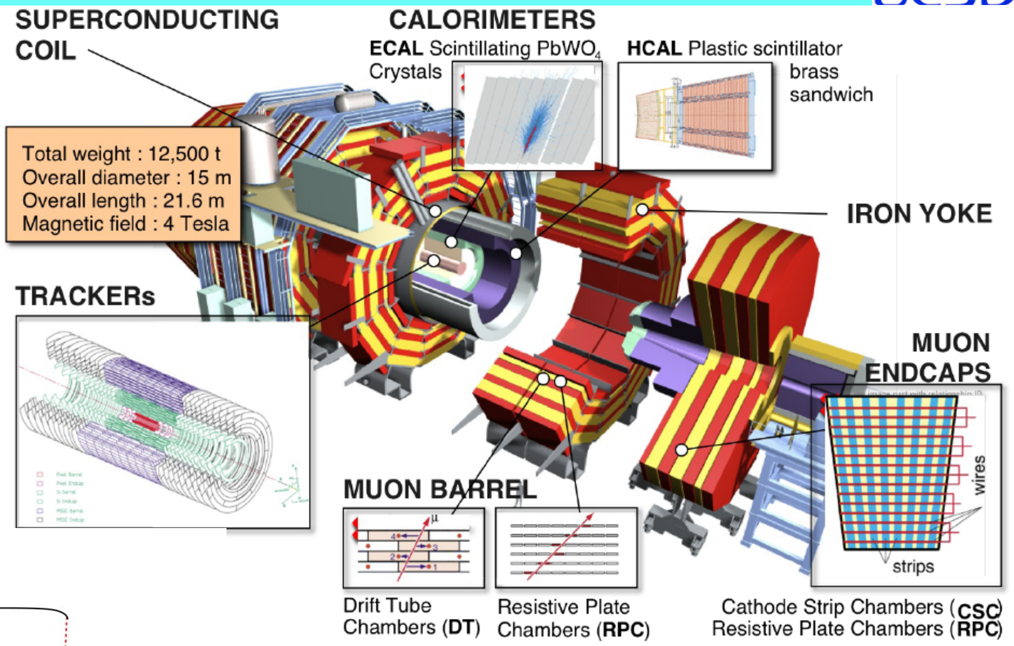




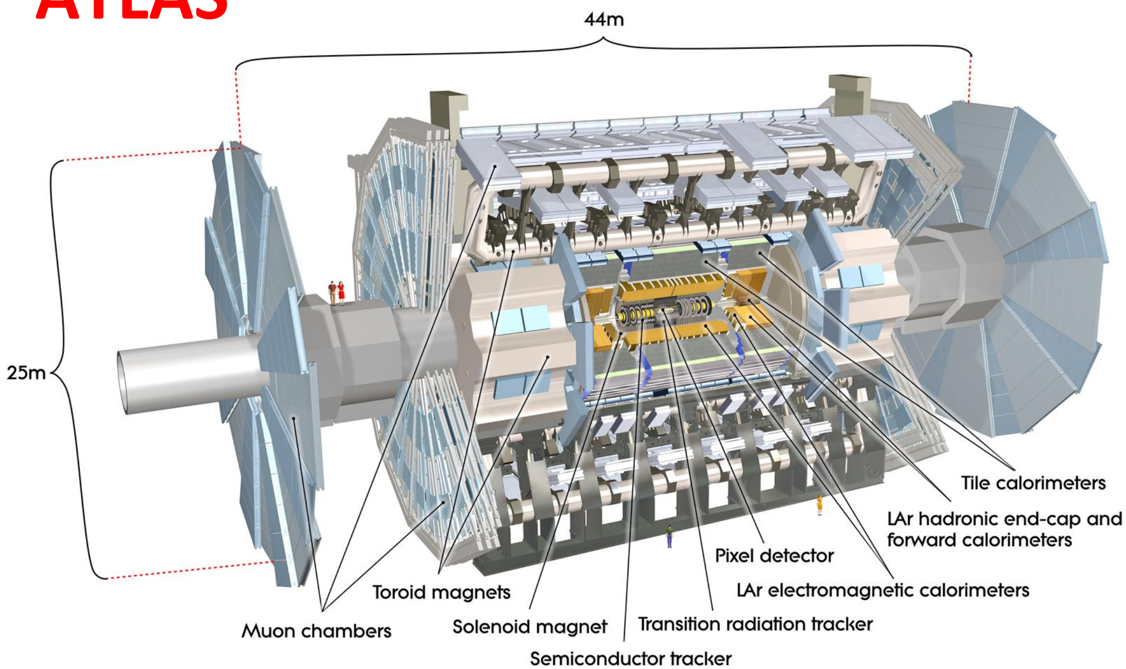
Backup

Detectors

CMS

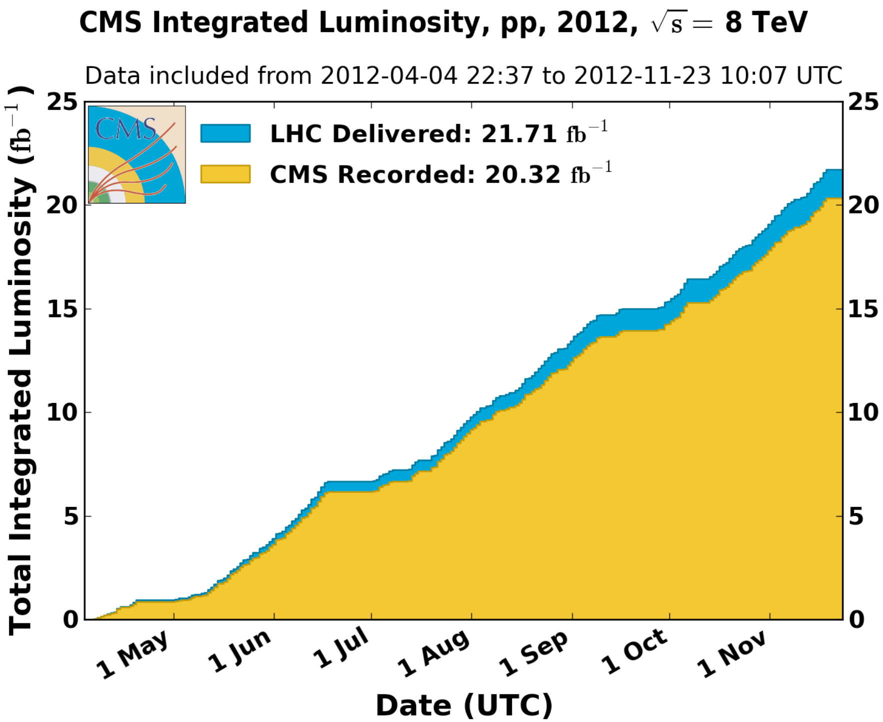


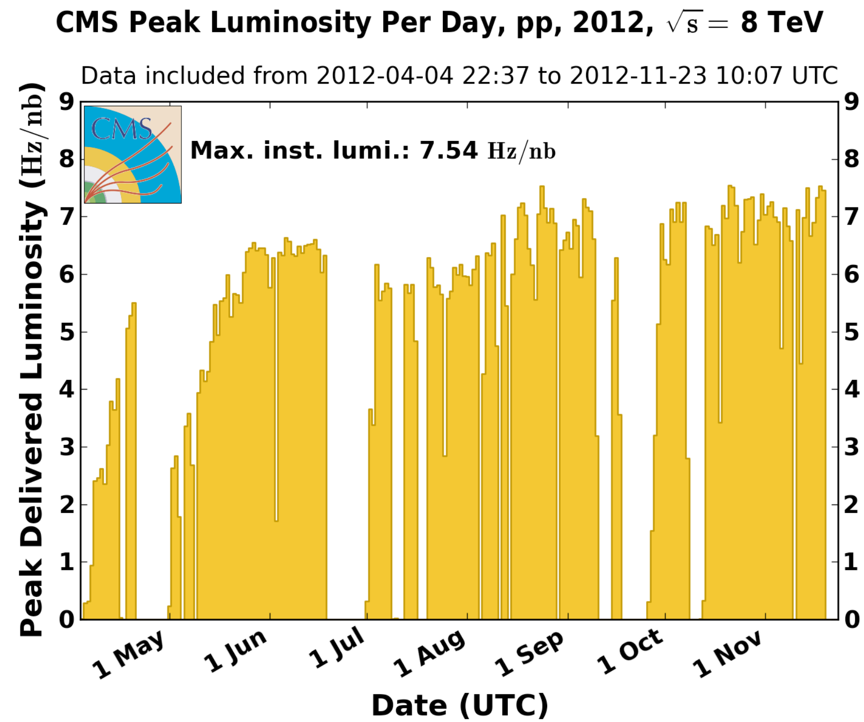
ATLAS



2012 data taking

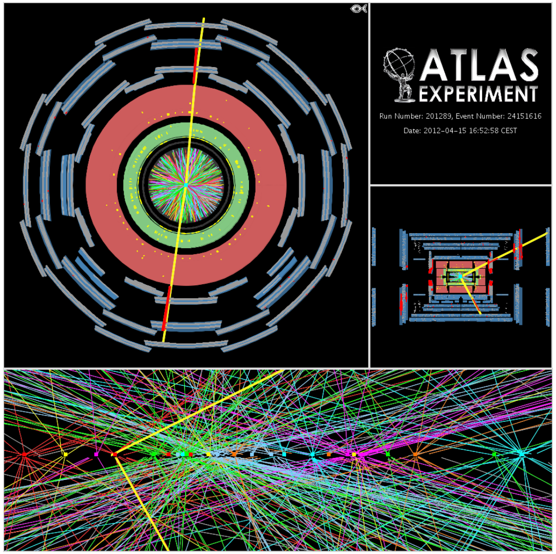
- LHC is running at 8 TeV since beginning of April
- Already exceeded 20 fb^{-1} per experiment of collected data
- Maximum luminosity 7.5 x 10^{33} $cm s^{-2} s^{-1}$

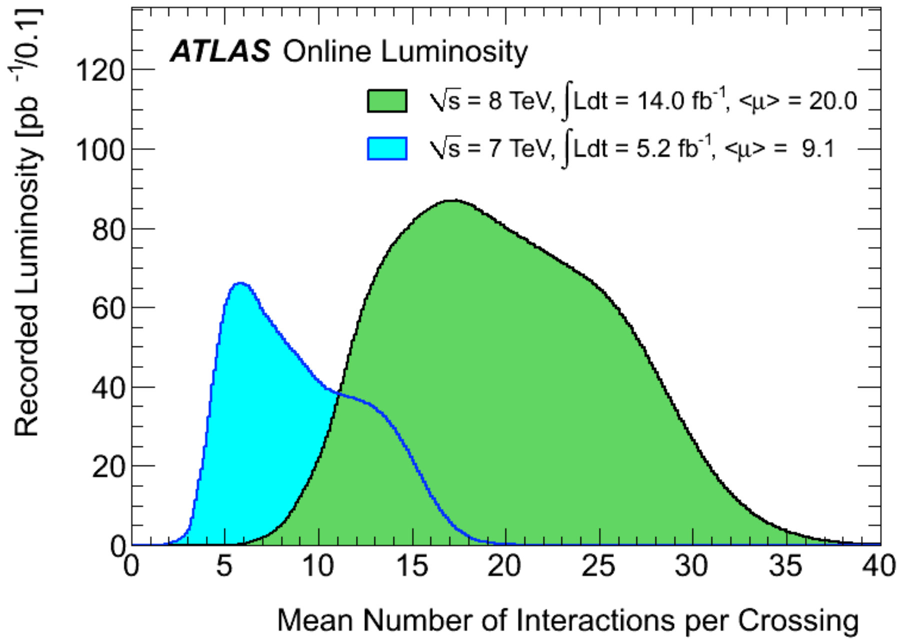




Pileup

- Multiple interactions occur for each bunch crossing (in-time and out-of-time pileup)
- Mean PU ~10 events in 2011 and ~20 events in 2012

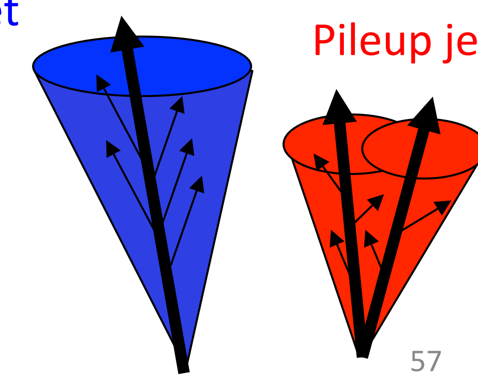




- Effects of pileup:
  - Slightly deteriorates energy resolution for electrons and photons and jets
    - Apply corrections event by event for photons and jets
  - Adds energy in isolation cones
    - corrected for pileup energy estimated event by event
  - PU jets affect central jet veto and VBF jet tagging
    - Try to reject PU jets (wider and with tracks coming from different PV)

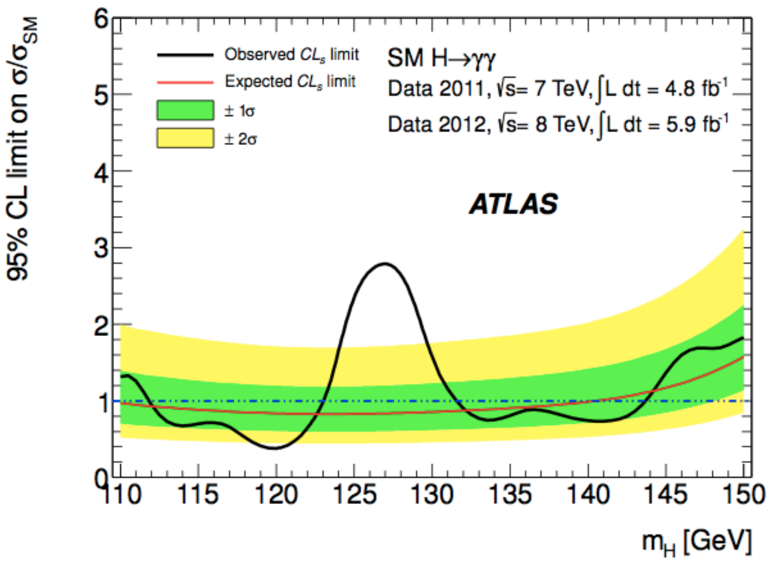
Hard interaction jet

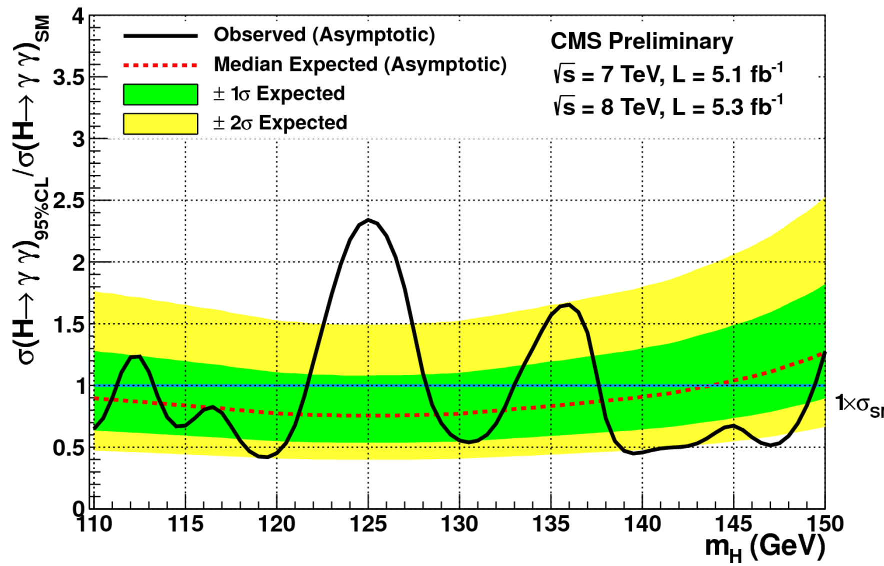
Pileup jet



H→γγ results: exclusion

Results not updated after discovery papers in July



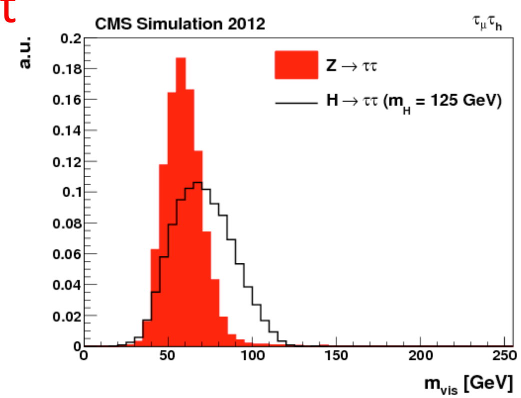


	ATLAS	CMS
Expected exclusion 95% CL	0.8 x SM at 125 GeV	0.76 x SM at 125 GeV
Observed exclusion 95% CL	112.0-122.5, 132.0-143.0 GeV	110.0-111.0, 114-121, 129-132, 138-149 GeV

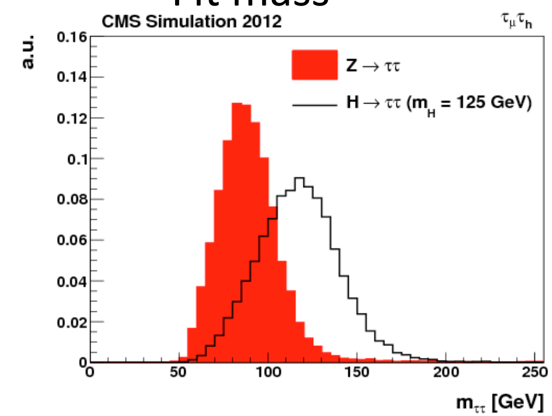
H→ττ strategy

- Trigger important, not fully efficient for hadronic τ decays
- Invariant mass calculation
  - Use full kinematical fit
  - Mass resolution: 15-20%

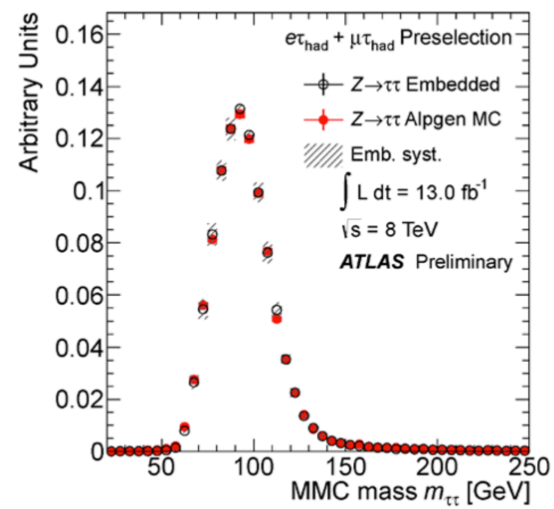
Visible mass



Fit mass

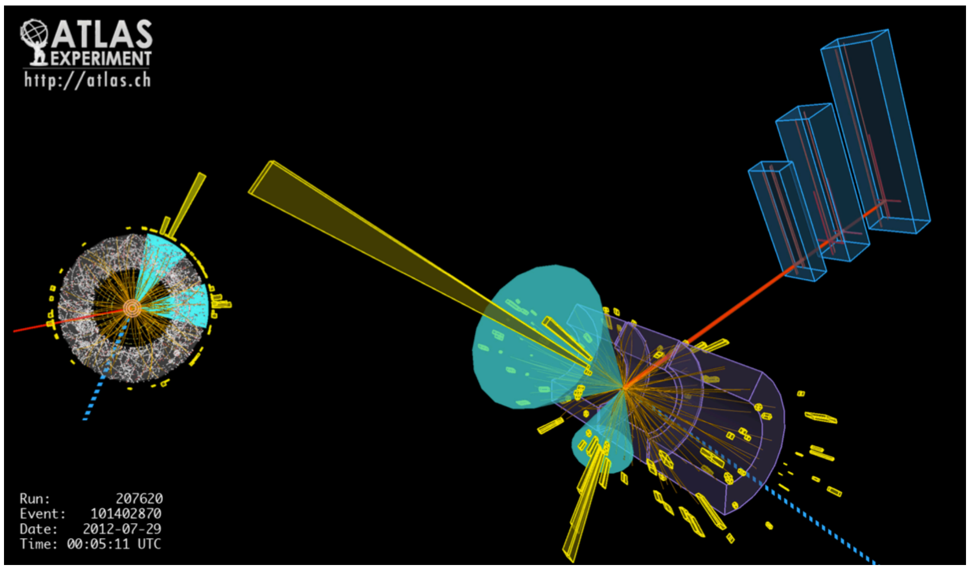


- Background in all channels is dominated by Z -> ττ
- Use real Z -> μμ events. Replace muons in data with fully simulated τ, referred as "τ embedding"

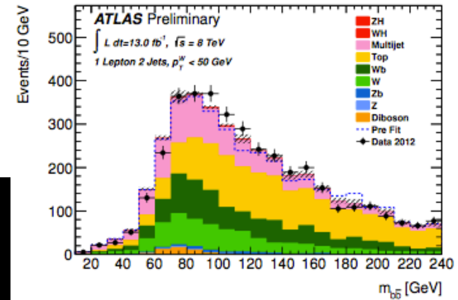


ATLAS H→bb channel

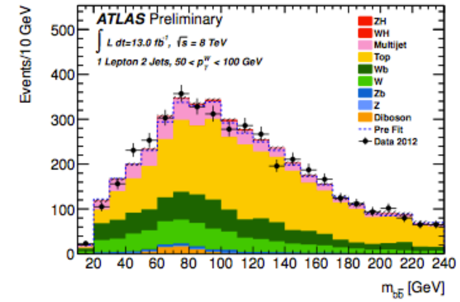
μνbb Candidate



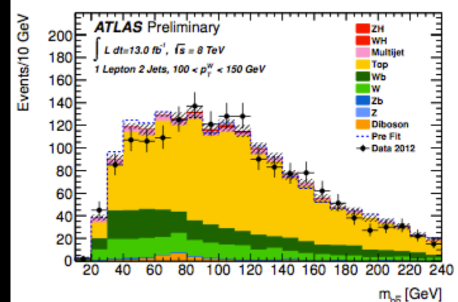
1-lepton tag, categorize in p_T^W



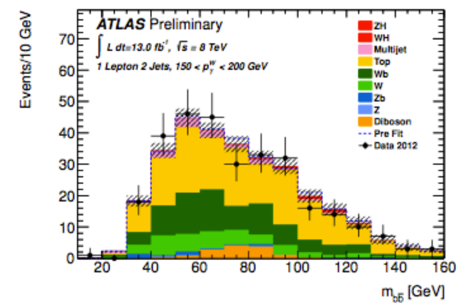
(a) $p_T^W < 50$ GeV



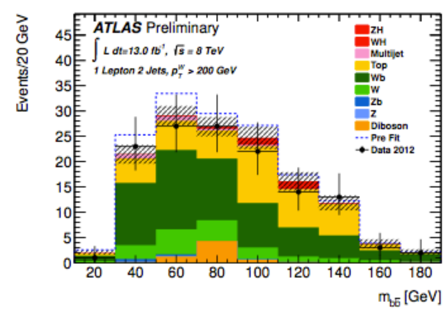
(b) $50 < p_T^W < 100$ GeV



(c) $100 < p_T^W < 150$ GeV



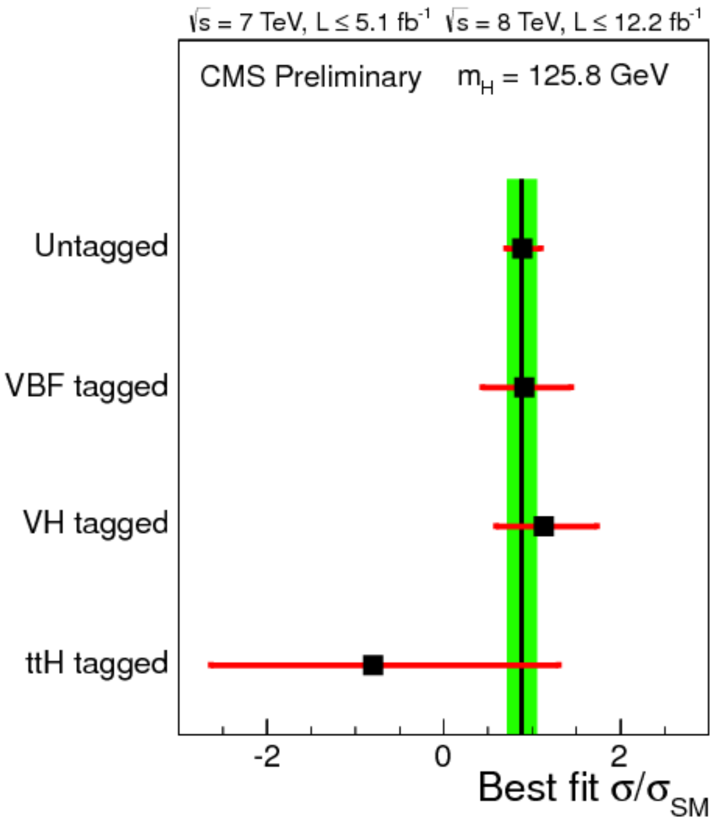
(d) $150 < p_T^W < 200$ GeV



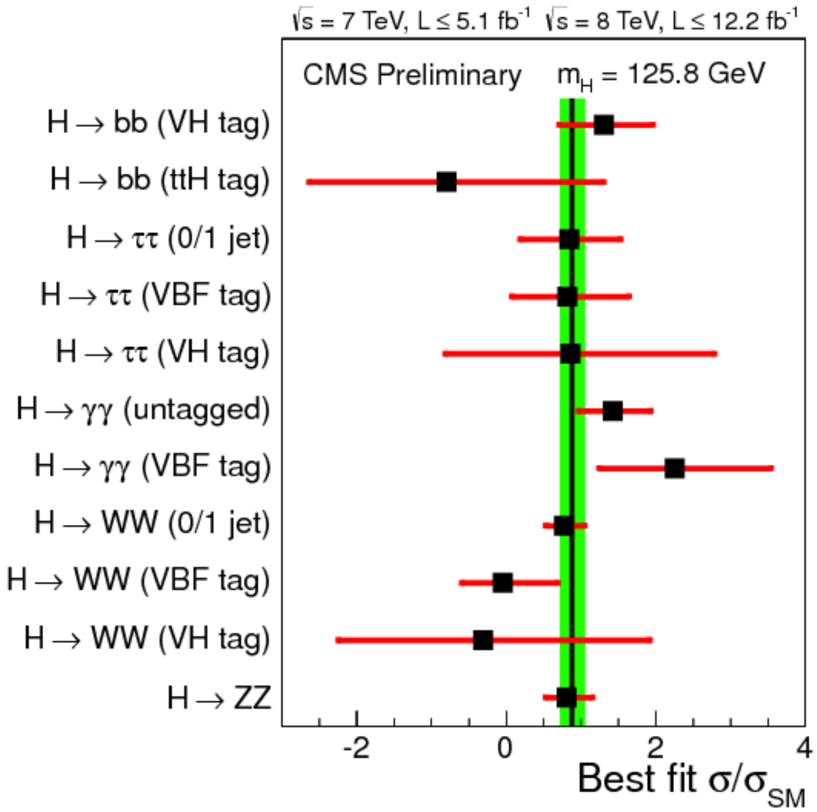
(e) $p_T^W > 200$ GeV

CMS, other combination compatibility plots

Tagged modes



Tagged modes and separate decays

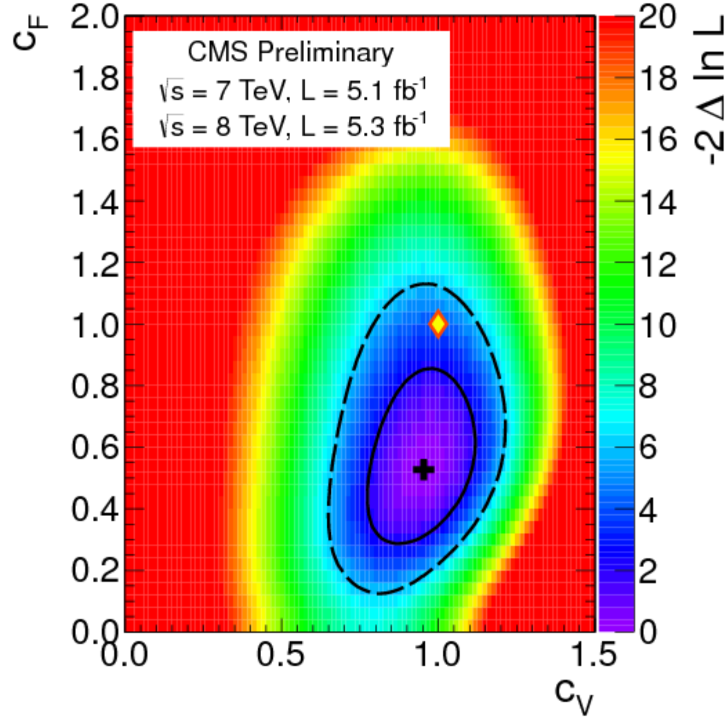


Couplings CMS at ICHEP

- First measurement of new boson couplings when interpreted as a Higgs boson
- Scale vectorial and fermionic couplings by C_V and C_F (use LO)

Production	Decay	LO SM	
VH	$H \to bb$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ttH	$H \to bb$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
VBF	$H \to \tau\tau$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to \tau\tau$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
ggH	$H \to ZZ$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to WW$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to WW$	$\sim \frac{C_V^2 \times C_V^2}{C_F^2}$	$\sim C_V^4/C_F^2$
ggH	$H \to \gamma\gamma$	$\sim \frac{C_F^2 \times (8.6 C_V - 1.8 C_F)^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to \gamma\gamma$	$\sim \frac{C_V^2 \times (8.6 C_V - 1.8 C_F)^2}{C_F^2}$	$\sim C_V^4/C_F^2$

HIG-12-020



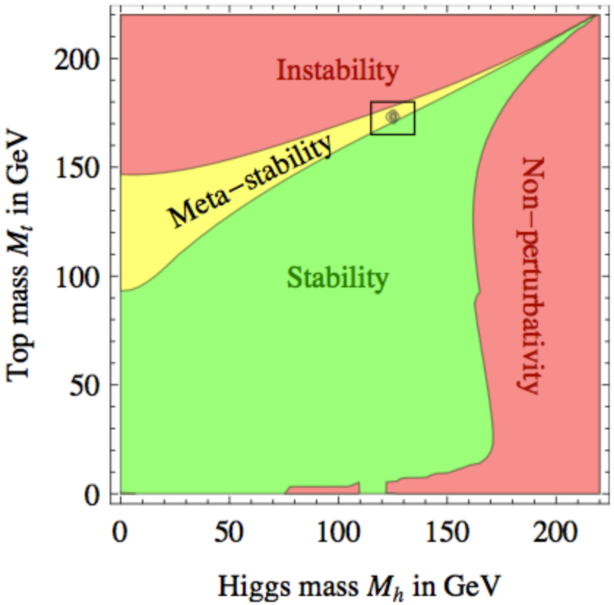
- Best fit: $(C_V, C_F) = (1, 0.5)$
- Consistent within 2σ with the SM Higgs boson

Solid contour: 68% CL

Dashed contour: 95% CL

- From inclusive ZZ→4l and WW→2l2ν
  - $R_{WW/ZZ} = 0.9^{+1.1}_{-0.6}$

arXiv:1205.6497



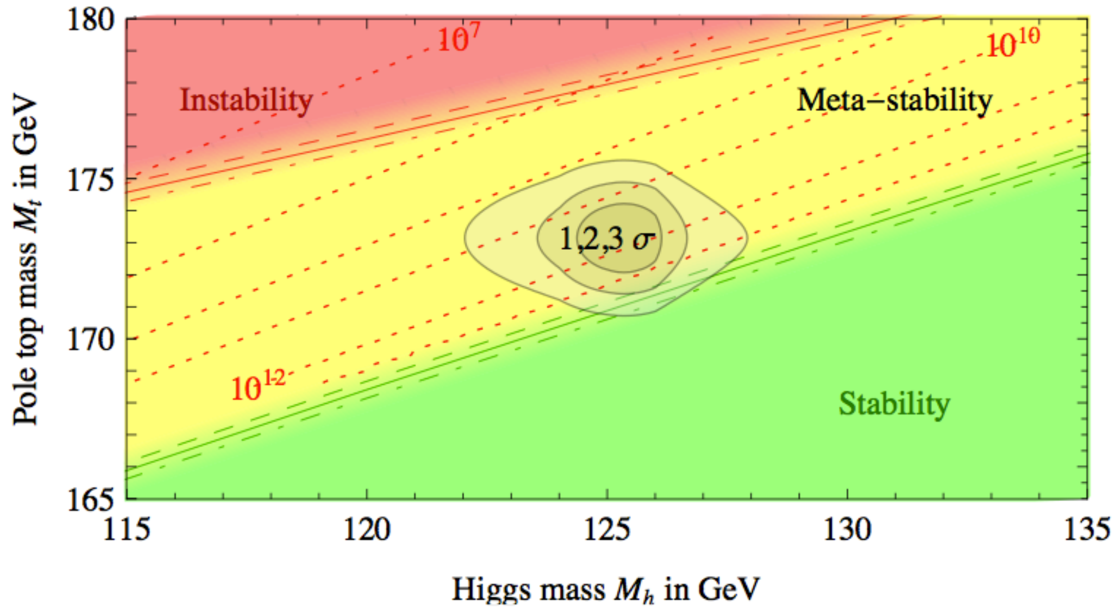
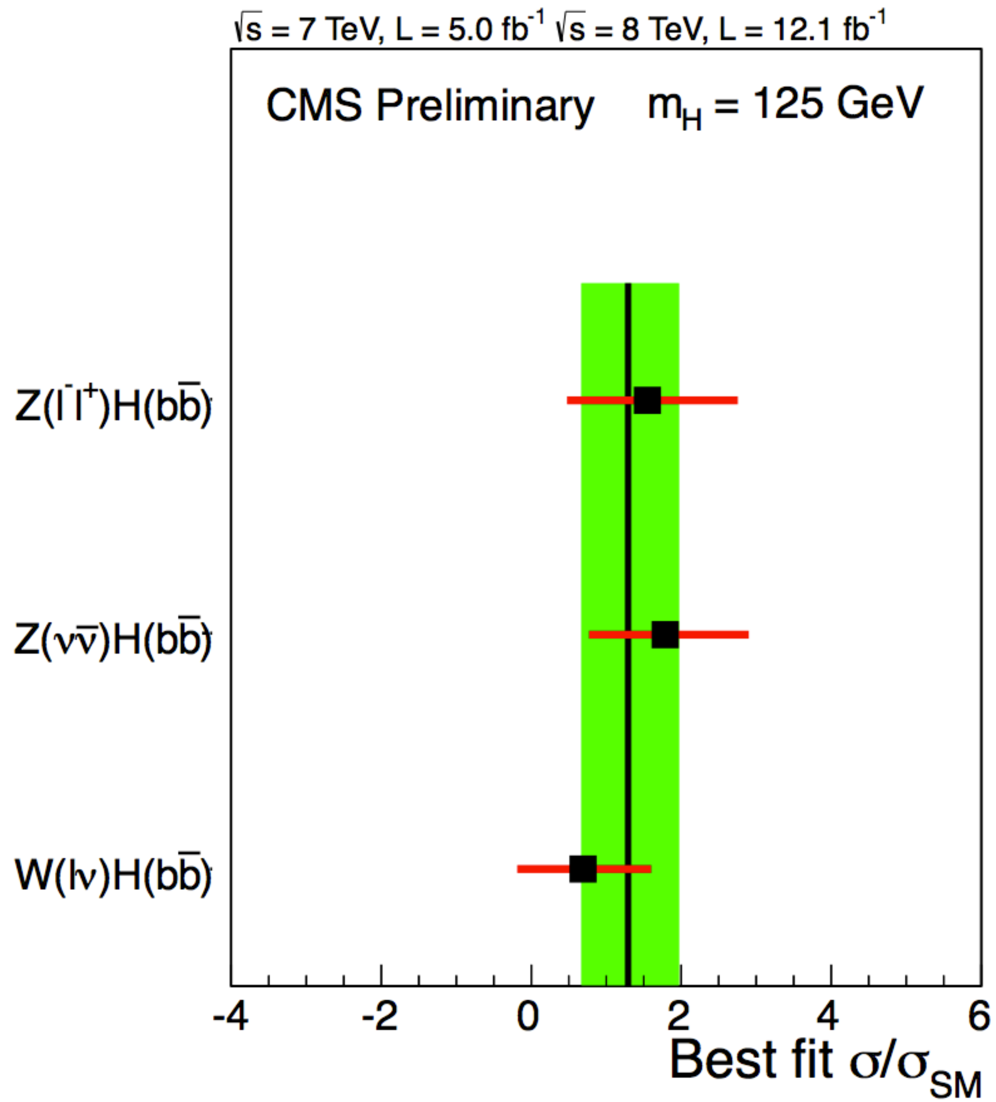


Figure 5: *Regions of absolute stability, meta-stability and instability of the SM vacuum in the M_t–M_h plane.* **Right**: *Zoom in the region of the preferred experimental range of M_h and M_t (the gray areas denote the allowed region at 1, 2, and 3σ). The three boundaries lines correspond to $\alpha_s(M_Z) = 0.1184 \pm 0.0007$, and the grading of the colors indicates the size of the theoretical error. The dotted contour-lines show the instability scale Λ in GeV assuming $\alpha_s(M_Z) = 0.1184$.*

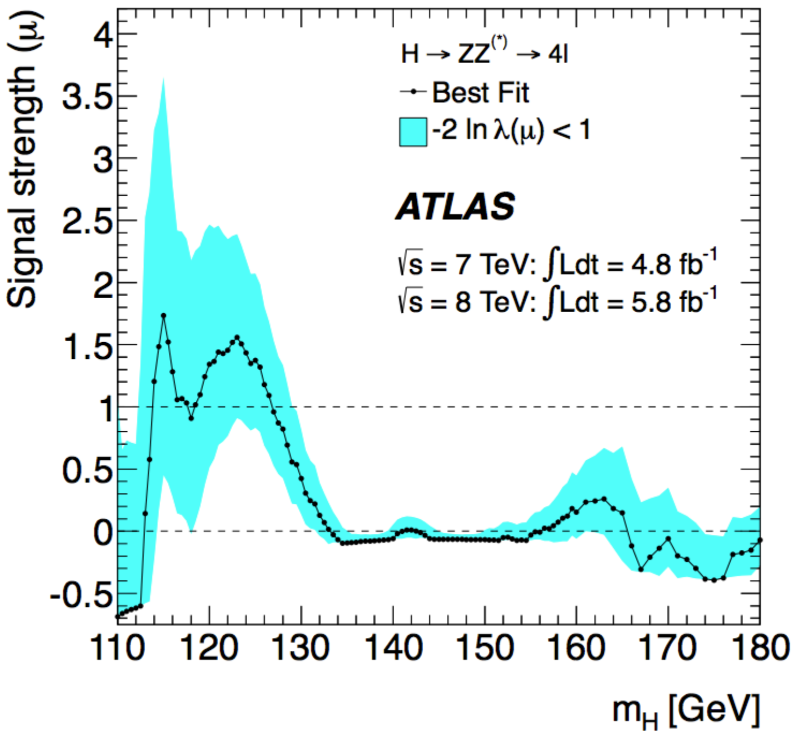
CMS H→bb

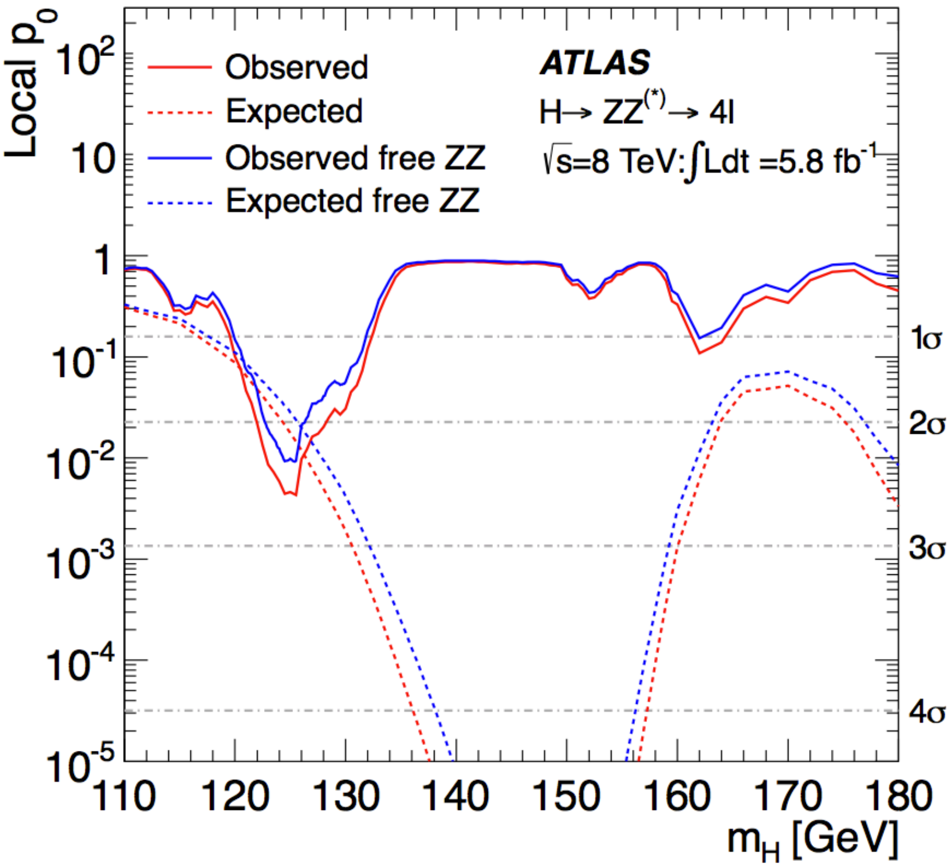


√s = 7 TeV, L = 5.0 fb-1 √s = 8 TeV, L = 12.1 fb-1
CMS Preliminary
mH = 125 GeV
Z(l-l+)H(bb̄)
Z(νν̄)H(bb̄)
W(lν)H(bb̄)
-4
-2
0
2
4
6
Best fit σ/σSM

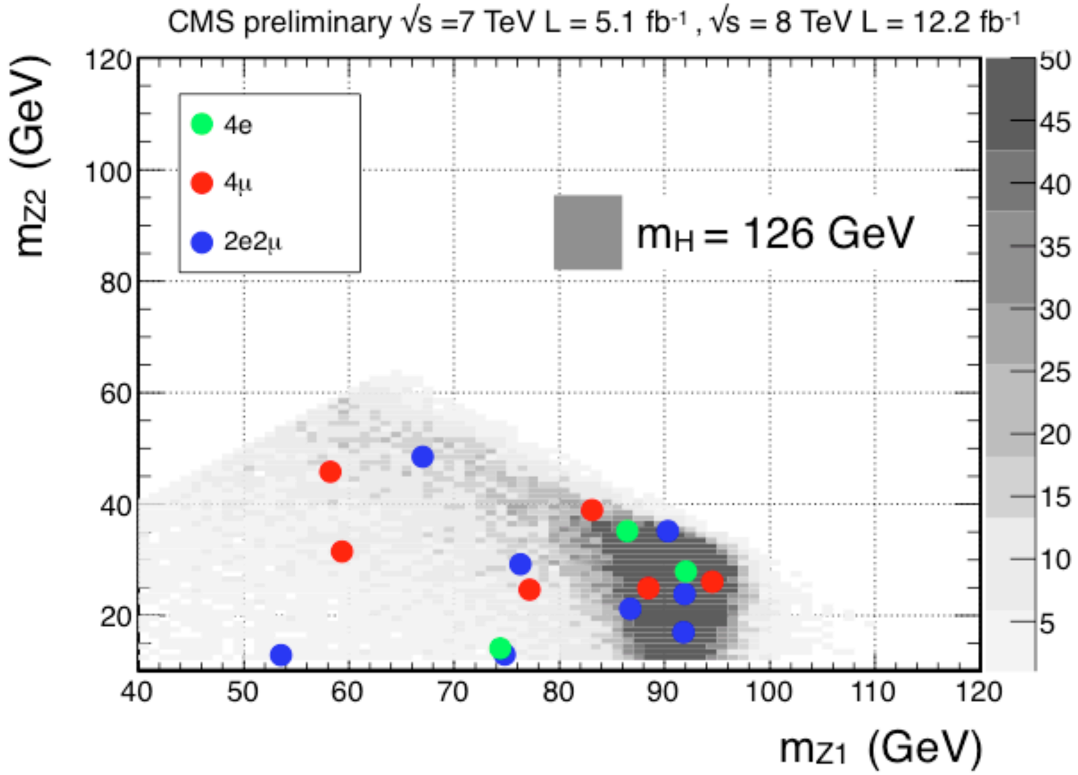
ATLAS ZZ additional

- Best fit value at m_H=125 GeV (lowest p-value): 1.4 ± 0.6



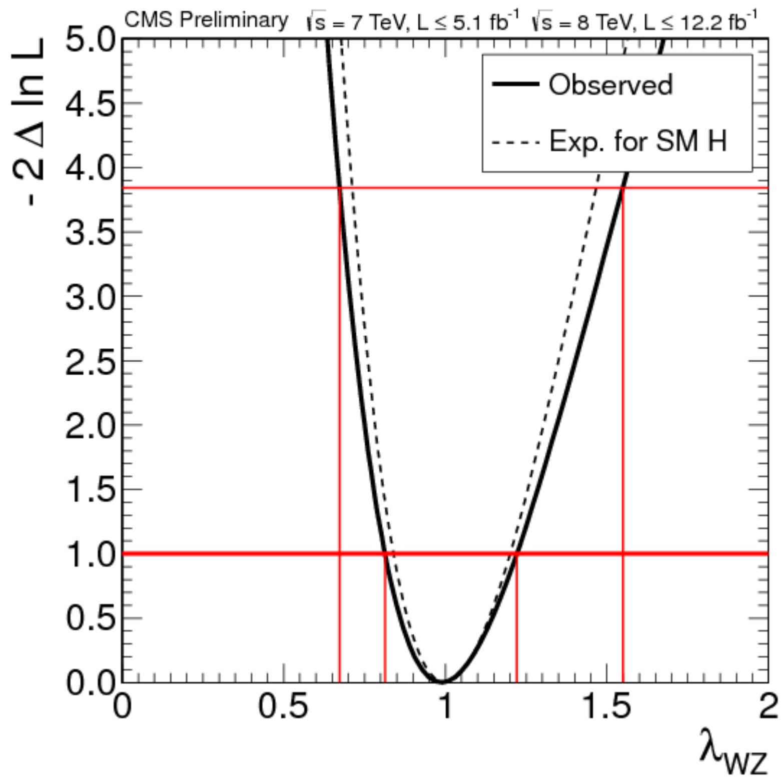


CMS H->ZZ->4l MZ2 vs MZ1

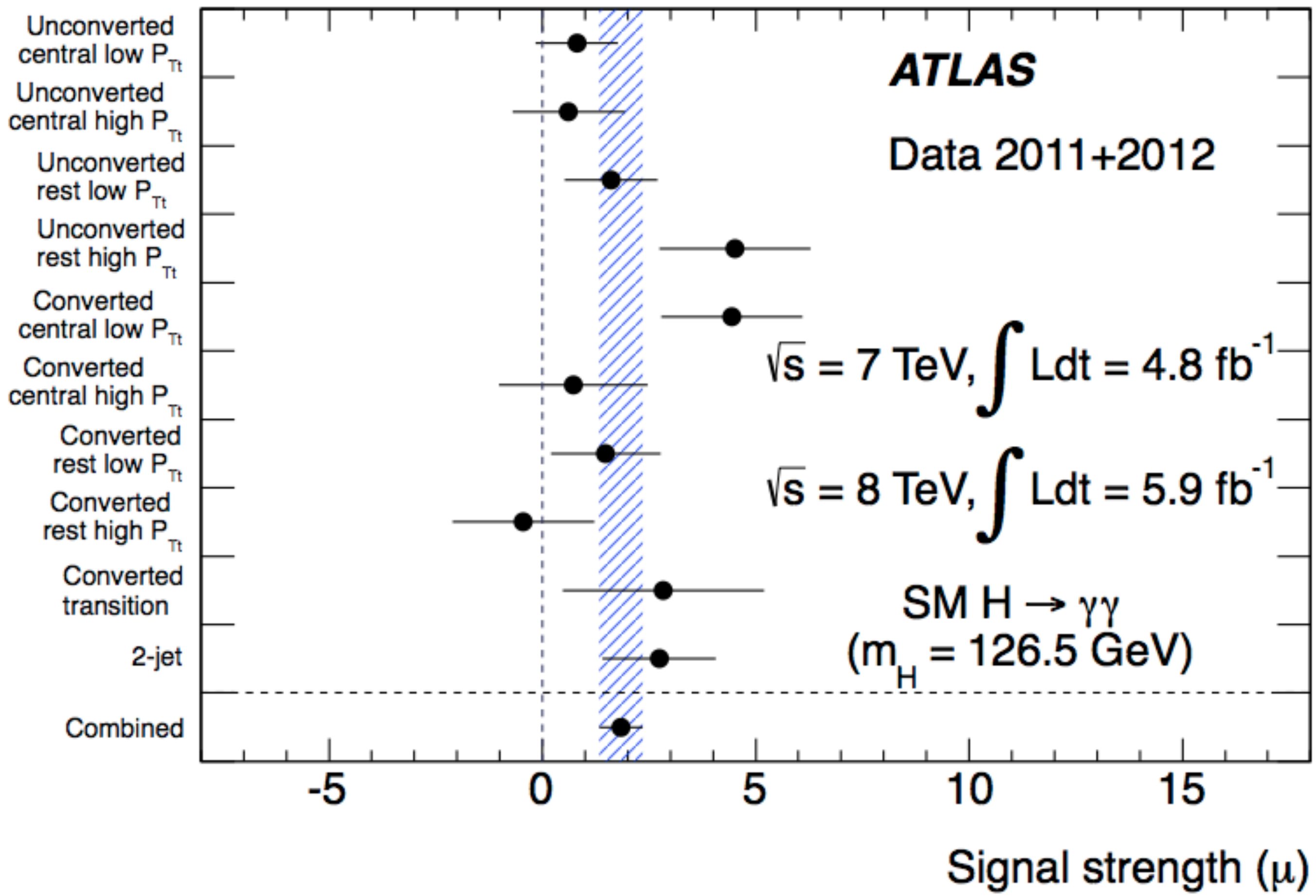


Custodial symmetry

- Couplings to W and Z boson scale together in SM.
- Parameterization:
  - κF, κZ, $\lambda_{WZ}=\kappa W/\kappa Z$
  - κF, κZ profiled
- Result are consistent with SM:
  - λ_{WZ} in [0.68-1.55] at 95% CL

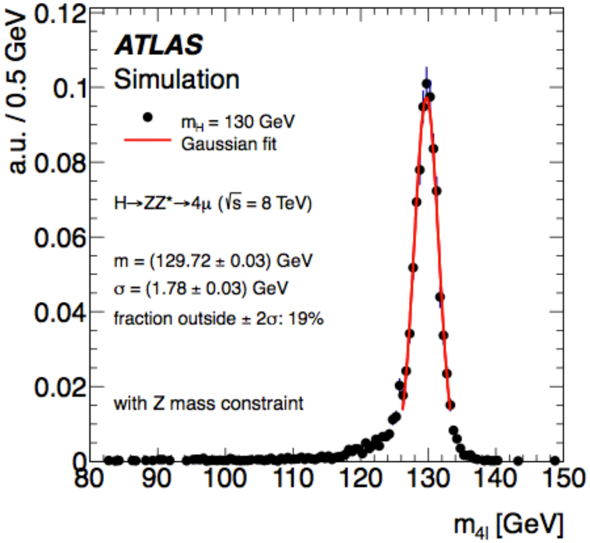


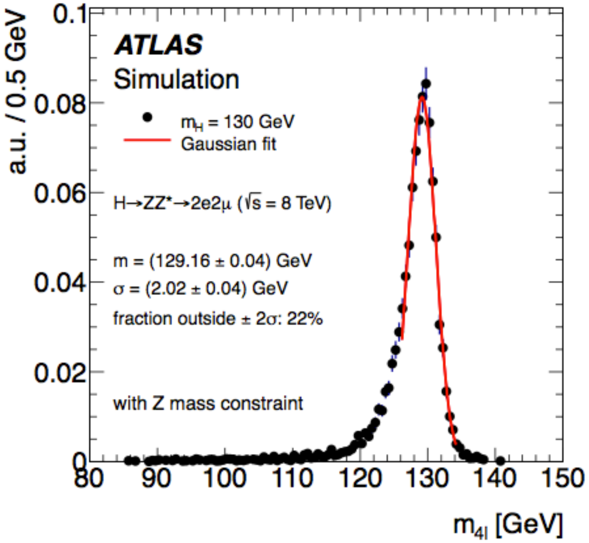
ATLAS H -> γγ

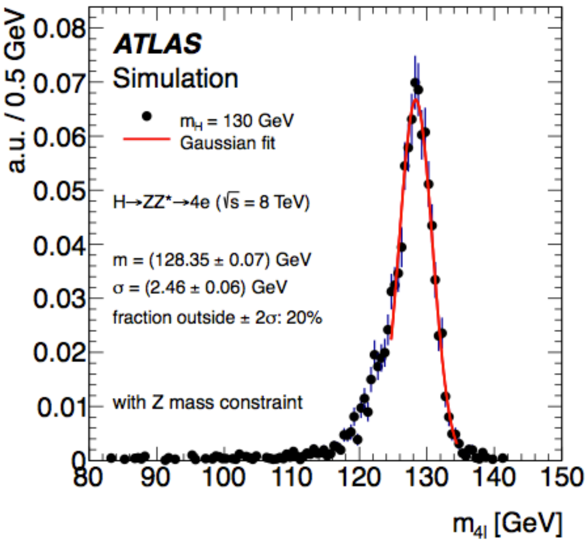


Unconverted central low P_Tt
Unconverted central high P_Tt
Unconverted rest low P_Tt
Unconverted rest high P_Tt
Converted central low P_Tt
Converted central high P_Tt
Converted rest low P_Tt
Converted rest high P_Tt
Converted transition
2-jet
Combined
ATLAS
Data 2011+2012
√s = 7 TeV, ∫Ldt = 4.8 fb-1
√s = 8 TeV, ∫Ldt = 5.9 fb-1
SM H → γγ
(mH = 126.5 GeV)
-5
0
5
10
15
Signal strength (μ)

ATLAS ZZ mass resolution







Coupling scale factors

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \kappa_W^2$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = \kappa_t^2$$

Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma_{WW^{(*)}}^{SM}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma_{ZZ^{(*)}}^{SM}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{SM}} = \kappa_\tau^2$$

$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases}$$

Currently undetectable decay modes

$$\frac{\Gamma_{t\bar{t}}}{\Gamma_{t\bar{t}}^{SM}} = \kappa_t^2$$

$$\frac{\Gamma_{gg}}{\Gamma_{gg}^{SM}} : \text{see Section 3.1.2}$$

$$\frac{\Gamma_{c\bar{c}}}{\Gamma_{c\bar{c}}^{SM}} = \kappa_t^2$$

$$\frac{\Gamma_{s\bar{s}}}{\Gamma_{s\bar{s}}^{SM}} = \kappa_b^2$$

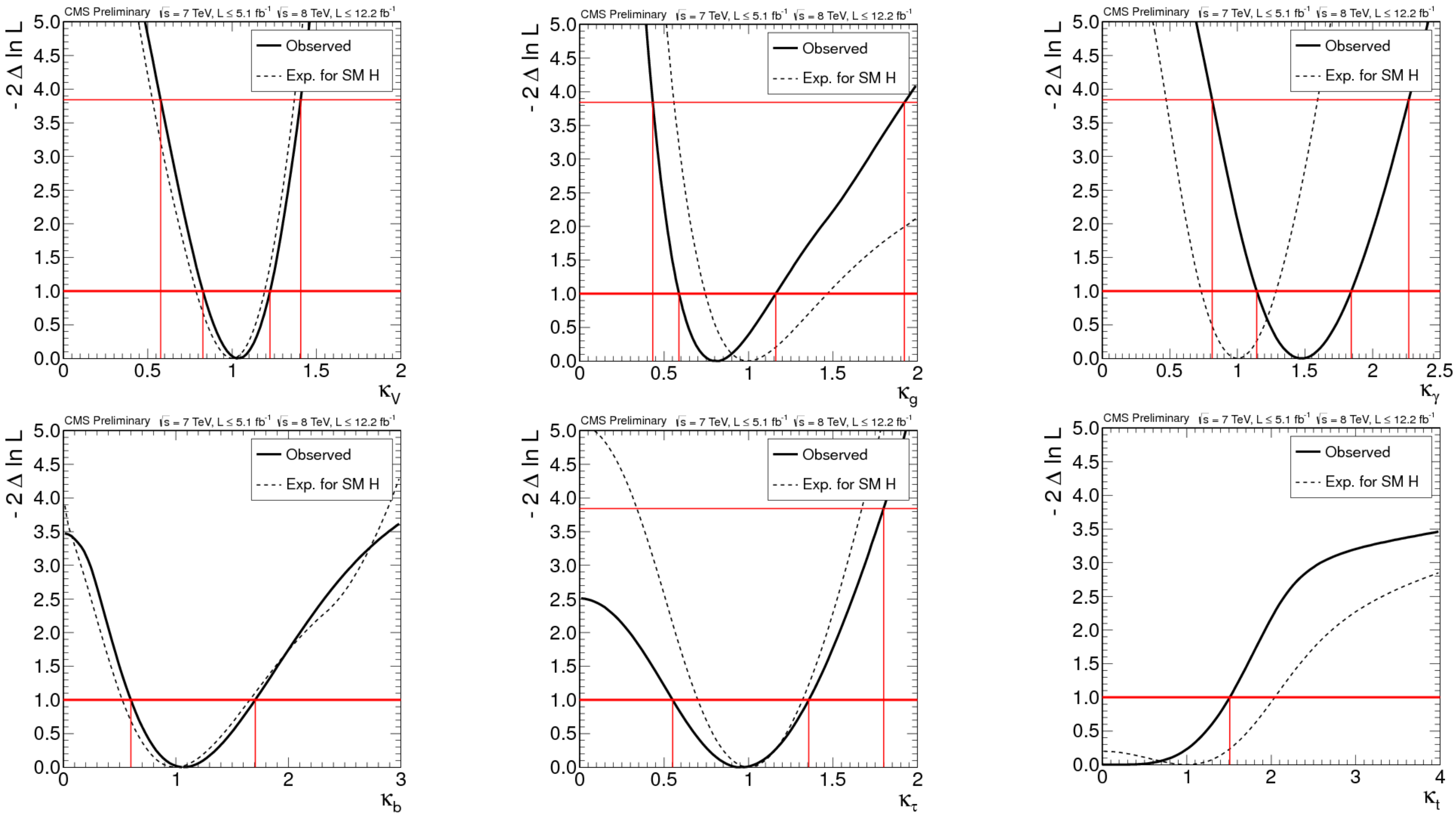
$$\frac{\Gamma_{\mu^-\mu^+}}{\Gamma_{\mu^-\mu^+}^{SM}} = \kappa_\tau^2$$

Total width

$$\frac{\Gamma_H}{\Gamma_H^{SM}} = \begin{cases} \kappa_H^2(\kappa_i, m_H) \\ \kappa_H^2 \end{cases}$$

Individual couplings

- 6 scale factors:
  - κV, κt, κb, κτ, κg, κγ
- Fit them individually while profiling the others



Glossary

- BG: background
- MVA: MultiVariate Analysis
  - usually Boosted Decision Tree (BDT), could also be Neural Network (NN)
- VBF: Vector Boson Fusion process
- P-value: probability to observe a background fluctuation from background only, larger that the one observed in data
- VH: WZ, HZ associated production