ATLAS and CMS results for BEH → VV

Xavier Janssen

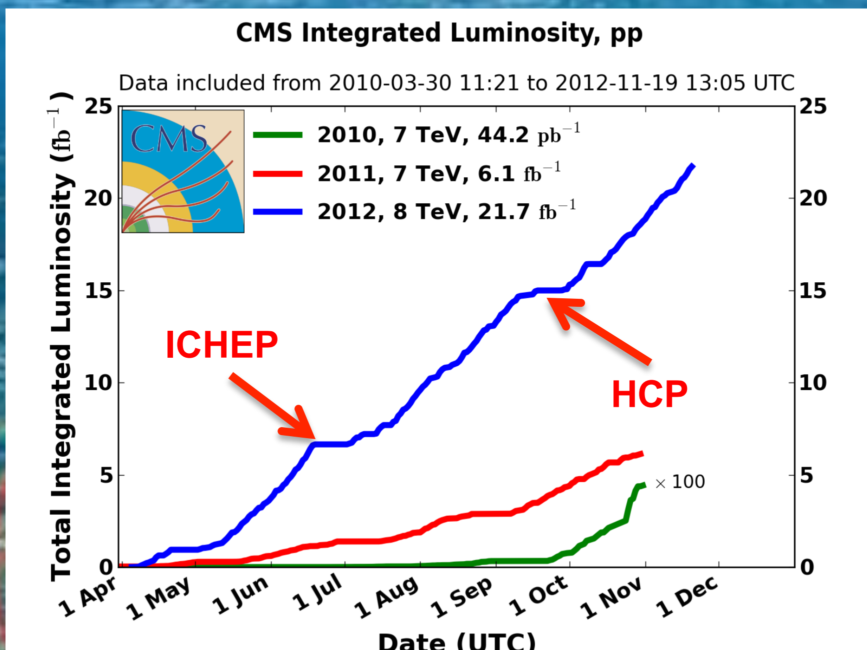
Higgs-search-in-Belgium mini workshop

Louvain-La-Neuve

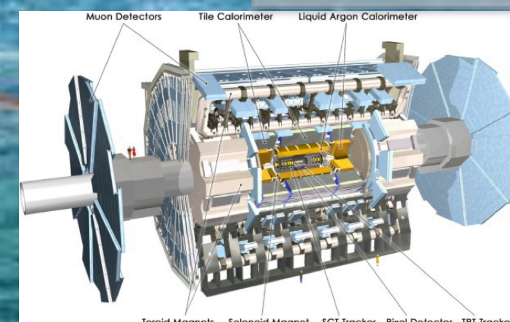
November 22, 2012

The Large Hadron Collider @ CERN

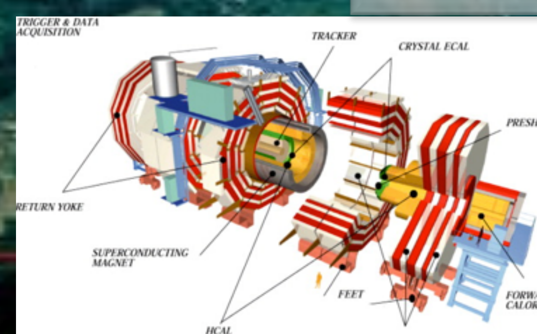
Proton-proton collisions at 7 TeV (2010/11) & 8 TeV (2012)
(and ~14 TeV after 2013/14 upgrade)



ATLAS

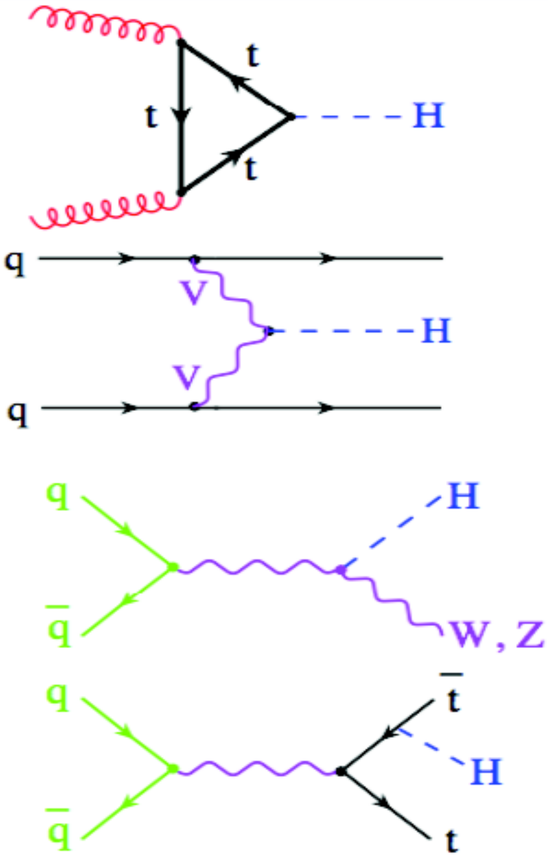


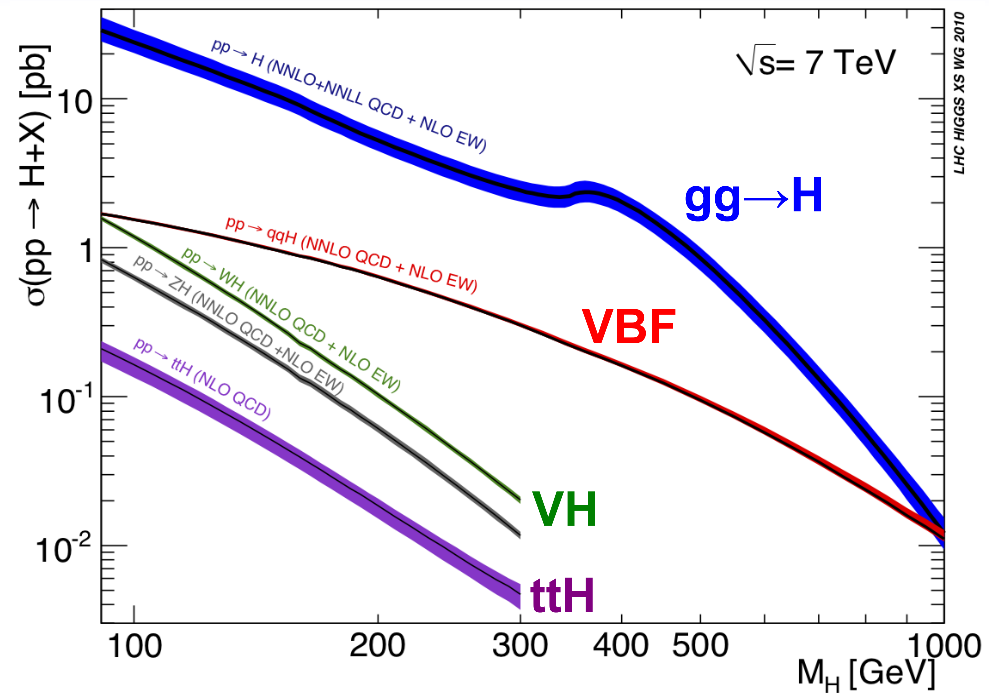
CMS

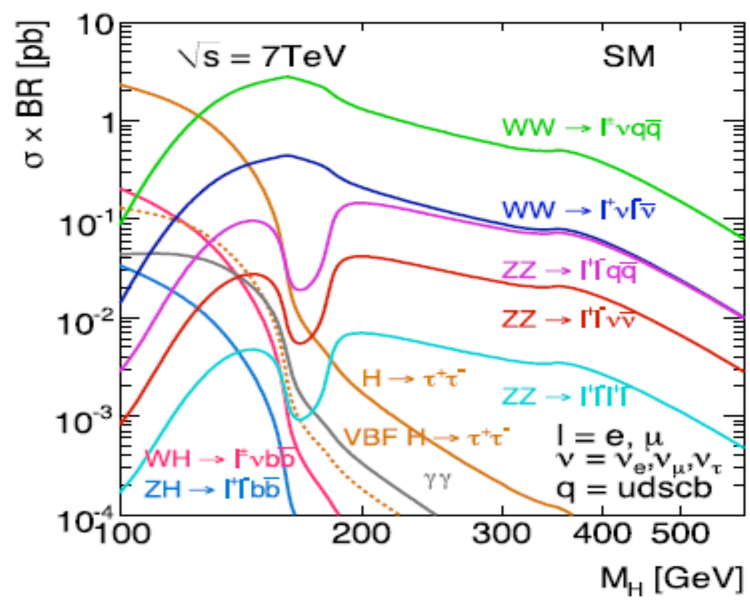


SM Higgs Boson Production and Decay at LHC

- Gluon fusion
- VBF
- VH
- ttH





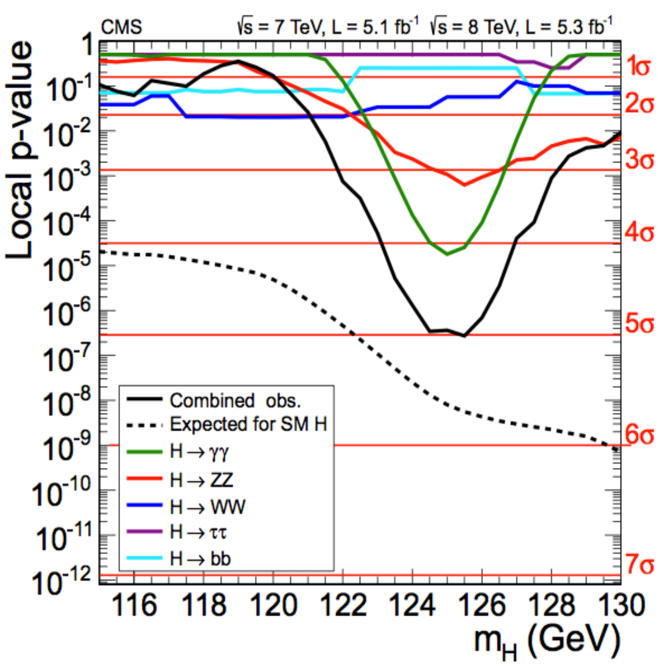


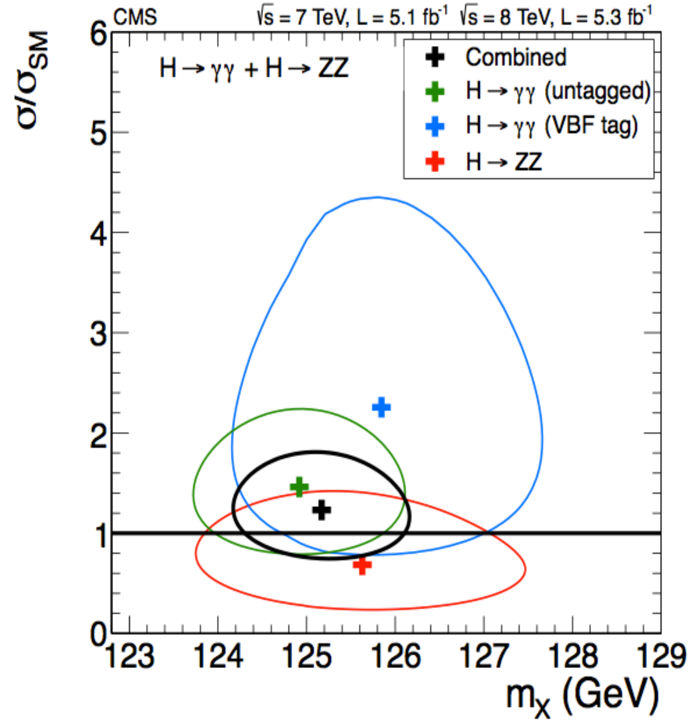
Gluon fusion (gg→H) it the dominant production mechanism at LHC but VBF, VH and ttH allow to test H properties.

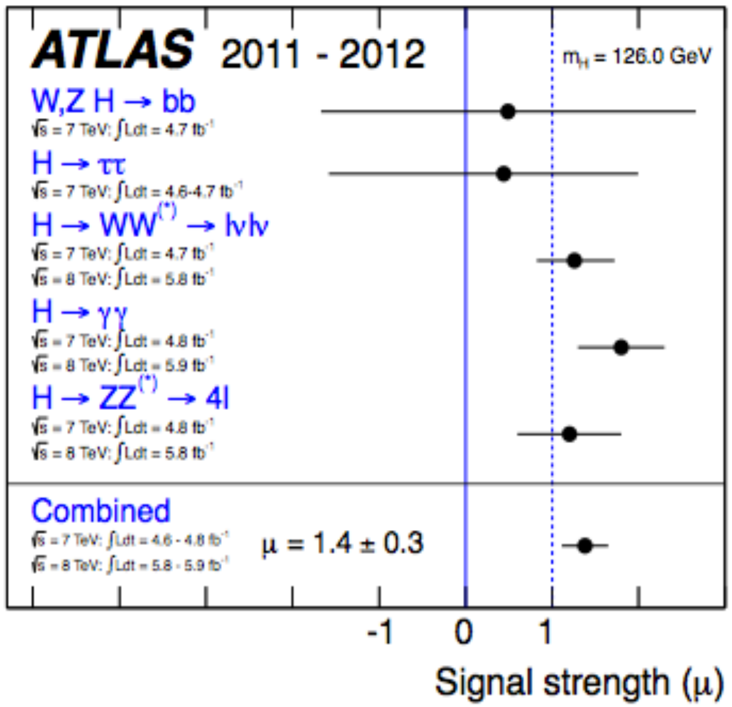
WW and ZZ decays are largest contributions but γγ, ττ and bb decays important at low mass due to large SM irreducible backgrounds: WW, ZZ, …

Observation of a new boson at a mass of ~126 GeV

Results from "July" papers:







	ATLAS	CMS
Local p-value	6.0 σ + Nothing else significant	5.0 σ + Nothing else significant
Mass [GeV]	126.0 ± 0.4 (stat.) ± 0.4 (syst.)	125.3 ± 0.4 (stat.) ± 0.5 (syst.)
Signal Strength	1.4 ± 0.3	0.87 ± 0.23

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→ **Compatible with Standard Model expectation**

CERN

Rolf Heuer:

'We have it!'

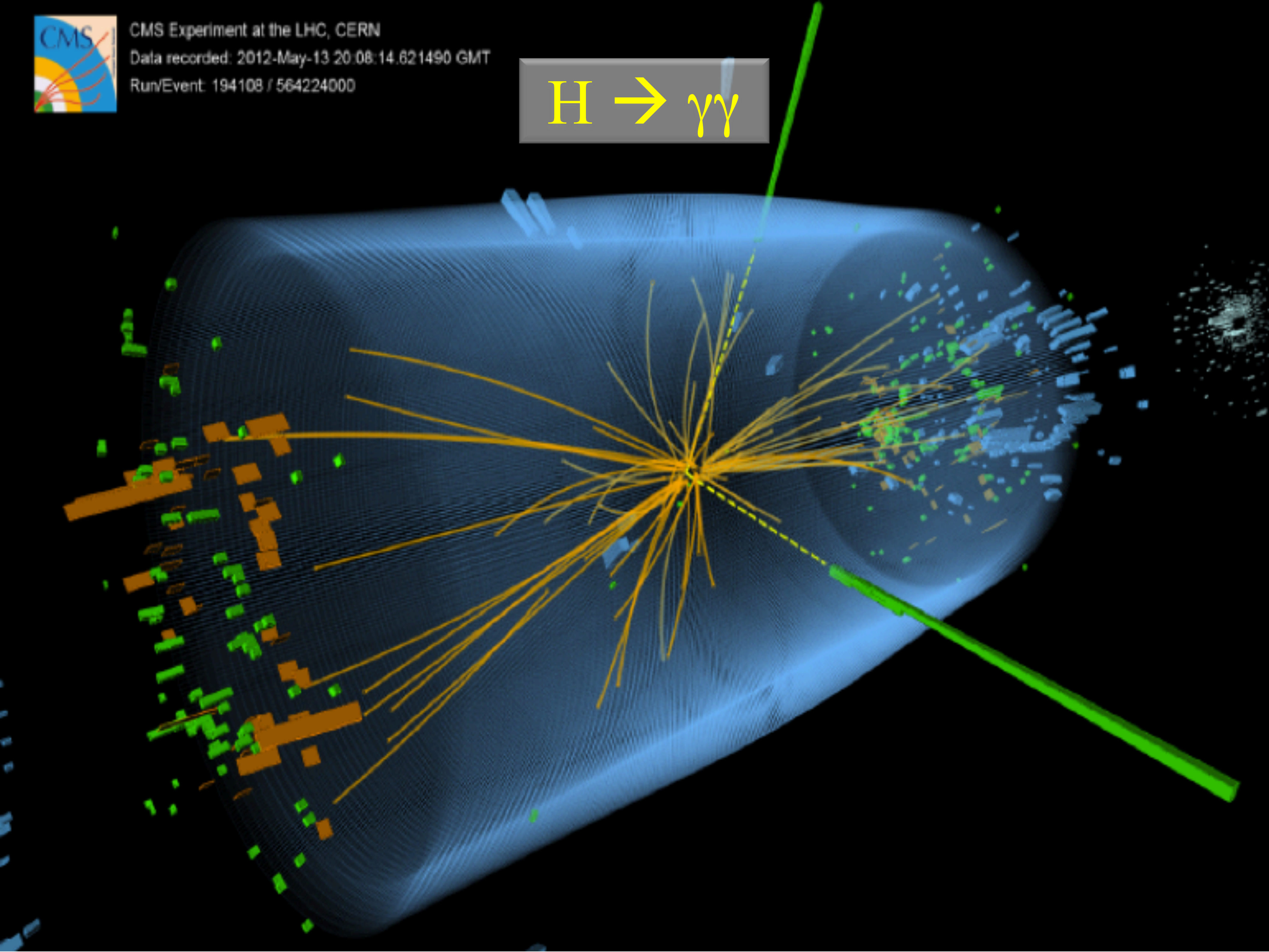
Melbourne

But is it THE Standard Model Brout-Englert-Higgs Boson ?

- ❑ **Does it couple/decay to fermions (τ, b) as expected in the SM ?** → Jesus talk
- ❑ **Are all the couplings (γ, W, Z, t, b, gluons, …) SM-like ?** → Pavel talk
- ❑ **What are its quantum numbers (Spin and CP) ?**
- ❑ **What about individual production mechanism strength (gg, VBF, VH, ttH) ?**

$H \rightarrow VV$ Analyses Overview

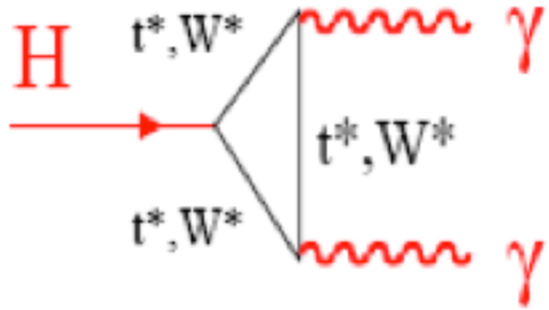
	Probed Prod. Mech.	Mass range [GeV]	ATLAS		CMS	
			7 TeV [fb^{-1}]	8TeV [fb^{-1}]	7 TeV [fb^{-1}]	8 TeV [fb^{-1}]
$H \rightarrow \gamma\gamma$	gg VBF	110-150	4.8	5.9	5.1	4.8
$H \rightarrow ZZ \rightarrow 4l$	Untag	110-600 CMS → 1000	4.8	5.8	5.1	12.2
$H \rightarrow ZZ \rightarrow 2l2\nu$	gg VBF	200-600	4.7	--	5	5
($H \rightarrow ZZ \rightarrow lljj$)	~ gg	120-600	4.7	--	4.6	--
$H \rightarrow WW \rightarrow 2l2\nu$	gg VBF	110-600	4.7	13	4.9	12.1
$H \rightarrow WW \rightarrow l\nu jj$	~ gg	160-600	4.7	--	5	12
$WH \rightarrow WWW \rightarrow 3l3\nu$	VH	110-200	4.7	--	4.9	5.1
($VH \rightarrow VWW \rightarrow jj2l\nu$)	VH	120-190	--	--	4.9	--


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H → γγ

CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000

No update since ICHEP

$H \rightarrow \gamma\gamma$



Overall small signal
BR between 0.14% and 0.23%
for $110<M_H<150$ GeV

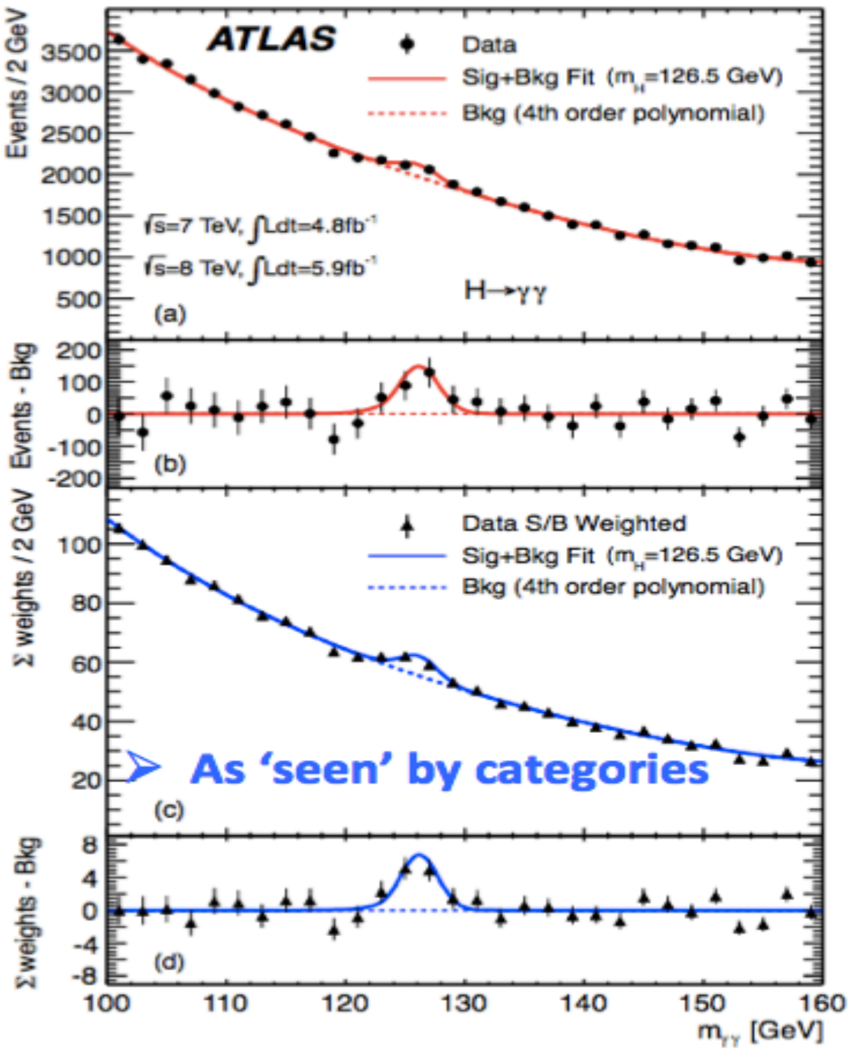
→ **Clean final-state topology: two isolated and high-Pt photons**
→ **Small-narrow peak on large continuous background**

Crucial ingredients $m_{\gamma\gamma}^2 = 2^*E_1E_2(1 - \cos\alpha)$

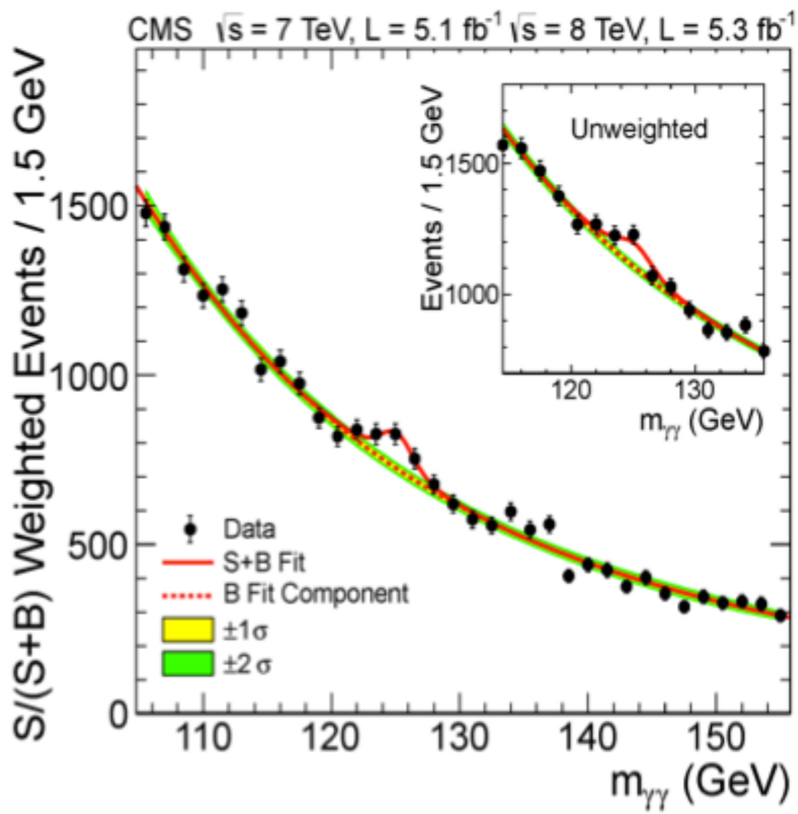
- ❑ **Robust photon reco, isolation and identification**
- ❑ **Good energy calibration and primary vertex reconstruction (*α depends on PV and cluster position*)**
- ❑ **Good background modeling**

$H \rightarrow \gamma\gamma$: Analysis Method

- Analysis separated in several di-photon categories based on p_T, η, photon ID, vertex info, mass resolution … to exploit different S/B ratio.
- Dedicated VBF categories: 2 jets well separated in pseudo-rapidity
- Background shape fitted from the data

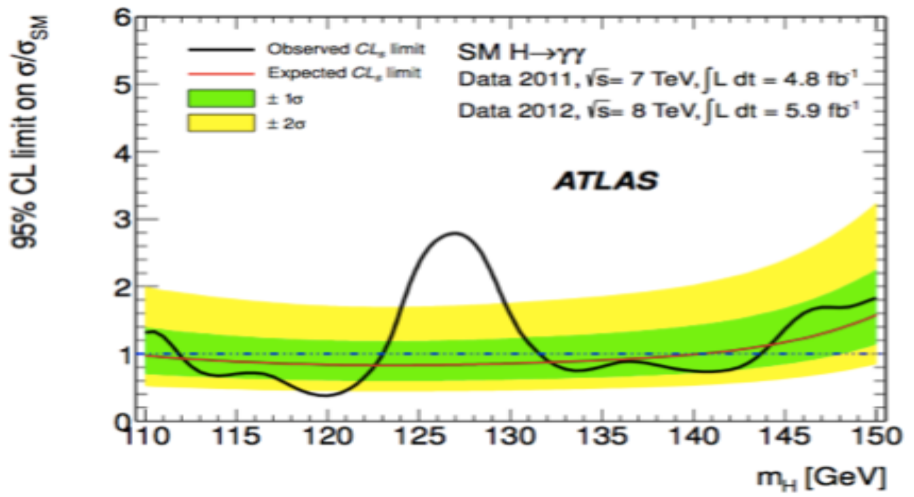


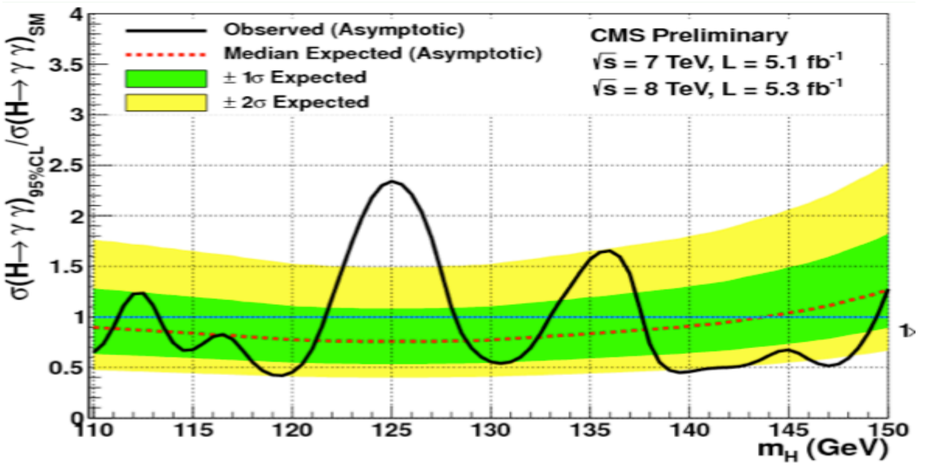
➢ As 'seen' by categories

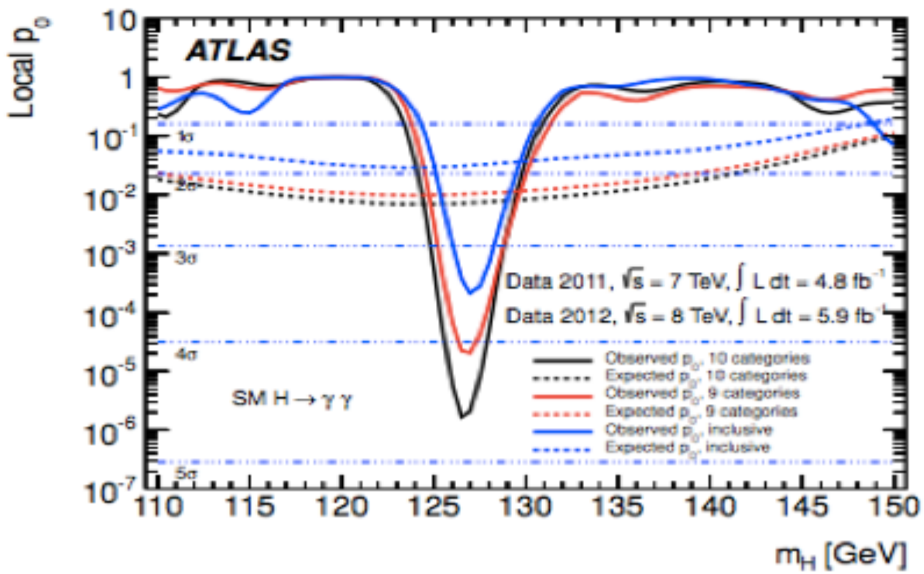


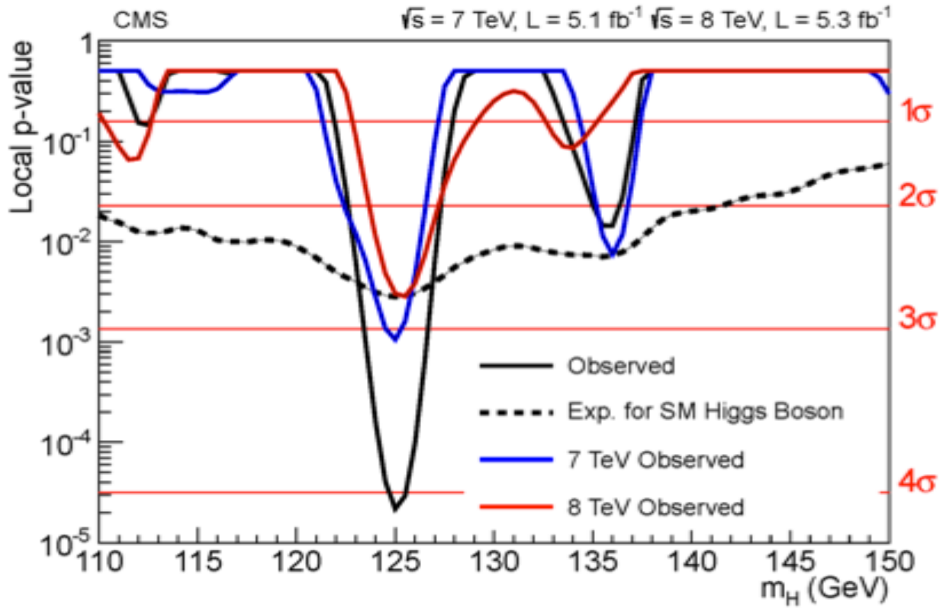
→ Mass peak in all category combined with and without S/B weighting

H → γγ : CLs and significance





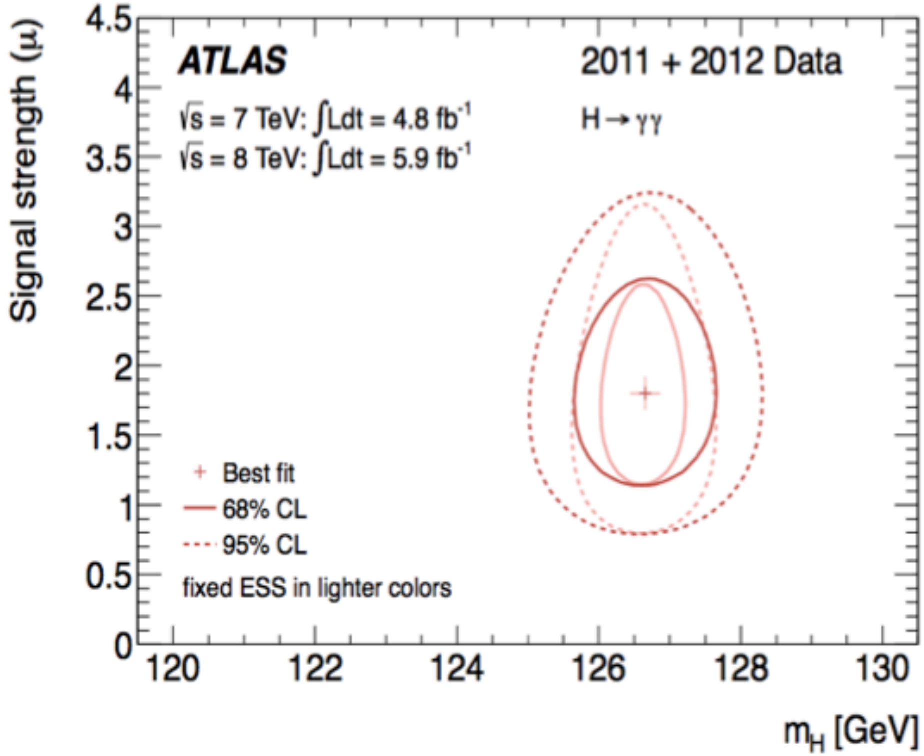




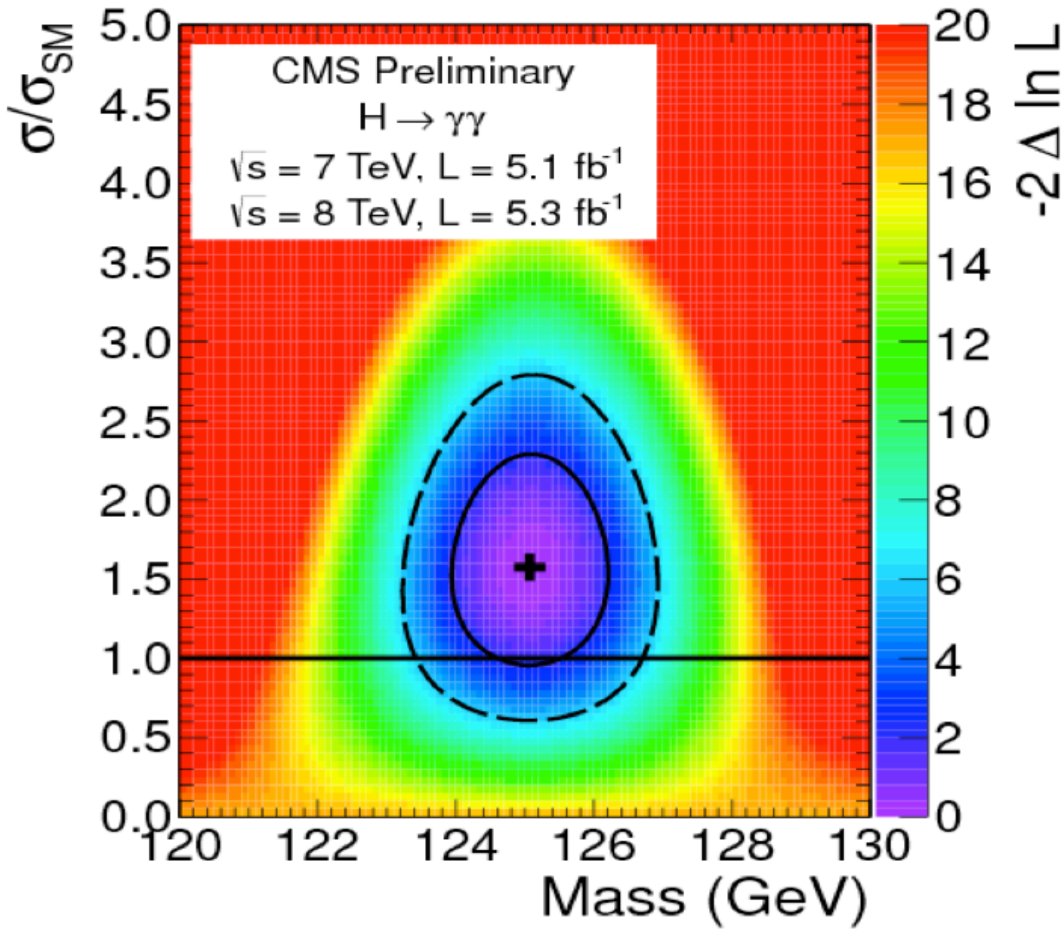
- ❑ **Large excess around 126 (125) GeV observed by ATLAS (CMS)**
- ❑ **Results consistent between 7 & 8 TeV and improved by VBF category**
- ❑ **Over 4σ observed local significance for both ATLAS and CMS**

H → γγ : Mass and signal strength

ATLAS



CMS

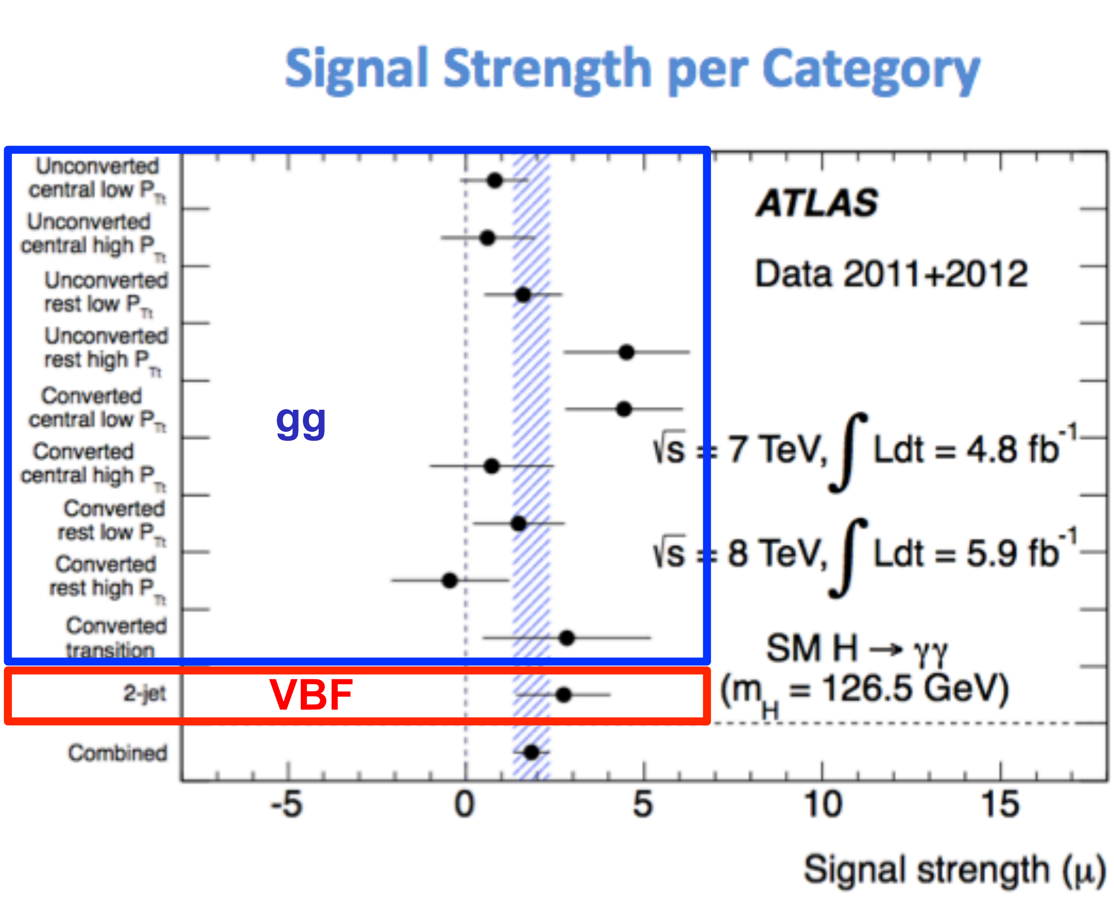


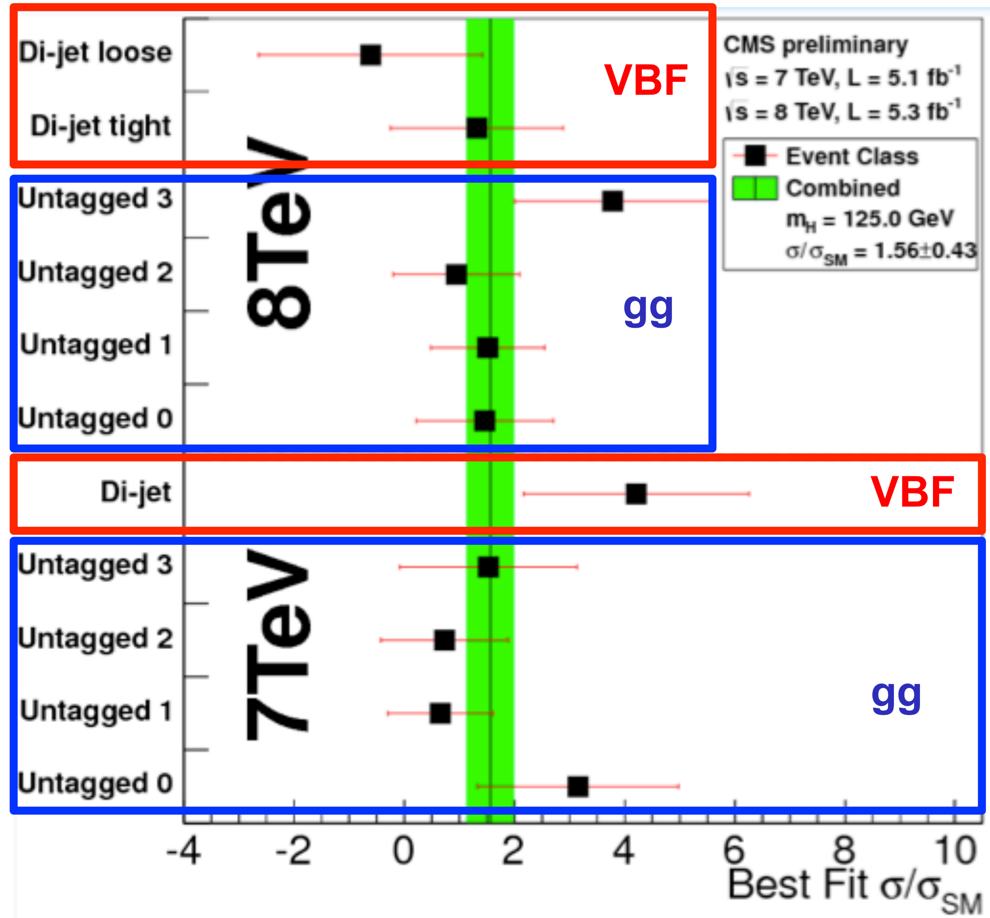
$M_{\gamma\gamma}$ ~ 126.5 GeV

$M_{\gamma\gamma}$ = 125.1 GeV ± 0.4 (stat) ± 0.6 (sys)

- **Signal strength compatible with SM within the present uncertainties**

H → γγ : Signal strength per category



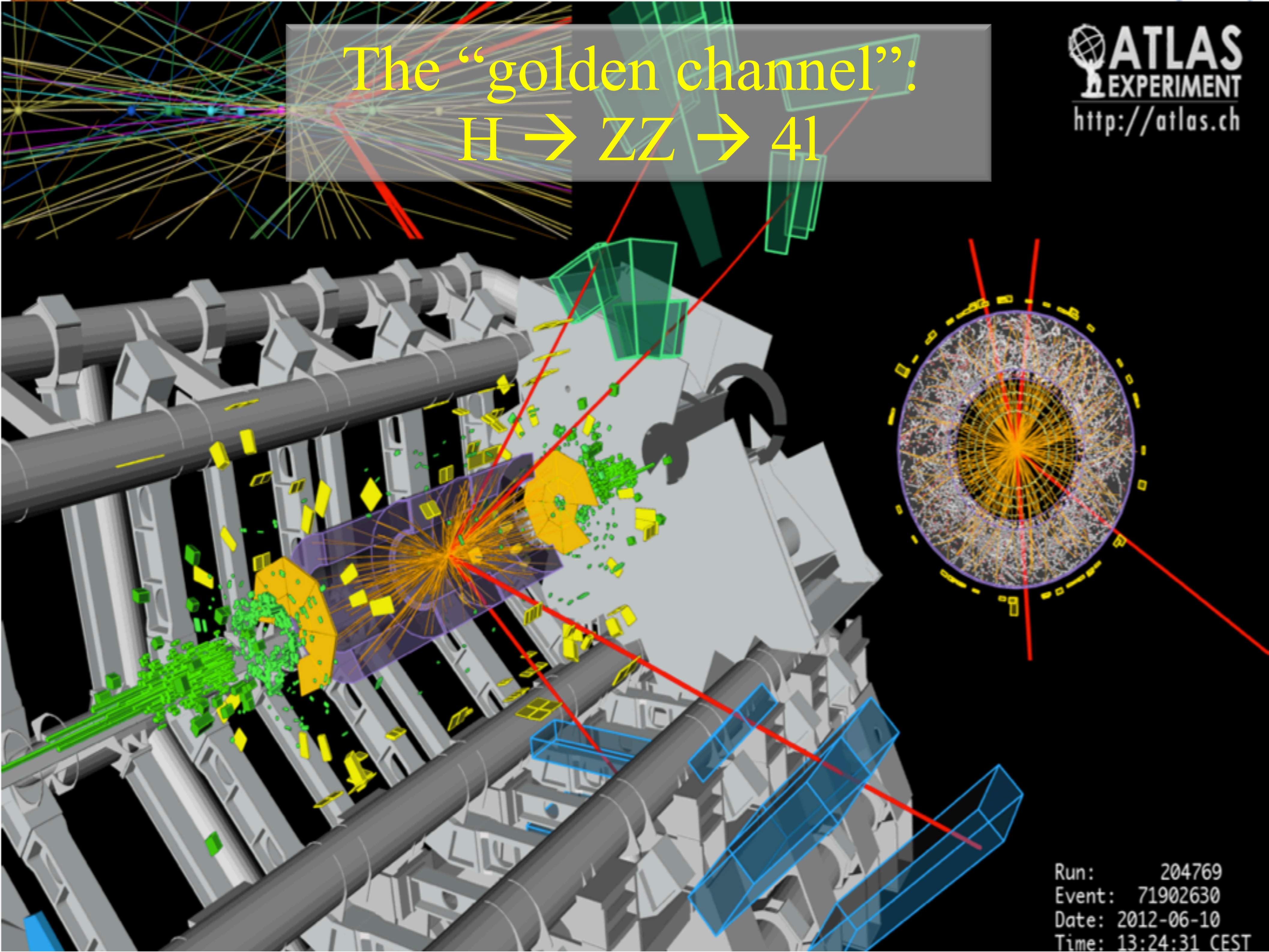


ATLAS: σ/σ_{SM} = 1.8 ± 0.5

CMS: σ/σ_{SM} = 1.56 ± 0.43

- Compatible with SM within the present uncertainties
- No difference between gg and VBF signal strength within uncertainties
- New data being analyzed but need a bit more time/scrutiny
  → Possibility to measure some J^{CP} properties + add VH/ttH categories

The “golden channel”: H → ZZ → 4l



The "golden channel": H → ZZ → 4l

Small rates, but high S/B

Can be fully reconstructed; mass resolution ~2% at 130 GeV

- Backgrounds:
  - Irreducible: $pp \to ZZ^{(*)} \to 4l$ (precise EWK prediction)
  - Reducible: Z+jets, $Zb\bar{b}$, $t\bar{t}$ (sizeable at low Higgs masses)

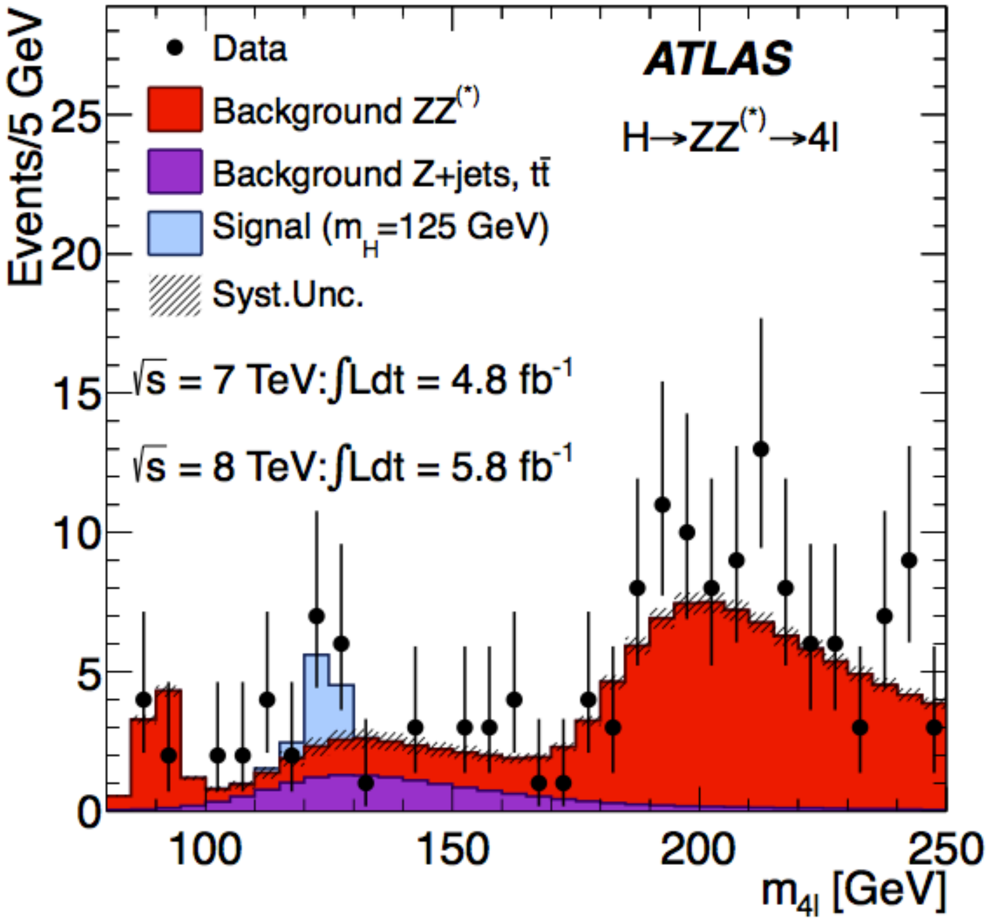
Considered channels:

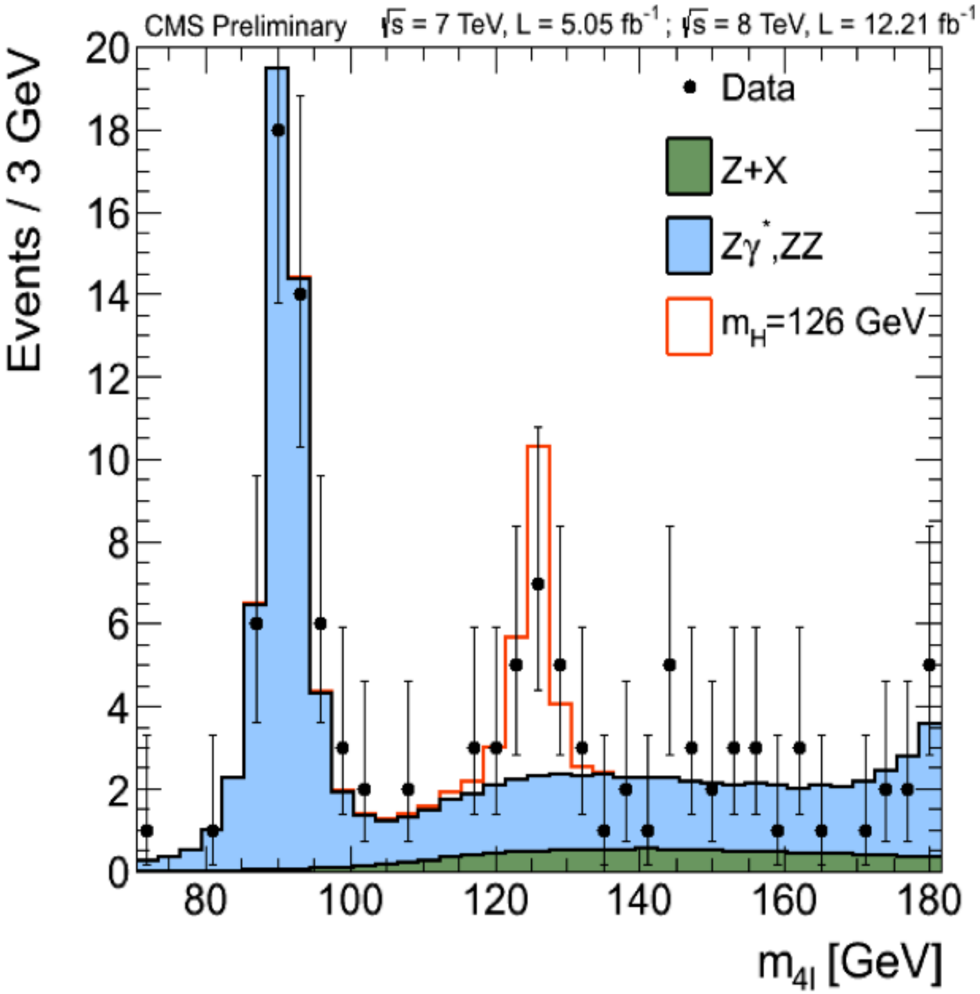
- **ATLAS : ZZ → 4l ; l = e, μ**
- **CMS : ZZ → 4l ; l = e, μ**
  ZZ → 2l2τ ; l = e, μ

ATLAS EXPERIMENT
http://atlas.ch

204769
Event: 71902630
Date: 2012-06-10
Time: 13:24:31 CEST

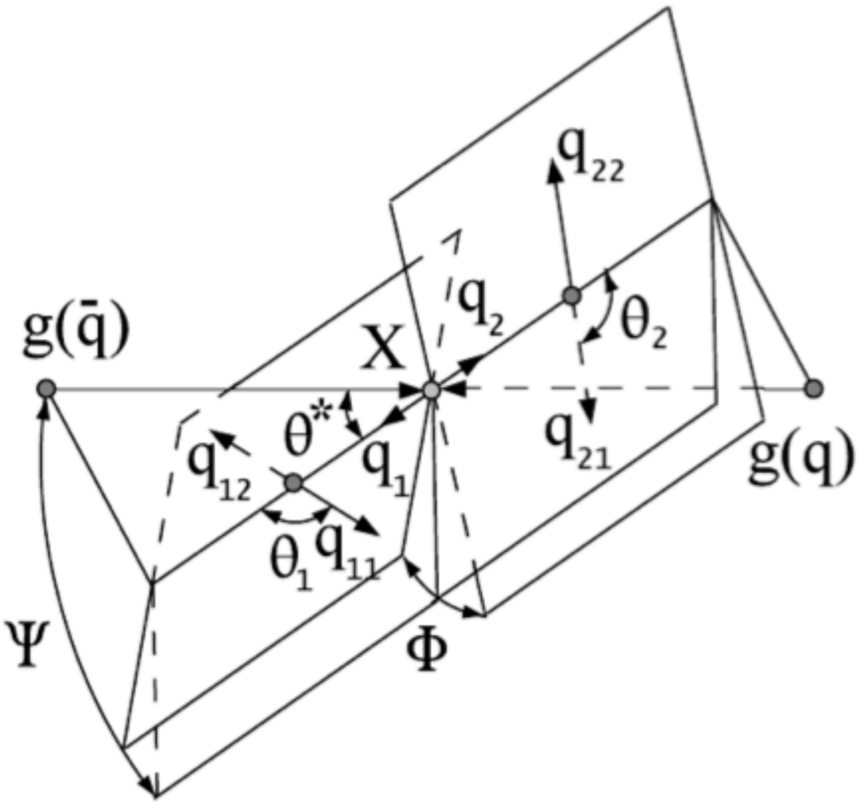
H→ZZ→4l: Invariant mass

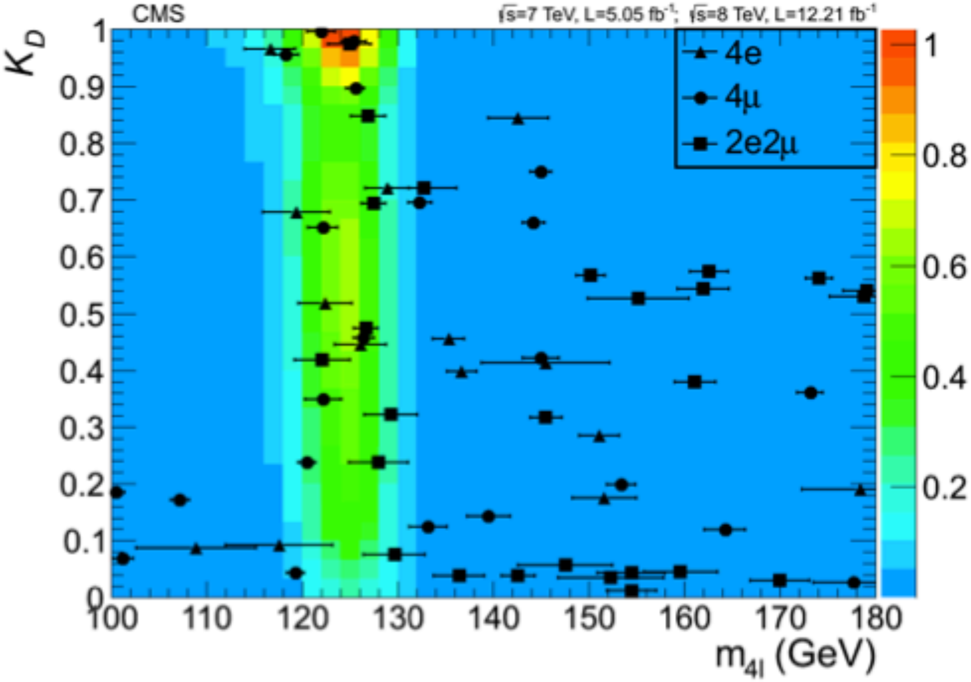


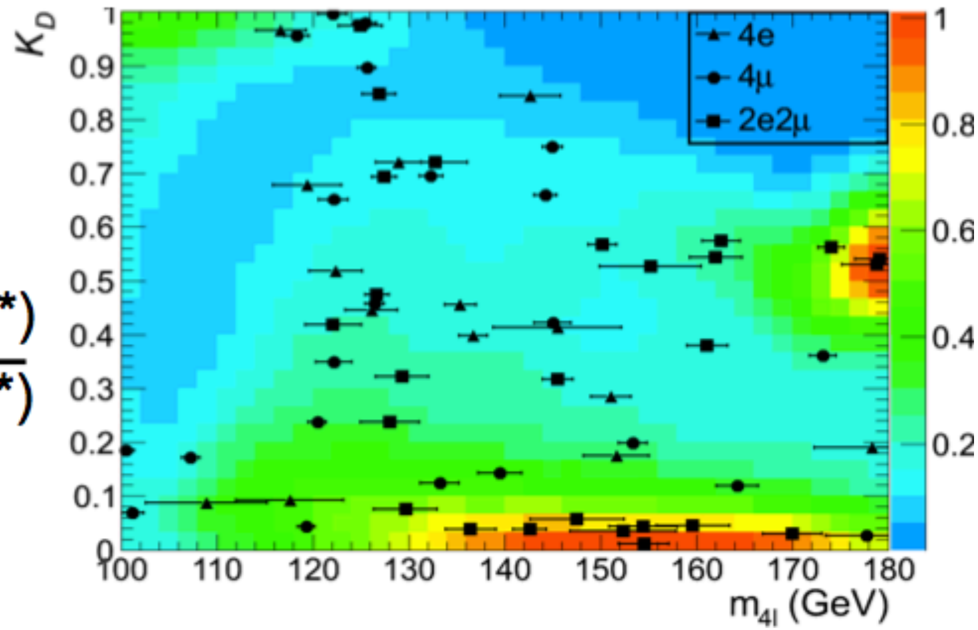


→ Peak around 126 GeV on top of a relatively flat background both in ATLAS (4.8+5.8 fb^{-1}) and CMS (5+12 fb^{-1}) analysis

H→ZZ→4l: CMS Kinematic Discriminant





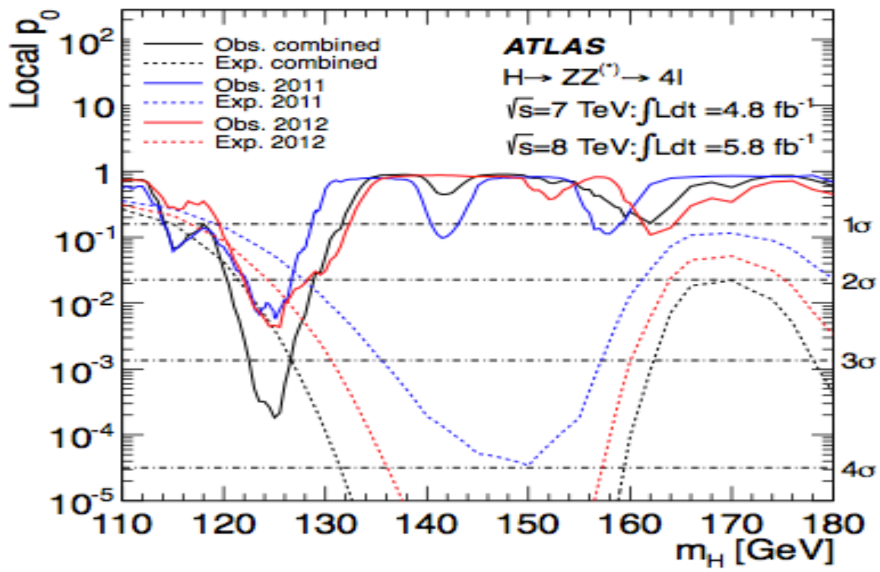


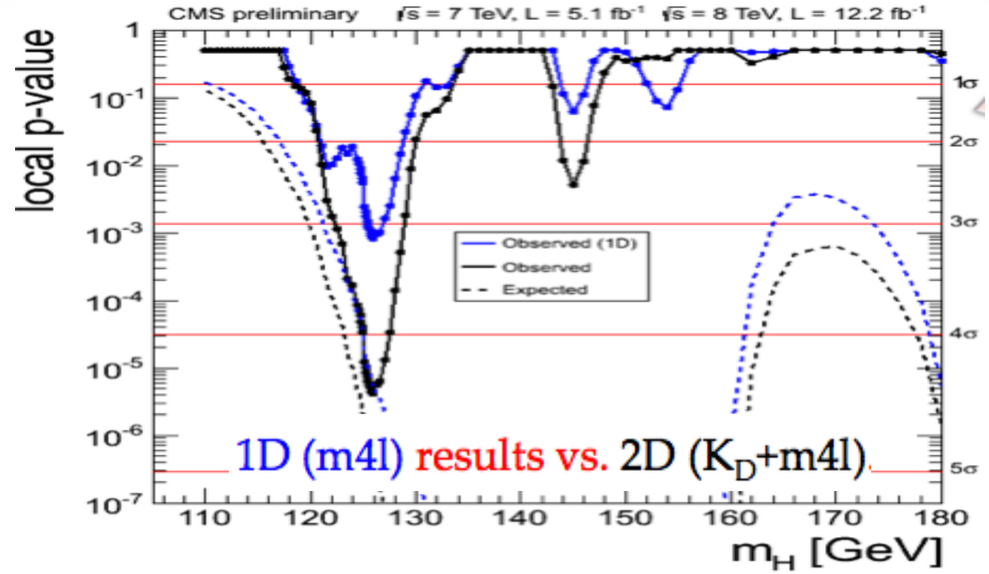
Angular analysis in CMS

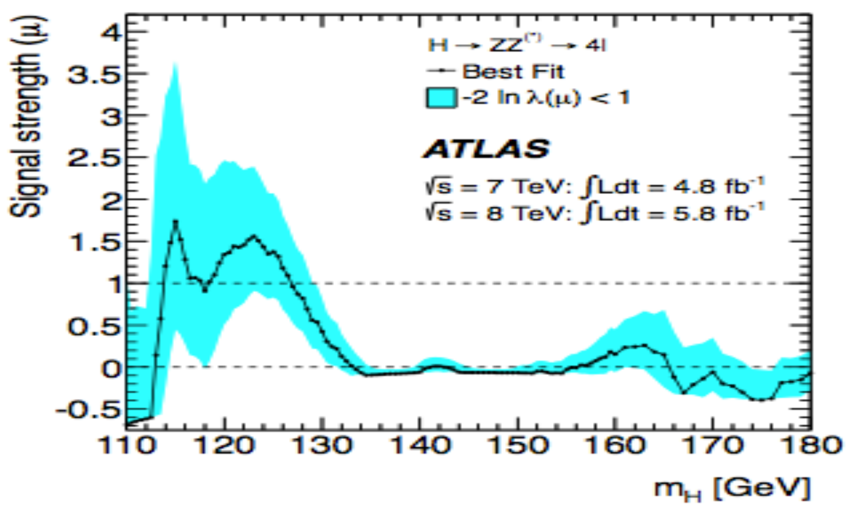
$$1/K_D = 1 + \frac{P_{background}(m_1,m_2,\theta_1,\theta_2,\Psi,\Phi,\theta^*)}{P_{signal}(m_1,m_2,\theta_1,\theta_2,\Psi,\Phi,\theta^*)}$$

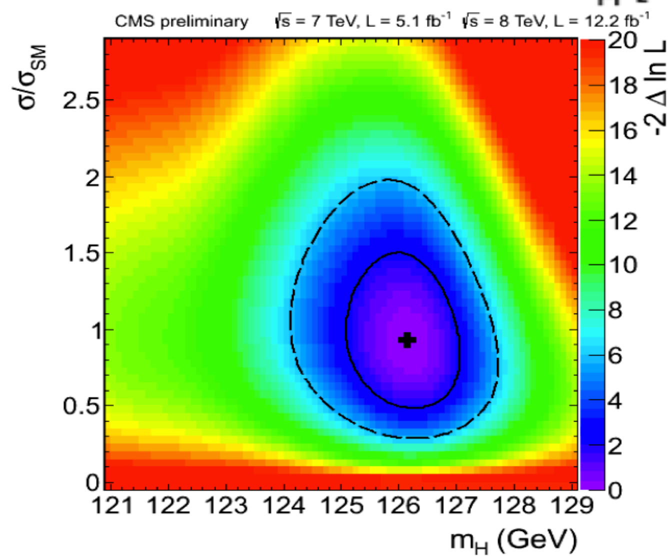
enhances analysis sensitivity

H→ZZ→4l: Results









@125 GeV: ATLAS: 3.6 σ

μ = 1.4 ± 0.6

CMS: 4.5σ

$\mu = 0.8^{+0.35}_{-0.28}$

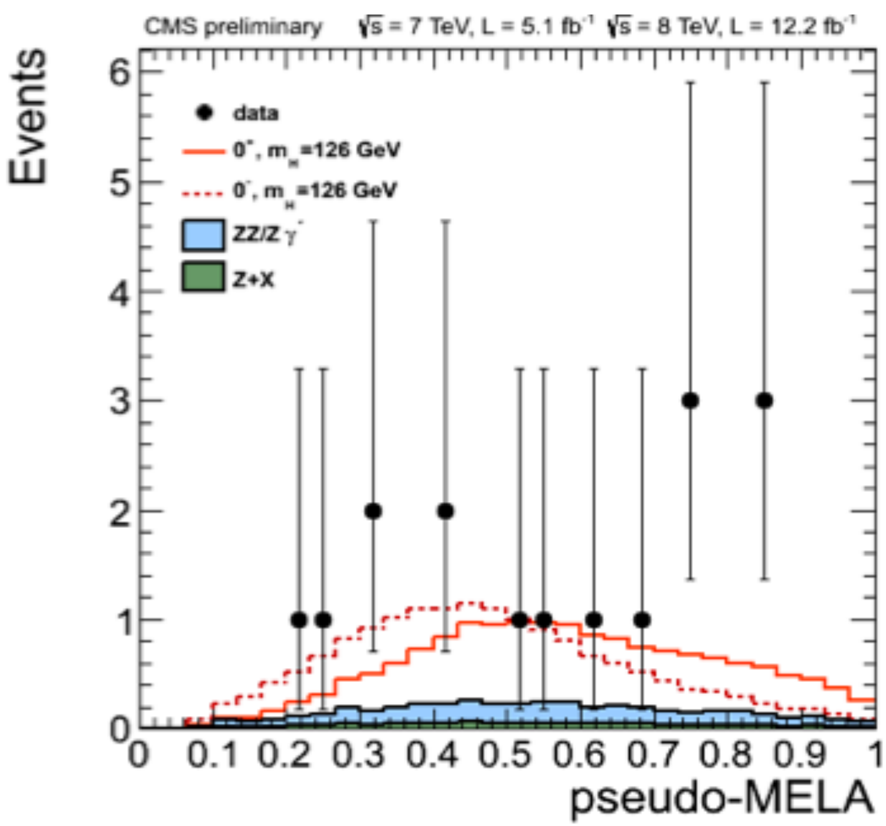
126.2 ± 0.6(stat.) ± 0.2(syst.) GeV

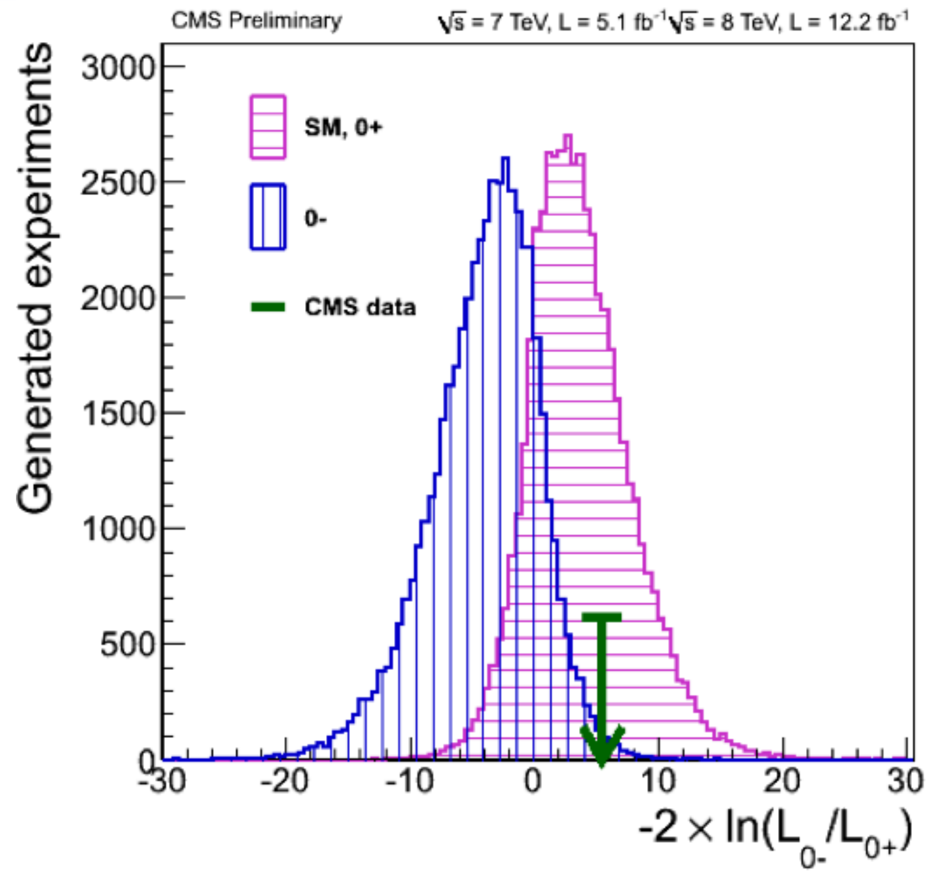
H→ZZ→4l: Spin/Parity Measurement (CMS)

- Using K_D to discriminate between different states

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

  - Final results are for using 2D fit: KD(+)D_{JP}, where KD has m4l added as well.





0+ vs. 0-:
Expected separation: 1.93 σ
Observed:
0- is consistent with observation within 2.45 σ (2.4% using CLs)
0+ - is within 0.53 σ

H→ZZ→4l: Extending to 1 TeV (CMS)

New since ICHEP:

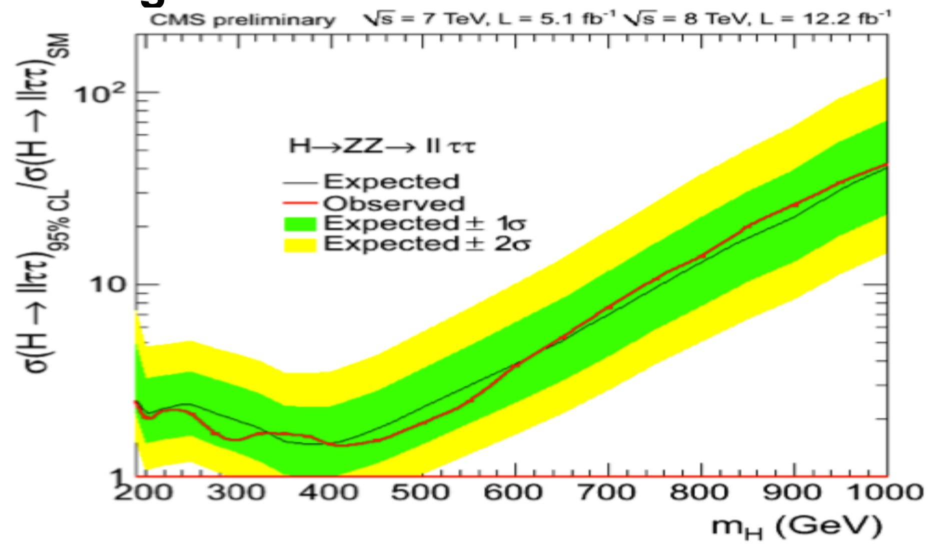
- **Reweight of high mass Higgs lineshape Including interference effects according to:**
  - N. Kauer et al. [arXiv:1201.1667,1206.4803]
  - G. Passarino [arXiv:1206.3824]
  - S. Goria et al. [arXiv:1112.5517]
  - J.-M. Campbell [arXiv:1107.5569]
  - V. Hirshi et al. [in preparation]

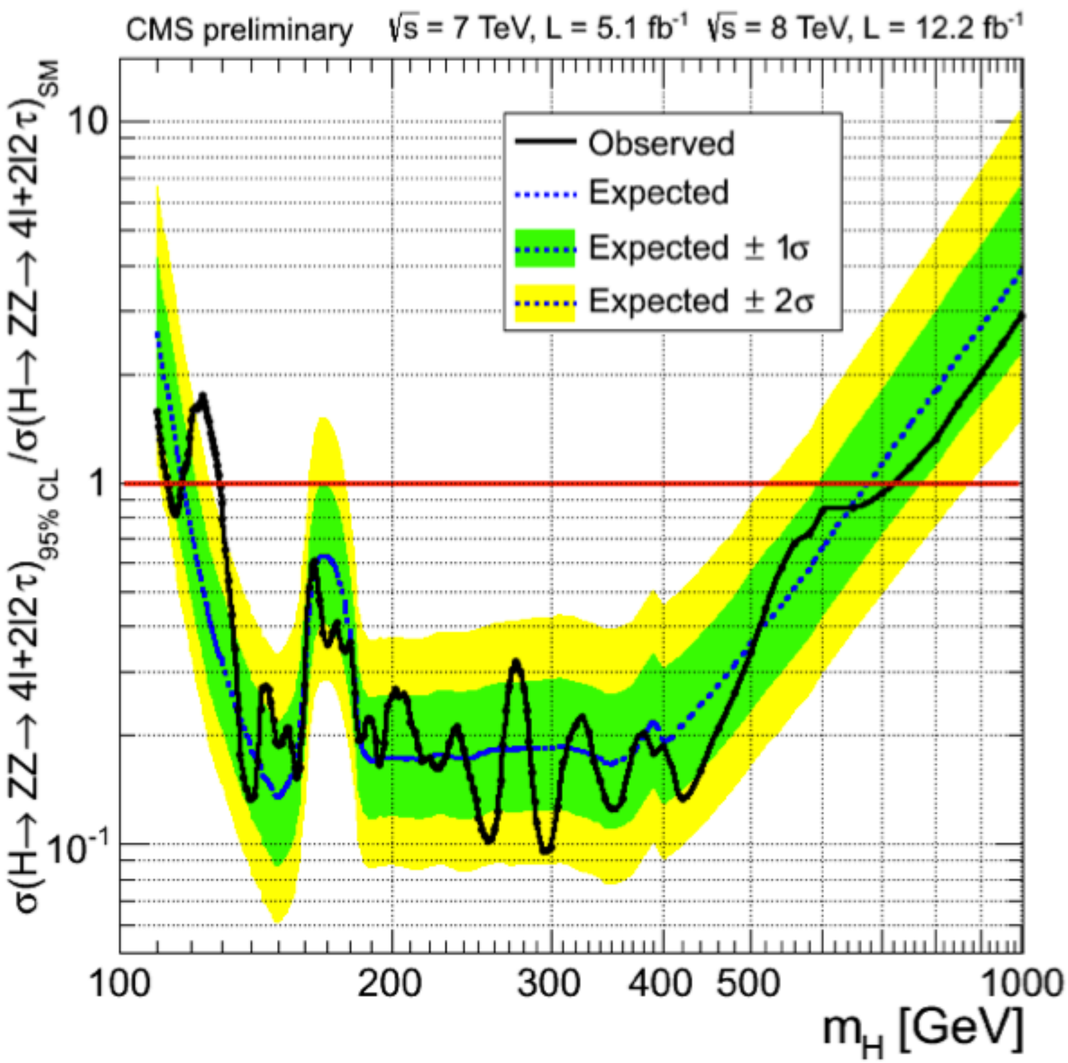
  → Effect important for mH >~ 500 GeV

  → Also applied in all post-ICHEP high mass analysis:
  - H → WW → 2l2ν
  - H → WW → lνjj

  \+ future updates (H→ZZ→2l2ν, …)

- **Merged with H → ZZ → 2l2τ channel**

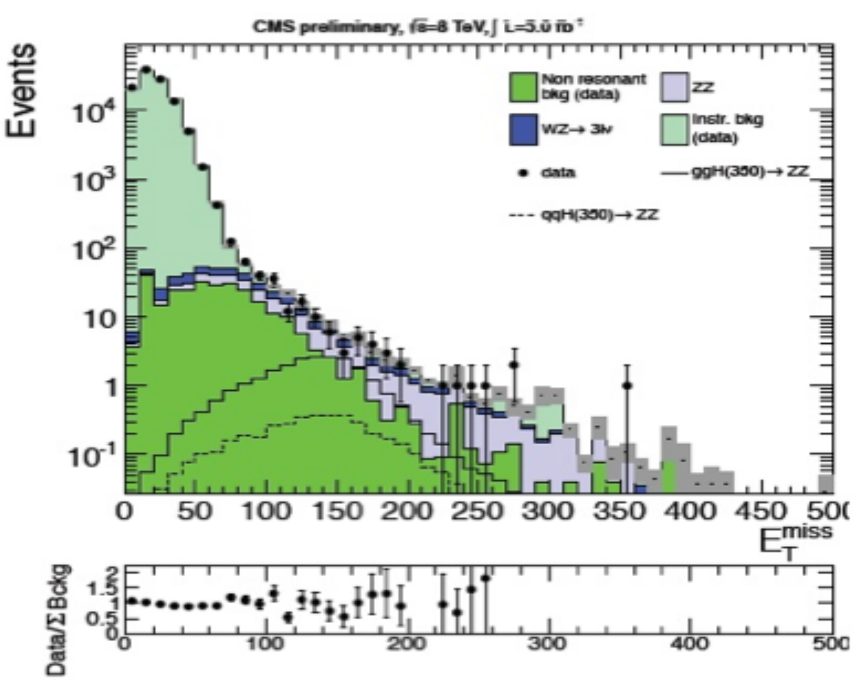




→No significant SM Higgs-like excess beyond 126 GeV one

H → ZZ → 2l2ν: Search strategy (CMS example)

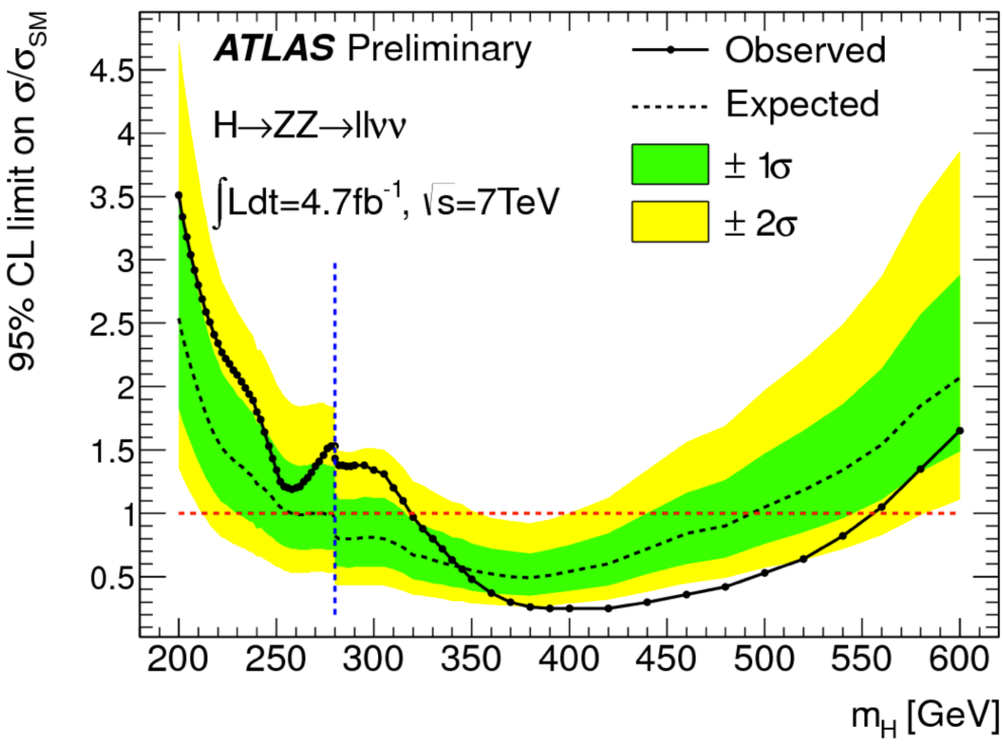
- Well identified and isolated ee or μμ: invariant mass close to Z boson mass
- Selection efficiencies corrected for data/MC difference
- **Z+jets background**
  - Fake MET due to jet mis-measurement
  - Cut on MET and veto jet faking MET events
  - Modeled from γ+jets data

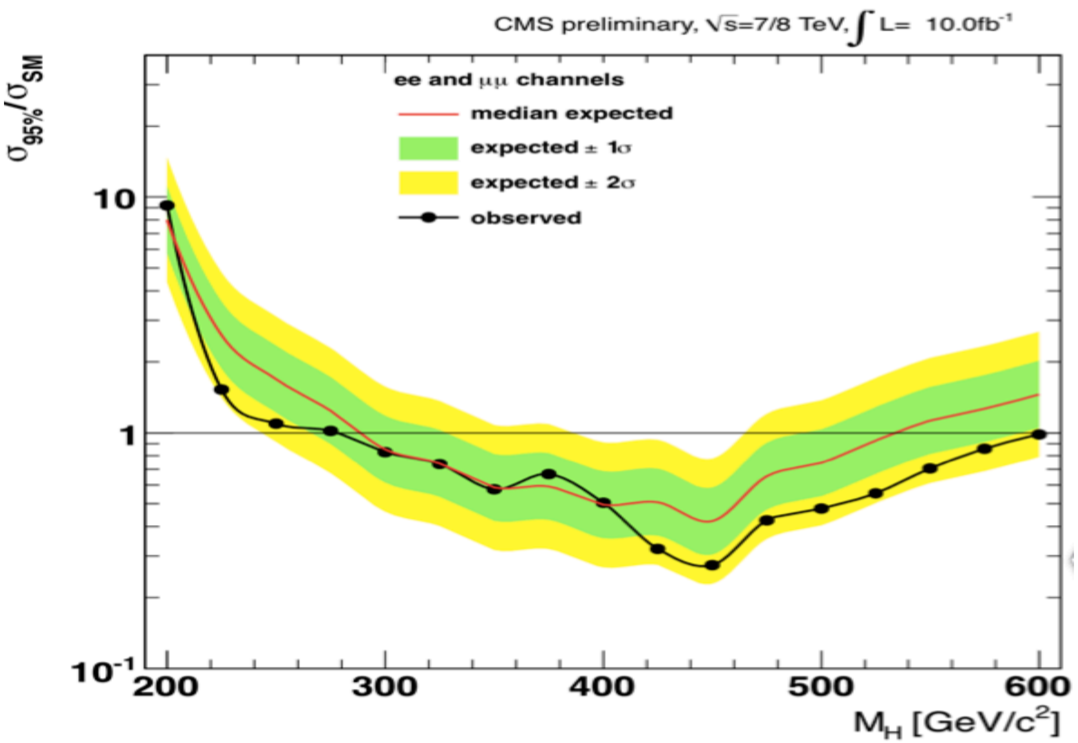


- Extra lepton veto
- b-tagged jet veto
- **Non-resonant backgrounds**
  - Select eμ events, applied ll/eμ scale factors
  - Scale factors computed in Z mass peak sideband events
- MET and transverse mass cuts tuned for different signal mass hypothesis to look for excess above background
- $$M_T^2 = \left[\sqrt{p_{T,\ell\ell}^2 + m_{\ell\ell}^2} + \sqrt{E_T^{miss,2} + m_{\ell\ell}^2}\right]^2 - \left[\vec{p}_{T,\ell\ell} + \vec{E}_T^{miss}\right]^2$$

More details in Jian's talk (CMS only session)

H → ZZ → 2l2ν: Results

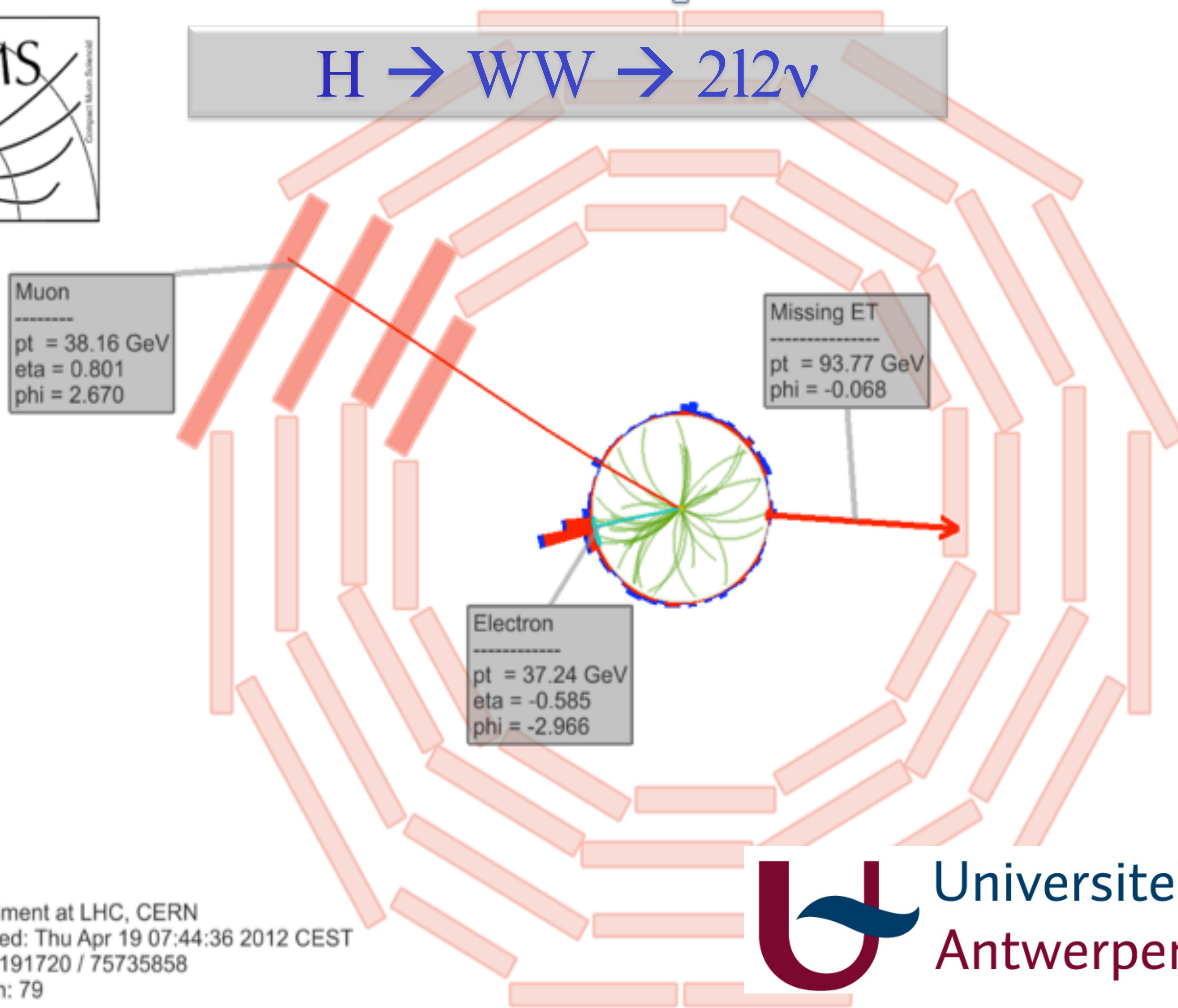




- No significant excess → Excluding SM Higgs for m_H in [228,600] GeV for CMS

- One of the most sensitive channel at high mass → Looking forward for updates …
- IIHE also pursuing non-resonant ZZ→2l2ν analysis:
  → Understand background to H studies
  → Limits on anomalous TGC
- **Open theory points:**
  → Prediction for interference between gg->H->2l2ν and gg->2l2ν
  → gZZ & ZZZ TGC only available in Sherpa !

H → WW → 2l2ν

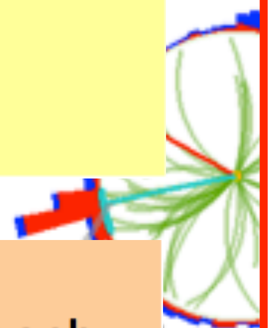


CMS Experiment at LHC, CERN
Data recorded: Thu Apr 19 07:44:36 2012 CEST
Run/Event: 191720 / 75735858
Lumi section: 79

H → WW → 2l2ν

Event Signature:

- 2 isolated, high p_T leptons (e or m only in this analysis) with small opening angle
- High Missing E_T from escaping n's
- Analysis performed on exclusive jet multiplicities (0, 1, 2-jet bins)
  → **WW (and Top for 1/2-jet bins) are "irreducible" backgrounds**



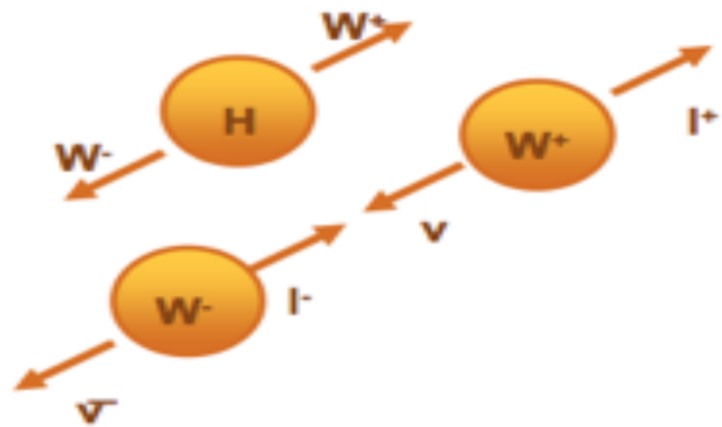
Signal Extraction:

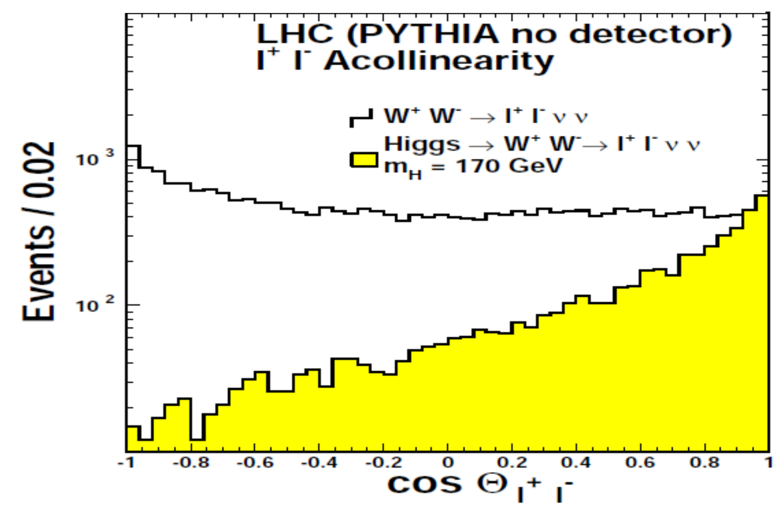
- Optimized **Cut Based** selection for each Higgs mass hypothesis:
  - p_T(l), m_{ll}, m_T and Df(ll) as discriminating variables in 0/1 jet bins
  - Dedicated VBF selection for 2-jet bin
- **Shape Analysis** for 0/1 jet bins

→Channel with best S/B in a wide mass range but no mass peak (resolution)
→ event counting analysis

CMS
Data
Run/E
Lumi

Use of different helicity correlations of the leptons for WW and H->WW to further separate them (smaller opening angle for H->WW) :





H → WW → 2l2ν : CMS Analysis Strategy

- **12.1 fb^{-1} @ 8 TeV:**

0-jets, shape	1-jet, shape	2-jets, VBF	different flavor, DF
0-jets	1-jets	2-jets, VBF	same flavor, SF substantial DY background

jets with p_T > 30 GeV

– different flavor (DF) most sensitive (0 and 1 jet categories)
– shape analysis for those two DF categories only
– other categories use easier to control cut-and-count strategy

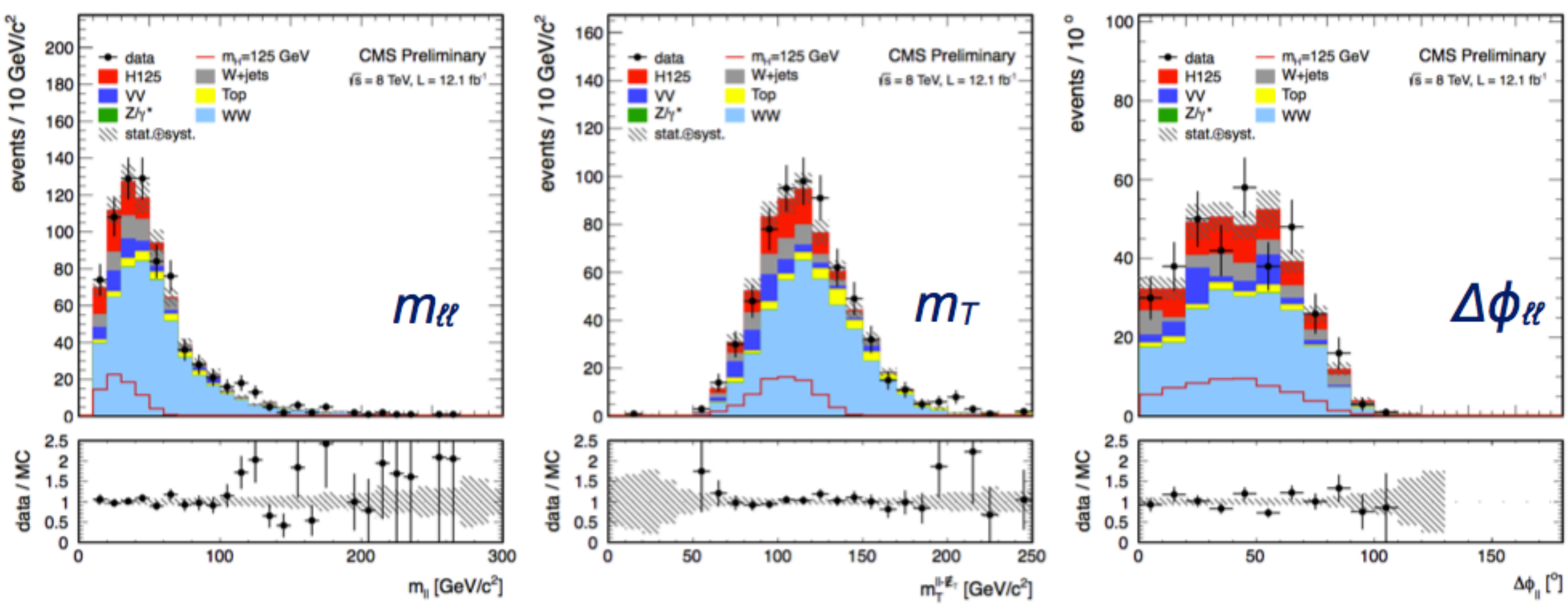
New for HCP

– shape analysis uses (m_{ll}-m_T) plane
– mass independent DY rejection, VBF selection optimized

- **Combine with published 7 TeV analysis (4.9 fb^{-1})**

$H \to WW \to 2l2\nu$: CMS Cut&Count (0 jet DF)

m_H	$H \to W^+W^-$	$pp \to W^+W^-$	$WZ+ZZ$ $+Z/\gamma^* \to \ell^+\ell^-$	Top	W + jets	$W\gamma^{(*)}$	all bkg.	data
0-jet category $e\mu$ final state								
120	34.0 ± 7.3	162 ± 16	5.3 ± 0.5	8.6 ± 2.0	38 ± 14	23.1 ± 8.8	237 ± 23	285
125	58 ± 12	203 ± 19	6.6 ± 0.6	11.0 ± 2.5	44 ± 16	25.6 ± 9.5	291 ± 27	349
130	86 ± 18	226 ± 21	7.1 ± 0.7	12.2 ± 2.8	47 ± 17	27 ± 10	319 ± 29	388
160	238 ± 51	125 ± 12	3.7 ± 0.4	13.1 ± 3.1	5.9 ± 2.7	2.6 ± 1.5	160 ± 13	197
200	95 ± 21	204 ± 19	6.3 ± 0.6	28.9 ± 6.4	7.7 ± 3.5	1.3 ± 0.9	278 ± 21	309
400	40 ± 11	133 ± 15	6.2 ± 0.7	50 ± 11	7.6 ± 3.3	3.5 ± 2.1	200 ± 19	198
600	6.6 ± 2.3	42.2 ± 4.8	2.5 ± 0.3	16.5 ± 3.8	4.4 ± 2.0	2.4 ± 1.8	67.9 ± 6.7	64



H → WW →2l2ν : CMS 2D Shape

Exploits the correlation of two kinematic variables in 2D

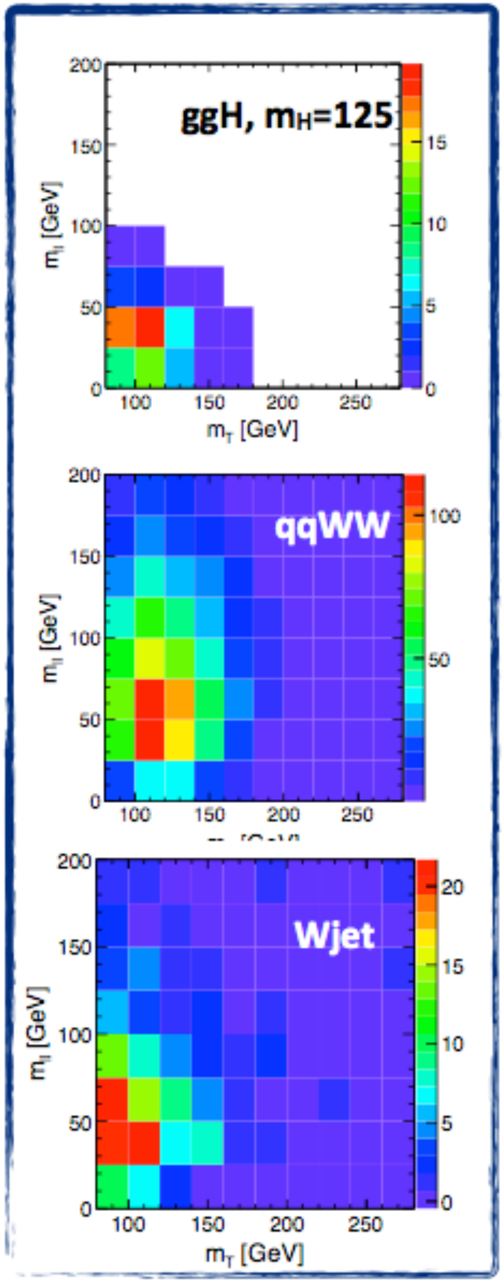
- Easier interpretation than multivariate discriminants
- Use of **mass-like variables**
  - **m_T: higgs transverse mass** $$m_T = \sqrt{2p_T^{\ell\ell} E_T^{\rm miss}\left(1-\cos\Delta\phi_{E_T^{\rm miss}\ell\ell}\right)}$$
  - **$m_{\ell\ell}$: di-lepton invariant mass**
- Different backgrounds peaking at **different location**

Relaxed selection with respect to cut-based

- Exploit the **full range** of the variables
- Improved sensitivity at low m_H from additional **sideband constraint of backgrounds**
- Mass independent selection for low/high mass searches

Applied to **DF 0/1-jet** channels

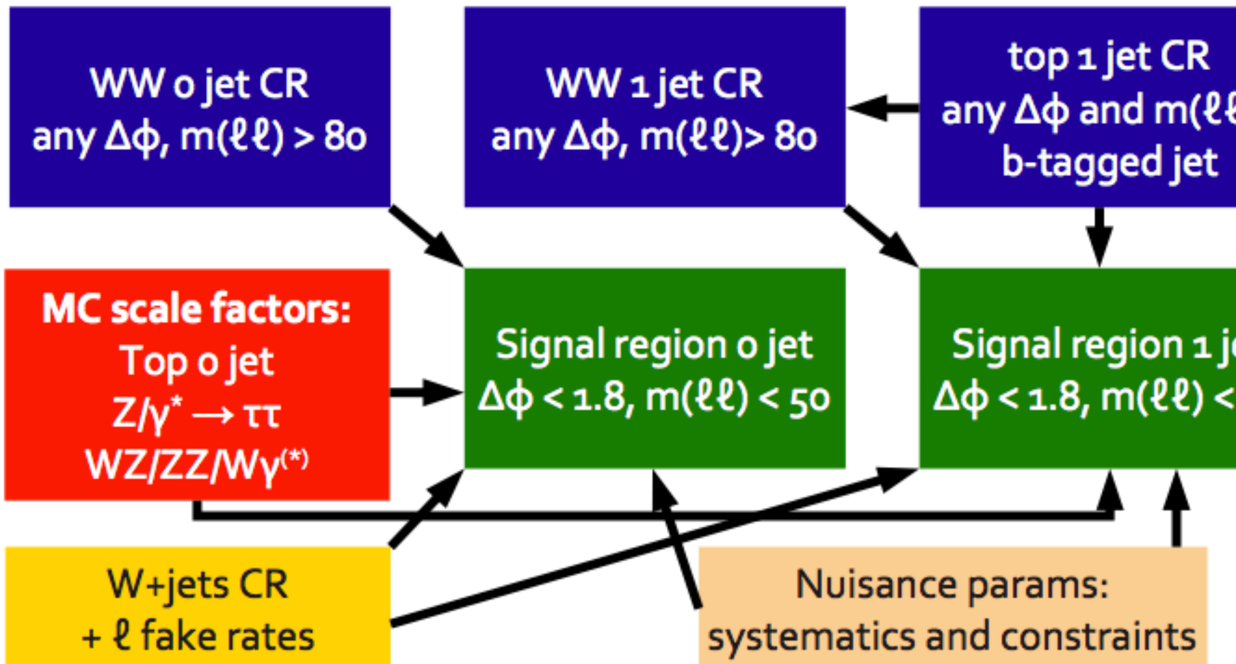
- Most sensitive channels with sufficient statistics for a 2D analysis



H → WW →2l2ν : ATLAS Analysis Strategy

→ 13 fb^{-1} @ 8 TeV:

- Fit the m_T spectrum of the signal region and the normalizations of (blue) control regions
  - systematics included as nuisance parameters

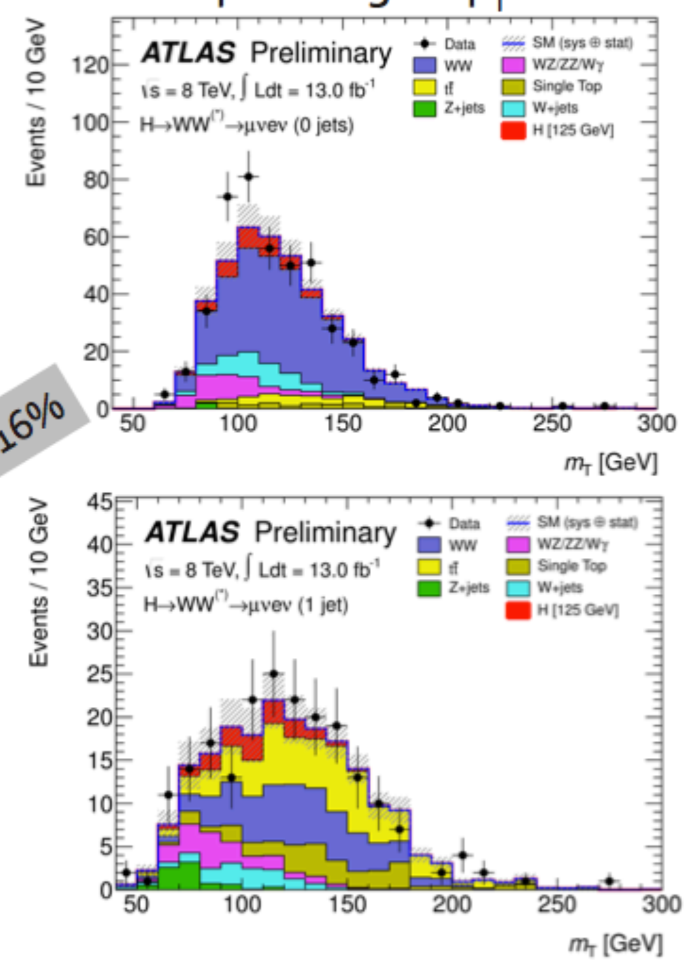


S/B: 13-16%

μ has higher p_T

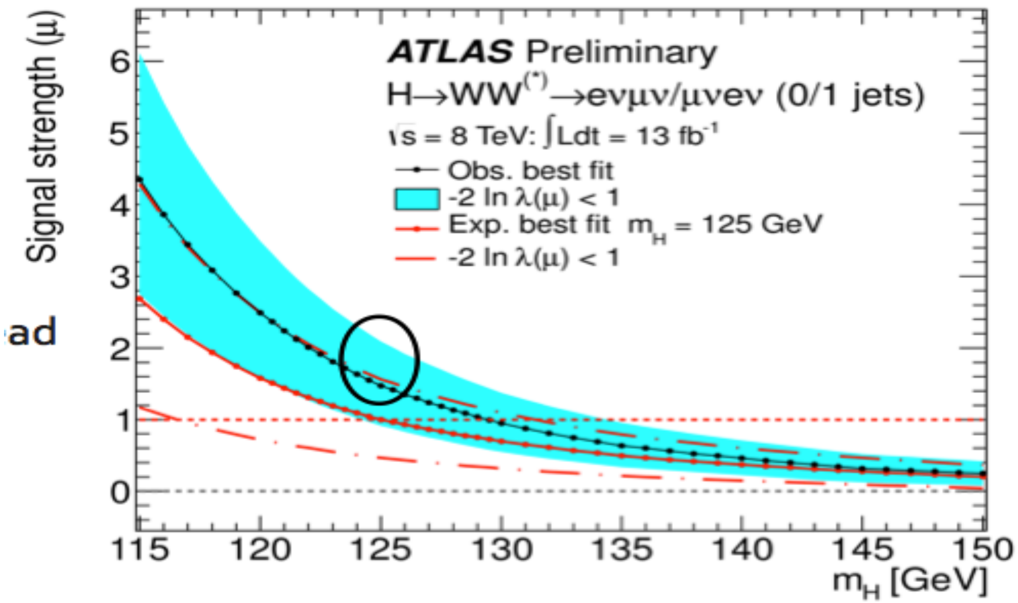
0 jet

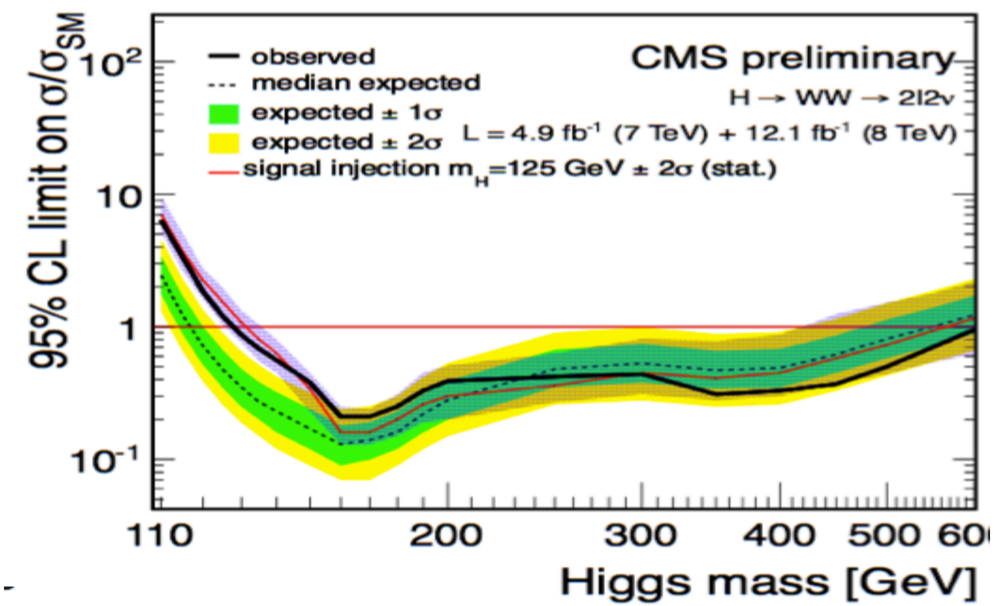
1 jet

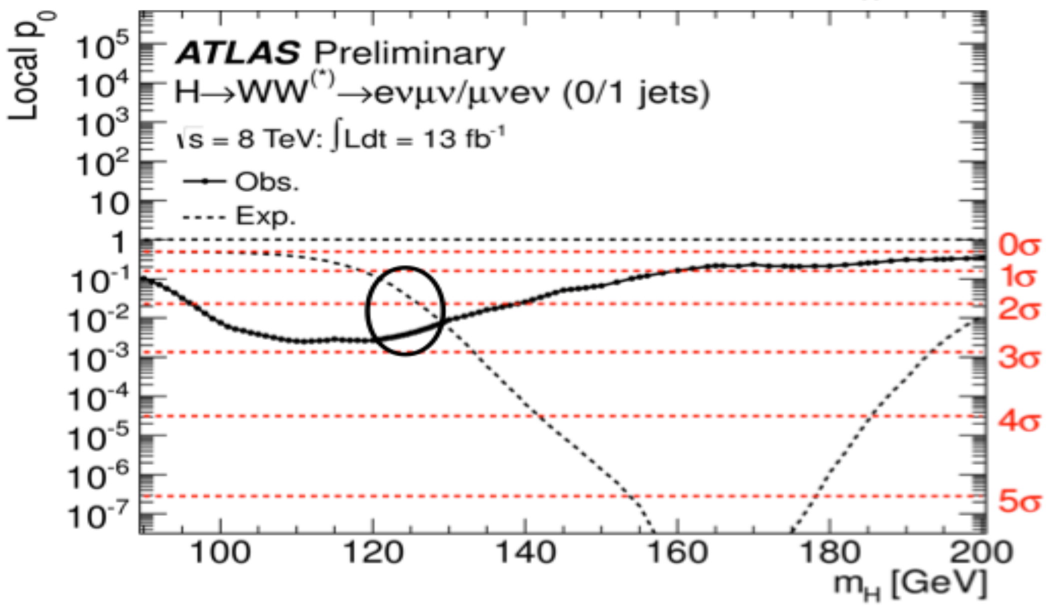


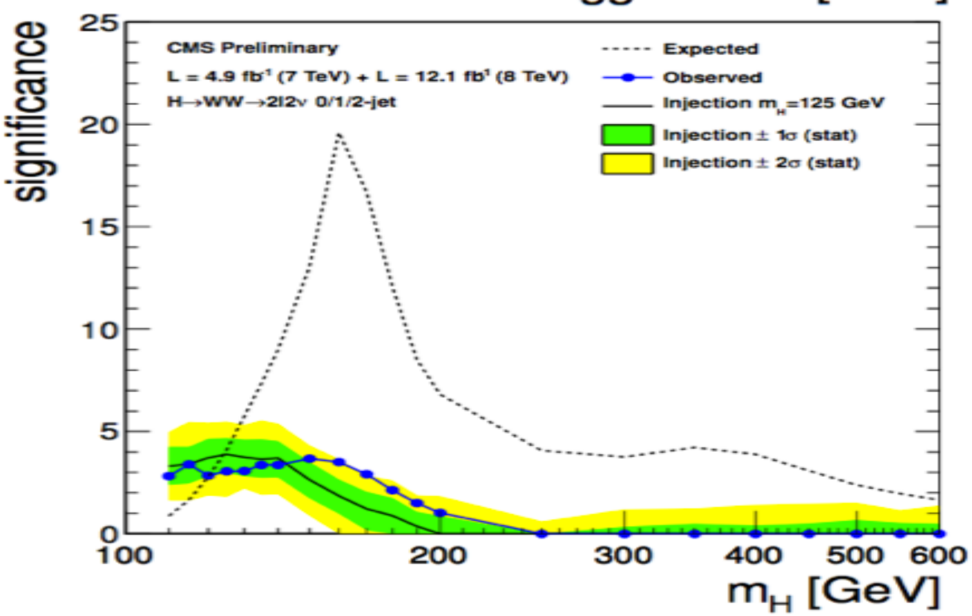
- Plan to update to full 2012 dataset and combine with improved 7 TeV result in the future

H → WW →2l2ν : Results





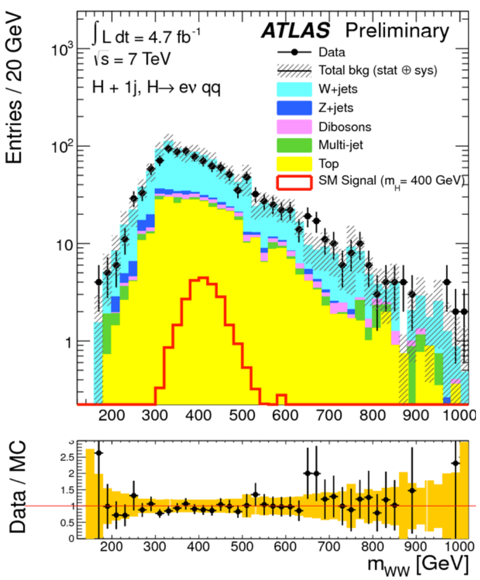


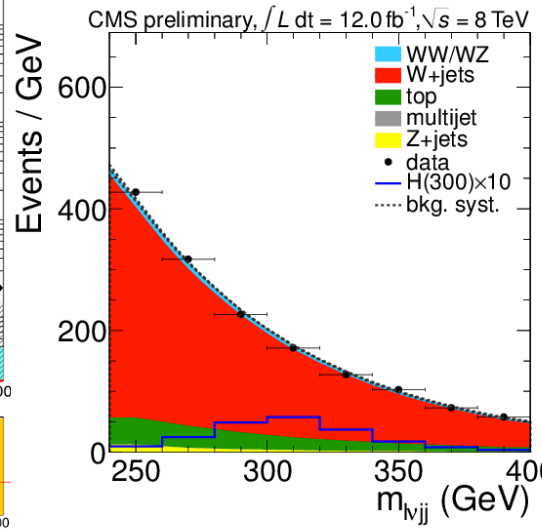


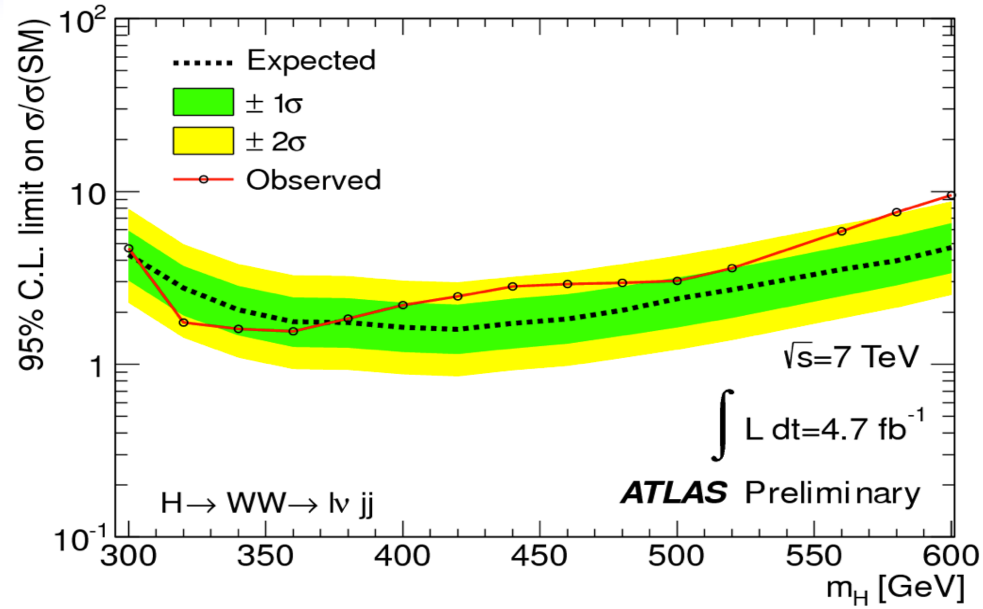
@125 GeV: ATLAS: 2.6σ (expected 1.9σ) **CMS: 3.1σ (expected 4.1σ)**

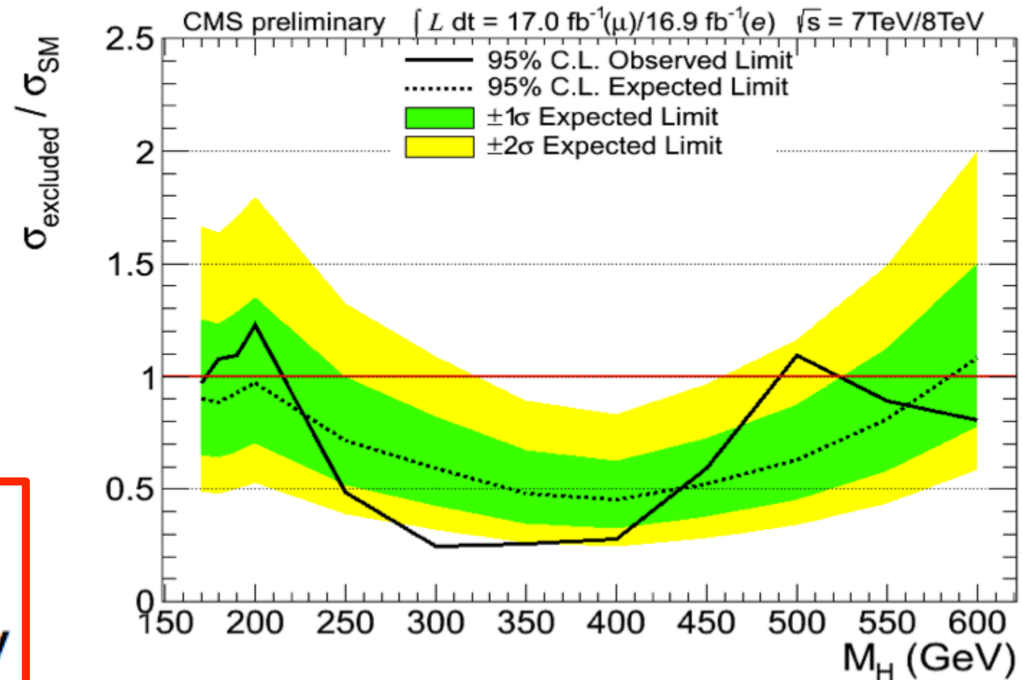
$H \rightarrow WW \rightarrow l\nu jj$

- **Reconstruct $m_{WW} = m_{l\nu jj}$**
- 4 categories (e | μ) x (2j | 3j)
  - apply the same techniques
- Implement MVA
- **Data-driven techniques** for high rate backgrounds









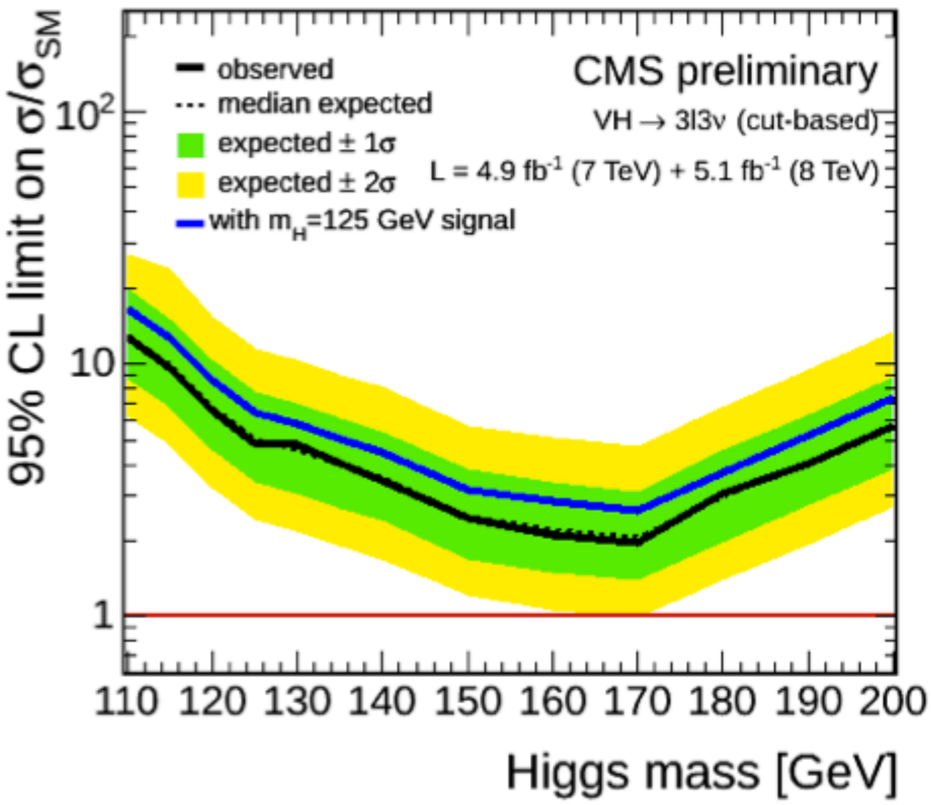
CMS:

Expected limit: 220-560 GeV

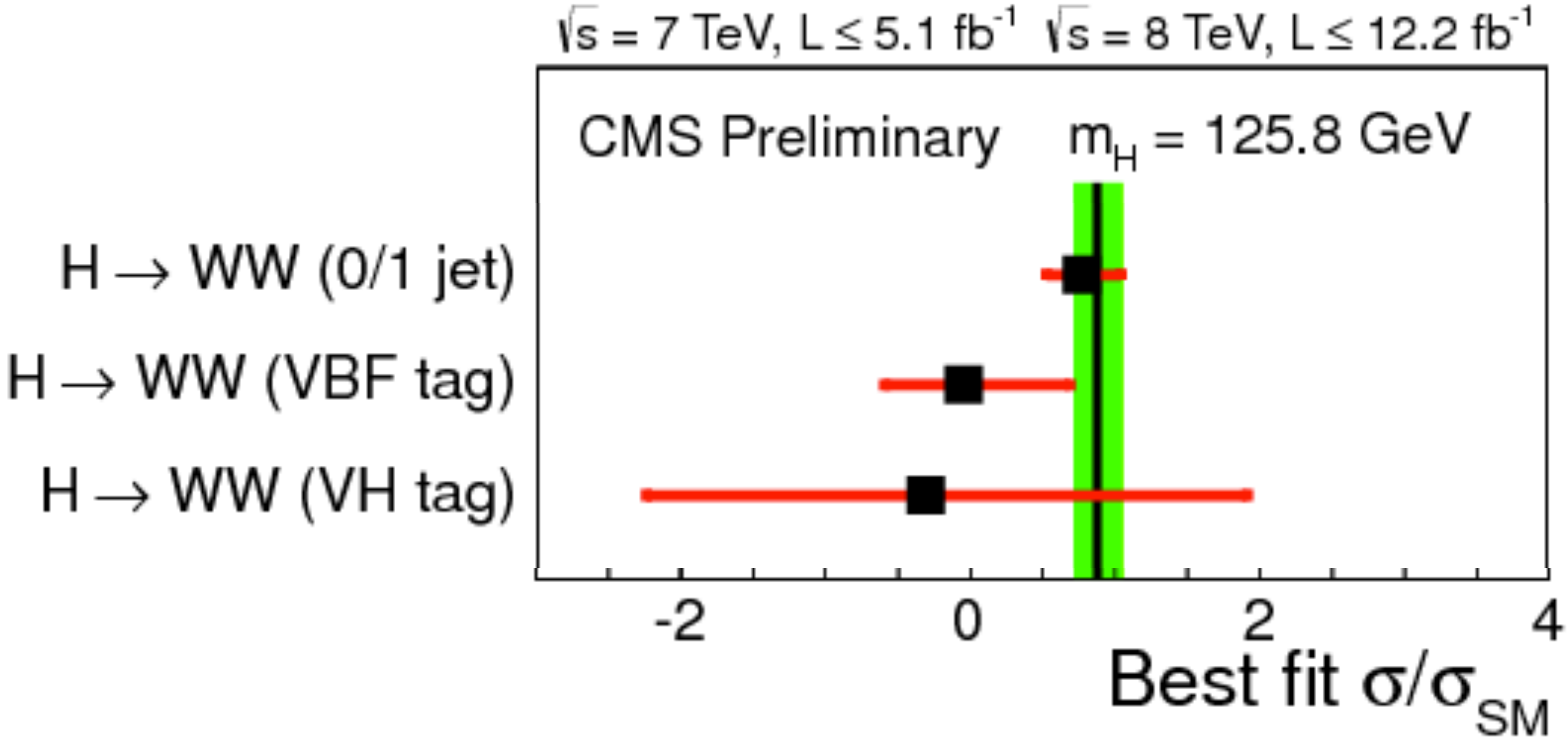
Observed limit: 225-485, 550-600 GeV

WH → WWW → 3l3ν

- $\sigma(WH_{SM}(m_H=125))$~0.7 pb, drops rapidly
- Analysis based on ICHEP dataset (10 fb^{-1})
- Cut-and-count, optimize for M_H = 125 GeV
- Include WH→ττ in the signal
- Apply many of the same techniques as 2l2ν
- Good agreement between data and background prediction
- Upper limits calculated on 10 fb-1 of data from 2011 and 2012
- The limits are ~5 times larger than SM expectation for M_H= 125 GeV
- Analysis of 2012 data continues



H → WW: ggH, VBF and VH (CMS)



- ggH → Compatible with average signal strength (all decays: γγ, ZZ, WW, ττ, bb)
- VBF → Only 1s lower than average signal strength
- VH → Uncertainty remains large at the present luminosity

→ No significant difference between the 3 production mechanisms

CONCLUSIONS

H → γγ

- **Over 4σ** observed local significance for both ATLAS and CMS for m_X ~ 126 GeV
- **μ = 1.56 ± 0.43 (1.8±0.5)** for m_X ~ 126 GeV for CMS (ATLAS)
- **Evidence for the existence of a new boson decaying in two photons excludes the spin 1 hypothesis**

H → ZZ → 4l

- **CMS update to 5+12 fb-1 with 7+8 TeV datasets**
- **4.5 (3.6) σ** of local significance for m_X ~ 126 GeV for CMS (ATLAS)
- **μ = 0.8+0.35-0.8 (1.4±0.6)** for m_X ~ 126 GeV for CMS (ATLAS)
- CMS: Upper limits at 95% CL exclude the SM Higgs boson in the ranges 113-116 and 129-720 GeV
- **CMS: 2.5 standard deviations disfavoring particle to be pseudo scalar**

H → WW

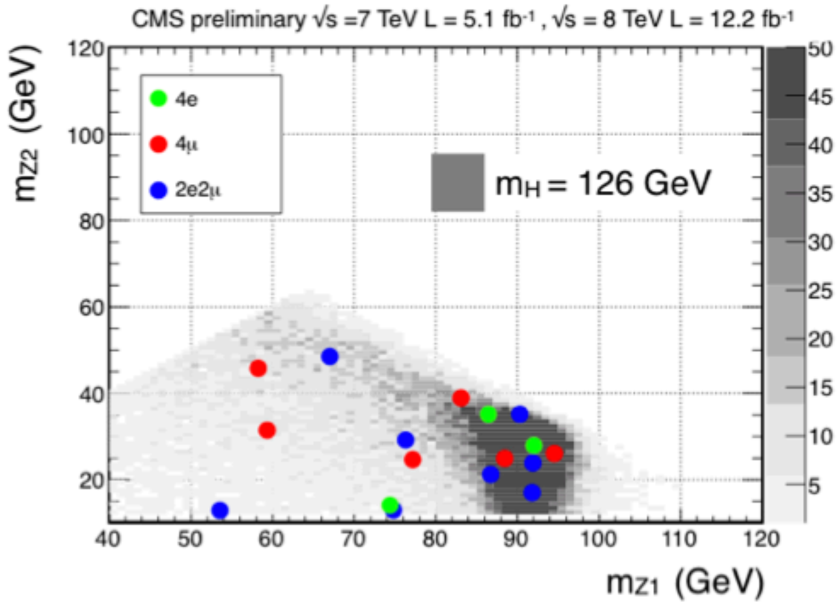
- Study of gg, VBF and VH
- **3.1 (2.6) σ** of local significance for m_X ~ 126 GeV for CMS (ATLAS) in **H → WW → 2l2ν**
- Additional SM Higgs-like bosons are excluded to at least 95% CL from 128-600 GeV

→ New results consistent with publications and the SM Higgs expectation

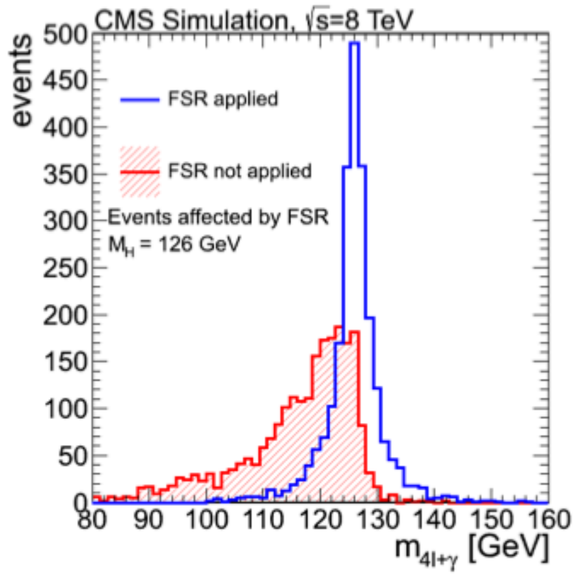
BACKUP

Building 4l-candidates

- Pair #1
  - 40<m(ll)<120 GeV, nearest to Z0 mass
  - Final state radiation recovery (FSR)
  - Lepton isolation
- Pair #2
  - 12<m(ll)<120 GeV, highest PT leptons
  - FSR
  - Lepton isolation

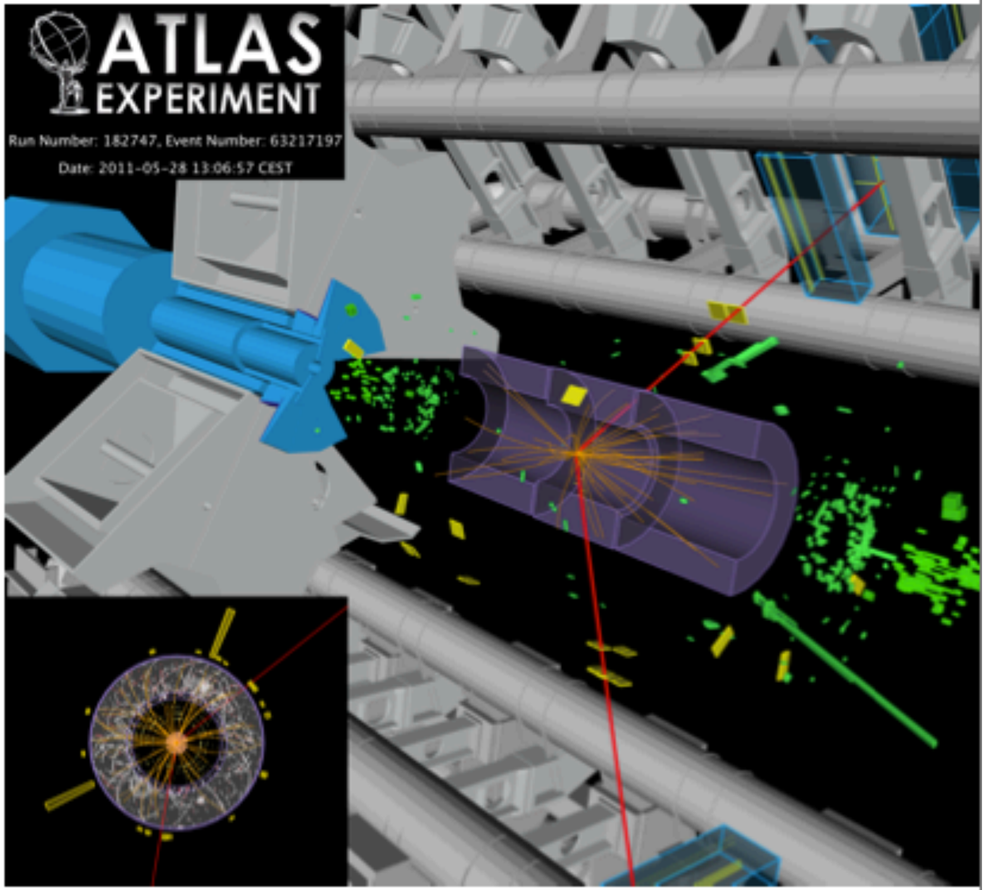


- Note on FSR photon:
  - accept if dR(l,γ)<0.07 PT>2 GeV
    OR: dR(l,γ)<0.5 PT>4 GeV plus isolated
    Condition: $|m(ll\gamma)-mZ^0| < |m(ll)-mZ^0|$
  - FSR expected in 6.8% events (observed: 6±2%)

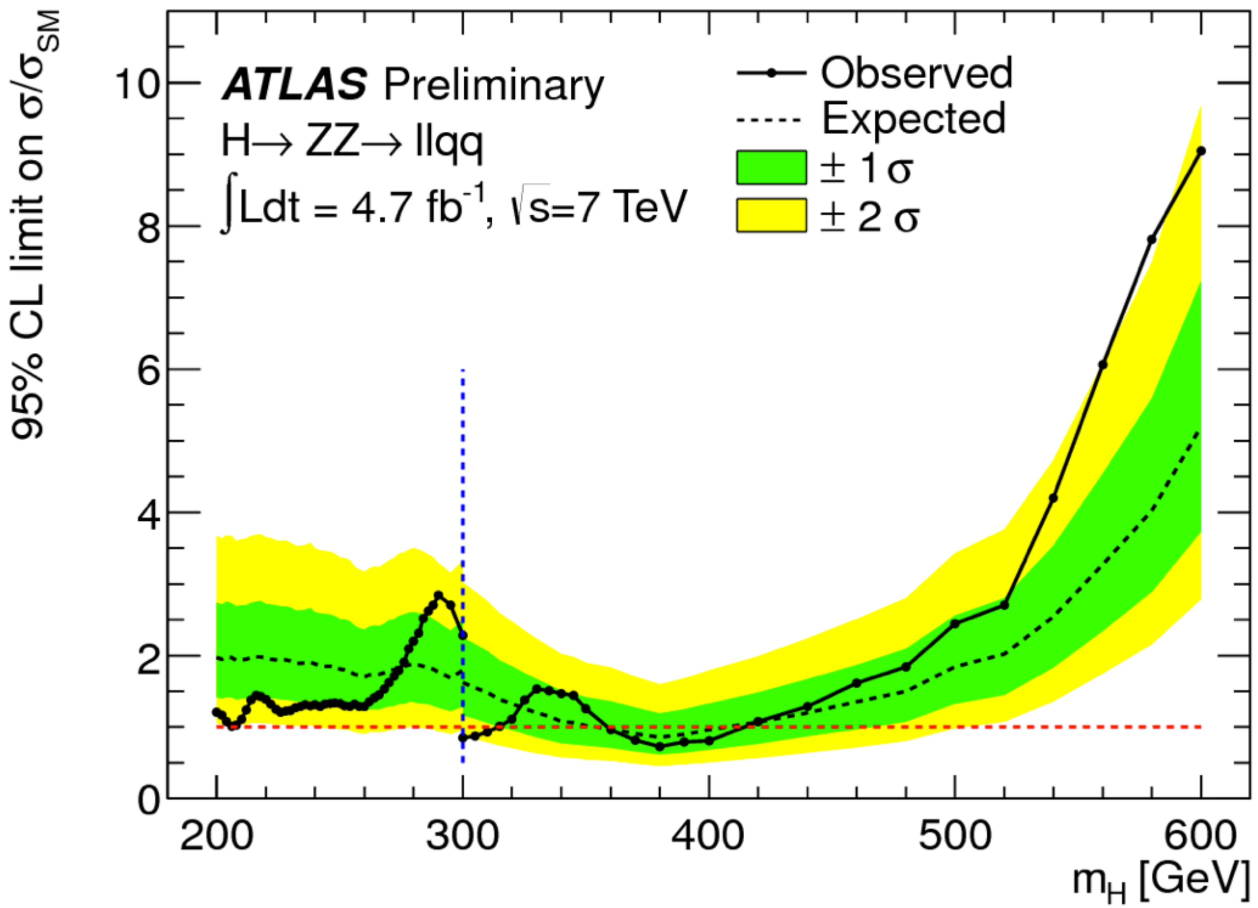


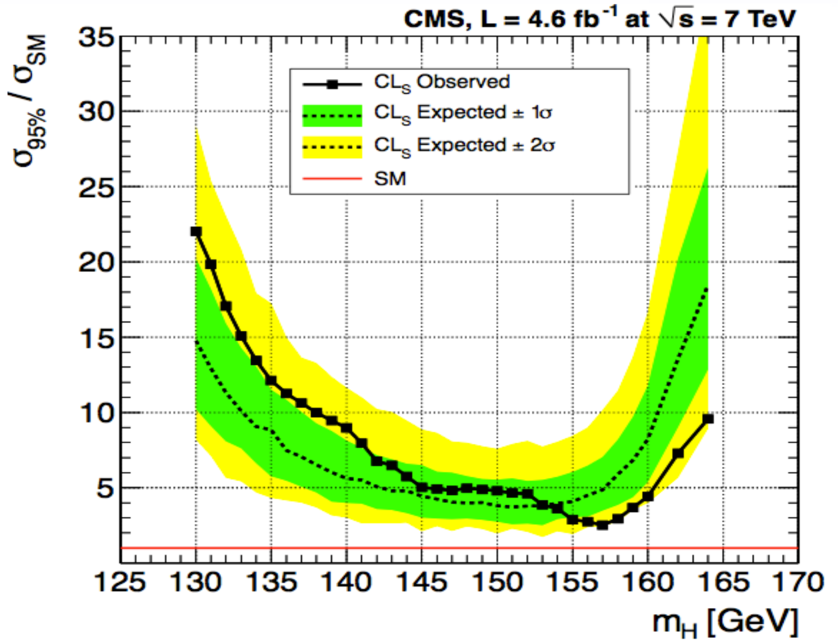
Event Selection

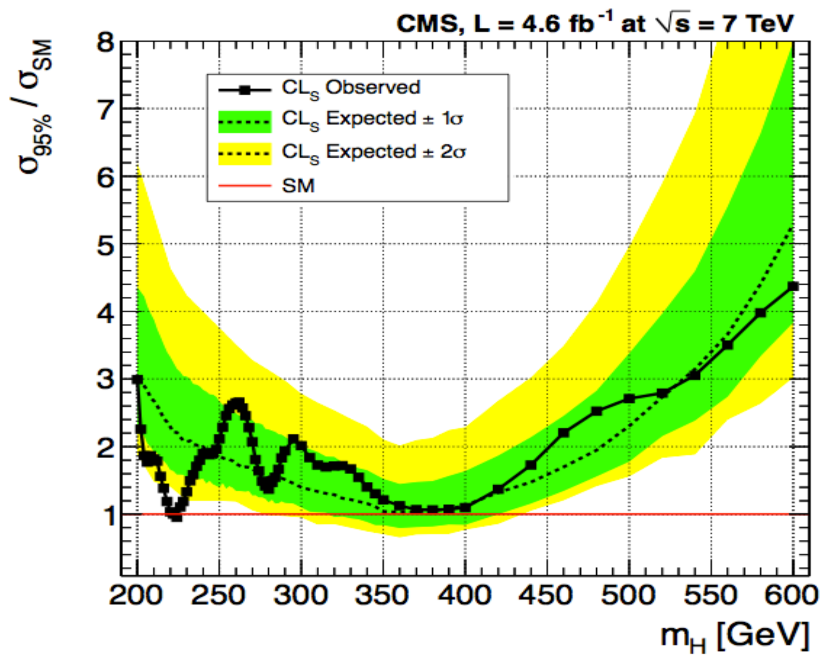
- **Two same-flavour opposite-sign di-leptons (e/μ)**
- Optimised phase space to enhance low mass sensitivity
  - $p_T^{1,2,3,4}$ > 20,15, 10, 7 GeV (6 GeV for μ)
  - Leading di-lepton mass : $50 < m_{12} < 106$GeV
  - Sub-leading di-lepton mass :
    - m_{thr} (m_{4l}) < m_{34} < 115 GeV ;m_{thr} = 17.5 - 50 GeV
  - all same-flavour opposite-sign pairs m_{ll}>5 GeV
  - ΔR(l,l′) > 0.10(0.20) for all same(different)-flavour
- Additional requirements to reduce background
  - Calorimeter isolation
  - Track isolation
  - Impact parameter significance
- Z mass constraint of leading Z



H → ZZ → 2l2j


ATLAS Preliminary
H→ ZZ→ llqq
∫Ldt = 4.7 fb-1, √s=7 TeV
Observed
Expected
± 1 σ
± 2 σ
95% CL limit on σ/σSM
mH [GeV]

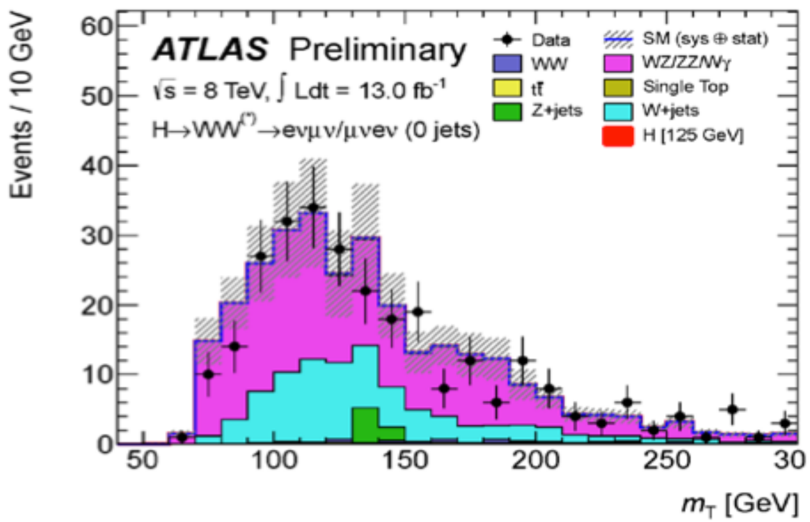

CMS, L = 4.6 fb-1 at √s = 7 TeV
CLS Observed
CLS Expected ± 1σ
CLS Expected ± 2σ
SM
σ95% / σSM
mH [GeV]


CMS, L = 4.6 fb-1 at √s = 7 TeV
CLS Observed
CLS Expected ± 1σ
CLS Expected ± 2σ
SM
σ95% / σSM
mH [GeV]

H → WW → 2l2ν : Backgrounds

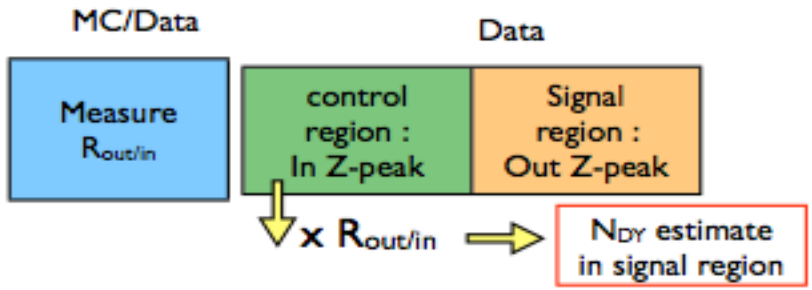
Predictions taken from MC:
- Wγ and Zγ
- Wγ* (CMS: 1.6+-0.3 normalization from 3 lepton events)
- Di-bosons: ZZ, WZ

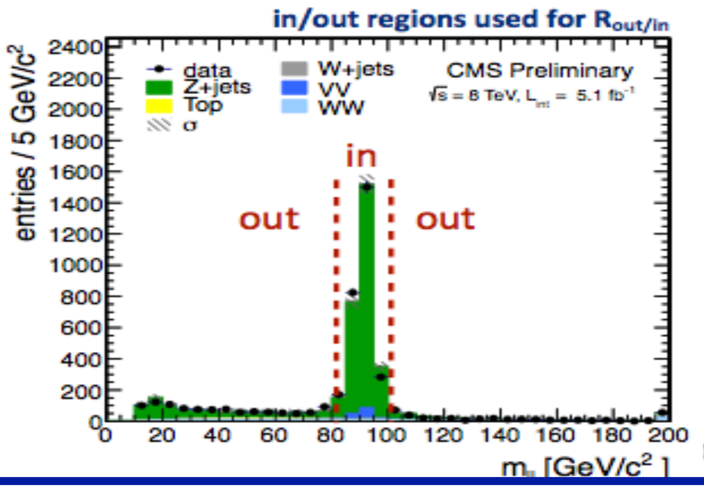
W+Jets:
- Propagate fake lepton ID rate from di-jet sample with looser lepton selection
- Cross-check in same-sign events:



- Large uncertainties:
  - ATLAS: 50%
  - CMS : 36%

Drell-Yan in Same Flavour (ee/μμ):
- ATLAS: not using SF data
- CMS: Estimate contribution from Z peak control region:



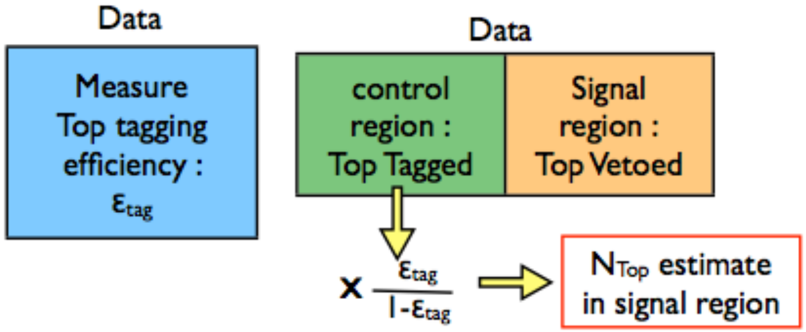


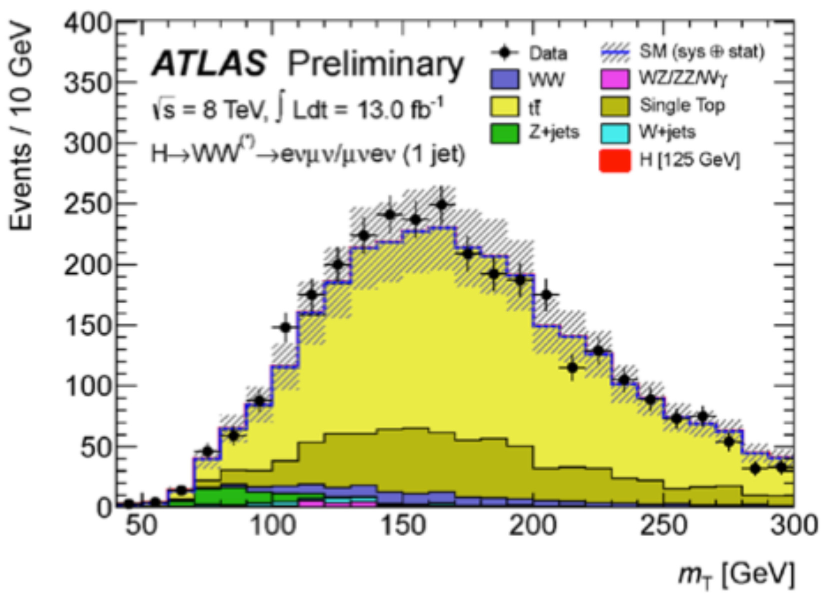
DY->ττ in Different Flavour (eμ):
- ATLAS: MC normalized from control region
- CMS: Use Z→ll (l=2,μ) events and replace by τ decayed via Tauola package

H → WW →2l2ν : Backgrounds

Top (tt & tW):

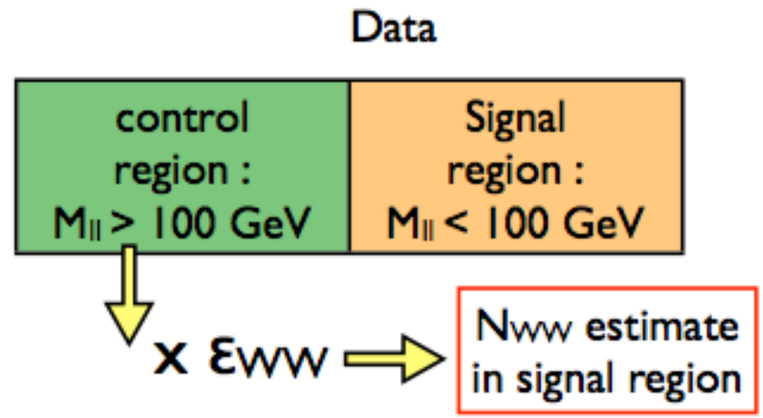
- Dominant background in 1 and 2 jet bins
- Measure Top tagging efficiency from data
- Control region in data enriched in tt/tW by inverting top veto:

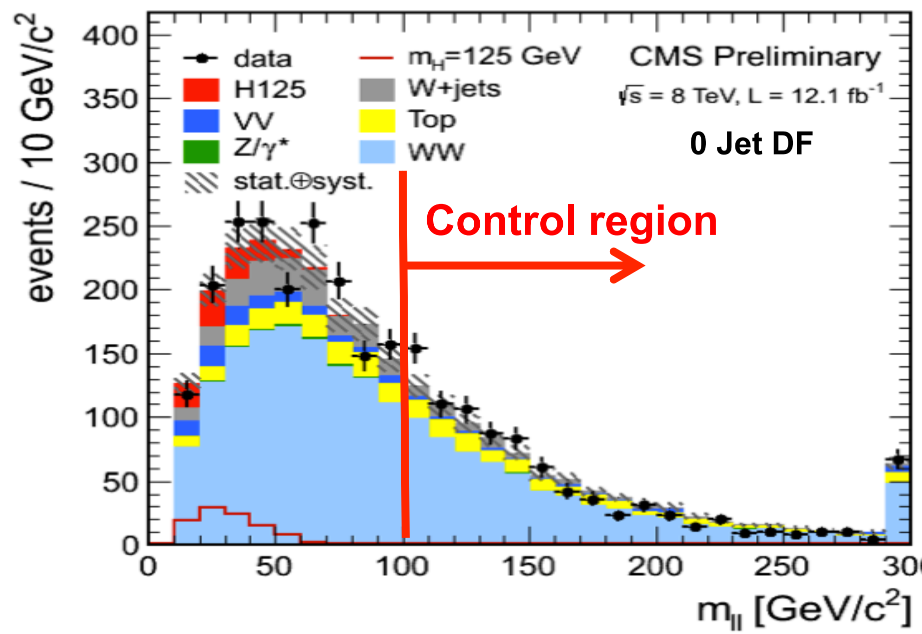




Non resonant WW:

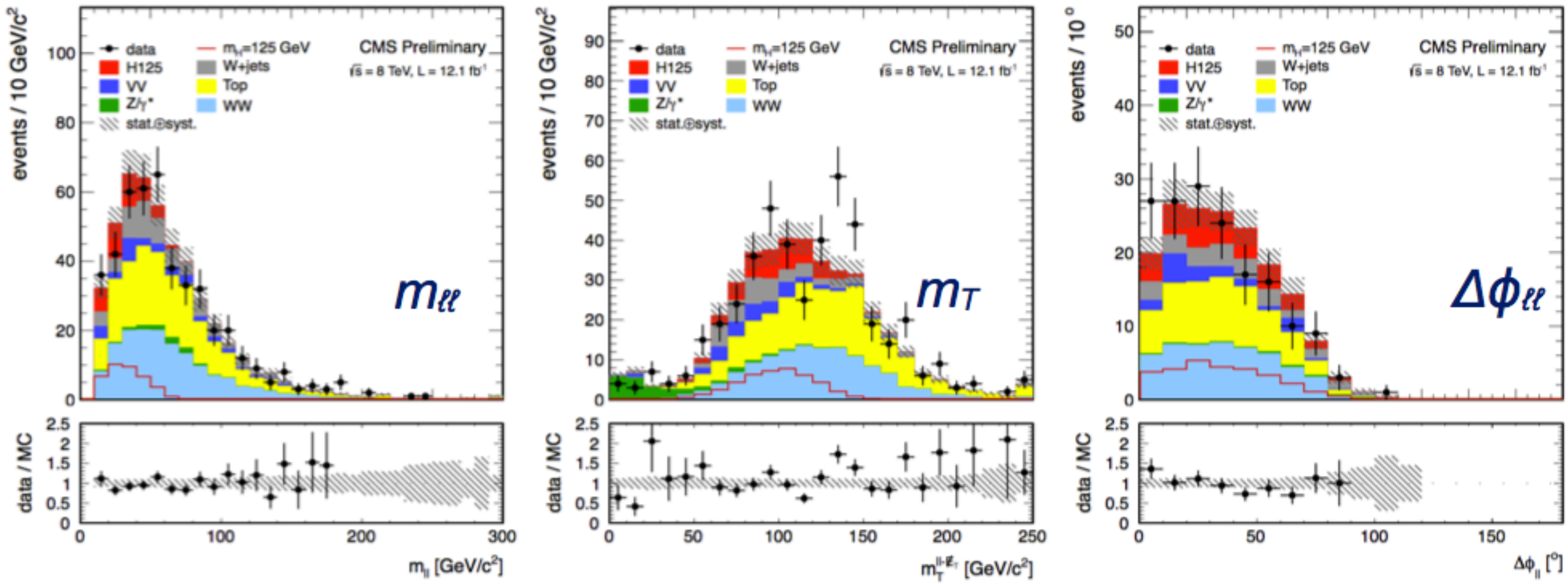
- For low mass Higgs, normalize WW from high lepton invariant mass region in data:





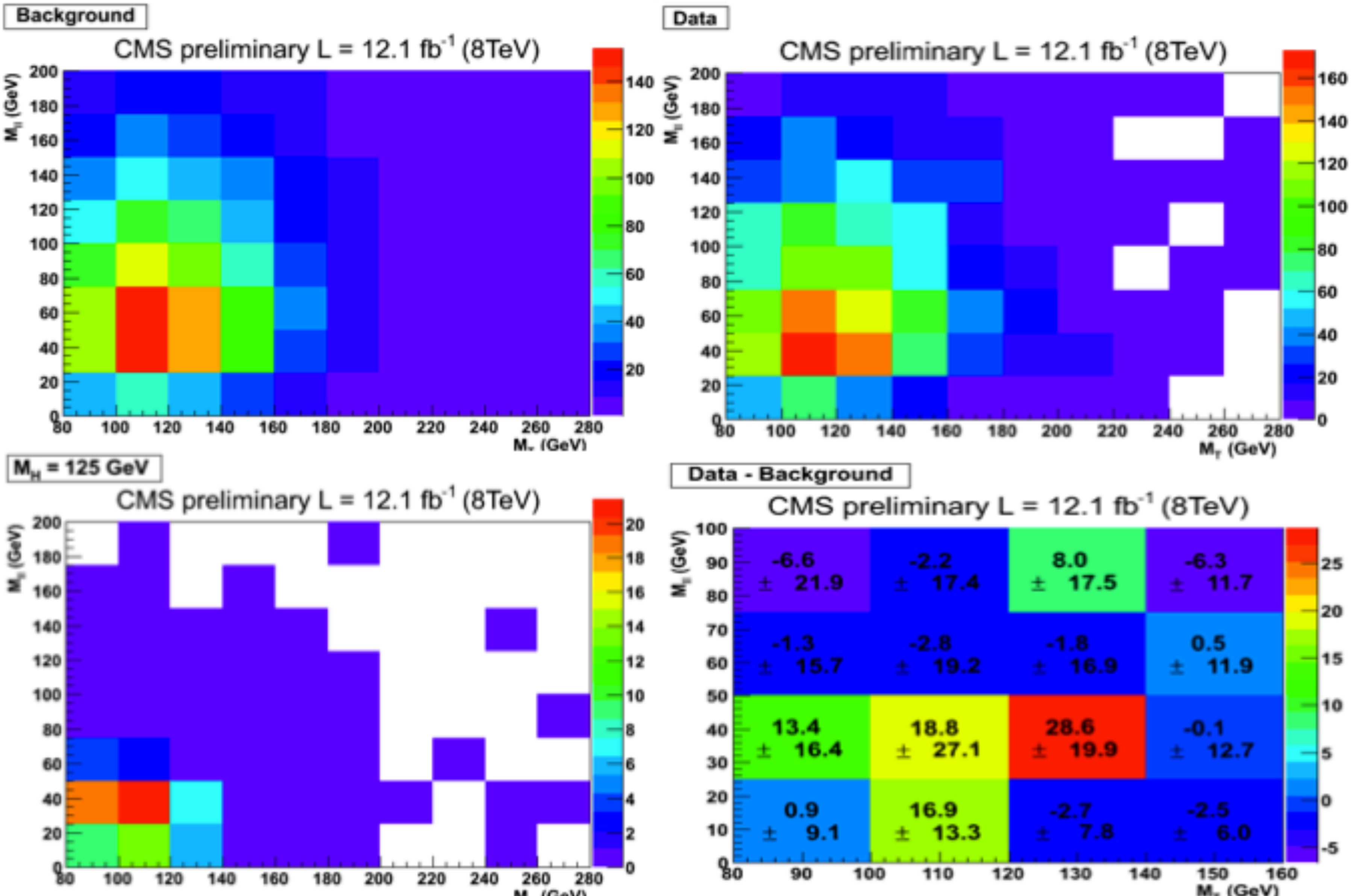
H → WW →2l2ν : CMS Cut&Count (1 jet DF)

m_H	H $\to W^+W^-$	pp $\to W^+W^-$	WZ + ZZ $+Z/\gamma^* \to \ell^+\ell^-$	Top	W + jets	$W\gamma^{(*)}$	all bkg.	data
1-jet category $e\mu$ final state								
120	14.9 ± 4.3	38.9 ± 6.4	5.3 ± 0.6	40.3 ± 3.0	19.1 ± 7.4	7.1 ± 3.4	111 ± 11	123
125	27.3 ± 8.0	47.9 ± 7.8	6.5 ± 0.7	49.5 ± 3.3	22.4 ± 8.6	7.1 ± 3.4	134 ± 13	160
130	40 ± 12	53.9 ± 8.8	7.3 ± 0.8	55.2 ± 3.6	24.5 ± 9.4	7.1 ± 3.4	148 ± 14	182
160	131 ± 37	44.4 ± 7.0	5.3 ± 0.7	51.8 ± 3.5	9.0 ± 3.9	0.6 ± 0.4	111.1 ± 8.8	145
200	58 ± 15	80 ± 13	6.8 ± 0.8	114.6 ± 6.5	16.1 ± 6.5	0.4 ± 0.3	238 ± 16	276
400	29.4 ± 8.1	81 ± 13	7.9 ± 1.2	129.0 ± 7.1	16.8 ± 6.6	0.6 ± 0.5	235 ± 16	226
600	6.9 ± 1.8	30.0 ± 4.8	3.1 ± 0.4	40.3 ± 3.0	8.4 ± 3.5	0.0 ± 0.0	81.8 ± 6.6	74

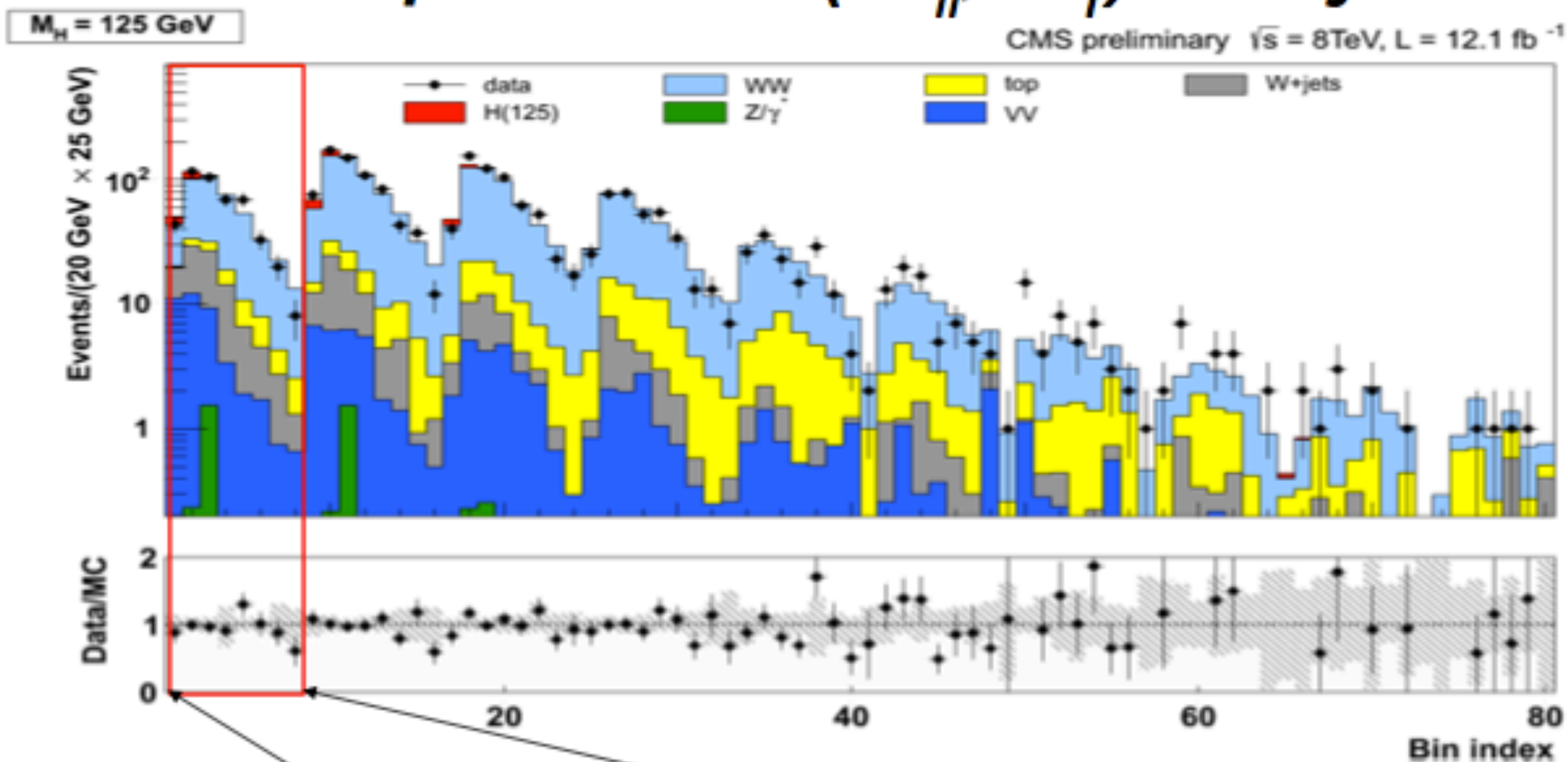


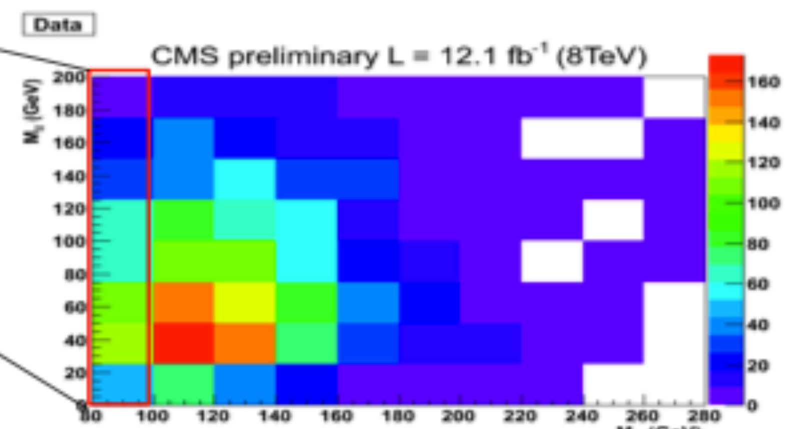
H → WW → 2l2ν

New Shape Analysis – Ex. DF 0-jet



Shape – 2 D (m_{ll}, m_T) – 0 jet



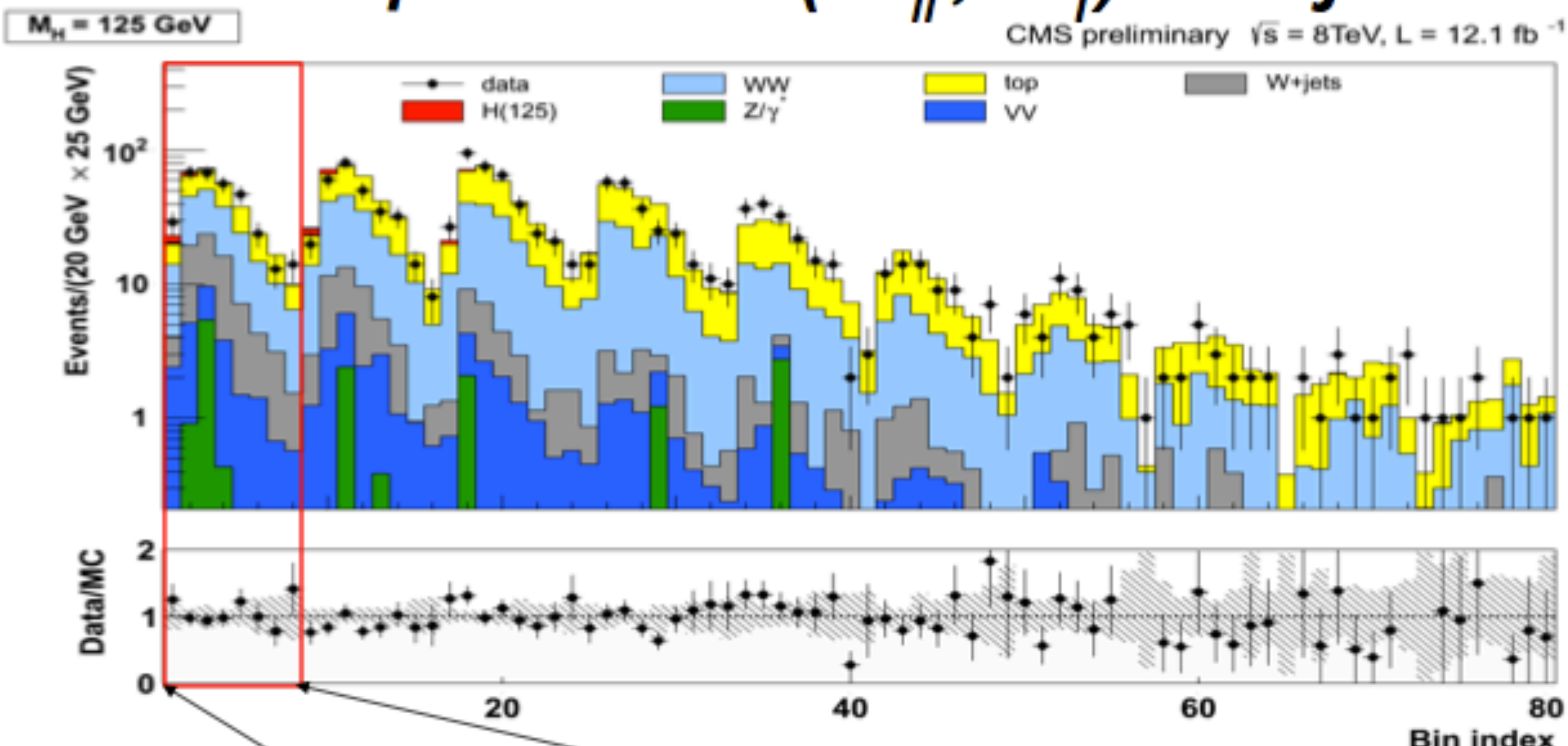


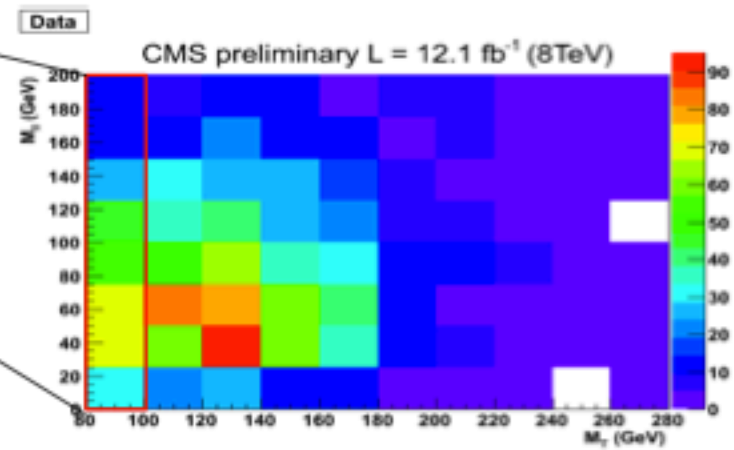
Unrolling 2D distributions

– quantitative comparison

H → WW → 2l2ν

Shape – 2 D (m_{ll},m_T) – 1 jet

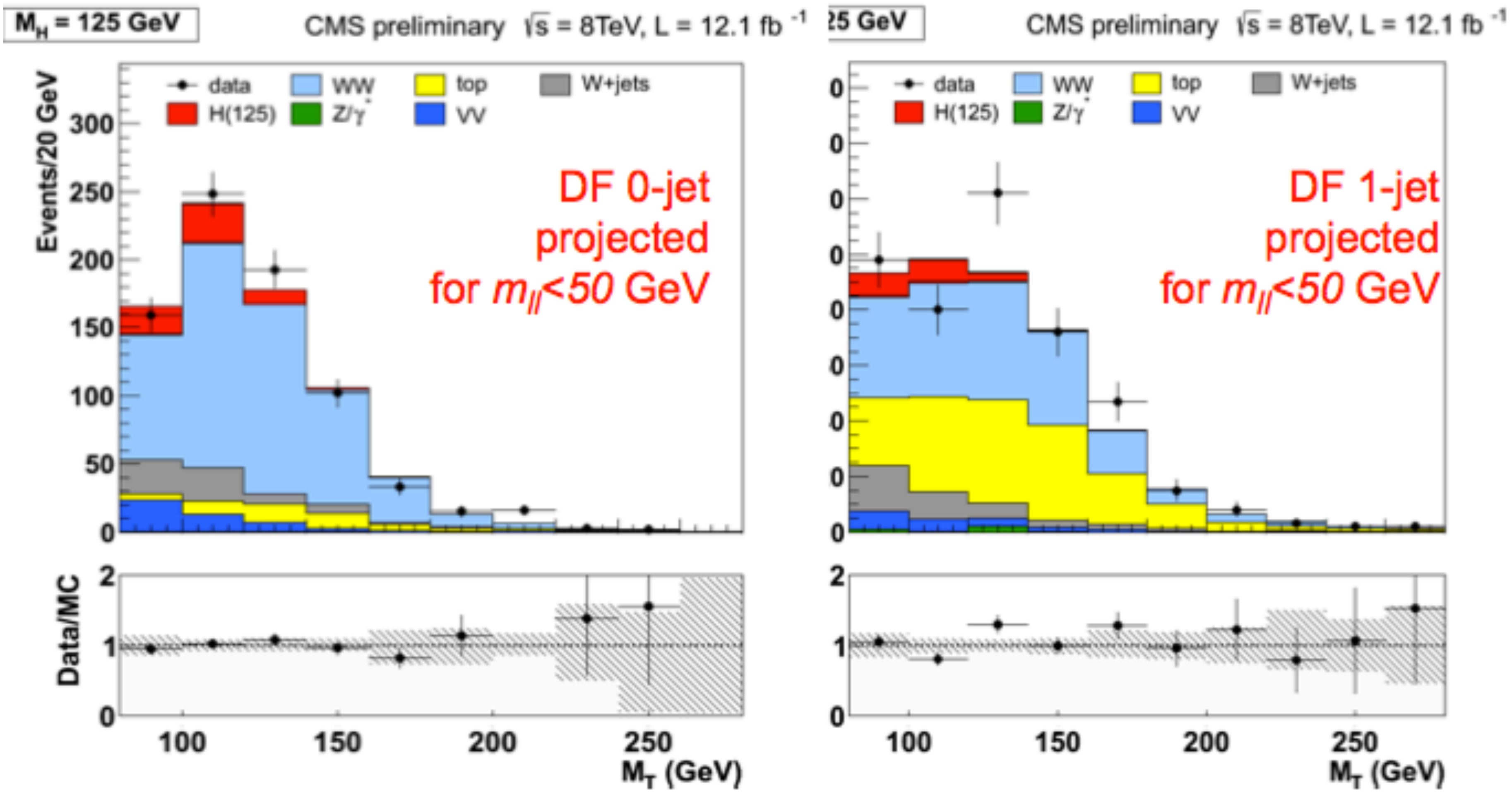




Unrolling 2D distributions
– quantitative comparison

Shape – 2 D (m_{ll},m_T) projected

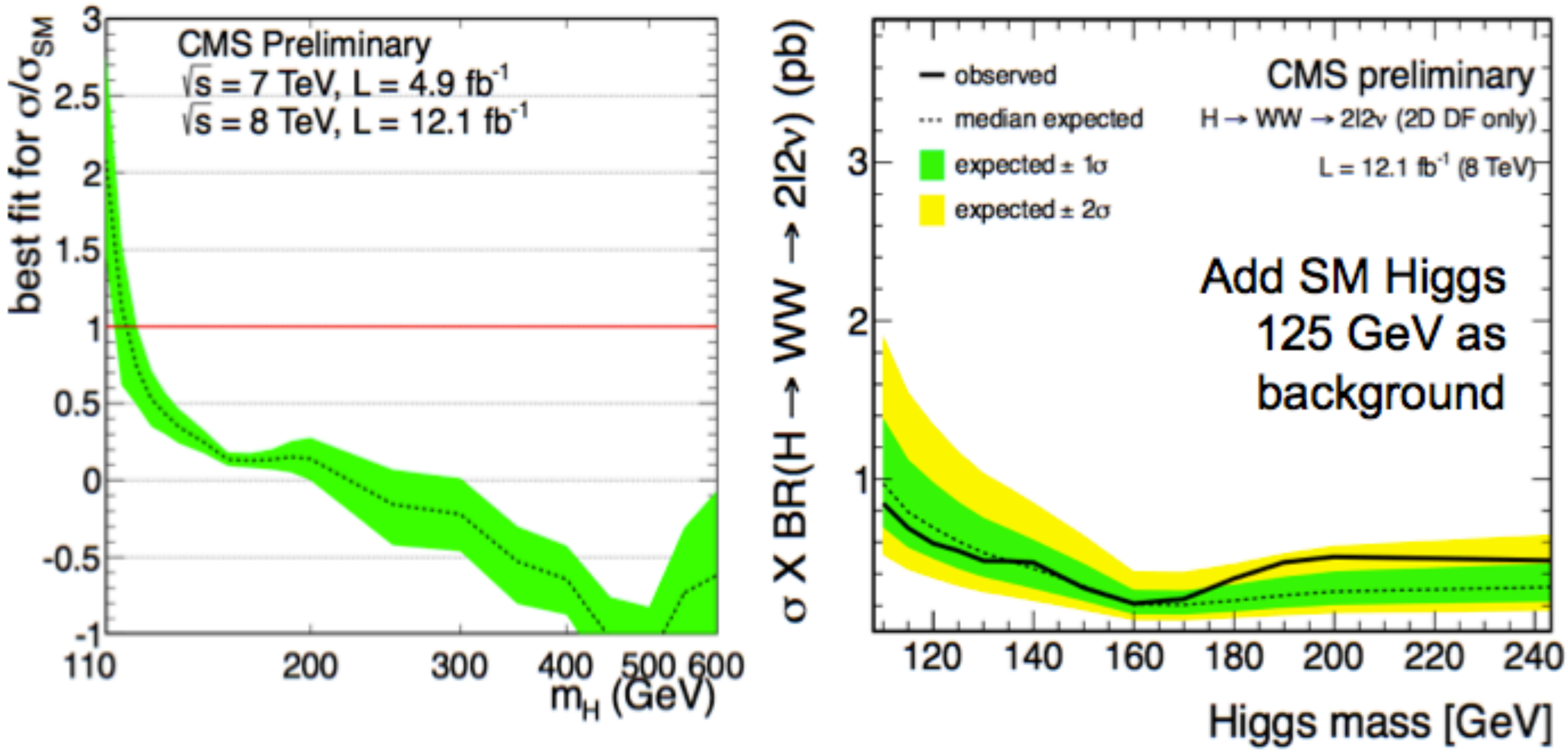
30



Projected the signal is better visible

– clear enhancement in data where signal is predicted

Signal Strength



Steeply falling signal strength versus mass

- measure signal strength: 0.74 ± 0.25 (at m_H = 125 GeV)
- 7 TeV as published, 8 TeV data with new 2D shape analysis