Universiteit Antwerpen

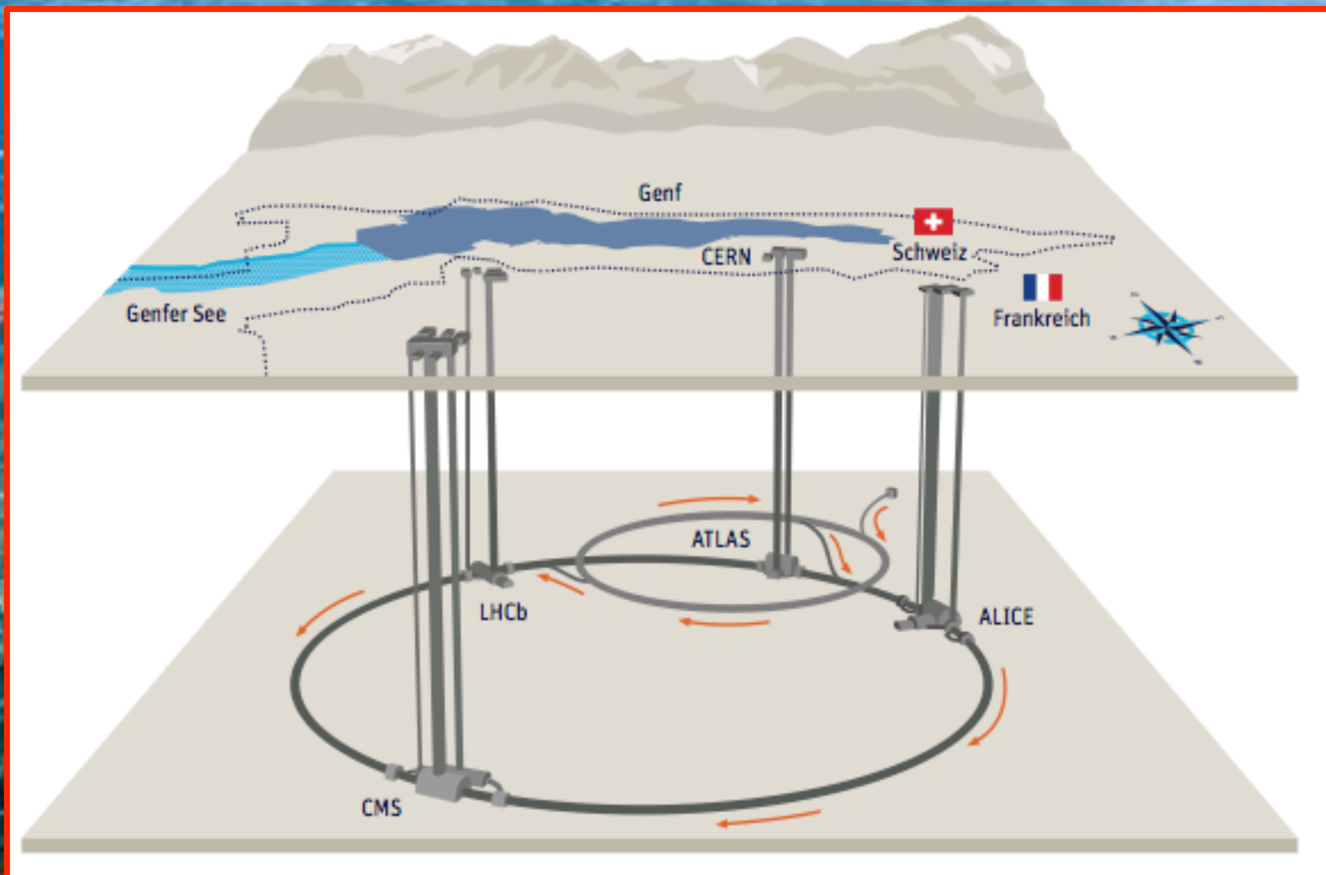
Higgs Results from CMS

Xavier Janssen
On behalf of the CMS Collaboration

SILAFAE 2012
Sao Paulo, Brazil
December 11, 2012

The Large Hadron Collider @ CERN

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



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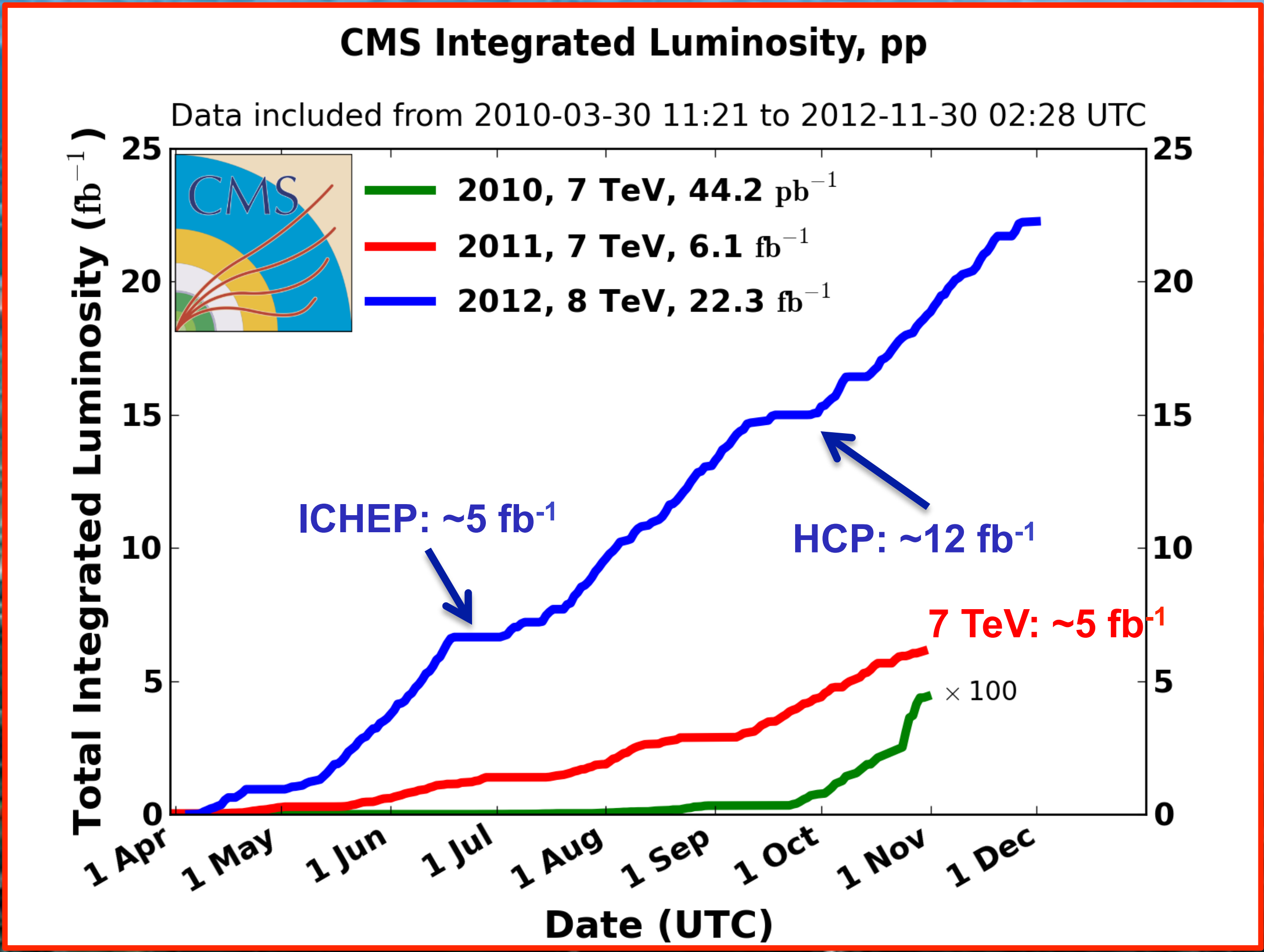

The CMS Collaboration

41 Countries, 179 institutes, ~3000 Authors including ~2200 PhD's and ~800 PhD students

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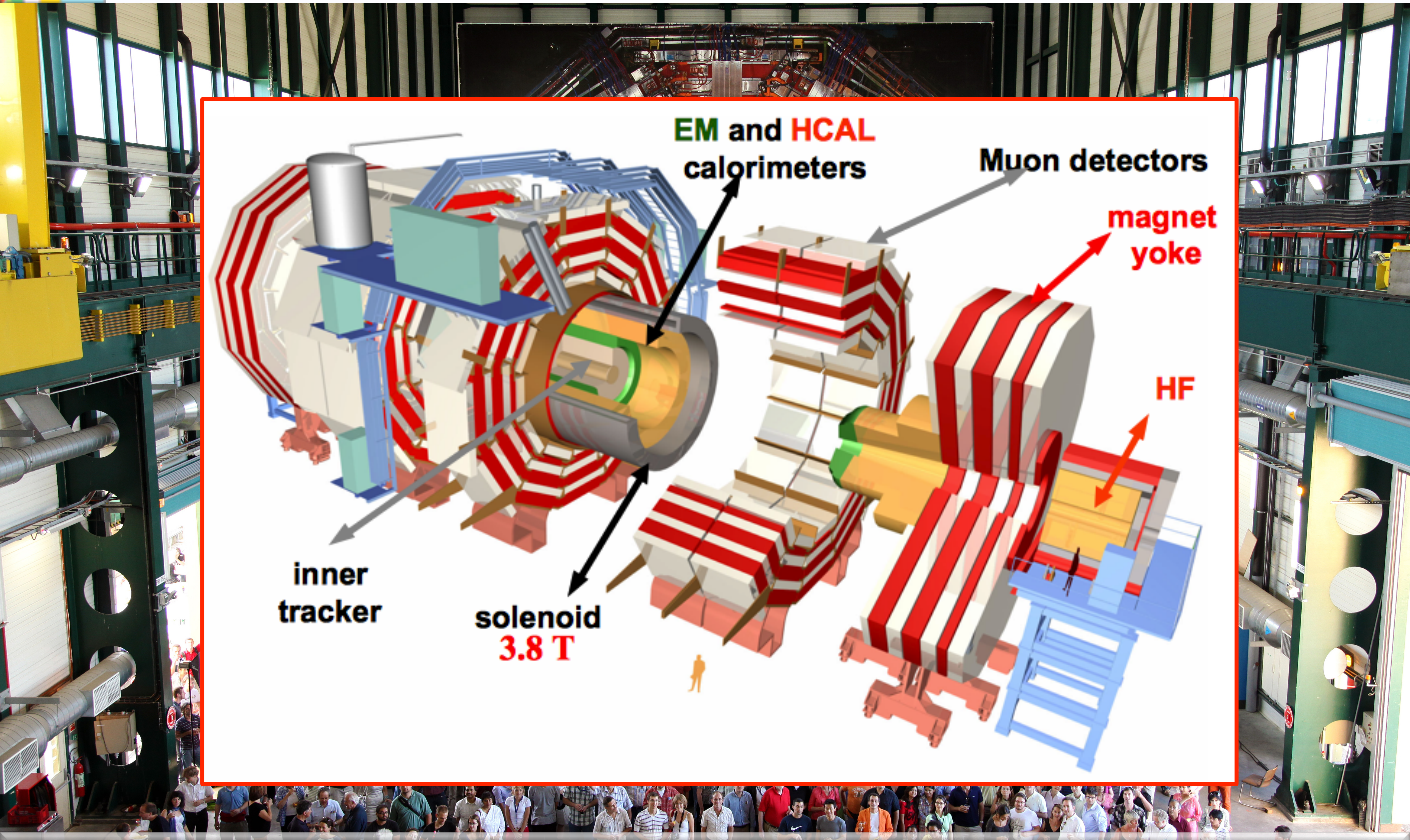

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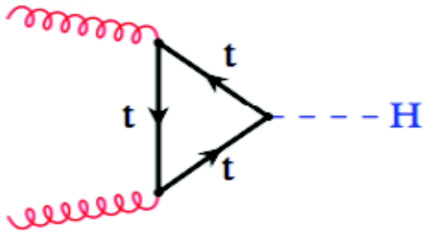
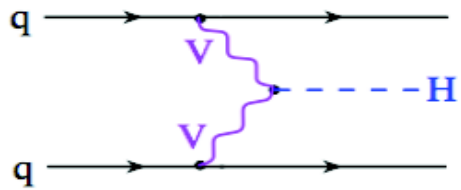
SM Higgs Boson Production and Decay at LHC

- Gluon fusion

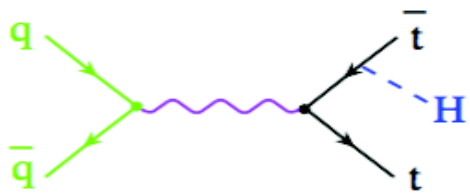


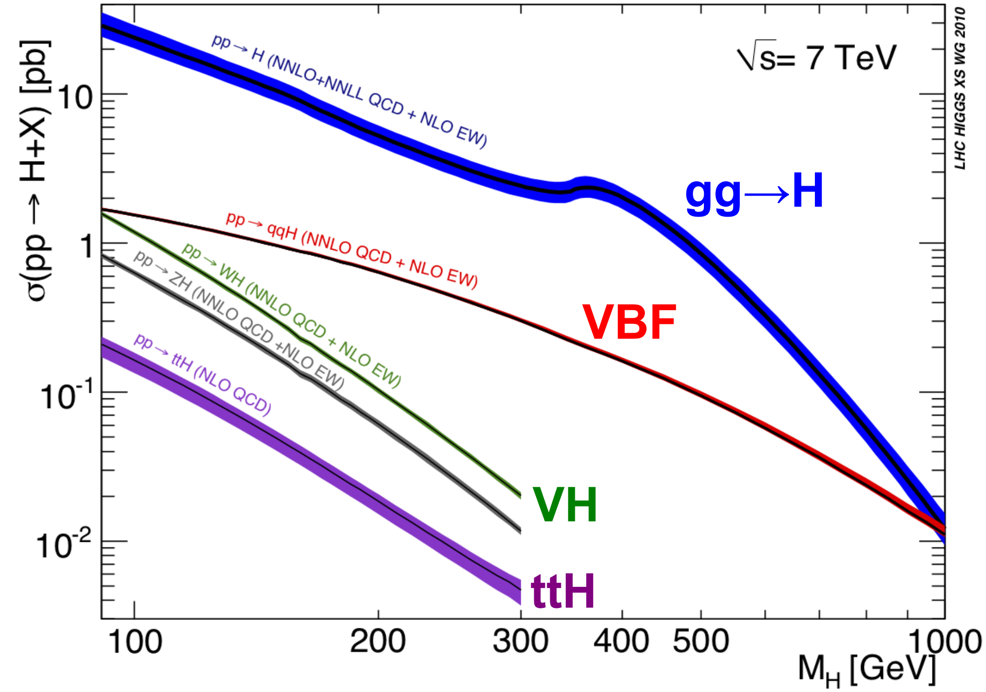
- VBF

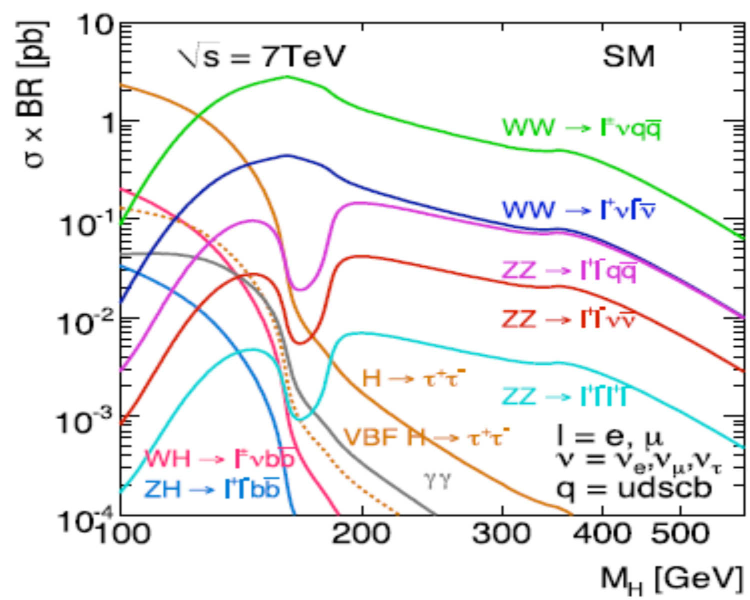


- VH

- ttH



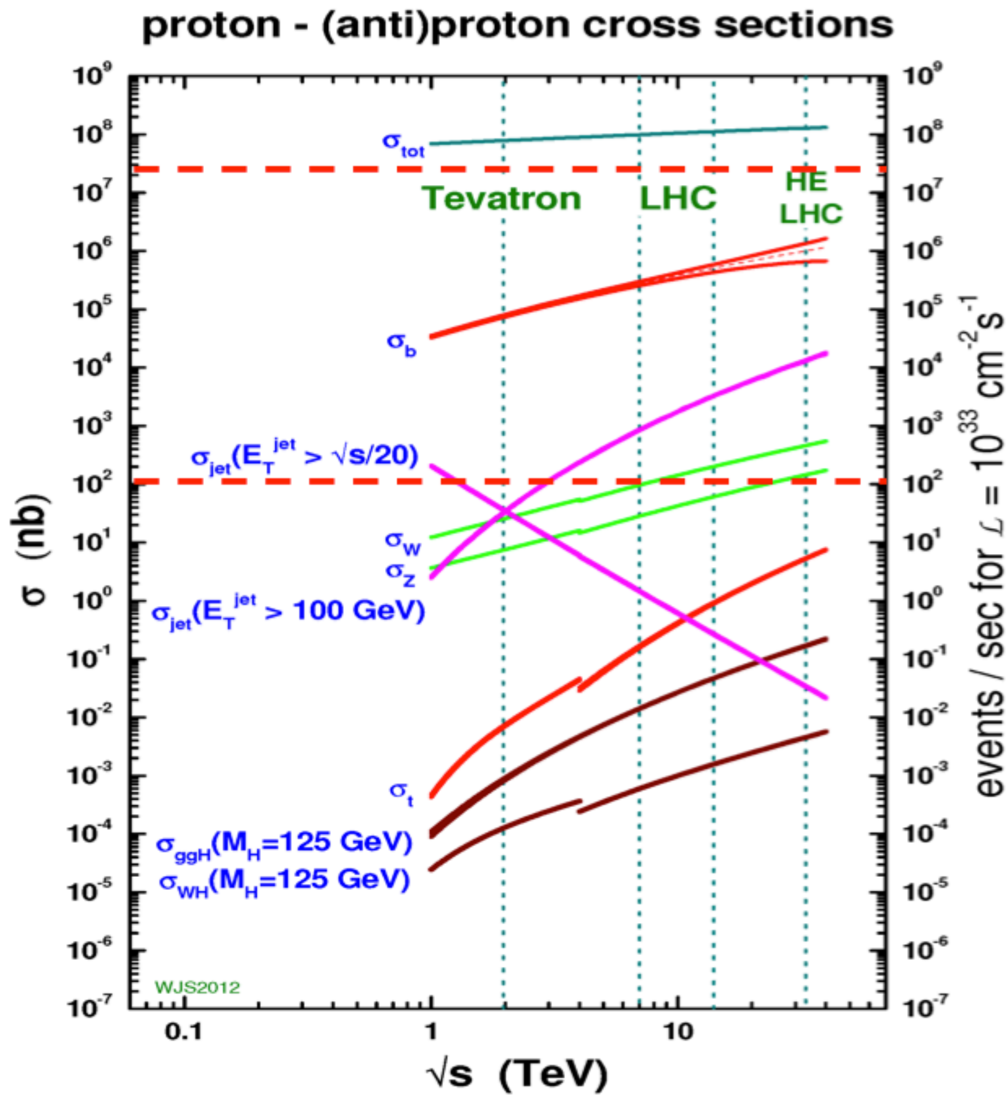




Gluon fusion (gg→H) it the dominant production mechanism at LHC but VBF, VH and ttH allow to test H properties.

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, …

Look for a “Higgs”–needle in a “SM process”–stack



Collision rate: ~20 MHz
→ 2 staged trigger system
Recording rate: o(300) HZ
→ still: ~3 PetaByte/Year

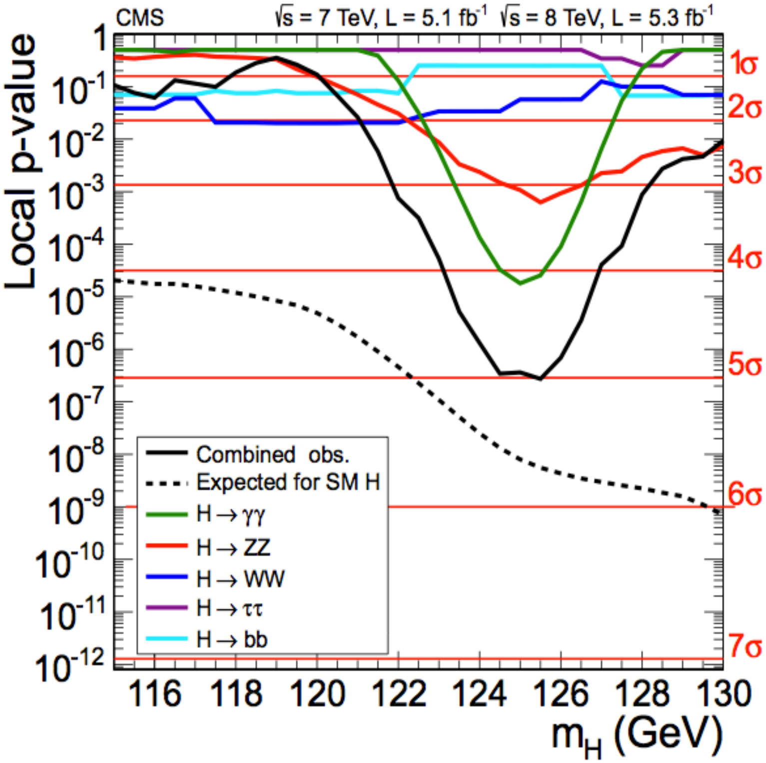
Analysed data ~10 to ~17 fb^{-1}
(~1/3 at 7 TeV in 2011
+ ~2/3 at 8TeV in 2012)

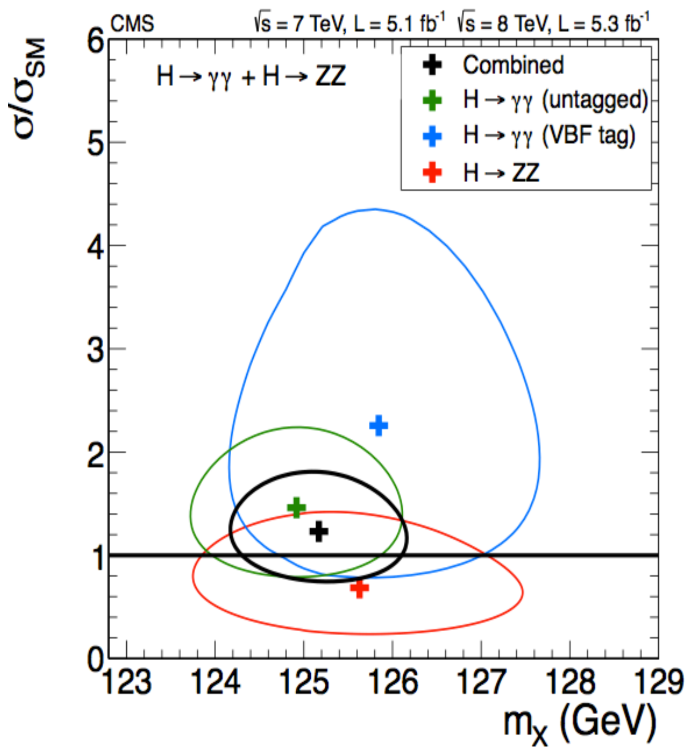
This corresponds to:
~ 1.7 10^{15} collisions
~ 7 10^{9} recorded ones
~ 350000 produced Higgs bosons (125 GeV)
But only
~700 decaying via H→γγ
~50 decaying via H→ZZ→4l

Searches for Higgs Boson require control of SM background normalization, dedicated triggers and good understanding of experimental effects but several backgrounds remain irreducible (e.g. ZZ vs H→ZZ)

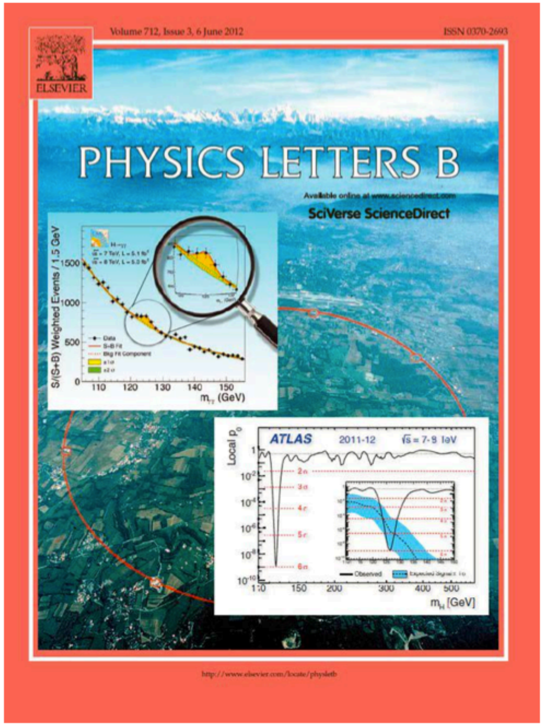
Observation of a new boson at a mass of 125 GeV

Results from "July 4th" papers:





Phys. Lett. B 716 (2012)



	CMS
Local p-value	5.0 σ + Nothing else significant
Mass [GeV]	125.3 ± 0.4 (stat.) ± 0.5 (syst.)
Signal Strength (γγ+ZZ+WW+ττ+bb)	0.87 ± 0.23

Observation of a new boson at a mass of 125 GeV

Results from "July 4th" papers:

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

→ Compatible with Standard Model expectation

CERN

Rolf Heuer:

'We have it!'

Melbourne

But is it THE Standard Model Higgs Boson ?

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

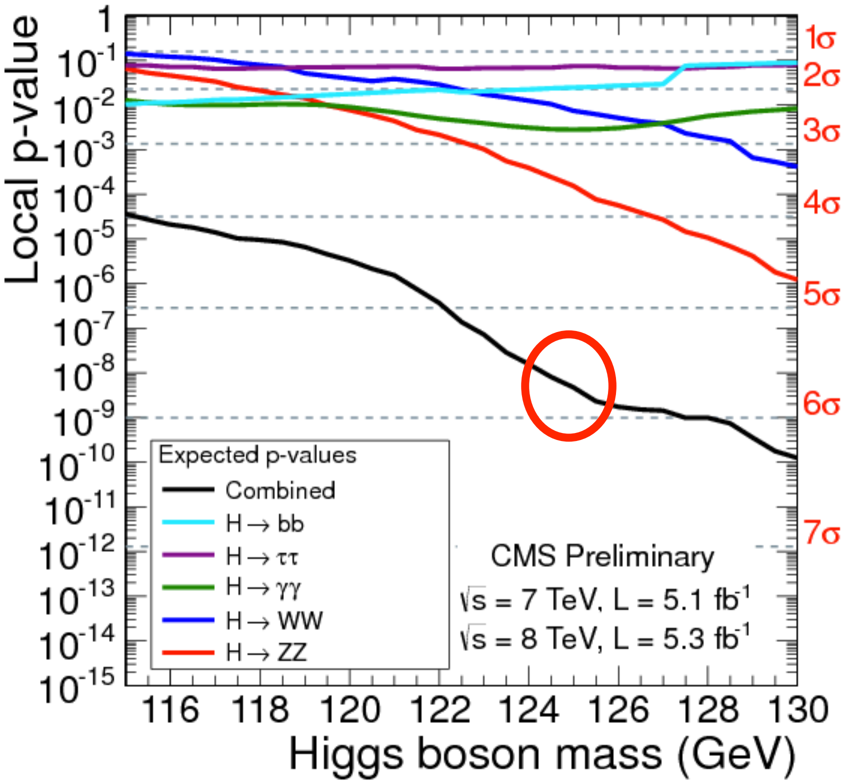
CMS Higgs Analyses Overview

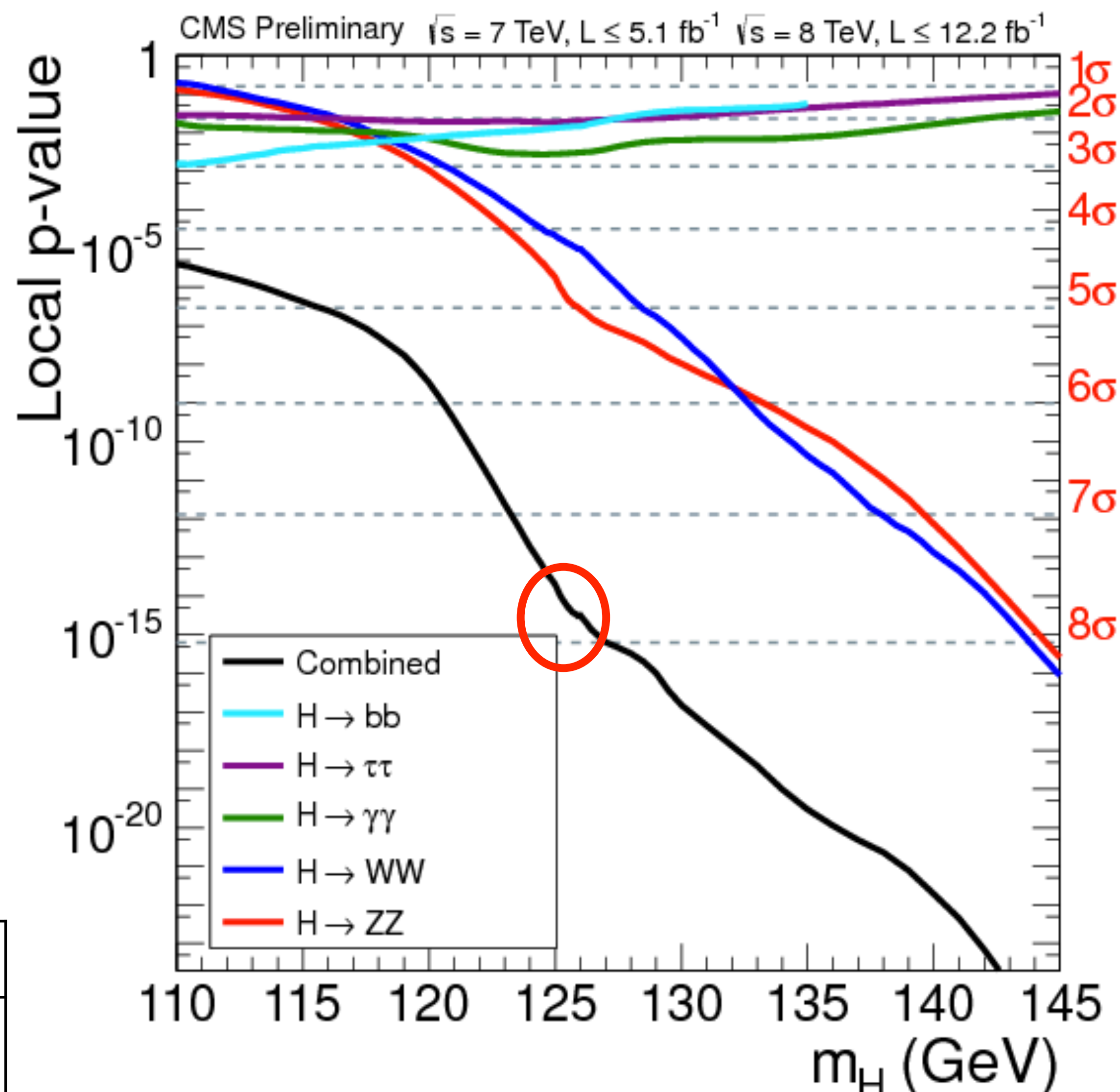
Higgs decay mode	Higgs production mechanism	Mass range [GeV]	Data used		Mass resolution	Used in the combination
			7 TeV [fb^{-1}]	8 TeV [fb^{-1}]		
γγ	Untag (~gg)	110 – 150	5.1	5.3	1–2%	✔
	VBF-tag	110 – 150	5.1	5.3	1–2%	✔
bb	VH-tag	110 – 135	5.0	12.1	10%	✔
	ttH-tag	110 – 140	5.0	–	–	✔
ττ	1-jet (~gg)	110 – 145	4.9	12.1	20%	✔
	VBF-tag	110 – 145	4.9	12.1	20%	✔
	ZH-tag	110 – 160	5.0	–	–	✔
	WH-tag	110 – 140	4.9	–	–	✔
ZZ → 4l	Inclusive	110 –1000	5.0	12.2	1–2%	✔
ZZ → 2l2τ	Inclusive	180 –1000	5.0	12.2	10–15%	✔
ZZ → 2l2ν	Inclusive	200 – 600	4.7	5.0	–	
ZZ → lljj	Inclusive	120 – 600	4.7	–	–	
WW → 2l2ν	0/1-jets (~gg)	110 – 600	4.9	12.1	20%	✔
	VBF-tag	110 – 600	4.9	12.1	20%	✔
	WH-tag	110 – 200	4.9	5.1	–	✔
WW → lljj	Untag (~gg)	170 – 600	5.0	12.1	–	✔

CMS Higgs Expected Performance

ICHEP/PLB: L = ~ 10 fb^{-1}

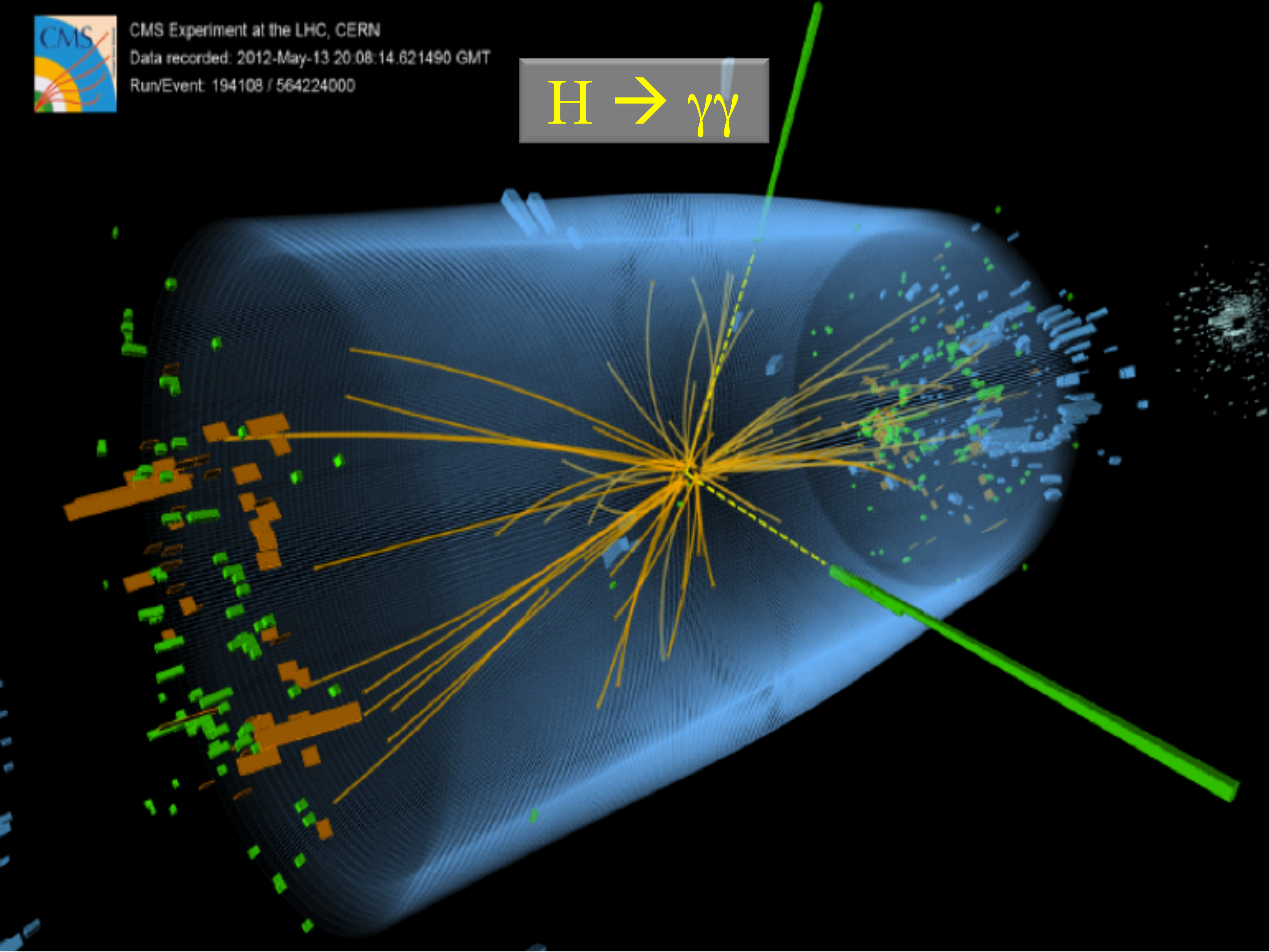
HCP: L <= ~ 17 fb^{-1}
(γγ as ICHEP)





Increase in performance:

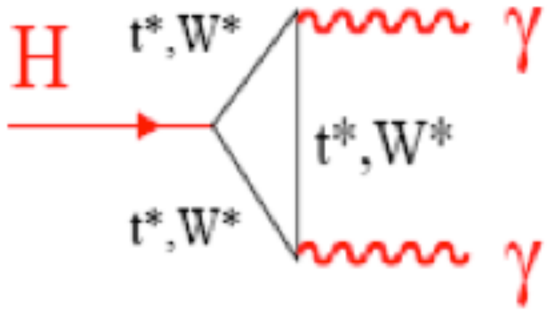
Expected p-value @ 125 GeV	ICHEP	HCP
	5.8	7.8


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

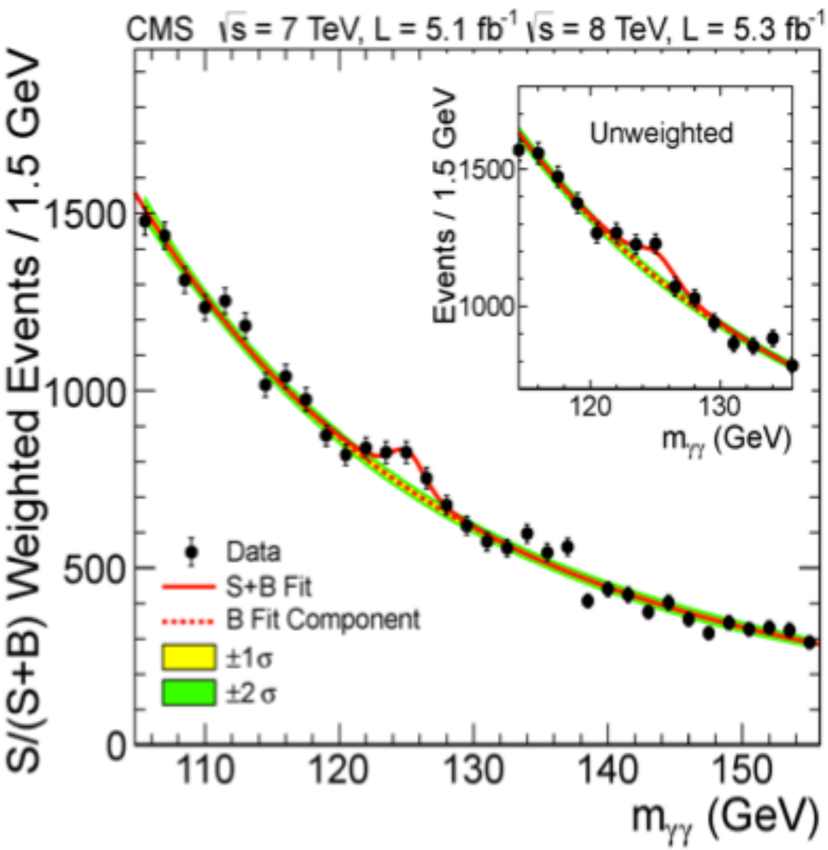
→ **Clean final-state topology: two isolated and high-Pt photons**
→ **Small-narrow peak on large continuous background**

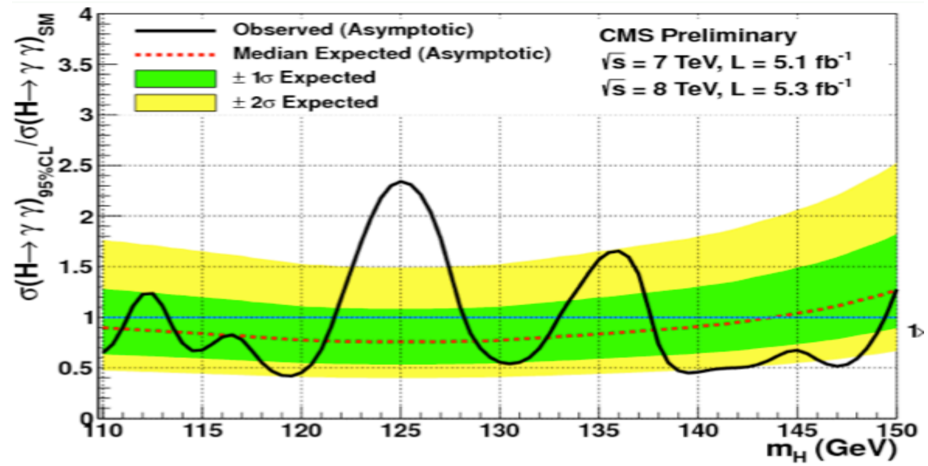
Crucial ingredients $m_{\gamma\gamma}^2 = 2 * E_1 E_2 (1 - \cos\alpha)$

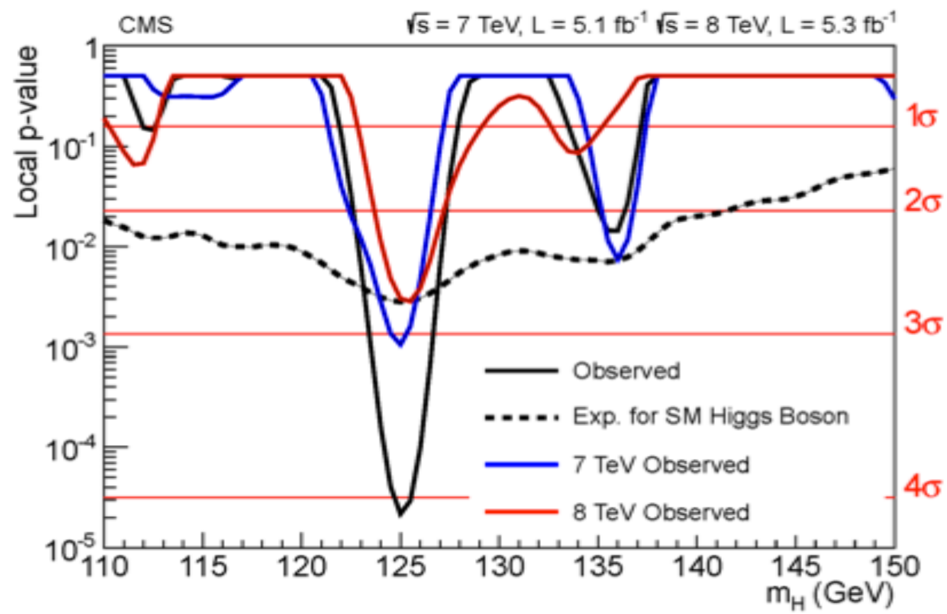
- ❑ **Robust photon reco, isolation and identification**
- ❑ **Good energy calibration and primary vertex reconstruction (*α depends on PV and cluster position*)**
- ❑ **Good background modeling**

H → γγ : Limit and Significance

- ❑ Analysis separated in several di-photon categories to exploit different S/B ratio.
- ❑ Dedicated VBF categories: 2 jets well separated in pseudo-rapidity
- ❑ Background shape fitted from the data

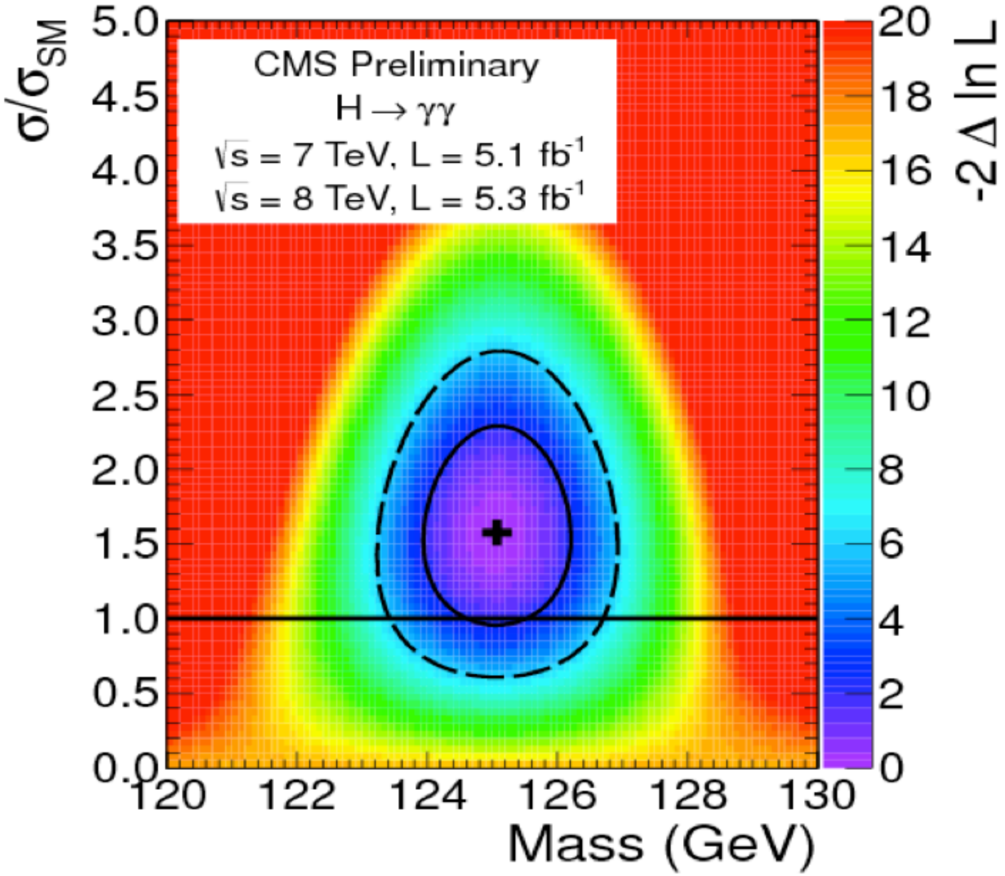


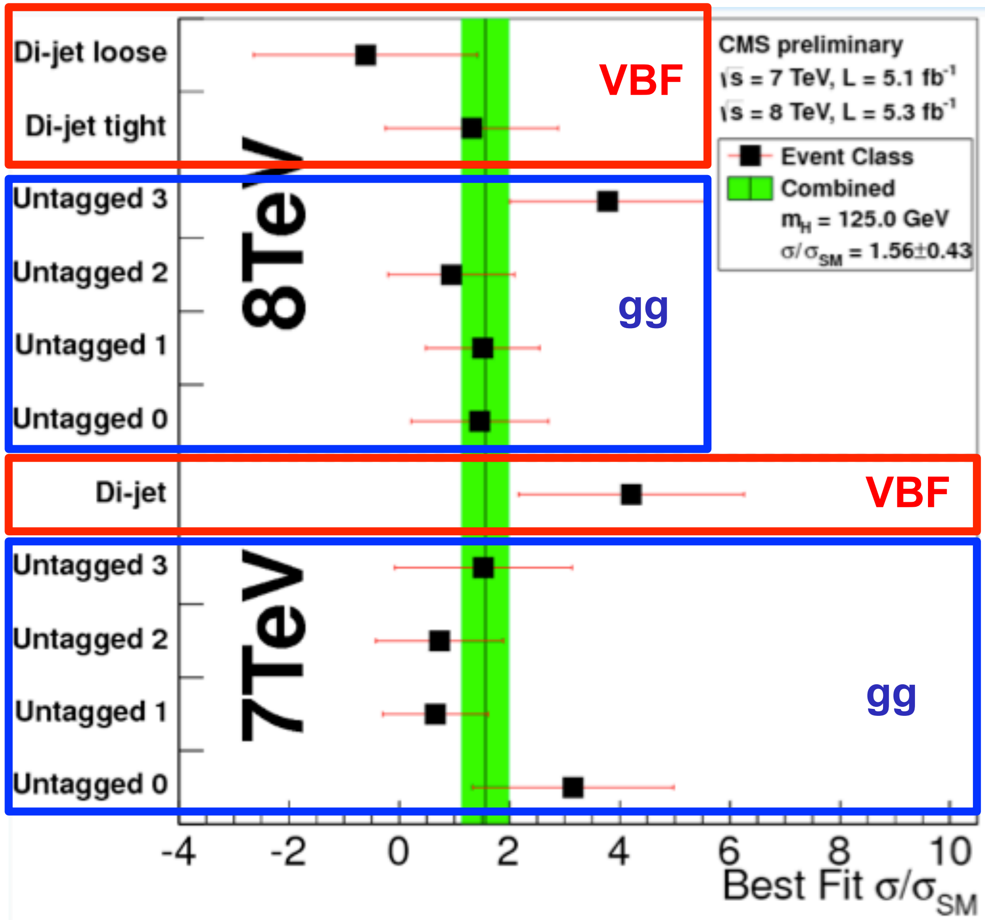




- ❑ Nice peak around 125 GeV
- ❑ Over 4σ observed local significance

$H \rightarrow \gamma\gamma$: Mass and signal strength



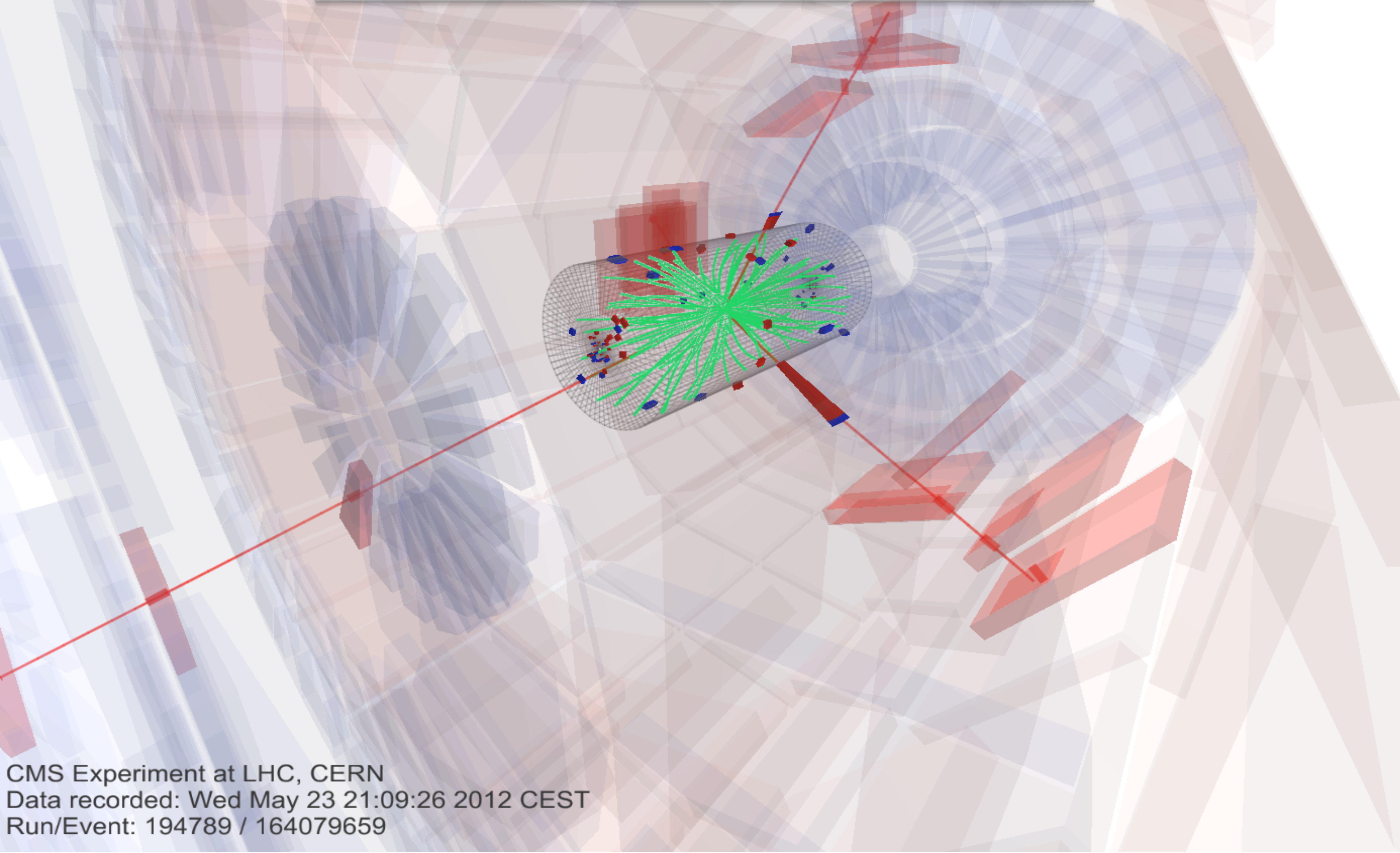


$M_{\gamma\gamma}$ = 125.1 ± 0.4 (stat) ± 0.6 (sys) GeV

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**

The “golden channel”: H → ZZ → 4l



The "golden channel": $H \rightarrow ZZ \rightarrow 4l$

Signal:
- 4 isolated high pT leptons
- from same vertex
- consistent with Z decays
- good mass resolution → 2-4 GeV

Backgrounds:
- Irreducible: $pp \rightarrow ZZ^{(*)} \rightarrow 4l$ (precise EWK prediction)
- Reducible: Z+jets, Zbb, tt (lepton from b-decays are non–isolated / displaced)

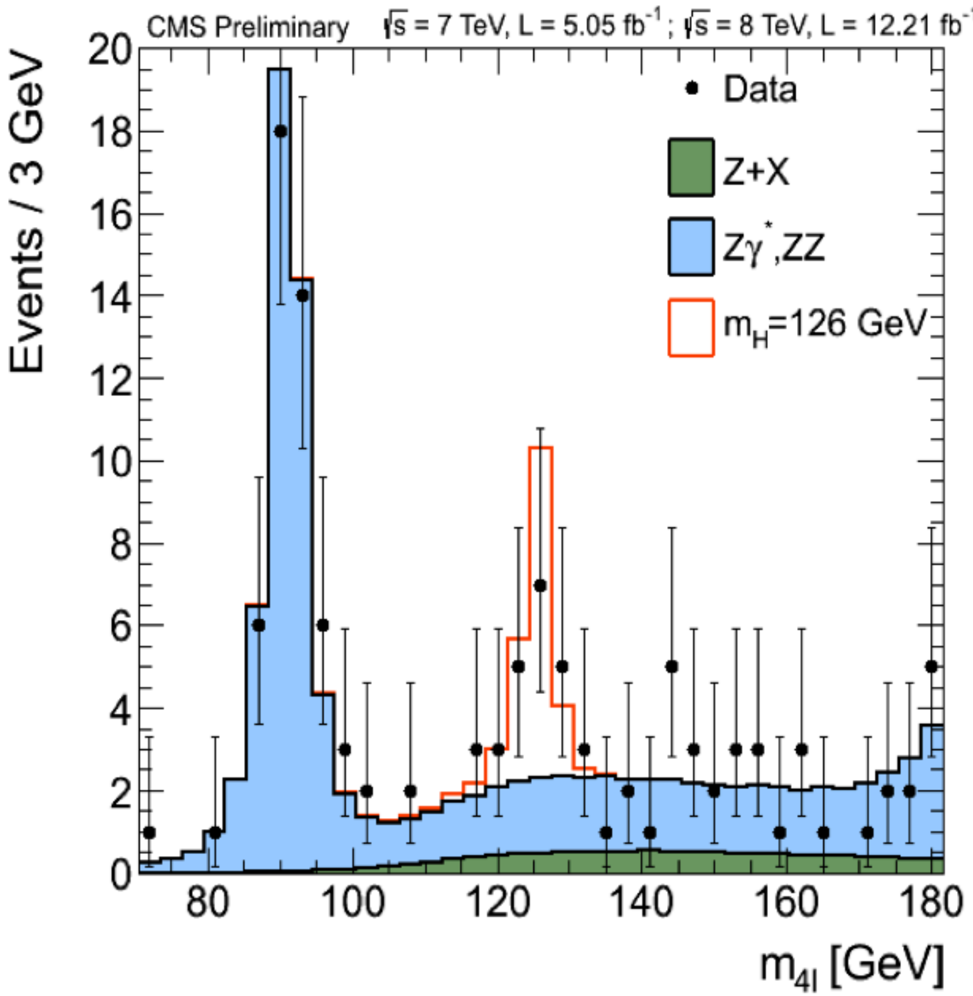
→ Small Signal rates but high Signal/Background

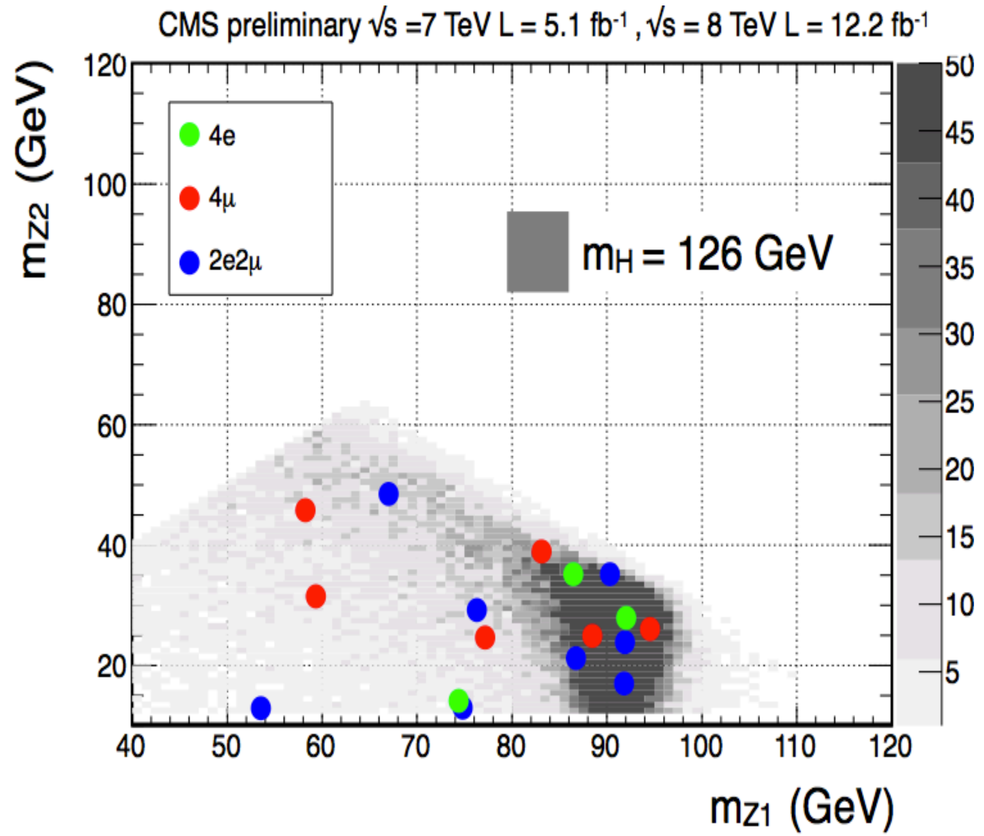
Channels:
- $ZZ \rightarrow 4l$; $l = e, \mu$
- $ZZ \rightarrow 2l2\tau$; $l = e, \mu$

→ Both channels extended to $m_H = 1$ TeV since ICHEP

CMS Experiment at LHC, CERN
Data recorded: Wed May 23 21:09:26 2012 CEST
Run/Event: 194789 / 164079659

H→ZZ→4l: Invariant mass



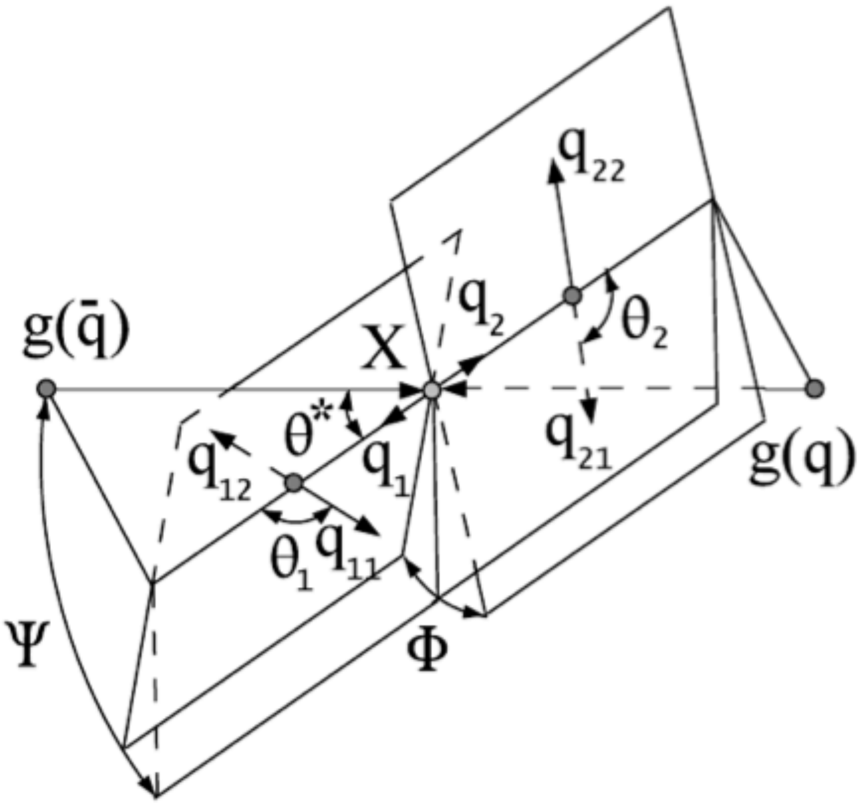


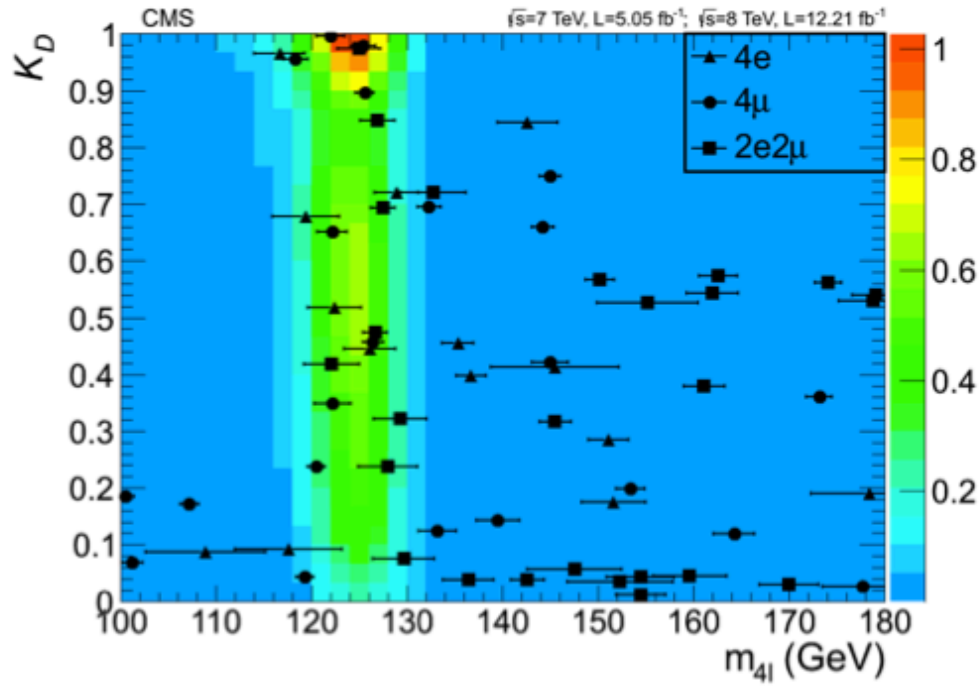
→ Z→4l peak in agreement with expectation / 4l mass fit shows $\delta m \sim 0.4 \pm 0.28$ GeV → expected resolution

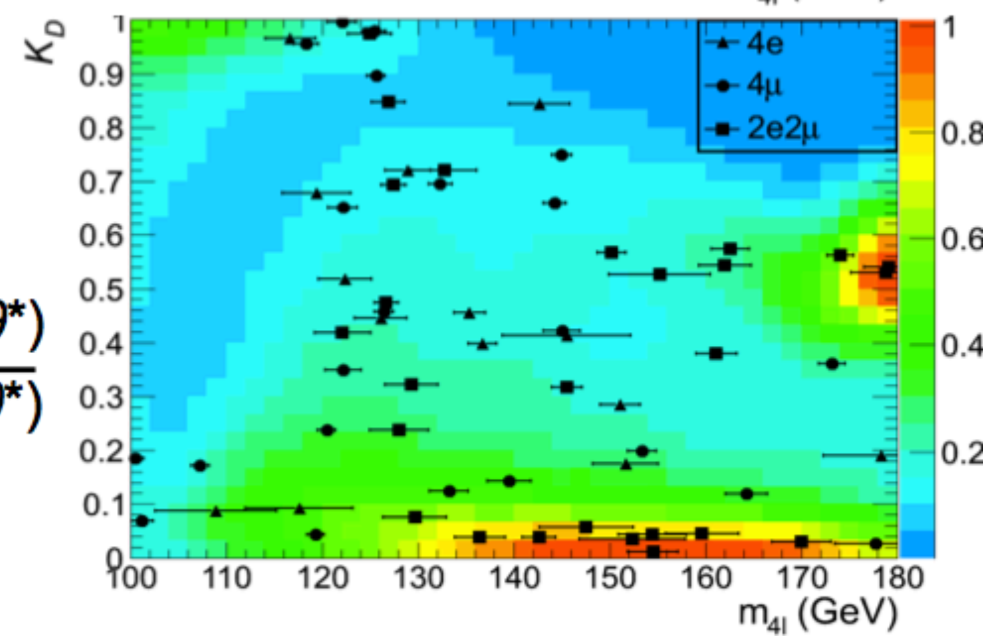
→ Peak around 126 GeV increased since July 4th

→ m_{Z1} vs m_{Z2} distributions in 126 GeV peak looks as expected

H→ZZ→4l: Kinematic Discriminant





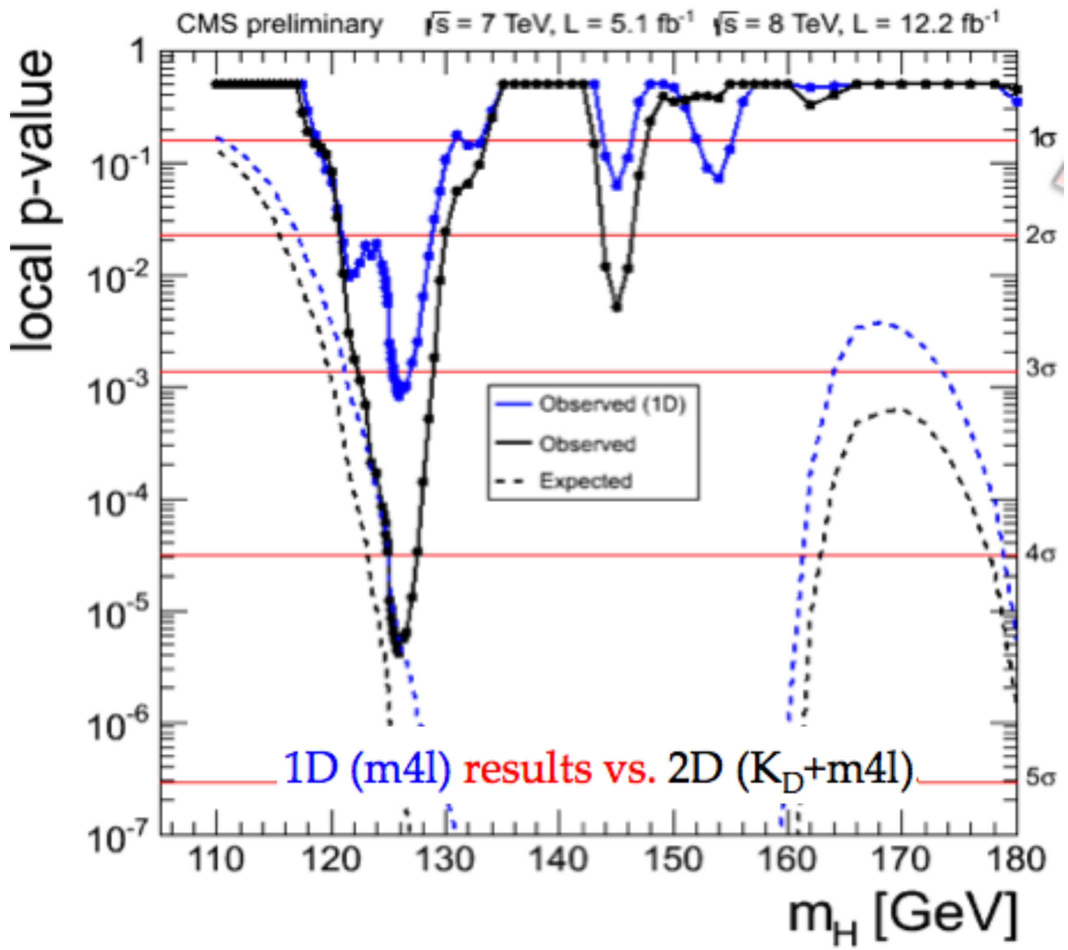


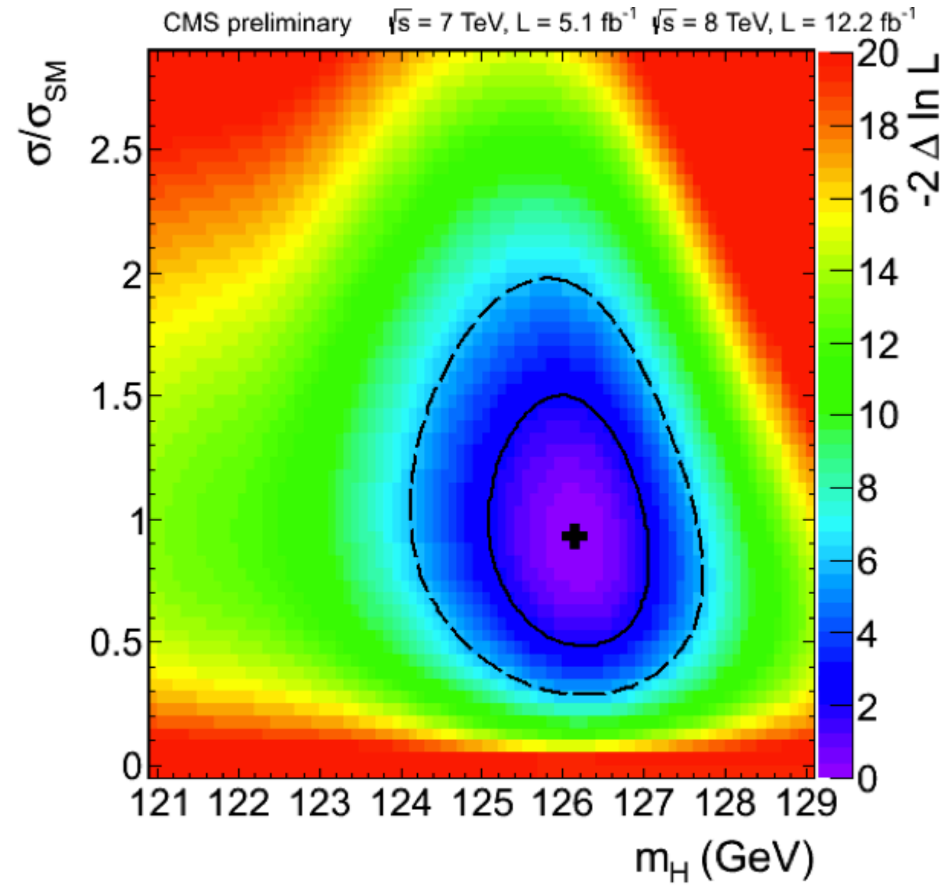
Angular analysis in CMS

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

enhances analysis sensitivity

H→ZZ→4l: Results





Observed p-value : 4.5 σ
Signal strength : 0.8 $^{+0.35}_{-0.28}$

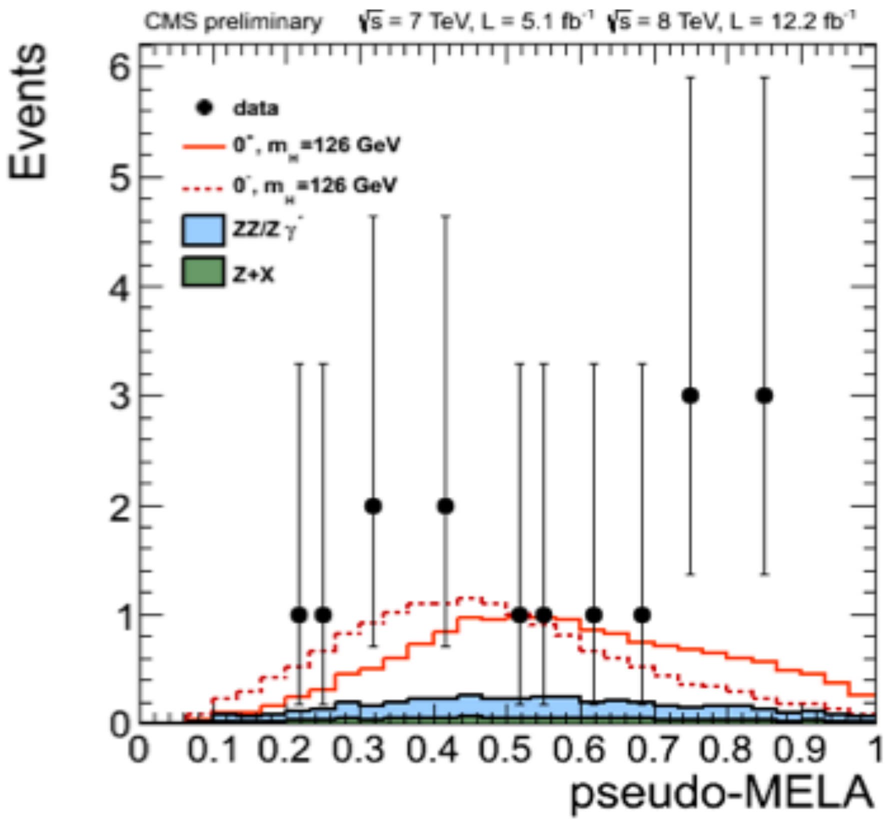
126.2 ± 0.6(stat.) ± 0.2(syst.) GeV

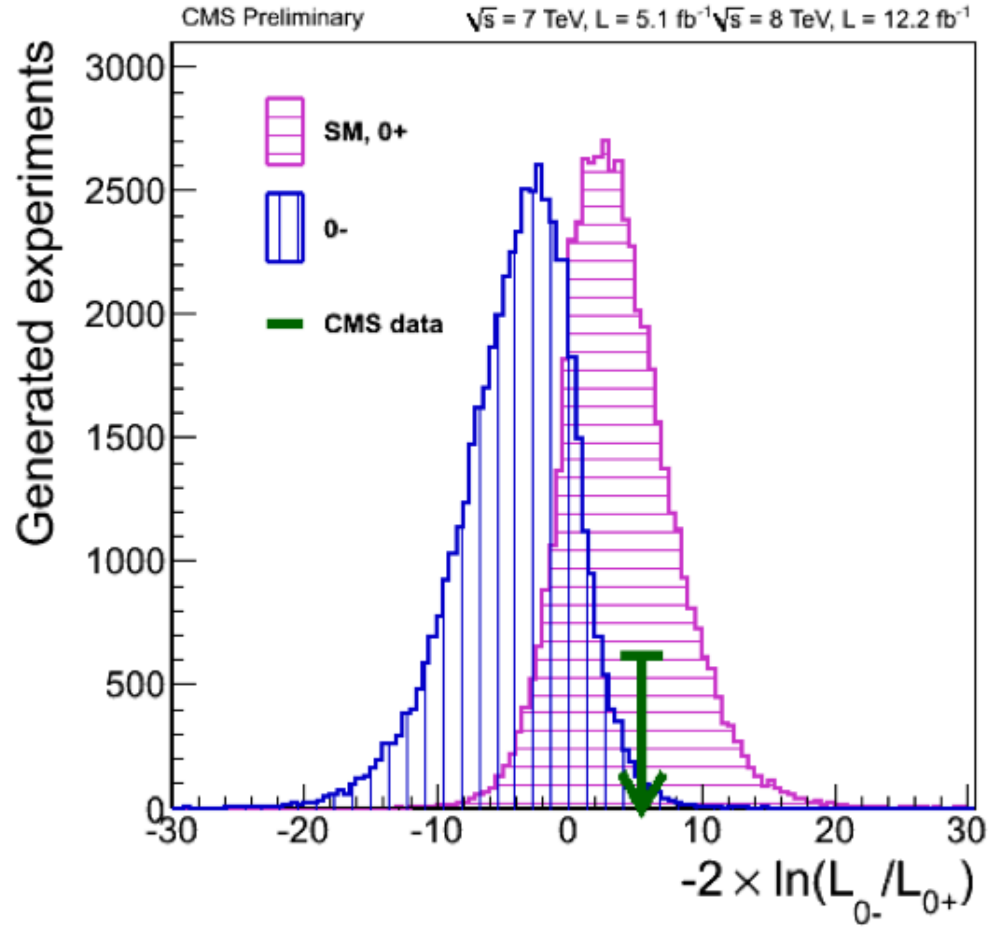
H→ZZ→4l: Parity Measurement

- 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: ~2 σ
- Scalar (0+): data consistent (0.6 σ)
- Pseudo-scalar (0-): data different by 2.5 standard deviations

H→ZZ→4l: Extending to 1 TeV

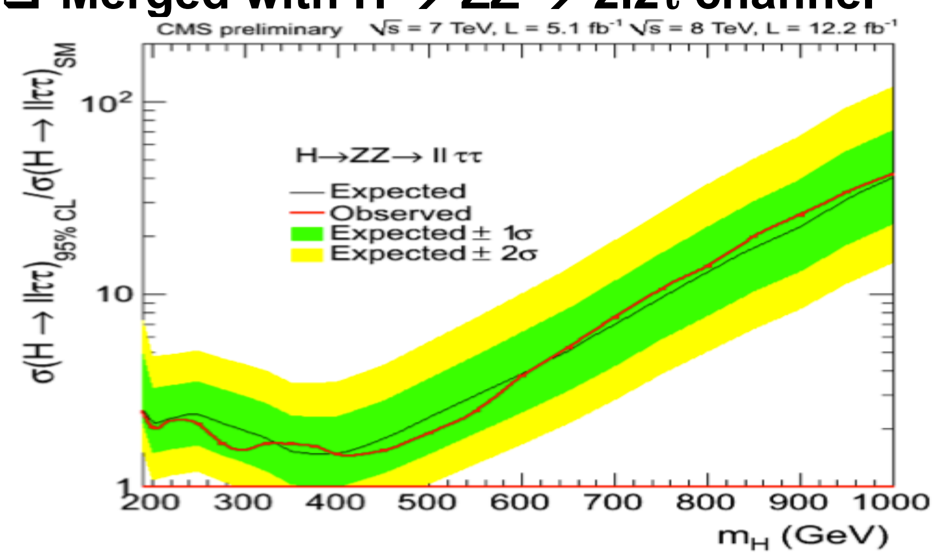
New since ICHEP:

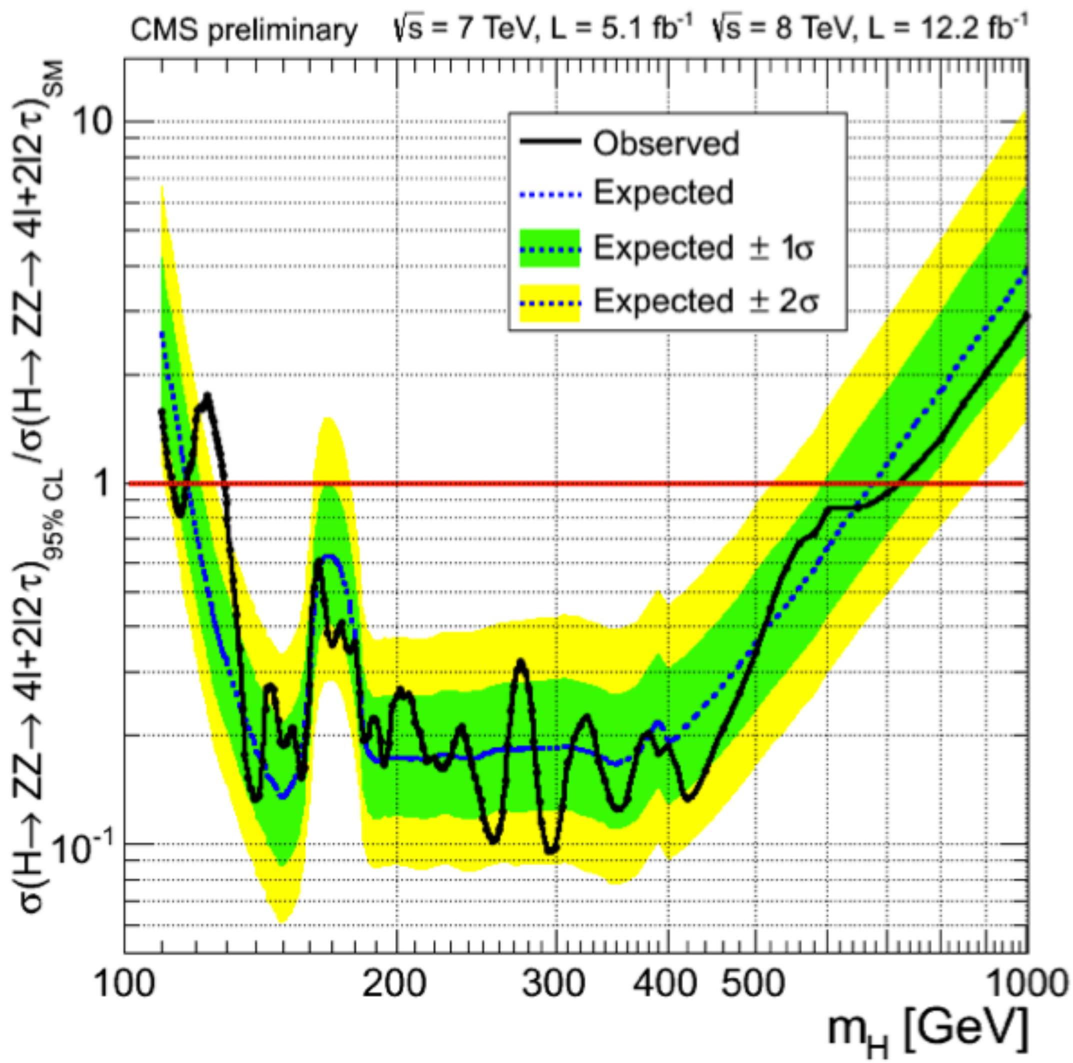
- **Reweight of high mass Higgs lineshape Including interference effects according to:**
  - N. Kauer et al. [arXiv:1201.1667,1206.4803]
  - G. Passarino [arXiv:1206.3824]
  - S. Goria et al. [arXiv:1112.5517]
  - J.-M. Campbell [arXiv:1107.5569]
  - V. Hirshi et al. [in preparation]

  → **Effect important for mH >~ 500 GeV**

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

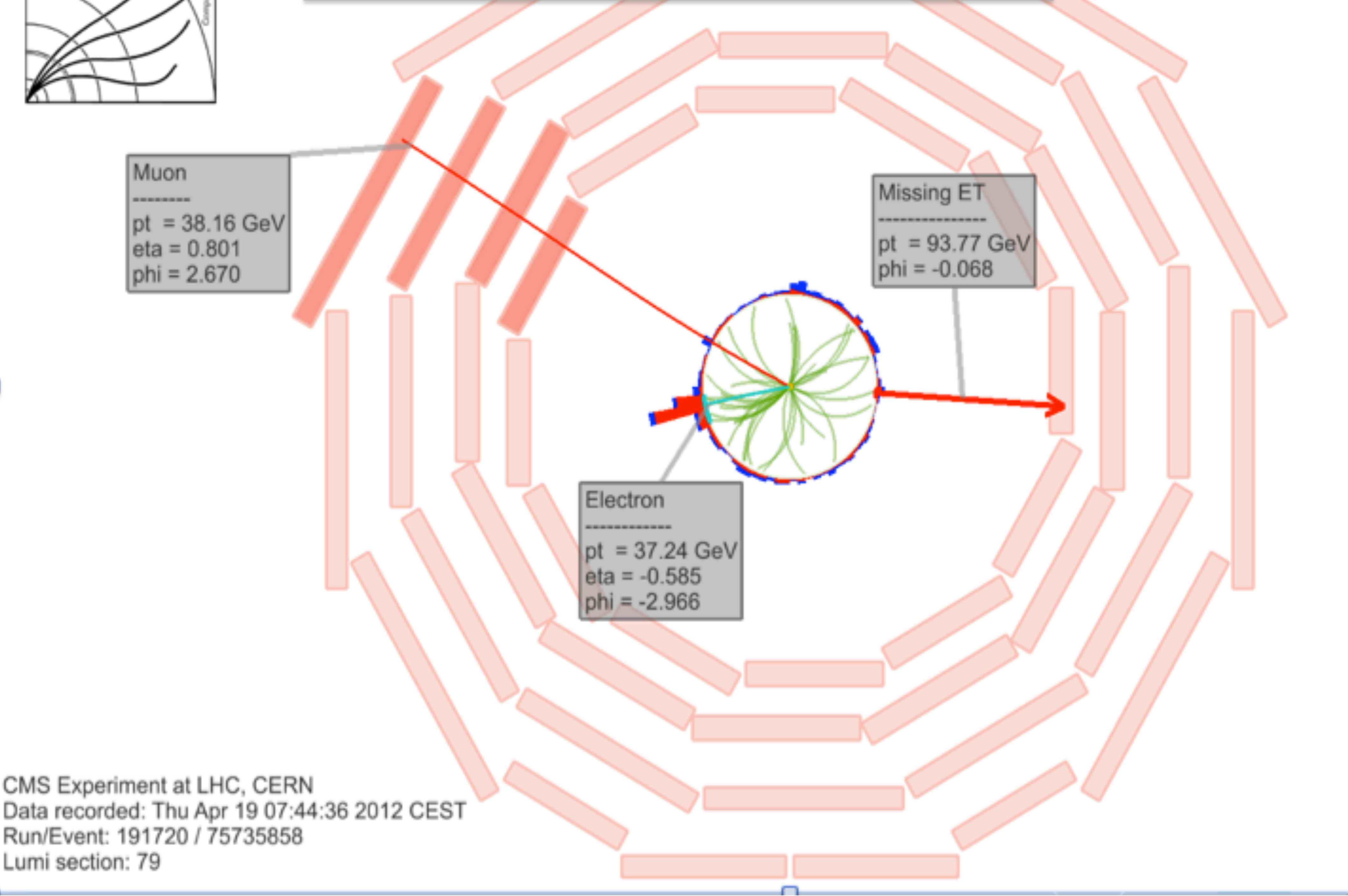
  + future updates (H→ZZ→2l2ν, …)
- **Merged with H → ZZ → 2l2τ channel**





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

H → WW → 2l2ν


Muon
----
pt = 38.16 GeV
eta = 0.801
phi = 2.670
Missing ET
----
pt = 93.77 GeV
phi = -0.068
Electron
----
pt = 37.24 GeV
eta = -0.585
phi = -2.966
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)

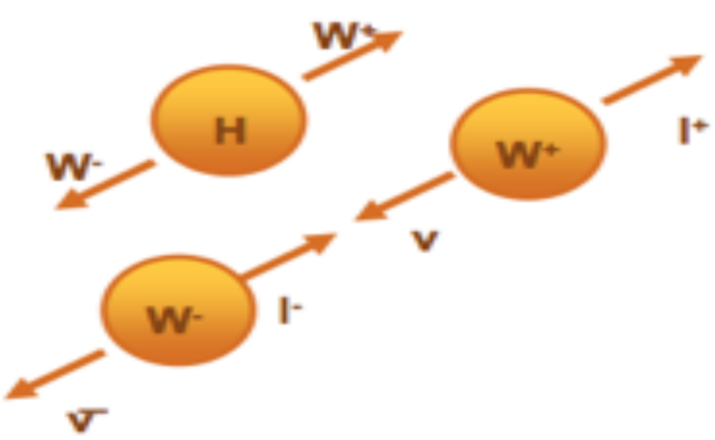
→ **WW (and Top for 1/2-jet bins) are "irreducible" backgrounds**

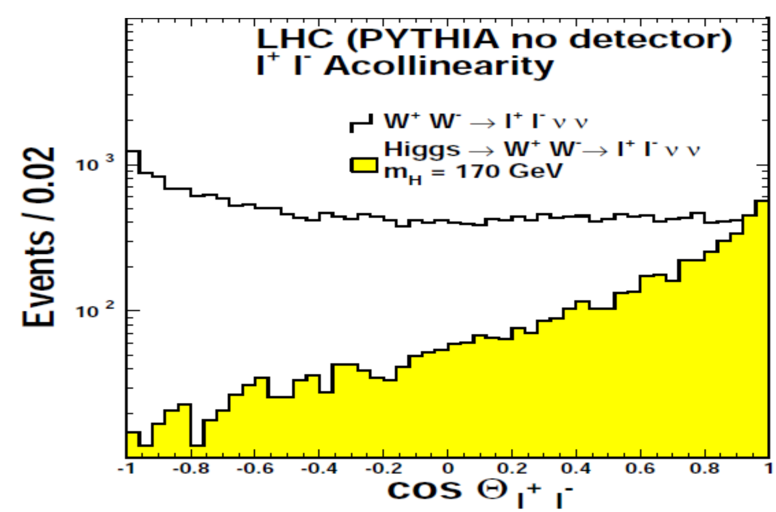
Signal Extraction:

- 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

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





CMS
Data
Run/
Lumi

H → WW → 2l2ν : 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

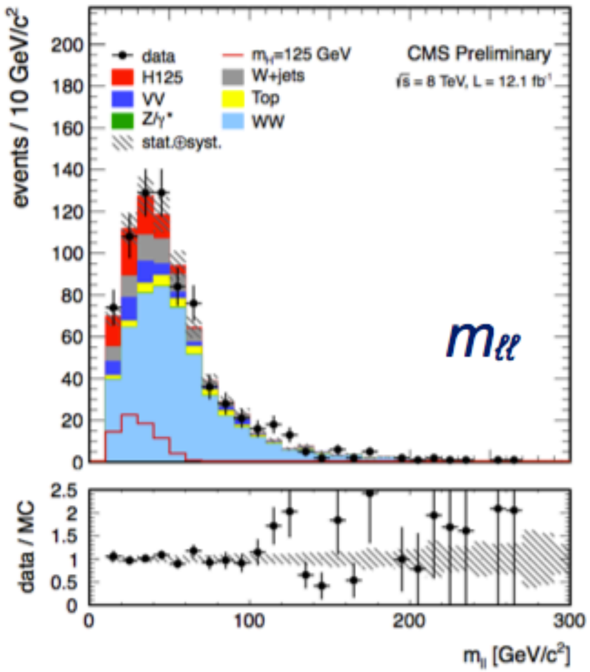
New for HCP

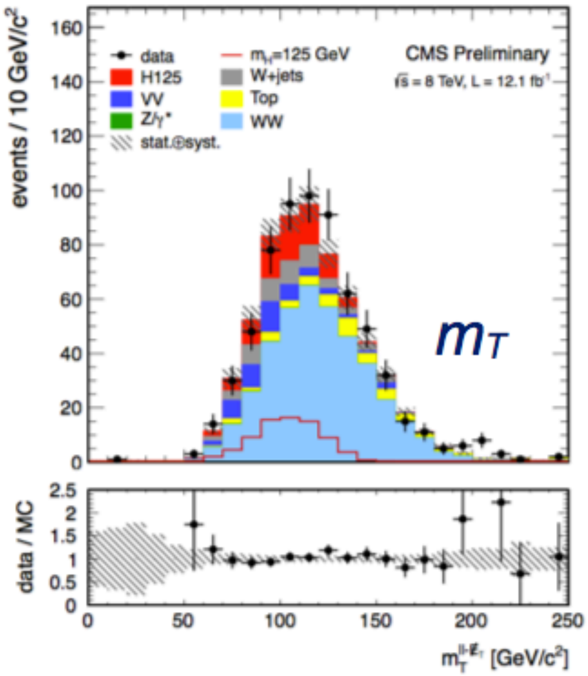
- shape analysis uses (m_{ll}-m_T) plane
- mass independent DY rejection, VBF selection optimized

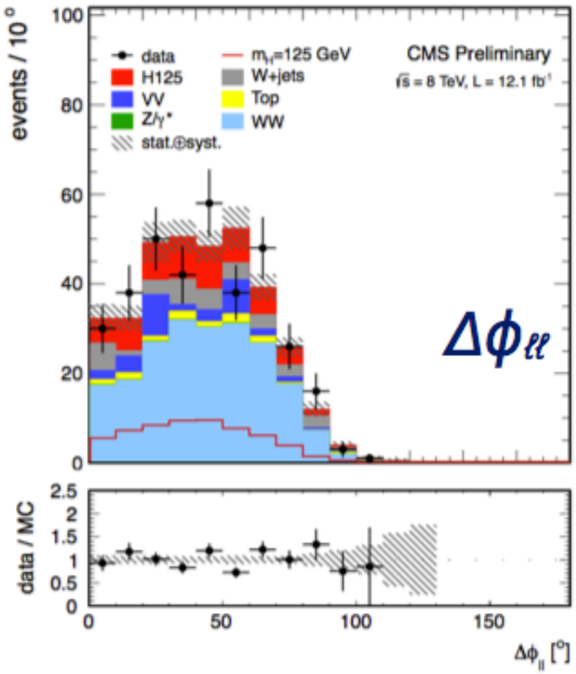
- **Combine with published 7 TeV analysis (4.9 fb^{-1})**

H → WW →2l2ν : 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 : 2D Shape Analysis

Exploits the correlation of two kinematic variables in 2D

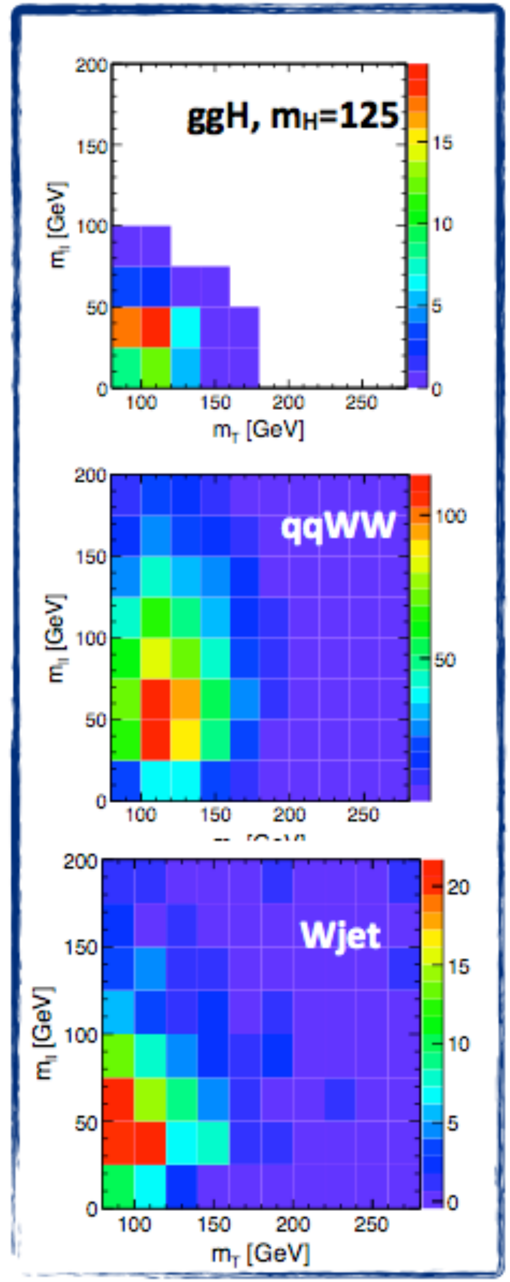
- Easier interpretation than multivariate discriminants
- Use of **mass-like variables**
  - **m_T: higgs transverse mass** $$m_T = \sqrt{2 p_T^{\ell\ell} E_T^{\rm miss} \left(1 - \cos \Delta\phi_{E_T^{\rm miss} \ell\ell}\right)}$$
  - **$m_{\ell\ell}$: di-lepton invariant mass**
- Different backgrounds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

Relaxed selection with respect to cut-based

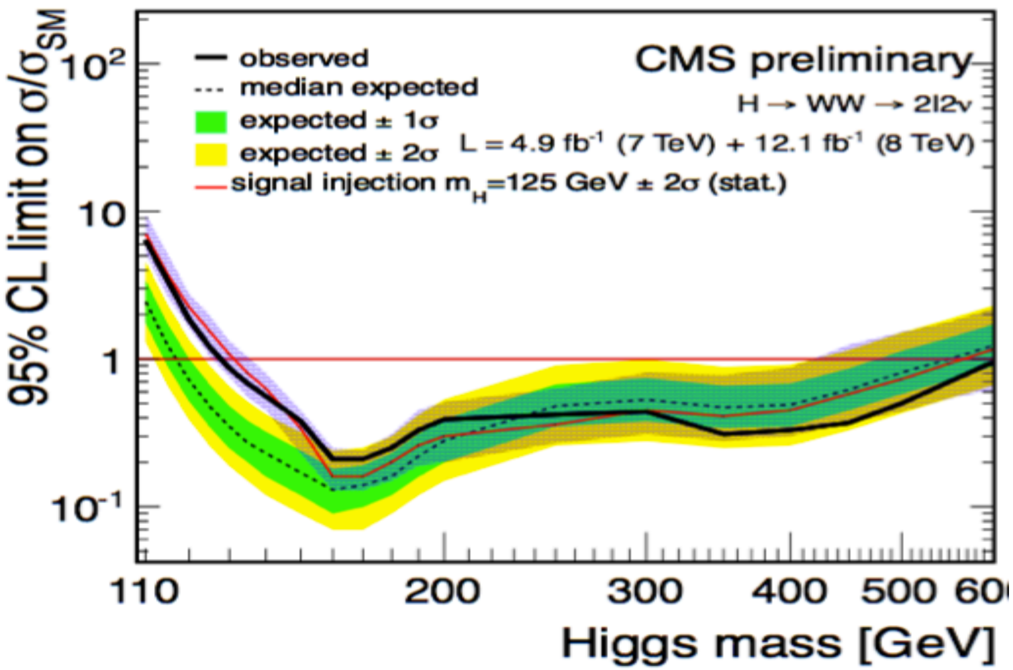
- Exploit the **full range** of the variables
- Improved sensitivity at low m_H from additional **sideband constraint of backgrounds**
- Mass independent selection for low/high mass searches

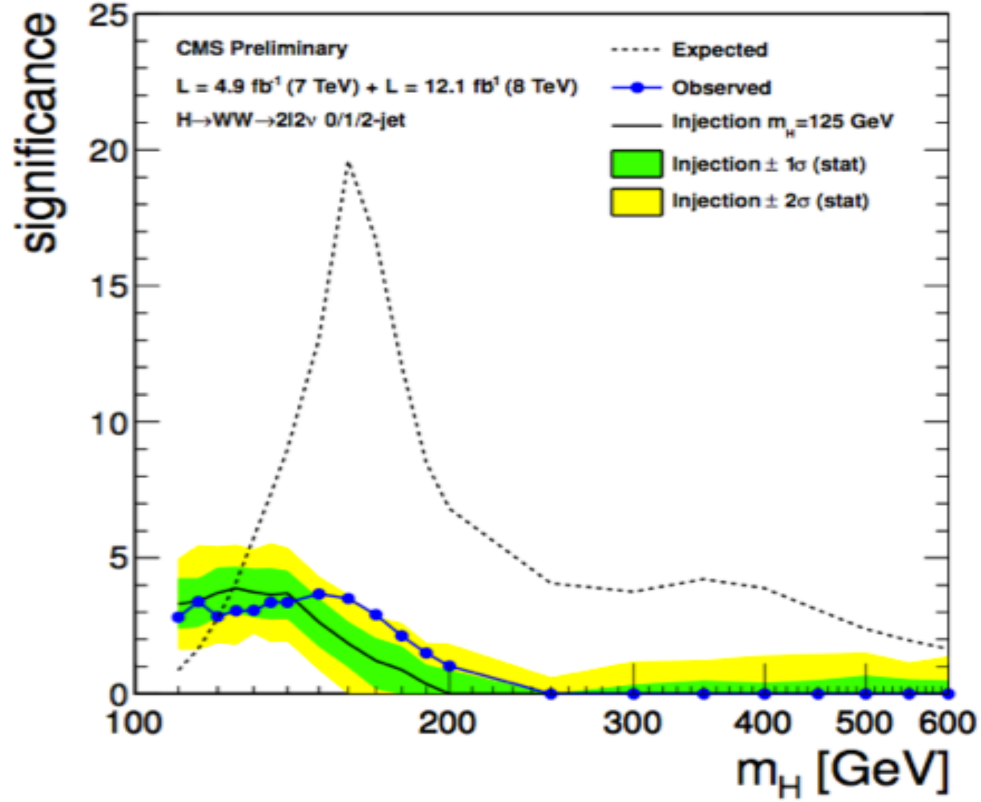
Applied to **DF 0/1-jet** channels

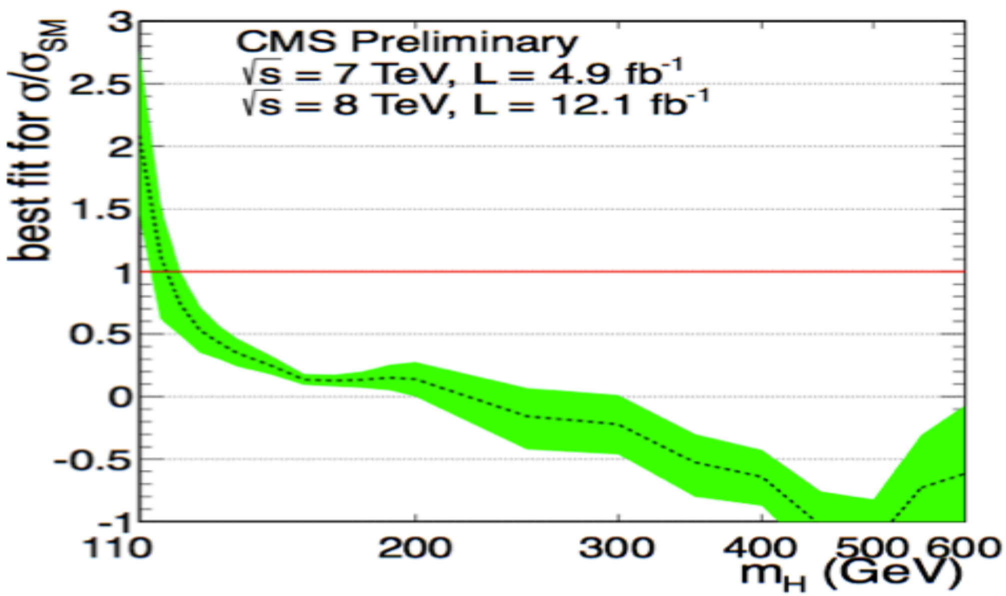
- Most sensitive channels with sufficient statistics for a 2D analysis



H → WW →2l2ν : Results





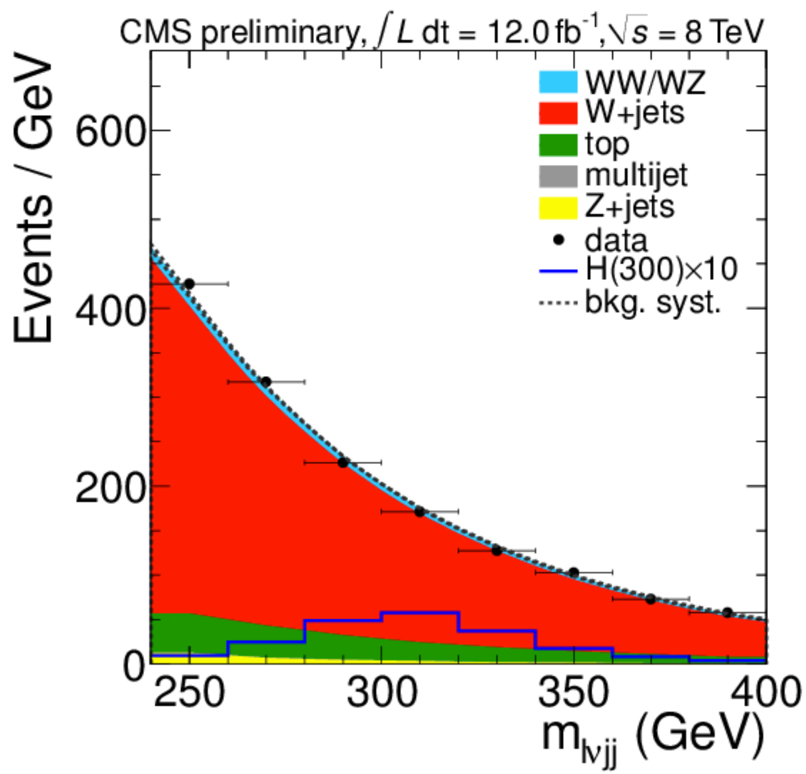


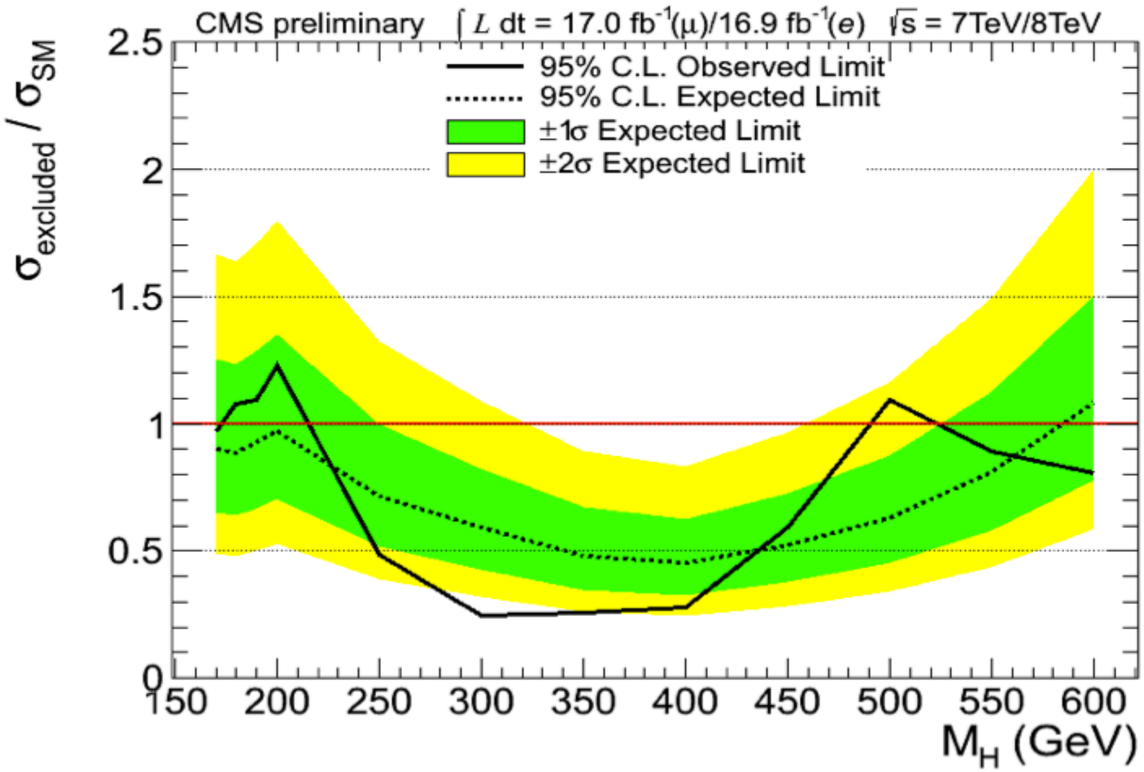
Large excess at low m_H from 2D 8 TeV + published 7 TeV analysis:

- ❑ **3.1σ (expected 4.1σ) @ 125 GeV**
  → Compatible with signal injection
- ❑ **μ = 0.74 0.25 @ 125 GeV**

H → WW → lνjj

- **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



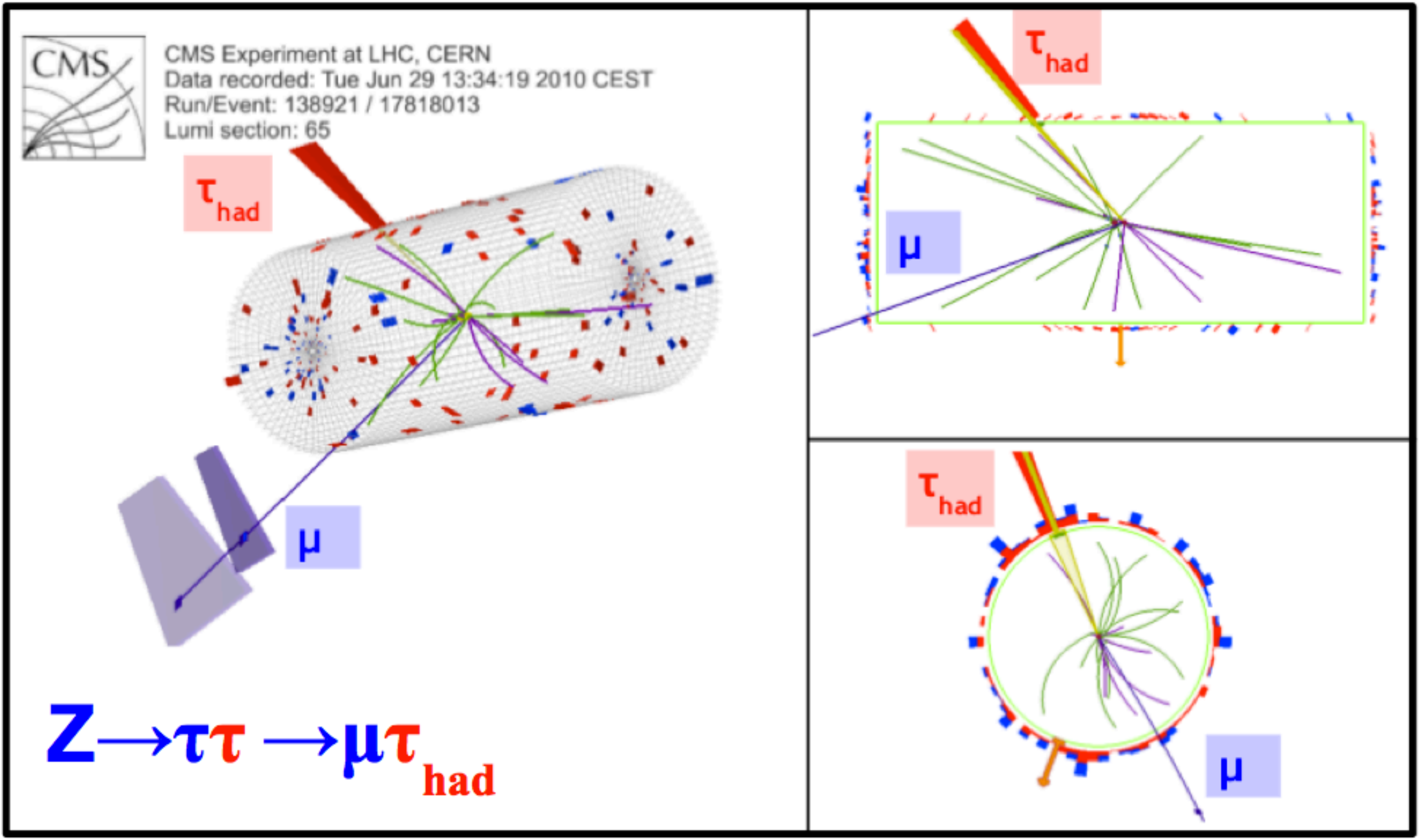


CMS:

Expected limit: 220-560 GeV

Observed limit: 225-485, 550-600 GeV

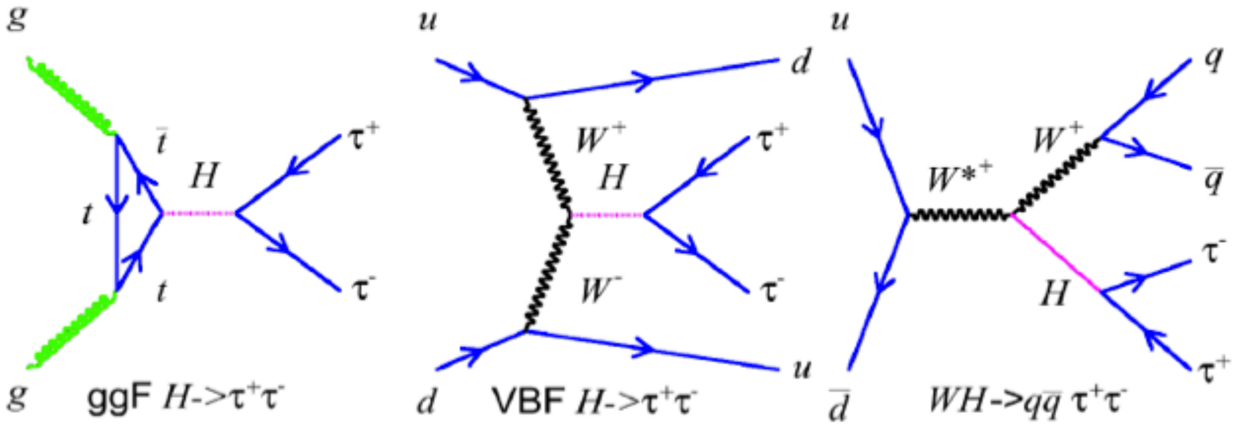
H → ττ



$Z \rightarrow \tau\tau \rightarrow \mu\tau_{had}$

$H \rightarrow \tau\tau$: Analysis overview

- **Search in ggH, VBF and VH production modes and five di-τ final states:**



- $H \rightarrow \tau\tau \rightarrow \mu\mu$ $(\tau_\mu \tau_\mu)$,
- $H \rightarrow \tau\tau \rightarrow e\mu$ $(\tau_e \tau_\mu)$,
- $H \rightarrow \tau\tau \rightarrow \mu$+had. $(\tau_\mu \tau_h)$,
- $H \rightarrow \tau\tau \rightarrow e$+had. $(\tau_e \tau_h)$,
- $H \rightarrow \tau\tau \rightarrow$ had.+had. $(\tau_h \tau_h)$.

- **Separation in categories to enhance S/B:**

0-Jet
In situ calbration of backgrounds

- 0-Jet, low p_T(lep.)
- 0-Jet, high p_T(lep.)

No attempt to extract signal from these categories.

1-Jet
Suppression of backgr. from $Z \rightarrow \tau\tau$

- 1-Jet, low p_T(lep.)
  - Large statistics.
- 1-Jet, high p_T(lep.)
  - Improved resolution of $m_{\tau\tau}$.
  - Less background from $Z \rightarrow \tau\tau$.

2-Jet/VBF
Most sensitive single evt. category.

- 2-Jet, VBF
  - Cut based: m_{jj}>500 GeV, $|\Delta\eta|$>3.5, central jet veto.

Increasing $p_T(\tau/\mu)$

VH (V = W or Z)
smaller background w.r.t. inclusive $H \rightarrow \tau\tau$ analysis

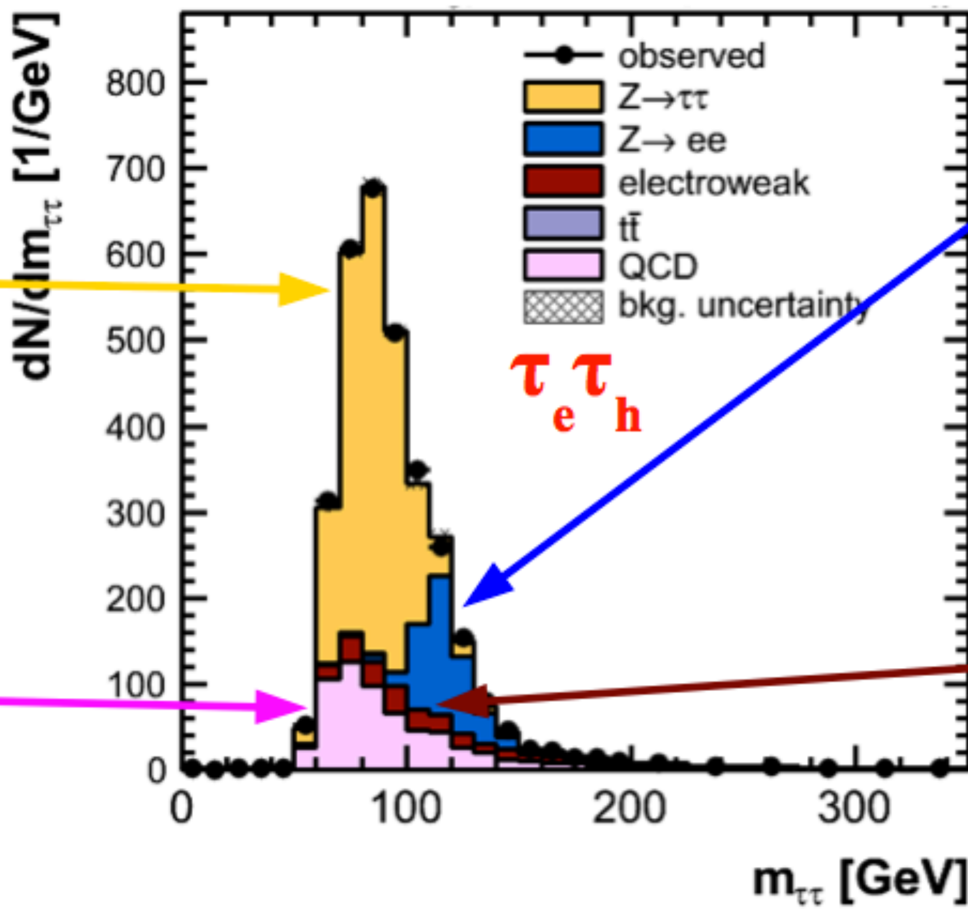
Analysis Methods:
- 0-jet categories only for background normalization in 1-jet and VBF analysis
- 1-jet/VBF: Template fit to $m_{\tau\tau}$ with B and S+B model
- VH: Fit to visible mass

H→ττ : Dominant backgrounds (0/1-jet & VBF)

Z→ττ:
- Embedding: in Z→μμ, replace μ by sim. τ decay.
- Normalized from Z→μμ events.

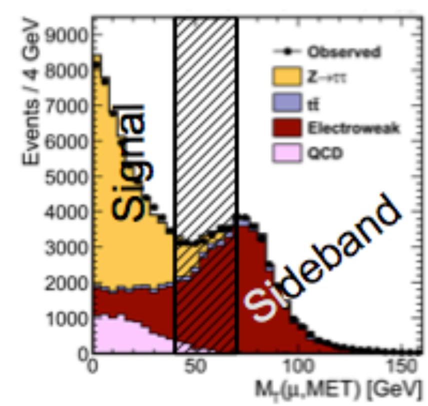
QCD:
- Normalization & shape taken from LS/OS or fakerate.

ttbar:
- From simulation.
- Normalization from sideband.



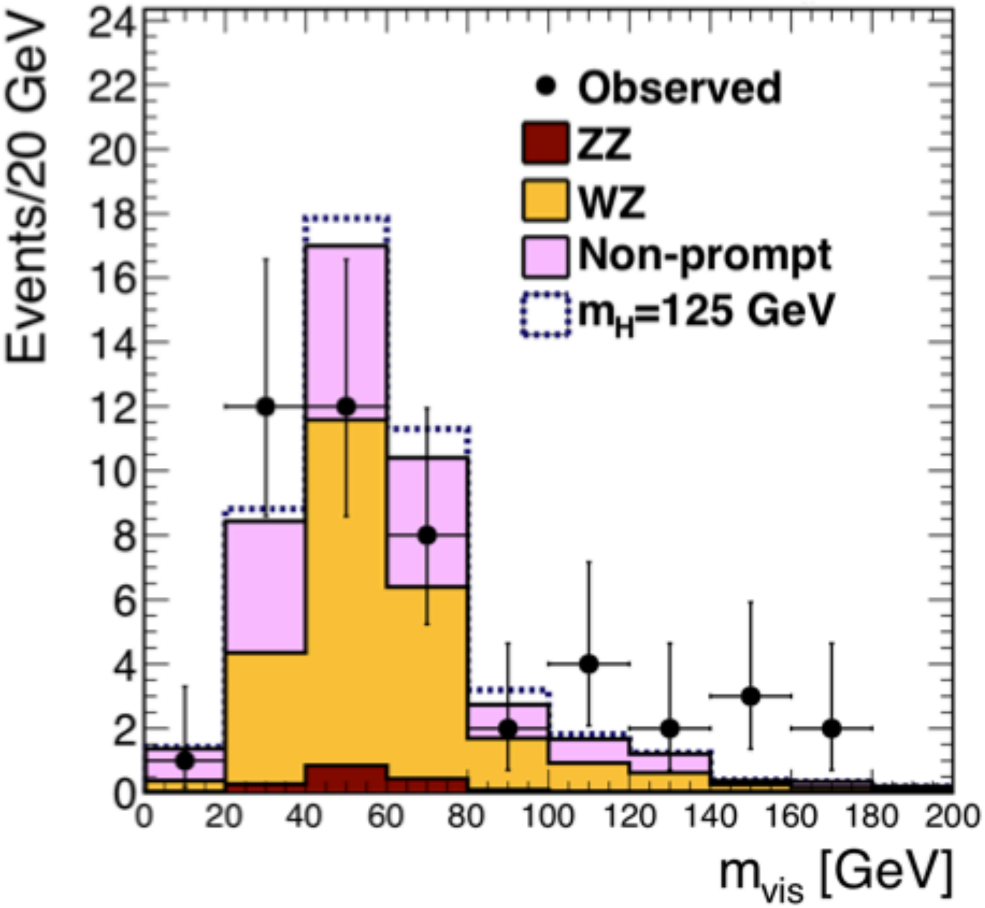
Z→ee(/μμ):
- From simulation.
- Corrected for jet→τ, e/μ→τ fakerate.

Diboson/W+jets:
- From simulation.
- Normalization from sideband.

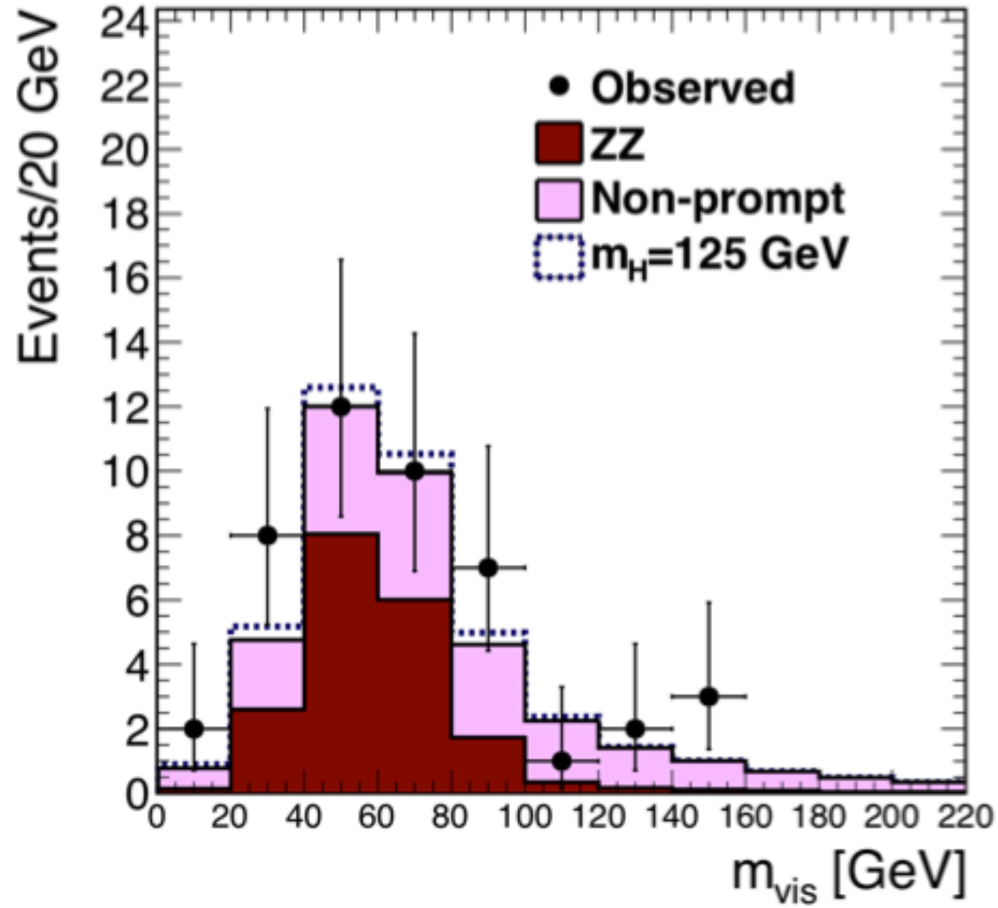


H→ττ : VH Analysis

WH→lττ mode:

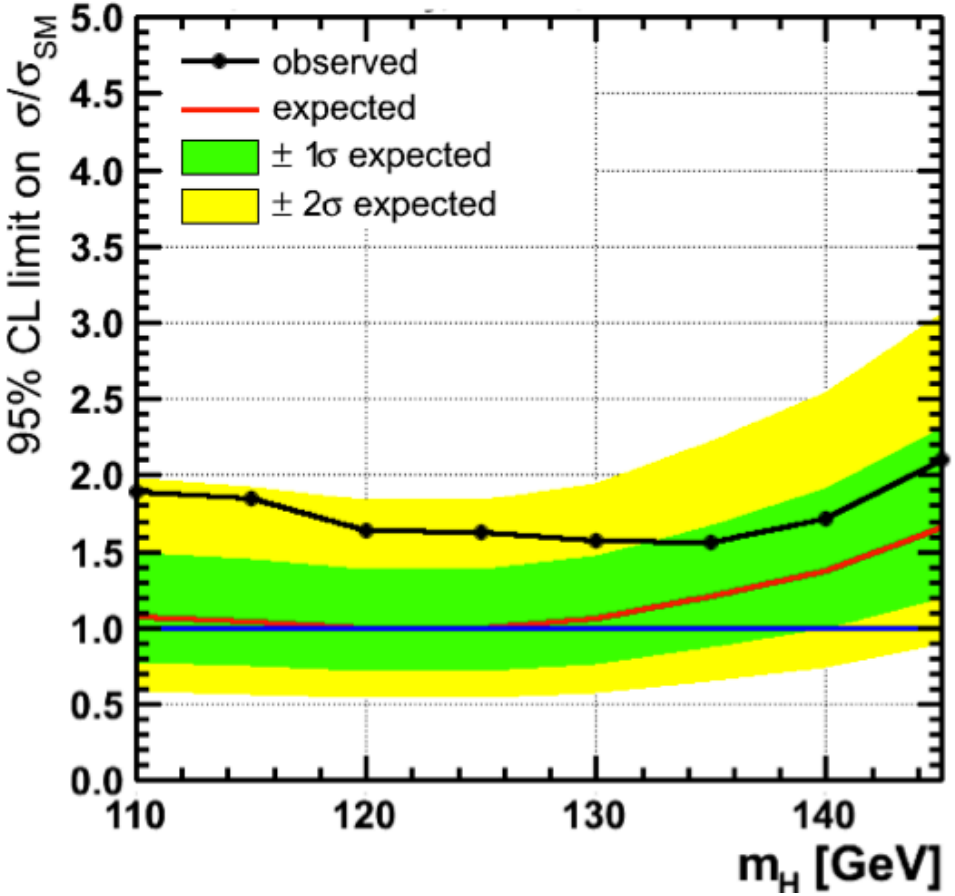


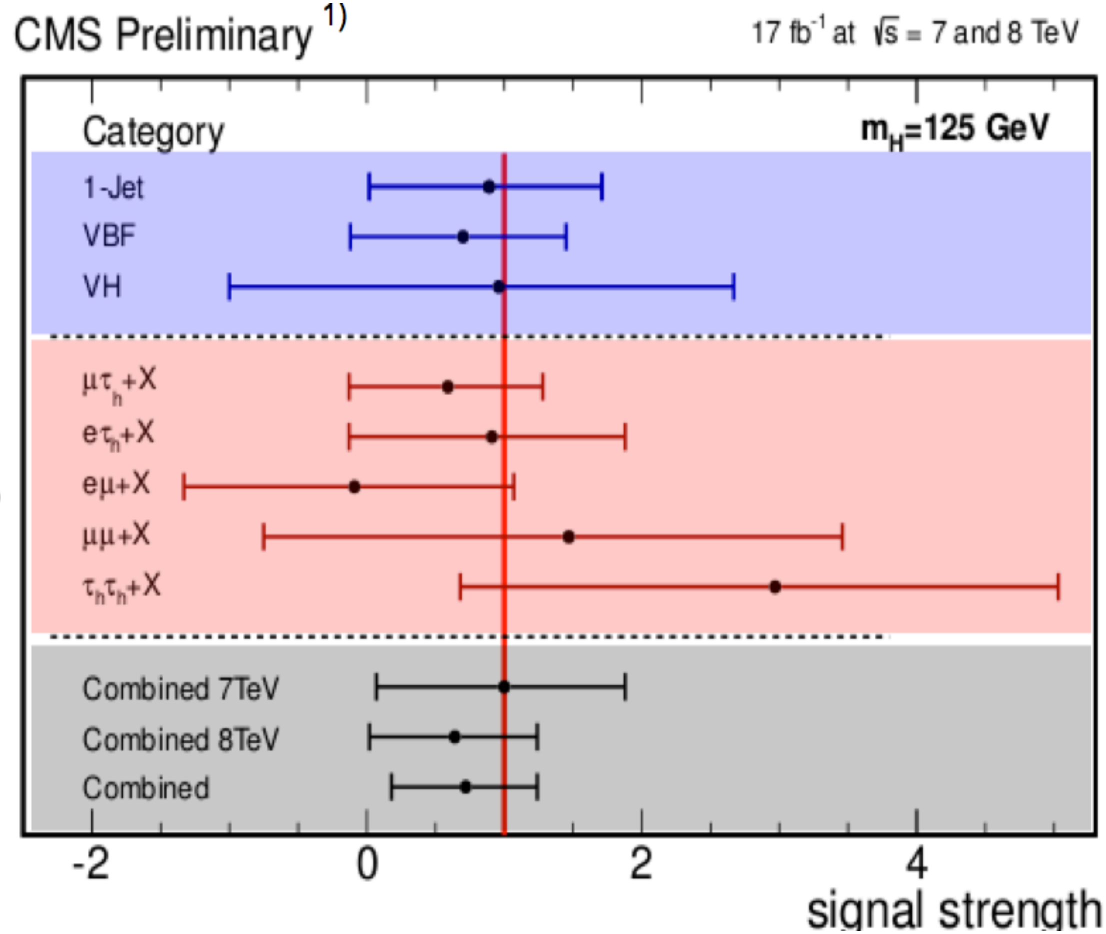
ZH→llττ mode:



- ❑ **Signal extracted from mass of visible decay products (m_{vis}).**
- ❑ **Small background wrt. to inclusive H→ττ decay channels.**

$H \rightarrow \tau\tau$: Results

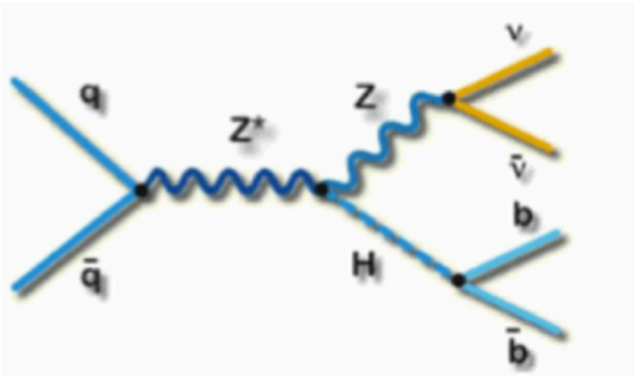




- Sensitivity(125 GeV)=1.05. Observed limit(125 GeV)=1.66.
- Compatible with Higgs boson signal at 125 GeV but also with background only hypothesis.
- Signal strength after fit: **0.72±0.52** (well compatible with SM).

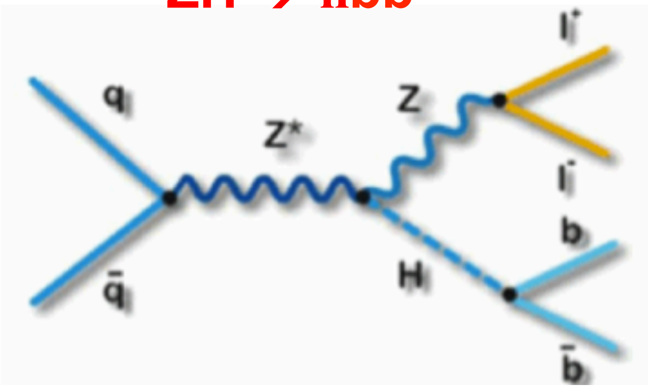
VH → bb

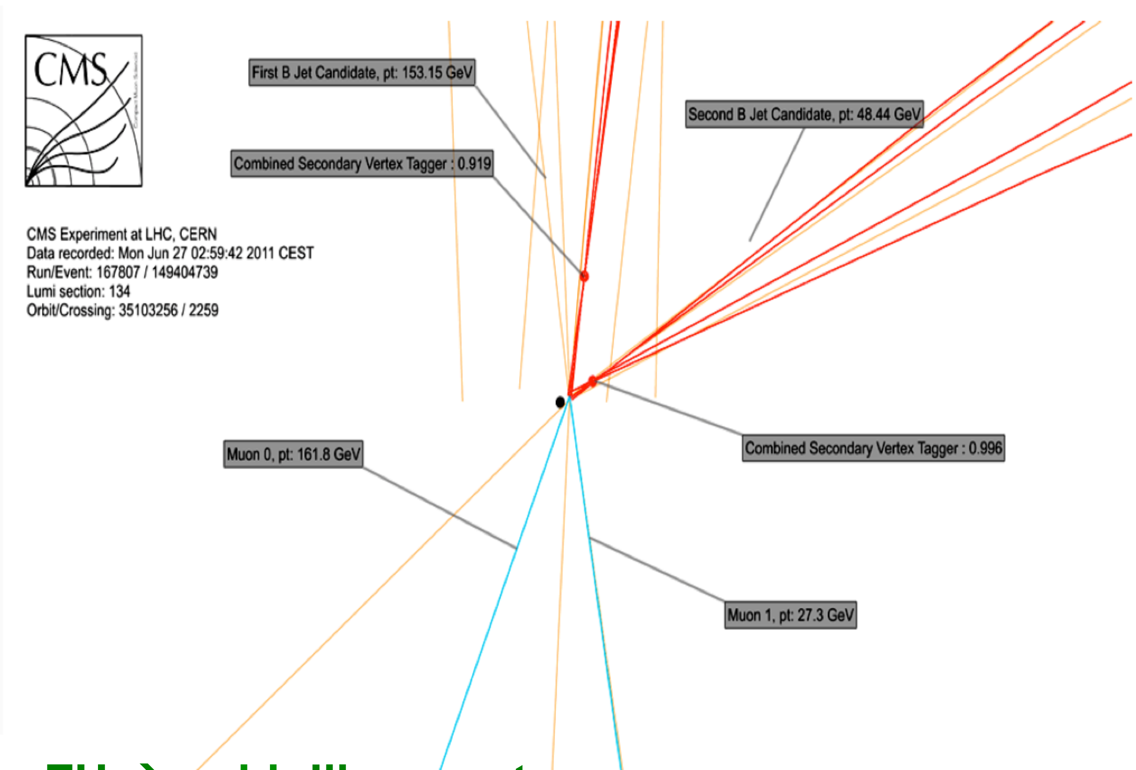
ZH → ννbb



WH → lνbb

ZH → llbb





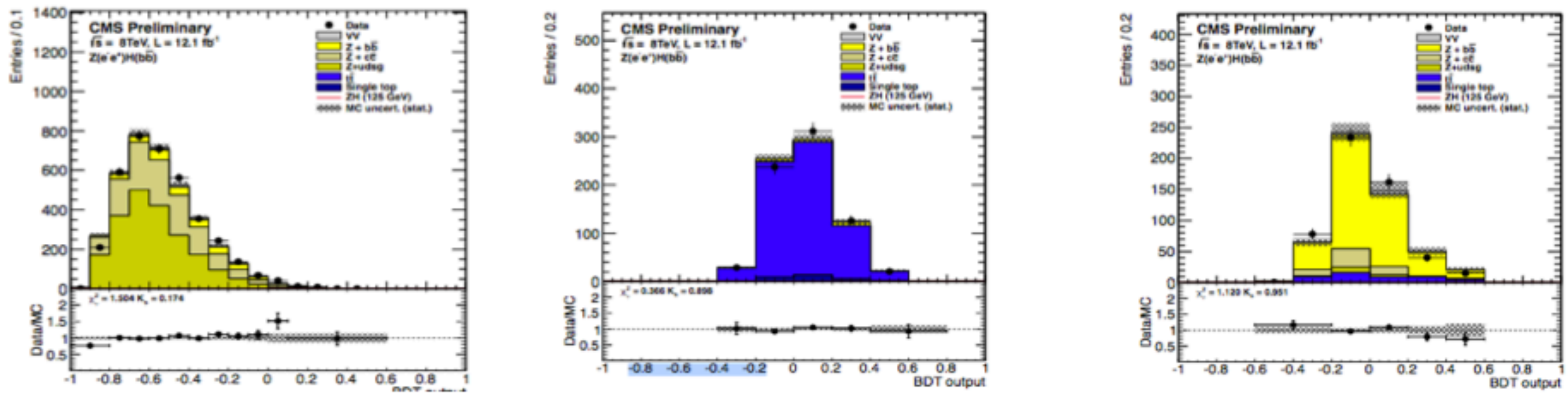
ZH → μμbb like event

- Largest number of Higgs decays at low mass but Lots of background (jets)
- Trigger based on leptons and missing E_T
- *b-jets* identified through displaced tracks
- Go to high p_T where Higgs is enhanced
- Main background: W/Z+jets and top

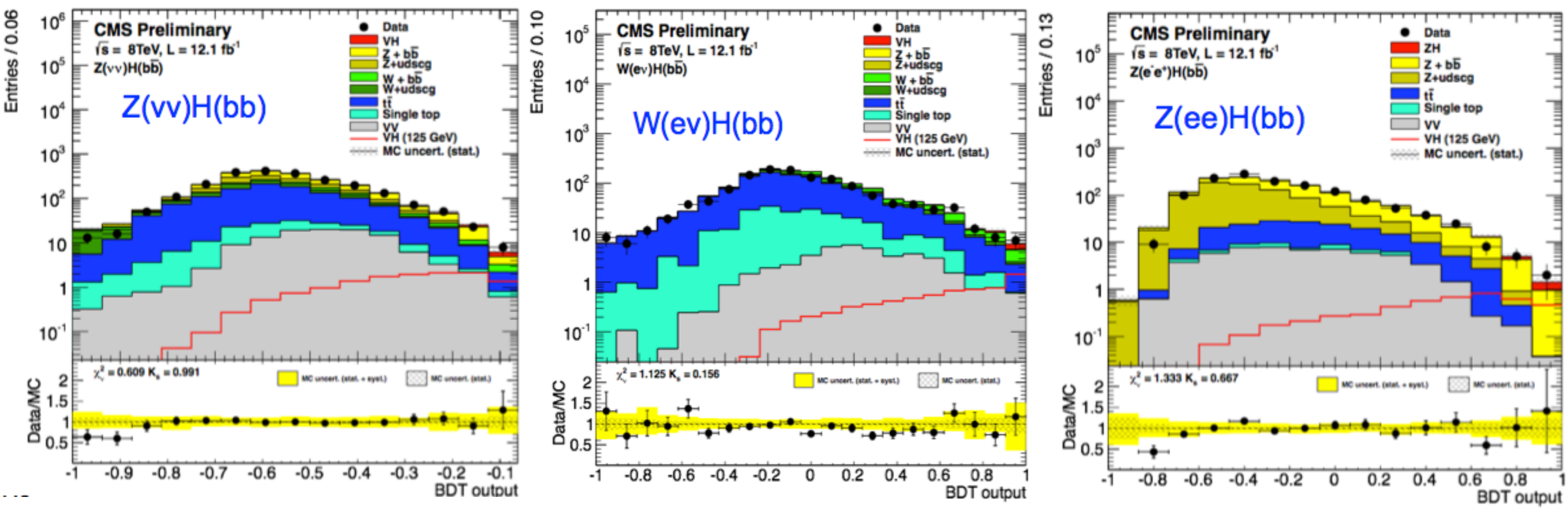
VH → bb

- Extrapolate backgrounds from control regions:

Z Light CR | TTbar CR (in ZH) | Z Heavy CR

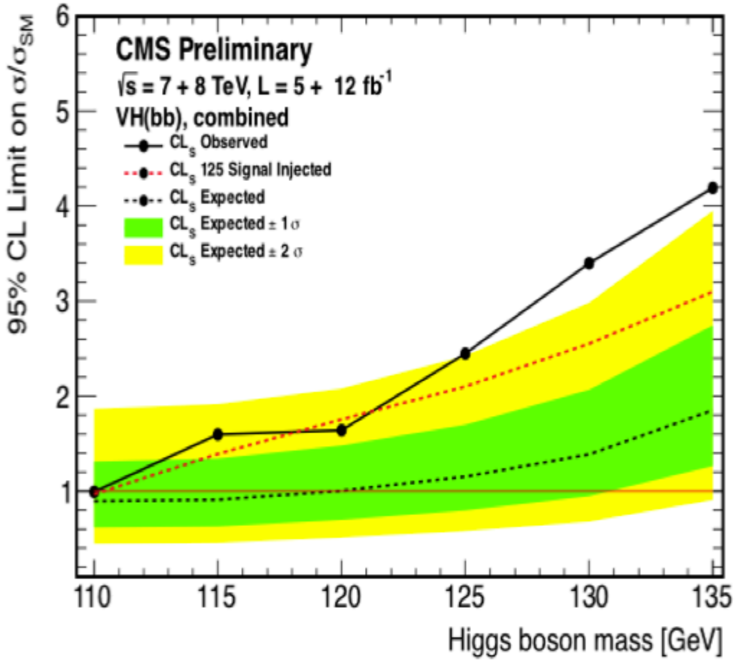


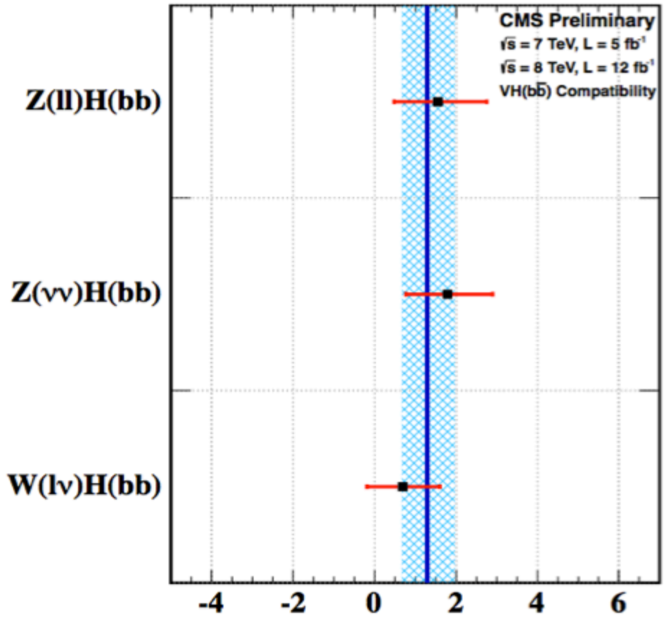
- Multivariate Discriminants (BDT) to separate signal:



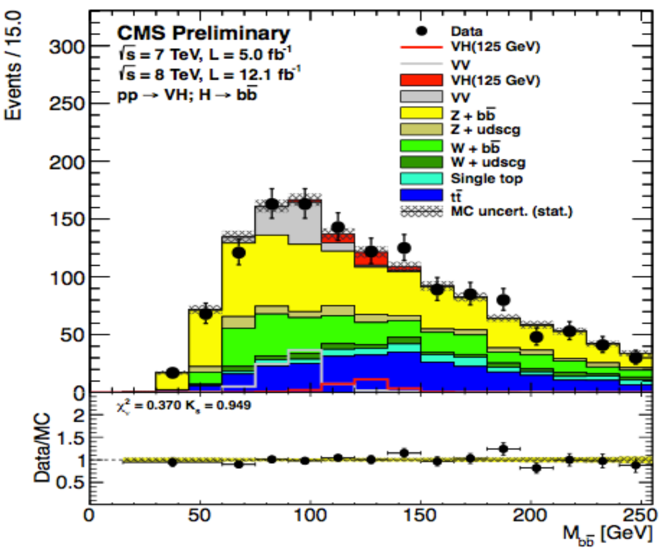
→Small Excess of events observed for all channels in the BDT fit

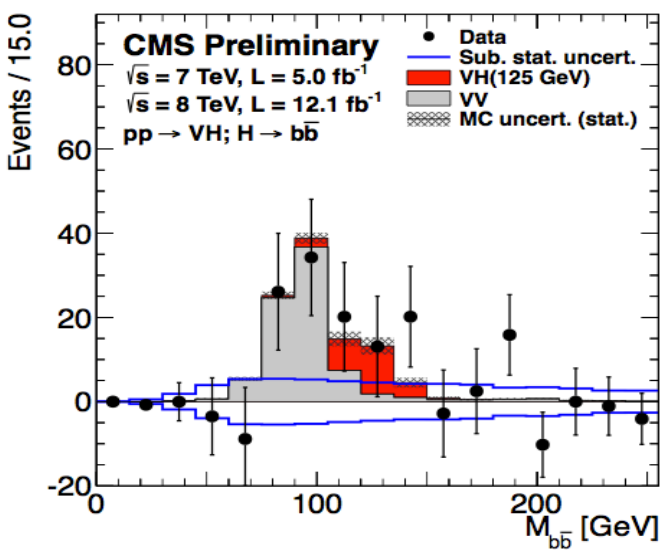
VH → bb : Results





- Mild excess of 2.2 standard deviation building up
- Coherent picture between the sub channels

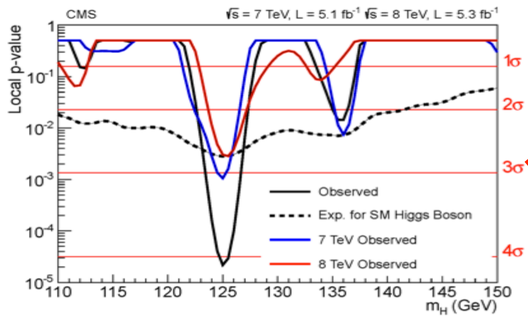




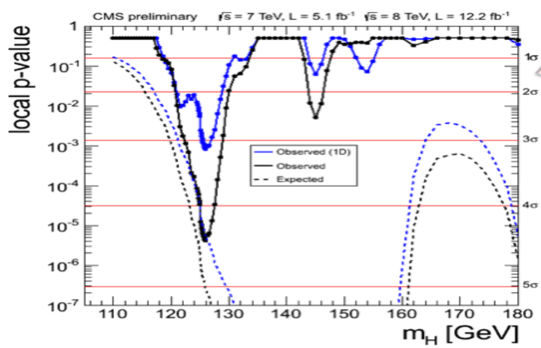
- Small excess in the signal region observed in the M_{bb} distribution

COMBINED RESULTS

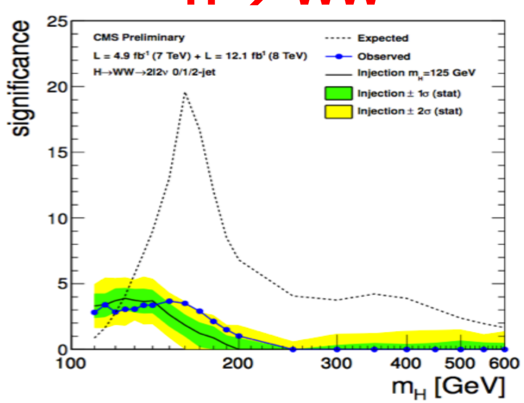
H → γγ



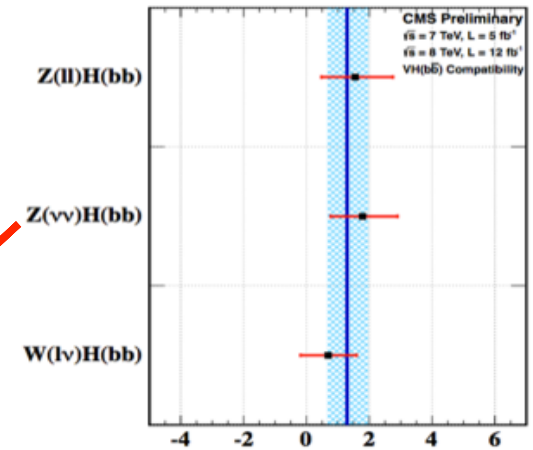
H → ZZ



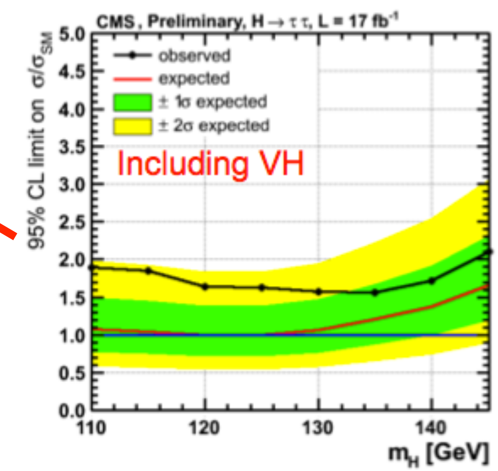
H → WW



H → bb

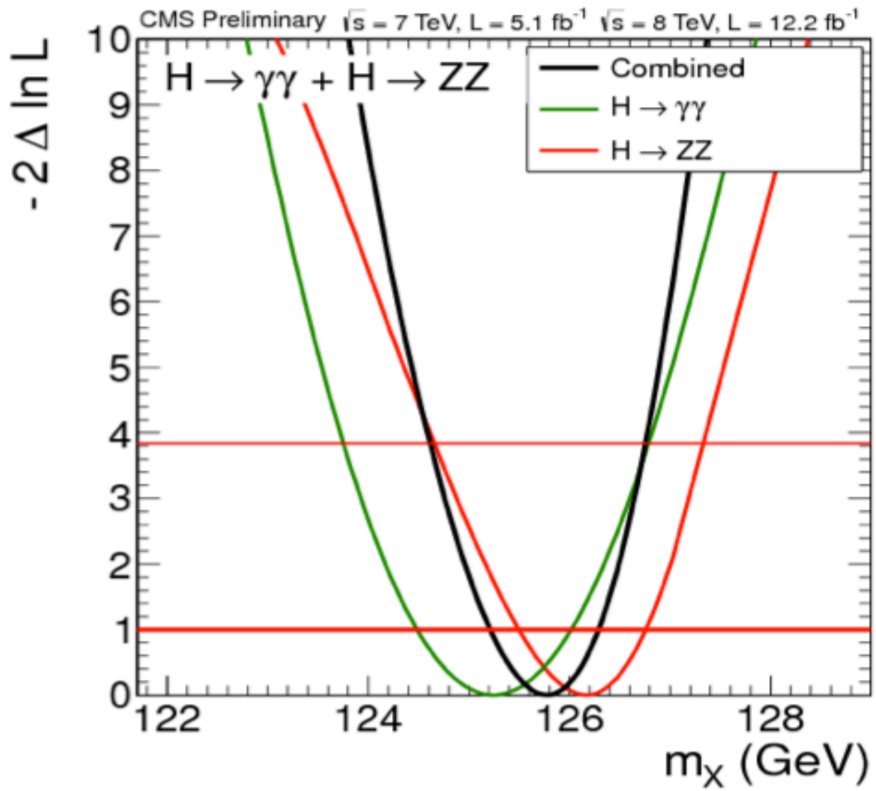


H → ττ



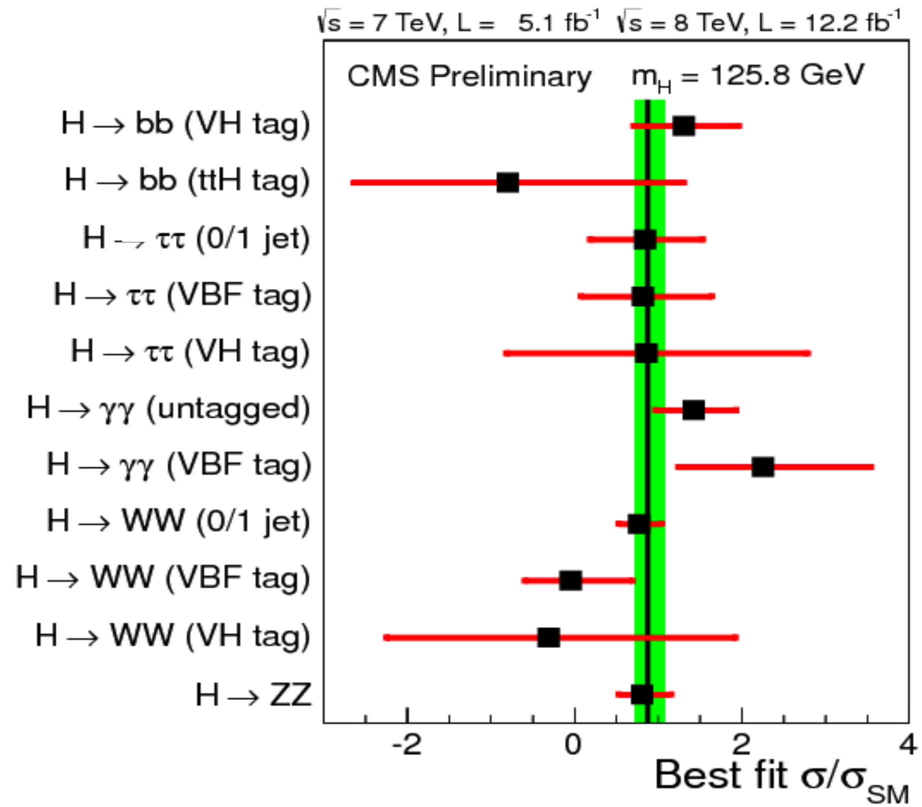
Mass measurement & Signal strength

- **Combine information from the high resolution channels measurements:**
  - H → ZZ
  - H → γγ (ggH and VBF)
- **Signal cross section for the channels left floating independently in the fit**



→ m_X = 125.8 ± 0.4 (stat) ± 0.4 (syst) GeV

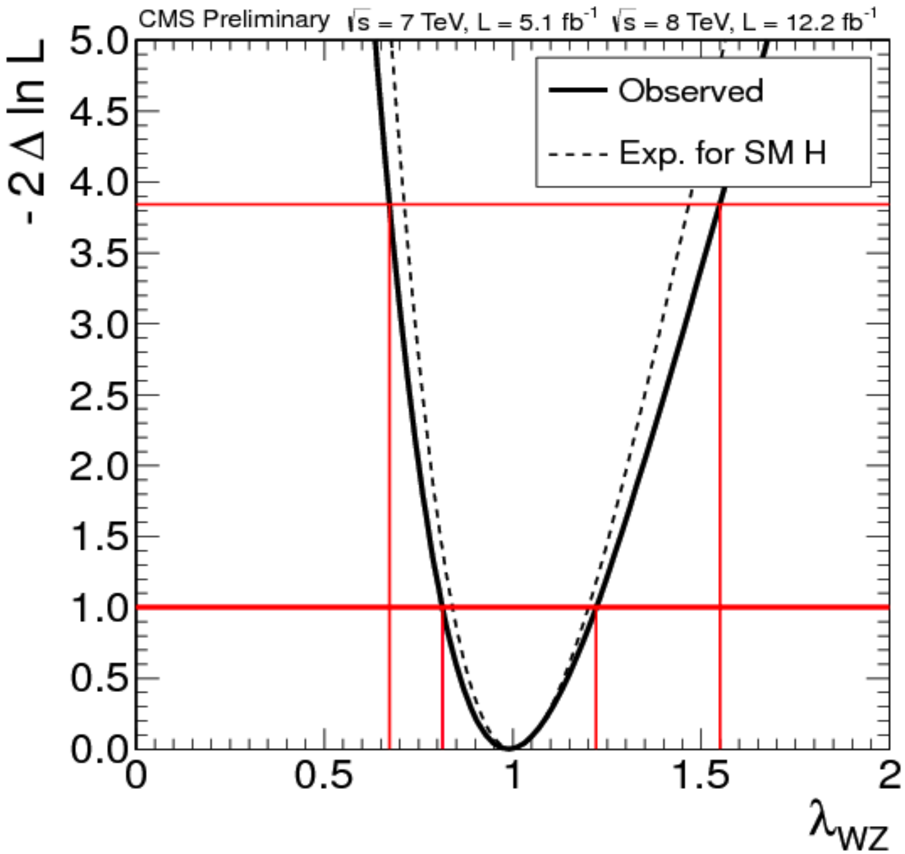
Signal strength from all channels at m_H = 125.8 GeV if SM Higgs



→ σ/σ_{SM} = 0.88 ± 0.21
→ Compatible with SM Higgs
→ Compatibility within ~1σ for each decay channel / production mode

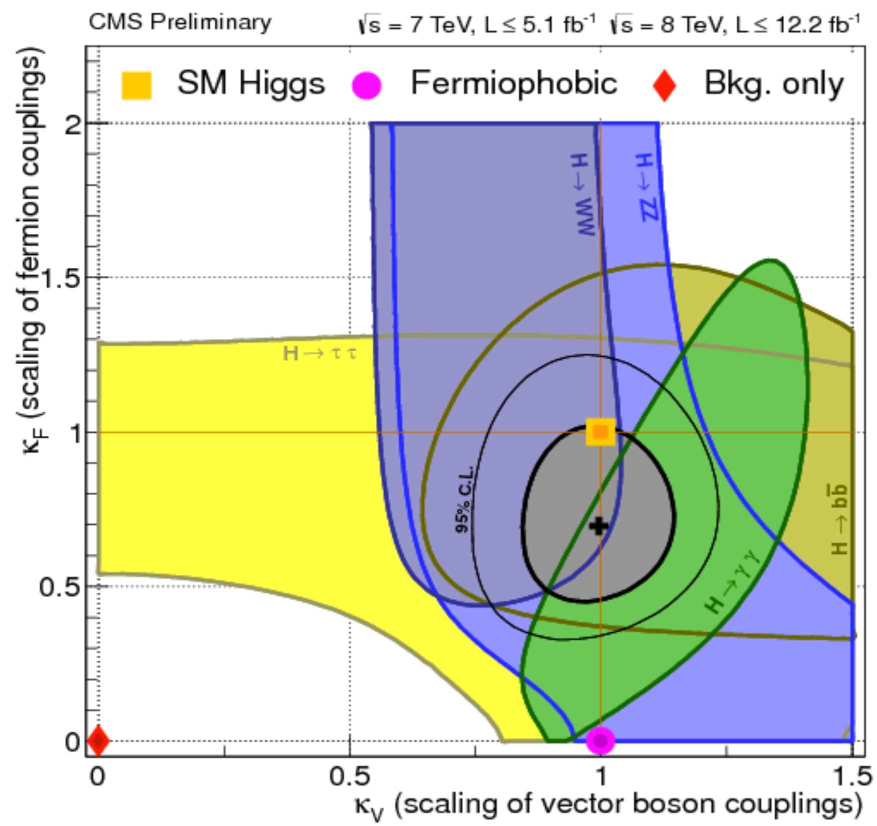
Custodial symmetry & Coupling to fermions

- Couplings to W and Z boson should scale together: cornerstone of electroweak Symmetry Breaking
- Parameterization: κ_F, κ_Z, $\lambda_{WZ}=\kappa_W/\kappa_Z$



→ λ_{WZ} in [0.57-1.65] at 95% CL
→ Result well consistent with theory

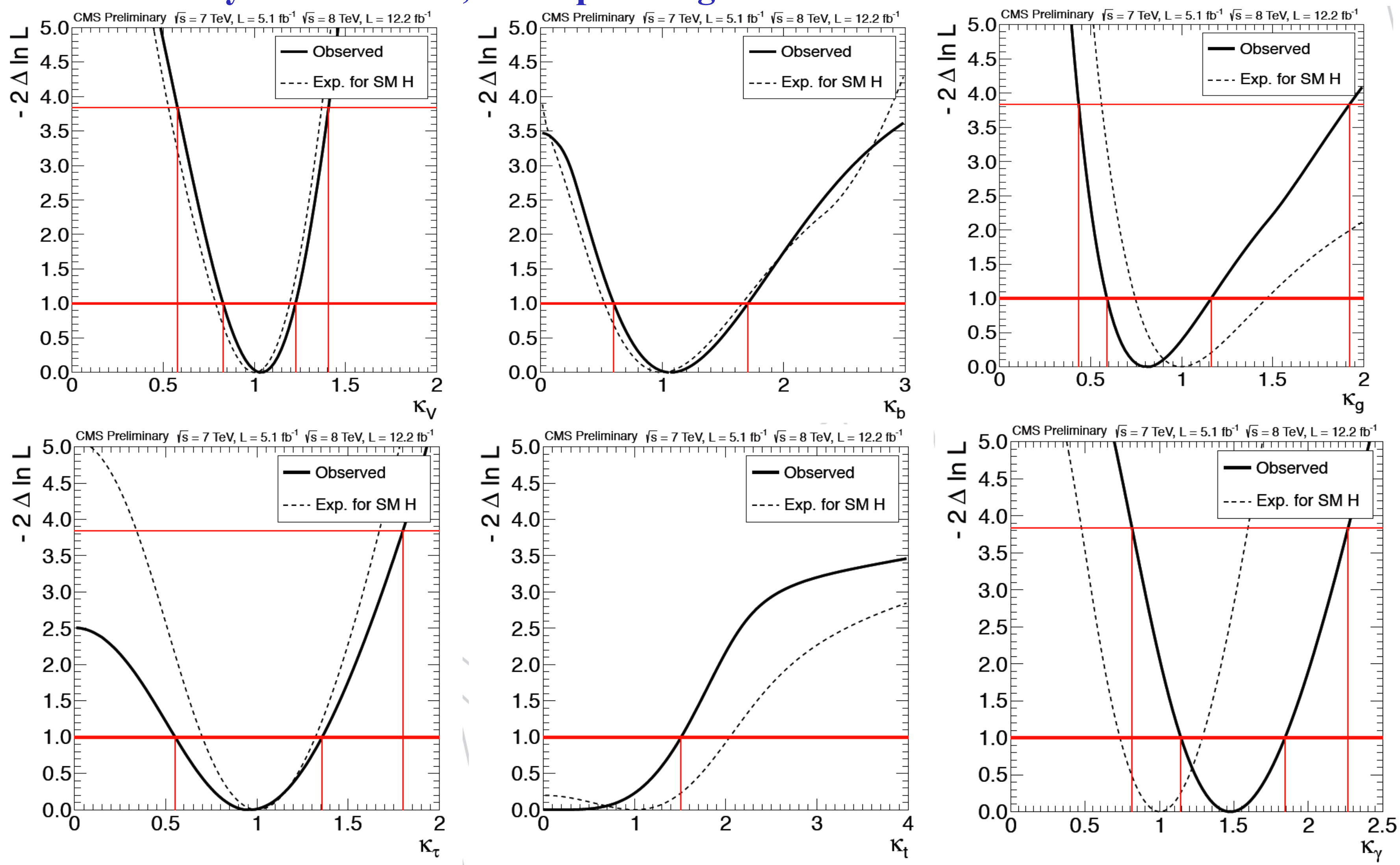
- Fermions versus vector bosons



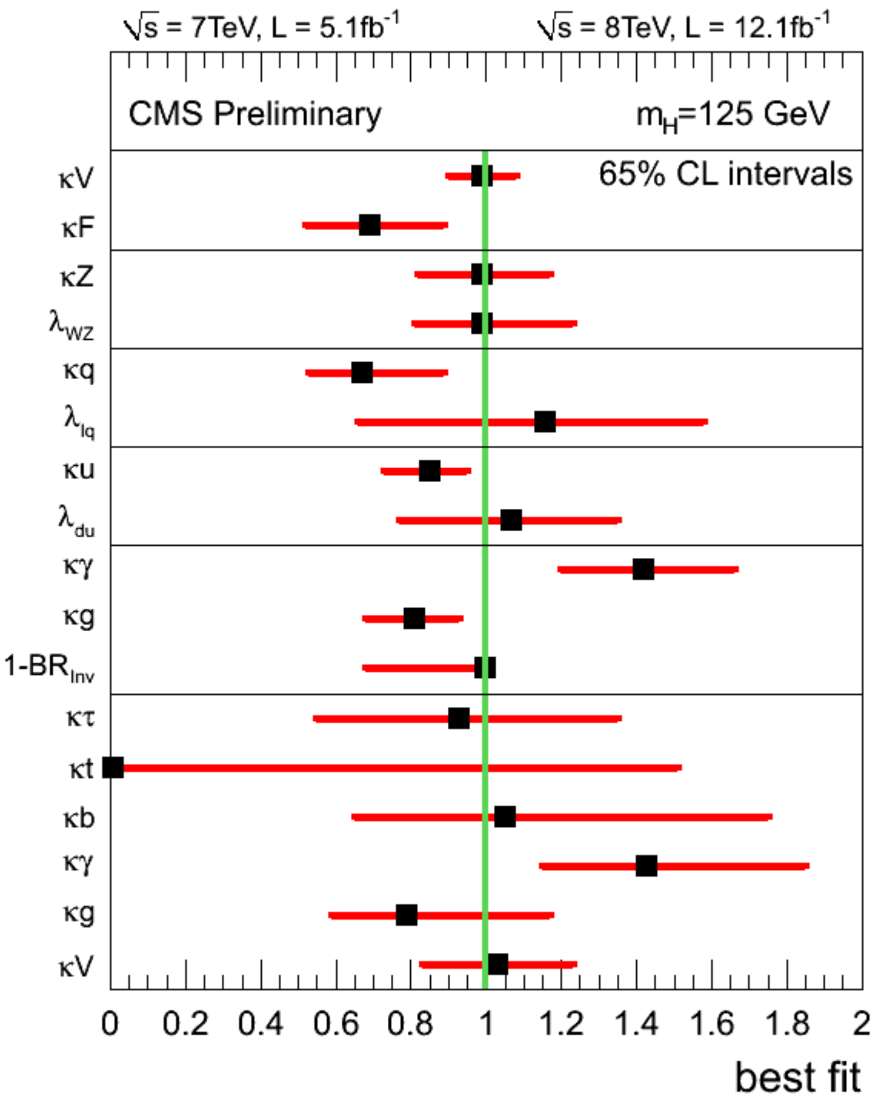
→ Couplings consistent within 1σ with SM Higgs
→ Fermiophobic scenario exclude at >4σ level

Individual couplings

- Assess individual couplings assuming only custodial symmetry and without resolving the loops structure
- End up with 6 scale factors: κ_V, κ_t, κ_b, κ_τ, κ_g, κ_γ
- Fit individually each of those, while profiling the others



Coupling summary



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]

→ **Overall compatibility with SM predictions**
→ **Still limited precision**

CONCLUSIONS

- The analyses performed on the dataset delivered by the LHC till September 2012 strengthened the significance of the new bosonic state announced on July 4th.
  - → Over 4σ in both $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ$
  - → 3.1σ evidence in $H \rightarrow WW \rightarrow 2l2\nu$ (@ 125 GeV)
  - → Mild excess in $H \rightarrow \tau\tau$ compatible with both SM Higgs and background
  - → 2.2σ excess in $H \rightarrow bb$

- $M_X = 125.8 \pm 0.4$ (stat) ± 0.4 (sys) GeV

- Best fit value for $\sigma/\sigma_{SM} = 0.88 \pm 0.21$

- 2.5 standard deviations disfavoring particle to be pseudo-scalar

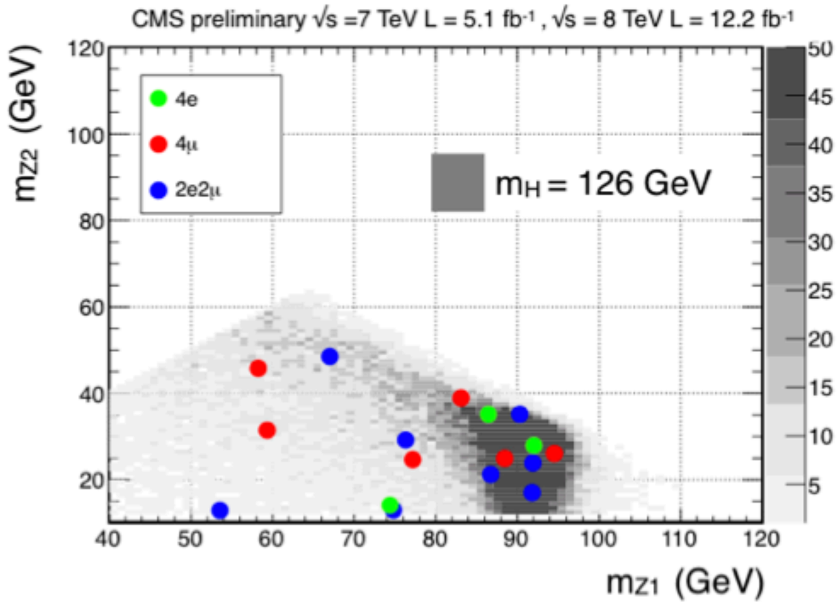
- The coupling structure has been confronted to the SM predictions.
  - → Overall very good agreement observed but too early to draw any conclusions although most couplings are within 1σ of SM

→ Everything still compatible with SM expectations
→ Stay tuned, winter conferences will include more data

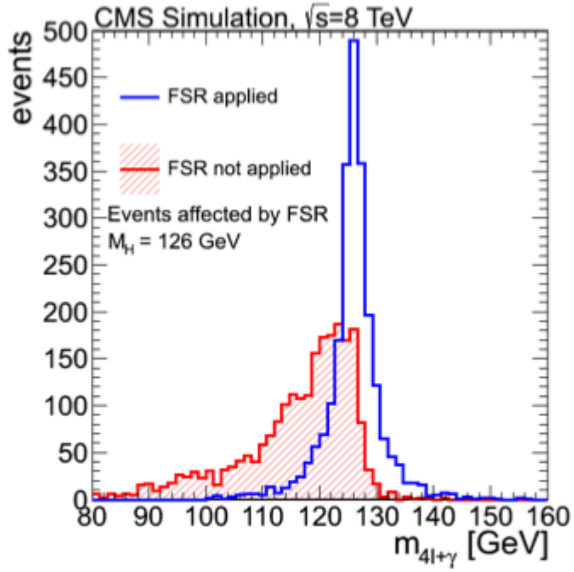
BACKUP

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

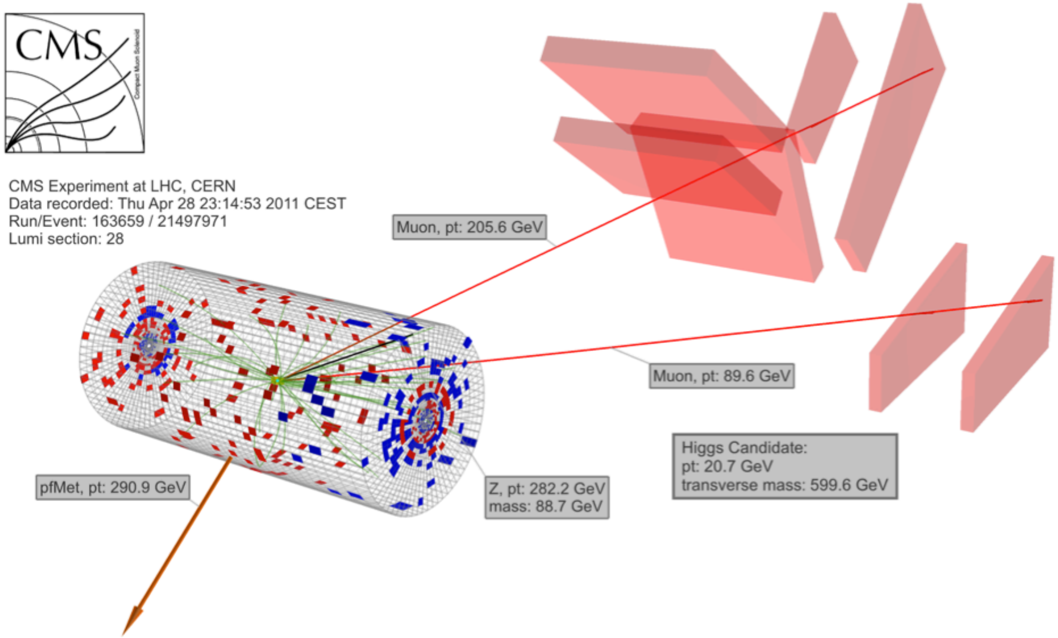


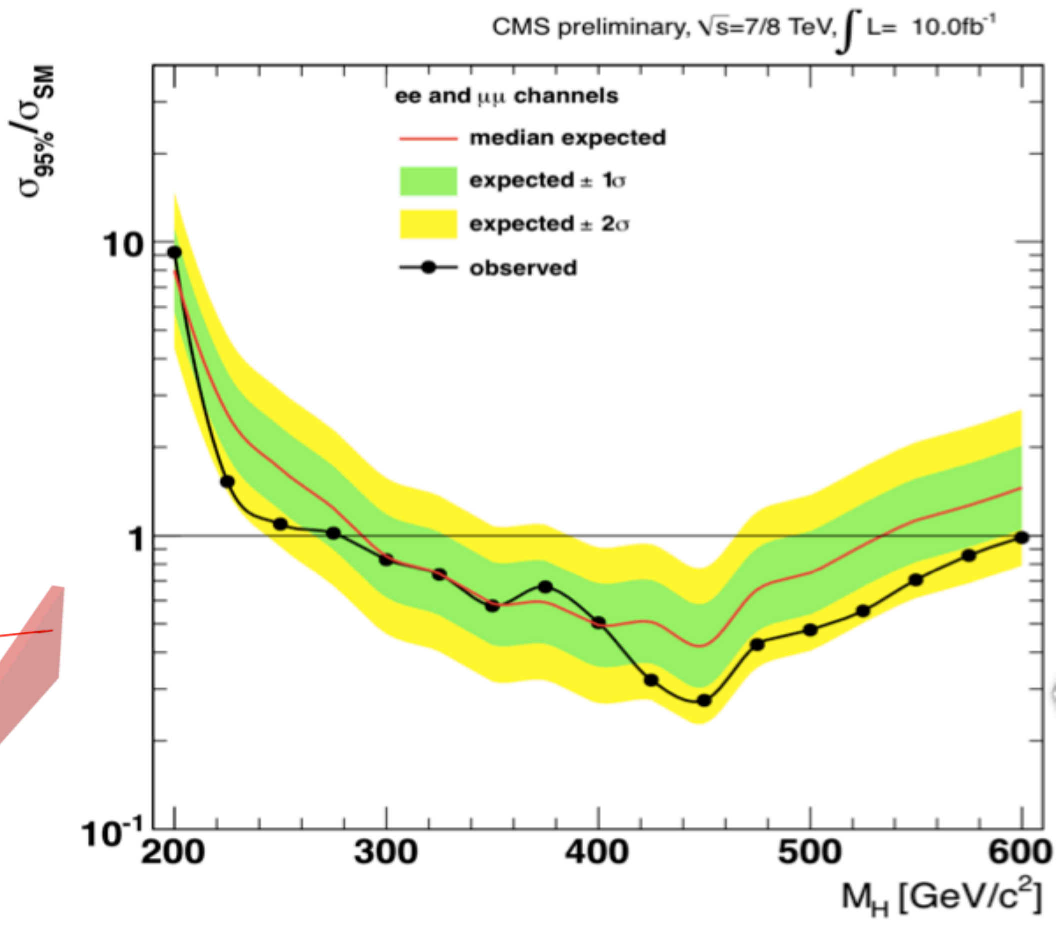
- Note on FSR photon:
  - accept if dR(l,γ)<0.07 PT>2 GeV
    OR: dR(l,γ)<0.5 PT>4 GeV plus isolated
    Condition: |m(llγ)-mZ⁰|<|m(ll)-mZ⁰|
  - FSR expected in 6.8% events (observed: 6±2%)



H → ZZ → 2l2ν

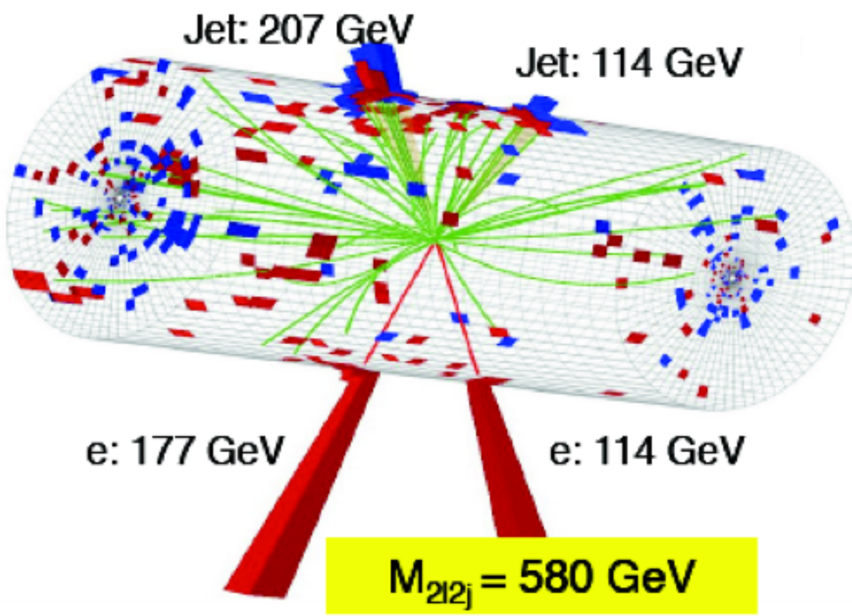
- Well isolated ee or μμ with invariant mass compatible with Z boson
- Missing E_T from escaping ν's
- Main bacground: Z+jets with fake missing ET → modelled from γ+jets events

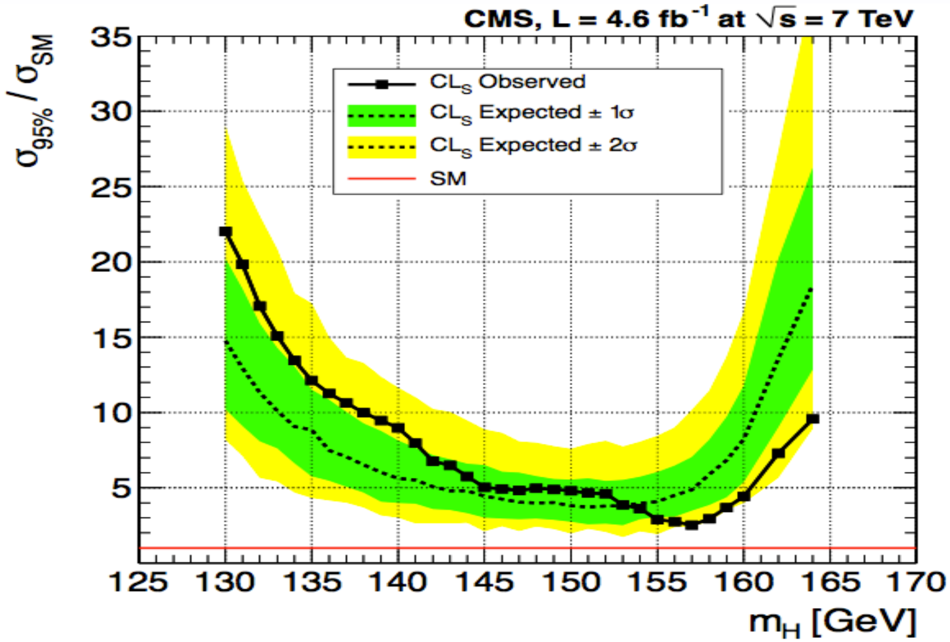


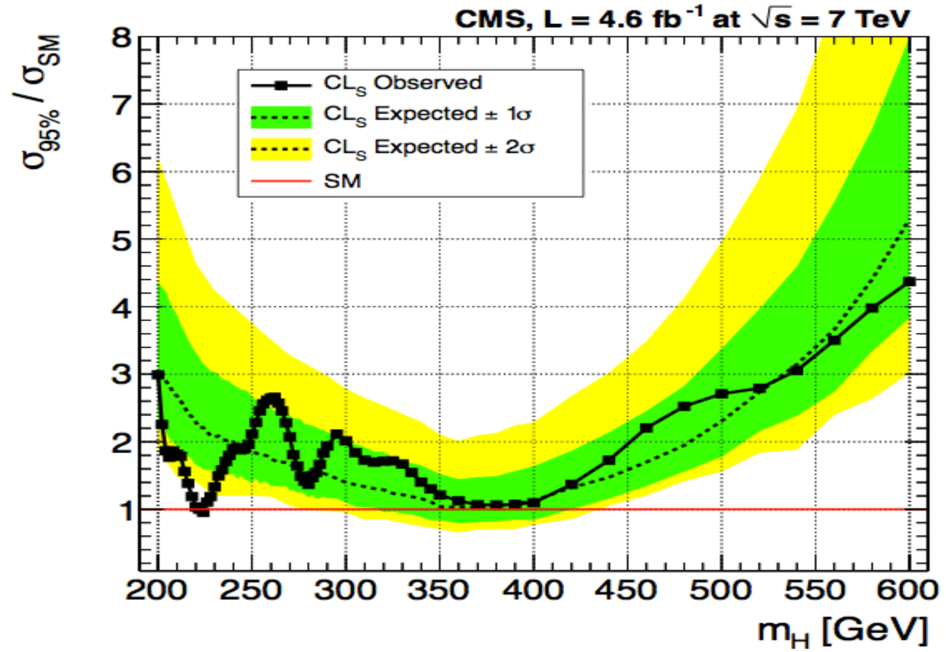


- No significant excess → Excluding SM Higgs for m_H in [228,600] GeV
- One of the most sensitive channel at high mass → looking forward for more luminosity and extending to 1 TeV mass range.

H → ZZ → 2l2j





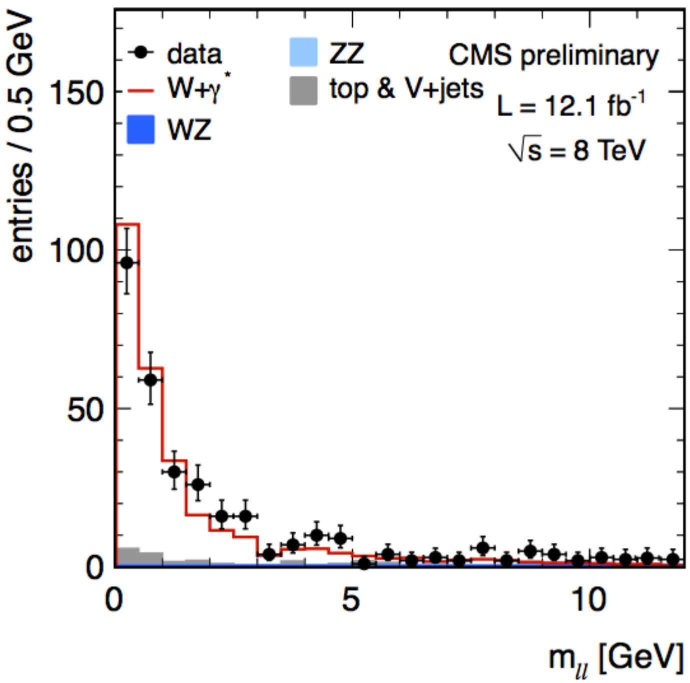


- **Since LP: Added low mass** in M_{2l2j} distribution
- Events categorized by presence of 0, 1, 2 b-jets
- Major background: Z+jets ; ttbar suppressed by ME_T significance requirement
- Use 5 angles of scalar H → ZZ → 2l 2q in an angular likelihood discriminant
- Quark-gluon discriminant to reject Z +jets
- Background shape, normalization ← data sideband

$H \rightarrow WW \rightarrow 2l2\nu$: Backgrounds

Predictions taken from MC:

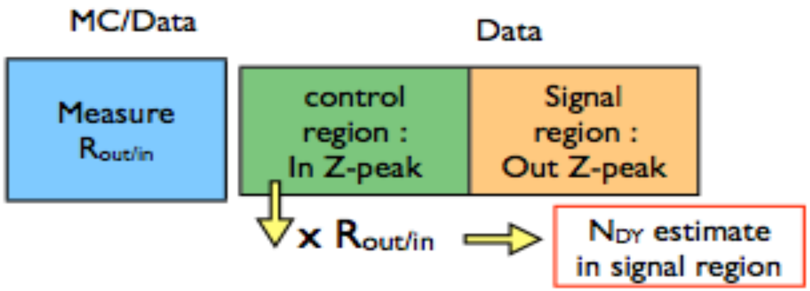
- ❑ $W\gamma$ and $Z\gamma$
- ❑ $W\gamma^*$ (CMS: 1.6+-0.3 normalization from 3 lepton events)

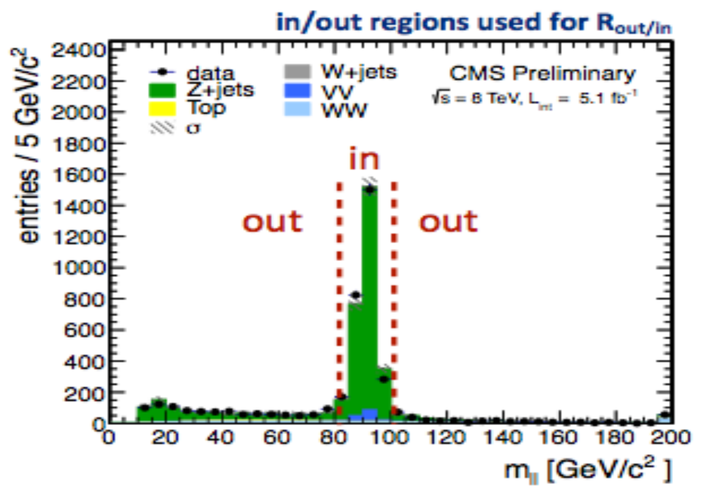


- ❑ Di-bosons: ZZ, WZ

Drell-Yan in Same Flavour (ee/μμ):

Estimate contribution from Z peak control region:





W+Jets:

- ❑ Propagate fake lepton ID rate from di-jet sample with looser lepton selection
- ❑ Cross-check in same-sign events
- ❑ Large uncertainties: 36%

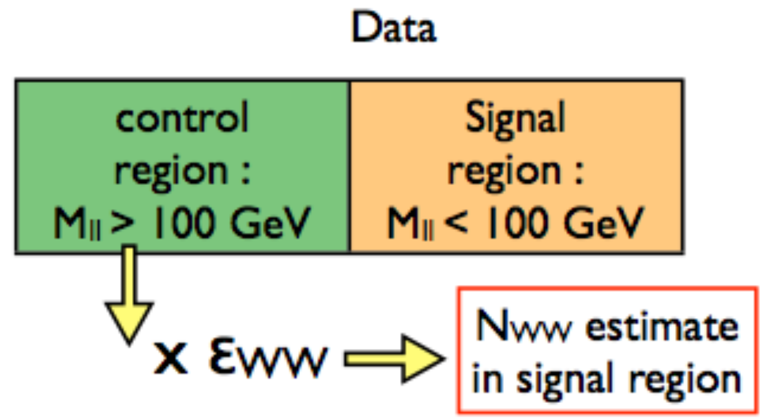
DY->ττ in Different Flavour (eμ):

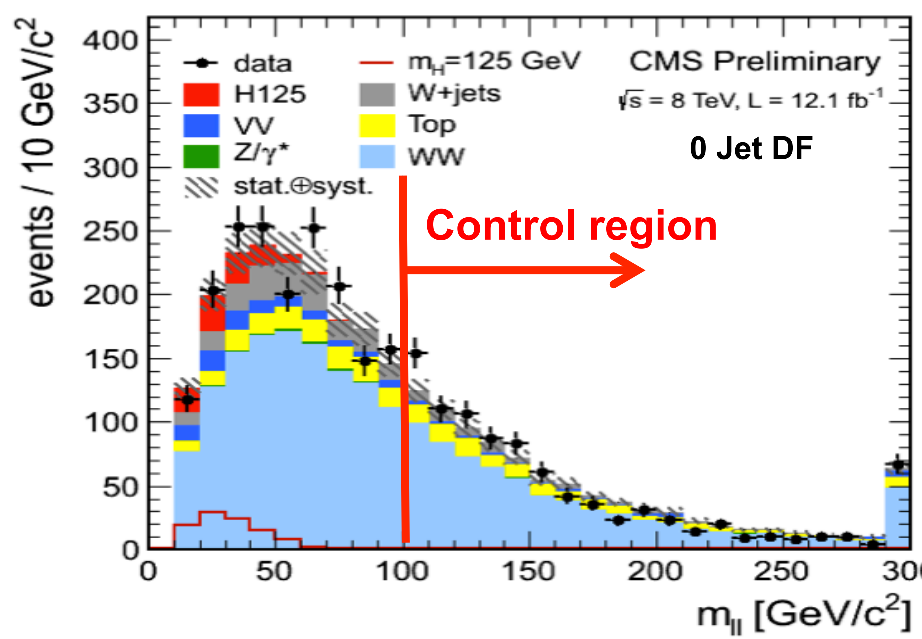
Use Z→ll (l=2,μ) events and replace by τ decayed via Tauola package

H → WW → 2l2ν : Backgrounds

Non resonant WW:

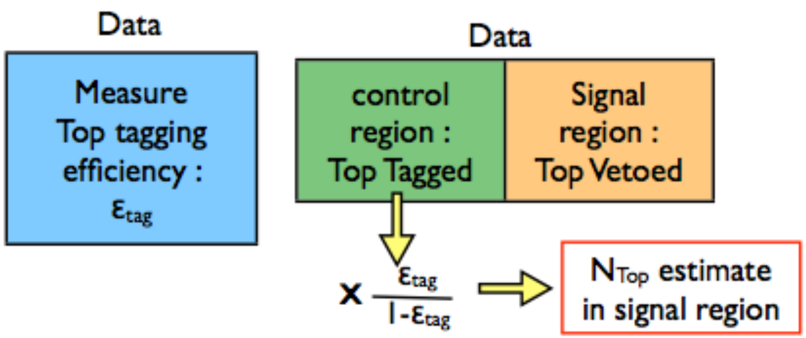
- For low mass Higgs, normalize WW from high lepton invariant mass region in data:





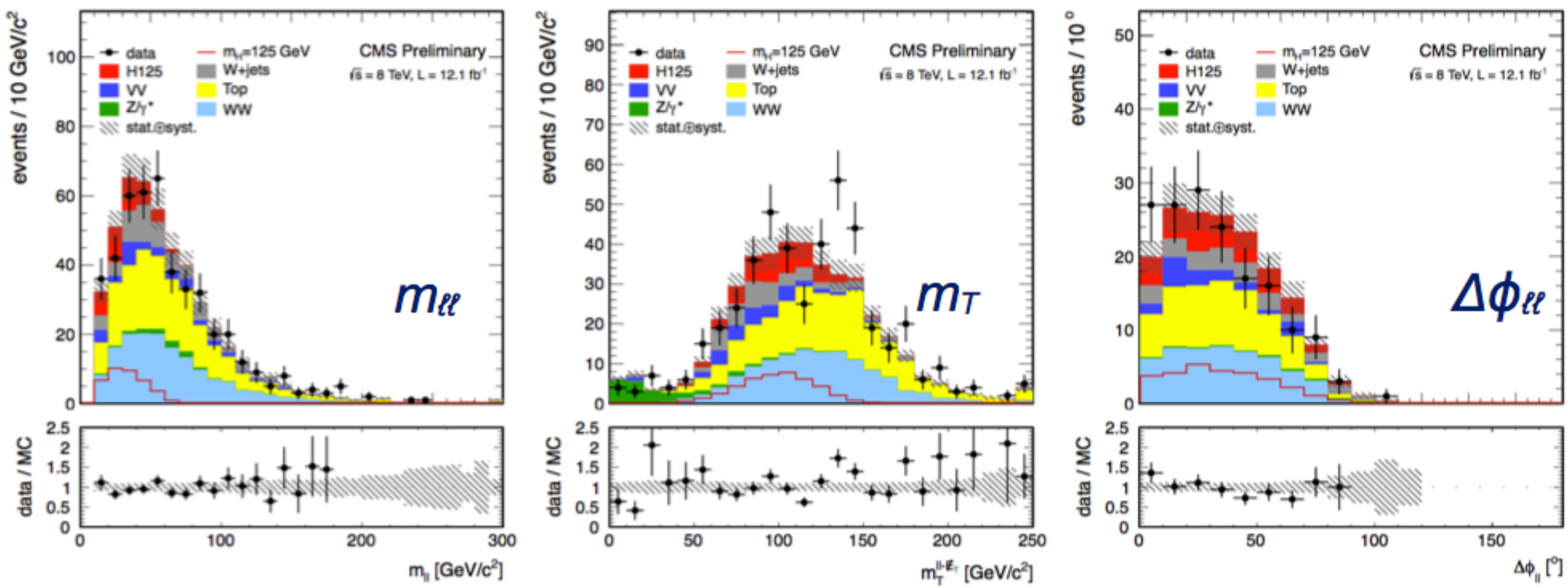
Top (tt & tW):

- 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:

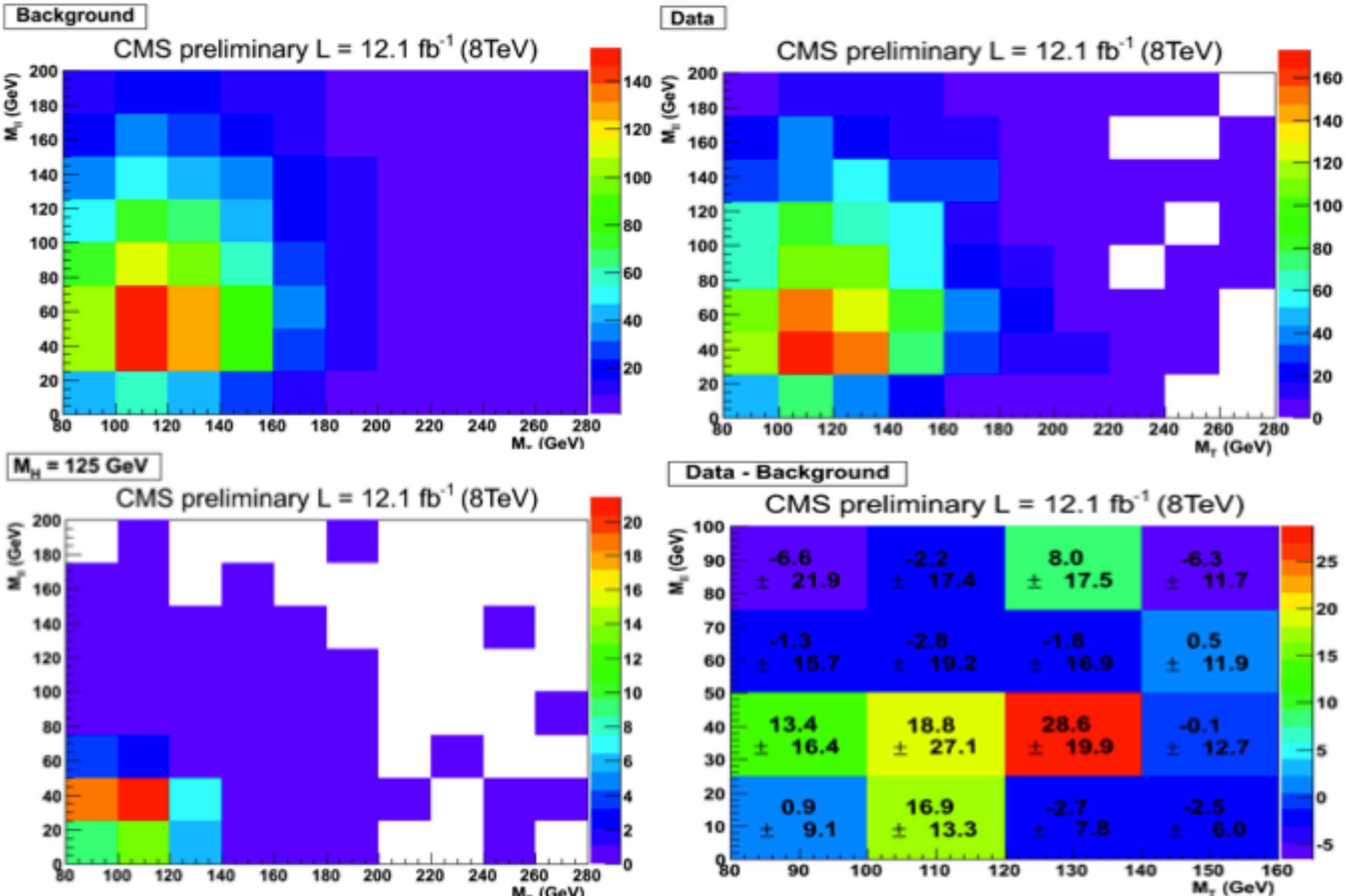


H → WW →2l2ν : CMS Cut&Count (1 jet DF)

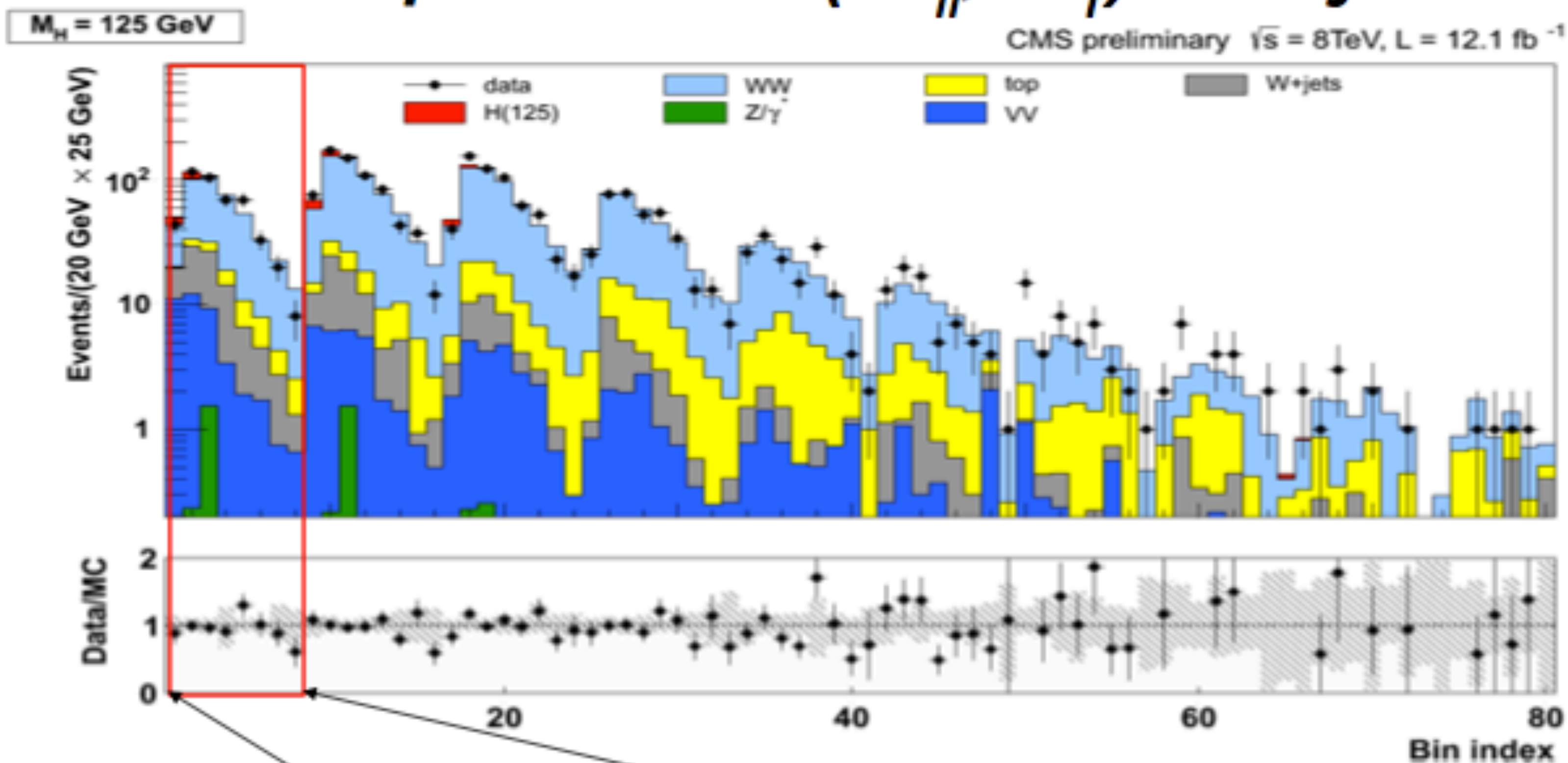
m_H	$H \to W^+W^-$	$pp \to W^+W^-$	$WZ+ZZ$ $+Z/\gamma^* \to \ell^+\ell^-$	Top	W + jets	$W\gamma^{(*)}$	all bkg.	data
1-jet category $e\mu$ final state								
120	14.9 ± 4.3	38.9 ± 6.4	5.3 ± 0.6	40.3 ± 3.0	19.1 ± 7.4	7.1 ± 3.4	111 ± 11	123
125	27.3 ± 8.0	47.9 ± 7.8	6.5 ± 0.7	49.5 ± 3.3	22.4 ± 8.6	7.1 ± 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

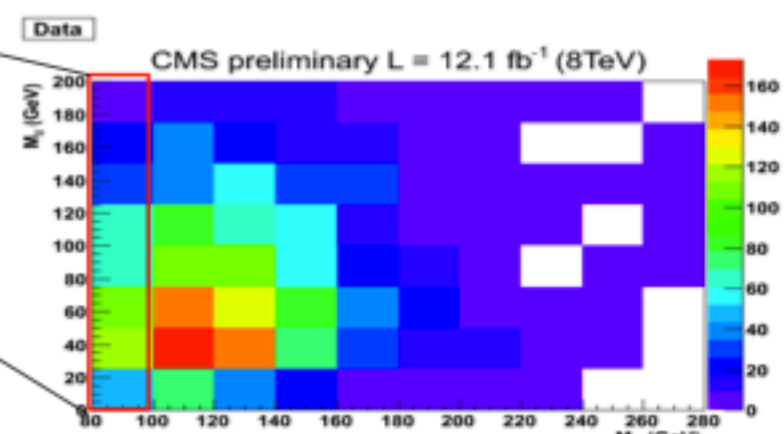


New Shape Analysis – Ex. DF 0-jet



Shape – 2 D (m_{ll}, m_T) – 0 jet

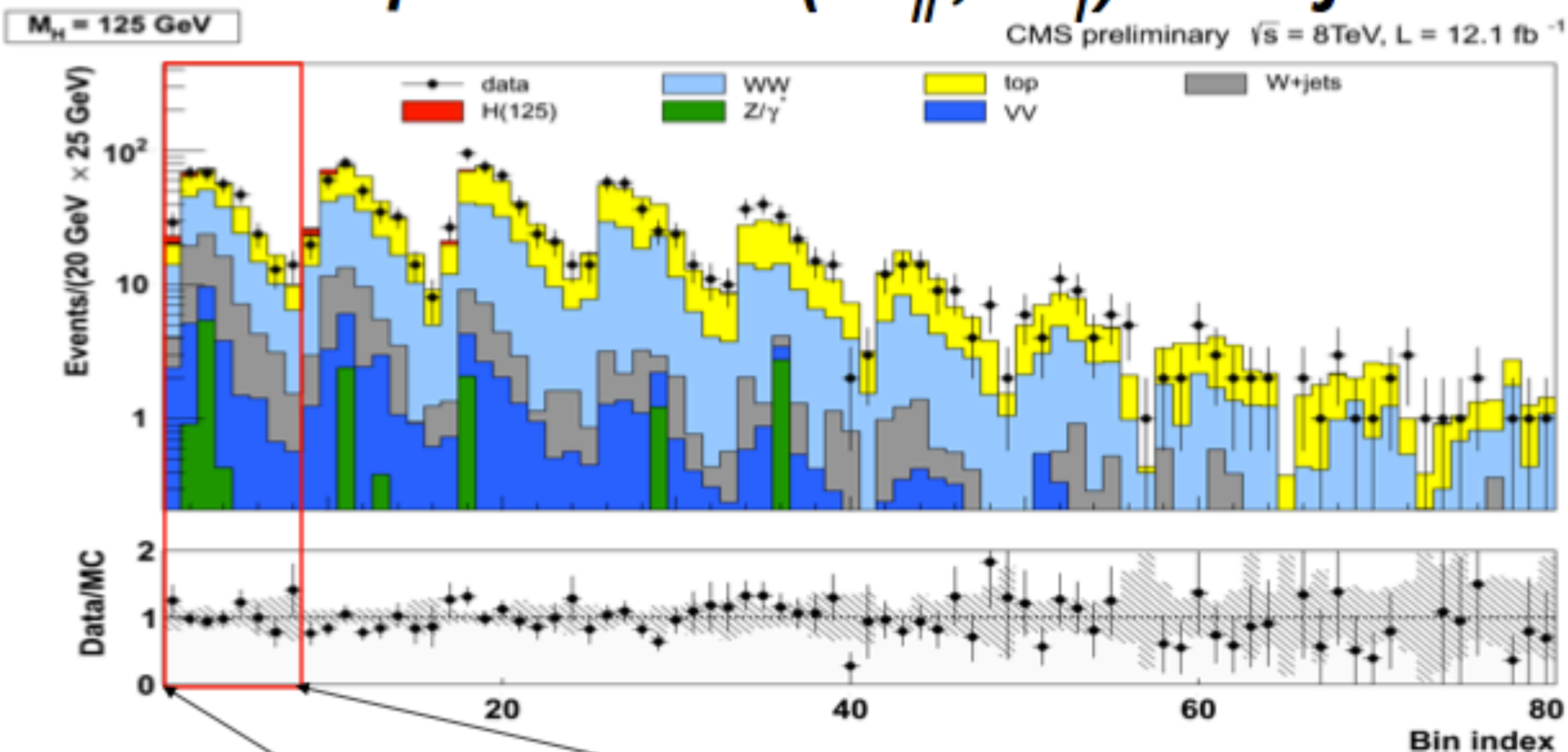


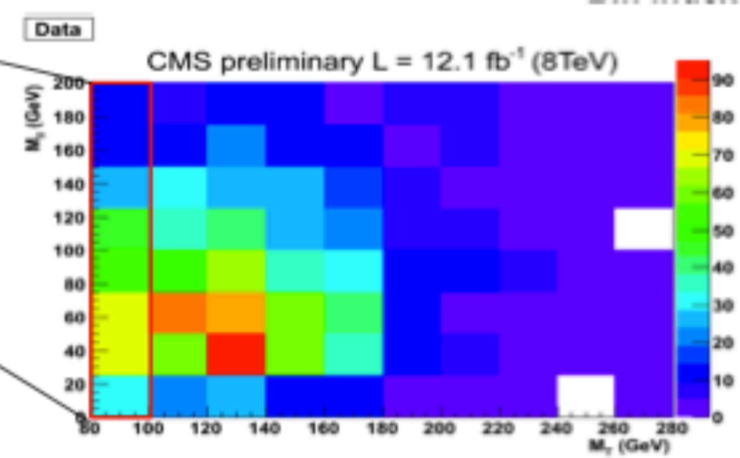


Unrolling 2D distributions

– quantitative comparison

Shape – 2 D (m_{ll}, m_T) – 1 jet



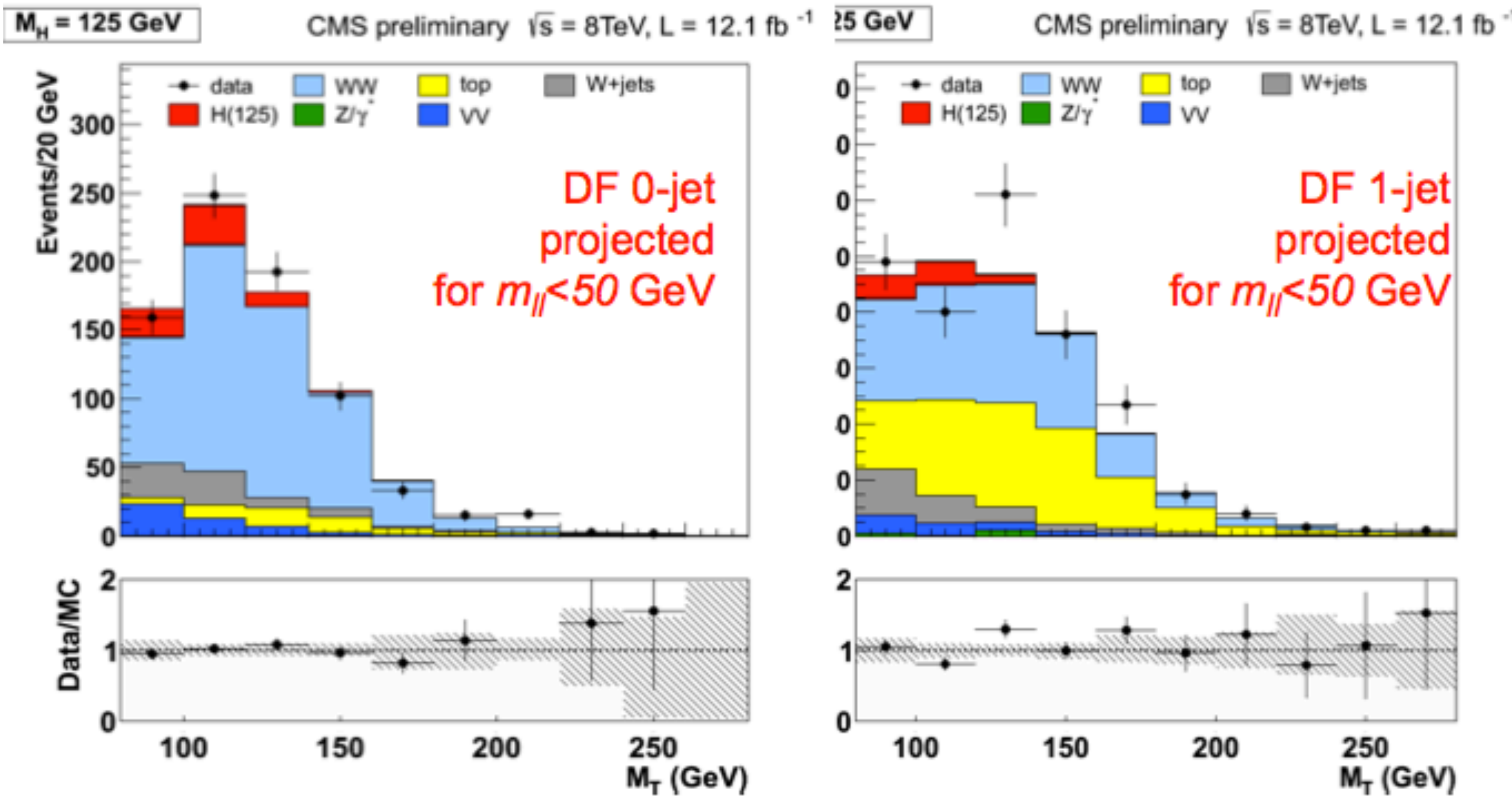


Unrolling 2D distributions

– quantitative comparison

30

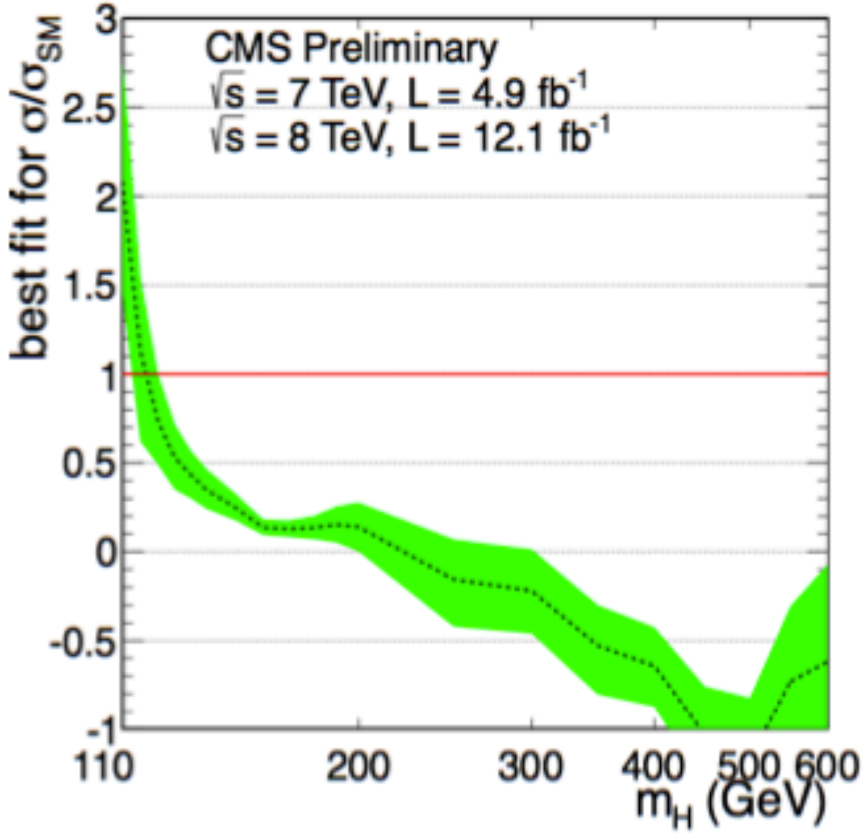
Shape – 2 D (m_{ll},m_T) projected

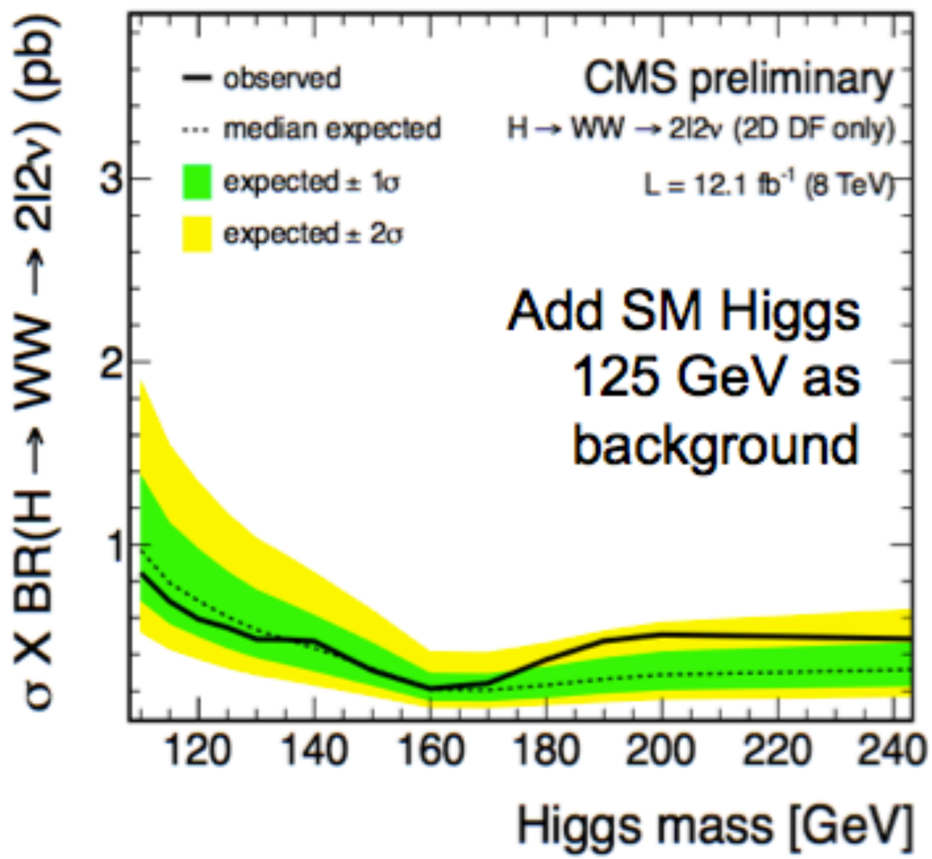


Projected the signal is better visible

– clear enhancement in data where signal is predicted

Signal Strength



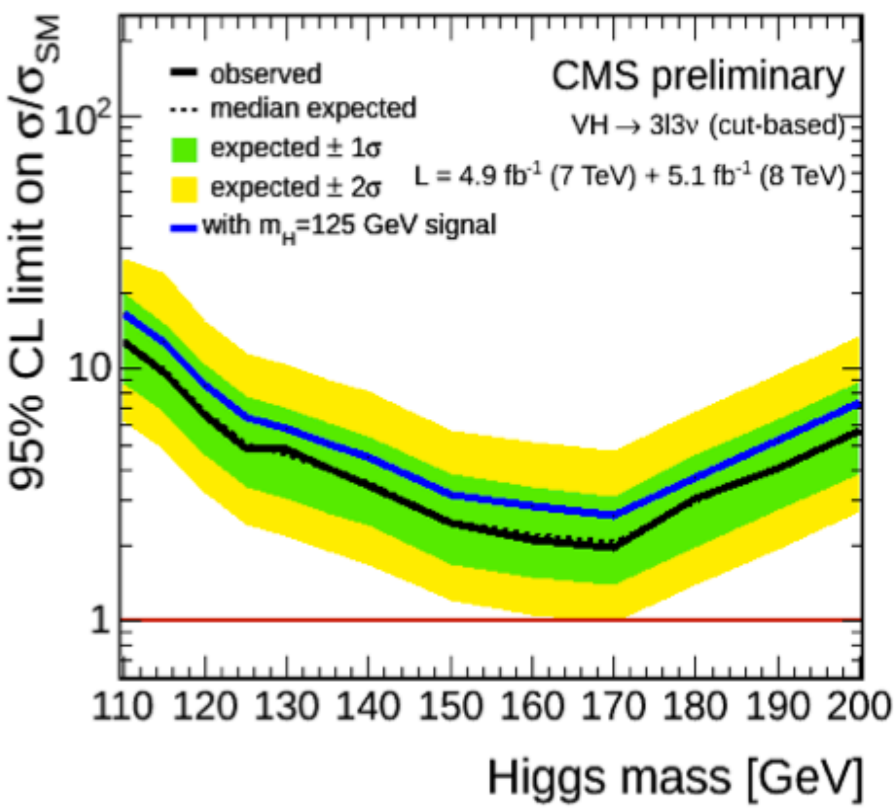


Steeply falling signal strength versus mass

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

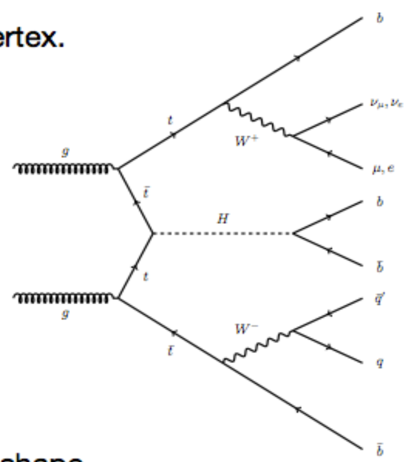
WH → WWW → 3l3ν

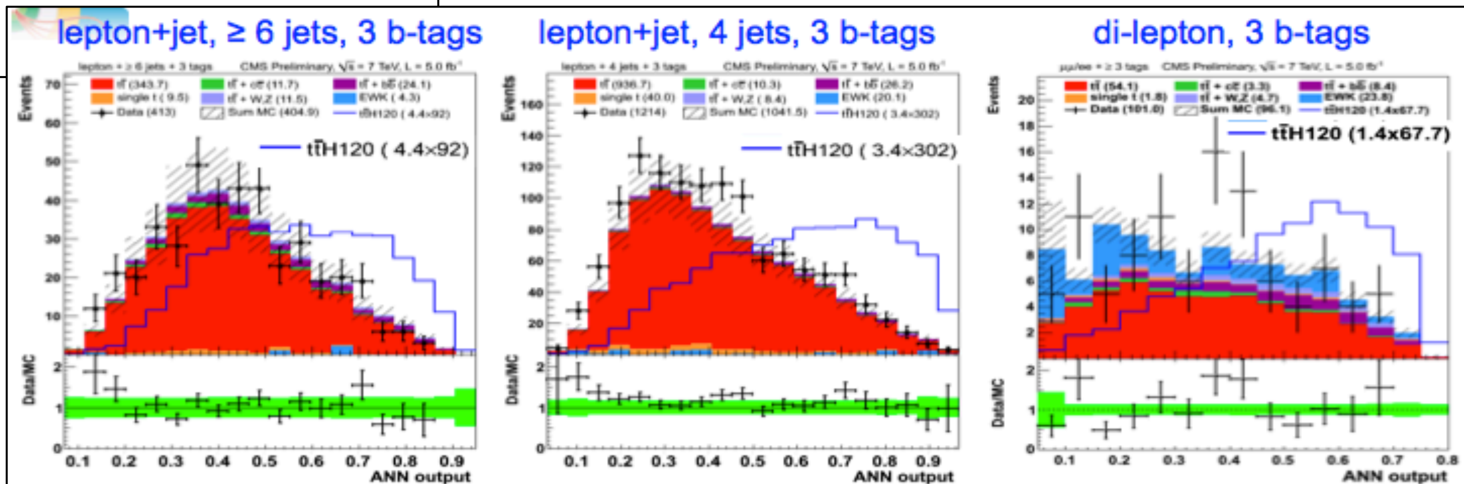
- $\sigma(WH_{SM}(m_H{=}125))$~0.7 pb, drops rapidly
- Analysis based on ICHEP dataset (10 fb^{-1})
- Cut-and-count, optimize for M_H = 125 GeV
- Include WH→ττ in the signal
- Apply many of the same techniques as 2l2ν
- Good agreement between data and background prediction
- Upper limits calculated on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

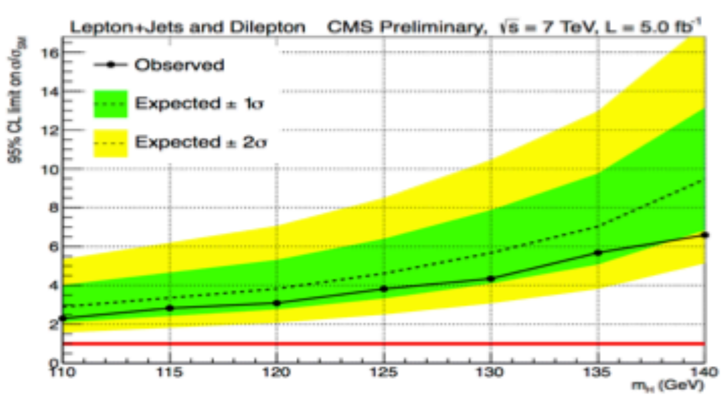


ttH , H→bb

- Main opportunity to directly probe the ttH vertex.
- Categorisation
  - di-lepton and lepton+jet
  - number of jets and b-tags
- Trigger: Isolated lepton
- Main background from top pair (+jets)
- Signal extraction
  - Simultaneous fit of neural network (ANN) shape.
  - Main inputs to ANN: b-tag, kinematic and angular correlations.
- Data: 5.0 fb^{-1} at 7 TeV



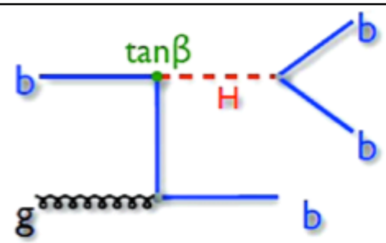




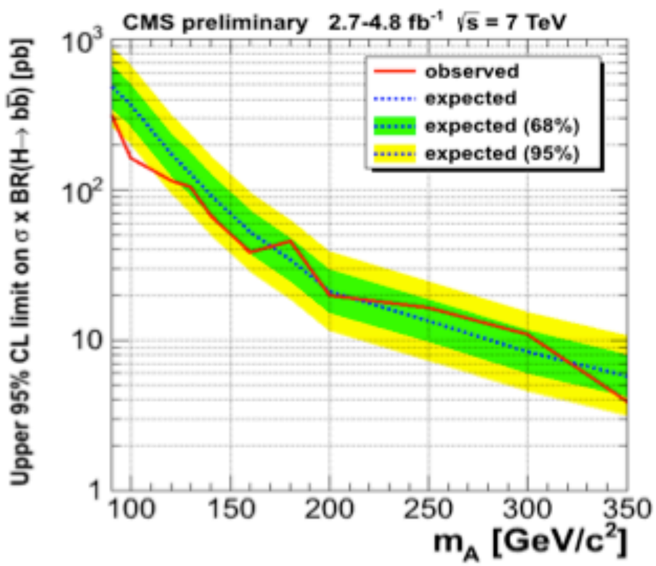
- Lepton+jet channel is the most sensitive, di-lepton improves 5-10%.
- No evidence of an excess: exp(obs) 95%CL limit on σ/σ_{SM} at $m_H(125)$ = 4.6 (3.8)

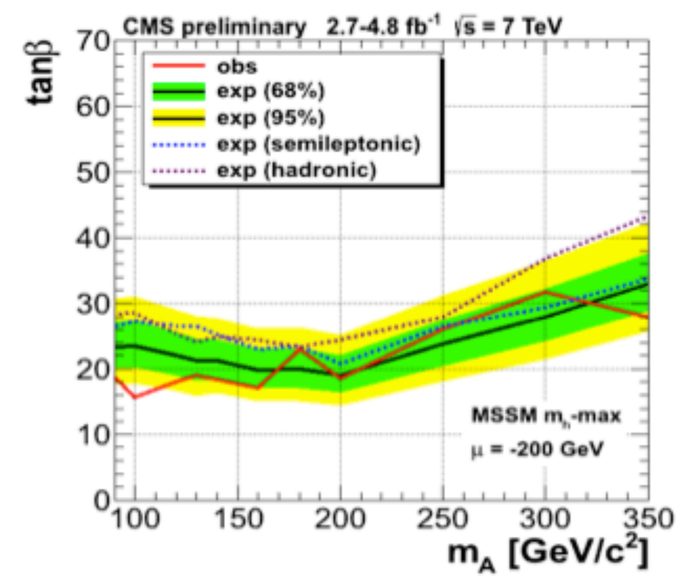
MSSM H→bb

- MSSM neutral Higgs boson produced in association with b quark(s)
- Two analyses:
  - All-hadronic (CMS PAS-HIG-12-026)
  - Semi-leptonic (CMS PAS-HIG-12-027)
- Triggers: jets + b-tagging (+ muon)
- Event selection; ≥ 3 jets + 3 leading jets b-tagged (+ ≥ 1 muon)
- Data: 2.7 fb^{-1} – 4.8 fb^{-1} at 7 TeV
- Background: heavy flavour multi-jet
  - Derived from the data.



- Combination of both analyses (new for HCP12):
  - All-hadronic and semi-leptonic analysis are almost orthogonal, 2-3% overlap.
  - Set upper limits at the 95% CL on σ(pp→bΦ)×BR(Φ→bb).
  - Exclude large tanβ region at the 95% CL in the MSSM parameter space (m_h-max scenario)



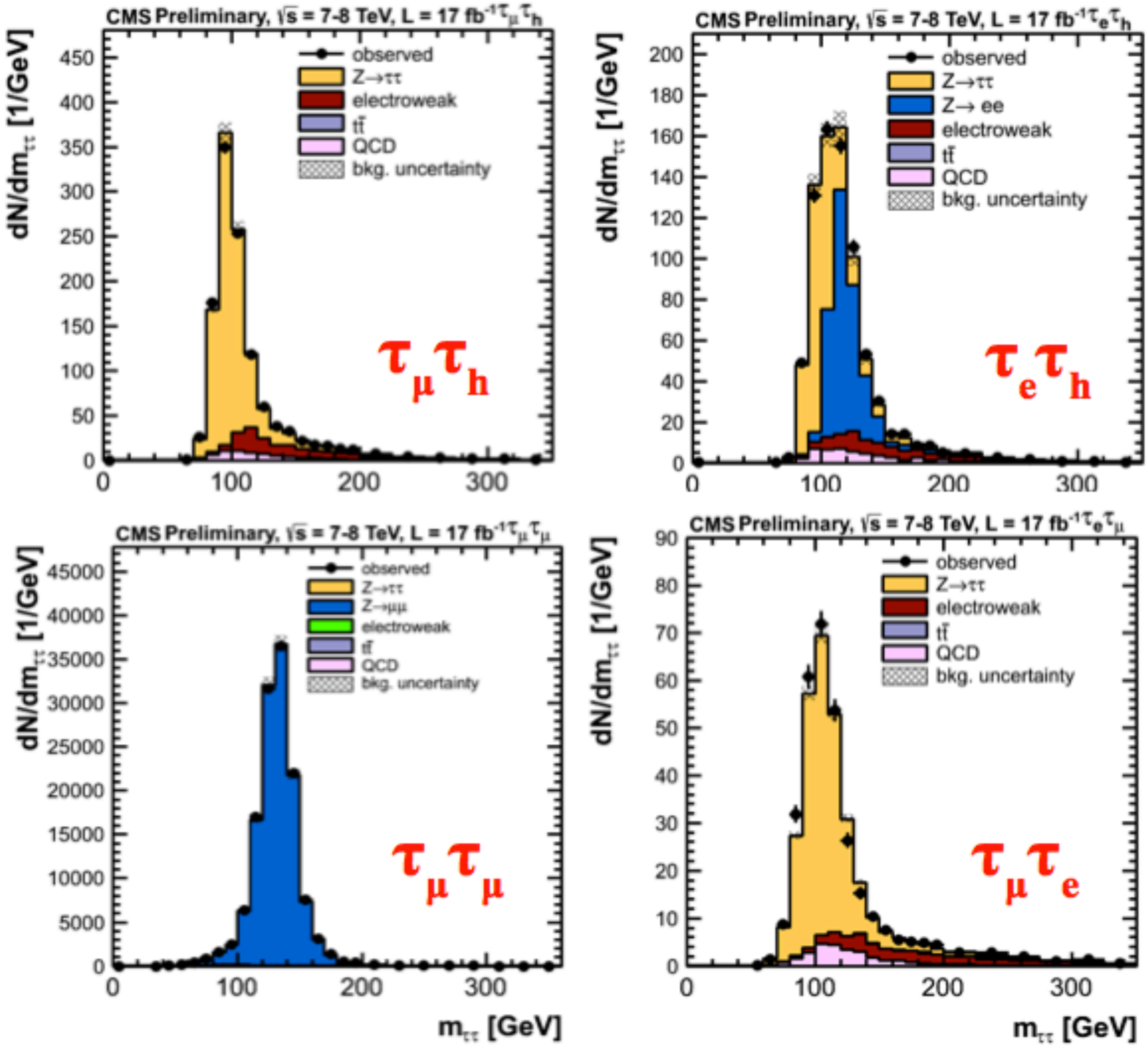


- Tevatron 2σ excess at low mass not confirmed.

H→ττ: 0-jet Category (low+high p_T)

Summary

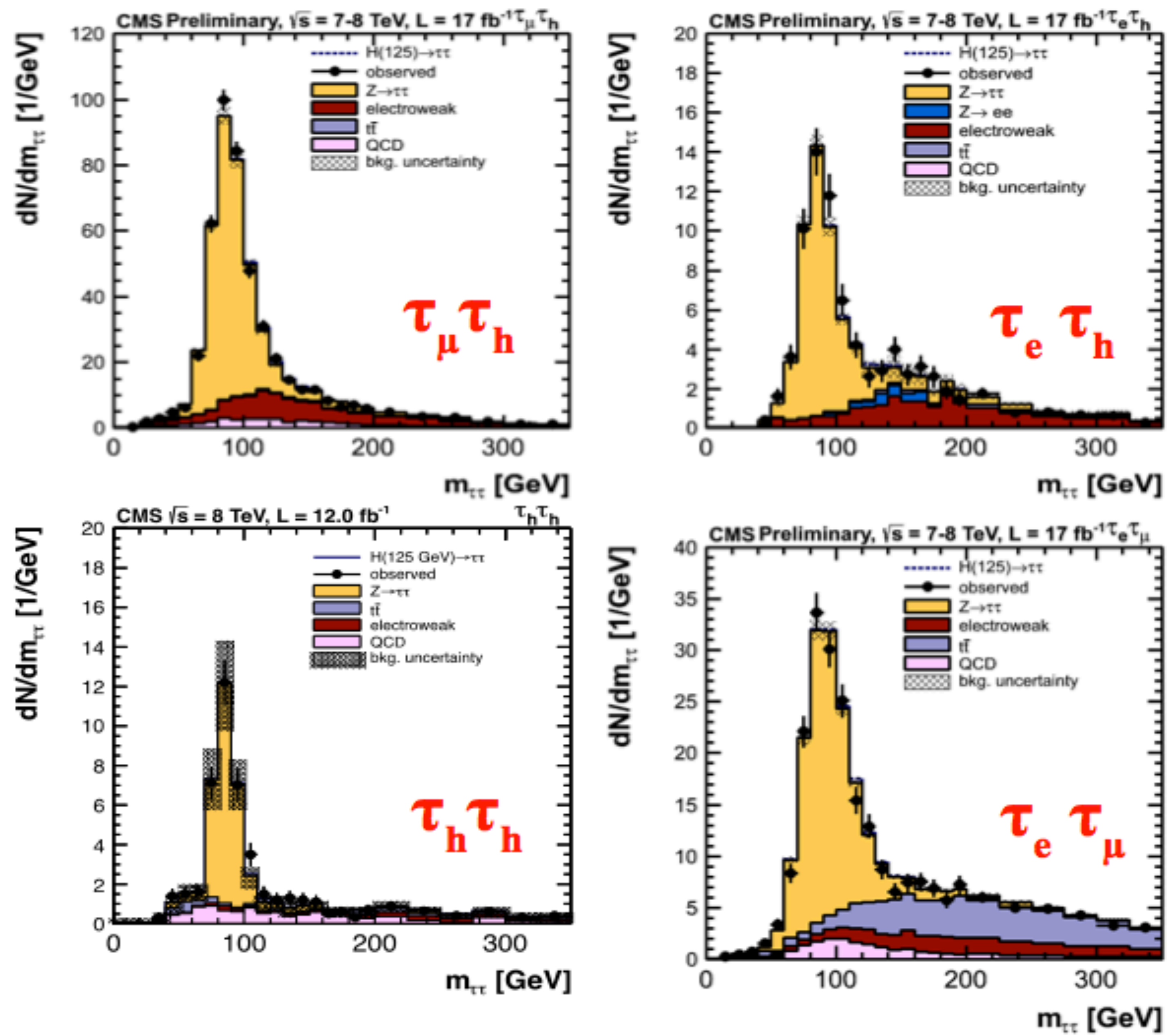
- most events go here
- minimal signal
- background fit only
- constrains background for all categories



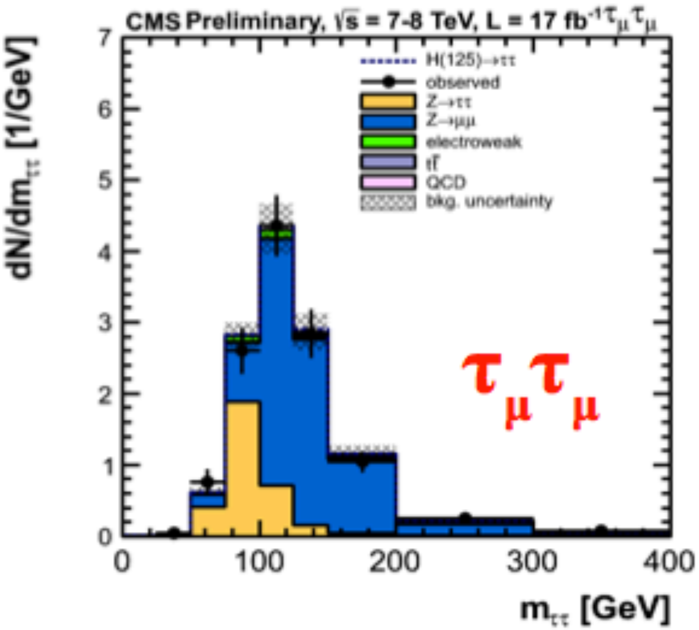
$H \rightarrow \tau\tau$: 1-jet Category (low+high p_T)

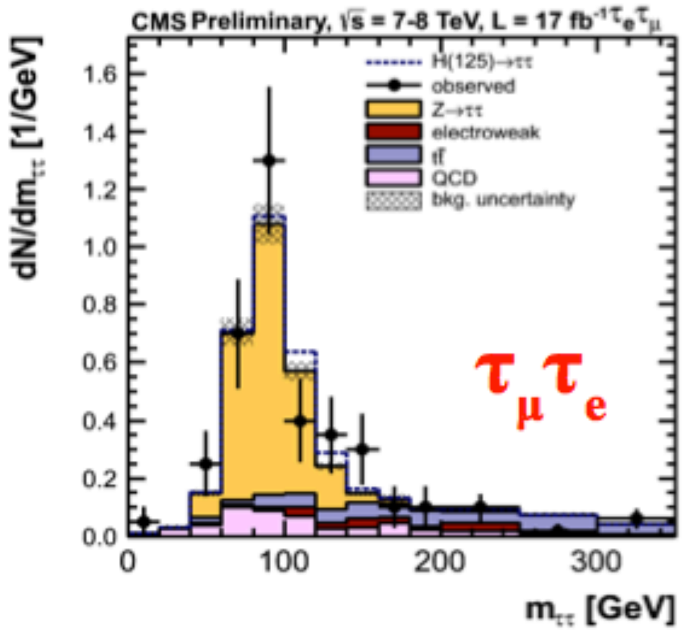
Summary

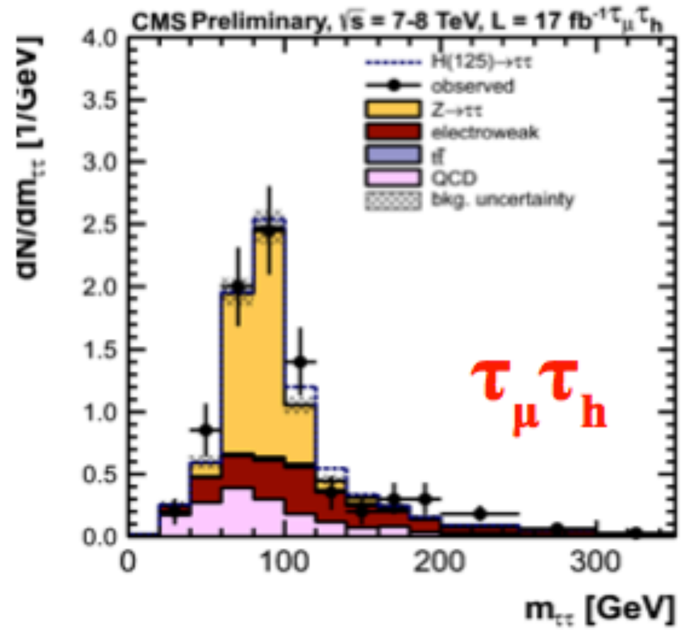
- enhanced gluon fusion production
- Improved mass resolution

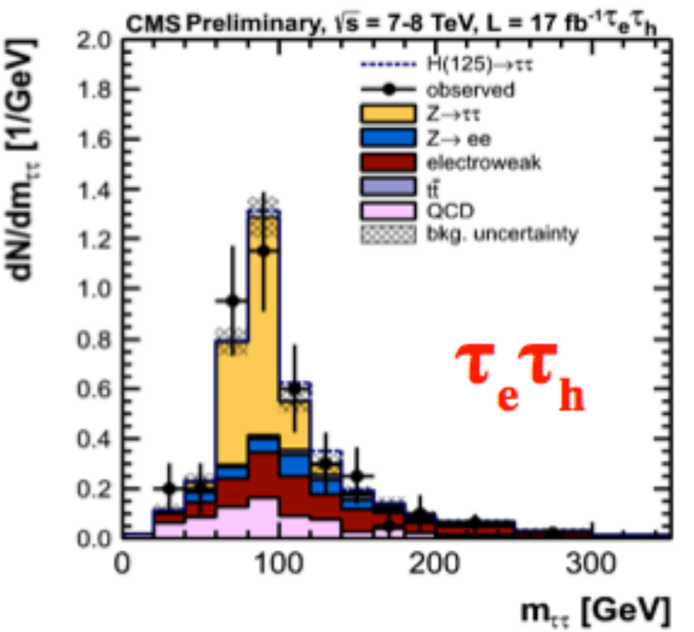


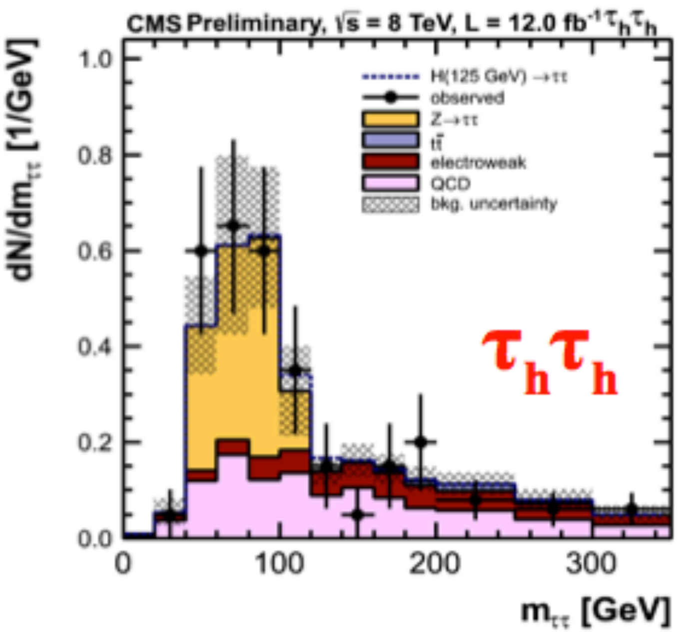
H→ττ: VBF Category











Summary

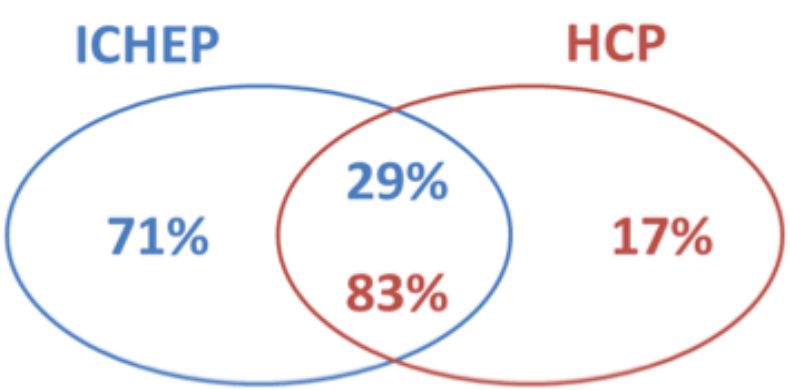
- enhanced VBF production
- shaded bands are uncert. after fit

H → ττ

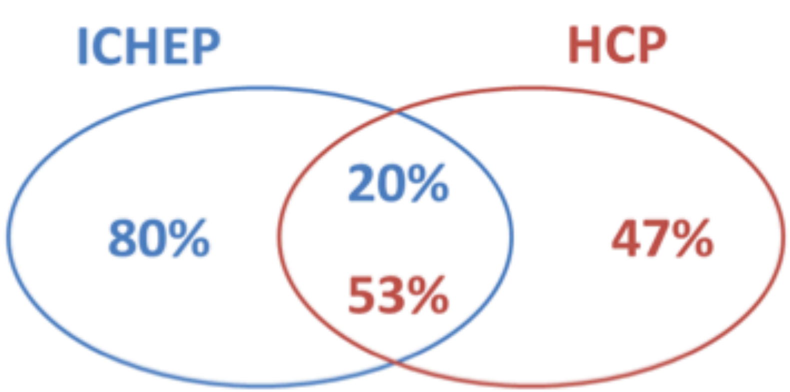
Compatibility of Results with ICHEP Results (1)

- Low observed in ICHEP analysis was driven by VBF category.
- Three major changes since ICHEP:
  - Re-reconstruction of 2012 dataset improved description of forward jet response.
  - Significantly improved $\not{E}_T$ resolution (changes events themselves).
  - Simplification of VBF selection (unification across all Higgs decay channels, stricter selection than before).

Event overlap in VBF in **2011**



Event overlap in VBF in **2012**



Compatibility of Results with ICHEP Results (2)

- Event overlap small: treat limits as independent.
- Estimated statistical compatibility of the two observed results: ~12% corresponding to 1.6σ.
- Sensitivity of the analyses at 125 GeV:

	ICHEP	HCP
VBF only	2.04	1.93
comb	1.27	1.25