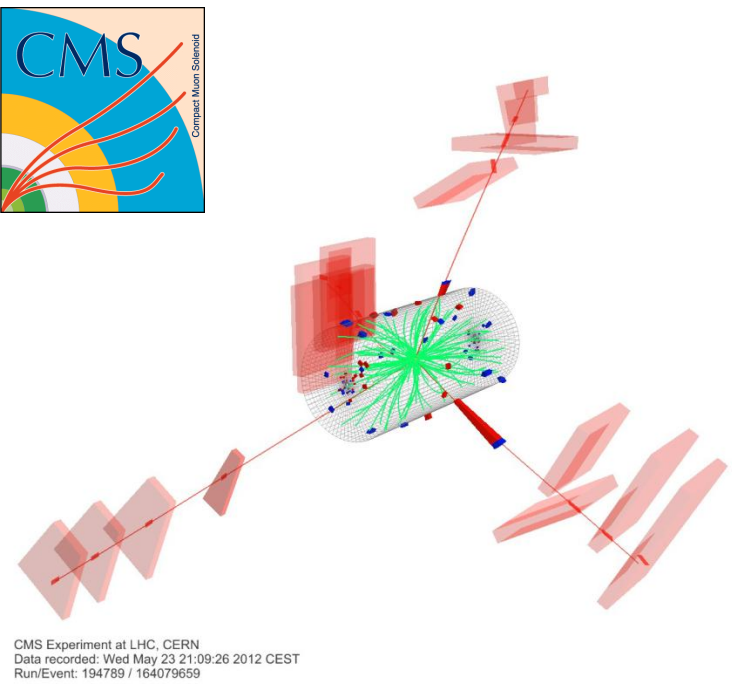
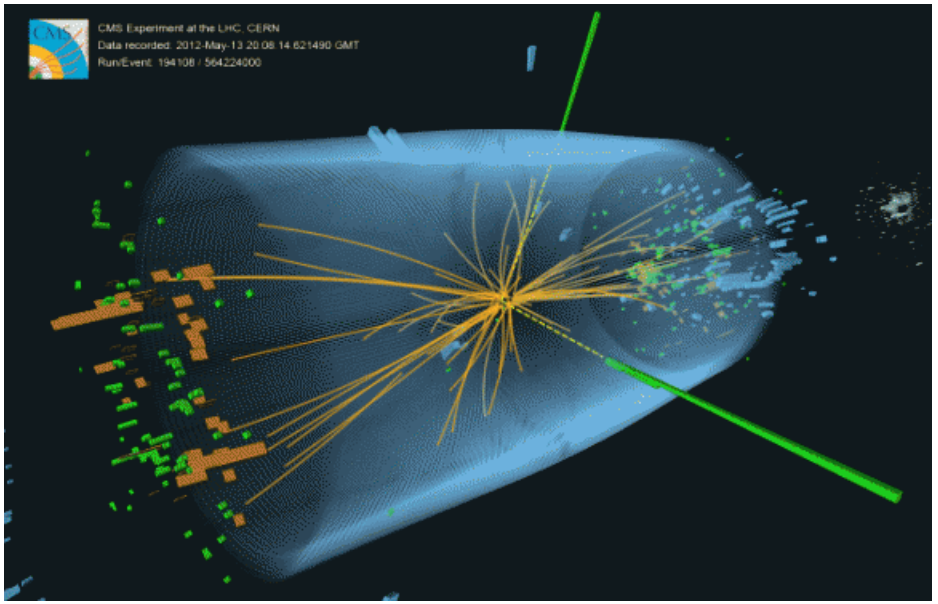




OVERVIEW OF HIGGS RESULTS FROM CMS

N. van Remortel

Universiteit Antwerpen, Belgium

On behalf of the CMS Collaboration

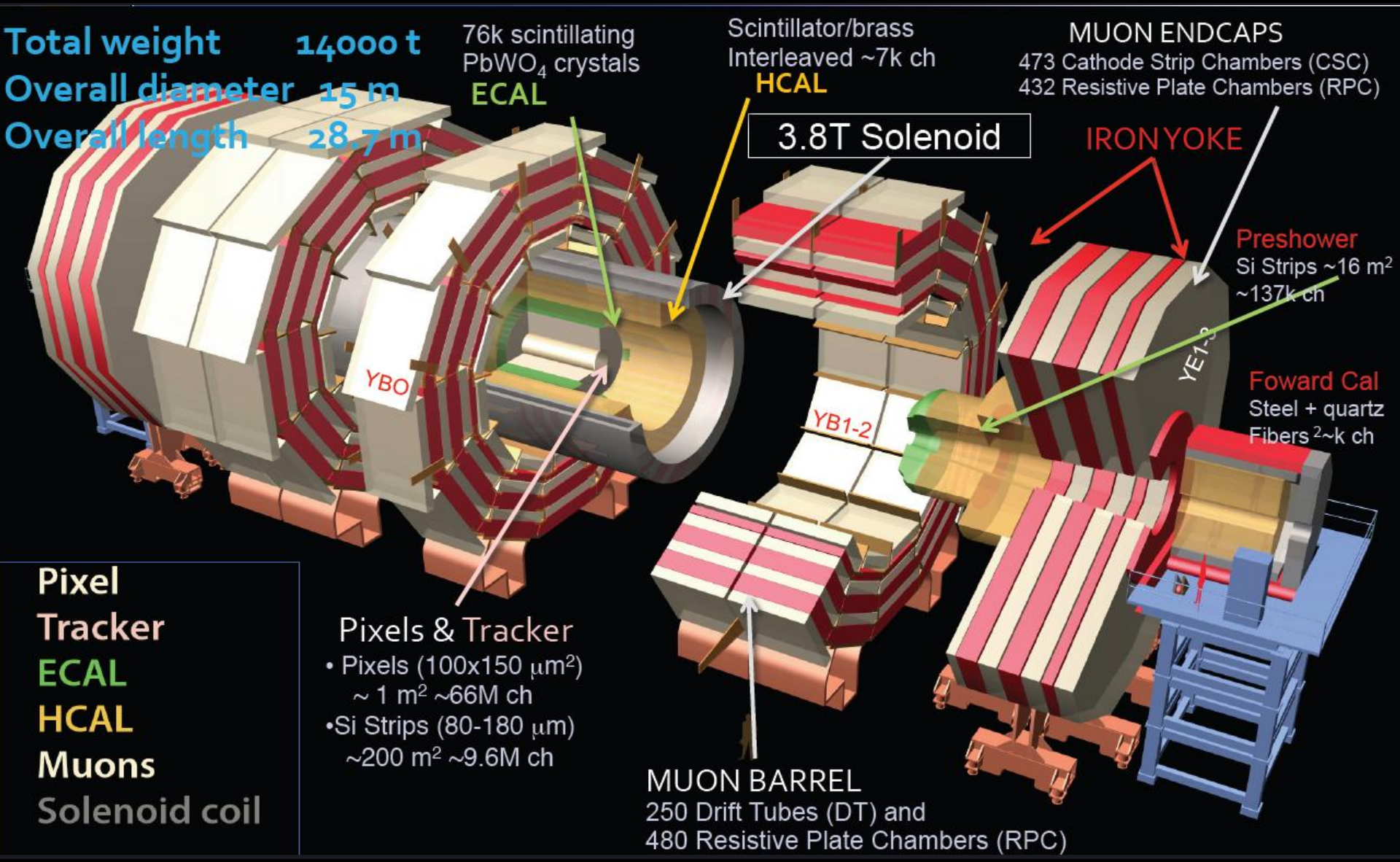
VIIIth Rencontres du Vietnam, 16-22/12/2012

DISCLAIMER: Due to limited time

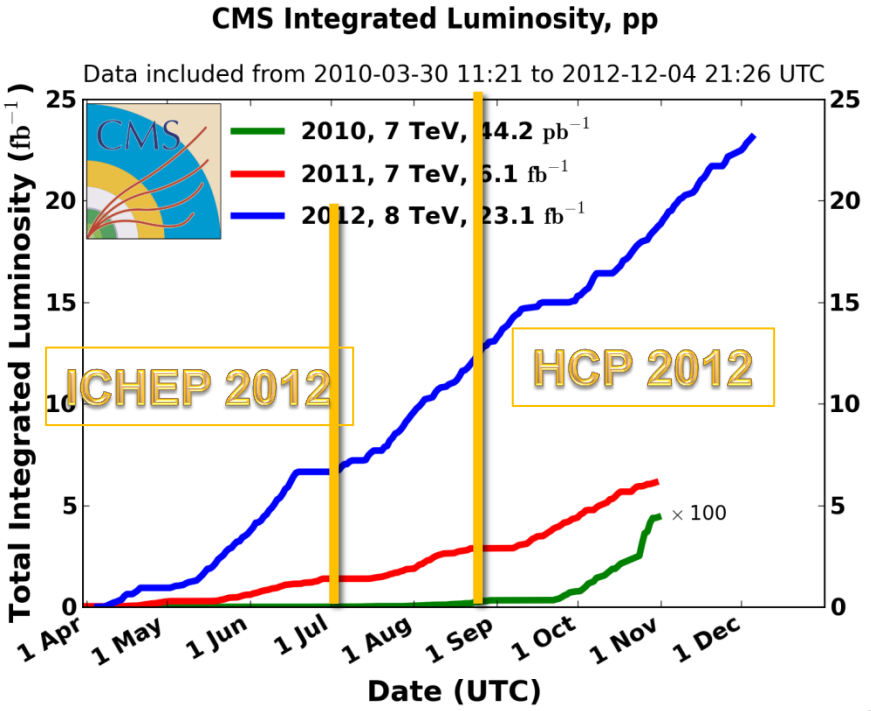
- Only Standard Model Scalar search is covered
- No specific details on each analysis concerning:
  - Object reconstruction and event selection
  - Background estimation
  - Systematics
  - Consistency checks (vs energy, run period, subchannels, …)
- Assume you are familiar with statistical methods for limit setting & significance calculation, combination, …
- For more detailed info on 9 updated (wrt. Summer 2012) results, see http://cms.web.cern.ch/org/cms-papers-and-results or talk to me during a coffee break ;-)

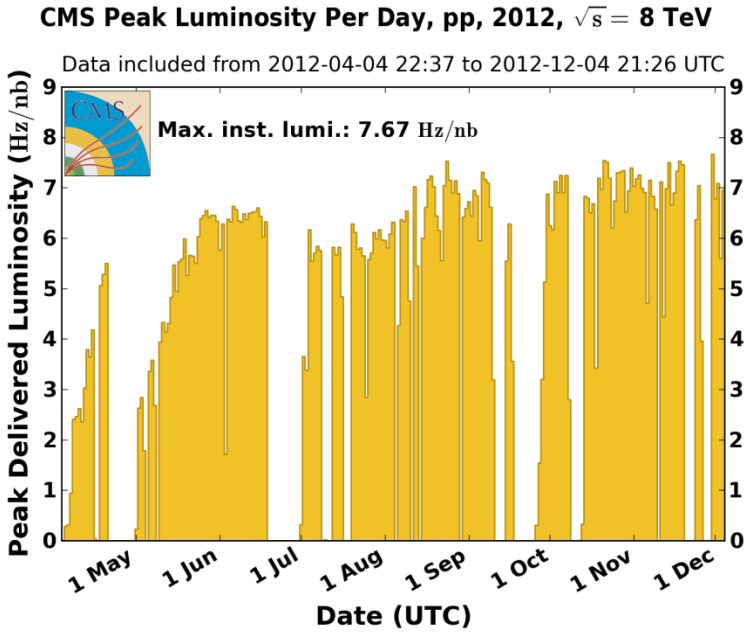
- This talk, arranged by decay:
  - Bosonic decay channels ($\gamma\gamma$, ZZ, WW)
  - Fermionic decays ($\tau\tau$, bb)
  - Combined significances and limits
  - Properties (couplings, mass, quantum numbers)

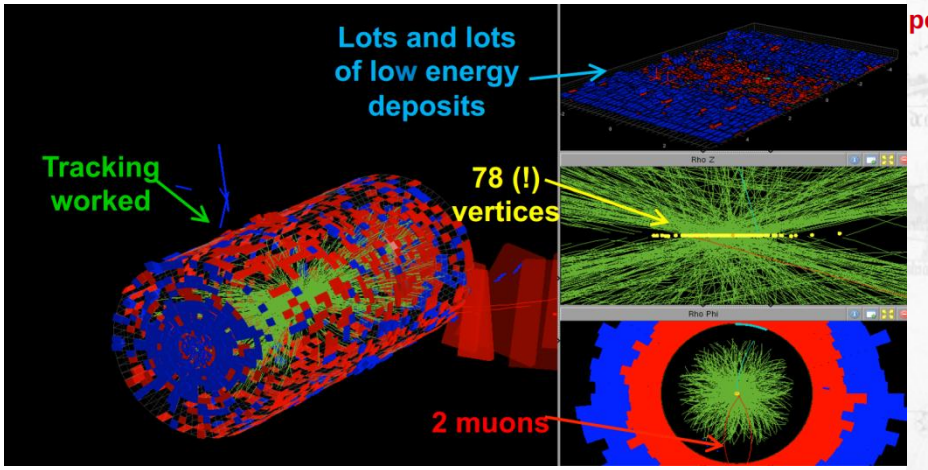
CMS DETECTOR

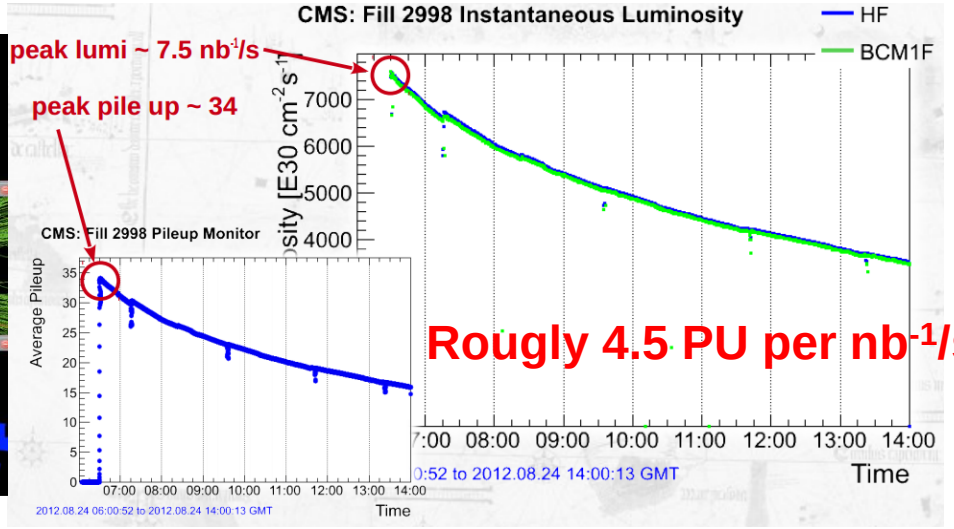


LHC performance

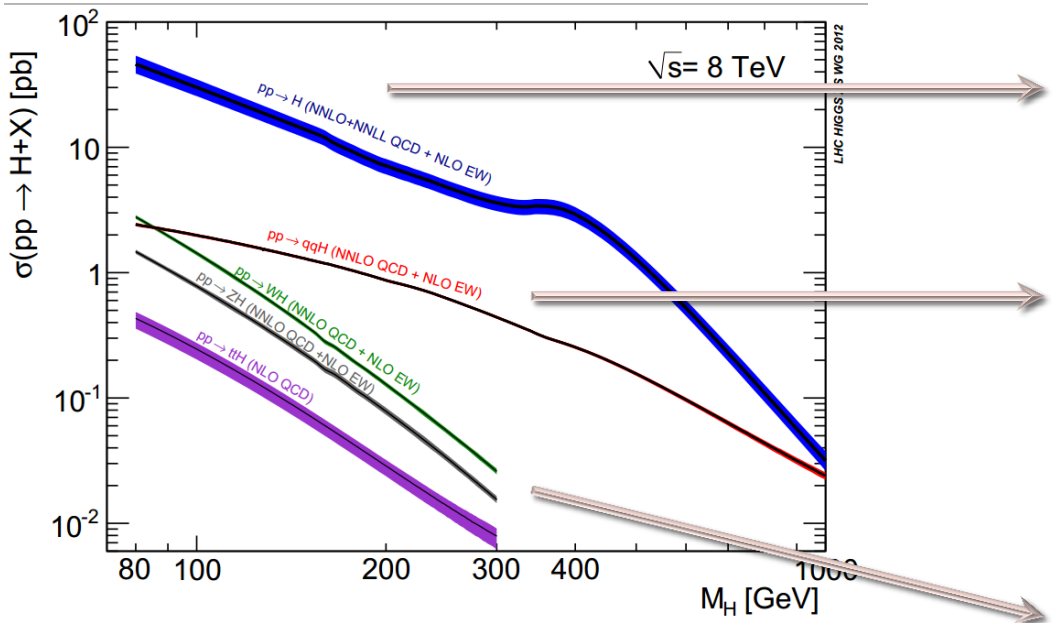


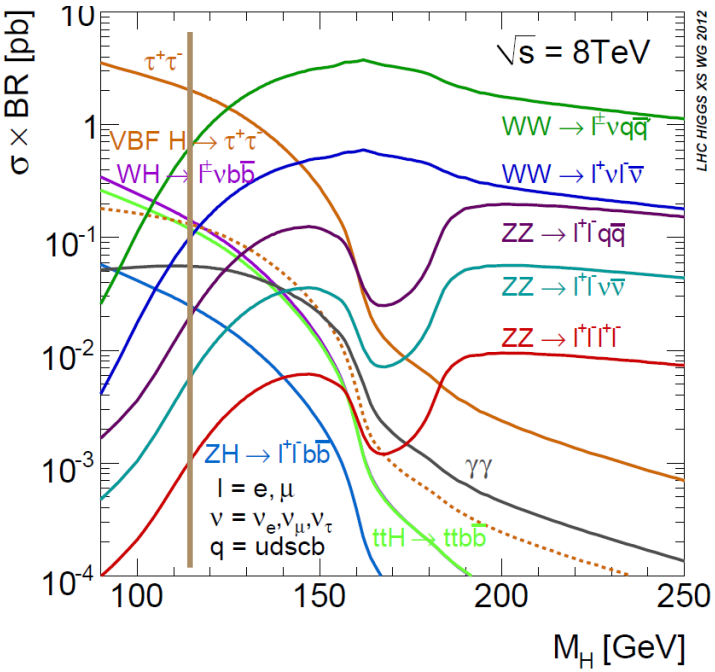


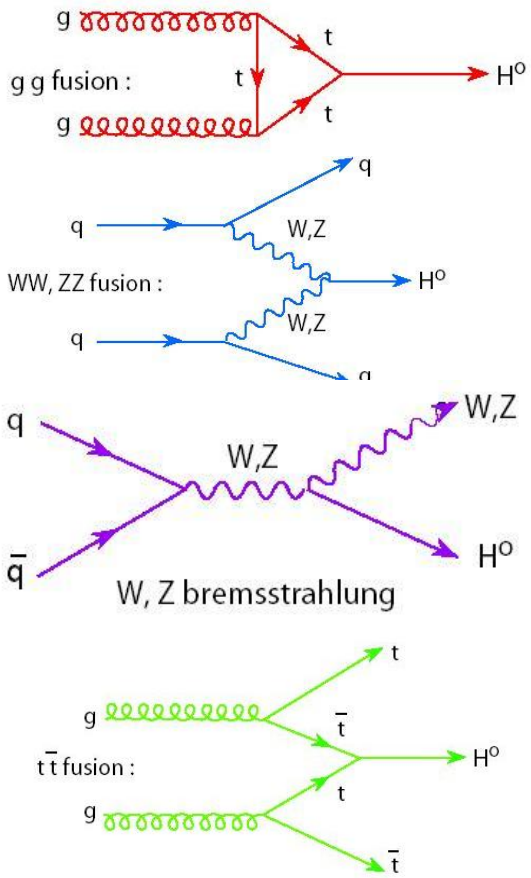




SM H Production & Decay







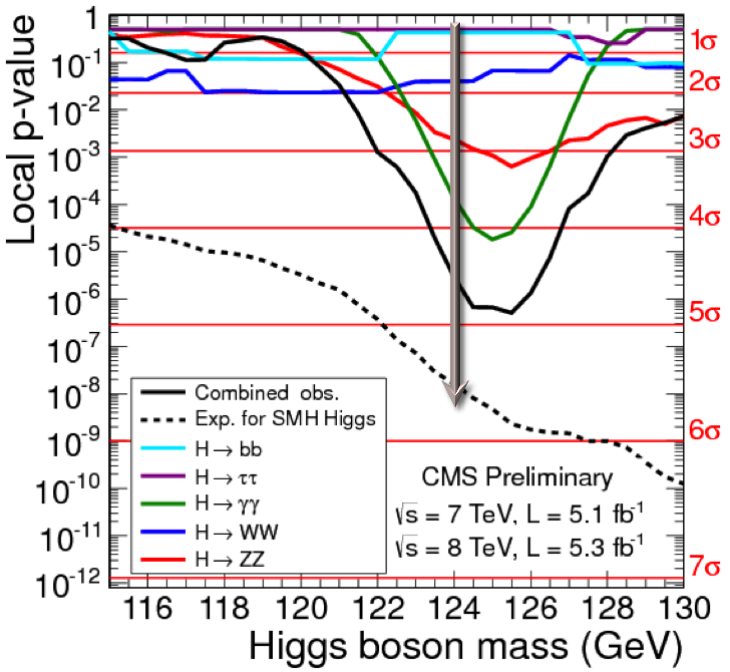
~100 Higgs produced per hour
At low M_H, all production modes and many decay channels become relevant

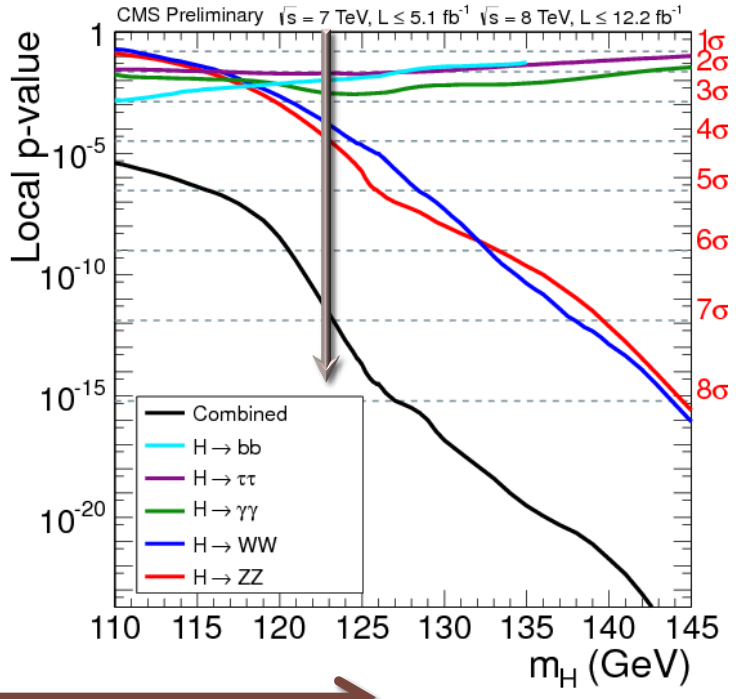
CMS Higgs program: From exclusion to discovery to measurements ..

July 4th 2012: 10fb^{-1}	CMS
95% exclusion	$m_H \notin [110,122.5] \& [127,600]$ GeV
Local p-value	5.0 σ + Nothing else significant
Mass [GeV]	125.3 ± 0.4 (stat.) ± 0.5 (syst.)
Signal Strength ($\gamma\gamma$+ZZ+WW+$\tau\tau$+bb)	0.87 ± 0.23

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)





+7 fb^{-1} extra data and analysis improvements

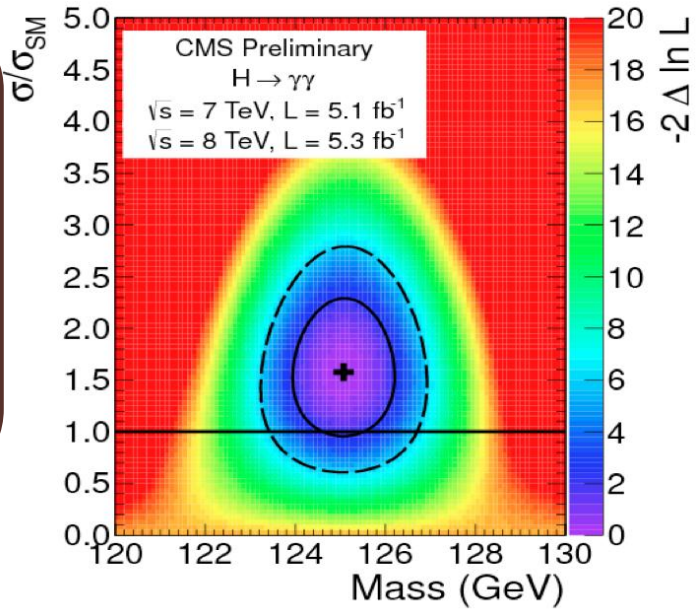
Overview of CMS SM Higgs analyses

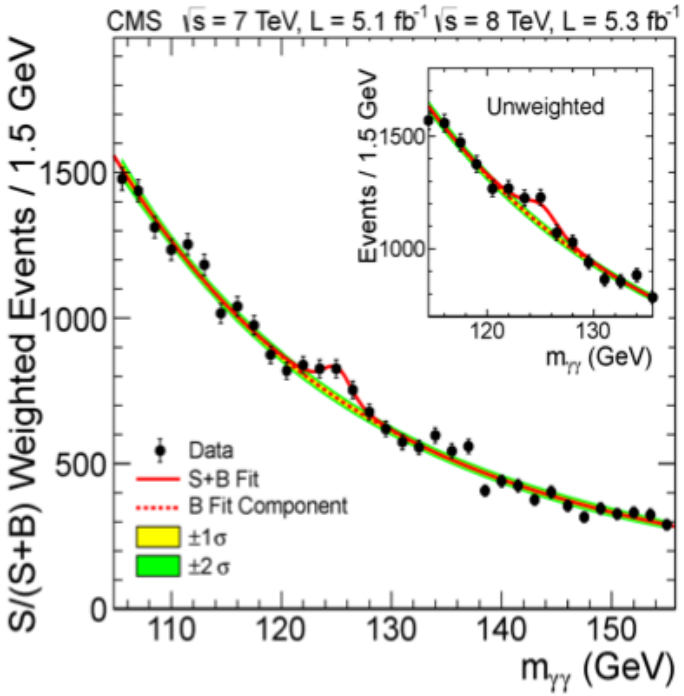
Higgs decay mode	Higgs production mechanism	Mass range [GeV]	Data used		Mass resolution	Used in CMS comb
			7 TeV [fb^{-1}]	8 TeV [fb^{-1}]		
$\gamma\gamma$	Untag (~gg)	110 – 150	5.1	5.3	1–2%	✔
	VBF-tag	110 – 150	5.1	5.3	1–2%	✔
bb	VH-tag	110 – 135	5.0	12.1	10%	✔
	ttH-tag	110 – 140	5.0	–	–	✔
$\tau\tau$	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	–	✔

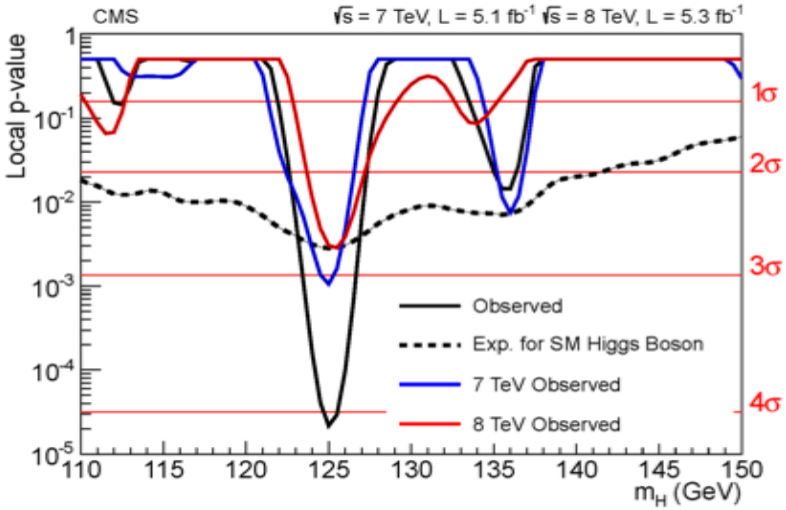
H→γγ (6 channels)

- Clean final state with 2 isolated photons
- Narrow mass peak on continuum
- Very precise ECAL energy calibration
- Need underlying event for vertexing
- Background shape extracted from data
- Fits in subcategories with distinct resolution and S/B improves total sensitivity
- Also includes VBF production channel

$$m^2_{\gamma\gamma} = 2E_1E_2(1-\cos\alpha)$$







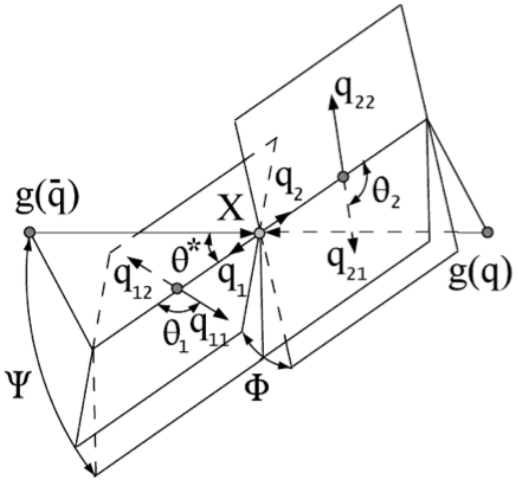
$m_{\gamma\gamma}$ = 125.1 ± 0.4 (stat) ± 0.6 (sys) GeV

σ/σ_{SM} = 1.56 ± 0.43

H→ZZ (11 channels)

Main features:
- High lepton reconstruction efficiencies for m_{4l}>100 GeV
- Standard reference candle: single-resonant Z→4l
- Irreducible backgrounds: direct ZZ or Zγ*
- 2D discriminant exploiting production&decay kinematics

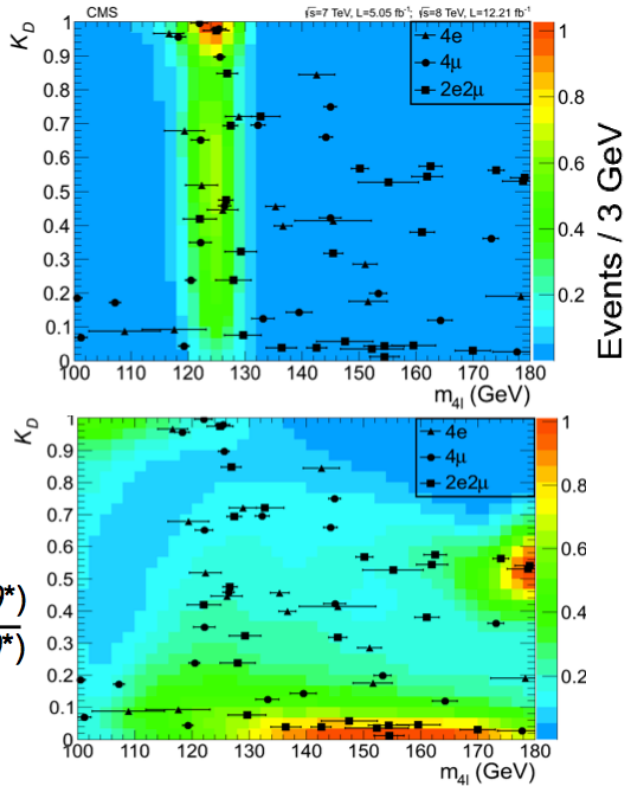
Improvements:
- Inclusion of 2l2τ final state w. leptonic and hadronic τ decays
- Improved lepton reconstruction & isolation efficiencies
- Measurement of spin&parity

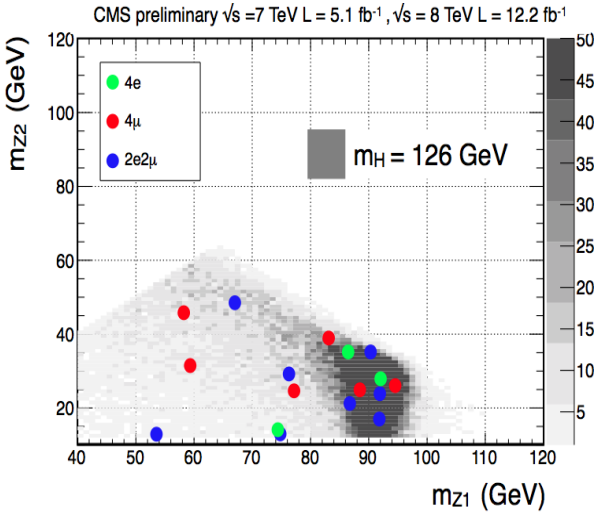


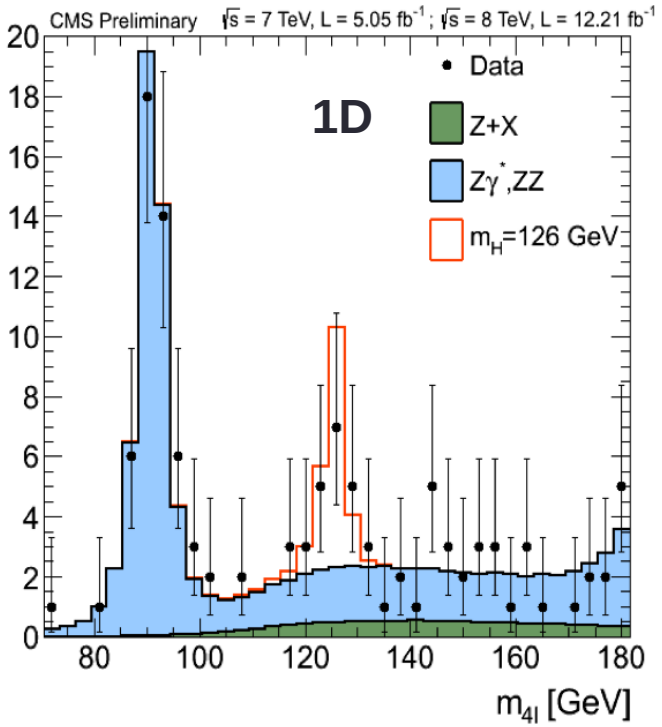
Angular analysis in CMS

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

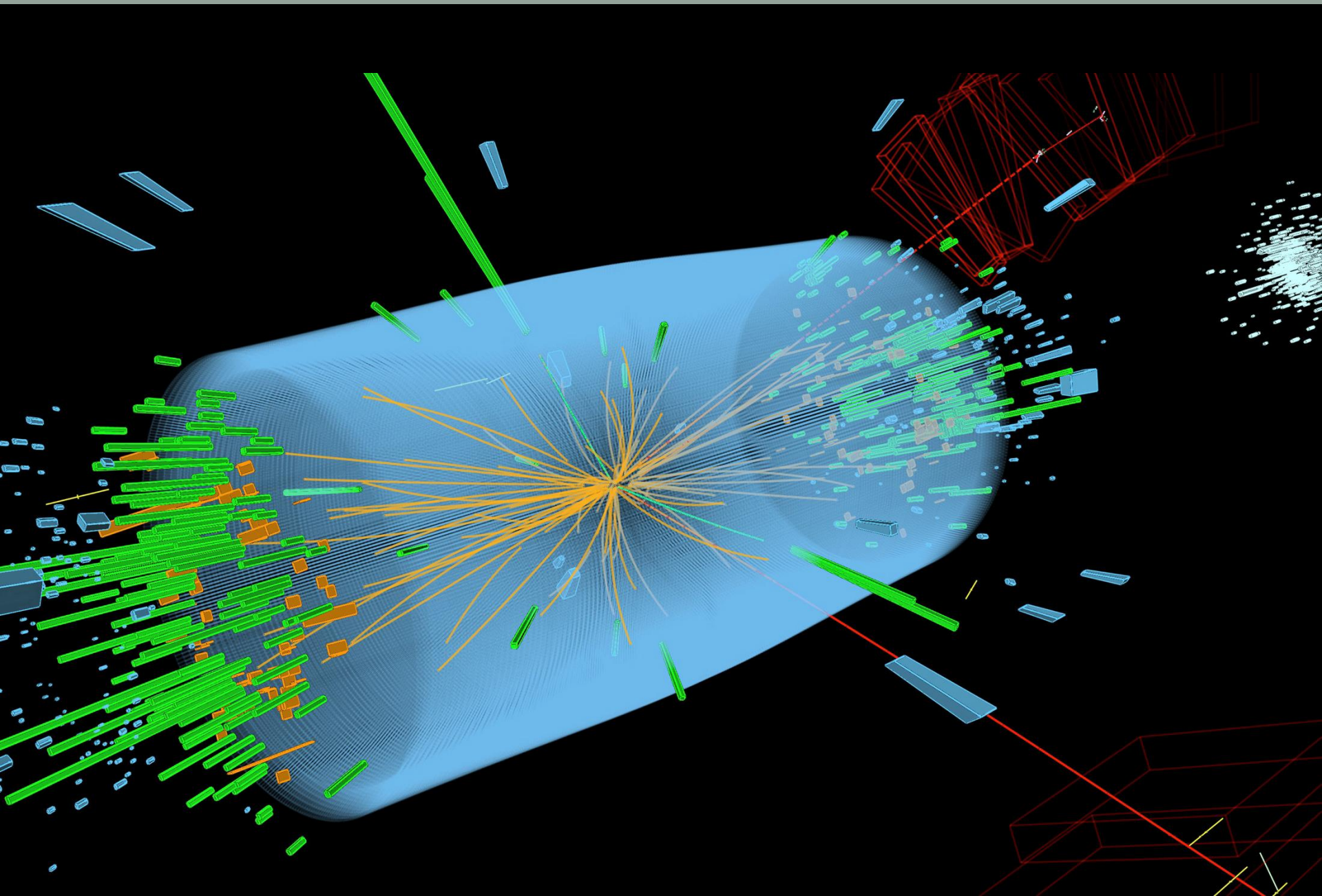
enhances analysis sensitivity





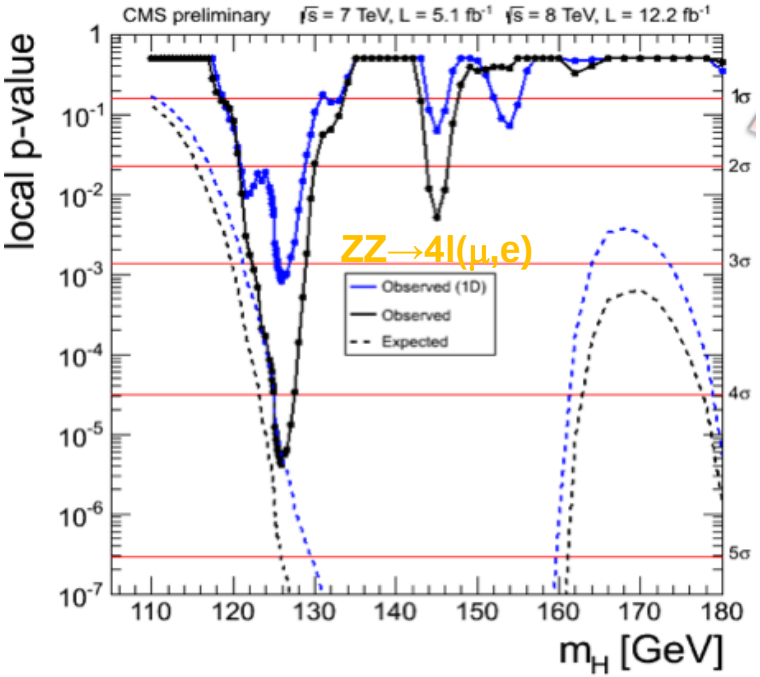


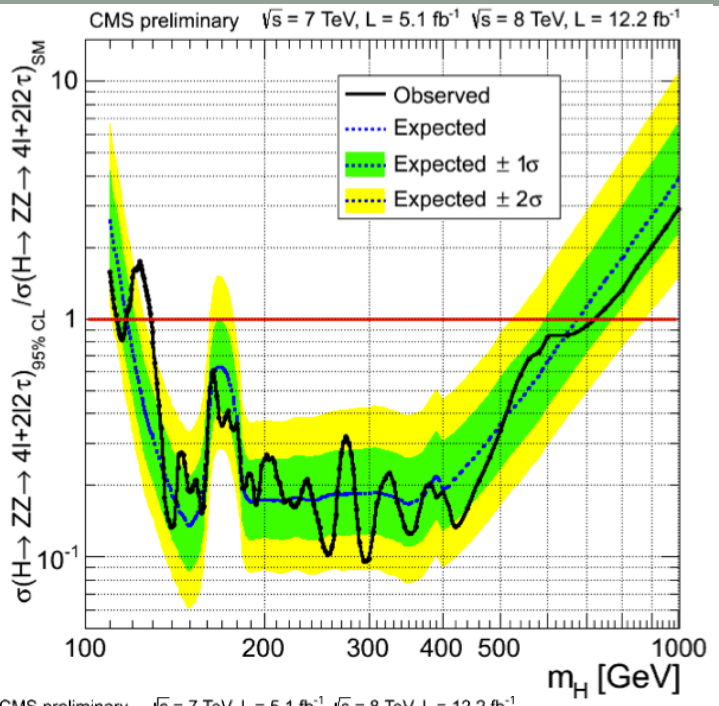
H→ZZ →2e2μ candidate



H→ZZ high mass exclusion and low mass significance

1D (m4l) results vs. 2D (K_D+m4l)





Observed p-value in 4l+2l2τ: 4.6 σ

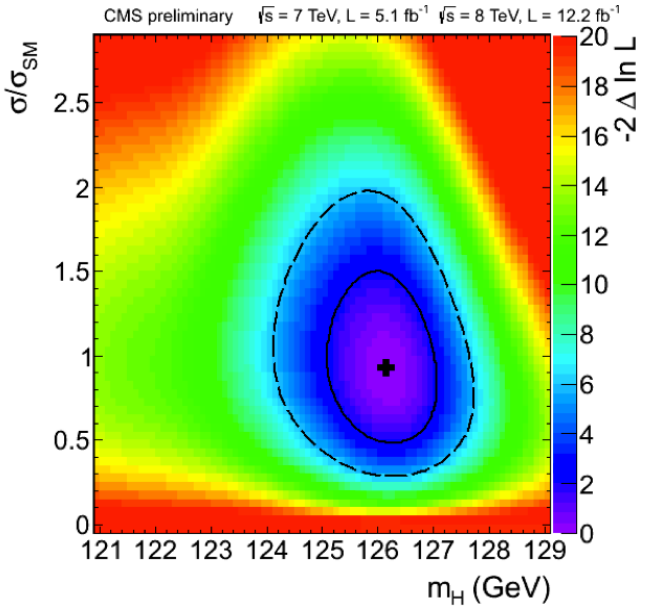
Signal strength @ 126 GeV : $0.78^{+0.34}_{-0.27}$

SM Higgs-like excess at 126 GeV

SM exclusion up to $129<m_H<700$ GeV

Reweight of high mass Higgs lineshape

Including interference effects



$$m_H = 126.2 \pm 0.6\,(stat.) \pm 0.2\,(syst.)\,GeV$$

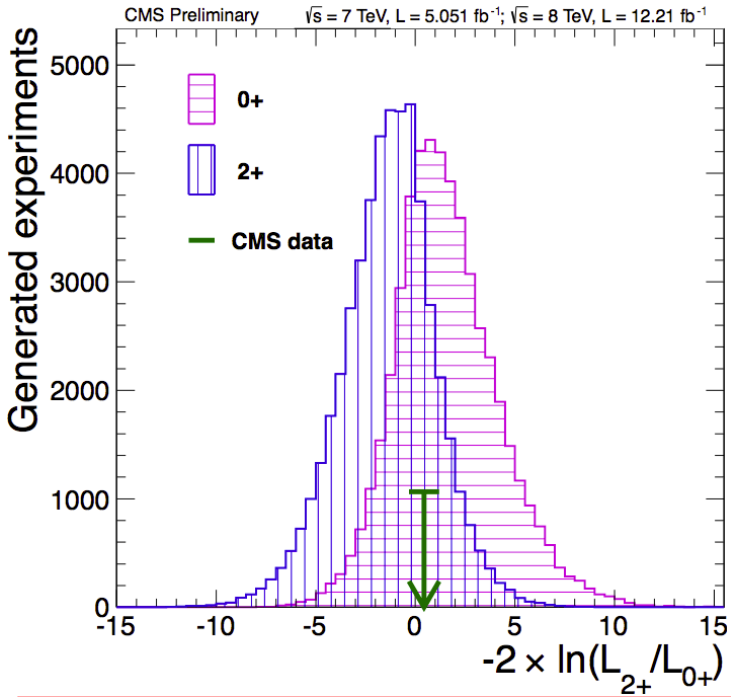
H→ZZ →4l Spin&Parity measurement

NEW

- Using K_D to discriminate between different states

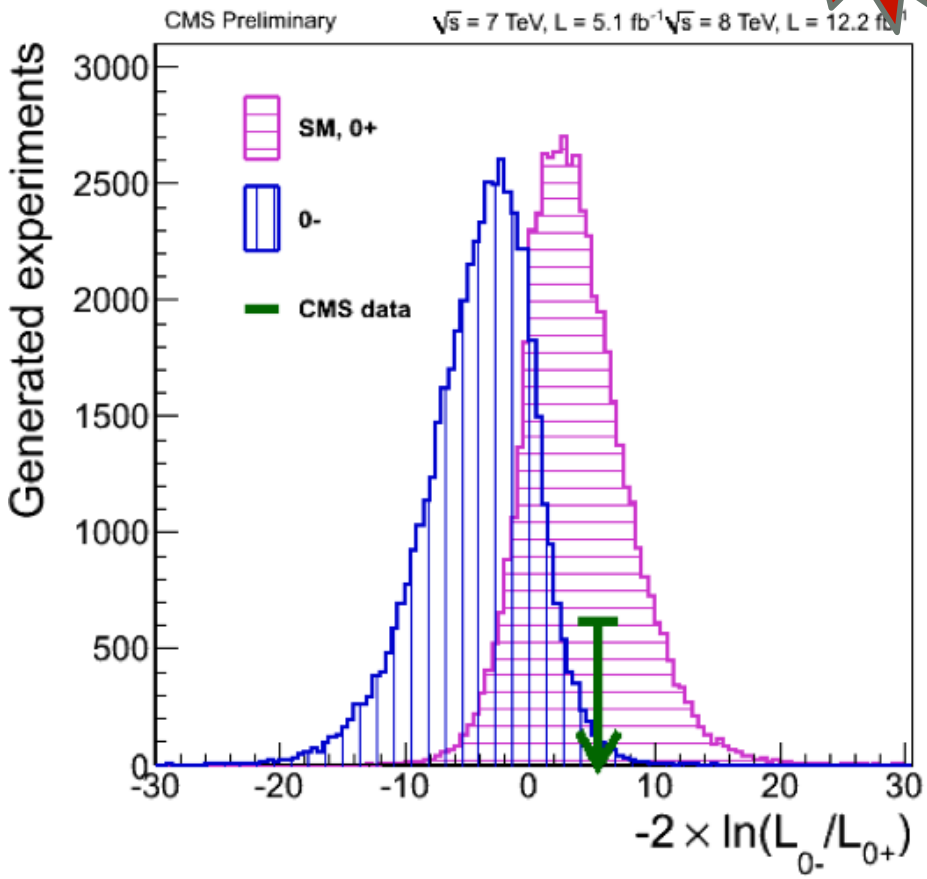
$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{SM}}{\mathcal{P}_{SM} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_1, m_2, \vec{\Omega}|m_{4\ell})}{\mathcal{P}_{SM}(m_1, m_2, \vec{\Omega}|m_{4\ell})}\right]^{-1}$$

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



0+ vs 2+

- Expected separation: ~1 σ
- WW and gg channels are more sensitive



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→WW →2l2ν (6 channels)

Main features:

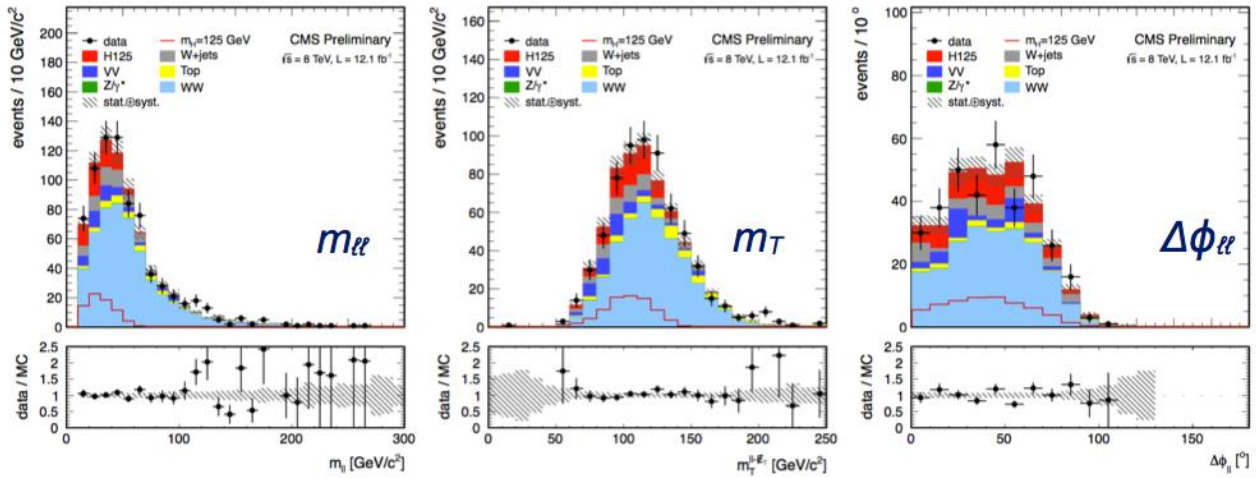
- 2 well isolated leptons (e or μ) with small opening angle due to helicity conservation, some feedthrough from leptonic τ's
- Large amount of missing E_T (neutrino's), no mass peak
- Separate treatment of same (SF) and different flavor (DF) leptons: DY background is absent for DF
- Analysis in bins of jet multiplicity (0,1,2OR3) , includes VBF mode WW bg dominates in 0-jet, ttbar in higher jet multiplicities

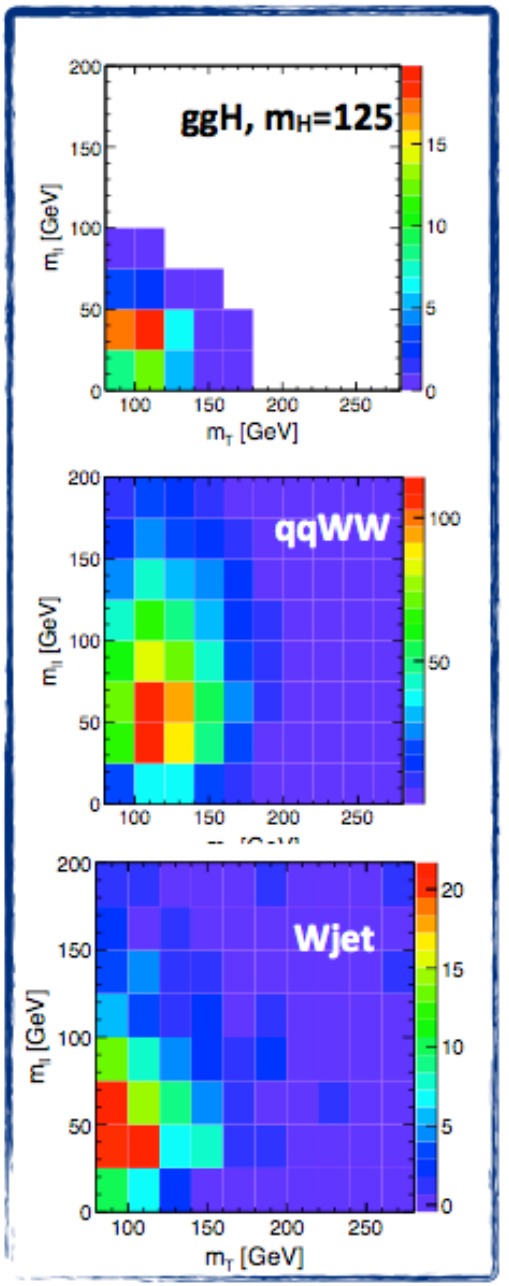
Improvements:

- Shape analysis in DF on 0&1 jet bins, cut&count elsewhere
- 2D shape (m_{ll},m_T) replaces BDT, $m_T = \sqrt{2p^{ll}{}_T ET^{miss}(1 - cos\Delta\phi_{ETmiss,ll})}$

Cut&count 0-jet DF (e,μ) final yields

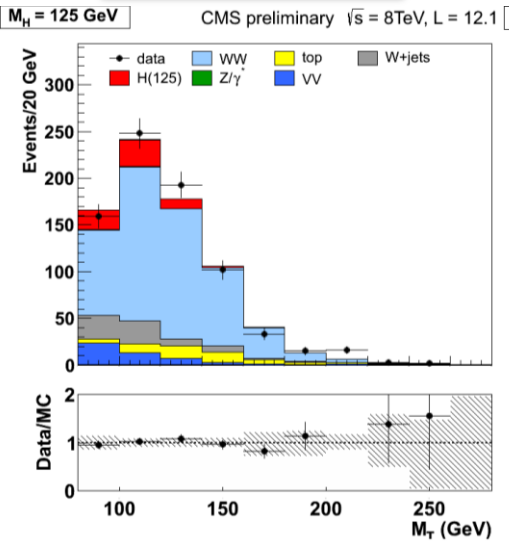
m_H	H → W⁺W⁻	pp → W⁺W⁻	WZ + ZZ +Z/γ*→ ℓ⁺ℓ⁻	Top	W + jets	Wγ(*)	all bkg.	data
0-jet category eμ final state								
120	34.0 ± 7.3	162 ± 16	5.3 ± 0.5	8.6 ± 2.0	38 ± 14	23.1 ± 8.8	237 ± 23	285
125	58 ± 12	203 ± 19	6.6 ± 0.6	11.0 ± 2.5	44 ± 16	25.6 ± 9.5	291 ± 27	349
130	86 ± 18	226 ± 21	7.1 ± 0.7	12.2 ± 2.8	47 ± 17	27 ± 10	319 ± 29	388



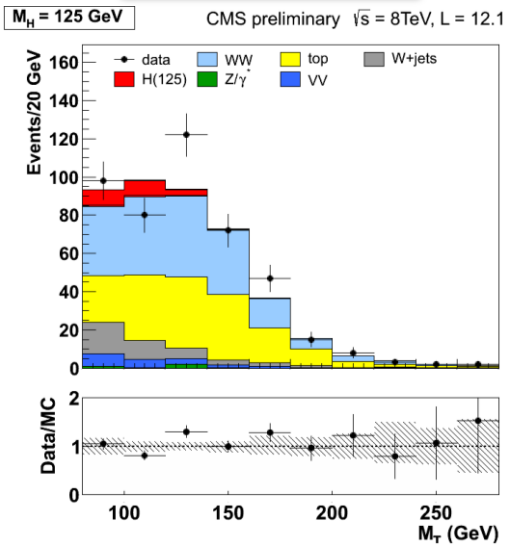


H→WW→2l2ν limits and signal strength

0-jet , M_{ll}<50 GeV



1-jet , M_{ll}<50 GeV



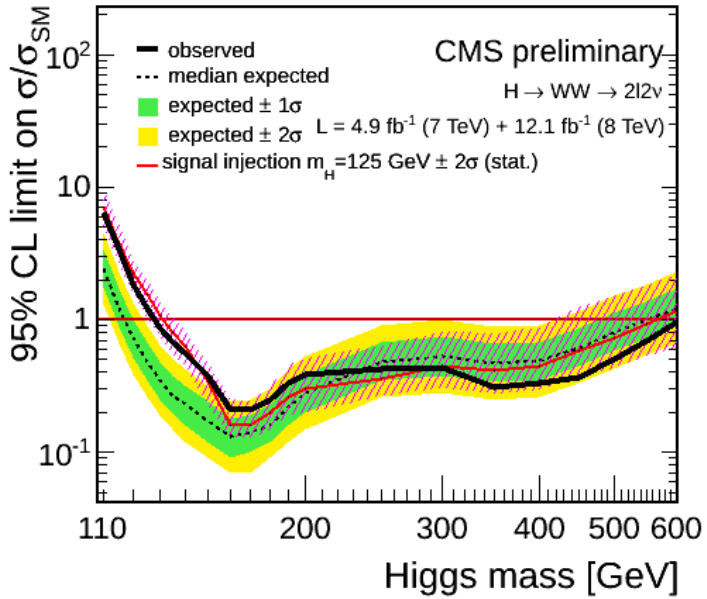
Combined limit including new 2D analysis at 8 TeV and BDT at 7 TeV

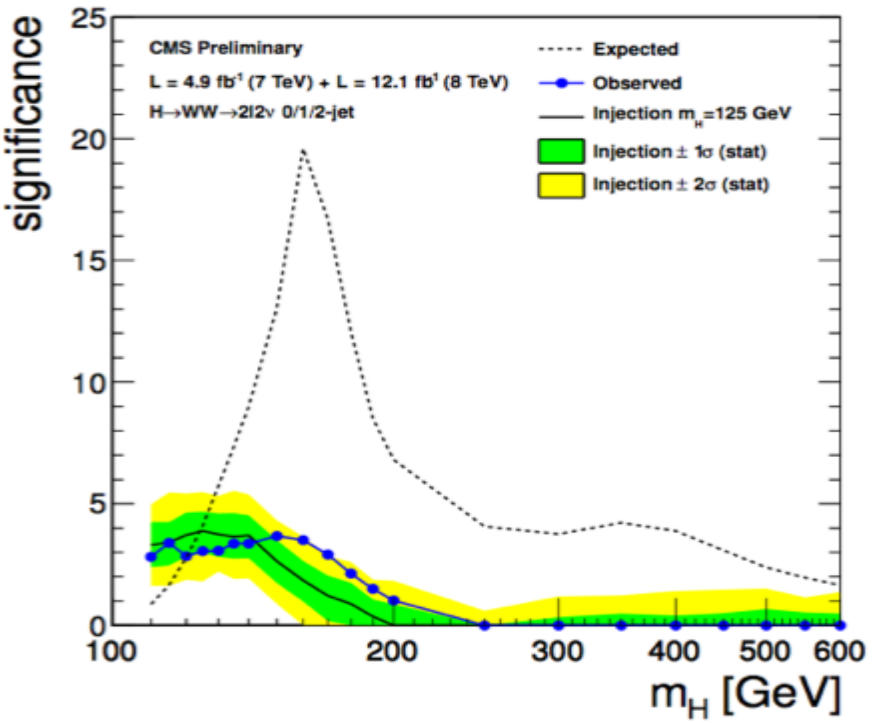
- **Exclusion of wide mass range $128<m_H<600$ GeV**

Significant excess at low mass

- **3.1σ (expected 4.1σ) @ 125 GeV**
  → **Compatible with signal injection**
- **$\sigma/\sigma_{SM} = 0.74 \pm 0.25$ @ 125 GeV**

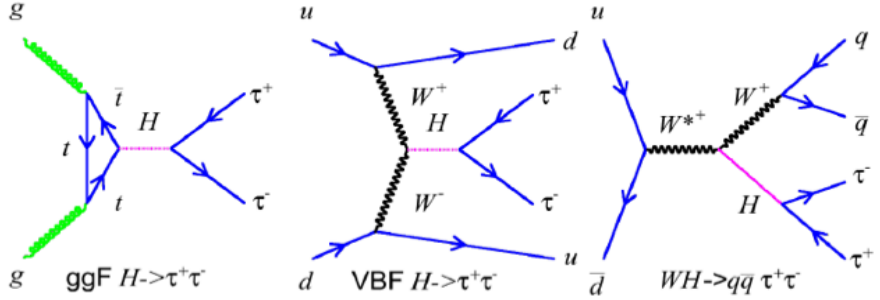
All combined





H→ττ (25 channels)

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

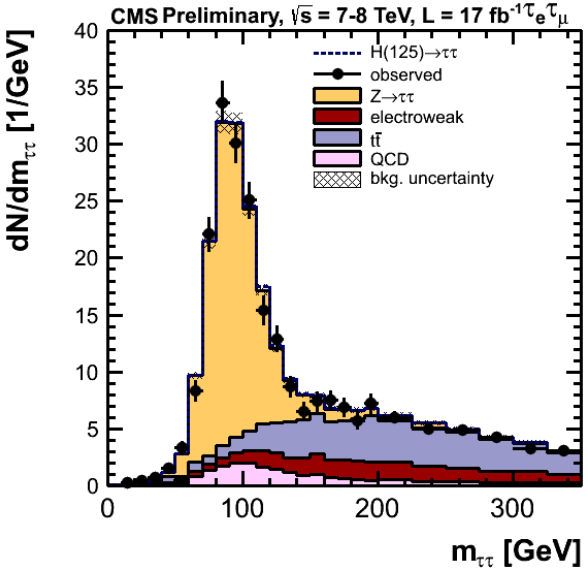


- $H \to \tau\tau \to \mu\mu$ $(\tau_\mu \tau_\mu)$,
- $H \to \tau\tau \to e\mu$ $(\tau_e \tau_\mu)$,
- $H \to \tau\tau \to \mu + had.$ $(\tau_\mu \tau_h)$,
- $H \to \tau\tau \to e + had.$ $(\tau_e \tau_h)$,
- $H \to \tau\tau \to had. + had.$ $(\tau_h \tau_h)$.

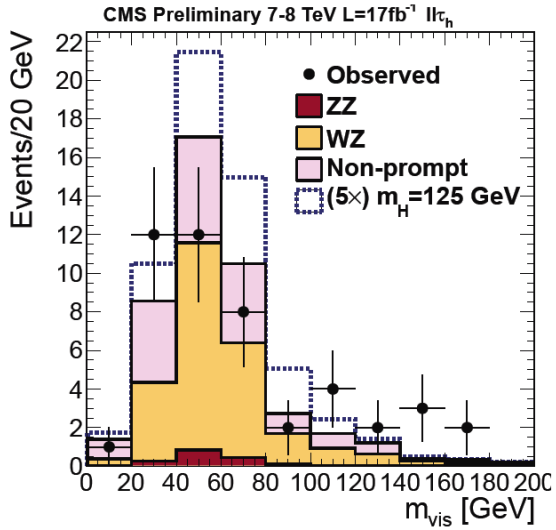
- **MVA based object reconstruction and cut-based event selection**
- **Separated in categories (τ decays, jet bins and τ p_t) to enhance S/B (0-jet bin only for background control, highest sensitivity from 1-jet bin and high τ p_t)**
- **Revised Missing ET reconstruction using multivariate regression**
- **Maximum likelihood fit to reconstruct $m_{\tau\tau}$ for incompletely constrained τ decays: 12-20% resolution**
- **Simultaneous binned likelihood fit to $m_{\tau\tau}$**

Dedicated V(ll,ν)H(ττ) analysis

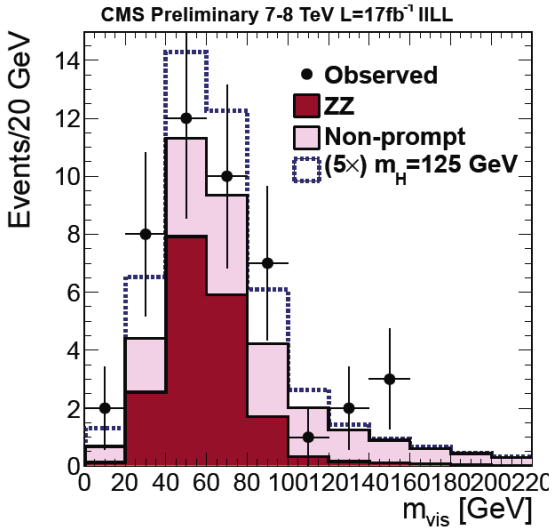
1-jet $\tau_e\tau_\mu$



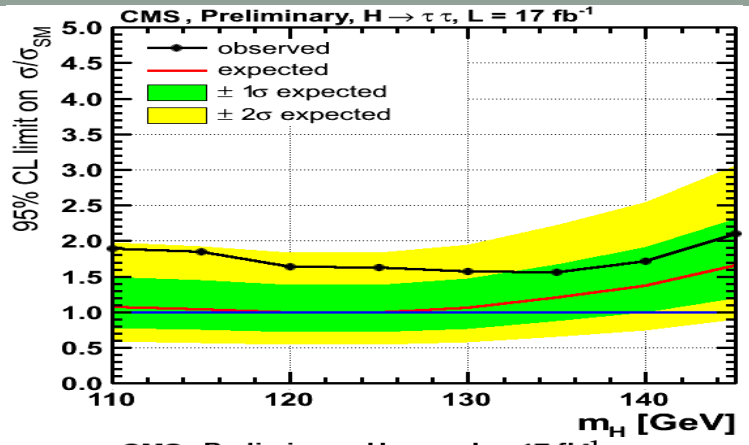
$WH \to ll\tau_h$

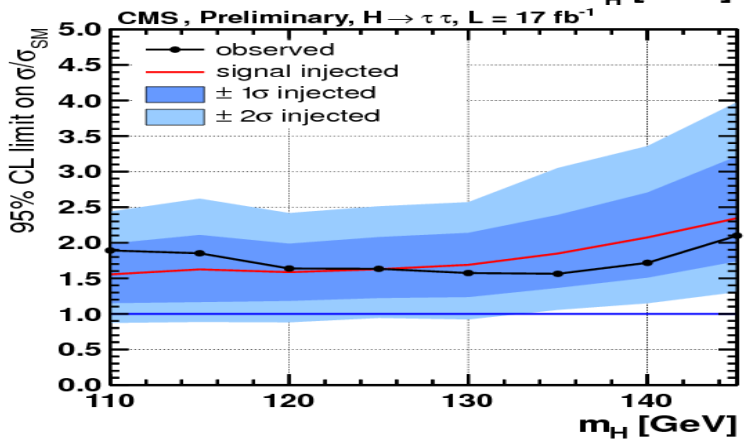


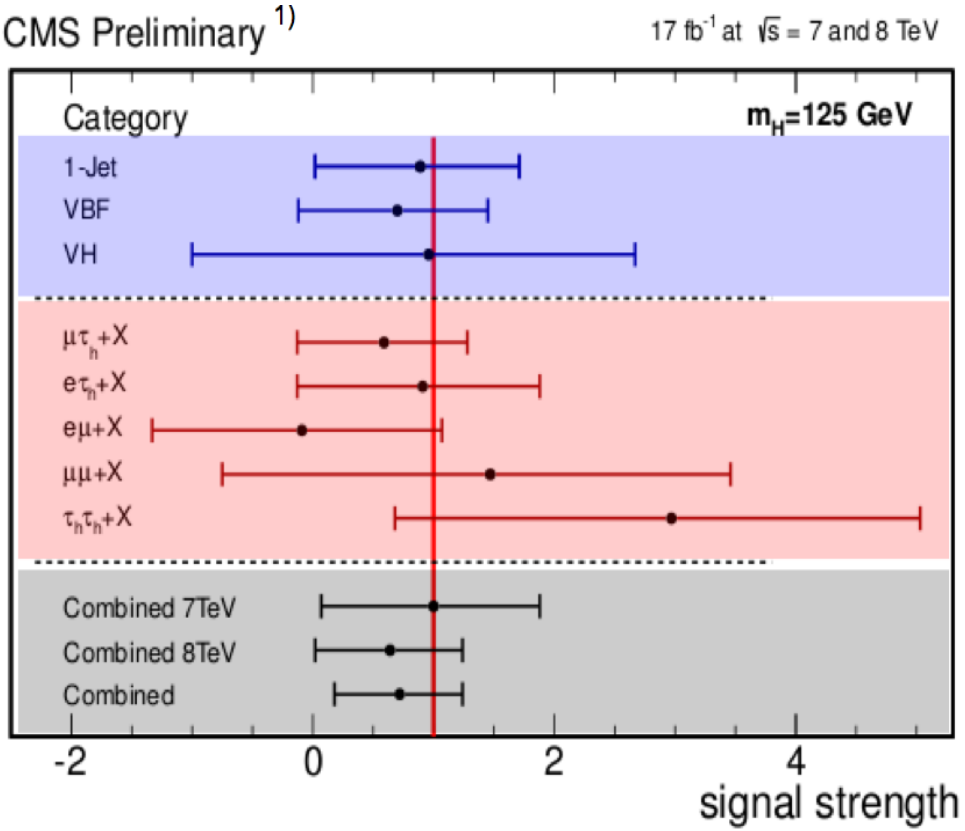
$ZH \to ll\tau\tau$



H→ττ combined limits and signal strength





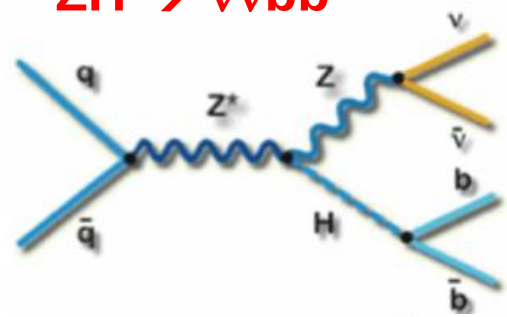


Reaching sensitivity to SM cross section

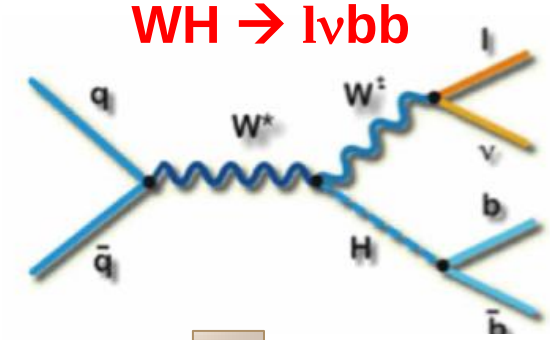
- **Expected limit at m_H=125 GeV in absence of signal: 1.05xσ_{SM}**
  Observed limit combining all sub-channels: 1.66xσ_{SM}
- **Consistency among all channels and CM energies**
- **Extracted signal strength compatible with SM:**
  $\sigma/\sigma_{SM} = 0.7 \pm 0.5$ @ 125 GeV

VH→bb (13 channels)

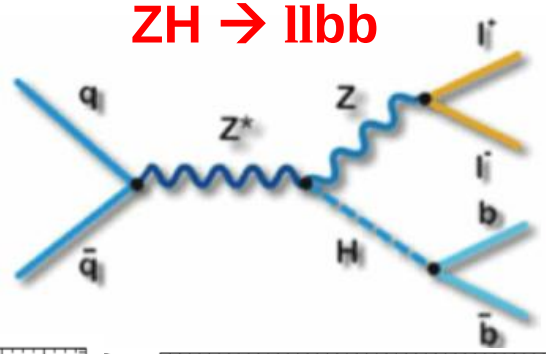
ZH → νν̄bb̄

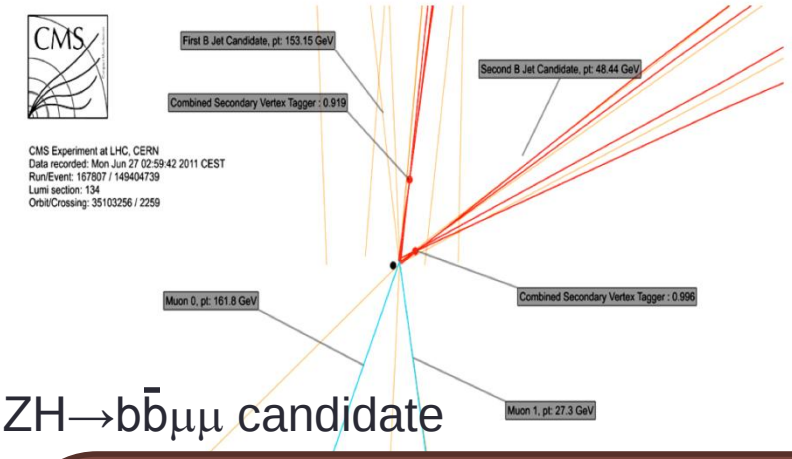


WH → lνbb̄



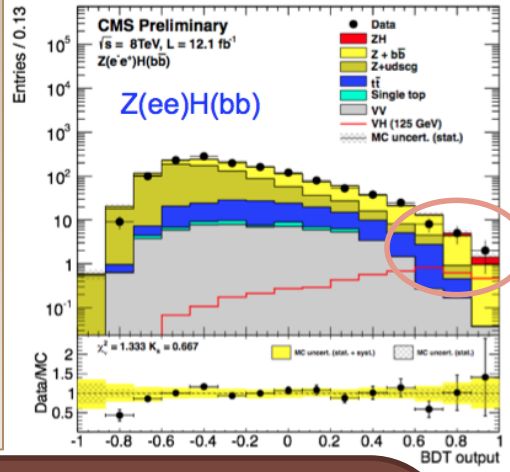
ZH → llbb̄

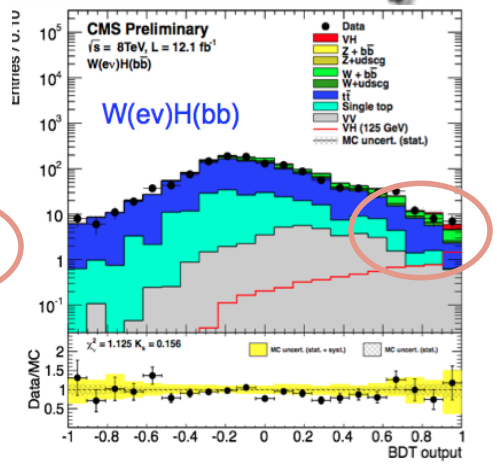


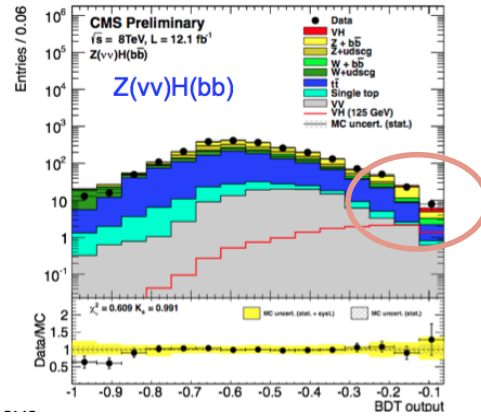


ZH→bb̄μμ candidate

High $p_t(V)$, tight btag







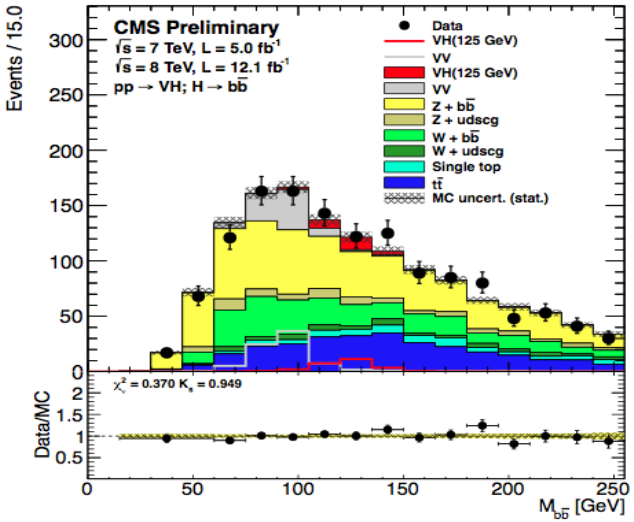
Main features:

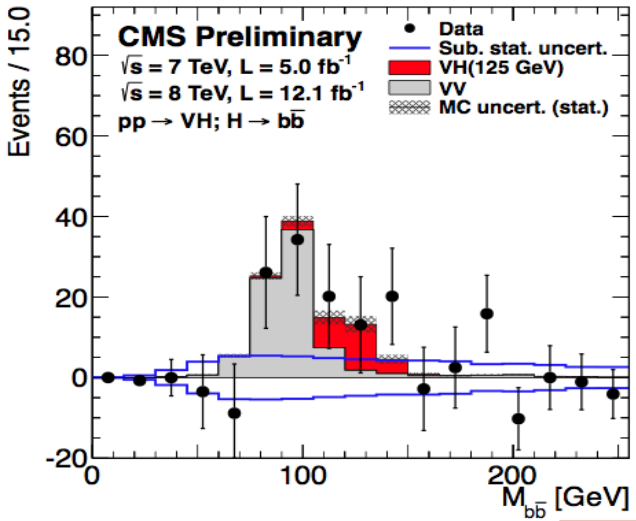
- **Careful pile-up subtraction from jets (10% m_{bb} resolution)**
- **B-tagging based in likelihood discriminant**
- **Huge background contribution (V+jets, tt, diboson, t, QCD)**
- **Backgrounds reduced by selecting highly boosted H (and V) with large opening angle**
- **BDT analysis, signal extracted from fit to output shapes**

Improvements:

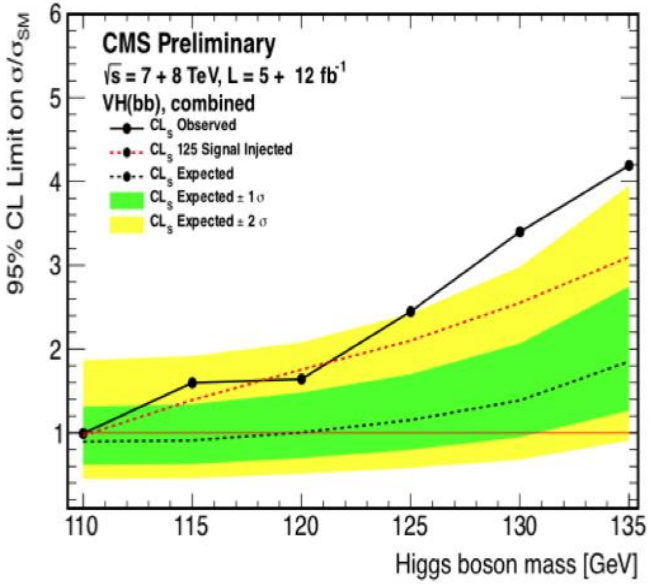
- **Improved b-jet energy measurement with multivariate regression**
- **Dedicated optimization for high $p_t(V)$ events**

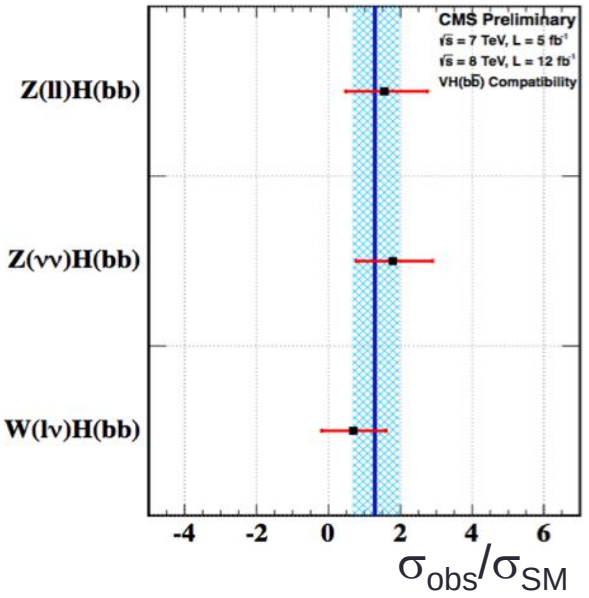
VH→bb summary





Combined regressed M_{bb} spectrum for cut based selection (not used for signal extraction)

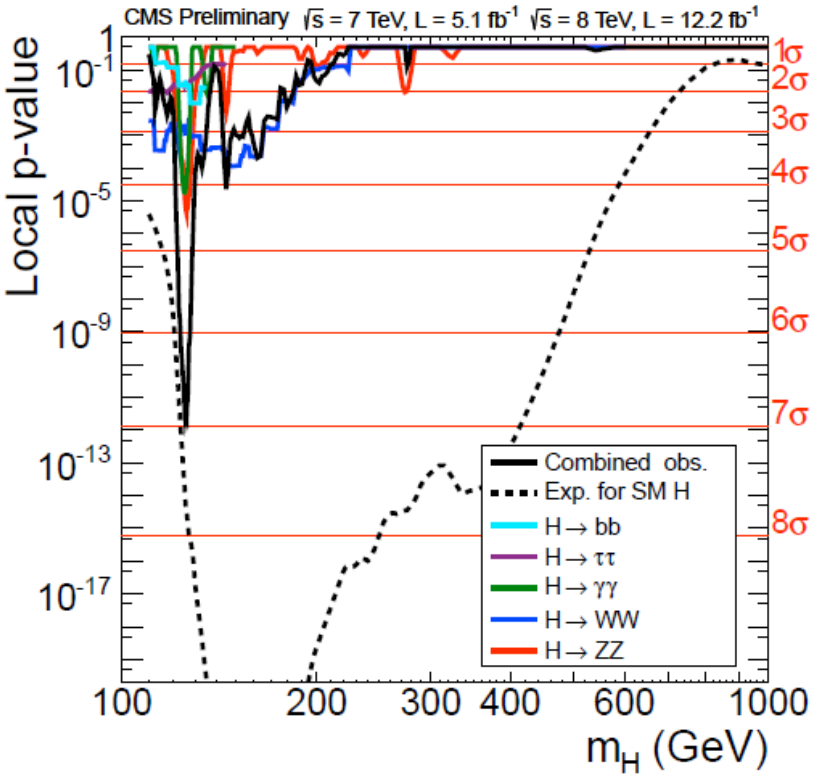




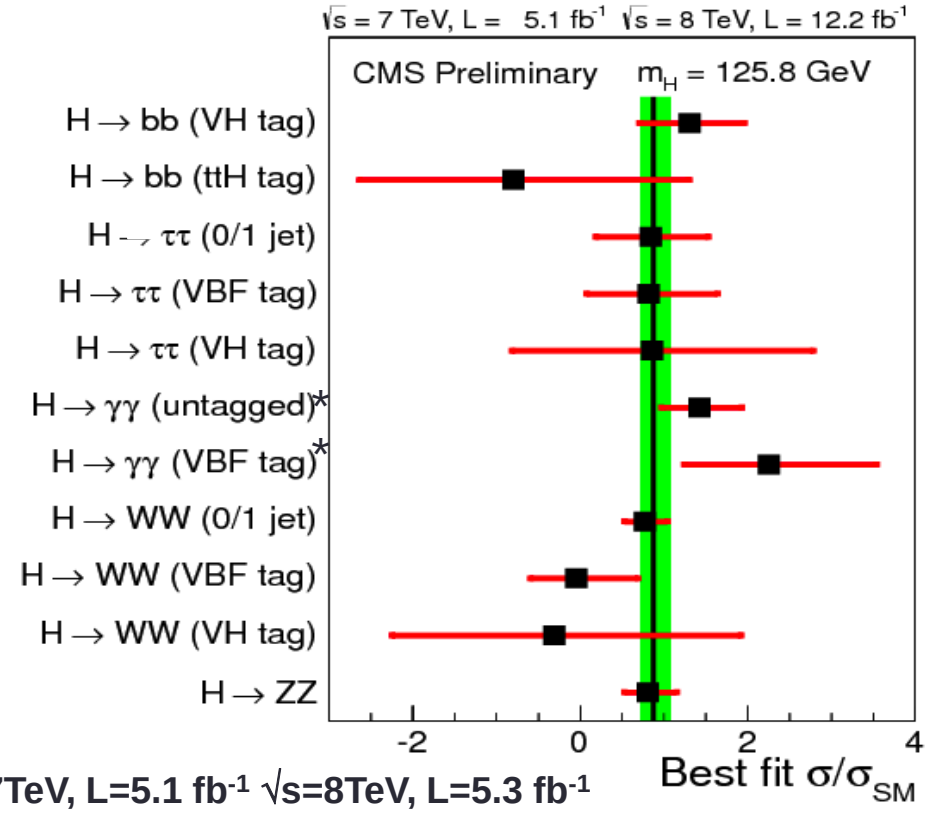
- **Observed limit at m_H=125 GeV: 2.5xσ_{SM}**
- **Expected limit at m_H=125 GeV: 1.2xσ_{SM}**
- **Coherent picture between sub channels**
- **Small excess around Mbb=125 GeV with local significance of 2.2 σ, consistent with signal injection**

Combination

P-value and related significance



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



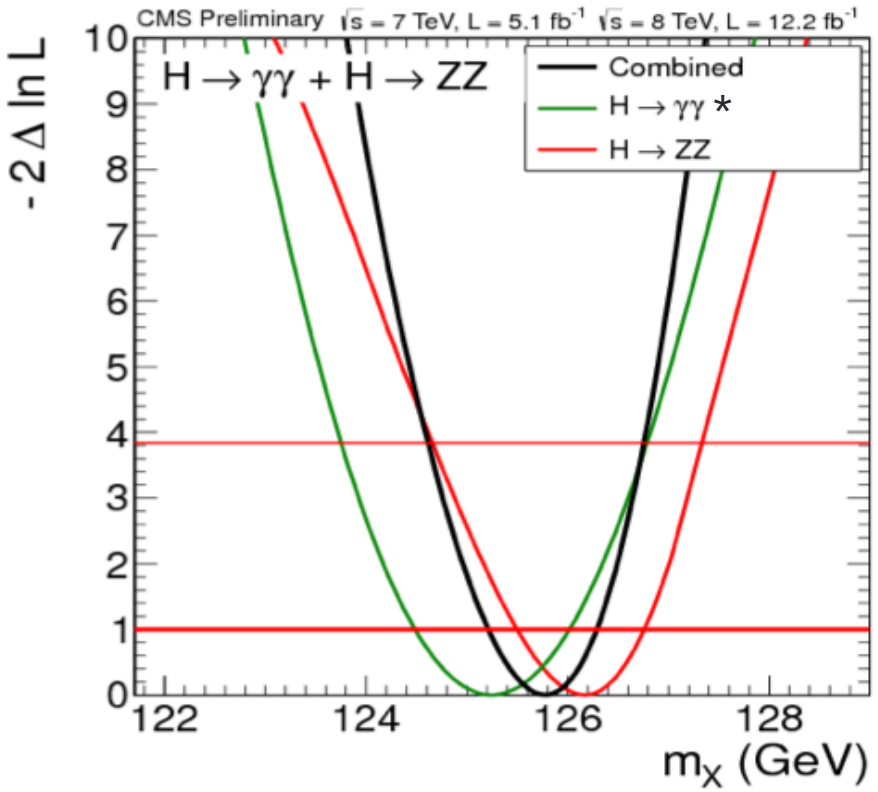
* √s=7TeV, L=5.1 fb^{-1} √s=8TeV, L=5.3 fb^{-1}

→ Largest local significance of 6.9 σ at m_H=125 GeV
→ Expected significance at m_H=125 GeV is 7.8 σ

→ $\sigma/\sigma_{SM} = 0.88 \pm 0.21$
→ Compatible with SM Higgs
→ Compatibility within 1σ for each decay channel / production mode

Properties

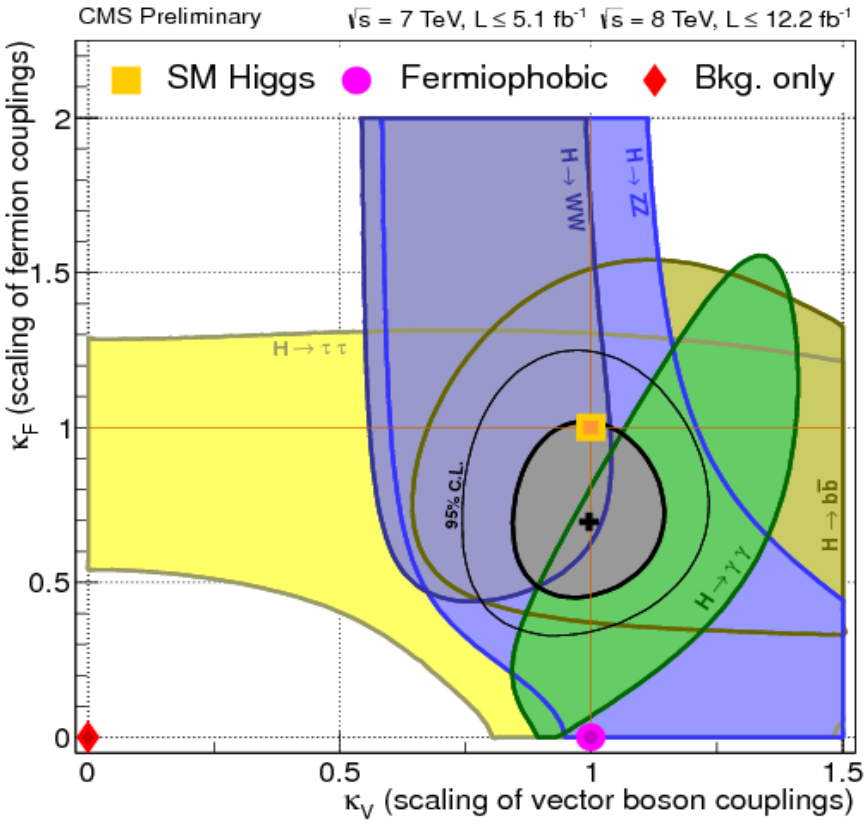
- **MASS: Combine information from the high resolution channels measurements:**
  - **H → ZZ**
  - **H → γγ (ggH and VBF)**
- **Signal cross section for the channels left floating independently in the fit**



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

* √s=7TeV, L=5.1 fb^{-1} √s=8TeV, L=5.3 fb^{-1}

- **Fermions versus vector bosons**

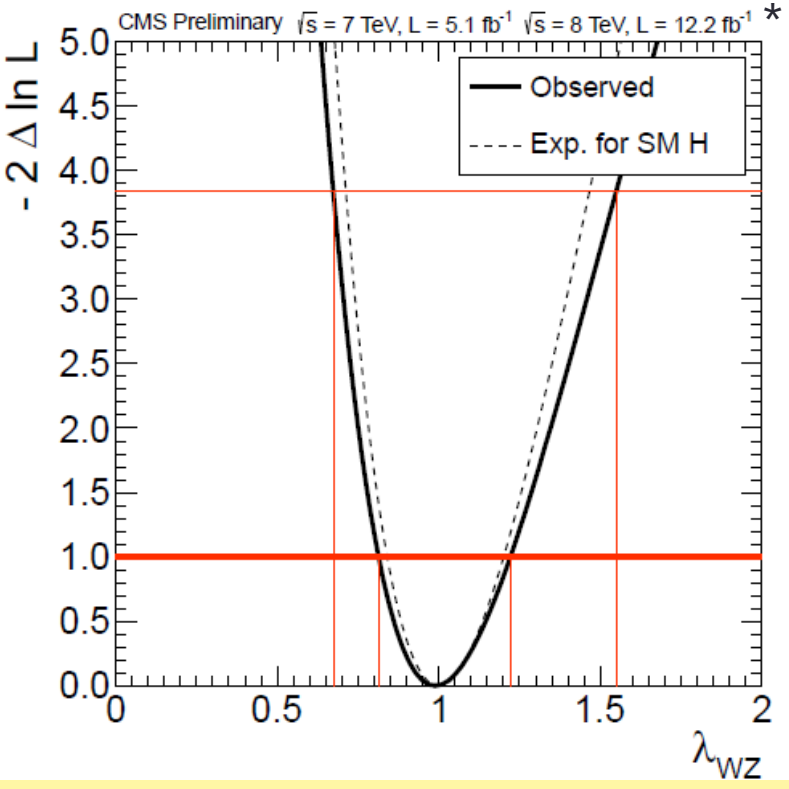


→8 partial decay widths transformed into coupling modifiers, κ_i (=1 for SM)
→ Fermiophobic scenario excluded at >4σ level

Properties

- **Custodial symmetry: Couplings to W and Z boson should scale together: cornerstone of electroweak Symmetry Breaking**
- **Parametrerized as**

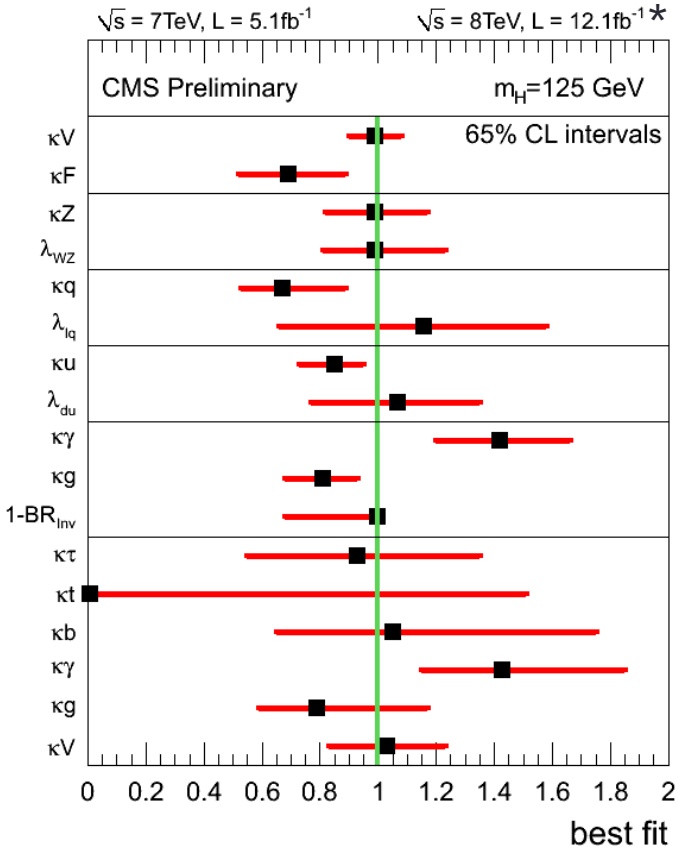
κ_F, κ_Z, $\lambda_{WZ}=\kappa_W/\kappa_Z$



→ λ_{WZ} in [0.57-1.65] at 95% CL

→ Result well consistent with SM

- **All possible coupling modifiers and assymetry parameters**
- **Any deviation from 1 hints at non-SM behavior**



* H→γγ : √s=7TeV, L=5.1 fb^{-1} √s=8TeV, L=5.3 fb^{-1}

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→γγ and H→ZZ
  - → 3.1σ evidence in H→WW→2l2ν (@ 125 GeV)
  - → Mild excess in H→ττ compatible with both SM Higgs and background
  - → 2.2σ excess in H→bb
  - → Total significance amounts to nearly 7 σ

- CMS measured the mass to be 125.8 ± 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

- More channels added/updated, more measurements for RC de Moriond 2013!