Study of Higgs production in bosonic decay channels at CMS

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on behalf of the CMS collaboration

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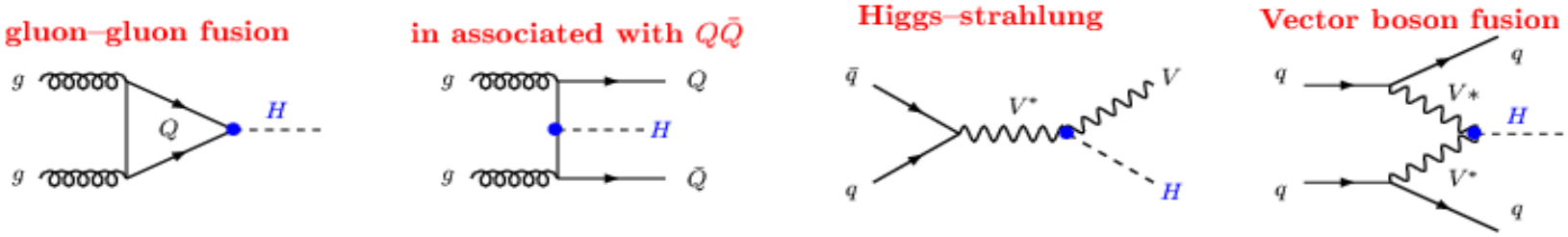
3 - 8 July 2016

Introduction

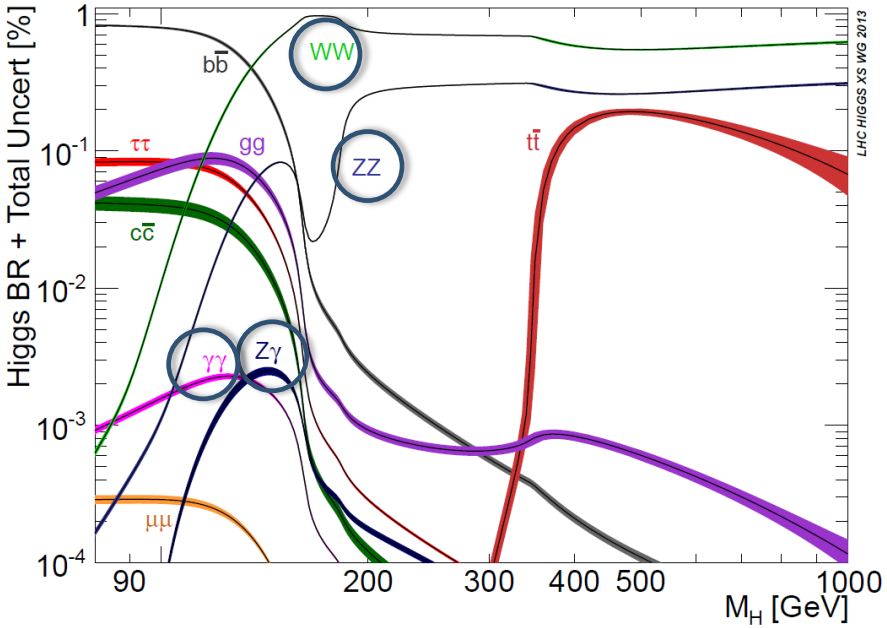
Higgs boson production:

- All production modes accessible at LHC



Higgs decays:

- Given the Higgs mass at 125 GeV, the branching ratios are determined from theory:



Higgs->ff (fermions):

- H→bb, H→ττ : [jets/MET] "low mass resolution"
- H→μμ : small BR

Higgs->VV (bosons):

- H → γγ
- H → ZZ→ 4ℓ

} "high mass resolution"

- H → WW : large x-sec
- H→Zγ; rare

Overview of CMS searches

CMS Run1 (2011-2012):

$\sqrt{s}$ = 7 TeV , L ~5.1 fb^{-1} and $\sqrt{s}$ = 8 TeV, L ~ 19.6 fb^{-1}.

H → ***γγ*** , **H** → **ZZ** and **H** → **WW** channels

- Higgs discovery and measurements of its properties
- Higgs mass and width
- signal strength measurements in event categories
- production and decay: couplings / cross-section / spin and parity measurements
- BSM searches: additional Higgs partners , (non-)resonant HH

CMS Run2 (2015):

$\sqrt{s}$ = 13 TeV , L~2.9 fb^{-1} .

- Towards Higgs re-discovery: H → *γγ*, H → ZZ→ 4*ℓ* and properties
- Searches for high mass resonances in γγ / Zγ and ZZ→ (4l, 2l2ν, 2l2q) final states
- HH resonant: e.g. H(bb)H(WW) etc

H→γγ (run1)

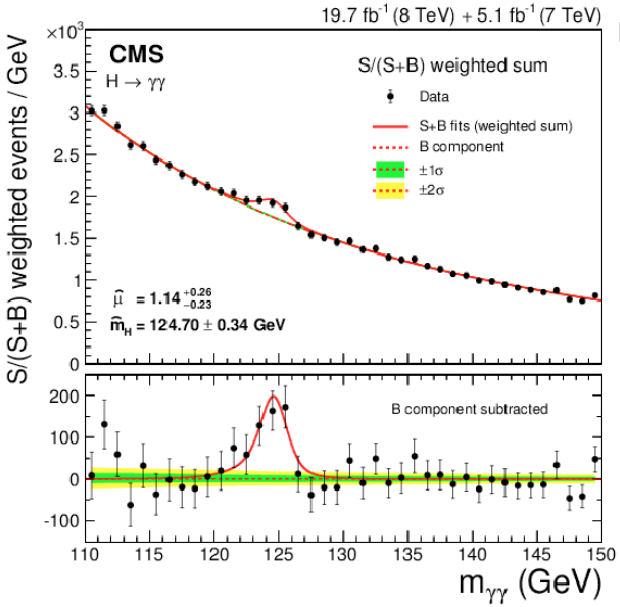
CMS-HIG-13-001
Eur. Phys. J. C 74 (2014) 3076

Observation of Higgs in the di-photon decay channel

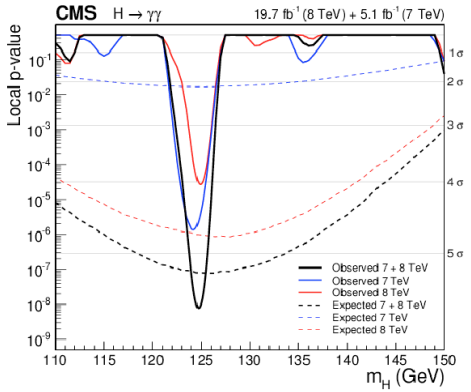
- Small BR~0.2% but good S/B and high mass resolution.
- Backgrounds from irreducible SM γγ production and γ−jet reducible sources.

Event categorization according to photon quality (MVA), kinematics and presence of objects to probe different production modes

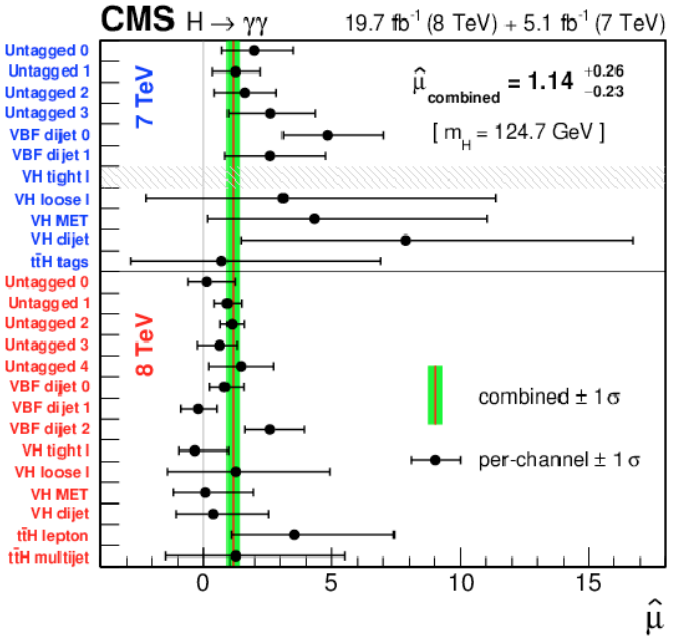
- ttH, VBF [dijet0,1], VH [MET, dijet], Untagged 0,1,2,3



m_H = 124.70 ± 0.34 GeV = 124.70 0.31 (stat) ± 0.15 (syst) GeV



local significance :
5.7σ (obs) vs 5.2σ expected



H→ZZ→4ℓ (run1)

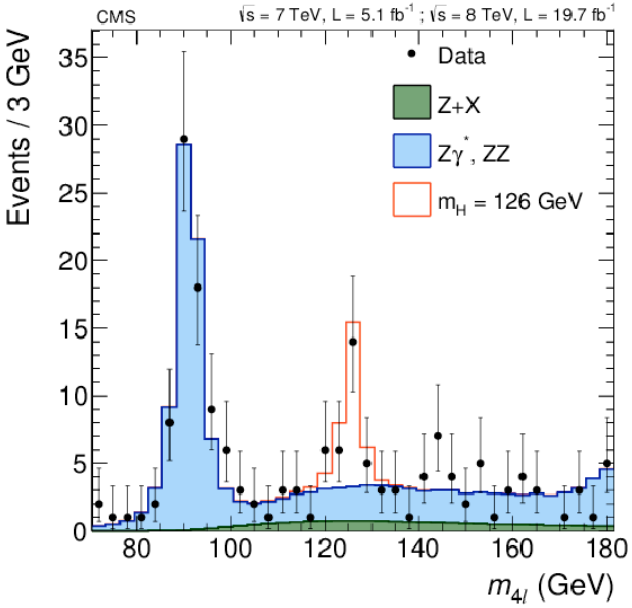
CMS-PAS-HIG-13-002
PRD 89 (2014) 092007

Observation of Higgs as a narrow resonance in the 4-lepton invariant Mass

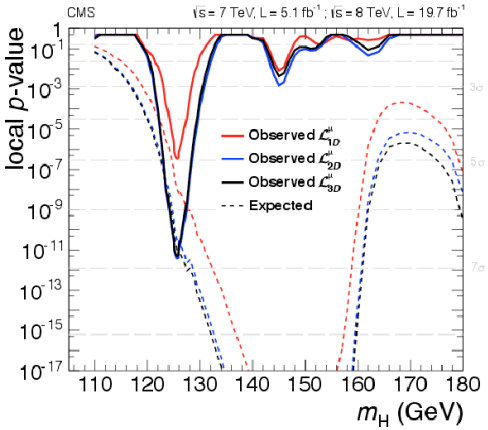
- Backgrounds: ZZ and Zγ* estimate from simulation; reducible Zbb, tt and instr. Z+X from control regions in data.
- Excellent mass resolution; relies on calibration of the lepton p_T scale and resolution / lepton selection efficiencies.

Events split in categories to allow sensitivity to diff production mechanisms:

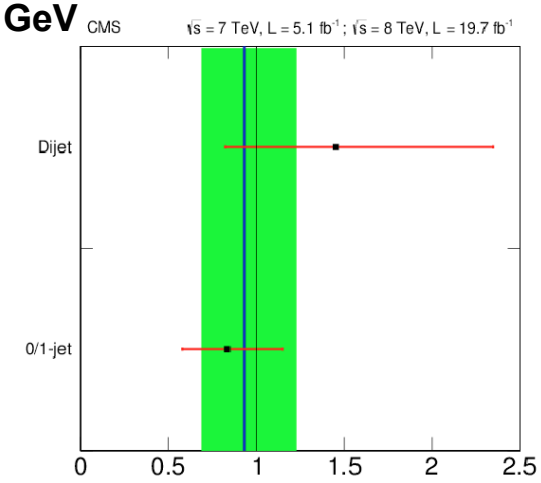
- **Cat. I**: < 2jets; 4-lep p_T/m_{4l} discriminates VBF and VH from gluon fusion
- **Cat. II** : >= 2jets; VBF-like variables $\Delta\eta_{jj}$ and Mjj



m_H = 125.80 ± 0.5 (stat) ± 0.2 (syst) GeV



local significance :
6.7σ (obs) vs 7.2σ expected



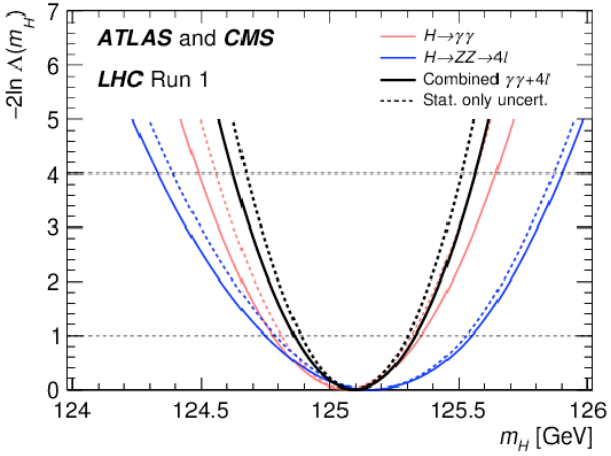
μ = 0.91 $^{+0.30}_{-0.24}$

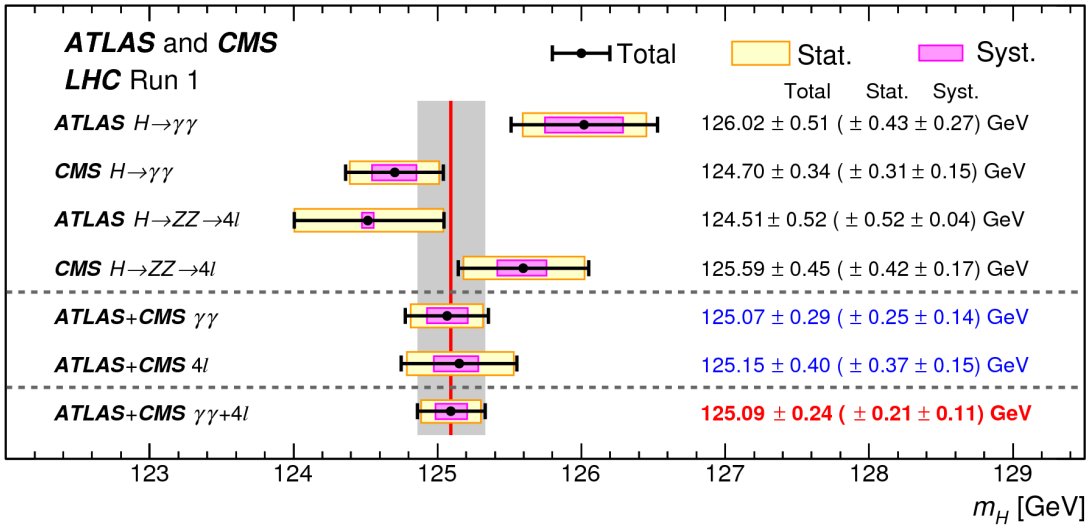
Higgs mass: combination

ATLAS-HIGG-2014-14
CMS-PAS-HIG-14-042

A combined ATLAS and CMS mass measurement with H→γγ and H→ZZ→4ℓ channels

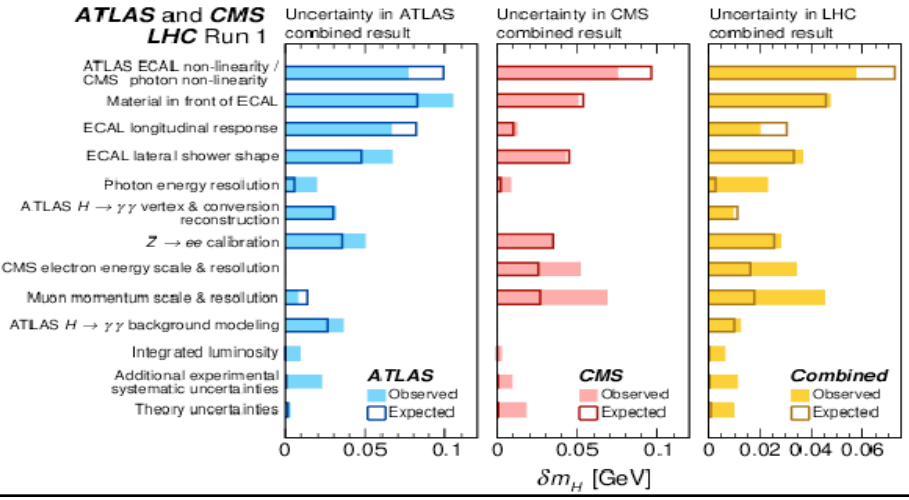
- Simultaneous fit to the inv. Mass peaks in the two channels for ATLAS and CMS





Dominant systematic uncertainties:

- experimental: photon, electron/muon p_T scale and resolution
- theory: Higgs x-sections and BRs, SM backgrounds normalization etc



Higgs production and decay

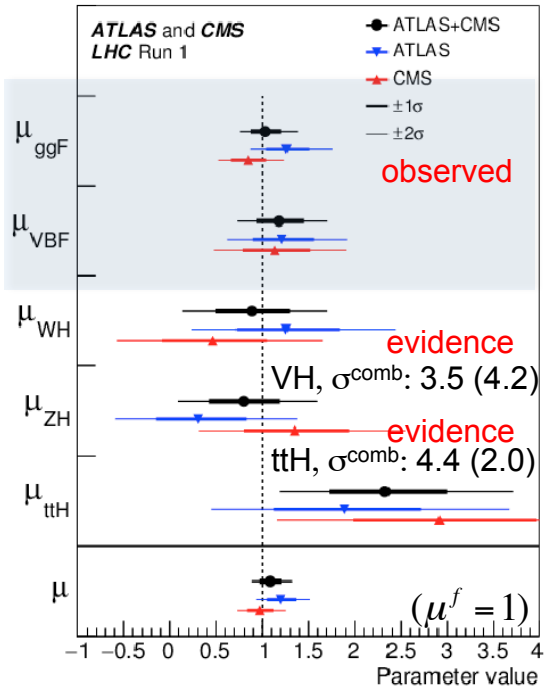
CMS-PAS-HIG-14-009
CMS-HIG-15-002; ATLAS-HIGG-2015-07

Compatibility tests with SM expectations:

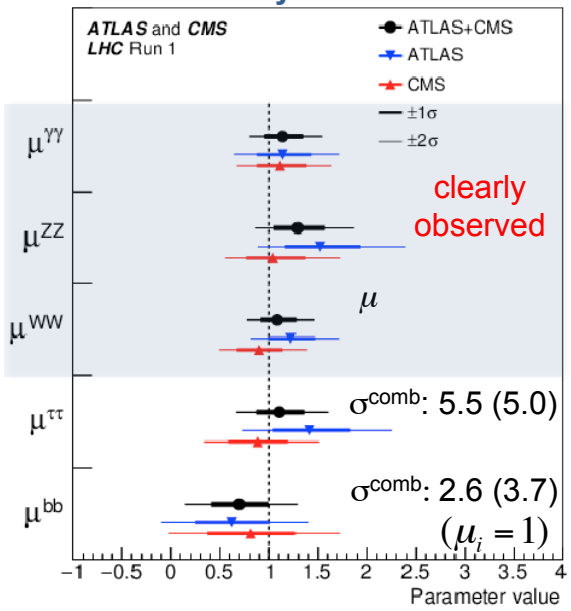
$$\mu_i = \frac{\sigma_i}{(\sigma_i)_{SM}}$$

$$\mu^f = \frac{BR^f}{(BR^f)_{SM}}$$

Production modes

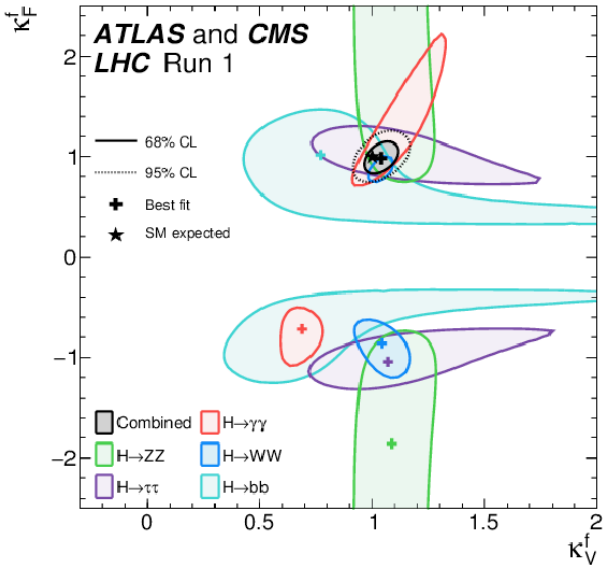


Decay channels



Constraints on the couplings:

Hff vs HVV



$$k_j^2 = \frac{\Gamma^j}{(\Gamma^j)_{SM}}$$

	Best fit μ	Uncertainty			
		Total	Stat	Expt	Thbgd	Thsig
ATLAS + CMS (measured)	1.09	$^{+0.11}_{-0.10}$	$^{+0.07}_{-0.07}$	$^{+0.04}_{-0.04}$	$^{+0.03}_{-0.03}$	$^{+0.07}_{-0.06}$
ATLAS + CMS (expected)		$^{+0.11}_{-0.10}$	$^{+0.07}_{-0.07}$	$^{+0.04}_{-0.04}$	$^{+0.03}_{-0.03}$	$^{+0.07}_{-0.06}$

Global signal strength μ compatible with SM within 1σ; dominant systematic term from theory unc. on ggF

Spin and parity

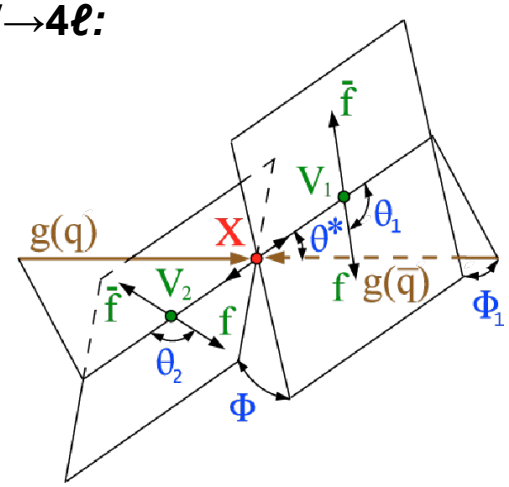
CMS-HIG-14-018

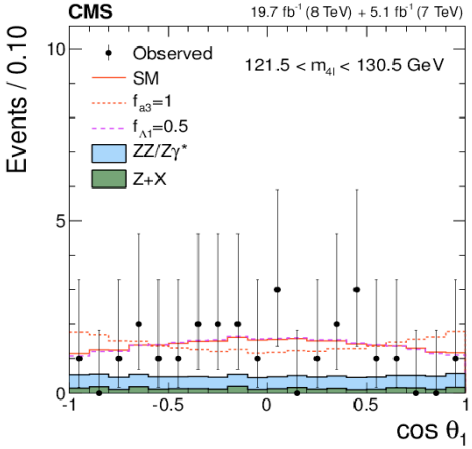
Phys. Rev. D 92 (2015) 012004

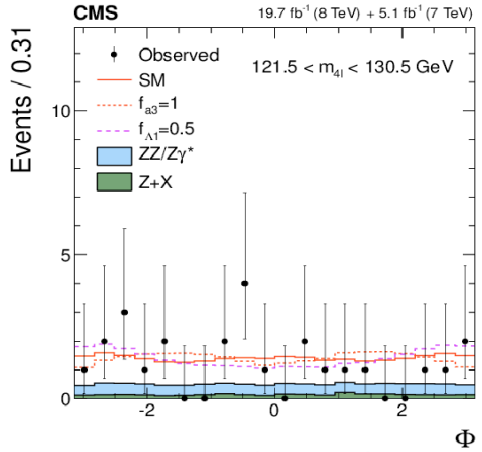
Studied using the H → ZZ*→ 4ℓ, H → WW → ℓνℓν, and H → γγ decay modes.

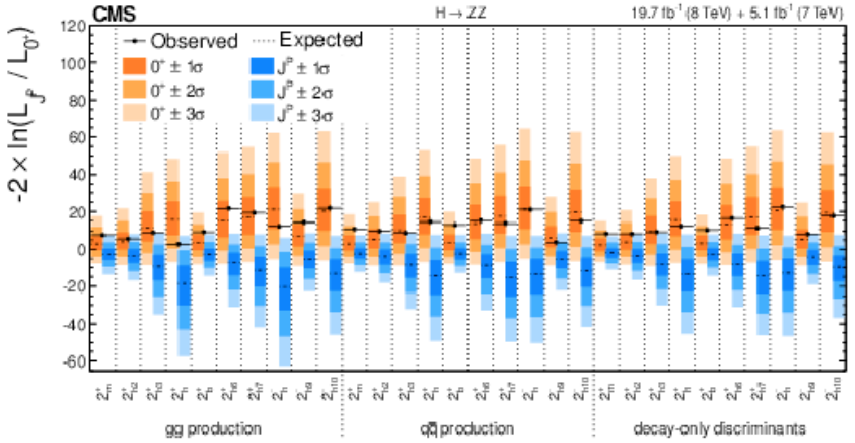
- H → γγ (sensitive to spin-2+ , excludes spin-1)
- H → ZZ→ 4ℓ (sensitive to all spin-parity)
- H → WW → ℓνℓν (sensitive to spin-1 and spin-2)

H→VV→4ℓ:









All consistent with the expectations for the standard model Higgs boson quantum numbers $J^{PC} = 0^{++}$.

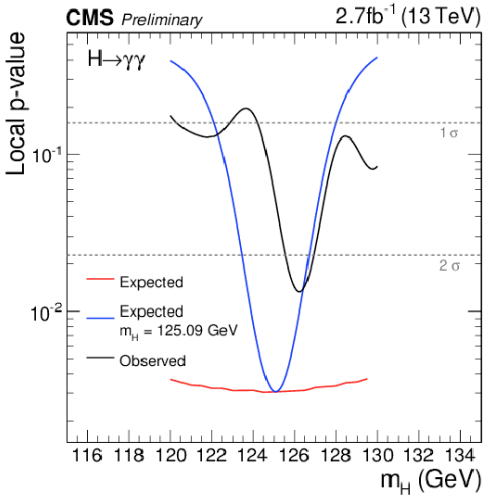
H→γγ / ZZ (run2)

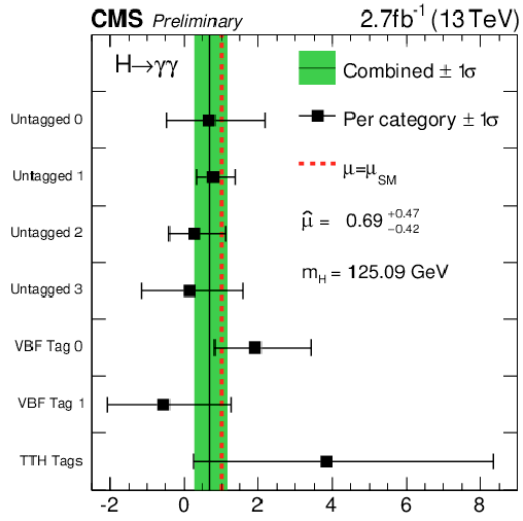
13 TeV

CMS-PAS-HIG-15-004
CMS-PAS-HIG-15-005

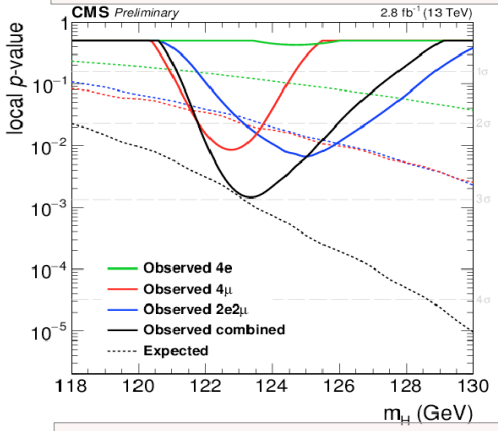
Higgs boson re-discovery in γγ and ZZ→4l final states; mass is fixed to 125.09 GeV

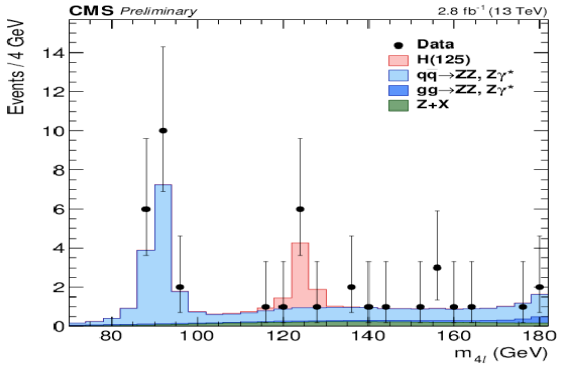
- Event categorization similar to Run1 (except where low statistics are expected)





Hγγ : for m_H = 125.09, obs. significance is 1.7σ (2.7σ expected)





HZZ->4l : for m_H = 125.09, obs. significance is 2.5σ (3.4σ exp.)

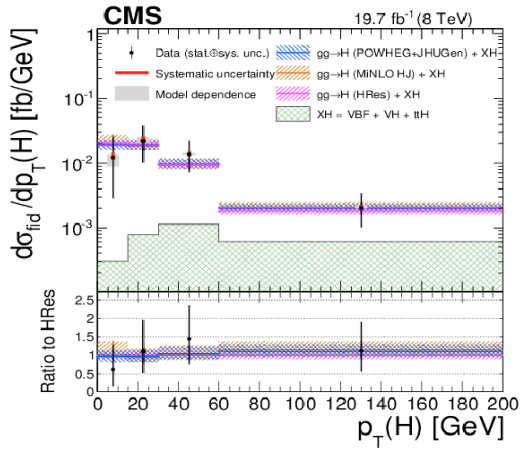
- Not yet as competitive as in Run1

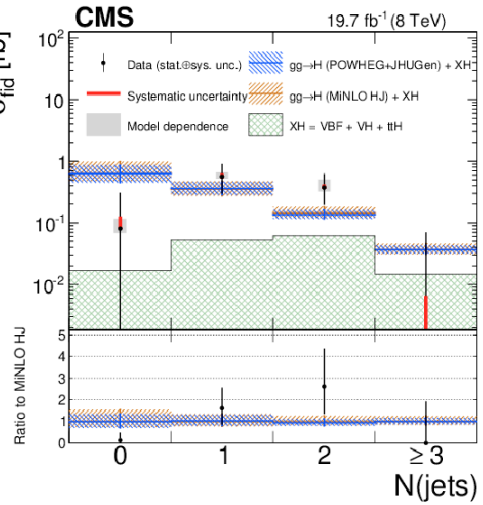
Cross sections: H→ZZ

CMS-PAS-HIG-14-028 [JHEP 04 (2016) 005]
CMS-PAS-HIG-14-016 [EPJ C 76 (2016) 13]
CMS-PAS-HIG-15-004

Differential cross-sections in terms of quantities like $p_T(H)$, $|\eta(H)|$ and Njet multiplicity

- Statistical uncertainties (23% - 75%) dominate all differential distributions



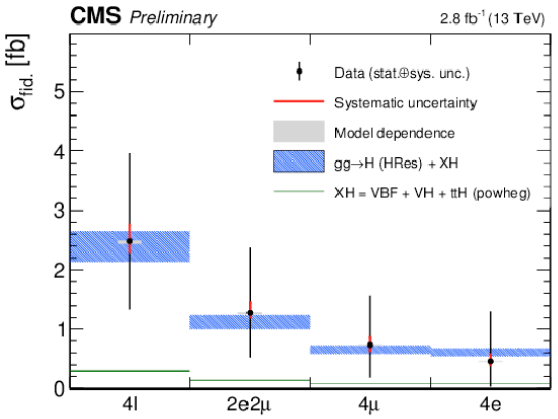


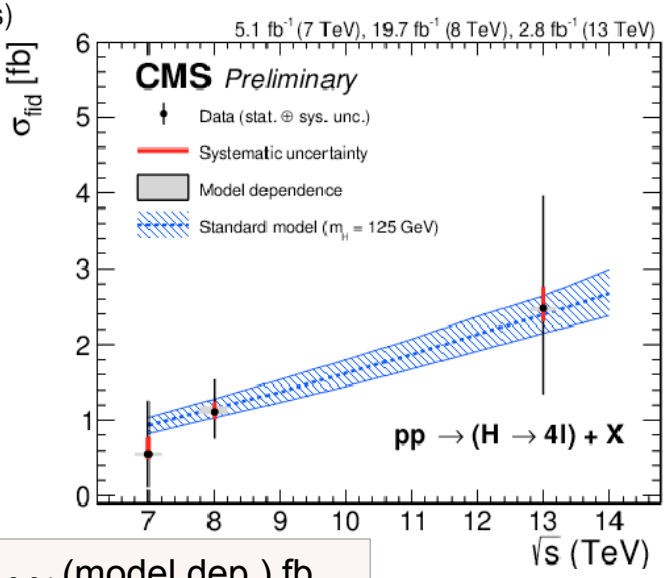
7 TeV : $\sigma^{fid} = 0.56\ ^{+0.67}_{-0.44}(stat)\ ^{+0.21}_{-0.06}(syst)$ fb

8 TeV: $\sigma^{fid} = 1.11\ ^{+0.41}_{-0.35}(stat)\ ^{+0.14}_{-0.10}(syst)$ fb

Compatible with SM estimates up to NNLO accuracy

13 TeV





13 TeV: $\sigma^{fid.} = 2.48^{+1.48}_{-1.14}$ (stat ⊕ syst) $^{+0.01}_{-0.04}$ (model dep.) fb.

Cross-sections: H→WW

CMS-PAS-HIG-15-010

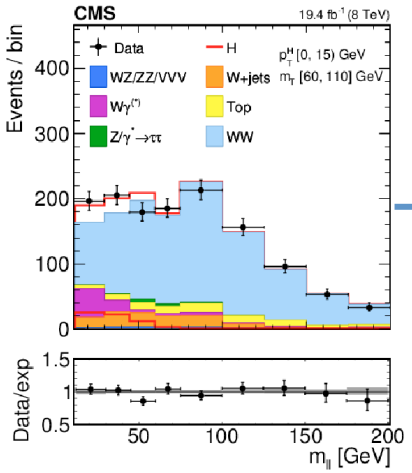
Fiducial cross-section measurement in the Higgs transverse momentum distribution

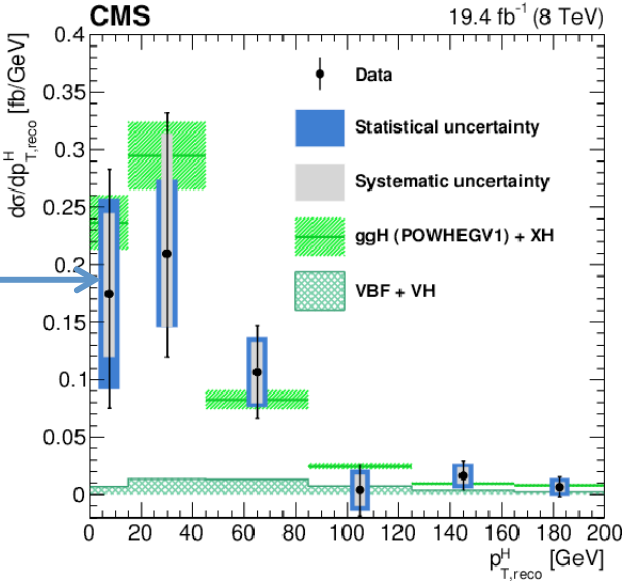
- Allows to test possible deviations from the SM predictions.

H→WW→2ℓ2ν fiducial selection:

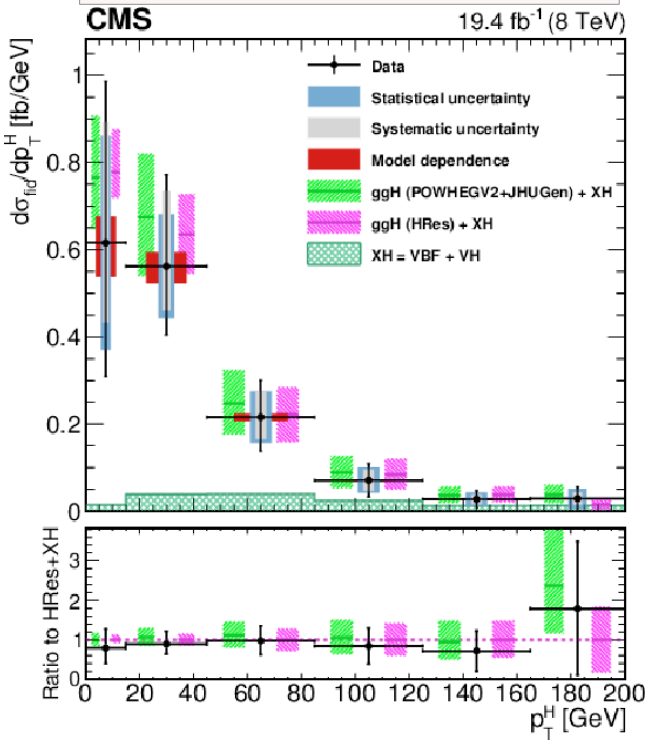
Physics quantity	Requirement
Leading lepton p_T	$p_T > 20$ GeV
Subleading lepton p_T	$p_T > 10$ GeV
Pseudorapidity of electrons and muons	$\|\eta\| < 2.5$
Invariant mass of the two charged leptons	$m_{\ell\ell} > 12$ GeV
Charged lepton pair p_T	$p_T^{\ell\ell} > 30$ GeV
Invariant mass of the leptonic system in the transverse plane	$m_T^{\ell\ell\nu\nu} > 50$ GeV
E_T^{miss}	$E_T^{miss} > 0$

mll in p_T^H:[0,15] – M_T:[60,110]





dσ/dx vs $p_T^H = p_T^{(ll)}$ + MET after the unfolding



$$\sigma_{fid} = 39 \pm 8\,(stat) \pm 9\,(syst)\ fb,$$

- Inclusive in Njet to reduce syst. from theory modeling of H + jets associated production.

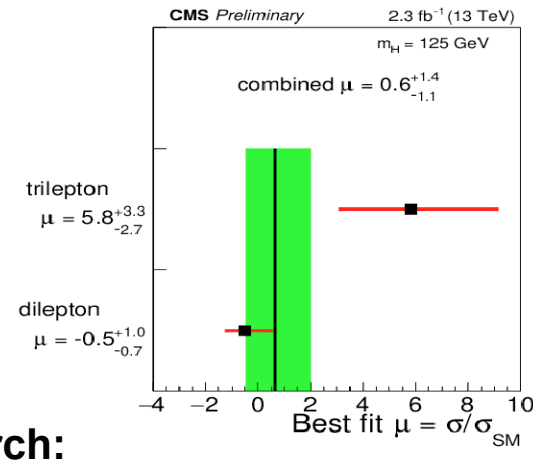
More from run2

13 TeV

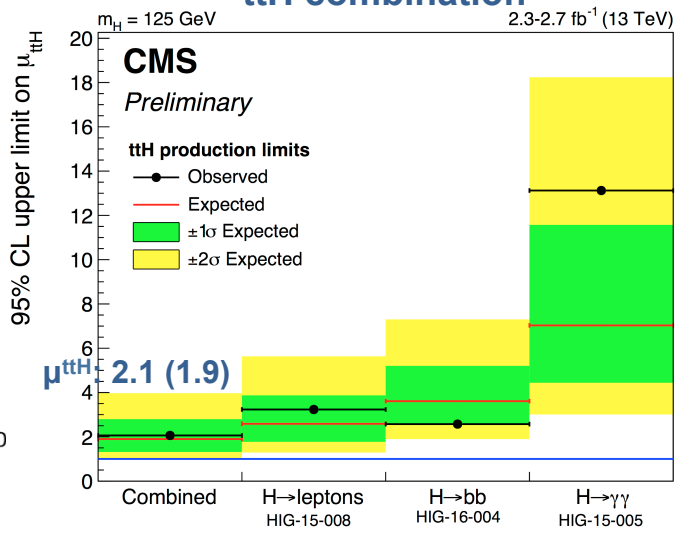
CMS-PAS-HIG-15-008
CMS-PAS-HIG-16-011

Search for ttH (multi-leptons) in ZZ*, WW* and ττ decay channels

- 2 same-sign leptons or >= 3 leptons + b jets

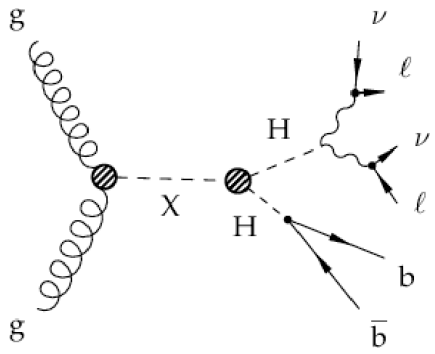


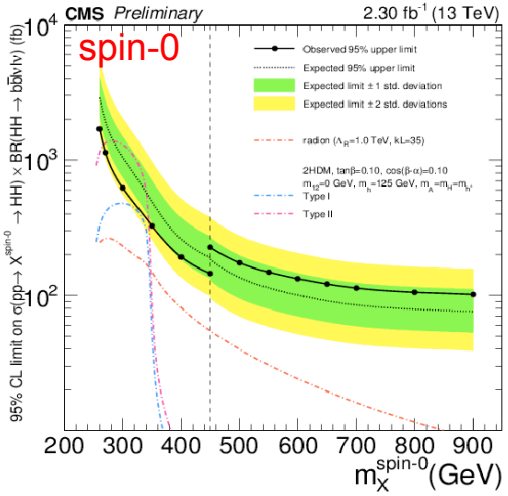
ttH combination

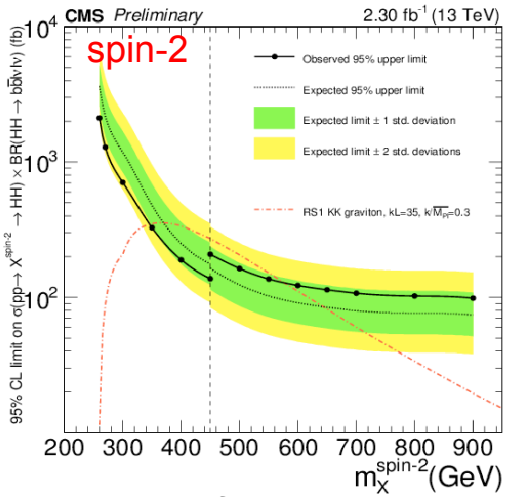


Resonant H(bb)H(WW) search:

- spin-0/2 resonance X decay to H boson pairs:







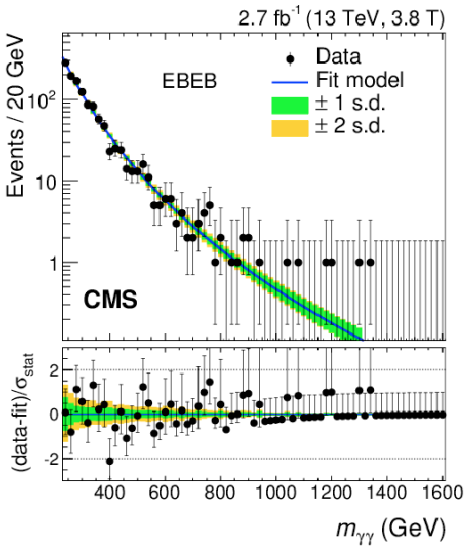
- For m_X= [500, 900] GeV, set limits on cross-section x branching ratio of a spin-0 particle from 174 to 101 (exp. 135 to 75.8) fb

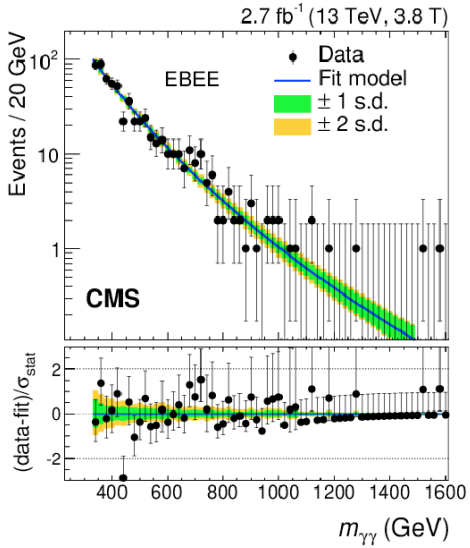
High mass resonances in H→γγ / Zγ

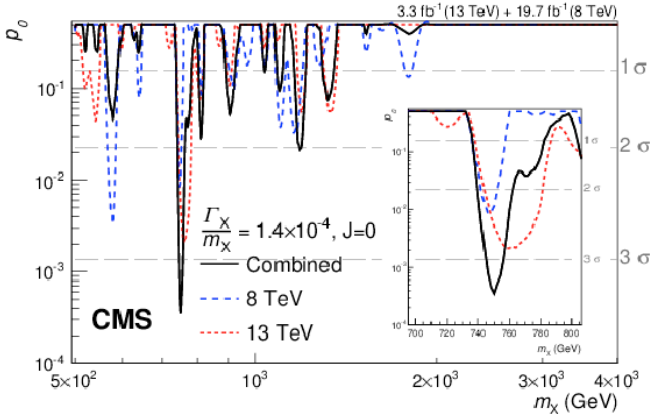
CMS-PAS-EXO-16-018
CMS-PAS-HIG-16-014

γγ final states:

- spin-0/ -2 resonances for m_X: [0.5, 4] TeV and width Γ_X/m_X: [1.4x10^{-4}, 5.6x10^{-2}]







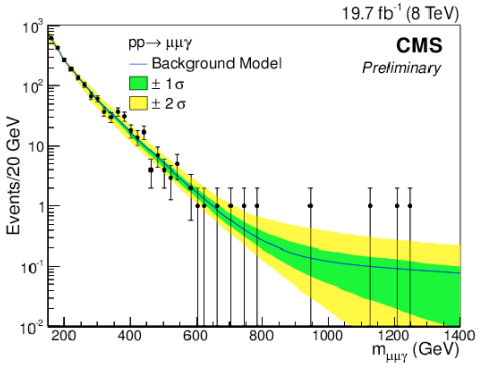
For m_X~750 GeV, Γ_X/m_X = 1.4x10^{-4}:

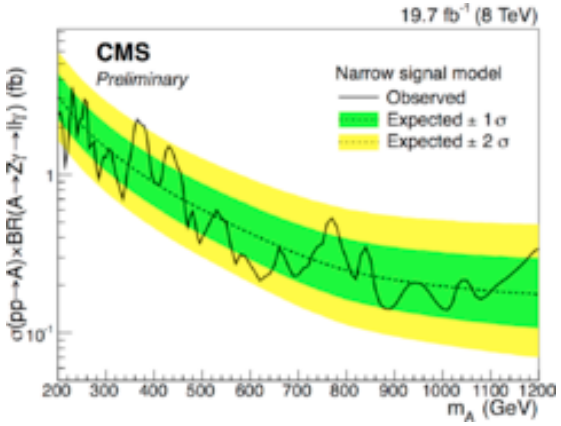
sign. of 3.4σ [8TeV + 13 TeV]

Zγ final states:

- A→Zγ→ℓℓγ

- For m_A: [200,1200] GeV, set upper limits on σ x BR : [0.15, 3.8] fb





High mass resonances in H→ZZ

13 TeV

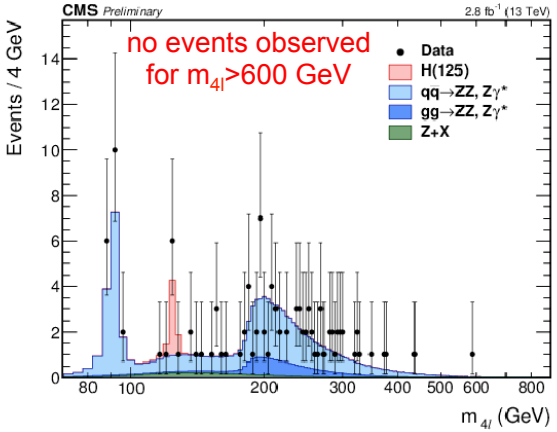
CMS-PAS-HIG-16-004
CMS-PAS-HIG-16-001

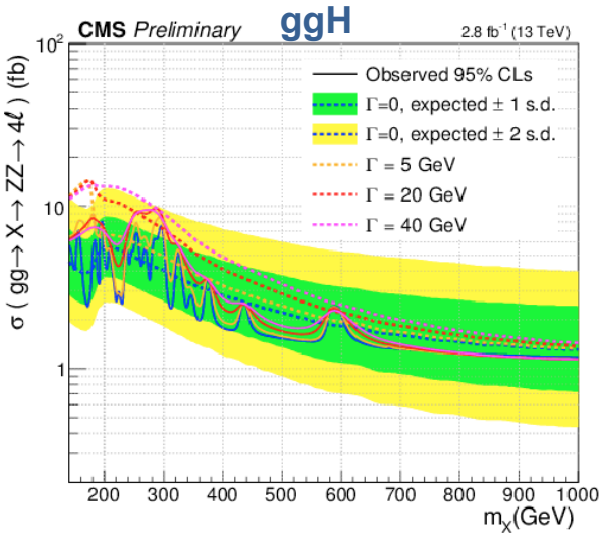
Limits on additional resonance H (m_X, Γ_X) for masses up to ~1 TeV:

- Limits for a heavy Higgs-like particle
- EWS, 2HDM interpretations

H→ZZ→4ℓ :

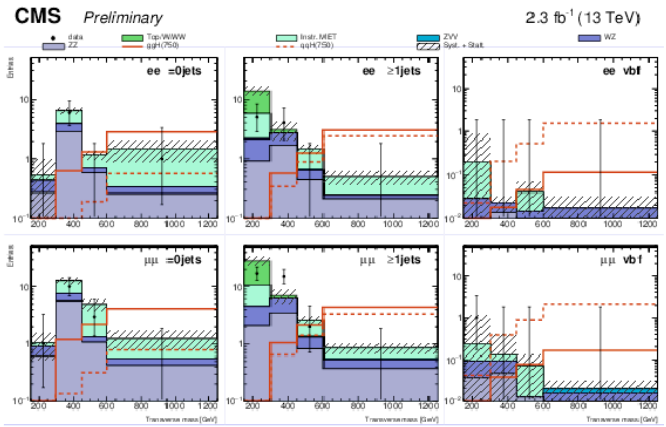
- Fit in the m(4l) distribution:

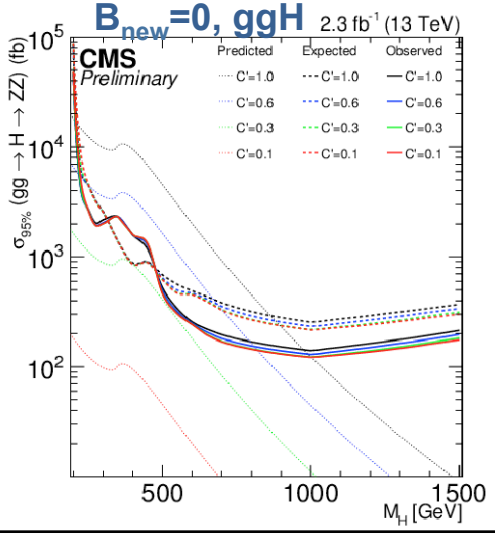


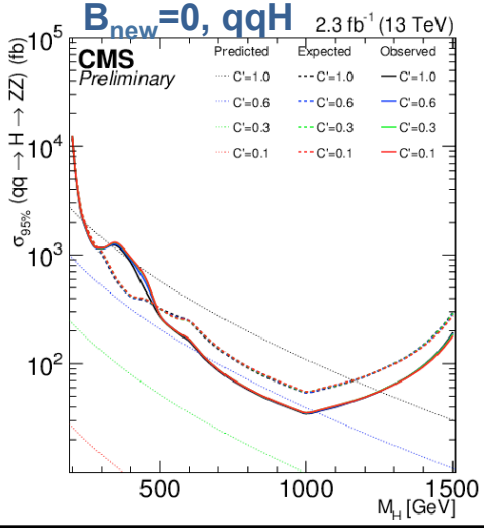


H→ZZ→2ℓ2ν :

- Event categorization in 0/1-jet, VBF; use MET (>125 GeV) and M_T variables:







Summary

Run1: very important measurements of the Higgs sector from the bosonic channels:

- $H \rightarrow ZZ$, $Z\gamma^{*} \rightarrow 4\ell$, $H \rightarrow WW \rightarrow \ell\nu\ell\nu$, and $H \rightarrow \gamma\gamma$

- Higgs discovery and measurement of its properties: Mass, width, spin, σ, $d\sigma/dX$, signal strength (production and decay), couplings =>
- Higgs profile fully consistent with the SM expectations

Run2: 2015 was a commissioning phase in the Higgs sector; not yet as competitive

Bosonic channels offer important tool in searches for New Physics:

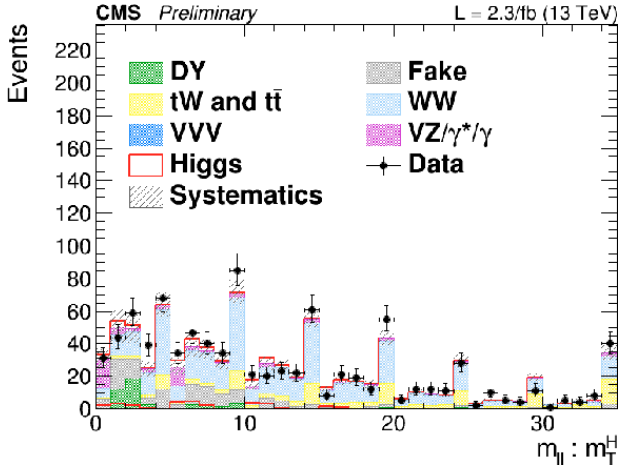
- High mass resonances, HH resonances etc

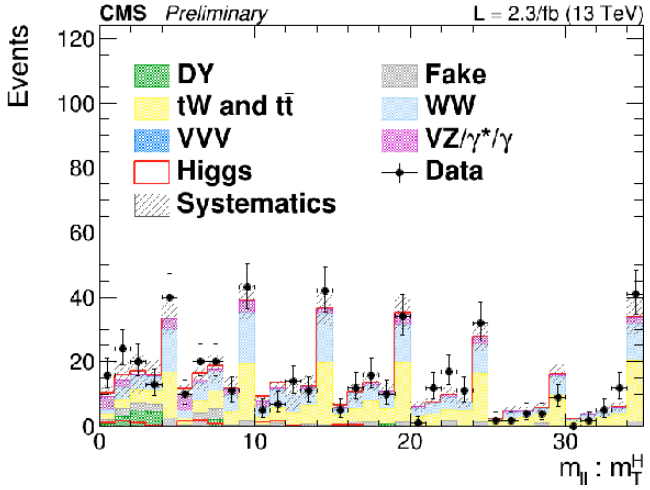
Back-ups: H→WW (run2)

13 TeV

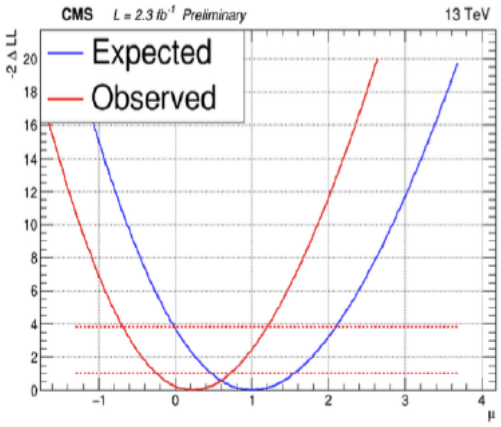
CMS-PAS-HIG-15-003

H→WW→eμ + νν : opposite-charge eμ in association with large MET for up to 1-jet.





For m_H=125. GeV, obs. significance is 0.7σ (2.0σ expected); best fit signal strength σ/σ_{SM} = 0.3 ± 0.5



Category	Expected significance	Observed significance	Expected error on σ/σ_{SM}	σ/σ_{SM}
0-jet μe	1.1	1.3	$^{+0.91}_{-0.88}$	$1.13\,^{+0.9}_{-0.9}$
0-jet $e\mu$	1.3	0.4	$^{+0.82}_{-0.77}$	$0.33\,^{+0.7}_{-0.7}$
1-jet μe	0.8	0	$^{+1.30}_{-1.21}$	$-0.11^{+0.5}_{-1.7}$
1-jet $e\mu$	0.9	0	$^{+1.17}_{-1.10}$	$-0.54^{+1.4}_{-1.4}$
0-jet	1.6	1.3	$^{+0.63}_{-0.61}$	$0.71^{+0.6}_{-0.5}$
1-jet	1.2	0	$^{+0.87}_{-0.83}$	$-0.56^{+1.0}_{-1.0}$
Combination	2.0	0.7	$^{+0.53}_{-0.51}$	$0.33^{+0.5}_{-0.5}$