

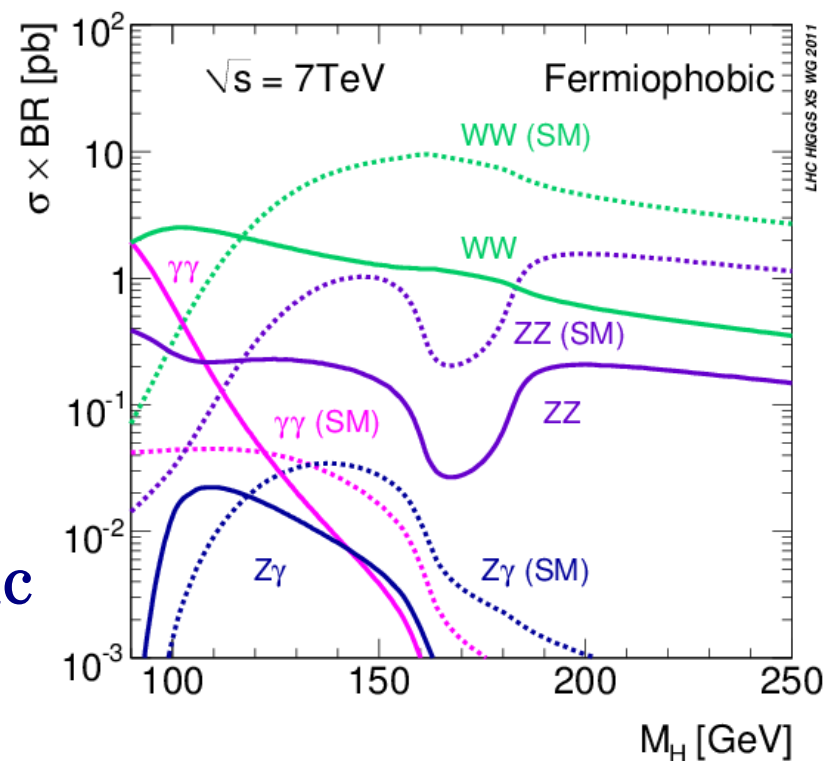
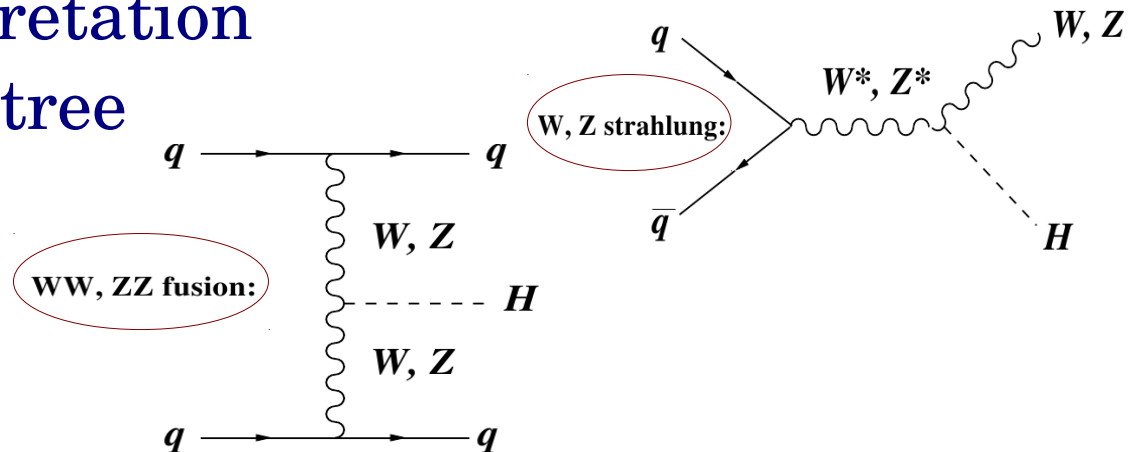


Search for a Fermiophobic Higgs Particle

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on behalf of the CMS Collaboration

Fermiophobic Higgs (FP)

- In the Fermiophobic interpretation the Higgs boson couples at tree level only with W and Z .
- FP Higgs has SM-like production cross-section for VBF and VH, while gluon fusion and ttH are absent at tree level.
- Only decay modes: WW , ZZ and $\gamma\gamma$:
 - Branching ratio at low mass enhanced with respect to SM.
- LEP, Tevatron and ATLAS excluded at 95% C.L. a Fermiophobic Higgs boson lighter than **121 GeV**.



- The search for a Fermiophobic Higgs at CMS consists of separated analysis for each exclusive channel (in $\gamma\gamma$ and WW decay modes):
 - Di-jet tag events (VBF production);
 - Lepton and MET tag events (VH production).
- Analysis also exploit the boosted kinematic of the Fermiophobic production mechanisms (e.g. 2D fit).
- In addition $H \rightarrow ZZ$ Standard Model analysis has been re-interpreted in the context of FP Model.
- The combination of the analysis of 2011 data ($L=4.9-5.1 \text{ fb}^{-1}$) is reported together with the updated result with additional 5.3 fb^{-1} (2012 data) for $\gamma\gamma$ decay mode.

**References: CERN-PH-EP-2012-174 submitted to JHEP
CMS-HIG-PAS-012-022**

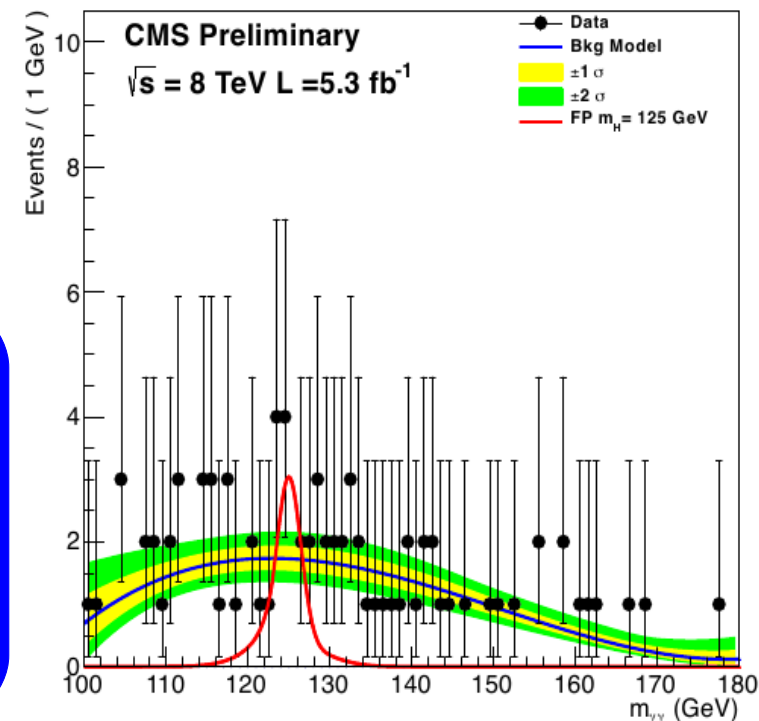
- Two isolated photons selected using cut-based photon ID implemented for the inclusive SM search:
 - Main background: irreducible di-photon prompt production, reducible γ +jets and di-jet QCD.
- Four mutually exclusive channels (selections optimized minimizing expected limit).
- Di-jet tag:** two high E_T jets with wide η separation typical of the VBF signature: $S/B \sim 1$.

Di-jets tag selection

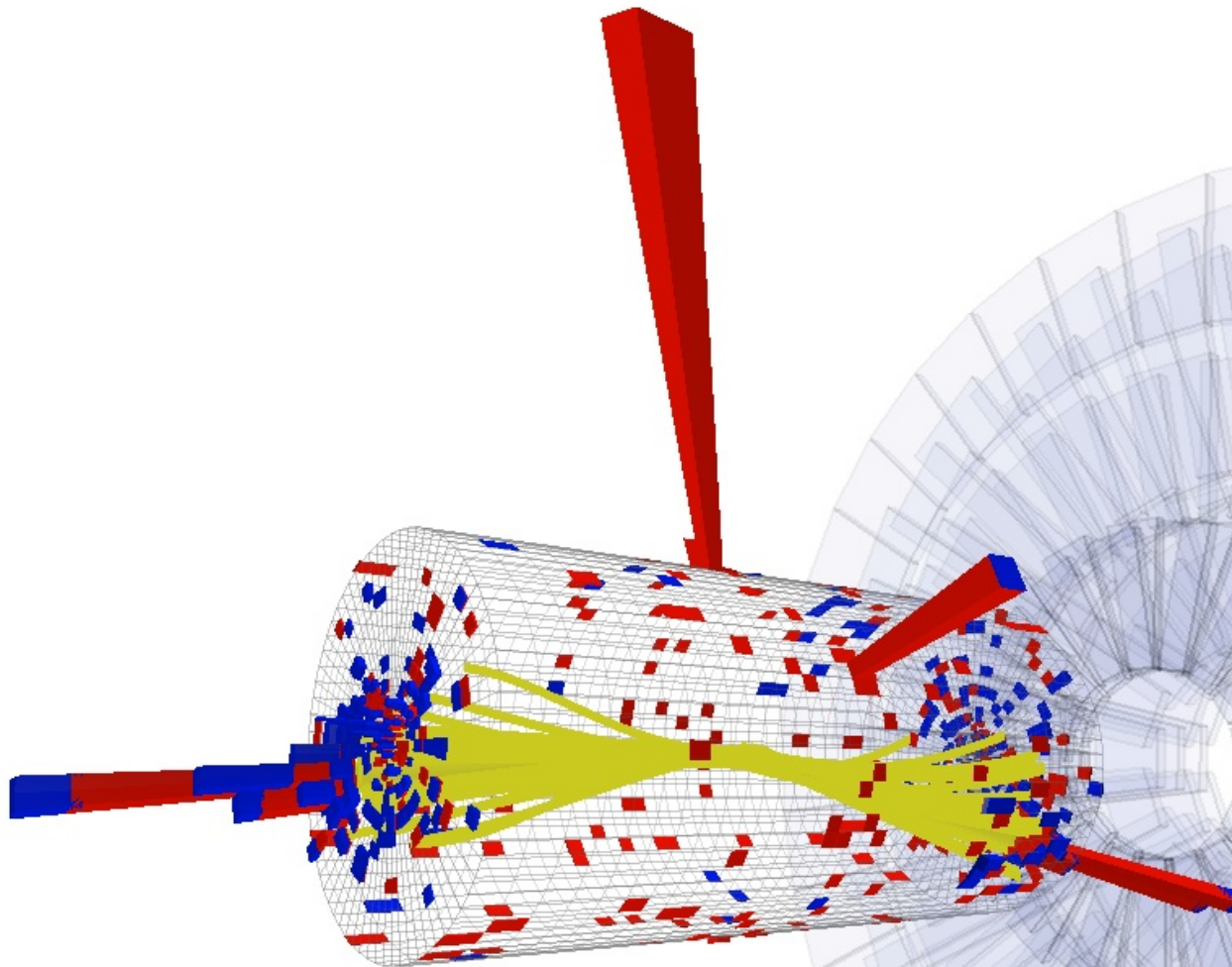
$E_T(\text{Jets})$ 20, 30 GeV; $m_{jj} > 250$ GeV

$\Delta\eta(j;j) > 3.5$; $\Delta\phi(\gamma\gamma; jj) > 2.6$; Zeppenfeld variable < 2.5

(only 2012 analysis) class subdivided in two according to amount of background contamination using m_{jj} .



Di-jet Tagged Event



$M_{\gamma\gamma} = 121.9 \text{ GeV}$
 $E_T(\gamma 1) = 193.9 \text{ GeV}$
 $E_T(\gamma 2) = 78.0 \text{ GeV}$
 $\eta(\gamma 1) = -0.405$
 $\eta(\gamma 2) = 0.037$
 $M_{jj} = 1460 \text{ GeV}$
 $E_T(j 1) = 288.8 \text{ GeV}$
 $E_T(j 2) = 189.1 \text{ GeV}$
 $\eta(j 1) = -2.022$
 $\eta(j 2) = 1.860$

CMS Experiment at LHC, CERN
 Data recorded: Mon Sep 26 20:18:07 2011 CEST
 Run/Event: 177201 / 625786854
 Lumi section: 450

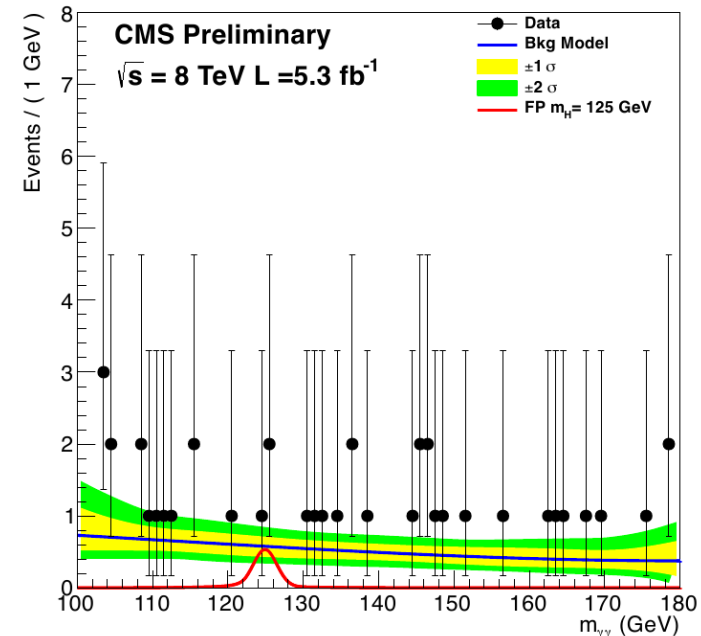
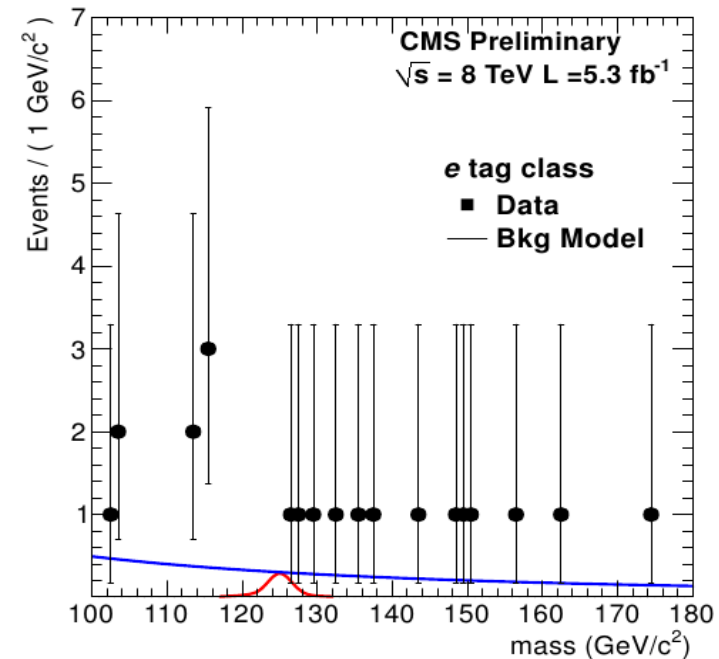
$\gamma\gamma$ Decay Mode

- Lepton tag:** aim to select VH events, with V decaying to leptons: S/B large compared to inclusive analysis due to requirements on isolated leptons.

CMS Standard cut-based lepton ID updated in 2012 analysis to cope with new data taking conditions
 $dR(l, \gamma) > 1$. (reject FSR γ)
 $|dM|(e\gamma; Z) > 5 \text{ GeV}$ (reject $Z\gamma$)

- MET tag:** (only 2012 analysis) complementary to Lepton tag selects VH production with $Z \rightarrow \nu\nu$.

γ in the endcap are not considered due to negligible contribution
 $\text{MET} > 70 \text{ GeV}$

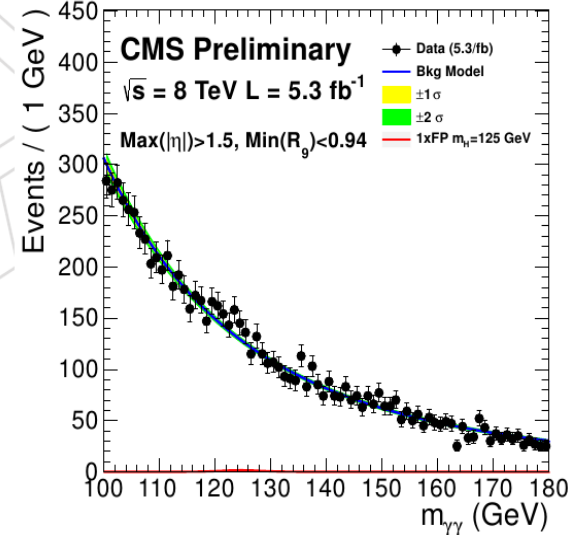
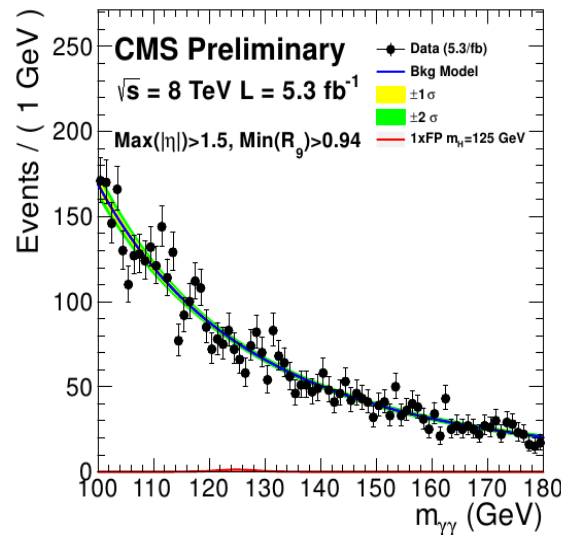
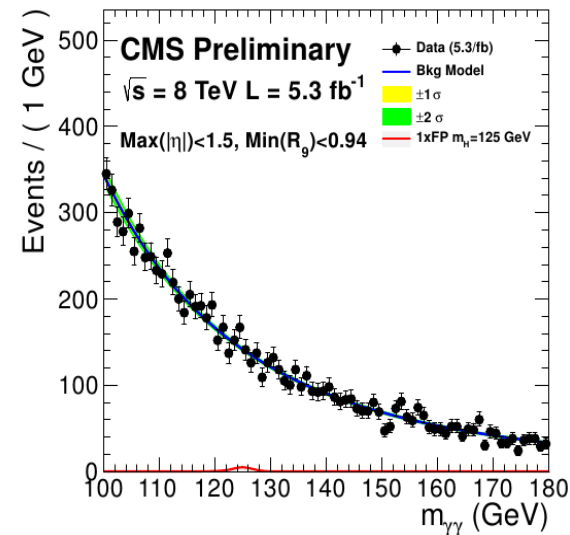
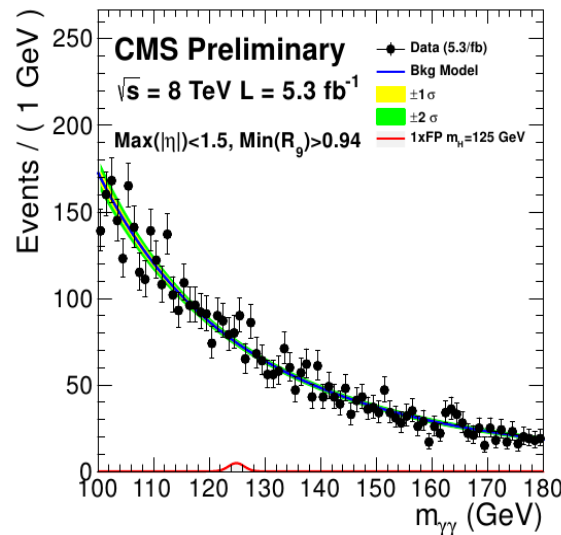


- **Untagged:** events passing inclusive selection but not belonging to one of the above classes: $S/B \ll 1$:

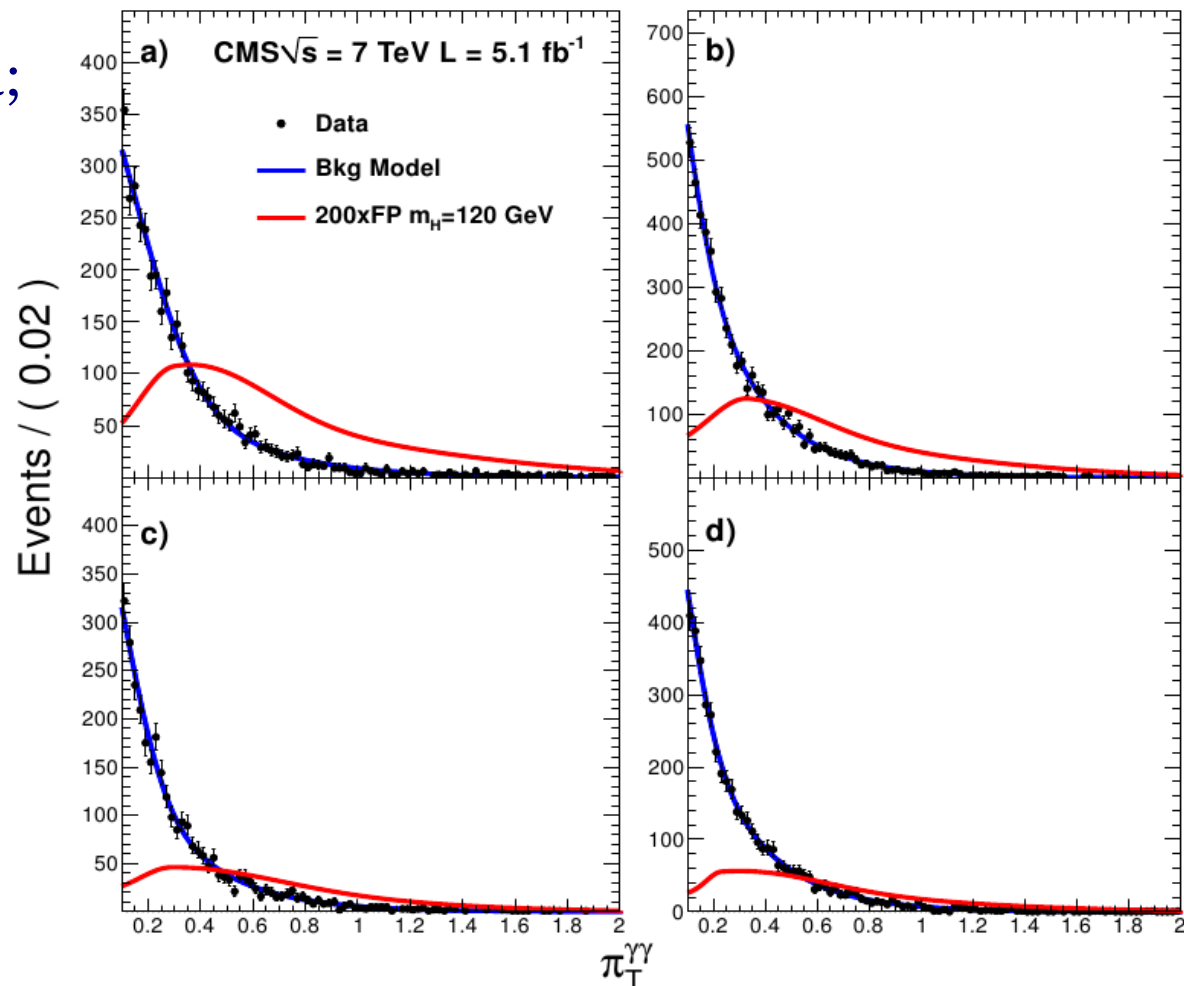
- Events are further classified following pseudorapidity and shower shape properties of the γ ; with such categorization events with similar di-photon mass resolution are grouped together.

Exploit harder VBF, VH
di-photon p_T spectrum

$$\pi^\gamma = p_T^\gamma / m_{\gamma\gamma} > 0.1$$

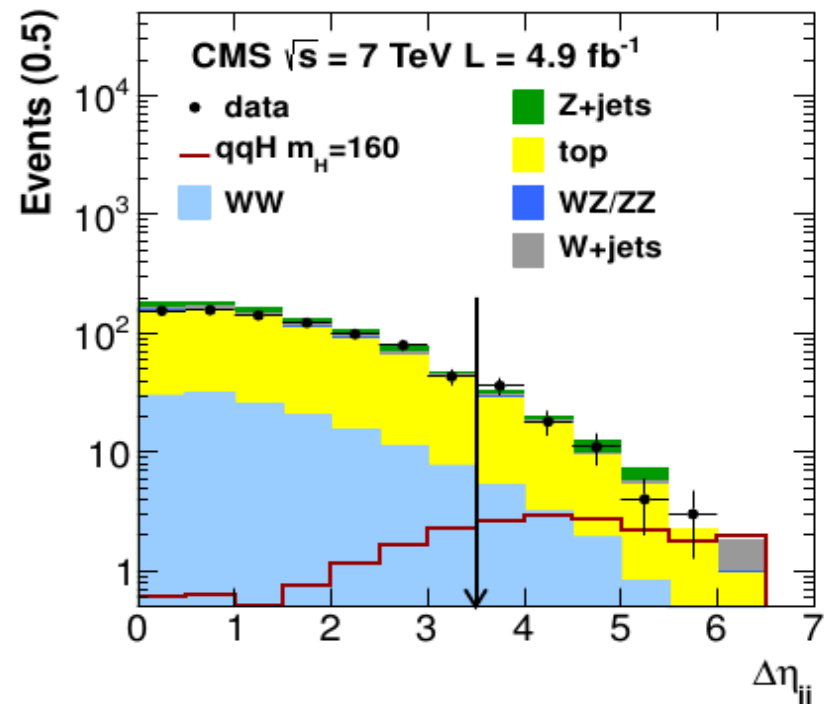
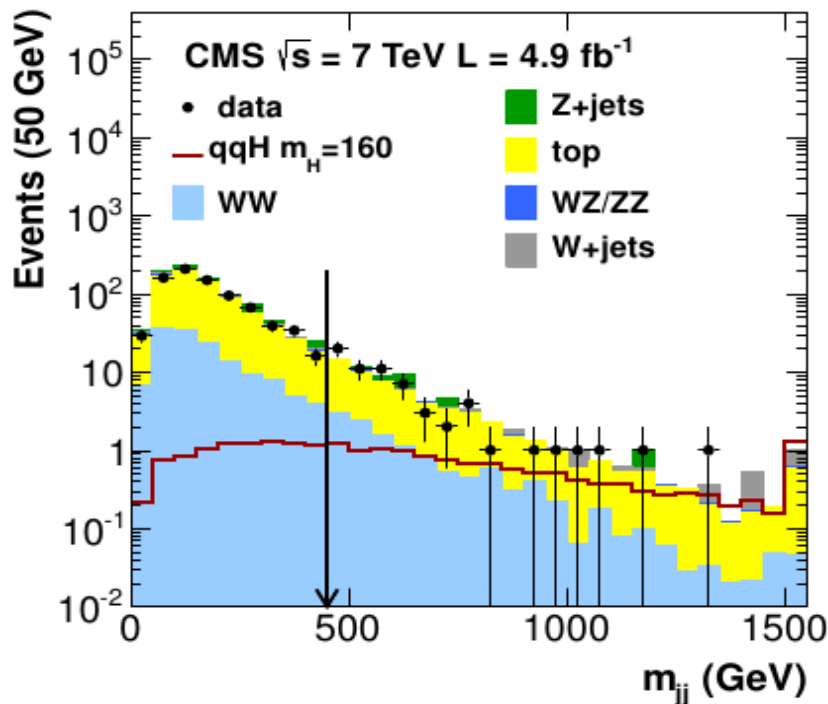


- Likelihood function based on pdf for signal and background shapes:
 - **Signal model:** estimated from simulation;
 - **Background model:** derived directly from data;
 - Checks for possible biases on the limit due to different shape choice.
- Di-photon mass is used as physical observable in all event classes.
- In the untagged class a **2D** model is constructed using also $\pi_T^{\gamma\gamma} = p_T^{\gamma\gamma}/m_{\gamma\gamma}$.



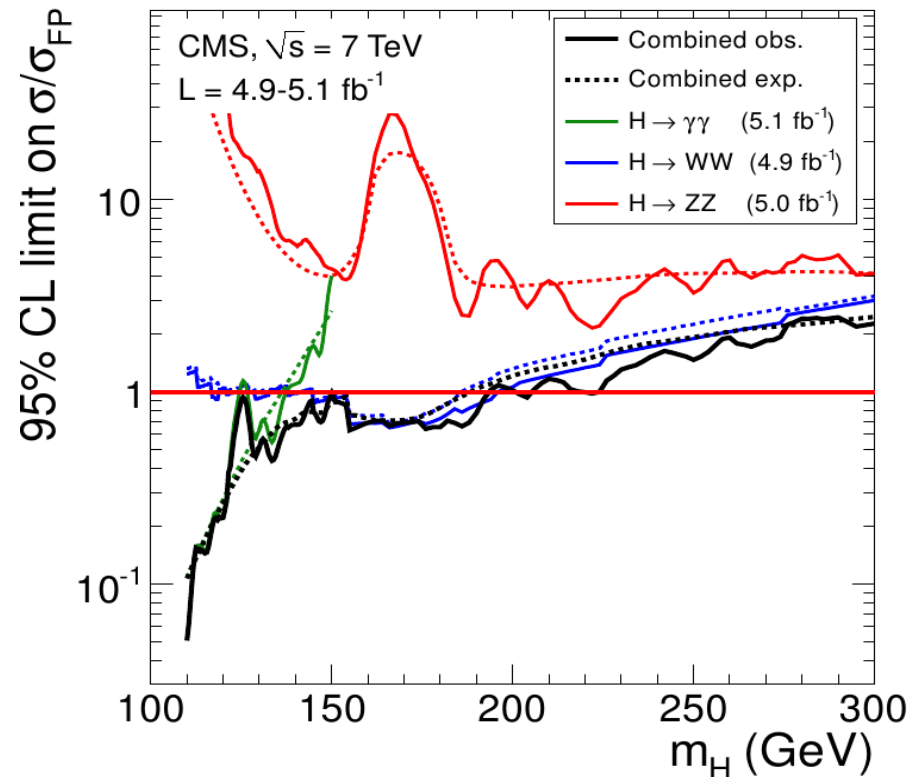
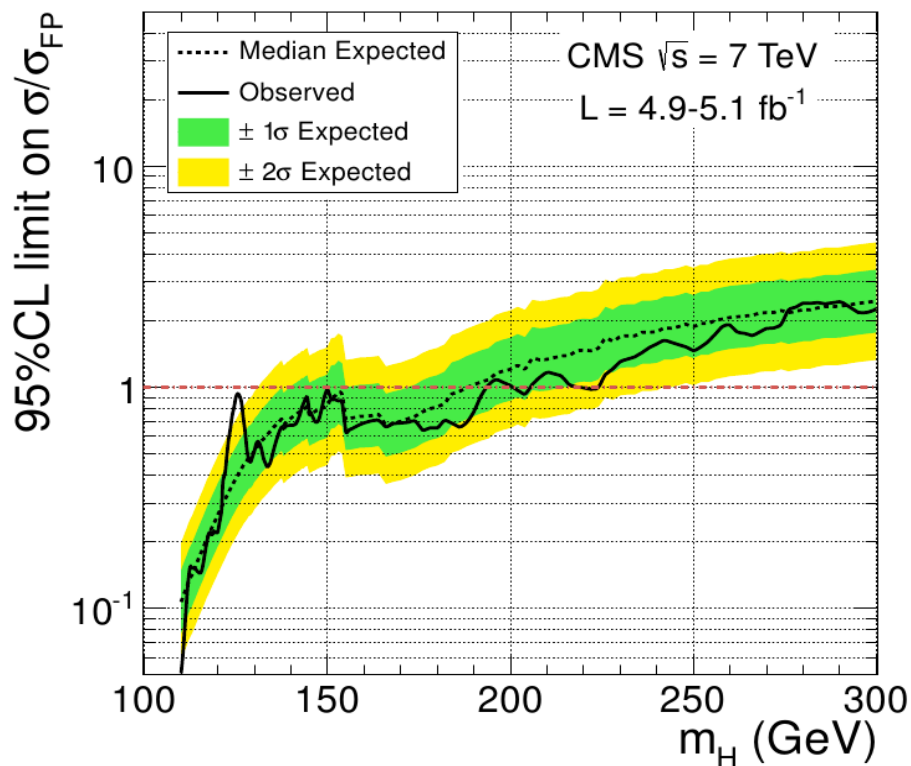
WW Decay Mode

- **Di-jet tag:** final state with two opposite charged isolated leptons, large MET and two jets with VBF topology:
 - Expected 10-20 events (depending on Higgs mass hypothesis), all main background (WZ, Z+jets) are estimated from data (small ZZ contribution from simulation).
- **Lepton tag:** (WH→WW events) look for three leptons final state, large MET and low hadronic activity.



Combined Exclusion Limits (2011)

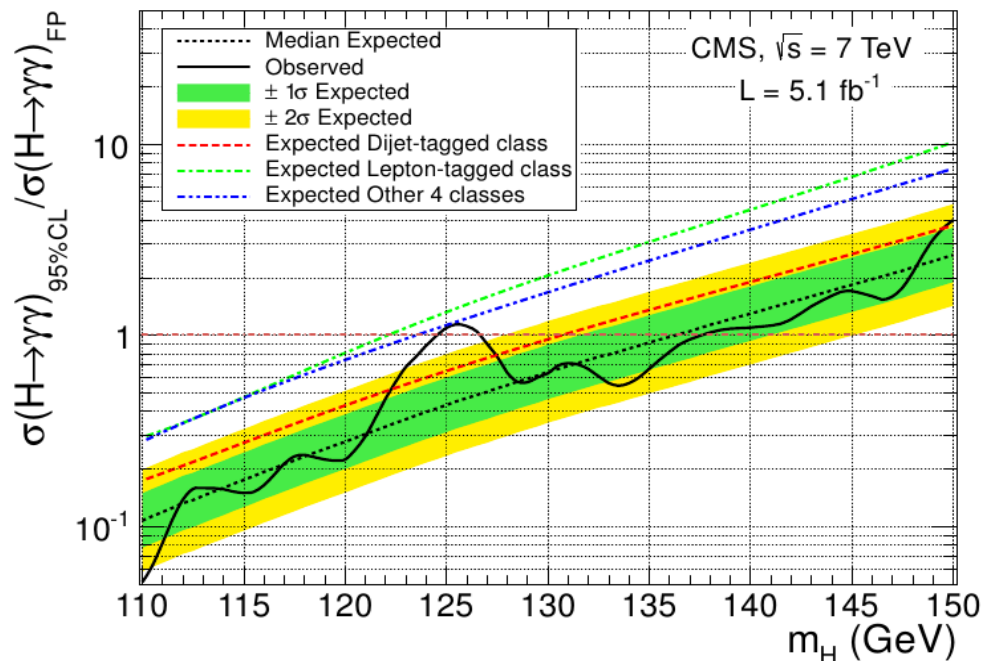
- Exclusion limit at 95% C.L. relative to FP model expectation as a function of the Higgs mass combining all three decay modes:
 - A Fermiophobic Higgs boson is excluded at 95% C.L. in the mass range **[110-192] GeV**.
 - At 99% C.L. we exclude a FP Higgs in the range **[110-188] GeV** except for **[124.5-128]** and **[148-154] GeV**.



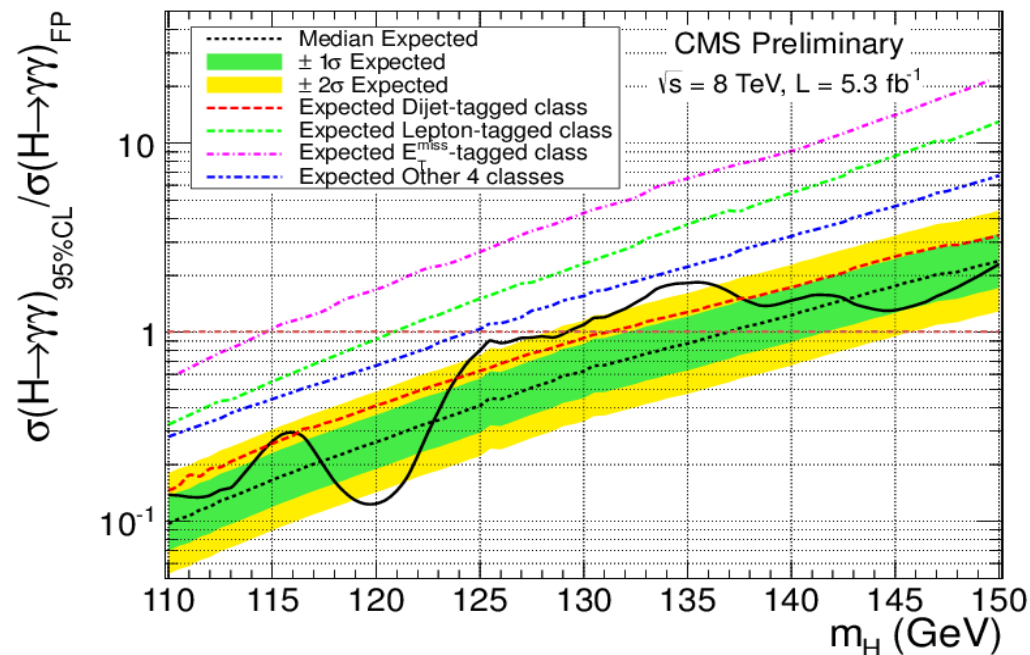
Updated Results (2012)

- $\gamma\gamma$ decay mode results have been updated analyzing 5.3 fb^{-1} data collected in 2012 at $\sqrt{s} = 8 \text{ TeV}$.
- Exclusion limit at 95% C.L. relative to FP model expectation as a function of the Higgs mass for 2011 and 2012 data.

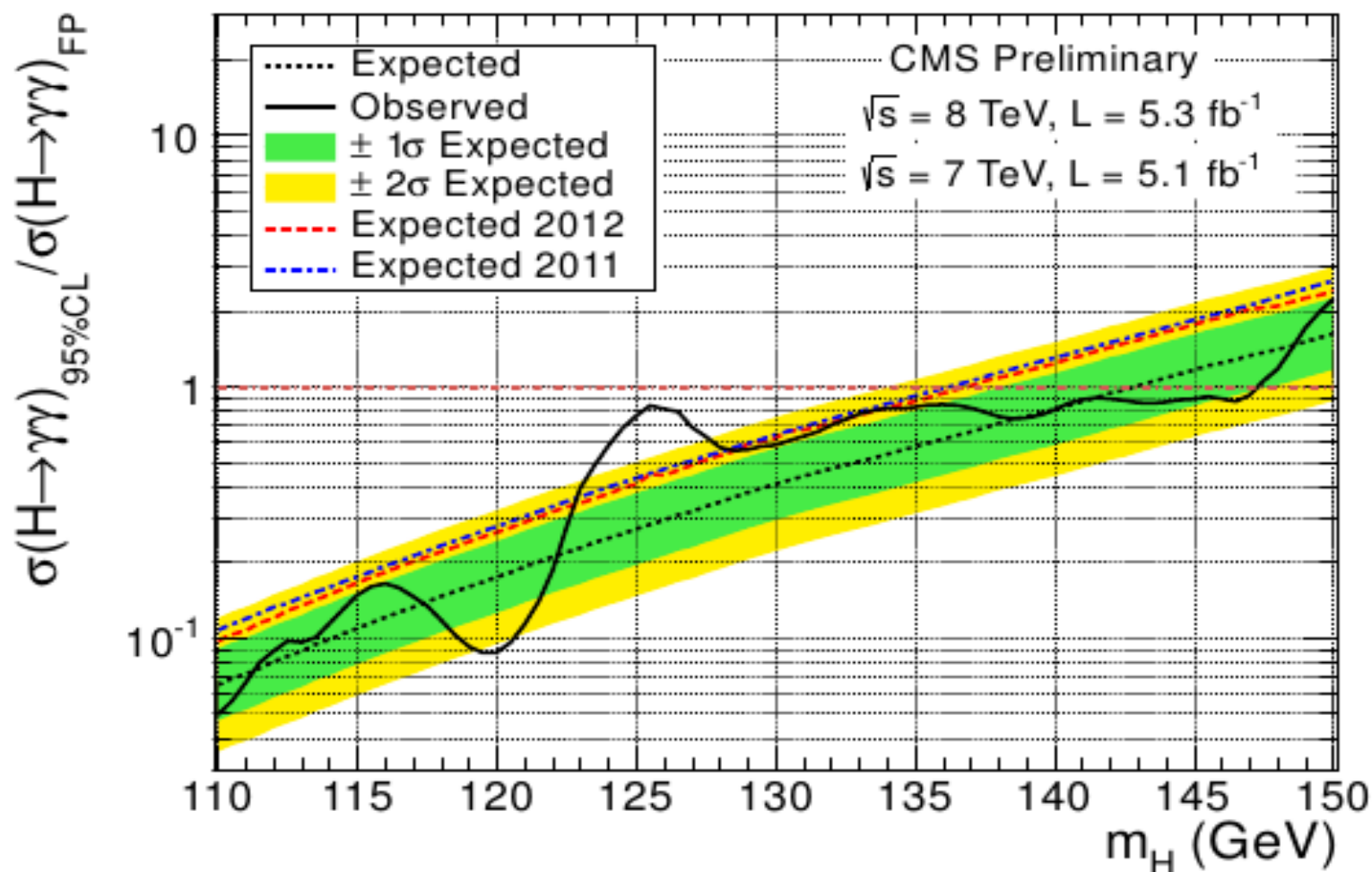
2011



2012



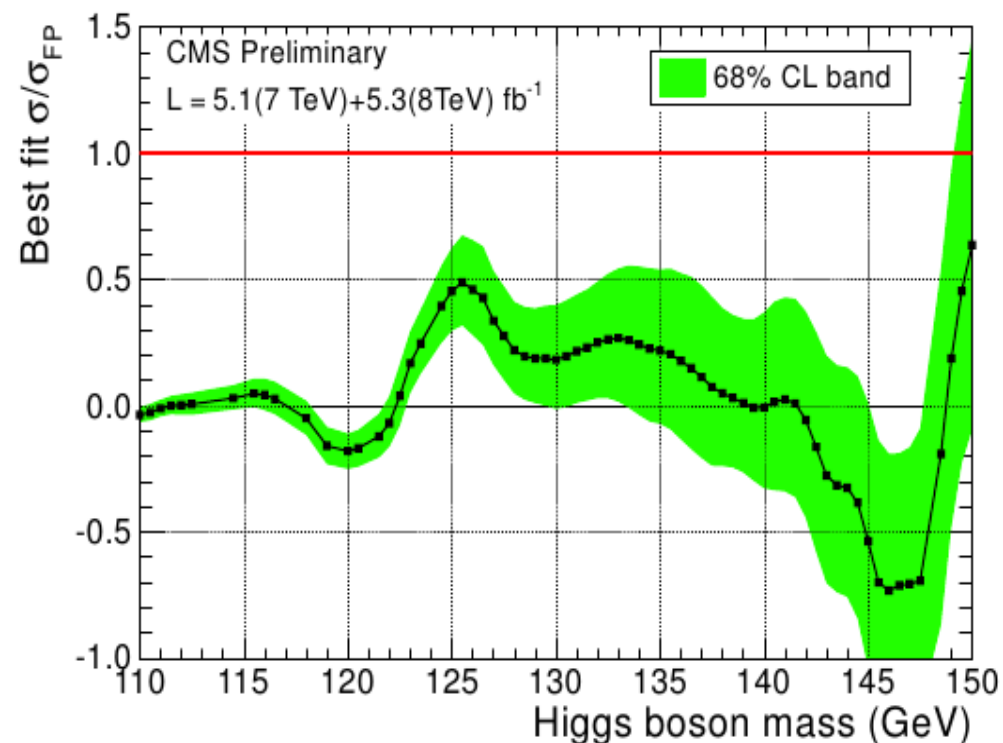
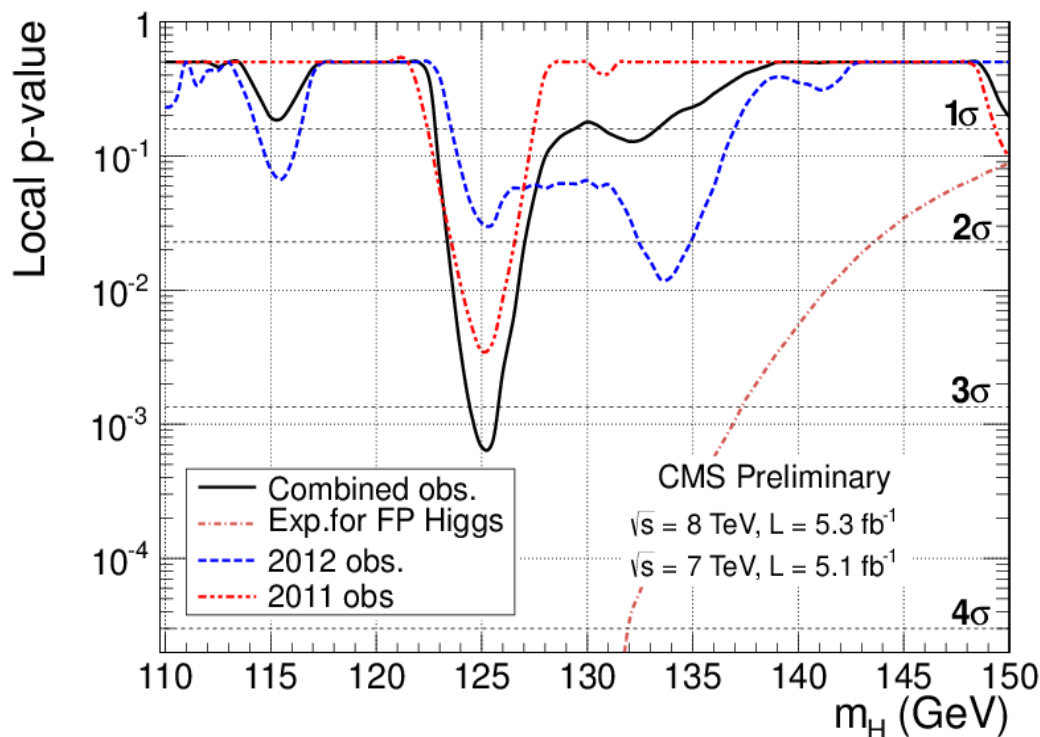
Exclusion Limit (2011+2012)



The FB Higgs boson is excluded at 95% C.L. in the mass range [110-147] GeV.

At 99% C.L. we exclude the FP Higgs in the range [110-134] GeV.

- Local p-value as a function of the Higgs mass:
 - The global significance of the largest upward fluctuation at **125.5 GeV** is **3.2σ** ;
 - This deviation is too weak to be consistent with the Fermiophobic hypothesis as shown by observed signal strength for a FP Higgs boson (**0.49 ± 0.18**).



Summary

- The results of the search of Higgs boson in the context of Fermiophobic interpretation using pp collisions at $\sqrt{s} = 7$ and 8 TeV collected by the CMS experiment have been presented:
 - The mass range explored is [110-150] GeV.
- The combination of the results of the three decay mode analysis on 2011 data (5.1 fb^{-1}) allows to exclude at 99% C.L. a FP Higgs in the range **[110-188] GeV** except for the intervals **[124.5-128]** and **[148-154] GeV**.
- $\gamma\gamma$ analysis has been updated adding the data collected so far in 2012 (corresponding to a total of 10.4 fb^{-1}):
 - A Fermiophobic Higgs boson is excluded at 95% C.L. in the interval **[110-147] GeV**.
 - In the mass range **[110-134] GeV** FP Higgs boson is excluded at 99% C.L.



Backup

Photon-Lepton Selection

Photon ID cuts

- $p_T(\text{subleading}) > 25 \text{ GeV}$; $p_T(\text{leading})$ cut varies according to the analysis.

	barrel		endcap	
	$R_9 > 0.94$	$R_9 < 0.94$	$R_9 > 0.94$	$R_9 < 0.94$
PF isolation sum, chosen vertex	6	4.7	5.6	3.6
PF isolation sum worst vertex	10	6.5	5.6	4.4
Charged PF isolation sum	3.8	2.5	3.1	2.2
$\sigma_{i\eta i\eta}$	0.0108	0.0102	0.028	0.028
H/E	0.124	0.092	0.142	0.063
R_9	0.94	0.298	0.94	0.24

Electron ID cuts

	<i>loose WP</i>	
	Barrel	Endcap
$\sigma_{i\eta i\eta}$	0.01	0.03
$\Delta\phi_{in}$	0.015	0.010
$\Delta\eta$	0.007	0.009
$\sigma_{i\eta i\eta}$	0.01	0.03
H/E	0.12	0.10
d_0 w.r.t. selected vertex	$< 0.02 \text{ cm}$	
d_z w.r.t. selected vertex	$< 0.2 \text{ cm}$	
$ 1/E - 1/p $	0.05	
Combined relative PF isolation	0.15	
vertex fit probability (conv. rej)	10^{-6}	
missing hits (conv. rej.)	1	

Muon ID cuts

Description	criterion
Number of pixel hits	> 0
$\chi^2/\text{n.d.f}$	< 10
Number of muon hits	> 0
Number of matched muon stations	> 1
Number of tracker layers	> 5
d_0 w.r.t. selected vertex	$< 0.02 \text{ cm}$
d_z w.r.t. selected vertex	$< 0.05 \text{ cm}$
Combined relative PF isolation	< 0.2

VBF

p_T leptons $> 20, 10$ GeV
MET > 40 GeV
 $p_T(j) > 30$ GeV
 $\Delta\eta(jj) > 3.5$
 $M_{jj} > 450$ GeV
No other jet with
 $p_T > 30$ GeV in between
B-veto on the tag jets
Other requirements:
 $\Delta M(Z)$
No additional leptons
with $p_T > 10$ GeV

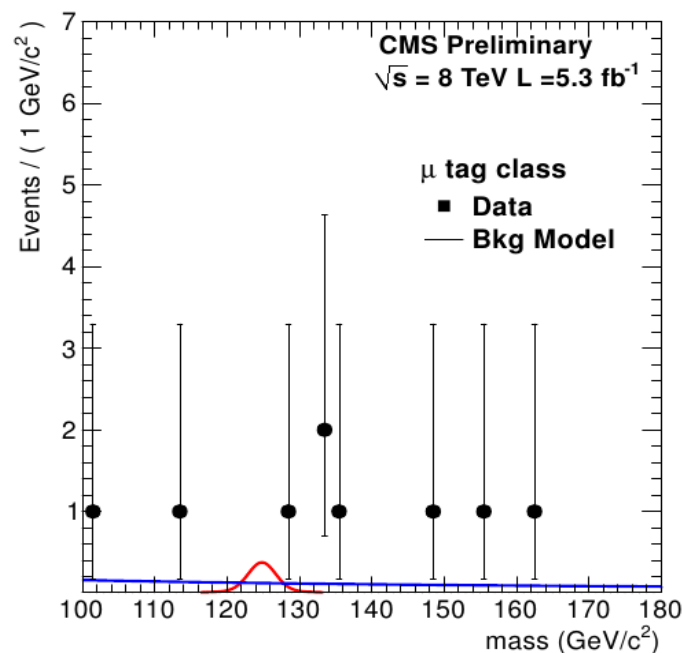
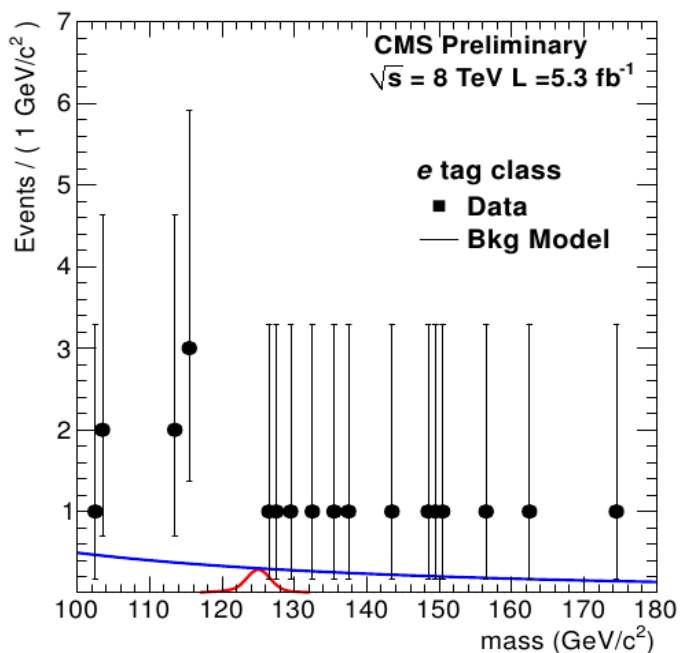
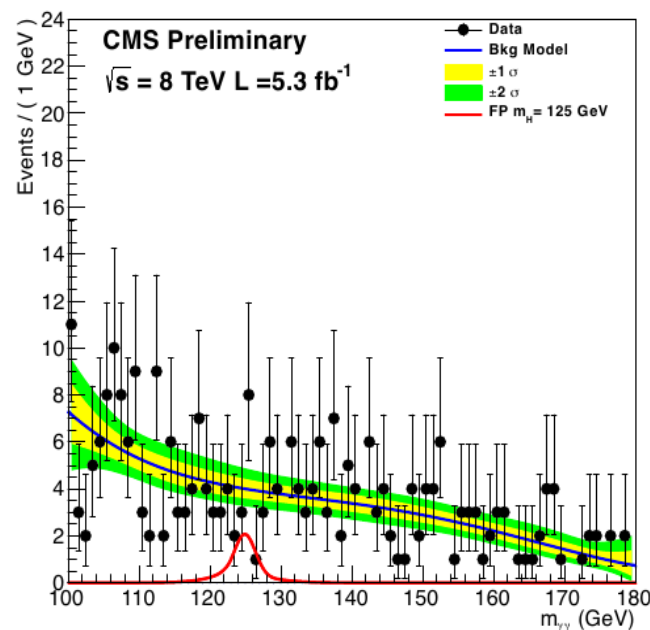
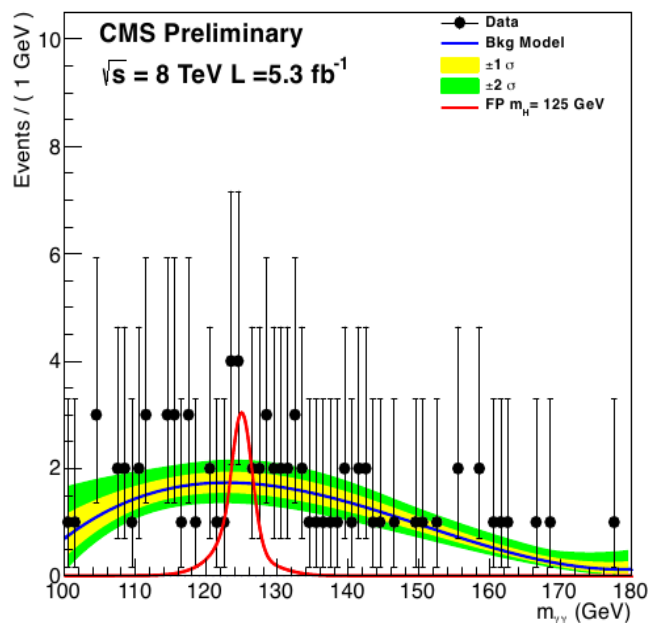
WH

3rd lepton isolated, $p_T > 10$ GeV
Same flavor oppositely charged
leptons away M_Z
Smallest m_{ll} in $[12-100]$
Smallest dR oppositely charged
leptons < 2

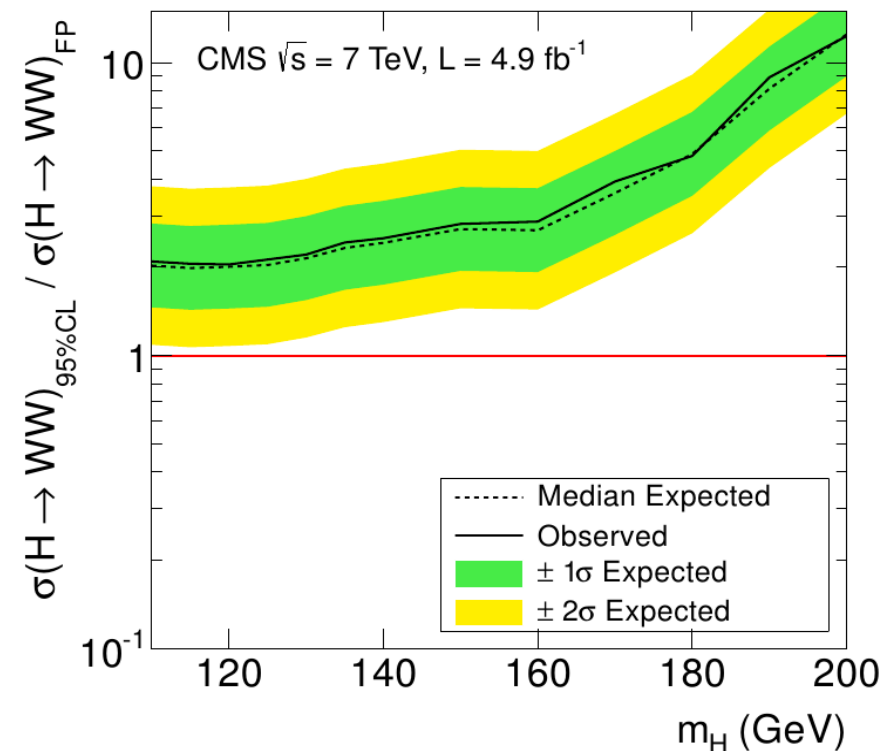
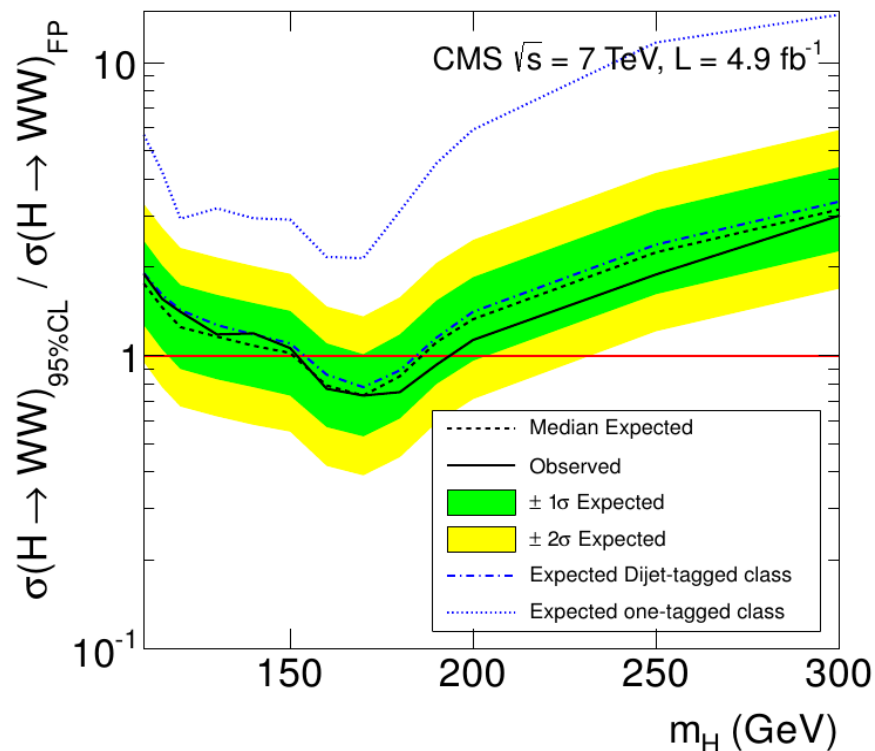
$\gamma\gamma$ Decay Mode (Event Yields)

	E_T^{miss} tag	Dijet high m_{jj}	Dijet low m_{jj}	Lepton tag	Untagged			
					(a)	(b)	(c)	(d)
Signal ($m_H = 120 \text{ GeV}$)	3.8	21.5	15.3	5.7	29.2	37.9	18.5	22.0
Data ($115 < m_{\gamma\gamma} < 125 \text{ GeV}$)	4	20	36	6	683	1712	902	1755
Data ($100 < m_{\gamma\gamma} < 180 \text{ GeV}$)	41	84	271	30	4992	9546	5105	8574
$\sigma_{\text{eff}} \text{ (GeV)}$	1.91	1.98	2.02	2.0	1.44	2.00	3.72	3.76

Invariant Mass Distributions



- 95% C.L. exclusion limit relative to FP expectation for VBF (left) and WH (right):
- Observed exclusion [140-190] GeV



- Signal and background model are based on number of expected events (likelihood built with Poissonian statistic).

ZZ Decay Mode

- Signature: mass peak over small continuum background;
 - μ , e sub-channels analyzed separately for differences in mass resolution and background rate (due to jets faking leptons)
 - The main irreducible ZZ background estimated from simulation, while the smaller reducible Z+jets from data.
- Search performed combining all possible final states: **4l**, **2l2 ν** , **2l2j**, **2l2 τ** .

- Likelihood function as sum of analytic pdf for signal and background.

$$\mathcal{L}(m|\vec{\theta}) = \frac{e^{-N(\mu_s n_s + n_b)} N^N}{N!} \prod_{i=1}^N (\mu_s n_s \mathcal{P}_s^i(m|\vec{\theta}_1) + n_b \mathcal{P}_b^i(m|\vec{\theta}_2))$$

- 2D model in absence of correlations: $\mathcal{P}_{s(b)} = \mathcal{M}_{s(b)}(\mathbf{m}^{\gamma\gamma}) \times \mathcal{K}_{s(b)}(\pi_T^{\gamma\gamma})$

(Gaussian + Crystal Ball)

$$\mathcal{M}_s(\mathbf{m}^{\gamma\gamma}|m_0, \sigma_{CB}, \alpha, n, f_G, \sigma_G) = (1 - f_G) \mathcal{C}(\mathbf{m}^{\gamma\gamma}|m_0, \sigma_{CB}, \alpha, n) + f_G \mathcal{G}(\mathbf{m}^{\gamma\gamma}|m_0, \sigma_G)$$

(Gaussian + bifurcated Gaussian)

$$\mathcal{K}_s(\pi_T^{\gamma\gamma}|\mu_c, \sigma_c, f_c, \mu_o, \sigma_L, \sigma_R) = f_c \mathcal{G}(\pi_T^{\gamma\gamma}|\mu_c, \sigma_c) + (1 - f_c) \mathcal{B}(\pi_T^{\gamma\gamma}|\mu_o, \sigma_L, \sigma_R)$$

- For background factorization is a too rude approximation:

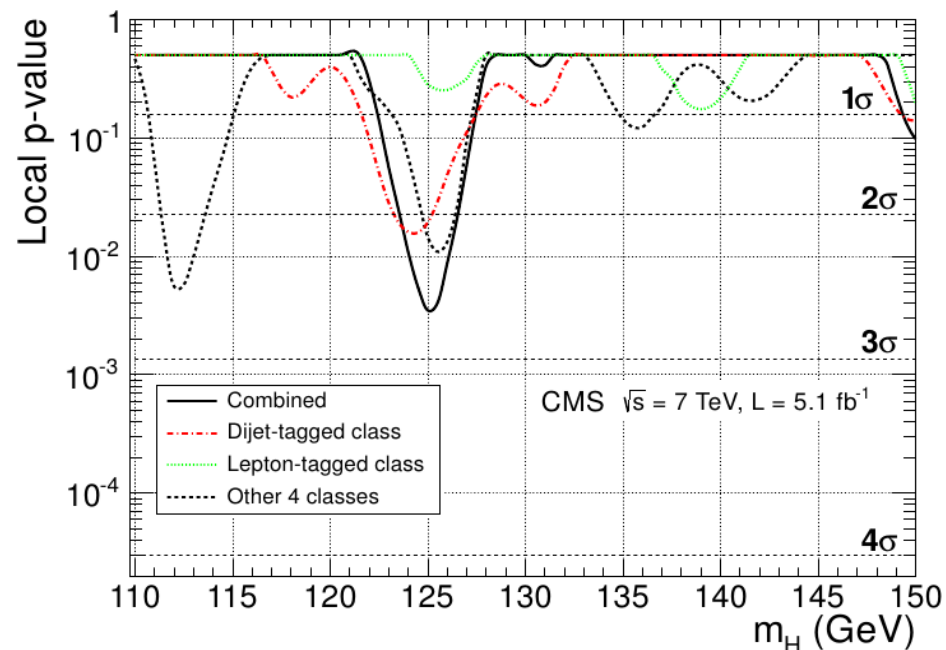
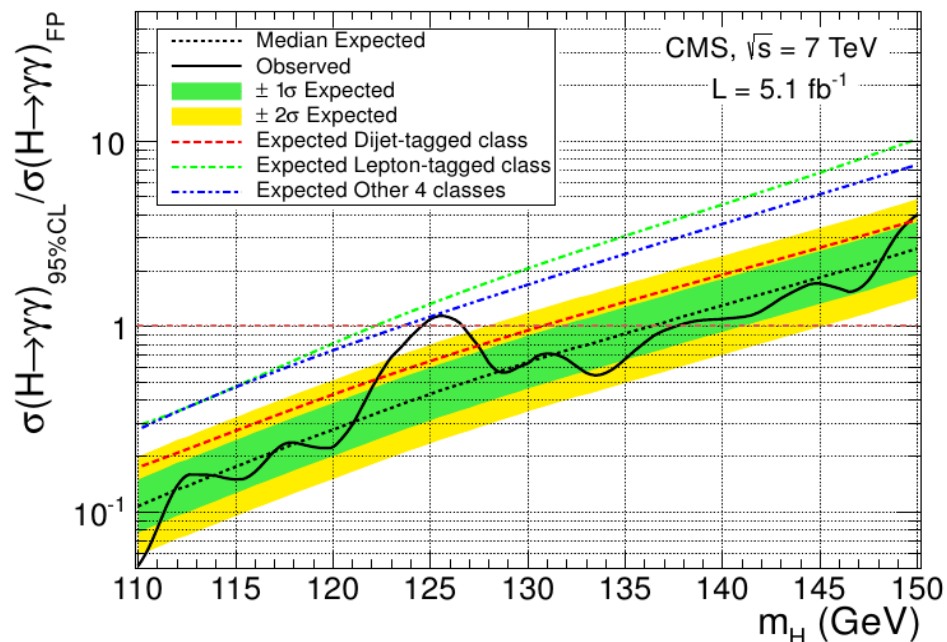
(Power law with linear correlation; bias for higher order correlation estimated to be low)

$$\mathcal{P}_b = \mathcal{M}_b(\mathbf{m}, \pi_T|a_0, a_1) \times \mathcal{K}_b(\pi_T) = \mathbf{m}^{a_0 + a_1 \pi_T} \times \mathcal{K}_b(\pi_T)$$

(Exponential + Gaussian)

$$\mathcal{K}_b(\pi_T^{\gamma\gamma}|\tau_B, f_d, \sigma_G) = f_d \mathcal{E}(\pi_T^{\gamma\gamma}|\tau_B) + (1 - f_d) \mathcal{G}(\pi_T^{\gamma\gamma}|0, \sigma_G)$$

- Limit relative to the FP model expectation (left):
 - Expected exclusion at 95% C.L. covers [110-136] GeV, observed exclusion covers [110-124] and [128-136] GeV
- Local p-value (right):
 - p-value of largest upwards fluctuation in limit (126 GeV) 2.7σ



- Local p-value as a function of the Higgs mass:
 - The larger upward fluctuation has a local significance of **2.7σ** ; considering the look-elsewhere effect in the range [100-150] GeV the global significance of the excess at about **126 GeV** is **1.2σ** .
 - This excess is too weak to be consistent with the FP hypothesis as shown by observed signal strength for a FP Higgs boson.

