Search for Standard Model Low Mass Higgs with CMS

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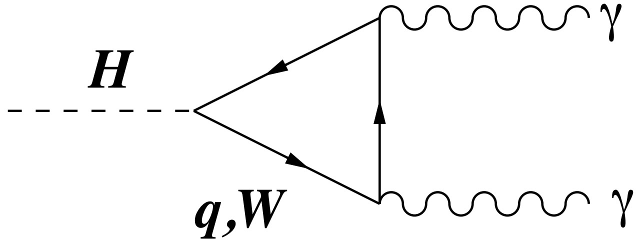
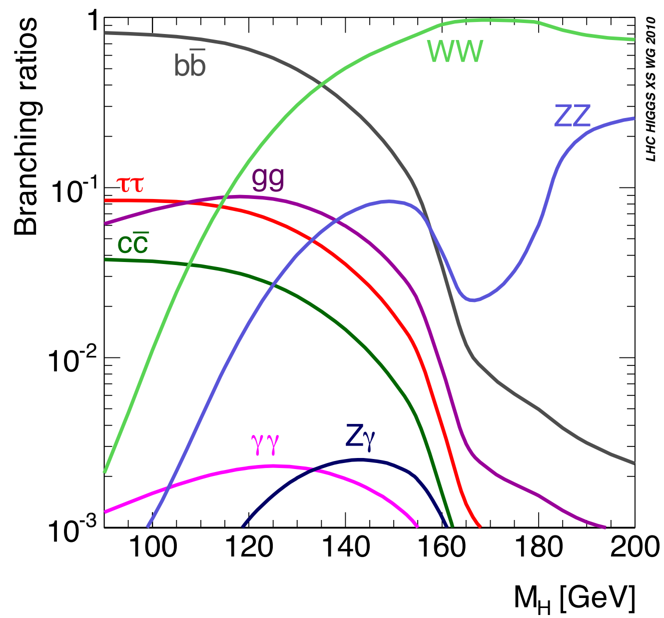
H → γγ

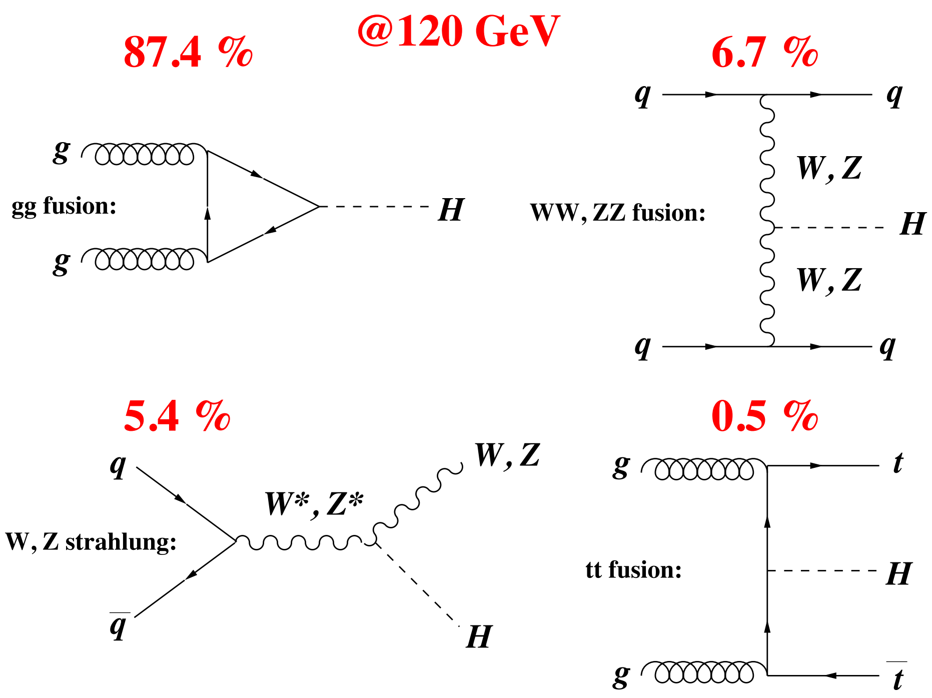
- H → γγ is a discovery channel for low mass SM Higgs, between LEP limit (114.4 GeV) and LHC exclusion (145 GeV)
  - low signal rate with B ~ 10^{-3}
  - decay involves q,W loops;
  - clean signature (contrarily to H → $\bar{b}$b);

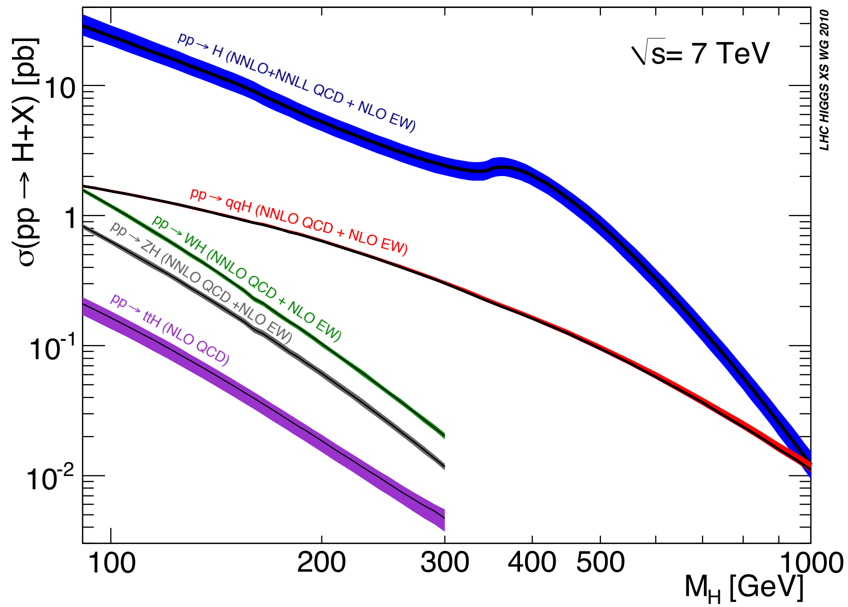


- CMS performs searches for two models
  - Standard Model (SM) h → γγ
    - most likely scenario after first LHC results
  - Fermiophobic (FP) h_f → γγ
    - has particular interest for beyond the SM scenario of EWSB (2 HDM)
    - sensitive to new physics effects
    - no fermion couplings ⇒ enhance B(h_f → γγ)



Rates and Cross Sections for SM Higgs



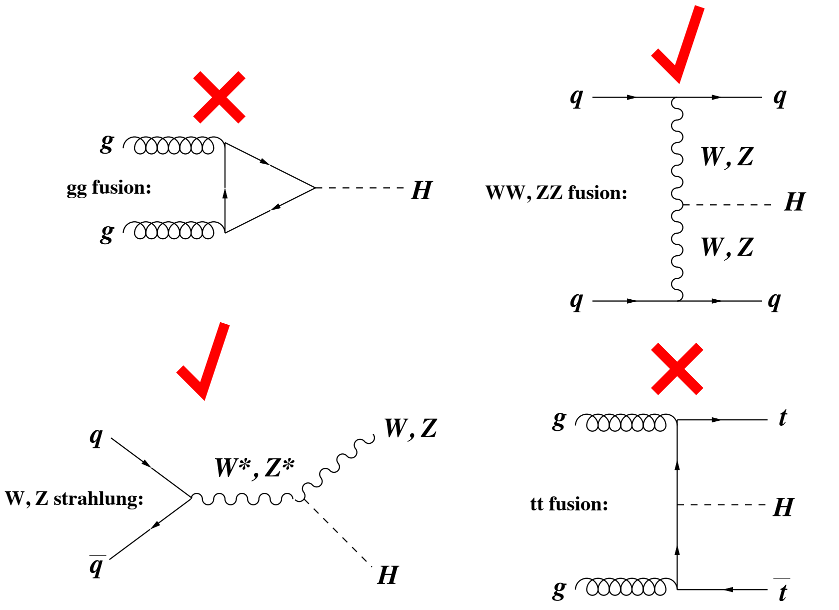


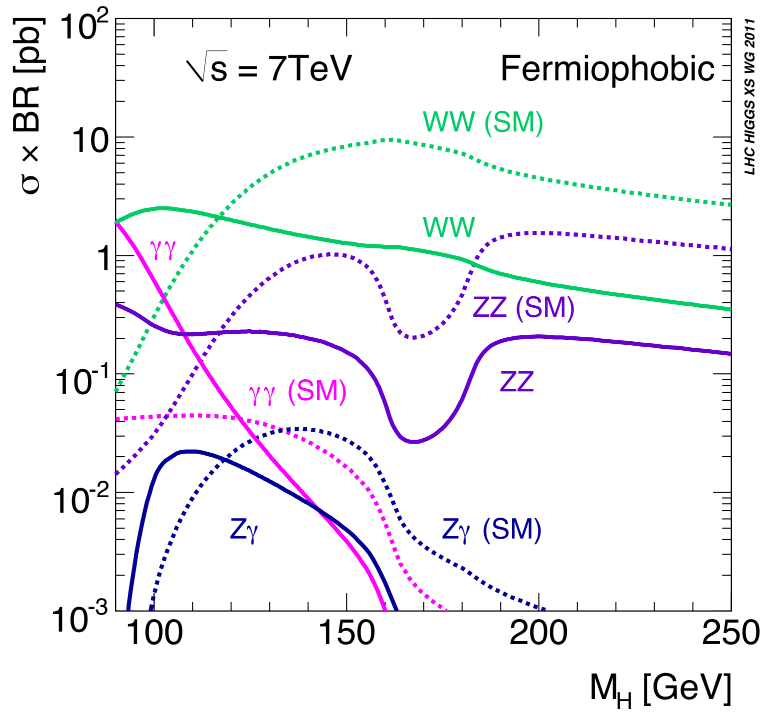
- ggH is the dominant production mechanism for SM Higgs at LHC.
  - associated jets produced in soft gluon radiation (NLO)
  - high k-factor (~2)
  - large theoretical uncertainties

NNLO cross sections and branching ratios (SM)

M_h (GeV)	110	115	120	130	140	150
σ ggH (pb)	19.8	18.1	16.6	14.1	12.1	10.5
σ VBF (pb)	1.40	1.33	1.27	1.15	1.05	0.96
σ WH (pb)	0.88	0.75	0.66	0.50	0.39	0.30
σ ZH (pb)	0.47	0.41	0.36	0.28	0.22	0.17
σ $t\bar{t}$H (pb)	0.13	0.11	0.10	0.08	0.06	0.05
Total σ (pb)	22.7	20.7	19.0	16.1	13.8	12.0
$\mathcal{B}(h \to \gamma\gamma)$, %	0.20	0.21	0.23	0.23	0.19	0.14
$\sigma \times \mathcal{B}$ (fb)	44.7	43.5	43.7	37.0	26.2	16.8

Rates and Cross Sections for Fermiophobic Higgs





- FP Higgs production is driven by VBF and VH
  - jets and leptons produced at LO.
  - low k-factor (~1)
  - small theoretical uncertainties
- SM and FP signal yields are comparable for Higgs at 125 GeV.

NNLO cross sections and branching ratios (FP)

M_{h_f} (GeV)	90	100	110	120	130	140	150
σ VBF (pb)	1.71	1.55	1.40	1.27	1.15	1.05	0.96
σ WH (pb)	1.64	1.19	0.88	0.66	0.50	0.39	0.30
σ ZH (pb)	0.86	0.63	0.47	0.36	0.28	0.22	0.17
Total σ (pb)	4.21	3.37	2.75	2.29	1.93	1.66	1.43
$\mathcal{B}(h_f \to \gamma\gamma)$, %	41.0	18.0	6.2	2.8	1.9	0.61	0.20
$\sigma \times \mathcal{B}$ (fb)	1726	607	170.5	64.1	36.7	10.1	2.9

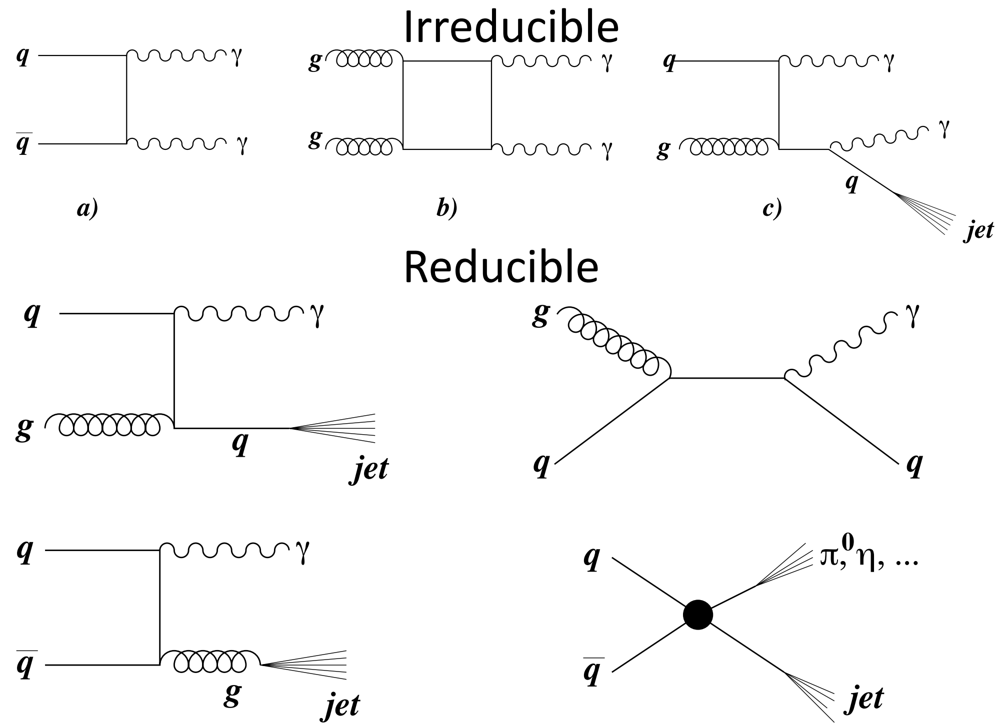
Backgrounds

- Irreducible backgrounds:
  - Born (a), Box (b), and isolated bremsstrahlung (c).
- Reducible backgrounds:
  - QCD with hard jets, where neutral hadrons (π^0,η) fake photons.
  - Need jet suppression at 10^4 level.
- Differential rates of irreducible backgrounds

$$d\sigma/dm_{\gamma\gamma} \sim 100\,\mathrm{fb}/\,\mathrm{GeV}/c^2$$

drive need for mass resolution

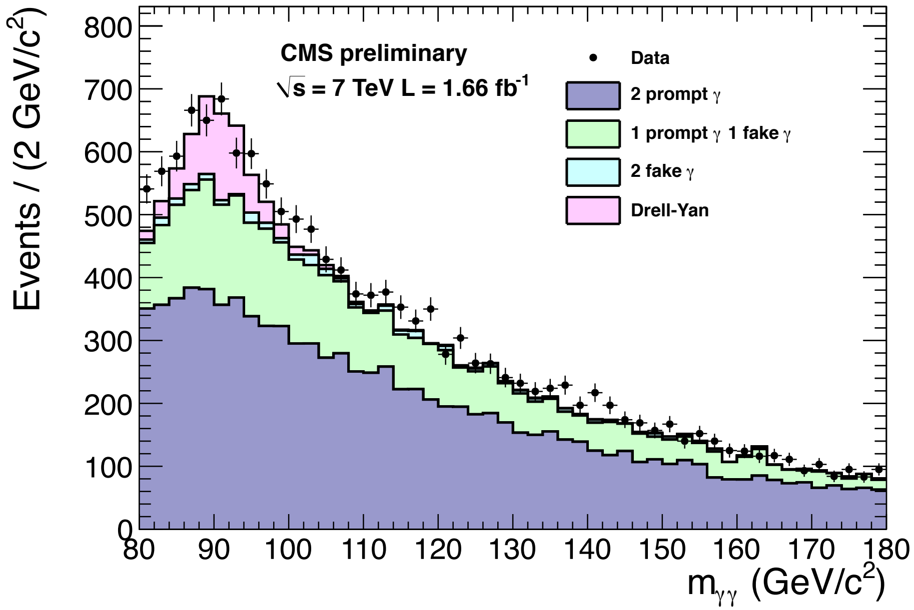
$$\Delta M_{\gamma\gamma} \sim 1\,\mathrm{GeV}/c^2$$



Process	p_T (GeV/c)	σ_{LO} (pb)
$H \to \gamma\gamma$ (120 GeV/c^2)	–	0.044 (NNLO)
pp→ $\gamma\gamma$ (Born)	> 25	22.4
pp→ $\gamma\gamma$ (Box)	> 25	12.4
pp→ γ+jet	> 30	2.0×10^4
pp→jets	> 30	6.0×10^7
Drell Yan ee	–	3×10^3

Analysis Strategy (I)

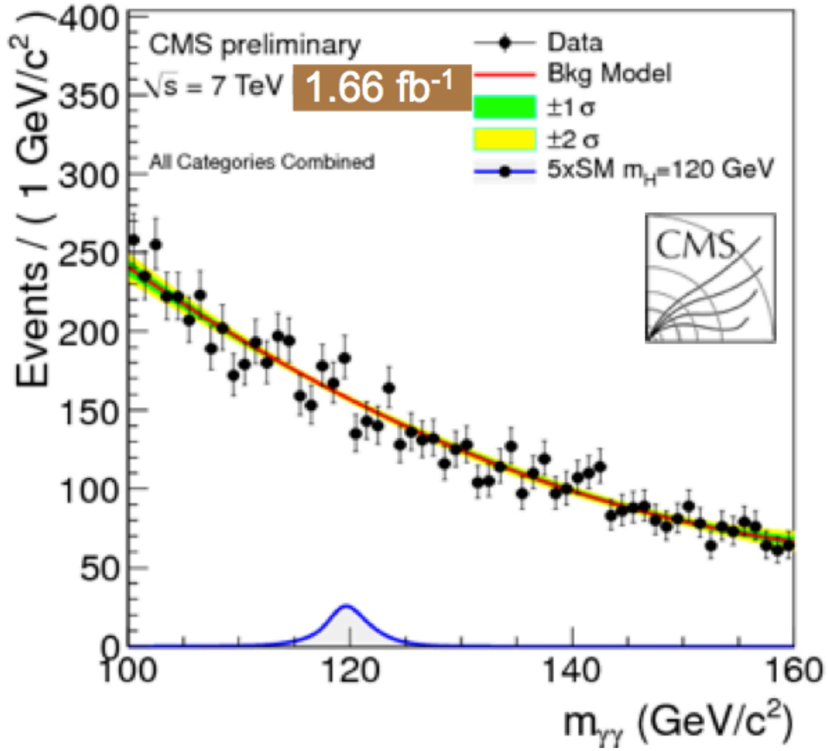
- Trigger on di-photon candidates with low E_T thresholds 26(18)
  - tightening isolation (Track, ECAL, HCAL) to deal with PU.
  - Efficiency ~100% w.r.t. analysis.
- Search for a narrow resonance in the di-photon continuum background.
- Reduce background:
  - tight ID (shower shape)
  - Isolation
  - Electron veto against DY→ee
- Estimate the remaining background (80% irreducible) from the sidebands using a fit. Modeling is fully data driven.



MC is simulated with Madgraph, using k-factors from existing QCD measurements. MC is used only to optimize selection cuts.

Analysis Strategy (II)

- To maximize sensitivity. di-photon data are divided in 8 categories corresponding to expected mass resolution and S/B
  - Converted/unconverted × η × p_T (γγ)
  - E_T(γ1) >40 GeV, E_T(γ2) >30 GeV
  - Fit $M_{\gamma\gamma}$ with 2^{nd} order polynomial (Decision is driven by high p_T categories where spectrum is shifted towards high mass region)

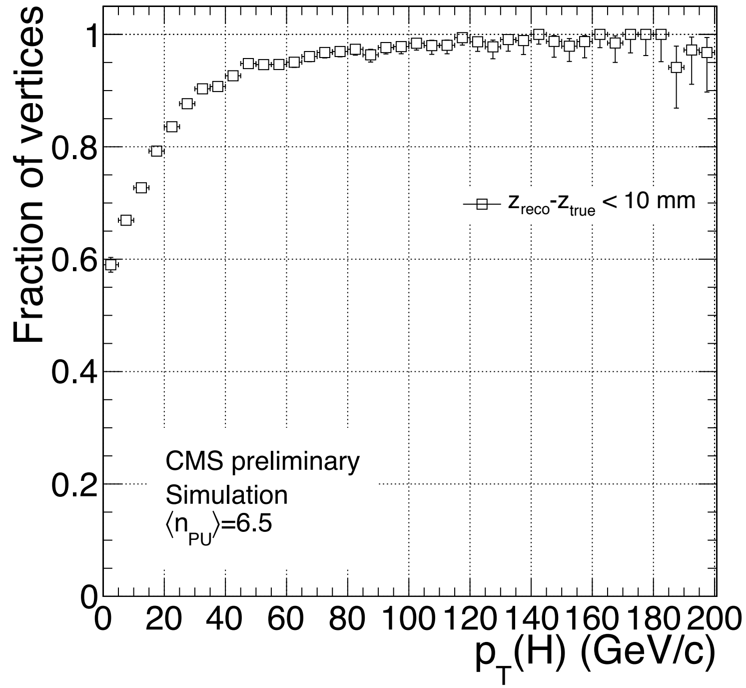


- Higgs signal model is derived from MC applying corrections for photon identification/ isolation efficiencies and energy resolution extrapolated from data using Z→ e^+e^-.

Mass Resolution and Vertex Identification

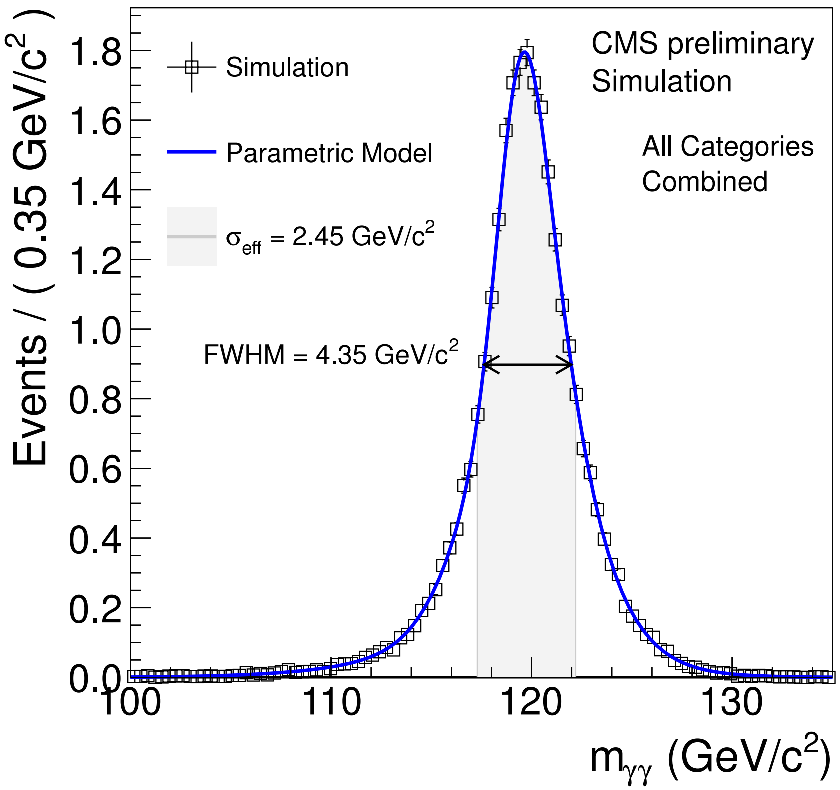
- Energy scale (ΔE) and mass resolution (σ_m) are dominant systematics
  - mass scale is equivalent to energy scale: Δm ≡ ΔE
    $m^2 = 2E_1E_2(1 - \cos\theta)$
  - σ_m depends on energy (σ_E) and angular (σ_θ) resolutions

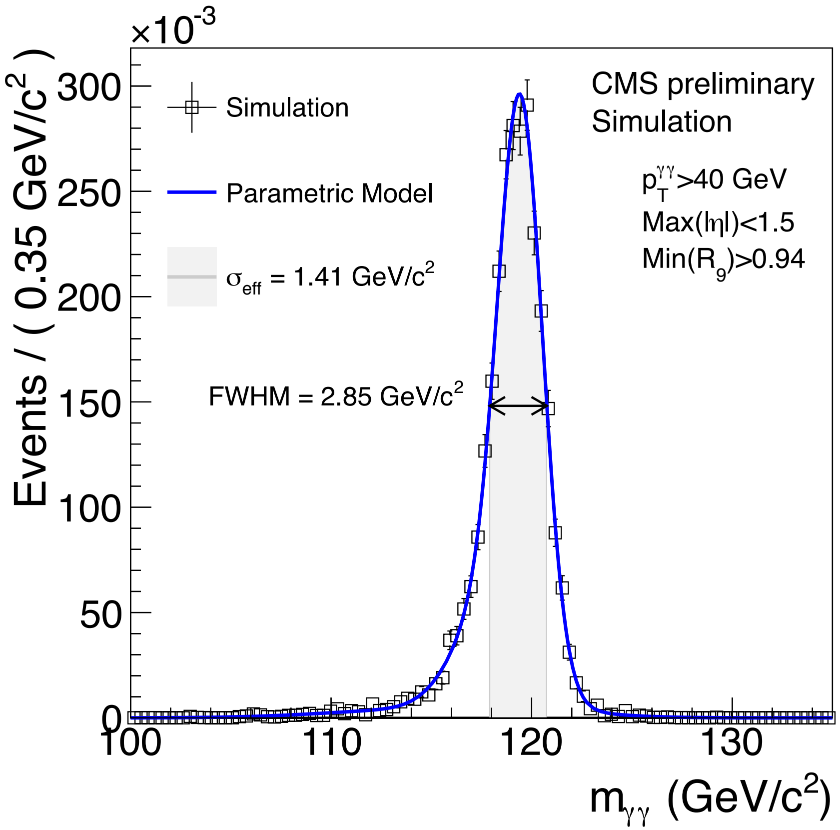
$$\frac{\sigma_m}{m} = \frac{1}{2}\left(\frac{\sigma_{E_1}}{E_1} \oplus \frac{\sigma_{E_2}}{E_2} \oplus \frac{\sigma_\theta}{\tan\theta/2}\right)$$



- Vertex misidentification has a small effect (PU)
  - angular term is negligible for Higgs emerged at rest.
  - for the boosted Higgs, efficiency of vertex identification is high due to presence of recoil objects.
- Higgs is produced in association with tracks from:
  - underlying event
  - initial stated gluon radiation
  - associative particles qqH, VH
  - photon conversion

Resolution Model





- Use sum of Gaussians
  - check it with Crystal Ball plus Gaussian outliers.

- Iimprovement in mass resolution is expected for the winter update
  - New energy correction schema
  - Improved ECAL calibration

Systematic Uncertainties

- Signal
  - luminosity;
  - theory;
  - efficiency;
  - resolution;
  - energy scale;
- Background
  - slope;
  - normalization;
- Implemented into a likelihood model via penalty:

$$-\log \mathcal{L} - \log g(\theta_s) = NLL_0 + NLL_P$$

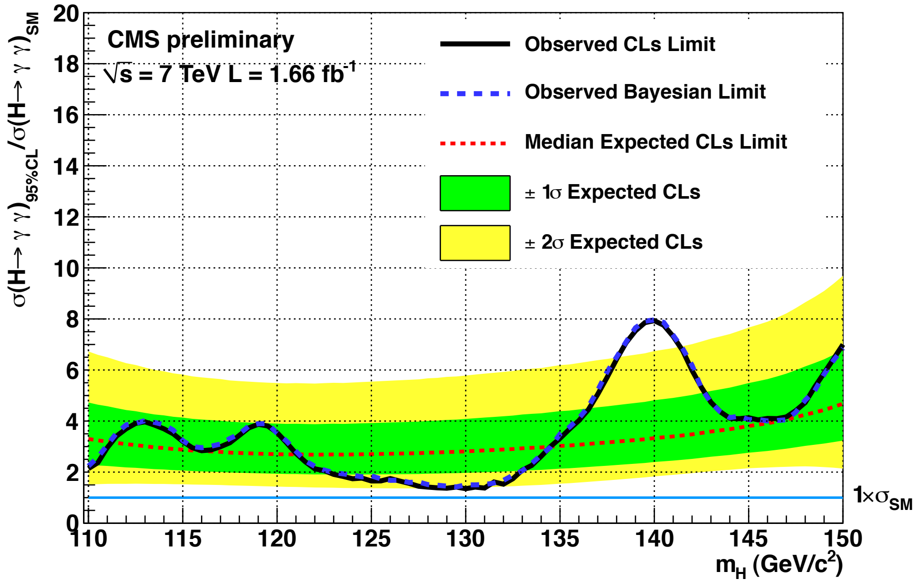
	Source	Uncertainty
Standard Model	gg cross section (scale)	12.5%
	gg cross section (PDF)	7.9%
fermiophobic model	VBF cross section (scale)	0.5%
	WH cross section (scale)	0.8%
	ZH cross section (scale)	1.6%
	VBF + VH cross section (PDF)	3.1%
	fermiophobic $H^0 \to \gamma\gamma$ BR	5%

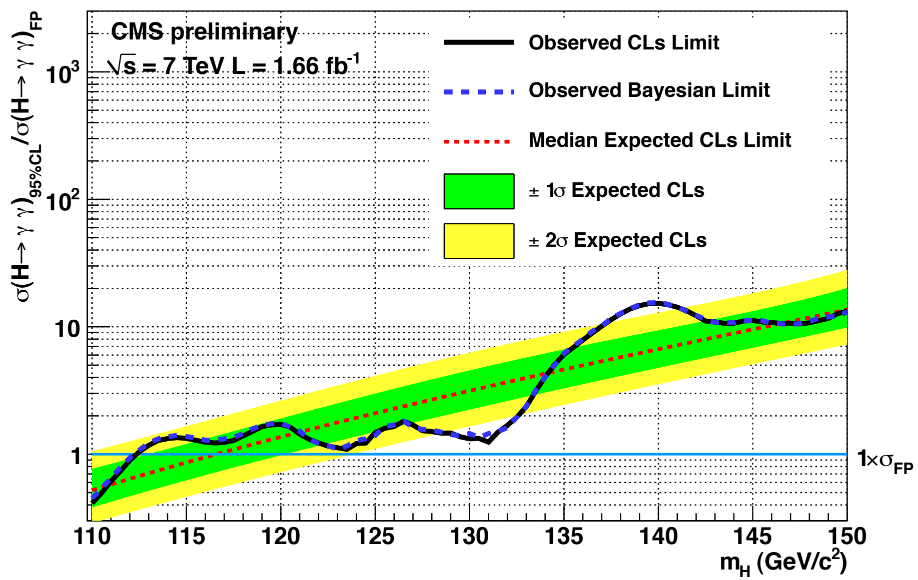
Source		Uncertainty	
Photon identification efficiency			
	barrel	1.0%	
	endcap	2.5%	
R_9 >0.94 efficiency (results in class migration)	barrel	4%	
	endcap	6.5%	
		$R_9 > 0.94$	$R_9 < 0.94$
Energy resolution ($\Delta\sigma/E_{MC}$)			
	barrel	0.2%	0.4%
	endcap	0.5%	0.4%
Energy scale ($(E_{data} - E_{MC})/E_{MC}$)			
	barrel	0.1%	0.4%
	endcap	0.3%	0.4%

Source	Uncertainty
Integrated luminosity	4.5%
Trigger efficiency	
both photons in barrel	1.0%
one or more photon in endcap	1.0%
Vertex finding efficiency	0.5%
$p_T{}^H$ >40 GeV/c in gluon fusion (class migration)	6%

Current Exclusion Limits

CMS-PAS-HIG-11-021



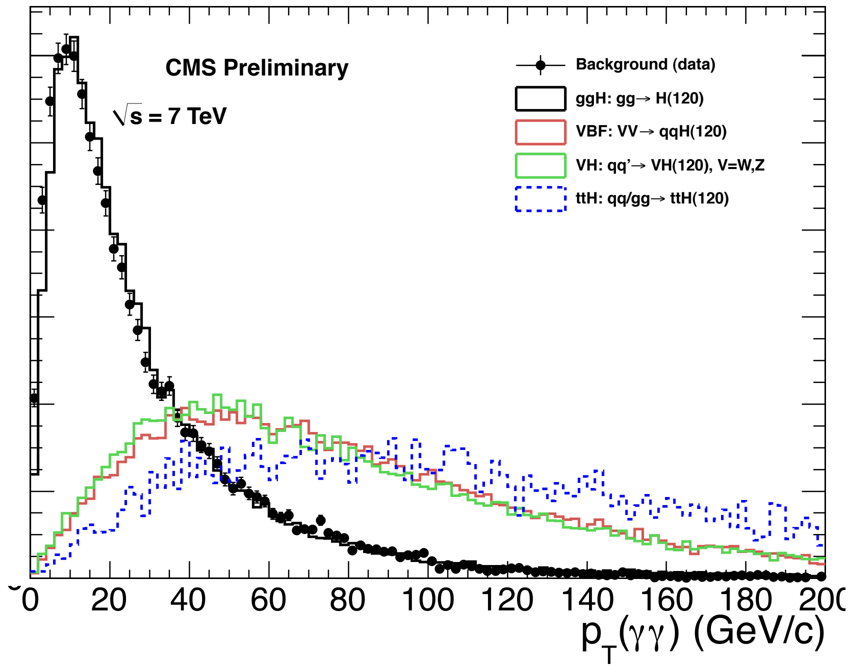


- Standard Model
  - gluon fusion is dominant;
  - Higgs is produced almost at rest
  - exclusion 95% C.L. for 2.7 - 4.7 times SM cross section
  - CMS see an excess around 140 GeV: local p-value slightly less than 3 σ ,global p-value ≈ 1.6 σ.

- Fermiophobic:
  - enhancement in B(H → γγ);
  - VBF and VH only (boosted H)
  - exploit pT kinematics
  - exclude 110-112 GeV/c2 at 95% C.L.

Diphoton Kinematics

- Difference in the signal and background kinematics has a potential for improvement to the current analysis:
  - exploit Higgs kinematical properties
  - include recoil objects in signature
- Current study use two pT categories $p_T(\gamma\gamma)$ <(>) 40 GeV
  - NNLO pT spectrum for ggH is similar to background
  - marginal improvement with 6% category migration systematic.
  - $p_T(\gamma\gamma)$>40 GeV enhances VBF and VH for FP scenario

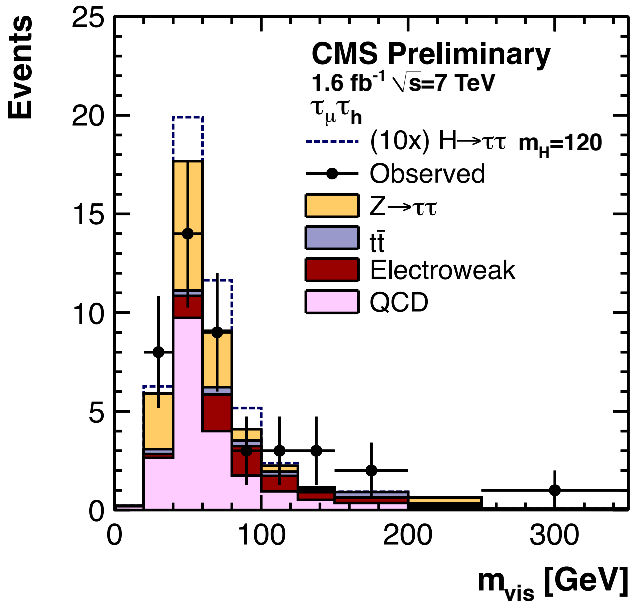


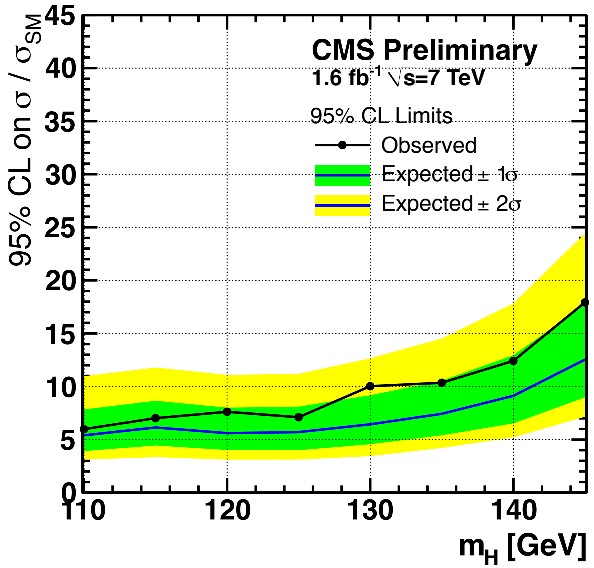
ggH spectrum is reweighted using NNLO/NLO corrections (HqT)

Understanding of theoretical uncertainties will lead to analysis improvements.

H → ττ

- Sensitive channel at low m_H (110-140) due BR (5-10%)
  - Interesting in the MSSM context
- Final states used in analysis
  - $\tau_l\tau_{had}$: high BR, golden channels, $\tau_l\tau_l$: clean final state, eμ easier then 2μ or 2e
- Search for a peak in the di-tau mass
  - Profit from advanced reconstruction algorithms to account for MET.
- Backgrounds: Z+jets (Z→ττ largely irreducible), W+jets, QCD, dibosons, top are reduced by τ(ID+ISO), b-tag veto, topological cuts.





CMS-HIG-11-020

Maximum sensitivity for VBF channels: presence of tagging jets suppresses backgrounds.

H(VH) → bb

- ggH and VBF H → bb are the dominant low M_H Higgs production/ decay modes but search is extremely difficult due to overwhelming QCD background. Still is useful in search for associated production with vector bosons (WH,ZH).

Final states:

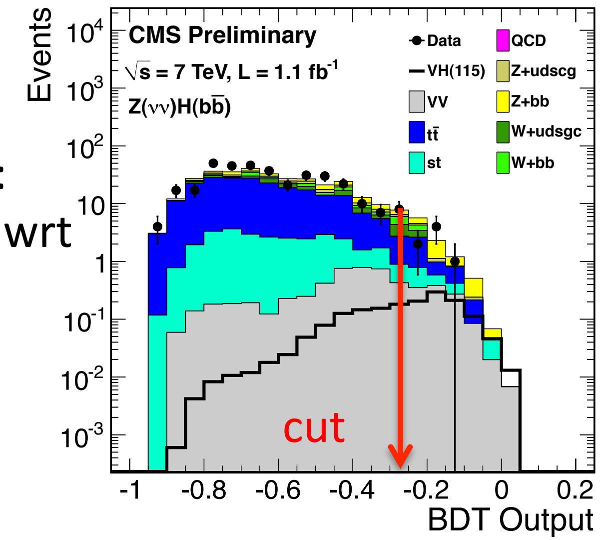
- W(lv)H(bb): 1 isolated lepton + MET, 2 bjets
- Z(ll)H(bb): 2 leptons, 2 bjets
- Z(vv)H(bb): high MET + 2 bjets

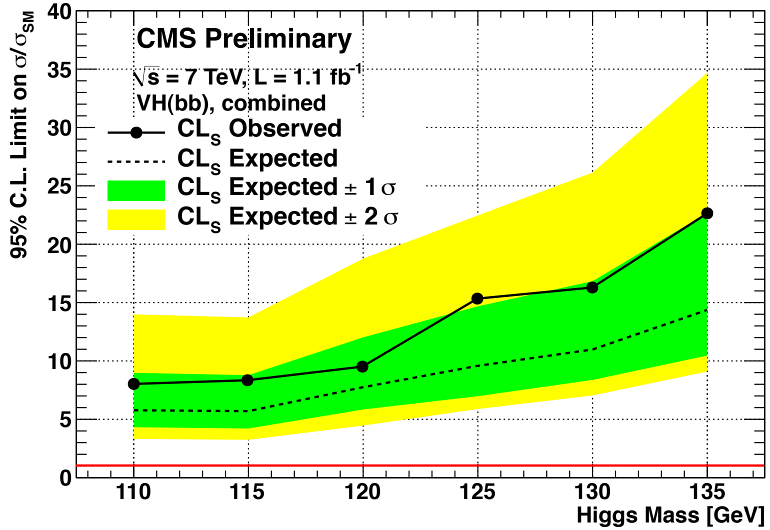
Major backgrounds: W/Z+jets, top, dibosons W/Z+Z(bb)

- Tight b-tagging (for W/Z+light jets)
- Boosted jet pairs (against W/Z+jets).
- Veto on additional jet and lepton activity (top)

CMS-HIG-11-012

Applying a cut on multivariate output: improve sensitivity wrt simple cut based by 5-10%. Background shapes validated in control regions.





Conclusions

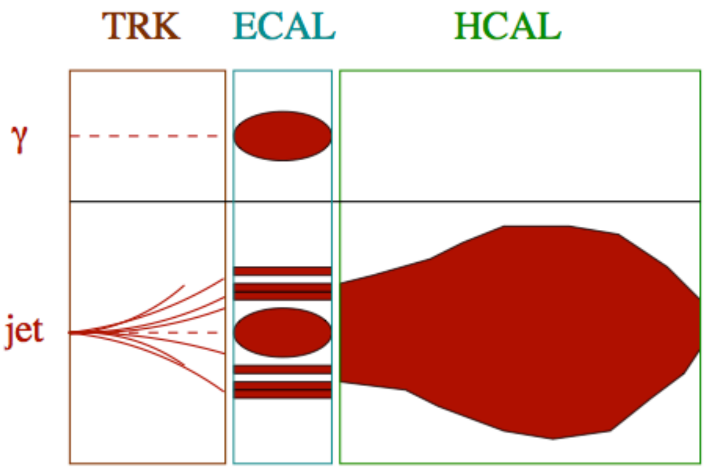
- CMS reported searches for low M_H
  - In H → γγ channel with 1.6 fb^{-1} of data
    - SM: Expected limit at 95% C.L is ~3 times SM cross section in the range 110-150 GeV. Observed data exclude 1.5 to 8 SM.
    - FP: Expected limit exclude fermiophobic model in the mass range 110-116.5 GeV, while data exclude 110-112 GeV.
  - As expected, H → ττ and H → bb channel have lower sensitivity
    - SM: Expected limit at 95% C.L is 5-15 times SM cross section in the range 110-150 GeV. Observed data exclude 5 to 20 SM.
- In the meantime, CMS recorded total of ~ 5 fb^{-1} of good data
  - Improved analyses with new data will be ready for winter conferences.
    - New calibration, new analysis techniques.
  - Stay tuned as we are approaching limits of 1 x SM and 1 x FP Higgs cross sections in low M_H region.

Photon Selection

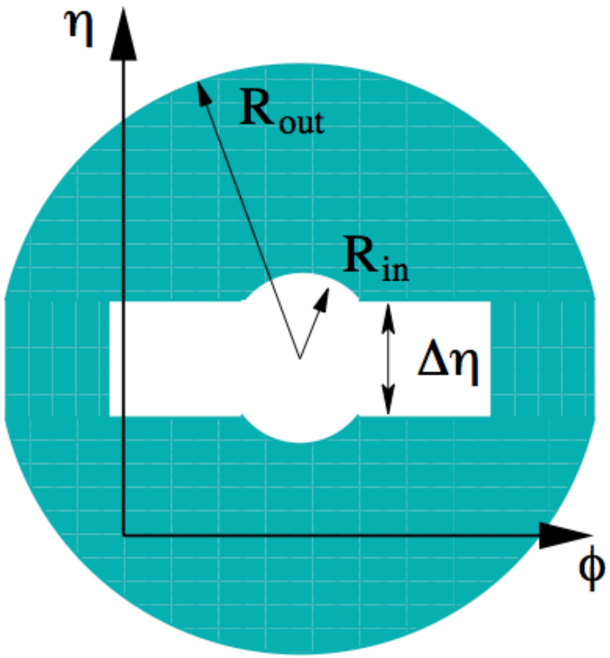
Photon candidate categories used for photon selection

Category	Photon requirement
1	$\|\eta\|$ <1.4442, R_9 >0.94
2	$\|\eta\|$ <1.4442, R_9 <0.94
3	1.566< $\|\eta\|$ <2.5, R_9 >0.94
4	1.566< $\|\eta\|$ <2.5, R_9 <0.94

Isolation



Variable	R_{out}	R_{in}	$\Delta\eta$
$\mathrm{Iso}_{\mathrm{TRK}}$	0.4	0.04	0.015
$\mathrm{Iso}_{\mathrm{ECAL}}$	0.4	3.5 crystals	2.5 crystals
$\mathrm{Iso}_{\mathrm{HCAL}}$	0.4	0.15	-
H/E	0.15	-	-



- π^0 accompanied by other particles
- Isolation $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$
  - $\mathrm{Iso}_{\mathrm{TRK}} = \Sigma p_T$ in tracker
  - $\mathrm{Iso}_{\mathrm{ECAL}} = \Sigma E_T$ in ECAL
  - $\mathrm{Iso}_{\mathrm{HCAL}} = \Sigma E_T$ in HCAL
- Low value of H/E identifies photons
- Suited for use an electron control sample

p-value

CMS see an excess around 140 GeV:
local p-value slightly less than 3 σ
Trial factor estimated ≈ 20 (bringing global p-value ≈ 1.6 σ)