Low-mass scalar search at CMS

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INDO-FRENCH CEFIPRA INFRE-HEPNET AND LIA THEP MEETING

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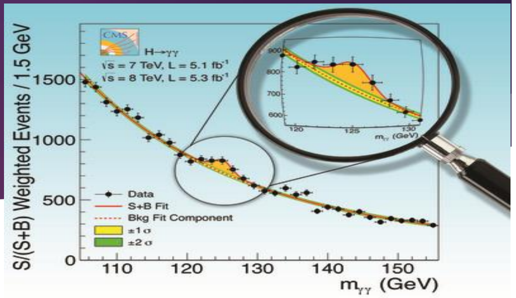
Motivation



- The observation of a new Higgs-like particle in 2012 is already a nostalgic memory.
- Its observation just closed a chapter in the construction of the SM.
- The SM leaves ajar the door for further model building as it fails to explain several important features of nature such as the hierarchy problem or the nature of dark matter, neutrino oscillation etc.
- It is expected that new particles exist in nature in order to understand this unexplained phenomena.
- But the hypothetical existence of new particles raises new questions: **Is the 125GeV scalar really the Standard Model Higgs Boson? Is it the lightest?**
- Some BSM theories predict modified and extended Higgs sectors, possibly with additional low-mass (m_H < 125GeV) scalars / pseudo-scalars.

Models

- **General 2Higgs Doublet Model (2HDM) :**

– 2 Higgs doublets → 5 Higgs bosons : h, H, a, $H^{\pm}$

Can be the observed Higgs Boson

– 4 types, main parameters : tanβ, α

– compatible with a 125GeV SM-like scalar (h or H) + a light Higgs Boson (a or h)

- **Next-to-Minimal Supersymmetric Standard Model (NMSSM) :**

– 2 Higgs doublets + 1 singlet → 7 Higgs bosons : h_1, h_2, h_3, a_1, a_2, $H^{\pm}$

– compatible with a 125 GeV SM-like scalar (h_1 or h_2) + a mostly "singlet-like" light Higgs Boson (a_1 or h_1)

Models

- **General 2HDM**

Different possible couplings

	Type I	Type II	Flipped (Type Y)	Lepton Specific (Type X)
Up-type quark	ϕ_2	ϕ_2	ϕ_2	ϕ_2
Down-type quark	ϕ_2	ϕ_1	ϕ_1	ϕ_2
Leptons	ϕ_2	ϕ_1	ϕ_2	ϕ_1

e with a 1 … r (h or H) + a light Higgs Boson (a or h)

Other BSM theories also search for a low-mass Higgs boson, such as dark-SUSY models or general 2HDM+S

Two complex SU(2) scalar doublet

- **MSSM :**

  – minimal supersymme … ype II

  – low-mass (pseudo) scalars disfavored within th

- **NMSSM :**

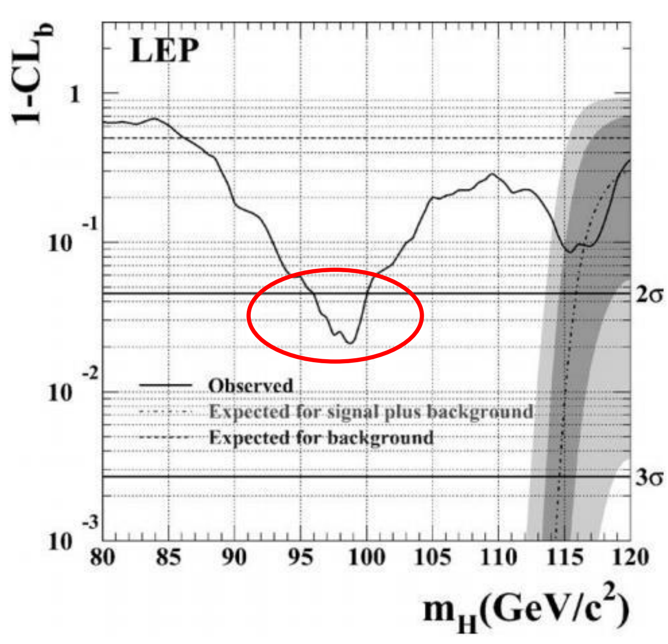
  – 2 Higgs doublets + 1 singlet 7 Higgs bosons : $h_1, h_2, h_3, a_1, a_2, H^{\pm}$

  – compatible with a 125 GeV SM-like scalar (h1 or h2) + a mostly "singlet-like" light Higgs Boson (a_1 or h_1)

List of analyses searching for Low-mass scalar at CMS

- $h \rightarrow a\,a \rightarrow 4\mu$ 8 TeV Phys. Lett. B 752 (2016) 146
  - 13 TeV CMS PAS HIG-16-035
- $h \rightarrow a\,a \rightarrow 4\tau$ 8 TeV JHEP 01 (2016) 079
  - CMS PAS HIG-16-015
- $h \rightarrow a\,a \rightarrow 2\mu\,2\tau$ 8 TeV CMS PAS HIG-16-015
- $h \rightarrow a\,a \rightarrow 2\mu\,2b$ 8 TeV CMS PAS HIG-16-015
- $h \rightarrow \gamma\,\gamma$ 8 TeV CMS PAS HIG-14-037
  - 13 TeV CMS PAS HIG-17-013
- bbA, $A \rightarrow \mu\,\mu$ 8 TeV CMS PAS HIG-15-009
- bbA, $A \rightarrow \tau\,\tau$ 8 TeV Phys. Lett. B 758 (2016) 296

LEPHWG, Phys. Lett. B565 :61-75, 2003



List of analyses searching for Low-mass scalar at CMS

▶ h → a a → 4μ	8 TeV	Phys. Lett. B 752 (2016) 146
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▶ h → a a → 2μ 2b	8 TeV	CMS PAS HIG-16-015
▶ h → γ γ	8 TeV	CMS PAS HIG-14-037
	13 TeV	CMS PAS HIG-17-013
▶ bbA, A → μ μ	8 TeV	CMS PAS HIG-15-009
▶ bbA, A → τ τ	8 TeV	Phys. Lett. B 758 (2016) 296

In this talk

Search for new resonances in di-photon final state in the mass range 70-110 GeV

Search for new resonances in di-photon final state in the mass range 70-110 GeV

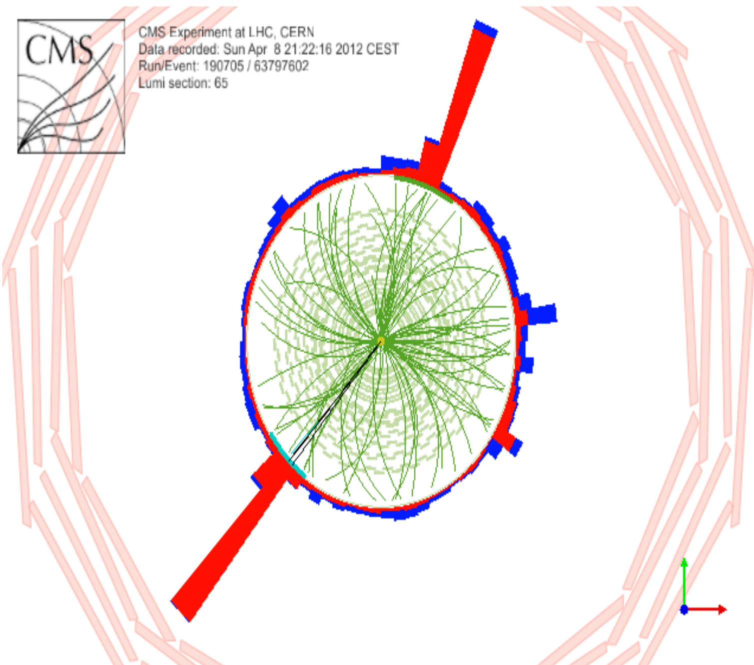
- **Similar methodology as the standard H → γγ analysis, but in different region**
  - **8 TeV: 80 < $m_{\gamma\gamma}$ < 110 GeV** — $19.7\ fb^{-1}$
  - **13 TeV: 70 < $m_{\gamma\gamma}$ < 110 GeV** — $35.9\ fb^{-1}$
- Main differences:

  - Lower E_T, a bit more aggressive selection criteria

  - **Edge of the trigger acceptance**

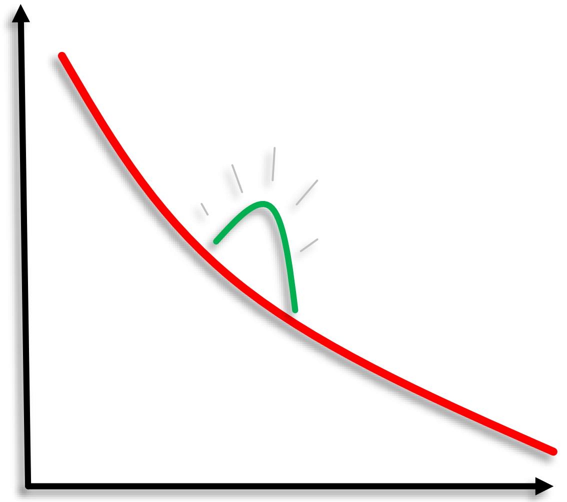
  - Important Z → e^+e^- background
- Note: **8 TeV analysis limited at 80 GeV because of trigger, this was improved at 13 TeV**

h → γ γ



- Clean final state topology : Two isolated photons.
- Large smoothly-decreasing background (continuum)
  - Reducible (jet-jet and γ+jet with jet faking photon) and
  - Irreducible (γ γ)
- Low-mass analysis specificity : Drell-Yan background, with electrons from the Z misidentified as photons
  - Use of a stricter electron veto based on the Pixel detector
  - Include relic DY contribution in background model
- Mass resolution is crucial (calibrations, energy regression and vertex identification)
- Classification of diphoton events to gain in sensitivity
- Analysis inherited from the “standard H→γ γ ” analysis

$h \rightarrow \gamma\gamma$



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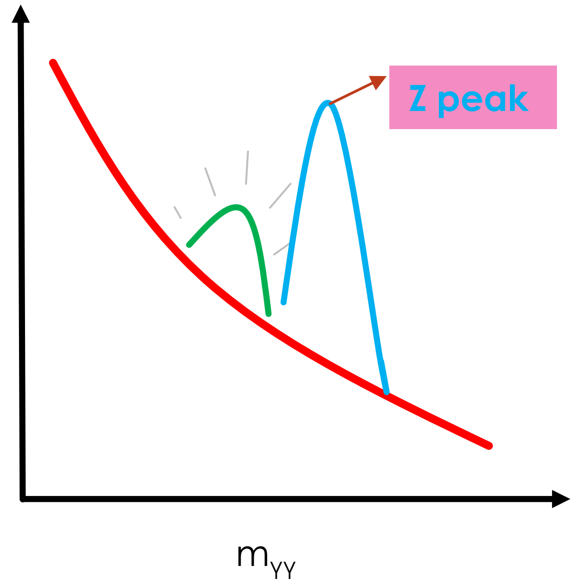
h → γ γ



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h → γ γ

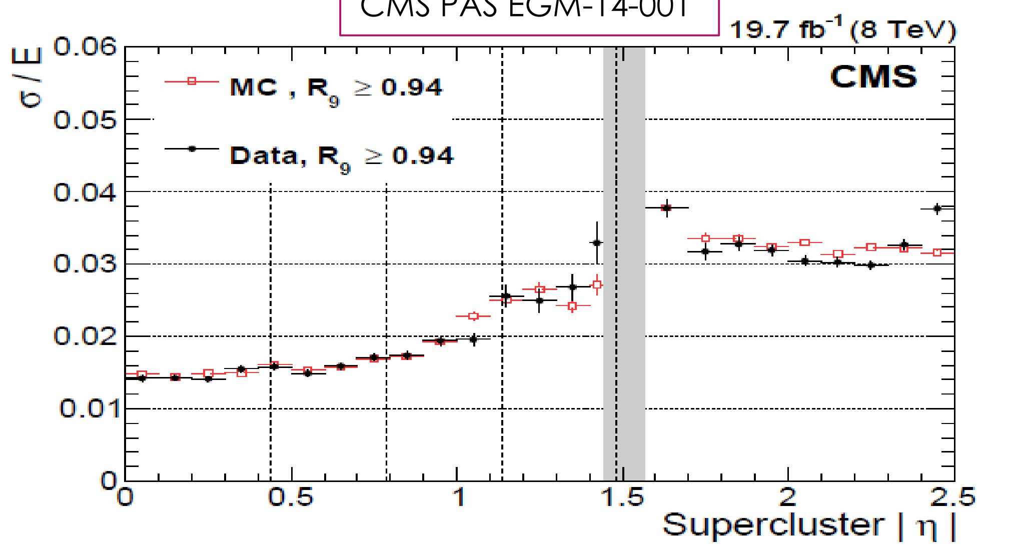
$$M_{\gamma\gamma} = \sqrt{(4\, E_{\gamma_1} E_{\gamma_2}\, sin^2\frac{\theta}{2})}$$

ECAL performance

Vertex Identification

We use Boosted Decision Trees (BDT) to identify the primary vertex, based on the kinematics of the recoiling tracks + the tracks of identified conversions

CMS PAS EGM-14-001



- Mass resolution is crucial (calibrations, energy regression and vertex identification)
- Classification of diphoton events to gain in sensitivity
- Many analysis elements inherited from the "standard H→ γ γ " analysis

Event selection

- E_T > 30/18 GeV **TRIGGER**
- Pixel veto for electron rejection
- $m_{\gamma\gamma}$ > 55 GeV
- Distinguish photons in barrel and endcap:

  - In endcap

    - Additional shower shape selections

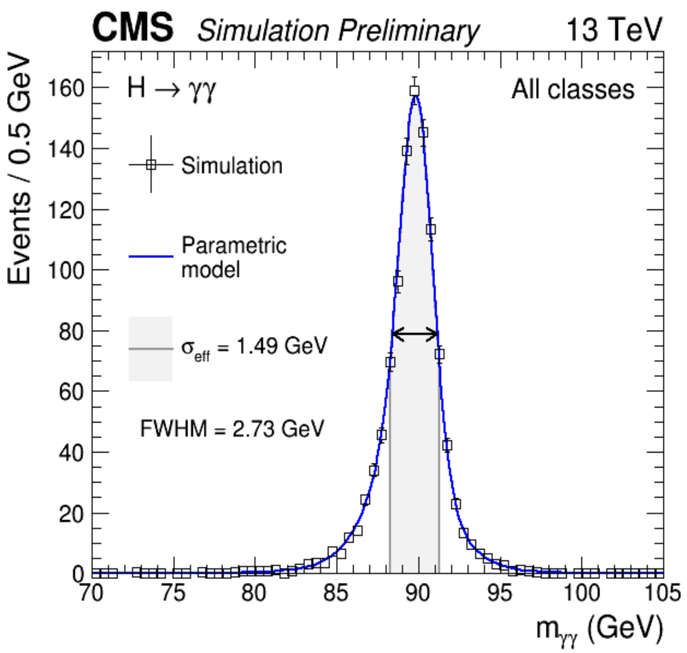
    - Cuts on hadronic/EM energy

    - Isolation

- $p_T^{\gamma^1}/m_{\gamma\gamma}$ > 30.6/65
- $p_T^{\gamma^2}/m_{\gamma\gamma}$ > 18.2/65
- MVA based Single photon selection criteria (reducible)
- MVA (BDT) to reject non-prompt photon pairs
- BDT to classify events (based on kinematics, photon ID, mass resolution) in three classes.

Signal Modelling

- **A parametric model is used to describe the shape of the signal in each event class**
- Same as the original standard H→γγ analysis method
- Use sum of Gaussian functions to fit signal MC at each mass point, for each production process and for right and wrong vertex choice, in each of the 3 event classes (3 or 4 Gaussians for right choice, 2 or 3 for wrong)
- Full signal model is constructed by taking linear interpolation of each fit parameter between individual mass points

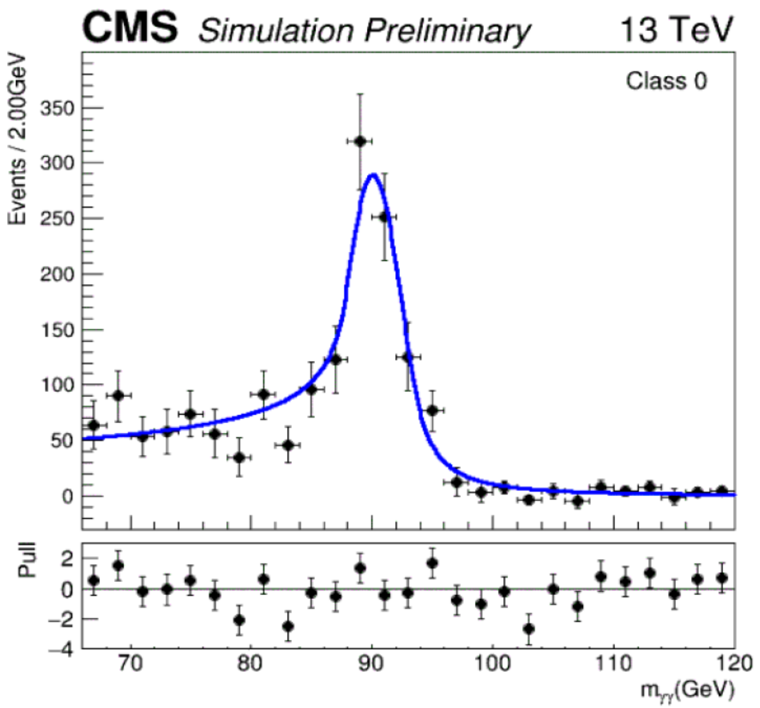


Background modelling

Z→ee relic 'double-fake' background component

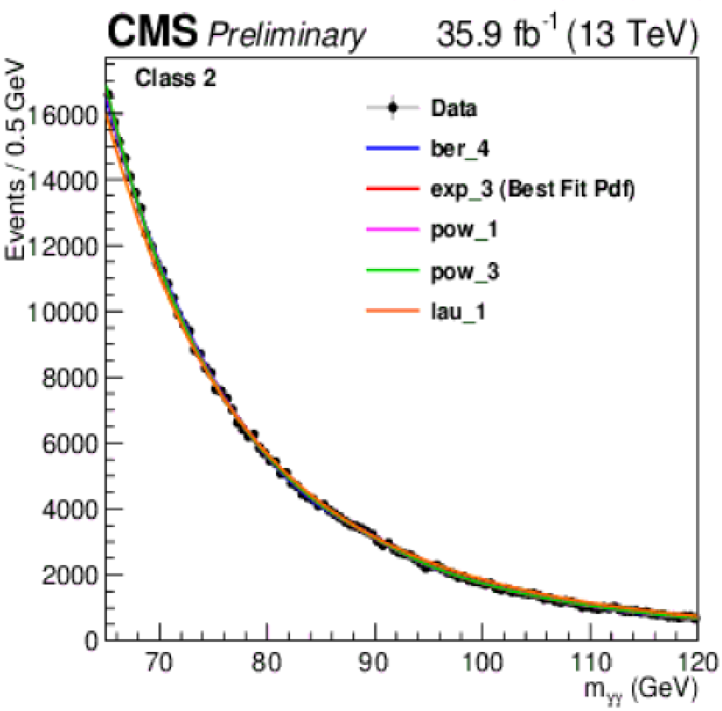
Drell-Yan contribution in the background with 2 electrons misidentified as photons ("double-fake" events) even after electron veto :

Fit Model : double-sided Crystal Ball (DCB)

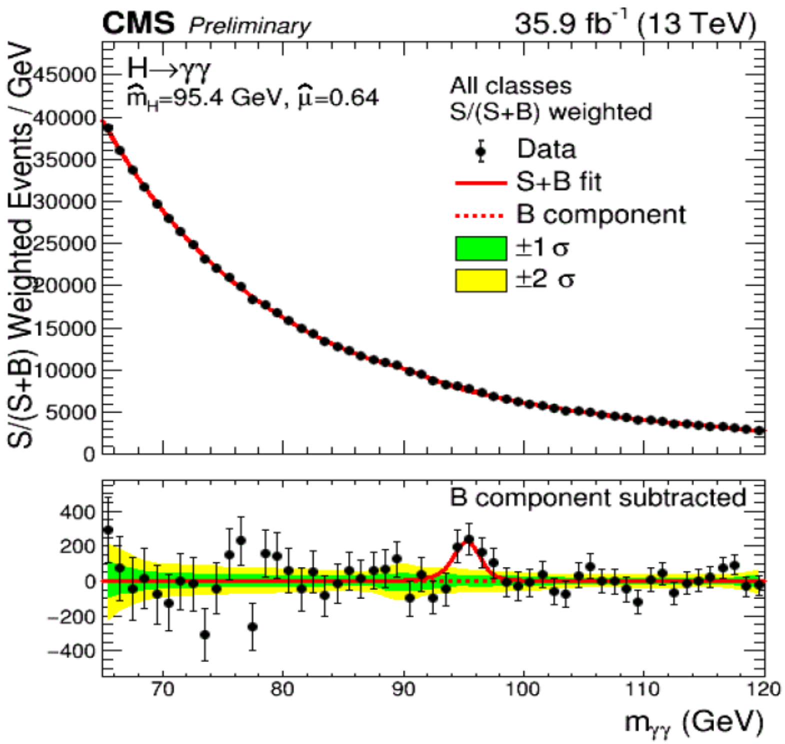


Background modelling

- Fit model : **Four families of analytic functions** (sum of exponentials, sum of Bernstein polynomials, Laurent series, sum of power laws) **+ DCB** (fraction left floating)
- **Built directly from data** using the diphoton mass spectrum (65-120GeV) in each event class.



Invariant mass fit

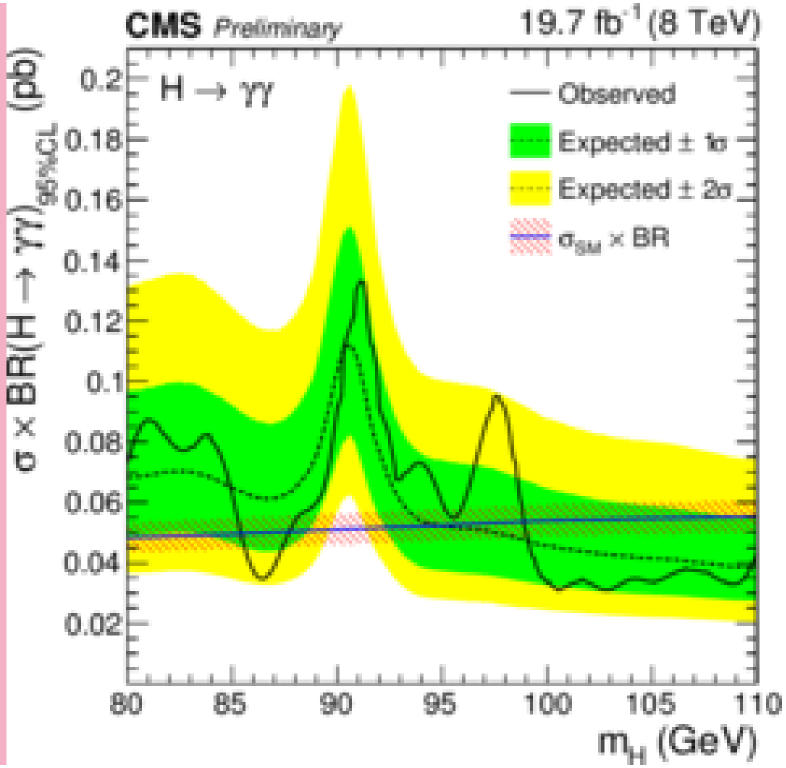


- Fits of S+B model over all event classes
- Each event weighted by the ratio S/(S+B) for its event class.
- **Main systematic uncertainties:**
  - Photon identification BDT distribution shape, largest unc. 14.6% (VBF, 13 TeV)
  - Per-photon energy resolution 13.7% (ggh, 8 TeV)
  - Due to QCD scale variations 7.5% (ggh, 8 TeV)
  - Trigger efficiency 5.5% (13 TeV)

Limit Run-I

May be skipped

- **Expected and observed exclusion limits (95% CL) on the production cross section times BR into two photons for an SM-like second Higgs boson in the asymptotic CLs approximation.**
- The inner green and outer yellow bands indicate the regions containing 68% and 95% of the distribution of limits expected under the background-only hypothesis.
- $\sigma_{SM} \times BR$ **is shown as a blue line with red hatched band indicating its uncertainty. (LHC Higgs Cross section working group)**



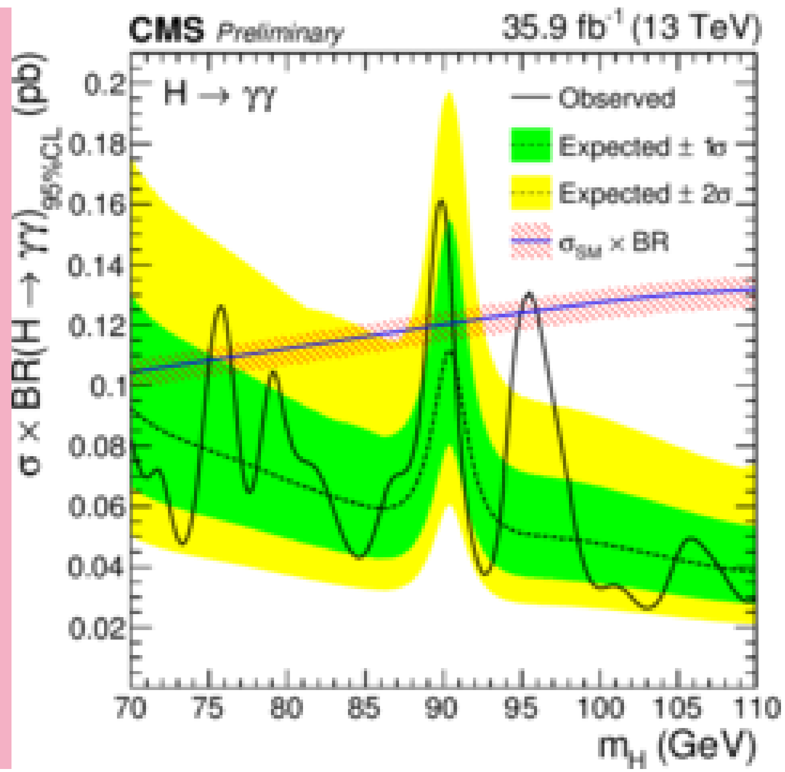
Limit Run-II

- The minimum(maximum) limit on cross-section times branching has increased from

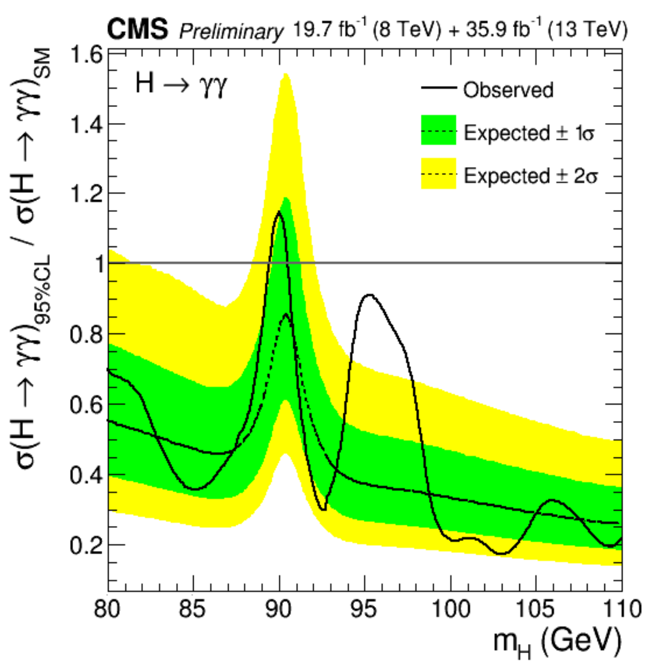
31(133) fb at m=102.8(91.1) GeV at 8 TeV

↓

26(161) fb at m=103.0(89.9) GeV at 13 TeV



Combination (Run-I + Run-II)

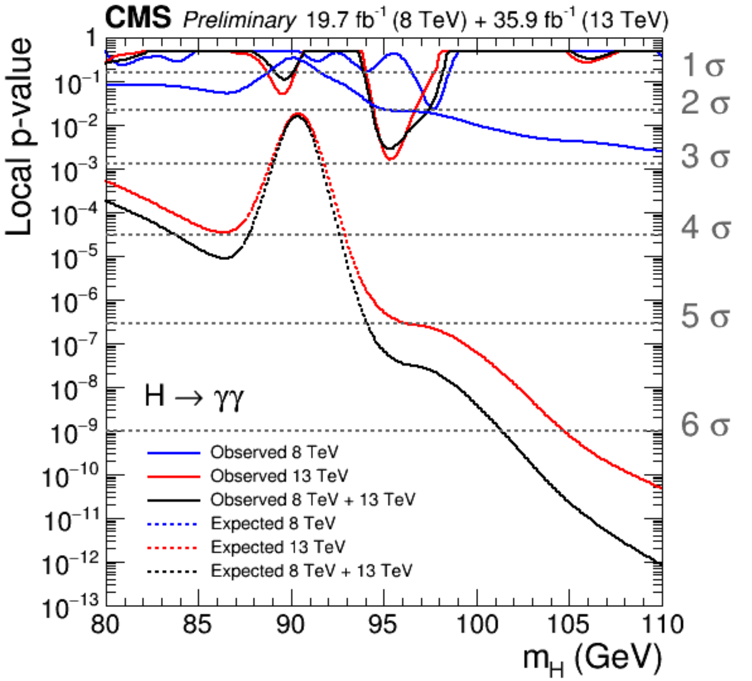


- **All experimental systematic + theoretical uncertainties on signal acceptance assumed uncorrelated except for the theoretical uncertainties on production cross-section 100% correlated).**
- **8 TeV+13 TeV: minimum(maximum) limit on ($\sigma \times$ Br)/ ($\sigma \times$ Br)$_{SM}$: 0.17(1.15) at m=103.0(90.0)GeV**
- Combined 8 TeV+13 TeV $\sigma \times$ BR limit normalized to SM expectation (production processes assumed in SM proportions).
- **There is an excess with respect to expected limits. More details in the next slide.**

Expected & Observed p-value

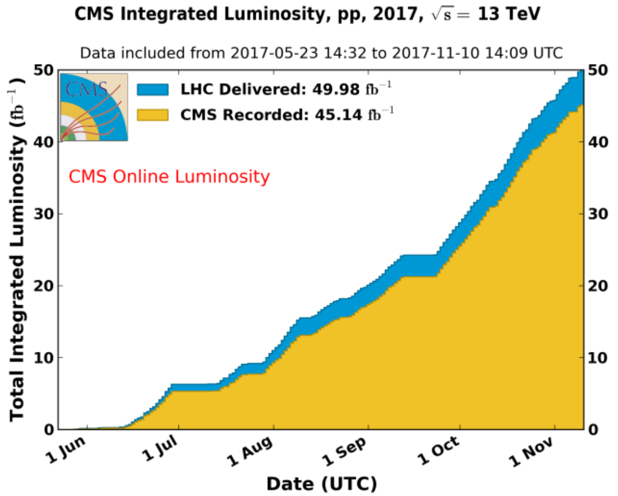
p-value: probability that BG only fluctuation is more signal-like than observation.

- 8 TeV: Excess ~2.0 σ local significance at m=97.6 GeV
- 13 TeV: Excess ~2.9 σ local (1.47 σ global) significance at m=95.3 GeV
- 8TeV+13 TeV: Excess ~2.8 σ local (1.3 σ global) significance at m=95.3 GeV
- More data are required to ascertain the origin of this excess



Summary

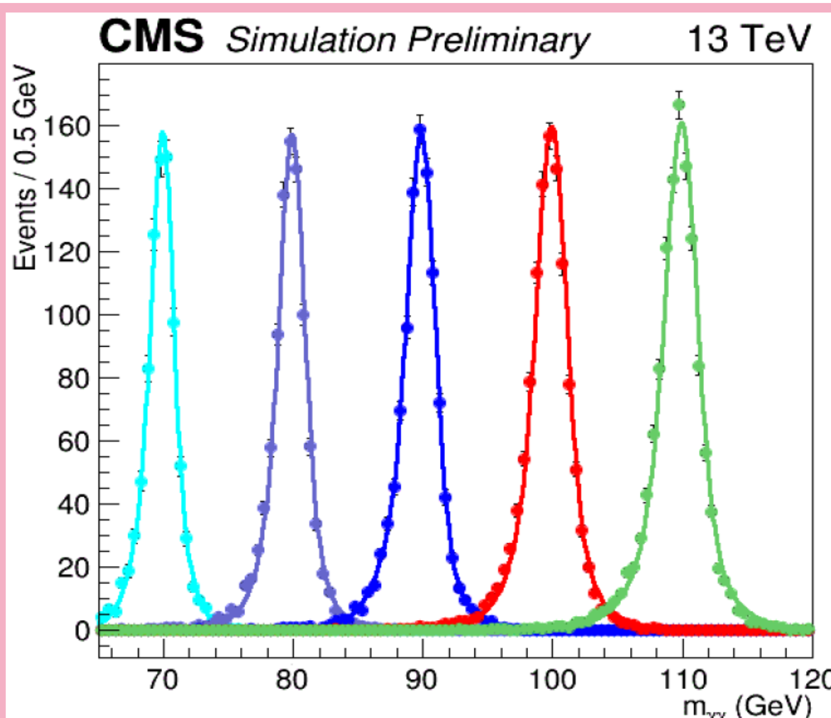
1. No significant excess is observed in h to diphoton channel. The maximum local significance corresponds to 2.8σ for all production mechanisms and event classes combined (1.3σ global) at m_H~ 95.3 GeV.
2. We have accumulated p-p collision events corresponding to 45 fb^{-1} in 2017.



THANK YOU

Backup

Signal Modelling



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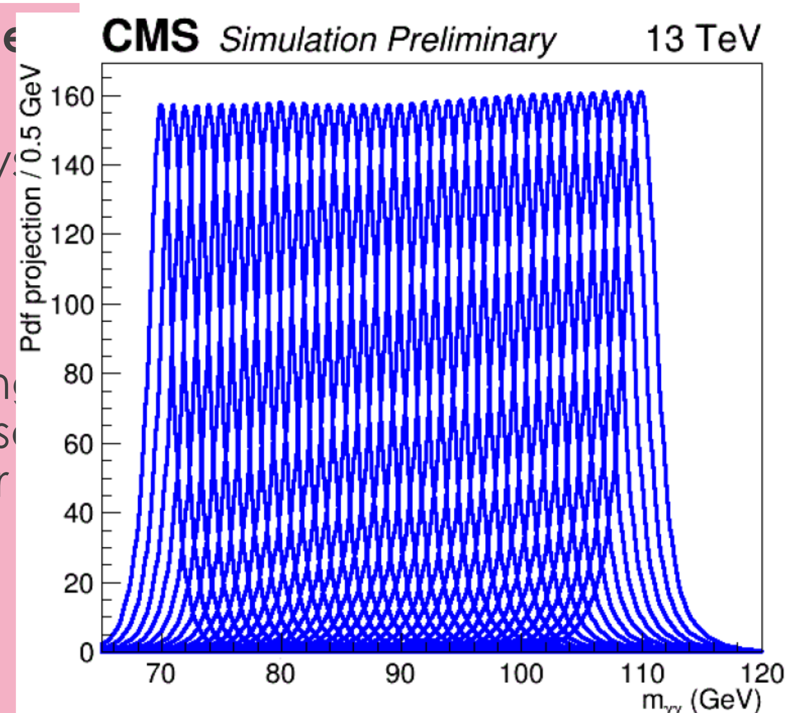

Background modelling

Z→ee comp

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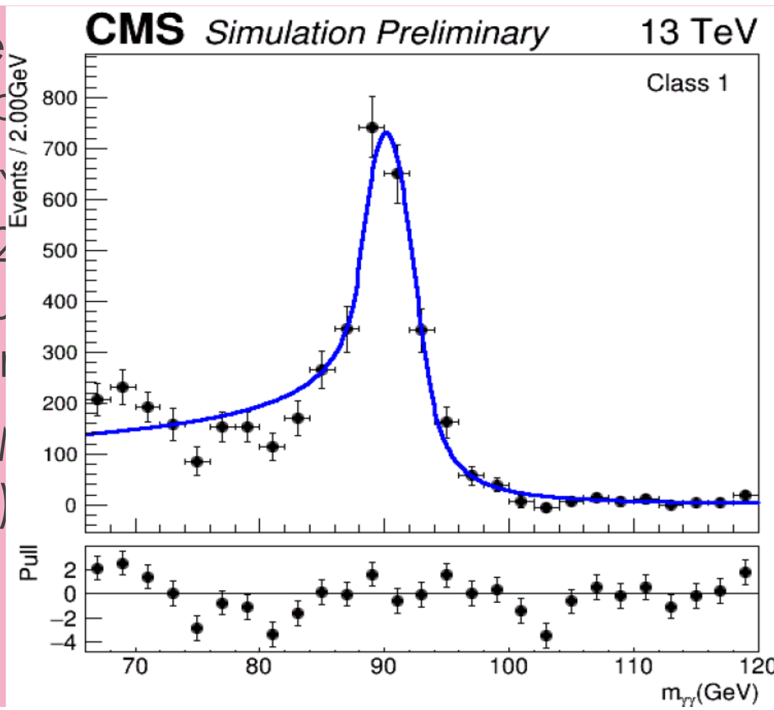
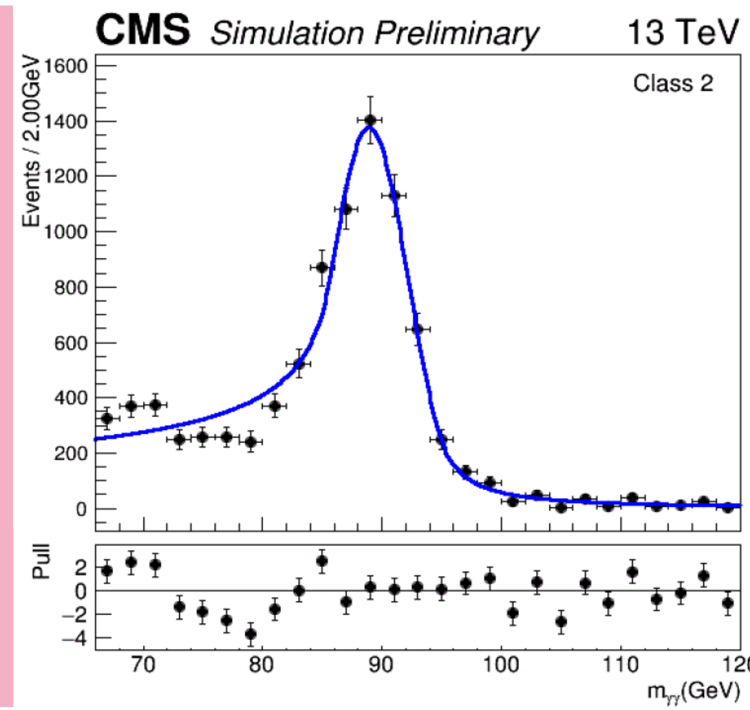
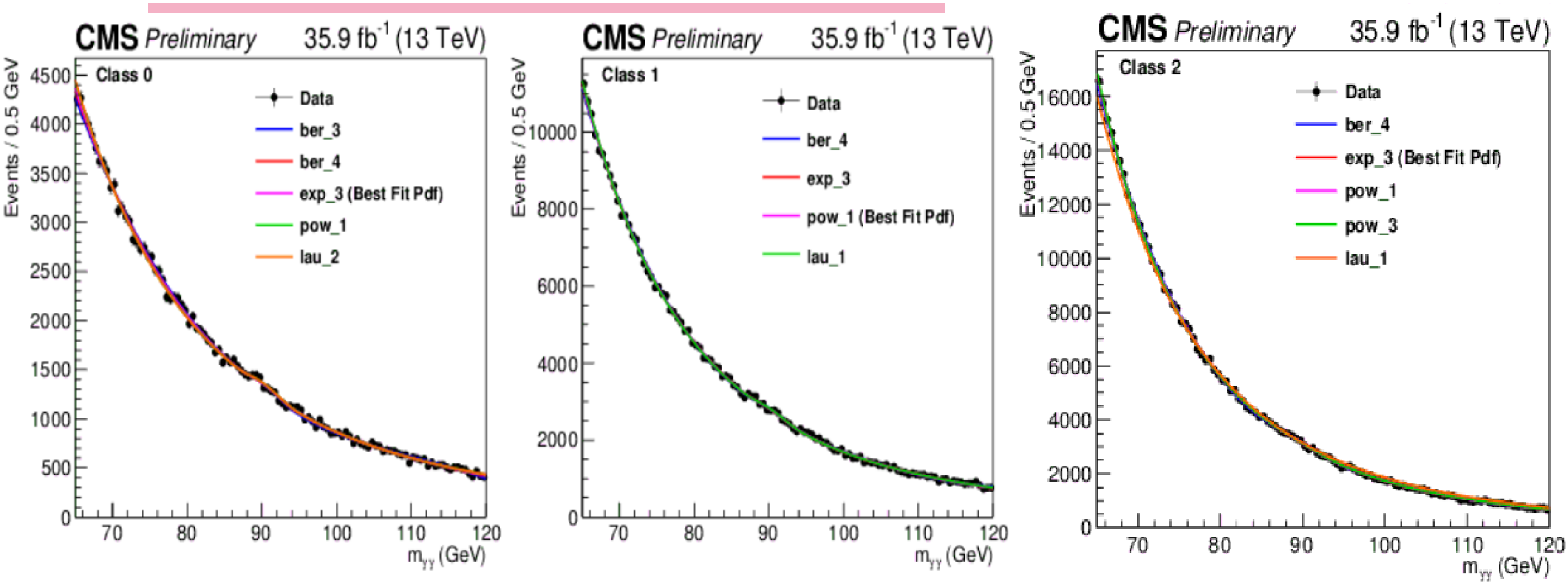
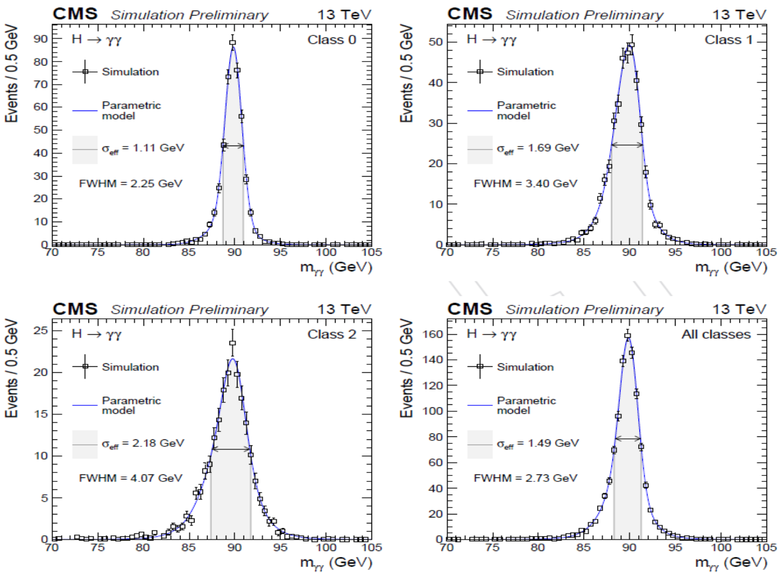




Background modelling




CMS Simulation Preliminary 13 TeV
H → γγ
Class 0
Simulation
Parametric model
σ_eff = 1.11 GeV
FWHM = 2.25 GeV
Class 1
σ_eff = 1.69 GeV
FWHM = 3.40 GeV
Class 2
σ_eff = 2.18 GeV
FWHM = 4.07 GeV
All classes
σ_eff = 1.49 GeV
FWHM = 2.73 GeV
Events / 0.5 GeV
m_γγ (GeV)

$$NExp(x) + DCB(x) = \sum_{i=1}^{N} \beta_i e^{\alpha_i x} + DCB(x),$$

$$NPow(x) + DCB(x) = \sum_{i=1}^{N} \beta_i x^{-\alpha_i} + DCB(x),$$

$$NBer(x) + DCB(x) = \sum_{i=0}^{N} \beta_i b_{i,N} + DCB(x) \quad with \quad b_{i,N} = \begin{pmatrix} N \\ i \end{pmatrix} x^i (1-x)^{N-i},$$

$$NLau(x) + DCB(x) = \sum_{i=1}^{N} \beta_i x^{(-4+\sum_{j=1}^{i}(-1)^j (j-1))} + DCB(x).$$