Search for a new Higgs boson-like low-mass resonance in the diphoton final state at $\sqrt{s}$ = 8+13 TeV in pp collisions at CMS

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On behalf of the CMS Collaboration

IRN TERASCALE
Marseille (France)

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Theoretical Motivations

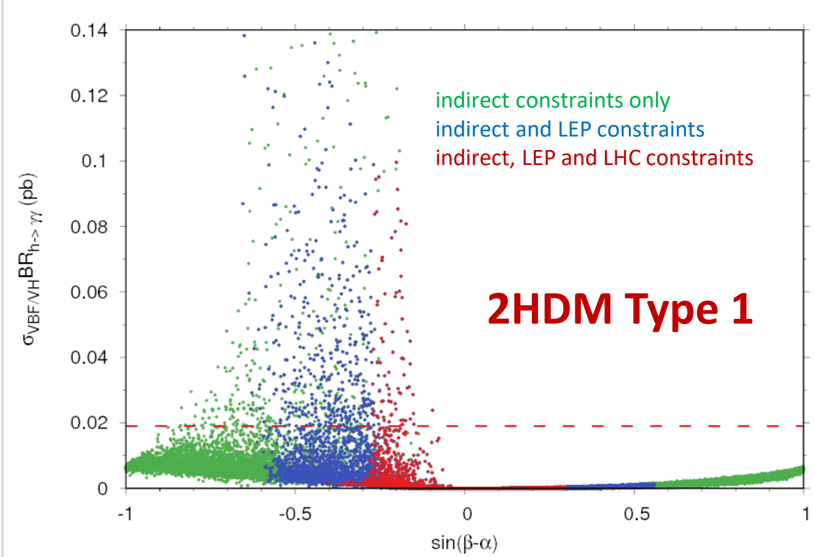
Is the new particle discovered in 2012 by the CMS and ATLAS Collaborations at a mass of 125 GeV really the Standard Model Higgs boson?

Some **BSM theories** predict **modified** and **extended Higgs sectors**:

- General Two Higgs Doublet Model (**2HDM**)
  - 2 Higgs Doublets ➡ 5 Higgs bosons: h, H, A, $H^{\pm}$
- 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, $H^{\pm}$

- The **Higgs boson at 125 GeV** can be identified as the **next-to-lightest scalar**, allowing to envisage a possible **lighter particle**

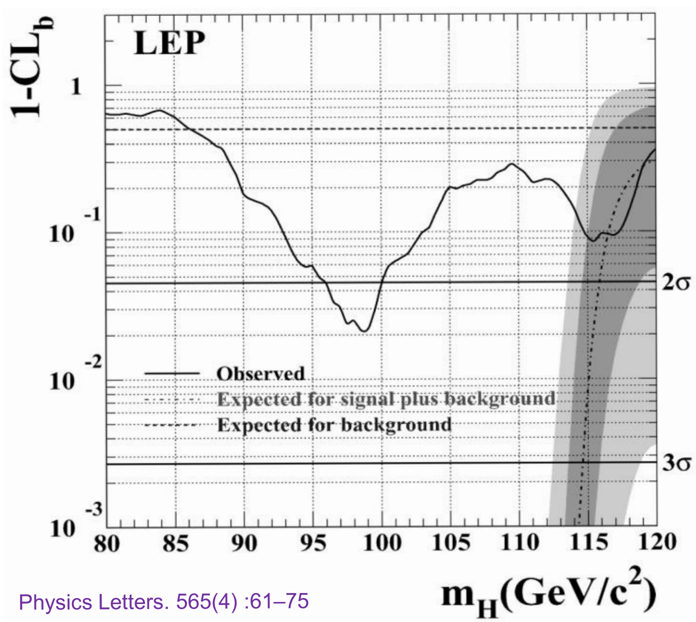
- Strong **interest** from the **theoretical community**



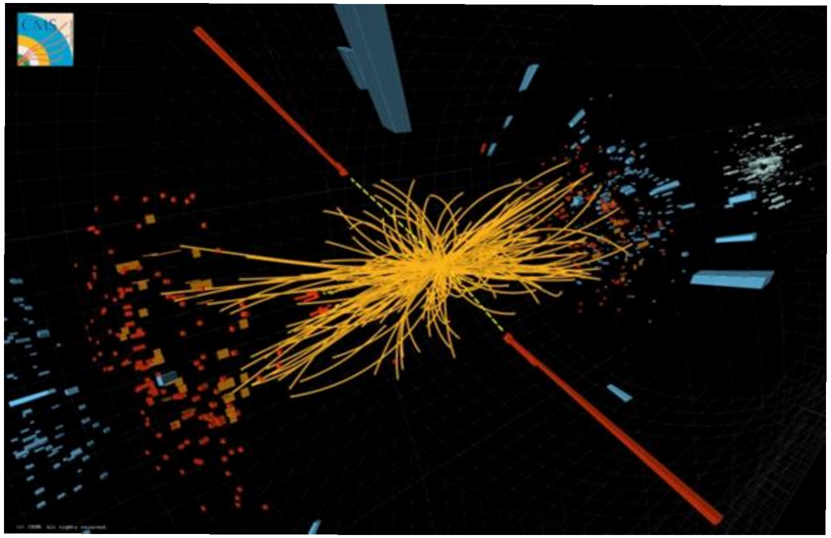
G. Cacciapagia et al., JHEP 1612 (2016) 068

Experimental Motivations

- **Small excess** of events (~2σ) at **LEP** observed by 3 of the 4 experiments in *bb*/*ττ* channels



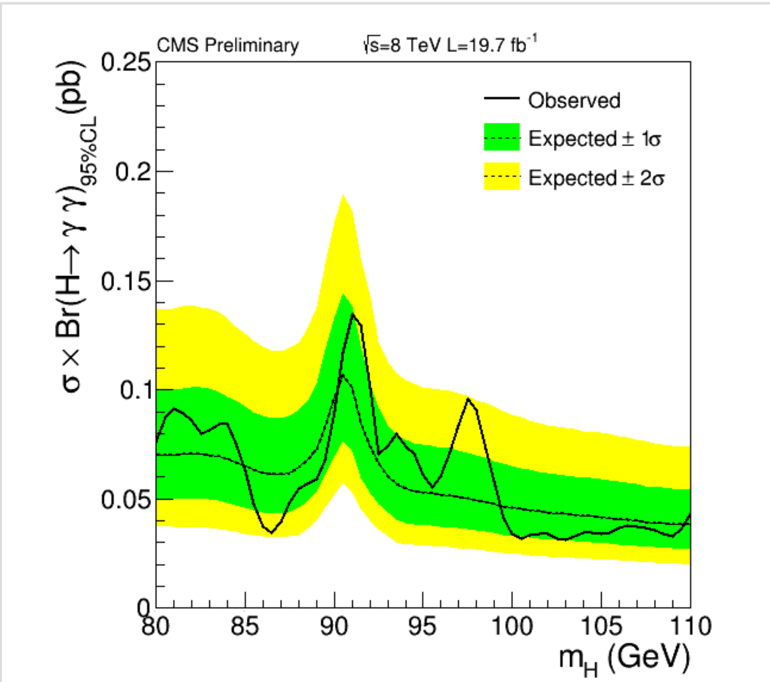
Physics Letters. 565(4) :61–75



- During LHC Run I, the standard $H\rightarrow\gamma\gamma$ **search range** was **[110,150] GeV**
- Clean signature with two **isolated and highly energetic photons**
- Final state fully reconstructed with **excellent mass resolution**
- **Background** from QCD (γγ – γj – jj) large enough to be **evaluated directly on data**

Run I Results

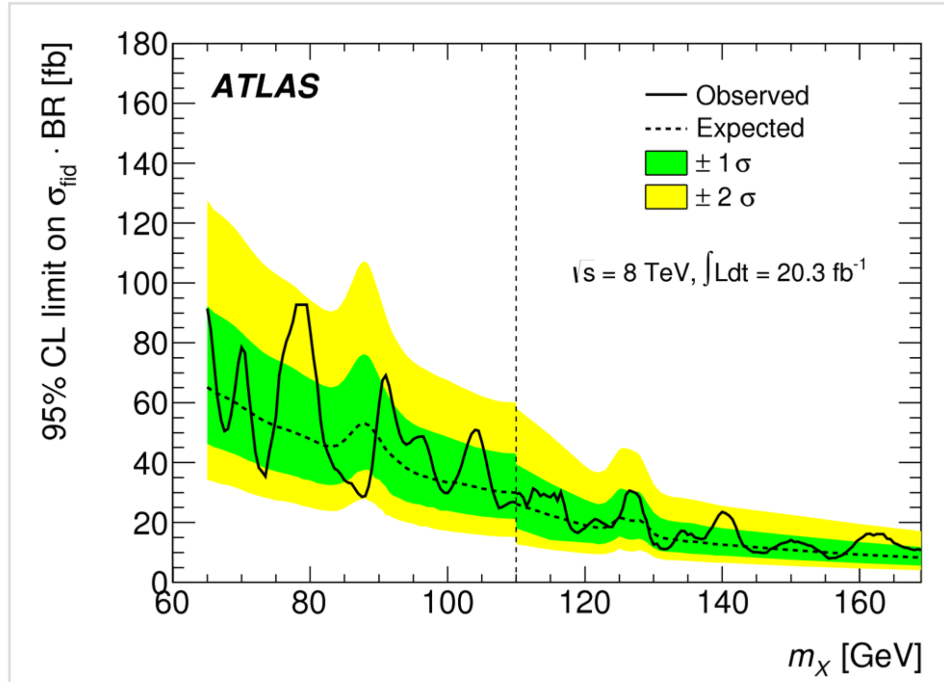
CMS RESULTS
CMS-PAS-HIG-14-037



- 80 GeV < $m_{\gamma\gamma}$ < 110 GeV
- 4 inclusive classes
- Floating normalization of relic *Z→ee*
- Total cross section

∼2σ excursion at ∼97.5 GeV

ATLAS RESULTS
PRL 113 171801 (2014)

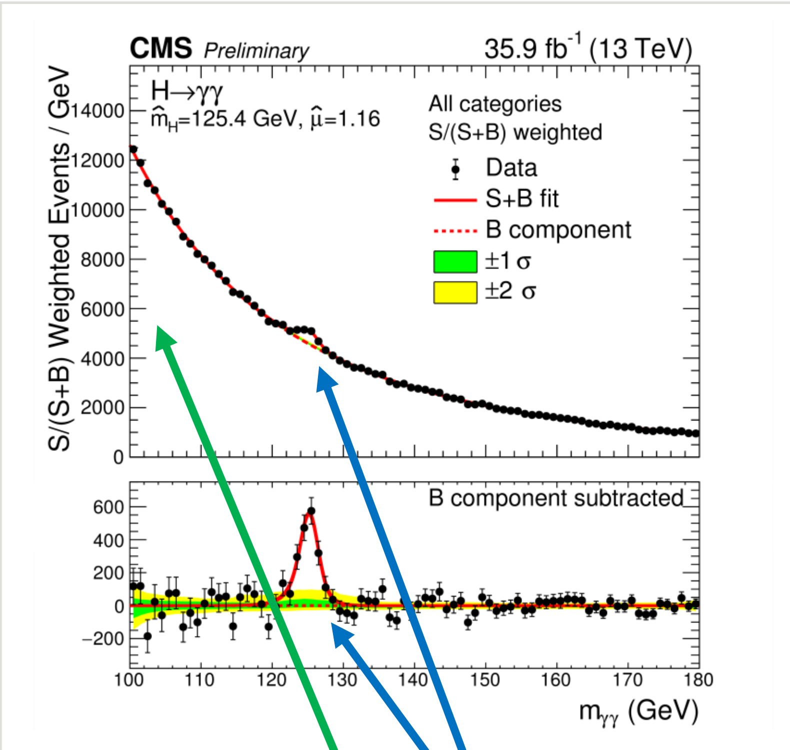


- 65 GeV < $m_{\gamma\gamma}$ < 110 GeV
- 3 classes: conversion status (0, 1, 2)
- Fixed normalization of relic *Z→ee*
- Fiducial cross section

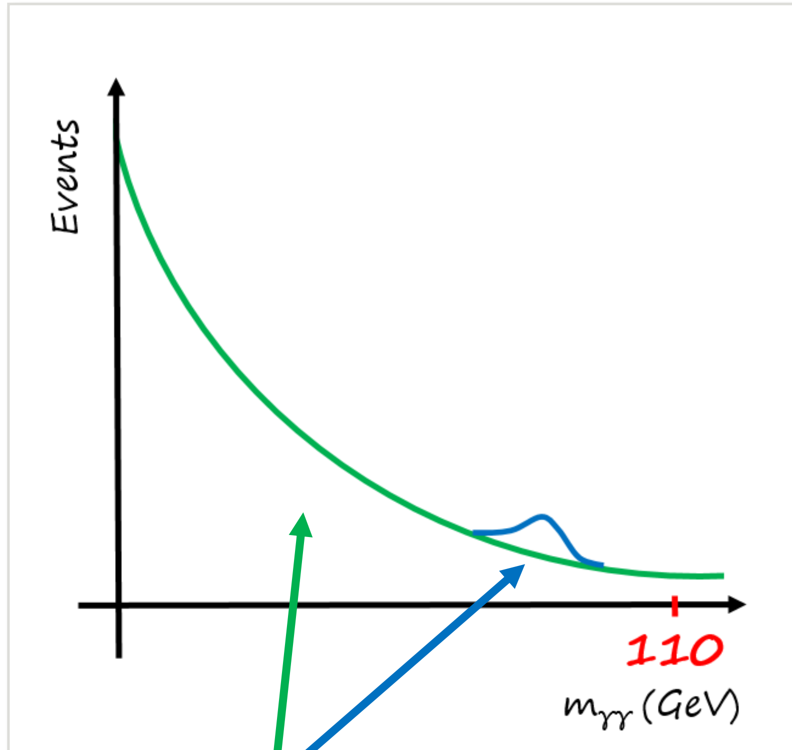
∼2σ excursion at ∼80 GeV

The $H\to\gamma\gamma$ Decay Channel at Low Mass

STANDARD $H\to\gamma\gamma$ ANALYSIS



LOW-MASS $H\to\gamma\gamma$ ANALYSIS



NARROW SIGNAL PEAK

LARGE FALLING BACKGROUND

The $H\rightarrow\gamma\gamma$ Decay Channel at Low Mass

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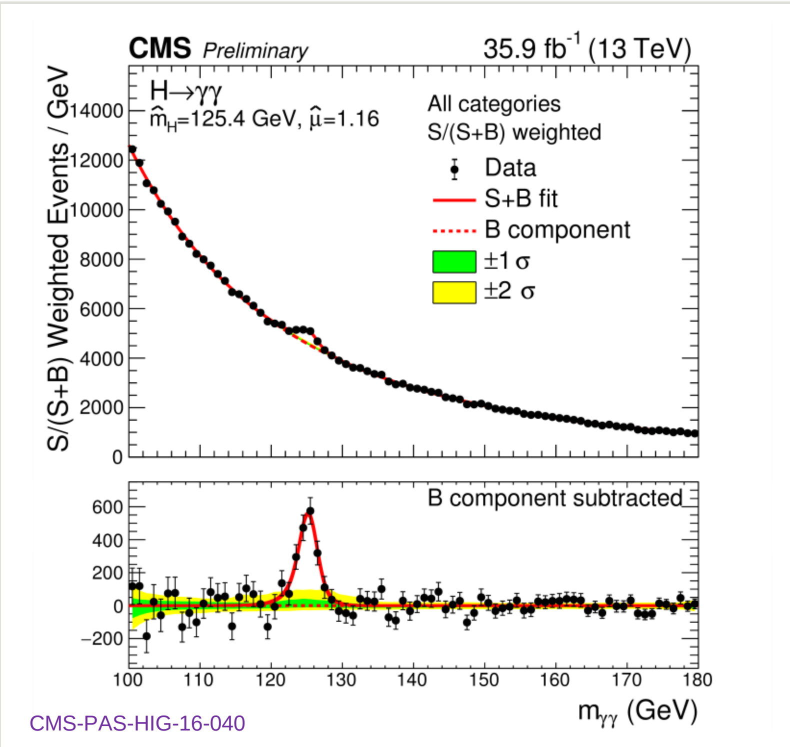

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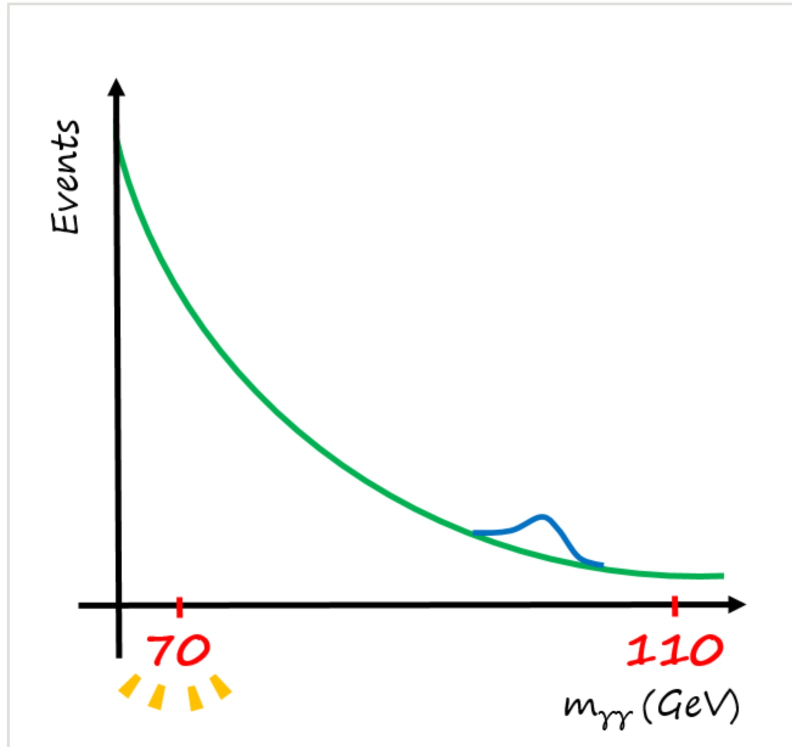


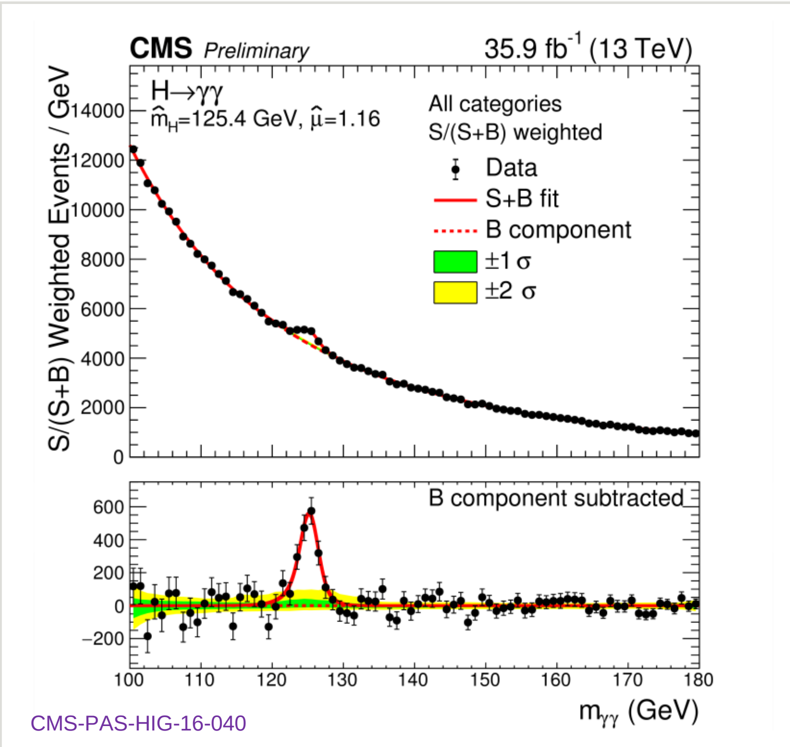
MAIN CHALLENGES:

- Difficulty to **extend the range** to very low mass values (mainly for the trigger)

→ Lower limit at 70 GeV

The $H \to \gamma\gamma$ Decay Channel at Low Mass

STANDARD $H \to \gamma\gamma$ ANALYSIS



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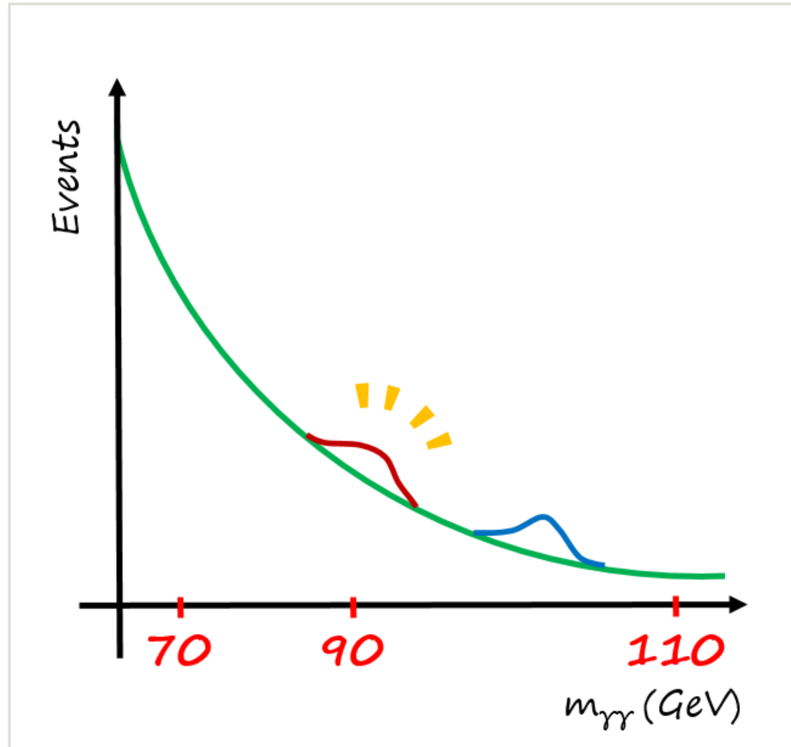


MAIN CHALLENGES:

- Additional Drell-Yan **background $Z \to ee$**, with electrons misidentified as photons

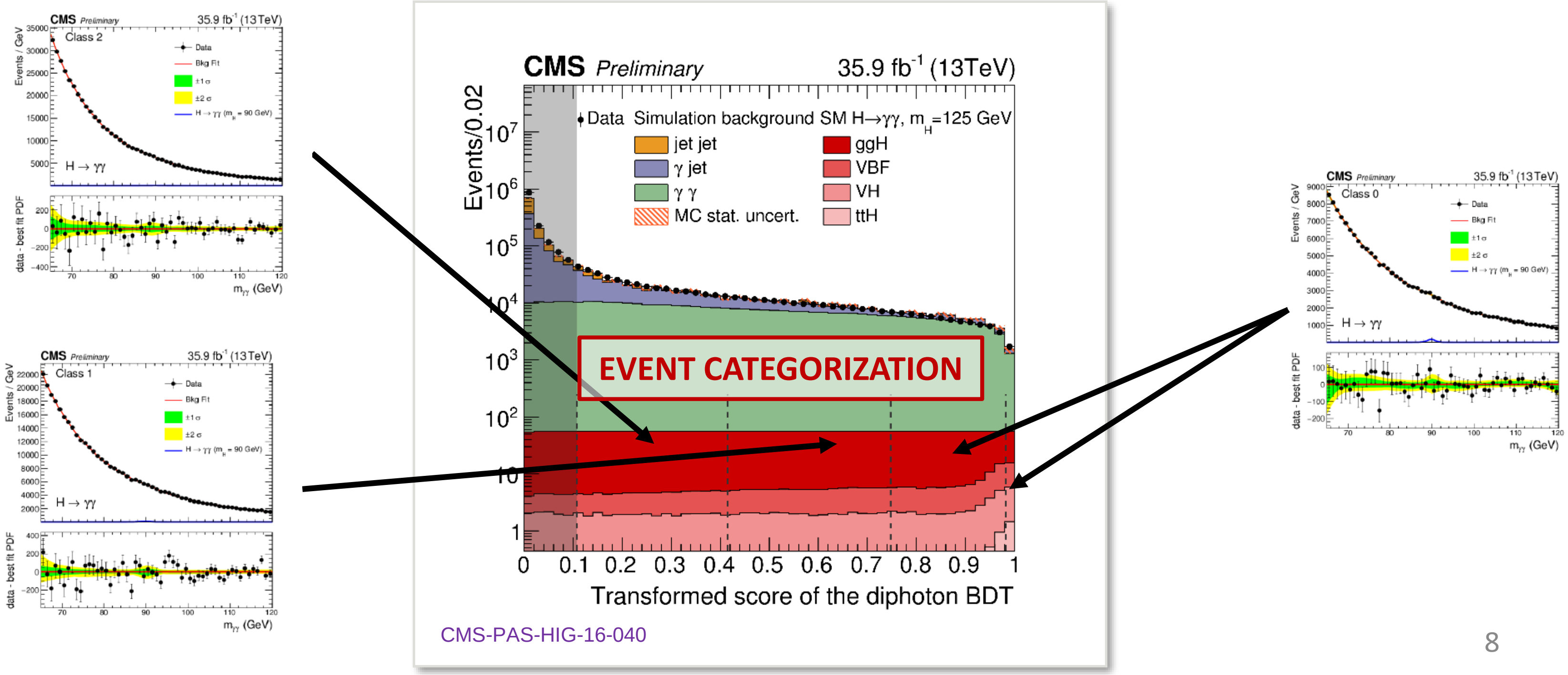
  ➡ Decrease in sensitivity around 90 GeV

Low-Mass Analysis Strategy

$$\boxed{m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}}$$

- Select two **"good quality" photons**
- Measure **photon energy** precisely
- Find the **primary vertex** of the decay

- Very **similar to the standard *H→γγ* analysis**
- **Event categorization** defined to maximize S/B
- Signal extracted from background by **fitting the observed diphoton mass distributions** in each category

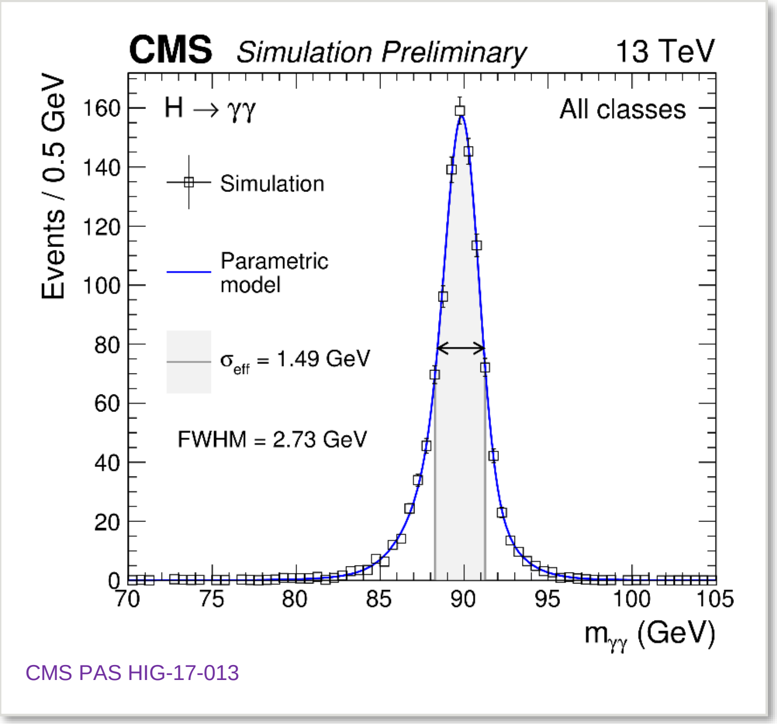


Photon Energy

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1 - \cos\theta)}$$

- Photon energy reconstructed by building **clusters of energy deposits** in the **electromagnetic calorimeter**.
- **Energy** and **its uncertainty** corrected for local and global shower containment
  ➡ **regression technique**:
  - corrects photons' energies
  - provides an estimate of energy resolution
- **Energy scale** in data **corrected** as a function of data taking epochs, pseudorapidity and EM shower width
- **Smearing** to the reconstructed photon energy in **MC** to match the resolution in data

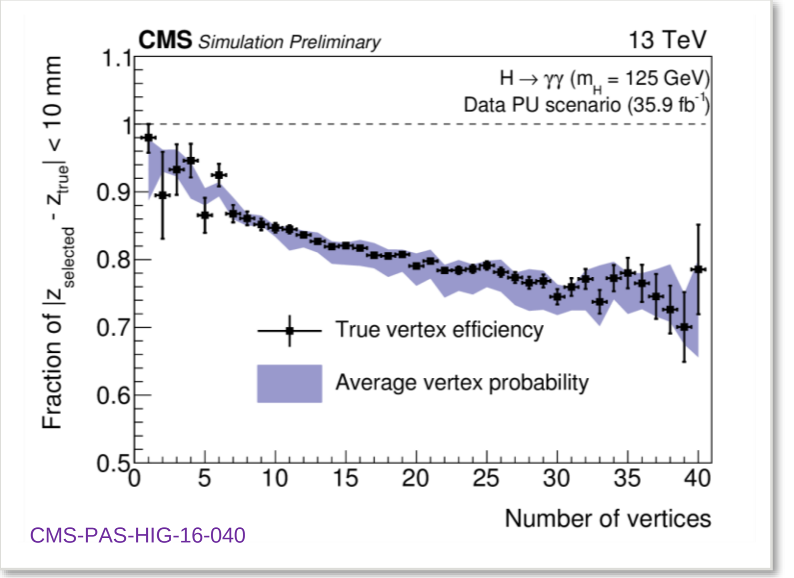
➡ **$Z \to ee$ peak** used as reference

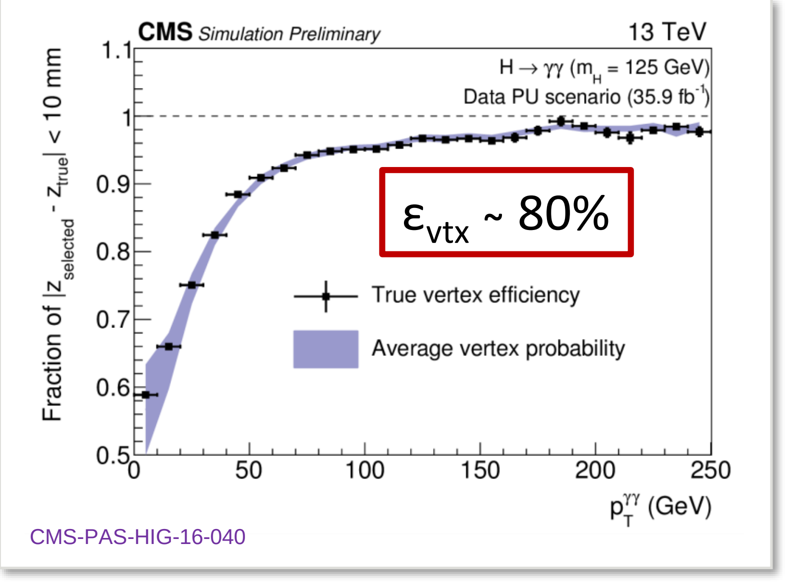


Vertex Identification

$$\boxed{m_{\gamma\gamma} = \sqrt{2E_1E_2(1 - \cos\theta)}}$$

- **Vertex assignment** considered as correct within **1 cm** of the diphoton interaction point
  ➡ **negligible impact** on mass resolution
- **Multi-variate approach**:
  - Observables related **to tracks recoiling** against the diphoton system
  - direction of **conversion tracks**
- **Second MVA discriminant** to estimate the probability for the vertex assignment to be within 1 cm
  ➡ used later for diphoton classification
- Method validated on $\boldsymbol{Z \to \mu\mu}$ **events**, by refitting vertices ignoring the muon tracks



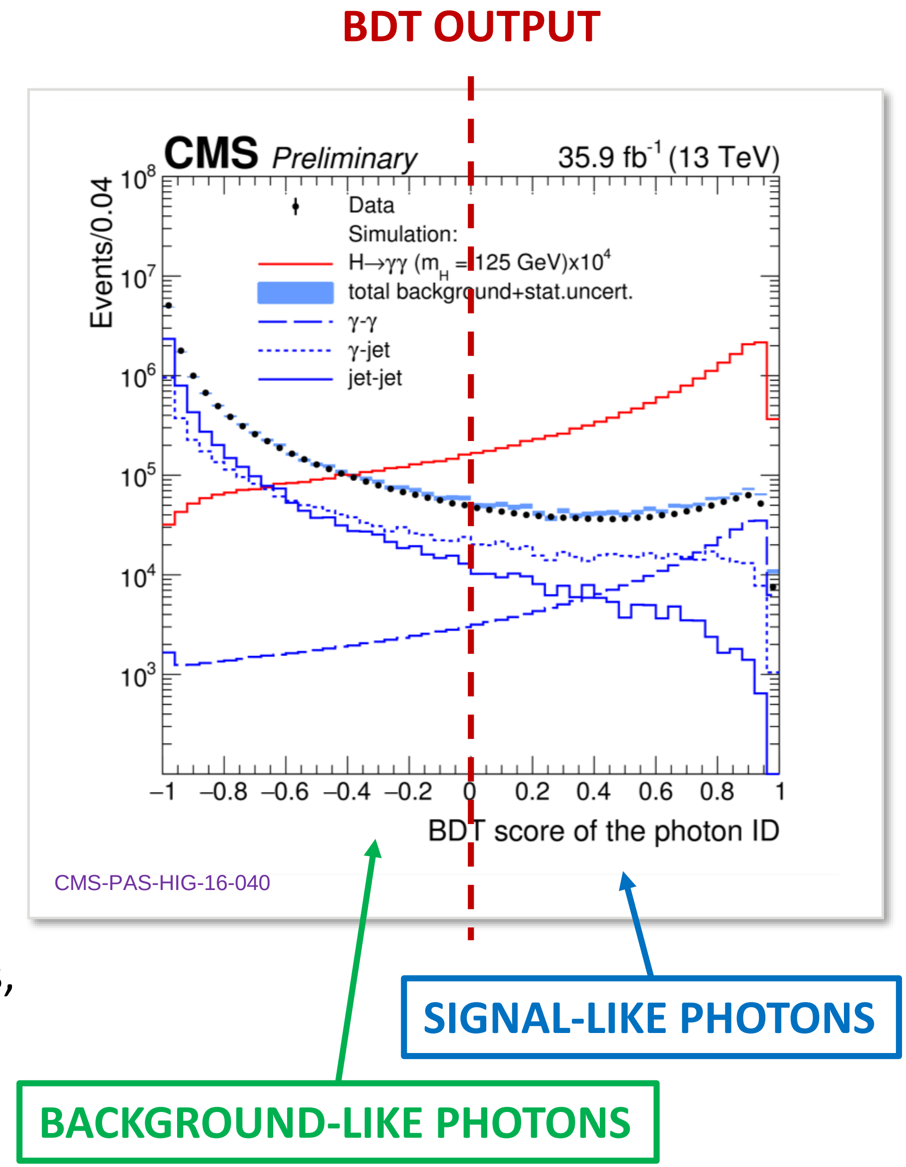


Photon Selection

- **Trigger selection**:
  Trigger paths based on transverse energy, H/E, electromagnetic shower shapes and isolation variables, $m_{\gamma\gamma}$
  ➡ Dedicated paths for low-mass analysis
  ➡ Search range extended at lower values

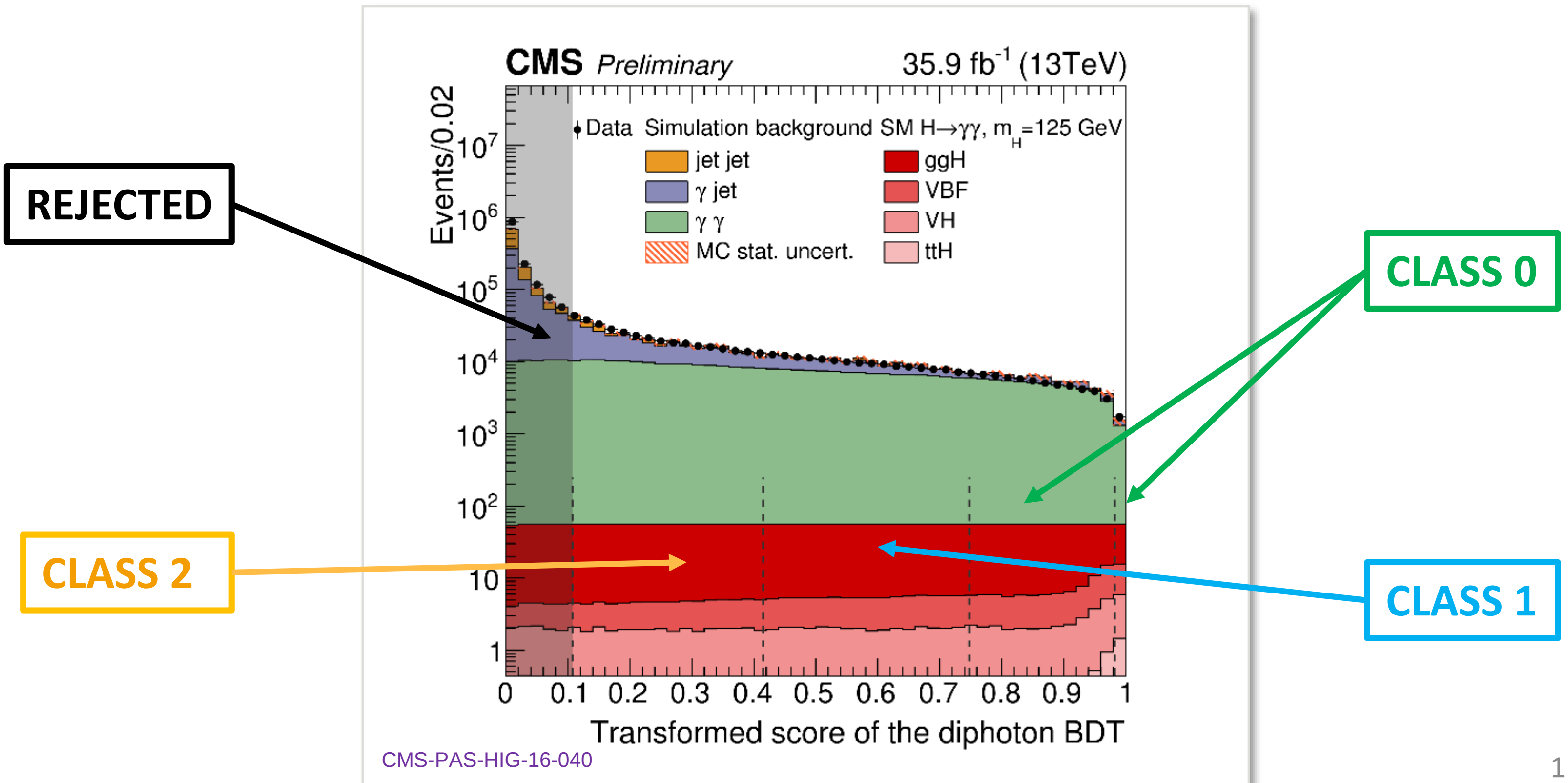
- **Preselection**:
  - Similar to trigger requirements, but more stringent
  - Specific cuts for the low-mass analysis
  - Electron veto based on pixel detector

- **Photon Identification**:
  - Multi-Variate approach (BDT) to reject fake photon candidates (mainly from π^0 mesons produced in jets)
  - Shower shape and isolation observables, median energy density (ρ)
  - BDT output provides an estimate of the per-photon quality



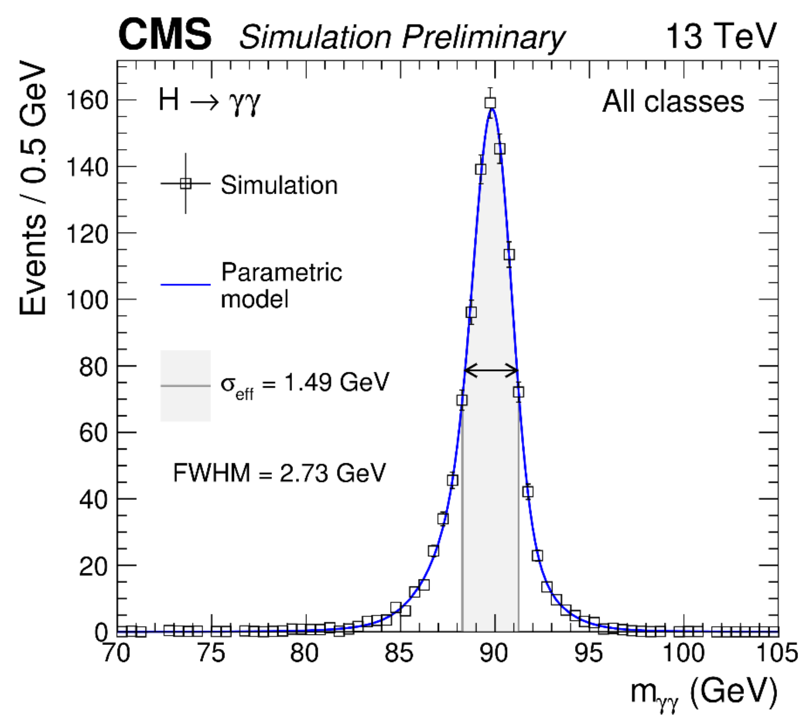
Event Categorization

- To gain sensitivity, events are **split into classes** according to their expected signal/ background ratio
- Events are categorized according to the **photon kinematics**, per-event **mass resolution, photon ID** and **good vertex probability** by a **multivariate classifier** (same as the standard $H\rightarrow \gamma\gamma$ analysis)
- **Number of classes** limited by **MC Drell-Yan statistics** (one class less than the standard analysis, no exclusive classes tagging production modes like in standard analysis)



Signal Model

- $H \to \gamma\gamma$ MC samples with m_H from **70 to 110 GeV** are used (5 GeV steps)
- The signal is fitted by a **sum of Gaussian distributions** in each event class and for each production process and best and worst vertex choices (then combined together)
- The model is **interpolated between the mass points**
- The **signal shape** corresponds to a **standard Higgs boson**



CMS PAS HIG-17-013

Background Model

CONTINUUM BACKGROUND

- Modeled with a sum of polynomials (from 4 families, order chosen with a p-value test)

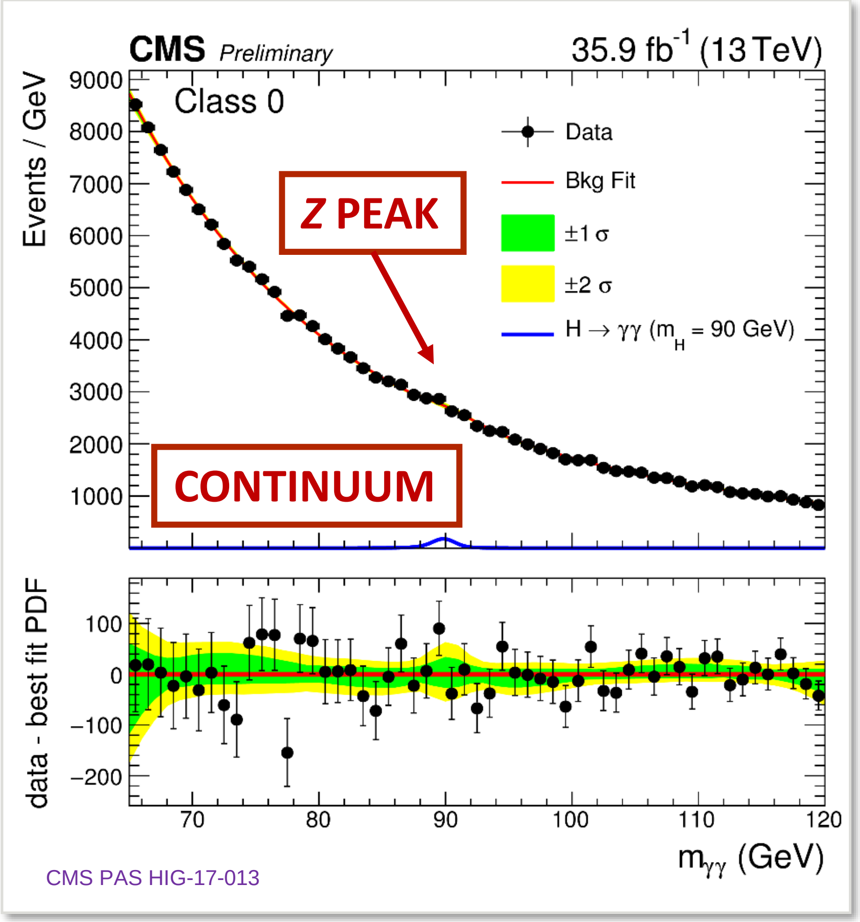
DRELL-YAN CONTRIBUTION

- Modeled with a double-sided Crystal Ball (DCB) distribution
- Shape parameters extracted by fitting MC $Z \to ee$ events passing the whole analysis selection (double-fake events)
- Data/MC systematic uncertainty estimated from single-fake $Z \to ee$ events

FINAL BACKGROUND MODEL

Polynomial + double-sided Crystal Ball

- Fitted to the data
- DCB fraction let floating



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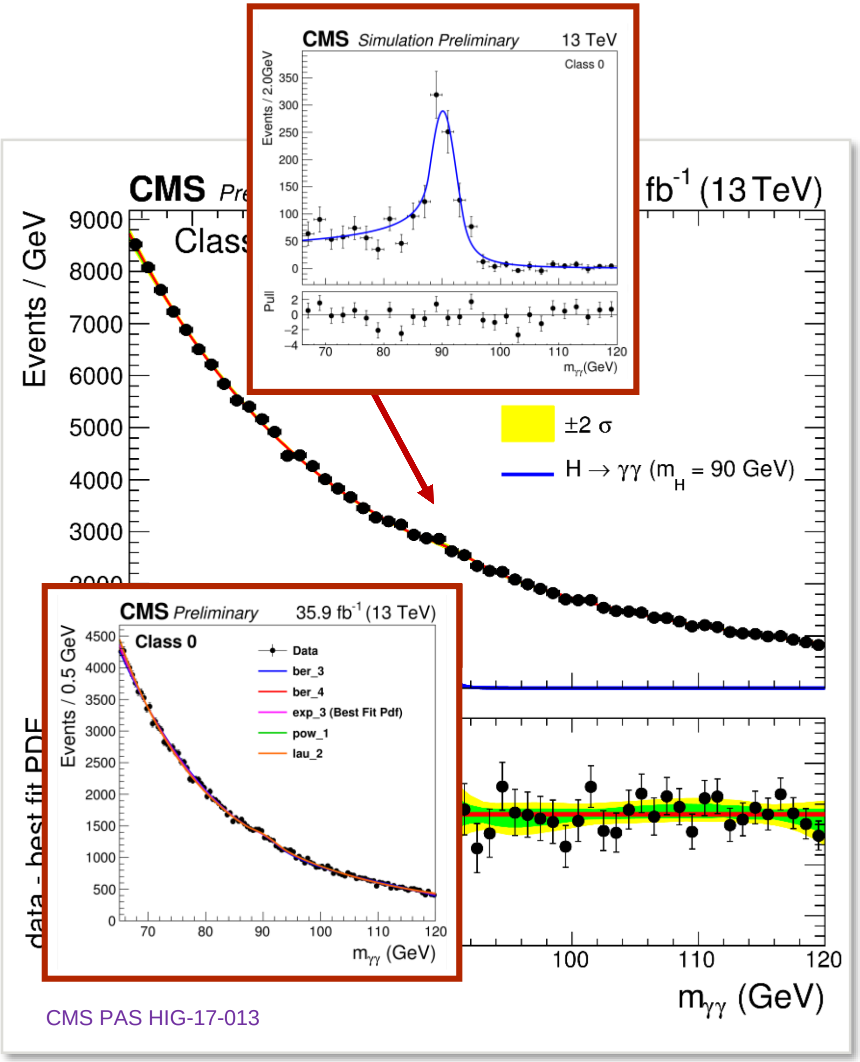
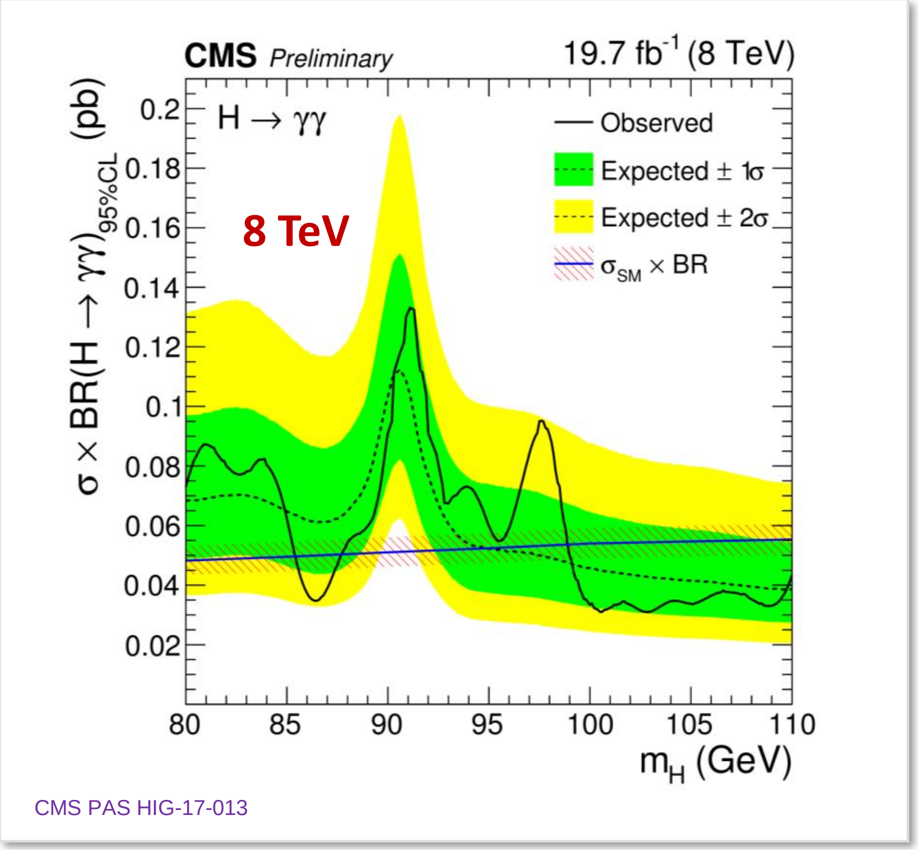


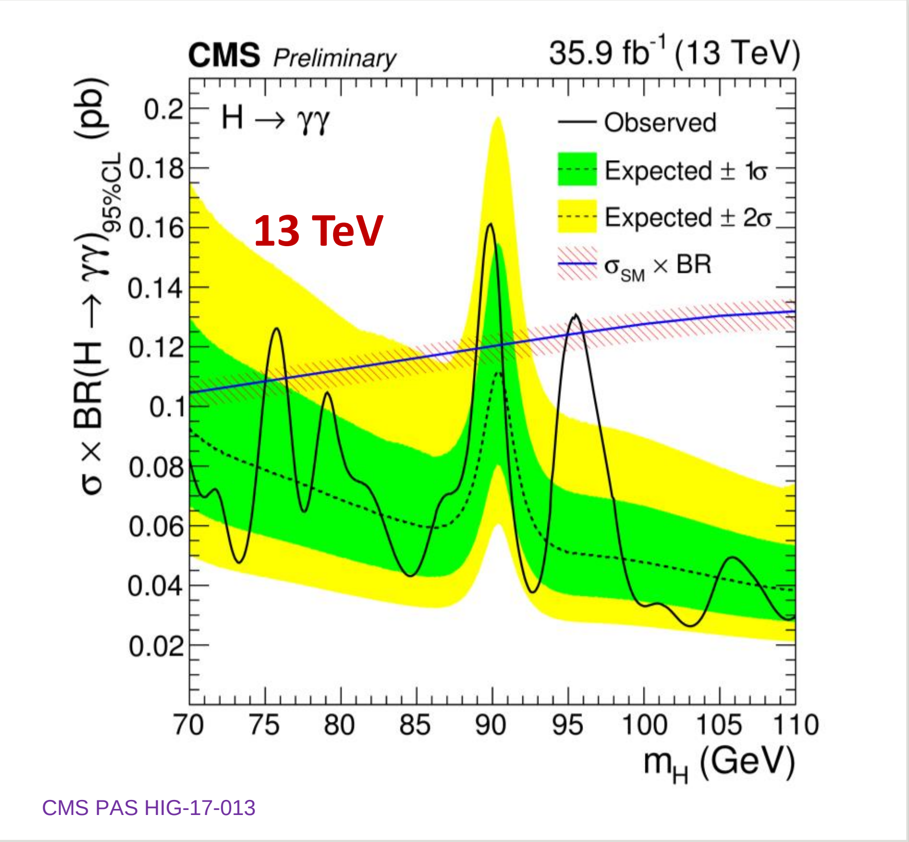
Results (Runs I and II)

CMS-PAS-HIG-17-013

- **8 TeV limits** on σ×BR **redone** with 0.1 GeV step
- **No significant excess** with respect to expected limits **observed**
- **Decreased sensitivity** around the ***Z* boson mass**

Production processes assumed in **SM proportions**





Results – Gluon Induced

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- **8 TeV limits** on σ×BR **redone** with 0.1 GeV step
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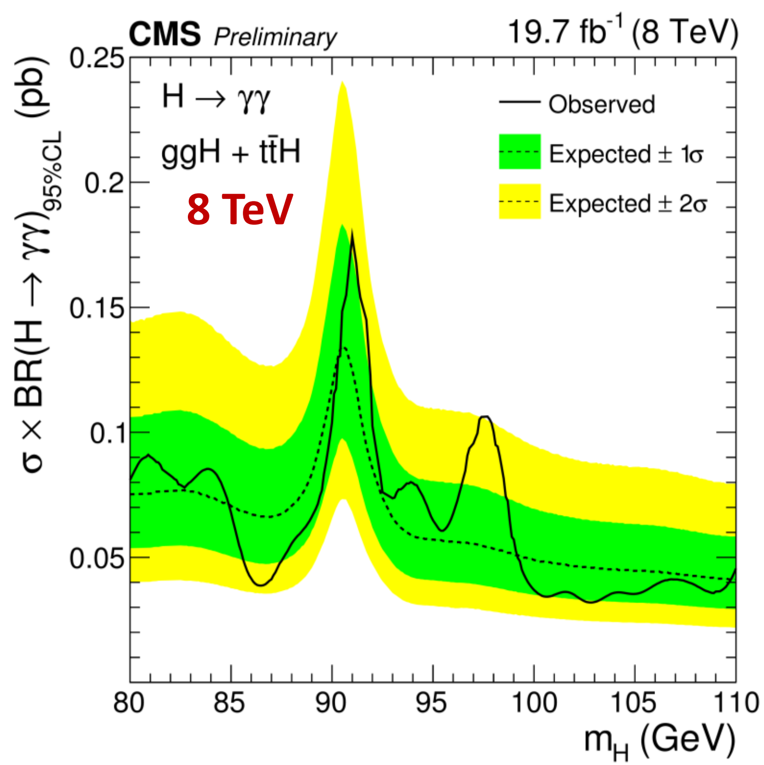
Per-process limits assuming **100% gluon-induced** processes



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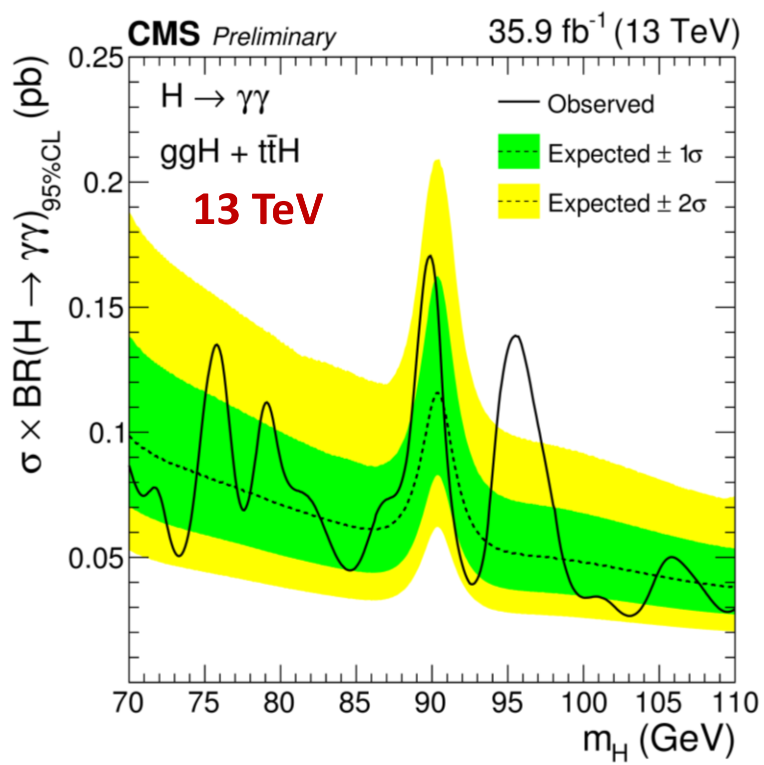

CMS PAS HIG-17-013

Results – Fermion Induced

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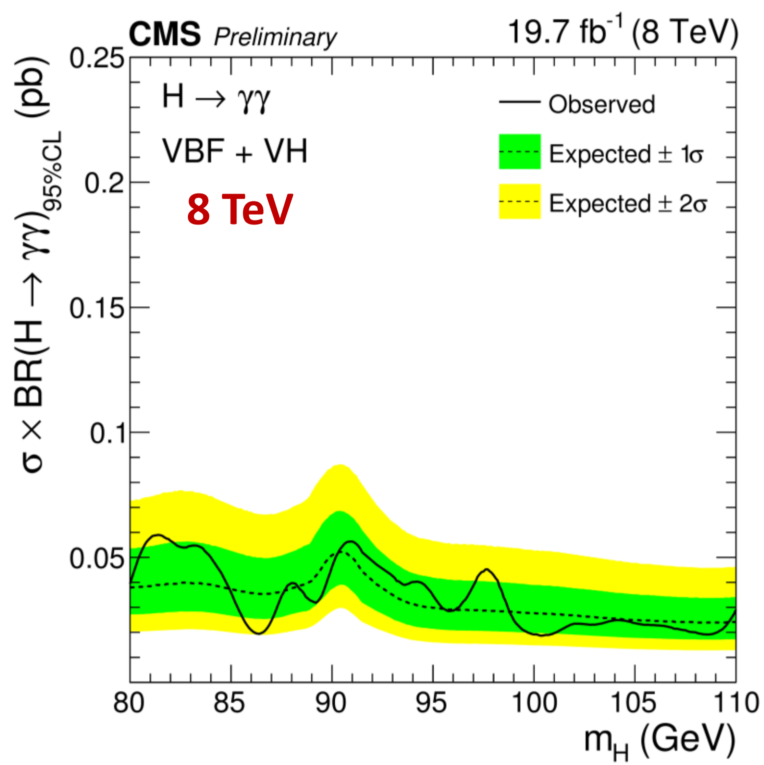
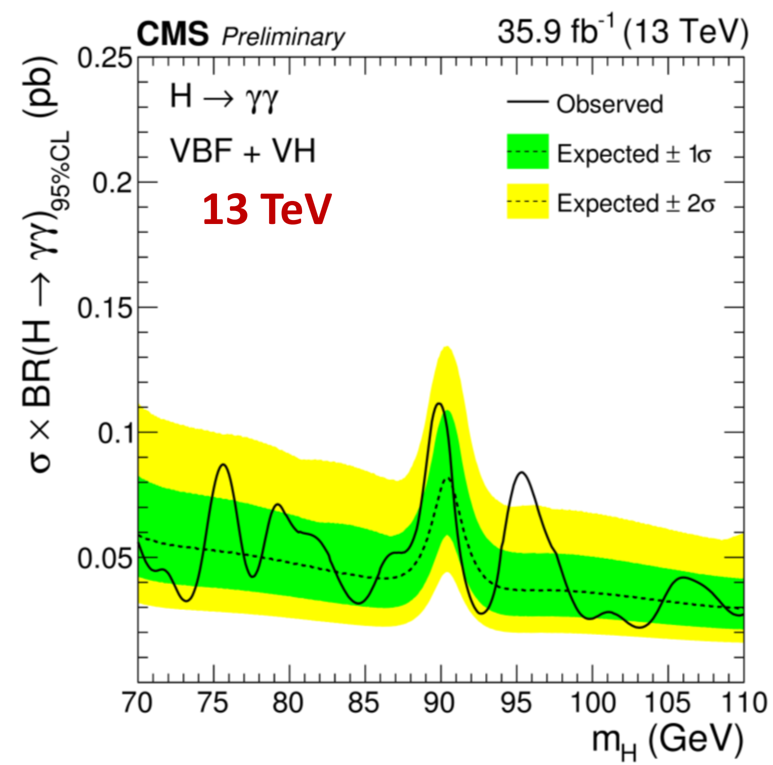
Per-process limits assuming **100% fermion-induced** processes



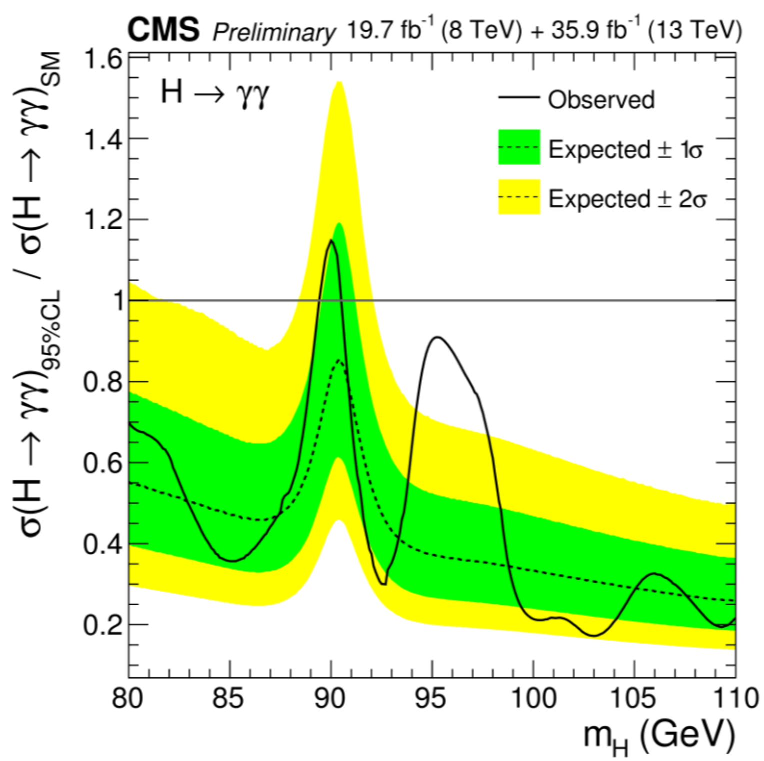
CMS PAS HIG-14-037



CMS PAS HIG-17-013

Results – Combination of Run I and II

- **Combined 8 TeV + 13 TeV** σ×BR limit normalized to SM expectation:
  - Production processes assumed in SM proportions
  - **No significant excess** with respect to expected limits
- Expected and observed local p-values for **8 TeV**, **13 TeV** and their **combination**



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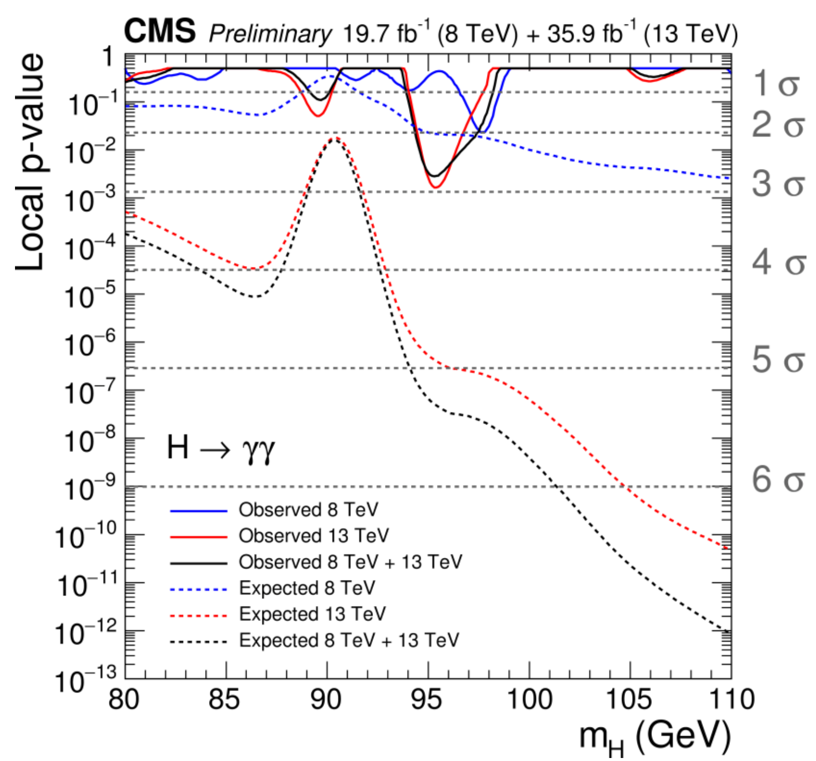

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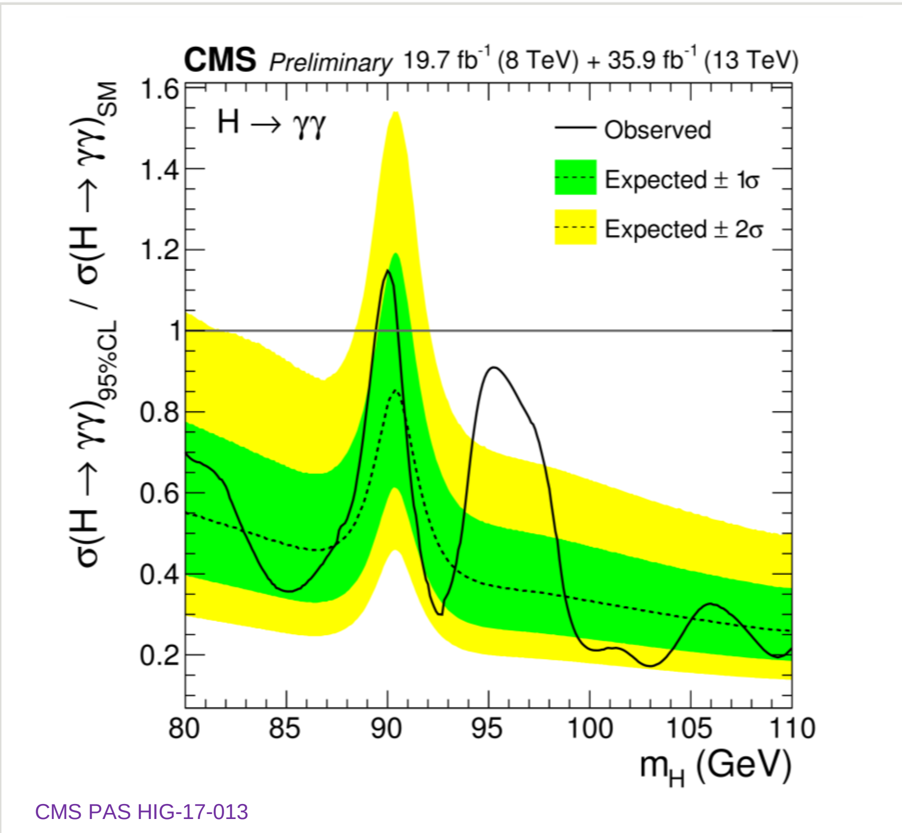

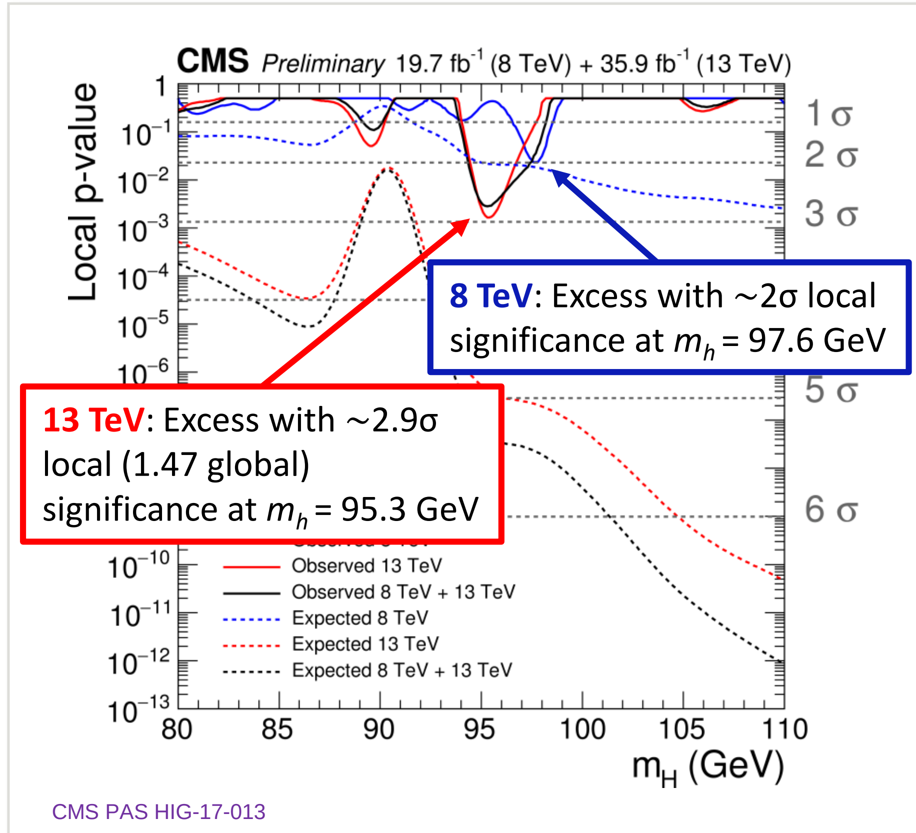

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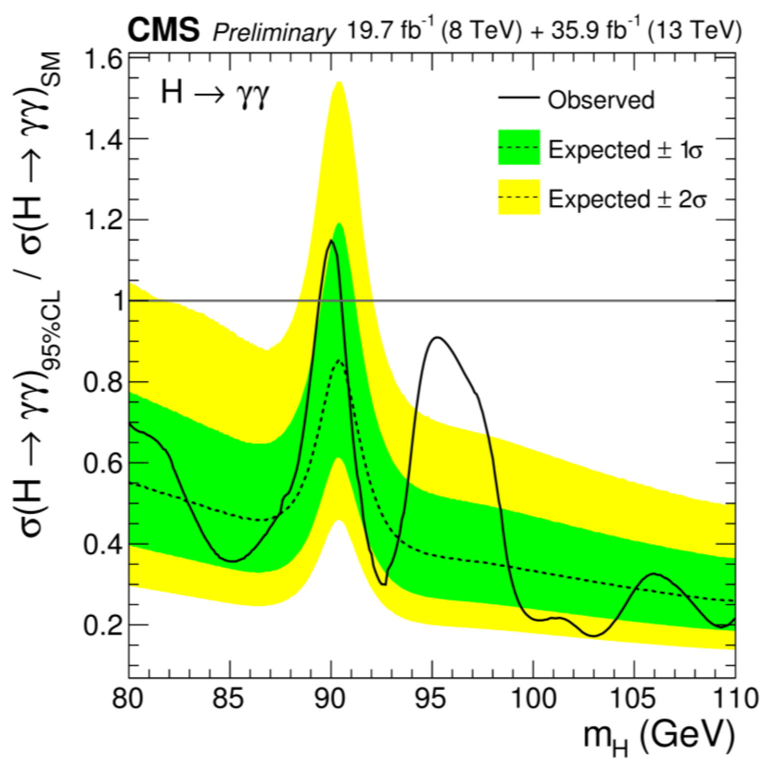

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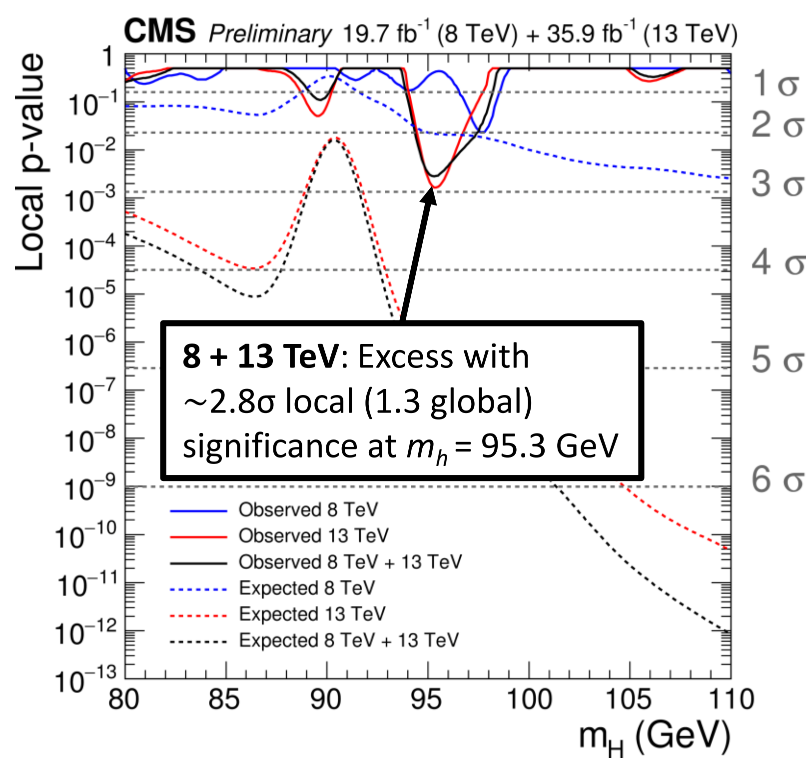


CMS PAS HIG-17-013

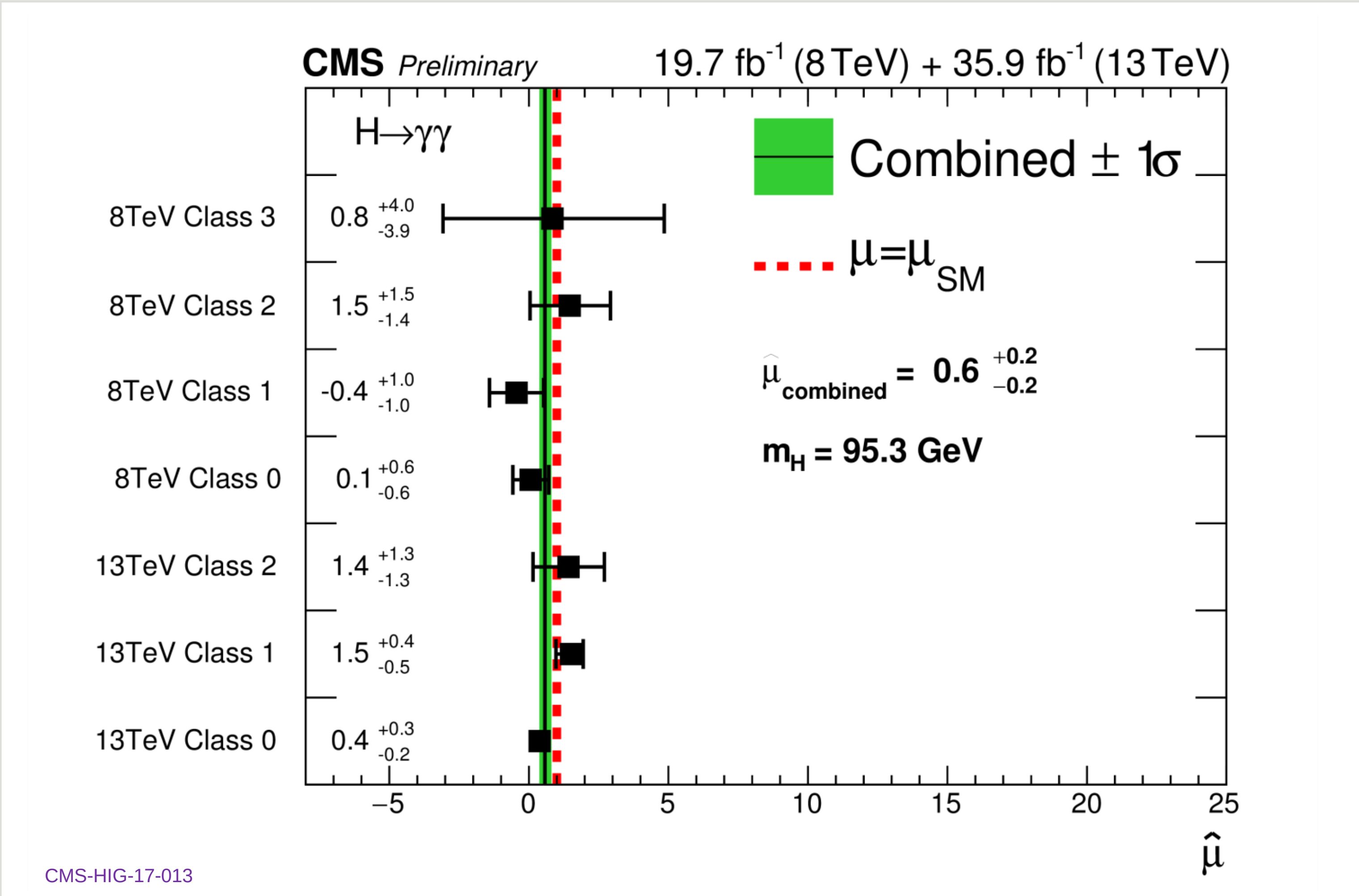
Conclusions

- The search for a **Higgs boson at low mass** values is strongly motivated by **theoretical predictions** (2HDM, NMSSM)
- The low-mass analysis has **specific features**, in particular the Drell-Yan contribution
- The **standard $H \rightarrow \gamma\gamma$ analysis** has been **extended** to the mass range **[70, 110] GeV**, analyzing and combining Run I and II data collected by CMS
- An excess with $\sim 2.8\sigma$ local (1.3 global) significance at $m_h = 95.3$ GeV has been observed (combining 8 and 13 TeV results)
- **More data** are required to ascertain the **origin of this excess**

Looking forward to adding 2017 data!

Backup

Signal Strength



Signal and Background Events

Event Class	Expected SM-like Higgs boson signal $m_H = 90\,\text{GeV}$, $\sqrt{s} = 8\,\text{TeV}$								Bkg (GeV^{-1})
	Total	ggH	VBF	WH	ZH	$t\bar{t}H$	σ_{eff}	σ_{HM}	
0	64.0	68.9 %	15.0 %	8.8 %	4.8 %	2.5 %	0.94	0.78	262.8
1	99.5	87.5 %	5.2 %	4.3 %	2.3 %	0.7 %	1.20	0.96	922.6
2	121.1	89.9 %	3.9 %	3.7 %	2.0 %	0.5 %	1.61	1.26	1844.4
3	88.9	92.2 %	2.8 %	3.1 %	1.6 %	0.3 %	2.11	1.68	3098.6
Total	373.5	86.2 %	5.9 %	4.6 %	2.5 %	0.8 %	1.47	1.05	6128.4

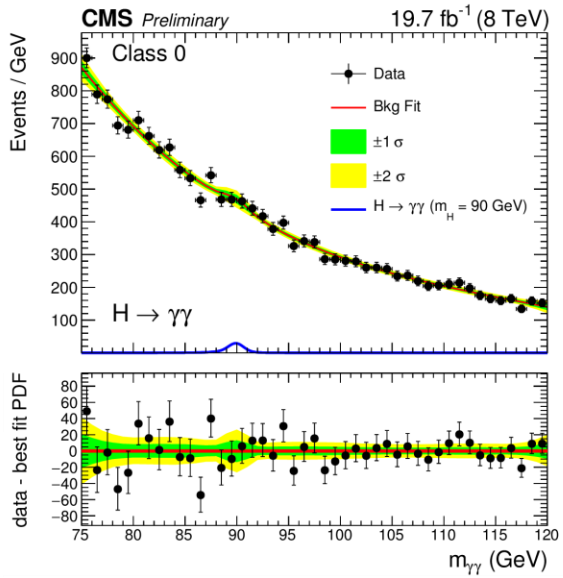
CMS-HIG-17-013

Event Class	Expected SM-like Higgs boson signal $m_H = 90\,\text{GeV}$, $\sqrt{s} = 13\,\text{TeV}$								Bkg (GeV^{-1})
	Total	ggH	VBF	WH	ZH	$t\bar{t}H$	σ_{eff}	σ_{HM}	
0	456.8	80.1 %	9.7 %	4.9 %	2.8 %	2.5 %	1.11	0.96	1870.6
1	394.9	90.1 %	4.1 %	3.2 %	1.7 %	0.9 %	1.69	1.45	3876.1
2	214.1	92.0 %	3.3 %	2.6 %	1.4 %	0.7 %	2.18	1.73	4301.0
Total	1065.8	86.2 %	6.3 %	3.8 %	2.1 %	1.6 %	1.49	1.16	10047.7

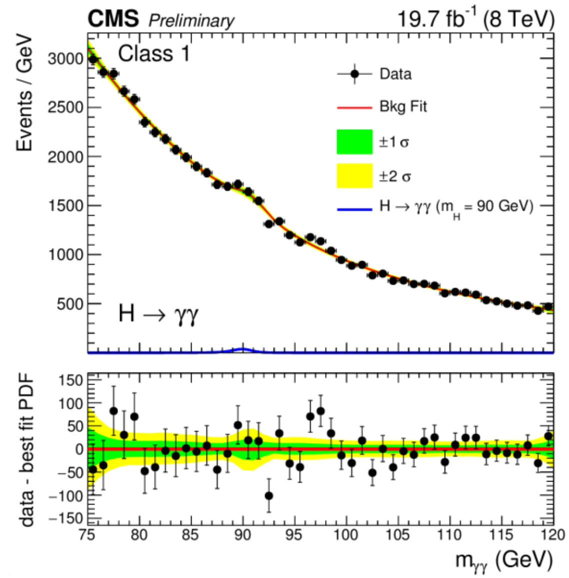
CMS-HIG-17-013

Mass Spectra (8 TeV)

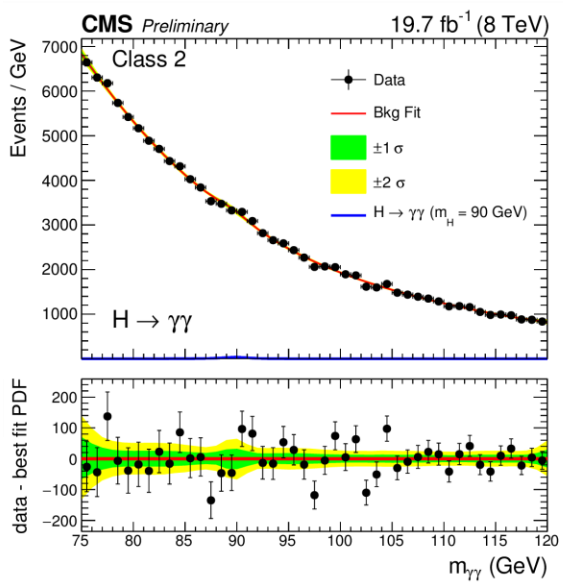
CLASS 0



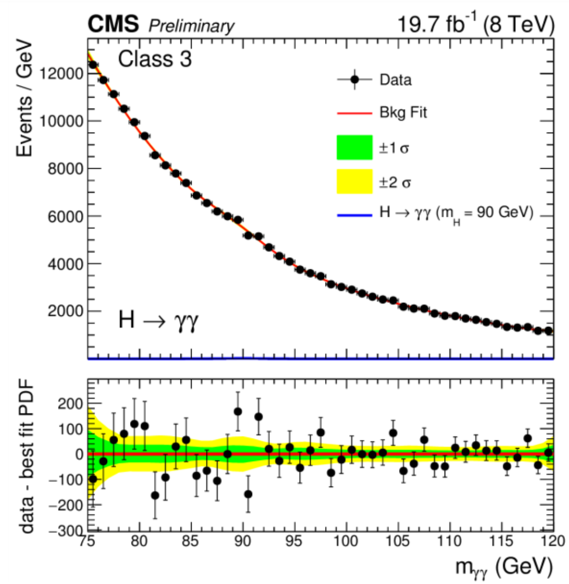
CLASS 1



CLASS 2

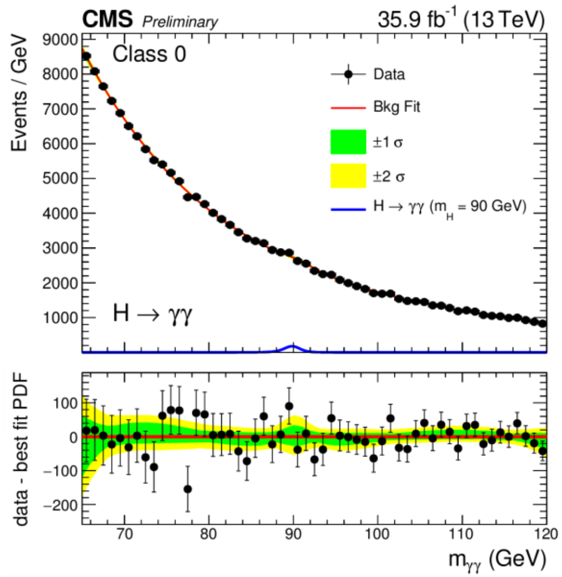


CLASS 3

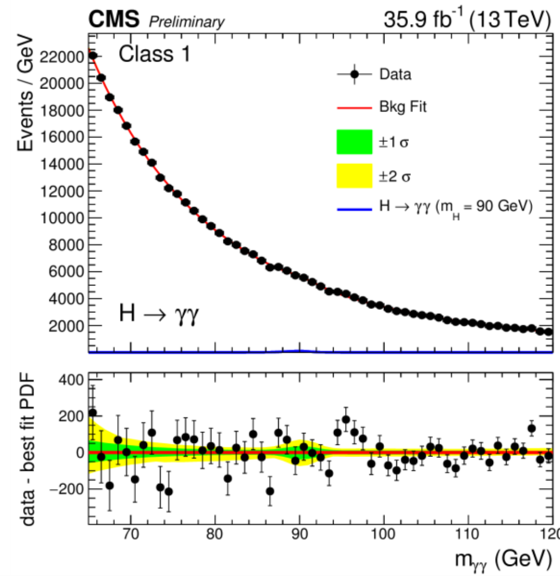


Mass Spectra (13 TeV)

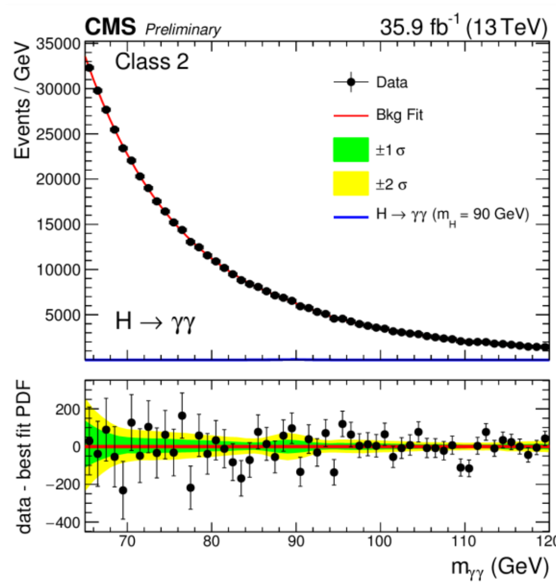
CLASS 0



CLASS 1



CLASS 2



Event Categorization (8 TeV)

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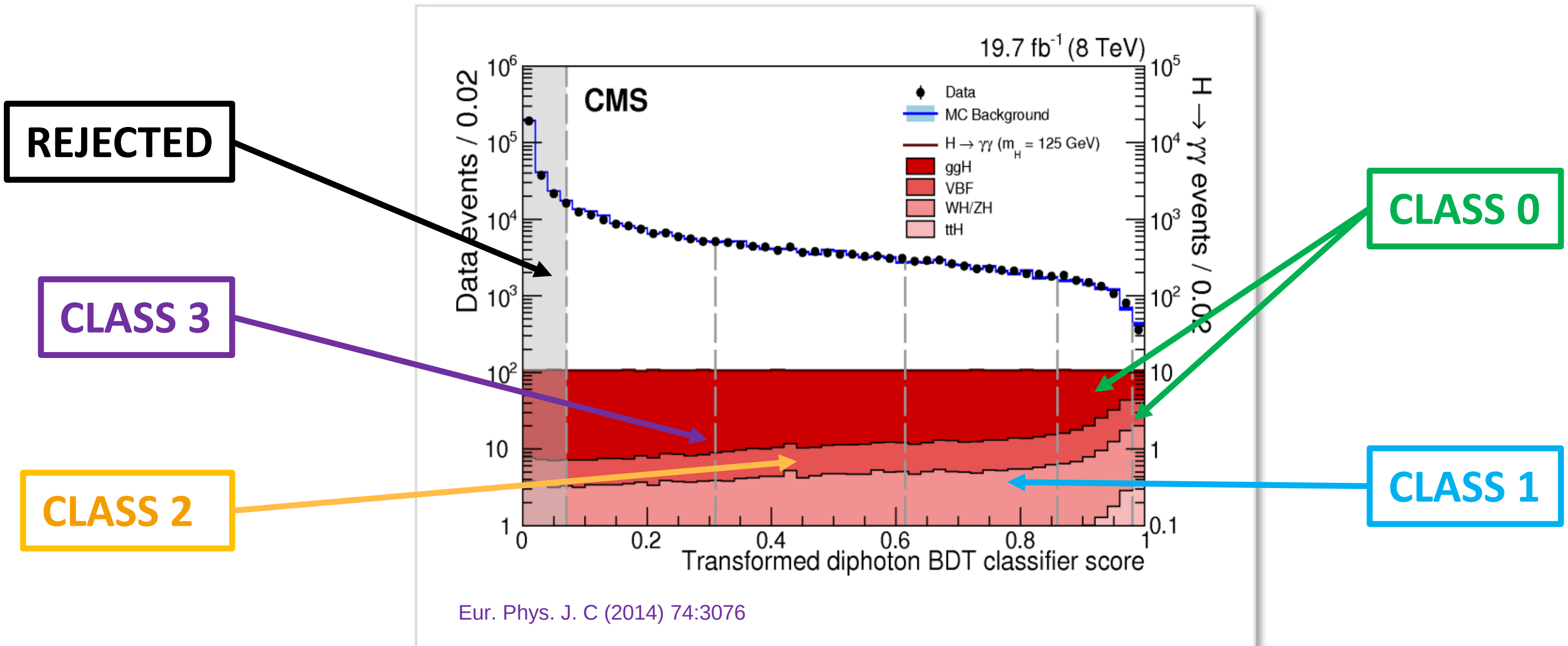
- Events are categorized according to the **photon kinematics**, per-event **mass resolution, photon ID** and **good vertex probability** by a **multivariate classifier** (same as the standard $H \rightarrow \gamma\gamma$ analysis)
- **Number of classes** limited by **MC DY statistics** (4 classes, no exclusive classes tagging production modes like in standard analysis)



Mass Resolution