Search for Low-Mass Scalar Bosons at the LHC

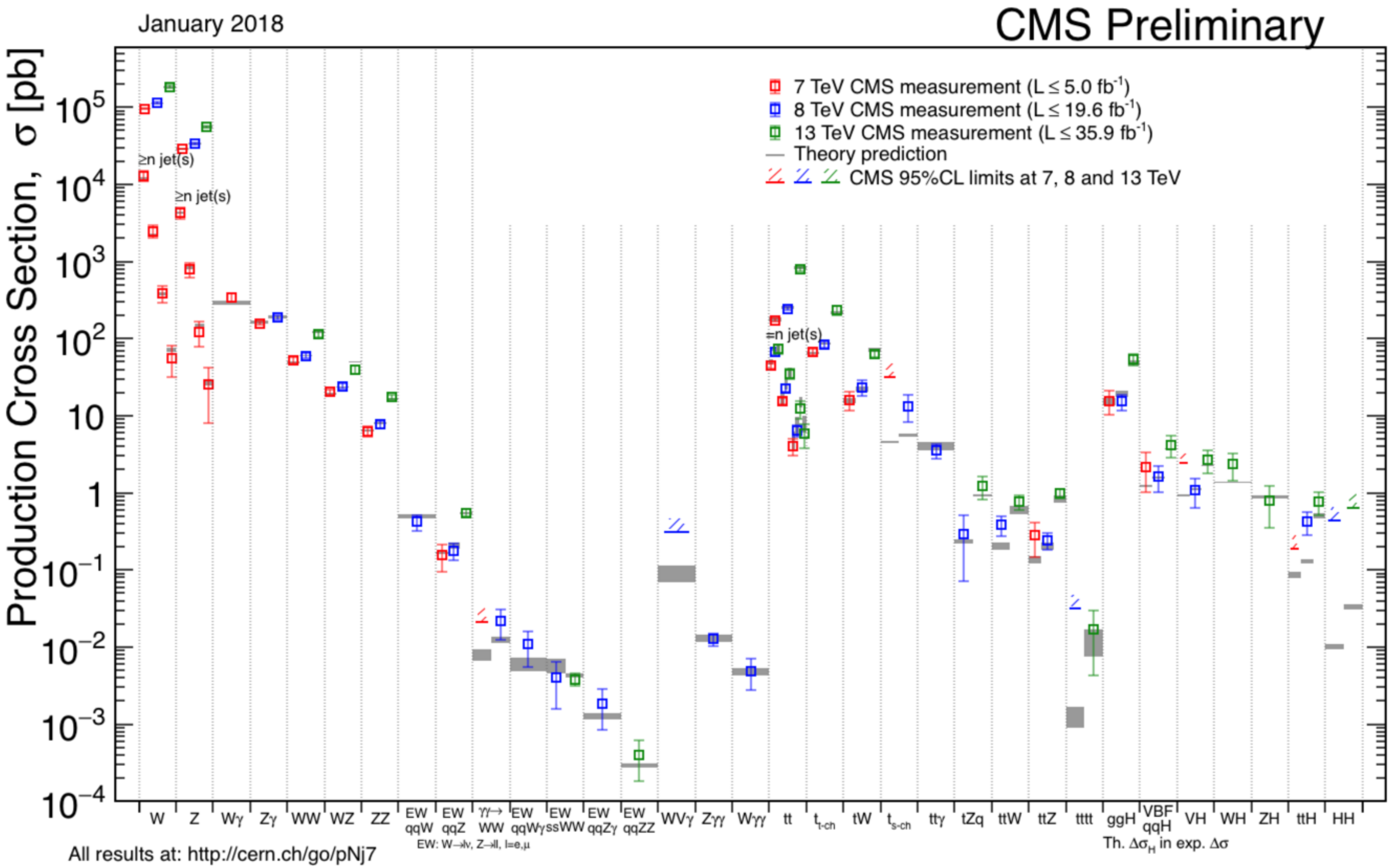
Linda Finco

IPN Lyon (IN2P3-CNRS)/UCB Lyon 1, France

Strasbourg (France)

March 23rd 2018

Standard Model of Particle Physics

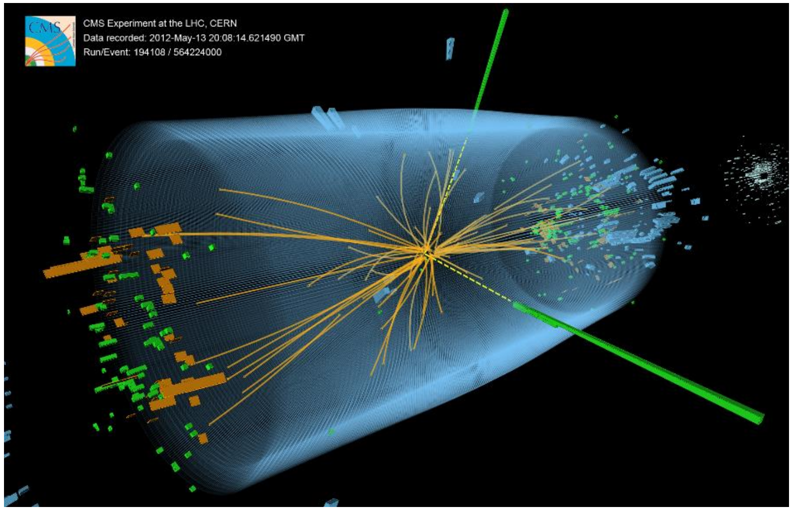


https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsCombined/SigmaNew_v0.pdf

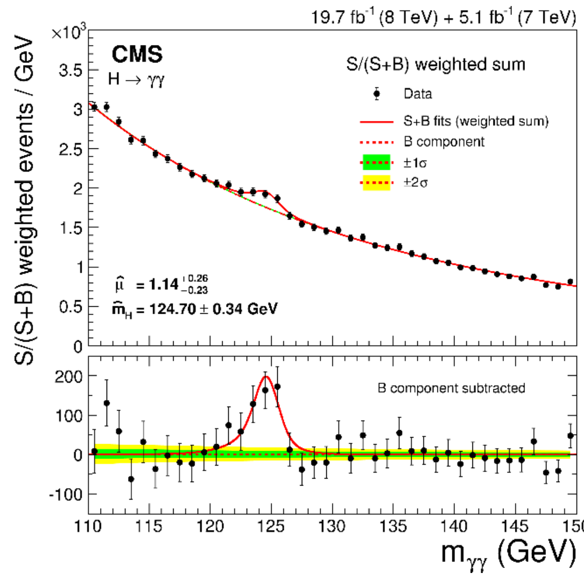
- The SM describes the **elementary particles** and their **interactions**
- **Experimental results** have shown up to now an amazing **agreement** with its predictions
- Thanks to the **good understanding of detectors** and the **accurate theory predictions**, SM processes are known with an **incredible precision**

Higgs Discovery Seminar

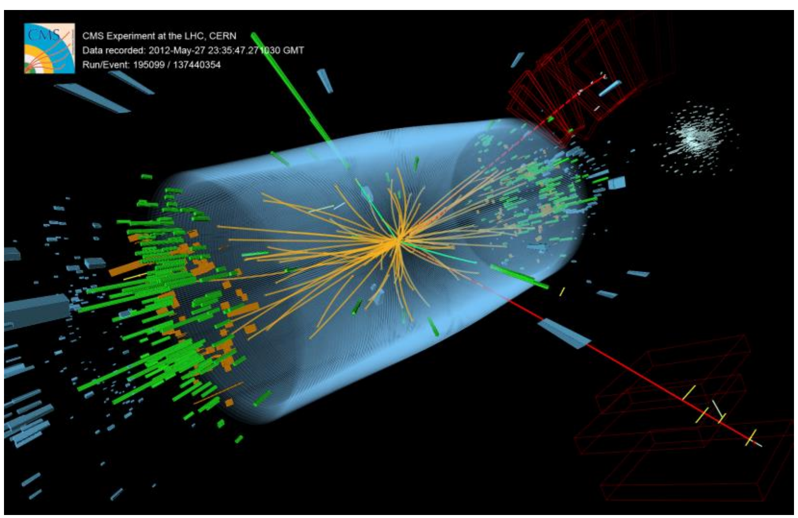
A Higgs Boson



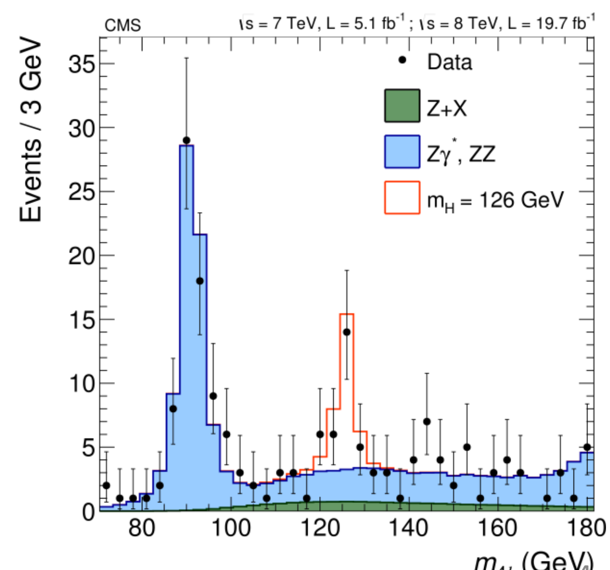
$H \rightarrow \gamma\gamma$



Eur. Phys. J. C 74 (2014) 3076



$H \rightarrow 4\ell$

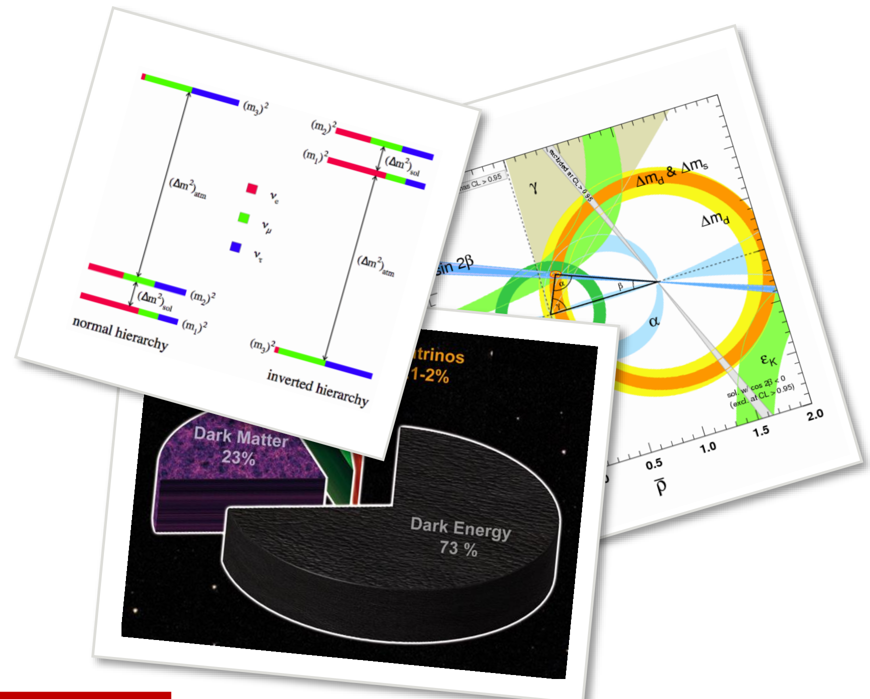


Phys. Rev. D 89 (2014) 112001

Still, a lot to be discovered…

- The **discovery of a new boson** consistent with the SM Higgs boson has **completed the theory**

- Nevertheless, the **SM cannot address** several **crucial issues**



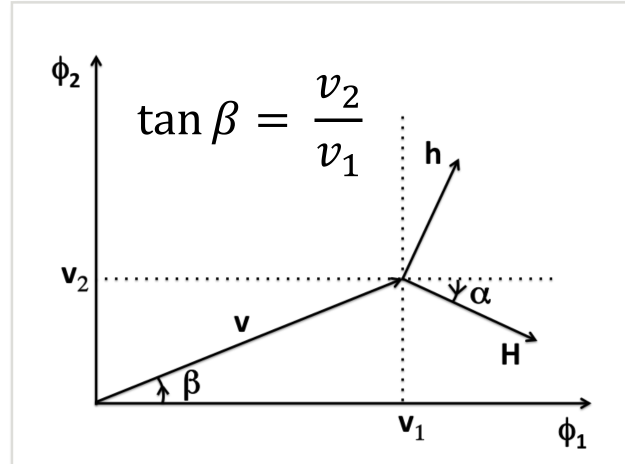
Direct evidence from observation:
- existence of neutrino masses
- existence of dark matter and dark energy
- matter-antimatter asymmetry

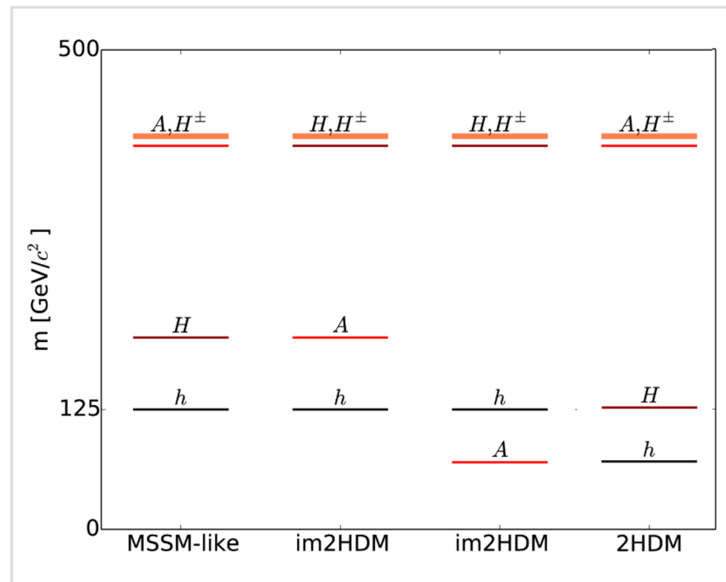
Conceptual problems in the SM:
- the large number of free parameters
- the "hierarchy problem"
- the coupling unification

Strong indications that the SM is only a low-energy expression of a more global theory

Two Higgs Double Models (+ Singlet)

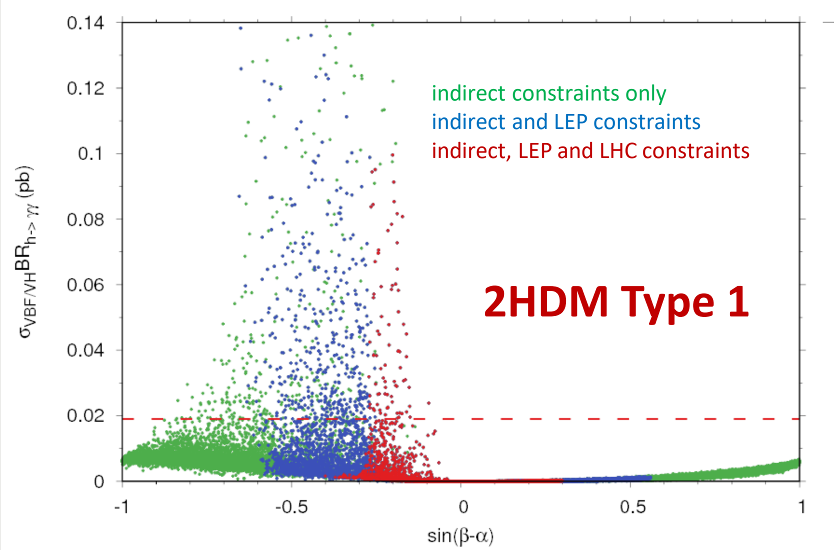
- Two-Higgs-doublet models are simple **extensions of the SM**
- They introduce **two doublets** of scalar fields, ϕ_1 and ϕ_2, in the SM Lagrangian of the scalar sector
- After symmetry breaking, **five physical states are left**: two CP-even ($\boldsymbol{h}$ and $\boldsymbol{H}$), one CP-odd ($\boldsymbol{A}$), and two charged ($\boldsymbol{H}^{\pm}$) bosons
- **Four types**, according to different patterns of **quark and lepton couplings** (most commonly considered are Type 1 and Type 2)
- **Different possibilities** of **mass** hierarchy
- In **2HDM+S** a **complex scalar singlet** is added, leading to a pseudoscalar $\boldsymbol{a}$ and a scalar $\boldsymbol{s}$ (NMSSM)





Search for BSM Physics at the LHC

LHC data are **sensitive** to the presence for some combinations of the **2HDM parameters**



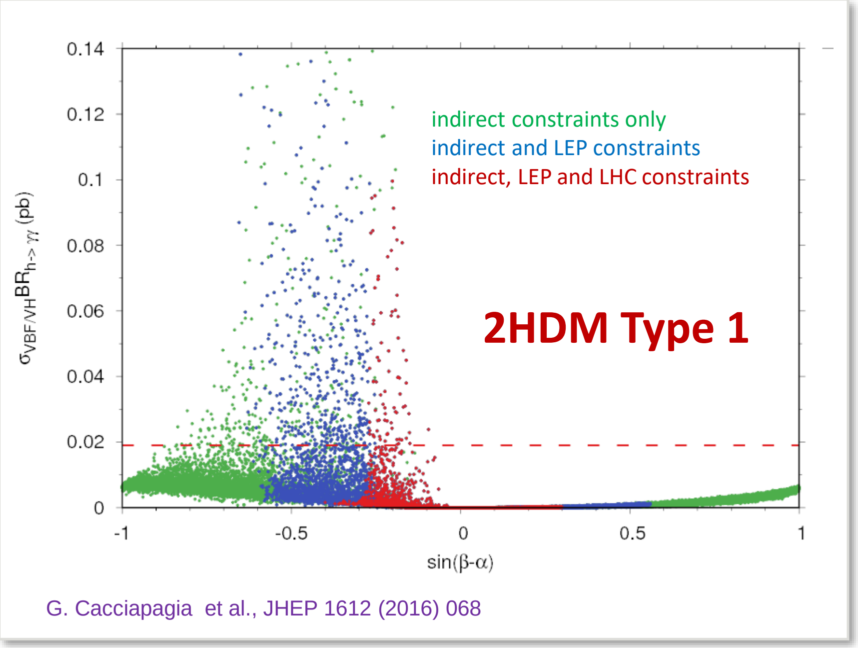
G. Cacciapagia et al., JHEP 1612 (2016) 068

How new Physics can be discovered?

- **Precision measurements** of the properties of the h(125 GeV) scalar boson
- Observation of BSM physics in **indirect searches** involving **scalar bosons**
- Discovery of **BSM decays** of the h(125 GeV) scalar boson
- Direct **discovery** of new **scalar particles**

Search for BSM Physics at the LHC

LHC data are **sensitive** to the presence for some combinations of the **2HDM parameters**



How new Physics can be discovered?

- **Precision measurements** of the properties of the h(125 GeV) scalar boson
- Observation of BSM physics in **indirect searches** involving **scalar bosons**

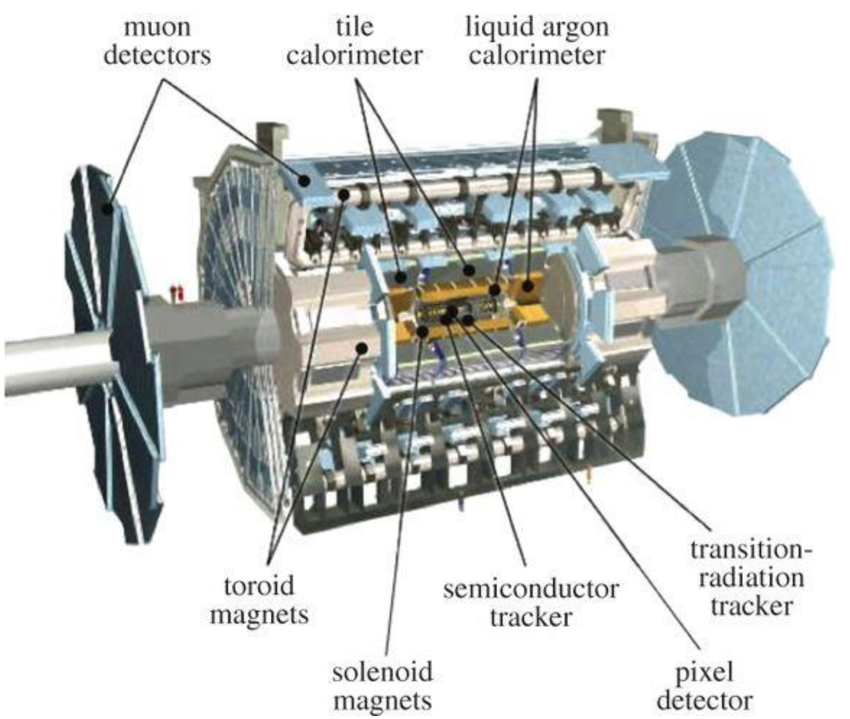
THIS TALK

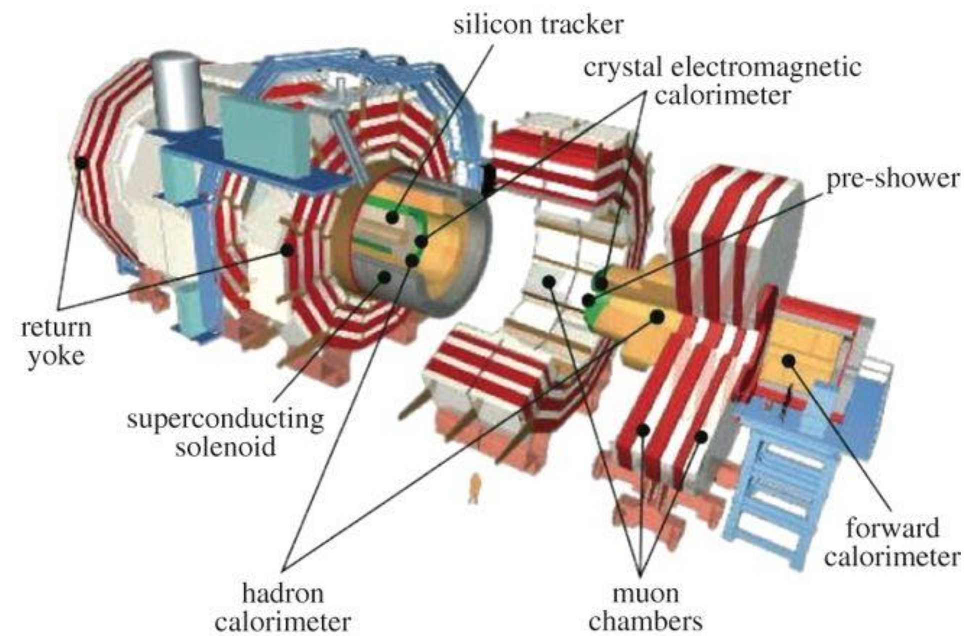
Discovery of **BSM decays** of the h(125 GeV) scalar boson

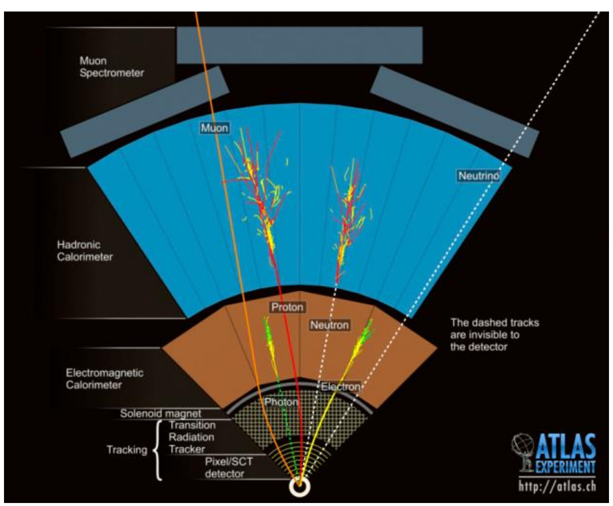
Direct **discovery** of new **scalar particles**

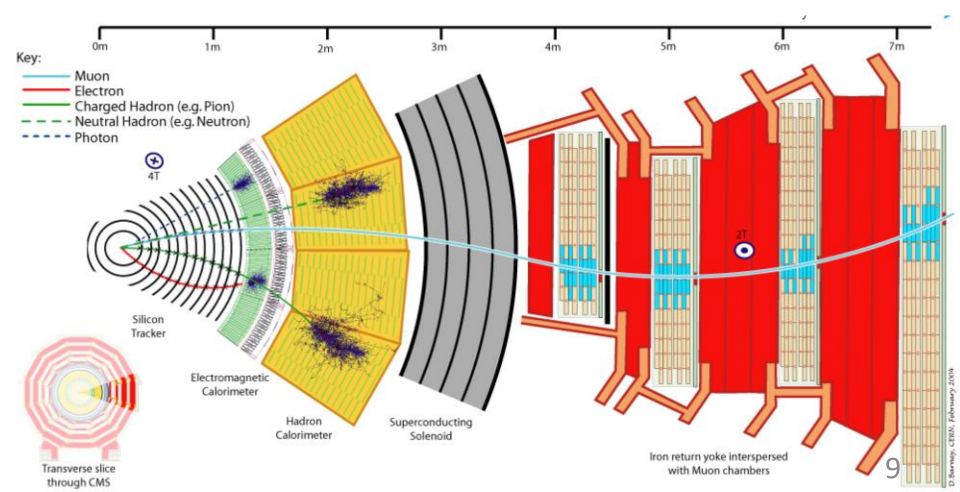
AT LOW-MASS VALUES

ATLAS and CMS Detectors





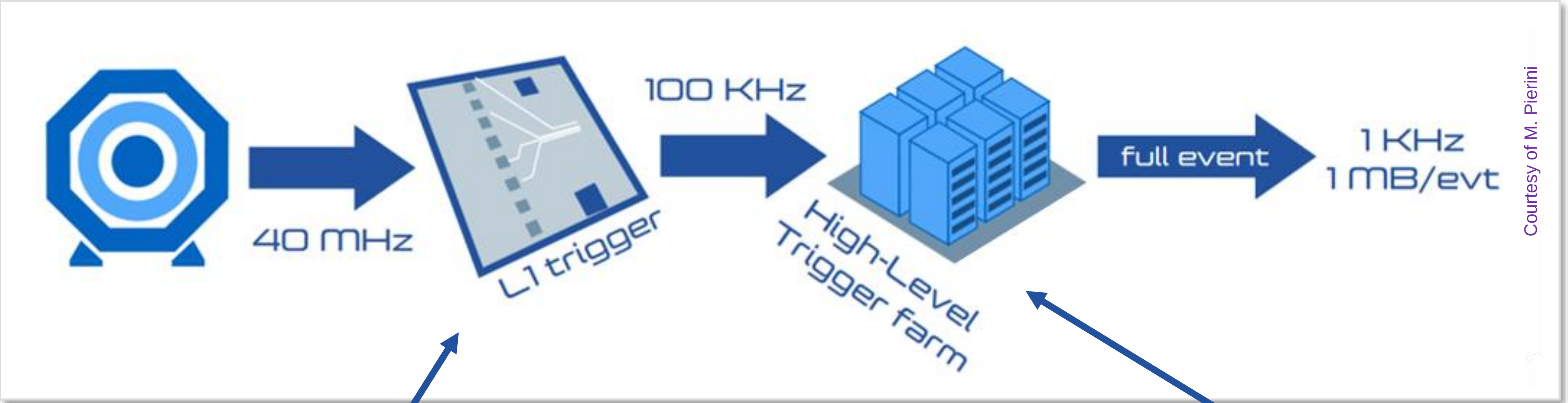




Challenges at Low-Mass

Low-mass searches are among the most **difficult** analyses at LHC:

- **Theoretical guidance** sometimes **limited**
- **Special tuning** of selection tools
- **Trigger** issues: because of the **limited bandwidth**, low energy events are generally discarded (high thresholds for single and double objects)

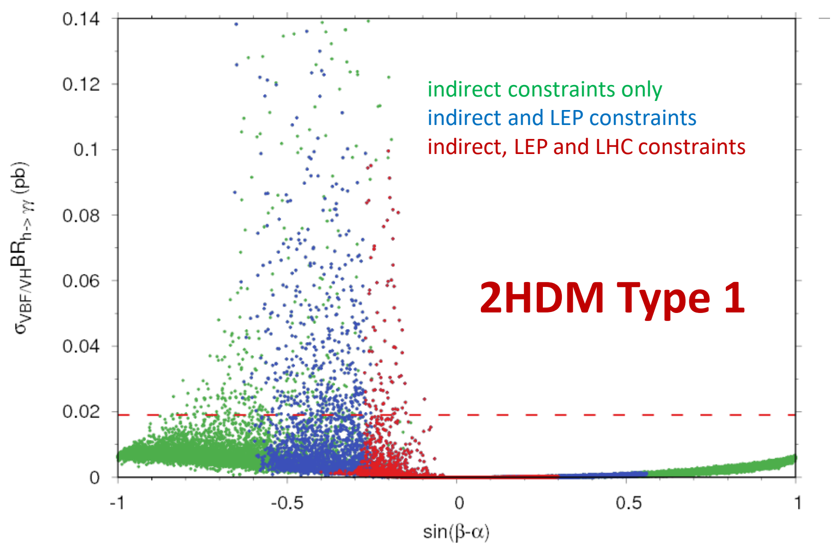


- Only calorimeters and muons
- High thresholds for one and two objects

- Can use the tracker
- Need to develop dedicated algorithms

Search for BSM Physics at the LHC

LHC data are **sensitive** to the presence for some combinations of the **2HDM parameters**



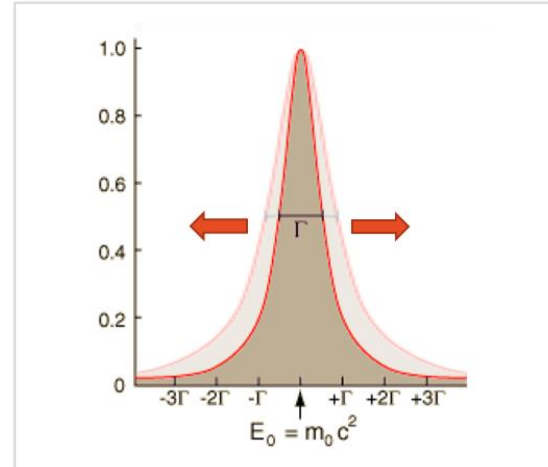
G. Cacciapagia et al., JHEP 1612 (2016) 068

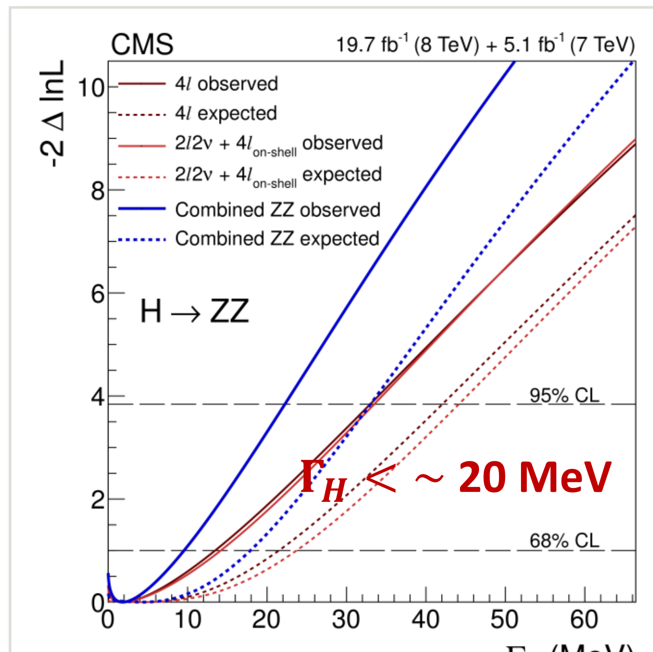
How new Physics can be discovered?

- **Precision measurements** of the properties of the h(125 GeV) scalar boson
- Observation of BSM physics in **indirect searches** involving **scalar bosons**
- Discovery of **BSM decays** of the h(125 GeV) scalar boson
- Direct **discovery** of new **scalar particles**

Exotic Decays of the h(125)

- The **Scalar Sector** of the SM is **not** very well **known**
- The **SM Higgs** boson has a **very narrow width** (~4 MeV): small **coupling to a light state** could lead to $\mathcal{B}(h \to BSM)$ of the order of **several percent**
- The scalar sector could be a **portal to New Physics**
- Exotic decays are allowed in **many models**
- Still **consistent** with all the **LHC measurements** so far
- One possibility is to search for $\boldsymbol{h(125) \to aa}$ (a pseudoscalar of 2HDM+S)





Phys. Lett. B 736 (2014) 64

Final States of h(125)→ aa Decays

$a \rightarrow bb$

- ✓ **Large BR** if couplings proportional to fermion mass
- ✗ Hard to trigger
- ✗ Low identification efficiency
- ✗ High p_T thresholds
- ✗ Large jet-backgrounds

$a \rightarrow \tau\tau$

- ✓ **Large BR** if mass-proportional couplings
- ✓ Possible to **trigger** on leptonic τ decays
- ✗ Low τ_h identification efficiency, with high p_T thresholds (> 20 GeV)

$a \rightarrow \mu\mu$

- ✓ Excellent **mass resolution**
- ✓ Easy to trigger
- ✓ Easy identification, with low p_T
- ✓ Open for any m_a>2m_μ
- ✗ Low BR if couplings proportional to fermion mass

With **SM-like couplings**:

$\mathcal{B}(a \rightarrow bb)$

$\sim 9 \times \mathcal{B}(a \rightarrow \tau\tau)$

$\sim 1700 \times \mathcal{B}(a \rightarrow \mu\mu)$

Thanks to C. Caillol

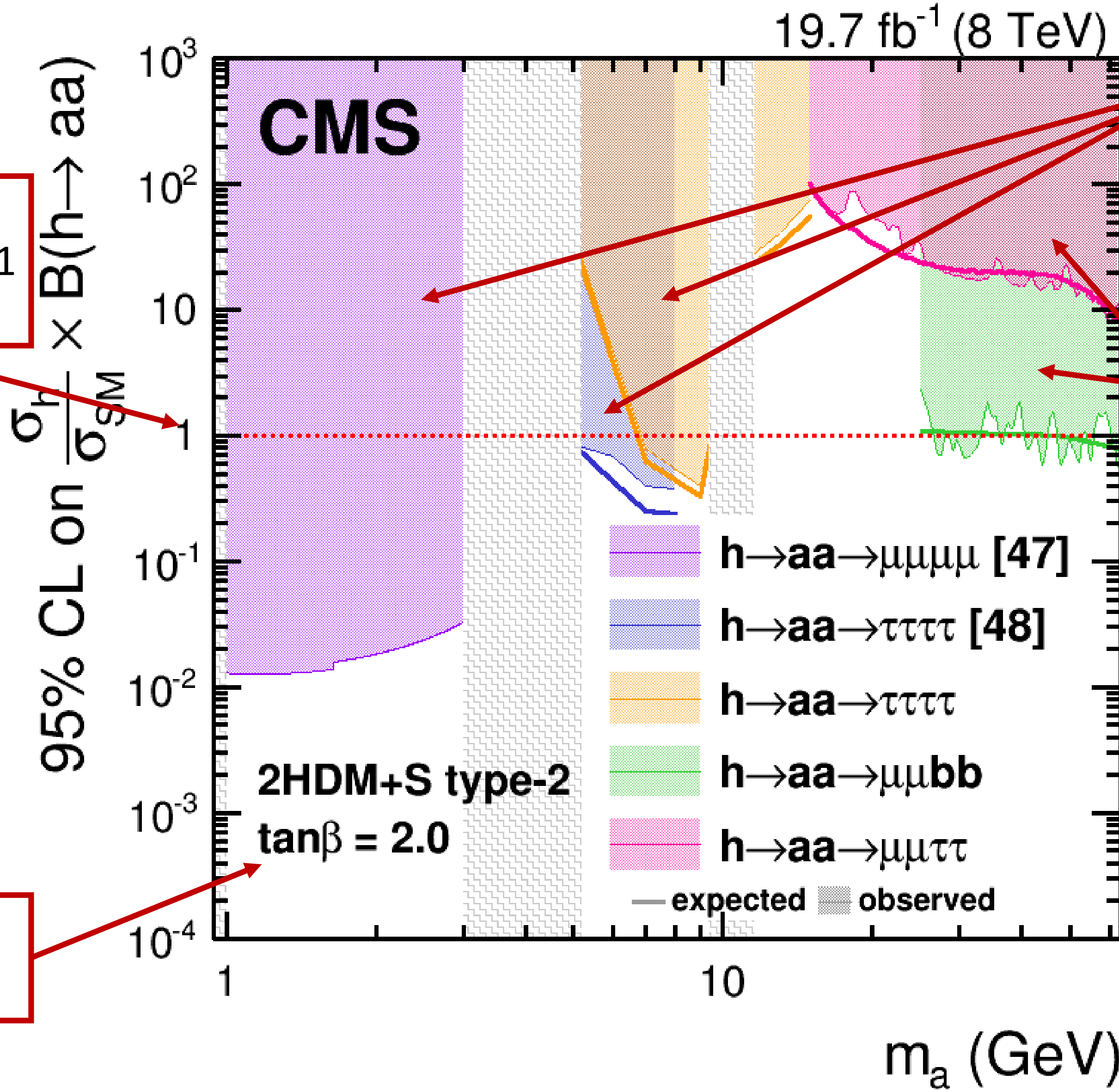
Exotic Decays of the h(125) – Run I

Sensitivity to $\mathcal{B}(h \rightarrow aa) = 1$ if $\sigma_h = \sigma_{SM}$

Boosted reconstruction techniques

Well separated decay products

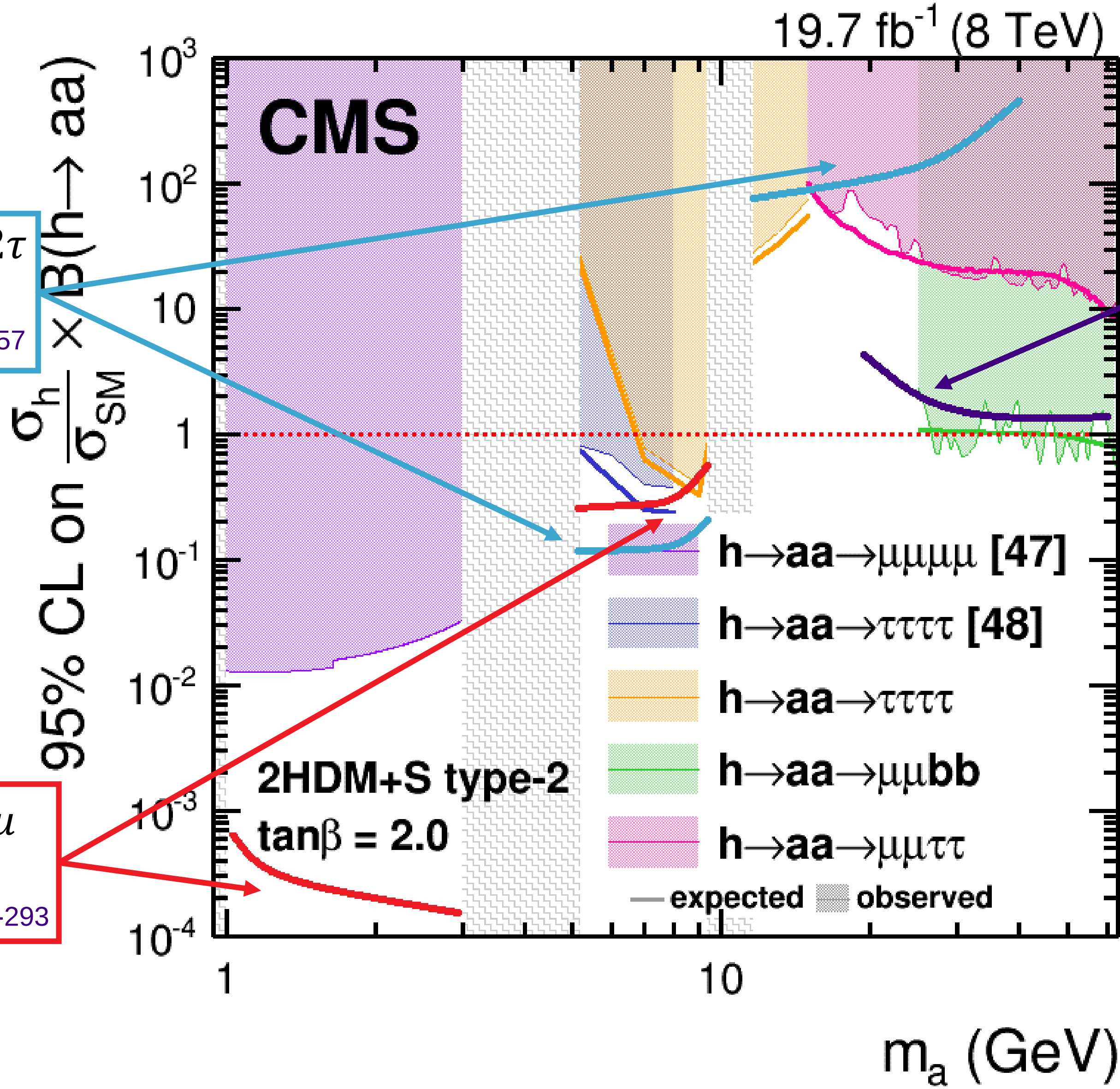
Model dependency



JHEP 10 (2017) 076

Thanks to C. Caillol

Exotic Decays of the h(125) – ATLAS



$h \to aa \to 2\mu 2\tau$
(2012 Data)
CERN-PH-EP-2015-057

$h \to aa \to 4b$
(2015 Data)
CERN-PH-EP-2016-135

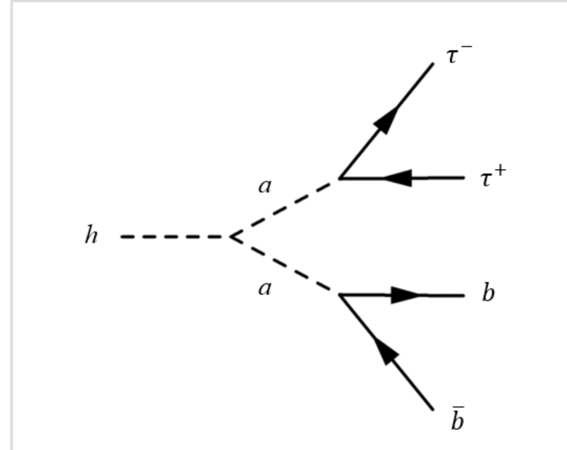
$h \to aa \to 4\mu$
(2016 Data)
CERN-PH-EP-2017-293

Thanks to C. Caillol

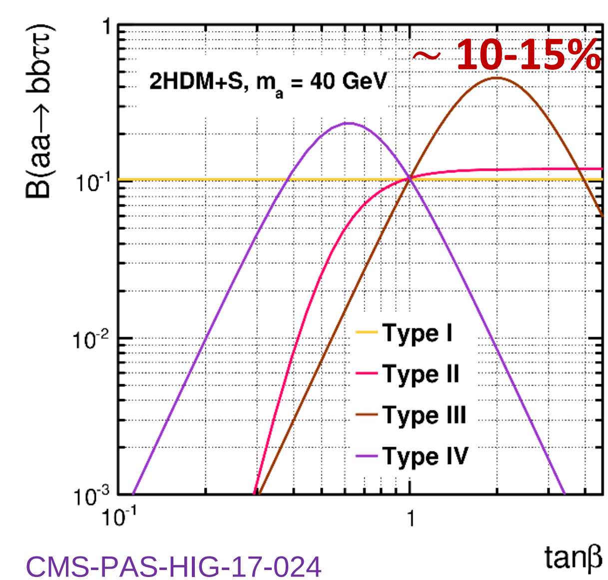
Exotic Decays h(125)→ aa → 2b2τ

- New **Run II result** (presented at Moriond EW 2018)
- If $\mathcal{B}(a \to ff) \propto m_{ff}^2$
  ➡ $\boldsymbol{a \to bb}$ and $\boldsymbol{a \to \tau\tau}$ are the **dominant** and **subdominant decays**
- $h \to aa \to \boldsymbol{4b}$ is **difficult to trigger** (4 soft b-jets)
- $h \to aa \to \boldsymbol{2b2\tau}$ easier to **trigger**, thanks to the **leptons** originating from τ decays
- 3 di-τ final states: $\boldsymbol{e\tau_h}$, $\boldsymbol{\mu\tau_h}$ and $\boldsymbol{e\mu}$
- At least **1 b-tagged jet** with p_T > 20 GeV

CMS-PAS-HIG-17-024



BR in 2HDM+S

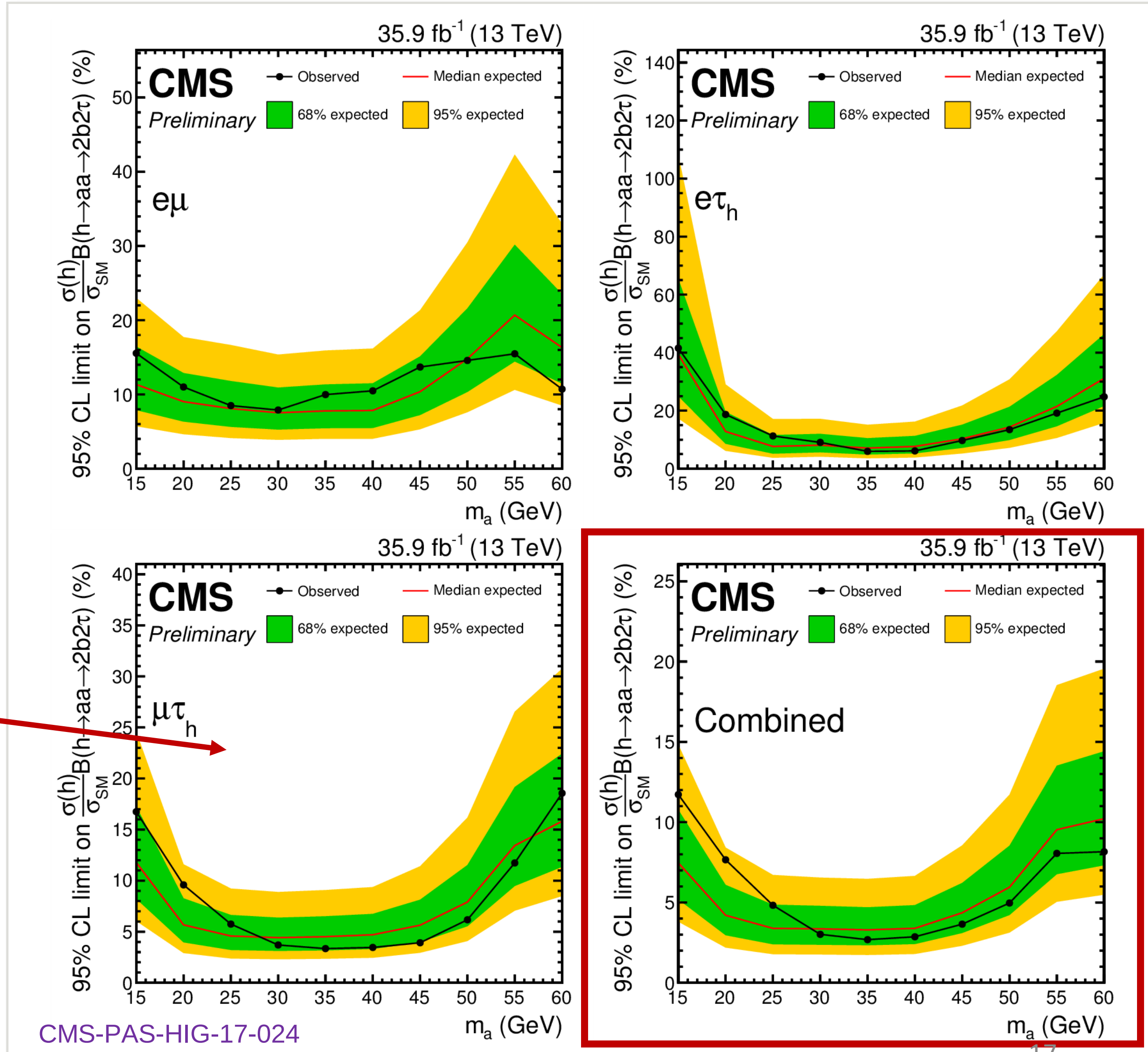


Exotic Decays h(125)→ aa → 2b2τ

No excess is observed

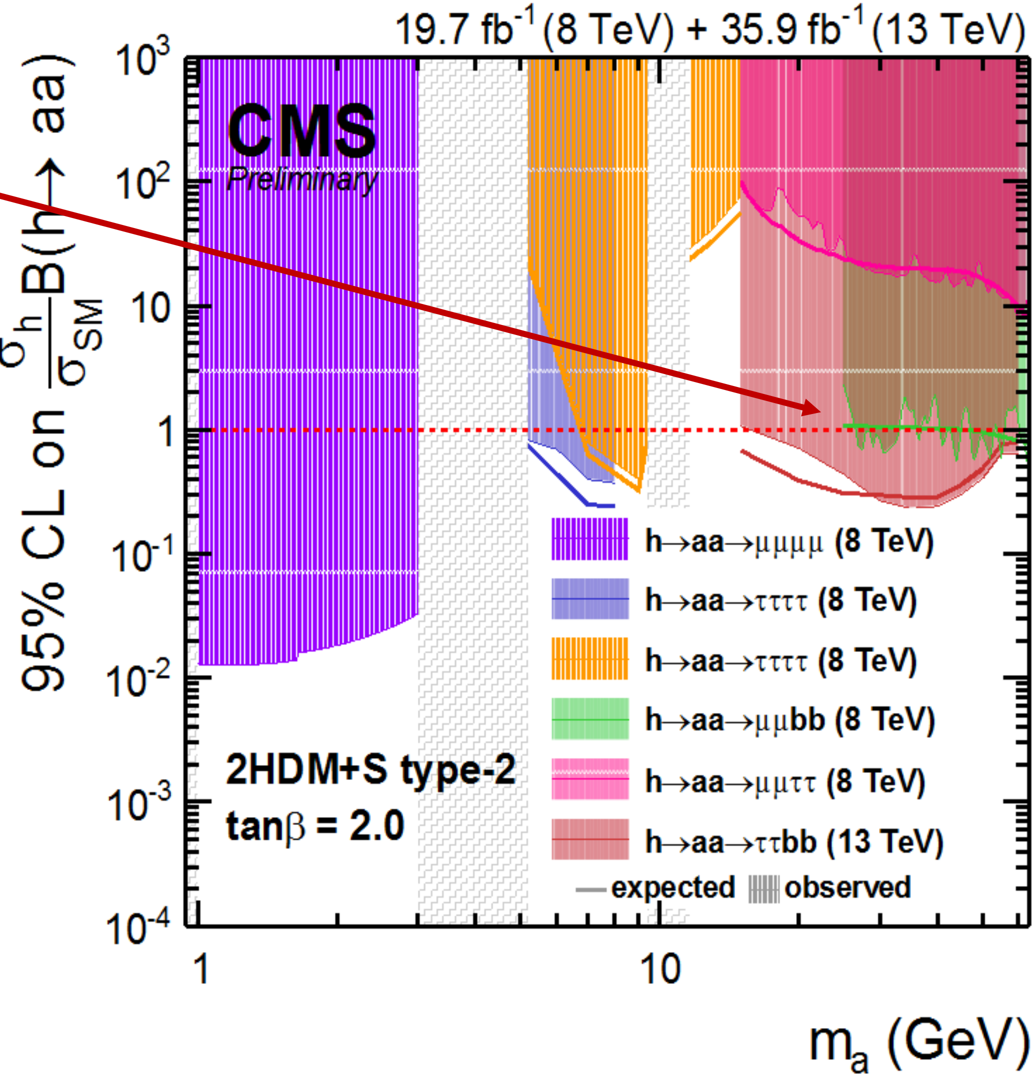
$\mu\tau_h$ is the **most sensitive** channel:

- Larger BR wrt $e\mu$
- Lower trigger thresholds wrt $e\tau_h$



Exotic Decays h(125)→ aa → 2b2τ

Results of
$h \to aa \to 2b2\tau$

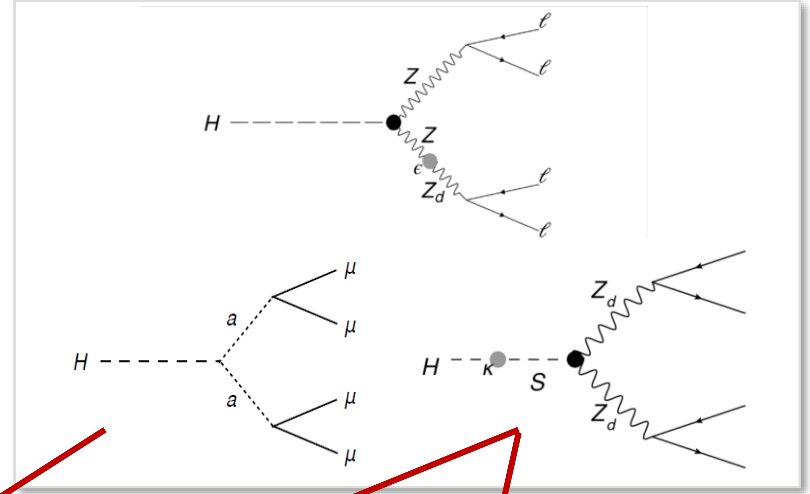


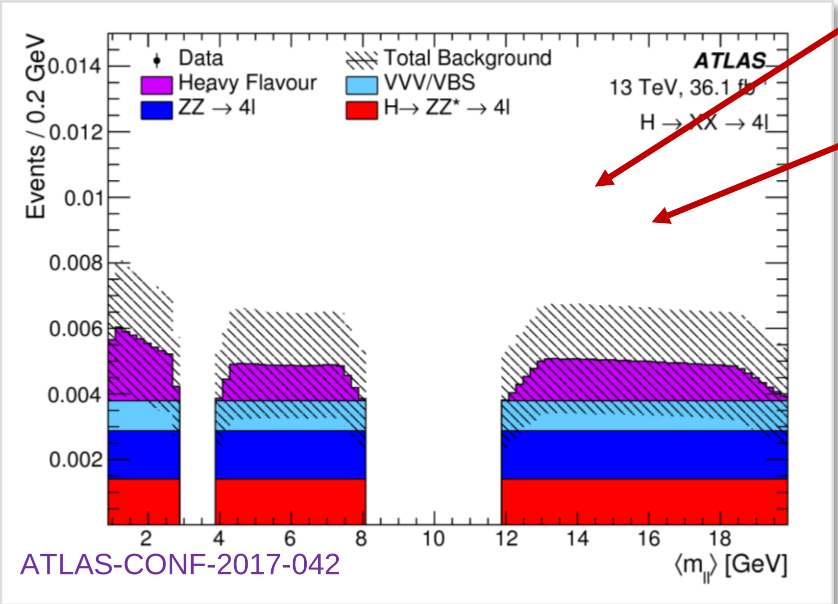
- In the 2HDM+S type-2, $\mathcal{B}(h \to aa)$ > 23% excluded at 95% CL for m_a~35 GeV
  ➡ **most sensitive results** so far at the LHC
- **Limits improved** by several factors in 25 < m_a < 62.5 GeV, and by more than 1 order of magnitude in 15 < m_a < 25 GeV

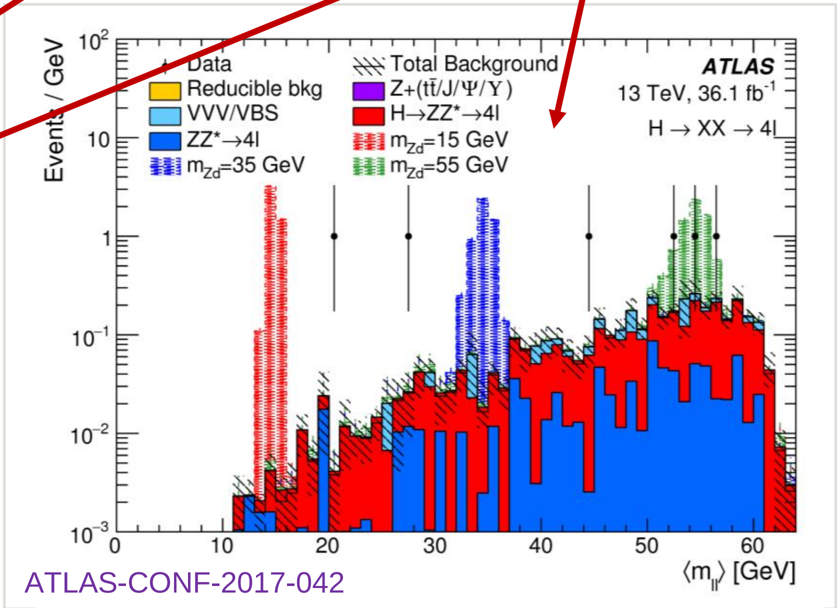
Exotic Decays $h(125) \rightarrow aa/Z_dZ_d \rightarrow 4\ell$

- Three different interpretations: Hypercharge portal, Higgs portal, 2HDM+S
- Dedicated selections are defined for each of the three decay channels
- Observable $\langle m_{\ell\ell} \rangle = \frac{1}{2}(m_{12} + m_{34})$

ATLAS-CONF-2017-042 (Sub. to JHEP)



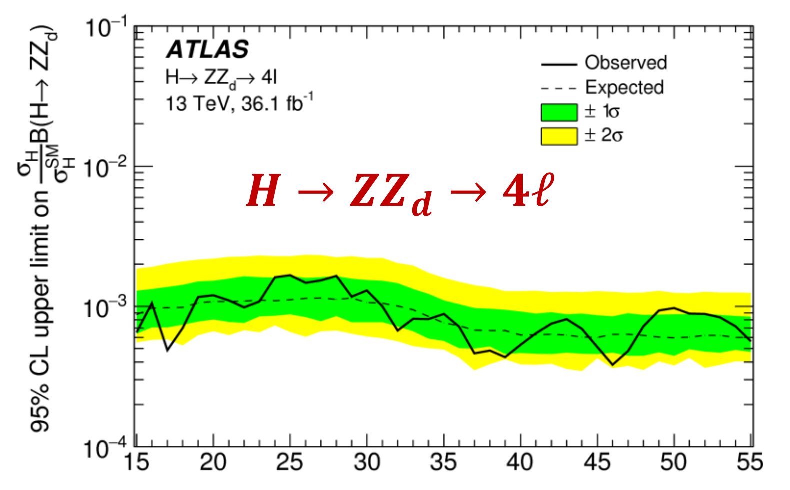




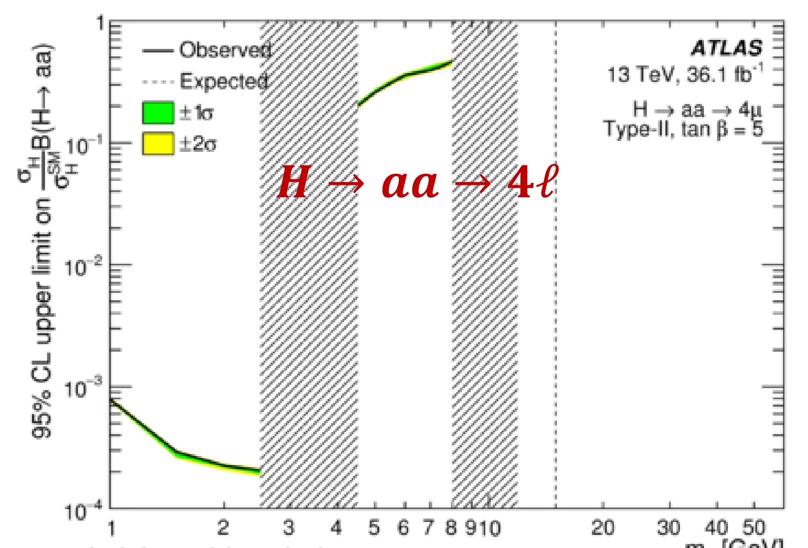
Exotic Decays $h(125) \rightarrow aa/Z_d Z_d \rightarrow 4\ell$

- Three different interpretations: Hypercharge portal, Higgs portal, 2HDM+S
- Dedicated selections are defined for each of the three decay channels
- Observable $\langle m_{\ell\ell} \rangle = \frac{1}{2}(m_{12} + m_{34})$

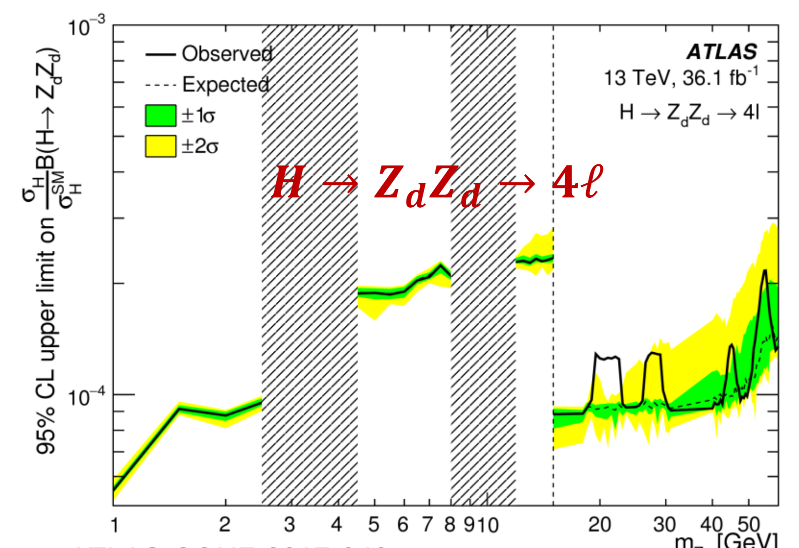
ATLAS-CONF-2017-042 (Sub. to JHEP)



ATLAS-CONF-2017-042



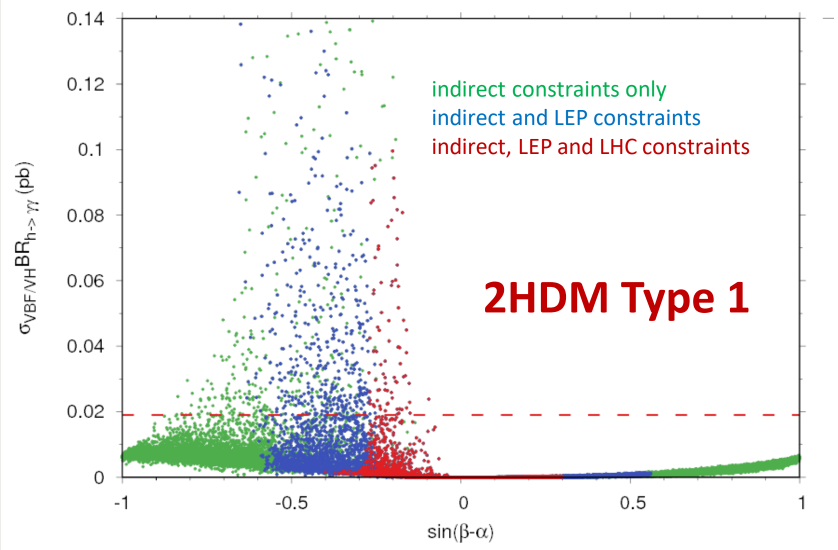
ATLAS-CONF-2017-042



ATLAS-CONF-2017-042

Search for BSM Physics at the LHC

LHC data are **sensitive** to the presence for some combinations of the **2HDM parameters**



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

How new Physics can be discovered?

- **Precision measurements** of the properties of the h(125 GeV) scalar boson
- Observation of BSM physics in **indirect searches** involving **scalar bosons**
- Discovery of **BSM decays** of the h(125 GeV) scalar boson
- Direct **discovery** of new **scalar particles**

Search for Low Mass A

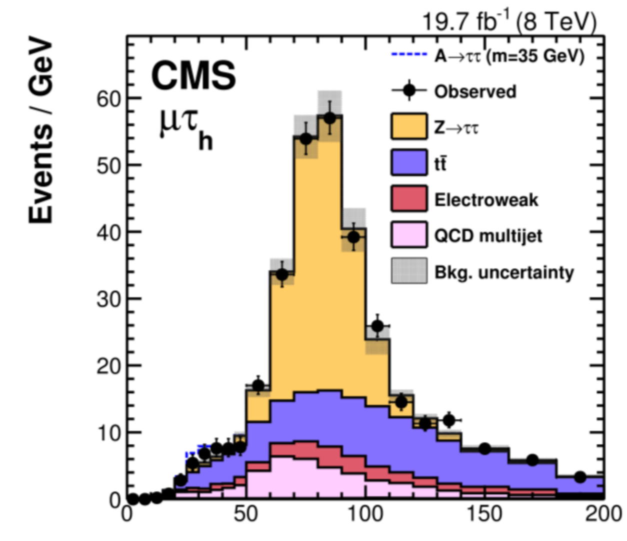
- The 2HDM includes a **CP-odd Higgs boson**, A, that could be lighter than h(125)
- At the LHC A could be produced in **association with bottom quarks**
  - ➡ In some schemes, $\sigma(pp \to bbA) \times \mathcal{B}(A \to \ell\ell)$ could be very large for m_A < 60 GeV

$bbA \to bb\tau\tau$ — *Phys. Lett. B 758 (2016) 296*

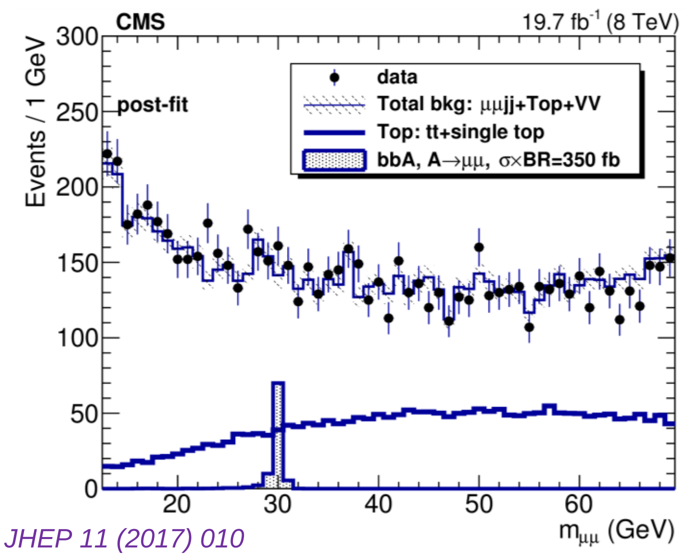
- $e\tau_h$, $\mu\tau_h$ and $e\mu$ final states
- Trigger seeded by single muon or electron
- At least **1 b-tagged jet** with p_T > 20 GeV
- Simultaneous fit to the $m_{\tau\tau}$ distributions of the 3 final states

$bbA \to bb\mu\mu$ — *JHEP 11 (2017) 010*

- Trigger seeded by single muon
- At least **1 b-tagged jet** with p_T > 20 GeV
- Fit to the $m_{\mu\mu}$ distribution with signal and background template from simulation



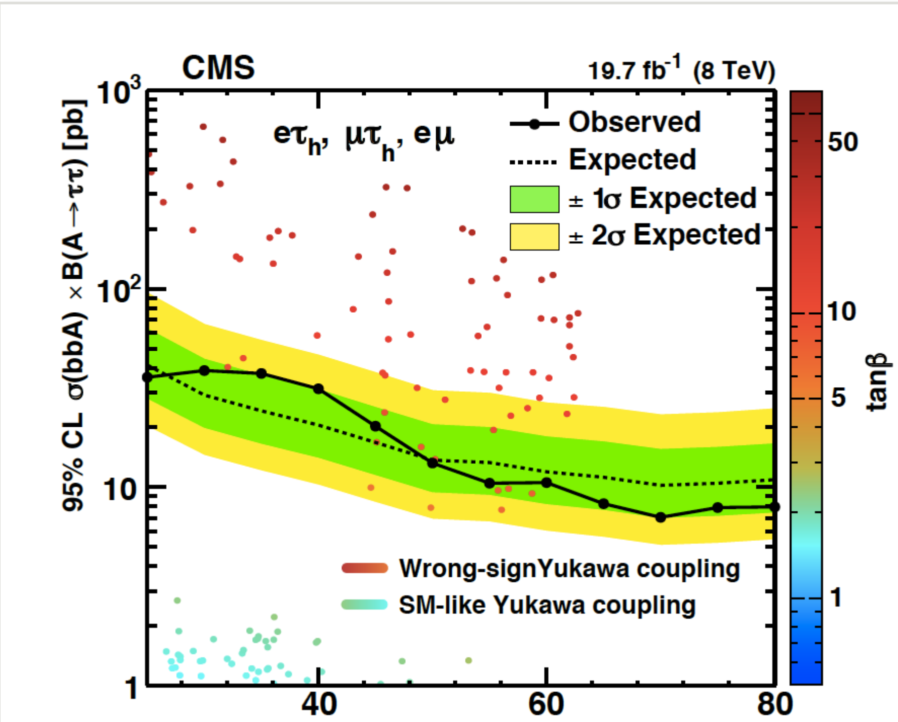
Phys. Lett. B 758 (2016) 296



JHEP 11 (2017) 010

Search for Low Mass A

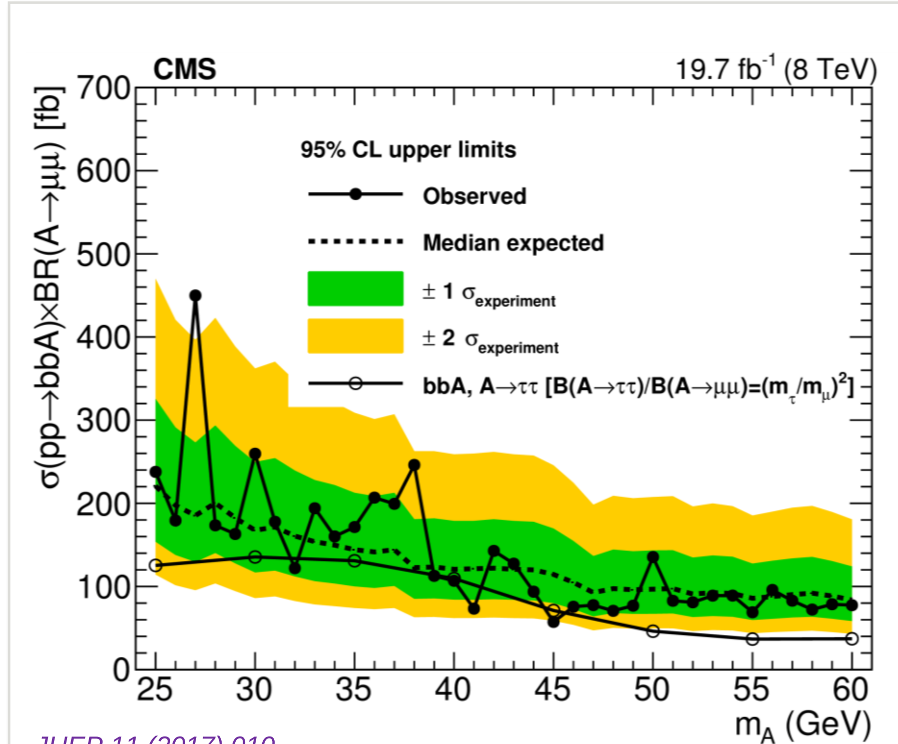
$bbA \rightarrow bb\tau\tau$



Phys. Lett. B 758 (2016) 296

A 2HDM, type II, with SM-like Higgs boson negative couplings to down-type fermions is excluded

$bbA \rightarrow bb\mu\mu$

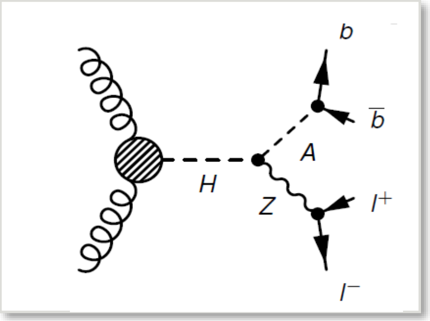


JHEP 11 (2017) 010

limits comparable to $A \rightarrow \tau\tau$ can be translated to $A \rightarrow \mu\mu$

$$\frac{\mathcal{B}(A \rightarrow \tau\tau)}{\mathcal{B}(A \rightarrow \mu\mu)} = \left(\frac{m_\tau}{m_\mu}\right)^2$$

Search for H and A in pp → H → ZA

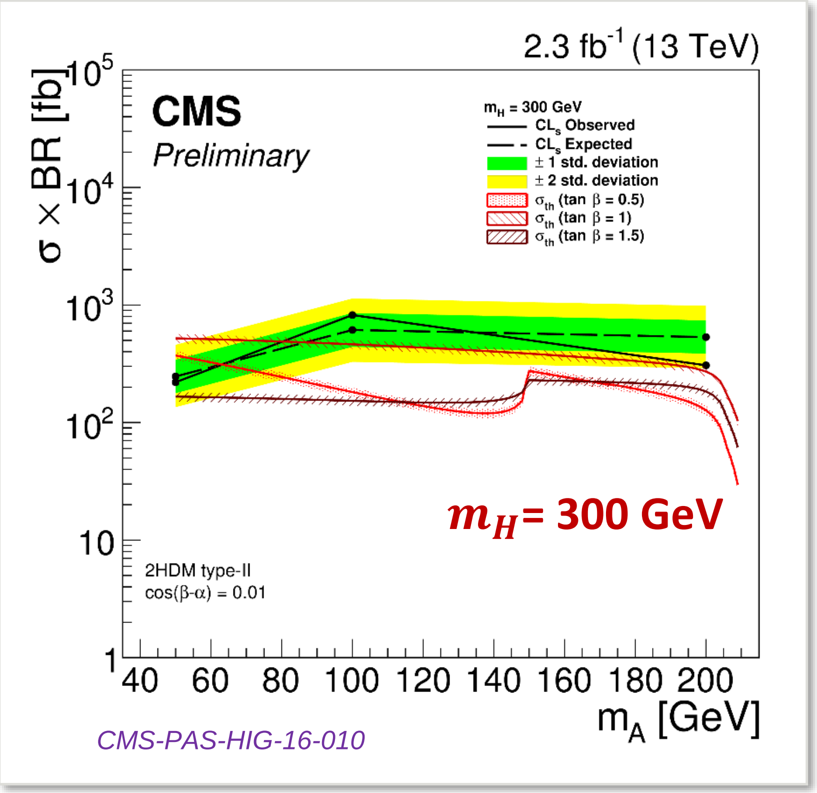


- In 2HDMs **several mass hierarchies** of the 5 Higgs bosons are possible
- Inverted mass hierarchy with a **heavy H** and a **light pseudoscalar A** is well motivated
- If **$\tan\beta$** ranges between **0.5 and 1.5**, the decay mode $H \to ZA$ is **dominant** and the decay mode $A \to bb$ is **large**

$H \to ZA \to \ell\ell bb$

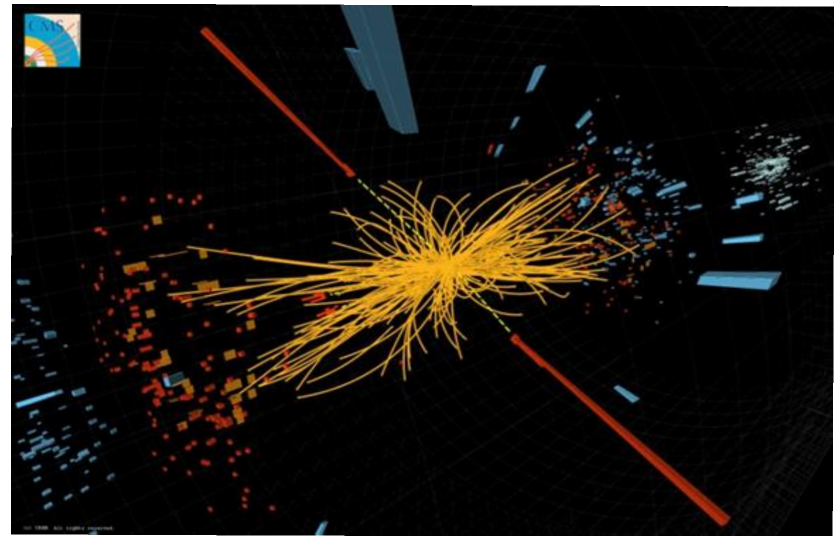
- Use of **dilepton trigger**
- Three **choices of m_H** and for each of them, between three and five **hypotheses of m_A**
- Search for excess in **(m_{bb}, $m_{\ell\ell bb}$) plane**

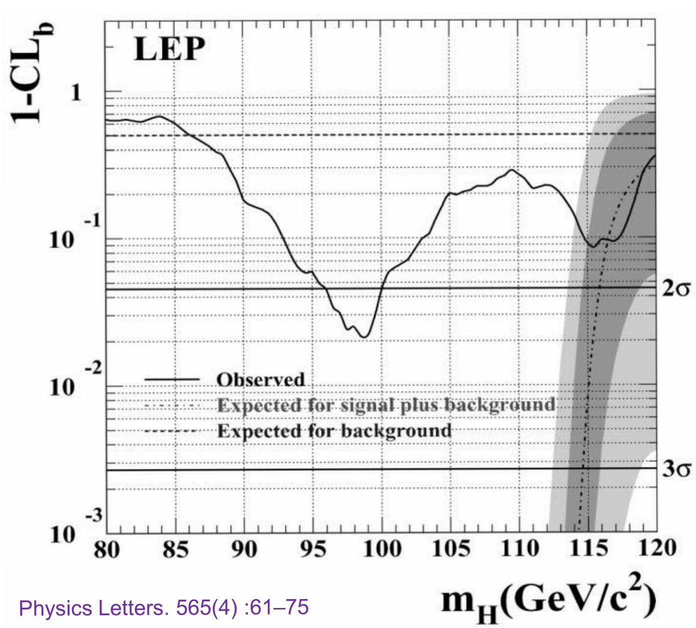
CMS-PAS-HIG-16-010



Search for $h \to \gamma\gamma$ at Low Mass

- The **Higgs boson at 125 GeV** can be identified as the **heavier scalar H**, allowing to envisage a possible **lighter particle h**
- **Small excess** of events (~2σ) at **LEP** observed by 3 of the 4 experiments in $bb/\tau\tau$ channels



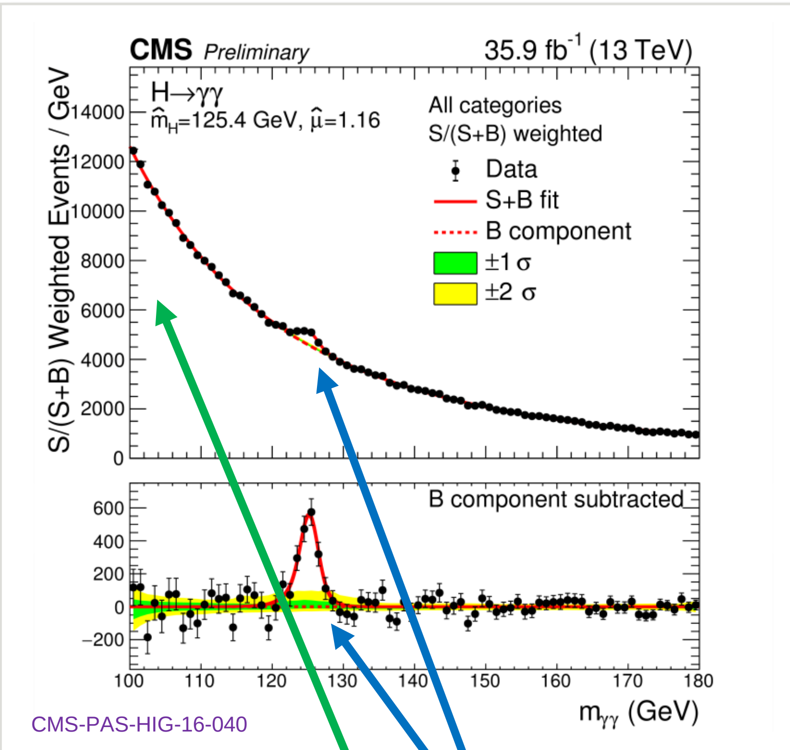


Physics Letters. 565(4) :61–75

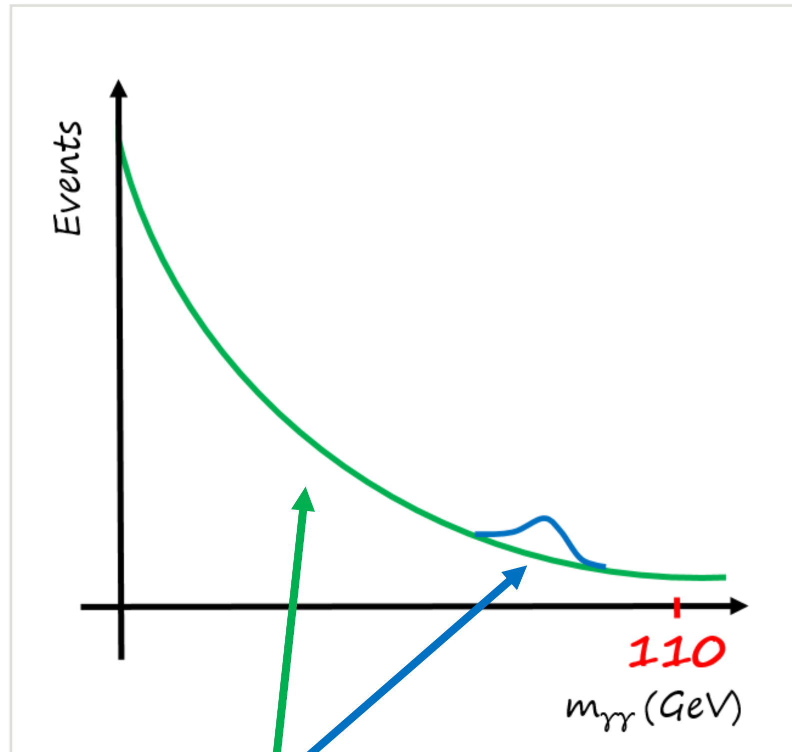
- During LHC Run I, the standard $H \to \gamma\gamma$ **search range** was **[110,150] GeV**
- Clean signature with two **isolated and highly energetic photons**
- Final state fully reconstructed with **excellent mass resolution**
- **Background** from QCD ($\gamma\gamma - \gamma j - jj$) large enough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

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

STANDARD MODEL $H\rightarrow\gamma\gamma$ ANALYSIS



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

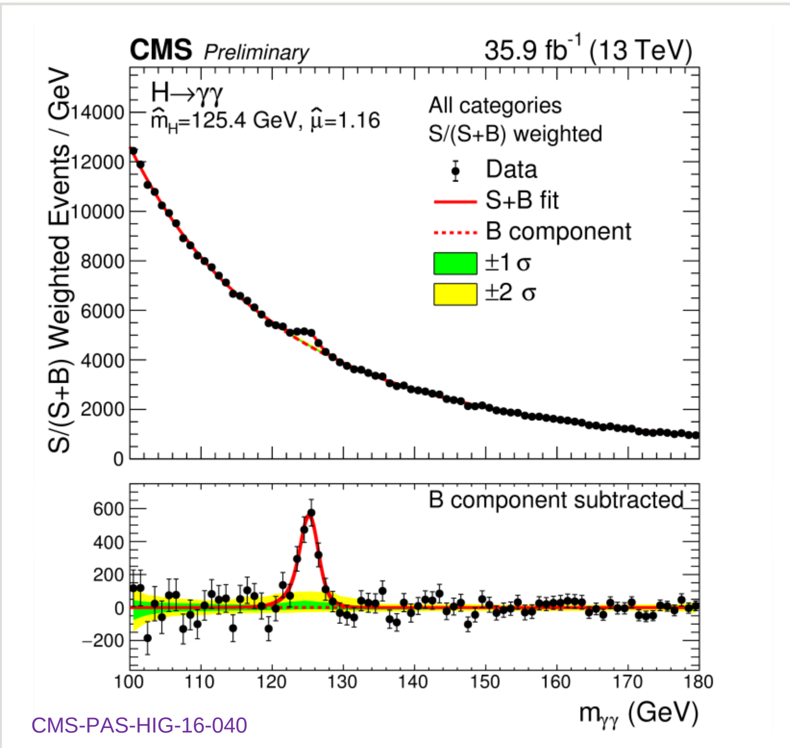


NARROW SIGNAL PEAK

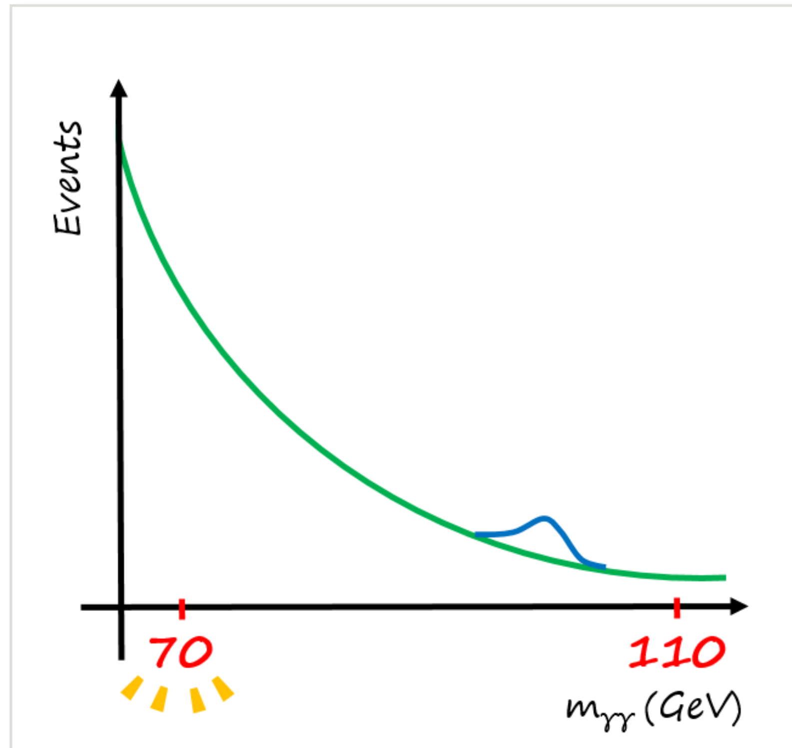
LARGE FALLING BACKGROUND

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

STANDARD MODEL $H\rightarrow\gamma\gamma$ ANALYSIS



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



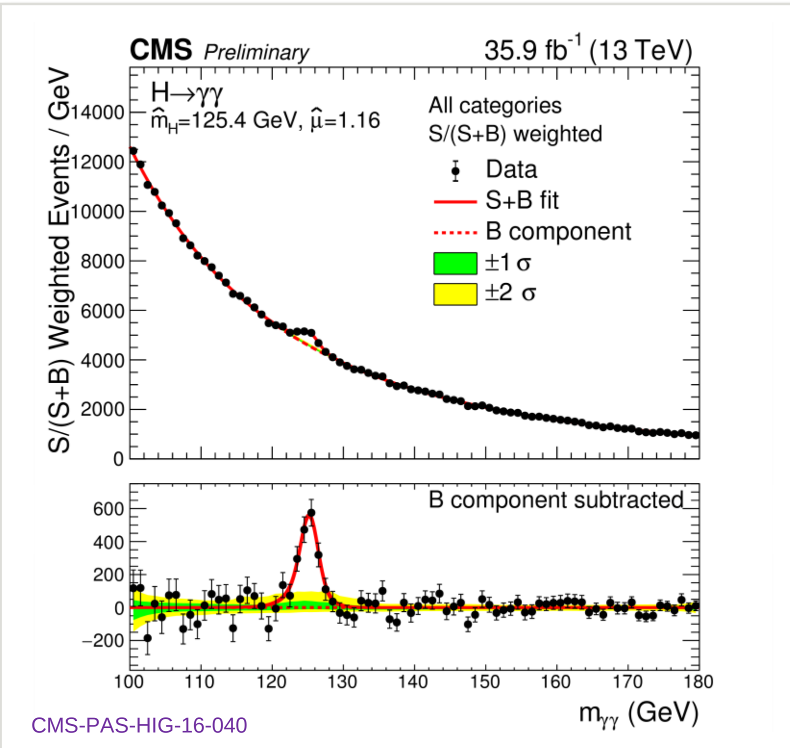
MAIN CHALLENGES:

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

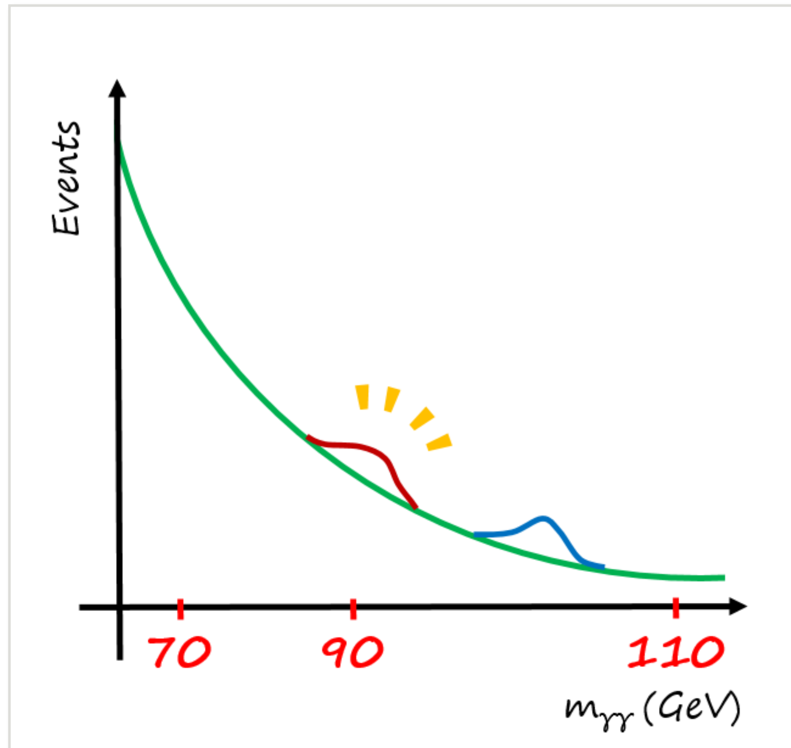
  ➡ Lower limit at > 65 GeV

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

STANDARD MODEL $H \to \gamma\gamma$ ANALYSIS



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



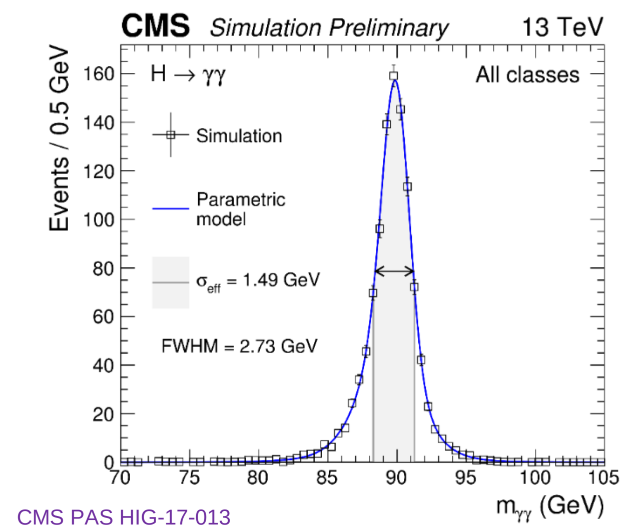
MAIN CHALLENGES:

- Additional Drell-Yan **background *Z* → *ee***, with electrons misidentified as photons

  ➡ Decrease in sensitivity around 90 GeV

Signal and Background Model

- **Event categorization** defined to maximize S/B
- Signal extracted from background by **fitting the observed diphoton mass distributions** in each category



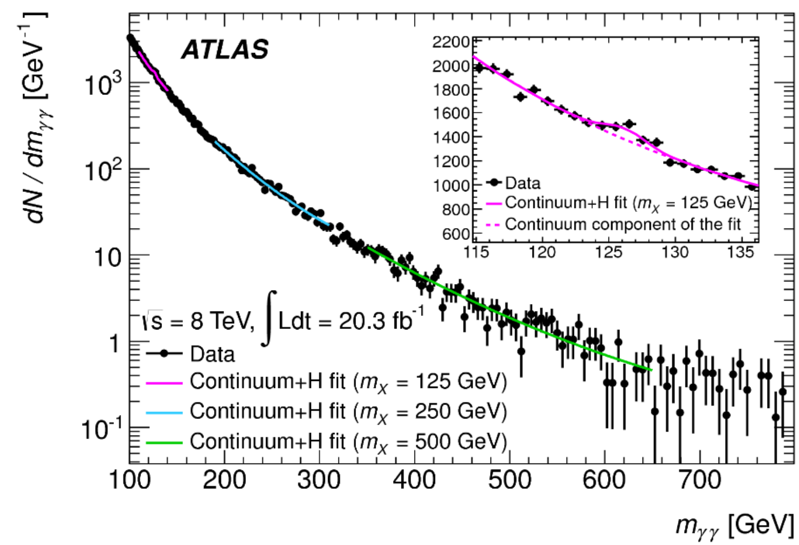
CMS PAS HIG-17-013

SIGNAL

- The **signal shape** corresponds to a **standard Higgs boson** in both **CMS** and **ATLAS** analyses
- The signal is fitted by a **sum of Gaussian distributions**/**Double-sided Crystal Ball** in each event class (then combined together)

BACKGROUND

- **Continuum background** modeled with a **sum of polynomials**/**Landau and exponential** distribution
- **Drell-Yan contribution** modeled with a double-sided Crystal Ball distribution
- **Final background model** is fitted to data

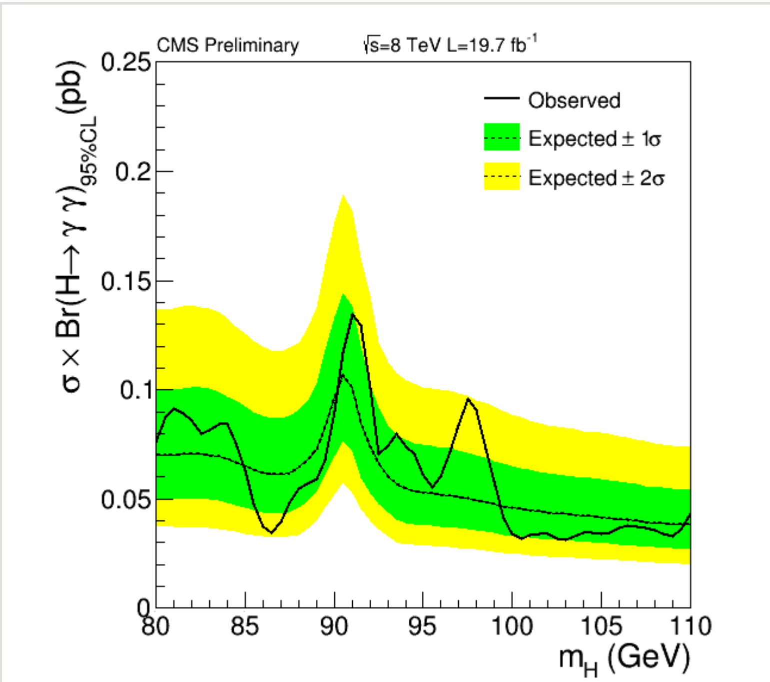


PRL 113 171801 (2014)

Run I Results

CMS RESULTS

CMS-PAS-HIG-14-037

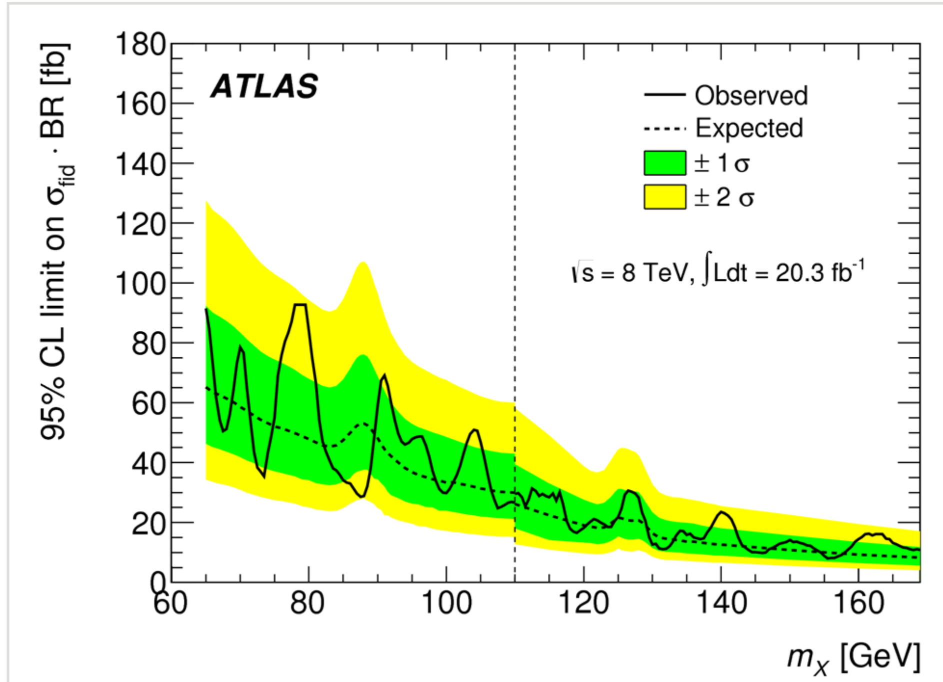


- 80 GeV < $m_{\gamma\gamma}$ < 110 GeV
- 4 inclusive classes
- Floating normalization of relic *Z*→*ee*
- Total cross section

∼**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

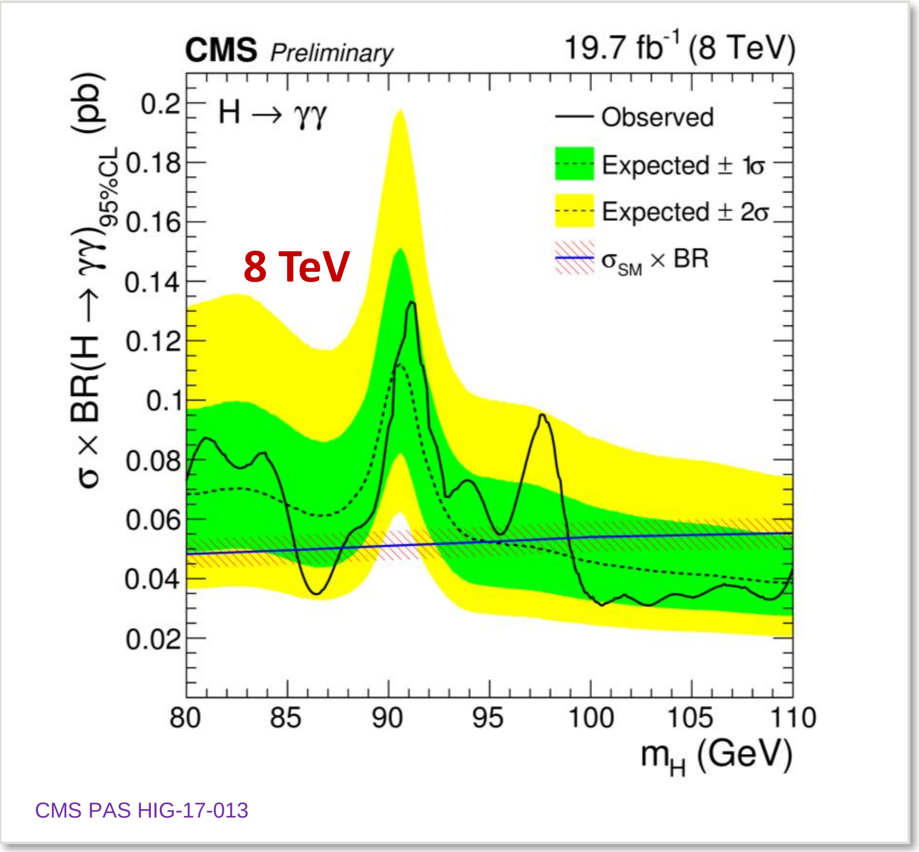
∼**2σ** excursion at ∼**80 GeV**

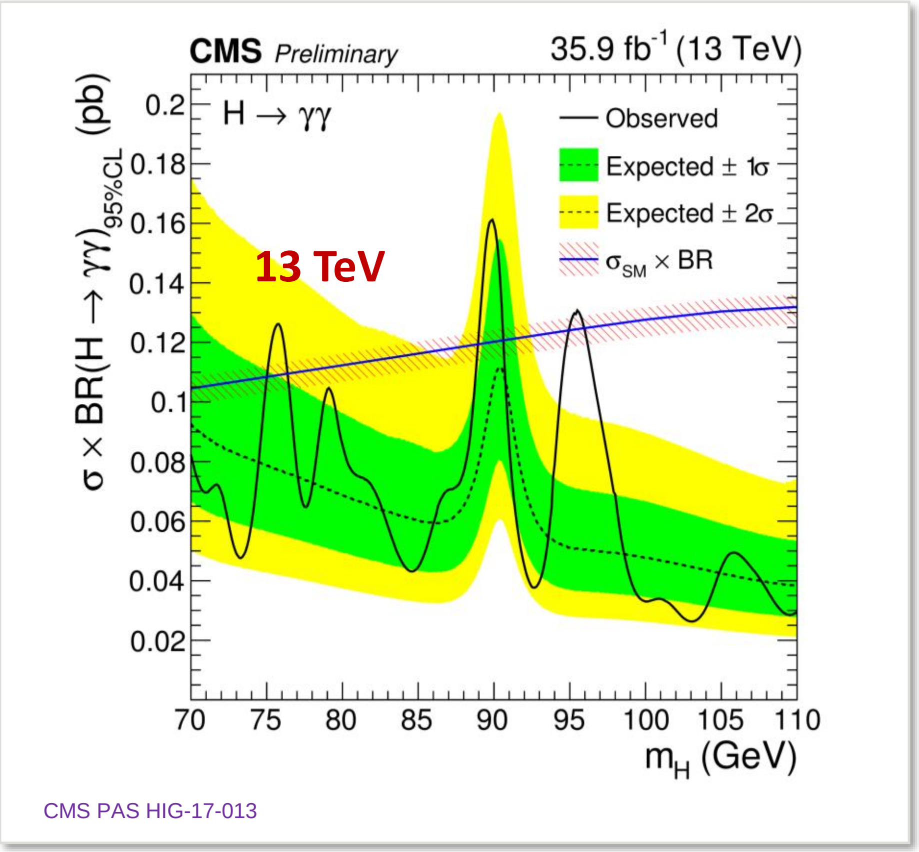
Results (Runs I and II)

CMS-PAS-HIG-17-013

- **8 TeV limits** on σ×BR **redone** with 0.1 GeV step
- **No significant excess** with respect to background expectations

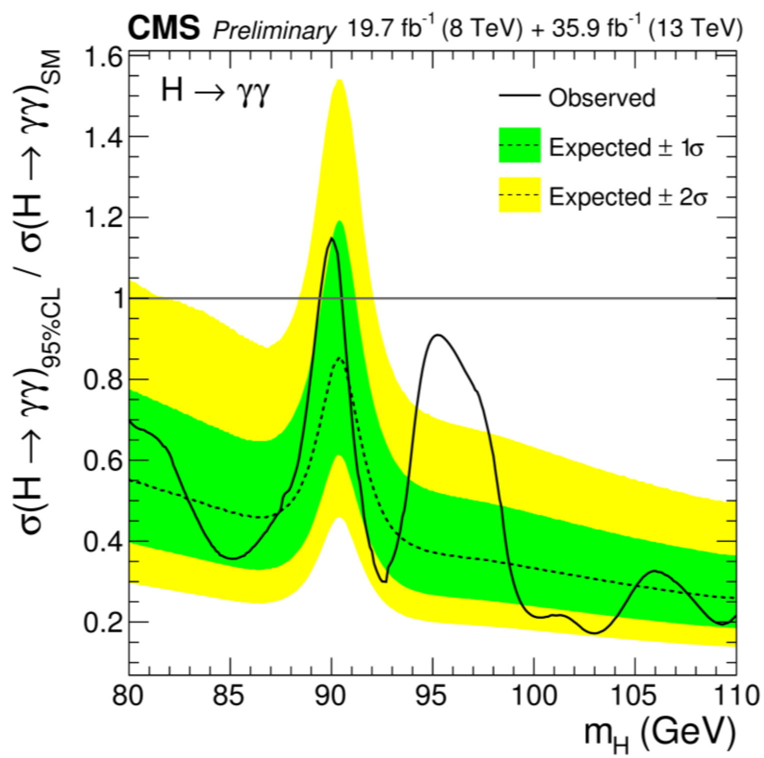
Production processes assumed in **SM proportions**



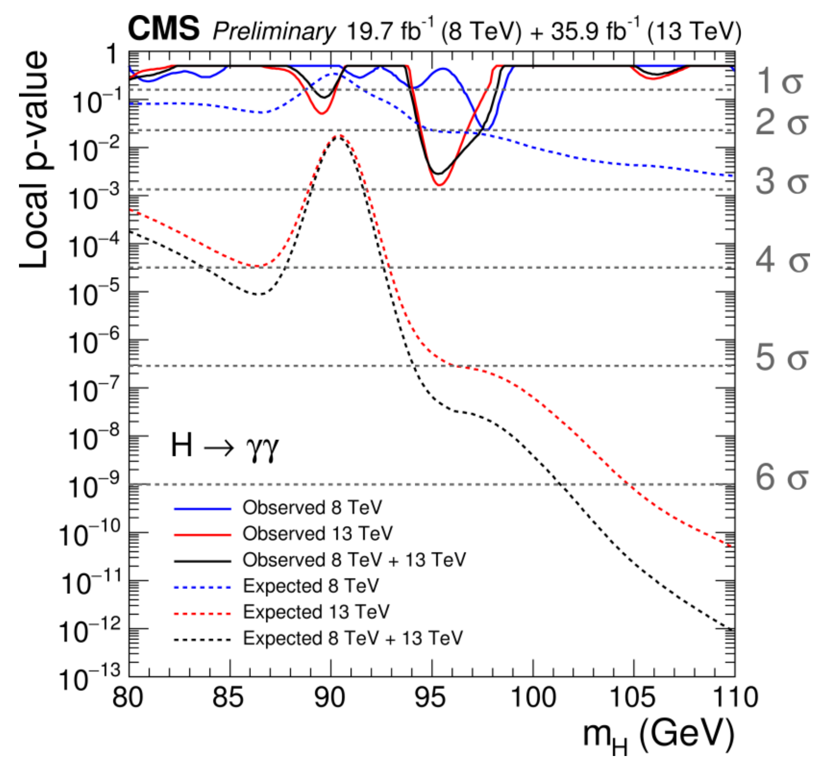


Results – Combination of Run I and II

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



CMS PAS HIG-17-013

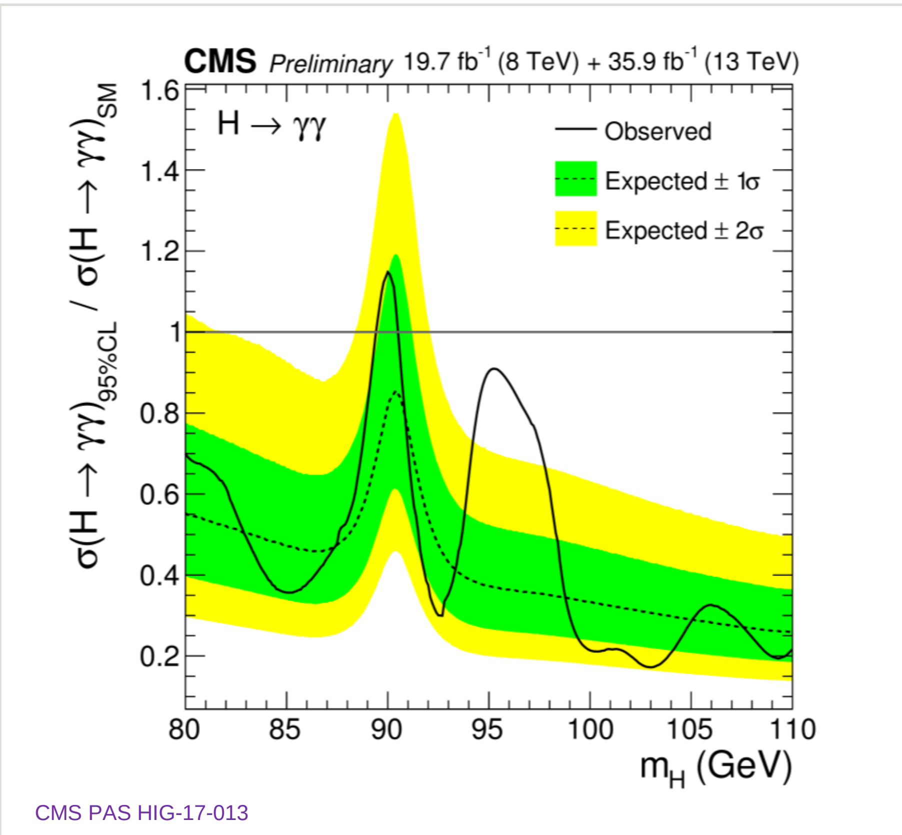


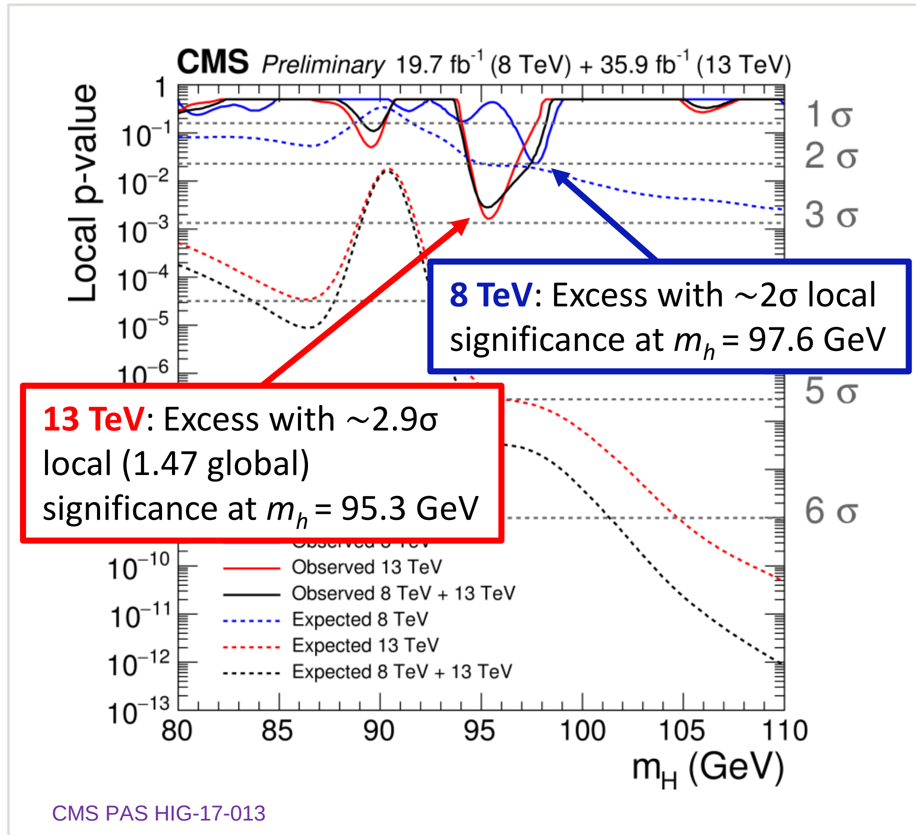
CMS PAS HIG-17-013

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 background expectations
- Expected and observed local p-values for **8 TeV**, **13 TeV** and their **combination**

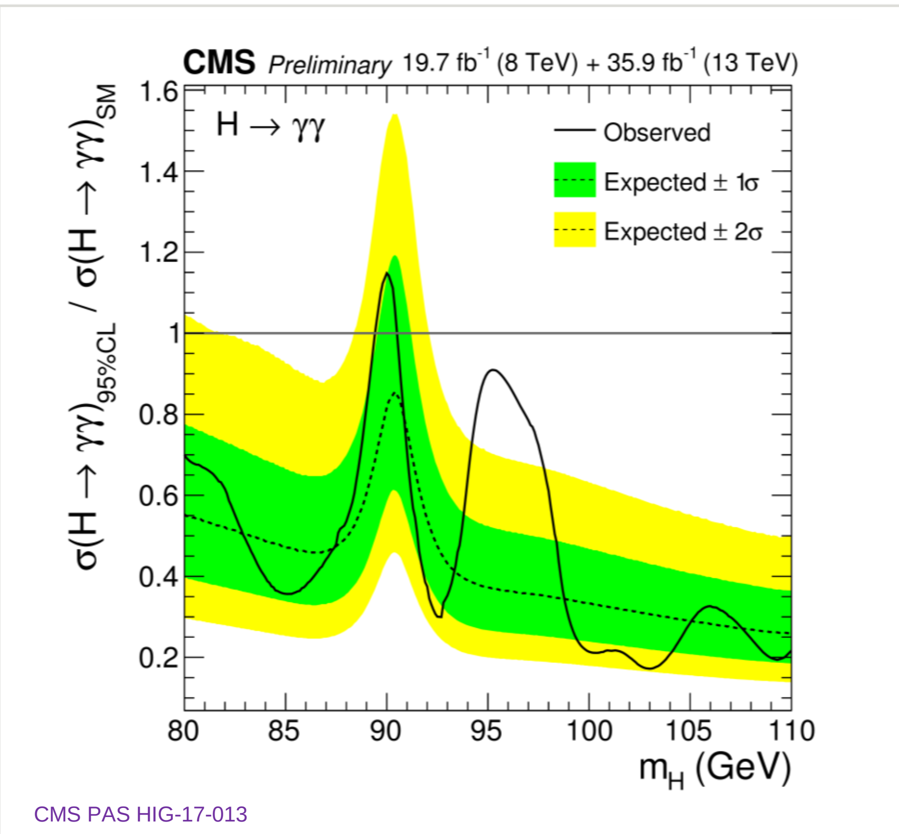


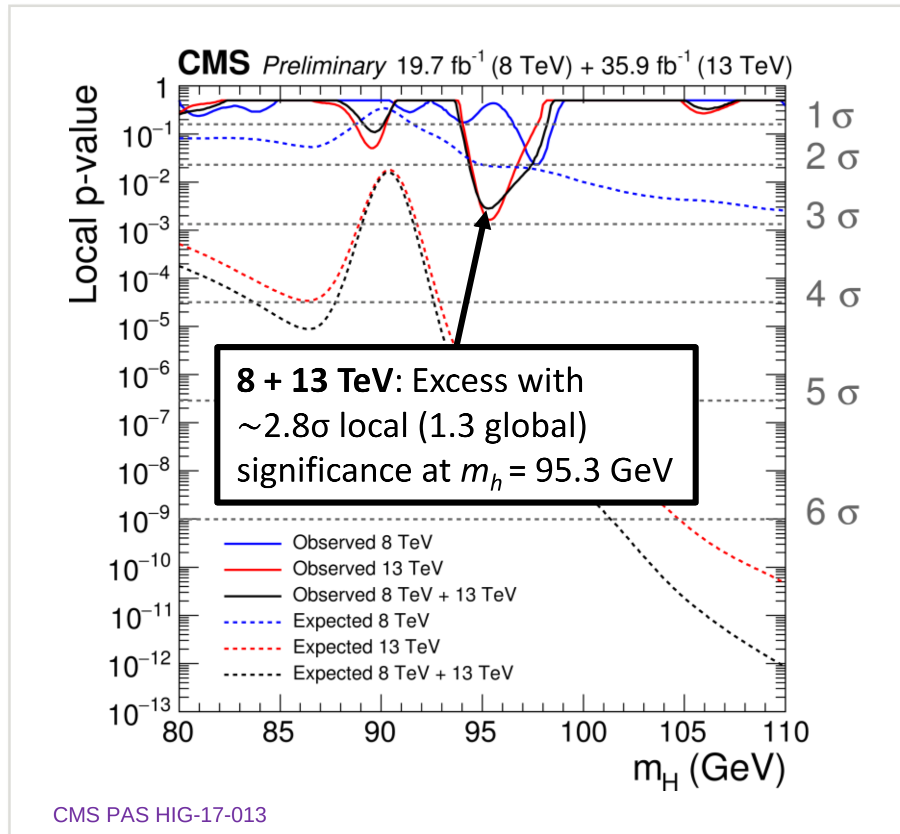


CMS-PAS-HIG-17-013

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 background expectations
- Expected and observed local p-values for **8 TeV**, **13 TeV** and their **combination**

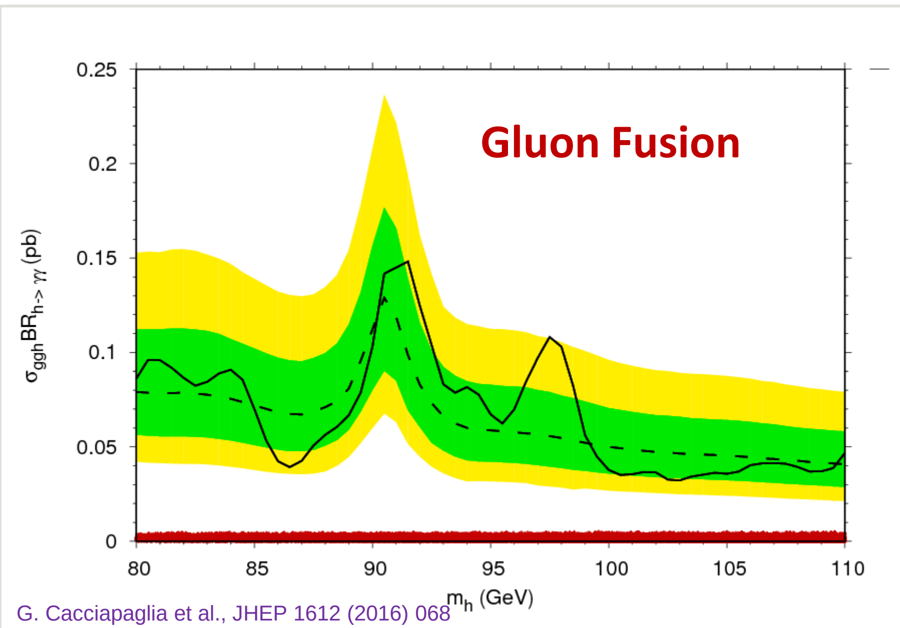


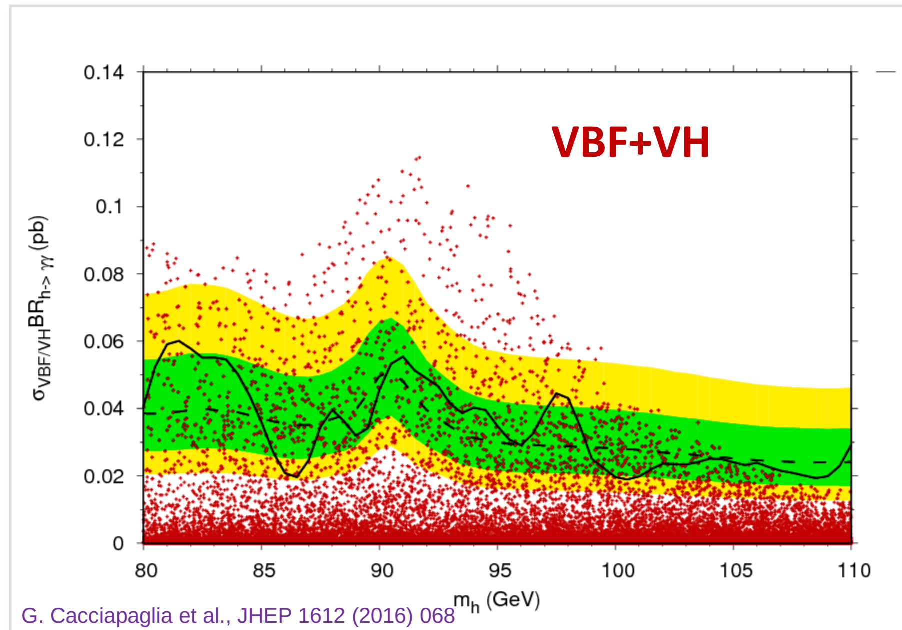


CMS-PAS-HIG-17-013

Phenomenological Interpretations

- CMS **Run I results interpreted** in the contest of **2HDM**
- Points generated in the **2HDM Type I** passing **indirect**, **LEP** and **LHC constraints**
- Some **exclusion** possible with **VBF + VH**, m_h ~< 105 GeV





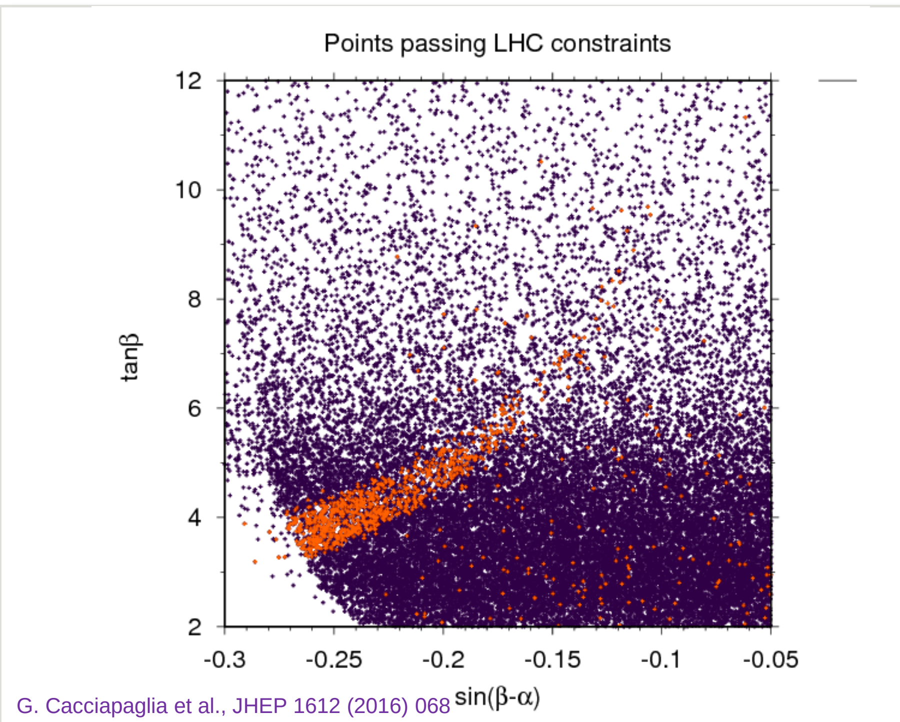
m_h (GeV)	m_H (GeV)	m_A (GeV)	$m_{H^\pm}$ (GeV)	$\sin(\beta-\alpha)$	$\tan\beta$	$m12^2$
[80;110]	125	[60;650]	[80;630]	[-0.3;-0.05]	[2;12]	[-(100)^2;+(100)^2]

JHEP 1612 (2016) 068

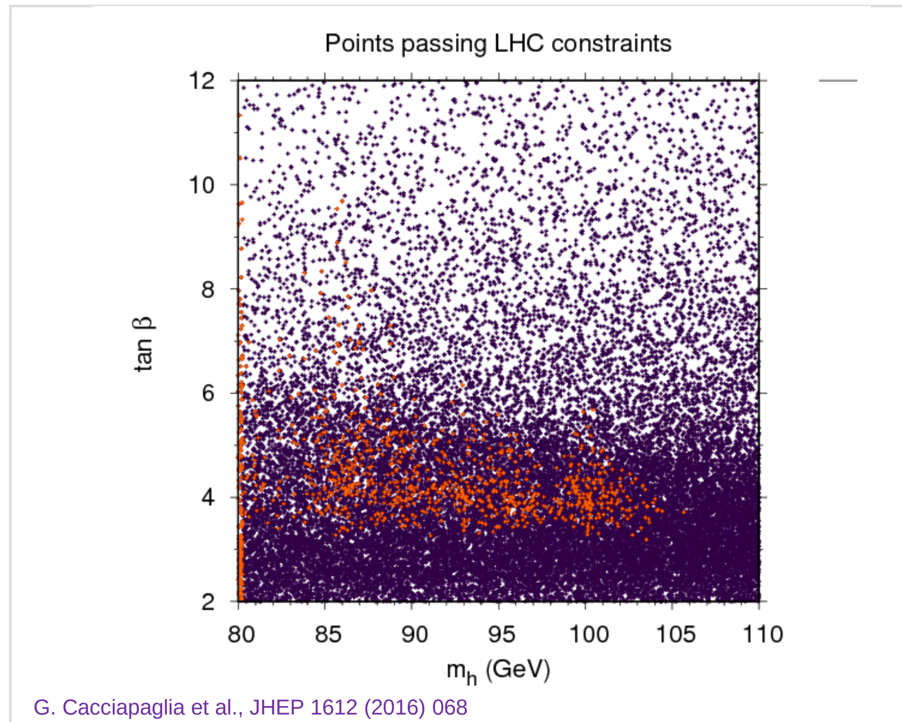
Phenomenological Interpretations

- Projections of **red** points on previous slide:
  - **orange** if $\sigma \times \mathcal{B}$ > CMS observed limit (excluded)
  - **violet** if $\sigma \times \mathcal{B}$ < CMS observed limit (still permitted)

$\tan\beta$ vs $\sin(\beta-\alpha)$



$\tan\beta$ vs m_h



JHEP 1612 (2016) 068

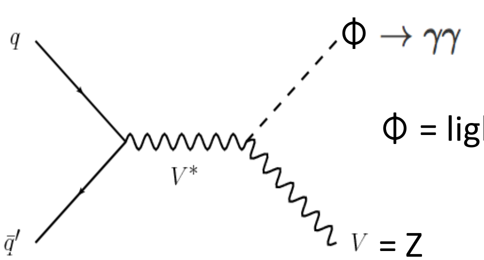
Future Perspectives

For (pseudo-) scalars below $m_\phi \sim 70$ - 80 GeV:

- Decay $\phi \to ZZ^*$ kinematically closed
- Gluon fusion mechanism not promising
- Take advantage of the $Z \to \ell\ell$ from $\boldsymbol{pp \to Z\phi}$ (triggering on lepton instead of on photons)

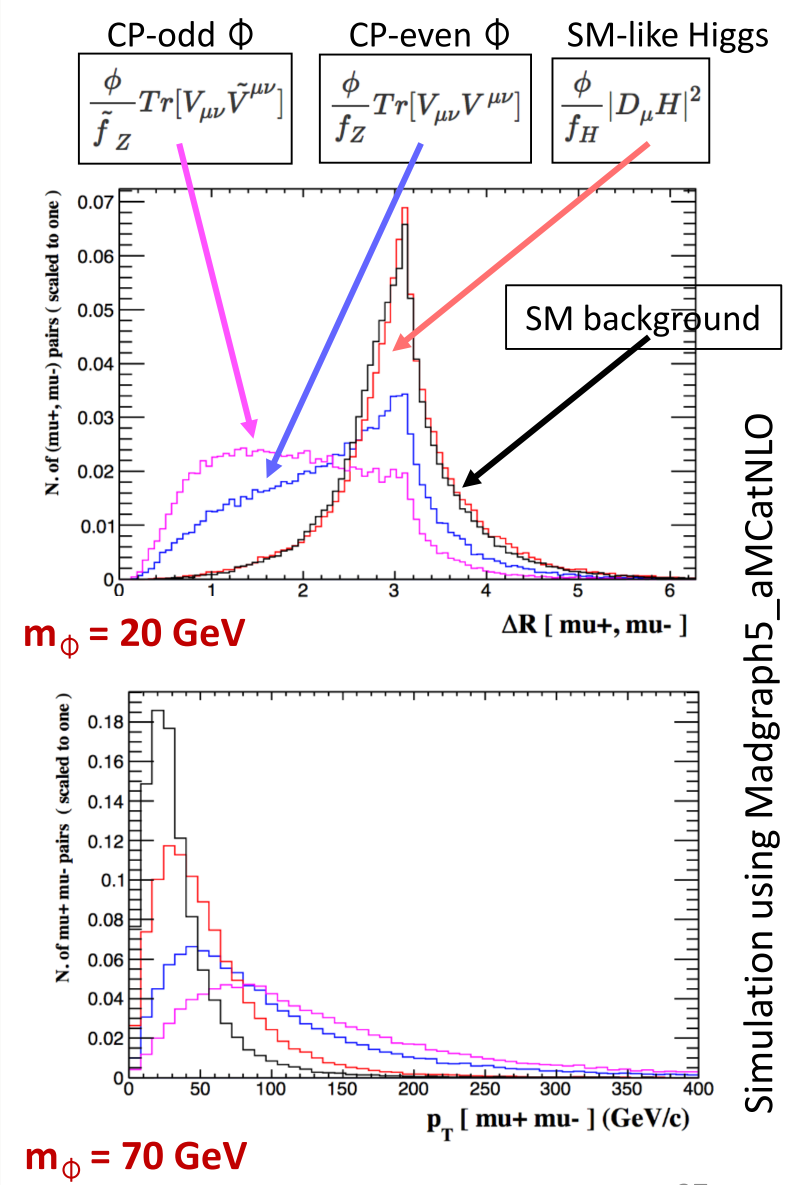
Using **generic** (EFT) **parameters** so that any BSM model can be constrained

Very preliminary results from Les Houches 2017 (A. Angelescu, G. Moreau, S. Fichet, S. Gascon, L.Finco, S. Zhang)



Φ = light Higgs, radion, dilaton, axion…

$$\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$$



Conclusions

- The **Scalar Sector of the SM** is a favored place to look for **new physics effects**
- **LHC data** are **sensitive** to some theoretical models (2HDM, NMSSM…)
- We have **just started** to extract the physics **potential of the 13 TeV** dataset
- We have a **comprehensive view** of the potential of the main channels from the **Run1 experience**
- Necessary to develop **dedicated triggers**, **tools** and studies for **low p_T searches**
- **Feedback** with **theory community** fundamental to keep interest in exploring these signatures

Backup

2HDM Types

	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

Photon Energy

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

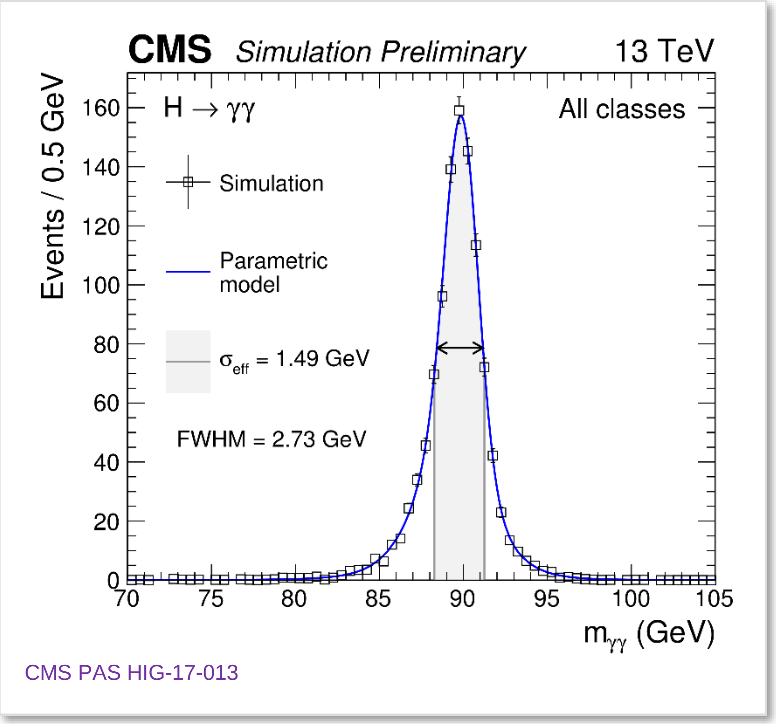
- Photon energy reconstructed by building **clusters of energy deposits** in the **electromagnetic calorimeter**.

- **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

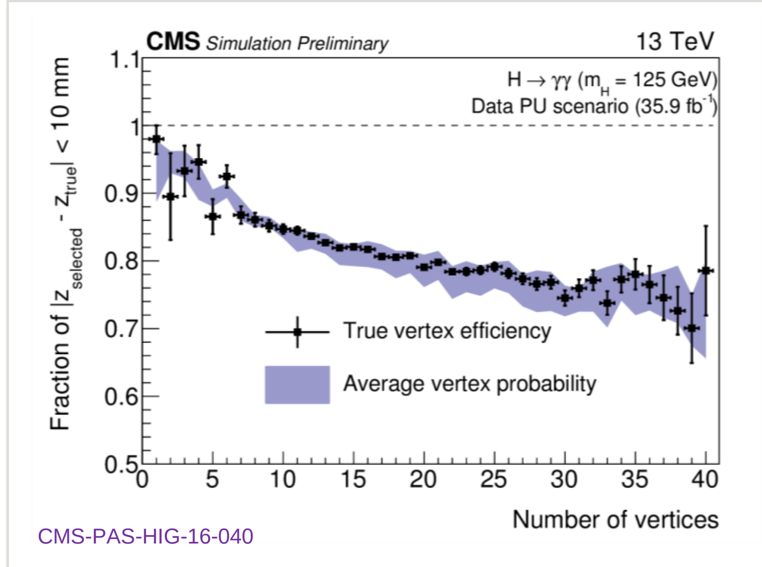
➡ $\boldsymbol{Z \to ee}$ **peak** used as reference

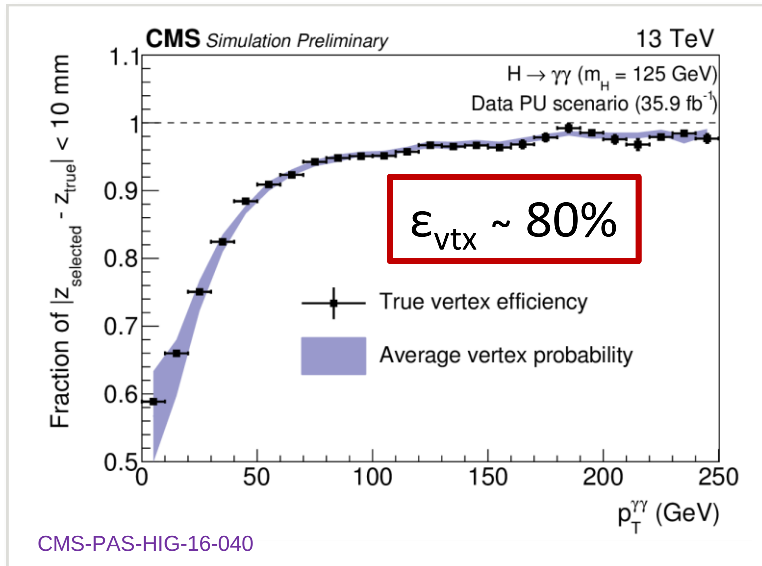


Vertex Identification

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

- **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 ***$Z \to \mu\mu$* events**, by refitting vertices ignoring the muon tracks

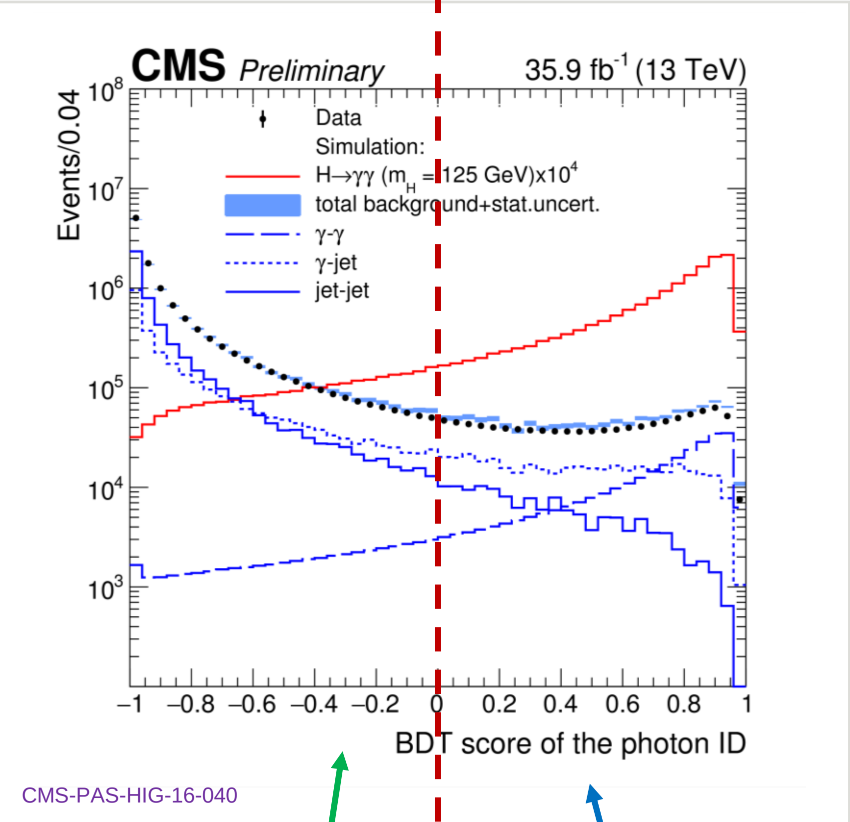




Photon Selection

- **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

BDT OUTPUT

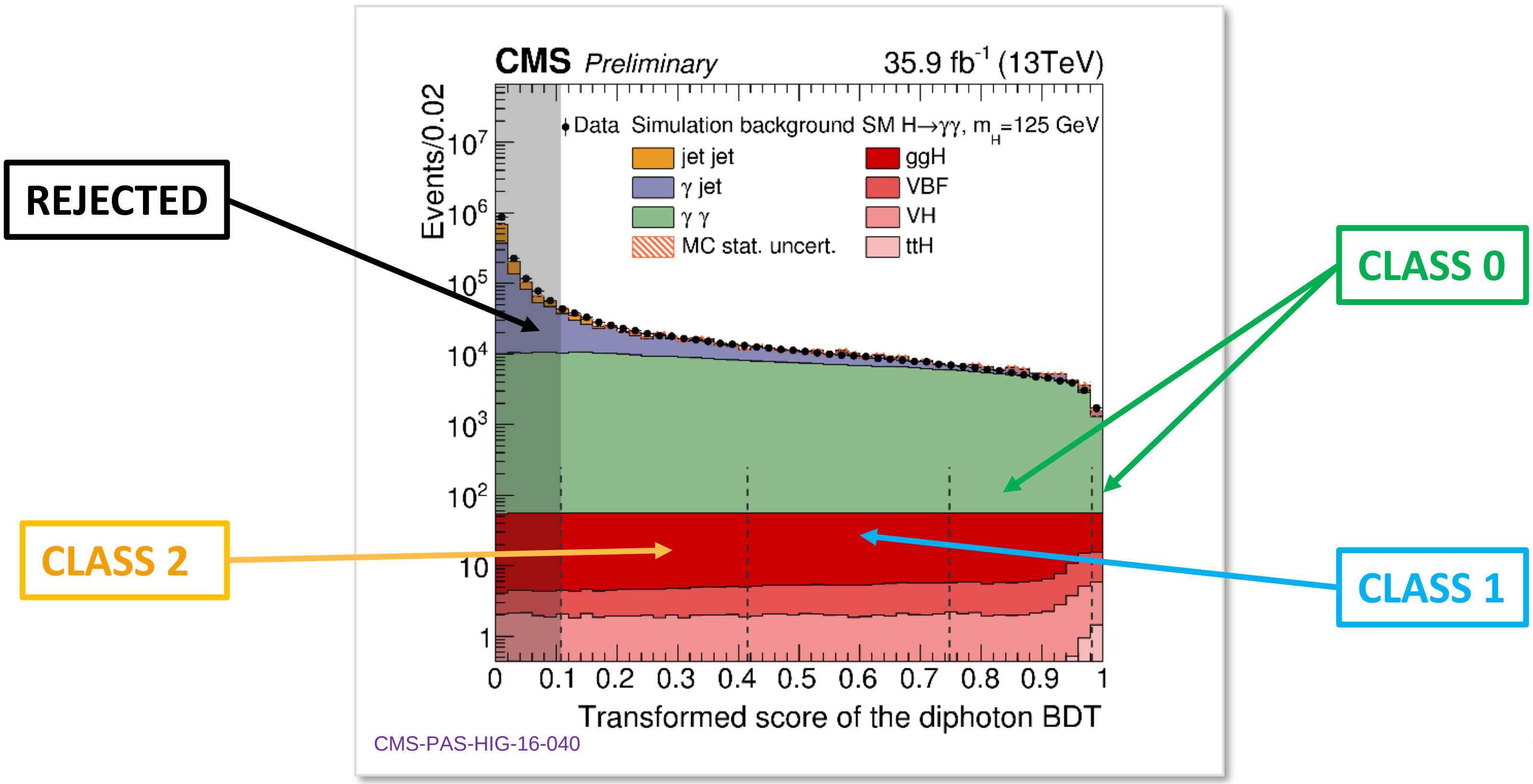


SIGNAL-LIKE PHOTONS

BACKGROUND-LIKE PHOTONS

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)



Background Model

CONTINUUM BACKGROUND

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

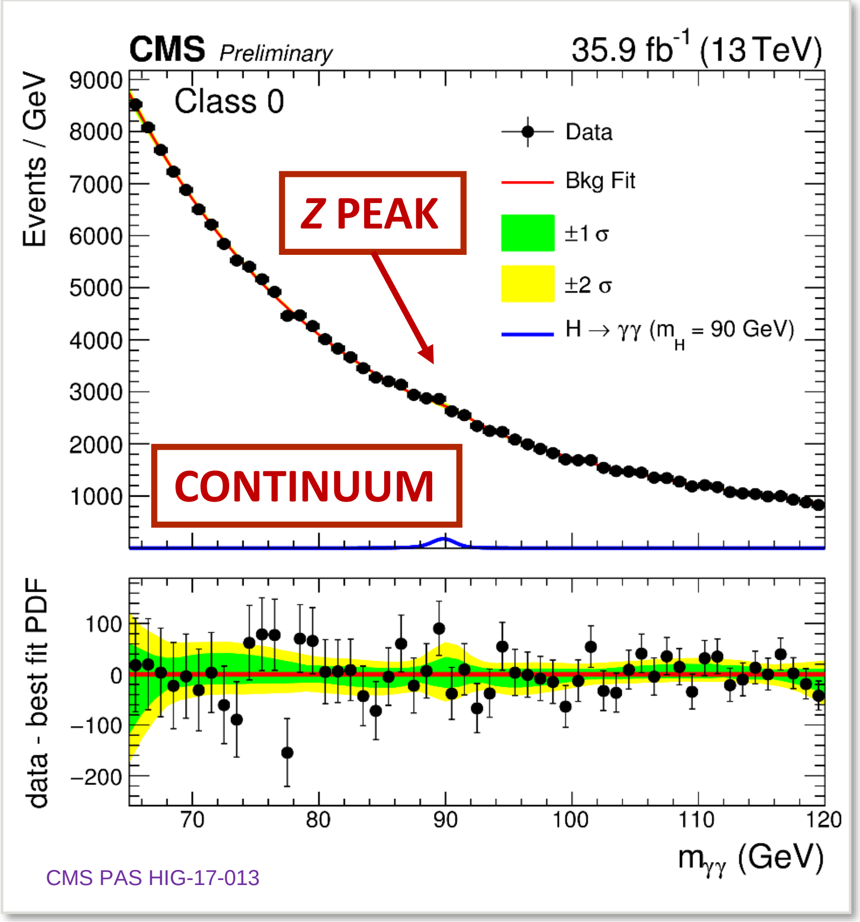
DRELL-YAN CONTRIBUTION

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

FINAL BACKGROUND MODEL

Polynomial + double-sided Crystal Ball

- Fitted to the data
- DCB fraction let floating



Background Model

CONTINUUM BACKGROUND

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

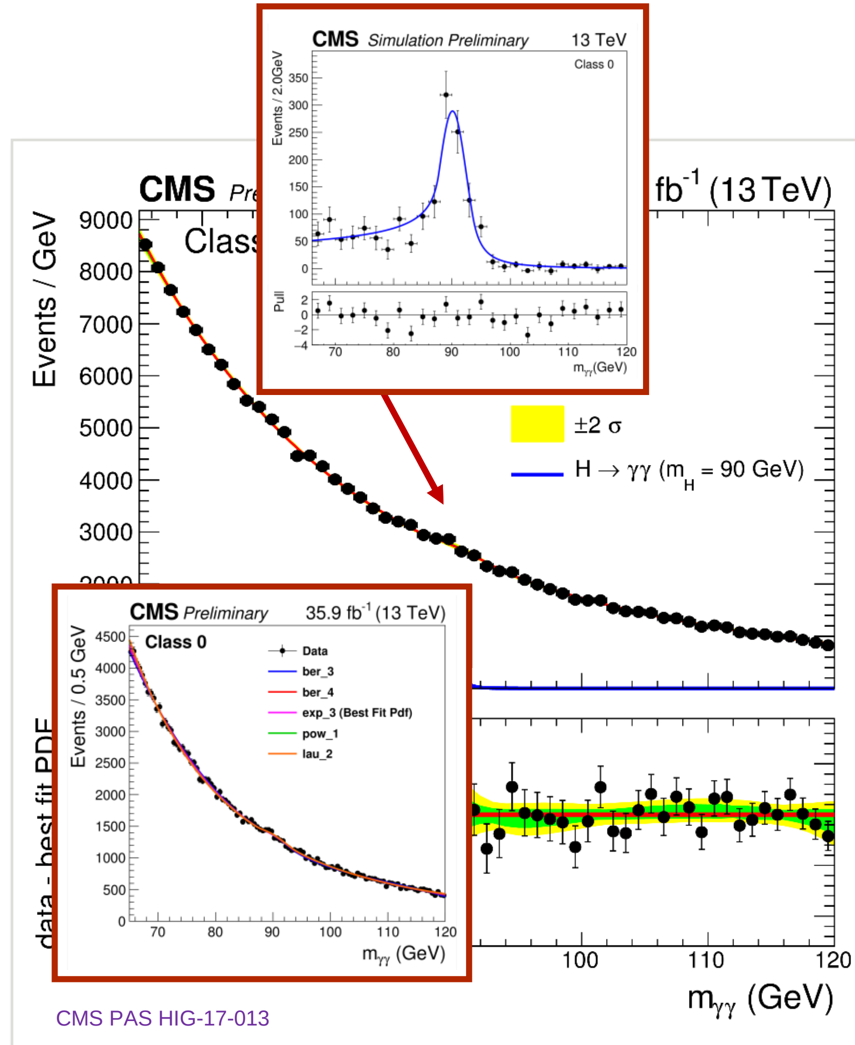
DRELL-YAN CONTRIBUTION

- 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

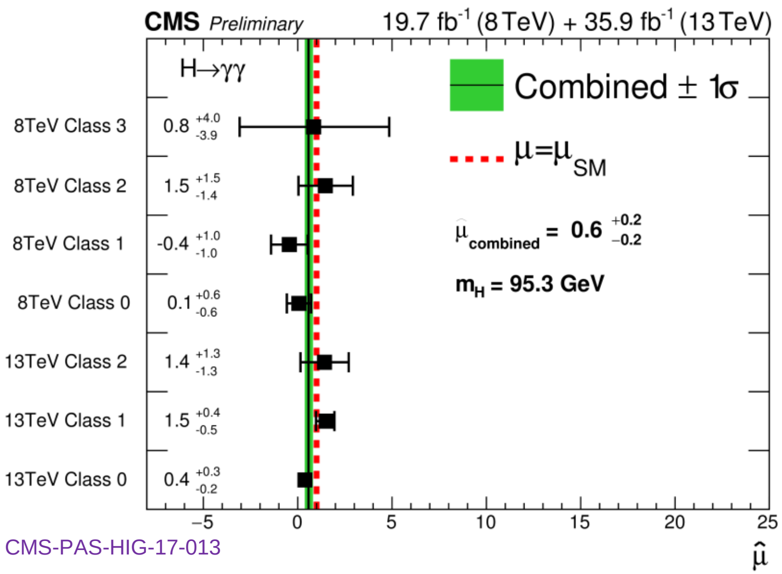
FINAL BACKGROUND MODEL

Polynomial + double-sided Crystal Ball

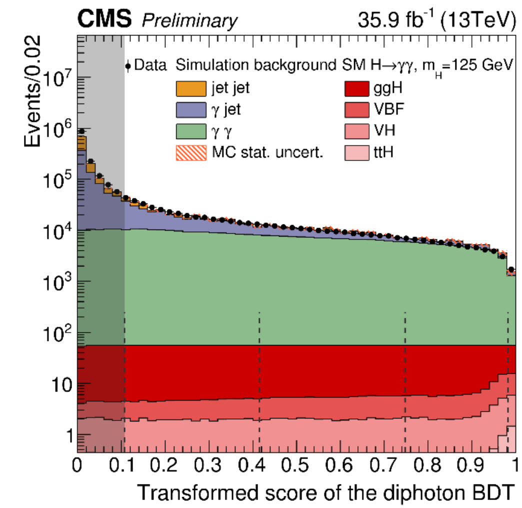
- Fitted to the data
- DCB fraction let floating



Recherche de $h \to \gamma\gamma$ à Basse Masse



CMS-PAS-HIG-17-013



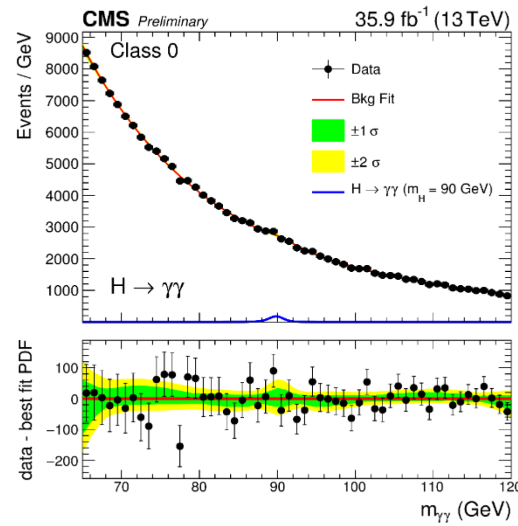
CMS-PAS-HIG-16-040

CMS-PAS--HIG-17-013

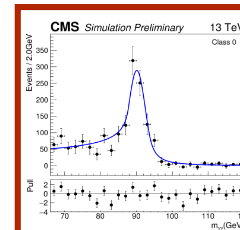
Event Class	Expected SM-like Higgs boson signal $m_H = 90\,\text{GeV}$, $\sqrt{s} = 8\,\text{TeV}$								Bkg (GeV^{-1})
	Total	ggH	VBF	WH	ZH	$t\bar{t}H$	σ_{eff}	σ_{HM}	
0	64.0	68.9 %	15.0 %	8.8 %	4.8 %	2.5 %	0.94	0.78	262.8
1	99.5	87.5 %	5.2 %	4.3 %	2.3 %	0.7 %	1.20	0.96	922.6
2	121.1	89.9 %	3.9 %	3.7 %	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

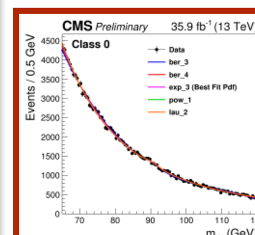
CMS-PAS-HIG-17-013

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

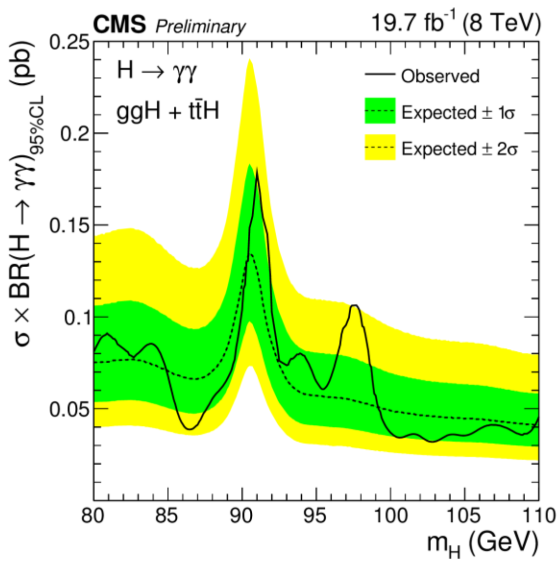


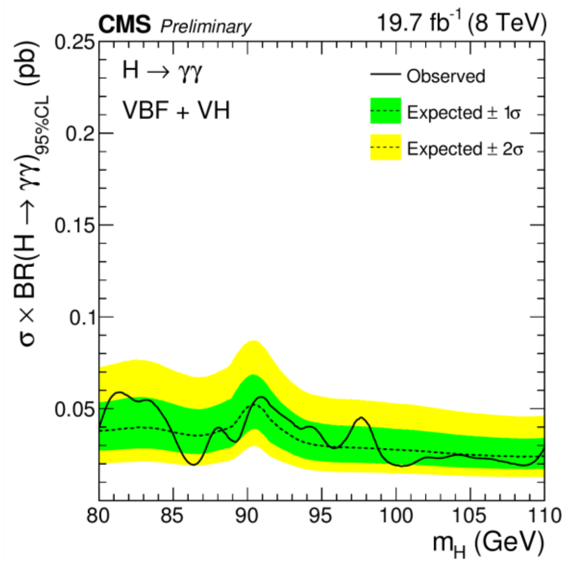
CMS PAS HIG-17-013

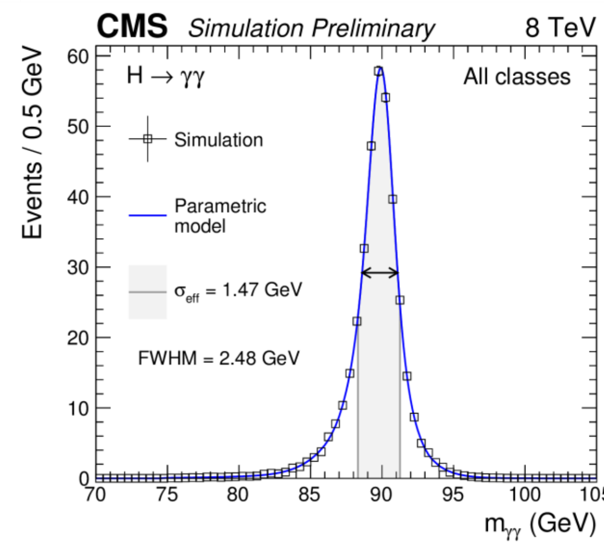




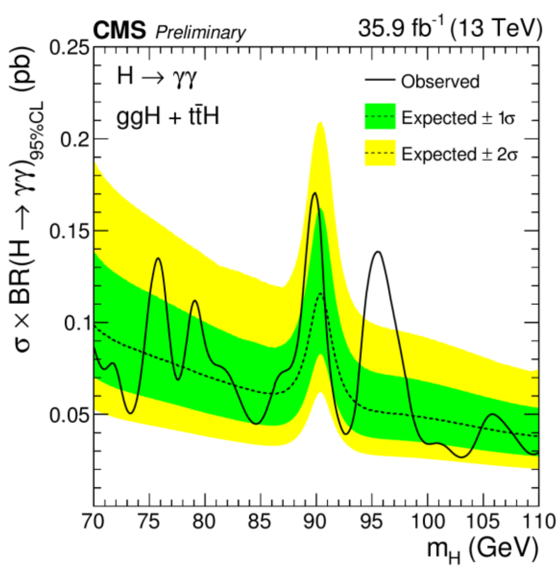
Recherche de *h* → γγ à Basse Masse

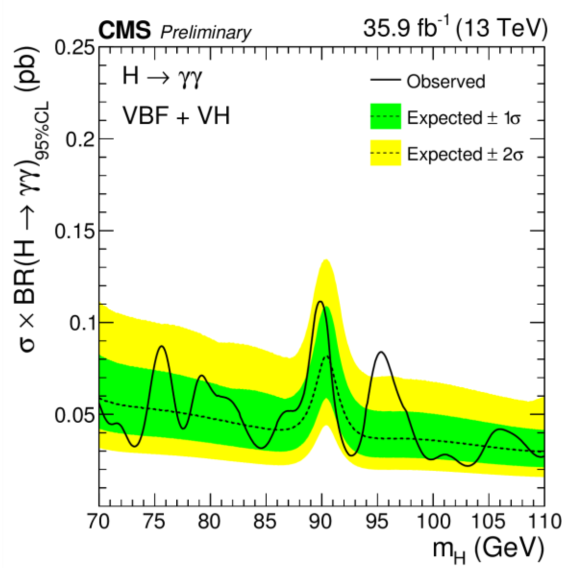


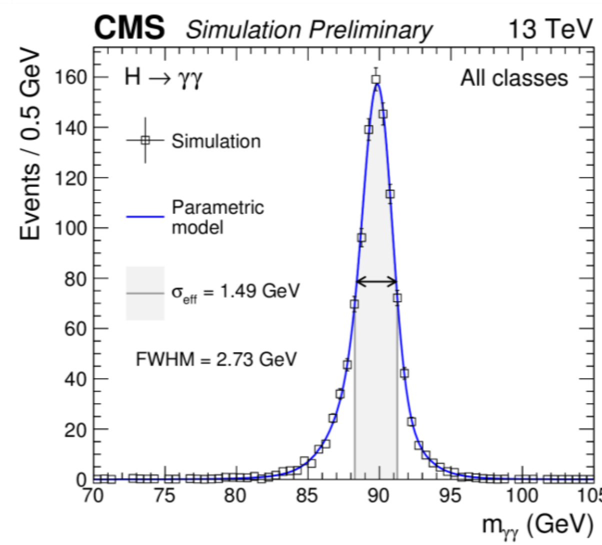




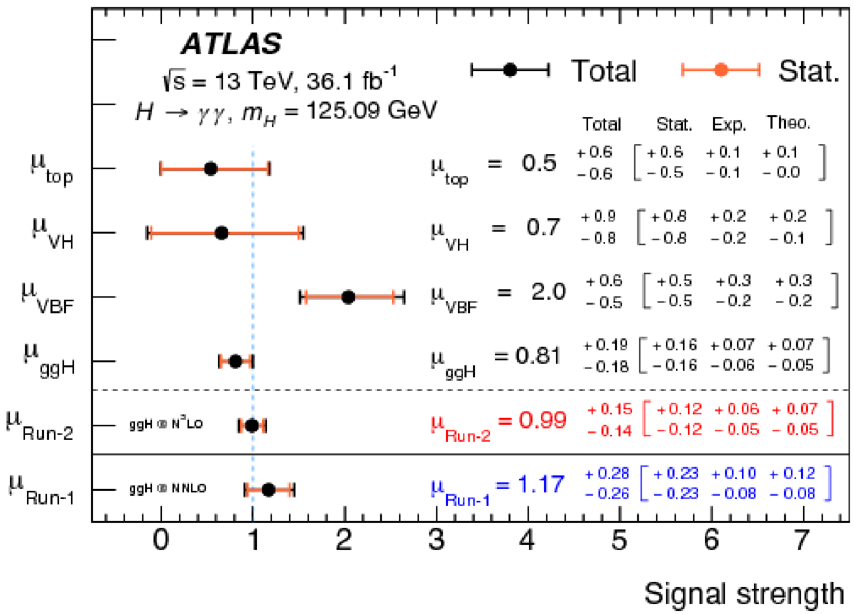
CMS-PAS-HIG-17-013



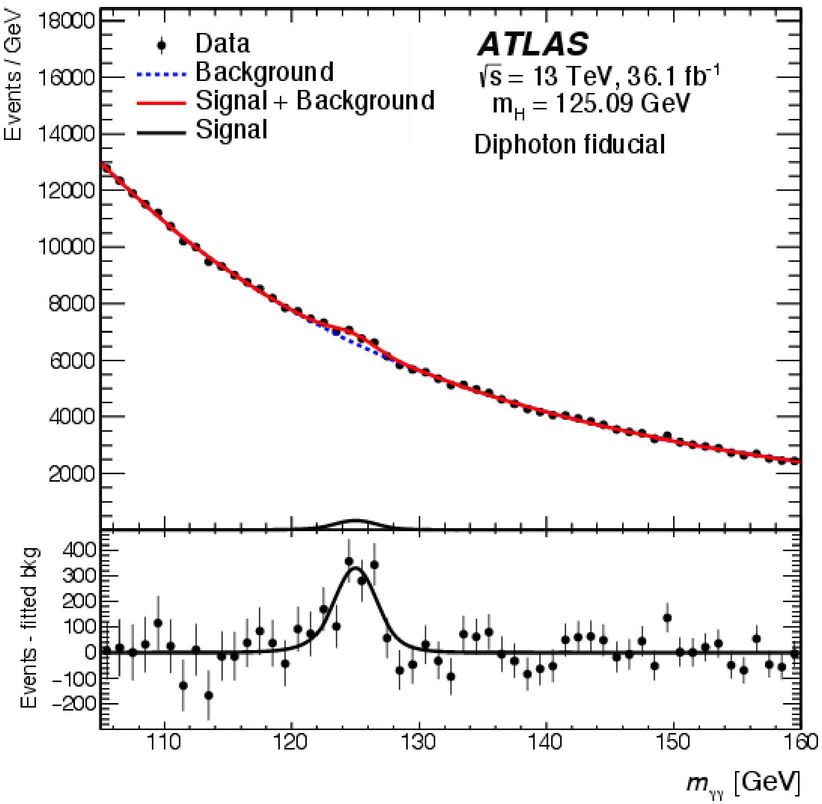




H→ γγ à ATLAS



arXiv:1802.04146



Signal and Background Events

Event Class	Expected SM-like Higgs boson signal $m_{\mathrm{H}} = 90\,\mathrm{GeV}$, $\sqrt{s} = 8\,\mathrm{TeV}$								Bkg (GeV^{-1})
	Total	ggH	VBF	WH	ZH	$\mathrm{t\bar{t}H}$	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

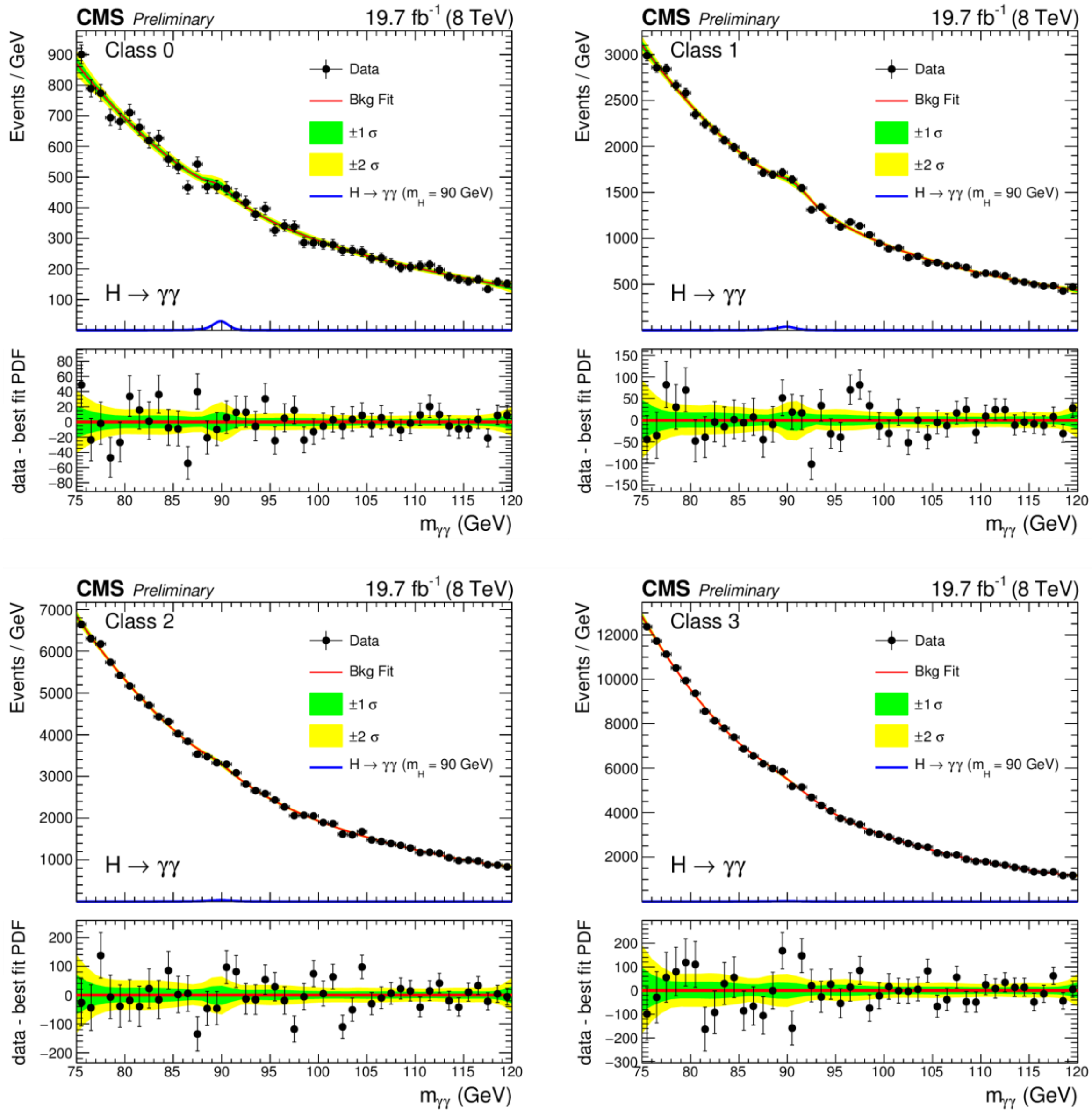
Event Class	Expected SM-like Higgs boson signal $m_{\mathrm{H}} = 90\,\mathrm{GeV}$, $\sqrt{s} = 13\,\mathrm{TeV}$								Bkg (GeV^{-1})
	Total	ggH	VBF	WH	ZH	$\mathrm{t\bar{t}H}$	σ_{eff}	σ_{HM}	
0	456.8	80.1 %	9.7 %	4.9 %	2.8 %	2.5 %	1.11	0.96	1870.6
1	394.9	90.1 %	4.1 %	3.2 %	1.7 %	0.9 %	1.69	1.45	3876.1
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

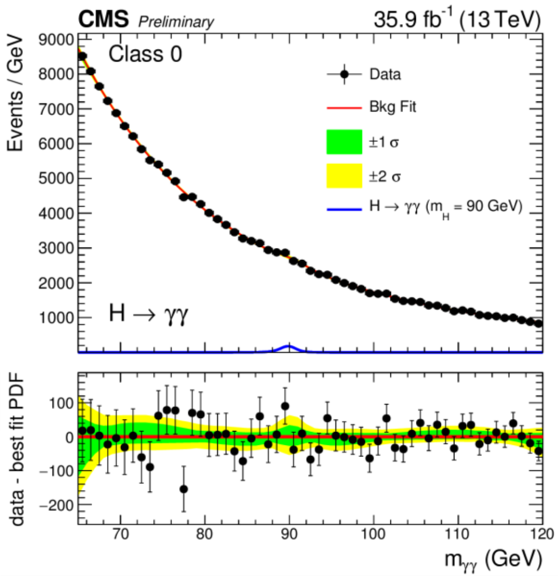


CLASS 2

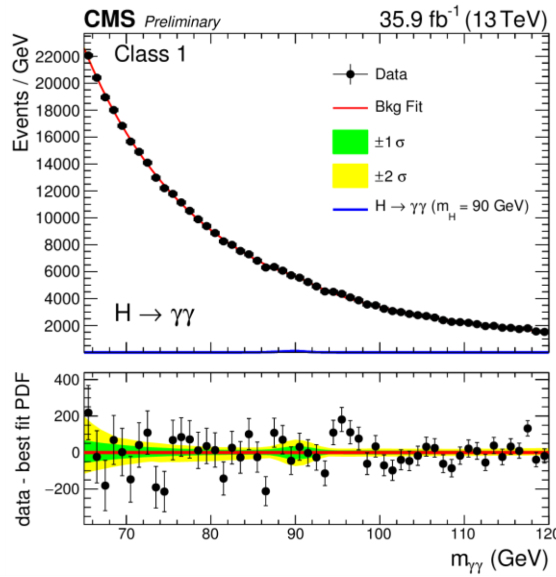
CLASS 3

Mass Spectra (13 TeV)

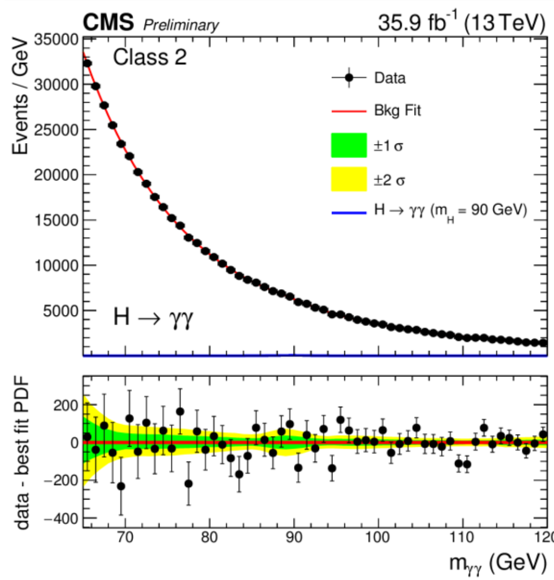
CLASS 0



CLASS 1



CLASS 2



Mass Resolution