Search for additional scalars with two photons in the final state at CMS

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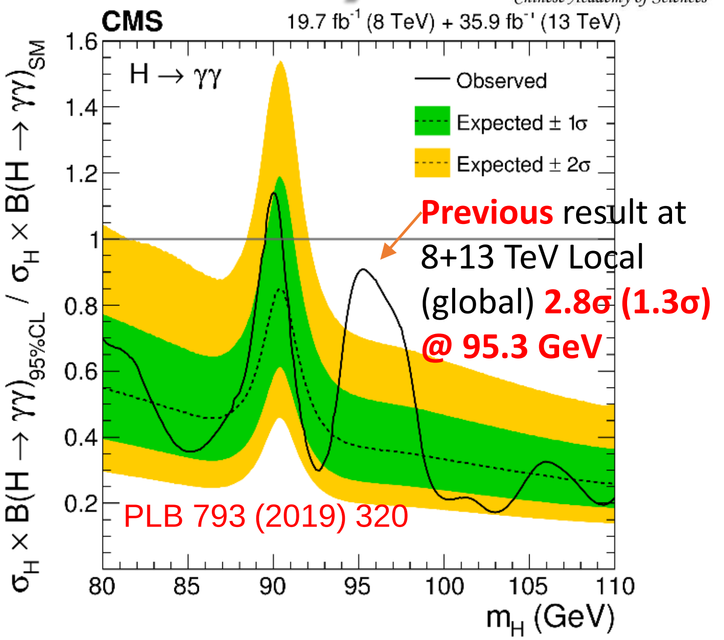
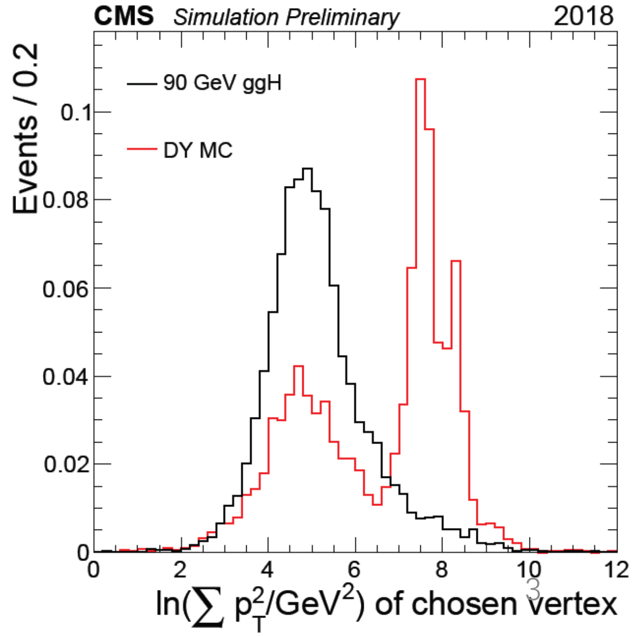
Introduction

- Although the Higgs boson discovered at LHC so for is compatible with the SM Higgs boson, there is still room for BSM
- Many **BSM models** (e.g. NMSSM, 2HDM, Georgi-Machacek model) provide a Higgs boson that is compatible with the LHC observed 125 GeV boson, and additional Higgs bosons or (pseudo-)scalars
- **Discovery of additional scalars would be an unequivocal sign of new physics**
- In this talk, CMS latest results of the searches for **additional scalars** with **at least two photons included in the final states** will be included and presented
  - ✓ **Direct search for a SM-like low-mass Higgs boson with H→γγ (70 GeV<m_H<110 GeV)** CMS-PAS-HIG-20-002
  - ✓ **Exotic decays of Higgs boson with the new scalar (a/A) decaying into diphoton**
    - **H→Za→ll + γγ** : CMS-PAS-HIG-22-003
    - **H→aa/AA→γγγγ : resolved** (CMS-PAS-HIG-21-003, arXiv:2208.01469) and **boosted** (CMS-PAS-HIG-21-016, arXiv:2209.06197)
  - ✓ **Search for high-mass exclusive diphoton production with tagged protons** CMS-PAS-EXO-21-007
- All using **full LHC Run 2 data**!

SM-like H→γγ (70 GeV<m_H<110 GeV)

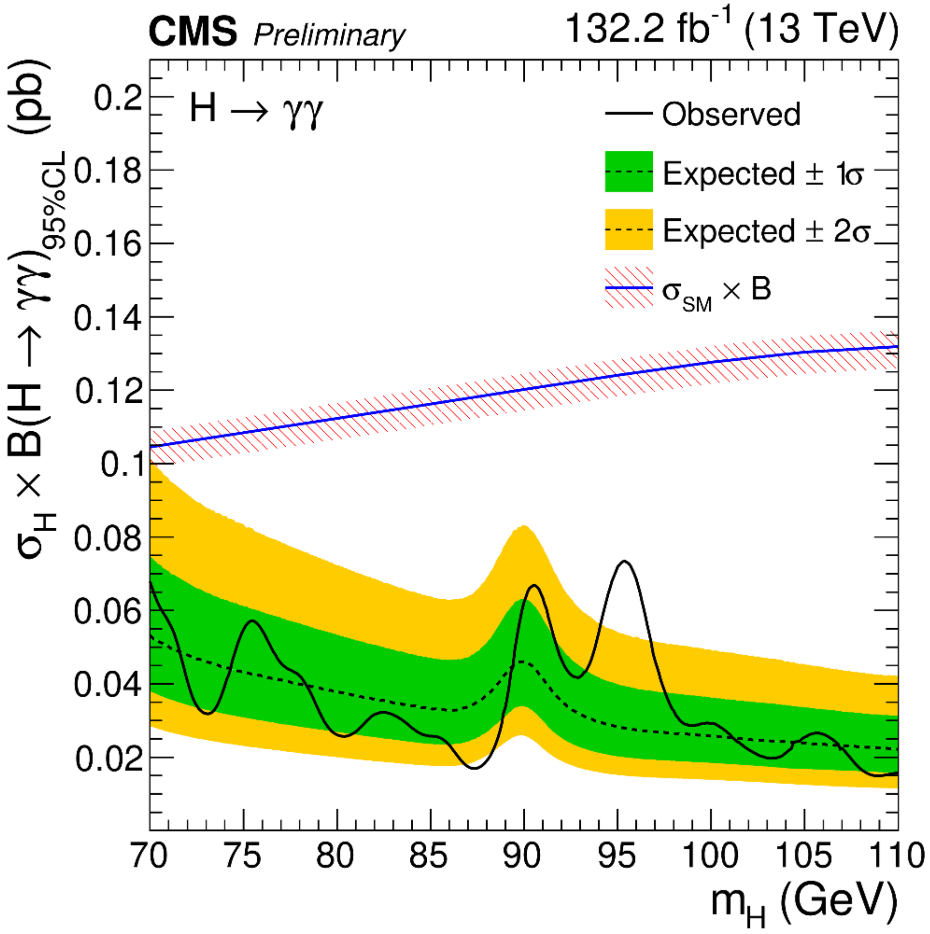
- Similarly as the SM H(125), a clean final-state topology that allows the **mass** of a Higgs boson to be reconstructed with **high precision**
  - ✓ search for narrow signal peak over smoothly-falling background (direct γγ , γ + jet, jet+jet processes) except for relic Z→ee
- **Production modes:** SM-like, so gluon fusion (ggH), vector boson fusion (VBF), in association with a W or Z boson (VH), or with a ttbar pair (ttH)
  - ✓ Cross sections and BR : LHC Higgs XS Working Group YR4
- **Data samples**: full Run2 132.2 fb^{-1} data
  - ✓ lost ~5 fb^{-1} as HLT path was absent from start of 2018 data-taking
- **Major changes** wrt prior version (PLB 793 (2019) 320) (2012+2016 data):
  - A kinematic **event selection BDT** ($p_t/m_{\gamma\gamma}$, η , cos(ϕ1−ϕ2), both Photon ID BDT outputs, mass resolution wrt correct and incorrect vertices, vertex probability) **retrained and reoptimized** for event categorization for low-mass case
  - Electron/**relic Z→ee veto** (based on pixel detector hits) reinforced with:
    - Rejection of photon candidates also reconstructed as electrons
    - Maximum value of ln ($\Sigma p_T^2/GeV^2$)[tracks in chosen vertex] as function of $p_{T\gamma\gamma}$
  - 2017/18: events with additional jets selected for class targeting **VBF process**
  - 2016: data reanalyzed with **improved calibration** (legacy data)





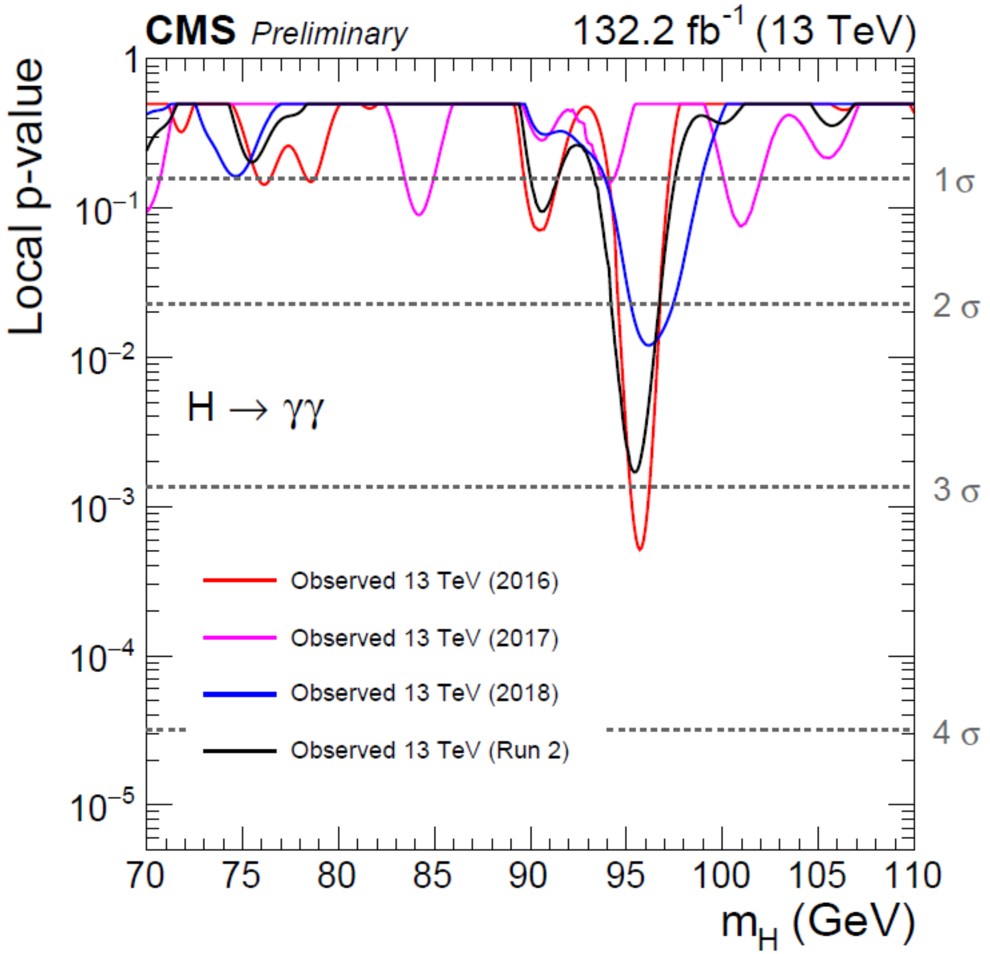
SM-like H→γγ (70 GeV<m_H<110 GeV)

- **Observed absolute 95% CL upper limit (UL) on σ X B** between **15-73 fb** (22-53 fb expected)



CMS-PAS-HIG-20-002

- **Observed local p-values** for 2016, 2017, 2018 and combination



- **Modest excess with ~2.9σ local (1.3σ global) significance at $m_{\gamma\gamma}$=95.4 GeV, need more data for a definitive conclusion!**

SM-like H→γγ (70 GeV<m_H<110 GeV)

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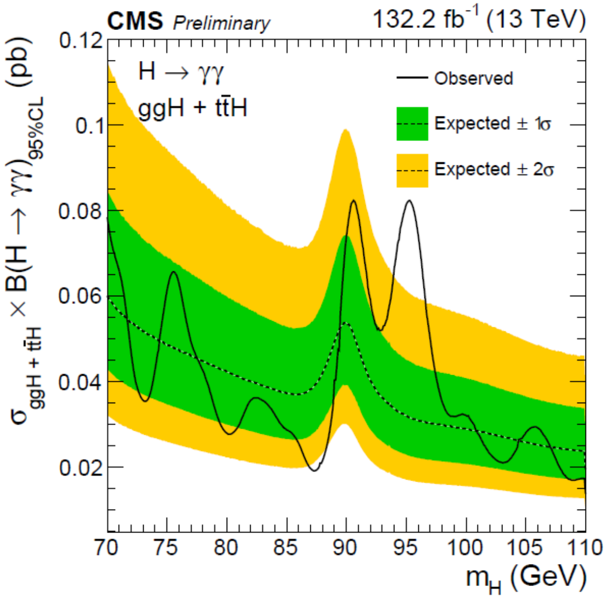
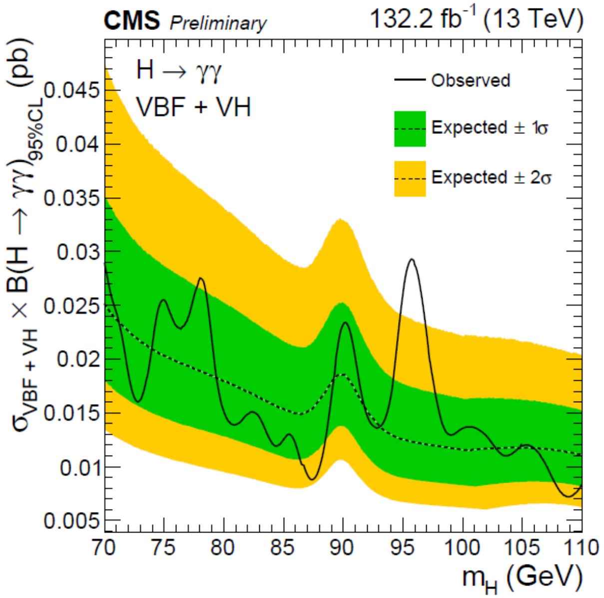
➢ Observed and expected 95% CL UL on σ X B by production process (integrated over all event classes)



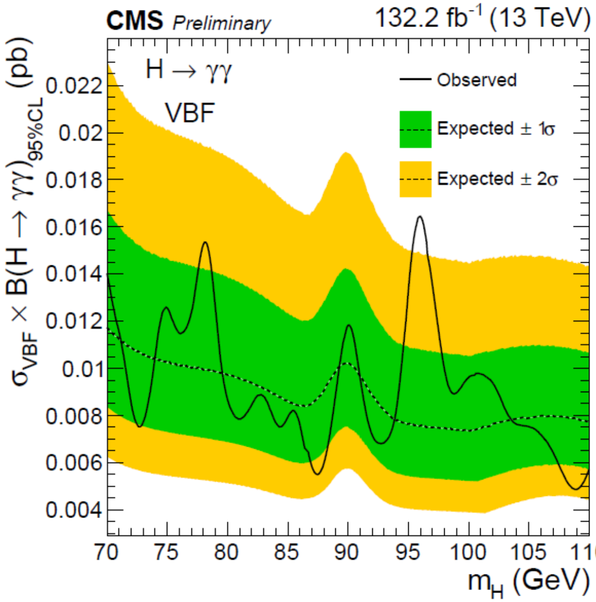
- 100% production via gluon-induced processes (**ggH, ttbarH** in SM proportions)

17-83 fb observed



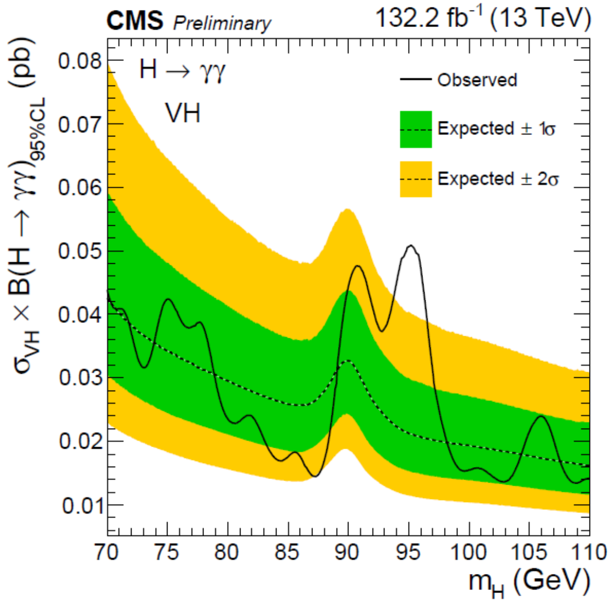
- 100% production via fermion-induced processes (**VBF, VH** in SM proportions)

7-29 fb observed



- 100% production via **VBF**

5-17 fb observed



- 100% production via **VH**

13-51 fb observed

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More interpretation results will be public in near future

SM-like H→γγ (70 GeV<m_H<110 GeV)

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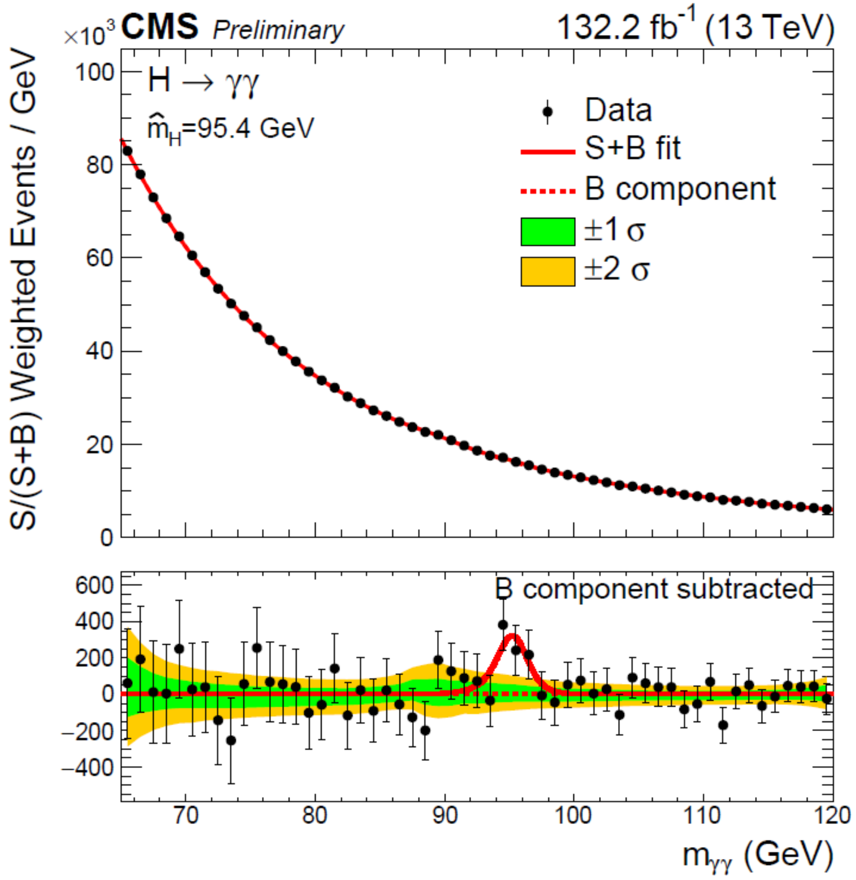
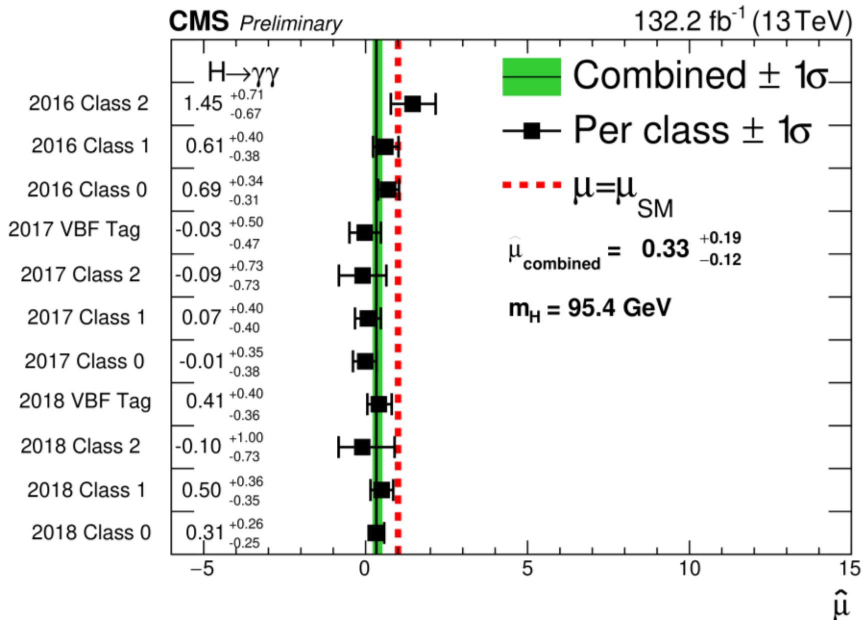
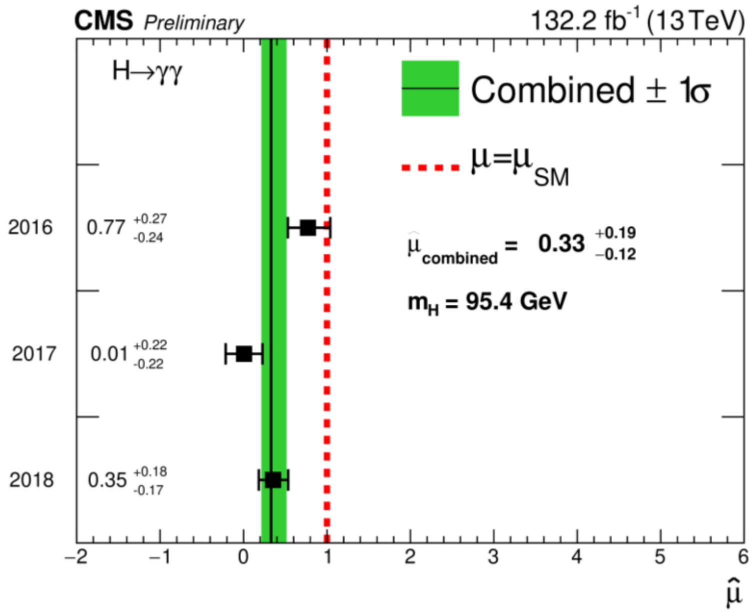
- **S/(S+B)-weighted** $m_{\gamma\gamma}$ distribution with S+B fit for **m_H=95.4 GeV**



- **'Signal' strengths μ fixing m_H=95.4 GeV**



- for the 11 event classes : χ^2 compatibility probability: 68%



- for the 3 years χ^2 compatibility probability: 6%

CMS-PAS-HIG-20-002

First search for new diphoton resonances in this mass range with full LHC Run 2 data!

H→Za→ll + γγ

CMS-PAS-HIG-22-003

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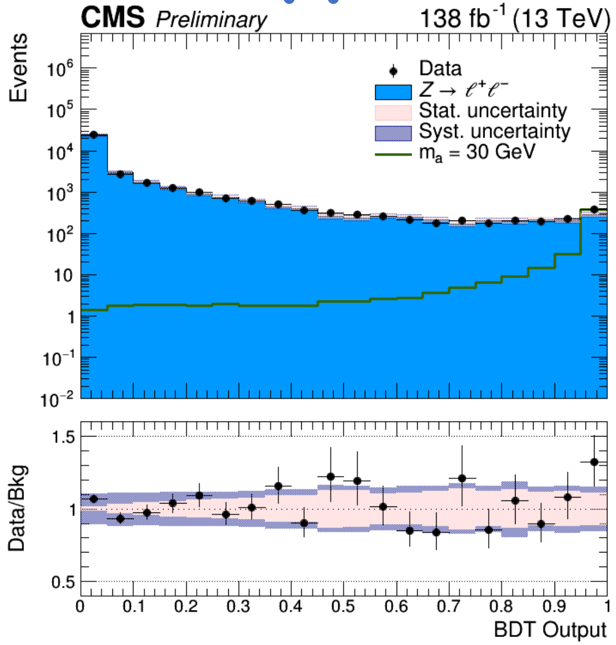
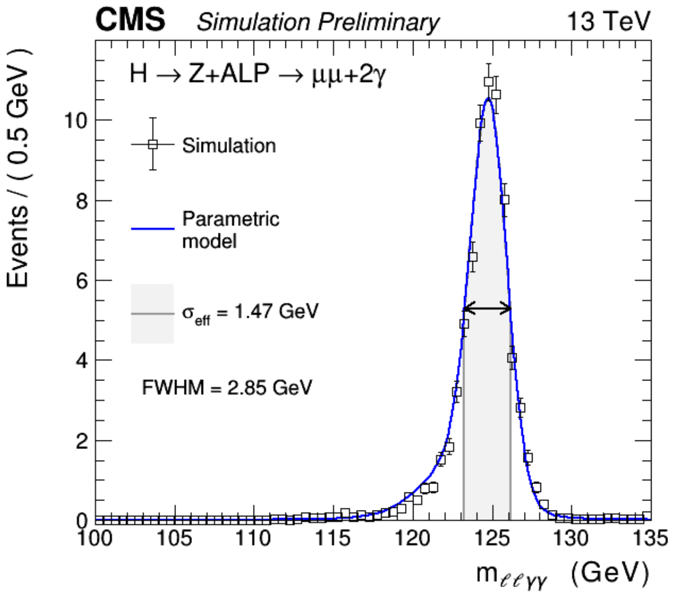
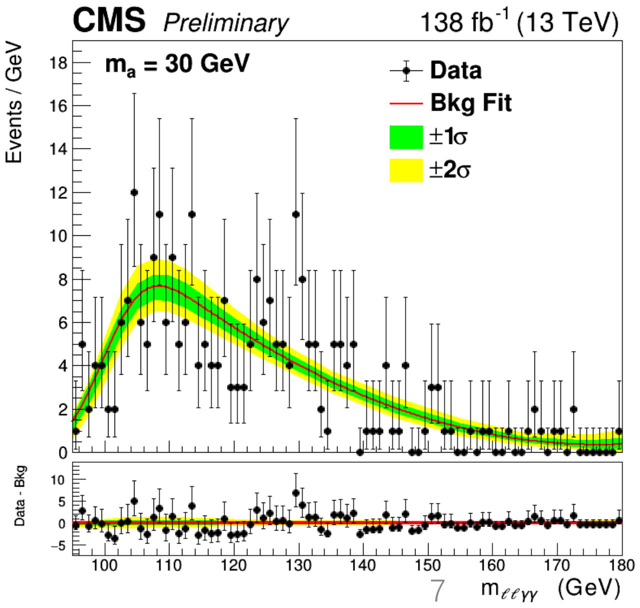
- **Two photon resolved** case with $m_a \in [1, 30]$ GeV
- Developed **dedicated photon ID** by removing $\sigma_{i\eta i\eta}$ and PF Photon Isolation from official cut-based photon ID
- Trained an **event BDT** for event categorization to improve the sensitivity
- Use **llγγ invariant mass** (90-180GeV) spectrum to extract signal in data
- Signal $m_{ll\gamma\gamma}$ shape is modeled using a sum of Gaussians
  - ✓ $m_{ll\gamma\gamma}$ shape taken from the nearest nominal mass hypothesis
  - ✓ normalization interpolated between two nearest nominal mass hypotheses
- Bkg modeling : **data from three years merged** to build background model
  - ✓ Turn-on component included
  - ✓ Unique background model built for each m(a)
- **Statistical uncertainties dominate**



m_a (GeV)	Min. BDT output value	Signal efficiency	Background yields
1	0.955	0.492	83.2 ± 27.3
2	0.980	0.669	26.4 ± 10.3
3	0.985	0.763	7.89 ± 4.87
4	0.980	0.842	5.06 ± 4.50
5	0.985	0.849	5.12 ± 3.92
6	0.990	0.817	2.49 ± 2.24
7	0.985	0.860	5.26 ± 3.98
8	0.990	0.799	11.4 ± 4.78
9	0.990	0.784	15.5 ± 5.60
10	0.990	0.771	10.8 ± 4.65
15	0.990	0.701	13.4 ± 5.23
20	0.990	0.626	18.4 ± 6.12
25	0.985	0.644	36.6 ± 10.5
30	0.980	0.674	43.6 ± 13.2

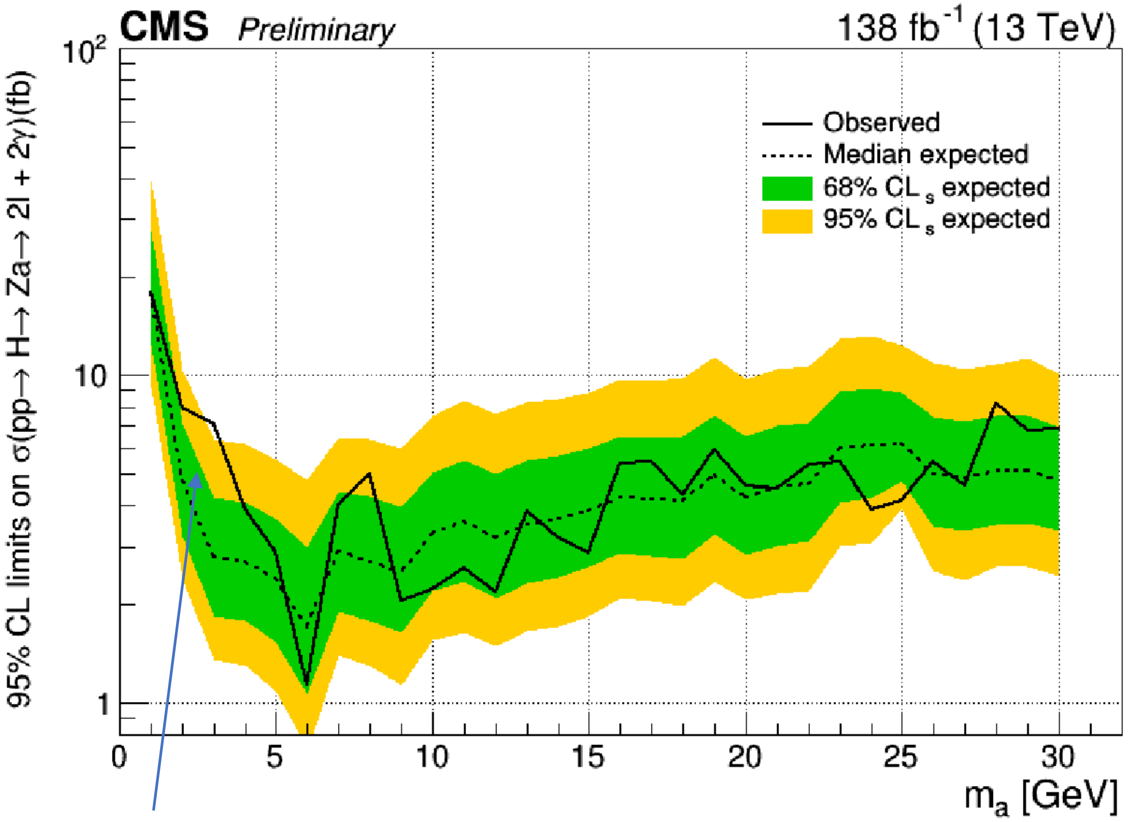




H→Za→ll + γγ

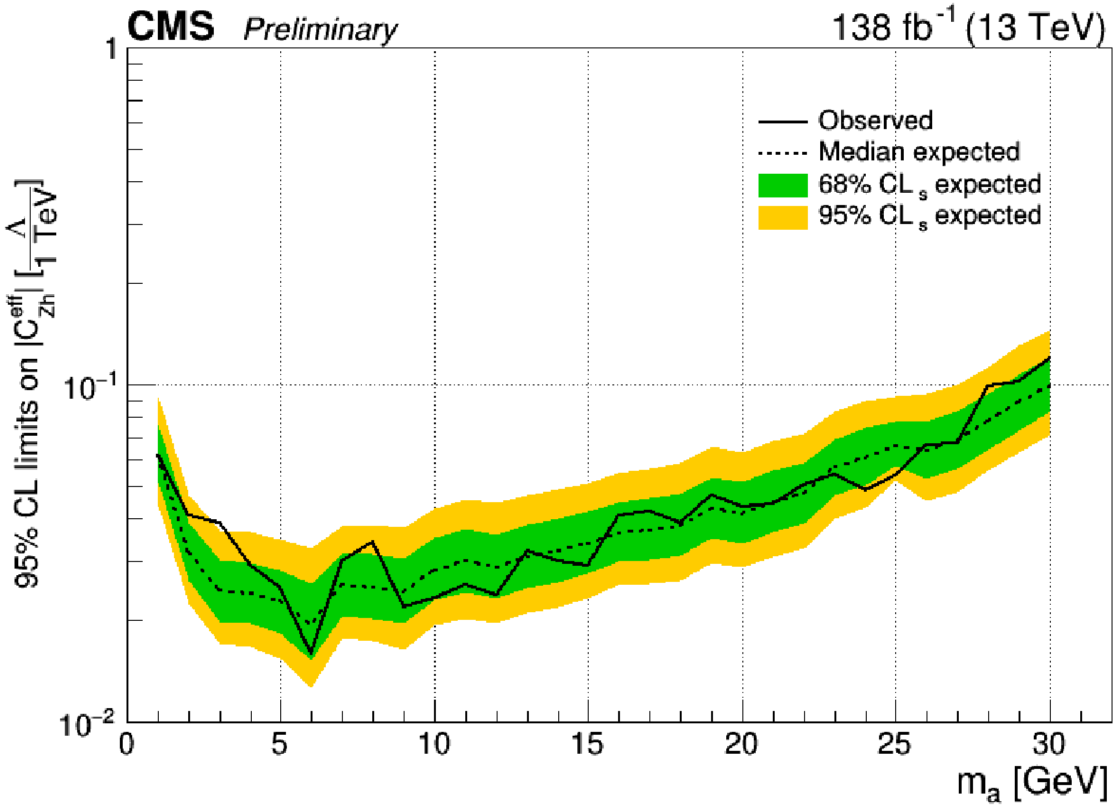
CMS-PAS-HIG-22-003

- 95% CL upper limits on σ(pp→H)×B(H→Za→ℓℓγγ) : **4.7-17.8** (6.9-17.9) **fb** observed (expected)



2.6(1.3)σ local (global) significance at m_a=3 GeV

- **Result is also interpreted within ALP model : 95% CL UL on the Wilson coefficient, C_{ZH}^{eff}/Λ**, the effective coupling parameter of the Higgs boson, the Z boson, and the ALP, and Λ is the new physics scale (assuming BR(a→γγ)=1)

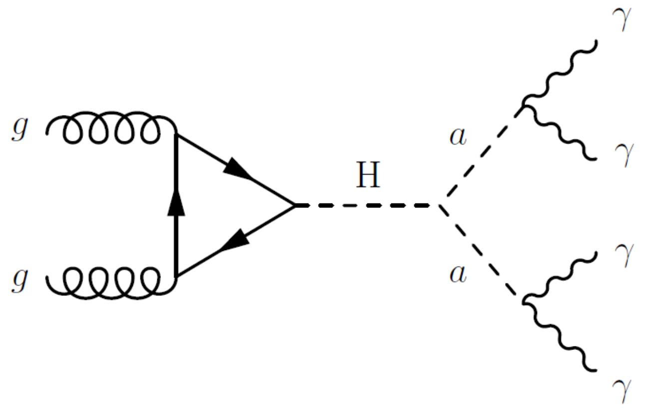


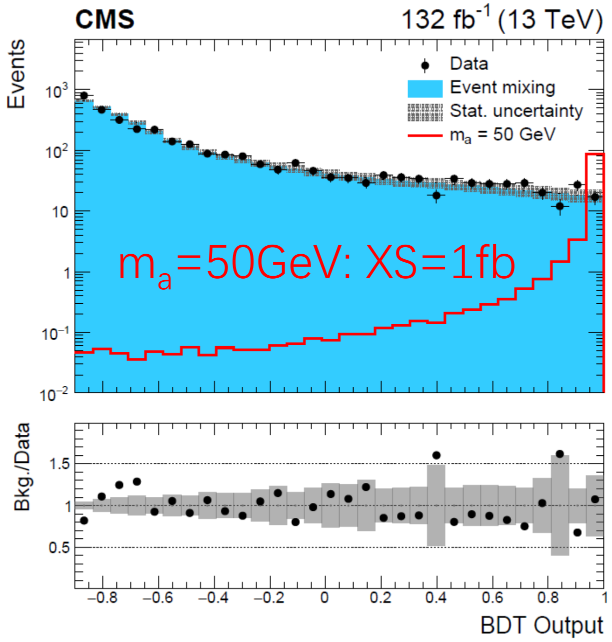
First LHC result in the H→Za→llγγ final state

H→aa→γγγγ resolved

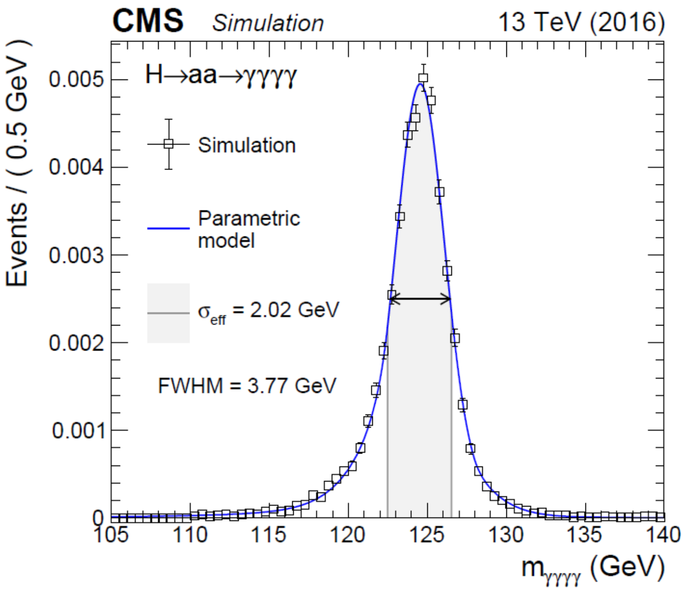
CMS-PAS-HIG-21-003
arXiv:2208.01469

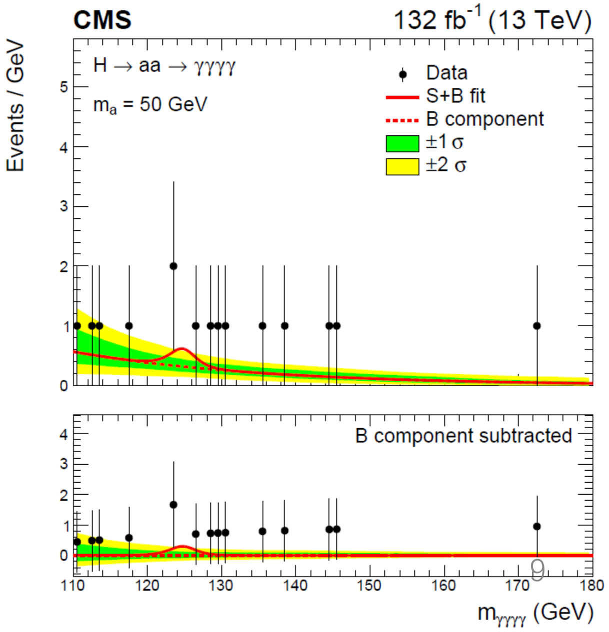
- Probes pseudoscalar masses (m_a) in the range **15-62 GeV**
- **Four well-isolated photons** in the final state
- A dedicated **primary vertex (PV) BDT** is trained on simulated H→aa→γγγγ events, to select PV with highest BDT score
- To improve the sensitivity, a **4-photon event classifier** is trained to separate sig events from bkg events: **a single category** optimized based on the BDT output, for each **m_a**
- An unbinned maximum likelihood fit of the signal and background models to the **observed $m_{\gamma\gamma\gamma\gamma}$ distribution** in data (100-180 GeV), to extract signal
  - ✓ Sig modeled by a double-sided Crystal Ball (CB) function, for each m_a
  - ✓ Bkg modeling : discrete profiling method





m_a=15 GeV





H→aa→γγγγ resolved

- **Analysis sensitivity is primarily limited by the expected signal event yields**
  - ✓ **Impact of other systematic uncertainties** on the expected limit is about **1%** across the m_a range

Table 2: Summary of the systematic uncertainties considered in this analysis.

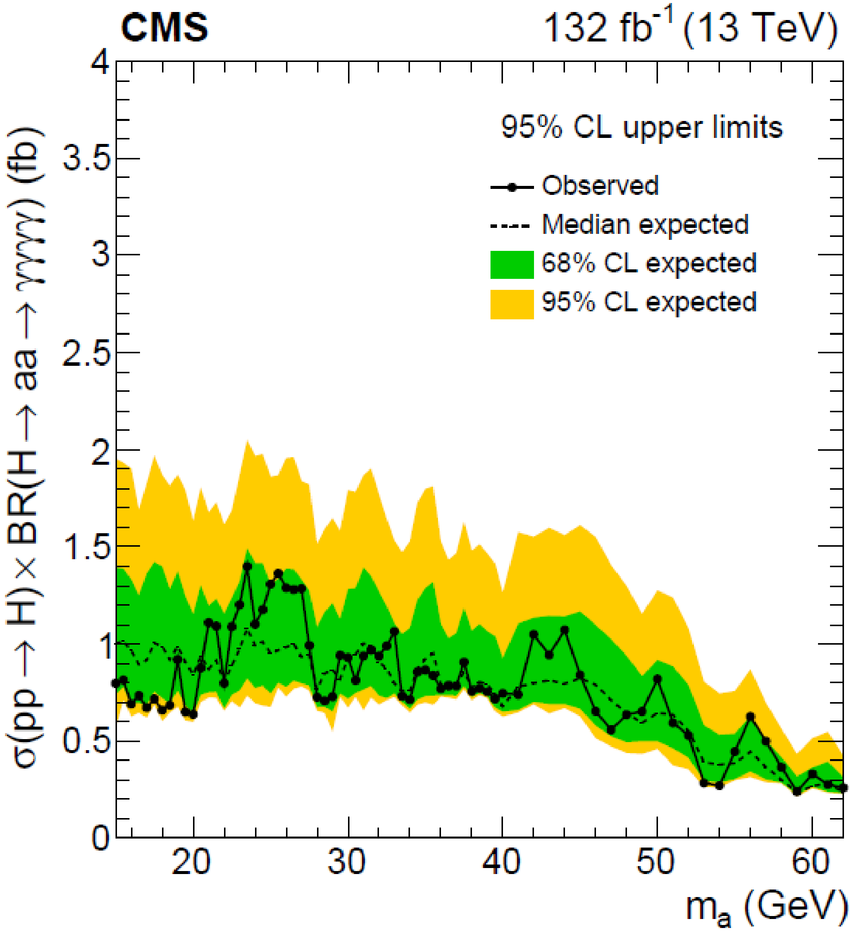
$m_{\gamma\gamma\gamma\gamma}$ distribution shape	2016–2018
Photon energy scale and resolution	0.05–0.15%
Nonlinearity of the photon energy scale	0.10%
Shower shape corrections	0.01–0.15%
Nonuniformity of light collection	0.07–0.25%
Modeling of material in front of the ECAL	0.02–0.05% (EB) and 0.24% (EE)

Signal model normalization	2016	2017	2018
Integrated luminosity	1.20%	2.30%	2.50%
Photon identification	0.25%	0.25%	0.25%
Trigger efficiency	0.50%	1.50%	0.50%
Photon preselections	5.00%	5.00%	5.00%

CMS-PAS-HIG-21-003
arXiv:2208.01469

First CMS search in this channel

- **No significant deviation** from the standard model expectation is observed
- **95% CL upper limit** $\sigma_H B(H \to aa \to \gamma\gamma\gamma\gamma)$: **0.26-0.80** (0.24-1.0) **fb** observed (exp.)

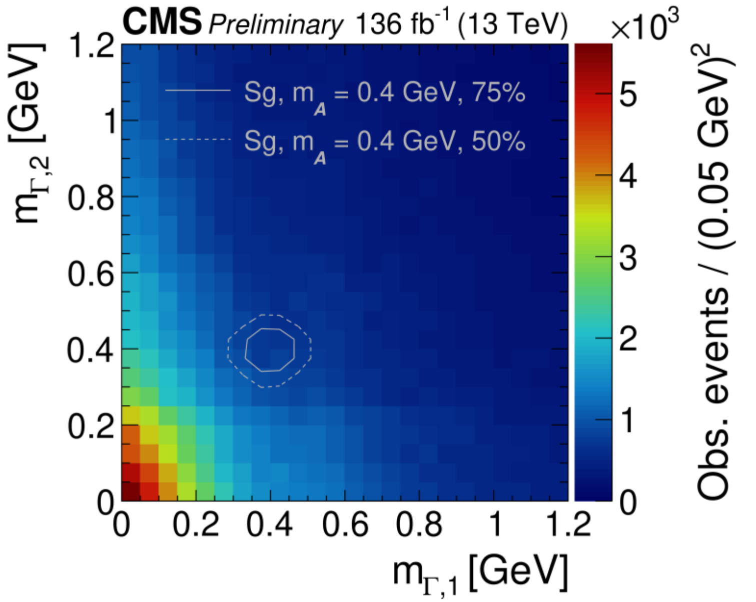


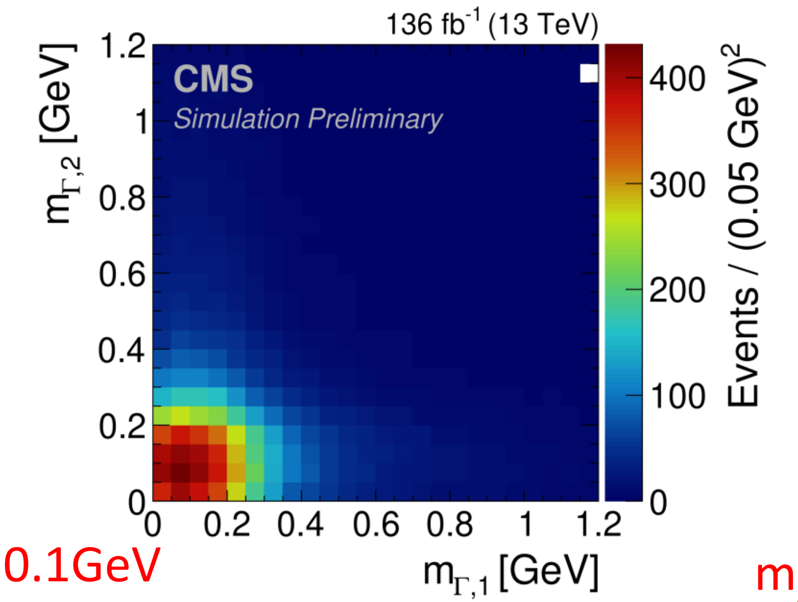
$H \rightarrow AA \rightarrow \gamma\gamma\gamma\gamma$ boosted

- **Search range of $m_A \in [0.1, 1.2]$ GeV**
- Two collimated γ reconstructed as single Γ: $110 < m_{\Gamma\Gamma} < 140$GeV
- Deep-learning used to reconstruct m_Γ of collimated di-γ
- Signal templates built in $m_{\Gamma 1}$ - $m_{\Gamma 2}$ plane
- Backgrounds
  - ✓ $H \rightarrow \gamma\gamma$ from MC
  - ✓ Prompt-diphoton and QCD/γ + j from **data in $m_{\Gamma\Gamma}$ sideband** regions (100-110 GeV and 140-180 GeV)

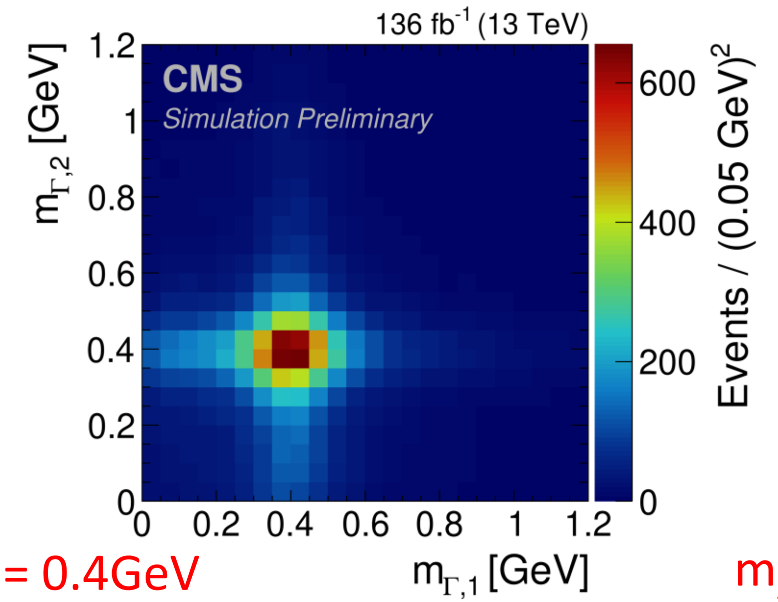
CMS-PAS-21-016,
arXiv:2209.06197

Observed data: 2D m_Γ

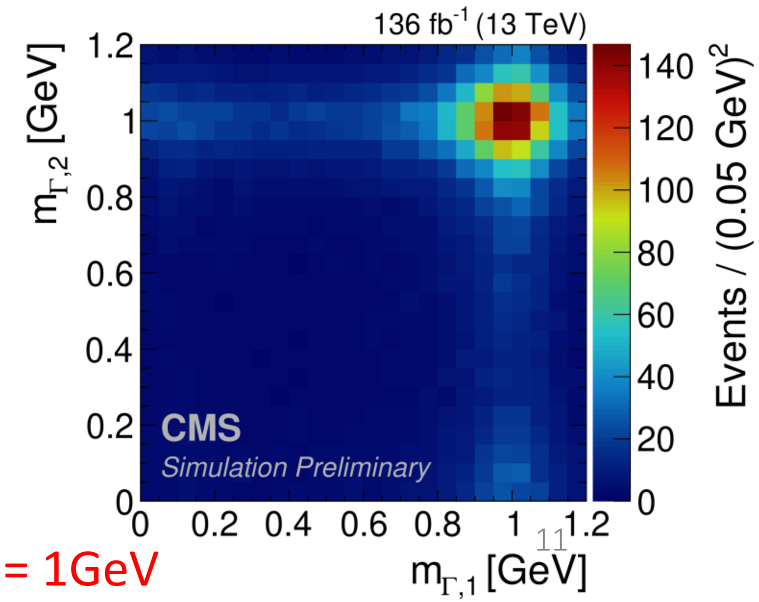




m_A = 0.1GeV



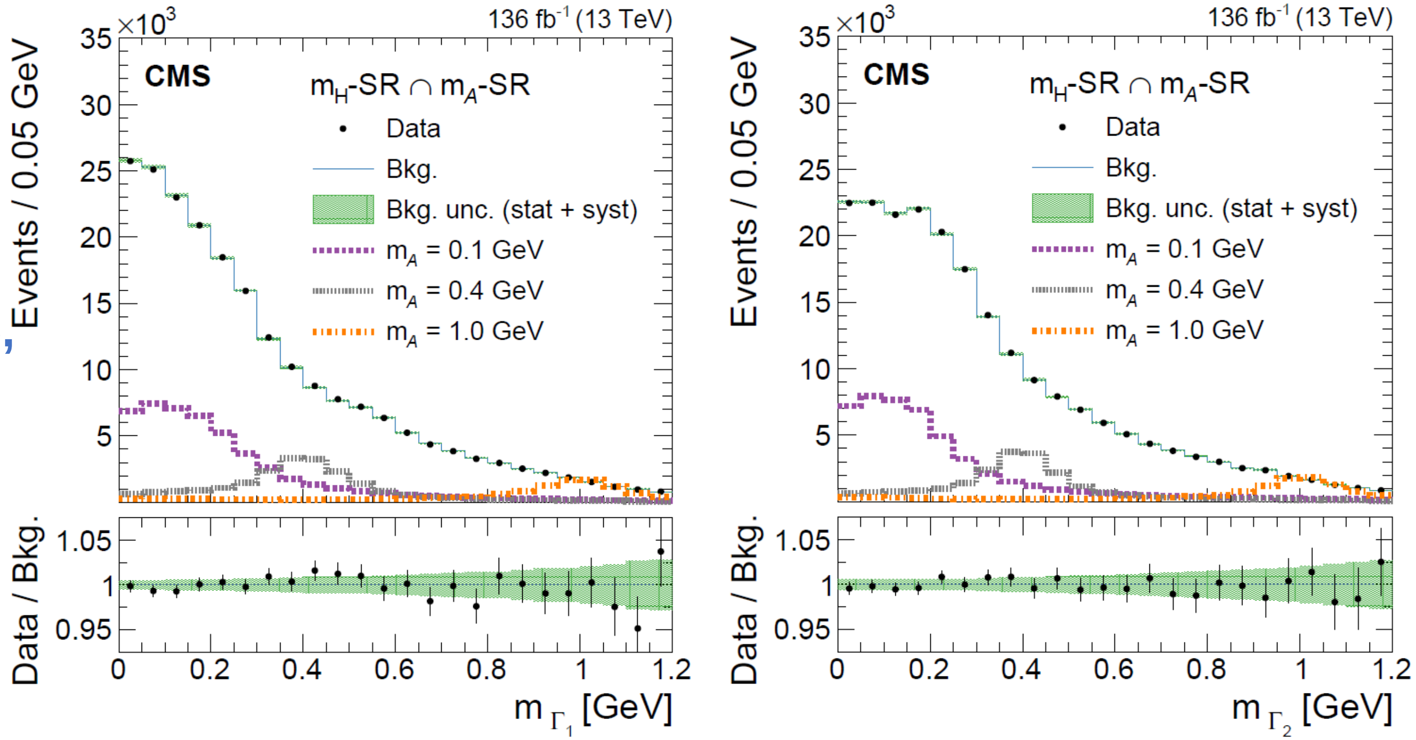
m_A = 0.4GeV



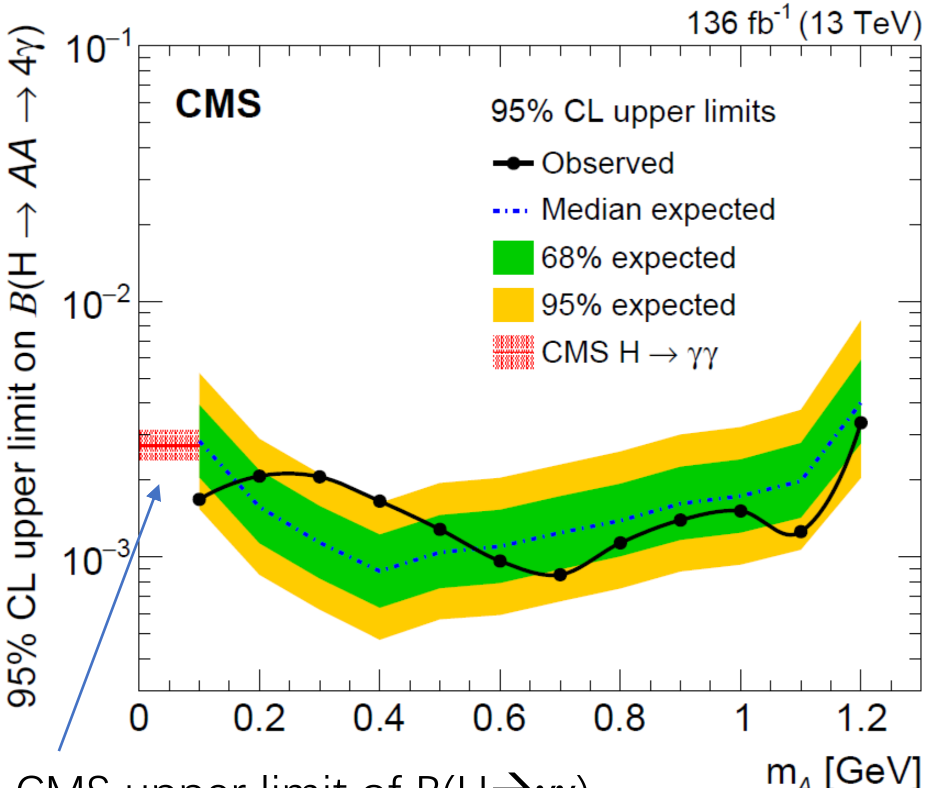
m_A = 1GeV

H→AA→γγγγ boosted

- No excess observed in μS + B fit in m_Γ distributions →



- Upper limits on the branching fraction $B(H \to AA \to 4\gamma)$ of **(0.9-3.3) × 10⁻³** at 95% CL **CMS-PAS-21-016,** [arXiv:2209.06197](https://arxiv.org/abs/2209.06197)



CMS upper limit of B(H→γγ)

- **Upper limit on B interpreted for long-lived A at m_A = 0.1 (0.4) GeV**
  - ✓ 1.6 (0.9) times the prompt-decay UL for $c\tau_0$ = 1 mm
  - ✓ 30 (3) times the prompt-decay UL for $c\tau_0$ = 10 mm

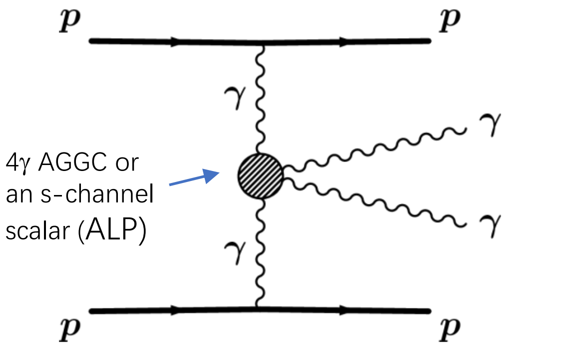
Best constraints for this decay mode in the studied m_A range

High-mass exclusive diphoton production

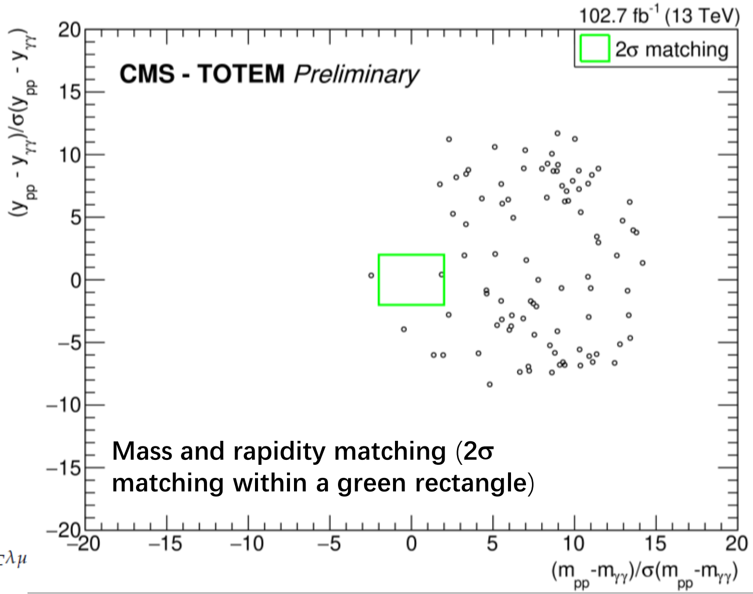
- To probe **4γ** Anomalous Quartic Gauge Coupling (aQGC) and search for a (pseudo-)scalar Axion-like particle (ALP)
- Events are selected: two high pT(>75/100GeV in 2016/17-18) photons that are back-to-back in azimuth and with a large $m_{\gamma\gamma}$(>350 GeV)
- To remove the bkg, the tagged final state protons are required to match the kinematics of the final state photons
- **No excess** is observed above the SM prediction
- Limits at 95% CL on the **4γ aQGC parameters** for $|\zeta_1| < 7.3\times10^{-14}$ GeV^{-4}, $|\zeta_2| < 1.5 \times 10^{-13}$ GeV^{-4} using an effective field theory: **strongest upper limit** on the anomalous 4γ coupling cross section $\sigma(pp \to p\gamma\gamma p|\xi_p \in \xi^{\mathrm{PPS}}) < 0.61$ fb
- ALPs are excluded in the mass range of 500 to 2000 GeV

Strongest limits on ALP production in this search range

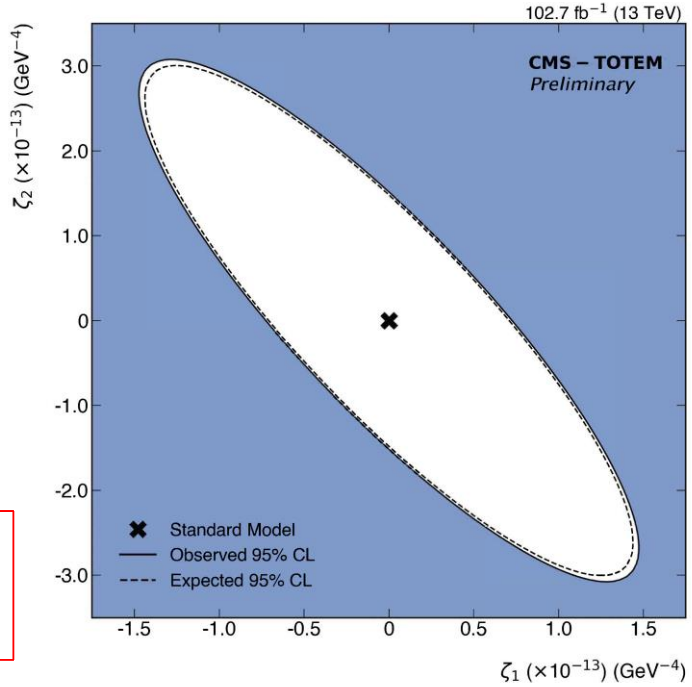
CMS-PAS-EXO-21-007

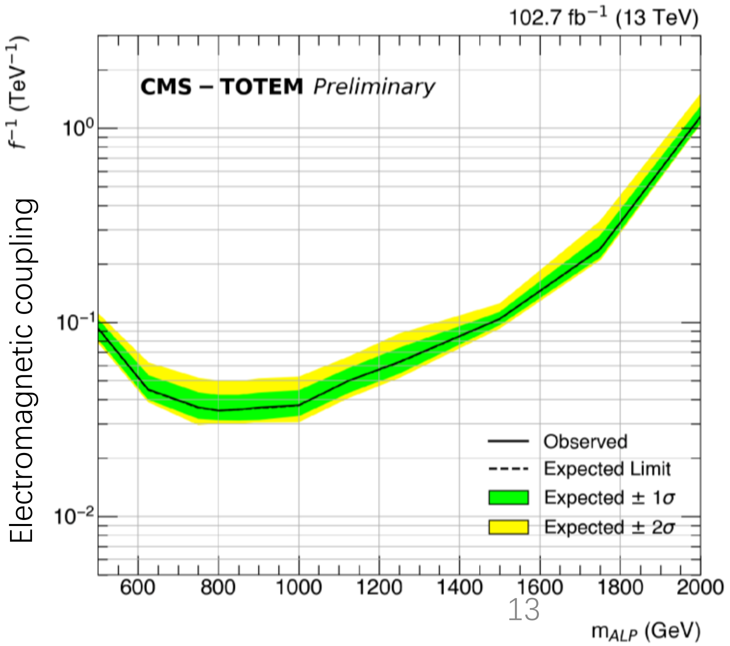


CMS+TOTEM Precision Proton Spectrometer (PPS)



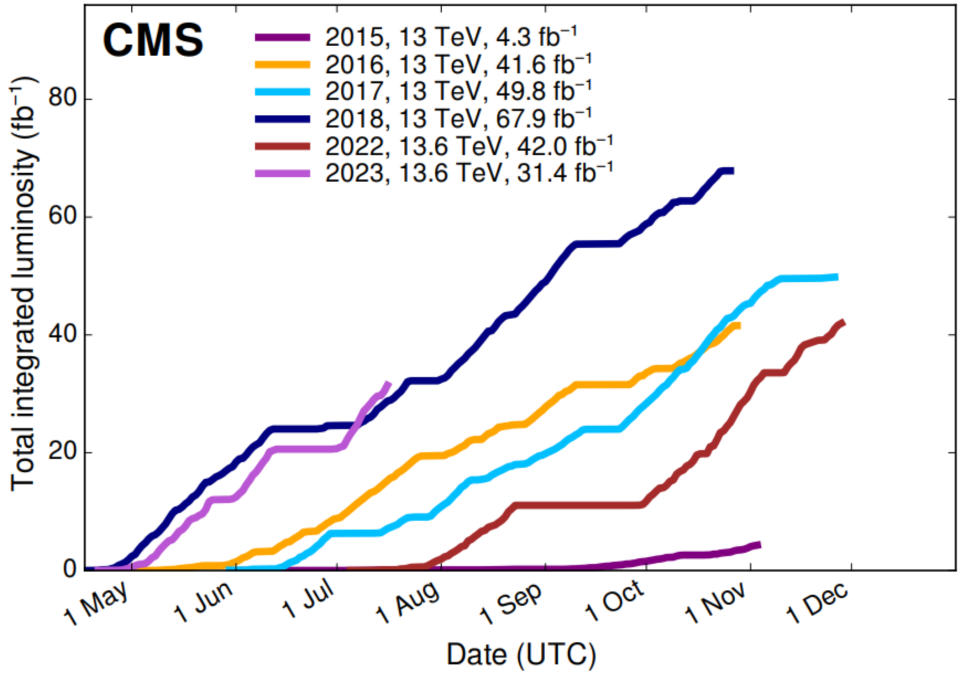
D8 operators $\mathcal{L}_{4\gamma} = \zeta_1 F_{\mu\nu}F^{\mu\nu}F_{\rho\sigma}F^{\rho\sigma} + \zeta_2 F_{\mu\nu}F^{\nu\rho}F_{\rho\lambda}F^{\lambda\mu}$





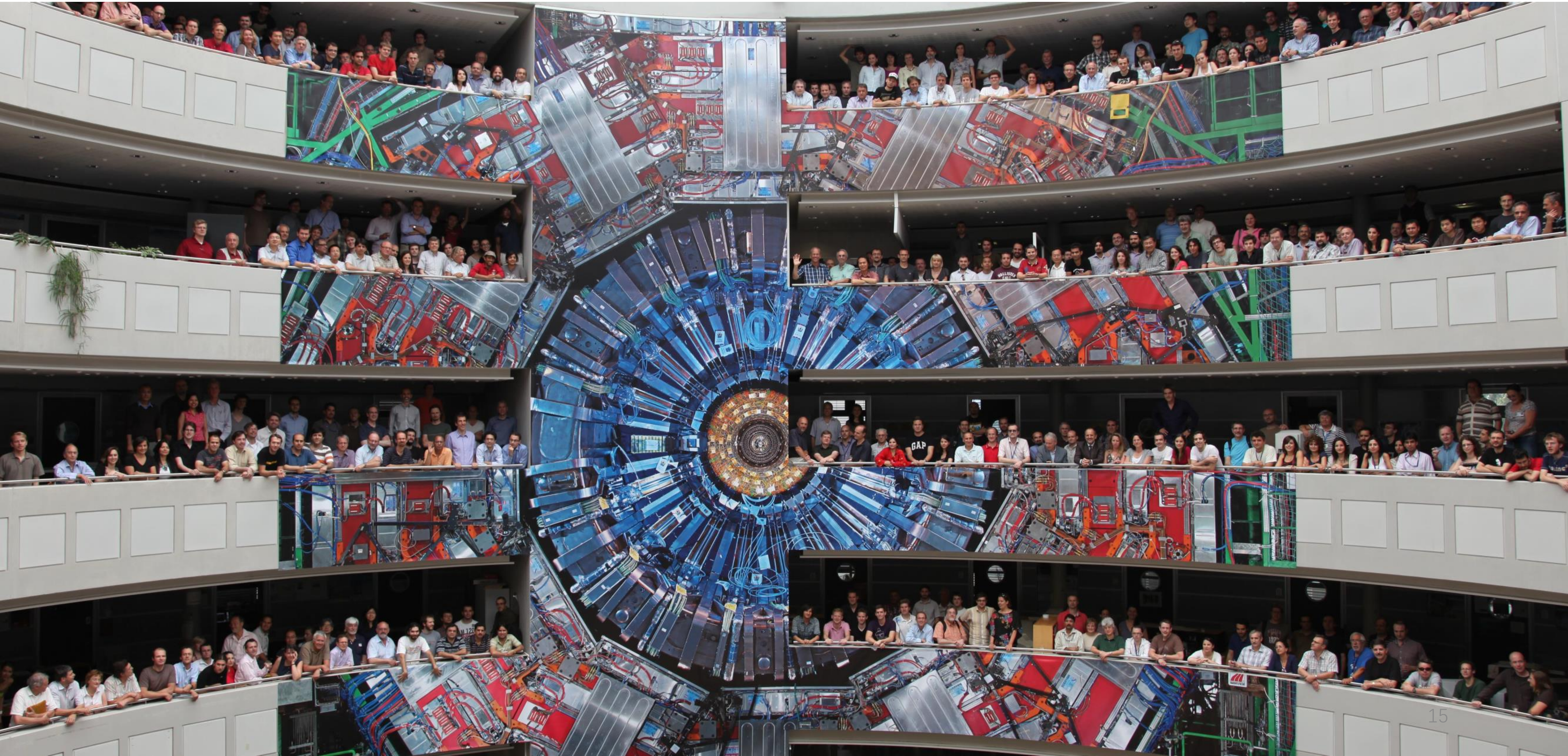
Summary

- CMS latest results of the searches for **additional scalars** with **at least two photons included** in the final states are presented
- **No evidence for the existence of extra scalars is found so far**
- **Low-mass H→γγ** (m_H∈[70, 110] GeV): modest **excess at $m_{\gamma\gamma}$=95.4 GeV with 2.9σ local** (1.3σ global) significance; more data is needed to conclude on the nature of this excess
- **H→Za→llγγ** (m_a ∈ [1, 30] GeV): **first LHC result** in the llγγ final state
- **H→aa→γγγγ resolved** (m_a ∈ [15, 62] GeV): **first CMS search** in this channel
- **H→AA→γγγγ boosted** (m_A ∈ [0.1, 1.2] GeV): **best constraints** for this decay mode in the studied m_A range
- **pp→γγ+pp** (possible ALP with m_A ∈ [500, 2000] GeV) : **strongest limits** on ALP production in the search range
- More (Run3) data are coming … **stay tuned!**



https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

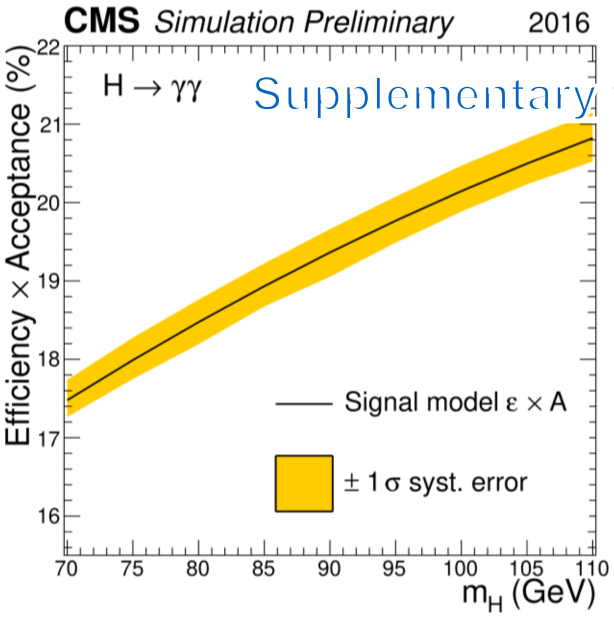
Thanks for your attention!



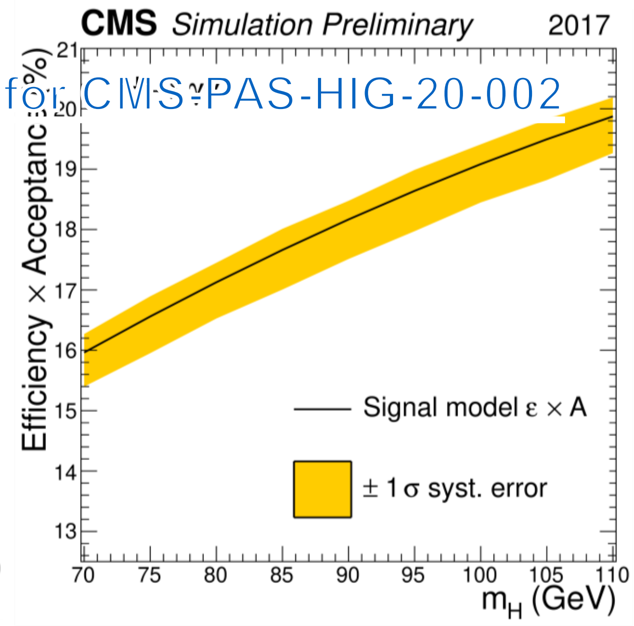
Backup slides

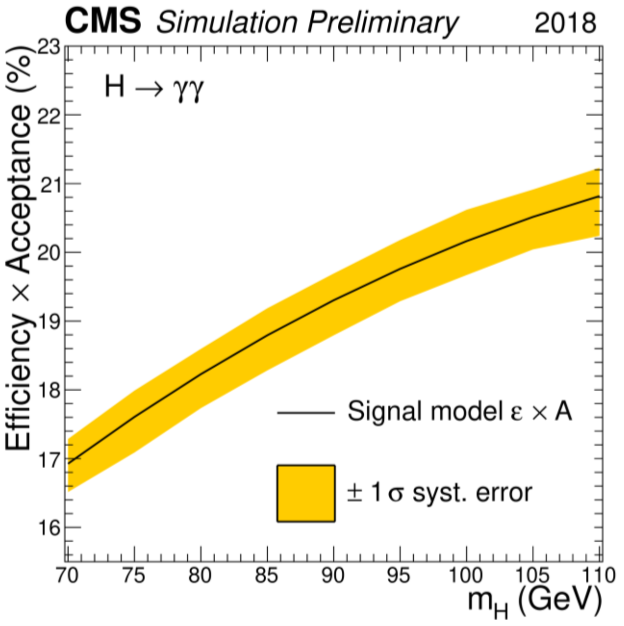
HIG-20-002: Signal efficiency and parametric shapes

- **Signal efficiency x acceptance** as a function of mass hypothesis
  - ✓ Different selections for 3 years i.e. trigger, offline selections etc
  - ✓ 1σ systematic error band is also shown

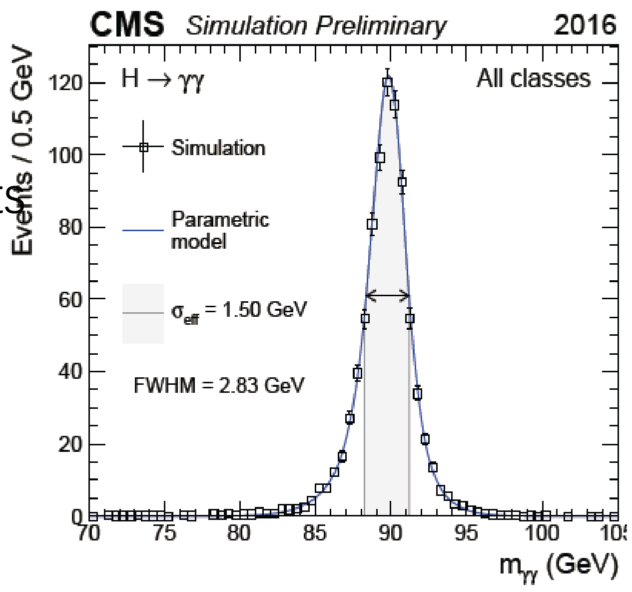


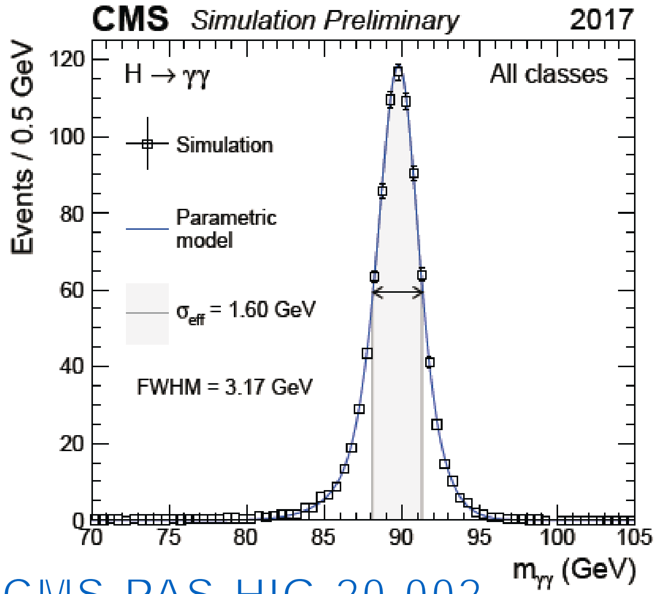
Supplementary for CMS-PAS-HIG-20-002

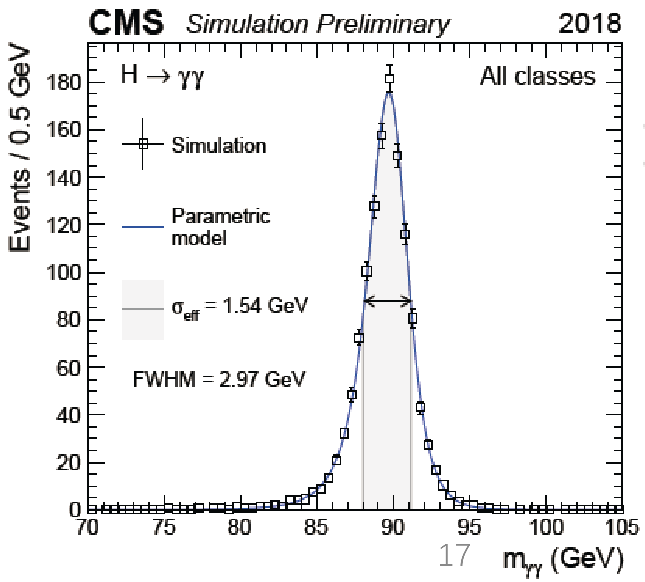




- Full parameterized signal shape, integrated over all event classes, in simulated signal events with m_H = 90 GeV
  - ✓ **Signal modeling** (sum of Gaussian functions): event classes x production modes x correct/incorrect vertex







CMS-PAS-HIG-20-002

HIG-20-002: bkg modeling

- **Background modeling** (discrete profiling): *sums of continuous functions* (different families/orders) with *DCB+exponential* (relic DY, normalization floating)

$$Nf \times Exp(x) + N(1-f)(DCB(x)+exp(x)) = Nf \times \sum_{i=0}^{...} \beta_{2i} e^{\beta_{2i+1}x} + N(1-f)(DCB(x)+exp(x))$$

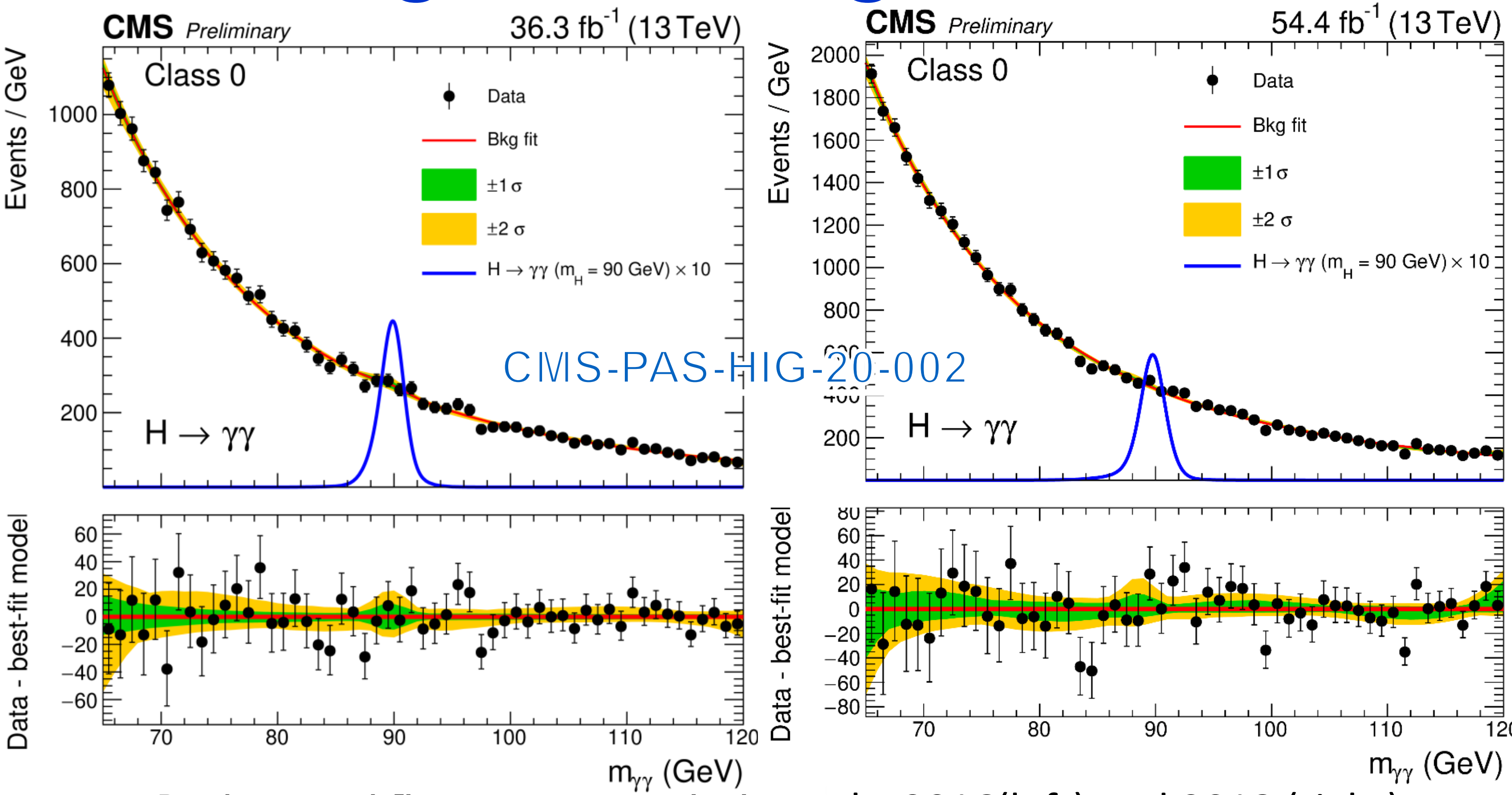
$$Nf \times Pow(x) + N(1-f)(DCB(x)+exp(x)) = Nf \times \sum_{i=0}^{M} \beta_{2i} x^{\beta_{2i+1}} + N(1-f)(DCB(x)+exp(x))$$

$$Nf \times Ber(x) + N(1-f)(DCB(x)+exp(x)) = Nf \times \sum_{i=0}^{M} \beta_i b_{i,M} + N(1-f)(DCB(x)+exp(x))$$

$$\text{with} \quad b_{i,M} = \binom{M}{i} x^i (1-x)^{M-i}$$

$$Nf \times Lau(x) + N(1-f)(DCB(x)+exp(x)) = Nf \sum_{i=0}^{M} \beta_i x^{-\alpha_i} + N(1-f)(DCB(x)+exp(x))$$

$$\text{with} \quad \alpha_i = 4,5,3,6,2,7,... \quad \text{for} \quad i = 0,1,2,3,4,5,...$$



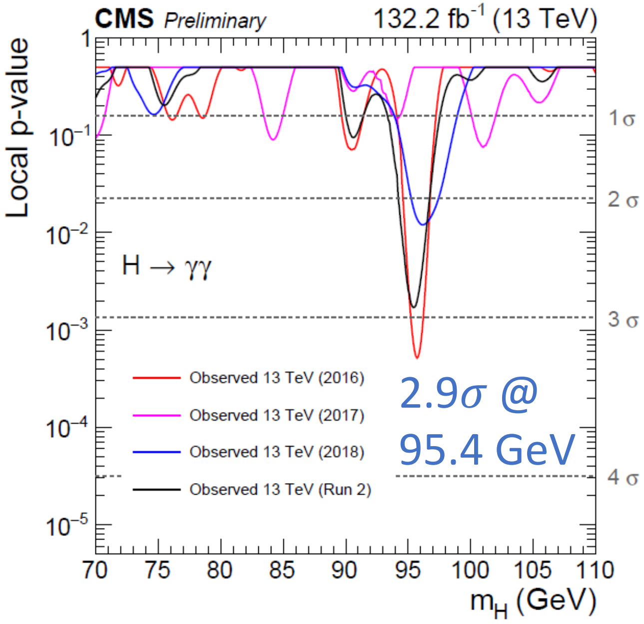
CMS-PAS-HIG-20-002

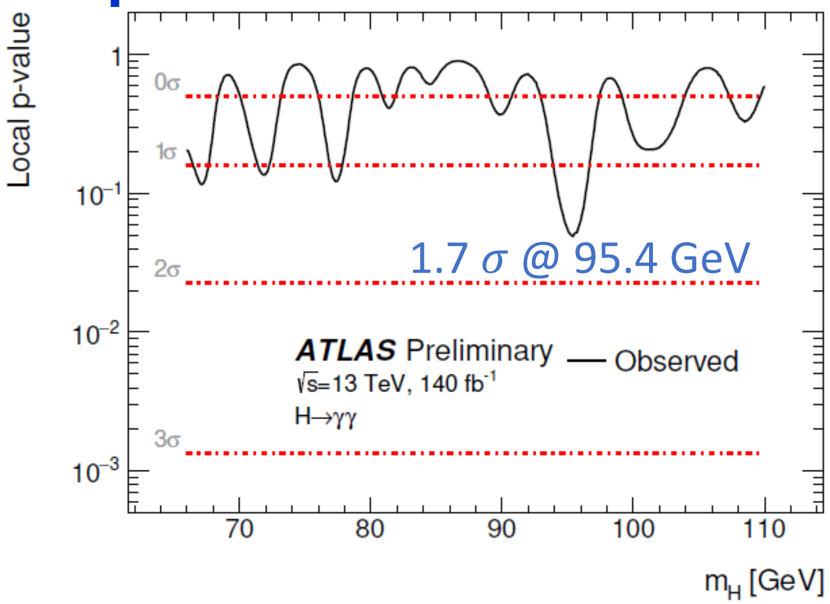
- Background fit, stat. uncertainties only, 2016(left) and 2018 (right)

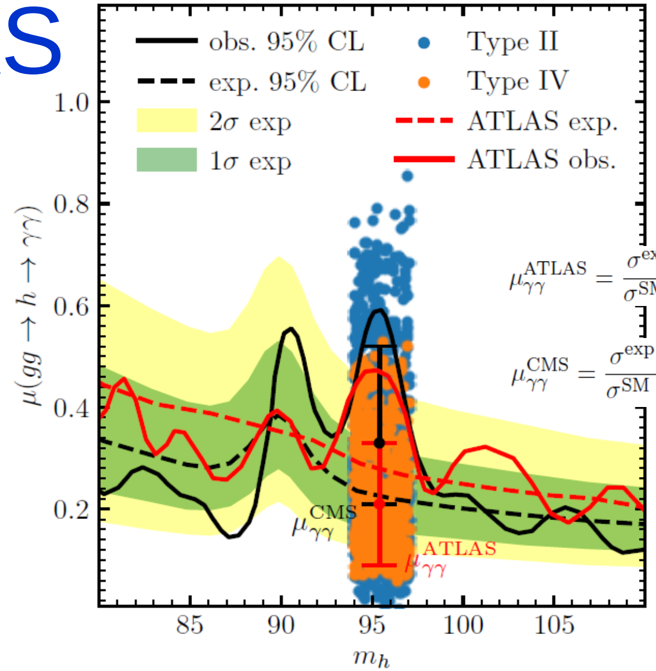
Best-fit background functions w/ DCB+exponential fractions (0.5% - 4.8%)

Event class		0	1	2	VBF
2016	Family/Order	Power Law 1	Bernstein 4	Exponential 3	
	DCB + Exp. Fraction (%)	3.0	3.1	3.3	
2017	Family/Order	Bernstein 3	Exponential 3	Bernstein 4	Bernstein 3
	DCB + Exp. Fraction (%)	2.7	1.4	1.9	2.6
2018	Family/Order	Laurent 1	Bernstein 4	Exponential 3	Bernstein 2
	DCB + Exp. Fraction (%)	0.5	4.1	4.8	0.8

HIG-20-002: comparison with ATLAS







Extension of the 2HDM by a complex singlet (S2HDM)

$$\mu_{\gamma\gamma}^{\text{ATLAS}} = \frac{\sigma^{\text{exp}}(gg \to \phi \to \gamma\gamma)}{\sigma^{\text{SM}}(gg \to H \to \gamma\gamma)} = 0.21^{+0.12}_{-0.12}$$

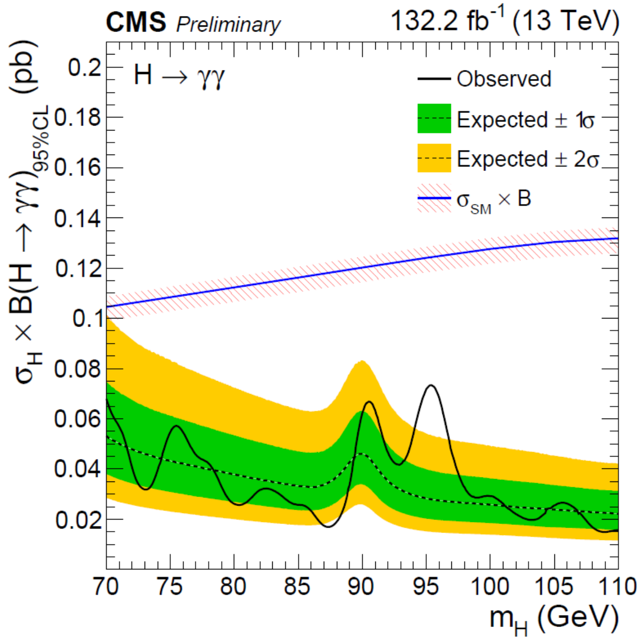
$$\mu_{\gamma\gamma}^{\text{CMS}} = \frac{\sigma^{\text{exp}}(gg \to \phi \to \gamma\gamma)}{\sigma^{\text{SM}}(gg \to H \to \gamma\gamma)} = 0.33^{+0.19}_{-0.12}$$

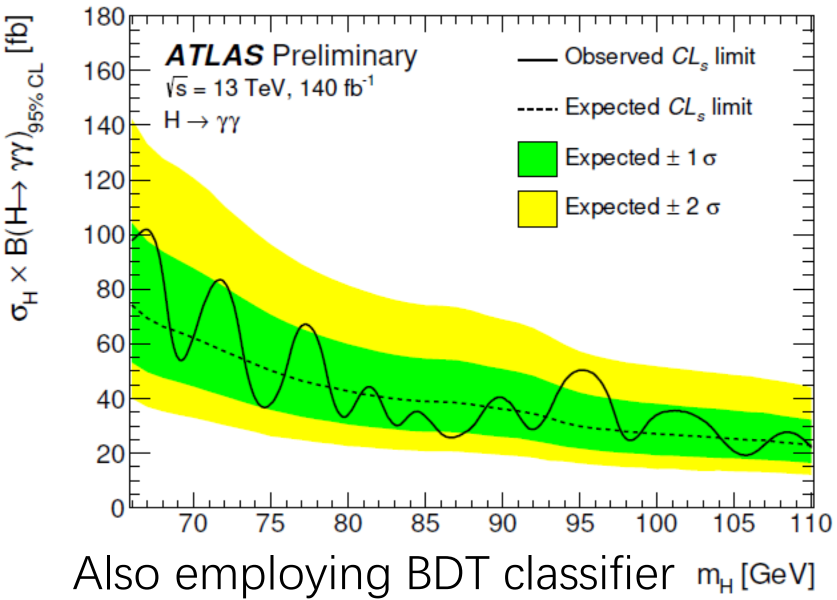
arXiv:2306.03889

CMS-PAS-HIG-20-002 (Moriond2023)

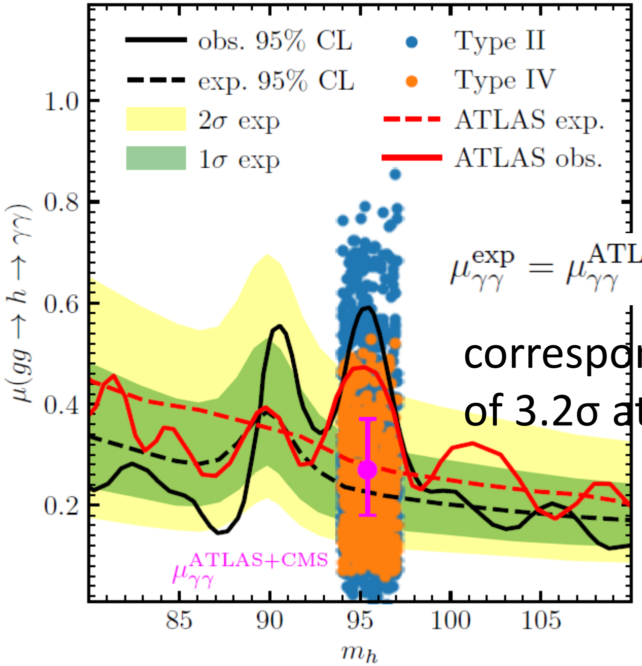
ATLAS-CONF-2023-035

June 6, 2023





Also employing BDT classifier



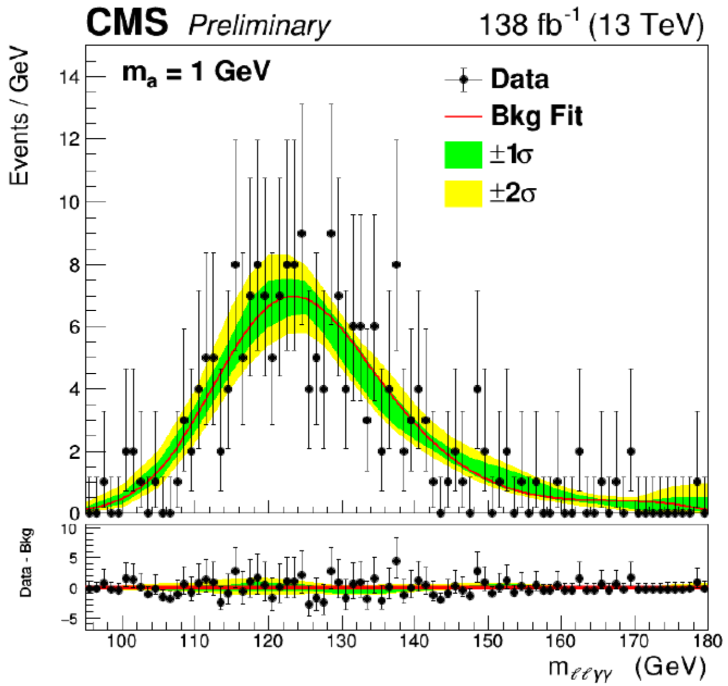
$$\mu_{\gamma\gamma}^{\text{exp}} = \mu_{\gamma\gamma}^{\text{ATLAS+CMS}} = 0.27^{+0.10}_{-0.09}$$

corresponding to an excess of 3.2σ at 95.4 GeV

$H \to Za \to ll + \gamma\gamma$

CMS-PAS-HIG-22-003

- **Selections**
  - ✓ Leptons: leading muon (electron) is required to have pT > 20 (25) GeV and the subleading one pT > 10 (15) GeV; $|\eta| < 2.5/2.4$ for e/μ
  - ✓ Photons: pT > 10 GeV, $|\eta|<2.5$
  - ✓ $\Delta R(l, \gamma) > 0.4$
  - ✓ $m_{ll} > 50$ GeV, 95 GeV < $m_{ll\gamma\gamma}$ < 180 GeV
  - ✓ Za candidate with m_{ll} closest to the nominal Z boson mass is chosen



- **Bkg modeling** : data from three years merged to build background model
  - ✓ Turn-on component included
  - ✓ Unique background model built for each m(a)

$$\mathcal{F}(m_{\ell\ell\gamma\gamma};\mu,\sigma,s,\vec{\alpha}) := \int_a^b \mathcal{N}(\mu,\sigma)(m_{\ell\ell\gamma\gamma}-t)f(t;\vec{\alpha})\Theta(s,t)$$

- N is a Gaussian function with mean m and standard deviation σ
- Θ is the Heaviside step function
- f is a falling spectrum functions : exponentials, Bernstein polynomials, Laurent series, and power-law functions

Table 2: Sources of systematic uncertainties and their magnitudes for each data taking period.

$m_{\ell\ell\gamma\gamma}$ distribution shape	2016	2017	2018
Photon energy scale	< 0.1%	< 0.1%	< 0.1%
Photon energy resolution	5.72%	3.45%	4.50%
Electron energy scale	< 0.1%	< 0.1%	< 0.1%
Electron energy resolution	11.90%	4.20%	4.90%
Muon energy scale	< 0.1%	< 0.1%	< 0.1%
Muon energy resolution	4.90%	4.4%	5.2%
Signal model normalization			
Integrated luminosity	1.2%	2.3%	2.5%
Pileup reweighting	2.9%	2.9%	2.5%
Photon efficiency	10.3%	10.0%	10.3%
Electron efficiency	1.7%	1.5%	1.6%
Muon efficiency	0.8%	0.5%	0.5%

H→aa→γγγγ resolved

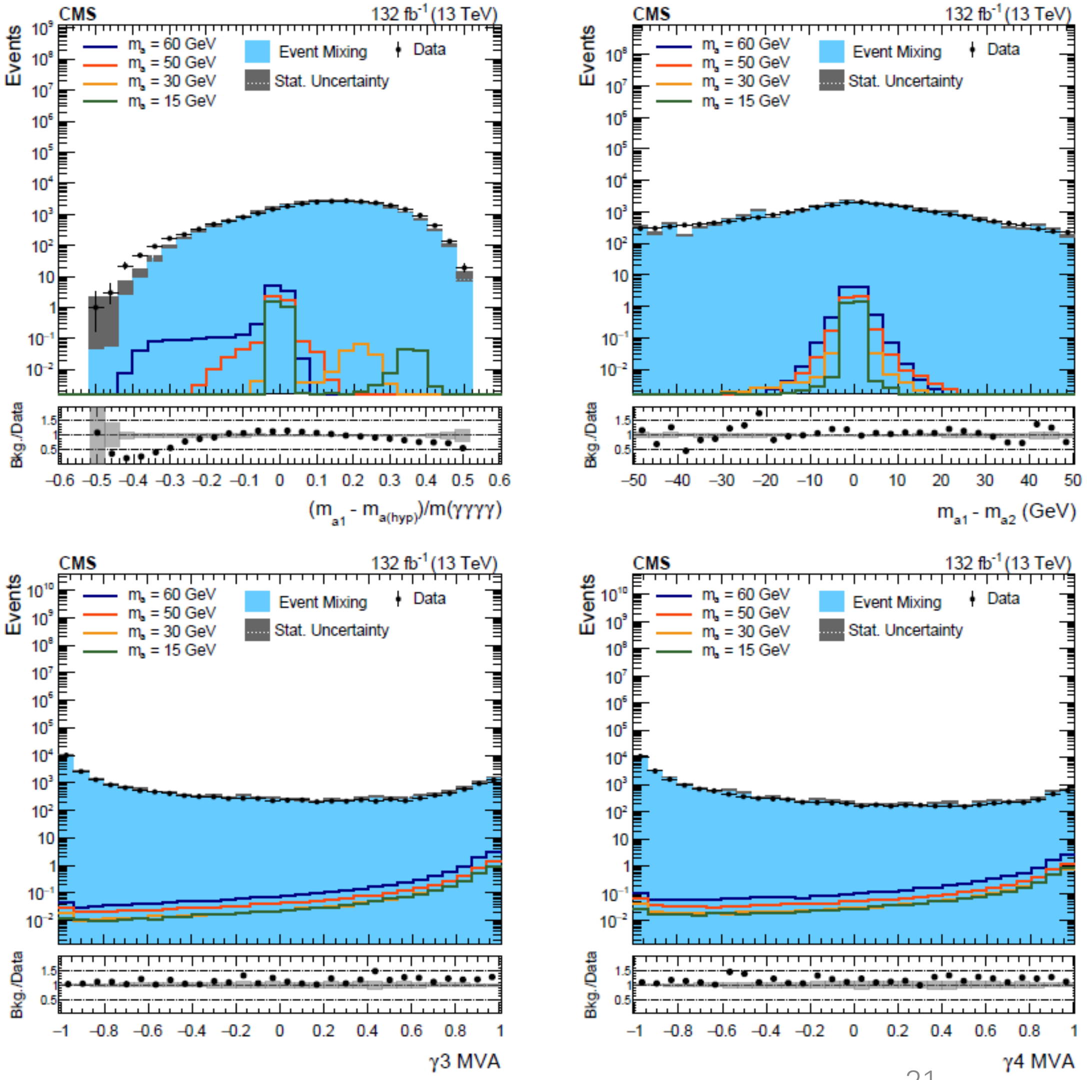
- Vertex BDT: uses input variables related to tracks recoiling against the four-photon system and information related to photons converted in the tracker material, similar SM H→γγ
- pT>30/18 GeV for the first-/second-leading photons
- pT > 15 GeV for the third- and fourth-leading photons, since photon ID MVA optimized with pT>15 GeV
- Mixed data events with a multi-dimensional per-event weight for training the 4-photon classifier: replacing three out of the four reconstructed photons in each event with reconstructed photons from three consecutive events
- Input variables for the classifier

1. Photon identification BDT score for all four photons.
2. p_T of the two pseudoscalar boson candidates, i.e., $p_{T,a1}$ and $p_{T,a2}$.
3. Difference between the reconstructed invariant mass of the pseudoscalar boson candidates, i.e., $m_{a1} - m_{a2}$.
4. Difference between the invariant masses of the pseudoscalar boson candidate and the $m_{a,\mathrm{hyp}}$ parameter divided by $m_{\gamma\gamma\gamma\gamma}$, i.e., $(m_{a1} - m_{a,\mathrm{hyp}})/m_{\gamma\gamma\gamma\gamma}$ and $(m_{a2} - m_{a,\mathrm{hyp}})/m_{\gamma\gamma\gamma\gamma}$.
5. Angular distance $\Delta R_{a_1 a_2}$ divided by $m_{\gamma\gamma\gamma\gamma}$, i.e., $\Delta R_{a_1 a_2}/m_{\gamma\gamma\gamma\gamma}$.
6. Angle $\cos\theta^*_{a\gamma}$ in the pseudoscalar boson rest frame, between the leading pseudoscalar boson candidate and the leading photon produced from its decay, chosen in the laboratory frame. This variable is sensitive to the spin of the pseudoscalar boson object.

CMS-PAS-HIG-21-003

arXiv:2208.01469

four most highly ranked discriminating variables



H→aa→γγγγ resolved

CMS-PAS-HIG-21-003
arXiv:2208.01469

- Summary of the **optimized BDT output threshold values** and the **efficiency** with respect to a selection on this output for each of the nominal signal hypothesis

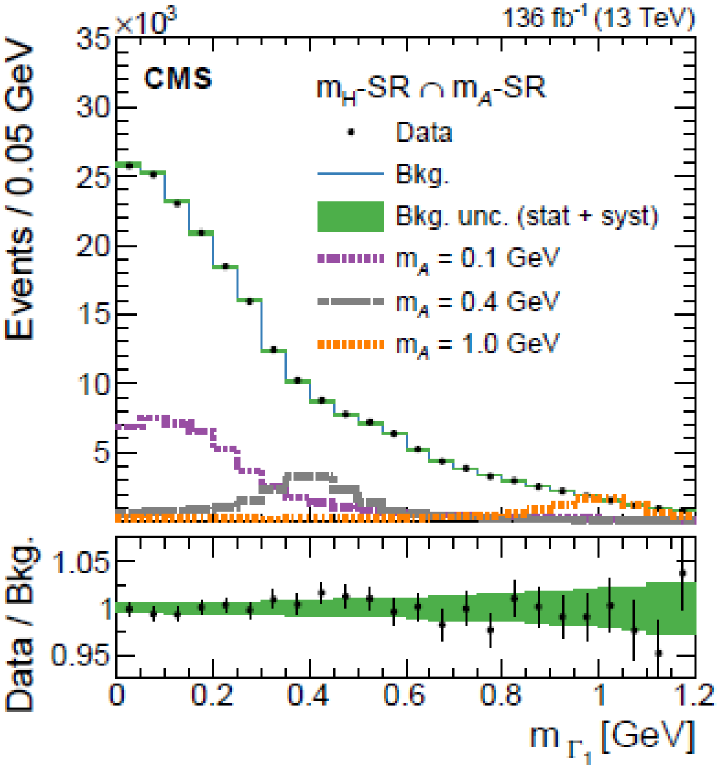
m_a (GeV)	Minimum 4-photon event classification BDT output value	Signal efficiency of the selection on BDT
15	0.883	88%
20	0.891	87%
25	0.876	86%
30	0.897	84%
35	0.931	82%
40	0.945	78%
45	0.952	80%
50	0.958	80%
55	0.976	77%
60	0.987	71%

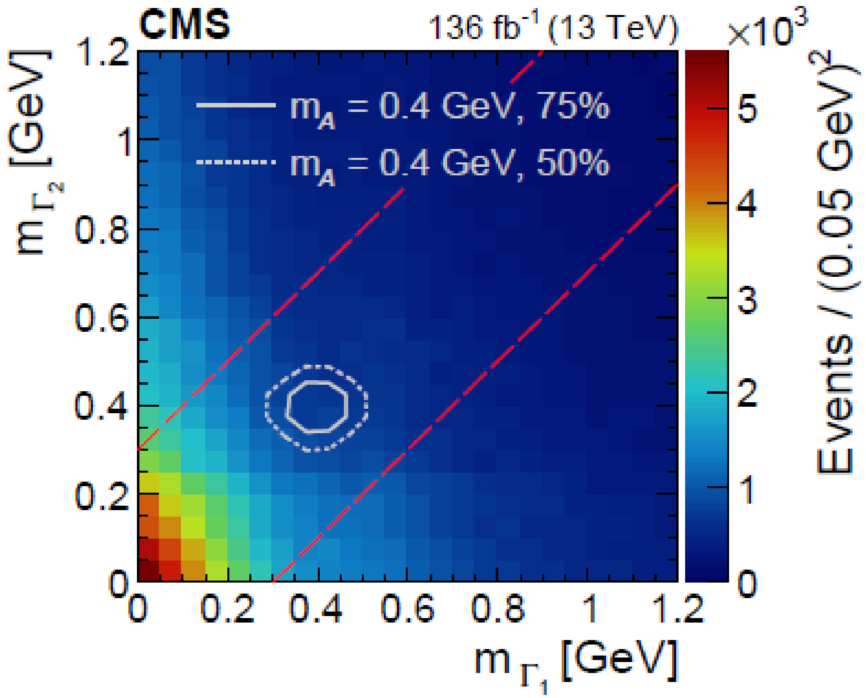
H→AA→γγγγ boosted

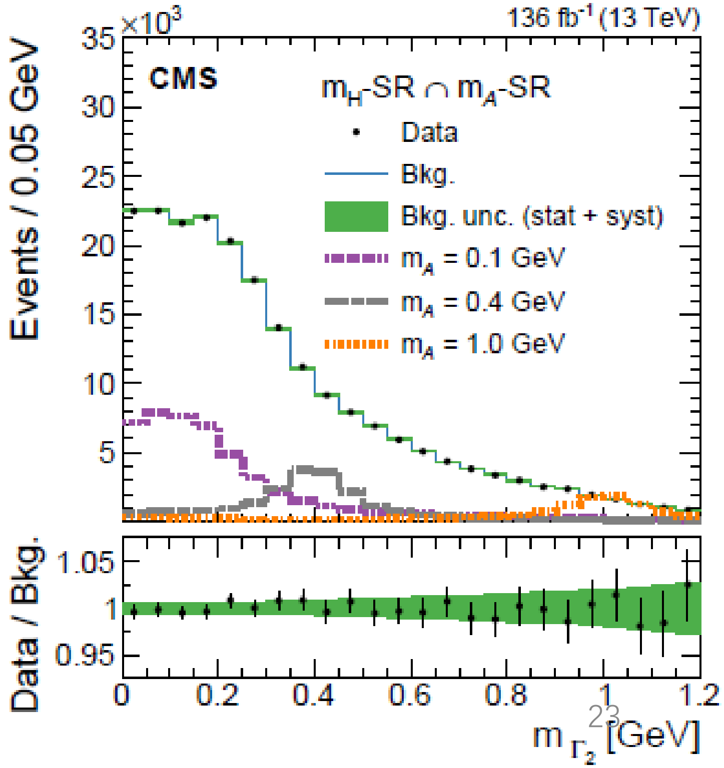
CMS-PAS-21-016,
arXiv:2209.06197

- Signal selection eff. 8-24% decreasing with m_A
- $\Gamma_{1(2)}$ is the higher- (lower-) energy reconstructed photon
- m_Γ resolution varies from ~ 100% to 20% for m_A = 0.1 to 1.2 GeV
- Mass distributions from selected events in data

- Dominated by **statistical uncertainty of S and B template** : ~10-25% on the best fit signal strength

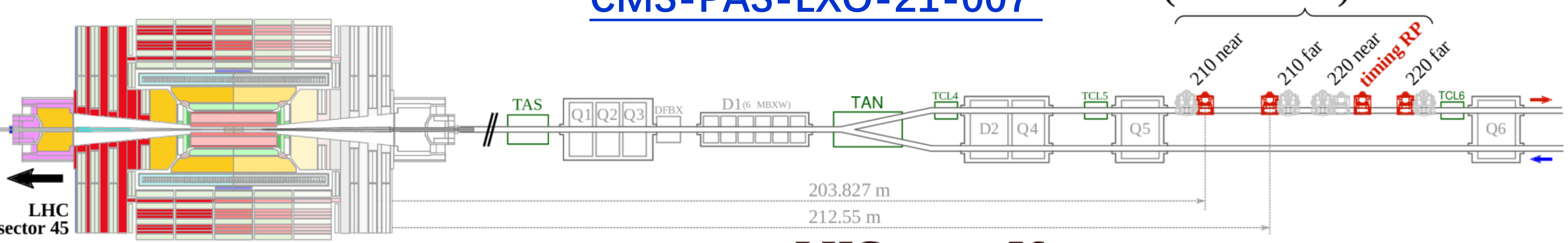






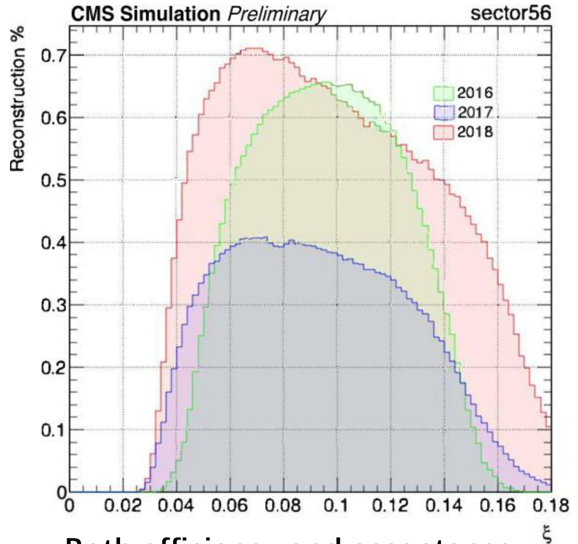
High-mass exclusive diphoton production

CMS-PAS-EXO-21-007

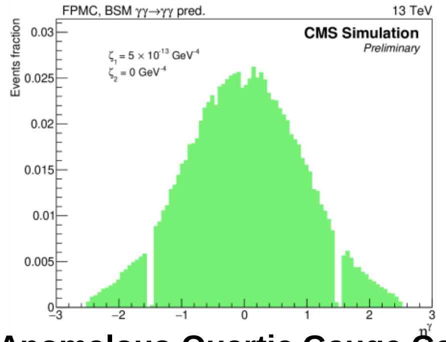


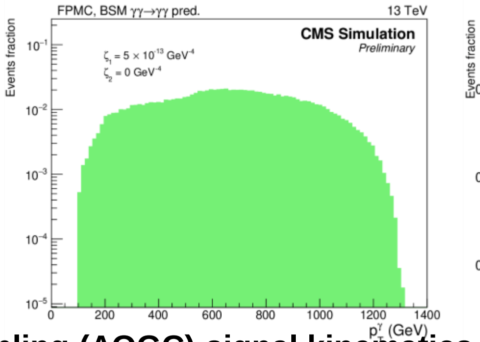
- ➢ 102.7 fb^{-1} of data collected by the CMS +TOTEM PPS in Run2 (2016-2018)

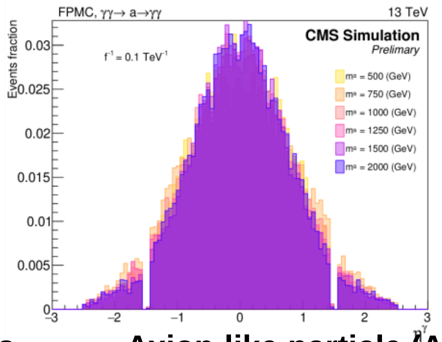
Source	2016	2017	2018
CMS Luminosity	1.2%	2.3%	2.5%
Background estimation	23.3%	25.2%	20.9%
Photon ID scale factors	3.1%	7.0%	2.9%
Rapidity Gap Survival Probability	10%	10%	10%
Particle Showers in PPS	–	–	1.7%

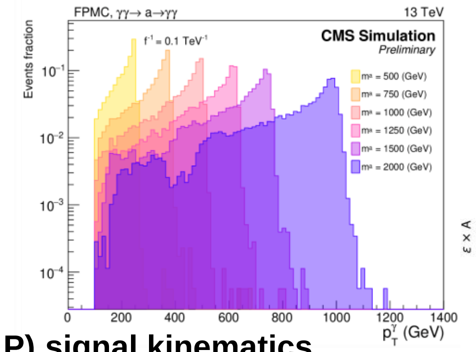


Both efficiency and acceptance effects parameterized as function of the proton ξξ for all years

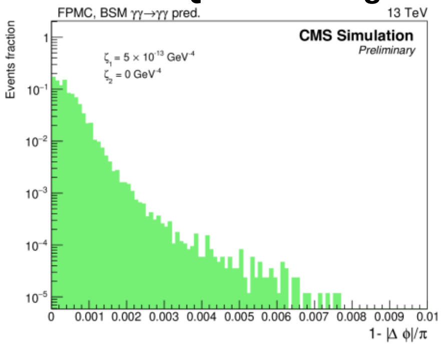


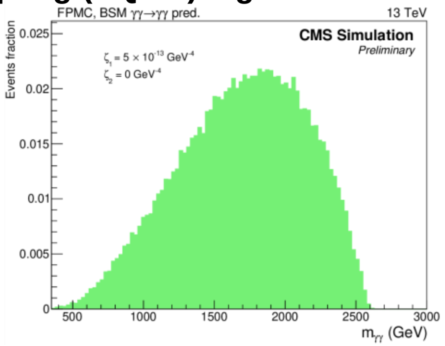


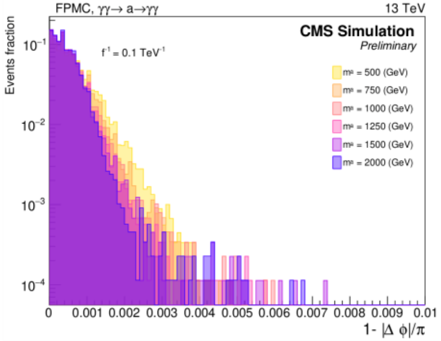


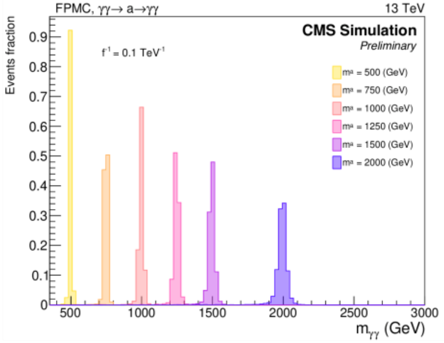


Anomalous Quartic Gauge Coupling (AQGC) signal kinematics **Axion-like particle (ALP) signal kinematics**

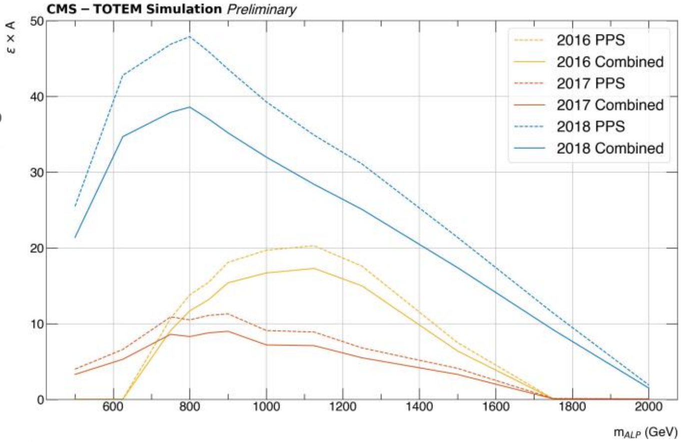








ALP signal efficiency times acceptance (ϵ×A)



High-mass exclusive diphoton production

CMS-PAS-EXO-21-007

- Kinematic distributions for events passing the $\xi_{\gamma\gamma} \in$ PPS signal selection
- Number of data and simulated background events are shown for three sequential selection regions

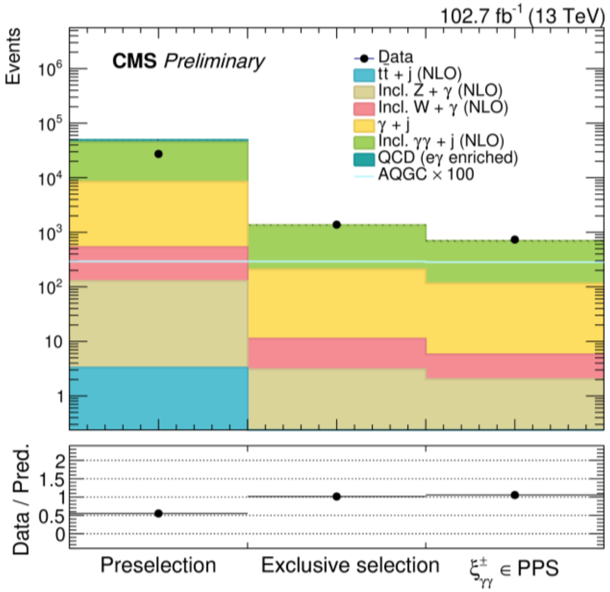
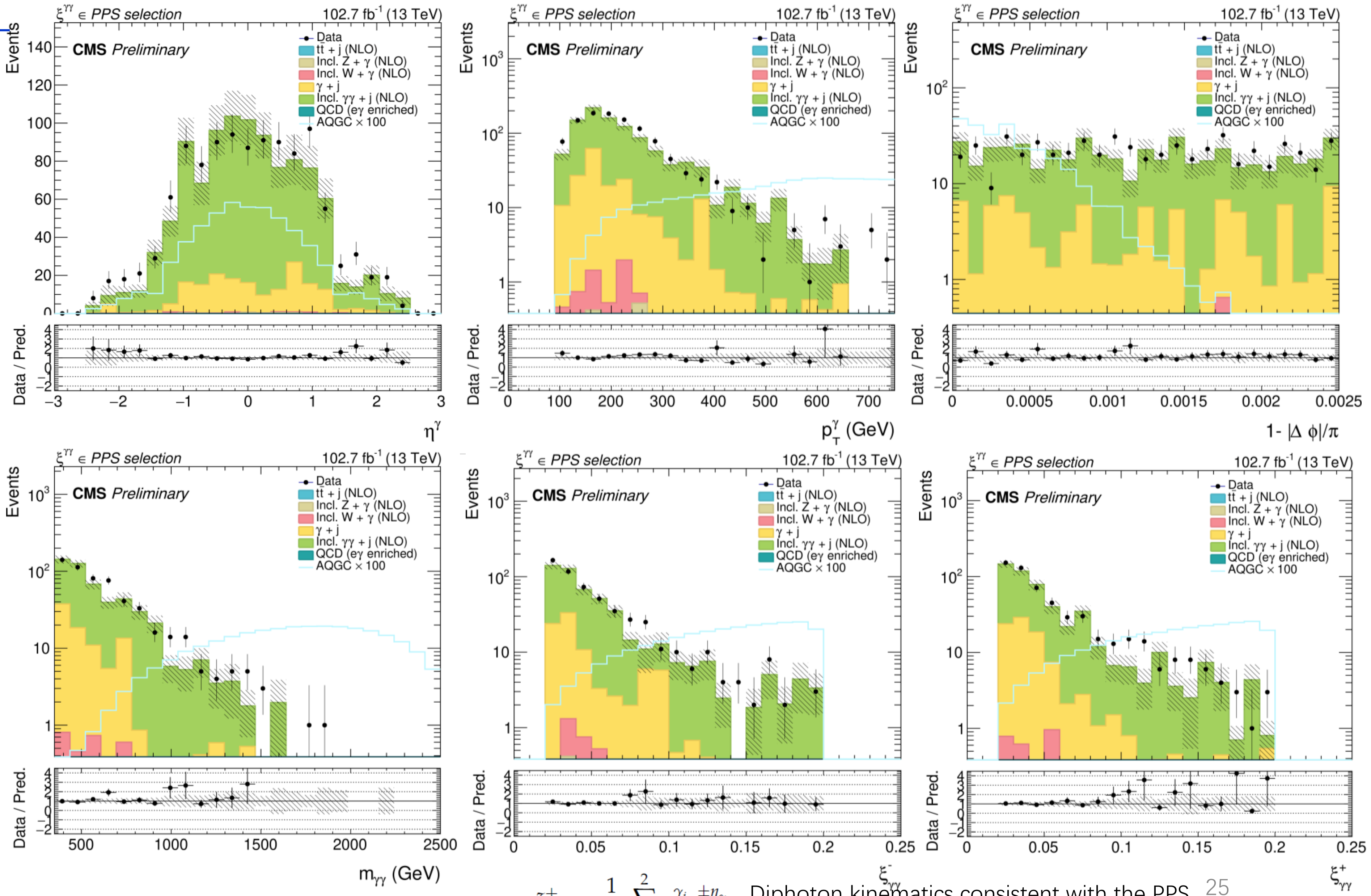


Table 3: A summary of the selection regions defined in the text.

Region	Selection
Preselection	Double photon HLT $p_T^{\gamma} > 75$ (100) GeV for 2016 (2017-2018) $H/E < 0.10$ MVA WP90 photon ID with electron veto $\lvert\eta^{\gamma}\rvert < 2.5$ (transition veto) $m_{\gamma\gamma} > 350$ GeV
Exclusive selection	$a < 0.0025$
$\xi \in$ PPS	$0.02 < \xi^{\pm}_{\gamma\gamma} < 0.20$
Asymmetric ξ acceptance	$0.035 < \xi_{PPS} < 0.15$ (0.18) for sector-45 (sector-56)

$a \equiv 1 - \lvert \Delta\phi^{\gamma\gamma}/\pi \rvert$

An asymmetric fractional momentum loss of proton (ξ values)



$$\xi^{\pm}_{\gamma\gamma} = \frac{1}{\sqrt{s}} \sum_{i=1}^{2} p_T^{\gamma_i} e^{\pm\eta_{\gamma_i}}$$

Diphoton kinematics consistent with the PPS acceptance **by asking it between 0.02-0.20**