Search for additional scalars at CMS

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on behalf of the CMS collaboration

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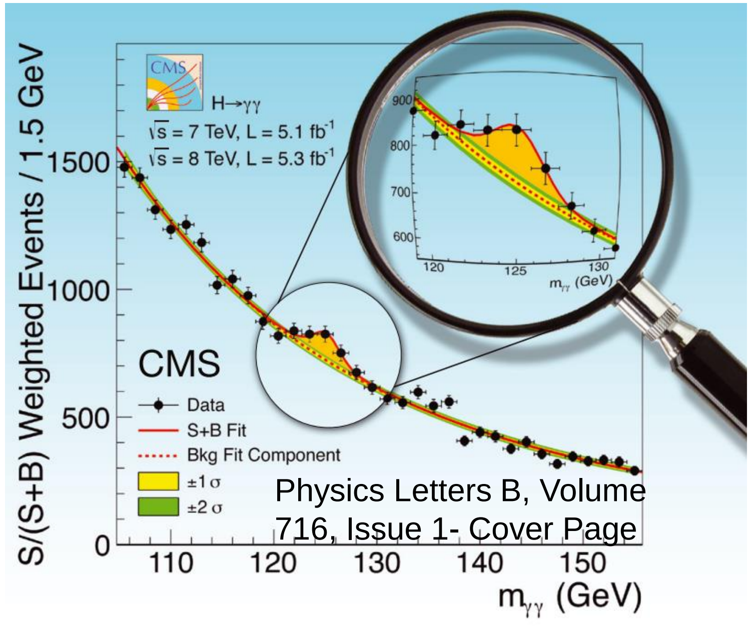
Introduction

- Although the **Higgs boson discovered** at LHC so for is compatible with the SM Higgs boson, there is **still room for BSM**

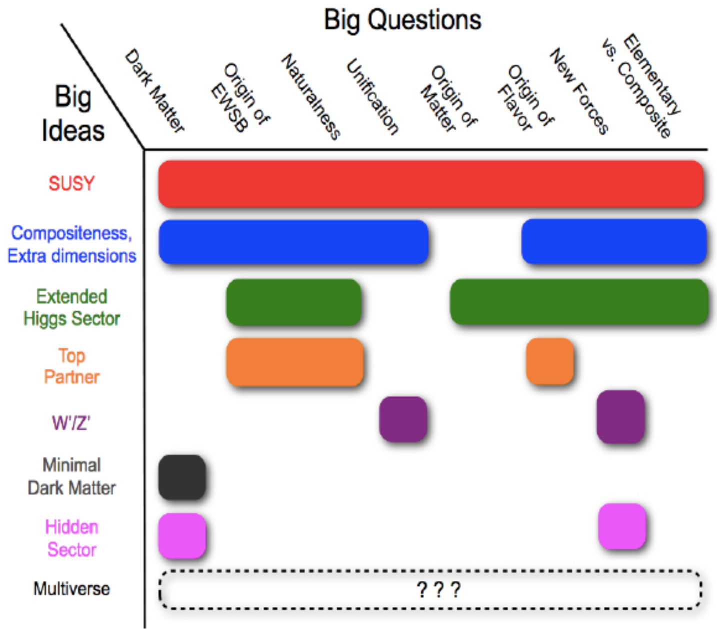
- Many **BSM models** (e.g. NMSSM, 2HDM, Georgi-Machacek model) provide a Higgs boson that is **compatible with the LHC observed 125 GeV boson**, and **additional Higgs bosons or (pseudo-)scalars**

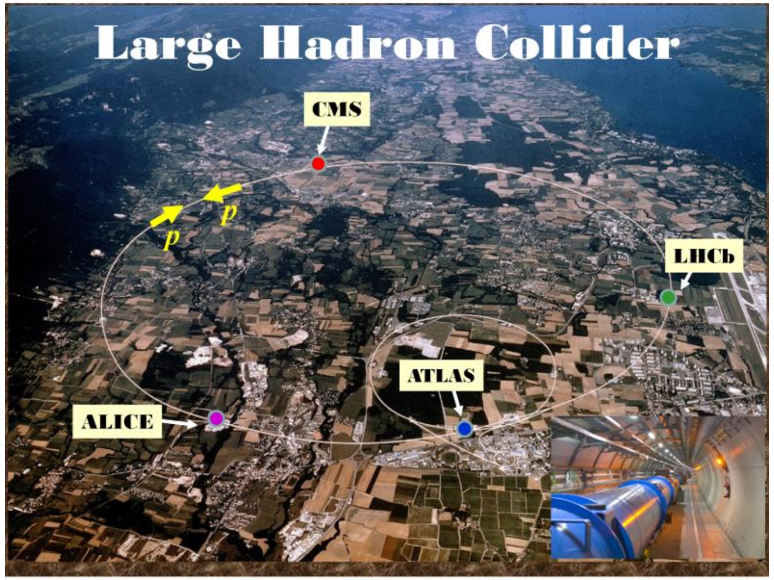
- **Discovery of extra scalars would be an unequivocal sign of new physics**

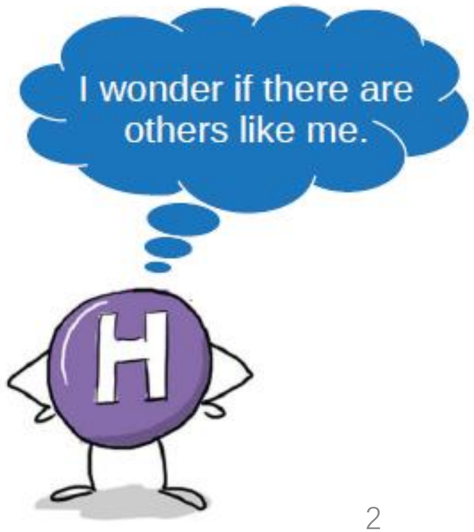
- **LHC is currently the most powerful discovery machine**
  -- Hope to find **hints of BSM**



Physics Letters B, Volume 716, Issue 1- Cover Page







Extra scalar searches at CMS

- Large group of **extra (pseudo-)scalar searches** being covered with **full Run-2 (2016-2018)**

BSM particle searches

Neutral scalars (H, A, X, ϕ)

Charged H/X

- HIG-20-002 (arXiv:2405.18149): **light H→γγ**
- EXO-22-024 (arXiv:2405.09320) : High mass X→γγ
- CMS-PAS-HIG-20-016: High mass X→ WW
- JHEP 07 (2023) 073: ϕ→ττ
- CMS-PAS-EXO-24-007: ϕ→ bb
- PRD 110, 012013: Vϕ/ttϕ → ll
- EXO-22-022 (arXiv:2405.00834): boosted multi-γ X→ ϕϕ → 4γ
- CMS-PAS-HIG-22-004: A →ZH, H→ττ
- HIG-22-002 (arXiv:2305.18106): LFV X→eμ
- JHEP 09 (2023) 032: H$^{\pm}$ → H(200)W → (ττ) (ℓv /qq):
- EXO-21-017(arXiv:2406.05737): X$^{\pm}$ →Wγ

Exotic Decays

Light pseudo-scalar

- H→aa
- H→Za

- EPJC 84, 493 (2024) : H → aa → μμbb/ττbb
- JHEP07(2023)148: H → aa → 4γ resolved
- PRL131 (2023) 101801: H → AA → 4γ merged
- EPJC 84, 493 (2024): H → aa → 2b2τ/2b2μ
- *PLB* 852 (2024) 138582: **H→ Za→ll + γγ** (see Zebing's talk)

Multi-Higgs resonances

X → HH Searches
X → HY Searches

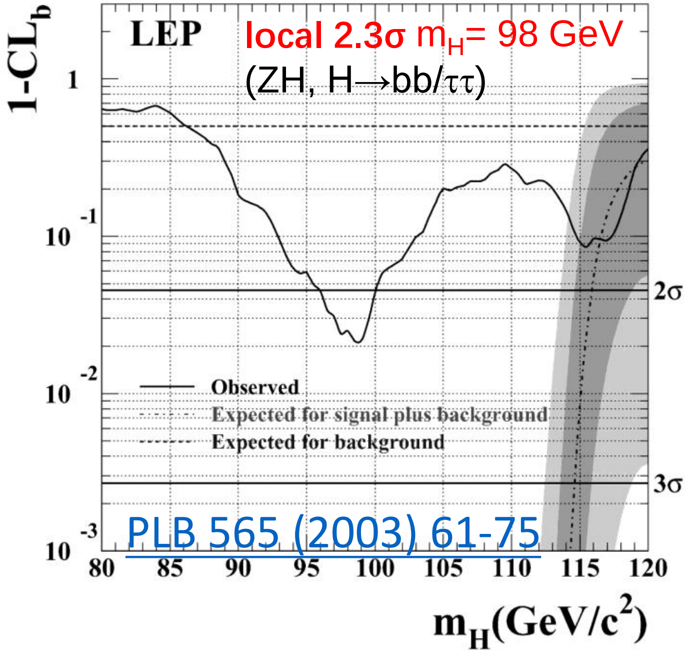
- HIG-21-005 (arXiv:2403.09430): X → HH → bbWW
- JHEP05(2024)316 : **X → HH/YH → bb$\gamma\gamma$**
- CMS-PAS-HIG-22-012: **X → HH/YH → ττ$\gamma\gamma$**

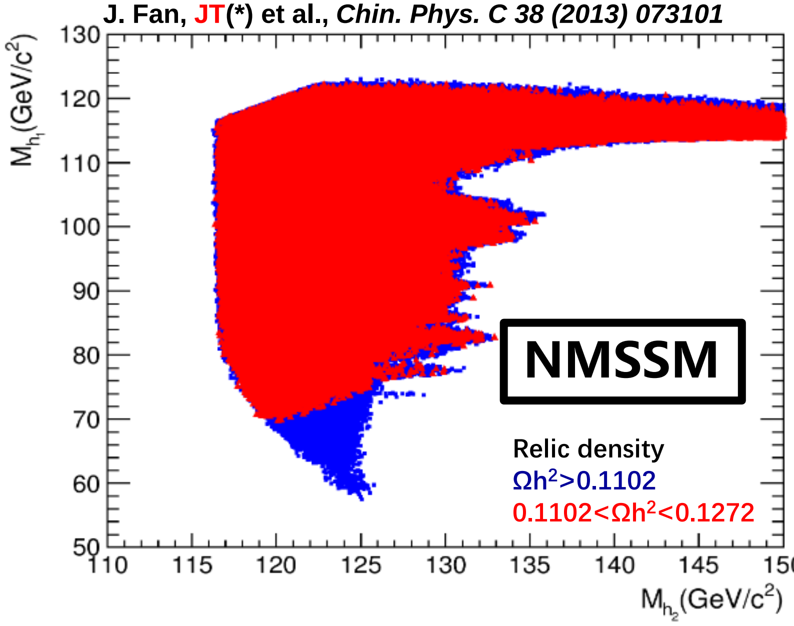
- **Selected results** will be presented

Many other list : CMS Publication List

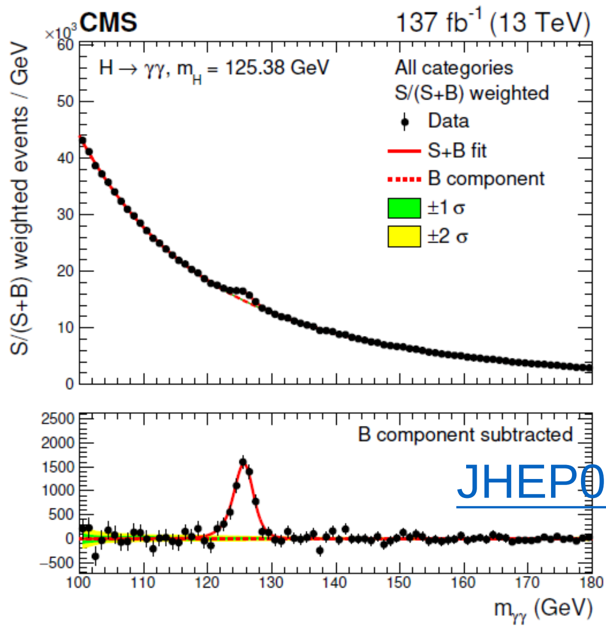
Search for low-mass (m_H<125 GeV) H→γγ

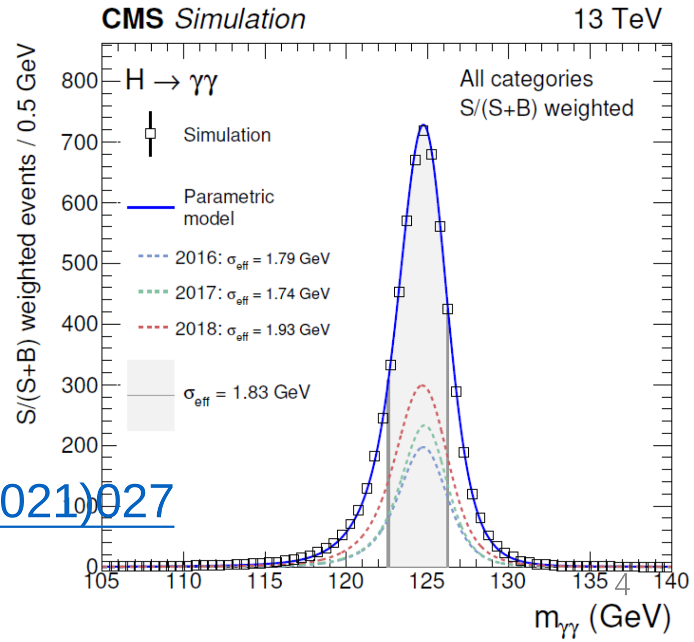
- **Why low-mass Higgs?**
  - ✓ Final LEP SM Higgs boson search results: 2.3σ local excess at m_H= 98 GeV
  - ✓ Several BSM (**NMSSM/2HDM)** predict additional Higgs bosons with some of which could have **masses < 125 GeV**





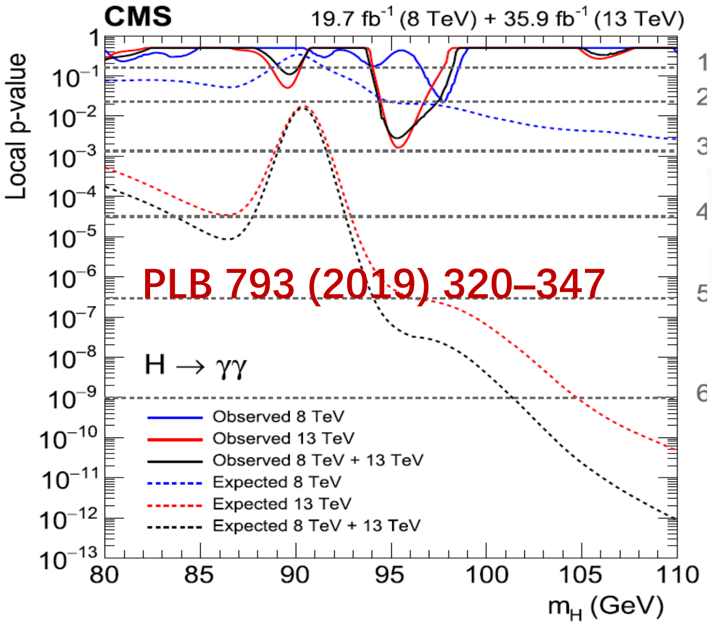
- **Why h/H→γγ?**
  - ✓ One of the major channels for Higgs discovery and property measurements
  - ✓ A clean final-state topology that allows the mass of a Higgs boson to be reconstructed with high precision (1-2%)

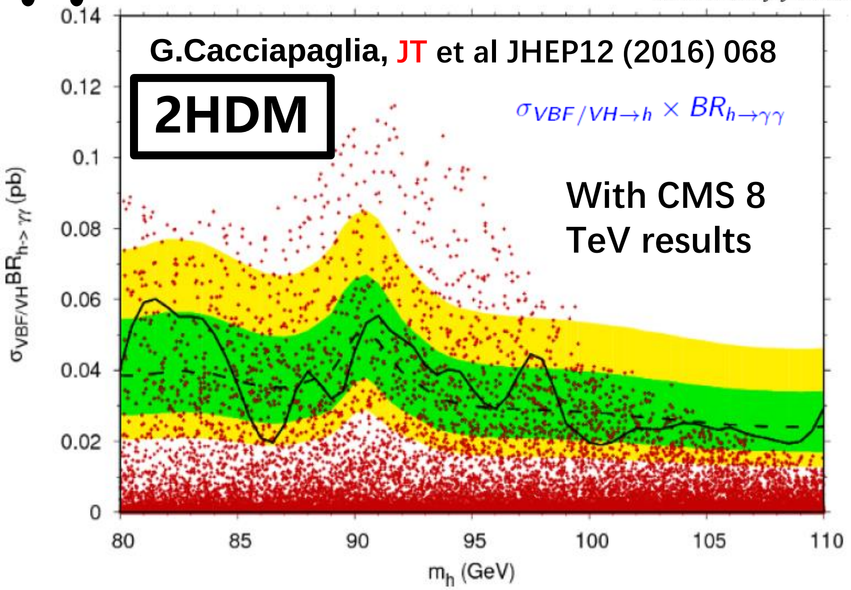




Search for low-mass H→γγ at CMS

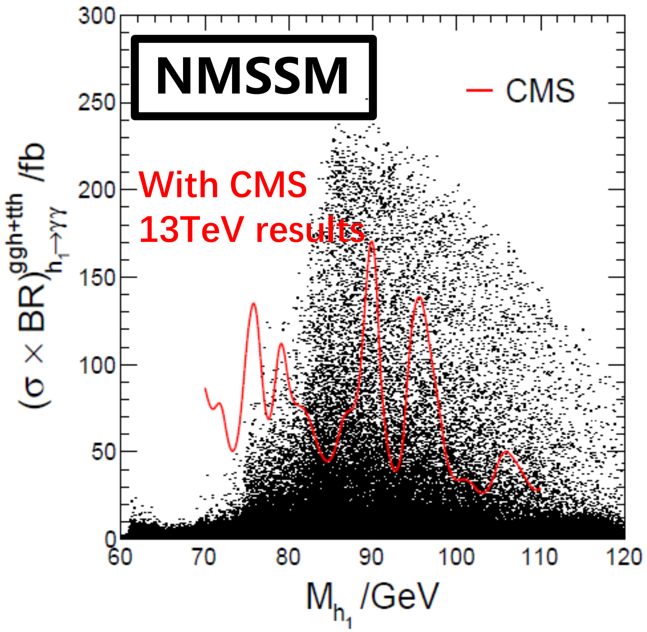
- We **(IHEP+…)** have performed the **LM H→γγ search** **since Run1 at CMS**
  - ✓ 2012 data (**HIG-14-037**, **PAS only**) : **~2σ local at 97.5 GeV**
  - ✓ 2016 + 2012 data (**HIG-17-013, PLB 793 (2019) 320–347**): **2.8σ local (1.3σ global) at 95.3 GeV**
- **Performed interpretations with several BSM**

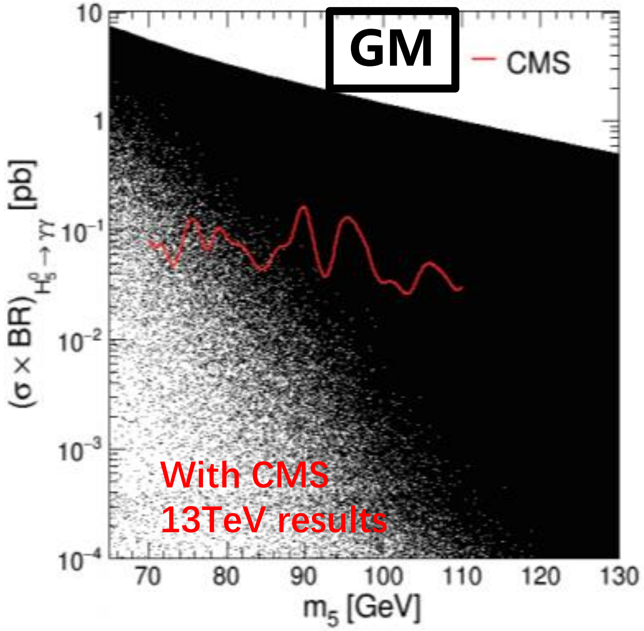




JT et al., CPC 42 (2018) 10, 103107

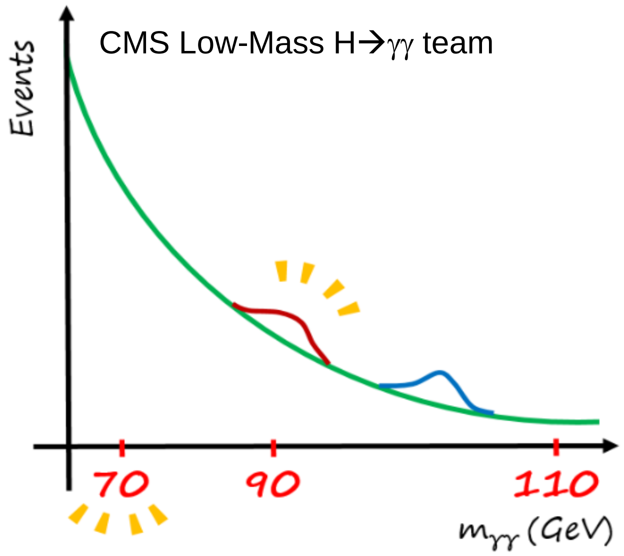
C. Wang, JT(*) et al., *CPC 46 (2022) 8, 083107*

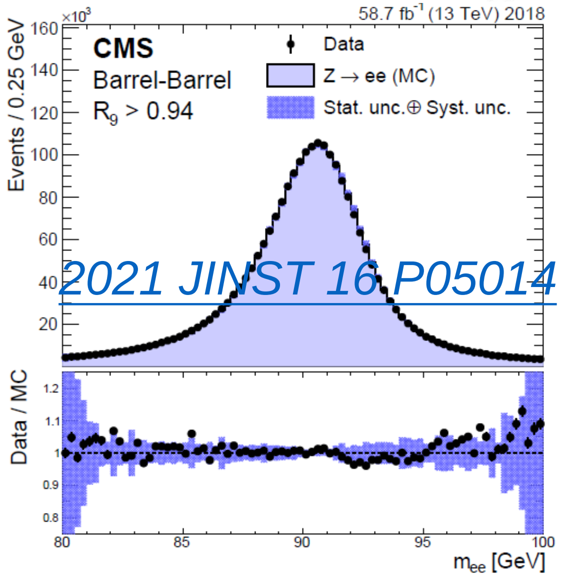




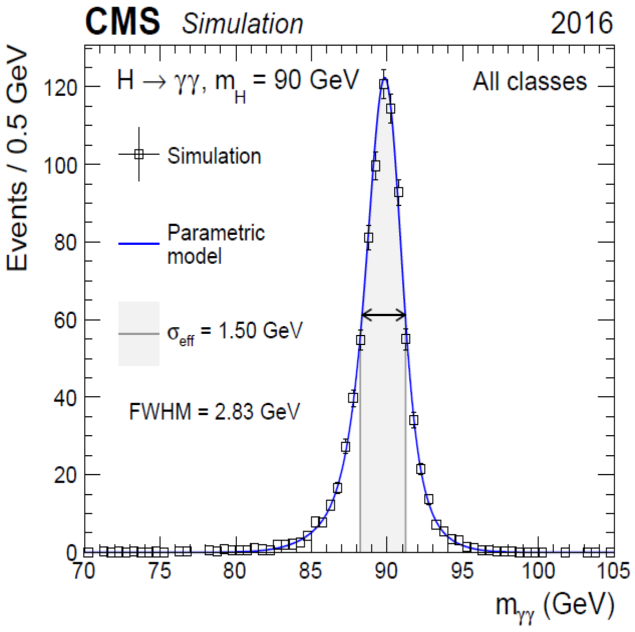
SM-like low-mass H→γγ :70<m_H<110 GeV

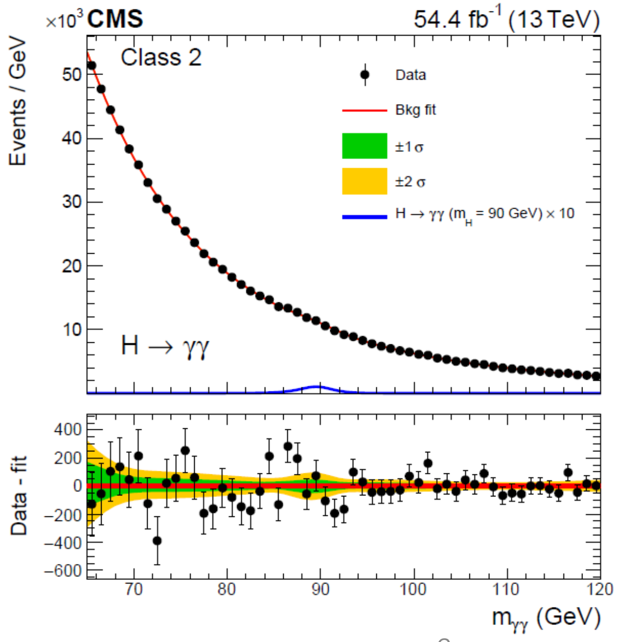
- Search for **narrow signal peak** over **smoothly-falling background** (direct γγ , reducible γ + jet, jet+jet processes) except for **relic Drell-Yan** (Z→ee), in the diphoton mass spectrum
- **Signal searching region: 70-110 GeV**, backgoud fitting range 65-120 GeV
  - ✓ To avoid the distortion of the $m_{\gamma\gamma}$ spectrum, due to turn-on effects from the **HLT criteria** (**M>55 GeV**)
- Many **elements and techniques** (γ energy calibration, signal and data-driven background modeling, …) inherited from **SM H→γγ analysis** (see Chenguang's talk), but with **dedicated updates and optimizations** in low-mass case
  - ✓ Dedicated **HLT** paths then event (pre-) **selections**
  - ✓ Dedicated **DY suppression** strategy
  - ✓ Retrained **photon ID MVA** and **diphoton BDT** training, optimization of **event categorization**
  - ✓ More in arXiv:2405.18149





2021 JINST 16 P05014





arXiv:2405.18149

Low-mass H→γγ results

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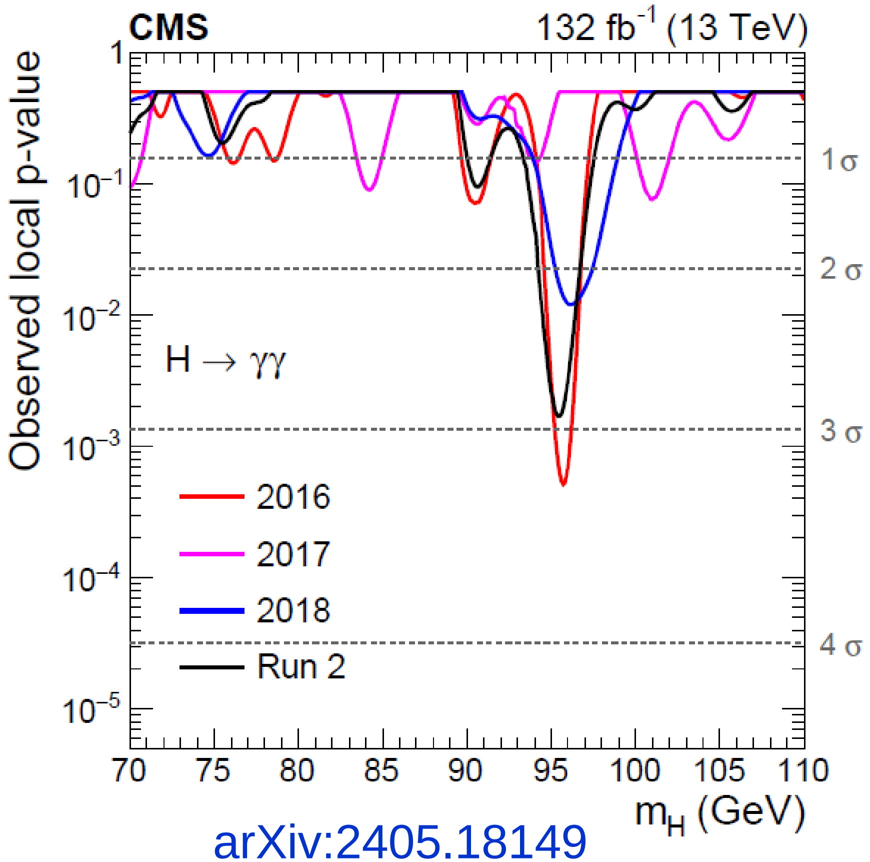
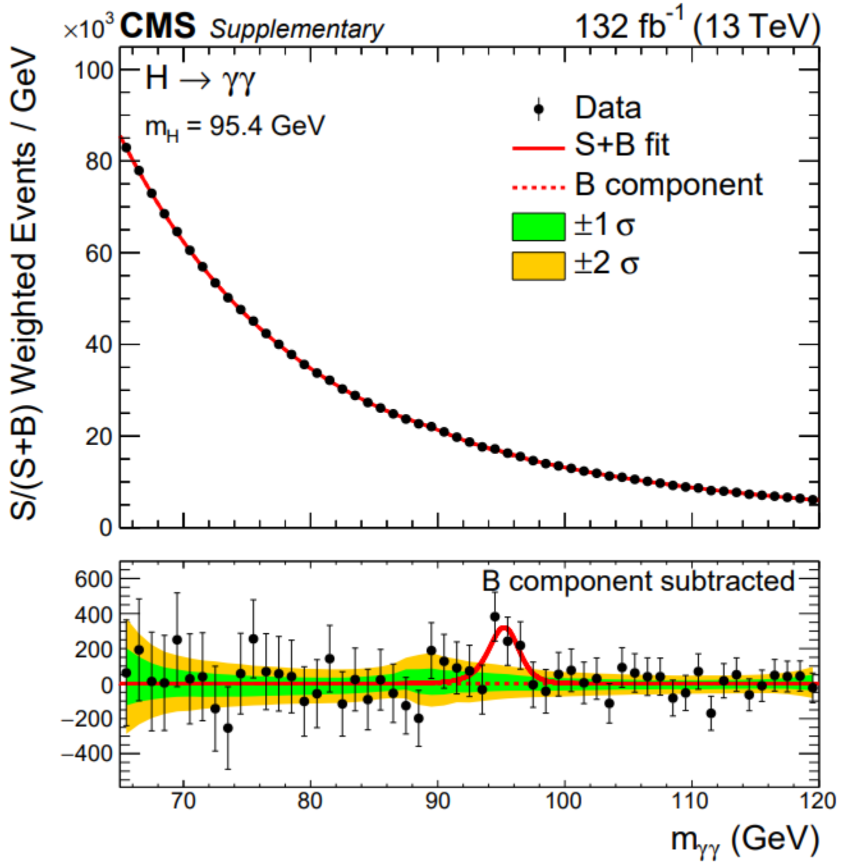
- **Observed local p-values** for 2016, 2017, 2018 and combination

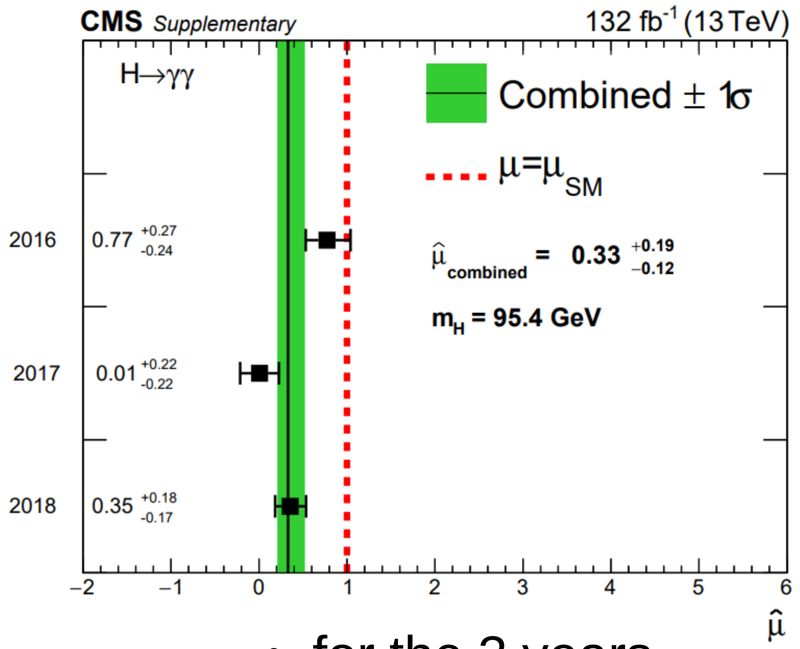


arXiv:2405.18149

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



More results and interpretations



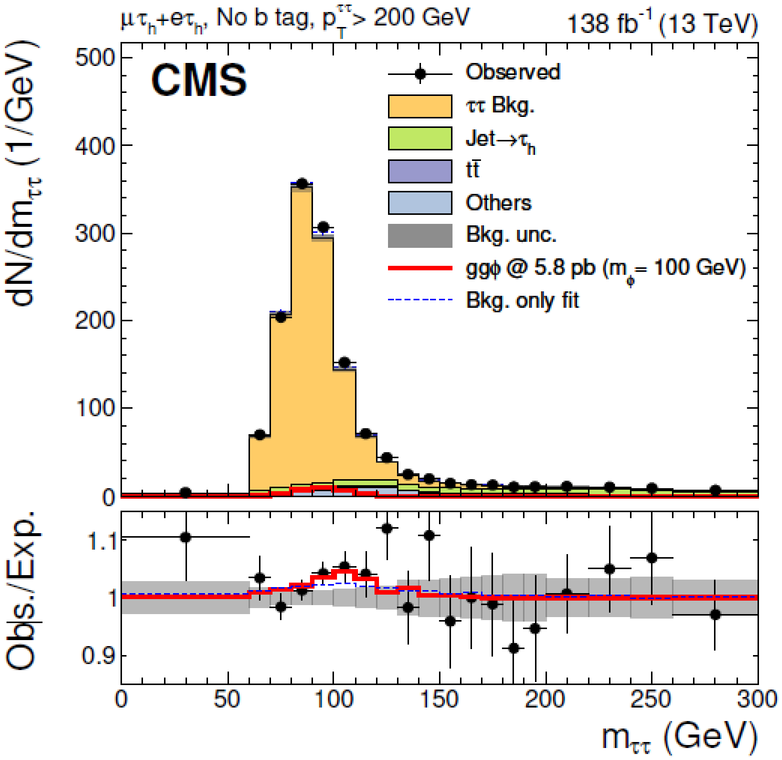
- for the 3 years χ^2 compatibility probability: 6%

- Modest excess with **~2.9σ local (1.3σ global) significance at $m_{\gamma\gamma}$= 95.4 GeV**

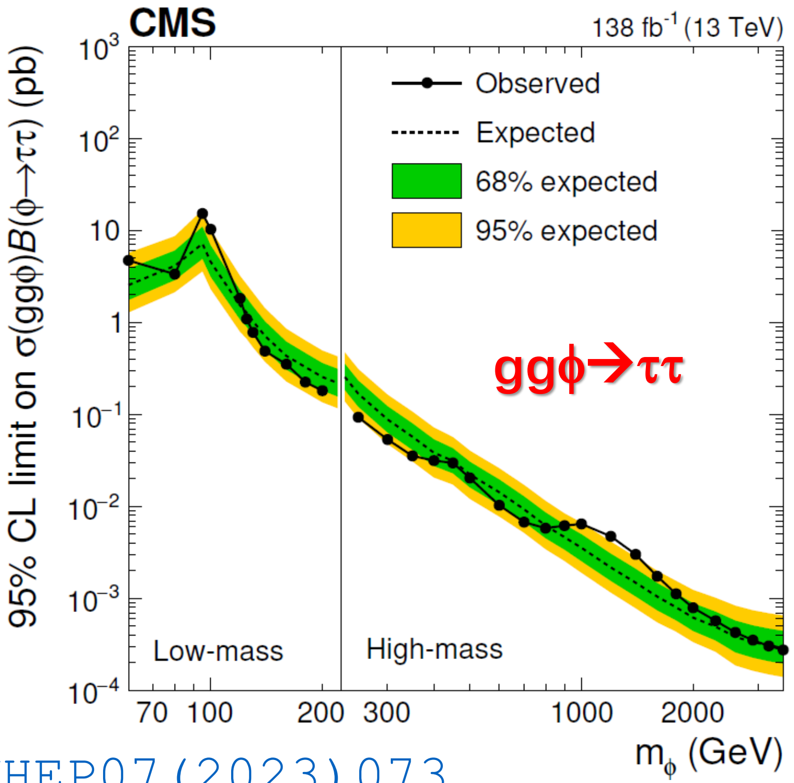
The excess did not grow with luminosity, but remains intriguing

Search for neutral scalar $\phi \rightarrow \tau\tau$

- $\tau\tau$ final state: identified with **higher purity than b; well estimated $\tau\tau$ bkg**; typically **larger BR**; …
- Production via **gluon fusion** ($gg\phi$) or **in association with b** quarks ($bb\phi$)
- Performed in 4 $\tau\tau$ final states : $e\mu$, $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$
- Event categorization : split into **no b-tag (N_{bjets}=0)** and **b-tag** categories
  - ✓ For no b-tag category split events based on **reconstructed $p_T^{\tau\tau}$**



"Low-mass" (60–250 GeV): fitting on $m_{\tau\tau}$ to extract signal



JHEP07(2023)073

3.1σ(2.7σ) local (global) @ 100 GeV

2.6σ(2.3σ) local (global) @ 95 GeV

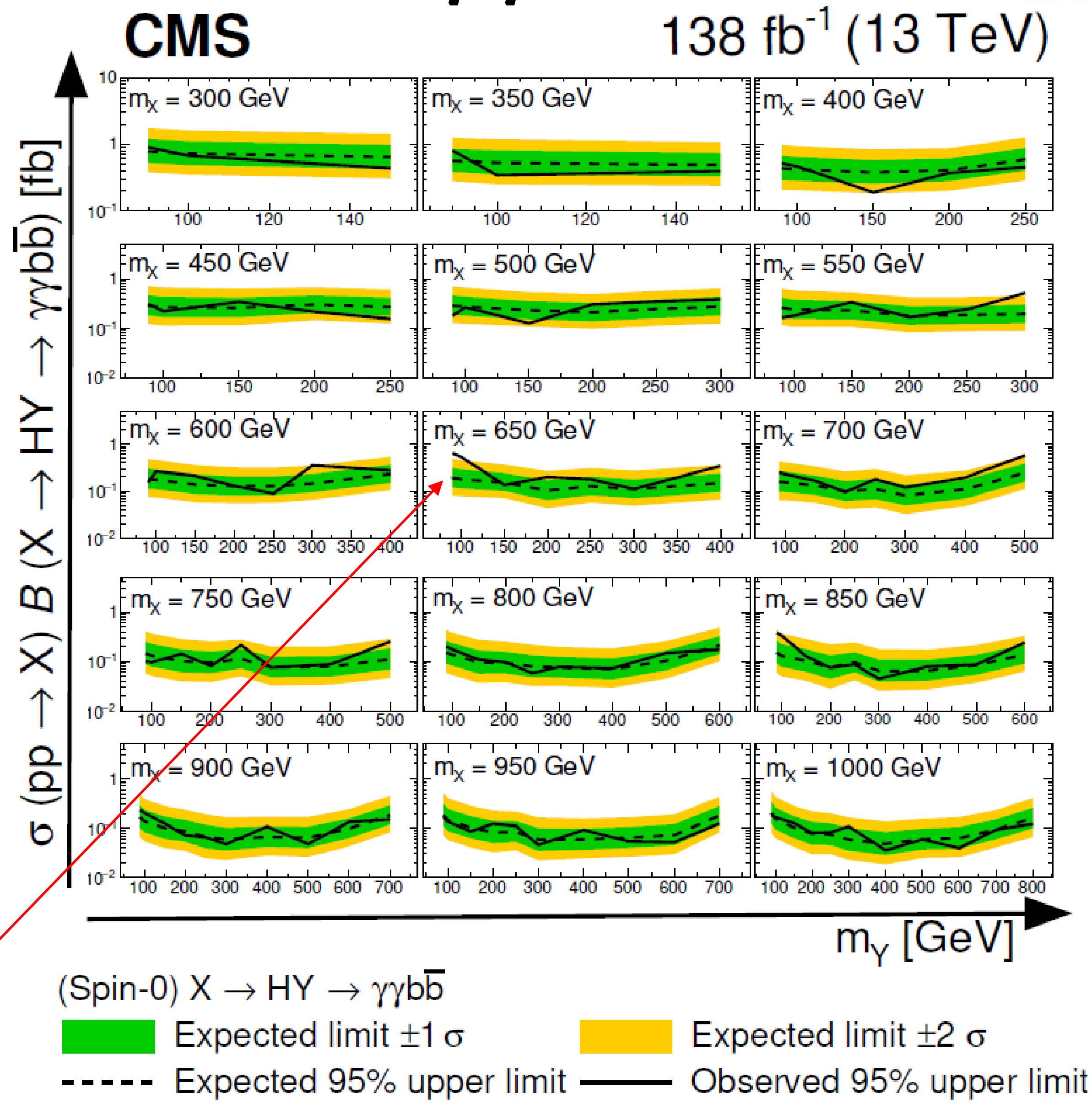
2.8σ(2.2σ) local (global) @ 1.2 TeV

Not seen in $bb\phi$ production

$X \rightarrow HH/YH \rightarrow bb\gamma\gamma$

- Search for **a new boson X** decays into **two spin-0 bosons**, with **2γ** and **2b quarks**
  - Relatively **large signal purity in H→γγ**
  - Large branching fraction of decaying into bb
- Focus on X decays into an H(→γγ) and **a new spin-0 boson Y**(→bb) in this talk
- BDT (DNN) scores to separate signals and non-resonant (resonant) backgrounds
- Six BDT training accounts for different signal **m_X-m_Y** mass ranges
  - 3 event classes based on BDT output
- A parametric fit in the **($m_{\gamma\gamma}$, m_{jj})** plane is performed for signal extraction

3.8σ local (2.8σ global) for m_X = 650 GeV and **m_Y = 90 GeV**



JHEP05(2024)316

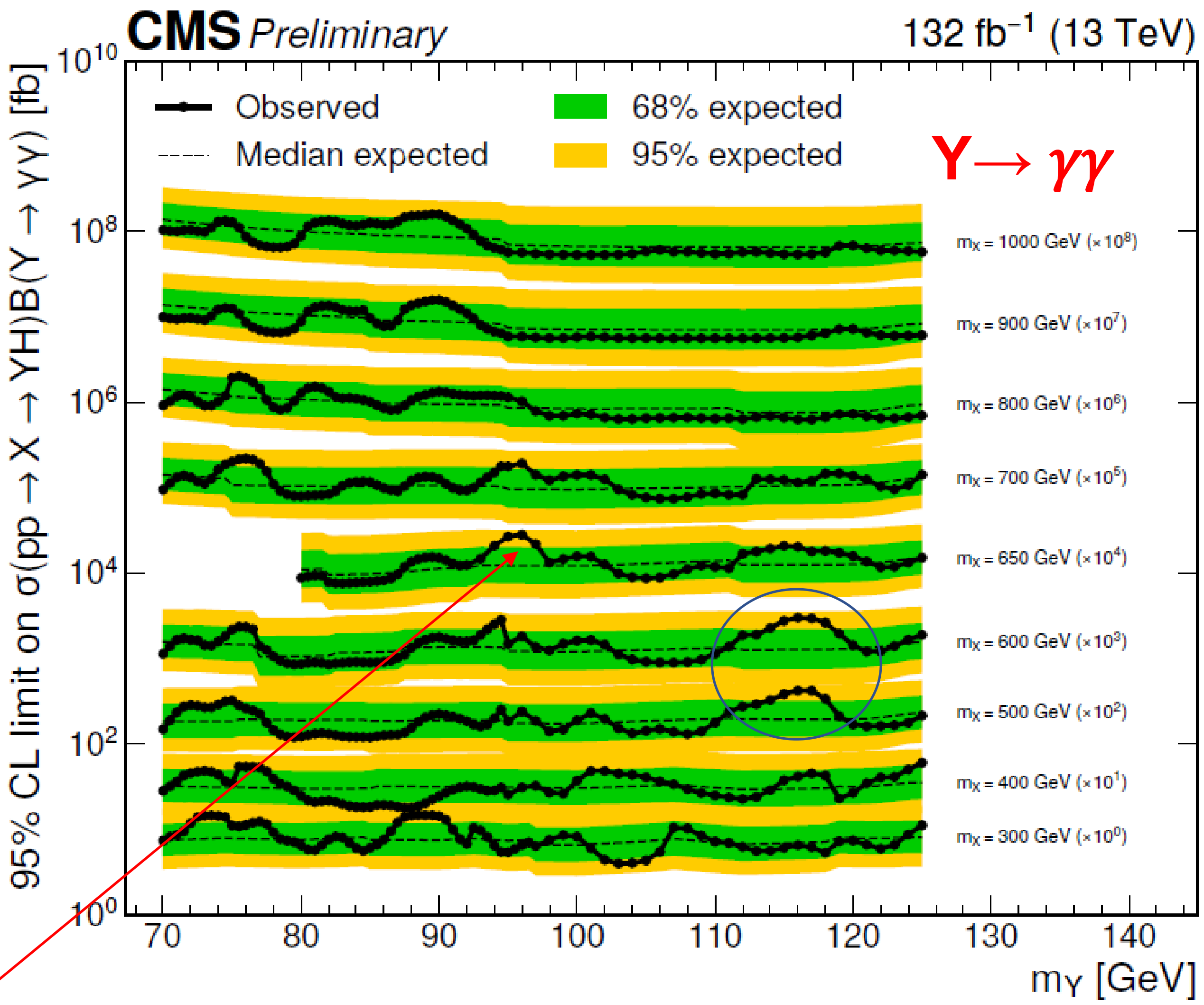
$X \rightarrow HH/YH \rightarrow \tau\tau\gamma\gamma$

- Diphoton pair offers a clean experimental signature to **trigger** on with **a good mass resolution**, whilst the additional **tau leptons** in the event help further **isolate signal from bkg**

- **Three search channels of $X \rightarrow YH \rightarrow \tau\tau\gamma\gamma$**:
  - ✓ $X \rightarrow Y(\tau\tau)\ H(\gamma\gamma)$
  - ✓ Low-mass $X \rightarrow Y(\gamma\gamma)\ H(\tau\tau)$ (Y mass 70-125 GeV)
  - ✓ High-mass $X \rightarrow Y(\gamma\gamma)\ H(\tau\tau)$ (Y mass 125 -800 GeV)

- A Parametric Neural Network (pNN) trained to identify sig from bkg and for event categorization

$Y \rightarrow \gamma\gamma$: the largest local significance of **3.4σ** (0.1σ global) @ **m_X = 525 GeV**, **m_Y = 115 GeV**



local 2.3σ @ m_X = 650 GeV, m_Y = 95 GeV is interesting

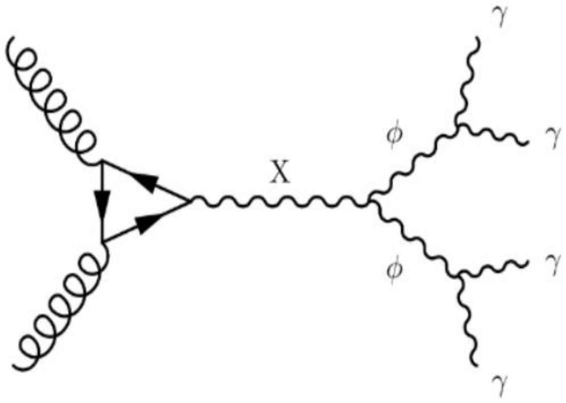
CMS-PAS-HIG-22-012

Boosted multi-photon $X \rightarrow \phi\phi \rightarrow 4\gamma$

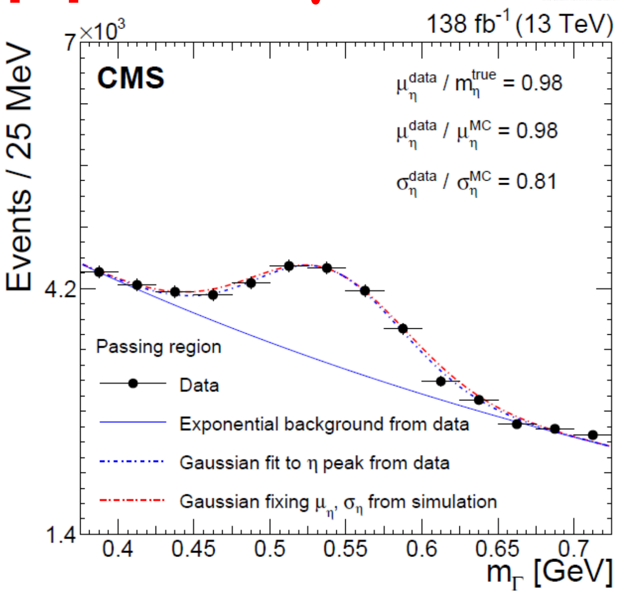
- Highly boosted ϕ resulting in merged photon pairs : need new ML analysis techniques

Analysis Regime:

- 300 GeV < M_X < 3000 GeV
- 0.005 < α < 0.025 $\alpha = M_\phi / M_X$
- Barrel Only



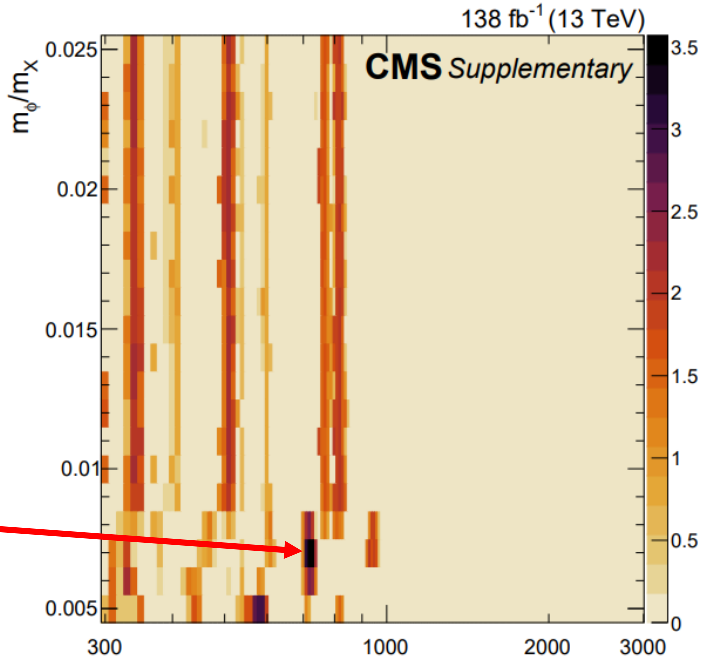
CMS-EXO-22-022, *arXiv:2405.00834*



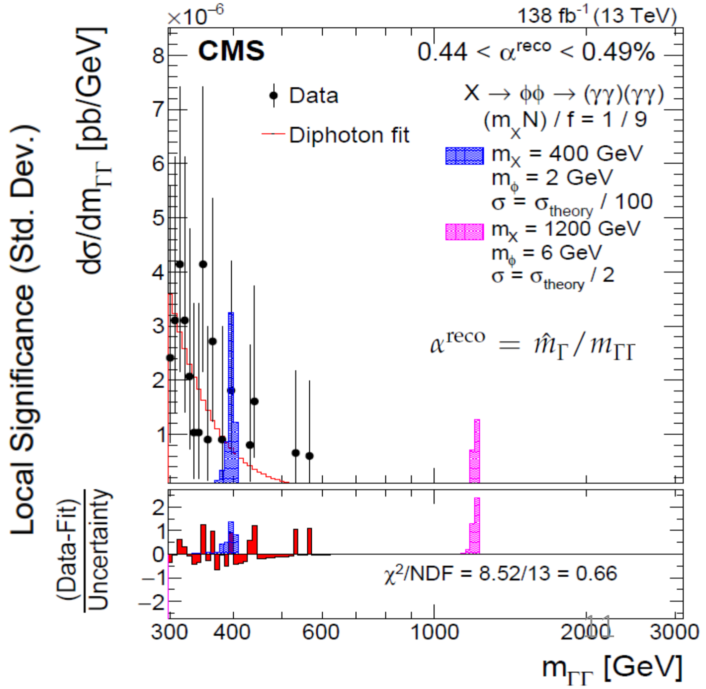
- **Two convolutional neural networks**
  - **Classification NN1:** selects diphotons from single photons and hadrons
  - **Regression NN2:** predicts the diphoton mass (m_Γ)
  - Validations of CNN: $\eta \rightarrow \gamma\gamma$

- **Final search is a bump hunt in $M_{\Gamma\Gamma}$** (reconstructed X or four-photon mass)

3.57σ (1.07σ) local (global) excess @ m_X = 720 GeV, m_ϕ = 5.04 GeV



public-results



LFV X→eμ

arXiv:2305.18106

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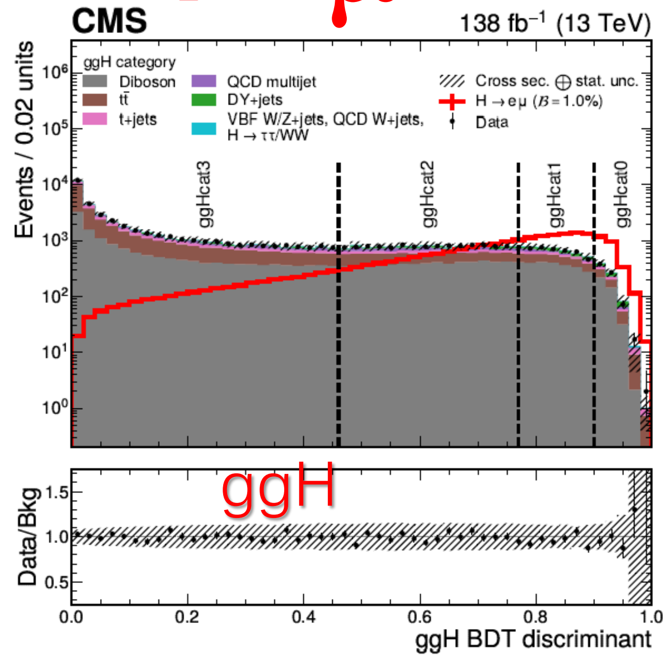
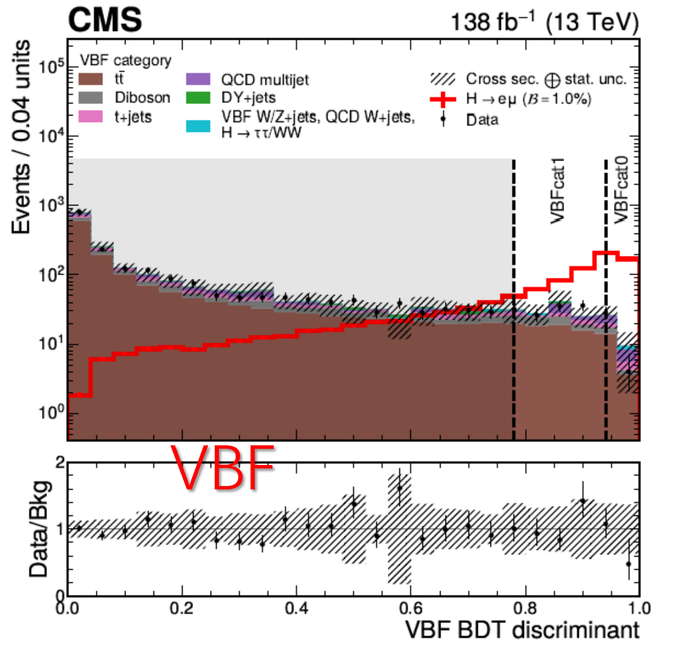
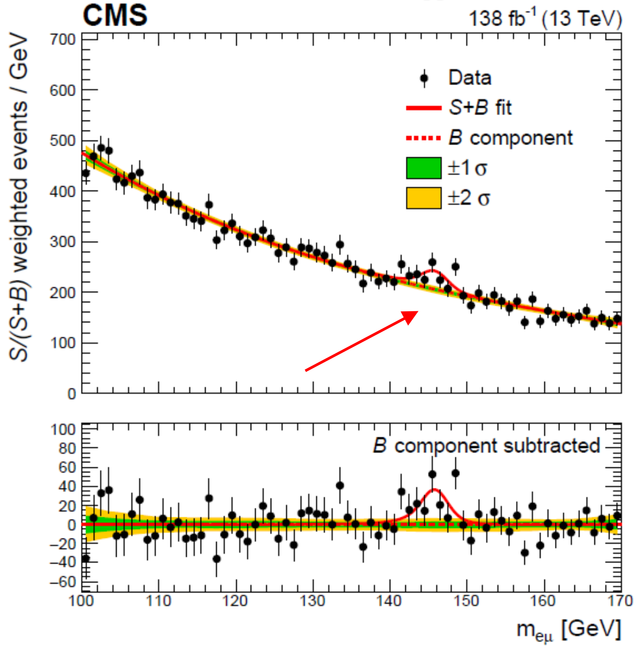
Additional Higgs bosons with **mass below $2m_W$** in the **lepton-flavor violating** decay channels is important to **constrain the Type-III 2HDM model**

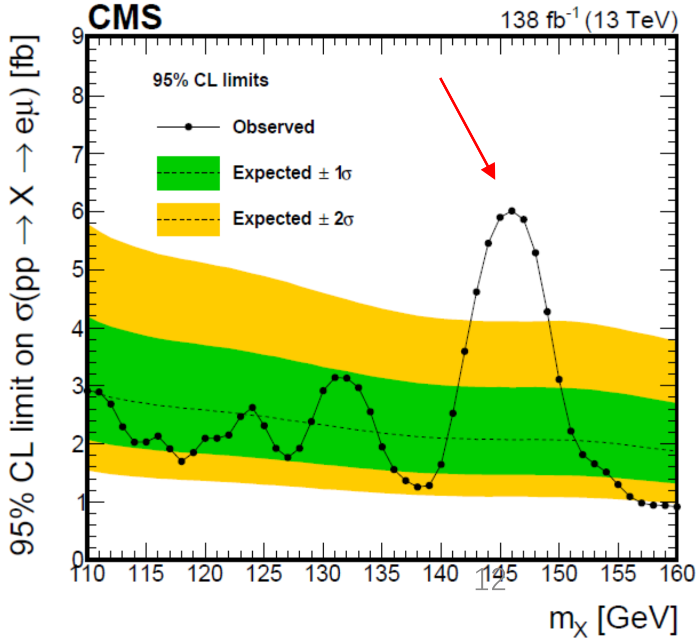
- **First direct search at the LHC**
- Signal topology : **opposite-sign eμ pair**; possible additional jets (no b-jets)
- Events are split into **production modes**, then into categories based on the **output of BDTs**
- Signal is extracted from bkg using a parametric fit to the **$m_{e\mu}$ distribution**

3.8σ (2.8σ) local (global) excess @ 146 GeV







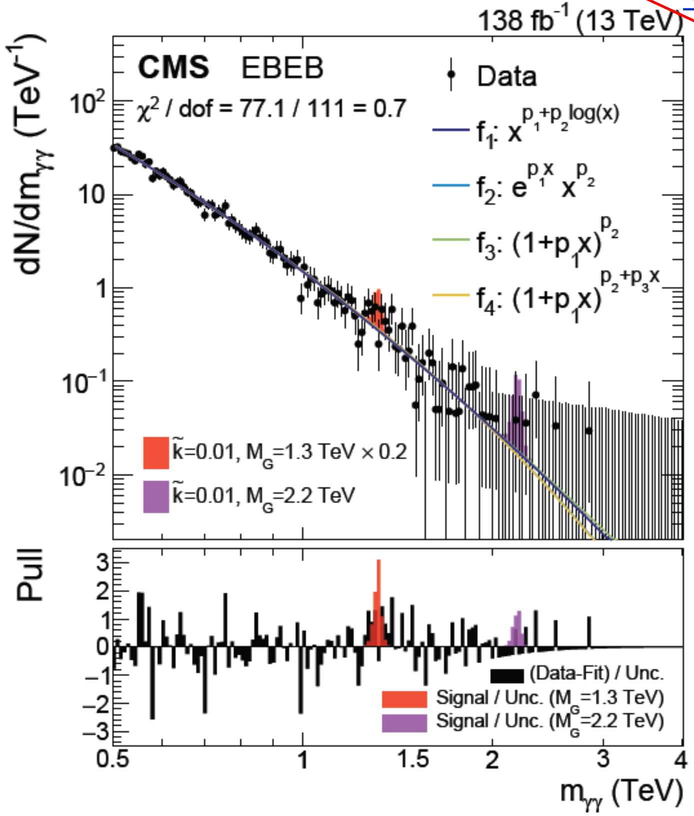


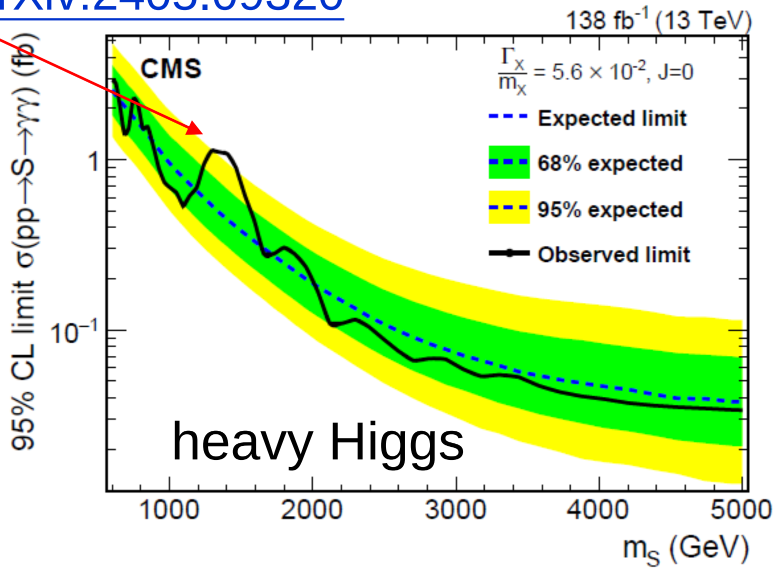
High mass X→γγ / Wγ / WW

- **X→γγ: bump search in the diphoton mass spectrum (> 500 GeV)**
- Two channels: EB+EB, EB+EE

2.6σ (0.8σ) local (global) excess @ ~1.3 TeV for the broad resonance model

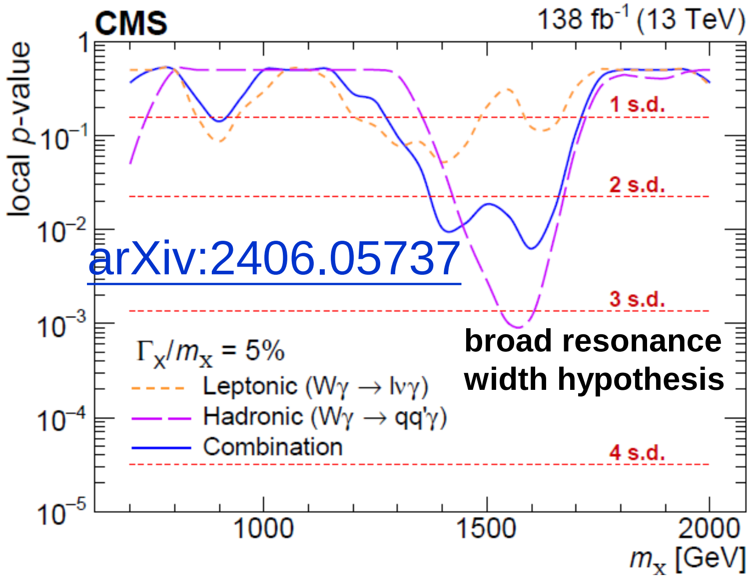
arXiv:2405.09320





- **X→Wγ : W both leptonic and hadronic decays**

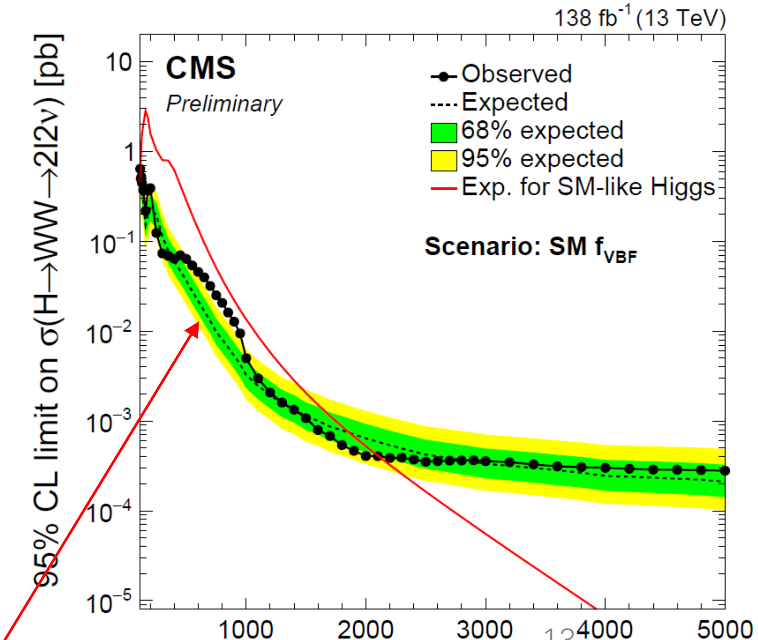
Local excess of 3.1σ in the hadronic analysis reduced to 2.5σ with the two channels combined, at ~1.58 TeV



arXiv:2406.05737

- **ggF/VBF X→WW : W fully leptonic decay (eμ, μμ, ee)**

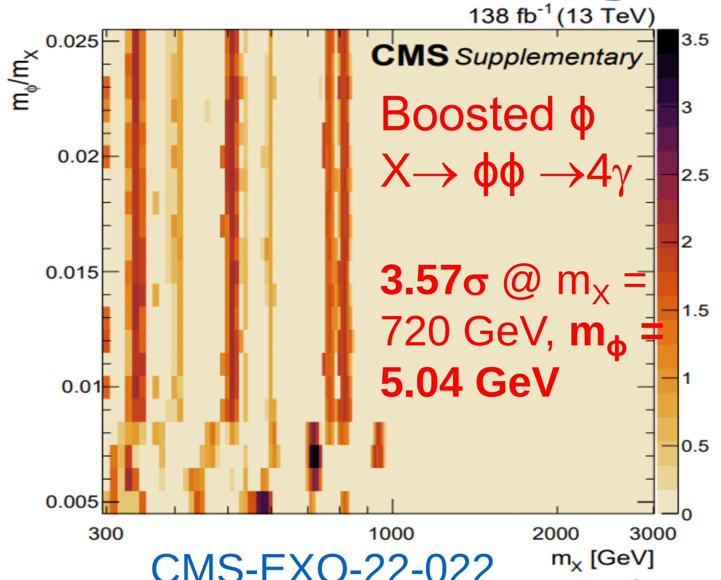
over 2σ between 500-900 GeV



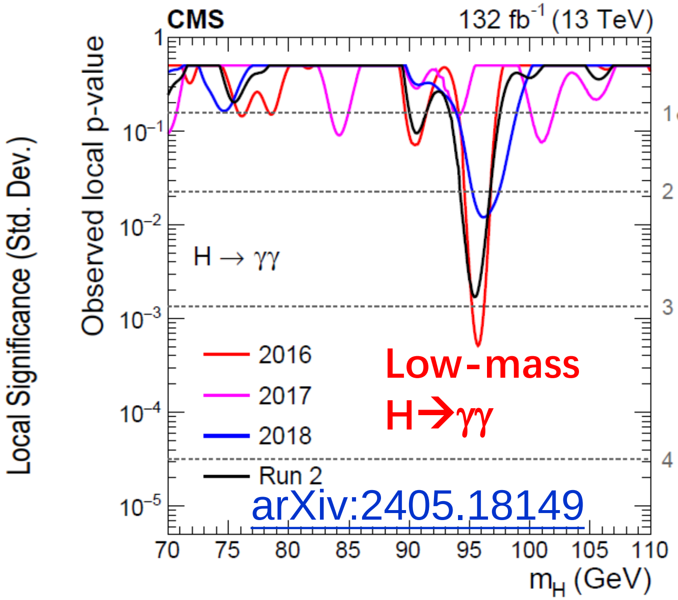
CMS-PAS-HIG-20-016

Summary

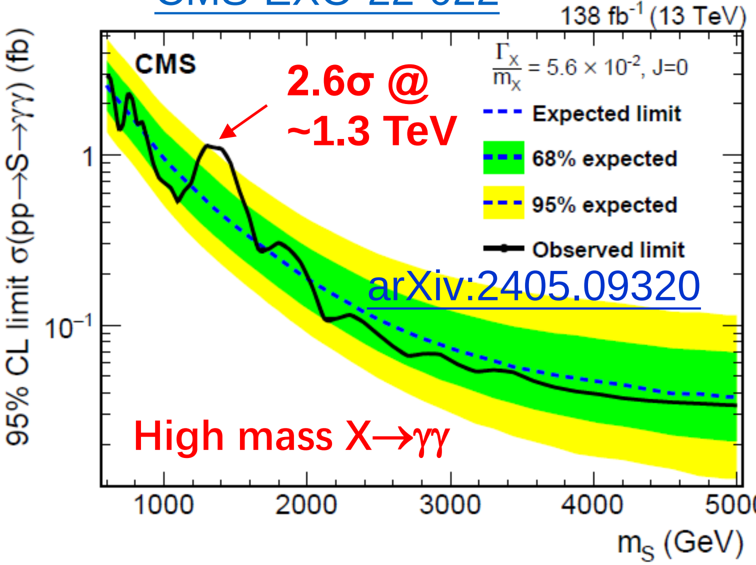
- Selected **CMS** latest results of searches for **additional scalars** using full Run2 data are presented
- **No direct evidence of new physics yet, but several mild excesses**
- More data is needed to conclude on the nature of these excesses
- Run3 (now ~140 fb^{-1}) is expect to collect ~1.5 times data than Run2

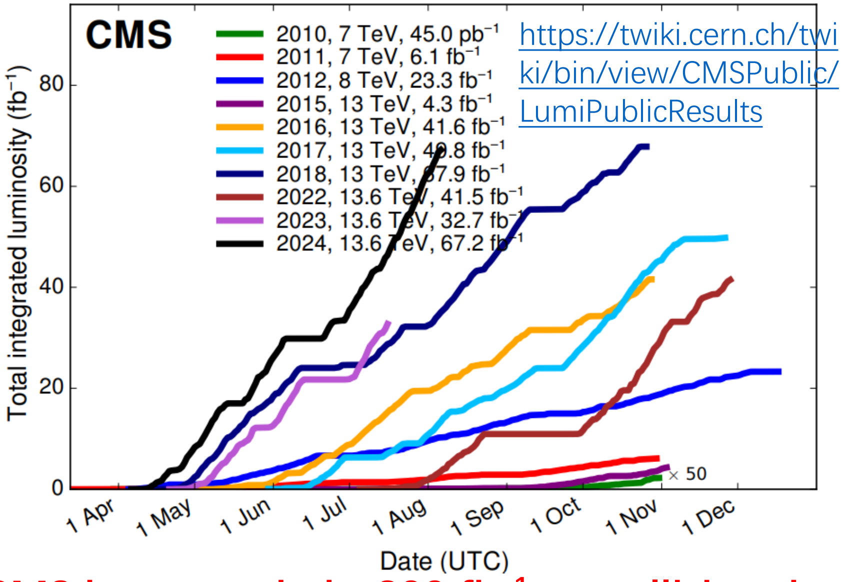


CMS-EXO-22-022



2.9σ @ 95.4 GeV

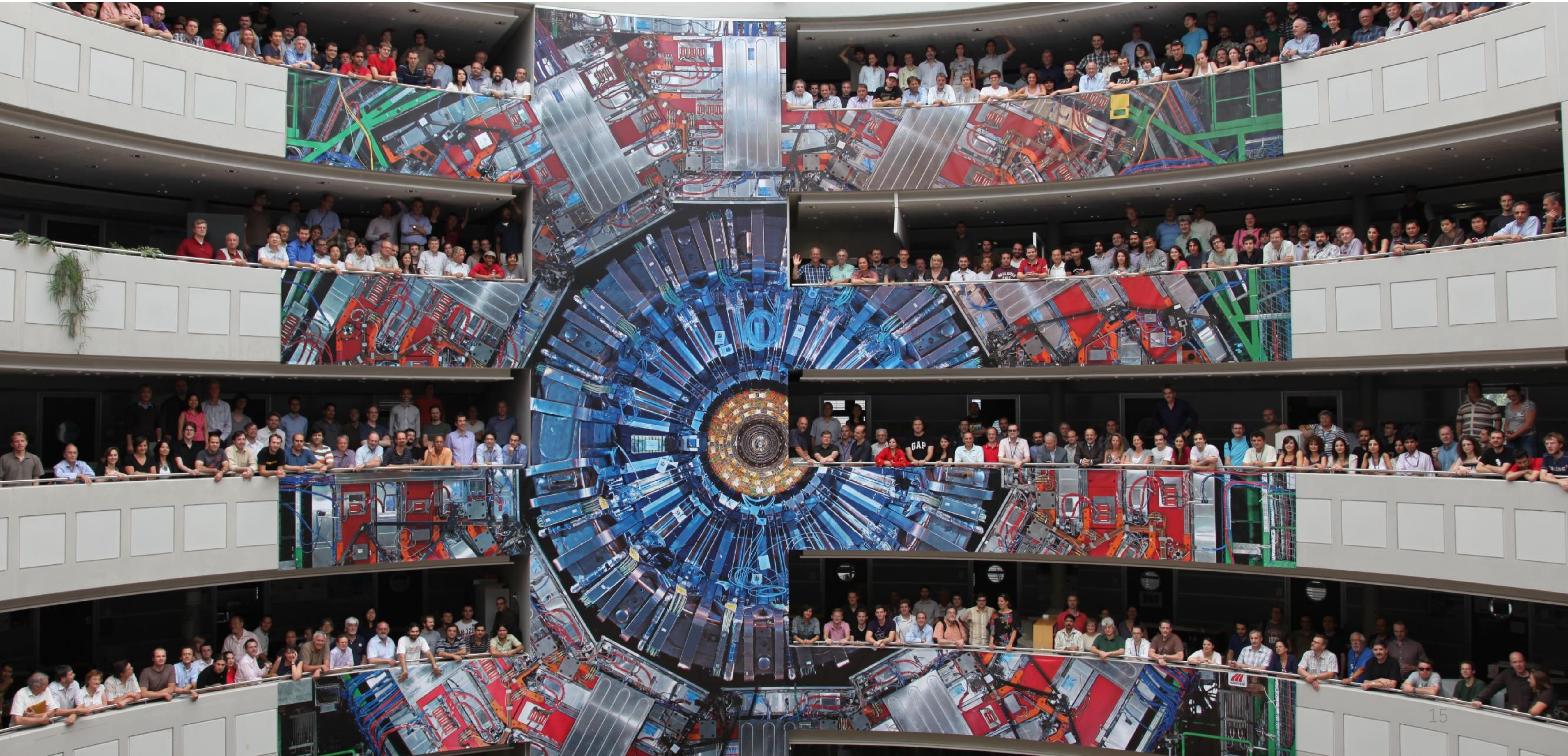




CMS has recorded >300 fb^{-1} pp collision data

Stay tuned for Run3 results !

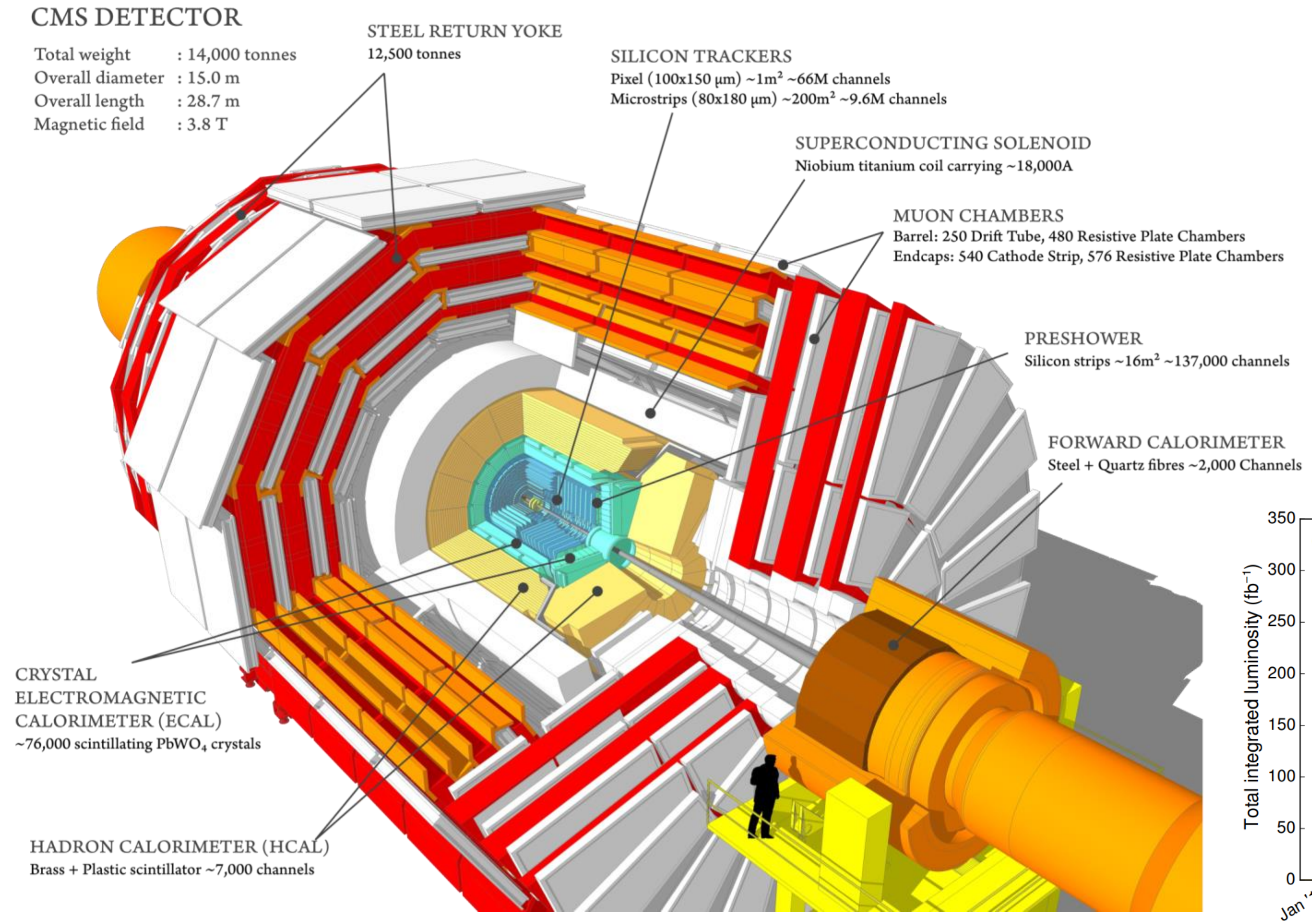
Thanks for your attention!



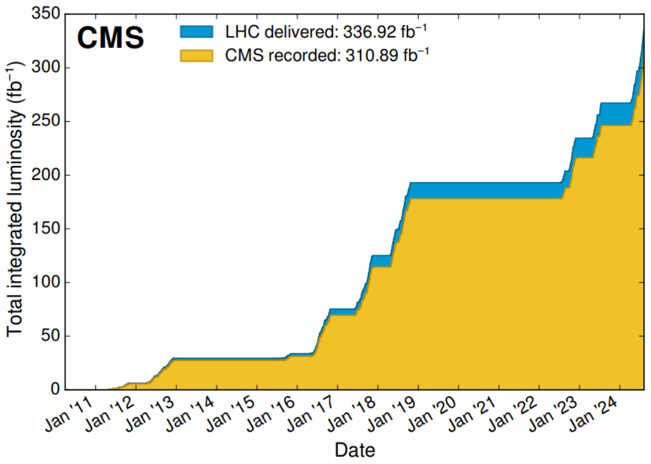
Backup slides

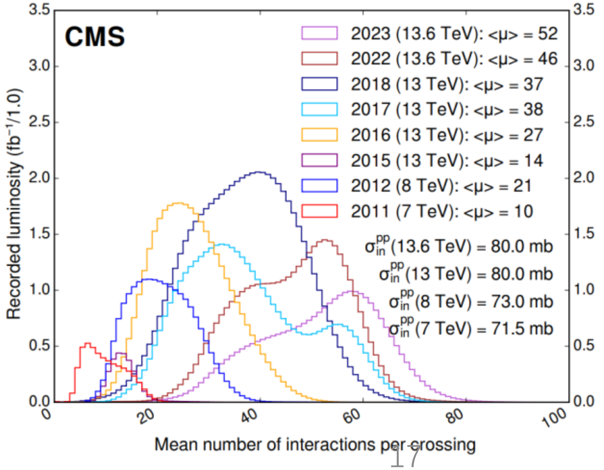
CMS experiment at the LHC

- CMS (Compact Muon Solenoid) detector is a **general-purpose detector**, designed to observe any **new physics** phenomena (including Higgs boson)



- **Data-taking started 14 years ago!**



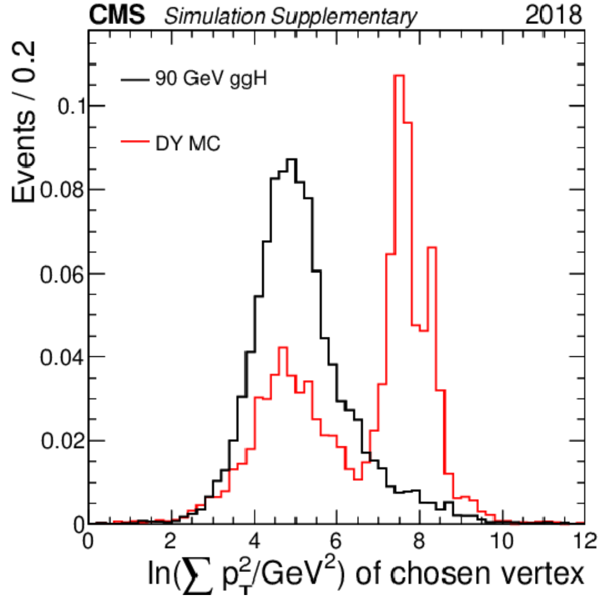


https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults

SM-like LM H→γγ search with full Run2

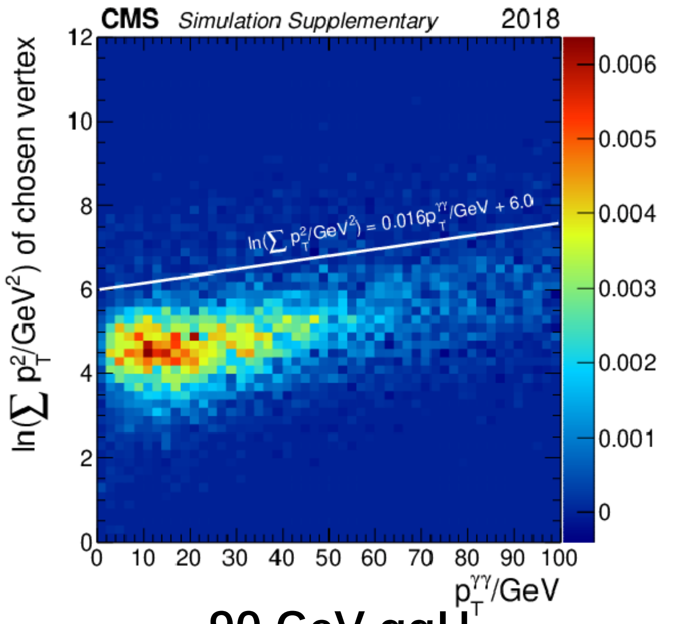
- **Major changes** wrt prior version (*PLB 793 (2019) 320*) (2012+2016 data):
  - ✓ A Kinematic **diphoton BDT** ($pt/m_{\gamma\gamma}$, η, $cos(\phi_{\gamma 1}-\phi_{\gamma 2})$, *both Photon ID MVA scores, mass resolutions wrt correct and incorrect vertices, vertex probability*) for **sig and bkg discrimination** **retrained and reoptimized** for events categorization, **for low-mass case**
  - ✓ **Relic DY (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 $p_T^{\gamma\gamma}$ (GeV)**:

      $\ln(\Sigma p_T^2) < 0.016\, p_T^{\gamma\gamma} + 6$
  - ✓ **2017/18**: events with additional jets selected for class targeting VBF process
  - ✓ **2016**: data reanalyzed with an **improved calibration (legacy data)**

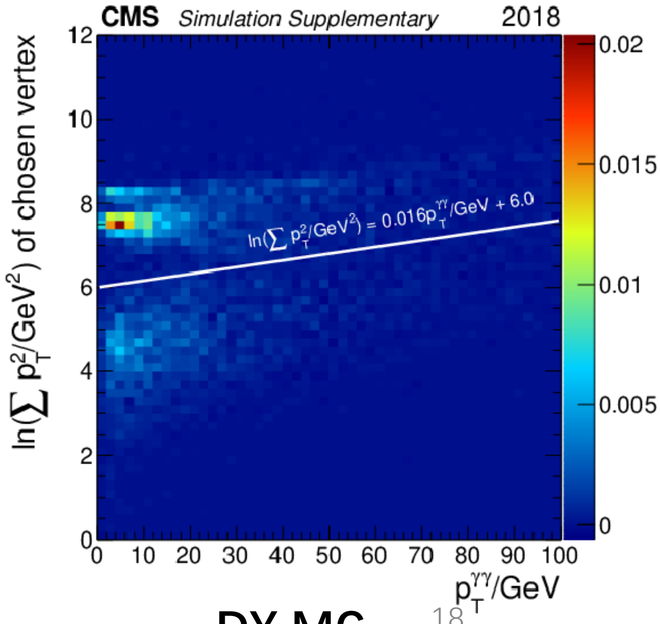


Public results

The 2 additional cuts can reject ~60%-70% of the relic DY events while keeping ~92% 90GeV signal efficiency in 2016-2018 analysis, on top of pixel seed e-veto

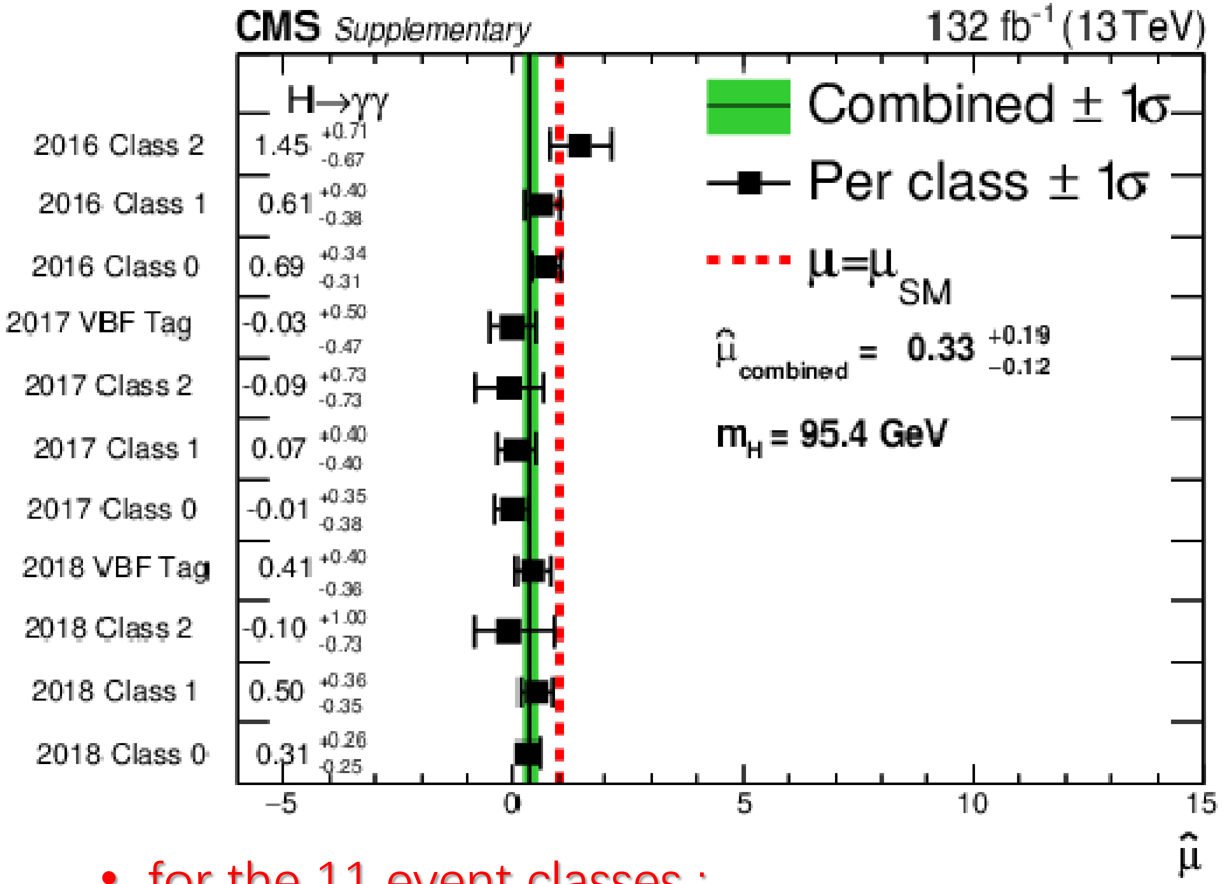


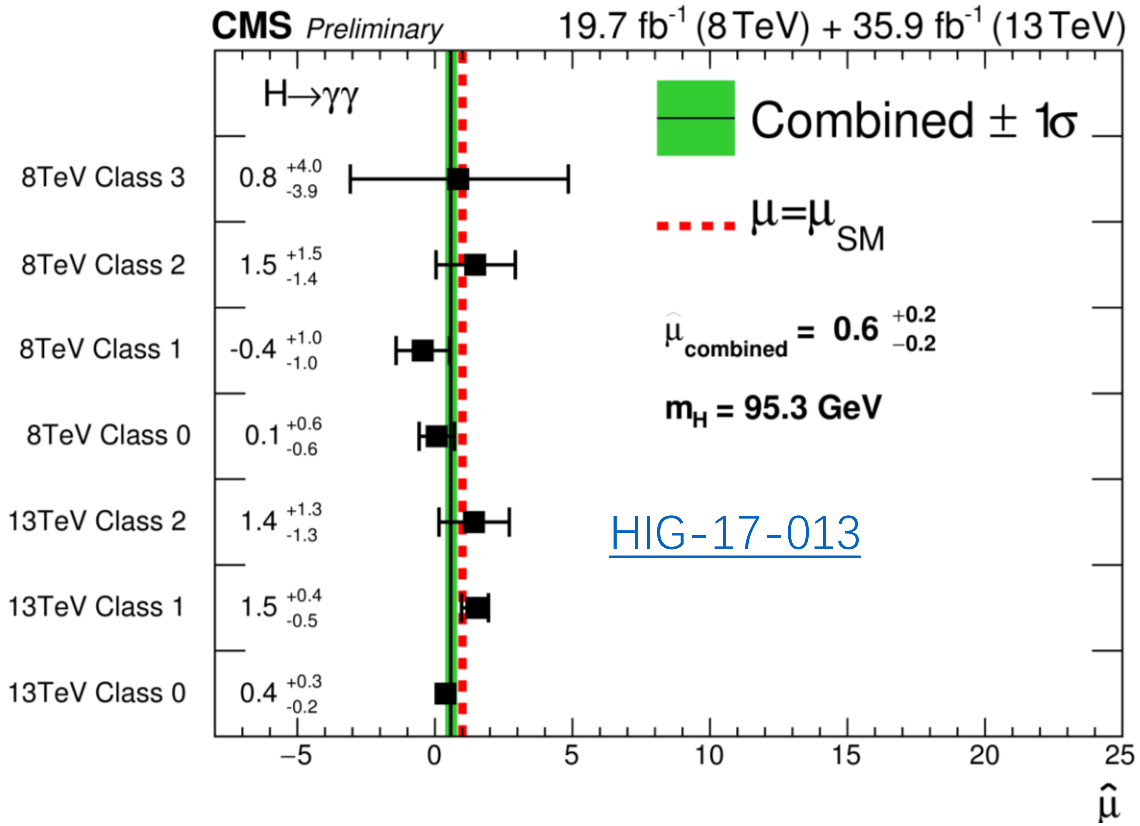
90 GeV ggH



DY MC

LM H→γγ 'signal' strength compatibility





HIG-17-013

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

HIG-20-002
Public results

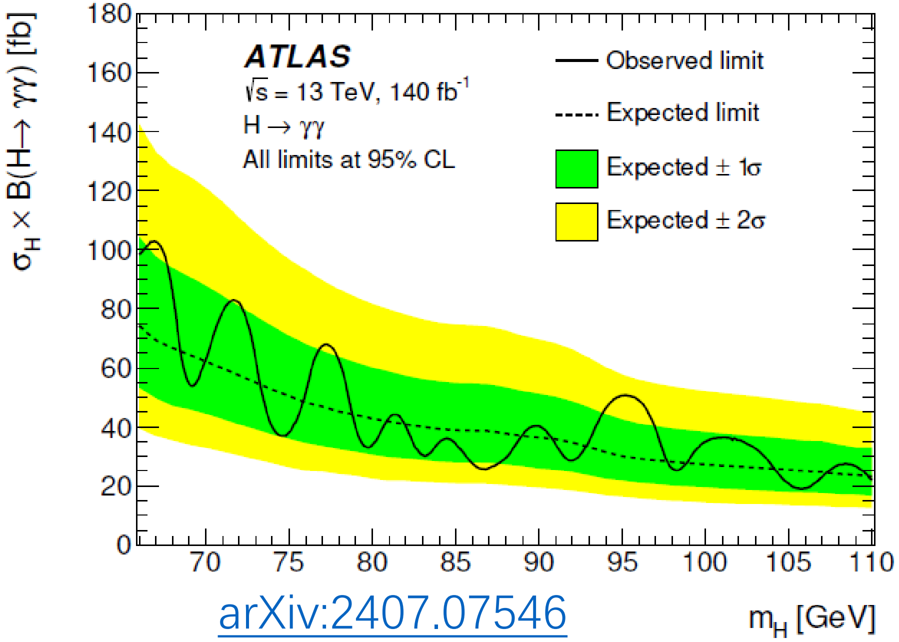
ATLAS full Run2 LM H→γγ results

ATLAS-CONF-2023-035

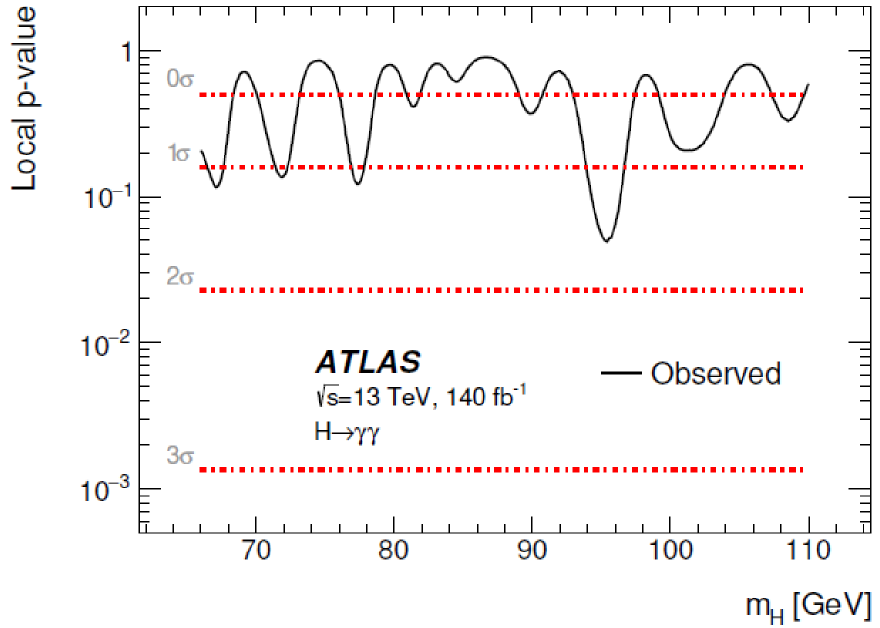
Released in June 2023 (~3 months later than CMS)

- ➢ **A kinematic diphoton BDT to separate sig from bkg, used for event classification**
- ➢ **Event categorization**
  - ✓ **3 conversion categories**
    - 2 unconverted photons (UU)
    - 1 converted photon only (UC+CU)
    - 2 converted photons (CC)
  - ✓ **BDT score** is used to further define **3 categories in each conversion cat**
  - ✓ **9 event classes in total**
- ➢ No significant excess is observed
- ➢ Upper limit $\sigma_{tot} \times$ BR = [19,102] fb @ 95 % CL

1.7σ @ 95.4 GeV

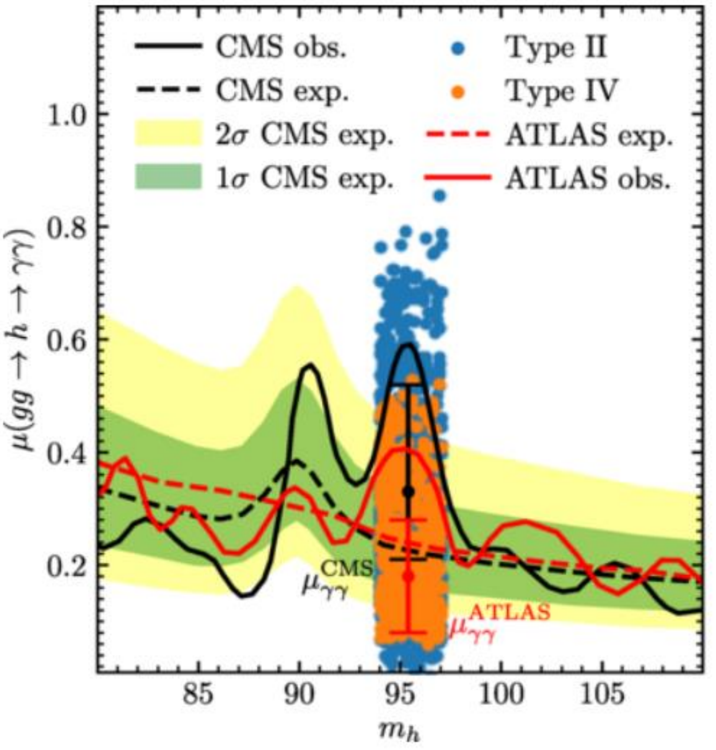


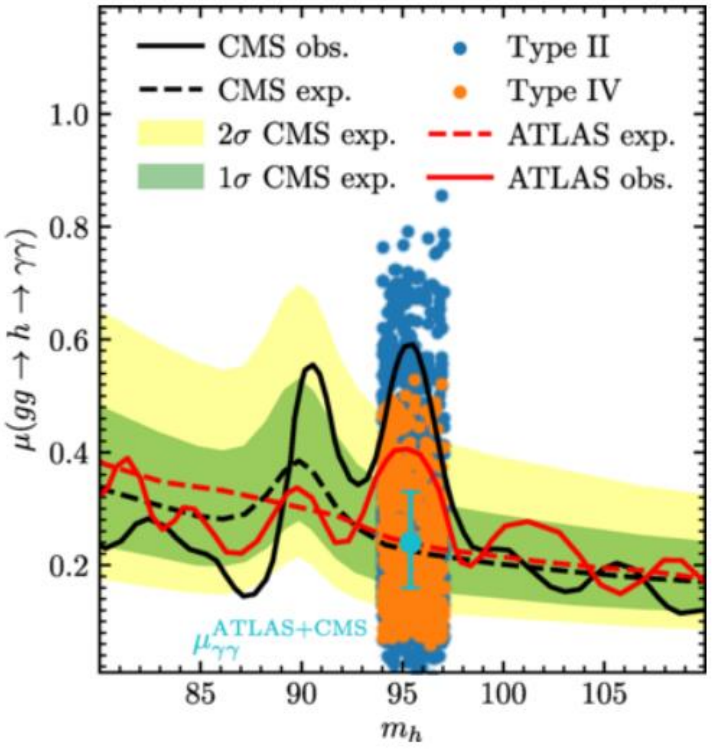
arXiv:2407.07546



Comparison, combination and BSM interpretations

T. Biekötter, S. Heinemeyer, G. Weiglein Phys. Rev. D **109**, 035005





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

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

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

corresponding to an excess of **3.2σ at 95.4 GeV**

CMS/ATLAS: 2.9 σ / 1.7 σ @ 95.4 GeV

CMS still has better sensitivity (except Z-peak region) than ATLAS, even with less data (132 vs 140 fb^{-1})

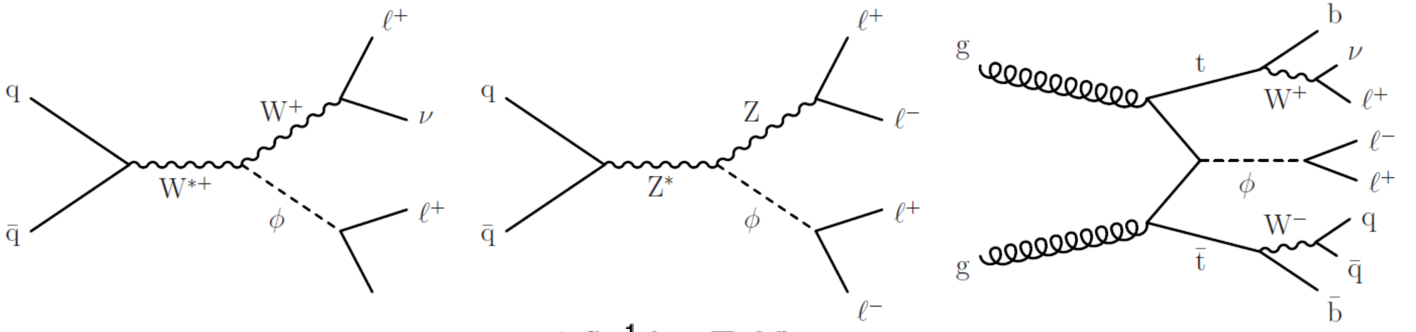
From Thomas Biekötter at the "Collider Cross Talk at CERN" (Sept. 2023)

Authors	Model	arXiv	Excesses	Comments
Cao, Guo, He et al.	nNMSSM	1612.08522	$bb + \gamma\gamma$	
Fox, Weiner	2HDM + VL	1710.07649	$bb + \gamma\gamma$	
Haisch, Malinauskas	2HDM	1712.06599	$bb + (\gamma\gamma)$	
TB, Heinemeyer, Muñoz	$\mu\nu$SSM	1712.07475	$bb + \gamma\gamma$	EW seesaw
Liu, Liu, Wagner, Wang	$U(1)_{L_\mu - L_\tau}$	1805.01476	$bb + \gamma\gamma$	B-anomalies
Domingo, Heinemeyer, Paßehr, Weiglein	NMSSM	1807.06322	$bb + \gamma\gamma$	
Hollik, Liebler, Moortgat-Pick et al.	μNMSSM	1809.07371	$bb + \gamma\gamma$	Inflation
TB, Chakraborti, Heinemeyer	N2HDM	1903.11661	$bb + \gamma\gamma$	
Cline, Toma	pNG + squarks	1906.02175	$bb + \gamma\gamma$	DM
Choi, Hui Im, Sik Jeong et al.	gNMSSM	1906.03389	$bb + \gamma\gamma$	
Cao, Jia, Yue et al.	nNMSSM	1908.07206	$bb + \gamma\gamma$	Type-I seesaw
Aguilar-Saavedra, Joaquim	SM + $U(1)_{Y'}$	2002.07697	$bb + \gamma\gamma$	
TB, Olea-Romacho	S2HDM	2108.10864	$bb + \gamma\gamma$	DM, GC excess
TB, Grohsjean, Heinemeyer et al.	NMSSM	2109.01128	$\gamma\gamma$	400 GeV excess
Heinemeyer, Lika, Moortgat-Pick et al.	2HDM+s	2112.11958	$bb + \gamma\gamma$	
TB, Heinemeyer, Weiglein	N2HDM	2203.13180	$bb + (\tau\tau) + \gamma\gamma$	
TB, Heinemeyer, Weiglein	N2HDM	2204.05975	$bb + (\tau\tau) + \gamma\gamma$	CDF M_W
Benbrik, Boukidi, Moretti et al.	A2HDM-III	2204.07470	$bb + \gamma\gamma$	LFV
TB, Heinemeyer, Weiglein	S2HDM	2303.12018	$bb + (\tau\tau) + \gamma\gamma$	DM
Azevedo, TB, Ferreira	C2HDM	2305.19716	$bb + \tau\tau + \gamma\gamma$	
Bonilla, Carcamo, Kovalenko et al.	Left-Right model	2305.11967	$\gamma\gamma$	DM
TB, Heinemeyer, Weiglein	S2HDM	2306.03889	$bb + (\tau\tau) + \gamma\gamma$	ATLAS-$\gamma\gamma$
Escribano, Martín Lozano, Vicente	Scotogenic	2306.03735	$bb + \gamma\gamma$	DM, ν masses
Belyaev, Benbrik, Boukidi et al.	A2HDM	2306.09029	$bb + (\tau\tau) + \gamma\gamma$	
Ashanuman, Banik, Coloretti et al.	$Y = 0$ triplet	2306.15722	$\gamma\gamma$	CDF M_W
Aguilar-Saavedra, Camara, Joaquim et al.	UN2HDM	2307.03768	$(\tau\tau)$, $\gamma\gamma$	

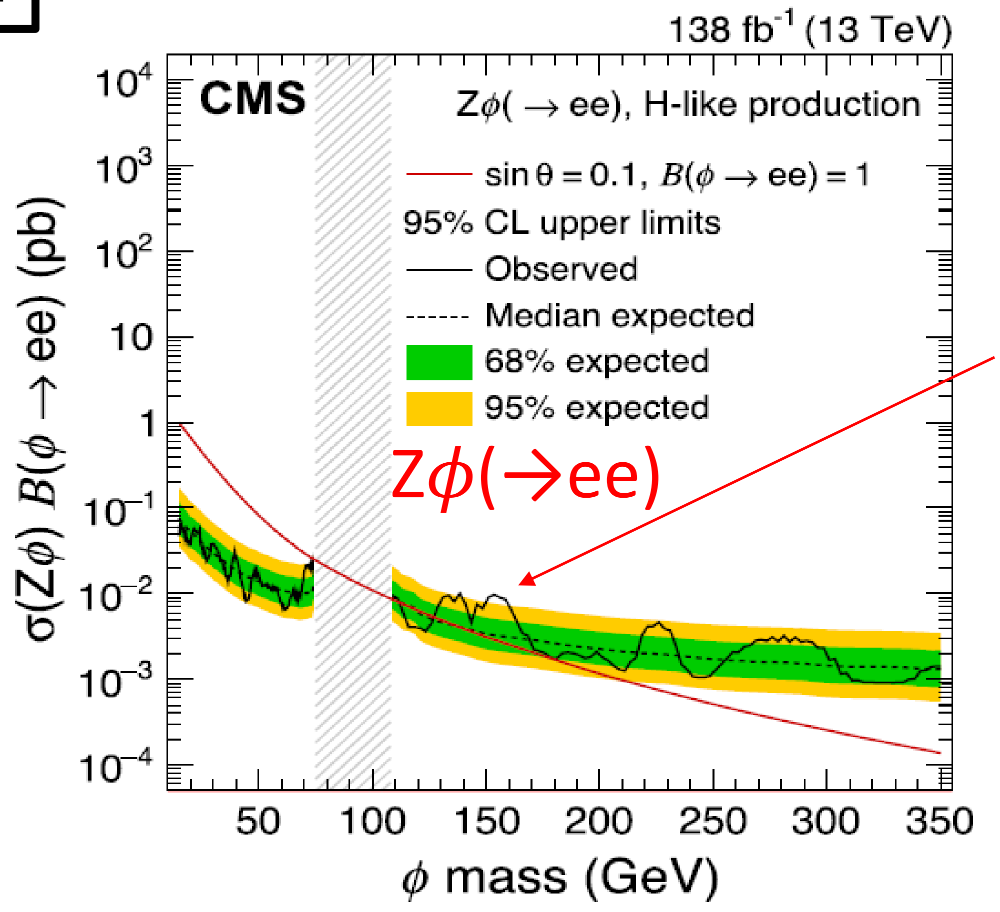
Green: 2HDM(+X); Blue: Susy; Red: Extra charged fields

Search for tt/Z $\phi \rightarrow ll$

First direct search for ϕ decays into all lepton flavors, with ϕ produced in association with **a massive vector boson** or **ttbar**



- **24 ϕ** signal scenarios for production mode, coupling, and decay are probed independently
- Signal is extracted based on $\mathbf{m_{ll}^{min}}$ ($\mathbf{m_{ll}^{max}}$) for low (high) mass search
- **No significant deviation** from the SM expectations



Phys. Rev. D 110, 012013

2.9σ (1.4σ) local (global) excess @ 156 GeV in Zϕ(→ee)

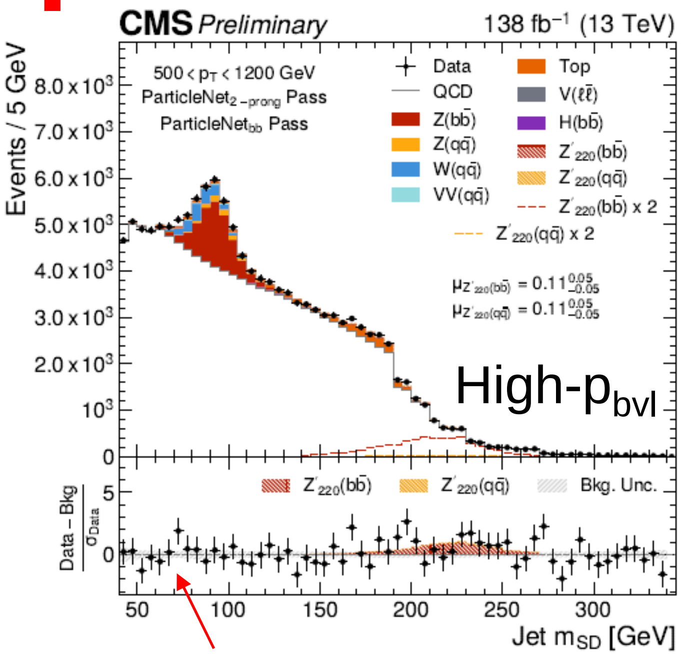
Not seen in Zϕ(→μμ), Wϕ, ttϕ production

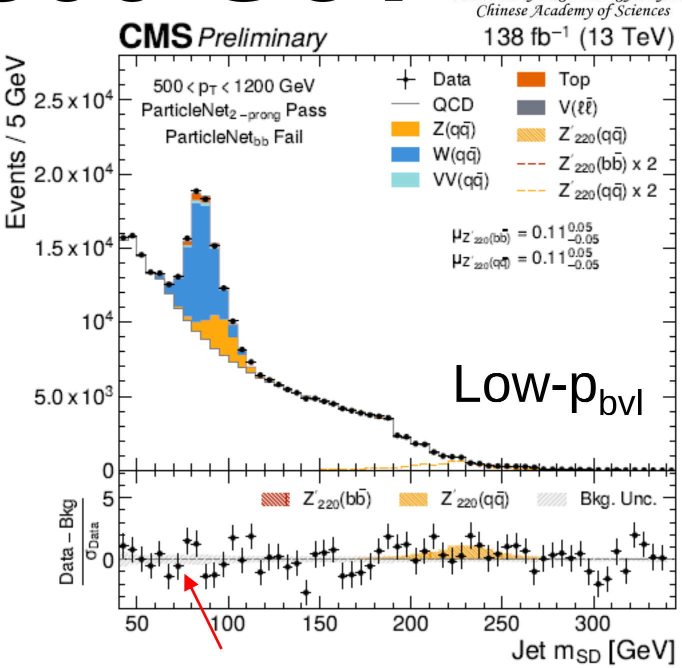
Search for scalar $\phi \rightarrow bb$: 50-300 GeV

- **Soft-drop jet mass** [1], m_{SD}, and the **mass-decorrelated ParticleNet (PN-MD) jet tagging** algorithm [2] are used to identify the signal resonances (X=Z'/ϕ/A) and distinguish them from the dominant QCD

[1] A. J. Larkoski, S. Marzani, G. Soyez, and J. Thaler, "Soft Drop", JHEP **05** (2014) 146

[2] H. Qu and L. Gouskos, "ParticleNet: Jet Tagging via Particle Clouds", Phys. Rev. D **101**(2020), no. 5, 056019



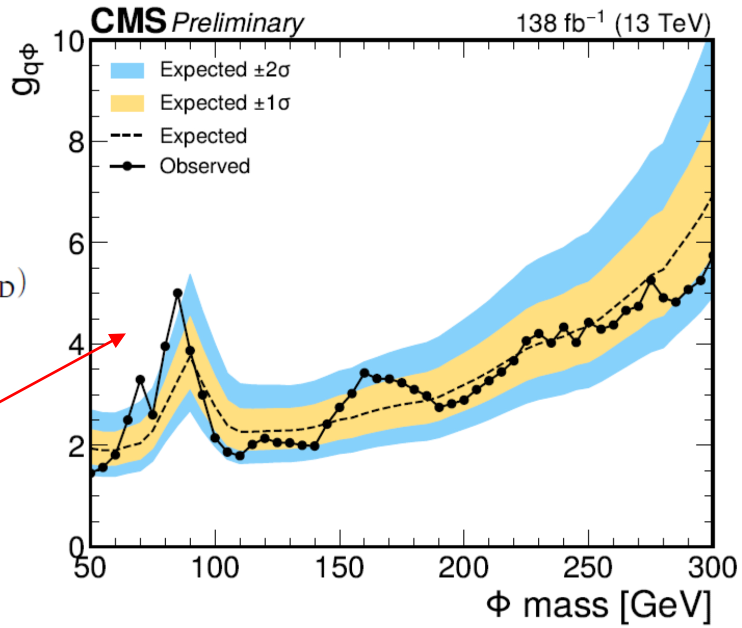


- **Two discriminants**, $p_{2\text{-prong}}$ to distinguish two-pronged resonances of any flavor from the **QCD background** and p_{bvl} discriminant to distinguish bb resonances from **cc** and $q_l q_l$ (**light quark-antiquark pairs**) resonances

$$p_{2\text{-prong}} \equiv (PN_{X\to b\bar{b}} + PN_{X\to c\bar{c}} + PN_{X\to q_l\bar{q}_l}) / (PN_{X\to b\bar{b}} + PN_{X\to c\bar{c}} + PN_{X\to q_l\bar{q}_l} + PN_{QCD})$$

$$p_{bvl} \equiv PN_{X\to b\bar{b}} / (PN_{X\to b\bar{b}} + PN_{X\to c\bar{c}} + PN_{X\to q_l\bar{q}_l})$$

Most significant deviation :
2.6σ (1.6σ) local (global)
deviation @ m_ϕ = 75 GeV



CMS-PAS-EXO-24-007

Upper limits on $g_{q\phi}$ range from 1.5–5.8
(coupling equal to the SM Yukawa coupling times a flavor-universal scaling factor)

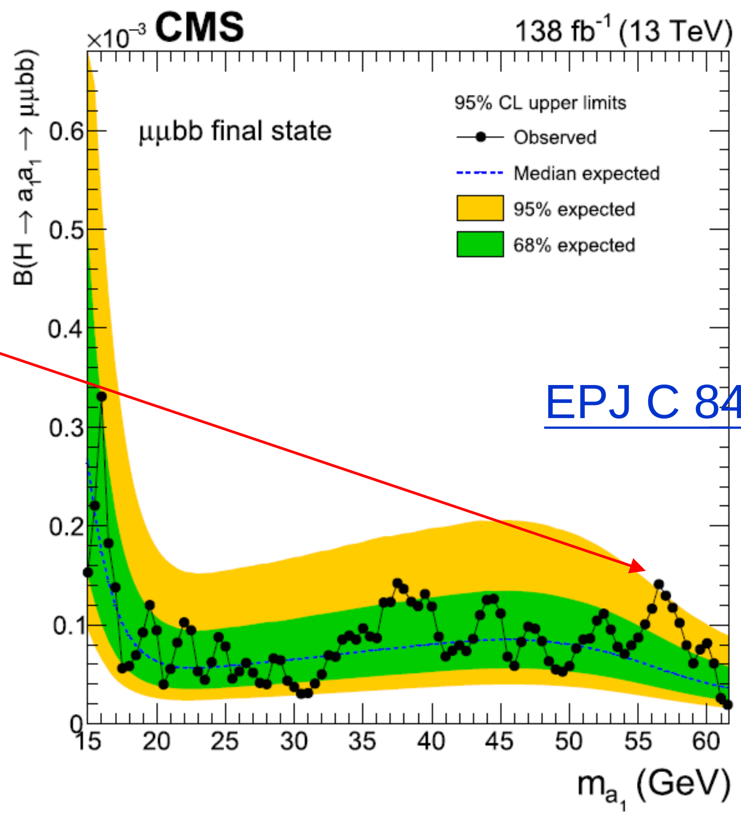
Most sensitive limits to date on dijet resonances with masses from 50–300 GeV

$H \rightarrow aa \rightarrow 2b2\mu$ / $2b2\tau$

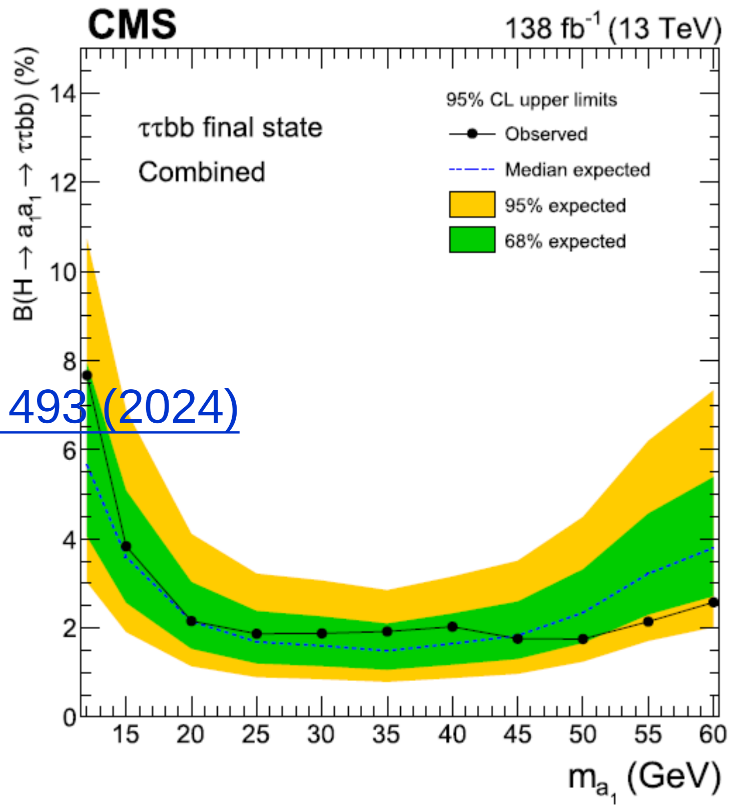
- **$2b2\mu$:** clean signature with a precise mass resolution from $m_{\mu\mu}$ and large branching ratio from bb
- Search for $15 < m_a < 62.5$ GeV GeV with fit to invariant mass $m_{\mu\mu}$
- Even categorization based on the b tagging working points (TL, TM, TT) : also included are dedicated VBF and low pT category

- **$2b2\tau$:** analysis categorization is based on lepton flavors and **number of b jets**
  - $\tau_e\tau_\mu b$, $\tau_\mu\tau_h b$, $\tau_e\tau_h b$
  - $\tau_e\tau_\mu bb$, $\tau_\mu\tau_h bb$, $\tau_e\tau_h bb$
- A **DNN** is used to define multiple categories in each category, to optimize the sensitivity

$2b2\mu$: over 2σ local @ ~57 GeV



EPJ C 84, 493 (2024)



$2b2\tau$: no excess is found

Both analyses provide the most stringent expected limits to date

H→aa→γγγγ

Resolved

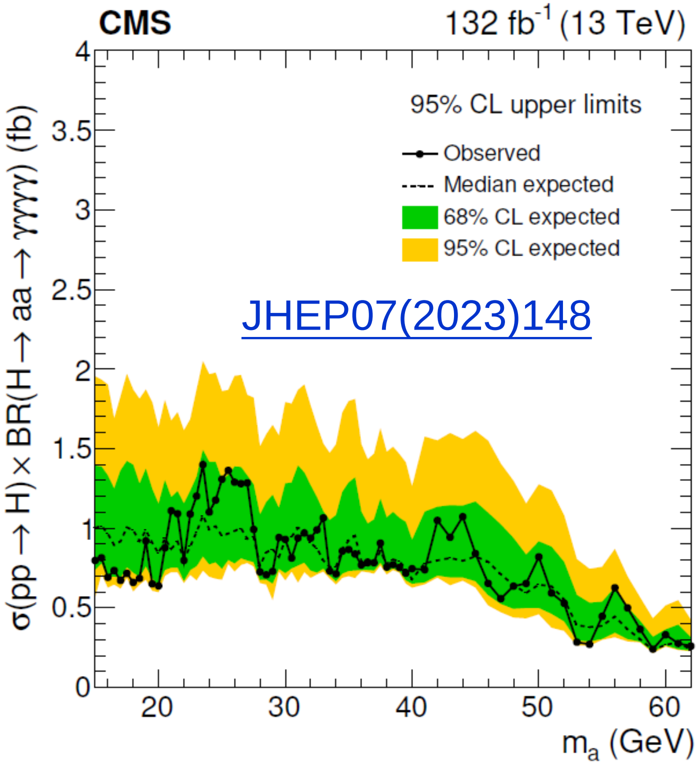
- **Four well-isolated photons** in the final state
- A dedicated **primary vertex (PV) BDT** is trained, to select PV with highest BDT score
- To improve the sensitivity, a **4-γ event classifier** is trained to separate sig from bkg: **a single category** optimized based on BDT output, for each m_a
- $m_{\gamma\gamma\gamma\gamma}$ **distribution** is used to extract signal
- **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.)

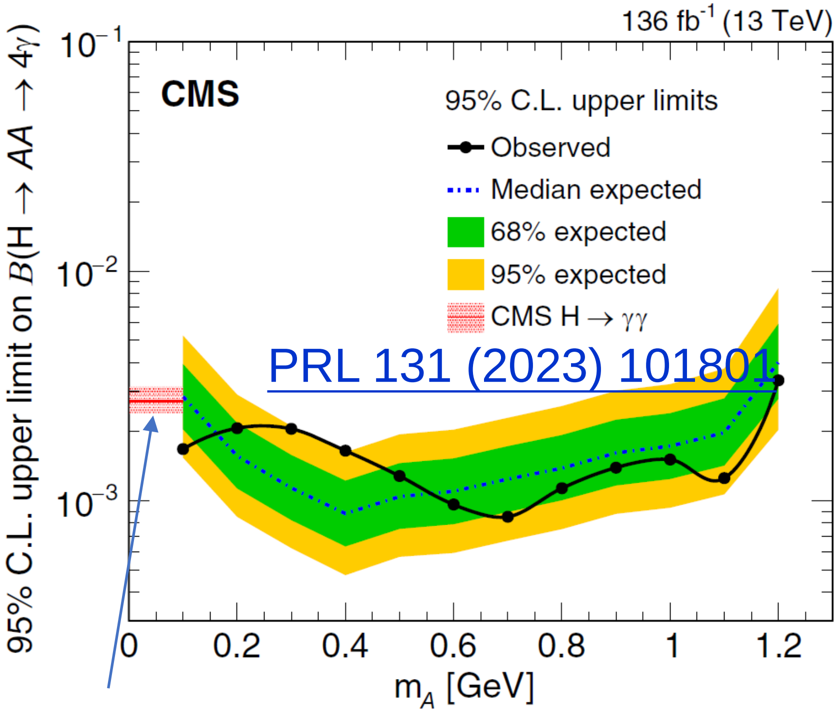
First CMS search in this channel

Boosted

- Two merged γ reconstructed as single Γ: 110 < $m_{\Gamma\Gamma}$ < 140GeV
- **Deep-learning used to reconstruct m_Γ of collimated di-γ**
- *Upper limits on the branching fraction* $B(H \to AA \to 4\gamma)$ of **(0.9-3.3) × 10^{-3}** at 95% CL

No excess observed

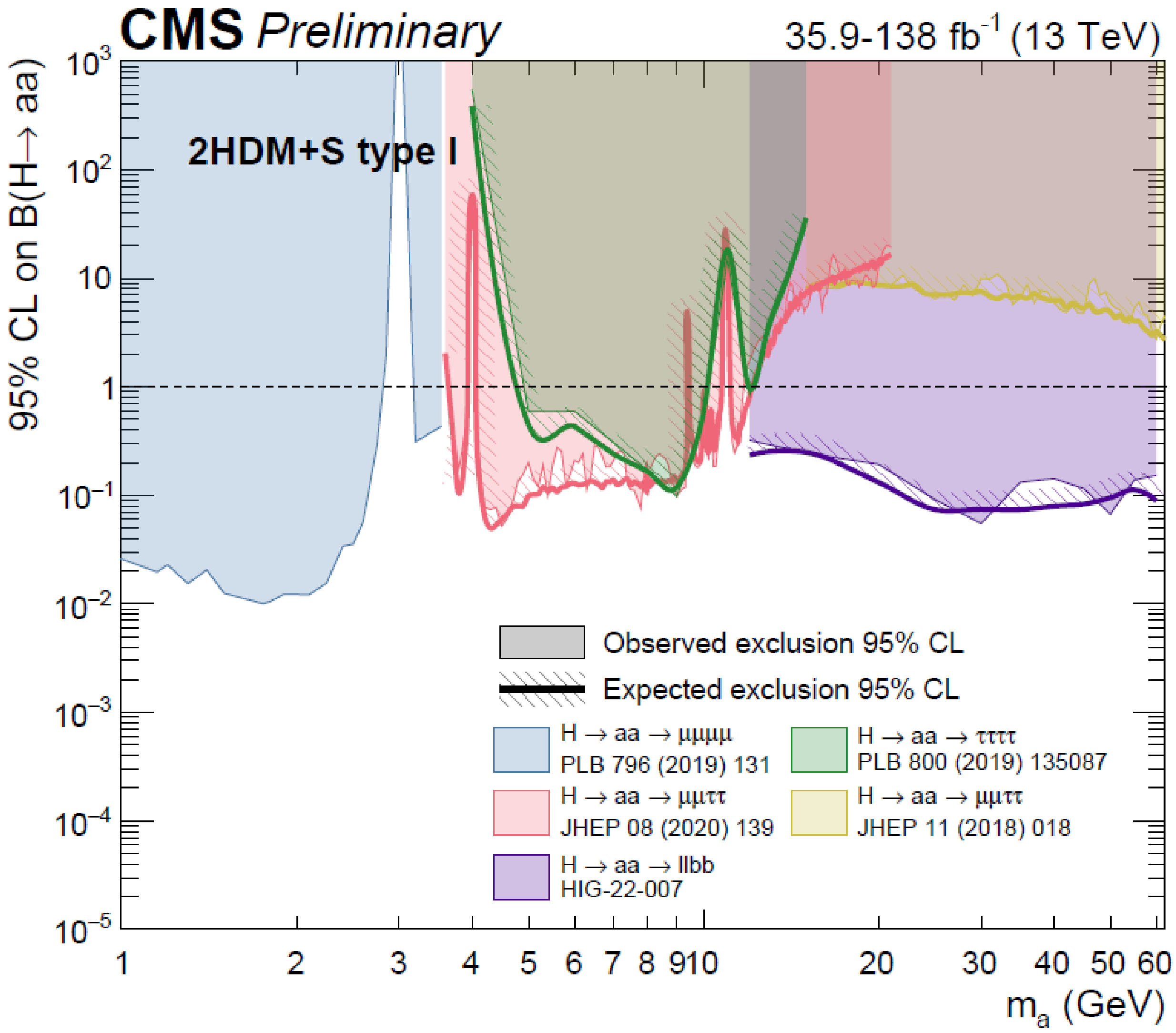


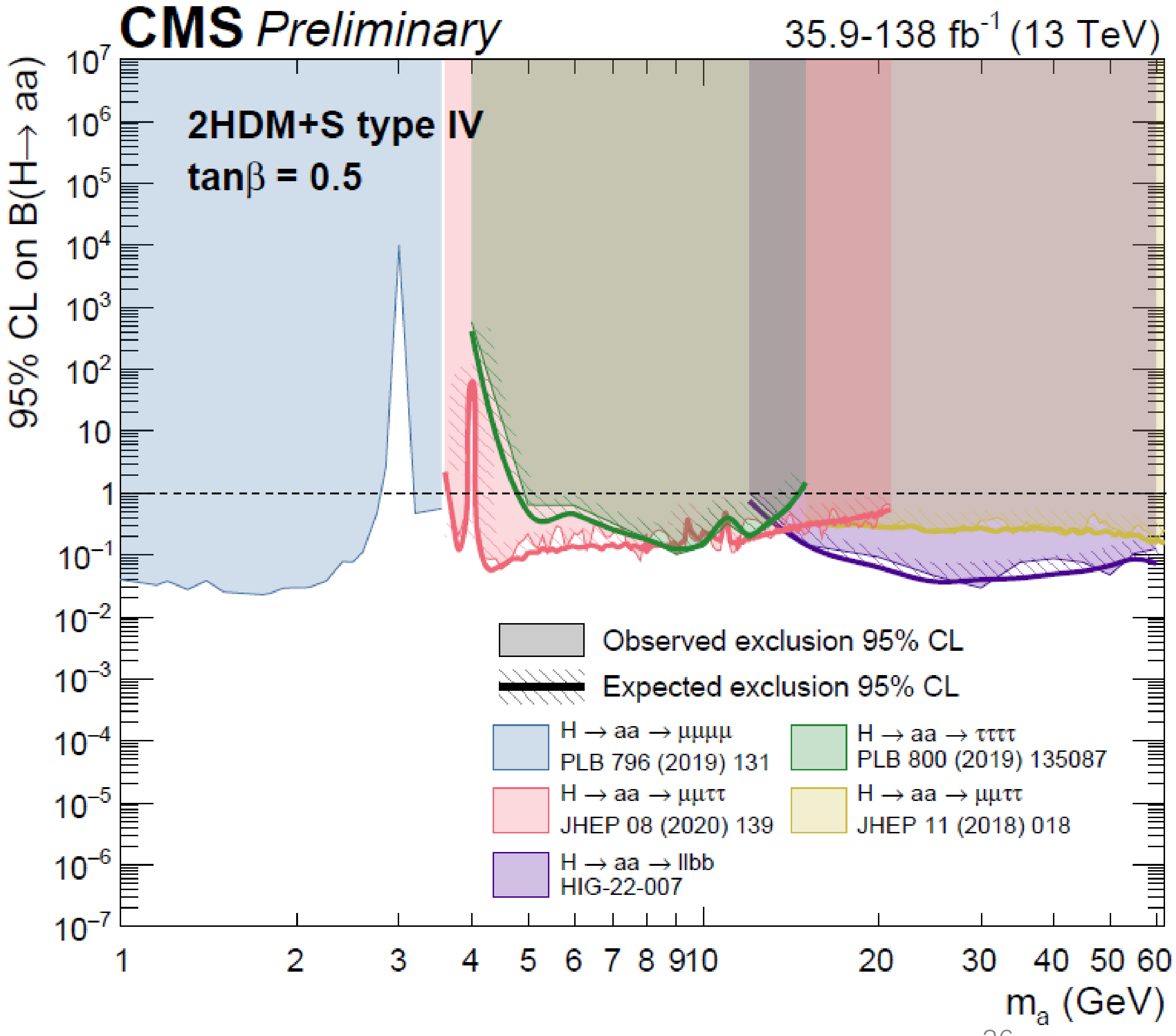


CMS upper limit of B(H→γγ)

Summary of H→aa limit

- Upper limit on BR(H→aa) depend on the 2HDM Types and model parameters





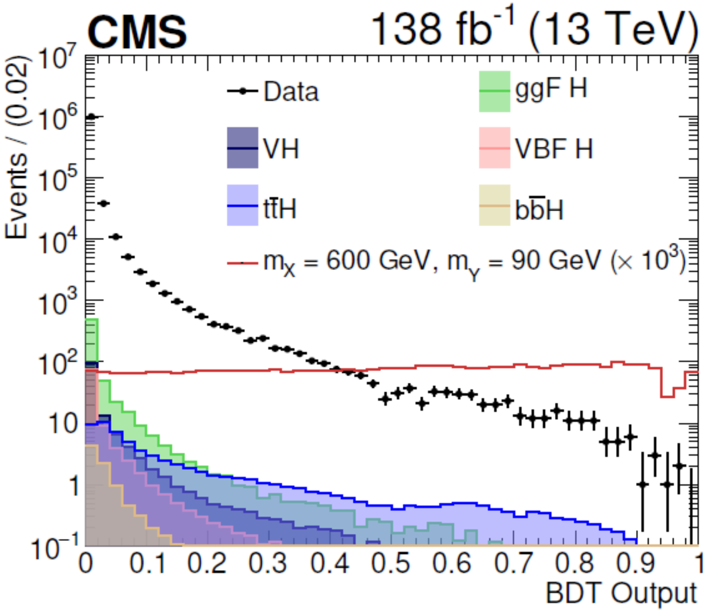
CMS public Higgs 2HDMS Summary Plot

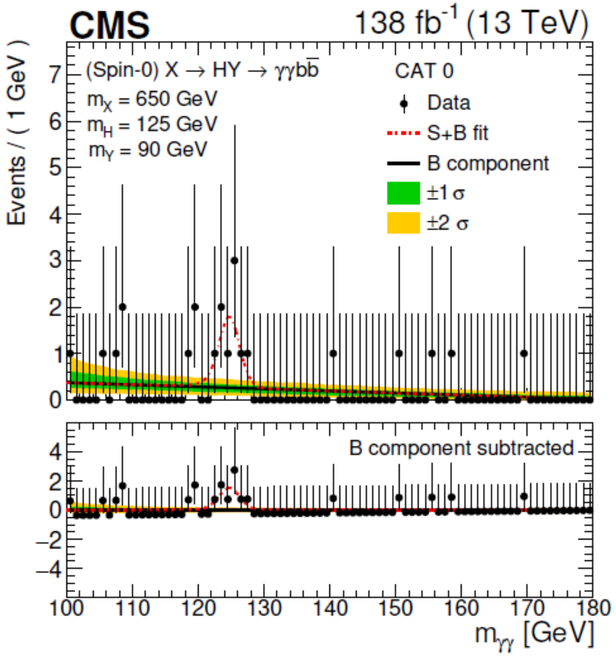
$X \to HH/YH \to bb\gamma\gamma$

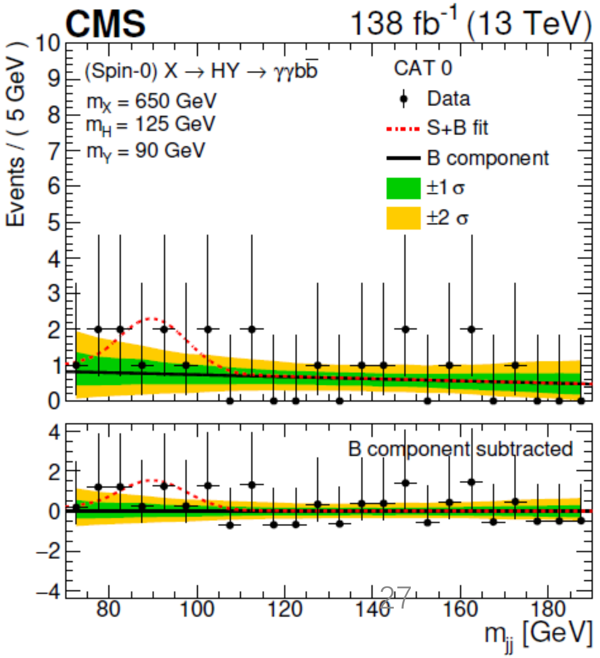
[JHEP05(2024)316](https://doi.org/10.1007/JHEP05(2024)316)

	$m_Y < 300$ GeV	$m_Y = [300–500]$ GeV	$m_Y > 500$ GeV
$m_X < 500$ GeV	CAT 0 = 0.63–1.0		
	CAT 1 = 0.33–0.63		
	CAT 2 = 0.17–0.33		
$m_X = [500–700]$ GeV	CAT 0 = 0.55–1.0	CAT 0 = 0.60–1.0	
	CAT 1 = 0.40–0.55	CAT 1 = 0.35–0.60	
	CAT 2 = 0.21–0.40	CAT 2 = 0.18–0.35	
$m_X > 700$ GeV	CAT 0 = 0.50–1.0	CAT 0 = 0.35–1.0	CAT 0 = 0.40–1.0
	CAT 1 = 0.30–0.50	CAT 1 = 0.24–0.35	CAT 1 = 0.29–0.40
	CAT 2 = 0.21–0.30	CAT 2 = 0.18–0.24	CAT 2 = 0.13–0.29

Table 2. The BDT based event classification according to defined m_X (and m_Y) ranges for HH (and HY) searches. For HH searches, the column with $m_Y < 300$ GeV is used. The number represents the BDT scores showing a decreasing signal purity region from category 0 to 2.

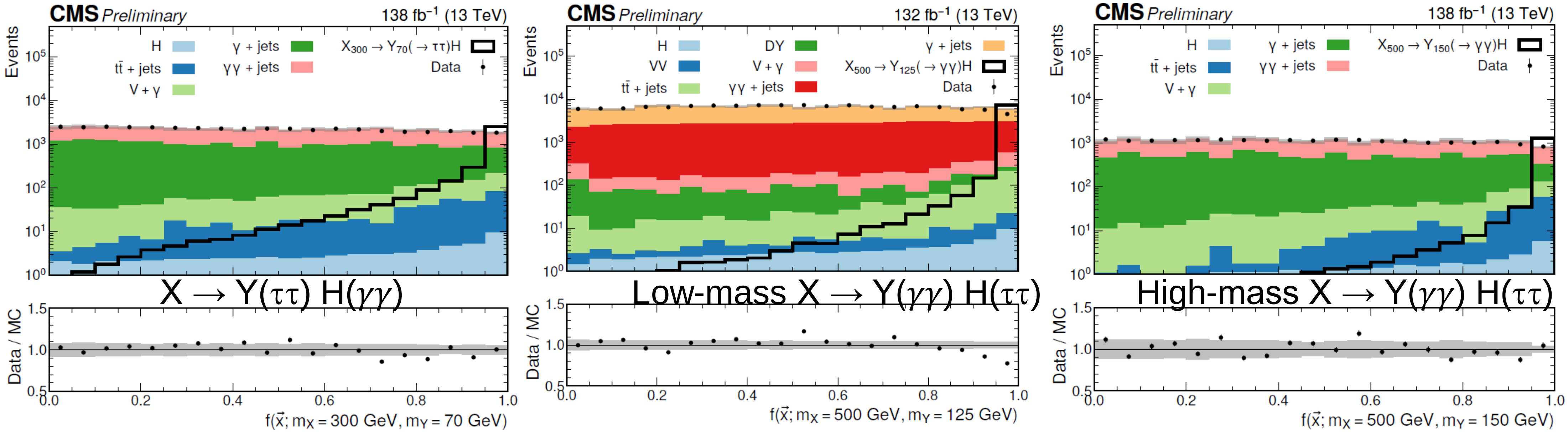




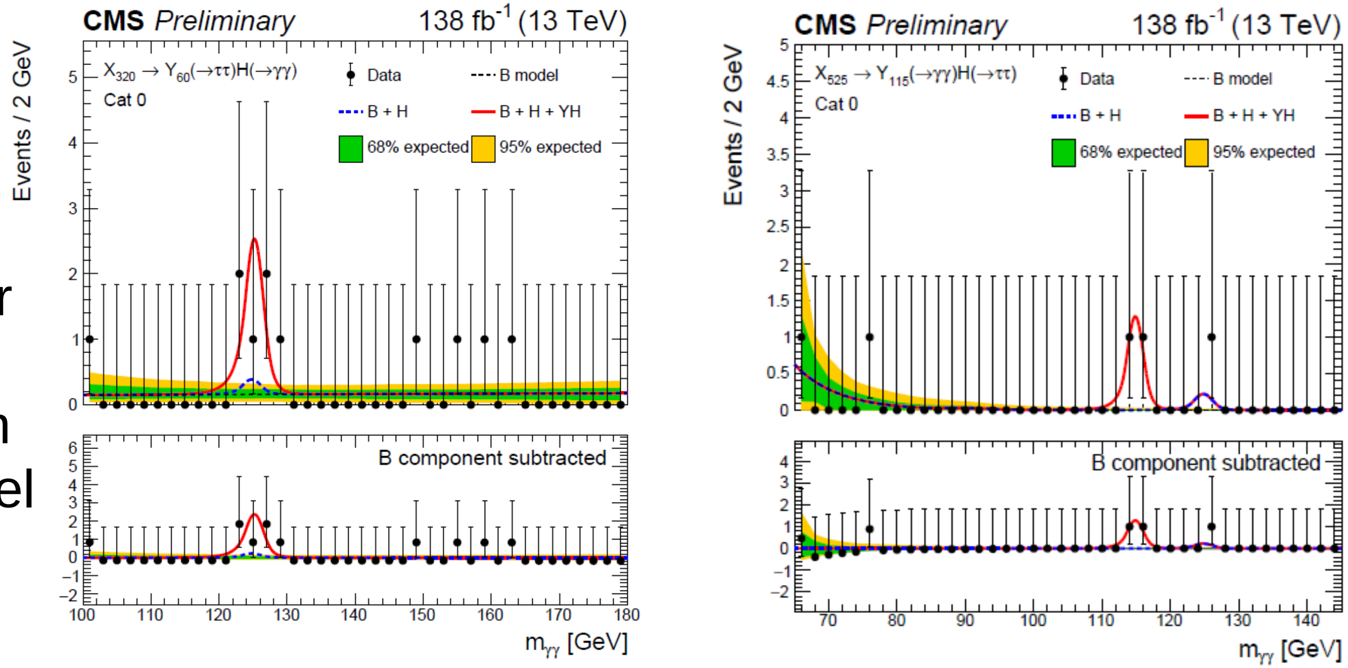


X → HH/YH → ττγγ

Transformed output of the pNNs



Data points (black) and S+B models for the most sensitive analysis category in each search channel



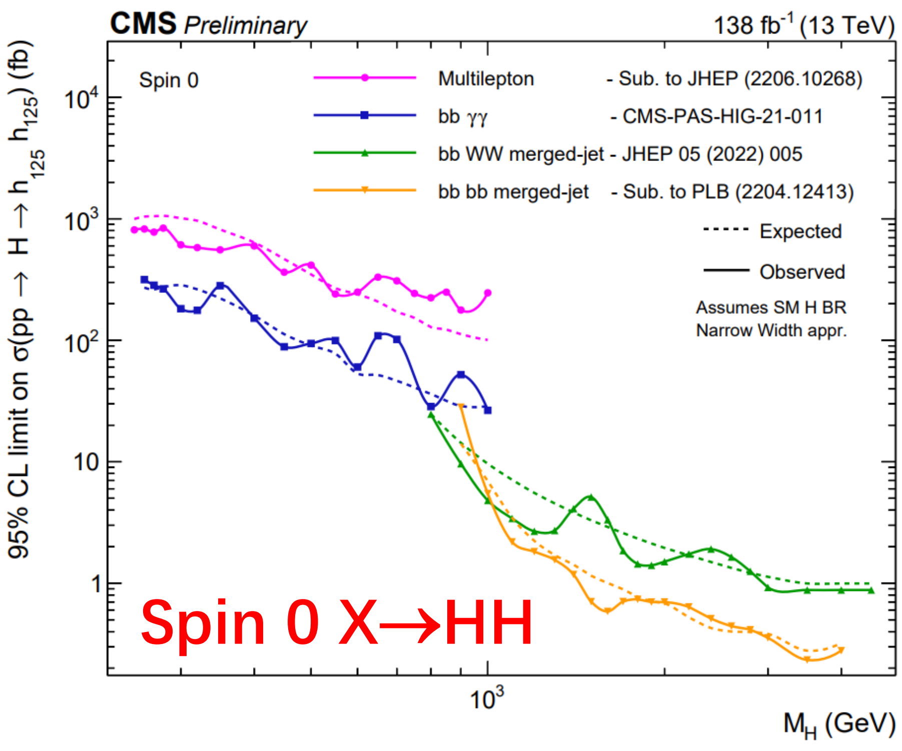
[CMS-PAS-HIG-22-012]

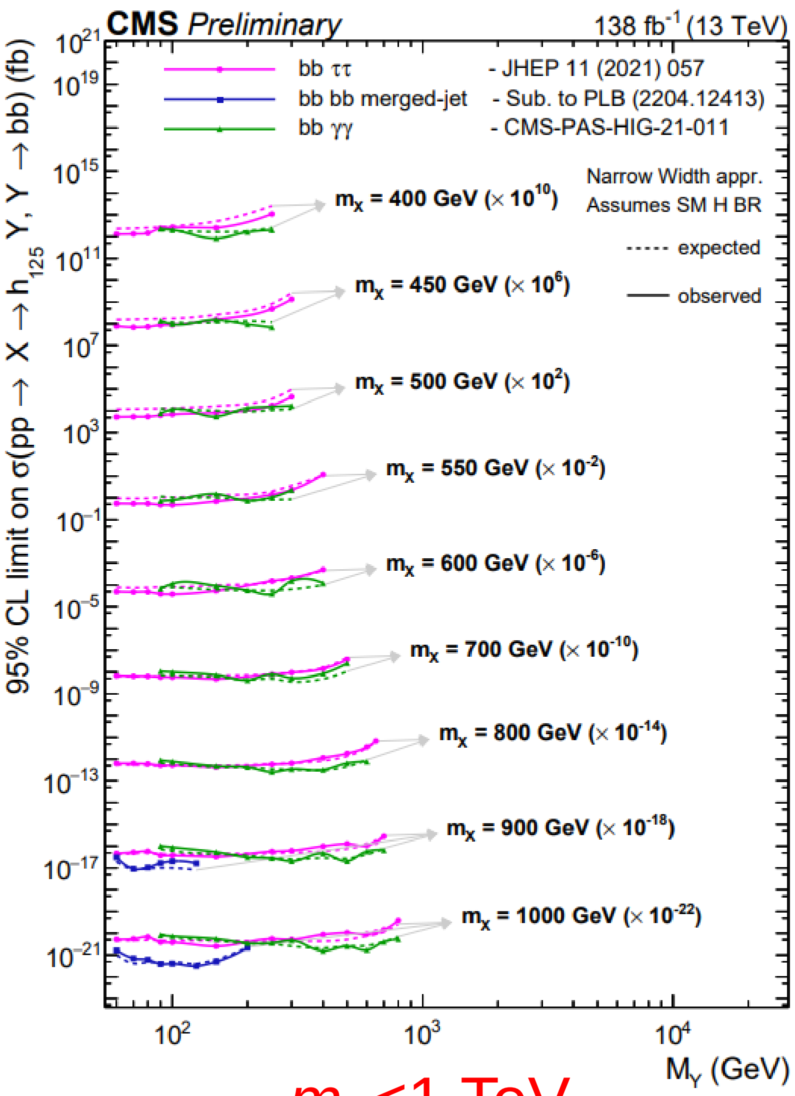
A sliding blinded region to construct mass sidebands for Y(γγ) H(ττ)

$$m_Y \pm 10\,\mathrm{GeV} \cdot \frac{m_Y}{125.38\,\mathrm{GeV}}$$

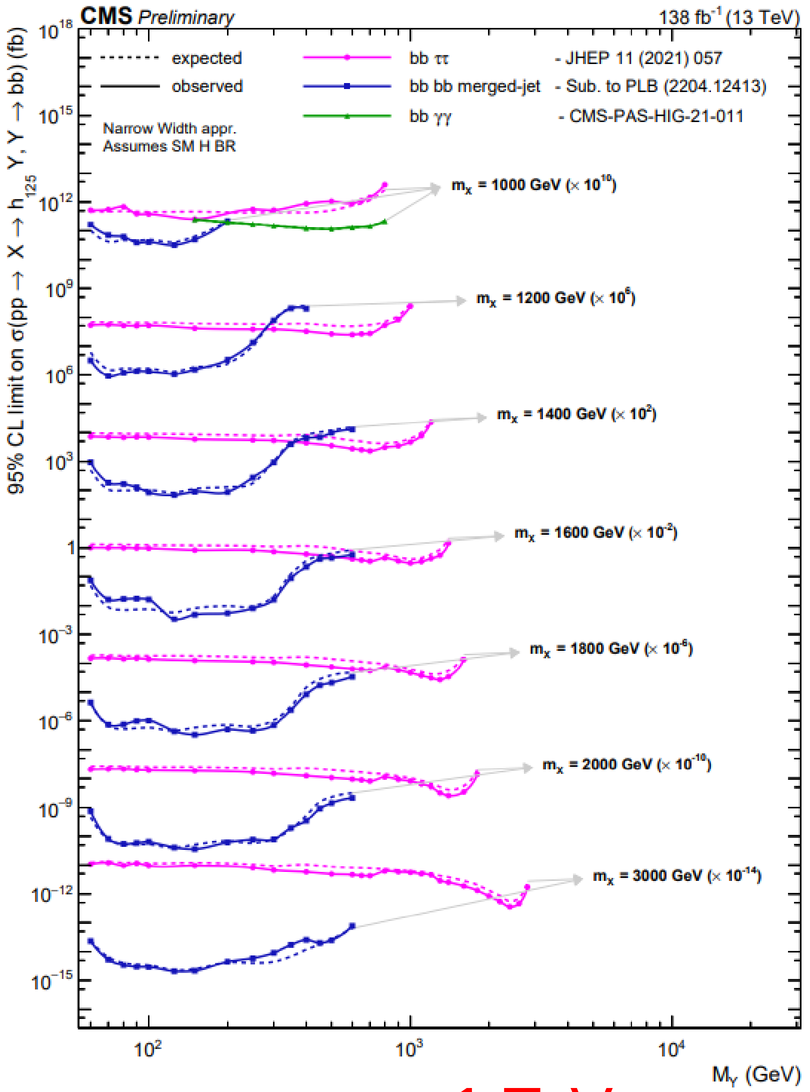
中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

Summary of BSM X → HH / YH





m_X<1 TeV



m_X>1 TeV

[Higgs PAG Summary Plots]

Also see [ChuWang's talk]