Higgs boson property measurements and new resonance searches in the diphoton channel at CMS

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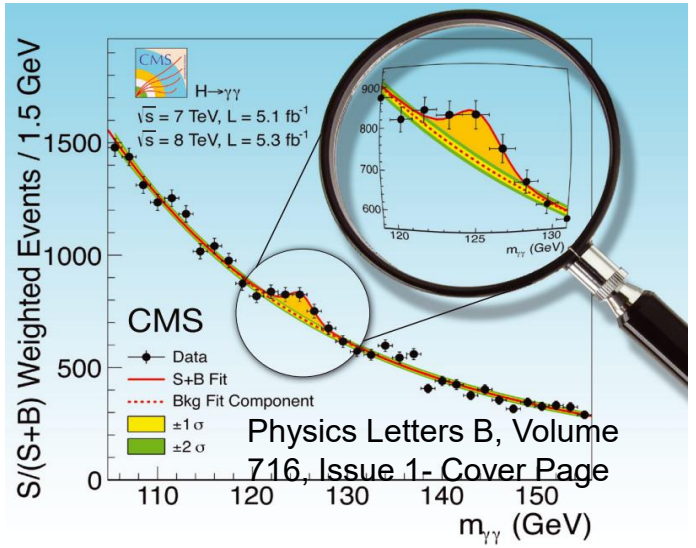
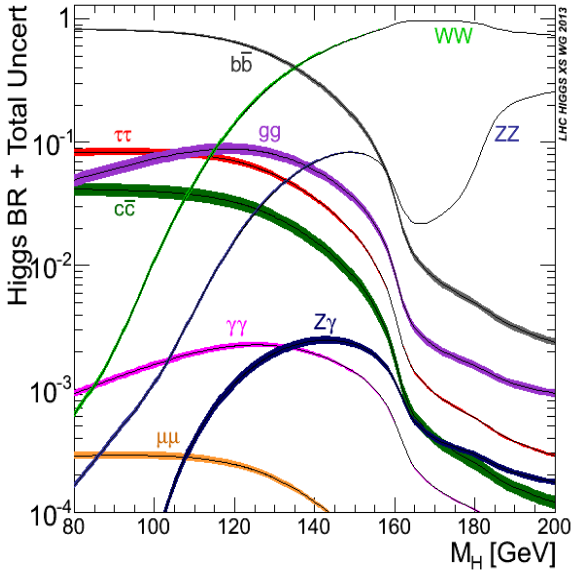
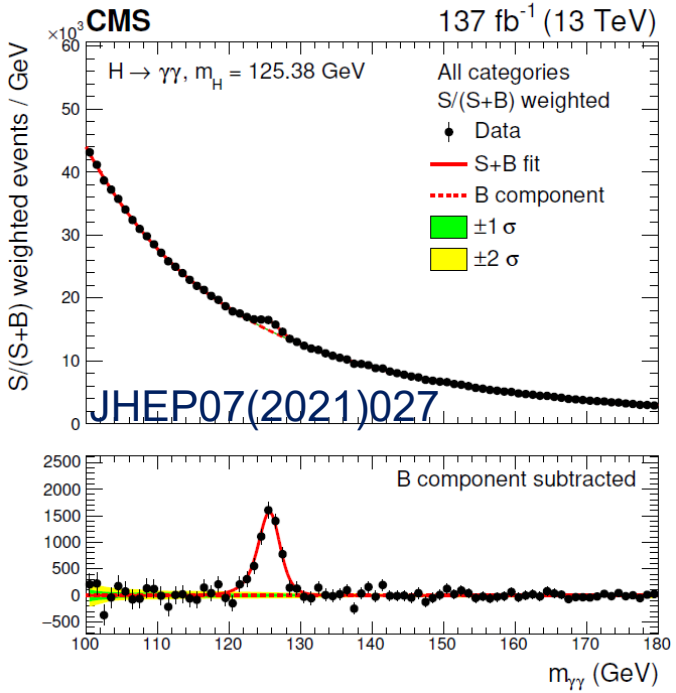
Introduction of H→γγ

- **H→γγ** is one of the most important channels for the **discovery of Higgs boson** and **measurements of its properties**
  - ✓ Small branching fraction (~0.23%) and large background
  - ✓ Clean final state **fully reconstructed** with high energy resolution and **$m_{\gamma\gamma}$ resolution (1-2%)**

- γγ final state also important for **additional resonances searches**
  - ✓ Direct search for **X→γγ** (high mass, low mass)
  - ✓ **Exotic decays of Higgs boson** with the new scalar (a/A) decaying into diphoton (**H→aa→γγγγ**, **H→Za→llγγ**)
  - ✓ **Multi-Higgs resonances**: **X→HH/HY** with one H/Y decaying into γγ







Relevant results in last ~2 years

➢ Higgs property measurements with H→γγ

Some results in backup

- ◆ **Mass (♥)**: CMS-PAS-HIG-24-007, released on 03/2026
- ◆ **Width from signal-background interference**: CMS-PAS-HIG-25-004, released on 08/2025
- ◆ **Cross section** with **partial Run3 data**: JHEP09(2025)070
- ◆ **Couplings**
  - ✓ ***Anomalous couplings***: arXiv:2605.14245 , submitted to JHEP on 05/2026
  - ✓ ***Self-couplings***: **HH→ττγγ** (JHEP05(2026)186), **HH→bbγγ (partial Run3**, CMS-PAS-HIG-25-007, 10/2025), **ttHH with HH→γγ+ bb/WW/ττ** (CMS-PAS-HIG-23-004, 04/2025) and **HHH→4bγγ** (CMS-PAS-HIG-24-015, 07/2025)

Jin Wang's dedicated HH talk

Chuxue Yang's dedicated Run3 HH→bbγγ talk

➢ Search for new resonances with H/a/Y→γγ

- ◆ **Direct search for low-mass** (♥, PLB 860 (2025) 139067) and **very low-mass H→γγ** (arXiv:2603.03250, submitted to PRD on 03/2026)
- ◆ **Exotic decays of H_{125}: H→Za→llγγ (♥, *PLB* 852 (2024) 138582), H→aa→4γ** (arXiv:2601.00183, submitted to JHEP 01/2026)
- ◆ **X→HH/HY → bbγγ** (JHEP05(2024)316, JHEP 12 (2025) 178) or ττγγ (JHEP05(2026)186) : more results (**WWγγ ♥**, **high mass bbγγ ♥** resonances) in Shaowei's talk

♥ IHEP members as contact; technical contributions (H→γγ common tools ..) from IHEP in the rest

Analysis Strategy

Samples (data, MC)

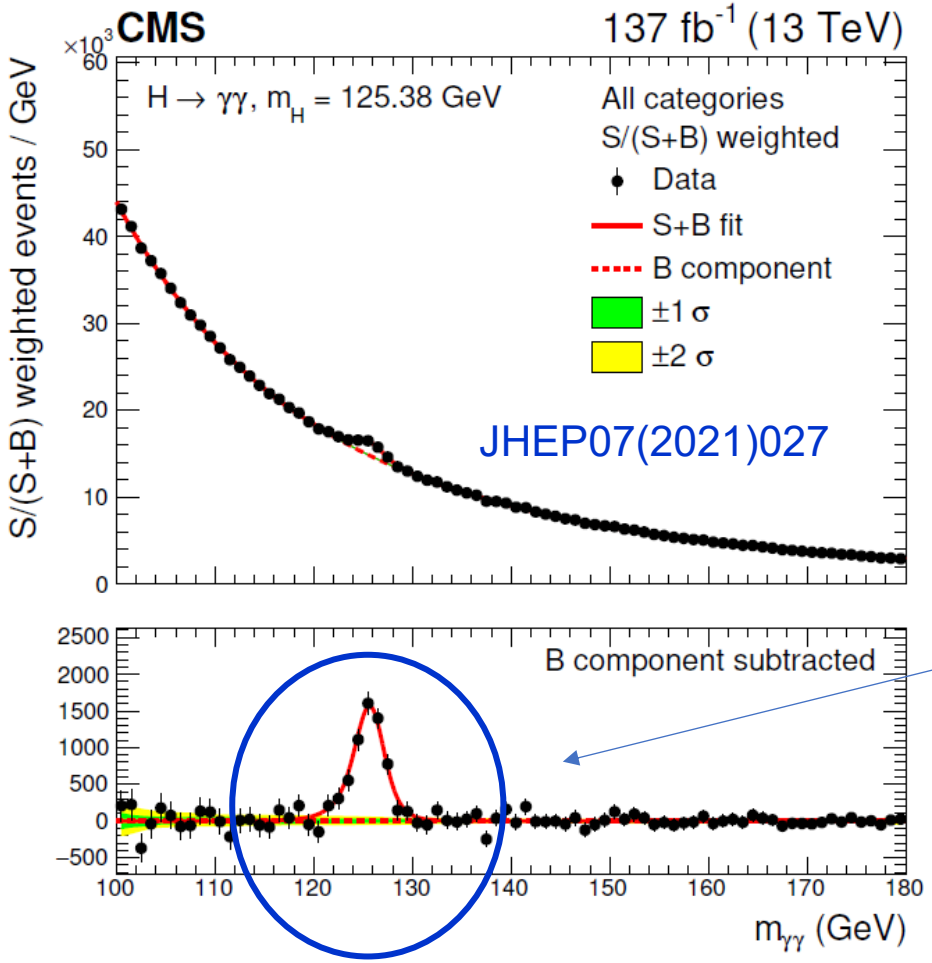
Data events passing (diphoton) HLT-paths

Preselection to mimic HLT, photon ID MVA cut (>-0.9) , electron-veto, photon $p_T/M_{\gamma\gamma}$ …

Event categorization on **production modes**, **mass resolution** and **S/B** to improve the analysis sensitivity

Sig and bkg modeling based on $m_{\gamma\gamma}$

Results



Signal is extracted *by a simultaneous maximum-likelihood fit to the* ***diphoton mass*** *in all event classes*

125 GeV Higgs boson: mass, signal strength, cross sections (inclusive, differential, STXS), couplings and anomalous couplings, CP,…

BSM Higgs: upper limits and significances

H→γγ mass

- **Why measuring the Higgs boson mass (m_H) is important?**
  - ✓ Free parameter of the Standard Model
  - ✓ Other properties of the Higgs boson depend on m_H (e.g. XS, couplings, BRs)

- Can be measured with high precision in the two golden channels $H \to ZZ^* \to 4\ell$ and $H \to \gamma\gamma$

- Previous CMS mass measurement in the γγ channel [PLB 805 (2020)135425] using 2016 data:

$$m_H = 125.78 \pm 0.18(\text{stat}) \pm 0.18(\text{syst})$$ **~0.2% precision**

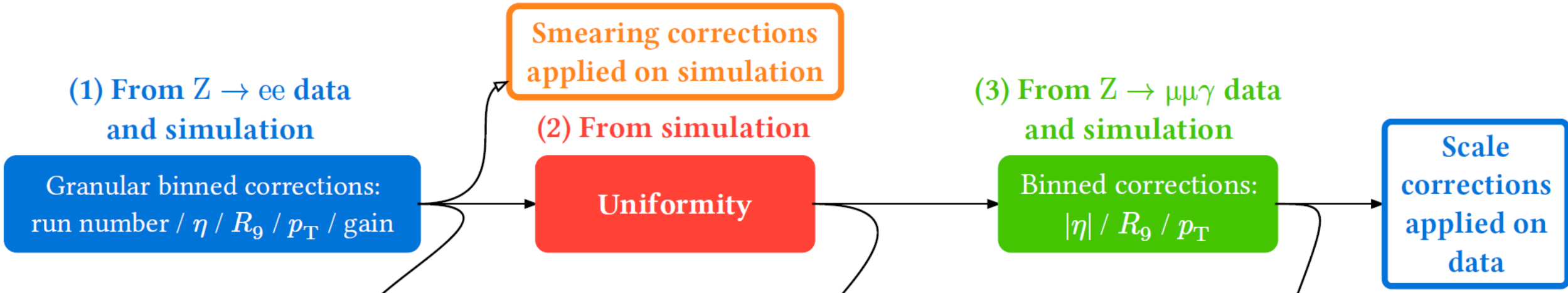
- **New features** compared to the previous measurement
  - ✓ **More statistics** available: 138 fb^{-1} vs 36 fb^{-1}
  - ✓ **Refined reconstruction** with **fine-tuned calibration of the ECAL** : up to 15% improvement on the electromagnetic object energy resolution
  - ✓ Improved **photon energy scale corrections**
  - ✓ Improvement from event categorization to maximize the **significance × resolution**

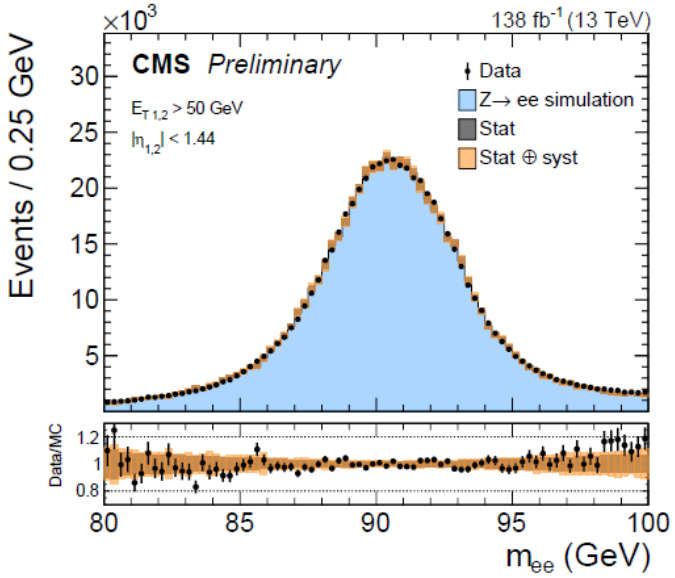
H→γγ mass : photon energy corrections

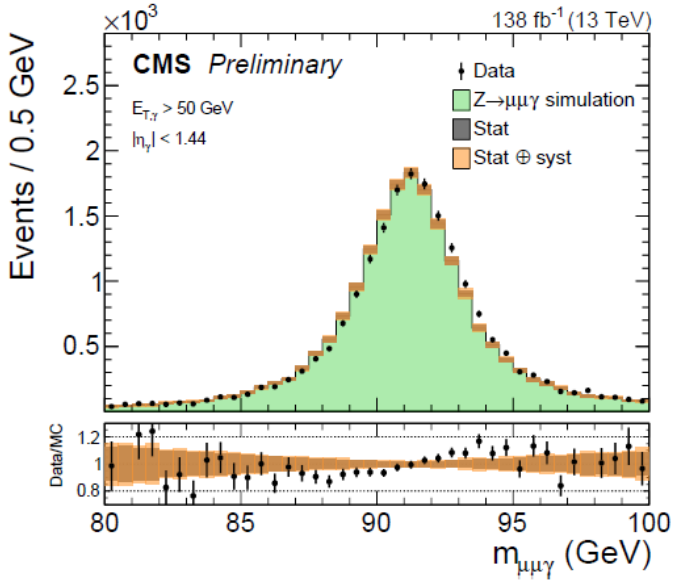
A dedicated **calibration of each ECAL channel** has been performed [CMS-DP-2020-021]

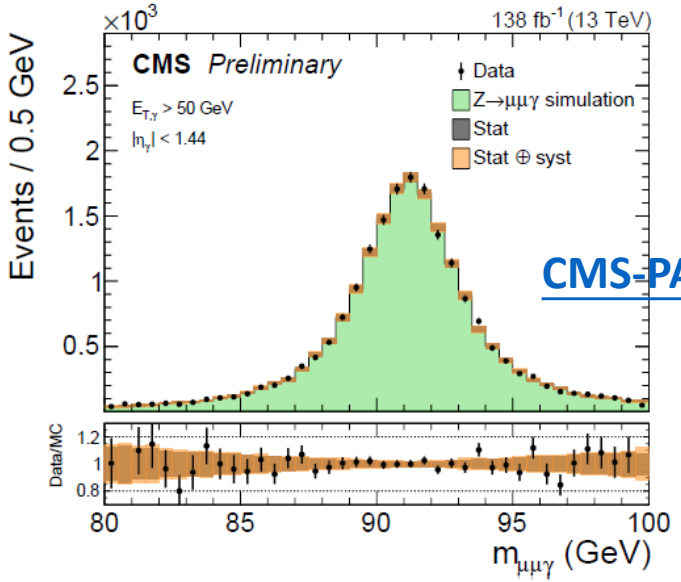
Binned energy scale and smearing corrections from Z → ee : as a function of η, R_9, p_T and gain

Residual photon energy scale from Z → μμγ events: measured in bins of pT, $|\eta|$ and R_9









CMS-PAS-HIG-24-007

H→γγ mass results

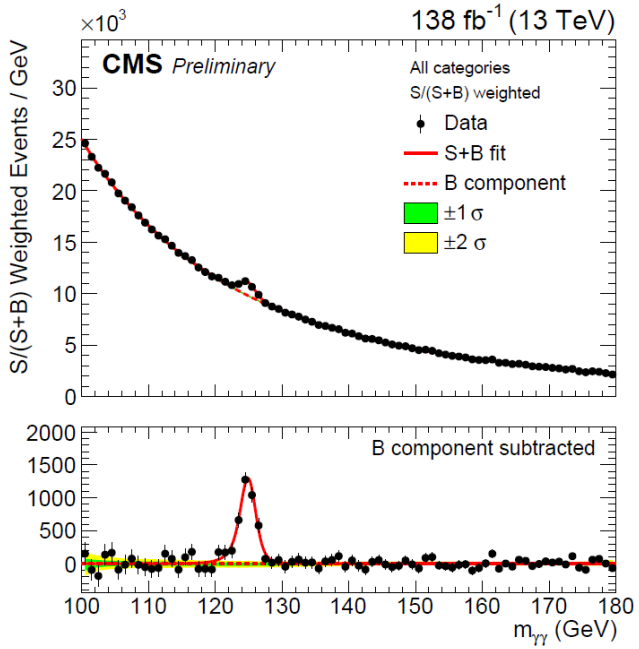
Run 2 H → γγ mass result:

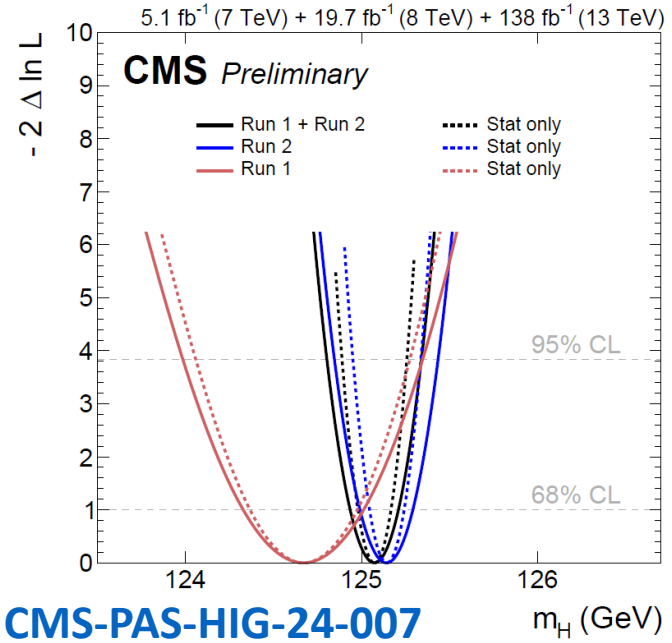
$m_H = 125.14 \pm 0.10(\text{stat}) \pm 0.11(\text{syst})$ GeV

$= 125.14 \pm 0.15$ GeV

Source	Contribution (MeV)
Photon energy scale	
Statistical uncertainty of muon sample	75
Residual non-linearity	64
Muon momentum	38
Electromagnetic shower	23
Photon energy resolution	7
Interference between ggH signal and background	27
Other sources	13
Statistical uncertainty	100
Total uncertainty	150

photon scale uncertainty is limited by the available Z → μμγ statistics





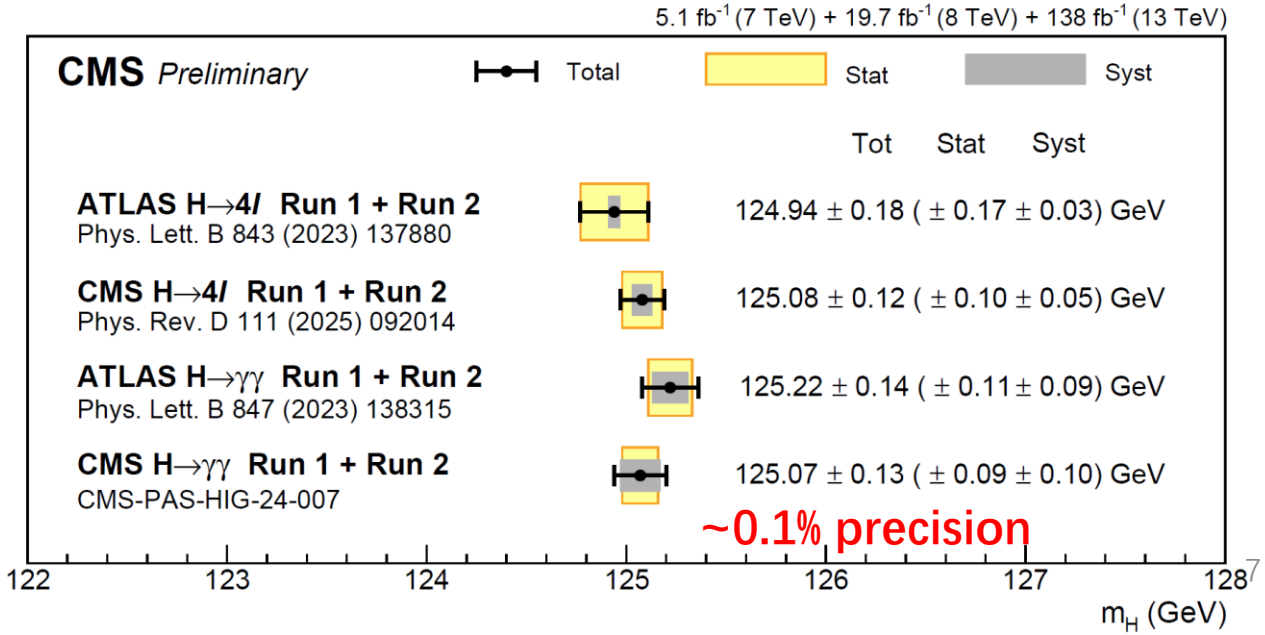
CMS-PAS-HIG-24-007

Combined Run2 + Run1 H → γγ mass result:

$m_H = 125.07 \pm 0.09(\text{stat}) \pm 0.10(\text{syst})$ GeV

$= 125.07 \pm 0.13$ GeV

CMS H → γγ	m_H	stat	syst	Total
Run 1	124.70	0.31	0.15	0.34
Run 2	125.14	0.10	0.11	0.15
Run 1 + Run 2	125.07	0.09	0.10	0.13



$H \to \gamma\gamma$ width from sig-bkg interference

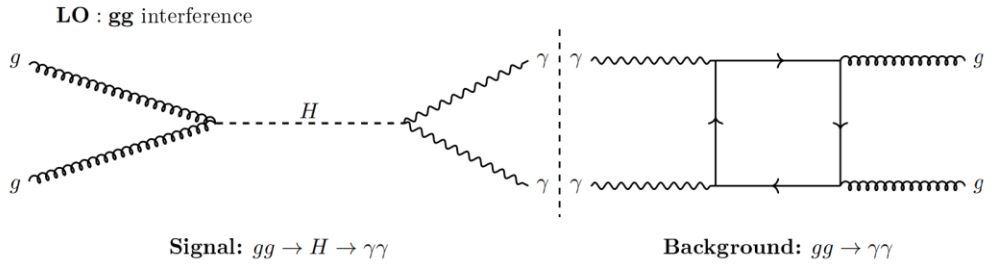
- Γ_H = 4.1 MeV in SM → **measurement limited by the detector resolution (~1 GeV)**
- On-shell and **off-shell H→ZZ→4l** measurements performed: on-shell Γ_H< 330 MeV and off-shell **Γ_H< 7.9 MeV** 95% CL [Phys. Rev. D 111 (2025) 092014]
- **Differential cross section** including both **ggH resonant** diphoton production (signal) and **interference** with the continuum diphoton process

$$\frac{d\sigma^{gg\to H\to\gamma\gamma}_{on-shell}}{dm_{\gamma\gamma}} + \frac{d\sigma_{Int}}{dm_{\gamma\gamma}} = c^2_{g\gamma}\frac{\Gamma_{SM}}{\Gamma}S_{ggH} + c_{g\gamma}\,I =$$

$$= \mu_F\, S_{ggH} + c_{g\gamma}\, I = \left(\mu_F - c_{g\gamma}\right) S_{ggH} + c_{g\gamma}\left(S_{ggH} + I\right)$$

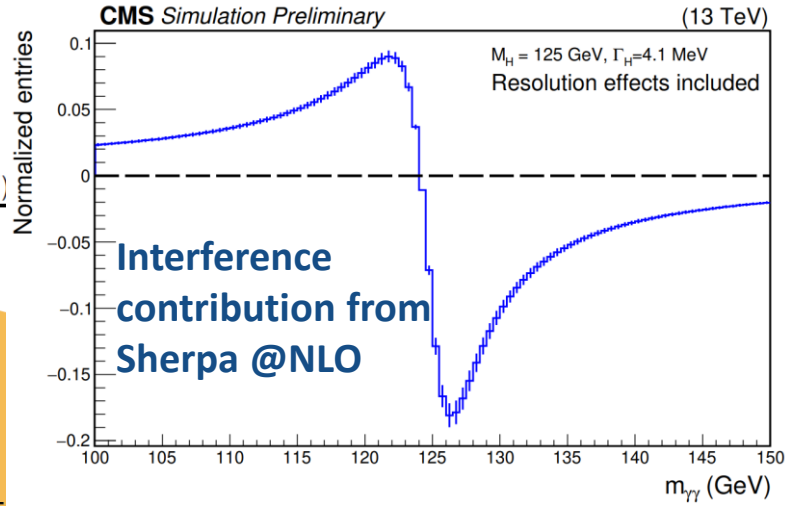
$c_{g\gamma} = \sqrt{\mu_F \Gamma_H / \Gamma_H^{SM}}$ ➡ Measure Γ_H from the measurement of this diff. cross-section

on-shell signal strength (μ_F) and the couplings ($c_{g\gamma}$)



$$|A_S + A_B|^2 = \frac{c^2_{g\gamma}}{\Gamma_H} S + c_{g\gamma} I + B$$

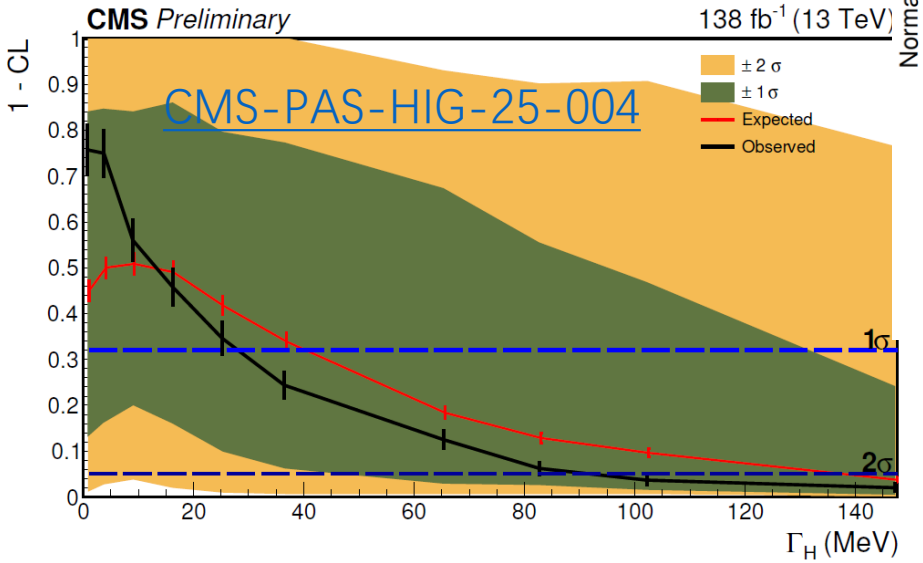
Imaginary term: XS ~-2% (*J. Tao et al MPLA 28 (2013) 1350081*); **Real term: mass shape effect, used to constrained width**: *Martin (PRD 2012) & Dixon, Li (PRL 2013)*



- **Events are categorized:**

- 10 categories for ggH production, based on ***diphoton-pT (5 bins)*** and ***diphotom-BDT (2 bins)***

- 1 VBF category to mitigate the dilution of the ggH fusion sample with events from VBF

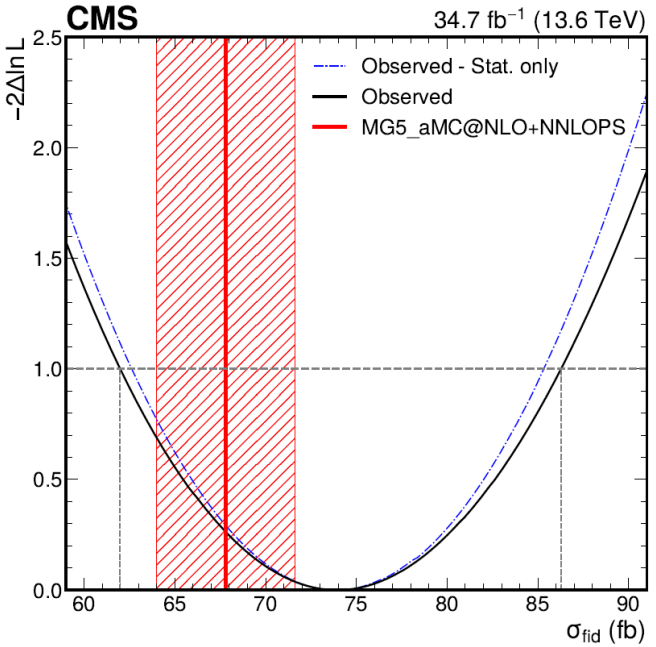


First analysis at LHC on Γ_H in $H \to \gamma\gamma$

Run 2: Γ_H < 92(138) MeV obs. (exp.) at 95% CL

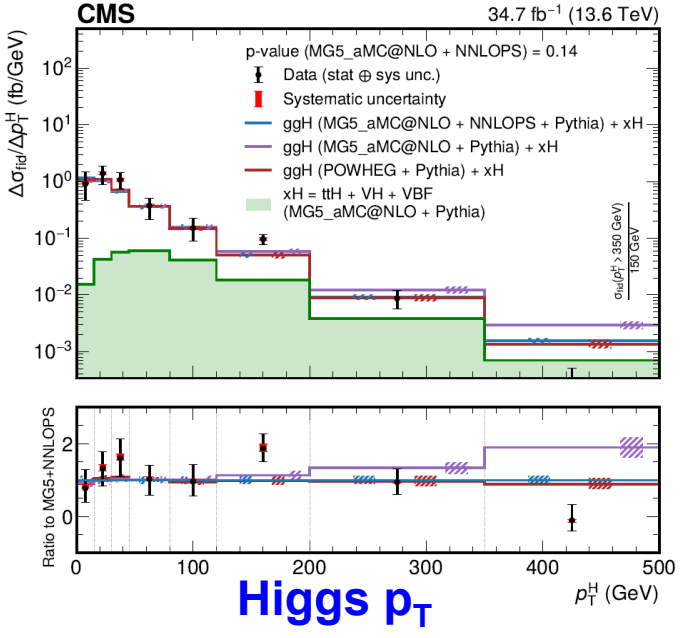
H→γγ fiducial and differential XS (Run3)

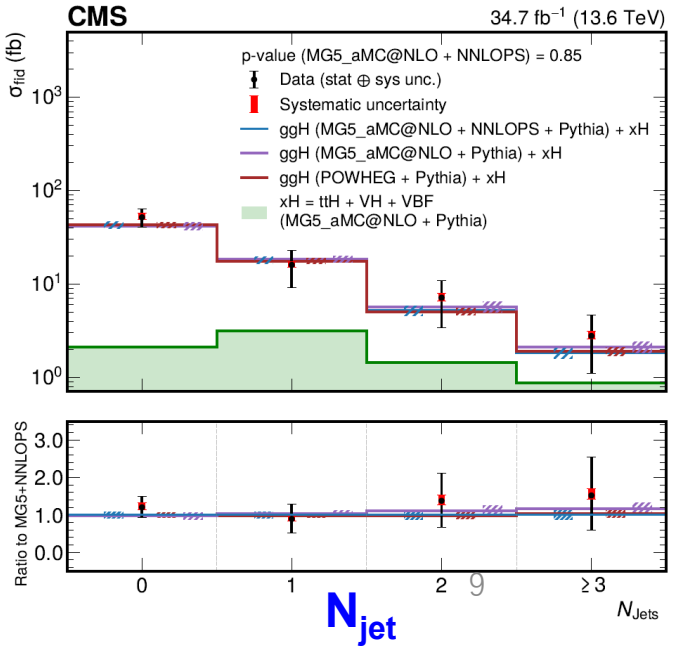
- **Fiducial cross sections aim at providing a set of model independent results**
- **Measurements of H→γγ inclusive and differential fiducial XS with 2022 data: First CMS Run3 H →γγ measurements**
- A new **normalizing-flow-based method** [arXiv:2403.18582] is applied to correct the imperfect modelling of reconstructed photon variables in the simulation and to reduce the associated systematic uncertainties
- Selected events are **categorized** based on the **relative mass resolution σ_m/m**, decorrelated with the quantile morphing algorithm [*JHEP* **07** (2023) 091]
- Fiducial cross section in **4 differential observables** Higgs p_T and |y|, N_{jet}, and jet pT
- **Measured results in agreement with the SM predictions**



Observable	Selection
$\sqrt{p_T^{\gamma_1} p_T^{\gamma_2}}/m_{\gamma\gamma}$	>1/3
$p_T^{\gamma_2}/m_{\gamma\gamma}$	>1/4
$\mathcal{I}^{\gamma}_{gen}$	<10 GeV
$\lvert\eta^{\gamma}\rvert$	<2.5

JHEP09(2025)070

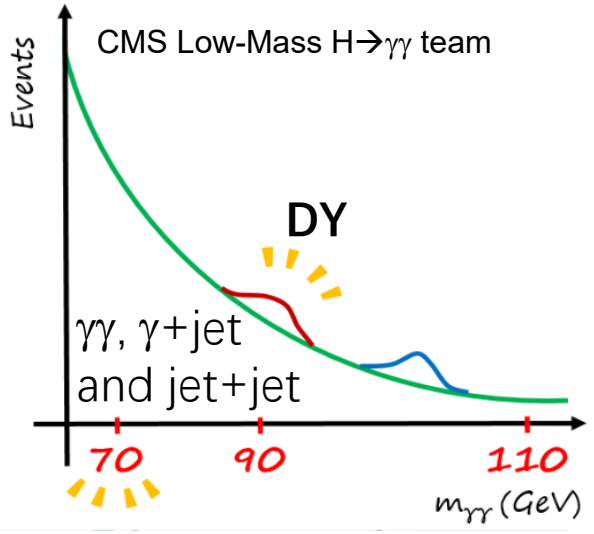


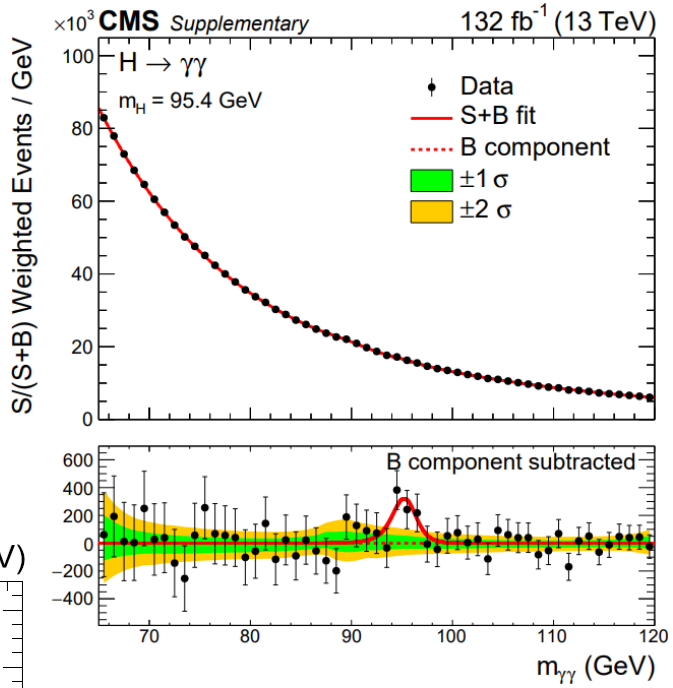


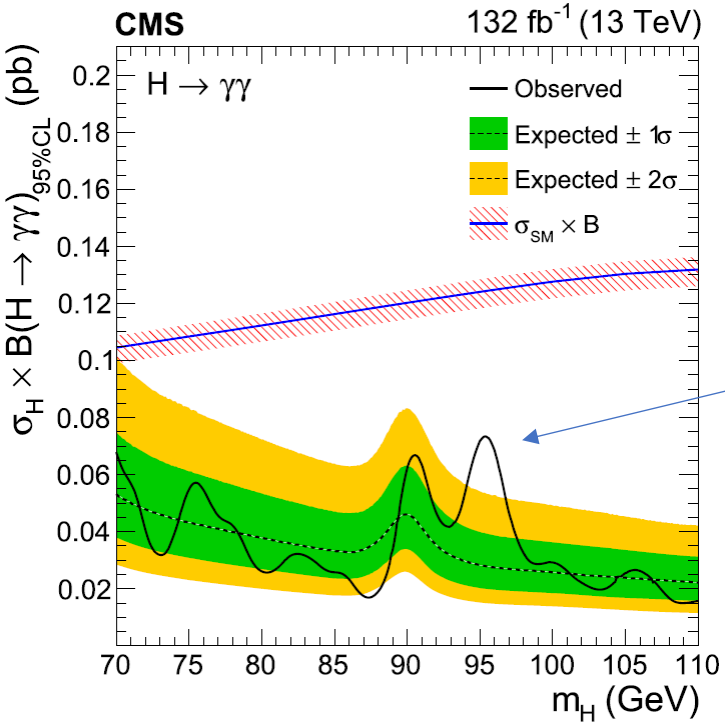
Low-mass H→γγ

- Many BSM models (e.g. 2HDM, NMSSM) predict additional Higgs bosons : some of which could have masses < 125 GeV : γγ final state is important for **additional resonances searches**
- **CMS** searching range **70-110 GeV,** limited by **HLT criteria** (M>55 GeV in 2016/2017) and offline **selections**

- Many **techniques** inherited from **SM H→γγ analysis** but with **dedicated updates and optimizations in low-mass case**
  - ✓ Dedicated **HLT** then event (pre-) **selections;** Dedicated **DY suppression** strategy; Retrained **photon identification MVA,** and an **event Boost Decision Tree (BDT)** to identify signal and for **event categorization**
  - ✓ Signal modeled by a sum of Gaussians
  - ✓ Background modeled with discrete profiling or "envelope" method (arXiv:1408.6865)







PLB 860 (2025) 139067

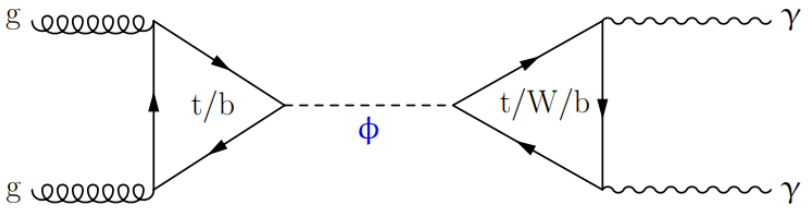
- **Excess with ~2.9σ local (1.3σ global) significance at $m_{\gamma\gamma}$= 95.4 GeV**

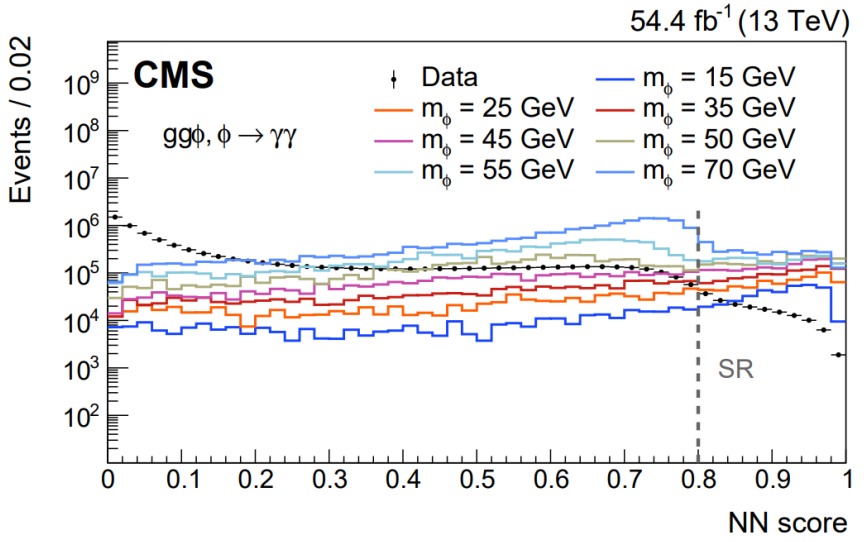
Lower mass γγ resonances

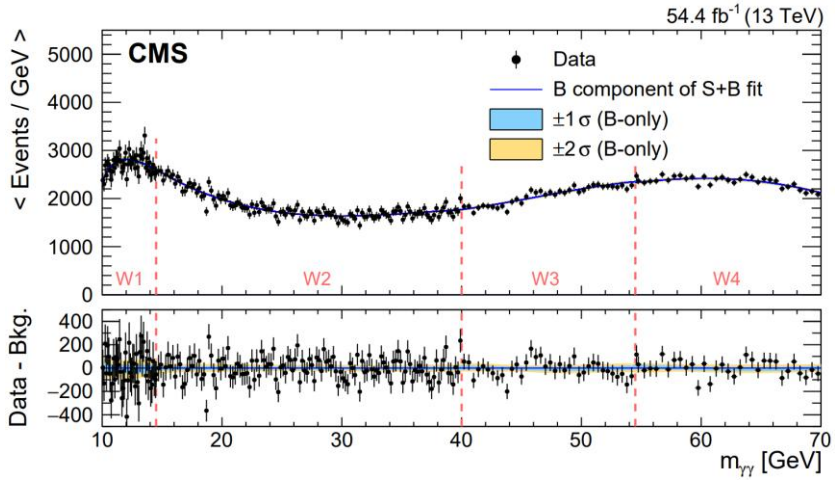
- **Search for [10,70] GeV resonance** using **2018 data** without mass cut in trigger

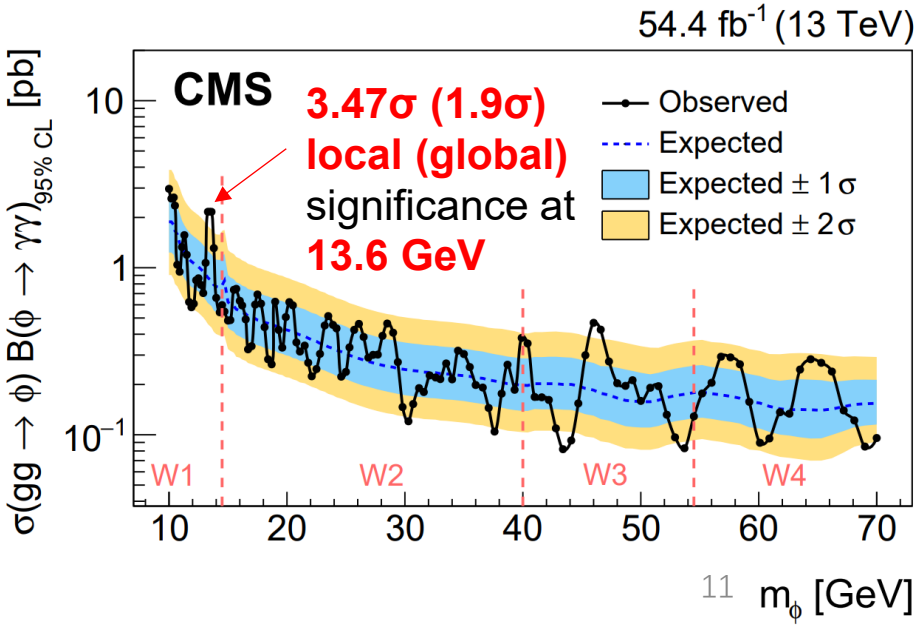
- A neural network (**NN**) is employed to enhance the selection
  - ✓ Variable inputs include photon kinematics and diphoton features along with discrete mass hypothesis
  - ✓ Signal region (SR) : **NN score>0.8** with highest sensitivity

- Background model: in four sub mass ranges, with the **discrete profiling method** in each one







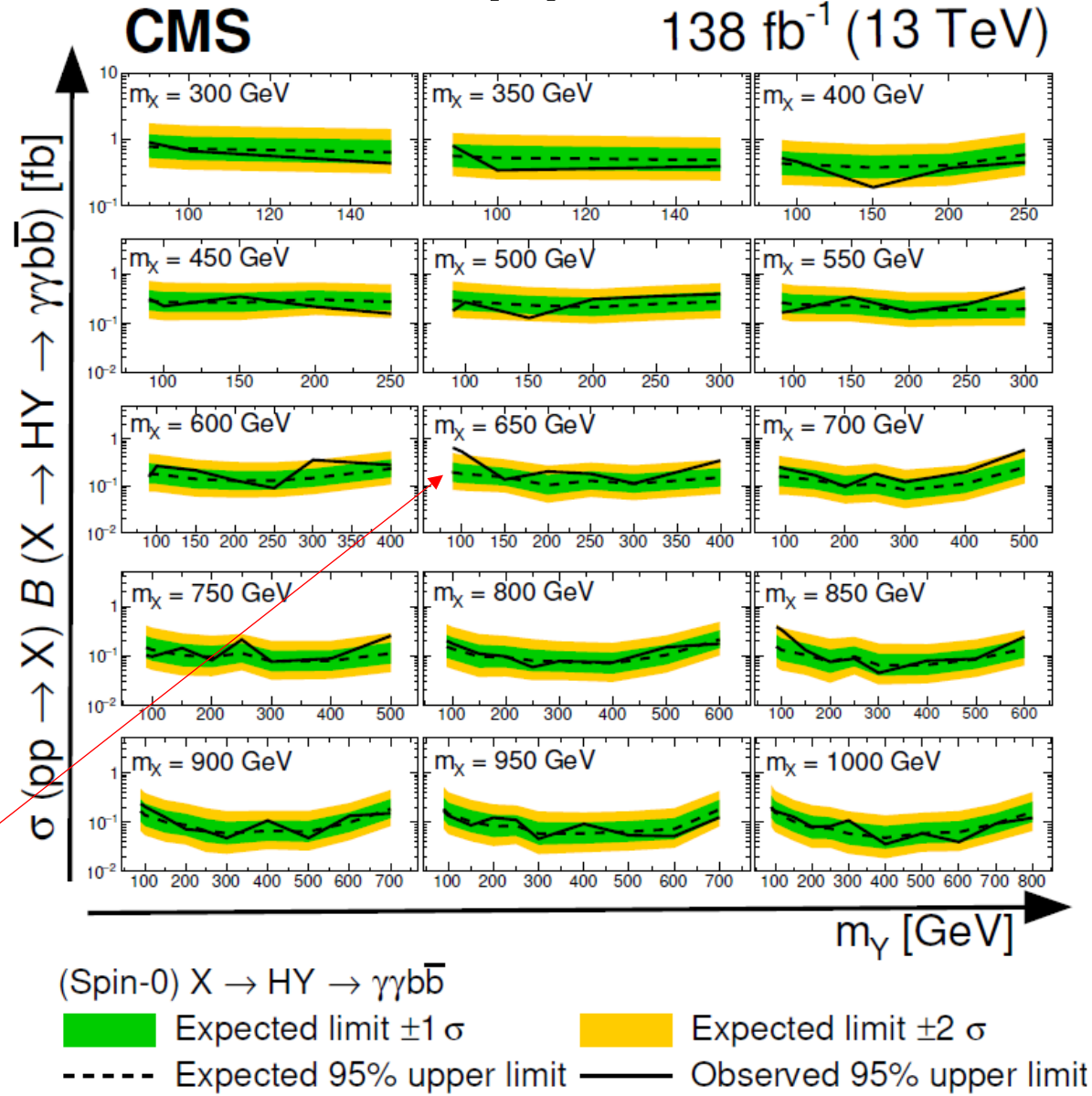


arXiv:2603.03250

CMS X → YH → bbγγ

- Relatively **large signal purity in H→γγ** and large branching fraction of decaying into bb
- **BDT** used to separate **signal from non-resonant backgrounds**, and **DNN** used to separate **signal from resonant backgrounds.**
- **Six BDT** trainings account for different signal $\mathbf{m_X}$-$\mathbf{m_Y}$ 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**



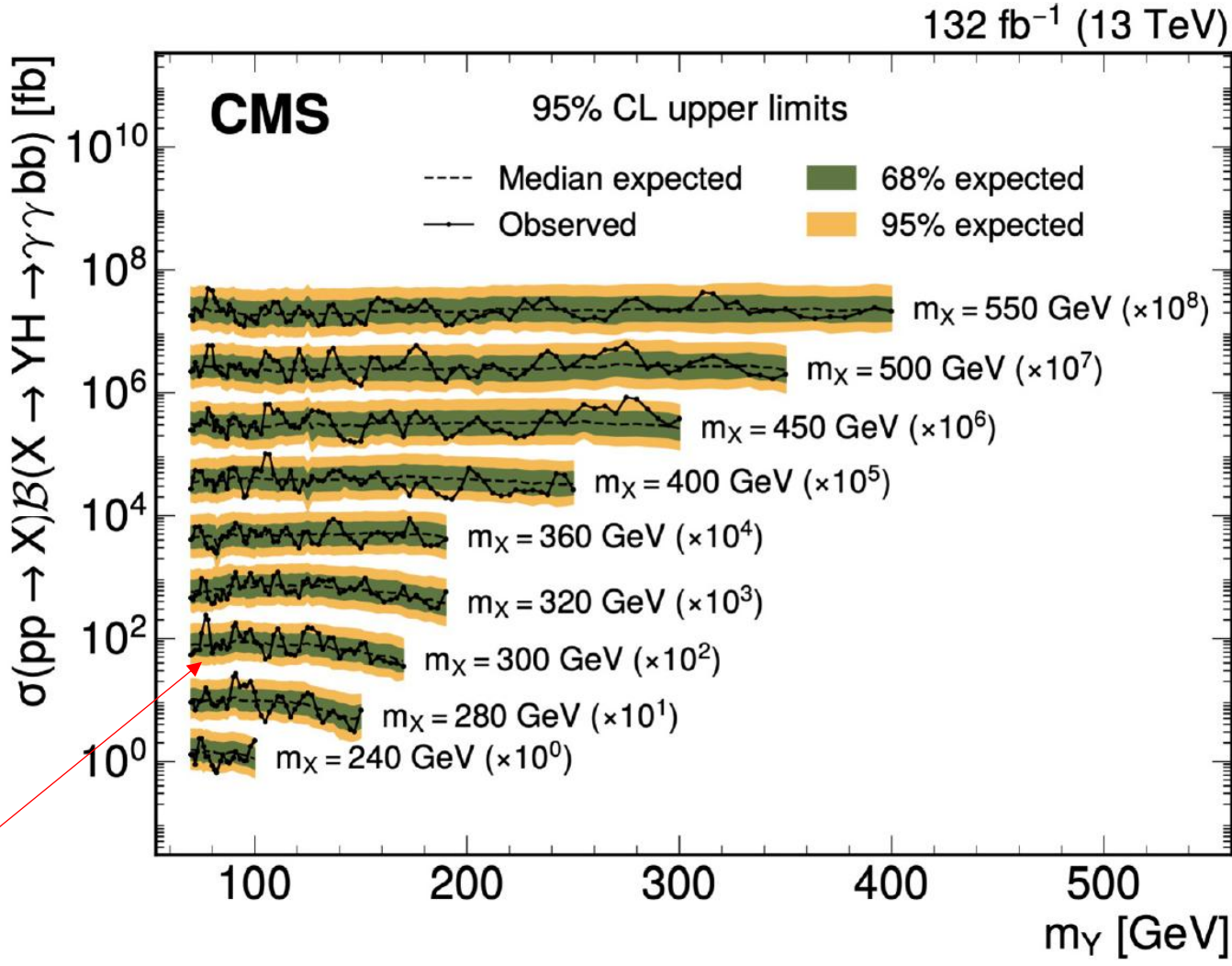
JHEP05(2024)316

CMS X → YH → bbγγ

- CMS also performed the search with H→bb and **Y→γγ**, with m_X **240−1000** GeV and m_Y **70−800** GeV
- A Parametric Neural Network (**pNN**) is trained to identify sig from bkg and employed for event categorization
- **$m_{\gamma\gamma}$ is used to extract signal**

At m_X =650 GeV and m_Y =90 GeV the observed limit is in agreement with the SM

Most significant : 3.33σ
(0.65σ) local (global) at **m_X =300 GeV and m_Y =77 GeV**



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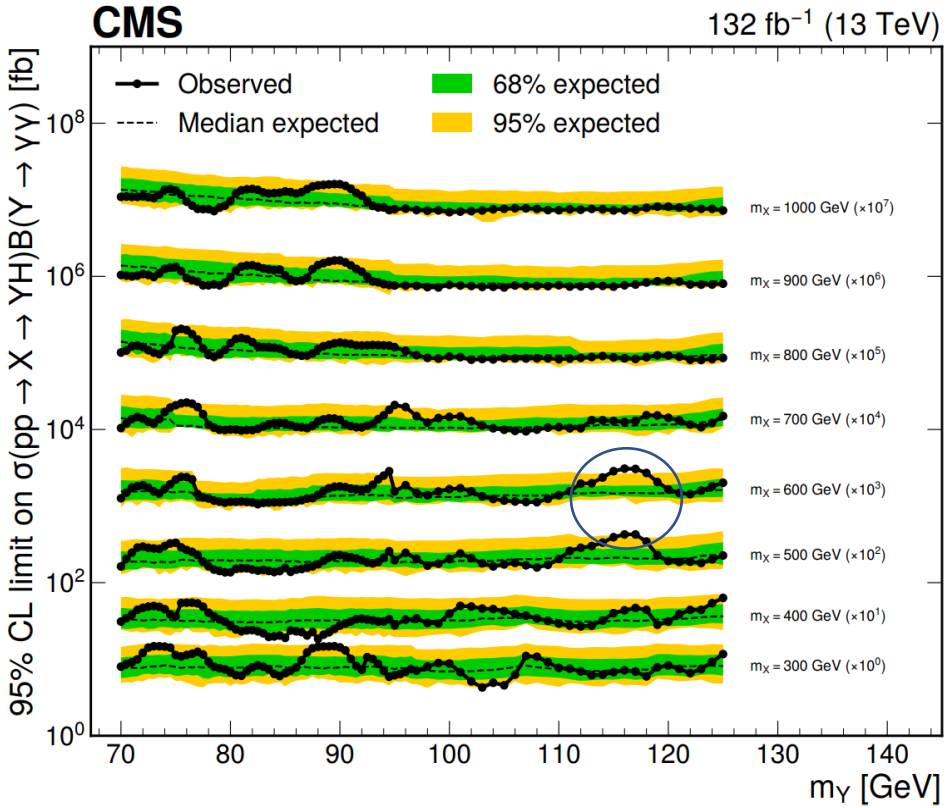
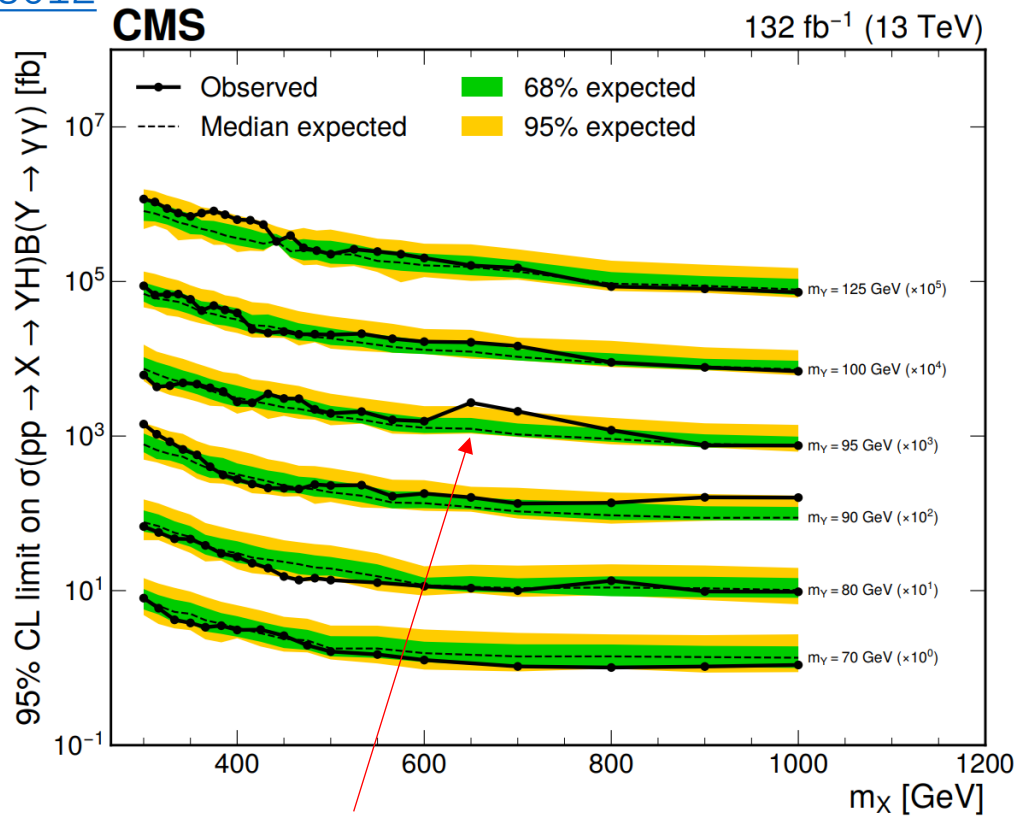
CMS low-mass X→Y(γγ) H(ττ)

- X mass 300-1000 GeV, **Y mass 70-125 GeV**
- Additional **tau leptons** in the event help further **identify signal from bkg**
- A **pNN** trained to identify sig from bkg and for event categorization

arXiv:2506.23012



Largest local significance of **3.4σ** (0.1σ global) @ **m_X = 525 GeV**, **m_Y = 115 GeV**



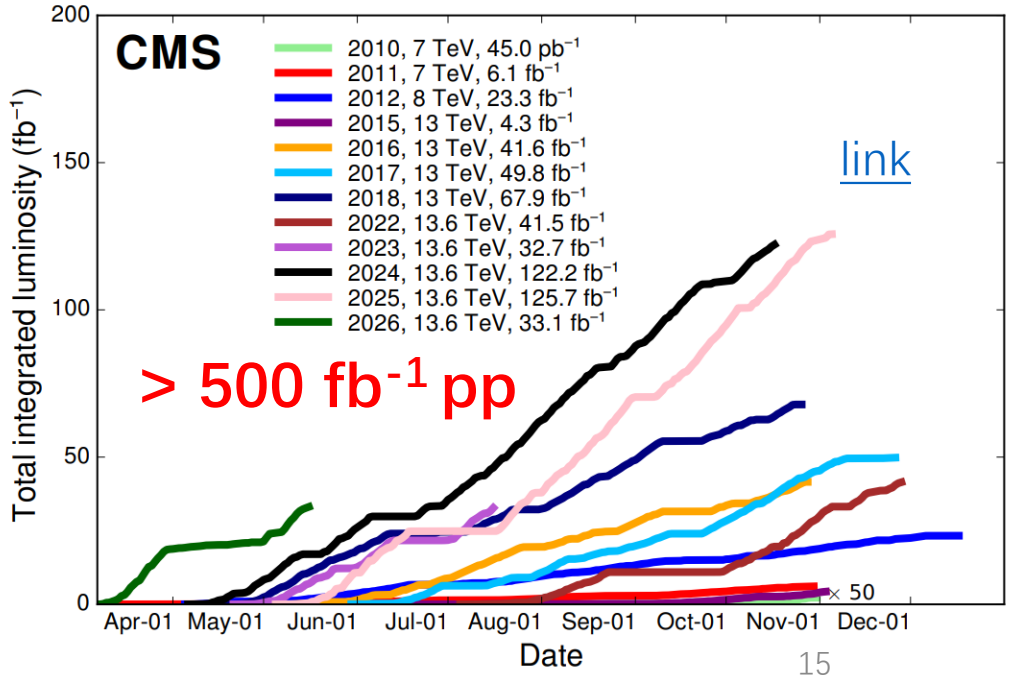
Local 2.3σ @ m_X = 650 GeV, m_Y = 95 GeV

Summary

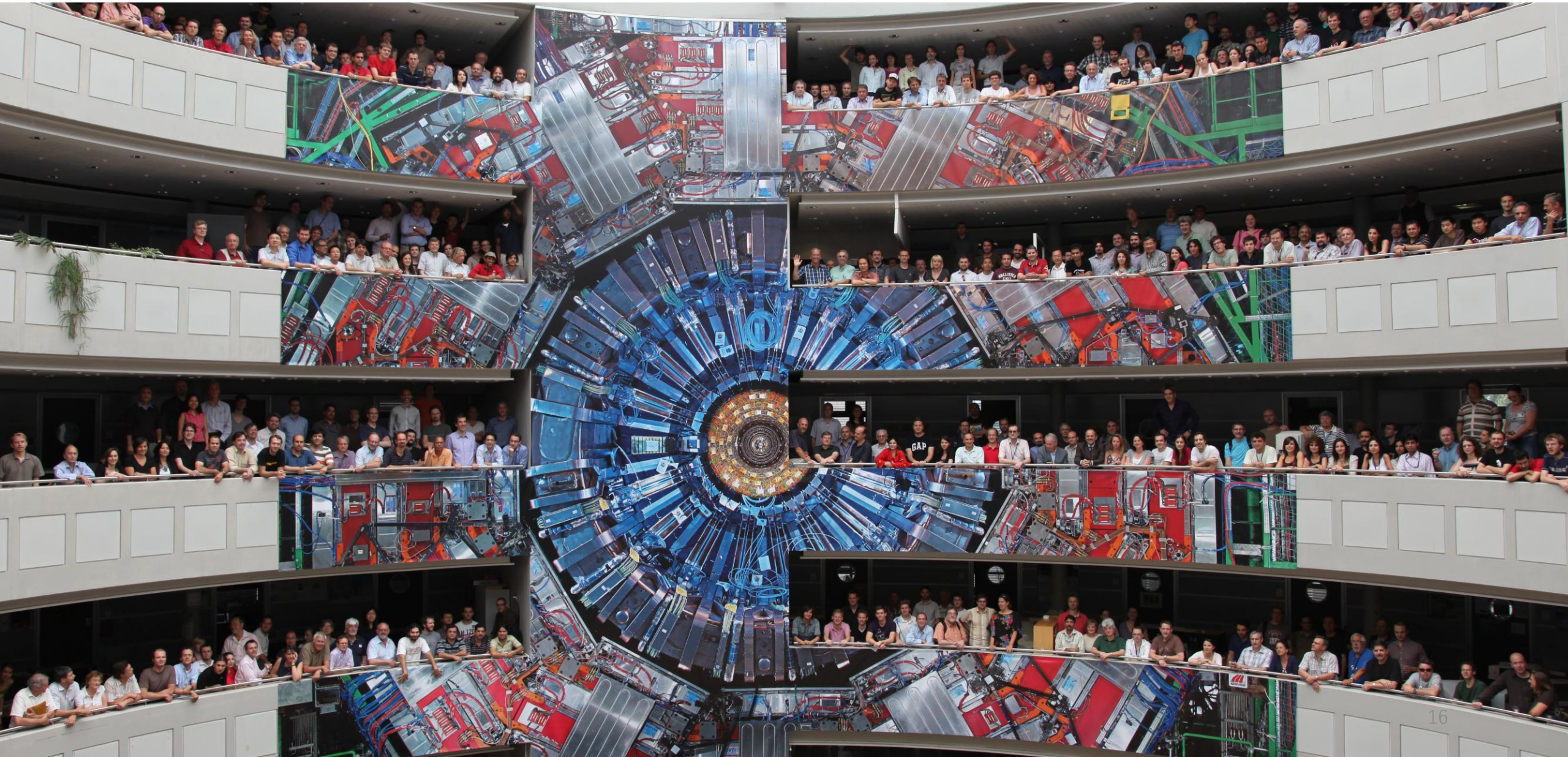
- Some **latest results** of **Higgs boson property measurements and new resonance searches**, **with $\gamma\gamma$ in the final state**, are presented
  - ✓ **Precise measurements** of the Higgs boson properties: **mass**, width, cross sections and couplings
  - ✓ **No direct evidence of new resonances yet,** but a few notable deviations (up to ~2.8σ global): ~95 GeV excess in several independent analyses worths further investigation

- Full **Run-3** with ~2 times more data than Run-2, will allow to measure Higgs boson properties more precisely and check all the interesting Run-2 excesses, also opportunity to explore several other final states accessible to LHC!

- **Stay tuned!**



Thanks for your attention!

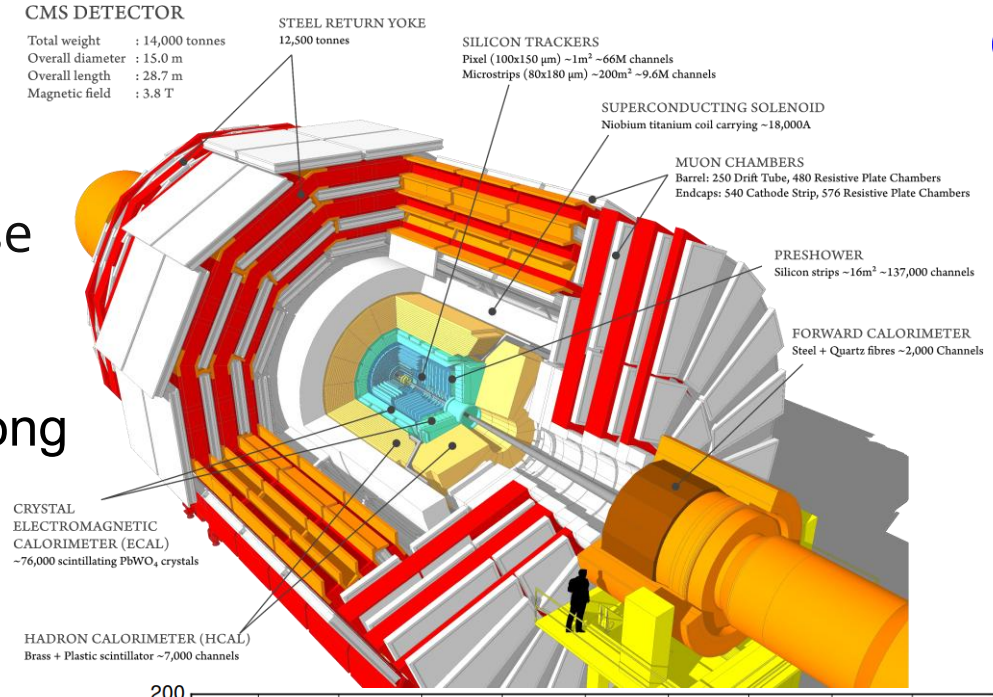


Backup

CMS and CMS Data

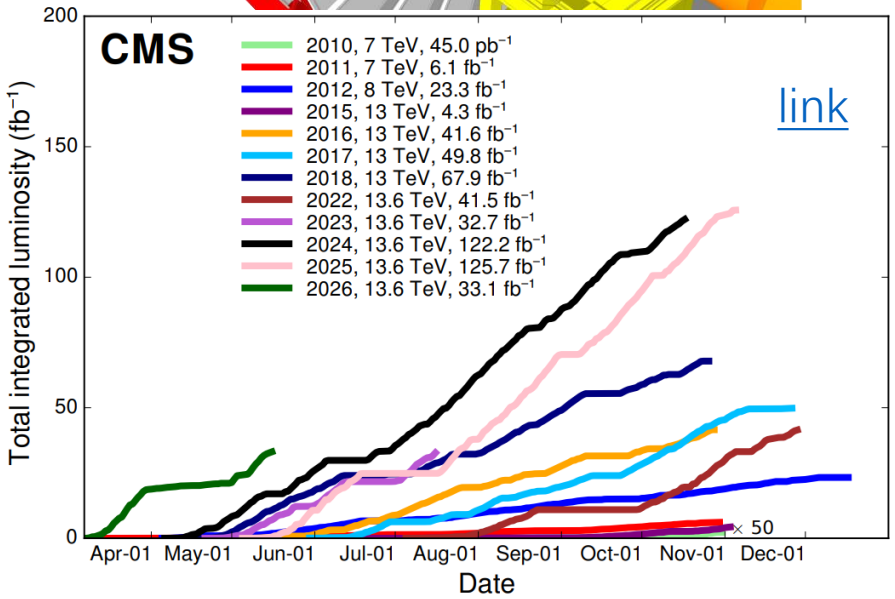
Compact Muon Solenoid (or CMS) detector

- One of two general-purpose detectors at LHC
- 14,000-tonne detector, 15 meters high and 21 meters long
- Higgs boson + new physics phenomena



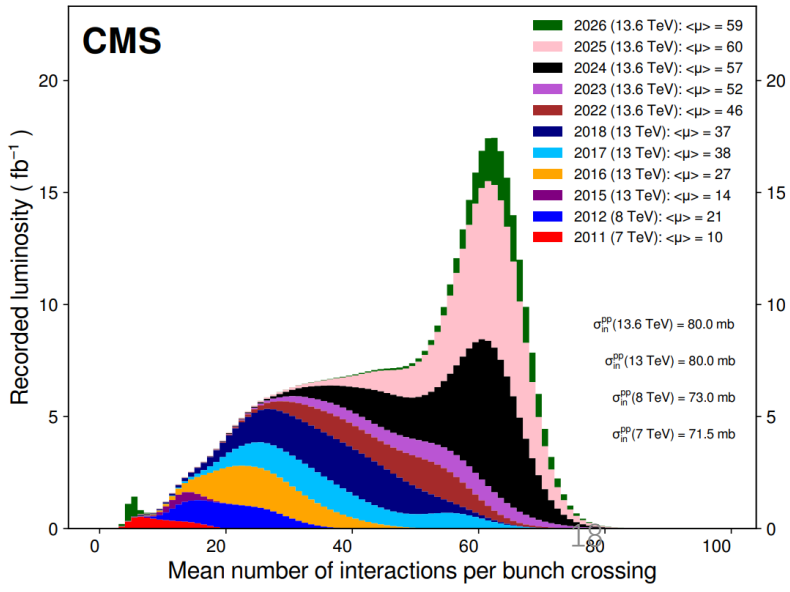
CMS data

- **Run1**: 2011 @ 7 TeV and 2012 @ 8 TeV
  - ✦ Milestone of **Higgs discovery**
- **Run2**: 2015-2018 @ 13TeV
  - ✦ Comprehensive **Higgs property measurements**
- **Run3**: 2022 - 2026 @ 13.6TeV
  - ✦ Typical pile-up: 60 collisions/bunch crossing



CMS collaboration

- > 5000 participants, ~259 institutes and universities, > 50 countries
- 11 units from China (mainland): IHEP/CAS, PKU, THU, USTC, BUAA, FDU, SYSU, ZJU, SDU, NNU, SCNU



H→γγ anomalous couplings

- In SM Higgs boson $J^{CP} = 0^{++}$
- Limited precision of previous measurements **allow small anomalous couplings** and **CP violation** → Probe HVV couplings, through VBF and VH production, and Hff through ggH (in the loop)
- **SM and Anomalous couplings between spin-0 H and VV (WW, ZZ, Zγ, γγ, gg)**

$$\mathcal{A}(\mathrm{HV_1V_2}) \sim \left[a_1^{\mathrm{VV}} + \frac{\kappa_1^{\mathrm{VV}} q_{V1}^2 + \kappa_2^{\mathrm{VV}} q_{V2}^2}{\left(\Lambda_1^{\mathrm{VV}}\right)^2} \right] m_{\mathrm{V1}}^2 \epsilon_{\mathrm{V1}}^* \epsilon_{\mathrm{V2}}^* + a_2^{\mathrm{VV}} f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + a_3^{\mathrm{VV}} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\mu\nu}$$

  - ✓ The only nonzero SM contributions at tree level are a_1^{WW} and a_1^{ZZ} which are assumed to be equal under custodial symmetry
  - ✓ Considerations of symmetry and gauge invariance require

$$a_1^{Z\gamma} = a_1^{\gamma\gamma} = a_1^{gg} = 0,\ \kappa_1^{ZZ} = \kappa_2^{ZZ},\ \kappa_1^{\gamma\gamma} = \kappa_2^{\gamma\gamma} = 0,\ \kappa_1^{gg} = \kappa_2^{gg} = 0, \text{ and } \kappa_1^{Z\gamma} = 0$$

  - ✓ A total of 13 independent parameters that describe the HVV coupling and two that describe the Hgg coupling
- **Effective cross section ratios f_{ai} are measured, rather than the direct anomalous couplings a_i**

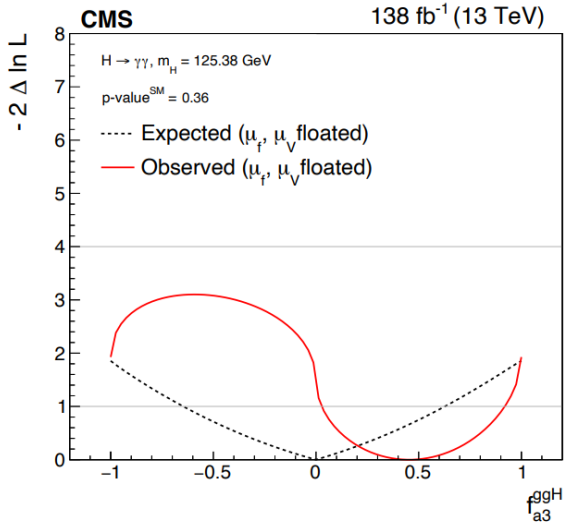
$$f_{ai} = \frac{|a_i|^2 \sigma_i}{|a_1|^2\sigma_1 + |a_2|^2\sigma_2 + |a_3|^2\sigma_3 + \tilde{\sigma}_{\Lambda_1}/(\Lambda_1)^2 + \tilde{\sigma}_{\Lambda_1}^{Z\gamma}/(\Lambda_1^{Z\gamma})^2} \times \mathrm{sgn}\left(\frac{a_i}{a_1}\right)$$

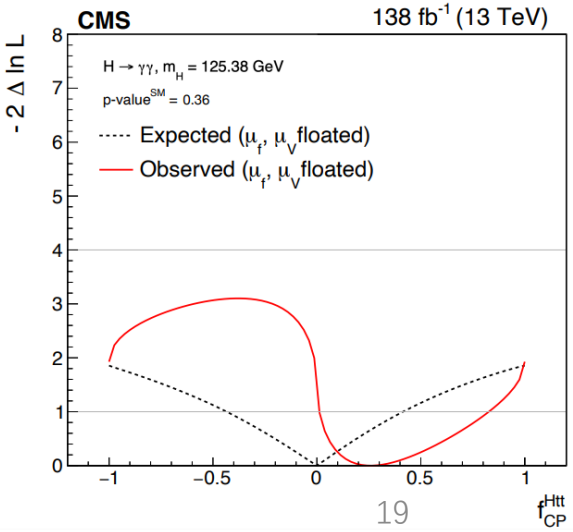
- **Event categorization on Matrix Element VBF, VH and ggH discriminants is performed optimizing S/B**

HVV analysis: using the VBF and VH categories

Parameter	Observed [$\times 10^{-4}$] $H \to \gamma\gamma$ (68% CL)	Expected [$\times 10^{-4}$] $H \to \gamma\gamma$ (68% CL)
f_{a3}	$0.00^{+0.39}_{-0.39}$	$[+2.1, -2.1]$
f_{a2}	$-0.81^{+0.65}_{-2.0}$	$[-2.3, +3.1]$
$f_{\Lambda 1}$	$-0.014^{+0.032}_{-0.14}$	$[-0.12, +0.35]$
$f_{\Lambda 1}^{Z\gamma}$	$0.83^{+1.5}_{-0.92}$	$[-3.3, +3.7]$

arXiv:2605.14245



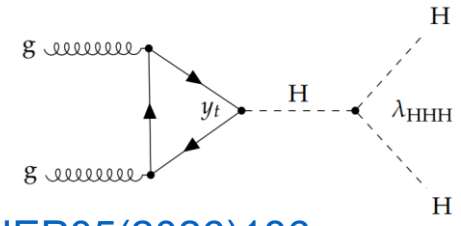


H self-coupling in HH with one H→γγ

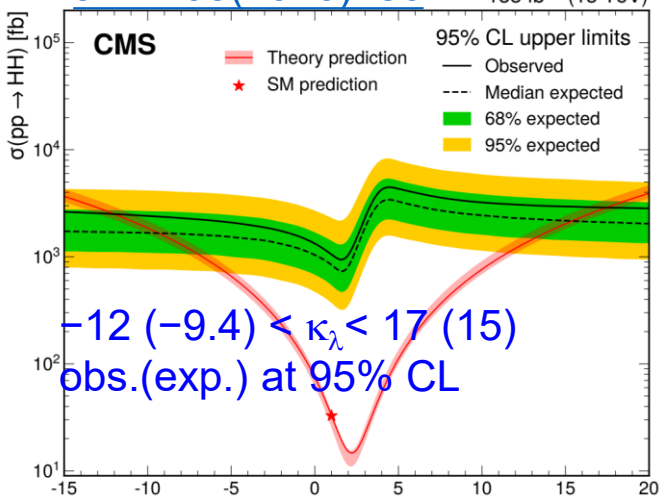
- Higgs boson **self-coupling** λ_{HHH} can be directly constrained through measurements of Higgs boson pair (HH) production

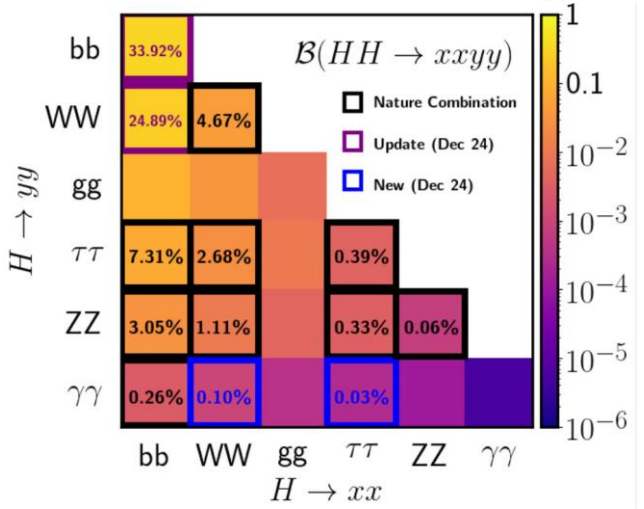
- HH→ττγγ (JHEP05(2026)186) with Run2 data:
  - ✓ Small BR, diphoton pair ofers a clean experimental signature to trigger on with a good mass resolution, additional tau leptons in the event help further isolate signal from background
  - ✓ A BDT discriminant is trained to distinguish sig from bkg and for event categorization: 2 cats with higher BDT scores
  - ✓ Obs.(exp.) UL on HH production: 33 (26) σ_{SM}

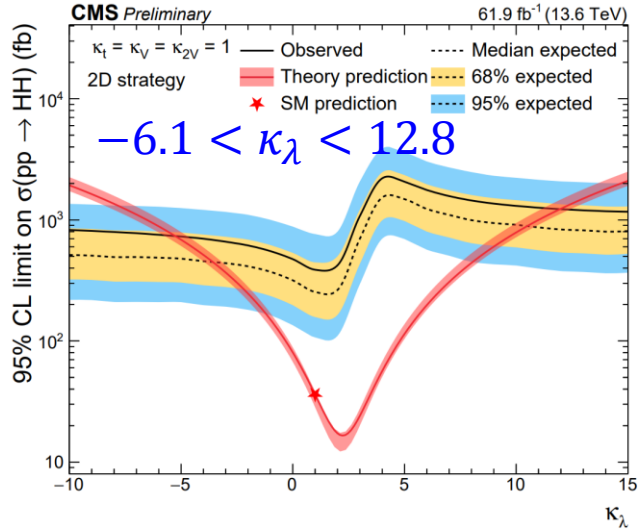
- **Non-resonant HH→bbγγ with Run3 data (2022+2023)** : CMS-PAS-HIG-25-007 ,released on 10/2025)
  - ✓ Large BR(H→bb), good mass resolution of γγ
  - ✓ ML-based discriminant to separate sig & bkg and for event categorization
  - ✓ boosted Higgs-tagging to improve significance: allows to exploit high-p_T H→bb
  - ✓ DNN-based regression to further improve jet mass resolution m_{jj}

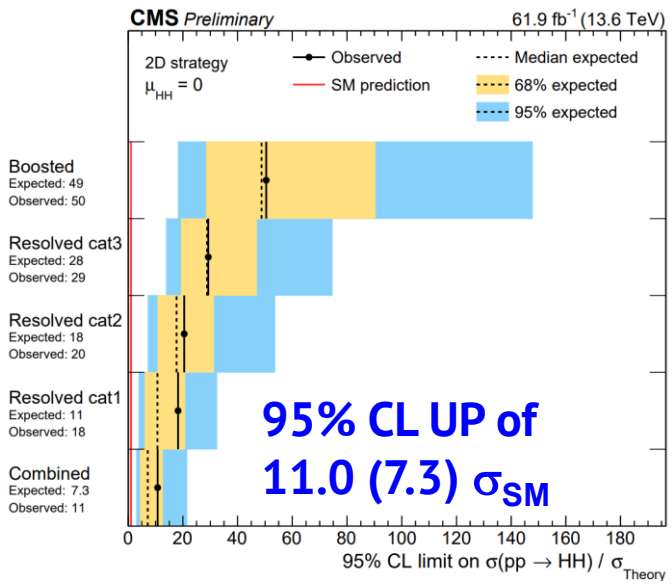


JHEP05(2026)186





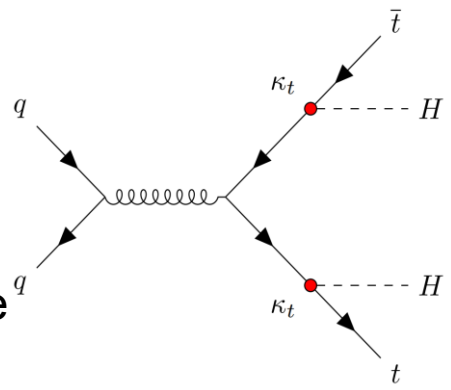


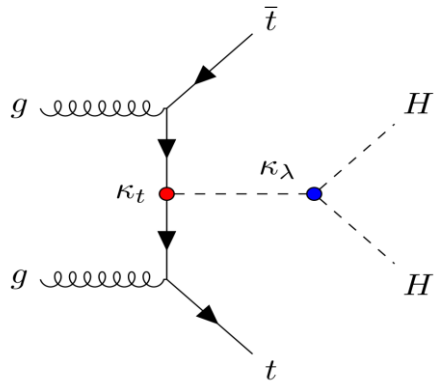


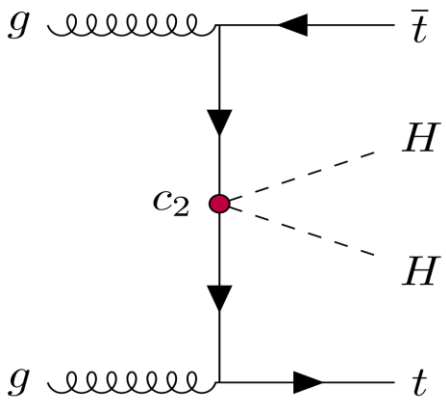
CMS-PAS-HIG-25-007

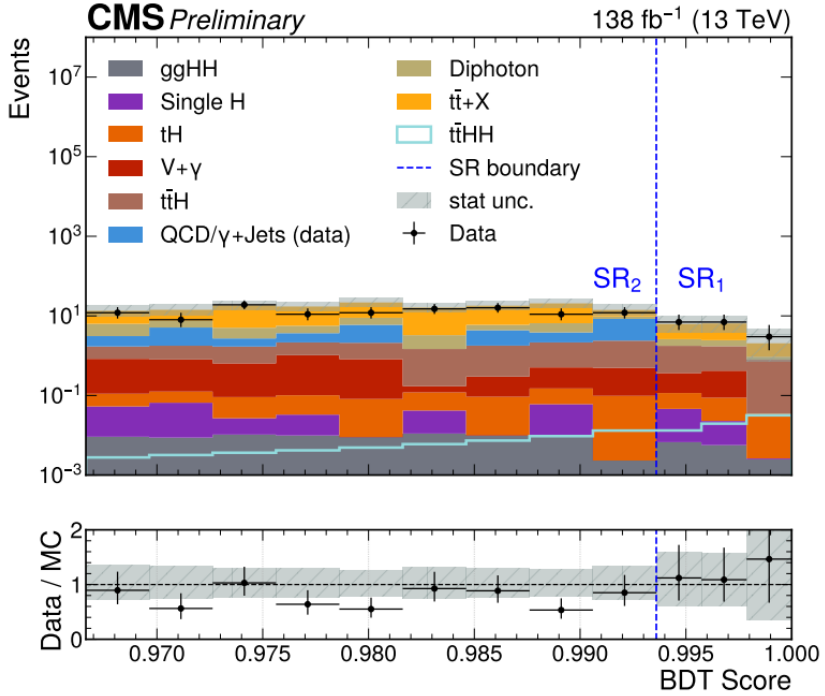
ttHH with HH→γγ+ bb/WW/ττ

- Searching for **ttHH** targeting final states containing two photons and multiple jets or leptons: directly constrain c_2, also be sensitive to BSM
- A fit to the $\mathbf{m}_{\gamma\gamma}$ to extract results for the different ttHH search channels
- A multivariate approach (**MVA**) is used to identify optimal search regions







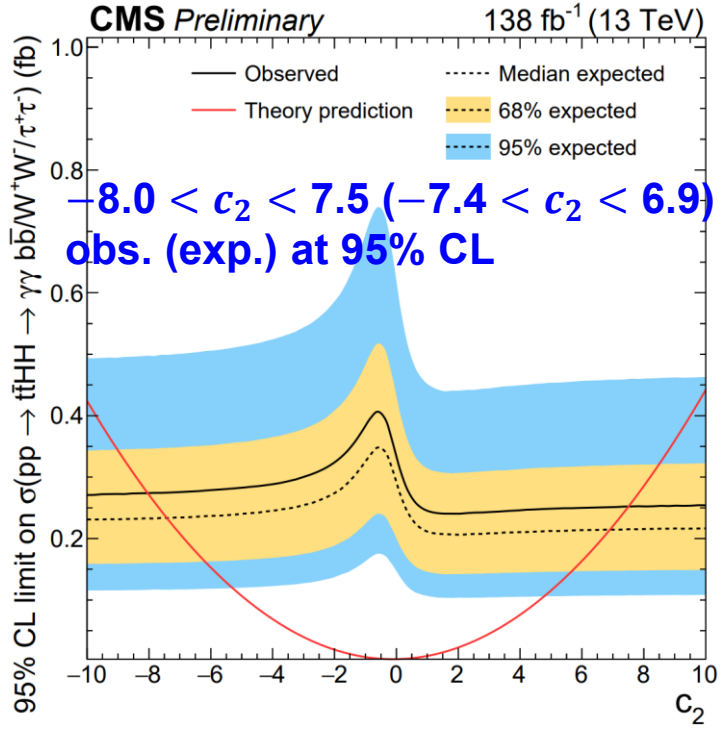


CMS-PAS-HIG-23-004

Upper limits on SM tt̄HH cross section

	σ/σ_{SM} (stat)	σ/σ_{SM} (stat+syst)
median	81.9	85.9
1σ	56.3 122.0	58.7 129.4
2σ	40.9 175.1	42.3 187.6
observed	107.1	119.4

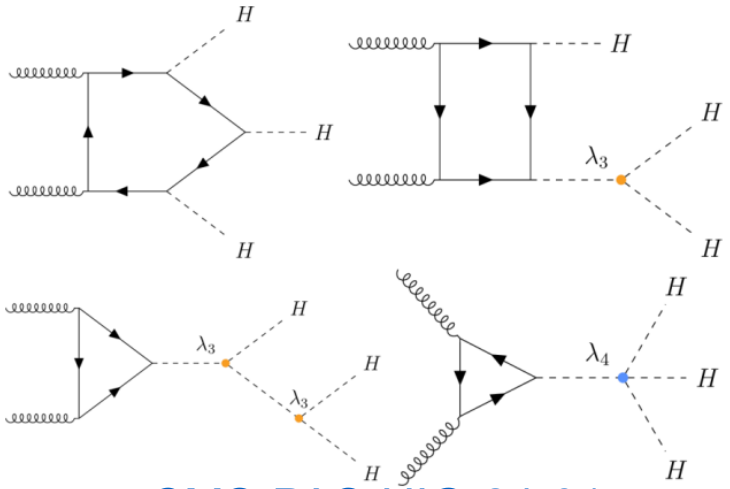
Upper limits at the 95% CL on tt̄HH production cross section: 119.4 (85.9)

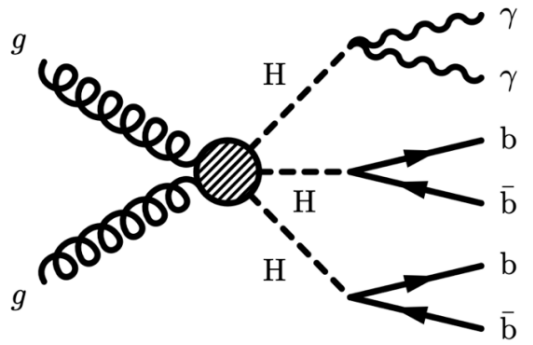


$-8.0 < c_2 < 7.5$ ($-7.4 < c_2 < 6.9$) obs. (exp.) at 95% CL

Triple Higgs hunting: HHH→4b2γ

- Tiny cross section: σ_{HHH}~0.09 fb at 13 TeV
- Probing for enhanced trilinear and quartic couplings sensitive to $\kappa_{\lambda 3}$ and $\kappa_{\lambda 4}$

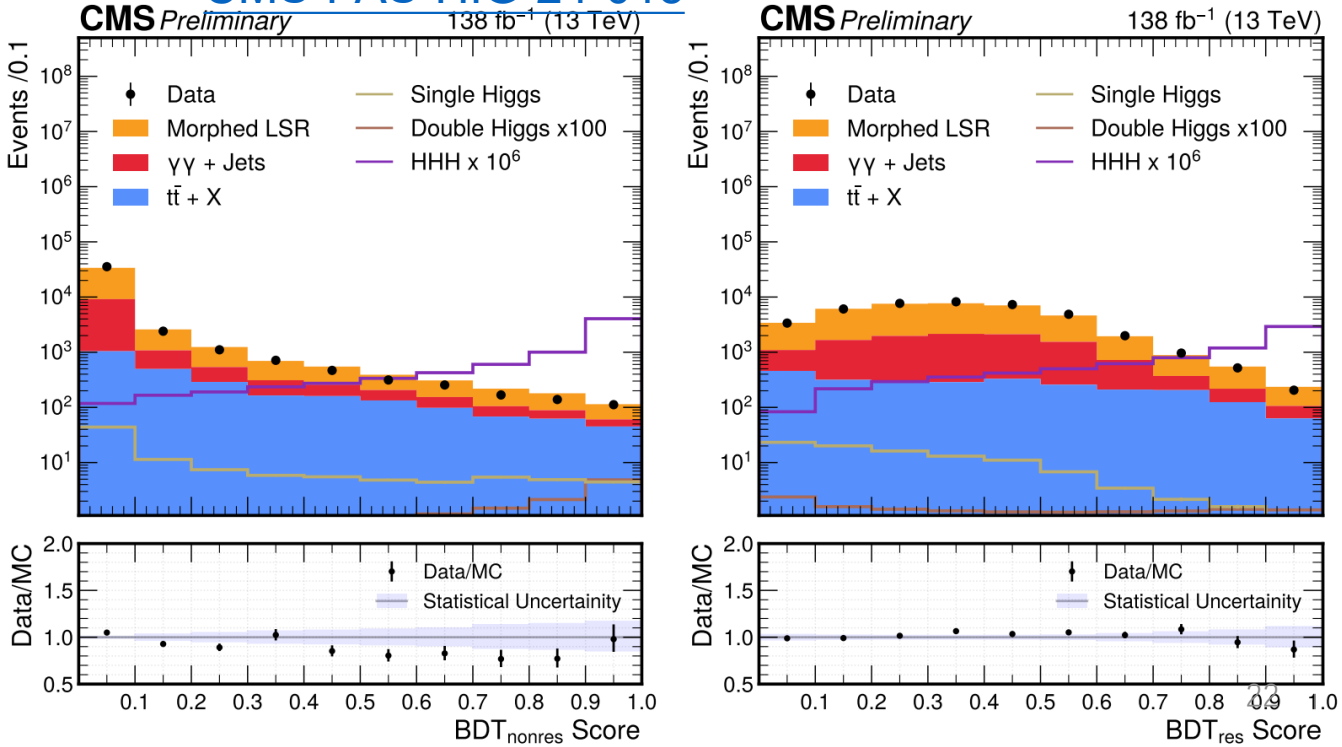




- **Two dedicated BDTs** trained using photon identification, b-tagging score, kinematic variables of final states, and geometric variables as input features
  - ✓ **Signal v.s. non-resonant backgrounds** (QCD, γ+jets and diphoton, and inclusive ttbar production)
  - ✓ **Signal v.s. resonant backgrounds** (H, HH with at-least one H → 2γ)
- **Data-driven QCD background** estimation using "Low Score Region" (LSR), where photon identification failed

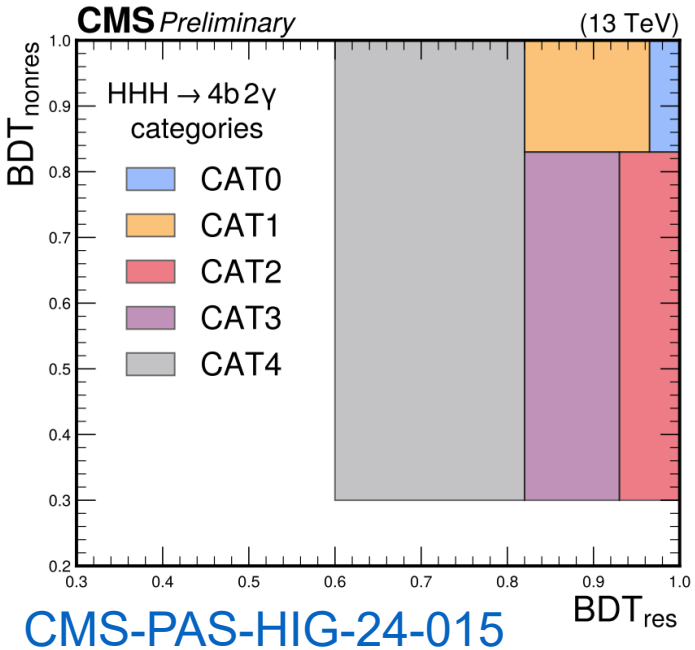
CMS-PAS-HIG-24-015

BR (HHH→4b2γ) = 0.23%
~ 0.03 events

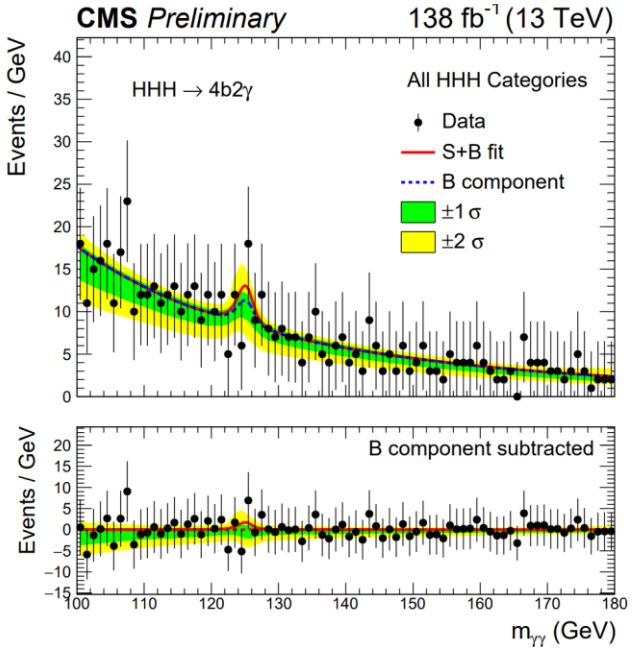


HHH→4b2γ

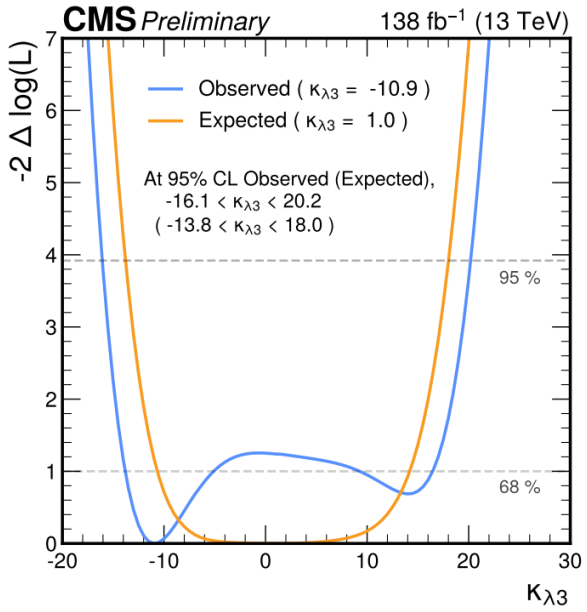
- **5 categories** defined based on 2-D cuts on BDT_{res} & BDT_{nonres} values
- Simultaneous fits performed to $m_{\gamma\gamma}$ distribution
- **Slight excess** observed in data (**within 1σ**)
- **Interpretation**: 1D and as well as 2D scan

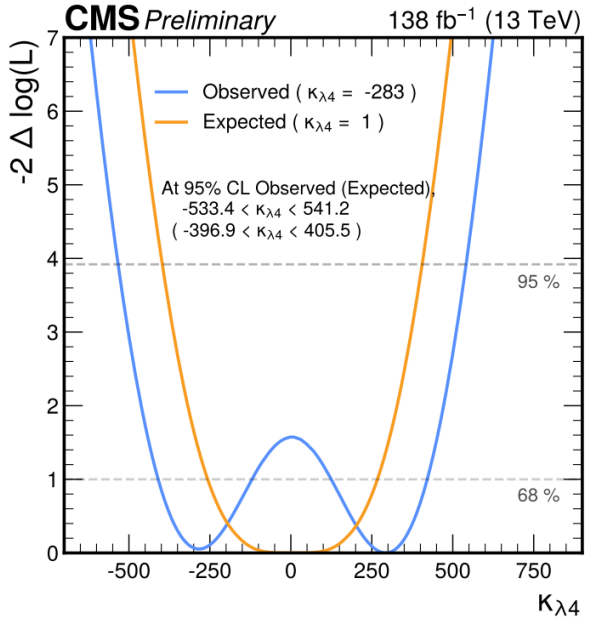


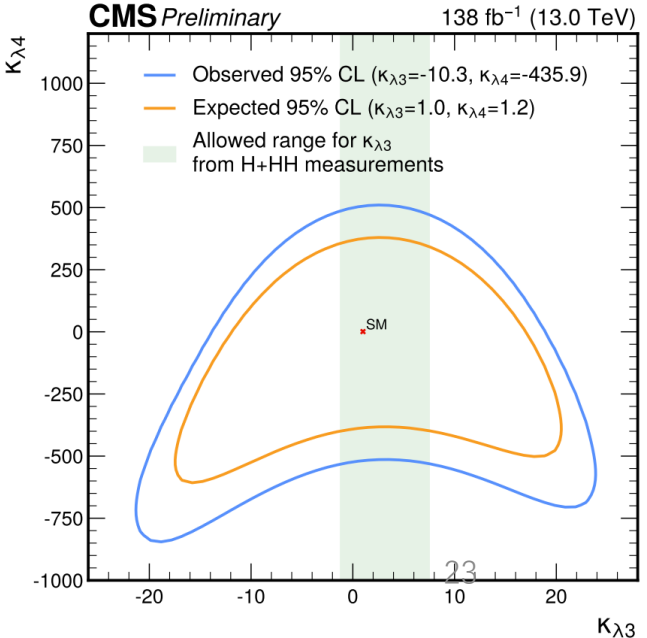
CMS-PAS-HIG-24-015



- ✓ **Observed (expected) upper limit of 3400 (2086) × σ_{SM}^{HHH}**
- ✓ **$-16.1 < \kappa_{\lambda 3} < 20.2$ and $-533 < \kappa_{\lambda 4} < 541$**







$H \rightarrow Za \rightarrow ll+\gamma\gamma$

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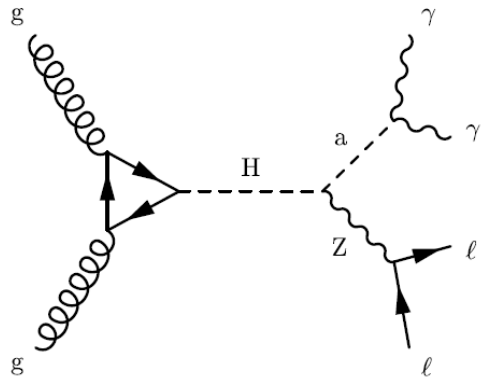
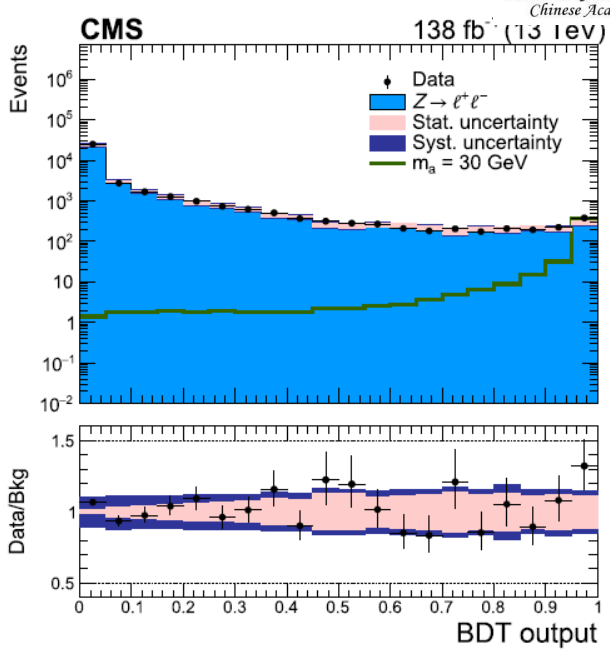
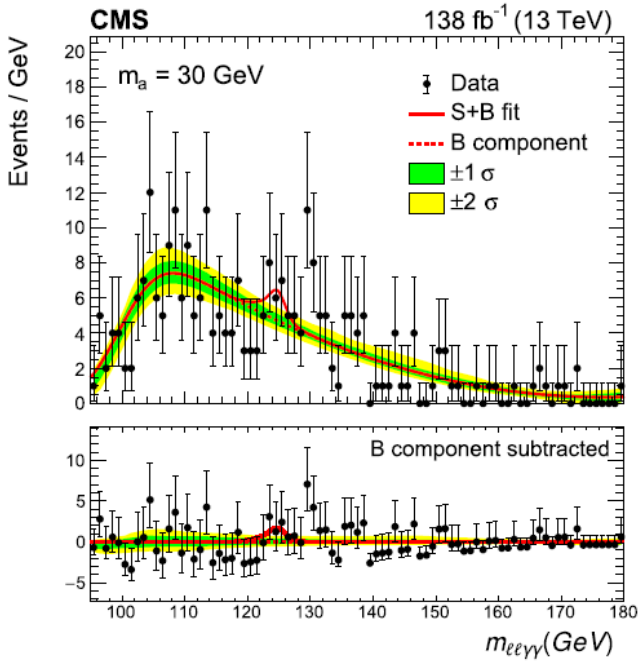
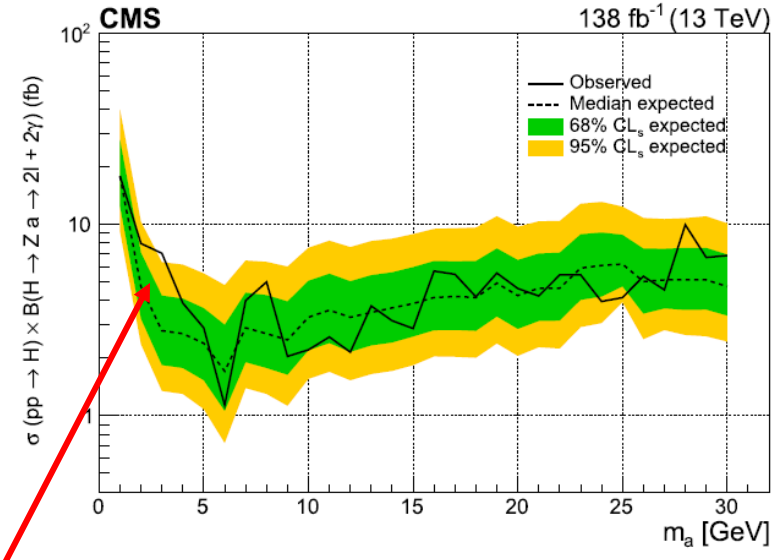
- **Two photon resolved** case with $m_a \in$ [1, 30] GeV, with **Z→μμ or ee**
- Developed **dedicated photon ID** by removing some shower-shape and isolation requirements, since *two photon are much close to each other*
- Trained an **event BDT** for event categorization to improve the sensitivity
- Use **llγγ invariant mass** spectrum to extract signal in data

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









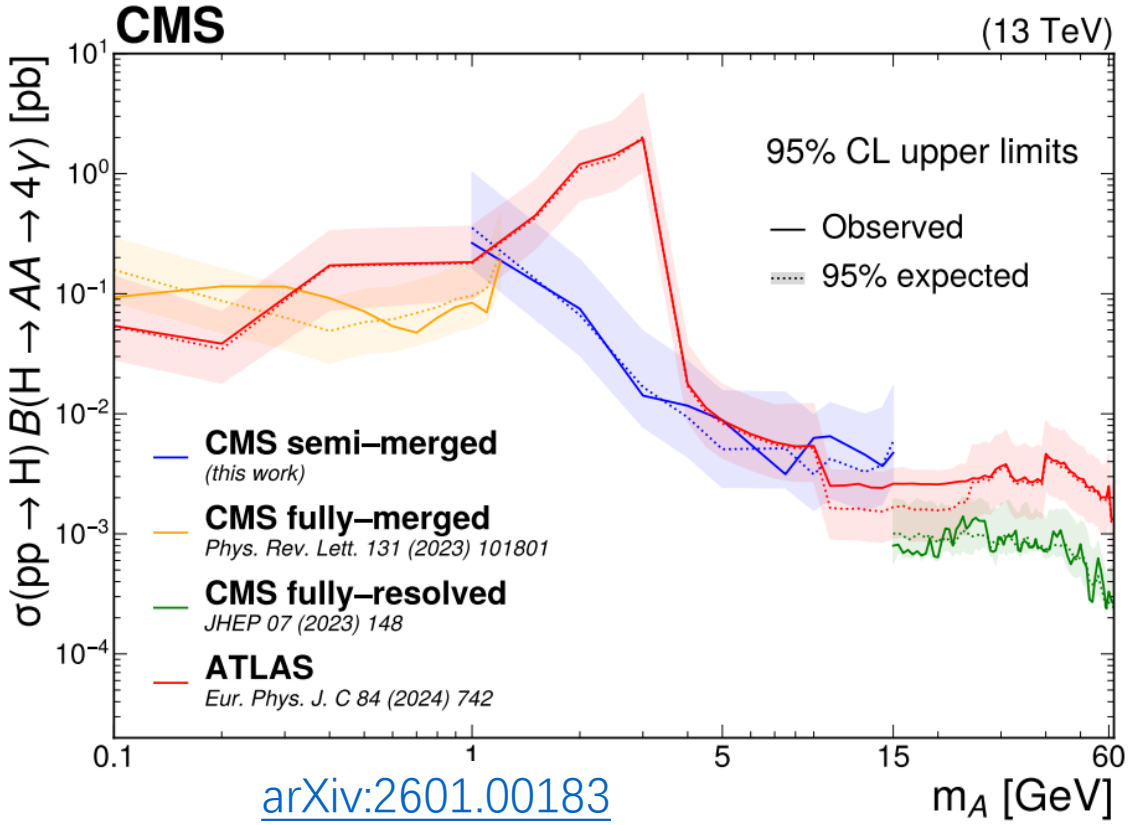
2.6σ (1.3σ) local (global) significance at m_a=3 GeV

$H \rightarrow aa \rightarrow 4\gamma$

- **CMS** performed the searches separately for **fully-merged** ($m_a \in [0.1, 1.2]$ GeV), **fully-resolved** ($m_a \in [15, 62]$ GeV) and **semi-merged** ($m_a \in [1, 15]$ GeV)

- **From latest semi-merged search**
  - ✓ **1 merged pair of photons**, **1 resolved photon,** → 3 reconstructed photons required!
  - ✓ **GNN** used for reconstruction of merged $\gamma\gamma$: from energy deposits in ECAL

- Signal extracted from **2D mass distribution** of $a's$



arXiv:2601.00183

Statistically limited and no significant deviation from background is observed

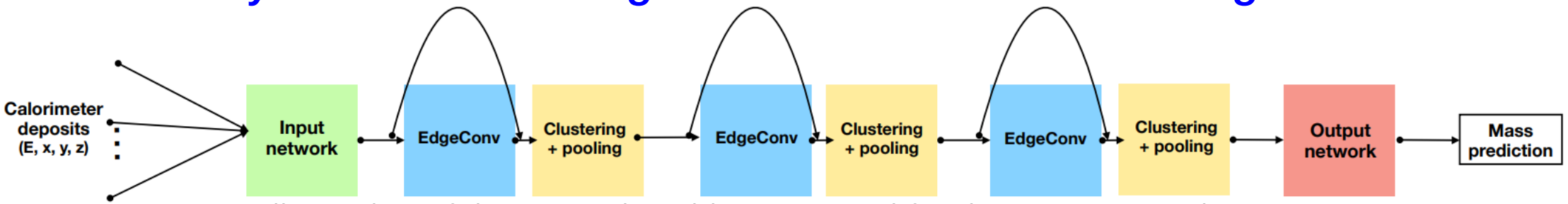


Illustration of the network architecture used for the mass regression