Recent results on Higgs properties

on behalf of
the CMS collaboration

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Topics covered

- ❑ Mass and width
- ❑ Couplings and cross sections
- ❑ CP structures

Mass and width

Higgs mass m_H: not predicted by SM

- the only free parameter in the scalar sector.
- fix all SM Higgs properties
- input parameter to global electroweak fits :
  connected with the stability of the electroweak vacuum

Higgs width Γ_H: encodes the sum of all its possible decays

SM prediction: 4.07 ± 0.16 MeV << mH

bound on Γ_H globally limits BSM physics:

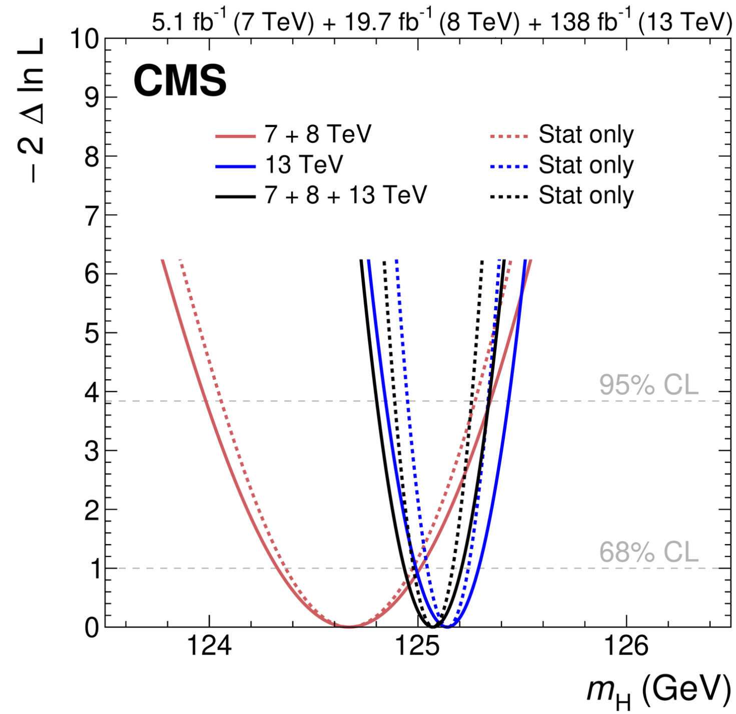
additional width beyond the SM could arise from invisible or exotic decays

Mass and width: *Hγγ* on-shell

Photon energy measurement by the CMS ECAL:

- $Z \rightarrow ee$ events :
  derive energy scale and resolution corrections
- MC simulation :
  corrected for differences in the energy scale between electrons and photons
- $Z \rightarrow \mu\mu\gamma$ events :
  account for any residual energy-scale difference

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 bac	27
Other sources	13
Statistical uncertainty	100
Total uncertainty	150



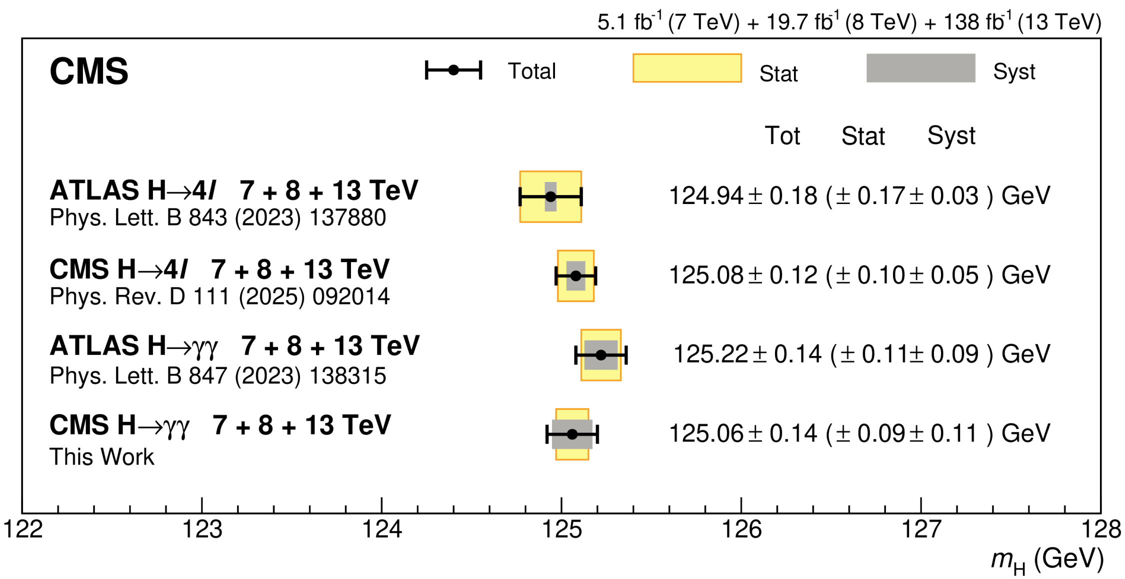
arXiv:2607.28396

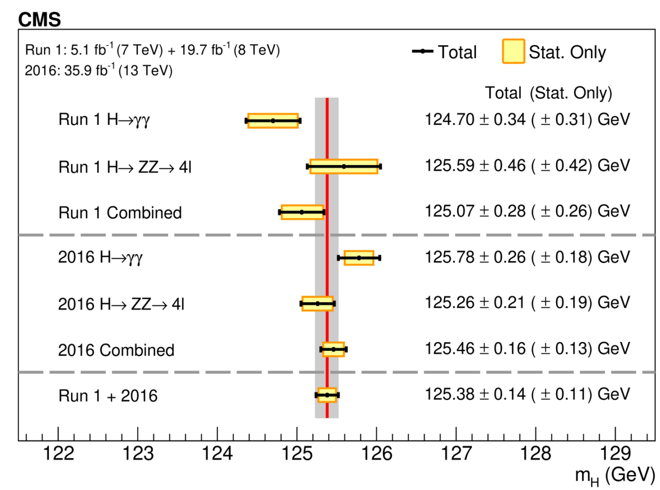
Submitted to Physics Letters B

Run-2 : m_H = 125.13 ± 0.10 (stat) ± 0.12 (syst) GeV

Run-2 + Run-1 : m_H = 125.06 ± 0.09 (stat) ± 0.11 (syst) GeV

Mass and width: summary





Phys. Lett. B 805 (2020) 135425

$H \to 4l$: $m_H = 125.08 \pm 0.10$ (stat.) $\pm$ 0.05 (syst.) GeV

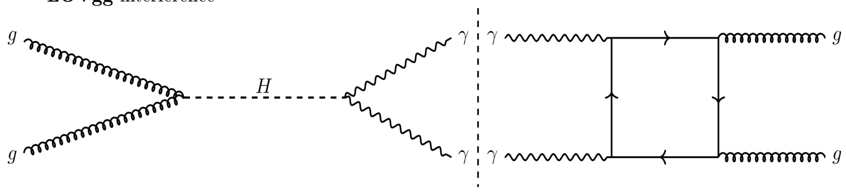
$H \to \gamma\gamma$: $m_H = 125.06 \pm 0.09$ (stat) $\pm$ 0.11 (syst) GeV

arXiv:2607.28396

Submitted to Physics Letters B

Mass and width: $H\gamma\gamma$ on-shell

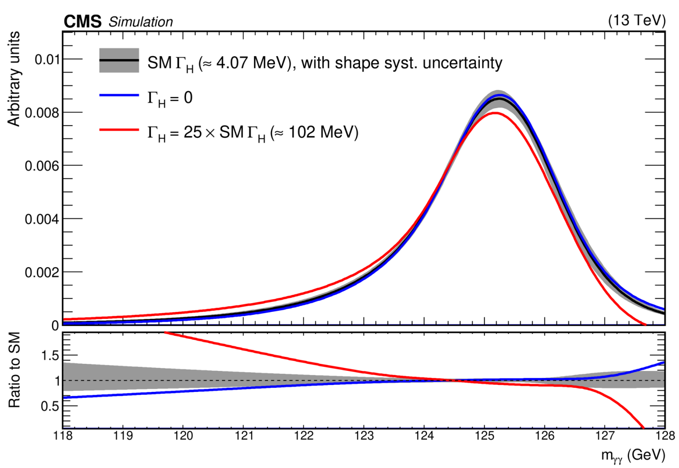
LO : gg interference



Signal: $gg \to H \to \gamma\gamma$

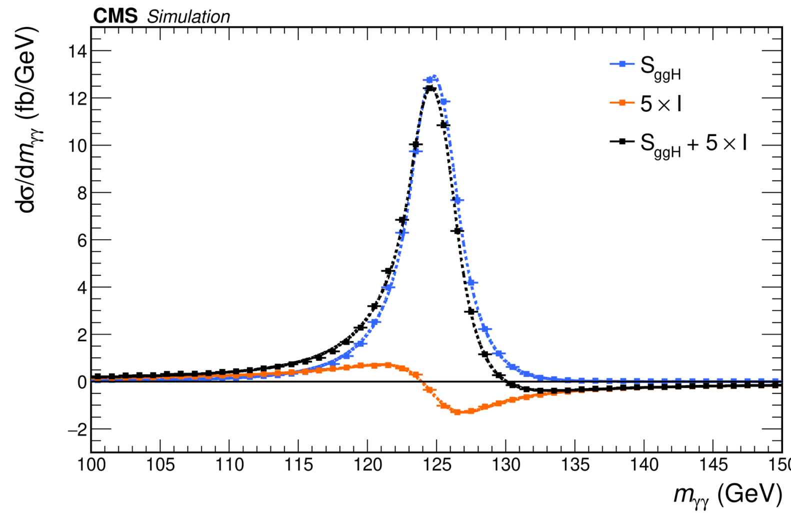
Background: $gg \to \gamma\gamma$

Interference **induces distortions** in the mass spectrum and also a shift in the Higgs boson mass peak :
a feature to measure Γ_H from the $m_{\gamma\gamma}$ shape.



[arXiv:2609.01385](https://arxiv.org/abs/2609.01385)

Submitted to Physical Review Letters

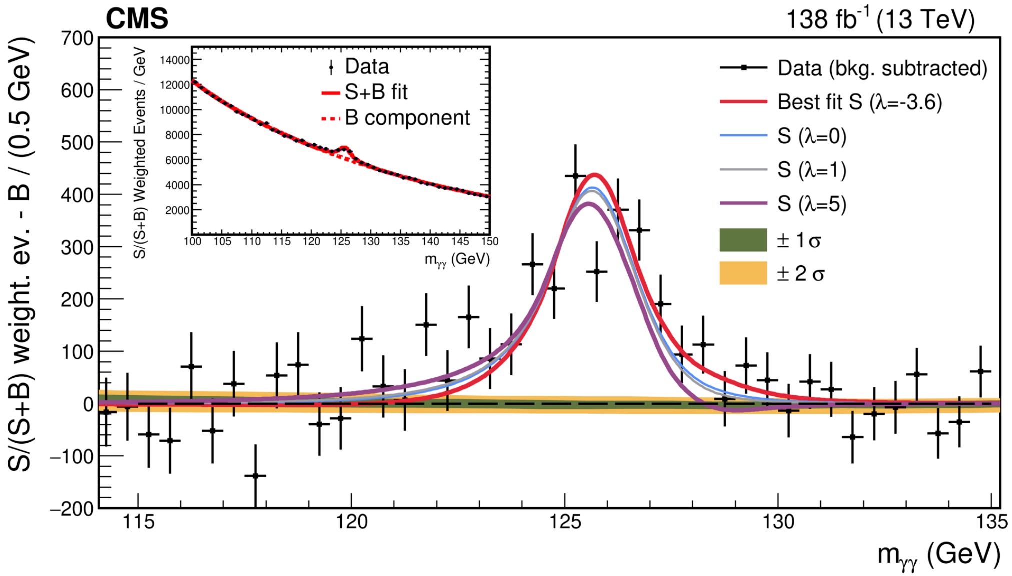


Differential distribution includes both signal and interference with the continuum diphoton process:

$$d\sigma_s^{ggH}/dm_{\gamma\gamma} = \frac{c_{g\gamma}^2}{\Gamma_\mathrm{H}} \Gamma_\mathrm{H}^{SM} \mathcal{S}_{ggH}(m_{\gamma\gamma}) = \mu_F \mathcal{S}_{ggH}(m_{\gamma\gamma})$$

$$d\sigma_i/dm_{\gamma\gamma} = c_{g\gamma} \mathcal{I}(m_{\gamma\gamma})$$

Mass and width: $H\gamma\gamma$ on-shell



arXiv:2609.01385

Submitted to Physical Review Letters

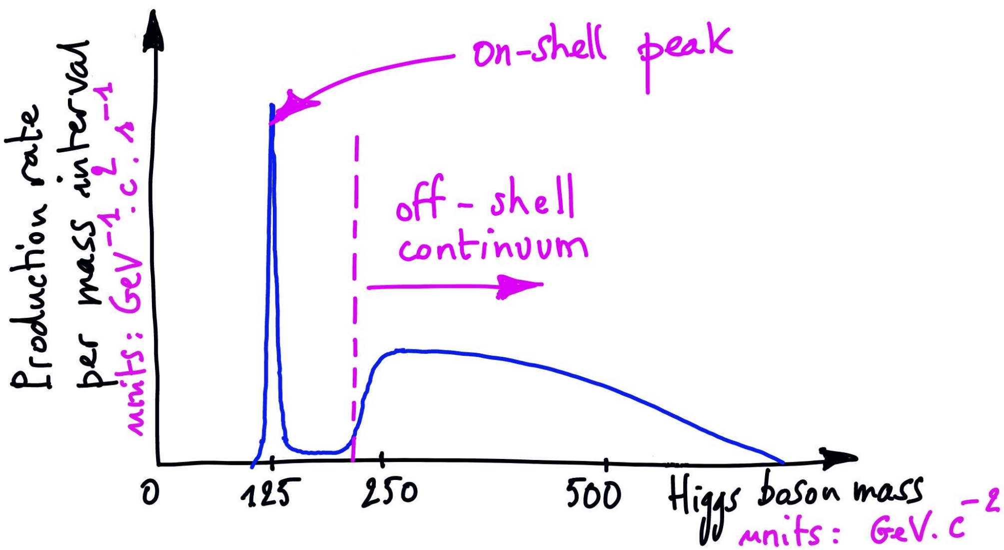
$$\frac{d\sigma_s^{ggH}}{dm_{\gamma\gamma}} + \frac{d\sigma_i}{dm_{\gamma\gamma}} + \frac{d\sigma_s^{V}}{dm_{\gamma\gamma}} + \frac{d\sigma_b}{dm_{\gamma\gamma}} =$$

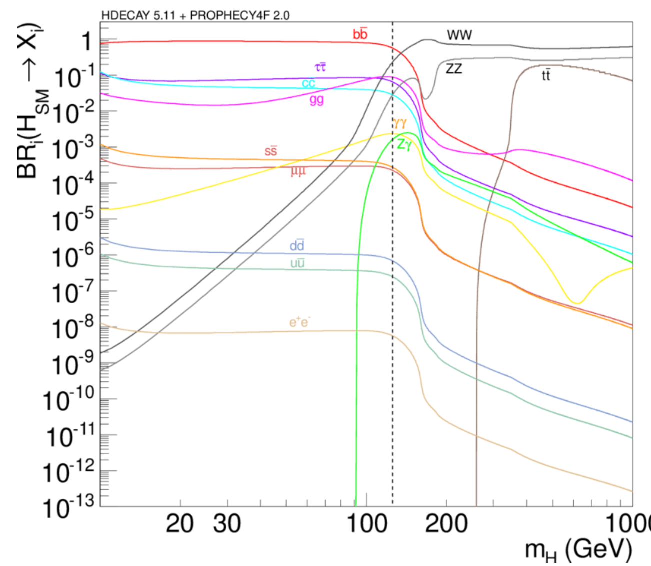
$$\left(\mu_F - \sqrt{\mu_F \frac{\Gamma_{\mathrm{H}}}{\Gamma_{\mathrm{H}}^{SM}}}\right) \mathcal{S}_{ggH} + \sqrt{\mu_F \frac{\Gamma_{\mathrm{H}}}{\Gamma_{\mathrm{H}}^{SM}}} (\mathcal{S}_{ggH} + \mathcal{I}) + \mu_V \sum_{j \in \{\mathrm{VBF, VH}\}} \mathcal{S}_{V,j} + \frac{d\sigma_b}{dm_{\gamma\gamma}}$$

Maximum likelihood fit to the data, combining all categories and data-taking years.

$\Gamma_H < 91.8$ MeV (expected $\Gamma_H < 138.2$ MeV) at 95% CL.

Mass and width : off-shell

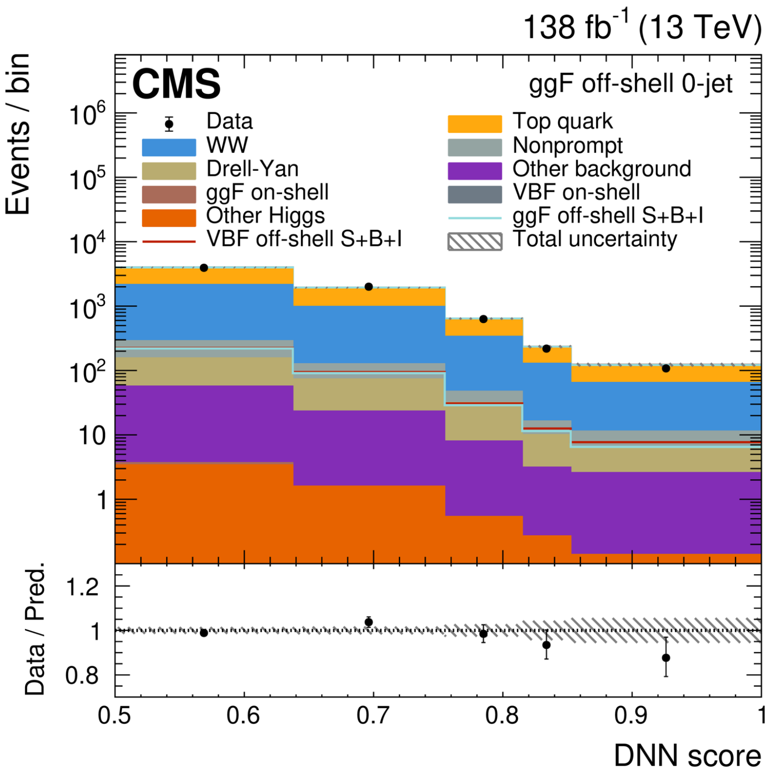




$$\sigma^{off-shell} \propto \int \frac{g^2_{prod}\, g^2_{dec}}{(q_H^2 - m_H^2)^2} dq_H^2 \propto \mu_{off-shell} \propto \boxed{\mu_{on-shell} \times \Gamma_H/\Gamma_{SM}}$$

Width can be extracted combining on-shell and off-shell measurements.

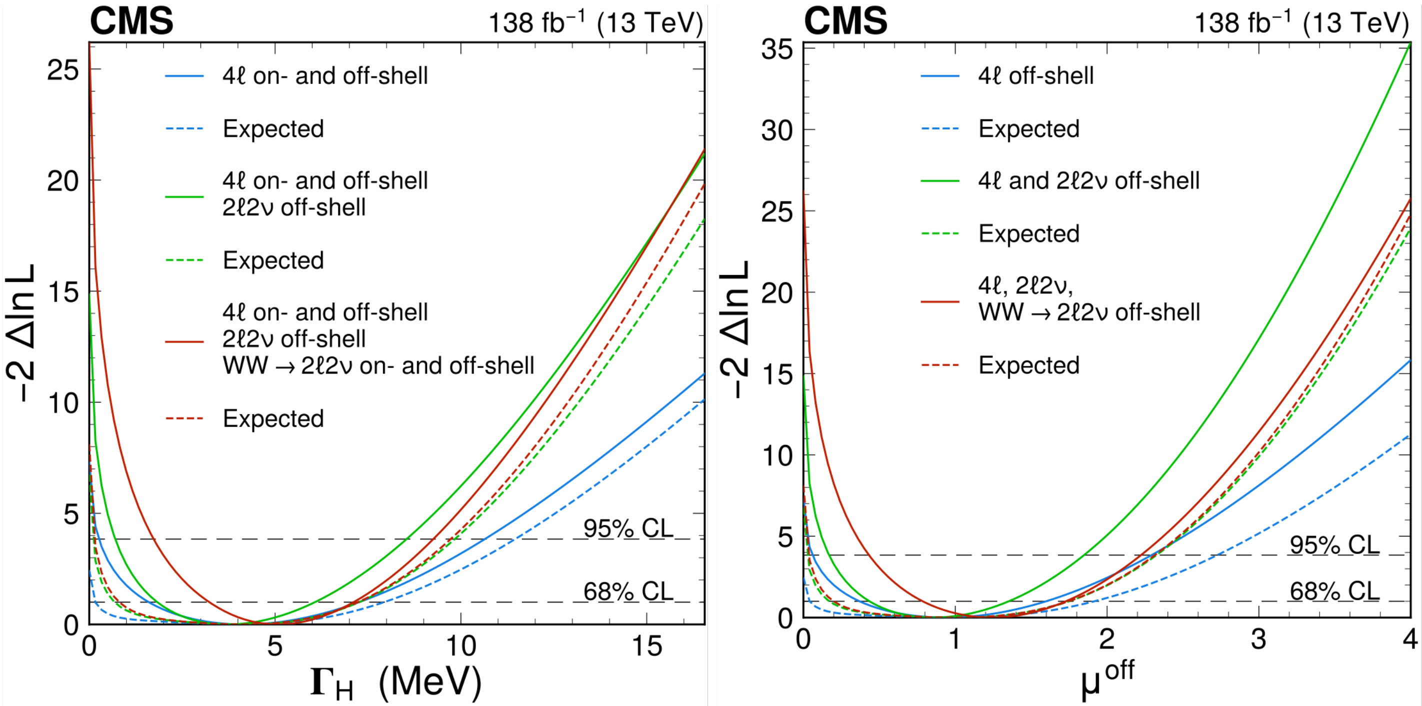
Mass and width : off-shell



[*Phys. Rev. D 113 (2026) 092014*]()

- Dileptonic decay channel: $WW \rightarrow 2\ell 2\nu$
- DNN for event selection categorization:
  - Input: leptons/MET/jets kinematics
  - Output: likelihood for a given event to belong to each category (off-shell, on-shell, backgrounds)
- Categorize events in signal and control regions.

Mass and width : off-shell summary



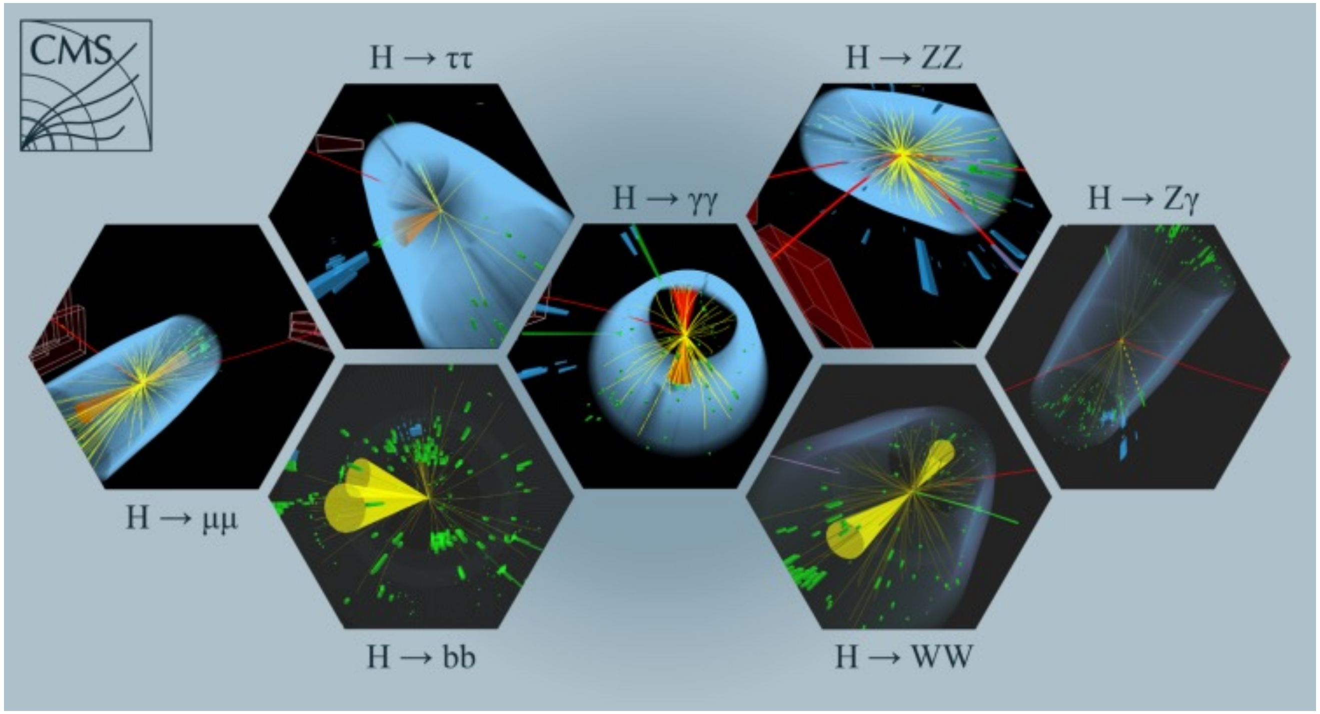
Strong evidence of **Higgs off-shell production**:
3.6σ in HZZ, 3.4σ in HWW.

arXiv:2607.23352
Submitted to Physical Review D

The hypothesis of no off-shell Higgs boson production was excluded at the 5 standard deviation level.

Couplings and cross sections

The legacy combination of Higgs boson using the full LHC Run 2 data, provides the most precise and comprehensive measurement of the Higgs boson by CMS to date.

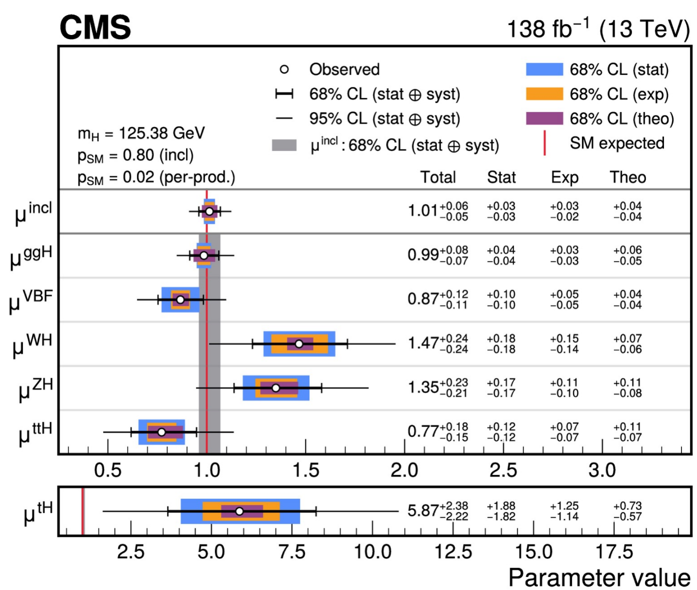


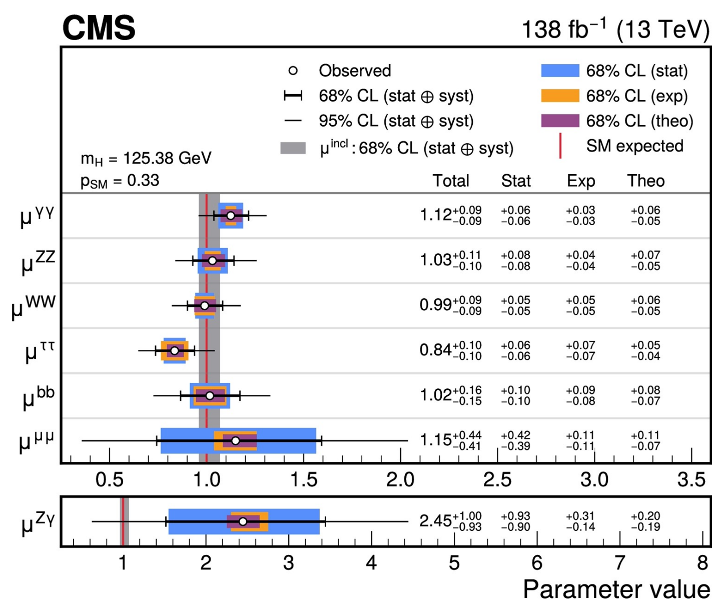
[*Rep. Prog. Phys. 89 (2026) 087801*]

Couplings and cross sections : signal strength

$$\mu^{\text{incl}} = 1.014^{+0.055}_{-0.053} = 1.014^{+0.040}_{-0.039}\,(\text{theo})^{+0.025}_{-0.024}(\text{exp}) \pm 0.028\,(\text{stat})$$

<u>5% precision :</u>
Dominant uncertainty: signal theory uncertainty (on signal modelling affecting the measurement, and SM prediction)

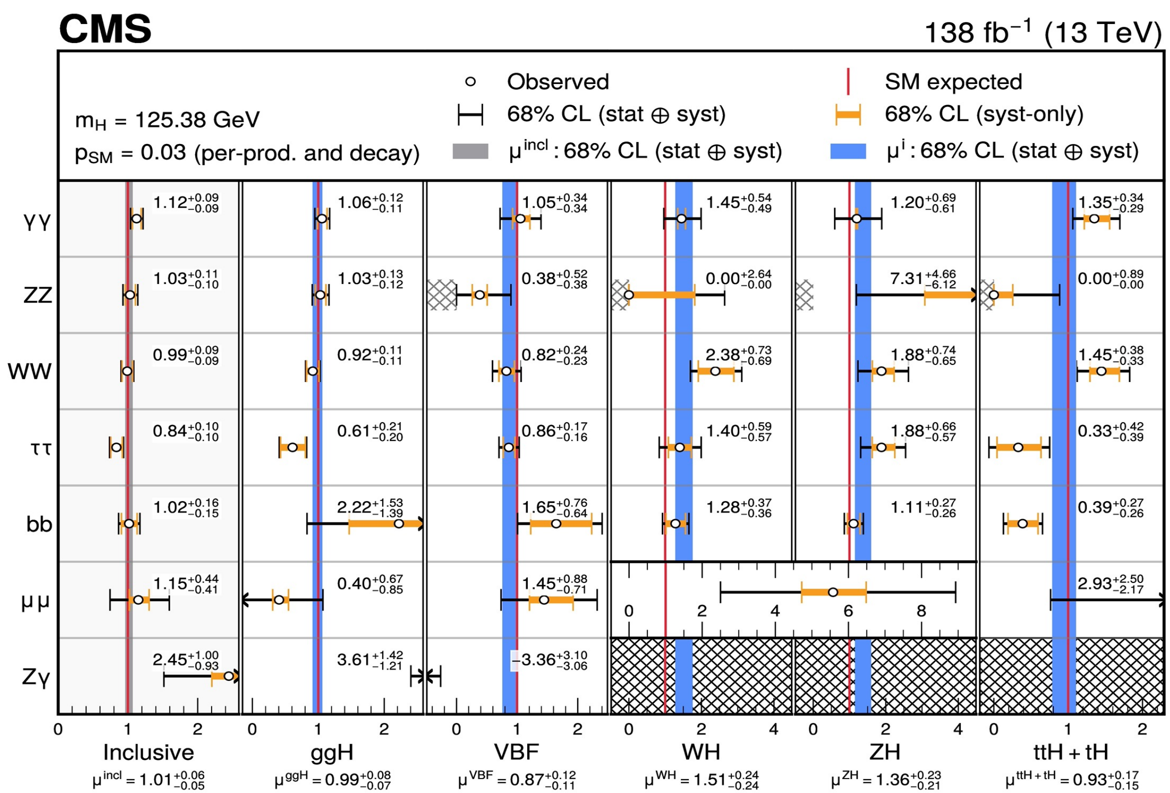




slight upward deviation in WH, ZH, and tH of roughly 2σ

$\mu^{\mu\mu}$ with <40% precision (3σ evidence)
$\mu^{Z\gamma}$ gives an upward deviation (2.7σ)

Couplings and cross sections : signal strength



$$\mu_{if} = \left(\sigma_i/\sigma_i^{\mathrm{SM}}\right) \times \left(B_f/B_f^{\mathrm{SM}}\right)$$

signal strength for each production-decay channel combination

a small tension (p = 0.03) is driven by the $ggH \to \tau\tau$, $WH \to WW$, $ttH + tH \to bb$, and $H \to Z\gamma$ channels

Couplings and cross sections : coupling modifier

Modifiers κ quantifies the deviation from SM at level of each coupling:

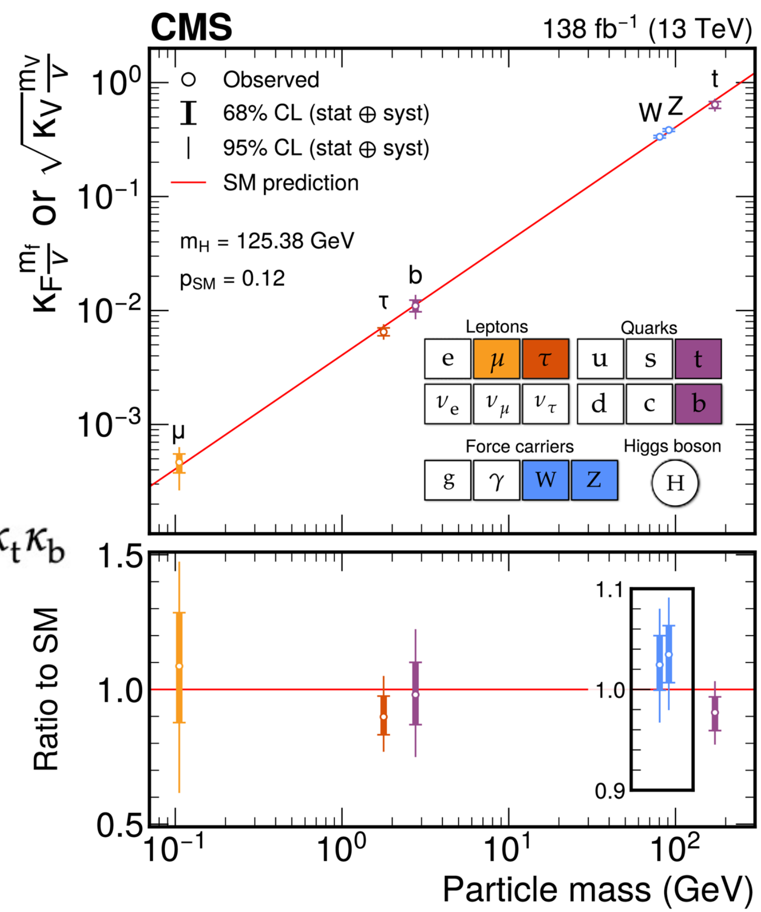
- ☐ is not naively sqrt of signal strength
- ☐ interfering terms can be used to determine their relative signs

  for e.g.,

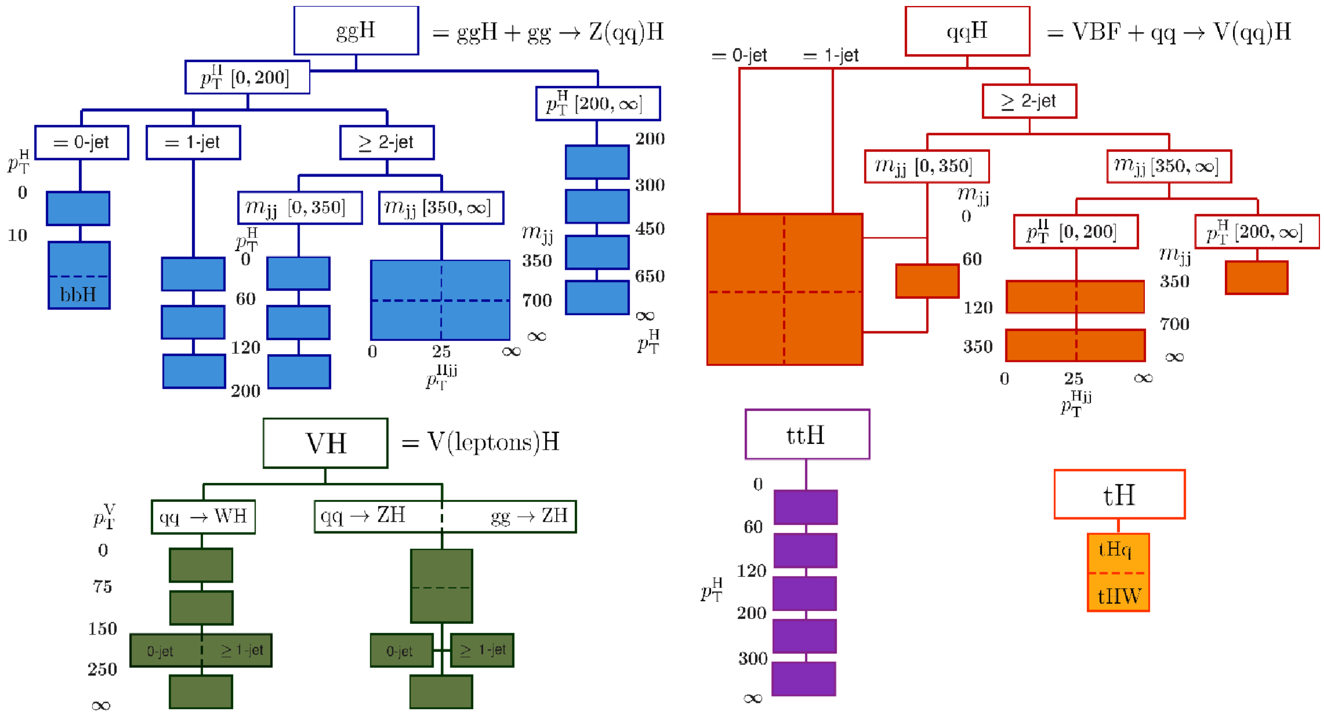
  ggH are scaled by $1.04\kappa_t^2 + 0.002\kappa_b^2 - 0.038\kappa_t\kappa_b$

- ☐ combination also allows for BSM Higgs decays, loops are fitted with effective coupling (see backup slide)

- ☐ couplings are indeed proportional to mass in a wide range of energy scales



Couplings and cross sections : STXS

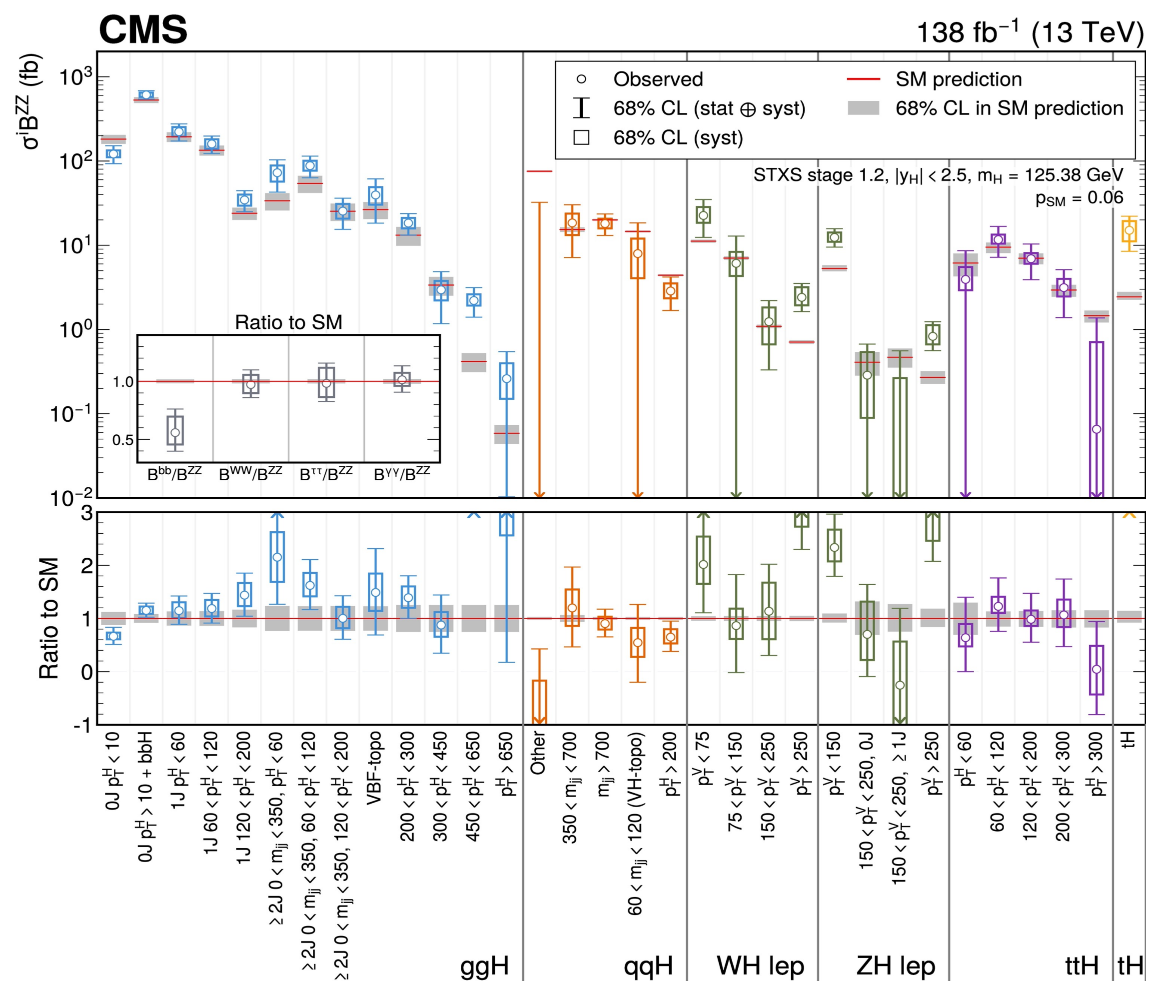


- Split phase space of Higgs production processes
- Defined by kinematics of Higgs boson and associated W/Z
- Provide differential cross-section measurements while easy to combine multiple production/decay channels

Couplings and cross sections : STXS

Some deviations observed:

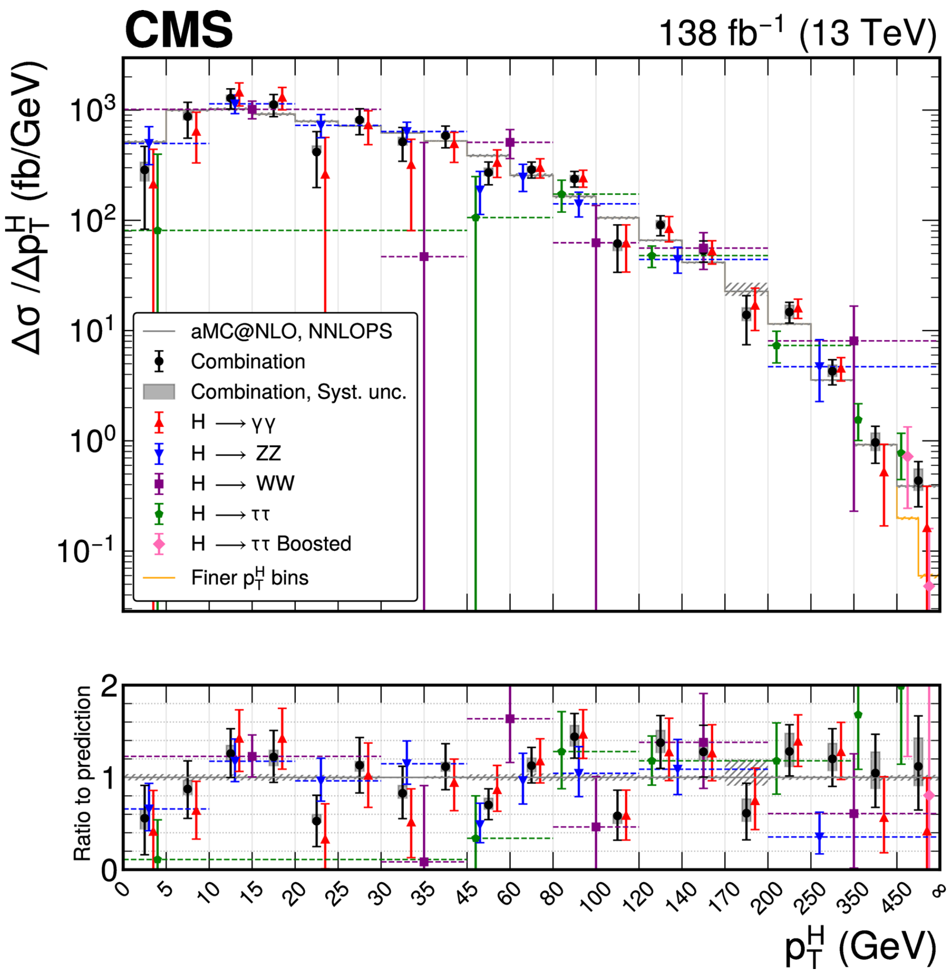
- $WH(2.2\sigma)/ZH(2.1\sigma)$
  for $p_T > 250GeV$
- $ggH\ 0jet\ (2.5\sigma)$
  for $450 < p_T < 650GeV$
- $tH(2\sigma)$



Couplings and cross sections : differential XS

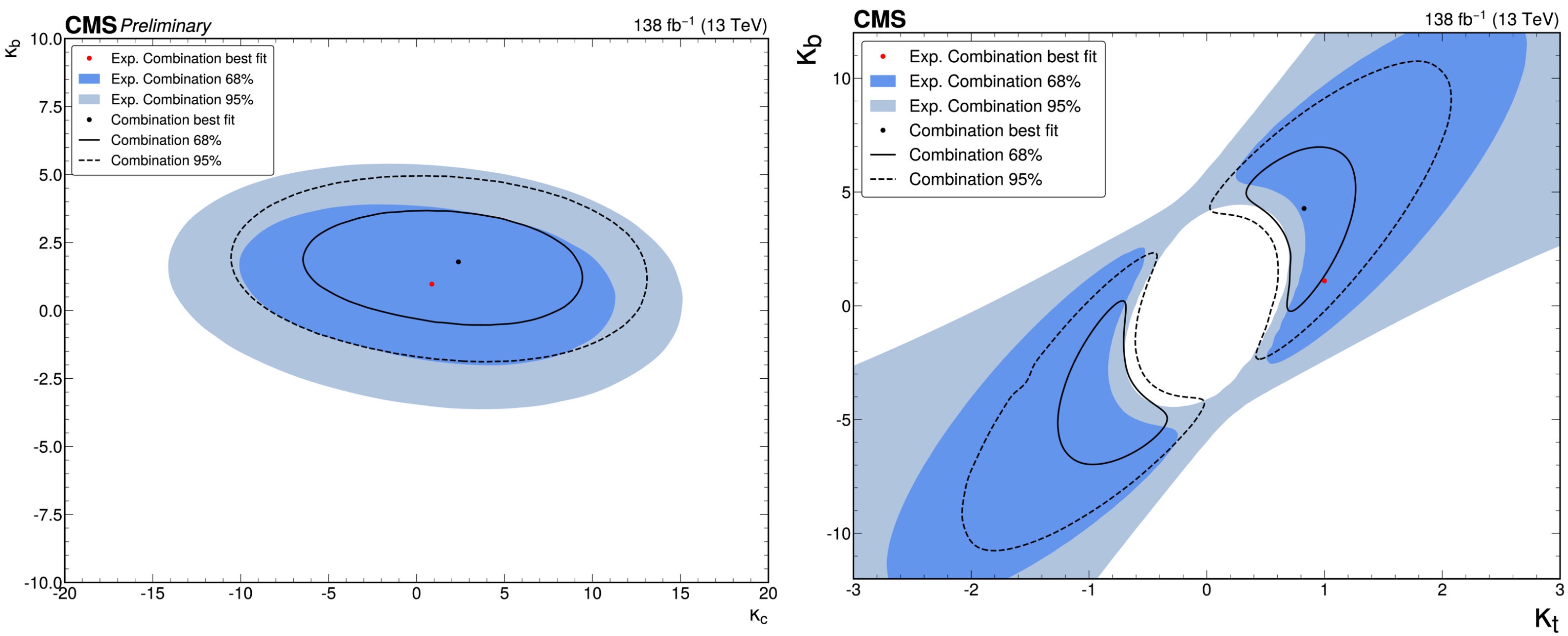
Fiducial differential measurements represents another way to measure Higgs boson cross section

- Binned in kinematic observables
- Probe Higgs production mechanisms
- Test the Standard Model with high precision and search for deviations in specific kinematic regions
- Sophisticated statistical techniques are used to combine fiducial measurements in different decay channels.



[JHEP04 (2026) 093]

Couplings and cross sections : differential XS



Combined fiducial differential measurements can be interpreted in coupling modifier : for example,
Higgs boson $p_T$measurements is used to set constraints on κ_t, κ_b and κ_c. The results are in very good agreement with the SM expectations.

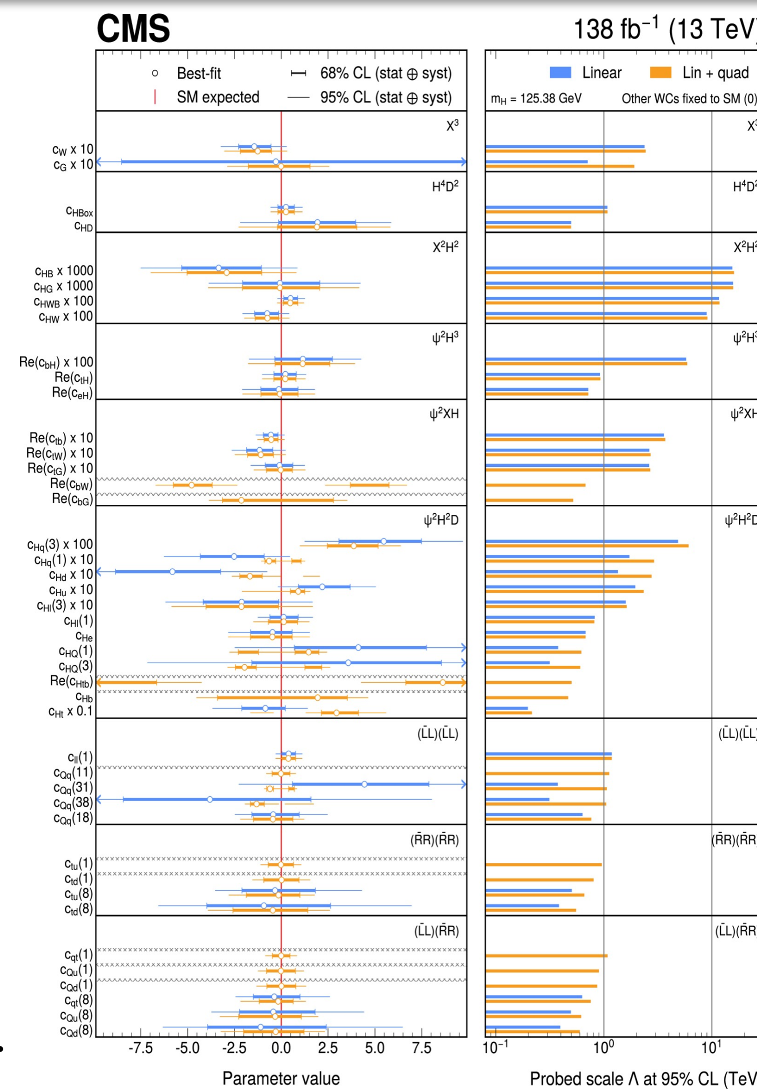
Couplings and cross sections : SMEFT

SMEFT provides another way to quantify the deviation to the SM in STXS and fiducial differential measurements.

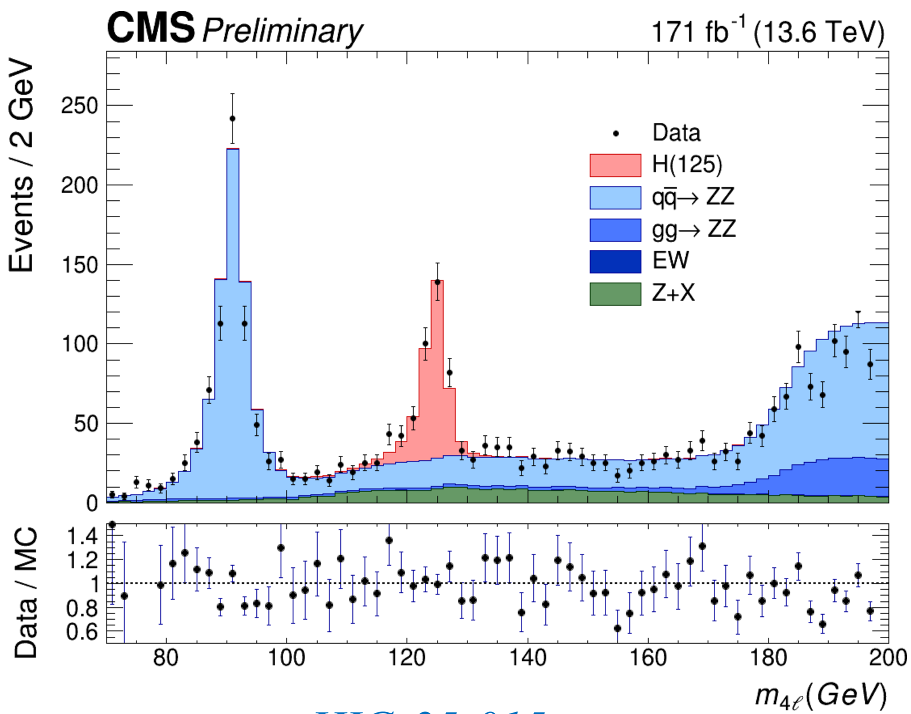
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_{d}^{N} \sum_{j \in \mathcal{O}^{(d)}} \frac{c_j^{(d)}}{\Lambda^{d-4}} \mathcal{O}_j^{(d)}$$

- Individual constraints on the SMEFT WCs are set from the linear (blue) and linear-plus-quadratic (orange) parametrizations.

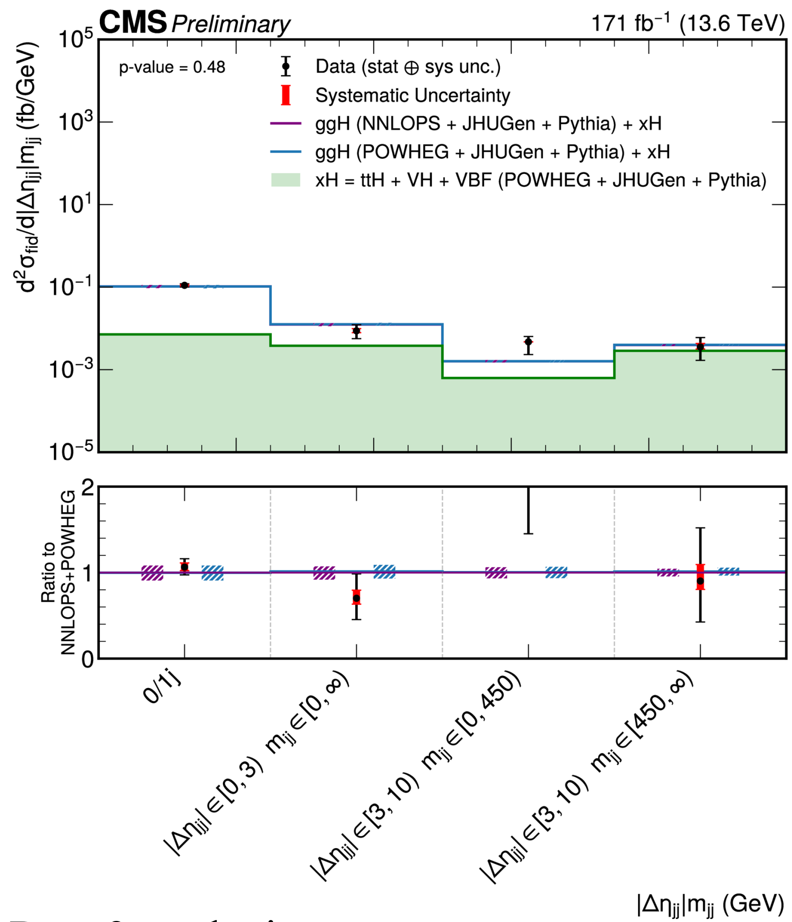
- "Principal Component Analysis" scenario is applied to select linear combinations of the coefficients where the data are more sensitive and fit those instead (see backup).



Couplings and cross sections : H-to-4l in Run-3



HIG-25-015



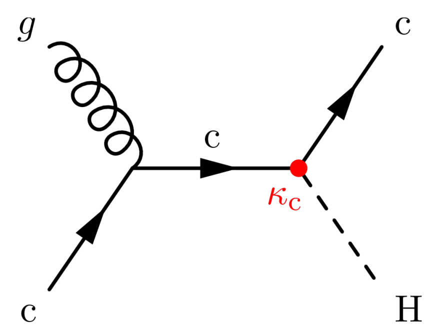
- 2022-2024 13.6TeV data are included in Run-3 analysis
- Double differential measurement sensitive to VBF production
  - $|\Delta\eta_{jj}|$ *vs* m_{jj} included for first time

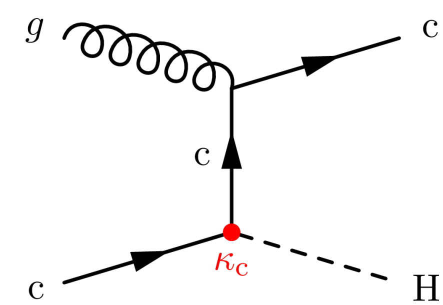
Couplings and cross sections : from rare productions and decays

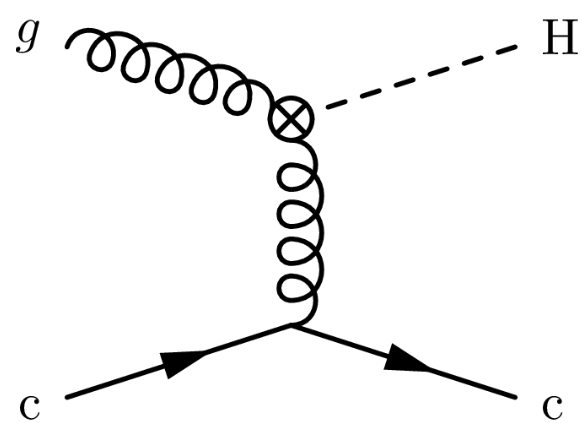
$H + c$ production

Higgs produced together with a jet originated from a charm quark

- cross section ≈ 90 fb at 13 TeV : about 0.2% of σ(H)
- κ_c-dependent with a ccH vertex
- κ_c -independent top-loop with an effective ggH vertex





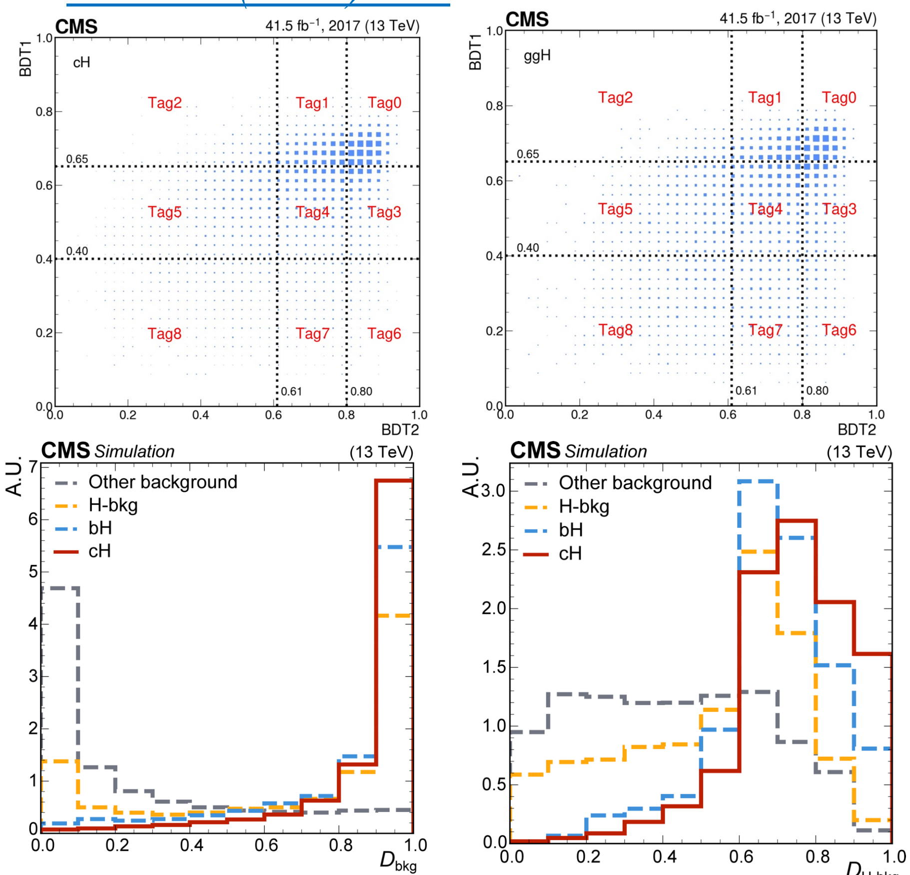


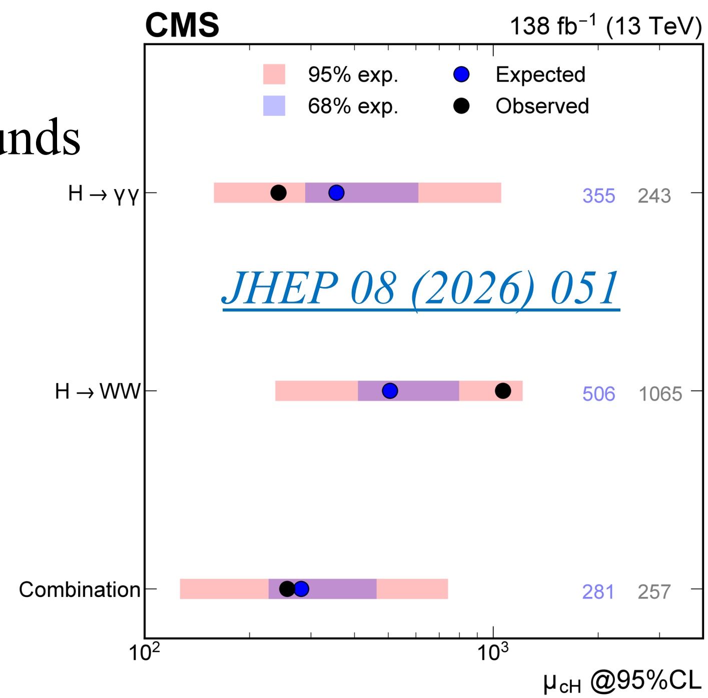
Couplings and cross sections : from rare productions and decays

$H + c$ production in $H\gamma\gamma + HWW$:

two BDTs to separate ggH and other backgrounds

JHEP11 (2025) 060



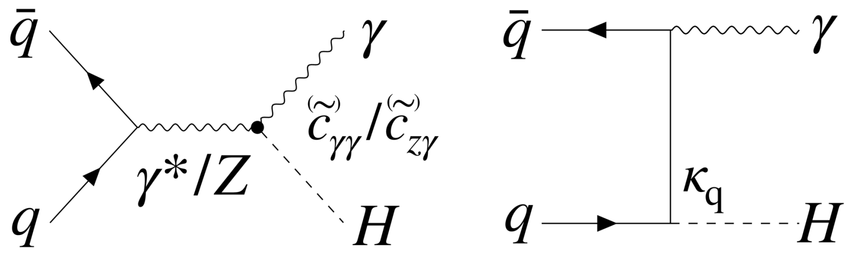


Combined results at 95% CL: constraints from **production-side,** in complementary to Hcc

- ☐ $\mu_{cH} < 257\ (281)$
- ☐ $|\kappa_c| < 47\ (51)$

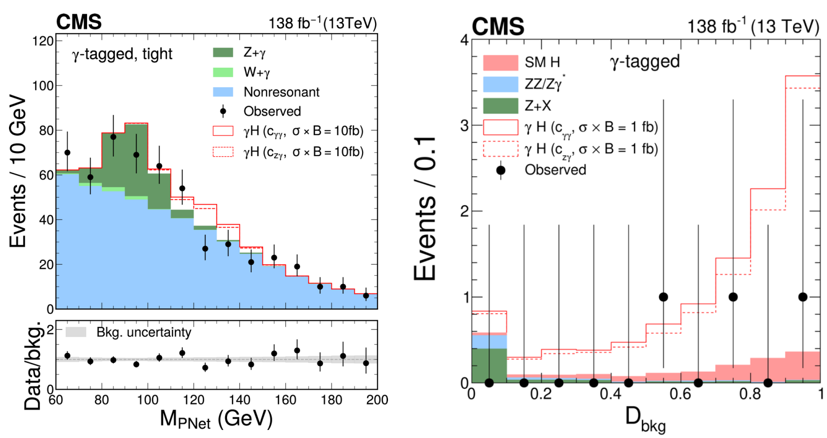
Couplings and cross sections : from rare productions and decays

$H + \gamma$ production : SM cross section σ(γH) < 5 fb at 13 TeV



$H + \gamma$: Higgs produced in association with a photon

- SM cross section σγH < 5 fb at 13 TeV



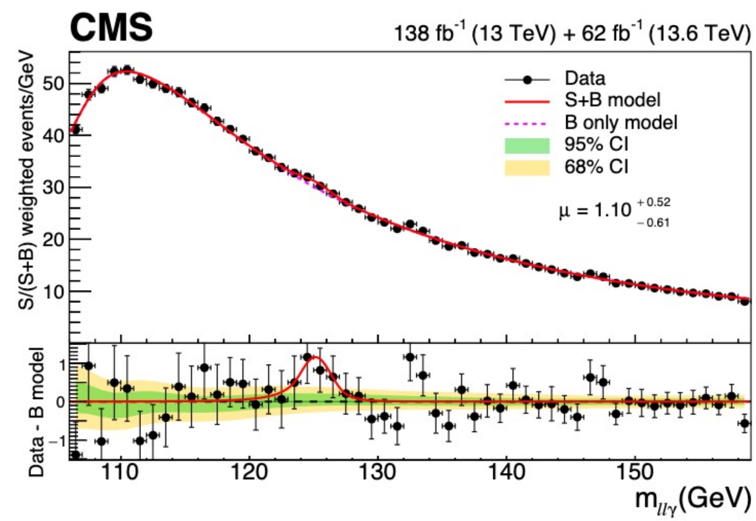
Combined Hbb and HZZ^*4l fit interpreted as light quark Yukawa couplings: excludes $y_{u,c} = y_t$ and $y_{d,s} = y_b$ at >95% CL

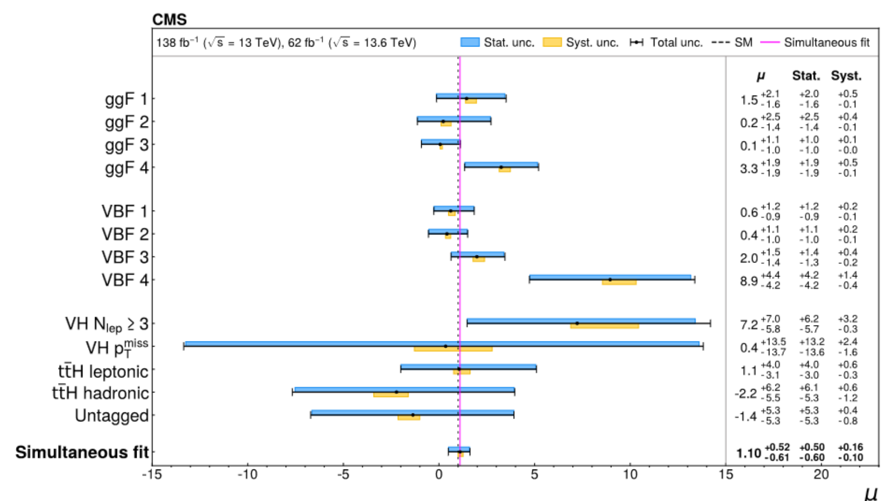
Couplings and cross sections : rare productions and decays

arXiv:2609.04402

submitted to Physics Letter B

- Run-2 and part Run-3 data combination
- Obs (exp) signal strength:
  $\mu = 1.10^{+0.52}_{-0.61}(1.00^{+0.49}_{-0.46})$
- Obs (exp) excess significance of the σ = 1.9 (2.3)
- High degree of compatibility across the categories.





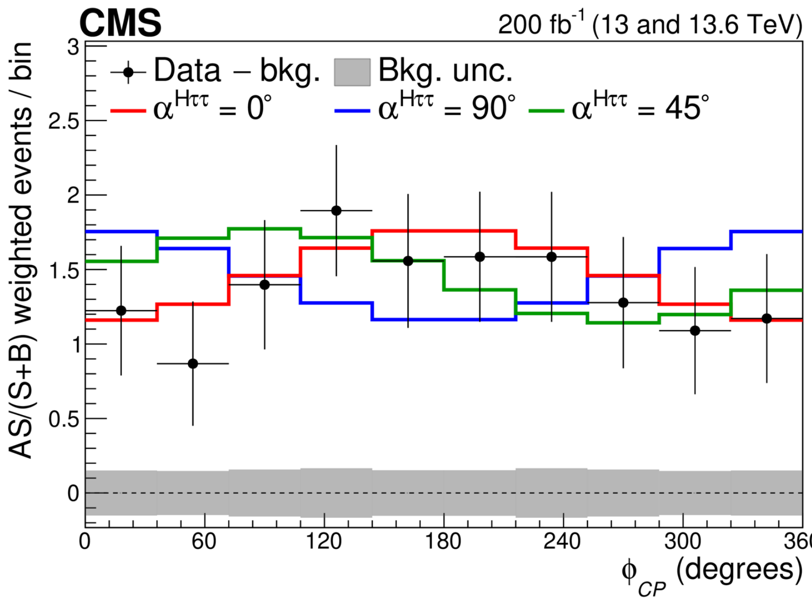
CP structure : H decays to τ-leptons

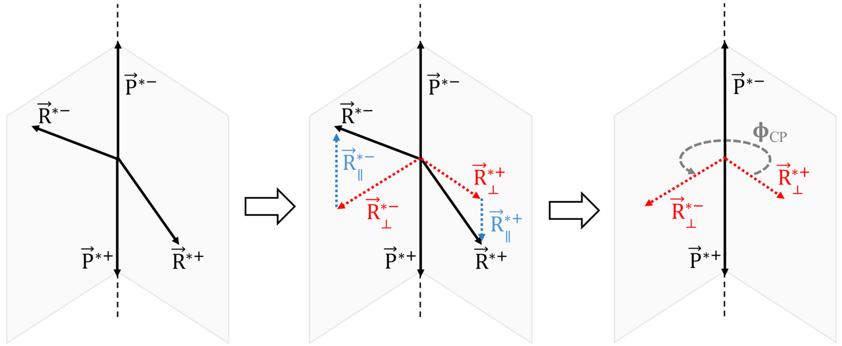
$$\mathcal{L}_Y = -\frac{m_\tau}{v} H \left(\boxed{\kappa_\tau \bar{\tau}\tau} + \boxed{\tilde{\kappa}_\tau \bar{\tau} i \gamma_5 \tau} \right)$$

The cross section is modulated by the angular of two tau decay planes in the Higgs rest frame ϕ_{CP} and the CP mixing angle ϕ_τ

$$\frac{d\Gamma}{d\phi_{CP}}(H \to \tau^+\tau^-) \sim 1 - b(E^+)b(E^-)\frac{\pi^2}{16}\cos(\phi_{CP} - 2\alpha^{H\tau\tau})$$

$$\tan(\alpha^{H\tau\tau}) = \frac{\tilde{\kappa}_\tau}{\kappa_\tau}$$





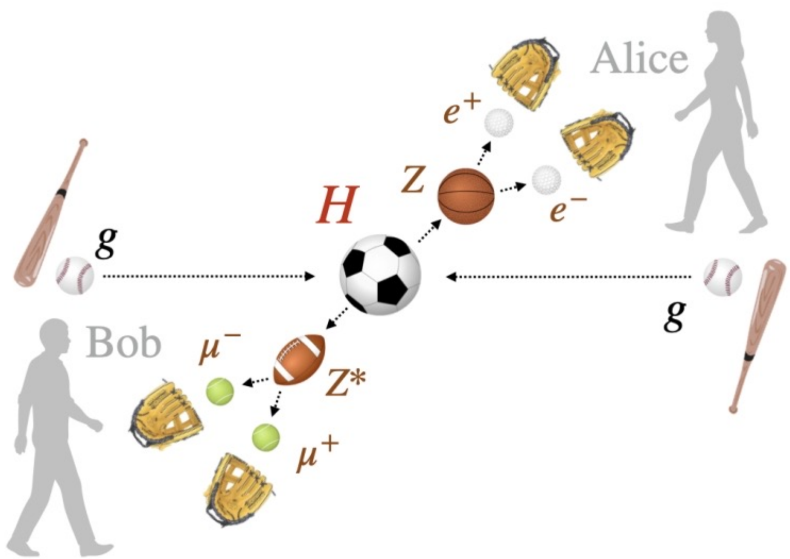
$$\alpha^{H\tau\tau} = 36^\circ \, {}^{+33}_{-30} (0 \pm 19^\circ \;\; 13.6\text{TeV})$$

$$\alpha^{H\tau\tau} = 7 \pm 16^\circ \;\; (0 \pm 14^\circ \;\; 13{+}13.6\text{TeV})$$

arXiv:2606.03510

Accepted by JHEP

CP structure : H decays to ZZ*



Test quantum entanglement in qudit: $|++>, |-->$, and $|00>$

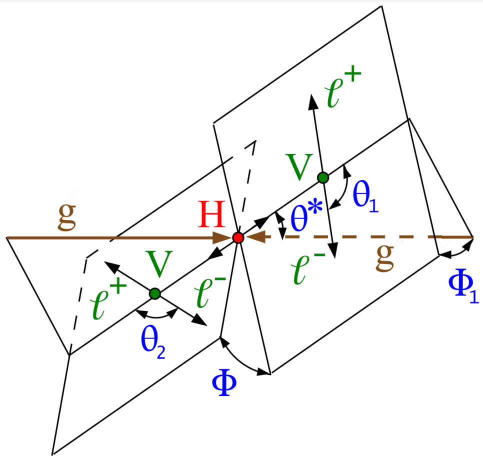
Figure from Physics Brief

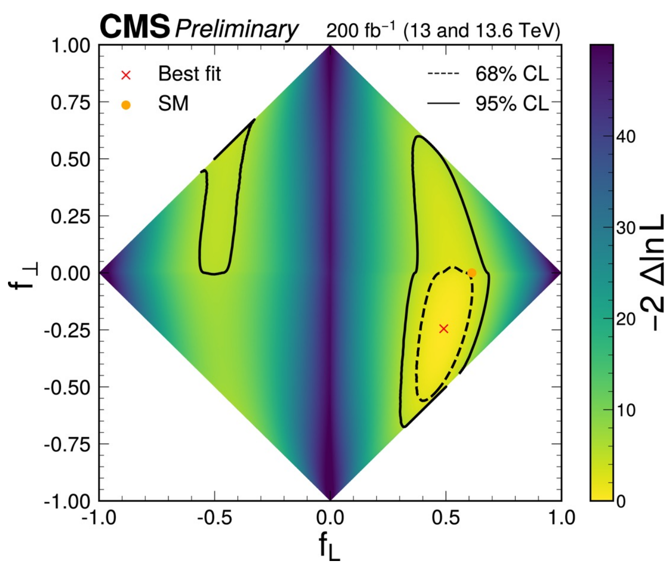
$$A_{00} = -\frac{\sqrt{1+x}\,m_{\mathrm{H}}^2}{v} a_1(m_1, m_2) - \frac{x m_1 m_2}{v} a_2(m_1, m_2), \quad \text{longitudinal}$$

$$A_{\parallel} = \frac{A_{++} + A_{--}}{\sqrt{2}} = \frac{\sqrt{2} m_{\mathrm{H}}^2}{v} a_1(m_1, m_2), \quad \text{transverse CP even}$$

$$A_{\perp} = \frac{A_{++} - A_{--}}{\sqrt{2}} = i\frac{\sqrt{2x}\,m_1 m_2}{v} a_3(m_1, m_2), \quad \text{transverse CP odd}$$

CP structure : H decays to ZZ*





- using decay angles θ_1, θ_2 , Φ and background discriminant D_{bkg} to build signal template
- rejecting purely longitudinal polarization $f_L = 0.49(0.61)$ (proof of entanglement when no CP violation)
- CP violation fraction $f_\perp$ is compatible with SM

[HIG-25-011]

Summary

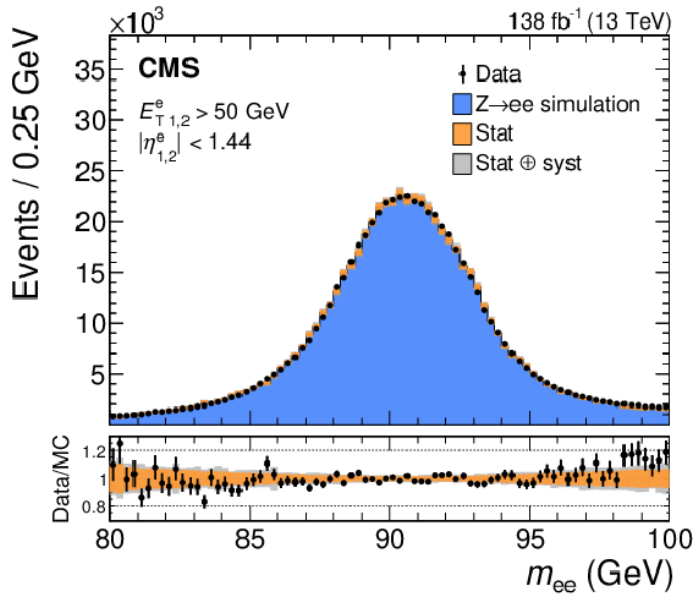
- Higgs mass are measured combining Run-1 and Run-2 data
  - $H\gamma\gamma$ and $H4l$ are getting much more compatible than Run-1
- Precise measurements of Higgs width combine HZZ and HWW
  - The hypothesis of no off-shell Higgs boson production was excluded at the 5 standard deviation level.

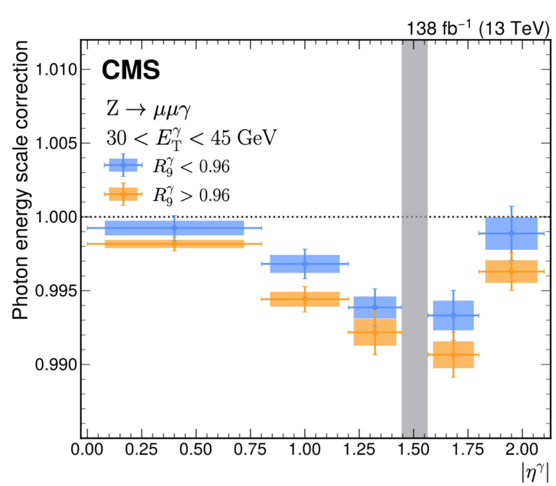
- Legacy combination of Run-2 data provide the most accurate measurements on Higgs couplings and cross sections.
  - theoretical uncertainties becomes equally important
  - differential measurements in STXS and fiducial cross section
  - results are interpreted in κ framework and SMEFT

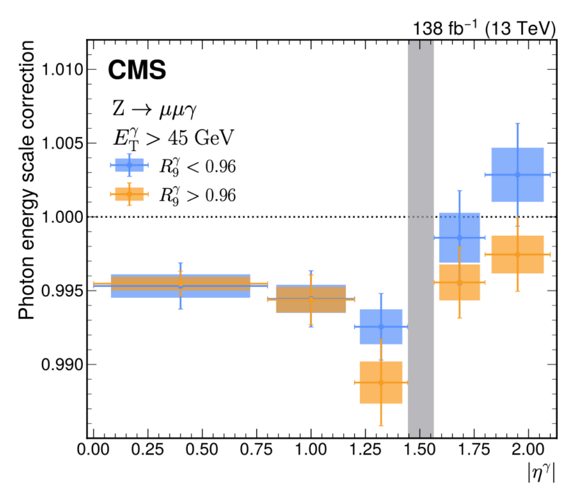
- CP structures
  - No significant CP violating have been observed including Run-3 data.
  - Polarization studies provide evidence that H → ZZ^* decays produce an entangled state assuming no CP violation.

Backup

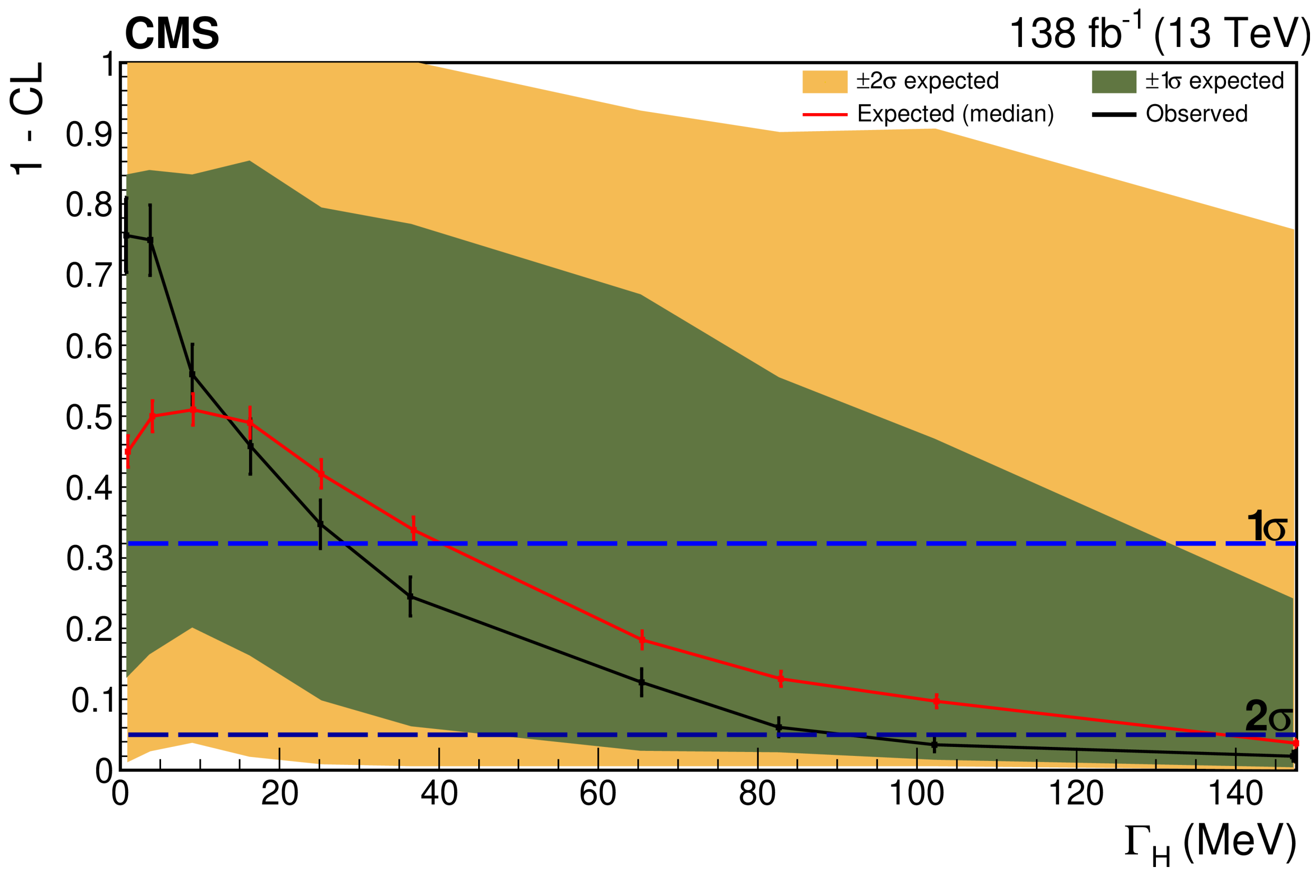
Mass and width : *Hγγ*







Mass and width: *Hγγ* on-shell



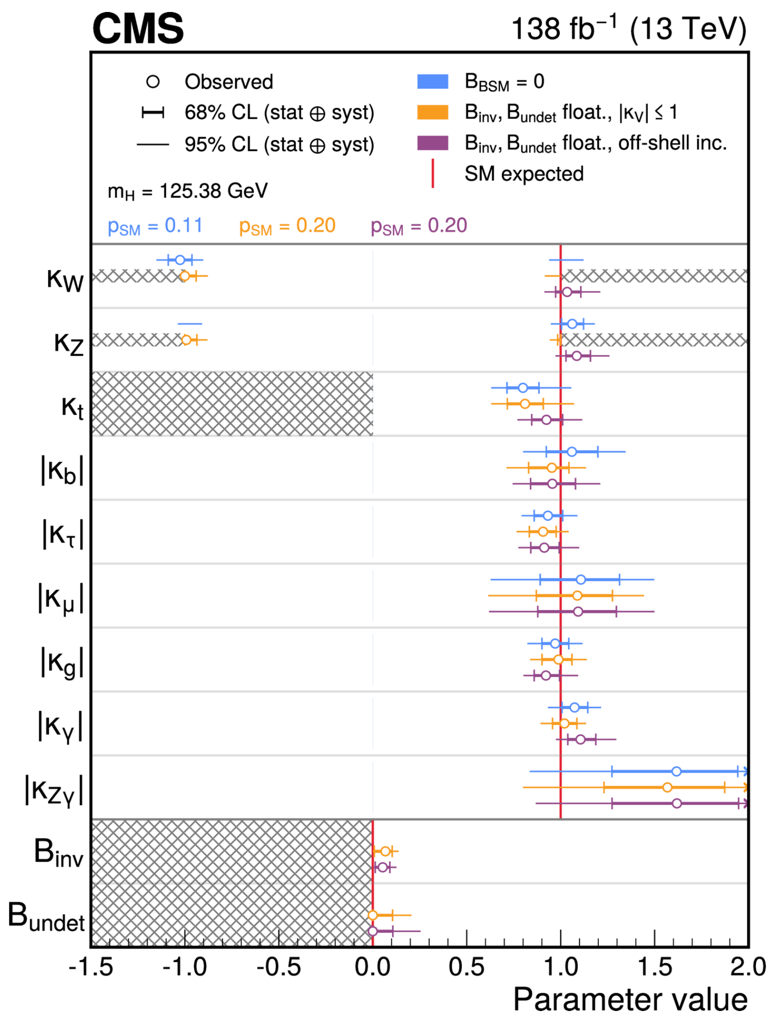
[arXiv:2609.01385](https://arxiv.org/abs/2609.01385)

Submitted to Physical Review Letters

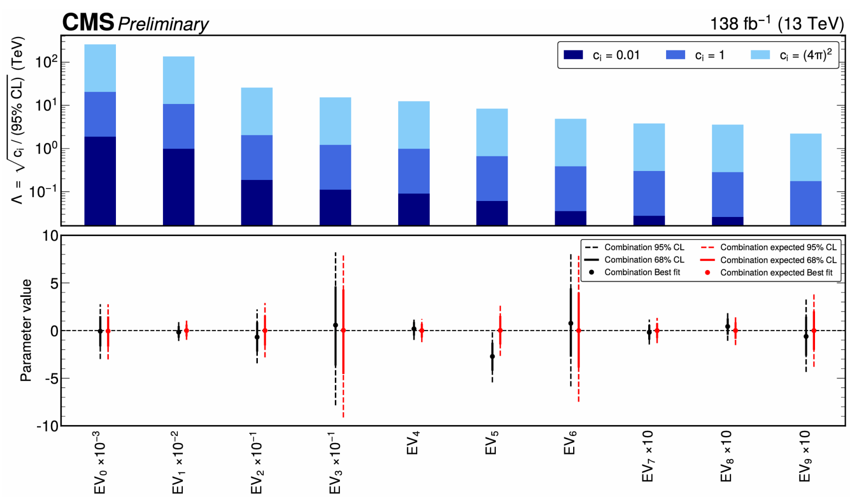
Couplings and cross sections : combination

Input analysis	Decay channels targeted	Production targeted	Signal granularity	References
$\mathrm{H} \to \gamma\gamma$	$\gamma\gamma$	ggH, (NJ, $p_{\mathrm{T}}^{\mathrm{H}}$, m_{jj}) bins VBF, ($p_{\mathrm{T}}^{\mathrm{H}}$, m_{jj}, $p_{\mathrm{T}}^{\mathrm{Hjj}}$) bins VH hadronic WH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins ZH leptonic ttH, $p_{\mathrm{T}}^{\mathrm{H}}$ bins tH	STXS stage 1.2	[42]
$\mathrm{H} \to \mathrm{ZZ} \to 4\ell$	4μ, $2\mathrm{e}2\mu$, 4e	ggH, (NJ, $p_{\mathrm{T}}^{\mathrm{H}}$, m_{jj}) bins VBF, (NJ, $p_{\mathrm{T}}^{\mathrm{H}}$, m_{jj}, $p_{\mathrm{T}}^{\mathrm{Hjj}}$) bins VH hadronic VH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins ttH	STXS stage 1.2	[43]
$\mathrm{H} \to \mathrm{WW} \to \ell\nu\ell\nu$	$\mathrm{e}\mu/\mu\mathrm{e}$, $\mathrm{ee}+\mu\mu$, $\mathrm{e}\mu$+jj 3ℓ, 4ℓ	ggH, (NJ, $p_{\mathrm{T}}^{\mathrm{H}}$) bins VBF-like ($p_{\mathrm{T}}^{\mathrm{H}}$, m_{jj}) bins VH hadronic WH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins ZH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins	STXS stage 1.2	[44]
$\mathrm{H} \to \tau\tau$	$\mathrm{e}\mu$, $\mathrm{e}\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$ $\mathrm{e}\tau_h+2\ell$, $\mu\tau_h+\ell/2\ell$, $\tau_h\tau_h+\ell/2\ell$	ggH, (NJ, $p_{\mathrm{T}}^{\mathrm{H}}$, m_{jj}) bins VBF, (NJ, $p_{\mathrm{T}}^{\mathrm{H}}$, m_{jj}) bins WH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins ZH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins	Inclusive production processes or STXS stage 1.2	[45]
$\mathrm{H} \to \mathrm{bb}$ boosted	bb	ggH, high-$p_{\mathrm{T}}^{\mathrm{H}}$ bins VBF, high-$p_{\mathrm{T}}^{\mathrm{H}}$ bins	Inclusive production processes or STXS stage 1.2	[27]
VBF ($\mathrm{H} \to \mathrm{bb}$)	bb	VBF	Inclusive production processes	[26]
VH ($\mathrm{H} \to \mathrm{bb}$)	bb	WH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins ZH leptonic, $p_{\mathrm{T}}^{\mathrm{V}}$ bins	STXS stage 1.2	[30]
t(t)H ($\mathrm{H} \to \mathrm{bb}$)	bb	ttH, $p_{\mathrm{T}}^{\mathrm{H}}$ bins tH	Inclusive production processes or STXS stage 1.2	[31]
t(t)H ($\mathrm{H} \to$ leptons)	2ℓ(same charge), 3ℓ, 4ℓ $1\ell+2\tau_h$, 2ℓ(same charge)$+1\tau_h$, $3\ell+1\tau_h$	ttH, tH	STXS stage 1.2	[46]
$\mathrm{H} \to \mu\mu$	$\mu\mu$	ggH, VBF, VH, ttH	Inclusive production processes	[47]
$\mathrm{H} \to \mathrm{Z}\gamma \to \ell\ell\gamma$	$\ell\ell\gamma$	ggH, VBF	Inclusive production processes	[48]
$\mathrm{H} \to$ inv	Large $p_{\mathrm{T}}^{\mathrm{miss}}$	Monojet VBF VH leptonic VH/ttH hadronic	Inclusive production processes	[49,50,51,29]
Off-shell ($\mathrm{H} \to \mathrm{ZZ} \to 4\ell$)	4ℓ	Off-shell	Off-shell contributions (cf. Eq. (??))	[28]

Couplings and cross sections : coupling modifier including BSM

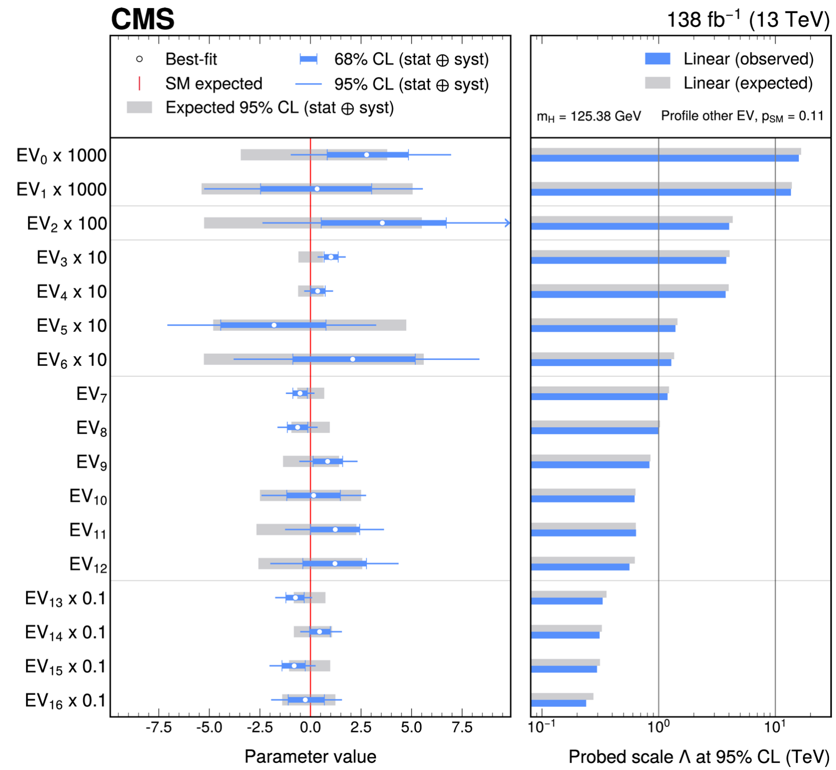


Couplings and cross sections : SMEFT PCA



Fiducial differential

[JHEP04(2026)093]



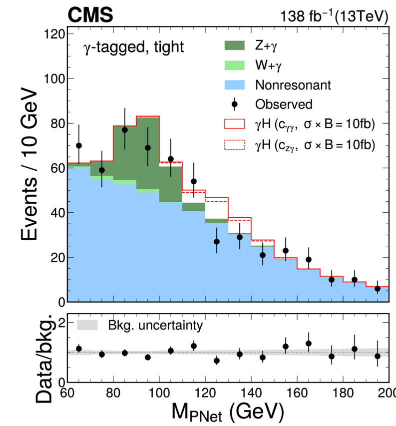
STXS differential

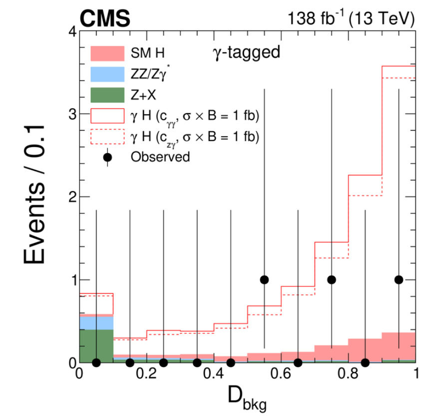
[Rep. Prog. Phys. 89 (2026) 087801]

Couplings and cross sections : rare productions and decays

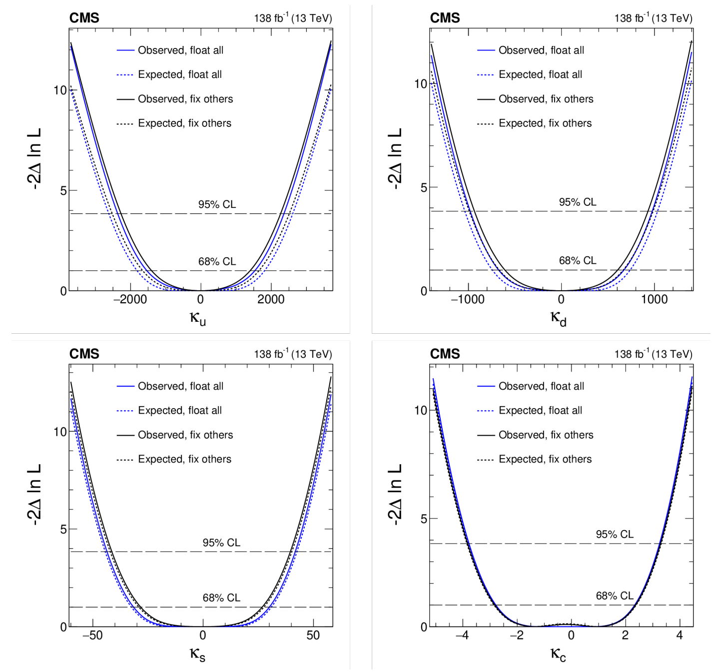
$H + \gamma$ production

- Boosted H → bb:
  pT(H) > 300 GeV, PNet Xbb WPs
- H → 4ℓ: standard ZZ*4ℓ selection
+ MELA Dbkg





all four EFT couplings free
- σγH < 16.4 (21.5) fb at 95% CL
- | cγγ | < 0.84 at 95% CL
- | cZγ | < 0.30 at 95% CL



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CP structure : H decays to ZZ*

$\vec{f}$	Observed 68% CL	Observed 95% CL	Expected 68% CL	Expected 95% CL	Correlation obs. / exp.
f_L	$0.49^{+0.08}_{-0.07}$	$[-0.48, -0.40] \cup [0.34, 0.64]$	0.61 ± 0.07	$[0.47, 0.74]$	$-0.268 / +0.001$
$f_\perp$	$0.25^{+0.21}_{-0.22}$	$[-0.62, 0.40] \cup [0.52, 0.60]$	0.00 ± 0.06	$[-0.20, 0.20]$	
f_L	$0.52^{+0.08}_{-0.06}$	$[0.38, 0.67]$	0.61 ± 0.07	$[0.47, 0.74]$	fix $f_\perp$ & $C_\parallel$
f_L	$0.53^{+0.06}_{-0.07}$	$[0.38, 0.66]$	0.61 ± 0.07	$[0.47, 0.74]$	$+0.069 / +0.054$
$C_\parallel$	$0.19^{+0.46}_{-0.45}$	$[-0.68, 1.00]$	$0.91^{+0.09}_{-0.47}$	$[0.00, 1.00]$	

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