

Higgs property measurements from CMS

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Higgs production and decay channels at the LHC

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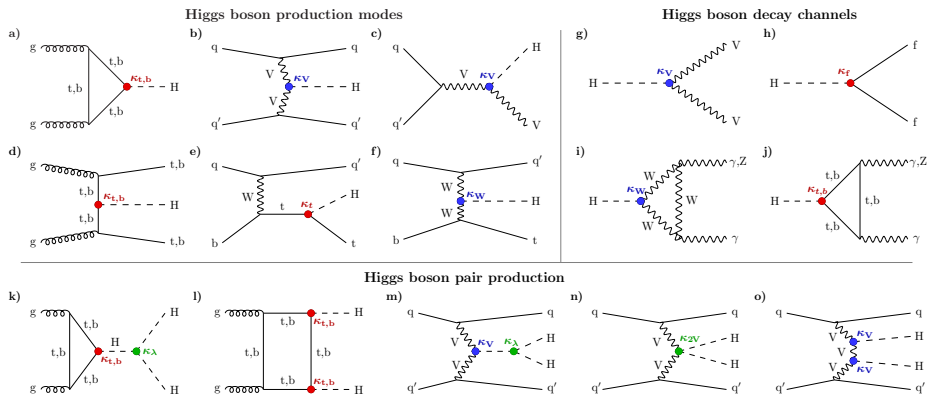


Figure: Leading Higgs production and decay mechanisms. At $m_H \simeq 125$ GeV, ggH contributes about 87% of inclusive production, followed by VBF (7%) and VH (4%); the main branching fractions are $b\bar{b}$ (58%), WW (21.5%), gg (8.2%), $\tau\tau$ (6.3%), ZZ (2.6%), and $\gamma\gamma$ (0.23%).

CMS and Higgs properties

- CMS (Compact Muon Solenoid) reconstructs photons, leptons, hadronic taus, jets, and missing transverse momentum.
- Higgs properties include its **mass and width**, **production and decay rates**, **kinematics**, and **interaction structure**.
- Clean **$\gamma\gamma$ and 4ℓ channels** enable precise mass, rate, and kinematic measurements; **$\tau\tau$ and $b\bar{b}$** probe Yukawa couplings; **rare decays** test loop-induced interactions.

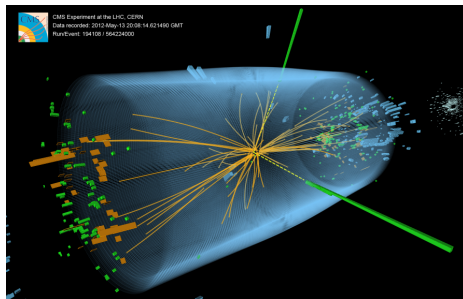


Figure: A CMS event display illustrating a **Higgs candidate decaying to two photons**: dashed yellow lines show the photon trajectories and green towers their electromagnetic-calorimeter energy; orange lines are charged-particle tracks and orange towers show hadronic-calorimeter energy.

From discovery to precision Higgs physics

- Run 1 (24.8 fb⁻¹ at $\sqrt{s} = 7-8$ TeV): ATLAS and CMS **observed** a new boson near 125 GeV (2012).
- Run 2 (138 fb⁻¹ at $\sqrt{s} = 13$ TeV): **established precision measurements** of production, decay, mass, and couplings.
- Run 3 (171 fb⁻¹ at $\sqrt{s} = 13.6$ TeV up to 2024): enables **differential $H \rightarrow 4\ell$** , **CP -sensitive $H \rightarrow \tau\tau$** , and **rare $H \rightarrow Z\gamma$** measurements.

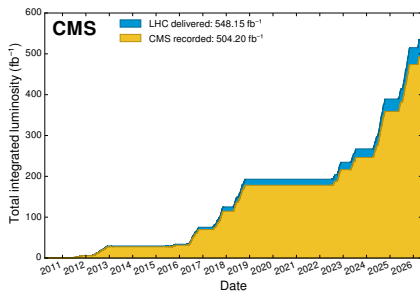


Figure: Cumulative delivered and recorded luminosity versus time for pp data.

The program has moved from establishing the resonance to testing the **structure of its interactions**.

Outline

- **Mass:** fixes precision SM predictions; measured in $H \rightarrow \gamma\gamma$.
- **Width:** tests total interaction strength; accessed through on-shell interference and off-shell $H \rightarrow VV$.
- **CP:** tests the scalar nature of the state; accessed through the $H\tau\tau$ Yukawa coupling.
- **Other recent results:** rare decays, differential production, and anomalous couplings complement the core measurements.

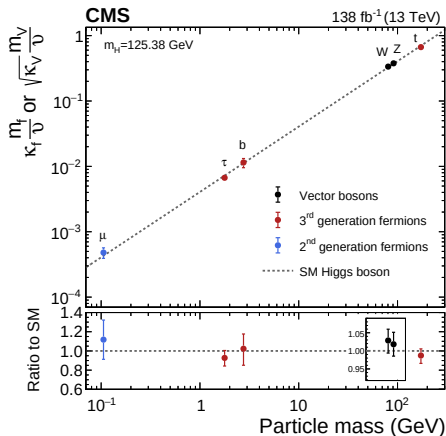


Figure: CMS summary of Higgs coupling strengths versus particle mass.

HIG-24-007: Higgs boson mass in $H \rightarrow \gamma\gamma$

CMS-PAS-HIG-24-007, Run 1 + Run 2

The **Higgs mass** is an essential input to precision SM predictions, such as the Higgs boson production cross sections and branching fractions.

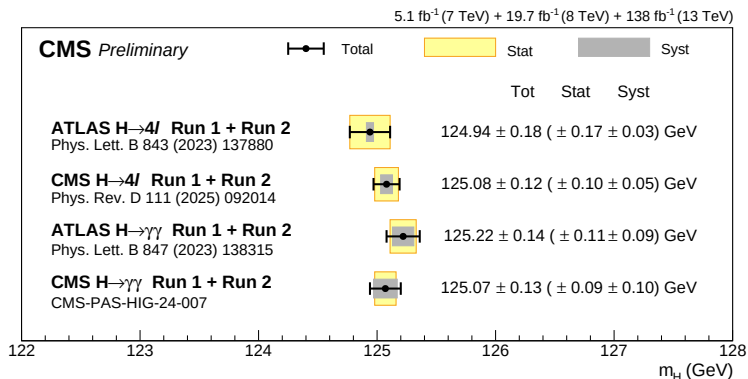


Figure: CMS diphoton mass result compared with earlier LHC measurements in the $H \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels. The combined result is $m_H = 125.11 \pm 0.09$ (stat) ± 0.06 (syst) GeV.

HIG-24-007: dedicated photon-energy calibration

CMS-PAS-HIG-24-007, Run 1 + Run 2

- $Z \rightarrow e^+e^-$ data determine the ECAL energy **scale and resolution** corrections.
- In $Z \rightarrow \mu\mu\gamma$, the photon is predominantly final-state radiation; comparing $m_{\mu\mu\gamma}$ in data and simulation derives the residual **electron–photon scale difference**.

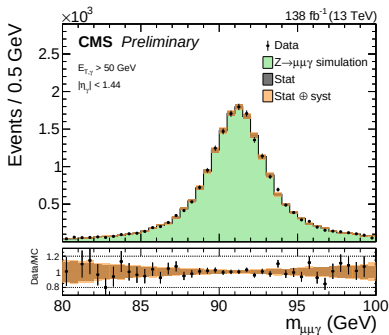
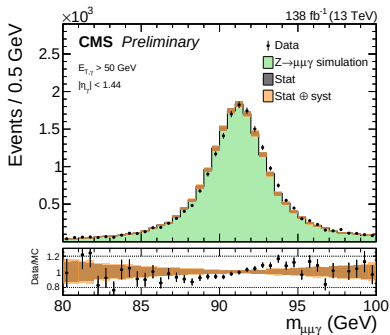


Figure: $m_{\mu\mu\gamma}$ distributions **before** (left) and **after** (right) the final FSR-based photon energy scale **correction** for barrel photons with $E_{T,\gamma} > 50$ GeV.

HIG-24-007: the calibrated diphoton mass fit

CMS-PAS-HIG-24-007, Run 1 + Run 2

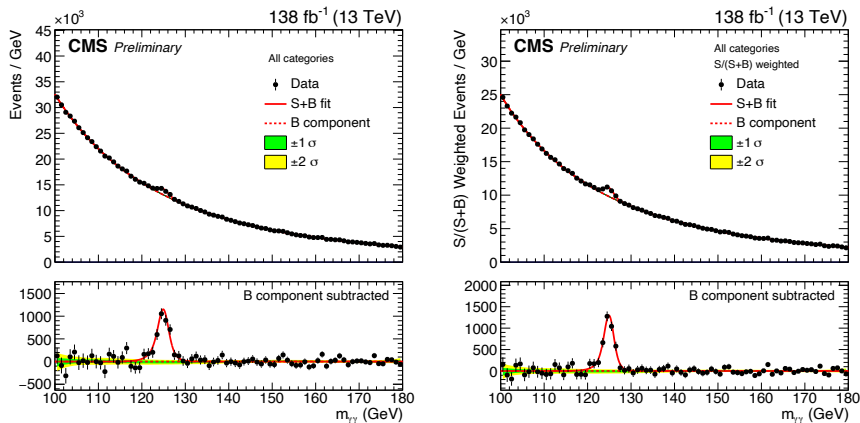


Figure: Combined signal and background fits for all categories, **unweighted (left)** and **sensitivity-weighted (right)**. Bands show the background uncertainty at one (green) and two (yellow) standard deviations; lower panels show background-subtracted residuals.

HIG-25-004: width from signal-background interference

CMS-PAS-HIG-25-004, Run 2

- $\Gamma_H^{\text{SM}} \approx 4 \text{ MeV}$ is far below the detector resolution in a direct measurement.
- The Higgs and continuum $\gamma\gamma$ amplitudes **interfere**; the resulting **line-shape distortion** depends on Γ_H , enabling an indirect measurement.

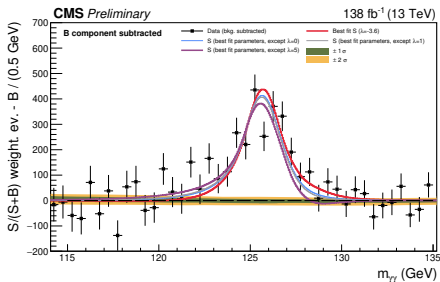
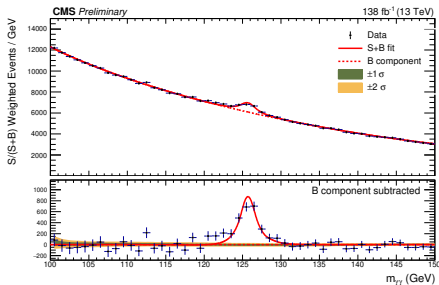


Figure: Signal-plus-background line shape and background-subtracted diphoton spectrum for representative width hypotheses. $\lambda = \pm \sqrt{\Gamma_H / \Gamma_H^{\text{SM}}}$.

HIG-25-004: observed on-shell width constraint

CMS-PAS-HIG-25-004, Run 2

The Feldman–Cousins scan converts the interference distortion into a direct on-shell width constraint.

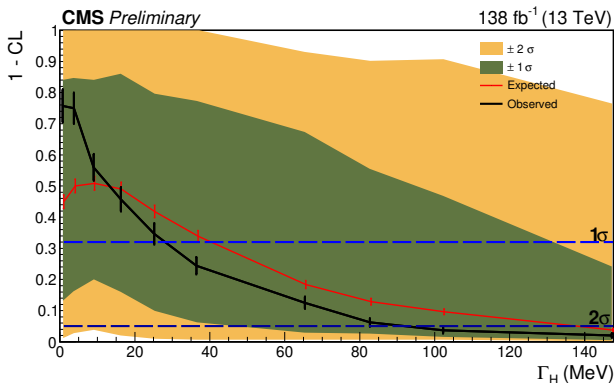


Figure: Observed and expected confidence levels versus assumed width. $\Gamma_H < 92$ MeV observed (138 MeV expected) at 95% CL; the first direct CMS on-shell interference constraint.

HIG-25-003: off-shell production opens a wider window

CMS-HIG-25-003, Run 2

- The off-shell region probes the Higgs propagator far from the 125 GeV resonance and complements on-shell rate measurements.
- Higgs compositeness scale Λ_H extracted by fitting the distinct signal, continuum-background, and interference shapes above the ZZ threshold.

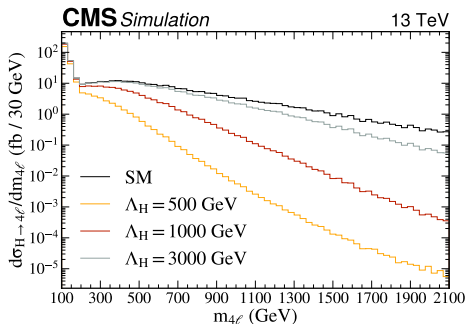


Figure: Expected high-mass four-lepton spectrum for several Higgs-compositeness hypotheses; $\Lambda_H > 870$ (1050) GeV observed (expected) at 95% CL (first direct test).

HIG-25-003: combined width and observation of off-shell production

CMS-HIG-25-003, Run 2

- Combining on- and off-shell $H \rightarrow ZZ$ and $H \rightarrow WW$ adds complementary final states, mass reach, and background composition.
- Final result: $\Gamma_H = 5.1^{+2.0}_{-1.8}$ MeV; off-shell production is observed at more than 5σ (expected 2.9σ).

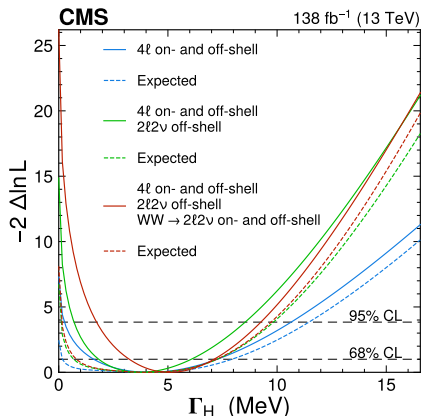


Figure: Width likelihood scans for successive channel combinations.

HIG-25-012: CP structure of the $H \rightarrow \tau\tau$ Yukawa coupling

JHEP accepted (CMS-HIG-25-012), Run 2 + 2022–2023

- A nonzero CP -odd component of the Higgs–tau Yukawa coupling signals BSM physics.
- CMS exploits tau-decay angular correlations to constrain the scalar–pseudoscalar mixing angle $\alpha^{H\tau\tau}$.

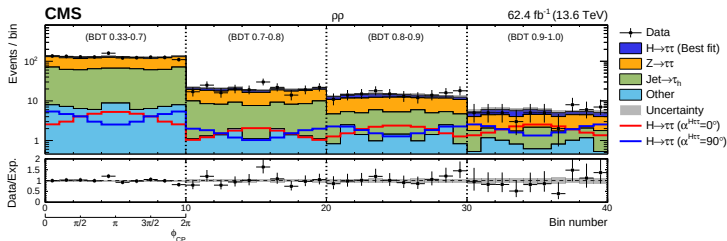


Figure: ϕ_{CP} distribution in the $\rho\rho$ decay channel for increasing Higgs-category purity.

The discriminating power comes from tau-spin correlations.

HIG-25-012: the $H\tau\tau$ coupling is compatible with CP even

JHEP accepted (CMS-HIG-25-012), Run 2 + 2022–2023

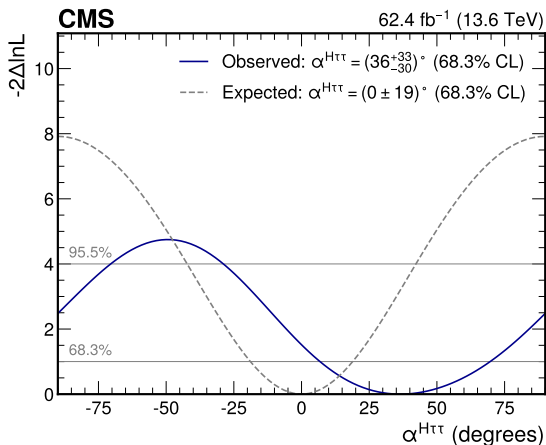


Figure: Observed and expected likelihood scan of the $H\tau\tau$ CP mixing angle in Run 3 data. Run 2 + Run 3 gives $\alpha^{H\tau\tau} = 7 \pm 16^\circ$, compatible with a CP -even Yukawa coupling.

Rare decay frontier: $H \rightarrow Z\gamma$

CMS-PAS-HIG-25-010, Run 2 + 2022–2023

- New particles in the loop could modify the rare $H \rightarrow Z\gamma$ decay rate.
- ggF, VBF, and VH+ttH categories are individually optimized for a combined $m_{\ell\ell\gamma}$ fit.
- $\mu = 1.10^{+0.52}_{-0.61}$ (1.9σ , expected $1.00^{+0.49}_{-0.46}$), consistent with the SM.

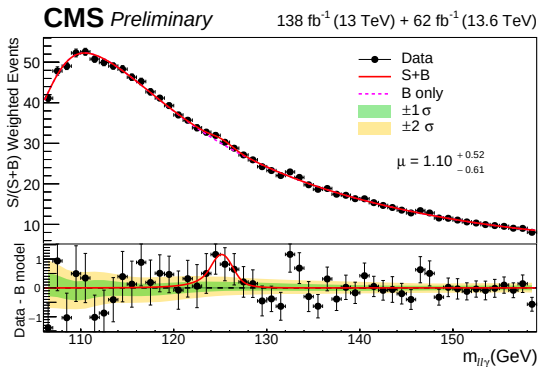


Figure: $m_{\ell\ell\gamma}$ distribution weighted by $S/(S+B)$, with the signal-plus-background fit.

Run 3 $H \rightarrow ZZ \rightarrow 4\ell$: differential cross section

CMS-PAS-HIG-25-015, Run 3 2022–2024

- Inclusive and differential fiducial cross sections are measured for the 2022–2024 dataset.
- Beyond the 2022 result [JHEP 05 \(2025\) 079](#) (HIG-24-013): broad production, jet, and decay observables, including dedicated VBF sensitivity.

- The inclusive result is $\sigma_{\text{fid}} = 3.11 \pm 0.22 (\text{stat})^{+0.14}_{-0.12} (\text{syst}) \text{ fb}$, consistent with the SM prediction $3.05^{+0.17}_{-0.22} \text{ fb}$.

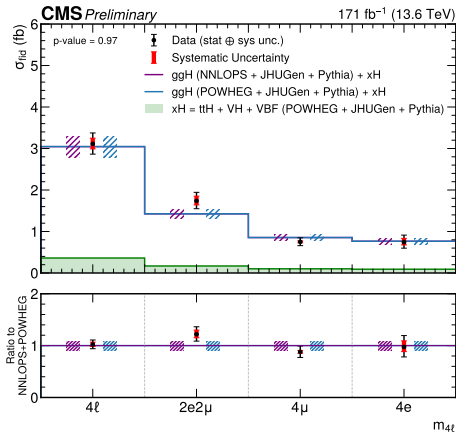


Figure: Fiducial cross-section likelihood scans for the inclusive 4ℓ sample and its three final states.

Anomalous Higgs couplings in $H \rightarrow \gamma\gamma$

CMS-HIG-24-006, Run 2

- $H \rightarrow \gamma\gamma$ probes anomalous HVV and loop-induced Hgg couplings.
- VBF/VH and ggH+2j categories use matrix-element and multivariate discriminants to extract anomalous fractions f_i .
- The fitted anomalous tensor and CP -odd fractions in the studied HVV and Hgg coupling hypotheses are consistent with the SM.

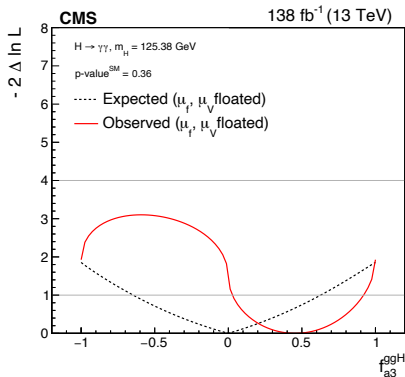


Figure: Likelihood scan for a CP -odd anomalous coupling of the Higgs boson to gluons.

Summary

- Higgs-property measurements test the mass, width, coupling structure, and kinematics of the 125 GeV boson.
- The updated $H \rightarrow \gamma\gamma$ mass measurement reaches a total precision of about 0.15 GeV.
- On-shell interference gives $\Gamma_H < 92$ MeV (95% CL); the combined on/off-shell fit gives $\Gamma_H = 5.1^{+2.0}_{-1.8}$ MeV and $\Lambda_H > 870$ GeV.
- The tau Yukawa test gives $\alpha^{H\tau\tau} = 7 \pm 16^\circ$, consistent with CP even.
- Recent differential, rare-decay, and anomalous-coupling measurements also show agreement with the SM within current precision.

Thanks for your attention!

Backup

HIG-25-003: gluon-fusion loop and heavy-quark effects

CMS-HIG-25-003

- The combined on- and off-shell fit probes CP-even and CP-odd contributions in the ggH loop, including possible heavy BSM states, while allowing κ_Z and κ_W to vary independently.
- All fitted heavy-quark directions remain compatible with the SM; for example, $\kappa_Q = 0.10^{+0.33}_{-0.48}$ with custodial symmetry imposed.

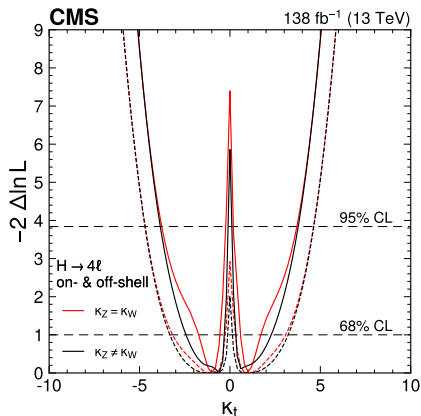


Figure: Profile-likelihood scans for heavy-loop couplings.

HIG-25-003: light-quark Yukawa couplings

CMS-HIG-25-003

- Off-shell production breaks the degeneracy between the total width and the Higgs–vector-boson coupling, enabling a more model-independent fit of the light-quark Yukawas.
- The fit remains meaningful after relaxing $|\kappa_Z| \leq 1$ and $\kappa_Z = \kappa_W$, removing assumptions used in on-shell-only interpretations.

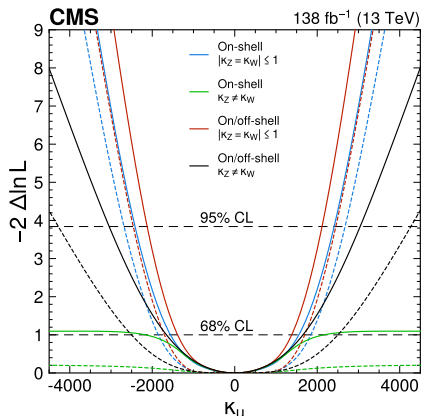


Figure: Combined on- and off-shell scans for light-quark coupling modifiers.

HIG-25-003: first off-shell constraint on the self-coupling

CMS-HIG-25-003

- Loop corrections from the trilinear Higgs self-coupling distort both the yield and the $m_{4\ell}$ shape in the off-shell region, providing a complementary probe to direct HH production.
- The result is $\kappa_\lambda = 2^{+17}_{-15}$ at 68% CL, with $-21 < \kappa_\lambda < 27$ at 95% CL.

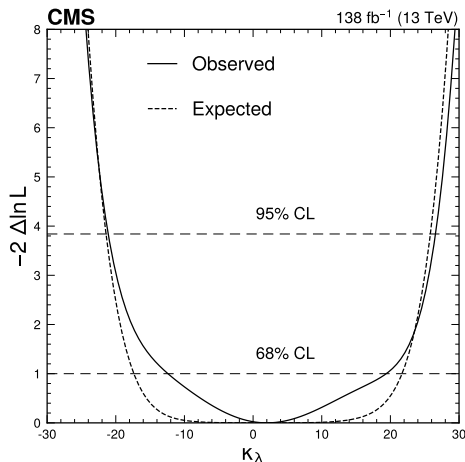


Figure: Profile-likelihood scan for κ_λ .

HIG-25-003: width constraints under BSM hypotheses

CMS-HIG-25-003

- The width fit is repeated while allowing custodial-symmetry breaking, heavy BSM loop states, and enhanced light-quark Yukawas, testing the robustness of the off-shell method beyond the simplest assumptions.
- In the most general tested scenario, $\Gamma_H < 34.8 \text{ MeV}$ at 95% CL in $ZZ \rightarrow 4\ell$.

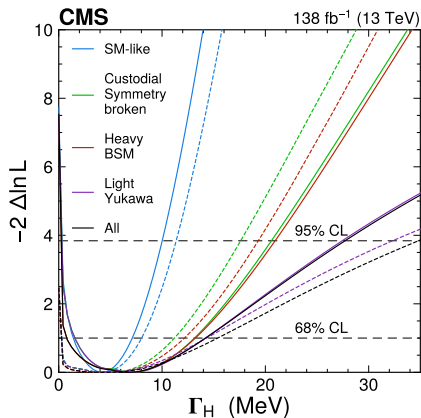


Figure: Width scans for progressively general BSM scenarios.