Constraints on the γH production in pp collisions and on anomalous H boson couplings with the CMS detector

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On behalf of the CMS Collaboration

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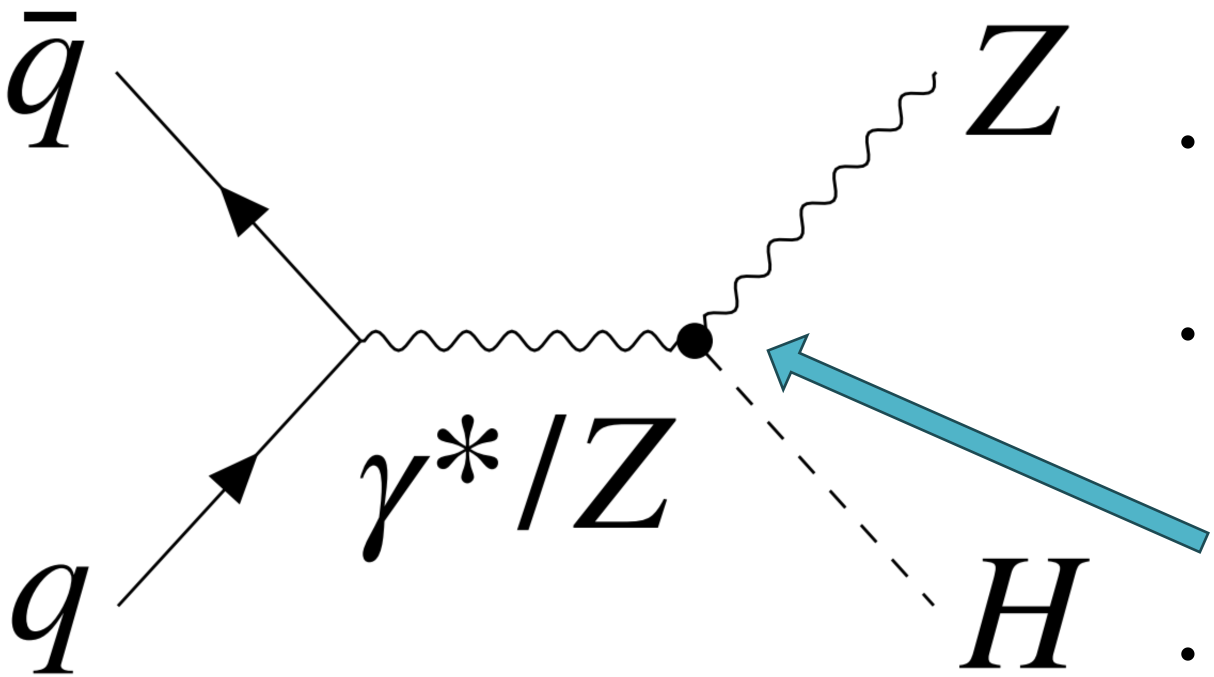
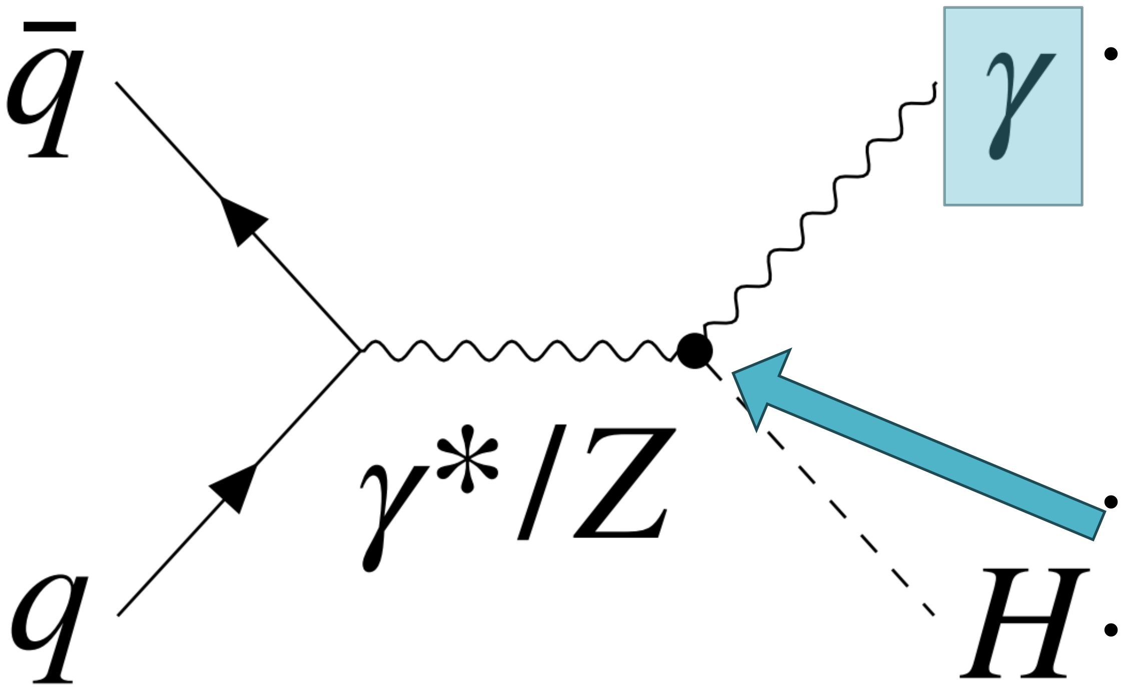
Motivation: Process of Interest



- VH production well studied at LHC
- Typically consider associated Z or W
- Cross section large enough to target in dedicated analysis (Tree level SM process)
- Various EFT operators can enter VH vertex

Motivation: Process of Interest



- Equivalent to ZH or WH, we could have γH as well
- This process has **not yet been studied at the LHC**
  - Diagram does not happen at tree-level in SM
  - Small cross-section
  - Signal indicates BSM physics
- Various EFT operators can be present in this vertex
- 4 in mass eigenstate basis
  - CP-Even: $c_{Z\gamma}$, $c_{\gamma\gamma}$,
  - CP-Odd: $\tilde{c}_{Z\gamma}$, $\tilde{c}_{\gamma\gamma}$
- 6 in in weak eigenstate basis:
  - CP-Even: c_{HW}, c_{HWB}, c_{HB}
  - CP-Odd: $c_{H\widetilde{W}}$, $c_{H\widetilde{WB}}$, $c_{H\widetilde{B}}$

- EFT simulation of γ+H at LO performed with JHUGen and MELA weights

Motivation: Constraints on EFT operators

Four Wilson Coefficients generate γH (Can rotate to 6 gauge eigenstates)

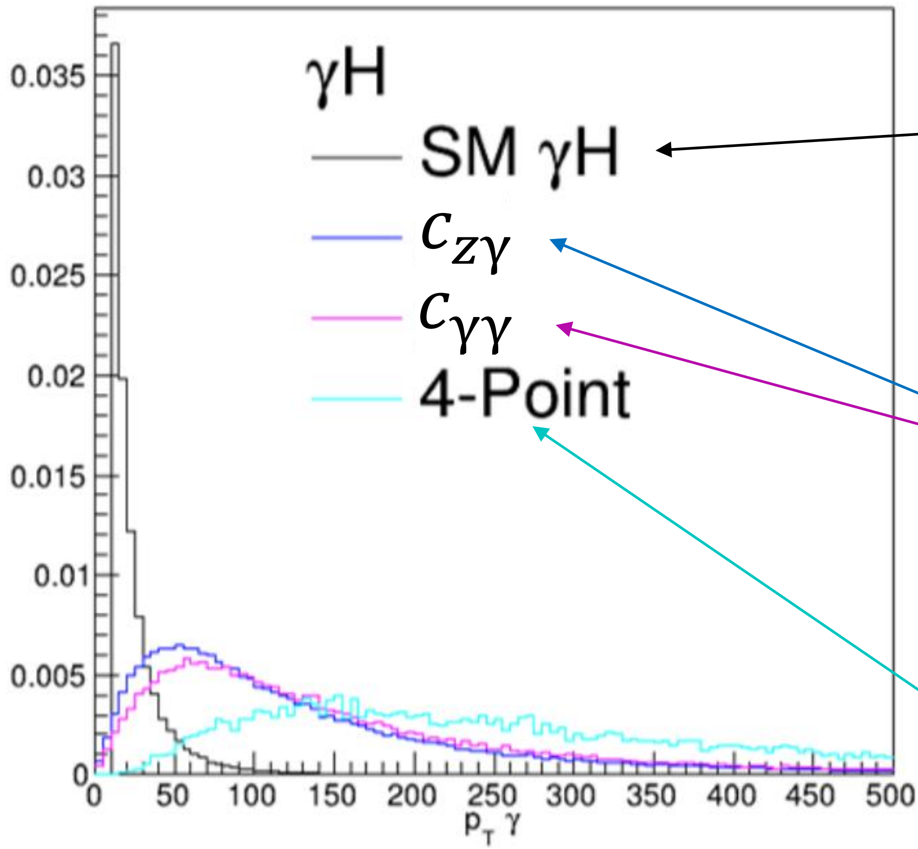
$$\mathcal{L}_{\text{hvv}} = \frac{h}{v}\Big[M_Z^2(1+\delta c_z)Z_\mu Z^\mu + \frac{M_Z^2}{v^2}c_{zz}Z_{\mu\nu}Z^{\mu\nu} + \frac{e^2}{s_w^2}c_{z\Box}Z_\mu\partial_\nu Z^{\mu\nu} + \frac{M_Z^2}{v^2}\tilde{c}_{zz}Z^{\mu\nu}\tilde{Z}_{\mu\nu}$$
$$+2M_W^2(1+\delta c_w)W_\mu^+W^{-\mu} + 2\frac{M_W^2}{v^2}c_{ww}W_{\mu\nu}^+W^{-\mu\nu} + \frac{e^2}{s_w^2}c_{w\Box}\left(W_\mu^-\partial_\nu W^{+\mu\nu} + \text{h.c.}\right)$$
$$+\frac{e^2}{2s_w^2}\tilde{c}_{ww}W^{+\mu\nu}\tilde{W}_{\mu\nu}^- + \frac{e^2}{2s_w c_w}c_{z\gamma}Z_{\mu\nu}A^{\mu\nu} + \frac{e^2}{2s_w c_w}\tilde{c}_{z\gamma}Z_{\mu\nu}\tilde{A}^{\mu\nu} + \frac{e^2}{s_w c_w}c_{\gamma\Box}Z_\mu\partial_\nu A^{\mu\nu}$$
$$+c_{\gamma\gamma}\frac{e^2}{4}A_{\mu\nu}A^{\mu\nu} + \tilde{c}_{\gamma\gamma}\frac{e^2}{4}A^{\mu\nu}\tilde{A}_{\mu\nu} + c_{gg}\frac{g_s^2}{4}G_{\mu\nu}^aG^{a\mu\nu} + \tilde{c}_{gg}\frac{g_s^2}{4}G^{a\mu\nu}\tilde{G}_{\mu\nu}^a\Big],$$

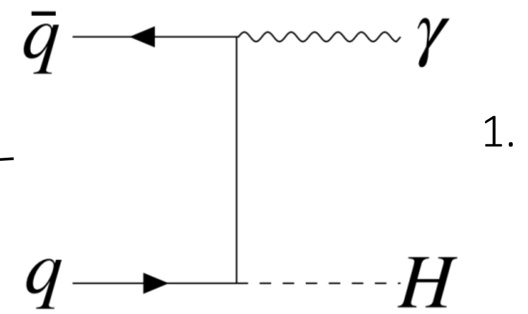
Analysis Goal: Measure γ+H cross-section and interpret result as constraint on Dim-6 operators. **Combine H->4l** and **H->bb** channel

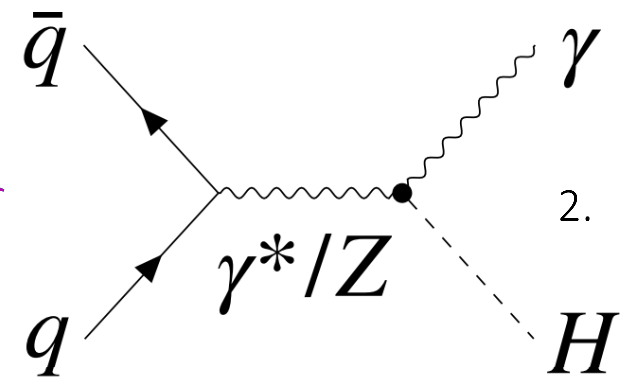
$$\frac{\sigma(qq\to\gamma H)}{\sigma_{\text{ref}}^{\gamma H}} = (c_{z\gamma})^2 + (\tilde{c}_{z\gamma})^2 + 0.0982\,(c_{\gamma\gamma})^2 + 0.0982\,(\tilde{c}_{\gamma\gamma})^2$$
$$-0.243\,c_{z\gamma}c_{\gamma\gamma} - 0.243\,\tilde{c}_{z\gamma}\tilde{c}_{\gamma\gamma}$$

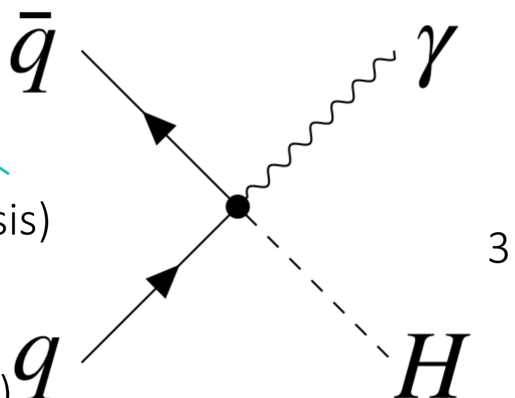
$\sigma_{\text{ref}}^{\gamma H}$ = 180.3 fb

Other γH Diagrams







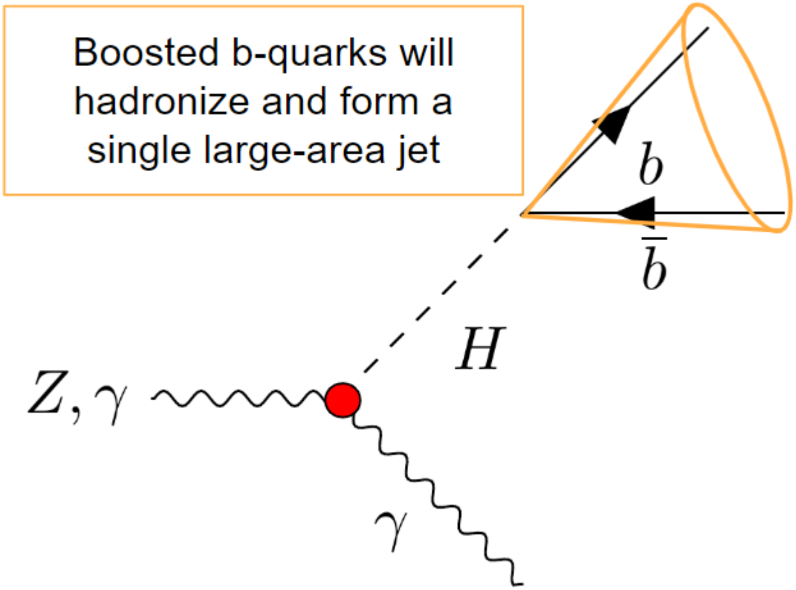


3 Main γ+H topologies:

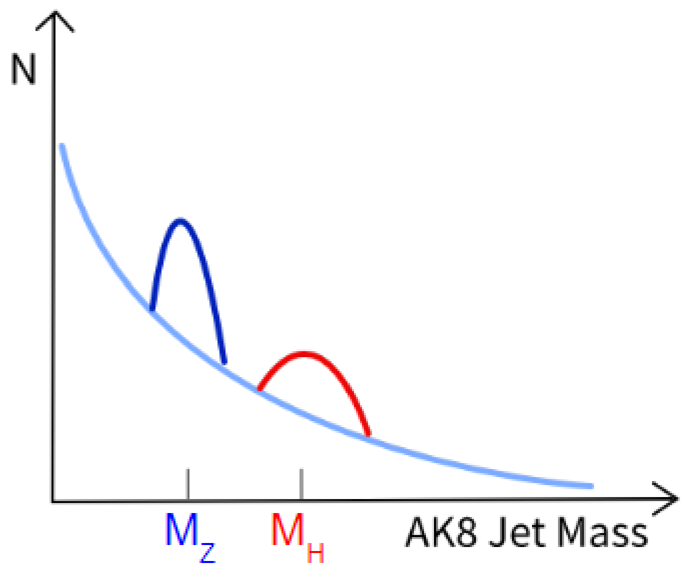
1. SM Tree-level (Photon Pt too low for reconstruction in analysis)
   - Targeted in WW+γ (PRL)
2. EFT induced VH topology (Targeted in Analysis)
3. EFT induced four point interaction (Better constrained by Zff)

Analysis Strategy: H → bb

- Select photon + AK8 jet events with high p_T
  - High p_T dramatically reduces non-resonant background
- Fit the distribution of AK8 jet mass
  - Using ParticleNet mass regression (M_{PNet})
- Searching for a Higgs mass bump

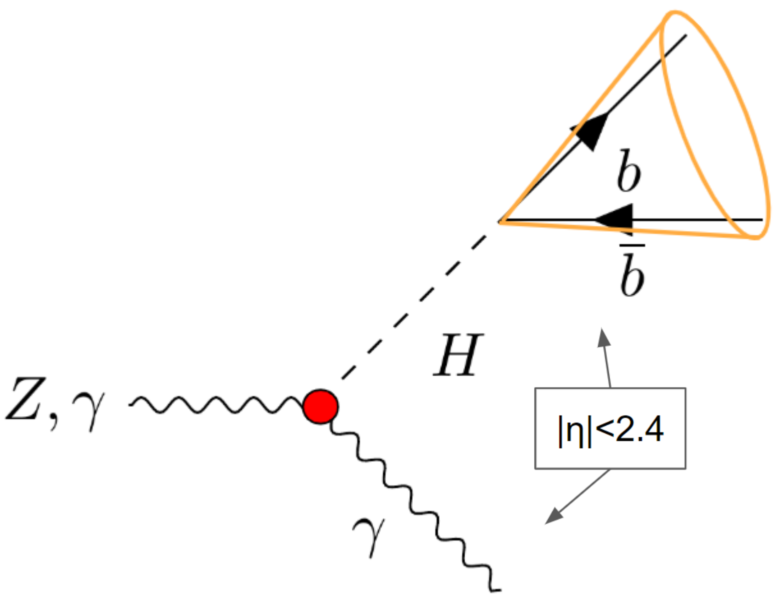


- V+ɣ background modelled using simulation
  - Modelling improved with a dedicated event category
- Non-resonant background modelled with data-driven method
  - Based on pass-to-fail ratios ($R_{P/F}$)



Event Selection: Photon Category H→bb

Leading AK8 = Higgs candidate
p_T>300 GeV



ParticleNetXbbVsQCD score defines "tight", "medium" and "fail" regions

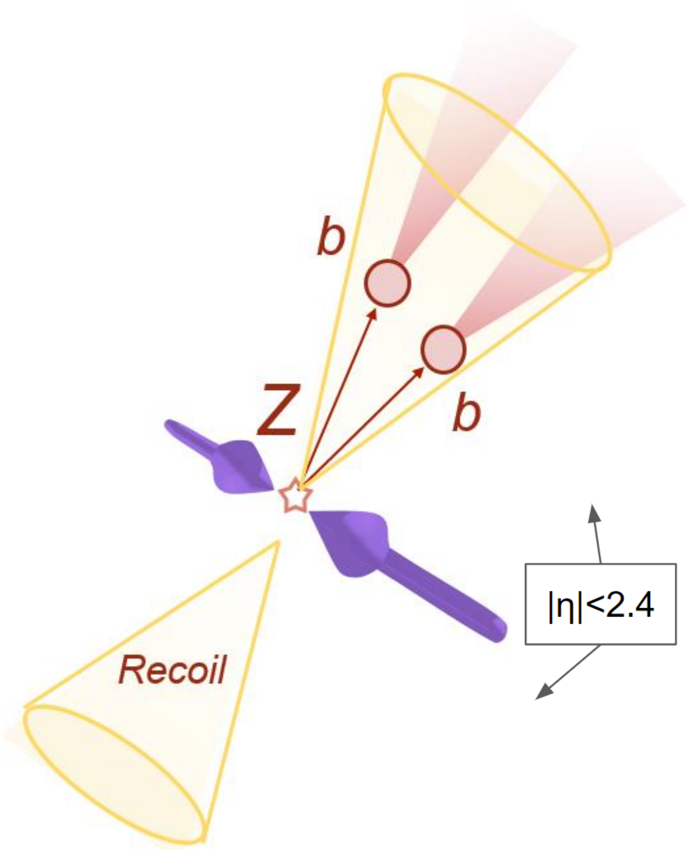
HLT_Photon175/200 trigger
Leading photon p_T>300 GeV
Photon Fall17V2 ID at tight WP

Vetos

- N_e=0 and N_μ=0
- top veto: no b-tagged AK4 jets with ΔR(AK4,H)>0.8 allowed

Event Selection: Untagged Category H → bb

Z candidate: p_T^{AK8}>450 GeV
Subleading Jet: p_T^{AK8}>200 GeV



ParticleNetXbbVsQCD score defines "tight", "medium" and "fail" regions

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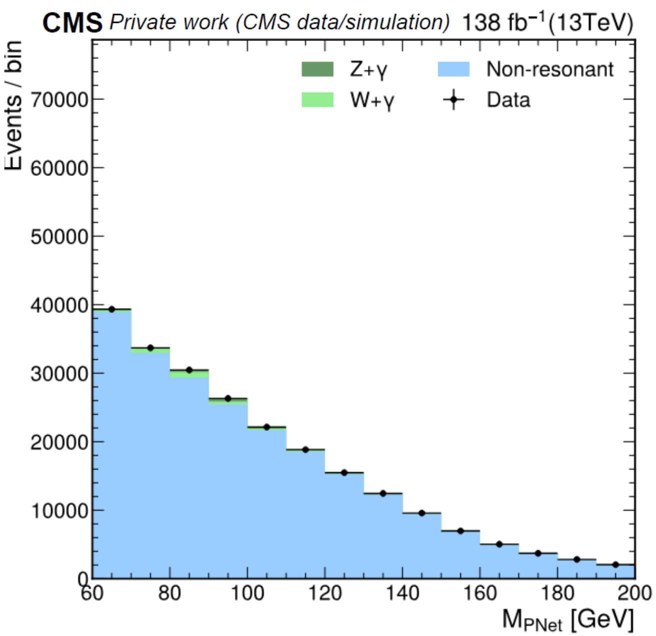
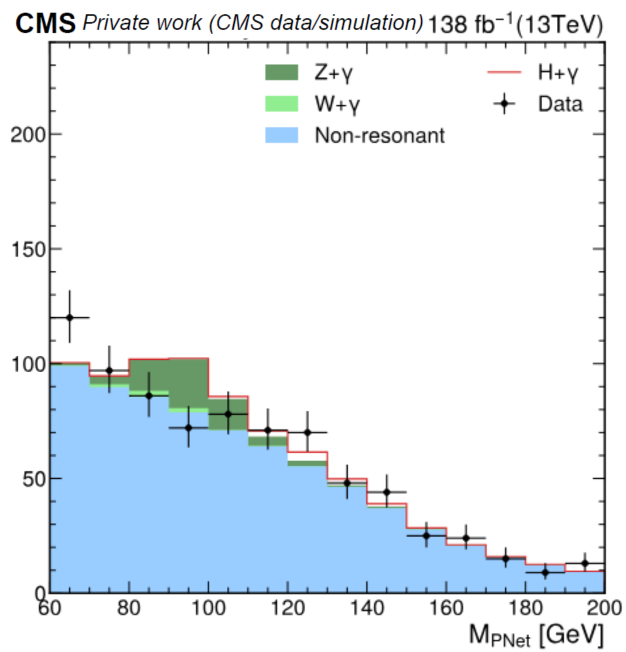
- N_e=0 and N_μ=0
- top veto: no b-tagged AK4 jets with ΔR(AK4,H)>0.8 allowed

HLT_Photon175/200 trigger
Leading photon p_T>300 GeV
Photon Fall17V2 ID at tight WP

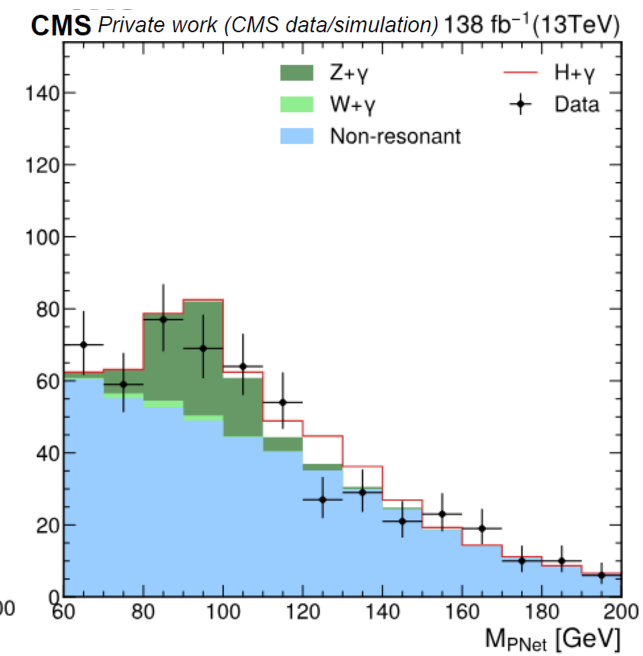
Observables: H → bb (Photon Category)



Fail



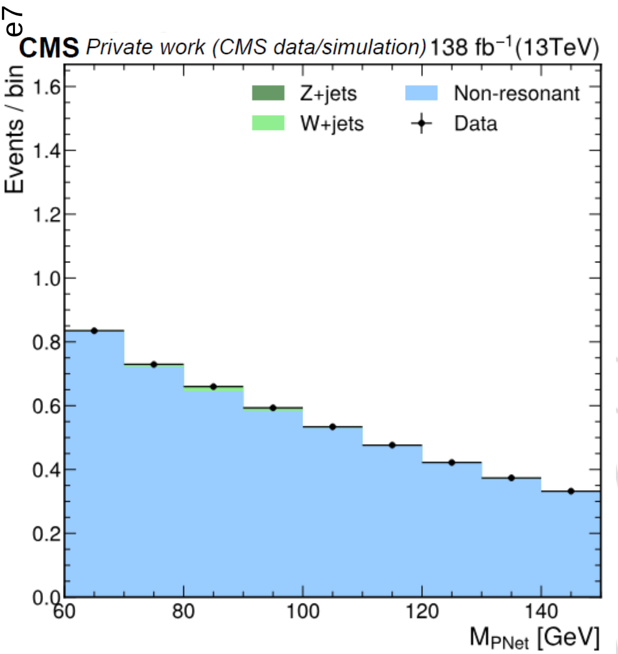
Medium



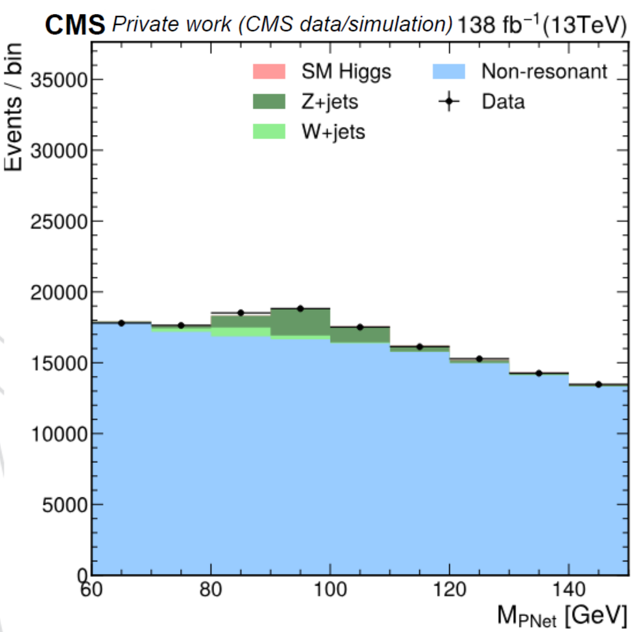
Tight

- Showing the background-only fit
  - Signal on plots with prefit normalization, σ(pp→Hɣ→bbɣ) = 10 fb

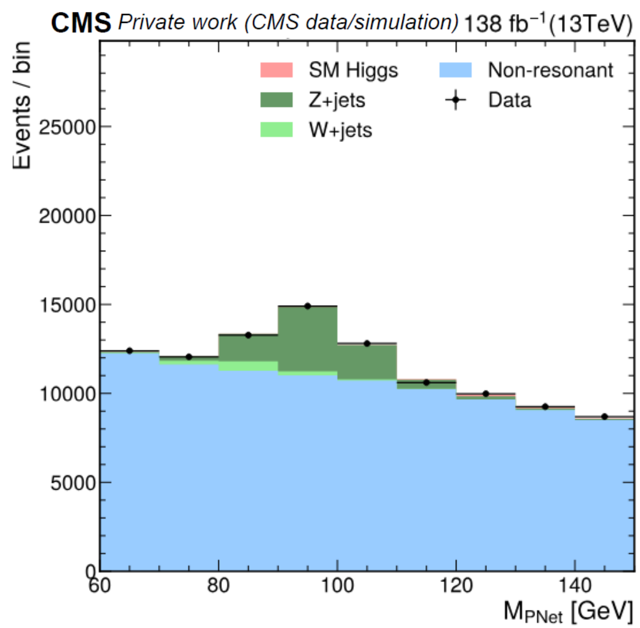
Observables: H → bb (Untagged Category)



Fail



Medium



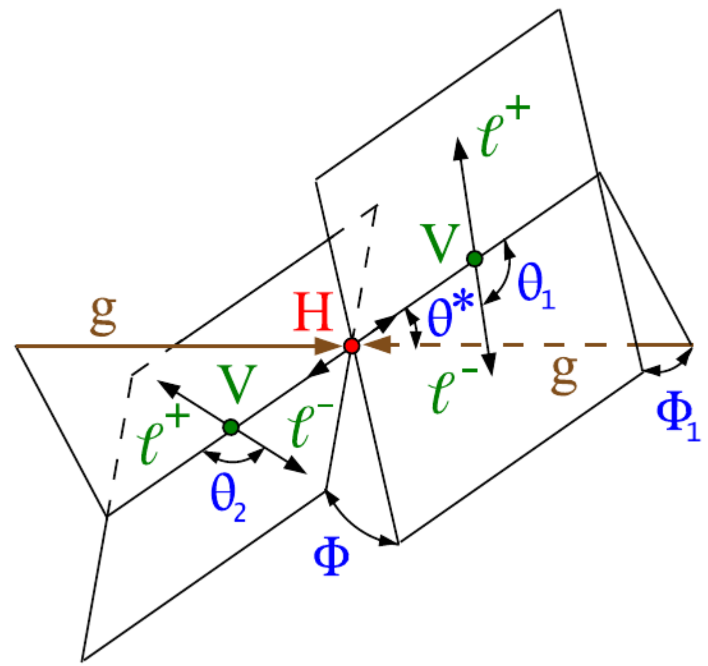
Tight

- Showing the background-only fit

Analysis Strategy: H → 4l

- Select events with 4 leptons
- *Categorize events based on **photon selection***
- Calculate a discriminant score to separate signal-like events from background
- Fit the distribution of the discriminant to extract signal yield

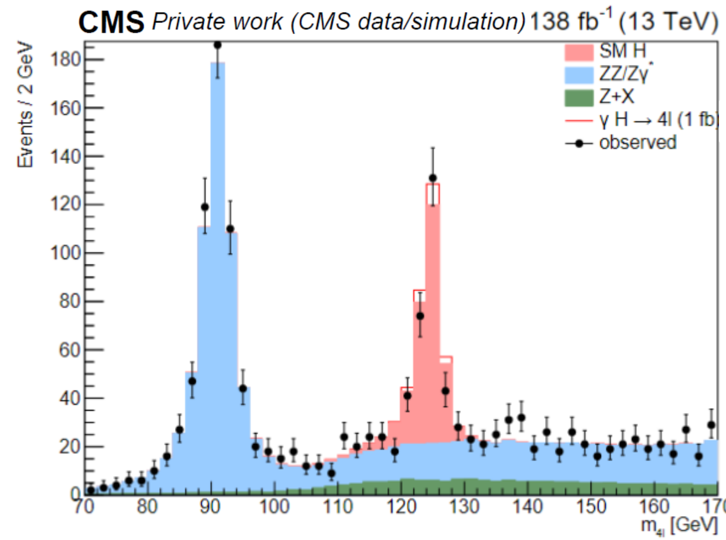
- Signal/Background Modelling:
- **SM Higgs and ZZ/ɣ*(4l)** processes modelled using simulation
- **Z+X** modelled with data-driven method using a data control region
  - Based on the lepton misidentification rate
  - Same procedure used in other H → 4l analysis



H → 4l decay angles used as observables when calculating discriminant

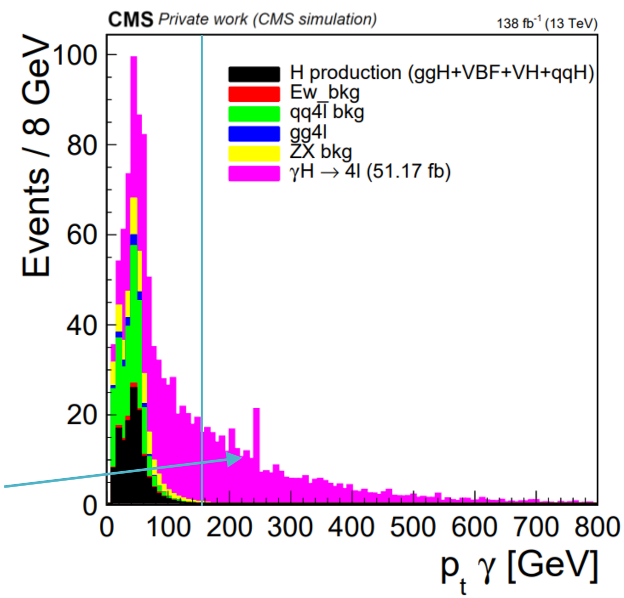
Event Selection : H → 4l

- Consider 3 channels: 4e, 4μ, 2e2μ, for the 4 lepton final state
- *2 Leptons: p_T > 10GeV*
- *1 Lepton: p_T > 20GeV*
- *All Lepton Pairs: m_{ll} > 4GeV*
- *1 Z candidate: m_{ll} > 40GeV*
- *Both Z candidates: 12 GeV < m_{ll} < 120GeV*
- *105 GeV < m_{4l} < 140 GeV*



- Event Categorization:
- ***γH-tagged:***
  - *p_T of leading photon > 150GeV*
  - *Passed **Photon Loose Cut Based ID***
- *Untagged: All other events*

Low background in this region



Observables: H → 4l

- Matrix Elements used to construct optimal observables
- *D_{bkg}: Matrix element based discriminator for separating H → 4l from background*
- *Combines m_{4l} information along with decay kinematics*

Discriminant value from 0 to 1 ⇨

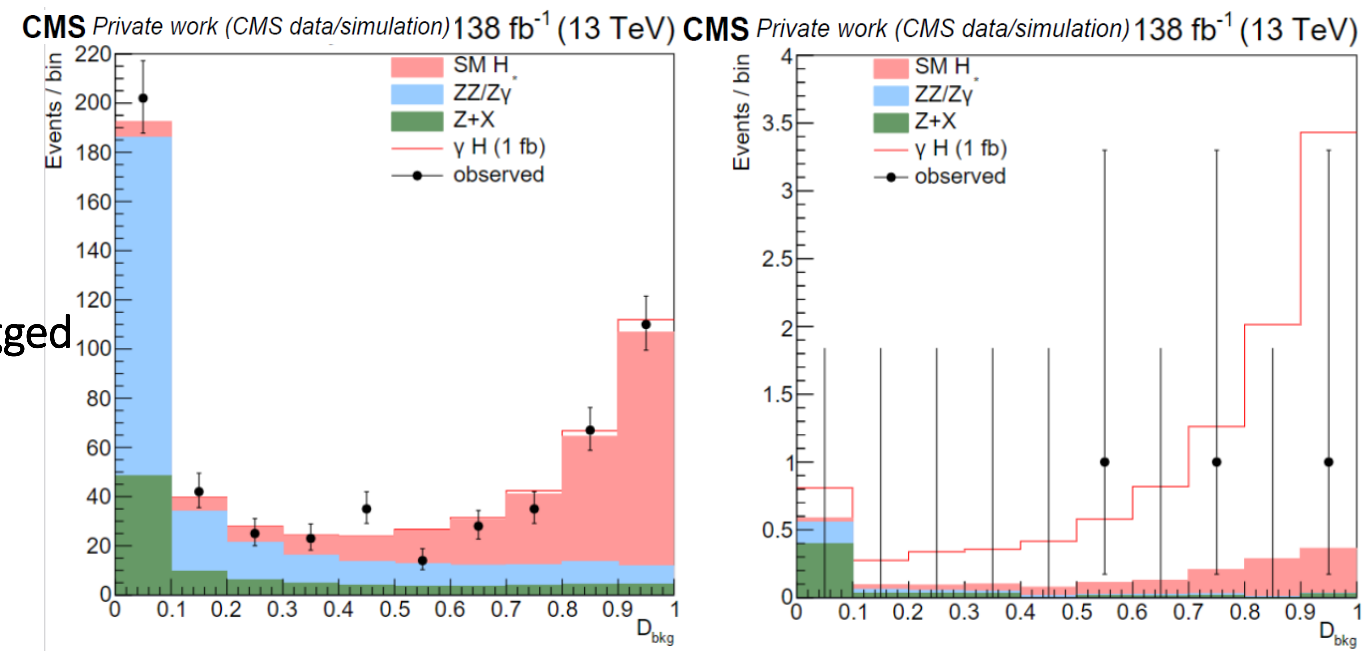
$$\mathcal{D}_{\rm alt}(\Omega) = \frac{\mathcal{P}_{\rm sig}(\Omega)}{\mathcal{P}_{\rm sig}(\Omega) + \mathcal{P}_{\rm alt}(\Omega)}$$

Ω = set of observables

In D_{bkg} case:
P_{sig}=Probability of Higgs
P_{alt}=Probability of Background

Probabilities from MELA

Untagged

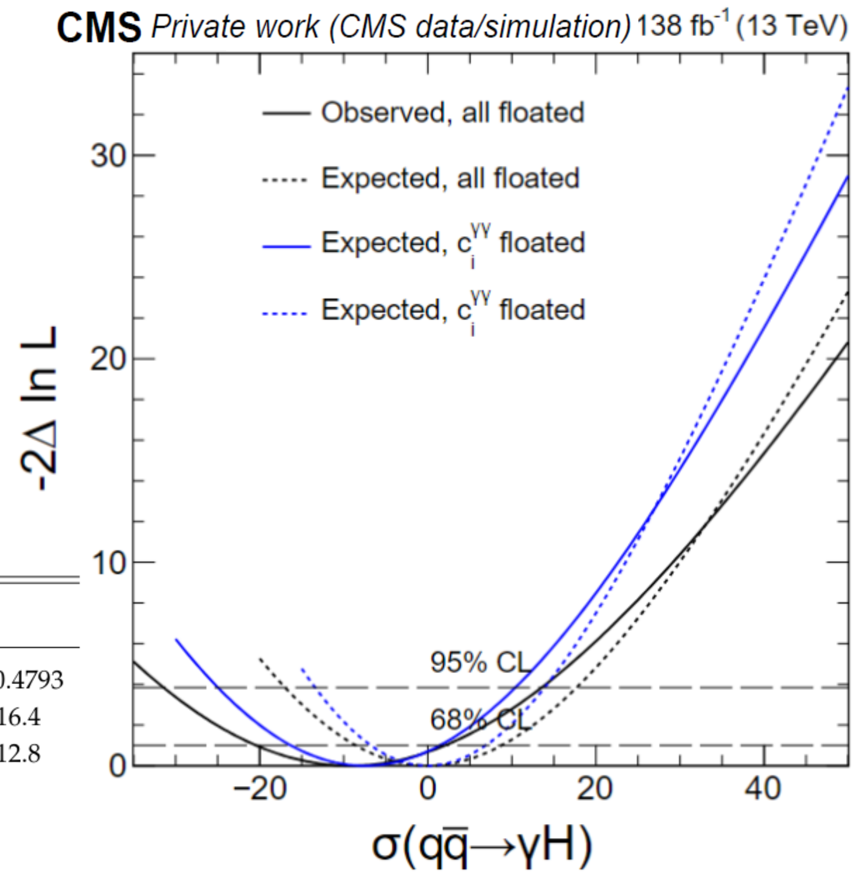


γH - tagged

Cross section limits

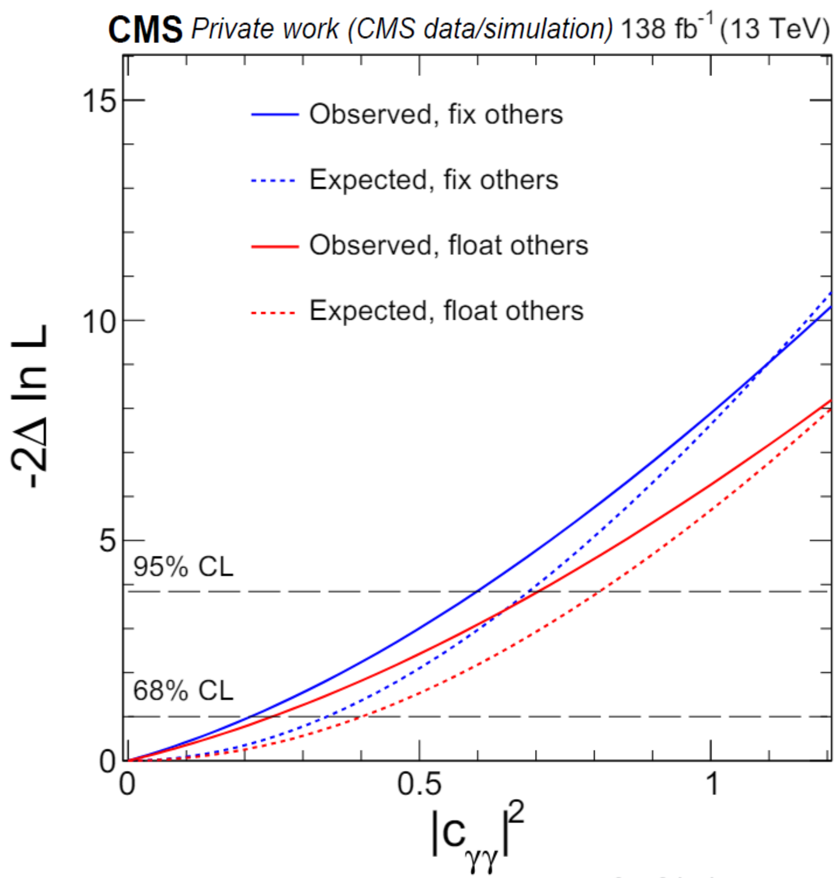
- Likelihood scan for production cross-section under assumption all other Higgs couplings are at SM prediction.
- Full Run 2 Combination of H → bb and H → 4l decay channels
- Numerical constraints:

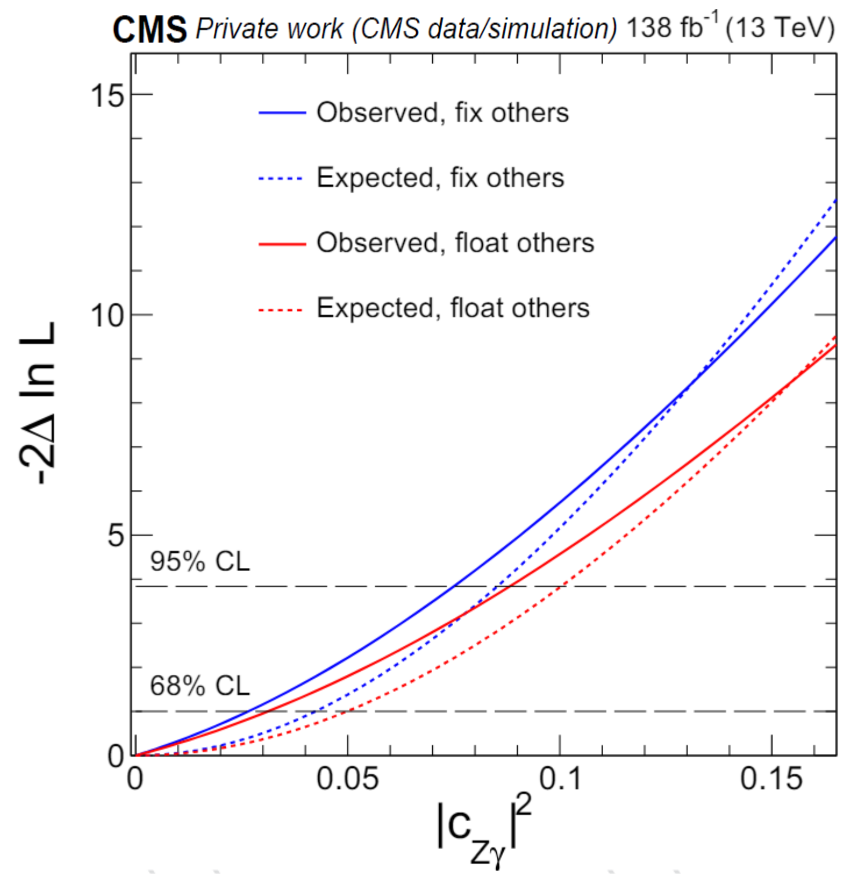
Parameter	Scenario	Observed	Expected
$\sigma_{\gamma\mathrm{H}}$ (fb) x BR($\mathrm{H} \to 4l$)	no constraints	$0.1000^{+0.286}_{-0.0000} < 0.7648$	$0.0000^{+0.172}_{-0.0000} < 0.4793$
$\sigma_{\gamma\mathrm{H}}$ (fb)	no constraints	$-9.2759^{+11.3479}_{-11.1611} < 13.5288$	$0.0^{+8.0}_{-8.0} < 16.4$
$\sigma_{\gamma\mathrm{H}}$ (fb)	$c_{z\gamma} = \tilde{c}_{z\gamma} = 0$	$-7.4961^{+8.9398}_{8.8015} < 10.4119$	$0.0^{+6.3}_{-6.3} < 12.8$



Constraints are dominated by H->bb channel

Constraints on Wilson Coefficients

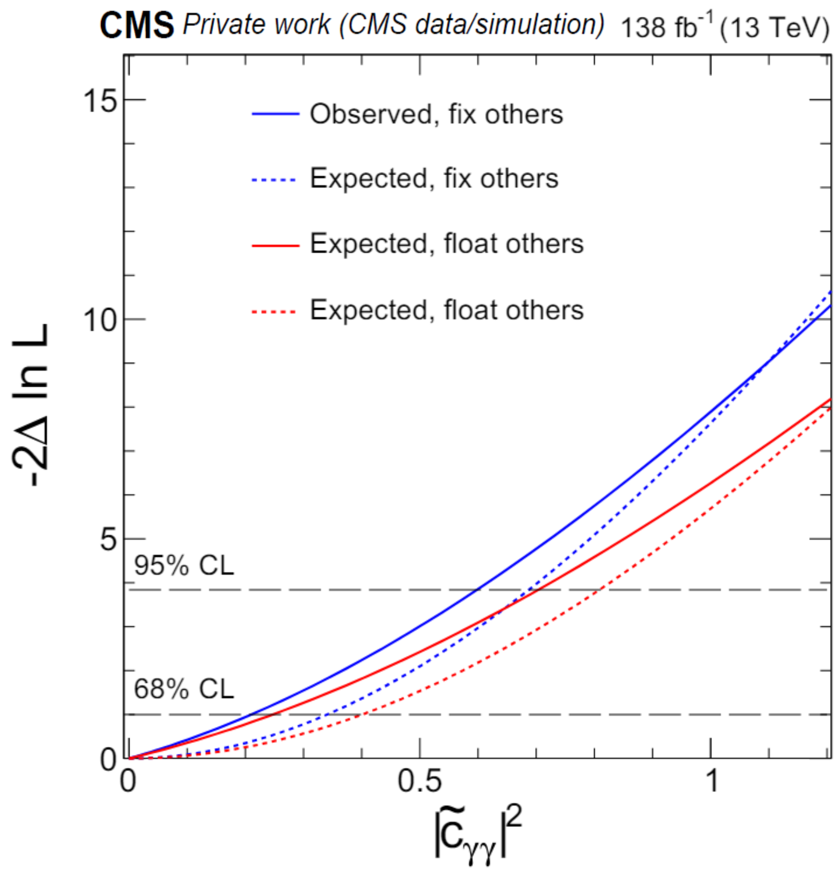


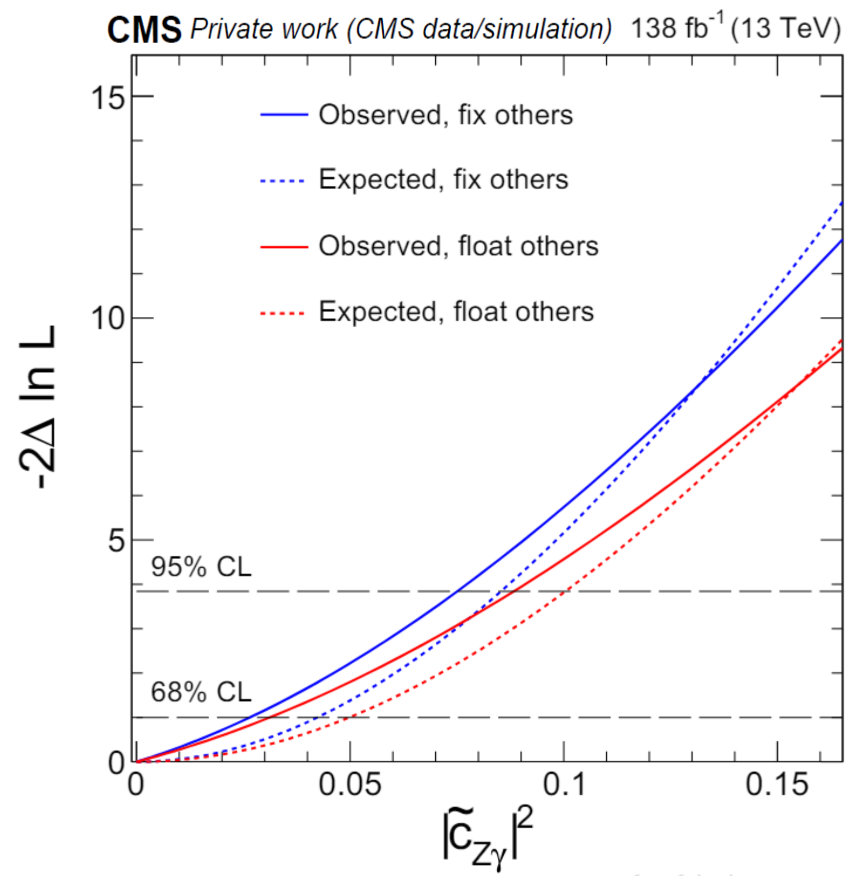


Parameter	Scenario	Observed	Expected
$c_{\gamma\gamma}$	no constraints	$-0.0000^{+0.497}_{0.497} < 0.8387$	$0.0000^{+0.6332}_{0.6332} < 0.8993$
$c_{\gamma\gamma}$	fix other $c_i = 0$	$-0.0006^{+0.4591}_{0.4591} < 0.7735$	$0.0000^{+0.5838}_{0.5838} < 0.8291$

Parameter	Scenario	Observed	Expected
$c_{z\gamma}$	no constraints	$-0.0001^{+0.1766}_{0.1766} < 0.297$	$0.0000^{+0.2232}_{0.2232} < 0.3168$
$c_{z\gamma}$	fix other $c_i = 0$	$-0.0002^{+0.1631}_{0.1631} < 0.2739$	$0.0000^{+0.2057}_{0.2057} < 0.2921$

Constraints on Wilson Coefficients





Parameter	Scenario	Observed	Expected
$\tilde{c}_{\gamma\gamma}$	no constraints	$-0.0000^{+0.497}_{0.497} < 0.8387$	$0.0000^{+0.6332}_{0.6332} < 0.8993$
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Likelihood for CP-Even and CP-odd Wilson coefficients is exactly the same.
Expected since we are not sensitive to CP-structure when measuring a production cross-section

Conclusion

- Presented preliminary constraints on the γH production in pp collisions and on anomalous H boson couplings with the CMS detector in the H → bb and H → 4l channels
- Limits are presented on the qq → γ+H cross section and on various Wilson coefficients in the EFT framework
- While the H → ZZ channel is not as powerful at constraining anomalous Zγ and γγ couplings. We are working on using this channel to constrain Yukawa couplings to light quarks
- *Results were not approved to show at conference*