Higgs Boson Coupling Measurements and New Interactions with EFT - CMS

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on behalf of The CMS collaboration

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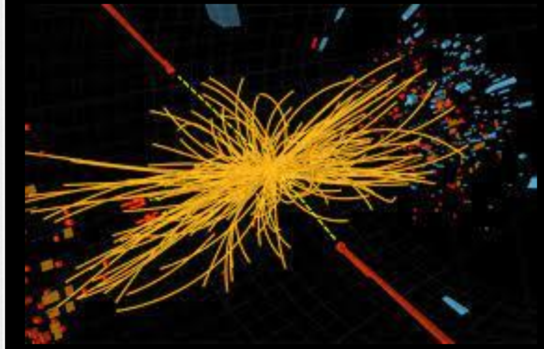
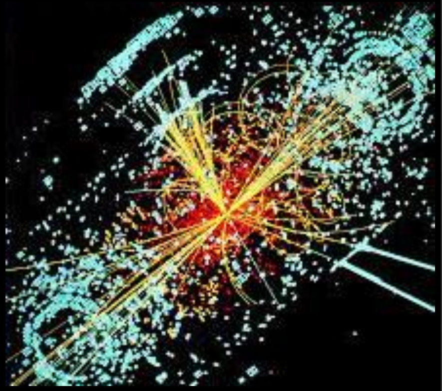


Higgs Hunting 2025 workshop

Orsay & Paris - France

15-17 July 2025



Higgs Boson Coupling Measurement

- At first: Signal Strength (μ) Measurements: $$\mu = \frac{\sigma \cdot \mathrm{BR}}{(\sigma \cdot \mathrm{BR})_{\mathrm{SM}}}$$
  - This tells us if the observed rate matches the SM expectation (μ = 1) or if there's a deviation → new physics?
- κ-framework
  - To interpret μ in terms of couplings, we use the κ-framework: k parameters act as linear modifiers to H coupling strengths
  - Fit all these κ parameters simultaneously using many production and decay channels.
  - SM expectation (k=1)

$$\sigma_i B^f = \frac{\sigma_i(\vec{\kappa})\Gamma^f(\vec{\kappa})}{\Gamma_{\mathrm{H}}(\vec{\kappa})}$$

$$\kappa_j^2 = \sigma_j/\sigma_j^{\mathrm{SM}} \quad \text{or} \quad \kappa_j^2 = \Gamma^j/\Gamma^j_{\mathrm{SM}}$$

- The above measurement can be interpreted in EFT framework

See Suman's talk

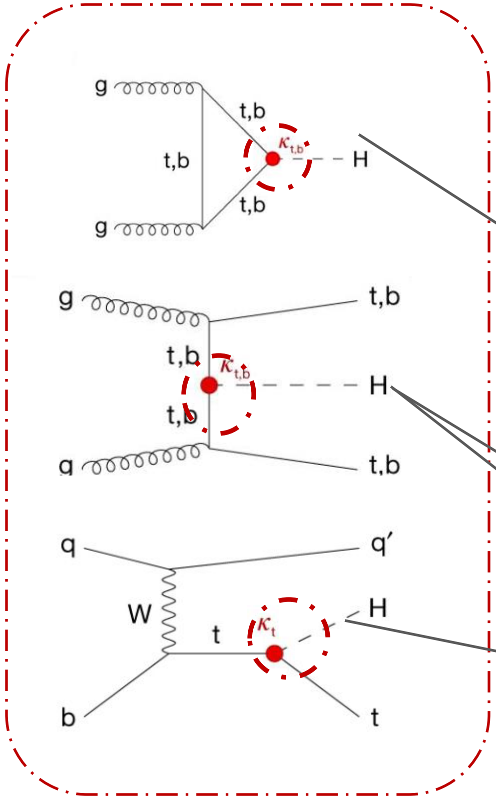
This talk presents an overview of recent Higgs boson coupling measurements at CMS, with a focus on new results from WH(H → $\tau\tau$), $t\bar{t}$H(H → $c\bar{c}$), and VVH(H → $b\bar{b}$) analyses.

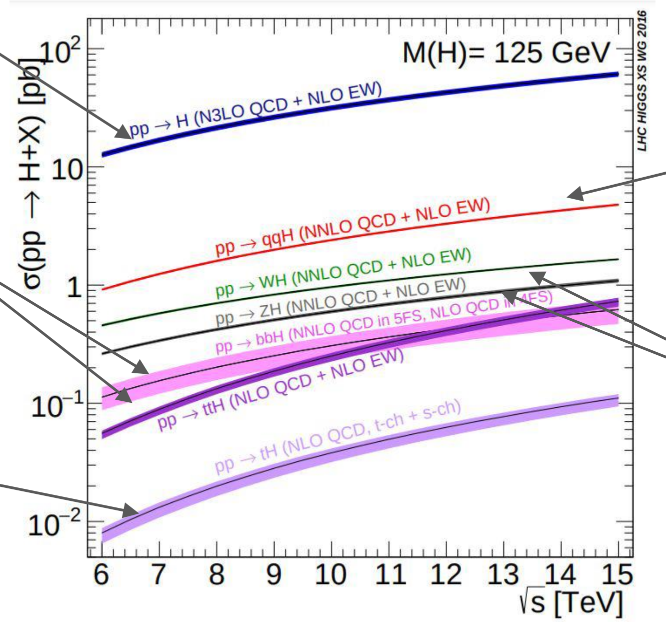
SM Higgs Boson production @ LHC

Rich phenomenology at the LHC

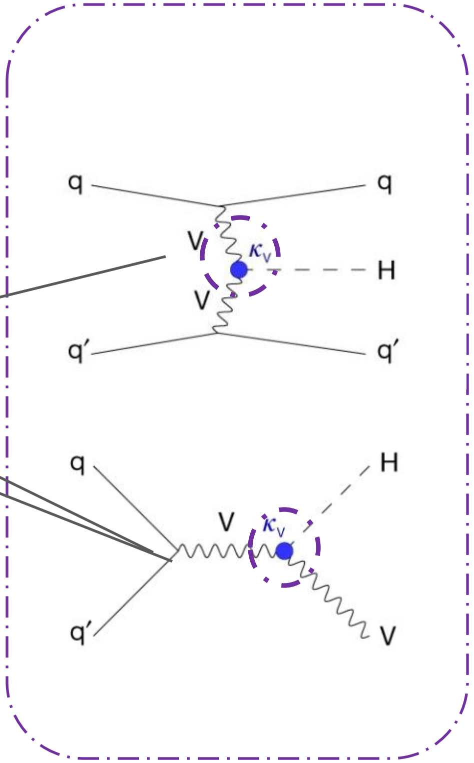
- production modes: ggH, VBF, VH, ttH, tH
- The inclusive signal-strength is measured to be: $\mu=1.014^{+0.055}_{-0.053}$

Can probe fermionic couplings of the Higgs

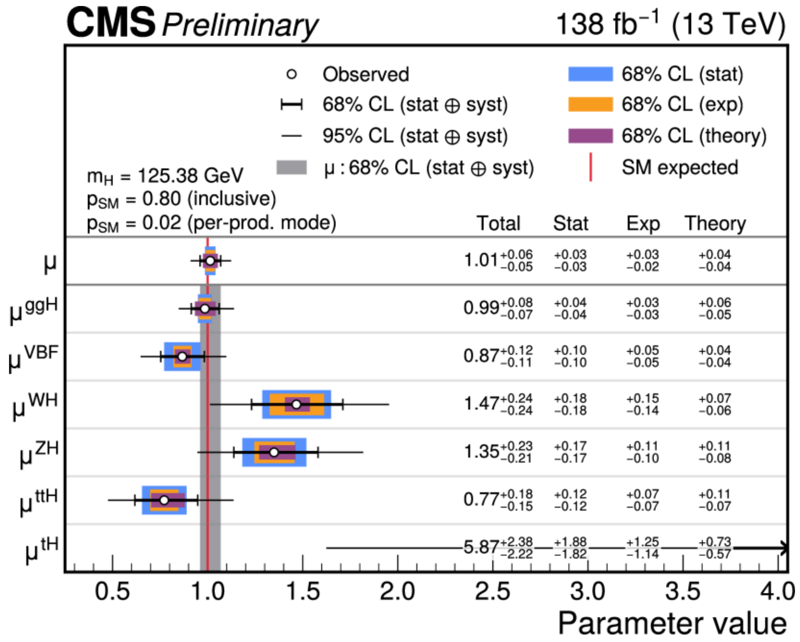




Can probe bosonic couplings of the Higgs



- ✓ Main 4 production modes have been observed with significance ≥ 5 σ
- ✓ Signal strength = $\mu_{if} = \frac{\sigma_i}{\sigma_i^{SM}} \times \frac{B_f}{B_f^{SM}}$
- ✓ Higgs signal strength parameters extracted for various production modes μ_i, assuming $B_f = (B_f)_{SM}$



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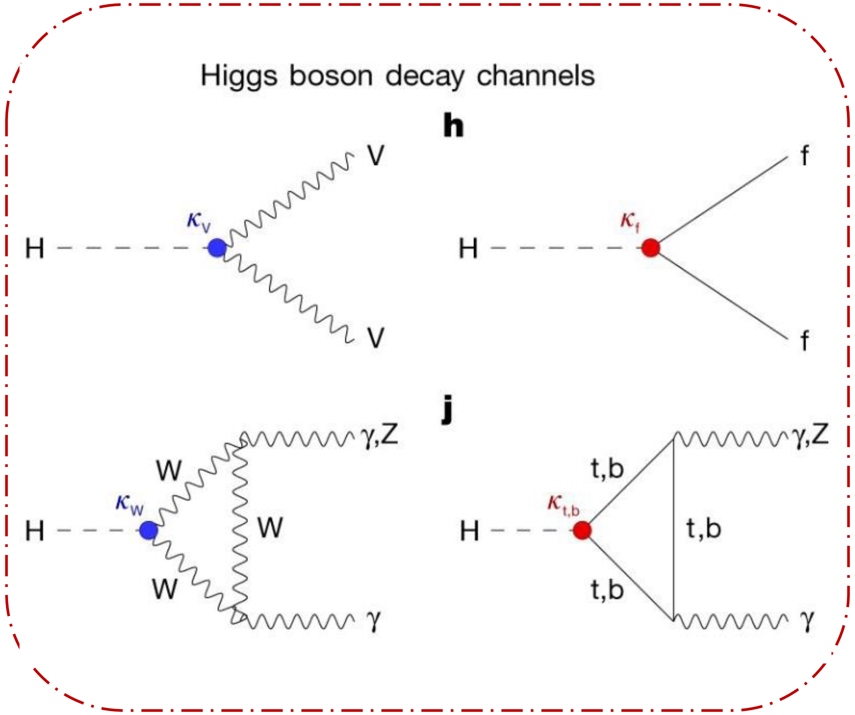
SM Higgs Boson decays @ LHC

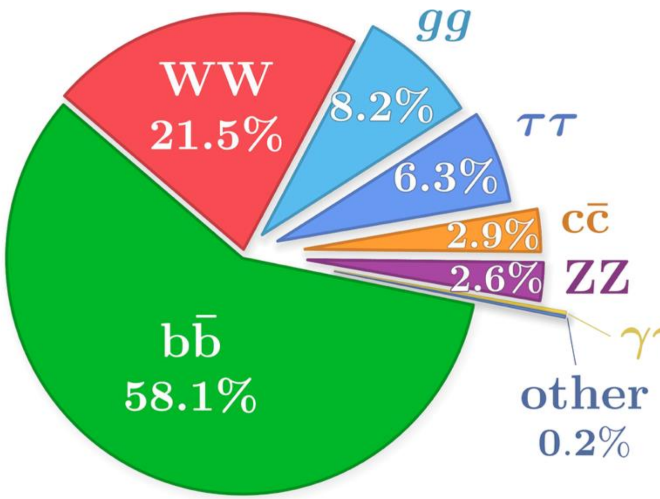
Rich phenomenology at the LHC

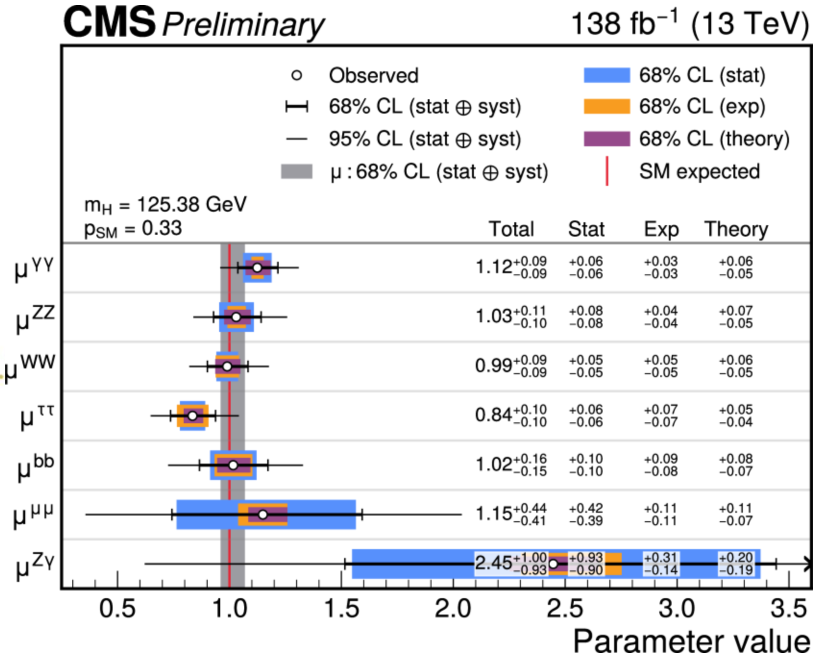
- Decays: $\gamma\gamma$, ZZ$\longrightarrow$ 4ℓ, WW $\longrightarrow \ell\nu\ell\nu$, $\tau\tau$, bb, $\mu\mu$, Zγ

✓ Couplings to weak gauge bosons (V=W/Z) and to 3rd generation fermions established well.

✓ First evidence of H decays to 2nd generation fermions. ($H\rightarrow\mu\mu$) and Higgs rare decay ($H\rightarrow$ Zγ).







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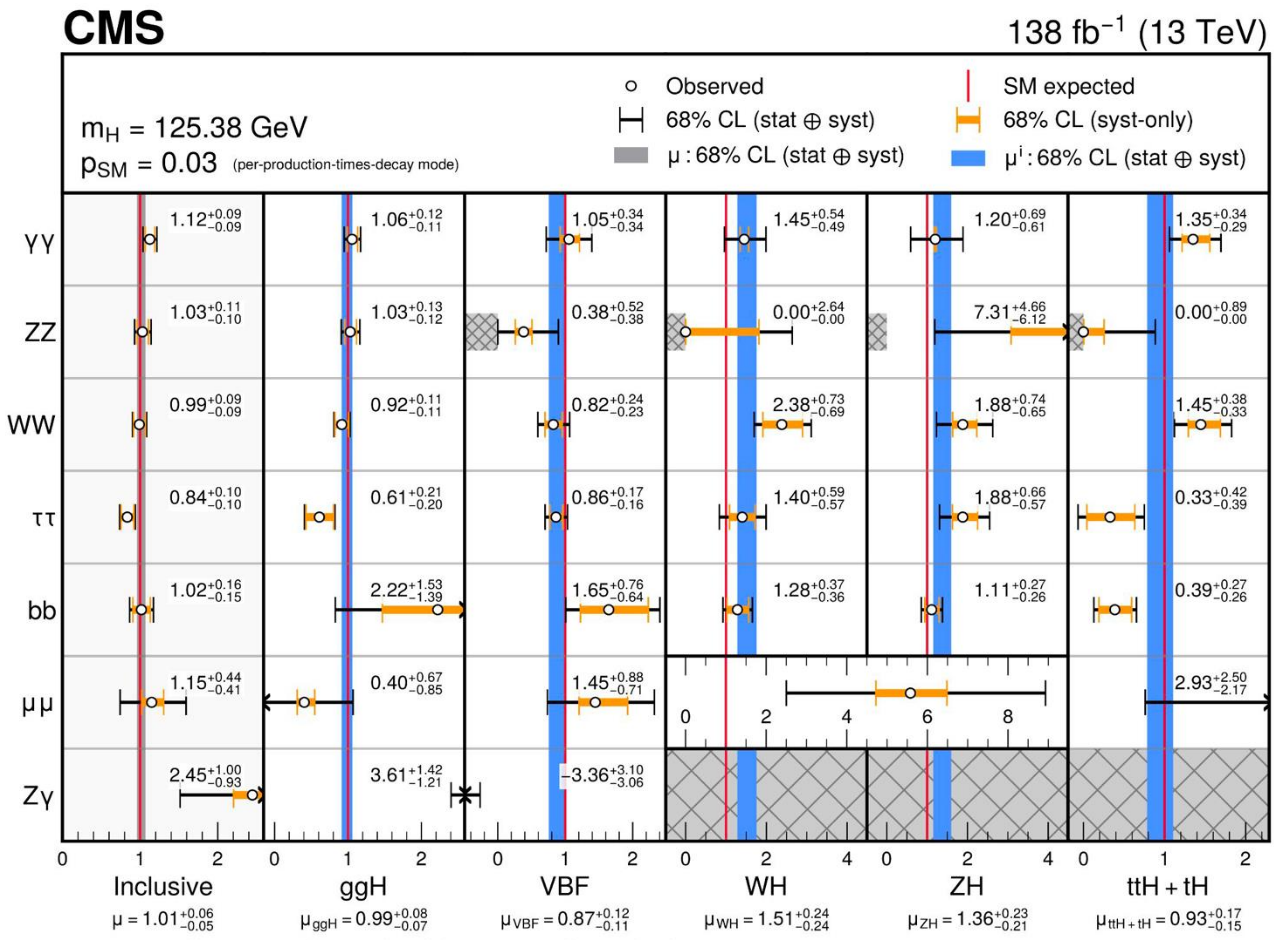
➢ The dominant decay mode is $H\rightarrow$ $b\bar{b}$(58.2%)

- Other $H\rightarrow$fermions scale $\propto m_f{}^2$
- Can also measure decay to $\tau\tau$(6.3%) and $\mu\mu$(0.02%)

➢ Cleanest decay modes and best mass resolution are ZZ(2.6%), $\gamma\gamma$(0.23%).

Combined Measurements of H Production and Decay - Results

- A deep examination of the Higgs mechanism done with full combination of available experimental observables.
- A good agreement with SM is observed at the current precision
- Few discrepancies in channels with limited statistical precision.



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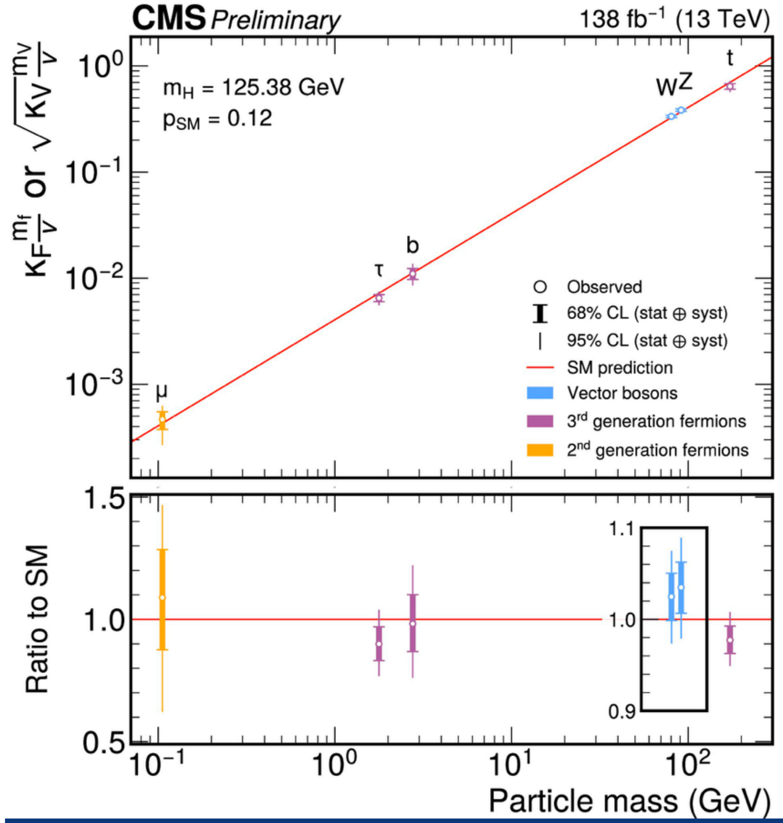
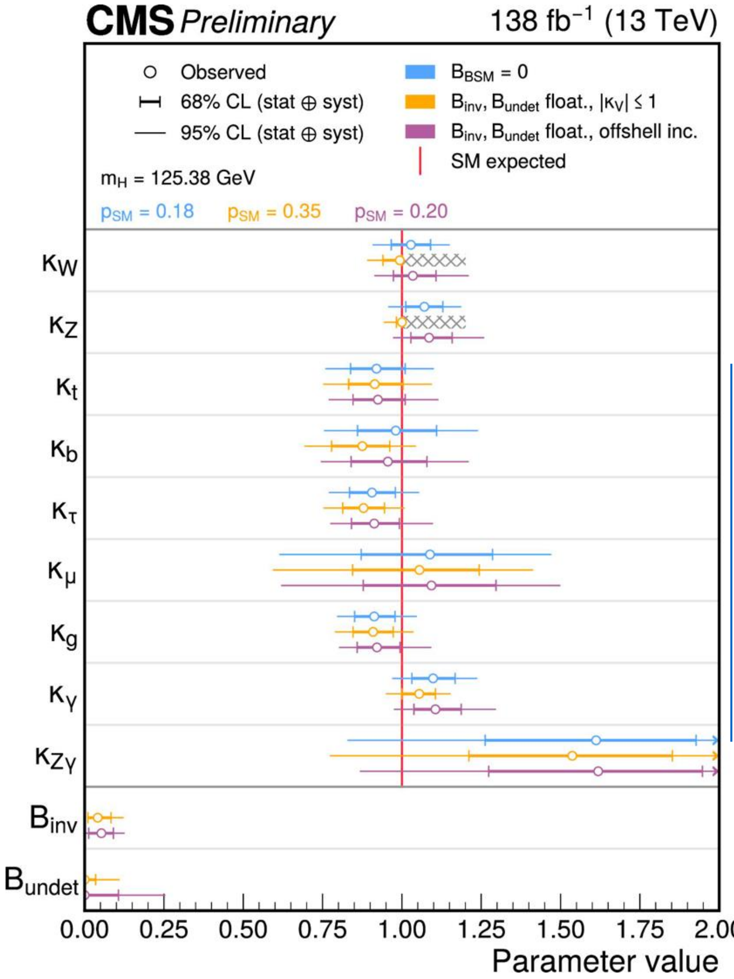
Combined Higgs Boson Coupling Measurement

- Coupling modifiers probed in 3 models:
  - No BSM contribution to Γ_H (blue)
  - BMS contributions constrained by $|\kappa_Z|$, $|\kappa_W| \leq 1$ (orange)
  - BMS contributions constrained by offshell $H \longrightarrow ZZ \longrightarrow 4\ell$ (purple)
- The invisible and undetected branching fraction is constrained to be: B_{inv} < 13% and B_{undet} < 25% @ 95% CL.



- **Bosons**: κ_W and κ_Z : ~ 5% precision
- **third generation quarks:** κ_t and κ_b 5% and 12% precision
- **Leptons:** κ_τ and κ_μ : 8% and 20% precision



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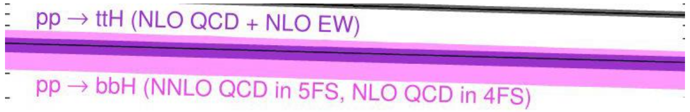
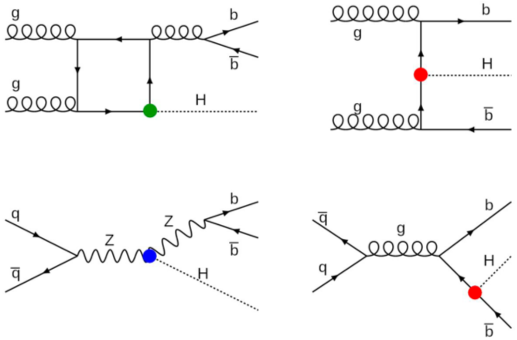
No significant deviations from the SM for large a mass range!

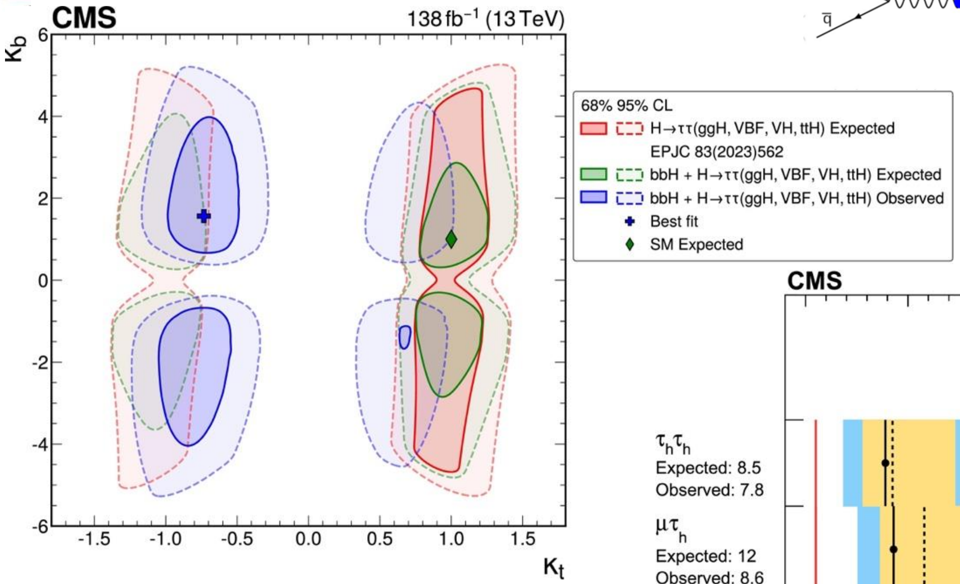
Rare Higgs production mode bbH

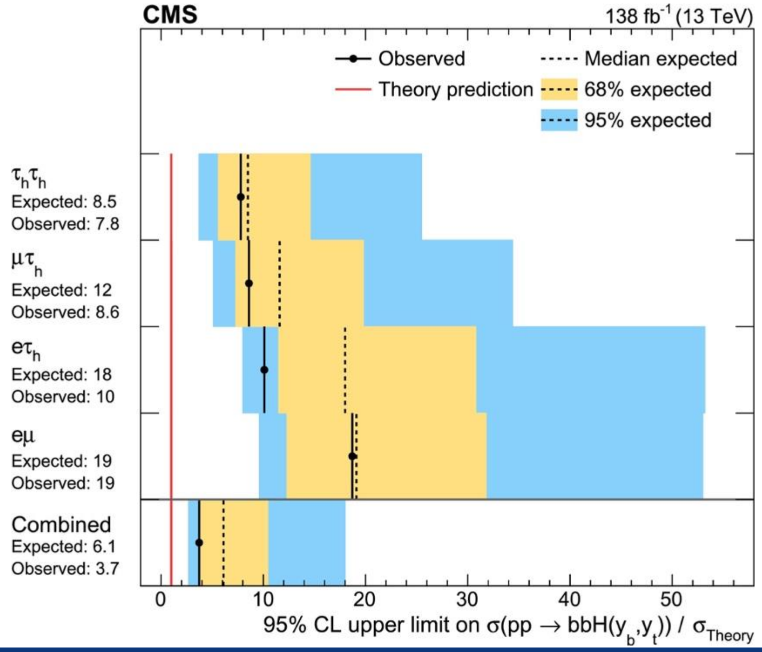
- Rare Higgs production mode, sensitive to the coupling to top and bottom quarks.





- Similar production cross section as ttH, but experimentally even more challenging
- WW and $\tau\tau$ final states
- Observed (expected) upper limit 3.7 (6.1) times the SM prediction @ 95% CL
- Results also interpreted in terms of couplings to top and bottom quarks
  - Best fit values (κ_t, κ_b)= (-0.73,1.58)
  - Compatible with SM within 2 $\boldsymbol{\sigma}$





First upper limit, combined with Eur. Phys. J. C 83 (2023) 562 (ggF+VBF H→ $\tau_{had}\tau_{had}$) and interpreted in terms of κ_t, κ_b

PLB 860 (2024) 139173

WH(H→$\tau\tau$)

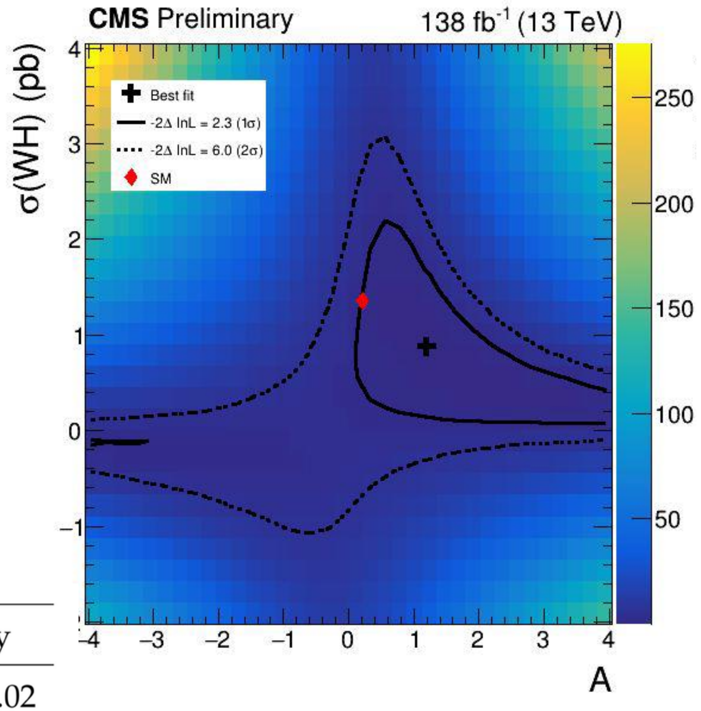
- First Measurement of charge asymmetry (A), $\sigma(W^+H)$, and $\sigma(W^-H)$ in $W(\nu\ell)H(\tau\tau)$

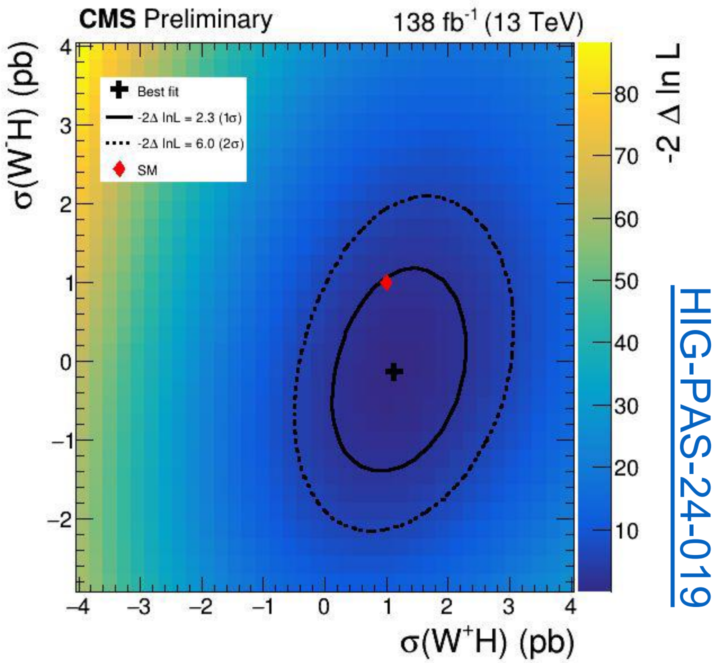
Where:

$$A = \frac{\sigma(W^+H) - \sigma(W^-H)}{\sigma(W^+H) + \sigma(W^-H)}$$

- WH (with H → WW) is treated as signal in the fit
- All measurements are consistent with Standard Model predictions
- Results can be interpreted in terms of constraints on Yukawa couplings

Quantity	Observed	Expected	Theory
$\sigma(W^+H)$ [pb]	$0.96^{+0.61}_{-0.58}$	$0.83^{+0.61}_{-0.58}$	0.83 ± 0.02
$\sigma(W^-H)$ [pb]	$-0.05^{+0.46}_{-0.44}$	$0.53^{+0.51}_{-0.49}$	0.53 ± 0.01
$\sigma(WH)$ [pb]	$0.96^{+0.86}_{-0.82}$	$1.36^{+0.90}_{-0.84}$	1.36 ± 0.03
A	$1.18^{+0.00}_{-0.75}$	$0.22^{+0.66}_{-0.56}$	0.22 ± 0.01
$\mu(W^+H)$	$1.16^{+0.74}_{-0.70}$	$1.00^{+0.73}_{-0.69}$	
$\mu(W^-H)$	$-0.15^{+0.87}_{-0.83}$	$1.00^{+0.96}_{-0.91}$	
$\mu(WH)$	$0.71^{+0.63}_{-0.60}$	$1.00^{+0.65}_{-0.62}$	

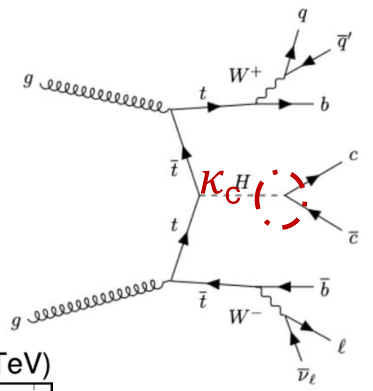




HIG-PAS-24-019

New

- **First analysis of $t\bar{t}H(c\bar{c})$.**
  - $H \rightarrow c\bar{c}$ is rare (~3% BR) and experimentally challenging — direct sensitivity to the charm Yukawa coupling.
  - Focus on $t\bar{t}H$ with single-/multi-lepton final states.
    - $0L(t\bar{t} \rightarrow q\bar{q}q\bar{q})$ & $1L(t\bar{t} \rightarrow q\bar{q}\ell\nu)$ & $2L(t\bar{t} \rightarrow \ell\nu\ell\nu)$
  - Physics-oriented ML used in both event classification & c-tagging.
  - Limits set on $\mu_{t\bar{t}H(H\rightarrow c\bar{c})}$, constraining charm Yukawa.



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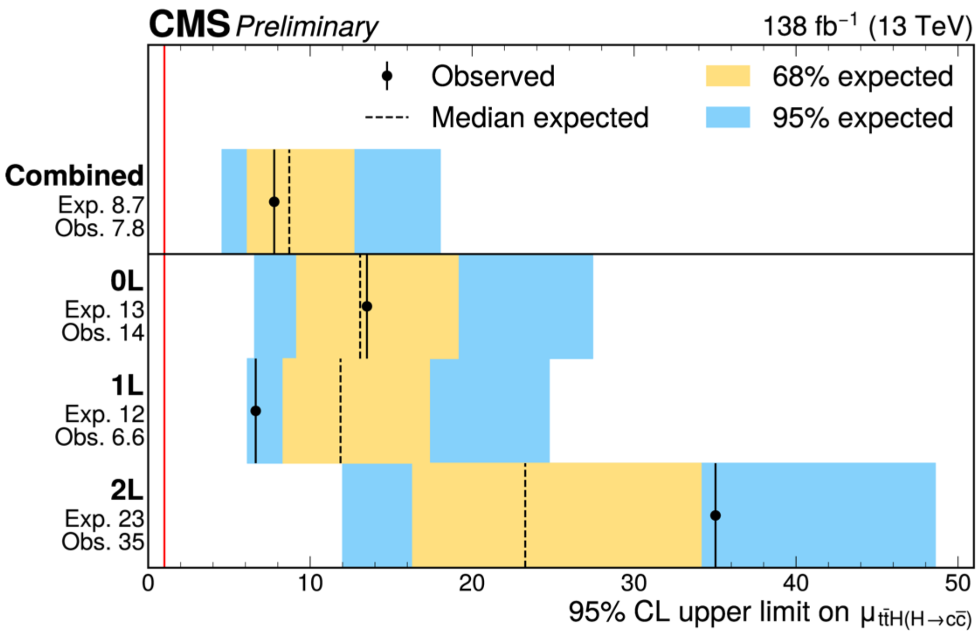
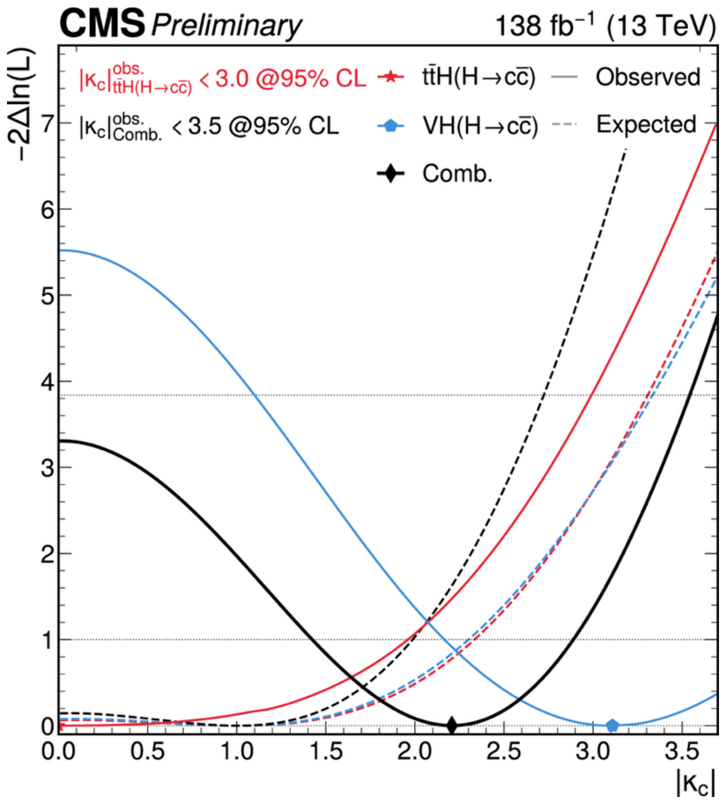
$\mu_{t\bar{t}H(H\rightarrow c\bar{c})} < 7.8$ @ 95%





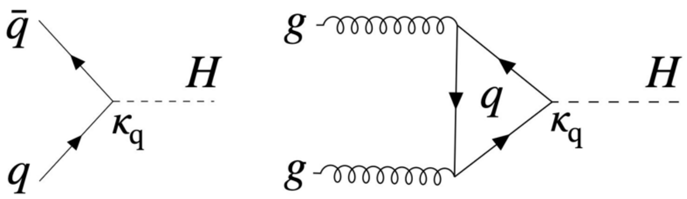
$t\bar{t}H(H\rightarrow c\bar{c}) + VH(H \rightarrow c\bar{c})$:
$|\kappa_c| < 3.5$ @ 95% CL

Light-Quark Yukawa Couplings

First study of γ + H @ LHC

Light-quark Yukawa couplings:

- difficult to measure directly
- changes production rates
- changes total Higgs boson width



H → ZZ → 4l analysis:

- decay unaffected of κ_q
- cross section decreases with increasing κ_q

➡ set constraints on light-quark couplings simultaneously

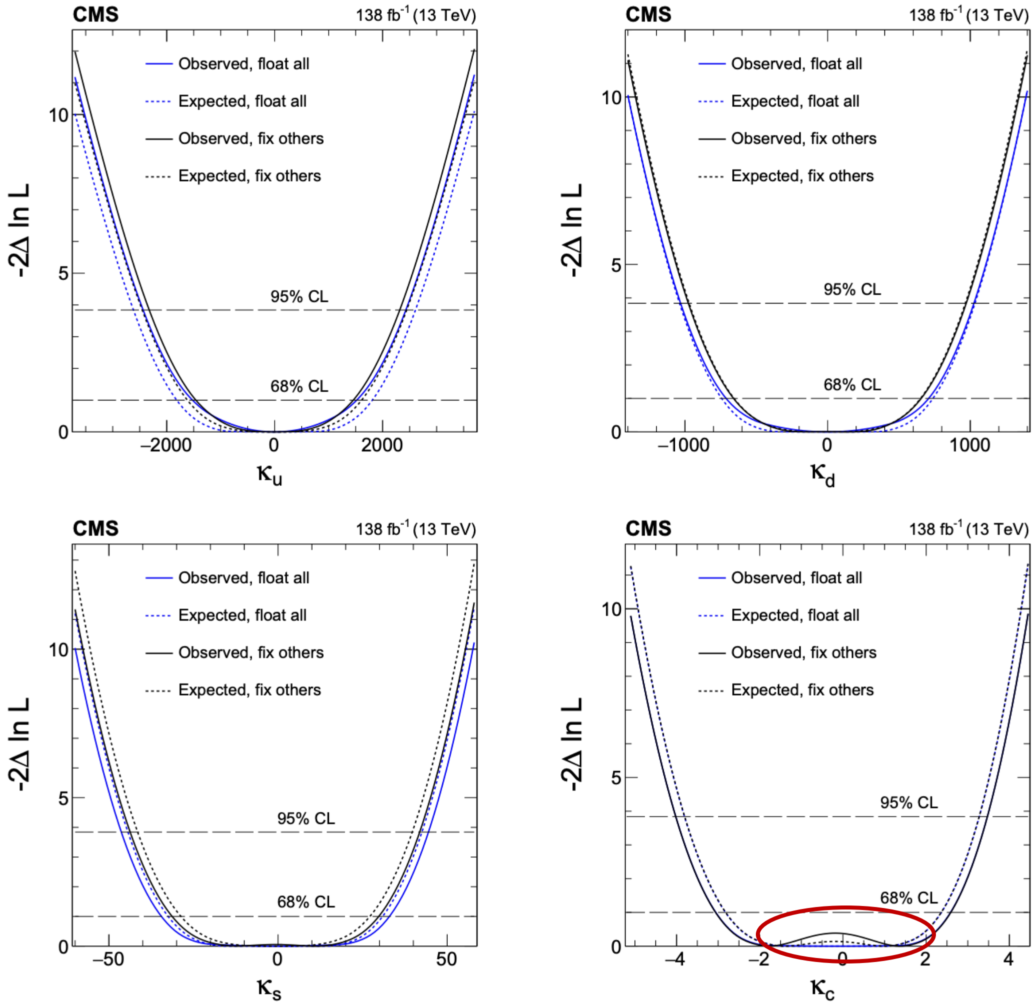
$$\sigma_{H\to 4\ell} = \frac{\Gamma^{SM}_{H\to 4\ell}\,\kappa^2_{ZZ}}{\Gamma_H(\kappa_{u,d,s,c,b})}\left(R_{gg}(\kappa_{u,d,s,c,b})\,\sigma^{SM}_{ggH} + \sum_q \kappa_q^2\,\sigma^{SM}_{q\bar{q}H} + \sigma^{SM}_{t\bar{t}H} + \sigma^{SM}_{tH} + \sum_{VV}\kappa^2_{VV}\,\sigma^{SM}_{VVH}\right)$$

First scenario:

- ✓ All couplings except the one being shown are fixed at their SM values.(Black)
- ✓ $\kappa_{zz} = 1$ & $\Gamma^H_{BSM} = 0$

Second scenario:

- ✓ The Yukawa couplings for the three other light quarks are left unconstrained (Blue)
- ✓ $\kappa_b = \kappa_t = 1$ & $\kappa^2_{ZZ} \leq 1$ & $\Gamma^H_{BSM} \geq 0$



arXiv:2502.05665

See Angela's talk

Constrained $\kappa_c = 0.0^{+2.7}_{-3.0}$

Higgs self-coupling

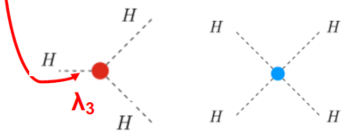
- The double Higgs processes (HH) provides a direct probe to the Higgs self-coupling but very challenging as its XS is 3 orders of magnitude smaller than the single Higgs (direct measurement).
- The Higgs self-coupling affects the Higgs propagator and enters single Higgs production via loops . Combining several channels together, it is possible to extract limits on the Higgs trilinear coupling k_λ (indirect measurement).

$$V(h) = \boxed{\lambda v^2 h^2} + \boxed{\lambda_3 v h^3} + \boxed{\frac{1}{4}\lambda_4 h^4} + \cdots$$

Higgs mass term   Higgs self-coupling

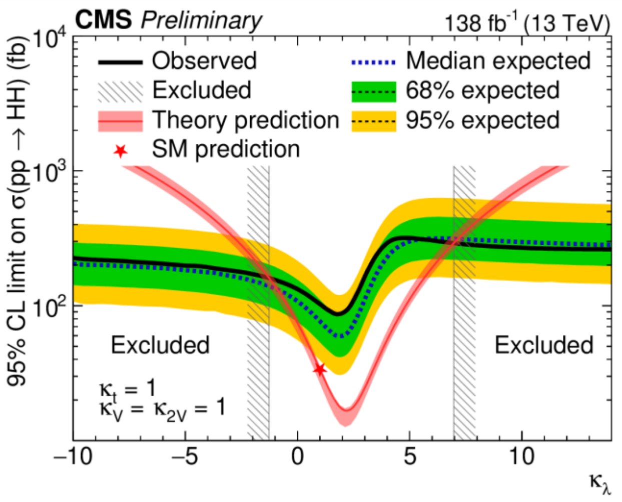
In SM

$$\lambda (= \lambda_3 = \lambda_4) = \frac{m_h^2}{2v^2} \sim 0.13$$

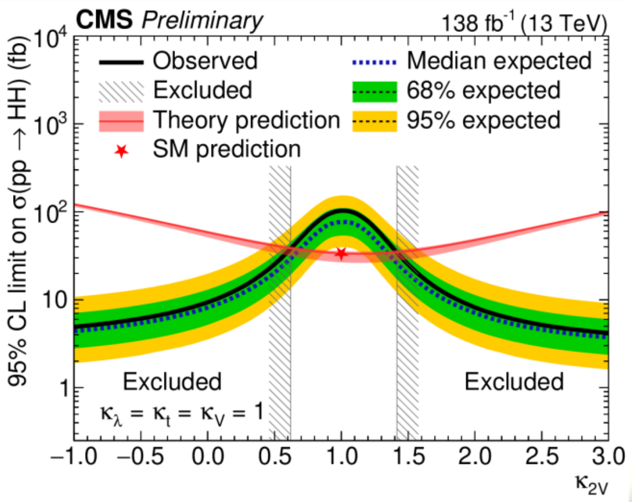


Direct measurement

- Combined results from di-Higgs searches (4b, $bb\gamma\gamma$, $bb\tau\tau$, bbZZ)



$-1.24 < \kappa_\lambda < 6.49$@ 95% CL

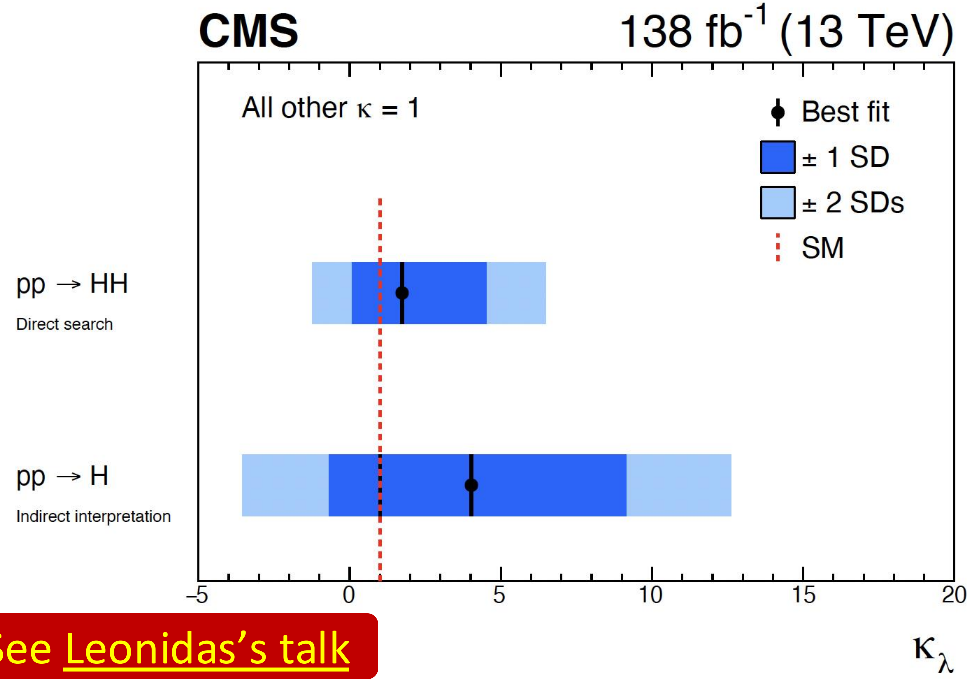


$0.67 < \kappa_{2V} < 1.38$

($k_{2V} = 0$ excluded by 6.6σ)

CMS-PAS-HIG-20-011

- By combining the direct and indirect measurement it is possible to profit from the **higher precision** of the direct measurement.

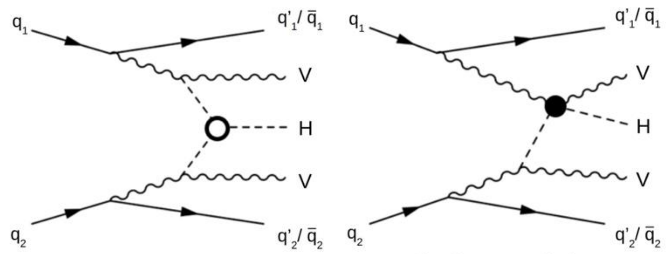


See Leonidas's talk

Nature 607 (2022) 60-68

VVH($H \to b\bar{b}$)

- The VBS VVH production is sensitive to deviations both in the Higgs self coupling (C_λ) or in the quartic gauge coupling (C_{2V})
- As both W and Z bosons can be involved in the VBS VVH production and are present in the final state, the process is also sensitive to variations of C_{2W} and C_{2Z}.



New

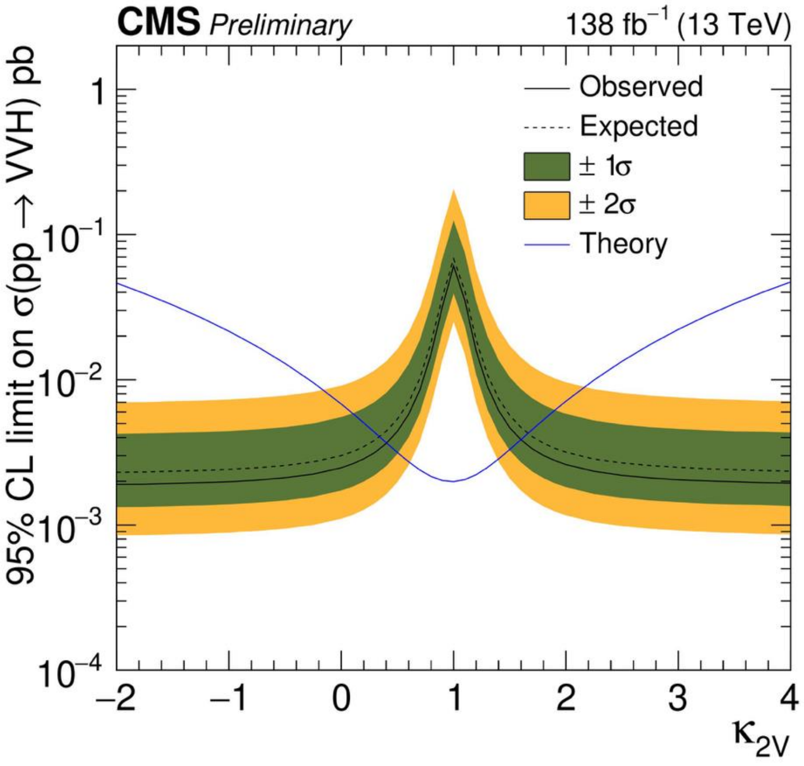
- Set limit on K_{2v} - approaching current constraints from di-Higgs:

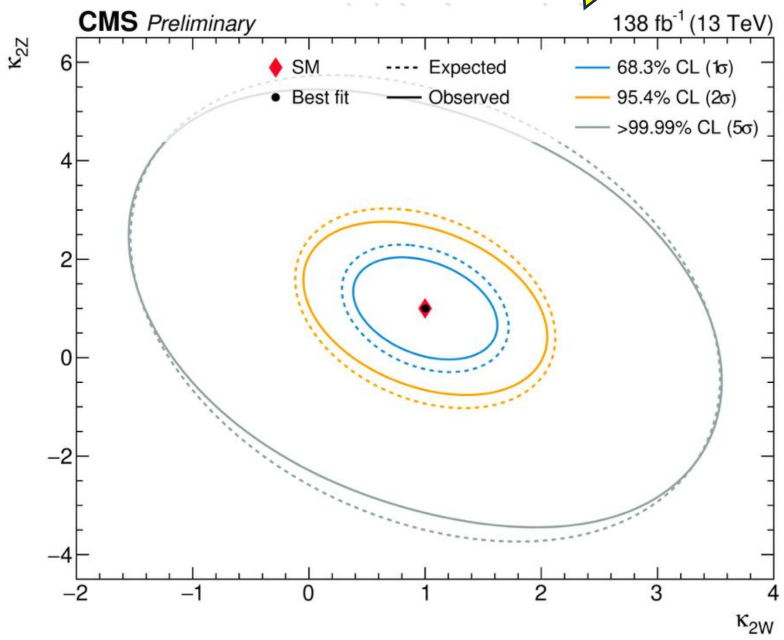
$0.41 < \kappa_{2V} < 1.59$

- Produced current tightest limits on K_{2W} and K_{2Z} :

$0.17 < \kappa_{2W} < 1.80$

$-0.37 < \kappa_{2Z} < 2.37$





HIG-PAS-24-003

Summary

- Significant progress thanks to:
  - ✓ Advanced analysis techniques
  - ✓ Improved detector performance
  - ✓ Enhanced flavour tagging algorithms
- Couplings to 3rd-generation fermions measured with ~10% precision
- Challenging second-generation fermions
  - ✓ Already 3-sigma evidence for $H \to \mu\mu$
  - ✓ Competitive limits on the κ_c coupling modifier
- Combination of H and HH measurements constrains the **Higgs self-coupling**

✓ Run3 Higgs physics ongoing

. Much larger dataset

⇨ New physics may appear in coming years

Stay tuned for Run3 results!