Higgs boson coupling and cross section measurements at CMS

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on behalf of the CMS collaboration

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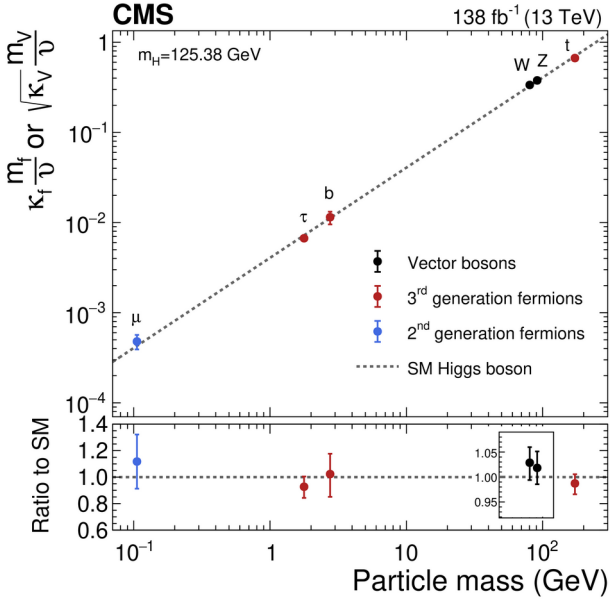
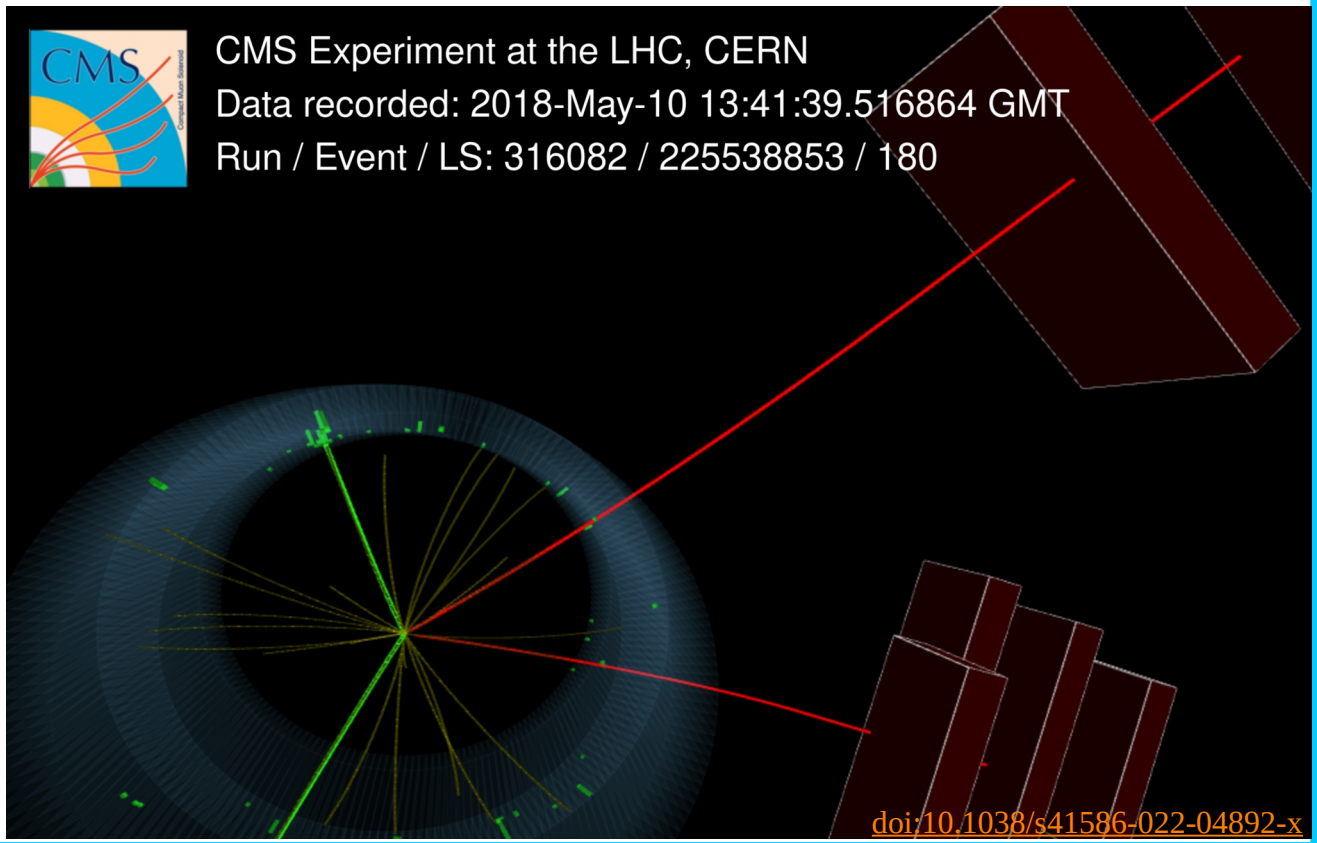
11 years of Higgs physics

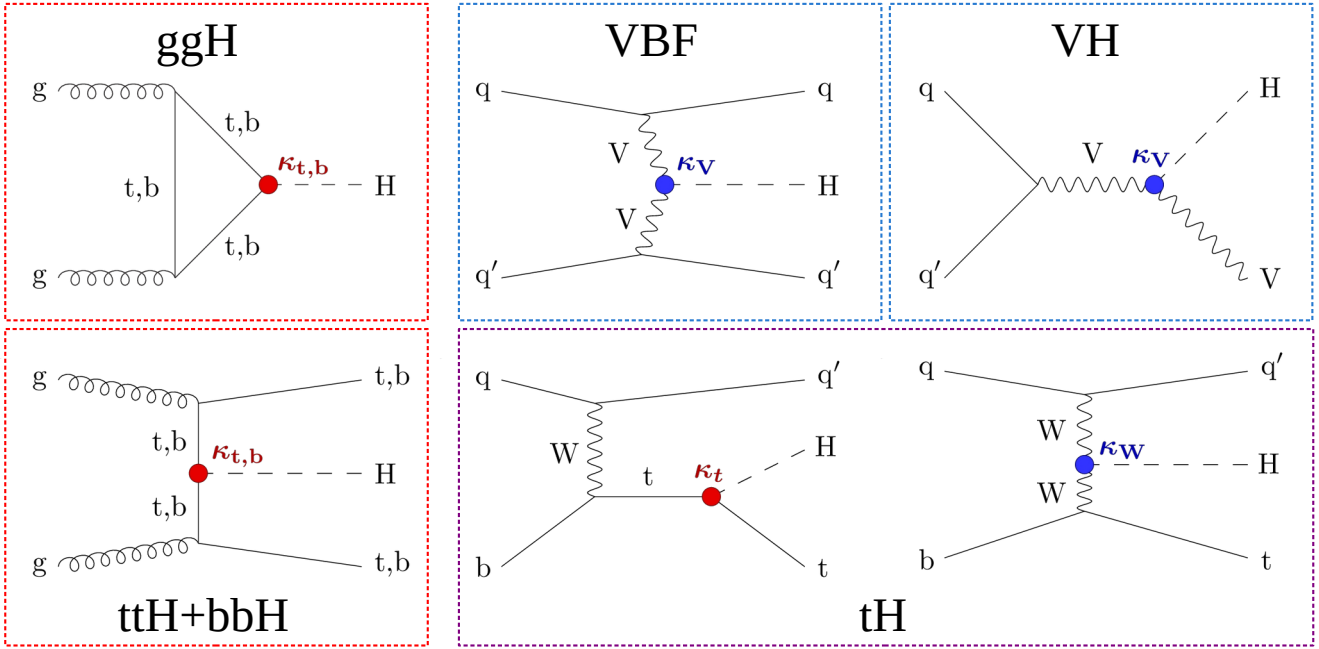
- The Higgs discovery has been one of the highlights of the LHC program
- The discovery in the H→ 4 lepton and H→γγ final states was followed by 11 years of discoveries and observations:
  - Production mechanisms
  - Decays
  - Anomalous couplings

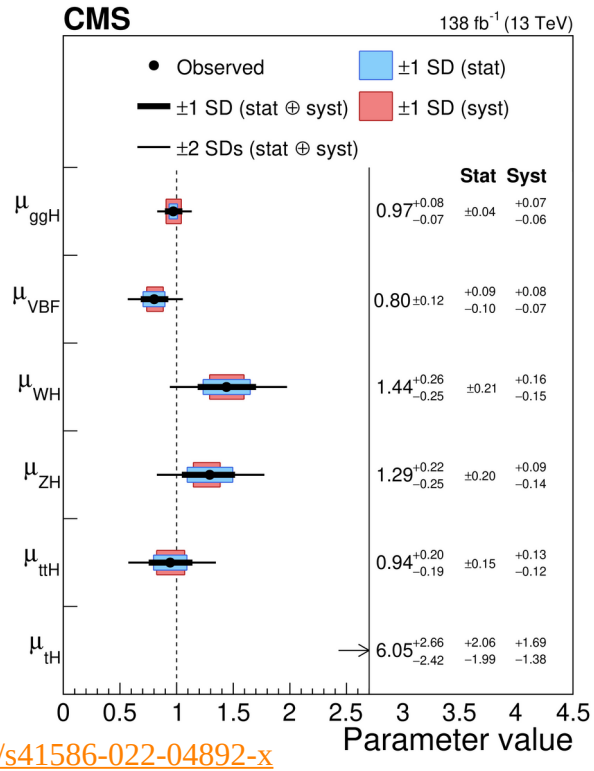




Single Higgs production mechanisms

- Single Higgs production mechanisms probe both **bosonic** and **fermionic** couplings
  - Dominant production mechanisms observed: ggH, VBF, VH, ttH
  - Pieces of the puzzle missing: bbH + observation of tH





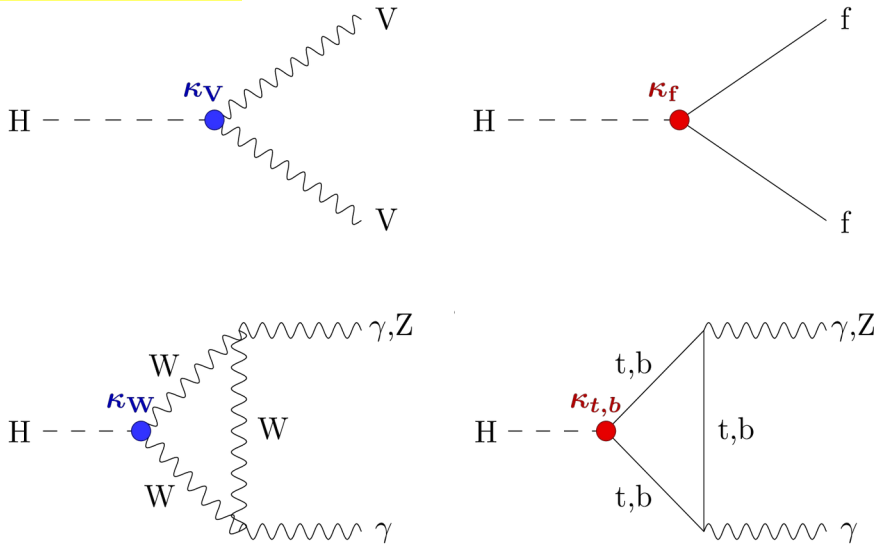
- All observations consistent with the SM

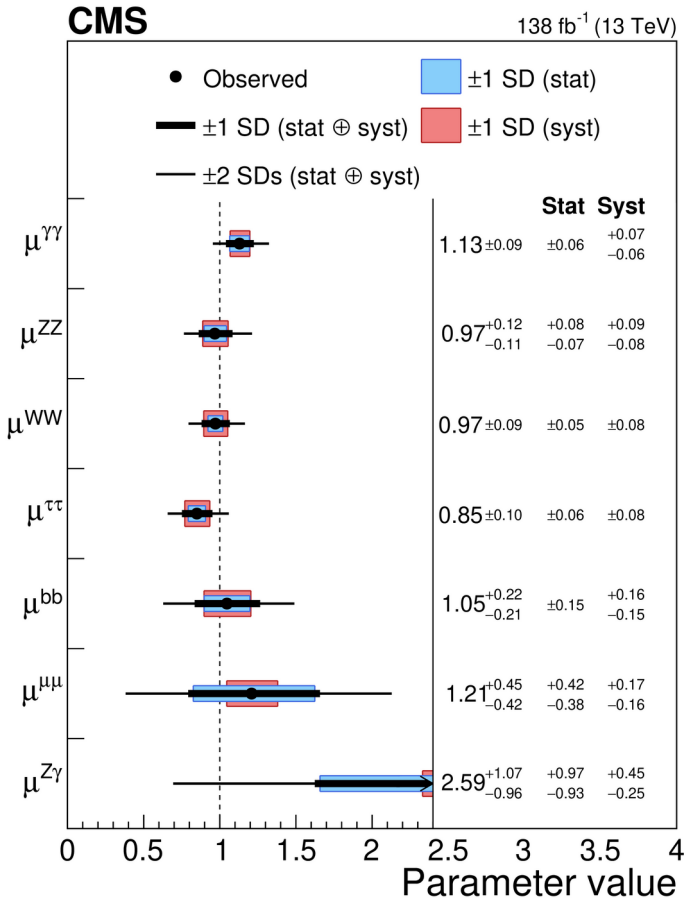
doi:10.1038/s41586-022-04892-x

Higgs decays

- Direct Higgs decays to vector bosons and fermions
- Loop decays to γγ, γZ and gg final states
- Other decays considered:
  - Lepton flavor violating couplings to eμ final state
  - Higgs to invisible

New!





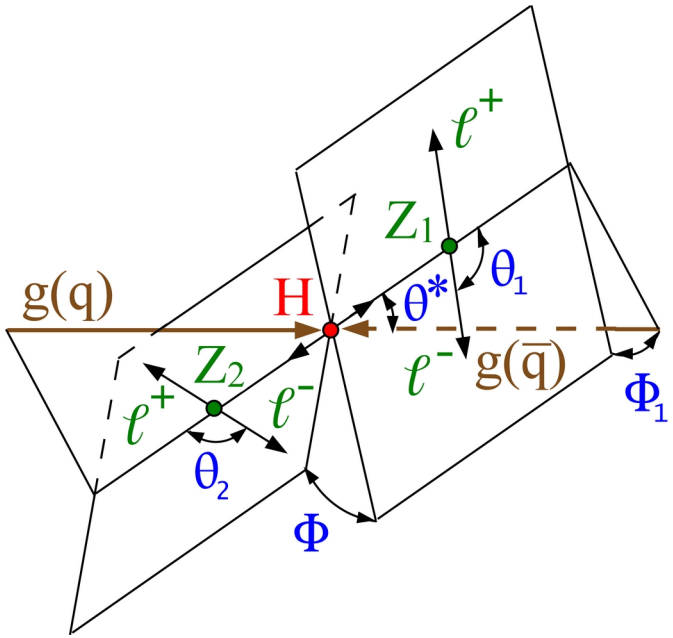
- All observed couplings consistent with SM expectations

doi:10.1038/s41586-022-04892-x

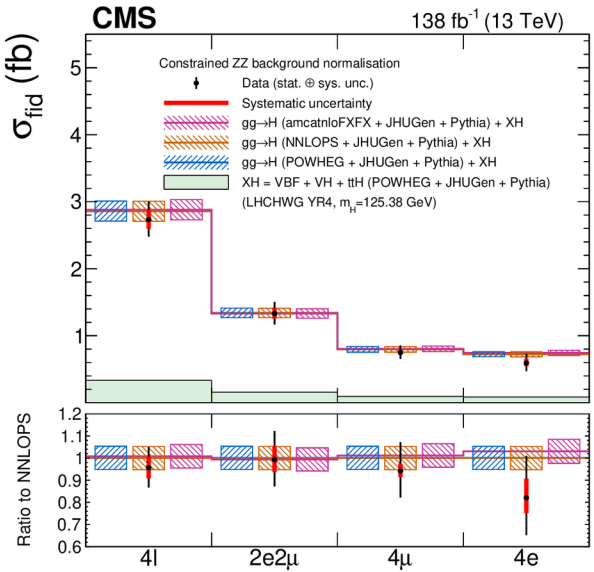
H → ZZ* → 4 leptons differential cross-section

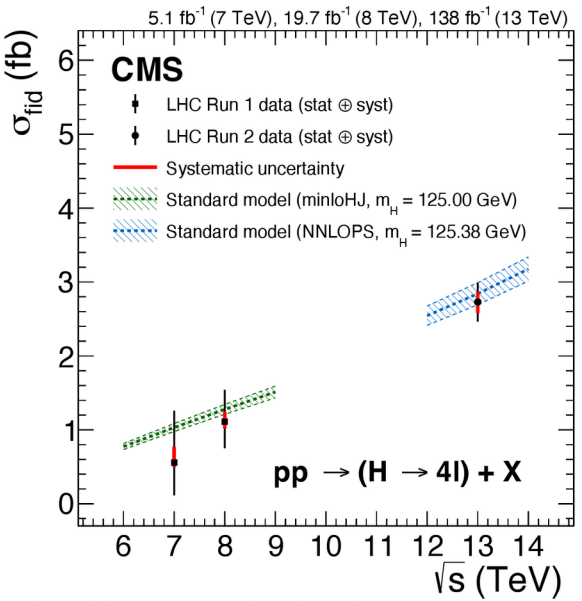
New!

- Higgs decays to 4 leptons were used already in the Higgs discovery
- Excellent handle to measure Higgs properties: mass, spin, width, and CP properties
- Differential measurement performed with respect to angular variables, Higgs momentum, and accompanying jet pT → sensitivity to loop correction and BSM operators



Inclusive fiducial cross-section



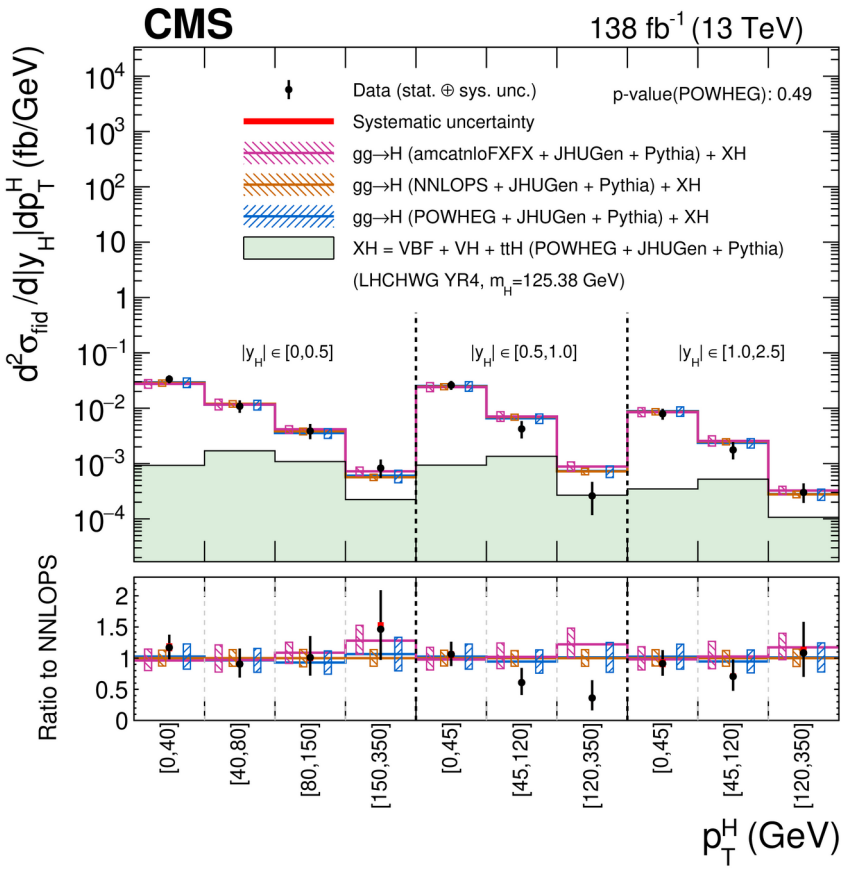


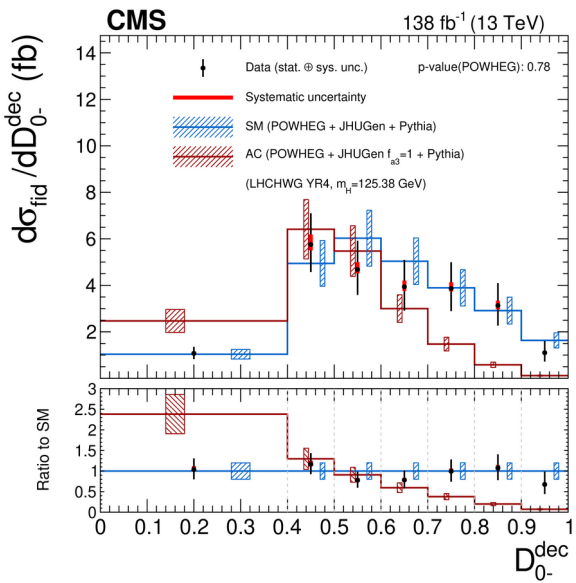
doi:10.48550/arXiv.2305.07532

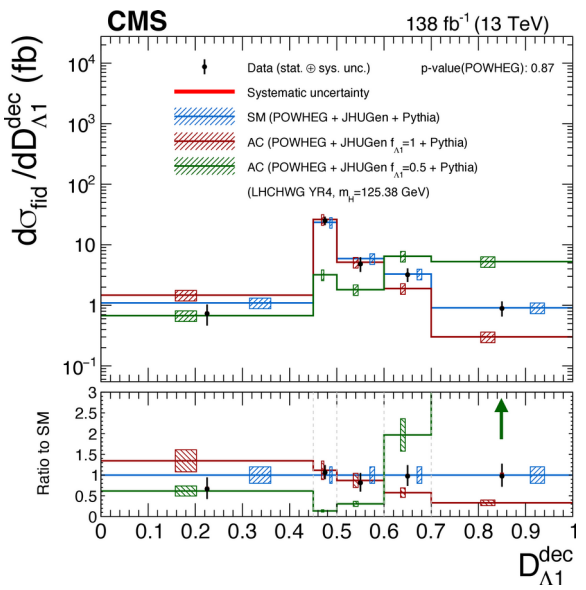
$H \to ZZ^* \to 4$ leptons differential cross-section

New!

- Differential measurement performed with respect to 4 lepton kinematics, Higgs boson momentum, and discriminators sensitive to HVV anomalous couplings







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- All differential distributions agree with the latest SM predictions

H → Zγ combination

New!

- Searches for Higgs decays to a Zγ pair have been performed separately by CMS and ATLAS
- Both analyses achieved a significance above 2 standard deviations:

Experiment	Observed sig.	Expected sig.
ATLAS	2.2σ	1.2σ
CMS	2.6σ	1.1σ

- Their combination with the LHC Run 2 data allowed to declare an **evidence** for H → Zγ decays!

- **First CMS+ATLAS combination to achieve evidence for a process!**

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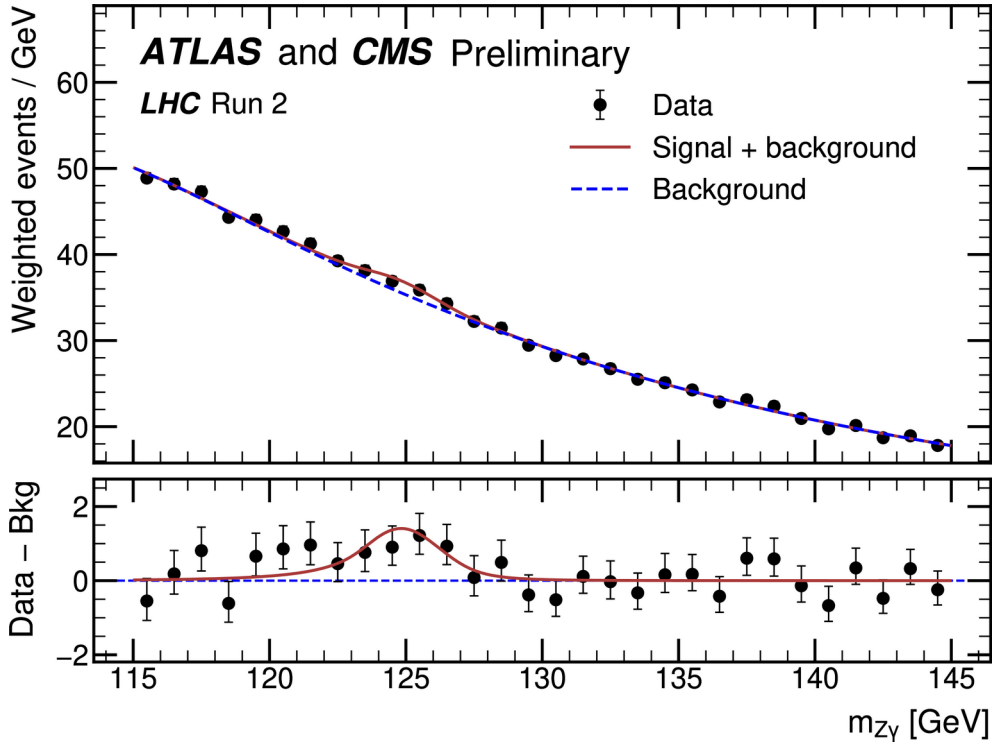

H → Zγ combination

New!

- Both experiments found a signal strength above 1 resulting in the higher observed significance

Experiment	Obs. sig. strength	Exp. sig. strength
ATLAS	$2.0^{+1.0}_{-0.9}$	$1.0^{+0.9}_{-0.9}$
CMS	$2.4^{+1.0}_{-0.9}$	$1.0^{+1.0}_{-0.9}$
Combination	$2.2^{+0.7}_{-0.7}$	$1.0^{+0.6}_{-0.6}$

- The combined result of 2.2±0.7 is compatible with the SM at 95% CL
- Further studies are needed during the LHC Run 3 in order to measure more precisely the effective H → Zγ coupling

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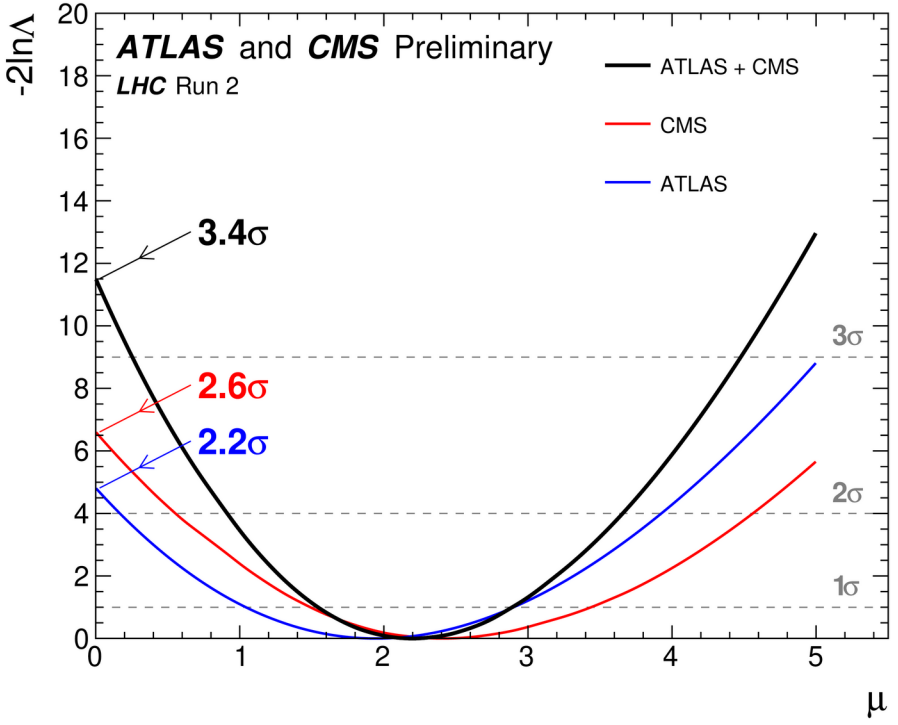
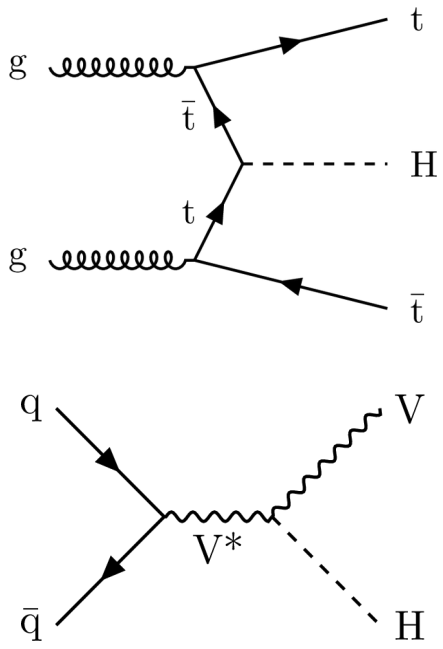
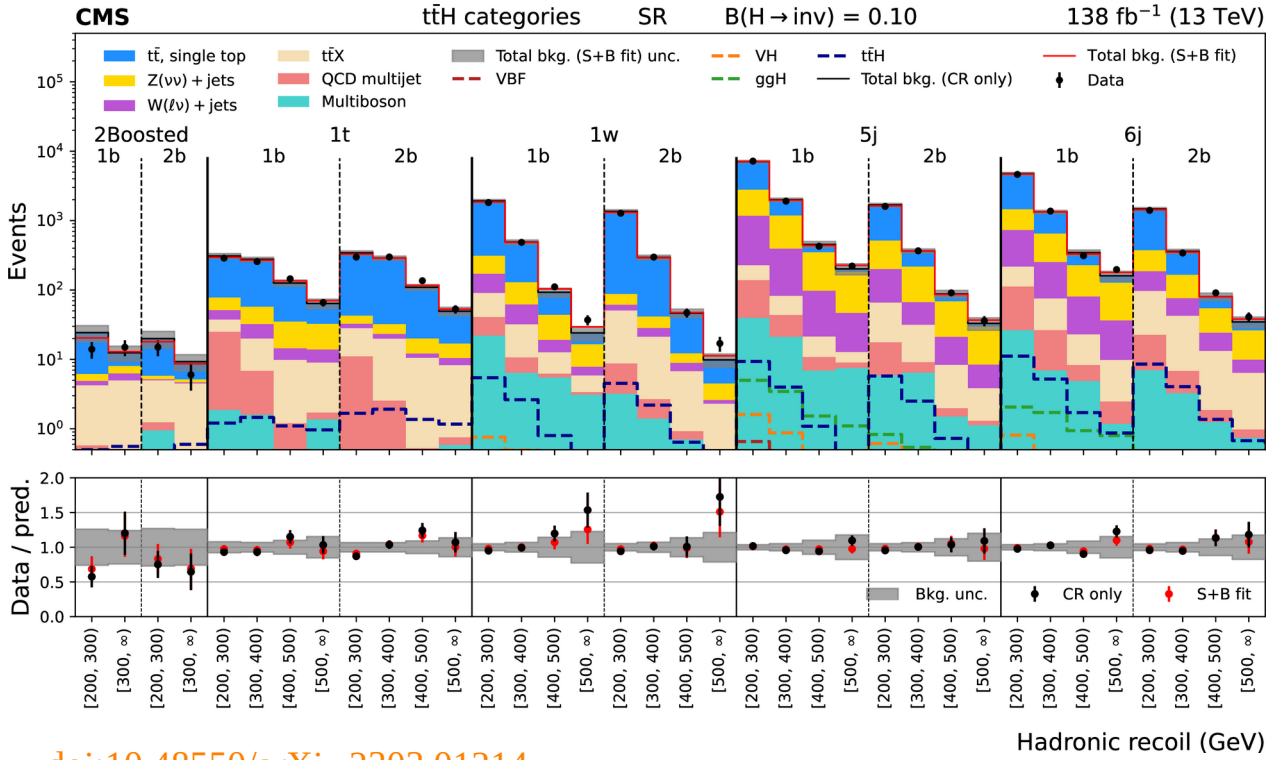


Search for H → invisible

- Search for Higgs decays to invisible particle performed by studying hadronic recoil in ttH and VH topologies

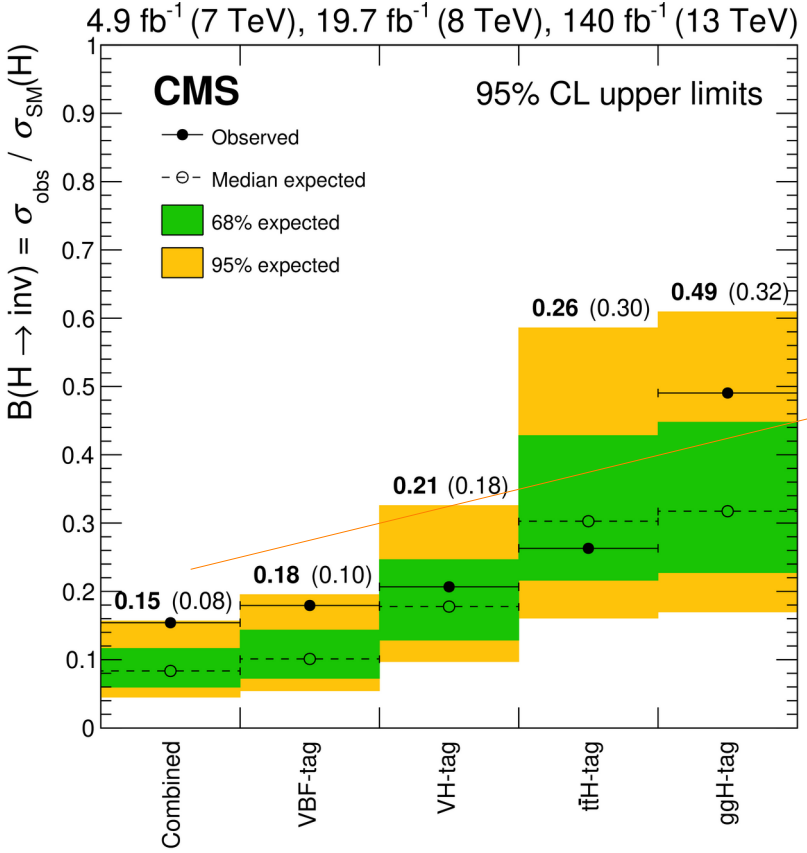


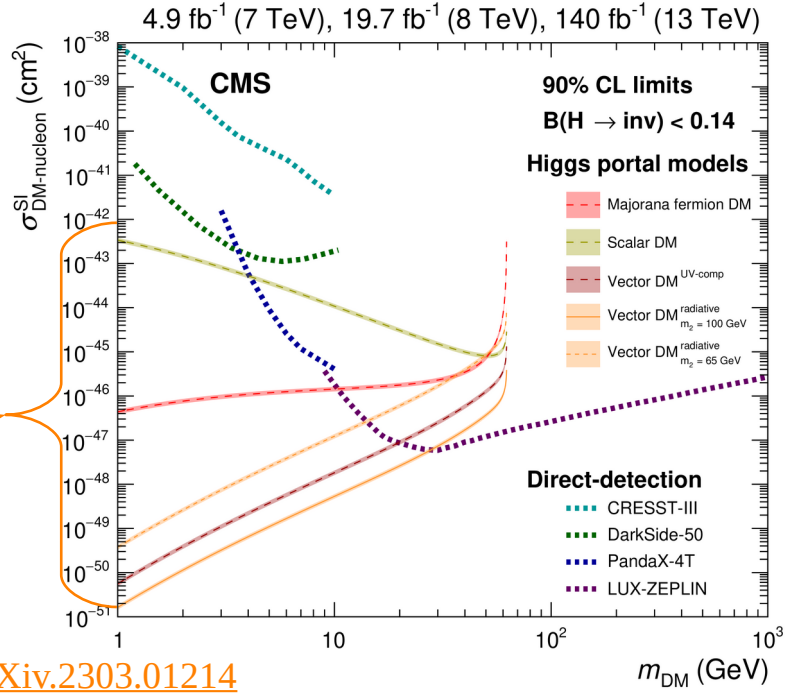


doi:10.48550/arXiv.2303.01214

Search for H → invisible

- Analysis combined with previous results for different production mechanisms to provide precise limits for H → invisible branching fraction





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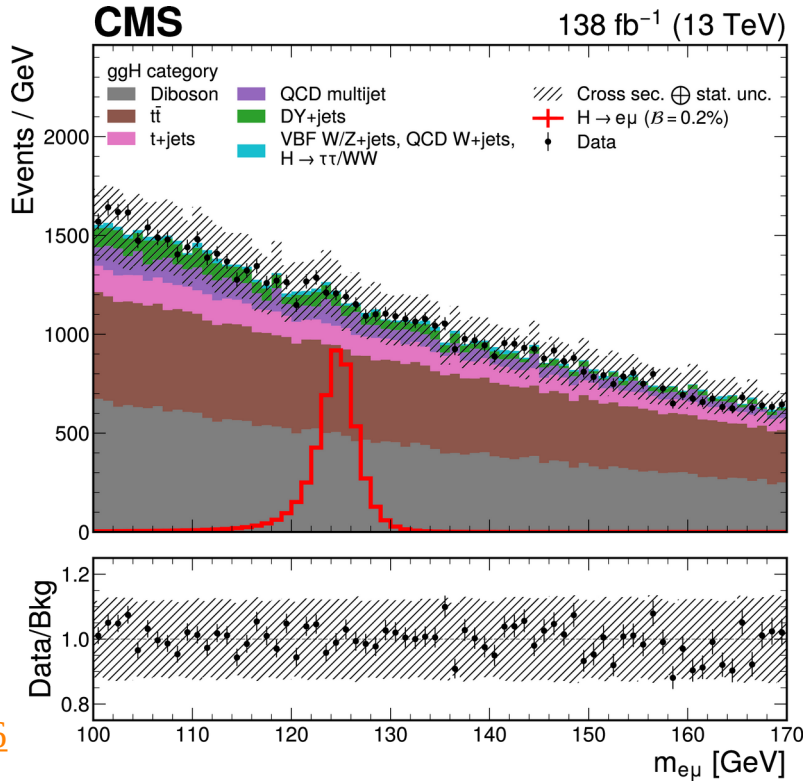
- Results interpreted as limits for the production of DM candidates having masses between 1 and 10 GeV and compared with other measurements

H → eμ LFV decays

New!

- Higgs fermionic decays are mediated by the Yukawa interaction
  - Lepton flavor is conserved → the Yukawa matrix is diagonal wrt lepton generations
- In BSM theories which include more Higgs doublets, or a composite Higgs state, the Yukawa matrix acquires off-diagonal elements
  - A search for H → eμ decays can hint towards sources of new physics
  - Search performed in mass window 110< $m_{e\mu}$ <160 GeV
  - Analysis exploits BDT to improve S/B ratio in two signal categories: ggH and VBF



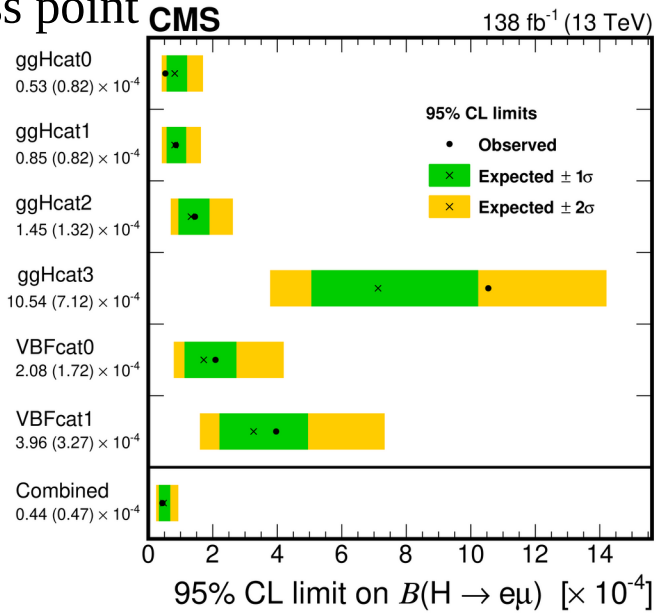
doi:10.48550/arXiv.2305.18106

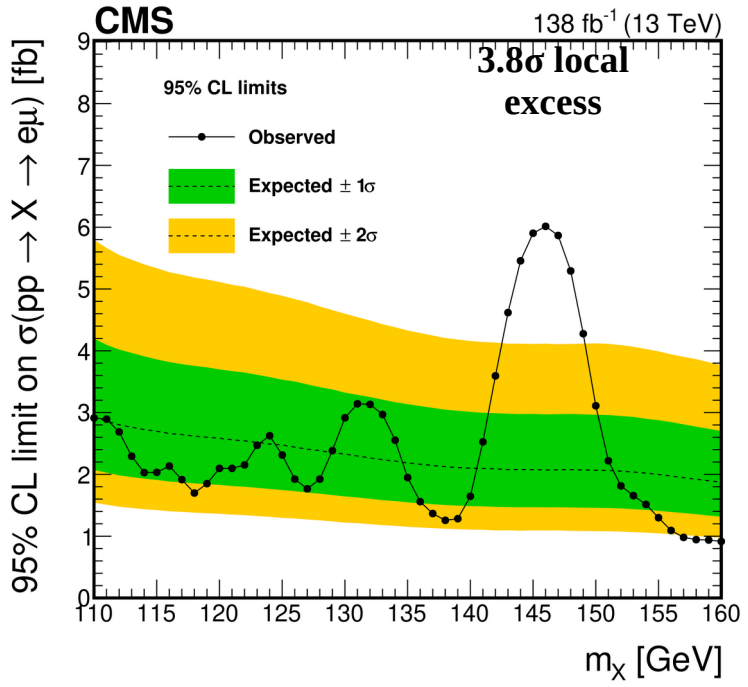
H → eμ LFV decays

New!

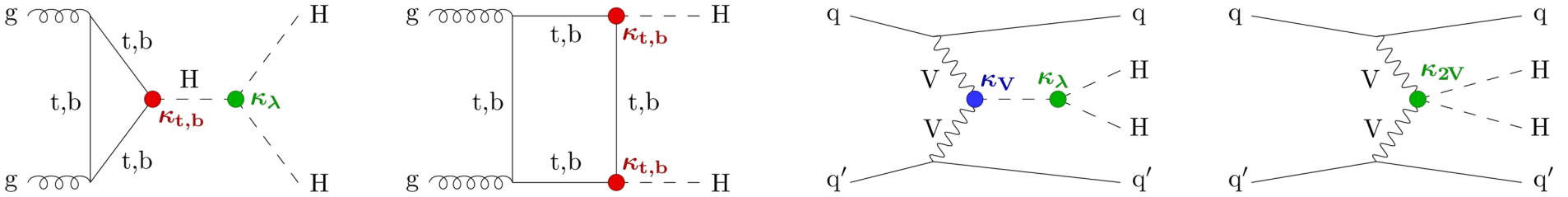
- Constraints on the H → eμ branching fraction determined for SM-like H(125) and more generally for generic scalar particle X of mass between 110 and 160 GeV
  - **First direct search for eμ resonance in chosen mass range**
- Observed (expected) limit on $\mathcal{B}(H \to e\mu) < 4.4\ (4.7) \times 10^{-5}$ at 95% for a SM-like Higgs
- The X → eμ search presents a local (global) excess of 3.8σ (2.8σ) for the 146 GeV mass point
- The best fit signal for this mass point has a cross-section of 3.89±1.25 fb
- More data is needed to investigate this excess

doi:10.48550/arXiv.2305.18106

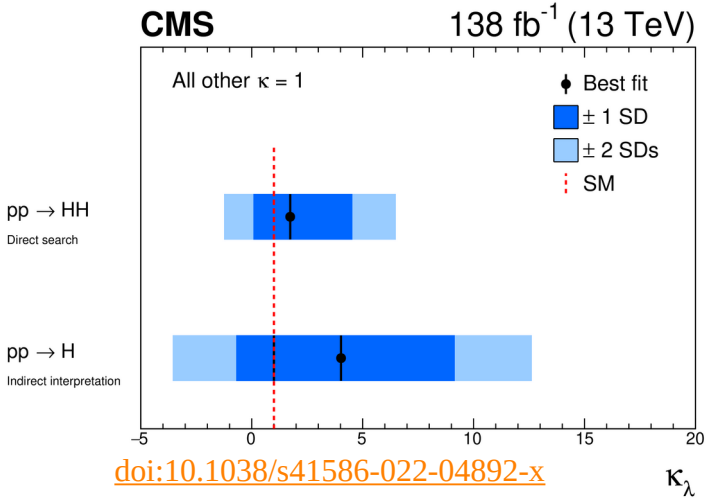




Higgs pair production



- Precise single Higgs production can help constraining the Higgs self-coupling
- However the Higgs pair production offers the highest sensitivity to **Higgs self coupling + quartic coupling to vector bosons**



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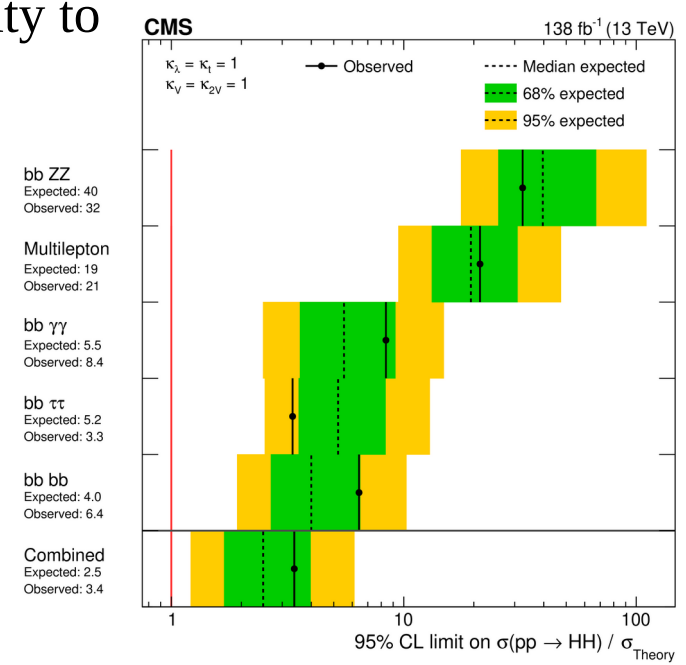
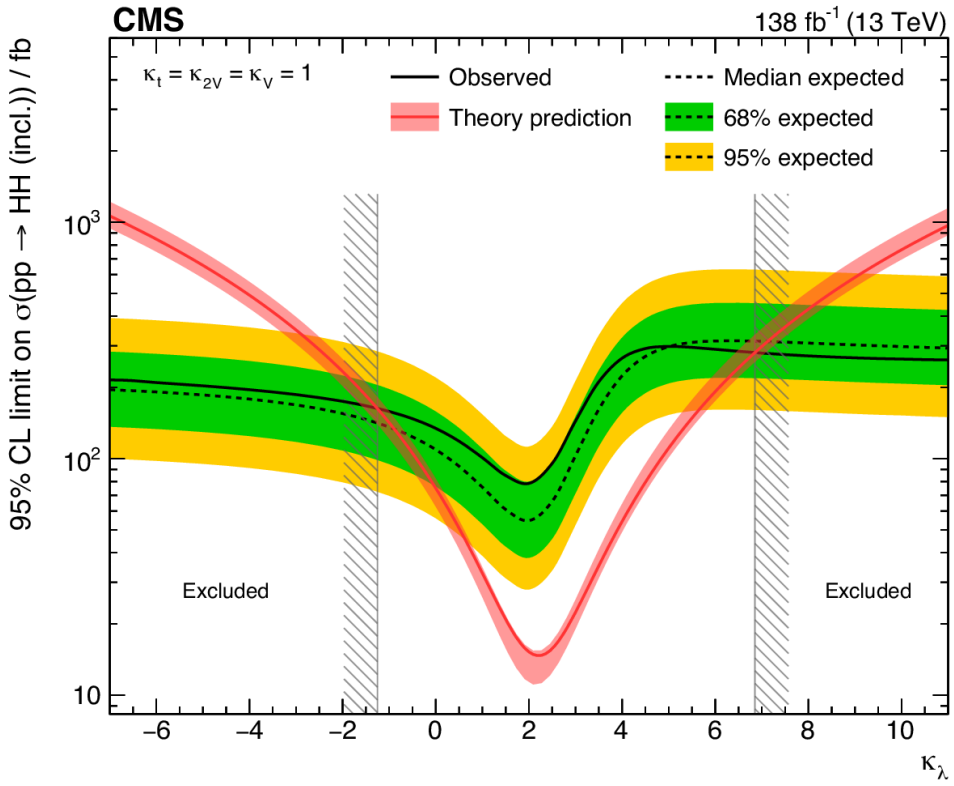
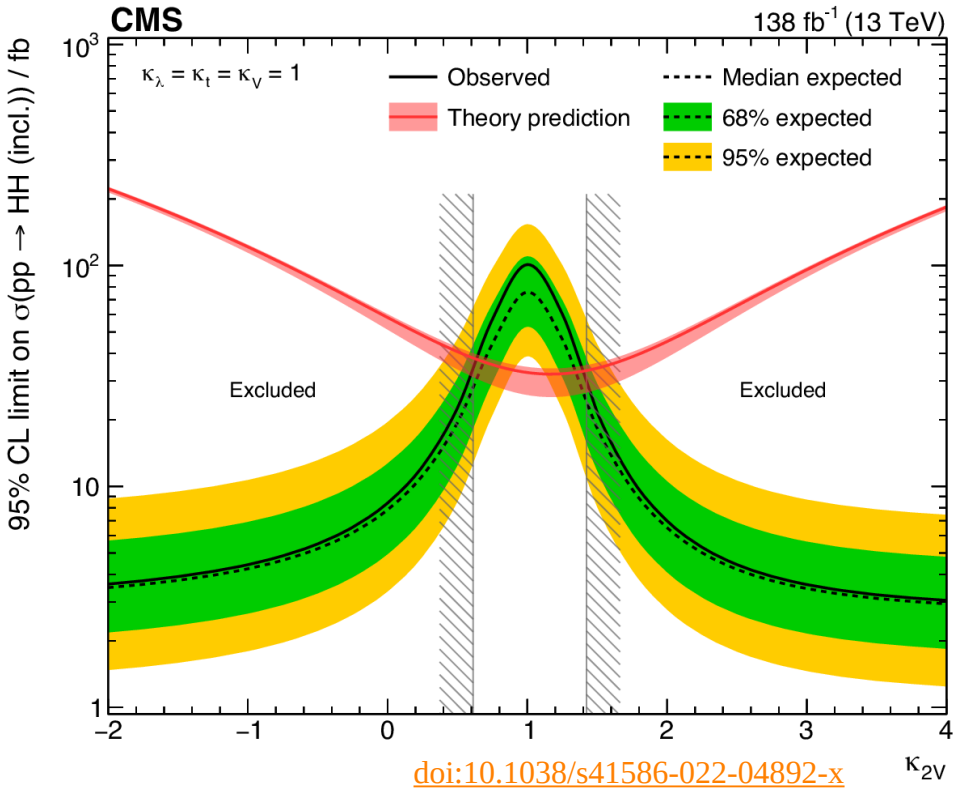
- Upper limits on the Higgs production cross-section have remarkably improved with the LHC Run 2 but require more statistic



Higgs pair production

- The Higgs pair production is one of the main goals for the HL-LHC operation
- Measuring the Higgs self-coupling will improve our understanding of the Higgs potential





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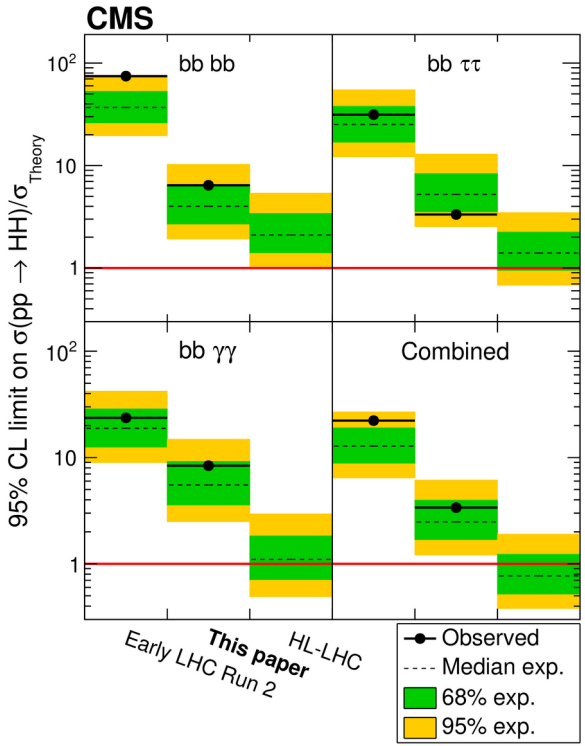
The future for Higgs physics

- The LHC Run 2 was marked by a leap in analysis techniques and furthered our understanding of the Higgs boson
- The progress will continue with the LHC Run3 and HL-LHC
- The HL-LHC will provide enough statistics to constrain most Higgs couplings at percent level



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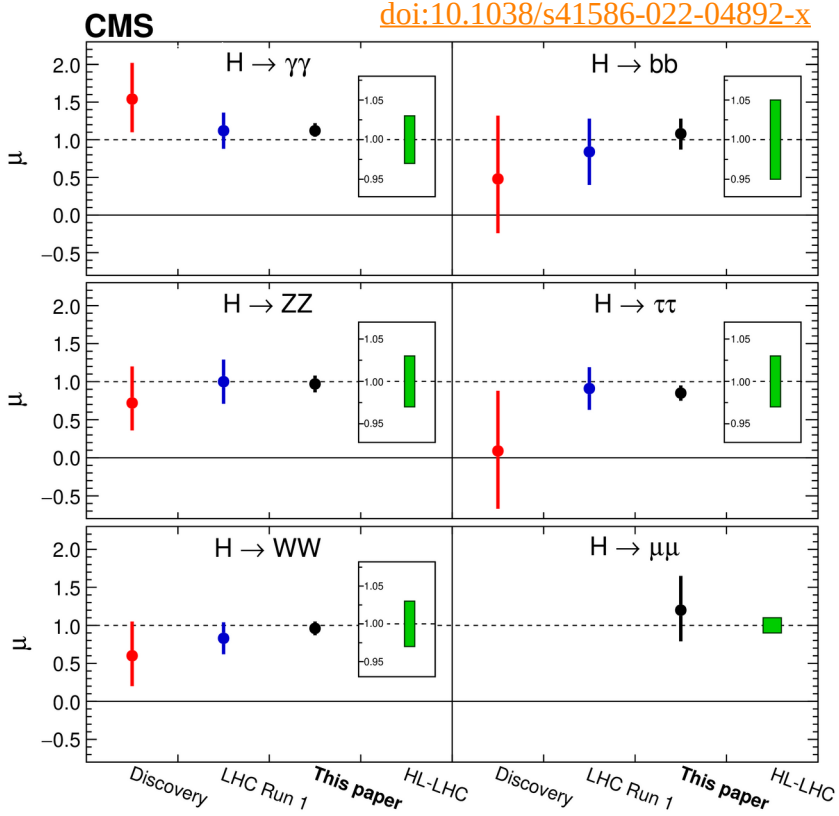

To be continued in **Run 3**

Thanks for the attention.

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CP violation in HVV (and ggH)

- Investigating CP violation in HVV with an EFT approach
  - Amplitude for Higgs coupling to two spin 1 particles (VV= WW, ZZ, Zγ, γγ, gg etc.) with operators up to dimension 6

Tree level CP-even coupling (=0 if absent in SM)

CP-even anomalous higher order couplings

$$\mathscr{A}(HVV) \simeq \left[a_1^{VV} + \frac{k_1^{VV} q_1^2 + k_2^{VV} q_2^2}{(\Lambda_1^{VV})^2} + \frac{k_3^{VV} (q_1+q_2)^2}{(\Lambda_Q^{VV})^2}\right] m_V^2 \varepsilon_{V1}^* \varepsilon_{V2}^*$$

$$+ a_2^{VV} f_{\mu\nu}^{*(1)} f^{*(2)\mu\nu} + a_3^{VV} f_{\mu\nu}^{*(1)} \tilde{f}^{*(2)\mu\nu} \ ,$$

CP-even anomalous coupling

CP-odd anomalous coupling

$$f_{a3} = \frac{\sigma(a_3 = 1, a_{i!=3} = 0)}{\sum_i \sigma_i}$$

  - Effect on cross-section parametrized as the fractional contribution of the anomalous coupling to the total cross-section

- Theoretical approach includes also Hγγ and Hgg with tree level coupling being set to 0