Institute of High Energy Physics
Chinese Academy of Sciences

CMS
Compact Muon Solenoid

Higgs boson couplings at CMS

LHCP 2023

24th May 2023

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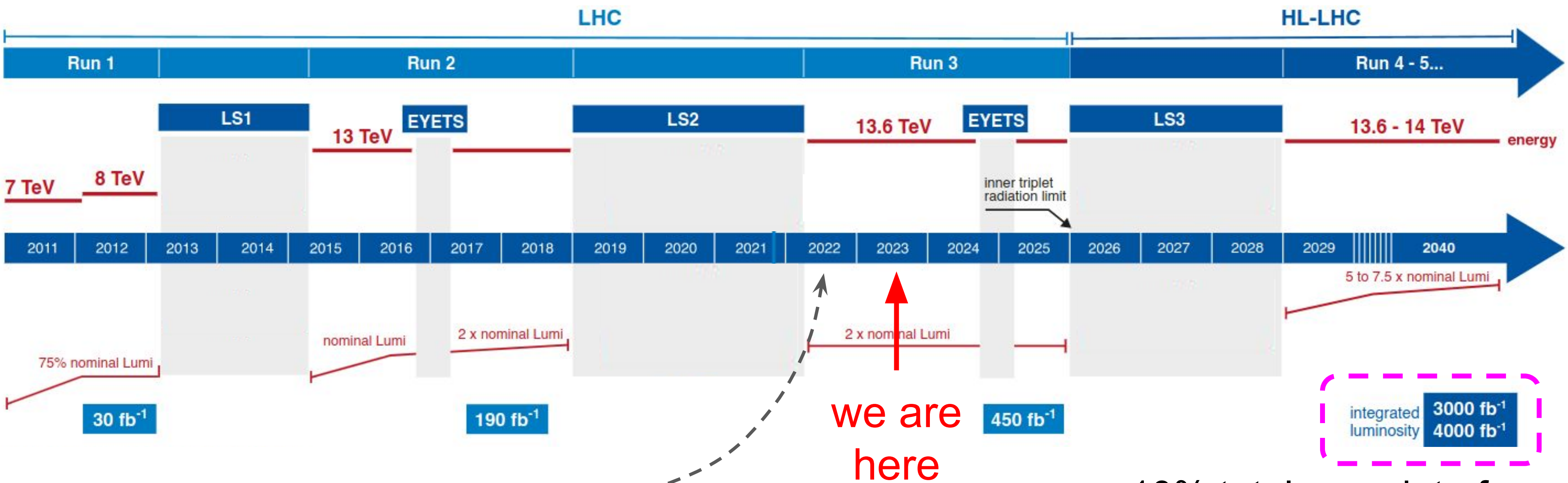
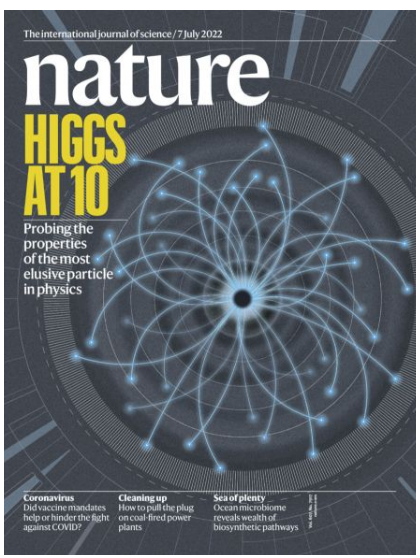
on behalf of the CMS Collaboration

Context



< 10% total exp. data from LHC collected so far

Nature 607, 60-68 (2022)



- In this presentation H coupling measurements with CMS Run 2 data and perspectives for HL-LHC
- Run 3 ongoing → stay tuned for new exciting results!

Nature 607, 41–47 (2022)

Goal of Higgs boson measurements

Several open questions in particle physics call for a deeper understanding of the Higgs boson

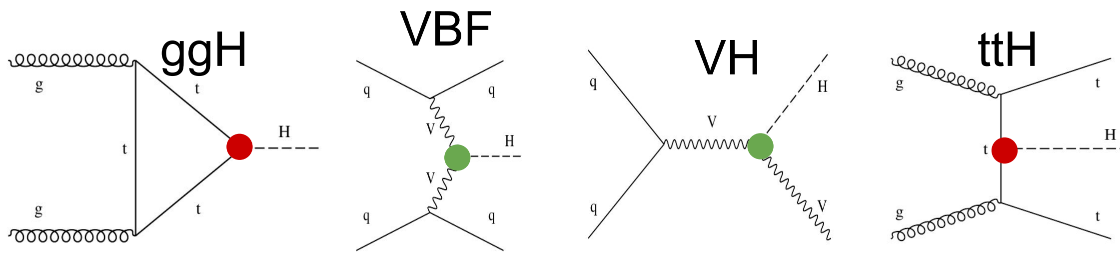
Dark matter	Asymmetry of matter vs antimatter in the universe	Hierarchy of fermion masses	….

- ➢ Test compatibility with SM
  - Precise measurements of the main H production XS and decay BR
  - Search for rare H (and HH) processes
- ➢ Measurement of H coupling to fermions and vector bosons
  - Probe possible BSM effects inducing deviations from SM
- ➢ Probe properties of the H potential from H self-coupling

H couplings to fermions & vector bosons

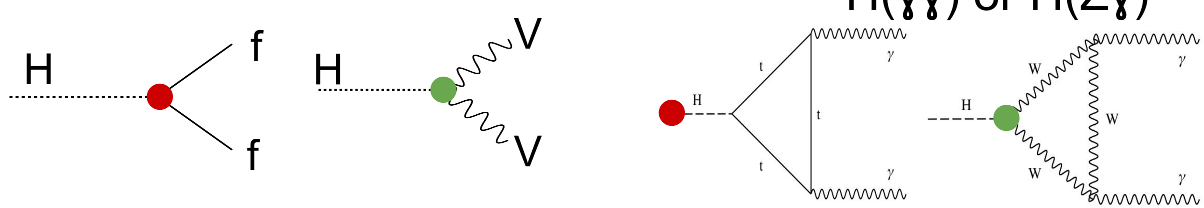
● fermionic coupling
● bosonic coupling

Main H production mechanisms at LHC



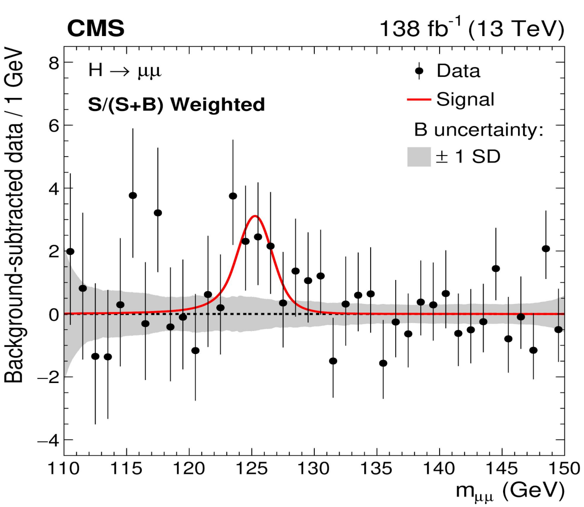
+ tH and bbH

Main H decay channels at LHC

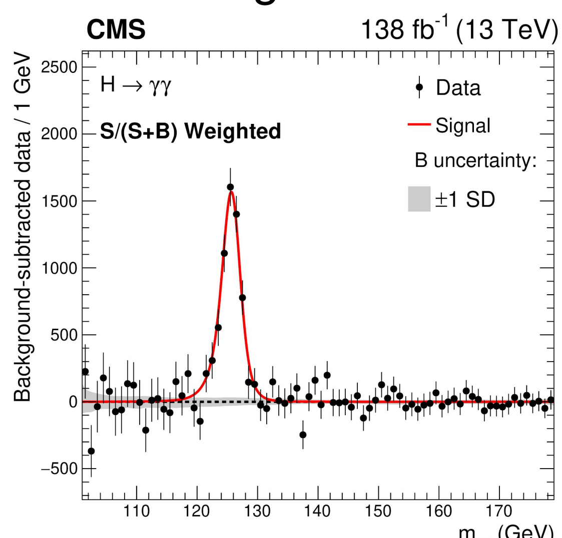


+ H(gg)

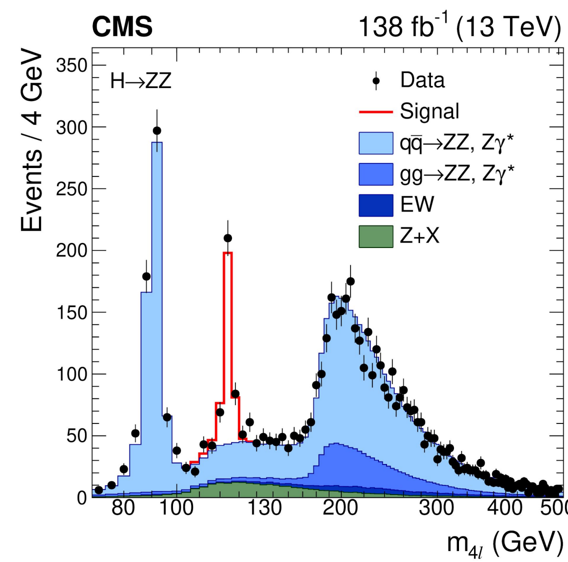
Mass of H(μμ) candidates after bkg subtraction



Mass of H(γγ) candidates after bkg subtraction



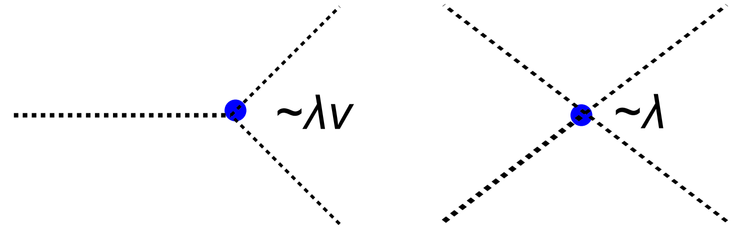
Mass of H(4ℓ) candidates



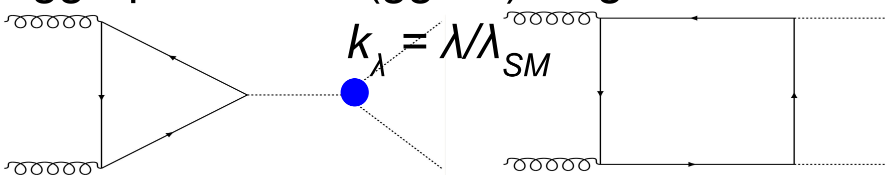
H self-couplings

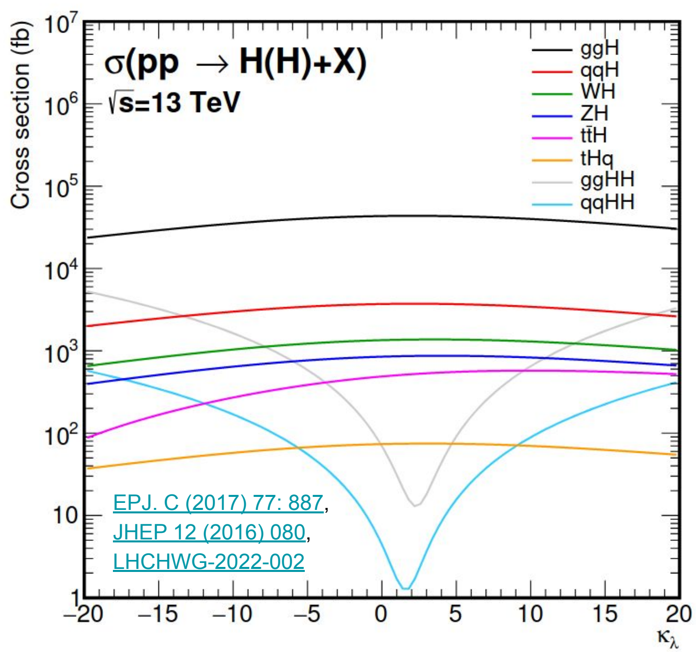
- HH production XS's sensitive at LO to the Higgs trilinear coupling λ

In SM $\lambda = m_H^2 / 2v^2$ with v H vacuum exp. value



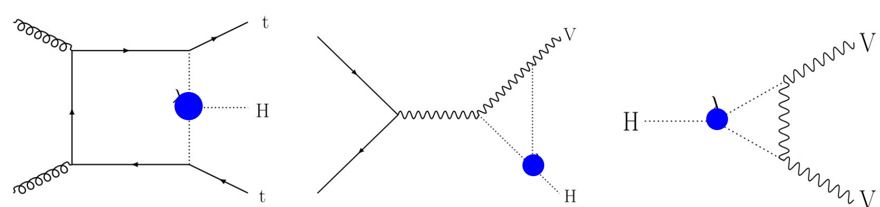
ggF production (ggHH) diagrams at LO





- k_λ-dependent NLO electroweak corrections to H XS and BR
  - Modification of total and differential H XS's and H BR's

Examples of k_λ-dependent diagrams for single-H prod. mechanisms and H→VV decay

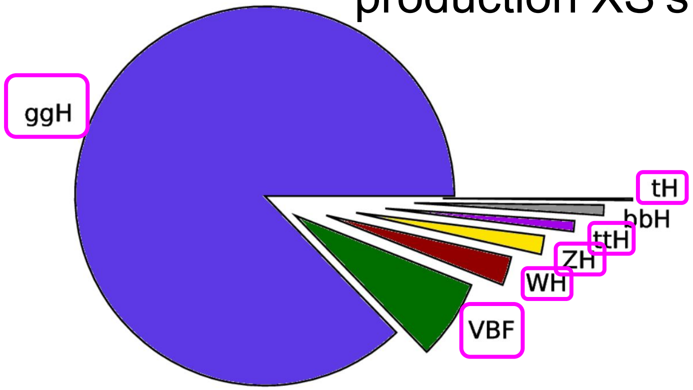


Combination of Higgs boson measurements

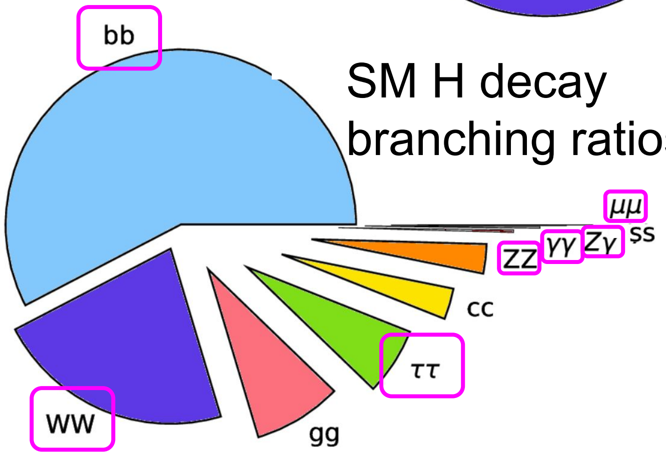
- Combination of H production & decays ch's to reduce uncertainties & exploit ch's complementarity

Analyses	Integrated lumi (fb^{-1})
H(γγ)	138
H(ZZ→4l)	138
H(WW)	138
H(Zγ)	138
H(bb)	36(ttH) 77(VH) 138(ggH)
H(ττ)	138
ttH multilepton (ττ, WW, and ZZ)	138
H(μμ)	138
H(invisible)	138

Relative SM H production XS's

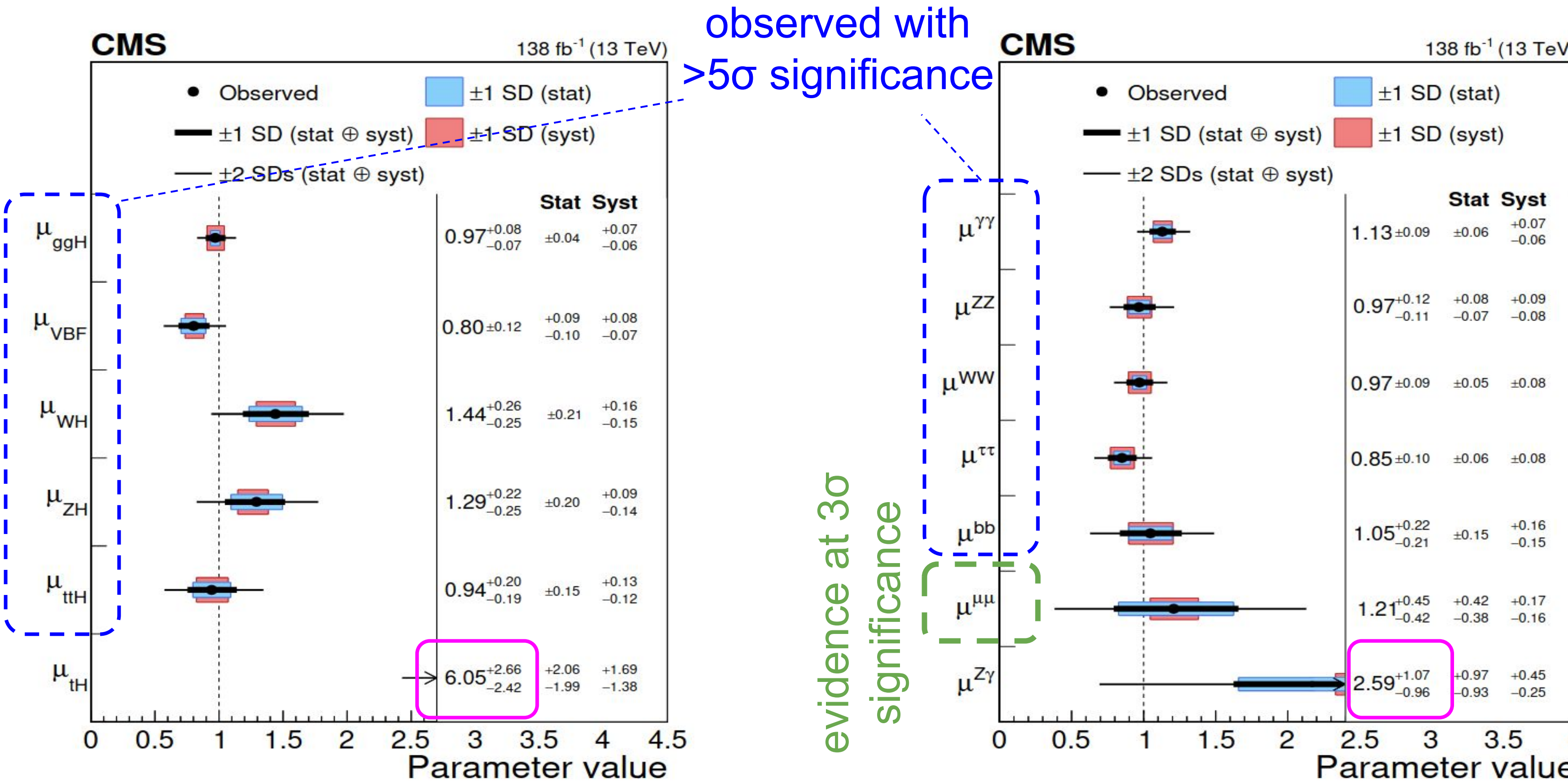


SM H decay branching ratios



- Main H production and decay channels covered with up to full Run 2 dataset (2016-2018)

Test XS and BR compatibility with the SM



- ➢ Good compatibility with SM for main H production & decay
- ➢ Small excesses in μ_{tH} and in $\mu_{Z\gamma}$→interesting to see with Run 3 data
- ➢ Evidence of H→Zɣ from the CMS+ATLAS Run2 comb.!

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Test XS and BR compatibility with the SM

- Compatibility with SM of inclusive H cross section

$\mu = 1.002 \pm 0.057$ [$\pm$ 0.036 (theory) $\pm$ 0.033 (exp.) $\pm$ 0.029 (stat.)]

➢ Systematics uncertainties crucial for H measurements today and even more in future
  - Reduce exp. uncertainties with new or improved approaches
  - Need of more precise theory predictions

➢ Good compatibility with SM for main H production & decay

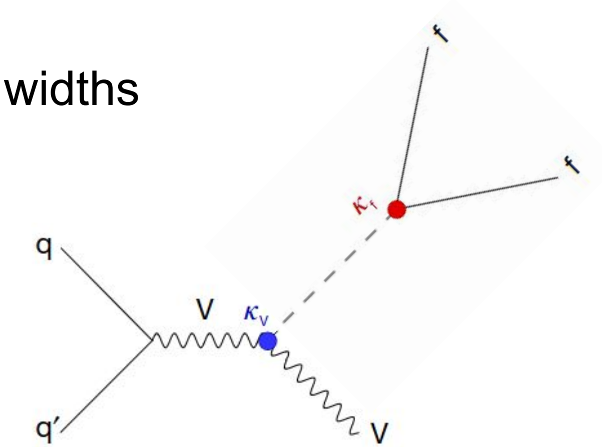
➢ Small excesses in μ_{tH} and in $\mu_{Z\gamma}$ → interesting to see with Run 3 data

kappa-framework

- Coupling modifiers k to quantify couplings deviations from SM predictions

Factorize deviations of H production XS's & decay widths

$$\sigma(i \to \mathrm{H} \to f) = \sigma_i(\vec{\kappa}) \frac{\Gamma_f(\vec{\kappa})}{\Gamma_H(\vec{\kappa})}$$



Scalings inclusive XS's & partial decay widths

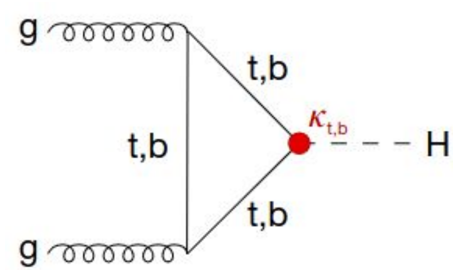
$$\sigma_i(\vec{\kappa}) = k_i^2 \cdot \sigma_i^{SM} \qquad \Gamma_j(\vec{\kappa}) = k_j^2 \cdot \Gamma_j^{SM}$$

Can account for invisible decays and undetected BSM decays

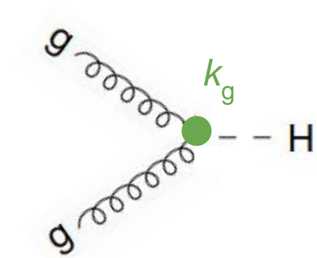
$$\Gamma_H(\vec{\kappa}) = \frac{\sum_j \Gamma_j(\vec{\kappa})}{1 - BR_{BSM}}$$

In future possibility of constrain Γ_H from off-shell H production Nat. Phys. 18 (2022) 1329

Alternative treatments of loop-induced production and decays



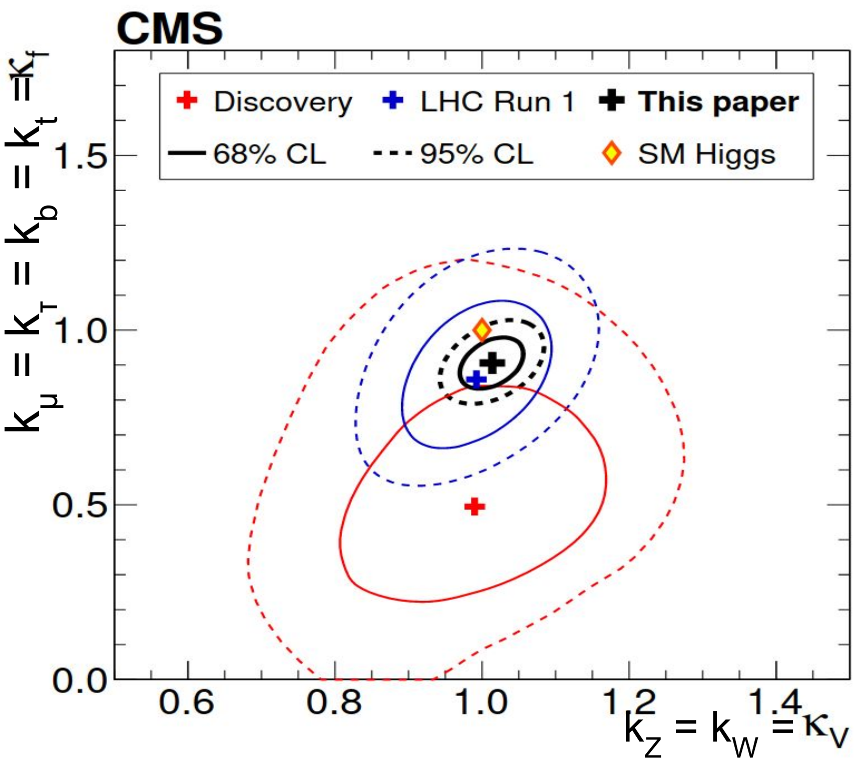
resolved loops



effective couplings

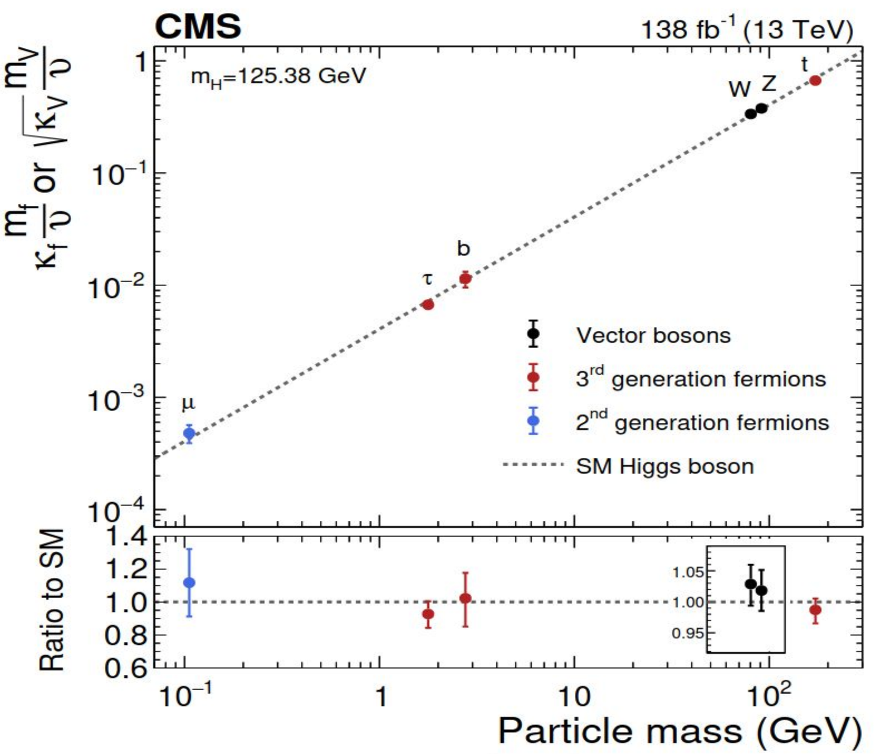
H couplings to fermions and vector bosons

Likelihood scan of (k_f, k_V)



- Compatibility with SM within 10%

H couplings vs particle mass



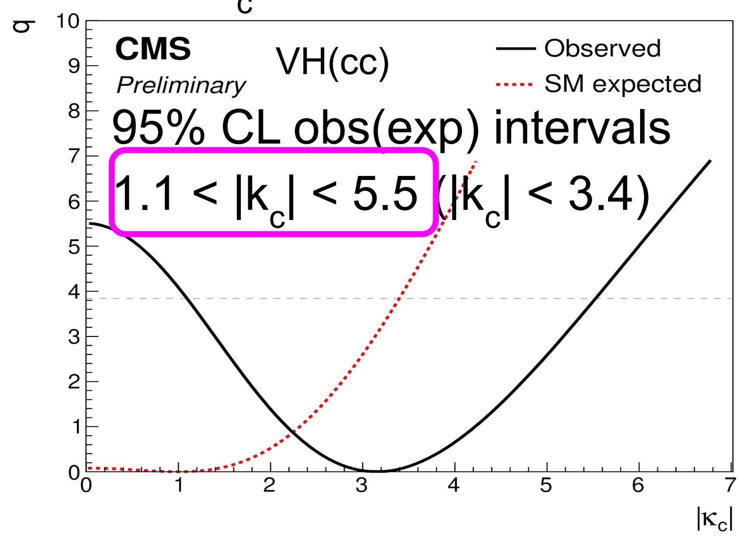
- Agreement with SM for masses within 0.1 - 200 GeV arXiv:2205.05550(VH) & arXiv:2211.14181(ggH)

H coupling to electrons and charm quark

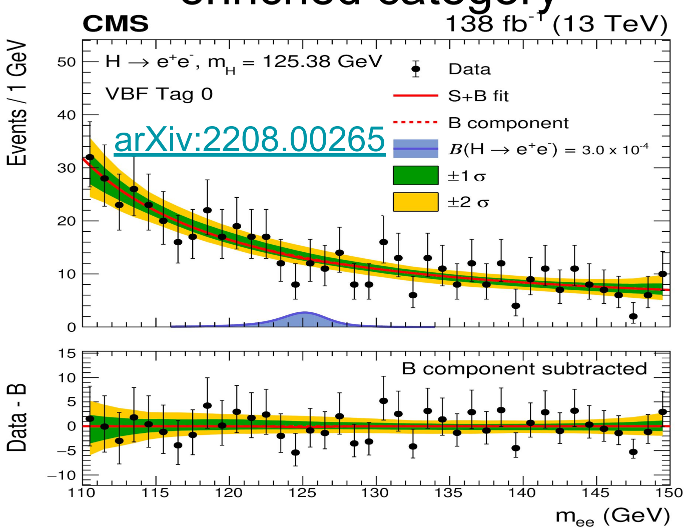
- SM BR(H→cc) ≈ 2.9%
- Search for H→cc via ggH and VH mechanisms

+ Constraints on k_c from p_T(H) ggH spectrum & H→J/ψ+γ search

k_c likelihood scan



m_{ee} distribution in a VBF enriched category



- Search for H→e^+e^- via ggH and VBF
  - Peak search in the m_{ee} distribution
- Obs. upper limit on BR(H→ee) at 95% CL of $3.0 \cdot 10^{-4} \rightarrow 6 \cdot 10^{4} \times$ SM

More details in T. Orimoto talk

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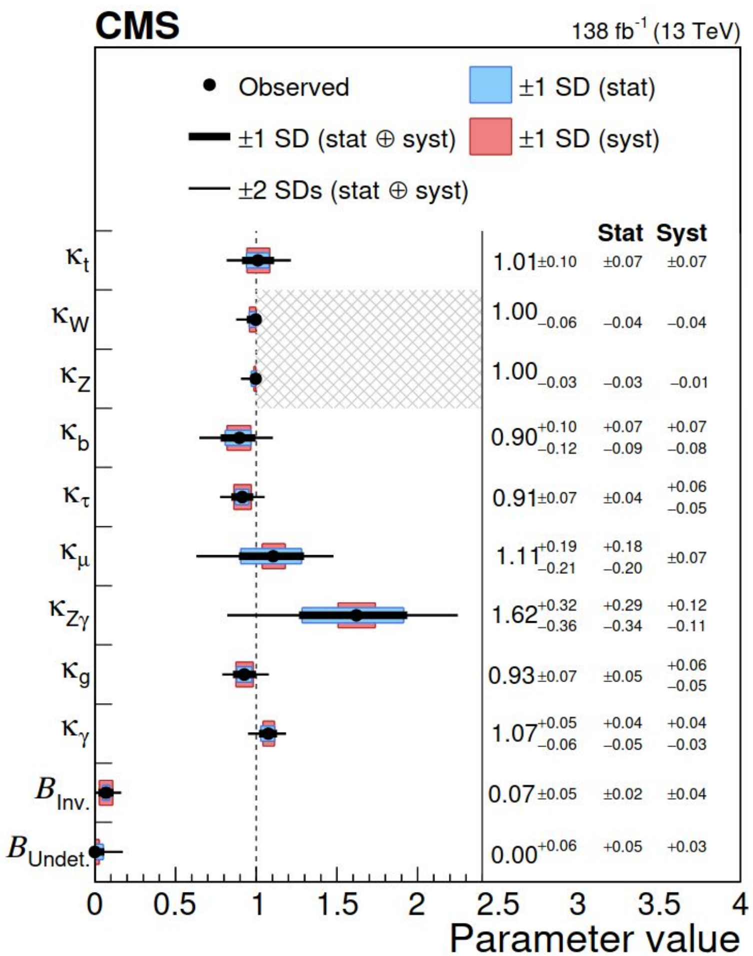
H couplings under more general assumptions

- Assuming ggH, Hγγ, and HZγ effective couplings and accounting for invisible and undetected H decays



- ➢ p-value SM = 33%
- ➢ Stat. unc ≈ syst unc except for k_μ and $k_{Z\gamma}$
- ➢ Invisible and undetectable BR's compatible with SM
  - ○ SM invisible: BR(H→ZZ→4ν) ≈ 0.1

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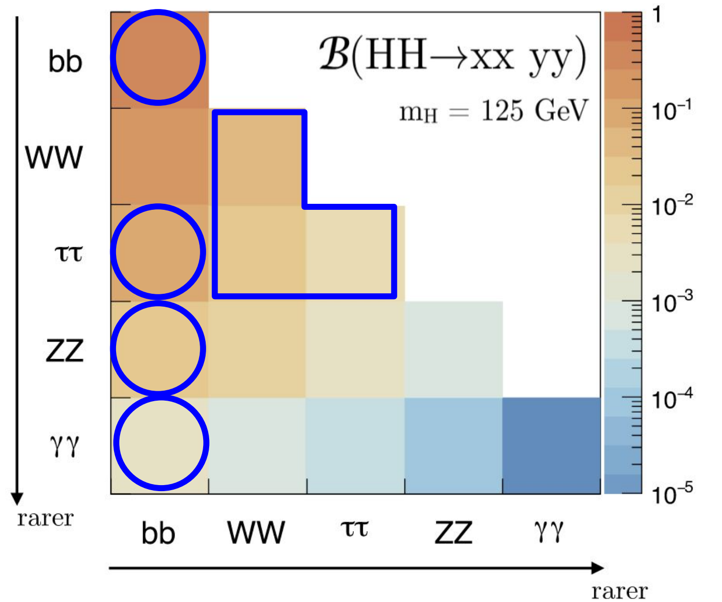
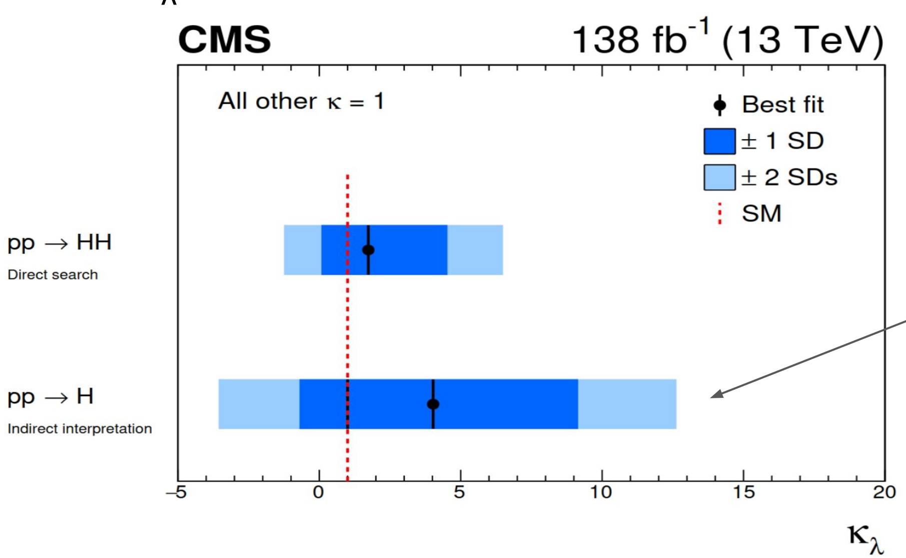
Constraints on the H trilinear self-coupling λ

- Constrain k_λ from combination of searches for HH in the most sensitive decay channels
  - More details in S. Nandan talk
- Constrain k_λ from combination of H measurements

HH BR map with channels included in the combination

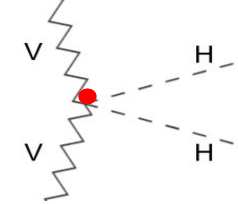


k_λ measurement from HH or single-H



First CMS measurement of k_λ from single-H exploiting differential effects on XS

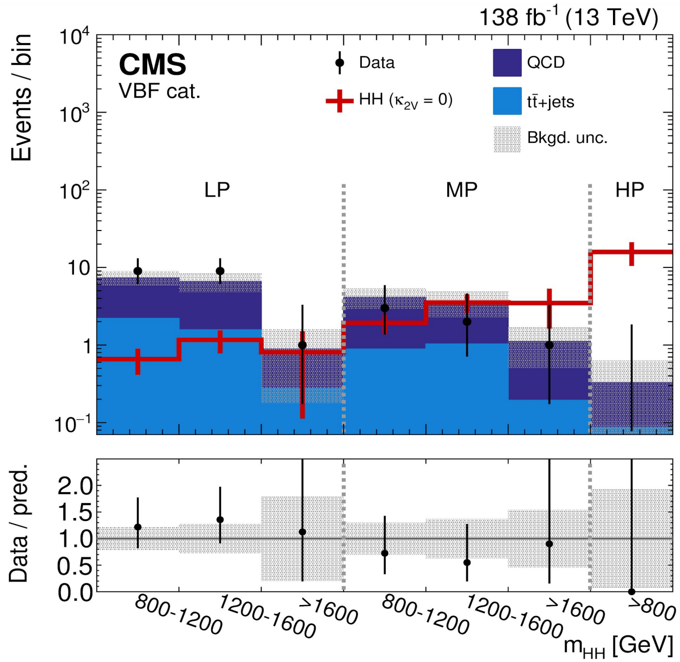
Constraints on HHVV coupling



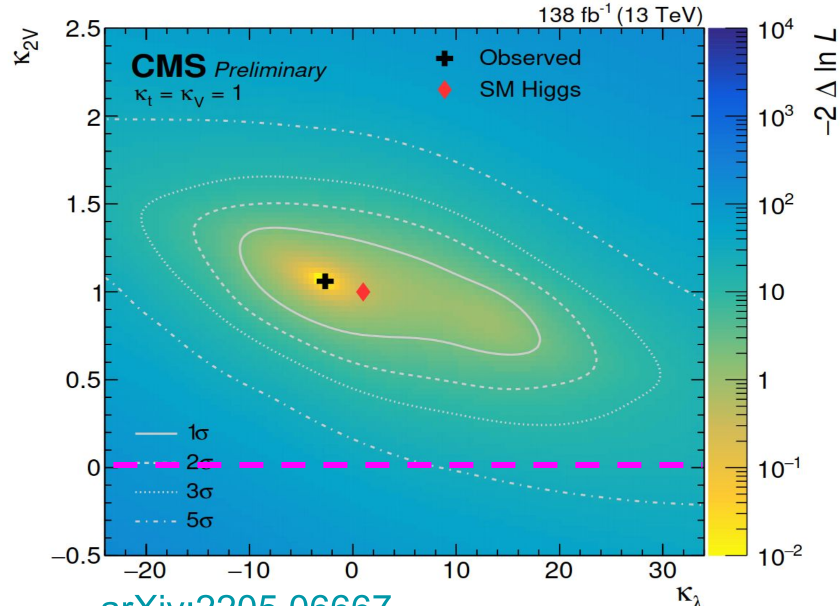
$\sim k_{2V} = c_{2V} / c_{2V}^{SM}$

- HH production via VBF sensitive to HHVV coupling c_{2V}
  - Tiny SM cross section (1.7 fb) but for k_{2V} = 0 large XS & large p_T(H)

m(HH) distribution of signal candidates in VBF HH(4b) cat's



(k_λ, k_{2V}) likelihood scan from search for HH→4b in merged-jets final state



arXiv:2205.06667

More details in S. Nandan talk

➢ k_{2V} = 0 excluded at >5σ assuming $k_\lambda = k_t = k_V = 1$

➢ k_{2V} = 0 excluded at >3σ for any value of k_λ

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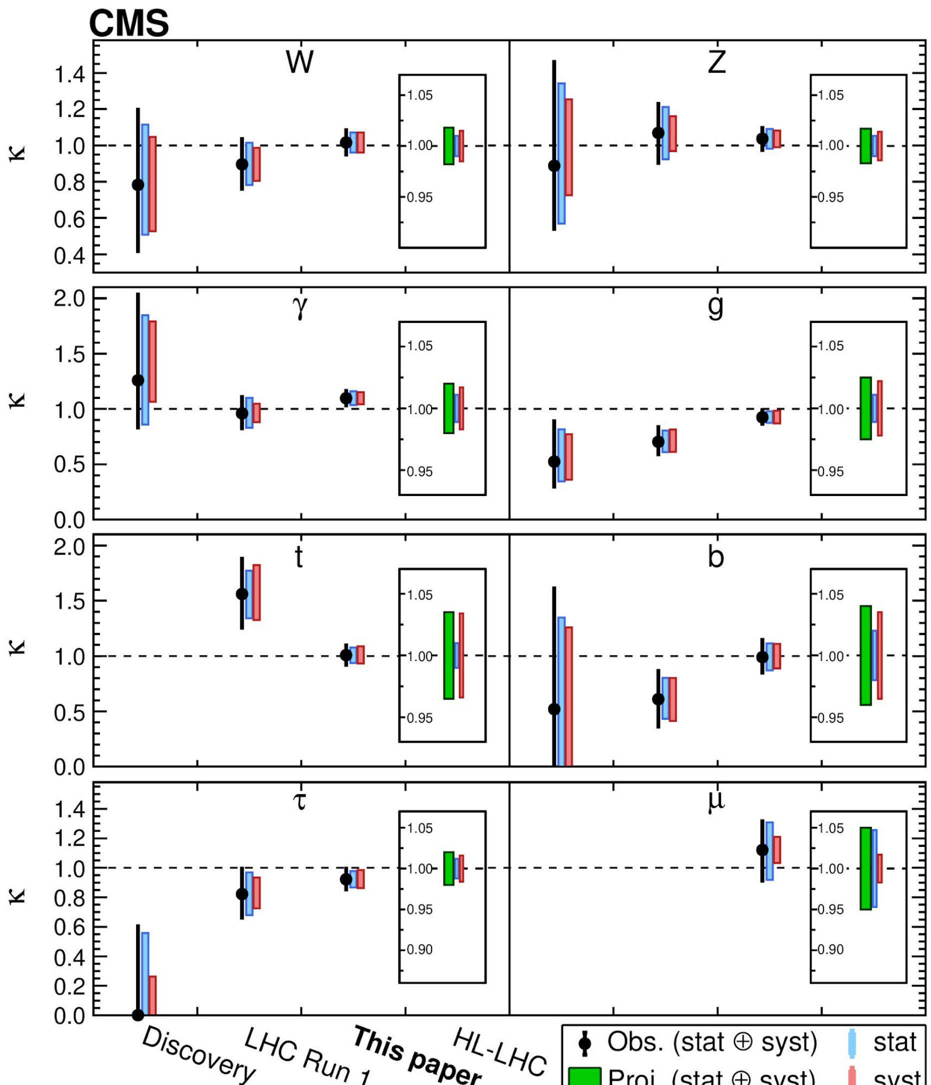
Evolution from the H discovery towards HL-LHC



- At HL-LHC high precision tests of the SM
  - Precision below 5% for all the considered couplings
- Potential for more extensive tests of SM, e.g. EFT
- Differential XS measurements with fine granularity to probe subtle BSM effects

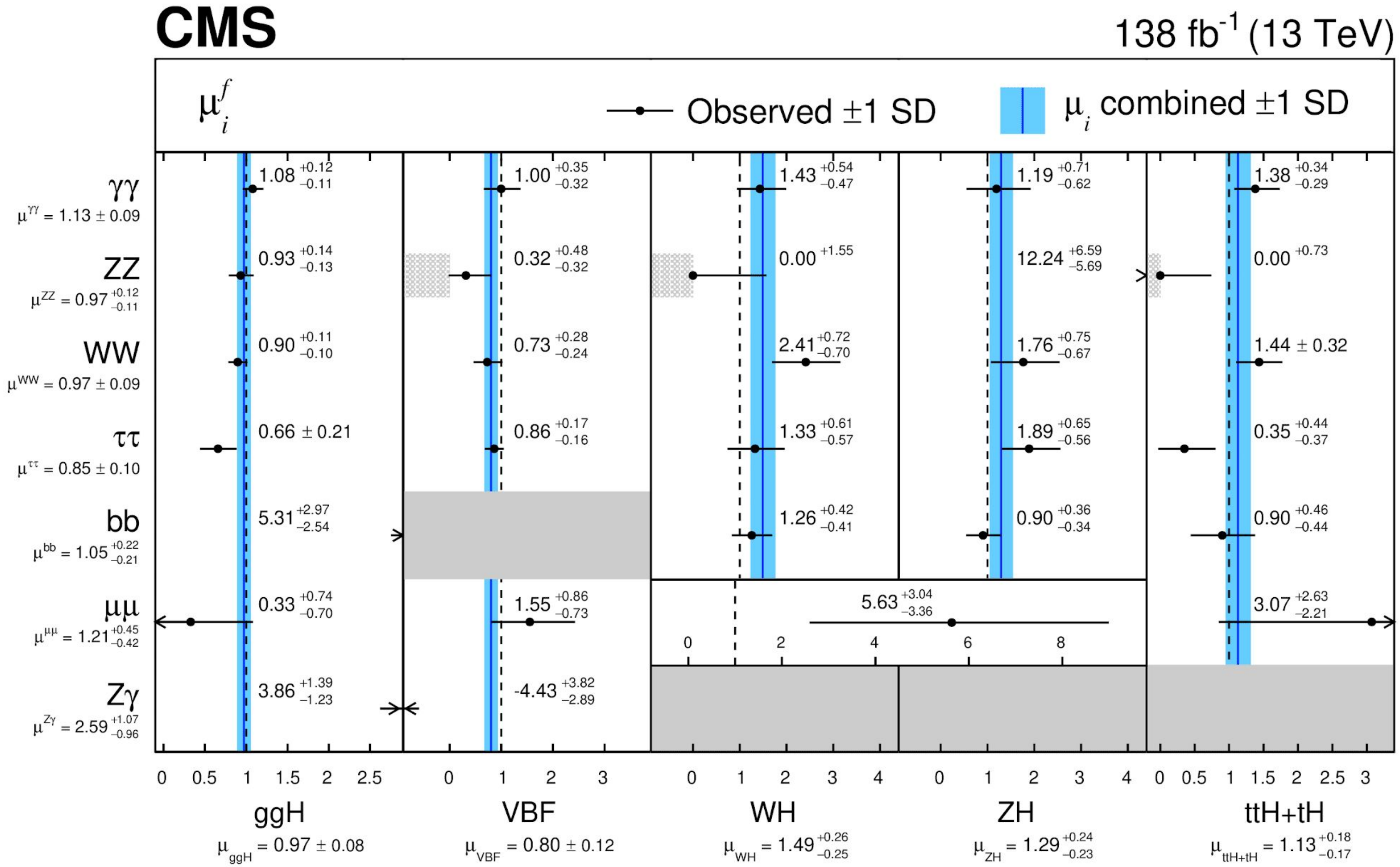
Summary

- H measurements are fundamental extensive tests of SM
- Presented H coupling measurements with CMS Run 2 data
  - Good compatibility with SM predictions
  - Precision better than 10% for most of the considered coupling modifiers
- Statistical uncertainties comparable to systematics ones for main H production and decay channels
- At HL-LHC high-precision tests of the SM

Rich and extensive Higgs physics program with exciting future perspectives

BACKUP

Test XS and BR compatibility with the SM

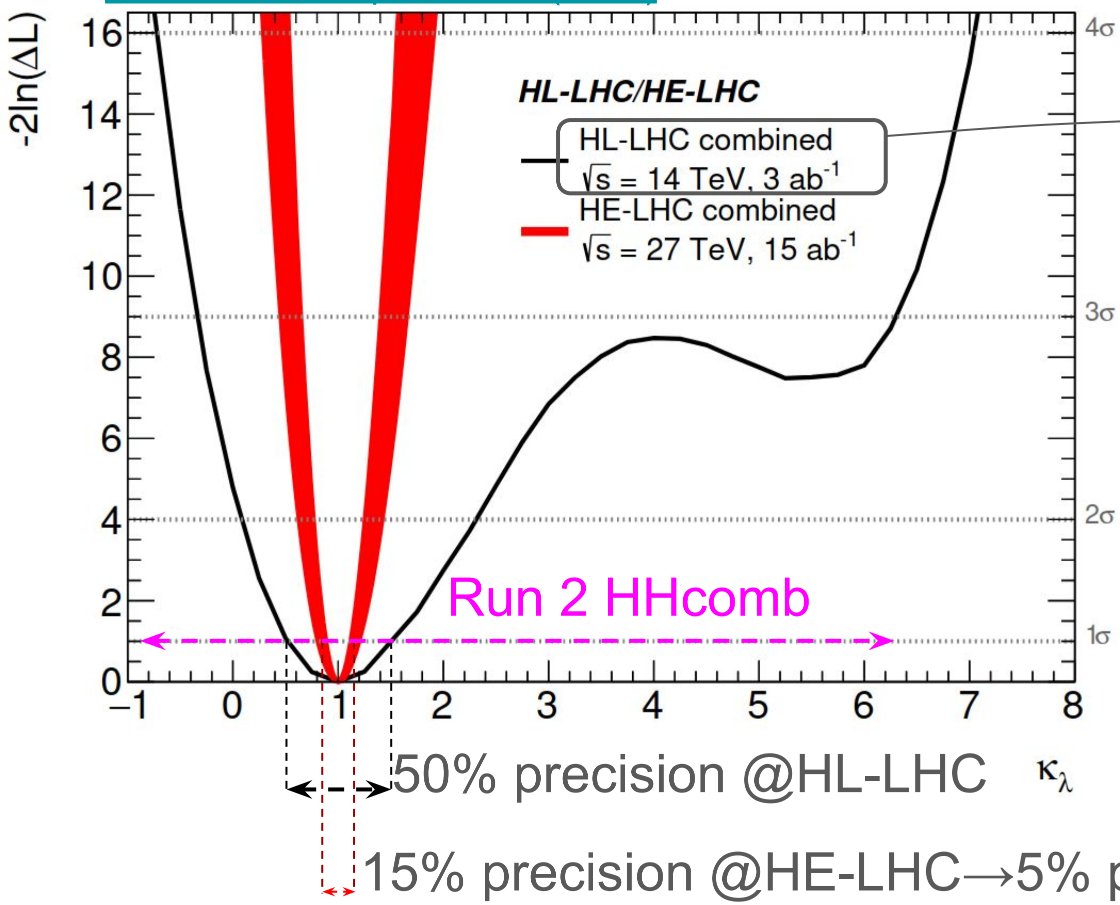


➢ Good compatibility with SM for main H production & decay

Outlook for the future

Projection of ATLAS+CMS combination of HH searches @HL-LHC and HE LHC

CERN Yellow report Vol. 7 (2019)



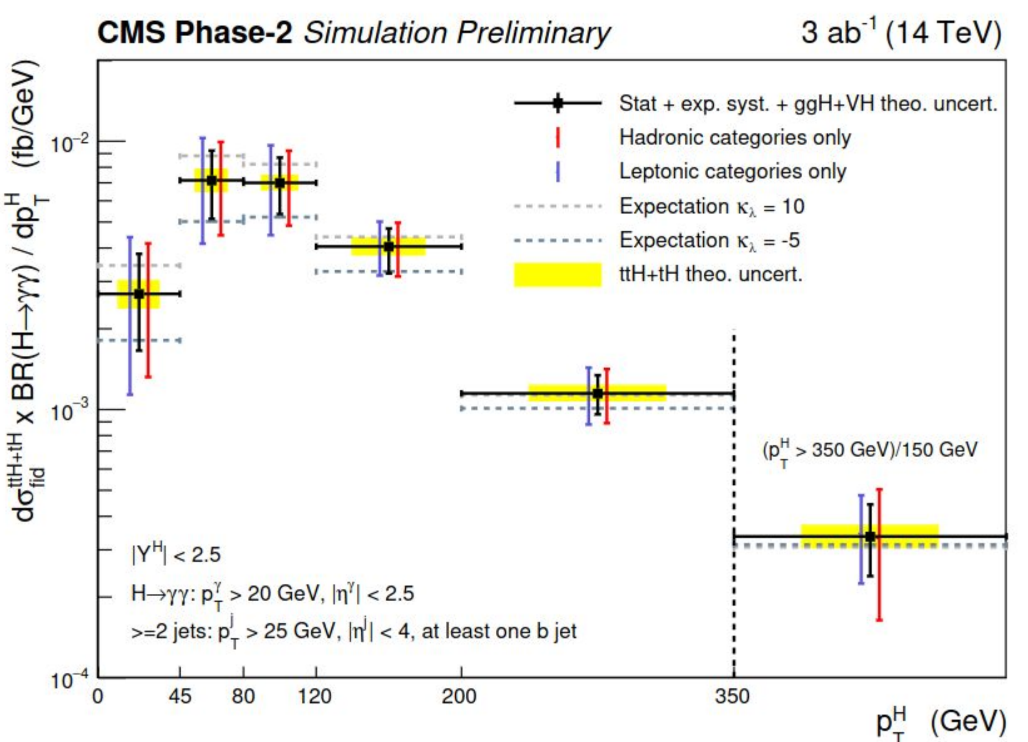
- Evidence of SM HH expected with 4σ
- Further improvement possible through new techniques & ideas→observation?

50% precision @HL-LHC

15% precision @HE-LHC→5% precision with 100 TeV & 30 ab^{-1}

H couplings from differential H XS measurements

HL-LHC projections for $p_T(H)$ measurements in the ttH(γγ) channel to constrain k_λ



[CERN Yellow report Vol. 7 (2019)]