Institute of High Energy Physics
Chinese Academy of Sciences

H(125) general combination at the CMS experiment

Higgs Hunting 2022

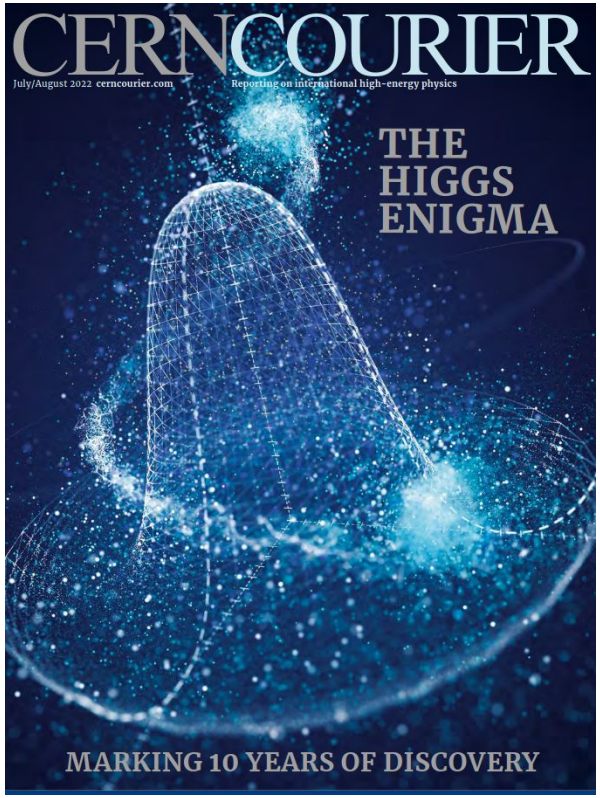
12th September 2022

Fabio Monti

on behalf of the CMS Collaboration

Outline

Recently 10th anniversary of the Higgs boson discovery



- In 2012 H observation @CMS with up to 10.4 fb^{-1} at 7-8 TeV

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC

CMS Collaboration

- Today H precision measurements with Run 2 data: 138 fb^{-1} at 13 TeV
  + Recently started Run 3 data-taking
- From 2029 HL-LHC targeting 3000 fb^{-1} in ~10 years of operations

In this presentation CMS Run 2 H comb results and perspectives for HL-LHC

H combination with CMS Run 2 data *Nature 607, 60-68 (2022)*

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

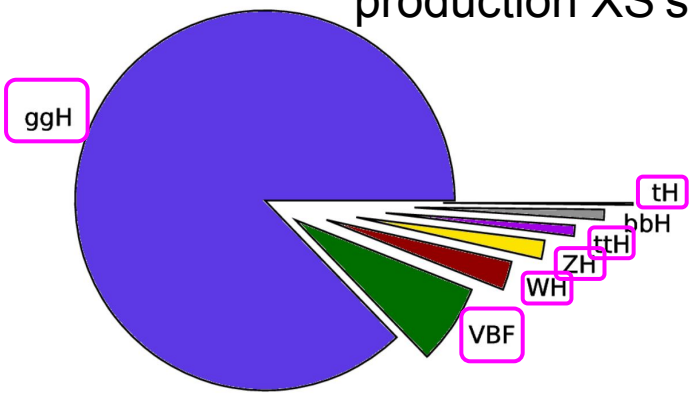
- Test compatibility with SM
  - Precise measurements of the main H production XS and decay BR
- Measurement of H coupling to fermions and vector bosons
  - Probe possible BSM effects inducing deviations from SM
- Probe properties of the H potential from H self-coupling

Accessible via HH
(M. Rieger talk)

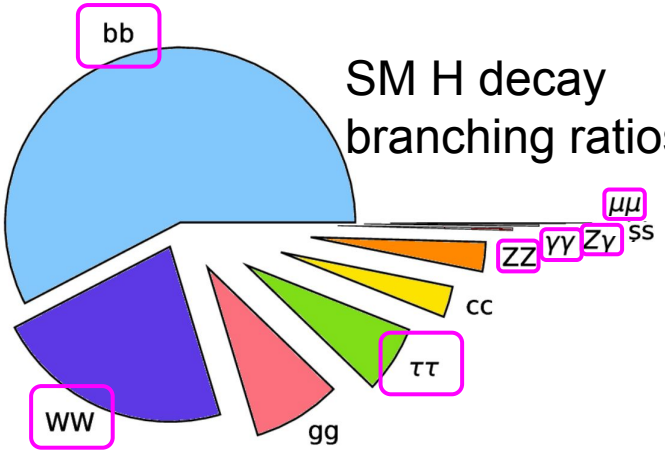
Analyses included in the combination

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)
- H(cc) and H(ee) discussed in C. Reissel talk

Evolution since discovery

H Discovery (up to 10.4 fb^{-1} at 7-8 TeV)

$\mu = 0.87 \pm 0.23$ [dominated by stat.]

Run 1 comb (up to 24.8 fb^{-1} at 7-8 TeV)

$\mu = 1.00 \pm 0.13$ [+0.08/-0.07 (theory) ± 0.07 (exp.) ± 0.09 (stat.)]

This combination (up to 138 fb^{-1} at 13 TeV)

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

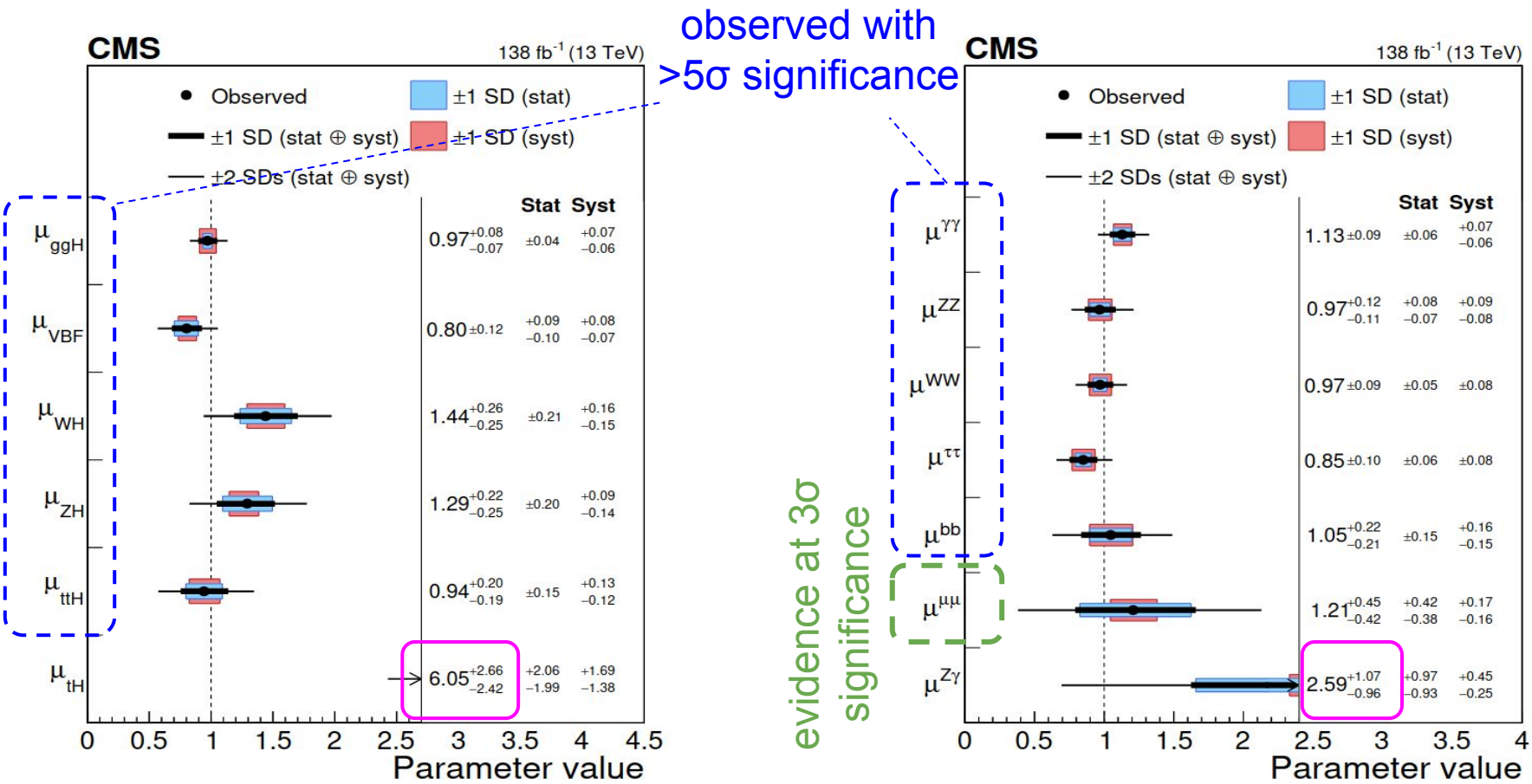
- Systematics uncertainties crucial for H measurements today and even more in future
  - Reduce exp. uncertainties with new or improved approaches
  - Need of more precise theory predictions

Improvements during Run 2

Reduction of exp. and stat. uncertainties beyond simple increase of dataset size

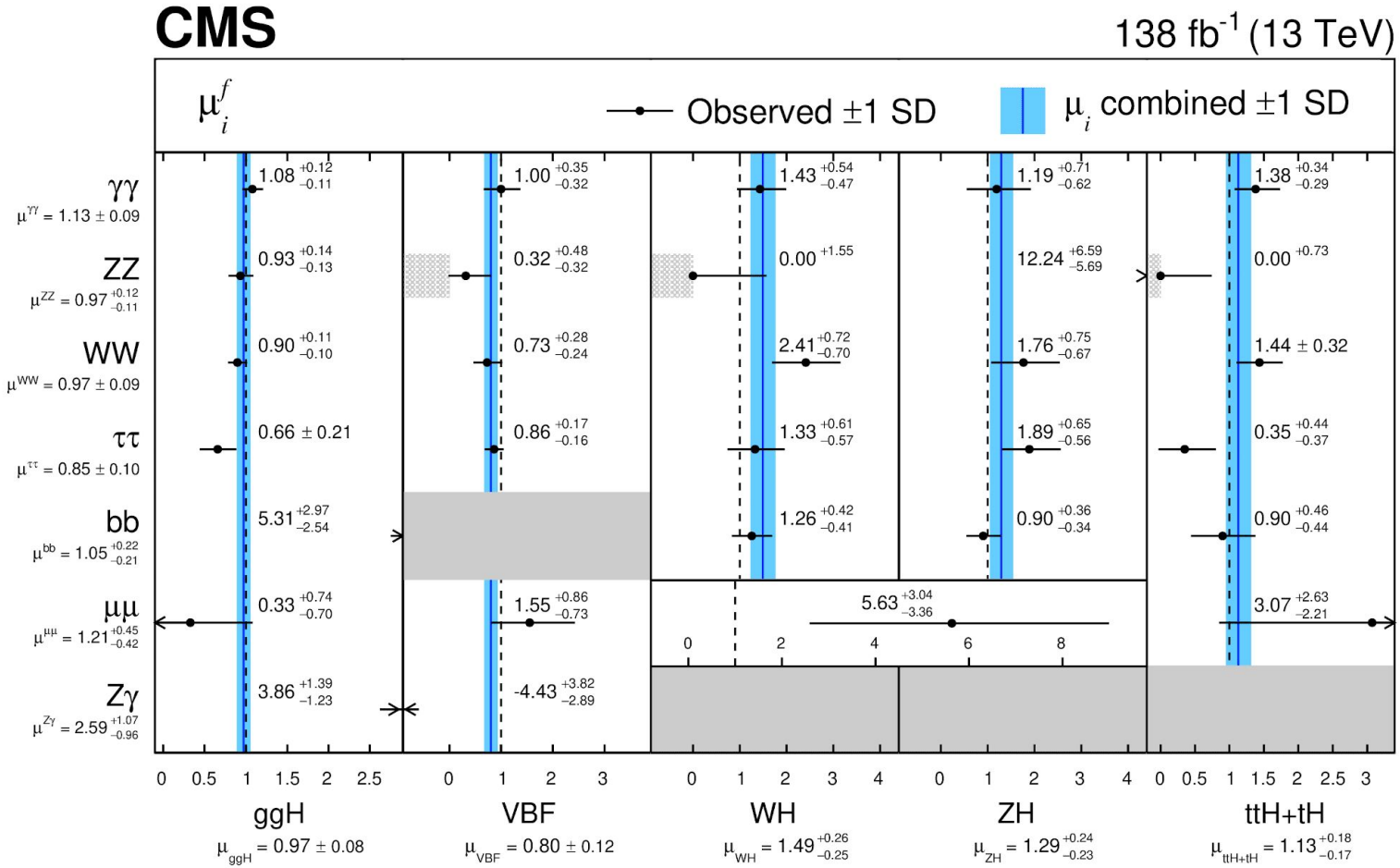
- CMS detector upgrades including:
  - New silicon pixel detector → ×2 improvement in H(bb) sensitivity
  - L1 trigger upgrade to operate with Run 2 pile-up and lumi conditions
- Extensive usage of ML in regression and classification algorithms
- Optimized detector calibration and physics objects reconstruction
  - ~stable detector performance despite higher Run 2 pile-up

Test XS and BR compatibility with the SM



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

Test XS and BR compatibility with the SM



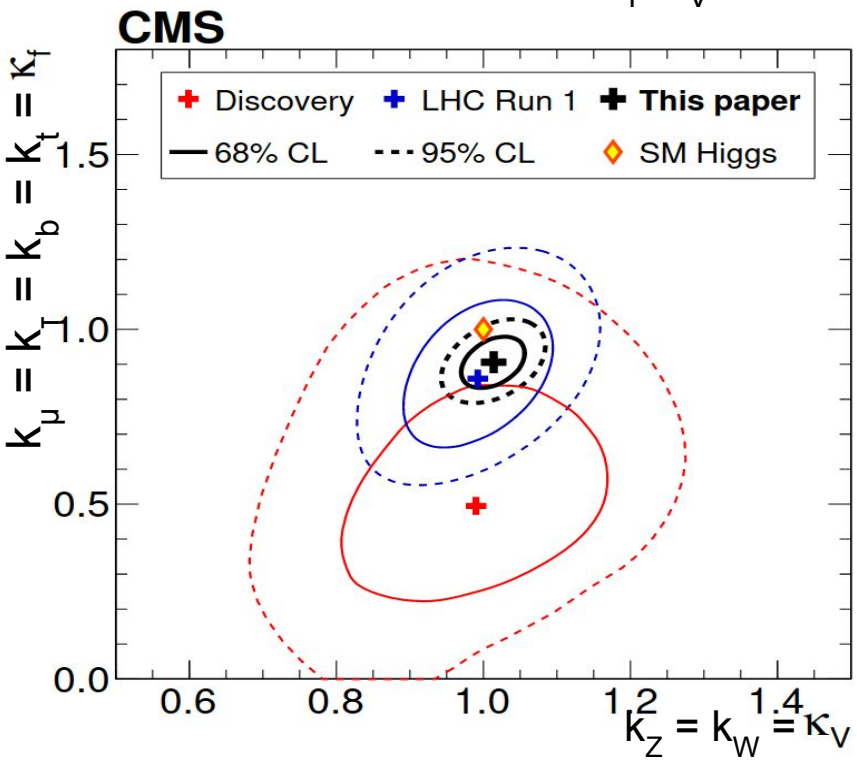
- Good compatibility with SM for main H production & decay

H couplings to fermions and vector bosons

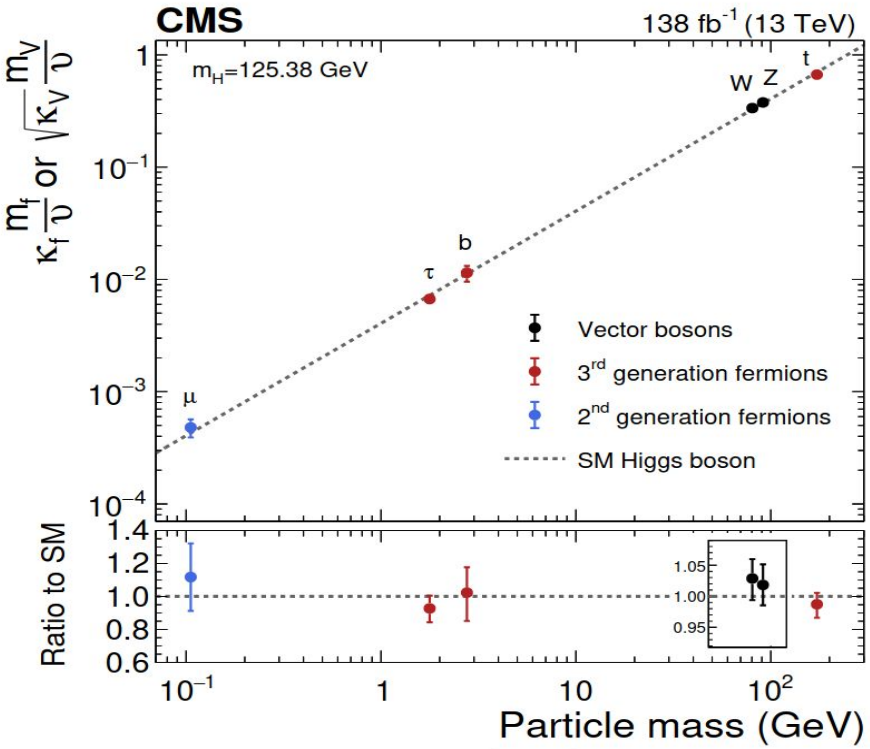
- Coupling modifiers k to quantify couplings deviations from SM predictions

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

Likelihood scan of (k_f, k_V)



H couplings vs particle mass

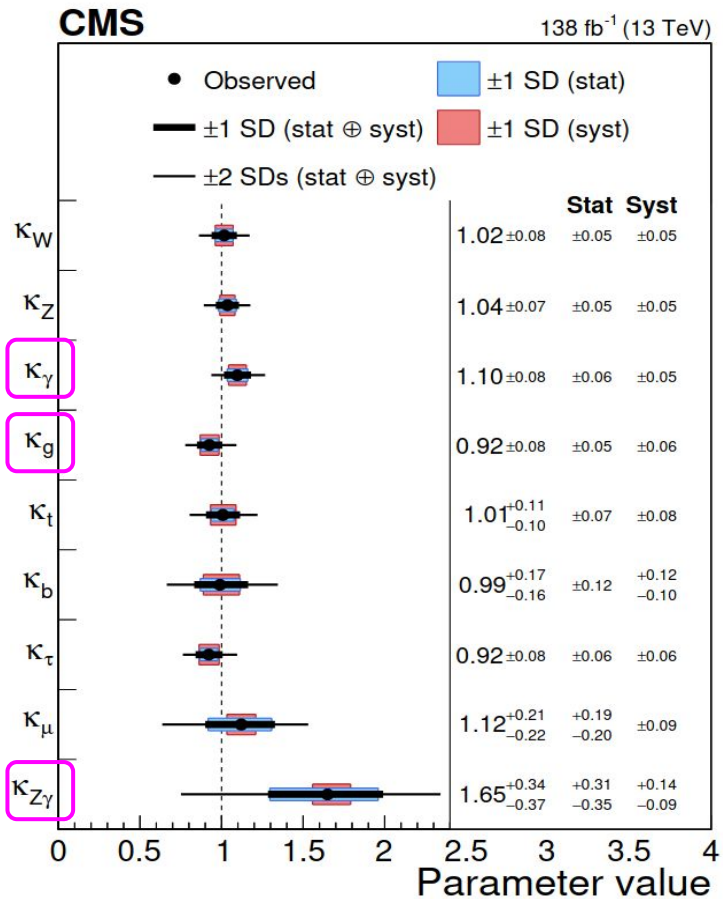


- Compatibility with SM within 10%
- ~5× improvement wrt discovery

- Agreement with SM for masses within 0.1 - 200 GeV

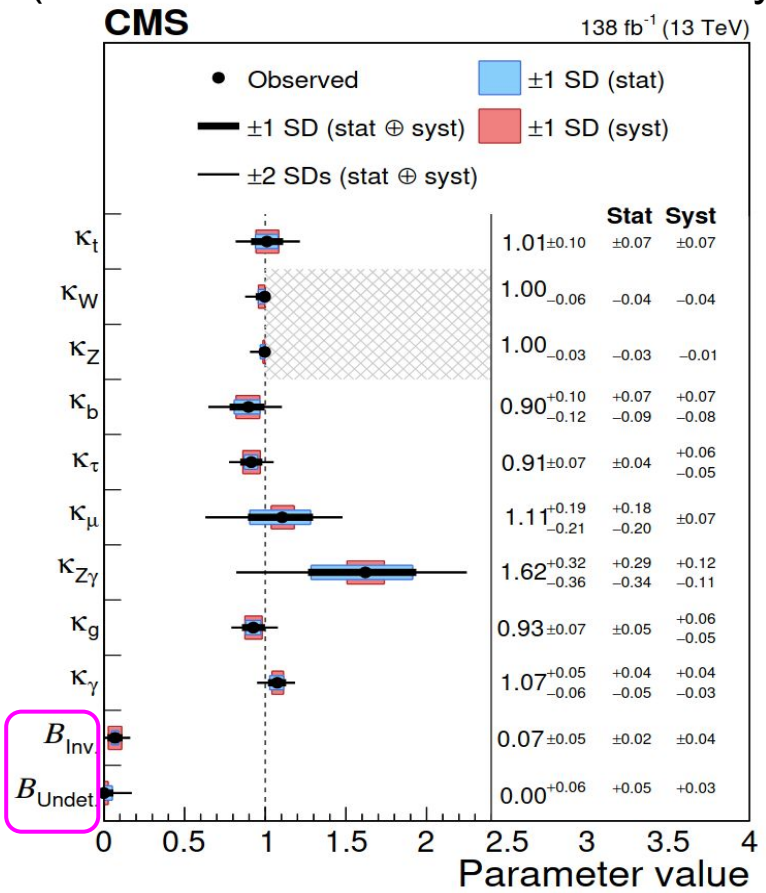
H couplings with more general assumptions

Measurement assuming effective couplings for ggH, Hγγ, and HZγ



Stat. unc ≅ syst unc except for k_μ and and $k_{Z\gamma}$

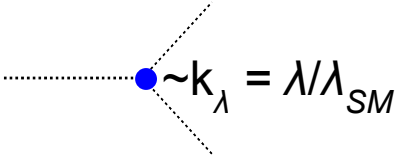
Assuming also H decays to invisible(=missing p_T) & undetectable (=non-closure of other BR's to unity)



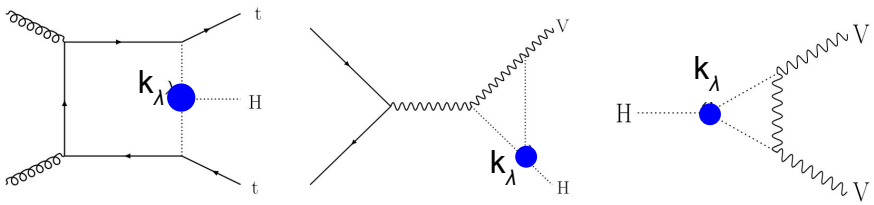
Both invisible and undetectable BR's compatible with zero

Constraints on the H trilinear self-coupling λ

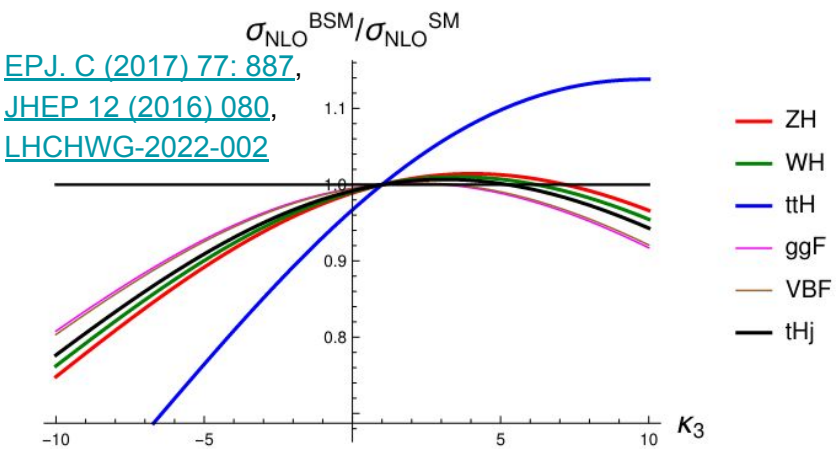
- k_λ-dependent NLO electroweak corrections to H XS and BR



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



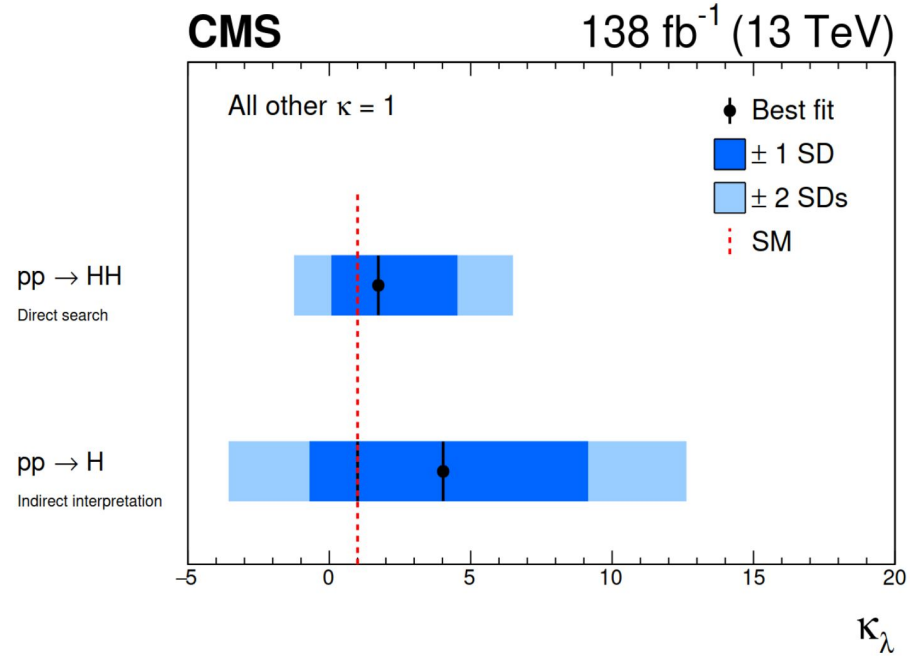
Modification of total XS vs k_λ



EPJ. C (2017) 77: 887, JHEP 12 (2016) 080, LHCHWG-2022-002

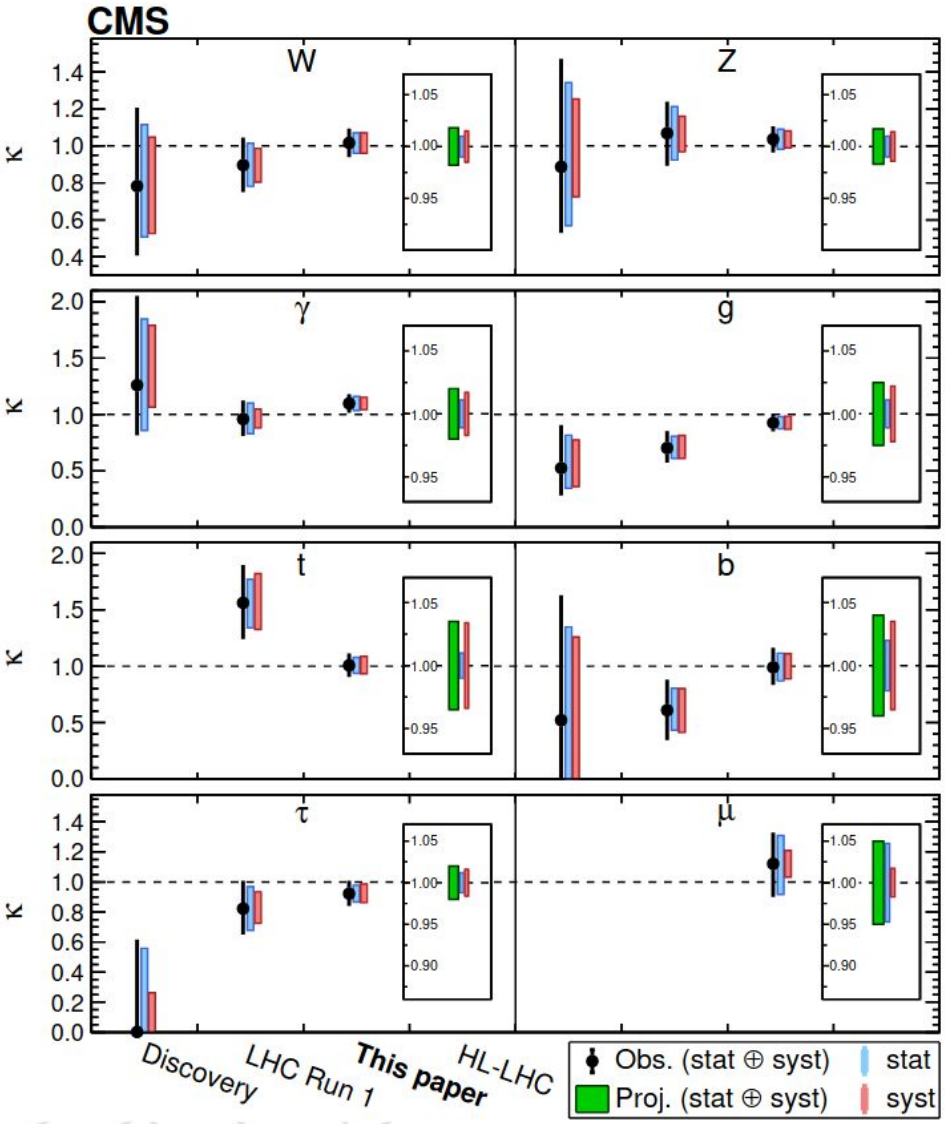
+ effects on differential XS and on BR

k_λ measurement from HH or single-H



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

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

Summary

- H comb provides fundamental extensive tests of the SM
- Presented results of H comb with CMS Run 2 dataset
- Good compatibility of observations with SM predictions
  - $\mu = 1.002 \pm 0.057$
  - Precision better than 10% for most of the considered H coupling modifiers
- Statistical uncertainties comparable to systematics ones for main H production and decay channels
- At HL-LHC high-precision tests of the SM

Great progresses in understanding the Higgs boson since its discovery and exciting times ahead!

BACKUP

Analyses included in the combination

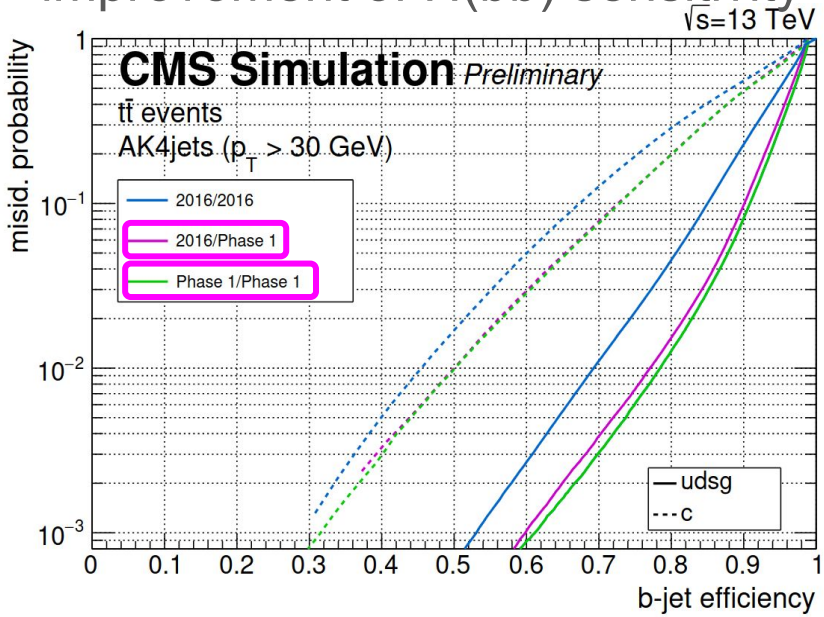
Analyses	Integrated lumi (fb^{-1})	ggH	qqH	VH	ttH & tH
H(γγ)	138	X	X	X	X
H(ZZ→4l)	138	X	X	X	X
H(WW)	138	X	X	X	
H(ττ)	138	X	X	X	
ttH multilepton(ττ, WW, and ZZ)	138				X
H(Zγ)	138	X	X	X	X
H(bb)	36(ttH) 77(VH) 138(ggH)	X	X	X	X
H(μμ)	138	X	X	X	X
H(invisible)	138	X	X	X	

- Main H production and decay channels covered with up to full Run 2 dataset (2016-2018)
- H(cc) and H(ee) discussed in C. Reissel talk

Improvements during Run 2

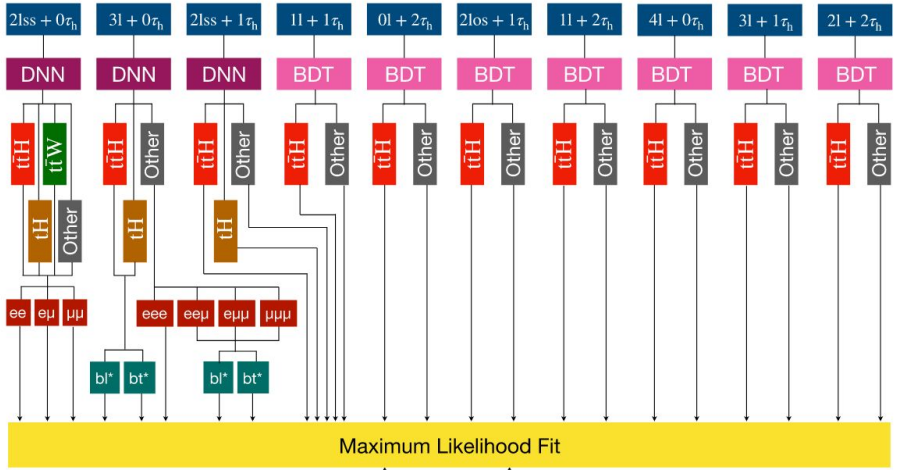
CMS detector upgrades

- e.g. new Si pixel detector → ×2 improvement of H(bb) sensitivity



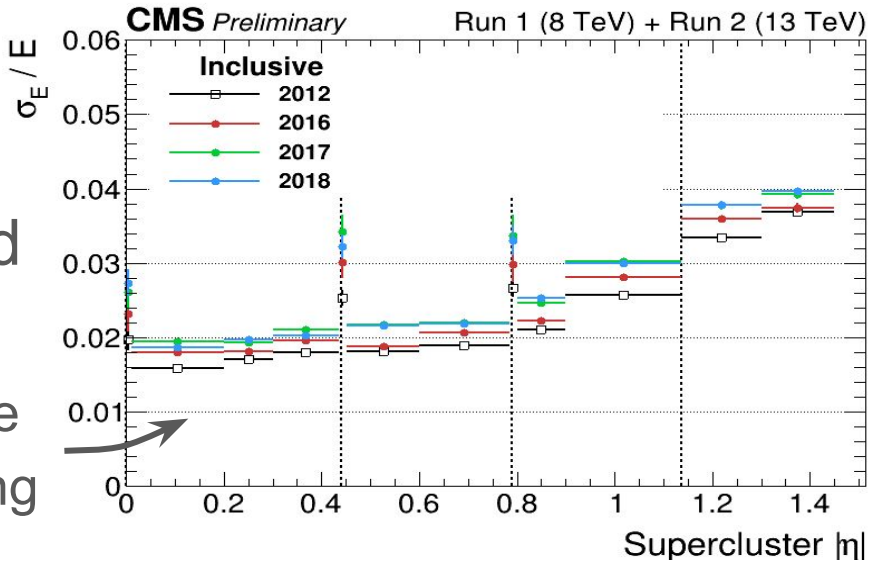
Extensive usage of ML

ttH multilepton analysis workflow



Optimized detector calibration and physics objects reco

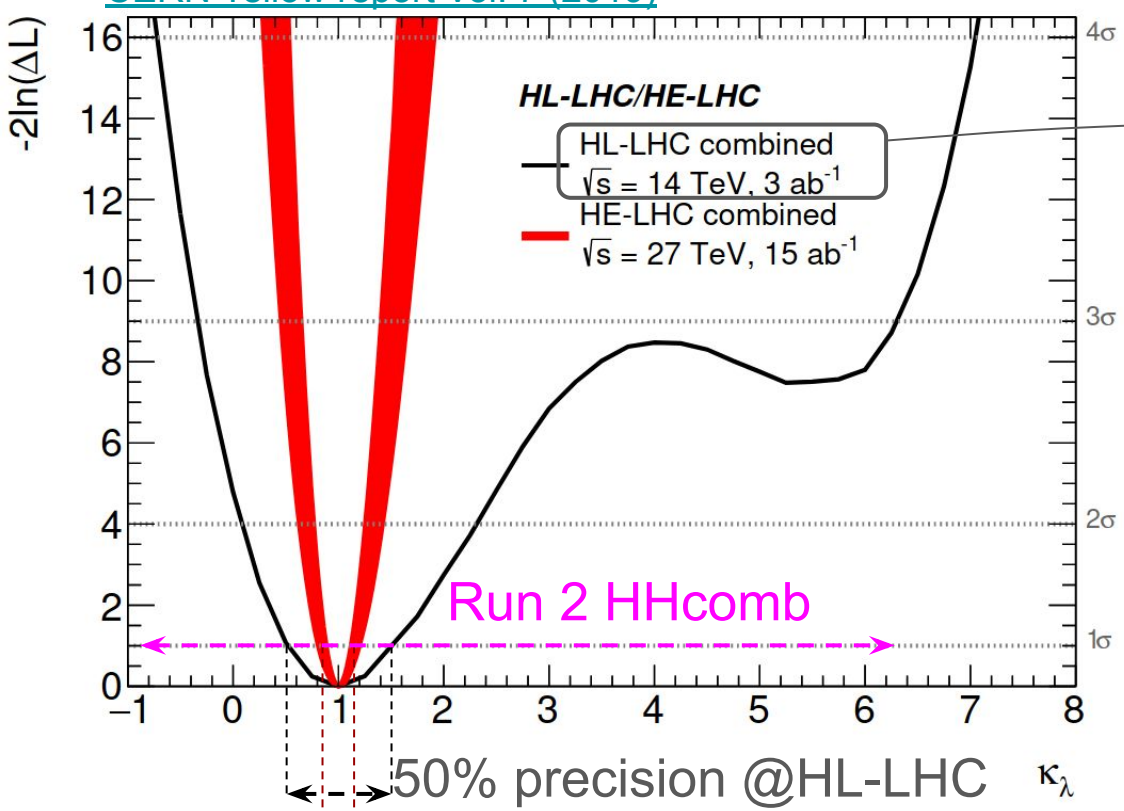
- e.g. stable e/γ energy resolution despite higher pile-up and ECAL detector ageing



Outlook for the future

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

CERN Yellow report Vol. 7 (2019)



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

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