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Combined measurement of Higgs properties at CMS



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Introduction



A great success of SM: the discovery of Higgs boson in 2012



- Many important questions remain unanswered:
 - neutrino mass, hierarchy problem, matter antimatter asymmetry, the nature of dark matter and dark energy etc.
- Higgs physics could be the key to answer these questions

CMS in LHC



Large Hadron Collider (LHC) : Largest accelerator and currently the only place to study the Higgs boson CMS: General purpose detectors in LHC with Higgs physics as one of the main goals



Higgs combination in LHC Run 2

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- Precise measurements of the main H production cross section and decay branching ratios
 - Test compatibility with SM
- Measurement of H coupling to fermions and vector bosons
 - Probe anomalies from BSM contributions
- Probe properties of the H potential from H selfcoupling

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A portrait of the Higgs boson by the CMS experiment ten years after the discovery

Nature article

The CMS Collaboration

<u>Nature</u> 607, 60–68 (2022) | <u>Cite this article</u> 10k Accesses | 2 Citations | 401 Altmetric | <u>Metrics</u>

Analyses included in the combination

Analyses	Lumi (fb-1)	ggH	qqH	VH	ttH and tH
<u>Η(</u> <u>γ</u> <u>γ</u> <u>)</u>	138	Х	Х	Х	Х
<u>H(ZZ)</u>	138	Х	Х	Х	Х
<u>H(WW)</u>	138	Х	Х	Х	Х
<u>H(Zɣ)</u>	138	Х	Х		
H(bb)	<u>36(ttH) 77(VH) 138(ggH)</u>	Х	Х	Х	Х
<u>Η(ττ)</u>	138	Х	Х	Х	Х
<u>ttH multilepton(ττ, WW, and ZZ)</u>	138				Х
<u>Η(μμ)</u>	138	Х	Х		Х
<u>H(invisible)</u>	138	Х	Х	Х	

- Main H production and decay channels covered
- More channels and additional interpretation to be expected in the near future

Higgs production signal strength since discovery

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<u>Higgs discovery</u>

- Data: up to 5.1 fb-1 at 7 TeV and 5.3 fb-1 at 8 TeV
- $\mu = 0.87 \pm 0.23$ [dominated by statistic uncertainty]

$$\mu = \sigma_{obs.} / \sigma_{SM}$$

- Run 1 Higgs combination
 - Data: up to 5.1 fb-1 at 7 TeV and 19.7 fb-1 at 8 TeV
 - $\mu = 1.00 \pm 0.13$ [+0.08/-0.07 (theory) ± 0.07 (exp.) ± 0.09 (stat.)]
- Run 2 Higgs combination
 - Data: up to 138 fb-1 at 13 TeV
 - μ = 1.002 ± 0.057 [± 0.036 (theory) ± 0.033 (exp.) ± 0.029 (stat.)]
- Systematics uncertainties crucial for H measurements today and even more in future
 - Reduce experimental uncertainties with improved or new approaches
 - Need of more precise theory predictions

Test XS and BR compatibility with the SM



- Good compatibility for main H production XS & decay BR
- > Intriguing excesses in μ_{tH} and in $\mu_{Z_{y}}$ → among CMS priorities in Run 3

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H couplings to fermions and vector bosons

 Coupling modifiers k_i to quantify couplings deviations from SM predictions



➤ Good compatibility with SM

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• Precision of ~3% on vector boson and of 5-20% on fermion coupl.

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H couplings with different assumptions

Measurement assuming effective couplings for ggH, Hyy, and HZy



Assuming also H decays to invisible(MET) & undetectable



Both invisible and undetectable BR's compatible with zero

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Higgs self-coupling measurement

- Higgs self-coupling crucial for understanding the Higgs field potential
 - Understand the electroweak symmetry breaking mechanism





- Higgs self-coupling with H and HH in CMS
 - Measure coupling modifiers k_{λ}

• $k_{\lambda} = \lambda / \lambda_{SM}$

- Indirect constraints from H measurement
- Direct probes from HH measurements (<u>Talk by Chu Wang</u>)

Constraints on the H self-coupling

• k_{λ} -dependent NLO electroweak corrections to H XS and BR

 k_{λ} measurement from HH vs from single-H

Examples of k_{λ} -dependent diagrams for single-H prod. mechanisms and H \rightarrow VV decay



- > HH and single-H have comparable sensitivities to k_{λ}
- First CMS measurement from single-H considering differential effects

Higgs property measurement 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

- $\circ~$ H-HH comb including k_{_{\!\!\lambda}} in the fit
- EFT interpretations

Summary

- Higgs combination with full Run 2 data at CMS
 - Provides extensive tests of the SM and probes potential BSM effects
 - Higgs production cross sections and branching ratios, H couplings measurements
 - Systematics start to dominant the uncertainties
 - Overall observed good compatibility with SM
 - Higgs self-coupling measurement

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- First measurement of k_{λ} from single-H taking into account differential XS at CMS
- Significant improvement on precisions achieved in Run 2 with respect to the Higgs discovery and early analyses
- Stay tuned for more exciting results with full Run 2 data and Run 3!