Prospects for HH measurements in the HH → bb4l channel with the CMS experiment at the HL-LHC

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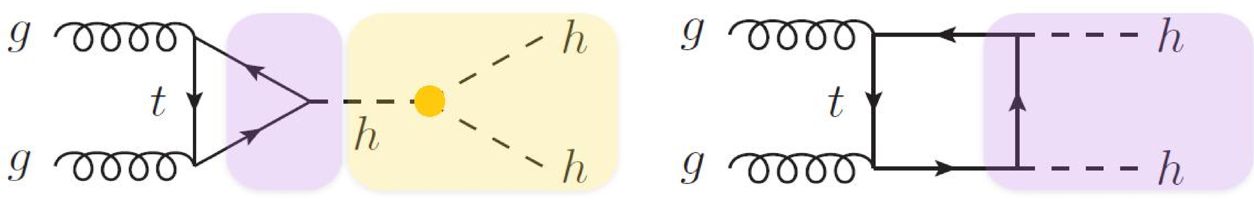
Di-Higgs searches in CMS during Run 2

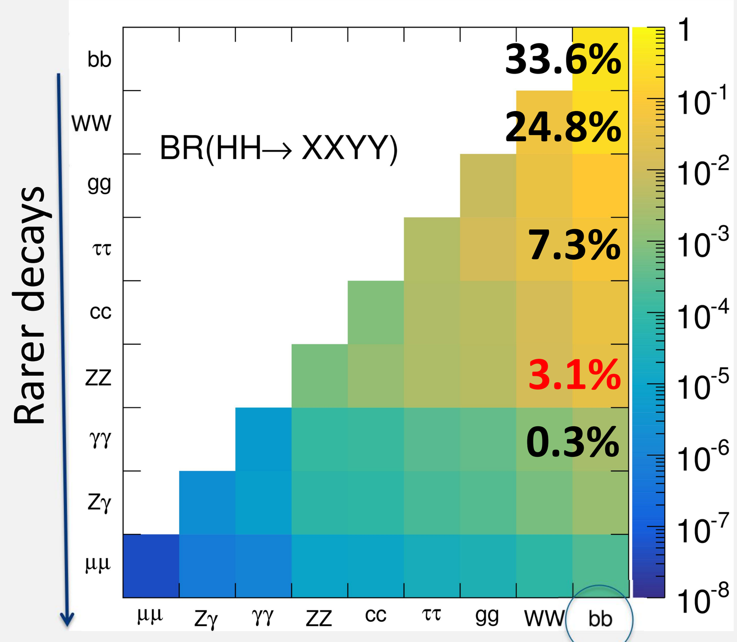
The determination of processes which involve multi-Higgs production is crucial to anayze the Higgs potential, because this is the standard process to study the **Higgs boson self-interactions**, predicted by the Standard Model (SM). Moreover, it represents a unique way to probe the existence of physics beyond the standard model (BSM) that may manifest as a modification of the Higgs self-coupling (λ_{HHH}).

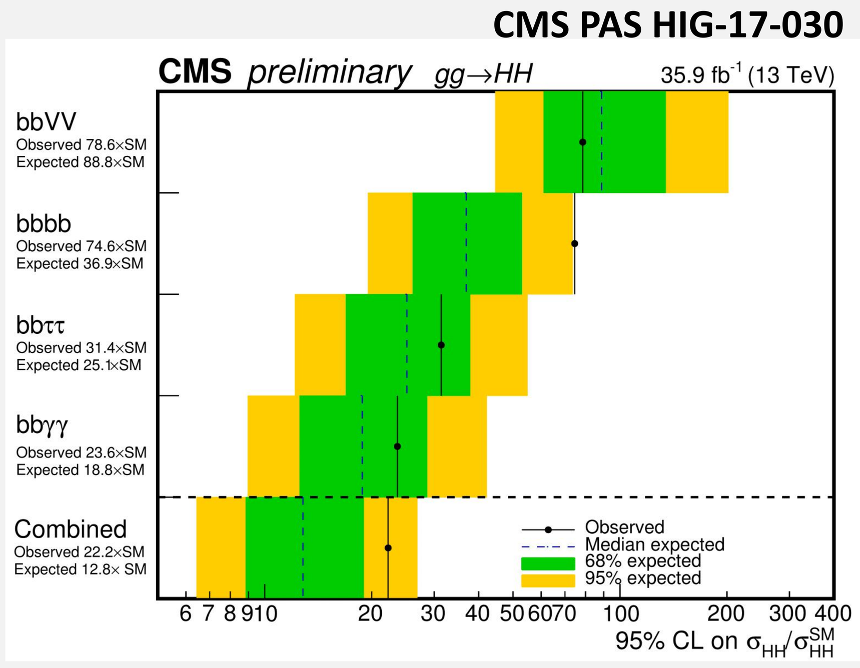


σ_{HH}	
13 TeV	31.05 fb
14 TeV	36.6 fb

Searches for HH processes based on the current Run 2 dataset are not yet sensitive to SM HH production because of the small cross section and the presence of large backgrounds.

CMS PAS HIG-17-030





The low signal rate leads to consider mostly final states with a sizable BR (for this reason, one of the two Higgs is always searched in the bb decay channel).

The HH → bb4l analysis at the HL-LHC

In view of the HL-LHC, some **rare but clean processes** have been re-considered because of the increasing available statistics and the challenging conditions due to the enormous number of pile-up events.

SIGNAL - The presence of four leptons associated with two b-jets leads to a clean final state topology allowing to maintain a rather good signal selection efficiency and to control the backgrounds.

BACKGROUNDS - The main background processes are ttH(ZZ), ttZ, ggH and ZH, followed by minor contributions such as WH and single Higgs production via vector boson fusion (VBF). ZZ and ttH(WW) contributions are found to be negligible.

Madgraph5_aMC@NLO
Parton level generation

Pythia8
Parton shower and decay

Simulated all signal and backgrounds (except for ggH and VBF) privately

Delphes
Simulation of the upgraded CMS detector:
- PU 200
- loose ID for Muons
- medium ID for Electrons
- medium BTag with MTD for PUPPI jets

Process	σ x BR [fb]
gg → HH → bbZZ*(4l)	0.0053
gg → ttH(4l)	0.0761
gg → Z(bb)H(4l)	0.0183
gg → WH(4l)	0.1876
gg → ttZ(2l)	69.224
VBF H(4l)	1.1690
gg → H(4l)	15.007

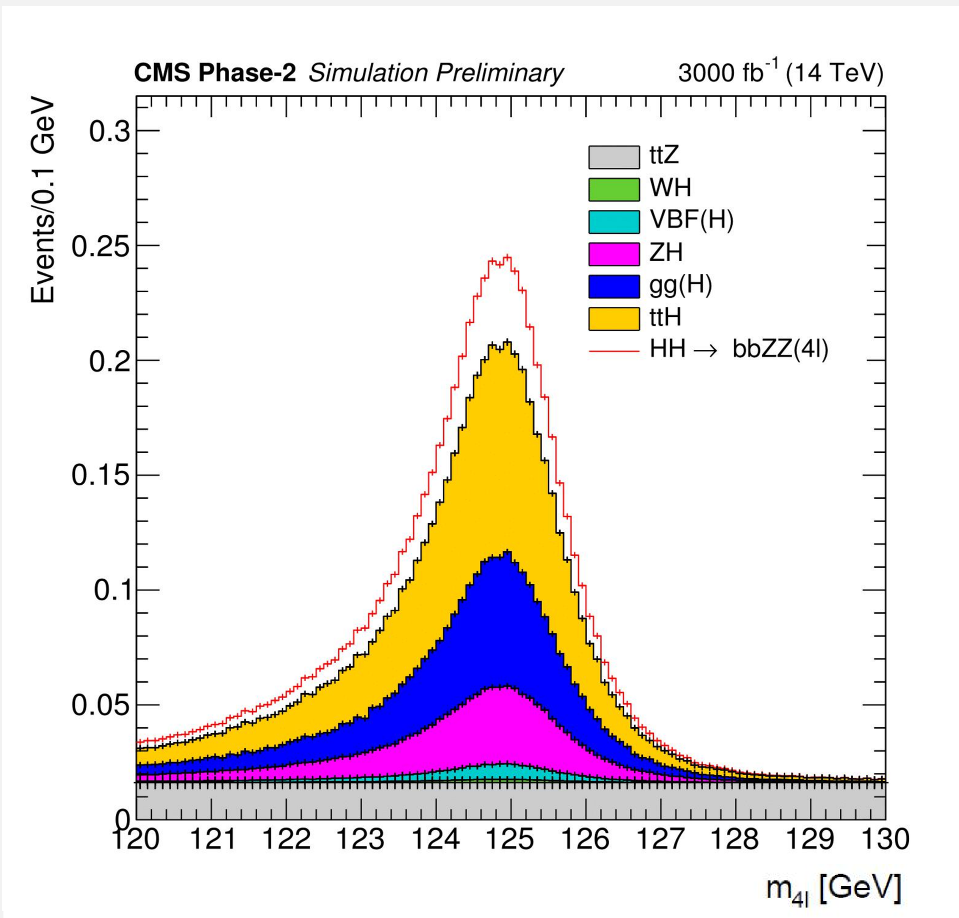
The signal and the backgrounds are studied using an optimized **cut-flow based analysis**

Pre-selection

Leptons and jets
- $|\eta| < 2.8$
- $p_T > 5$ (7) GeV for μ (e)
- Relative isolation < 0.7
- $\Delta R\ (l_i - l_j,\ j \neq i) > 0.02$
- Anti-kt jet algorithm with R=0.4

Selection

4l (H peak search) + 2 b-jets
- $N(l) \geq 4$
- N (di-leptons) ≥ 2
- $50\ GeV \leq m_{Z1} \leq 100\ GeV$
- $12\ GeV \leq m_{Z2} \leq 60\ GeV$
- $p_T(l)$ cuts (> 20/> 10 GeV)
- $120\ GeV < m_{4l} < 130\ GeV$
- $2 \leq N_{b\text{-jet}} \leq 3$
- $80\ GeV \leq m_{bb} \leq 160\ GeV$
- $0.5 \leq \Delta R_{bb} \leq 2.3$
- MET < 150 GeV
- $\Delta R_{HH} > 2.0$



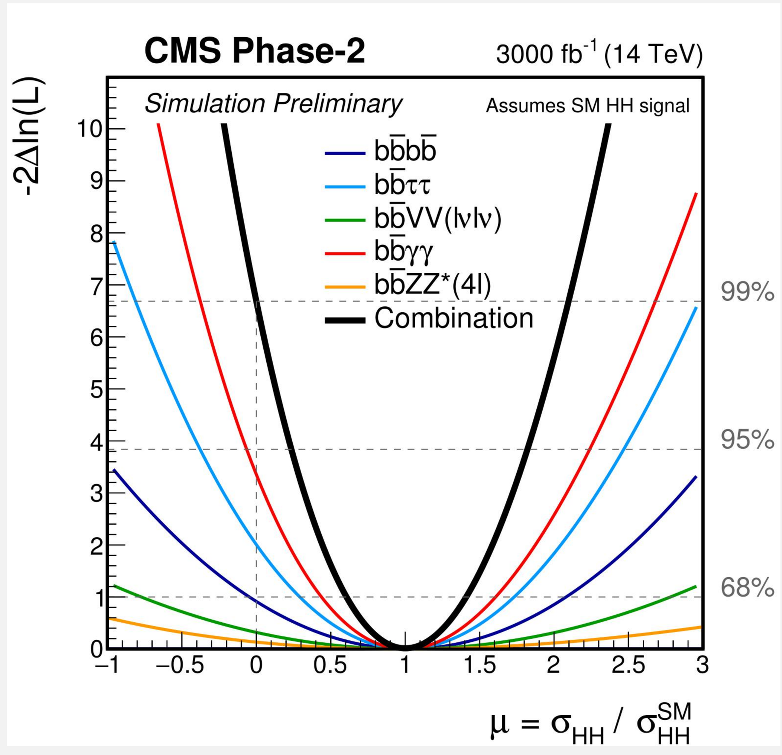
Event yield in the bbZZ*(4l) channel for 3000 fb^{-1}

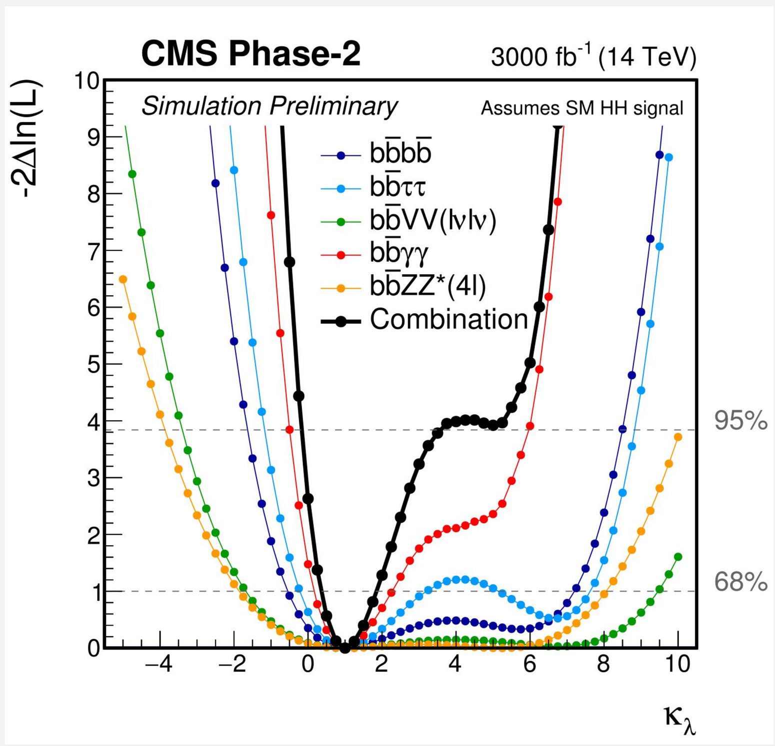
	HH	$t\bar{t}$H	ggH	ZH	WH	VBF	$t\bar{t}$Z
$b\bar{b}4\ell$	1.0	2.5	1.5	$9.4 \cdot 10^{-1}$	$4.0 \cdot 10^{-2}$	$1.7 \cdot 10^{-1}$	1.6
$b\bar{b}4\mu$	$4.9 \cdot 10^{-1}$	1.3	$6.9 \cdot 10^{-1}$	$4.9 \cdot 10^{-1}$	$2.2 \cdot 10^{-2}$	$1.1 \cdot 10^{-1}$	$8.1 \cdot 10^{-1}$
$b\bar{b}4e$	$8.8 \cdot 10^{-2}$	$2.0 \cdot 10^{-1}$	$5.3 \cdot 10^{-2}$	$6.9 \cdot 10^{-2}$	$2.9 \cdot 10^{-3}$	$1.1 \cdot 10^{-2}$	0
$b\bar{b}2e2\mu$	$2.6 \cdot 10^{-1}$	$7.5 \cdot 10^{-1}$	$2.7 \cdot 10^{-1}$	$5.9 \cdot 10^{-2}$	$7.2 \cdot 10^{-3}$	$1.5 \cdot 10^{-2}$	$8.1 \cdot 10^{-1}$

Considering the channels investigated, **1 HH event** for a total background yield of 6.8 in the inclusive bb4l final state is expected for an integrated luminosity of 3000 fb^{-1}.

The combined upper limit at the 95% CL on the HH cross section corresponds to **6.6 times the SM prediction**, with a corresponding significance of **0.37σ**.

The impact of the systematic uncertainties on the analysis is found to be almost negligible.
The most sensitive channel is bb4μ, but a sizeable contribution to the sensitivity also comes from the bb2e2μ and bb4e final states.





A projection for the sensitivity on the Higgs self-coulpling modifier is studied:

$k_\lambda = \lambda_{HHH}/\lambda^{SM}_{HHH}$

In addition to the SM scenario ($k_\lambda = 1$), samples with several other values of k_λ are generated, ranging from $k_\lambda = -10$ to $k_\lambda = 10$.

Approach to model anomalous k_λ signals (**counting experiment**): yield parametrized vs k_λ with a quadratic function by fitting various k_λ samples after the full selection.

COMBINATION RESULTS

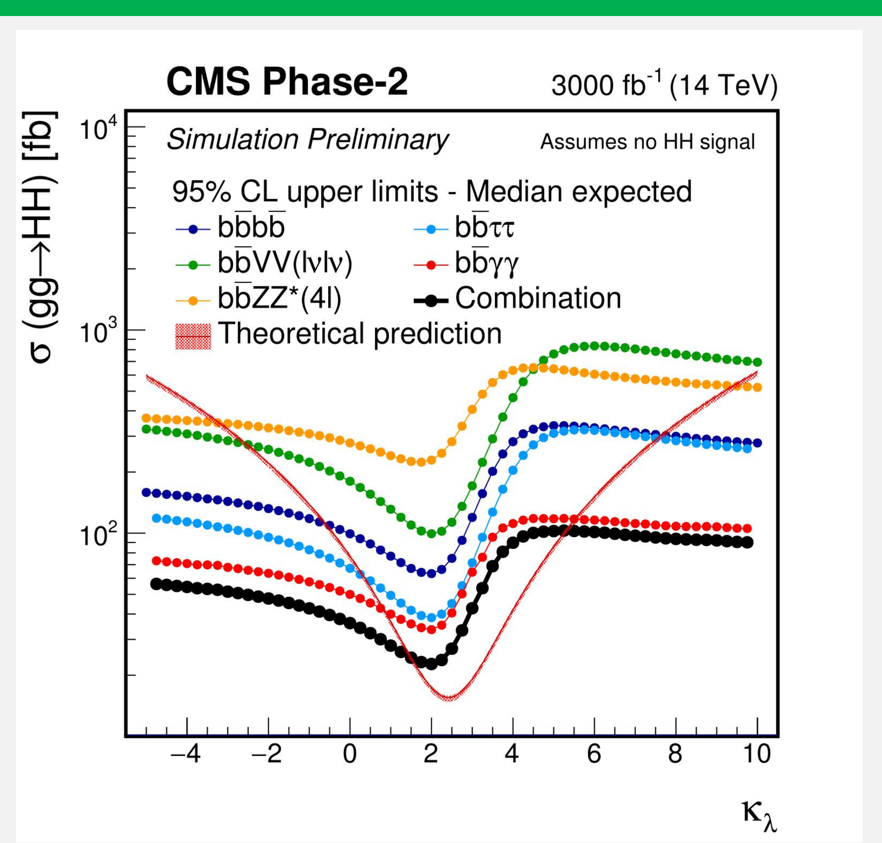
Main reference:

CMS FTR-18-019

HH →	bbbb	bbττ	bbγγ	bbVV(lνlν)	bbZZ*(4l)
Significance	0.95	1.4	1.8	0.56	0.37
Limit @ 95% CL	2.1	1.4	1.1	3.5	6.6

The statistical combination of five decay channels (bbbb, bbττ, bbγγ, bbVV(lνlν), bbZZ*(4l)) results in an expected significance for the Standard Model HH signal of **2.6σ**, corresponding to a combined 95% CL upper limit on the SM HH cross section of **0.77 times the SM prediction**.
Both systematic and statistical uncertainties are considered. The analyses of of the five decay channels are designed to be orthogonal.

Prospects are also studied for the measurement of the trilinear Higgs boson coupling. The expected 68% and 95% confidence level intervals for the self-coupling modifier $k_\lambda = \lambda_{HHH}/\lambda^{SM}_{HHH}$ are **[0.35, 1.9]** and **[0.18, 3.6]**, respectively.



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