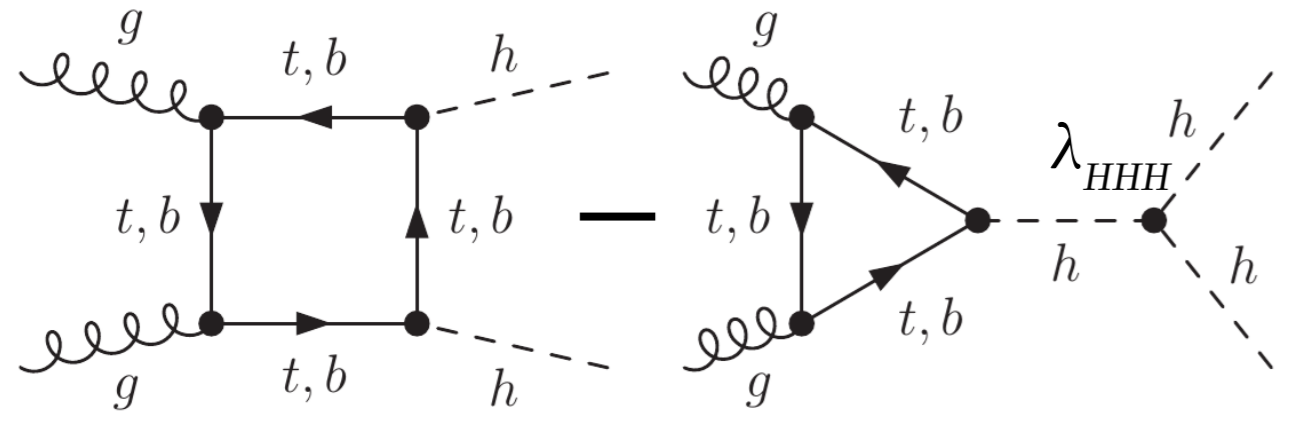


# Prospects for HH measurements at the HL-LHC with CMS

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## Introduction

- HH allows direct access to the Higgs self-coupling,  $\lambda_{HHH}$



- Destructive interference
  - Low cross section ( $40 \text{ fb}^{-1}$ )
  - Sensitive to variations of  $\kappa_\lambda = \lambda/\lambda_{SM}$
- No excess observed yet
  - $\sigma_{obs}/\sigma_{SM} < 22.2$  @ 95% CL
  - $-11.8 < \kappa_\lambda < 18.8$  @ 95% CL

- More data is needed
- HL-LHC upgrade
  - Up to  $3 \text{ ab}^{-1}$  over a decade
  - Detector upgrade needed to keep current performances under  $\langle \text{PU} \rangle \sim 140 - 200$

- Analysis projections using a parametric simulation of the detector
  - With the TDR design
  - Delphes-based
  - Tuned with Full-sim

## HH → bbbb

$$\mathcal{B} = 33.6\%$$

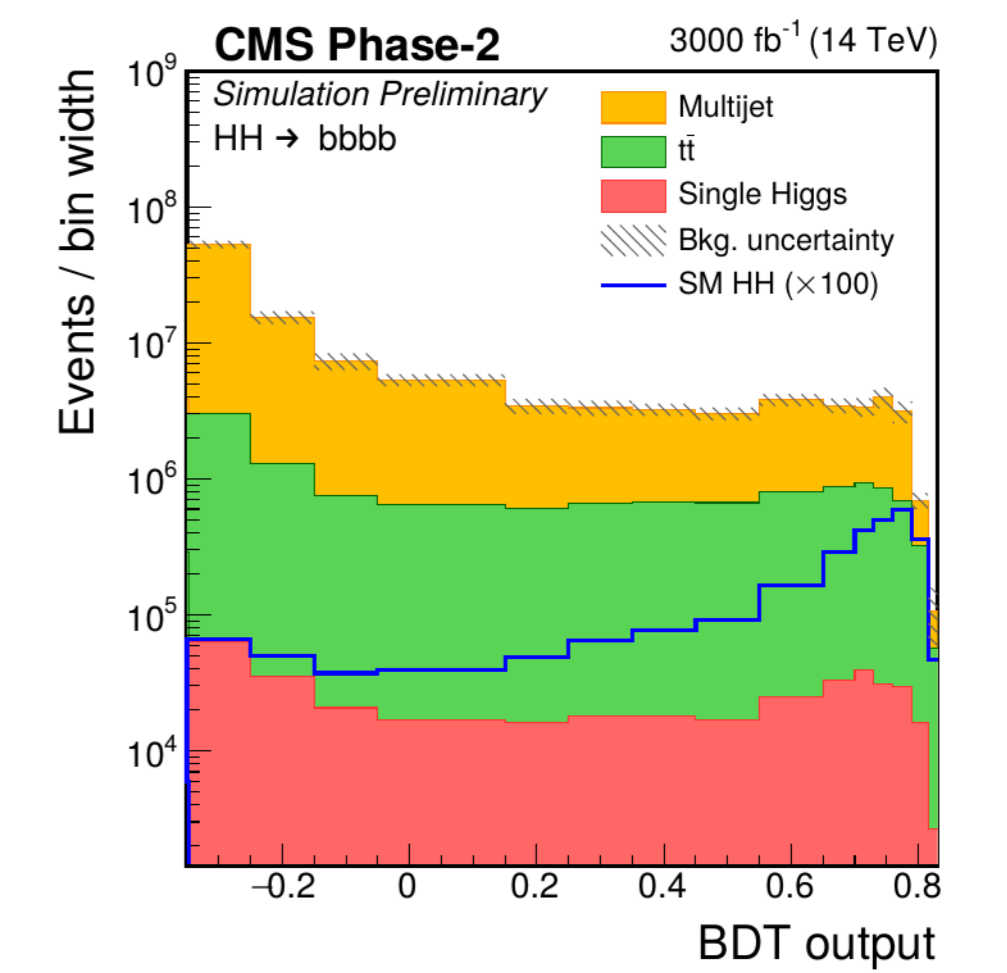
Selection:

- At least 4 b-jets paired to minimise difference in  $m_{bb}$
- $(m_{bb1} - 120 \text{ GeV})^2 + (m_{bb2} - 120 \text{ GeV})^2 < (40 \text{ GeV})^2$

Expected yield :

- 1370 Signal events
- $1.1 \times 10^7$  Background events
- $S/N = 1.2 \times 10^{-4}$

- A Boosted Decision Tree based on 13 kinematic variables is used.



## HH → bbττ

$$\mathcal{B} = 7.3\%$$

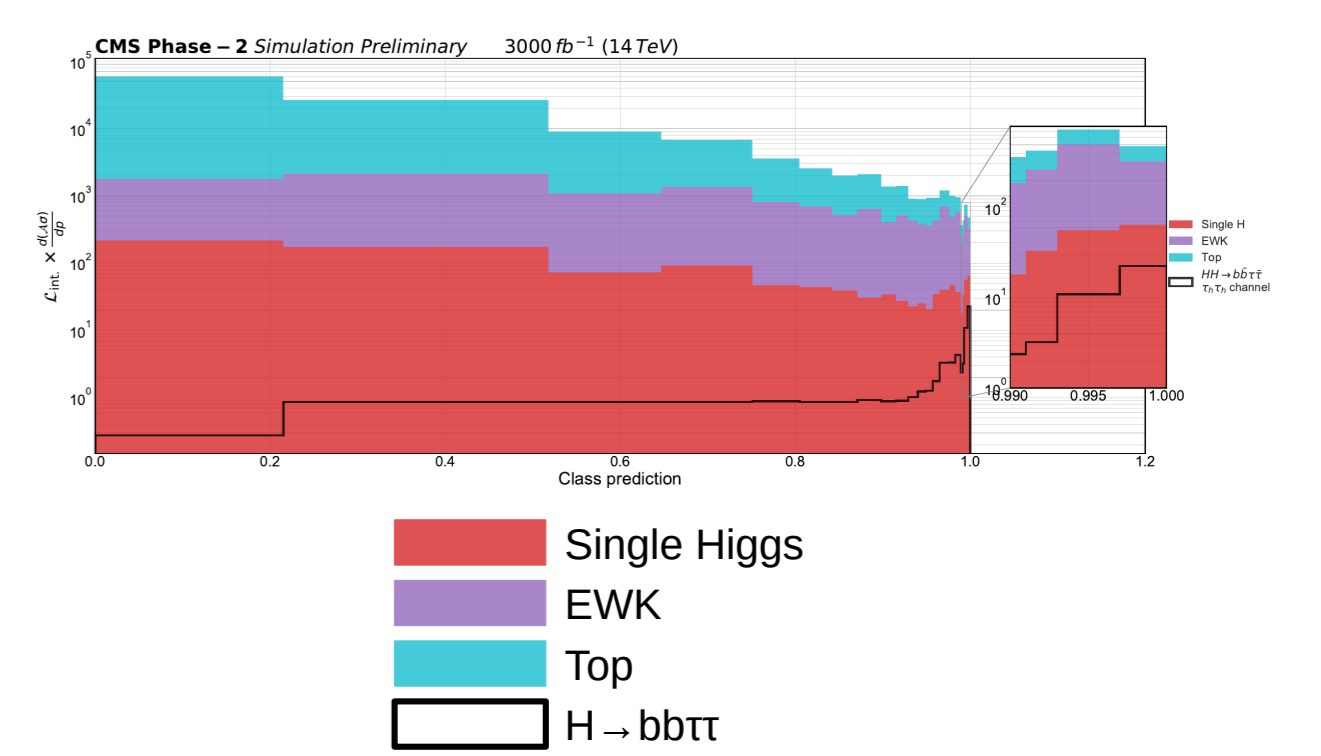
Selection:

- At least 2 b-jets
- $e\tau_h, \mu\tau_h$  or  $\tau_h\tau_h$
- No extra lepton

Expected yield :

- 230 Signal events
- $8.5 \times 10^6$  Background events
- $S/N = 2.7 \times 10^{-5}$

- 27 basic, 21 reconstructed and 4 global features combined in a NN-based discriminant



## HH → bbWW(lνlν)

$$\mathcal{B} = 1.7\%$$

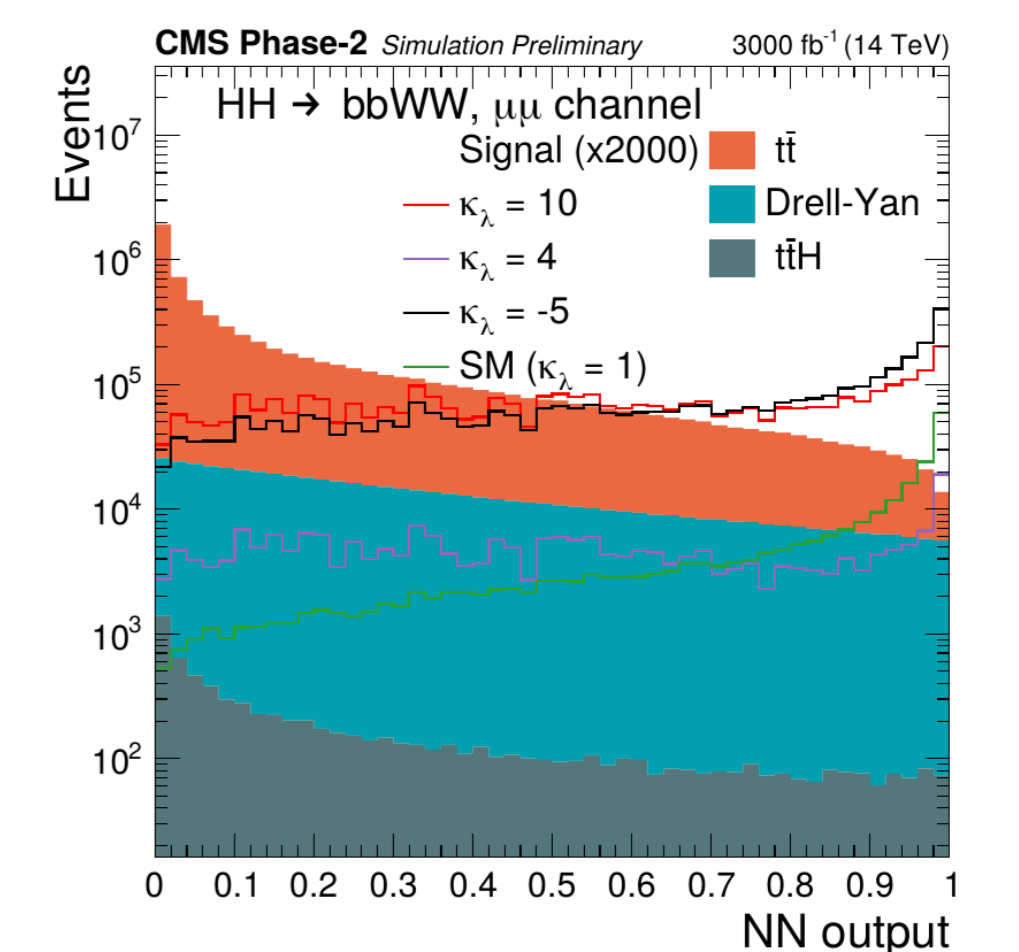
Selection:

- At least 2 b-jets
- Opposite sign  $\mu\mu, ee$  or  $e\mu$
- $m_{ll} < m_z - 15 \text{ GeV}$

Expected yield :

- 320 Signal events
- $1.9 \times 10^7$  Background events
- $S/N = 1.7 \times 10^{-5}$

- 9 reconstructed kinematic variables are combined in NN discriminants
- Global fit in  $\mu\mu, ee$  and  $e\mu$



## HH → bbγγ

$$\mathcal{B} = 0.26\%$$

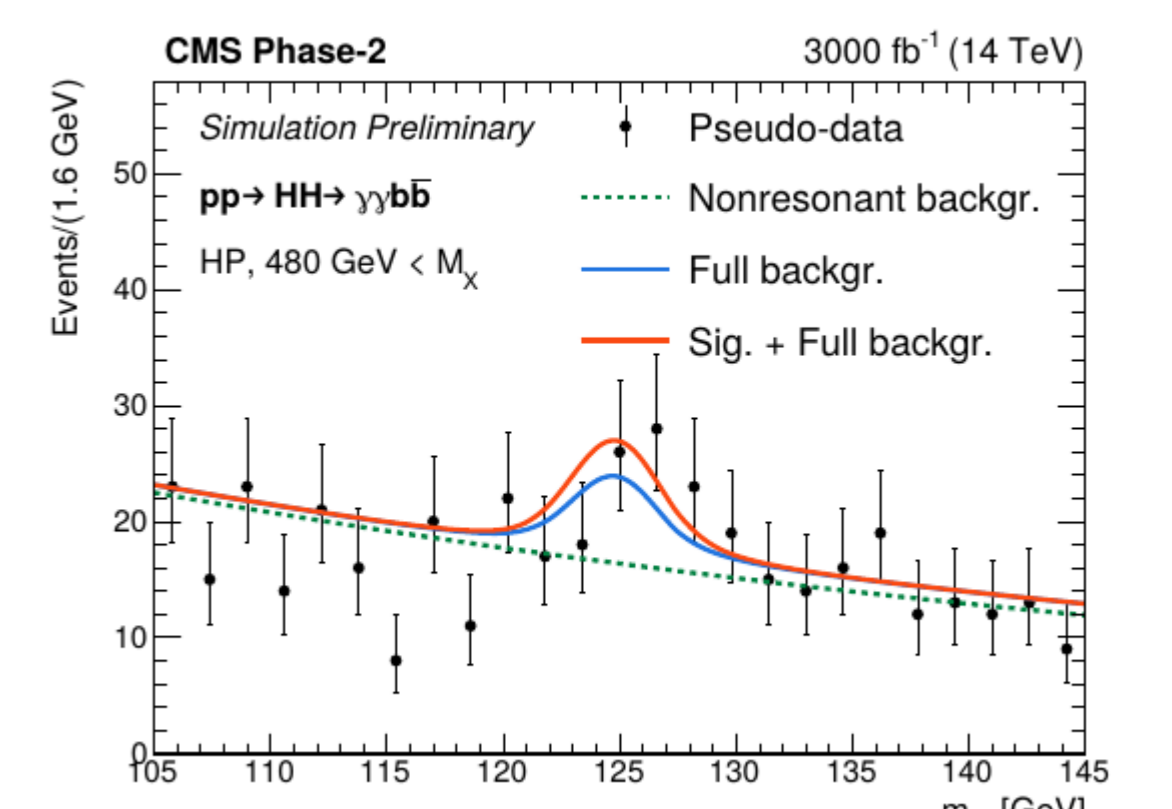
Selection :

- 2 b-jets with  $80 \text{ GeV} < m_{bb} < 190 \text{ GeV}$
- 2 photons with  $100 \text{ GeV} < m_{\gamma\gamma} < 180 \text{ GeV}$

Expected yield :

- 40 Signal events
- 3790 Background events
- $S/N = 1.1 \times 10^{-2}$

- ttH suppressed using a BDT classifier combining 8 variables
- Global  $m_{\gamma\gamma}$  fit in 2 BDT x 3  $M_x$  categories where  $M_x = m_{bb\gamma\gamma} - m_{bb} - m_{\gamma\gamma} + 250 \text{ GeV}$



## HH → bbZZ(4l)

$$\mathcal{B} = 0.015\%$$

Selection:

- 2 Z( $ee, \mu\mu$ ) candidates with  $50 \text{ GeV} < m_{Z1} < 100 \text{ GeV}$
- $12 \text{ GeV} < m_{Z2} < 60 \text{ GeV}$
- $120 \text{ GeV} < m_{llll} < 130 \text{ GeV}$

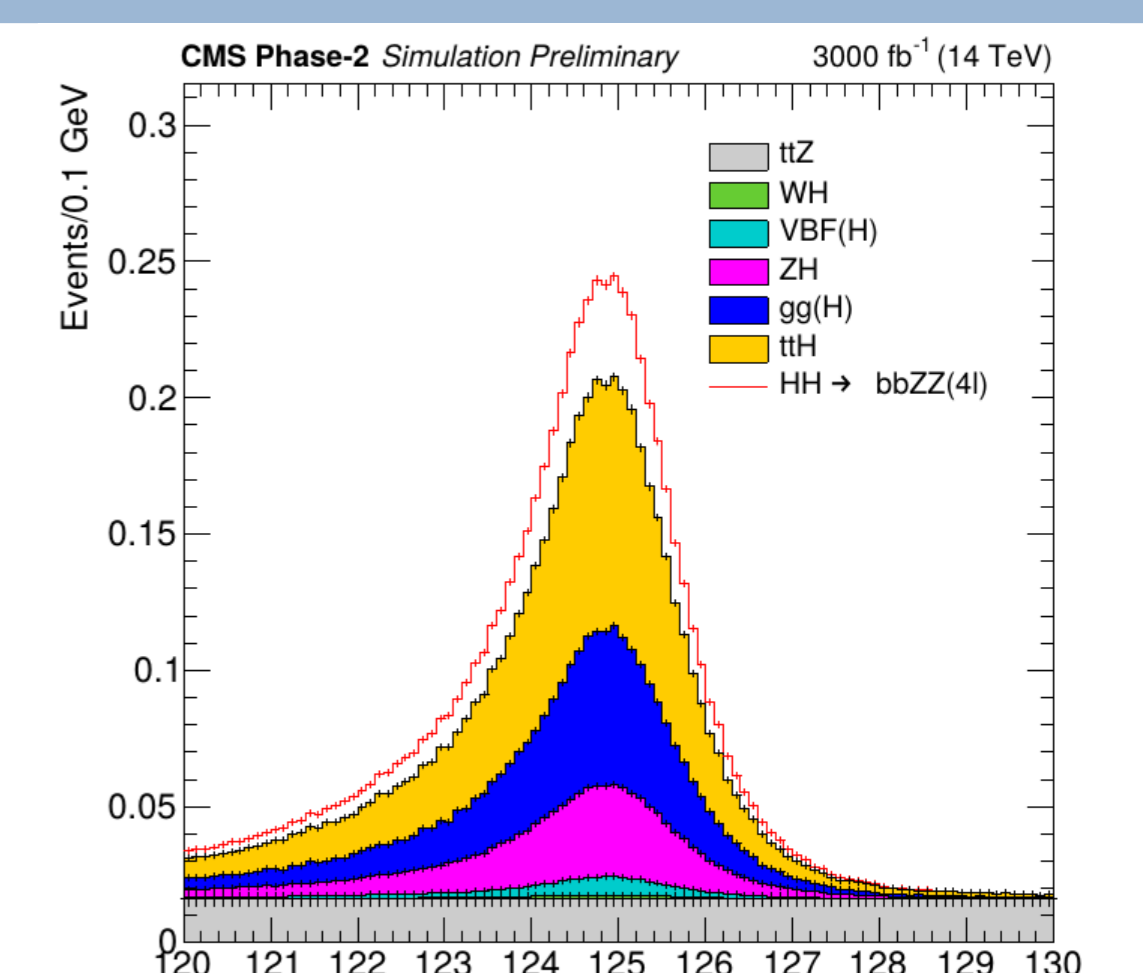
Selection :

- 2 or 3 b-jets with  $90 \text{ GeV} < m_{bb} < 150 \text{ GeV}$

Expected yield :

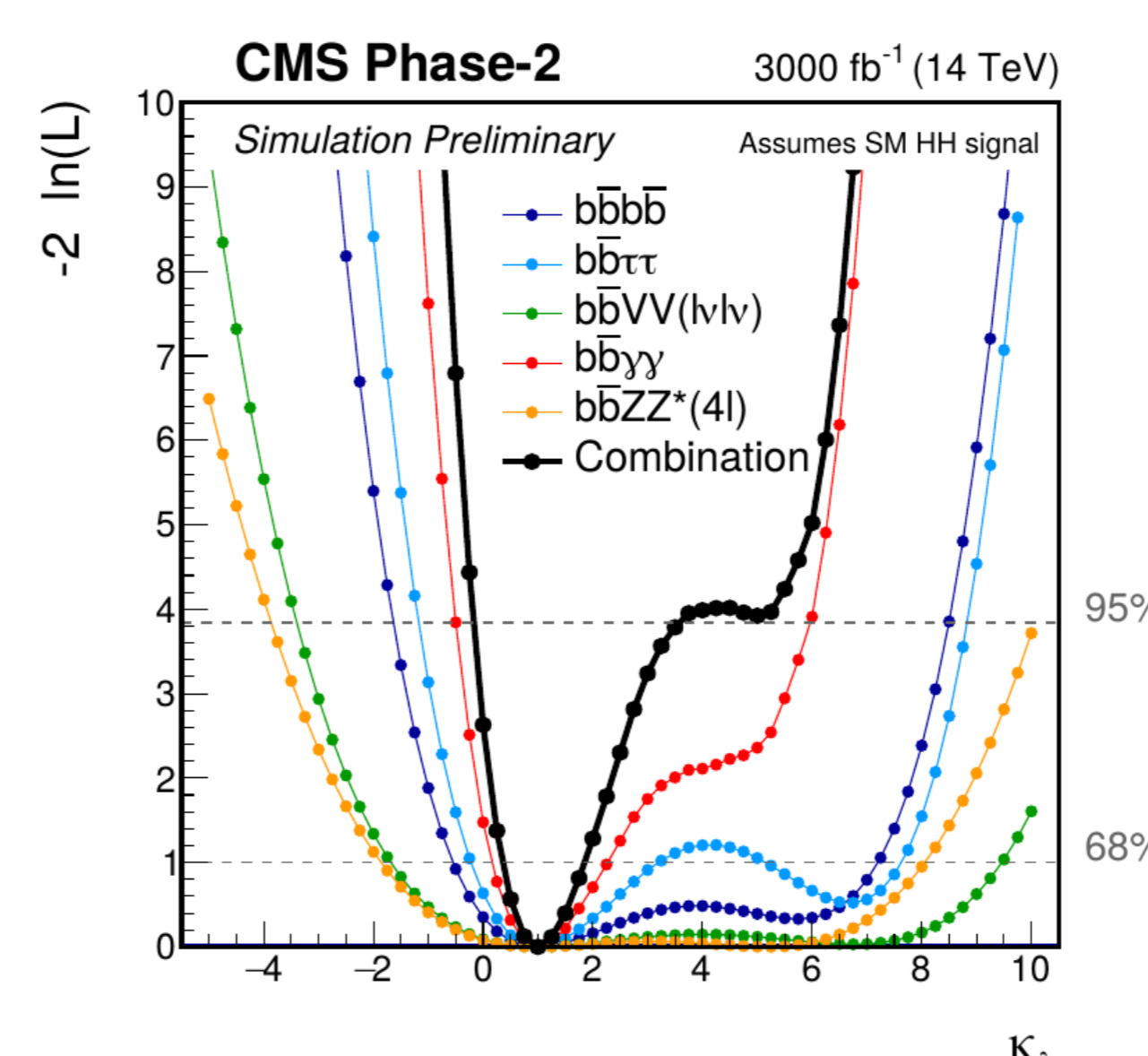
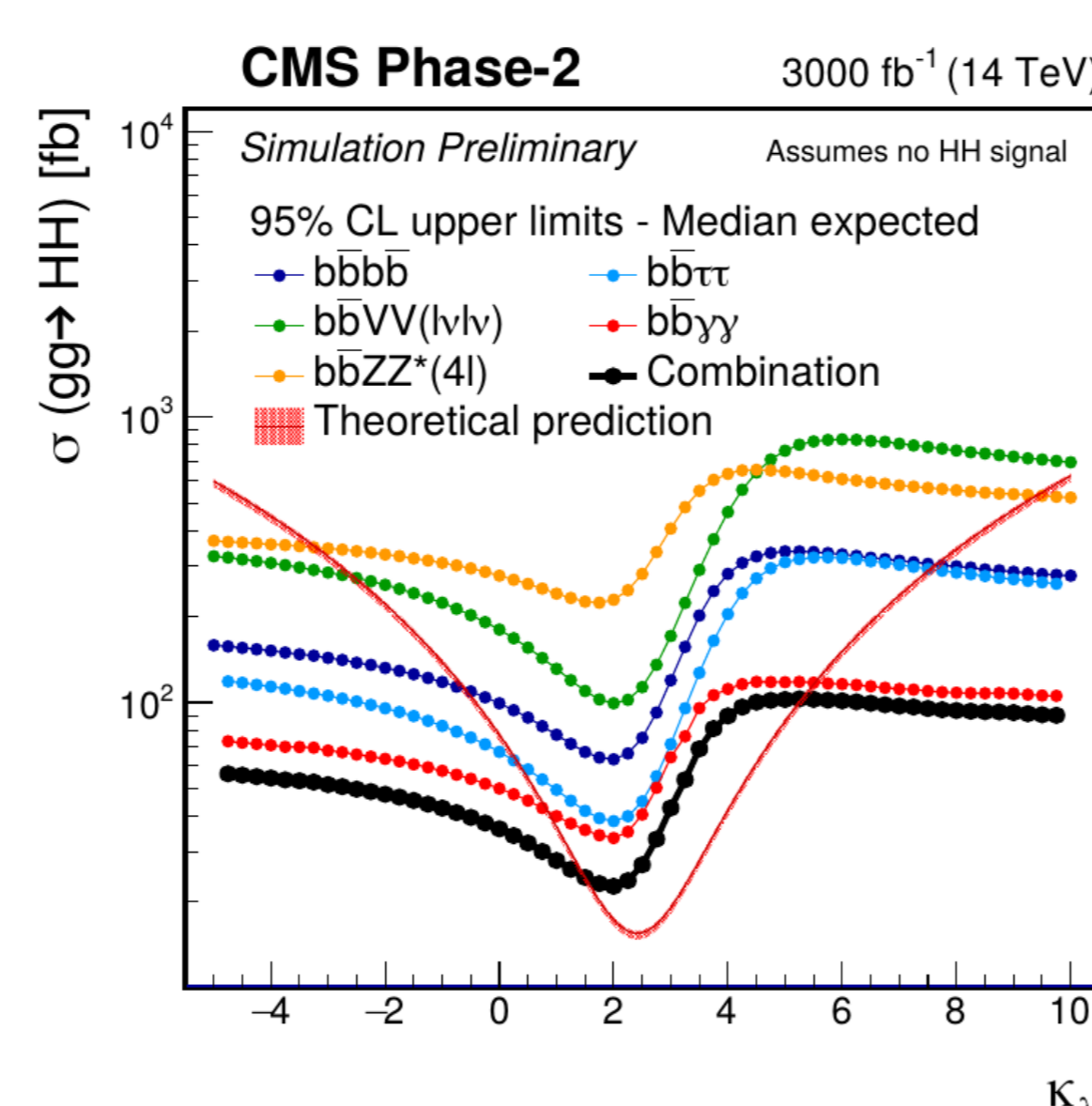
- 1 Signal event
- 6.8 Background events
- $S/N = 0.15$

- Kinematic cuts make the final state very clean, but with a very low signal yield



## Results and combination

Channel	Significance	
	Stat. + syst.	Stat. only
bbbb	0.95	1.2
bbττ	1.4	1.6
bbWW(lνlν)	0.56	0.59
bbγγ	1.8	1.8
bbZZ(llll)	0.37	0.37
Combination	2.6	2.8



- $0.35 < \kappa_\lambda < 1.9$  at 68 % Confidence level
- $-0.18 < \kappa_\lambda < 3.8$  at 95 % Confidence level

## Summary

- Challenging even at HL-LHC with  $3000 \text{ fb}^{-1}$
- $2.6 \sigma$  expected
- $-0.18 < \kappa_\lambda < 3.8$  expected

## Reference

- CMS PAS HIG-17-030, Combination of searches for Higgs boson pair production in proton-proton collisions at  $\sqrt{s} = 13 \text{ TeV}$
- CMS PAS FTR-18-019, Prospects for HH measurements at the HL-LHC