Prospects for di-Higgs measurements in the $bb\gamma\gamma$ final state at the High-Luminosity LHC with the PhaseII CMS detector

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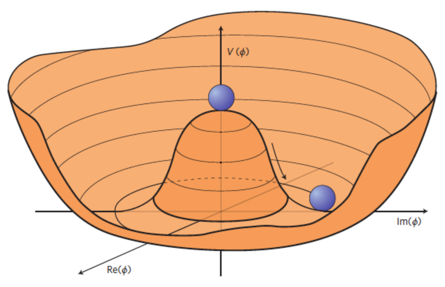
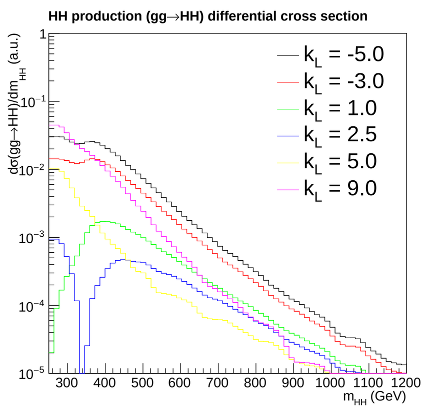
Why are di-Higgs measurements so interesting?

Observation of HH production and direct measurement of the Higgs boson self-coupling constant λ are among the most challenging targets of CMS at the High-Luminosity Phase



Measurements of fundamental properties of Standard Model

- The shape of the Higgs-boson-field potential depends on the λ parameter
- Test the Standard Model expectation for λ

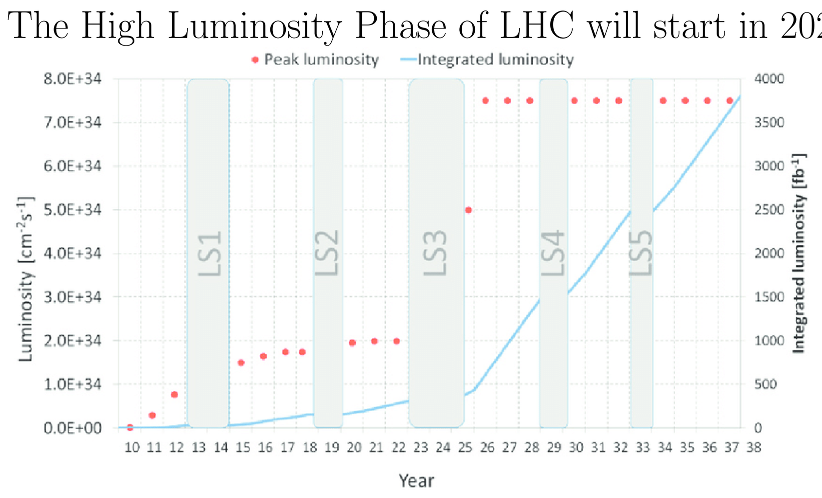


Search for effects Beyond Standard Model

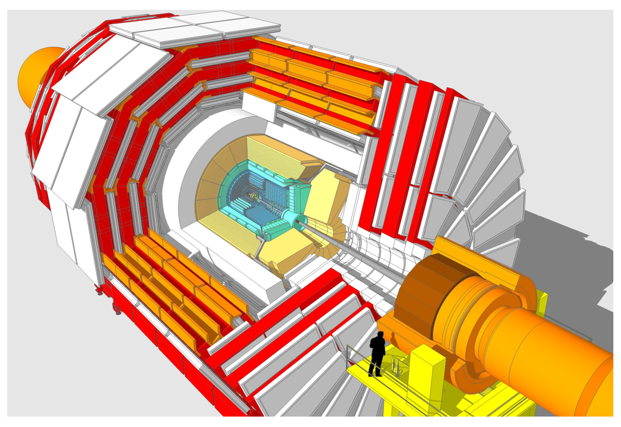
- di-Higgs production cross section is sensitive to possible BSM Higgs Boson couplings → modification of the value of $k_\lambda = \lambda/\lambda_{SM}$
  - → Modification of the total cross section
  - → Modification of the kinematics → differential cross section
- Powerful tool to test BSM theories

The High-Luminosity Phase of the LHC

The High Luminosity Phase of LHC will start in 2025. An **upgraded CMS detector** will cope with the **increase of the instantaneous luminosity**, hence increase of pileup and radiation damage.



- **Increase of instantaneous luminosity by a factor ~ 4**
  - → 140-200 collisions per bunch crossing
  - → Increase of pileup and radiation damage of detector subcomponents
- Data equivalent to $\mathbf{L = 3000\ fb^{-1}}$ of luminosity expected **at the end** of 10 years of operations, 4000 fb^{-1} in an optimistic scenario



- **Upgrade of trigger**: increase L1 rate to 750 KHz and HLT to 7.5 kHz
- **Upgrade of tracker**: higher granularity and coverage extended up to $\eta = 3$
- **Upgrade of ECAL**: front-end electronics
- **Upgrade of muon detector**: DT and CSC electronics and new forward detector
- Installation of the **new timing detector**
- Installation of the **new High Granularity (forward) Calorimenter**: replacing ECAL and HCAL endcaps

- About 10^5 expected di-Higgs production events (gluon fusion) in Standard Model hypothesis

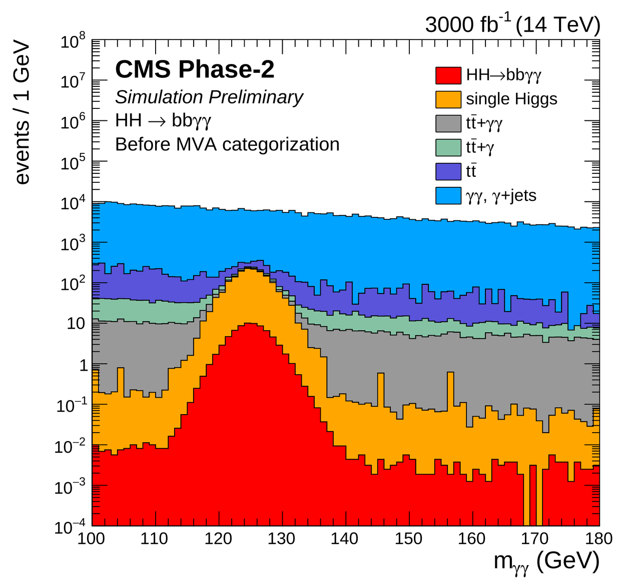
Search in $HH \to bb\gamma\gamma$ decay channel

- Whereas $bb\gamma\gamma$ decay channel has a relatively **low branching ratio**, the signature with **two highly energetic photons with di-photon mass consistent with the Higgs Boson mass makes this channel very clean, and provides a high sensitivity**

Channel	$B.R.\%$
$bbbb$	33.6
$bbtt$	7.3
$bbWW(l\nu l\nu)$	1.7
$bb\gamma\gamma$	**0.26**
$bbZZ(llll)$	0.015

- Kinematic selections aiming to **select events with two high-energy photons and two high-energy heavy-flavoured jets**

Photon selections	Jet selections
$p_T/M_{\gamma\gamma} > 1/3$ (leading γ), $> 1/4$ (subleading γ)	$p_T > 25$ GeV
$\lvert\eta\rvert < 1.44$ or $1.57 < \lvert\eta\rvert < 2.5$	$\lvert\eta\rvert < 2.5$
100 GeV$< M_{\gamma\gamma} < 180$ GeV	80 GeV$< M_{jj} < 190$ GeV
	$\Delta R_{\gamma j} > 0.4$
	At least 2 b-tagged jet (loose WP)

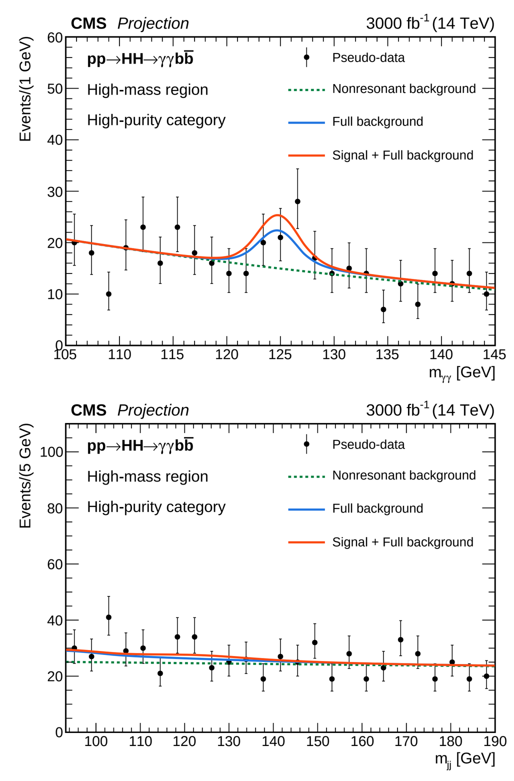


- **Main background** contributions:
  - → **di-photon** production in association with jets
  - → **single photon** production in association with jets, with one jet misidentified as a photon
  - → **single-Higgs background**, in particular from Higgs Boson associated production with two top quarks (**ttH**)

- *ttH-tagger*: **Boosted Decision Tree to discriminate signal from ttH events**
  - → Very similar signature
  - → Achieve 75% background rejection for 90% efficiency
- *HH-tagger*: **Boosted Decision Tree to discriminate signal from all the background excluding ttH**
- Event categorization: **categorize events depending on m_X and BDT score**
  - → Define $m_X[\text{GeV}] = m_{\gamma\gamma jj} - m_{\gamma\gamma} - m_{jj} + 250$ (for signal $m_X \simeq m_{HH}$)
  - → 3 mass intervals and 2 orthogonal BDT-score intervals for a total of 6 categories
  - $* m_X$ intervals (GeV): $[250, 350] - [350, 480] - [480, +\infty)$

Limits extraction procedure for $bb\gamma\gamma$ channel

- **Simultaneous fit of m_{jj} and $m_{\gamma\gamma}$** considering them uncorrelated
- ~ 40 selected $HH \to bb\gamma\gamma$ SM signal events
  - → Efficiency × acceptance $\simeq 14\%$
- **Most of selected HH events (35/40) are in the 4 high mass categories**
  - → Background per category is $\sim$ **30** for **single Higgs** and $\sim$ **200**(**900**) for **continuum background** in high(medium) BDT purity categories within 2σ of $m_{\gamma\gamma}$ peak
  - → Low mass categories have low signicance for SM analysis but are fundamental for k_λ scan



Results of projections at 3000 fb^{-1}

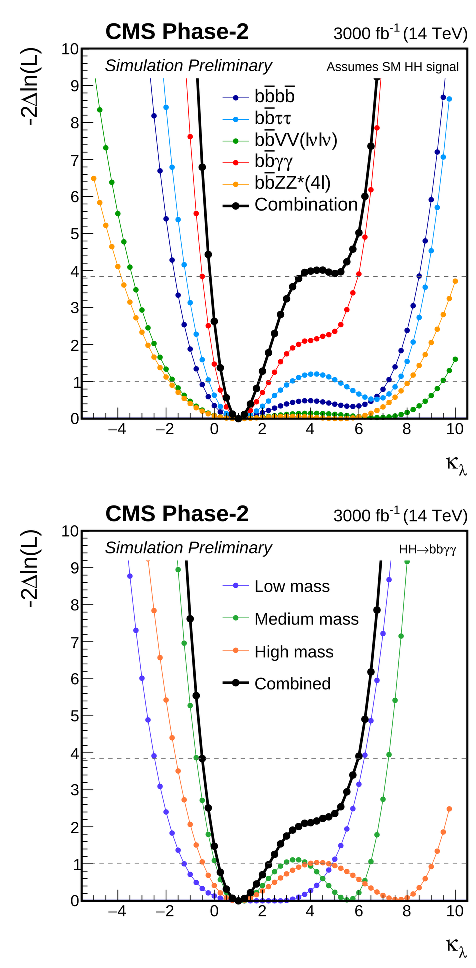
SM analysis: **Most significant contribution** for the limit to σ_{SM} **from bb$\gamma\gamma$ channel**

Channel	Significance		95% CL limit on $\sigma_{HH}/\sigma_{HH}^{SM}$	
	Stat. + syst.	Stat. only	Stat. + syst.	Stat. only
$bbbb$	0.95	1.2	2.1	1.6
$bb\tau\tau$	1.4	1.6	1.4	1.3
$bbWW(l\nu l\nu)$	0.56	0.59	3.5	3.3
$bb\gamma\gamma$	**1.8**	**1.8**	**1.1**	**1.1**
$bbZZ(llll)$	0.37	0.37	6.6	6.5
Combination	2.6	2.8	0.77	0.71

Search for di-Higgs anomalous couplings

1. Reweight SM signal accordingly to the each k_λ hypothesis, all the other possible BSM couplings are constrained to their SM value
2. Compute the corresponding likelihood given the SM hyphothesis

- **Most stringent constraint** comes **from HH → bb$\gamma\gamma$ channel**
  - → $-0.5 < k_\lambda < 6$ at 95% C.L. using only $bb\gamma\gamma$ channel
  - → $\mathbf{-0.18 < k_\lambda < 0.36}$ **at** 95% **C.L. combining all channels**
  - → Very good result achieved thanks to the mass categorization



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