Probing the Higgs self couplings via single-Higgs differential measurements

At the HL-LHC

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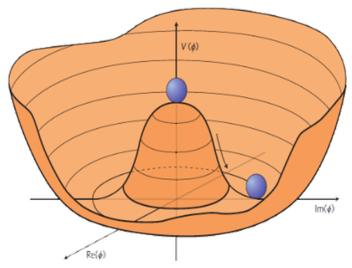
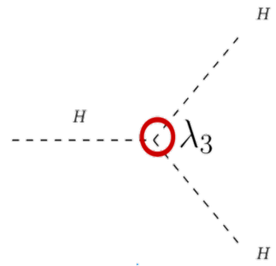
Motivation

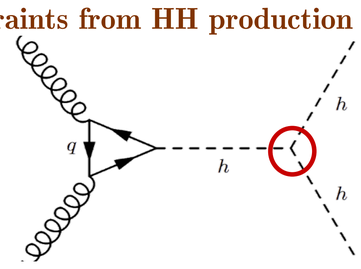
- Higgs self couplings offer particle physics' only probe of Higgs scalar potential

$$V(H) = \frac{m_H^2}{2}H^2 + \lambda_3 v H^3 + \frac{1}{4}\lambda_4 H^4$$



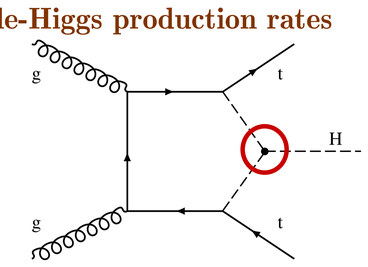


- Constraints from HH production remain limited:



- Extremely small SM cross-section
- Difficult final states

- Alternative: exploit radiative corrections to single-Higgs production rates
- λ_3 dependent corrections modify external Higgs boson kinematics



Precision measurements of single-Higgs differential cross sections: access λ_3

What is the HL-LHC?

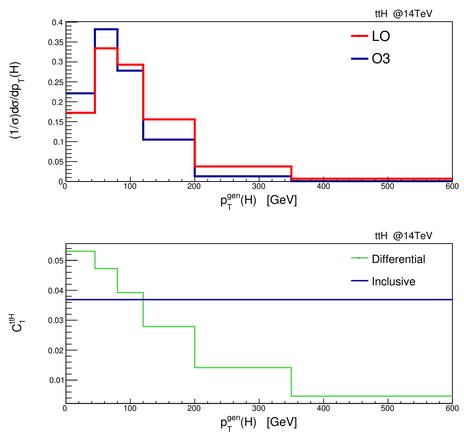
- Future upgrade of the LHC machine: start data taking in 2026
- Improved magnets: drives a factor of 5 increase in instantaneous luminosity
- **CMS Phase-2**: major improvements across all sub-systems of the detector
- 3000 fb^{-1} of pp-collision data @ 14 TeV, allows such Higgs precision measurements!
- But... beware of pile-up!

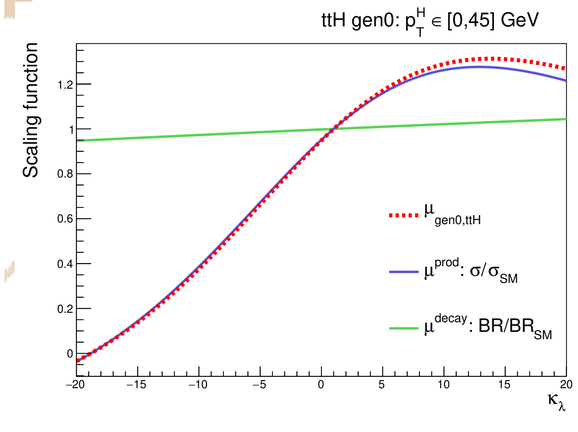
Theoretical framework

- Anomalous coupling parameterisation: $\kappa_\lambda = \lambda_3/\lambda_3^{\rm SM}$

$$\frac{\sigma_i}{\sigma_i^{\rm SM}} = \mu_i^{\rm prod}(\kappa_\lambda, C_1^i) \quad \& \quad \frac{\rm BR}{\rm BR_{SM}} = \mu^{\rm decay}(\kappa_\lambda)$$

- Cross section & BR scale as a function of κ_λ
- Different scaling factor in each bin (i) of Higgs boson observable
- C_1^i : production mode + kinematic dependence. Largest for **ttH** (at threshold)!
  - enhanced κ_λ dependence due to heavy mass of top quark legs

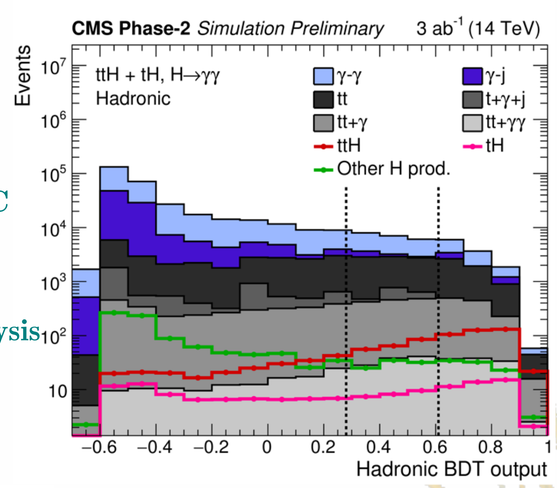


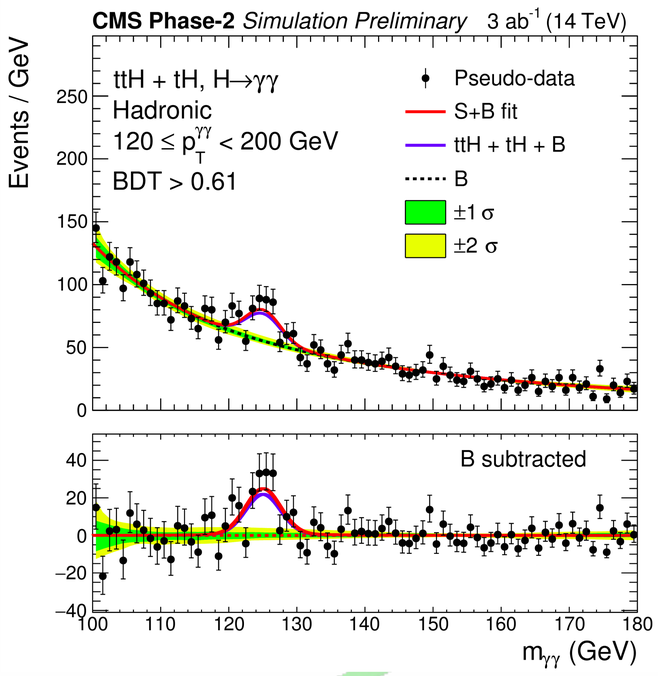


Motivates ttH (+tH) $d\sigma/dp_T^H$ measurements!

Analysis Overview $ttH + tH(H \to \gamma\gamma)\, d\sigma/dp_T^H$

- Diphoton final state:
  Low bkg + good photon energy resolution
- Delphes simulation: CMS Phase-2 @ HL-LHC
  Assuming 3000 fb^{-1}, 14 TeV CoM energy
- Event selection: based on 2018 ttH($\gamma\gamma$) analysis
  Both hadronic & leptonic decay channels:
  1) Initial pre-selection
  2) BDT: improve S/B





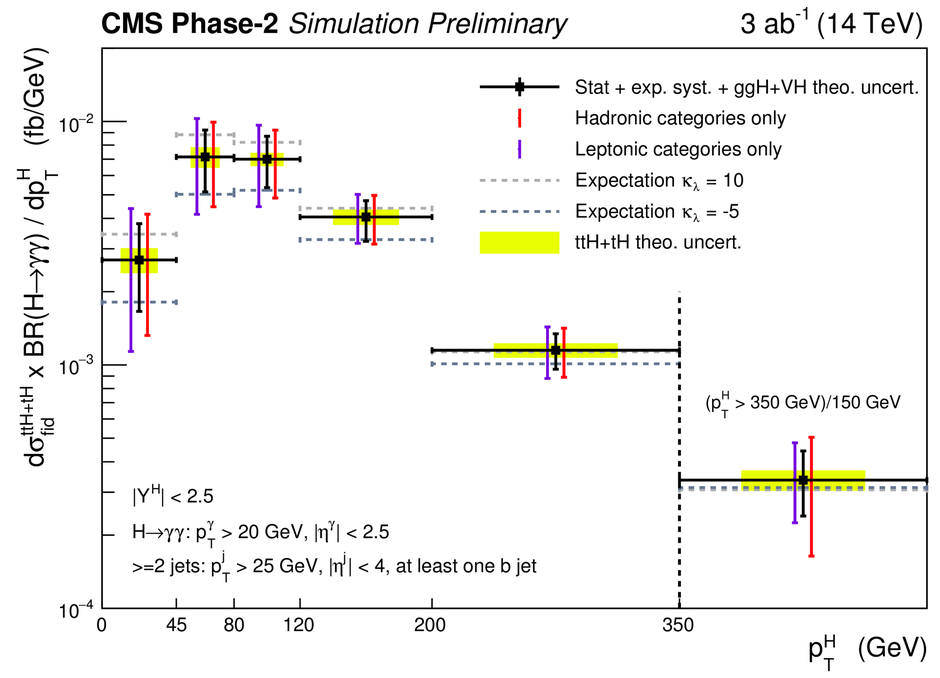
- Fit sig+bkg model to $m_{\gamma\gamma}$ spectrum spectrum in bins of p_T^H
- Bins chosen to maximise sensitivity to κ_λ
- Unfold detector effects: extract generator-level p_T^H spectrum
- Likelihood scan, allowing signal processes to scale according to:

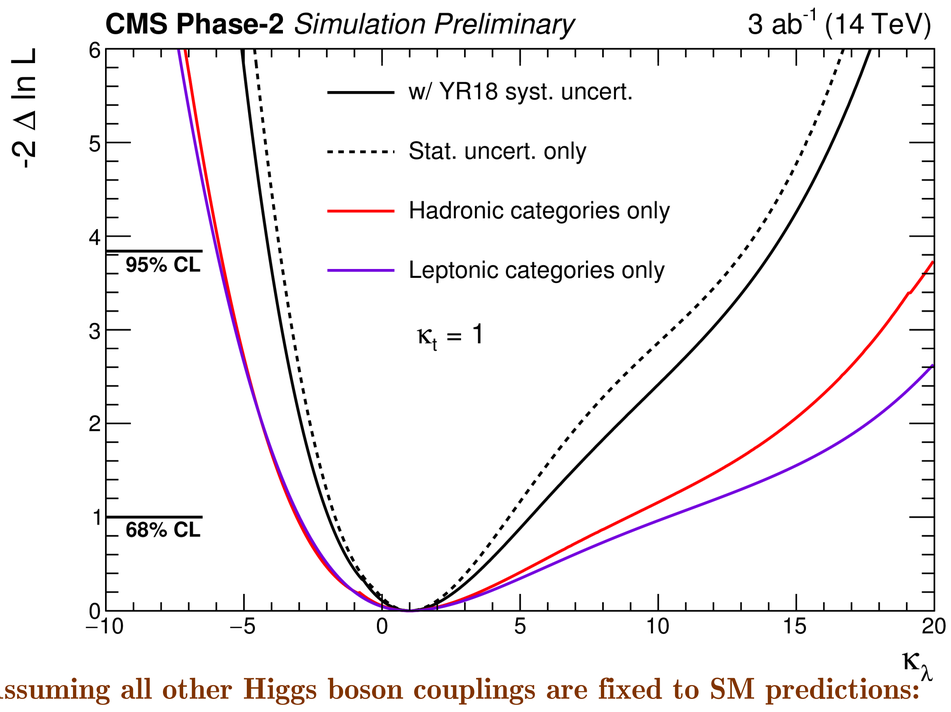
$$\mu_i^{\rm prod}(\kappa_\lambda, C_1^i) \times \mu^{\rm decay}(\kappa_\lambda)$$

- Using respective C_i[1]

Extract HL-LHC constraints on κ_λ via indirect, complementary probe!

Results





- Assuming all other Higgs boson couplings are fixed to SM predictions:

$$-4.1 < \kappa_\lambda < 14.1 \ @\ 95\%\ \text{C.L.}$$

Conclusions

- Proof of concept: additional sensitivity to λ_3
- Possible to disentangle λ_3 deviations from other anomalous couplings using differences in shape of measured spectrum
- Only considered ttH+tH in $\gamma\gamma$ final state: other channels provide extra sensitivity
- Complementary measurement to HH. Increasingly important at far future colliders (e.g. FCC) where HH becomes systematically limited

Where to find out more?

- **CMS-PAS-FTR-18-020:**
  http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/FTR-18-020/index.html
- **Higgs Physics at the HL-LHC and HE-LHC (Chapters 2.4.2 and 3.5.2):**
  https://arxiv.org/abs/1902.00134

JHEP, 08:054, 2016 *Phys. Rev.* D92:092994, 2015 *JHEP*, 12:080, 2016 *Eur. Phys. J.*, C77(12):887, 2017