Constraints on the Higgs boson self-coupling from the combination of single-Higgs and double-Higgs production analyses performed with the ATLAS experiment

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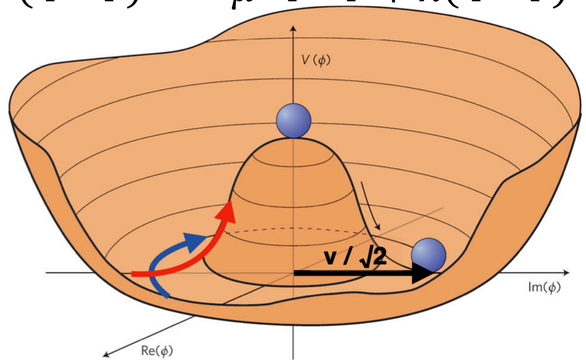
Introduction

$$V(\Phi^+\Phi) = -\mu^2\Phi^+\Phi + \lambda(\Phi^+\Phi)^2$$



- The scalar sector is the cornerstone of the SM
- A scalar potential with a vacuum expectation value $v \neq 0$ originates a spontaneous breaking of the electroweak symmetry (Higgs mechanism)
- $V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_{HHH} v H^3 + \frac{1}{4}\lambda_{HHHH} H^4 - \frac{\lambda}{4} v^4$
- $\lambda_{SM} = \frac{m_H^2}{2v^2}$

- Measuring the strength of the **self-coupling λ** is important to probe the properties of the scaler sector and to precisely describe the shape of Higgs boson potential

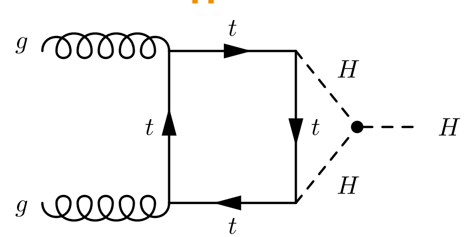
- The properties of **Higgs boson self-coupling** are largely unconstrained
- Measuring the Higgs self-coupling is also one of the main goals of HL-LHC and future colliders

- Combine **single-Higgs** and **double-Higgs** production analyses could maximize the sensitivity to constrain $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$

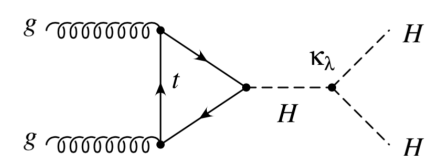
- **Data and input measurement**

Analysis	Integrated luminosity (fb^{-1})
$H \to \gamma\gamma$	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VH, $H \to b\bar{b}$	79.8
$t\bar{t}H$, $H \to b\bar{b}$ and $t\bar{t}H$ multilepton	36.1
$HH \to b\bar{b}b\bar{b}$	27.5
$HH \to b\bar{b}\tau^+\tau^-$	36.1
$HH \to b\bar{b}\gamma\gamma$	36.1

H



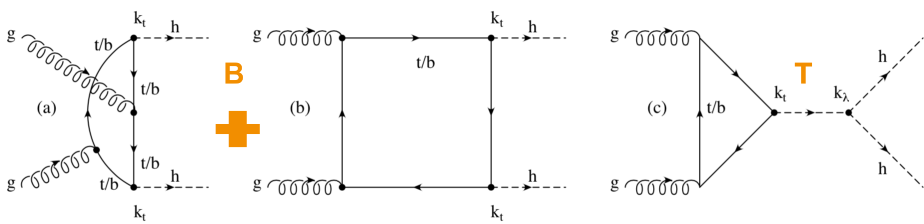
HH



- The **single-Higgs** and **double-Higgs** analyses are not all orthogonal by construction
- The overlap has been studied, the $ttH(\gamma\gamma)$ categories have been removed as they show large overlap with the $HH \to bb\gamma\gamma$ categories

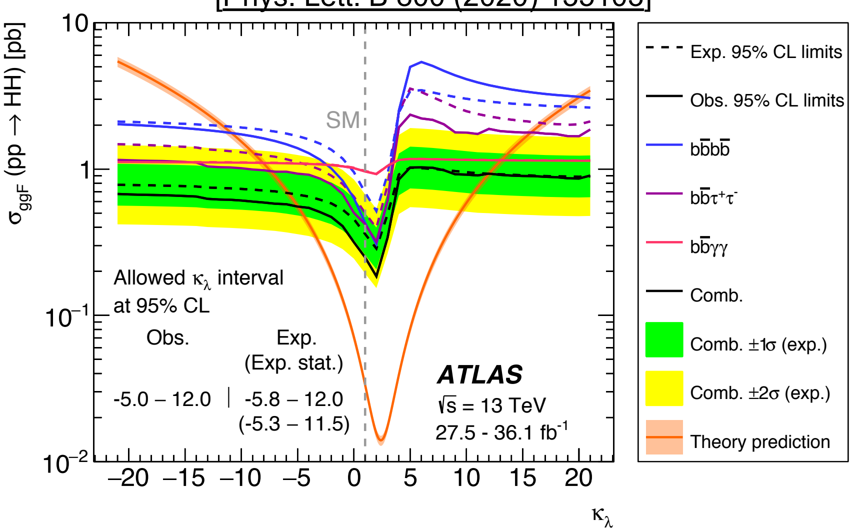
Higgs self-coupling interpretations

- The **non-resonant HH** production processes (ggF) provide a unique chance to probe κ_λ with direct measurements

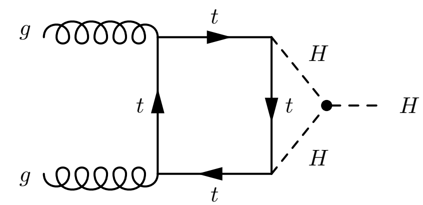


- $\sigma(pp \to HH) \sim \kappa_t^4 \left[|B|^2 + \frac{\kappa_\lambda}{\kappa_t}(B^*T + TB^*) + \left(\frac{\kappa_\lambda}{\kappa_t}\right)^2 |T|^2 \right]$

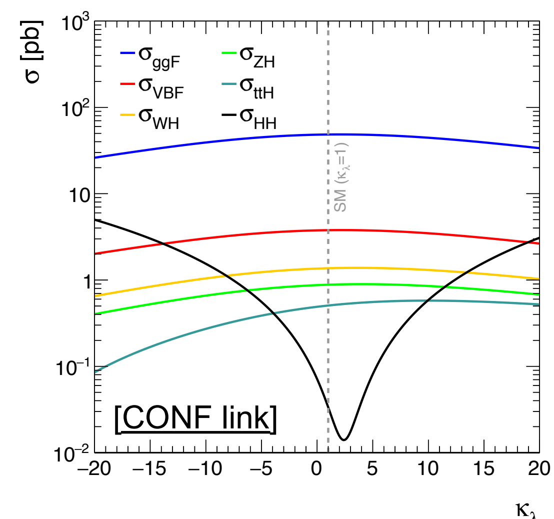
[Phys. Lett. B 800 (2020) 135103]



- **Single Higgs** processes do not depend on λ_{HHH} at LO, while its contributions need to be considered for the complete **NLO EWK** corrections



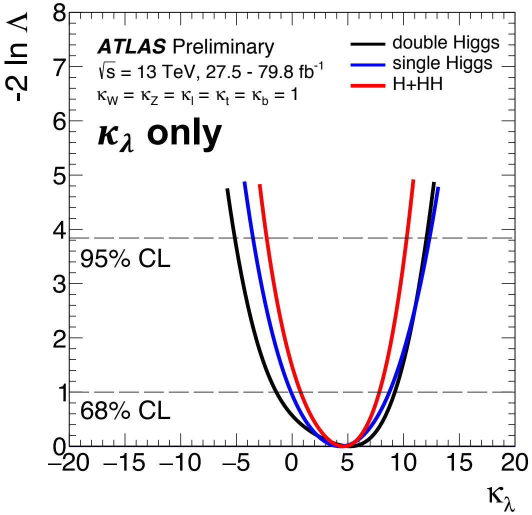
- An **indirect constraint** on λ_{HHH} can be extracted in correcting signal strength for the λ_{HHH} -dependent NLO EW effects
- $\mu_{if}(\kappa_\lambda) = \mu_i(\kappa_\lambda) \times \mu_f(\kappa_\lambda) \equiv \frac{\boldsymbol{\sigma_i(\kappa_\lambda)}}{\boldsymbol{\sigma_{SM,i}}} \times \frac{\boldsymbol{BR_f(\kappa_\lambda)}}{BR_{SM,f}}$

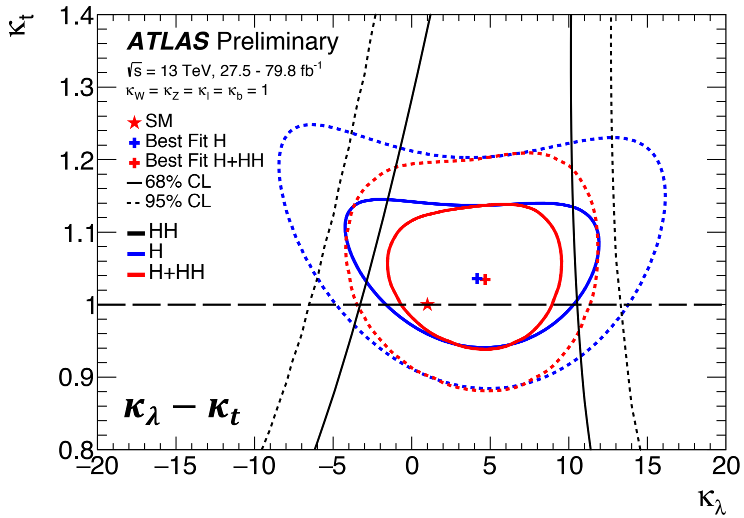


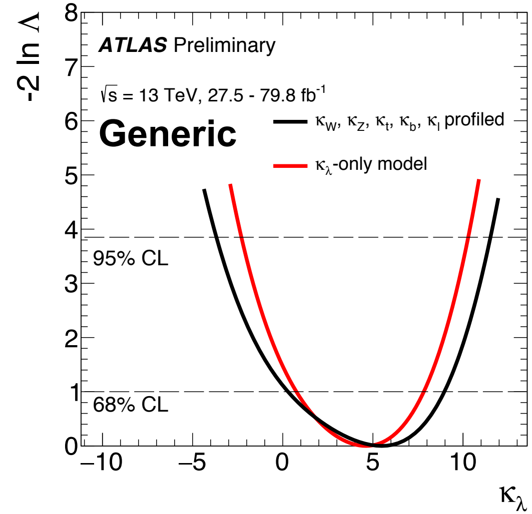
Higgs self-coupling combination results

- A likelihood fit is performed to constrain κ_λ in the **combination** of single-Higgs and double-Higgs

[ATLAS-CONF-2019-049]







- $\kappa_\lambda = 4.6^{+3.2}_{-3.8}\left(4.6^{+2.9}_{-3.5}(stat.)^{+1.2}_{-1.2}(exp.)^{+0.7}_{-0.5}(sig.th.)^{+0.6}_{-1.0}(bkg.th.)\right)$ (**κ_λ only**)

95% CL (κ_λ only)	Obs.	Exp.
H [ATL-PHYS-PUB-2019-009]	[-3.2, 11.9]	[-6.2, 14.4]
HH [Phys. Lett. B 800 (2020) 135103]	[-5.0, 12.0]	[-5.8, 12.0]
H+HH [ATLAS-CONF-2019-049]	[-2.3, 10.3]	[-5.1, 11.2]

- The sensitivity from **single-Higgs** and **double-Higgs** is similar
- The **double-Higgs** analysis alone doesn't have sensitivity to constrain **κ_λ and κ_t** simultaneously
- Only the **single-Higgs** and **double-Higgs combination** can give enough sensitivity to exploit the generic model
- The combination can better constrain κ_λ (~20% improvement in 95% CL)