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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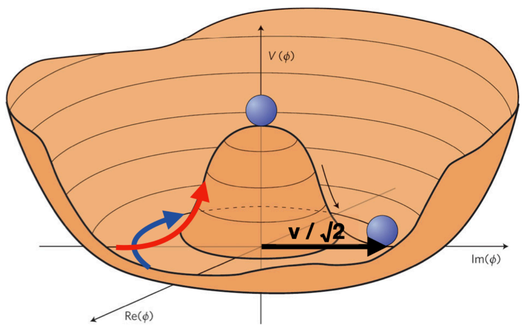
The scalar sector and the self-coupling



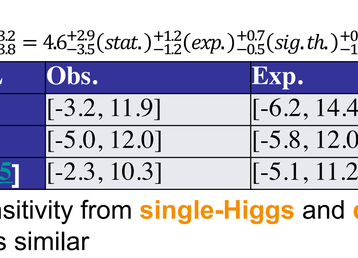
$$V(\Phi^+\Phi) = -\mu^2\Phi^+\Phi + \lambda(\Phi^+\Phi)^2$$

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).**

$$V(H) = \frac{1}{2}m_H^2H^2 + \lambda_{HHH}vH^3 + \frac{1}{4}\lambda_{HHHH}H^4 - \frac{\lambda}{4}v^4$$

$$\lambda_{SM} = \frac{m_H^2}{2v^2}$$

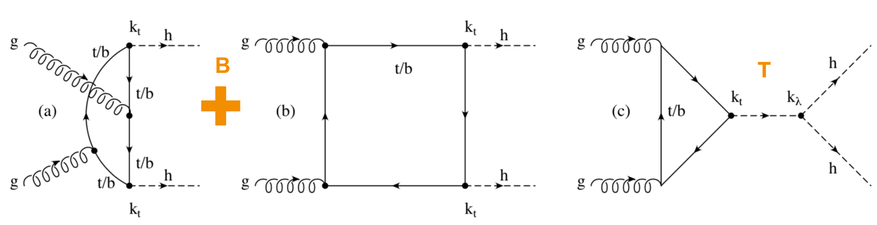
Measuring the strength of the **self-coupling λ** is important to probe the properties of the scaler sector and to precisely describe the shape of Higgs boson potential.



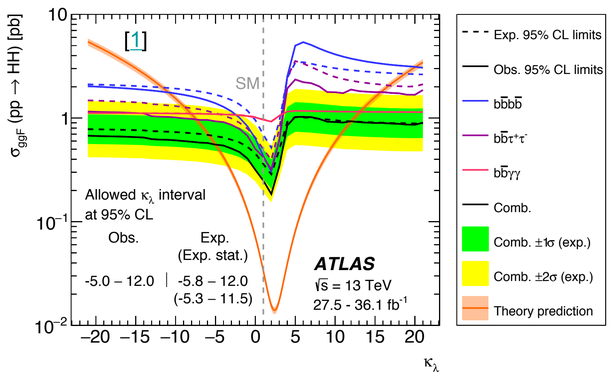
The properties of **Higgs boson self-coupling** are largely unconstrained.
Measuring the Higgs self-coupling is also one of the main goals of HL-LHC and future colliders.

Direct searches for HH

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

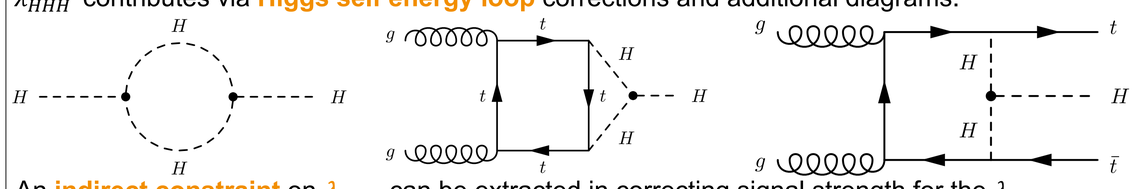


$$\sigma(pp \to HH) \sim \kappa_t^4\left[|B|^2 + \frac{\kappa_\lambda}{\kappa_t}(B^*T + TB^*) + \left(\frac{\kappa_\lambda}{\kappa_t}\right)^2|T|^2\right]$$



Indirect measurements of κ_λ using single Higgs production

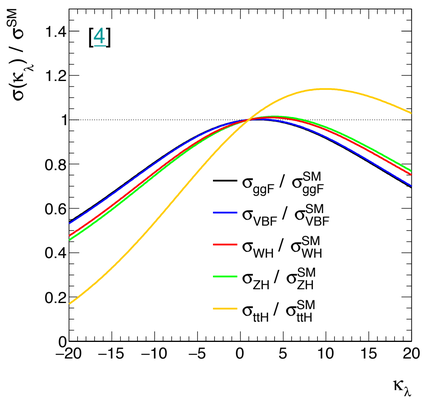
Single Higgs processes do not depend on λ_{HHH} at LO, while its contributions need to be considered for the complete **NLO EWK** corrections.
λ_{HHH} contributes via **Higgs self energy loop** corrections and additional diagrams.



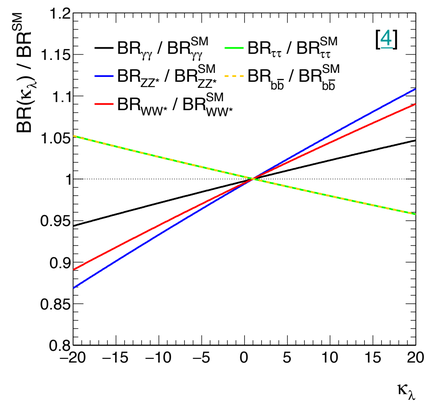
An **indirect constraint** on λ_{HHH} can be extracted in correcting signal strength for the λ_{HHH} -dependent NLO EW effects.

Signal strength: $\mu_{if}(\kappa_\lambda) = \mu_i(\kappa_\lambda)\times\mu_f(\kappa_\lambda) \equiv \frac{\sigma_i(\kappa_\lambda)}{\sigma_{SM,i}} \times \frac{BR_f(\kappa_\lambda)}{BR_{SM,f}}$

Production mode



Higgs boson decay rates



The combination of single-Higgs and double-Higgs production analyses

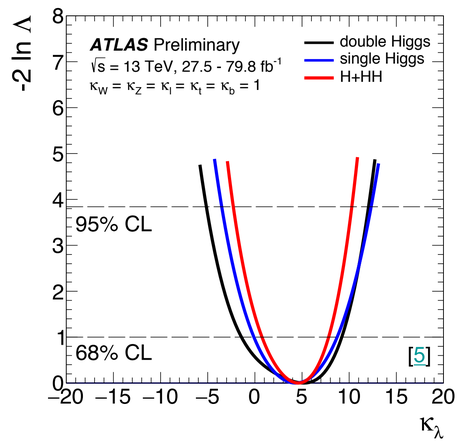
Combine **single-Higgs** and **double-Higgs** together to maximize the sensitivity to constrain κ_λ.

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

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.

κ_λ-only results



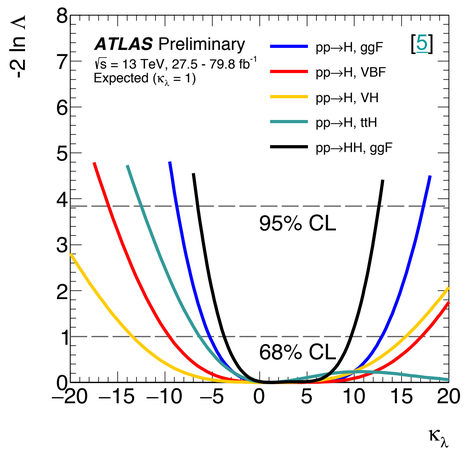
$$\kappa_\lambda = 4.6^{+3.2}_{-3.8} = 4.6^{+2.9}_{-3.5}(stat.)^{+1.2}_{-1.2}(exp.)^{+0.7}_{-0.5}(sig.th.)^{+0.6}_{-1.0}(bkg.th.)$$

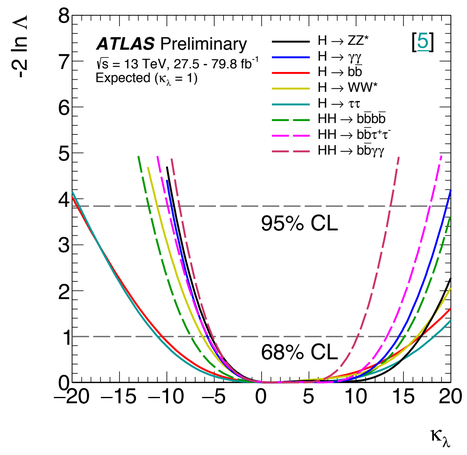
95% CL	Obs.	Exp.
H [4]	[-3.2, 11.9]	[-6.2, 14.4]
HH [1]	[-5.0, 12.0]	[-5.8, 12.0]
H+HH [5]	[-2.3, 10.3]	[-5.1, 11.2]

The sensitivity from **single-Higgs** and **double-Higgs** is similar
The combination can better constrain κ_λ (~20% improvement in 95% CL).

Higgs production/decay contributions

With SM expectation ($\kappa_\lambda = 1$), estimate the contributions from different **productions (including double-Higgs)** and **decay modes.**

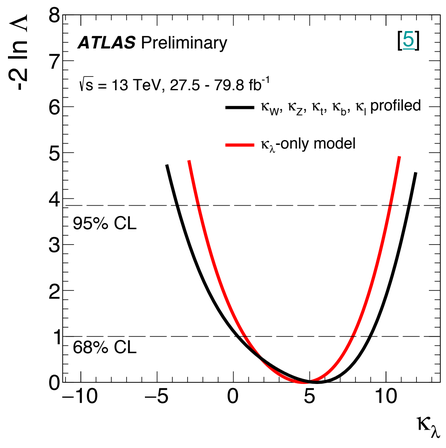




With the present analysis statistics,
HH (ggF) production is the most **sensitive** channel among all Higgs production processes, followed by **ggF, single H.**
$HH \to bb\gamma\gamma$, $HH \to bb\tau\tau$ give the largest contributions in constraining κ_λ, followed by $H \to \gamma\gamma$.

Generic model

For a more **model-independent** measurement, a likelihood fit is performed to constrain simultaneously κ_λ, κ_W, κ_Z, κ_t, κ_b and κ_l.



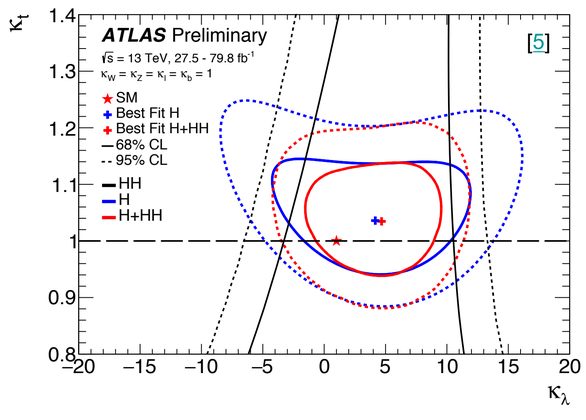
Only the **single-Higgs** and **double-Higgs combination** can give enough sensitivity to exploit this generic model.

$\kappa_\lambda - \kappa_t$ measurement

To constrain κ_λ, κ_t simultaneously, other **Higgs couplings** are fixed to the **SM** (i.e κ_W, κ_Z, κ_b, κ_l).

The **double-Higgs** analysis alone (black in the figure) doesn't have sensitivity to constrain κ_λ **and** κ_t simultaneously.

The **combination** of single-Higgs and double-Higgs can provide greater constraining power.



References

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[2] Probing the Higgs self coupling via single Higgs production at the LHC, arXiv: 1607.04251
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[4] Constraint of the Higgs boson self-coupling from Higgs boson differential production and decay measurements, ATL-PHYS-PUB-2019-009
[5] Constraints on the Higgs boson self-coupling from the combination of single-Higgs and double-Higgs production analyses performed with the ATLAS experiment, ATLAS-CONF-2019-049

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