Laboratoire d'Annecy de Physique des Particules

Higgs-boson self-coupling constraints from single Higgs, double Higgs and Electroweak measurements

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IRN Terascale, 5/07/2021

Enigmass
The enigma of mass

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Physics motivation

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\psi} \not{D} \psi + h.c. + \bar{\psi}_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

- Measuring the Higgs-boson self-couplings is a crucial validation of the Brout-Englert-Higgs (BEH) mechanism.
- The self-couplings determine the shape of the potential, that is linked to many open questions of particle physics and cosmology, like the phase transition of the early universe from the unbroken to the broken electroweak symmetry.

$$V_H = \mu^2 \phi^\dagger \phi + \frac{1}{2} \lambda (\phi^\dagger \phi)^2$$

- The Higgs-potential low energy expansion around its minimum includes **triple** and quartic terms:

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

- In the SM, the Higgs field is fully determined by only two parameters, $v = (\sqrt{2} G_\mu)^{-1/2} \sim 246$ GeV, and λ.
- In the case of extended scalar sectors or in presence of new dynamics at higher scales, the trilinear and quartic couplings typically depend on additional parameters and their values can depart from the SM predictions.
- New physics effects can be parameterised via a single parameter κ_λ, i.e. the rescaling of the **SM trilinear coupling**, λ_3^{SM} :

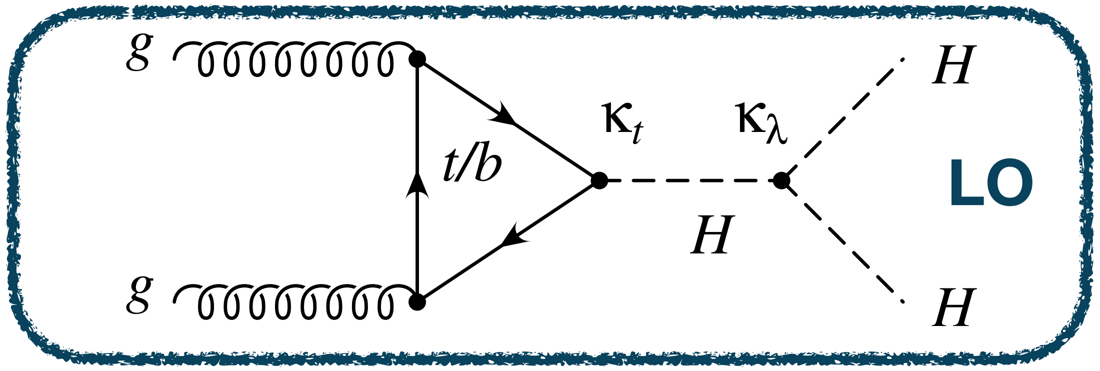
$$\kappa_\lambda = \frac{\lambda_3}{\lambda_3^{SM}}$$

Physics motivation

Study a BSM scenario where the dominant effect of an unknown new physics (NP) is concentrated on the modification of the Higgs potential.

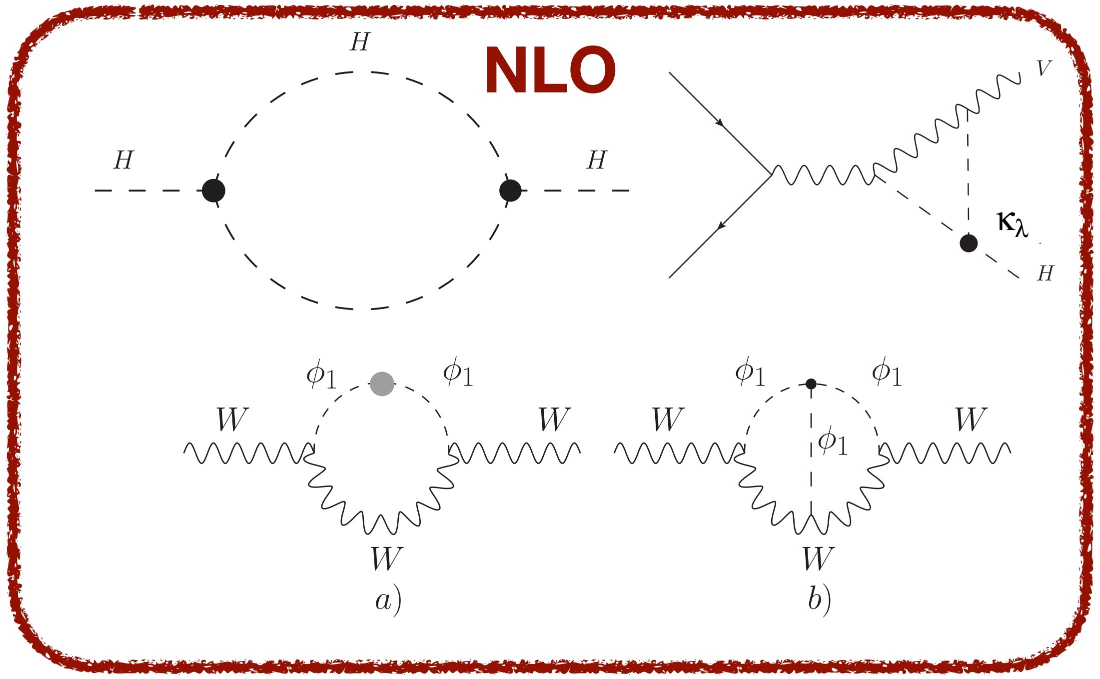
λ_3 can be probed at the LHC using:

- production of Higgs-boson pairs (tree level);



ATLAS and CMS combined at HL-LHC $-0.52 < \kappa_\lambda < 1.5$ *at* $68\,\%$ *CL* **CERN-LPCC-2018-04**

- alternative strategy: exploit higher precision measurements, e.g. single-Higgs processes or electroweak observables-> loop level corrections (one/two loop).



$$\mathcal{O}_{\text{BSM}} = \mathcal{O}_{\text{SM}}\ \left(1 + (\kappa_\lambda - 1)C_1 + (\kappa_\lambda^2 - 1)C_2\right)$$

- $\mathcal{O}$ is a generic observable defined in the BSM scenario or in the SM respectively;
- C_1 and C_2 are finite numerical coefficients, i.e. their values do not depend on Λ_{NP}.

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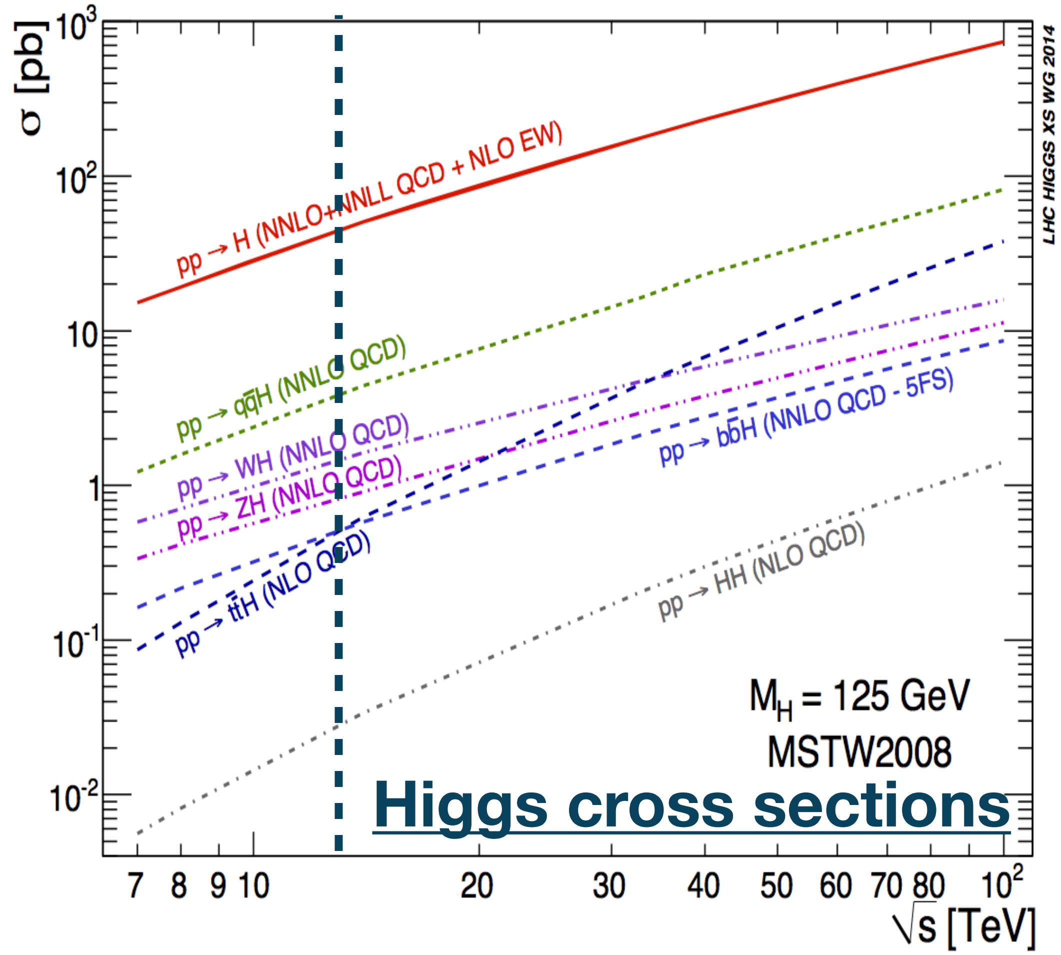
The constraint on λ_3 can be strengthened by combining the public measurements available for the double and single-Higgs processes with the information coming from the EWPO (m_W and $sin^2\theta_{eff}^{lep}$, the leptonic effective Weinberg angle).

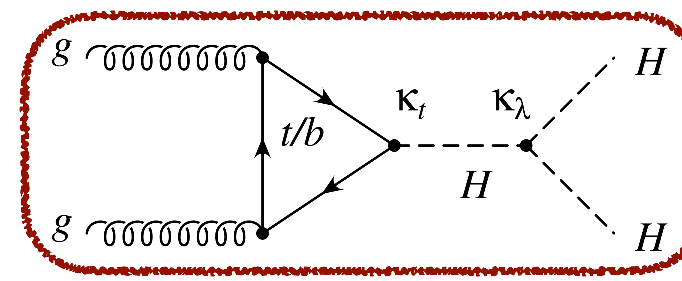
Higgs pair production

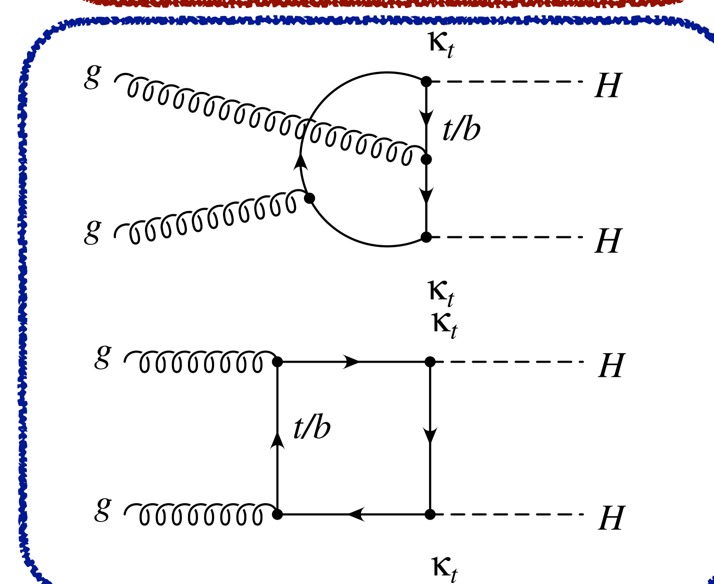


Di-Higgs decay modes and relative branching fractions:

	bb	WW	ττ	ZZ	γγ
bb	33%				
WW	25%	4.6%			
ττ	7.4%	2.5%	0.39%		
ZZ	3.1%	1.2%	0.34%	0.076%	
γγ	0.26%	0.10%	0.029%	0.013%	0.0005%

10.23731/CYRM-2017-002





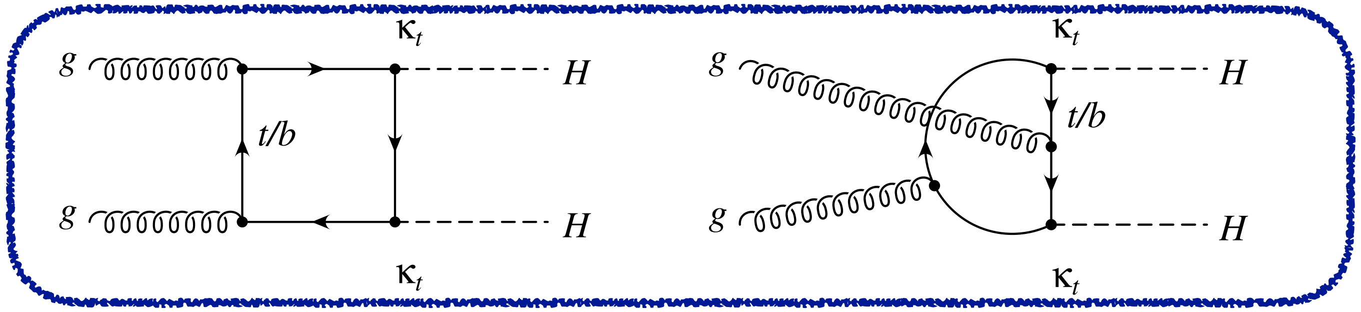
- Main production mode (90%): ggF

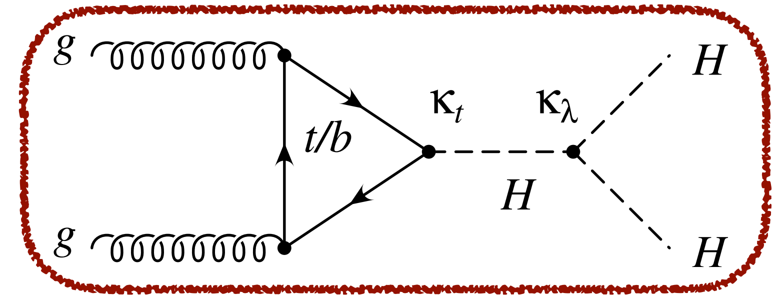
$$\sigma^{ggF}_{pp\rightarrow HH} = 31.05\ \mathrm{fb}^{(+2.2\%)}_{(-5.0\%)}\ \mathrm{(scale)}\ \pm 3.0\%\ (\mathrm{PDF} + \alpha_S)\ \pm 2.6\%\ (\mathrm{m}_{top}\ \mathrm{unc})$$

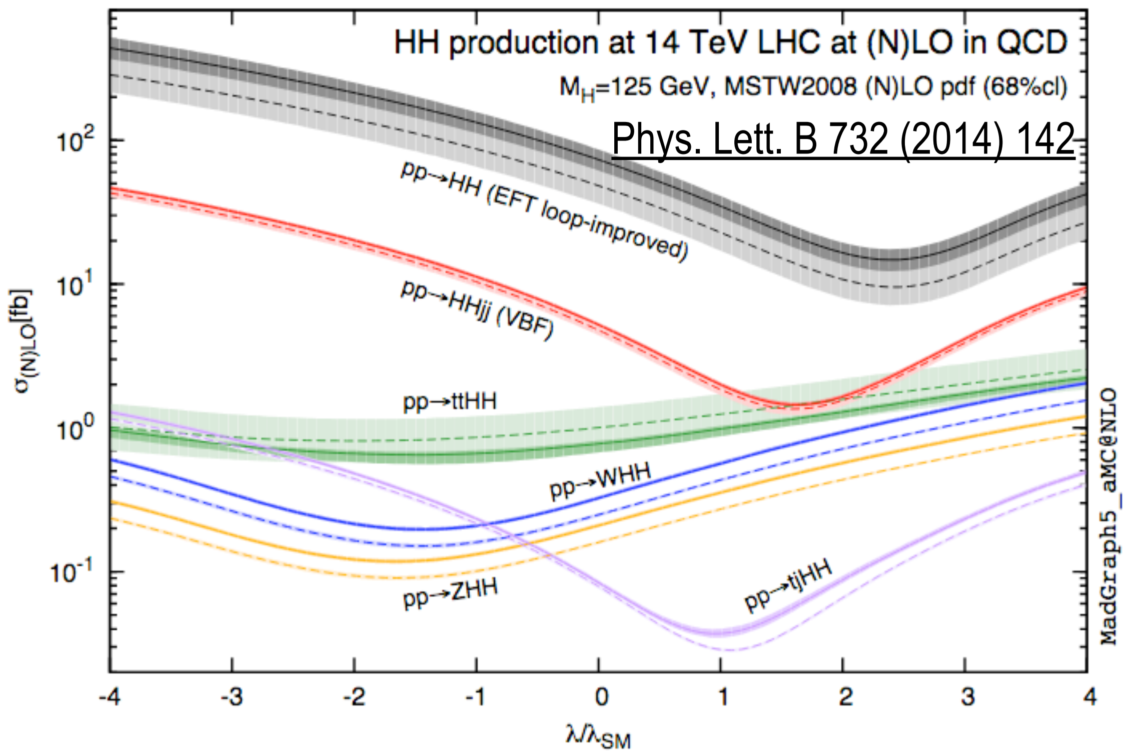
- Rare process of the Standard Model:
  – destructive interference between triangle and box diagrams
  – $\sigma(HH)/\sigma(H) = 0.1\ \%$

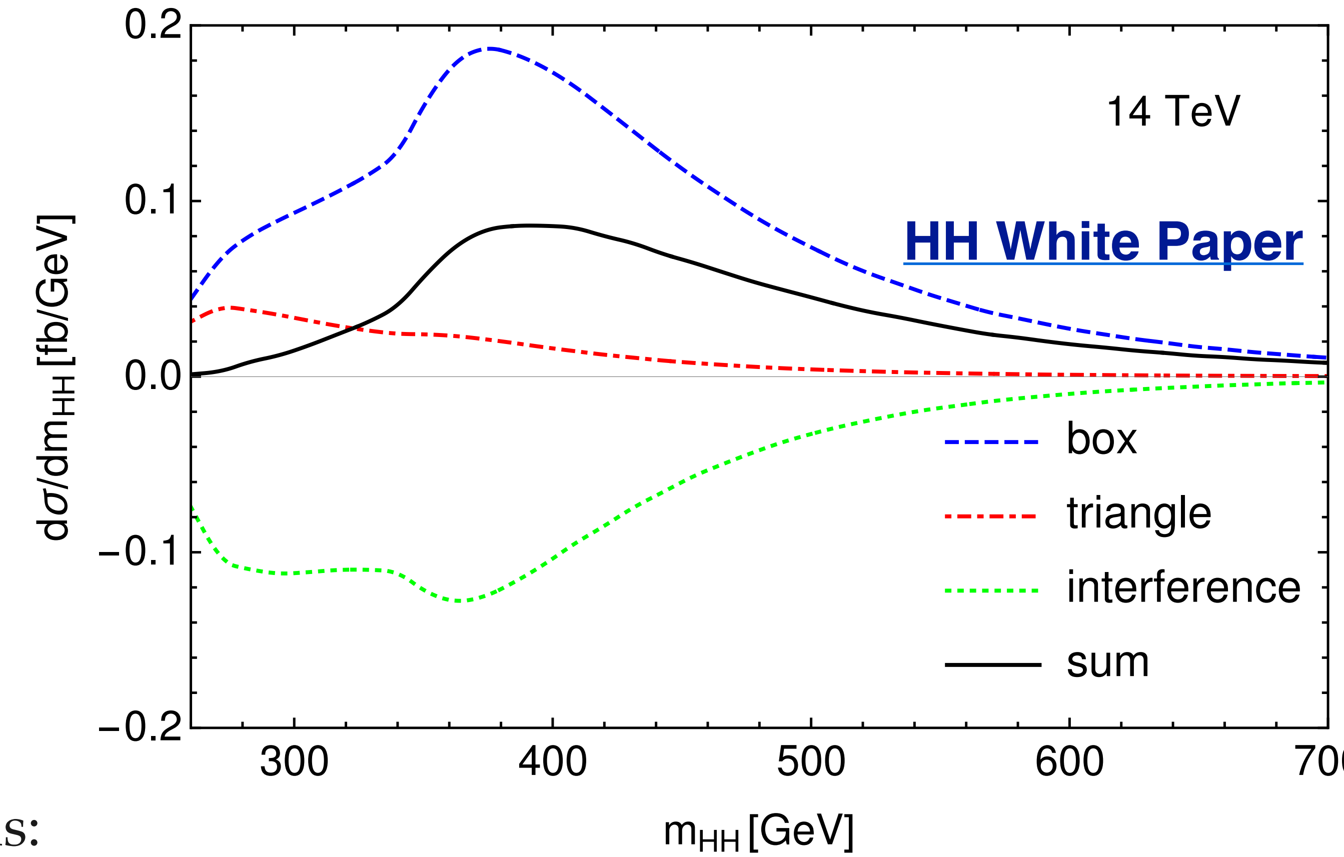
$HH \rightarrow bbbb$	Highest BR, large multi-jet background
$HH \rightarrow b\bar{b}\tau^+\tau^-$	Relative large BR, cleaner final state
$HH \rightarrow b\bar{b}\gamma\gamma$	small BR, clean signal extraction

Higgs pair production









The amplitude of the process can be expressed as:

$$\mathcal{A}(\kappa_t, \kappa_\lambda) = \kappa_t^2 \mathcal{A}_1 + \kappa_t \kappa_\lambda \mathcal{A}_2$$

- The $\mathcal{A}_1$ amplitude is proportional to the square of the Higgs boson coupling to the top-quark, and the $\mathcal{A}_2$ amplitude to the product of the coupling to the top-quark and the Higgs boson self-coupling.
- Information on κ_λ can be obtained from both the total and the differential cross section.

Single-Higgs production

Theoretical framework mainly described in

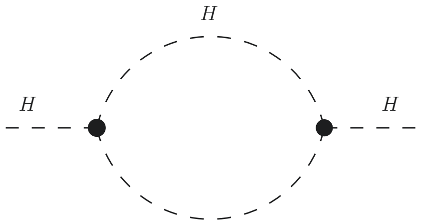
- ✳ JHEP 1612, 080 (2016) G. Degrassi, P.P. Giardino, F. Maltoni, D. Pagani
- ✳ Eur. Phys. J. C (2017) 77: 887 F. Maltoni, D. Pagani, A. Shivaji, X. Zhao

Single-Higgs processes are sensitive to λ_3 via loop corrections.

NLO EW κ_λ-dependent corrections can be divided into two categories:

- a universal part, **quadratically dependent on** λ_3, which originates from the diagram in the wave function renormalisation constant of the external Higgs field.
- a process-dependent part (C_1) **linearly proportional to** λ_3 which is different for each process and **kinematics**.

Universal part

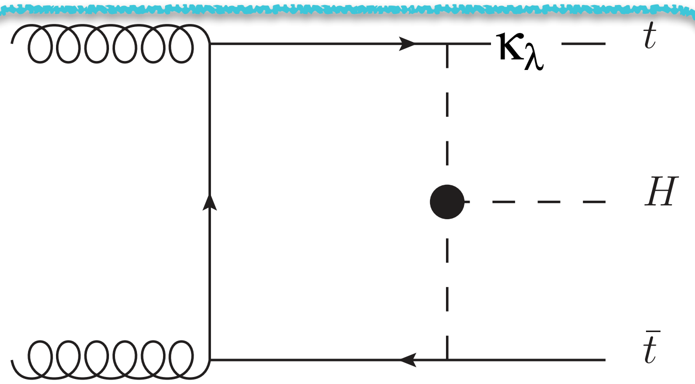


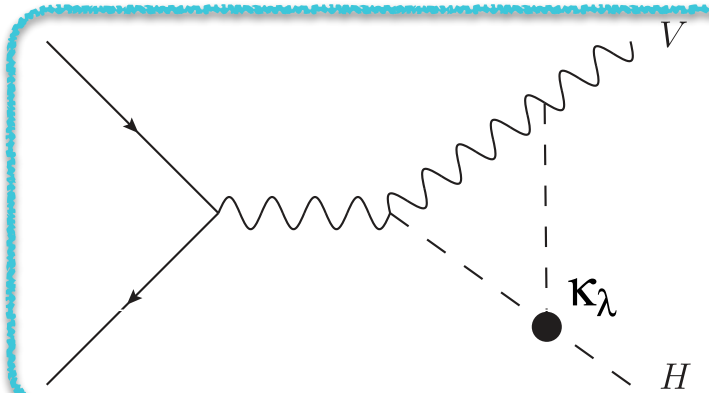
$$|\kappa_\lambda| \lesssim 20$$

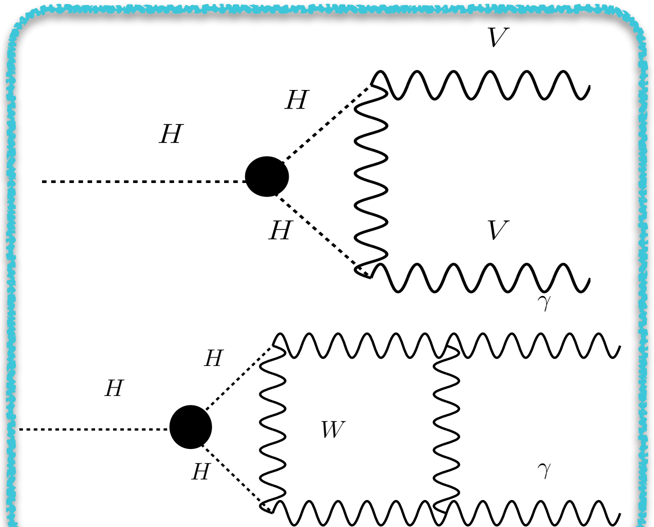
NLO EW κ_λ-dependent corrections affect:

- inclusive cross-sections ($t\bar{t}H, ggF, ZH, WH, VBF$);
- Higgs-boson branching fractions;
- (**kinematics** properties of the event (differential distributions)).

Examples of process-dependent part:







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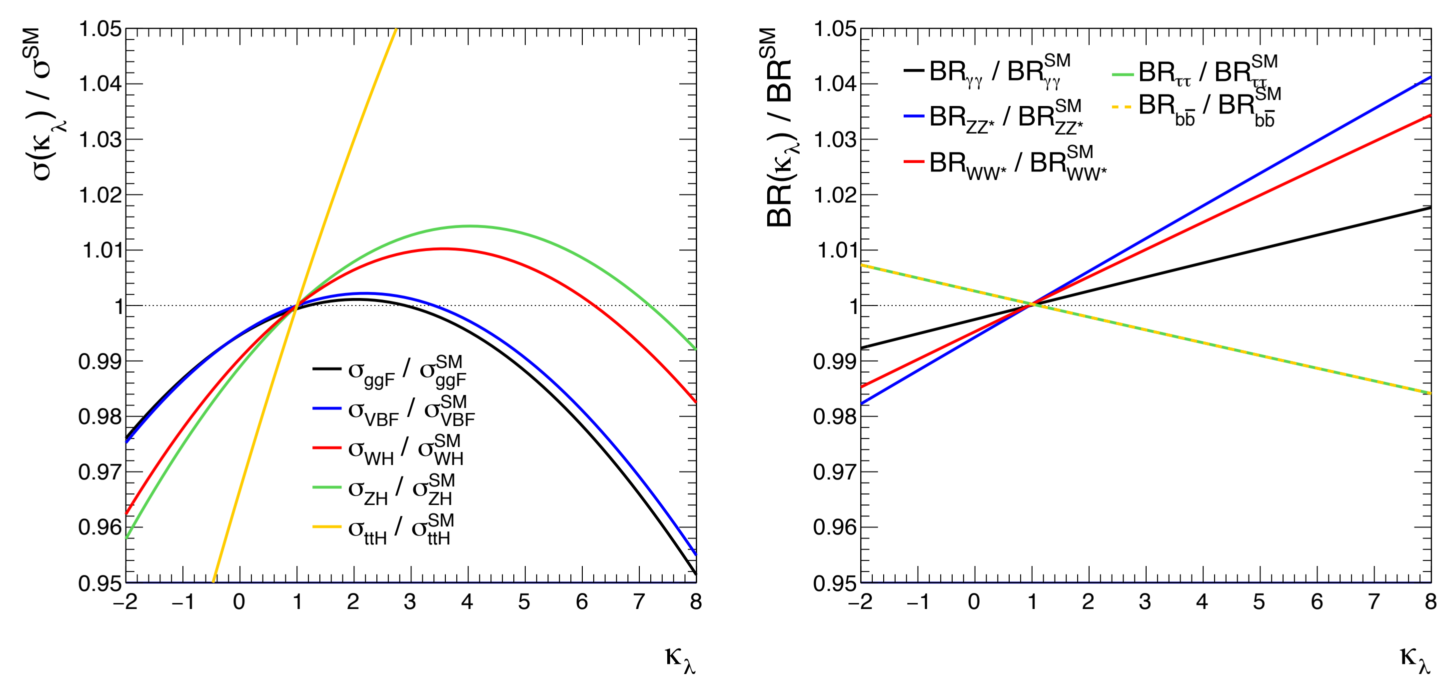
- a process-dependent part (C_1) **linearly proportional to** λ_3 which is different for each process and **kinematics**.

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

$$\mu_i(\kappa_\lambda, \kappa_i) = \frac{\sigma^{BSM}}{\sigma^{SM}} = Z_H^{BSM}(\kappa_\lambda)\left[\kappa_i^2 + \frac{(\kappa_\lambda - 1)C_1^i}{K_{EW}^i}\right]$$

$$\mu_f(\kappa_\lambda, \kappa_f) = \frac{BR_f^{BSM}}{BR_f^{SM}} = \frac{\kappa_f^2 + (\kappa_\lambda - 1)C_1^f}{\sum_j BR_j^{SM}\left[\kappa_j^2 + (\kappa_\lambda - 1)C_1^j\right]}$$

JHEP 1612, 080 (2016)



EW observables

Theoretical framework mainly described in

- [JHEP 1704, 155 (2017)](#)
- [Physics Letters B 817 (2021) 136307](#)

- In the $\overline{MS}$ formulation of the radiative corrections the theoretical predictions of m_W and $sin^2\theta_{eff}^{lep}$, the leptonic effective Weinberg angle, are expressed in terms of the pole mass of the particles, the $\overline{MS}$ Weinberg angle and the $\overline{MS}$ electromagnetic coupling, defined at the 't-Hooft mass scale μ, usually chosen to be equal to m_Z.

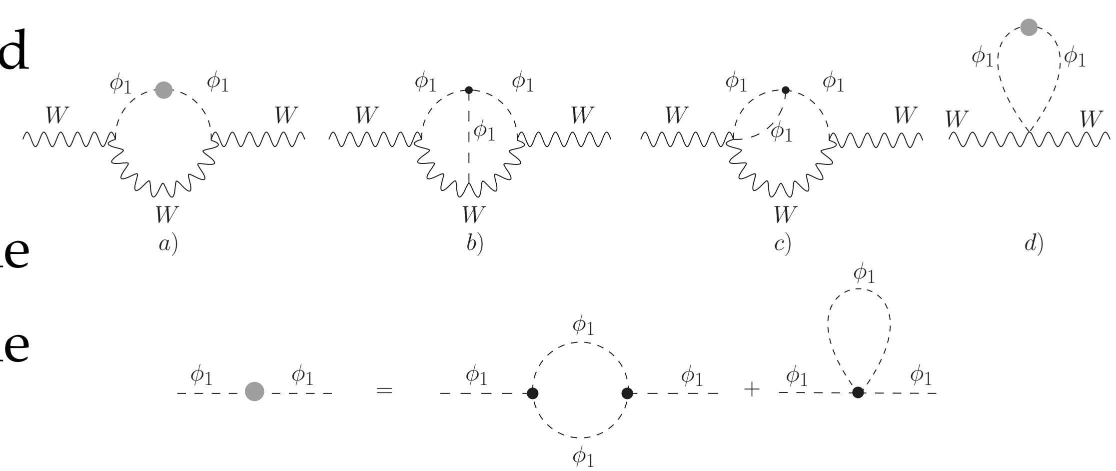
$$m_W^2 = \frac{\hat{\rho}\, m_Z^2}{2}\left\{1 + \left[1 - \frac{4\hat{A}^2}{m_Z^2\hat{\rho}}(1+\Delta\hat{r}_W)\right]^{1/2}\right\}$$

$$\sin^2\theta_{\rm eff}^{\rm lep} = \hat{k}_\ell(m_Z^2)\hat{s}^2, \qquad \hat{k}_\ell(m_Z^2) = 1 + \delta\hat{k}_\ell(m_Z^2),$$

$$\frac{G_\mu}{\sqrt{2}} = \frac{\pi\hat{\alpha}(m_Z)}{2m_W^2\hat{s}^2}(1+\Delta\hat{r}_W), \qquad \hat{\alpha}(m_Z) = \frac{\alpha}{1-\Delta\hat{\alpha}(m_Z)}$$

$$\hat{\rho} \equiv \frac{m_W^2}{m_Z^2\hat{c}^2} = \frac{1}{1-Y_{\overline{MS}}},$$

The two-loop diagrams in the W self energy that are sensitive to a modification of the Higgs self couplings



- The modifications of the scalar potential affect the radiative parameters $\Delta\hat{r}_W$ and $Y_{\overline{MS}}$ at the two-loop level while $\Delta\hat{\alpha}$ and $\delta\hat{k}_\ell(m_Z^2)$ are going to be affected only at three loops.
- Recalling that the present knowledge of m_W and $sin^2\theta_{eff}^{lep}$ in the SM includes the complete two-loop corrections, only the modifications induced in $\Delta\hat{r}_W$ and $Y_{\overline{MS}}$ have been considered.

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$$m_W^2 = \frac{\hat{\rho}\, m_Z^2}{2}\left\{1 + \left[1 - \frac{4\hat{A}^2}{m_Z^2\hat{\rho}}(1+\Delta\hat{r}_W)\right]^{1/2}\right\}$$

$$\sin^2\theta_{\rm eff}^{\rm lep} = \hat{k}_\ell(m_Z^2)\hat{s}^2, \qquad \hat{k}_\ell(m_Z^2) = 1 + \delta\hat{k}_\ell(m_Z^2),$$

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$$\hat{\rho} \equiv \frac{m_W^2}{m_Z^2\hat{c}^2} = \frac{1}{1-Y_{\overline{MS}}},$$

- The latest SM theoretical predictions for m_W [1] and $sin^2\theta_{eff}^{lep}$ [2] were used to refine the calculation of the coefficients.

- As SM predictions m_W = 80.359 ± 0.06 GeV and $sin^2\theta_{eff}^{lep}$ = 0.23151 ± 0.00006 have been employed:
  - the errors reported are obtained combining in quadrature the parametric uncertainties with our estimate of the missing higher order terms.

	C_1	C_2
m_W	5.62×10^{-6}	-1.54×10^{-6}
$\sin^2\theta_{\rm eff}^{\rm lep}$	-1.56×10^{-5}	4.55×10^{-6}

[1] J. Erler, M. Schott, Prog. in Part. and Nuc. Phys. 106 (2019) 68

[2] I. Dubovyk, A. Freitas, J. Gluza, T. Riemann and J. Usovitsch, JHEP 08 (2019) 113

Data and input measurements

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Double Higgs-boson production (ATLAS data)			
Channel		$\mathcal{L}$ [fb^{-1}]	
$pp \to HH \to b\bar{b}\gamma\gamma$	**HH combination**	36.1	JHEP11(2018)040
$pp \to HH \to b\bar{b}b\bar{b}$	Phys. Lett. B 800 (2020) 135103	27.5	JHEP01(2019)030
$pp \to HH \to b\bar{b}\tau^+\tau^-$		36.1	Phys. Rev. Lett. 122, 089901 (2019)

Single Higgs-boson production (ATLAS data)			
Decay Channel	Production Mode	$\mathcal{L}$ [fb^{-1}]	
$H \to \gamma\gamma$	ggF, VBF, WH, ZH	139	ATLAS-CONF-2020-027
$H \to ZZ^*$	ggF, VBF, WH, ZH, $t\bar{t}H$	36.1 - 139	
$H \to W^+W^-$	ggF, VBF, $t\bar{t}H$	36.1	
$H \to \tau^+\tau^-$	ggF, VBF, $t\bar{t}H$	36.1	
$H \to b\bar{b}$	VBF, WH, ZH, $t\bar{t}H$	24.5 - 139	

Precision electroweak observables			
Observable	Value	Reference	
m_W	80.379 ± 0.012 GeV	PDG World Average	Review of Particle Physics - PDG
$\sin^2\theta_{\rm eff}^{lep}$	0.23151 ± 0.00021	LEP/SLD/Tevatron/LHC	Prog. in Part. and Nuc. Phys. 106 (2019) 68

- The $sin^2\theta_{eff}^{lep}$ measurements are slightly inconsistent due to a discrepancy at the level of 3σ between the LEP and the SLD most accurate measurements.
- In order to not underestimate the error on the average, from combining discrepant measurements, and to be conservative, we assume that the discrepancy is due to an underestimated systematic error that affects all measurements $sin^2\theta_{eff}^{lep} = 0.23151 \pm 0.00014$ -> $sin^2\theta_{eff}^{lep} = 0.23151 \pm 0.00021$

Data and input measurement

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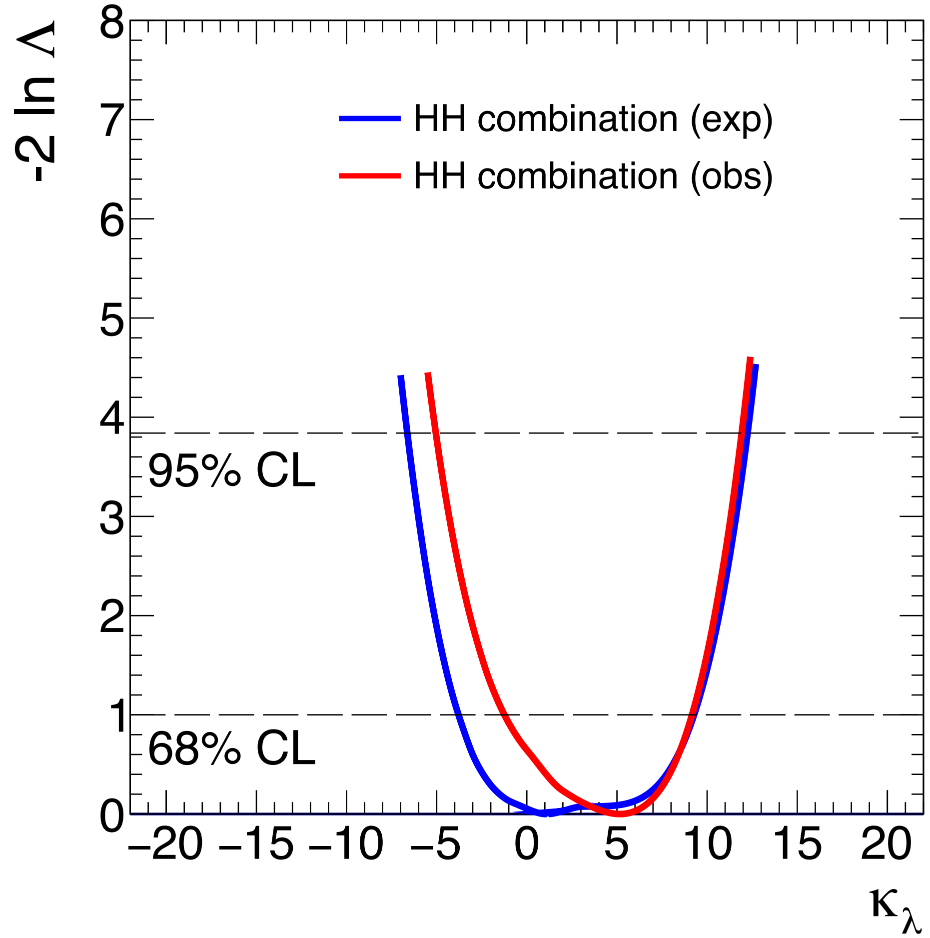

- The likelihood shapes have been taken from arXiv:2010.05252 and Il Nuovo Cimento C43 (2020) 95 .
- The shape of the expected and observed likelihood of the combination $HH \to b\bar{b}b\bar{b}$, $HH \to b\bar{b}\gamma\gamma$ and $b\bar{b}\tau^+\tau^-$ has been first scanned and then interpolated using a third degree polynomial.
- Continuity of the first and the second derivative has been imposed at each point of the scan.

Data and input measurement

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} ATLAS-CONF-2020-027

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- $\mu_i \times \mu_f$ was used in the fit procedure, i.e. the product $\sigma \times BR$ normalised to its Standard Model expectation;
- the uncertainties on the signal strengths have been symmetrised by averaging the squares of the positive and negative uncertainties;
- to avoid double counting between this channel and the $pp \to HH \to b\bar{b}\gamma\gamma$ channel, $t\bar{t}H \to \gamma\gamma$ was excluded from the fit.
- Correlation matrix of the signal strength measurements used in the fit:
  - only elements larger or equal to 0.05 are used in the fit.

$\mu_i \times \mu_f$	ggF	VBF	ZH	$t\bar{t}H$
$\gamma\gamma$	1.03 ± 0.11	1.31 ± 0.25	1.32 ± 0.32	–
ZZ^*	0.94 ± 0.11	1.25 ± 0.46	1.53 ± 1.03	–
W^+W^-	1.08 ± 0.19	0.60 ± 0.35	–	1.72 ± 0.55
$b\bar{b}$	–	3.03 ± 1.65	1.02 ± 0.18	0.79 ± 0.60
$\tau^+\tau^-$	1.02 ± 0.58	1.15 ± 0.55	–	1.20 ± 1.00

	ggF	VBF				VH	$t\bar{t}H$	
ρ	$\tau^+\tau^-$	$\gamma\gamma$	ZZ^*	W^+W^-	$\tau^+\tau^-$	ZZ^*	W^+W^-	$\tau^+\tau^-$
ggF								
$\gamma\gamma$	0.06	-0.11						
ZZ^*			-0.21			-0.28		
W^+W^-				-0.08				
$\tau^+\tau^-$					-0.45			
VBF								
$\gamma\gamma$			0.07					
VH								
ZZ^*							-0.07	
$t\bar{t}H$								
W^+W^-								-0.42

Data and input measurement

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ATLAS-CONF-2020-027

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$\tau^+\tau^-$	1.02 ± 0.58	1.15 ± 0.55	–	1.20 ± 1.00

Assumptions adopted:

- $\kappa_\lambda \neq 1$ affects differently the WH and ZH cross sections; the VH signal strength is assigned to ZH:
  - the sensitivity of the VH result is dominated by the $H \to b\bar{b}$ channel where ZH provides the most accurate measurement of the VH signal strength value.
  - the impact of this assumption has been tested assigning the VH signal strength of the $\gamma\gamma$ channel to WH and decoupling the WH and ZH signal strengths in the $H \to b\bar{b}$ channel using inputs from Eur. Phys. J. C 81 (2021) 178 -> the impact on the result has been found to be negligible.
- The signal strength relative to $t\bar{t}H + tH$ of the original paper has been assigned to $t\bar{t}H$ being the tH contribution negligible, and the VV channel has been assigned to W^+W^- that dominates the sensitivity.

Fit procedure

The fit procedure is performed by building up a likelihood function as a product of the likelihood function associated to each experimental measurement; $\Lambda(\kappa_\lambda) = L(\kappa_\lambda)/L(\hat{\kappa}_\lambda)$ is used to extract the best fit values and confidence intervals:

$$\mathcal{L} = \mathcal{L}_H \times \mathcal{L}_{HH} \times \mathcal{L}_{m_W} \times \mathcal{L}_{\sin^2\theta_{\rm eff}^{\rm lep}} \xrightarrow{\textbf{minimisation}} -2\ln\Lambda = -2\ln\mathcal{L}_H - 2\ln\mathcal{L}_{HH} - 2\ln\mathcal{L}_{m_W} - 2\ln\mathcal{L}_{\sin^2\theta_{\rm eff}^{\rm lep}} + 2\ln\mathcal{L}(\hat{\kappa}_\lambda)$$

$$-2\ln\mathcal{L}_H = \chi^2_H = \left[\vec{\mu}^{\rm exp} - \vec{\mu}^{\rm theo}(\kappa_\lambda)\right]^T C(\kappa_\lambda)^{-1}\left[\vec{\mu}^{\rm exp} - \vec{\mu}^{\rm theo}(\kappa_\lambda)\right]$$

- $\vec{\mu}^{exp}$ is a fifteen dimensional vector containing the measurements $\mu_i \times \mu_f$ and their theoretical expectation as a function of κ_λ.
- The matrix $C(\kappa_\lambda)^{-1}$ is the inverse of the covariance matrix $C(\kappa_\lambda) = C^{theo}(\kappa_\lambda) + C^{exp}$ where C^{exp} is built from the uncertainties and the correlation matrix, while $C^{theo}(\kappa_\lambda)$ is a diagonal matrix containing the square of the theoretical uncertainties on $\mu_i \times \mu_f$ due to missing higher order terms.

$$-2\ln\mathcal{L}_{m_W} = \chi^2_{m_W} = \frac{[m_W^{\rm exp} - m_W^{\rm theo}(\kappa_\lambda)]^2}{[\sigma^{2\,exp}_{m_W} + \sigma^{2\,theo}_{m_W}]^2}$$

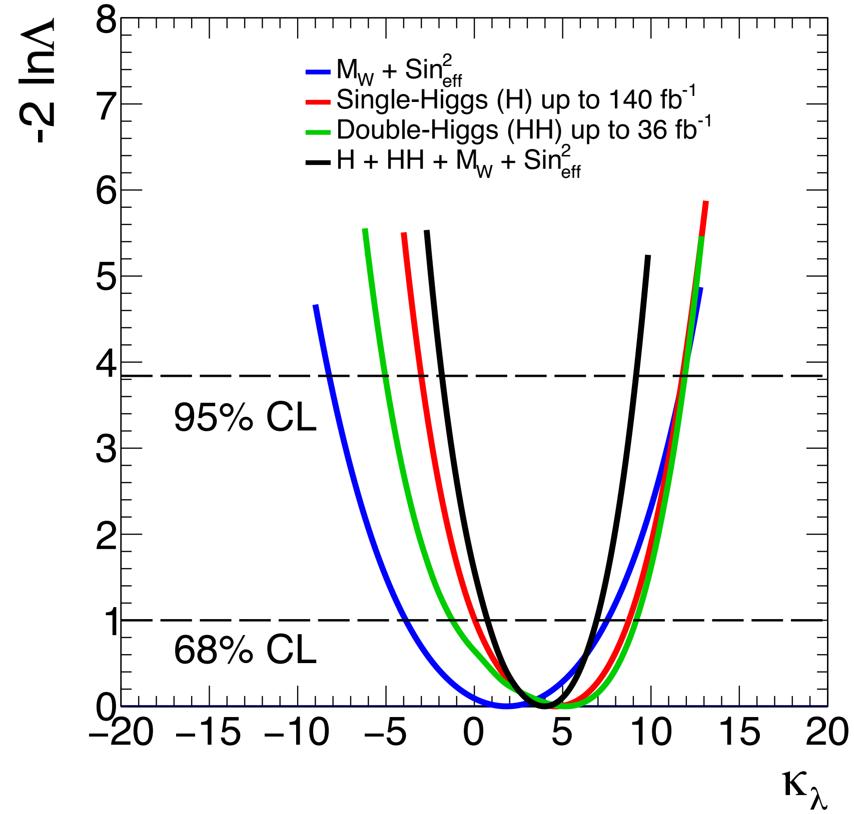
$$-2\ln\mathcal{L}_{\sin^2\theta_{\rm eff}^{\rm lep}} = \chi^2_{\sin^2\theta_{\rm eff}^{\rm lep}} = \frac{\left[\sin^2\theta_{\rm eff}^{\rm lep,exp} - \sin^2\theta_{\rm eff}^{\rm lep,theo}(\kappa_\lambda)\right]^2}{\left[\sigma^{2\,\rm exp}_{\sin^2\theta_{\rm eff}^{\rm lep}} + \sigma^{2\,\rm theo}_{\sin^2\theta_{\rm eff}^{\rm lep}}\right]^2}$$

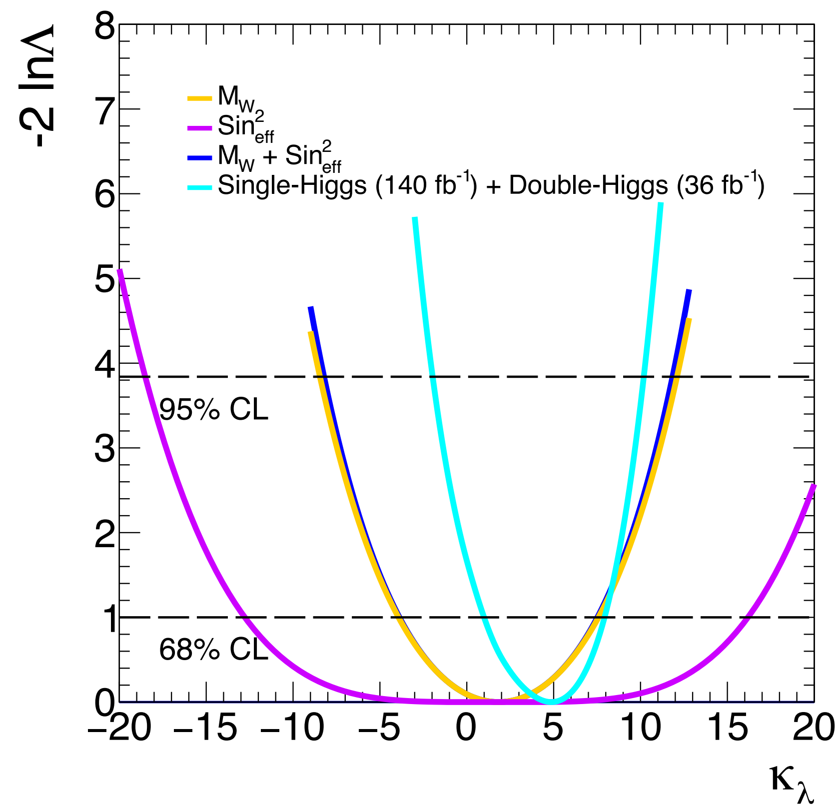
- the κ_λ-dependent uncertainty associated to missing higher orders, i.e. $O(\kappa_\lambda^3\alpha^2)$ terms, have been included in the theoretical uncertainties for both EWPO; a very mild dependence on this uncertainty has been found.

Results (observed)

- For positive κ_λ values, i.e. when the interference between the box and the self-coupling diagram in the pp → HH process is destructive and brings to a sensitivity loss of the double-Higgs channel, all the three measurements (HH, single-H and EWPO) show a comparable constraining power, with a stronger impact of the EWPO for low values of κ_λ.
- For negative κ_λ values, the higher statistics of the single-Higgs analyses allows to reach a better constraint on κ_λ while the EWPO have a smaller impact on the result.
- The impact on the fit of the two EWPO has been obtained disentangling the likelihood functions of m_W and $sin^2\theta_{eff}^{lep}$ from the $m_W + sin^2\theta_{eff}^{lep}$ combination.
- The sensitivity of the EWPO is dominated by the m_W measurement that represents an important addition to the single-Higgs and double-Higgs combination.

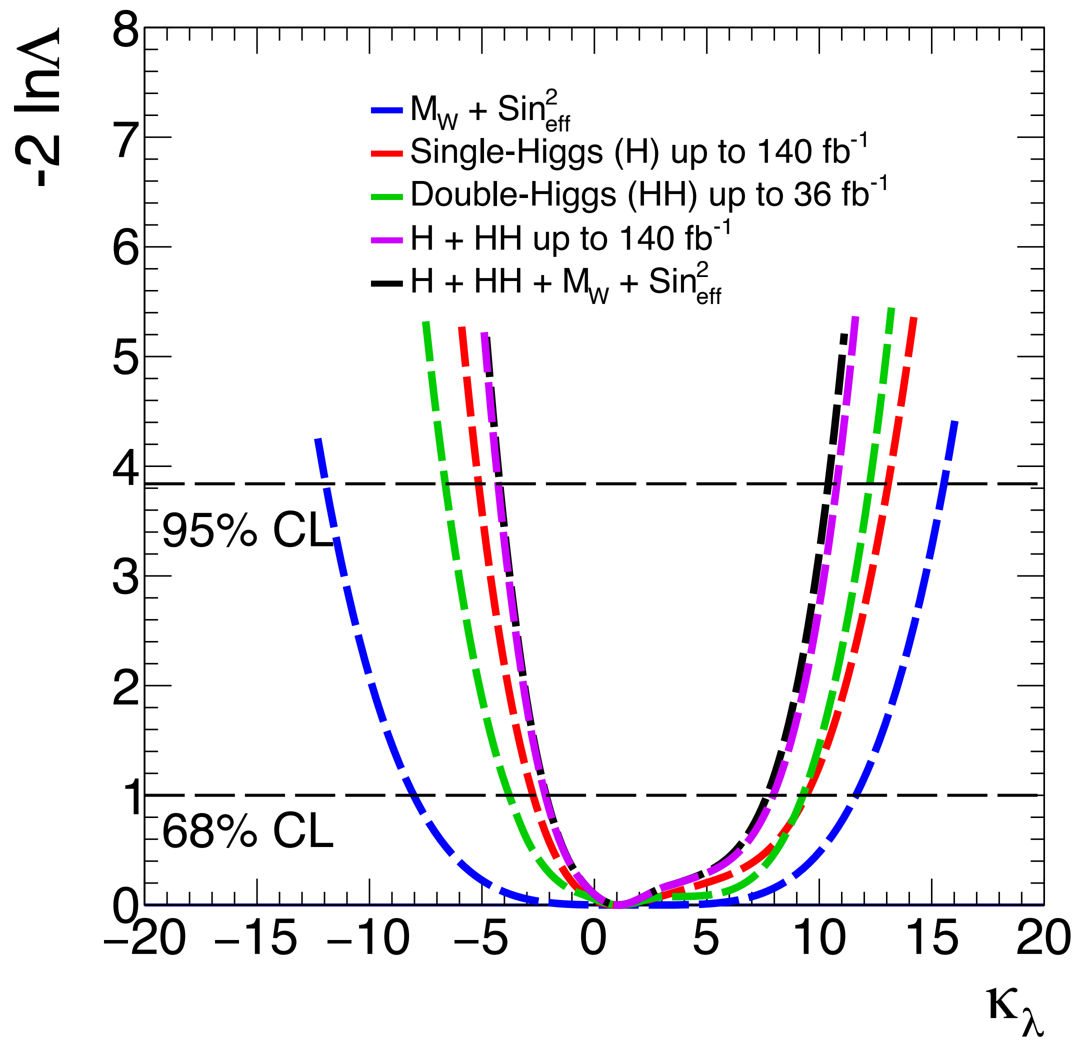
observables	best fit	68 % CL interval	95 % CL interval
$\sin^2\theta_{\rm eff}^{\rm lep}$	0.2	-12.8 – 16.2	-18.5 –[> 20]
m_W	1.8	-3.9 – 7.6	-8.4 – 12.1
$m_W + \sin^2\theta_{\rm eff}^{\rm lep}$	1.8	-3.9 – +7.5	-8.2 – 11.8
HH	5.2	-1.2 – +9.2	-5.0 – 11.9
single-H	4.6	+0.05 – +8.8	-3.0 – 11.8
Combination	4.0	0.7 – 6.9	-1.8 – 9.2





Results (expected)

- In order to investigate if this result is due to the intrinsic sensitivity of the EWPO, the likelihood scan has been performed setting all the fit parameters to their SM expectations.
- For the single-Higgs analyses and the EWPO, it has been assumed that the correlation matrix and the fractional error on the fitted parameters don't change when the parameters move from their observed values to their expected ones.
- The constraining power of the EWPO is expected to be lower than what observed in data, in fact the full combined -2lnΛ doesn't show large differences with respect to the combination of only the single-Higgs and double Higgs -2lnΛ.



Conclusion

- ATLAS data analyses of the single-Higgs and double-Higgs processes have been combined with the information coming from the EWPO in order to constrain the Higgs boson trilinear self-coupling modifier κ_λ.
- Under the assumption that NP affects only the Higgs potential kappa lambda values outside the interval $-1.8 < \kappa_\lambda < 9.2$ have been excluded at 95% CL.
- The inclusion in the fit of the information coming from the EWPO m_W and $sin^2\theta_{eff}^{lep}$ gives rise to a stronger constraint on κ_λ, in particular on the positive side of the CL interval.
- At the moment, the information coming from EWPO gives an indication for λ values closer to λ^{SM} than the single and double-Higgs analyses.
- It is interesting to see if, in the future, with the LHC collaborations analysing larger set of single and double-Higgs data and with possible improvements on the measurement of the m_W from LHC, this different indication will remain in the data.
- Many updates, on all different fronts mentioned, are foreseen with the analysis of the full Run2 dataset.
- Several interesting ATLAS and CMS results are currently coming out showing more and more power in constraining κ_λ exploiting the HH analyses.

BACKUP

BSM Models

Phys. Rev. D 88, 055024 (2013)

The maximal self-coupling deviation from its SM value in different BSM theories.

Model	$\Delta g_{hhh}/g_{hhh}^{SM}$
Mixed-in Singlet	$-18\,\%$
Composite Higgs	tens of %
Minimal Supersymmetry	$-2\,\%^{a}$ $-15\,\%^{b}$
NMSSM	$-25\,\%$

- Mixed-in Singlet Model: a theory with an extra singlet where the singlet mixes with the SM Higgs through a renormalisable operator.
- Composite Higgs Model: composite Higgs models are speculative extensions of the Standard Model (SM) where the Higgs boson is a bound state of new strong interactions.
- Minimal Supersymmetry Model: the Minimal Supersymmetric Standard Model (MSSM) exhibits an extended Higgs sector with two Higgs boson doublets, H_d and H_u, which couple to down- and up-type quarks, respectively.
- NMSSM Model: extension of the MSSM adding a mass term μ in a way similar to the generation of quark and lepton masses in the SM.

Single-Higgs production

- The production cross sections σ_i and the branching fractions BR_f normalised to their SM values, i.e. μ_i and μ_f, are parameterised as functions of κ_λ:

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

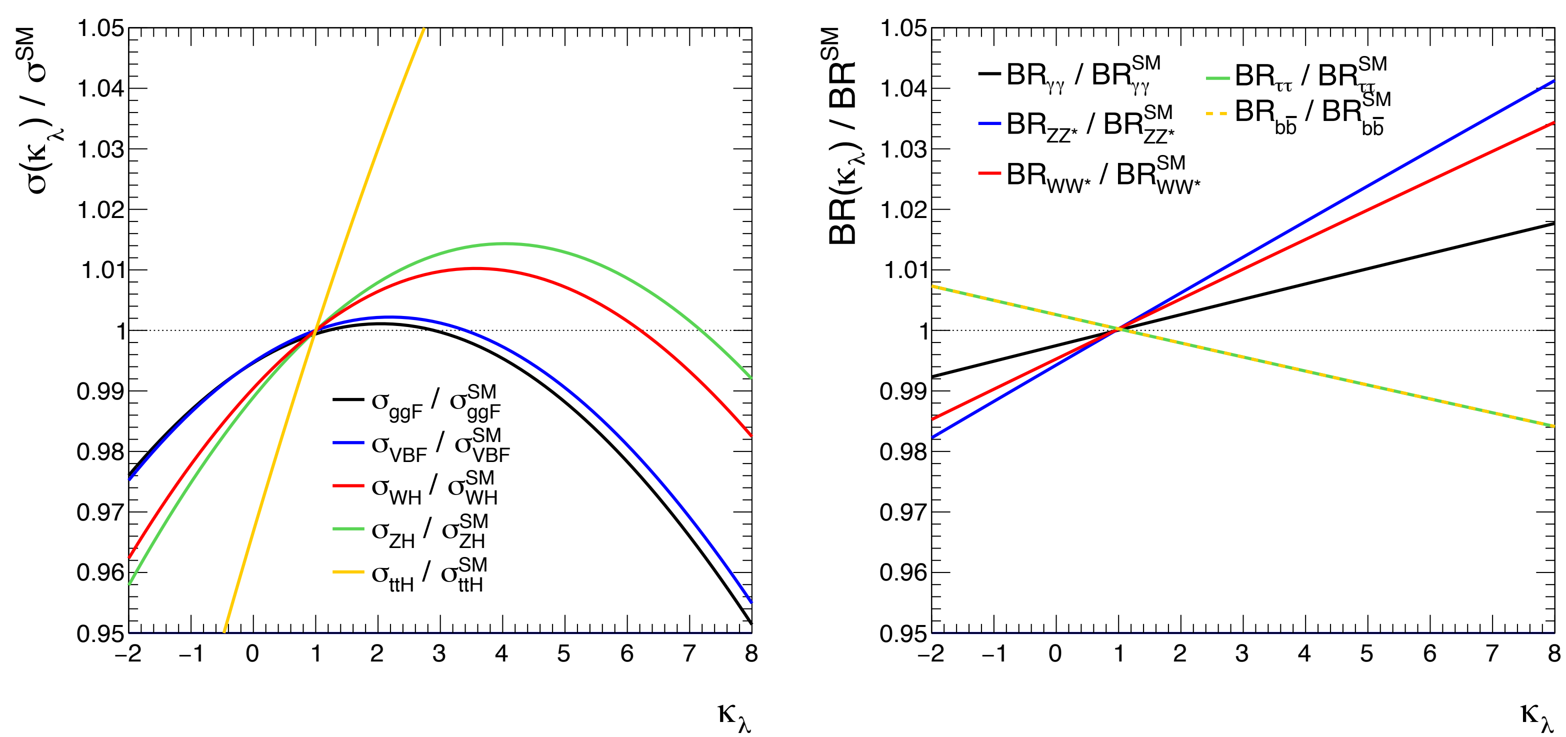
$$\mu_i(\kappa_\lambda, \kappa_i) = \frac{\sigma^{BSM}}{\sigma^{SM}} = Z_H^{BSM}(\kappa_\lambda)\left[\kappa_i^2 + \frac{(\kappa_\lambda - 1)C_1^i}{K_{EW}^i}\right]$$

$$\mu_f(\kappa_\lambda, \kappa_f) = \frac{BR_f^{BSM}}{BR_f^{SM}} = \frac{\kappa_f^2 + (\kappa_\lambda - 1)C_1^f}{\sum_j BR_j^{SM}\left[\kappa_j^2 + (\kappa_\lambda - 1)C_1^j\right]}$$

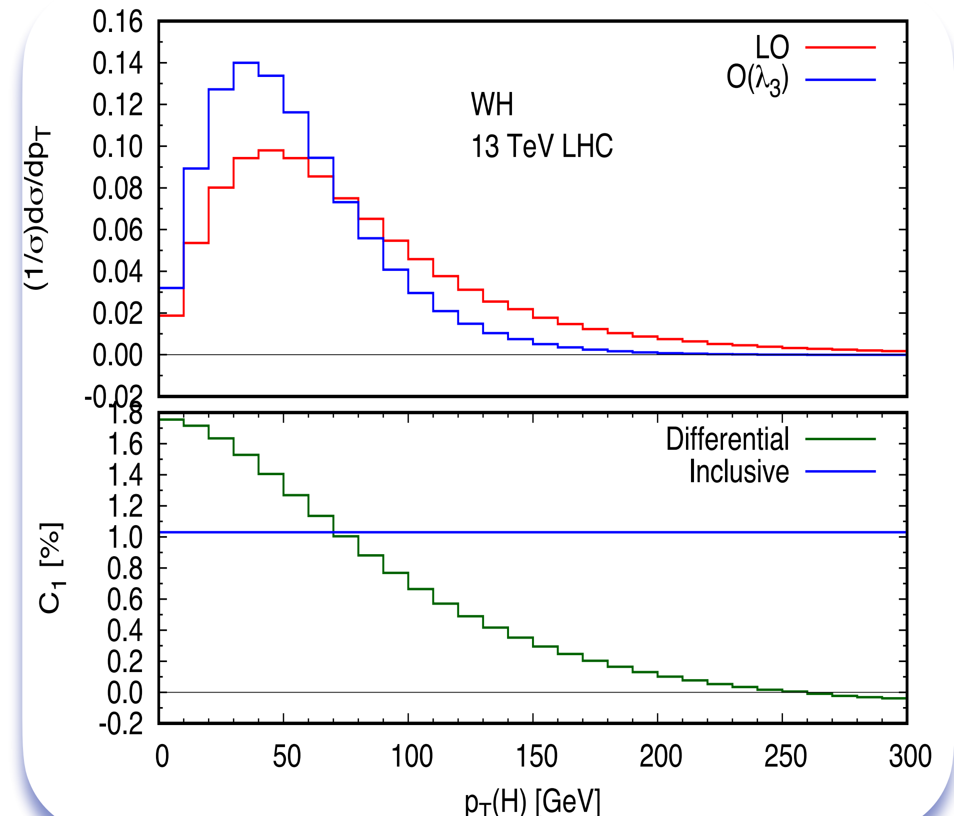
- κ_i and κ_f represent multiplicative modifiers to other Higgs boson couplings for initial and final states, parameterised as in the LO κ-framework;

- $K_{EW}^i = \sigma_{NLO}^{SM,i}/\sigma_{LO}^{SM,i}$ accounts for the complete NLO EW correction of the production cross section for the process in the SM hypothesis (i.e. κ_λ=1).

JHEP 1612, 080 (2016)



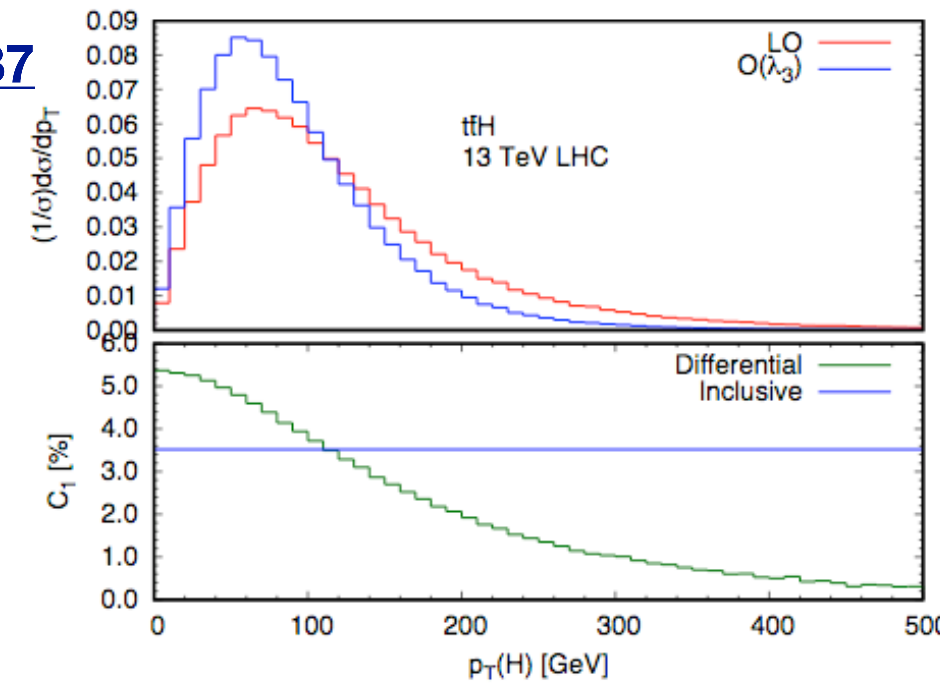
Eur. Phys. J. C (2017) 77: 887



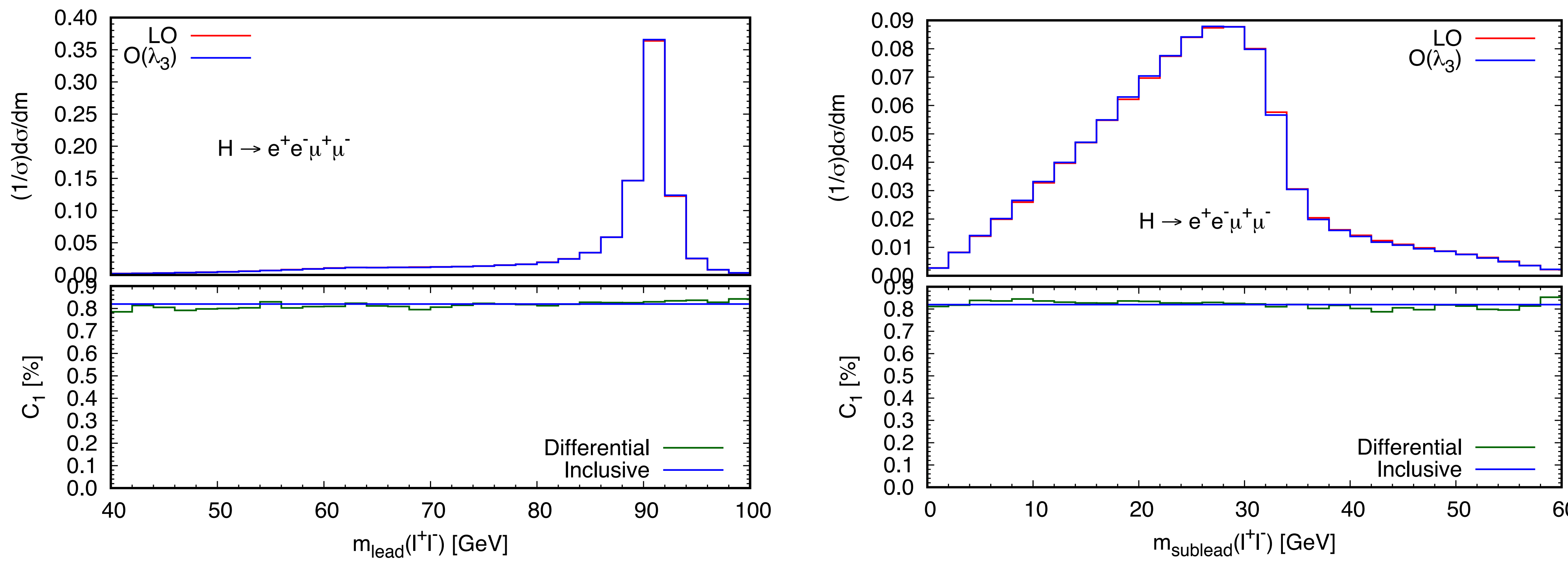
Single-Higgs production

- The $t\bar{t}H$ production mode represents the process receiving much larger corrections (~10% at $\kappa_\lambda = 10$) with respect to the others, due to the fact that, being able to interact with another final-state particle, like WH and ZH production processes, it receives a Sommerfeld enhancement in the non-relativistic regime.

[Eur. Phys. J. C (2017) 77: 887]



- The origin of the large phase-space dependence of C_1 is again due to Sommerfeld enhancements in the threshold regions that are induced by interactions among the top (anti)quark and the Higgs boson.
- C_1 for total cross section is 3.52% and can increase up to ~5% in p_T distributions.



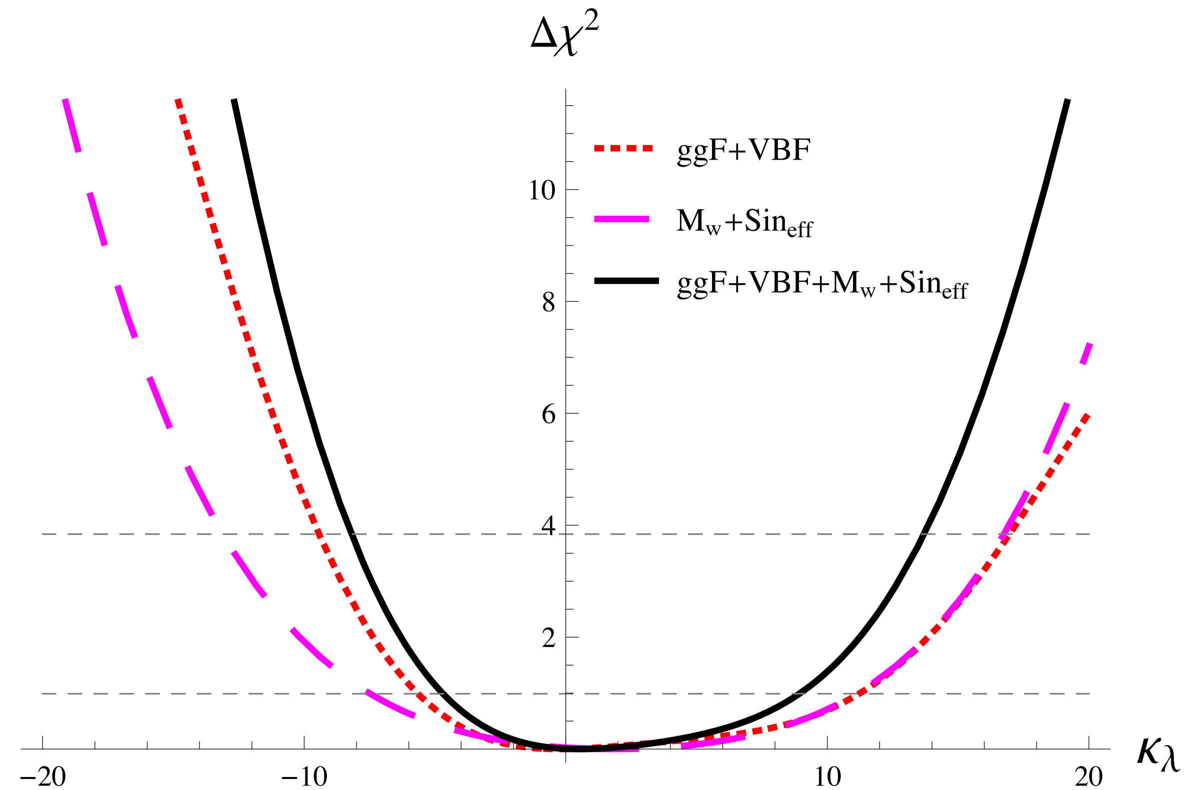
Higgs self-coupling via precision measurements

JHEP 1704, 155 (2017)

- The effects of NP at the weak scale are parameterised via a single parameter, κ_λ;
- the effects induced by an anomalous Higgs trilinear coupling at the loop level in the predictions of m_W and $sin^2\theta^{lep}_{eff}$, i.e. in the two-loop W and Z boson self-energies which are the relevant quantities entering in the two-loop determination of m_W and $sin^2\theta^{lep}_{eff}$, are computed in the unitary gauge.

$$O = O^{SM}[1 + (\kappa_\lambda - 1)C_1 + (\kappa_\lambda^2 - 1)C_2]$$

	C_1	C_2
m_W	6.27×10^{-6}	-1.72×10^{-6}
$\sin^2\theta^{\rm lep}_{\rm eff}$	-1.56×10^{-5}	4.55×10^{-6}



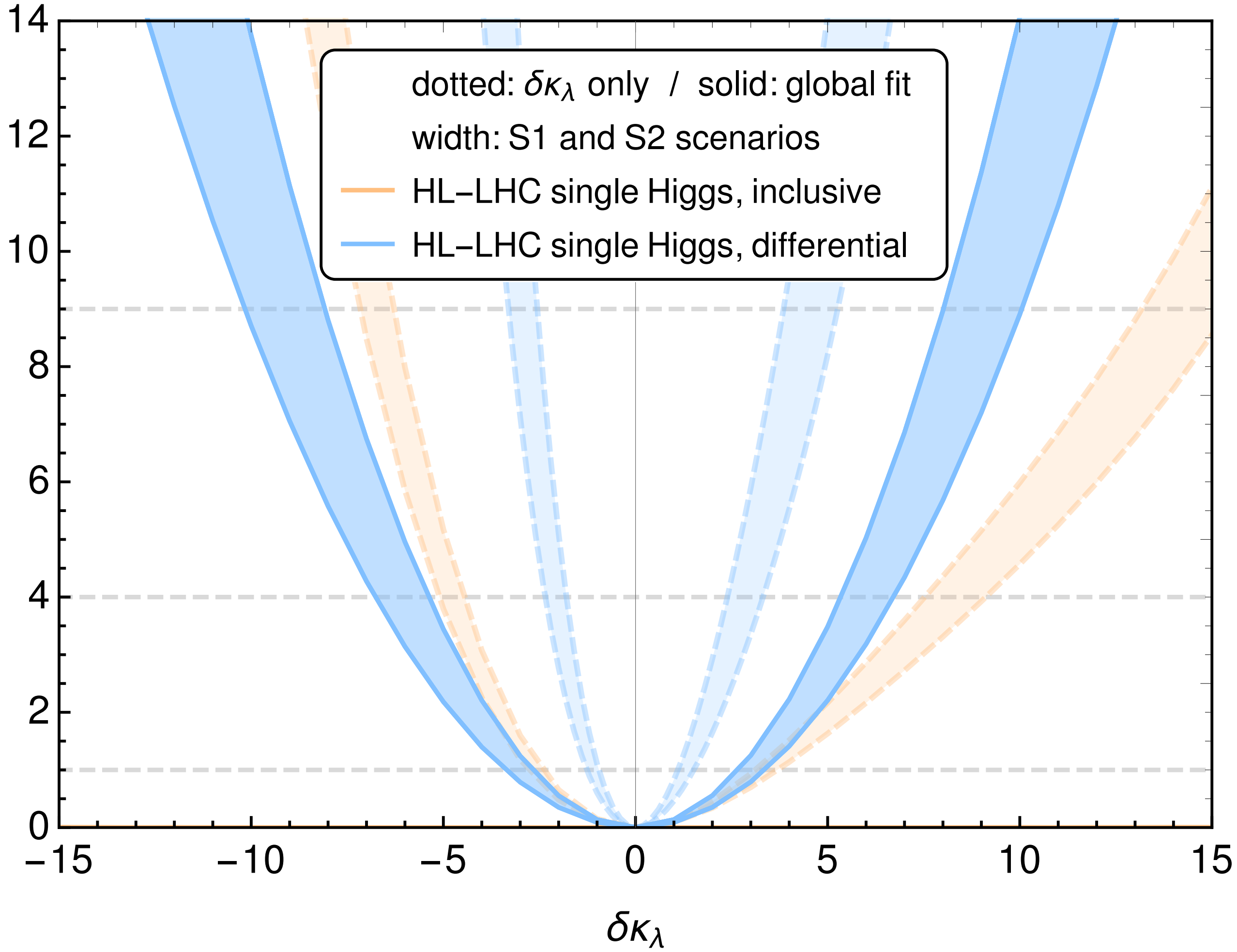
Combination of precision observables + ggF+VBF 2σ ***interval*** $: -8.2 < \kappa_\lambda < 13.7$

ggF+VBF 2σ ***interval*** $: -9.4 < \kappa_\lambda < 17.0$

HL-LHC prospects

- HH analyses currently are very limited by statistics also in its systematic uncertainties (eg. bkg systematics), therefore at HL-LHC they can gain (obviously) a lot in sensitivity.
- The gain for single Higgs is not so enhanced by the increasing of luminosity since at a certain point it becomes limited by systematic uncertainties, that in the HL projection are not so much reduced.
- Differential information has a great impact on the measurement.

HL-LHC prospects, Yellow Report results



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