Constraining the Higgs boson self-coupling in a combined measurement of single and double Higgs boson channels at the ATLAS experiment

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on behalf of the ATLAS Collaboration

ATLAS EXPERIMENT

ROMA TRE UNIVERSITÀ DEGLI STUDI

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University of Pittsburgh

INFN Istituto Nazionale di Fisica Nucleare

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 which is connected to 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.
- 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

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

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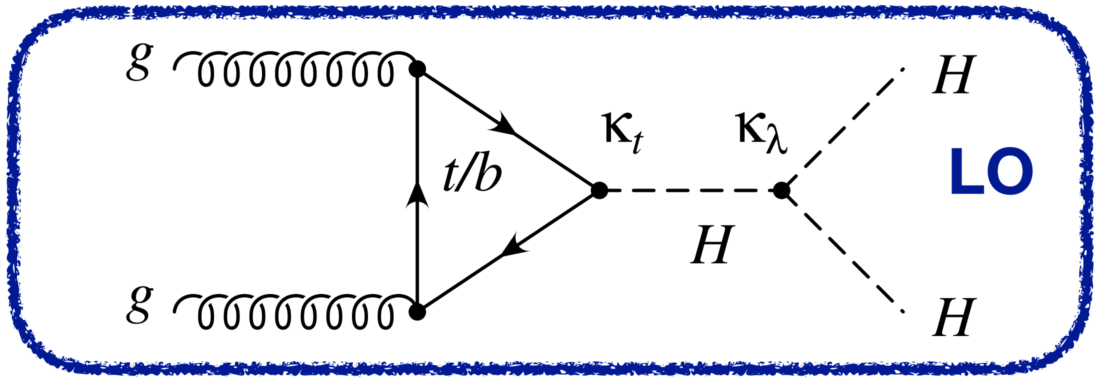
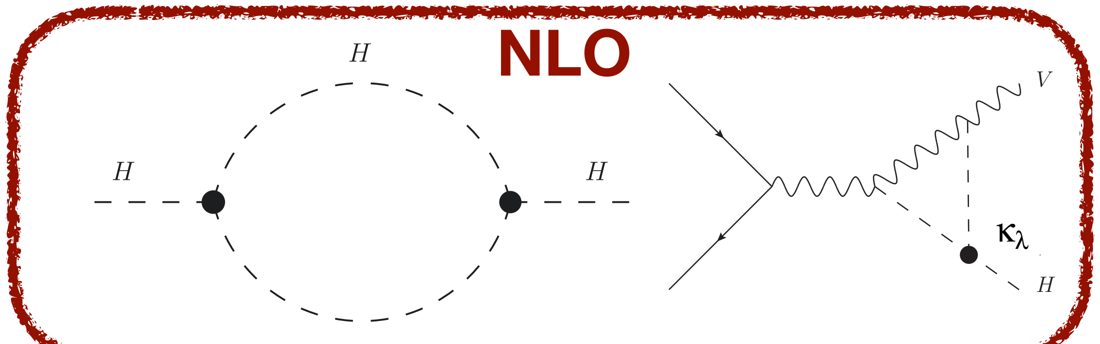
$$V(H) = \frac{m_H^2}{2} H^2 + \lambda_3 v H^3 + \lambda_4 H^4$$

λ_3 can be probed at the LHC using:

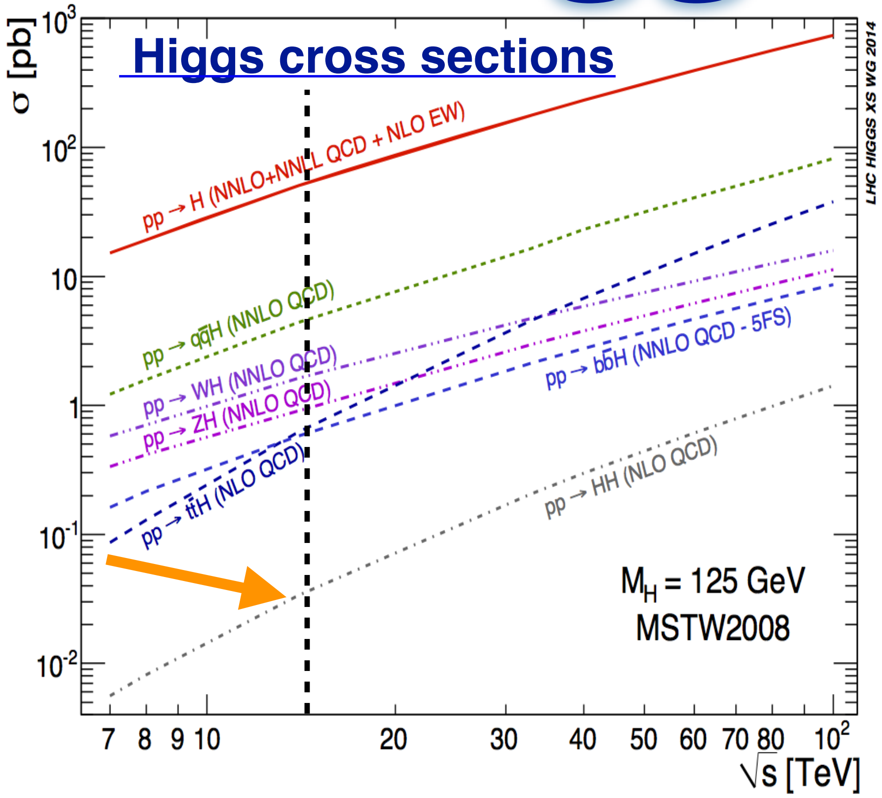
- production of Higgs boson pairs;
- Next-to-Leading Order (NLO) electroweak (EW) corrections to single-Higgs processes.

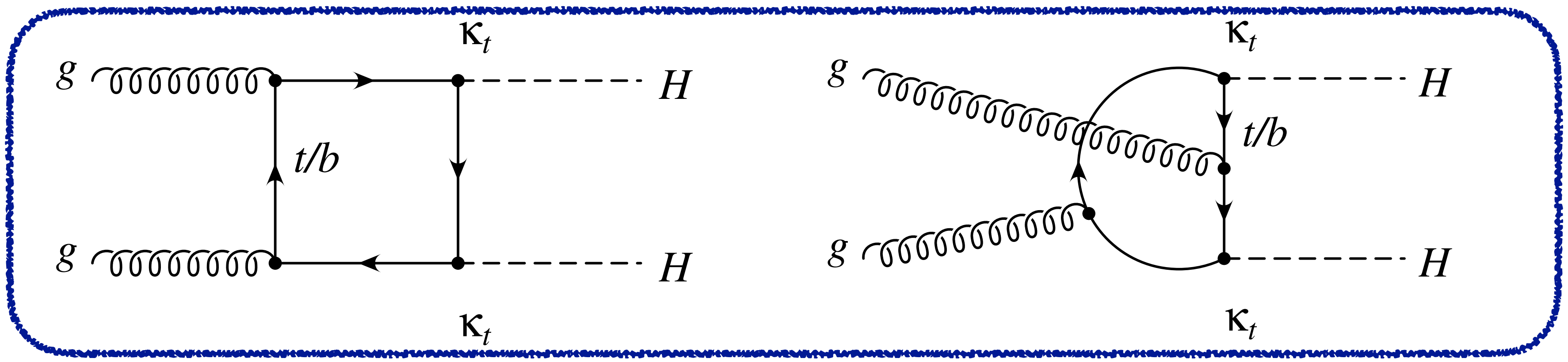
$$\kappa_\lambda = \frac{\lambda_3}{\lambda_3^{SM}}$$

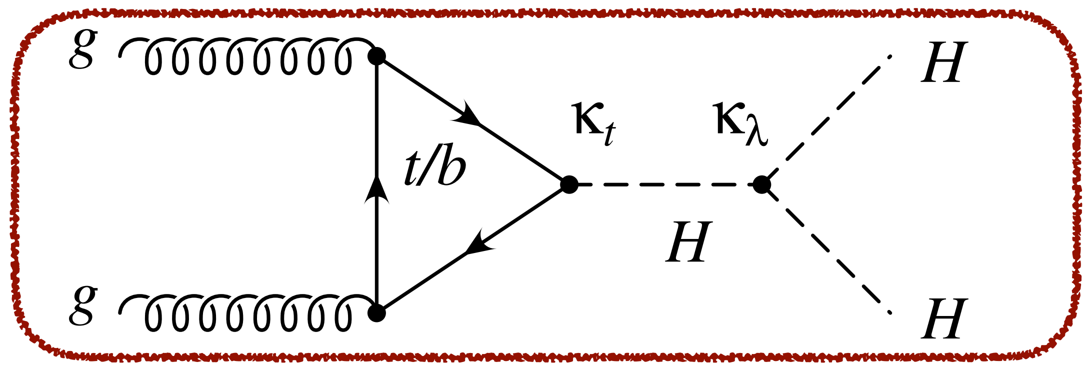




Higgs pair production







- Rare process of the Standard Model:
  - main production mode (90%) ggF: $\sigma^{ggF}_{pp\rightarrow HH} = 31.05\ \text{fb}^{(+2.2\%)}_{(-5.0\%)}$ (scale) $\pm 3.0\%$ (PDF + α_S) $\pm 2.6\%$ (m_{top} unc)
  - the interference between box and triangle diagrams is destructive

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

$$\kappa_t = \frac{y_t^{BSM}}{y_t^{SM}}$$

  - sensitive to the trilinear Higgs self-coupling at leading order in EW.

- $\sigma_{ggF}(pp \rightarrow HH)$ in terms of κ_λ and κ_t : $\sigma_{\text{ggF}}(pp \rightarrow HH) \sim \kappa_t^4 \left[|\mathcal{A}_1|^2 + 2\frac{\kappa_\lambda}{\kappa_t} \Re \mathcal{A}_1^* \mathcal{A}_2 + \left(\frac{\kappa_\lambda}{\kappa_t}\right)^2 |\mathcal{A}_2|^2 \right]$
  - the κ_t^4 factor affects only the total cross section; kinematic distributions and signal acceptances depend only on κ_λ/κ_t.

Single-Higgs production

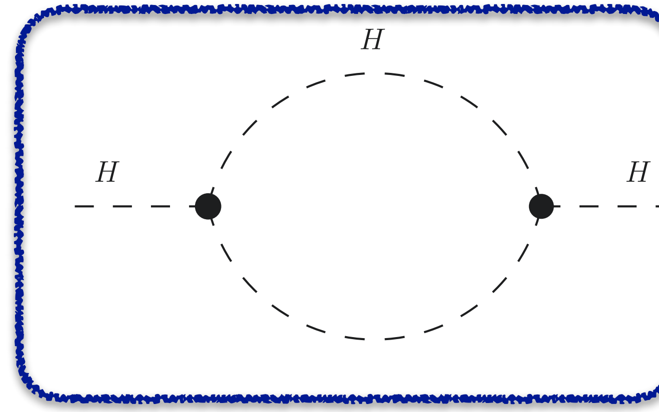
Theoretical framework described in
- [JHEP 1612, 080 (2016)](#) G. Degrassi, P.P. Giardino, F. Maltoni, D. Pagani
- [Eur. Phys. J. C (2017) 77: 887](#) F. Maltoni, D. Pagani, A. Shivaji, X. Zhao

Single-Higgs processes are sensitive to λ_3 via loop corrections.
NLO EW κ_λ-dependent corrections can be divided into two categories:

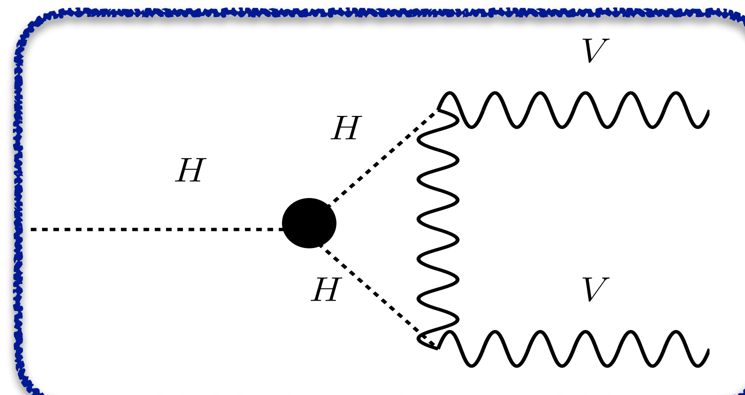
- a universal part, **quadratically dependent on λ_3**, which originates from the Higgs-boson self-energy diagram;
- a process-dependent part, **linearly proportional to λ_3**.

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

Universal part



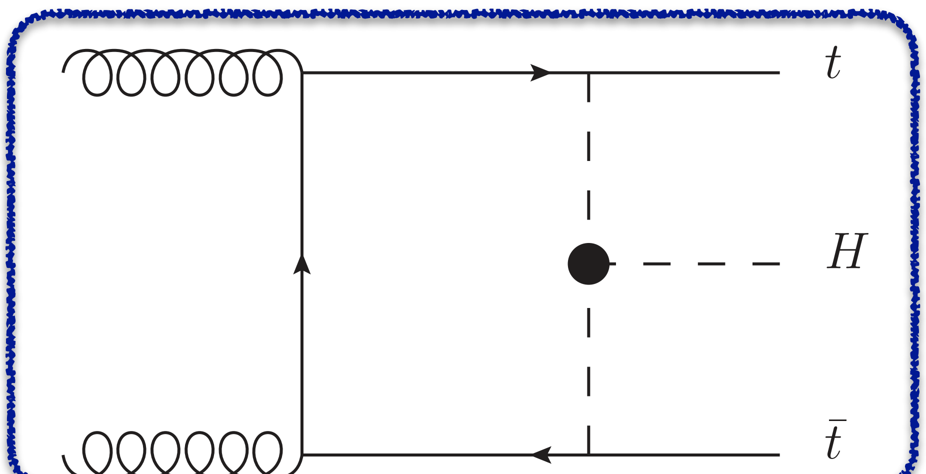
corrections to VV



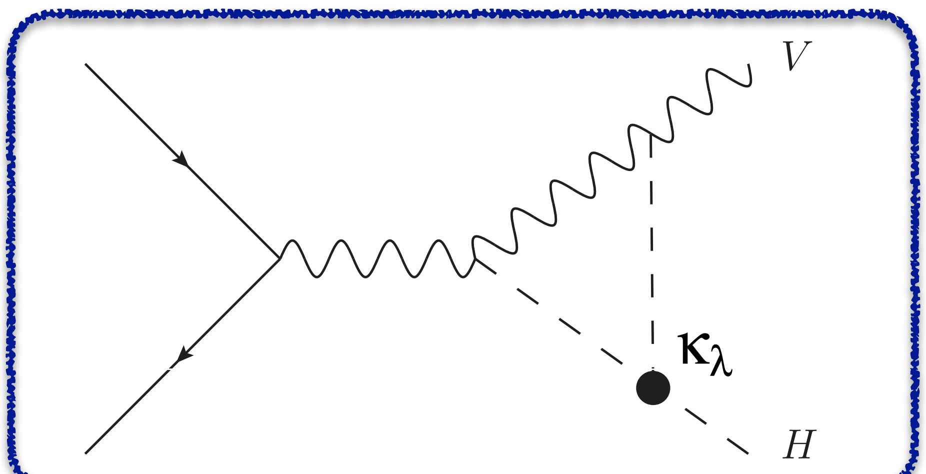
$$|\kappa_\lambda| \lesssim 20$$

Examples of process-dependent part:

corrections to $t\bar{t}H$



corrections to VH



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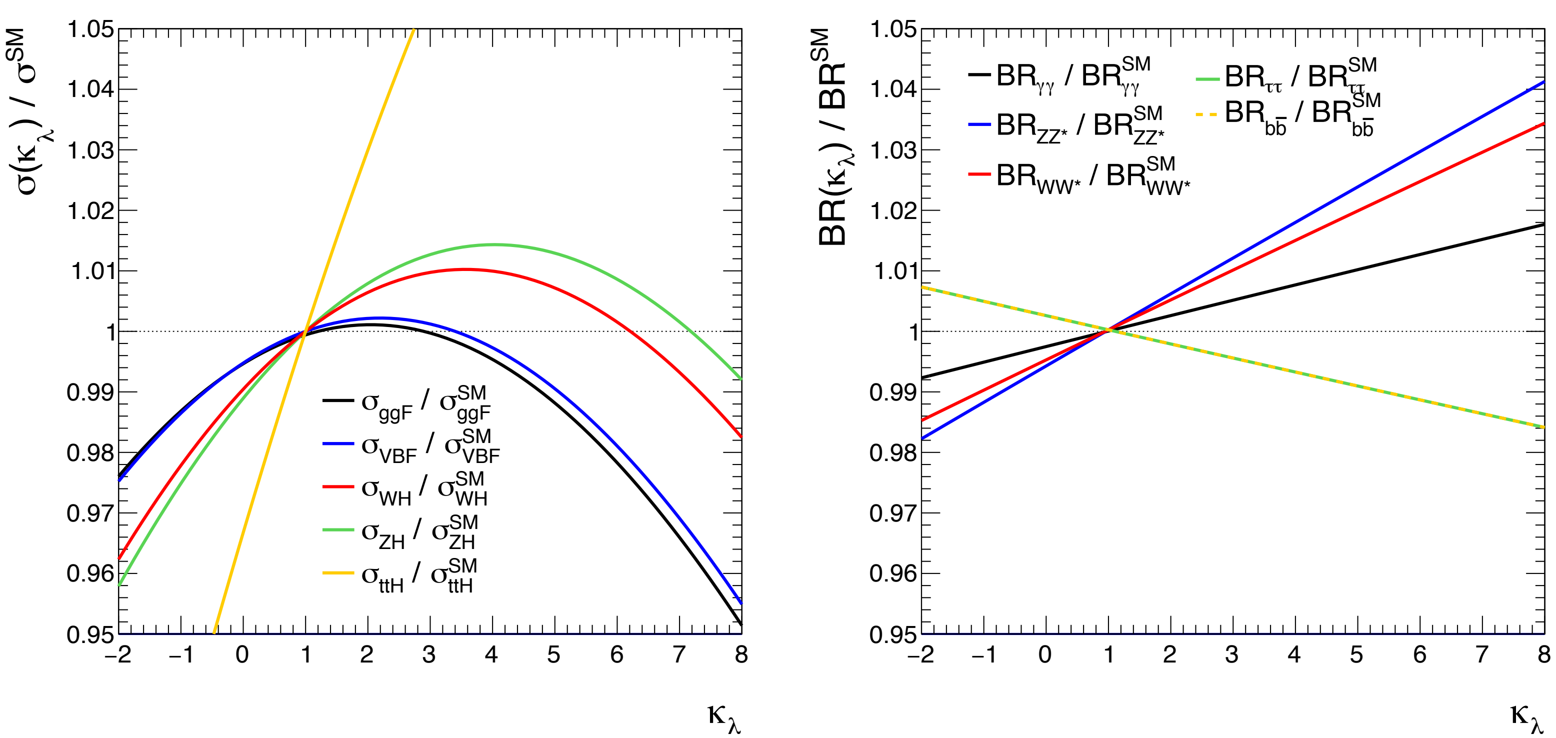
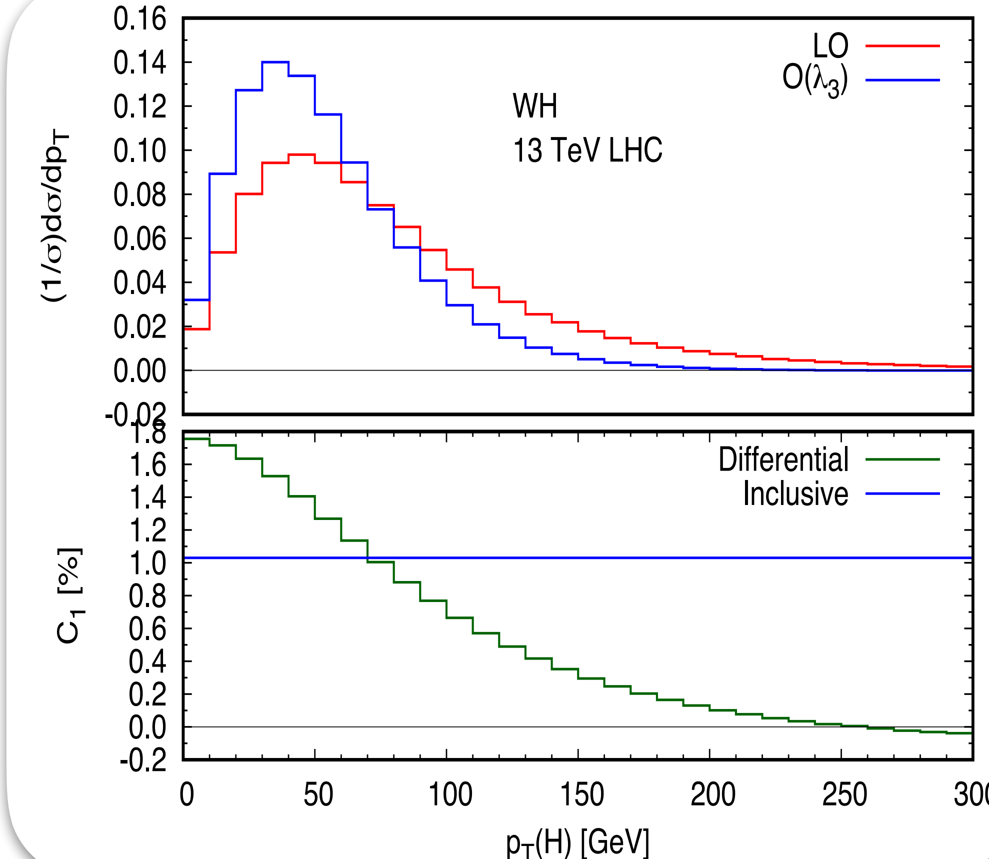
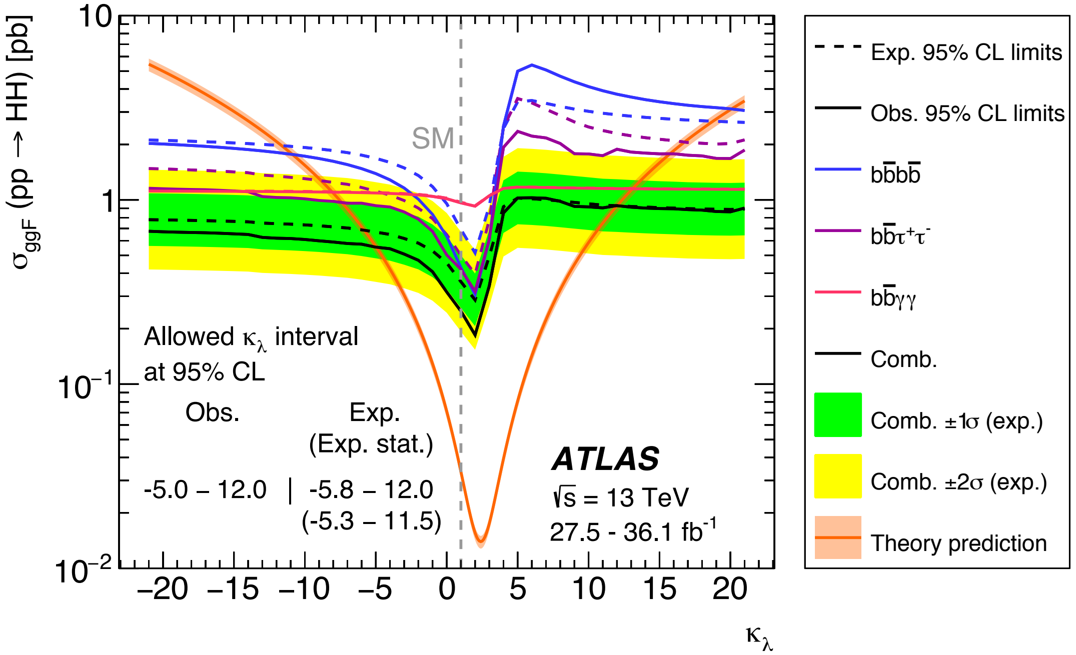




Latest ATLAS experimental results



Double-Higgs production

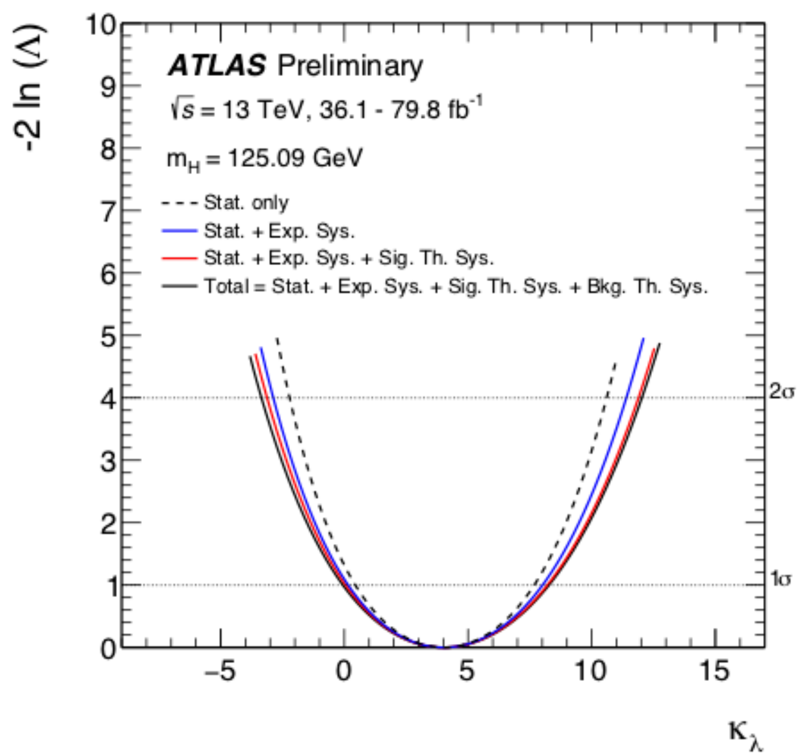
Phys. Lett. B 800 (2020) 135103

$-5.0 < \kappa_\lambda < 12.0\ (obs)\ at\ 95\,\%\ CL$

$-5.8 < \kappa_\lambda < 12.0\ (exp)\ at\ 95\,\%\ CL$

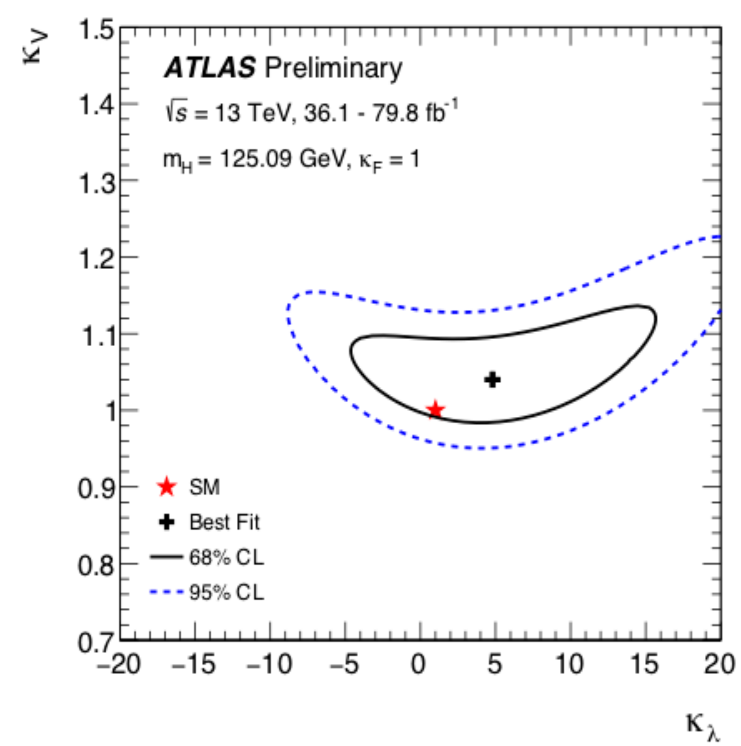
Single-Higgs production

ATL-PHYS-PUB-2019-009

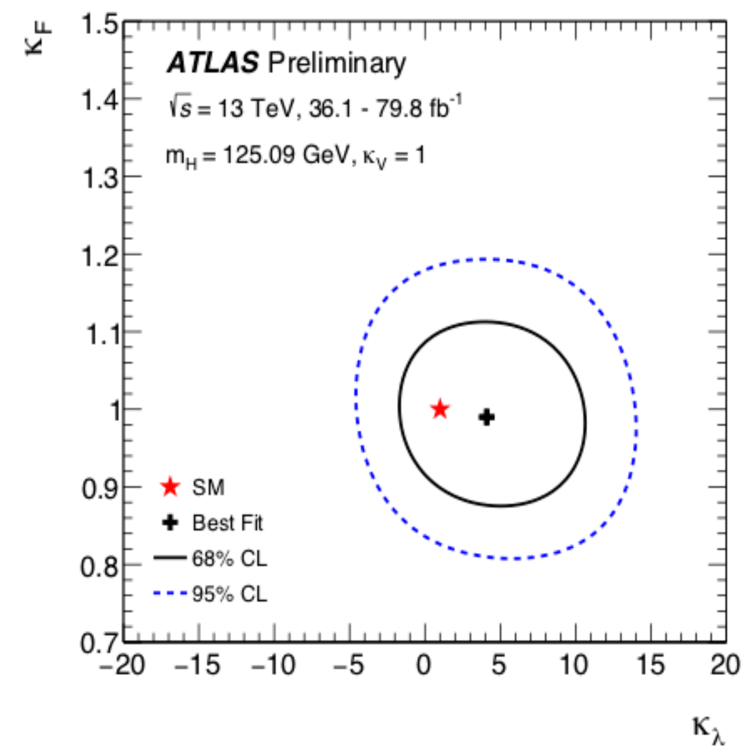


$-3.2 < \kappa_\lambda < 11.9\ (obs)\ at\ 95\,\%\ CL$

$-6.2 < \kappa_\lambda < 14.4\ (exp)\ at\ 95\,\%\ CL$



$-6.7 < \kappa_\lambda < 18.4\ (obs)\ at\ 95\,\%\ CL$



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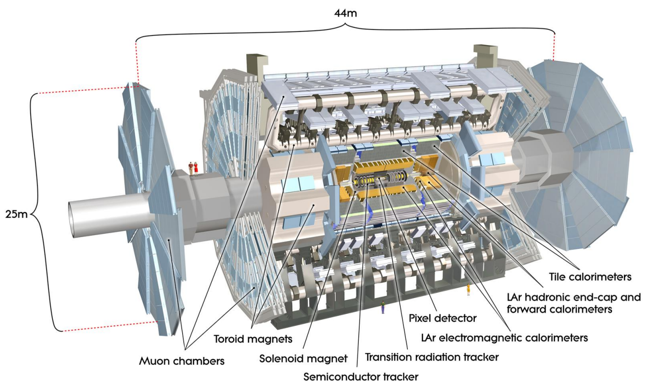
Data and input measurements

ATLAS-CONF-2019-049

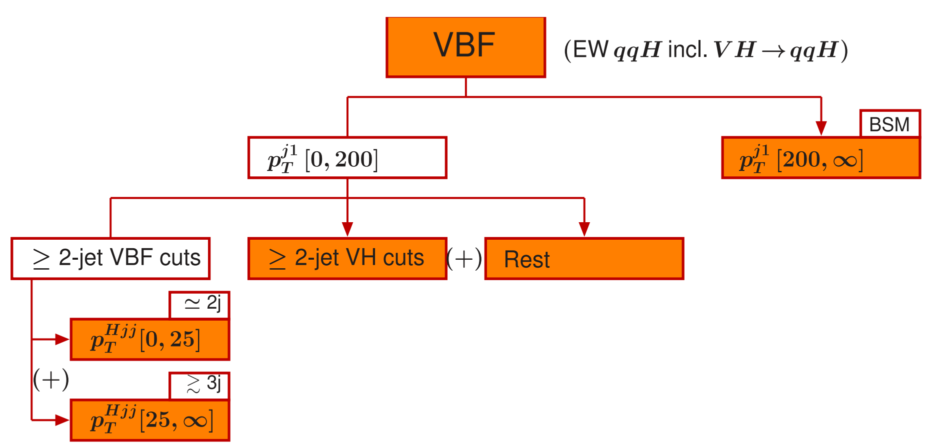


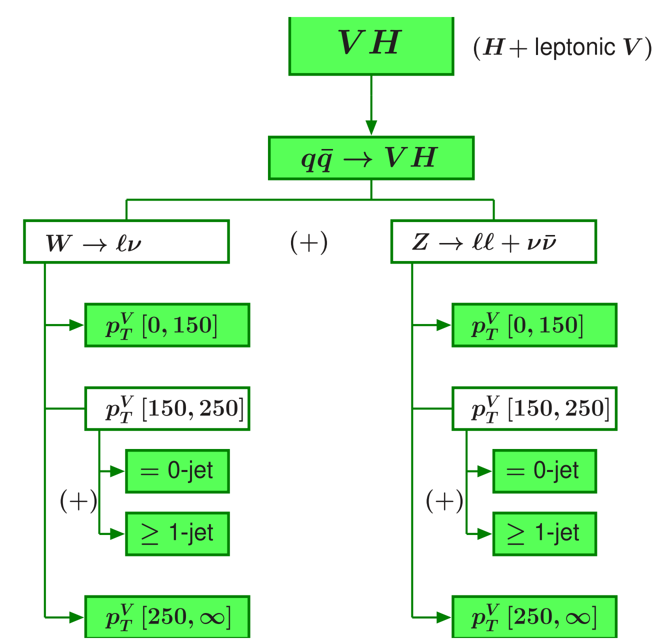
Analysis	Integrated luminosity (fb^{-1})
$H \to \gamma\gamma$	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VH, $H \to b\bar{b}$	79.8
$t\bar{t}H$, $H \to b\bar{b}$ and $t\bar{t}H$ multilepton	36.1
$HH \to b\bar{b}b\bar{b}$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

2015-2017

Single-Higgs inputs containing production and decay modes exploit:

- a luminosity of up to 80 fb^{-1};
- inclusive cross sections, branching fractions, and also differential information for VBF and VH production modes (using STXS truth bin definitions);

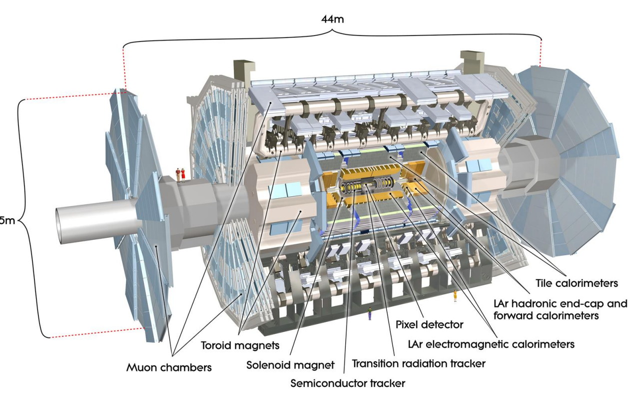




- the $t\bar{t}H \to \gamma\gamma$ categories included in $H \to \gamma\gamma$ analysis have been removed from the combination because they largely overlap with events selected by $HH \to b\bar{b}\gamma\gamma$.

Data and input measurements

ATLAS-CONF-2019-049



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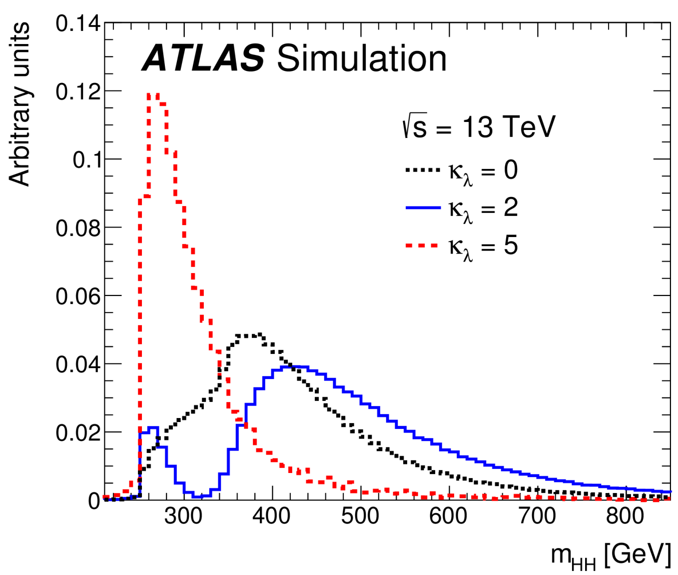
2015-2017

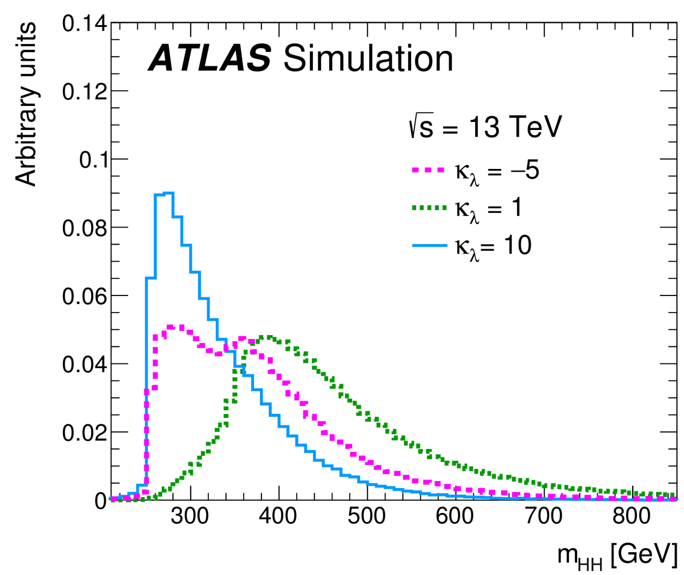
Double-Higgs inputs exploit:

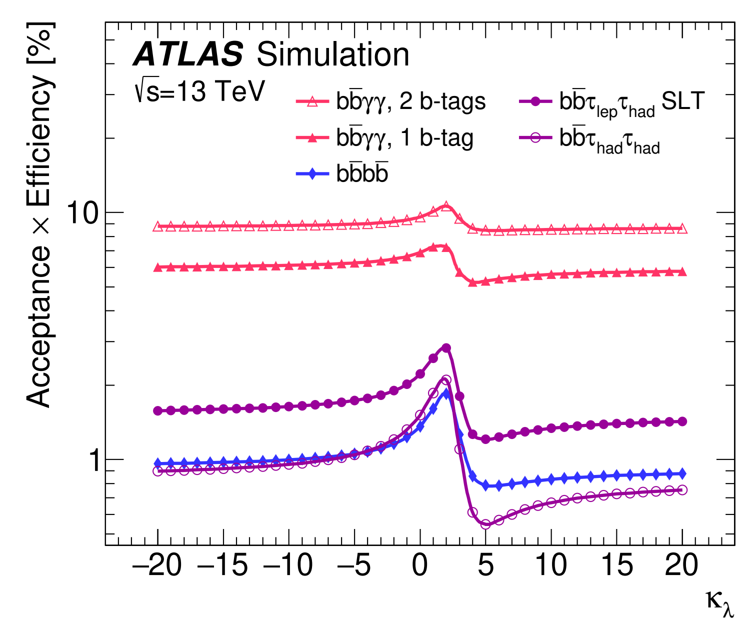
- a luminosity of up to 36.1 fb^{-1};
- the three most sensitive double-Higgs channels, used to produce latest double-Higgs results.
- variations of the inclusive cross section and branching fractions, and variations in the kinematic distributions.

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

Phys. Lett. B 800 (2020) 135103



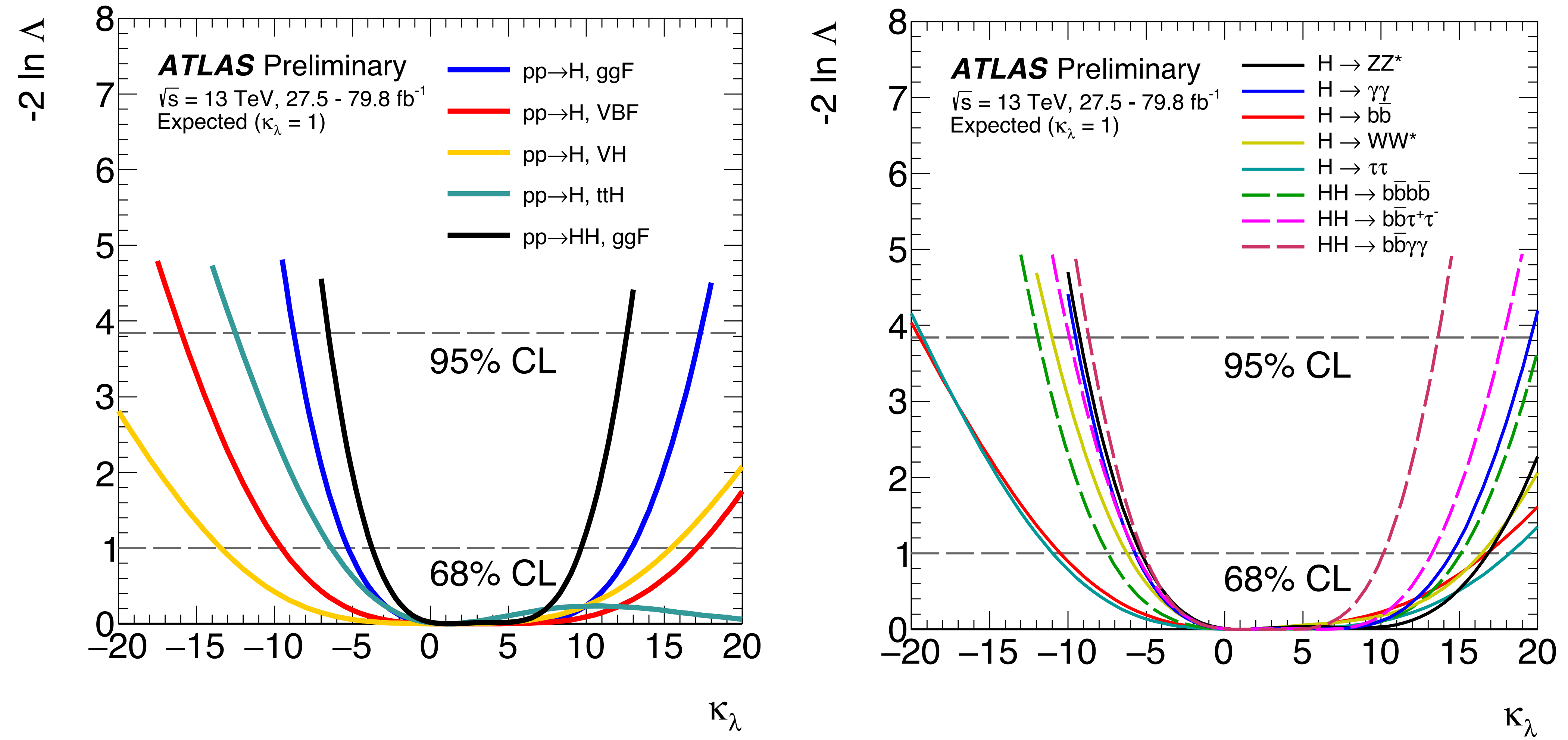




H+HH combination: results of fit to κ_λ (production+decay modes)

ATLAS-CONF-2019-049

- The global likelihood shape depends on combining the contributions from the different **production** and **decay modes.**
- The decomposition of each production and decay contribution is based on the Asimov dataset.
- The dominant contributions to the κ_λ sensitivity derive from the *HH* channels, from the di-boson decay channels $\gamma\gamma$, **ZZ***, **WW*** and from the **ggF** and **$t\bar{t}H$** production modes.



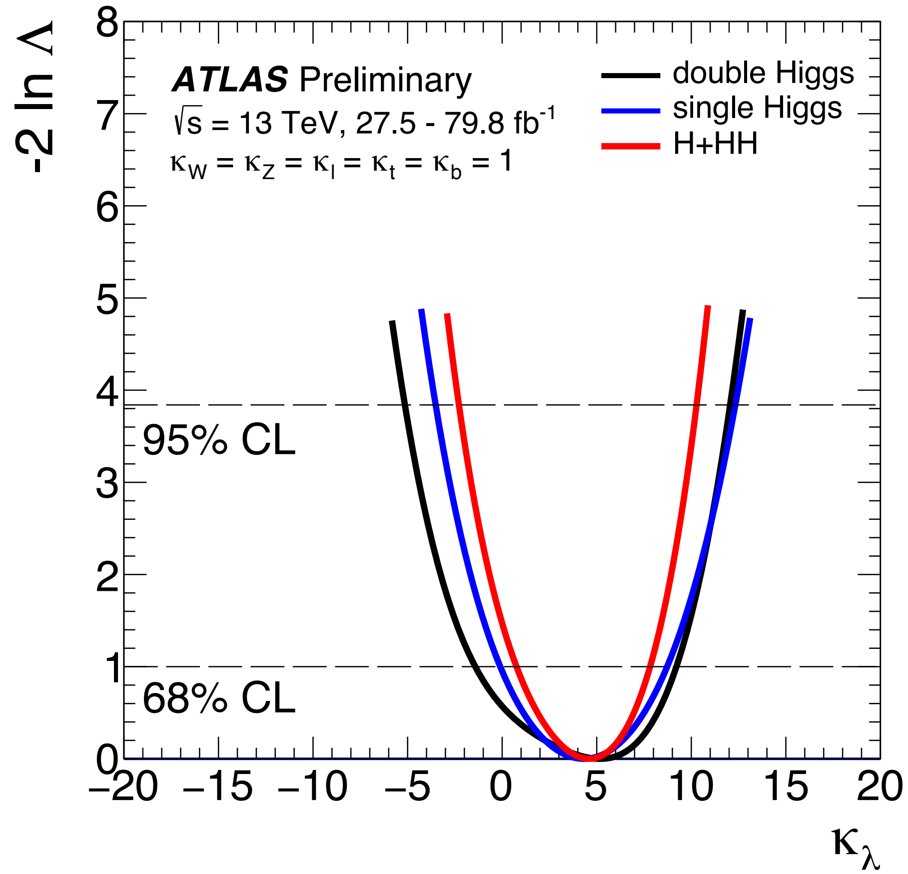
H+HH combination: results of fit to κ_λ

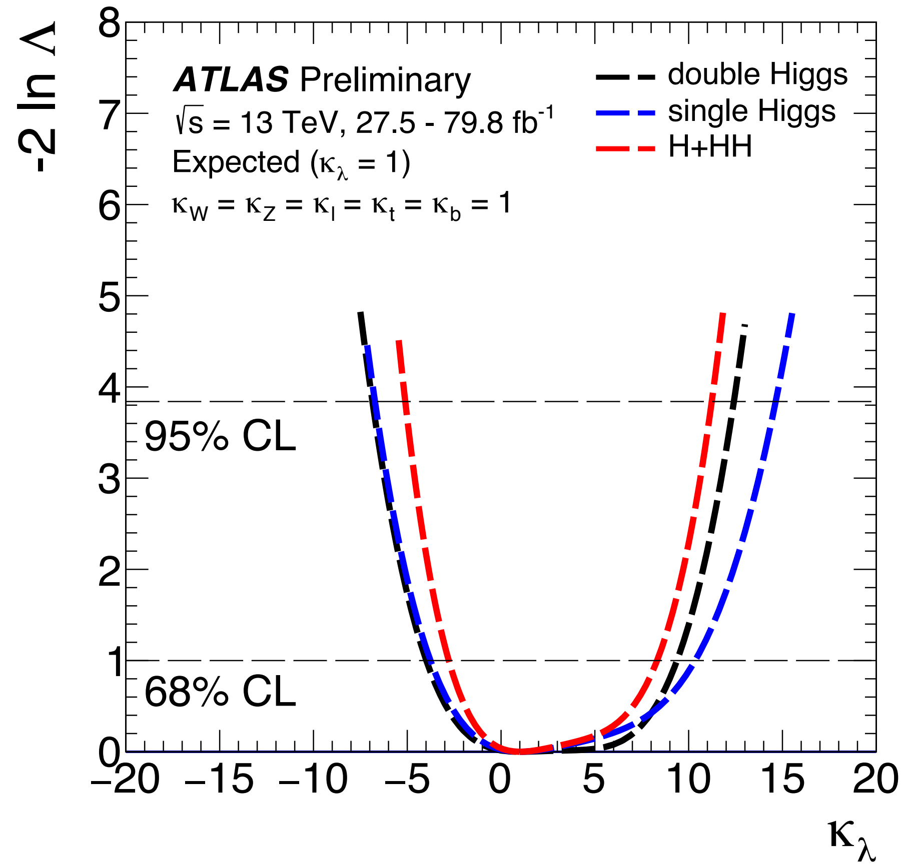
ATLAS-CONF-2019-049

- A likelihood fit is performed to constrain the value of κ_λ in the theoretical allowed range $-20 < \kappa_\lambda < 20$; all other couplings are set to their SM values.

$$\kappa_\lambda = 4.6^{+3.2}_{-3.8} = 4.3^{+2.9}_{-3.5}\,(\text{stat.})\,^{+1.2}_{-1.2}\,(\text{exp.})\,^{+0.7}_{-0.5}\,(\text{sig. th.})\,^{+0.6}_{-1.0}\,(\text{bkg. th.})(obs.)$$

$-2.3 < \kappa_\lambda < 10.3\ (obs)\ at\ 95\,\%\ CL$ $\quad$ $-5.1 < \kappa_\lambda < 11.2\ (exp)\ at\ 95\,\%\ CL$

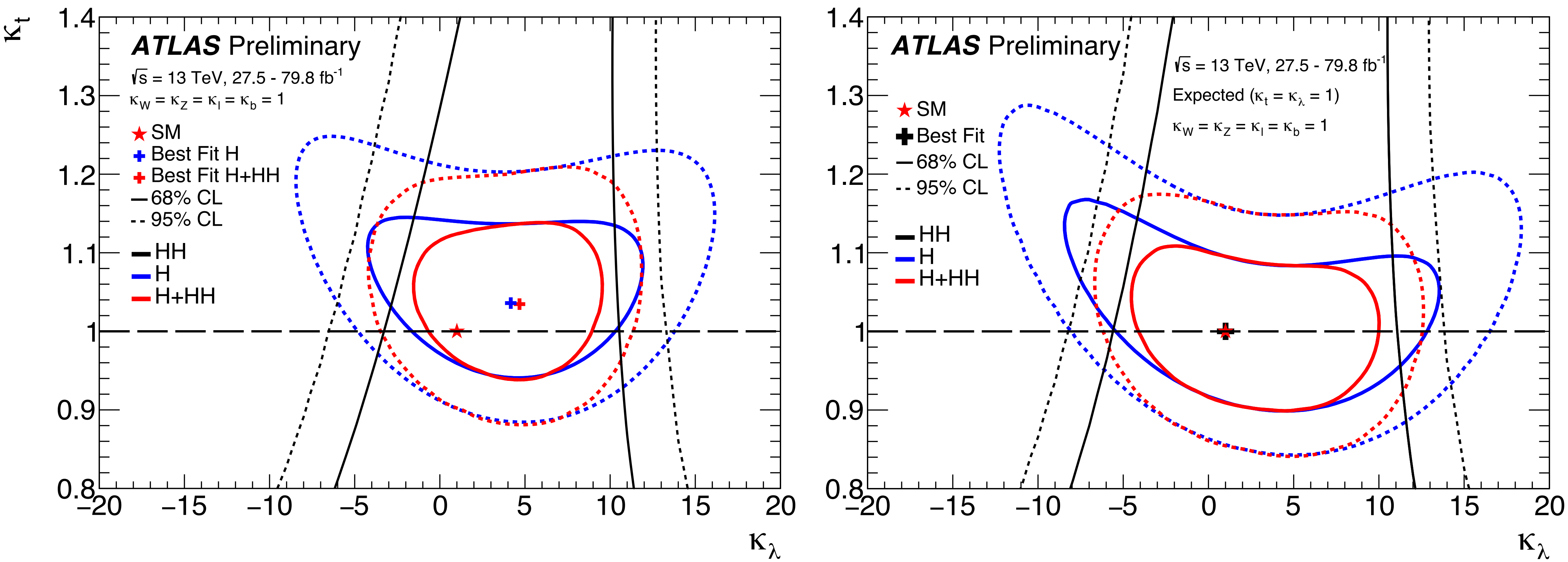




- The double-Higgs boson production measurements are more sensitive than the single-Higgs boson measurement for $\kappa_\lambda \gg 1$ and show similar sensitivity for negative κ_λ.
- The combination significantly improves the constraining power on κ_λ.

H+HH combination: results of fit to κ_λ and κ_t

- A likelihood fit is performed to constrain at the same time κ_λ and κ_t; all other couplings are set to their SM values.
- Double–Higgs analyses alone cannot constrain κ_λ and κ_t simultaneously.
- The combination with single-Higgs measurements allows the determination of κ_t to a sufficient precision to restore most of the ability of the double-Higgs analyses to constrain κ_λ.



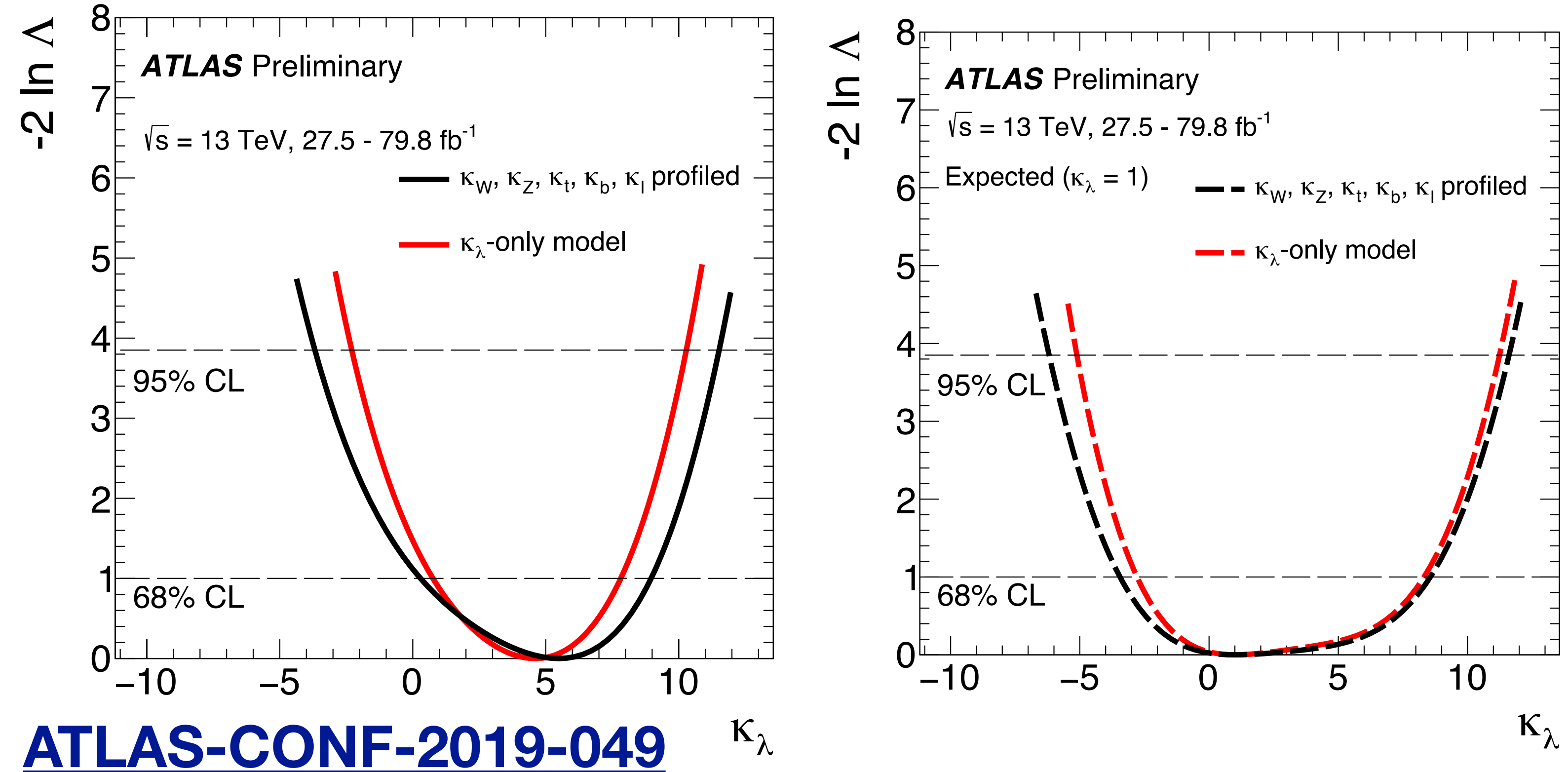
ATLAS-CONF-2019-049

H+HH combination: generic model

- The constraining power of the single Higgs-boson production measurement, allows to perform a fit in a more generic model, fitting simultaneously κ_λ- κ_W - κ_Z - κ_{lepton}- κ_b- κ_t.
- The combination of single- and double-Higgs analyses allows to put sizeable constraints even in this generic model.

Model	$\kappa_W{}^{+1\sigma}_{-1\sigma}$	$\kappa_Z{}^{+1\sigma}_{-1\sigma}$	$\kappa_t{}^{+1\sigma}_{-1\sigma}$	$\kappa_b{}^{+1\sigma}_{-1\sigma}$	$\kappa_\ell{}^{+1\sigma}_{-1\sigma}$	$\kappa_\lambda{}^{+1\sigma}_{-1\sigma}$	κ_λ [95% CL]	
κ_λ-only	1	1	1	1	1	$4.6^{+3.2}_{-3.8}$	[−2.3, 10.3]	obs.
						$1.0^{+7.3}_{-3.8}$	[−5.1, 11.2]	exp.
Generic	$1.03^{+0.08}_{-0.08}$	$1.10^{+0.09}_{-0.09}$	$1.00^{+0.12}_{-0.11}$	$1.03^{+0.20}_{-0.18}$	$1.06^{+0.16}_{-0.16}$	$5.5^{+3.5}_{-5.2}$	[−3.7, 11.5]	obs.
	$1.00^{+0.08}_{-0.08}$	$1.00^{+0.08}_{-0.08}$	$1.00^{+0.12}_{-0.12}$	$1.00^{+0.21}_{-0.19}$	$1.00^{+0.16}_{-0.15}$	$1.0^{+7.6}_{-4.5}$	[−6.2, 11.6]	exp.

sensitivity degraded by ~20 %



ATLAS-CONF-2019-049

Summary

- In the simplified assumption that all deviations from the SM expectation have to be interpreted as modifications of the trilinear coupling of the Higgs boson, the best fit value of κ_λ from the combination of single and double-Higgs analyses is $\kappa_\lambda = 4.6^{+3.2}_{-3.8}$ excluding at the 95% CL values outside the interval $-2.3 < \kappa_\lambda < 10.3$.
- The $H + HH$ combination result constitutes a **significant improvement** on the constraints on κ_λ obtained from single-Higgs and double-Higgs analyses alone.
- Moreover, the $H + HH$ combination allows to **decouple** the self-coupling and top-Yukawa coupling as well as other couplings.
- Further improvements are expected with the **increasing luminosity**, as well as with the implementation of the **differential information** in analyses like $t\bar{t}H$.
- The ATLAS experiment has set the **most stringent constraints on** κ_λ from experimental data.

BACKUP

The Higgs-boson self-coupling

Phys. Rev. D 88, 055024 (2013)

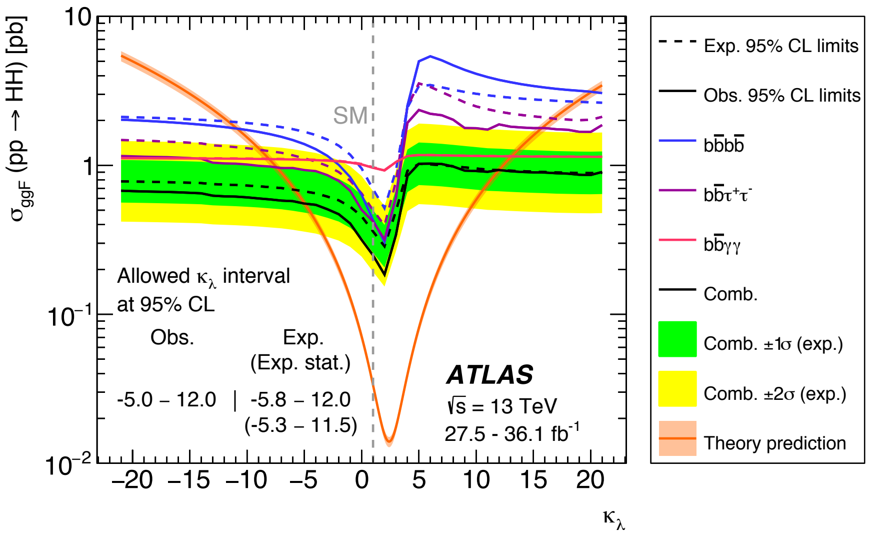
The maximal self-coupling deviation from its SM value in different BSM theories.

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.

Latest experimental results

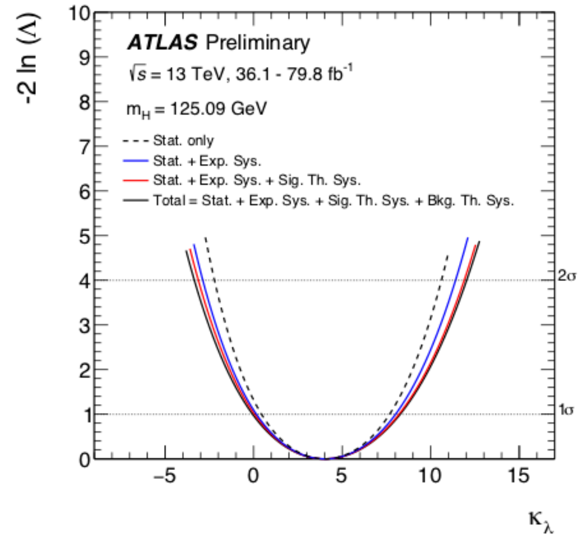
ATLAS: Phys. Lett. B 800 (2020) 135103



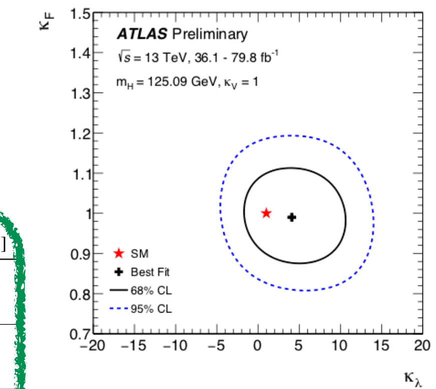
$$-5.0 < \kappa_\lambda < 12.0\ (obs)\ at\ 95\,\%\ CL$$

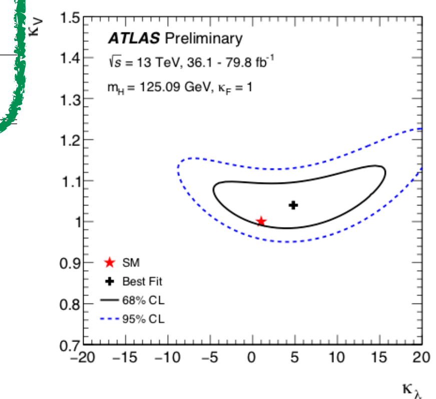
$$-5.8 < \kappa_\lambda < 12.0\ (exp)\ at\ 95\,\%\ CL$$

ATLAS: ATL-PHYS-PUB-2019-009



POIs	Granularity	$\kappa_F{}^{+1\sigma}_{-1\sigma}$	$\kappa_V{}^{+1\sigma}_{-1\sigma}$	$\kappa_\lambda{}^{+1\sigma}_{-1\sigma}$	κ_λ [95% C.L.]
κ_λ	STXS	1	1	$4.0^{+4.3}_{-4.1}$ $1.0^{+8.8}_{-4.4}$	[−3.2, 11.9] [−6.2, 14.4]
κ_λ	inclusive	1	1	$4.6^{+4.3}_{-4.2}$ $1.0^{+9.5}_{-4.3}$	[−2.9, 12.5] [−6.1, 15.0]
κ_λ, κ_V	STXS	1	$1.04^{+0.05}_{-0.04}$ $1.00^{+0.05}_{-0.04}$	$4.8^{+7.4}_{-6.7}$ $1.0^{+9.9}_{-6.1}$	[−6.7, 18.4] [−9.4, 18.9]
κ_λ, κ_F	STXS	$0.99^{+0.08}_{-0.08}$ $1.00^{+0.08}_{-0.08}$	1	$4.1^{+4.3}_{-4.1}$ $1.0^{+8.8}_{-4.4}$	[−3.2, 11.9] [−6.3, 14.4]

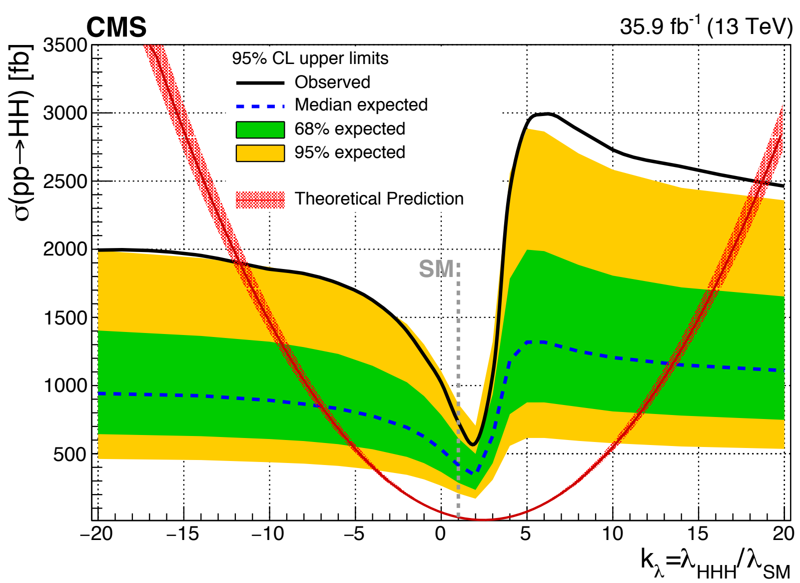




$$-3.2 < \kappa_\lambda < 11.9\ (obs)\ at\ 95\,\%\ CL$$

$$-6.2 < \kappa_\lambda < 14.4\ (exp)\ at\ 95\,\%\ CL$$

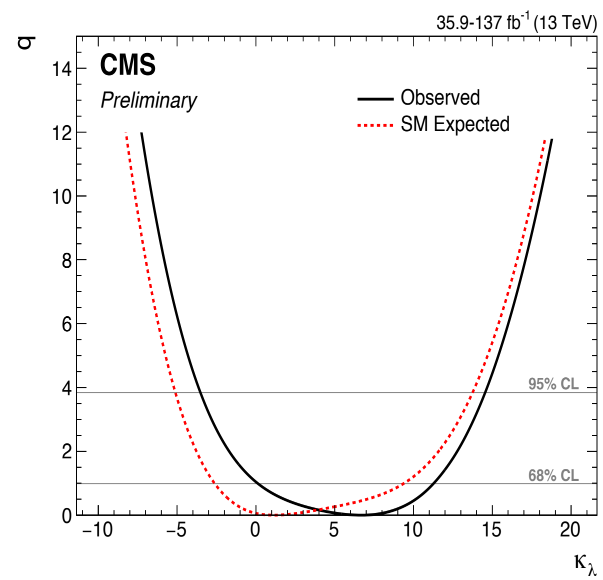
CMS: Phys. Rev. Lett. 122, 121803 (2019)



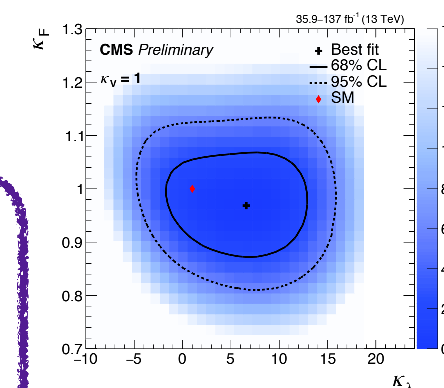
$$-11.8 < \kappa_\lambda < 18.8\ (obs)\ at\ 95\,\%\ CL$$

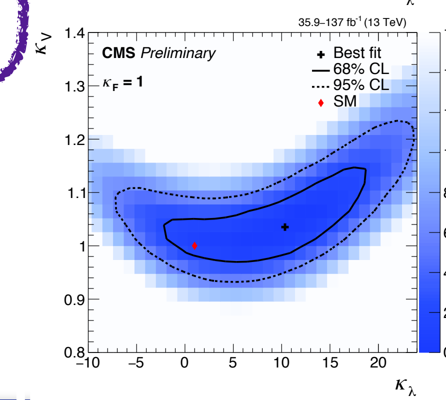
$$-7.1 < \kappa_\lambda < 13.6\ (exp)\ at\ 95\,\%\ CL$$

CMS: CMS-PAS-HIG-19-005



Assumption	Best fit κ_λ	95% CL interval
$\kappa_F = \kappa_V = 1$	$6.7^{+4.6}_{-6.6}$ $\left(^{+8.3}_{-3.8}\right)$	$[-3.5, 14.5]$ $\left([-5.1, 13.7]\right)$
$\kappa_F = 1$	$10.3^{+6.1}_{-10.0}$ $\left(^{+8.8}_{-5.0}\right)$	$[-5.5, 21.7]$ $\left([-7.4, 17.2]\right)$
$\kappa_V = 1$	$6.6^{+4.5}_{-6.1}$ $\left(^{+8.2}_{-4.0}\right)$	$[-3.3, 14.4]$ $\left([-5.5, 13.8]\right)$





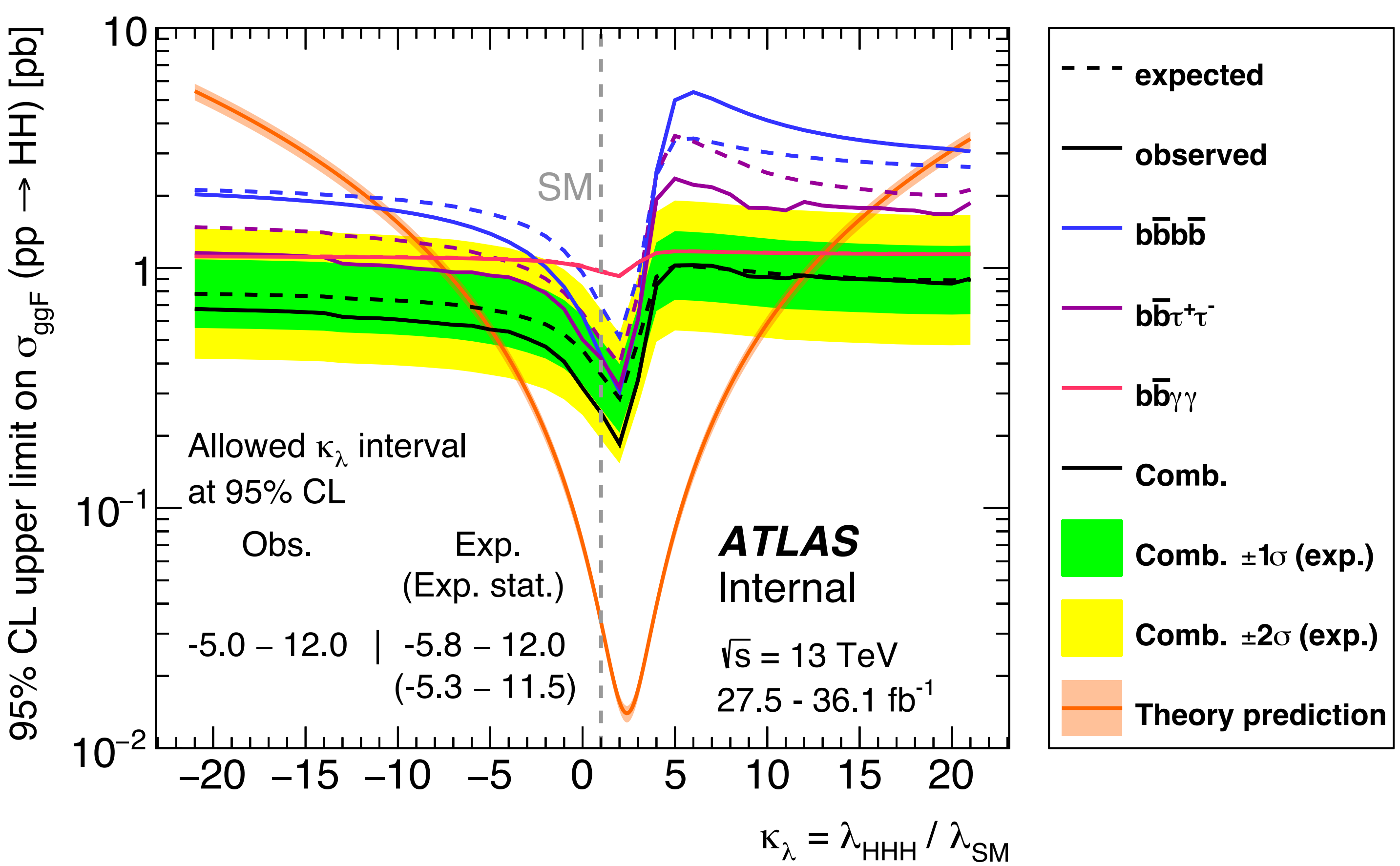
$$-3.5 < \kappa_\lambda < 14.5\ (obs)\ at\ 95\,\%\ CL$$

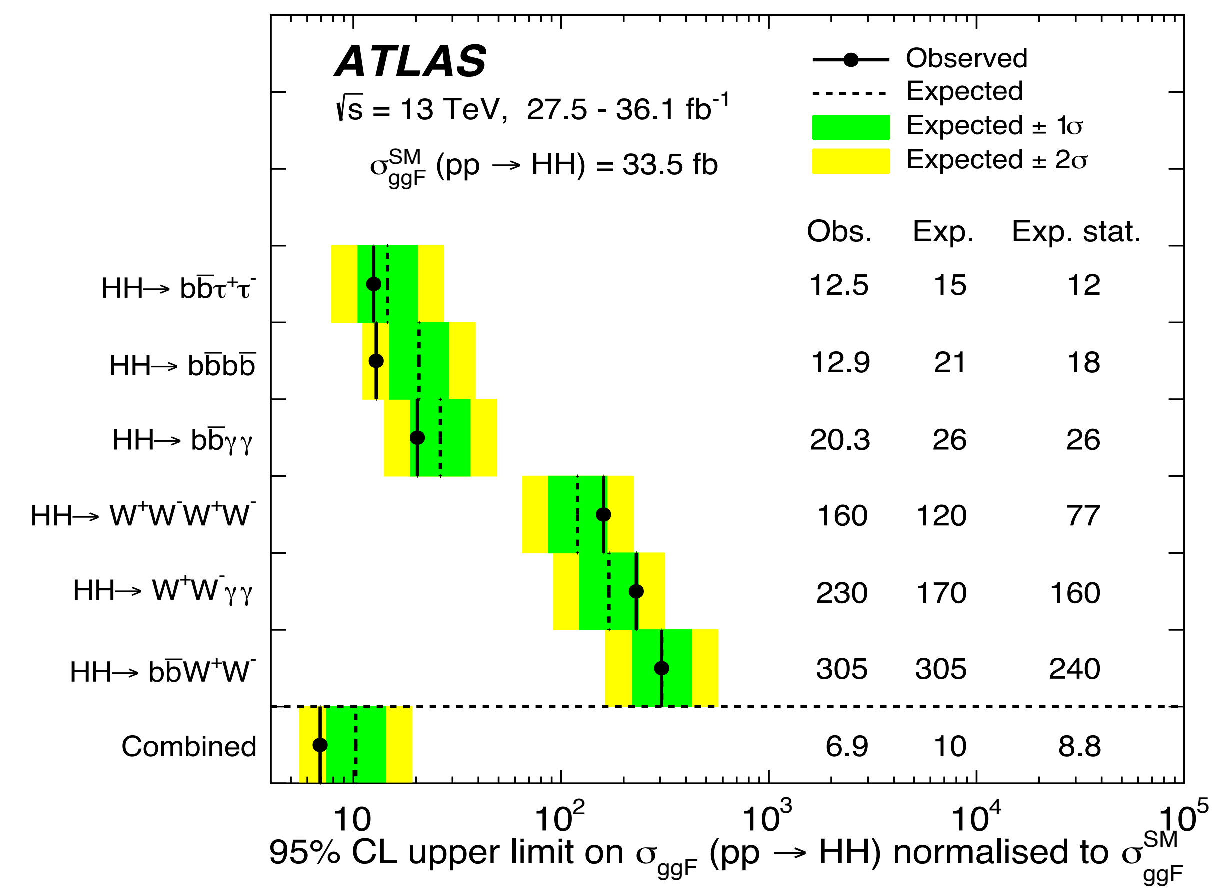
$$-5.1 < \kappa_\lambda < 13.7\ (exp)\ at\ 95\,\%\ CL$$

Double-Higgs production: latest results

Phys. Lett. B 800 (2020) 135103

- The dependences on κ_λ of the Higgs boson branching fractions and of the single-Higgs background have been neglected;
- all couplings except the Higgs-boson self-coupling have been set to their SM values;
- exclusion limits have been set after a κ_λ-scan on the cross section and a comparison with the theoretical $\sigma_{ggF}(pp \rightarrow HH)$ cross section as a function of κ_λ.





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:

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

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

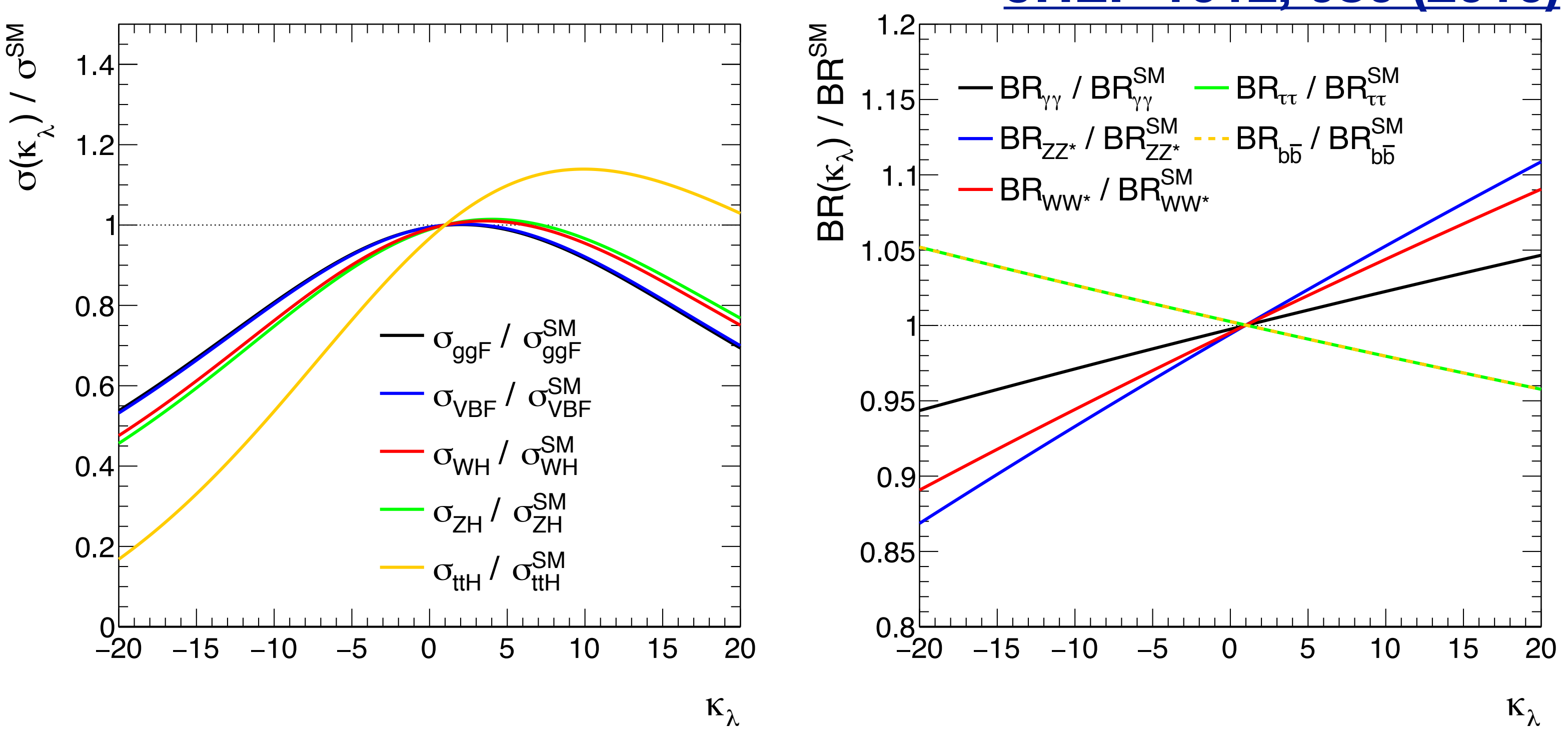
$$\mu_f(\kappa_\lambda, \kappa_f) = \frac{BR_f^{BSM}}{BR_f^{SM}} = \frac{\kappa_f^2 + (\kappa_\lambda - 1)C_1^f}{\sum_j BR_j^{SM}\left[\kappa_j^2 + (\kappa_\lambda - 1)C_1^j\right]}$$

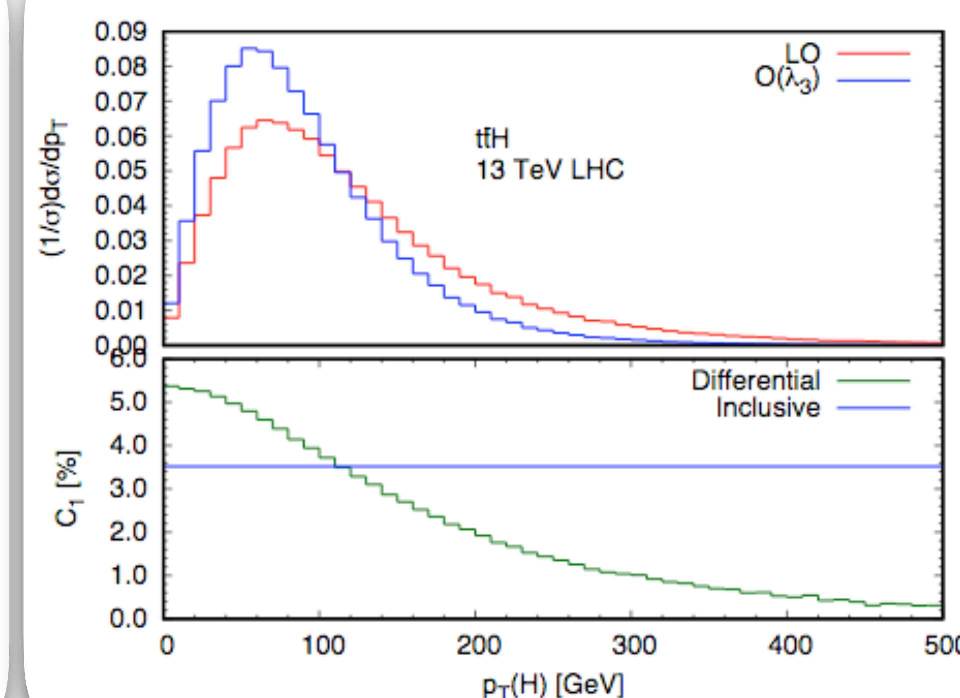
- κ_i and κ_f represent multiplicative modifiers to other Higgs boson couplings for initial and final states, parameterised as in the LO κ-framework;

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

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

JHEP 1612, 080 (2016)



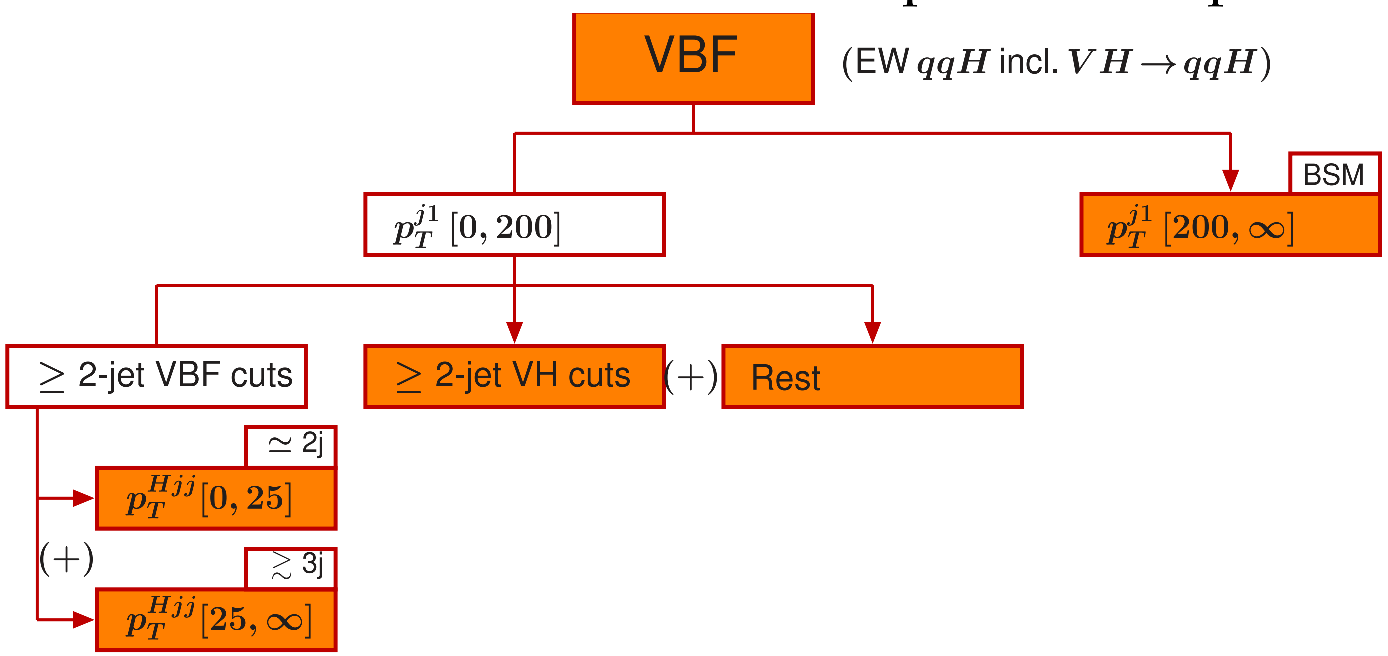


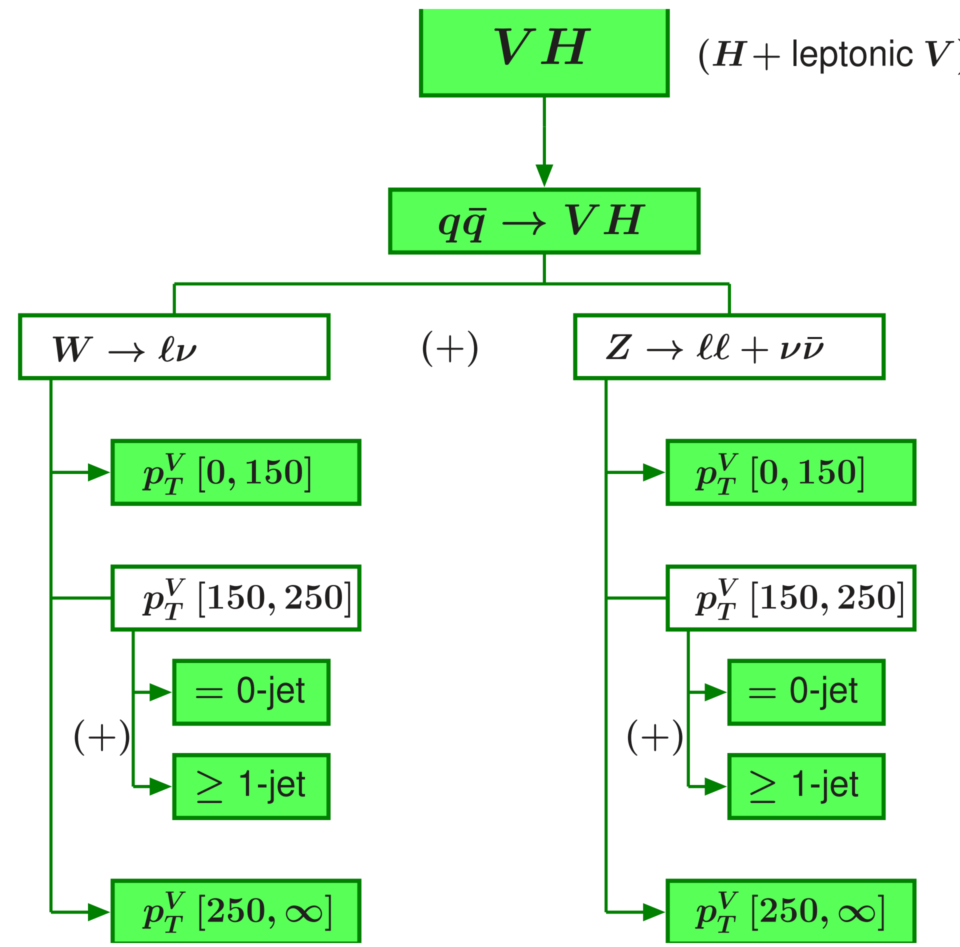
Single-Higgs production: data and input measurements

The results are obtained using ATLAS data corresponding to a luminosity of up to 80 fb^{-1}.

Two different inputs, (containing production and decay modes) have been considered:

- one is used for inclusive estimations;
- the second one is profiled in bins of truth-level observables, p_T^H (Simplified Template Cross Sections STXS bins); it can be used for differential estimations; the analysis *VBF* $H \to b\bar{b}$ has been excluded from the input (low impact + no STXS bins).



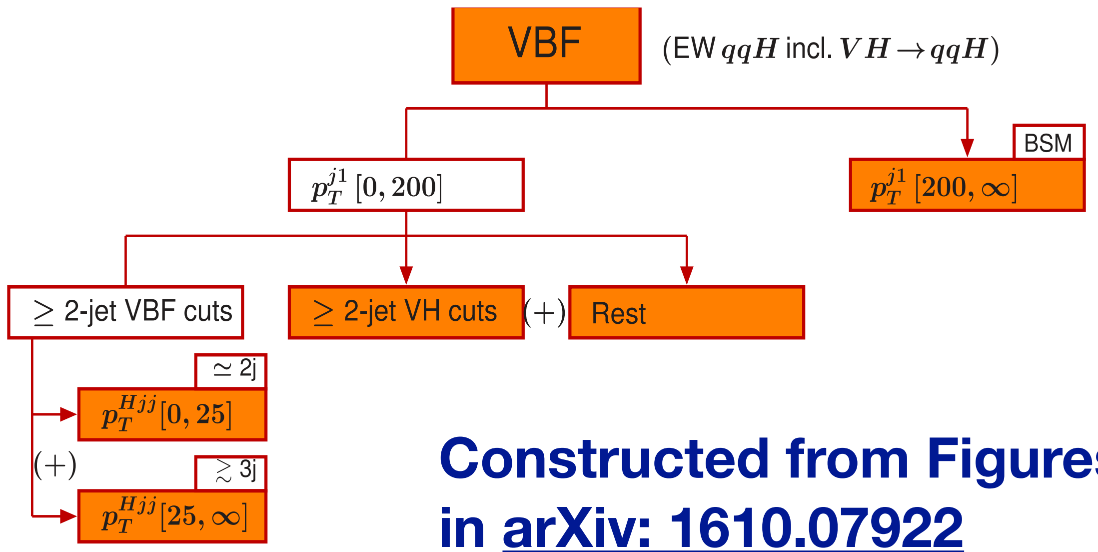


Analysis	Integrated luminosity (fb^{-1})
$H \to \gamma\gamma$ (including $t\bar{t}H$, $H \to \gamma\gamma$)	79.8
$H \to ZZ^* \to 4\ell$ (including $t\bar{t}H$, $H \to ZZ^* \to 4\ell$)	79.8
$H \to WW^* \to e\nu\mu\nu$	36.1
$H \to \tau\tau$	36.1
VH, $H \to b\bar{b}$	79.8
$t\bar{t}H$, $H \to b\bar{b}$ and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

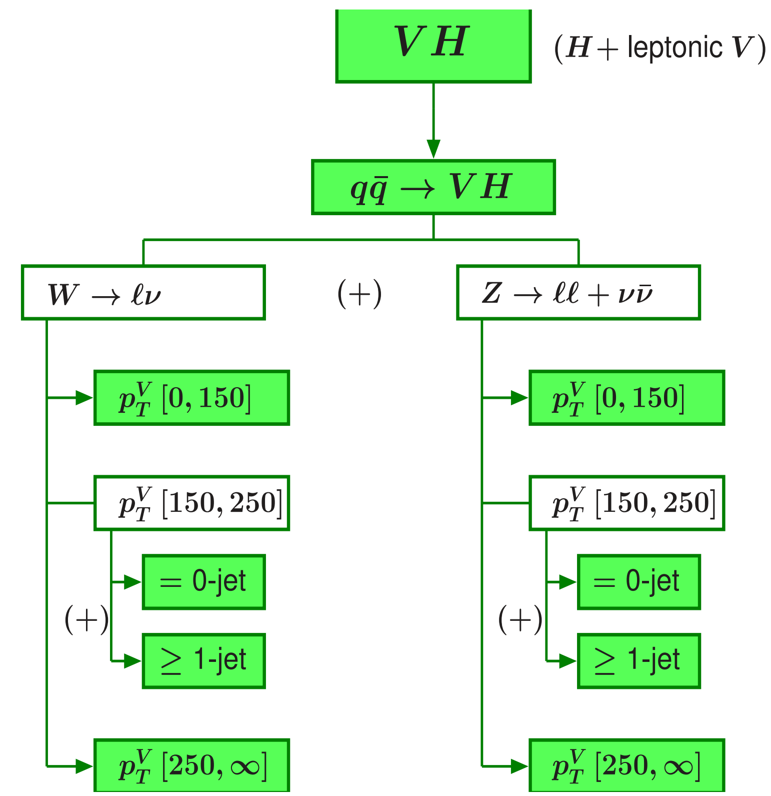
Constructed from Figures in arXiv: 1610.07922

Single-Higgs production: kinematic dependent coefficients

- The parameterisation of the variation of the production cross-section as a function of κ_λ can be adapted to describe the cross-section in each single STXS region.
- This requires re-deriving the values of the kinematic dependent coefficients C_1^i in each region defined in the measurement.



Constructed from Figures in arXiv: 1610.07922



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STXS region		VBF	WH	ZH
		$C_1^i \times 100$		
$VBF + V(\text{had})H$	$VBF\text{-cuts} + p_T^{j1} < 200$ GeV, $\leq 2j$	0.63	0.91	1.07
	$VBF\text{-cuts} + p_T^{j1} < 200$ GeV, $\geq 3j$	0.61	0.85	1.04
	$VH\text{-cuts} + p_T^{j1} < 200$ GeV	0.64	0.89	1.10
	no VBF/VH-cuts, $p_T^{j1} < 200$ GeV	0.65	1.13	1.28
	$p_T^{j1} > 200$ GeV	0.39	0.23	0.28

STXS region		VBF	WH	ZH
		$C_1^i \times 100$		
$qq \to H\ell\nu$	$p_T^V < 150$ GeV		1.15	
	$150 < p_T^V < 250$ GeV, $0j$		0.18	
	$150 < p_T^V < 250$ GeV, $\geq 1j$		0.33	
	$p_T^V > 250$ GeV		0	
$qq \to H\ell\ell$	$p_T^V < 150$ GeV			1.33
	$150 < p_T^V < 250$ GeV, $0j$			0.20
$qq \to H\nu\nu$	$150 < p_T^V < 250$ GeV, $\geq 1j$			0.39
	$p_T^V > 250$ GeV			0

Single-Higgs production: results of fit to κ_λ

ATL-PHYS-PUB-2019-009

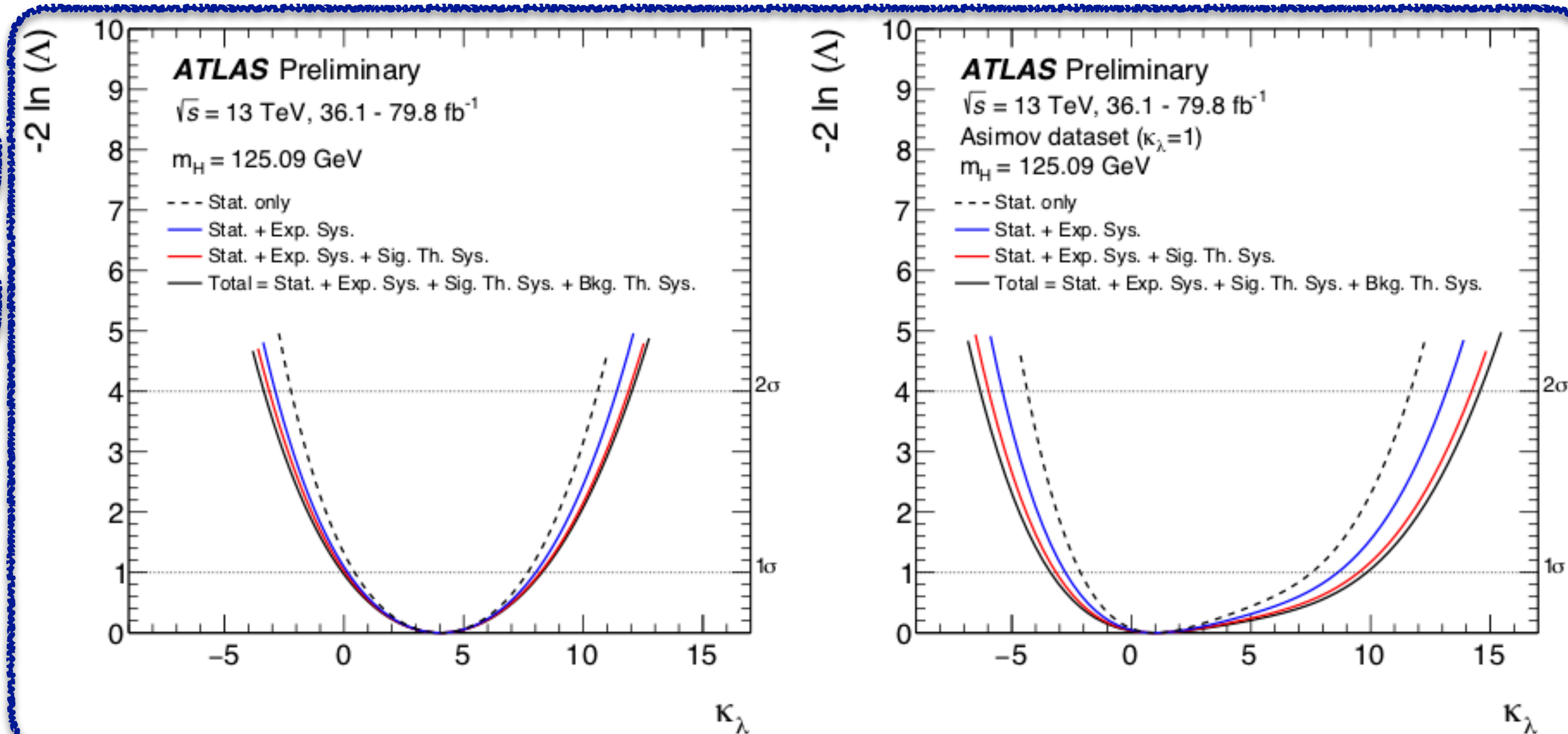
- Exploiting NLO electroweak corrections to single-Higgs processes, it is possible to extract constraints on κ_λ through a global likelihood fit in the range $|\kappa_\lambda| < 20$.
- The impact on the κ_λ determination of using an inclusive cross-section measurement, rather than the differential cross-section information contained in the STXS bins, has been studied; thus *VBF*, *WH* and *ZH* production modes have been considered as single inclusive bins.
- Compared to the use of differential information, the inclusive fit does not currently lead to a significant loss in sensitivity to κ_λ.

Results exploiting differential information

$$\kappa_\lambda = 4.0^{+4.3}_{-4.1} = 4.0^{+3.7}_{-3.6}\,(\text{stat.})\,^{+1.6}_{-1.5}\,(\text{exp.})\,^{+1.3}_{-0.9}\,(\text{sig. th.})\,^{+0.8}_{-0.9}\,(\text{bkg. th.})$$

$$-3.2 < \kappa_\lambda < 11.9\ (obs)\ at\ 95\,\%\ CL$$

$$-6.2 < \kappa_\lambda < 14.4\ (exp)\ at\ 95\,\%\ CL$$

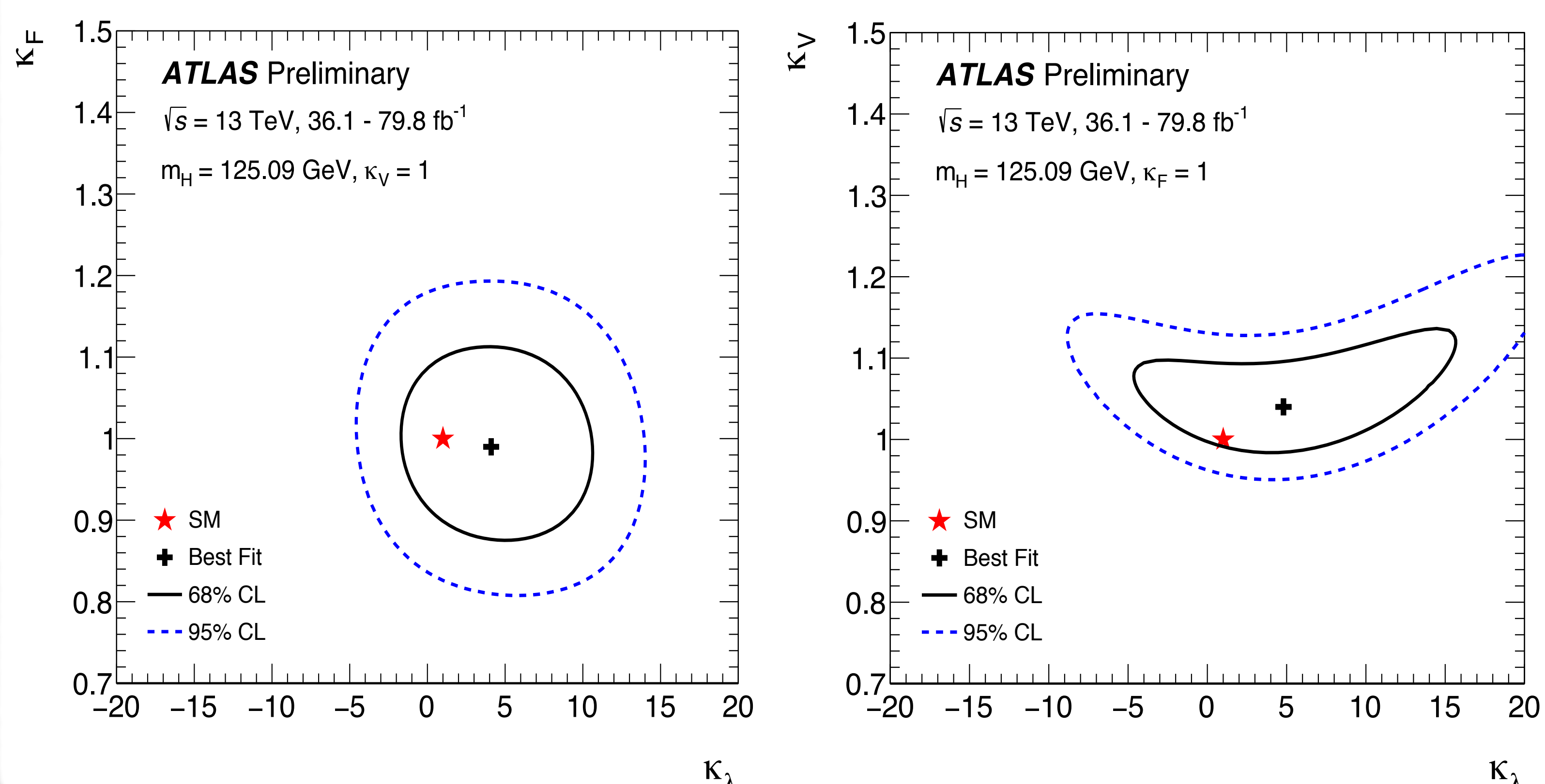


Single-Higgs production: results of fit to κ_λ and κ_F or κ_λ and κ_V

ATL-PHYS-PUB-2019-009

- In order to target BSM models where new physics could affect only the Yukawa type terms of the SM ($\kappa_V = 1$) or only the couplings to vector bosons ($\kappa_F = 1$), in addition to the Higgs-boson self-coupling κ_λ, a simultaneous fit is performed to κ_λ and κ_F, and to κ_λ and κ_V; the remaining coupling modifier is kept fixed to the SM prediction.
- The sensitivity is not much degraded when simultaneously fitting κ_λ and κ_F while it is degraded by 50% in the case κ_λ and κ_V.
- An even less constrained fit, performed by fitting simultaneously κ_λ, κ_F and κ_V results in nearly no sensitivity to κ_λ.

POIs	Granularity	$\kappa_F{}^{+1\sigma}_{-1\sigma}$	$\kappa_V{}^{+1\sigma}_{-1\sigma}$	$\kappa_\lambda{}^{+1\sigma}_{-1\sigma}$	κ_λ [95% C.L.]
κ_λ	STXS	1	1	$4.0^{+4.3}_{-4.1}$	[−3.2, 11.9]
				$1.0^{+8.8}_{-4.4}$	[−6.2, 14.4]
κ_λ	inclusive	1	1	$4.6^{+4.3}_{-4.2}$	[−2.9, 12.5]
				$1.0^{+9.5}_{-4.3}$	[−6.1, 15.0]
κ_λ, κ_V	STXS	1	$1.04^{+0.05}_{-0.04}$	$4.8^{+7.4}_{-6.7}$	[−6.7, 18.4]
			$1.00^{+0.05}_{-0.04}$	$1.0^{+9.9}_{-6.1}$	[−9.4, 18.9]
κ_λ, κ_F	STXS	$0.99^{+0.08}_{-0.08}$	1	$4.1^{+4.3}_{-4.1}$	[−3.2, 11.9]
		$1.00^{+0.08}_{-0.08}$		$1.0^{+8.8}_{-4.4}$	[−6.3, 14.4]



HL-LHC projection

- 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-LHC projection are not so much reduced.
- Differential information has a great impact on the measurement.

HL-LHC prospects, Yellow Report results **CERN-LPCC-2018-04**