Single Higgs production at LHC as a probe for an anomalous Higgs self coupling

Pier Paolo Giardino

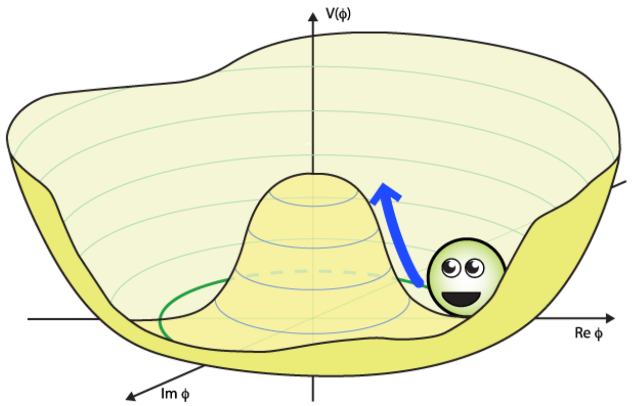
Brookhaven National Laboratory

ICHEP 2016,
Chicago

Based on
arXiv:1607.0425 [hep-ph];

Giuseppe Degrassi, P.P.G, Fabio Maltoni, Davide Pagani.

Framework



quantumdiaries.com

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

$$V(H) = \frac{1}{2} M_H^2 H^2 + \frac{M_H^2}{2v} H^3 + \frac{M_H^2}{8v^2} H^4$$

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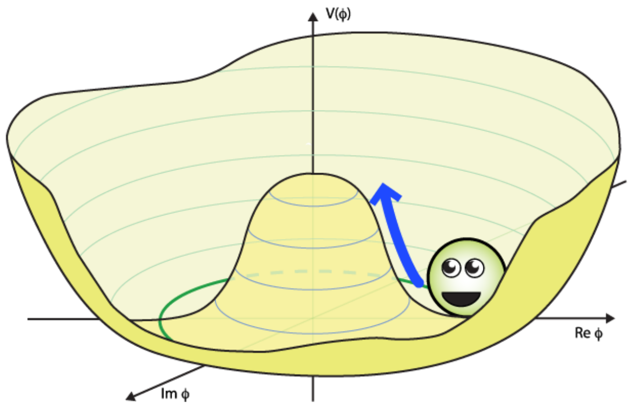

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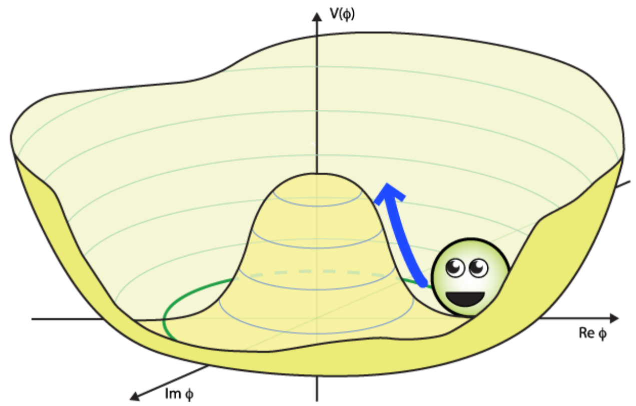

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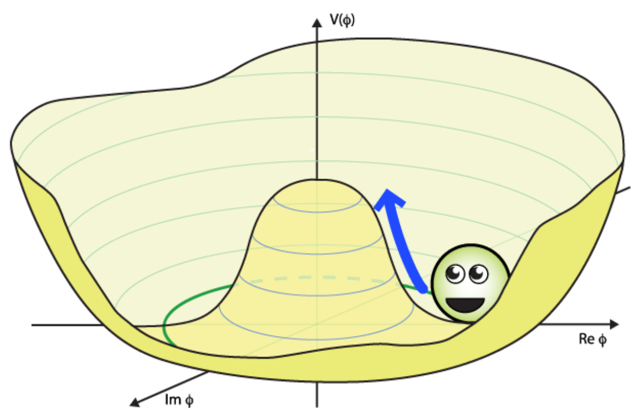

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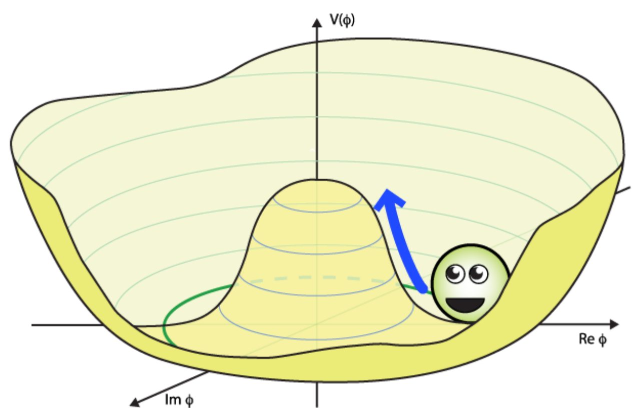

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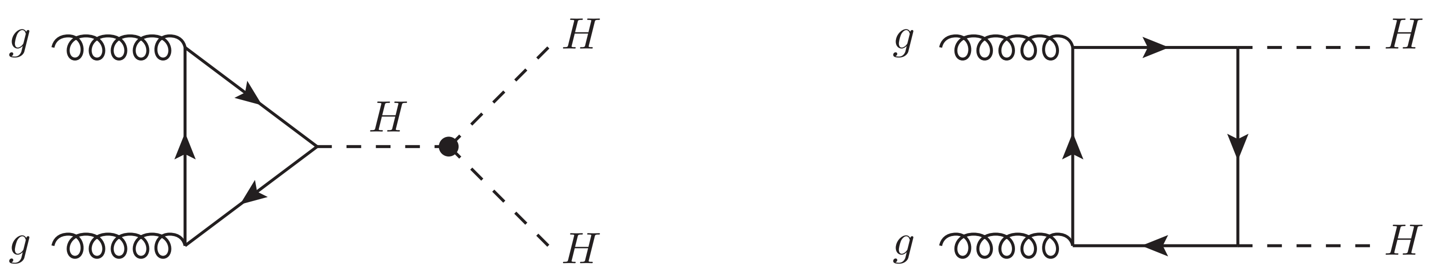
How can we exclude an anomalous trilinear?

(maybe with the wrong sign)

Higgs Pair Production



- Very small Cross Section.
  - Heavier final state.
  - Additional weak coupling.
- At least one Higgs into bottoms.

$$gg \to H \sim 50 \text{ pb } (13 \text{ TeV})$$

$$gg \to HH \sim 35 \text{ fb } (13 \text{ TeV})$$

Assuming no change in the other Higgs couplings, ATLAS and CMS at 8 TeV exclude the regions

$$(-\infty, -12] \cup [17, \infty)$$

$$(-\infty, -17.5] \cup [22.5, \infty)$$

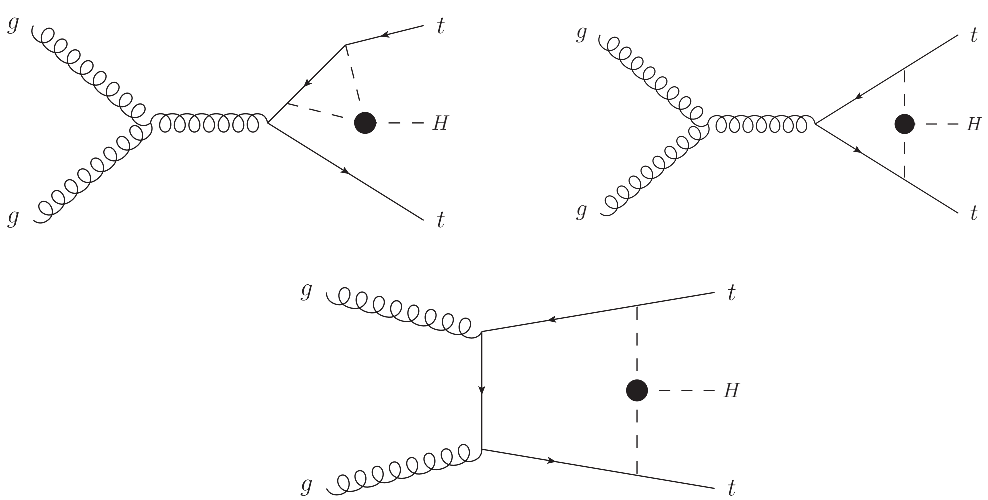
arXiv:1509.0467; arXiv:1506.0028; arXiv:1603.0689

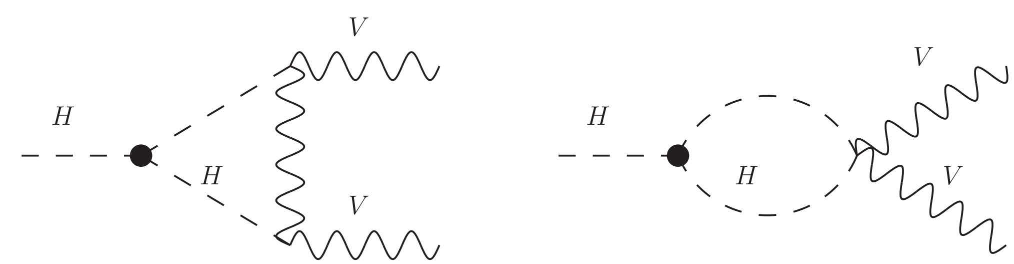
At 3000 fb^{-1} the exclusion region should be $(-\infty, -1.3] \cup [8.7, \infty)$

ATL-PHYS-PUB-2014-019; ATL-PHYS-PUB-2015-046

Single Higgs

The trilinear appears at NLO in Single Higgs processes.





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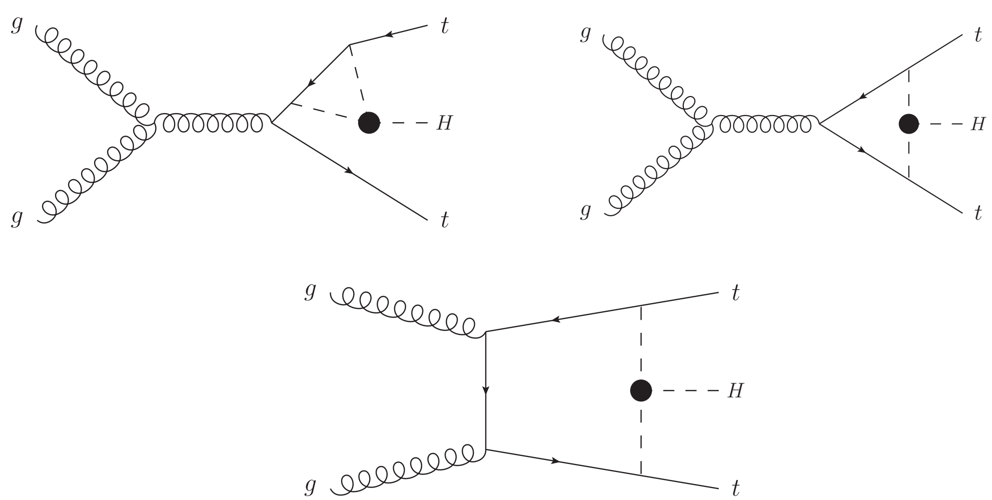
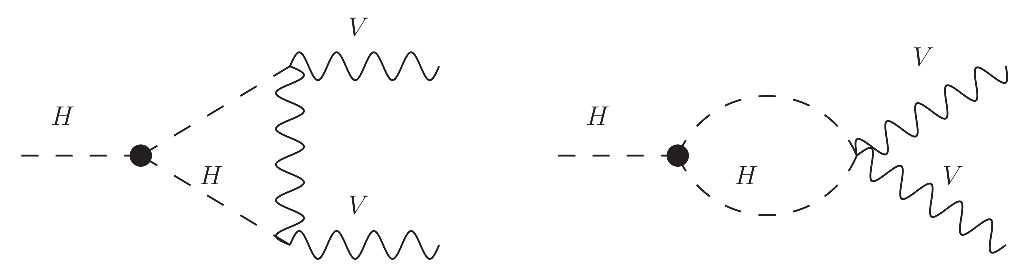
$$V_{H^3} = \lambda_3 v H^3 \equiv \kappa_\lambda \lambda_3^{\mathrm{SM}} v H^3$$





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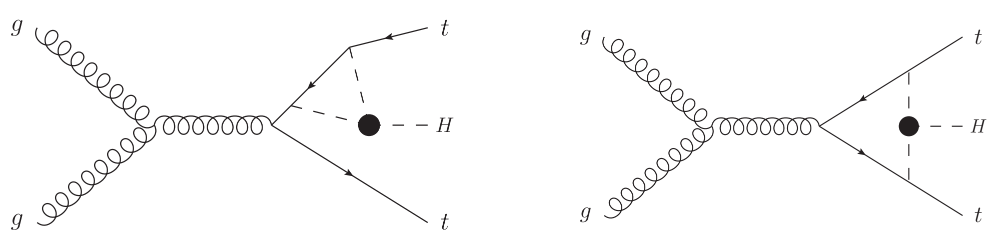

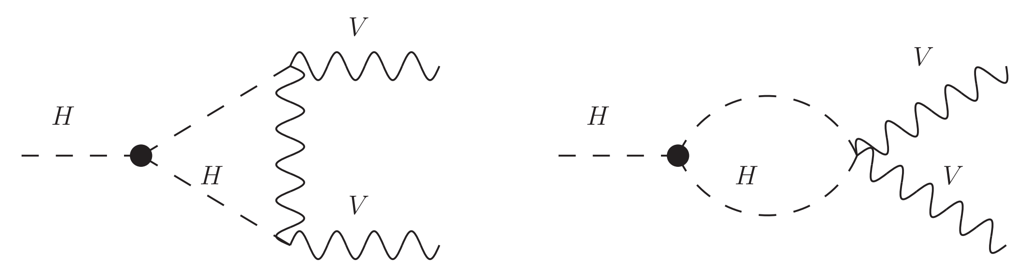

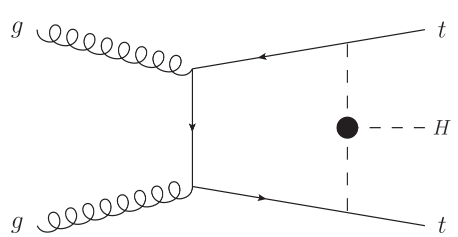

Due to the presence of different Loop structures these contributions cannot be captured by a local rescaling.

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C₁ coefficients

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C_1 coefficients

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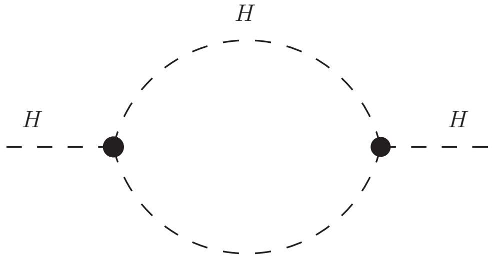
$$Z_H = \frac{1}{1 - \kappa_\lambda^2 \delta Z_H}$$



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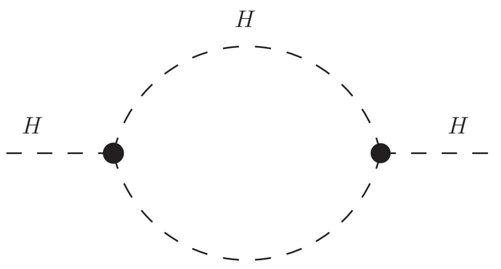

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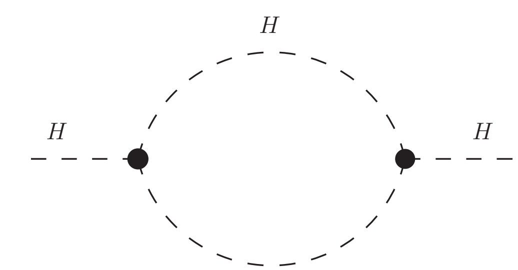

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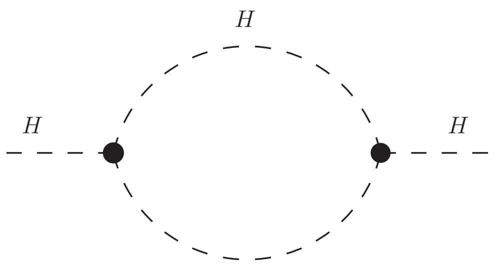

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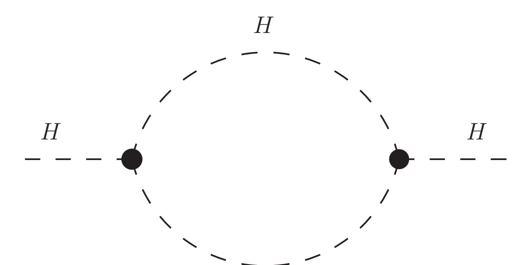

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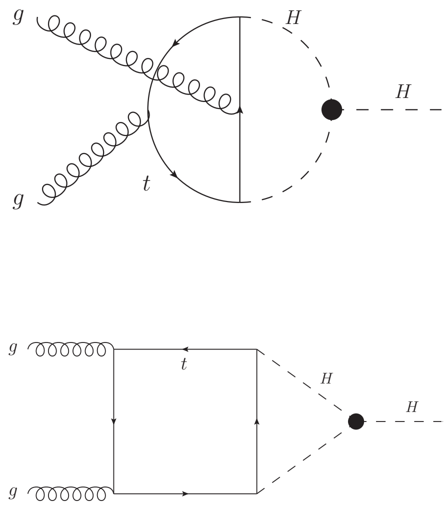
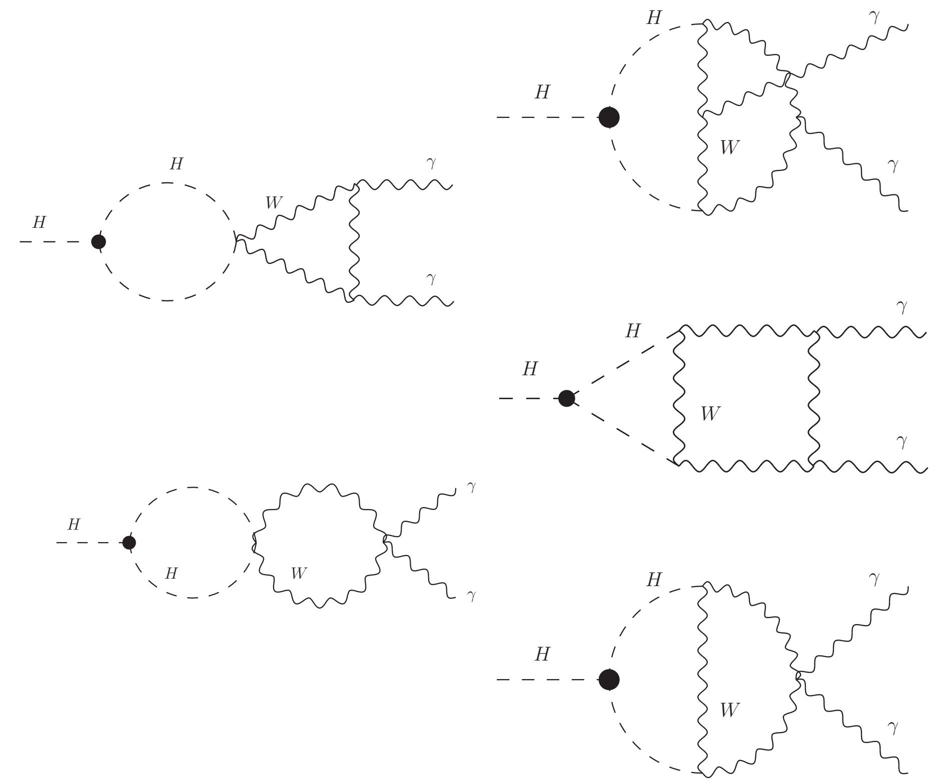
Amplitudes generated by FeynArts, computed by FormCalc interfaced to Loop-Tools, checked with FeynCalc.

C_1 coefficients: 2 Loops





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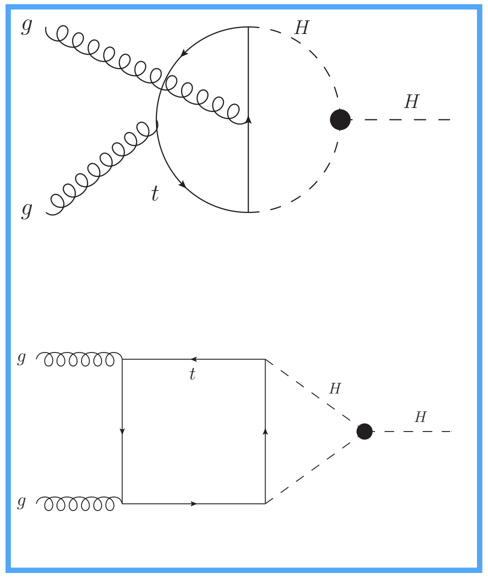

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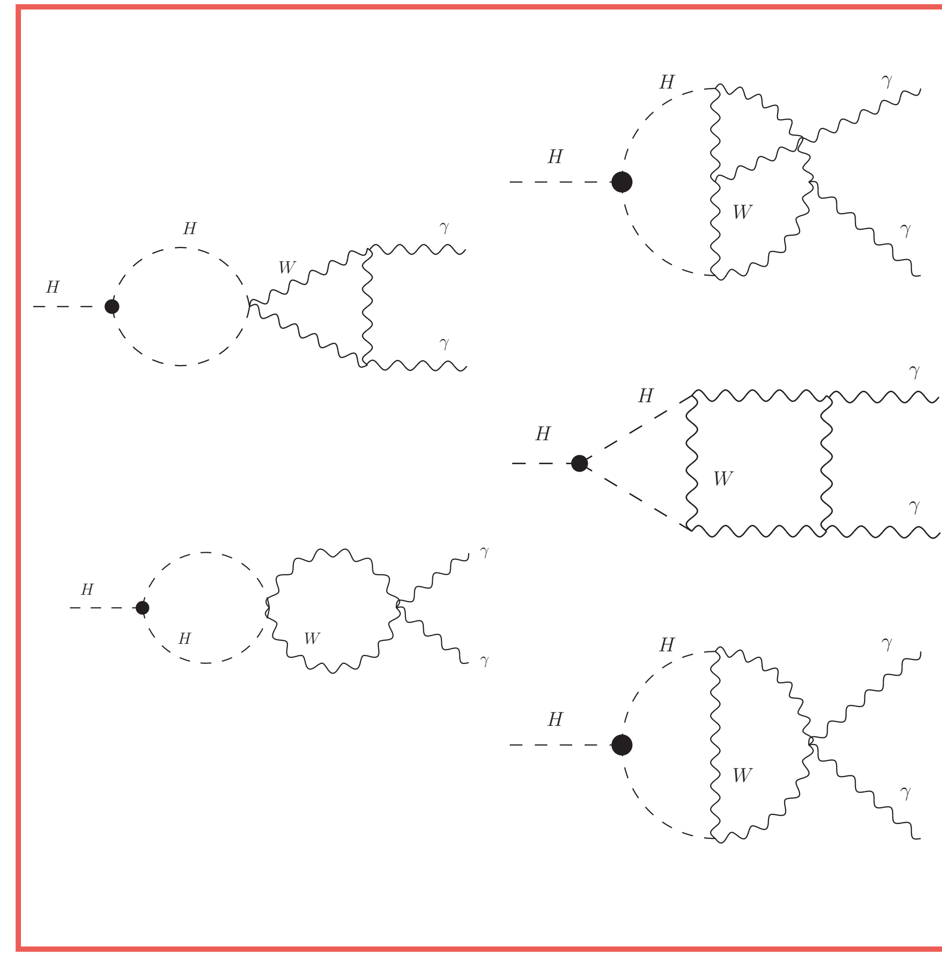

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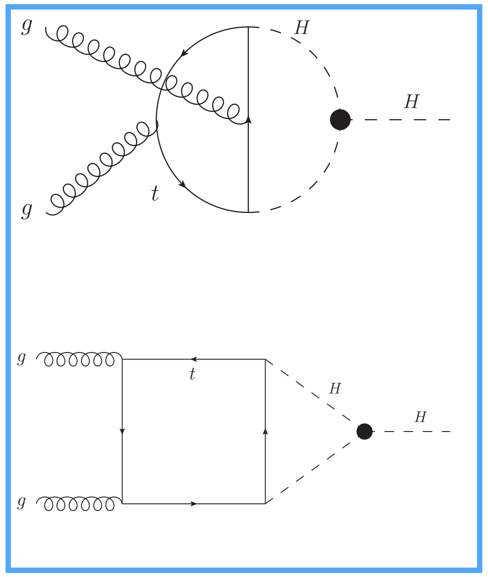

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We computed the correction with an asymptotic expansion in large top mass.

C_l coefficients: 2 Loops

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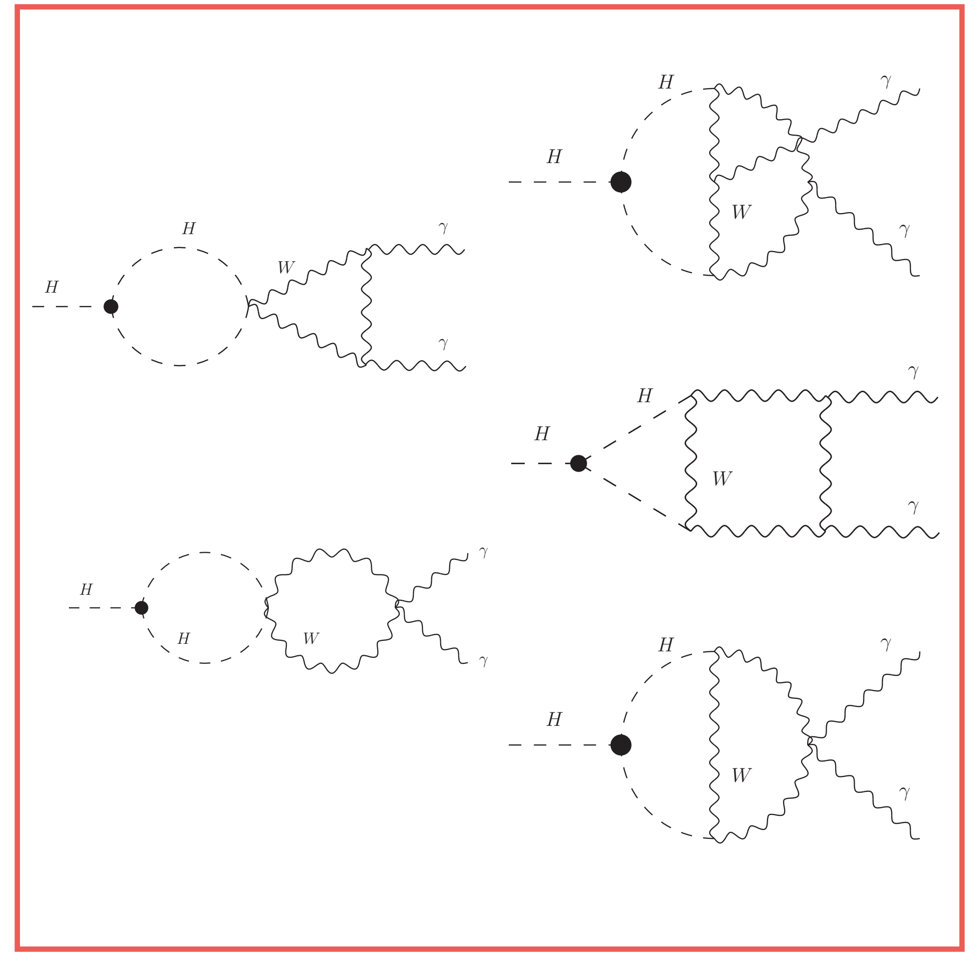

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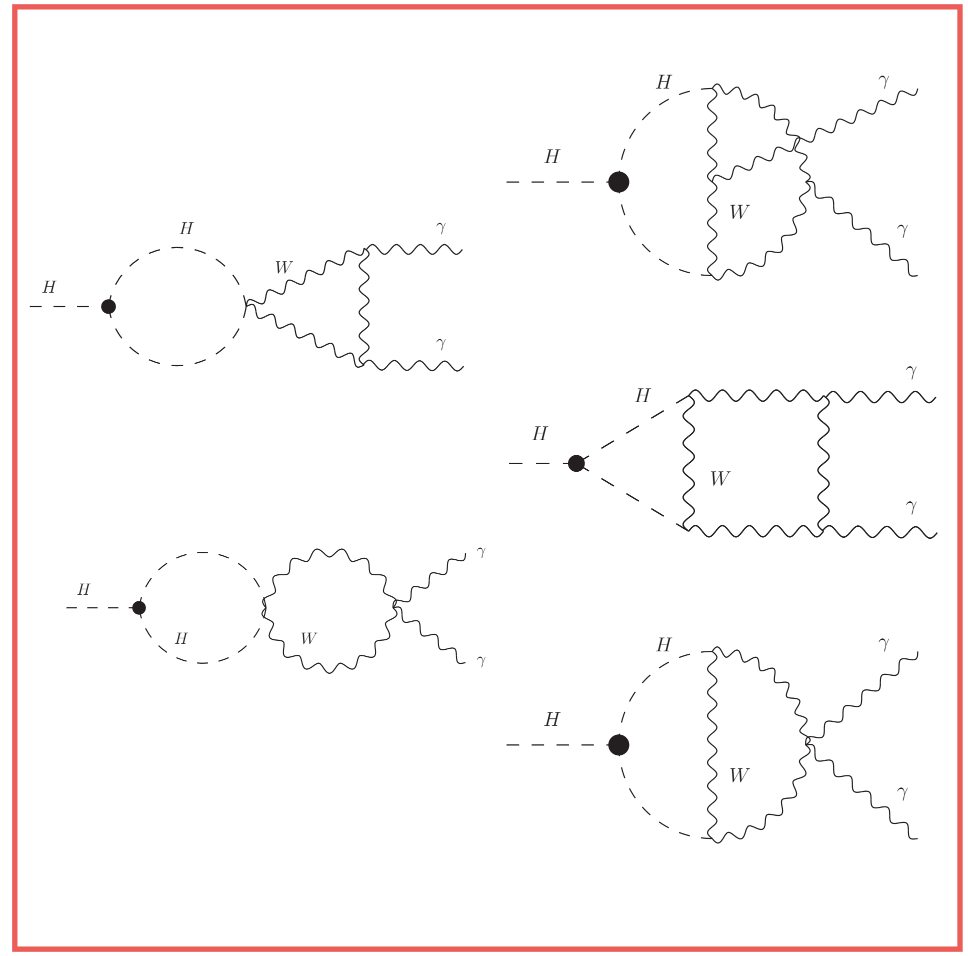

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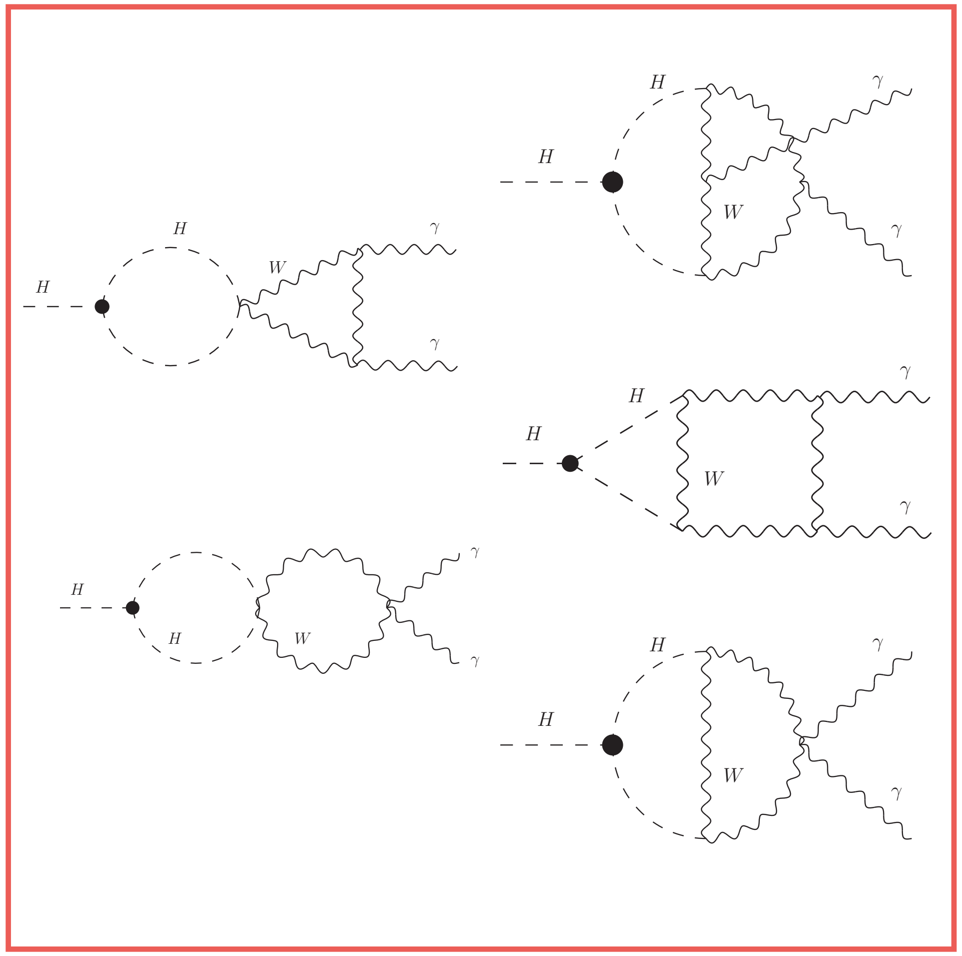

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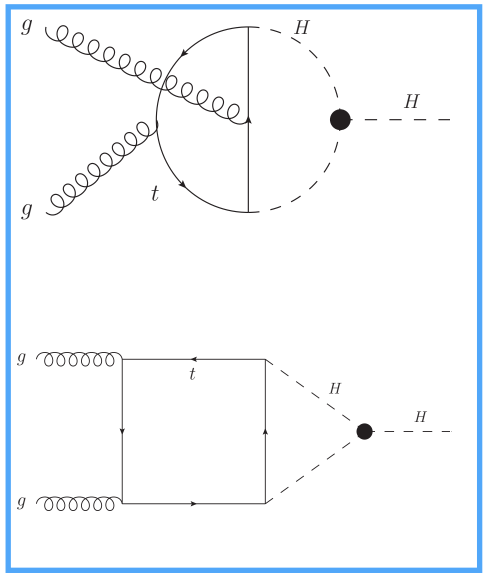

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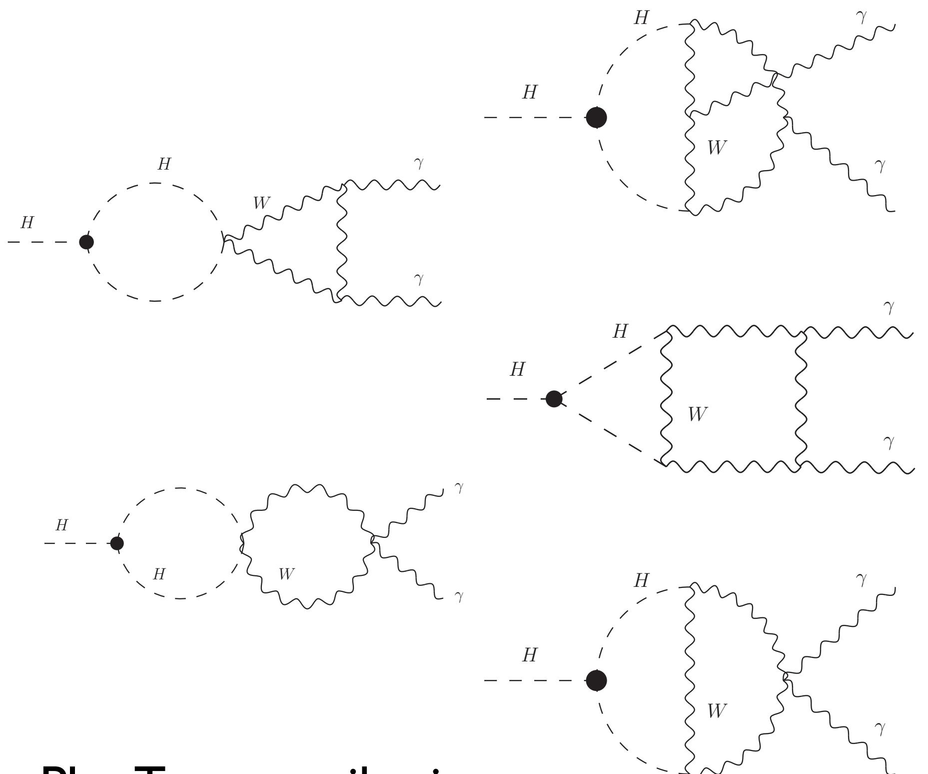

Plus Top contributions (obtained from $gg \to H$)

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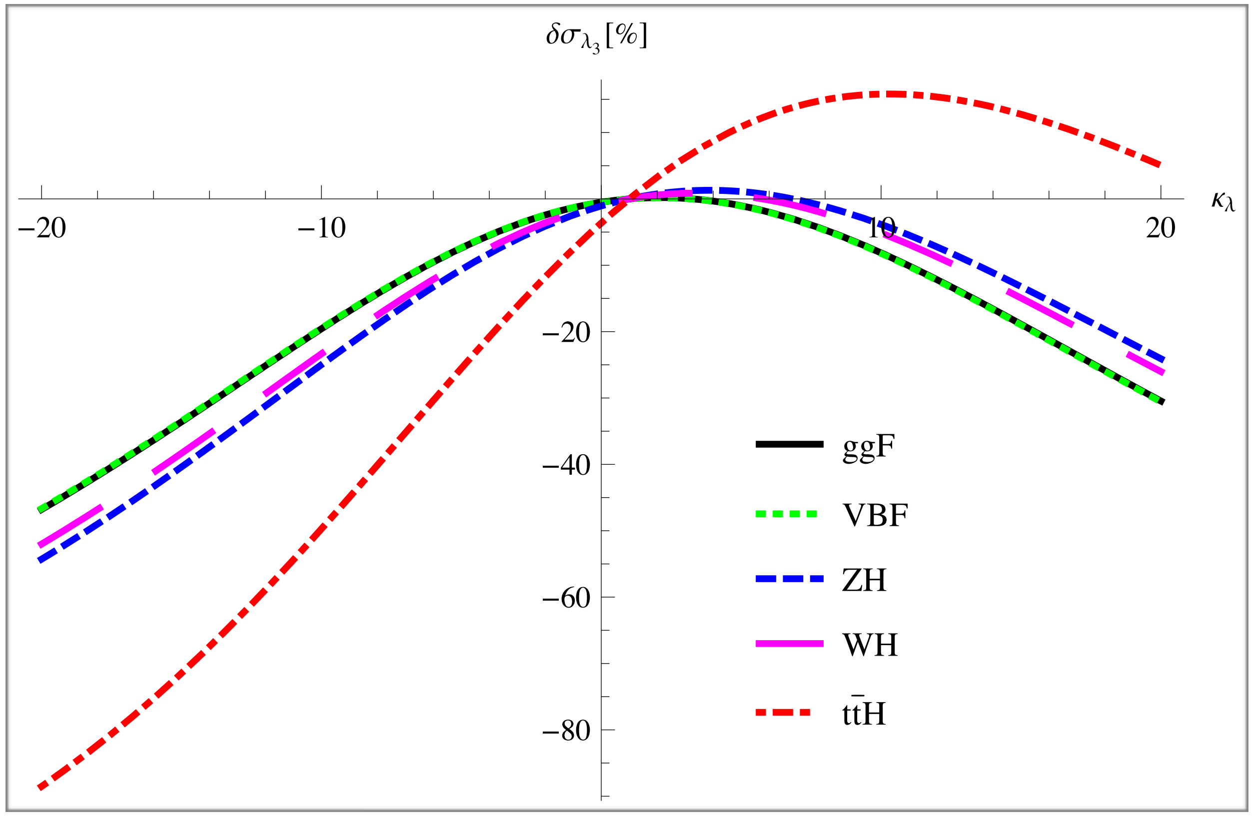
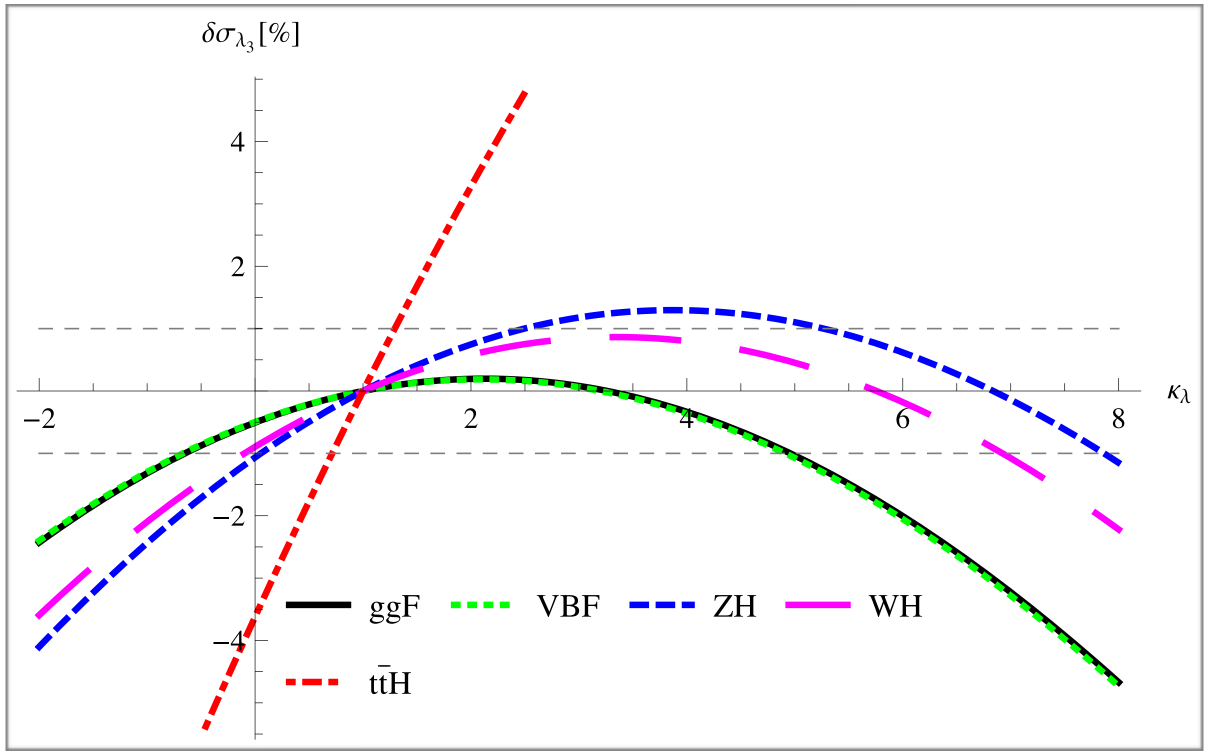
Results: σ

$C_1^\sigma[\%]$	ggF	VBF	WH	ZH	$t\bar{t}H$
8 TeV	0.66	0.65	1.05	1.22	3.78
14 TeV	0.66	0.64	1.03	1.18	3.47





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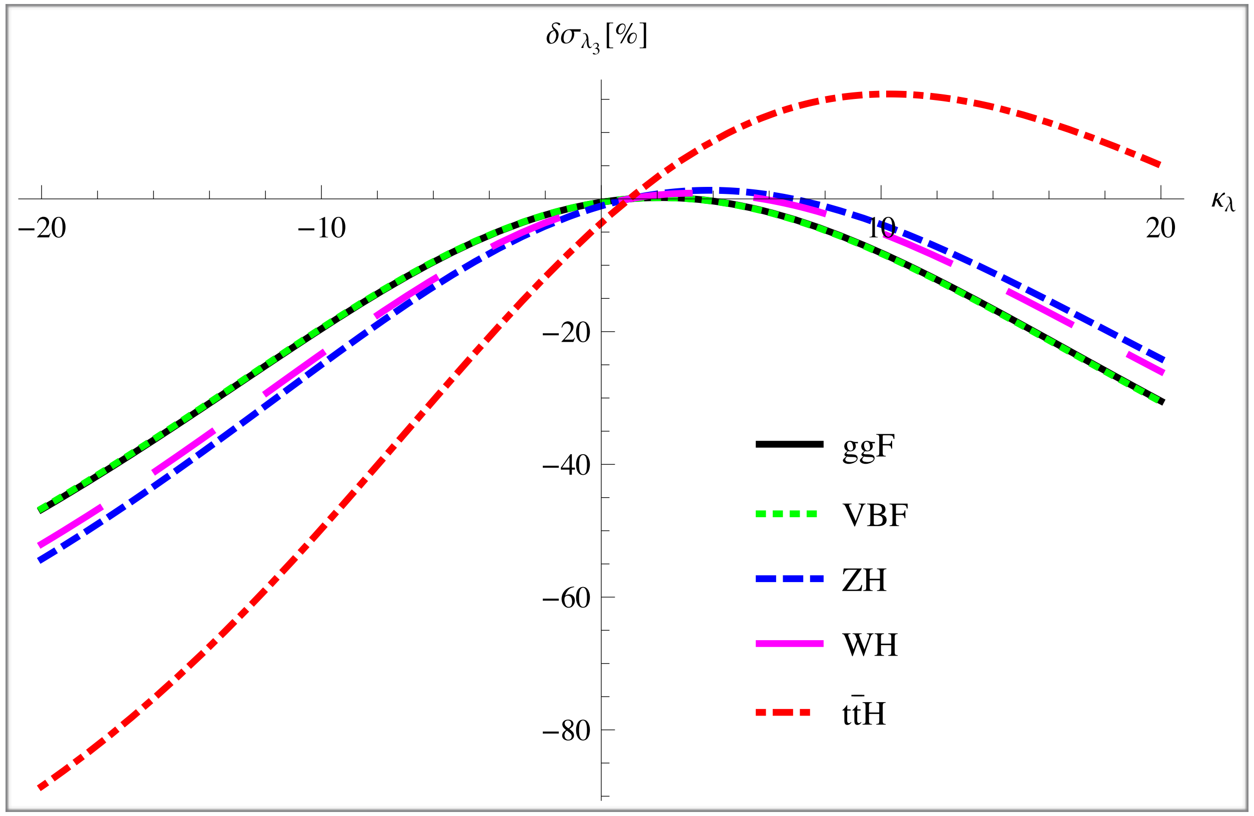

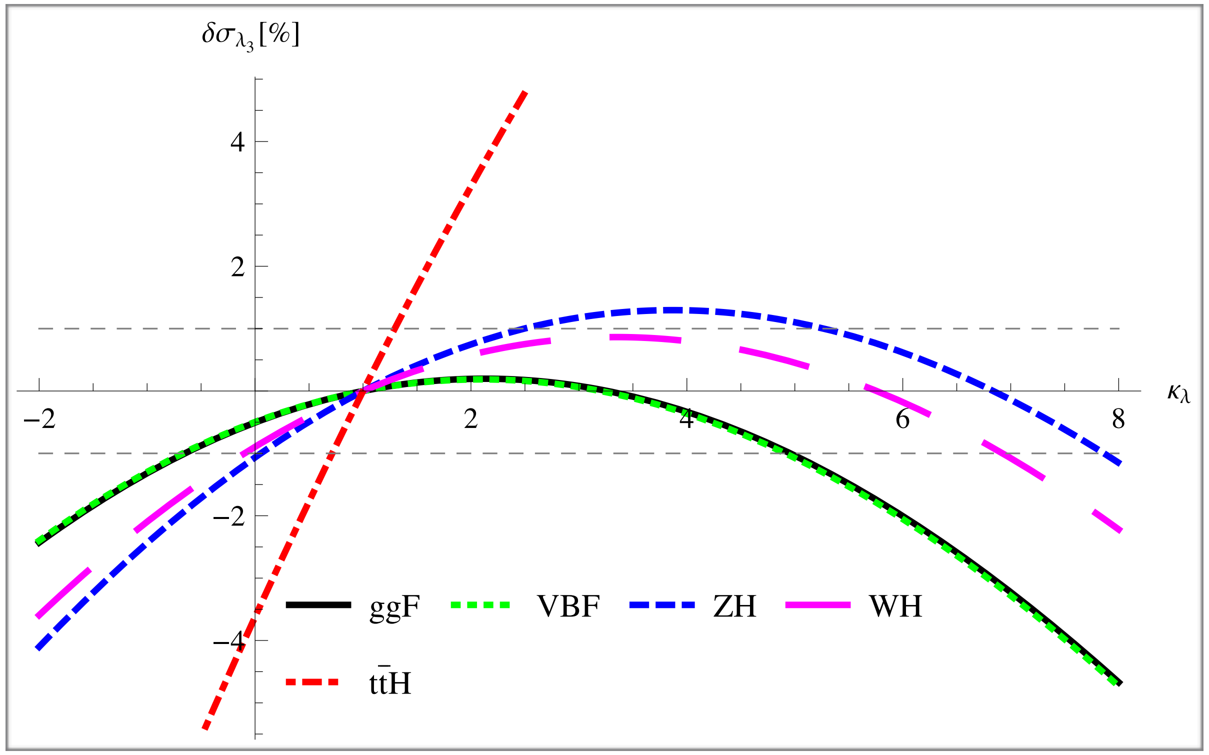

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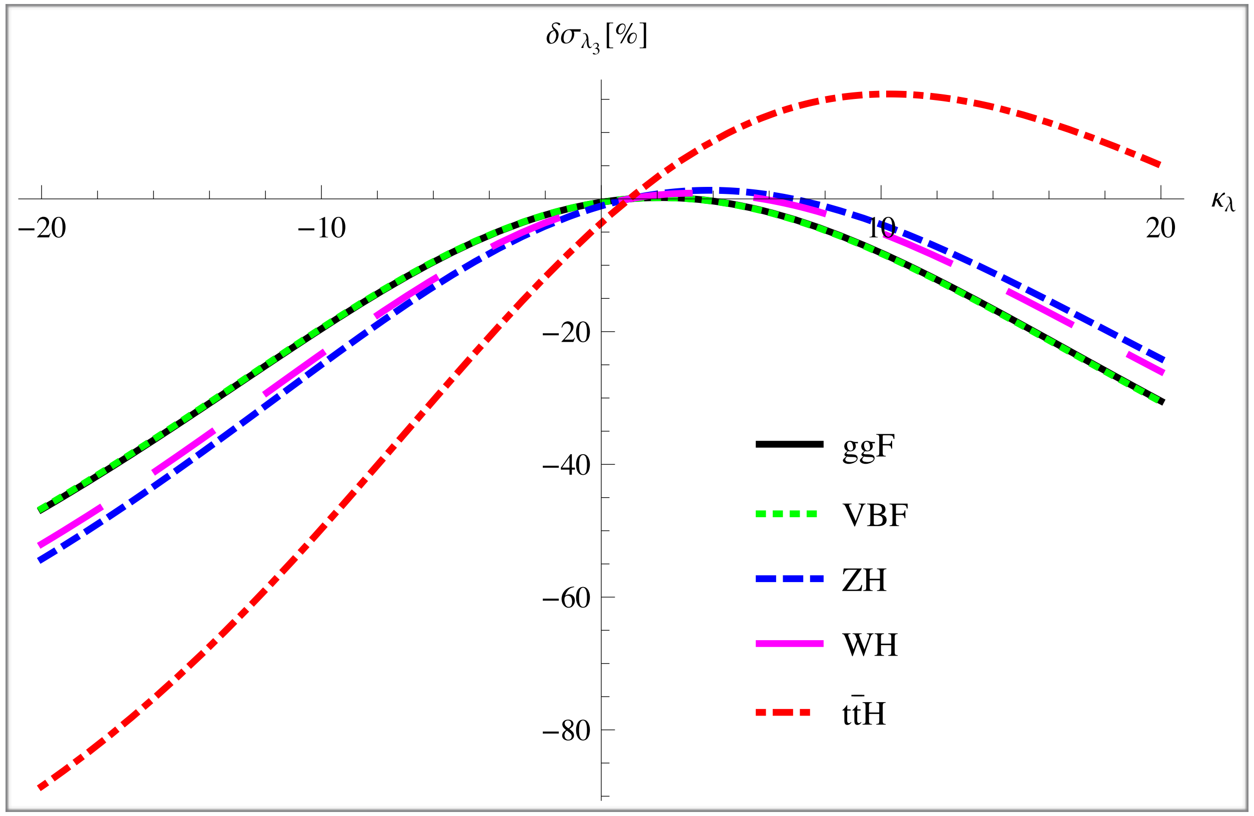

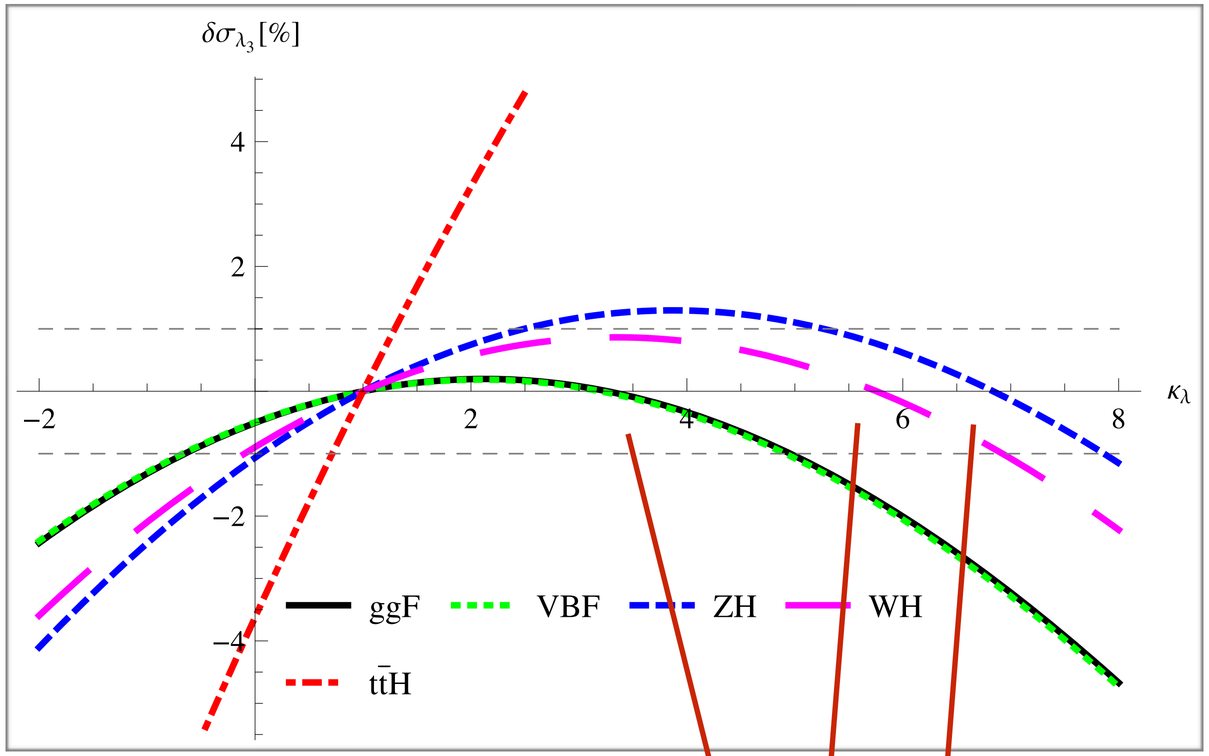

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Here δσλ is the same of the SM (κλ=1)

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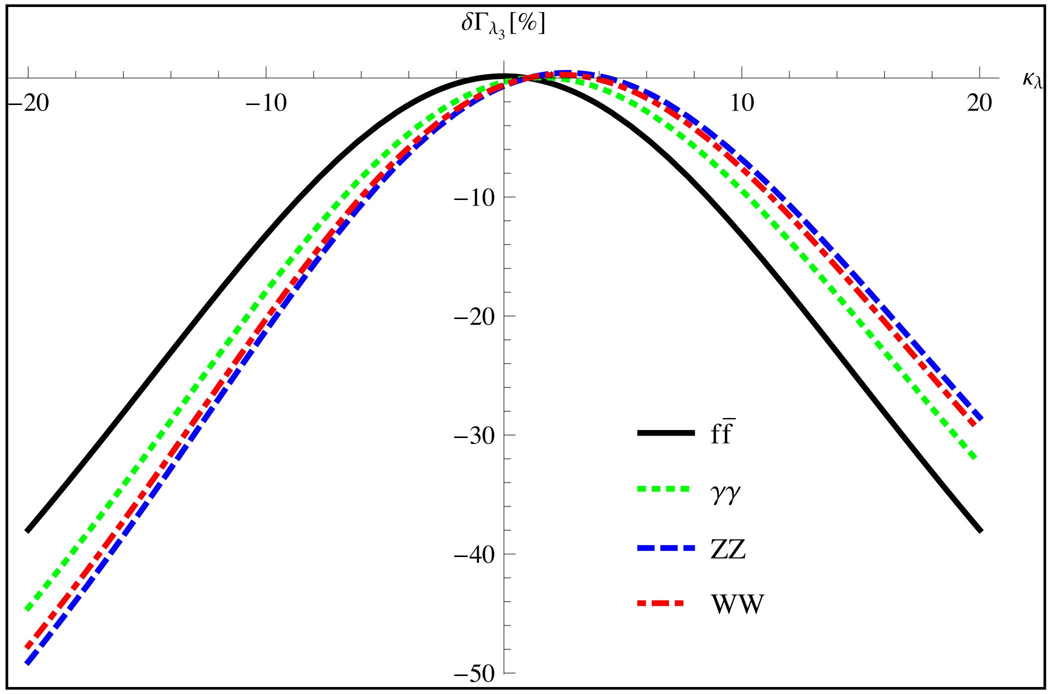

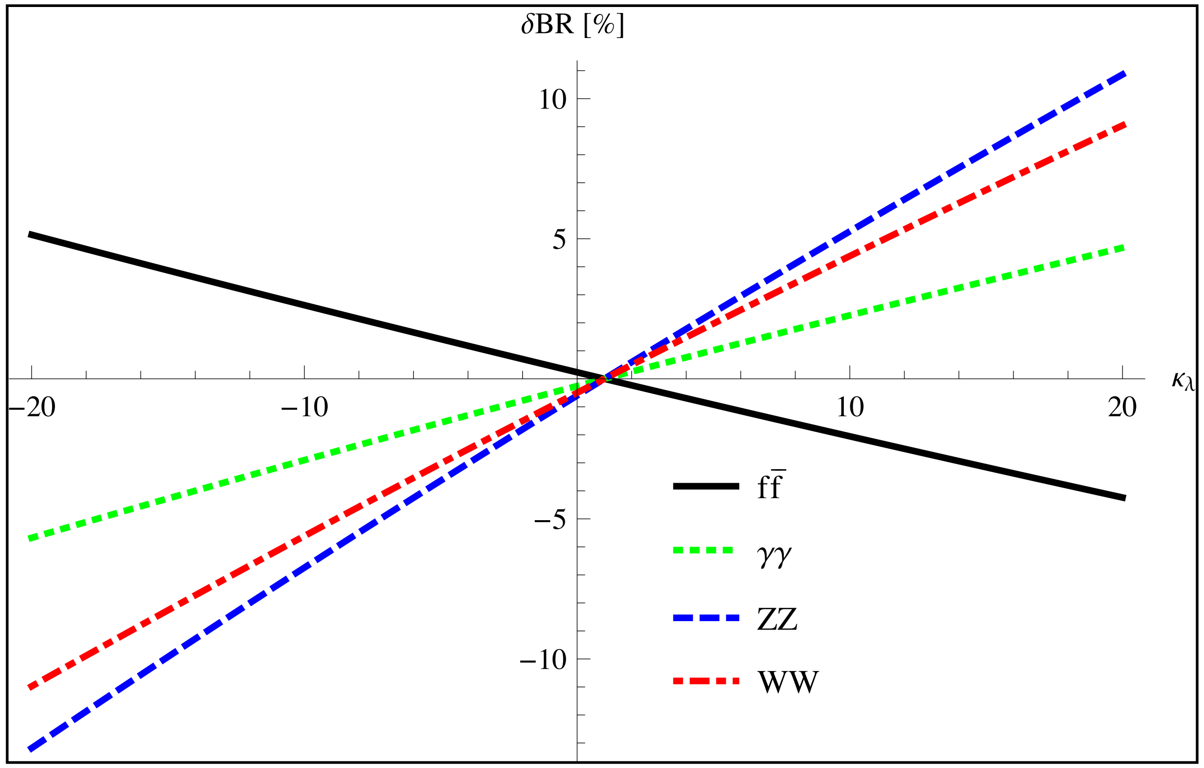

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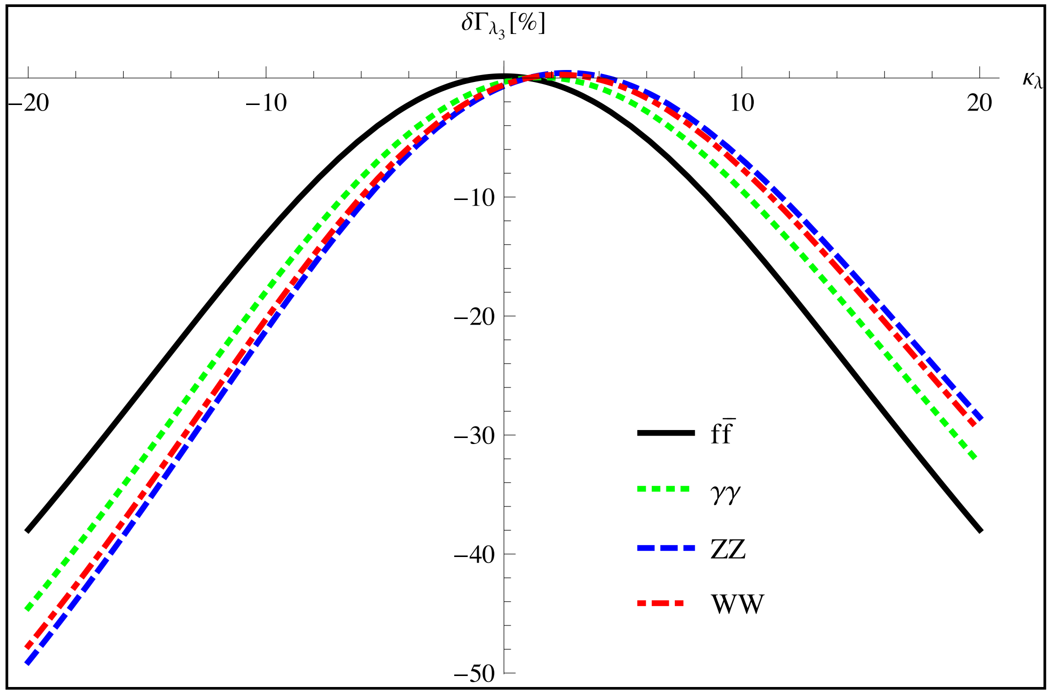

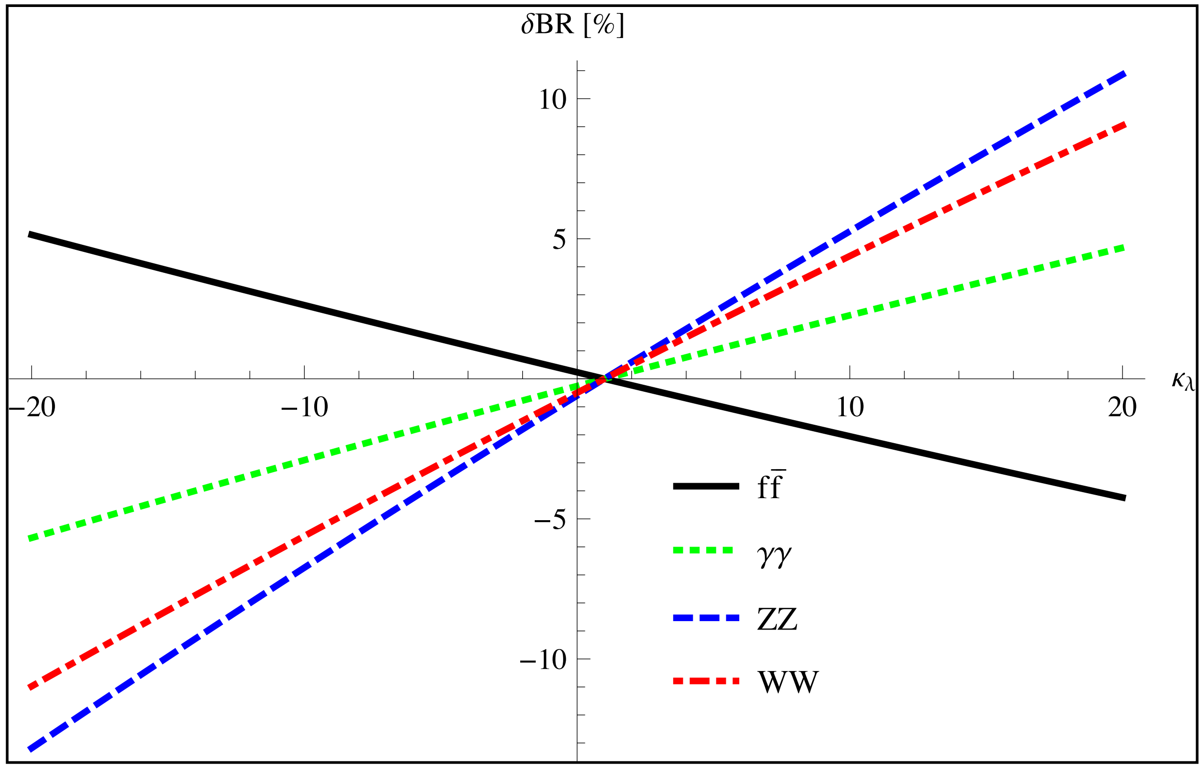

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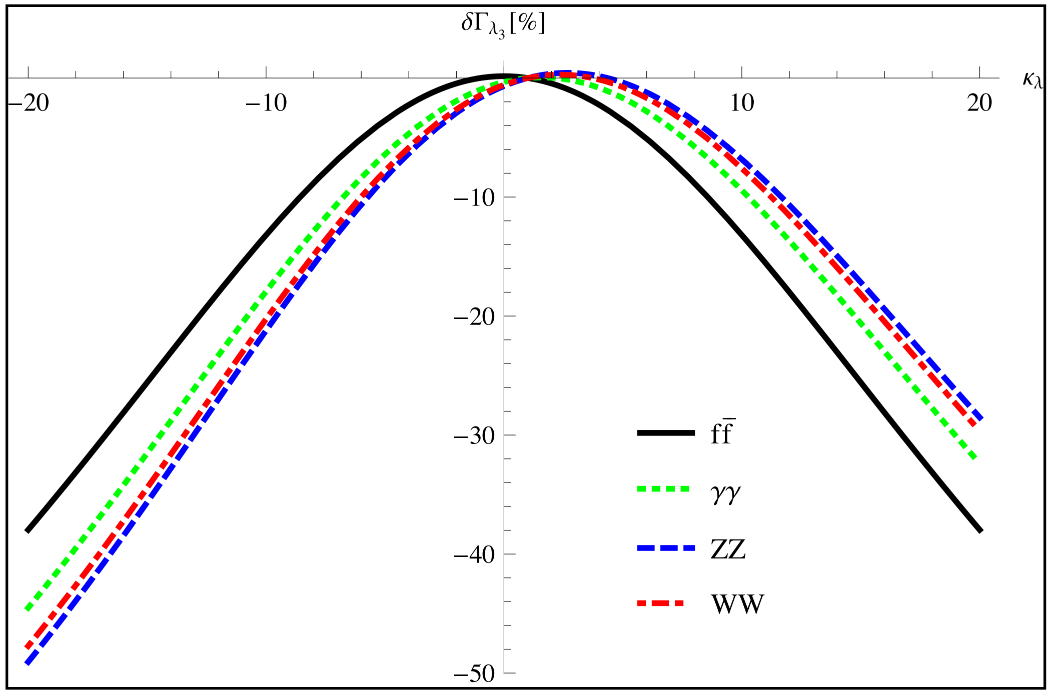

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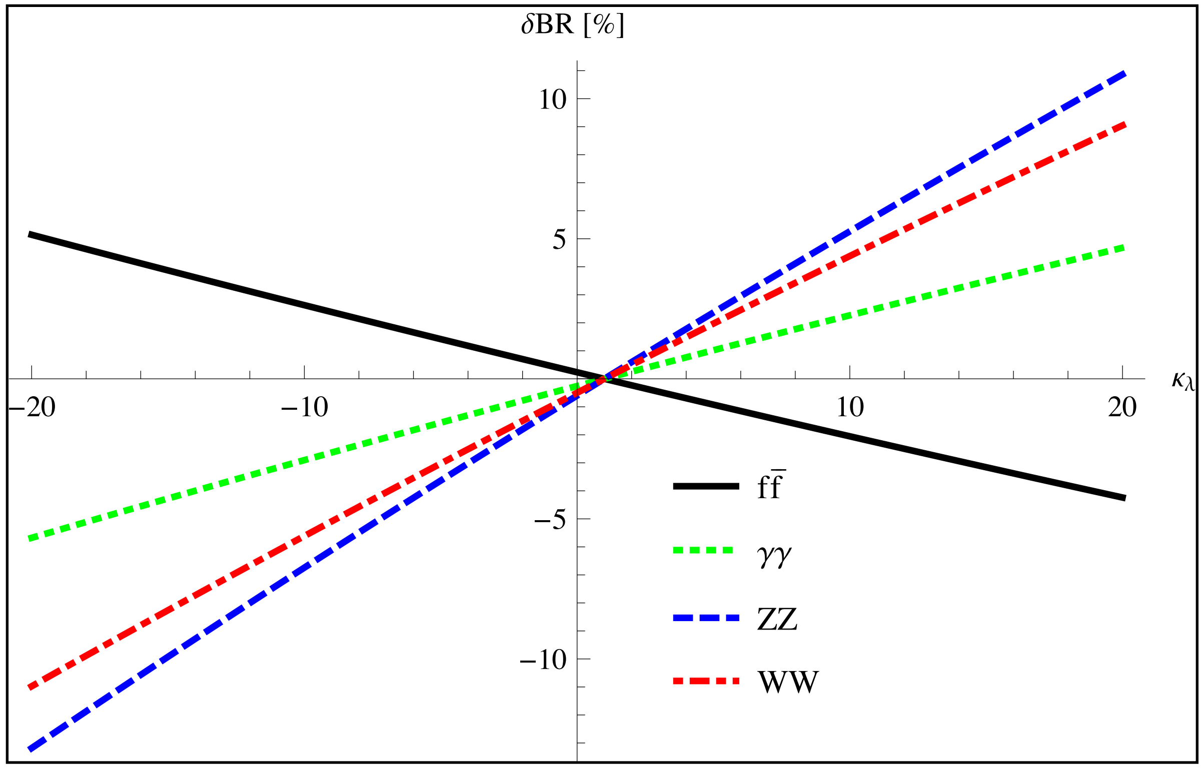

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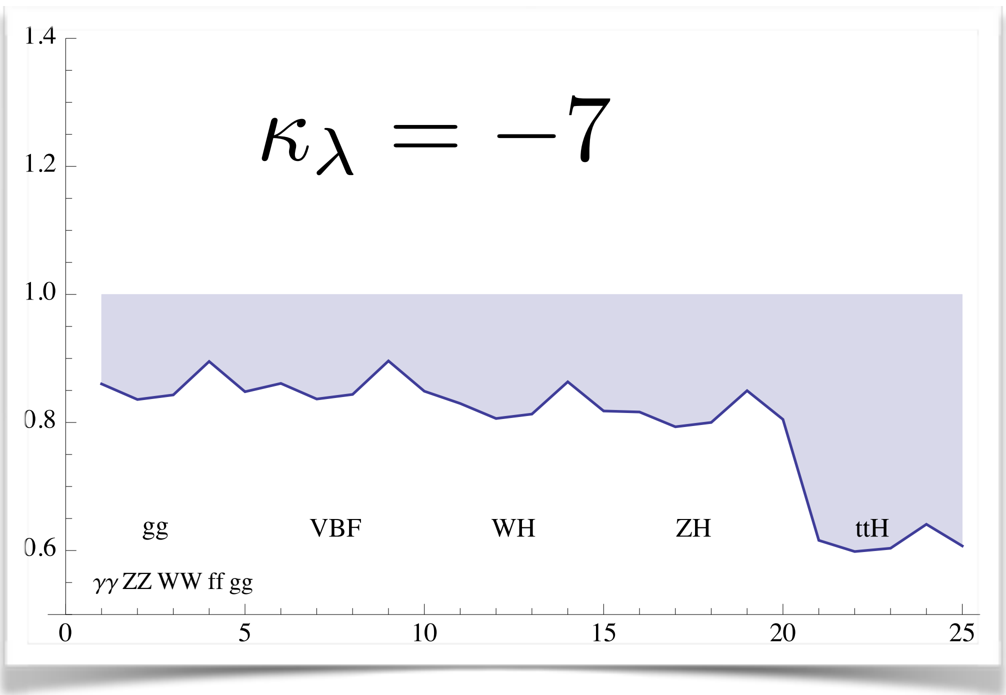
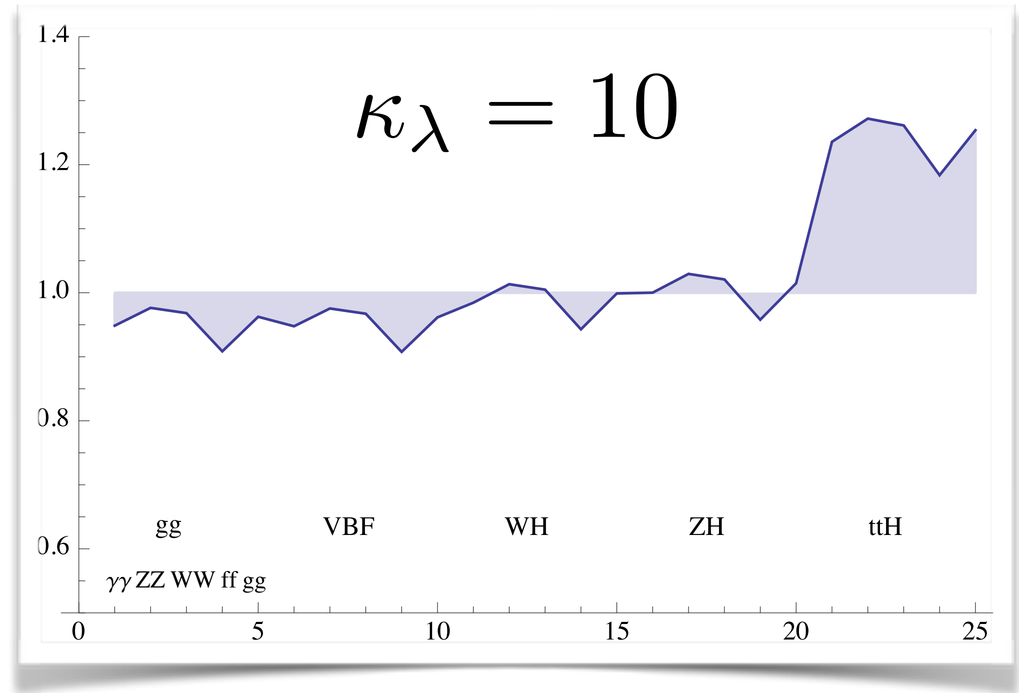
However the (positive) δBR are usually larger than the δσ.

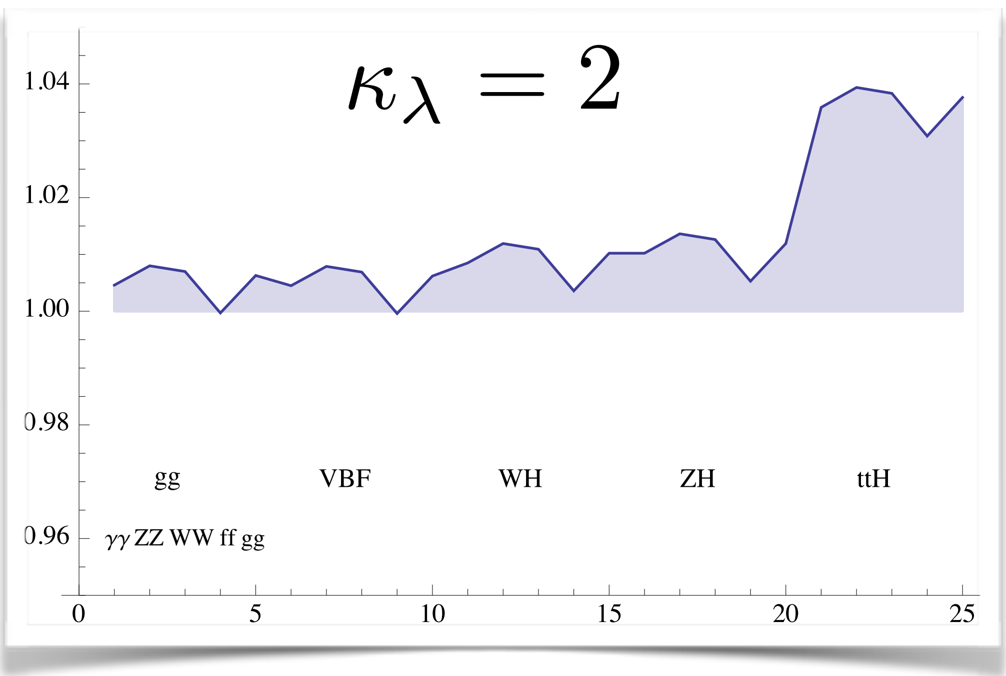
$$\delta BR_{\lambda_3}(i) = \frac{(\kappa_\lambda - 1)(C_1^\Gamma(i) - C_1^{\Gamma_{tot}})}{1 + (\kappa_\lambda - 1)C_1^{\Gamma_{tot}}}$$

In other words, in the range close to the SM, the decays are more sensitive to κ_λ than the production processes.

Results: σ BR







All the available Single Higgs processes depend on the single Parameter κ_λ. So in principle a global fit can be very powerful in constraining the Higgs trilinear coupling.

Constraints on λ: present

$$\chi^2(\kappa_\lambda) \equiv \sum_{\bar{\mu}_i^f} \frac{(\mu_i^f(\kappa_\lambda) - \bar{\mu}_i^f)^2}{(\Delta(\kappa_\lambda))^2}$$

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In this fit we consider different "scenarios".

Data from arXiv:1606.02266

ATLAS-CMS 8 TeV data combination

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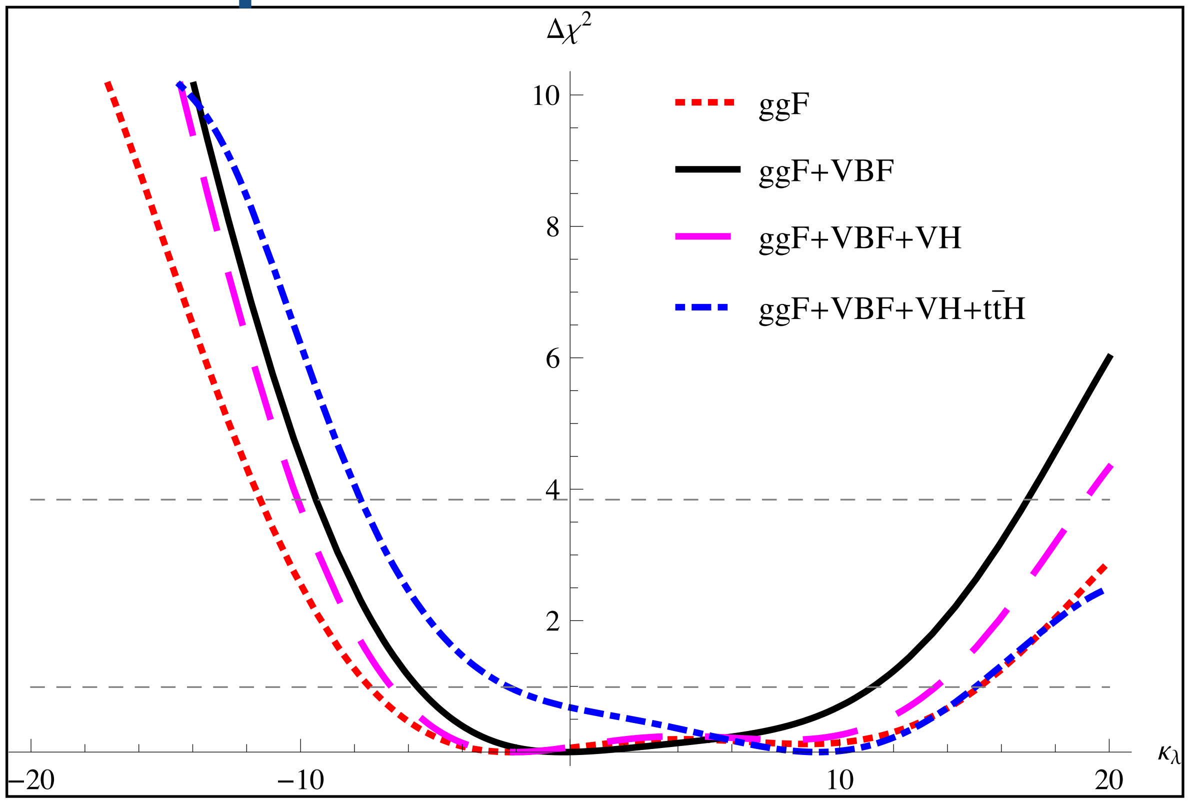


For ggF+VBF: $\kappa_\lambda^{\text{best}} = -0.24$

$\kappa_\lambda^{1\sigma} = [-5.65, 11.21]$ $\kappa_\lambda^{2\sigma} = [-9.43, 16.97]$

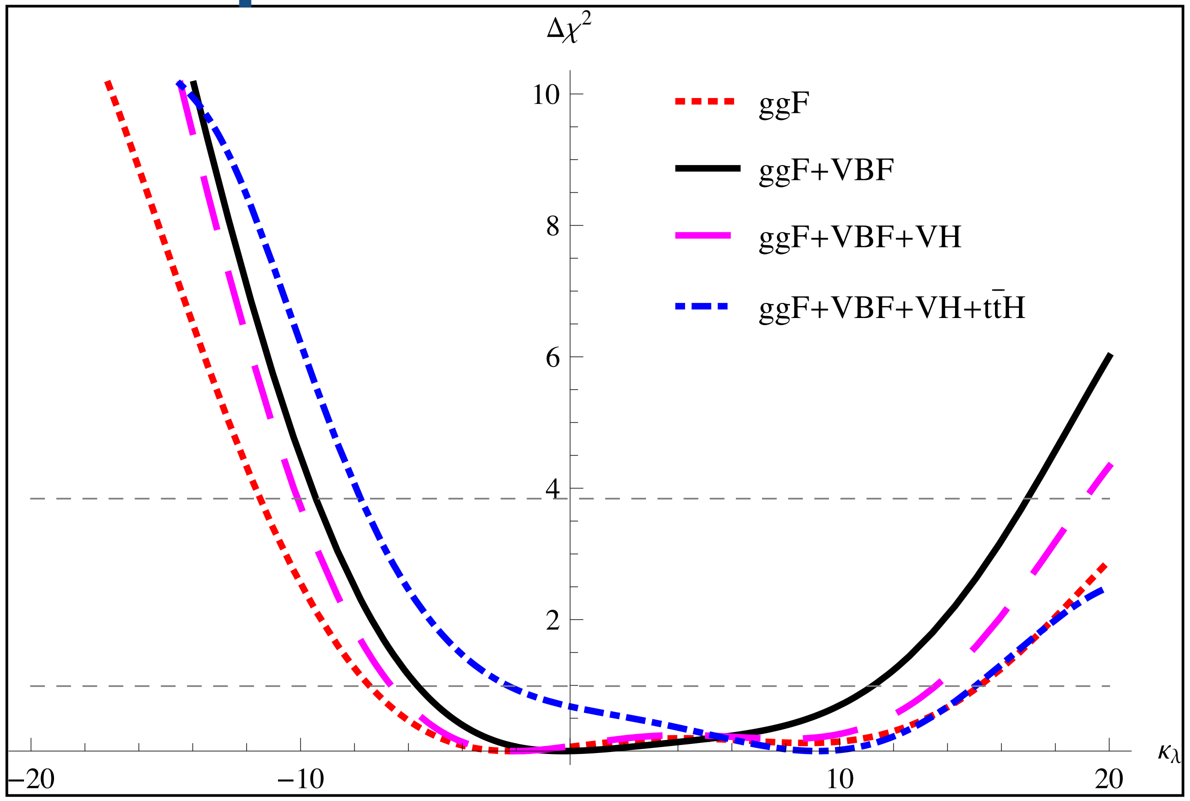
Constraints on λ: present

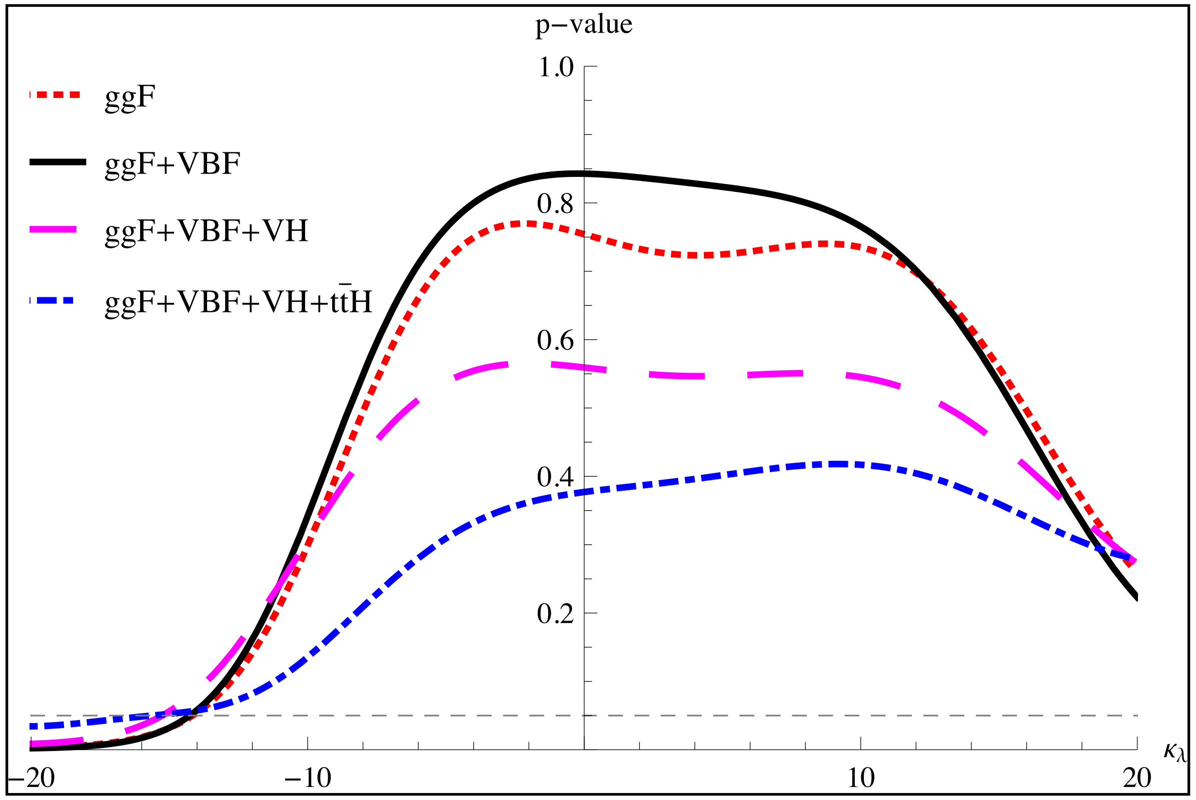
$$\chi^2(\kappa_\lambda) \equiv \sum_{\bar{\mu}_i^f} \frac{(\mu_i^f(\kappa_\lambda) - \bar{\mu}_i^f)^2}{(\Delta(\kappa_\lambda))^2}$$

In this fit we consider different "scenarios".

Data from arXiv:1606.02266

ATLAS-CMS 8 TeV data combination





For ggF+VBF: $\kappa_\lambda^{\text{best}} = -0.24$

$\kappa_\lambda^{1\sigma} = [-5.65, 11.21]$ $\kappa_\lambda^{2\sigma} = [-9.43, 16.97]$

Requiring p>0.05 we are able to exclude, at more than 2 σ, that a model with an anomalous coupling can explain the data if

$$\boxed{\kappa_\lambda < -14.26}$$

Constraints on λ: future

Using the uncertainties presented in arXiv:1312.4974, and assuming that LHC will measure SM, we can estimate the future capabilities of LHC.

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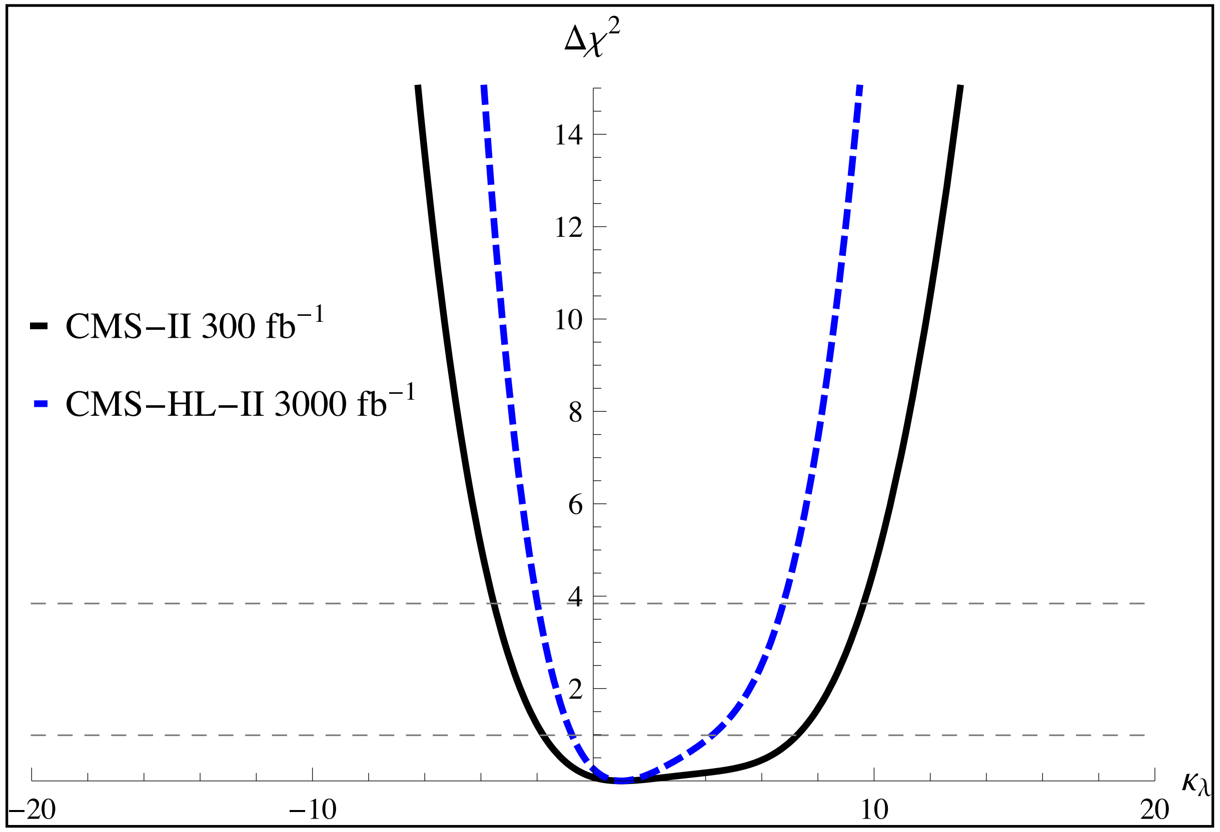
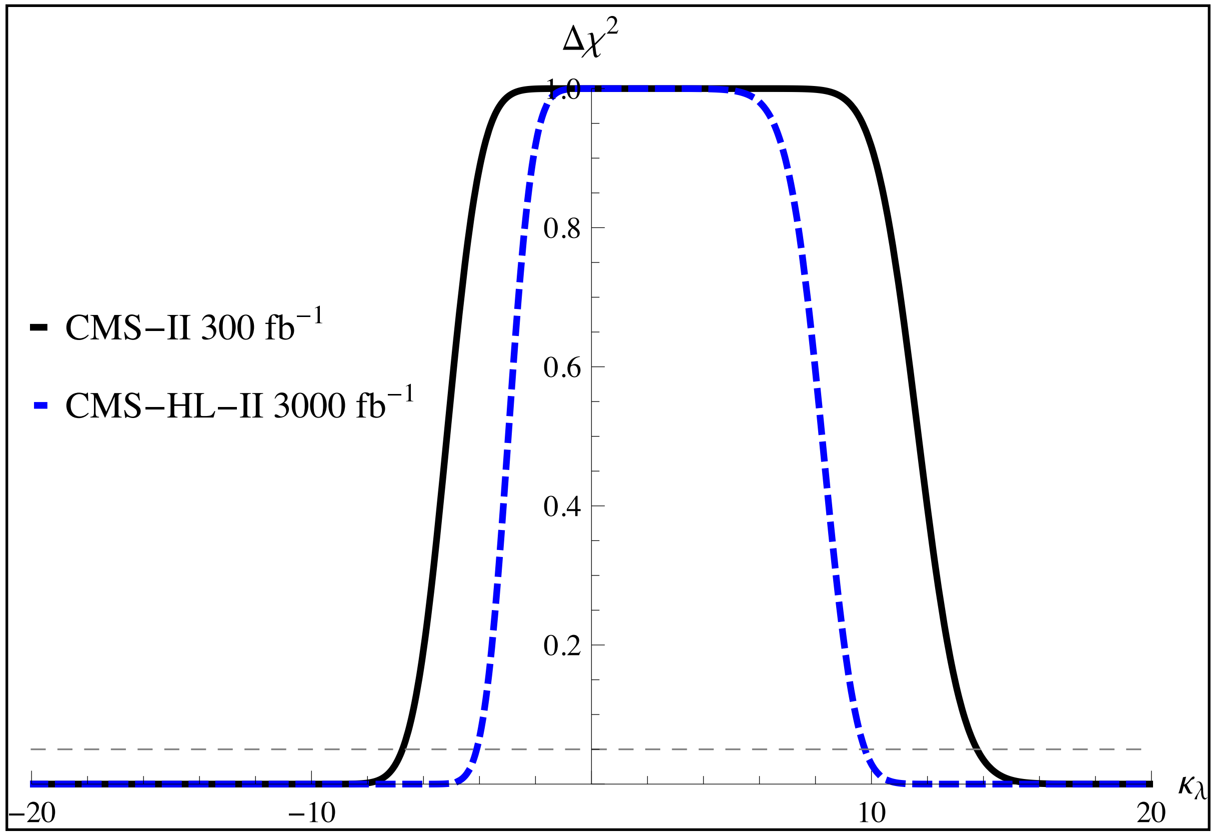




For CMS-HL-II 3000 fb^{-1}

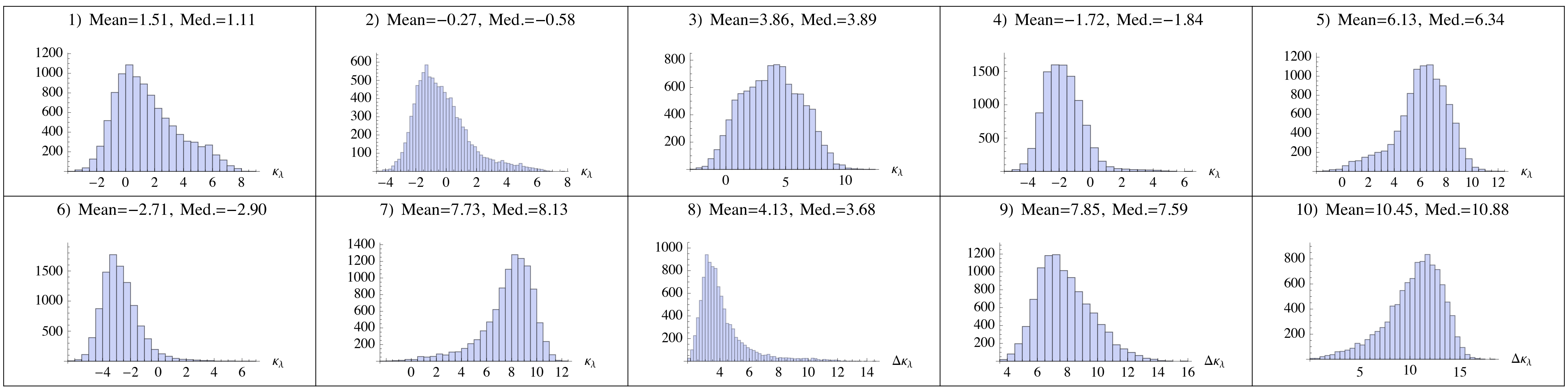
$$\kappa_\lambda^{1\sigma} = [-0.75, 4.23] \qquad \kappa_\lambda^{2\sigma} = [-1.99, 6.77]$$

$$\kappa_\lambda^{p>0.05} = [-4.10, 9.77]$$

Constraints on λ: future

A more reliable approach is to consider central values compatible with SM.

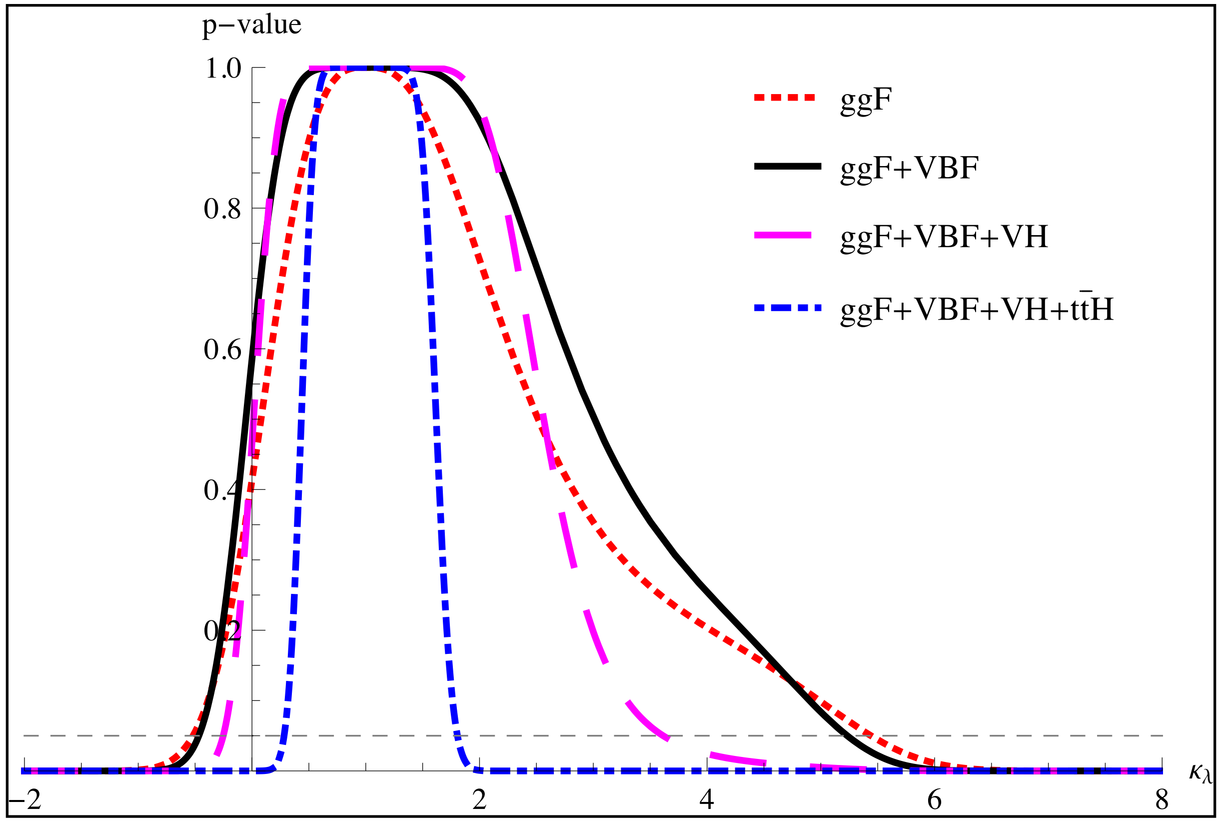
We produce a collection of pseudo-measurements randomly generated with a gaussian distribution around the SM.

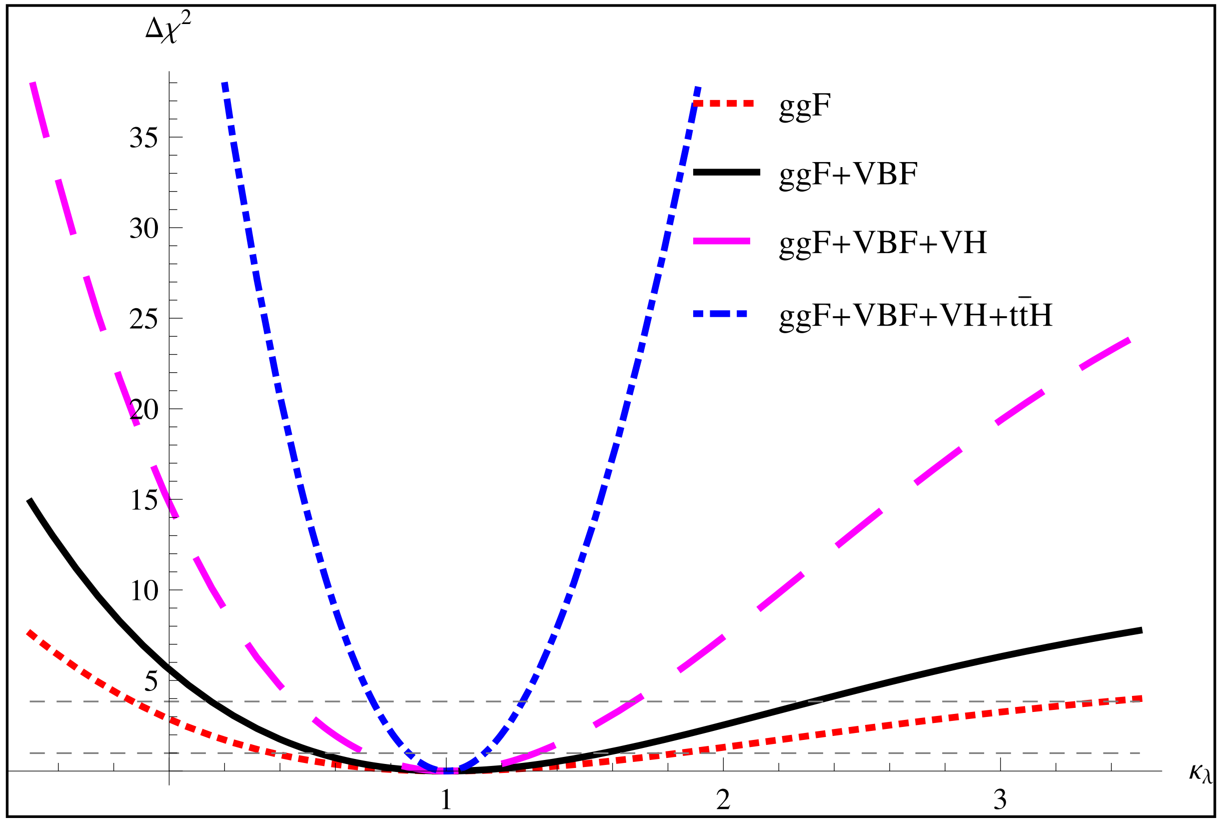


1) best values, 2) 1σ region lower limit, 3) 1σ region upper limit, 4) 2σ region lower limit, 5) 2σ region upper limit, 6) $p > 0.05$ region lower limit, 7) $p > 0.05$ region upper limit, 8) 1σ region width, 9) 2σ region width, 10) $p > 0.05$ region width.

Constraints on λ: future(?!?)

An interesting scenario is the one where the uncertainties are 1% for all the channels





As expected a precise measurement of the $t\bar{t}H$ would lead to a sizeable improvement in the fit.

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- Compared to Higgs pair production, the bounds obtained are competitive and complementary.
- This approach is model dependent,
  - however the condition for the other couplings to be SM can be lifted.
- The biggest role is played by the top-top-Higgs associated production.