One-loop corrections to trilinear Higgs couplings in the RxSM

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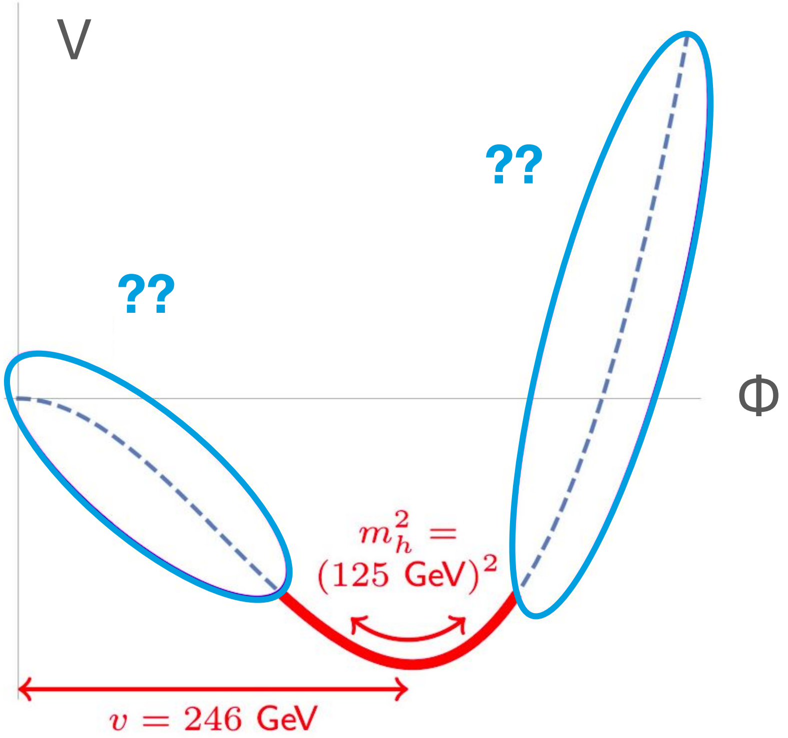
Motivation

- Why BSM models?
  - BAU, dark matter, neutrino masses…
- Why trilinear Higgs couplings?
  - Not measured: good portal for new physics
  - We don't know the shape of the Higgs potential
  - It has an impact in the history of the universe: BAU and SFOEWPT

Di-Higgs production as a tool to probe trilinear Higgs couplings



Taken from J. Braathen

Real singlet extension of the SM (RxSM)

EW doublet: $\Phi = \begin{pmatrix} 0 \\ \frac{\phi+v}{\sqrt{2}} \end{pmatrix}$

Singlet: $S = s + v_S$

Potential:

$$V(\Phi, S) = \mu^2(\Phi^\dagger\Phi) + \frac{\lambda}{2}(\Phi^\dagger\Phi)^2 + \kappa_{SH}(\Phi^\dagger\Phi)S + \frac{\lambda_{SH}}{2}(\Phi^\dagger\Phi)S^2 + \frac{M_S}{2}S^2 + \frac{\kappa_S}{3}S^3 + \frac{\lambda_S}{2}S^4$$

Mass matrix:

$$\begin{pmatrix} \frac{d^2V}{d\phi^2} & \frac{d^2V}{d\phi ds} \\ \frac{d^2V}{d\phi ds} & \frac{d^2V}{ds^2} \end{pmatrix} = \begin{pmatrix} M_\phi^2 & M_{\phi s}^2 \\ M_{\phi s}^2 & M_s^2 \end{pmatrix}$$

Masses & mixing angle:

$$m_h^2 = M_\phi^2 \cos^2(\alpha) + M_s^2 \sin^2(\alpha) + M_{\phi s}^2 \sin(2\alpha)$$

$$m_H^2 = M_\phi^2 \sin^2(\alpha) + M_s^2 \cos^2(\alpha) - M_{\phi s}^2 \sin(2\alpha)$$

$$\tan(2\alpha) = \frac{2M_{\phi s}^2}{M_\phi^2 - M_s^2}.$$

Real singlet extension of the SM (RxSM): Tadpoles

Minimization conditions:

$$\left|\frac{dV}{d\phi}\right|_{\phi=0,s=0} = t_\phi, \qquad \left|\frac{dV}{ds}\right|_{\phi=0,s=0} = t_s$$

Tadpole equations:

$$\mu^2 v + \frac{\lambda v^3}{2} + \kappa_{SH} v v_S + \frac{\lambda_{SH} v v_S^2}{2} = t_\phi,$$

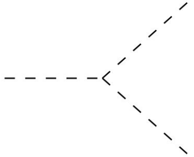
$$M_S v_S + 2\lambda_S v_S^3 + \kappa_S v_S^2 + \frac{\kappa_{SH} v^2}{2} + \frac{\lambda_{SH} v^2 v_S}{2} = t_s$$

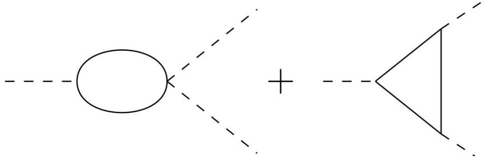
One-loop corrections: NOTATION

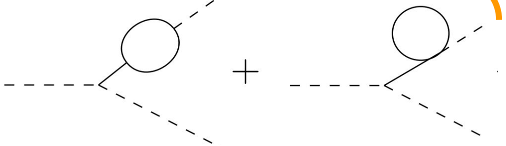
- Bare parameter: x^0
- Tree-level parameter: $x^{(0)}$
- Genuine one-loop contribution: $\delta^{(1)}x$
- One-loop counter term: $\delta^{\mathrm{CT}}x$
- One-loop renormalized value: $\hat{x}^{(1)}$

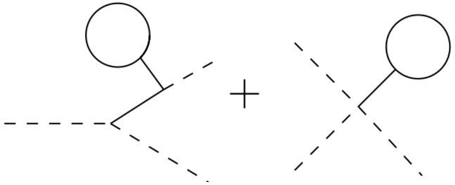
Diagramatic one-loop corrections

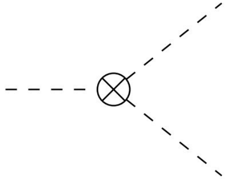
$$\hat{\lambda}^{(1)}_{ijk} = \underbrace{\lambda^{(0)}_{ijk}} + \underbrace{\delta^{(1)}\lambda_{ijk}} + \underbrace{\delta^{\mathrm{WFR}}\lambda_{ijk}} + \underbrace{\delta^{\mathrm{TAD}}\lambda_{ijk}} + \underbrace{\delta^{\mathrm{CT}}\lambda_{ijk}}$$











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- Tree level: $\lambda^{(0)}_{ijk}$
- Genuine one loop: $\delta^{(1)}\lambda_{ijk}$
- One-loop counter term: $\delta^{\mathrm{CT}}\lambda_{ijk}$
- Genuine tadpole contribution: $\delta^{\mathrm{TAD}}\lambda_{ijk}$
- External leg corrections: $\delta^{\mathrm{WFR}}\lambda_{ijk}$

Tree level triple Higgs couplings

Parameters in scalar sector: $m_h^2, m_H^2, v, \alpha, v_S, \kappa_S, \kappa_{SH}, t_\phi, t_s$

$$\lambda^{(0)}_{hhh} = \frac{1}{8vv_S^2}(6v_S(-\kappa_{SH}v^2 + (2m_h^2 + m_H^2)v_S)c_\alpha + 3v_S(2\kappa_{SH}v^2 + 3m_h^2 v_S - m_H^2 v_S)c_{3\alpha} + 3(m_h^2 - m_H^2)v_S^2 c_{5\alpha} + 9\kappa_{SH}v^3 s_\alpha + 6vv_S(m_h^2 + 2m_H^2 - \kappa_S v_S)s_\alpha + v(-3\kappa_{SH}v^2 + v_S(3m_h^2 - 9m_H^2 + 2\kappa_S v_S))s_{3\alpha} + 3(m_H^2 - m_h^2)vv_S s_{5\alpha})$$

$$\lambda^{(0)}_{hhH} = \frac{s_\alpha}{8vv_S^2}(-v_S(2\kappa_{SH}v^2 + m_h^2 v_S + 5m_H^2 v_S) - 2v_S(3\kappa_{SH}v^2 + (m_h^2 + 2m_H^2)v_S)c_{2\alpha} + (m_H^2 - m_h^2)v_S^2 c_{4\alpha} + v(3\kappa_{SH}v^2 + 6m_h^2 - 2\kappa_S v_S^2)s_{2\alpha} + (m_h^2 - m_H^2)vv_S s_{4\alpha}).$$

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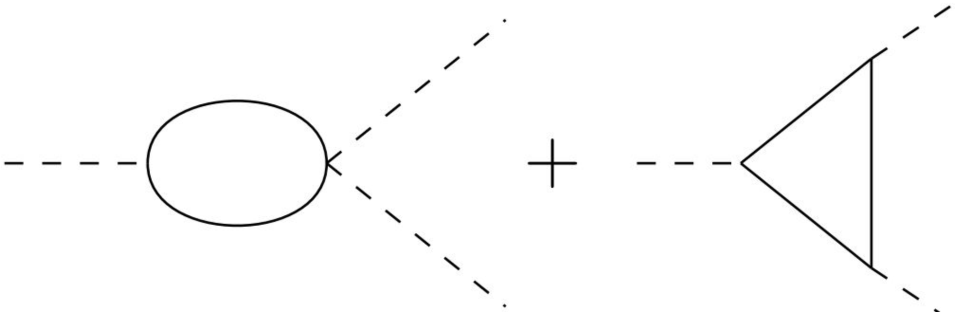
Genuine one loop

Computation of the 1PI one-loop diagrams that contribute to the three point function using the codes **anyH3** and **anyBSM**



In detail in Kateryna Radchenko Serdula´s talk (previously)

anyH3 [Bahl, Braathen, Gabelmann, Weiglein, ‘23]

anyBSM [Bahl, Braathen, Gabelmann, Radchenko Weiglein, WIP]

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One-loop counter term

Triple Higgs coupling CT:

$$\delta^{\mathrm{CT}}\lambda_{ijk} = \sum_{l} \frac{\partial \lambda^{(0)}_{ijk}}{\partial x_l} \delta^{\mathrm{CT}} x_l$$

Parameter expansion:

$$\delta^{\mathrm{CT}}\lambda_{ijk} = \frac{\partial \lambda^{(0)}_{ijk}}{\partial m^2_{h,H}} \delta^{\mathrm{CT}} m^2_{h,H} + \frac{\partial \lambda^{(0)}_{ijk}}{\partial v} \delta^{\mathrm{CT}} v + \frac{\partial \lambda^{(0)}_{ijk}}{\partial v_s} \delta^{\mathrm{CT}} v_s + \frac{\partial \lambda^{(0)}_{ijk}}{\partial \alpha} \delta^{\mathrm{CT}} \alpha + \frac{\partial \lambda^{(0)}_{ijk}}{\partial \kappa_{S,SH}} \delta^{\mathrm{CT}} \kappa_{S,SH} + \frac{\partial \lambda^{(0)}_{ijk}}{\partial t_{\phi,s}} \delta^{\mathrm{CT}} t_{\phi,s}$$

We need counter terms for:

$$m^2_h, m^2_H, v, \alpha, v_S, \kappa_S, \kappa_{SH}, t_\phi, t_s$$

Renormalization scheme: m_h^2, m_H^2

We first renormalize the fields, then the two-point function and finally imposing the OS conditions we obtain the mass and the field counterterms

OS conditions

$$\mathrm{Re}[\hat{\Sigma}_{hH}(m_h^2)] = \mathrm{Re}[\hat{\Sigma}_{Hh}(m_H^2)] = 0$$

$$\mathrm{Re}[\hat{\Sigma}_{hh}(m_h^2)] = \mathrm{Re}[\hat{\Sigma}_{HH}(m_H^2)] = 0$$

$$\mathrm{Re}\left[\frac{\partial \hat{\Sigma}_{hh}(p^2)}{\partial p^2}\bigg|_{p^2=m_h^2}\right] = \mathrm{Re}\left[\frac{\partial \hat{\Sigma}_{HH}(p^2)}{\partial p^2}\bigg|_{p^2=m_H^2}\right]$$

$$\mathrm{Re}[\delta^{CT} m_h^2] = \mathrm{Re}[\Sigma_{hh}(m_h^2)]$$
$$\mathrm{Re}[\delta^{CT} m_H^2] = \mathrm{Re}[\Sigma_{HH}(m_H^2)]$$

$$\delta Z_{hh} = -\mathrm{Re}\left[\frac{\partial \Sigma_{hh}(p^2)}{\partial p^2}\right]_{p^2=m_h^2}$$

$$\delta Z_{HH} = -\mathrm{Re}\left[\frac{\partial \Sigma_{HH}(p^2)}{\partial p^2}\right]_{p^2=m_H^2}$$

$$\delta Z_{hH} = \frac{\mathrm{Re}[\Sigma_{hH}(m_H^2)]}{m_h^2 - m_H^2}$$

$$\delta Z_{Hh} = \frac{\mathrm{Re}[\Sigma_{Hh}(m_h^2)]}{m_H^2 - m_h^2}$$

Renormalization scheme: v

Definition of the EW vev: $$v^2 = \frac{m_W^2}{\pi \alpha_{EM}}\left(1 - \frac{m_W^2}{m_Z^2}\right)$$

The vector boson masses and the fine structure constant are automatically renormalized OS by anyH3

$$\frac{\delta v}{v} = \frac{1}{2}\left(\frac{s_W^2 - c_W^2}{s_W^2}\frac{\mathrm{Re}[\Sigma_{WW}(m_W^2)]}{m_W^2} + \frac{c_W^2}{s_W^2}\frac{\mathrm{Re}[\Sigma_{ZZ}(m_Z^2)]}{m_Z^2} - \frac{d}{dp^2}\Sigma_{\gamma\gamma}(p^2)\Big|_{p^2=0} - \frac{2 s_W}{c_W}\frac{\Sigma_{\gamma Z}(0)}{m_Z^2}\right)$$

Renormalization scheme: v_S

The one-loop RGE of the singlet vev does **not have UV divergences**, therefore the singlet vev counter term does not introduce a Q dependence in the trilinear

We define an MS counter term equal to 0

$$\delta^{\mathrm{CT}} v_{\mathrm{S}} = 0$$

Renormalization scheme: α

[S.Kanemura, Y. Okada,E. Senaha, C.P. Yuan, '04]
[S. Kanemura, M. Kikuchi, K. Yagyu, '15]
KOSY scheme

- Rotate the bare fields and switch to the renormalize fields:

$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \mathrm{R}^{\mathrm{T}}_{\alpha^0} \begin{pmatrix} s^0 \\ \phi^0 \end{pmatrix} \to \mathrm{R}^{\mathrm{T}}_{\delta\alpha^{\mathrm{CT}}} \mathrm{R}^{\mathrm{T}}_{\hat{\alpha}} \begin{pmatrix} s^0 \\ \phi^0 \end{pmatrix} = \mathrm{R}^{\mathrm{T}}_{\delta\alpha^{\mathrm{CT}}} \mathrm{R}^{\mathrm{T}}_{\hat{\alpha}} \sqrt{Z_{\phi,s}} \begin{pmatrix} \hat{s} \\ \hat{\phi} \end{pmatrix} = \mathrm{R}^{\mathrm{T}}_{\delta\alpha^{\mathrm{CT}}} \mathrm{R}^{\mathrm{T}}_{\hat{\alpha}} \sqrt{Z_{\phi,s}} \mathrm{R}_{\hat{\alpha}} \mathrm{R}^{\mathrm{T}}_{\hat{\alpha}} \begin{pmatrix} \hat{s} \\ \hat{\phi} \end{pmatrix} =$$

$$= \mathrm{R}^{\mathrm{T}}_{\delta\alpha^{\mathrm{CT}}} \mathrm{R}^{\mathrm{T}}_{\hat{\alpha}} \sqrt{Z_{\phi,s}} \mathrm{R}_{\hat{\alpha}} \begin{pmatrix} \hat{h} \\ \hat{H} \end{pmatrix} = \sqrt{\tilde{Z}} \begin{pmatrix} \hat{h} \\ \hat{H} \end{pmatrix} = \sqrt{Z} \begin{pmatrix} \hat{h} \\ \hat{H} \end{pmatrix}$$

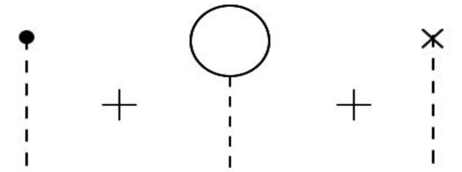
- Equate the fields renormalization matrices:

$$\sqrt{\tilde{Z}} = \mathrm{R}^{\mathrm{T}}_{\delta\alpha^{\mathrm{CT}}} \mathrm{R}^{\mathrm{T}}_{\hat{\alpha}} \sqrt{Z_{\phi,s}} \mathrm{R}_{\hat{\alpha}} = \begin{pmatrix} 1 + \frac{\delta Z_{hh}}{2} & \delta C_{hH} - \delta\alpha^{\mathrm{CT}} \\ \delta C_{Hh} + \delta\alpha^{\mathrm{CT}} & 1 + \frac{\delta Z_{HH}}{2} \end{pmatrix} = \sqrt{Z}$$

$$\delta\alpha = \frac{1}{2(m_H^2 - m_h^2)} \mathrm{Re}[\Sigma_{hH}(m_h^2) + \Sigma_{hH}(m_H^2) - 2\delta D^2_{hH}]$$

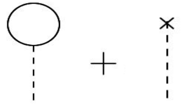
Renormalization scheme: t_ϕ, t_s

$$\hat{t}_i^{(1)} = t_i^{(0)} + \delta t_i^{(1)} + \delta t_i^{\mathrm{CT}} = 0$$



$$t_i^{(0)} = 0$$

$$\delta t_i^{(1)} + \delta t_i^{\mathrm{CT}} = 0$$



OS

$$\delta^{CT} t_\phi = -(\cos(\alpha)\delta^{(1)} t_h|^{\mathrm{FIN}} - \sin(\alpha)\delta^{(1)} t_H|^{\mathrm{FIN}})$$

$$\delta^{CT} t_s = -(\sin(\alpha)\delta^{(1)} t_h|^{\mathrm{FIN}} + \cos(\alpha)\delta^{(1)} t_H|^{\mathrm{FIN}})$$

Renormalization scheme: κ_S, κ_{SH}

- $\overline{\text{MS}}$ kappas and no RGE running:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{(0)}) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\text{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\text{CT}}_{\overline{MS}}\kappa)$$

- $\overline{\text{MS}}$ kappas and RGE running:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{\text{RGE}}_{\overline{MS}}(Q)) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\text{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\text{CT}}_{\overline{MS}}\kappa)$$

- OS kappas:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{(0)}) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\text{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\text{CT}}_{OS}\kappa)$$

Renormalization scheme: κ_S, κ_{SH}

- $\overline{\text{MS}}$ kappas and no RGE running:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{(0)}) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\mathrm{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\mathrm{CT}}_{\overline{MS}}\kappa)$$

Large Q dependence

- $\overline{\text{MS}}$ kappas and RGE running:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{\mathrm{RGE}}_{\overline{MS}}(Q)) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\mathrm{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\mathrm{CT}}_{\overline{MS}}\kappa)$$

- OS kappas:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{(0)}) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\mathrm{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\mathrm{CT}}_{OS}\kappa)$$

Renormalization scheme: κ_S, κ_{SH}

- $\overline{\text{MS}}$ kappas and no RGE running:

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Large Q dependence

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Large Q dependence

- OS kappas:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{(0)}) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\text{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\text{CT}}_{OS}\kappa)$$

Renormalization scheme: κ_S, κ_{SH}

- $\overline{\text{MS}}$ kappas and no RGE running:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{(0)}) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\text{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\text{CT}}_{\overline{MS}}\kappa)$$

Large Q dependence

- $\overline{\text{MS}}$ kappas and RGE running:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{\text{RGE}}_{\overline{MS}}(Q)) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\text{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\text{CT}}_{\overline{MS}}\kappa)$$

Large Q dependence

- OS kappas:

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk}(\kappa^{(0)}) + \delta^{(1)}\lambda_{ijk}(\kappa^{(0)}) + \delta^{\text{CT}}\lambda_{ijk}(\kappa^{(0)}, \delta^{\text{CT}}_{OS}\kappa)$$

OS condition?

Renormalization scheme: κ_S, κ_{SH}

Renormalization conditions:

$$\hat{\lambda}^{(1)}_{hHH} \stackrel{!}{=} \lambda^{(0)}_{hHH} \qquad \hat{\lambda}^{(1)}_{HHH} \stackrel{!}{=} \lambda^{(0)}_{HHH}$$

$$\lambda^{(0)}_{hHH} + \delta\lambda^{(1)}_{hHH} + \delta\lambda^{m^2}_{hHH} + \delta\lambda^{v}_{hHH} + \delta\lambda^{tad}_{hHH} + \delta\lambda^{wfr}_{hHH} + \delta\kappa_S^{\mathrm{CT}} \frac{\partial\lambda^{(0)}_{hHH}}{\partial\kappa_S} + \delta\kappa_{SH}^{\mathrm{CT}} \frac{\partial\lambda^{(0)}_{hHH}}{\partial\kappa_S H} = \lambda^{(0)}_{hHH}$$

$$\lambda^{(0)}_{HHH} + \delta\lambda^{(1)}_{HHH} + \delta\lambda^{m^2}_{HHH} + \delta\lambda^{v}_{HHH} + \delta\lambda^{tad}_{HHH} + \delta\lambda^{wfr}_{HHH} + \delta\kappa_S^{\mathrm{CT}} \frac{\partial\lambda^{(0)}_{HHH}}{\partial\kappa_S} + \delta\kappa_{SH}^{\mathrm{CT}} \frac{\partial\lambda^{(0)}_{HHH}}{\partial\kappa_S H} = \lambda^{(0)}_{HHH}$$

Renormalization scheme: κ_S, κ_{SH}

$$\delta\kappa_S^{\mathrm{CT}} = \frac{\frac{\partial\lambda_{HHH}^{(0)}}{\partial\kappa_{SH}}\left(\delta\lambda_{hHH}^{(1)} + \sum\delta\lambda_{hHH}^{i}\right) - \frac{\partial\lambda_{hHH}^{(0)}}{\partial\kappa_{SH}}\left(\delta\lambda_{HHH}^{(1)} + \sum\delta\lambda_{HHH}^{i}\right)}{\frac{\partial\lambda_{hHH}^{(0)}}{\partial\kappa_{SH}}\frac{\partial\lambda_{HHH}^{(0)}}{\partial\kappa_{S}} - \frac{\partial\lambda_{hHH}^{(0)}}{\partial\kappa_{S}}\frac{\partial\lambda_{HHH}^{(0)}}{\partial\kappa_{SH}}}$$

$$\delta\kappa_{SH}^{\mathrm{CT}} = \frac{\frac{\partial\lambda_{hHH}^{(0)}}{\partial\kappa_{S}}\left(\delta\lambda_{HHH}^{(1)} + \sum\delta\lambda_{HHH}^{i}\right) - \frac{\partial\lambda_{HHH}^{(0)}}{\partial\kappa_{S}}\left(\delta\lambda_{hHH}^{(1)} + \sum\delta\lambda_{hHH}^{i}\right)}{\frac{\partial\lambda_{hHH}^{(0)}}{\partial\kappa_{SH}}\frac{\partial\lambda_{HHH}^{(0)}}{\partial\kappa_{S}} - \frac{\partial\lambda_{hHH}^{(0)}}{\partial\kappa_{S}}\frac{\partial\lambda_{HHH}^{(0)}}{\partial\kappa_{SH}}}$$

Renormalization scheme: OS scheme

• Masses: m_h^2, m_H^2	OS renormalization of two-point functions
• EW VEV: v	OS SM-like electroweak sector
• Singlet VEV: v_S	No divergences
• Mixing angle: α	KOSY scheme
• Tadpoles: $t_\phi,\ t_s$	OS/Standard scheme
• Kappas: κ_S, κ_{SH}	OS condition BSM trilinear

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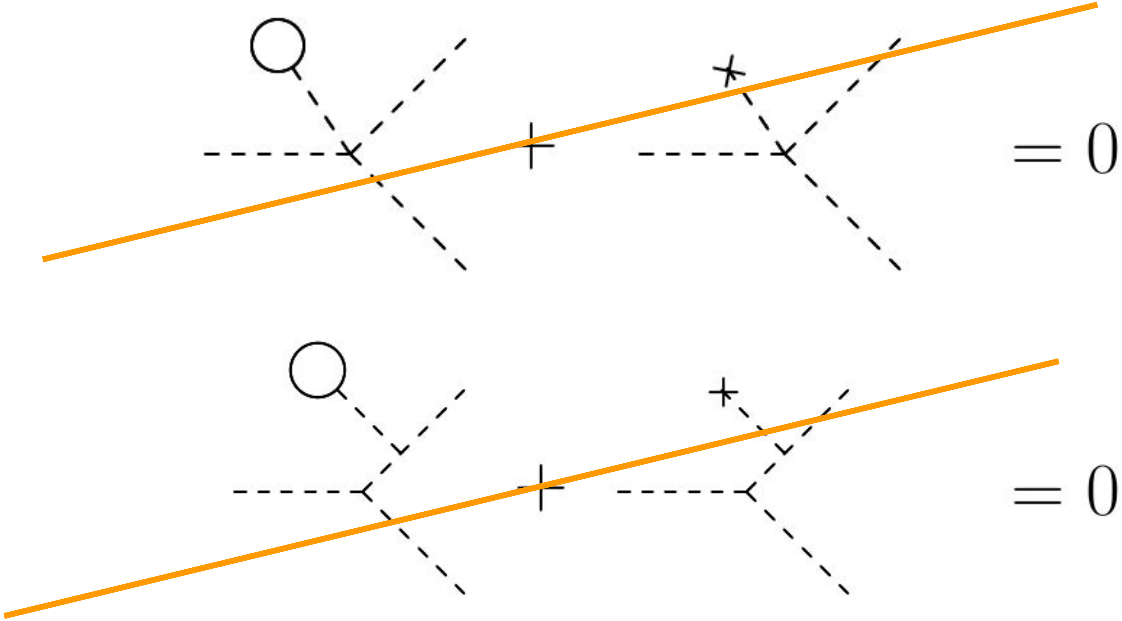
Genuine tadpole contribution

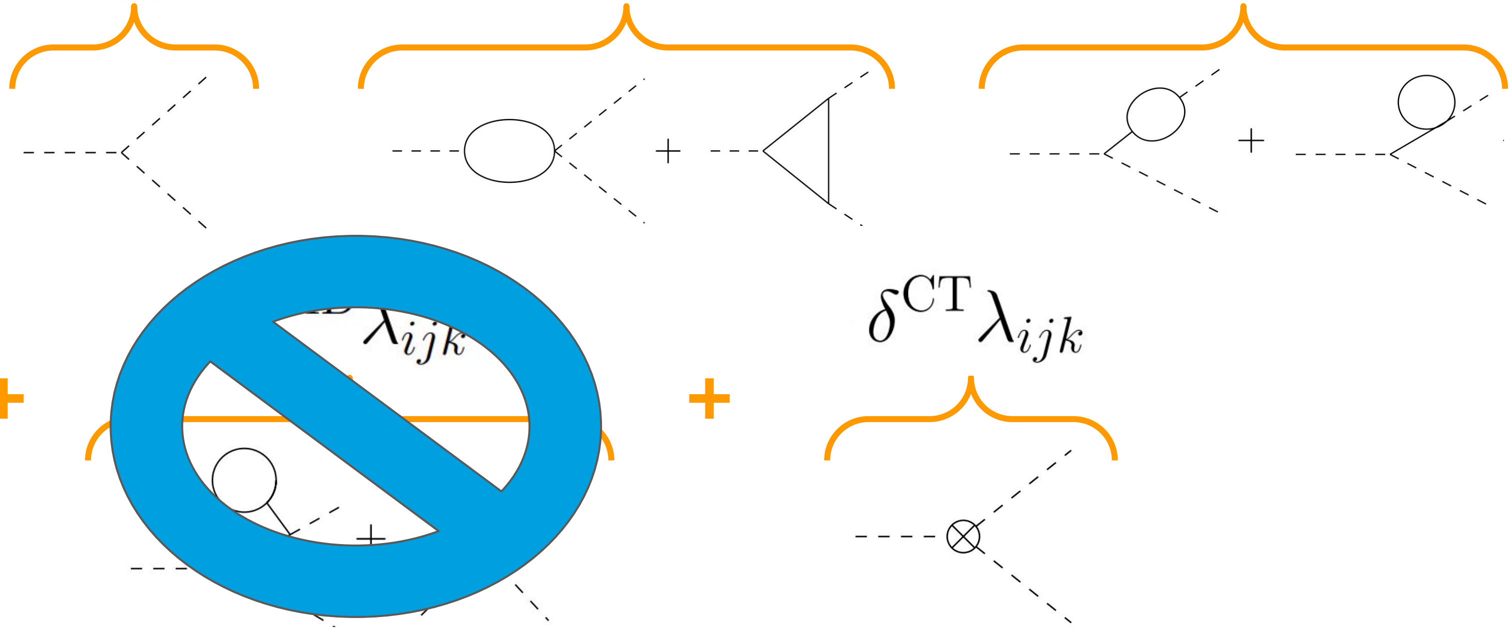
OS



NO genuine tadpole contribution

Genuine tadpole contribution

$$\hat{\lambda}^{(1)}_{ijk} = \lambda^{(0)}_{ijk} + \delta^{(1)}\lambda_{ijk} + \delta^{\mathrm{WFR}}\lambda_{ijk} + \ldots\lambda_{ijk} + \delta^{\mathrm{CT}}\lambda_{ijk}$$



OS tadpoles

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External leg corrections

$$\delta^{\rm WFR}\lambda_{hhh} = \frac{3}{2}\delta Z_{hh}(m_h^2)\lambda_{hhh}^{(0)} + 3\delta Z_{hH}(m_h^2)\lambda_{hhH}^{(0)} = \frac{3}{2}\Sigma'_{hh}(m_h^2)\lambda_{hhh}^{(0)} + 3\frac{\Sigma_{hH}(m_h^2)}{m_h^2 - m_H^2}\lambda_{hhH}^{(0)}$$

No field mixing **Field mixing**

$$\delta^{\rm WFR}\lambda_{hhH} = \delta Z_{hh}(m_h^2)\lambda_{hhH}^{(0)} + \frac{1}{2}\delta Z_{HH}(m_H^2)\lambda_{hhH}^{(0)} + 2\delta Z_{hH}(m_h^2)\lambda_{hHH}^{(0)} + \delta Z_{Hh}(m_H^2)\lambda_{hhh}^{(0)} =$$

$$\Sigma'_{hh}(m_h^2)\lambda_{hhH}^{(0)} + \frac{1}{2}\Sigma'_{HH}(m_H^2)\lambda_{hhH}^{(0)} + 2\frac{\Sigma_{hH}(m_h^2)}{m_h^2 - m_H^2}\lambda_{hHH}^{(0)} + \frac{\Sigma_{hH}(m_H^2)}{m_H^2 - m_h^2}\lambda_{hhh}^{(0)}$$

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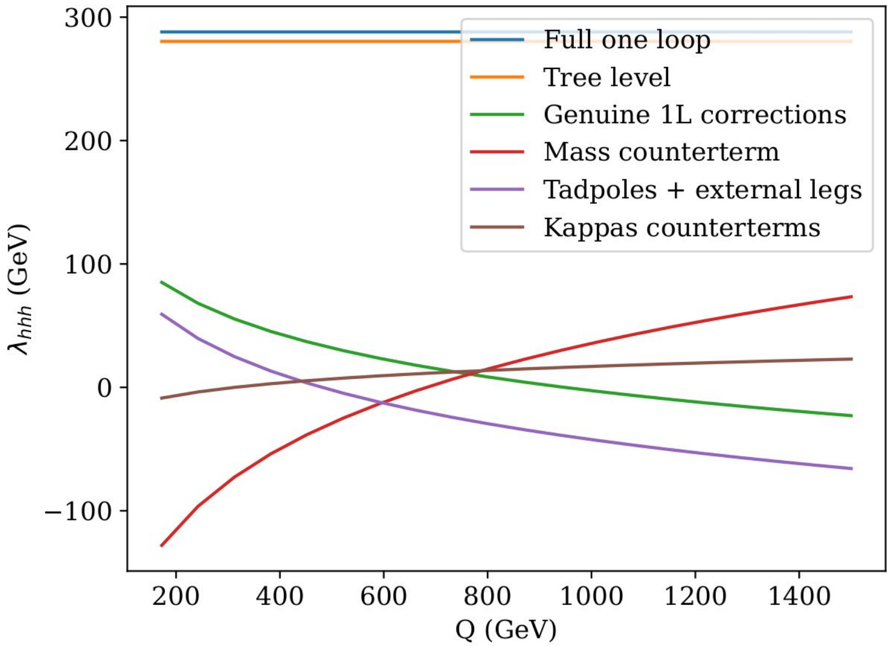
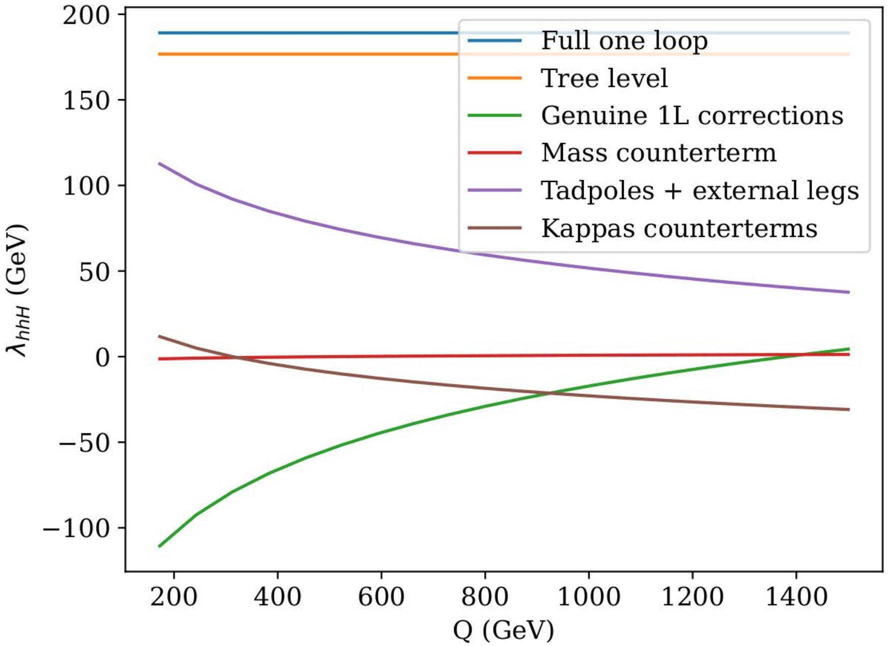
Renormalization scheme: Q dependence



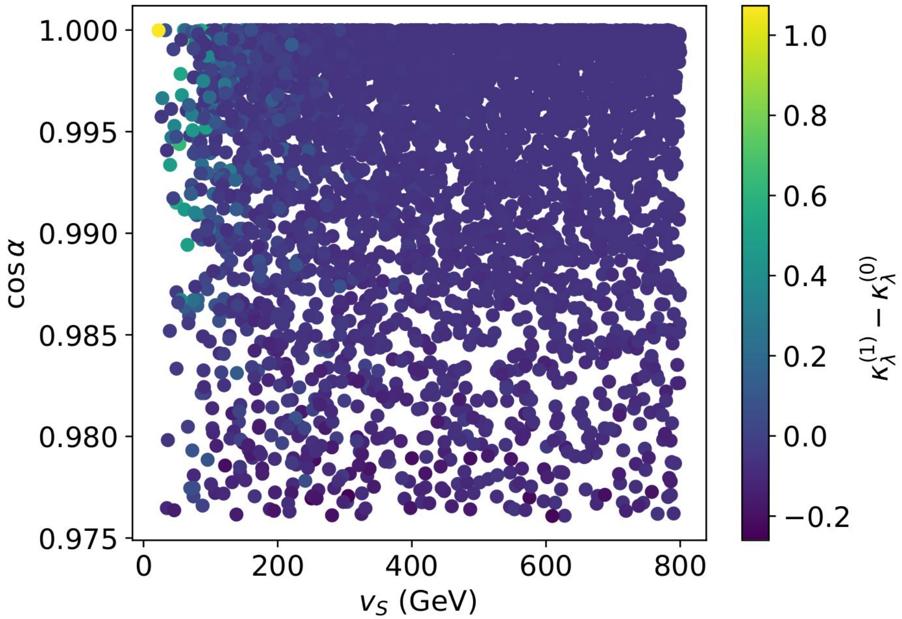


Computed with anyH3 [Bahl, Braathen, Gabelmann, Weiglein, '23]

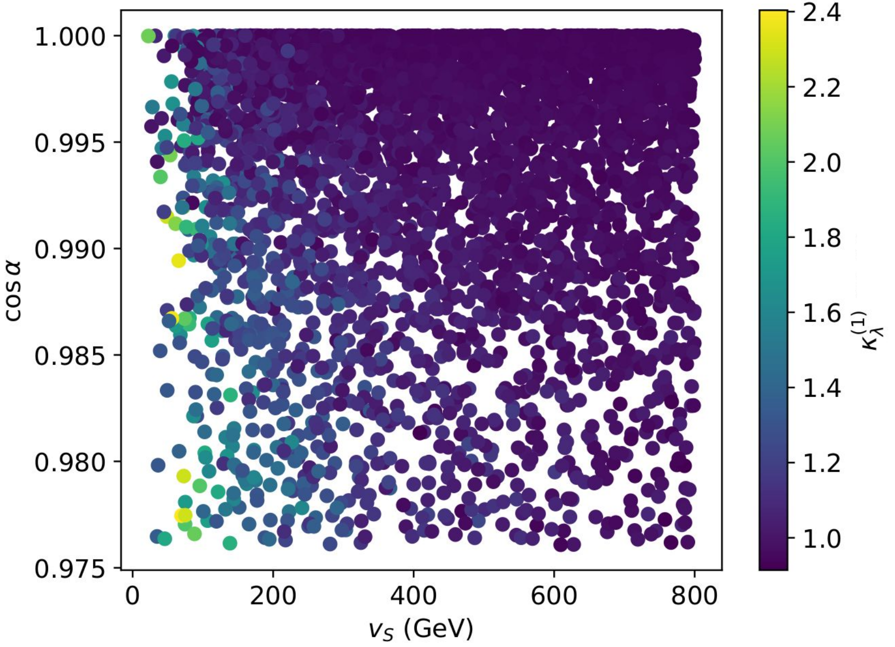
One loop corrections to κ_λ

$$\kappa_\lambda = \frac{\lambda_{hhh}}{\lambda_{hhh}^{\mathrm{SM},(0)}}$$

Difference between one loop and tree level

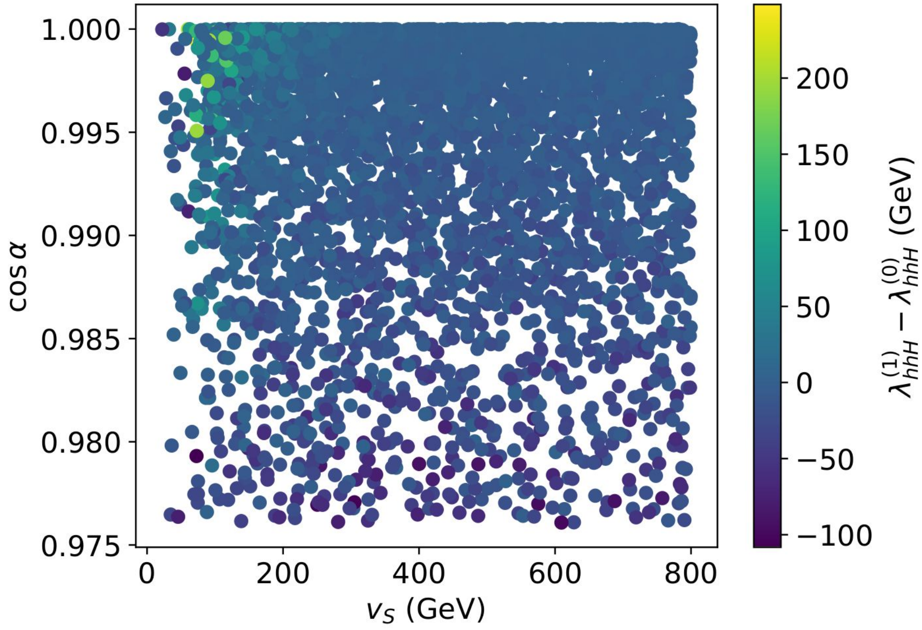


One loop value

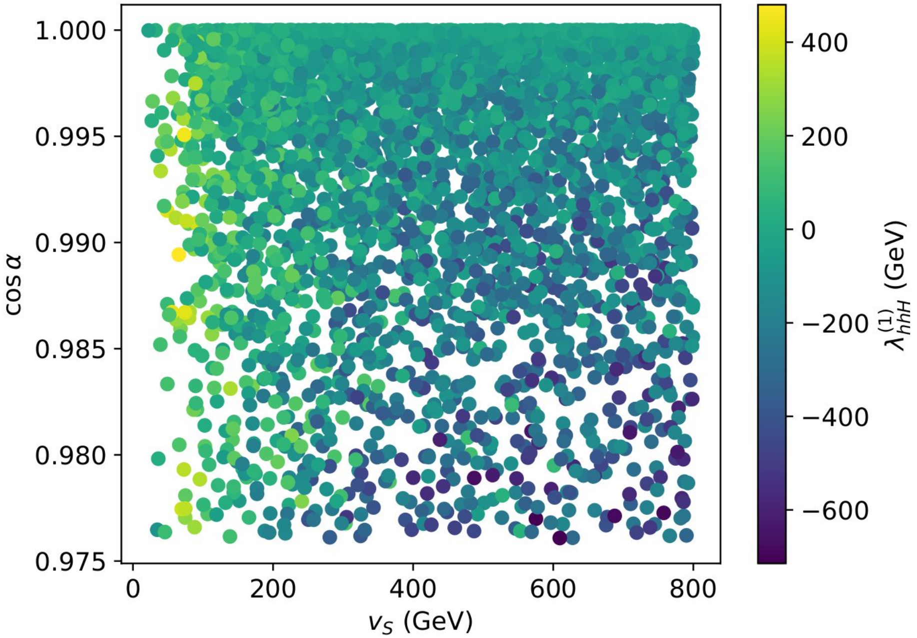


One loop corrections to λ_{hhH}

Difference between one loop and tree level



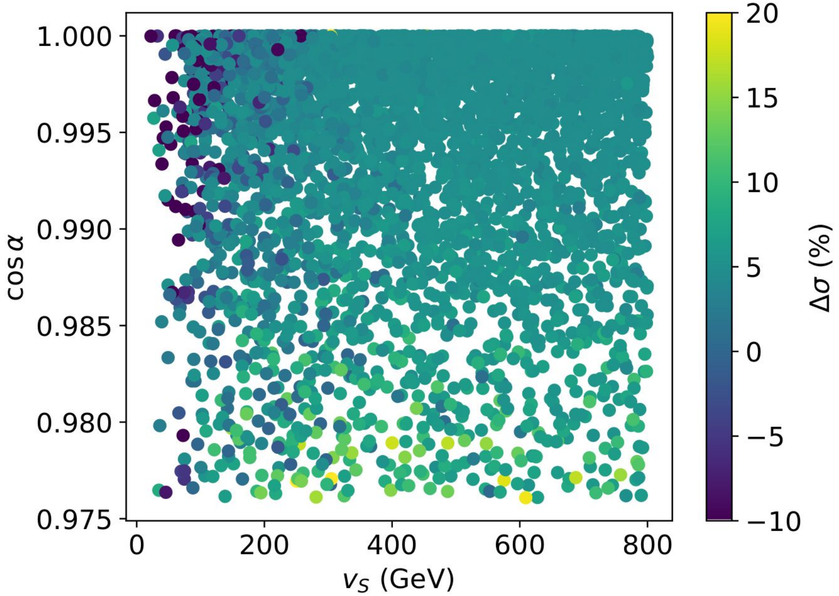
One loop value

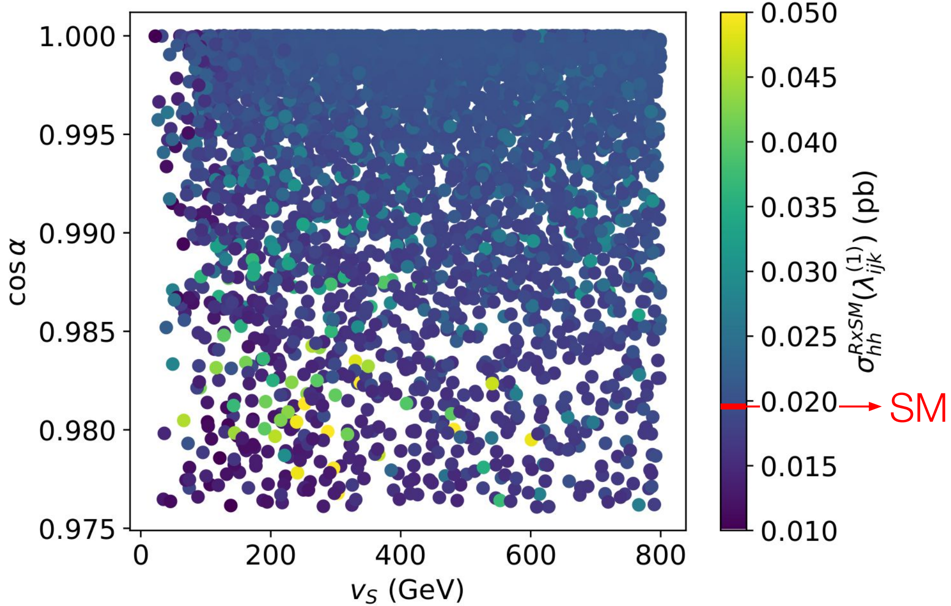


Total di-Higgs production cross section at HL-LHC

$$\Delta\sigma = \frac{\sigma_{hh}(\lambda^{(1)}_{ijk}) - \sigma_{hh}(\lambda^{(0)}_{ijk})}{\sigma_{hh}(\lambda^{(0)}_{ijk})}$$

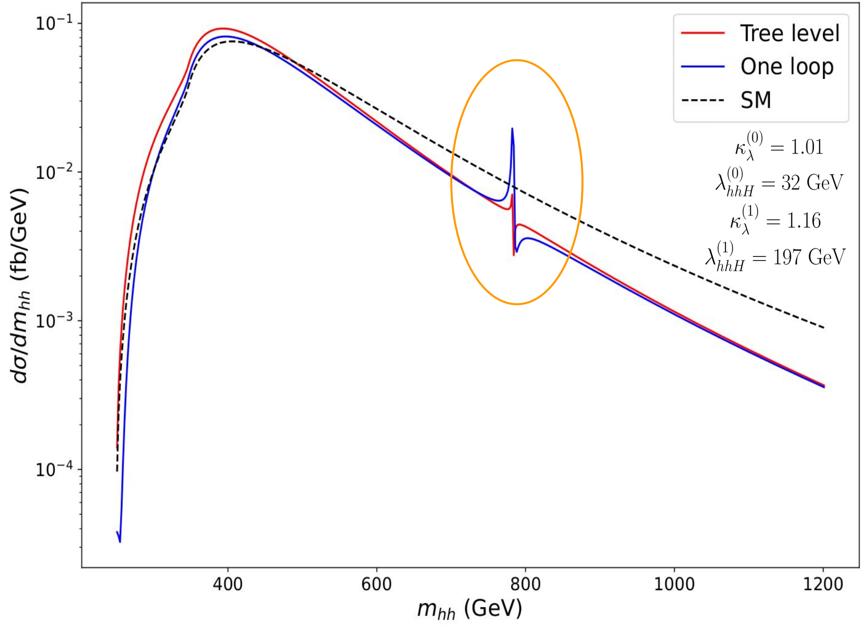
Total cross-section value in the RxSM using one loop trilinears

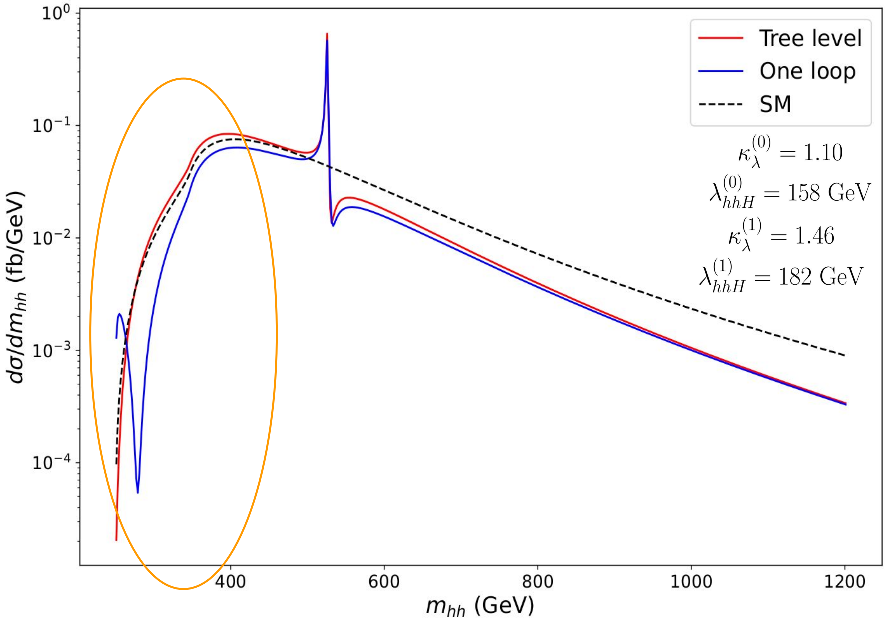




HPAIR [T. Plehn, M. Spira, P.M. Zerwas, '96] [S.Dawson, S.Dittmaier, M.Spira, '98][Abouabid et al., '22]

Di-Higgs invariant mass distributions





Previously seen in: [S. Heinemeyer, M. Mühlleitner, K. Radchenko, G. Weiglein '24] for 2HDM

Conclusions

We defined a full **Q independent one-loop renormalization scheme** of the trilinear Higgs couplings λ_{hhh}, λ_{hhH} for the non Z2 symmetric RxSM.

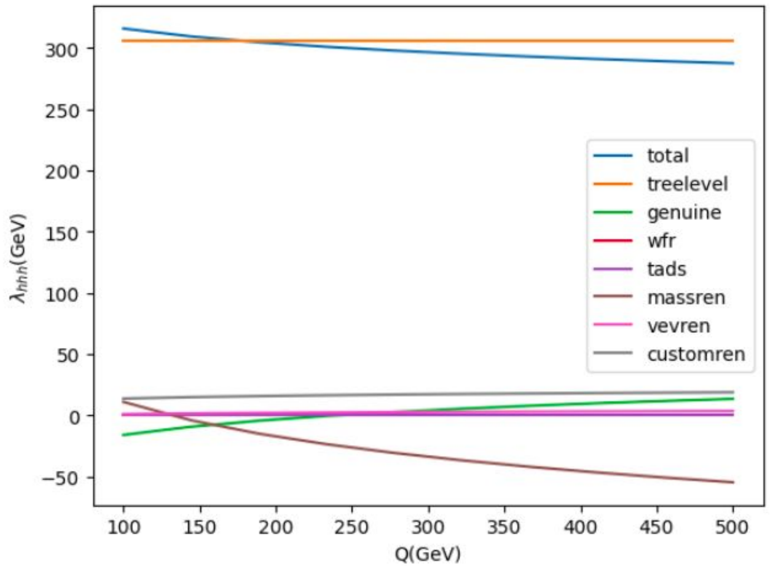
We observed for both couplings that the **one-loop corrections are of the order of the tree level contribution**.

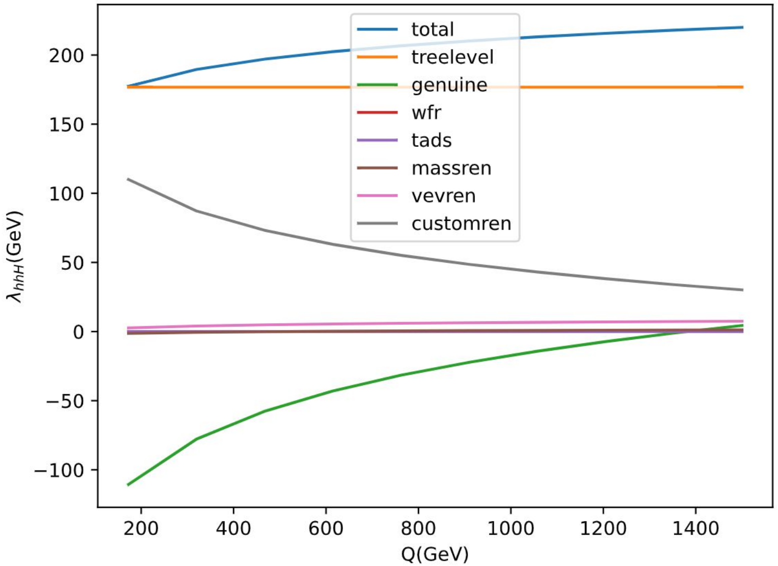
We observed a **relevant impact** of the one-loop corrections to the trilinear Higgs couplings **in the di-Higgs production cross section**.

Thank you for your attention

Renormalization scheme: κ_S, κ_{SH}

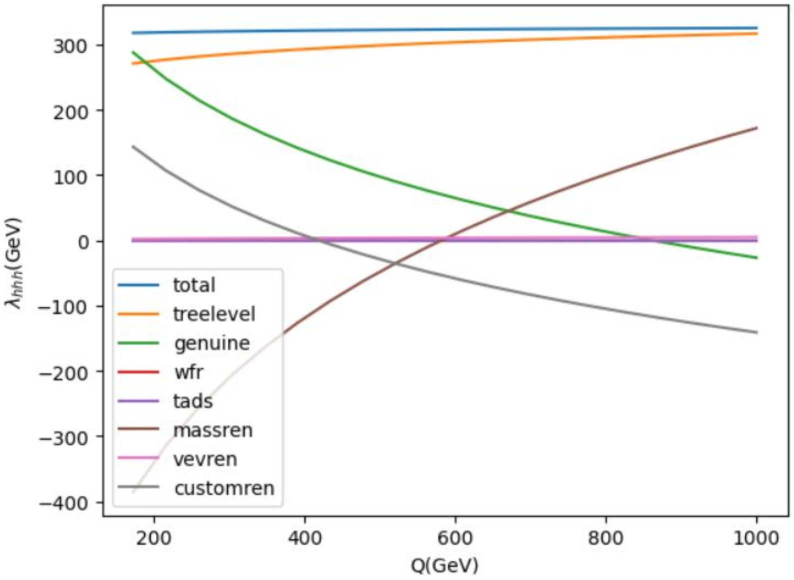
MS kappas and not RGE running

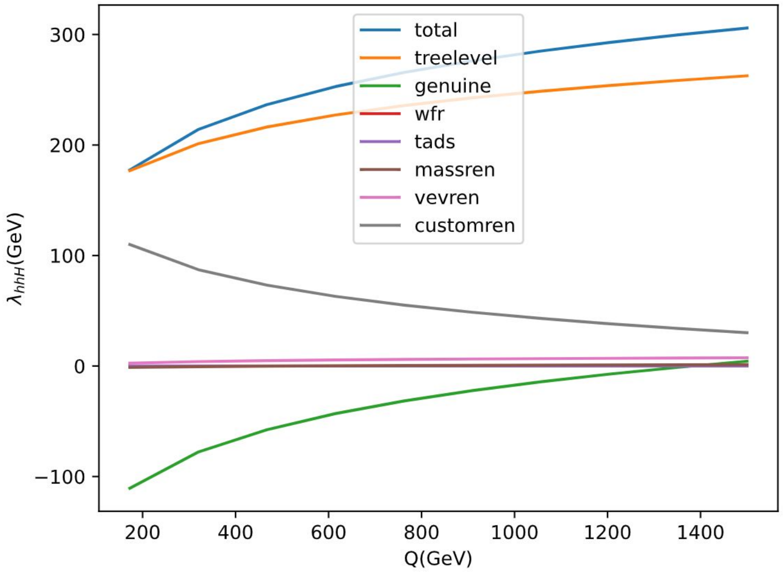




Renormalization scheme: κ_S, κ_{SH}

MS kappas with RGE running at tree level





Loop correction set-up

Theoretical constraints → One-loop corrections → Experimental constraints → Cross section calculation

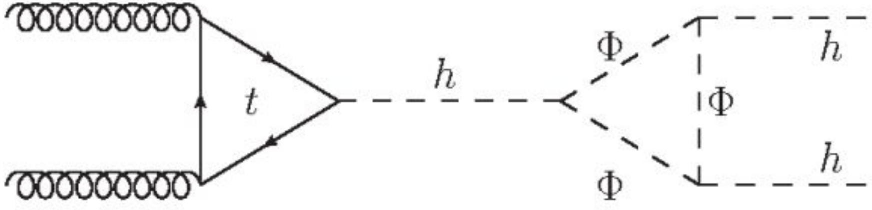
Potential stability

Coupling pertubativity
[Li, Ramsey-Musolf, Willocq, '19]

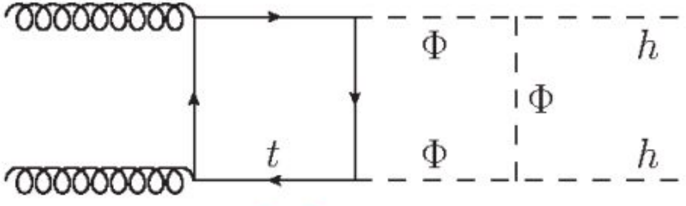
anyH3
[Bahl, Braathen, Gabelmann, Weiglein, '23]
anyBSM
[Bahl, Braathen, Gabelmann, Radchenko Weiglein, WIP]

HiggsTools
[Bahl et al., '22]
HiggsBounds
[Bechtle et al., '20]
HiggsSignals
[Bechtle et al., '21]

HPAIR
[T. Plehn, M. Spira, P.M. Zerwas, '96]
[S.Dawson, S.Dittmaier, M.Spira, '98]
[Abouabid et al., '22]



$\propto \mathcal{O}(y_t g_{hh\Phi\Phi}^3)$ ***included***



$\propto \mathcal{O}(y_t^2 g_{hh\Phi\Phi}^2)$ ***not included***

Taken from J. Braathen