

# Higgs decay into a lepton pair and a photon revisited

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<sup>1</sup>Based on arXiv:2001.06516

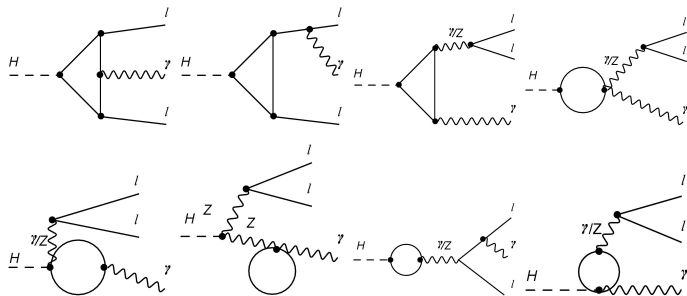
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# Motivation

- In order to explain phenomena like baryogenesis or DM it is important to find a deviation from the SM. Rare Higgs decays are sensitive to new physics ( $H \rightarrow \gamma\gamma$  ruled out a fourth fermion generation).
- We study the rare processes  $H \rightarrow \bar{\ell}\ell\gamma$ , where  $\ell = e, \mu$ . The decay rate for  $H \rightarrow \bar{e}e\gamma$  is much larger than  $H \rightarrow \bar{e}e$  and of the same order for ( $\mathcal{B}(H \rightarrow \bar{\mu}\mu\gamma) = 6.7 \times 10^{-5}$  vs  $\mathcal{B}(H \rightarrow \bar{\mu}\mu) = 2 \times 10^{-4}$ ). The leading contribution for the process  $H \rightarrow \bar{\ell}\ell\gamma$  comes from the one-loop, it is not vanishing even for  $m_\ell = 0$ .
- There are discrepancies in literature [Y. Sun et al., arXiv:1303.2230], [T. Han and X. Wang, arXiv:1704.00790], [G. Passarino, arXiv:1308.0422], [L. Wang et al. arXiv:1701.02678], [D. A. Dicus and W. W. Repko, arXiv:1302.2159].

# Calculation

- We calculated the SM processes  $H \rightarrow \bar{\ell}\ell\gamma$  in general  $R_\xi$ -gauge.
- 2 tree level and 119 one-loop diagrams are generated with *FeynArts*. Loop diagrams can be divided into 13 classes:



- The diagrams are evaluated with *FeynCalc*. For some checks we use *Package-X* connected to *FeynCalc* via *FeynHelpers*.
- Gauge parameters  $\xi_A$ ,  $\xi_Z$  and  $\xi_W$  are canceled independently.
- For the cancellation of  $\xi_W$  dependence the condition  $m_W = \cos\theta_W m_Z$  is important. This provides restriction for the choice of the fine-structure constant  $\alpha$  ( $\alpha^{-1} \simeq 132$ ).
- The final result is UV and IR convergent.

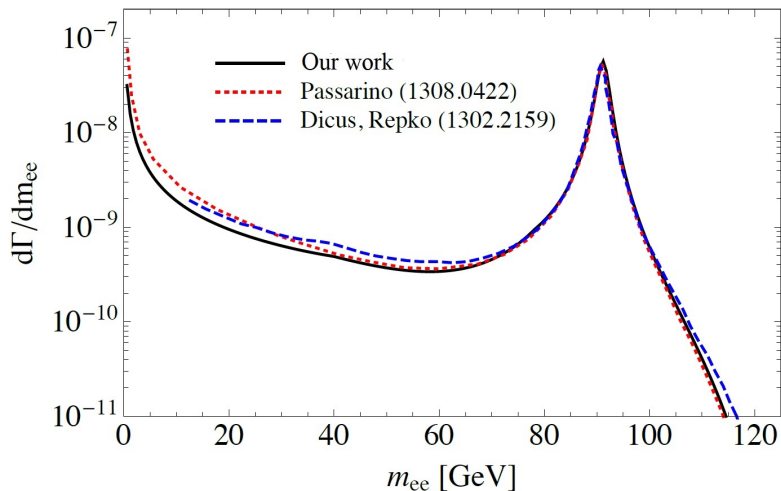
- The Ward structure of the loop contribution can be written as

$$\begin{aligned} \mathcal{A}_{\text{loop}} = & \left[ (k_\mu p_{1\nu} - g_{\mu\nu} k \cdot p_1) \bar{u}(p_2) (a_1 \gamma^\mu P_R + b_1 \gamma^\mu P_L) v(p_1) \right. \\ & \left. + (k_\mu p_{2\nu} - g_{\mu\nu} k \cdot p_2) \bar{u}(p_2) (a_2 \gamma^\mu P_R + b_2 \gamma^\mu P_L) v(p_1) \right] \varepsilon^{\nu*}(k). \end{aligned}$$

where  $a_1$ ,  $a_2$ ,  $b_1$  and  $b_2$  are coefficients dependent on  $s$ ,  $t$ ,  $u$  and the particle masses,  $k$ ,  $p_1$  and  $p_2$  are photon and leptons momenta [A. Kachanovich et al., arXiv:2001.06516].

- We evaluated the process with Breit-Wigner propagator to avoid Z-pole (also the result have been compared with the result in the complex mass scheme, for details [A. Denner, J.-N. Lang, arXiv:1406.6280]).

# Results



**Figure:** Differential decay rate with respect to the invariant dilepton mass for electrons

# Results

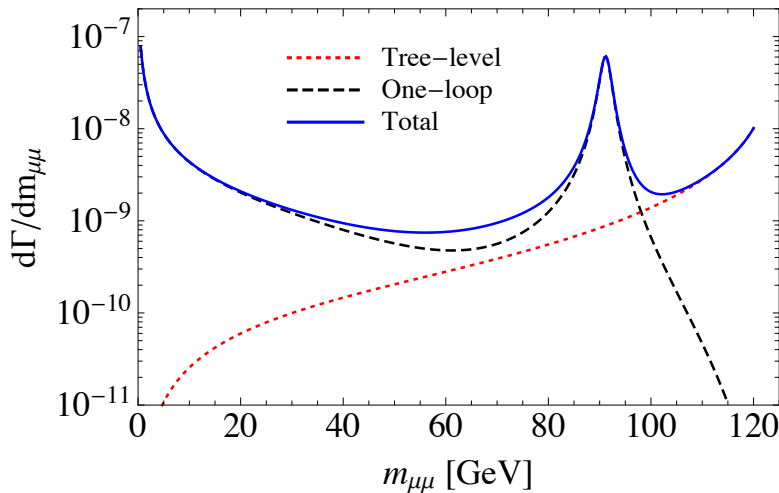
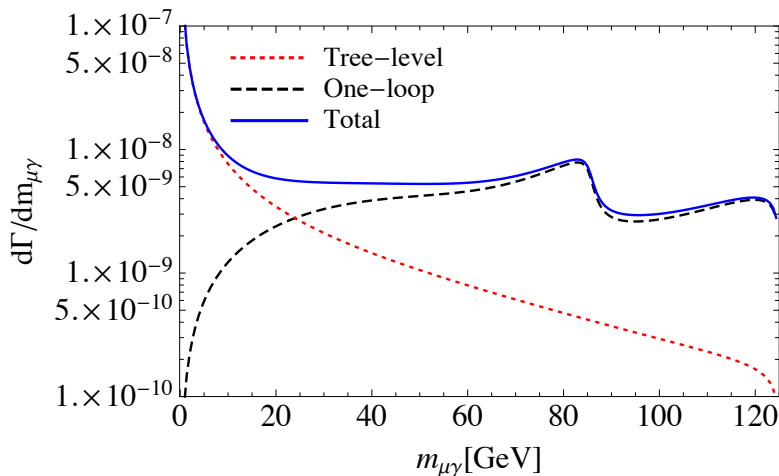


Figure: Differential decay rate with respect to the invariant dilepton mass for muons.

# Results



**Figure:** Differential decay rate with respect to the invariant mass  $\sqrt{t} \equiv m_{\mu\gamma}$  of the muon-photon pair. No cuts on  $s$  are introduced.

- Forward-backward asymmetry with respect to  $\theta^{(\ell)}$  is defined as

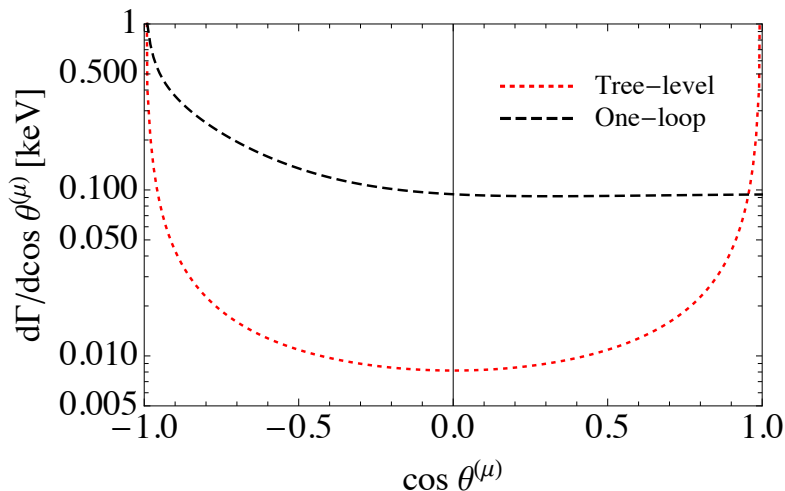
$$\mathcal{A}_{\text{FB}}^{(\ell)} = \frac{\int_{-1}^0 \frac{d\Gamma}{d \cos \theta^{(\ell)}} - \int_0^1 \frac{d\Gamma}{d \cos \theta^{(\ell)}}}{\int_{-1}^0 \frac{d\Gamma}{d \cos \theta^{(\ell)}} + \int_0^1 \frac{d\Gamma}{d \cos \theta^{(\ell)}}}.$$

- The numerical values are

$$\mathcal{A}_{\text{FB}}^{(e)} = 0.366, \quad \mathcal{A}_{\text{FB}}^{(\mu)} = 0.280.$$

- The contribution of the tree-level diagrams to the numerators of the asymmetries can be neglected because of dominant role of the one-loop contribution. The numerators for the electron and muon case are similar.

# Results



**Figure:** Differential decay rate with respect to  $\cos\theta^{(\mu)}$ , where  $\theta^{(\mu)}$  is the angle between the lepton and the photon in the rest frame of the Higgs boson.

# Conclusion

- For typical choices of cuts we find the branching ratios  $B(H \rightarrow e\bar{e}\gamma) = 6.1 \cdot 10^{-5}$  and  $B(H \rightarrow \mu\bar{\mu}\gamma) = 6.7 \cdot 10^{-5}$  and the forward-backward asymmetries  $\mathcal{A}_{\text{FB}}^{(e)} = 0.366$  and  $\mathcal{A}_{\text{FB}}^{(\mu)} = 0.280$ .
- The results in the literature show some level of disagreement.
- More deeper analysis needed to understand the discrepancies between different approaches.
- Gauge parameter cancellation requires the contribution of all diagrams.
- $m_W = \cos\theta_W m_Z$  is very important for the gauge parameters cancellation.