Higgs decay into a lepton pair and a photon revisited

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[1] Based on arXiv:2001.06516

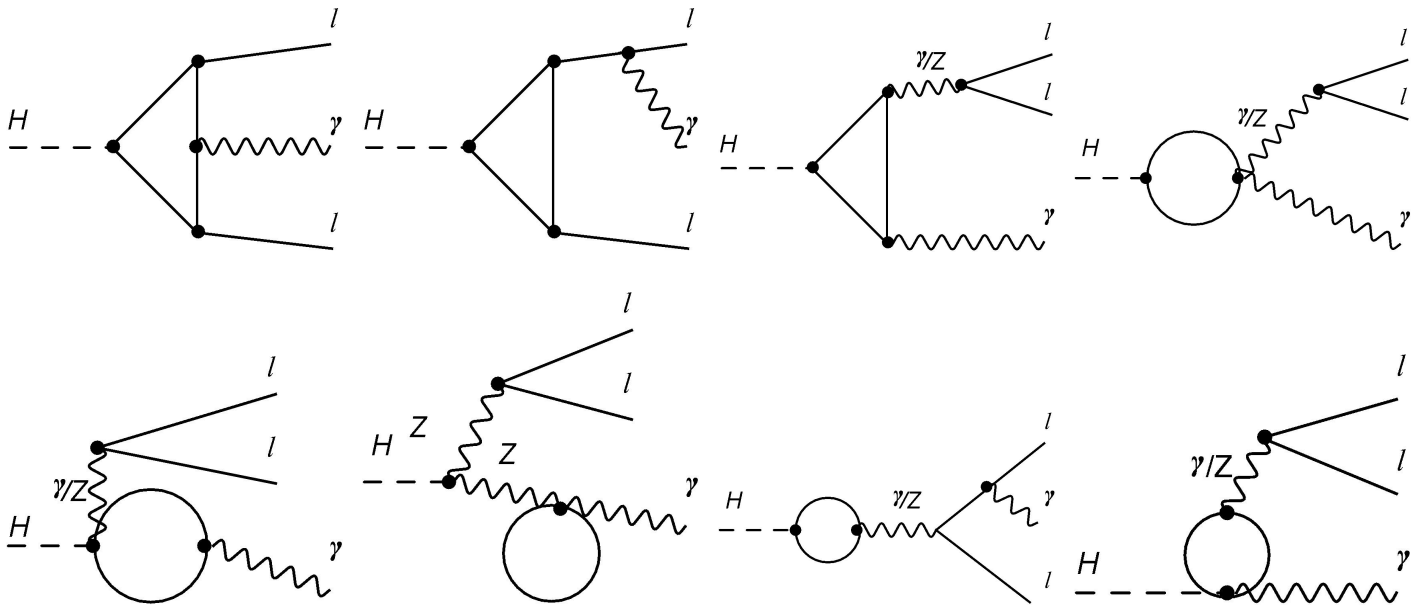
Plan

Motivation

- To explain phenomena like baryogenesis or DM it is important to find a deviation from the SM. Rare Higgs decays sensitive to new physics ($H \to \gamma\gamma$ ruled out a fourth fermion generation).
- We study the rare processes $H \to \bar{\ell}\ell\gamma$, where $\ell = e, \mu$. The decay rate for $H \to \bar{\ell}\ell\gamma$ is much larger than $H \to \bar{\ell}\ell$ for $\ell = e$ and of the same order for $\ell = \mu$ $\left(\mathcal{B}(H \to \bar{\ell}\ell\gamma) = 6.7 \times 10^{-5}\right.$ vs $\left.\mathcal{B}(H \to \bar{\ell}\ell) = 2 \times 10^{-4}\right)$. The leading contribution for the process $H \to \bar{\ell}\ell\gamma$ comes from the one-loop, it is not vanishing even for zero lepton masses.
- 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 $H \to \bar{\ell}\ell\gamma$ in general R_ξ-gauge.
- 2 tree level and 119 one-loop diagrams are generated with *FeynArts*. Loop diagrams can be divided into 13 classes:



Calculation

- The diagrams are evaluated with *FeynCalc*. For some checks we use *Package-X* connected to *FeynCalc* via *FeynHelpers*.
- The only two classes of diagrams are separately R_ξ independent and satisfies the Ward identity.
- Gauge parameters ξ_A, ξ_Z and ξ_W are canceled independently.
- For the cancellation of ξ_W dependence is important the condition $m_W = \cos\theta_W m_Z$. This provides restriction for the choice of the fine-structure constant α ($\alpha^{-1} \simeq 132$).
- The final result is UV and IR convergent.

Calculation

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

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

  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

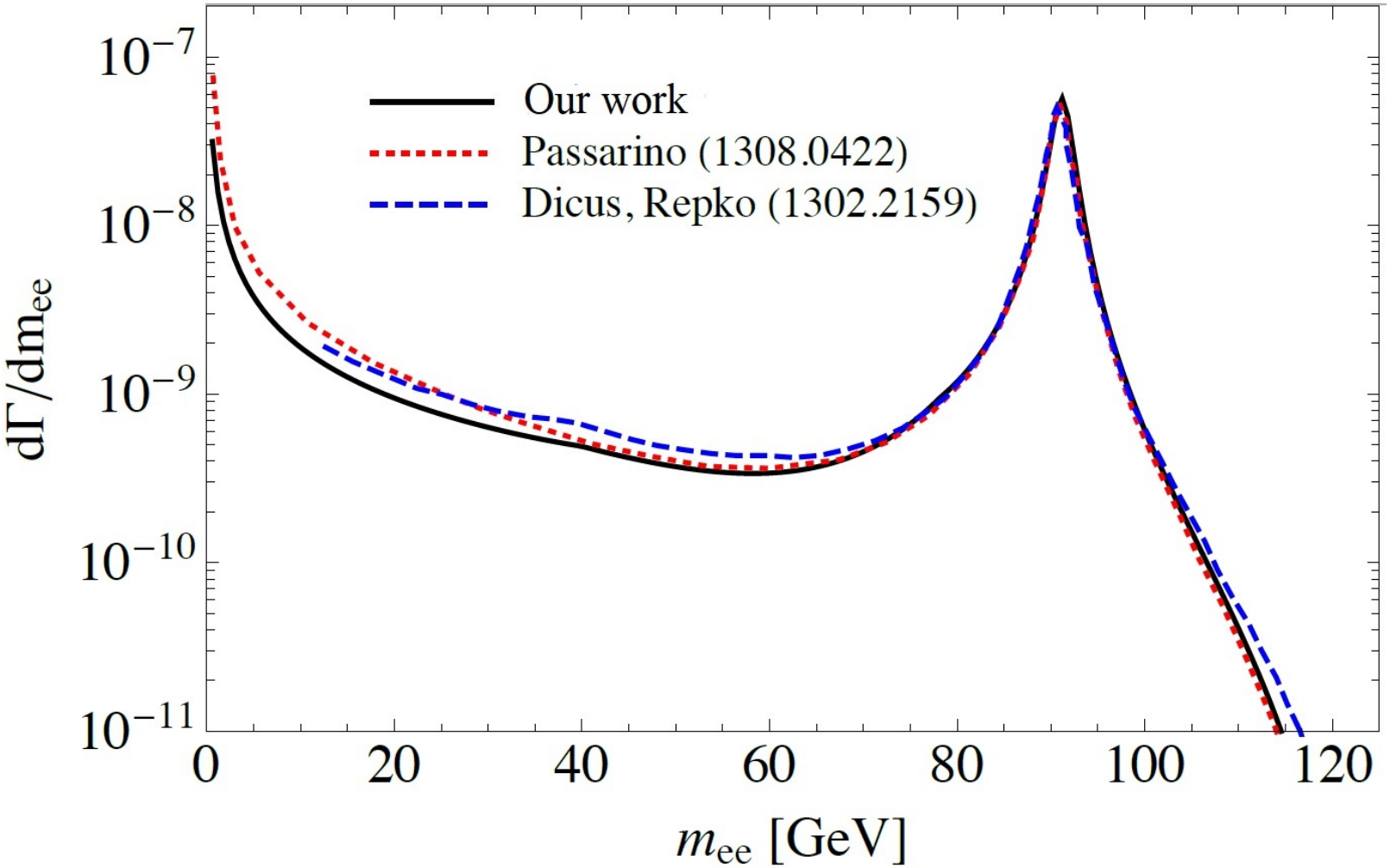


Figure: Differential decay rate with respect to the invariant dilepton mass for electrons

Results

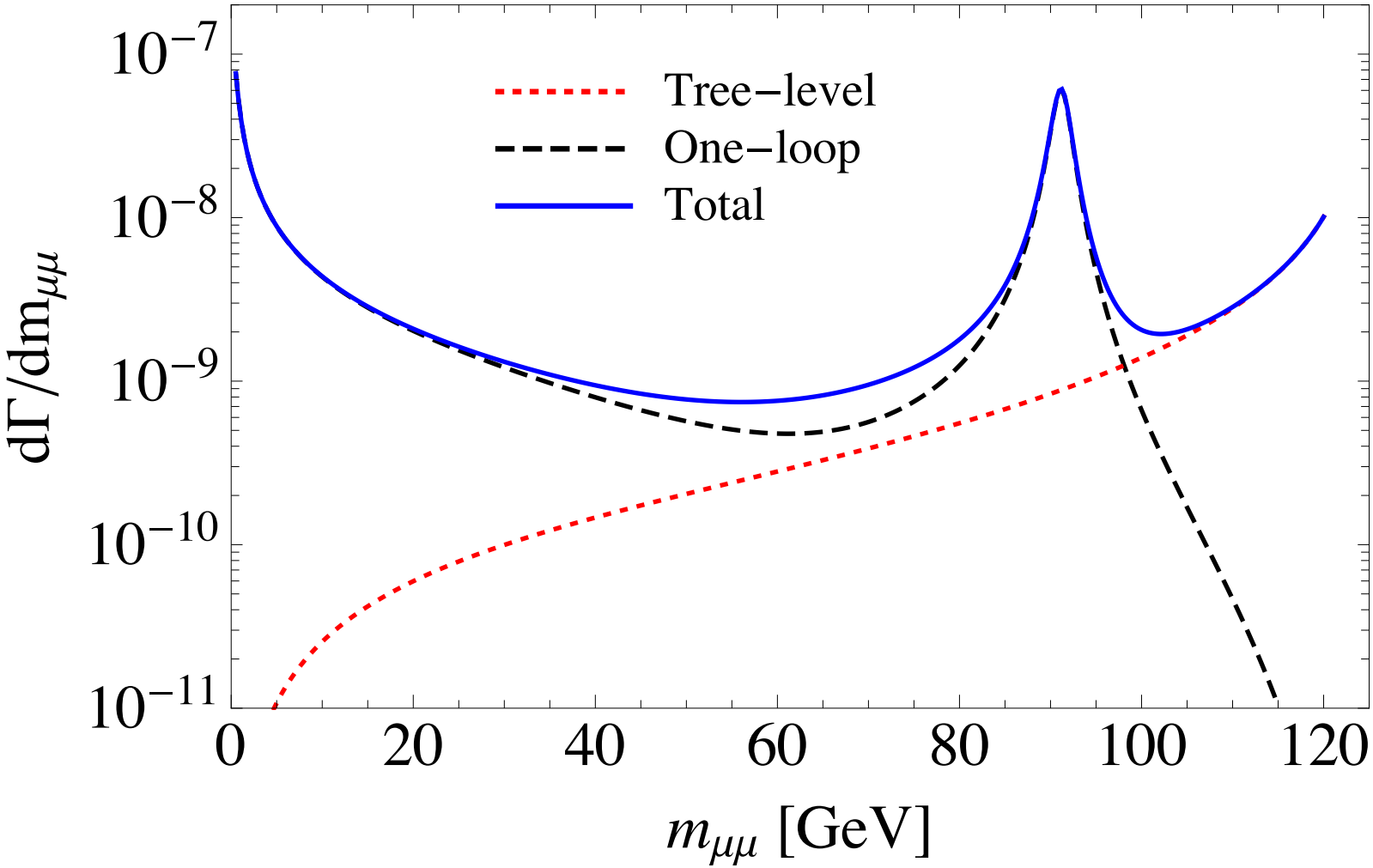


Figure: Differential decay rate with respect to the invariant dilepton mass for muons.

Results

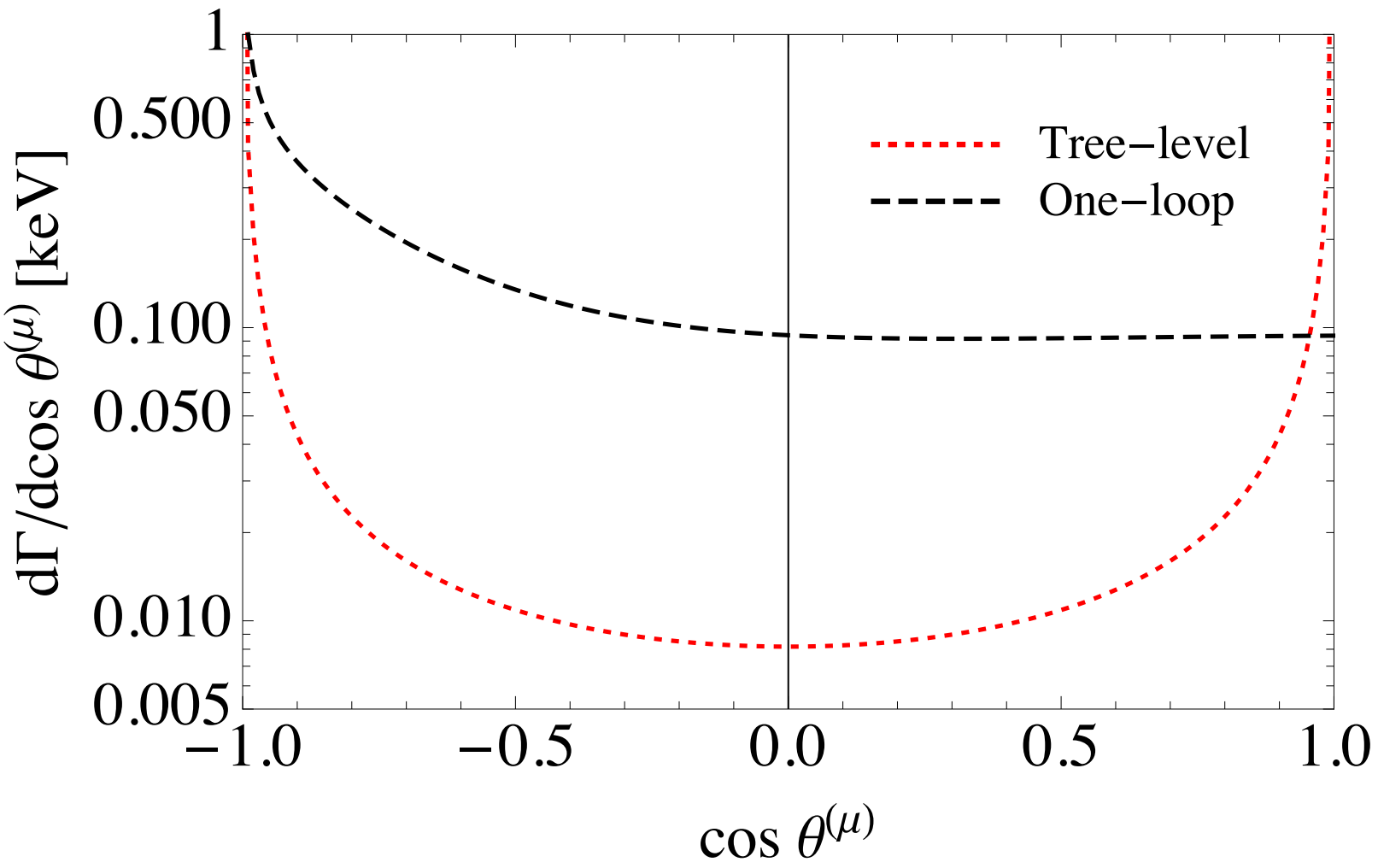


Figure: Differential decay rate with respect to $\cos\theta^{(\mu)}$, where $\theta^{(\mu)}$ is the angle between the lepton and the photon in the rest frame of the Higgs boson.

Conclusion

- For typical choices of cuts we find the branching ratios $B(H \to e\bar{e}\gamma) = 6.1 \cdot 10^{-5}$ and $B(H \to \mu\bar{\mu}\gamma) = 6.7 \cdot 10^{-5}$ and the forward-backward asymmetries $\mathcal{A}_{\mathrm{FB}}^{(e)} = 0.366$ and $\mathcal{A}_{\mathrm{FB}}^{(\mu)} = 0.280$.
- 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.