Higgs decay into photon and invisible

Aliaksei Kachanovich

Université libre de Bruxelles

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Plan

Motivation

Motivation

The Standard Model is a highly successful yet incomplete theory of particle physics. Major challenges that remain unexplained within its framework include:

- Dark Matter,
- lepto- and baryogenesis,
- strong CP-problem,
- neutrino masses,
- gravity,
- origin of the 19 parameters of the SM,
- ...

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Motivation

- Rare processes can provide hints for extensions of the Standard Model (SM).
- The decay of the Higgs boson into a photon and two neutrinos is a rare process within the Standard Model.
- In revisited calculation the total decay rate is $\Gamma(H \to \nu\bar{\nu}\gamma) = 1.33, \mathrm{keV}$, which is in close agreement with the narrow-width approximation (NWA) for the intermediate Z boson.
- The differential decay rate with respect to the photon's energy is evaluated, revealing that the kinematic region associated with high-energy photons is notably affected by non-resonant contributions from box diagrams beyond the narrow-width approximation (NWA), where the intermediate Z boson is off-shell.

Motivation

- The results of previous studies differ from each other.
- We perform the calculation in a general R_ξ gauge and provide as many details as possible about our calculations
- We studied the contribution of box diagrams to the differential decay rate.

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Theory

Theory

- The amplitude for $H \to \bar{\nu}_\ell \nu_\ell \gamma$ is

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

  where p_1, p_2, k are the momenta of outgoing neutrino, antineutrino and photon, respectively.
- The loop coefficients $b_{1,2}$ are functions of Mandelstam variables:

$$s = (p_1 + p_2)^2, \quad t = (p_1 + k)^2, \quad u = (p_2 + k)^2 = m_H^2 - s - t\,.$$

- The loop function b_2 can be obtained from b_1 by a variable exchange:

$$b_2(t, u) = b_1(u, t)\,.$$

Theory

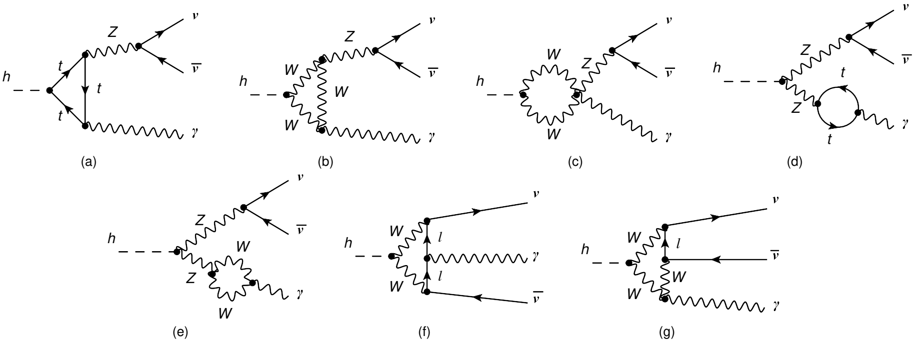

Figure: Sample set of Feynman diagrams for $h \to \nu\bar{\nu}\gamma$ decay process in R_ξ gauge. The diagrams (a-e) are examples of what we refer to as 'pole' contributions - these involve the coupling of Z propagator to the neutrino pair. The diagrams (f) and (g) are sample box diagrams.

Theory

- The gauge-invariant loop coefficients are split into two components,

$$b_{1,2} = b_{1,2}^{\text{pole}} + b_{1,2}^{\text{box}} ,$$

  where the term $b_{1,2}^{\text{pole}}$ includes contributions of the resonant diagrams, while $b_{1,2}^{\text{box}}$ contains contributions originating from the box diagrams.
- Replacing the pole propagator in the $b_{1,2}^{\text{pole}}$ functions with the Breit-Wigner propagator resolves the divergence issue

$$\frac{1}{s - m_Z^2} \to \frac{1}{s - m_Z^2 + i\Gamma_Z m_Z} .$$

- This replacement affect on gauge amplitude gauge dependence.

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Theory

- The differential decay rate with respect to the Mandelstam variables s and t is given as

$$\frac{d\Gamma}{ds\,dt} = \frac{3}{512\pi^3 m_H^3} s\left(t^2|b_1|^2 + u^2|b_2|^2\right) .$$

- It is more appropriate to consider the decay distribution with respect to E_γ, the photon's energy in the Higgs boson rest frame:

$$\frac{d\Gamma}{dE_\gamma\,dt} = 2m_H \frac{d\Gamma}{ds\,dt}\bigg|_{s\to m_H^2 - 2m_H E_\gamma} .$$

Phenomenology

Phenomenology

- The total decay rate

$$\Gamma(H \to \nu\bar{\nu}\gamma) = 1.33\,\text{keV}\,,$$

  where a minimal cut of $E_\gamma > 5\,\text{GeV}$ is implemented, with a negligible impact on the result.

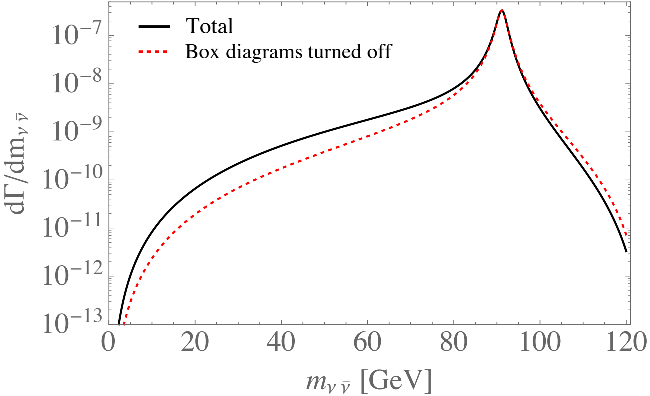
- The branching ratio of this process is

$$BR(H \to \nu\bar{\nu}\gamma) = 3.2\, \cdot 10^{-4}\,.$$

- The narrow width approximation (NWA),

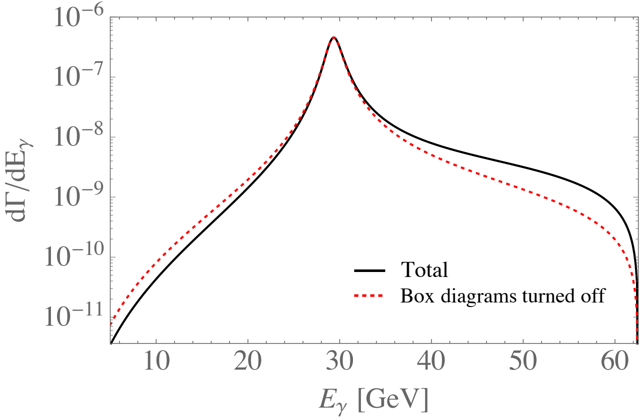
$$\Gamma_{\text{NWA}} = \Gamma(H \to Z\gamma) \cdot BR(Z \to \nu\bar{\nu}) = 1.31\,\text{keV}\,.$$

Phenomenology



Differential decay rate with respect to the invariant missing mass of the neutrino pair with all three neutrino flavors included.

Phenomenology



Differential decay rate with respect to the photon energy in the Higgs boson rest frame.

Phenomenology

- The non-resonant contributions have a notable effect in the off-shell region associated with high-energy photons. The total rate over E_γ in the range $(40, \text{GeV}, m_H/2)$ is

$$\Gamma[40\,\text{GeV}, m_H/2] = 7.0 \cdot 10^{-2}\,\text{keV}\,.$$

- Decay rate in this region without box-diagrams is

$$\Gamma[40\,\text{GeV}, m_H/2]\Big|_{\text{non-box}} = 3.4 \cdot 10^{-2}\,\text{keV}\,.$$

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Conclusion

Conclusion

- New result for the decay rate $\Gamma(H \to \nu\nu\gamma) = 1.33$ keV that is closer to the NWA $\Gamma_{NWA} = 1.31$ keV, if compare with previous results $\Gamma(H \to \nu\nu\gamma) = 1.65$ keV (arXiv:2106.14466[hep-ph]) $\Gamma(H \to \nu\nu\gamma) = 1.41$ keV (arXiv:1310.8404[hep-ph]).
- Analysis of box diagram contribution.
- A simple analytical result.