Higgs in Quark Gluon Plasma

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The Higgs boson in the standard model with a mass of 125 GeV [1] has a very low decay width of 4 MeV. Thus the lifetime of 50 fm is much larger than QCD time scale of 1 fm (say) whereas the lifetime of the QGP created in relativistic heavy-ion collisions is 10 fm. Interaction of Higgs with partons through coupling with quarks and gluons in the QCD medium which is the topic of discussion for Future Circular Collider [2], where non-negligible impact of QCD medium may be faced by Higgs.

The particles in the standard model acquire mass through the Higgs mechanism. Spontaneous symmetry breaking is the background theory governing Higgs mechanism. Starting from massless field of Lagrangian density with a Mexican hat potential, given by Fig. 1, the standard methodology of Higgs mechanism provide a mass to the field, when system choose one of the degenerate vacuum expectation value via spontaneous symmetry breaking.

When Higgs mechanism is applied in quantum chromodynamics (QCD) sectors with a vacuum expectation value $v = 246$ GeV for building the current quark masses (m_q), we get an Yukawa type Higgs-Quark interaction

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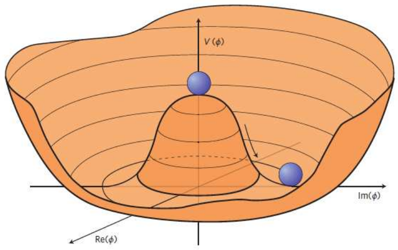

FIG. 1: A sketch of Mexican Hat type potential $V(\phi)$, having degenerate vacuums, one of which is chosen during the spontaneous symmetry breaking in Higgs mechanism.

Lagrangian density,

$$\mathcal{L}_{Hq\bar{q}} = -\frac{m_q H \psi_q \bar{\psi}_q}{v} , \quad (1)$$

from where $H \rightarrow q\bar{q}$ decay channel can be estimated. Using finite temperature field theory, the Higgs self-energy for quark-anti-quark loop diagram

$$\Pi(q) = \int \frac{d^4q}{(2\pi)^4} L(k,q) D_k D_{k-q} \quad (2)$$

where

$$L(k,q) = \left(\frac{-im_q}{v}\right)^2 Tr[(\not{k}+m)(\not{k}-\not{q}+m)] = -\frac{4m_q^2}{v^2}\left[k^2 - \frac{q^2}{2} + m^2\right] \quad (3)$$

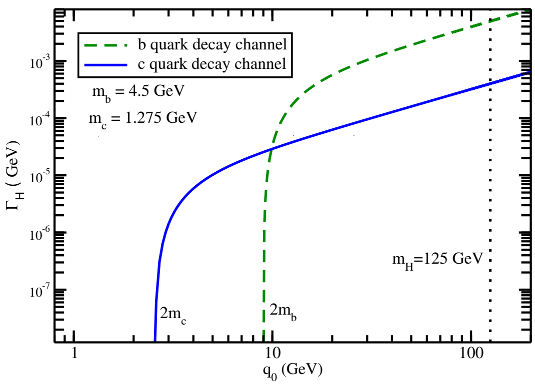

FIG. 2: off-mass shell distribution of vacuum widths for $H \to b\bar{b}$ and $H \to c\bar{c}$ decay channels.

and D_k , D_{k-q} are the scalar part of the quark propagator, having vacuum and thermal components. Collecting the vacuum part, we can estimate the vacuum decay width

$$\Gamma_{\rm Vac}(q_0) = \frac{1}{q_0}{\rm Im}\Pi(q_0, \vec{q} = 0) = \frac{m_q^2 q_0}{8\pi v^2}\Big[1 - \frac{4m_q^2}{q_0^2}\Big]^{3/2} , \quad (4)$$

which are plotted for c and b quarks in Fig. (2). The off-shell distribution of $H \to b\bar{b}$ and $H \to c\bar{c}$ starts from their respective threshold $2m_b$ and $2m_c$ but for on-shell value, we have to focus on $q_0 = m_H = 125$ GeV, which gives roughly $\Gamma_{\rm vac} = 4$ MeV, 0.4 MeV. Now collecting thermal components of propagators, we get the thermal correction,

$$\delta\Gamma = {\rm Im}\Pi(q_0 \approx m_H, \vec{q}, T) = \frac{m_q^2 m_H}{8\pi v^2 |\vec{q}|}\Big[1 - \frac{4m_q^2}{m_H^2}\Big] \int_{\omega^-}^{\omega^+} d\omega \Big[\frac{-1}{e^{\beta\omega} + 1} - \frac{1}{e^{\beta(m_H - \omega)} + 1}\Big] \quad (5)$$

with $\omega_k^{\pm} = \frac{1}{2}\Big[m_H \pm |\vec{q}|\sqrt{1 - \frac{4m_q^2}{m_H^2}}\Big]$. Numerical values of $\delta\Gamma$ is highly suppressed with respect to $\Gamma_{\rm Vac}$, as $m_H = 125$ GeV is very much larger than the temperature scale (even if we assume maximum value $T = 1$ GeV for FCC).

In this context, J. Ghiglieri, U. A. Wiedemann [3] have found $\frac{\delta\Gamma}{\Gamma_{\rm Vac}} \approx \left(\frac{T}{M_H}\right)^4 \approx 10^{-8}$ via operator product expansion (OPE) method, which is quite suitable for Higgs decay limit $m_H >> T$. Its background framework can be found in the pioneering work by Simon Caron Huot [4], who have used OPE [5] techniques to study the asymptotic of different spectral functions and stress tensors at finite temperature in the high-energy time-like region $q_0 >> T$.

There has also been a recent study by D. dEnterria, C. Loizides [6], who have considered approximately μb scattering cross section of Higgs-quark-gluon interaction, which exhibit a non-negligible in-medium effect of H, hopefully observed in FCC facilities.

The present calculation shows that standard thermal field theoretical calculation of $H \to q\bar{q}$ decay channels almost face a negligible thermal correction. As an alternative methodology of present study, a non-equilibrium effect of b and c quarks in Higgs decay width is our proposed plan, whose investigation is in progress. Here, by introducing a finite drag or diffusion in c or b quark propagators, we can get their non-equilibrium spectral function, and then plug in to field theoretical calculation of Higgs diagram, we might get some non-negligible in-medium effect of H.

References

[1] Abdelhak Djouadi, Phys. Rept. **457** (2008) , 1-216

[2] A. Dainese et al. arxiv:1605.01389 [hep-ph]

[3] J. Ghiglieri and U. A. Wiedemann, Phys. Rev. D**99** ,(2019) no. 5, 054002.

[4] S. Caron-Huot, Phys. Rev. D **79** (2009) 125009.

[5] K.G. Wilson, Phys. Rev. **179**, 1499 (1969); K.G. Wilson and W. Zimmermann, Commum. Math. Phys. **24** (1972) 87.

[6] David d' Enterria and C. Loizides, [arxiv:1809.06832[hep-ph]]