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Calculation of width of low mass Higgs-like particles

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In general there are 3 way to force new BSM particles interact with SM ones:

Gauge group,

Conserved quark/lepton vector current,

Higgs sector.

In the last case we have a new Higgs-like scalar that appears as a result of mixing the BSM scalar particle with SM Higgs. Here we consider the case when this particle has a few GeV mass and plays a role of mediator between SM and Dark Matter. We show that perturbative QCD allows a robust calculation of light scalar width and perform a matching with calculations in chiral model.

Amplitude of hGG interaction.

Interaction of scalar particle *h* with quarks

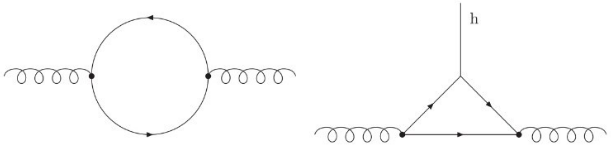
$$L = -\lambda \sum_q m_q h \bar{\psi}_q \psi_q \qquad \lambda = 1/vev \qquad in\ SM$$

leads to interaction of h with gluons

$$\mathcal{L}_{eff} = -\lambda h C_1 G_{\mu\nu} G^{\mu\nu}$$

Coefficient C_1 in $M_h << M_q$ limit can be presented by the formula (Chetyrkin 1998)

$$C_1 = -\frac{1}{2} \sum_{k>l} m_k^2 \frac{d \log(\alpha_l)}{d m_k^2}$$



where m_k are running MS-bar masses of heavy quarks, and *l* is the number of light quarks. For C_1 calculation we use $\alpha_{n-1}(\alpha_n)$ relations at flavor threshold. S

Mass variation leads to variation of flavor threshold

$$\frac{\delta \mu_n}{\mu_n} = \frac{1}{1 - 2\gamma_n(\mu_n)} \frac{\delta m_n}{m_n}$$

It leads to variation of α_n and α_{n-1} at $\mu+\delta\mu$

$$\delta \alpha_n = 2\beta_n(\mu_n) \delta \mu_n / \mu_n$$

$$\delta \alpha_{n-1} = 2 \frac{d\alpha_{n-1}}{d\alpha_n} \beta_n(\mu_n) \delta \mu_n / \mu_n$$

And then at μ

$$\delta \alpha_{n-1} = (2\beta_n(\mu_n) \frac{d\alpha_{n-1}}{d\alpha_n} - 2\beta_{n-1}(\mu_n)) \delta \mu_n / \mu_n$$

and finally at flavor threshold we get $$m_n^2 \frac{d\alpha_{n-1}}{dm_n^2}(\mu_n) = \frac{\frac{d\alpha_{n-1}}{d\alpha_n}\beta_n(\mu_n) - \beta_{n-1}(\mu_n)}{1-2\gamma_n(\mu_n)}$$

where we use $\beta_n(\mu)=\beta_n(\alpha_n(\mu))$, $\gamma_n(\mu)=\gamma_n(\alpha_n(\mu))$.

For other scales, because $$\delta\alpha_k(\mu_1) = \delta\alpha_k(\mu_2)\frac{\beta_k(\mu_1)}{\beta_k(\mu_2)}$$

$$m_n^2 \frac{d\alpha_{n-1}}{dm_n^2}(\mu) = \frac{\beta_{n-1}(\mu)}{\beta_{n-1}(\mu_n)} \frac{\frac{d\alpha_{n-1}}{d\alpha_n}(\mu_n)\beta_n(\mu_n) - \beta_{n-1}(\mu_n)}{1-2\gamma_n(\mu_n)}$$

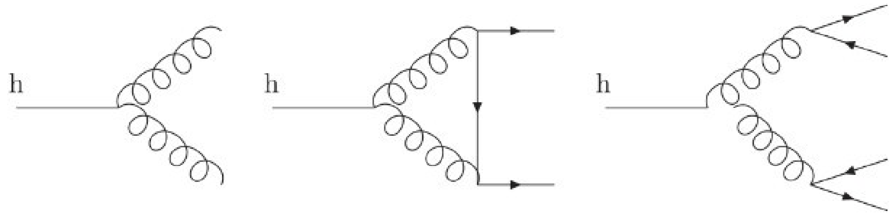
$$C_1 = -\frac{1}{2}\frac{\beta_{n-1}(\mu)}{\alpha_{n-1}(\mu)} \frac{\frac{d\alpha_{n-1}}{d\alpha_n}(\mu_n)\frac{\beta_n(\mu_n)}{\beta_{n-1}(\mu_n)} - 1}{1-2\gamma_n(\mu_n)}$$

For scalar whose mass is below than double mass of b-quark

$$C_1 \approx -\frac{1}{2}\frac{\beta_{n-2}(\mu)}{\alpha_{n-2}(\mu)}\frac{d\alpha_{n-2}}{d\alpha_{n-1}}\frac{\beta_{n-1}(\mu_{n-1})}{\beta_{n-2}(\mu_{n-1})} \frac{\frac{d\alpha_{n-1}}{d\alpha_n}(\mu_n)\frac{\beta_n(\mu_n)}{\beta_{n-1}(\mu_n)} - 1}{1-2\gamma_n(\mu_n)}$$

h→GG width

$$w_h = \frac{\lambda^2 C_1^2}{M_h} Im < O_1|O_1 > \quad \text{where} \quad Im < O_1|O_1 >= \frac{2M_h^4}{\pi} G(n_f, \alpha, M_h/\mu)$$



Both C_1 and $<0_1|O_1>$ depend on μ, but w_h – not. **To avoid μ dependence usually people express C_1 in terms of $\alpha_{n-1}(\mu)$.** It leads to cumbersome formulas.

The μ dependence of C_1 has the form β/α. If we'll use

$$w_{h\to gg} = \frac{2\lambda^2 M_h^3}{\pi} \tilde{C}_1^2 \tilde{G}(n_l, \alpha_{n_l}(M_h))$$

where $\tilde{C}_1 = \frac{\alpha}{\beta} C_1 \qquad \tilde{G}(n_l, \alpha) = \frac{\beta(\alpha)^2}{\alpha^2} G(n_l, \alpha, M_h/\mu) == \frac{\beta(\alpha)^2}{\alpha^2} G(n_l, \alpha, 1)$

then we can calculate $\hat{C}_1$ at high scale and avoid an appearance of cumbersome expressions. Also $\hat{G}(nl, \alpha)$ has to be calculated one time

$$\tilde{g}_5(\alpha) = \alpha^2(0.372215 + 1.769896\alpha + 3.940999\alpha^2 + 0.485222\alpha^3 - 27.595818\alpha^4)$$

$$\tilde{g}_3(\alpha) = \alpha^2(0.512938 + 2.988810\alpha + 10.265142\alpha^2 + 22.331087\alpha^3 + 17.871924\alpha^4)$$

Standard Model Mh=125GeV Higgs

$$\lambda = \sqrt{G_F\sqrt{2}}$$

$$w_h = \frac{4G_F M_h^3}{\sqrt{2}\pi} 1.7173 \cdot 10^{-5}$$

Herzog 2017 Difference with leading order - factor 2

$$w_h = \frac{4G_F M_h^3}{\sqrt{2}\pi} 1.7158 \cdot 10^{-5}$$

My calculation

Convergence for 2-GeV scalar

$$\lambda = \sqrt{G_F\sqrt{2}}$$

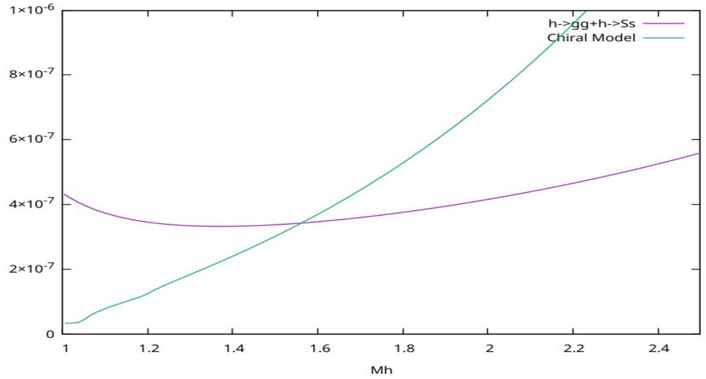
nLoop	α_h	$w[GeV]$
1	2.75E-01	4.25E-8
2	3.04E-01	1.55E-7
3	3.07E-01	2.80E-7
4	3.08E-01	3.68E-7
5	3.08E-01	3.94E-7

Difference with leading order - factor 9
Last correction – 7%

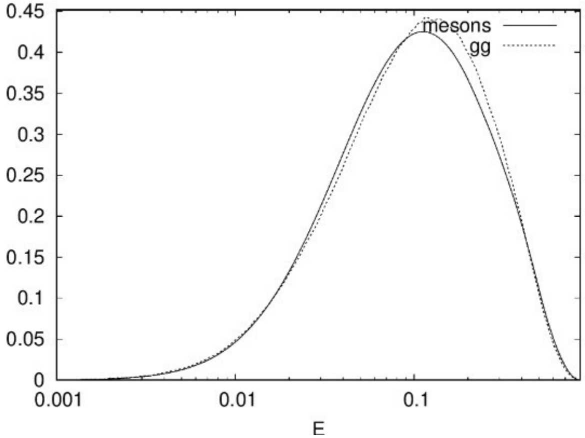
QCD and chiral model

$$L_{eff} = -h\lambda C_1 G_{\mu\nu}G^{\mu\nu} = -h\lambda \tilde{C}_1 \frac{\beta}{\alpha} G_{\mu\nu}G^{\mu\nu} = -2\lambda \tilde{C}_1 \Theta^\mu_\mu$$

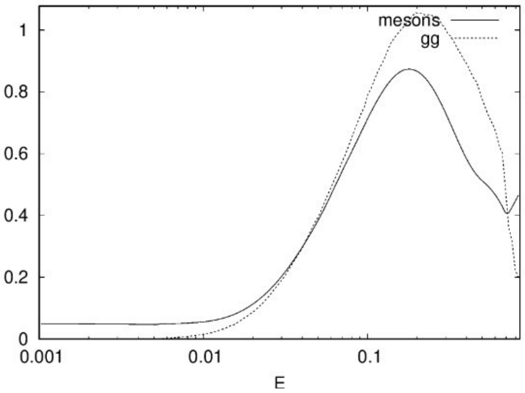
For massless scalars (π, K -mesons) $\Theta^\mu_\mu = \frac{1}{2}\partial_\mu\phi\partial^\mu\phi; \quad \lambda m_q \bar{\psi}\psi \;\rightarrow\; \frac{\lambda}{2} M_\phi^2 \phi^2$



Comparison of hadronization Glu,Glu state with Pythia with mesons decays in Chiral model



electrons



photons