Prospects for probing light Yukawa at future hadron colliders via HH production

Snowmass letter of intent

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In the Standard Model (SM), quark masses are generated via Yukawa interactions with the Higgs field

$$\mathcal{L}_y = -y^u_{ij}\overline{Q}^i_L\tilde{\phi}u^j_R - y^d_{ij}\overline{Q}^i_L\phi d^j_R + h.c.\,, \tag{1}$$

when the Higgs field acquires a non-vanishing vacuum expectation values v. The mass of the fermions are hence related to the Yukawa coupling $m_q = v g_{hq\bar{q}}$ (with $g_{hq\bar{q}} = y_q/\sqrt{2}$) thus fixing the value of the Higgs coupling to quarks. The unexplained mass hierarchy (the so-called "flavour-puzzle") hence resumes into a hierarchy in the Higgs couplings to fermions, see fig. 1. While the LHC so far is mostly probing the Higgs boson couplings to first and second generation quarks, New Physics (NP) models [1, 2] could potentially modify the couplings to first and second generations of quarks while addressing the flavour puzzle.

Due to the small couplings, the measurement of the Higgs coupling to the second and first generation quarks is though rather difficult. The best prospects can be obtained from a global fit, i.e. ref. [3] for the HL-LHC, finding

$$|\kappa_u| < 570\,, \quad |\kappa_d| < 270\,, \quad |\kappa_s| < 13\,, \quad |\kappa_c| < 1.2\,, \tag{2}$$

for $\kappa_i = g_{h\bar{q}_iq_i}/g^{SM}_{h\bar{q}_iq_i}$, where $g_{h\bar{q}_iq_i}$ denotes the Higgs coupling to $i = u, d, s, c$ quarks. One should note though that the prospective sensitivities hinge on the assumptions made for the extraction of the Higgs total width and are hence not completely model independent. It is hence desirable to obtain a direct bound on the Higgs couplings to first and second generation quarks. Diverse ideas have been discussed in the literature [4–9].

We propose to study Higgs pair production as a potential probe of light-quark Yukawa couplings. In ref. [10] we have demonstrated that indeed the Higgs pair production could be

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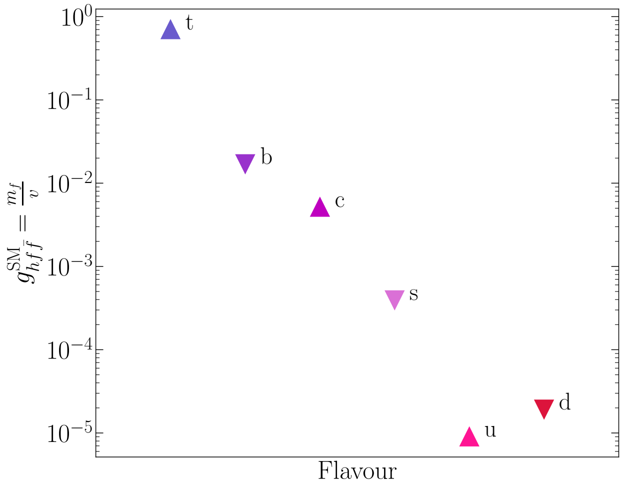

Figure 1: The hierarchy between the Yukawa couplings amongst the quark generations.

a competitive process for a direct measurement of Yukawa couplings of light flavours. This is due to an increased cross section due to a coupling of two fermions to two Higgs bosons which in the in the language of Standard Model effective field theory is connected to the coupling of one Higgs boson to fermions. Alternatively, in a non-linear effective description one can probe the couplings of two Higgs boson to quarks, which allows, combined with other measurements, to distinguish between a linear or non-linear effective description.

For Snowmass 21 we are interested in extending our study [10] to future collider options and confront with other direct measurements of the Higgs couplings to first and second generation quarks.

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