Probing light Yukawa at hadron colliders via HH production

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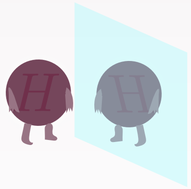
Knowns and unknowns about the Higgs

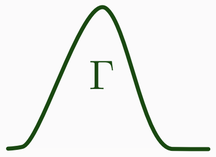
Properties

mass 124.94 GeV ATLAS, 1806.00242

spin 0 ATLAS 1506.05669

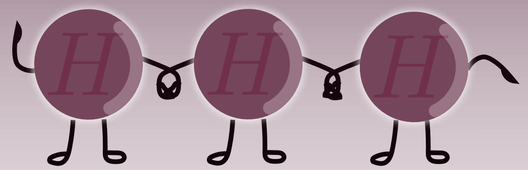


CP even mixture of CP even and odd is not fully excluded ATLAS 1506.05669



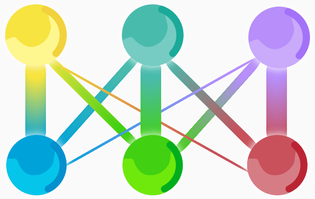
width $\Gamma < 3\Gamma_{SM}$

The LHC will not be able to measure the width better than this ATLAS 1808.001191



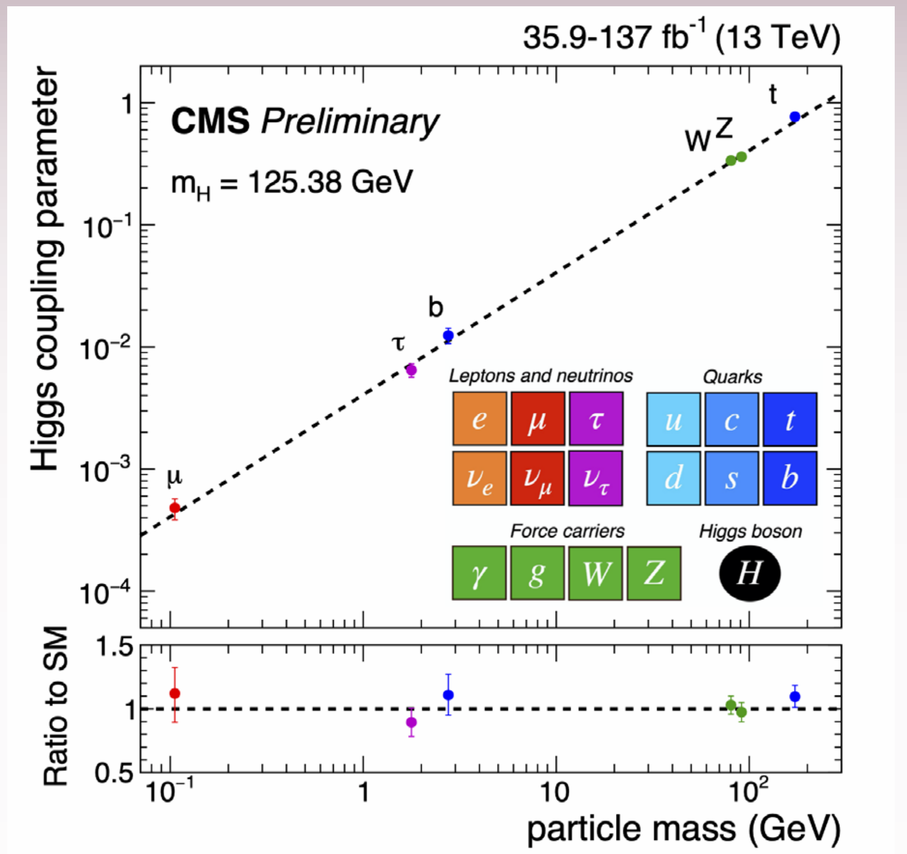
Not much is known about the trilinear coupling :(

$$g_{hX}^{SM} \sim M_X$$



Coupling to lighter quarks and quark mixing remains a puzzle !

Couplings



CMS-PAS-HIG-19-005

State of the art

Current bounds on 1st and 2nd gen. Yukawa, model-dependent global fit

$$|\kappa_u| \leq 570, \quad |\kappa_d| \leq 270, \quad |\kappa_s| \leq 13, \quad |\kappa_c| \leq 1.2$$ de Blas et al '19

Ways for *direct* measurement

- Higgs kinematics: Higgs+jet transverse momentum distribution
  [Bishara Haisch, Monni, Re '16;Soreq, Zhu, Zupan '16]
- Higgs decays to photon and vector mesons
  [Bodwin, Pietrello, Stoynev, Velasco '13; Kagan,Perez, Pietrello, Soreq, Stoynev, Zupan '14; Alte, König, Neubert '16 , ATLAS 1712.02758, CMS 2007.05122]
- Light flavour tagging
  [Perez, Soreq, Stamou, Tobioka '15; Brivio, Goertz, Isidori '15; ATLAS 1802.04329, CMS 1912.01662; Duarte-Campderros, Perez, Schlaffer, Soffer '18]
- Double Higgs production (Why ?)
  [L.A, R. Corral Lopez and R Gröber '19]

Direct measurement of light quark couplings, sensitive to non-linearities,
Simultaneous measurement of the trilinear coupling and light Yukawa !

SMEFT 101

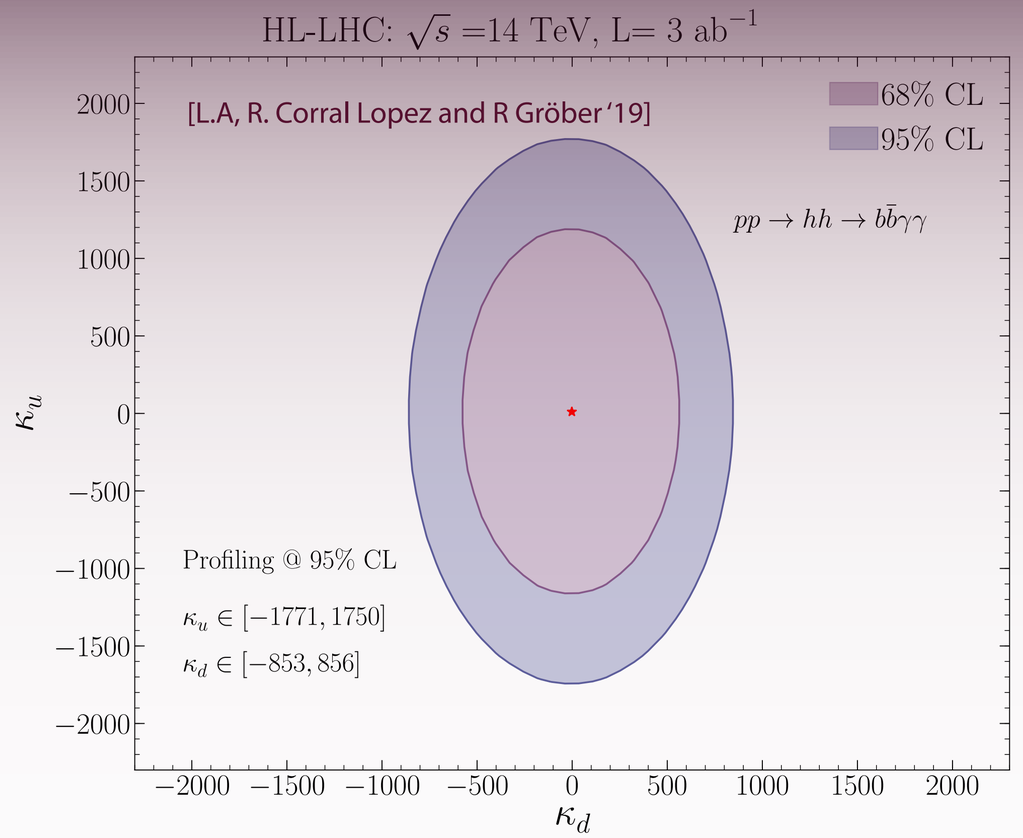
$$\mathscr{L}^{(6)} \supset \frac{C_{dH}}{\Lambda^2}\,(H^\dagger H)\,\bar{d}_L H d_R + \frac{C_{uH}}{\Lambda^2}\,(H^\dagger H)\,\bar{u}_L \tilde{H} u_R + \text{h.c.}$$

$$\Downarrow$$

$$g_{h\bar{q}q} = \kappa_q\, g^{SM}_{h\bar{q}q}$$

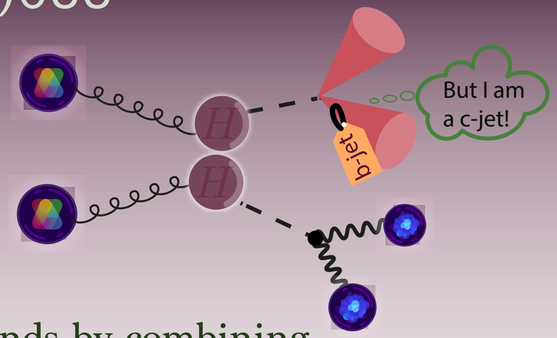
$$g_{hh\bar{q}q} = -\frac{2}{2\sqrt{2}v}(1-\kappa_q) g^{SM}_{hh\bar{q}q}$$

Previous work (prospects for HL-LHC) JHEP 11 (2019)088



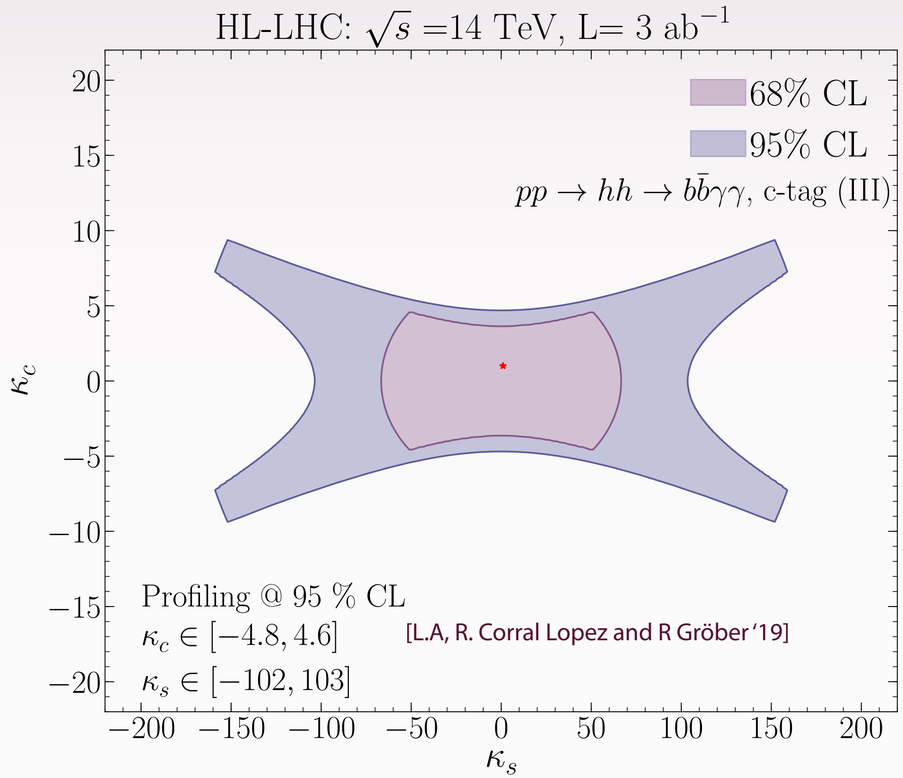
We studied the process

$$pp \to hh \to b\bar{b}\gamma\gamma$$

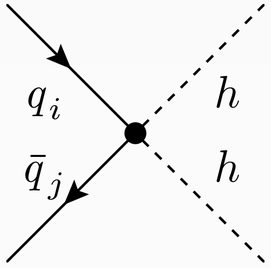


Improve 2nd gen. bounds by combining B-mis-tagging of c-jets and c-tagging, expanding the search to include also the process $pp \to hh \to c\bar{c}\gamma\gamma$

[Kim et al '16. Perez et al. '15 '16]



For enhanced 1st gen. Yukawa, the quark annihilation channel becomes dominant

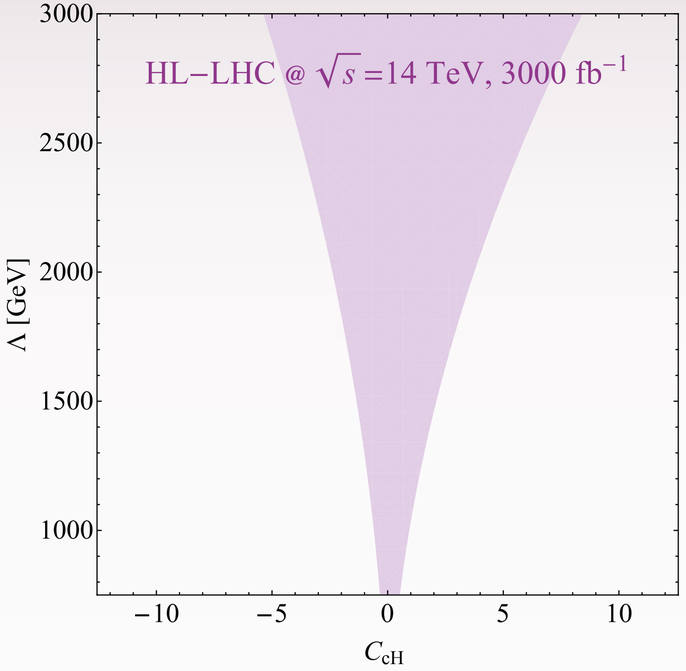


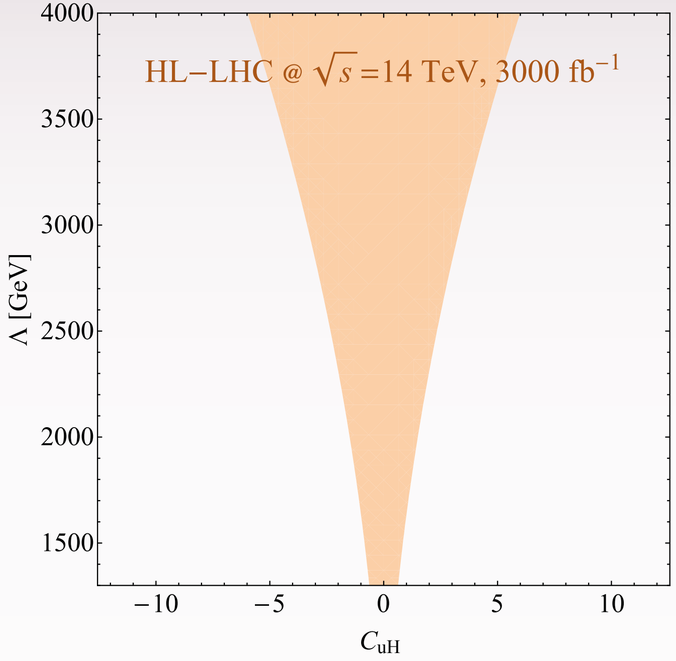
SMEFT bounds

How these bounds (in κ formalism) translate to SMEFT ?

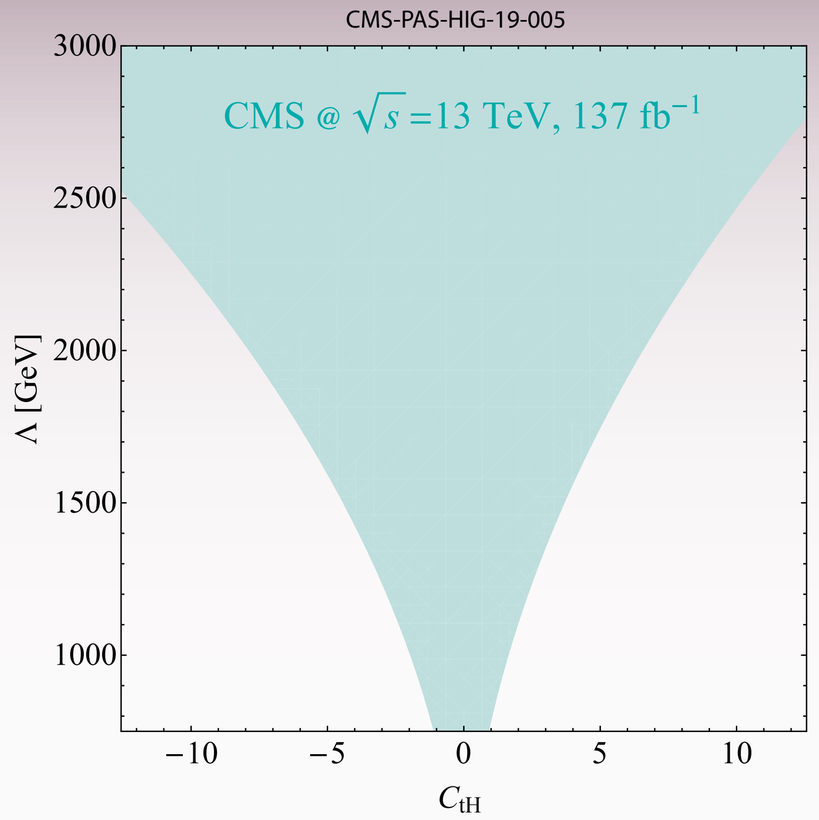
Plugging in our projected bounds for the HL-LHC

$$\frac{C_{qH}}{\Lambda^2} = \frac{\sqrt{2}\, m_q}{v^3}\,(1-\kappa_q)$$





Interesting for investigating NP models



Compared to the current top-Higgs coupling, the projected bounds are quiet good!

Next step: Future hadron colliders

Why probing light quark coupling to Higgs via HH in Future colliders ?

$$N = \int \mathcal{L} dt \cdot \sigma(pp \to hh) \cdot 2\mathcal{B}(h \to \gamma\gamma) \cdot \mathcal{B}(h \to b\bar{b}) \cdot \epsilon$$

- Expect higher luminocity in the future, with systematics dropping with $\left(\int \mathcal{L} dt\right)^{-\frac{1}{2}}$ Maybe improved efficiency and flavour tagging
- The cross-section scales like $\frac{\sigma(E_1)}{\sigma(E_2)} \sim \left(\frac{E_1}{E_2}\right)^2$ Future colliders will have higher energy!
- At higher eneries, the 2nd gen. quark PDF's become more abundant.

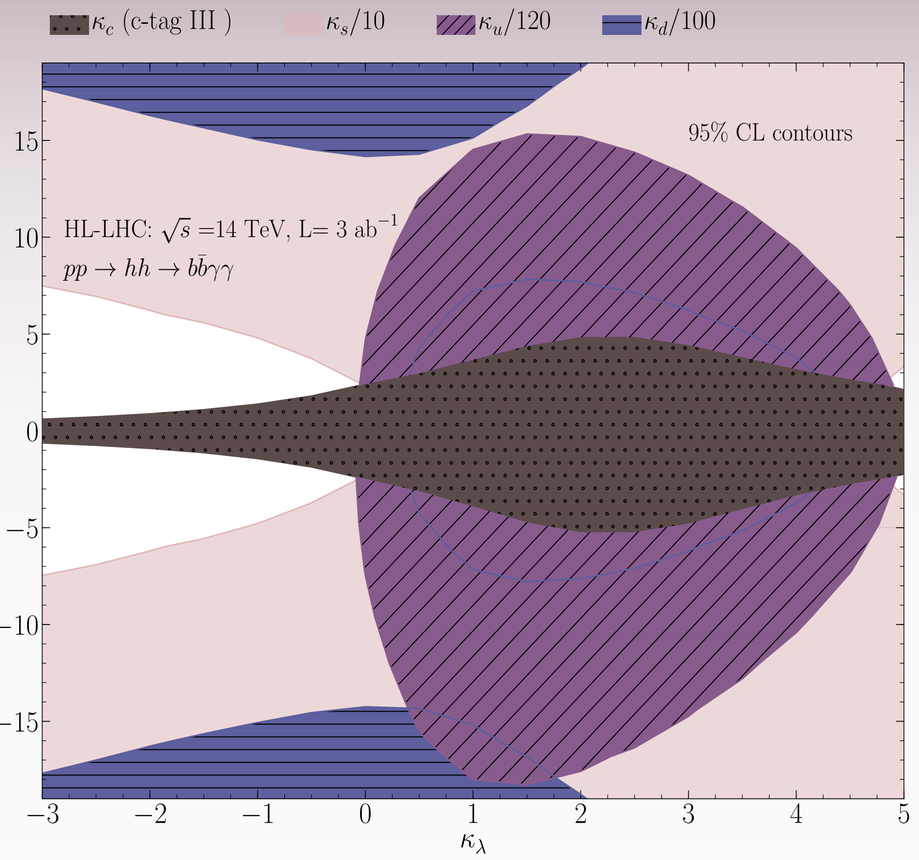
e.g. for a collider with E=27 TeV, we could expect 4 times more HH events that the HL-LHC

Back of the envelop projected bounds on 1st gen. $|\kappa_u| < 450, \quad |\kappa_d| < 212$

$\Rightarrow$ Many NP models could be probed by these colliders !

Backup plots

Probing non-linear couplings



Simultaneous fit