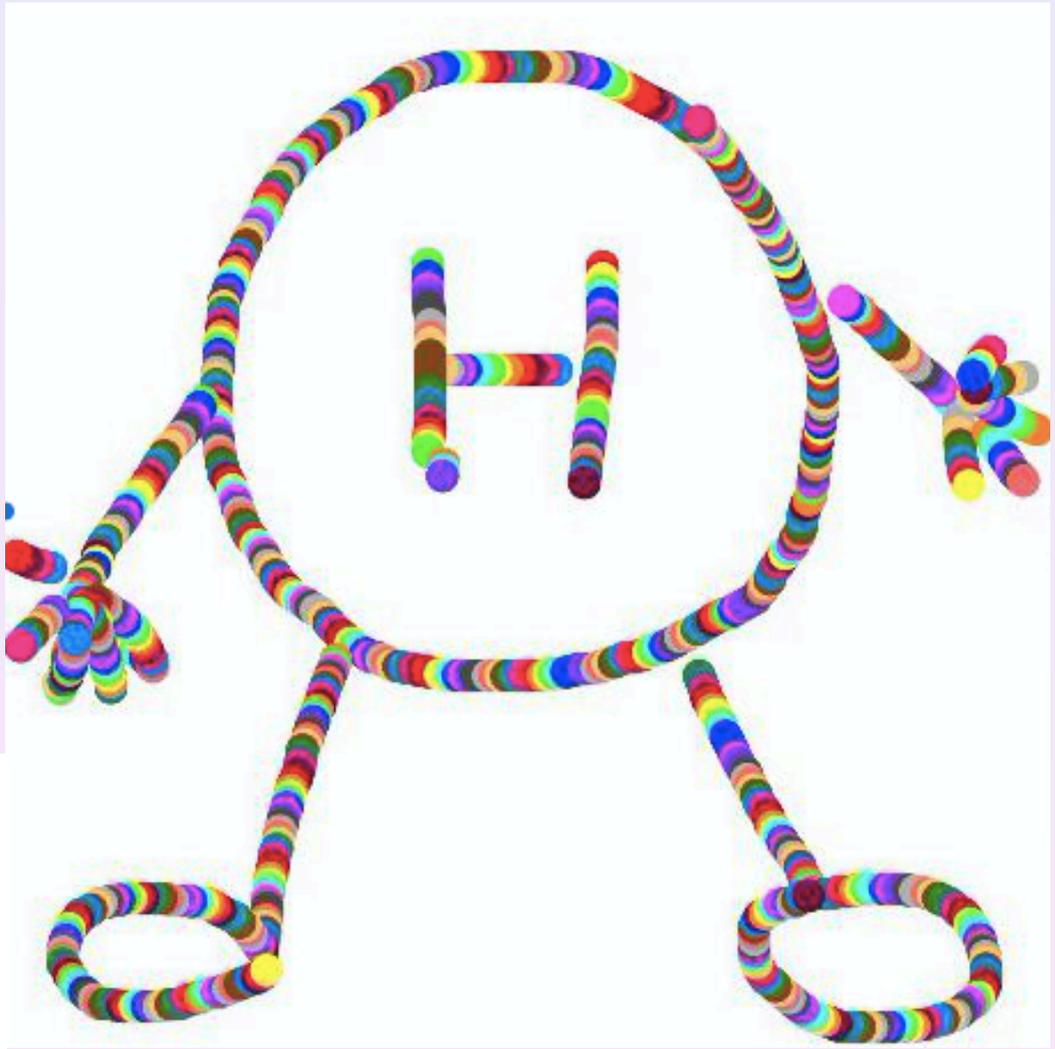
Probing light Yukawa couplings in Higgs pair production

Ramona Gröber

based on work with L. Alasfar and
R. Corral Lopez, JHEP 11 (2019)088



07/08/2020

Light quark Yukawa couplings

HL-LHC prospects for measurement of 1st and 2nd generation quark Yukawa couplings

$\kappa = y_q / y_q^{SM}$

[de Blas, Cepeda, d'Hondt et al '19]

$$|\kappa_u| \leq 570, \qquad |\kappa_d| \leq 270, \qquad |\kappa_s| \leq 13, \qquad |\kappa_c| \leq 1.2$$

global fit, not completely model-independent

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Alternative ways:

- 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]

- Charm tagging (strange tagging at lepton colliders)

[Perez, Soreq, Stamou, Tobioka '15; Brivio, Goertz, Isidori '15; ATLAS 1802.04329, CMS 1912.01662; Duarte-Campderros, Perez, Schlaffer, Soffer '18]

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In this talk: explore the potential of Higgs pair production for measuring the light quark Yukawa couplings

SMEFT

$$\mathscr{L}_{SM} \supset -y^u_{ij}\bar{Q}^i_L\tilde{\phi}u^j_R - y^d_{ij}\bar{Q}^i_L\phi d^j_R + h\,.\,c\,.$$

At dim-6 level the Higgs couplings to fermions are modified by the operator

$$\mathscr{L}_{dim\,6} \supset \frac{c^u_{ij}}{\Lambda^2}(\phi^\dagger\phi)\bar{Q}^i_L\tilde{\phi}u^j_R + \frac{c^d_{ij}}{\Lambda^2}(\phi^\dagger\phi)\bar{Q}^i_L\phi d^j_R + h\,.\,c\,.$$

Couplings:

$$g_{h\bar{q}_iq_j} = \frac{m_{q_i}}{v}\delta_{ij} - \frac{v^2}{\Lambda^2}\frac{c^q_{ij}}{\sqrt{2}}$$

$$g_{hh\bar{q}_iq_j} = -\frac{3}{2\sqrt{2}}\frac{v^2}{\Lambda^2}c^q_{ij}$$

direct coupling to Higgs pair

In the following consider only flavour diagonal case.

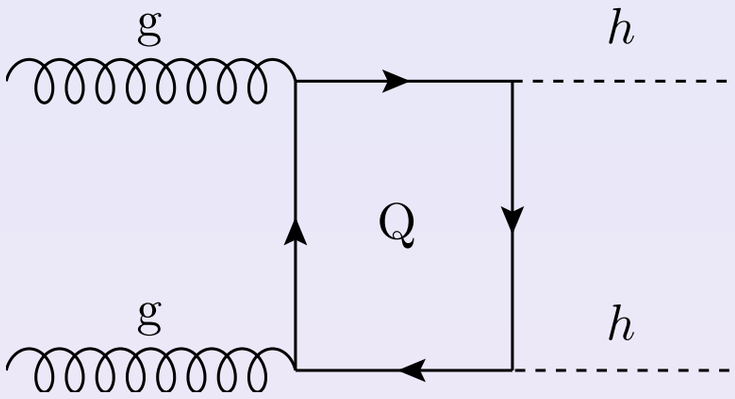
Notation:

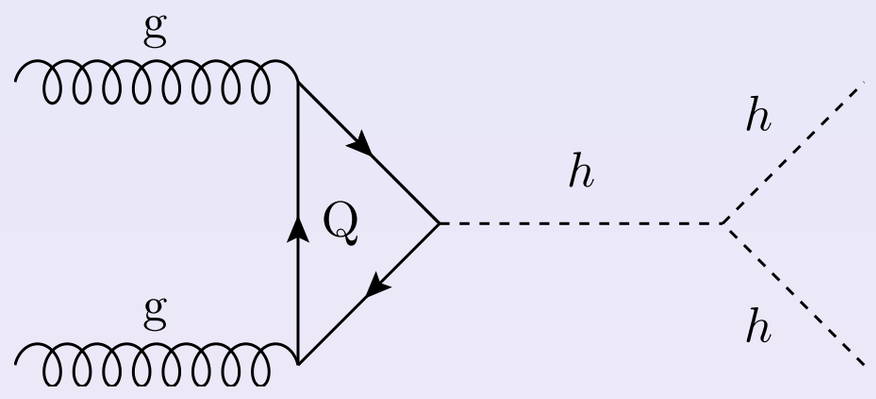
$$g_{h\bar{q}q} = \kappa_q g^{SM}_{h\bar{q}q}$$

$$g_{hh\bar{q}q} = -\frac{3}{2}\frac{1-\kappa_q}{v}g^{SM}_{h\bar{q}q}$$

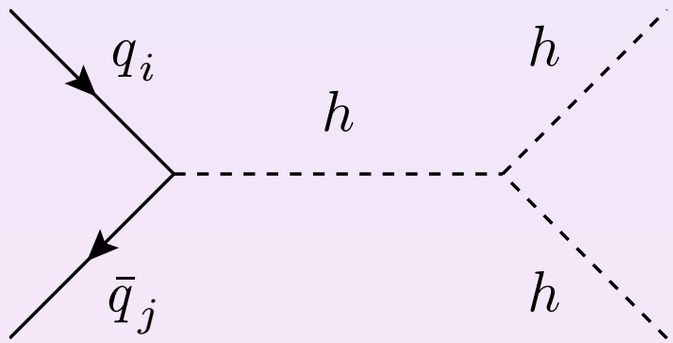
Higgs pair production

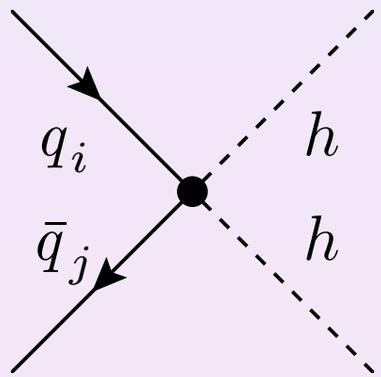
Higgs pair production in SM, gluon fusion dominated by heavy quark loops

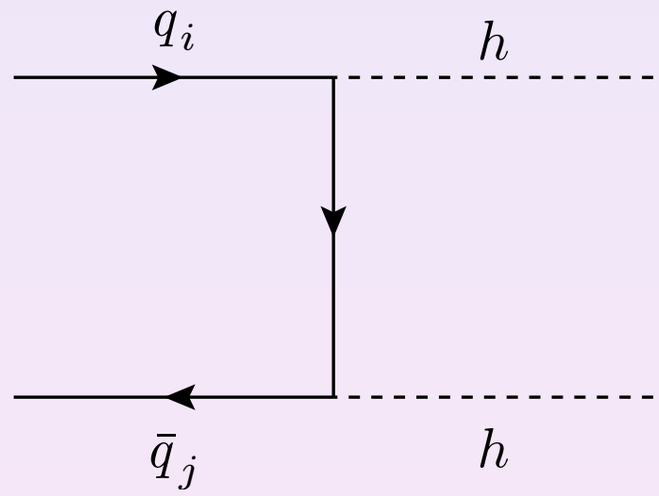




enhanced light Yukawa couplings

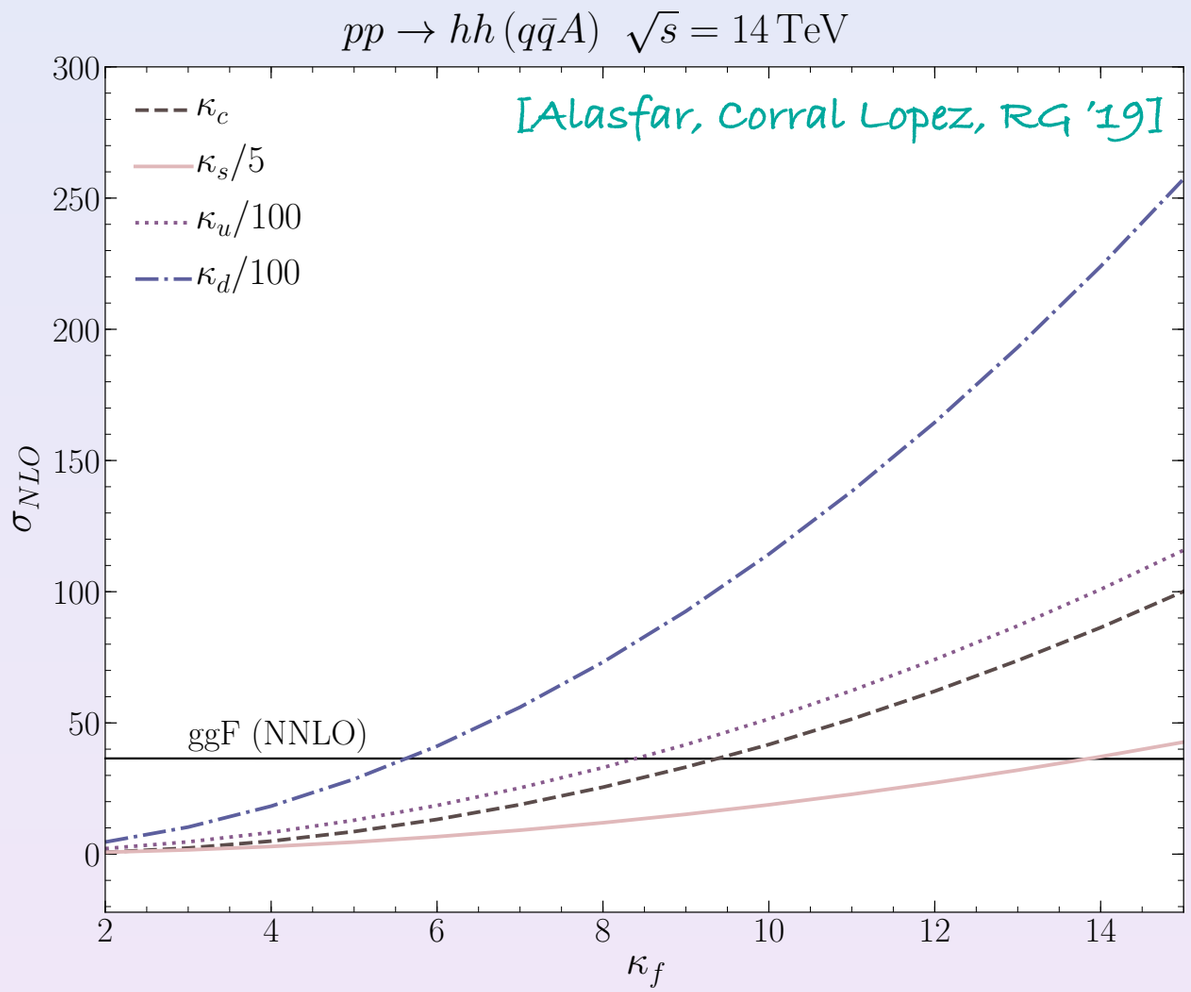




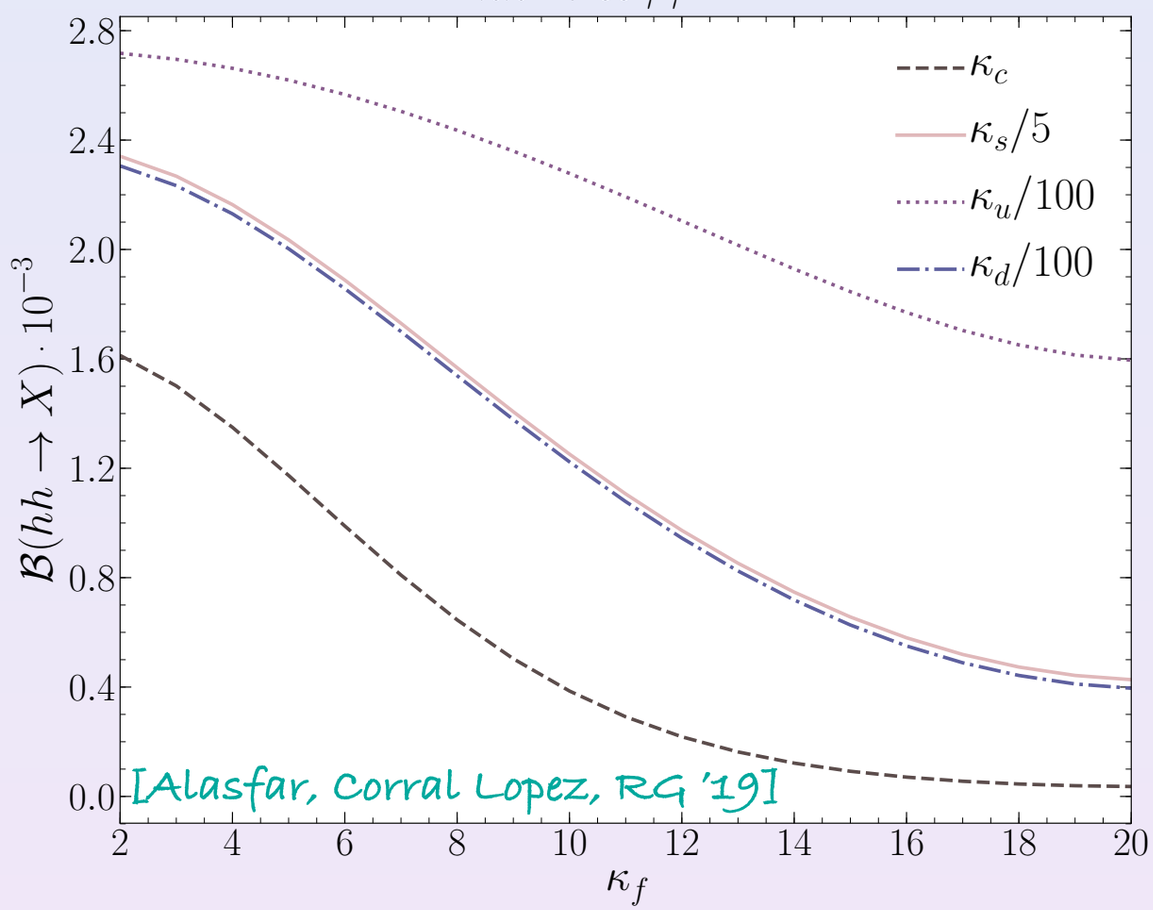


contribution most important for 1st generation (given the coupling limits)

Higgs pair production

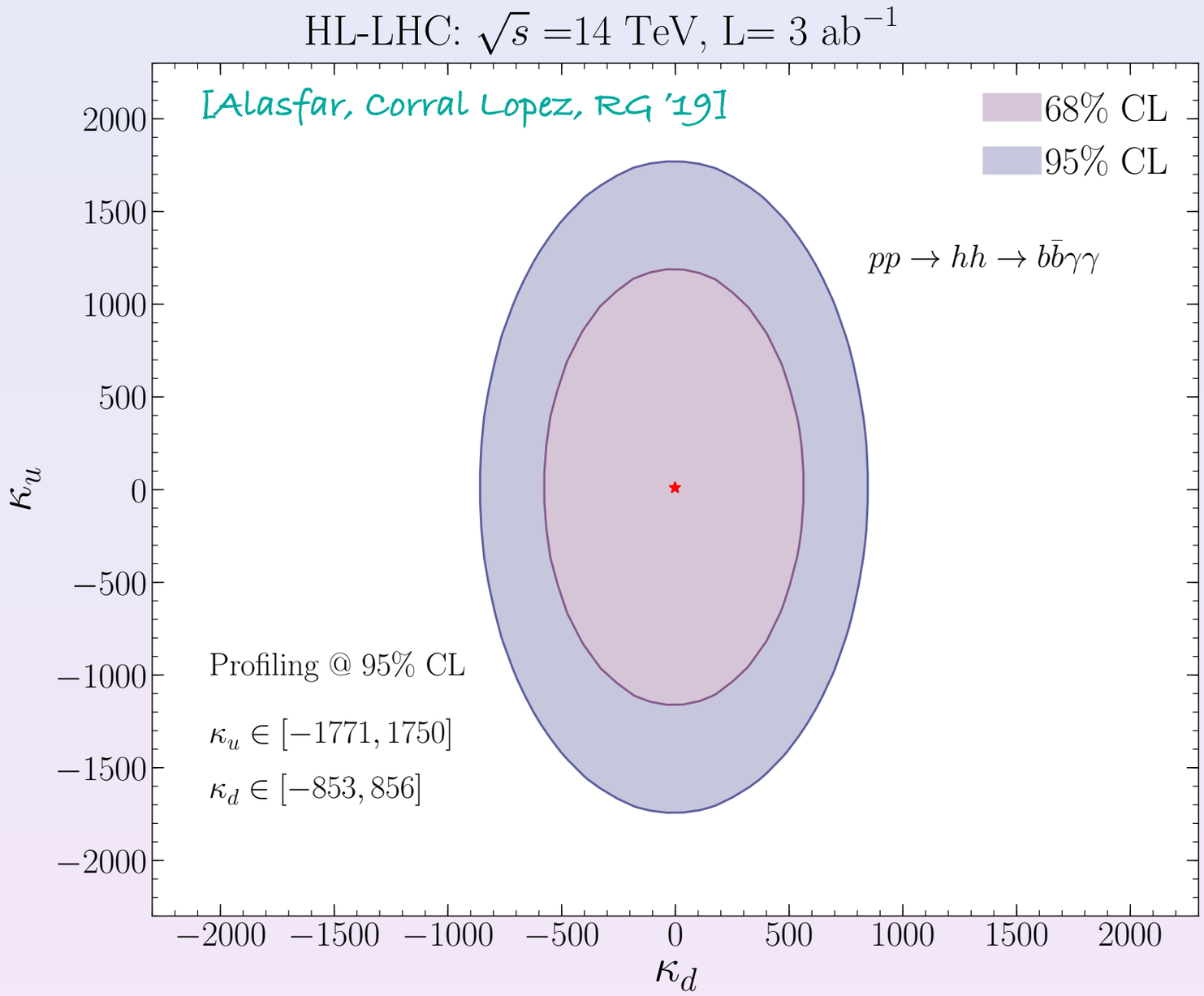


increase of cross section,
(also modified distributions)



decrease of BR for typical di-Higgs final state

Results 1st generation



Expected sensitivity likelihood fit for HL-LHC

Results comparable to other direct methods,
note that one can probe "non-linarities" in 1st/2nd generation

Results 2nd generation

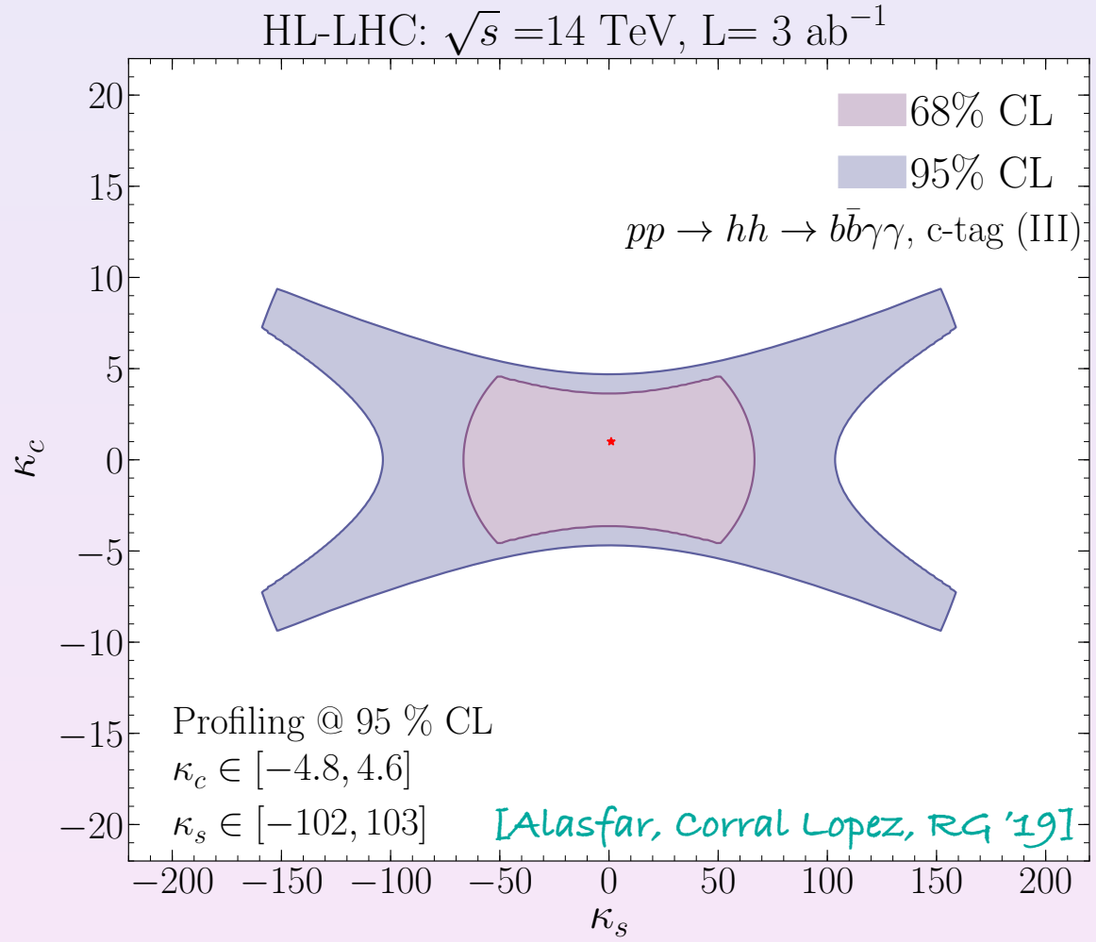
Making use of techniques applied in [Kim et al '16. Perez et al. '15 '16]

The final state $hh \to \bar{c}c\gamma\gamma$ can be probed making use of b-mistagging in $hh \to \bar{b}b\gamma\gamma$

$$\hat{\mu} = \frac{\sigma_{hh}\,\mathcal{B}_b\;\epsilon_{b1}\,\epsilon_{b2}\,\epsilon_f + \sigma_{hh}\,\mathcal{B}_c\,\epsilon_{b\to c,1}\,\epsilon_{b\to c,2}\,\epsilon_f}{\sigma_{hh}^{\rm SM}\,\mathcal{B}_b^{\rm SM}\,\epsilon_{b1}\,\epsilon_{b2}},$$

c-jet contamination of tagged b-jets

Not yet sufficient to obtain good sensitivity, introduce also c-tagging.



Conclusion

Higgs pair production can provide DIRECT bounds on light quark Yukawa couplings.

Increase of cross section due to $hh\bar{q}q$ coupling.

2nd generation: exploit charm tagging.

Study for snowmass:

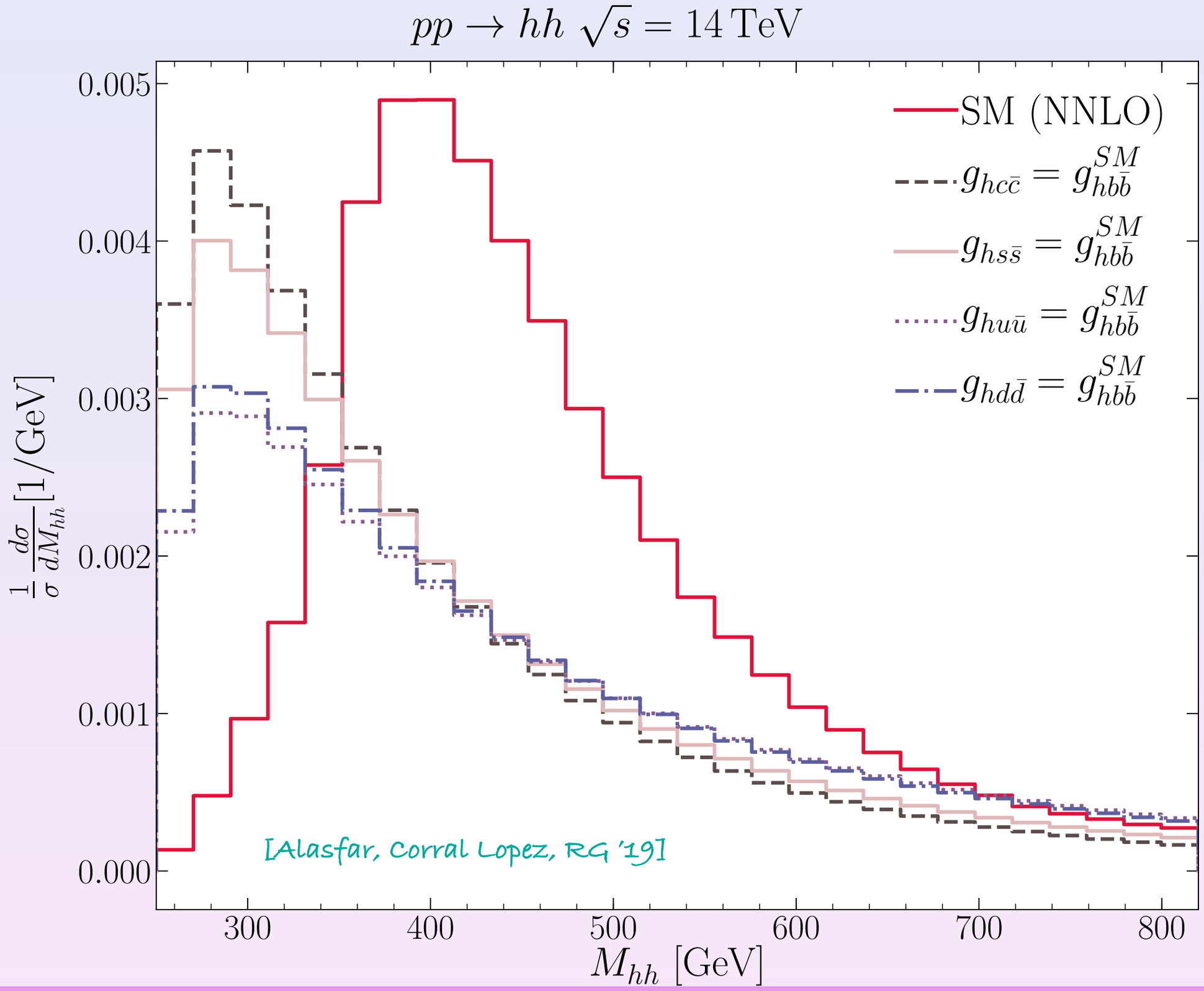
- Investigate future collider options
- Confront with other direct probes (Higgs+jet, ...)
- UV-models [see Samuels and Douglas talk today]

Thanks for your attention and:

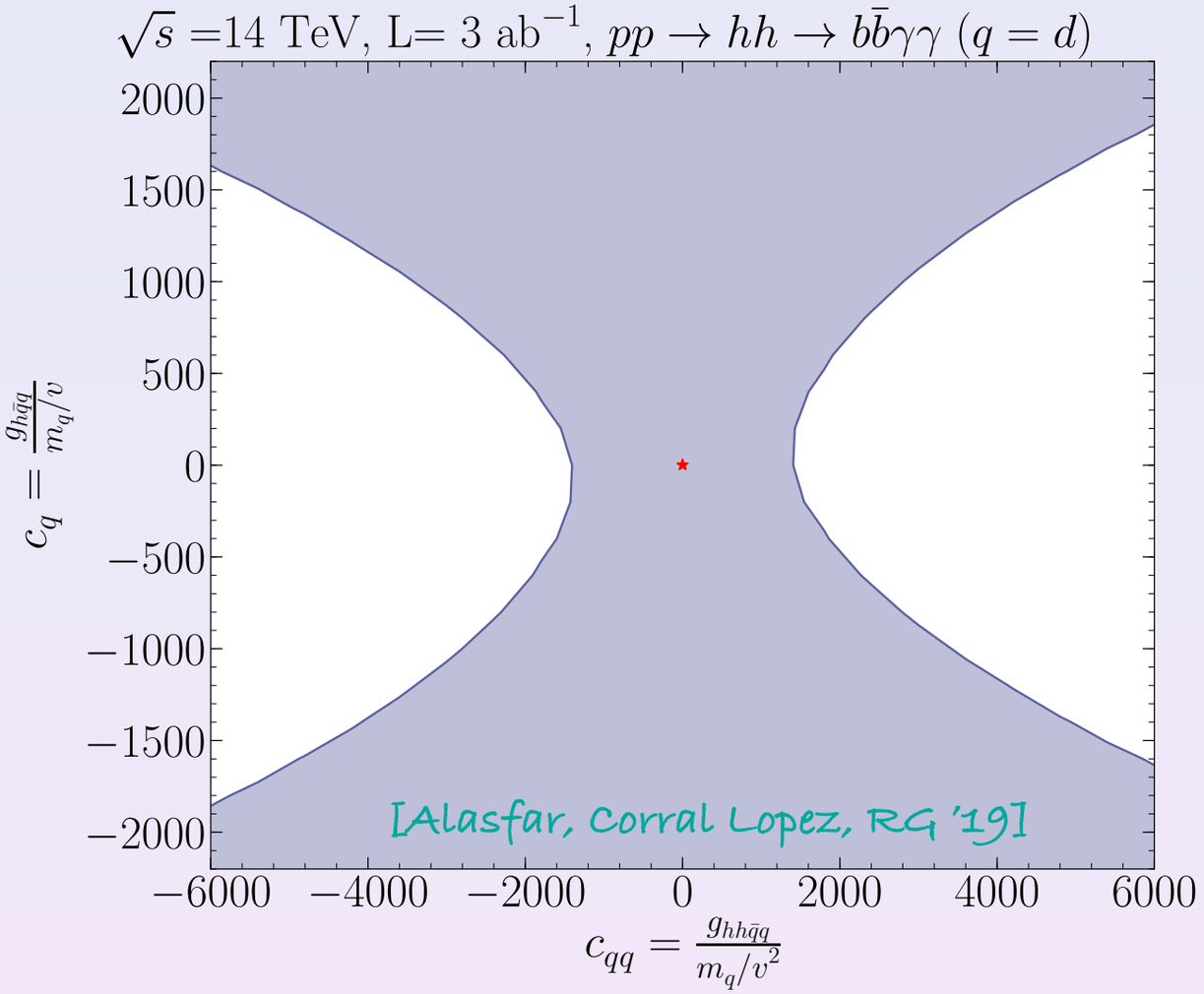
Let us know if you like to join forces!

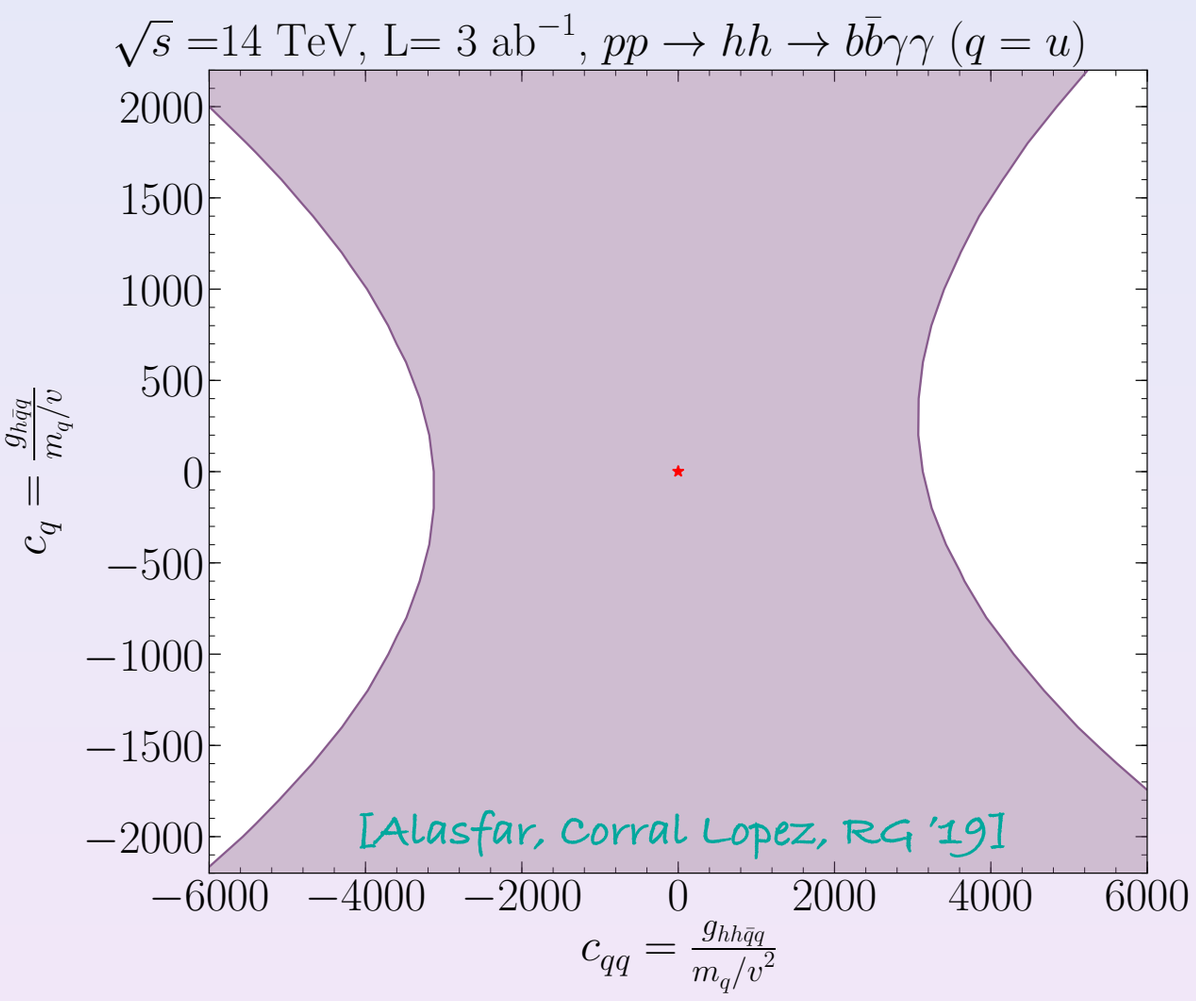
Backup

Invariant mass distribution



Non-linearities





$$-\mathcal{L} = \overline{q}_L \frac{m_q}{v}\left(v + c_q h + \frac{c_{qq}}{v}h^2 + \dots\right) q_R + h.c,$$

Di-Higgs can tell us if the Higgs behaves non-linearly

Charm tagging working points

c-tagging	ϵ_c	$\epsilon_{c \to b}$	$\mu_c(up)$ 95% CL
c-tag I	19%	13%	10.1
c-tag II	30%	20%	8.2
c-tag III	50%	20%	3.8

c-tag I based on ATLAS scharm analysis (1501.01325), c-tag I and II based on ATLAS-TDR-19 and ATLAS-PHYS-PUB-018-2015