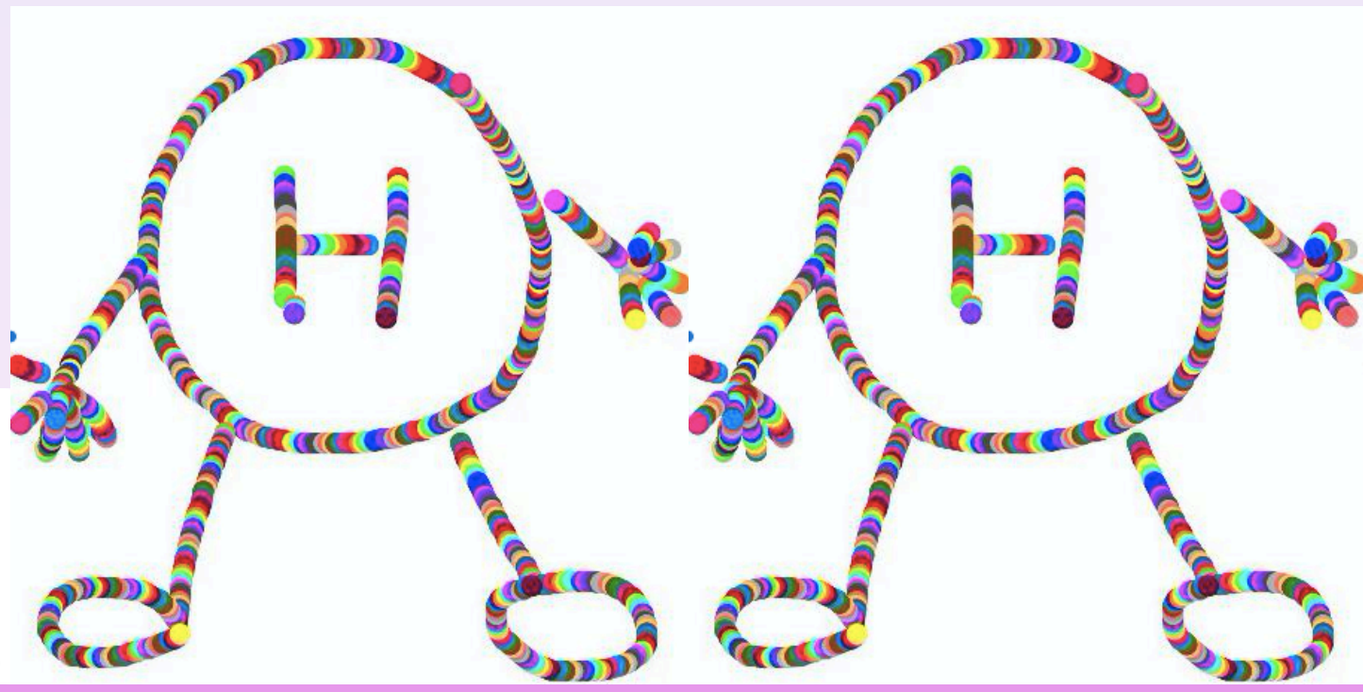
Towards HH in a global EFT fit

Ramona Gröber

talk based on discussions with various theory and experimental colleagues

08/06/2021



Outline

- Effective Field Theory for HH

- HH at NLO

- single Higgs production and global fit

Effective Theory for the Higgs boson

There exist two fundamentally different choices for an EFT.

SMEFT

The Higgs boson transforms in a SU(2) doublet. The Lagrangian contains all possible operators allowed by the symmetries. Ordering by operator dimension and suppression

$$(1/\Lambda)^n$$

leading Higgs deviations for n=2.

Different choices of operators connected by equations of motion. Warsaw basis

SILH basis

equivalent for HH

HEFT (or Electroweak Chiral Lagrangian)

Higgs transforms as gauge singlet.

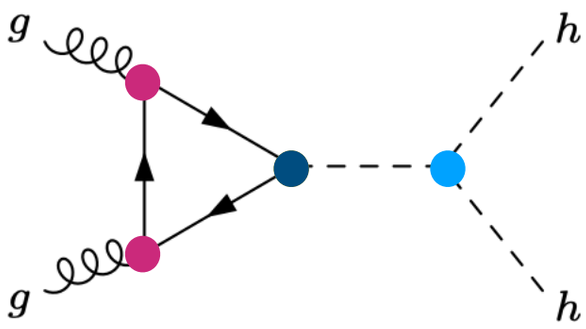
Based on chiral perturbation theory.

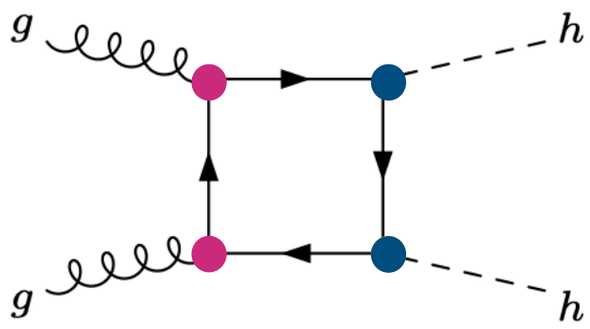
Ordering of operators not unique but for instance by chiral dimension.

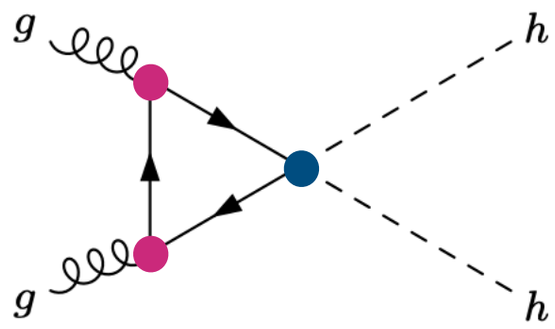
Effective Theory for HH

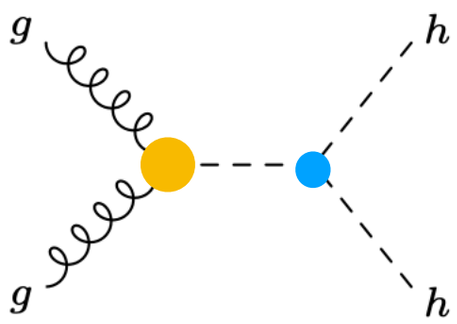
Status:

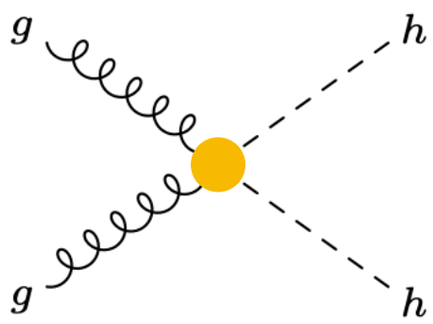
Predictions given only for variation of κ_λ

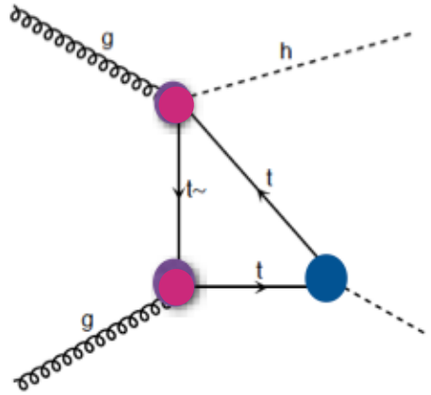












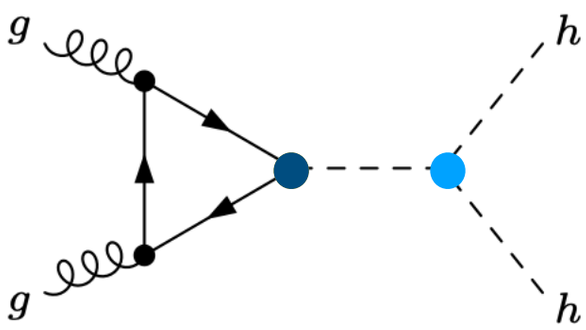
SMEFT:

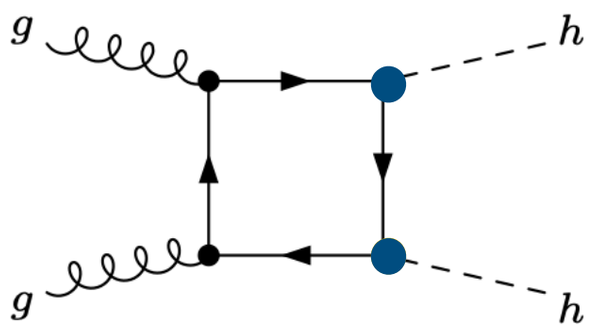
$$\mathscr{L} = \frac{c_H}{\Lambda^2}(H^\dagger \partial_\mu H)^2 + \frac{c_6}{\Lambda^2}|H|^6 + \frac{c_g}{\Lambda^2}|H|^2 G_{\mu\nu}G^{\mu\nu} + \frac{y_t c_y}{\Lambda^2}\bar{Q}_L \tilde{H} t_R |H|^2 + h.c. + \frac{c_{tG}}{\Lambda^2}\bar{Q}_L \sigma_{\mu\nu} T^a \tilde{H} t_R G^a_{\mu\nu} + h.c.$$

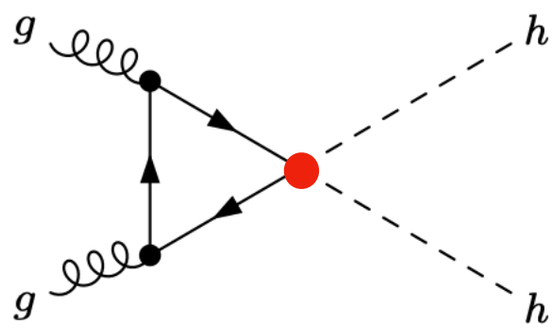
Effective Theory for HH

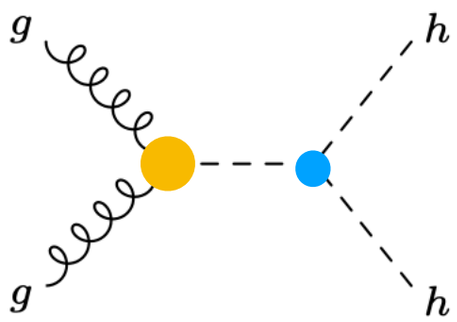
Status:

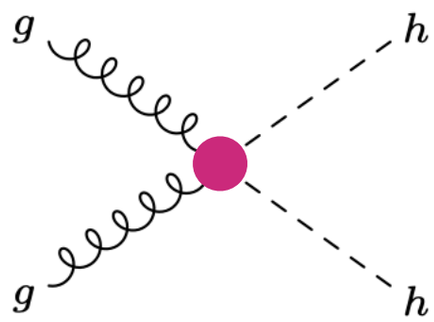
Predictions given only for variation of κ_λ











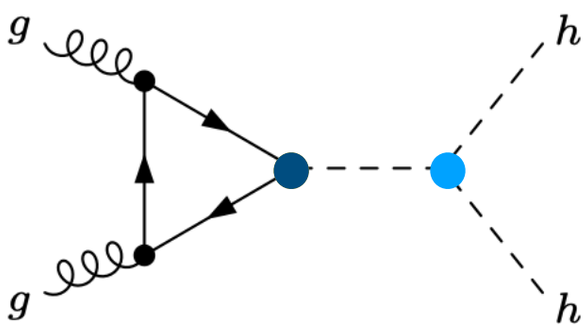
HEFT:

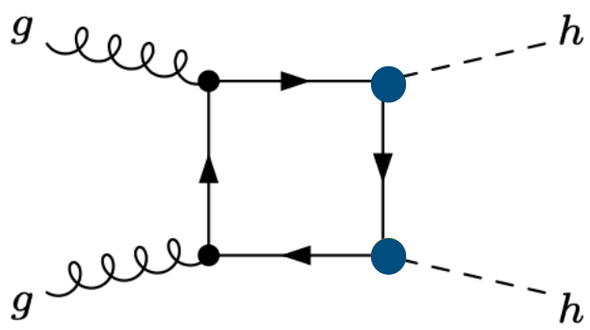
$$\mathscr{L} = -m_t \bar{t} t \left(c_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) + \frac{\alpha_s}{8\pi} \left(c_g \frac{h}{v} + c_{gg} \frac{h^2}{v^2} \right) G^{\mu\nu} G_{\mu\nu} + c_{hhh} \frac{m_h^2}{2v} h^3$$

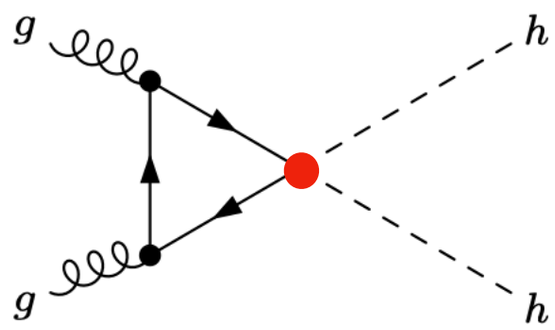
Effective Theory for HH

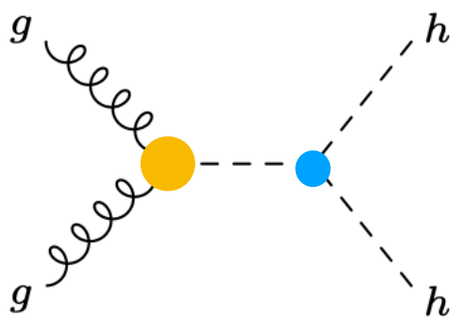
Status:

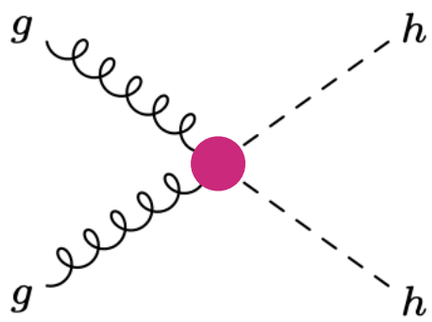
Predictions given only for variation of κ_λ











HEFT: two Higgs couplings only to be probed in HH

$$\mathscr{L} = -m_t \bar{t} t \left(c_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) + \frac{\alpha_s}{8\pi} \left(c_g \frac{h}{v} + c_{gg} \frac{h^2}{v^2} \right) G^{\mu\nu} G_{\mu\nu} + c_{hhh} \frac{m_h^2}{2v} h^3$$

HEFT/SMEFT for HH?

HEFT

⊕ NLO results available

[Buchalla et al '18; Heinrich et al '20]

⊕ di-Higgs is THE place to probe differences in one or two Higgs couplings

⊖ many more couplings only in HH: degeneracies?

⊖ UV models that don't linearise to SMEFT?

SMEFT

⊕ contains dipole operator (which by power counting is expected to be of higher order though)

⊕ Combination with single Higgs fits simpler

HH at NLO

HH production has large QCD corrections

Complicated to compute due to various mass scales.

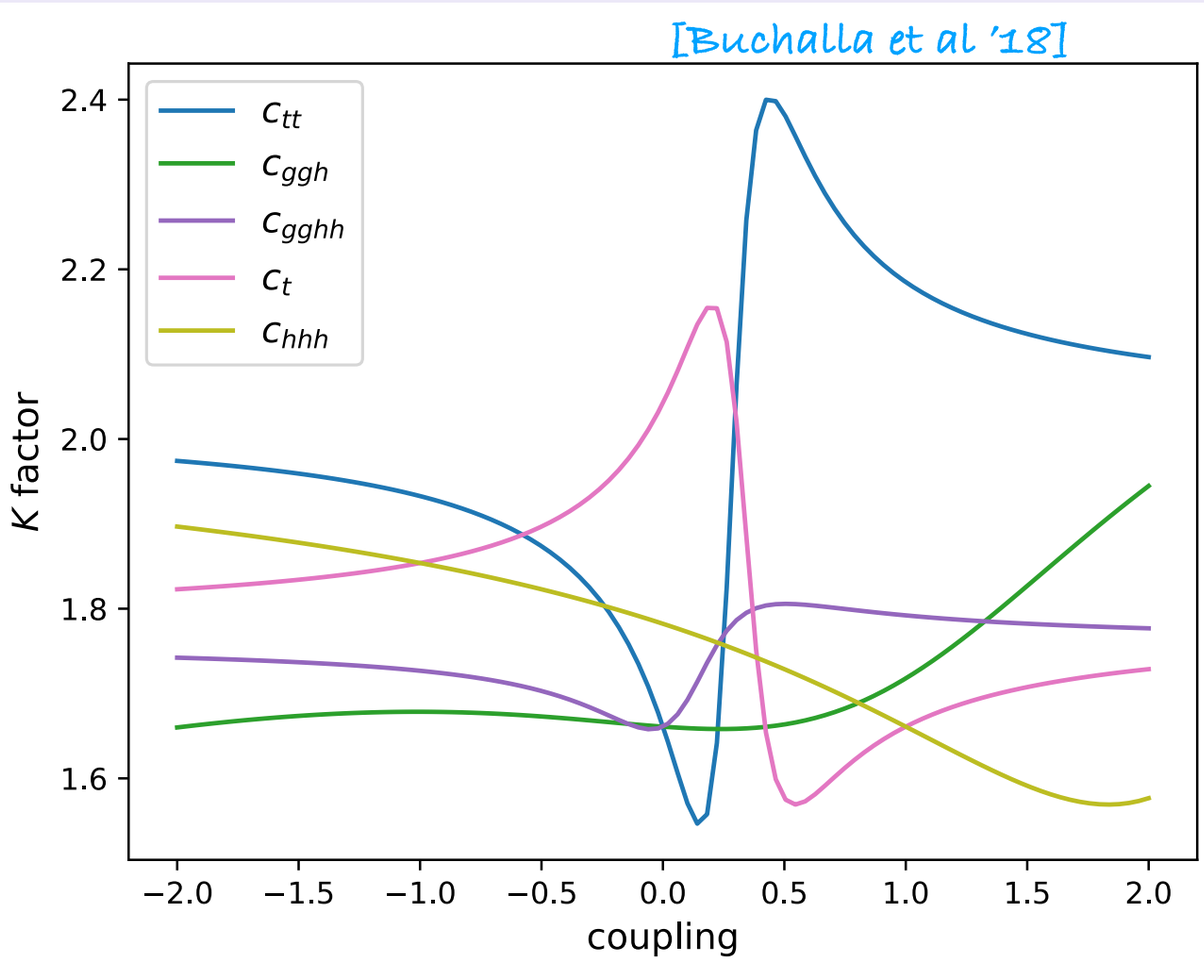
Full top mass dependent computations for NLO QCD available numerically.

[Borowka et al. '16, Baglio et al. '19]

POWHEG implementation of HEFT HH @ NLO QCD available.

[Buchalla et al '18; Heinrich et al '20]

[Buchalla et al '18]



Strong dependence on EFT coefficient!

Problem:

Uncertainties to be understood:

- large m_t renormalization scheme uncertainty
  [Baglio et al. '19, Baglio et al. '20]
- intrinsic uncertainty from numerical evaluation

HH at NLO

HH production has large QCD corrections

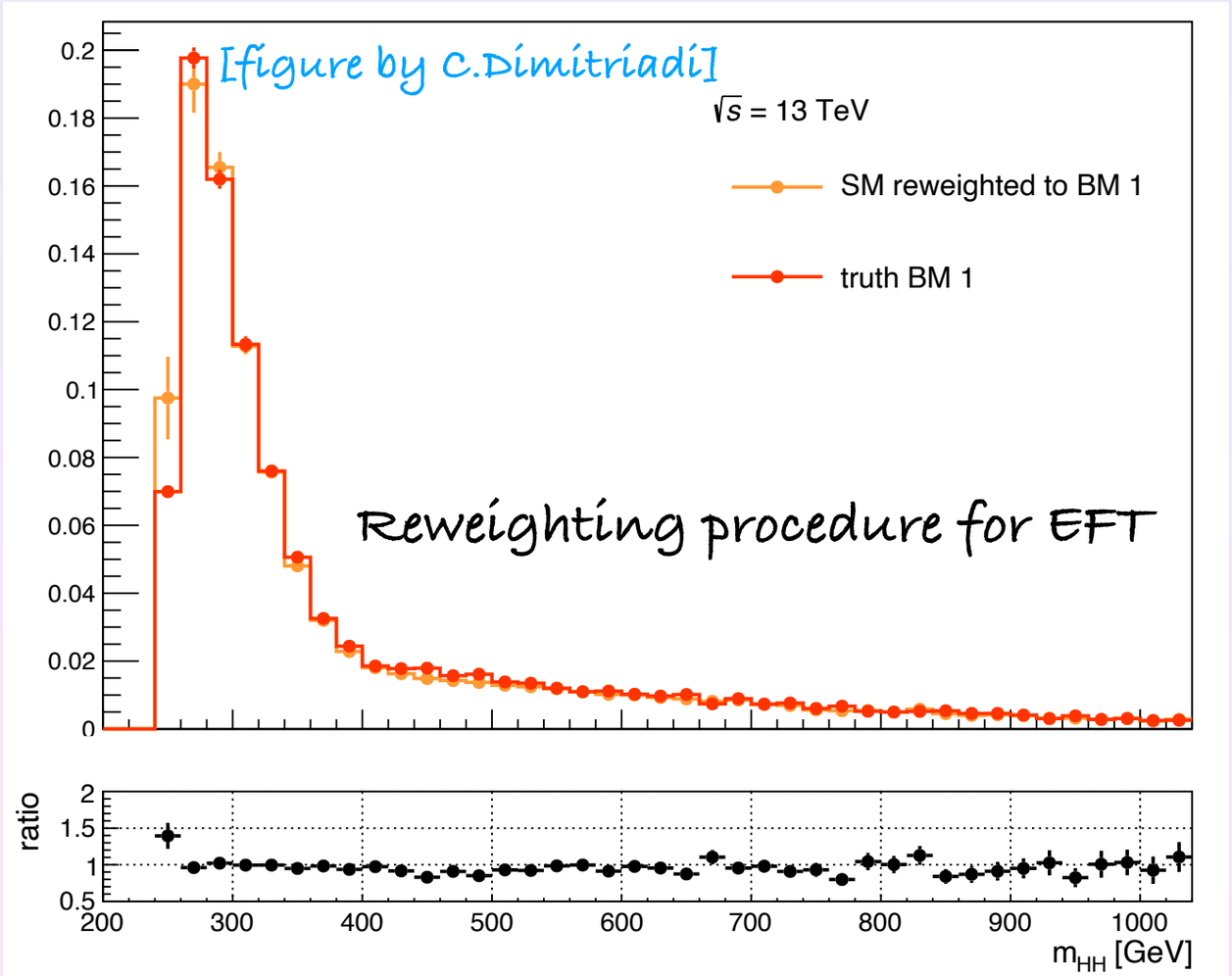
Complicated to compute due to various mass scales.

Full top mass dependent computations for NLO QCD available numerically.

[Borowka et al. '16, Baglio et al. '19]

POWHEG implementation of HEFT HH @ NLO QCD available.

[Buchalla et al '18; Heinrich et al '20]



Recommendations on the way

[Alasfar, Cadamuro, Dimitriadi, Ferrari, RG, Heinrich, Lang, Ördek, Pereira Sanchez, Scyboz]

Benchmarks by [Carvalho, Dall'Osso, Dorigo, Goertz, Gottadro '15]

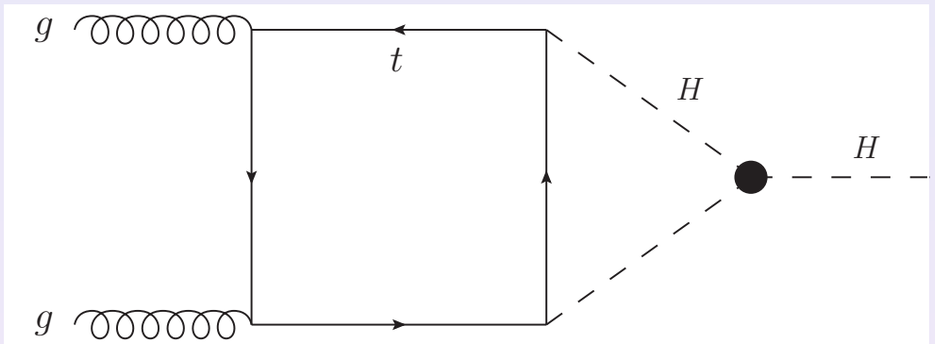
EFT Single Higgs production

Single Higgs production provides bounds to the single Higgs couplings

We do not expect that HH can improve on them (though maybe for degeneracies)

[Gillioz, RG, Grojean, Mühlleitner, Salvioni '12, Azatov, Contino, Panico, Son '15, Azatov, Grojean, Paul, Salvioni '16]

Trilinear Higgs self-coupling enters via electroweak loops to single Higgs production



[McCullough '14, Gorbahn, Haisch '16, Degrassi, Giardino, Maltoni, Pagani '16, Bizon, Gorbahn, Haisch Zanderighi '16]

Global fit necessary, including HH and differential measurements to resolve degeneracies

[Di Vita, Grojean, Panico, Rimbau, Vantalon '17, Maltoni, Pagani, Shivaji, Zhao '18]

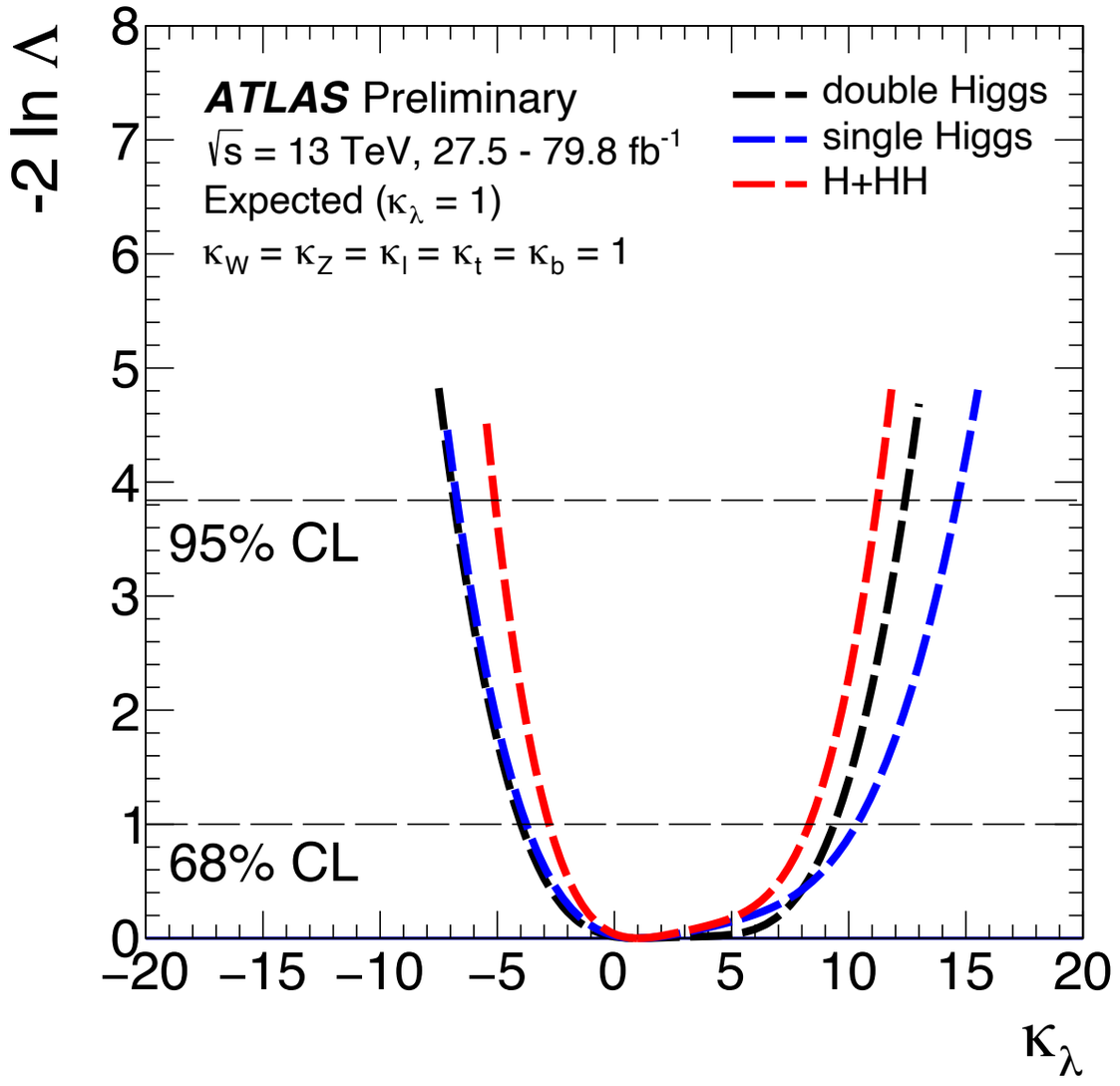
EFT Single Higgs production

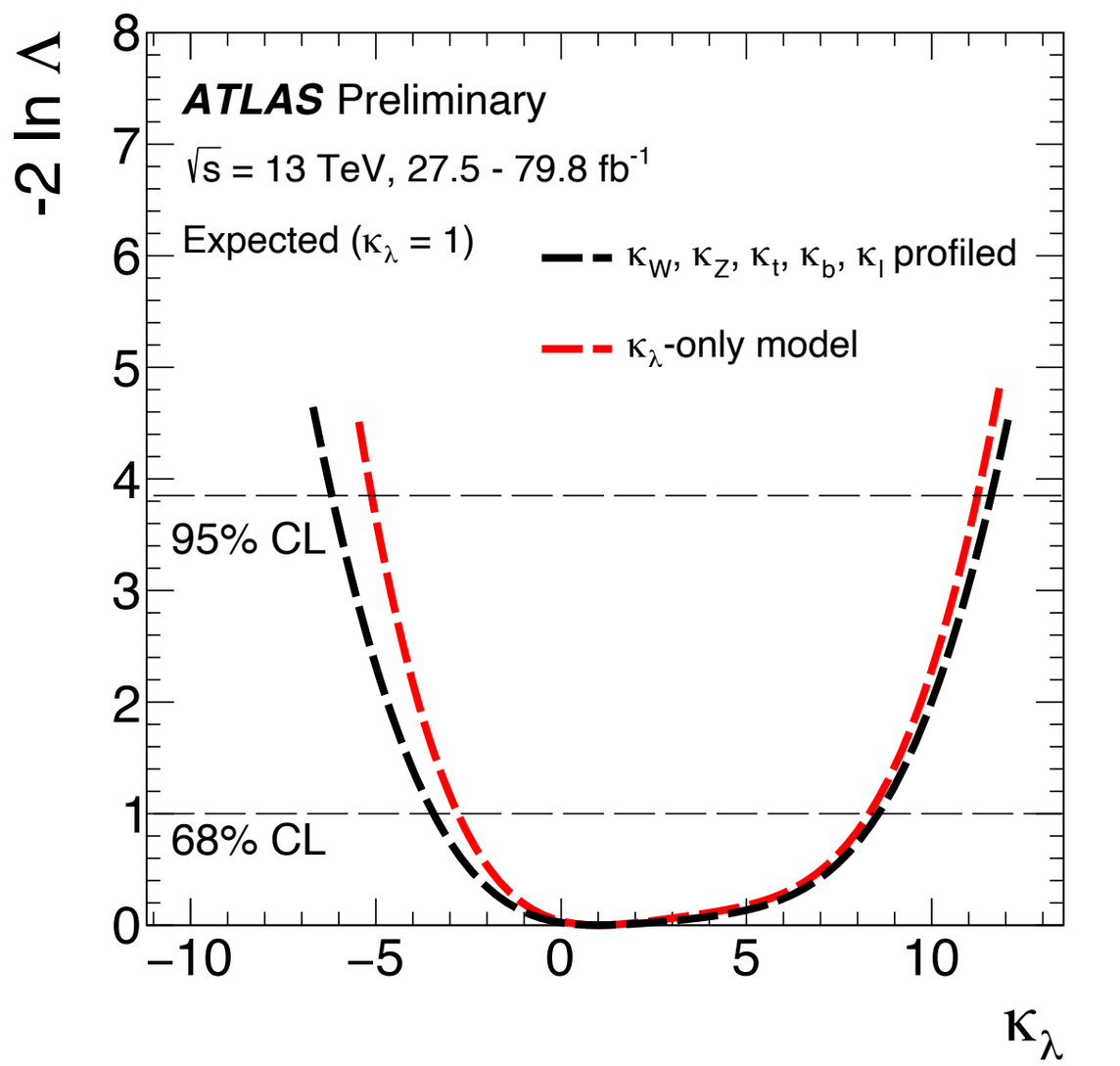
Single Higgs production provides bounds to the single Higgs couplings

We do not expect that HH can improve on them (though maybe for degeneracies)

[Gillioz, RG, Grojean, Mühlleitner, Salvioni '12, Azatov, Contino, Panico, Son '15, Azatov, Grojean, Paul, Salvioni '16]

Trilinear Higgs self-coupling enters via electroweak loops to single Higgs production





EFT Single Higgs production

Single Higgs production provides bounds to the single Higgs couplings

We do not expect that HH can improve on them (though maybe for degeneracies)

[Gillioz, RG, Grojean, Mühlleitner, Salvioni '12, Azatov, Contino, Panico, Son '15, Azatov, Grojean, Paul, Salvioni '16]

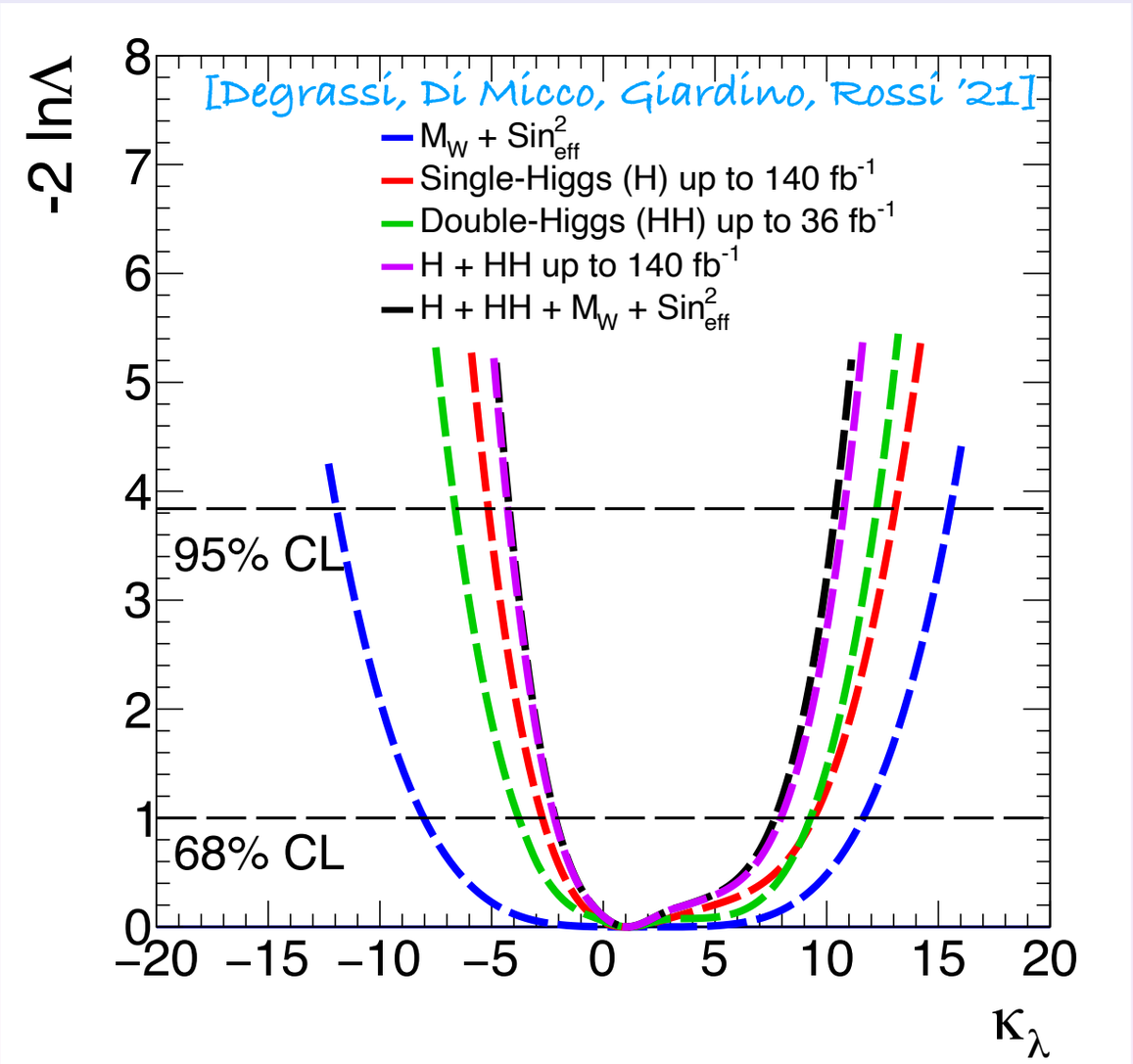
Trilinear Higgs self-coupling enters via electroweak loops to single Higgs production

Trilinear Higgs self-coupling enters also in electroweak precision observables

[Degrassi, Fedele, Giardino '17, Kribs, Maier, Rzehak, Spannowsky, Waite '17]

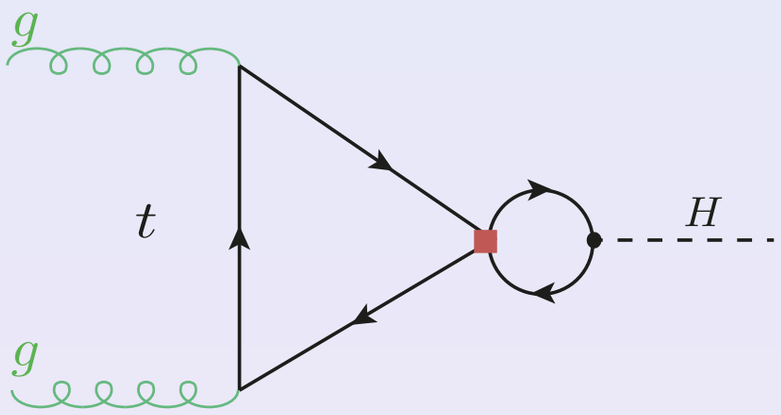
Impact on fit though small

[Degrassi, Di Micco, Giardino, Rossi '21]



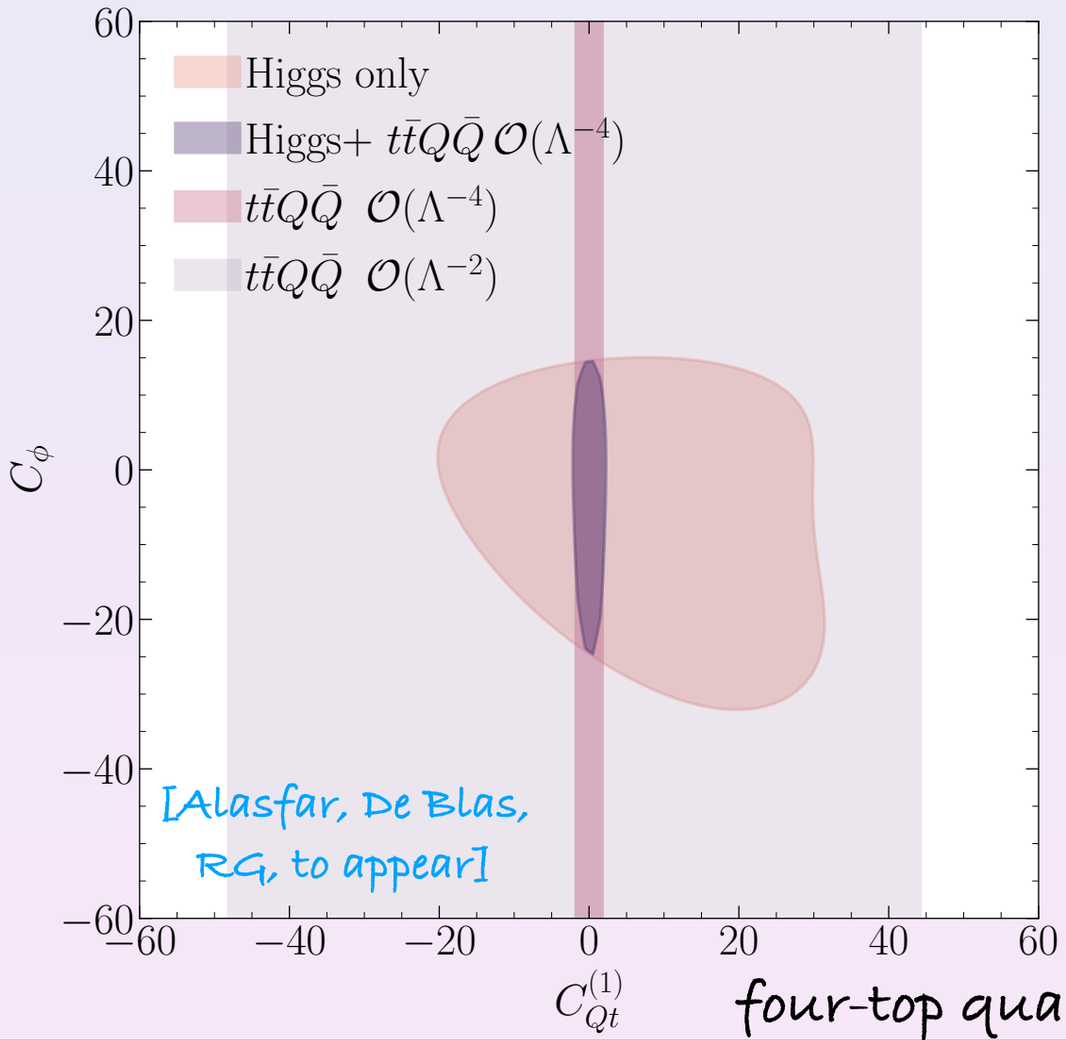
Operators entering at NLO

But is it enough to include the tree-level operators into the global fit?



E.g. poorly constrained four-fermion operators enter at NLO to single Higgs production

[work in progress with L. Alasfar and J. De Blas]



self-coupling modification

four-top quark singlet operator

[bounds from 4 top production from SMEFiT collaboration '21]

Conclusions

- Di-Higgs production provides new information beyond pure trilinear coupling
- HEFT/SMEFT? di-Higgs production could potentially distinguish, BUT: two new unconstrained parameters
- also single Higgs production can be used to constrain trilinear Higgs self-coupling
- though keeping in mind that more weakly constrained operators enter into single Higgs production

Conclusions

- Di-Higgs production provides new information beyond pure trilinear coupling
- HEFT/SMEFT? di-Higgs production could potentially distinguish, BUT: two new unconstrained parameters
- also single Higgs production can be used to constrain trilinear Higgs self-coupling
- though keeping in mind that more weakly constrained operators enter into single Higgs production

Thanks for your attention!

Zoom discussion:

Meeting ID: 898 2336 1625
Passcode: same as session