Hurdles towards gg->ZH @ NLO

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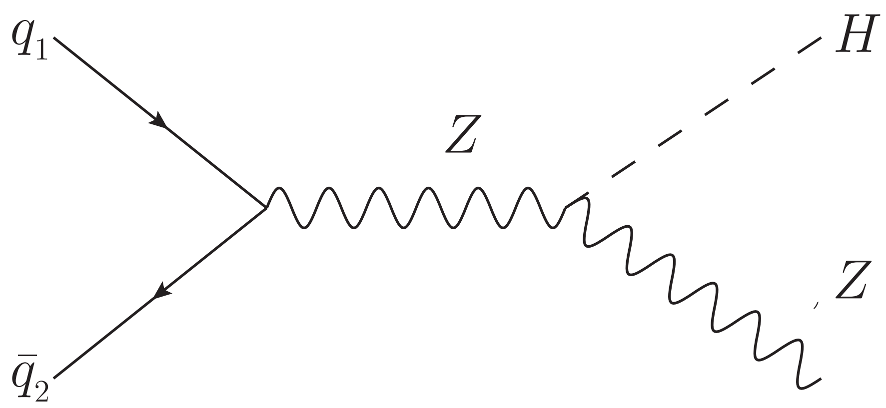
HXSWG VH subgroup meeting, 29th June 2017

Disclaimer

- views are my own
- other people might have more/other insights

Why the gg channel is interesting

- LO process is Higgs-Strahlung



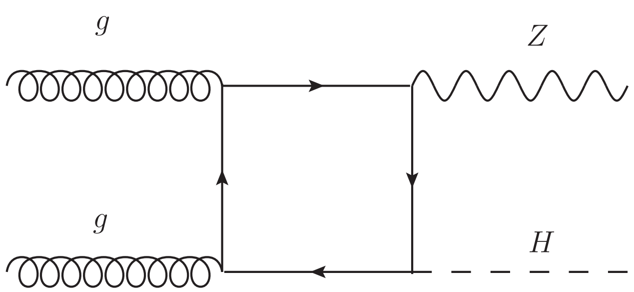
- Drell-Yan component known up to NNLO

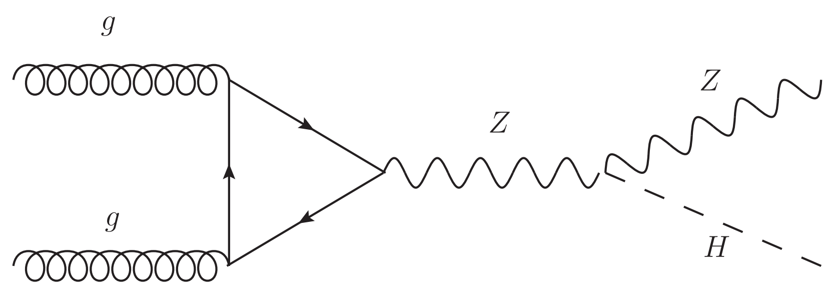
  Hamberg, Neerven, Matsuura '91, Harlander, Kilgore '02, Brein, Djouadi,Harlander '04

- LO gg channel enters at NNLO with ~10% Brein, Harlander, Zirke '12
- gluon fusion scale uncertainty large (~30%), dominates overall pp->ZH uncertainty at NNLO
- gg->ZH @NLO with full top-mass dependence desirable

gg->ZH diagrams

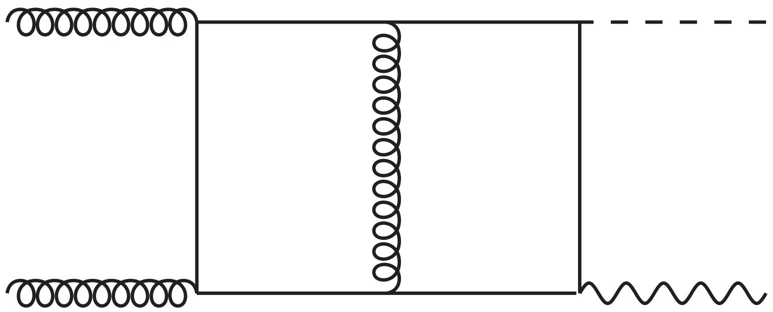
Leading Order:

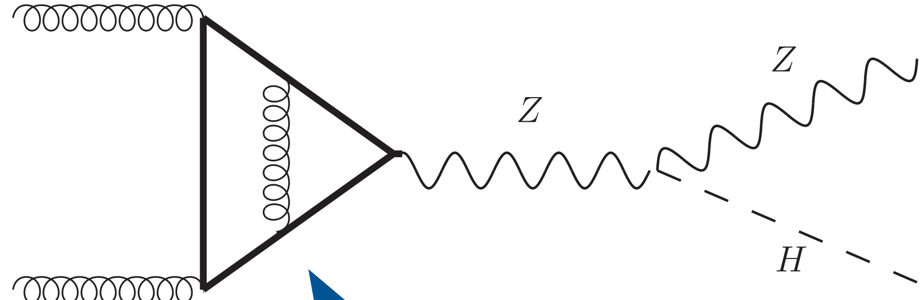




Dicus, Kao '88; Kniehl '90

Exact virtual NLO part:





not known yet

master integrals known from
Gehrmann, Huber,Maitre '05

Exact real radiation for NLO by: Hespel, Maltoni, Vryonidou '15

Going back to the gg->HH case

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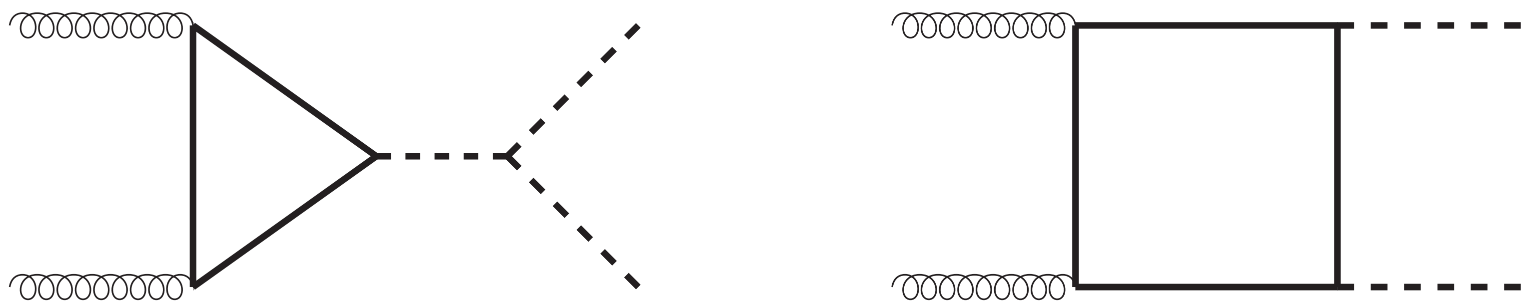
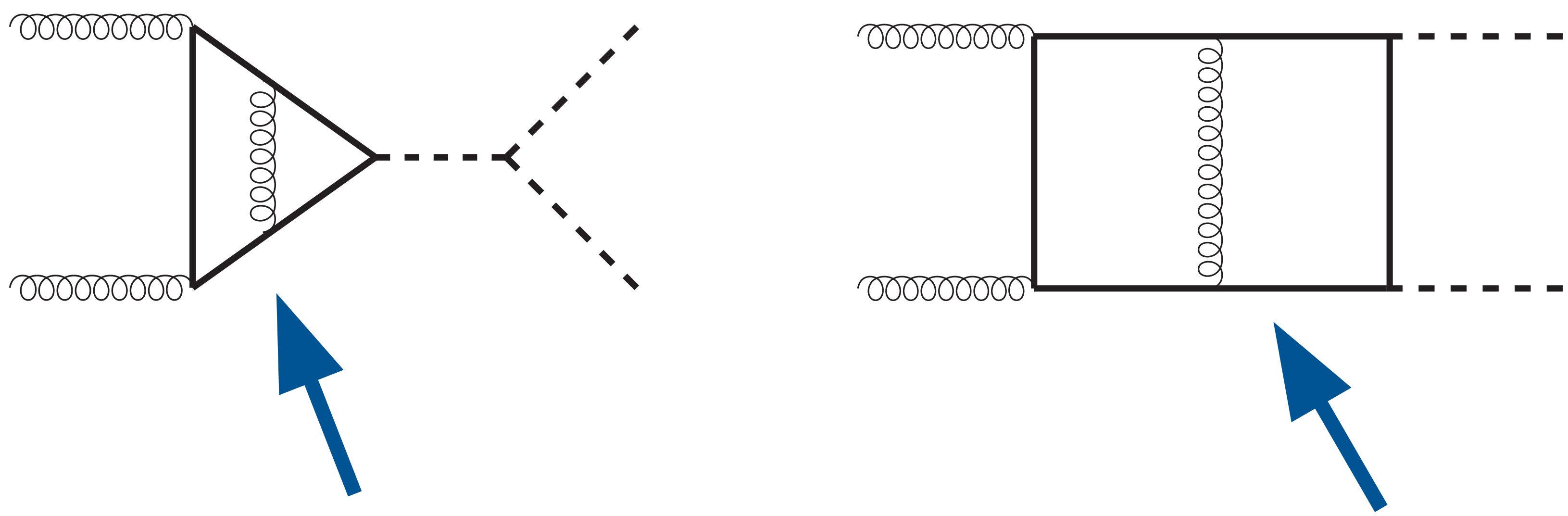


Glover, van der Bij '88

Virtual part of next-to-leading Order:



master integrals known analytically
from single Higgs production

Harlander, Kant '05

only known numerically

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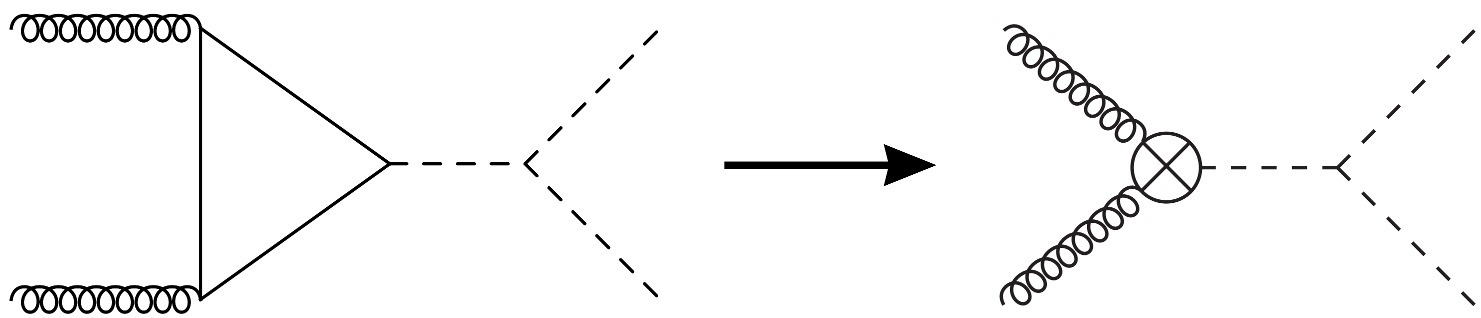
J. Schlenk, U. Schubert, T. Zirke '16

Alternative: infinite top-mass limit

Higgs effective field theory:



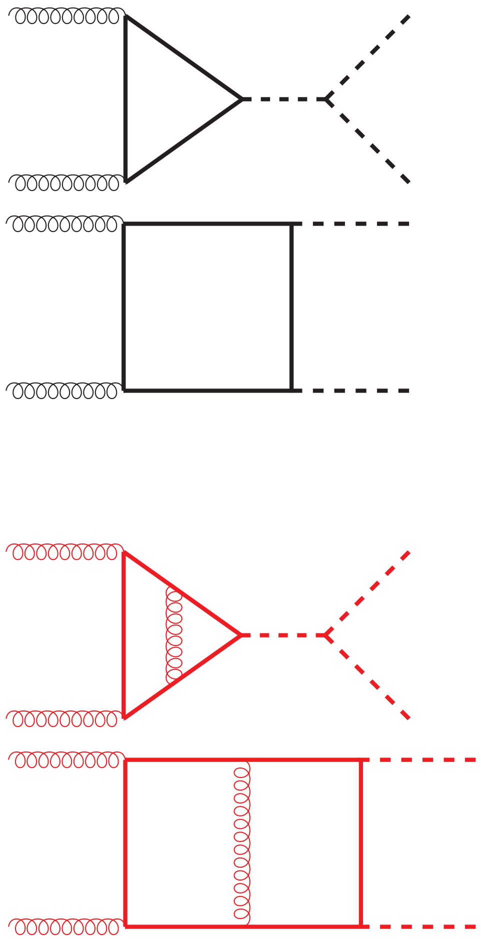
gg->HH, LO up to NNLO differential in HEFT: Glover, van der Bij '88; Plehn, Spira, Zerwas '96; Dawson, Dittmaier, Spira '98; De Florian, Mazzitelli '13; Frederix, Hirschi, Mattelaer, Maltoni, Torrielli, Vryonidou, Zaro '14; Maltoni, Vryonidou, Zaro '14; De Florian, Mazzitelli '15; Degrassi, Giardino, Gröber '16; De Florian, Grazzini, Hanga, Kallweit, Lindert, Maierhöfer, Mazzitelli, Rathlev '16

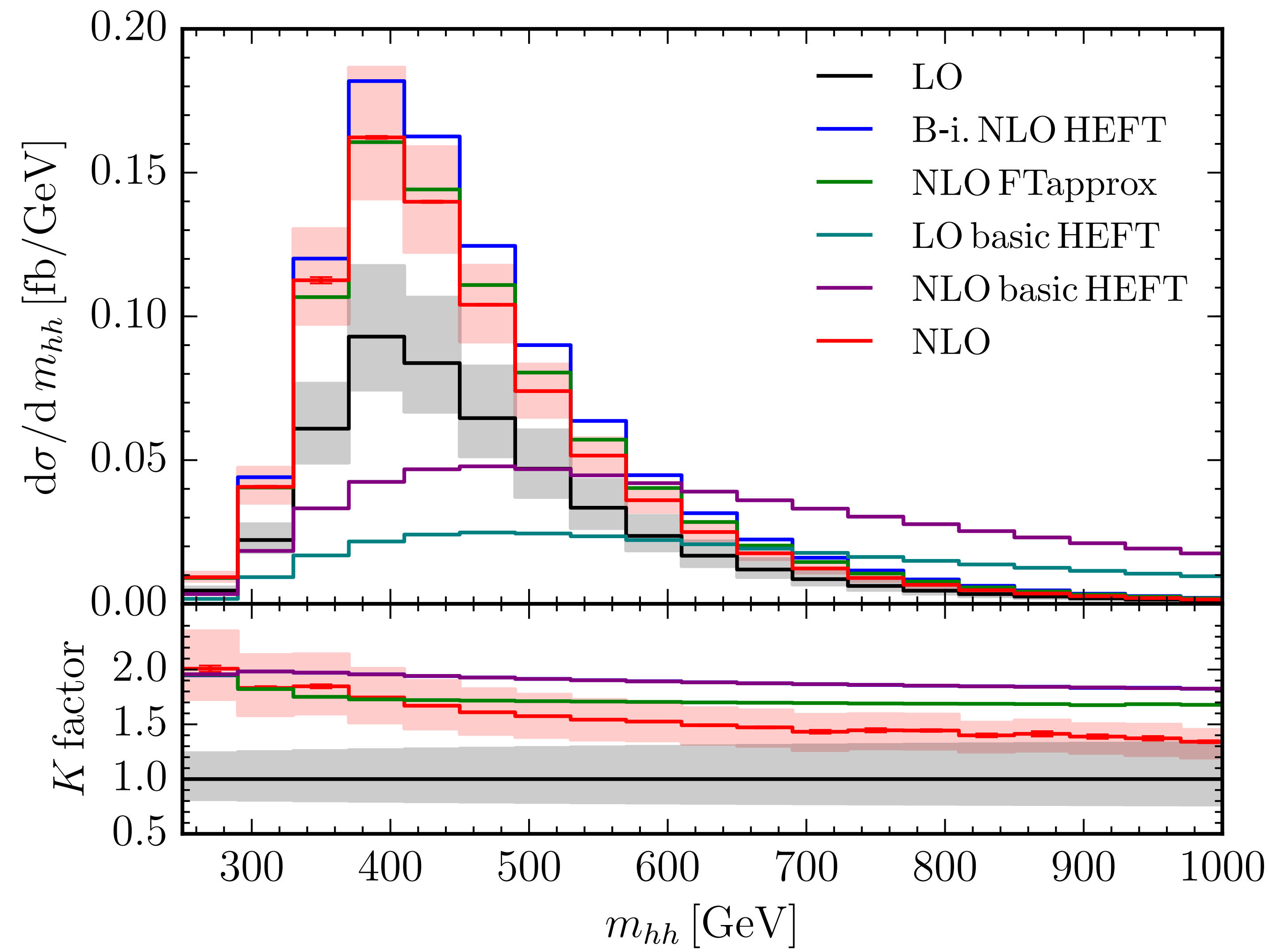
maximal range of validity: $\sqrt{\hat{s}} < 2\,m_t \approx 346\,\mathrm{GeV}$

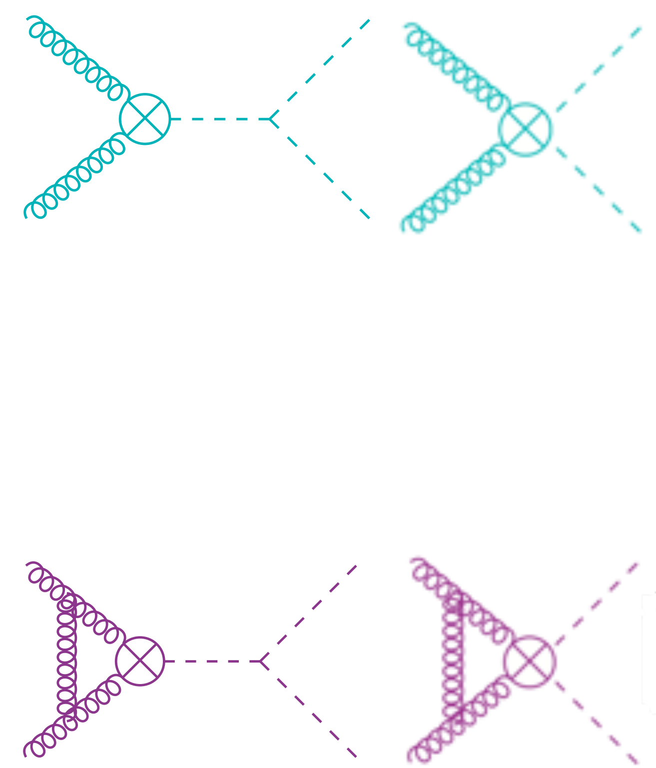
- → Higgs-boson pair production threshold at $\sqrt{\hat{s}} = 250\,\mathrm{GeV}$
- → ZH production threshold at $\sqrt{\hat{s}} = 216\,\mathrm{GeV}$

Higgs-boson pair production at LO and NLO

SB, N. Greiner, G. Heinrich, S.P. Jones, M. Kerner, J. Schlenk, U. Schubert, T. Zirke '16





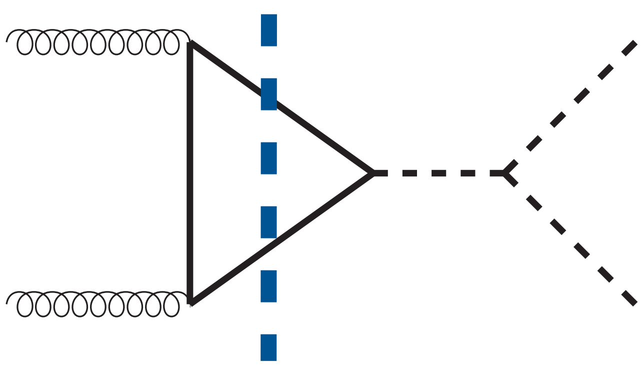


➡ indeed Higgs effective theory breaks down

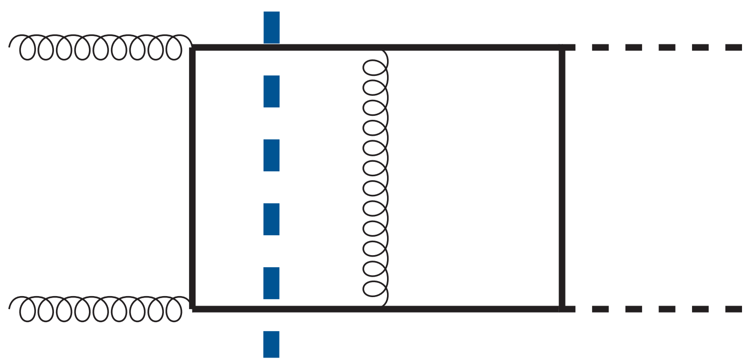
HH: Differences between SM and HEFT

- what happens in the exact Standard Model

  - threshold effects can show up



$m_{hh} = 2\,m_t$



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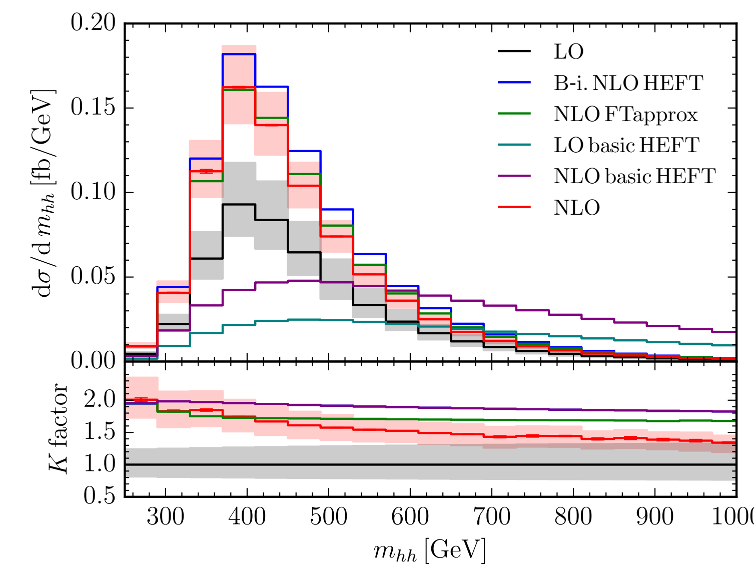

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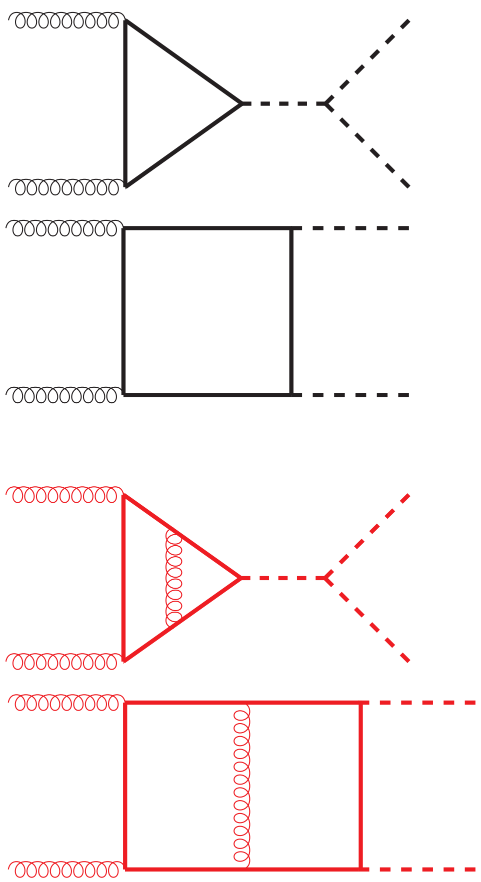
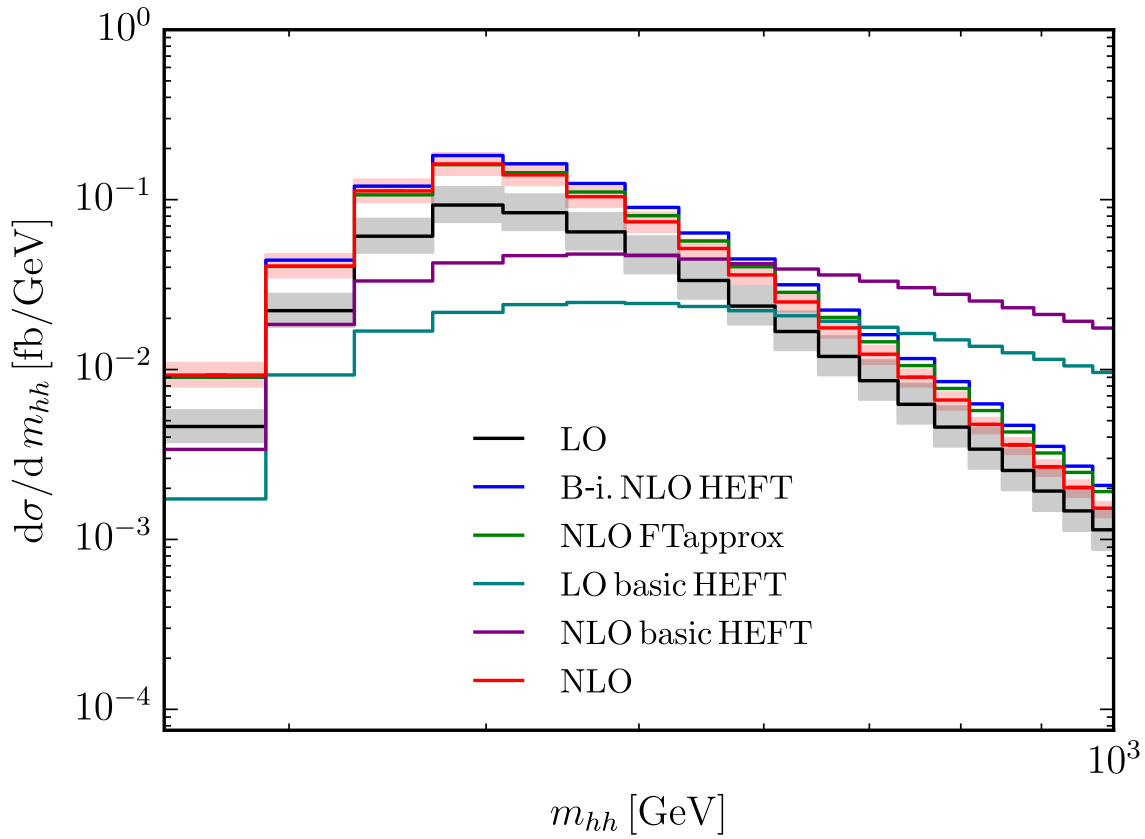
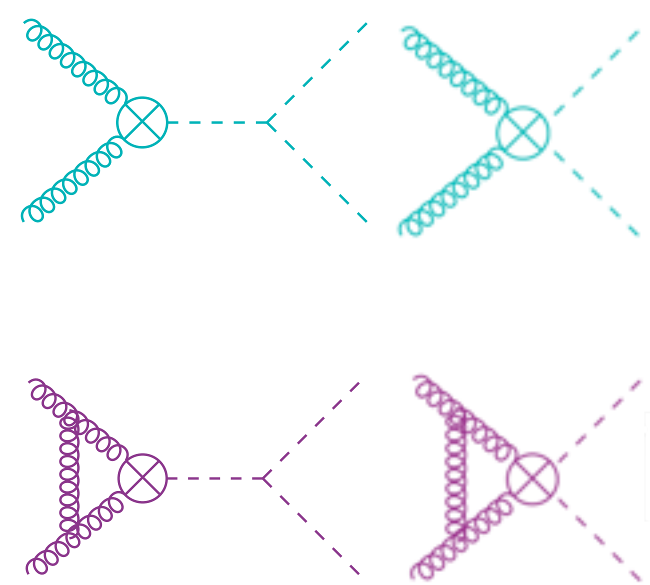
HH: Differences between SM and HEFT

→ what happens in the exact Standard Model

→ scaling behavior is different







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ZH production in gluon fusion

- similar effects expected in gg->ZH production
  - no way around computation of exact two-loop integrals with exact top-mass dependence
  - with current technology the only way is to tackle the double-box integrals involved numerically
  - numerical approach worked well for gg->HH but we were also lucky

Schematic gg->HH setup (virtual NLO)

generation of diagrams for amplitude → reduction of amplitude to set of master integrals → computation of master integrals

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- reduction programs:
FIRE, KIRA, LiteRed, REDUZE
Smirnov ’15; Maierhöfer, Usovitsch, Uwer ’17; Lee ’13; von Manteuffel, Studerus ’12

- REDUZE can generate quasi-finite basis

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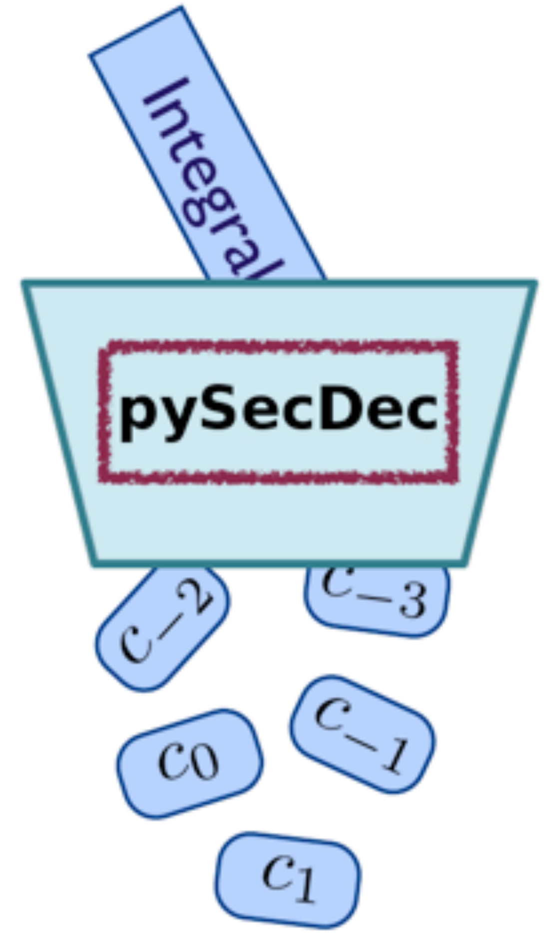

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Important for success:

+ use quasi-finite basis Panzer '14; von Manteuffel, Panzer, Schabinger '14
+ use QMC Dick, Kuo, Sloan '13; Li, Wang, Zan, Zhao '15;
+ only integrate up to necessary accuracy
(2 form factors for HH, 3% for one form factor, ≈10% for the other, depending on the ratio of the two)

Problems that may occur in gg->ZH

- additional mass scale makes reduction much more involved
- if reduction not available no transformation into quasi-finite basis possible
- if double-box integrals are not finite, numerical convergence significantly worse
- form factors may may be of similar importance (high accuracy also needed for most complicated integrals)
- numerical convergence in general slower the more scales are involved

But...

- bringing the current reduction programs to their optimum might still lead to a full reduction
- if full reduction not available: writing individual integral in terms of quasi-finite basis might just work because the reduction for that particular integral is possible
- maybe there is a way of cleverly grouping integrals
- colleagues are excellent: further improvements in reduction programs + integration can be expected

Summary

- the computation of exact NLO with full top-quark mass dependence for gg->HH was extremely hard
- but developed approach can be used to compute technically similar processes
- one of them is ZH production in gg fusion at NLO with exact top-quark mass dependence

- very likely: more technical developments to compute gg->ZH still needed
  - improvement in reduction programs highly desirable
  - new ways of improving the integration highly desirable