LHCP 2014
The Second Annual Conference on Large Hadron Collider Physics

Thursday, 6/5/2014
Columbia University, New York

N^3LO corrections to Higgs production

Elisabetta Furlan

Fermilab

Work in collaboration with C. Anastasiou, C. Duhr, F. Dulat, T. Gehrmann, F. Herzog and B. Mistlberger [arxiv:1403.4616]

Motivation

- the era of precision Higgs physics has just begun!

➡ it is important to have reliable theoretical predictions

accurate determination of Higgs couplings

potential (small) signals of new physics

Motivation

- current status

theory

	$\sigma^{8\,\mathrm{TeV}}\,[\mathrm{pb}]$	$\frac{\delta\sigma^{\mathrm{scale}}}{\sigma}$
LO	10.1	$\sim$25%
NLO	17.3	$\sim$18%
NNLO	20.2	$\sim$ 8%
$\mathrm{N^3LO}$	?	$\sim$ 4% S. Buelher et al., JHEP 1310, 096 (2010)

$K_{NLO} \sim 1.7$

$K_{NNLO} \sim 2.0$

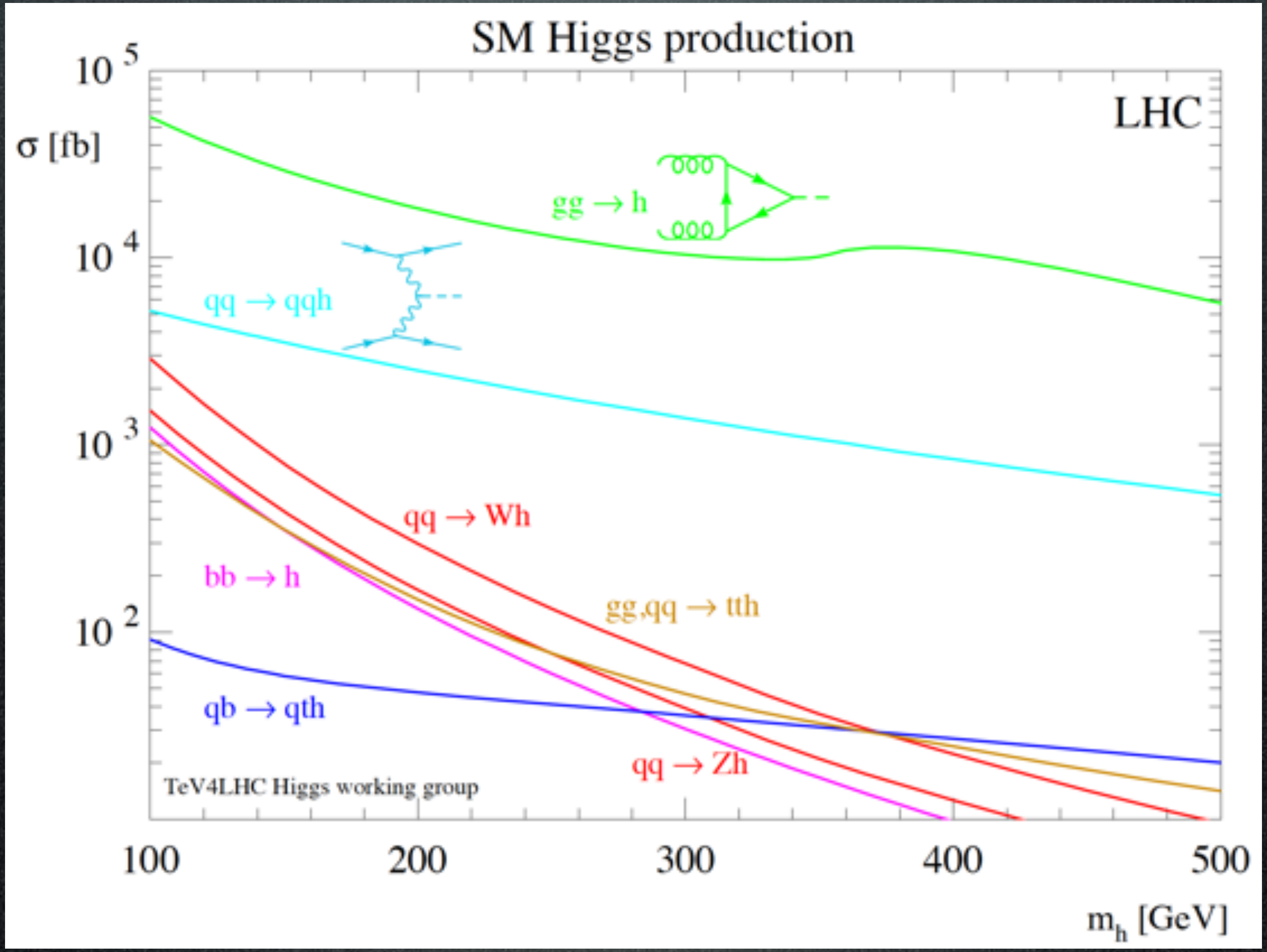
experiment

- current precision
  $\sim$ 30%
- end of Run 2 (300 $\mathrm{fb^{-1}}$,13 TeV)
  $\sim$ 10%

S. Dawson et al., *Higgs WG report of the Snowmass 2013 Community Planning Study*

Gluon fusion Higgs production

- the main mechanism for Higgs production at the LHC is gluon fusion



Gluon fusion Higgs production

- at the partonic level, the cross section $\hat{\sigma}$ depends on just one parameter,

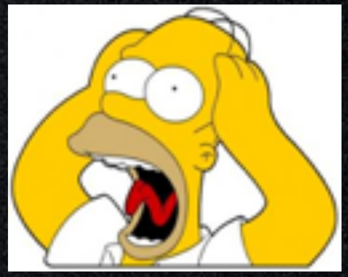
$$z \equiv \frac{m_H^2}{\hat{s}} \overset{\text{threshold}}{\sim} 1$$

➡ perform a threshold expansion

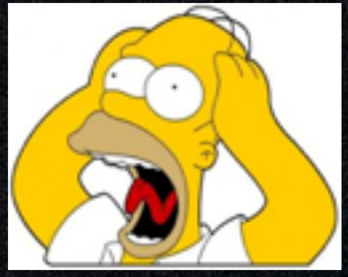
$$\hat{\sigma}(z) = \hat{\sigma}^{SV} + \hat{\sigma}^{(0)} + (1-z)\hat{\sigma}^{(1)} + \dots$$

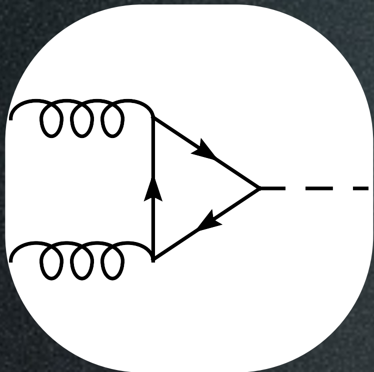
N^3LO soft-virtual term

→ N^3LO virtual corrections to $gg \to H$

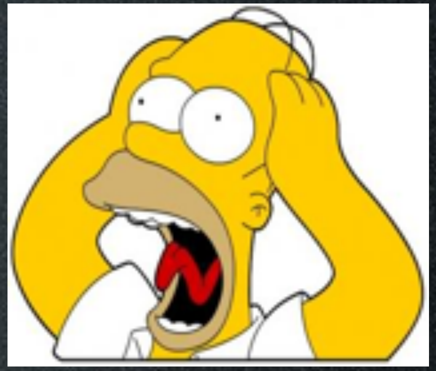


→ real (soft) radiation





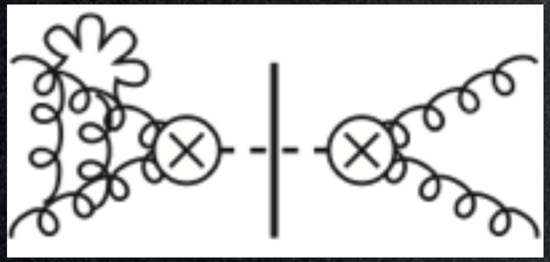
Gluon fusion Higgs production



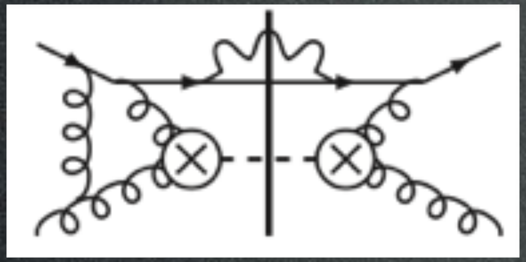
- at LO, gluon-fusion Higgs production is mediated by *one* loop of heavy quarks

➡ $\mathrm{N^3LO}$ → four loops! (~ 15000 diagrams)

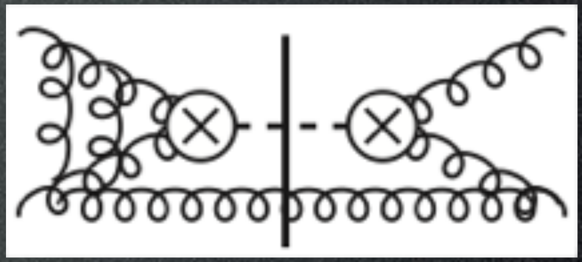
- huge number of contributions from "real" radiation (~100000 interference diagrams)



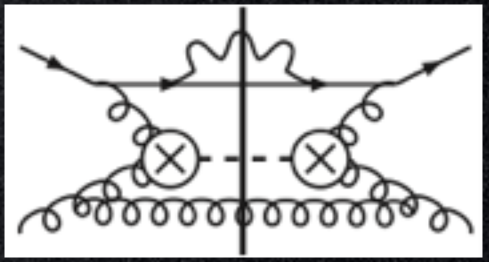
Baikov et al., Phys. Rev. Lett. 102, 212002 (2009); Gehrmann et al., JHEP 1006, 094 (2010)



Gehrmann et al., JHEP 1201, 056 (2012); Duhr et al., Phys. Lett. B 727, 452 (2013); Li et al., JHEP 1311, 080 (2013)

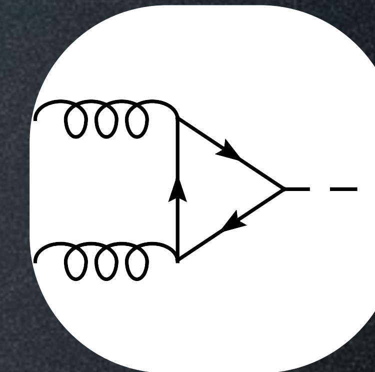


Anastasiou et al., JHEP 1312, 088 (2013); Kilgore, Phys. Rev. D 89 073008 (2014)



Anastasiou et al., JHEP 1307, 003 (2013)

Calculation: the virtual corrections



- for a light Higgs boson, the top quark can be integrated out

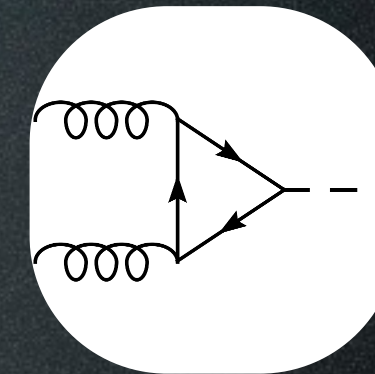
➡ construct an heavy quark effective theory

$$\mathcal{L} \rightarrow \mathcal{L}_{light} - \frac{\alpha_s}{4\pi} C H G^a_{\mu\nu} G^{a\mu\nu}$$

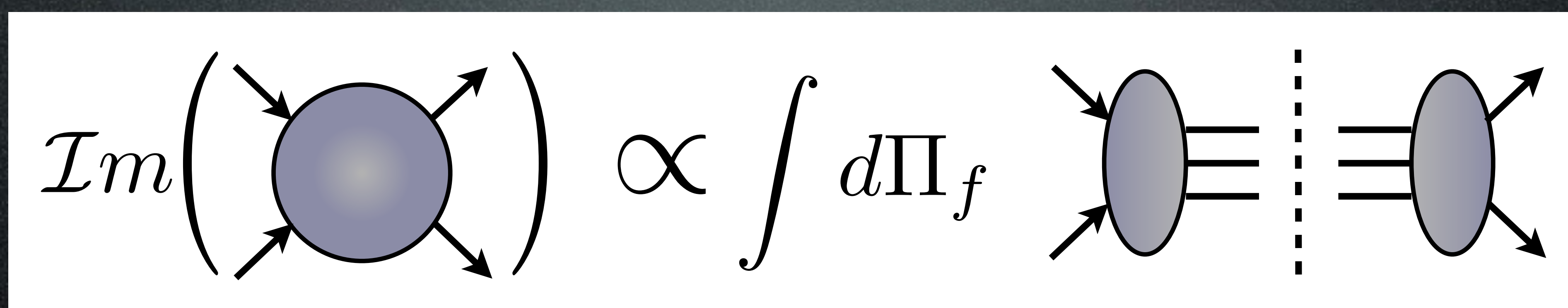
➡ this approach allowed for the calculation of the N^{3}LO Wilson coefficient

Chetyrkin et al., Nucl. Phys. B744, 21 (2006)
Y. Schroder et al., JHEP 0601, 051 (2006)

Calculation: the real radiation



- write the phase space integrals as loop integrals using reverse unitarity



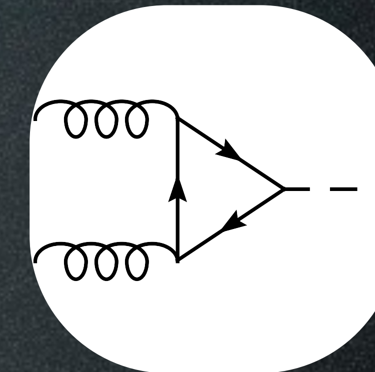
unitarity methods

Bern, Dixon, Kosower, Nucl. Phys. B 513, 3 (1998)
Britto, Cachazo, Feng, Nucl. Phys. B 725, 275 (2005)
Ossola, Papadopoulos, Pittau, Nucl. Phys. B 763, 147 (2007)

reverse unitarity

Anastasiou, Melnikov, Nucl. Phys. B 646, 220 (2002)

Calculation: the real radiation



- apply the known techniques for loop integrals calculation:

  ➡ relate the integrals by integration by part identities

  Chetyrkin, Tkachov, Nucl. Phys. B 192, 159 (1981)
  Tkachov, Phys. Lett. B 100, 65 (1981)

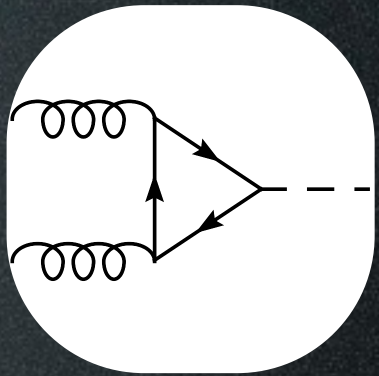
  ➡ solve them through the Laporta algorithm

  Laporta, Int. J. Mod. Phys. A 15, 5087 (2000)

  ➡ express all the integrals in terms of a “limited” number of master integrals

  ↳ still $\sim$1000 integrals to compute!

Calculation: the real radiation



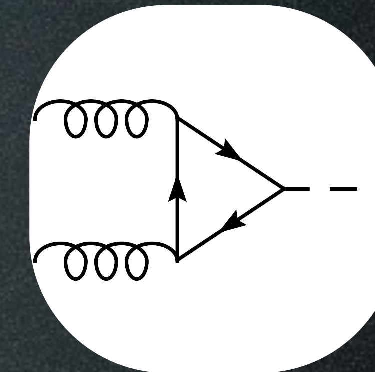
- automation is crucial!
- work at the leading order in the soft threshold expansion

➡ only the gluon-initiated processes contribute

➡ expand all integrals considering the momenta of the final states as soft

➡ $\sim$ 50 master integrals

Calculation: the real radiation



- the calculation of the master integrals themselves is nontrivial

➡ need to use a number of different techniques

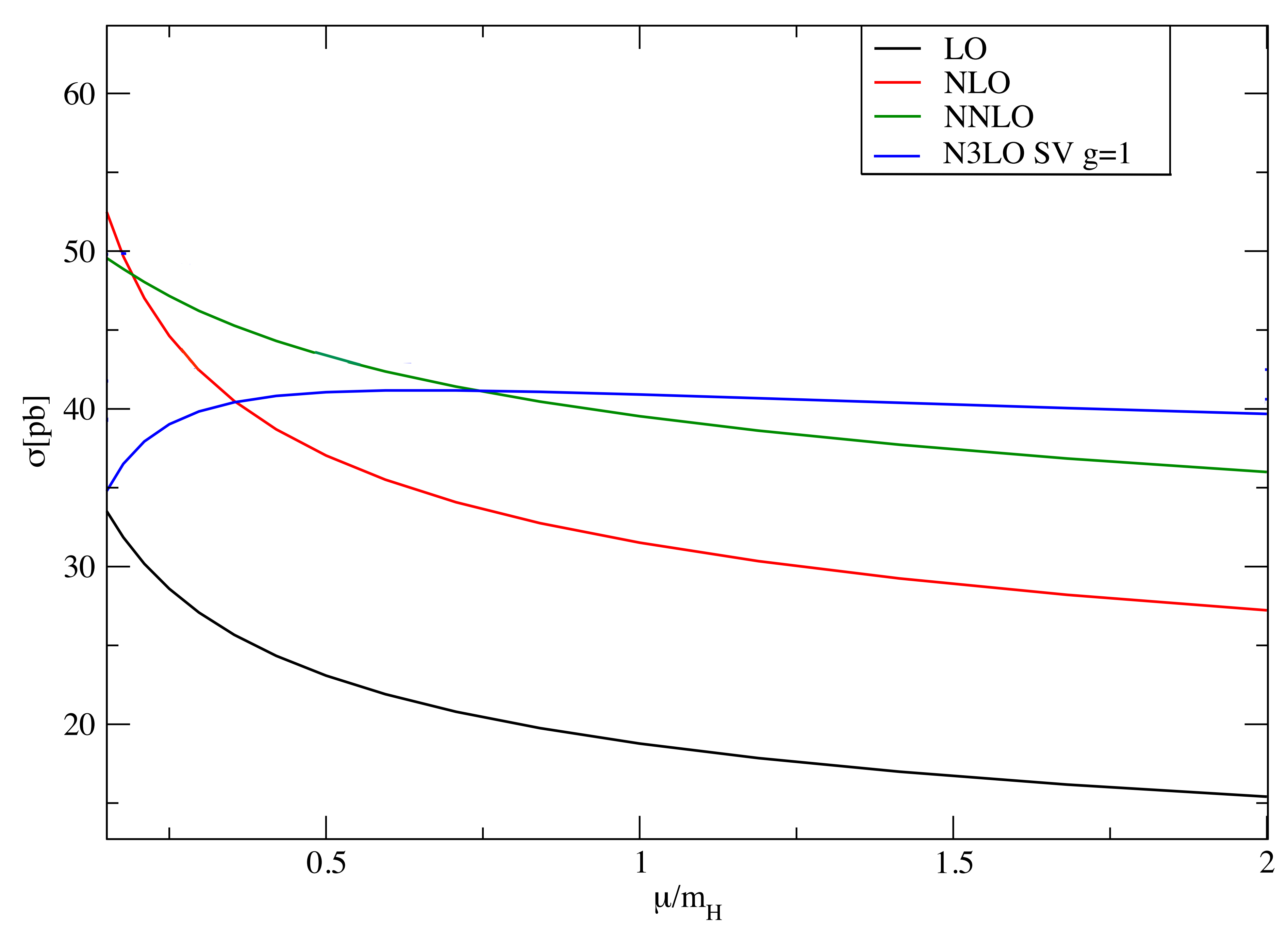
➡ develop new techniques from number theory as well

Anastasiou et al., JHEP 1312, 088 (2013)

Results

$$
\begin{aligned}
\hat{\eta}^{(3)}(z) = \delta(1-z) \Bigg\{ & C_A^3 \left(-\frac{2003}{48}\,\zeta_6 + \frac{413}{6}\,\zeta_3^2 - \frac{7579}{144}\,\zeta_5 + \frac{979}{24}\,\zeta_2\,\zeta_3 - \frac{15257}{864}\,\zeta_4 - \frac{819}{16}\,\zeta_3 + \frac{16151}{1296}\,\zeta_2 + \frac{215131}{5184} \right) \\
& + N_F \left[C_A^2 \left(\frac{869}{72}\,\zeta_5 - \frac{125}{12}\,\zeta_3\,\zeta_2 + \frac{2629}{432}\,\zeta_4 + \frac{1231}{216}\,\zeta_3 - \frac{70}{81}\,\zeta_2 - \frac{98059}{5184} \right) \right. \\
& \left. + N_F^2 \left[C_A \left(-\frac{19}{36}\,\zeta_4 + \frac{43}{108}\,\zeta_3 - \frac{133}{324}\,\zeta_2 + \frac{2515}{1728} \right) + C_F \left(-\frac{1}{36}\,\zeta_4 - \frac{7}{6}\,\zeta_3 - \frac{23}{72}\,\zeta_2 + \frac{4481}{2592} \right) \right] \right] \Bigg\} \\
+ \left[\frac{1}{1-z} \right]_+ \Bigg\{ & C_A^3 \left(186\,\zeta_5 - \frac{725}{6}\,\zeta_3\,\zeta_2 + \frac{253}{24}\,\zeta_4 + \frac{8941}{108}\,\zeta_3 + \frac{8563}{324}\,\zeta_2 - \frac{297029}{23328} \right) + N_F^2\,C_A \left(\frac{5}{27}\,\zeta_3 + \frac{10}{27}\,\zeta_2 - \frac{58}{729} \right) \\
& + N_F \left[C_A^2 \left(-\frac{17}{12}\,\zeta_4 - \frac{475}{36}\,\zeta_3 - \frac{2173}{324}\,\zeta_2 + \frac{31313}{11664} \right) + C_A\,C_F \left(-\frac{1}{2}\,\zeta_4 - \frac{19}{18}\,\zeta_3 - \frac{1}{2}\,\zeta_2 + \frac{1711}{864} \right) \right] \Bigg\} \\
+ \left[\frac{\log(1-z)}{1-z} \right]_+ \Bigg\{ & C_A^3 \left(-77\zeta_4 - \frac{352}{3}\,\zeta_3 - \frac{152}{3}\,\zeta_2 + \frac{30569}{648} \right) + N_F^2\,C_A \left(-\frac{4}{9}\,\zeta_2 + \frac{25}{81} \right) \\
& + N_F \left[C_A^2 \left(\frac{46}{3}\,\zeta_3 + \frac{94}{9}\,\zeta_2 - \frac{4211}{324} \right) + C_A\,C_F \left(6\,\zeta_3 - \frac{63}{8} \right) \right] \Bigg\} \\
+ \left[\frac{\log^2(1-z)}{1-z} \right]_+ \Bigg\{ & C_A^3 \left(181\,\zeta_3 + \frac{187}{3}\,\zeta_2 - \frac{1051}{27} \right) + N_F \left[C_A^2 \left(-\frac{34}{3}\,\zeta_2 + \frac{457}{54} \right) + \frac{1}{2}\,C_A\,C_F \right] - \frac{10}{27}\,N_F^2\,C_A \Bigg\} \\
+ \left[\frac{\log^3(1-z)}{1-z} \right]_+ \Bigg\{ & C_A^3 \left(-56\,\zeta_2 + \frac{925}{27} \right) - \frac{164}{27}\,N_F\,C_A^2 + \frac{4}{27}\,N_F^2\,C_A \Bigg\} \\
+ \left[\frac{\log^4(1-z)}{1-z} \right]_+ & \left(\frac{20}{9}\,N_F\,C_A^2 - \frac{110}{9}\,C_A^3 \right) + \left[\frac{\log^5(1-z)}{1-z} \right]_+ 8\,C_A^3 \,.
\end{aligned}
$$

Results



Herzog, Mistlberger, arxiv:1405.5685

Conclusions and Outlook

- we computed the leading term in the soft expansion of the gluon-fusion Higgs production cross section at N^3LO
- huge complexity (number of diagrams, master integrals to compute)

➡ automation

➡ development of new techniques

Conclusions and Outlook

- need to improve on the soft-virtual approximation
  - ➡ next terms in the soft expansion
  - ➡ eventually, “full” result?