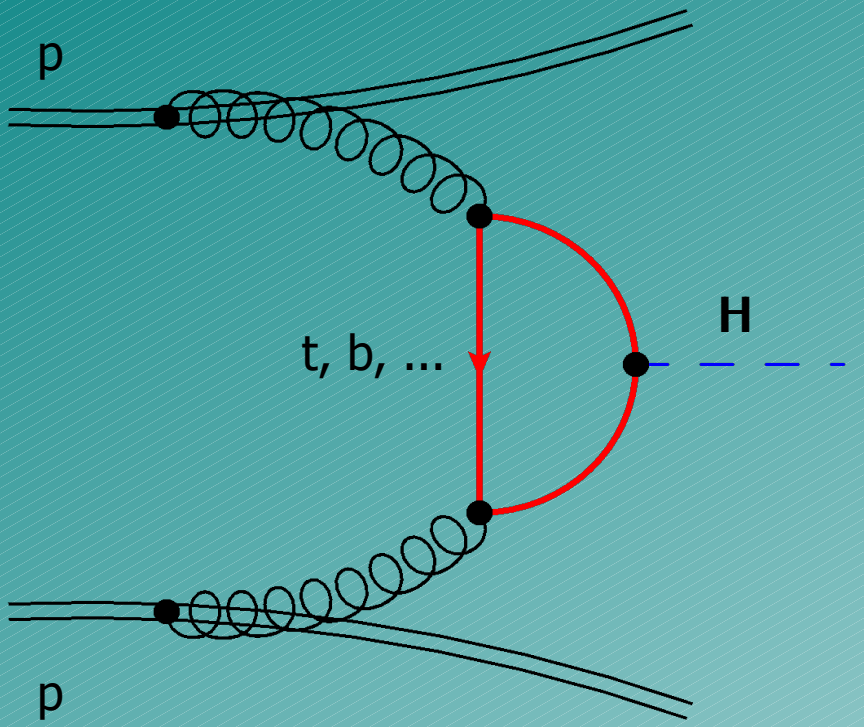
Beyond the heavy top limit in $gg \to H$ at the LHC

Alexey Pak, TTP Karlsruhe

work done in collaboration with
Matthias Steinhauser and Mikhail Rogal

Higgs boson production at the LHC: pp → H+X



Dominant channel (for intermediate m_h):

gg → H via a top-quark loop

Very well studied process!

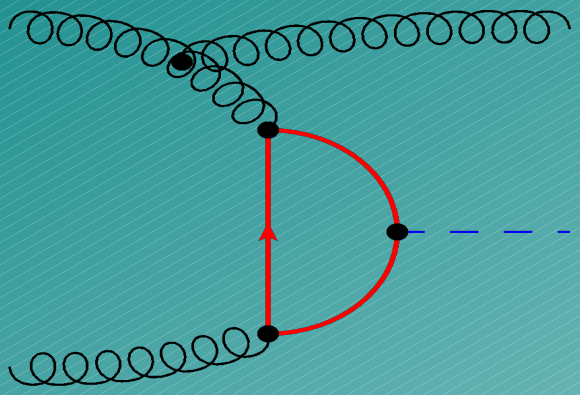
Relevant scales:

$$\sqrt{s} \sim 100 - 14000\,\mathrm{GeV}$$
$$m_h \sim 100 - 300\,\mathrm{GeV}$$
$$m_t \sim 170\,\mathrm{GeV}$$

Leading order: **[Geordi, Glashow, Machacek, Nanopoulos '78]**
(full dependence on m_h/m_t)

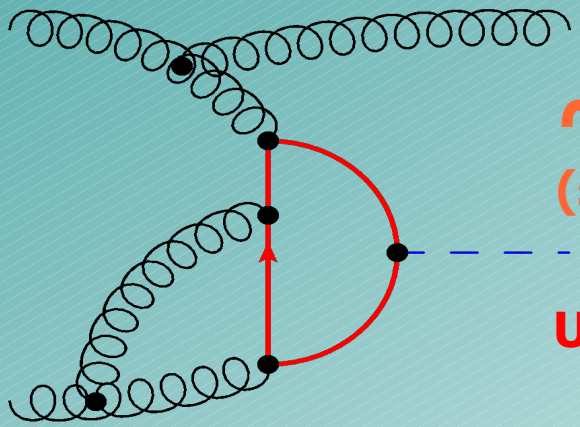
QCD corrections: large!

Next-to-leading order:
[Dawson; Djouadi, Spira, Zerwas '91] (effective theory)
[Spira et al '95] (exact)



~ O(70%)

Next-to-next-to-leading order:
[Harlander, Kilgore '02] (soft expansion)
[Anastasiou, Melnikov '02],
[Ravindran, Smith, van Neerven '03]



~ O(10%)
(scale uncertainties: O(%)

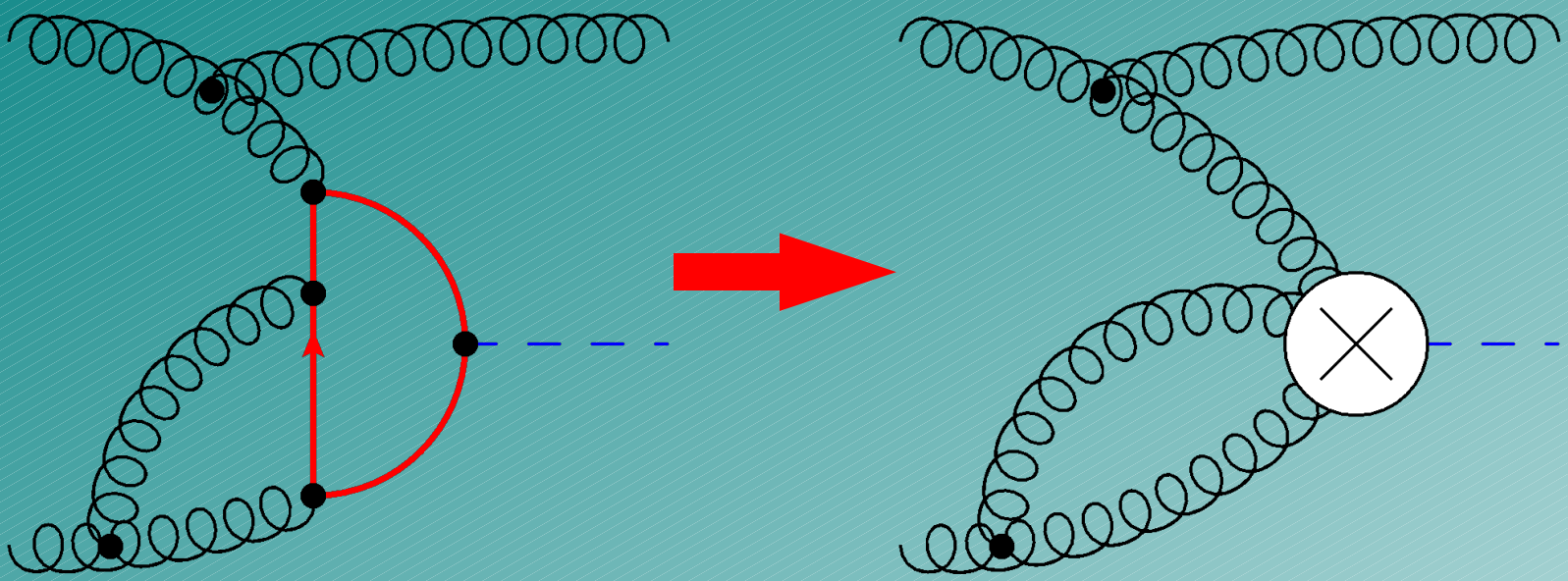
Also available:

EW, QCD-EW, NNLO+NNLL, N^3LO threshold enhanced, π^2-resummation, NNLO differential distributions...

Catani, de Florian, Grazzini, Nason; Ahrens, Becher, Neubert, Yang; Actis, Passarino, Sturm, Uccirati; Anastasiou, Boughezal, Petriello; de Florian, Grazzini

Until recently, only available in the heavy top limit

Heavy top limit: effective theory



$$L_{eff} = C \cdot G_{\mu\nu} G^{\mu\nu}$$

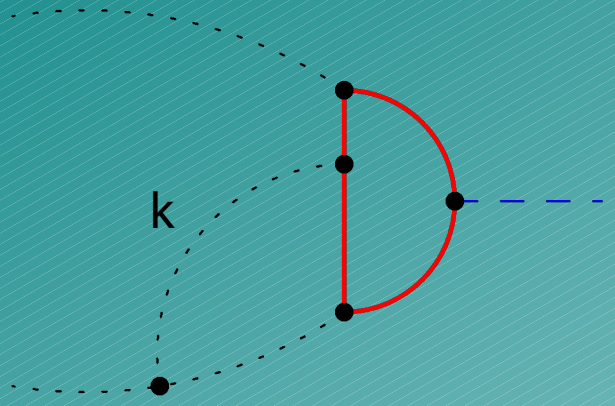
Works for $\frac{m_h^2}{4 m_t^2} \ll 1$

Have to assume: $\frac{m_t}{m_h} \to \infty \,, \frac{m_t}{\sqrt{s}} \to \infty$

Are the O(1/m$_t$) terms important?

Asymptotic expansion in m_h/m_t

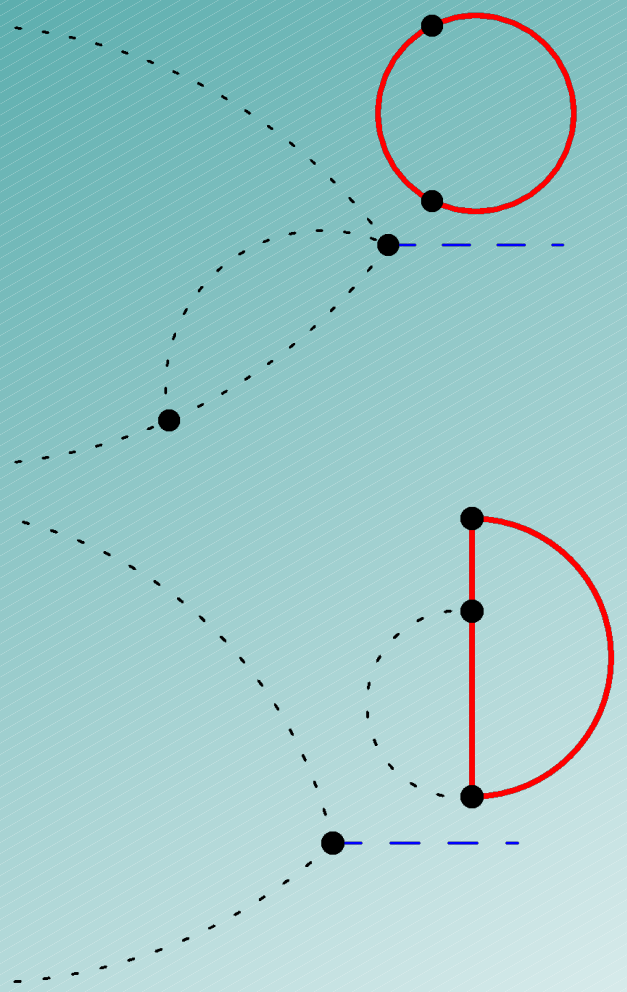
3 scale-integrals



$k \sim m_h, s$

$k \sim m_t$

2 x 1 scale- integrals



At NNLO, need to calculate

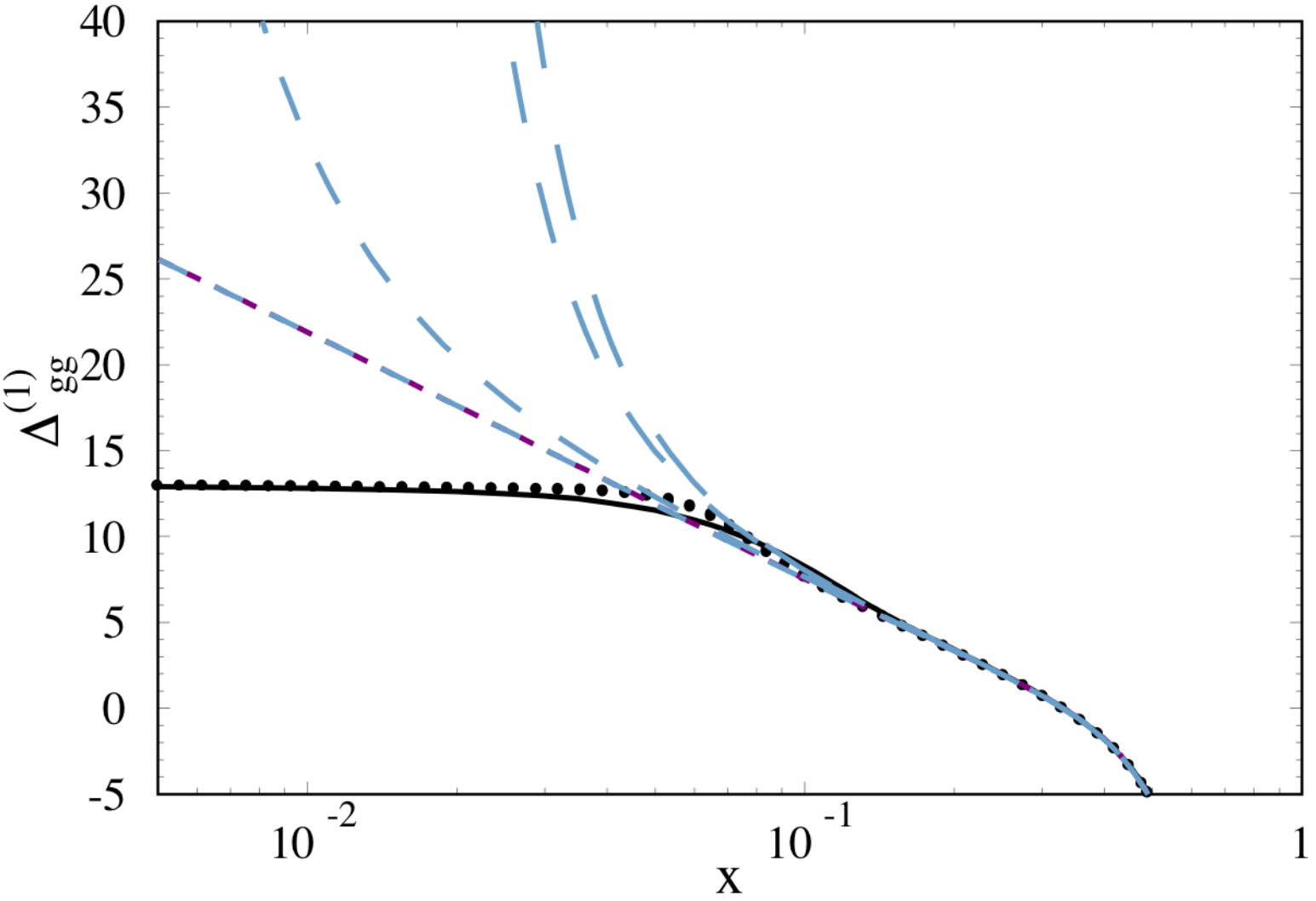
(1,2,3-loop) vacuum bubbles

times

(2-loop 2→1, 1-loop 2→2, tree-level 2→3) functions

No need for higher order operators

NLO gg channel: top mass effects



$$x = \frac{m_h^2}{s_{g\,g}}$$

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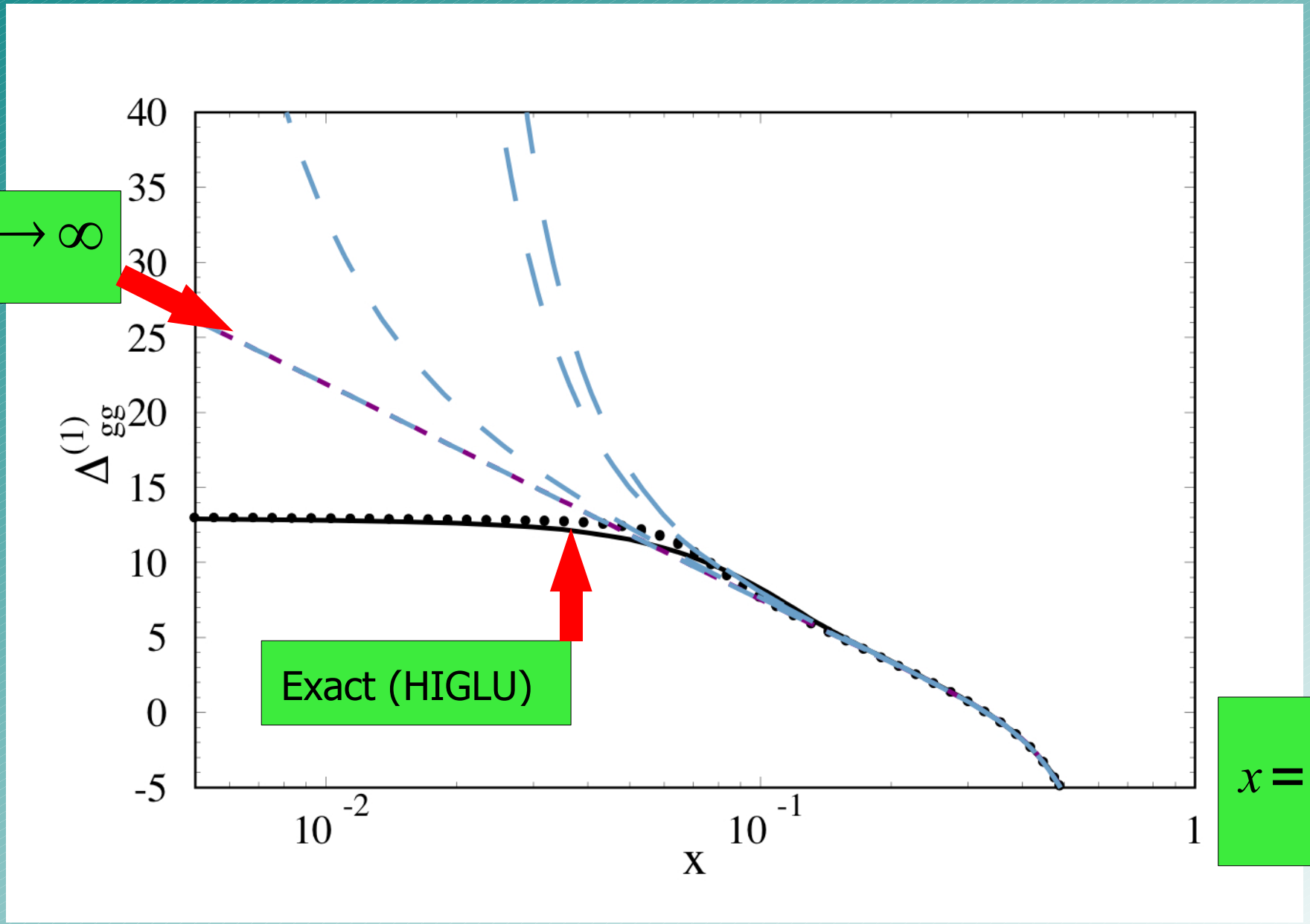
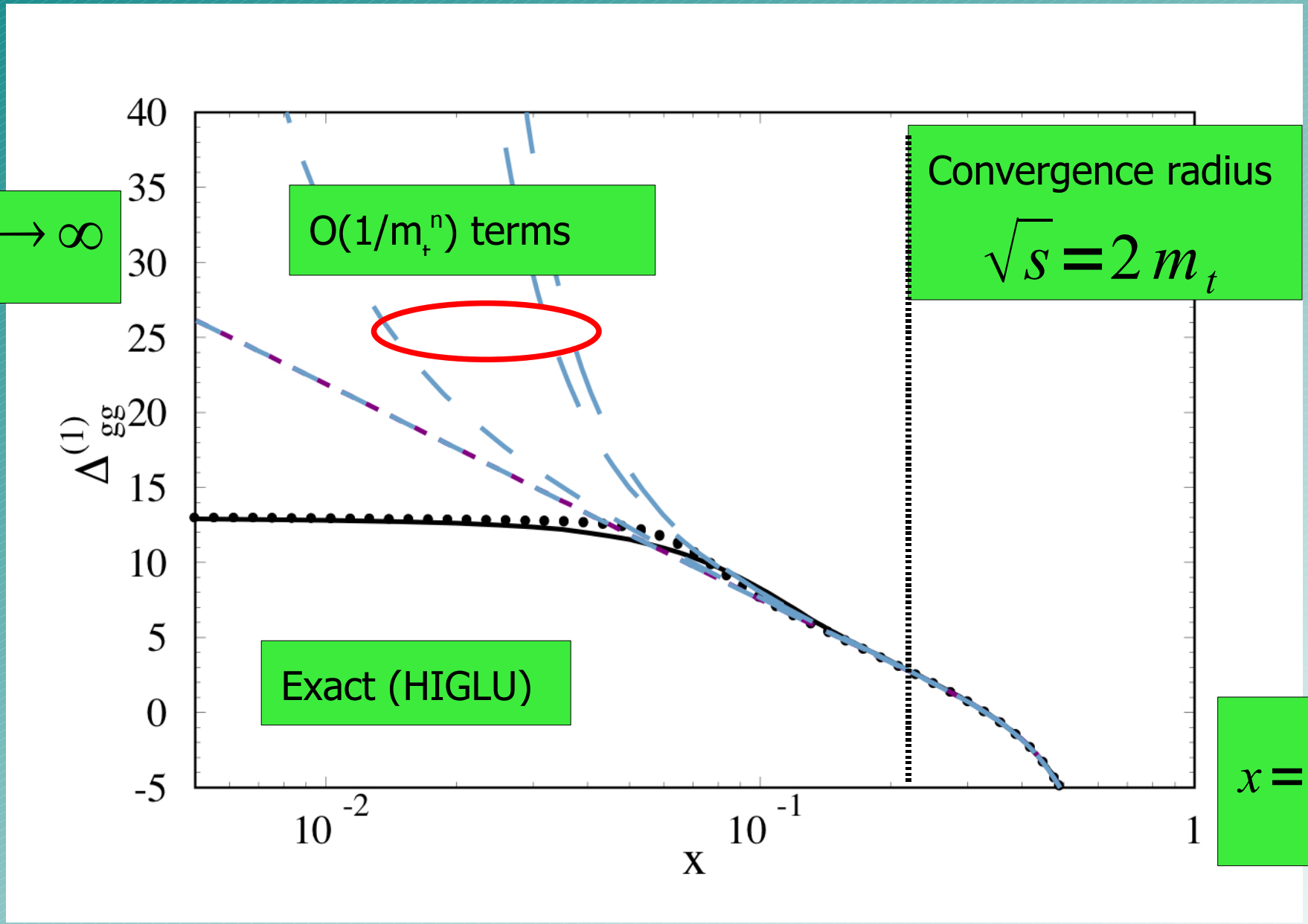
NLO gg channel: top mass effects



NLO gg channel: top mass effects



NLO gg channel: top mass effects

NLO and NNLO asymptotics:
[Marzani, Ball, Del Duca, Forte, Vicini '08]

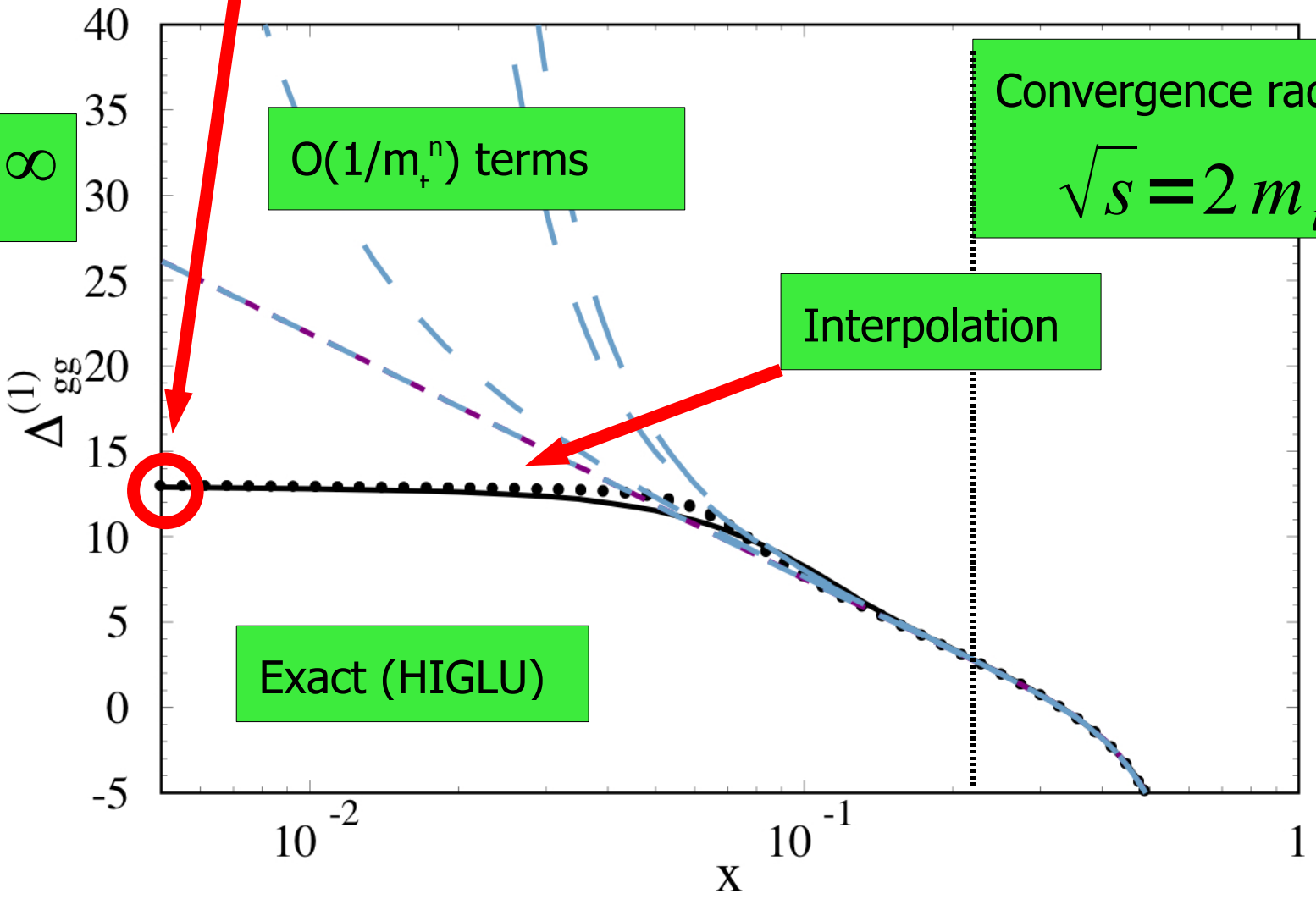
$m_t \to \infty$

O($1/m_t^n$) terms

Convergence radius
$\sqrt{s} = 2\, m_t$

Interpolation

Exact (HIGLU)

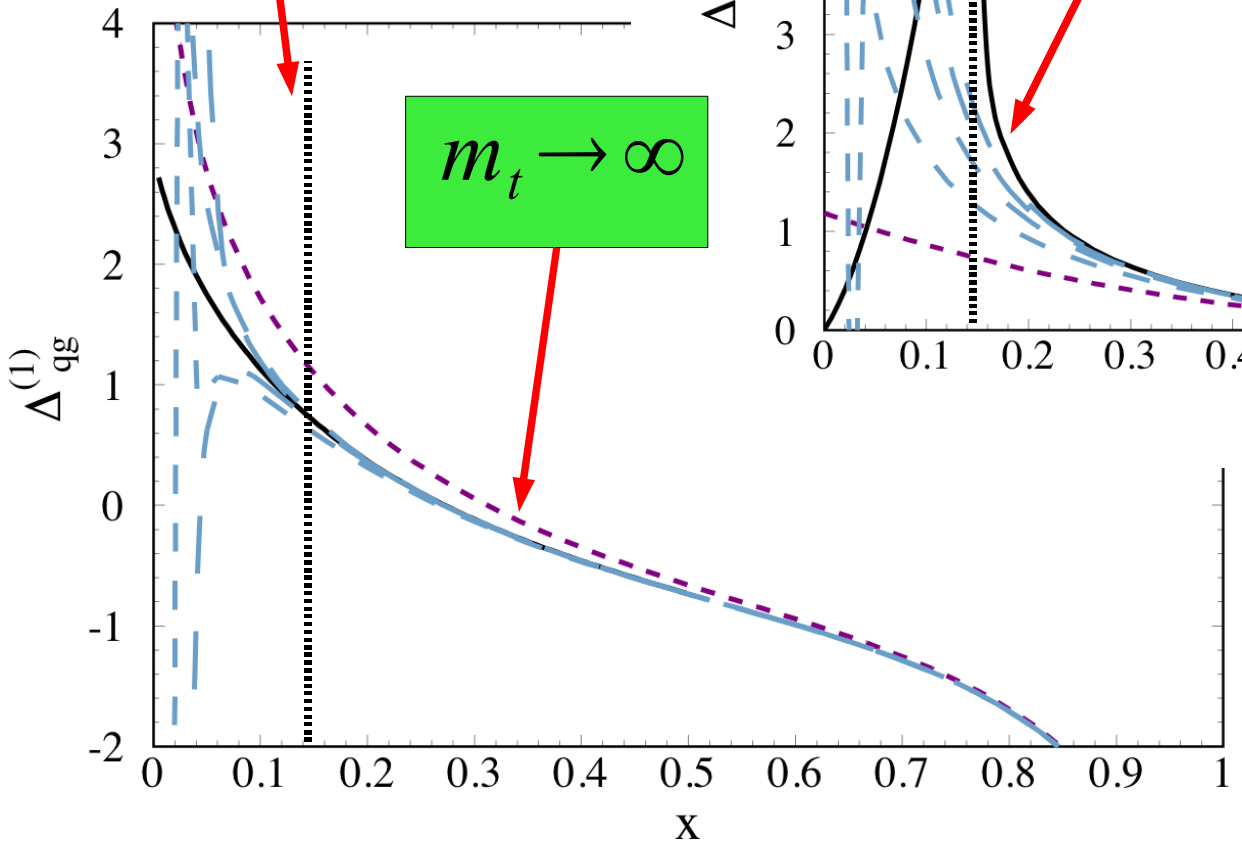


$x = \dfrac{m_h^2}{s_{gg}}$

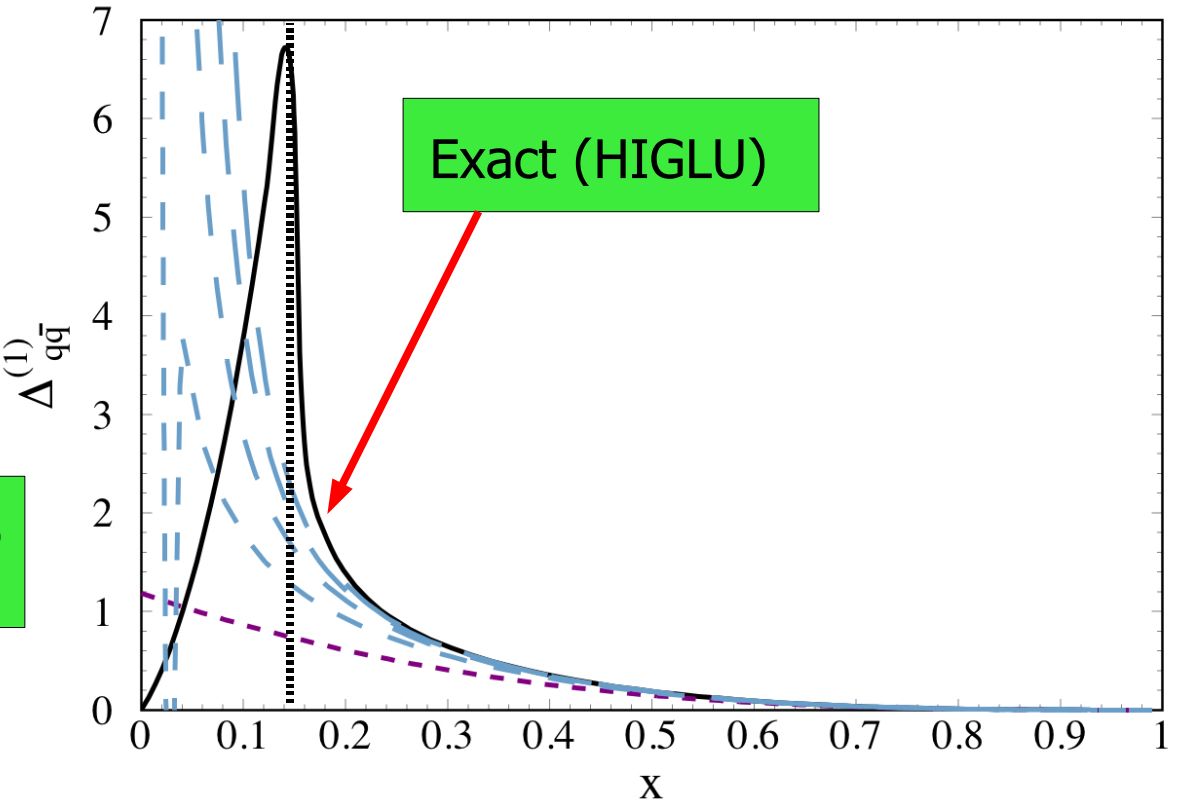
NLO qg and qqbar: partonic cross-sections

Real top pair production threshold

$m_t \to \infty$

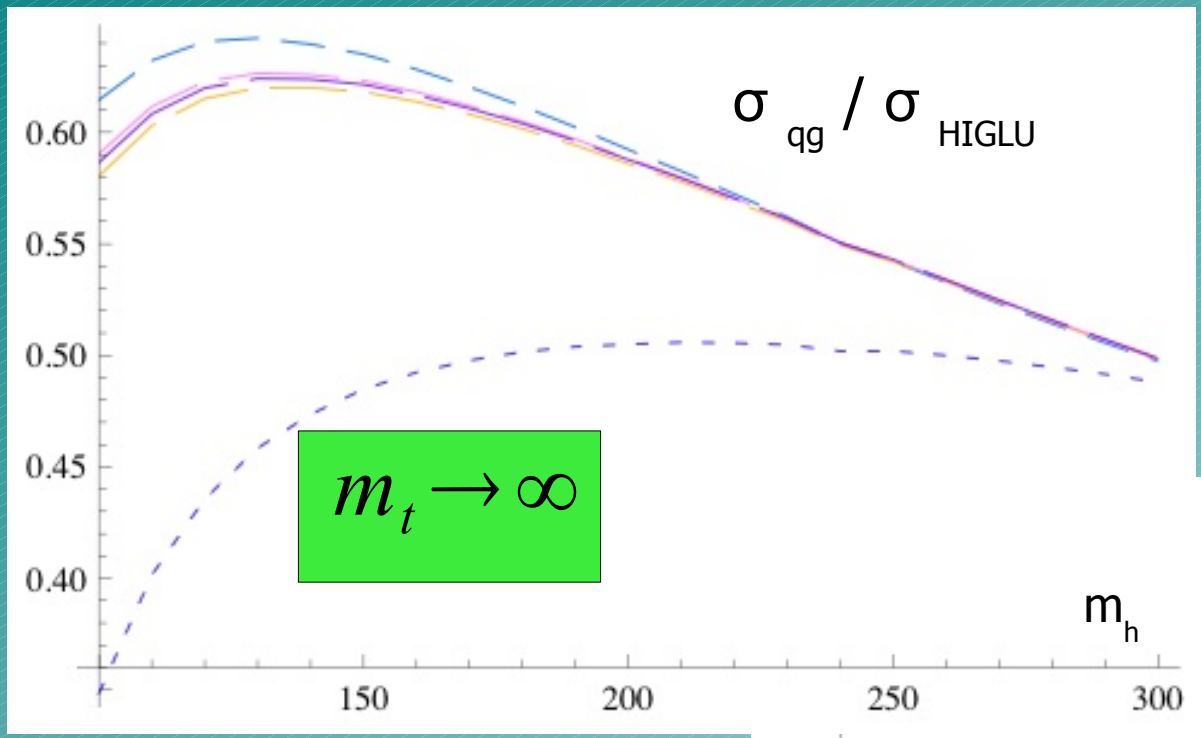


Exact (HIGLU)

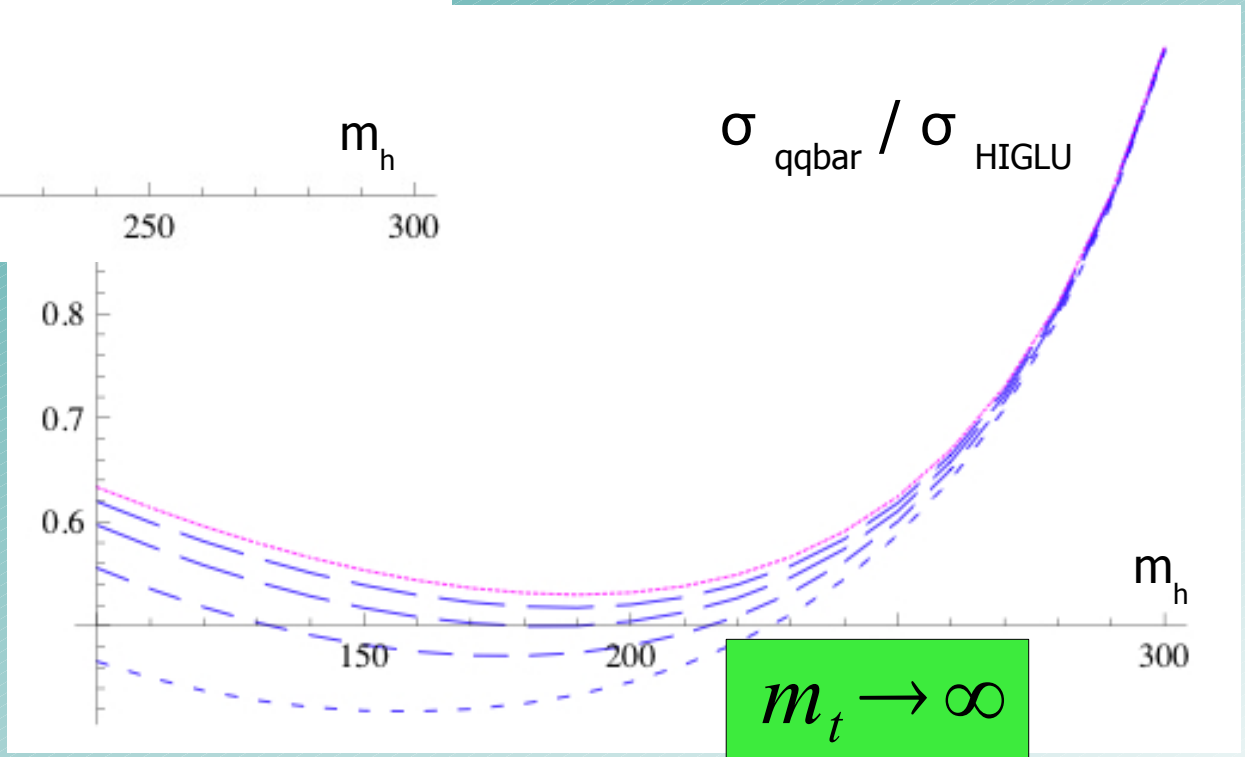


Unfortunately, at NNLO asymptotics not available

NLO qg and qqbar: hadronic study



Poor-man's recipe:
use $1/m_t$ expansion
below threshold, and
heavy top limit above



Not particularly bad:
O(40%) difference
for subleading terms

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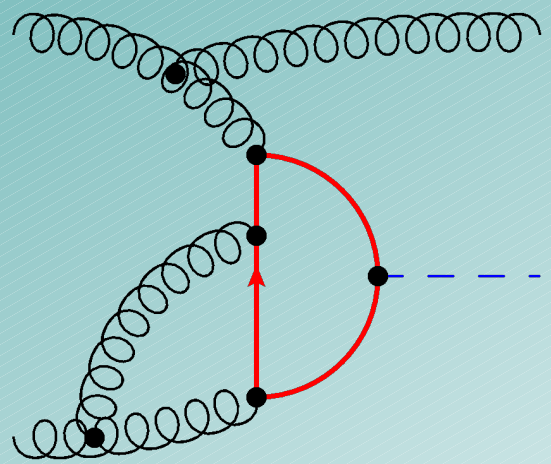
NNLO top mass effects

Virtual corrections: known to $O(1/m_t^8)$

[Harlander, Ozeren '09], [Pak,Rogal,Steinhauser '09]

Full NNLO result: (see R.Harlander's talk)
[Harlander, Ozeren '09]

- $O(1/m_t^6)$ corrections calculated
- $2 \to 2$, $2 \to 3$ phase space integration
- Result as a series in (1-x) to 13-th order



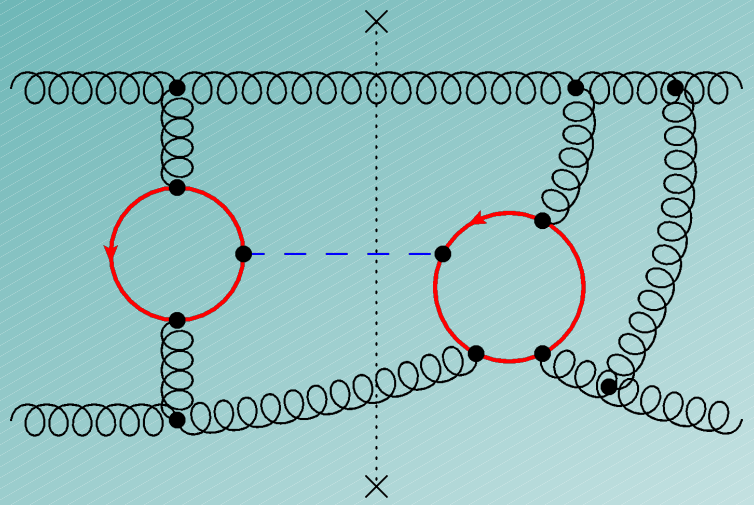
A very challenging calculation;
a cross-check is desirable!

NNLO calculation

Our approach:

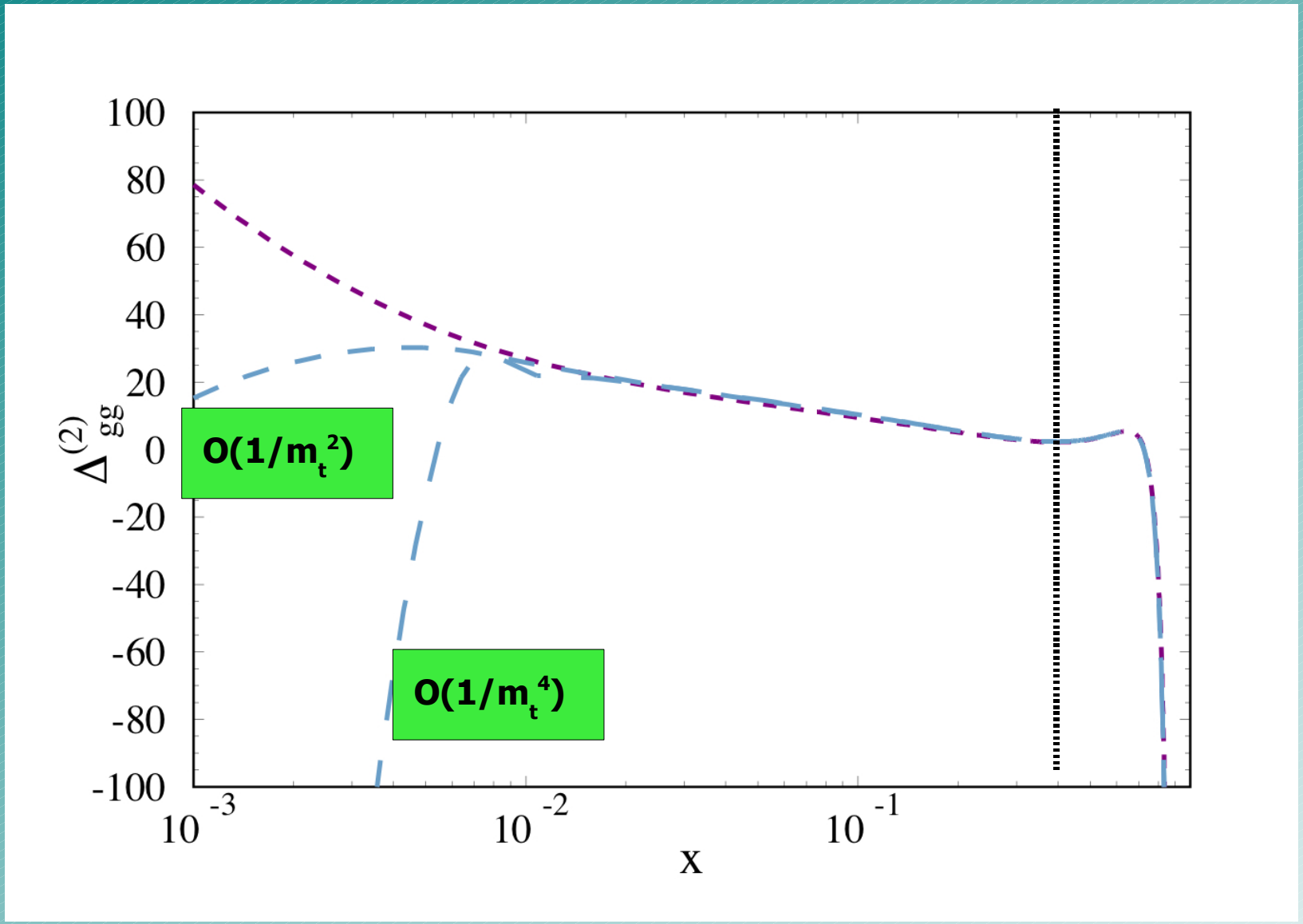
- Compute imaginary part of 4-loop diagrams
- Diagrams: QGRAF **[Nogueira '93]**, zeros filtered
- Two independent calculations (Q2E/EXP + a custom program)
- Reduction by Laporta algorithm (retaining full x-dependence)
- 2-loop x-dependent master integrals: re-calculated using differential equations and soft expansion in terms of HPLs
- **Result: few first terms in ρ expansion, full dependence on x**

~ 20000 non-zero diagrams
~ 1 month of 100 x CPU for $O(1/m_t^6)$ terms



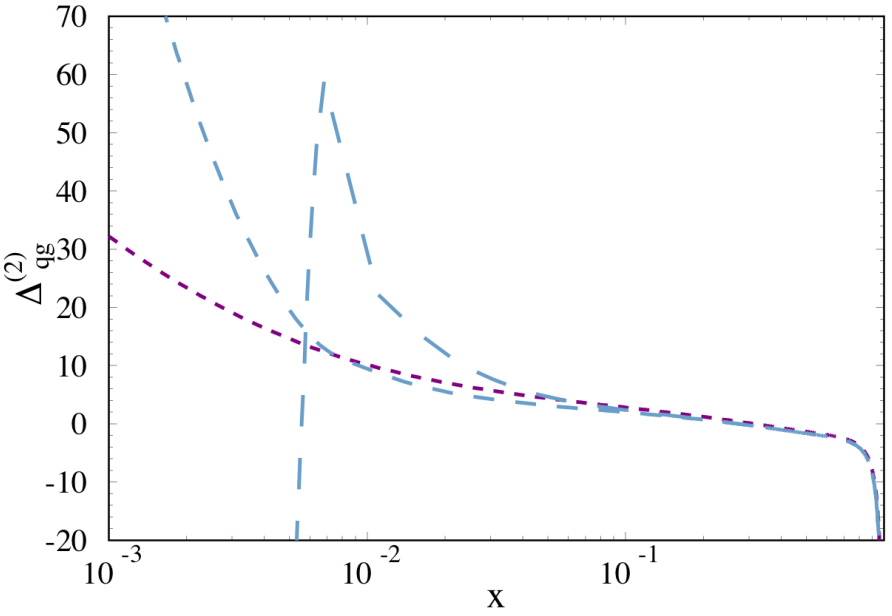
$$x = \frac{m_h^2}{s_{g\,g}}\,,\ \rho = \frac{m_h^2}{m_t^2}$$

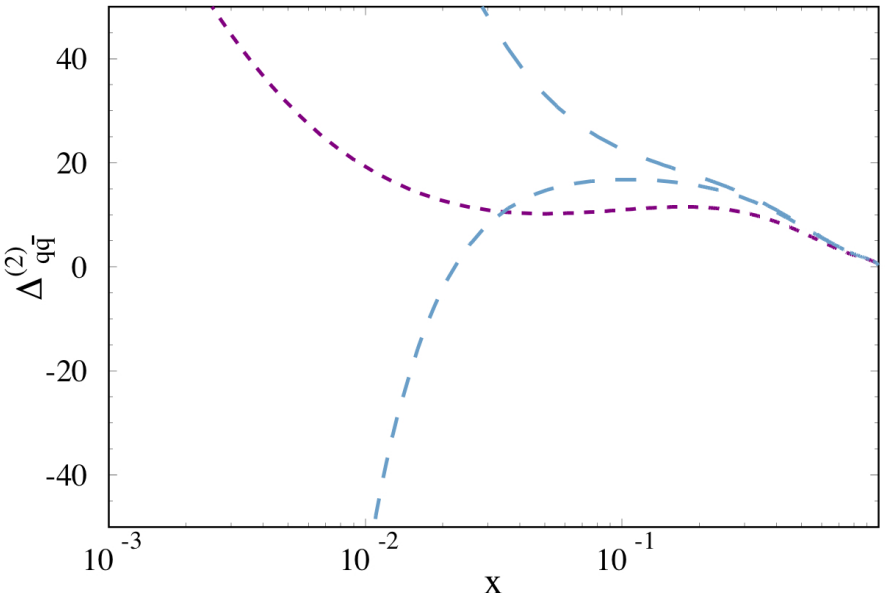
NNLO partonic results: gg channel

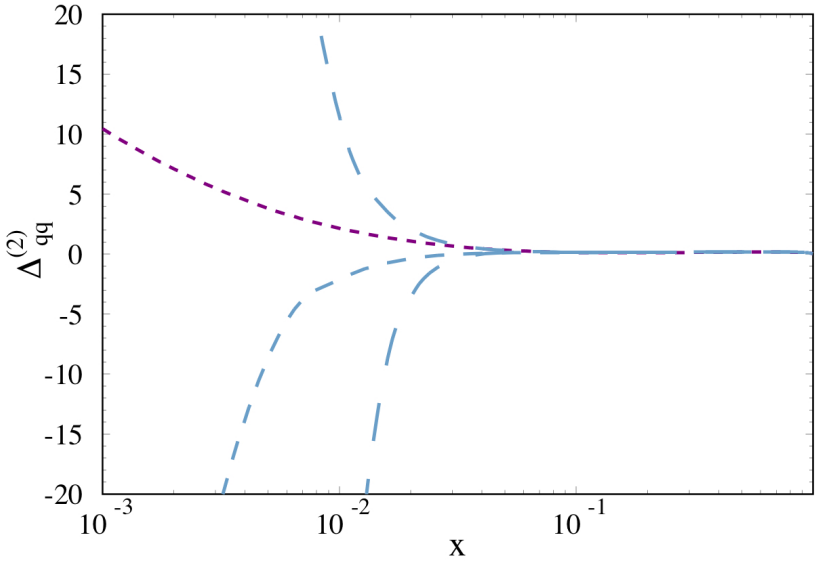


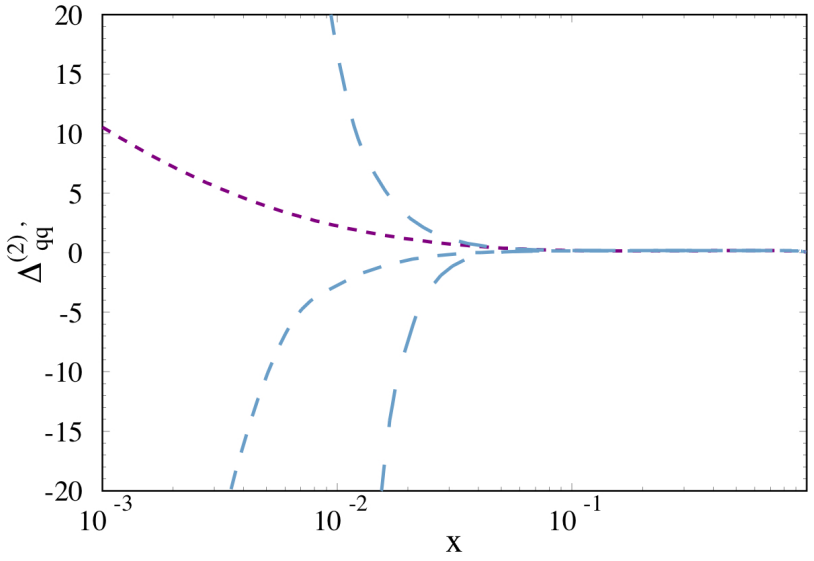
Full analytic agreement with results by Harlander and Ozeren!

NNLO partonic results: subleading channels

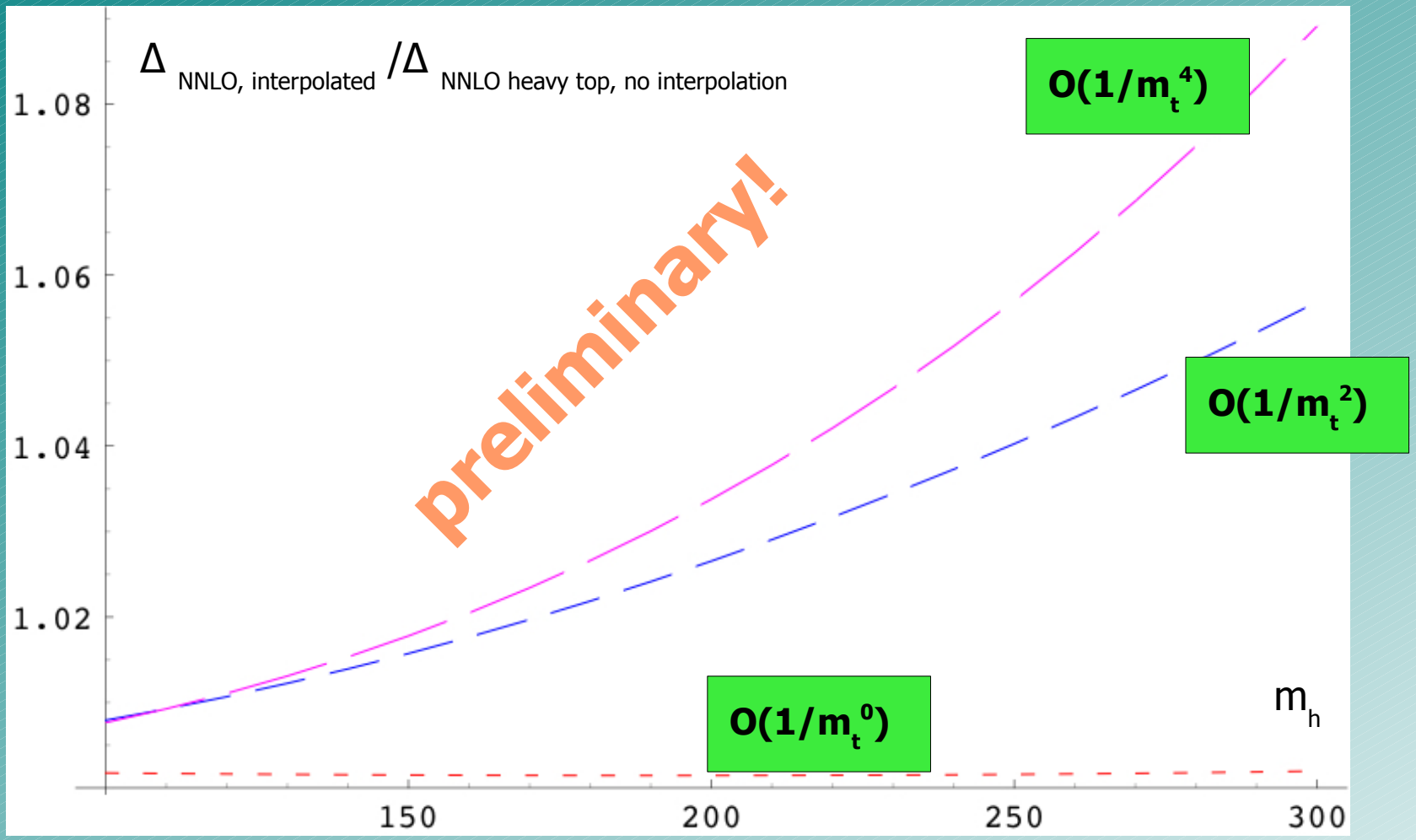






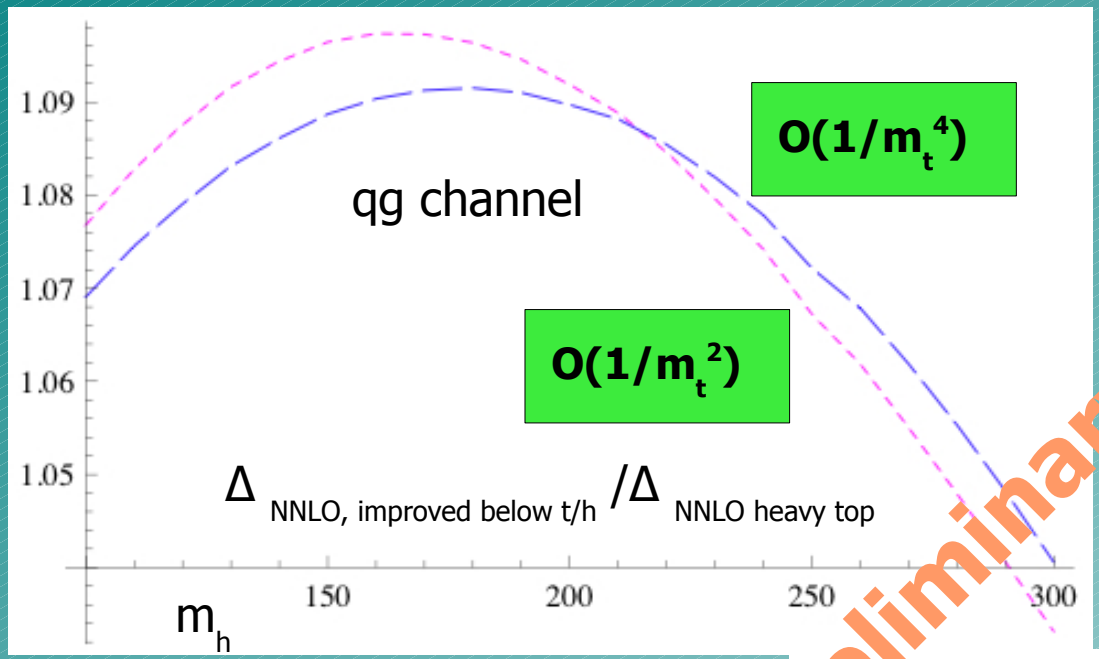


NNLO hadronic results: gg channel

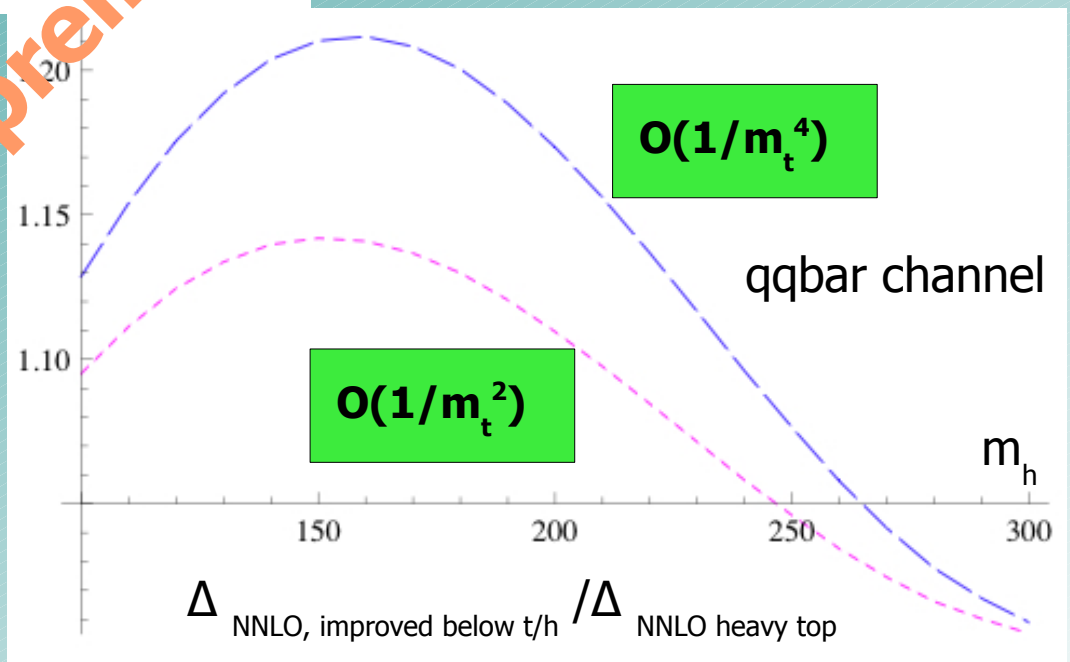


Effect on the cross-section < 1%

NNLO hadronic results: subleading channels



preliminary!



Shifts not dramatic, very small impact

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Summary

- Top mass corrections to Higgs production have been found exactly in x, existing expansions (by Harlander and Ozeren) around soft limit confirmed
- Shift of hadronic results smaller than scale uncertainties (a non-trivial result!)
- Results and a more detailed phenomenology analysis to be published soon

Thank you for your attention!