Finite top quark mass effects in NNLO Higgs boson production

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Outline

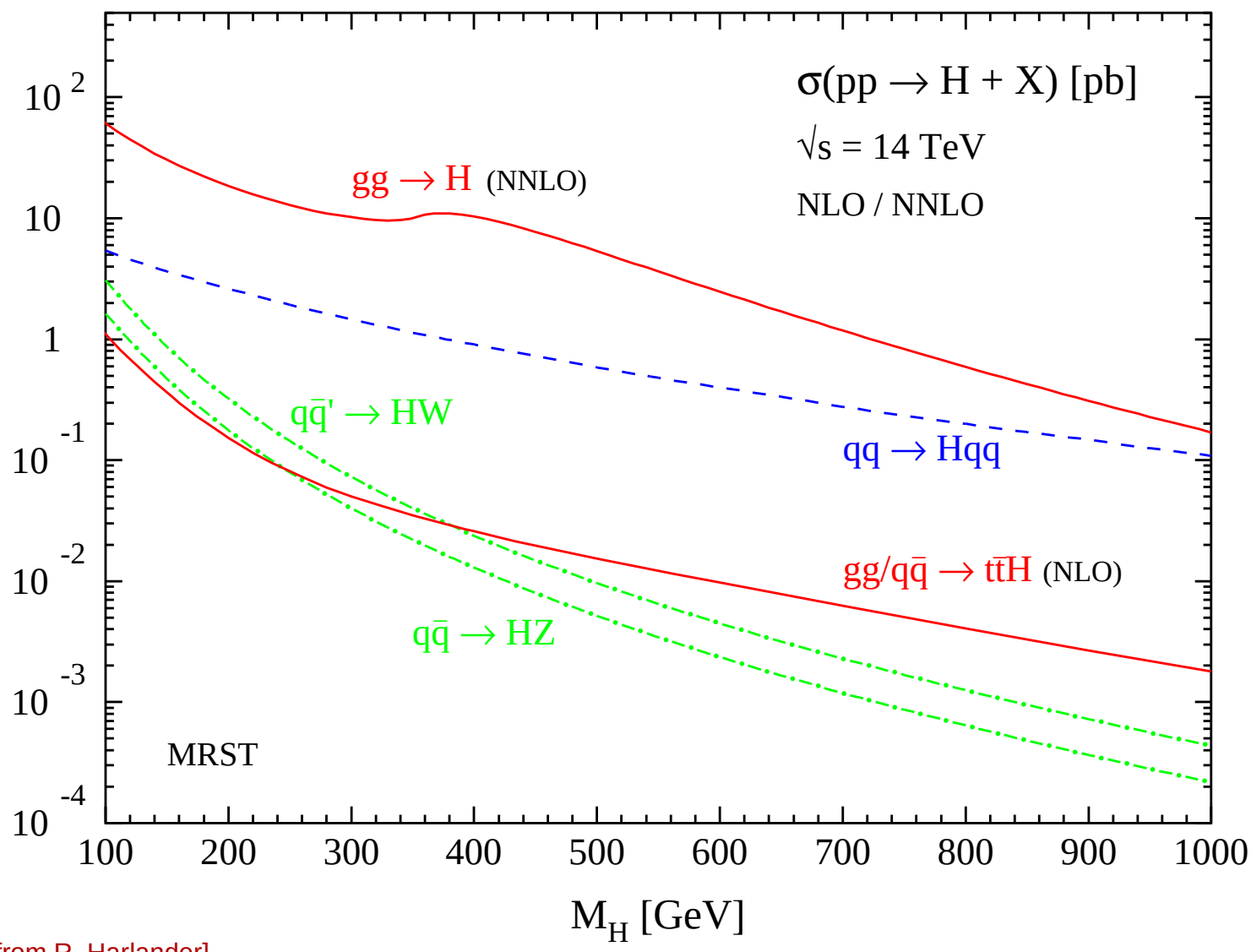
I. Introduction

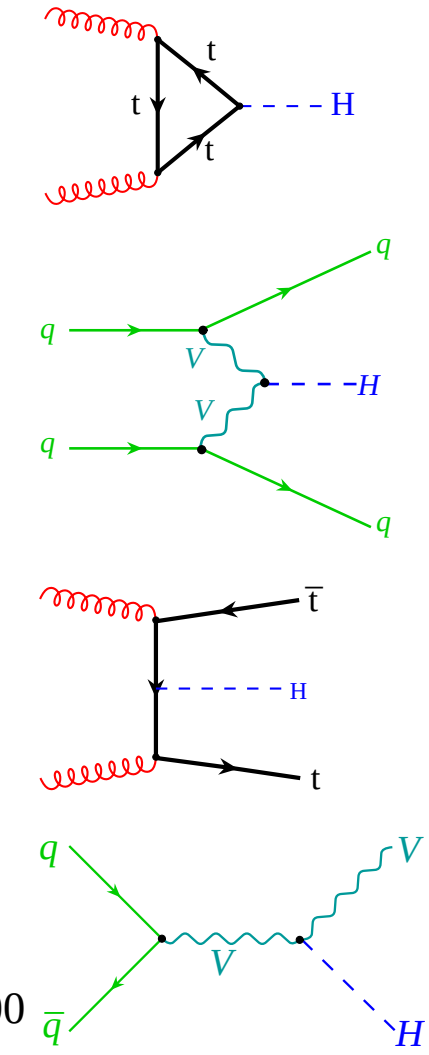
II. $gg \to H$ in effective theory

III. Finite M_t

IV. Conclusions

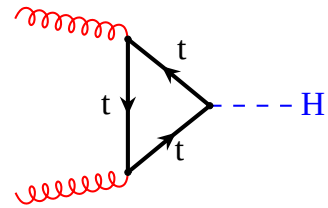
Higgs production mechanisms



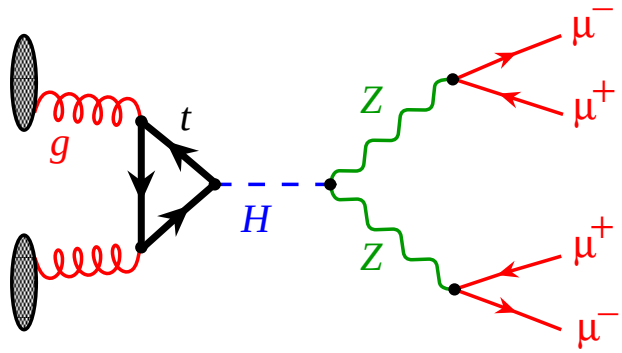


[from R. Harlander]

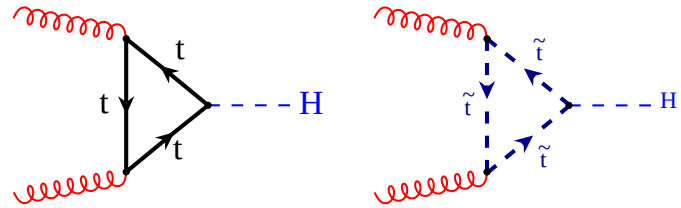
Gluon fusion



- largest cross section
- $gg \to H \to ZZ \to 4\mu$: gold plated mode for $M_H \gtrsim 135\,\text{GeV}$

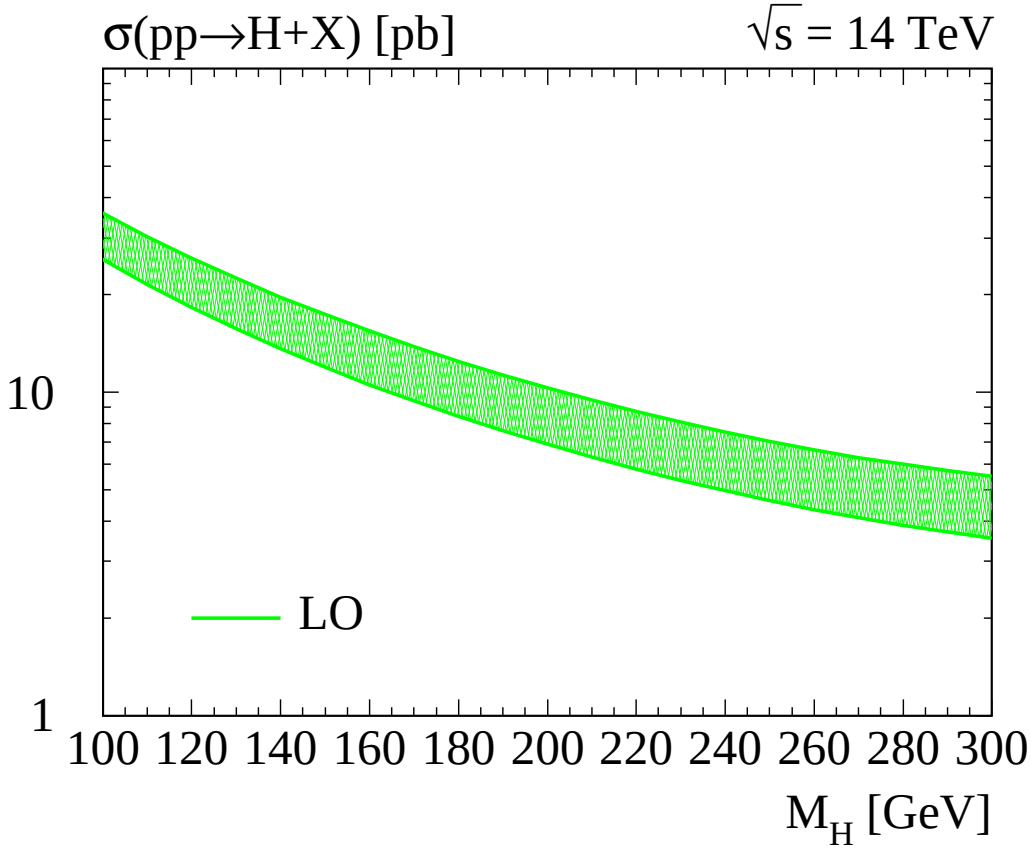


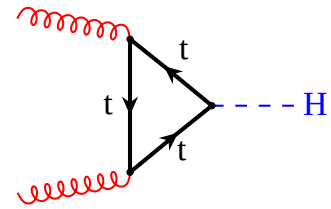
- sensitive to heavy particles, supersymmetry



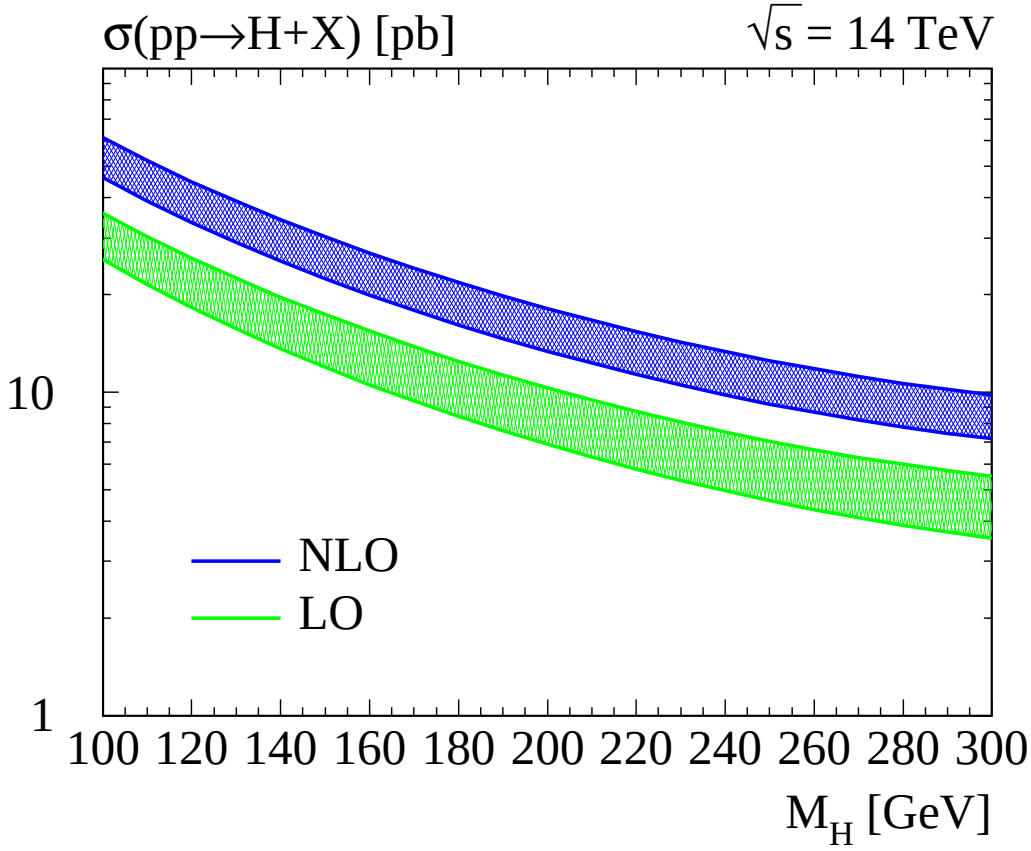
- top Yukawa coupling

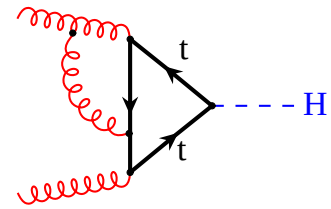
Gluon fusion to NNLO





Gluon fusion to NNLO

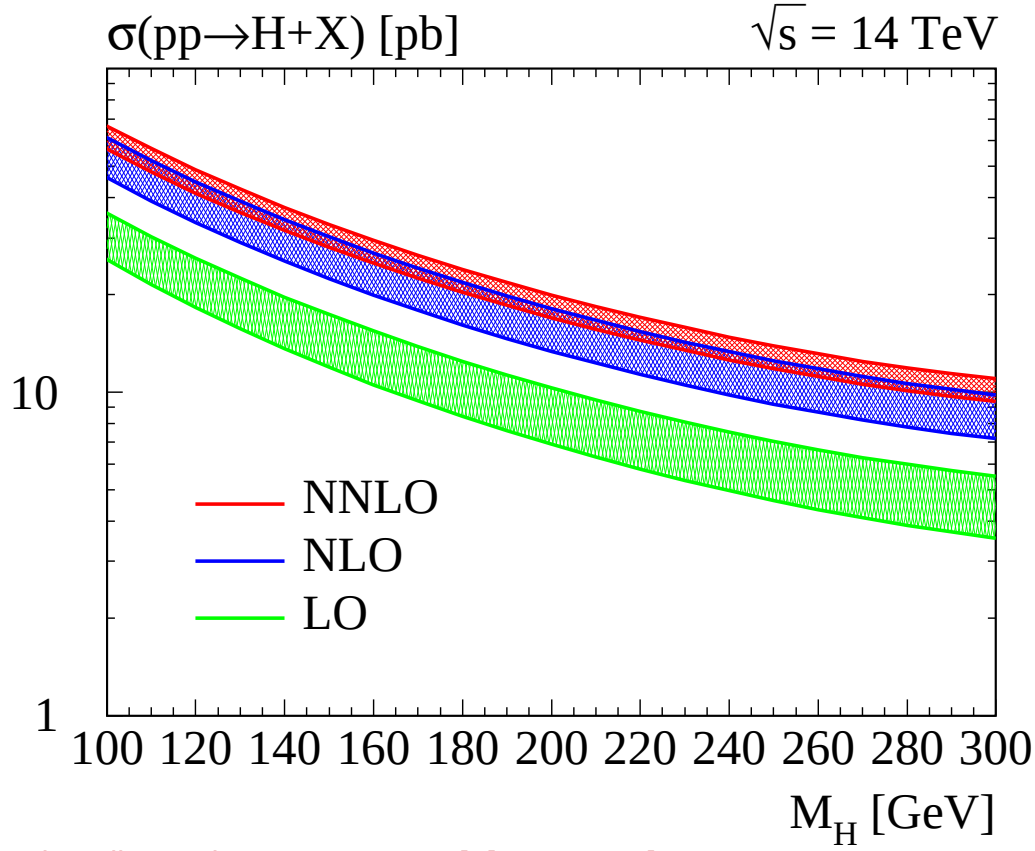


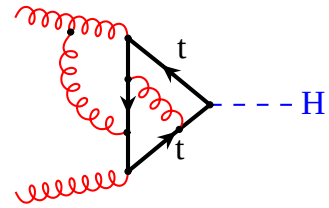


70%-100% correction!

[Spira,Djouadi,Graudenz,Zerwas'91'93] [Dawson'91]

Gluon fusion to NNLO



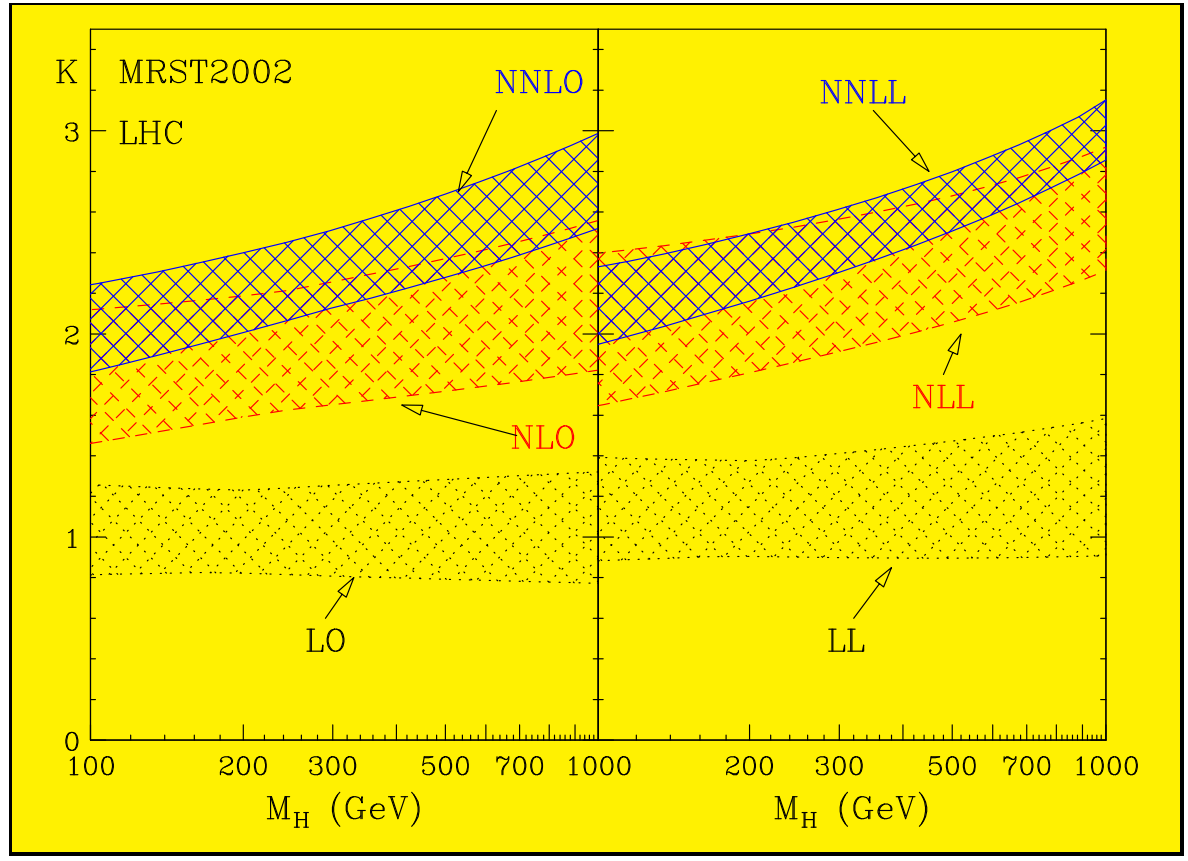


[Spira,Djouadi,Graudenz,Zerwas'91'93] [Dawson'91]

[Harlander,Kilgore'02], [Anastasiou,Melnikov'02],[Ravindran,Smith,v.Neerven'03]

NLO:	exact
NNLO:	$M_t \to \infty$

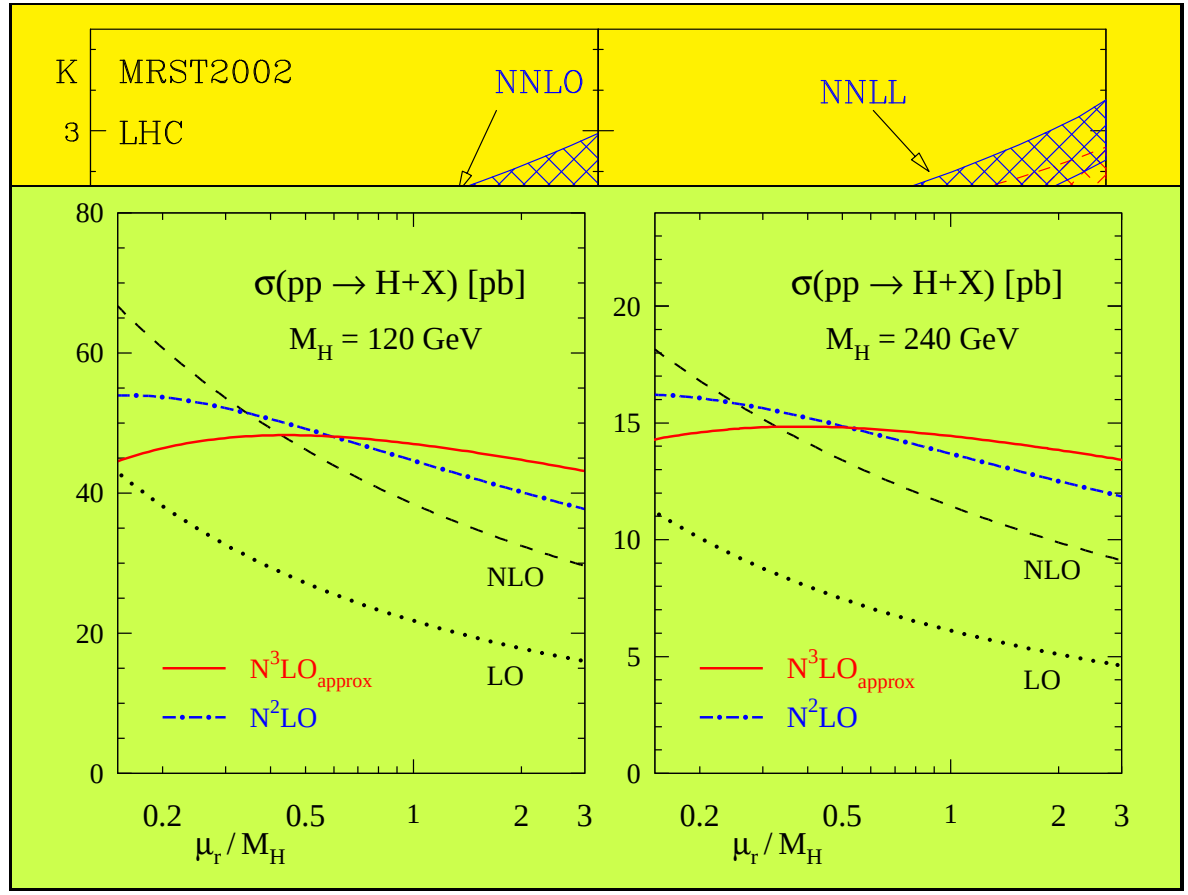
Resummations



soft gluons

[Catani,de Florian,Grazzini,Nason'03]

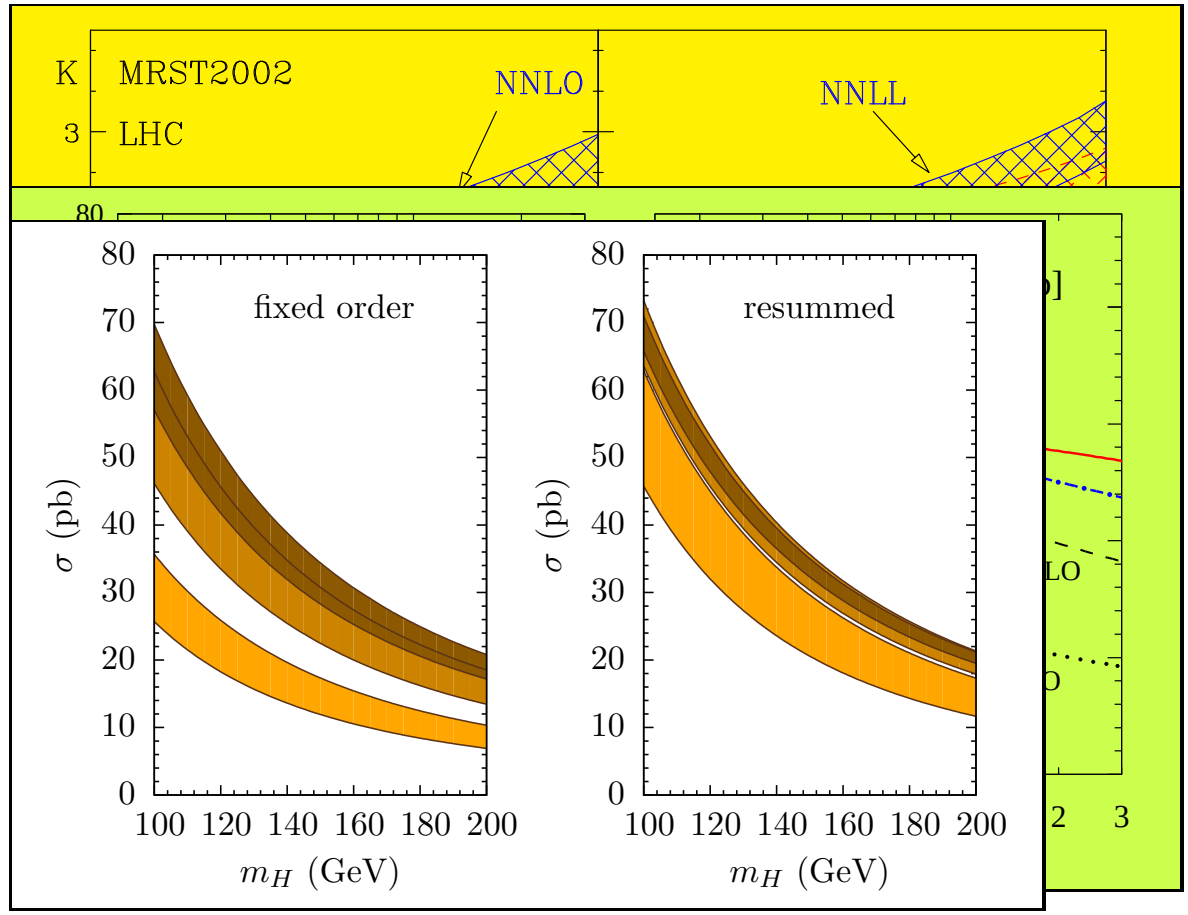
Resummations



soft gluons to NNNLL

[Moch,Vogt'05,Ravindran'05'06]

Resummations



„π^2-Resummation“

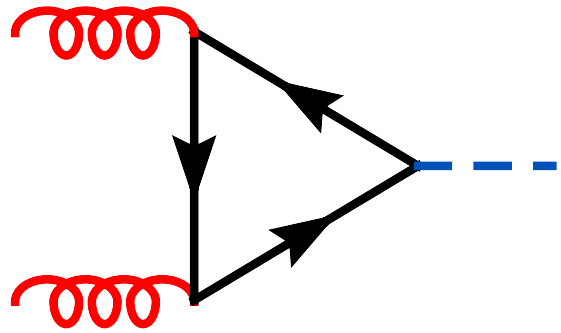
[Ahrens,Becher,Neubert,Yang'08]

all based on “heavy-top approximation”

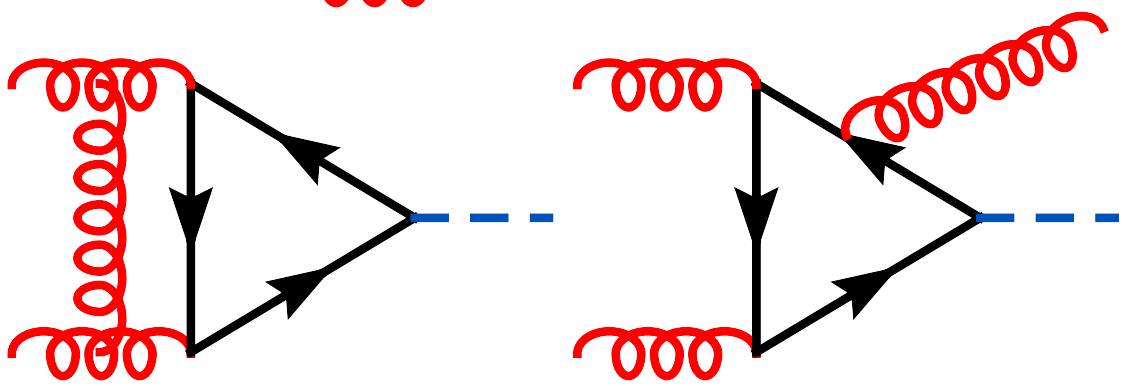
$gg \to H$: LO, NLO

Higgs production in gluon fusion at LHC

LO



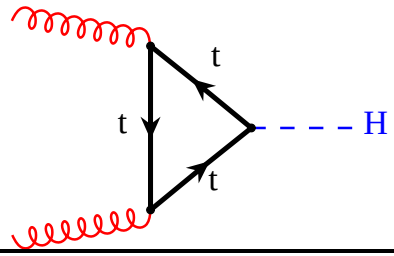
NLO



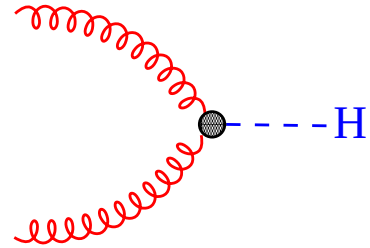
complete dependence on $\hat{s}, M_t, M_H$

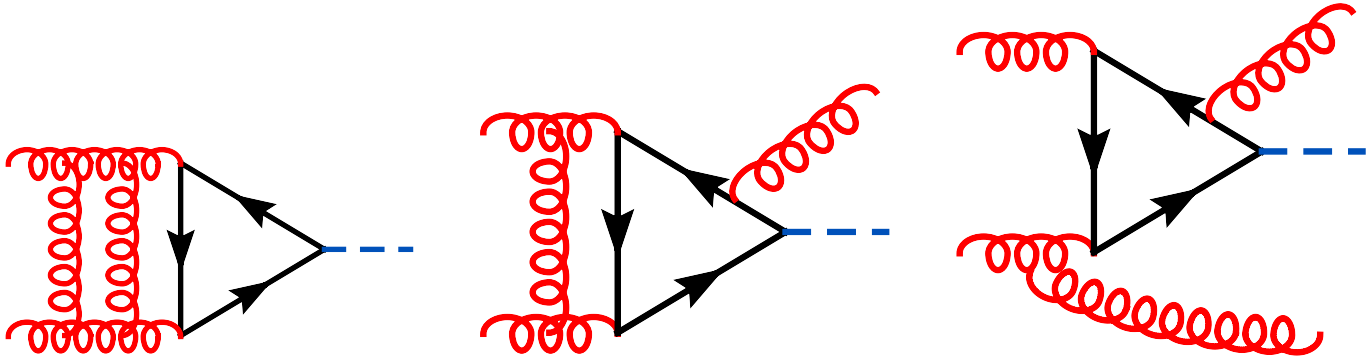
[Dawson'90; Spira,Djouadi,Graudenz,Zerwas'91'95]

Effective theory

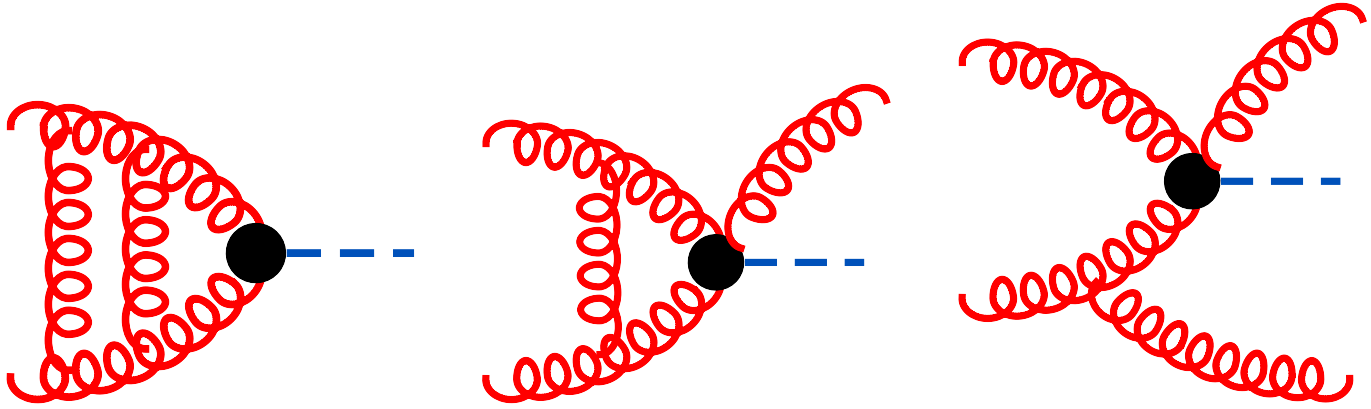


$$\overset{M_t \gg M_H}{\longrightarrow} \quad C(M_t, \alpha_s) \times$$

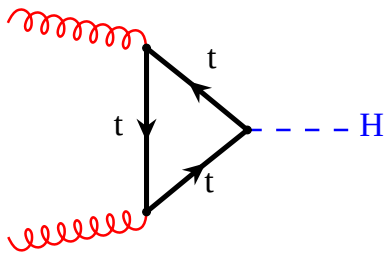




$$\Downarrow \quad M_t \to \infty: \quad \mathcal{L}^{\text{eff}} = \frac{H}{v} C_1 \left(G^a_{\mu\nu}\right)^2 \quad \Downarrow$$

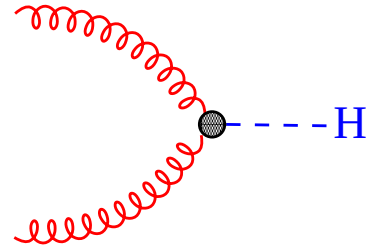


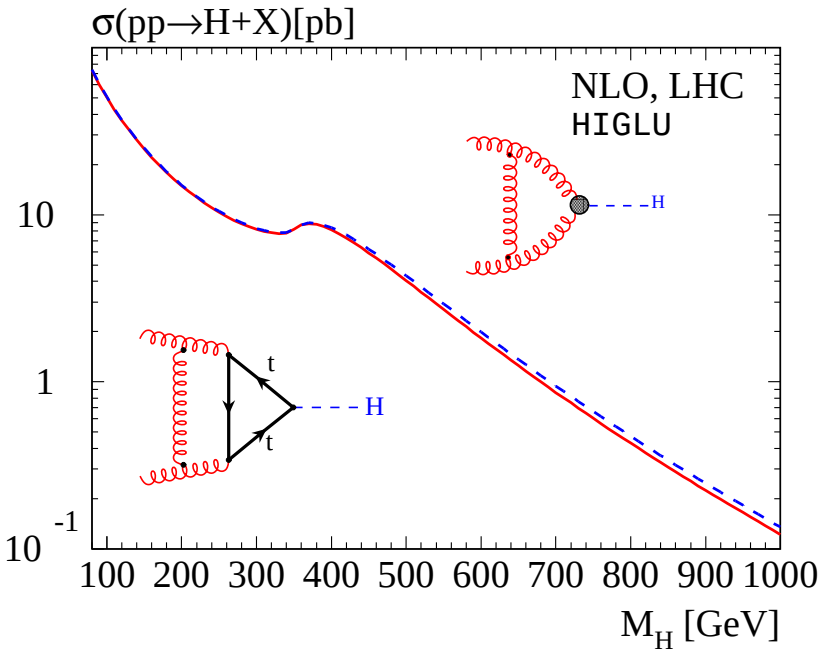
Effective theory



$$M_t \gg M_H \longrightarrow$$

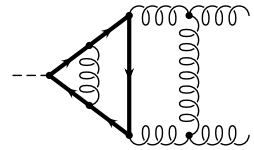
$$C(M_t, \alpha_s) \times$$





$$\sigma_\infty^{\rm HO} = \sigma^{\rm LO}(M_t) \left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}}\right)_{M_t \to \infty}$$

1. step: $C(M_t, \alpha_s)$ to NNLO



[Chetyrkin,Kniehl,Steinhauser'96] [Krämer,Laenen,Spira'96]

(even known to NNNLO [Chetyrkin,Kniehl,Steinhauser'98]

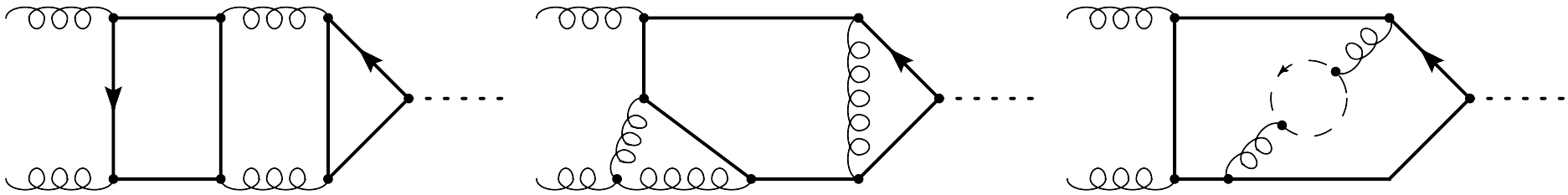
and (almost) to NNNNLO

[Schöder,Steinhauser'04; Chetyrkin,Kühn,Sturm'04])

2. step: real and virtual corrections within effective theory

Why? NNLO?

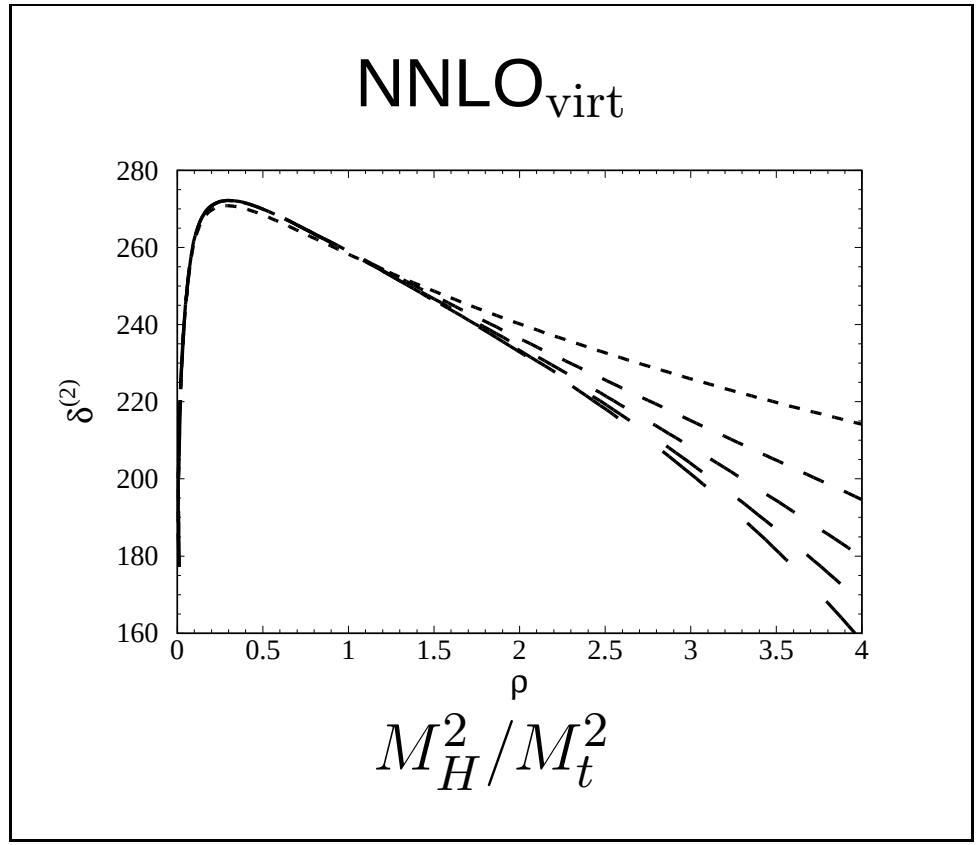
A. Virtual corrections



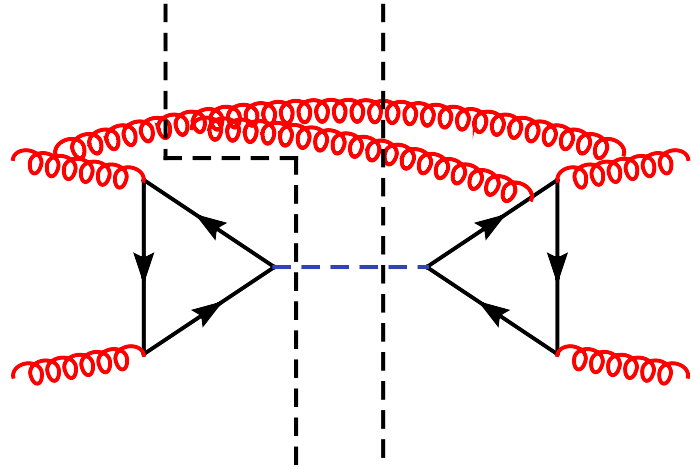
- $\hat{s} = M_H^2$
- promising: expansion for $M_t^2 \gg M_H^2$ (asymptotic expansion)

[Pak,Rogal,Steinhauser'09]

[Ozeren,Harlander'09]

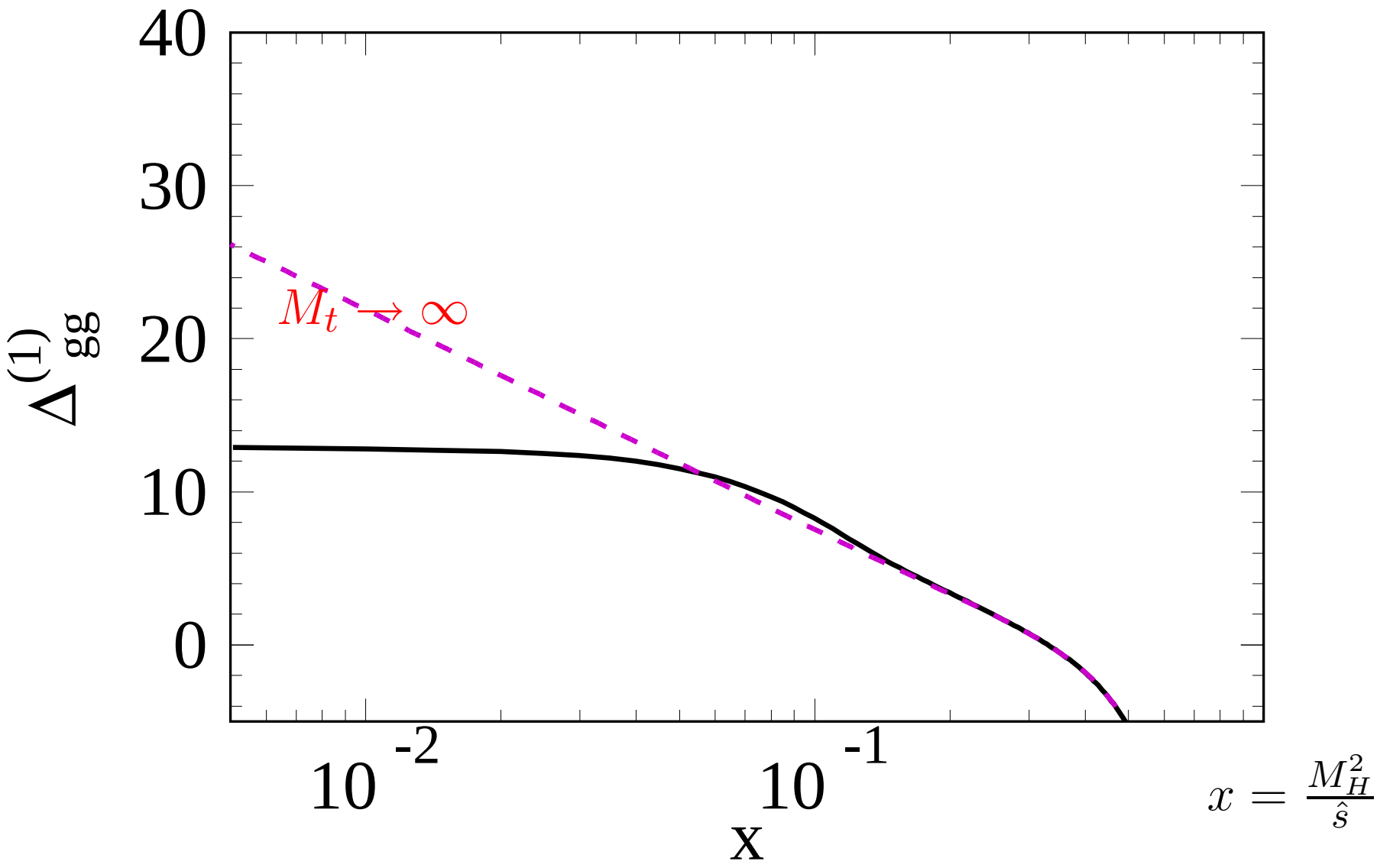


B. Real corrections

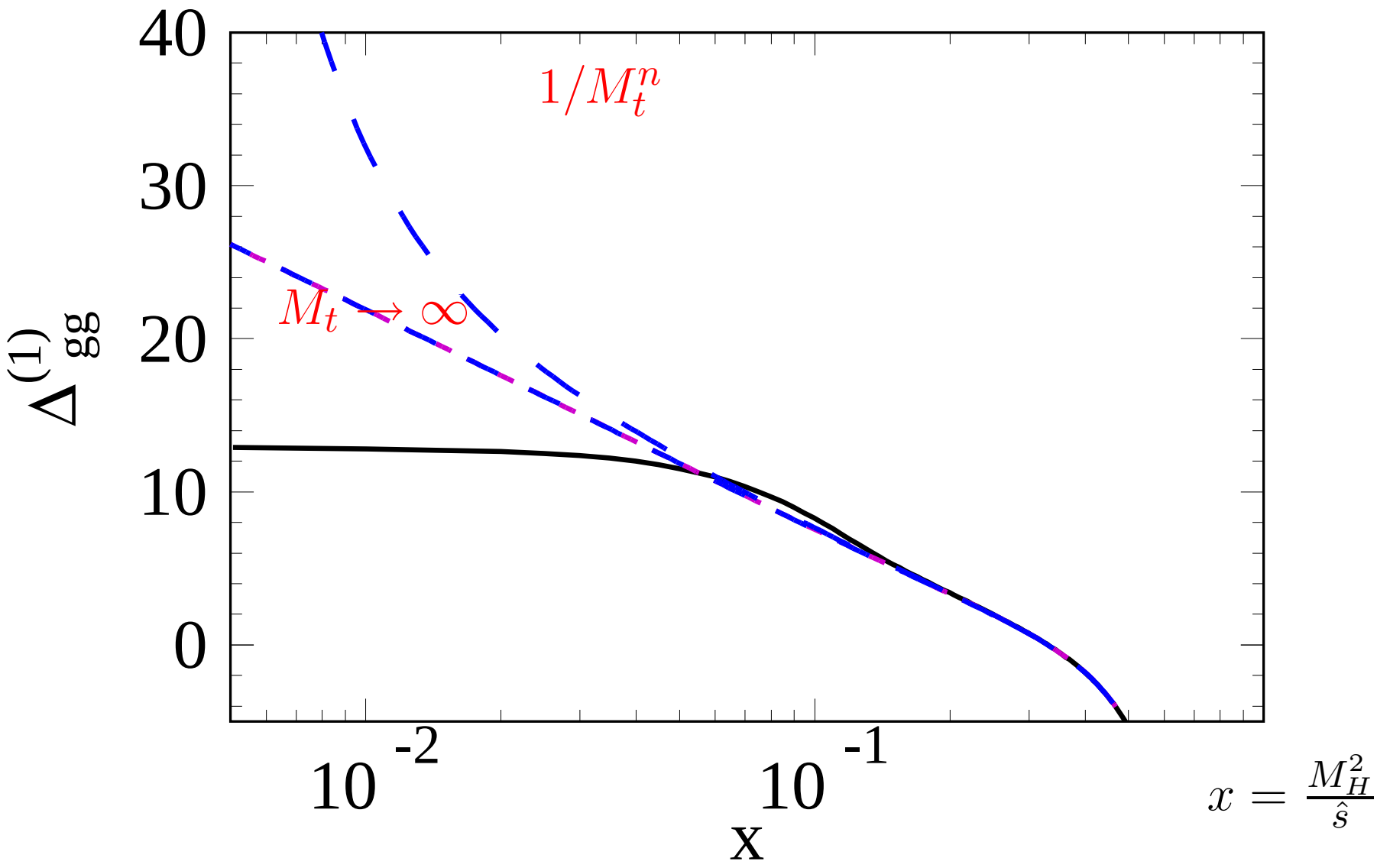


- optical theorem
- asymptotic expansion: $M_t^2 \gg M_H^2, \hat{s}$
- $\approx 20\,000$ Feynman diagrams
- several weeks of CPU time
- initial states: gg, qg, $q\bar{q}$, qq, qq'
- $gg \approx$ 95% of total cross section @ LHC

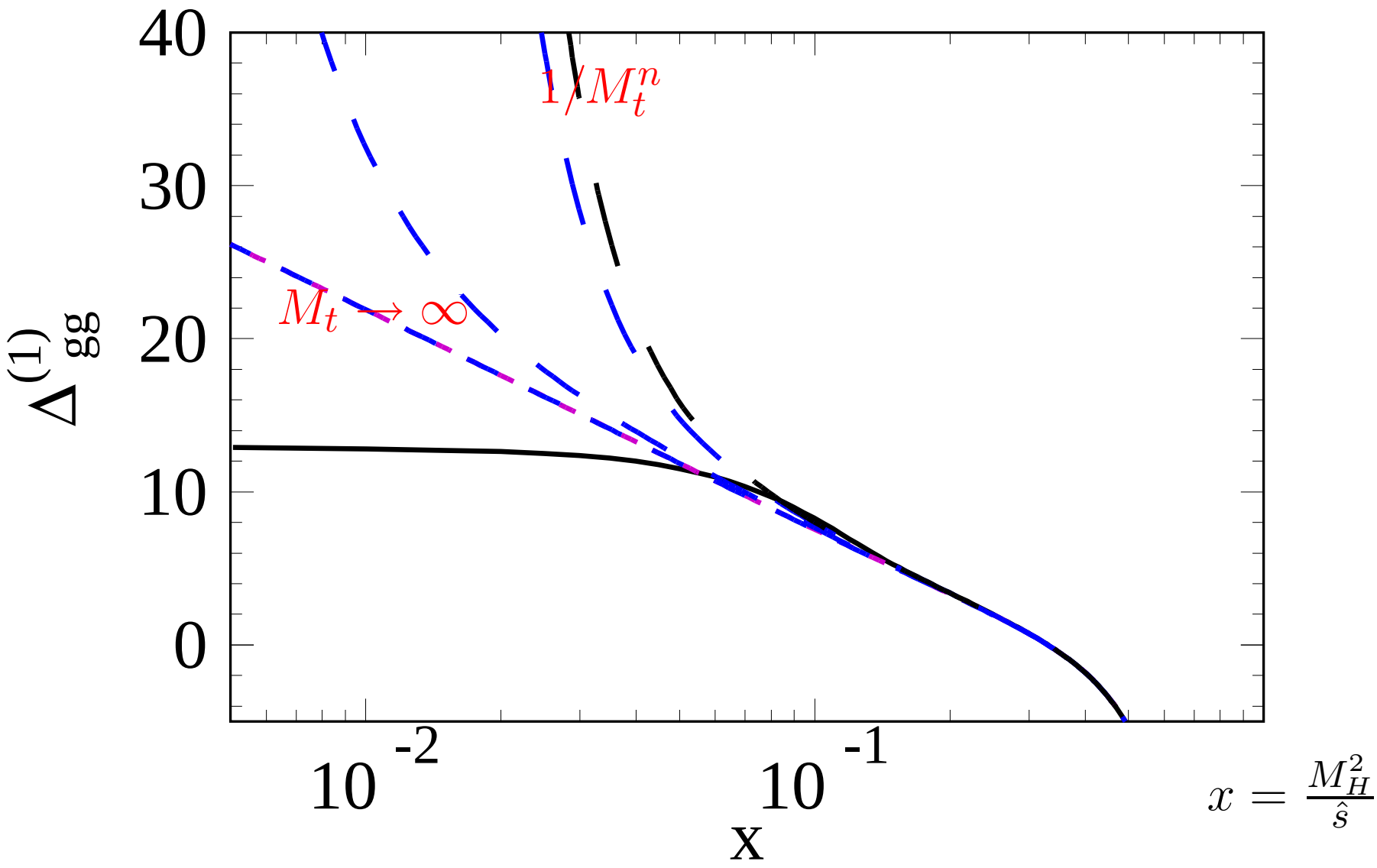
NLO partonic cross section



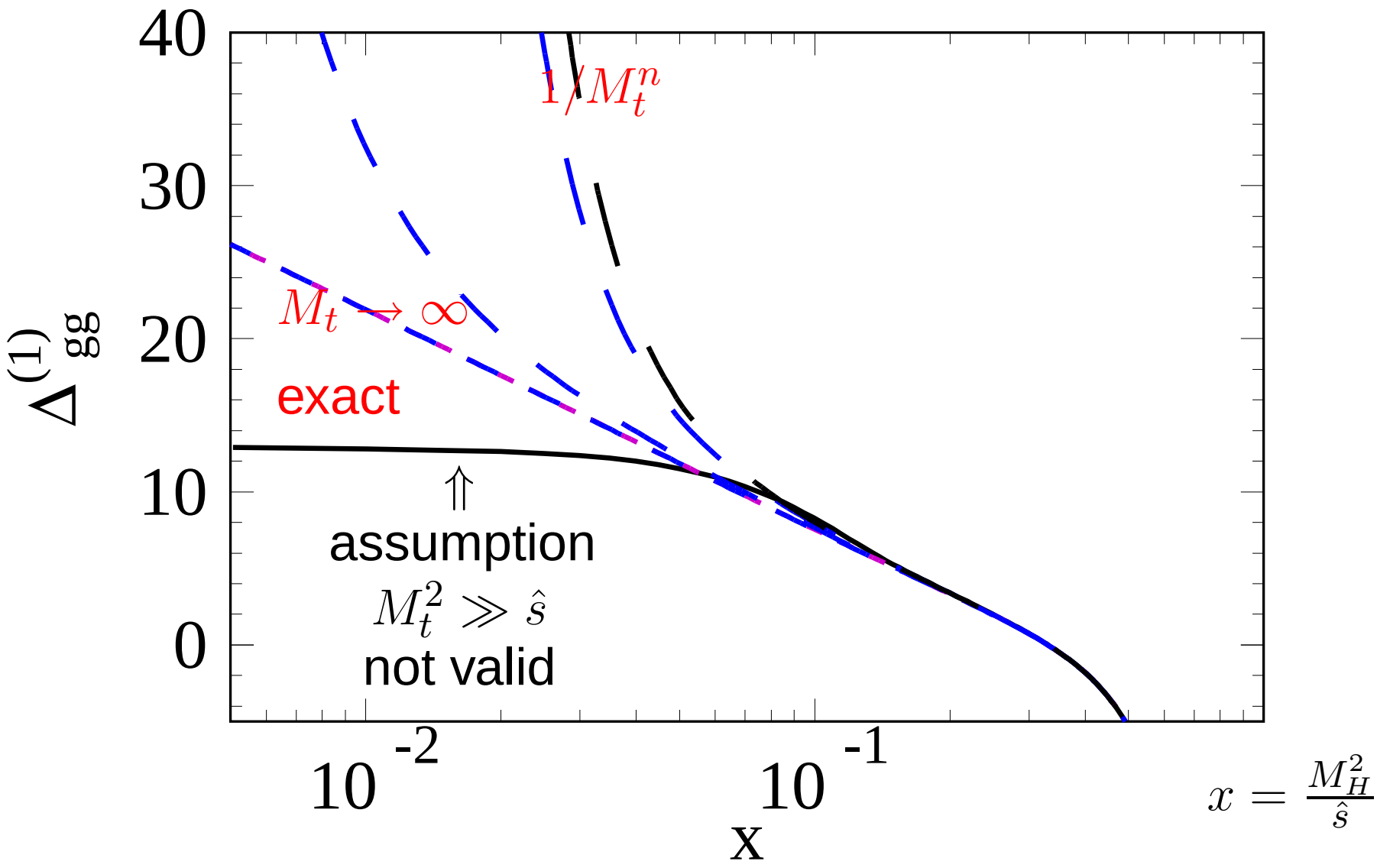
NLO partonic cross section



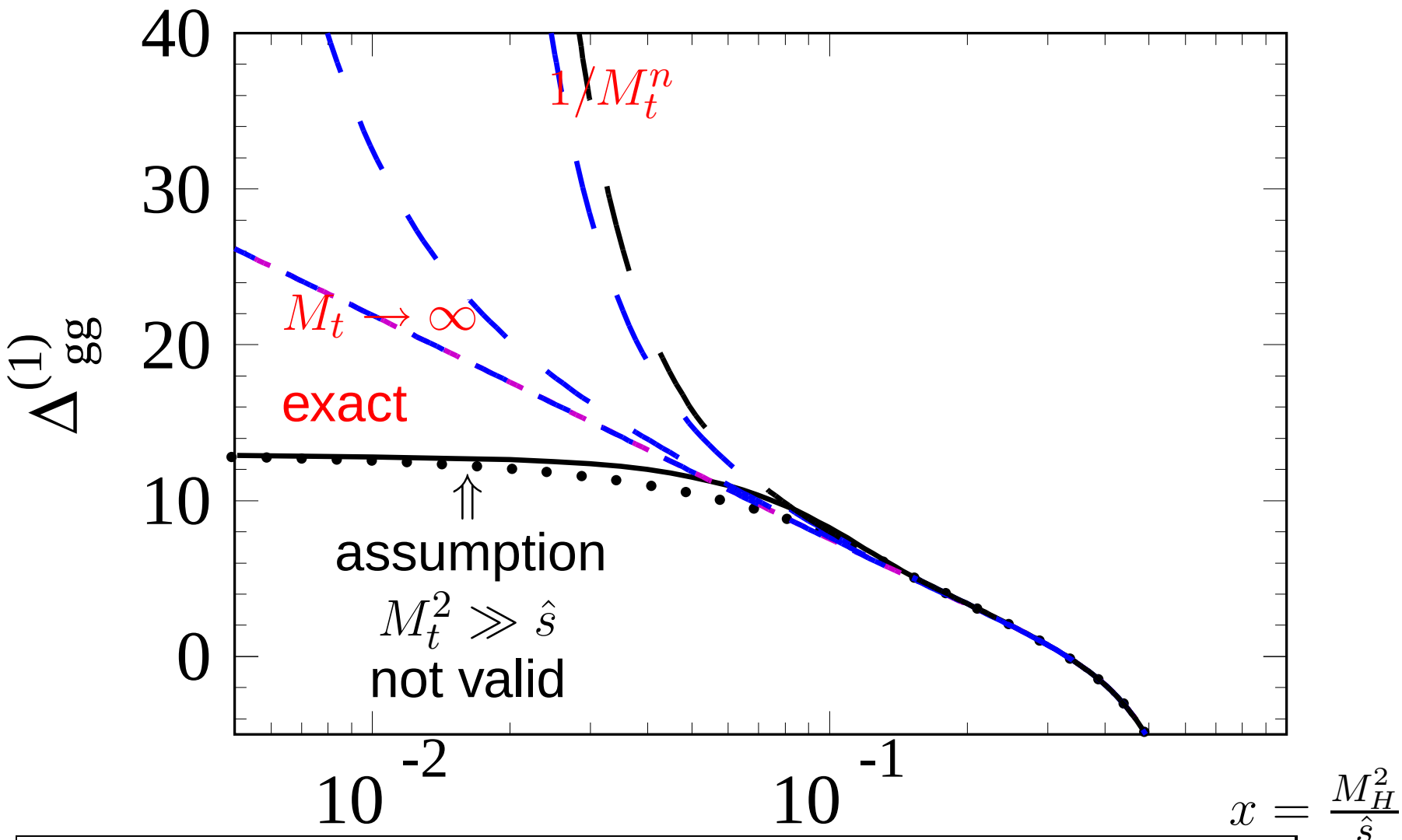
NLO partonic cross section



NLO partonic cross section

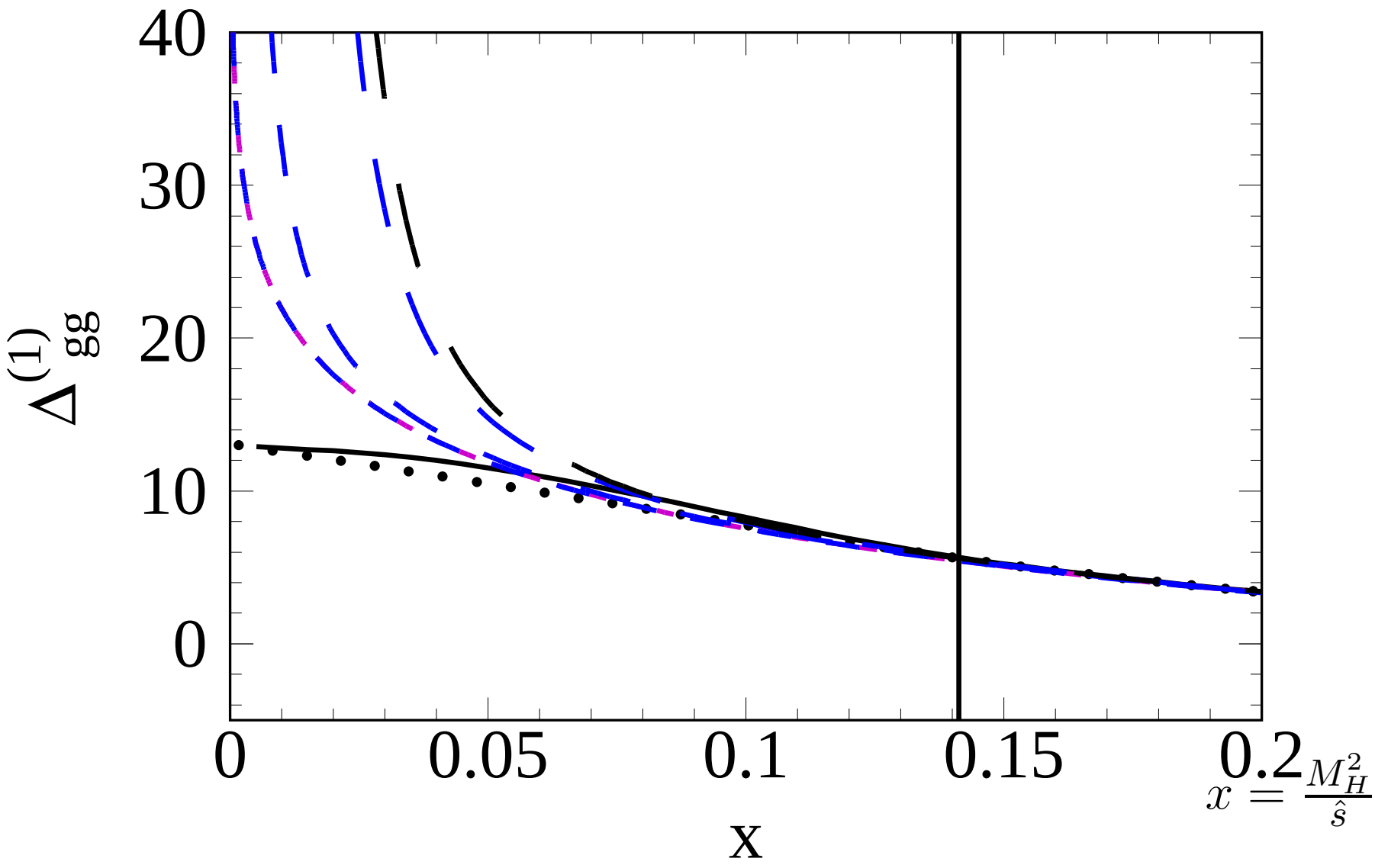


NLO partonic cross section



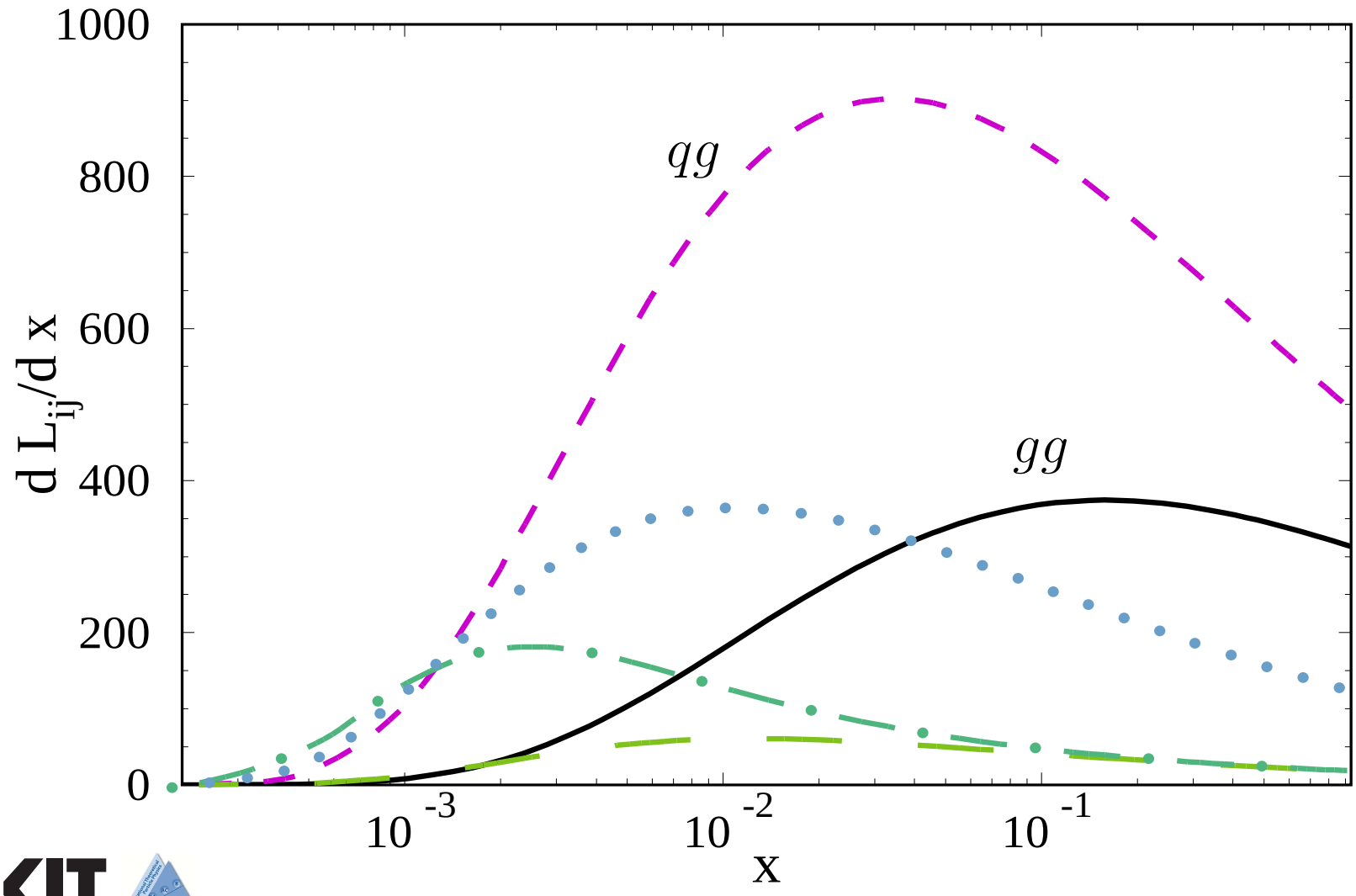
Solution: match to $\hat{s} \to \infty$ result [Marzani,Ball,Del Duca,Forte,Vicini'08]

NLO partonic cross section

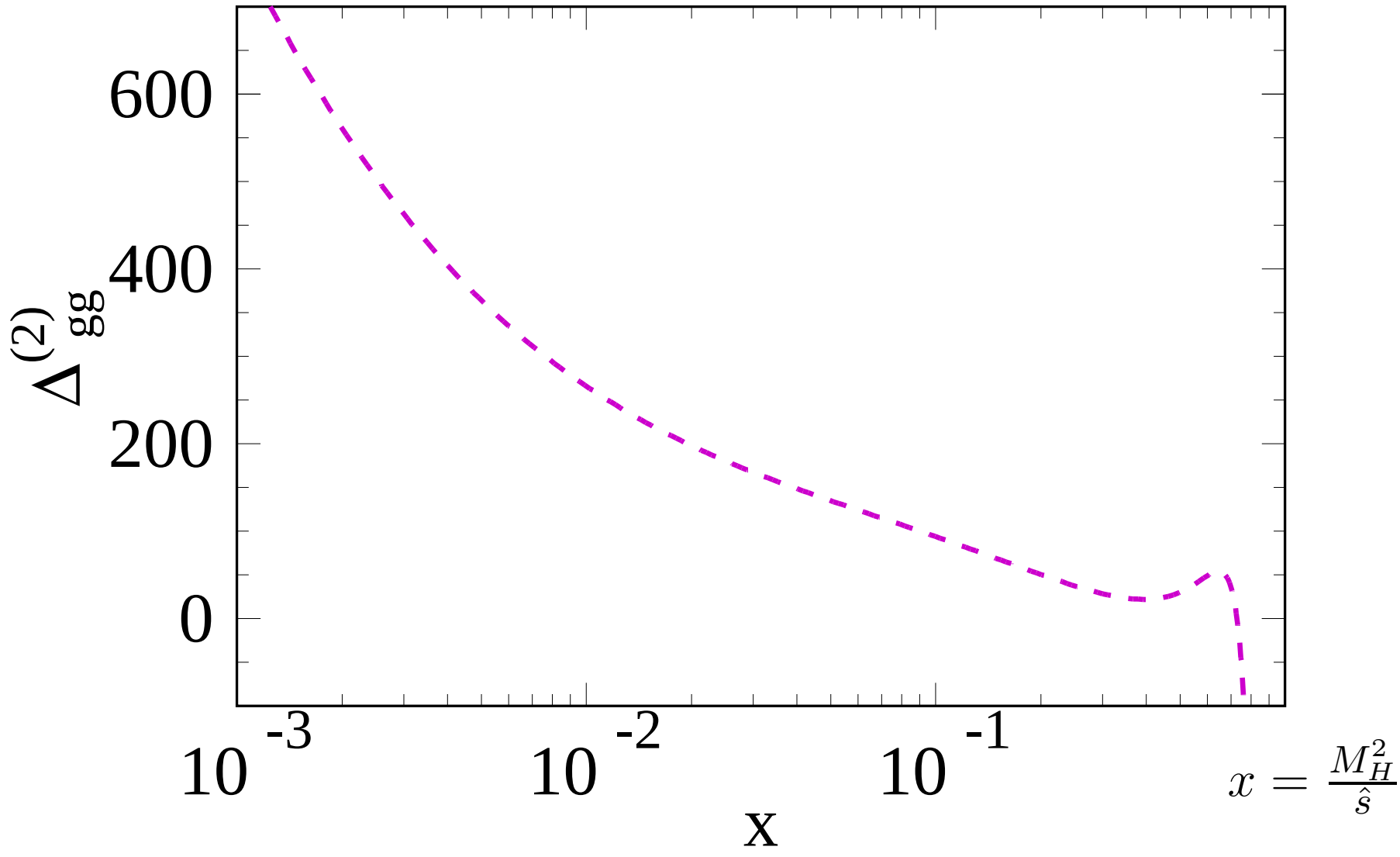


Luminosity function

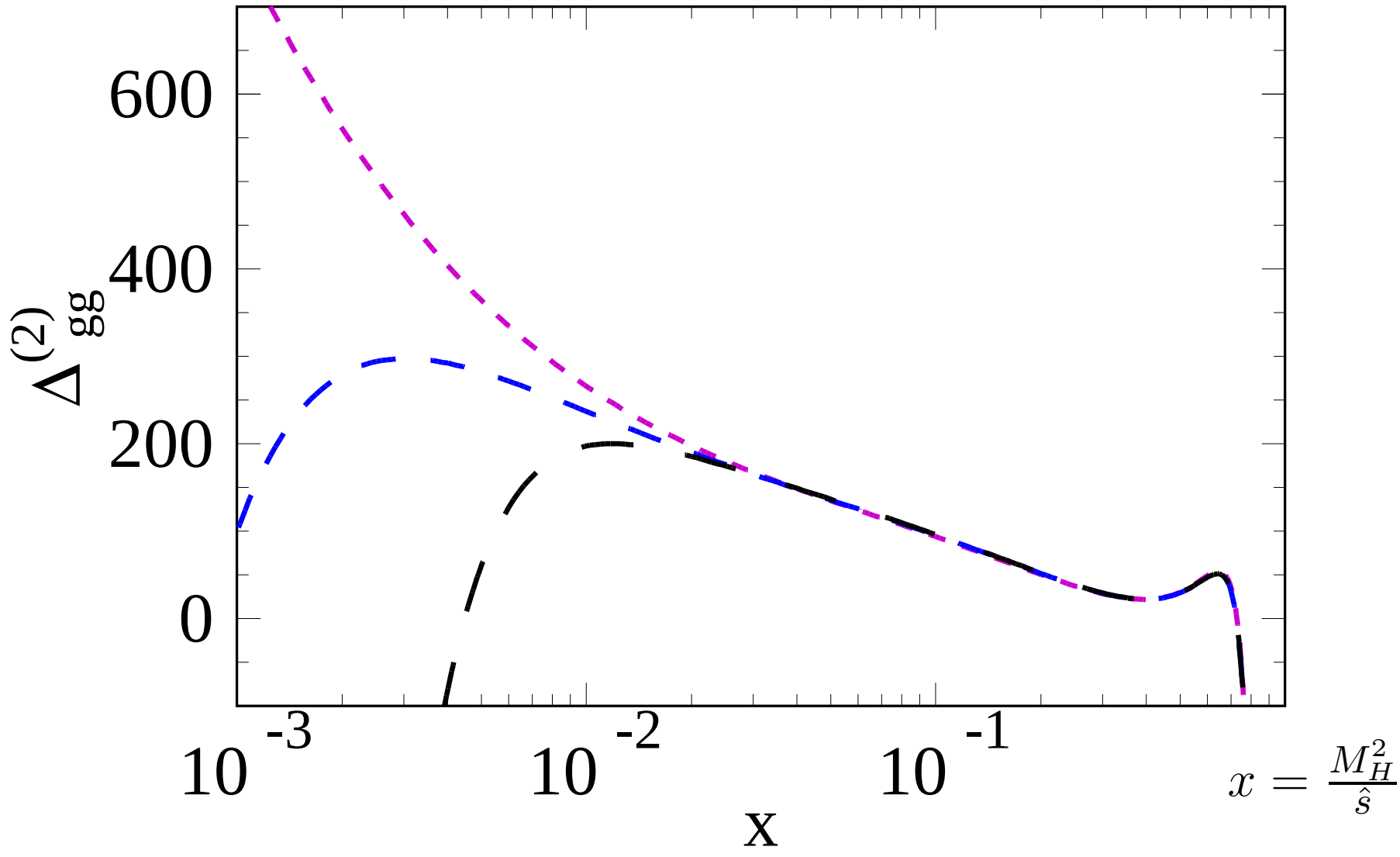
$$\sigma_{pp'\to H+X}(s) = \sum_{ij\in\{gg,\ qg,\ q\bar{q},\ qq,\ qq'\}} \int_{M_H^2/s}^1 \mathrm{d}x \left[\frac{\mathrm{d}\mathcal{L}_{ij}}{\mathrm{d}x}\right](x,\mu_f^2)\ \hat{\sigma}_{ij\to H+X}(x,\mu_f^2)$$



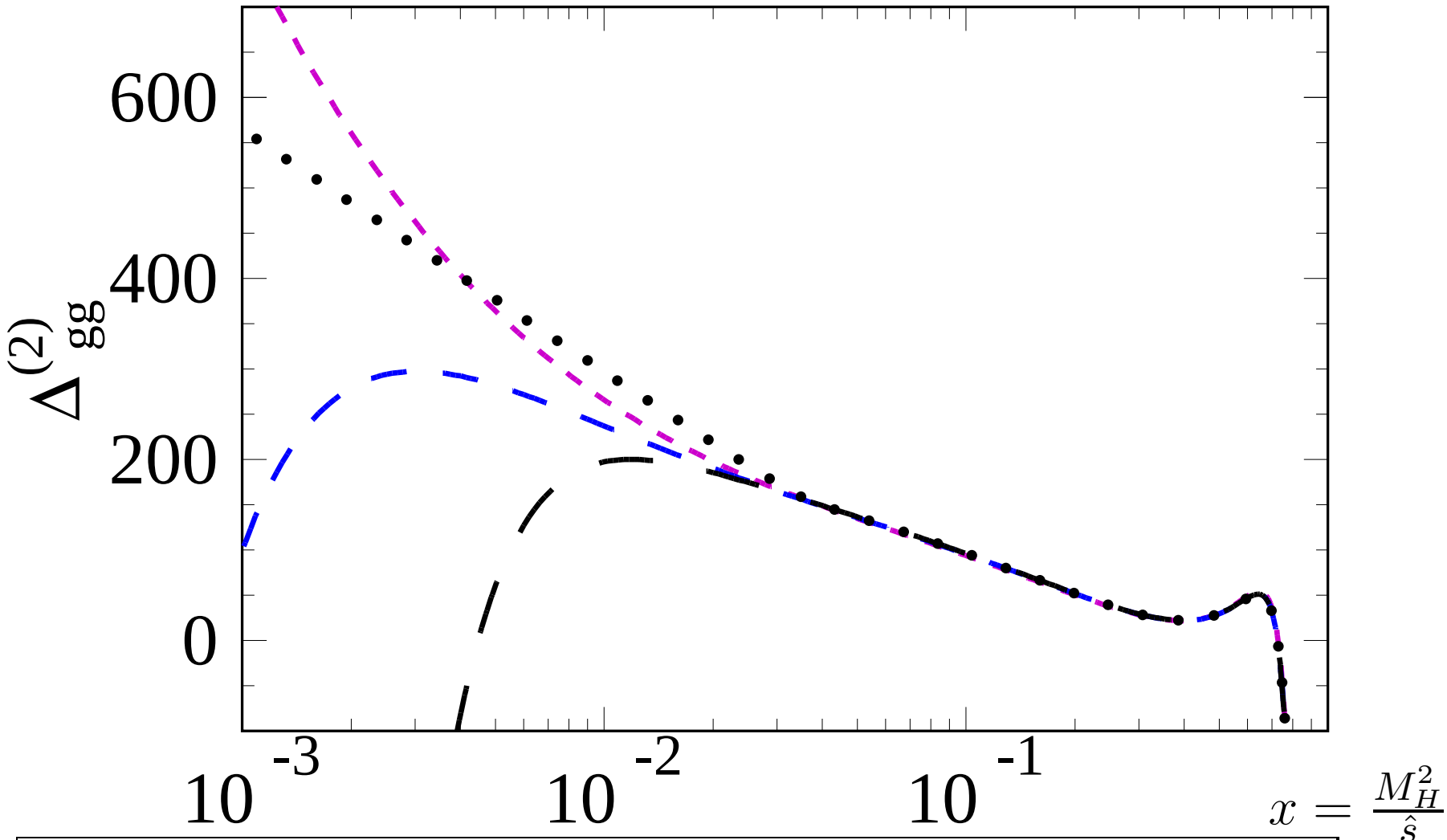
NNLO partonic cross section



NNLO partonic cross section

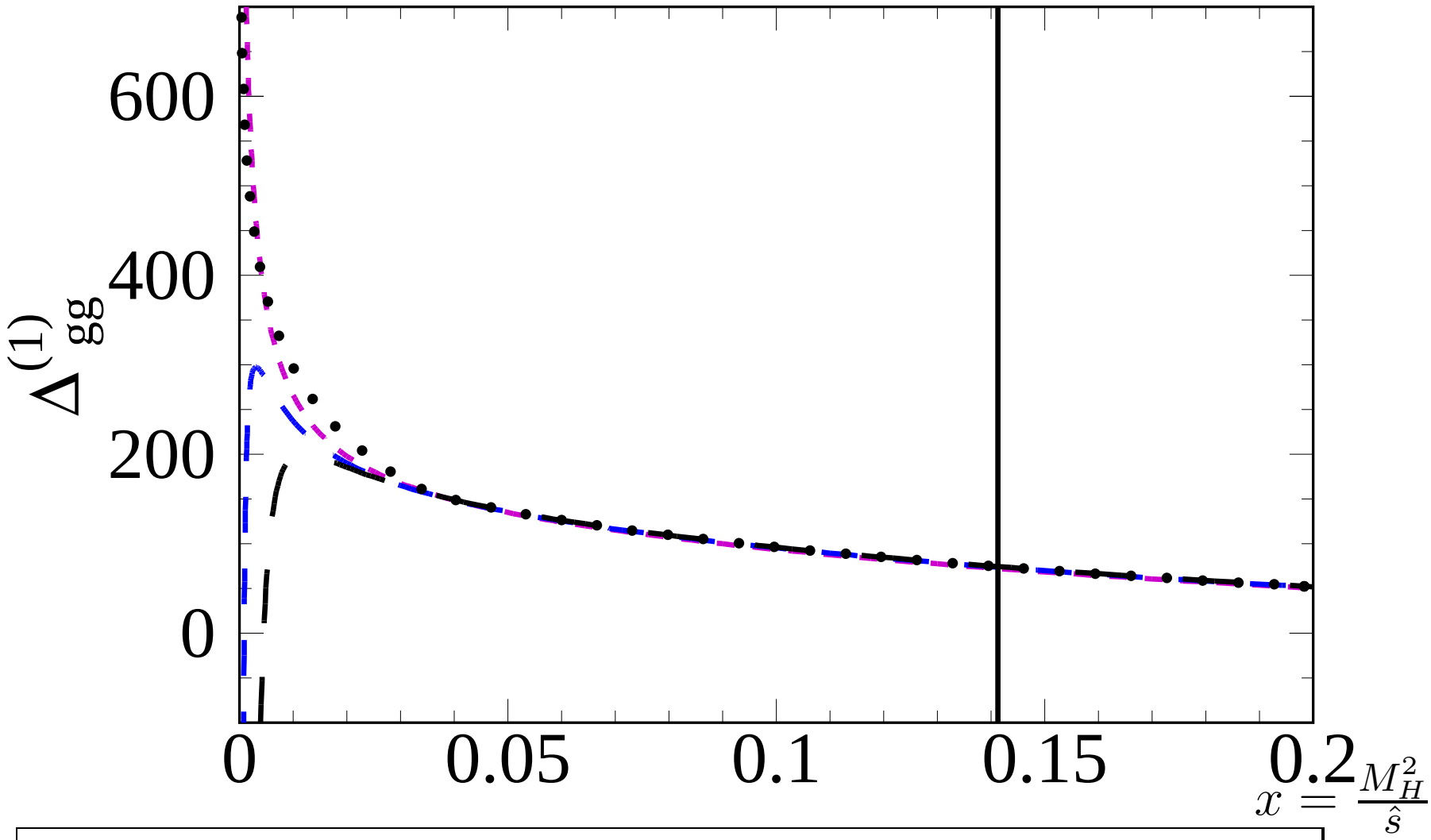


NNLO partonic cross section



Dotted: match to $\hat{s} \to \infty$ result [Marzani,Ball,Del Duca,Forte,Vicini'08]

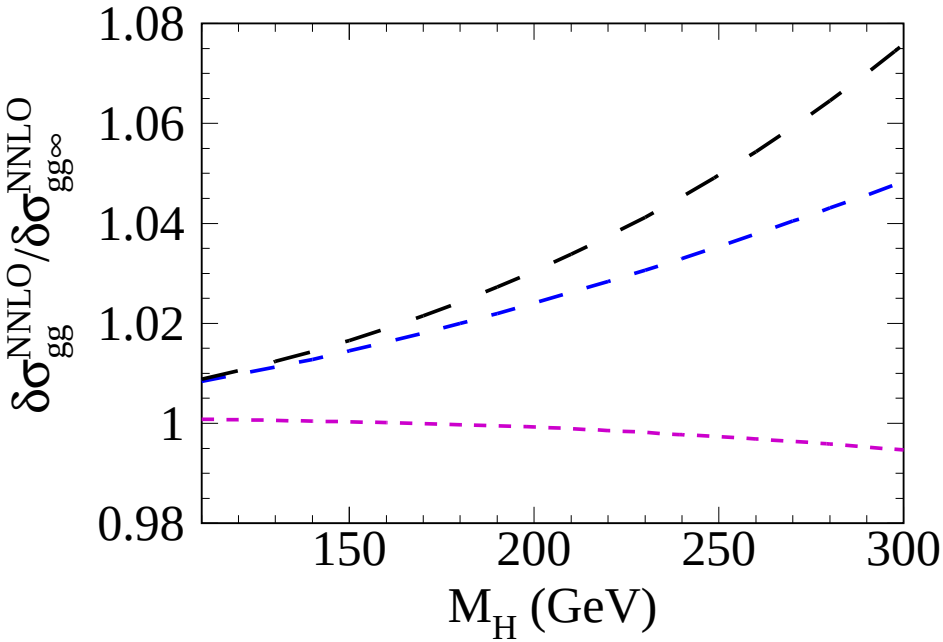
NNLO partonic cross section



Dotted: match to $\hat{s} \to \infty$ result [Marzani,Ball,Del Duca,Forte,Vicini'08]

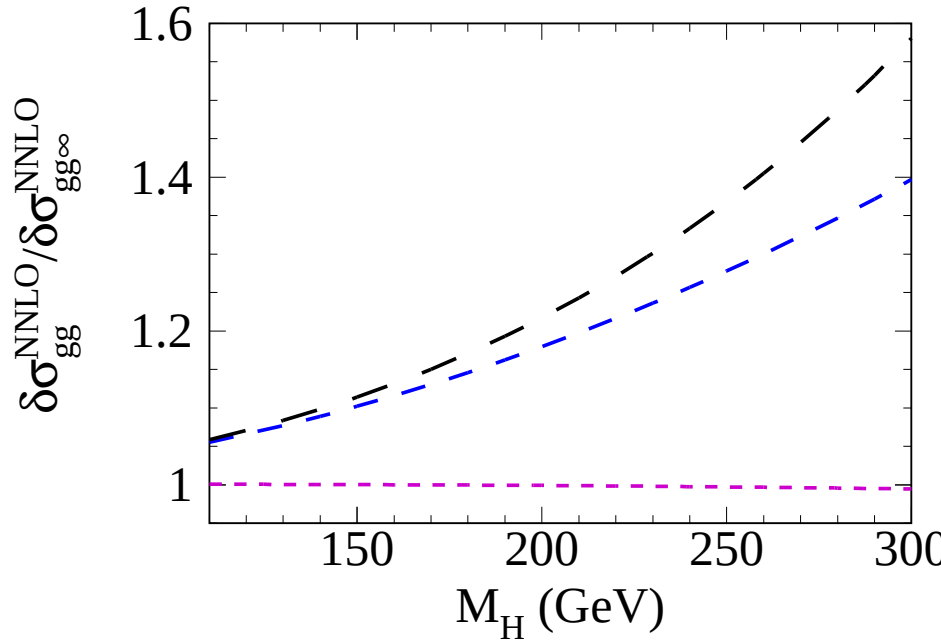
Hadronic results

$$\sigma_{\infty}^{\rm HO} = \sigma^{\rm LO}(M_t) \left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}}\right)_{M_t\to\infty}$$



factorized

$$\sigma_{\infty}^{\rm HO} = \left(\sigma^{\rm HO}\right)_{M_t\to\infty}$$



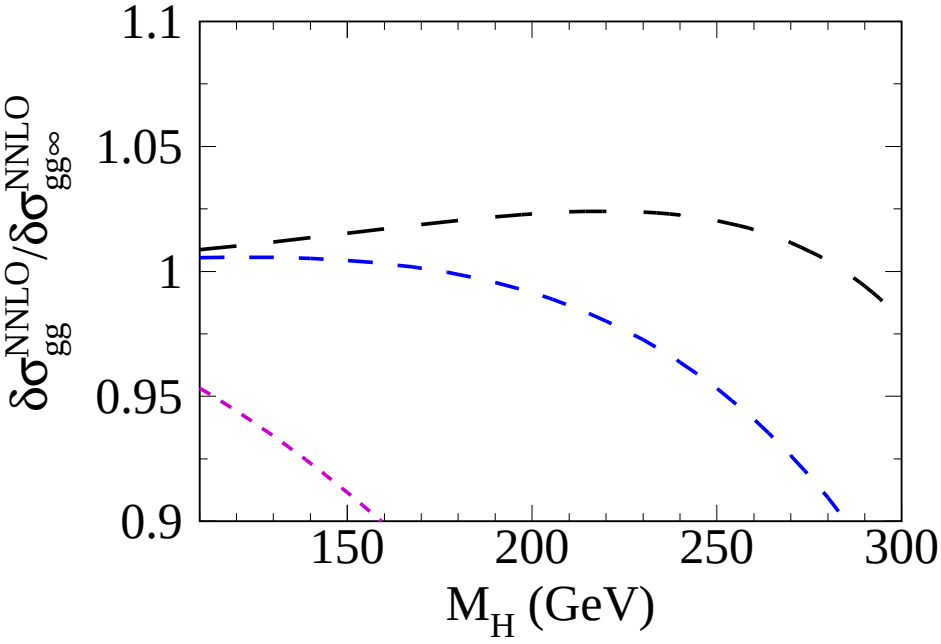
expanded

[Pak,Rogal,Steinhauser'09]

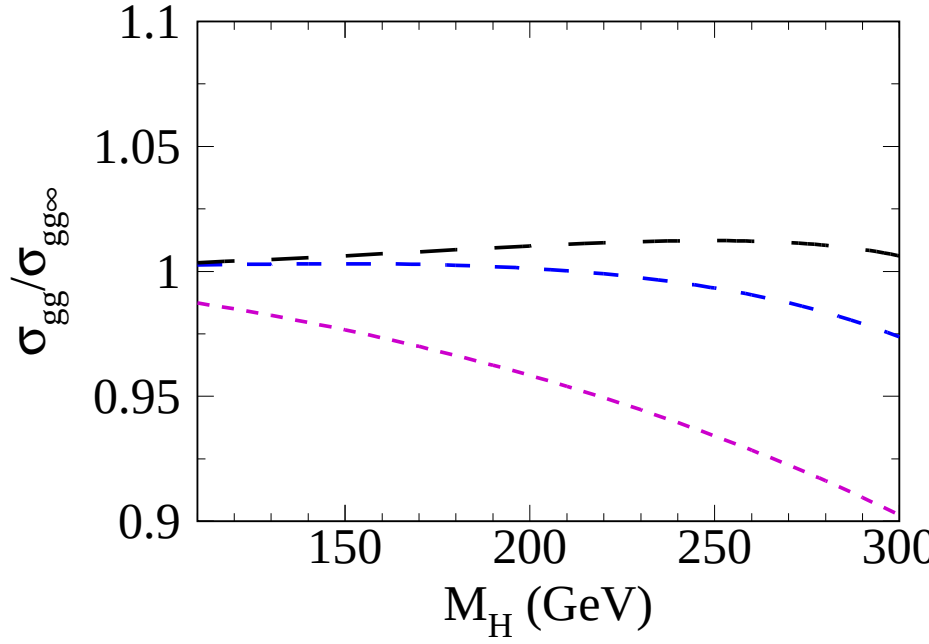
Hadronic results (2)

$\sigma_{gg\infty}$,$\delta\sigma_{gg\infty}$: $\sigma_\infty^{\rm HO} = \sigma^{\rm LO}(M_t)\left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}}\right)_{M_t\to\infty}$

σ_{gg},$\delta\sigma_{gg}$: expand in $1/M_t$



NNLO



LO + NLO + NNLO

[Pak,Rogal,Steinhauser'09]

Independent calculation: [Ozeren,Harlander'09]

Conclusions

- $pp \to H + X$ @ NNLO, finite top quark mass
- "matched results" for all initial states gg, qg, $q\bar{q}$, qq, qq'
- $1/M_t$ corrections small if complete LO M_t-dependence is factored out
- Our calculation:
  justification of "heavy-M_t" approximation!
- Independent calculation: [Ozeren,Harlander'09]