Higgs boson production at LHC to NNLO accuracy and finite top quark mass effects

Matthias Steinhauser
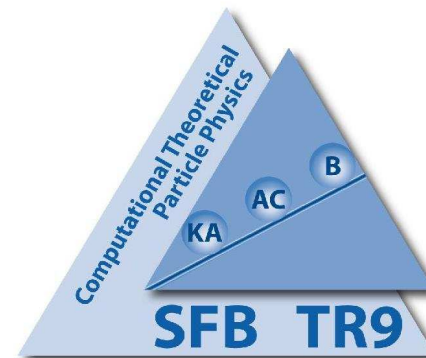
KIT

ICHEP 10, Paris, July 2010

(in collaboration with A. Pak and M. Rogal)
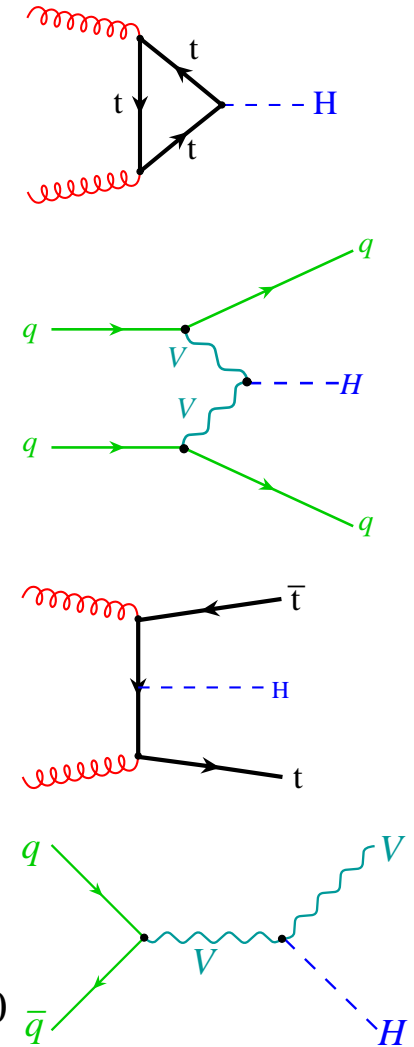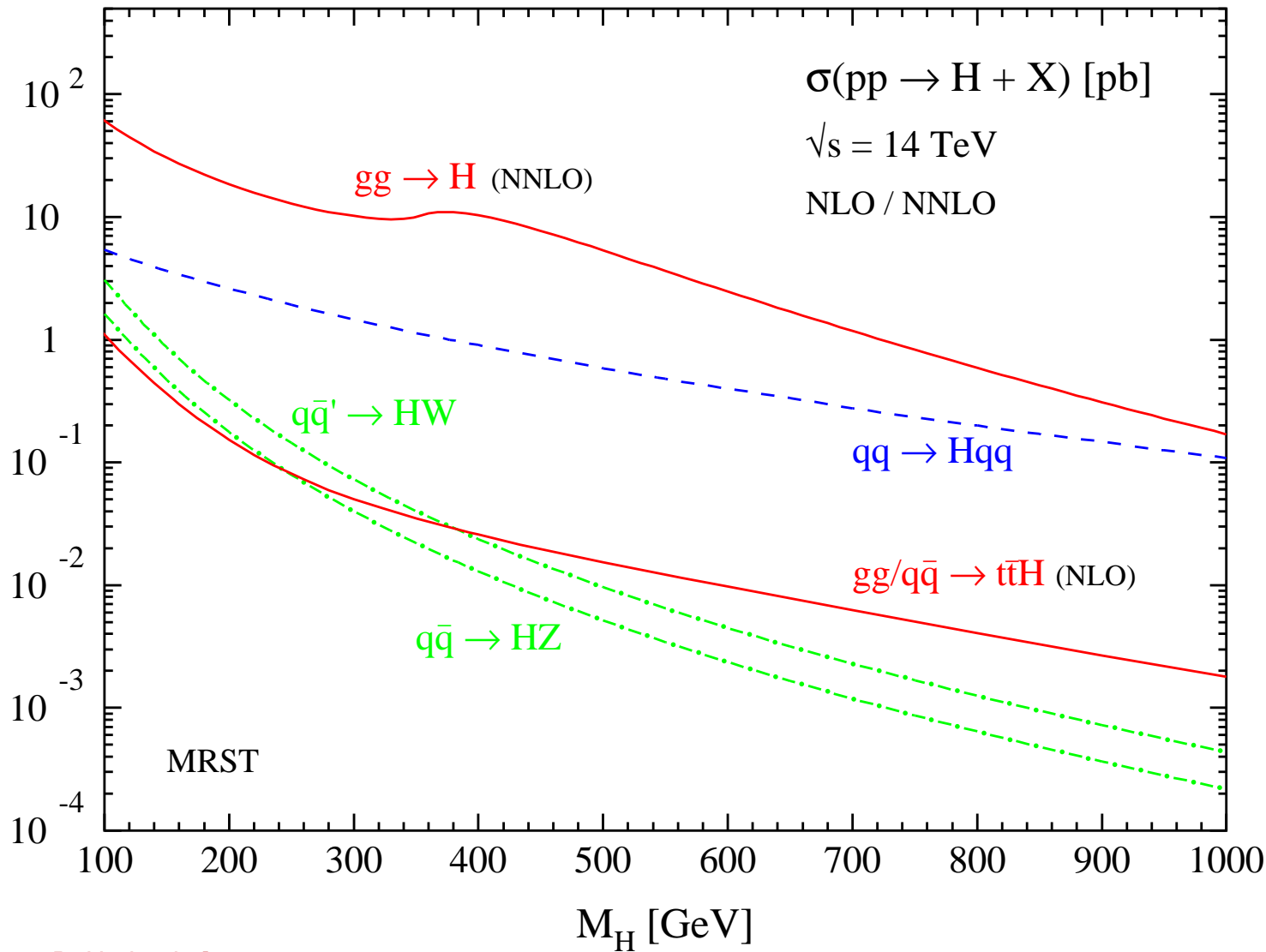
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Outline

Higgs production mechanisms

$\sigma(pp \to H + X)$ [pb]

$\sqrt{s} = 14$ TeV

NLO / NNLO

$gg \to H$ (NNLO)

$q\bar{q}' \to HW$

$qq \to Hqq$

$gg/q\bar{q} \to t\bar{t}H$ (NLO)

$q\bar{q} \to HZ$

MRST

M_H [GeV]
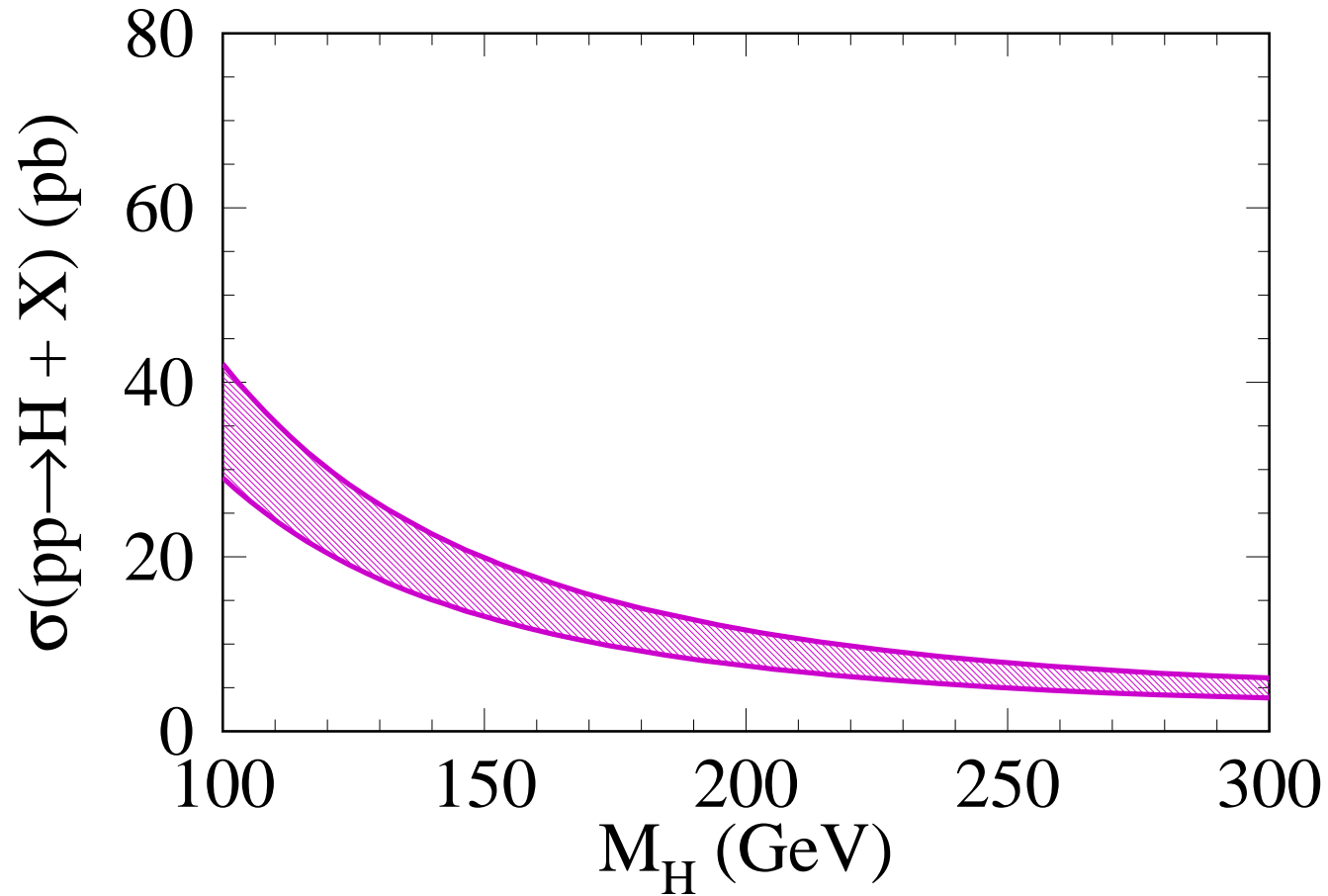
Gluon fusion

- largest cross section

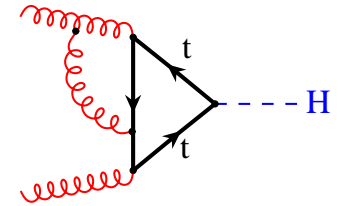- $gg \to H \to ZZ \to 4\mu$: gold plated mode for $M_H \gtrsim 135\,$GeV
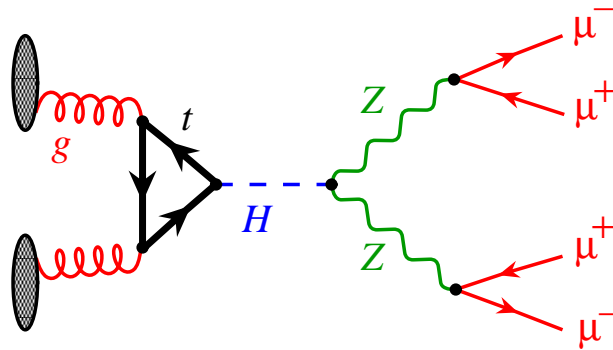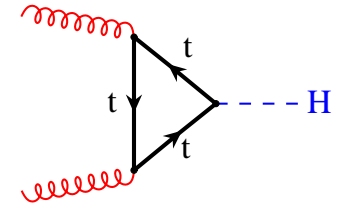
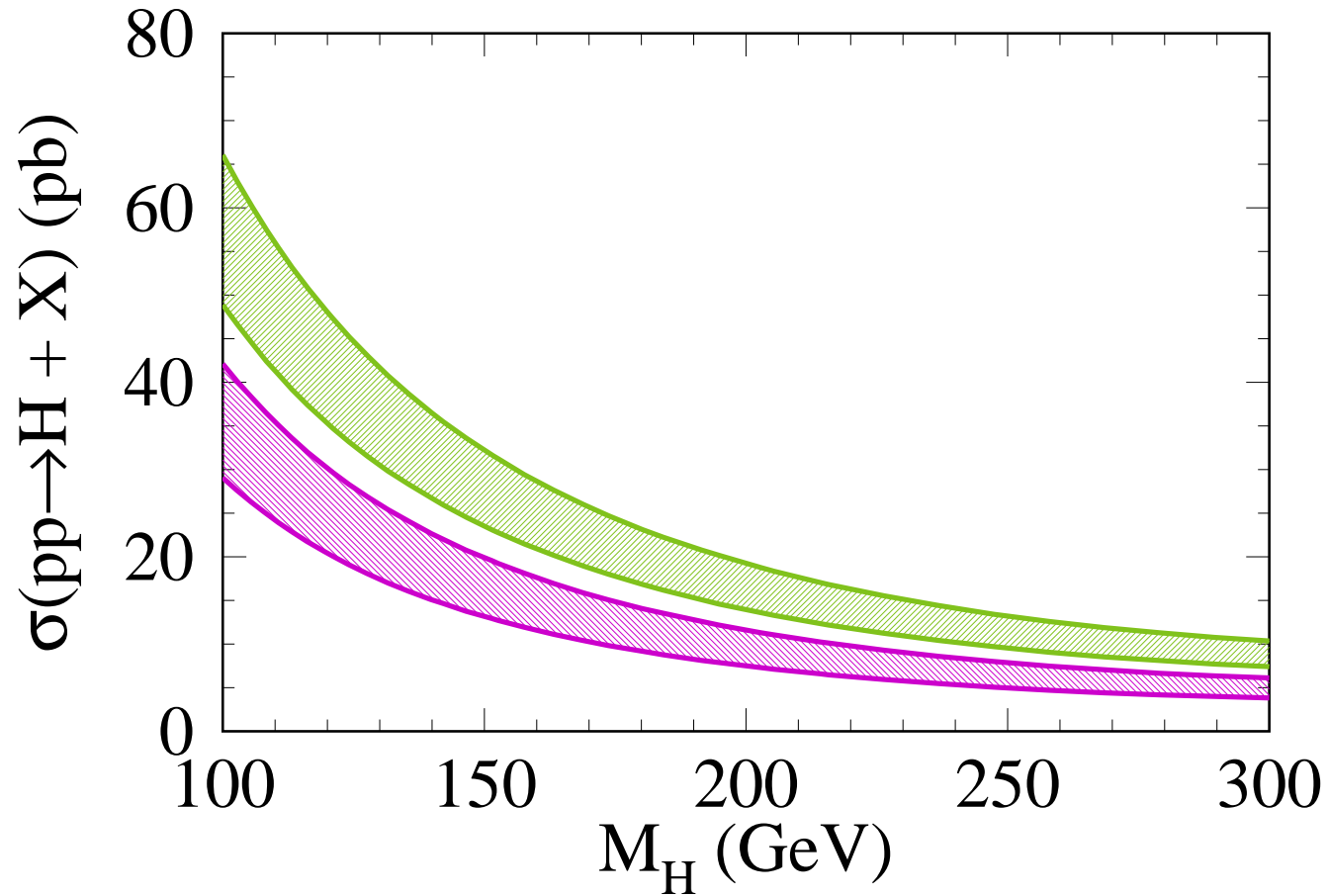- sensitive to heavy particles, supersymmetry

- top Yukawa coupling
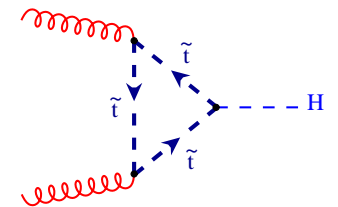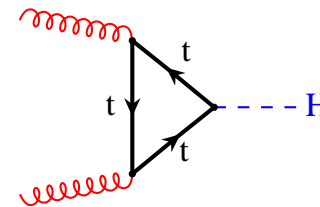
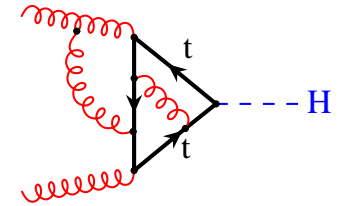# Gluon fusion to NNLO
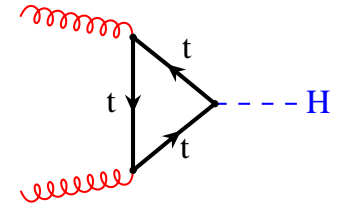
Gluon fusion to NNLO

70%-100% correction!

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

Gluon fusion to NNLO
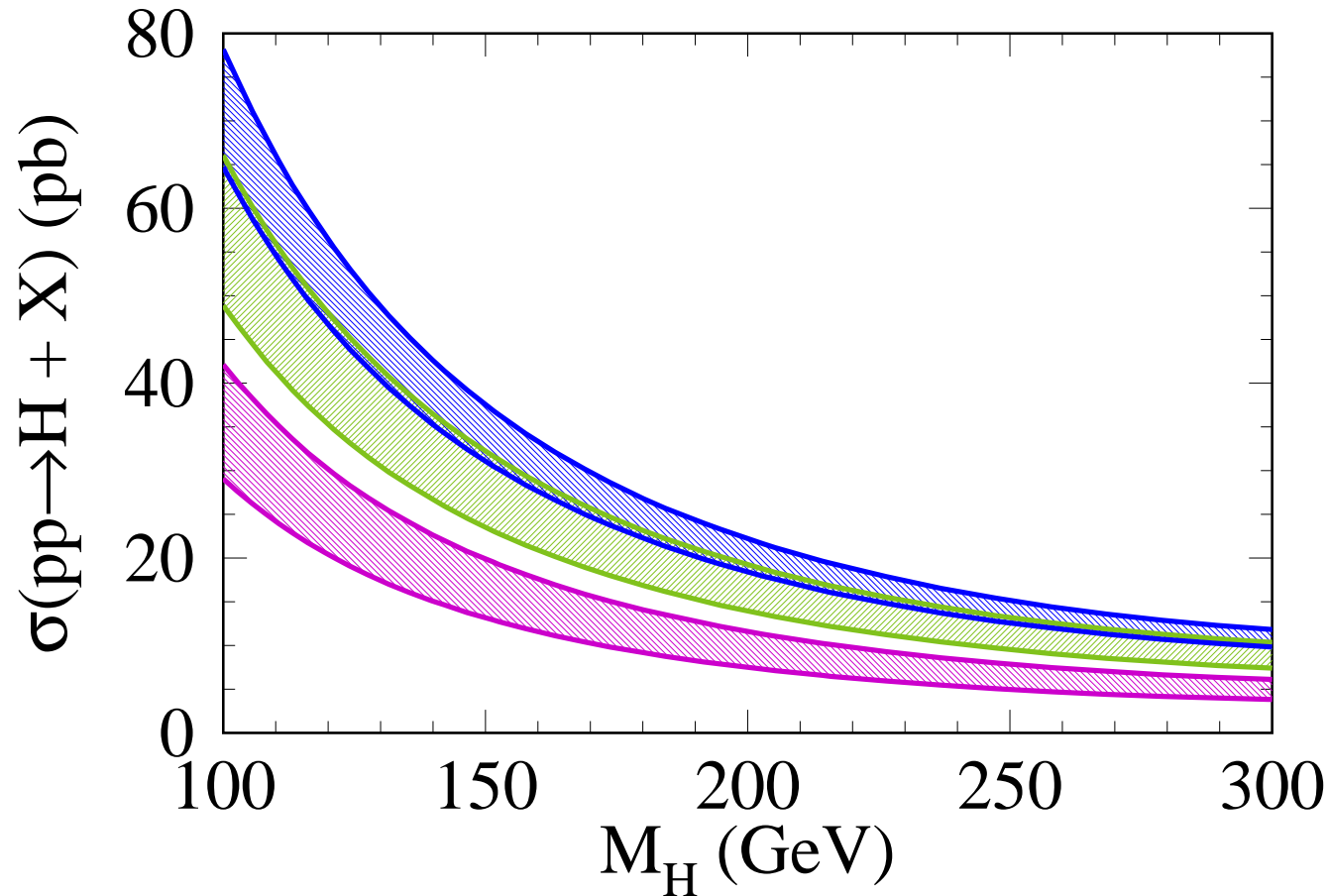
[Dawson'91] [Spira,Djouadi,Graudenz,Zerwas'91'93]

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

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

Resummations
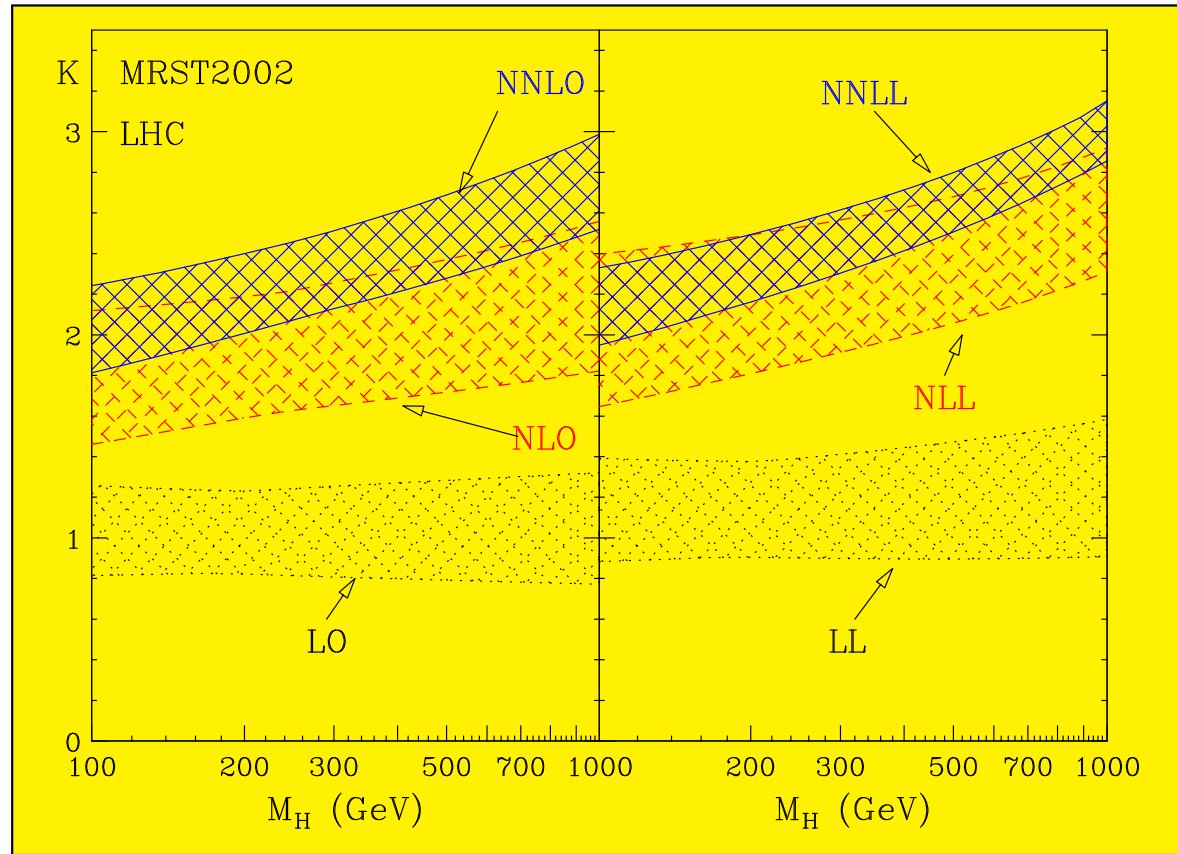
soft gluons

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

Resummations
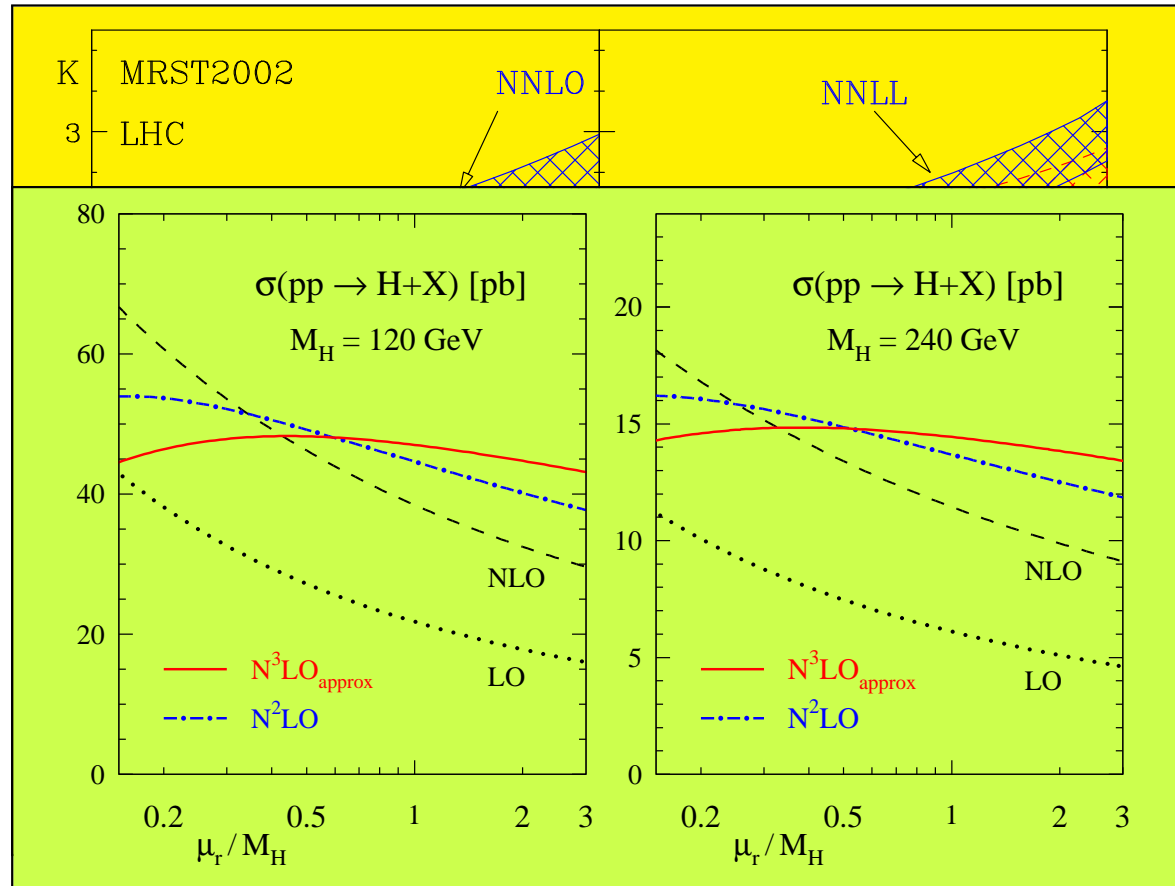
soft gluons to NNNLL

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

Resummations

„π^2-Resummation"

[Ahrens, Becher, Neubert, Yang'08]

all based on "heavy-top approximation"

Matthias Steinhauser – p.6

$gg \rightarrow H$: **LO, NLO**

Higgs production in gluon fusion at LHC

LO
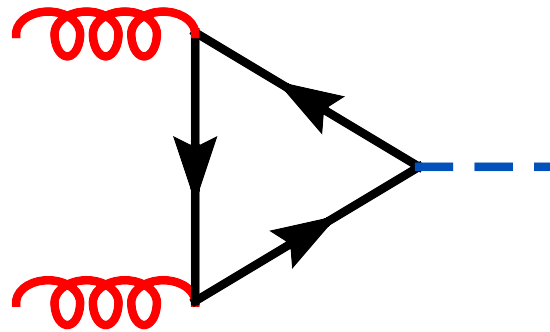
NLO

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

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

Effective theory
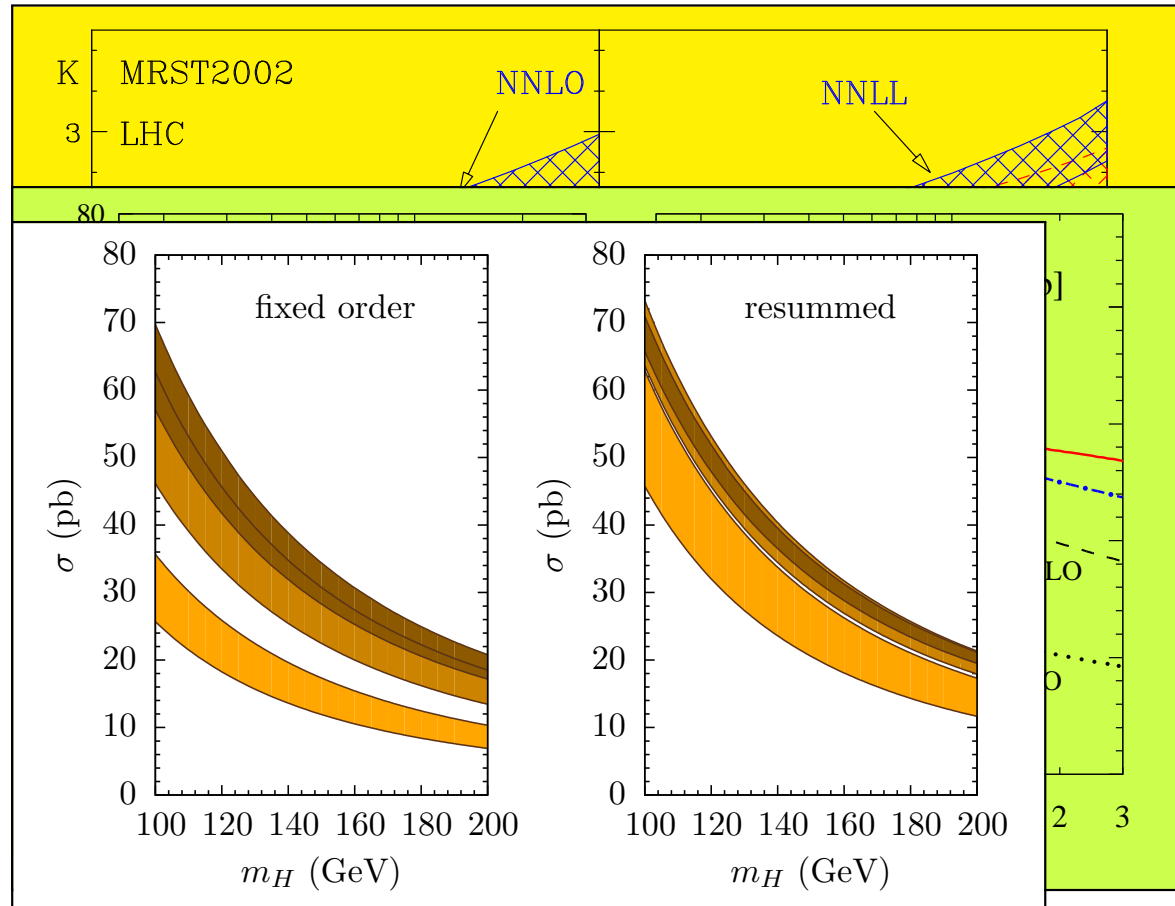

$$M_t \gg M_H \longrightarrow \qquad C(M_t, \alpha_s) \times$$

$$\Downarrow \qquad M_t \to \infty: \qquad \mathcal{L}^{\mathrm{eff}} = \frac{H}{v} C_1 \left(G_{\mu\nu}^a \right)^2 \qquad \Downarrow$$

Effective theory

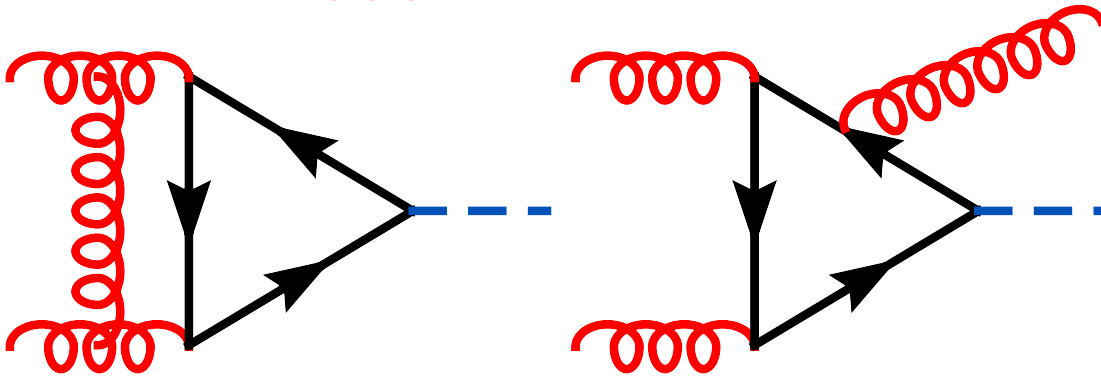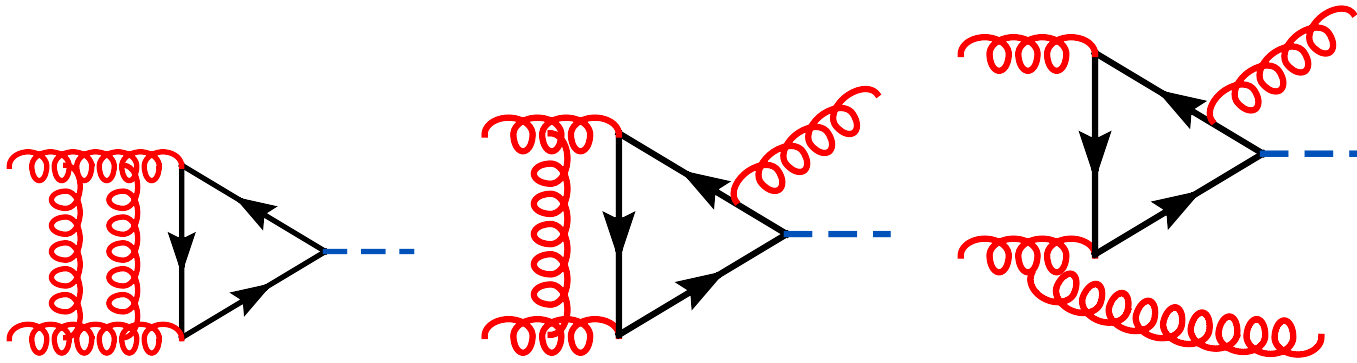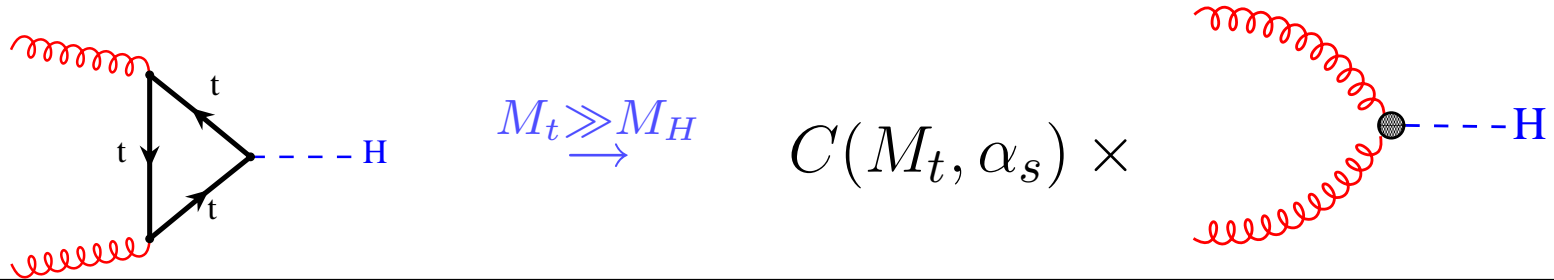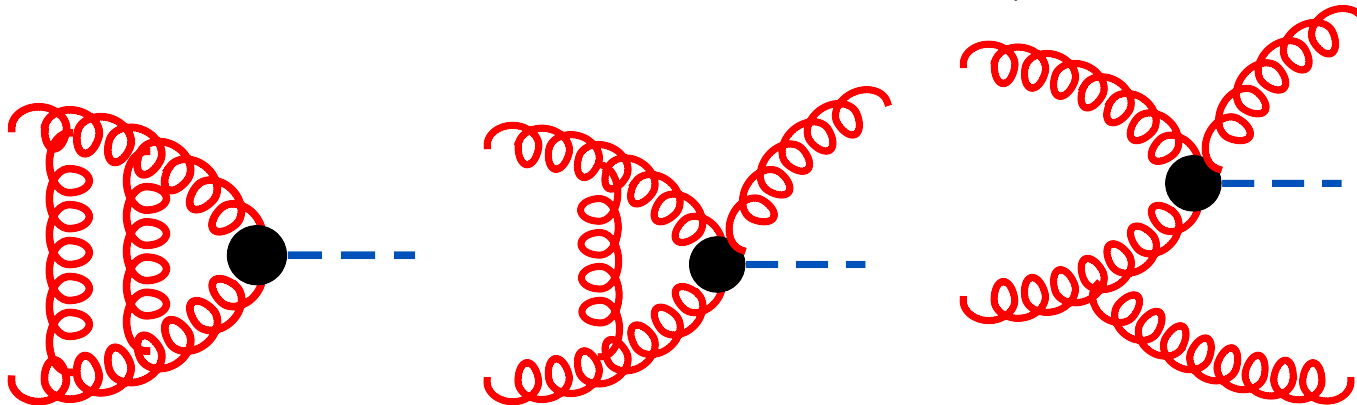$$M_t \gg M_H \atop \longrightarrow \qquad C(M_t, \alpha_s) \times$$

σ(pp→H+X)[pb]

NLO, LHC
HIGLU

10

1

10^{-1}

100 200 300 400 500 600 700 800 900 1000

M_H [GeV]

$$\sigma_\infty^{\mathrm{HO}} = \sigma^{\mathrm{LO}}(M_t) \left(\frac{\sigma^{\mathrm{HO}}}{\sigma^{\mathrm{LO}}} \right)_{M_t \to \infty}$$
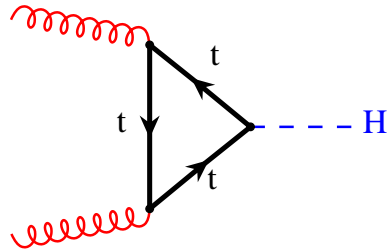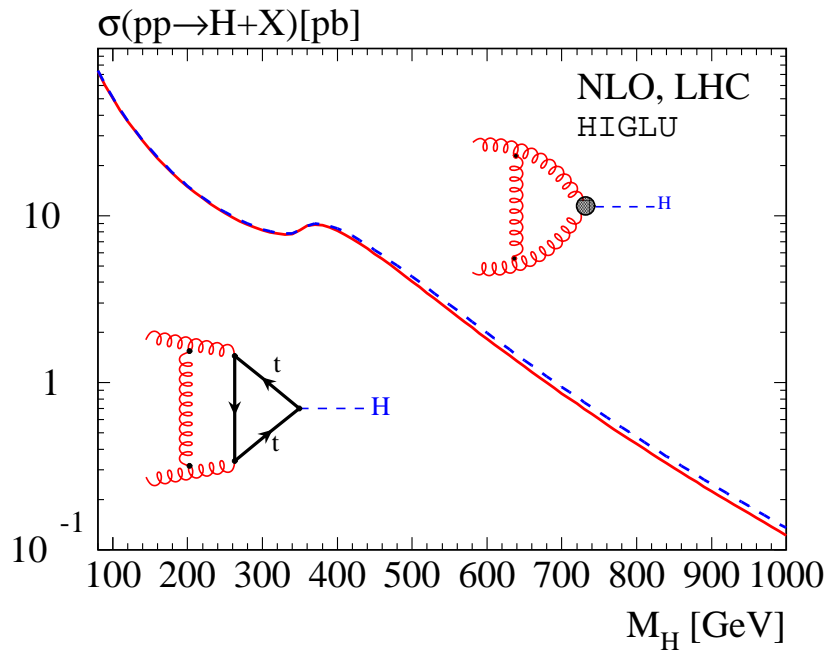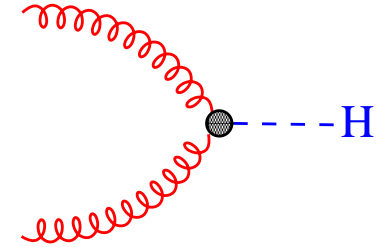
1. step: $C(M_t, \alpha_s)$ to NNLO
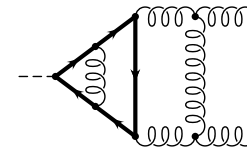
[Chetyrkin,Kniehl,Steinhauser'96] [Krämer,Laenen,Spira'96]

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

and (almost) to NNNNLO

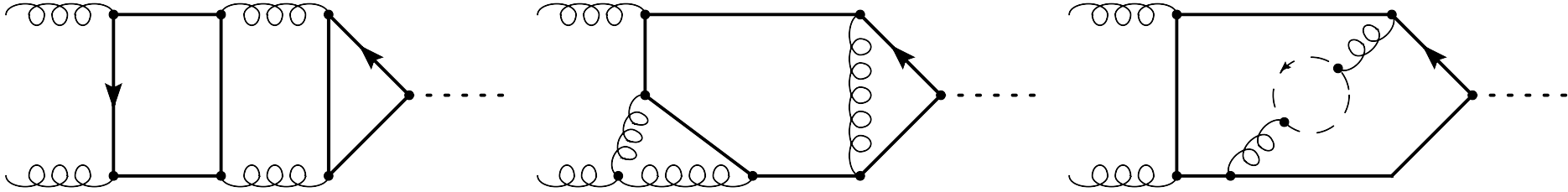[Schöder,Steinhauser'04; Chetyrkin,Kühn,Sturm'04])

2. step: real and virtual corrections within effective theory

Why? NNLO?

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]

$$NNLO_{virt}$$

$\delta^{(2)}$

ρ

$$M_H^2/M_t^2$$

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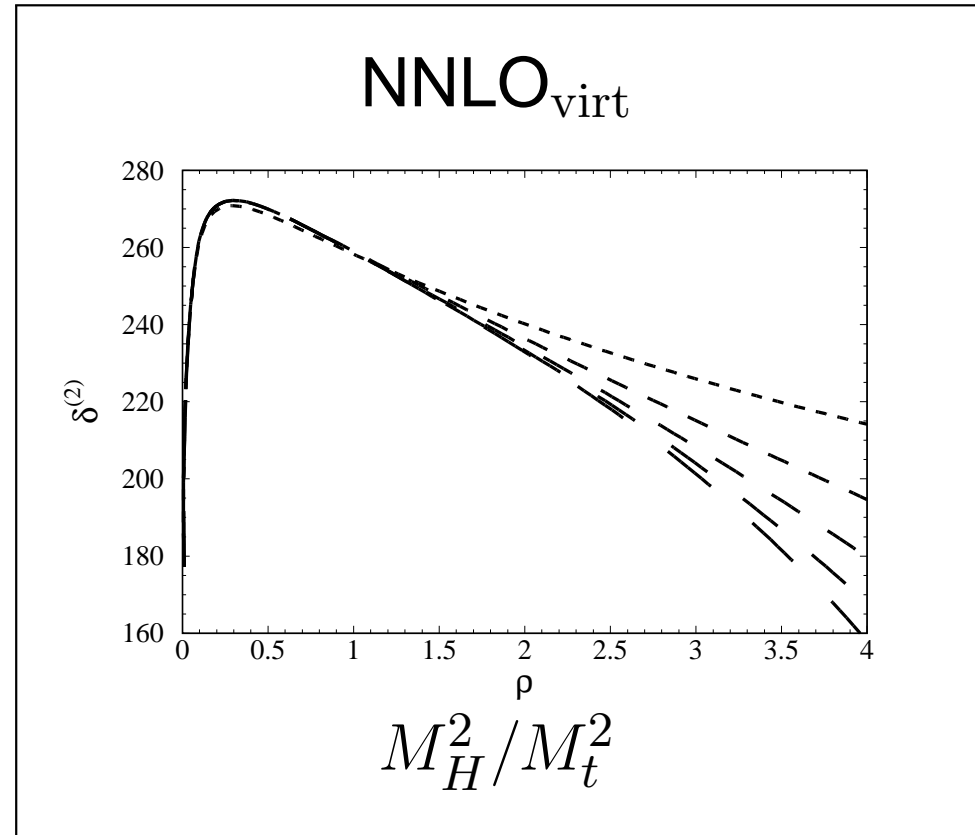
Real corrections
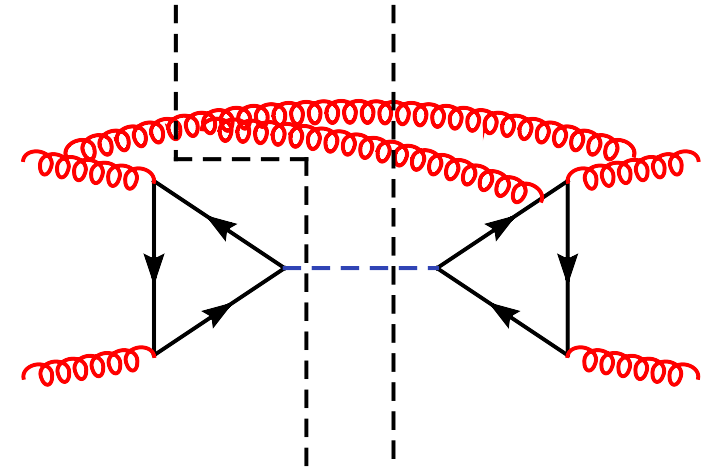
- optical theorem

- 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
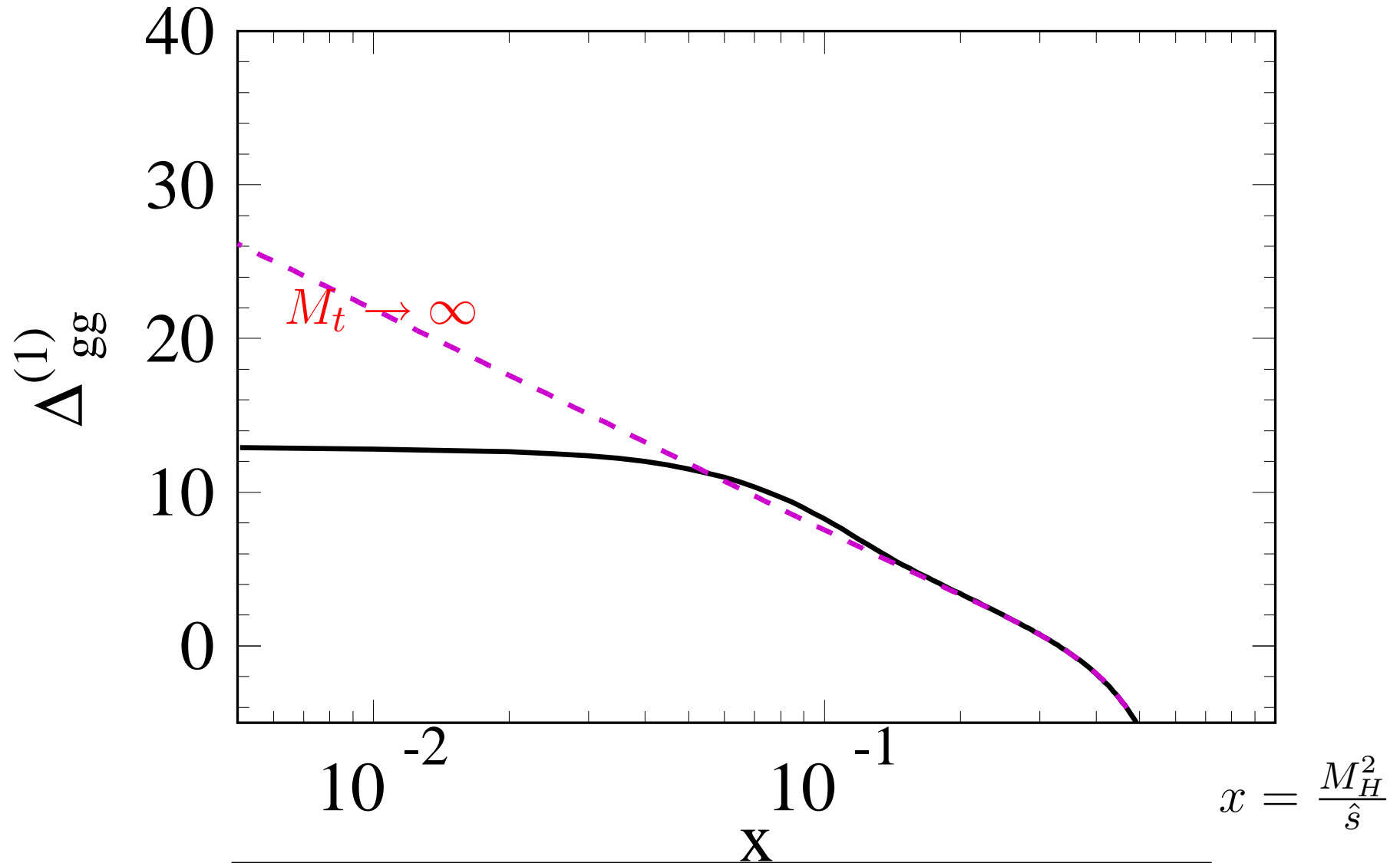
$$\hat{\sigma}_{ij \to H+X} = \hat{A}_{\text{LO}} \left(\Delta_{ij}^{(0)} + \frac{\alpha_s}{\pi} \Delta_{ij}^{(1)} + \left(\frac{\alpha_s}{\pi} \right)^2 \Delta_{ij}^{(2)} + \dots \right)$$

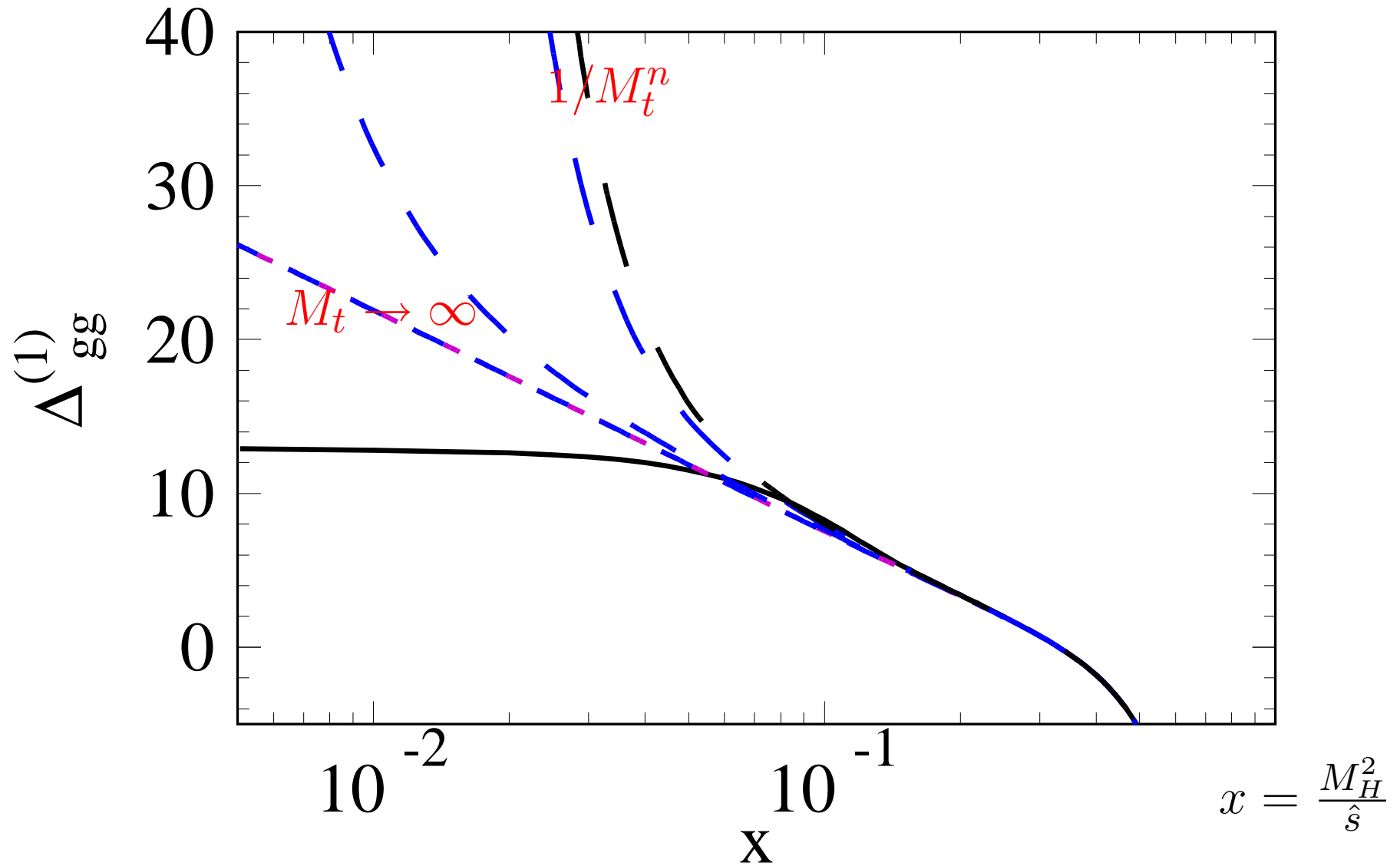# NLO partonic cross section

$1/M_t^n$

$M_t \rightarrow \infty$

$\Delta_{gg}^{(1)}$

$x = \frac{M_H^2}{\hat{s}}$
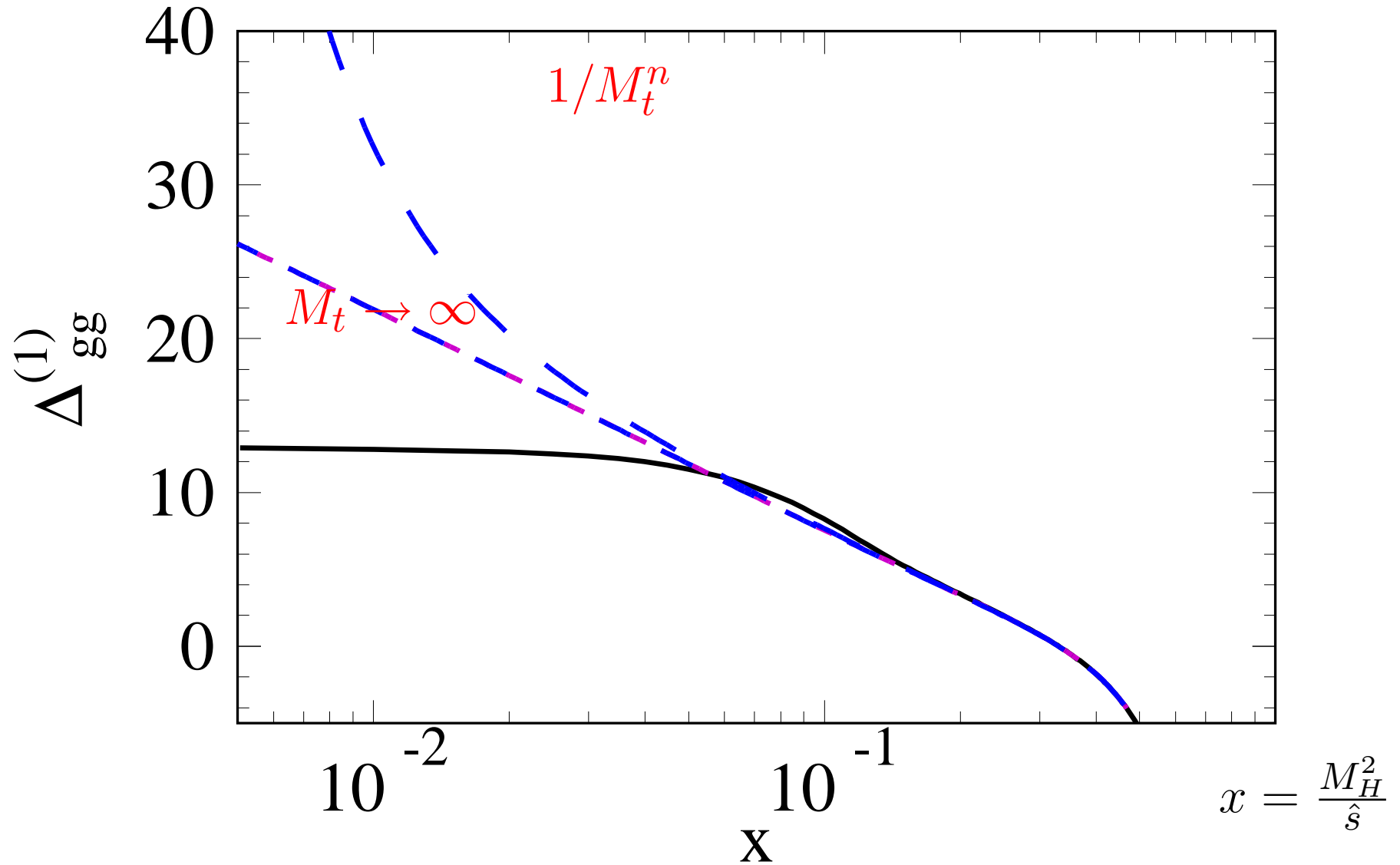
[Dawson,Kauffman'94]

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

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

NNLO partonic cross section

$$\hat{\sigma}_{ij \to H+X} = \hat{A}_{\mathrm{LO}} \left(\Delta_{ij}^{(0)} + \frac{\alpha_s}{\pi} \Delta_{ij}^{(1)} + \left(\frac{\alpha_s}{\pi}\right)^2 \Delta_{ij}^{(2)} + \dots \right)$$
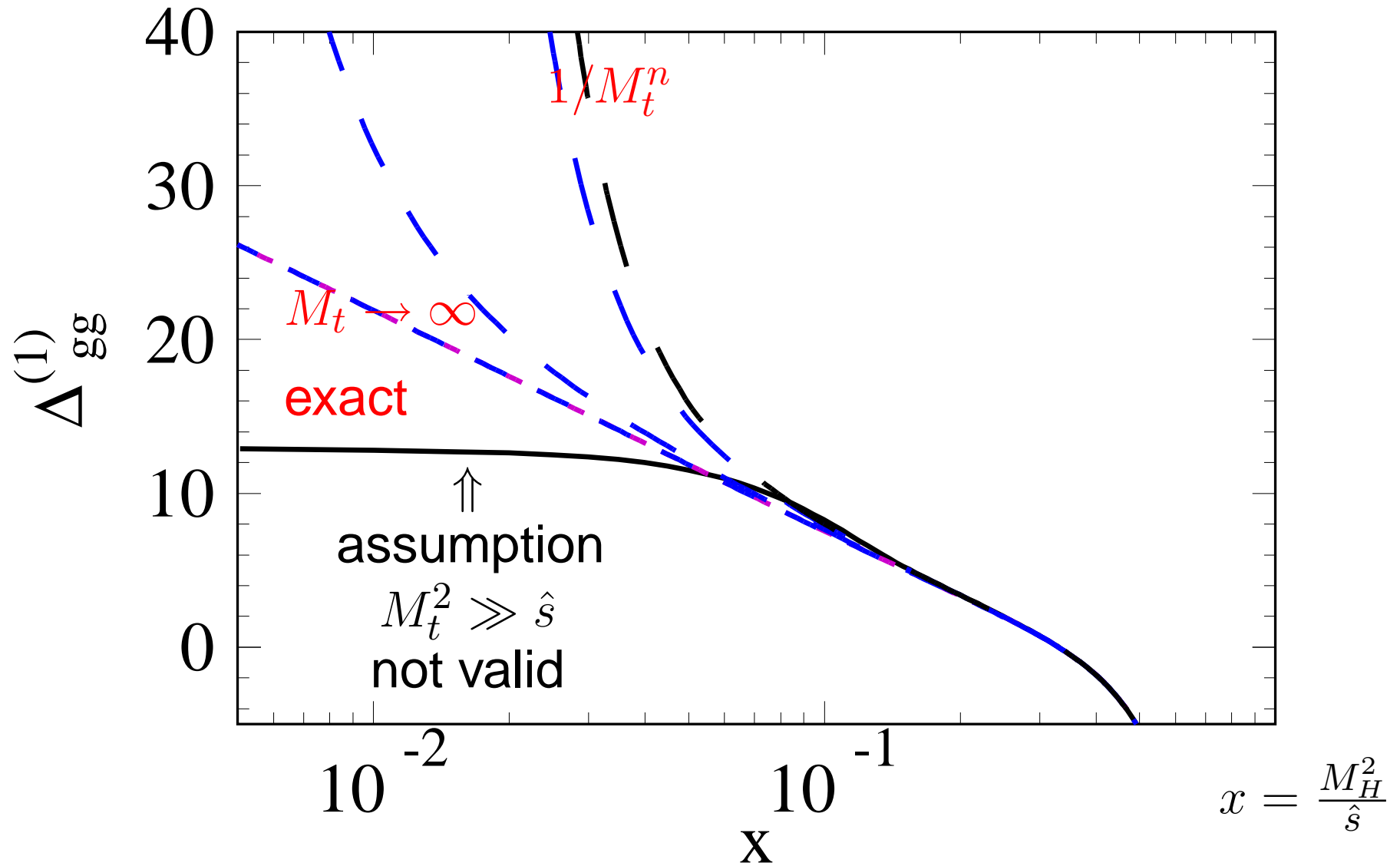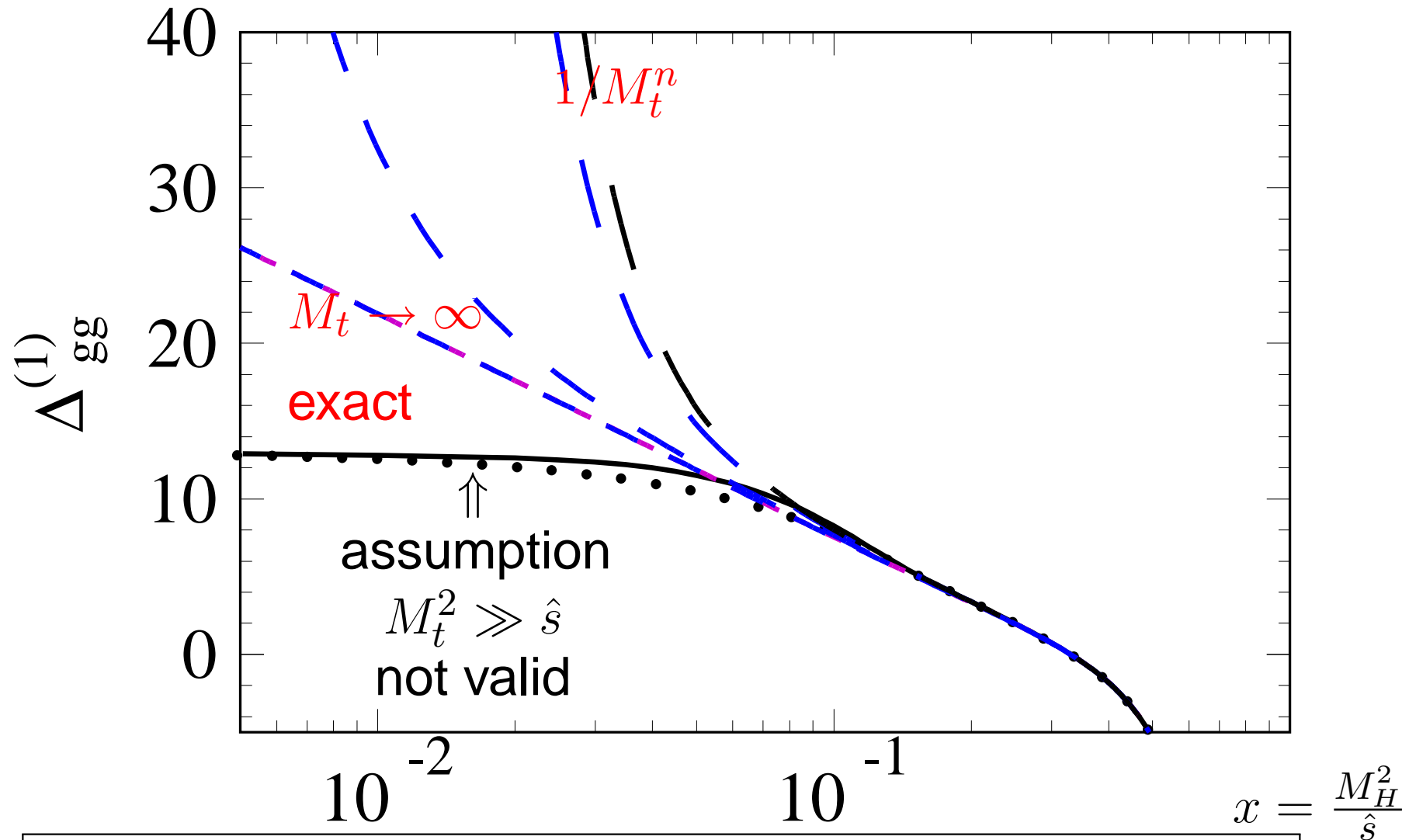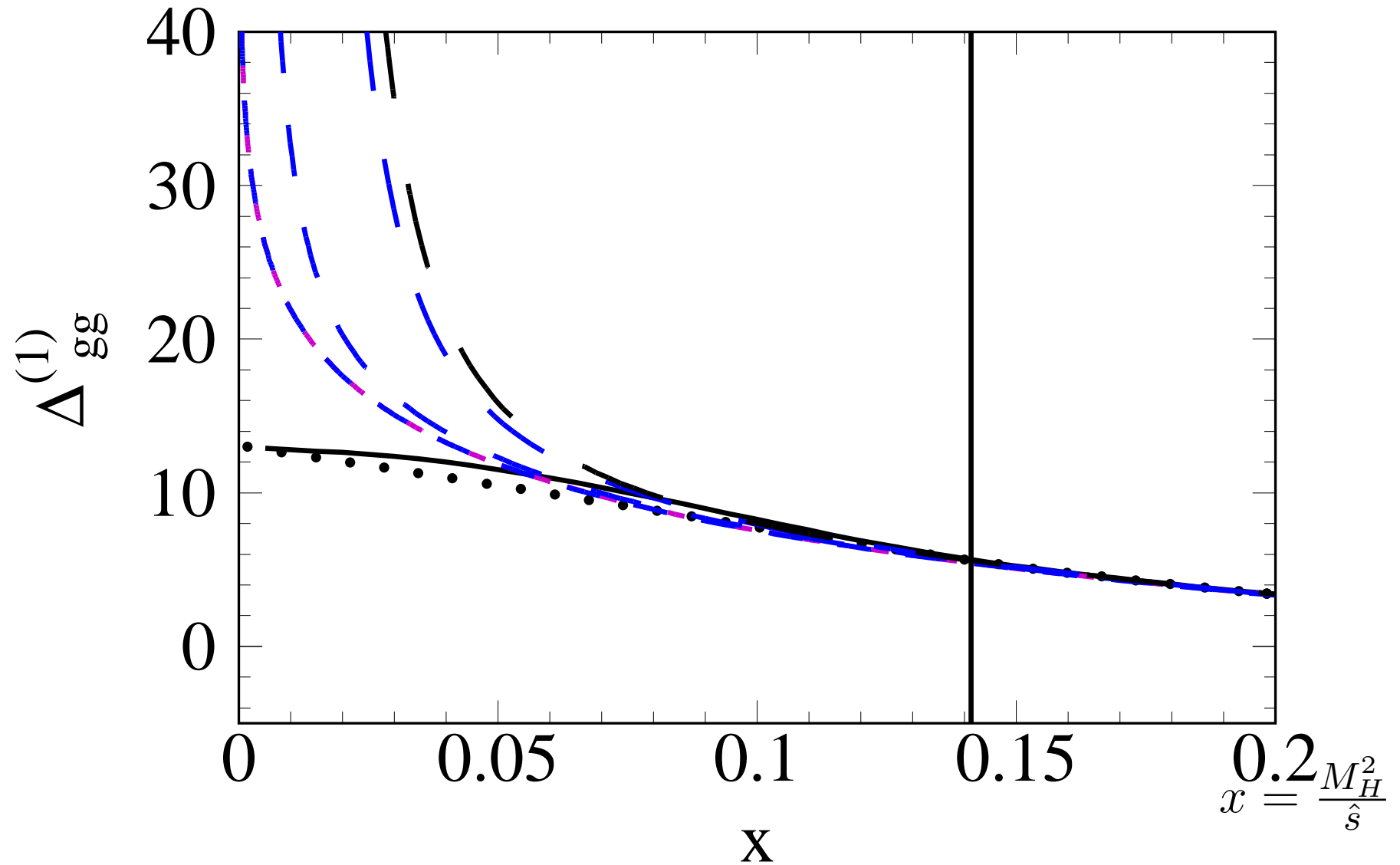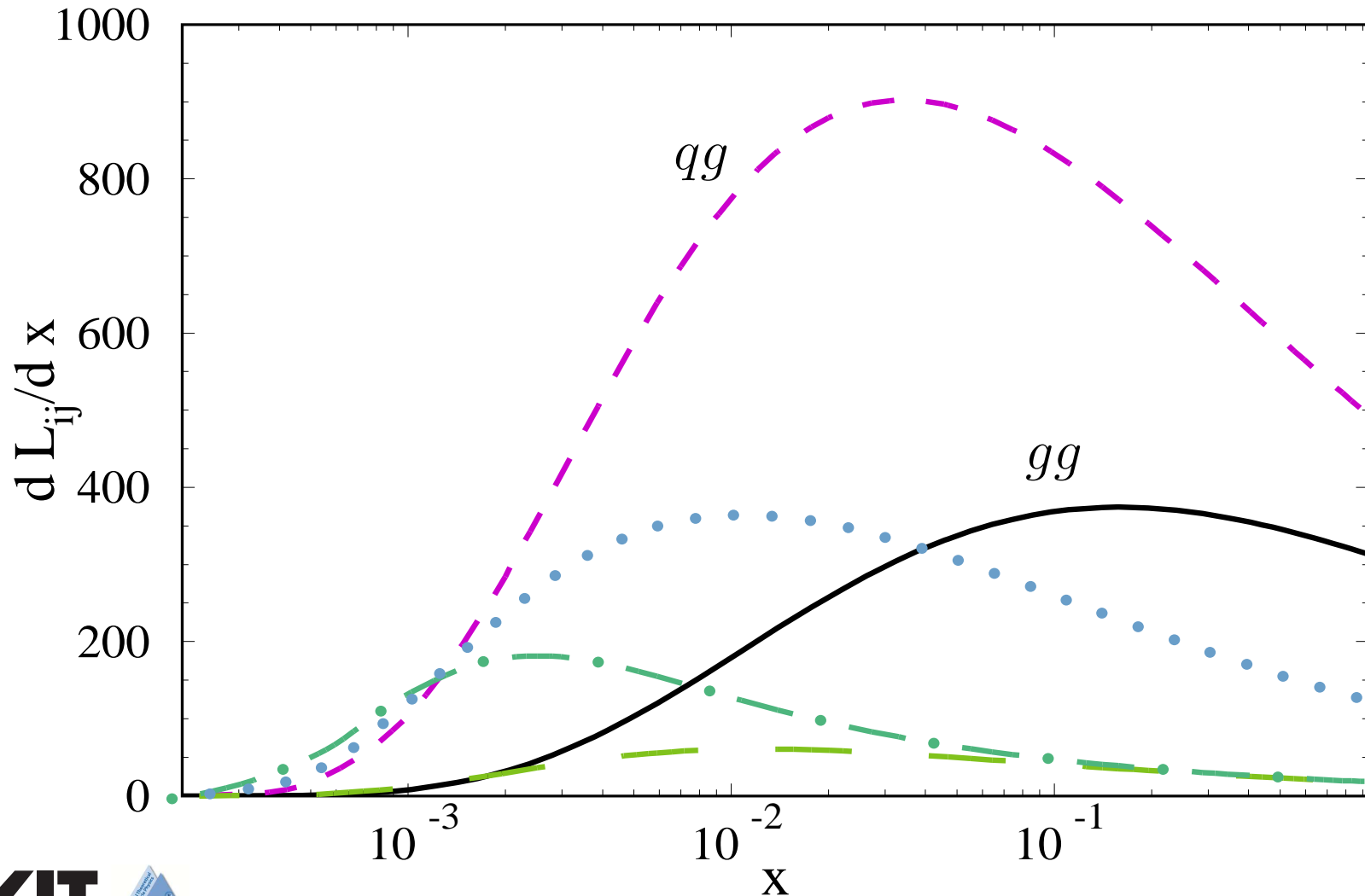
NNLO partonic cross section

NNLO partonic cross section

$$\Delta^{(2)}_{gg}$$

$$x = \frac{M_H^2}{\hat{s}}$$

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

NNLO partonic cross section

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

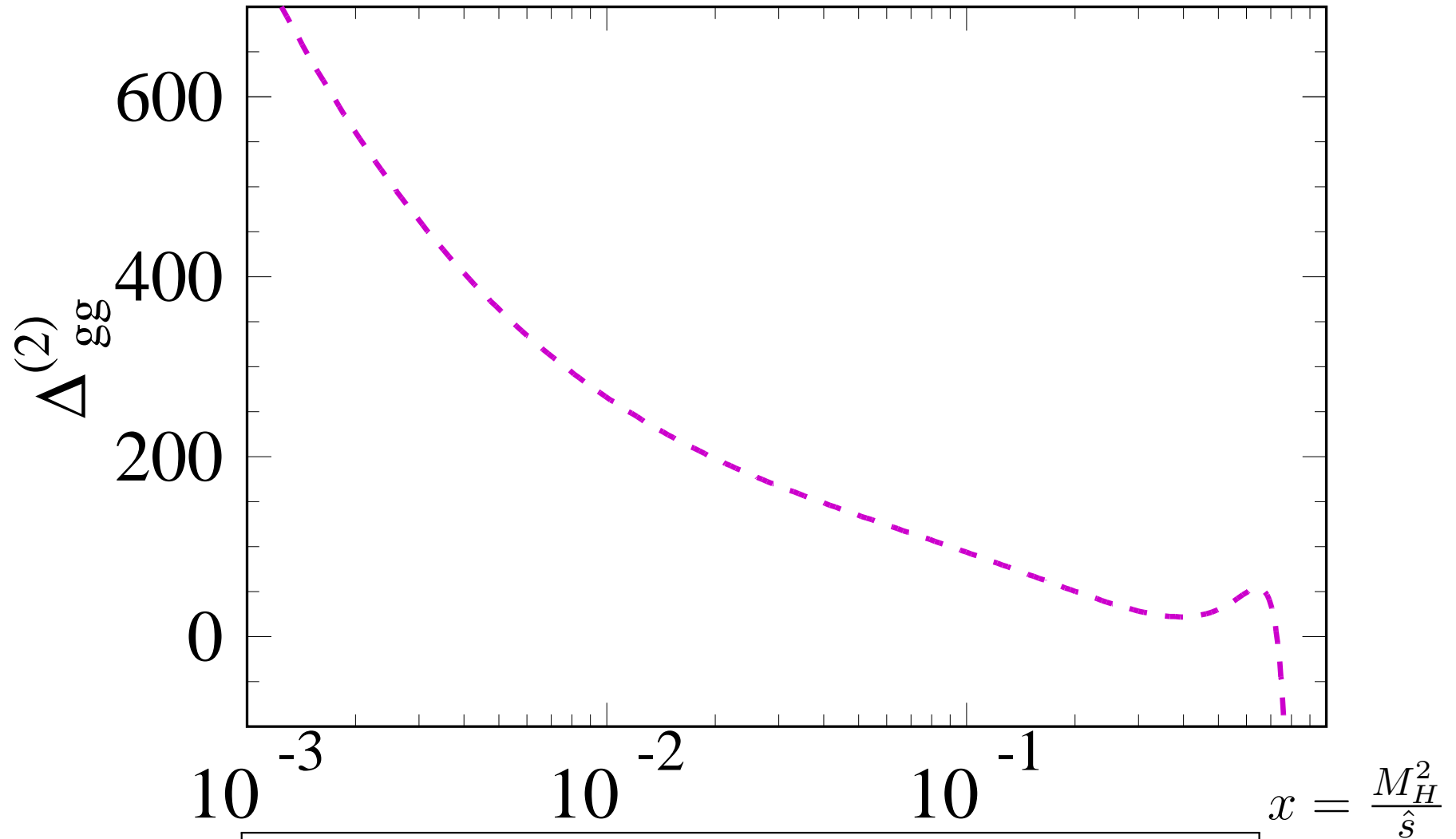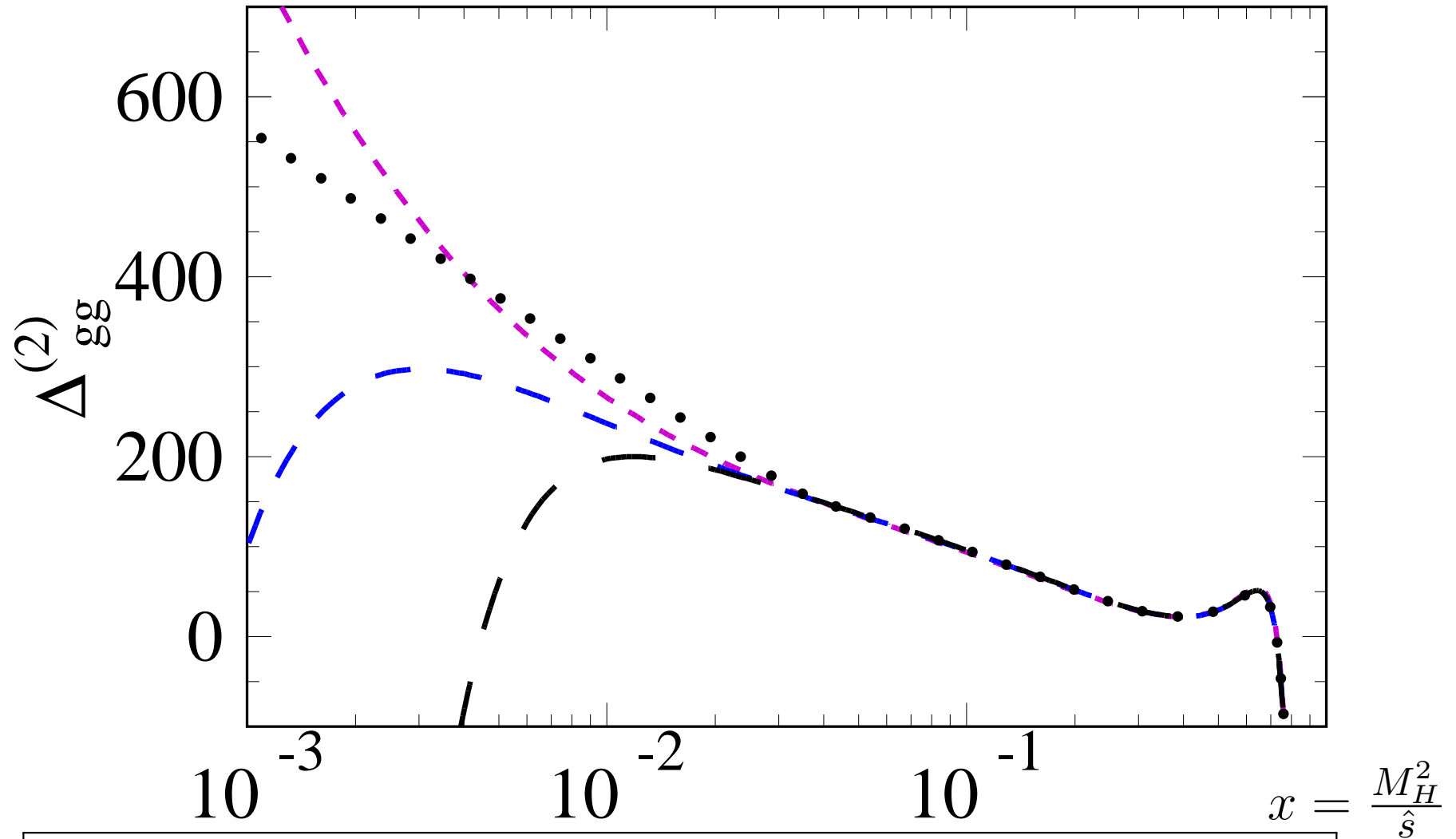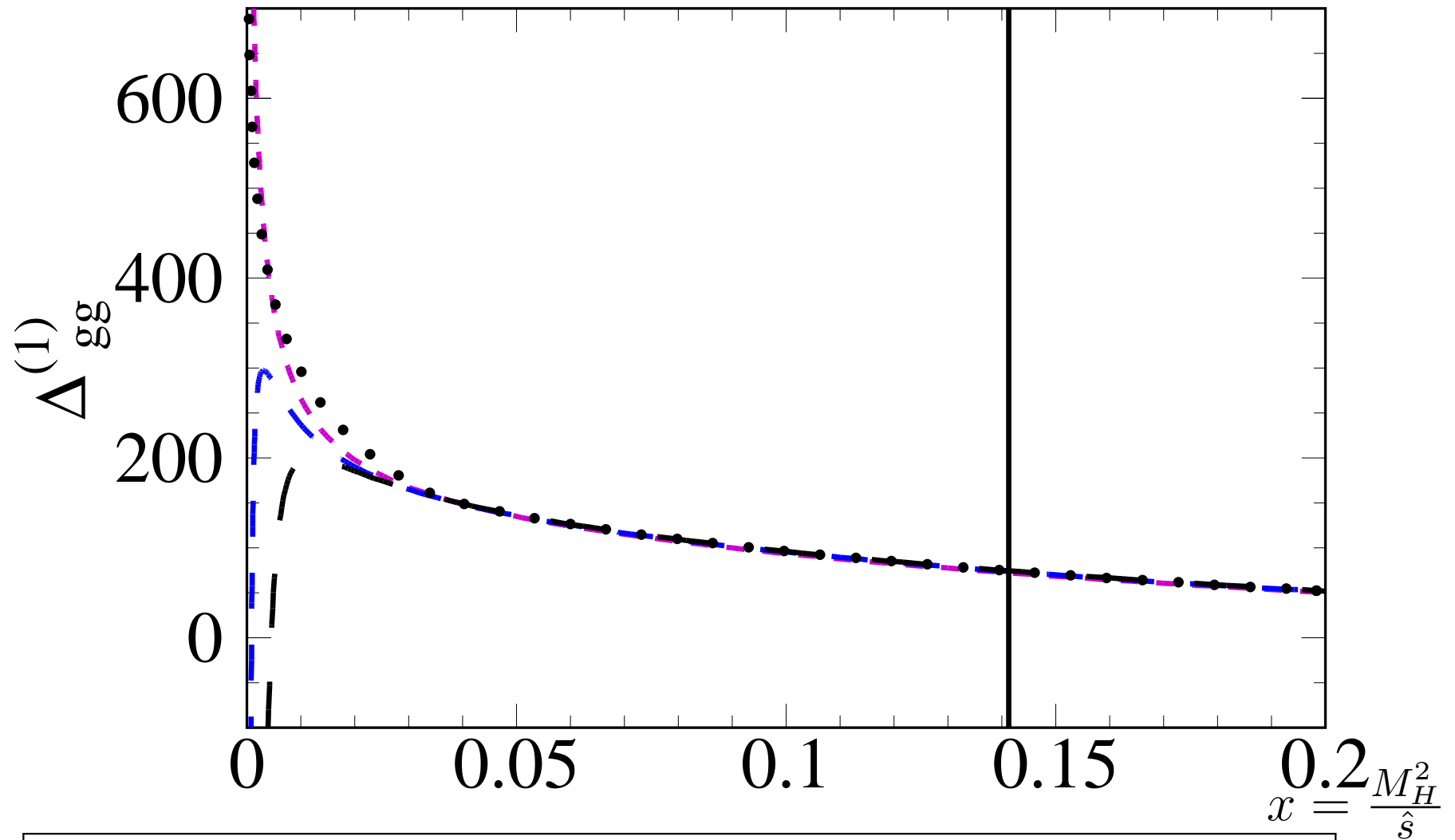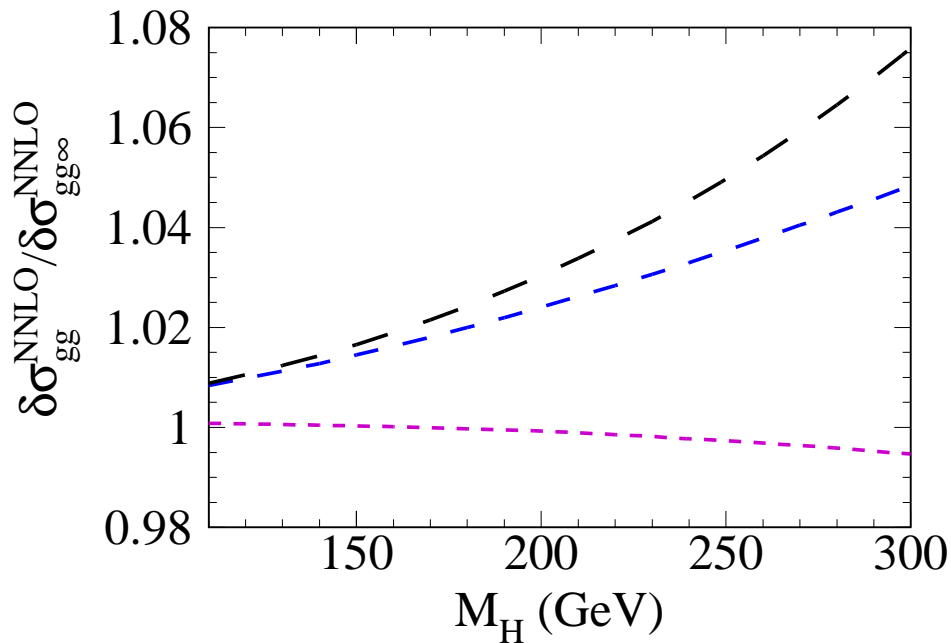Axis labels: $\Delta^{(1)}_{gg}$ (vertical), $x = \frac{M_H^2}{\hat{s}}$ (horizontal)

Hadronic results

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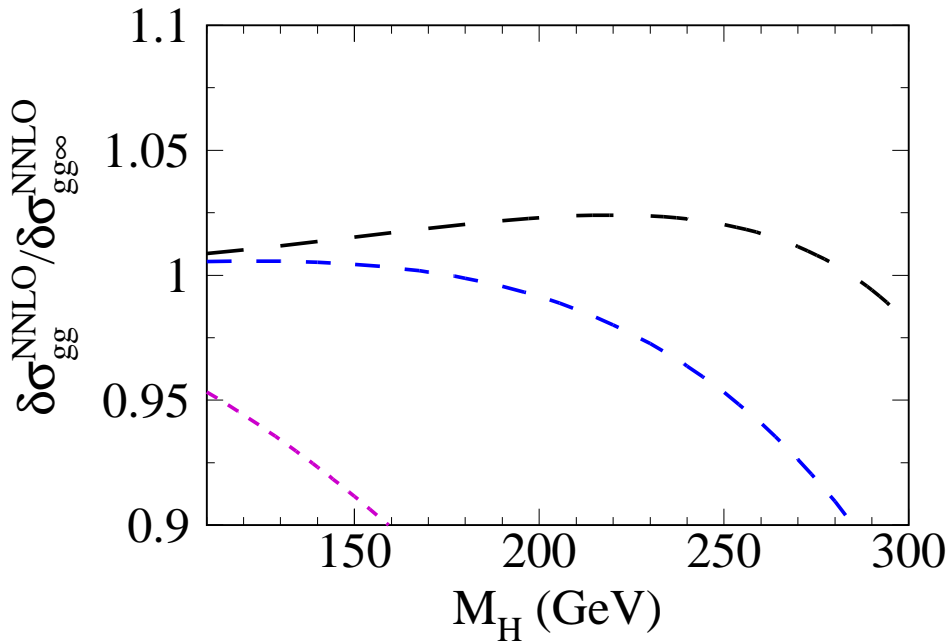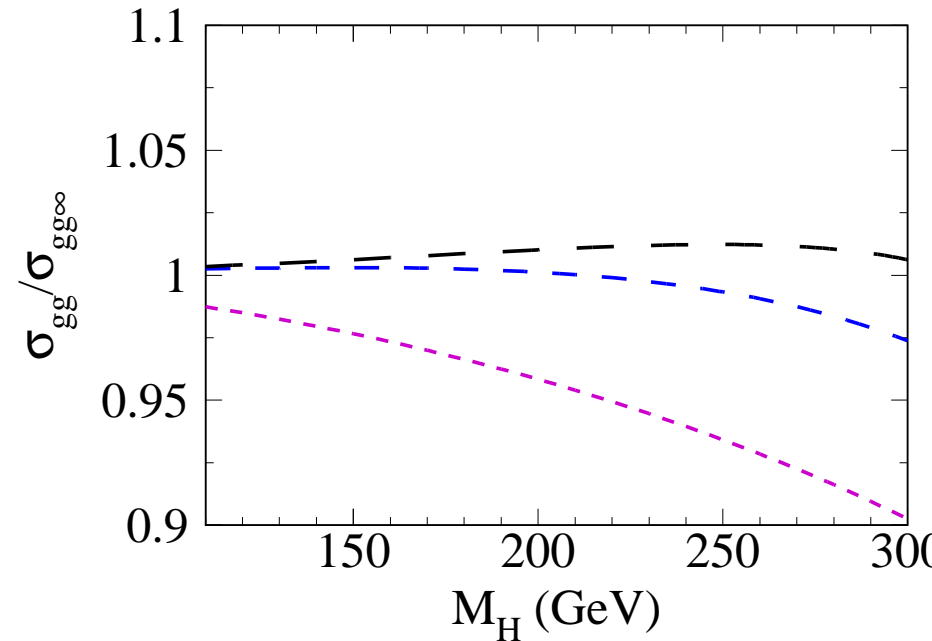

factorized
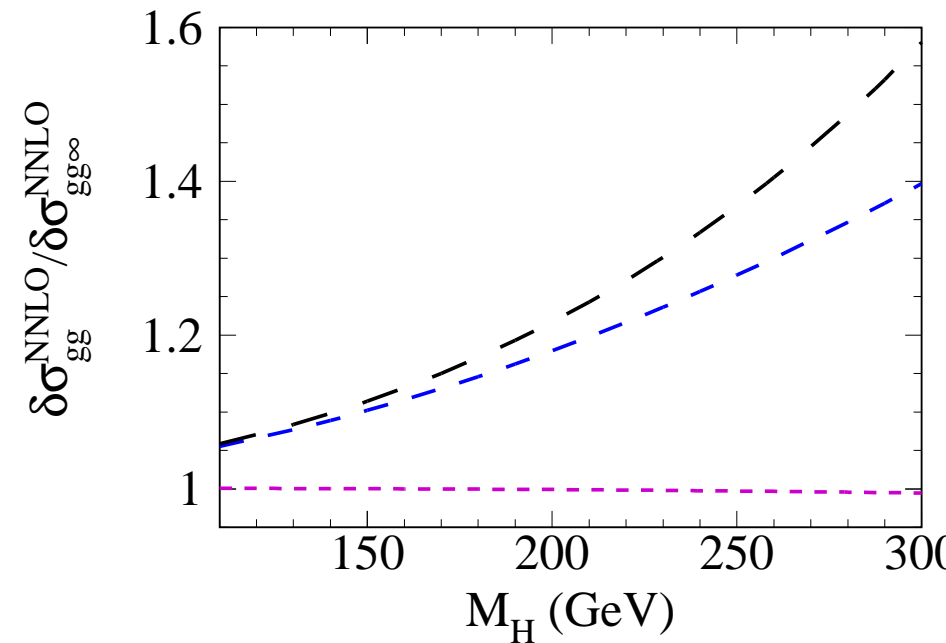
expanded

[Pak,Rogal,Steinhauser'09]

Hadronic results (2)

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

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

NNLO

LO + NLO + NNLO

[Pak,Rogal,Steinhauser'09]

Independent calculation: [Ozeren,Harlander'09;Robert V. Harlander, Mantler,Marzani,Kemal,Ozeren'10]

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!