Higgs production at the LHC at NNLO

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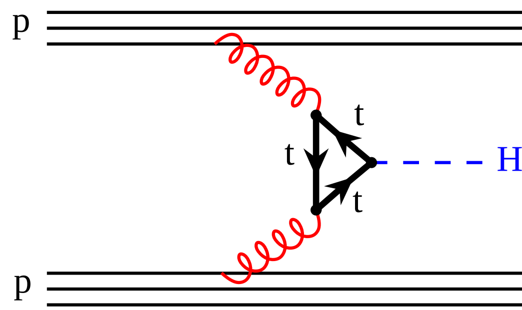
hep-ph/0102241, PRD in print.

see also: [Catani, de Florian, Grazzini, hep-ph/0102227]

What am I going to say?

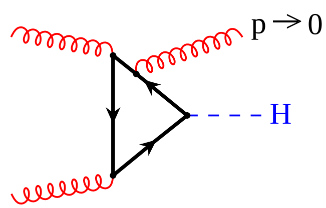
- gluon fusion: dominant Higgs production mechanism at LHC



- NLO corrections are huge: 50-100%

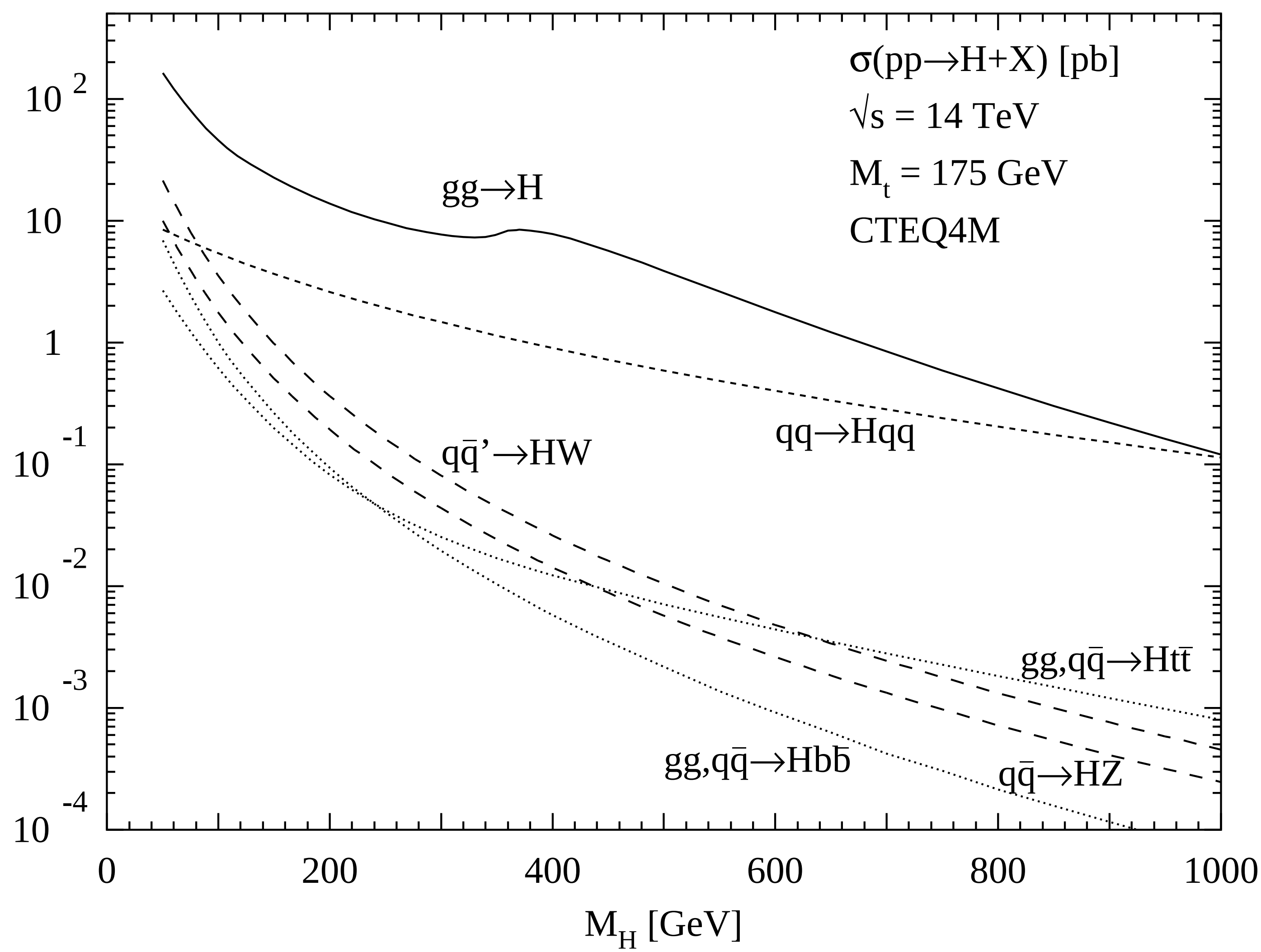
- NNLO — with approximations:

1. limit $4m_t^2 \gg M_H^2$ OK! $[M_H^2/(4m_t^2) \approx 0.1]$

2. soft gluons: 

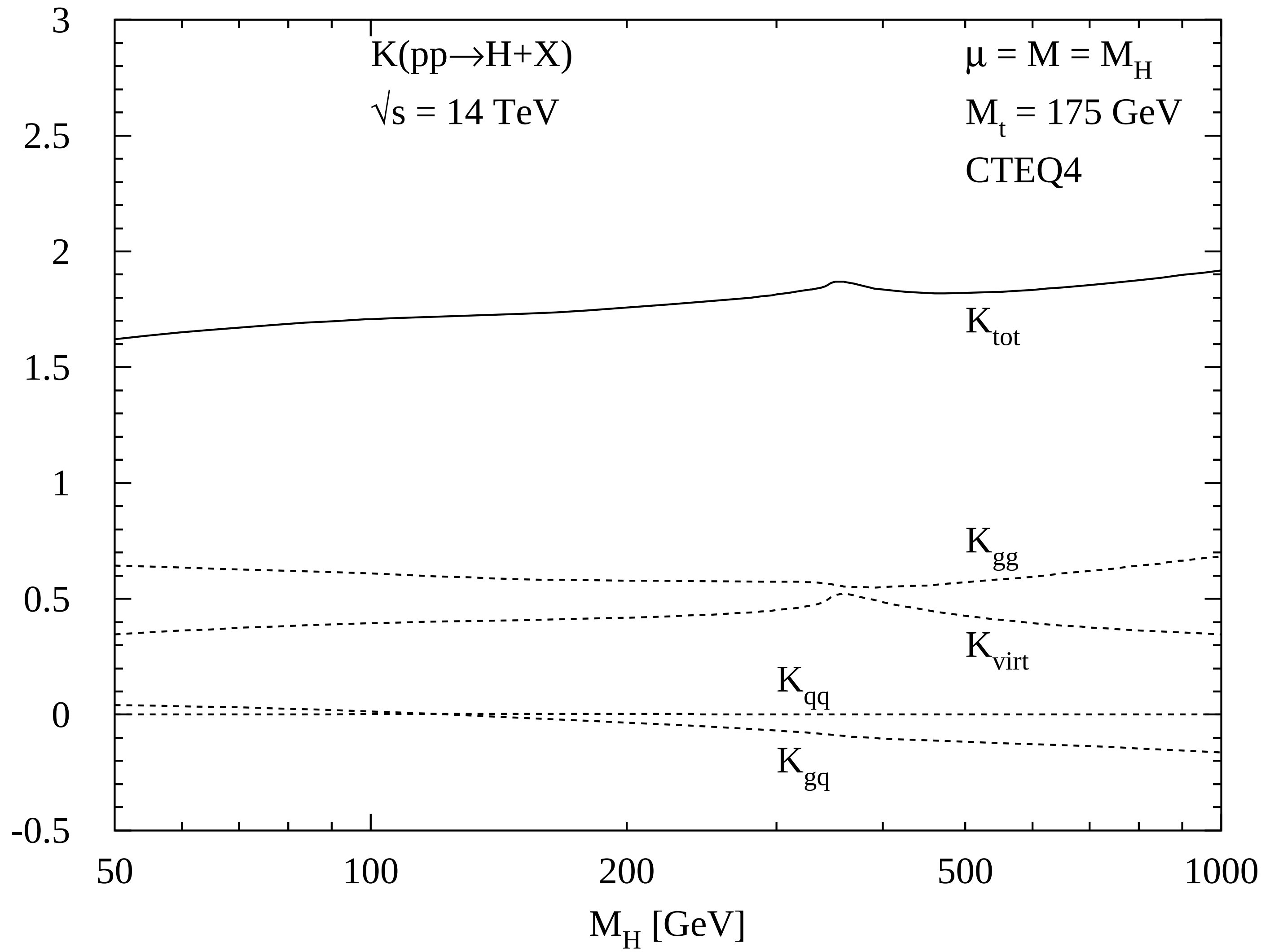
i.e. $M_H^2/\hat{s} \equiv x \to 1$?

Higgs production at the LHC



taken from [Spira '97]

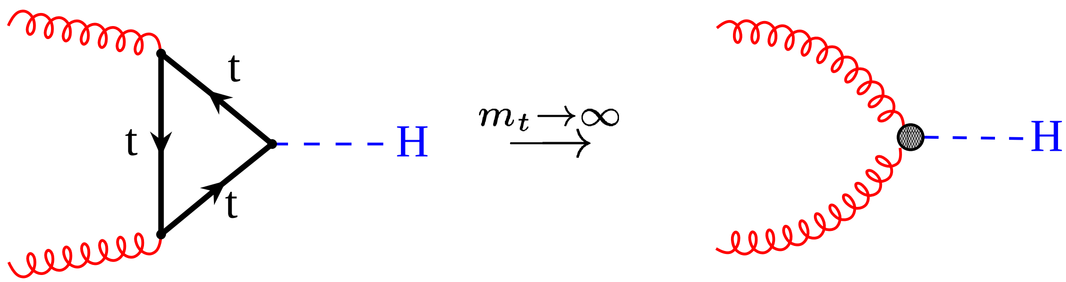
NLO K-factor



taken from [Spira '97]

Effective Lagrangian

Integrating out the top quark: $\mathcal{L}_{\text{eff}} = C(\alpha_s)\, H\, G^{a}_{\mu\nu} G^{a,\mu\nu}$



$C(\alpha_s)$: remnant of top triangle (contains $\ln m_t$!)

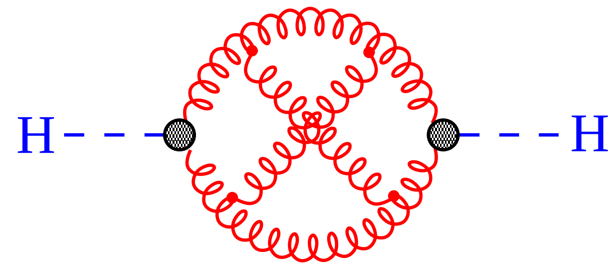
known to $\mathcal{O}(\alpha_s^4)$ [Chetyrkin, Kniehl, Steinhauser '98]

LO result:

$$\sigma_{\text{LO}}(gg \to H) = \frac{G_{\text{F}}\alpha_s^2}{288\sqrt{2}\pi}\,\delta(1-x), \quad x \equiv M_H^2/s$$

"Reverse" Process: $H \to gg + X$

- inclusive process: use optical theorem:

$$\Gamma(H \to gg + X) \quad \sim \quad \mathrm{Im}\Big[$$  $$\Big]$$

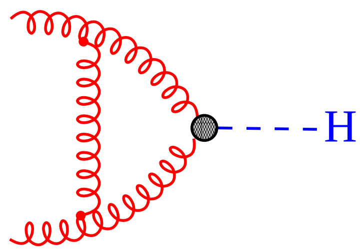
- use well known tools for 3-loop 2-point functions
- result [Chetyrkin, Kniehl, Steinhauser '97]:

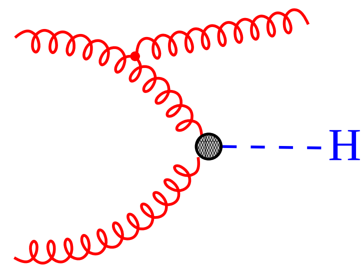
$$\Gamma(H \to gg + X) = \Gamma_0 \left[1 + \underbrace{0.66}_{\text{NLO}} + \underbrace{0.21}_{\text{NNLO}}\right]$$

- large corrections, but good convergence

NLO

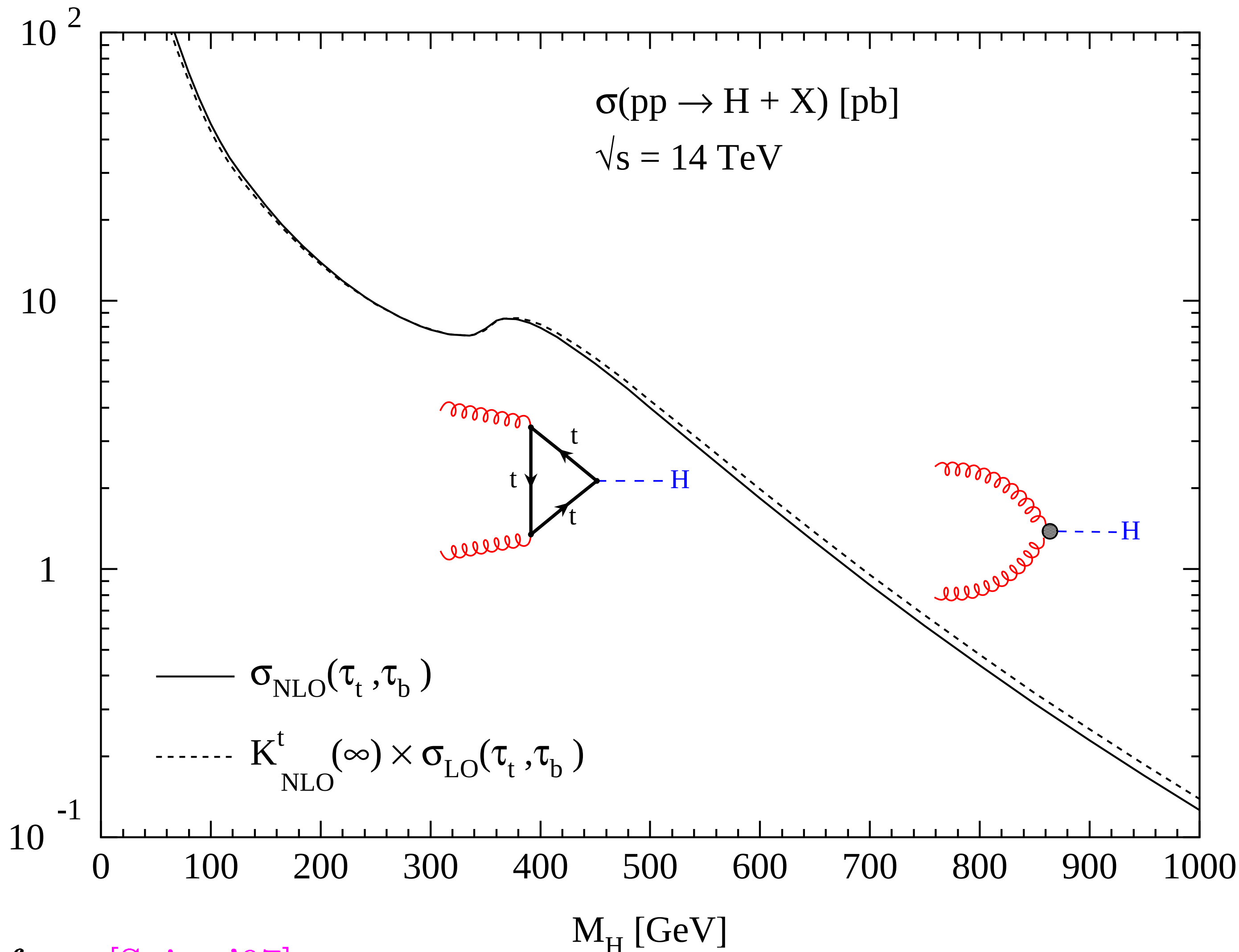
[S. Dawson '91], [Djouadi, Spira, Zerwas '91]

virtual: 

+ real: 

- NLO corrections are huge!
- effective theory ($m_t \to \infty$) is excellent approximation
  - subleading m_t terms: [Dawson, Kauffman '92]
  - full m_t dependence (numerical): [Graudenz, Spira, Zerwas '93]

NLO – effective/full theory

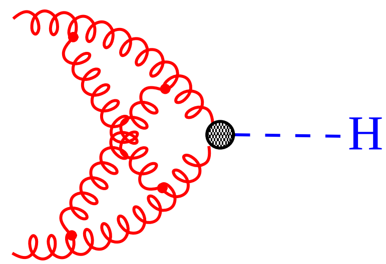


taken from [Spira '97]

NNLO

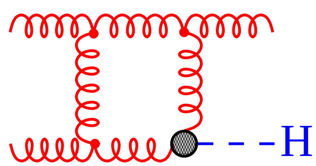
Different contributions:

- virtual 2-loop: [R.H. '00]



$\sim \delta(1-x), \qquad x = \frac{M_H^2}{s}$

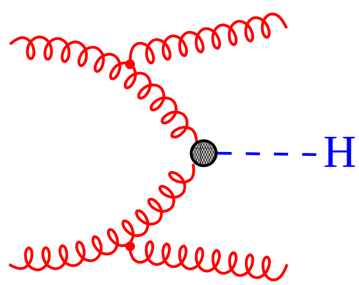
- real, 1-loop:



more complicated dependence on $x = \frac{M_H^2}{s}$

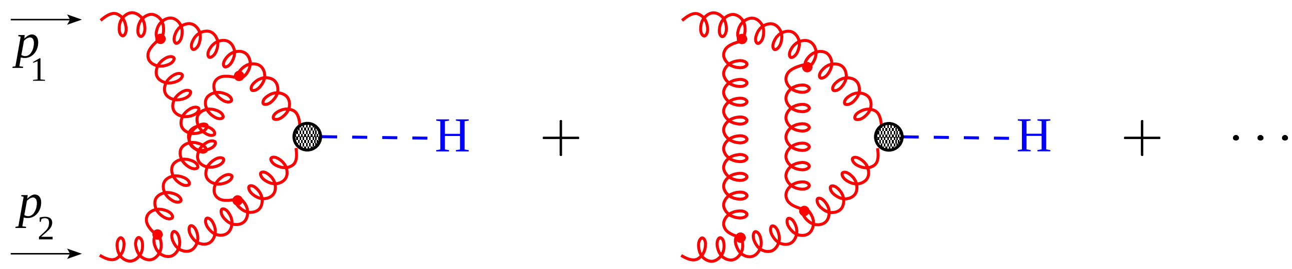
first step: soft limit, i.e. $x \to 1$

- tree:



NNLO: Virtual Corrections

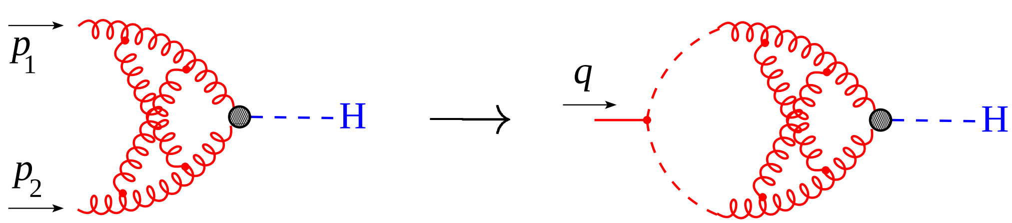
[R.H., PLB 492 (2000) 367]



- external gluons are on-shell: $p_1^2 = p_2^2 = 0$

  $\Rightarrow$ result depends only on $q^2 = (p_1 + p_2)^2 = M_H^2$

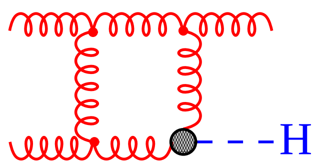
- map 2-loop vertex diagrams to 3-loop propagators:
  [Baikov, Smirnov '00]



evaluate analytically:
"Integration-by-parts"
[Chetyrkin,
Tkachov '81]

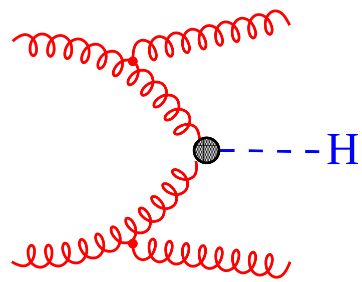
NNLO: Real Radiation

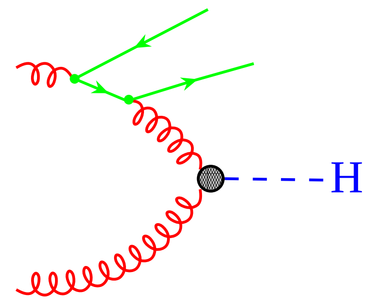
1-loop single:



- amplitude: [C. Schmidt '97]
- phase space integration:
  full dependence on $x = M_H^2/s$: [Kilgore '01 (in prep.)]
  (here only soft limit: $x \to 1$)

tree-level double:





- general x-dependence: very hard!
  (cf. Drell-Yan [Matsuura, v.d. Marck, v. Neerven '89])

- soft limit: $x \to 1$
  - $\delta(1-x)$: cf. virtual corrections
  - $\dfrac{\ln^n(1-x)}{1-x}$: "large logarithms"
  - other terms (e.g. $\ln^n(1-x)$, $(1-x)^n$) are dropped
  - $\Rightarrow$ phase space integration greatly simplifies!

- question: Is this a good approximation?

Partonic cross section

virtual + single real + double real $\to$ finite!

$\to$ strong check on individual terms!

other checks: RG invariance, Sudakov resummation, ...

result: [R.H., W. Kilgore, hep-ph/0102241]
[S. Catani, D. de Florian, M. Grazzini, hep-ph/0102227]

$$\sigma(gg \to H) = \frac{\pi}{576 v^2}\left(\frac{\alpha_s}{\pi}\right)^2 (1 + \underbrace{0.548}_{\text{NLO}} + \underbrace{0.107}_{\text{NNLO}})\,\delta(1-x) + \text{“large logarithms”} + \cdots$$

$\to$ nice convergence!

Collinear Resummation

- observation at NLO: soft approximation insufficient
- including non-soft terms $\sim \ln^n(1-x)$: good approximation at NLO and – for Drell-Yan – also at NNLO
- $\Rightarrow$ derive leading non-soft terms for $gg \to H$ at NNLO from resummation formula [Krämer, Laenen, Spira '98]
- result:

NLO: $\delta(1-x), \quad \frac{\ln^n(1-x)}{1-x} \quad (n=0,1) \qquad \to$ soft

$\ln(1-x) \qquad \to$ collinear

NNLO: $\delta(1-x), \quad \frac{\ln^n(1-x)}{1-x} \quad (n=0,1,2,3) \qquad \to$ soft

$\ln^3(1-x) \qquad \to$ collinear

Hadronic Cross Section

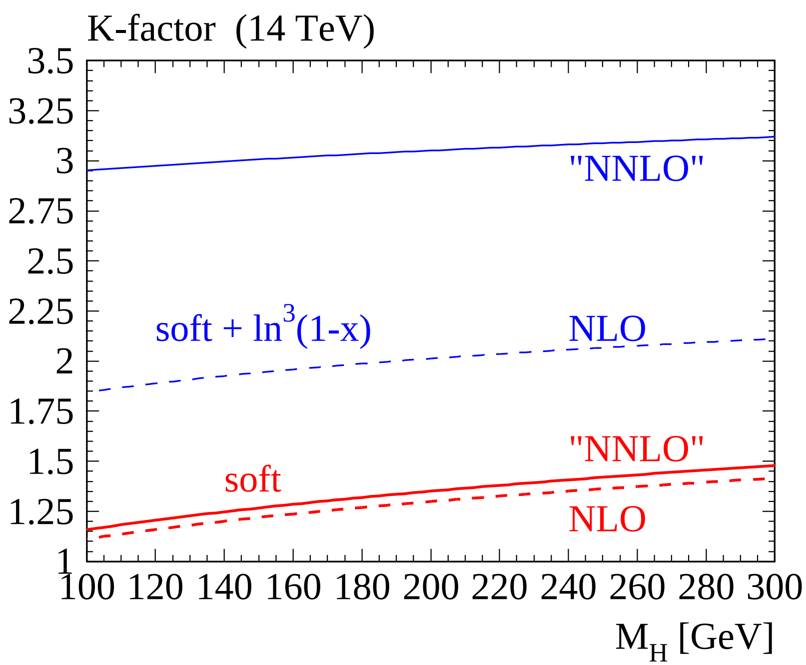
- convolution with parton distribution functions:

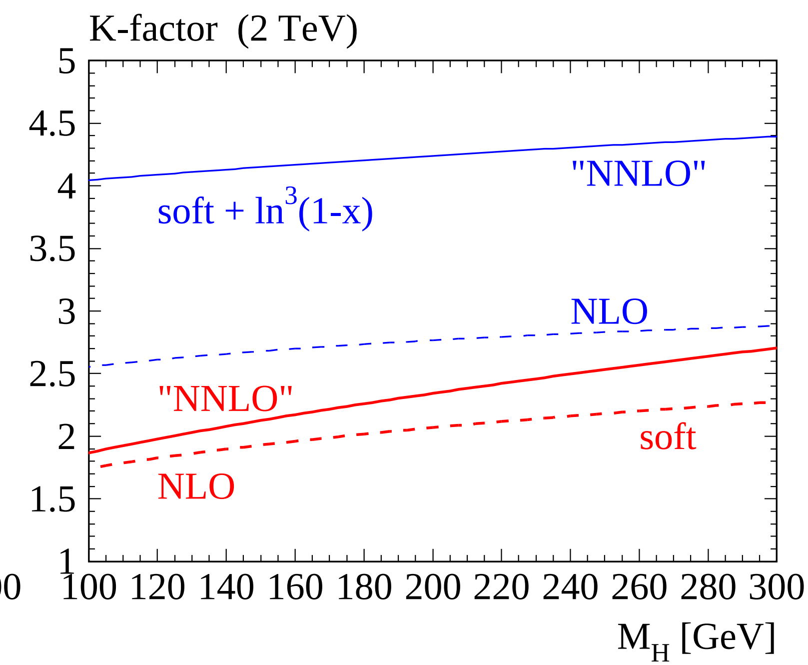
$$\sigma_{pp\to H}(s) = \int \mathrm{d}x_1 \mathrm{d}x_2\, g(x_1) g(x_2)\, \sigma_{gg\to H}(s/x_1 x_2)$$

$\Rightarrow$ NNLO pdf's not yet available!

- use NLO pdf's at NNLO $\to$ inconsistency!
- use caution in interpretation of hadronic NNLO results

Results





- "subleading" terms $\sim \ln^3(1-x)$ dominate!
- "NNLO": pdf's not yet available
- need contributions from hard gluons!

Conclusions

- NLO QCD corrections to $gg \to H$ up to 100%
  $\Rightarrow$ NNLO required
- here: soft + virtual contributions
- first step towards full calculation
  (but numerically sub-dominant)
- partonic results: good convergence
- outlook: full calculation, application to SUSY Higgs