Direct Higgs production at hadron colliders

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Outline

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- Soft-gluon resummation
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Motivations

- Several constraints indicate $100 < M_H < 200$ GeV
- SM Higgs boson with $M_H \sim 115$ GeV 'found' at LEP?
- Next search at Hadron Colliders: Run II at Tevatron and LHC
- Dominant production mechanism: gg fusion through a heavy-quark loop
- NLO QCD corrections known to be large

A.Djouadi, M.Spira, P.Zerwas (1991)
S.Dawson (1991)

- Estimates of higher order corrections still sizable

M.Krämer, E.Laenen, M.Spira (1998)

$$\Downarrow$$

NNLO calculation highly demanded

Direct Higgs production at NNLO

Recently: evaluation of NNLO corrections completed

- Two-loop amplitude $gg \to H$ $(M_H/M_t \ll 1)$

  R.Harlander (2000)

- Soft and virtual contributions

  S.Catani, D. de Florian, M.G. (2001)
  R.Harlander, W.Kilgore (2001)

- Hard contributions:
  - as series expansion around threshold

    R.Harlander, W.Kilgore (2002)

  - New: Full calculation

    C.Anastasiou and K.Melnikov (2002)

Together with approximated NNLO pdf's available:
MRST2001 (kernels from van Neerven, Vogt)

$$\Downarrow$$

Consistent calculation of
the hadronic cross section at NNLO

The $M_H \ll m_{top}$ approximation

For a light Higgs it is possible to use an effective lagrangian in the limit $m_{top} \to \infty$:

$$\mathcal{L}_{eff} = -\frac{1}{4}\left[1 - \frac{\alpha_S}{3\pi}\frac{H}{v}(1+\Delta)\right] Tr G_{\mu\nu}G^{\mu\nu}$$

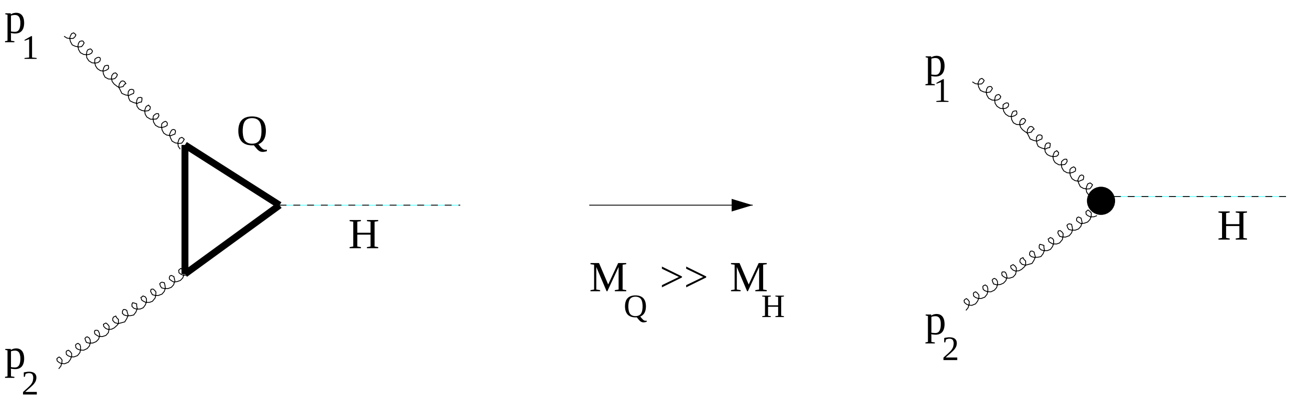
J.Ellis, M.K.Gaillard, D.V.Nanopoulos (1976)
M.Voloshin, V.Zakharov, M.Shifman (1979)

The correction Δ is known up to $\mathcal{O}(\alpha_S^3)$

K.G.Chetyrkin, B.A.Kniehl, M.Steinhauser (1997)

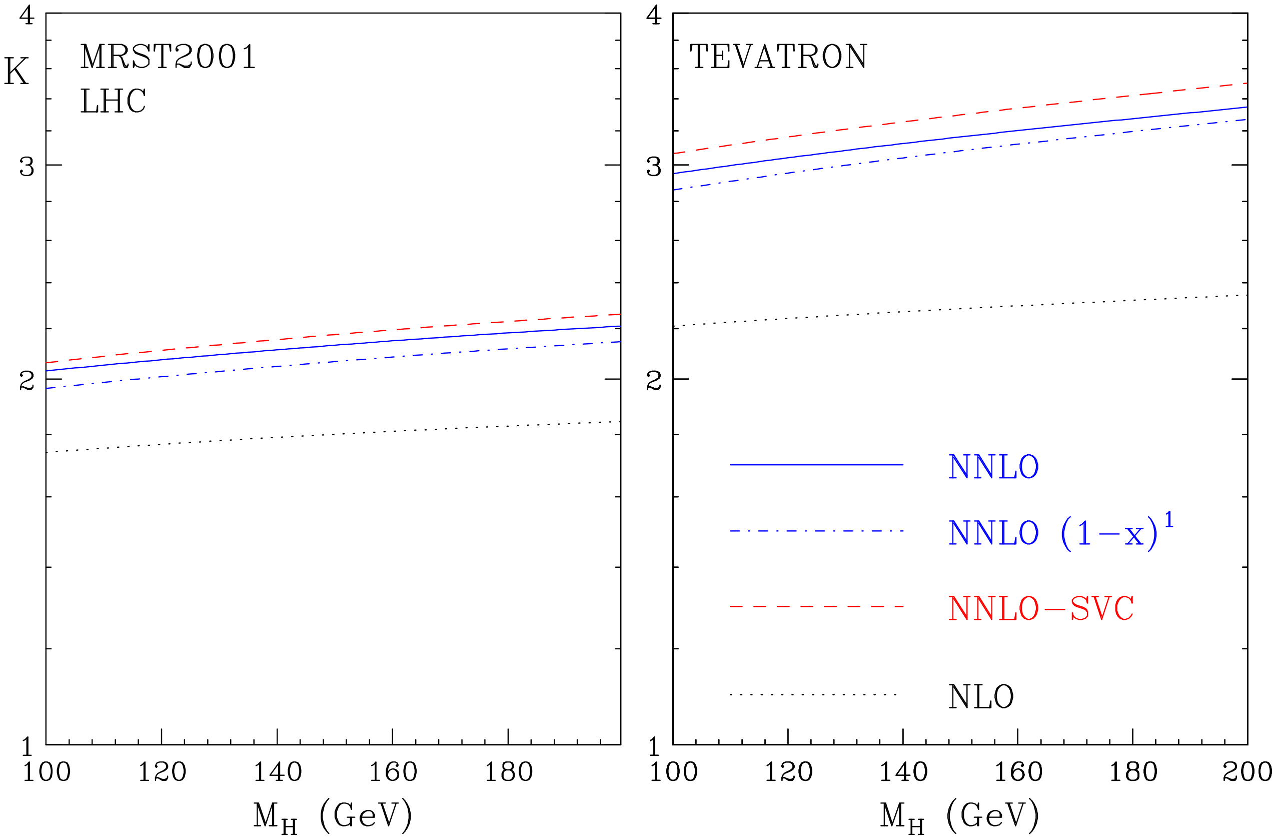
The approximation is correct within 5% if $M_H < 2\, m_{top}$

Effective vertex: one loop less



The approximation works well even for large M_H if full Born result is retained

Results



Effect wrt NLO: +15% at the LHC
+35% at the Tevatron

The soft + virtual + leading collinear (SVC) contributions provide an excellent approximation of the full result

The hard contribution is about 2% at LHC and 4% at the Tevatron

Why does the soft approximation work so well ?

The hard cross section is convoluted with the parton distributions that are strongly peaked at small x:
$< \hat{s} > = < x_1 x_2 > s \ll s$

$\Rightarrow$ The hard cross section is almost always evaluated close to threshold

Soft gluon resummation

S.Catani, D.de Florian, P.Nason, M.G. (2002)

Inclusive cross section dominated by soft and collinear emission $\Rightarrow$Multiple soft emission beyond NNLO can be important

In N-space the large logarithmic corrections appear as $\alpha_S^n \log^{2n} N$

This large corrections can be resummed to all orders:

$$G_{gg\to H,N}(\alpha_S) = C(\alpha_S) \exp\Big\{ \ln N g_1(\beta_0\alpha_S \ln N) + g_2(\beta_0\alpha_S \ln N) + \alpha_S\, g_3(\beta_0\alpha_S \ln N) + \dots \Big\}$$

The function g_1 controls the LL contributions g_2 the NLL contributions g_3 the NNLL ones and so on

At NNLL three new coefficients appear:

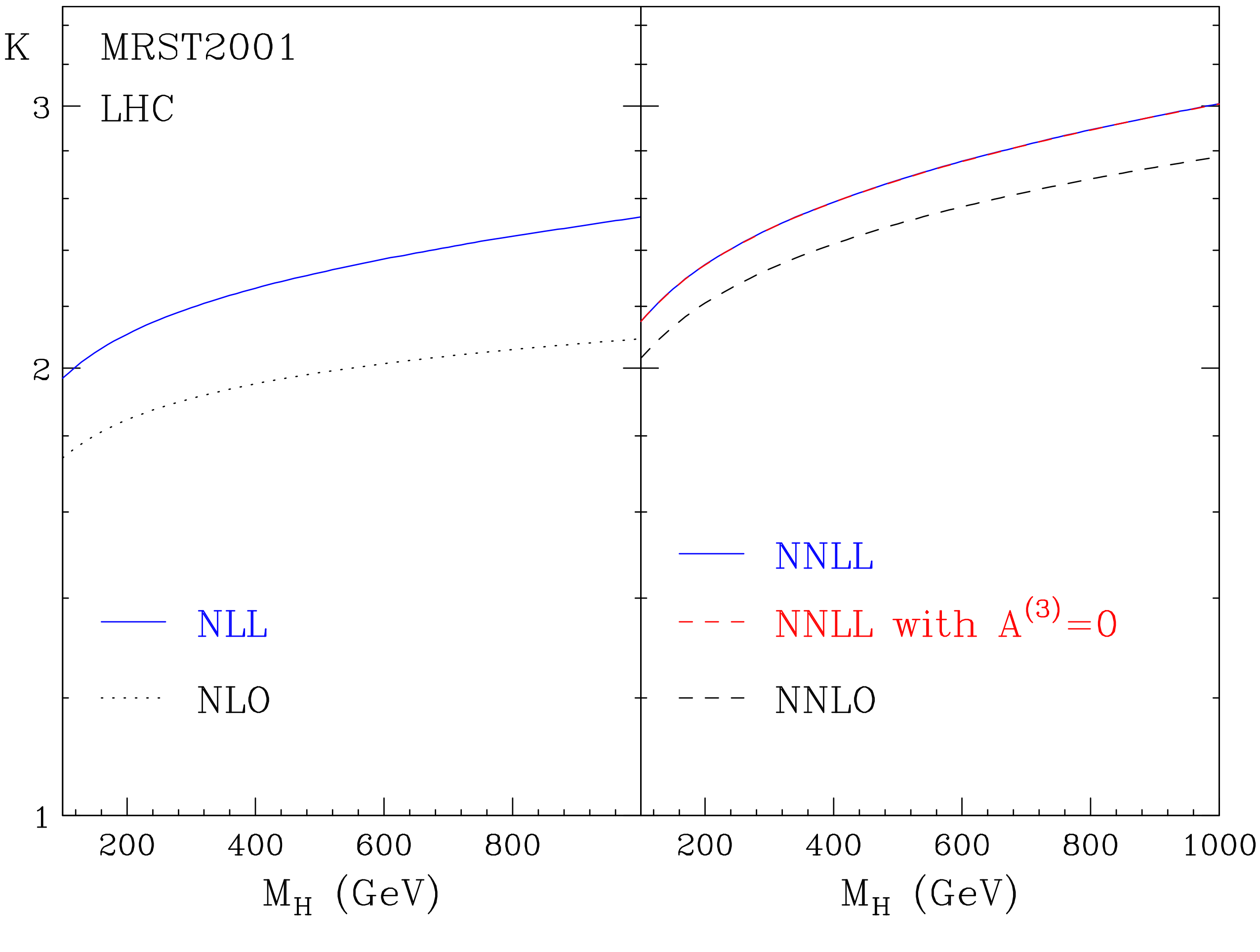
- $D^{(2)}$, $C^{(2)}$ that can be obtained from the NNLO result
- $A^{(3)}$ which is known numerically

A.Vogt (2000)

Results at the LHC

- MRST2001 $\Rightarrow$ "LO" = LO dist. + 1 loop α_S
  "NLO" = NLO dist. + 2 loop α_S
  "NNLO" = NNLO dist. + 3 loop α_S

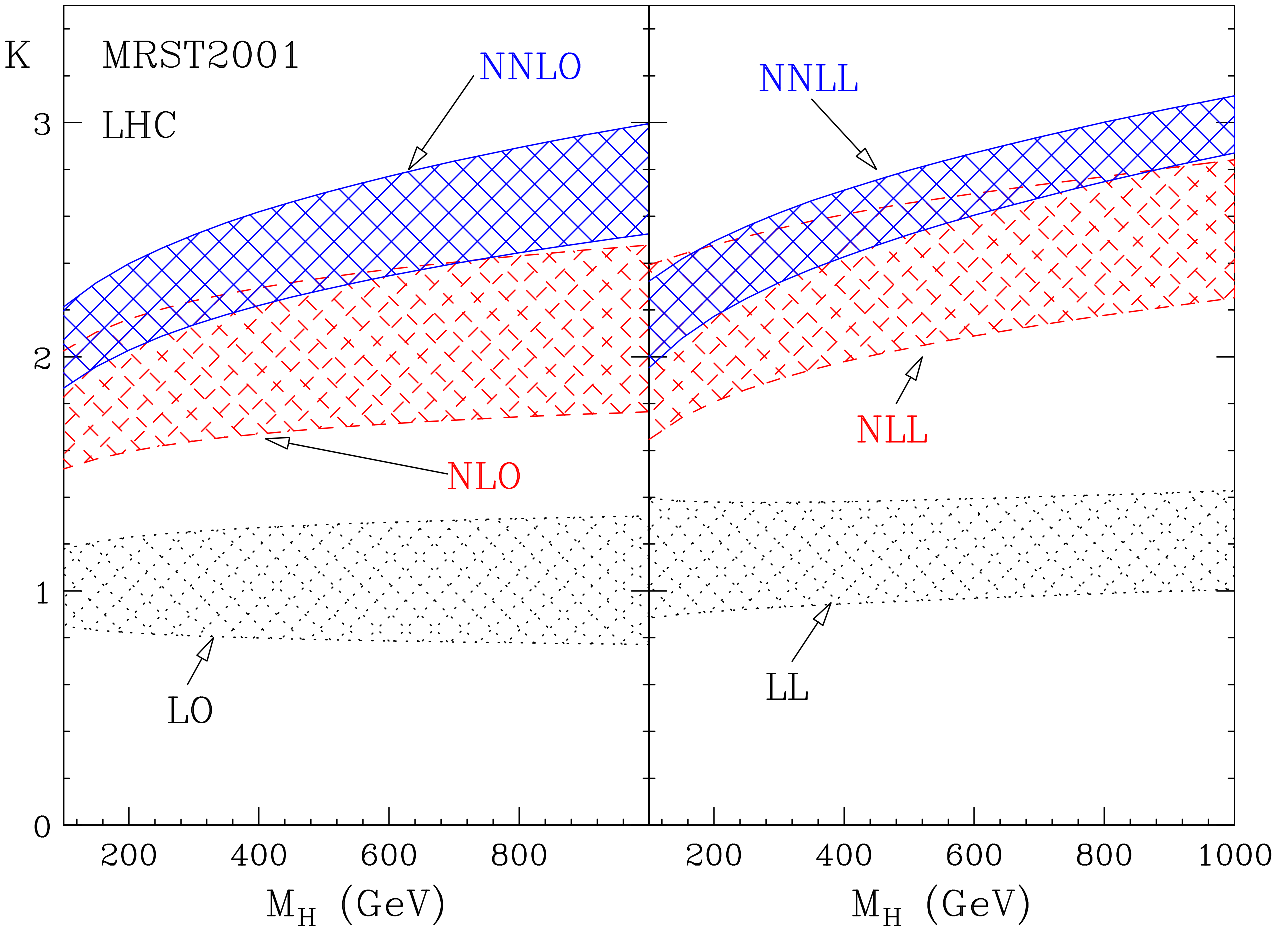
- Resummed result matched to corresponding fixed order



- The effect of $A^{(3)}$ is neglible

- The NNLL effect is about 6% with respect to NNLO for $M_H \lesssim 200$ GeV

Results at the LHC

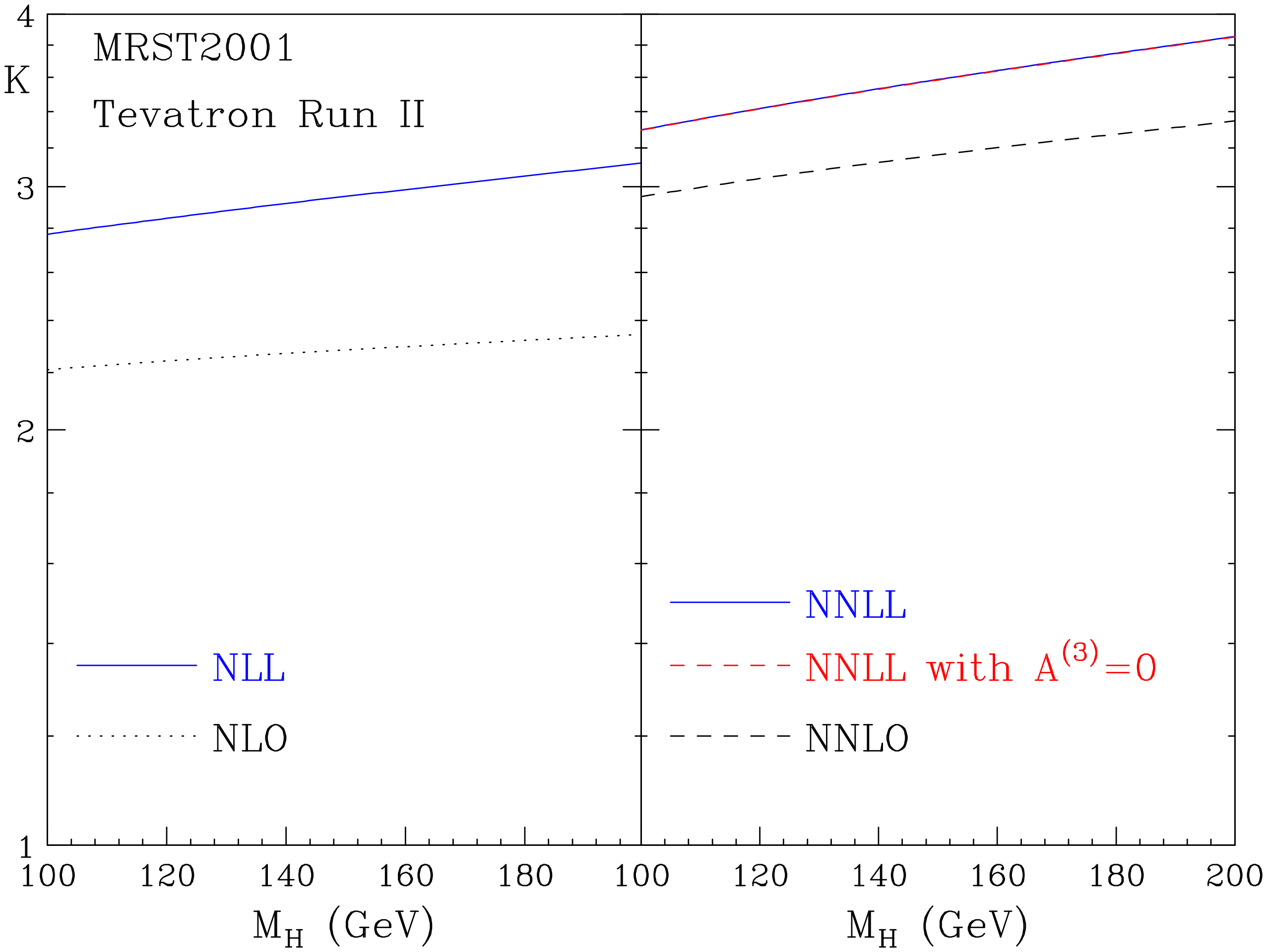


- K factors $\dfrac{\sigma^{NLO/NNLO}(\mu_{F,R})}{\sigma^{LO}(\mu{=}M_H)}$

- Uncertainty band:
  - Fixed order: $\mu_F = \mu_R = \chi M_H \qquad 1/2 < \chi < 2$
  - Resummed result: $\mu_F = M_H$
    $\mu_R = \chi M_H \qquad 1/2 < \chi < 2$

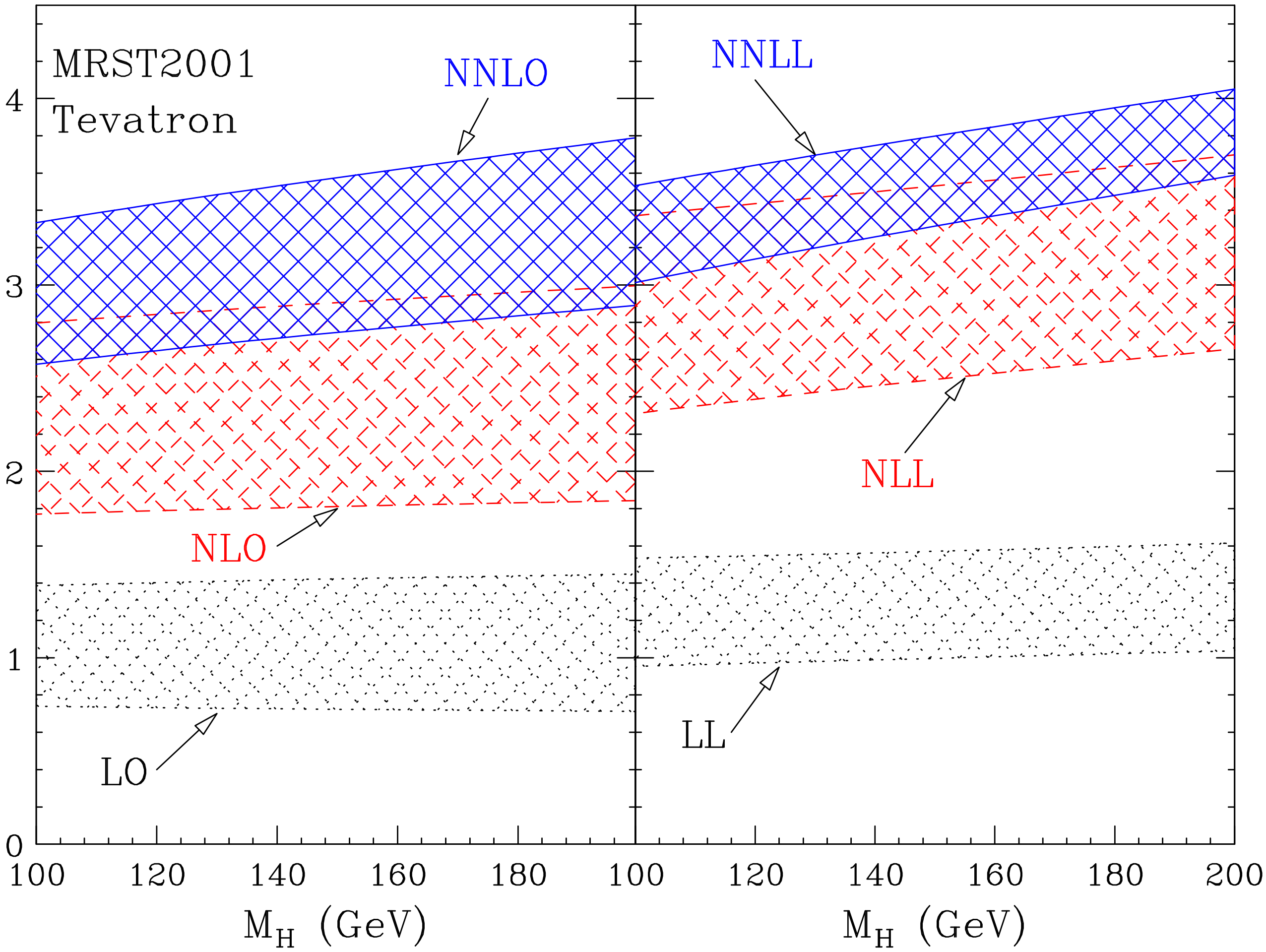
- Residual theoretical uncertanty at NNLL of about $\pm 10\%$ ($M_H \lesssim 200$ GeV)

Results at the Tevatron



The NNLL effect here is larger and increases the cross section by about $12-15\%$ with respect to NNLO

Results at the Tevatron



- Bands defined as for LHC
- Residual scale uncertanty of about $\pm 10\%$ at NNLL

Summary

- NNLO calculation for direct Higgs production through gg fusion completed:
  - The effect is an increase of the cross section of $\sim 15\%$ at the LHC and of $\sim 35\%$ at the Tevatron
  - SV/SVC $\Rightarrow$dominant terms
- We have evaluated the contribution of multiple soft-gluon emissions to all orders:
  - Effect moderate at LHC: for a light Higgs $+6\%$ with respect to NNLO
  - A bit larger at the Tevatron: $+12-15\%$ with respect to NNLO

$\Rightarrow$ Perturbative result under better control now