THE TRANSVERSE MOMENTUM DISTRIBUTION OF THE HIGGS BOSON AT THE LHC

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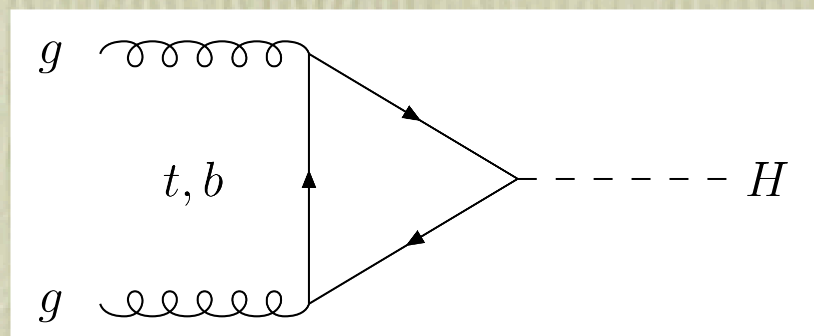
Outline

- Introduction
- The Higgs q_T spectrum
- The program HqT
- NLL+LO and NNLL+NLO results
- Conclusions

Introduction



$gg \to H$ is the dominant SM Higgs production mechanism at hadron colliders

NLO QCD corrections to the total rate computed more than 10 years ago and found to be large

A. Djouadi, D. Graudenz, M. Spira, P. Zerwas (1991)

They increase the LO result by about 80%!

They are well approximated by the large-m_{top} limit

S.Dawson (1991)
M.Kramer, E. Laenen, M.Spira(1998)

NNLO corrections in this approximation are now known

S. Catani, D. De Florian, MG (2001)
R.Harlander, W.B. Kilgore (2001,2002)
C. Anastasiou, K. Melnikov (2002)
V. Ravindran, J. Smith, W.L.Van Neerven (2003)

NEW :

NNLO corrections now implemented for distributions
First NNLO calculation at the fully exclusive level

C. Anastasiou, K. Melnikov, F. Petrello (2004)

The large-m_{top} approximation

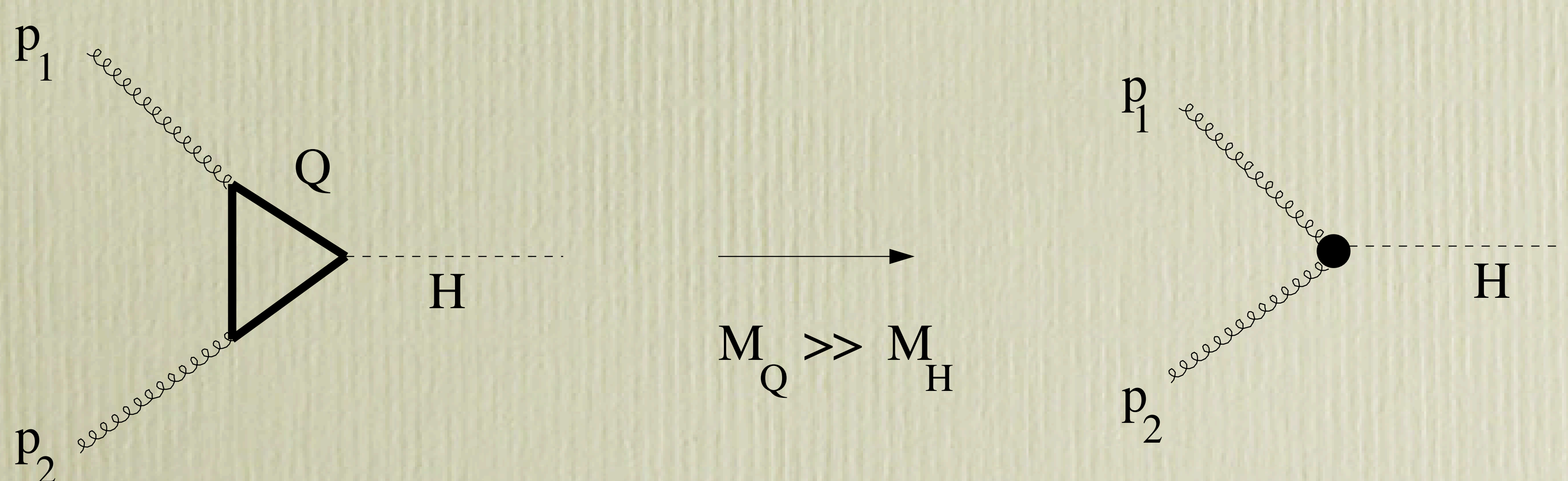
For a light Higgs it is possible to use an effective lagrangian approach obtained when $m_{top} \to \infty$

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

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

Known to $\mathcal{O}(\alpha_S^3)$

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



Effective vertex: one loop less !

The q_T spectrum of the Higgs boson

G. Bozzi, S. Catani, D. de Florian, MG (2003)

Signal and background have different shape in q_T

→ a precise knowledge of the spectrum can help to devise strategies to improve statistical significance

Studies of the Higgs q_T distribution have been performed at various levels of accuracy

I. Hinchliffe, S.F. Novaes (1988)
R.P. Kauffman (1992)
C.P. Yuan (1992)
C. Balazs, C.P. Yuan (2000)
E.L. Berger, J. Qiu (2002)
A.Kulesza, G.Sterman, W. Vogelsang (2003)

Our work →

- Include the best information available now: NNLL resummation at small q_T and NLO pert. theory at large q_T
- Improve the resummation formalism

The region $q_T \sim M_H$

To have $q_T \neq 0$ the Higgs has to recoil against at least one parton → the LO is $\mathcal{O}(\alpha_S^3)$

The LO calculation shows that the large m_{top} approximation works well if both M_H and q_T are smaller than m_{top}

R.K.Ellis, I.Hinchliffe, M.Soldate, J.J.van der Bij (1988)
U. Baur, E.W.Glover (1990)

NLO corrections to Higgs+jet(s) computed in this limit

D. de Florian, Z.Kunszt, MG (1999)

Amplitudes used at NLO:

- One loop: $gg \to gH$, $q\bar{q} \to gH$ C.Schmidt (1997)
- Bremssstrahlung: $gg \to ggH$, $q\bar{q} \to q\bar{q}H$, $q\bar{q} \to ggH$

R. Kauffmann, S.Desai, D.Risal (1997)

Implemented in a parton level MC → HIGGSJET NLO code

NOTE: same amplitudes implemented in recent full NNLO calculation

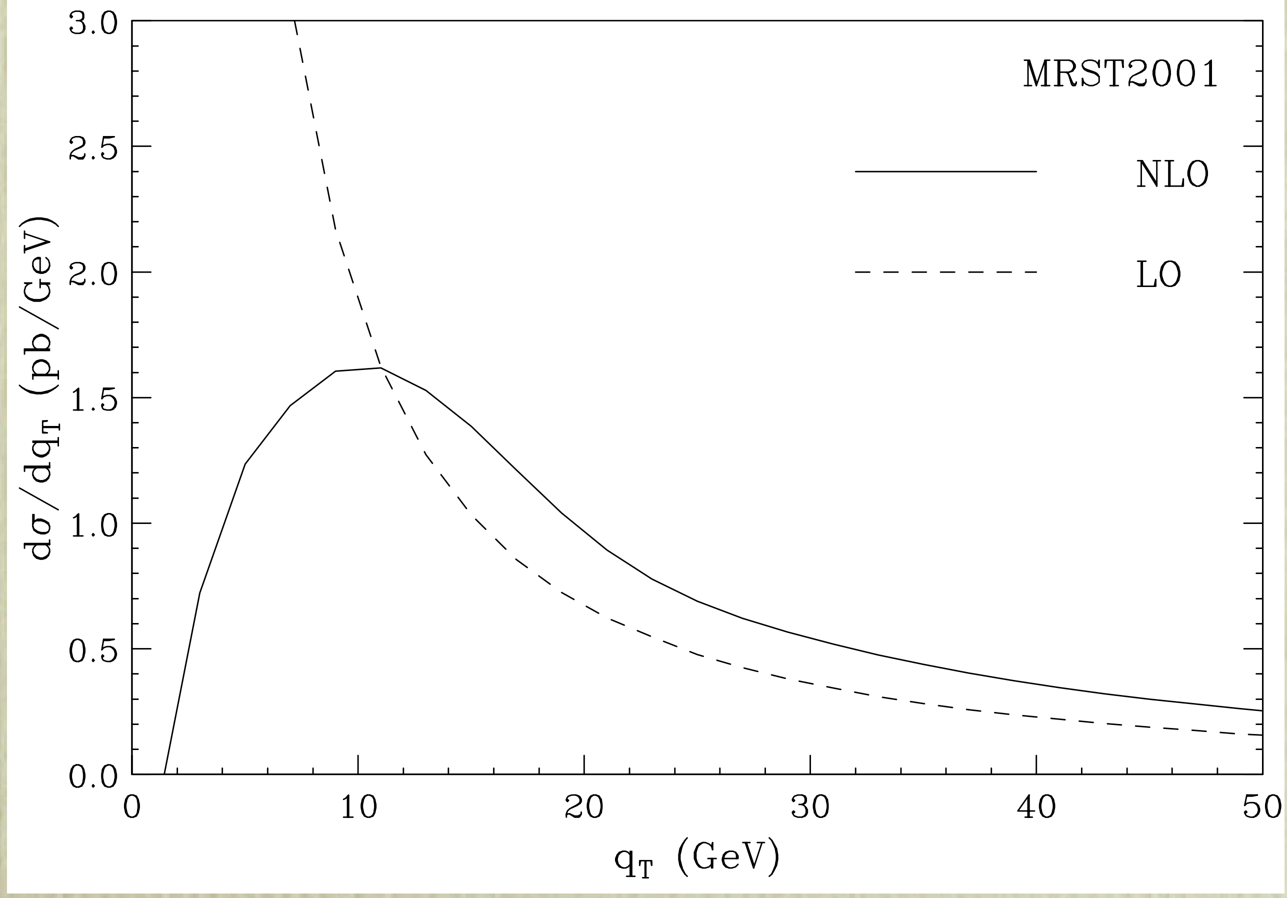
C. Anastasiou, K. Melnikov, F. Petrello (2004)

The region $q_T \ll M_H$

The small q_T region is the most important because it is here that the bulk of events is expected

When $q_T \ll M_H$ large logarithmic corrections of the form $\alpha_S^n \ln^{2n} M_H^2/q_T^2$ appear that originate from soft and collinear emission

➡ the perturbative expansion becomes not reliable



LO: $\frac{d\sigma}{dq_T} \to +\infty$ as $q_T \to 0$

NLO: $\frac{d\sigma}{dq_T} \to -\infty$ as $q_T \to 0$

This is a general problem in the production of systems of high mass Q^2 in hadronic collisions (DY, $\gamma\gamma$ .....) ➡ RESUMMATION

The resummation formalism has been developed in the eighties

Y.Dokshitzer, D.Diakonov, S.I.Troian (1978)
G. Parisi, R. Petronzio (1979)
G. Curci, M.Greco, Y.Srivastava(1979)
J. Kodaira, L. Trentadue (1982)
J. Collins, D.E. Soper, G. Sterman (1985)

As usual in QCD resummations one has to work in a conjugate space to allow the kinematics of multiple gluon emission to factorize

In this case, to exactly implement momentum conservation, the resummation has to be performed in impact parameter b-space

The standard (CSS) formalism has several disadvantages:

- The resummation coefficients are process dependent

  D. de Florian, MG (2000)

- The integral over b involves and extrapolation of the pdf to the NP region

- The resummation effects are large also at small b

→ - No control on the normalization
  - Problems in the matching to the PT result

Our formalism

A version of the b-space formalism has been proposed that overcomes all these problems

S. Catani, D. de Florian, MG (2000)

Parton distributions are factorized at $\mu_F \sim M_H$

$$\frac{d\hat{\sigma}_{ac}^{(\mathrm{res.})}}{dq_T^2} = \frac{1}{2}\int_0^\infty db\, b\, J_0(bq_T)\, \mathcal{W}_{ac}(b, M_H, \hat{s}; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2)$$

$$\mathcal{W}_N(b, M_H; \alpha_S(\mu_R^2), \mu_R^2, \mu_F^2) = \mathcal{H}_N\left(\alpha_S(\mu_R^2) M_H^2/\mu_R^2, M_H^2/\mu_F^2\right)$$
$$\times \exp\{\mathcal{G}_N(\alpha_S(\mu_R^2), bM_H; M_H^2/\mu_R^2, M_H^2/\mu_F^2)\}$$

where the large logs are organized as:

$$\mathcal{G}_N(\alpha_S, bM_H; M_H^2/\mu_R^2, M_H^2/\mu_F^2) = L\, g^{(1)}(\alpha_S L)$$
$$+ g_N^{(2)}(\alpha_S L; M_H^2/\mu_R^2) + \alpha_S\, g_N^{(3)}(\alpha_S L; M_H^2/\mu_R^2, M_H^2/\mu_F^2) + \dots$$

with $L = \ln M_H^2 b^2/b_0^2 \;\Rightarrow\; \tilde{L} = \ln\left(1 + M_H^2 b^2/b_0^2\right)$ and $\alpha_S = \alpha_S(\mu_R)$

- The form factor takes the same form as in threshold resummation
- Unitarity constraint enforces correct total cross section

The program HqT

We have improved our first numerical code in many respects

- We have implemented a recent analytical NLO calculation for the fixed order contribution C. Glosser, C. Schmidt (2002)

  A comparison with HIGGSJET program has been performed in all partonic channels → Excellent agreement

- The quality of the matching at low q_T is substantially improved

- Better control on NNLO normalization achieved

- Thanks to the implementation of analytical NLO calculation everything is built in a single fortran program: → HqT

Our program is now available upon request

Numerical results

I present NLL results matched to LO (NLL+LO) and NNLL results matched to NLO (NNLL+NLO) : we use MRST2004 pdf

- NLL+LO: NLO pdf +2-loop α_S
- NNLL+NLO: NNLO pdf +3-loop α_S

→ This is the accuracy available in MC@NLO

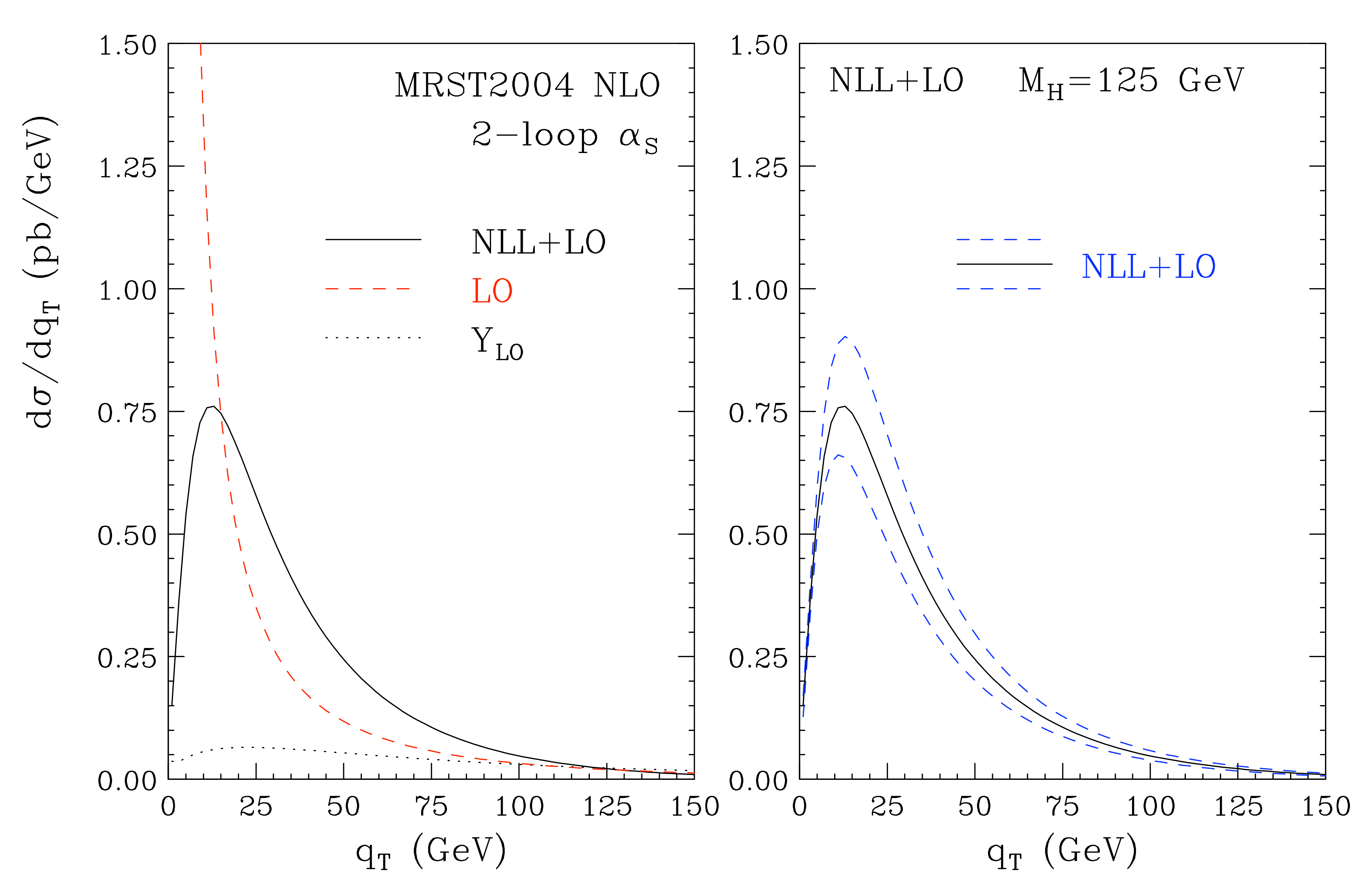
At NNLL+NLO the coefficients $A^{(3)}$, $\mathcal{H}^{(2)}$ are not known

For the coefficient $A^{(3)}$ we use the result available for threshold resummation

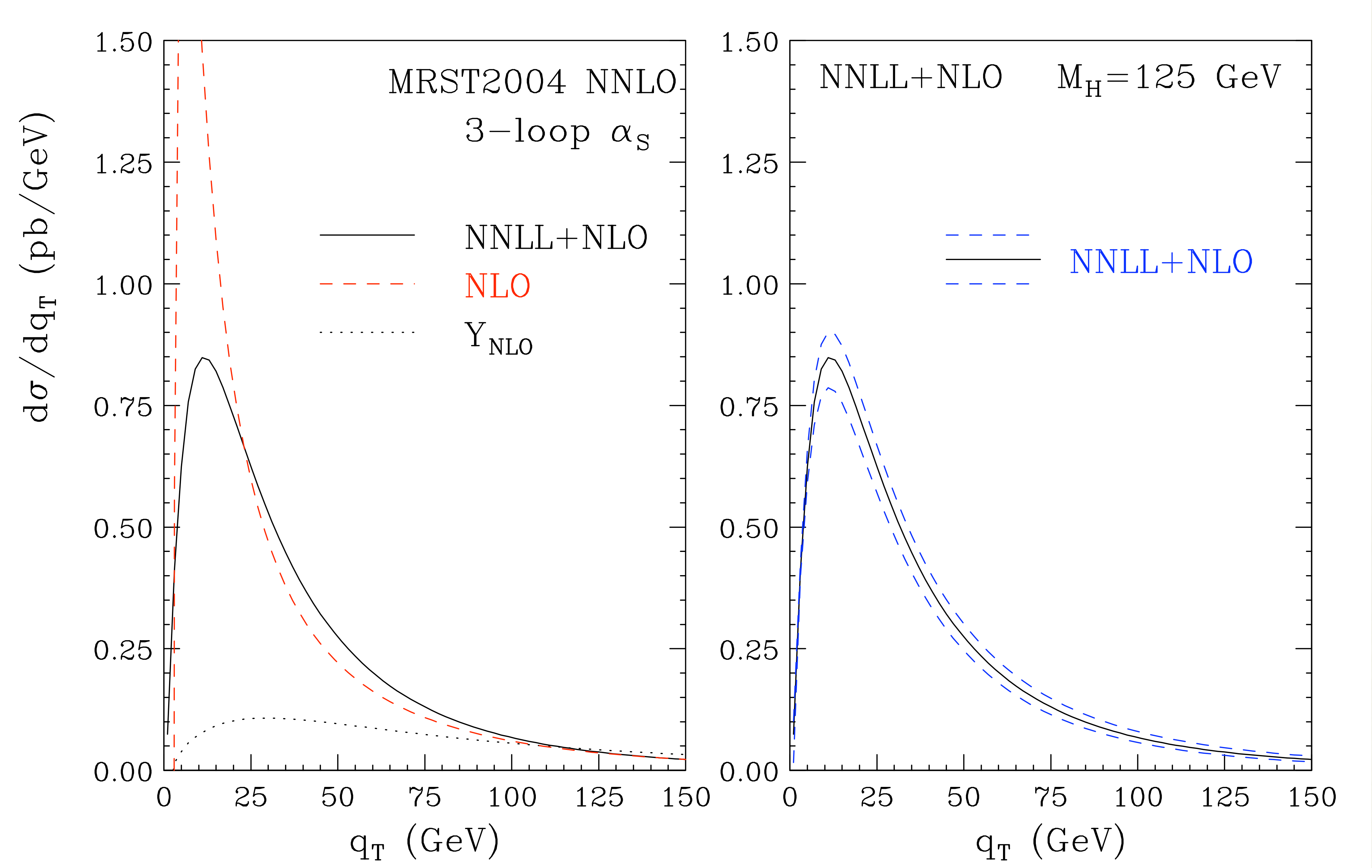
A.Vogt (2000)
A.Vogt, S.Moch, J.A.M. Vermaseren (2004)

The effect of $\mathcal{H}^{(2)}$ is included in approximated form using the result for the total NNLO cross section

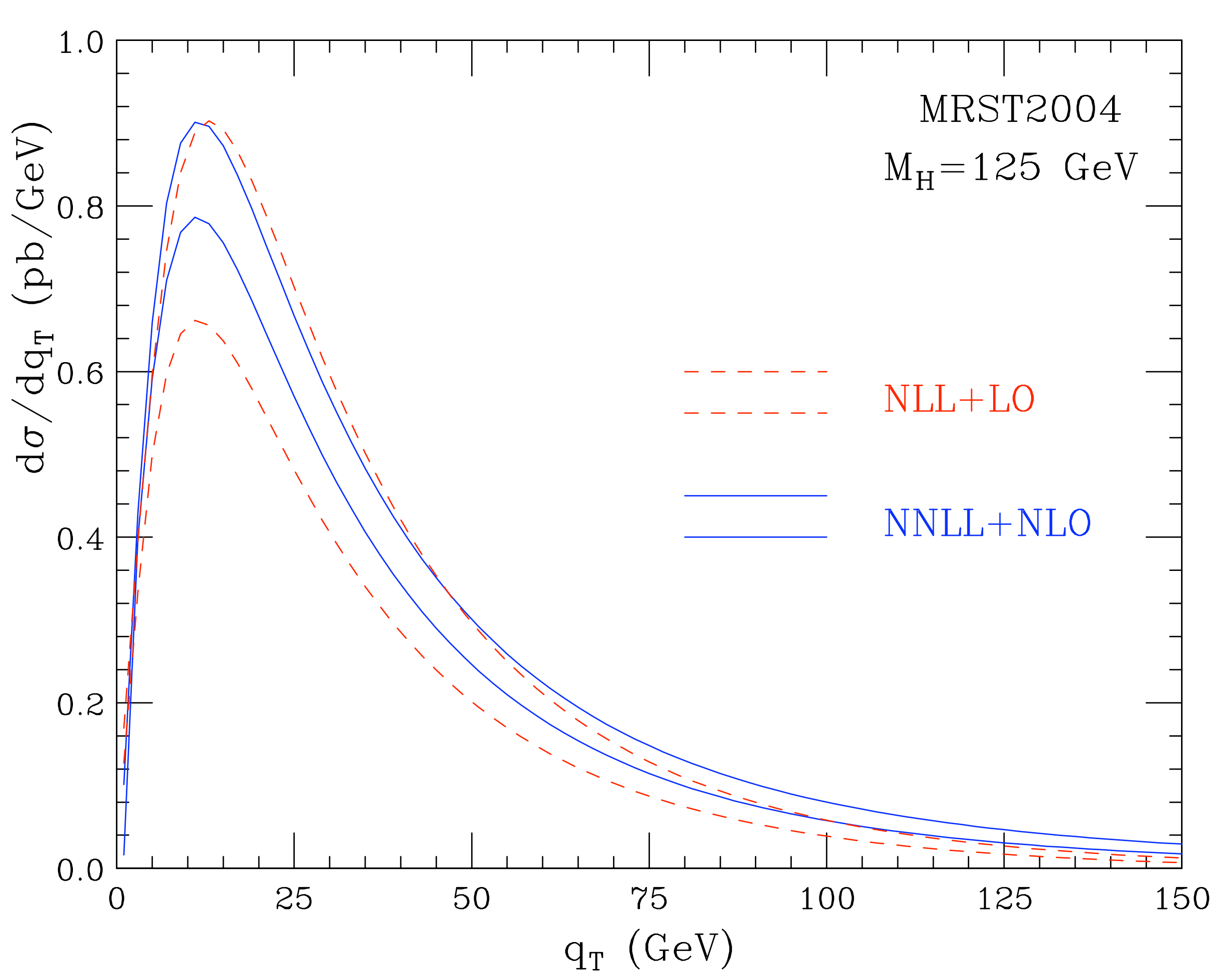
→ The approximation is excellent ! Correct NNLO cross section recovered in the relevant mass range to 1 % accuracy !

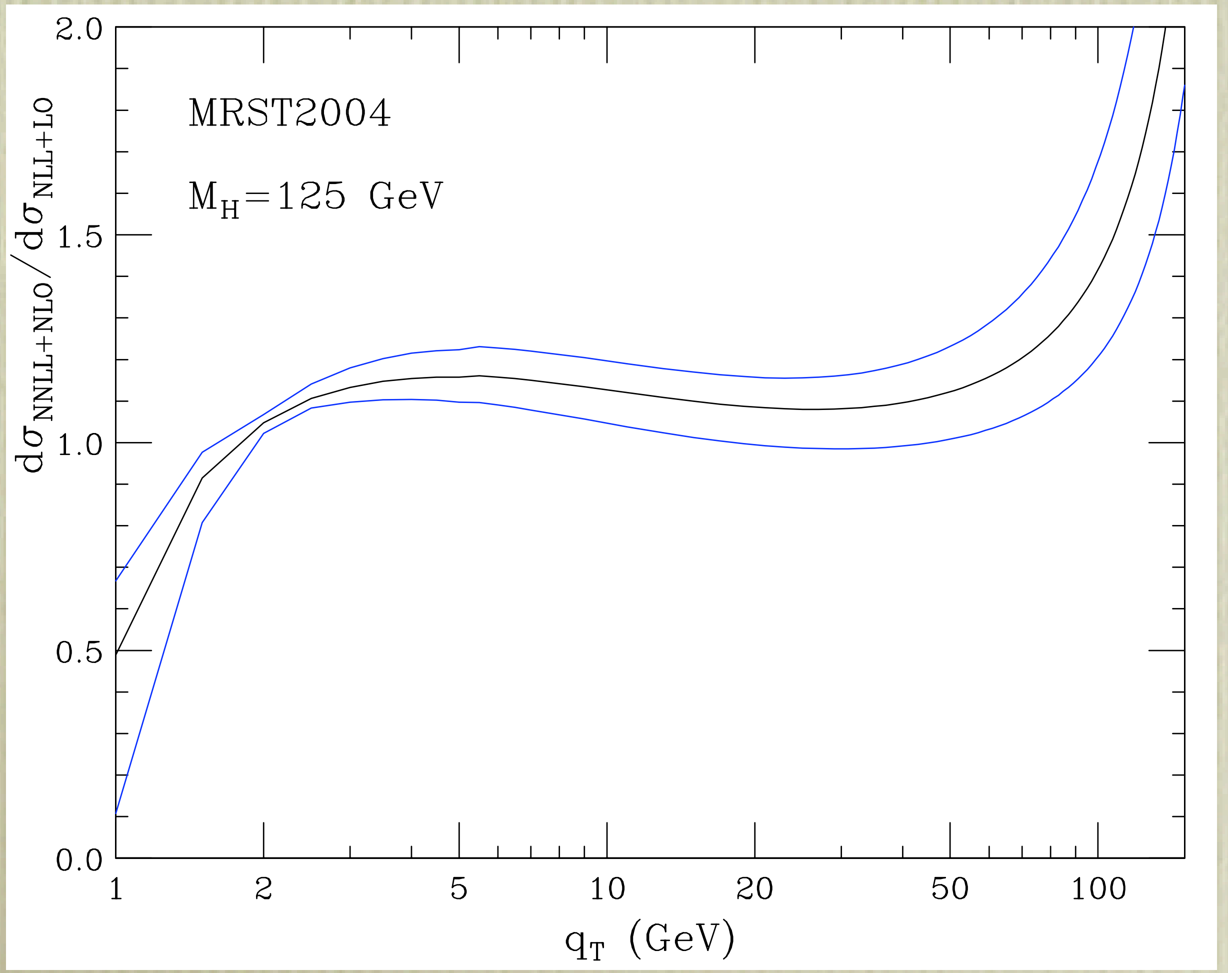


- The effect of resummation is relevant already below 100 GeV
- The integral of the spectrum in excellent agreement with the total NLO cross section (to better than 1 % !)
- Band obtained by varying μ_F, μ_R independently in the range $0.5M_H \le \mu_F, \mu_R \le 2M_H$ with $0.5 \le \mu_F/\mu_R \le 2$



- The NLO result diverges to $-\infty$ (unphysical peak) as $q_T \to 0$
- The effect of $A^{(3)}$ is neglible, whereas $\mathcal{H}^{(2)}$ gives $+20\%$
- Scale dependence reduced with respect to NLL+LO: it is about 10% at the peak





The bands nicely overlap for

$q_T \lesssim 100$ GeV

➡ Good stability of perturbative result

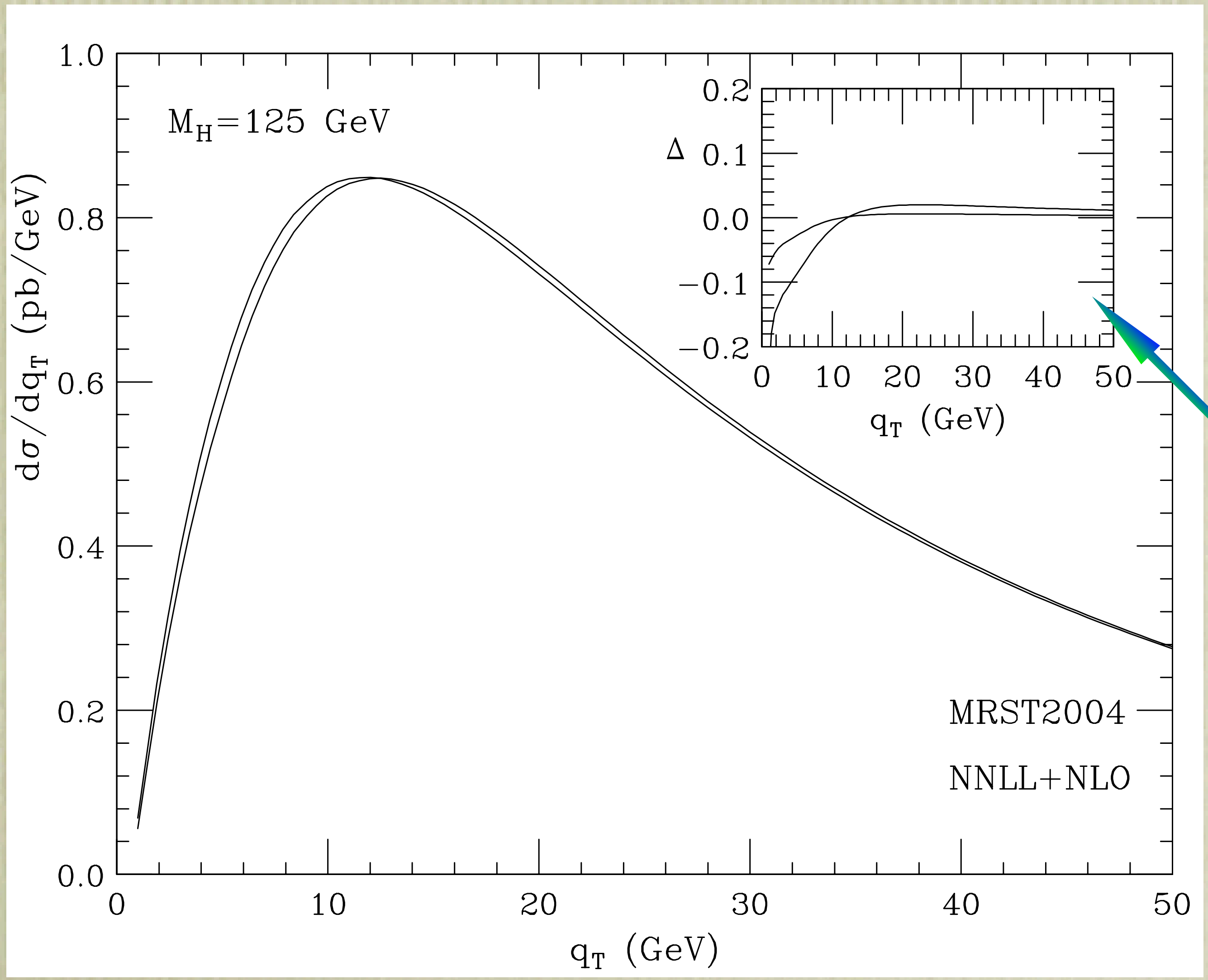
Note that the NNLL+NLO spectrum is harder than NLL+LO ➡

$$\frac{d\sigma_{NNLL+NLO}}{d\sigma_{NLL+LO}}$$ **depends on** q_T

Non perturbative effects

Non perturbative (NP) effects are known to be increasingly important as $q_T \to 0$

Usually NP effects are included through a NP smearing factor for which different forms have been tried



Here we try a simple gaussian form $S_{NP} = \exp\{-gb^2\}$ where the coefficient varies in the range suggested by a recent phenomenological study

A. Kulesza, J. Stirling (2002)

Relative difference wrt purely perturbative result

Uncertainty from unknown NP effects appears small

Conclusions

We have computed the q_T spectrum of the Higgs boson at the LHC

- We have implemented the most complete information available at present: all-order resummation of large logs at small q_T at NNLL level combined with NLO perturbation theory at large q_T
- Our approach allows a consistent study of th. uncertainties and implements a unitarity constraint such that the total cross section at the nominal accuracy is recovered by integration → **nice stable results**
- Implemented in a easy-to use numerical program → HqT it is available upon request

```
125d0 !  Higgs mass
2 !  order of calculation:  NLL+LO (1) NNLL+NLO (2)
72 3 !  pdf, nloop
14d3 !  centre of mass energy
125d0 125d0 !  mur muf
0d0 !  g:  NP smearing
1 !  inorm (0) mtop->infinity (1) full mt,mb dependence
1 21 2 !  qtmin qtmax qtbin
```