THE TRANSVERSE MOMENTUM DISTRIBUTION OF THE HIGGS BOSON AT THE LHC

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Outline

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- The Higgs q_T distribution
  - The region $q_T \sim M_H$
  - The region $q_T \ll M_H$ → resummation
- Our approach
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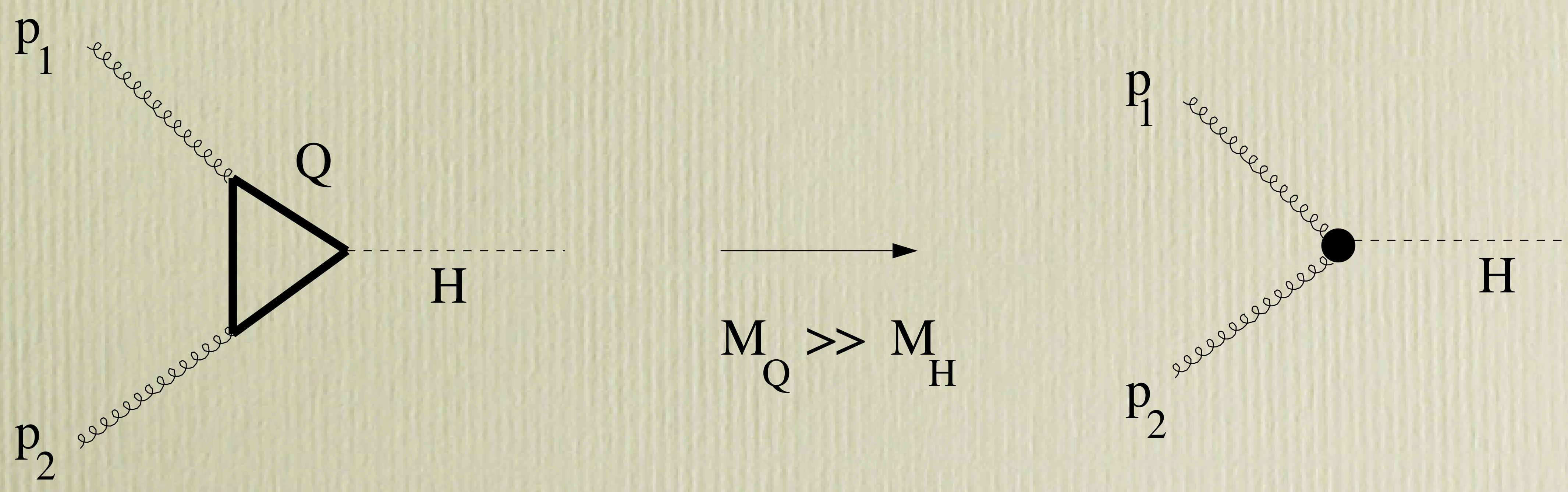
Introduction

Gluon-gluon fusion through a heavy-quark loop is the dominant mechanism for SM Higgs production at hadron colliders

NLO QCD corrections to $\sigma_{gg\to H}$ computed and found to be large

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

NLO corrections well approximated by their large-m_{top} limit



Effective vertex → one loop less

NNLO corrections to $\sigma_{gg\to H}$ recently computed in this limit

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)

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 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)

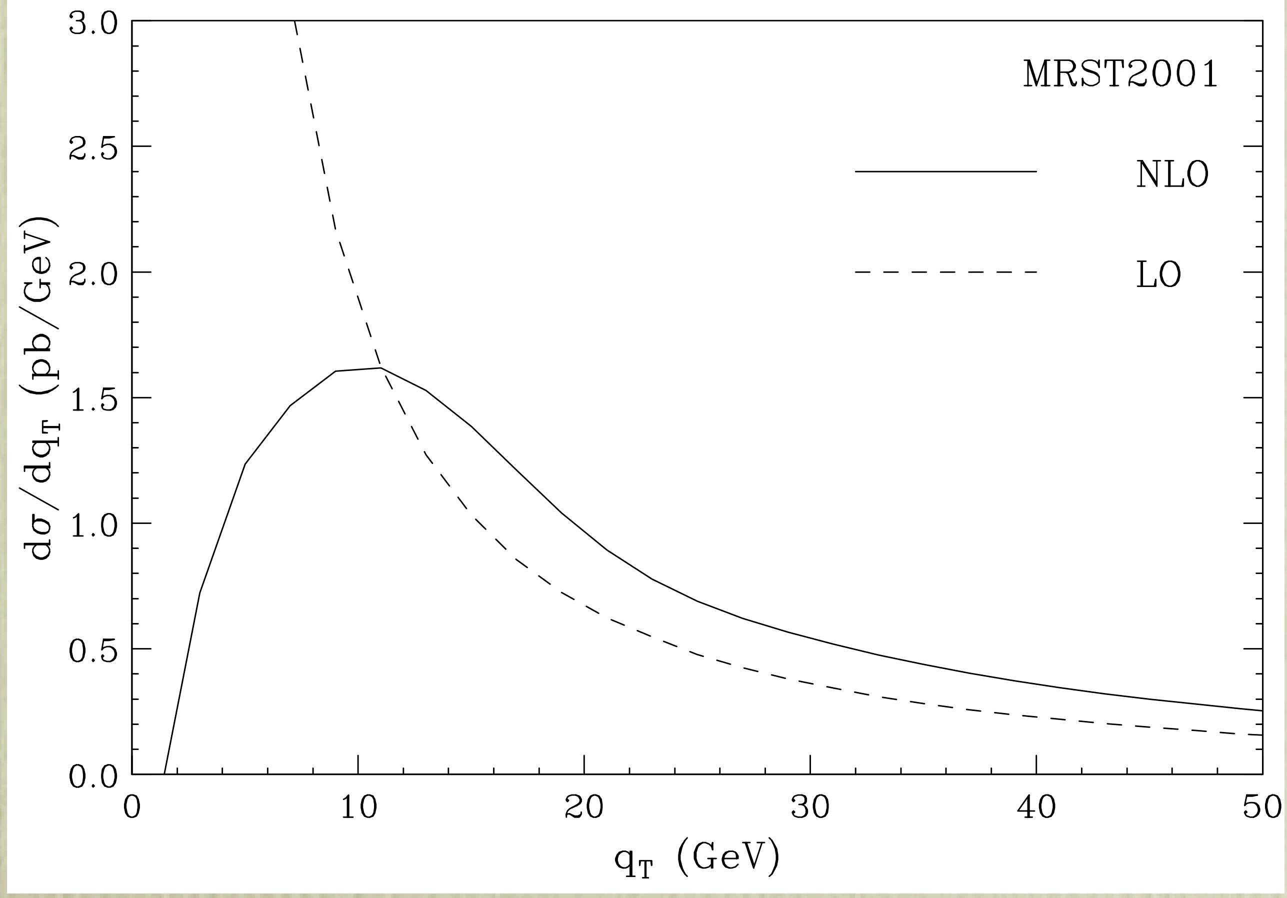
By using the subtraction method they were implemented in a parton level MC → HIGGSJET NLO code
It is possible to compute any IR safe observable with Higgs + jet(s)

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. Collins, D.E. Soper, G. Sterman (1985)

As it is customary in QCD resummations one has to work in a conjugate space in order 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 $L = \ln M_H^2 b^2/b_0^2$ ➡ $\tilde{L} = \ln\left(1 + M_H^2 b^2/b_0^2\right)$ 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

Numerical results

I present NLL results matched to LO (NLL+LO) and NNLL results matched to NLO (NNLL+NLO) → we use MRST2002 pdf

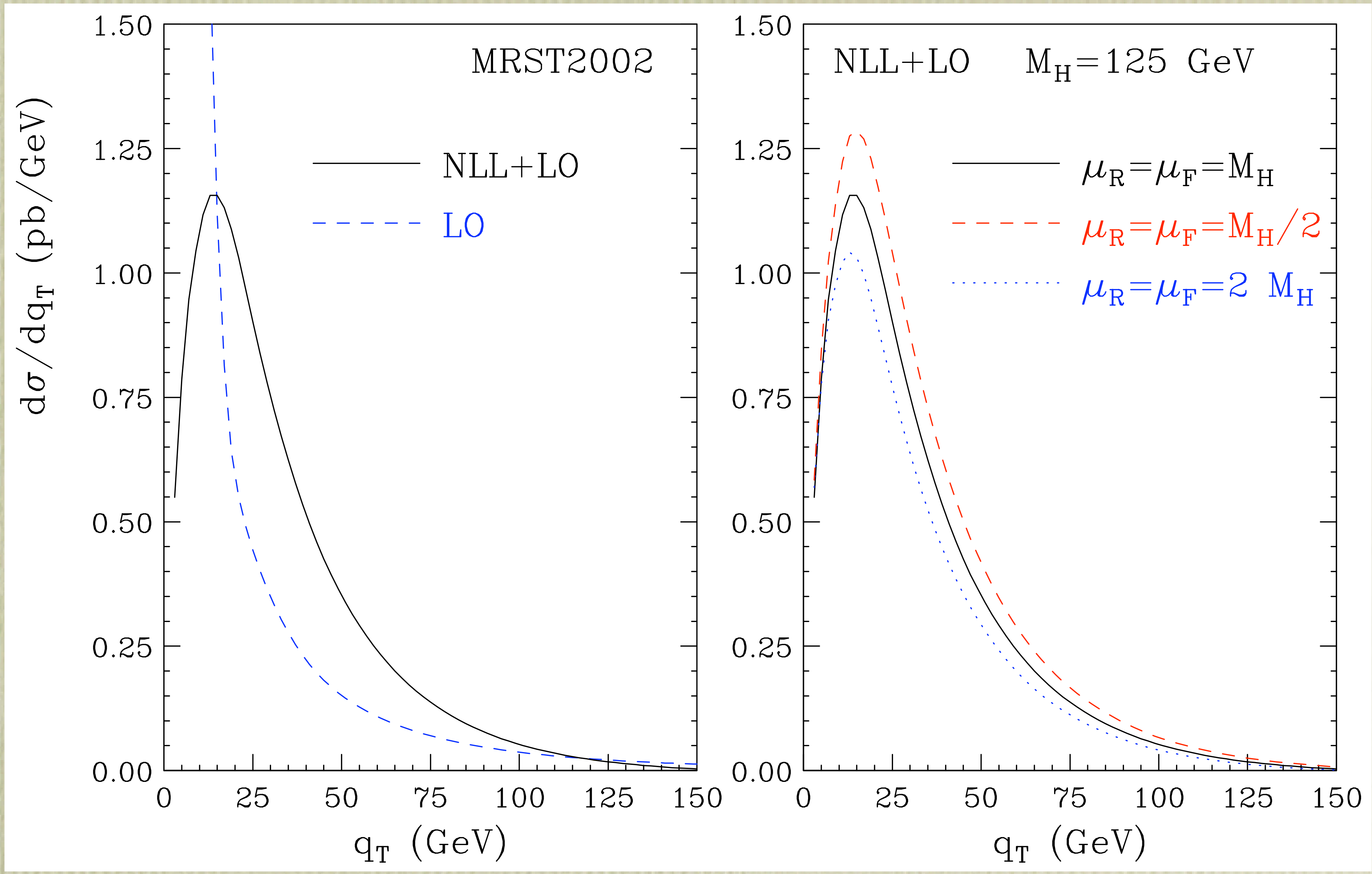
- NLL+LO: LO pdf +1-loop α_S
- NNLL+NLO: NLO pdf +2-loop α_S

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

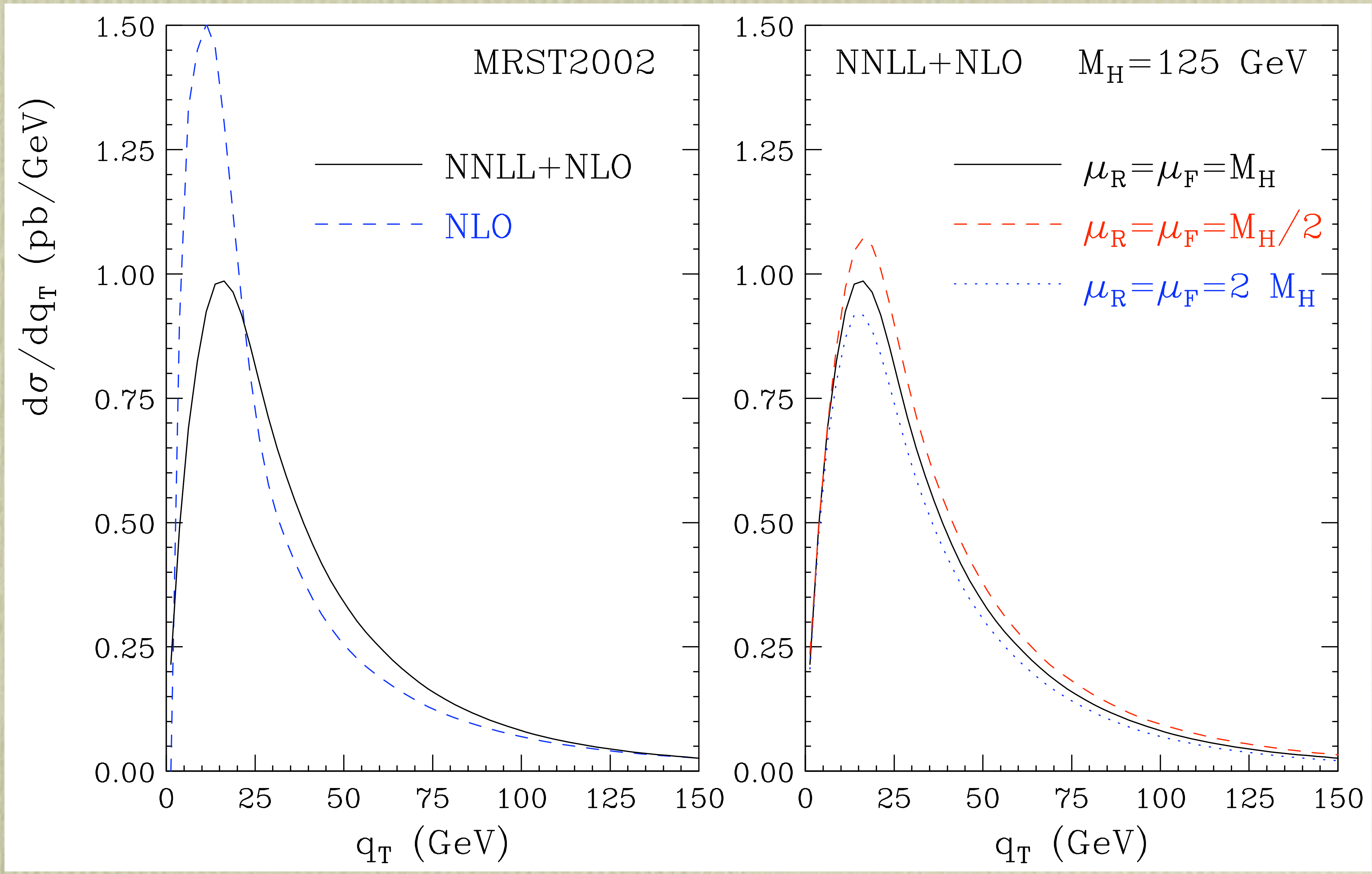
For the coefficient $A^{(3)}$ we use the numerical estimate available for threshold resummation

A. Vogt (2000)

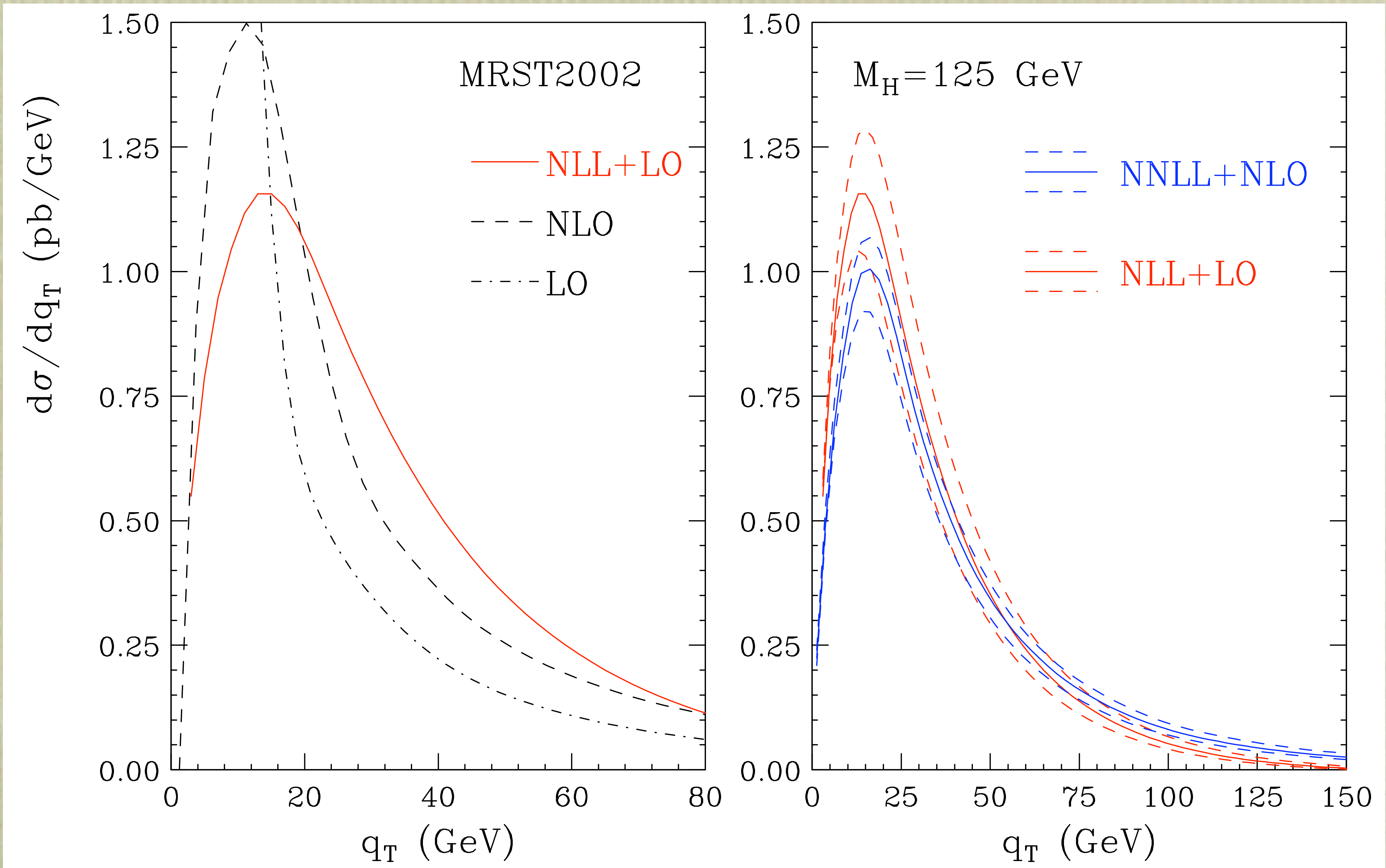
The effect of $\mathcal{H}^{(2)}$ is included in approximated form using the result for the total NNLO cross section



- The LO result diverges to $+\infty$ as $q_T \to 0$
- The effect of resummation is relevant already below $100\ \mathrm{GeV}$
- The integral of the spectrum in good agreement with the total NLO cross section



- 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



- In the intermediate region the cross section sizeably increases going from LO to NLO and from NLO to NLL+LO ➡ there are important contributions that must be resummed to all orders and not simply evaluated to the next order

- Bands overlap for $q_T \lesssim 100$ GeV

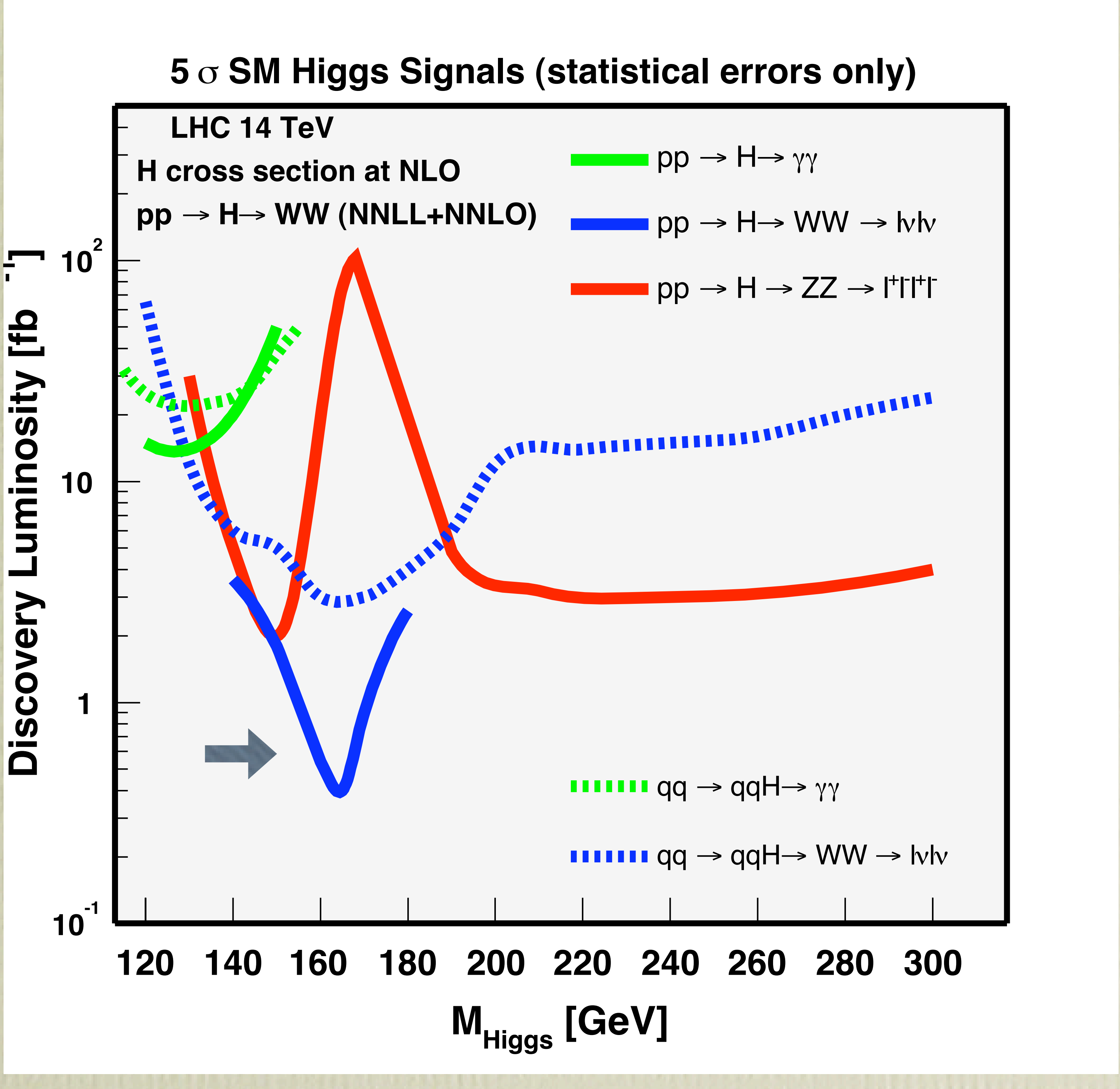
➡ Good stability of perturbative result

A recent application in $gg \to H \to WW \to l\nu l\nu$

G. Davatz, G. Dissertori, M. Dittmar, F. Pauss, MG (2004)

Use results for $gg \to H$ spectrum at NNLL+NLO to correct (reweight) events generated with PYTHIA

Apply the resummation formalism to WW pair production ➡ NLL+LO results used to correct PYTHIA main background



Summary

We have computed the q_T spectrum of the SM Higgs boson at the LHC in a purely perturbative framework

- 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

- Distinctive features of our approach are:

  - it allows a consistent study of theoretical uncertainties;

  - it avoids the introduction of unjustified higher order terms in the intermediate region by using a unitarity constraint
    ➡ Normalization OK !

- Results appear to be stable