Higgs q_T spectrum

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Higgs Cross Sections for the LHC
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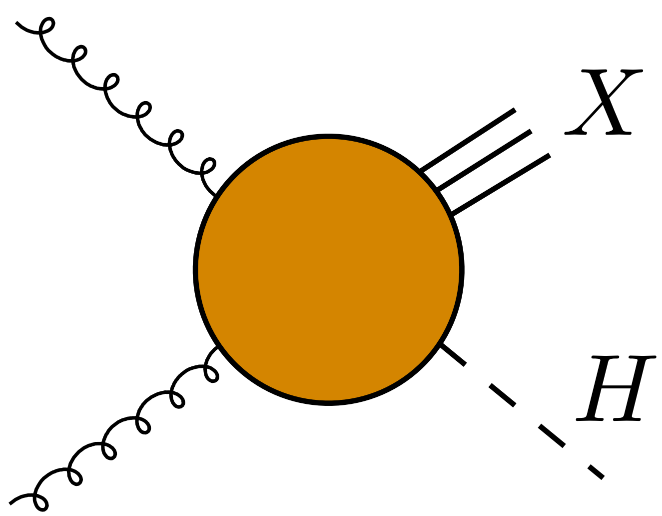
Introduction



Gluon-gluon fusion is the dominant production channel of the Higgs boson at hadron colliders

Enormous activity in the last few years

Total cross section up to NNLO

R.Harlander, W.B. Kilgore (2002)
C. Anastasiou, K. Melnikov (2002)
V. Ravindran, J. Smith, W.L.Van Neerven (2003)

EW corrections

U. Aglietti et al. (2004)
G. Degrassi, F. Maltoni (2004)
G. Passarino et al. (2008)

NNLO beyond large-m_{top} approximation

R.Harlander et al. (2009)
M.Steinhauser et al. (2009)

Fully exclusive NNLO calculations

→ FEHIP, HNNLO

C.Anastasiou, K.Melnikov, F.Petrello (2005)
C. Anastasiou, G.Dissertori, F.Stoeckli (2007)

S.Catani, MG (2007)
MG(2008)

....

Transverse-momentum spectrum

Among the various distributions an important role is played by the transverse momentum spectrum of the Higgs boson

Its accurate knowledge could help to find strategies to improve statistical significance

Transverse momentum (q_T) and rapidity (y) identify the Higgs kinematics

The shape of rapidity distribution mainly determined by PDFs

→ Effect of QCD radiation mainly encoded in the q_T spectrum

Moreover: the Higgs is a scalar → production and decay processes essentially factorized

When considering the transverse momentum spectrum it is important to distinguish two regions of transverse momenta

$q_T \sim M$

To have $q_T \neq 0$ the Higgs boson has to recoil against at least one parton ➡ the LO is of relative order α_S

NLO corrections are known

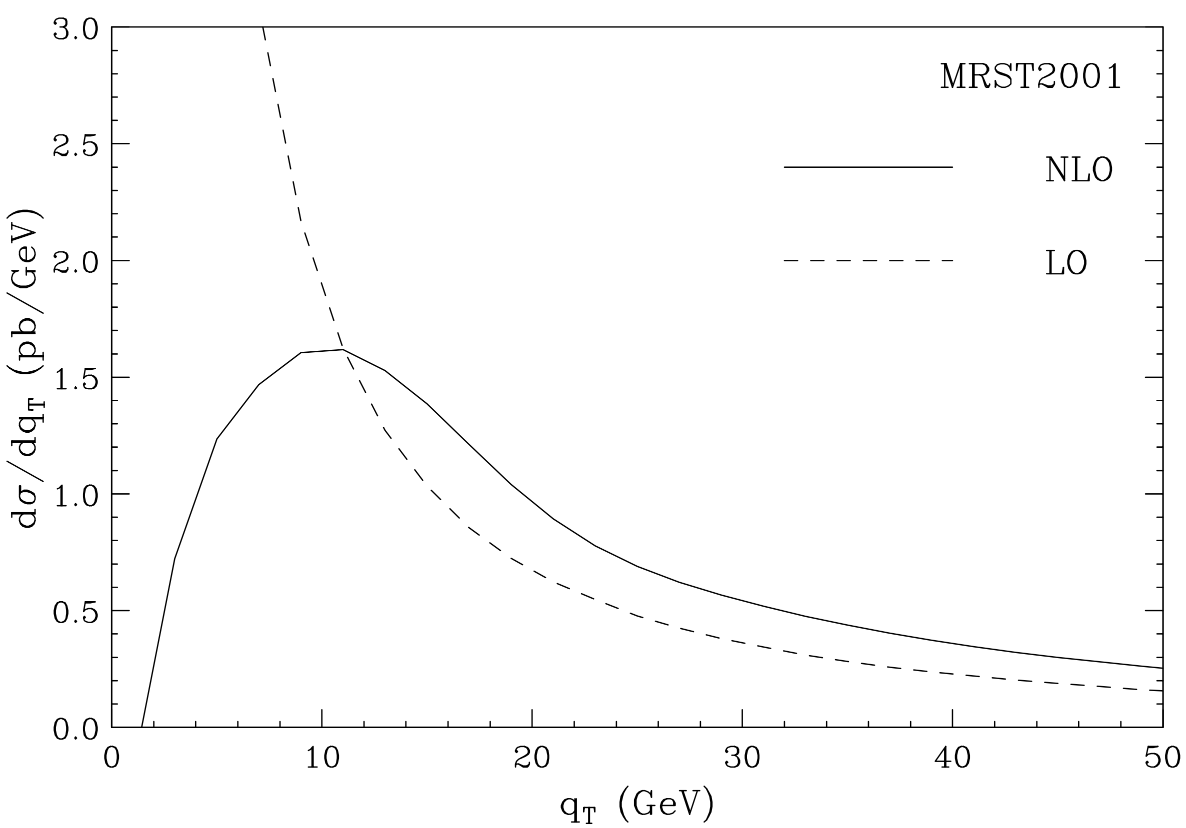
D. de Florian, Z.Kunszt, MG (1999)
V.Ravindran, J.Smith, V.Van Neerven (2002)
C.Glosser, C.Schmidt (2002)

↘ **Part of inclusive NNLO corrections**

$q_T << M$

Large logarithmic corrections of the form $\alpha_S^n \ln^{2n} M^2/q_T^2$ 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 $q_T \to 0$

➡ RESUMMATION NEEDED (effectively perfomed by standard MC generators)

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

Many phenomenological studies performed at different levels of theoretical accuracy

I.Hinchliffe, S.F.Novaes (1988)
R.P. Kauffmann (1991)
C.P.Yuan (1992)
C.Balazs, C.P.Yuan (2000)
E. Berger, J. Qiu (2003)
A.Kulezsa, J.Stirling (2003)
....

Recent studies also in the context of SCET

S.Mantry, F.Petriello (2009,2010)
T. Becher, M.Neubert (2010)
....

Our formalism

We proposed a version of the b-space formalism with some novel features

S.Catani, D. de Florian, MG (2000)
G. Bozzi, S.Catani, D. de Florian, MG(2005)

Parton distributions factorized at $\mu_F \sim M = m_H$

avoids PDF extrapolation to small scales

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

process dependent

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

universal

where the large logs are organized as:

$$\mathcal{G}_N(\alpha_S, L; M^2/\mu_R^2, M^2/Q^2) = L\, g^{(1)}(\alpha_S L) + g_N^{(2)}(\alpha_S L; M^2/\mu_R^2, M^2/Q^2) + \alpha_S\, g_N^{(3)}(\alpha_S L; M^2/\mu_R^2, M^2/Q^2) + \ldots$$

with $L = \ln M^2 b^2/b_0^2$ → $\tilde{L} = \ln\left(1 + Q^2 b^2/b_0^2\right)$ and $\alpha_S = \alpha_S(\mu_R)$

resummation scale

- **The form factor takes the same form as in threshold resummation**
- **Unitarity constraint enforces correct total cross section**
- **Allows a consistent study of perturbative uncertainties**

The resummed and fixed order calculations can then be combined to achieve uniform theoretical accuracy over the entire range of q_T

$$\frac{d\hat{\sigma}}{dq_T^2} = \frac{d\hat{\sigma}^{(\mathrm{res.})}}{dq_T^2} + \frac{d\hat{\sigma}^{(\mathrm{fin.})}}{dq_T^2}$$

→ **standard fixed order result minus expansion of resummed formula at the *same* order**

The calculation can be done at:

- NLL+LO*: we need the functions $g^{(1)}$, $g_N^{(2)}$ and the coefficient $\mathcal{H}_N^{(1)}$ plus the matching at relative order α_S
- NNLL+NLO*: we also need the function $g_N^{(3)}$ and the coefficient $\mathcal{H}_N^{(2)}$ plus the matching at relative order α_S^2

* **Note that here LO and NLO refer to the spectrum: they contribute to NLO and NNLO normalization !**

NNLL+NLO represents the highest accuracy available to date

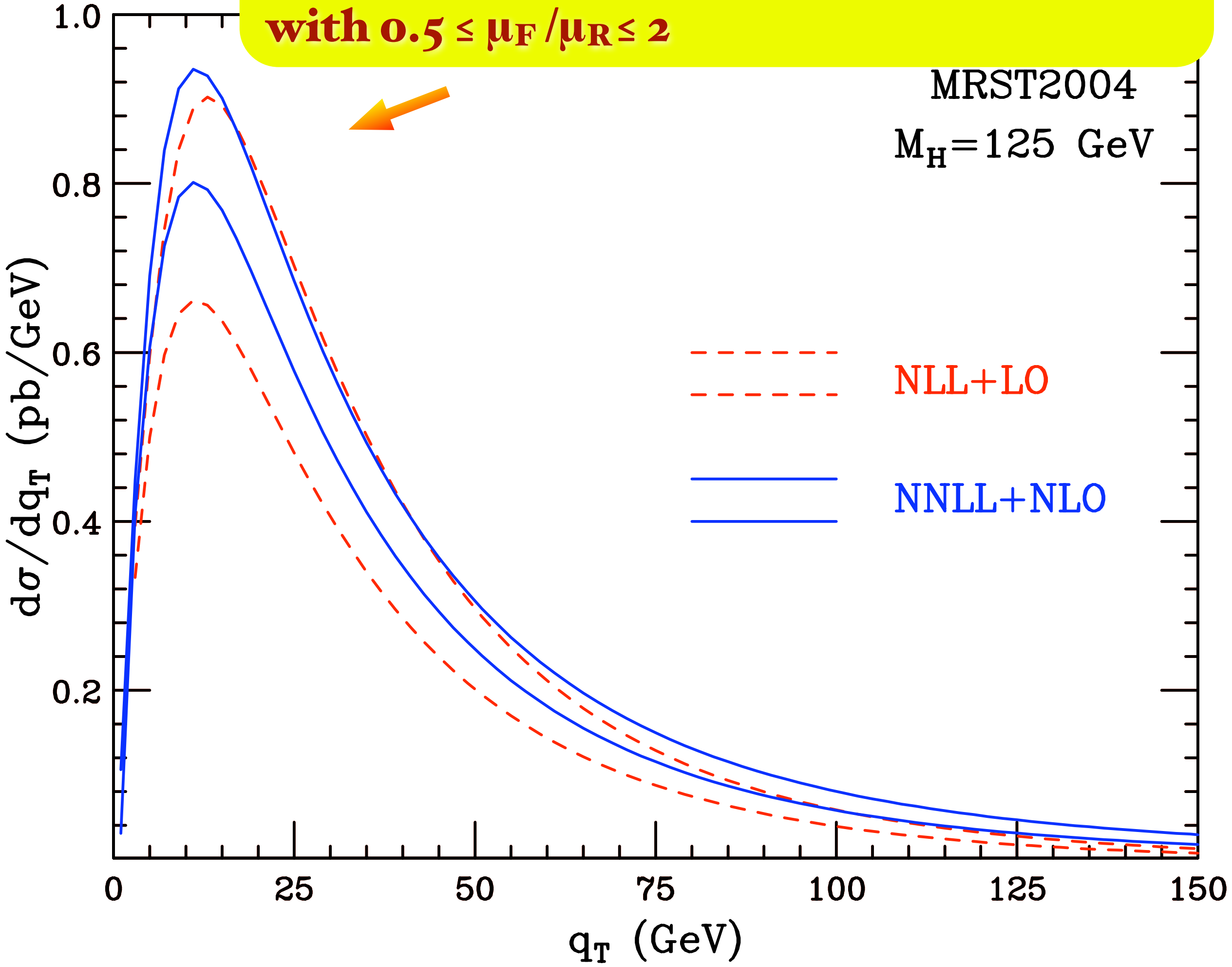
→ Implemented in HqT

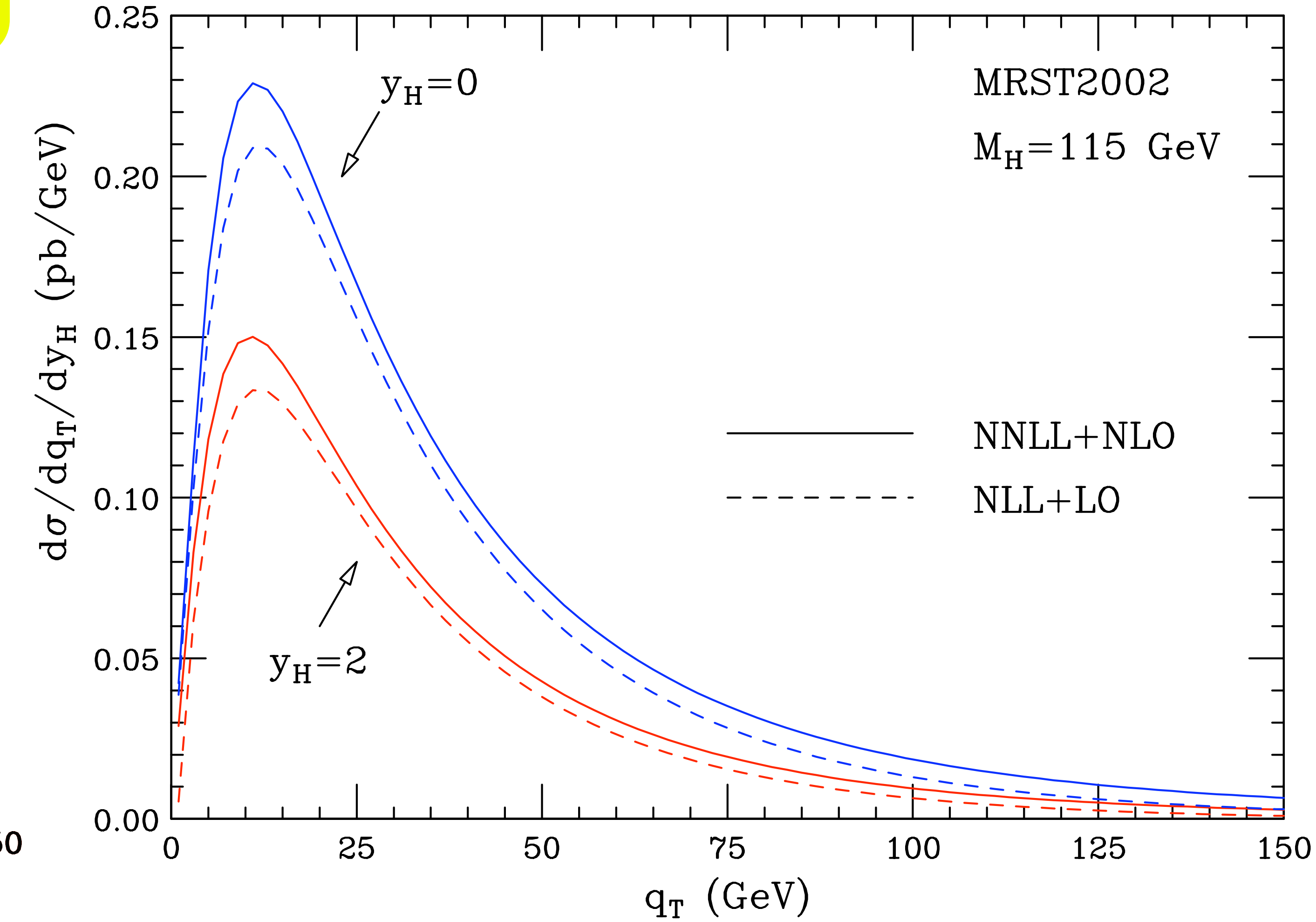
At NLL+LO the accuracy is essentially the same as in MC@NLO/POWEG

Results

G. Bozzi, S.Catani, D. de Florian, MG (2005,2007)

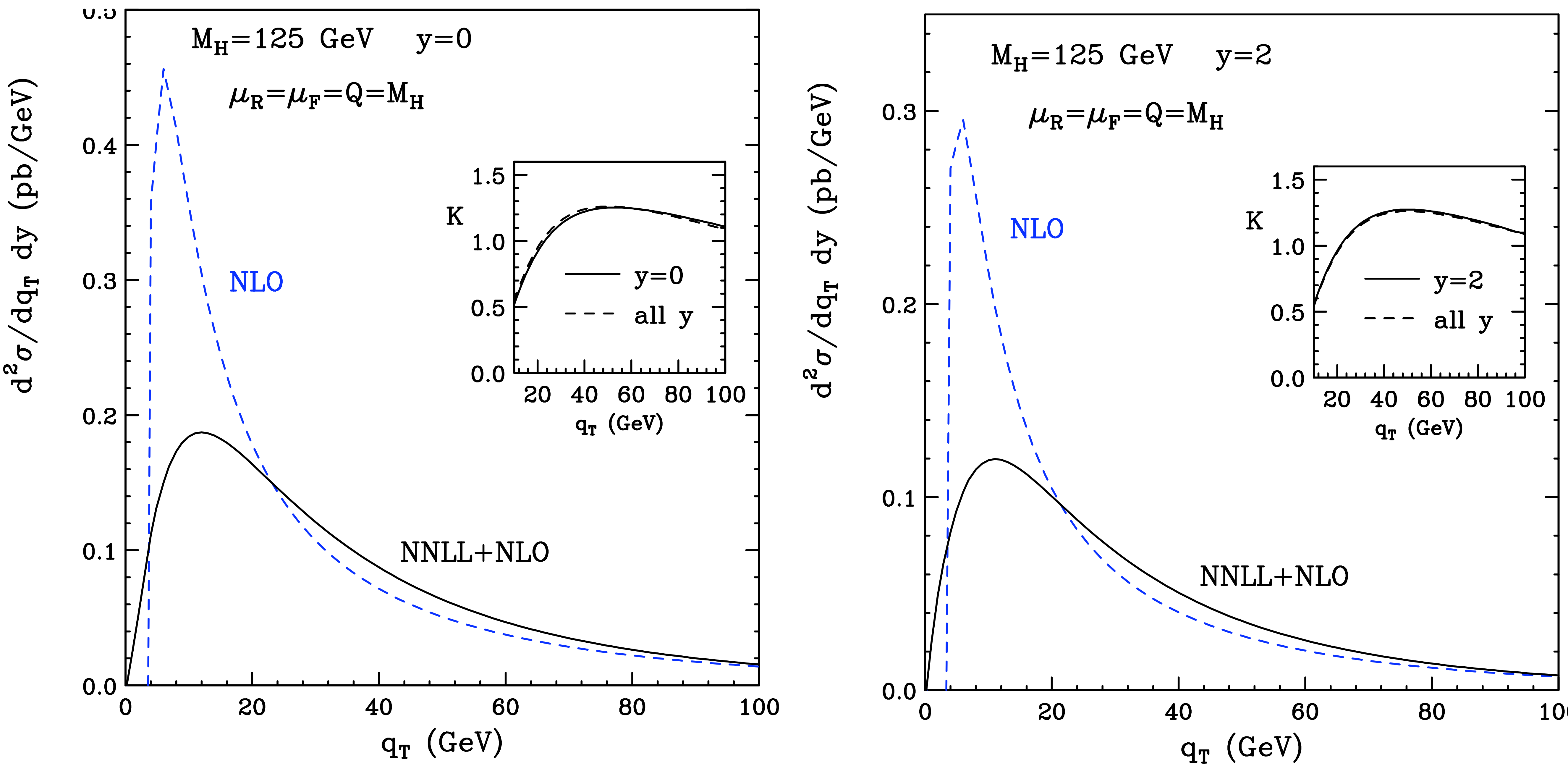
scale uncertainty computed by varying μ_F and μ_R in the range $0.5\ m_H \leq \mu_F, \mu_R \leq 2\ m_H$ with $0.5 \leq \mu_F/\mu_R \leq 2$





NNLL+NLO and NLL+LO bands overlap: nice convergence of the perturbative resummed result

Shape of resummed spectrum mildly dependent on rapidity



- Define $K(q_T, y) = \dfrac{d\sigma_{NNLL+NLO}/(dq_T dy)}{d\sigma_{NLO}/(dq_T dy)}$

→ Impact of resummation mildly dependent on rapidity

NEW: Preliminary: HqT2.0

D. de Florian, G.Ferrera, D. Tommasini, MG (2011)

Few improvements:

- The present version of HqT is based on a crude estimate of $\mathcal{H}_N^{(2)}$

$$\mathcal{H}^{(2)}_{gg\leftarrow ab}(z) \sim \delta_{ga}\delta_{gb}\delta(1-z)\left(\left(\frac{19}{8}+\frac{2}{3}n_F\right)\ln m_H^2/m_{top}^2 + c\right)$$

Consider only δ(1-z) term and fix its normalization using knowledge of total cross section ➡ works reasonably well both at the Tevatron and the LHC but now exact result is known and can be implemented

S.Catani, MG to appear

- Exact treatment of resummation scale Q

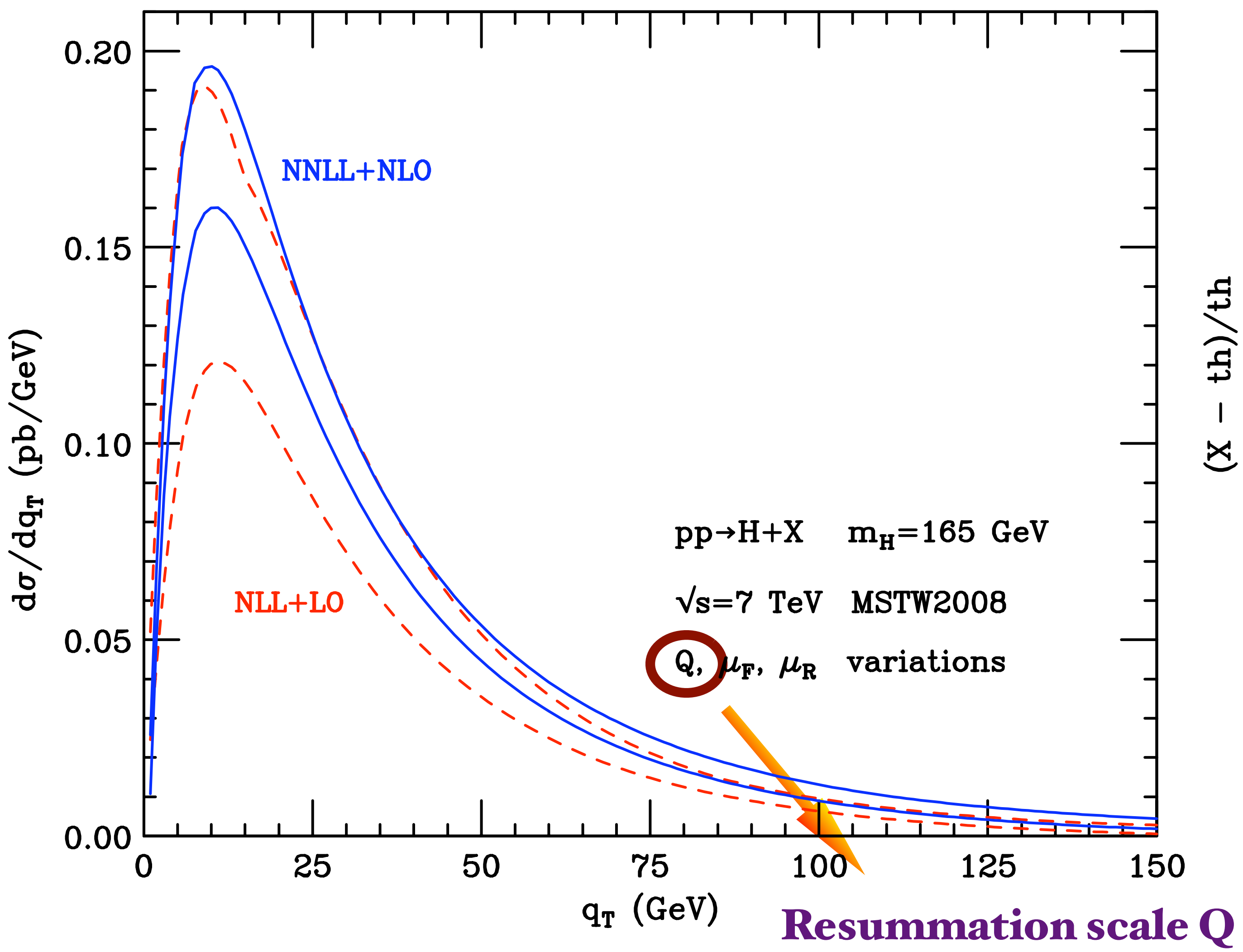
- Value of $A^{(3)}$ for q_T resummation implemented

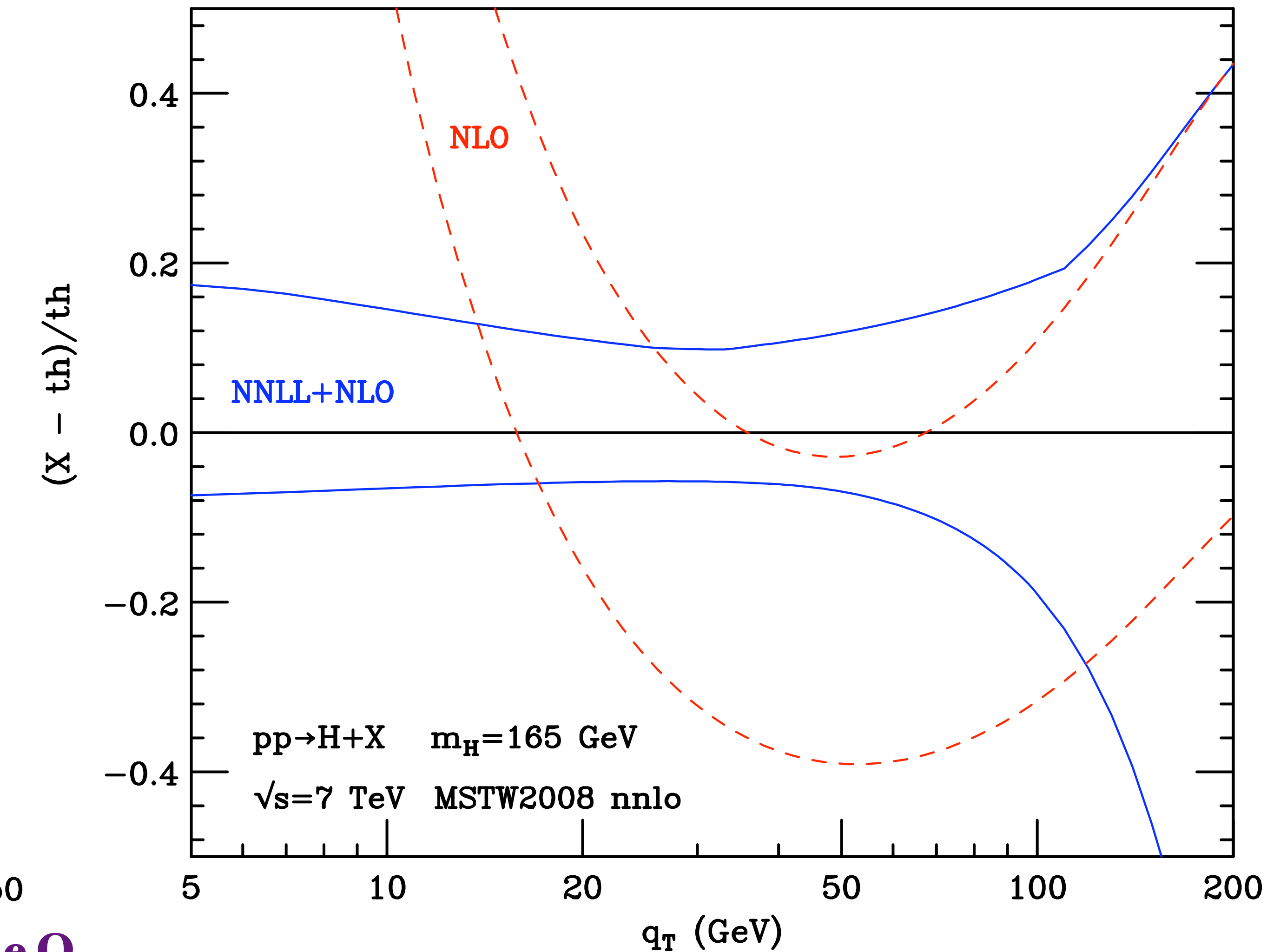
T.Becher, M.Neubert (2010)

- Interface with LHAPDF

Differences with current version at the percent level

NEW: Preliminary: HqT2.0





Scale uncertainty computed by independent variations of μ_F,μ_R and Q in the ranges $1/2\, m_H < \{\mu_F,\mu_R\} < 2m_H$ and $1/4\, m_H < Q < m_H$ with the constraints $1/2 < \mu_F/\mu_R < 2$ and $1/2 < Q/\mu_R < 2$

Perturbative uncertainty at NNLL+NLO ranges from about ±10% at the peak to about ±13% at q_T=75 GeV

At large values of q_T the resummed result looses predictivity: better to use NLO

Shape uncertainty

One of the main issues discussed at this workshop is how to evaluate the uncertainty on the cross section after cuts

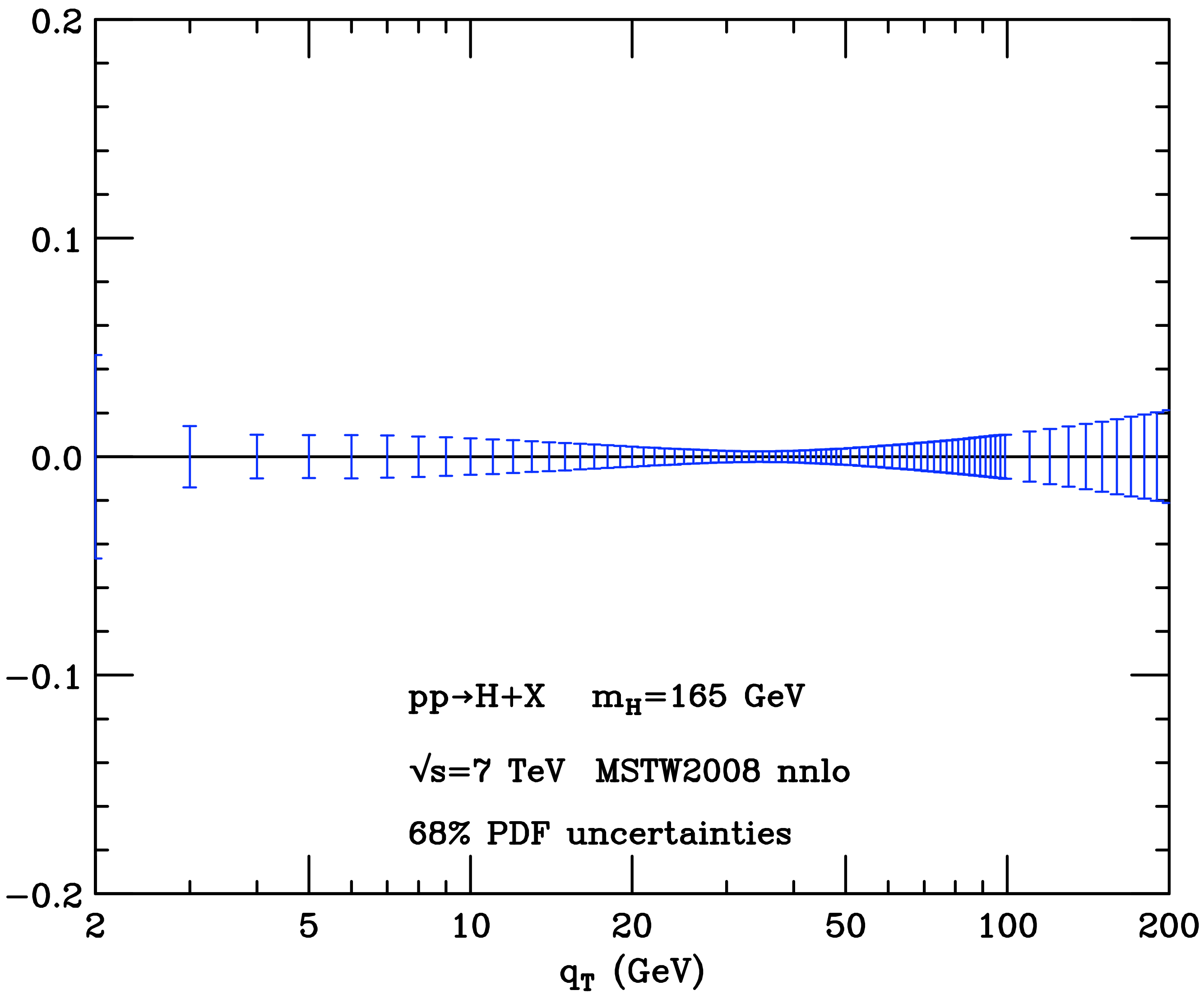
If HqT is used to reweight the spectrum of MC event generators

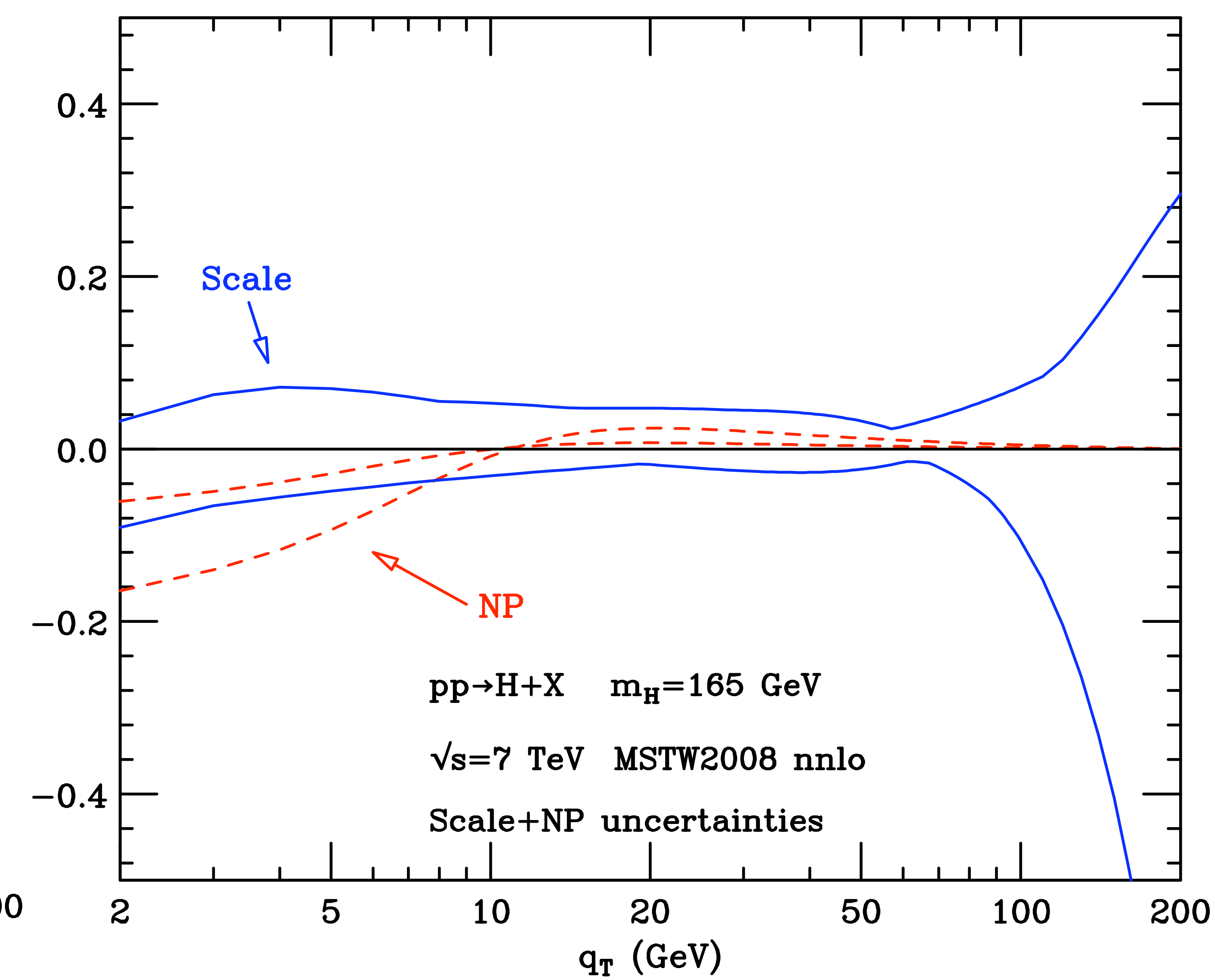
→ What matters is actually the uncertainty on the SHAPE of the q_T distribution provided by HqT

Sources of uncertainties:

- Scale dependence
- PDFs
- Non-perturbative effects
- Large m_{top} approximation ?

Shape uncertainty





PDF uncertainties apparently have a small impact on the shape of the spectrum

Scale uncertainties at the level of about ±5%
NP effects estimated as in Bozzi et al. (2005)

They become important at small q_T

As q_T increases different x ranges are probed

➡ Other PDFs could lead to more sizable effects

Summary & Outlook

- Among the various kinematical distributions in $gg \to H$ the q_T spectrum plays an important role
  - Embodies main effects of QCD radiation

- Standard procedure: reweight inclusive q_T spectrum according to NNLL+NLO result

- I have presented preliminary results of an updated version of HqT where some approximations are removed and a better treatment of scales is implemented

- I think these improvements are useful and should allow an easier estimate of theoretical uncertainties

- The uncertainties on the shape of the distribution need be taken into account if HqT is used to reweight the spectrum of MC generators