Higgs production at the LHC: transverse-momentum and rapidity dependence

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Outline

1. Overview of recent results for $gg \to H$
   - Total cross section
   - Differential distributions
2. The main ideas of resummation
   - Resummation
   - Exponentiation
   - Matching
3. Numerical results at the LHC
4. Summary

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Fixed-order perturbative results

- NLO ($\mathcal{O}(\alpha_s^3)$): increase LO cross section by about 80-100%!

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  [Djouadi,Spira,Zerwas(1991)]
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- NNLO ($\mathcal{O}(\alpha_s^4)$): another 15-20% enhancement ($m_t \to \infty$)

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- Higher-order perturbative contributions reliably estimated by resumming multiple soft-gluon emissions
- NNLL+NNLO: perturbative uncertainty reduced to $\pm$10%

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- Soft-gluon terms at NNNLO: effects consistent with NNLL+NNLO uncertainty

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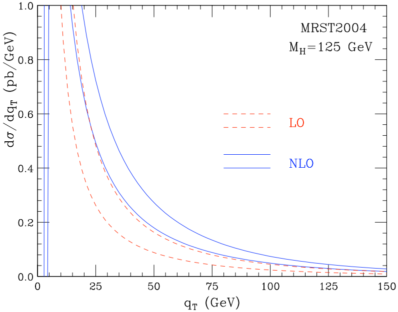
The small-q_T region ($q_T \ll M_H$)

- Bulk of the events in the region $q_T \ll M_H$
- Kinematical unbalance between real and virtual contributions

→ perturbative coefficients enhanced by $\alpha_S^n \log^m(\frac{M_H^2}{q_T^2})$

→ convergence of perturbative result completely spoiled



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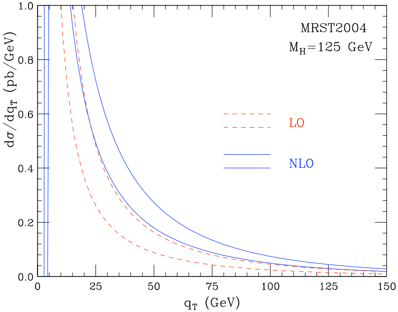

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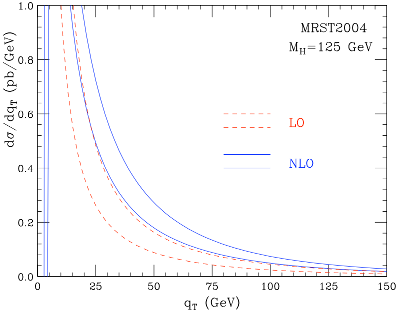

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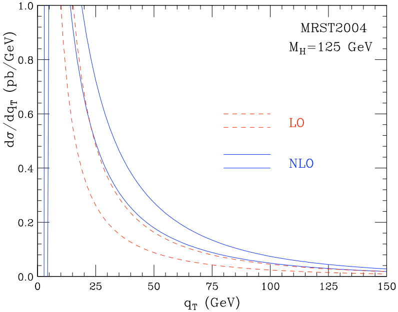

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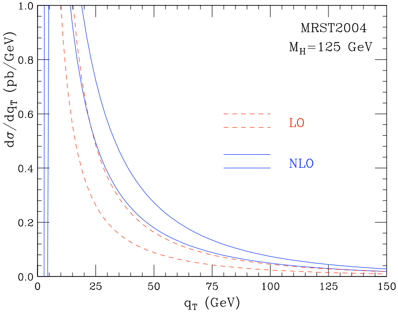

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Outline

Resummation: the main idea

$\alpha_s L^2$	$\alpha_s L$	$\dots$	$\dots$	$\mathcal{O}(\alpha_s)$	(LO)
$\alpha_s^2 L^4$	$\alpha_s^2 L^3$	$\alpha_s^2 L^2$	$\alpha_s^2 L$	$\mathcal{O}(\alpha_s^2)$	(NLO)
$\dots$	$\dots$	$\dots$	$\dots$	$\dots$	$\dots$
$\alpha_s^n L^{2n}$	$\alpha_s^n L^{2n-1}$	$\alpha_s^n L^{2n-2}$	$\dots$	$\mathcal{O}(\alpha_s^n)$	$(N^n LO)$
LL	NLL	NNLL	$\dots$	$\dots$	

- Ratio of two successive rows: $\mathcal{O}(\alpha_s L^2)$
- improved expansion
  - *reorganization* of the terms into *towers of logs*
  - *all-order summation* of the terms in each class
- key-point: *exponentiation*

$$\sigma^{res} \sim \exp\left[L g_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \dots\right]$$

- Ratio of two successive columns: $\mathcal{O}(1/L)$

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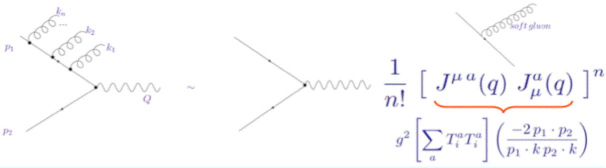
- dynamics (matrix element)
  - → in the soft limit, multigluon amplitudes fulfill *generalized factorization formulae* given in terms of *single gluon emission probability*



- kinematics (phase space)
  - → usually factorizable working in *conjugate space*

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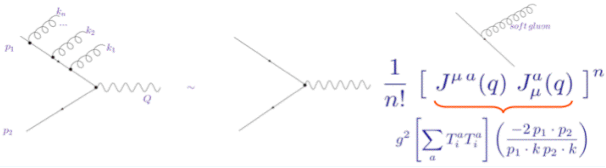

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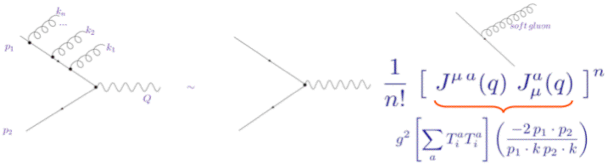

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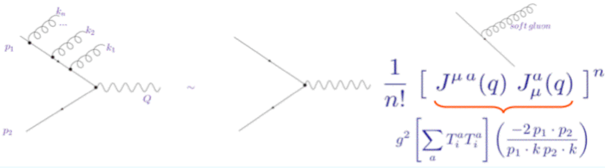

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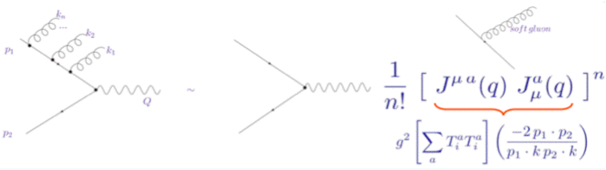

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In the Higgs case, resummation has been explicitly performed up to

- NLL [Catani,D'Emilio,Trentadue(1988)]
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The resummed result has to be properly matched with the fixed-order calculation to avoid double counting

$$\sigma = \sigma^{res} + \sigma^{fix} - \sigma^{asym}$$

where σ^{asym} = expansion of resummed result to same order

- $q_T \ll M_H$: $\sigma^{fix} \sim \sigma^{asym} \rightarrow \sigma = \sigma^{res}$
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- NLL [Catani,D'Emilio,Trentadue(1988)]
- NNLL [deFlorian,Grazzini(2000,2001)]

The resummed result has to be properly matched with the fixed-order calculation to avoid double counting

$$\sigma = \sigma^{res} + \sigma^{fix} - \sigma^{asym}$$

where σ^{asym} = expansion of resummed result to same order

- $q_T \ll M_H$: $\sigma^{fix} \sim \sigma^{asym} \rightarrow \sigma = \sigma^{res}$
- $q_T > M_H$: $\sigma^{res} \sim \sigma^{asym} \rightarrow \sigma = \sigma^{fix}$
- intermediate q_T: matching $\rightarrow \sigma$

Our work

[Bozzi,Catani,deFlorian,Grazzini(2003,2005)]

- Resummation at NNLL at small q_T
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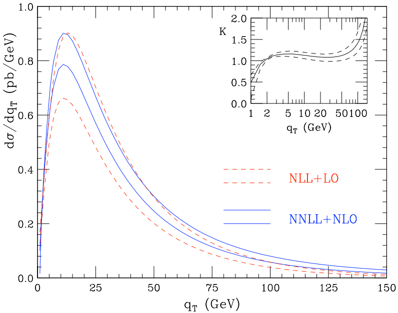
Outline

The q_T spectrum [BCdFG(2003,2005)]



- NNLL+NLO uncertainty band overlaps with NLL+LO one
  - → very good convergence of the resummed perturbative result
- q_T-dependent K-factor

$$K(q_T) = \frac{d\sigma_{NNLL+NLO}(\mu_F, \mu_R)}{d\sigma_{NLL+LO}(\mu_F = \mu_R = M_H)}$$

  - $\sim$ 1.1-1.2 in the central region
  - increase (decrease) drastically for $q_T > 50$ ($q_T < 2$)
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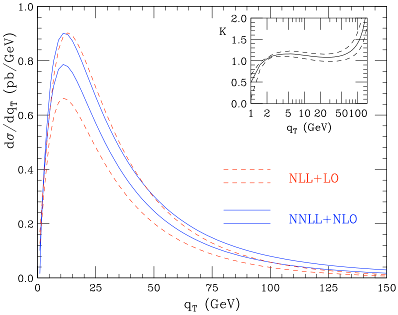

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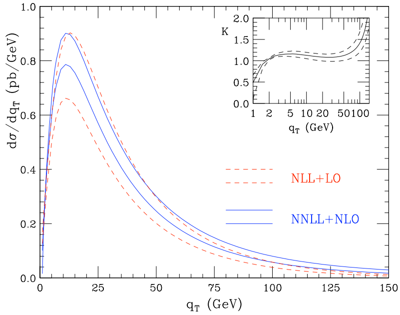

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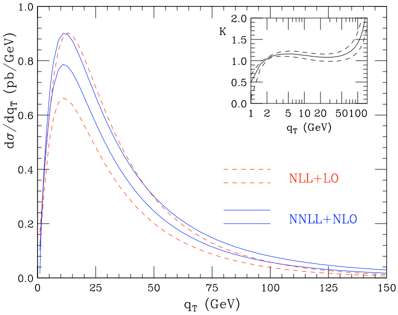

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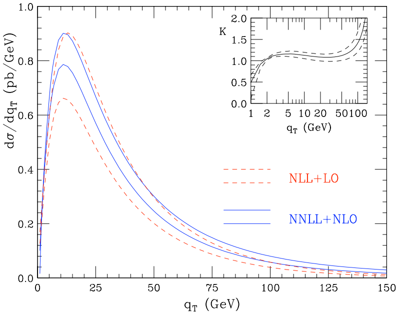

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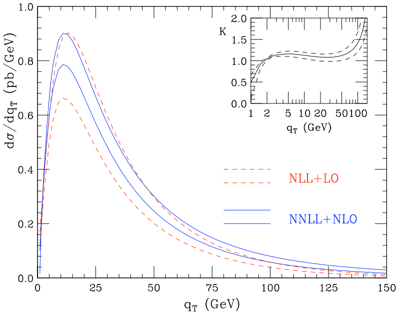

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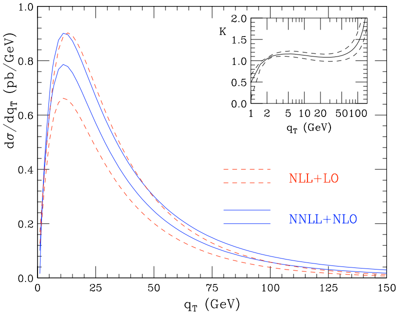

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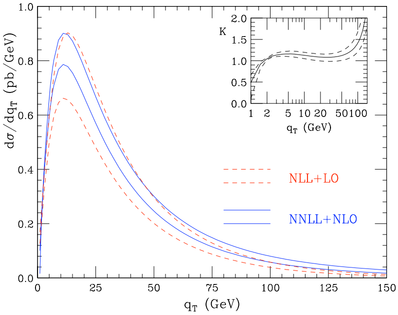

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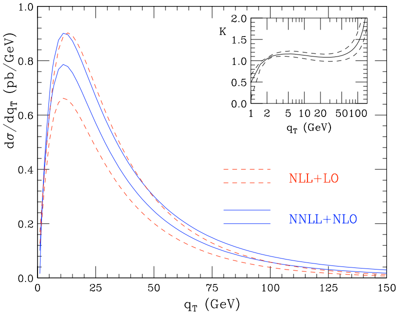

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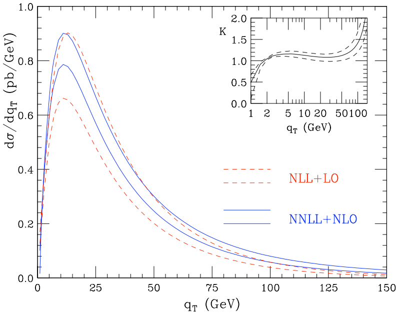

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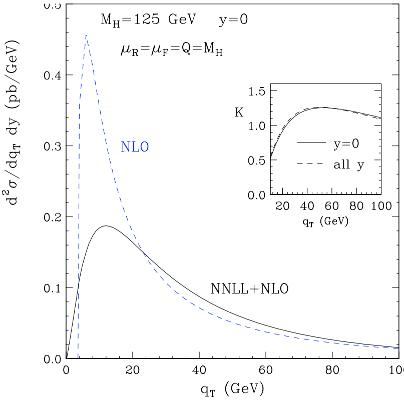

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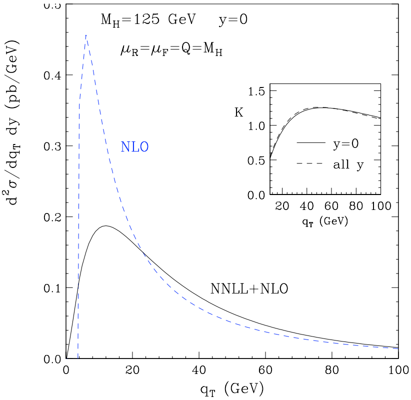

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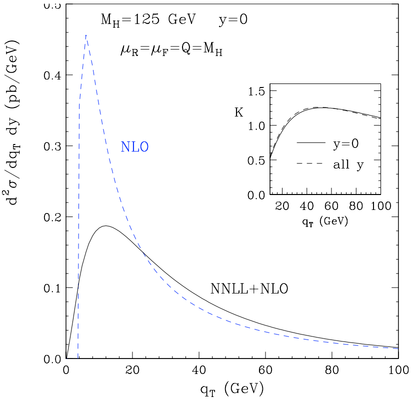

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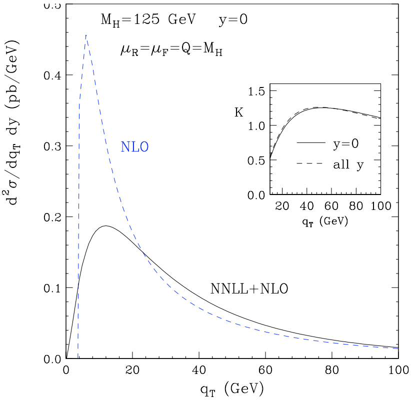

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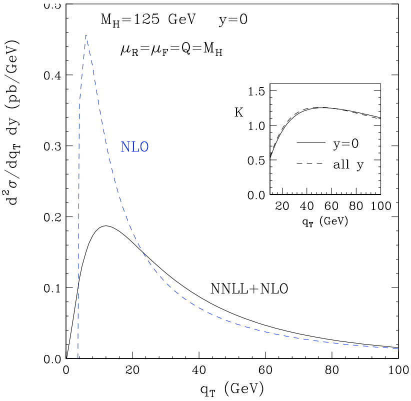

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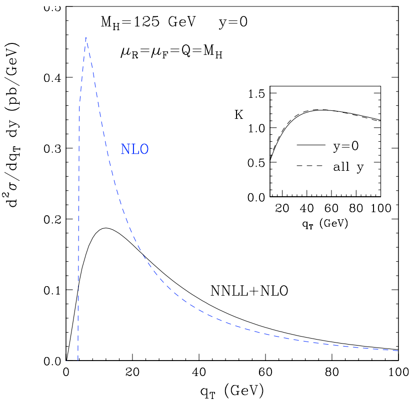

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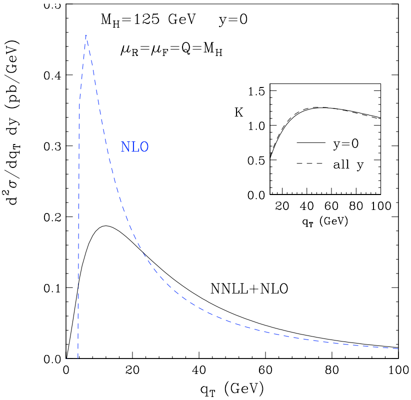

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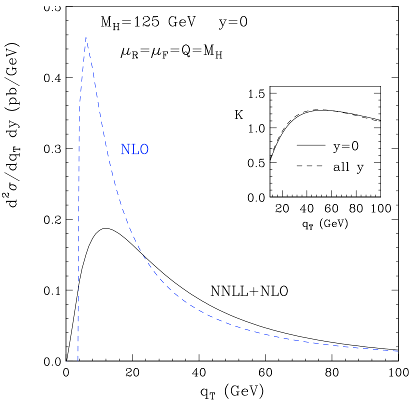

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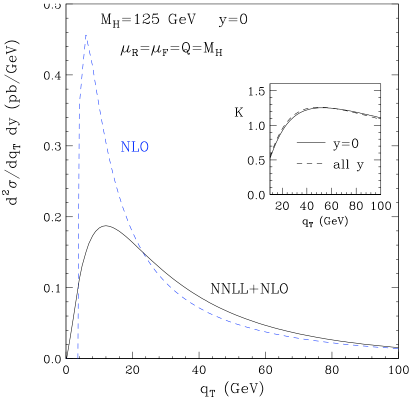

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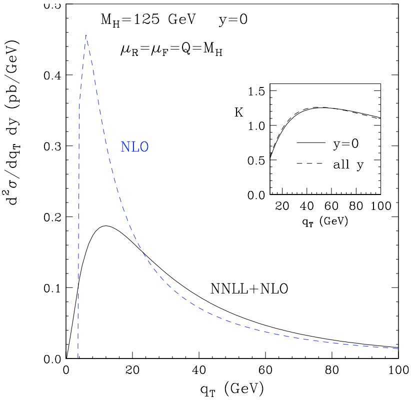

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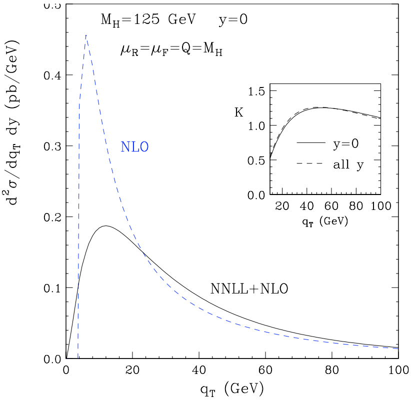

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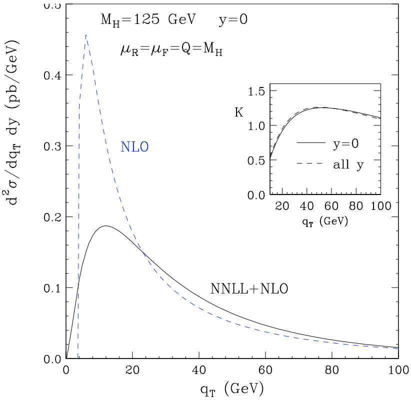

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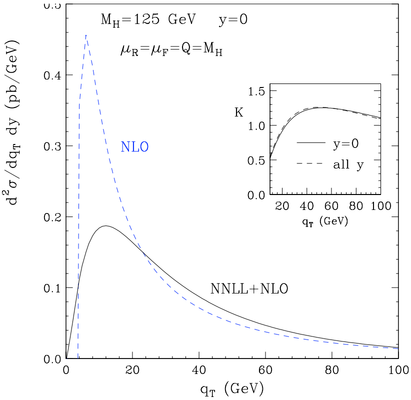

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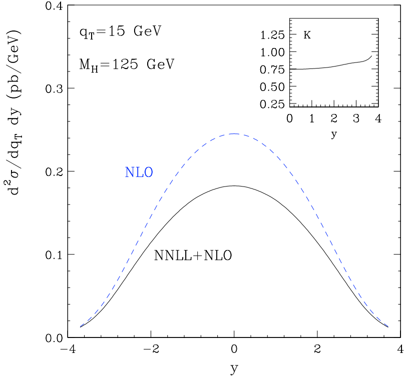

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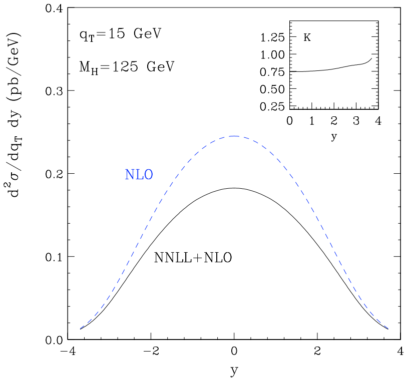

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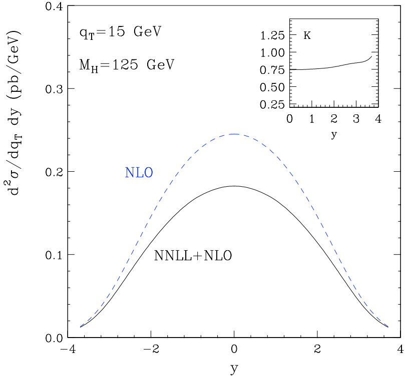

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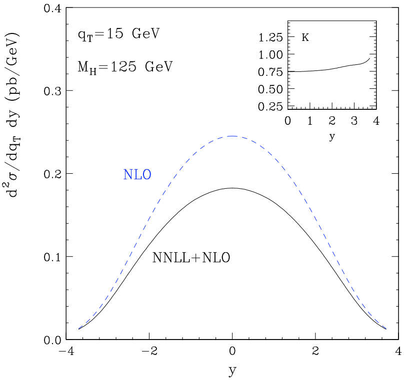

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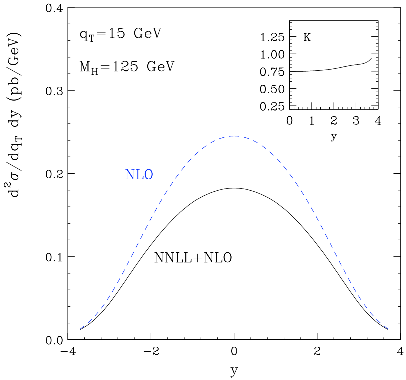

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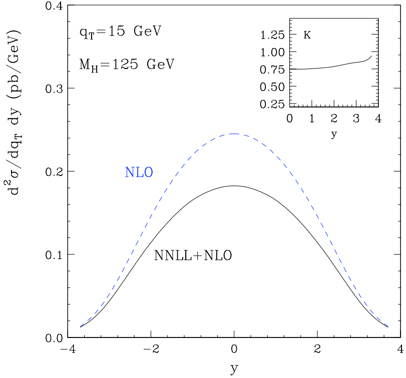

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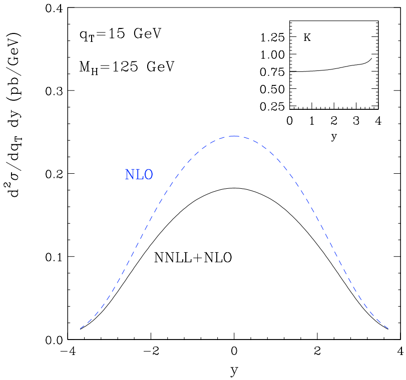

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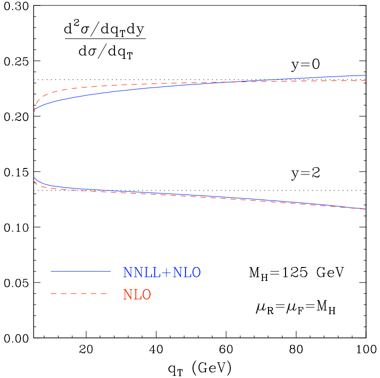

- y=0 lines above y=2 lines
  - → expected, since σ decrease with y
- q_T slope decreases with increasing rapidity
  - → q_T spectrum slightly softer at higher rapidity
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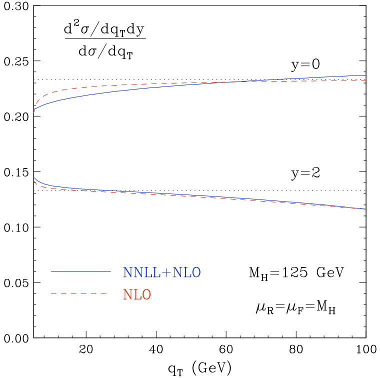

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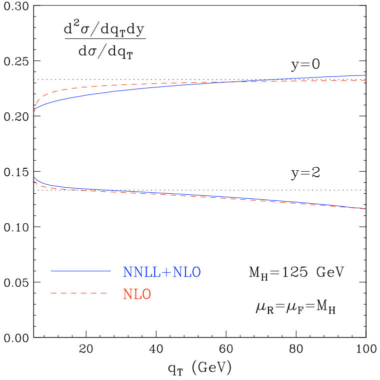

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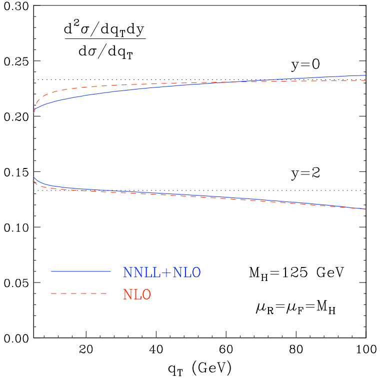

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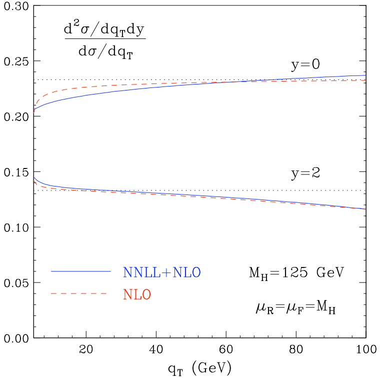

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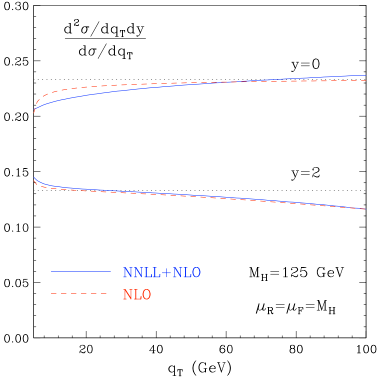

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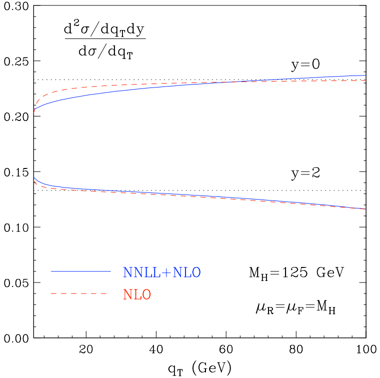

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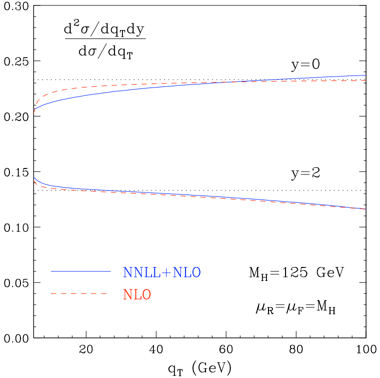

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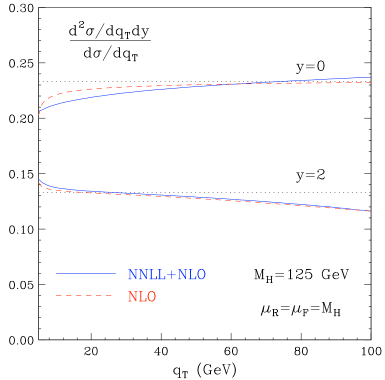

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Outline

Summary

- Precise knowledge of Higgs q_T and y spectrum very important to improve statistical significance
- Enormous theoretical effort in the last years
- Our contribution: $d\sigma/(dq_T\, dy)$ at NNLL+NLO
  - → importance of resummation at low and intermediate q_T
  - → stability of the main features with respect to perturbative uncertainties
- If the Higgs boson exists, no escape route for it at the LHC!

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