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# Open charm and bottom and nonphotonic electrons

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# Plan of the talk

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- Introduction
- Formalism
- Unintegrated parton distributions
- Heavy quark production
  - $c\bar{c}$  production for RHIC and Tevatron
  - $b\bar{b}$  production for RHIC and Tevatron
- Meson production
- Nonphotonic electrons
- Conclusions

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based on:

M. Luszczak and A. Szczurek, Phys. Rev.D73 (2006) 054028  
and work in progress

# Introduction

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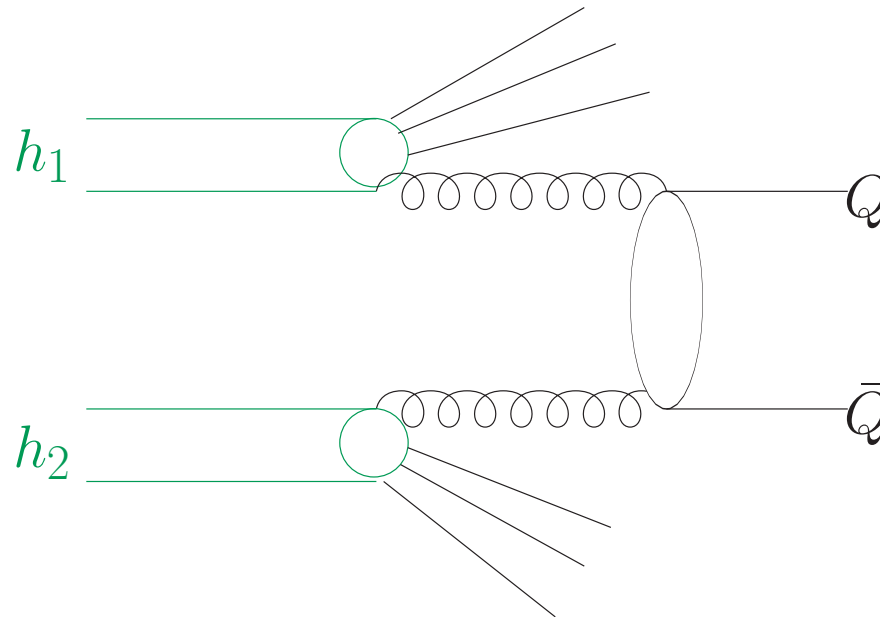
- The **heavy quark-antiquark hadroproduction** is known as one of the crucial tests of conventional gluon distributions within a standard factorization approach. At high energies one tests gluon distributions at low values of  $x$
- Standard collinear approach does not include **transverse momenta** of initial gluons
- The method to include transverse momenta:  
 **$k_t$  - factorization ( PDF  $\rightarrow$ UGDF or UPDF)**
- Different models of **UGDFs** in the literature
  - Some of them tested in other reactions

# Dominant mechanism

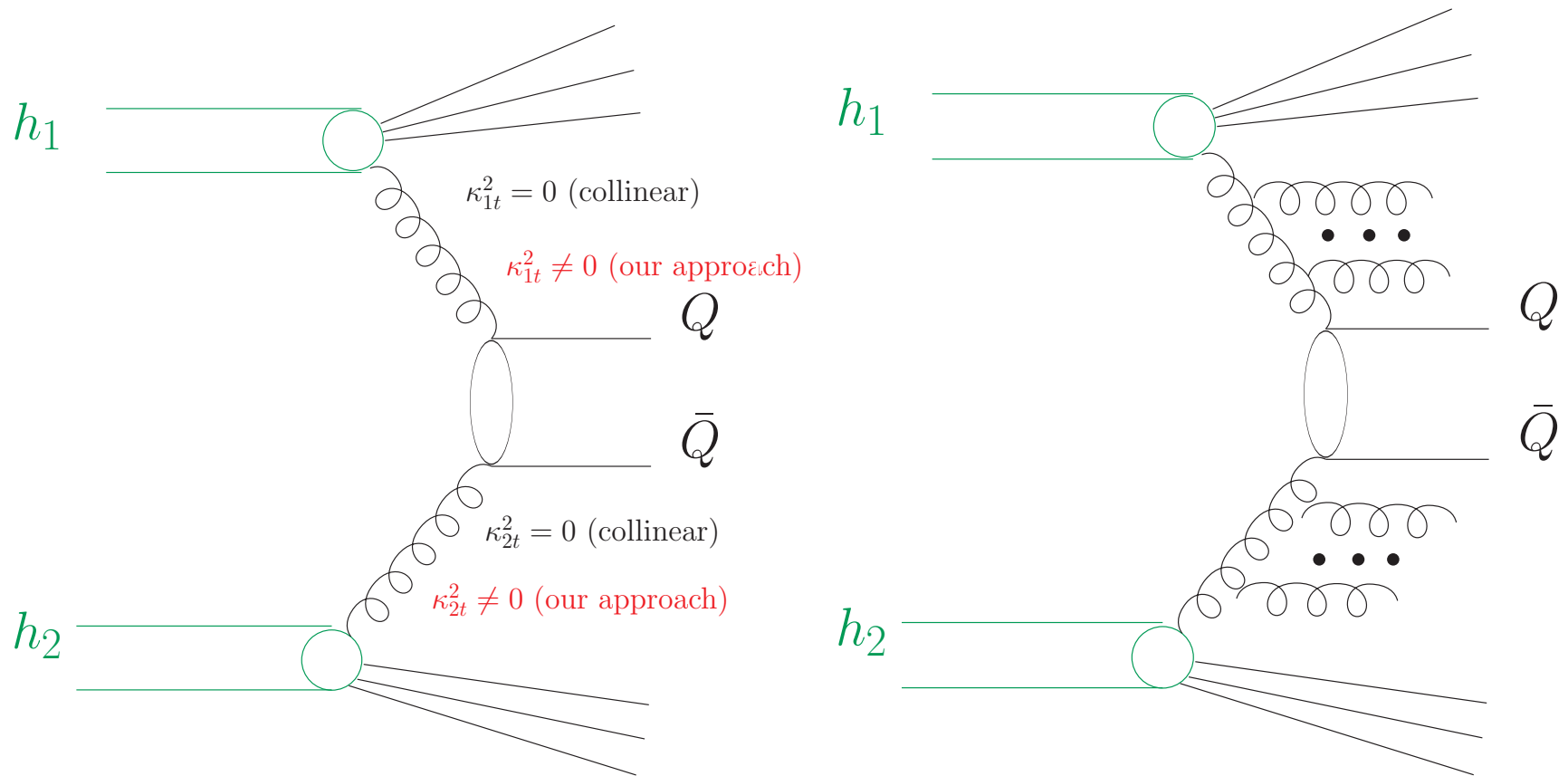
- LO collinear approach

- $(\vec{p}_g \parallel \vec{p}_h)$

- on-shell gluons



# $k_t$ -factorization, UGDF, multigluon emission



# Formalism

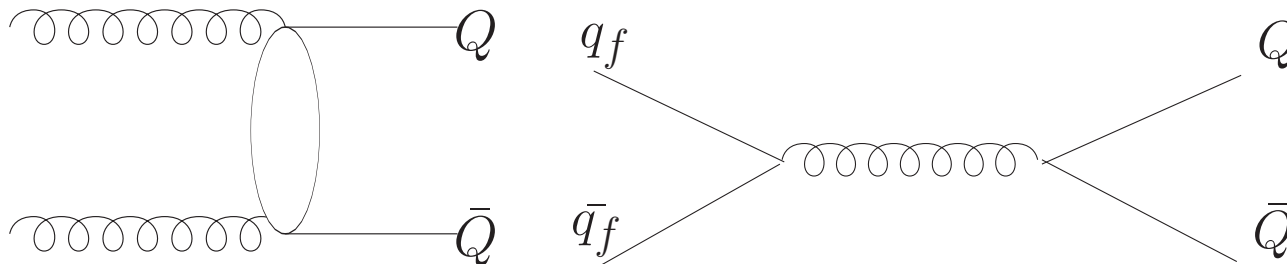
## LO collinear - factorization

$$\frac{d\sigma}{dy_1 dy_2 d^2 p_t} = \frac{1}{16\pi^2 \hat{s}^2} \sum_{i,j} x_1 p_i(x_1, \mu^2) x_2 p_j(x_2, \mu^2) \overline{|\mathcal{M}_{ij}|^2}$$

$$p_{1t} = p_{2t} = p_t$$

$$x_1 = \frac{m_t}{\sqrt{s}} (\exp(y_1) + \exp(y_2)),$$

$$x_2 = \frac{m_t}{\sqrt{s}} (\exp(-y_1) + \exp(-y_2))$$



# Formalism of $k_t$ -factorization

## ● LO $k_t$ -factorization

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2} \overline{|\mathcal{M}_{ij}|^2} \\ \delta^2(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}) f_i(x_1, \kappa_{1,t}^2) f_j(x_2, \kappa_{2,t}^2)$$

## ● $f_i(x_1, \kappa_{1,t}^2)$ and $f_j(x_2, \kappa_{2,t}^2)$ unintegrated parton distributions

$$x_1 = \frac{m_{1,t}}{\sqrt{s}} \exp(y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(y_2), \\ x_2 = \frac{m_{1,t}}{\sqrt{s}} \exp(-y_1) + \frac{m_{2,t}}{\sqrt{s}} \exp(-y_2).$$

$$m_t = \sqrt{p_t^2 + m^2} \text{ - transverse mass}$$

# Unintegrated parton distributions

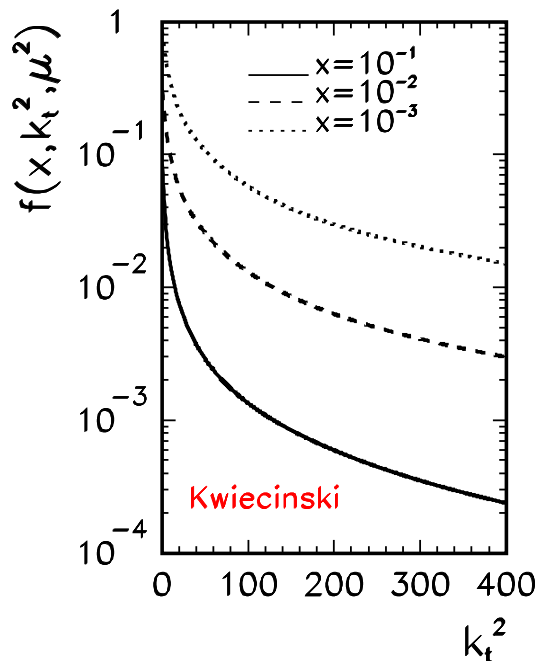
## ● Kwieciński parton distributions

$\tilde{f}_k(x, b, \mu^2)$  - solution of some integro-differential equations

$f_k(x, \kappa_t^2, \mu^2)$  - momentum space UPDF

$$f_k(x, \kappa_t^2, \mu^2) = \int_0^\infty db b J_0(\kappa_t b) \tilde{f}_k(x, b, \mu^2)$$

$$\tilde{f}_k(x, b, \mu^2) = \int_0^\infty d\kappa_t \kappa_t J_0(\kappa_t b) f_k(x, \kappa_t^2, \mu^2)$$



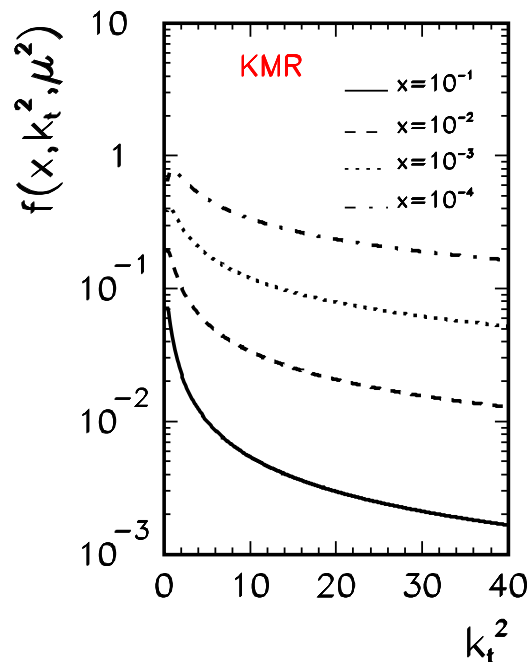
●  $\mu^2 = 100^2 \text{ GeV}^2$

# Kimber-Martin-Ryskin distributions

$$f_a(x, \kappa^2, \mu^2) = T_a(\kappa^2, \mu^2) \cdot \frac{\alpha_s(\kappa^2)}{2\pi} \sum_{a'} \int_x^{1-\delta} P_{aa'}(z) \left(\frac{x}{z}\right) a' \left(\frac{x}{z}, \kappa^2\right) dz$$

● The Sudakov form factor:

$$T_g(\kappa^2, \mu^2) = \exp \left( - \int_{\kappa^2}^{\mu^2} \frac{dp^2}{p^2} \frac{\alpha_s(p^2)}{2\pi} \int_0^{1-\delta} dz \left[ z P_{gg}(z) + \sum_q P_{qg}(z) \right] \right)$$



●  $\mu^2 = 100^2 \text{ GeV}^2$

# Unintegrated gluon distributions at small x

- BFKL gluon distribution (small x)

$$-x \frac{\partial f(x, q_t^2)}{\partial x} = \frac{\alpha_s N_c}{\pi} q_t^2 \int_0^\infty \frac{dq_{1t}^2}{q_{1t}^2} \left[ \frac{f(x, q_{1t}^2) - f(x, q_t^2)}{|q_t^2 - q_{1t}^2|} + \frac{f(x, q_t^2)}{\sqrt{q_t^4 + 4q_{1t}^4}} \right]$$

- Golec-Biernat-Wüsthoff gluon distribution (small x)

$$\alpha_s \mathcal{F}(x, \kappa_t^2) = \frac{3\sigma_0}{4\pi^2} R_0^2(x) \kappa_t^2 \exp(-R_0^2(x) \kappa_t^2)$$

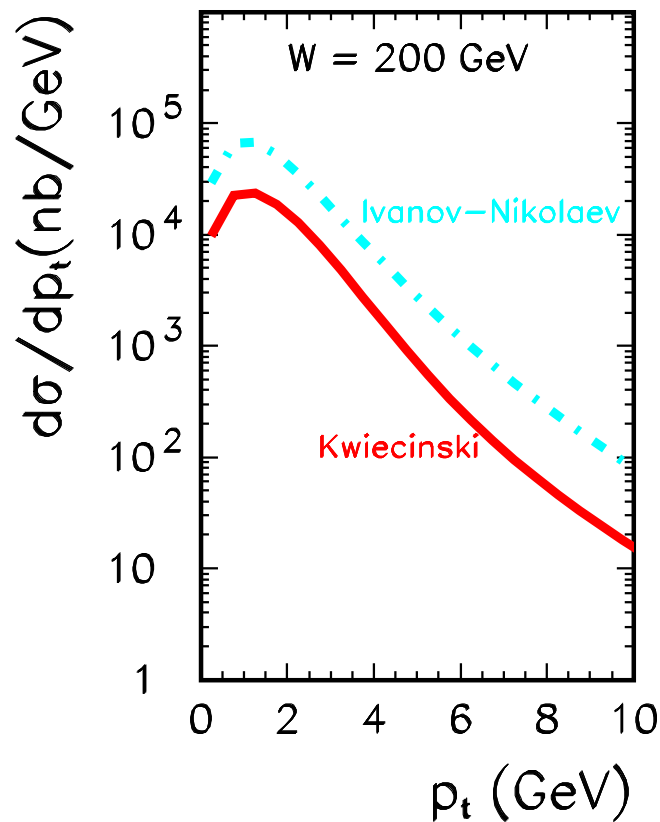
$$R_0(x) = \frac{1}{\text{GeV}} \left( \frac{x}{x_0} \right)^{\lambda/2} \quad (\text{HERA})$$

- Gluon distribution a la Kharzeev-Levin (small x)

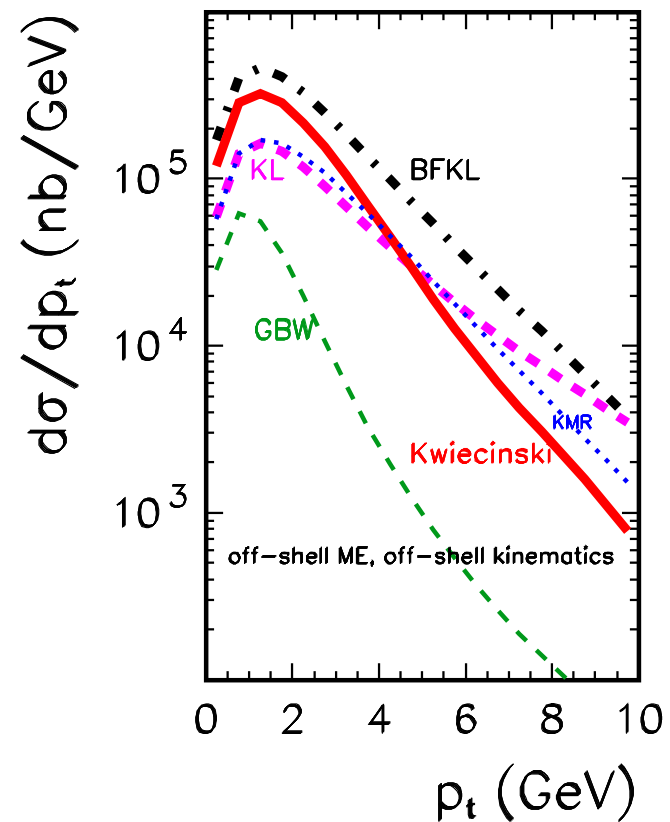
$$\mathcal{F}(x, \kappa^2) = \begin{cases} f_0 & \text{if } \kappa^2 < Q_s^2, \\ f_0 \cdot \frac{Q_s^2}{\kappa^2} & \text{if } \kappa^2 > Q_s^2. \end{cases} \quad (\text{RHIC})$$

# Charm-anticharm pair production

- Inclusive cross section for charm- anticharm production for different UGDFs for RHIC and Tevatron



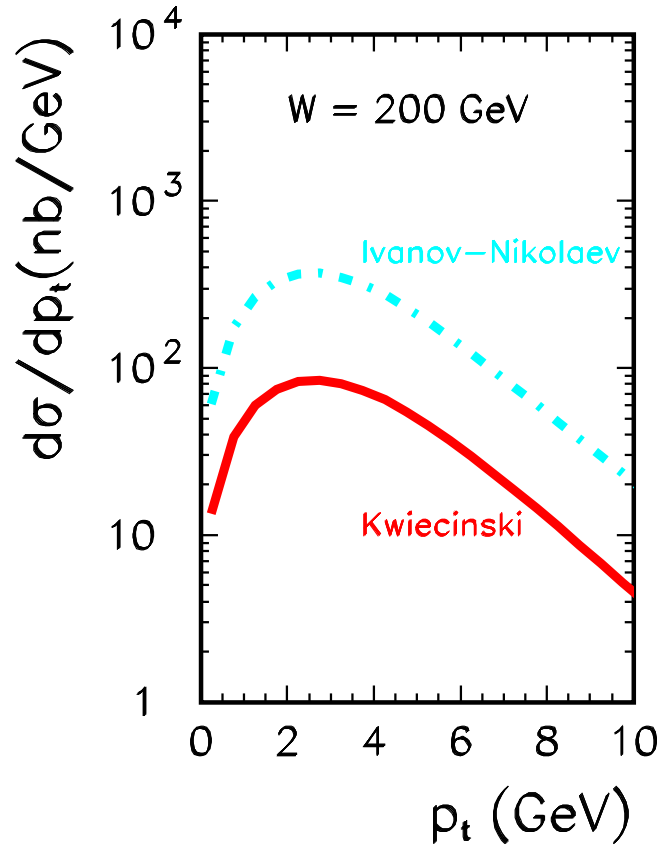
W = 200 GeV



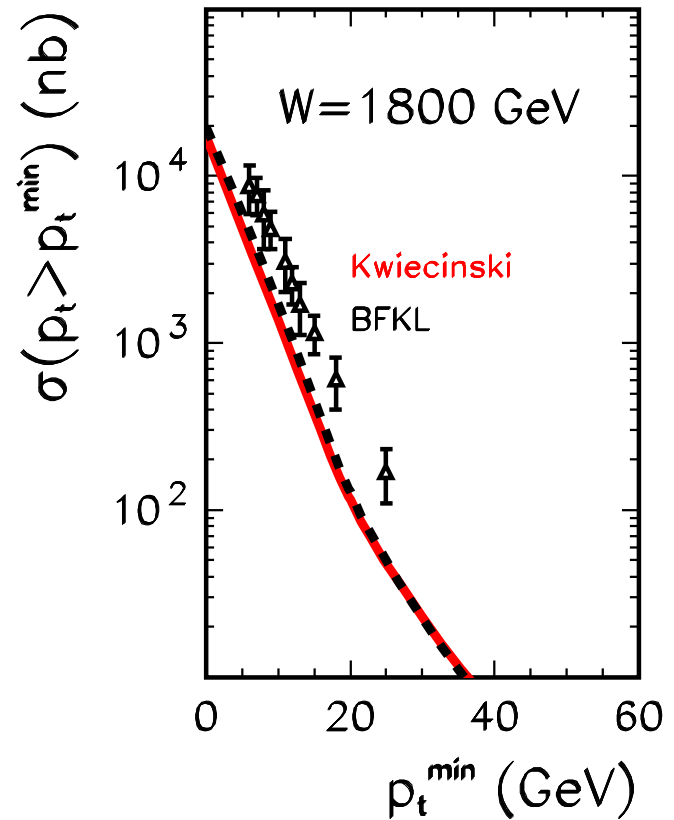
W = 1960 GeV

# Bottom production

- Experimental data from:  
D0[2] for  $W = 1800$  GeV



$W = 200$  GeV



$W = 1800$  GeV

# From quarks to mesons

- The inclusive distributions of **hadrons** are obtained through a convolution of inclusive distributions of **heavy quarks/antiquarks** and  **$Q \rightarrow h$  fragmentation functions**

$$\frac{d\sigma(y_h, p_{t,h})}{dy_h d^2p_{t,h}} = \int_0^1 \frac{dz}{z^2} D_{Q \rightarrow h}(z) \frac{d\sigma_{gg \rightarrow Q}(y_Q, p_{t,Q})}{dy_Q d^2p_{t,Q}} \Bigg|_{\substack{y_Q = y_h \\ p_{t,Q} = p_{t,h}/z}}$$

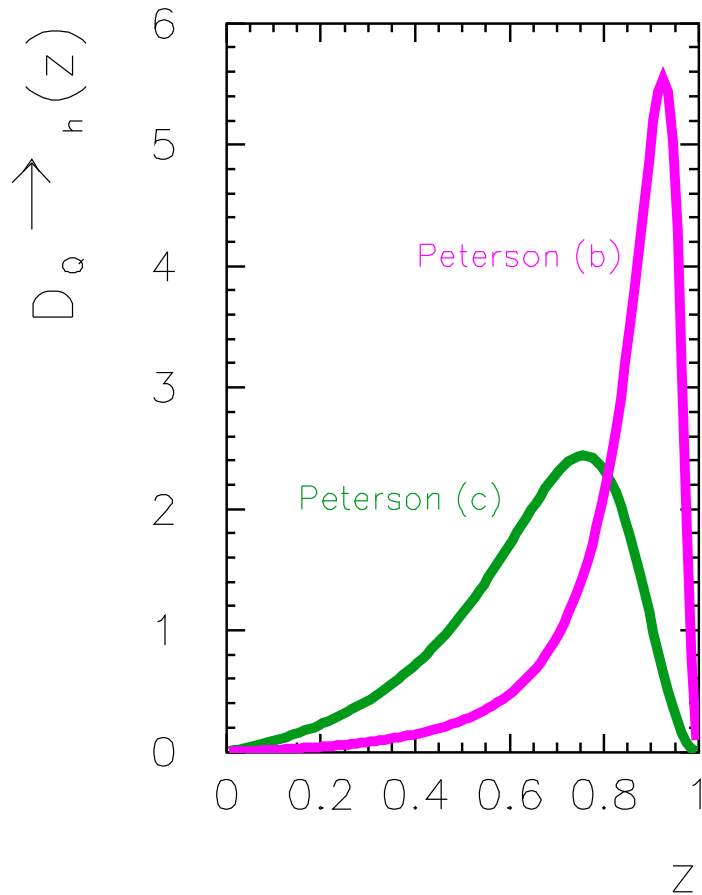
- **$D_{Q \rightarrow h}(z)$  - Peterson fragmentation function**

# Peterson fragmentation functions

● parameters from Particle Data Group

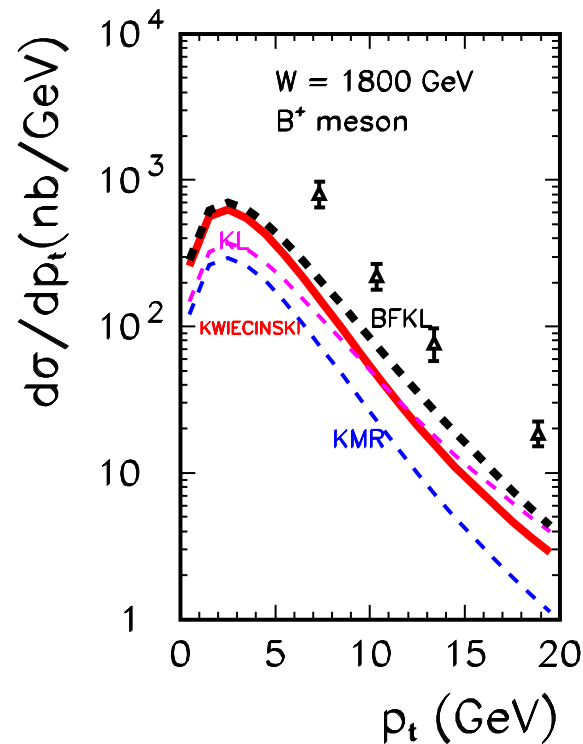
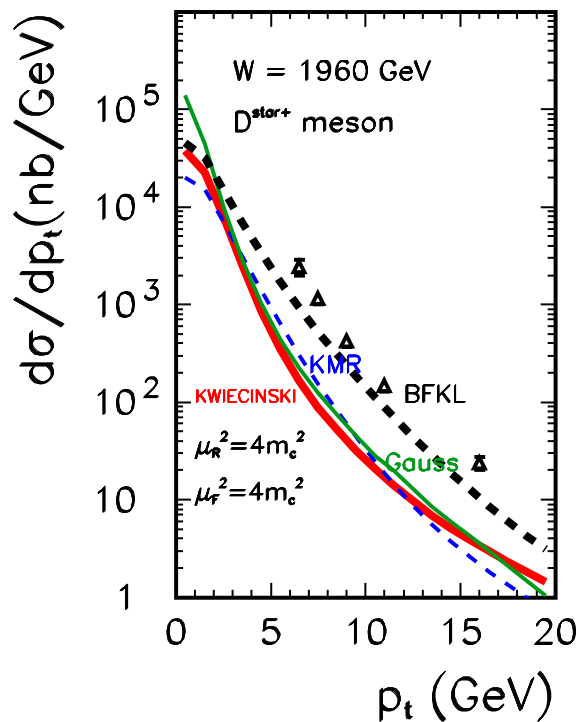
●  $\epsilon_c = 0.078$

●  $\epsilon_b = 0.006$

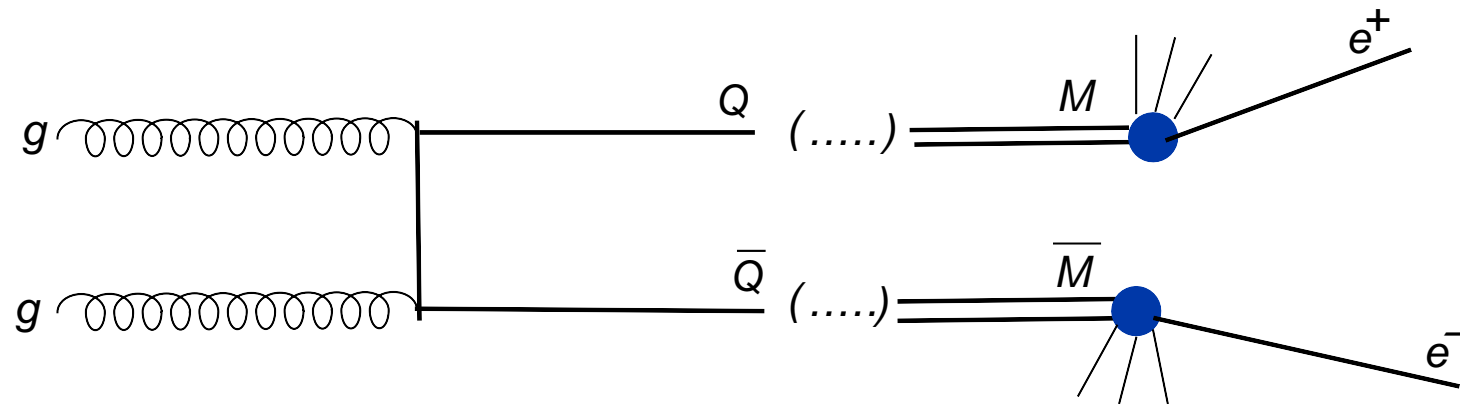


# Meson production- results

- $D^{*+}$  production (panel a)
- experimental data from the CDF collaboration
- $B^+$  production (panel b)



# Nonphotonic electrons



- $Q = c, b$  ( $\bar{Q} = \bar{c}, \bar{b}$ )
- $M = D, B$  ( $\bar{M} = \bar{D}, \bar{B}$ )

# Inclusive semileptonic decays

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## ● CLEO

- $e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D} \rightarrow e^+(e^-)X$

- $D\bar{D}$  (almost at rest)

## ● BABAR

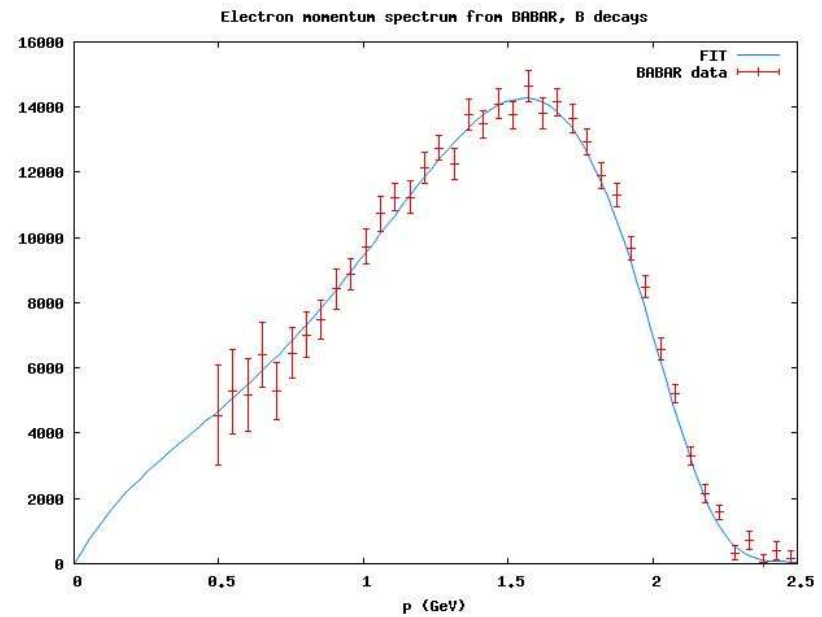
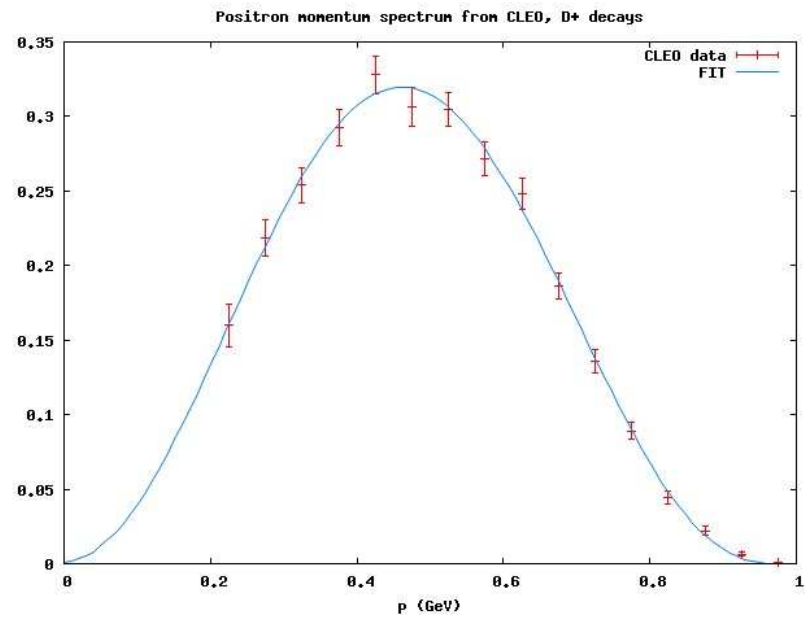
- $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B} \rightarrow e^+(e^-)X$

- $B\bar{B}$  (almost at rest)

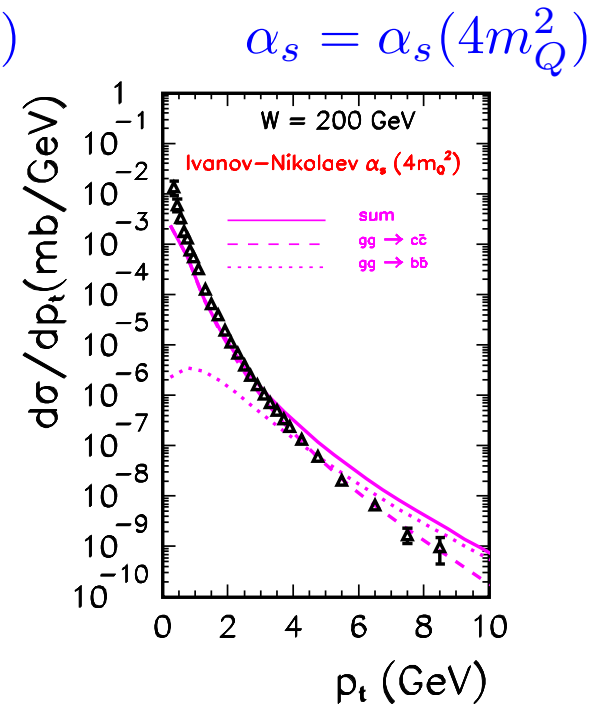
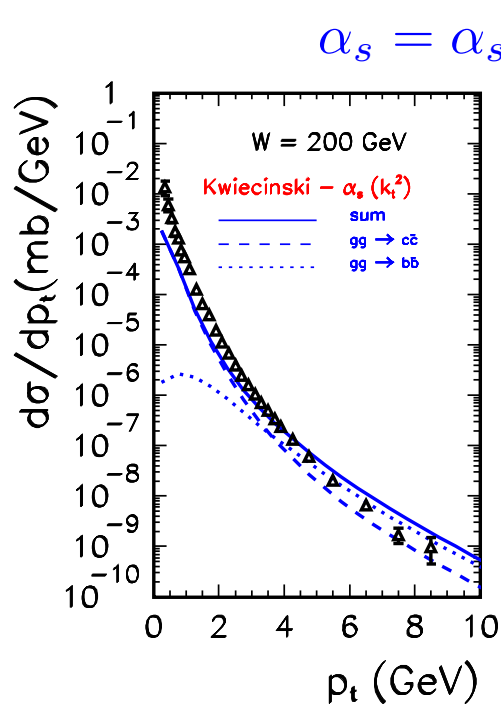
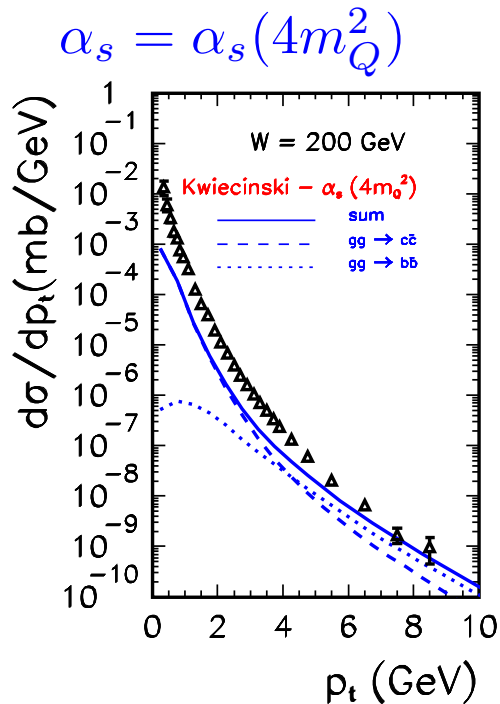
# Our fits

● CLEO,  $D^+$  decays (panel a)

● BABAR,  $B^+$  decays (panel b)



# Distributions of electrons, gg components

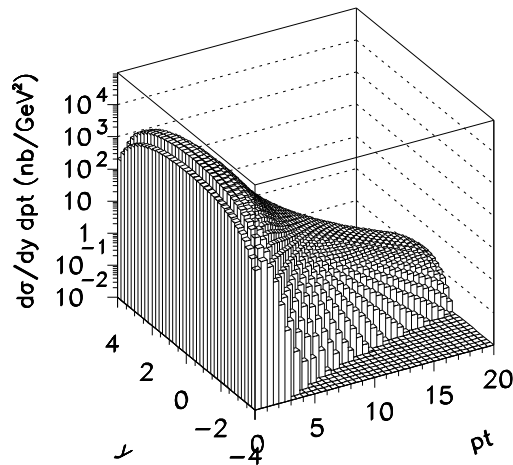


- Choice of the renormalization scale
- Standard collinear choice:
  - $\alpha_s = \alpha_s(m_c^2 + p_t^2)$
- $k_t$  - factorization choice ( PDF → UGDF or UPDF):
  - $\alpha_s = \alpha_s(4m_c^2)$
  - $\alpha_s = \alpha_s(\kappa_{1t}^2)$  or  $\alpha_s(\kappa_{2t}^2)$

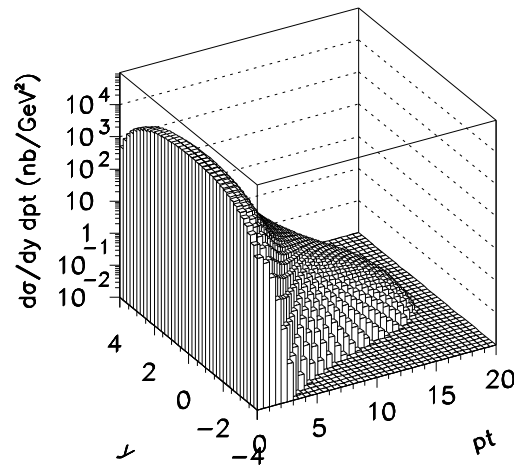
# Distributions of electrons in $p_t$ and $y$

- $W = 200 \text{ GeV}, \quad \alpha_s = \alpha_s(\kappa_t^2)$

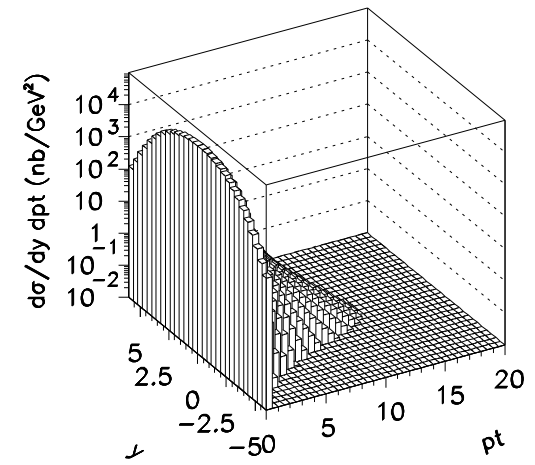
$$gg \rightarrow c\bar{c}$$



$$gg \rightarrow c\bar{c} \rightarrow D\bar{D}$$



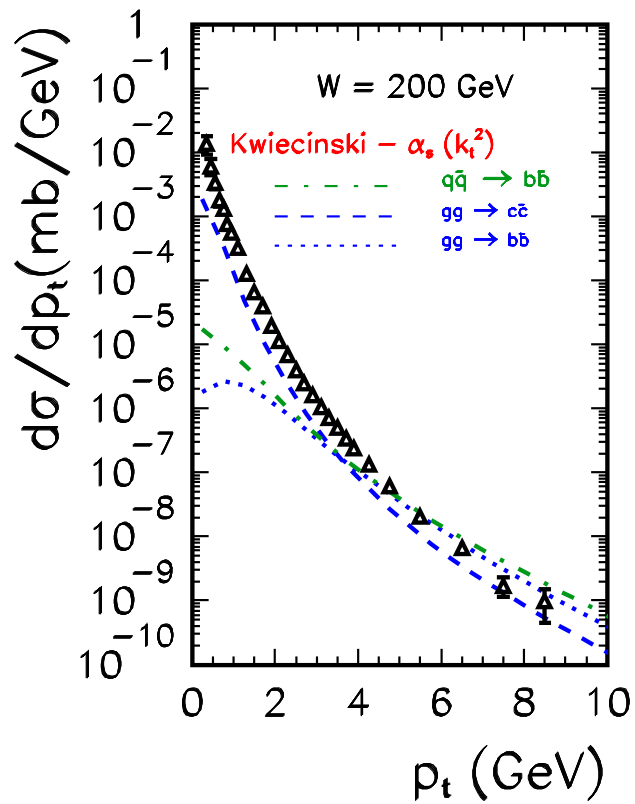
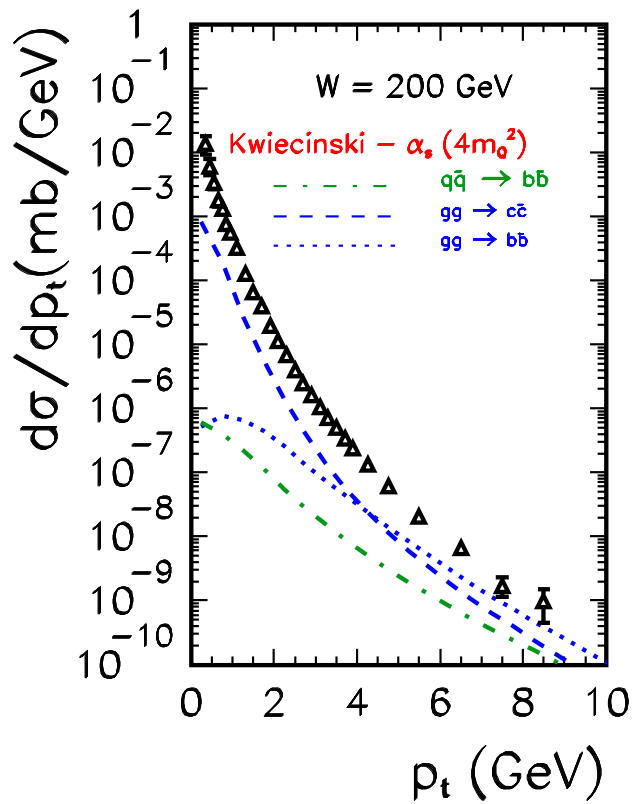
$$gg \rightarrow c\bar{c} \rightarrow D\bar{D} \rightarrow e^+e^-$$



- $y_l \rightarrow (-6, 6)$

- experimental data: PHENIX collaboration:  $y_l \rightarrow (-0.5, 0.5)$

# Distributions of electrons, $q\bar{q}$ components



# SUMMARY

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- Inclusive cross section for heavy quark - antiquark and heavy mesons in proton -(anti) proton collisions were calculated in the  $k_t$ -factorization approach.
- Different UGDFs give different results for inclusive distribution
- Distributions of electrons from
  - $gg \rightarrow c\bar{c} \rightarrow D\bar{D} \rightarrow e^+e^-$
  - $gg \rightarrow b\bar{b} \rightarrow B\bar{B} \rightarrow e^+e^-$
  - $q\bar{q} \rightarrow b\bar{b} \rightarrow B\bar{B} \rightarrow e^+e^-$
  - were calculated and compared with new PHENIX data

# SUMMARY

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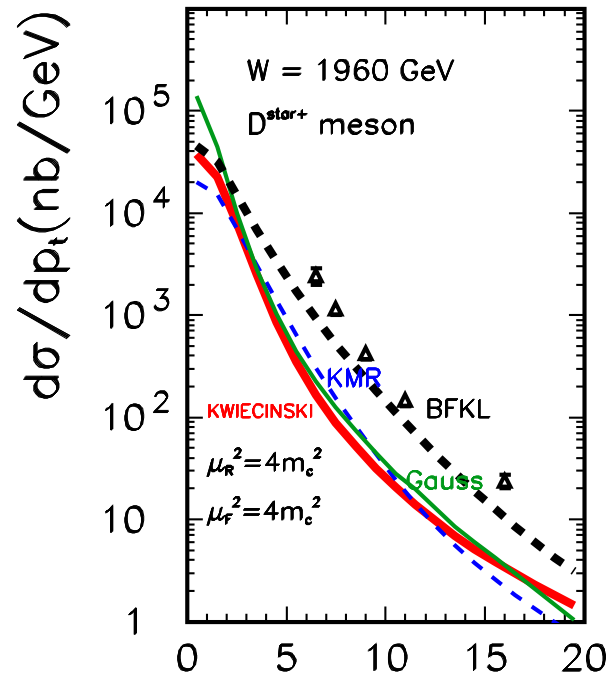
- Missing strength for heavy mesons
  - choice of renormalization scale?
  - heavy quark masses?
  - NLO?
  - other mechanisms?

# Charm meson production

The total cross section for  $D^{*+}$  production:

$$\frac{d\sigma(p_t)}{dp_t} = \int_{-1}^1 dy \frac{d\sigma(y, p_t)}{dy dp_t} \approx 2 \frac{d\sigma(y=0, p_t)}{dy dp_t}$$

Experimental data from the CDF collaboration



# Choice of the renormalization scale

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Standard coll. choice:

$$\alpha_s = \alpha_s(m_c^2 + p_t^2)$$

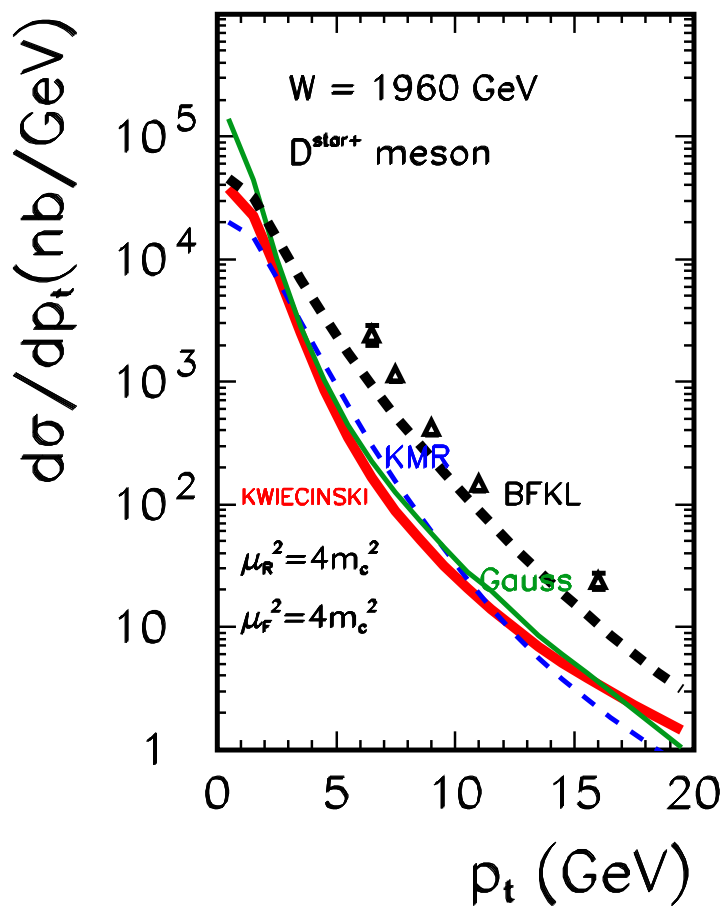
Our choice:

$$\alpha_s = \alpha_s(4m_c^2)$$

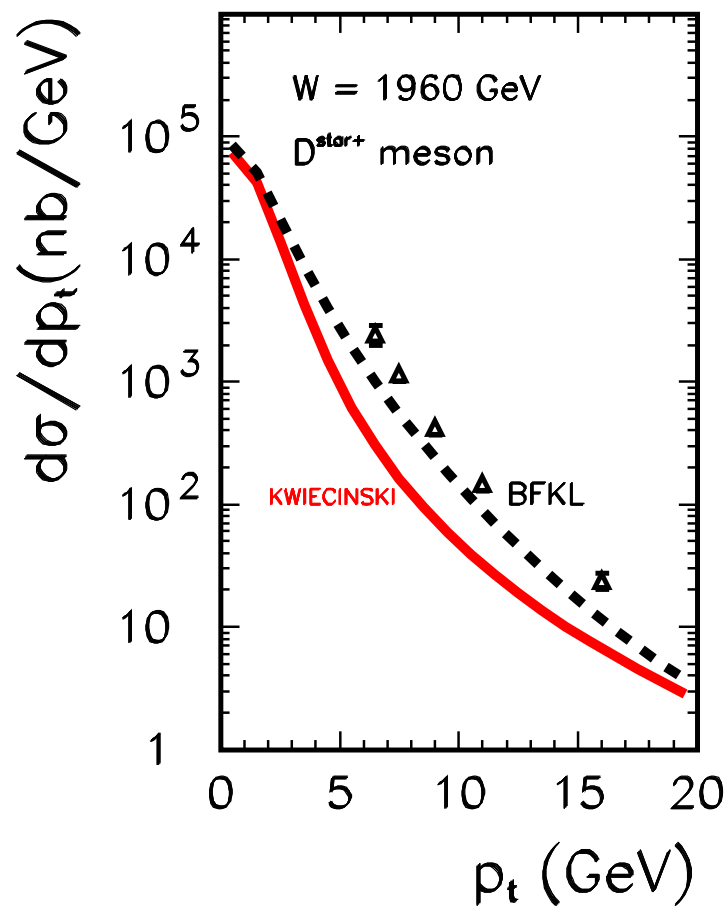
$k_t$ -factorization Russian choice:

$$\alpha_s = \alpha_s(\kappa_{1t}^2) \text{ or } \alpha_s(\kappa_{2t}^2)$$

# Choice of the renormalization scale

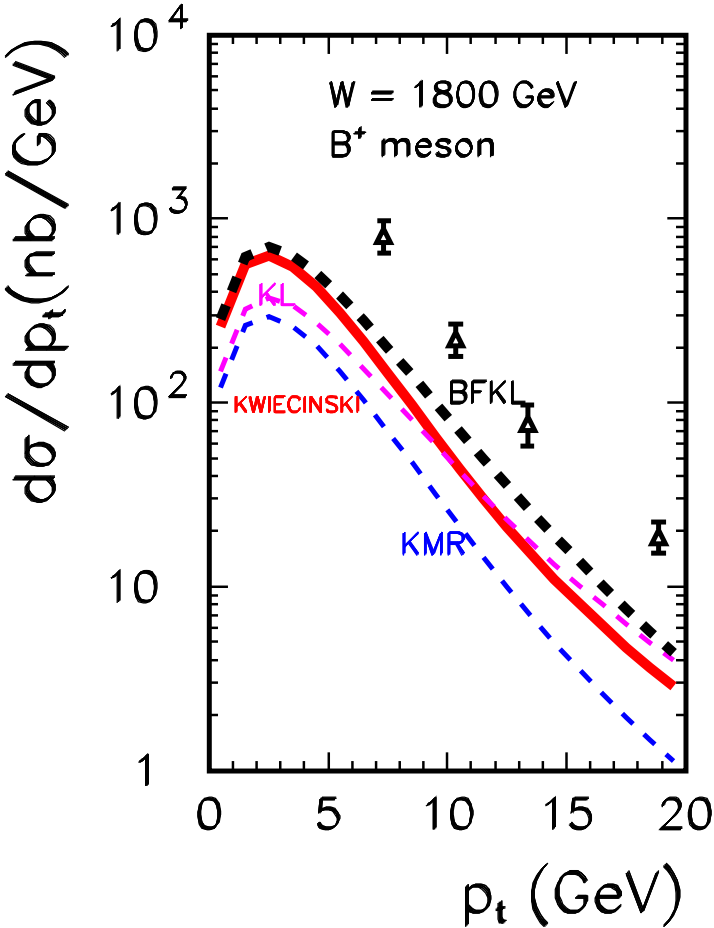


our choice

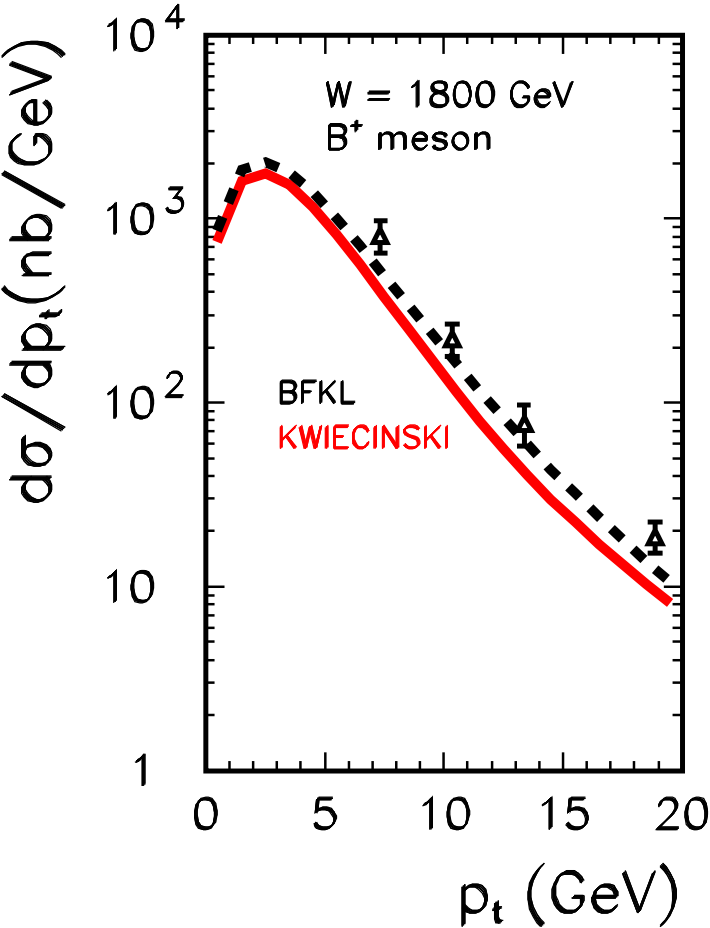


Russian choice

# Bottom meson production



our scale



Russian scale