Semileptonic decays of heavy mesons at RHIC

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Plan of the talk

- 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

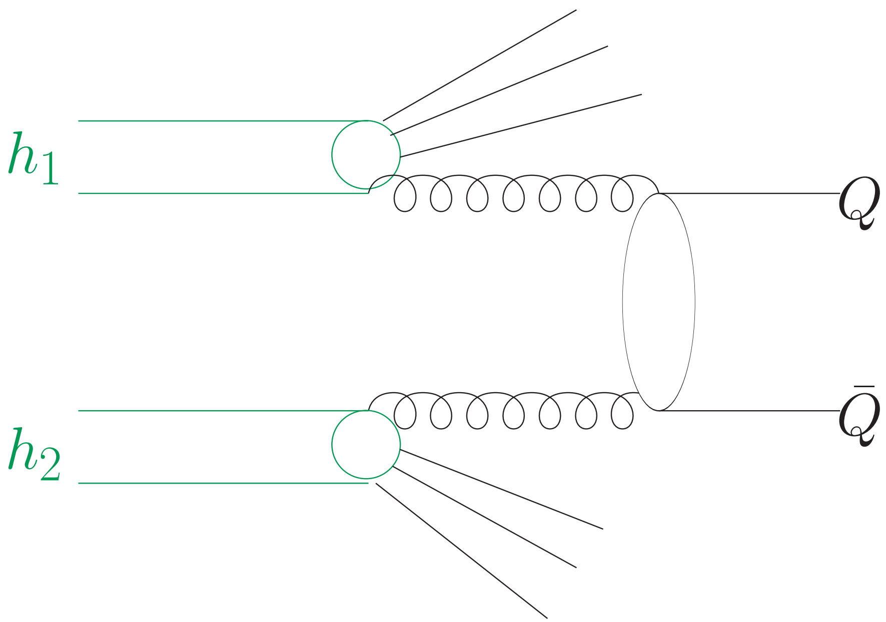
based on:
M. Luszczak and A. Szczurek, Phys. Rev.**D73** (2006) 054028
and work in progress

Introduction

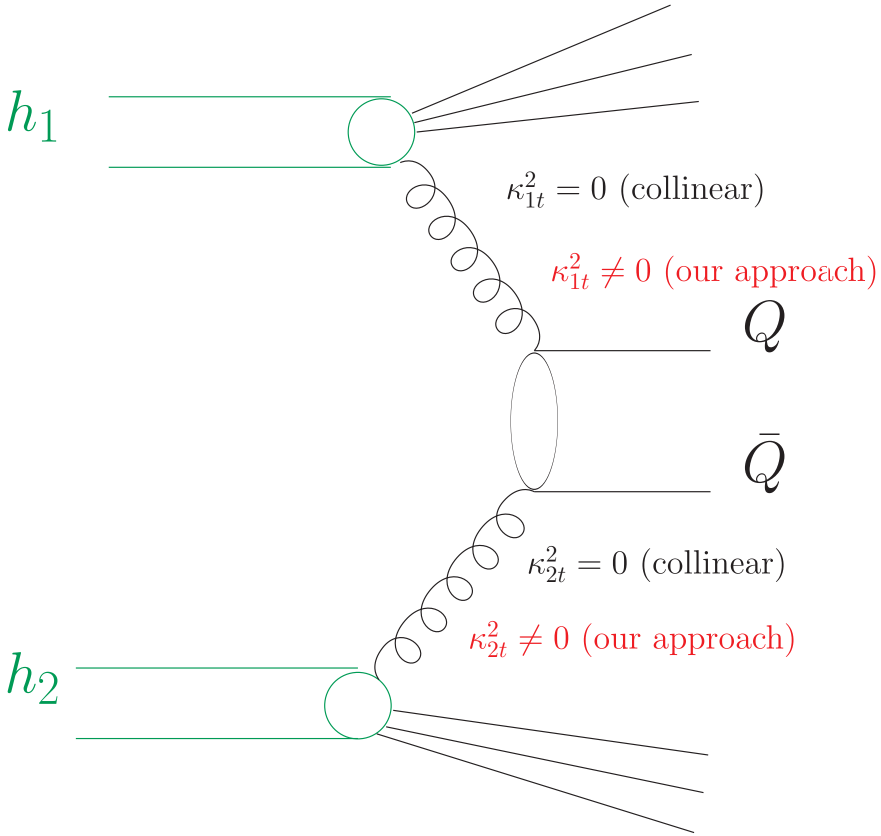
- The heavy quark-antiquark hadroproduction is known as one of the crucial tests of conventional gluon distributions within a standard factorization approach. At high energies one tests gluon distributions at low values of x
- Standard collinear approach does not include transverse momenta of initial 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

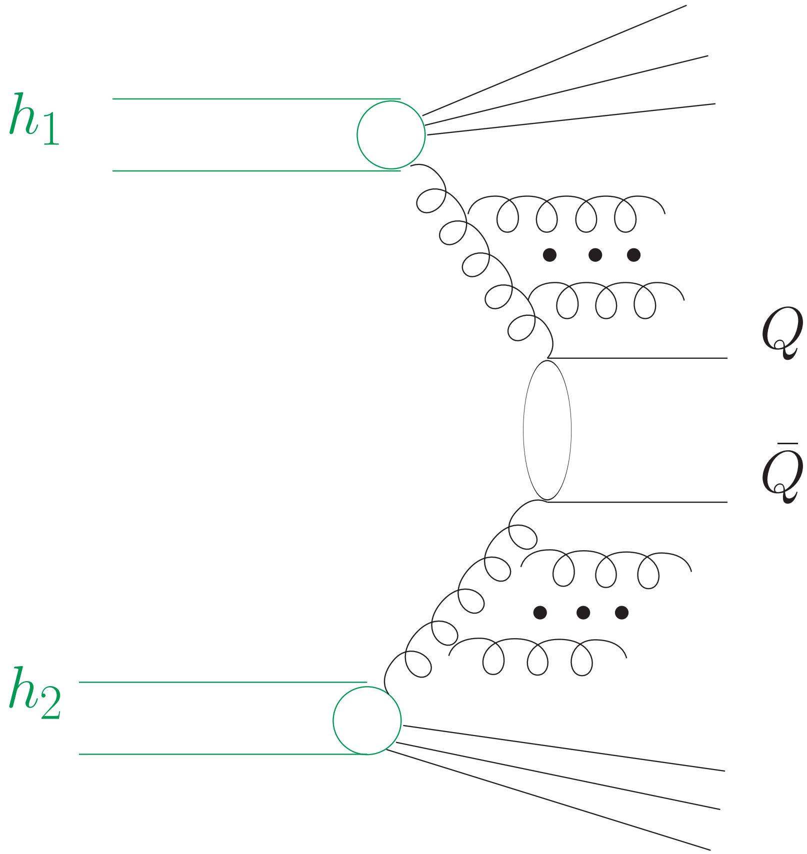
Dominant mechanism

- LO collinear approach
  - $(\vec{p}_g \;\; || \;\; \vec{p}_h)$
  - on-shell gluons



k_t-factorization, UGDF, multigluon emission





Formalism

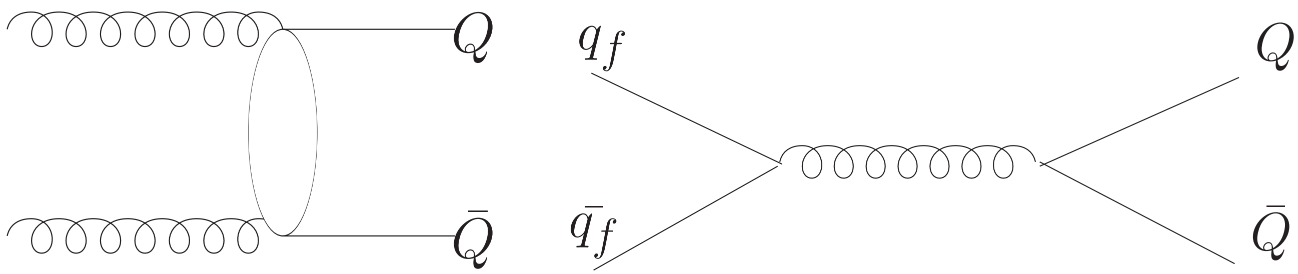
- LO collinear - factorization

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

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

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

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



Formalism of k_t-factorization

- LO k_t-factorization

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

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

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

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

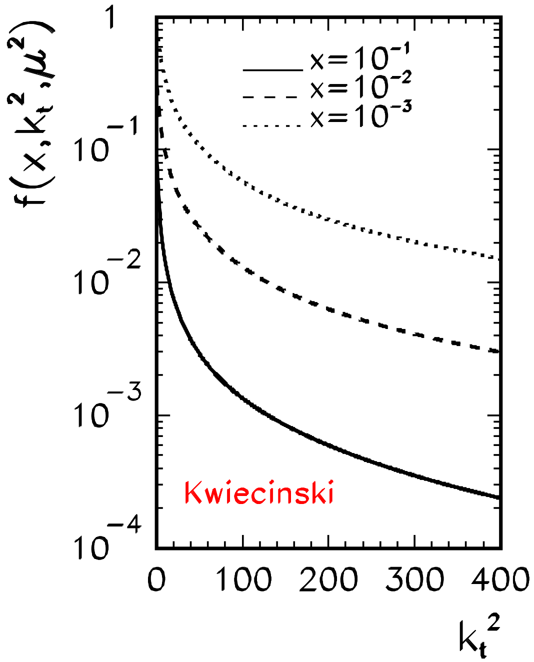
Unintegrated parton distributions

- 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

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

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



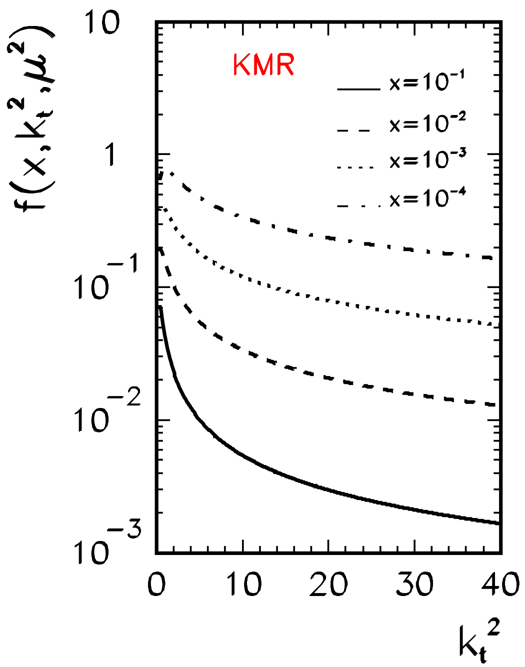
- $\mu^2 = 100^2 \quad GeV^2$

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:

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



- $\mu^2 = 100^2 \quad GeV^2$

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)

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

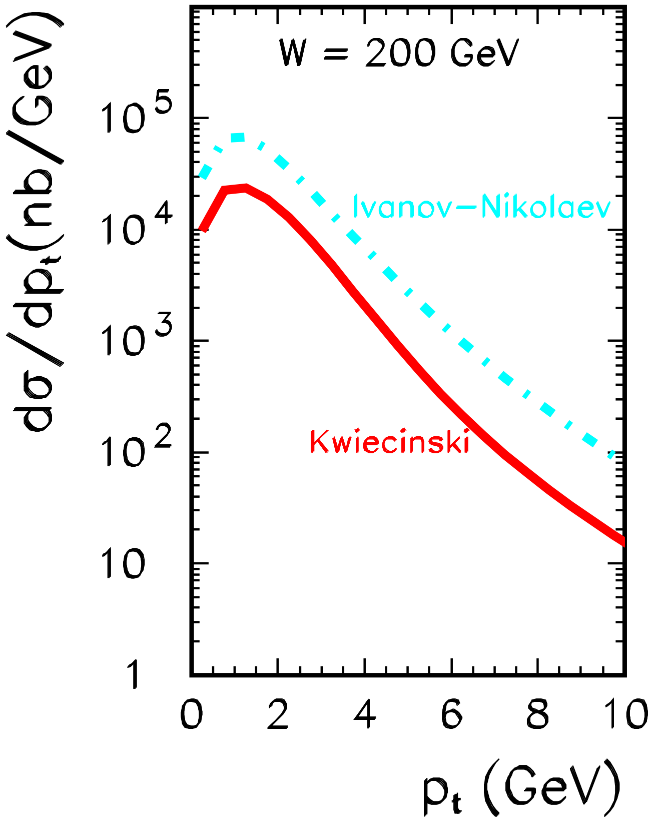
$$R_0(x) = \frac{1}{GeV}\left(\frac{x}{x_0}\right)^{\lambda/2} \qquad (HERA)$$

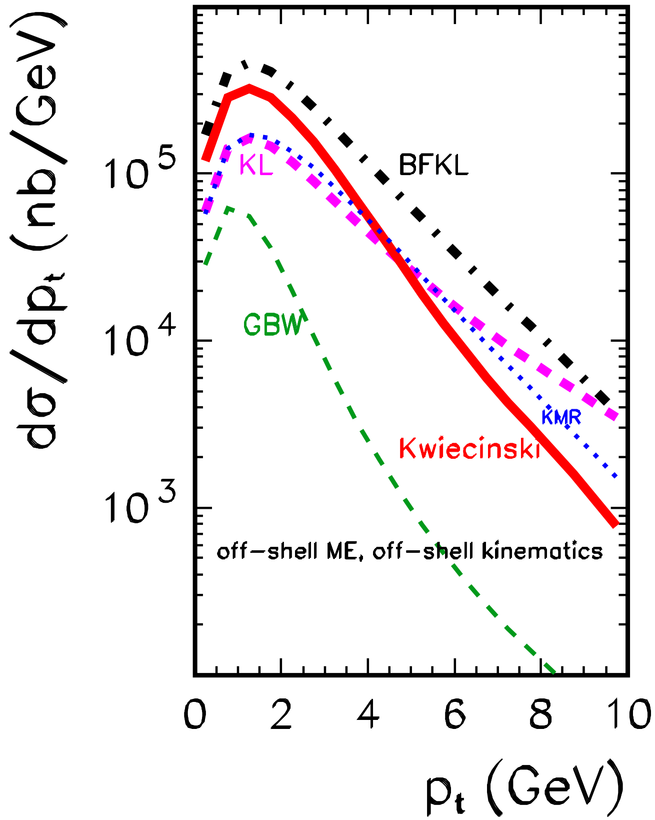
- Gluon distribution a la Kharzeev-Levin (small x)

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

Charm-anticharm pair production

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



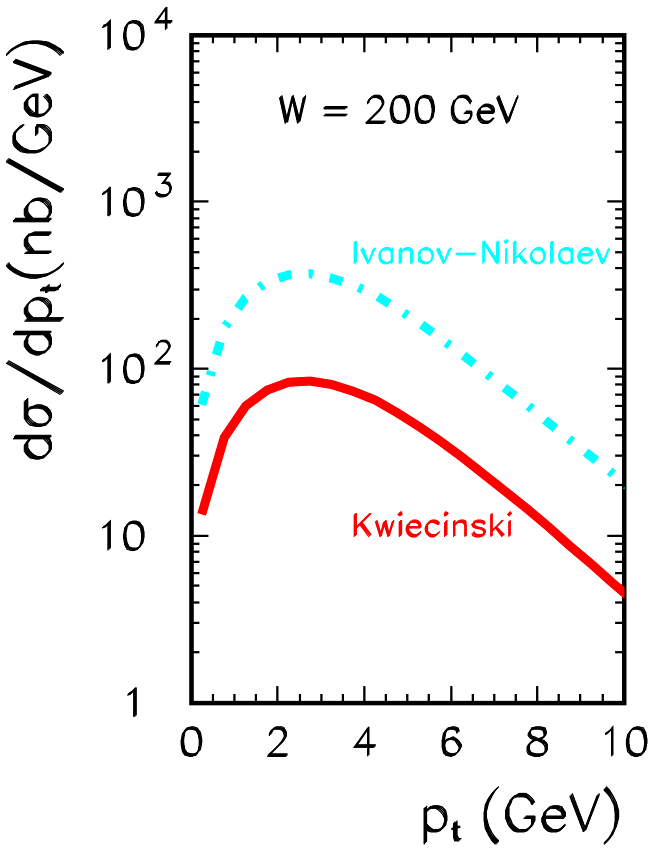


W = 200 GeV

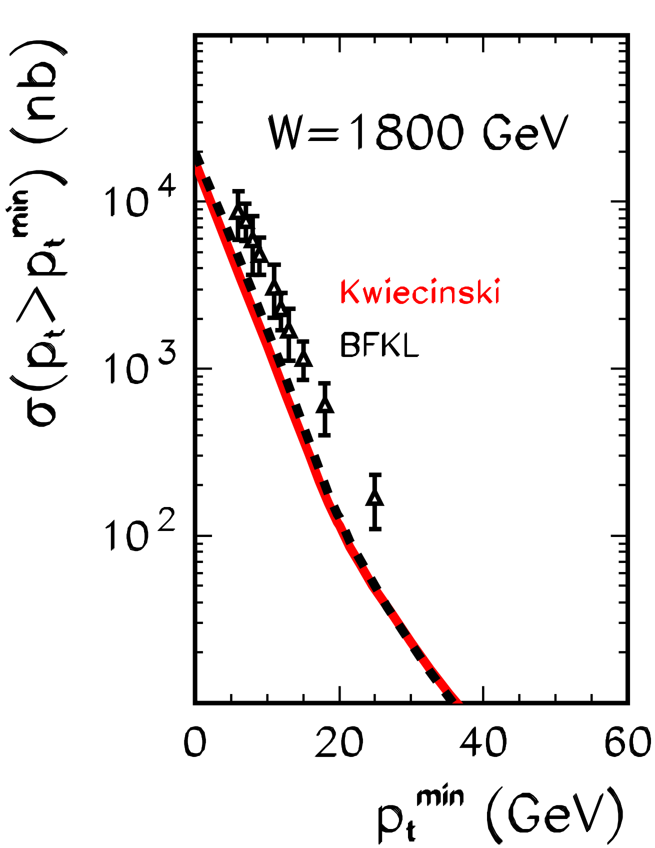
W = 1960 GeV

Bottom production

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



W = 200 GeV



W = 1800 GeV

From quarks to mesons

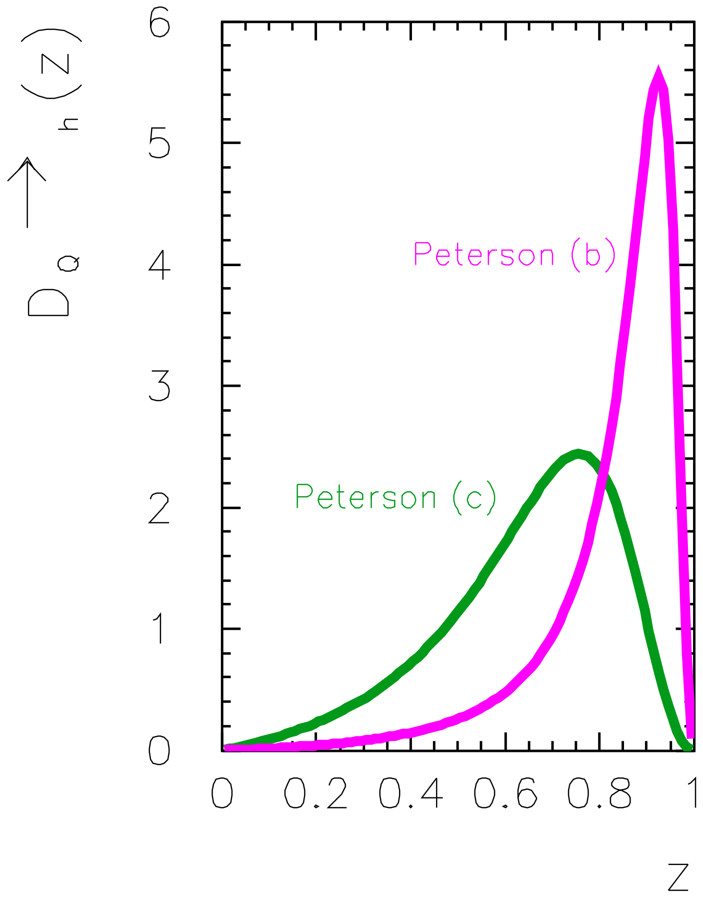
- The inclusive distributions of hadrons are obtained through a convolution of inclusive distributions of heavy quarks/antiquarks and $Q \to h$ fragmentation functions

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

  - $\mathbf{D_{Q \to h}(z)}$ - Peterson fragmentation function

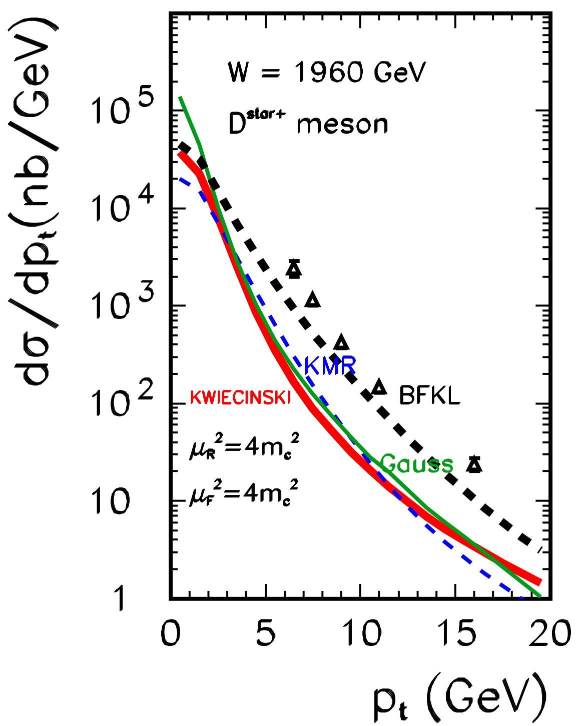
Peterson fragmentation functions

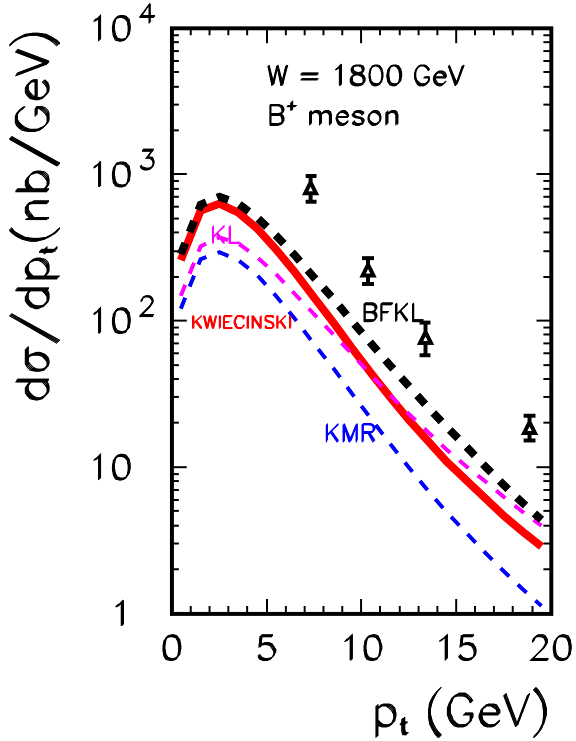
- parameters from Particle Data Group
  - ϵ_c = 0.078
  - ϵ_b = 0.006



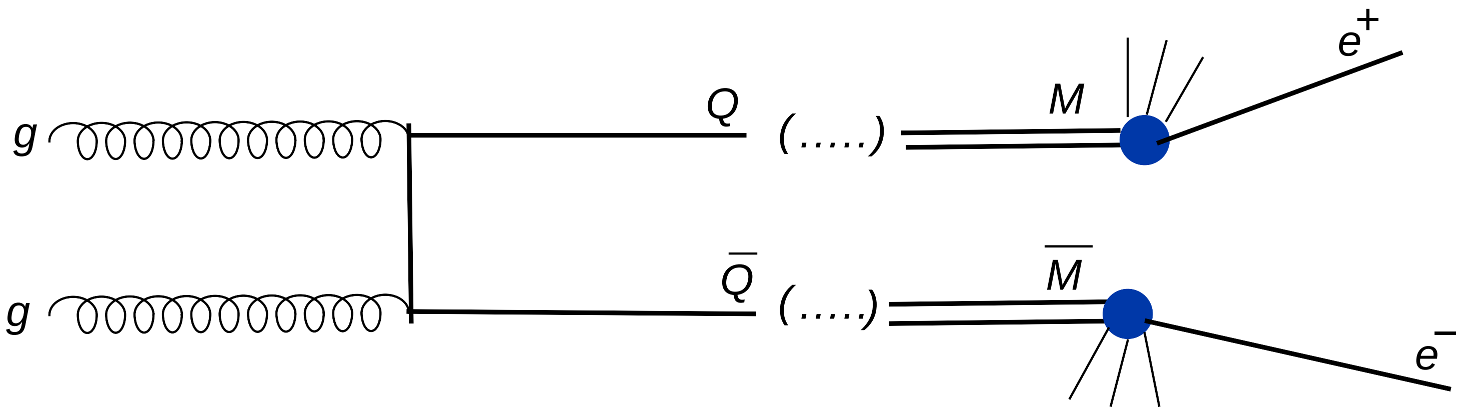
Meson production- results

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

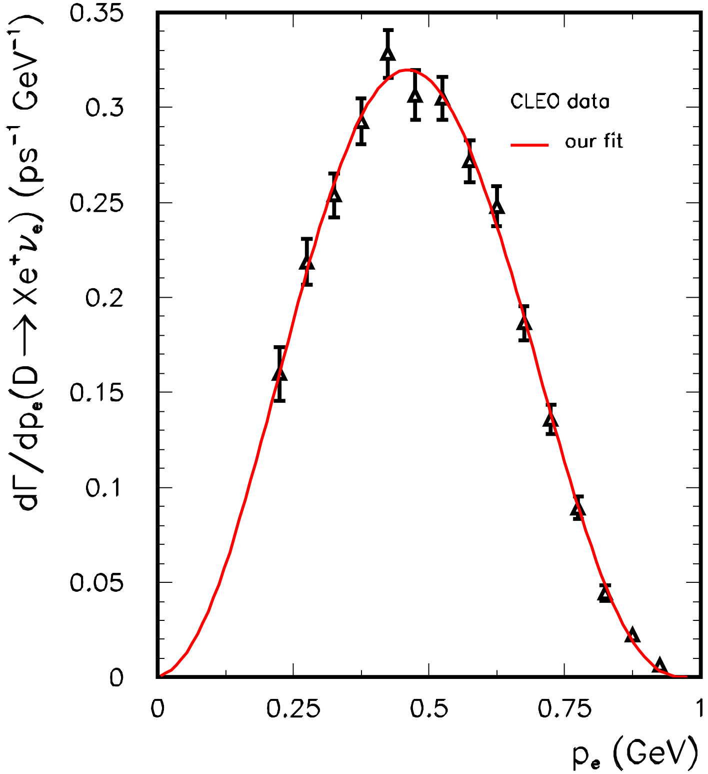
Inclusive semileptonic decays

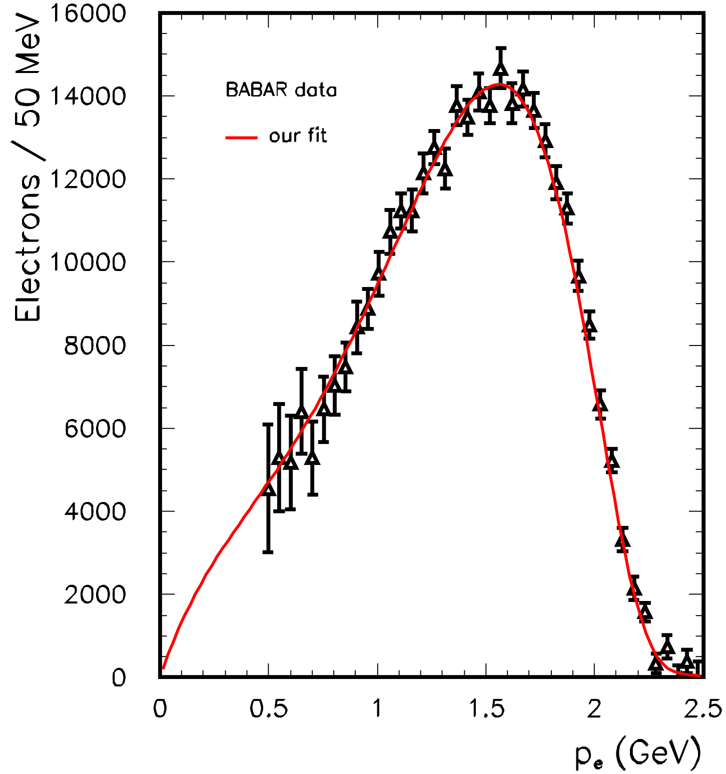
- CLEO
  - $e^+e^- \to \psi(3770) \to D\bar{D} \to e^+(e^-)X$
  - $D\bar{D}$ (almost at rest)

- BABAR
  - $e^+e^- \to \Upsilon(4S) \to B\bar{B} \to e^+(e^-)X$
  - $B\bar{B}$ (almost at rest)

Our fits

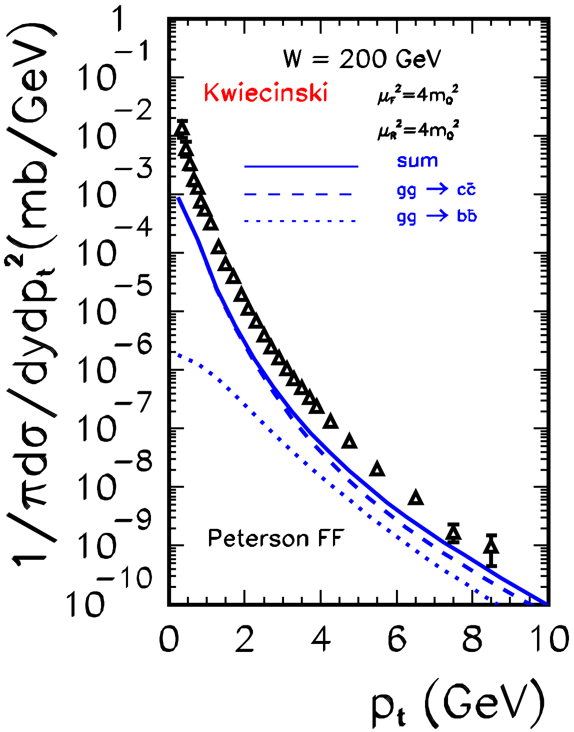
- CLEO, D^+ decays (panel a)
- BABAR, B^+ decays (panel b)

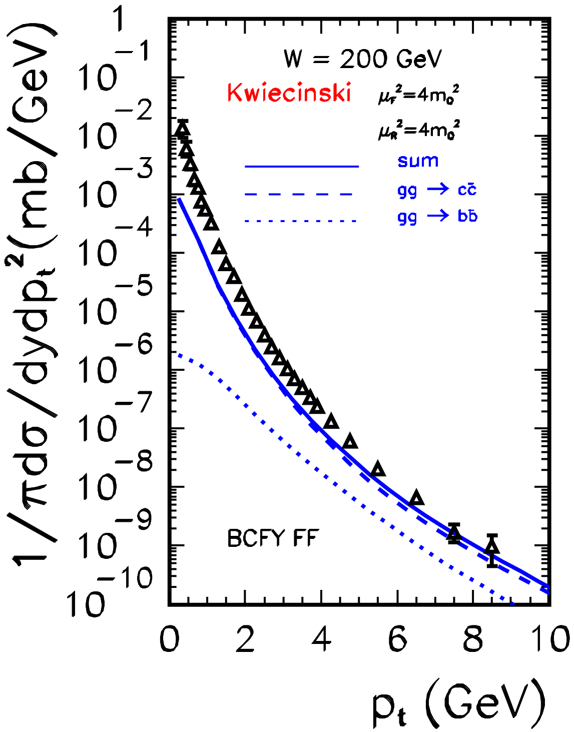




Distributions of electrons, gg components

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

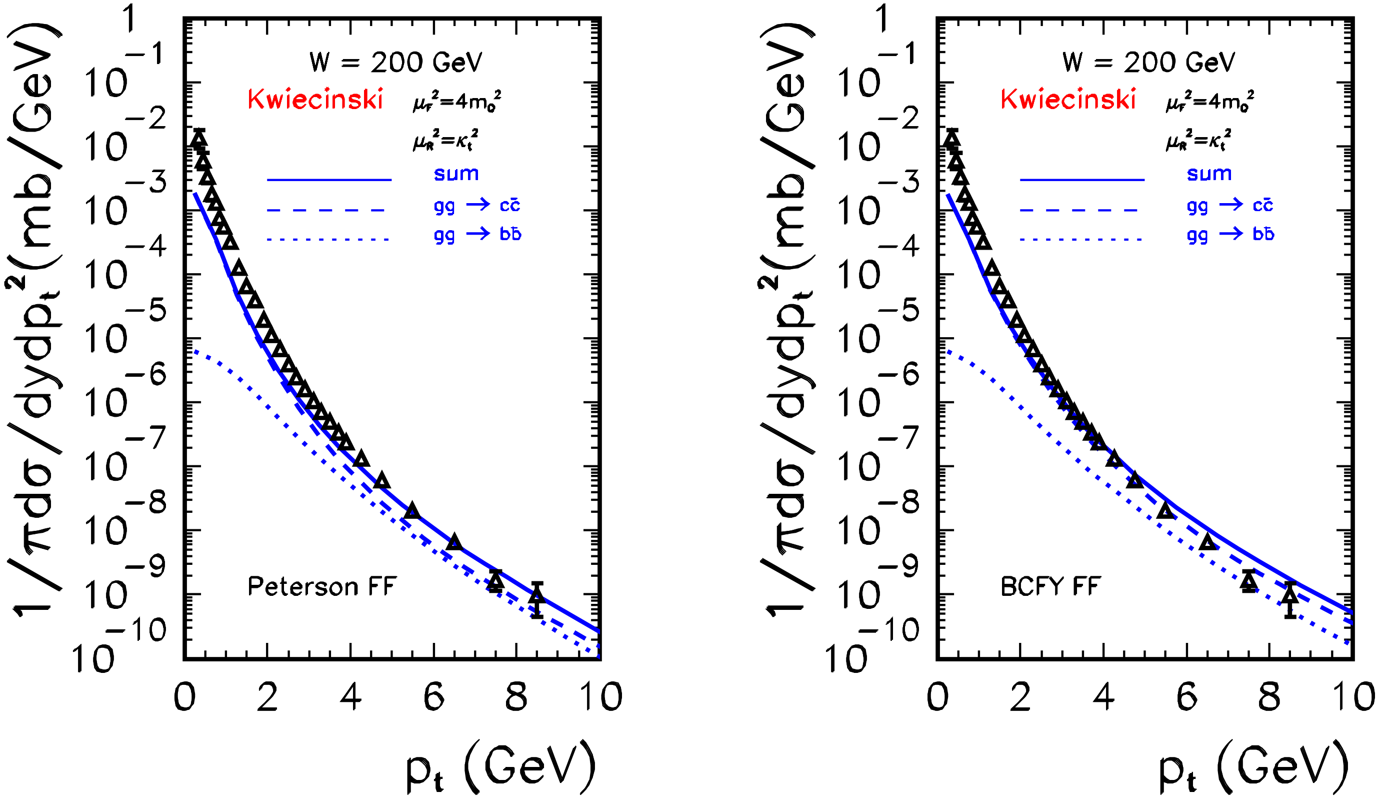




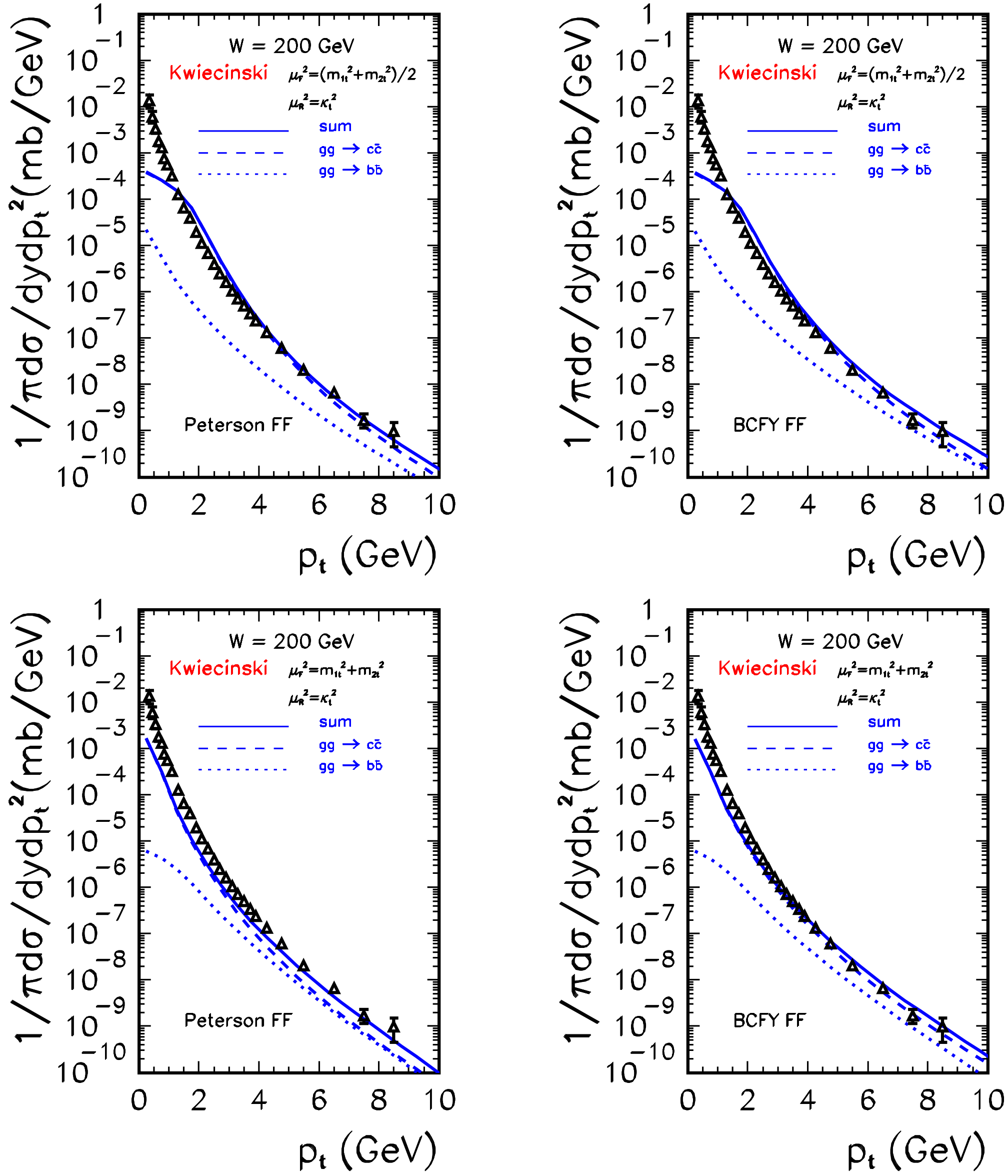
- Choice of the renormalization scale
- Standard collinear choice:
  - $\alpha_s = \alpha_s(m_c^2 + p_t^2)$
- k_t - factorization choice (PDF →UGDF or UPDF):
  - $\alpha_s = \alpha_s(4m_c^2)$
  - $\alpha_s = \alpha_s(\kappa_{1t}^2) \quad or \quad \alpha_s(\kappa_{2t}^2)$

Distributions of electrons, gg components

$\alpha_s = \alpha_s(\kappa_t^2)$

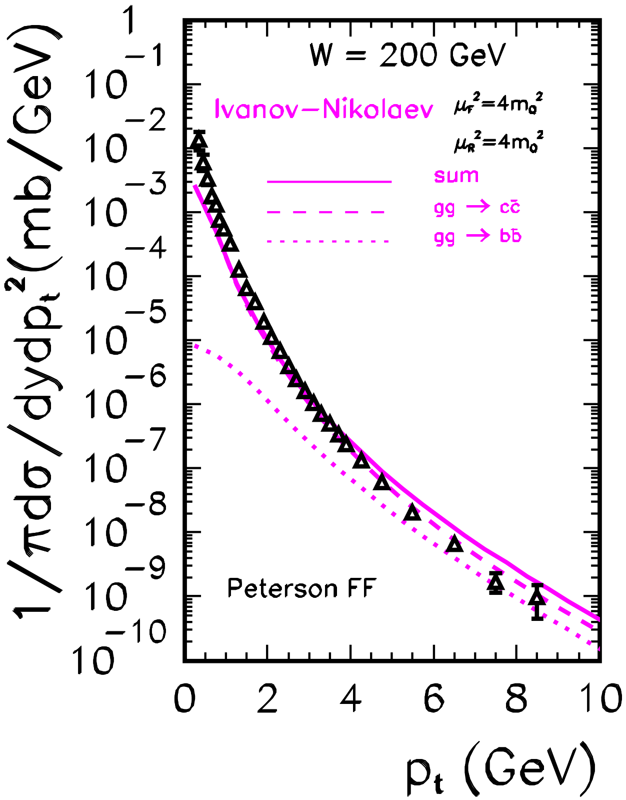


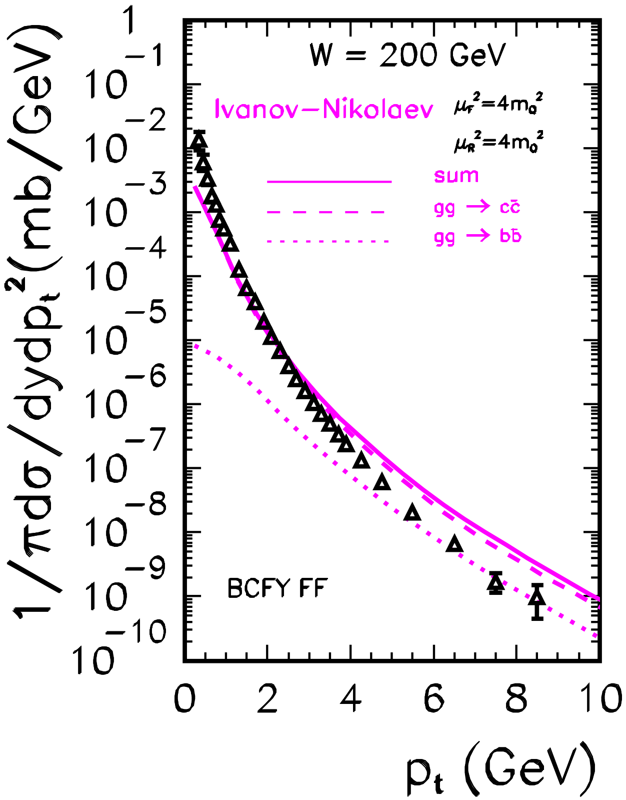
Distributions of electrons for different scales



Distributions of electrons

- Ivanov- Nikolaev distributions

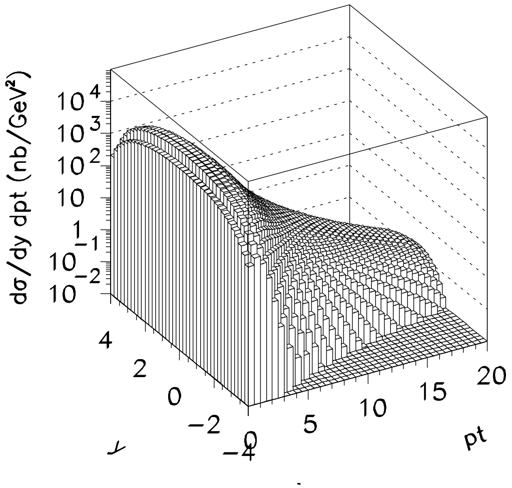




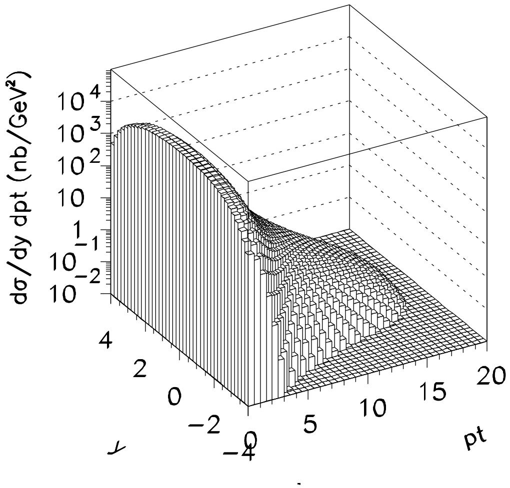
Distributions of electrons in p_t and y

- W = 200 GeV, $\alpha_s = \alpha_s(\kappa_t^2)$

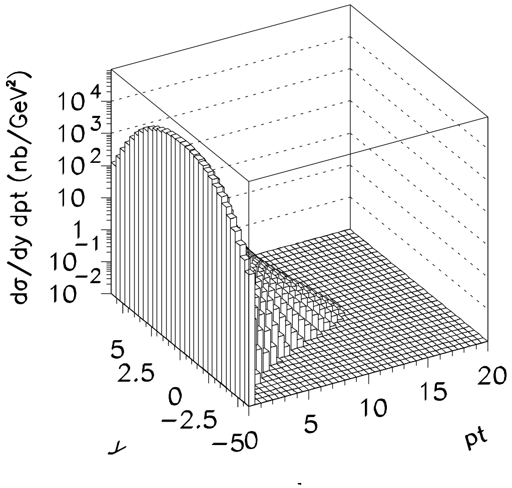
$gg \to c\bar{c}$



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

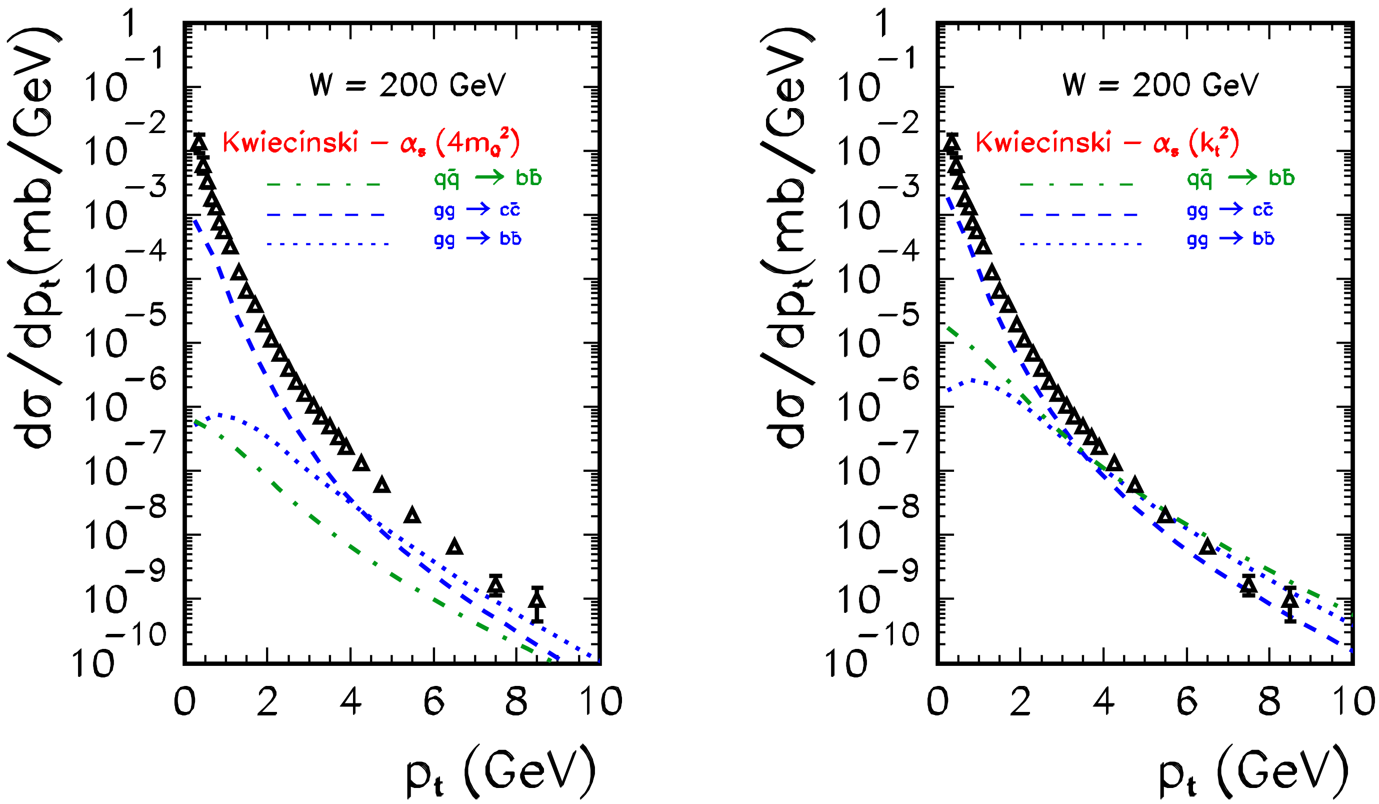


$gg \to c\bar{c} \to D\bar{D} \to e^+e^-$



- $y_l \to (-6, 6)$
- experimental data: PHENIX collaboration: $y_l \to (-0.35, 0.35)$

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



SUMMARY

- 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
  - $gg \to c\bar{c} \to D\bar{D} \to e^+e^-$
  - $gg \to b\bar{b} \to B\bar{B} \to e^+e^-$
  - $q\bar{q} \to b\bar{b} \to B\bar{B} \to e^+e^-$
  - were calculated and compared with new PHENIX data

SUMMARY

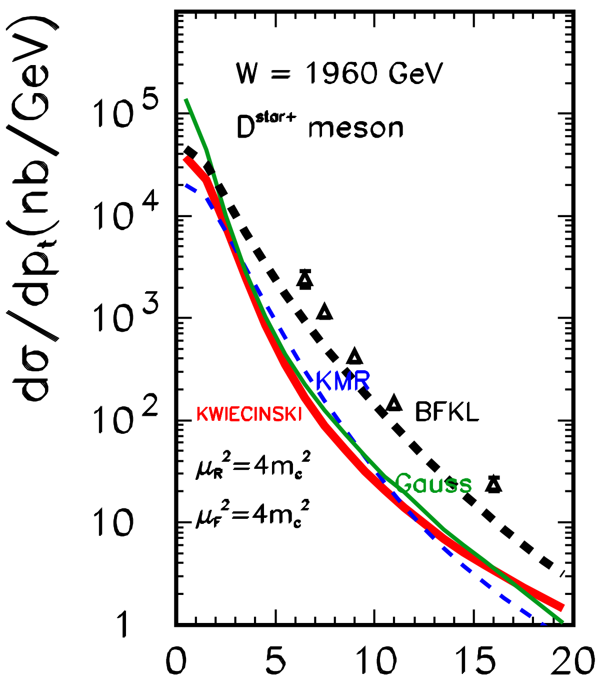
- Missing strength for heavy mesons
  - choice of renormalization scale?
  - heavy quark masses?
  - NLO?
  - other mechanisms?

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

Standard coll. choice:

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

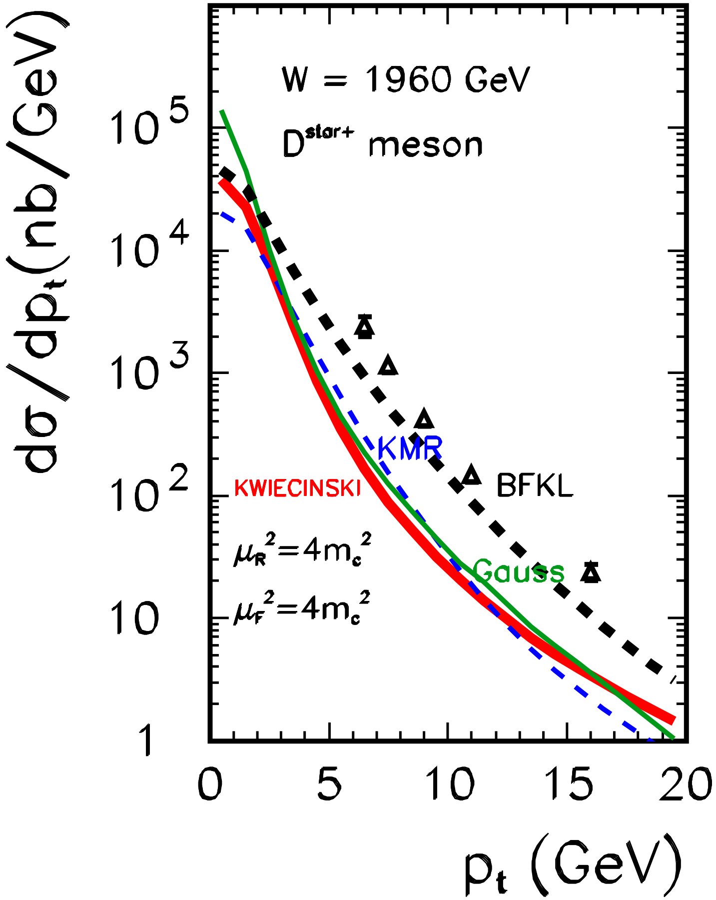
Our choice:

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

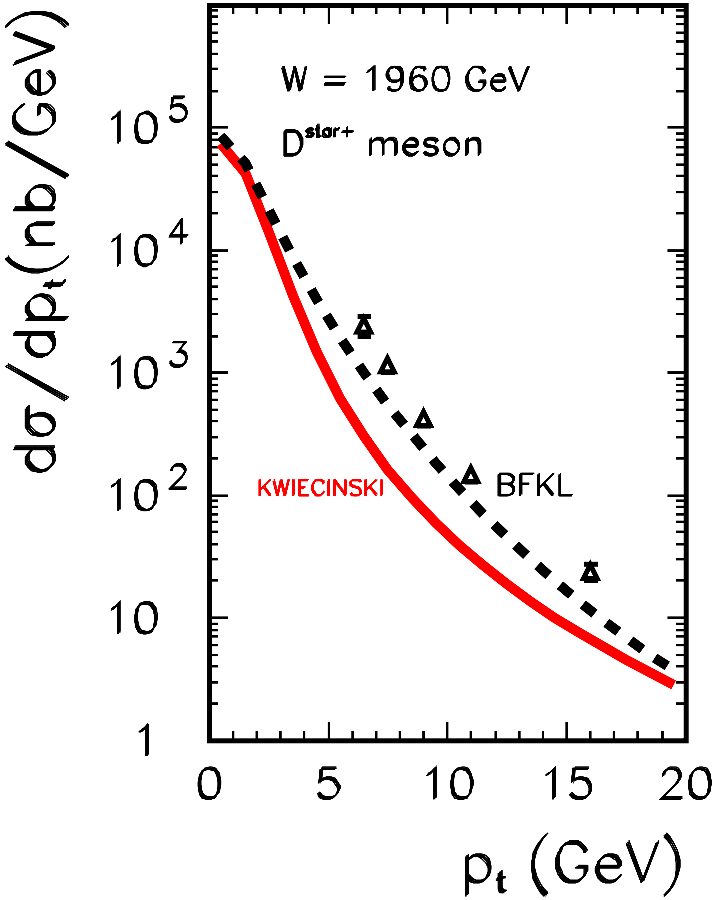
k_t-factorization Russian choice:

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

Choice of the renormalization scale

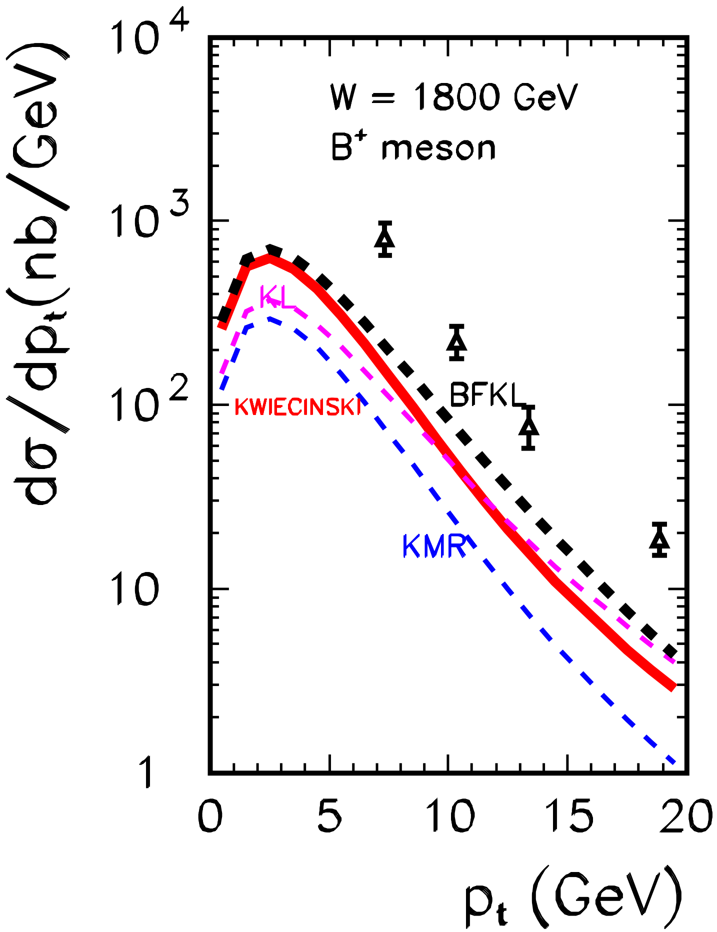


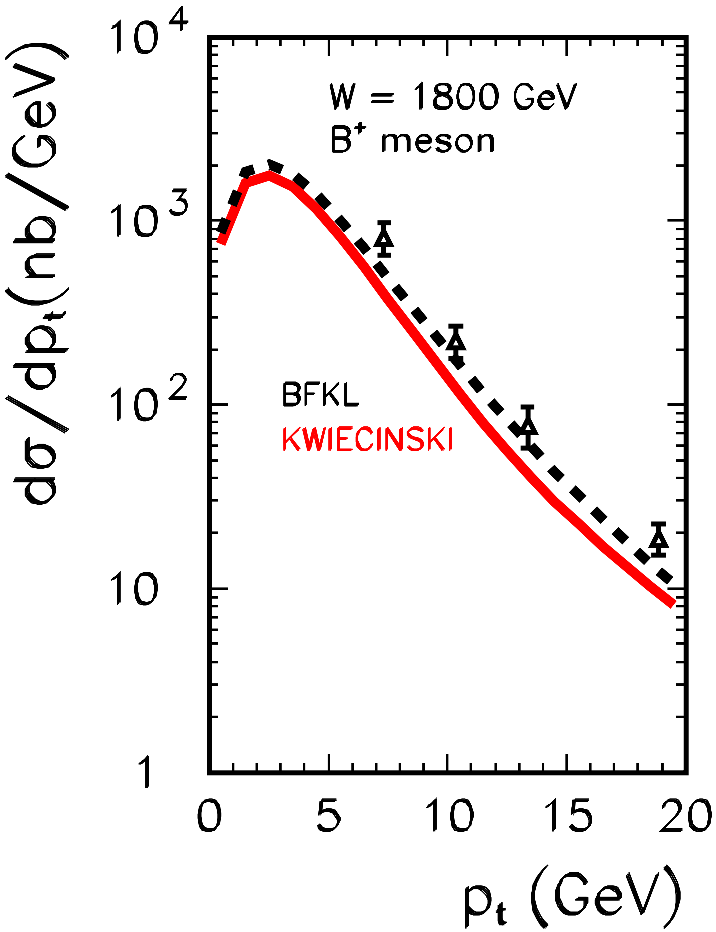
our choice



Russian choice

Bottom meson production





our scale

Russian scale