Heavy quark pair production in proton-proton collisions including subdominant terms.

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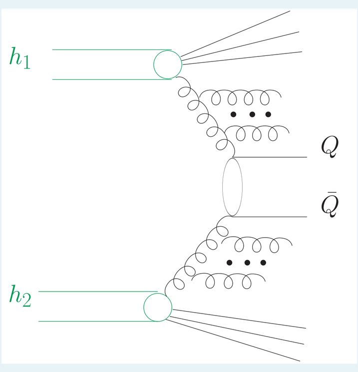
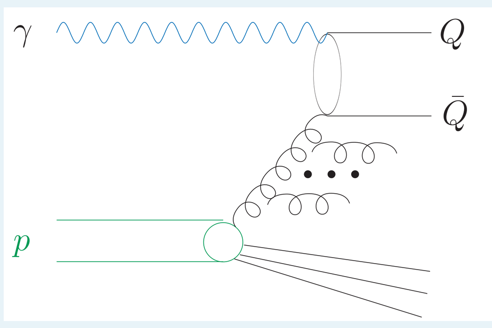
Abstract

Up to now, we have calculated the inclusive cross sections for heavy quarks production at hadron colliders. These calculations were performed using approach based on the unintegrated parton distributions functions. We have tested some of the models in photoproduction and in hadroproduction. For the ccbar and bbar production at high-energies the gluon-gluon fusion is assumed to be the dominant mechanism. This process was calculated in the NLO collinear as well as in the kt-factorisation approaches. Now, we study production of the charm and bottom quarks for following subprocesses: $gg \to Q\bar{Q}$, $\gamma g \to Q\bar{Q}$, $g\gamma \to Q\bar{Q}$, $\gamma\gamma \to Q\bar{Q}$. We used MRST-QED (Martin, Roberts, Stirling, Thorne) parton distributions. We would like to show detail analyzed that other processes ignored so far should be carefully evaluated.

Introduction

- Production of heavy quarks.
  - $h_1 + h_2 \to Q + \bar{Q} + X$ $\gamma + p \to Q + \bar{Q} + X$

- The inclusive heavy quark/antiquark production can be calculated in the framework of the k_t-factorization. In this approach transverse momenta of initial partons are included and emission of gluons is encoded in so-called unintegrated gluon distributions (UGDFs) [1].
  In the leading-order (LO) approximation within the k_t-factorization approach the quadruply differential cross section in the rapidity of Q (y_1), in the rapidity of $\bar{Q}$ (y_2) and the transverse momentum of Q (p_1, t) and Q (p_2, t) can be written as

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_{i,j} \int \frac{d^2\kappa_{1,t}}{\pi}\frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2(x_1x_2s)^2}\overline{|\mathcal{M}_{ij}|^2}$$

$$\delta^2\left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}\right)\ \mathcal{F}_i(x_1, \kappa_{1,t}^2)\ \mathcal{F}_j(x_2, \kappa_{2,t}^2)\ ,$$

where $\mathcal{F}_i(x_1, \kappa_{1,t}^2)$ and $\mathcal{F}_j(x_2, \kappa_{2,t}^2)$ are the so-called unintegrated gluon (parton) distributions. The unintegrated parton distributions must be evaluated at:
$x_1 = \frac{m_{1,t}}{\sqrt{s}}\exp(y_1) + \frac{m_{2,t}}{\sqrt{s}}\exp(y_2)$,
$x_2 = \frac{m_{1,t}}{\sqrt{s}}\exp(-y_1) + \frac{m_{2,t}}{\sqrt{s}}\exp(-y_2)$, where
$m_{i,t} = \sqrt{p_{i,t}^2 + m_Q^2}$.

The Parton Distributions

- Kwiecinski 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

$$f_k(x, \kappa_t^2, \mu^2) = \int_0^\infty db\ bJ_0(\kappa_t b)\tilde{f}_k(x, b, \mu^2)$$
$$\tilde{f}_k(x, b, \mu^2) = \int_0^\infty d\kappa_t\ \kappa_t J_0(\kappa_t b) f_k(x, \kappa_t^2, \mu^2)$$

- MRSTQ parton distributions.
  - The factorization of the QED-induced collinear divergences leads to QED-corrected evolution equations for the parton distributions of the proton [3].

$$\frac{\partial q_i(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{qq}(y)\ q_i(\frac{x}{y},\mu^2) + P_{qg}(y)\ g(\frac{x}{y},\mu^2)\Big\}$$
$$+ \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{\tilde{P}_{qq}(y)\ e_i^2 q_i(\frac{x}{y},\mu^2) + P_{q\gamma}(y)\ e_i^2\gamma(\frac{x}{y},\mu^2)\Big\}$$
$$\frac{\partial g(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha_S}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{gq}(y)\ \sum_j q_j(\frac{x}{y},\mu^2) + P_{gg}(y)\ g(\frac{x}{y},\mu^2)\Big\}$$
$$\frac{\partial \gamma(x,\mu^2)}{\partial \log \mu^2} = \frac{\alpha}{2\pi}\int_x^1 \frac{dy}{y}\Big\{P_{\gamma q}(y)\ \sum_j e_j^2\ q_j(\frac{x}{y},\mu^2) + P_{\gamma\gamma}(y)\ \gamma(\frac{x}{y},\mu^2)\Big\}\ ,$$

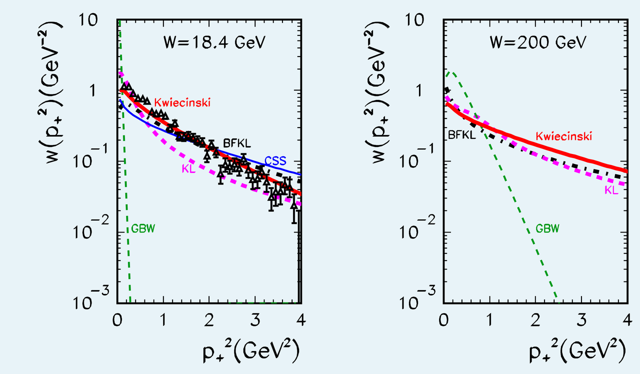
where

$$\tilde{P}_{qq} = C_F^{-1}P_{qq},\quad P_{\gamma q} = C_F^{-1}P_{gq},$$
$$P_{q\gamma} = T_R^{-1}P_{qg},\quad P_{\gamma\gamma} = -\frac{2}{3}\sum_i e_i^2\ \delta(1-y)$$

and momentum is conserved:
$\int_0^1 dx\ x\left\{\sum_i q_i(x,\mu^2) + g(x,\mu^2) + \gamma(x,\mu^2)\right\} = 1$.

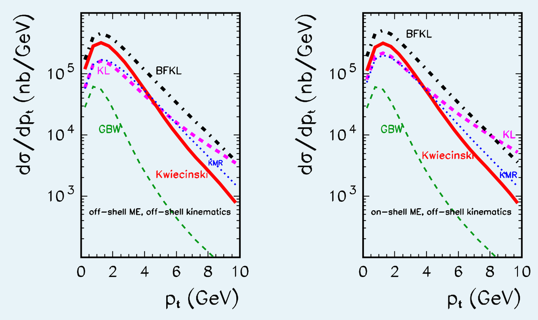
Results of k_t-factorization

- $\gamma p \to c\bar{c}$

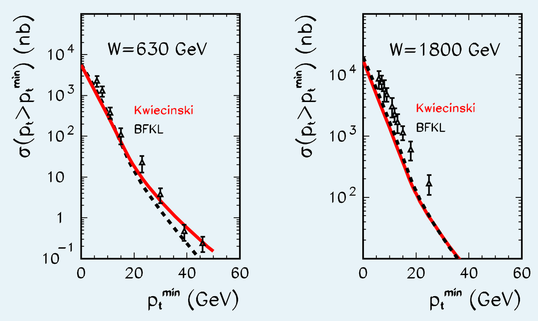


Results of k_t-factorization

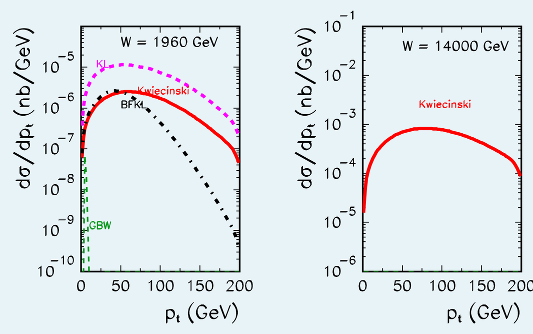
- $gg \to c\bar{c}$



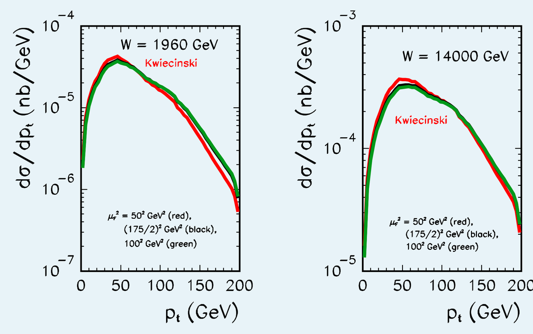
- $gg \to b\bar{b}$



- $gg \to t\bar{t}$

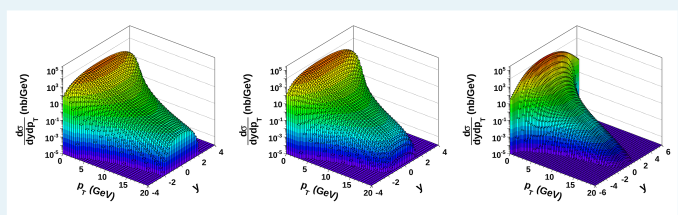


- $(q\bar{q} \to t\bar{t})$

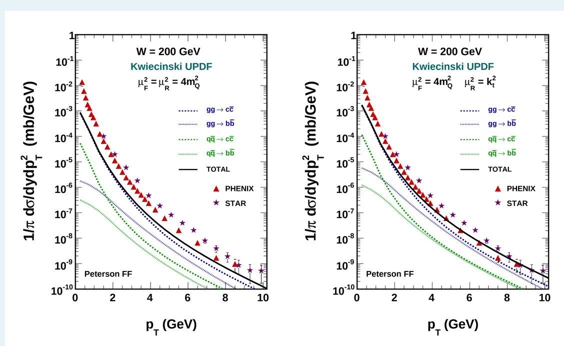


Results of k_t-factorization

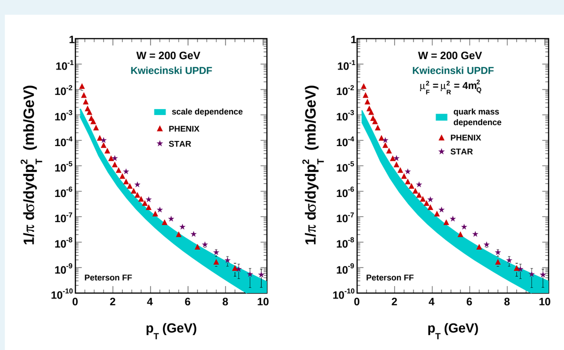
- Distributions of nonphotonic electrons
  - Two-dimensional distributions in rapidity and transverse momentum for charm quark/antiquark, D mesons and electrons/positrons.



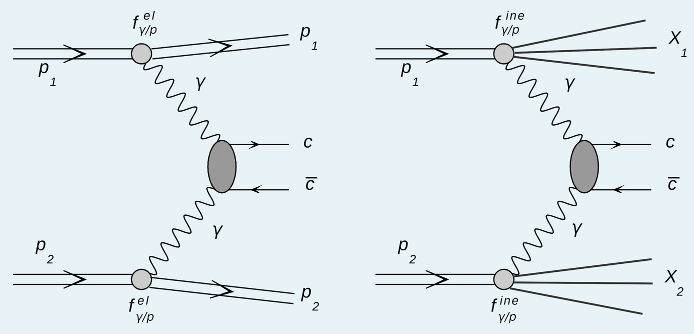
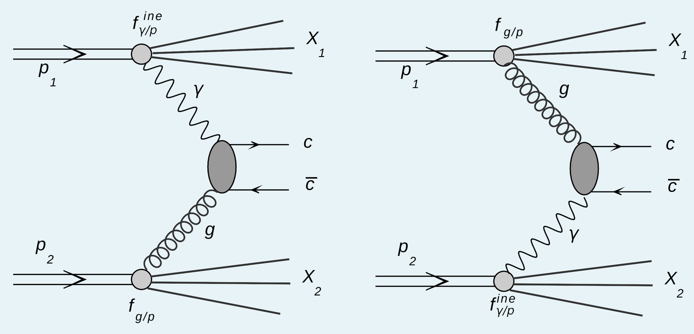
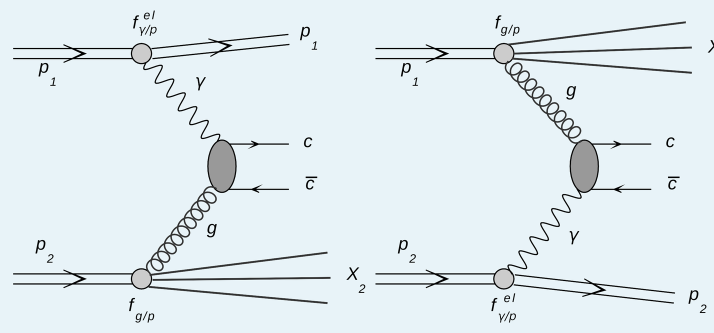
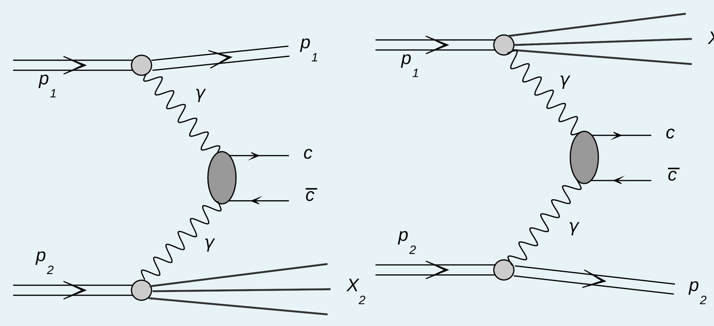
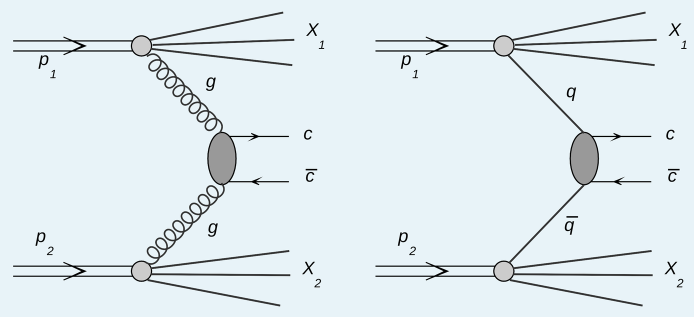
- p_t distributions of leptons with the Kwieciński UPDFs. Different combinations of factorization and renormalization scales are used [2] .



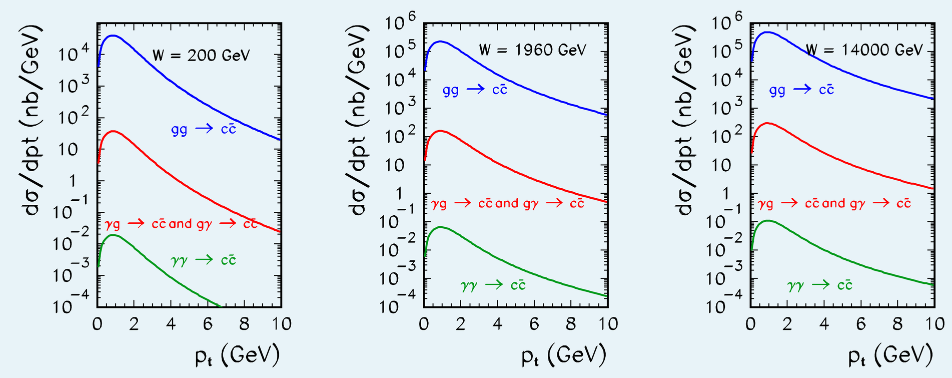
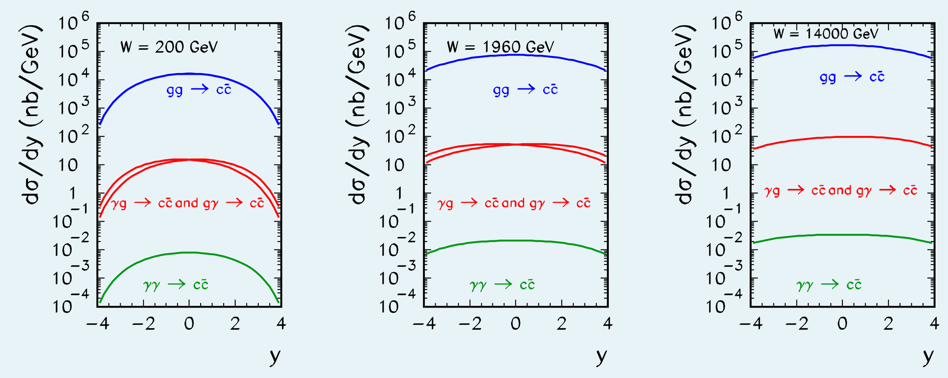
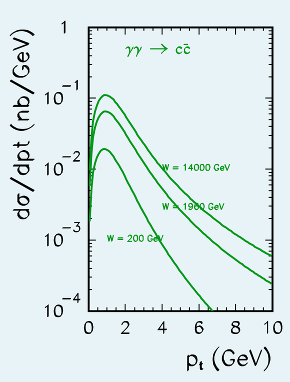
- Factorization and renormalization uncertainty band (left) and quark mass uncertainty band (right) of our k_t-factorization calculation.



MRSTQ parton distributions

Results of MRSTQ parton distributions

[1] M. Łuszczak and A. Szczurek, Phys. Rev. **D73** (2006) 054028

[2] M. Łuszczak, R. Maciuła, A. Szczurek, Phys. Rev. **D79** (2009) 034009

[3] A.D. Martin, R.G. Roberts, W.J. Stirling and R.S. Thorne, hep-ph/0411040v1