Drell-Yan lepton pair production at the Tevatron and LHC in the k_T-factorization approach

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JHEP 1112 (2011) 117

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Motivation

Drell-Yan pair production is highly sensitive to parton distributions in the hadron. So it provides a test of hard subprocess dynamics. Also the process contributes largely into the background of the 'new physics'. From this point of view the investigation of Drell-Yan pair production is a subject of a special interest.

In the present work we have studied the Drell-Yan lepton pair production in the k_T-factorization approach, which was successfully used before to describe other various high energy processes.

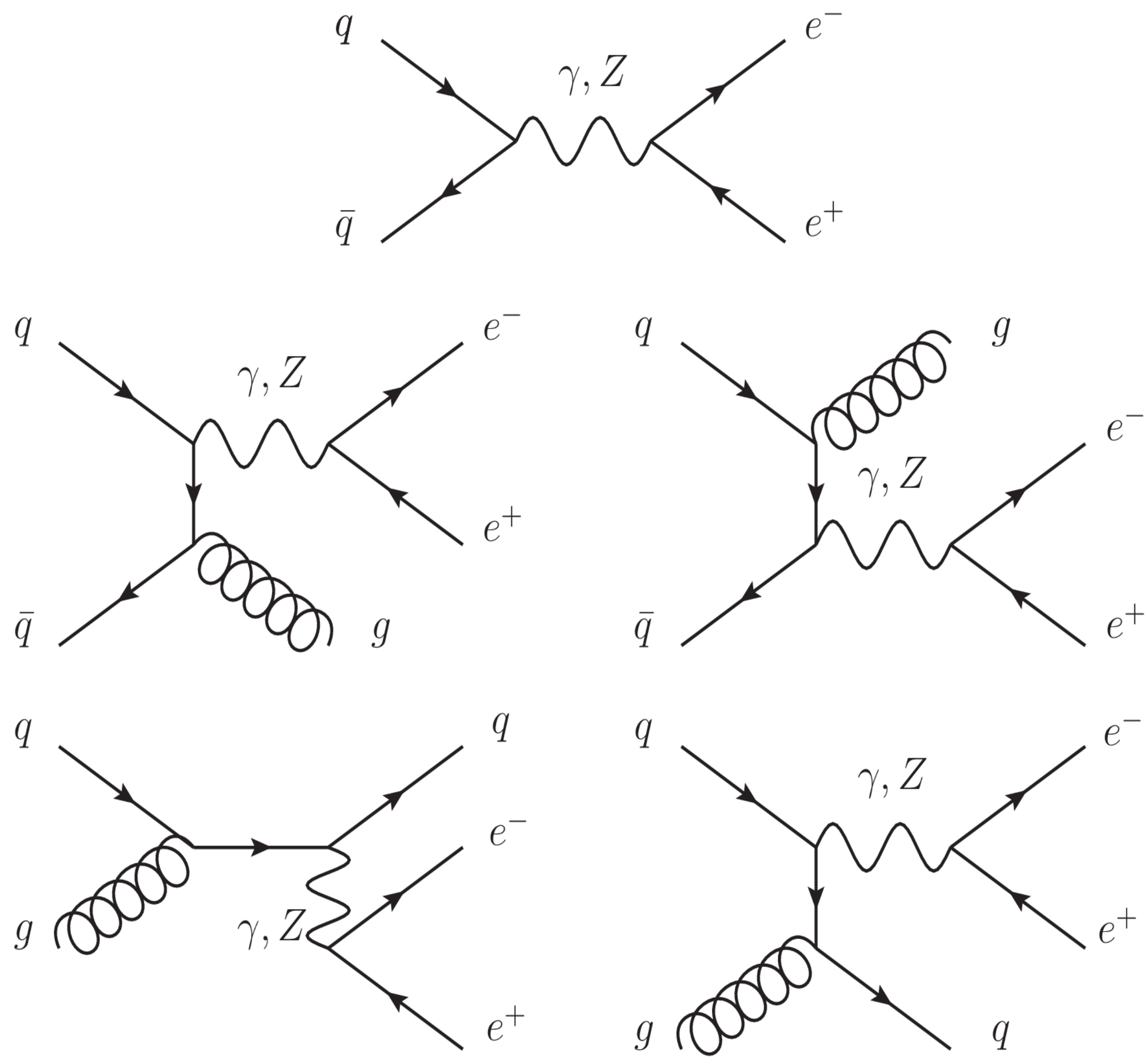
Recently new experimental data on Drell-Yan lepton pair production have been obtained at LHC by CMS collaboration. Here we present the theoretical description of the LHC results for Drell-Yan lepton pair production. Also we present the description of various published Tevatron data.

k_T-factorization approach

1. Matrix elements which depend on the transverse momenta of incoming gluons.
2. Unintegrated parton distributions

Considered subprocesses

1. $q\bar{q} \rightarrow e^+e^-$
2. $qg^* \rightarrow e^+e^-q$
3. $q\bar{q} \rightarrow e^+e^-g$ — already taken into account by quark-antiquark annihilation due to the initial gluon irradiation



Cross section

$$\sigma = \sum_q \int \frac{1}{16\pi(x_1 x_2 s)^2} |\bar{\mathcal{M}}_1^{\gamma,\,Z}|^2 \times$$

$$\times f_q(x_1, \mathbf{k}_{1T}^2, \mu^2) f_q(x_2, \mathbf{k}_{2T}^2, \mu^2) d\mathbf{p}_{1T}^2 d\mathbf{k}_{1T}^2 d\mathbf{k}_{2T}^2 dy_1 dy_2 \frac{d\phi_1}{2\pi}\frac{d\phi_2}{2\pi},$$

$$\sigma = \sum_q \int \frac{1}{256\pi^3(x_1 x_2 s)^2} |\bar{\mathcal{M}}_2^{\gamma,\,Z}|^2 \times$$

$$\times f_q(x_1, \mathbf{k}_{1T}^2, \mu^2) f_g(x_2, \mathbf{k}_{2T}^2, \mu^2) d\mathbf{p}_{1T}^2 d\mathbf{p}_{2T}^2 d\mathbf{k}_{1T}^2 d\mathbf{k}_{2T}^2 dy_1 dy_2 dy_3 \frac{d\phi_1}{2\pi}\frac{d\phi_2}{2\pi}\frac{d\psi_1}{2\pi}\frac{d\psi_2}{2\pi},$$

where φ_1, φ_2, ψ_1 and ψ_2 are the azimuthal angles of the incoming partons and produced leptons respectively. The matrix elements are convoluted with the unintegrated (i.e. depending on the transverse momenta) parton densities, which were taken in the KMR form.

Unintegrated parton distributions

KMR approach(Kimber, Martin, Ryskin) [M.A. Kimber, A.D. Martin, M.G. Ryskin, Phys. Rev. D **63**, 114027 (2001); G. Watt, A.D. Martin, M.G. Ryskin, Eur. Phys. J. C 31, 73 (2003)]. Weakening of the strong ordering:

$$k_{1,T} \ll ... \ll k_{n-1,T} \ll k_T \sim \mu$$

Unintegrated parton distributions

In the KMR approach the distribution functions start to depend on the transverse momenta of the partons, and $f_a(x,\mathbf{k}_T^2)=const$, if $\mathbf{k}_T^2<\mu_0^2\sim 1\ \mathrm{GeV}^2$, otherwise they take the form:

$$f_q(x,\mathbf{k}_T^2,\mu^2) = T_q(\mathbf{k}_T^2,\mu^2)\frac{\alpha_s(\mathbf{k}_T^2)}{2\pi}\times$$

$$\times\int\limits_x^1 dz\left[P_{qq}(z)\frac{x}{z}q\left(\frac{x}{z},\mathbf{k}_T^2\right)\Theta\left(\Delta-z\right)+P_{qg}(z)\frac{x}{z}g\left(\frac{x}{z},\mathbf{k}_T^2\right)\right],$$

$$f_g(x,\mathbf{k}_T^2,\mu^2) = T_g(\mathbf{k}_T^2,\mu^2)\frac{\alpha_s(\mathbf{k}_T^2)}{2\pi}\times$$

$$\times\int\limits_x^1 dz\left[\sum_q P_{gq}(z)\frac{x}{z}q\left(\frac{x}{z},\mathbf{k}_T^2\right)+P_{gg}(z)\frac{x}{z}g\left(\frac{x}{z},\mathbf{k}_T^2\right)\Theta\left(\Delta-z\right)\right]$$

Parameters

- Theoretical uncertainties are connected with the choice of the factorization and renormalization scales. We took $\mu_R = \mu_F = \mu = \xi M_{e+e-}$ for Drell-Yan production.
- We varied the scale parameter ξ between 1/2 and 2 about the default value $\xi = 1$.
- We neglected the quarks masses.
- For completeness, we use LO formula for the strong coupling constant $\alpha_s(\mu^2)$ with $n_f = 4$ active quark flavours at $\Lambda_{QCD} = 200$ MeV.

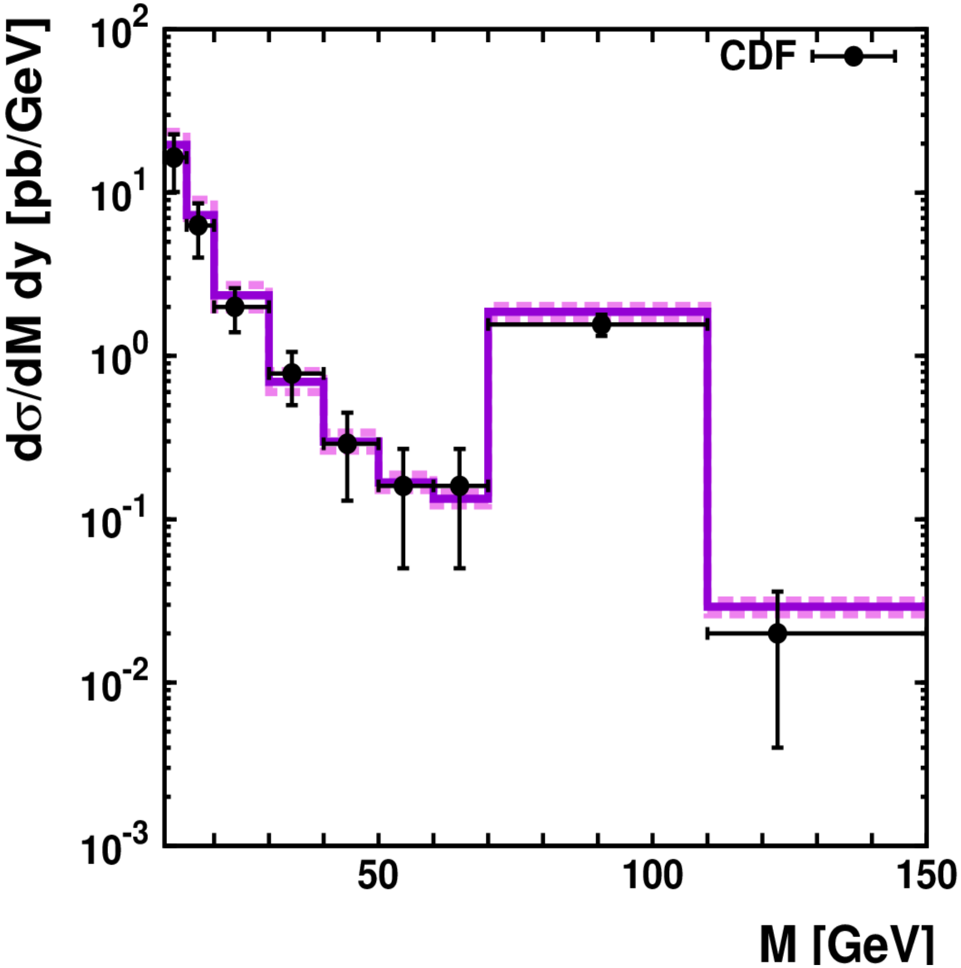
Non-logarythmic loop corrections

To take into account the non-logarithmic loop corrections we use the approach proposed in [G. Watt, A.D. Martin, and M.G. Ryskin, 2004]. It was demonstrated that the main part of the non-logarithmic loop corrections to the quark-antiquark annihilation cross section can be absorbed in the effective *K*-factor:

$$K = \exp\left(C_F \frac{\alpha(\mu^2)}{2\pi} \pi^2 \right)$$

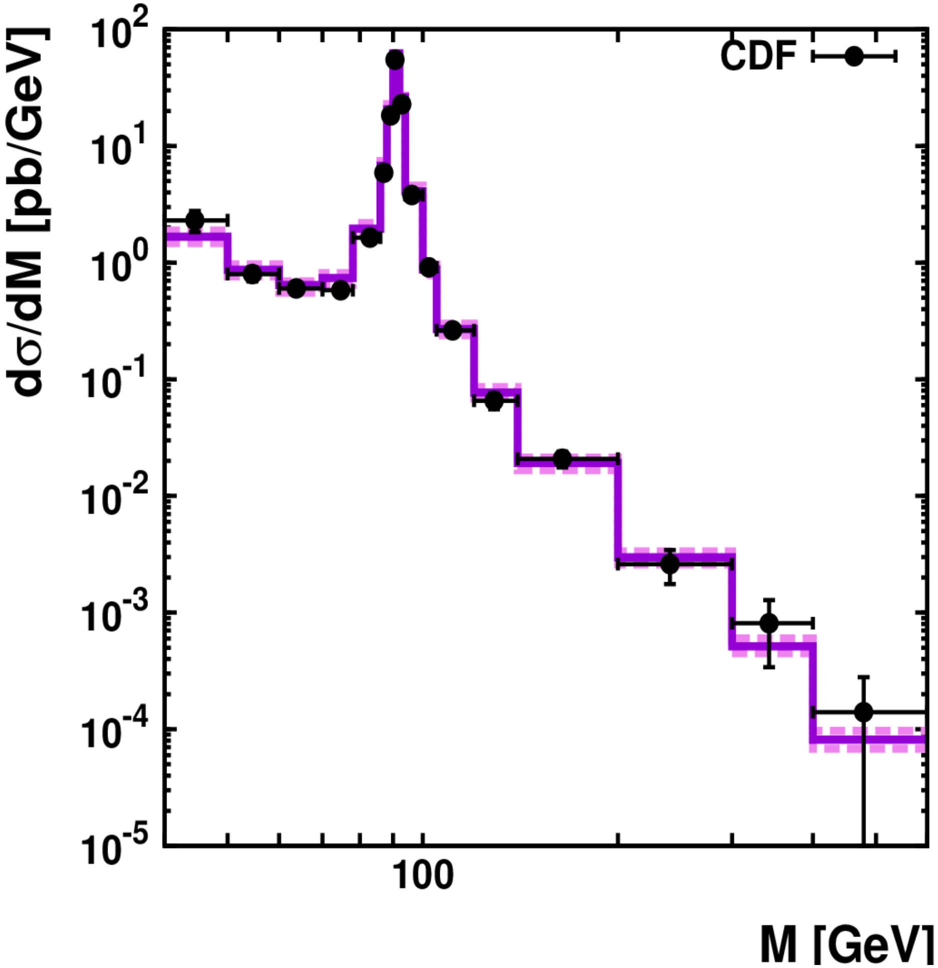
where color factor C_F = 4/3. A particular choice $\mu^2 = \mathbf{p}_T^{4/3} M^{2/3}$ was proposed to eliminate sub-leading logarithmic terms.

Numerical results



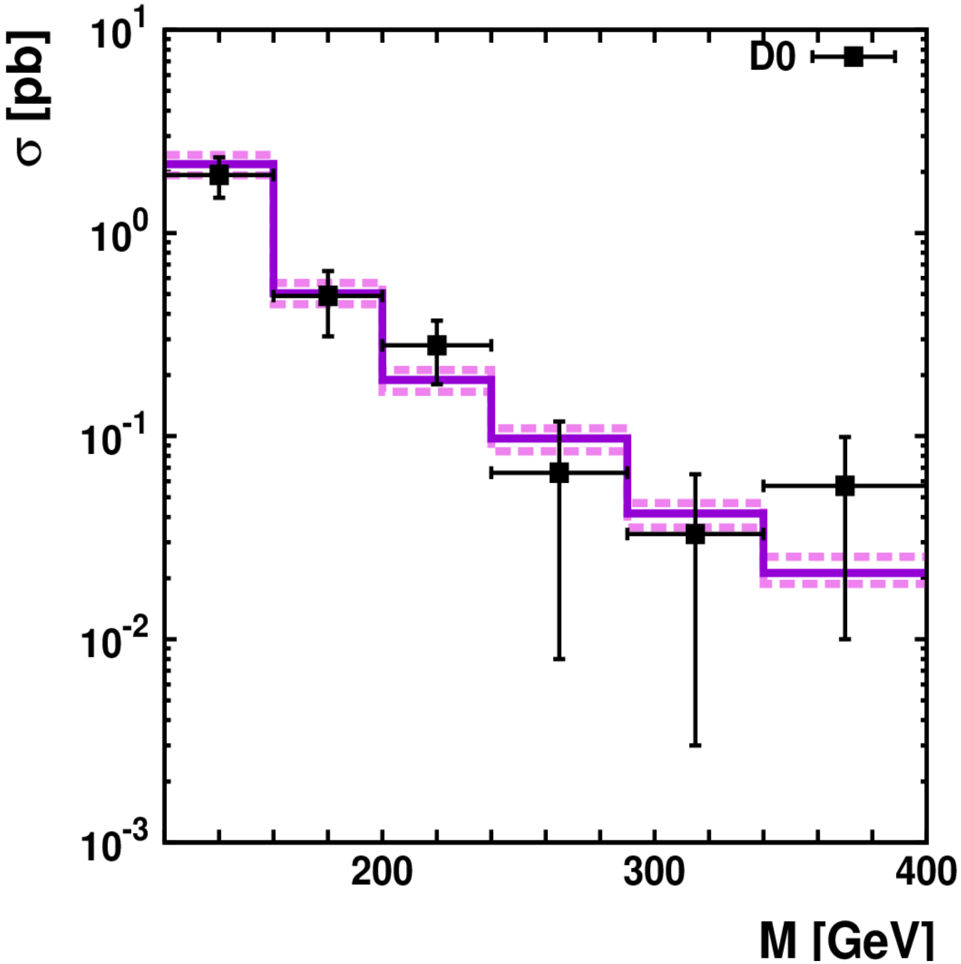
1. Differential cross section of Drell-Yan lepton pair production $p\bar{p}\to e^+e^-X$ at Tevatron energies ($\sqrt{S}$=1.8 TeV) as a function of the dilepton invariant mass *M*. The experimental data are of CDF ($|y|<1{,}45$).

Numerical results



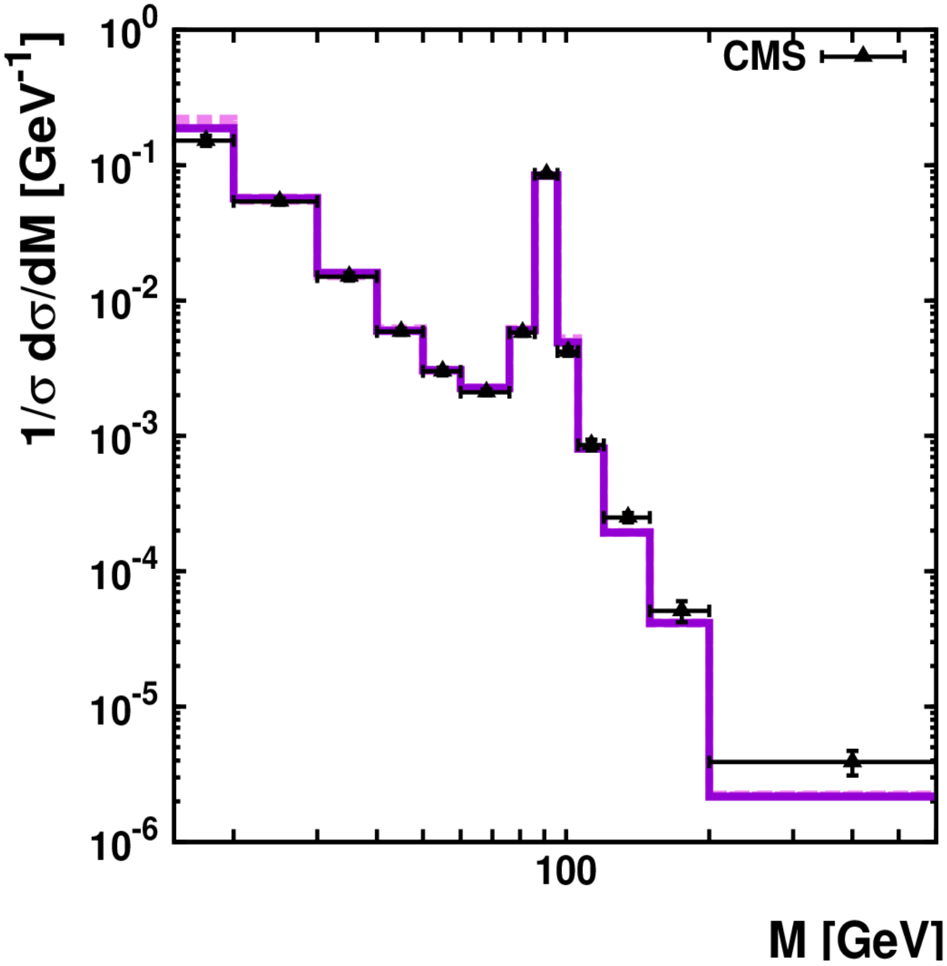
2. Differential cross section of Drell-Yan lepton pair production $p\bar{p} \rightarrow e^+e^-X$ at Tevatron energies ($\sqrt{S}$=1.8 TeV) as a function of the dilepton invariant mass *M*. The experimental data are of CDF (|*y*|<*0,6*).

Numerical results



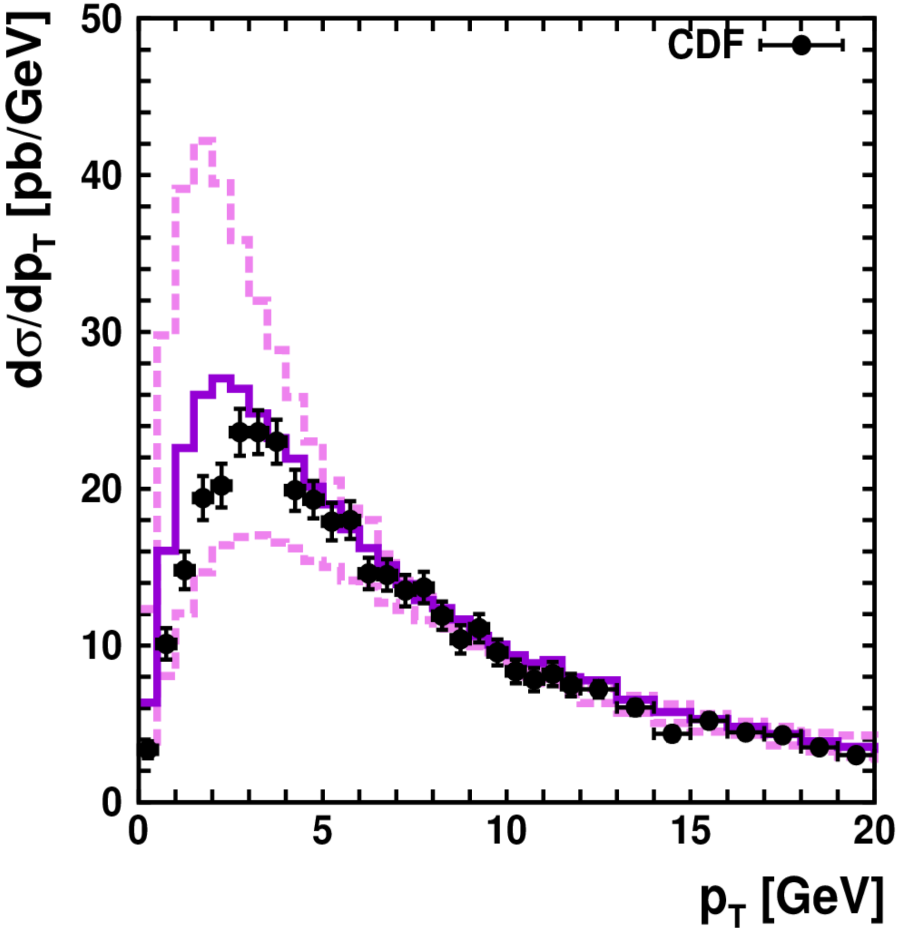
3. Differential cross section of Drell-Yan lepton pair production $p\bar{p} \to e^+e^- X$ at Tevatron energies ($\sqrt{S}$=1.8 TeV) as a function of the dilepton invariant mass *M*. The experimental data are of D0 ($|y|<0,6$).

Numerical results



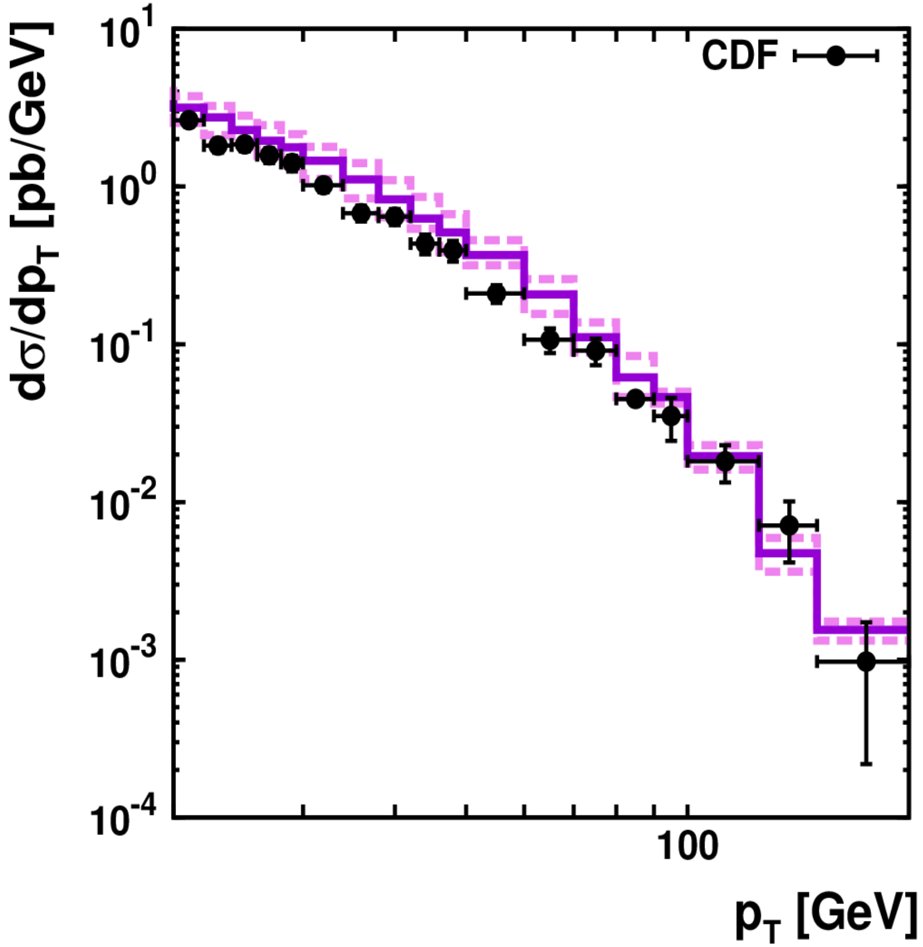
4. Differential cross section of Drell-Yan lepton pair production *pp*→*e+e-X* at LHC energies ($\sqrt{S}$=7 TeV) as a function of the dilepton invariant mass *M*. The experimental data are of CMS (|*y*|<*0,6*).

Numerical results



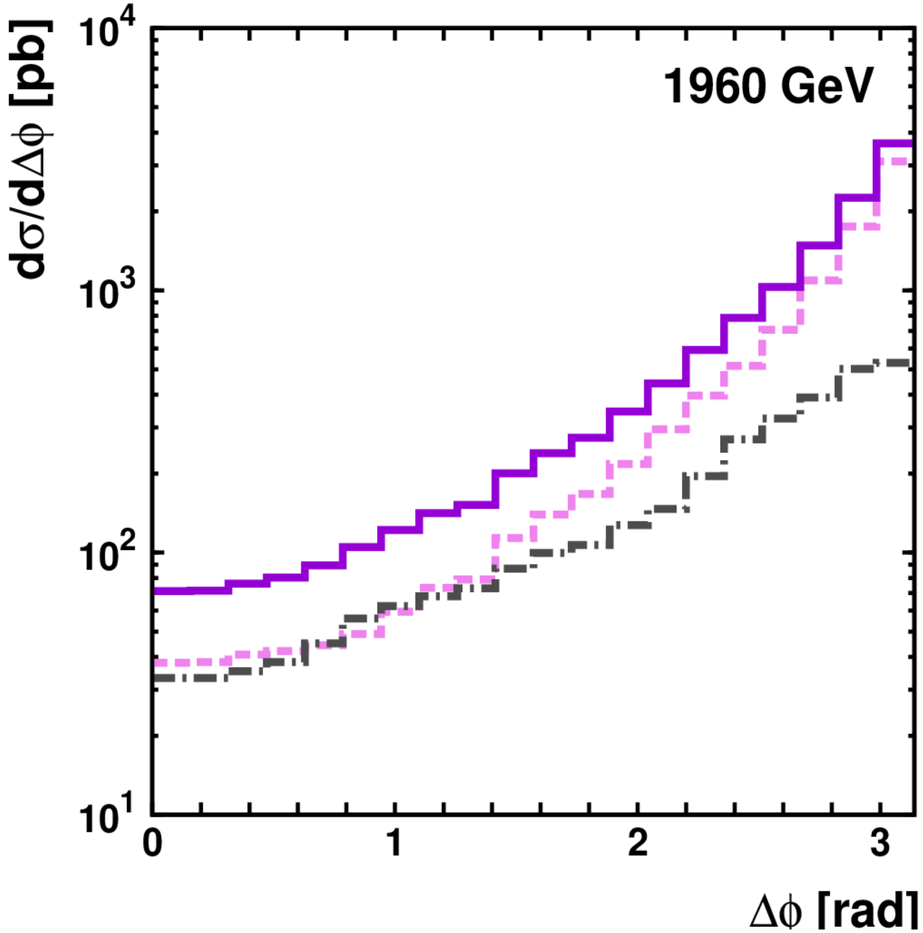
6. Differential cross section of Drell-Yan lepton pair production $p\bar{p} \to e^+e^-X$ at Tevatron energies ($\sqrt{S}$=1.8 TeV) as a function of the dilepton transverse momentum $\mathbf{p}_T$ in the transverse momenta range $0<\mathbf{p}_T<20$ GeV. The experimental data are of CDF.

Numerical results



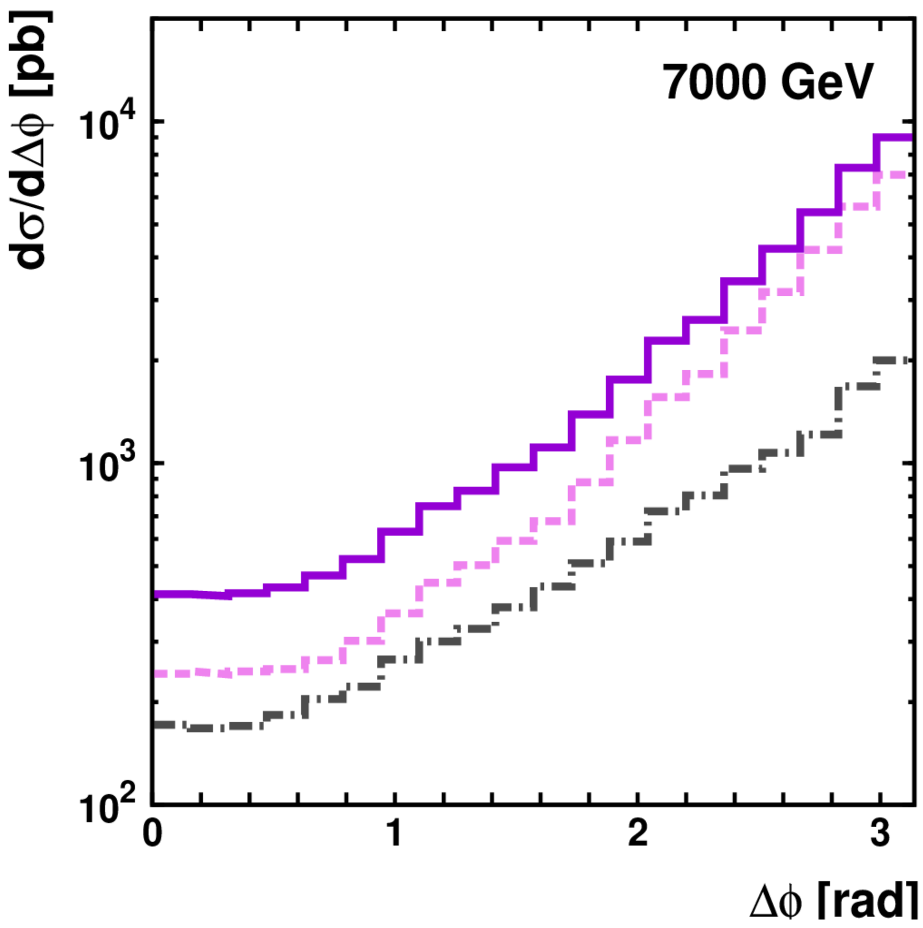
6. Differential cross section of Drell-Yan lepton pair production $p\bar{p} \to e^+e^-X$ at Tevatron energies ($\sqrt{S}$=1.8 TeV) as a function of the dilepton transverse momentum $\mathbf{p}_T$ in the transverse momenta range 20<$\mathbf{p}_T$<200 GeV. The experimental data are of CDF.

Numerical results



7. Different contributions to the Drell-Yan lepton pair production cross-section in $p\bar{p}$ collisions at Tevatron energies ($\sqrt{S}$=1.96 TeV) as a function of the azimuthal angle difference between the transverse momenta of the produced leptons. The dashed and dash-dotted histograms correspond to the contributions from quark-antiquark annihilation and QCD Compton subprocesses, respectively. The solid histogram represents the sum of these components.

Numerical results



7. Different contributions to the Drell-Yan lepton pair production cross-section in *pp* collisions at LHC energies ($\sqrt{S}$=7 TeV) as a function of the azimuthal angle difference between the transverse momenta of the produced leptons. The notations are the same.

Numerical results

Angular distributions

The general expression can be described by the polar θ and azimuthal φ angles of produced particles in the dilepton rest frame. When integrated over φ or cosθ, respectively, the angular distribution can be presented as follows:

$$\frac{d\sigma}{d\cos\theta} \sim (1+\cos^2\theta) + \frac{1}{2}A_0(1-3\cos^2\theta) + A_4\cos\theta,$$

$$\frac{d\sigma}{d\phi} \sim 1 + \beta_3\cos\phi + \beta_2\cos 2\phi,$$

where $\beta_3 = 3\pi A_3/16$ and $\beta_2 = A_2/4$.

Recently the CDF collaboration has reported the first measurments of A_0, A_2, A_3 and A_4 in Z-region [T. Aaltonen et al. (CDF Collaboration), Phys. Rev. Lett. **106**, 241801 (2011)]. The estimated values of the coefficients are shown on the following slides.

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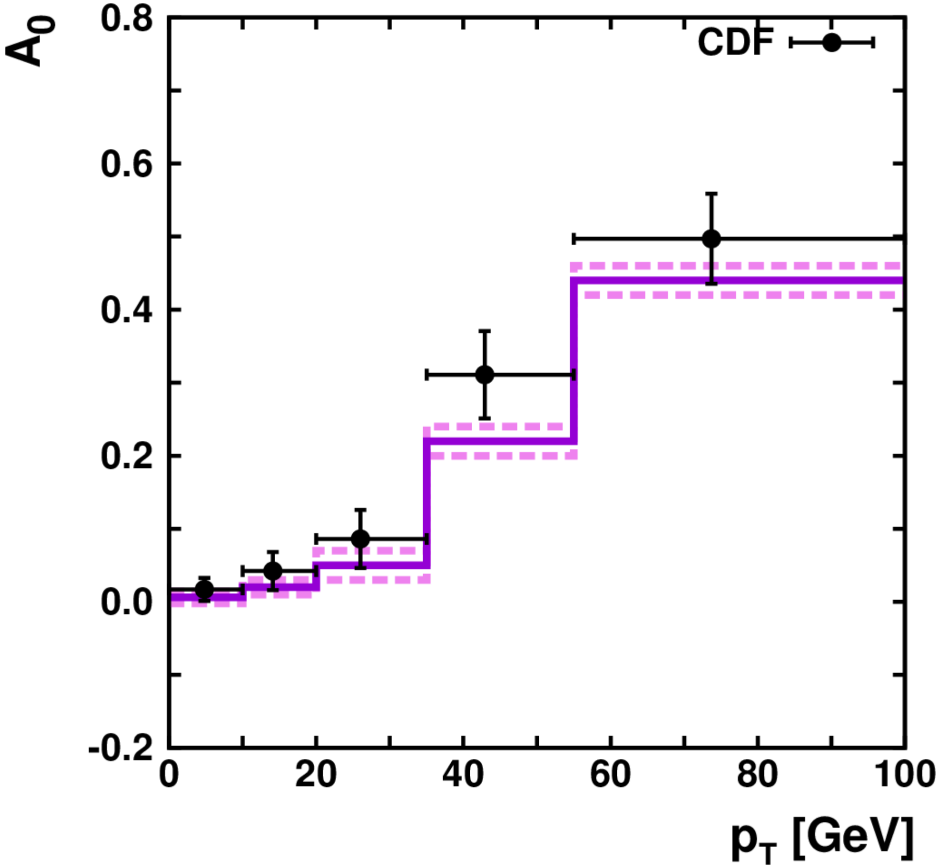
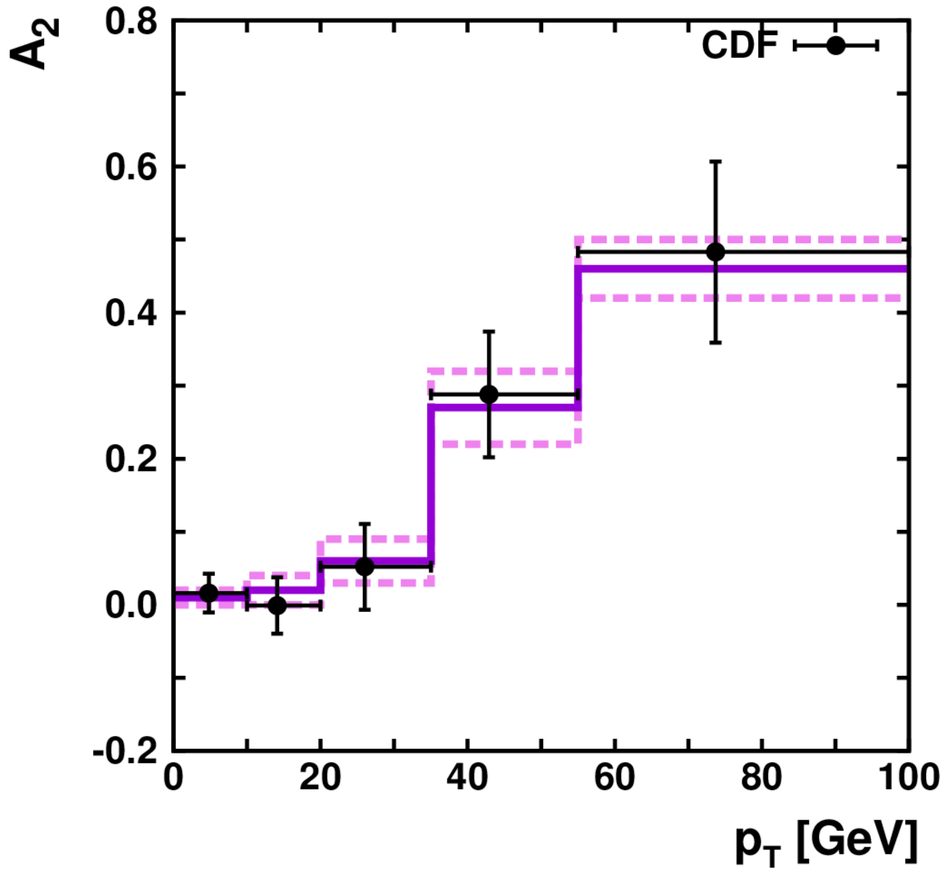
Numerical results



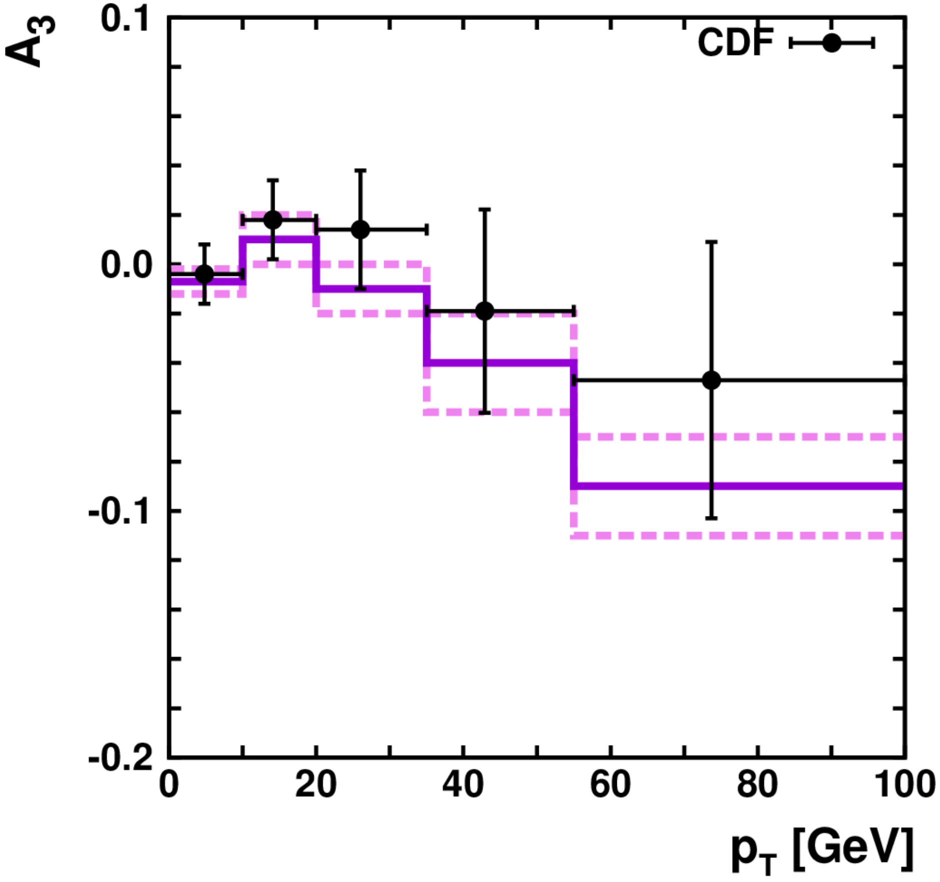
8. Angular coefficient A_0 of Drell-Yan lepton pair production $pp \to e^+e^- X$ at Tevatron energies ($\sqrt{S}$=1.96 TeV) in region 66 < M < 116 GeV.

Numerical results



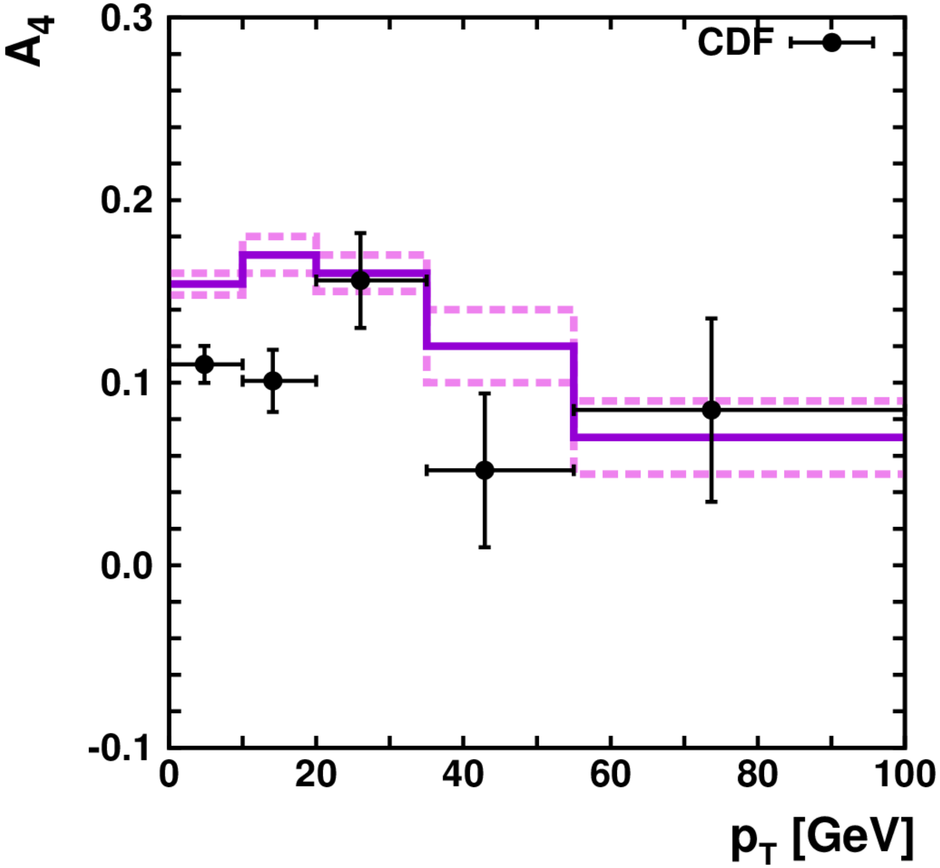
8. Angular coefficient A_2 of Drell-Yan lepton pair production *pp*→*e*+*e*-*X* at Tevatron energies ($\sqrt{S}$=1.96 TeV) in region 66 < *M* < 116 GeV. The Lam-Tung relation [C.S. Lam and W.K. Tung, Phys. Lett. **B 80**, 228 (1979).] $A_0 = A_2$ is valid for both quark-antiquark annihilation and QCD Compton subprocesses at $O(\alpha\alpha_s)$ order.

Numerical results



8. Angular coefficient A_3 of Drell-Yan lepton pair production *pp*→*e*+*e*-*X* at Tevatron energies ($\sqrt{S}$=1.96 TeV) in region 66 < *M* < 116 GeV. A_3 and A_4 originate from *γ*-*Z*-interference. Collinear QCD predicts a flat behaviour of A_3 in whole range of $\mathbf{p}_T$, when the CDF-data and our calcuations show a weak decreasing of A_3 as a function of $\mathbf{p}_T$

Numerical results



8. Angular coefficient A_4 of Drell-Yan lepton pair production $pp \to e{+}e{-}X$ at Tevatron energies ($\sqrt{S}$=1.96 TeV) in region 66 < M < 116 GeV.

Conclusion

In the presented talk processes of the Drell-Yan lepton pair production in the k_T-factorization QCD approach at Tevatron and LHC energies have been studied.

A reasonably good description of the experimental data of CDF, D0 and CMS collaborations for the lepton pair production at Tevatron and LHC has been obtained. A predictive power of the used approach has been shown. The CDF data for A_3 tend to support our predictions.

It will be interesting to work with LHCb experimental data at large rapidity, since the lepton pair production in forward region corresponds to very small x, up to 10^{-6}.

Back up

Off-shell quarks

In the presented work we used a method, described in the article [S.P. Baranov, A.V. Lipatov, N.P. Zotov, Phys. Rev **D 81**, 094034 (2010)]. According to this method, the off-shell quark spin density matrix has the form (in the limit of zero masses):

$$\sum_s u^s(k)\bar{u}^s(k) = x\hat{P}$$

Here *P* is the momentum of the incoming proton.