Drell-Yan Lepton Pair Production at the Tevatron and LHC in the k_T-factorization Approach

Artem Lipatov, Maxim Malyshev, Nikolai Zotov

Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, 119991 Moscow, Russia

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We present the results of the numerical calculations of Drell-Yan lepton pair production at Tevatron and LHC in the framework of the k_T-factorization approach. Our predictions are compared with the D0, CDF and CMS experimental data.

Our study is motivated by recent measurements of the Drell-Yan lepton pair production performed by the CMS collaboration at LHC [1], taken at the center-of mass energy 7 TeV.

We use the k_T-factorization approach, which previously was successfully applied to various high energy physics processes, such as the heavy flavour [2, 3], prompt photon [4] and top [5] production at the Tevatron and LHC energies.

According to the k_T-factorization theorem, to calculate the cross section of the Drell-Yan lepton pair production one should convolute the off-shell partonic cross sections with the relevant unintegrated quark and/or gluon distributions in the proton:

$$\sigma = \sum_{i,j=q,\,g} \int \hat{\sigma}^*_{ij}(x_1, x_2, \mathbf{k}^2_{1T}, \mathbf{k}^2_{2T})\, f_i(x_1, \mathbf{k}^2_{1T}, \mu^2) f_j(x_2, \mathbf{k}^2_{2T}, \mu^2)\, dx_1 dx_2\, d\mathbf{k}^2_{1T} d\mathbf{k}^2_{2T},$$

where $\hat{\sigma}^*_{ij}(x_1, x_2, \mathbf{k}^2_{1T}, \mathbf{k}^2_{2T})$ is the relevant partonic cross section. The initial off-shell partons have fractions x_1 and x_2 of initial protons longitudinal momenta and non-zero transverse momenta $\mathbf{k}_{1T}$ and $\mathbf{k}_{2T}$.

Concerning the unintegrated parton distributions we use the KMR prescription [6, 7]. It represents an approximate treatment of the parton evolution mainly based on the DGLAP equation and incorpotating the BFKL effects at the last step of the parton ladder only, in the form of the properly defined Sudakov formfactors $T_q(\mathbf{k}^2_T, \mu^2)$ and $T_q(\mathbf{k}^2_T, \mu^2)$, including logarithmic loops. In this approach both gluon and quark distributions can be obtained.

We have calculated matrix elements for $q\bar{q} \to \gamma/Z \to l^+l^-$ and $qg^* \to \gamma/Z + q \to l^+l^-q$. In the k_T-factorization approach the contribution from another subprocess, $q\bar{q} \to \gamma/Z + g \to l^+l^-g$ is already taken into account by the quark-antiquark annihilation due to the initial state radiation. So this subprocess has been taken out of our consideration in order to avoid double counting, which is in contrast with the collinear QCD factorization.

The calculation implies a modification of gluon polarization density matrix. It takes so called BFKL form: $\sum \epsilon^\mu \epsilon^{*\nu} = k^\mu_T k^\nu_T / \mathbf{k}^2_T$. In all other respects the evaluation follows the standard QCD Feynman rules.

To take into account the non-logarithmic loop corrections we use the approximation proposed in [8]. 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: $K = \exp(C_F \pi^2 \alpha_S(\mu^2)/2\pi)$, where the color factor $C_F = 4/3$. A particular choice $\mu^2 = \mathbf{p}_T^{4/3} M_{ll}^{2/3}$ has been proposed [8, 9] to eliminate sub-leading logarithmic terms. We chose this scale to evaluate the strong coupling constant in the expression for K.

In KMR unintegrated parton distributions we used the standard MSTW'2008 (LO) set [10] as an input. We took the renormalization and factorization scales $\mu_R^2 = \mu_F^2 = \xi^2 M_{ll}^2$. In order to evaluate theoretical uncertainties, we varied ξ between 1/2 and 2 about the default value $\xi = 1$. Following to [11], we set M_Z = 91.1876 GeV, Γ_Z =2.4952 GeV, $\sin^2\theta_W$ = 0.23122. We used the LO formula for the strong coupling constant $\alpha_s(\mu^2)$ with $n_f = 4$ active quark flavours at Λ_{QCD} =200 MeV, so that $\alpha_S(M_Z) = 0.1232$.

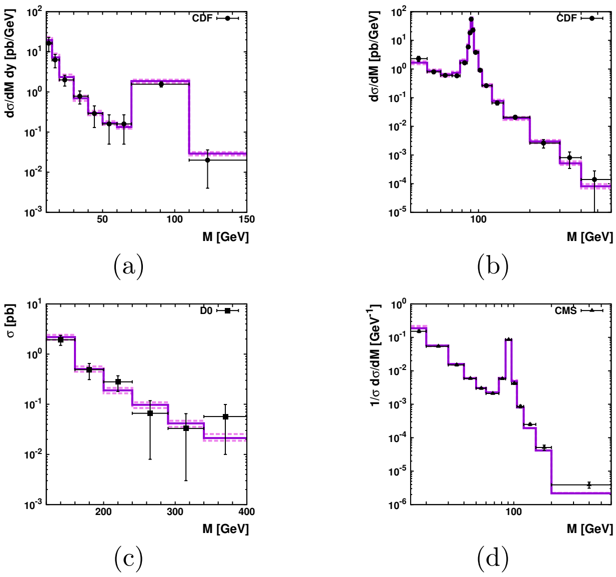

Figure 1: The differential cross sections of the Drell-Yan lepton production in hadron collisions as a function of M_{ll} calculated at $\sqrt{s}$ =1.8 TeV (a—c) and 7 TeV (d). The experimental data are from D0, CDF and CMS.

The results of our calculations [12] for Drell-Yan lepton pair production are presented in Fig. 1 in comparison with the D0 [13], CDF [14, 15] and CMS data [1]. Solid histograms are obtained by fixing both the factorization and renormalization scales at the default value $\mu = M_{ll}$, whereas the upper and lower dashed histograms correspond to the scale variation as it was described above. One can see that the Tevatron and LHC experimental data are reasonably well described by the k_T-factorization approach in the whole range of invariant masses.

Now we turn to an analysis of angular distributions in dilepton production. The general expression can be described by the polar θ and azimuthal ϕ angles of the produced particles in the dilepton rest frame. When integrated over ϕ or $\cos\theta$, respectively, the angular distribution can be presented as follows:

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

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

where $\beta_3 = 3\pi A_3/16$ and $\beta_2 = A_2/4$. Note that the angular coefficients A_0 and A_2 are the same for the γ^* or Z boson exchange, and A_3 and A_4 originate from the $\gamma^* - Z$ interference. The Lam-Tung relation [16] $A_0 = A_2$ is valid for both quark-antiquark annihilation and QCD Compton subprocesses at $\mathcal{O}(\alpha\alpha_s)$ order. Higher-order QCD calculations [17, 18] as well as QCD resummation up to all orders [19] indicate that violations of the Lam-Tung relation are small. Very recently the CDF collaboration reported [20] the first measurement of the angular coefficients A_0, A_2, A_3 and A_4 in the Z peak region ($66 < M_{ll} < 116$ GeV) at $\sqrt{s}$ =1960 GeV. Below we estimate these coefficients regarding the CDF measurements. Our evaluation generally followed the experimental procedure. We have collected the simulated events in the specified bins of dilepton transverse momentum, generated the decay lepton angular distributions according to the calculated matrix elements and then applied a two-parametric fit based on 1. The estimated values of angular coefficients in the Collins-Soper frame are shown in Fig. 2. Solid and two dashed histograms represent fitted values of angular coefficients and corresponding uncertainties of fitting procedure. The default scale $\mu = M$ has been applied. We find that our predictions agree well with the CDF data as well as collinear QCD predictions listed in [20]. We would like to only remark that the latter predict a flat behaviour of A_3 in a whole p_T range whereas CDF data tends to support our predictions (slight decreasing of A_3 when we move to large p_T values).

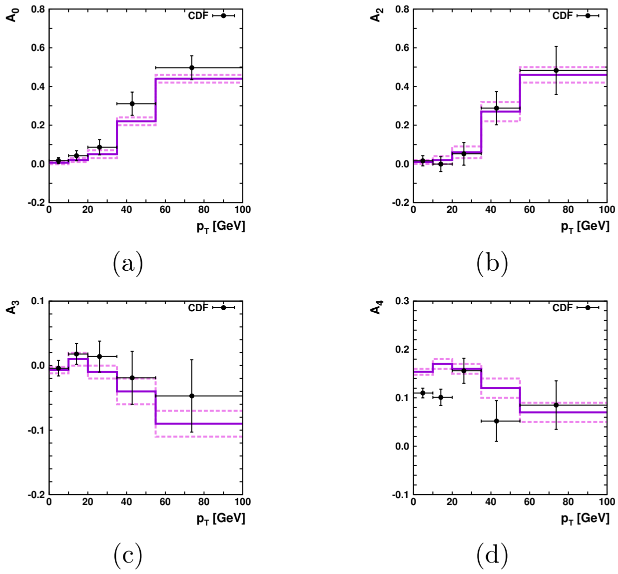

Figure 2: Angular coefficients A_0, A_2, A_3 and A_4 of dilepton production as a function of p_T calculated at $\sqrt{s}$ =1.96 TeV. The experimental data are from CDF.

In summary, we have studied the Drell-Yan lepton pair production in the k_T-factorization QCD approach at LHC energies. The matrix elements for $q\bar{q} \to \gamma/Z \to l^+l^-$ and $qg^* \to \gamma/Z + q \to l^+l^-q$ have been evaluated. A reasonably good description of D0, CDF and CMS data for the Drell-Yan lepton pair production at Tevatron and LHC has been obtained. A theoretical uncertainties investigation has been studied and a predictive power of the used approach has been shown. The CDF data for A_3 tend to support our predictions.

Acknowledgments

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