PROCEEDINGS OF SCIENCE

QCD k_t - smearing and Drell-Yan dilepton production

Gabriela Ślipek∗
Institute of Nuclear Physics, PL-31-342 Cracow, Poland
E-mail: Gabriela.Slipek@ifj.edu.pl

Antoni Szczurek
Institute of Nuclear Physics, PL-31-342 Cracow, Poland
and University of Rzeszów, PL-35-959 Rzeszów, Poland
E-mail: Antoni.Szczurek@ifj.edu.pl

The differential cross section for the dilepton production is calculated including internal motion of hadron constituents and emission from the ladders in the formalism of unintegrated parton distributions. We calculate azimuthal angular correlations between charged leptons and deviations from the $p_t(e^+) = p_t(e^-)$ relation. We concentrate on the distribution in dilepton-pair transverse momentum. We study also azimuthal correlations between jet and dilepton pair and correlation in the $(p_{1t}(jet), p_{2t}(l^+l^-))$ plane. The results are compared with experimental data.

High-pT Physics at LHC - Tokaj'08
16-19 March 2008
Tokaj, Hungary

∗Speaker.

 http://pos.sissa.it/

PoS(HIGH-pTLHC)013

1. Introduction

The Drell-Yan dilepton production is one of representative examples for which QCD collinear perturbative calculation can be performed order-by-order. In the 0-th order collinear approximation (quark-antiquark annihilation) the transverse momentum of the dilepton pair (sum of transverse momenta of opposite sign charged leptons) is zero due to momentum conservation. The 0th-order result is usually not included in calculating the distribution in dilepton transverse momentum. The lowest nonzero contributions are 1-st order quark-antiquark annihilation and QCD Compton. Due to inter-quark interactions the quarks/antiquarks, constituents of hadrons, are not at rest and posses nonzero transverse momenta. This effect causes that the 0-th order process contributes to the finite transverse momenta of the lepton pair. Furthermore the emissions of gluons before the $q\bar{q} \to l^+l^-$ hard process causes an extra k_t-smearing which, via momentum conservation, leads to finite transverse momenta of the dilepton pair (see Fig.1). The effect of internal motion as well as emission from the ladders can be easily included in the formalism of Kwiecinski unintegrated parton distributions [1]. We include both 0-th order and 1-st order contributions. We concentrate on the distributions in dilepton transverse momentum.This observable is extremely sensitive in the 0-th order to the initial transverse momenta of partons. Until now the transverse momentum of Drell-Yan pair was calculated within next-to-leading order perturbative QCD [2] as well as in the resummation formalism in the impact parameter space [3]. Here I present some selected results obtained within k_t-factorisation method [4]. More details can be found in our original paper [4].

2. 0-th order Drell-Yan cross section

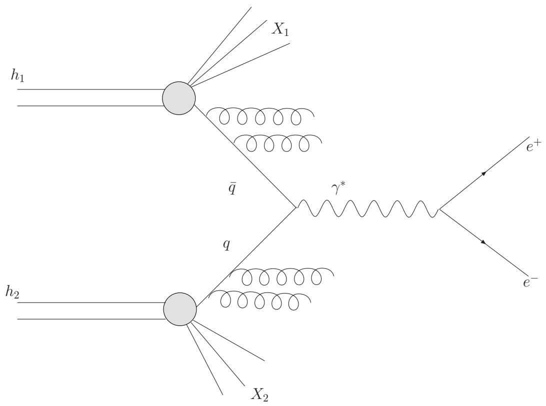

Figure 1: The diagram for the 0-th order Drell-Yan dilepton production with emissions from the ladders.

The differential cross section for the 0-th order contribution can be written as:

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_f \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2(x_1x_2s)^2} \tag{2.1}$$

$$\delta^2\left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t}\right) \left[f_{q_f}(x_1,\kappa_{1,t}^2)\ f_{\bar{q}_f}(x_2,\kappa_{2,t}^2)\ \overline{|M(q\bar{q} \to l^+l^-)|^2} \right.$$
$$\left. + f_{\bar{q}_f}(x_1,\kappa_{1,t}^2)\ f_{q_f}(x_2,\kappa_{2,t}^2)\ \overline{|M(q\bar{q} \to l^+l^-)|^2} \right],$$

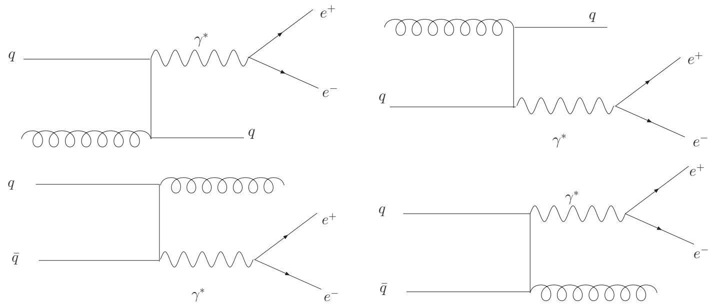

Figure 2: The subprocess diagrams for the 1-st order Drell-Yan dilepton prodution with initial emissions from the ladders.

where $f_i(x_1, \kappa_{1,t}^2)$ are unintegrated quark/antiquark distributions.

The longitudinal momentum fractions are evaluated in terms of final lepton rapidities and transverse momenta:

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

where $m_t = \sqrt{{p_t}^2 + m^2}$ is a so-called transverse mass.

Formally, if the following replacements

$$f_i(x_1, \kappa_{1,t}^2) \to x_1 p_i(x_1) \delta(\kappa_{1,t}^2) \, ,$$
$$f_j(x_2, \kappa_{2,t}^2) \to x_2 p_j(x_2) \delta(\kappa_{2,t}^2) \, .$$

are done one recovers standard text book Drell-Yan formulae.

3. 1-st order Drell-Yan cross section

In the first order in α_s there are two types of diagrams: QCD Compton and quark-antiquark annihilation. A typical diagrams for corresponding subprocesses are shown in Fig.2. For example the multidifferential cross section for the QCD Compton can be written in terms of unintegrated quark/antiquark and gluon distributions as:

$$\frac{d\sigma}{dy_1 dy_2 d^2p_{1,t} d^2p_{2,t}} = \sum_f \int \frac{d^2\kappa_{1,t}}{\pi} \frac{d^2\kappa_{2,t}}{\pi} \frac{1}{16\pi^2 (x_1 x_2 s)^2}$$
$$\delta^2 \left(\vec{\kappa}_{1,t} + \vec{\kappa}_{2,t} - \vec{p}_{1,t} - \vec{p}_{2,t} \right) \, [f_g(x_1, \kappa_{1,t}^2) \; f_{q_f}(x_2, \kappa_{2,t}^2) \; \overline{|M(gq \to \gamma^* q)|^2}$$
$$+ f_{q_f}(x_1, \kappa_{1,t}^2) \; f_g(x_2, \kappa_{2,t}^2) \; \overline{|M(qg \to \gamma^* q)|^2} \,]. \tag{3.1}$$

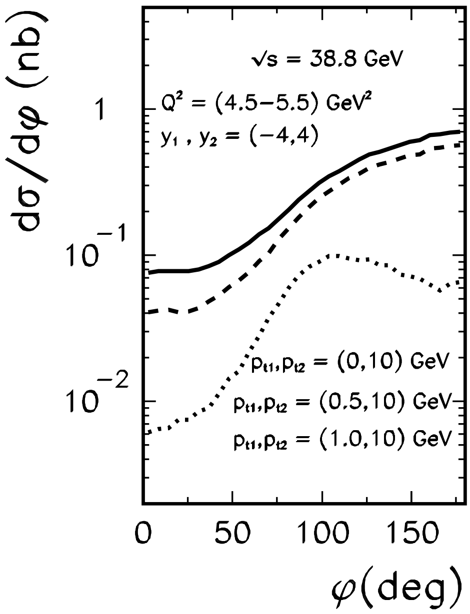

Figure 3: Distributions in azimuthal angle between electron and positron for W = 38.8 GeV (E772 experiment).

4. Results

Let us start with azimuthal angle correlations between outgoing leptons. In Fig.3 we show examples for the E772 experiment at Fermilab and diffrent cuts on lepton transverse momenta. The cuts not only lower the cross section but also modify the shape of azimuthal correlations.

Very interesting observable, which is singular in collinear approximation in leading-order, is the distribution in the transverse momentum of the dilepton pair (p_{t+}). In Fig.4 we show such a dependence on the incident center-of-mass energy for two different bins in photon virtuality. In general, the bigger energy the broader the distribution in p_{t+} [1].

The effect of broadening is summarized in Fig.5 where is show average value of the lepton-pair transverse momentum. The difference between different bins in photon virtuality is due to QCD evolution effect (we use photon virtuality Q^2 as a factorization scale in the Kwieciński unintegrated parton distributions). Similar effects were already discussed for dijet [5] and photon-jet correlations [6].

Finally we wish to confront our calculation with existing data for the Drell-Yan dilepton production. In Fig.6 we show our results with different values of the parameter b_0 in the Kwieciński UPDFs [1]. The dominant effect is probably the internal motion of nucleon constituents. This effect is often neglected in the standard QCD calculations. We get quite good description of the

[1] In collinear approach the distribution would be delta function in transverse momentum of the pair.

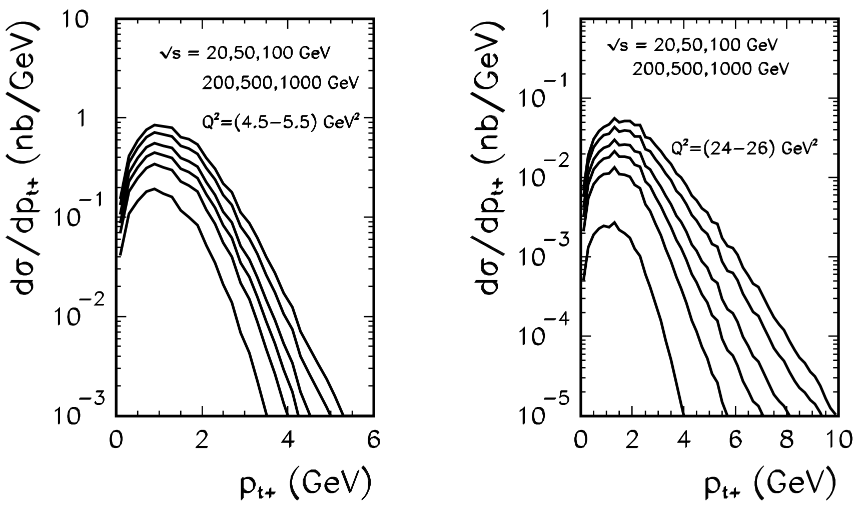

Figure 4: Distribution in p_{t+} for different beam energies specified in the figure and for two different windows in Q^2.

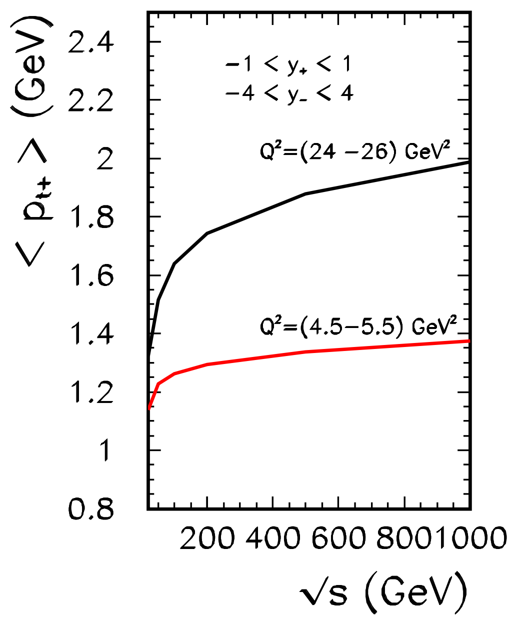

Figure 5: Average value of p_{t+} as a function of center-of-mass energy for two different windows of Q^2.

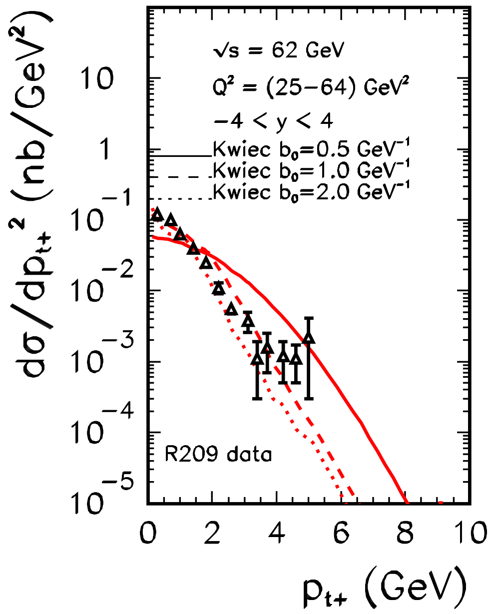

Figure 6: Distribution in p_{t+} for zeroth-order Drell-Yan in proton-proton collisions for W = 62 GeV. Different curves correspond to different values of the b_0 parameter in the Kwieciński UPDFs. The experimental data of the R209 collaboration are taken from [7].

R209 collaboration data already in the zeroth-order with b_0 = 1 - 2 GeV^{-1}. It seems therefore indespensible to include higher-orders in the k_t-factorization approach.

Let us now discuss contribution of processes of one order higher than in the previous section, with hard subprocesses shown in Fig.2 (these diagrams have to be inserted between two partonic ladders). In Fig.7 we show corresponding transverse momentum distribution of the dilepton pair for RHIC energy $\sqrt{s}$ = 200 GeV. For comparison we show also zeroth-order contribution discussed above. The zeroth-order contribution dominates at small transverse momenta, while the first-order contribution at transverse momenta larger than about 5 GeV.

In Fig.8 we show two-dimensional distributions in $(p_{1t}(jet), p_{2t}(e^+e^-))$ for Compton contributions for $\sqrt{s}$ = 200 GeV. We see broad distributions of the strength along diagonal $p_{1t} = p_{2t}$ with a smearing of the order of a few GeV. This smearing is a consequence of the convolution of two unintegrated parton distributions embodied in Eq.(3.2).

5. Conclusions

We have calculated both zeroth- and first-order contributions to dilepton production in the formalism with transverse momenta of initial partons taken into account. In these calculations we have used Kwieciński unintegrated parton distributions which include both smearing in parton

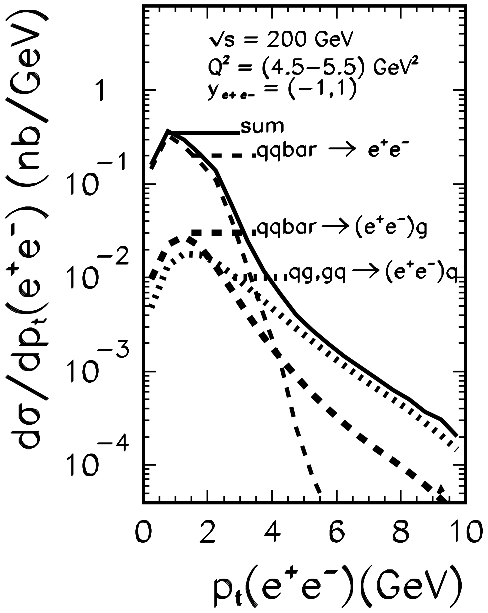

Figure 7: Distribution in p_{t+} for the RHIC energy W = 200 GeV. We show separately zeroth-order (dashed line) and first-order Compton (dotted line) contributions.

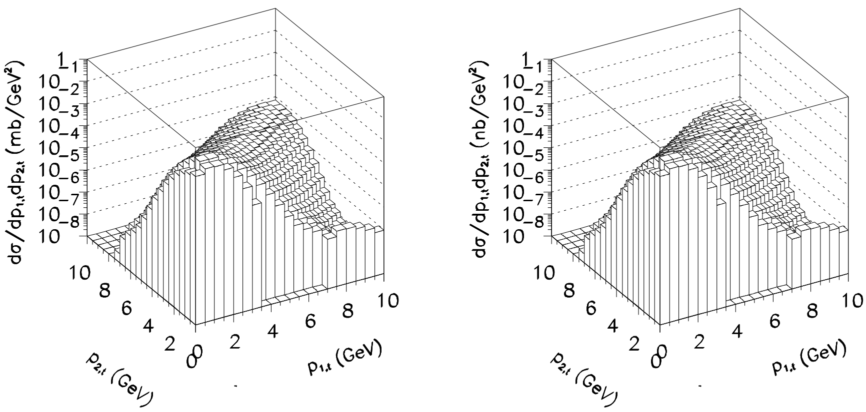

Figure 8: Two-dimensional distributions in $p_t(jet)$ and $p_t(e^+e^-)$ for the first-order gq and qg Compton contributions for W = 200 GeV and $Q^2 \in$ (4.5,5.5) GeV^2.

momentum due to nonperturbative effects in hadrons before collision as well as extra smearing due to QCD evolution effects in the collision process as encoded in the Kwieciński evolution equations.

We have calculated correlations in azimuthal angle between both charged leptons as well as correlations in the two-dimensional space of transverse momentum of the positron and transverse momentum of the electron. Both effect of the internal motion and effect of subsequent emissions from the ladder lead to deviations from the delta function in relative azimuthal angle centered at $\phi = \pi$ (collinear case) and deviations from p_t(electron) = p_t(positron) condition. The shape of the distribution in transverse momentum of the pair depends both on incident energy and virtuality of the time-like photon.

We predict larger smearing in transverse momentum of the dilepton pair for larger dilepton masses. The existing experimental data at $\sqrt{s}$ = 62 GeV can be well explained by the zeroth-order component by adjusting the parameter responsible for nonperturbative effects of internal motion of partons in hadrons. We have also calculated dilepton transverse momentum distribution in the first order for the matrix element. Inclusion of initial transverse momenta removes singularity at p_{t,l^+l^-} = 0. The first-order contribution dominates only at larger transverse momenta of the pair and is smaller than the zeroth-order contribution at low transverse momenta. We have also discussed analogous decorrelations on the $(p_t(jet), p_t(l^+l^-))$ plane. The initial transverse momenta lead to sizeable deviations from the collinear condition $p_t(jet) = p_t(l^+l^-)$.

References

[1] J. Kwieciński, Acta Phys. Polon. **B33** (2002) 1809. A. Gawron and J. Kwieciński, Acta Phys. Polon. **B34** (2003) 133. A. Gawron, J. Kwieciński and W. Broniowski, Phys. Rev. **D68** (2003) 054001.

[2] E. L. Berger, L.E. Gordon and M. Klasen, Phys. Rev. **D58** (1998) 074012.

[3] G. Fai, J. Qiu, X. Zhang, Phys. Lett. **B567** (2003) 243.

[4] A. Szczurek and G.Ślipek arXiv:0808.1360v1 [hep-ph].

[5] A. Szczurek, A. Rybarska and G. Ślipek, Phys. Rev. **D76** (2007) 034001.

[6] T. Pietrycki and A. Szczurek, Phys. Rev. **D76** (2007) 034003.

[7] D. Antreasyan et al. (R209 collaboration), Phys. Rev. Lett. **48** (1982) 302.

[8] C. Albajar et al. (UA1 collaboration), Phys. Lett. **B209** (1988) 397.

PoS(HIGH-pTLHC)013