# EXCLUSIVE AND DIFFRACTIVE PRODUCTION OF LEPTON PAIRS IN $pp$ COLLISIONS AT HIGH ENERGIES*

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We discuss exclusive production of lepton pairs via photon–photon fusion and photon–pomeron subprocesses. Predictions for this reactions are given using the $k_{\mathrm{t}}$-factorisation formalism. We also analyse inclusive diffractive dilepton production in $pp$ collisions using Ingelman and Schlein approach with pomeron flux factors and quark/antiquark distributions in the pomeron which were taken from the H1 Collaboration analysis of diffractive structure function and diffractive dijets at HERA. We calculated cross-section for single and central diffractive production of dileptons. Cross-sections for exclusive and inclusive diffractive processes are compared.

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## 1. Introduction

The diffractive processes were intensively studied in $ep$ collisions at HERA. A formalism has been developed how to calculate them in terms of the diffractive structure functions. Here, we wish to calculate their contribution for dilepton production. In this context we will use diffractive parton distributions found by the H1 Collaboration in the analysis of proton diffractive structure function $F_2^{(D)}$ as well as dijet production in DIS [1].

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It was discussed several times in the literature that the double-photon production of dileptons in the $pp \to ppl^+l^-$ reaction can be considered as a luminosity monitor for LHC [2]. Recently, we have studied the mechanism of dilepton production in $\gamma p \to l^+l^-p$ via exchange of gluonic ladder [3]. The same mechanism can be used in proton–proton collisions when the photon is in the intermediate state and couples to the parent nucleon through the proton electromagnetic form factor(s). It is, therefore, of interest how this mechanism competes with the photon–photon mechanism suggested as the luminosity monitor.

## 2. Formalism

### *2.1. Inclusive diffractive production of lepton pairs*

The mechanisms of the ordinary as well as diffractive production of dileptons are shown in Fig. 1. In the following we apply the Ingelman and Schlein approach [4]. In this approach one assumes that the pomeron has a well de-

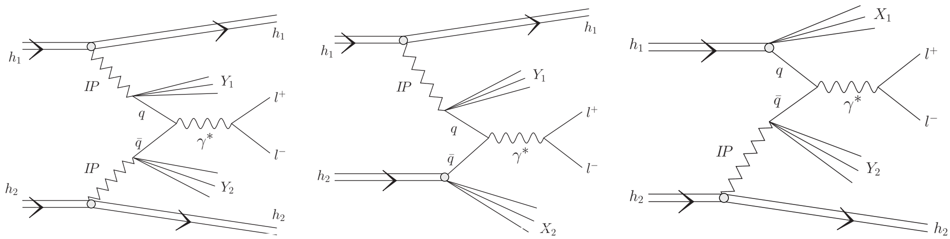


Fig. 1. The central-diffractive mechanism of the lepton pair production and the mechanism of single-diffractive production of dileptons.

fined partonic structure, and that the hard process takes place in a pomeron–proton or proton–pomeron (single diffraction) or pomeron–pomeron (central diffraction) processes. As an example, we show how we calculate triple differential distributions for single-diffractive production

$$\frac{d\sigma_{\rm SD}}{dy_1 dy_2 dp_{\rm t}^2} = K \frac{|M|^2}{16\pi^2 \hat{s}^2} \Big[ \left( x_1 q_f^D \left(x_1,\mu^2\right) x_2 \bar{q}_f \left(x_2,\mu^2\right)\right) + \left( x_1 \bar{q}_f^D \left(x_1,\mu^2\right) x_2 q_f \left(x_2,\mu^2\right)\right) \Big] , \quad (1)$$

where $|M|^2$ is the matrix element squared for the $q\bar{q} \to l^+l^-$ process and $x_1, x_2$ are longitudinal momentum fractions.

We do not calculate the higher-order Drell–Yan contributions and include them effectively with the help of a so-called $K$-factor which can be calculated as: $K = 1 + \frac{\alpha_s}{2\pi}\frac{4}{3}(1 + \frac{4}{3}\pi^2)$. The 'diffractive' quark distribution of flavour $f$ ($q_f^D(x,\mu^2)$) can be obtained by a convolution of the flux of pomerons $f_{\mathbb{P}}(x_{\mathbb{P}})$ and the parton distribution in the pomeron $q_{f/\mathbb{P}}(\beta,\mu^2)$.

### *2.2. Exclusive diffractive production of lepton pairs via photon–pomeron subprocesses*

In Fig. 2 we show the non-QED mechanism for the exclusive diffractive production of lepton pairs via $\gamma\mathbb{P}$ subprocess.

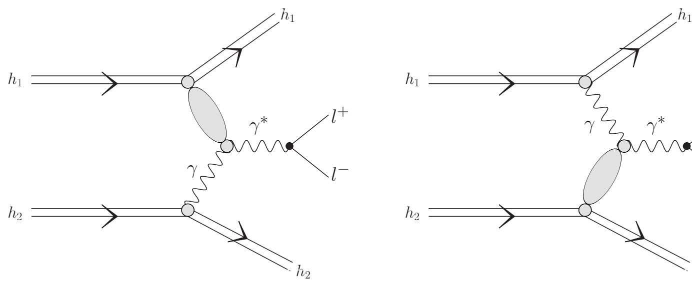


Fig. 2. An example of the non-QED mechanism for the production of opposite charge leptons in the $pp \to ppl^+l^-$ reaction.

The amplitude for the exclusive hadroproduction can be written schematically as

$$\begin{aligned}\mathcal{M}^{\lambda_3\lambda_4}_{pp\to ppl^+l^-} = & eF_1\left(q_1{}^2\right)(\bar{u}_1\gamma^\mu u_a)\left(\frac{-ig_{\mu\nu}}{t_1}\right)\Sigma_{\lambda_1}\epsilon^\nu(\lambda_1)\mathcal{M}^{\lambda_1\lambda_1{}'}_{\gamma p\to\gamma^* p}(W_2,t_2,M_{ll}) \\ & \times\Sigma_{\lambda_1'}\epsilon^{\alpha^*}\left(\lambda_1{}'\right)\left(\frac{-ig_{\alpha\beta}}{s_{34}}\right)e\bar{u}(\lambda_3,p_3)\gamma^\beta v(\lambda_4,p_4) \\ & + eF_1\left(q_2{}^2\right)(\bar{u}_2\gamma^\mu u_b)\left(\frac{-ig_{\mu\nu}}{t_2}\right)\Sigma_{\lambda_2}\epsilon^\nu(\lambda_2)\mathcal{M}^{\lambda_2\lambda_2{}'}_{\gamma p\to\gamma^* p}(W_1,t_1,M_{ll}) \\ & \times\Sigma_{\lambda_2{}'}\epsilon^{\alpha^*}\left(\lambda_2{}'\right)\left(\frac{-ig_{\alpha\beta}}{s_{34}}\right)e\bar{u}(\lambda_3,p_3)\gamma^\beta v(\lambda_4,p_4)\,, \qquad (2)\end{aligned}$$

where $\lambda_3,\lambda_4$ are helicities of $l^+$ and $l^-$, respectively. Above $M_{ll}$ is the invariant mass of the lepton pair, $F_1$ is the Dirac electromagnetic form factor and $\mathcal{M}^{\lambda\lambda'}_{\gamma p\to\gamma^* p}(W,t,M_{ll}) \propto \delta^{\lambda\lambda'}$ are amplitudes for the photon–proton subprocess.

### 2.3. Exclusive production of lepton pairs via photon–photon fusion

Here, we present a formalism necessary for the calculation of the amplitude and cross-section for the photon–photon fusion. The basic mechanism is shown in Fig. 3.

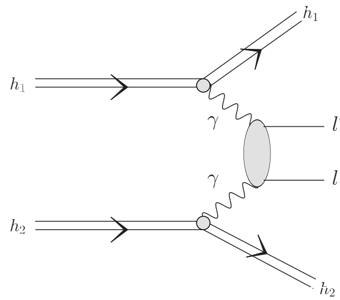


Fig. 3. The QED $\gamma\gamma$ fusion mechanism of the exclusive lepton pair production.

The amplitude for the two-photon $2 \to 4$ process can be written as

$$\mathcal{M}^{pp\to ppl^+l^-}_{\lambda_a\lambda_b\to\lambda_1\lambda_2\lambda_3\lambda_4} = \bar{u}(p_1,\lambda_1)\Gamma_1^{\mu_1}(q_1)u(p_a,\lambda_a)$$
$$\times\left(\frac{-ig_{\mu_1\nu_1}}{t_1}\right)V^{\nu_1\nu_2}_{\lambda_3\lambda_4}(q_1,q_2,p_3,p_4)\left(\frac{-ig_{\mu_2\nu_2}}{t_2}\right)\bar{u}(p_2,\lambda_2)\Gamma_2^{\mu_2}(q_2)u(p_b,\lambda_b)\,,$$

where $V^{\nu_1\nu_2}_{\lambda_3\lambda_4}(q_1,q_2,p_3,p_4)$ factor describes the production amplitude of a $l^+l^-$ pair with helicities $\lambda_3,\lambda_4$ and momenta $p_3,p_4$, respectively. Here, $\Gamma_1^{\mu_1}(q_1)$ and $\Gamma_2^{\mu_2}(q_2)$ are vertex functions describing coupling of virtual space like photon to the nucleon. More detailed discussion of the formalism used to above processes can be found in [5, 6].

## 3. Results

Here, we present predictions for the inclusive and exclusive diffractive production of the dilepton pairs. Let us start from the presentation of results for inclusive diffractive process. In Fig. 4 we show distribution in transverse momentum of individual leptons (on the left-hand side) and the rapidity distribution of the dilepton pair (on the right-hand side) for diffractive contributions at $\sqrt{s} = 1960$ GeV. For comparison we show also prediction for the ordinary Drell–Yan contribution. A somewhat strange shape for $p_{\rm t} \in$ (0–1) GeV is a consequence of the cut imposed on the dilepton invariant mass $M_{ll} > 1$ GeV, necessary to ensure validity of the perturbative calculation.

The rapidity distribution of the dilepton pair (on the right-hand side) is shown in Fig. 4. The distributions for the individual single diffractive mechanisms have maxima at large rapidities. The central diffractive contribution is concentrated at midrapidities.

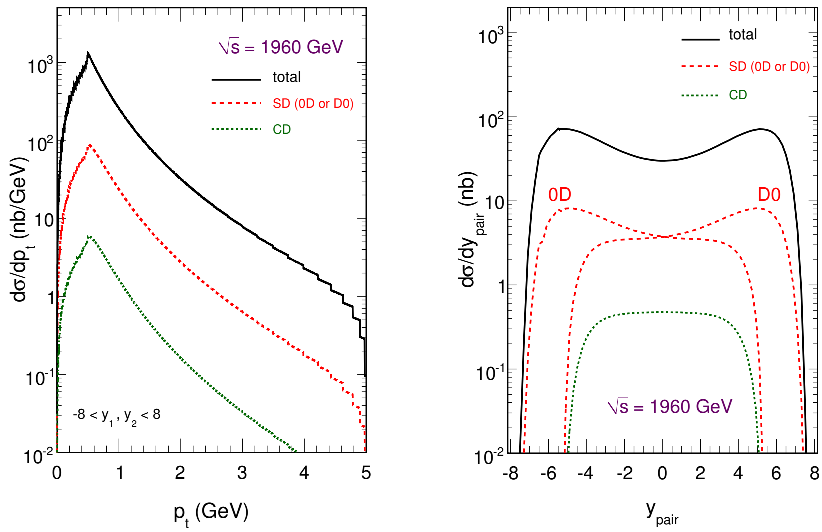


Fig. 4. Distribution in transverse momentum of lepton (left-hand side) and in the lepton pair rapidity ($y_{\rm pair}$) (right-hand side) for the ordinary Drell–Yan (black line), single diffractive DY (dashed/red online) and central diffractive DY (dotted/green online). Absorption effects are not included here.

In this section, we shall also present results for exclusive diffractive mechanism discussed above. Let us start from azimuthal correlations between the outgoing leptons for the $\gamma\gamma$ fusion (dashed line) and for the $\gamma\mathbb{P}+\mathbb{P}\gamma$ exchanges (solid line) presented in Fig. 5. Azimuthal angle distribution for the $\gamma\gamma$ process peaks sharply at $\phi\sim 180^\circ$ but for the $\gamma\mathbb{P}+\mathbb{P}\gamma$ process leptons prefers to go into the same hemisphere.

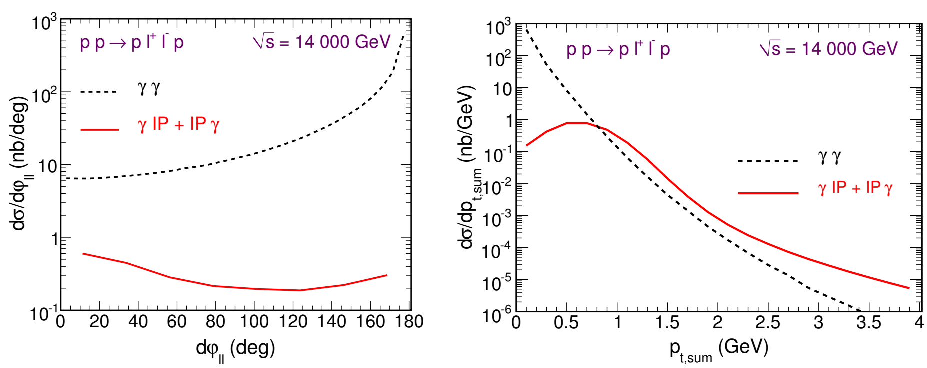


Fig. 5. Distribution in relative azimuthal angle between outgoing leptons and in transverse momentum of the dilepton pair ($p_{\rm t,sum}$) for the diffractive (solid line) and photon–photon (dashed line) contributions.

In Fig. 5 we show also distribution in transverse momentum of the dilepton pair ($\overrightarrow{p_{\rm t,sum}} = \overrightarrow{p_{1\rm t}} + \overrightarrow{p_{2\rm t}}$). As expected, the photon–photon contribution dominates at small transverse momenta of the pair, while the photon–pomeron (pomeron–photon) contributions at transverse momenta larger than about 1 GeV. Finally, in Fig. 6 we have collected lepton pair rapidity distributions for the exclusive mechanisms discussed in this paper. We observe that the cross-section for the $\gamma\gamma$ mechanism is larger than that for the single and central diffractive ones. On the other hand, the cross-section for exclusive diffractive production is only slightly smaller than that for the central diffractive mechanism.

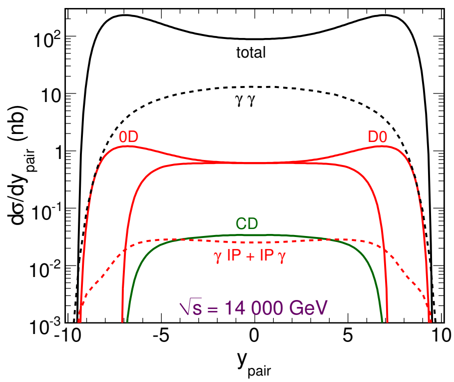


Fig. 6. Distribution in lepton pair rapidity for all processes considered in the present paper at the nominal LHC energy $\sqrt{s} = 14\,000$ GeV. The inclusive diffractive processes are shown by the solid lines and the exclusive ones by the dashed lines. Here we have included gap survival factors as explained in [6].

## 4. Conclusions

We have calculated distributions in lepton rapidity as well as lepton transverse momentum for inclusive single and central diffractive production of dileptons in proton–proton collisions. The distributions have been compared with the corresponding distributions for ordinary nondiffractive Drell–Yan process. The distribution in rapidity for the single-diffractive process is very similar to that for the nondiffractive case.

We have also calculated several differential distributions for exclusive diffractive production of dileptons. Here, the photon–pomeron (pomeron–photon) is the driving mechanism. We have applied here a formalism used previously for the $\gamma p \to l^+l^-p$ reaction. We have found regions of the phase space where the diffractive mechanism dominates over the QED photon–photon mechanism.

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