

EXCLUSIVE PHOTOPRODUCTION OF LEPTON PAIRS AT HIGH ENERGY*

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Using the formalism of k_t -factorization we study exclusive photoproduction of lepton pairs $\gamma p \rightarrow l^+ l^- p$ at high energies $W_{\gamma p} > 100$ GeV. Predictions for the $\gamma p \rightarrow l^+ l^- p$ reactions are given using an unintegrated gluon distribution. We calculate the invariant mass distribution of the lepton pair at different energies. We also discuss whether the production of timelike virtual photons can be approximated by continuing to the spacelike domain $q^2 < 0$. The amplitude will be used to predict the cross-section for exclusive production of lepton pair in hadronic reaction.

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1. Introduction

Measuring absolutely normalized cross-sections at the LHC is of great importance for the high-energy physics community. This requires having a well understood luminosity monitor. It is therefore very important to estimate other non-QED contributions to exclusive $l^+ l^-$ production. One possible source of dileptons is the exclusive production of vector mesons or Z bosons (see *e.g.* [1–3]).

In the present work we shall concentrate on the photon–pomeron subprocess. In Fig. 1 we show a QCD mechanism, where the photon splits into a quark–antiquark pair which interacts with the proton through the exchange of an off-diagonal QCD gluon ladder. In Fig. 1 the incoming photon is spacelike, (or quasireal) but the outgoing photon is timelike, *i.e.* $q^2 > 0$. In this work we present the momentum–space formulation of timelike Compton scattering at small- x , taking due account of the timelike nature of the final state photon.

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Now notice, that the invariant mass of the $q\bar{q}$ pair is given by

$$M^2 = \frac{k_{\perp}^2 + m_f^2}{z(1-z)}, \quad (2)$$

so that the second line of Eq. (1) suggests a change of variables from $(z, k_{\perp}^2) \rightarrow (M^2, k_{\perp}^2)$

$$\frac{dz dk_{\perp}^2}{z(1-z)} \longrightarrow \frac{dM^2 dk_{\perp}^2}{M^2 J}. \quad (3)$$

Using the $z \leftrightarrow 1-z$ symmetry we could restrict ourselves to $0 \leq z \leq 1/2$, so that from

$$z = z(M^2, k_{\perp}^2) = \frac{1}{2} \left[1 - \sqrt{1 - 4 \frac{k_{\perp}^2 + m_f^2}{M^2}} \right], \quad (4)$$

we obtain the Jacobian factor

$$J = \sqrt{1 - 4 \left(\frac{k_{\perp}^2 + m_f^2}{M^2} \right)}, \quad (5)$$

which introduces an integrable singularity (see *e.g.* Eq. 3). Finally, we can cast the amplitude in the form

$$\mathcal{M}_f(\gamma p \rightarrow \gamma^*(q^2) p) = W^2 16\pi^2 \alpha_{\text{em}} e_f^2 \int_{4m_f^2}^{\infty} \frac{a_f(W^2, M^2)}{M^2 - q^2 - i\varepsilon} dM^2. \quad (6)$$

Here $a_f(W^2, M^2)$ is related to the diffractive amplitude for the $\gamma p \rightarrow q\bar{q}p$ transition [5], however with the spinorial contractions from the final state performed. We refer to it as the spectral distribution or spectral density. Very detailed discussion concerning the spectral function can be found in our original paper [7].

As a last step we must extend our amplitude to finite momentum transfers. For simplicity we will assume it to have the following factorized form

$$\mathcal{M}_f(\gamma p \rightarrow \gamma^*(q^2) p; t) = \mathcal{M}_f(\gamma p \rightarrow \gamma^*(q^2) p) \exp[Bt]. \quad (7)$$

The total cross-section for the $\gamma p \rightarrow \gamma^* p$ process is obtained as

$$\sigma(\gamma p \rightarrow \gamma^*(q^2) p) = \frac{(\text{Re } e \frac{\mathcal{M}}{W^2})^2 + (\text{Im } m \frac{\mathcal{M}}{W^2})^2}{16\pi B}, \quad (8)$$

where for simplicity we take $B = 4 \text{ GeV}^{-2}$.

The invariant mass distribution of dileptons for the $\gamma p \rightarrow l^+ l^- p$ reaction is given by

$$\frac{d\sigma}{dq^2} (\gamma p \rightarrow l^+ l^- p) = \frac{\alpha_{\text{em}}}{3\pi q^2} \sigma (\gamma p \rightarrow \gamma^* (q^2) p), \quad (9)$$

where $l^+ l^-$ means either $e^+ e^-$ or $\mu^+ \mu^-$. This simple formula applies only when $q^2 \gg m_l^2$.

More detailed discussion of the formalism can be found in [7].

3. Results

Here we present predictions for the $\gamma p \rightarrow l^+ l^- p$ reaction.

In Fig. 2 we show the invariant mass distribution $d\sigma/dq^2$ of dileptons in the $\gamma p \rightarrow l^+ l^- p$ reaction as a function of photon–proton center-of-mass energy at fixed values of the invariant masses of the dilepton pairs (q^2). Here all flavours are included in the amplitude. In general, the higher invariant mass, the faster growth with the photon–proton energy. This points to the fact that the unintegrated glue is probed at on average harder scales, where it has a faster x –dependence.

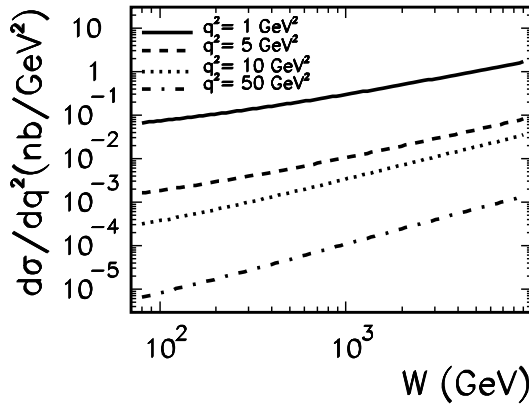


Fig. 2. The cross-section for $\gamma p \rightarrow l^+ l^- p$ as a function of center-of-mass photon–proton energy for fixed values of the dilepton invariant mass.

In Fig. 3 we show the invariant mass distribution of dileptons $d\sigma/dq^2$ as a function of dilepton invariant mass q^2 at fixed values of γp energy. An interesting feature of the invariant mass distribution is a cusp at $q^2 \sim 9 \text{ GeV}^2$. Notice that this is the vicinity of $q^2 \sim 4m_c^2$. Indeed the cusp is caused by the $c\bar{c}$ contribution to the amplitude which changes sign in this region.

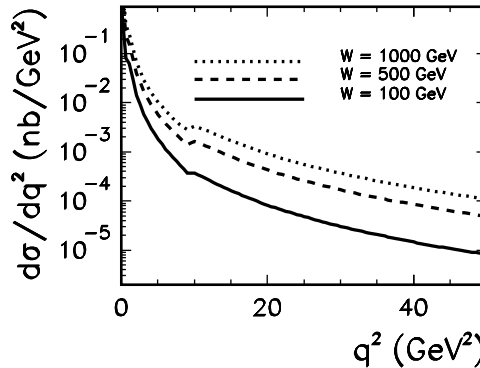


Fig. 3. Distribution in q^2 for $W = 100, 500, 1000$ GeV.

Finally, it is interesting to investigate how well the dilepton mass spectrum can be calculated from the amplitude for production of spacelike photons in the final state. In Fig. 4 we show the ratio of $d\sigma/dq^2$ for the timelike photons and the spacelike prescription (used previously in the literature) as a function of q^2 at various fixed energies. We observe that, the spacelike prescription does not reproduce the structure present in the timelike amplitude. The cross-section for timelike photons is bigger by a factor of 3–4 compared to the spacelike photon prescription.

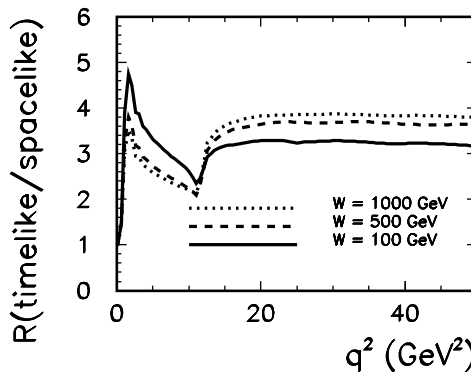


Fig. 4. The ratio of the cross-section $\frac{d\sigma}{dq^2}$ timelike/ $\frac{d\sigma}{dq^2}$ spacelike as a function of q^2 .

4. Conclusions

We have derived the amplitude for the exclusive diffractive photoproduction of lepton pairs in the $k_{\perp}$ -factorisation approach in the momentum space. We have discussed several details of the formalism as well as differences compared to the existing calculation in the literature which ignored the fact that the “produced” photons are timelike.

We have calculated the cross-sections as a function of photon–proton center of mass energy as well as a function of dilepton invariant mass. We have demonstrated how important is the inclusion of correct dynamics (timelike outgoing photons instead of spacelike outgoing photons).

The amplitude for the $\gamma p \rightarrow l^+ l^- p$ is the main ingredient of the diffractive amplitude for the $pp \rightarrow l^+ l^- pp$ process.

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