Central dileption production in proton-proton collisions with rapidity gap and with forward protons

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Abstract

We discuss photon-photon fusion mechanisms of dilepton production in proton-proton collisions with rapidity gap in the main detector and one forward proton in the forward proton detectors. This is relevant for the LHC measurements by ATLAS+AFP and CMS+PPS. Transverse momenta of the intermediate photons are taken into account and photon fluxes are expressed in terms of proton electromagnetic form factors and structure functions. Both double-elastic and single-dissociative processes are included in the analysis. Different parametrizations of the structure functions are used. Some differential distributions are presented. Some differences with respect to the results without proton measurement are discussed.

1 Introduction

Only recently the CMS collaboration [1] and very recently the ATLAS collaboration [2] presented results with at least one proton measured in forward direction. The experimental aparatus allows to measure only very forward protons. In theoretical calculations one has to impose experimental limits on so-called ξ-variables (longitudinal momentum fraction loss) [1, 2].

The results presented here (DIS2021) is based on our recent paper [3]. In our calculations we use the formalism developed in [4–6], which allows to calculate the cross section differential also in M_X or M_Y, masses of the excited proton remnants. In [7, 8] it was discussed how to calculate gap survival factor which is related to emission of (mini)jets produced in a DIS process associated with W^+W^- and $t\bar{t}$ production, respectively. We shall repeat such a calculation also here for $\mu^+\mu^-$ production. The absorption for double-elastic contribution was
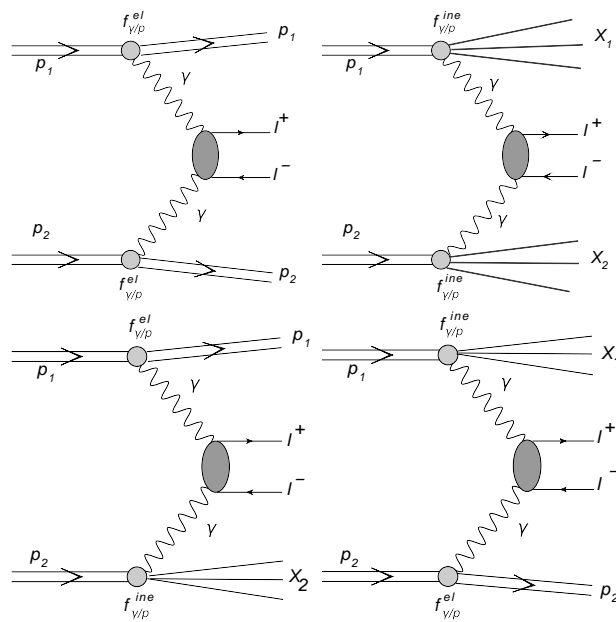
Figure 1: Four different categories of $\gamma\gamma$ fusion mechanisms of dilepton production in proton-proton collisions.

studied e.g. in [9,10] using the momentum space formalism. The impact parameter approach can be found e.g. in [11].

2 Basic formalism

There are four categories of the $\gamma\gamma$ processes as shown in Fig.1. We call them elastic-elastic, inelastic-inelastic, elastic-inelastic and inelastic-elastic. The double inelastic contribution is not included when proton is measured.

In the k_T-factorization approach [4, 5], the cross section for production of l^+l^- can be written in the form

$$\frac{d\sigma^{(i,j)}}{dy_1 dy_2 d^2\boldsymbol{p}_1 d^2\boldsymbol{p}_2} = \int \frac{d^2\boldsymbol{q}_1}{\pi\boldsymbol{q}_1^2}\frac{d^2\boldsymbol{q}_2}{\pi\boldsymbol{q}_2^2}\mathcal{F}^{(i)}_{\gamma^*/A}(x_1,\boldsymbol{q}_1)\mathcal{F}^{(j)}_{\gamma^*/B}(x_2,\boldsymbol{q}_2)\frac{d\sigma^*(p_1,p_2;\boldsymbol{q}_1,\boldsymbol{q}_2)}{dy_1 dy_2 d^2\boldsymbol{p}_1 d^2\boldsymbol{p}_2},$$
(1)

where the indices $i,j \in \{\text{el}, \text{in}\}$ denote elastic or inelastic final states. Here the photon flux for inelastic case is integrated over the mass of the remnant.

The ATLAS collaboration analysis imposes special condition on:

$$\xi_1 = \xi_{ll}^+ \,, \; \xi_2 = \xi_{ll}^- \,.$$
(2)

The longitudinal momentum fractions of the photons were calculated in the ATLAS analysis as:

$$\begin{aligned}\xi_{ll}^+ &= \left(M_{ll}/\sqrt{s}\right)\exp(+Y_{ll})\,, \\ \xi_{ll}^- &= \left(M_{ll}/\sqrt{s}\right)\exp(-Y_{ll})\,.\end{aligned}$$
(3)

Only lepton variables enter the formula.
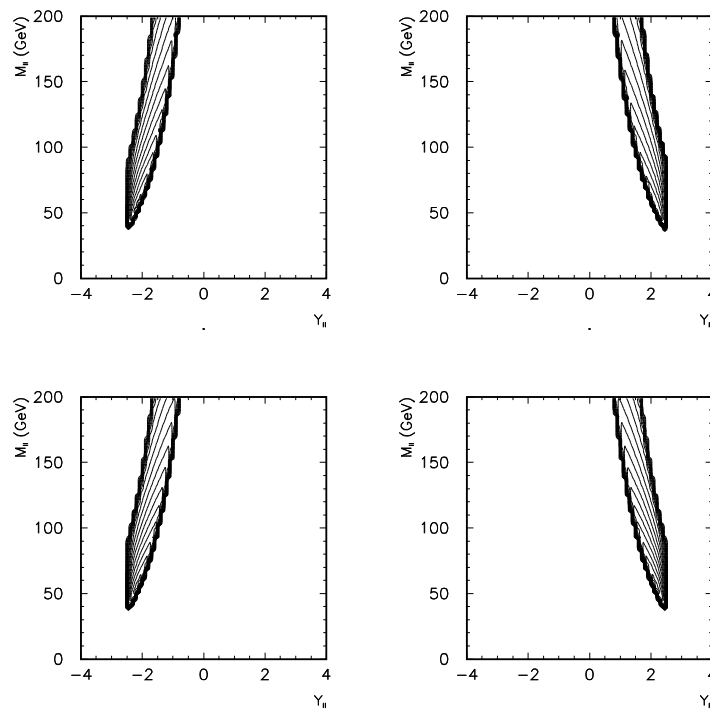
Figure 2: Two-dimensional distribution in (M_{ll}, Y_{ll}) for double-elastic contribution (upper row) and single dissociative (lower row). Here we have imposed experimental condition on ξ_2 (left panel) or ξ_1 (right panel) as explained in the main text. The $p_{t,\mu} > 15$ GeV condition was imposed in addition. The Szczurek-Uleshchenko structure function parametrization was used here for the single dissociative contribution for illustration.

3 Selected results

3.1 Our programs

The measurement of protons has strong influence on many fully leptonic observables. In Fig. 2 we show two-dimensional distributions in (M_{ll}, Y_{ll}) for fully elastic (upper panels) and single-dissociative (lower panels) contributions. A big part of the phase space is not accessible kinematically which is related to the cut on ξ's.

In Fig.3 we show a projection on Y_{ll}. One can observe a dip at $Y_{ll} \approx 0$ which is due to the imposed cuts. When the cuts are removed the dip is not present [3].

Many other distributions were discussed in [3].

3.2 SuperChic

In this subsection we show results obtained using the SuperChic-4 generator [12].

In Fig.4 we show corresponding gap survival factor calculated as:

$$S_G(Y_{ll}) \;=\; \frac{d\sigma/dY_{ll}|_{withSR}}{d\sigma/dY_{ll}|_{withoutSR}} \tag{4}$$

as a function of Y_{ll} variable.
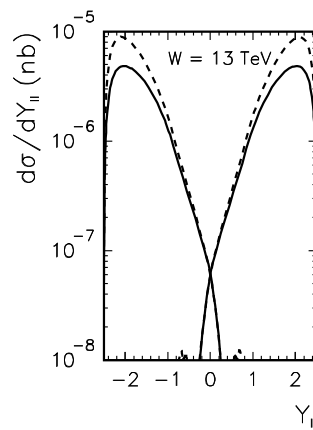
Figure 3: Distribution in dilepton rapidity for four different contributions considered. Here the cuts on ξ_{ll}^+ or ξ_{ll}^- are imposed. The solid line is for double elastic contribution and the dashed line is for single dissociation contribution.
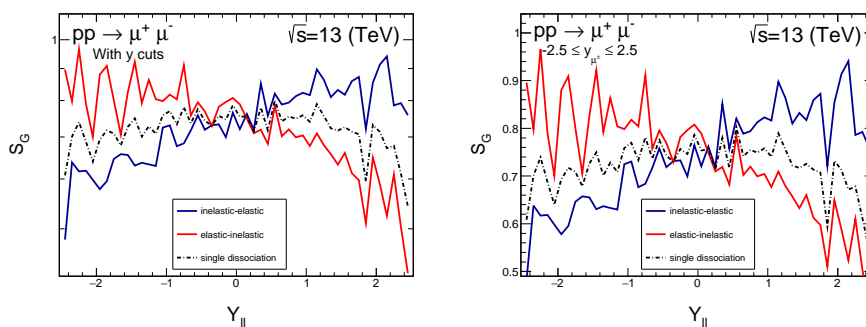
Figure 4: The soft gap survival factor as a function of rapidity of the $\mu^+\mu^-$ pair for single proton dissociation. We show the result without ξ cuts (left panel) and with ξ cuts (right panel). The dash-dotted black line represents effective gap survival factor for both single-dissociation components added together.

Without the ξ cut we observe quite different shapes of distributions in Y_{ll} without and with soft rapidity gap survival factor (see the left panel). When the ξ-cut is imposed the distributions with and without soft rapidity gap survival factor have very similar shapes. Then, however, the elastic-inelastic and inelastic-elastic contributions are well separated in Y_{ll}.

In Fig.5 we show the (mini)jet distribution in rapidity for elastic-inelastic and inelastic-elastic components. We show the distribution without imposing the ξ cut (left panel) and when imposing the ξ cut (right panel). One can observe slightly different shape for both cases. The corresponding gap survival factor (probability of no jet in the main detector) is 0.8 and 0.5, respectively.

4 Conclusion

Here we have reported our recent studies of l^+l^- production in proton-proton scattering with one forward proton, by imposing a cut on the so-called proton ξ variable. In this calculation
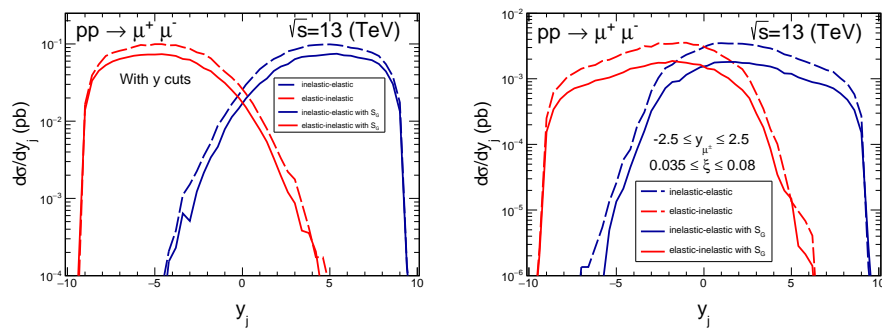
Figure 5: Distribution in the (mini)jet rapidity for the inclusive case with no ξ cut (left panel) and when the cut on ξ is imposed (right panel) for elastic-inelastic and inelastic-elastic contributions as obtained from the SuperChic generator. We show result without (dashed line) and with (solid line) soft rescattering correction.

we have included double-elastic and single dissociative contributions. In the latter case we have considered both continuum production as well as Δ^+ isobar production or production of other nucleon resonances, not discussed here explicitly (see [3]).

Several distributions were discussed in [3]. Here we have shown only some selected results. Particularly interesting is the distribution in Y_{ll} which has a minimum at $Y_{ll} \sim 0$. The minimum at $Y_{ll} = 0$ is caused by the experimental condition on $\xi_{ll}^{\pm}$ imposed on the leading proton.

We have also made calculations with the popular SuperChic generator and compared corresponding results to the results of our code(s). In general, the results are very similar to those obtained with our codes. We have shown also some results for kinematics-dependent gap survival factor. We have found some interesting dependence of gap survival factor on Y_{ll}. Finally we have shown rapidity distribution of a (mini)jet associated with partonic processes, also when including soft rescattering corrections.

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