

# Central exclusive production of $K^+K^-$ pairs in proton-proton collisions

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**Abstract.** We discuss central exclusive diffractive production of light mesons in the reactions  $pp \rightarrow pp\pi^+\pi^-$  and  $pp \rightarrow ppK^+K^-$ . The calculation is based on a tensor-pomeron approach. We include a purely diffractive dipion continuum, and the scalar  $f_0(980)$ ,  $f_0(1500)$ ,  $f_0(1710)$  and tensor  $f_2(1270)$ ,  $f_2'(1525)$  resonances decaying into pseudoscalar meson pairs. We include also photoproduction mechanisms for the nonresonant (Drell-Söding) and the  $\phi(1020)$  resonance contributions. The theoretical results are compared with existing CDF experimental data and predictions for being carried out LHC experiments are presented. The distributions in dimeson invariant mass and in a special "glueball filter variable" including the interference effects of resonance and dimeson continuum are presented.

## 1 Introduction

Diffractive studies are one of the important parts of the physics programme for the RHIC and LHC experiments. A particularly interesting classes are exclusive processes, where all centrally produced particles are detected. An example is the process of kaon pair production  $pp \rightarrow ppK^+K^-$ , which can be used for studies of low-mass resonances, including searches for glueballs. Such processes were studied extensively at CERN ISR [1–4] and WA102 [5, 6] experiments and are an attractive topic of current experimental studies: COMPASS [7, 8], STAR [9], CDF [10], LHCb [11–13], ALICE [14], CMS [15]. Feasibility studies for the  $pp \rightarrow pp\pi^+\pi^-$  process with proton tagging carried out for ATLAS + ALFA detectors are shown in [16].

On the theoretical side, the main contribution to the central diffractive exclusive production at high energies can be understood as being due to the exchange of two pomerons/reggeons ( $P/R$ ) between the external nucleons and the centrally produced hadronic system. One of the first calculations were concerned with continuum production in the  $pp \rightarrow pp\pi^+\pi^-$  [16–18],  $pp \rightarrow nn\pi^+\pi^+$  [19], and  $pp \rightarrow ppK^+K^-$  [20] reactions, where the amplitudes were written in terms of  $P/R$  exchanges with parameters fixed from phenomenological analyses of  $NN$ ,  $\pi N$  and  $KN$  total and elastic scattering.

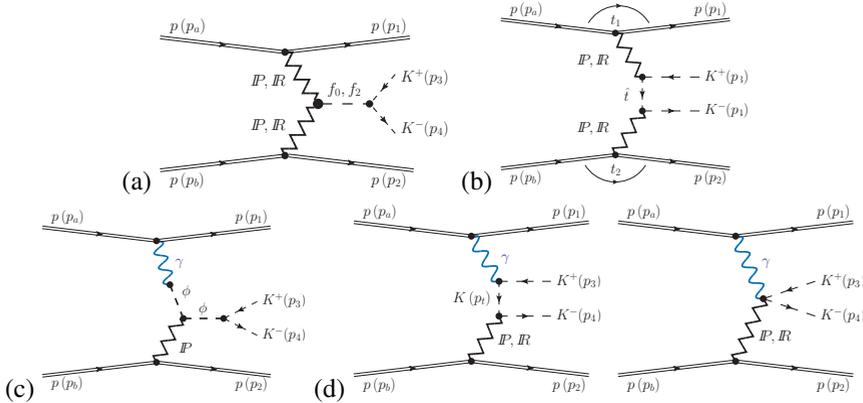
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In more recent studies we describe the soft pomeron as an effective rank-2 symmetric tensor exchange, as in the model of [21]. In [22] it was shown that the tensor-pomeron model is consistent with the experimental data on the helicity structure of  $pp$  elastic scattering at  $\sqrt{s} = 200$  GeV and small  $|t|$  from the STAR experiment [23]. In [24] the central exclusive production of several scalar and pseudoscalar mesons in the reaction  $pp \rightarrow ppM$  was studied for the relatively low WA102 energy. Then, the model was applied to the  $pp \rightarrow pp\pi^+\pi^-$  [25] and  $pp \rightarrow ppK^+K^-$  [26] reactions at high energies including the continuum and the dominant scalar and tensor resonances decaying into the pseudoscalar meson pairs. In [25] we considered all (seven) possible tensorial structures for the  $\mathbf{PP}f_2$  coupling. The resonant  $\rho^0$  and non-resonant (Drell-Söding)  $\pi^+\pi^-$  photoproduction was studied in [27]. The  $\rho^0$  production associated with a very forward/backward  $\pi N$  system in the  $pp \rightarrow p\rho^0(\pi N)$  processes was studied in [28]. The central exclusive  $\pi^+\pi^-\pi^+\pi^-$  production via the intermediate  $\sigma\sigma$  and  $\rho^0\rho^0$  states in  $pp$  collisions was discussed in [29]. Recently, in [30], the  $pp \rightarrow ppp\bar{p}$  reaction was studied. It should be emphasized that the latter process has a very different characteristics than the  $pp \rightarrow pp\pi^+\pi^-$  or  $pp \rightarrow ppK^+K^-$  one, which we predicted using the correct treatment of the spin degrees of freedom in the calculations.

## 2 Sketch of formalism

The Born level diagrams for the  $pp \rightarrow ppK^+K^-$  process are shown in Fig. 1. The total



**Figure 1.** Schematic Born-level diagrams of: (a) central exclusive purely diffractive scalar and tensor resonance and (b) continuum  $K^+K^-$  production, (c)  $\phi$  resonance and (d) non-resonant photoproduction.

amplitude is a coherent sum of continuum amplitudes and the amplitudes with the  $s$ -channel scalar ( $f_0(980)$ ,  $f_0(1500)$ ,  $f_0(1710)$ ) and tensor ( $f_2(1270)$ ,  $f_2'(1525)$ ) resonances.

For instance, the Born (without absorption effects) amplitude for the process  $pp \rightarrow pp(\mathbf{PP} \rightarrow f_2'(1525) \rightarrow K^+K^-)$  within the tensor-pomeron model can be written as

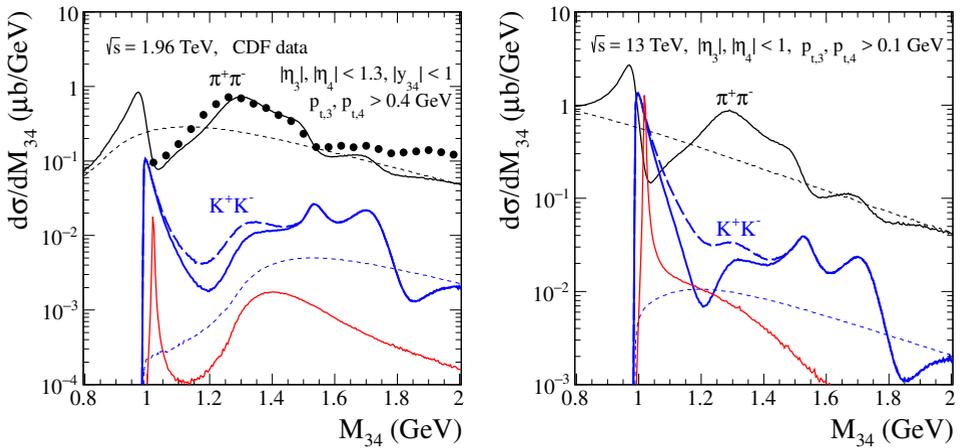
$$\begin{aligned} \mathcal{M}_{\lambda_a \lambda_b \rightarrow \lambda_1 \lambda_2 K^+ K^-}^{(\mathbf{PP} \rightarrow f_2' \rightarrow K^+ K^-)} &= (-i) \bar{u}(p_1, \lambda_1) i \Gamma_{\mu_1 \nu_1}^{(\mathbf{PP} p p)}(p_1, p_a) u(p_a, \lambda_a) i \Delta^{(\mathbf{P}) \mu_1 \nu_1, \alpha_1 \beta_1}(s_1, t_1) \\ &\quad \times i \Gamma_{\alpha_1 \beta_1, \alpha_2 \beta_2, \rho \sigma}^{(\mathbf{PP} f_2')} (q_1, q_2) i \Delta^{(f_2') \rho \sigma, \alpha \beta}(p_{34}) i \Gamma_{\alpha \beta}^{(f_2' K K)}(p_3, p_4) \\ &\quad \times i \Delta^{(\mathbf{P}) \alpha_2 \beta_2, \mu_2 \nu_2}(s_2, t_2) \bar{u}(p_2, \lambda_2) i \Gamma_{\mu_2 \nu_2}^{(\mathbf{PP} p p)}(p_2, p_b) u(p_b, \lambda_b), \quad (1) \end{aligned}$$

where  $t_1 = q_1^2 = (p_1 - p_a)^2$ ,  $t_2 = q_2^2 = (p_2 - p_b)^2$ ,  $s_1 = (p_a + q_2)^2 = (p_1 + p_{34})^2$ ,  $s_2 = (p_b + q_1)^2 = (p_2 + p_{34})^2$ ,  $p_{34} = p_3 + p_4$ .  $\Delta^{(\mathbf{P})}$  and  $\Gamma^{(\mathbf{PP} p p)}$  denote the effective tensor-pomeron propagator and proton vertex function, respectively. For the explicit expressions see

section 3 of [21]. Other details as form of form factors, the tensor-meson propagator  $\Delta^{(f_2)}$ , the  $PPf_2'$  and  $f_2'KK$  vertices are given in [26]. Our attempts to determine the parameters of pomeron-pomeron-meson couplings as far as possible from experimental data have been presented in section III of [26]. There are also the parameters of pomeron/reggeon-kaon couplings obtained from fits to kaon-nucleon total cross section data. The diffractive and photoproduction contributions to  $K^+K^-$  production must be added coherently at the amplitude level and in principle could interfere. In reality the Born approximation is not sufficient and absorption corrections (rescattering effects) have to be taken into account, see e.g. [31, 32].

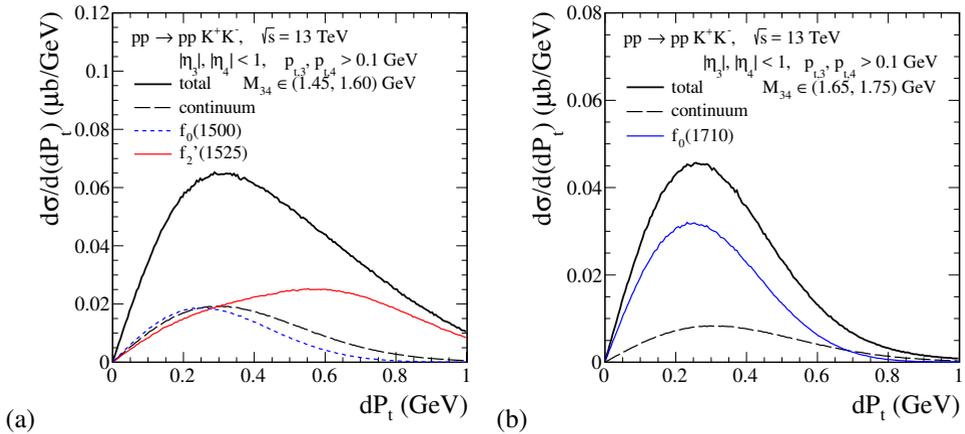
### 3 Selected results

In Fig. 2 we present the dika invariant mass distributions (the blue and red lines) imposing experimental cuts. We also show, for comparison, the purely diffractive contribution for the central production of  $\pi^+\pi^-$  pairs (see the upper black lines). The short-dashed lines represent the purely diffractive continuum term including both pomeron and reggeon exchanges, discussed in [25, 26]. For the  $pp \rightarrow ppK^+K^-$  reaction the solid lines represent the coherent sum of the diffractive continuum, and the scalar  $f_0(980)$ ,  $f_0(1500)$ ,  $f_0(1710)$ , and tensor  $f_2(1270)$ ,  $f_2'(1525)$  resonances. The lower red lines show the photoproduction term including the dominant  $\phi(1020) \rightarrow K^+K^-$  and the continuum (Drell-Söding) contributions. The narrow  $\phi$  resonance is visible above the continuum term. It may in principle be visible on top of the broader  $f_0(980)$  resonance. The coupling parameters of the tensor pomeron to the  $\phi$  meson have been fixed based on the HERA experimental data for the  $\gamma p \rightarrow \phi p$  reaction [33, 34].



**Figure 2.** The invariant mass distributions for centrally produced  $\pi^+\pi^-$  (the black top lines) and  $K^+K^-$  (the blue bottom lines) pairs with the relevant experimental kinematical cuts specified in the legend. Results including both the non-resonant continuum and the resonances are presented. The short-dashed lines represent the purely diffractive continuum term. For the  $pp \rightarrow ppK^+K^-$  reaction the solid and long-dashed blue lines correspond to the results for  $\phi_{f_0(980)} = 0$  and  $\pi/2$  in the coupling constant  $g_{f_0(980)K^+K^-} e^{i\phi_{f_0(980)}}$ , respectively. The lower red line represents the  $\phi(1020)$  meson plus continuum photoproduction contribution. The CDF experimental data from [10] in the top left panel for the  $p\bar{p} \rightarrow p\bar{p}\pi^+\pi^-$  reaction are shown for comparison. Absorption effects were taken into account effectively by the gap survival factors,  $\langle S^2 \rangle = 0.1$  for the purely diffractive contributions and  $\langle S^2 \rangle = 0.9$  for the photoproduction contributions.

In Fig. 3 we present distributions in a special "glueball filter variable"  $dP_t$  [35] defined by the difference of the transverse momentum vectors  $dP_t = |d\mathbf{P}_t|$ ,  $d\mathbf{P}_t = \mathbf{q}_{t,1} - \mathbf{q}_{t,2} = \mathbf{p}_{t,2} - \mathbf{p}_{t,1}$ . Results for the ALICE kinematics and for two regions of: (a)  $M_{34} \in (1.45, 1.60)$  GeV and (b)  $M_{34} \in (1.65, 1.75)$  GeV are shown. We see that the maximum for the  $q\bar{q}$  state  $f_2'(1525)$  is around of  $dP_t = 0.6$  GeV. On the other hand, for the scalar glueball candidates  $f_0(1500)$  and  $f_0(1710)$  the maximum is around  $dP_t = 0.25$  GeV, that is, at a lower value than for the  $f_2'(1525)$ . This is in accord with the discussion in Refs. [5, 6].



**Figure 3.** The differential cross sections  $d\sigma/d(dP_t)$  as a function of the  $dP_t$  "glueball filter" variable for the  $pp \rightarrow ppK^+K^-$  reaction. Calculations were done for  $\sqrt{s} = 13$  TeV,  $|\eta_K| < 1$ ,  $p_{t,K} > 0.1$  GeV, and in two dikaon invariant mass regions: (a)  $M_{34} \in (1.45, 1.60)$  GeV and (b)  $M_{34} \in (1.65, 1.75)$  GeV. No absorption effects were taken into account here.

## 4 Conclusions

In our recent paper [30] we have analysed the central exclusive production (CEP) of  $K^+K^-$  pairs in proton-proton collisions at high energies. We have taken into account purely diffractive and diffractive photoproduction mechanisms. For the purely diffractive mechanism we have included the continuum and the dominant scalar  $f_0(980)$ ,  $f_0(1500)$ ,  $f_0(1710)$  and tensor  $f_2(1270)$ ,  $f_2'(1525)$  resonances decaying into  $K^+K^-$  pairs. The amplitudes have been calculated using Feynman rules within the tensor-pomeron model [21]. The effective Lagrangians and the vertices for  $\mathbf{P}\mathbf{P}$  fusion into the scalar and tensor mesons were discussed in [24] and [25], respectively. Some model parameters (pomeron-pomeron-meson couplings, the off-shell dependence of form factors  $\Lambda_{off,M} = 0.7$  GeV) have been roughly adjusted to CDF data [10] and then used for predictions for the STAR, ALICE, ATLAS, CMS and LHCb experiments.

Exclusive production of light mesons both in the  $pp \rightarrow pp\pi^+\pi^-$  and  $pp \rightarrow ppK^+K^-$  reactions are measurable at RHIC and LHC. We have focused mainly on the invariant mass distributions of centrally produced  $K^+K^-$ . The pattern of visible structures in the invariant mass distributions is related to the scalar and tensor isoscalar mesons and it depends on experimental kinematics. One can expect, with our default choice of parameters, that the scalar  $f_0(980)$ ,  $f_0(1500)$ ,  $f_0(1710)$  and the tensor  $f_2(1270)$ ,  $f_2'(1525)$  mesons will be easily identified experimentally in CEP. The distributions, in the so-called glueball filter variable  $dP_t$ ,

show different behavior in the  $K^+K^-$  invariant mass windows around glueball candidates with masses  $\sim 1.5$  GeV and  $\sim 1.7$  GeV than in other regions.

The absorption effects lead to a huge damping of the cross section for the purely diffractive contribution and a relatively small reduction of the cross section for the  $\phi(1020)$  photoproduction contribution. Therefore we expect that that one could observe the  $\phi$  resonance term, especially when no restrictions on the leading protons are included. Finally we note that central exclusive production of  $\phi$  offers also the possibility to search for effects of the elusive odderon, as was pointed out in [36]. A Monte Carlo generator containing a various processes and including detector effects (acceptance, efficiency) would be useful in theory-data comparison. The GenEx Monte Carlo generator [37, 38] could be used in this context.

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