

# EXCLUSIVE OPEN STRANGENESS PRODUCTION IN THE $pp \rightarrow pp K^+ K^-$ REACTION AT HIGH ENERGIES AND A MEASUREMENT OF SCALAR $\chi_{c0}$ MESON\*

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We discuss the results of exclusive  $pp \rightarrow pp K^+ K^-$  reaction at high energies which constitutes an irreducible background to three-body processes  $pp \rightarrow pp M$ , where  $M = \phi, f_2(1275), f_0(1500), f'_2(1525), \chi_{c0}$ . We consider central diffractive contribution mediated by Pomeron and Reggeon exchanges including absorption effects due to proton–proton interaction and kaon–kaon rescattering. We make predictions for future experiments at RHIC, Tevatron and LHC. Differential distributions in invariant two-kaon mass, kaon rapidities and transverse momenta of kaons are presented. We discuss a measurement of exclusive production of scalar  $\chi_{c0}$  meson in the proton–(anti)proton collisions via  $\chi_{c0} \rightarrow K^+ K^-$  decay. The corresponding amplitude for exclusive central diffractive  $\chi_{c0}$  meson production is calculated within the  $k_t$ -factorization approach.

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## 1. Introduction

Processes of central exclusive production (CEP) became recently a very active field of research (*e.g.* Ref. [1]). Although the attention is paid mainly to high- $p_t$  processes that can be used for new physics searches (exclusive Higgs,  $\gamma\gamma$  interactions, *etc.*), measurements of low- $p_t$  signals are also very important as they can help to constrain models of the backgrounds for the former ones. We have studied  $pp \rightarrow pp \pi^+ \pi^-$  process for low and high energies [2, 3, 4] and  $pp \rightarrow nn \pi^+ \pi^+$  process at high energies [5]. In Ref. [6] a possible measurement of the exclusive  $\pi^+ \pi^-$  production at the LHC with tagged forward protons has been studied. Recently, we have discussed [7] the mechanisms of exclusive  $K^+ K^-$  production in hadron collisions at high

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energies. The  $pp \rightarrow pp K^+ K^-$  reaction is a natural background for exclusive production of resonances decaying into  $K^+ K^-$  channel, such as:  $\phi$ ,  $f_2(1270)$ ,  $f_0(1500)$ ,  $f_2'(1525)$ ,  $\chi_{c0}$ . The mass spectrum of the exclusive  $K^+ K^-$  system at the CERN Intersecting Storage Rings (ISR) was measured at  $\sqrt{s} = 63$  GeV [8] and at  $\sqrt{s} = 62$  GeV [9] (this is the highest energy at which normalized experimental data exist).

Recently, there was interest in central exclusive production of heavy resonance states (see Refs. [10, 11, 12, 13, 14]), where the QCD mechanism is similar to the exclusive production of the Higgs boson. We recall that the CDF measurement of  $\chi_c$  CEP [15] is based on the detection of the decay  $\chi_c \rightarrow J/\psi + \gamma$  with  $J/\psi \rightarrow \mu^+ \mu^-$  channel. At the Tevatron, the experimental invariant mass resolution  $M(J/\psi + \gamma)$  does not allow a separation of the different  $\chi_{cJ}$  states. Therefore, although the cross section for exclusive  $\chi_{c0}$  production obtained within the  $k_t$ -factorization [12] should be the largest among  $\chi_c$  states, the higher spin  $\chi_{c1}$  and  $\chi_{c2}$  states could give similar contributions to the observed  $J/\psi + \gamma$  decay channel, because of their much higher branching fractions [16].

The observation of  $\chi_{c0}$  CEP via two-body decay channels is of special interest for studying the dynamics of heavy quarkonia production. The measurement of exclusive production of  $\chi_{c0}$  meson in proton-(anti)proton collisions via  $\chi_{c0} \rightarrow \pi^+ \pi^-$  decay has been already discussed [17]. Recently, we have analyzed a possibility to measure  $\chi_{c0}$  via its decay to the  $K^+ K^-$  channel. The branching fraction to this channel is relatively larger for scalar meson than for the tensor meson [16] ( $\mathcal{B}(\chi_{c0} \rightarrow K^+ K^-) = (0.61 \pm 0.035)\%$ ,  $\mathcal{B}(\chi_{c2} \rightarrow K^+ K^-) = (0.109 \pm 0.008)\%$ ) and even absent for the axial meson. A much smaller cross section for  $\chi_{c2}$  production as obtained from theoretical calculation means that only  $\chi_{c0}$  will contribute to the signal.

## 2. Background and signal amplitudes

The dominant mechanism of the exclusive production of  $K^+ K^-$  pairs at high energies is sketched in Fig. 1 (a). The formalism used in the calculation of expected non-resonant background amplitude is explained in Ref. [7] including the absorptive corrections due to proton-proton interactions as well as kaon-kaon rescattering. The Regge parametrization of the  $K^\pm p \rightarrow K^\pm p$  scattering amplitude includes both Pomeron and Reggeon exchanges with the parameters taken from the Donnachie-Landshoff analysis [18] of the total cross sections. In Ref. [7] the integrated cross section for the total and elastic  $KN$  scattering was shown. Our model sufficiently well describes the elastic  $KN$  data for energy  $\sqrt{s} > 3$  GeV. The form factors correcting for the off-shellness of the intermediate kaons are parametrized as  $F_K(\hat{t}/\hat{u}) = \exp(\frac{\hat{t}/\hat{u} - m_K^2}{\Lambda_{\text{off}}^2})$ , where the parameter  $\Lambda_{\text{off}}^2 = 2 \text{ GeV}^2$  is obtained from a fit to the ISR experimental data [9].

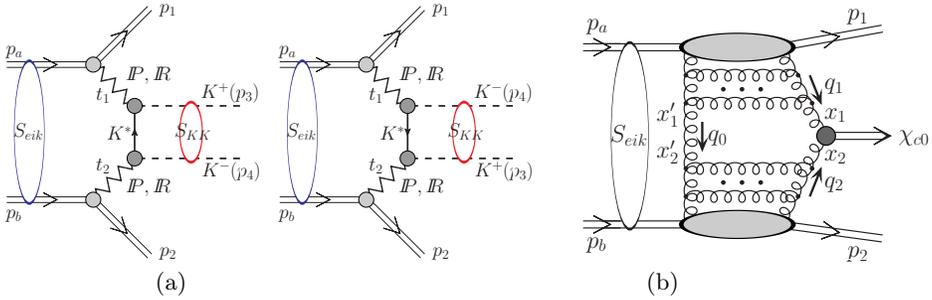


Fig. 1. The central diffractive mechanism of exclusive production of  $K^+ K^-$  pairs and the QCD mechanism of  $\chi_{c0}$  CEP including absorptive corrections.

The QCD amplitude for exclusive central diffractive  $\chi_{c0}$  meson production, sketched in Fig. 1 (b), was calculated within the  $k_t$ -factorization approach including virtualities of active gluons [10] and the corresponding cross section is calculated with the help of unintegrated gluon distribution functions (UGDFs). In Ref. [17] we have performed detailed studies of several differential distributions of  $\chi_{c0}$  meson production. In the calculation of the  $\chi_{c0}$  distributions we have used two choices of collinear gluon distributions: GRV94 NLO [20] and GJR08 NLO [21].

### 3. Results

In Fig. 2 we show differential distributions for the  $pp \rightarrow pp K^+ K^-$  reaction at  $\sqrt{s} = 7$  TeV. In these calculations we include absorption corrections. In most distributions the shape is almost unchanged. Our results show that the  $KK$ -rescattering leads rather to an enhancement of the cross section compared to the calculation without  $KK$ -rescattering. The camel-like shape of the rapidity distribution is due to the interference of different components in the amplitude. While the Pomeron–Pomeron exchanges peak at midrapidity, the Pomeron–Reggeon (Reggeon–Pomeron) exchanges peak at backward (forward) kaon rapidities.

Now, we wish to compare differential distributions of kaon from the  $\chi_{c0}$  decay with those for the continuum. In Fig. 3 we show two-kaon invariant mass distribution for the central diffractive  $KK$  continuum and the contribution from the decay of the  $\chi_{c0}$  meson (see the peak at  $M_{KK} \simeq 3.4$  GeV). In these figures the resonant  $\chi_{c0}$  distribution was parameterized in the Breit–Wigner form (see [7]). Results including the relevant kaon pseudorapidity restrictions  $-1 < \eta_{K^+}, \eta_{K^-} < 1$  (RHIC and Tevatron) and  $-2.5 < \eta_{K^+}, \eta_{K^-} < 2.5$  (LHC) are shown. Clear  $\chi_{c0}$  signal with relatively small background can be observed.

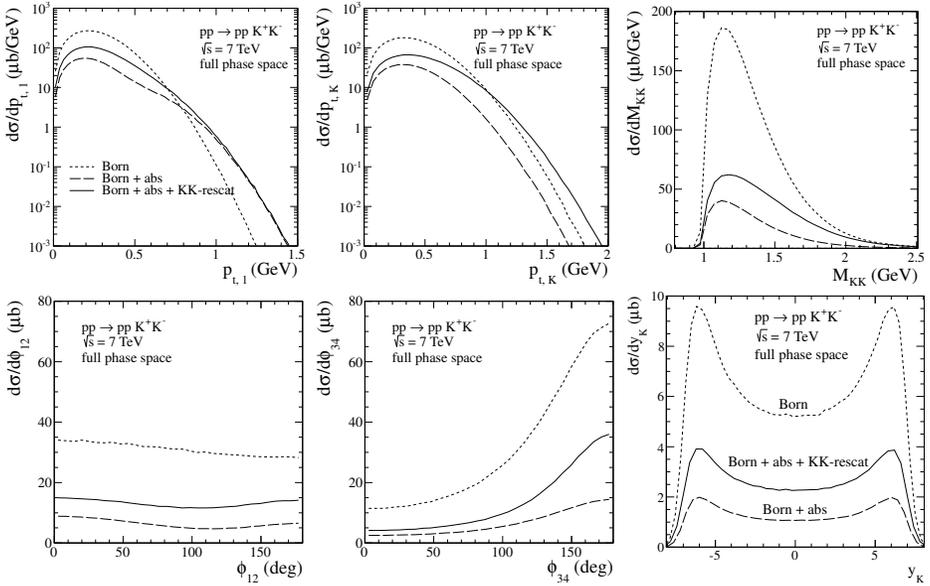


Fig. 2. Differential cross sections for the  $pp \rightarrow pp K^+ K^-$  reaction at  $\sqrt{s} = 7$  TeV without (dotted line) and with (solid line) the absorption effects.

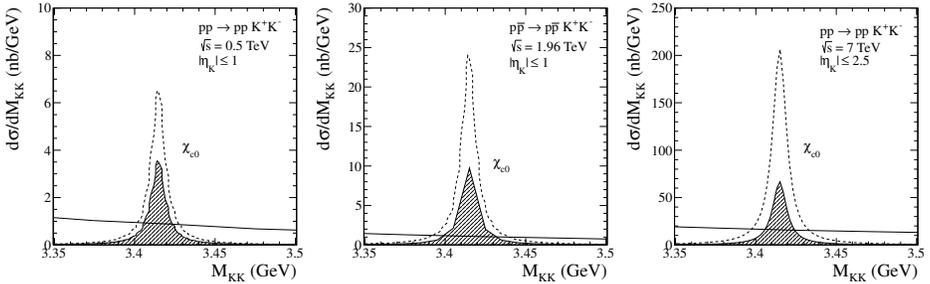


Fig. 3. The  $K^+ K^-$  invariant mass distribution at  $\sqrt{s} = 0.5, 1.96, 7$  TeV with the detector limitations in kaon pseudorapidities. The solid lines present the  $KK$ -continuum. The  $\chi_{c0}$  contribution is calculated with the GRV94 NLO (dotted lines) and GJR08 NLO (filled areas) collinear gluon distributions. The absorption effects have been included in the calculations.

In Fig. 4 we show distributions of kaon transverse momenta. The kaons from the  $\chi_{c0}$  decay are placed at slightly larger  $p_{t,K}$ . This can be therefore used to get rid of the bulk of the continuum by imposing an extra cut on the kaon transverse momenta. It is not the case for the kaons from the  $\phi$  meson decay which are placed at lower  $p_{t,K}$ .

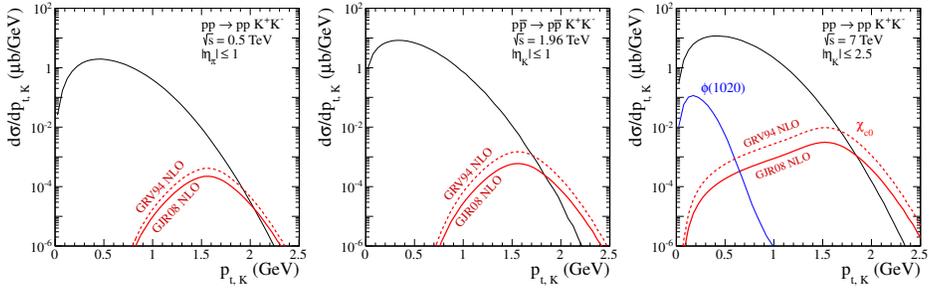


Fig. 4. Differential cross section  $d\sigma/dp_{t,K}$  at  $\sqrt{s} = 0.5, 1.96, 7$  TeV with cuts on the kaon pseudorapidities. Results for the diffractive background (solid lines) and the kaons from the decay of the  $\chi_{c0}$  meson including the  $K^+ K^-$  branching ratio are shown. In the right panel,  $\phi$  meson contribution calculated as in Ref. [19] is shown in addition. The absorption effects have been included here.

The integrated cross section for exclusive  $K^+ K^-$  production slowly rises with incident energy, see Table I.

TABLE I

Integrated cross sections in  $\mu b$  (with absorption corrections) for exclusive  $K^+ K^-$  production. In this calculations we have taken into account the relevant limitations:  $|\eta_K| < 1$  at RHIC and Tevatron,  $|\eta_K| < 2.5$  at LHC.

$\sqrt{s}$ [TeV]	full phase space	with cuts on $\eta_K$
0.5	18.47	1.21
1.96	27.96	1.37
7	41.14	7.38

## 4. Conclusions

We have calculated several differential observables for the exclusive  $pp \rightarrow pp K^+ K^-$  and  $p\bar{p} \rightarrow p\bar{p} K^+ K^-$  reactions. The full amplitude of central diffractive process was calculated in a simple model with parameters adjusted to low energy data. The energy dependence of the amplitudes of the  $KN$  subsystems was parametrized in the Regge form which describes total and elastic cross section for the  $KN$  scattering. We have predicted large cross sections for RHIC, Tevatron and LHC which allows to hope that presented by us distributions will be measured in near future.

At the Tevatron the measurement of exclusive production of  $\chi_c$  via decay in the  $J/\psi + \gamma$  channel cannot provide production cross sections for different species of  $\chi_c$ . In this decay channel the contributions of  $\chi_c$  mesons with different spins are similar and experimental resolution is not sufficient to distinguish them. However, at LHC situation should be better.

We have analyzed a possibility to measure the exclusive production of  $\chi_{c0}$  meson in the proton-(anti)proton collisions at the LHC, Tevatron and RHIC via  $\chi_{c0} \rightarrow K^+K^-$  decay channel. We demonstrated how to impose extra cuts in order to improve the signal-to-background ratio. For a more detailed discussion of this issue see [7]. We have shown that relevant measurements at RHIC, Tevatron and LHC are possible and could provide useful information about the  $\chi_{c0}$  exclusive production.

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