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CENTRAL EXCLUSIVE PRODUCTION OF PION PAIRS IN PROTON–(ANTI)PROTON COLLISIONS*

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We present our results for exclusive $pp \to pp\pi^+\pi^-$ or $p\bar{p} \to p\bar{p}\pi^+\pi^-$ processes at high energies. We discuss the role of new additional absorption corrections in the non-resonant Lebiedowicz–Szczurek model mediated by the Pomeron and Reggeon exchanges. We discuss also the role of the ρ^0 and the Drell–Söding photoproduction mechanism. We compare our predictions with recent experimental results obtained by the STAR and CDF collaborations. We present predictions for the ALICE, ATLAS and CMS experiments. Differential distributions in invariant two-pion mass and two-dimensional distributions in proton–proton relative azimuthal angle and transverse momentum of one of the protons are presented.

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1. Introduction

There is a growing experimental and theoretical interest in understanding of soft hadronic processes at high energy; for reviews, see *e.g.* [1] and references therein. One of the reactions which can be relatively easy to measure is $pp \to pp\pi^+\pi^-$ which constitutes an irreducible background to three-body processes $pp \to ppM$, where $M = \rho(770)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, χ_{c0}, $f_2(1270)$. There are recently several experimental projects by the COMPASS [2], STAR [3], CDF [4, 5], ALICE [6], ATLAS [7], CMS [8] and LHCb [9] collaborations which will measure differential cross sections for the $pp \to pp(M \to \pi^+\pi^-)$ reaction(s). The principal reason for studying central exclusive production of mesons is a search for glueballs [10, 11].

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The exclusive production of lower mass scalar and pseudoscalar resonances within a tensor Pomeron approach [12] was examined recently in [13]. The resonant $\rho^0(770) \to \pi^+\pi^-$ and non-resonant background (Drell–Söding) mechanism via the photon–Pomeron/Reggeon exchanges was considered in [14]. There, the effective vertices and propagators have been taken from Refs. [12] and [15]. The coupling parameters of tensor Regge exchanges are fixed based on the HERA data for the $\gamma p \to \rho^0 p$ reaction.

Some time ago, we proposed a simple phenomenological Regge-like model for the $\pi^+\pi^-$-continuum mechanism [16]. For early studies of two pion production, see Refs. [17,18]. Recently, the Lebiedowicz–Szczurek model [16] was implemented in GenEx MC [19]. Another related generator is DIME MC [20]. In Refs. [21,22], the continuum background was considered to the production of $\chi_c(0^+)$ decaying into $\pi^+\pi^-$ or K^+K^- channels. For exclusive production of other mesons, see *e.g.* [23–25], where mainly the non-central processes were discussed.

2. Sketch of formalism

The Born amplitude with the intermediate π-exchange can be written as

$$\mathcal{M} = M_{13}(s_{13},t_1)\frac{F_\pi^2(t)}{t-m_\pi^2}M_{24}(s_{24},t_2) + M_{14}(s_{14},t_1)\frac{F_\pi^2(u)}{u-m_\pi^2}M_{23}(s_{23},t_2)\,, \tag{1}$$

where the subsystem amplitudes $M_{ij}(s_{ij},t_i)$ denote "interaction" between forward proton ($i=1$) or backward proton ($i=2$) and one of the two pions ($j=3$ for π^+ or $j=4$ for π^-). In the Lebiedowicz–Szczurek model [16,21,26], the parameters of Pomeron and subleading Reggeon exchanges were adjusted to describe total and elastic πN scattering. The largest uncertainties in the model are due to the unknown form of off-shell pion form factor $F_\pi(k^2)$ and the absorption corrections calculated here in the eikonal approximation, see diagrams in Fig. 1. Recently, in [27], we estimated new absorptive corrections due to the proton–pion rescattering in the final state.

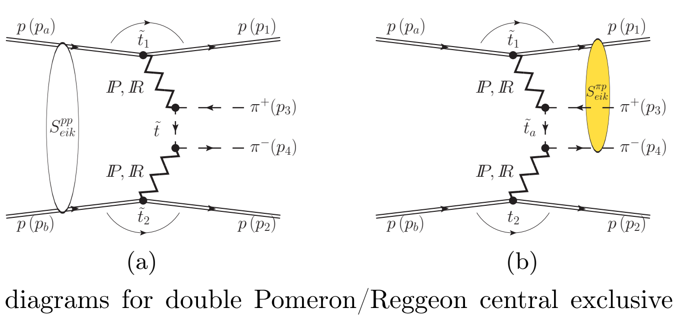

Fig. 1. The diagrams for double Pomeron/Reggeon central exclusive continuum $\pi^+\pi^-$ production including the absorptive corrections due to the pp interaction (diagram (a)) and due to the πp interaction (diagram (b)).

3. Results and conclusions

Recently, we have discussed the role of soft pp- and πp-rescattering corrections. In Fig. 2, we show two-dimensional distributions in proton–proton relative azimuthal angle and transverse momentum of one of the protons without (left panel) and with (right panel) the absorption corrections. The absorption effects lead to substantial damping of the cross section and to a shape deformation of differential distributions in contrast to the commonly used uniform factor known as the gap survival factor. The damping depends on the collision energy and kinematical variables. The ratio of full and Born cross sections $\langle S^2 \rangle$ (the gap survival factor) is approximately 0.20 (STAR), 0.09 (CDF), 0.12 (LHC). This could be verified in future in experiments where both protons are measured, such as ATLAS–ALFA or CMS–TOTEM.

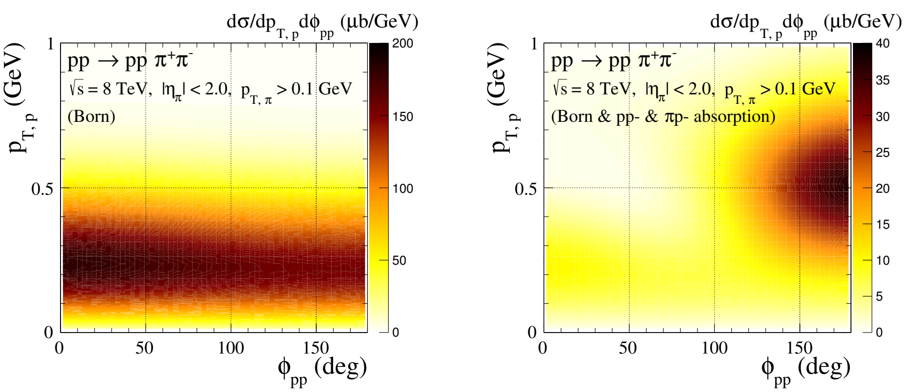

Fig. 2. Two dimensional distributions in $p_{t,p}$ and ϕ_{pp} at $\sqrt{s} = 8$ TeV with the CMS kinematical cuts. We show the distributions without and with the absorption corrections, see Fig. 1. In this calculation, we have used $\Lambda_{\mathrm{off},E} = 1.6$ GeV.

Now, we wish to compare predictions of the Lebiedowicz–Szczurek model with full absorption with the recent STAR and CDF data and present predictions for the LHC experiments. In Fig. 3, we show two-pion invariant mass distribution for different experiments with relevant kinematical cuts. At $M_{\pi\pi} \simeq 1$ GeV, the STAR and CDF data show a minimum due to interference of the $f_0(980)$ resonance contribution with the non-resonant background contribution. At higher $M_{\pi\pi}$, some structures could be attributed most probably to $f_2(1270)$, $f_0(1370)$, $f_0(1500)$, and $f_0(1710)$ resonant states[1]. One can observe that our predictions are quite sensitive to the form of the off-shell pion form factors and depend on the value of the cut-off parameters Λ_{off}. If we describe the maximum of the cross section around $M_{\pi\pi} \sim 0.6$ GeV

[1] The $f_0(1500)$ and the $f_0(1710)$ mesons are considered to be scalar glueball candidates [11], but mixing with quarkonium states complicates the issue.

measured by the STAR experiment, we overestimate the cross section in the interval $1 < M_{\pi\pi} < 2$ GeV. A part of the effect may be related to an enhancement of the cross section due to $\pi\pi$ low-energy final state interaction [16, 17, 28]. Therefore, we might expect that at higher masses, the non-resonant model gives realistic predictions with the off-shell pion form factor parameter $\Lambda_{\rm off} \approx 1$ GeV.

Using the tensor–Pomeron approach, we have included the $\rho(770)$ resonance and the non-resonant Drell–Söding contributions (the gray solid/green lines in Fig. 3) which constitute the main source of P-wave in the $\pi^+\pi^-$

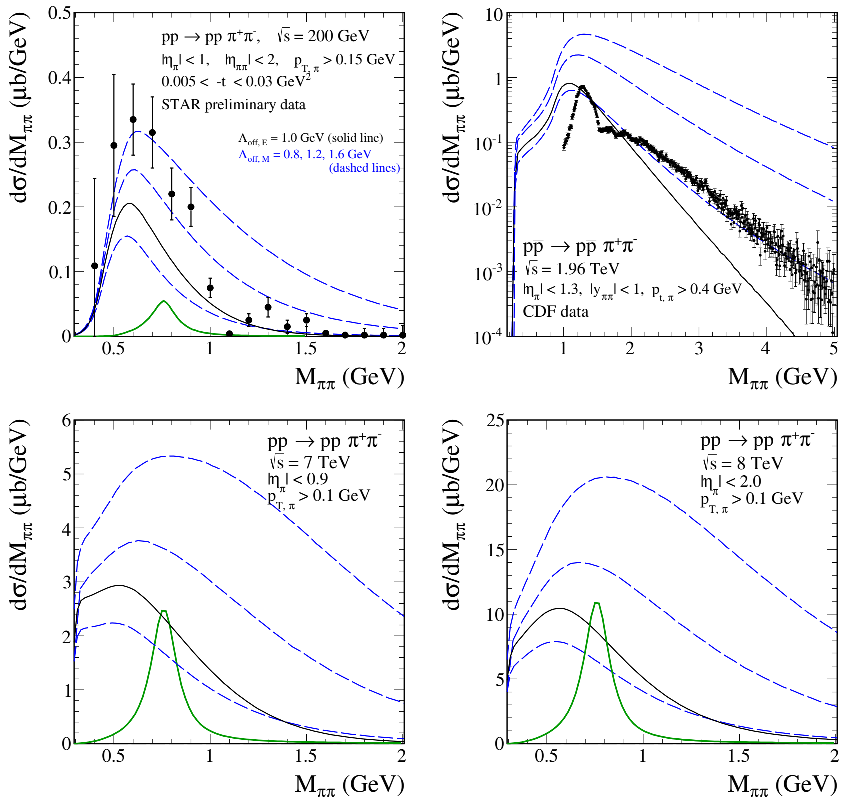

Fig. 3. Two-pion invariant mass distribution at $\sqrt{s} = 0.2, 1, 96, 7$ and 8 TeV with the experimental kinematical cuts indicated in the legend. We show results for the double Pomeron/Reggeon contribution including all absorption corrections discussed in [27]. The dashed/blue lines represent the results obtained for the monopole form factors in Eq. (1) $F_\pi(k^2) = (\Lambda^2_{{\rm off},M} - m^2_\pi)/(\Lambda^2_{{\rm off},M} - k^2)$ and $\Lambda_{{\rm off},M} = 0.8, 1.2, 1.6$ GeV (from bottom to top), while the solid/black lines are for the exponential form $F_\pi(k^2) = \exp[(k^2 - m^2_\pi)/\Lambda^2_{{\rm off},E}]$ and $\Lambda_{{\rm off},E} = 1.0$ GeV. The gray solid/green lines represent results for the photoproduction contribution [14]. The STAR [3] and CDF [4, 5] data are shown for comparison.

channel in contrast to even waves populated in double-Pomeron/Reggeon processes. Due to the photon propagators occurring in these diagrams, we expect these processes to be most important when at least one of the protons is undergoing only a very small momentum transfer $|t|$. We have observed that at midrapidities, imposing *e.g.* a cut $|\eta_\pi| < 0.9$, the photoproduction term could be visible in experiments. The absorptive corrections for photon induced reactions lead to only about 10% reduction of the cross section.

It would clearly be interesting to extend the studies of central meson production for other resonances such as the $f_0(980)$ and $f_2(1270)$ mesons decaying into $\pi^+\pi^-$ channel. Then, the interference effects of the resonance signals with the two-pion continuum has to be included in addition. This requires a consistent model of the resonances and the non-resonant background. The interference effects may depend on t_1 and t_2 that are very different for RHIC, Tevatron and LHC experiments. This aspects should be addressed in future [29].

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