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Charge “asymmetry” from the isospin symmetry in $pp \to pp\pi^+\pi^-$

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Abstract. Charge “asymmetry” meant as $\sigma_{+-} = \mathrm{d}\sigma/\mathrm{d}M_{p\pi^+} - \mathrm{d}\sigma/\mathrm{d}M_{p\pi^-}$ is easy to reproduce by the simple-minded reaction mechanism, which stems on the interference of Δ^{++} and Δ^0 excited in one of the colliding protons. High-quality experimental data for the $pp \to pp\pi^+\pi^-$ reaction taken at CELSIUS storage ring with the PROMICE/WASA detector can be described by the Lorentz-invariant phenomenological approach. The same approach is applied for the description of the asymmetry between $M_{pp\pi^+}$ and $M_{pp\pi^-}$ invariant-mass spectra.

PACS. 13.75.-n Hadron-induced low- and intermediate-energy reactions and scattering (energy ≤ 10 GeV) – 25.40.Ve Other reactions above meson production thresholds (energies > 400 MeV)

1 Introduction

Recent measurements of the two-pion production, $pp \to pp\pi^+\pi^-$ at the CELSIUS storage ring [1] reveal a pronounced asymmetry between $p\pi^+$ and $p\pi^-$, as well as between $pp\pi^+$ and $pp\pi^-$ invariant-mass spectra.

In this paper a possibility of the description of the observed anisotropy via $\Delta(1232)$ excitation in the intermediate state off one of the participating protons is examined. As follows from the isospin symmetry, contributions of Δ^{++} and Δ^0 are different, their relative contributions to the amplitude being independent of the isospin of the exchanged mesons. Besides, it looks probable that charge “asymmetry” is not sensitive to the particular dynamics of the $\Delta(1232)$ excitation. Schematically such a mechanism is depicted in figs. 1(a)-(b). Figure 1(c) stands for the contributions not concerned with $\Delta(1232)$ excitation (non-Δ terms). One of the possible scenarios of this kind has been considered in ref. [2]. The authors of this paper claim that the leading contribution is due to the excitation of the Roper resonance $N^*(1440)$ decaying as $N^* \to \Delta\pi$ or directly $N^* \to N\pi\pi$. However, the phenomenological approach [1] based on the results of the work [2] is not capable of describing the charge “asymmetry” observed in the reaction $pp \to pp\pi^+\pi^-$.

A simple phenomenological approach, discussed in this paper, allows to successfully describe the observed “asymmetry” within the framework of minimal assumptions. The approach is Lorentz invariant, and is therefore applicable at higher energies.

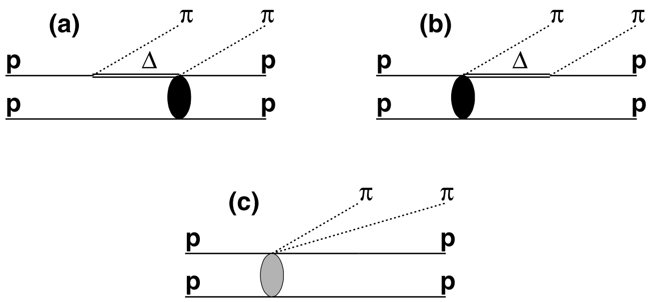

Fig. 1. Diagrams for the two-pion production reaction $pp \to pp\pi^+\pi^-$: (a) and (b): $\Delta(1232)$ excitation; (c): non-Δ terms.

2 Amplitude of the reaction $pp \to pp\pi^+\pi^-$

The Lorentz-invariant reaction amplitude, corresponding to the diagrams in figs. 1(a)-(c) can be written as

$$\mathcal{A} \sim A + B\ k_1^\mu k_2^\nu \left[\mathcal{D}_{\mu\nu}(P_{\Delta^0}) + 3\mathcal{D}_{\mu\nu}(P_{\Delta^{++}})\right] , \qquad (1)$$

where $k_{1,2}$ are pions 4-momenta, P_{Δ^0} and $P_{\Delta^{++}}$ are 4-momenta of the Δ^0 and Δ^{++}, respectively. A and B are considered as smooth functions of k_1 and k_2. $\mathcal{D}_{\mu\nu}(P)$

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stands for the symmetric part of the Δ-propagator:

$$\mathcal{D}_{\mu\nu}(P) = \frac{g_{\mu\nu}P^2 - P_\mu P_\nu}{P^2 - M^2 + iM\Gamma} \; . \tag{2}$$

M and Γ are the mass and width of the $\Delta(1232)$-resonance. Δ^0 and Δ^{++} contribute to the amplitude with different weights (see also [2]). It is this consequence of the isospin symmetry which gives rise to the asymmetry σ_{+-} between $p\pi^+$ and $p\pi^-$ invariant-mass spectra. The same holds true for the asymmetry between $pp\pi^+$ and $pp\pi^-$ spectra.

The complete expression for the Δ-propagator used in the numerical calculations looks as (see, *e.g.*, the review [3])

$$\frac{\hat{P} + M}{P^2 - M^2 + iM\Gamma} \times \left(-g_{\mu\nu} + \frac{\gamma_\mu \gamma_\nu}{3} + \frac{\gamma_\mu P_\nu - \gamma_\nu P_\mu}{3M} + \frac{2}{3}\frac{P_\mu P_\nu}{M^2} - \frac{2}{3}\frac{P^2 - M^2}{M^2}\left[\gamma_\mu P_\nu - \gamma_\nu P_\mu + (\hat{P} + M)\gamma_\mu \gamma_\nu\right] \right) \; . \tag{3}$$

This particular form of the Δ-propagator is dictated by the following physical requirements: low-energy πN scattering via Δ should follow a typical p-wave behaviour. By neglecting small antisymmetric terms in the propagator we arrive at the simple form (1) for the amplitude.

3 Results

Shown in figs. 2(a)-(b) are the numerical results of our calculations in comparison with the experimental data. We stress once again that the charge "asymmetry" is only slightly dependent on the particular parameterization of the functions A and B entering eq. (1). It points to an independence of the asymmetry from the details of the dynamics of the intermediate Δ production thus leaving room for a fit of the other invariant-mass spectra.

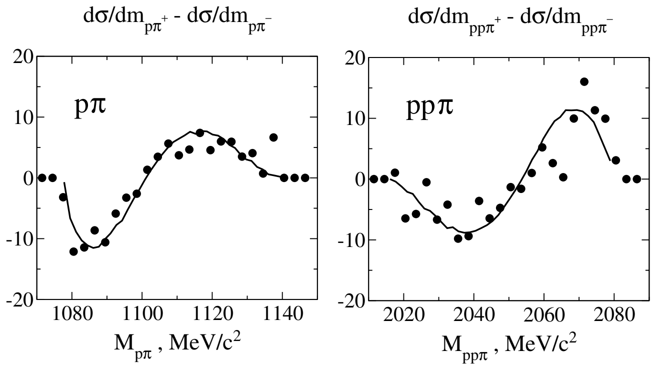

Fig. 2. The asymmetry σ_{+-} (nb $\cdot$ c^2/MeV) as a function of $p\pi$-invariant mass (left) and $pp\pi$-invariant mass (right). Solid lines: results of the calculations with the amplitude (1); dots: experimental data taken at CELSIUS [1].

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