Resonance behaviour of the reactions $pp \rightarrow \{pp\}_s\pi^0$ and $pd \rightarrow pd\pi\pi$ in the 1-2 GeV region

Yu.N. Uzikov[1,2,*]

[1]Joint Institute for Nuclear Researches, Dubna, Russia
[2]Dubna State University, Dubna, Russia

Abstract. Resonance peaks observed in the cross sections of the reaction $pp \rightarrow \{pp\}_s\pi^0$, where $\{pp\}_s$ is the $^1S_0$ state of the proton pair, and $pd \rightarrow pd\pi\pi$ in the GeV region are considered in the framework of mechanisms involving known baryon and two-baryon resonances.

1 Introduction

Before to discuss resonance structures observed recently in pp- and pd-collisions in the GeV region and their possible connection with exotic dibaryon states it is worth to remind some facts from physics at intermediate energies. In 1957 in Dubna was observed quasi-elastic knockout of a fast deuteron from the carbon target $p + {}^{12}C \rightarrow d + X$ at 670 MeV with unexpectedly large cross section [1]. Since the deuteron is a weakly bound system, its production with high transferred momentum and energy seems to be very unusual. Therefore D.I. Blokhintsev [2] assumed that some compact fluctuations (fluctons) of the nuclear density are probed in this reaction. This fruitful idea later on was reformulated as a hypothesis about multiquark configurations in nuclei which is developing up to now. However, just at 670 MeV in the reaction of backward elastic scattering of protons off the deuteron $pd \rightarrow dp$ the excitation of the $\Delta(1232)$-isobar dominates. For the first time it was shown within the mechanism of triangle diagram with one pion exchange [3], and later on by explicit inclusion of the double scattering mechanism with the Δ-isobar in the intermediate state [4]. Parameters of the Δ-isobar amplitude were not well justified in [4] that was a reason to introduce in [4] the three-baryon resonances (nine-quark configurations) into the $pd \rightarrow dp$ process. After correction the contribution of three-baryons was essentially diminished [5]. Mechanism with the Δ-isobar masks short-range NN-correlations and its spin structure is not well known,therefore, it is desirable to diminish its contribution. A possible way to suppress the Δ-contribution was suggested in [6] where the reaction $pd \rightarrow \{pp\}_s n$ with the final diproton $\{pp\}_s$ in the $^1S_0$ state instead of the deuteron was studied in kinematics of pd- backward (quasi)elastic scattering. In this reaction the Δ-isobar mechanism is suppressed by the isospin conservation [6, 7]. The corresponding experiment was performed at ANKE@COSY [8] and measured observables were found indeed to be very sensitive to behaviour of NN-interaction potential at short distances.

A rather similar situation occurs with the $pp \rightarrow d\pi^+$ reaction at 500-800 MeV, where the cross section has a resonance maximum. This maximum was explained as a result of the Δ-isobar excitation [9]. However, new analysis [10] shows that this mechanism is not sufficient

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*e-mail: uzikov@jinr.ru,

and, therefore, the dibaryon contribution was introduced in [10] to fit the data. Since the deuteron and diproton have different quantum numbers of spin and isospin ST=01 and 10, respectively, a study of the reaction $pp \rightarrow \{pp\}_s\pi^0$ in the same kinematics as the reaction $pd \rightarrow d\pi^+$ could give a new independent test of the dynamics of the single pion production.

2 Reaction $pp \rightarrow \{pp\}_s\pi^0$

Recently differential cross section and vector analyzing power A_y of the one-pion production reaction $pp \rightarrow \{pp\}_s\pi^0$, were measured by ANKE@COSY [11] at proton beam energies 0.3-0.8 GeV. A resonance behavior of the differential cross section was observed at 0.6-0.8 GeV. This behaviour and measured A_y were described using fit by two isovector Breit-Wigner resonances in the $^3P_0$ and $^3P_2$ states. Contribution of the Δ-isobar mechanism to this reaction depicted in Fig. 1 was studied in [12]. The parameters for the coupling constants and vertex
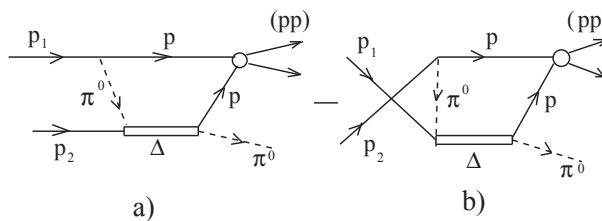

Figure 1. The Δ-isobar mechanism of the reaction $pp \rightarrow \{pp\}_s\pi^0$ with the direct (a) and exchange (b) terms.

form factors which were used to explain the COSY data on the reaction $dp \rightarrow \{pp\}_s\pi N$ [13], are applied here. The calculated energy dependence of the differential cross section of the reaction $pp \rightarrow \{pp\}_s\pi^0$ at zero angle of the pion is dominated by three partial waves of the pp-channel $^3P_0, ^3P_2$ and $^3F_2$ being in qualitative agreement in shape with the data at energy 350-800 MeV (Fig. 2). The model explains the position of the peak observed at ≈ 0.7 GeV and zero diproton scattering angle, but underestimates its absolute value if the off-shell 4-momenta of the pion and proton are taken into account in the $\pi N\Delta$-vertices [12]. Furthermore, the Δ-mechanism fails to describe anomalous sign of the slope of the angular dependence of $d\sigma/d\Omega$ and large analyzing power A_y observed in [11]. Therefore, non-one loop diagrams with the Δ-isobar cannot be excluded in the region of the observed peak.

3 Two-pion production in the reaction $pd \rightarrow pd\pi\pi$

Differential cross section the reaction $pd \rightarrow pd\pi\pi$ was measured in [16] at beam energies 0.8-2.0 GeV with high transferred momentum to the deuteron at small scattering angles of the final proton and deuteron. The resonance-like peaks in distribution over the invariant mass of the $d\pi\pi$ system are found close to 2.380 GeV that is the mass of the isoscalar two-baryon resonance $D_{IJ} = D_{03}$ observed by WASA@COSY in the reaction $pn \rightarrow d\pi^0\pi^0$ [17]. Two mechanisms of this reaction involving excitation of the Roper resonance $N^*(1440)$ and two Δ-isobars were studied in [18]. Both these mechanisms understimate the observed in [16] cross section by two orders of magnitude. The reason is that in the limit of impulse approximation these mechanisms contain the deuteron elastic formfactor $S(Q)$ at high transferred momentum Q to the deuteron that is small at high Q. Another mechanism suggested in [19] for the reaction $pn \rightarrow d\pi^0\pi^0$ does not involve the deuteron formfactor but involves
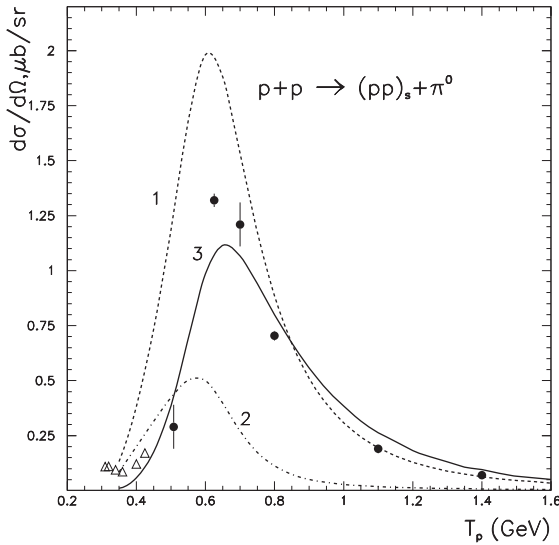
Figure 2. The differential cross section of the reaction $pp \rightarrow \{pp\}_s\pi^0$ at zero angle of the diproton. The lines show results of calculations [12] based on the Δ-mechanism (Fig. 1) for the direct (1), exchange (2) term and their coherent sum(3); experimental data are taken from Ref. [14] ($\bullet$), and Ref. [15] ($\triangle$).

two dibaryon resonances, $D_{03}(2380)$ and $D_{12}(2150)$. A modified version of this mechanism with the σ-meson exchange between the proton and deuteron is applied here to the process $pd \rightarrow pd\pi\pi$ (Fig. 3). Since the $\sigma d \rightarrow D_{03}$ partial width is not known so far, one cannot estimate the absolute value of the cross section within this mechanism. However, we find that this mechanism explains qualitatively the shape of the distribution over the invariant mass of two final pions $M_{\pi\pi}$ (see Fig. 4).
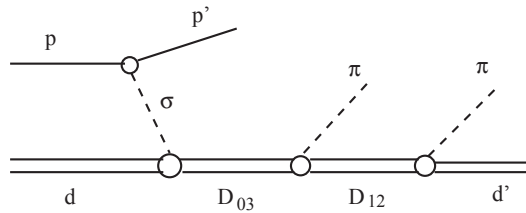
Figure 3. Two resonance mechanism of the reaction $pd \rightarrow pd\pi\pi$ (see text).

4 Conclusion

The cross section of the reaction $pp \rightarrow \{pp\}_s\pi^0$ in the region of the resonance peak observed at ≈ 0.7 GeV was considered on the basis of the $\Delta-$isobar excitation mechanism. Position of the peak is explained by this model, whereas its shape, magnitude and angular dependence of the differential cross section and A_y are not reproduced. Therefore, others mechanisms accounting for $\Delta - N$ interaction in the intermediate state may be important in this process. The magnitude of the resonance peaks in the $M_{d\pi\pi}$ distribution of the reaction $pd \rightarrow pd\pi\pi$ cannot be explained by the Roper resonance or Δ-isobar excitation in the impulse approximation [18]. The model with the $D_{03}(2380)$ and $D_{12}(2150)$ resonances leads to qualitative agreement with the shape of the $M_{\pi\pi}$- distribution.
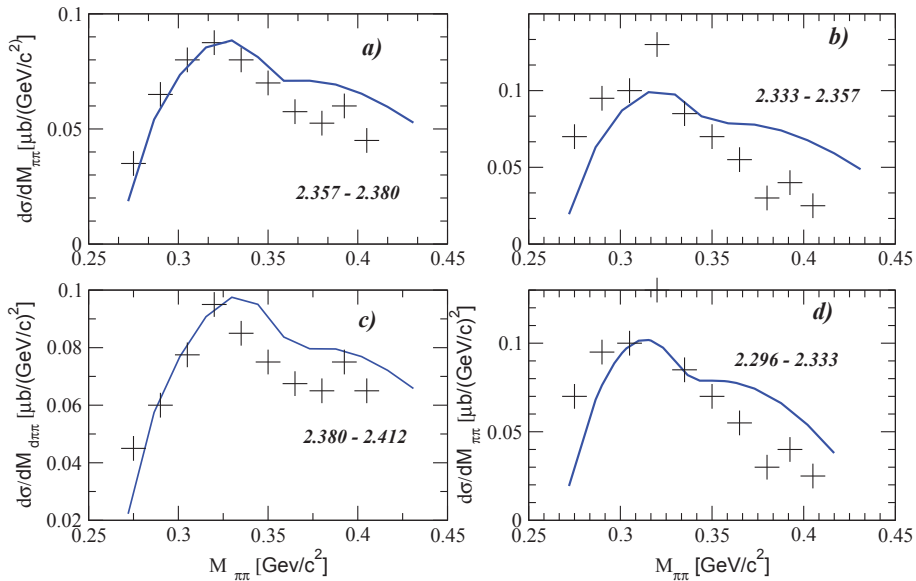
Figure 4. The distribution over the invariant mass of two final pions $M_{\pi\pi}$ calculated according to the mechanism in Fig. 3 in different intervals of the $d\pi\pi$ invariant mass (shown in pictures) in comparison with the data [16] (+) and normalized to these data.

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