

Measurement of the $pn \rightarrow pp\pi^0\pi^-$ Reaction in Search of the ABC Resonance

T. Skorodko^{1,2}, M. Bashkanov^{1,2}, H. Clement^{1,2,a}, E. Doroshkevich^{1,2}, E. Perez del Rio^{1,2},
A. Pricking^{1,2}, and G. J. Wagner^{1,2} for the WASA-at-COSY Collaboration

¹ Physikalisches Institut, Univ. Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

² Kepler Center for Astro and Particle Physics, Univ. Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

Abstract. With pd collisions at $T_p = 1.2$ GeV exclusive measurements of the quasi-free $pn \rightarrow pp\pi^0\pi^-$ reaction have been carried out. Using the WASA detector setup at COSY total and differential cross sections have been obtained for the energy region $\sqrt{s} = 2.35 - 2.48$ GeV. Though this includes the region of the ABC effect and its associated resonance structure, no low-mass enhancement (ABC effect) is found in the $\pi^0\pi^-$ -invariant mass spectrum – in agreement with the constraint from Bose statistics demanding the isovector pion pair to be in relative p -wave. Conventional calculations including t -channel processes for Roper, $\Delta(1600)$ and $\Delta\Delta$ excitations and their decays, which are well-known from the study of the two-pion production in pp collisions, provide a reasonable description of the data at high energies, but fall low at low energies. From this we conclude that a large contribution from a so far unknown isoscalar low-energy process is missed in the calculations. Inclusion of the ABC resonance at $m = 2.37$ GeV with $\Gamma = 70$ MeV and $I(J^P) = 0(3^+)$, which was recently observed in the $pn \rightarrow d\pi^0\pi^0$ reaction, leads to a much improved description of the data at low energies.

1 Introduction

Recent data on the basic double-pionic fusion reaction $pn \rightarrow d\pi^0\pi^0$ demonstrate that the so-called ABC effect is tightly correlated with a narrow resonance structure in the total cross section of this reaction [1, 2]. The ABC effect denoting a huge low-mass enhancement in the $\pi\pi$ invariant mass spectrum is observed to happen, if the initial nucleons or light nuclei fuse to a bound final nuclear system and if the produced pion pair is isoscalar. Since as of yet no quantitative understanding of this phenomenon has been available, it has been named after the initials of Abashian, Booth and Crowe, who first observed it in the inclusive measurement of the $pd \rightarrow {}^3\text{He}X$ reaction more than fifty years ago [3].

In exclusive high-statistics measurements of the isoscalar $pn \rightarrow d\pi^0\pi^0$ reaction it has recently been shown that this ABC effect is correlated with a pronounced resonance structure in the total cross section at $\sqrt{s} = 2.37$ GeV with a width of only 70 MeV and quantum numbers $I(J^P) = 0(3^+)$ [1]. This structure is situated about 90 MeV below $\sqrt{s} = 2m_{\Delta}$, the peak position of the conventional t -channel $\Delta\Delta$ process, and has a width, which is about three times narrower than this process. From the Dalitz plots of the $pn \rightarrow d\pi^0\pi^0$ reaction it is concluded that this resonance decays nevertheless via the intermediate $\Delta^+\Delta^0$ system into its final $d\pi^0\pi^0$ state.

If this scenario is correct, then also the $pn \rightarrow pp\pi^0\pi^-$ reaction should be affected by this resonance, since this channel may proceed via the same intermediate $\Delta^+\Delta^0$ system.

^a e-mail: clement@pit.physik.uni-tuebingen.de

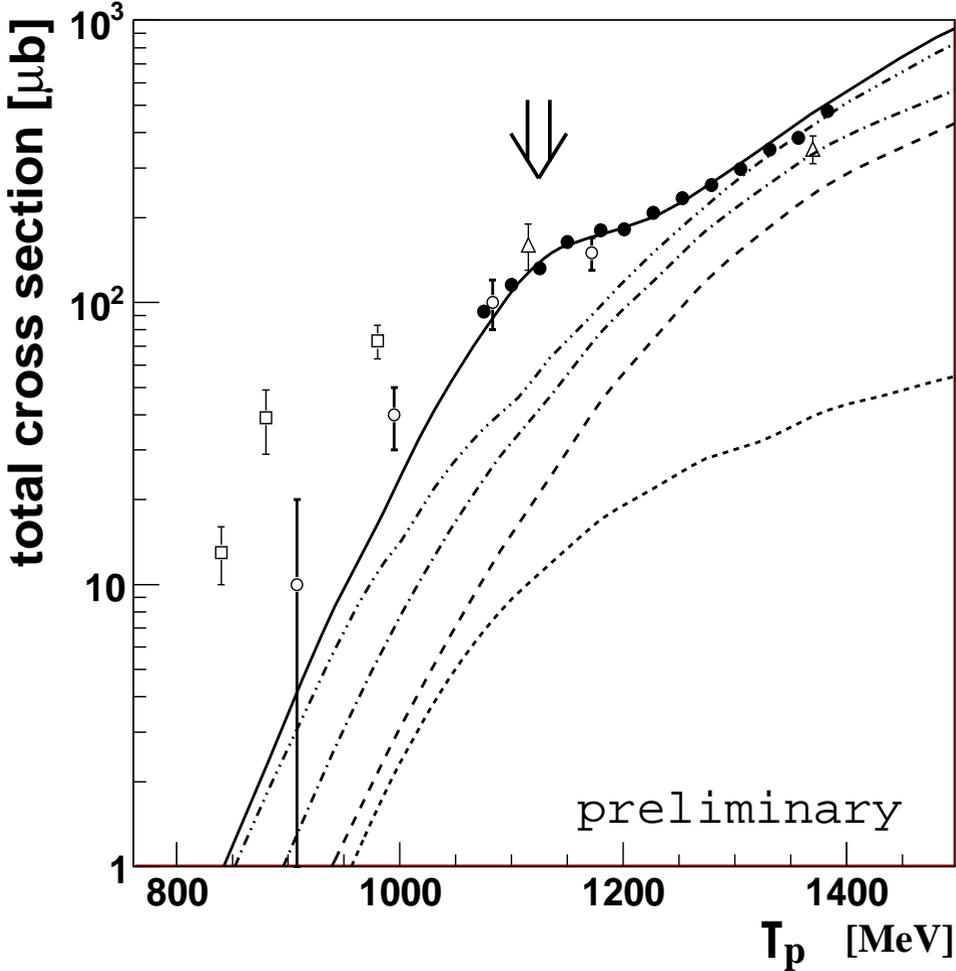


Fig. 1. Energy dependence of the total cross section for the $pn \rightarrow pp\pi^0\pi^-$ reaction. The preliminary results of this work are shown by the full circles, previous bubble-chamber measurements from KEK [7] by open circles, from NIMROD at RAL [8] by open triangles and from Gatchina [9] by open squares. The original Valencia model calculations are shown by the dash-dotted lines. Contributions from Roper excitation and its decay into $N^* \rightarrow \Delta\pi$ are given by the dotted lines and those from the t -channel $\Delta\Delta$ process by the dashed lines. The modified Valencia model calculation (see text) is shown by the dot-dot-dashed lines. The solid lines show the result, if the s -channel ABC resonance amplitude is added. The vertical arrow indicates the position of the ABC resonance.

2 Experiment and Results

We have investigated this question experimentally by using a pd run taken at $T_p = 1.2$ GeV with the WASA detector facility at COSY [4,5]. The data have been analyzed for the reaction $pd \rightarrow pp\pi^0\pi^- + p_{spectator}$ utilizing quasifree kinematics. That way we obtain a data sample spanning the energy region $2.35 \text{ GeV} \leq \sqrt{s} \leq 2.45 \text{ GeV}$ and thus also covering the region of the ABC effect and its associated resonance structure.

The observed differential cross sections are reasonably well described by conventional t -channel resonance processes [6]. In particular the $\pi^0\pi^-$ invariant mass spectra show no ABC effect – in agreement with the fact that the isovector pion pair must be in relative p -wave and hence strongly suppresses

any low-mass enhancement. Preliminary results for the total cross section are shown in Fig. 1 together with previous data from Bubble chamber measurements [7–9]. They exhibit a smoothly and monotonically rising total cross section with some indication of a flat top in the energy region of the ABC effect. As already observed in other two-pion production channels [10, 16] the Gatchina bubble-chamber data [9] (open squares in Fig. 1) lie high compared to all other data. Since there appears to be a systematic problem with these data, we omit them in the subsequent discussion.

Original Valencia model calculations [10], which are based on resonant and non-resonant t -channel processes for the two-pion production are depicted by the dash-dotted line with their largest contributions originating from Roper excitation and its decay route $N^* \rightarrow \Delta\pi$ (dotted) as well as from the $\Delta\Delta$ process, the mutual excitation of two nucleons into the $\Delta(1232)$ state (dashed). Modified calculations of the Valencia model, which are tuned to describe the isovector pp -induced channels quantitatively by modifications of the Roper decay process [11–14], the $\Delta\Delta$ excitation process [15] as well as inclusion of the $\Delta(1600)$ resonance [16, 17], give a somewhat larger cross section and lead to agreement with the data at high energies. However, at low energies they still under-predict the observed cross section severely. This failure points to an isoscalar reaction component, not included in the t -channel treatment of two-pion production.

It is intriguing that this failure appears to be largest in the energy region, where the ABC effect has been observed in the other isoscalar channel, the $d\pi^0\pi^0$ channel [1, 2]. Indeed, adding an amplitude for the ABC resonance at $m = 2.37$ GeV with $\Gamma = 70$ MeV, $I(J^P) = 0(3^+)$ and fitting the strength of its contribution to the data leads to a reasonable description of the total cross section also at low energies (solid line in Fig. 1). However, a simultaneous good description of the differential data is only achieved, if the phenomenologically introduced [1] form factor at the $\Delta\Delta$ decay vertex is omitted. Considerations to overcome this problem are worked on [6, 18].

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