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MEASUREMENT OF THE ABC-EFFECT IN THE MOST BASIC DOUBLE-PIONIC FUSION REACTION

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Abstract

The ABC effect - a puzzling low-mass enhancement in the $\pi\pi$ invariant mass spectrum - is known from inclusive measurements of two-pion production in nuclear fusion reactions. The first exclusive measurements carried out at CELSIUS-WASA for the most basic fusion reaction in this context - the $pn \rightarrow d\pi^0\pi^0$ reaction - reveal this effect to be a σ channel phenomenon associated with the formation of a $\Delta\Delta$ system in the intermediate state. The total cross section exhibits a resonance-like energy dependence with a width of 100 MeV or less. Both the ABC effect and the intriguing energy dependence can be accommodated by a quasibound state in the $\Delta\Delta$ system leading to a resonance in the pn and $d\pi^0\pi^0$ systems.

1 Introduction

The ABC effect - first observed by Abashian, Booth and Crowe [1] - in the double pionic fusion of deuterons and protons to ^{3}He, stands for an unexpected enhancement at low masses in the $M_{\pi\pi}$ spectrum. Follow-up experiments [2] revealed this effect to be of isoscalar nature and to show up in cases, when the two-pion production process leads to a bound nuclear system.

Initially the low-mass enhancement had been interpreted by an unusually large $\pi\pi$ scattering length and evidence for the σ meson, respectively [1]. Since the effect showed up particularly clearly at beam energies corresponding to the excitation of two Δs in the nuclear system, the ABC effect was interpreted later on by a $\Delta\Delta$ excitation in the course of the reaction process leading to both a low-mass and a high-mass enhancement in isoscalar $M_{\pi\pi}$ spectra [3–5]. In fact, the missing momentum spectra from inclusive measurements have been in support of such predictions. It has been shown [6] that these structures can be enhanced considerably in theoretical calculations by including ρ exchange and short-range correlations.

2 Experiment and Results

In order to shed more light on this issue, first exclusive measurements of the $pd \rightarrow pd\pi^0\pi^0$ reaction (T_p = 1.03 and 1.35 GeV) have been carried out at T_p = 1.03 and 1.35 GeV at CELSIUS using the 4π WASA detector setup including the deuterium pellet target system [2]. The $pd \rightarrow pd\pi^0\pi^0$ reaction is observed as quasifree $pn \rightarrow d\pi^0\pi^0$ reaction with a low-energetic spectator proton. Since all ejectiles except of the spectator have been measured, the

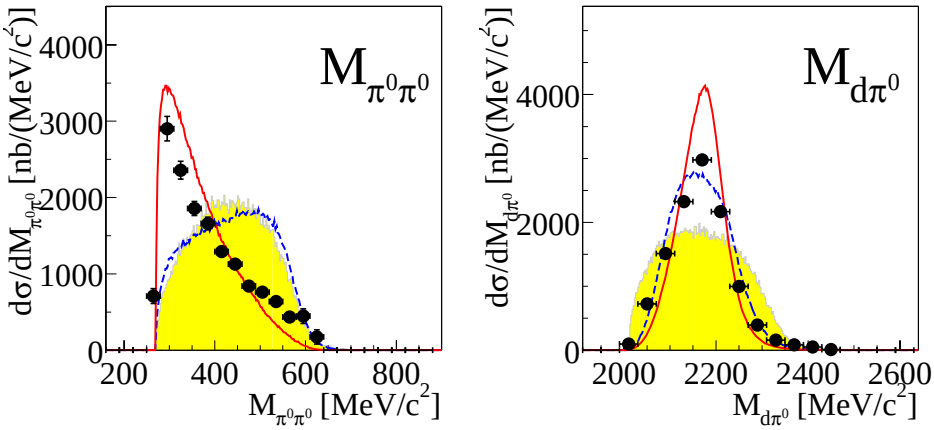

Figure 1: Distributions of the invariant masses $M_{\pi^0\pi^0}$ and $M_{d\pi^0}$ from the exclusive measurement of the quasifree $pn \rightarrow d\pi^0\pi^0$ reaction at a beam energy $T_p = 1.35$ GeV. The shaded areas show the pure phase space distributions. Solid and dashed curves give $\Delta\Delta$ calculations with and without the assumption of a quasibound state in the $\Delta\Delta$ system leading to a resonance in the pn and $d\pi^0\pi^0$ systems.

spectator momentum has been reconstructed by kinematical fits with three overconstraints.

Results of our measurements are shown in Fig. 1. Note that due to Fermi motion of the nucleons in the target deuteron the quasifree reaction process proceeds over a range of effective collision energies with according kinematical smearing in the differential distributions. This smearing may be reduced strongly by dividing the data into narrow bins of effective collision energy at the cost of statistics.

Fig. 1 depicts the spectra of the invariant masses $M_{\pi^0\pi^0}$ and $M_{d\pi^0}$ for the quasifree $pn \rightarrow d\pi^0\pi^0$ reaction at the beam energy $T_p = 1.35$ GeV. The $\pi^0\pi^0$ channel, which is free of any isospin I=1 contributions, exhibits a pronounced low-mass enhancement (ABC effect) in the $M_{\pi^0\pi^0}$ spectrum similar to the situation in the fusion process leading to ^{3}He [2]. The $M_{d\pi^0}$ spectrum shows clearly the excitation of the Δ resonance. The data are only consistently described, if two Δ states are excited simultaneously in this reaction. The spectra shown in Fig. 1 are very similar to the ones obtained at the lower energy [2], i.e. do not change with energy as predicted in previous $\Delta\Delta$ calculations.

Also the $\pi\pi$ low-mass enhancements observed in the exclusive data for the $\pi^0\pi^0$ channels turn out to be much larger than predicted in previous $\Delta\Delta$

calculations [3, 5, 6]. As an example we show by the dashed lines in Figs.1 model ansatz of Ref. [3], where we additionally included the pion angular distribution in Δ decay and the Fermi smearing of the nucleons bound in the final nucleus. Contrary to these predictions the data also do not exhibit any high-mass enhancement.

A clue to the real nature of the ABC effect is provided by the intriguing energy dependence [2] of the double-pionic fusion in the isoscalar channel, which exhibits a pronounced resonance-like excitation with a width of roughly 100 MeV or possibly even below, i.e. much smaller than twice the Δ width expected from usual $\Delta\Delta$ calculations. Both the energy dependence of the total cross section and the differential cross section data can be accommodated by the assumption of a quasibound state in the $\Delta\Delta$ system (solid lines in Fig. 1), which decays into this system to proceed via relative s-waves between the two Δs and which couples to the initial *pn* system.

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