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The ABC Effect in the Double-Pionic Fusion to ^{4}He.

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Abstract. The double-pionic fusion to ^{4}He was measured exclusively and kinematically complete with the WASA 4π detector at COSY for the reactions $dd \rightarrow ^4\mathrm{He}\pi^0\pi^0$ and $dd \rightarrow ^4\mathrm{He}\pi^+\pi^-$. The measurements were performed over the full energy region, where the so-called ABC effect was observed previously in inclusive measurements. Whereas the latter exhibit not only a low-mass enhancement – the ABC-effect – in the ^{4}He missing mass spectrum but also a prominent high-mass enhancement, we observe only a very strong low-mass enhancement and no pronounced high mass enhancement. This is in contrast to theoretical predictions based on *t*-channel $\Delta\Delta$ excitation. Also the energy dependence of the observed total cross section does not fit to such predictions. Both features, however, agree very well with the observations in the most basic double-pionic fusion process in the isoscalar channel $pn \rightarrow d\pi^0\pi^0$.

1 Introduction

The ABC effect – a strong and intriguing low-mass enhancement in the $\pi\pi$ invariant mass spectrum – is known from inclusive measurements of two-pion production in nuclear fusion reactions to the few-body systems d, ^{3}He and ^{4}He [1–11]. Its explanation has been a puzzle for 50 years now.

Initially the low-mass enhancement had been interpreted as an unusually large $\pi\pi$ scattering length and evidence for the σ meson, respectively [1]. Since the effect showed up particularily clear at beam energies corresponding to the excitation of two Δs in the nuclear system, the ABC effect was interpreted later on by a *t*-channel $\Delta\Delta$ 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 [12–17].

2 Experiments and their Results

In an effort to solve this long-standing problem by exclusive and kinematically complete high-statistics experiments, we have measured the fusion reactions to d, ^{3}He and ^{4}He with WASA [18] at COSY. Here we report on the measurements of the double-pionic fusion reactions $dd \rightarrow ^4\mathrm{He}\,\pi^0\pi^0$ and $dd \rightarrow ^4\mathrm{He}\,\pi^+\pi^-$, which have been carried out at nine beam energy settings in the range $T_p = 0.8 - 1.4$ GeV covering the full energy region, where the ABC effect has been observed previously in inclusive reactions. ^{4}He particles have been detected in the Forward Detector, the emitted pions in the Central detector. The neutral pions have been reconstructed from the decay gammas recorded in the Central Detector. By measuring all ejectiles the measurements are kinematically overdetermined permitting kinematic fits with 4 overconstraints in the $\pi^+\pi^-$ channel and 6 overconstraints in the $\pi^0\pi^0$ channel. The increase of overconstraints in the latter channel comes from the fact that for the reconstruction of each of the neutral pions two gammas have to be recombined to the π^0 mass.

The analysis of the full data base is still in progress, however, first results have been obtained for the $dd \rightarrow ^4\mathrm{He}\,\pi^0\pi^0$ reaction at all incident energies. According to previous inclusive single-arm magnetic spectrometer measurements conducted at Saclay [6], the measured energy range covers the full range of significant cross sections in this fusion process.

At all incident energies we find a strong low-mass enhancement in the $\pi^0\pi^0$-invariant mass $M_{\pi^0\pi^0}$ spectrum in qualitative agreement with previous results [6, 10]. However, we do not observe a pronounced high-mass enhancement, which is seen in the ^{4}He missing mass spectra of the inclusive measurements and which is predicted in conventional *t*-channel $\Delta\Delta$ calculations [10, 12, 15].

Figure 1 shows the differential cross sections in dependence of the invariant masses $M_{\pi^0\pi^0}$ and $M_{^4\mathrm{He}\pi^0}$ as well as the respective Dalitz plot at T_d = 1.05 GeV. This is the energy, where the total cross section reaches its maximum. We clearly see that the low-mass enhancement in the $M_{\pi^0\pi^0}$ spectrum is correlated with a $\Delta\Delta$ excitation.

Our results at T_d = 1.05 GeV are in reasonable agreement with the previous CELSIUS/WASA results [19] obtained at T_d = 1.03 GeV. Deviations on the quantitative level arise mainly from the fact, that in the analysis of the CELSIUS data no kinematic fit for the complete event has been carried out. As already was obvious from the CELSIUS data, the lack of a pronounced high-mass enhancement is at variance with the theoretical prediction based on a conventional reaction model [15] – though the theoretical predictions give a good account for the observed angular distributions.

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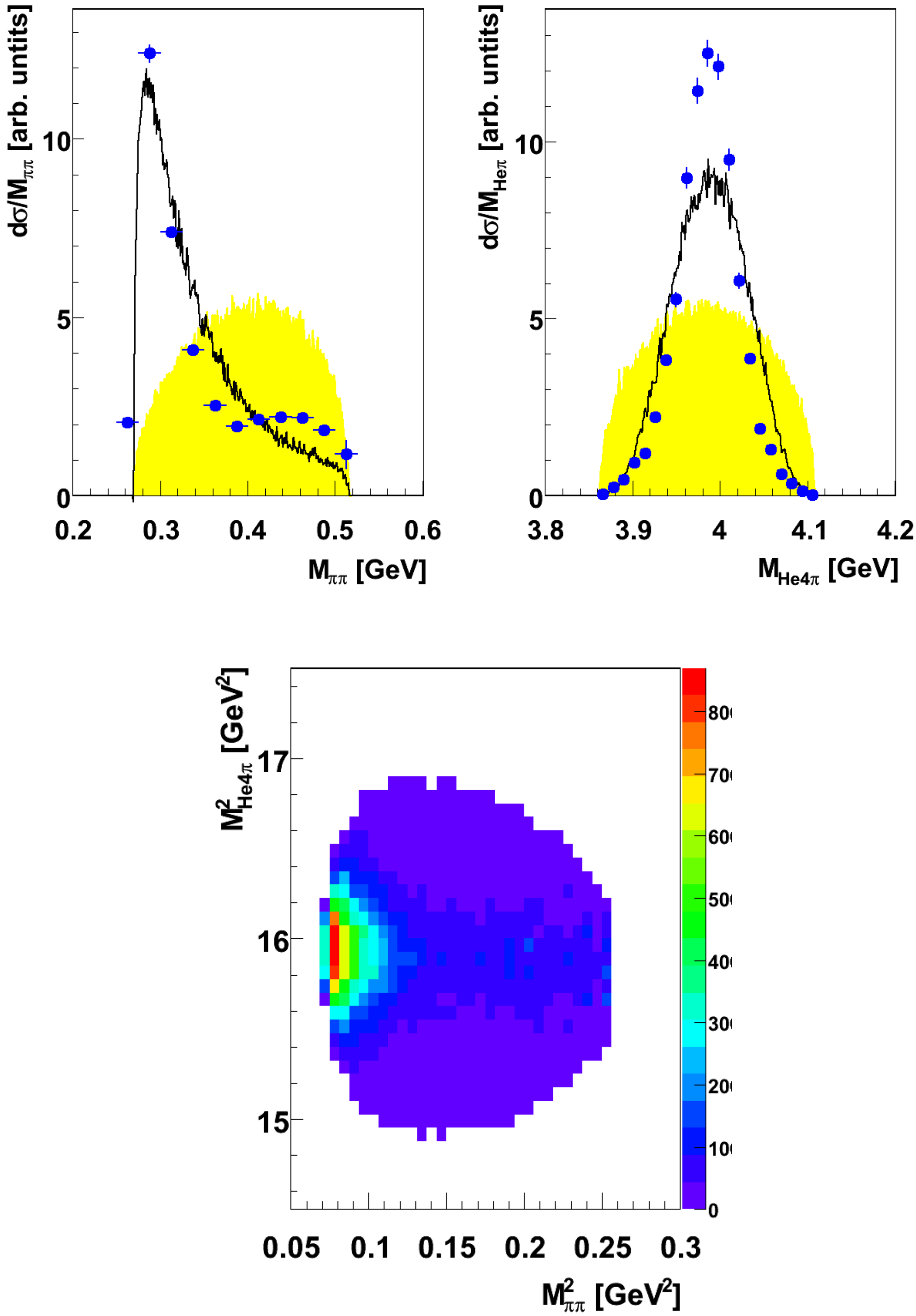

Fig. 1. Differential cross section of the $\pi^0\pi^0$ invariant mass $M_{\pi^0\pi^0}$ (**top left**) and the $^4\mathrm{He}\pi^0$ invariant mass $M_{^4\mathrm{He}\pi^0}$ (**top right**) of the $dd \rightarrow ^4\mathrm{He}\pi^0\pi^0$ reaction at T_d = 1.05 GeV. The solid dots represent the data of this work. The shaded area shows the distributions of pure phase space, whereas the curves are ABC resonance calculations with resonance parameters taken from the $pn \rightarrow d\pi^0\pi^0$ reaction [22, 23]. **Bottom**: Experimental Dalitz plot of $M^2_{\pi^0\pi^0}$ versus $M^2_{^4\mathrm{He}\pi^0}$.

The signatures in the Dalitzplot and its invariant mass projections are close to those observed in the $pd \rightarrow ^3\mathrm{He}\pi\pi$ reaction [20] as well as in the most basic double-pionic isoscalar fusion process, the $pn \rightarrow d\pi^0\pi^0$ reaction [21–24].

In the energy dependence of the total cross section we observe a resonance-like behavior with a cross section maximum roughly 80 MeV below the $\Delta\Delta$ mass — again in close resemblance of the situation observed in the basic reaction.

Hence we apply also for the ^{4}He case a *s*-channel resonance description ("ABC resonance") assuming a *pn* pair participating actively in the double-pion production process in the same way as in the basic process, whereas the other *pn* pair participates just passively as a spectator with the exception of Fermi motion. The result of such a calculation, where we use the resonance parameters from the basic $pn \rightarrow d\pi^0\pi^0$ reaction without any change, is shown by the solids lines in Fig. 1, top.

The Δ excitation (Fig. 1, top right) appears to be slightly narrower than the width of the free Δ, which is assumed in the ABC resonance calculations. This is surprising, since due to collision damping we would have expected to see an increased Δ width as is observed in the $pd \rightarrow ^3\mathrm{He}\pi\pi$ reaction [20].

From the fact that the ABC effect is observed also in the double-pionic fusion to ^{4}He with features as observed in the basic reaction, we conclude that this ABC resonance is obviously robust enough to survive even in nuclei.

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References

1. A. Abashian, N. E. Booth, and K. M. Crowe, Phys. Rev. Lett. **5**, (1960) 258
2. R. J. Homer *et al.*, Phys. Rev. Lett.**9**, (1964) 72
3. J. H.Hall *et al.*, Nucl. Phys. **B12**, (1969) 573
4. I. Bar-Nir *et al.*, Nucl. Phys. **B54**,(1973) 17
5. J. Banaigs *et al.*, Nucl. Phys. **B67**, (1973) 1
6. J. Banaigs *et al.*, Nucl. Phys. **B105**, (1976) 52
7. F. Plouin *et al.*, Nucl. Phys. **A302**, (1978) 413
8. A. Abdivaliev *et al.*, Sov. J. Nucl. Phys.**29**, (1979) 796
9. F. Plouin, P. Fleury, C. Wilkin, Phys. Rev. Lett. **65**, (1990) 690
10. R. Wurzinger *et al.*, Phys. Lett. **B445**, (1999) 423
11. for a review see A. Codino and F. Plouin, LNS/Ph/94-06
12. T. Risser and M. D. Shuster, Phys. Lett. **43B**, (1973) 68
13. I. Bar-Nir, T. Risser, M. D. Shuster, Nucl. Phys. **B87**, (1975) 109
14. J. C. Anjos, D. Levy, A. Santoro, Nucl. Phys. **B67**, (1973) 37
15. see, e.g., A. Gardestig, G. Fäldt, C. Wilkin, Phys. Rev. **C59**, (1999) 2608 and Phys. Lett. **B421**, (1998) 41
16. C. A. Mosbacher, F. Osterfeld, nucl-th/9903064
17. L. Alvarez-Ruso, Phys. Lett. **B452**, (1999) 207; PhD thesis, Univ. Valencia 1999
18. Chr. Bargholtz *et al.*, Nucl. Instr. Meth **A594**, (2008) 339
19. S. Keleta *et al.*, Nucl. Phys. **A825**, (2009) 81
20. M. Bashkanov *et al.*, Phys. Lett. **B637**, (2006) 223
21. H. Clement *et al.*, Prog. Part. Nucl. Phys. **61**, (2008) 276
22. M. Bashkanov *et al.*, Phys. Rev. Lett. **102**, (2009) 052301; arXiv: 0806.4942 [nucl-ex]
23. M. Bashkanov *et al.*, Proc. PANIC08 (Elsevier, eds. I. Tserruya, A. Gal, D. Ashery), (2009) 239; arXiv: 0906.2328 [nucl-ex]
24. M. Bashkanov *et al.*, contribution to this conference