Eur. Phys. J. A **18**, 297–299 (2003)
DOI 10.1140/epja/i2002-10220-8

THE EUROPEAN PHYSICAL JOURNAL A

Experiments on the search for the NN-decoupled NNπ-resonance d$'$

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Received: 30 September 2002 /
Published online: 22 October 2003 –

Abstract. The status on the search for NN-decoupled $NN\pi$-resonances is reviewed with regard to recent experimental searches in the pionic double-charge exchange in nuclei, the two-pion production in nucleon-nucleon collisions, the photo pion-production on the deuteron and the electro pion-production in nuclei.

PACS. 14.20.Gk Baryon resonances with $S = 0$ – 13.75.-n Hadron-induced low- and intermediate-energy reactions and scattering (energy $\leq$ 10 GeV) – 25.40.Ve Other reactions above meson production thresholds (energies 400 MeV)

1 Introduction

In QCD-inspired models a large number of dibaryon states of basic $6q$ structure have been predicted [1]. However, despite a vast number of dedicated experiments in search of such states not a single one could yet be identified unambiguously; for a review see, *e.g.*, [2]. In fact, dibaryons which by their quantum numbers can couple to the NN and/or $N\Delta$ channels cannot be expected to have narrow widths and hence should be hard to sense experimentally. But NN-decoupled dibaryon resonances may be rather narrow, if they are not far above the $NN\pi$ threshold. Indeed, such states at a mass as low as $m = 2.1$ GeV/c^2 with $I(J^P) = 0(0^-)$ and $0(2^-)$ have been predicted by Mulders *et al.* [1], though more recent theoretical work taking into account proper antisymmetrization [3] prefers the 0^- state to lie at a somewhat higher mass. Experimental studies for such dibaryon states were carried out in recent years in reactions of the pionic double-charge exchange (DCX) in nuclei, in π^0 photoproduction on the deuteron and in direct measurements of 3-particle final-state invariant-mass distributions.

2 Experiments

The measurements of the pionic DCX on nuclei $A(\pi^+,\pi^-)B$ exhibit at pion energies below the delta-resonance a peculiar resonance-like structure in the energy dependence of the forward-angle cross-section (fig. 1) [4–6]. This structure has peak cross-sections at incident energies of $T_\pi \approx$ 40–60 MeV, *i.e.* far below the Δ excitation. Assuming a narrow $NN\pi$-resonance, the so-called d', with $I(J^P)$ = even (0^-), $m \approx 2.06$ GeV/c^2 and $\Gamma_{NN\pi} \approx 0.5$, MeV the DCX data can be very well explained both in their energy and angular dependence.

However, since this reaction takes place in the nuclear medium, subtle medium effects cannot be excluded as origin of this structure. In fact, attempts have been made with some success to describe the observed resonance-like structures for specific nuclei by conventional models [7–9]. In order to minimize the effects of the nuclear medium, the DCX reaction has also been carried out on ^{3}He and ^{4}He [10]. However, in these cases there is no longer a bound nuclear state in the exit channel, and the process leads to the nuclear continuum only. Unfortunately, this situation leads to a much less conclusive signature of d' production, in particular, if collision damping of the d'-resonance with the neighboring nucleons is included [10].

The search for narrow isoscalar or isovector resonances, which couple to the γd channel has been carried out [11] at MAMI. Deviations $\Delta\sigma$ of the data for the total π^0 production cross-section from a smoothed fit of data is shown in fig. 2. In the range 2020 MeV/$c^2 < m <$ 2100 MeV/c^2, no narrow structures have been found on the 3σ level with upper limits in the range of a few microbarns for the production of isoscalar or isovector dibaryons. Yet, this limit is still an order of magnitude above the prediction for d' production [12] and hence not conclusive for this particular dibaryon candidate either.

The investigation of the $pp \to pp\pi^+\pi^-$ reaction should be a more sensitive test of the d' hypothesis, since both invariant-mass spectra $M_{pp\pi^+}$ and $M_{pp\pi^-}$ can be observed simultaneously and the cross-section of the conventional process is small. Exclusive measurements of the two-pion production in pp collisions have been carried out at CELSIUS at T_p = 725, 750 and 775 MeV using the

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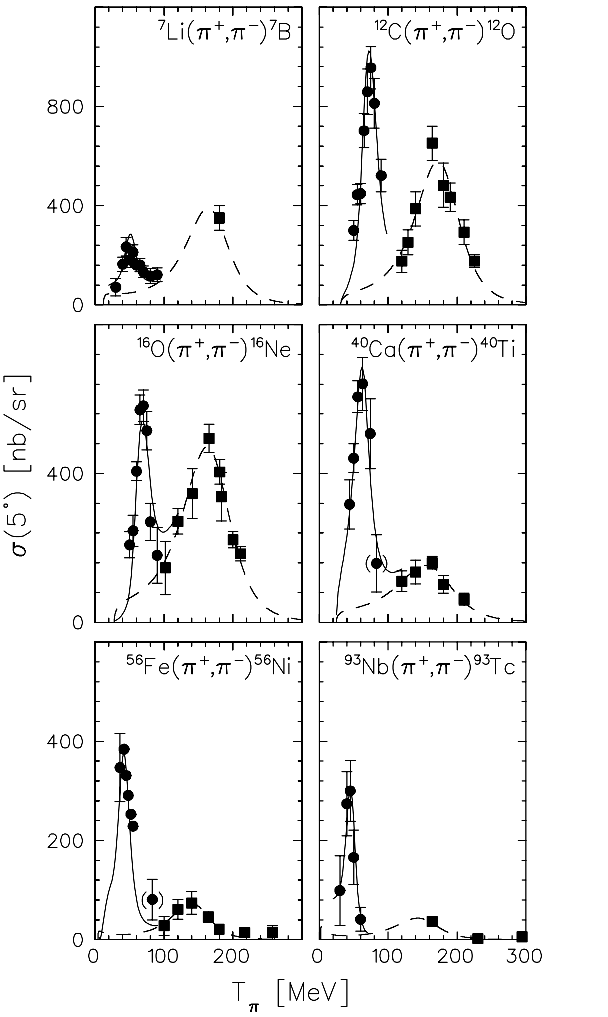

Fig. 1. Energy dependence of the forward-angle cross-section of the pionic DCX on nuclei. The solid lines show calculations assuming the formation of the hypothetical $NN\pi$-resonance d' interfering with the delta excitation (dashed lines) in this process. (from ref. [4]).

PROMICE/ WASA setup with a hydrogen cluster jet target [13]. For details of these measurements see refs. [14–18]. Since the decay of the hypothetical d'-resonance into $pp\pi^-$ is dominated by s-waves between outgoing particles, the two outgoing nucleons (*e.g.* two protons in the decay $d' \to pp\pi^-$) must be in the $^1S_0$-state. In this situation, the pp invariant-mass spectrum is strongly affected by the well-known Migdal-Watson–type final-state interaction (FSI) [19] leading to a considerable enhancement of the decay rate at small M_{pp}. In order to enhance the sensitivity to d' in $M_{pp\pi^-}$, a cut on small M_{pp} masses, $M_{pp} < 1896$ MeV/c^2, has been imposed. In the resulting spectra shown in fig. 3 no narrow structures of statistical significance in $M_{pp\pi^-}$ are observed with the possible exception of an enhancement at 2087 MeV/c^2 . Since this data bin is right at the high-energy end of the experimental acceptance range, where instrumental corrections are already substantial and not easily under control, any interpretation of this enhancement would be premature.

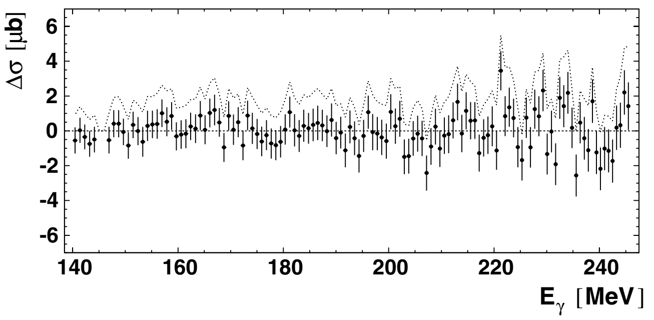

Fig. 2. Deviations $\Delta\sigma$ of the data for the total π^0 photoproduction cross-section on the deuteron. The deviations have been taken relative to a smoothed energy dependence fitted to the data. The dotted curve represents upper limits (90% C.L.) for underlying narrow structures averaged over the experimental energy resolution (from ref. [11]).

Its nature can only be solved by measurements at still higher energies. The upper limit (95% C.L.) for the production of narrow dibaryons is of the order $\sigma \lesssim 20$ nb for $m < 2087$ MeV/c^2. With respect to d', this upper limit is more than one order of magnitude below the theoretical prediction of $\sigma_{d'} \approx 300$–1000 nb [19,20].

We note in passing that in a preceding test run with much lower statistics a structure at 2.063 GeV/c^2 in $M_{pp\pi^-}$ had been observed [21] with a statistical significance of 2 to 3σ, depending on the treatment of background. At least part of this bump could meanwhile be associated to a previously unknown detector inefficiency [14–17]. We also note that in a measurement [22] of the same reaction at ITEP at $T_p = 920$ MeV a bump has been observed, too, near 2.06 GeV in $M_{pp\pi^-}$, if a cut on small M_{pp} masses was imposed. To our knowledge, no follow-up studies are under way at ITEP to resolve the nature of that bump.

Finally, there are so-called beamgas data from ARGUS at DESY at $E_e = 5$ GeV, which contain the electro pionproduction on ^{16}O of the form $\gamma^*\ ^{16}\mathrm{O} \to pp\pi^\pm X$. From the measured four-momenta of protons and pions $M_{pp\pi^+}$ and $M_{pp\pi^-}$ spectra have been obtained [23] with and without a constraint on low M_{pp} masses. In both cases, the $M_{pp\pi^+}$ data are in accordance with phase space, whereas in $M_{pp\pi^-}$ a bump near 2.06 GeV is observed with a significance of about 4σ under both conditions. From analysis of the $M_{p\pi^-}$ spectrum an admixture of misidentified Λ particles as a possible reason for this bump can be excluded [23]. For the $M_{pp\pi^-}$ region of the observed bump the corresponding M_{pp} spectrum exhibits an anomalously large pp FSI, in particular in connection with $M_{p\pi^-}$ values around the Λ mass. These findings would be in accordance with what is expected in case of d' production [23]. We note that the $M_{pp\pi^-}$ spectra constructed from $pp\pi^-\pi^\pm$ and $pp\pi^-\pi^+\pi^+$ event samples do not show any enhancements near 2.06 GeV —again as expected in case of d' electro-production on a np pair, since in this case there is only single-pion production. π^0 particles were not identified, hence their possible accompanying production cannot be excluded.

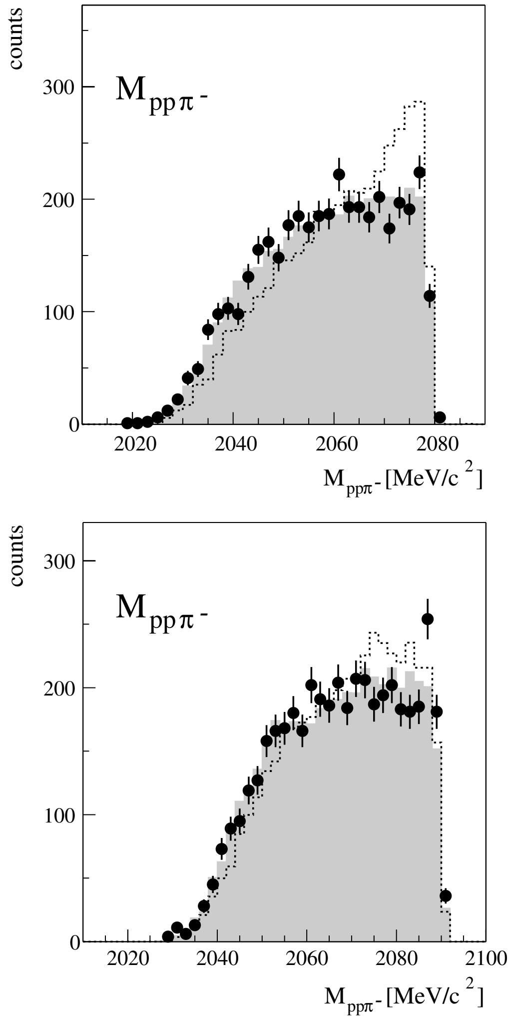

Fig. 3. Invariant mass spectra $M_{pp\pi^-}$ obtained from the exclusive measurements of the $pp \to pp\pi^+\pi^-$ reaction at $T_p = 750$ MeV (top) and $T_p = 775$ MeV (bottom). The spectra contain only events meeting the condition $M_{pp} < 1896$ MeV/c^2 (see text). The dotted lines represent a MC simulation assuming pure phase space for the reaction process, the shaded areas represent a model calculation, which quantitatively describes all differential cross-sections of the reaction (from ref. [14,15, 17]).

3 Conclusions

In recent years, high-statistics and high-resolution experiments have been carried out in search for a possible signature of d' in basic systems. In $\gamma d \to \pi^0 X$ and in $pp \to pp\pi^+\pi^-$ no narrow structures of statistical significance have been found. In the former reaction the deduced upper limits are still above the predicted d' production cross-sections; however, for the latter reaction they are below the predicted values by already one to two orders of magnitude.

Together with the findings on nuclei (DCX, γ^* ^{16}O $\to pp\pi^\pm X$) our results on the basic systems imply a number of consequences. Either d' does not exist at all, or its production cross-section in $pp \to pp\pi^+\pi^-$ is for some unknown reason much smaller than expected, or its mass outside the nuclear medium is above the mass range investigated so far, or it possibly exists only in the presence of the nuclear medium.

We acknowledge the support by BMBF (06 TU 987) and DFG (Europäisches Graduiertenkolleg 683).

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