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Dibaryons – a new state of matter?

M. Bashkanov[1,2,a], H. Clement[1,2], E. Perez del Rio[1,2], and T. Skorodko[1,2,3]
for the WASA-at-COSY Collaboration

[1] *Physikalisches Institut, Eberhard–Karls–Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany*
[2] *Kepler Center for Astro and Particle Physics, University of Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany*
[3] *Department of Physics, Tomsk State University, 36 Lenina Avenue, 634050 Tomsk, Russia*

Abstract. New results in the field of dibaryons are discussed concentrating on the $d^*(2380)$ resonance with $I(J^P) = 0(3^+)$, which has been observed first in the double-pionic fusion to deuterium and meanwhile also in neutron-proton scattering — establishing it thus as a genuine s-channel resonance. Double-pionic fusion reactions to the He isotopes demonstrate that this resonance survives also in a nuclear surrounding. It also has been shown to contribute to dilepton production helping thus to resolve the so-called DLS puzzle. Moreover, the existence of dibaryons has also an impact on the equation of state for nuclear matter.

1 Introduction

Despite their long painful and unsuccessful history – for a review see Refs. [1–3] – dibaryon searches have recently received new interest, in particular by the recognition that there are more complex quark configurations than just the familiar $q\bar{q}$ and qqq systems. The "hidden color" aspect makes dibaryons a particularly interesting object in QCD [4].

In general the term dibaryon means just a state with baryon number B=2 – independent of its internal structure. It may be a genuine six-quark state with all quarks confined in a single bag or just a baryonic molecule like, *e.g.*, the deuteron representing a sort of trivial dibaryon from the QCD point of view. Of course, the first category appears to be more exciting.

2 Experimental evidences for a dibaryon resonance

A narrow resonance-like structure was recently observed in the double-pionic fusion reactions to deuterium $pn \to d\pi^0\pi^0$ and $pn \to d\pi^+\pi^-$ at $\sqrt{s} \approx 2.37$ GeV with a width of only $\Gamma \approx 70$ MeV [5–7]. Based on angular distributions [5] and due to the fact that this resonance structure does not show up in pp induced, *i.e.* isovector two-pion production [7–18] its quantum numbers have been determined to be $I(J^P) = 0(3^+)$.

[a] e-mail: bashkano@pit.physik.uni-tuebingen.de

In a dedicated measurement of polarized neutron-proton scattering in the region of the resonance structure and its subsequent SAID partial-wave analysis [19] it has been demonstrated that the new data produce a pole in the coupled $^3D_3$ - $^3G_3$ partial waves at $(2380 \pm 10 - i\,40 \pm 5)$ MeV [20, 21] — verifying thus the resonance structure observed in double-pionic fusion to constitute a genuine *s*-channel resonance. Since it resembles features predicted for the so-called "inevitable dibaryon" d^* [22], it has has been denoted now $d^*(2380)$.

To investigate the resonance in detail the WASA-at-COSY collaboration has measured meanwhile its decay branches into the $d\pi^0\pi^0$ [5], $d\pi^+\pi^-$ [7], $pp\pi^0\pi^-$ [23], $np\pi^0\pi^0$ [24] and np [20, 21] channels by pd and dp collisions in the quasi-free reaction mode utilizing the WASA detector setup at COSY [25, 26]. The np decay channel was measured by use of polarized deuterons in inverse kinematics.

3 $d^*(2380)$ in nuclei

Since in the double-pionic fusion reactions to ^{3}He [27] and ^{4}He [28] the signature of this resonance is observed too, it obviously is robust enough to survive even in a nuclear surrounding, which may have interesting consequences for nuclear matter under extreme conditions.

The enhancement in the dilepton spectrum observed in heavy-ion collisions for invariant electron-positron masses in the range 0.15 GeV $< M_{e^+e^-} < 0.6$ GeV has recently been traced back to a corresponding enhancement in pn collisions relative to pp collisions [29]. Whereas the dilepton spectra from pp collisions are understood quantitatively, theoretical descriptions fail to account for the much higher dilepton rate in pn collisions - in particular regarding the region $M_{e^+e^-} > 0.3$ GeV at beam energies below 2 GeV ("DLS Puzzle" [30, 31]). In Ref. [32] it has been shown that the missing strength can be attributed to ρ^0-channel $\pi^+\pi^-$-production, which is dominated by conventional $\Delta\Delta$ excitation due to t-channel meson exchange and contributions from $d^*(2380)$.

4 $d^*(2380)$ in theoretical calculations

The first prediction for such a resonance has been given by Dyson & Xuong [33] back in 1964 – shortly after the appearance of the quark model. As it turns out now, its mass prediction has been already amazingly close to the now obtained experimental result. New state-of-the-art three-body [34, 35] and quark-model [36–38] calculations reproduce the mass quite well, partly also the width.

Dibaryons are bosons, hence not Pauli-blocked and as such allow for higher densities of compressed nuclear matter. The effect of dibaryons on the equation of state for nuclear matter has been considered in various theoretical investigations, see *e.g.* Refs. [39–41], most recently also in Ref. [42].

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