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Production and interaction of the η meson with nucleons and nuclei

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Abstract. We report on the status of the search for η-mesic nuclei and the studies of the interaction of the η meson with nucleons. Recently we have completed the analysis of the new WASA-at-COSY data on the production of the η meson with polarized proton beam. New results on the analyzing power for the $\vec{p}p \to pp\eta$ reaction with more than an order of magnitude improved precision shed a new light on the production mechanism of the η meson in nucleon-nucleon collisions. Also, the latest results of the search for η-mesic nuclei are discussed.

1 Introduction

The η particle together with isoscalar η' and isovector π^0 lay in the origin ($S = 0$, $I_3 = 0$) of the nonet of pseudoscalar mesons representation. However, its behaviour is very different with respect to its interaction with nucleons [1]. In the low energy region, the η meson interaction with nucleons is dominated by the S_{11} resonance, which with its mass of 1535 MeV lays very close to the η-N threshold. This makes the s-wave $\eta - N$ interaction very strong and - as shown the analysis of Bhalerao and Liu - attractive [2]. This can be contrasted with the pion case which, dominated by the p-wave interaction from the $\Delta(1232)$ resonance, is much weaker [3]. Also, the measurement of the η'N scattering length shows that its interaction is rather weak [4]. The large value of the η-N scattering length led to the hypothesis, proposed by the Haider and Liu, who postulated that the total interaction in a nucleus- system is strong enough to form a bound-state - the so called mesic nuclei [5]. The second question raised and not unequivocally answered by the earlier measurements was about the η production mechanism in the nucleon-nucleon collisions.

Due to the short lifetime of the meson ($t \approx 10^{-18}$ s) it is not feasible to create the η beam. Therefore, its interaction with nucleon or nuclei must be studied via the observation of final states of nuclear reactions including the η-nucleon (or η-nuclei) pair. The Final State Interaction between produced particles can strongly influence the production cross-sections and, in this way, can be used for studies of the interaction itself [6].

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In this contribution we discuss the η production mechanism in the interaction with nucleons and the search for the η-mesic nuclei in the context of the recent experimental results from WASA-at-COSY collaboration.

2 η production mechanism in the interaction with nucleons

The measurements of the large total cross-section of $NN \rightarrow NN\eta$ reaction near the η production threshold [7–18] motivated the two-step η production model proposed in [19]. In this scenario one of the proton is firstly excited through the exchange of a single meson and forms the S_{11} resonance, which in the second step deexcites via the emission of η and nucleon. In principle, the excitation to S_{11} state can occur by exchanging π, η, ω or/and ρ mesons. The measurements of total cross-section isospin dependence by WASA/PROMICE and COSY-11 showed that the η production in the total isosinglet state is much higher that in the isotriplet state [18, 20]. This result strongly suggest the isovector meson exchange, reducing the candidates to π and ρ particles [19, 21, 22]. To further distinguish between the π and ρ meson exchange models, the determination of the analysing power in the polarization measurement was required. The first measurement by COSY-11 gave a indication in favour of the pseudoscalar exchange model, although due to the limited statistics the decisive conclusions could not be done [23–25]. The WASA-at-COSY performed a high-statistics measurement of the $\vec{p}p \rightarrow pp\eta$ with the polarized beam. The spin of the polarization was flipped from cycle to cycle. The data was gathered for two separated beam momenta 2026 MeV/c and 2188 MeV/c, which correspond to excess energy over the η production threshold of 15 MeV and 72 MeV, respectively. More details of the analysis can be found in [26].

3 Search for the η-mesic nuclei

The recent reviews on the search for mesic nuclei can be found in [3, 27–33]. The WASA-at-COSY collaboration [34] performed three dedicated experiments with aim to search for the η-mesic nuclei in ^{4}He and ^{3}He systems in the deuteron-deuteron and proton-deuteron collisions, respectively [35–39]. The choice of the light nuclei was motivated by both theoretical considerations (see e.g. [40, 41]) as well as the earlier measurements by SATURNE, ANKE and COSY-11 [42–46], that provided strong experimental hints for the existence of the bound state in the $^3\text{He} - \eta$ and $^4\text{He} - \eta$ systems. The main experimental idea for the ^{4}He is based on the measurement of the excitation function of the $dd \rightarrow {}^3\text{He}N\pi$ reaction for energies in the vicinity of the η production threshold and on the selection of events with low ^{3}He center-of-mass (CM) momenta. In the case of existence of the $^4\text{He} - \eta$ bound state we expect to observe a resonance-like structure in the excitation function below the threshold for the production of the $^4\text{He} - \eta$ system. The ^{3}He state is investigated in proton on deuteron collisions. The details can be found in [47].

4 Summary

The latest preliminary results from the 2010 experiment in $^4\text{He}{-}\eta$ system, do not confirm the existence of the η-mesic nuclei. The preliminary value of the upper limit obtained from the simultaneous fit, taking into account the isospin dependence of the $dd \rightarrow ({}^4\text{He-}\eta)_{bound} \rightarrow {}^3\text{He}n\pi^0$ and $dd \rightarrow ({}^4\text{He-}\eta)_{bound} \rightarrow {}^3\text{He}p\pi^-$ excitation functions , of order of few nb can be compared to the theoretical estimate of 4 nb [48]. In case of the $^3\text{He} - \eta$ system, the analysis is ongoing. The current experimental upper limit for the production of $pd \rightarrow ({}^3\text{He-}\eta)_{bound} \rightarrow ppp\pi^-$ comes from the COSY-11 measurement and is equal to about 270 nb [49]. Due to the high statistics the expected sensitivity in current WASA analysis is of order of 10 nb, which, taking into account the theoretical estimate of 80 nb [50], should be sufficient to confirm or rule out the hypothesis of existence of the ^{3}He $-\ \eta$ mesic nuclei.

The WASA-at-COSY determined the analysing power in the $\vec{p}p \to pp\eta$ reaction with two order of magnitude higher precision than the previous COSY-11 measurement. The preliminary results of the angular dependency of the analysing power is in disagreement with the prediction by both the pseudo-scalar and the vector exchange models. For higher energy (Q =72 MeV), the Ps-Pp interference is clearly observed.

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