Study of the η-proton interaction via the reaction $pp \to pp\eta$

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A measurement of the $pp \to pp\eta$ reaction at the excess energy of Q = 15.5 $\pm$ 0.4 MeV has been carried out at the internal beam facility COSY-11 with an integrated luminosity of 811 nb^{-1}. The number of ~24000 identified events permits a precise determination of total (2.32 $\pm$ 0.05 $\pm$ 0.35 μb) and differential cross sections. Preliminary investigations show that the angular distribution of the η meson in the center-of-mass system is isotropic. A qualitative analysis of the Dalitz-plot distribution is presented.

1 Introduction

Investigations of the η meson production via the $pp \to pp\eta$ reaction address the question of the strength of the proton-η interaction at low relative momenta of the interacting particles. In the frame of the optical potential model this interaction can be expressed in terms of phase shifts, which in turn are described by the scattering length $a_{\eta N}$ and the effective range of the potential. Usually, the $a_{\eta N}$ is defined as a complex quantity with the imaginary part accounting for the $\eta N \to \pi N$ and $\eta N \to \pi\pi N$ processes. The real part of it is a direct measure of the formation – or non-formation – of an η-nuclear quasi-bound state [1]. At present it is still not known whether the attractive interaction between η meson and nucleons is strong enough to form an η-mesic nucleus or a quasi-bound ηNN state. The values of $\mathrm{Re}(\mathrm{a}_{\eta N})$ range between 0.25 fm and 1.05 fm depending on the analysis method and the studied reaction [2]. According to reference [3], within the present inaccuracy of $\mathrm{Re}(\mathrm{a}_{\eta N})$ the existence of quasi-bound η-mesic light nuclei could be possible. The shape of the energy dependence of the $pd \to {}^3\mathrm{He}\,\eta$ cross section implies that either the real or imaginary part of the $\eta\,{}^3$He scattering length has to be very large [4], which may be associated with a bound $\eta\,{}^3$He system. Similarly encouraging are results of reference [5], where it is argued that a three-body ηNN resonant state, which may be formed close to the ηd threshold, may evolve into a quasi-bound state for $\mathrm{Re}(a_{\eta N}) \geq 0.733$ fm. Also the close to threshold enhancement of the total cross section of the $pp \to pp\eta$ reaction [6] was interpreted as being either a Borromean (quasi-bound) – or a resonance ηpp state [7], provided that $\mathrm{Re}(a_{\eta N}) \geq 0.7$ fm. Contrary, recent calculations performed within a three-body formalism indicate [8] that a formation of a three-body ηNN resonance state is rather not possible, independently of the ηN scattering parameters. Moreover, the authors of reference [9] exclude the possibility of the existence of an ηNN quasi-bound state. However, results of both calculations [8,9], although performed within a three-body formalism, used the assumption of a separability of the two-body ηN and NN interactions, and hence the new quality in the three-body ηNN-interaction is not excluded and deserves experimental investigations.

2 Experimental results

A Close to threshold measurement of the $pp \to pp\eta$ reaction allows to study the interaction of the η-meson with the proton. At an excess energy of Q = 15.5 MeV, at which the reported measurement has been performed, the final state particles are in the range of the strong interaction much longer than 10^{-23} s – typical life-time of N* and Δ baryon resonances. Thus their mutual interaction may significantly influence the distributions of their relative momenta.

By means of the COSY-11 detection system [10], using a stochastically cooled proton beam of the cooler synchrotron COSY [11] and a hydrogen cluster target [12], we have performed a high statistics measurement of the $pp \to pp\eta$ reaction at an excess energy of Q = 15.5 MeV. The experiment was based on the four-momentum registration of both outgoing protons, whereas the η meson was identified via the missing mass technique. Figure 1a presents the missing mass spectrum, with the clear signal originating from ∼24000 events of the $pp \to pp\eta$ reaction seen on a flat distribution due to multi-pion production. By means of the simultaneous measurement of elastically scattered protons we were able to monitor not only the luminosity but also the synchrotron beam geometrical dimensions and its position relative to the target [13]. This, and the correction for the mean beam-momentum-changes determined by means of the Schottky-spectrum and the known beam optics, allow us to reproduce exactly the observed missing mass distribution as it is shown by the dashed line in Figure 1a, which is hardly distinguishable from the real data. Figure 1b shows that the full range of the η meson center-of-mass polar scattering angles has been covered by the detection system acceptance. This permitted to determine the angular distribution of the created η meson which, as can be seen in Figure 2a, is completely isotropic within the shown statistical errors. The observed distribution is consistent with the previous measurement performed at an excess energy of Q = 16 MeV at the CELSIUS facility [14]. However, it improves the former statistics by a factor of 80. The determination of the four-momentum vectors for both outgoing protons of each registered event gives the complete information of the ηpp-system allowing for investigations of the ηp and ηpp interactions. Figures 2b and 2c show the Dalitz-plots of the identified $pp\eta$ system corrected for the detection acceptance and the proton-proton interaction. The enhancement from the η-proton interaction at small $m^2_{p\eta}$ is evident. However, one can also easily recognize a difference between Figures 2b and 2c, which originates from various prescriptions of the proton-proton FSI enhancement factors. It is well established that for the close-to-threshold meson production the energy dependence of the total cross section and the distributions of the differential cross section are predominantly determined by the nucleon-nucleon final state interaction [15]. However, when reducing the proton-proton FSI effect to a multiplicative factor, one finds that it depends on the assumed nucleon-nucleon potential and on the produced meson mass [16]. Figures 2b and 2c present the extreme cases in the estimation of the proton-proton FSI effects [17]. Due

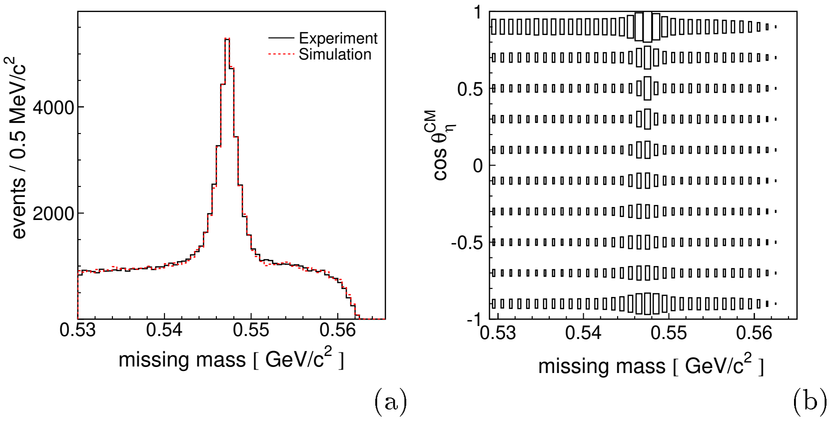

Figure 1: (a) Missing mass spectrum for the $pp \to ppX$ reaction determined at a beam momentum of 2.0259 GeV/c. The mass resolution amounts to 1 MeV/c^2 (σ). (b) Distribution of the center-of-mass polar angle of the produced system X as a function of the missing mass.

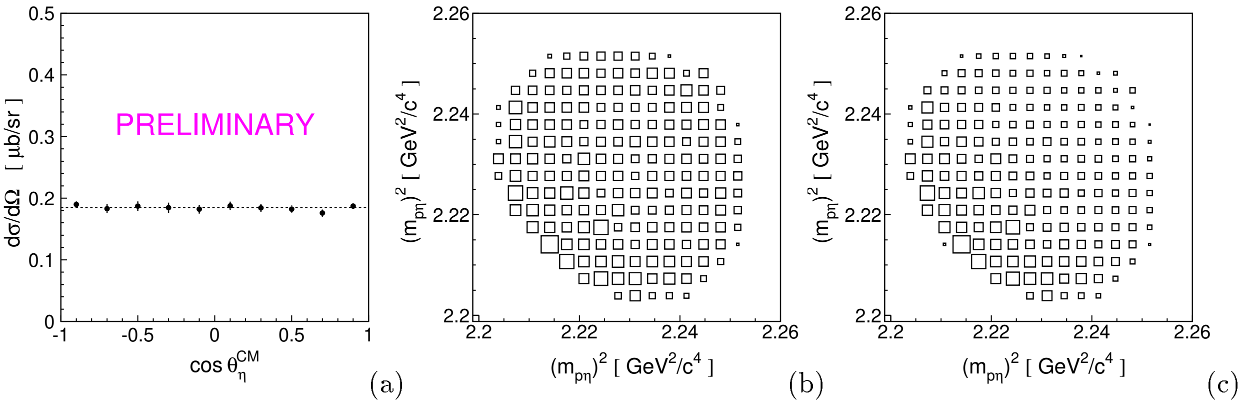

Figure 2: (a) Differential cross section of the $pp \to pp\eta$ reaction as a function of the η meson center-of-mass polar angle. (b) Dalitz-plot distribution corrected for the detection acceptance and the proton-proton FSI. For this plot only events with a mass differing by no more than 1 MeV/c^2 from the real η meson mass were taken into account. The proton-proton FSI enhancement factor was calculated as an inverse of the Jost function presented in reference [18]. (c) The same as (b) but the enhancement factor accounting for the proton-proton FSI was calculated as a square of the on-shell proton-proton scattering amplitude derived according to the modified Cini-Fubini-Stanghellini formula including Wong-Noyes Coulomb corrections [17, 19].

to these differences a derivation of the ηp or ηpp scattering length from the taken data will require a careful estimation of the model dependence of corrections for the proton-proton FSI.

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