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ETA MESON PRODUCTION IN NN COLLISIONS

J. HAIDENBAUER[a], V. BARU[a,b], A.M. GASPARYAN[a,b], C. HANHART[a]
and J. SPETH[a]

[a]*Institut für Kernphysik, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany*

[b]*Institute of Theoretical and Experimental Physics, 117259, B. Cheremushkinskaya 25, Moscow, Russia*

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A model calculation for near-threshold η meson production in nucleon-nucleon collisions is presented. The η meson production is described by elementary rescattering processes via MN→ ηN, with M = π, ρ, η and σ. Corresponding amplitudes are taken from a multi-channel meson-exchange model of the πN system developed by the Jülich group. Effects of the NN interaction in the final as well as in the initial state are taken into account microscopically.

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1. *Introduction*

Over the past few years, a wealth of accurate data on near-threshold η-meson production in nucleon-nucleon collisions has become available. This concerns reaction channels with a two-body final state, pn→ dη [1, 2], as well as those with three-body final states, namely pp→ppη [3 − 5] and pn→pnη [6]. While for the pn-induced channels so far only total cross sections have been measured, there are also data on differential cross sections and invariant-mass spectra [7 − 9] as well as analyzing powers [10] for pp→ppη.

Those data provide already a quite sensible testing ground for model calculations. Since η production near threshold is closely linked with the S_{11} N*(1535) resonance, it is hoped that the analysis of those data could give further information about the properties of this resonance. Also, since the η and the nucleons emerge at rather low kinetic energies, it is expected that the data exhibit some influence of the ηN interaction and, therefore, might provide the possibility to extract the value of the ηN scattering length.

In the present contribution, we report results of our investigation of η production in NN collisions [11]. The goal is a combined theoretical analysis of all measured channels of the reaction NN→NNη, namely pp→ppη, pn→pnη and pn→dη, by taking consistently into account the interaction between the nucleons in the final as well as in the initial state [12] and by utilizing a microscopic model of meson-nucleon (MN) scattering [13] for the description of the η-meson production process.

2. The model

We study η-meson production in distorted-wave Born approximation (DWBA). This means that the transition amplitude from the initial to the final state, $M_{2\to3}$, is given by the expression

$$M_{2\to3} = \langle\, \chi_{\rm f} \,|\, (1 + T^{\rm FSI}_{\rm NN} G_0) A_{2\to3} (1 + G_0 T^{\rm ISI}_{\rm NN}) \,|\chi_{\rm i}\rangle. \tag{1}$$

where $A_{2\to3}$ is the (elementary) production operator (cf. Fig. 1) and $T^{\rm ISI}_{\rm NN}$ and $T^{\rm FSI}_{\rm NN}$ are the NN reaction amplitudes in the initial and final states. Note that possible effects from the ηN FSI are neglected here for reasons explained in Ref. [11]. We will come back to this issue later in the discussion of the results. The production amplitude $A_{2\to3}$ consists of re-scattering diagrams with π, ρ, η, and σ meson exchanges (Fig. 1a) plus the direct η emission (Fig. 1b). One of the principal novelties of our study is the utilization of a realistic microscopic model for the elementary reaction amplitudes MN→ ηN entering in $A_{2\to3}$ (Fig. 1a), namely a coupled-channels model for πN scattering that has been developed recently by the Jülich group [13]. The interactions in and between the various channels (πN, ηN, ρN, σN, and $\pi\Delta$) are derived in the meson-exchange picture starting out from effective chiral Lagrangians. The model includes the N*(1535) resonance as an essential contribution but also various (t–channel) meson and (u–channel) baryon exchange diagrams. The parameters of the model are fixed by requiring a simultaneous description of the πN phase shifts and inelasticities as well as of the transition cross sections for the reactions πN→ ηN and πN→ ρN over an energy range that extends well beyond the ηN threshold. The reaction amplitudes are obtained by solving a coupled-channels relativistic scattering equation of the Lippmann-Schwinger type. Clearly, in such a

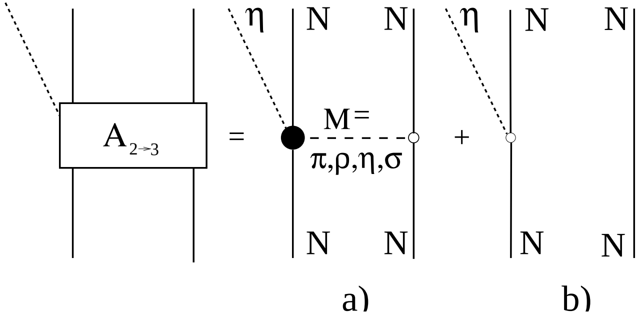

Fig. 1. Production mechanisms for the reaction NN → NNη *taken into account in our model: (a)* η *production via* MN → ηN *rescattering; (b) direct* η *production.*

model not only the πN→ ηN amplitude is determined by empirical data, but also the transition amplitudes involving heavier mesons are to a large extend constrained by the phase shifts and inelasticity parameters of πN scattering. This is also true for the relative phases between the various amplitudes.

Another merit of our model study of η production in NN collisions consists in the full and consistent treatment of effects from the NN FSI as well as ISI by employing an NN model that describes the relevant NN phase shifts reasonably well up to energies around the η production threshold [11, 12].

We focus on the description of η-meson production in the near-threshold region, i.e. for excess energies Q up to around 50 MeV. Therefore, we restrict our investigation to S-wave contributions.

3. *Results*

Results for the reactions pp→ppη, pn→pnη and pn→dη are presented in Fig. 2 and compared with empirical information from the Uppsala/Celsius [1, 2, 3, 6] and Jülich/COSY [4, 5] accelerator facilities. The dashed curves correspond to the calculation based on the original Jülich MN model [13] for the elementary η-production amplitude and the CCF NN model [12] for the ISI and FSI.

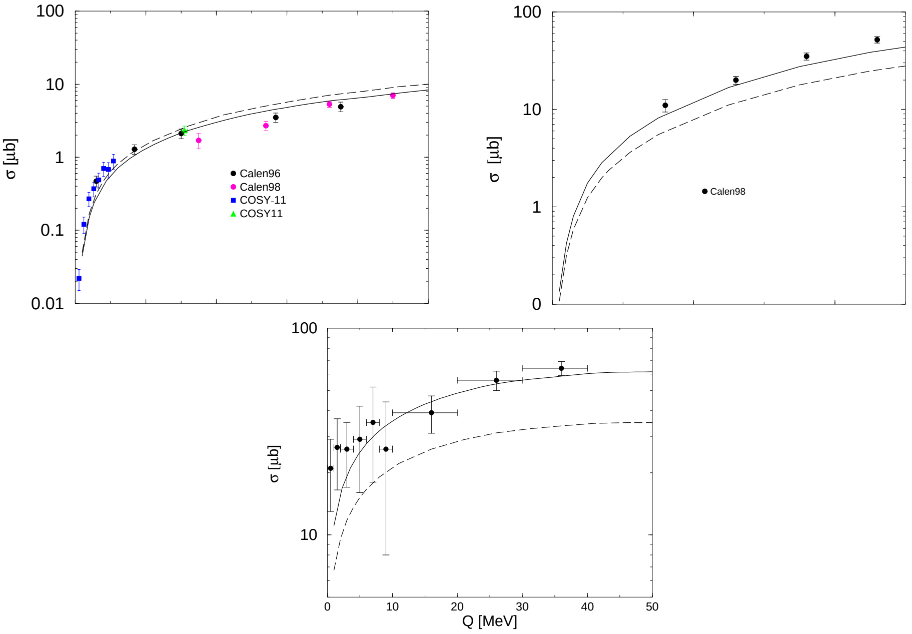

Fig. 2. Total cross sections of the reactions pp → ppη *(upper left),* pn → pnη *(upper right) and* pn → dη *(bottom). The dashed lines represent the results of our calculation with the original* MN *model of Ref. [13], whereas the solid lines are based on the extended* MN *model described in the text. Data are taken from Refs. [1 – 6].*

Evidently, the calculation based on the Jülich MN model [13] yields a qualitative overall description of the experimental data. This has to be certainly considered as success because there are no adjustible parameters in our calculation of NN→NNη. As one can observe from Fig. 2, for the ppη case we overestimate the cross section by approximately 30%, whereas for pn→pnη, the model calculation underestimates the experimental data by about 50%. The situation for pn→dη is very similar to pn→pnη since both processes are governed by the $I = 0$ isospin channel. As is known from earlier investigations [14, 15] for the latter reaction, the contribution of the $I = 1$ channel is much smaller than the one for $I = 0$.

It is interesting to investigate the sensitivity of our results to the MN amplitude and, in particular, to see whether the model predictions for NN→NNη can be improved by modifications in the MN model. Here specifically the ρN→ ηN transition amplitude is of interest because (i) in the original model [13] no direct ρN→ ηN transition potential was included and (ii) this particular transition amplitude plays a rather crucial role in the analysis of the reaction NN→NNη by Fäldt and Wilkin [14]. For this purpose we have created a variant of the MN model where we explicitly include a coupling of the ρN channel to the ηN channel via the S_{11} $\mathrm{N}^*(1535)$ resonance, cf. Ref. [11] for details. Varying the bare coupling constants ($g_{\rho\mathrm{NN}^*}$, etc.) we explored the variation in the amplitude for ρN→ ηN, while staying as close as possible to the experimental phase shift and inelasticity of the S_{11} πN partial wave and the πN→ ηN transition cross section produced by the original model. Thereby, it turned out that there is not much room for variations within our MN model. Obviously, the requirement of reproducing the πN phase shifts as well as the πN→ ηN transition cross section constrains also other transition amplitudes of the various coupled channels to a large extent. In particular, the magnitude of the amplitudes is basically fixed. Only the relative phase between the T-matrices could be changed within certain limits. For the original MN model, the amplitudes of the π- and ρ-exchange contributions to η production turned out to be almost orthogonal to each other. Thus, there is practically no interference between these contributions. The additional diagrams which we introduced into the MN model allow a slight modification of the orientation of these amplitudes and, as a consequence, now interference effects do occur. Specifically, it is possible to generate a destructive interference in the isotriplet channel ($I = 1$) and a constructive interference in the $I = 0$ case. This leads to a slight reduction of the cross section in the reaction pp→ppη and to a significant enhancement for pn→pnη, cf. the solid lines in Figs. 2, bringing now the results quite close to the experiment. Also the prediction for the reaction pn→dη is now in good agreement with the experimental data.

Let us now consider other observables that have been measured in the near-threshold region. The angular distributions in the reaction pp→ppη exhibit an isotropic structure at the excess energies $Q = 15$ MeV as well as at $Q = 41$ MeV [8]. The analyzing power, measured at $Q = 40$ MeV [10], is rather small and basically consistent with zero. Thus these observables are consistent with pure S-wave contributions and indeed are satisfactorily described by our model based on the extended MN interaction. However, the invariant-mass distributions reported in [8, 9] cannot be described by S-waves plus pp FSI alone as can be seen in Fig. 3. This could be an evidence that at least at the higher energy, P-waves already play a role [16], but also for the presence of a considerable ηN FSI [17].

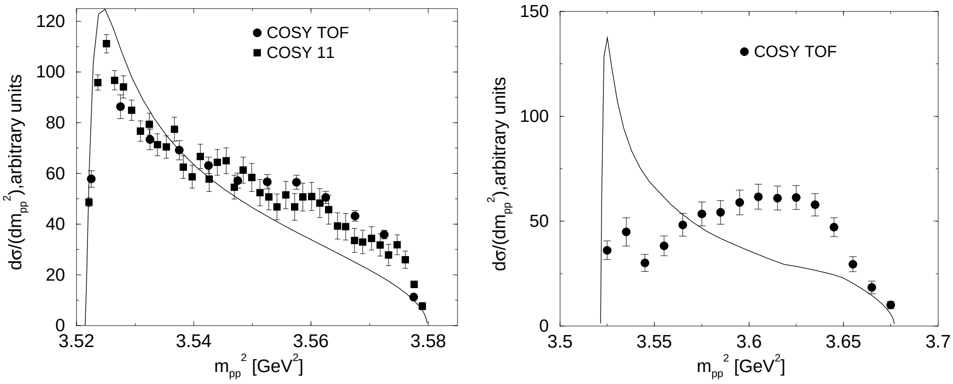

Fig. 3. pp *invariant mass distributions at the excess energies* $Q = 15$ MeV *(left) and* $Q = 41$ MeV *(right). Experimental data are from Refs. [8, 9].*

4. Summary

We performed a detailed theoretical calculation of the reactions pp→ppη, pn→pnη and pn→dη in the near-threshold region, i.e. for excess energies up to about 50 MeV. The mechanism for η meson production consists of the direct η emission and MN→ ηN re-scattering processes with M=π, ρ, η, σ, whose amplitudes are taken from a microscopic coupled-channel model of the πN interaction. Effects of the final and initial state interaction between the nucleons are fully taken into account. A quantitative description of the total cross sections can be obtained if one introduces small modifications of the MN→ ηN amplitudes by exploiting some freedom in the ρN→ ηN transition potential of the original MN model. Recent data on the invariant-mass distributions in the reaction pp→ppη, however, cannot be described. This could be a sign for the presence of a considerable ηN FSI, which was not taken into account in our present model calculation.

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TVORBA ETA MEZONA U NN SUDARIMA

Predstavljamo model za računanje tvorbe η mezona blizu praga u sudarima nukleon-nukleon. Tvorba η mezona opisuje se elementarnim procesima ponovnog raspršenja putem MN$\rightarrow \eta$N, sa M $= \pi$, ρ, η i σ. Odnosne amplitude uzimaju se od višekanalnog modela izmjene mezona u sustavu πN koji je razvila grupa u Jülichu. Učinci međudjelovanja u konačnom stanju kao i u početnom stanju uzeti su u obzir mikroskopski.