

Experimental study of the η -meson interaction with two-nucleons *

P. MOSKAL^{1,2}, H.-H. ADAM³, A. BUDZANOWSKI⁴, R. CZYŻYKIEWICZ²,
D. GRZONKA¹, M. JANUSZ², L. JARCZYK², B. KAMYS², A. KHOUKAZ³,
K. KILIAN¹, P. KOWINA^{1,6}, N. LANG³, T. LISTER³, W. OELERT¹,
T. ROŻEK^{1,6}, R. SANTO³, G. SCHEPERS¹, T. SEFZICK¹, M. SIEMASZKO⁶,
J. SMYRSKI², S. STELTENKAMP³, A. STRZAŁKOWSKI², P. WINTER¹,
M. WOLKE¹, P. WÜSTNER⁵, W. ZIPPER⁶

¹ IKP, Forschungszentrum Jülich, D-52425 Jülich, Germany

² Institute of Physics, Jagellonian University, PL-30-059 Cracow, Poland

³ IKP, Westfälische Wilhelms-Universität, D-48149 Münster, Germany

⁴ Institute of Nuclear Physics, PL-31-342 Cracow, Poland

⁵ ZEL, Forschungszentrum Jülich, D-52425 Jülich, Germany

⁶ Institute of Physics, University of Silesia, PL-40-007 Katowice, Poland

By means of the COSY-11 detection system, using a stochastically cooled proton beam of the Cooler Synchrotron COSY and a hydrogen cluster target, we have performed a high statistics measurement of the $pp \rightarrow pp\eta$ reaction at an excess energy of $Q = 15.5$ MeV. The experiment was based on the four-momentum determination of both outgoing protons. This permits to identify $pp \rightarrow pp\eta$ events and to derive the complete kinematical information of the ηpp -system allowing for subsequent investigations of the ηp interaction. The observed spectrum of the invariant mass of the proton-proton system deviates strongly from the phase-space distribution revealing the influence of the final-state-interaction among the outgoing particles or nontrivial features of the primary production mechanism.

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1. Introduction

Due to the short live time of the flavour-neutral mesons (eg. π^0 , η , η' , ω), the study of their interaction with nucleons or other mesons is at present not feasible in direct scattering experiments. One of the methods permitting such investigations is the production of a meson in the nucleon–nucleon interaction close to the kinematical threshold or in kinematics regions where the outgoing particles possess small

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relative velocities. When the relative kinetic energy is in the order of a few MeV, the final state particles remain much longer in the range of the strong interaction than the typical life-time of N^* or Δ baryon resonances with 10^{-23} s. Thus, they can easily experience a mutual interaction before escaping the area of an influence of the hadronic force. This interaction modifies the phase-space abundance and changes the distributions of the differential cross sections and the magnitude of the total reaction rate. A precise determination of the energy dependence of the total cross section close to the production threshold of the $pp \rightarrow pp\eta$ [1] and $pn \rightarrow d\eta$ reactions [2] revealed an enhancement at low excess energies generally accepted as a signal from the η -nucleon interaction. A similar effect is also observed in the photoproduction of η via the $\gamma d \rightarrow pn\eta$ reaction [3], indicating to some extent that the phenomenon is independent of the production process but is rather related to the interaction among η -meson and nucleons in the S_{11} region. Interestingly, out of all studied flavour-neutral mesons only the η -nucleon force is strong enough to manifest itself in the excitation function of the total cross section over the overwhelming nucleon-nucleon interaction. In the case of the production of other mesons no such enhancement has been observed, though the similar experimental precision has been achieved for example for the threshold production of π^0 [4] or η' [5] mesons. Hence, with the up-to-date experimental accuracy, from all *MesonNN*-systems the ηNN one reveals by far the most interesting features.

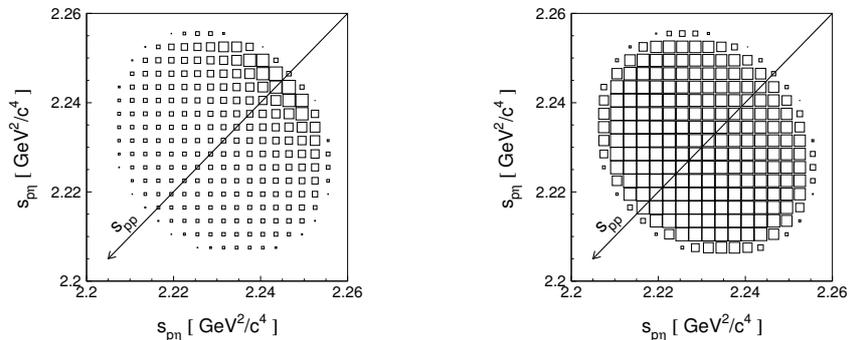


Fig. 1. Monte-Carlo simulations for the $pp \rightarrow pp\eta$ reaction at $Q = 16$ MeV: (left) Phase-space density distribution modified by the proton - proton final state interaction. (right) Phase-space density distribution modified by the proton- η interaction, with a scattering length $a_{p\eta} = 0.7 \text{ fm} + i 0.3 \text{ fm}$. Details of the calculations together with the discussion of the nucleon-nucleon and nucleon-meson final-state-interaction can be found in reference [8].

The interaction between particles depends on their relative momenta or equivalently on the invariant masses of the two-particle subsystems. Only two of the invariant masses of the three subsystems are independent. Therefore the entire principally accessible information about the final state interaction of the three-particle system can be presented in the form of the Dalitz plot. Figure 1(left) indi-

cates the event distribution over the available surface in the phase-space expected for the $pp\eta$ system at an excess energy of $Q = 16\text{MeV}$, assuming a homogeneous primary production and taking into account the S-wave interaction between the protons. The proton-proton FSI modifies the homogeneous Dalitz plot distribution of “non-interacting particles”, enhancing its population at a region where the protons have small relative momenta. Figure 1(right) shows the phase-space density distribution simulated when switching off the proton-proton interaction but accounting for the interaction between the η -meson and the proton. Due to the lower strength of this interaction the expected deviations from a uniform distribution is by about two orders of magnitude smaller, but still one recognizes a slight enhancement of the density in the range of low invariant masses of proton- η subsystems. However, due to weak variations of the proton- η scattering amplitude the enhancement originating from the η -meson interaction with one proton is not separated from the η -meson interaction with the second proton. Therefore an overlapping of broad structures occurs. It is observed that the occupation density grows slowly with increasing s_{pp} opposite to the effects caused by the S-wave proton-proton interaction, yet similar to the modifications expected for the P-wave one [6]. From the above example it is obvious that only in experiments with a high statistics, signals from the meson-nucleon interaction can appear over the overwhelming nucleon-nucleon final state interaction.

2. Experimental results

The enhancement observed in the total cross section encouraged us to perform the high statistics measurements of the $pp \rightarrow pp\eta$ reaction in order to investigate a possible manifestation of the η -nucleon-nucleon dynamics in the occupation of the available phase-space. Here we report on measurements of the $pp \rightarrow pp\eta$ reaction at an excess energy of $Q = 15.5\text{ MeV}$. The large number of identified $pp \rightarrow pp\eta$ events (24000) permits a statistically significant determination of the differential cross sections. The acceptance of the detection system covers the full range of the η meson center-of-mass polar scattering angles [7], and enables to prove that at this excess energy [8] the η meson is produced completely isotropically in the reaction center-of-mass system (fig. 2(left)), as expected. Figure 2(right) presents the Dalitz plot of the identified $pp\eta$ system corrected for the detection acceptance ~~and the proton-proton final state interaction performed under the assumption of that the occupation FSI effect can be separated from the observed prediction and stronger~~ overall enhancement factor can be factorized into the incoherent pairwise interactions. A deviation of the experimentally observed population of the phase-space from the expectation based on the mentioned assumptions is even better visible in figure 3.

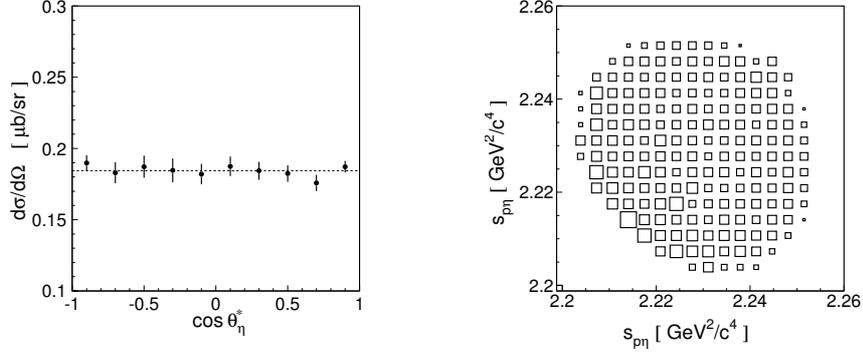


Fig. 2. (left) Experimentally determined differential cross section of the $pp \rightarrow pp\eta$ reaction as a function of the η meson center-of-mass polar angle at $Q = 15.5$ MeV. (right) Dalitz-plot distribution corrected for the detection acceptance and the proton-proton final-state-interaction. The proton-proton FSI enhancement factor has been calculated as the inverse of the Jost function given in reference [9].

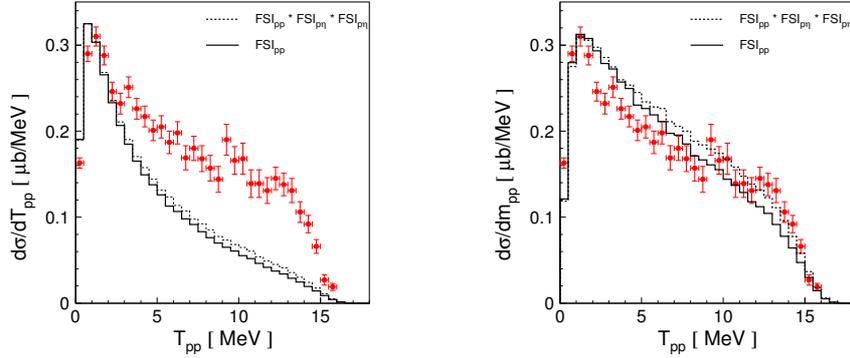


Fig. 3. Experimental distribution of the kinetic energy ($T_{pp} = \sqrt{s_{pp}} - 2m_p$) in the proton-proton subsystem determined experimentally for the $pp \rightarrow pp\eta$ reaction at the excess energy of $Q = 15.5$ MeV. The lines represent calculations as described in the text. They have been roughly normalized to the data at T_{pp} below 3 MeV.

This figure presents the projection of the phase-space distribution onto the $T_{pp} = \sqrt{s_{pp}} - 2m_p$ axis corresponding to the axis indicated by the arrows in the two parts of figure 1. The statistics allowed to identify the number of $pp \rightarrow pp\eta$ events in bins of 0.5 MeV of the kinetic energy of protons T_{pp} in their rest frame. As an example the missing mass spectra corresponding to the large, small and middle values of T_{pp} are shown in figure 4.

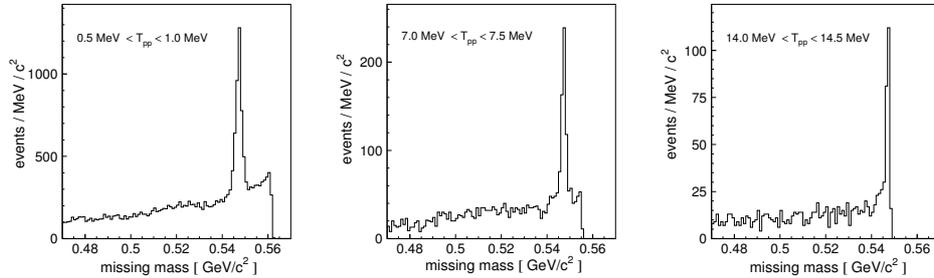


Fig. 4. Example of a missing mass distribution obtained for the $pp \rightarrow ppX$ reaction at three T_{pp} regions for small, intermediate and large T_{pp} values. A sharp peak corresponds to the $pp \rightarrow pp\eta$ events. The broad distribution is due to the multi-pion production via the reactions $pp \rightarrow pp2\pi$ and $pp \rightarrow pp3\pi$. Its contribution to the η -peak can not be discriminated on the event-by-event basis by means of the missing mass technique.

At each presented spectrum a signal originating from the $pp \rightarrow pp\eta$ reaction is evidently seen over a smooth distribution and allows for the model independent determination of the $d\sigma/dT_{pp}(T_{pp})$ distribution (fig. 3). The superimposed lines in figure 3 correspond to the calculations performed under the assumption that the production amplitude can be factorized into primary production and the final state interaction. The solid lines depict calculations where only the proton-proton FSI was taken into account, whereas the dashed lines present results where the overall enhancement was factorized into the corresponding pair interactions of the $pp\eta$ system. In the left panel the enhancement factor accounting for the proton-proton FSI has been 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 [8, 10, 11], whereas in the right panel the inverse of the Jost function presented in references [9, 12] was used. Though the simple phenomenological treatment – based on the factorization of the production amplitude into the constant primary production and the on-shell incoherent pairwise interaction among the exit particles – works astonishingly well in case of the total cross section energy dependence [8], it fails completely in the description of the differential cross section as can be inferred from figure 3(left). Taking instead the inverse of the Jost function as an enhancement factor of the proton-proton interaction, which should account approximately for the off-shell effects, one obtains a much better agreement with the data. However, the experimentally determined structure is not satisfyingly reproduced, and calls for a more sophisticated theoretical interpretation. The preliminary theoretical study indicates that the effect is selective for the the primary production mechanism [13]. It is worth to note that the obtained results are in agreement with the observation performed by the TOF collaboration using a completely different detection technique [14].

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