From Kaon Pairs to $\eta^{(\prime)}$-Mesons

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Abstract. The results of first measurements on the K^+K^- meson pair production in proton-proton collisions using the COSY-11 facility are presented and discussed. At a beam momentum of p_{beam} = 3.356 GeV/c a total cross section for the charged kaon pair production below the Φ meson threshold was successfully extracted. In parallel to these measurements, total and differential cross section information on the η' meson production in proton-proton collisions have been gained which extend the previously obtained data up to excess energies of Q = 47 MeV. Additionally, the results of first measurements at COSY-11 on the production of $\eta\,^3$He pairs at intermediate excess energies of Q = 5 to 40 MeV are presented and discussed.

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INTRODUCTION

The COSY-11 installation was particularly designed to perform near-threshold production experiments with high geometrical acceptance for charged ejectiles, and one main goal of this experiment was the investigation of the production of charged kaon pairs in proton-proton collisions. Additionally, this experimental facility was also highly suited to investigate the production of neutral mesons by applying the missing mass technique.

KAON PAIR AND η' PRODUCTION AT INTERMEDIATE EXCESS ENERGIES

Measurements on the K^+K^- meson pair production at COSY-11 are predominantly stimulated by the continuing discussion on the nature of the scalar resonances $f_0(980)$ and $a_0(980)$, which can decay into K^+K^- pairs and whose structure is still far from being well understood. Beside an interpretation as conventional $q\bar{q}$ states, different exotic models such as an identification as $qq-\bar{q}\bar{q}$ states or as $K\bar{K}$ molecules are considered. In the latter case the possibility of a $K\bar{K}$ molecule interpretation depends on the strength of the $K\bar{K}$ interaction, which can be probed in the near-threshold production of kaon-antikaon pairs, e.g. in measurements on the $pp \to ppK^+K^-$ reaction.

At COSY-11 the charged kaon pair production has been investigated at several excess energies (see [1, 2] and references therein). However, due to the low cross section the first clear evidence was obtained in measurements performed at an excess energy of Q = 17 MeV [2]. Since a charged kaon pair is heavier than an η' meson by approximately 30 MeV, data on the $pp \to pp\eta'$ reaction with high statistics have been extracted in parallel during the kaon pair measurements. By this the range of available excess energies close

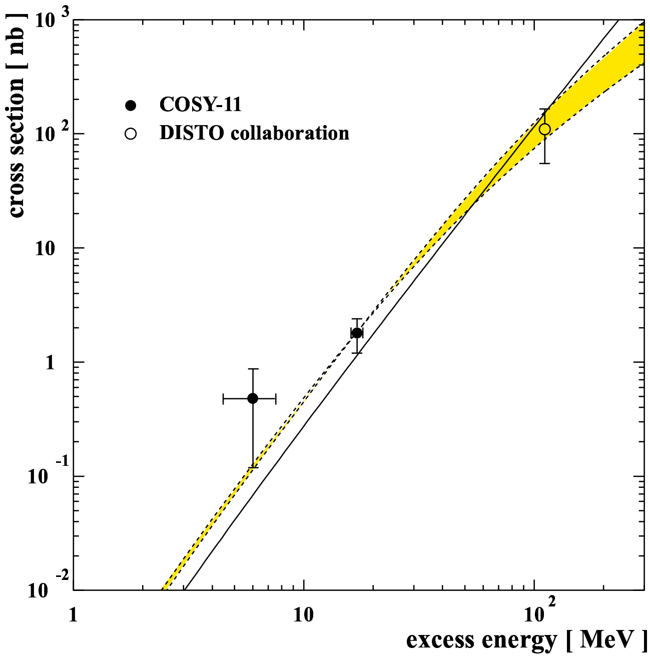

FIGURE 1. Total cross section data for the free K^+K^- pair production in proton-proton collisions. The data are taken from [1, 2, 4].

to threshold for the η' meson production was nearly doubled and differential cross sections at Q = 47 MeV could be provided [3].

K^+K^- meson pair production at threshold

The total cross section data obtained at COSY-11 at excess energies of Q = 6 MeV and Q = 17 MeV are shown in Fig. 1 together with results from the DISTO collaboration [4]. These data represent the first cross sections on this reaction channel close to threshold and allow, therefore, for the first time for quantitative investigations in the regime of low energies. In comparison, parametrizations of the energy dependence of the total cross section based on four-body phase-space behaviour including the pp FSI and Coulomb interaction (solid line) and for a resonant production via the f_0 (dashed lines) are included. In the latter case the effect of the large uncertainty about the width of the $f_0(980)$ resonance is indicated by the filled area. Obviously, within the experimental error bars and neglecting the possible influence of higher partial waves the data are consistent with both a non-resonant and resonant production. However, recent measurements from COSY-11 [5] indicate that data at lower excess energies exceed the predictions of these parametrizations. Therefore, further investigations are highly motivated to understand this effect. Details will be given in [6].

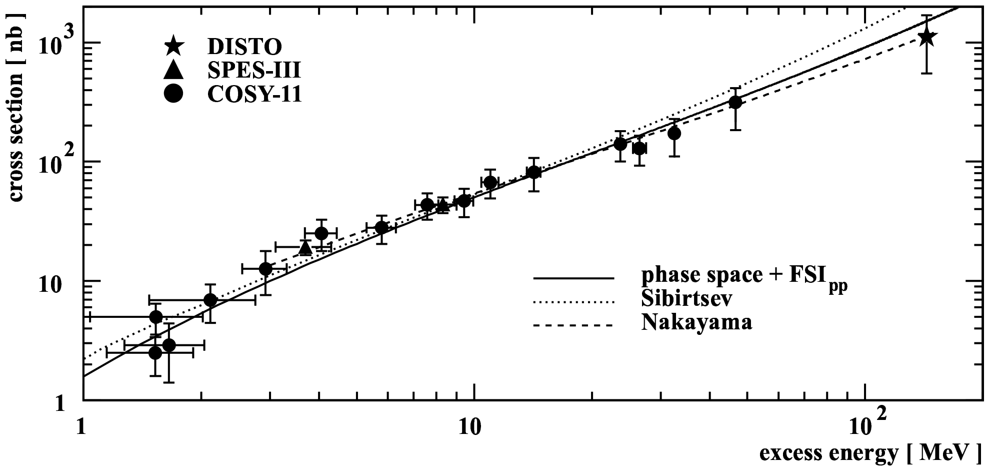

FIGURE 2. Total cross section data for the reaction $pp \to pp\eta'$ compared with different model calculations.

η' meson production above Q = 26 MeV

In parallel to the kaon pair production at COSY-11, the η' meson production has been investigated at excess energies of Q = 26.5, 32.5 and 46.6 MeV. These data fill the gap between the previously available data sets at lower excess energies [7, 8, 9] as well as one data point at Q = 144 MeV [10]. The results are shown in Fig. 2. The solid line represents an S-wave phase space calculation modified by the proton-proton final state interaction and Coulomb effects, scaled to fit the data. Within the experimental errors this fit is able to describe the whole set of existent data. Therefore, one can conclude that no further assumptions like a significant η'-proton final state interaction are needed for the description of the excitation function.

The dotted curve of Fig. 2 represents calculations from Sibirtsev et al. [11] based on an one-pion exchange diagram including the pp FSI. While for excess energies below Q = 25 MeV the observed excitation function is described well, the higher energy data are overestimated. In addition, calculations based on a relativistic meson exchange model and considering mesonic, nucleonic and nucleon resonance currents, have been performed by Nakayama [12] and fit to the existing data on the η' production in proton-proton and photo-production reactions. It was concluded that the data can be described best (dashed line in Fig. 2) assuming contributions of at least an S_{11} nucleon resonance in the mass region of 1650 MeV/c^2. Contributions from nucleonic exchange currents were estimated to be comparatively small.

In Fig. 3 the angular distribution of the emitted η' mesons in the center-of-mass system is presented for an excess energy of Q = 46.6 MeV. The differential cross sections are compatible with an isotropic emission (dotted line), indicating a dominance of S-wave in the final state. An inclusion of a $\cos^2(\vartheta)$ term to account for higher partial waves, i.e. D-waves, is shown by the dashed line and leads to an adequate description of the angular distributions. Additionally, the model calculations from Nakayama [12] result in an angular distribution given by the solid line, which is in very good agreement

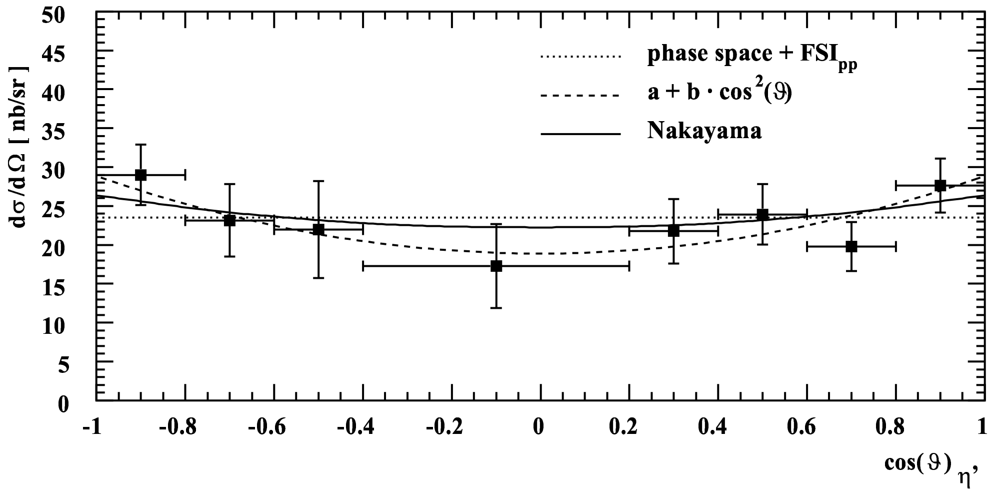

FIGURE 3. Angular distribution of the emitted η' mesons in the center-of-mass system at an excess energy of Q = 46.6 MeV.

with the data obtained at COSY-11.

PRODUCTION OF η ^{3}HE PAIRS AT INTERMEDIATE EXCESS ENERGIES

Investigations on the production of η ^{3}He pairs at low excess energies is of considerable interest with respect to the question of the existence of bound or quasi-bound states between an η meson and a nucleon or nucleus. Since available data sets on the reaction channel $pd(dp) \rightarrow^3$ Heη expose discrepancies as well show a lack of data at intermediate energies, total and differential cross section data have been taken at COSY-11 between Q = 5 MeV and 41 MeV [13].

Eliminating the pase space factor from the data, the absolute square of the production amplitudes $\overline{|f|^2}$ is obtained from the data using

$$\overline{|f|^2} = \frac{p_p}{p_\eta} \cdot \frac{d\sigma}{d\Omega}, \tag{1}$$

where p_p and p_η are the c.m.s. momenta of the initial proton and the η meson in the final state. The results of our measurements (filled circles) are compared to results from earlier measurements [14, 15, 16, 17] on this reaction channel as well as with recent photo-production data, obtained at MAMI [18] (filled stars). Our values of the production amplitudes close the gap between the SATURNE data [14, 15] at low excess energies and the higher energy data from WASA/PROMICE [17] and COSY-GEM [16], confirming the strong decrease of the production amplitude from threshold with increasing energies. This behaviour clearly differs from pure phase space expectations and was interpreted

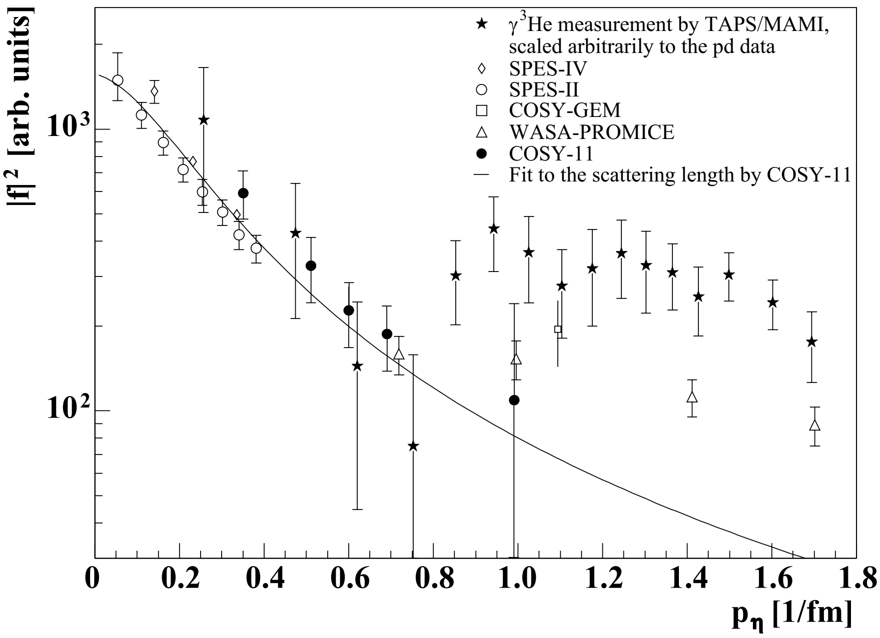

FIGURE 4. Squared absolute production amplitude for the $\eta\,^3$He final state in *pd* and γ^3He collisions. The photo-production data have been scaled arbitrarily to fit the *pd* data at $p_\eta < 0.8\ \mathrm{fm}^{-1}$.

by Wilkin as a signal of the $\eta\,^3$He final state interaction [19], parameterized by

$$\overline{|f|^2} = |\frac{f_B}{1 - i \cdot p_\eta \cdot a}|^2 = \frac{f_B^2}{1 + 2 \cdot p_\eta \cdot \Im(a) + p_\eta^2 \cdot \Im(a)^2 + p_\eta^2 \cdot \Re(a)^2}. \qquad (2)$$

As well as neglecting the effective range contribution, the implicit assumption here is that the threshold amplitude f_B varies only slowly with energy. A fit to the data using this approach is shown by the solid line of Fig. 4, considering only data up to Q = 11 MeV to assure predominantly S-wave scattering. Although this approach is only valid in the near-threshold region, for demonstration purposes the curve has been extended up to higher excess energies. Obviously, this curve describes also our highest energy data points and the lowest WASA/PROMICE data point, but fails to describe the data from WASA/PROMICE and COSY-GEM at higher excess energies.

Another hint that the observed excitation function is determined in large part by a FSI effect can be obtained by comparing the results with photo-production data for the reaction $\gamma^3\mathrm{He} \rightarrow^3 \mathrm{He}\,\eta$. Such measurements have been carried out at MAMI [18] and are compared to the results from proton-deuteron interactions (Fig. 4). When scaled arbitrarily to fit the lower energy points to the scattering-length-fit curve to the proton deuteron data, the shape of the excitation function is consistent with the close to threshold data and also with the $\eta\,^3$He FSI description. Furthermore, the photoproduction data of [18] reveal an enhancement in the excitation function at higher excess energies, as indicated at a lower level by the WASA/PROMICE data [17]. Therefore, the presented data from COSY-11 as well as the comparison with photo-production data clearly support a strong effect of the $\eta\,^3$He FSI.

Very recently new results from measurements on the $dp \to^3$ He η reaction have been presented by both the ANKE collaboration [20] and the COSY-11 collaboration [21]. Main focus of both measurements is the investigation of this reaction channel very close to threshold (Q $<$ 10 MeV) with high precision. Both data sets confirm the excitation function obtained by the SPES-II collaboration [15] and tighten the existence of a strong final state interaction. Details on these results are given in [22].

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