Study of the proton-η' and proton-η interaction

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The COSY-11 collaboration has measured the total cross section for the $pp \to pp\eta'$ and $pp \to pp\eta$ reactions in the excess energy range from Q = 1.5 MeV to Q = 23.6 MeV and from Q = 0.5 MeV to Q = 5.4 MeV, respectively. The obtained results agree well with the measurements performed at the accelerators SATURNE and CELSIUS. The energy dependence of the total cross section determined for the $pp \to pp\eta'$ reaction is well described by calculations based on the phase space volume and the proton-proton FSI implying a rather small proton-η' interaction. In contrary, close to threshold the total cross section of the $pp \to pp\eta$ reaction differs significantly from the expectations based on the above assumtions, due to the strong proton-η interaction. These observations imply that proton-η and proton-η' interactions are of significantly different strength, albeit both these mesons have the same quantum numbers and very similar quark contents.
Thus we intend to study quantitatively the completely unknown proton-η' interaction and also the not well established proton-η interaction by the measurement of the differential cross sections.

1. Status of the performed measurements

The COSY-11 collaboration has measured the total cross section for the $pp \to pp\eta'$ and $pp \to pp\eta$ reactions in the excess energy range from Q = 1.5 MeV to Q = 23.6 MeV and from Q = 0.5 MeV to Q = 5.4 MeV, respectively. Part of the data on the η' production for Q between 1.5 MeV and 4.1 MeV measured with the uncooled proton beam has been published last year [1]. The obtained results are in good agreement with the measurements performed by the SPES III collaboration at the SATURNE accelerator in Saclay [2].

A determined energy dependence of the total cross section indicated the strong repulsive proton-η' interaction [3, 4, 5, 6] in contrast to the attractive proton-η interaction which enhance the total cross section close to the kinematical threshold as reported by Calèn et al. [7].

However, further COSY-11 measurements on the $pp \to pp\eta'$ reaction performed in February 1998 with the stochastically cooled proton beam and with a factor four higher luminosity in the excess energy range from Q = 1.5 MeV to Q = 23.6 MeV show that the excitation function could be well described by the integral of the phase space volume weighted with the proton-proton scattering amplitude only, as depicted in Figure 1. Thus, former speculations about the influence of the repulsive proton-η' interaction

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should rather be rejected in view of the new results which are at present being prepared for publication.

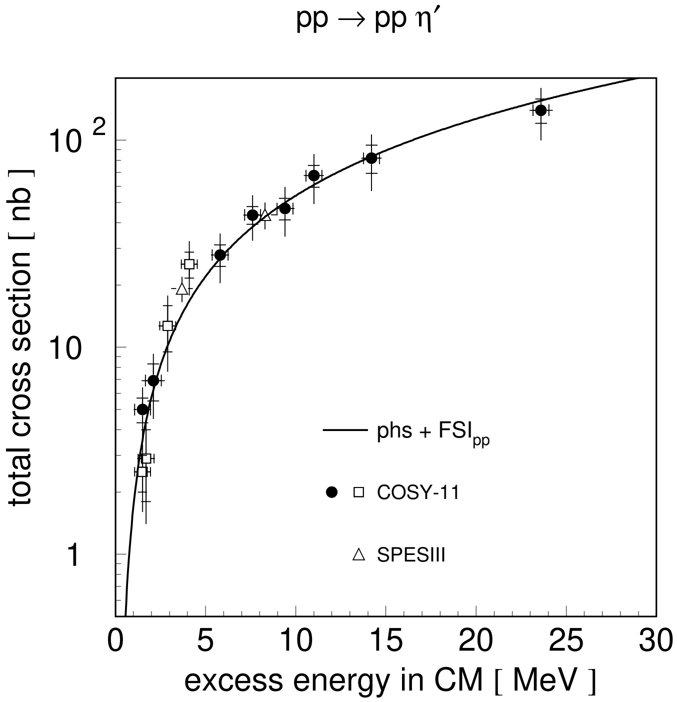

Fig. 1. Total cross section for the $pp \to pp\eta'$ reaction as a function of the center of mass excess energy. Open squares and triangles are from references [1] and [2], respectively. Filled circles indicate the results of the analysis of the COSY - 11 measurements performed in February 1998. Statistical and systematical errors are separated by dashes. The systematical error of the energy equals to 0.44 MeV constitutes of the 0.3 MeV due to the uncertainty in the detection system [8] and 0.14 MeV due to the uncertainty in the η' meson mass [9]. The systematical error of the cross section values, including the overall normalization uncertainty, amounts to 15 % [1, 5]. The solid line depicts calculations of the total cross section under assumption that the primary production amplitude is constant and that only a proton-proton interaction take place in the exit channel. The proton-proton scattering amplitude was computed according to the formulas from reference [10]. The obtained energy dependence agrees within a few line thickness with the Fäldt and Wilkin model [11] presented in Figure 2 as a solid line.

Figure 2 shows the compilation of the total cross sections for the η and η' meson production together with the new COSY-11 data shown as filled squares (η) and filled circles (η'). The COSY-11 data on the η production were taken changing the proton beam momentum continously during the measurement cycle. This technique allowed for the precise determination of the total cross section energy dependence near the kinematical threshold. The obtained result confirmed the enhancement of the close to threshold total cross section values compared to the predictions based on the phase space factors and the proton-proton FSI which was earlier observed by the PINOT [12], WASA [7], and SPES III [2, 13] collaborations.

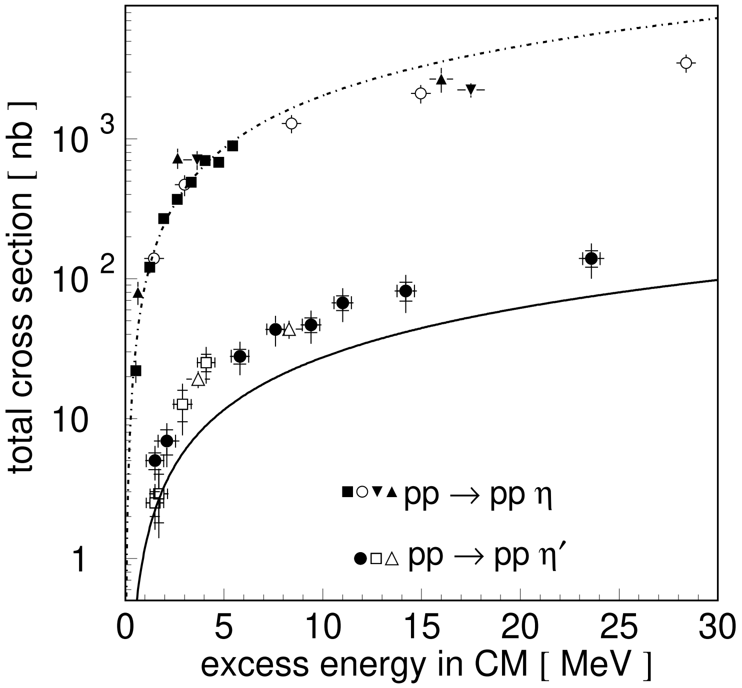

Fig. 2. Total cross section for the reactions $pp \to pp\eta$ (upper points) and $pp \to pp\eta'$ (lower points). Solid squares and solid circles corresponds to the yet unpublished COSY - 11 results. Triangles indicate measurements performed at SATURNE [2, 12], open circles at CELSIUS [7], and open squares at COSY [1]. The curves are explained in the text.

The dashed line in Figure 2 shows the energy dependence predicted by Fäldt and Wilkin [11] normalized now to the COSY-11 data points, and the solid line corresponds to the predictions based on a one boson exchange model adjusted to fit the close to threshold $pp \to pp\eta$ data (dashed line) [2]. This model underestimates the total cross sections for the $pp \to pp\eta'$ reaction by about a factor of two, which might be explained by additional short range production mechanisms as for example the mesonic currents [14] or more exotic processes like the production via a fusion of two gluons [15, 16]. The latter can contribute to the η' meson production since this meson is predominantly a flavour singlet state.

2. Motivation for further studies

The measurement of the total cross section for the η and η' mesons delivered the first constraints to the theoretical analysis of the microscopic description of the production mechanism [17, 18]. In case of the η meson it was found that its production is dominated by the excitation and decay of the S11(1535) baryonic resonance [19, 20, 21]. However, as pointed out recently by Nakayama et al. [14], it is very difficult to judge about the mechanisms responsible for the η' meson production from the total cross section alone. The authors studied contributions from the mesonic, nucleonic and resonance current and found that each one separately could describe the absolute values and energy dependence of the close to threshold data points after an appropriate adjustment of the ratio of the pseudoscalar to the pseudovector coupling. The only hope to disentangle the contributions from different mechanisms is to measure the cross sections at higher excess energies and to determine the differential cross section distributions. Such measurements should also give constraints on the proton-η' interaction, which appears to be too small to influence the energy dependence of the total cross section significantly within the up-to-date accuracy.

In the work of Baru et al. [3, 6], it is indicated that already at an excess energy of Q = 5 MeV the distribution of the proton-proton effective mass is very sensitive to the proton-η' interaction. Similarly, Moalem et al. [21], discussing the η meson production, claim, that the cross section dependence on the kinetic energy for the η mesons produced under zero degree "would provide a clear signature of the η-proton force which is almost independent of the not very well known reaction mechanism". Moreover, the authors predict that the cross section distributions as a function of the η kinetic energy will change its shape significantly when moving from Q = 1 MeV to Q = 30 MeV, and already at Q = 20 MeV the spectra should acquire a very peculiar form.

Therefore, we would like to continue the measurements of the η and η' mesons production in the proton-proton collisions using the COSY-11 detection system, in order to determine the differential cross sections which will help in answering questions about the production mechanism and particularly will allow to determine experimentally the scattering parameters for the proton-η and proton-η' interactions. Specifically, we intend to determine the invariant mass distributions of the proton-proton system and compare them with the theoretical predictions. Further we plan to compare the cross section distribution as a function of the kinetic energy of the produced meson with the theoretical calculations by Moalem et al. [21], and finally we would like to fill the Dalitz plot distributions. As already applied successfully for the $pp \to pK^+\Lambda$ reaction [22], the Dalitz plot analysis will allow to determine the correlation between the proton-η' scattering parameters.

3. Beam time request

In February 1998 we studied the $pp \to pp\eta'$ reaction with an average luminosity of 10^{30} cm^{-2} s^{-1}. Since that time the improvement of the COSY beam intensity increased the luminosity by about a factor of 2, which was confirmed in July 1999 investigating the K^+K^- production at the COSY-11 detection system. The number of $pp \to pp\eta'$ reactions registered and reconstructed in the February 1998 run amounted to about 250 events per day.

The proposed program for the experiment is presented in the table below:

reaction	excess energy $[MeV]$	reaction rate [events/day]	required time [day]	expected number of events
$pp \to pp\eta'$	4	500	8	4000
$pp \to pp\eta$	4	12000	1	12000
$pp \to pp\eta'$	8	500	11	5500
$pp \to pp\eta$	8	12000	1	12000
$pp \to pp\eta'$	35	500	6	3000
$pp \to pp\eta$	20	12000	1	12000
			28 days	

In the above estimations we assumed that events with the missing mass differing not more than one standard deviation from the meson mass will be taken into account only. Further we assumed that the proton-proton effective mass spectrum will be divided into ten partitions, and that in each partition the amount of events originating from the $pp \to pp\eta'$ reactions will result in a statistical error of less than 30%. In the calculations the signal to background ratio was assumed to be $\approx 1/2$ and $\approx 1/3$ for Q = 4 MeV and Q = 8 MeV, respectively, as determined in the February 1998 run. The form of the proton-proton effective mass distribution was assumed as shown in reference [6, 3].

For the η' mesurement at Q = 35 MeV the signal to background ratio of 1/9 was assumed as extrapolated from the measurements performed in February 1998, and furthermore we assumed the statistical accuracy to be better than 8 %. This is sufficient to distinguish between the extreme possibilities of production mechanisms investigated by Nakayama et al [14].

Since the signal to background ratio in case of the $pp \to pp\eta$ reaction, is in the order of 1%, as measured by means of the COSY - 11 detection system, and since the total cross section for this reaction is about 30 times larger than for the η' production it is sufficient to take one day of beam time for each energy point.

For the determination of the differential cross sections we chose the same excess energies for $pp \to pp\eta$ and $pp \to pp\eta'$ reactions, in order to have the possibility to compare the differential distributions, minimizing systematical uncertainties by measuring with the same apparatus at the same time.

For the $pp \to pp\eta$ reaction we would like to measure additionally at Q = 20 MeV since, for example the distribution of the η meson kinetic energy should have at this energy a peculiar form due to the proton-η interaction as predicted by Moalem et al. [21].

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