Investigation of the $pp \to pp\eta'$ reaction at COSY - 11

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Abstract

In September 1996 the $pp \to pp\eta'$ reaction has been measured at COSY at a proton beam momentum ranging from 3.200 GeV/c (about 8 MeV/c below the η' meson production threshold) to 3.224 GeV/c (about 16 MeV/c above threshold). The total cross section for four different excess energies $Q_{cm} = 1.5$ MeV, 1.7 MeV, 2.9 MeV and 4.1 MeV was evaluated to be 2.5$\pm$ 0.5 nb, 2.9$\pm$ 1.1 nb, 12.7$\pm$ 3.2 nb and 25.2$\pm$ 3.6 nb respectively. The inaccuracy in the absolute beam momentum was established to be 0.9 MeV/c ($\Delta Q_{cm} = 0.3$ MeV).

We intend to continue the investigation of the $pp \to pp\eta'$ reaction in the excess energy range from $Q_{cm} = 6$ MeV to $Q_{cm} = 12$ MeV.

Motivation

A detailed motivation for the investigation of the $pp \to pp\eta'$ reaction close to the production threshold is described in the COSY-11 proposal accepted by PAC in 1996.

The absolute cross section for the $pp \to pp\eta'$ reaction measured by the COSY-11 collaboration in September 1996 is about a factor 50 smaller than the total cross section for the production of η or π° mesons (see figure 6). This could indicate that the production of η' does not occur through an intermediate N^* resonance. The theoretical calculation performed recently in Jülich under assumption that the η' meson is produced directly on one of the protons, and that the interaction has the pseudovector character only, allows to speculate that the pseudovector coupling constant $f_{\eta' pp}$ is smaller than 1.25 (see figure 5). This results in an approximate upper limit for the pseudoscalar coupling constant $g_{\eta' pp}$ to be equal to 2.5 which would give a strong constrain for quark models. The model predictions given in the literature for the $g_{\eta' pp}$ range from $1.9 < g_{\eta' NN} < 7.5$ [1][2]. In view of the large error bars the interpretation of the experimental results are still uncertain.

It is seen in figure 5 that the direct production with the pseudovector interaction does not describe well the measured data points. It would be interesting now ,from the theoretical point of view, to calculate the excitation curve assuming the pseudoscalar interaction, or to estimate the contribution to the total cross section from heavy mesons exchange or other possible terms. Finally the decisive criterion will be the form of the excitation curve. Therefore more data points will be needed.

The COSY-11 group intend to continue the measurement of the absolute cross section for the $pp \rightarrow pp\eta'$ production up to an excess energy of 12 MeV. The data for higher excess energies namely $Q_{cm} = 31.5$ MeV and $Q_{cm} = 144$ MeV were taken by the DISTO collaboration at SATURNE and should deliver at least the ratio of the cross sections for the production of the η' to the η meson.

Status of the measurement of the $pp \rightarrow pp\eta'$ reaction

In September 1996 two weeks of beamtime were devoted to the study of the total cross section in the $pp \rightarrow pp\eta\prime$ reaction in the excess energy range up to 4.1 MeV. In the first week the measurement was performed during a slow ramping, a continuous proton beam momentum change from 3.200 GeV/c (about 8 MeV/c below the η' meson production threshold) to 3.224 GeV/c (about 16 MeV/c above the threshold). In the second week the experiment was continued at three discrete beam momentum settings, namely: 3.201 GeV/c (below threshold), 3.214 GeV/c and 3.222 GeV/c.

In the first stage of the data analysis events with two tracks in drift chambers were preselected. (For the description of the COSY - 11 apparatus see reference [3]). Knowing the direction of the track, the magnetic field in the dipole and the target position the momentum of each registered particle can be calculated. From the time of flight measured by means of the scintillator hodoscopes the particle velocity is given. Thus, having momentum and velocity the invariant mass of the particle can be calculated. Figure 1 shows the squared mass of two simultaneously detected particles. A clear separation of event groups with two protons, proton and pion or two pions is seen. The dashed line on the picture indicates a software cut performed in order to identify events with two registered protons, which were accepted for the further analysis. The knowledge of the momenta of both protons before and after a reaction allows to calculate a mass of a not observed particle or system of particles in the outgoing channels. Figure 2a shows a histogram of a missing mass obtained from the measurement below the threshold. This histogram does not contain any statistically significant structures and especially there is no enhancement in the region corresponding to the η' meson mass. In order to reduce the statistical fluctuations the histogram was smoothed out as indicated by the dashed line. The shape of the background is well reproduced in Monte Carlo simulations taking into account a multi-pion production. As an example figure 3 shows the missing mass spectrum obtained from a simulation of the $pp \rightarrow pp\pi^{\circ}\pi^{+}\pi^{-}$ reaction (dashed line) together with the distribution measured below threshold (solid line). Figure 2b shows the missing mass spectrum from the measurement at the excess energy of 4.1 MeV. By subtracting the smoothed missing mass spectrum measured below threshold from the histogram taken above threshold a distribution (see figure 2c) with a clear peak in the region corresponding to the η' meson mass is obtained. For the subtraction the spectrum from below threshold was shifted in such a way that the kinematical limits for both histograms, below and above threshold, are the same. Because the background is mainly due to two or three pion production the form of the missing mass distribution remains the same for measurements at 3.201 GeV/c and 3.222 GeV/c. (the threshold for $pp \rightarrow pp\pi^{+}\pi^{-}$ for example is at 1.219 GeV/c beam momentum.) Before the background subtraction the spectra were normalized to the same integrated (over measurement time) luminosities.

The luminosity was determined by measuring the elastically scattered protons. The yield of the events with the $pp \rightarrow pp$ reactions was determined as a function of the scattering angle Θ_{cm} in the center of mass system. In figure 4 the full circles indicate the angular distribution obtained in the experiment for the elastically scattered protons. The COSY - 11 data points are fitted to the result of the EDDA collaboration with the only free parameter being the integrated luminosity.

The total cross section at four different excess energy values are shown in figure 5. The vertical error bars denote the statistical errors only. The horizontal ones result from the inaccuracy of the absolute beam momentum determination.

The absolute beam momentum was calculated from the position of the η' peak in the missing mass spectrum. The inaccuracy of the missing mass calculation originate from the error in the computation of the momenta of registered protons. This, in turn, can be caused a) by wrong determination of the drift chamber angle or position, b) by an error in the definition of the reaction point c) or by the inaccuracy of the knowledge of the dipol magnetic field. All these possibilities were carefully studied by means of the COSY - 11 Monte-Carlo program and it was established that these effects can not change the reconstructed missing mass by more than 0.3 MeV. Thus the estimation of the absolute excess energy from the missing mass spectrum is done with an accuracy better than 0.3 MeV. This corresponds to an error in the absolute beam momentum of 0.9 MeV/c

Beam request

The results of the performed experiment shows that it is possible to measure the reaction $pp \rightarrow pp\eta'$ with the COSY - 11 apparatus. It appears that the production cross section of the $pp \rightarrow pp\eta'$ reaction is large enough to observe a signal from the $pp \rightarrow pp\eta'$ events on the multi-pion background.

We intend to continue the study of the $pp \rightarrow pp\eta'$ reaction at excess energies $Q_{cm} = 6$ MeV, 8 MeV, 10 MeV and 12 MeV. For the first three Q_{cm} values we would like to measure the absolute cross section and for the $Q_{cm} = 12$ MeV it is planned to perform a high statistics run in order to obtain the absolute cross section, the angular distribution and to fill a Dalitz plot.

In the mesurement in September 1996 at the excess energy of 4.1 MeV 164±23 events with the $pp \rightarrow pp\eta'$ reaction were observed during a 24 hours run. The averaged luminosity obtained in this experiment was $8 \cdot 10^{29} cm^{-2} s^{-1}$. In the last experiment carried out at COSY - 11 in June 1997, concerning the study of the $pp \rightarrow pK\Sigma$ reaction, a luminosity of $2 \cdot 10^{30} cm^{-2} s^{-1}$ was achieved.

Thus, with the acceptance of the COSY - 11 detection system which decreases aproximately as $1/Q_{cm}$ and with the assumption that the production cross section of the $pp \rightarrow pp\eta'$ reaction increases as Q^2_{cm} (see figure 5) one expects with a luminosity of $2 \cdot 10^{30} cm^{-2} s^{-1}$ the following counting rates:

$\sim$ 615 counts/day for Q_{cm} = 6 MeV,
$\sim$ 820 counts/day for Q_{cm} = 8 MeV,
$\sim$ 1025 counts/day for Q_{cm} = 10 MeV,
$\sim$ 1230 counts/day for Q_{cm} = 12 MeV.

The error in the absolute excess energy determination is equal to 0.3 MeV which corresponds to errors in the cross section of 5.0%,3.8% and 3.0% for excess energy values of 6 MeV, 8 MeV and 10 MeV. In order to get a statistical error of the total cross section of the same order as the error resulting from the uncertainty in the excess energy one needs to collect about 1000 events for Q_{cm} = 6 MeV, about 2000 events for Q_{cm} = 8 MeV and about 2500 events for Q_{cm} = 10 MeV. The estimation was performed under the assumption that the signal to background ratio will be 2/3 as can be seen in figure 3b.

In order to continue the investigation of the $pp \to pp\eta\prime$ reaction it is asked for two weeks of COSY beam time. The proposed program for the experiment is presented in the table below:

excess energy $[MeV]$	reaction rate [events/day]	required time [day]	expected number of events
-3 (below)	-	2	-
6	$\sim$615	1.5	$\sim$ 922
8	$\sim$820	2	$\sim$ 1640
10	$\sim$1025	2	$\sim$ 2050
12	$\sim$1230	6.5	$\sim$ 8000
		14 days	

References

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[3] S. Brauksiepe et al., Nucl. Inst. & Meth. in Phys. Res. **A376** (1996) 397-410

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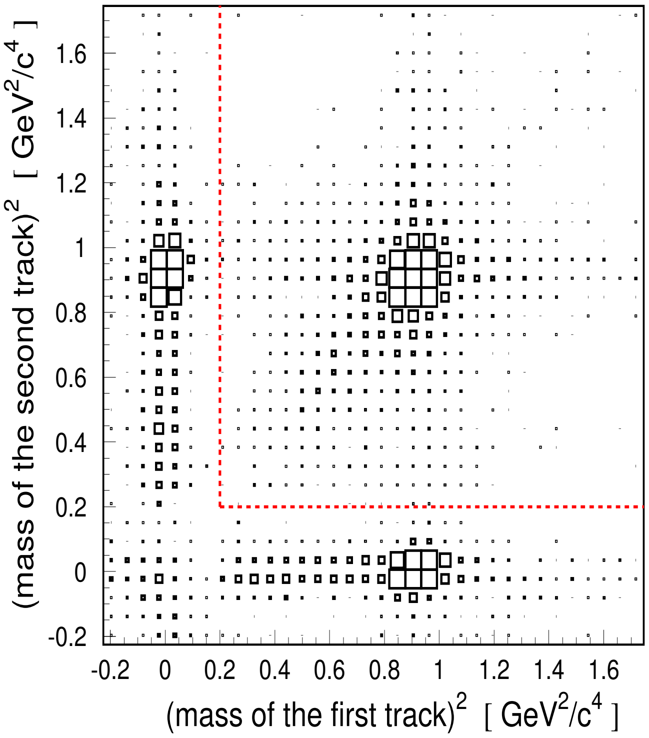

Figure 1: Squared masses of two particles measured in coincidence in the experiment.The pronounced peak close to the middle of the figure corresponds to two registered protons. The peaks in the left and lower part of the figure correspond to pion-proton pairs. The dashed line indicates a software cut performed in the analysis in order to identify events with two registered protons.

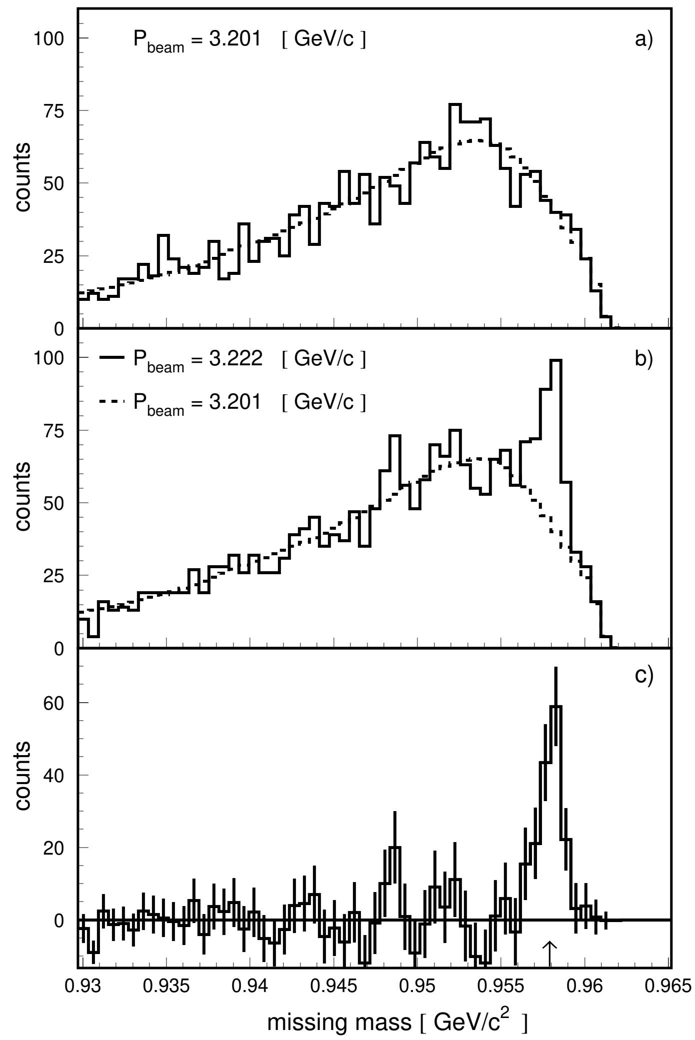

Figure 2: Missing mass of the unobserved particle in the $pp \to ppX$ reaction measured at a beam momentum of: a) 3.201 GeV/c (about 7 MeV/c below η' threshold) – the solid line represents the result of the measurement and the dashed line experimental result averaged over a few bins.
b) 3.222 GeV/c (about 14 MeV/c above η' threshold) – solid line. The dashed line on this figure represents background determined from the measurement below threshold.
c) difference between b) and a), the arrow indicates the η' meson mass, as given in the Particle Data Booklet 1996.

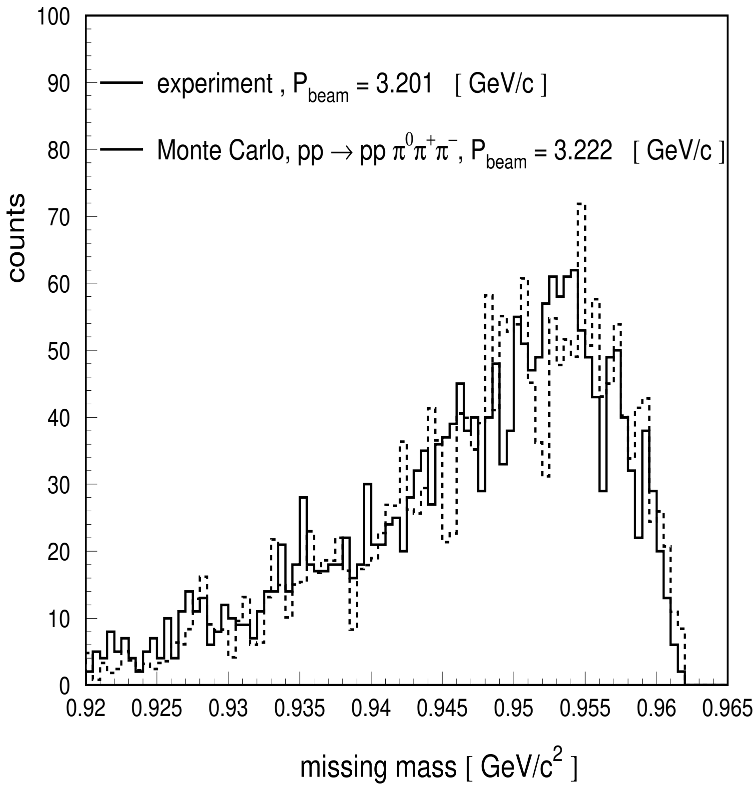

Figure 3: Missing mass distribution measured below threshold – solid line and from the simulation of the $pp \to pp\pi^{\circ}\pi^{+}\pi^{-}$ reaction – dashed line

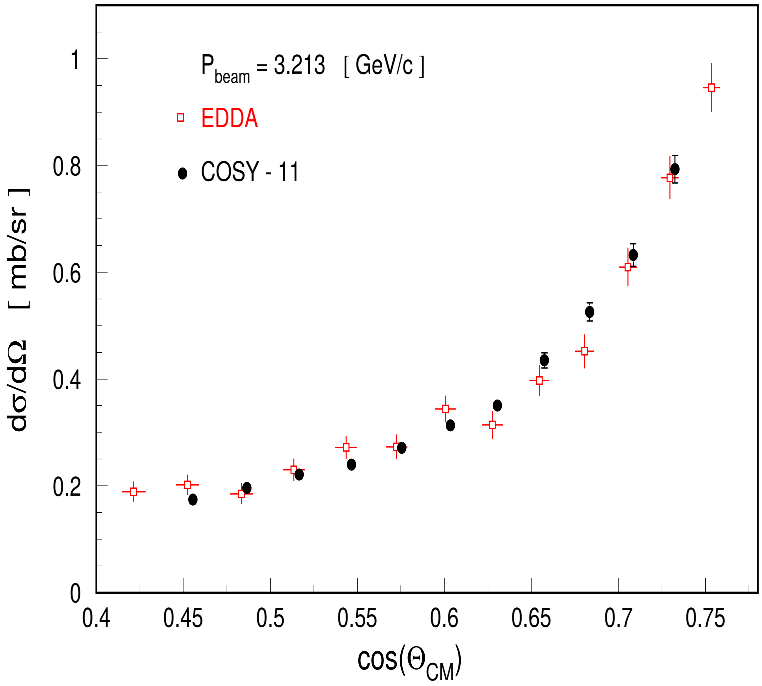

Figure 4: Differential cross section for the elastic proton-proton scattering.
Cross sections measured by the EDDA collaboration are shown by open squares. Full circles indicate differential cross sections measured by the COSY-11 collaboration. The COSY - 11 points are fitted in the overall normalization to the cross section measured by EDDA. To be better distinguishable the EDDA and COSY-11 points are shifted in the horizontal direction from each other by a half size of the point.

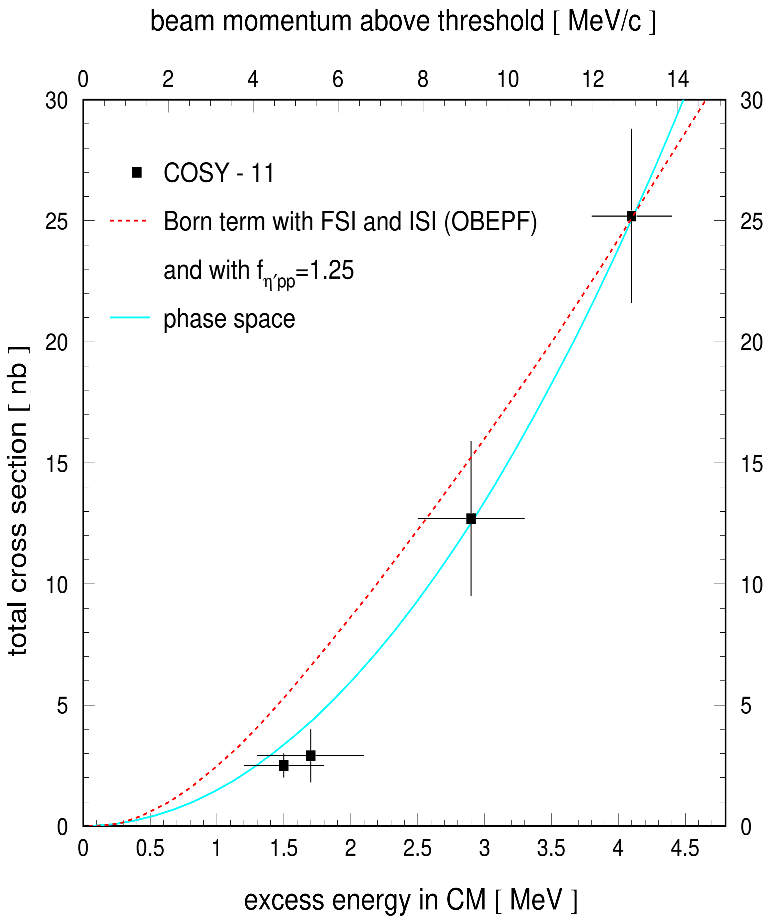

Figure 5: Total cross section for the $pp \to pp\eta'$ reaction versus excess energy in the center of mass system (lower horizontal axis) or versus beam momentum above threshold (upper horizontal axis). The dashed curve presents the result of the calculation which includes the Born term only. The interaction Lagrangian was assumed to be a pseudovector one and the interaction of protons in the initial and final channel was treated according to the OBEPF [4] potential. Calculations were performed in Forschungszentrum Juelich by C. Hanhart. The solid line shows the energy dependence of the total cross section as given by the phase space factors only. Both curves are normalized to the data point measured at the excess energy of 4.1 MeV.

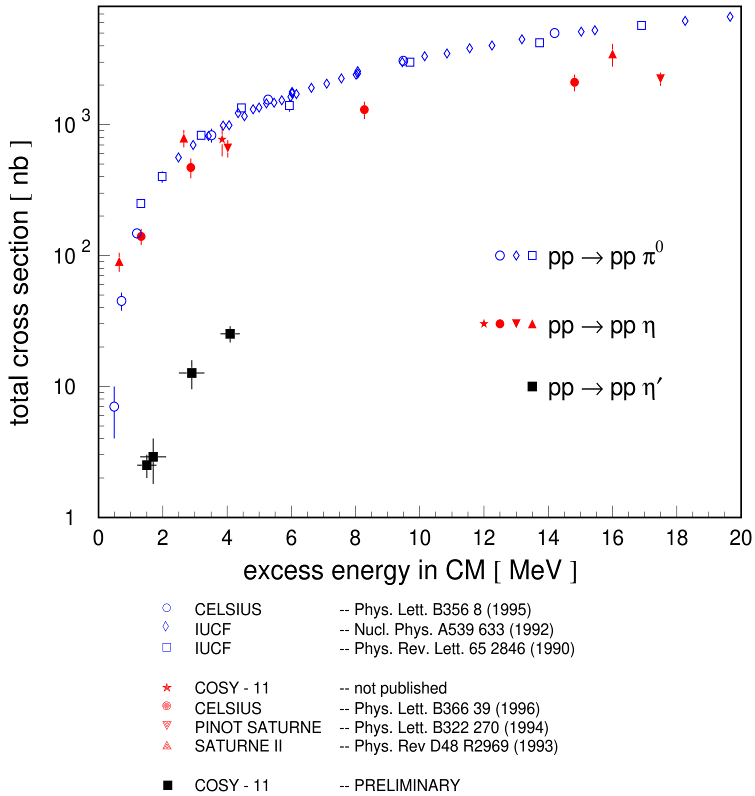

Figure 6: Total cross section for the reactions $pp \to pp\pi^\circ$, $pp \to pp\eta$ and $pp \to pp\eta'$