Total Cross Section of the $pp \to pp\eta'$ Reaction Measured at Threshold by Means of the COSY - 11 Detection System

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The η' meson is the last member of the pseudoscalar meson nonet which cross section for the close to threshold production in the $pp \to pp\ Meson$ reaction has not been measured so far. There exists only one measurement of the $pp \to pp\eta'$ reaction at the proton beam energy of about 5 GeV [1] which gives the upper limit of the total cross section to be $\sim 70\ \mu b$. Measurements of the cross sections close to the kinematical threshold are relevant for the study of the production mechanism. This is because the dominance of the s-wave allows a rather simple theoretical description.

In September 1996 two weeks of beamtime at COSY were devoted to the study of the total cross section in the $pp \to pp\eta'$ reaction in the excess energy range up to 4.1 MeV. First the measurement was performed during a slow ramping, a continuous proton beam momentum change from 3.200 GeV/c ($\sim$ 8 MeV/c below) to 3.224 GeV/c ($\sim$ 16 MeV/c above the η' meson production threshold). Next 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 ($\sim$ 6 MeV/c and $\sim$ 14 MeV/c above threshold, respectively). The two outgoing protons were analyzed by means of the standard COSY - 11 detection system [2] with drift chambers and scintillator hodoscopes. In the first step of the data analysis events with two tracks in drift chambers were preselected, and the mass of each particle was evaluated. Figure 1 shows the squared mass of two simultaneously detected particles. A clear separation into groups of events with two protons, proton and pion or two pions is seen. The dashed line indicates a software cut for the selection of events with two registered protons, which were accepted for the further analysis. The knowledge of the momenta of both protons before and after the reaction allows to calculate a mass of a not observed particle or system of particles in the outgoing channels. Figure 2b shows a histogram of the missing mass obtained from the measurement below threshold. This histogram does not contain any statistically significant structure 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

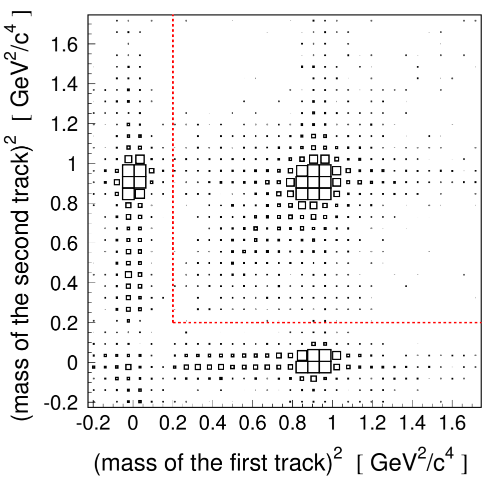

Figure 1: Squared masses of two particles measured in coincidence in the experiment.The pronounced peak close to the middle of the figure corresponds to two registered protons.

out as indicated by the dashed line. The shape of the background can be well reproduced by Monte Carlo simulations taking a multi-pion production into account. As an example figure 2a shows the missing mass spectrum obtained from a simulation of the $pp \to pp\pi^+\pi^-$ and $pp \to pp\pi^0\pi^+\pi^-$ reactions (dashed line) together with the distribution measured below threshold (solid line). Figure 2c 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 2d) 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, are the same. Since 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 the $pp \to pp\pi^+\pi^-$ reaction, for example, is at a beam momentum of 1.219 GeV/c.) Before the background subtraction the spectra were normalized to the same integrated

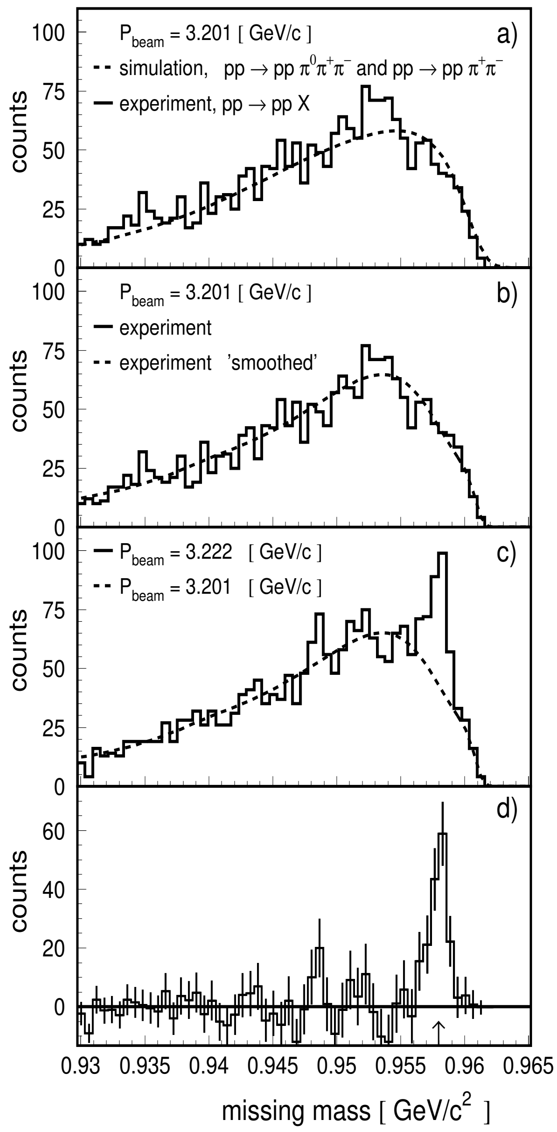

Figure 2: Missing mass of the unobserved particle or system of particles in the $pp \to ppX$ reaction.
a) The dashed line represents the missing mass distribution obtained from a Monte-Carlo simulation of the $pp \to pp\pi^+\pi^-$ and $pp \to pp\pi^0\pi^+\pi^-$ reactions. The solid line shows the result of the experiment performed at a beam momentum of 3.201 GeV/c ($\sim$ 7 MeV/c below the $pp \to pp\eta'$ reaction threshold)
b) Missing mass spectrum measured at a beam momentum of 3.201 GeV/c. The solid line indicates the result of the measurement and the dashed line show the experimental result averaged over a few bins.
c) Missing mass spectrum measured at a beam momentum of 3.222 GeV/c ($\sim$ 14 MeV/c above the $pp \to pp\eta'$ reaction threshold) – the solid line. The dashed line in this figure is the same as in figure b.
d) The difference between c) and b), the arrow indicates the η' meson mass, as given in the Particle Data Booklet 1996.

luminosities determined by measuring the elasti-

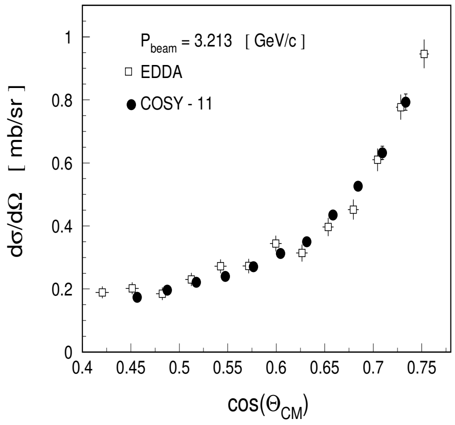

Figure 3: Differential cross section for the elastic proton-proton scattering.
Cross sections measured by the EDDA collaboration are shown by open squares [7]. Full circles indicate differential cross sections measured by the COSY-11 collaboration. The COSY - 11 points are fitted in the overall normalization to the cross section measured by EDDA. To be better distinguishable both the EDDA and COSY-11 points were shifted in the horizontal direction from each other by a half size of the point.

cally scattered protons. The yield of the events for the $pp \to pp$ reaction was determined as a function of the scattering angle Θ_{cm} in the center of mass system. In figure 3 the full circles indicate the angular distribution obtained in the experiment for the elastically scattered protons. The amplitude of this distribution was fitted to the data of the EDDA experiment [7] with the only free parameter being the integrated luminosity.
Figure 4 depicts the values of the total cross section obtained from the measurement. The vertical error bars denote the statistical errors only. The horizontal ones result from the inaccuracy of the absolute beam momentum determination [3]. The experimental result is compared with the pure phase space distribution and with the theoretical calculations performed recently by the Jülich group. The calculations are presented in figure 4 and have been performed under the assumption that the η' meson is produced directly on one of the protons, and that the interaction has a pseudovector character only. The energy dependence obtained under these simple assumptions does not agree well with the experimental data and thus indicates that the heavy meson exchange or other mechanisms may conribute significantly to the production of the η' meson in the $pp \to pp\eta'$ reaction.
The absolute cross section for the $pp \to pp\eta'$ reaction is about a factor of 50 smaller than the total cross section for the production of the η meson at the corresponding values of the excess energy (see figure 5a) and the η variable (see figure 5b). Where the parameter η stands for the maximum meson

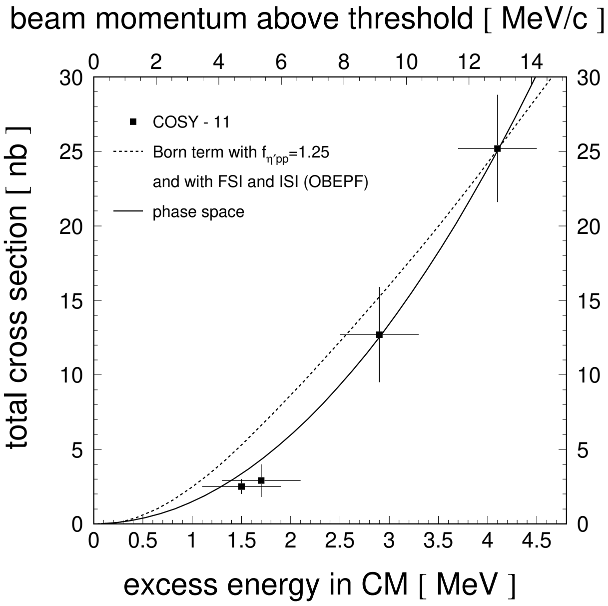

Figure 4: Total cross section for the $pp \to pp\eta'$ reaction versus excess energy in the center of mass system (lower horizontal axis) or versus beam momentum above threshold (upper horizontal axis). The dashed curve presents the result of a calculation which includes the Born term only. The interaction 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. The calculations were performed 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.

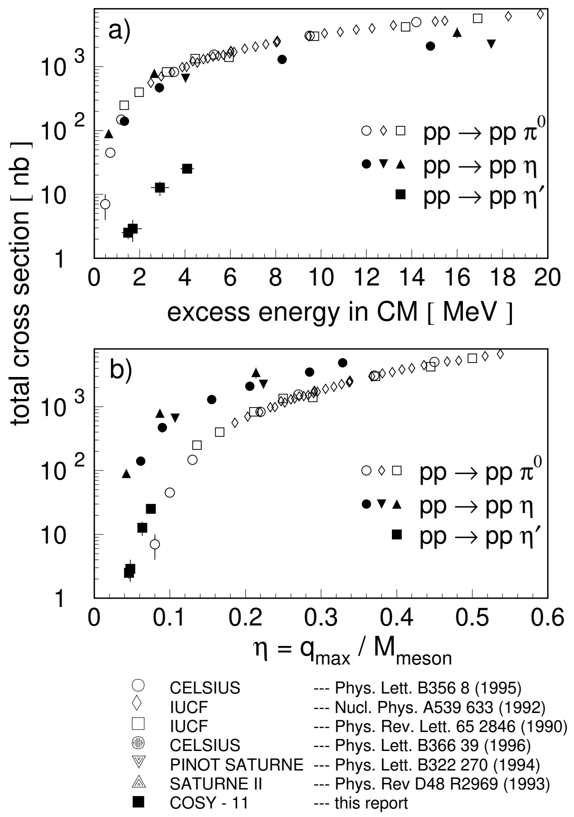

Figure 5: Total cross section for the reactions $pp \to pp\pi^0$, $pp \to pp\eta$ and $pp \to pp\eta'$.

momentum in the center of mass frame expressed in units of the meson mass. It is worth noting that the total cross section for the η' meson production is in the same order as the total cross section for the π^0 meson production at the same η values. It is established that the π^0 production in the $pp \to pp\pi^0$ reaction is not resonant. The similarity in the cross section for π^0 and η' meson production for the same value of the η - variable may indicate that the production of the η' meson does not occur through an intermediate N^* baryon resonance. Thus, knowing that the production amplitude from the heavy meson exchange has the same sign as the amplitude of the direct term [5] and assuming that the production process is not resonant one can estimate the upper limit for the pseudovector coupling constant $f_{\eta' pp}$. This is because the coupling constant is the only free parameter in the calculations of the production amplitude if only the direct term is considered. By fitting the theoretical result to the data points one obtains that the coupling constant $f_{\eta' pp}$ is smaller than 1.25. This gives the approximate upper limit for the pseudoscalar coupling constant to be $g_{\eta' pp} \cong 2.5$ if the pseudoscalar interaction has the same form of the excitation curve as the pseudovector one. In the case of the η photoproduction on a nucleon the production amplitude is insensitive to the choice of the pseudovector or pseudoscalar coupling at a meson nucleon vertex [6]. The quark models predictions for the $g_{\eta' pp}$ range from 1.9 to 7.5 [8] [9]

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