Proposal for the investigation of the $pp \to pp\eta'$ reaction at the COSY - 11 detection system

COSY - 11 collaboration
March 6, 1996

Abstract

The measurement of the η' meson production close to threshold yields important information concerning the η' structure as well as the (η' p) coupling. At low relative velocities in the center of mass system only a few partial waves contributes which simplifies the description of the reaction mechanism. Furthermore the final state interaction is increasing with reducing relative velocity which allows the extraction of the coupling constant.

The COSY - 11 installation is ideally suited for such studies due to the 100% acceptance at threshold for narrow resonances.

It is proposed to scan the momentum region at the η' production threshold within $\sim$ 10 MeV /c for total cross section data and to perform an extended measurement at one setting for a detailed study.

Motivation

The first evidence of the existence of the $\eta'(958)$ meson comes from the study of the $K^- + p \to \Lambda^0 + neutrals$ reaction performed by G.R. Kalbfleisch et al. [1] and independently by M.Goldberg et al. [2] in 1964. Already in 1976 it was well established that $\eta'(958)$ is the heaviest member of the ground state pseudoscalar meson nonet, and that its quantum numbers $I^G(J^{PC})$ are equal to $0^+(0^{-+})$ [3].

One usually considers η' meson as a mixture of η_1(singlet) state and η_8(octet) state of SU(3):

$$|\eta'> = cos\theta|\eta_1> - sin\theta|\eta_8>$$

The mixing angle θ determined from the quadratic mass formula amounts to 10^o, however the experimentally established value is equal to about 20^o [4] [5][6][7]. The Gell-Mann-Okubo mass formula for pure SU(3) states results in a η' mass which is much too small compared to the experimentally measured value [5]. Since many years this is the primary theoretical problem concerning the η' meson. It was proposed by J.L. Rosner [8] that the η' wave function may contain a gluonic component and could be parametrized as follows:

$$|\eta'> = X_{\eta'}|N> + Y_{\eta'}|S> + Z_{\eta'}|G>$$

with $X^2_{\eta'} + Y^2_{\eta'} + Z^2_{\eta'} = 1$, where N and S account for the non-strange and strange quark component, respectively, and G is the gluonic content. Namely:

$$|N> \equiv \frac{1}{\sqrt{2}}|u\bar{u} + d\bar{d}> \quad |S> \equiv |s\bar{s}> \quad |G> \equiv |gluonium>$$

In order to reproduce the η' mass a gluonium admixture ranging between $Z_{\eta'}=0.54$ and $Z_{\eta'}=0.73$ is required [4]. However, existing experimental estimates of $Z_{\eta'}$ are in obvious contradictions. In 1985 the MARK III group [9], basing on data of J/Ψ decay into η and η', showed that the η' nonstrange and strange quark content amounts to 65%±18% ($X^2_{\eta'} + Y^2_{\eta'} = 0.65$), which is in agreement with the hypothesis of the existence of other than quarkonium components in the η' meson. On the other hand, in 1990 J. Jousset et al. [7], analyzing branching ratios of J/Ψ decay, came to the conclusion that the gluonic part of the η' meson is in the order of $|Z_{\eta'}|^2 \sim 1\%$. The understanding of the η' structure and particularly the knowledge of the gluonium admixture in the η' state is important in the investigations of the glueball candidates [14][5]. Apart from the J.L Rosner phenomenological model there exist many other ones trying to explain the η' mass [13][10][11][12], mainly based on the U(1) anomaly proposed by G. 't Hooft [20].

Another quantity which can put constraints on the theoretical quark models is the η' -nucleon coupling constant $g_{\eta' NN}$ which has not been evaluated

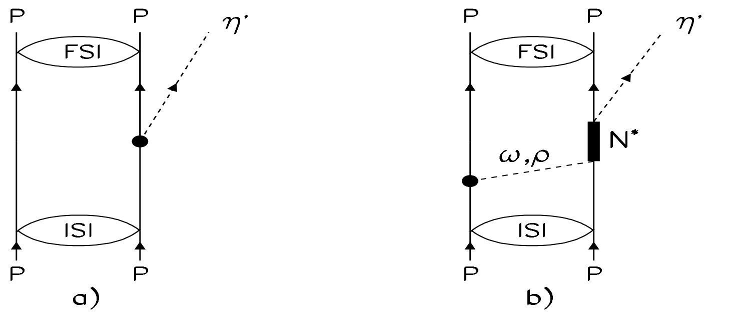

Figure 1: Feynman diagrams showing $\eta'(958)$ production in the proton proton collision a) direct term, b) production through the N^* resonance.

experimentally. The measurement of the cross section for the $pp \to pp\eta'$ reaction close to threshold gives an opportunity to establish the value of $g_{\eta' NN}$. As assumed for the η production [23][22], where only the mesonic level is regarded, the $pp \to pp\eta'$ reaction may occur through the direct production (figure 1a) or through the N^* resonance (figure 1b). In the η meson case the production through the $S_{11}(1535)$ resonance is dominant. However, there are practically no experimental evidence for baryon resonances decaying into $\eta'(958)$ and nucleon. The only indications comes from J.F Zhang et al. [15] and concerns the $D_{13}(2080)$ resonance. $D_{13}(2080)$ resonance has, however, spin $s=3/2$ and therefore its contribution should be suppressed in the close to threshold $pp \to pp\eta'$ reaction. Thus, for a first theoretical study one can assume that the production takes place only through the direct term. Then in the effective Lagrangian approach for the production vertex one may write [15][24] that

$$L_{\eta' NN} = -i g_{\eta' NN} \bar{\Psi}_N \gamma_5 \Psi_N \phi_{\eta'}$$

for the pseudoscalar coupling or

$$L_{\eta' NN} = g_{\eta' NN} \frac{1}{2M} \bar{\Psi}_N \gamma_\mu \gamma_5 \Psi_N \partial^\mu \phi_{\eta'}$$

for the pseudovector one. M. Benmerrouche and N. Mukhopadhyay found [24] that in the η case the $g_{\eta NN}$ coupling constant is not sensitive to the choice of the pseudoscalar or pseudovector coupling at a meson nucleon vertex. Transferring this treatment to the η' case the $g_{\eta' NN}$ would be the only fitted parameter. If $g_{\eta' NN}$ appears to be completely out of the range of the quark models predictions ($1.9 < g_{\eta' NN} < 6.2$ [15]; $g_{\eta' NN} = \frac{\sqrt{6}}{5} \cdot g_{\pi NN} \simeq 6.5$ [18]) this would be the indications for the existence of N^* resonance coupling to the η' meson. Another indication for such a resonance can come from the hit distribution on the Dalitz plot. The determination of its mass could be the next test for the quark models, which predicts many N^* resonances in the 2 GeV mass region [16][17], decaying into η' and nucleon which are till now not observed experimentally.

Recently data were published concerning the $\eta'(958)$ meson production in the $pd \rightarrow ^3HeX$ reaction performed in SATURNE at the SPES4 spectrometer [19]. The measured $d\sigma_{\eta'}/d\Omega^*$ amounts to 13 pb/sr, which, assuming an isotropic $d\sigma_{\eta'}/d\Omega^*$ for η' production, gives a total cross section of $\sigma_{\eta'} \simeq$0.16 nb. As a deuteron is built out of two nucleons one can suspect the cross section for the $pp \rightarrow pp\eta'$ reaction to be of the same order. However, till now there are no data concerning the production of η' meson in proton-proton collisions, except the prediction given in reference [21] according to which $\sigma_{pp \rightarrow pp\eta'}$ is two or three orders of magnitude smaller than $\sigma_{pp \rightarrow pp\eta}$. Thus, the η' is the last nonstrange meson of pseudoscalar nonet whose cross section for the production in two proton collisions is completely unknown.

The relative values of the $pd \rightarrow ^3He\omega$ and $pd \rightarrow ^3He\phi$ cross sections do not agree with the Okubo-Zweig-Izuka rule [19]. This may indicate the $s\bar{s}$ content in the nucleon which is also discussed in context of ϕ production in $N\bar{N}$ annihilations [27]. The investigation of the $pp \rightarrow pp\eta'$ reaction, together with planed studies of the $pp \rightarrow pp\phi$, $pp \rightarrow pp\omega$ and $pp \rightarrow pp\eta$ reactions, may also give some light on this problem.

Summary:

The experimental value of the cross section for $pp \rightarrow pp\eta'$ reaction shall contribute to give the answers to the questions of:

- the η' meson structure, and particularly of its gluonic content which is of importance to investigate possible glueball candidates [14],

- the nature of the meson nucleon coupling,
- the coupling to baryon resonances, decaying into η' , predicted by the quark models,
- the possible $s\bar{s}$ content in nucleon.

Status

In October 1996 the $pp \to ppX^0$ reaction at the beam momenta of 4 MeV/c above η' production threshold and 3 MeV/c below the threshold was measured at the COSY - 11 installation. For each beam momentum data for about 40 hours were gathered. The luminosity estimated by taking into account the target density and the beam intensity amouts to about $5 \cdot 10^{29} cm^{-2} s^{-1}$ and $2.5 \cdot 10^{29} cm^{-2} s^{-1}$ for the above and below threshold measurement, respectively. The events for η' meson production were identified via the missing mass method. The COSY - 11 detection system [25][26] allows to measure the velocity and momentum of each positively charged particle from which the mass can be calculated (see scatterplot in figure 2). By selecting events with two protons in the exit channel the missing mass spectra were generated. In figure 3 and 4 a preliminary analysis is shown for the higher and lower beam momentum, respectively. Above threshold a clear peak is observed which corresponds to the mass of the η' meson. Taking into account the time of the measurement, the luminosity and the number of measured reactions for both measurements the background was subtracted and at least fifty events which are due to the production of the η' meson were obtained.

Proposed measurement

It is proposed to measure the $pp \to pp\eta'$ reaction at three different beam momenta, 2 MeV/c, 4 MeV/c and 6 MeV/c above threshold. Additionally for background studies a measurement 3 MeV/c below threshold is needed.

These three measurements above threshold will give a first idea of the excitation function. For each momentum setting η' events in the order of 200 are sufficient. At 6 MeV/c above threshold a higher statistics run with about 1000 events is planed to get a first impression of a Dalitz plot distribution.

Beam request

The luminosity expected for the future measurement will be in the order of $2 \cdot 10^{30} cm^{-2} s^{-1}$ which was already obtained in the November 95 measurement after the new beam optic adjustment. This will result in about 120 events for η' meson production per day at a beam momentum of 4 MeV/c above threshold. The acceptance of the detection system for the beam momenta 2, 4, and 6 MeV/c above threshold amounts to 95%, 72% and 55%, extracted from Monte-Carlo calculation. In the simulation the events were generated according to phase space distribution without regarding the proton-proton final state interaction.

Under the assumption that close to threshold the cross section changes linearly with a beam momentum ($\sigma = const. \cdot [P_{beam} - P_{threshold}]$) the production rate for η' at considered momentum settings can be estimated. The following table lists the required measurement times and the expected number of events.

beam momentum $[MeV]$	momentum above threshold $[MeV/c]$	reaction rate events/day	required time [day]	expected number of events
3205	-3 (below)	~50	4	200
3210	2	~80	3	240
3212	4	~120	2	240
3214	6	~140	8	1120
			17 days	

Thus to perform the proposed measurements it is asked for 3 weeks (including time for beam preparation) of COSY operation.

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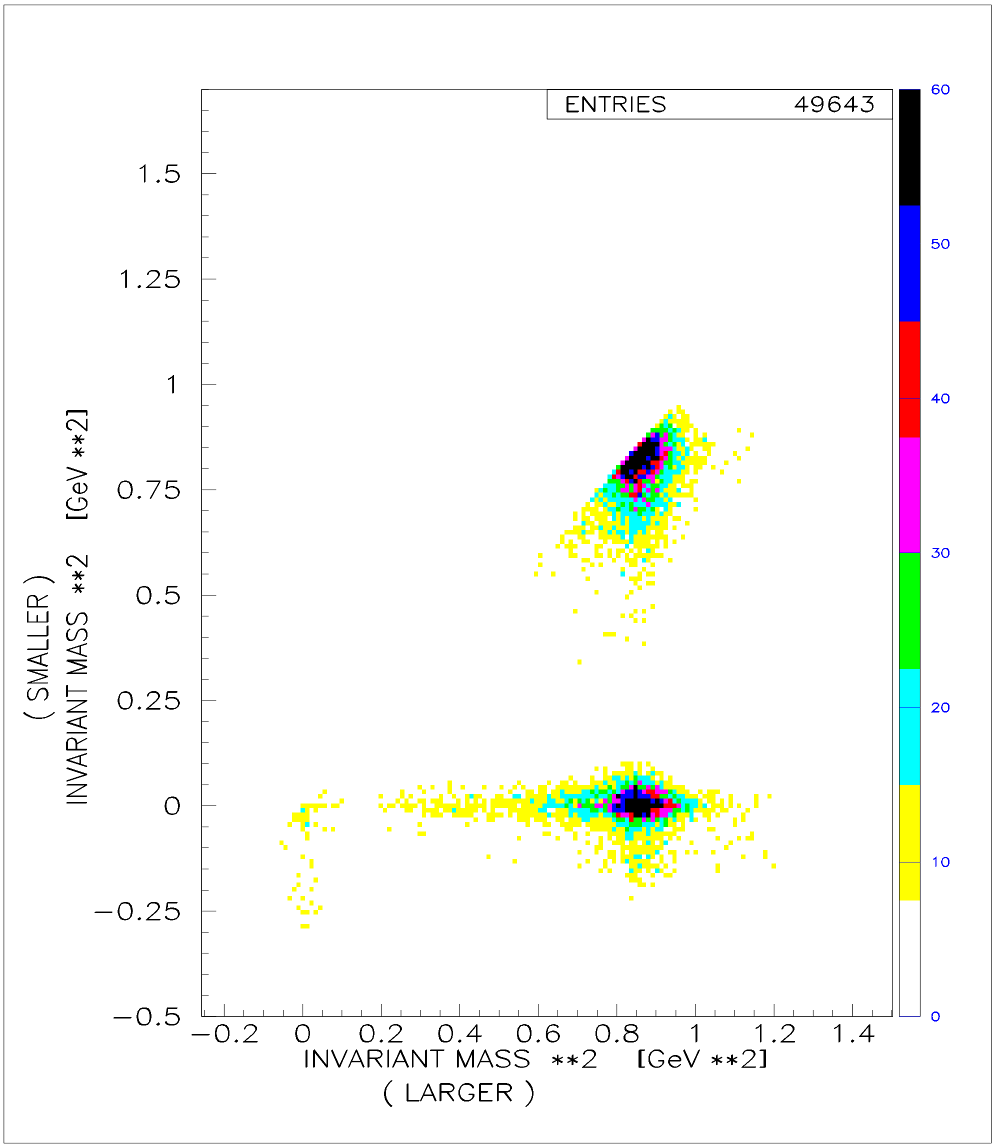

Figure 2: The scatterplot shows the separation of protons and pions. Each point on the picture corresponds to an event with two registered positively charged particles. Along both axes the squared mass of the particles are plotted. Always smaller versus larger.

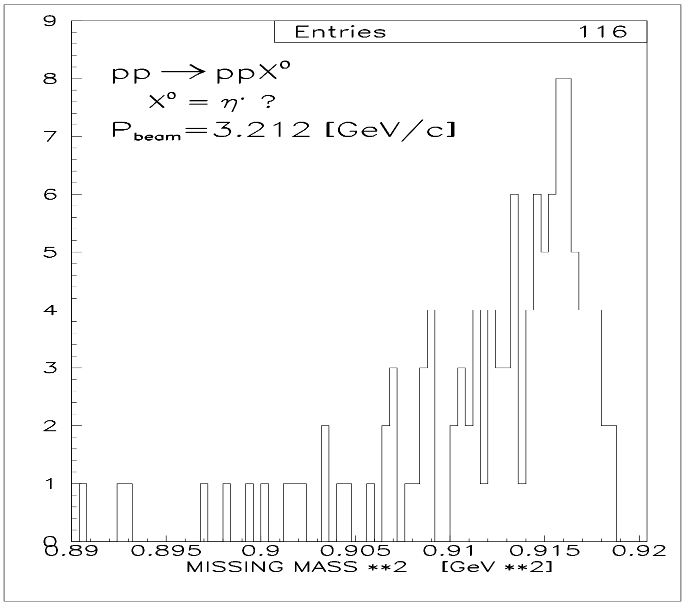

Figure 3: Missing mass of the unobserved particle in the $p+p \rightarrow p+p+X^{\circ}$ reaction at a beam momentum of 3.212 GeV/c, 4 MeV/c above threshold.

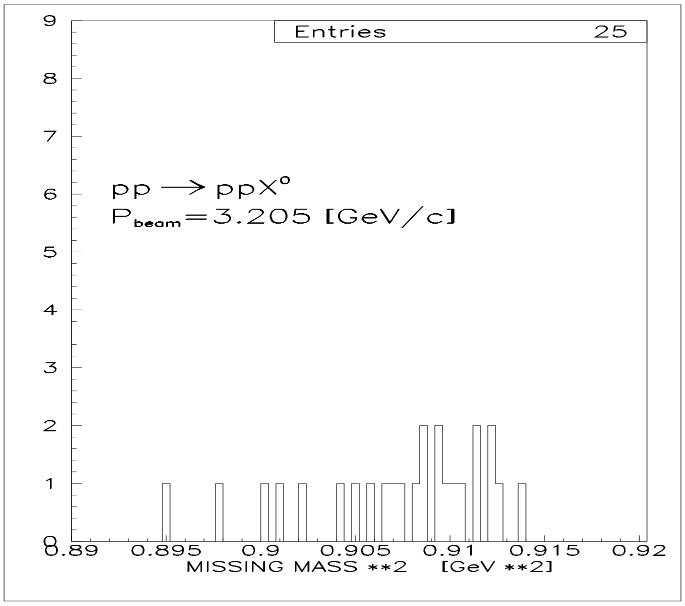

Figure 4: Missing mass of the unobserved particle in the $p+p \rightarrow p+p+X^{\circ}$ reaction at a beam momentum of 3.205 GeV/c, 3 MeV/c below threshold.