Investigation of the glue content in the η' meson

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Abstract. It is proposed to investigate the structure of the η' meson by comparing its close to threshold production cross section in the proton-proton and proton-neutron interaction. The comparison of the ratio $R_{\eta'} = \sigma(pn \to pn\eta')/\sigma(pp \to pp\eta')$ with $R_{\eta} = \sigma(pn \to pn\eta)/\sigma(pp \to pp\eta)$ will allow to infer about the gluonium content of the η' meson and the relevance of quark-gluon degrees of freedom when considering the close to threshold production of this meson.
In the extreme case when the η' meson is created only from glue being excited in the interaction region the ratio $R_{\eta'}$ should be close to unity after the correction for the final and initial state interaction between the interacting nucleons. Whereas a production mechanism dominated by the isovector meson exchange would yield a significantly larger ratio. In the latter case it is expected to be close to a value of 6.5 as already determined for the η meson production.

STRUCTURE OF THE η' MESON: DOES IT DIFFER FROM THE STRUCTURE OF THE MESON η?

The η' meson was first observed in 1964 [1,2] in the reaction $K^-p \to \Lambda\eta'$. Despite almost fourty years of investigations its structure is still not well determined. It appears that its properties cannot be described in terms of the mixture of the singlet ($\eta_1 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$) and octet ($\eta_8 = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$) states of the SU(3)-flavour pseudoscalar meson nonet. According to this classification the amount of singlet and octet components in the physical η and η' mesons wave functions is determined by the pseudoscalar mixing angle Θ [3]:

$$\eta = cos\Theta \cdot \eta_8 - sin\Theta \cdot \eta_1, \quad \eta' = sin\Theta \cdot \eta_8 + cos\Theta \cdot \eta_1.$$

The most up to date value of this angle is determined to be $\Theta = -15.5^\circ \pm 1.3^\circ$ [4] and implies that the percentage amount of the strange and non-strange quarkonium in both mesons is almost the same:

$$\eta = 0.77 \cdot \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) - 0.63 \cdot s\bar{s}, \quad \eta' = 0.63 \cdot \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) + 0.77 \cdot s\bar{s}.$$

Thus, in this scheme, the masses of these mesons should be almost equal, but they are not. The mass of the $\eta'(958)$ meson is almost two times larger than the mass of the meson $\eta(547)$. Moreover, it is the mass of the η' meson which does not fit to the SU(3) scheme. The masses of all other members of the pseudoscalar meson nonet, including the η meson, can be described within an accuracy of 2% by a phenomenological formula which assigns the meson mass to the sum of the quark and antiquark masses and their energy of the colour spin-spin coupling [5,6]. The difficulty in describing the η' mass becomes even more surprising when one realizes that not only the masses of pseudoscalar or vector mesons are well described in terms of quark models but also the masses of other hadrons like tensor mesons [7] or baryons [8].

However, in spite of the fact that the strange and non-strange quarkonium content of mesons η and η' is almost the same, due to the small mixing angle Θ, the η meson remains predominantly the SU(3)-flavour octet state and the η' meson the SU(3)-flavour singlet. This basic property of the η' – distinguishing it from the other pseudoscalar mesons – gives a hint for the explanation of its peculiar physical features.

In order to explain the large η' meson mass, the two-gluon annihilation process $gg \longleftrightarrow q\bar{q}$ is introduced as a contribution to the SU(3)-flavour singlet state [9,10]. Because of the small pseudoscalar mixing angle such an additional gluon-induced interaction should mainly affect the properties of the η' which is predominantly built out of the SU(3)-flavour singlet state. To reproduce the observed η' mass, a gluonium component ranging between 29% and 53% is required [11]. A more sophisticated theoretical calculation based on the $U_A(1)$- extended chiral Lagrangian indicates that gluonic degrees of freedom generate about 300-400 MeV of both the η and η' mesons [12].

A gluonic component of the η' meson is introduced as a flavour singlet state additionally to the η_1, which couples directly to the glue [13]. Thus, the η' meson can couple to gluons not only via its η_1 singlet component and the quark and antiquark triangle loop but also directly through its gluonic admixture as shown in Figure 1.

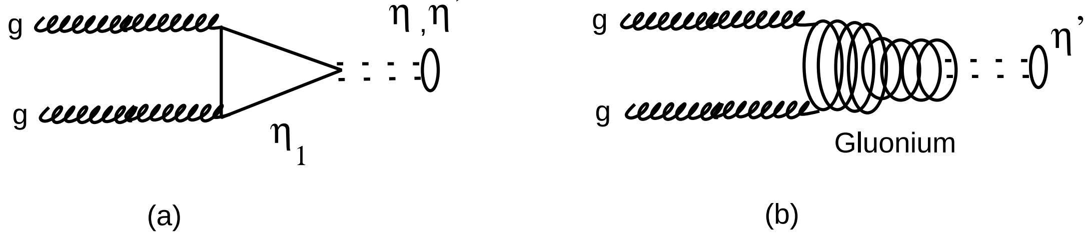

FIGURE 1. Coupling of η and η' to two gluons through quark and antiquark triangle loop (a) and through gluonic admixture (b). The Figure is taken from reference [13].

It is also possible that other states, predicted by the QCD theory, contribute to the η' wave function, as for example hybrids containig glue like $q\bar{q}g$, radially excited $q\bar{q}$ states as proposed by H. Lipkin [14], or heavier quarkonia like charmonium [15–17]. Out of the listed possibilities, the gluonium admixture is the one with the most theoretical considerations and is believed to be the most significant one [6,7,12,13,18–24].

The interest in the estimation of the gluonium content of the η' meson is also stimulated by the observation of an anomalously high η' appearance in the decays of B and D_s mesons. The branching ratio for $B^+ \to K^+\eta' = (6.5 \pm 1.7) \cdot 10^{-5}$ is much larger than the one for the corresponding η channel $B^+ \to K^+\eta < 1.4 \cdot 10^{-5}$. Similar relations are found in the decay of the D_s meson for which $\frac{\Gamma(D_s^+ \to \eta'\rho^+)}{\Gamma(D_s^+ \to \eta' e^+\nu)} = 12.0 \pm 4.3$ exceeds $\frac{\Gamma(D_s^+ \to \eta\rho^+)}{\Gamma(D_s^+ \to \eta e^+\nu)} = 4.4 \pm 1.2$ [25,26].

It is worth to stress that the observed branching ratios do not agree with the predictions which ignore the gluonic content of the η' [27] and also that these ratios for the η' meson differ significantly from those of the η.

The remarkable difference between the η and η' mesons is observed also in the close to threshold creation of these mesons in proton-proton collisions. The striking feature derived from experiments performed at CELSIUS [28,29], SATURNE [30–33], and COSY [34–36] is that the total cross sections for the $pp \to pp\eta'$ reaction is by about a factor of fourty smaller than the cross sections for the $pp \to pp\eta$ reaction at corresponding values of the excess energy. Trying to explain this large difference Hibou et al. [32] showed that a one-pion-exchange model with the parameters adjusted to fit the total cross section for the $pp \to pp\eta$ reaction underestimates the η' data by about a factor of two. This discrepancy suggests that short-range production mechanisms as for example heavy meson exchange, mesonic currents [37], or more exotic processes like the production via a fusion of gluons [20] may contribute significantly to the creation of η and η' mesons [38].

The momentum transfer required to create these mesons is much larger compared to the pion production, and already in case of pions a significant contribution from the short-range heavy meson exchange is necessary in order to obtain agreement with the experiments [39,40].

S. Bass et al. pointed out that the axial anomaly gluonic degrees of freedom may affect the threshold behaviour of η and η' photo- and proton-induced production inducing new gluonic coupling constants in the η and η' nucleon interactions [12].

At present, since the effective coupling constant describing the η'-proton-proton vertex is not known, it is even not possible to determine the contribution from the simplest possible production mechanism where the η' is supposed to be emitted as a bremsstrahlung radiation from one of the colliding protons as shown in Figure 2a. Consequently, investigations of the η' production have to deal with a few problems at the same time. Namely: unknown reaction mechanism, unknown coupling constant, and unknown proton-η' interaction.

The main difficulty in the determination of the $g_{NN\eta'}$ coupling constant is due to the fact that usually the direct production on the nucleon is either associated with the production through baryonic resonances, as in the case of the $\gamma p \to \eta' p$ reaction [41–43], or with the exchange of other mesons. Therefore, if the direct production mechanism is not dominant it is not possible to extract the $NN\eta'$ coupling without the clear understanding of the other mechanisms. However, it would be very interesting to determine the $g_{NN\eta'}$ coupling constant and to compare it with calculations performed on the quark level assuming the η' meson structure.

A first theoretical attempt to determine this quantity on the quark level shows that due to the 't Hooft interaction [44] the η'-quark coupling $g_{q\bar{q}\eta'}$ is significantly suppressed compared to the other pseudoscalar mesons. Consequently, the $\eta' NN$ vertex appears to be suppressed as compared to the ηNN one [45]. The anomalous coupling of the η'-gluon-gluon vertex is also widely discussed in context of the unexpectedly large B meson decays into η' and strange mesons [23,46,21], but also in view of the threshold η' production in the $pp \to pp\eta'$ reaction [20]. The present estimations for $g_{NN\eta'}$ deduced from different experiments are widely spread from 0.2 to 7.3 and are not consistent with each other [47]. More efforts are needed on the experimental as well as on the theoretical side to fix this important parameter.

The second interesting observation from the close to threshold production of η and η' is that the energy dependence of the total cross section for the reaction $pp \to pp\eta$ does not follow the predictions based on the phase space volume and the proton-proton final state interaction, which, however, is the case for the η' meson production in the $pp \to pp\eta'$ reaction.

The primary production amplitude for η' normalized to the one for the π^0 was found to be independent of the excess energy. In contrary, in case of η this normalized amplitude increases with decreasing energy [48]. Thus it was concluded that the η' meson interacts with the proton much weaker than the η [48], albeit both these mesons have very similar quark contents. Again, the gluonic admixture of η' will influence the η'-nucleon interaction via the U(1) anomaly [20]. The range of the glue induced η'-nucleon interaction, if determined by the two-gluon effective potential, would be in the order of 0.2-0.4 fm [49]. This is already large enough to be important in the threshold production of η' via the reaction $NN \to NN\eta'$ which occurs when the colliding protons are closer than 0.2 fm.

WHAT IS THE MECHANISM OF η' PRODUCTION IN THE $NN \to NN\eta'$ REACTION ?

Theoretical studies of the production mechanisms accounting for the π^0 and η mesons creation in the close to threshold $pp \to pp\pi^0(\eta)$ reactions have shown that the short-range component of the N-N force and the off-shell pion rescattering dominate the production process of the π^0 meson [39,40,50], whereas the η meson is predominantly produced through the excitation of the intermediate baryonic resonance $S_{11}(1535)$ [51–54,28]. However, the comparison of the experimentally determined η and η' ratio of the total cross sections with the predictions based on the one-pion-exchange model indicates that we are still far from the full understanding of the dynamics of the discussed processes. In particular, at present there is not much known about the relative contribution of the possible reaction mechanisms to the production of the η' meson. It is expected that – similarly to the case of pions – the η' meson can be produced as depicted in Figures 2a,b,c,d. However, because of the much larger four-momentum transfer short-range mechanisms – like heavy meson exchange (Figure 2c) or production via a mesonic current (Figure 2e), where the η' is created in a fusion of exchanged virtual ω, ρ, or σ mesons – are expected to contribute even more significantly.

Recently, Nakayama et al. [37], studied contributions from the *nucleonic* (Fig. 2b), *nucleon resonance* (Fig. 2d), and *mesonic* (Fig. 2e) currents and found that each one separately could describe the absolute values and energy dependence of the close to threshold η' data points [32,36], after an appropriate adjustment of the ratio of the pseudoscalar to the pseudovector coupling.

This rather pessimistic conclusion means that it is not possible to judge about the mechanisms responsible for the η' meson production from the total cross section of the reaction $pp \to pp\eta'$ only.

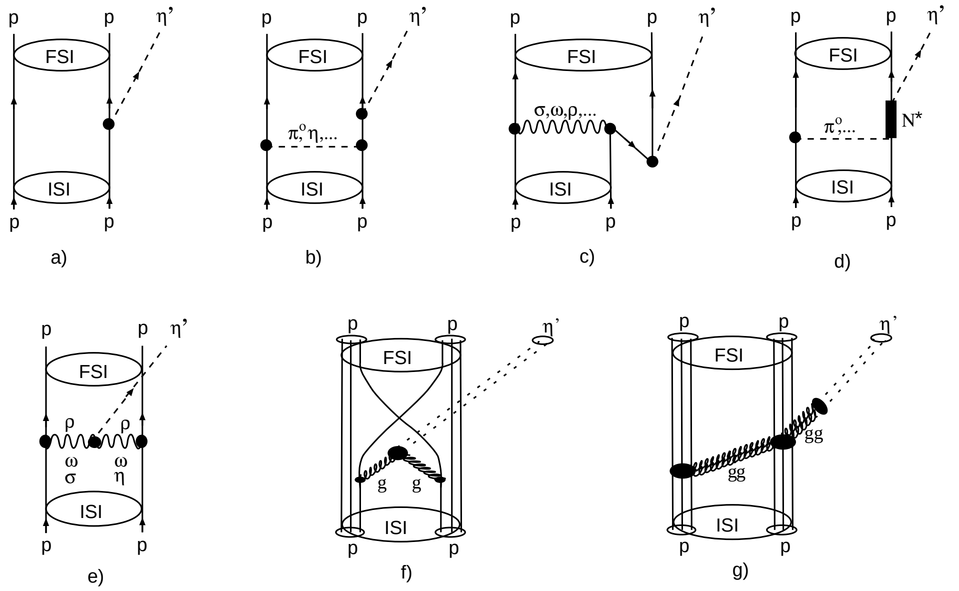

FIGURE 2. Diagrams for the $pp \to pp\eta'$ reaction near-threshold: (a)— η'-bremsstrahlung (nucleonic current) (b)— "rescattering" term (nucleonic current) (c)— production through heavy meson exchange (d)— excitation of an intermediate resonance (nucleon resonance current) (e)— emission from the virtual meson (mesonic current) (f)— production via a fusion of gluons [55] with rearangement of quarks (gluonic current). (g)— production via a rescattering of a "low energy pomeron" [56] (gluonic current).

Moreover, additionally to the mechanisms associated with the meson exchanges it is possible that the η' meson is created from the glue which is excited in the interaction region of the colliding protons [12,55]. The created gluons could couple to the η' meson directly via its gluonic component or through its flavour-singlet admixture η_1 (see Figure 1).

Figures 2f and 2g depict possible short-range mechanisms which may lead to the creation of the flavour singlet state via a fusion of gluons emitted from the exchanged quarks of the colliding protons [55] or via an exchange of a colour-singlet object made up from the glue, which then rescatters and converts into η' [56]. In contrary to the meson exchange mechanisms and the fusion of gluons of graph f, the production through the colour-singlet object proposed by Steven D. Bass (graph g) is isospin independent, and hence should lead to the same production yield of the η' meson in the $pp \to pp\eta'$ and $pn \to pn\eta'$ reactions after correcting for the final and initial state interaction between the nucleons.

In case of the η meson both these reaction channels were already measured. The ratio $R_\eta = \dfrac{\sigma(pn \to pn\eta)}{\sigma(pp \to pp\eta)}$ was determined to be about 6.5 in the excess energy range between 16 MeV and 109 MeV [57]. This implies that the production of the η meson with the total isospin equal to zero exceeds the production with the isospin $I = 1$ by a factor of 12, since $\sigma(pn \to pn\eta) = \dfrac{\sigma_{I=0} + \sigma_{I=1}}{2}$, and $\sigma(pp \to pp\eta) = \sigma_{I=1}$, and hence $\sigma_{I=0} = (2R_\eta - 1)\sigma_{I=1}$. This large difference of the total cross section between the isospin channels suggests the dominance of isovector meson (π and ρ) exchange in the creation of η in nucleon-nucleon collisions [38,57]. Moreover, this result together with the determined angular distributions of the produced η [58], permitted to infer that out of π and ρ meson exchanges ρ is the dominant one [38].

The comparison of the $pn \to pn\eta'$ and $pp \to pp\eta'$ total cross sections will allow to compare the production of the η' meson in the channels of isospin I = 0 and I = 1. By analogy to η production, in case of a dominant isovector meson exchange mechanism the ratio $R_{\eta'}$ is expected to be about 6.5. In the other scenario, when the η' is produced via its flavour-singlet or gluonic component from the colour-singlet glue excited in the interaction region, the ratio $R_{\eta'}$ should approach unity after the correction for the final and initial state interactions between the participating baryons [59]. This is because the glue does not distinguish between flavours.

"η' phenomenology is characterized by large OZI violations. It is natural to expect large gluonic effect in the $NN \to NN\eta'$ process, a measurement of $R_{\eta'}$ is urgently needed !" [59].

EXPERIMENTAL METHOD: QUASI-FREE PRODUCTION

In order to measure the $pn \to pn\eta'$ reaction by means of a proton beam it is necessary to use a nuclear target, since a pure neutron target does not exist. Similar to investigations of the η meson production in the $pn \to pn\eta$ reactions [60,29,57], a deuteron will be considered as a source of neutrons. Due to the small binding energy of the deuteron ($E_B = 2.2\ MeV$), the neutron struck by the proton incoming with 2540 MeV kinetic energy may approximately be treated as being a free particle. In this approximation the proton from the deuteron is considered as a spectator which does not interact with the bombarding proton, but rather escapes untouched and hits the detectors carrying the Fermi momentum possessed at the moment of the collision (Figure 3a). The momentum spectrum of the nucleons in the deuteron is shown in Figure 3b.

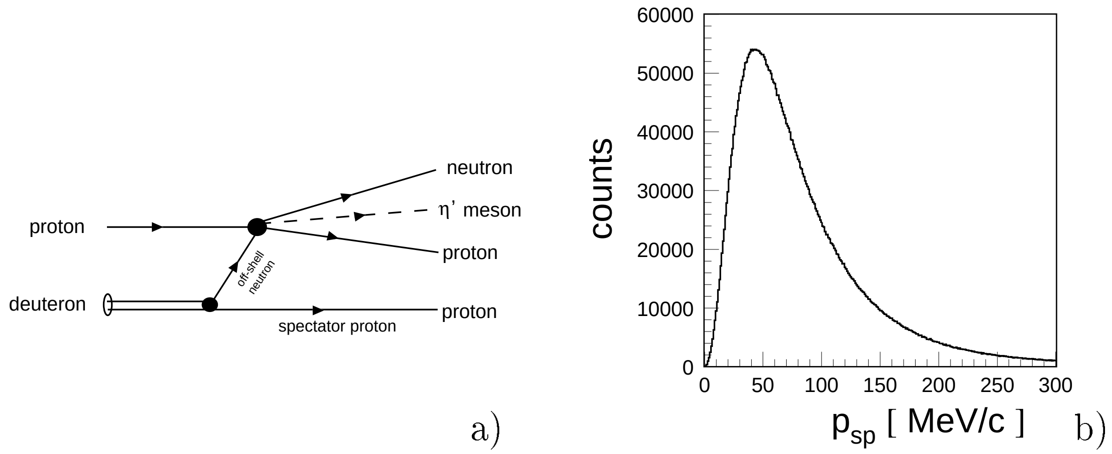

FIGURE 3. (a) Graph of the $pd \to p_{sp}pn\eta'$ reaction under the assumption of the quasi-free approximation for the $pn \to pn\eta'$ reaction. (b) The momentum distribution of the nucleons in the deuteron, generated according to an analytical parametrization of the deuteron wave function [61,62] calculated from the PARIS potential [63].

Since the neutron bound inside a deuteron is not at rest, and its momentum may change from event to event, the excess energy in the quasi-free proton-neutron reaction will also vary from event to event. This enables to scan a large range of excess energies with a constant proton beam momentum, but simultaneously requires the determination of this energy for each registered event, which can be done only if the neutron momentum vector is known. This may be realized experimentally either by determining the four-momentum vectors of outgoing proton, neutron and η' or by measuring the four-momentum of the spectator proton. Since at present none of the experimental facilities installed at COSY can fulfill the first requirement only the case with the registration of the spectator proton will be considered. From the measurement of the momentum vector of the spectator proton one can infer the momentum vector of the neutron at the time of the reaction, and hence calculate the excess energy. The distribution of the excess energy in a quasi-free $pn \to pn\eta'$ reaction, is presented in Figure 4a.

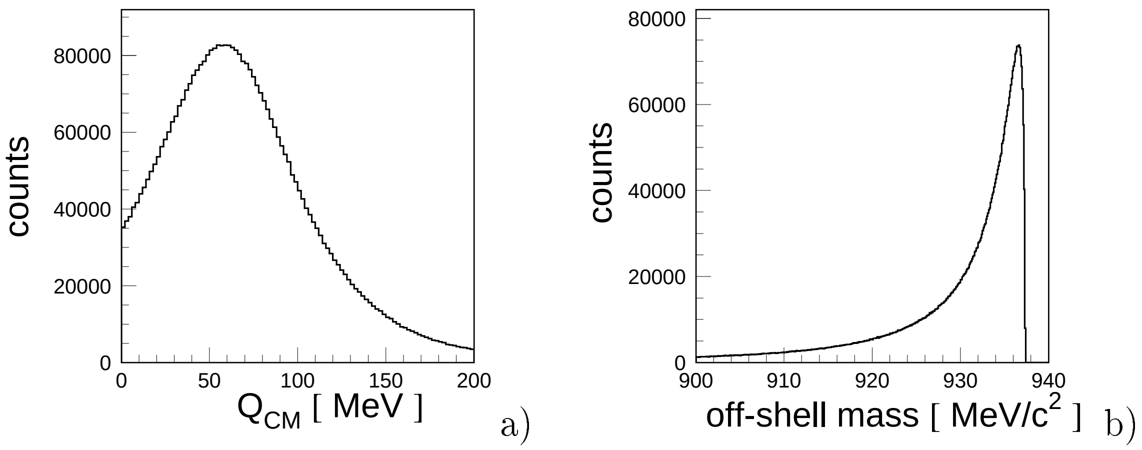

FIGURE 4. (a) Distribution of the excess energy Q_{CM} for the $pn\eta'$ particles outgoing from the reaction $pd \to p_{sp}pn\eta'$ calculated with a proton beam momentum of 3.350 GeV/c, and the neutron momentum smeared out according to the Fermi distribution shown in Figure 3b. The beam momentum of 3.350 GeV/c corresponds to an excess energy of $Q_{CM} = 44.7\ MeV$ for the free $pn \to pn\eta'$ reaction. (b) Spectrum of the off-shell mass of the interacting neutron, as calculated under the assumption of the impulse approximation.

In the frame of the considered impulse approximation (see Figure 3a) the spectator proton is a physical particle so it must be on its mass shell. This implies, however, that the reacting neutron is off its mass shell, and hence the extrapolation from the quasi-free to the free $pn \to pn\eta'$ must be done with care. The distribution of the off-shell mass of the interacting neutron is shown in Figure 4b. It can be seen that the maximum of this spectrum differs only by about 3 MeV from the free neutron mass ($m_n = 939.57\ MeV$), however on the average it is off by about 9 MeV. Mesurements performed at the CELSIUS accelerator showed, that within the statistical errors there is no difference between the total cross section obtained for the free $pp \to pp\eta$ reaction and the corresponding cross section for the quasi-free production on an off-shell proton from the deuteron target [29,57]. This observation allows to anticipate that in the case of the planned study of the η' in the $pd \to p_{sp}np\eta'$ reaction, the measured total cross section for the quasi-free $pn \to pn\eta'$ reaction will not differ from the on-shell one. In fact, the difference between off-shell and on-shell cross section of the η' meson production should be even smaller than in the case of the η, since in the former case the total energy of the interacting nucleons is much larger than in the latter one, and the mean difference between the off-shell and on-shell neutron mass remains the same.

Other nuclear effects in case of the production on the neutron bound in the nucleus are rather of minor importance. The effect of the reduction of the beam flux on a neutron due to the presence of the proton in the deuteron, referred to as a shadow effect, decreases the total cross section by about 4.5% [60] in case of η production [60]. Thus it should also have a minor influence on the evaluation of the total cross section for the $pn \to pn\eta'$ reaction. Similarly the reduction of the total cross section due to the reabsorbtion of the produced η' on the spectator proton should be negligible due to the weak proton-η' interaction. Even in case of the η meson, which interacts with protons much more strongly, this effect was found to be in the order of 3% [60].

WHERE CAN THE $PN \to PN\eta'$ REACTION BE MEASURED?

In order to identify the production of the meson η' in the proton-deuteron collision it is necessary either to measure the decay products of the meson or to register the outgoing nucleons and nuclei. At present only the second possibility can be considered at COSY experiments due to the lack of the appropriate detector[1]. The requirement of the spectator proton registration excludes the possibility of performing such an experiment by means of any external facilities which utilize liquid or solid targets.

At present, COSY-11 is the only internal facility at COSY, where the outgoing proton and neutron can be measured simultaneously. Since for the proposed study the ratio $R_{\eta'} = \sigma(pn \to pn\eta')/\sigma(pp \to pp\eta')$ has to be determined it would be extremely required to perform both the production on protons and on neutrons by means of the same detection system in order to reduce systematical uncertainties. In the last years close to threshold total cross sections for the $pp \to pp\eta'$ reaction have been succesfully determined at the COSY-11 facility [36,35]. Thus the proposed investigation is planned to be performed using the COSY-11 detection system with an additional silicon strip detector for the registration of the spectator proton. The shape of the COSY-11 scattering chamber close to the target allows for the installation of the spectator detectors which were already used succesfully at the CELSIUS accelerator for tagging of the quasi-free proton-neutron interactions. First preparations at the inside of the scattering chamber were already done during the December and January maintenance weeks. The installation of the detectors is foreseen during the COSY maintenance week in August, and starting November this year the first experimental run with the spectator tagger will be possible.

In Figure 5 a schematic view of the COSY-11 detection system together with the spectator detector is presented. The spectator detector consists of four modules with two layers of 0.3 mm thick silicon strips. Each module is further divided into

[1] The photon detector is planned to be build and installed at the ANKE facility, however, first experiments with this apparatus are foreseen for the end of the year 2004 [64].

six parts each of them with 3 strips of 20 mm x 5 mm. Both layers together can absorb protons up to a momentum of 130 MeV/c. On the other hand, protons with momenta lower than 30 MeV/c cannot be distinguished from the noise. Thus this detector allows the registration and identification of 71% of the spectator protons hitting its sensitive area (see Figure 3b).

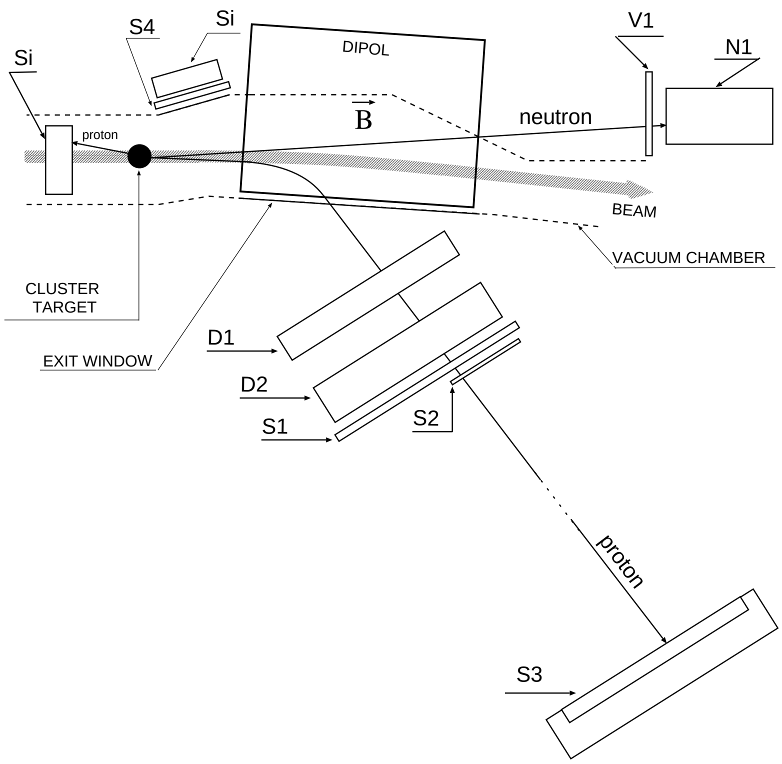

FIGURE 5. Schematic view of the COSY-11 detection setup [65]. Only detectors needed for the measurements of the $pd \to p_{sp}pn\eta(\eta')$ reactions are shown.
D1, D2 denotes the drift chambers; S1,S2,S3,S4 and V1 the scintillation detectors; N1 the neutron detector and Si the silicon strip detectors.

The physical properties of the detector were implemented into the COSY-11 Monte-Carlo programe and detailed simulations of the $pd \to p_{sp}pn\eta'$ reaction were performed, taking into account the momentum and dimension spread of the COSY beam, as well as the dimensions of the cluster target and the known resolution of the time and position measurements of the standard COSY-11 detectors.

Figure 6a presents the spectrum of the spectator proton momentum which will be registered in coincidence with the forward flying proton and neutron. The fact that the spectator protons with momentum larger than 130 MeV will not be registered has the advantage that events with neutron masses differing much from its on-shell value will be omitted (compare figures 4 b and 6 b).

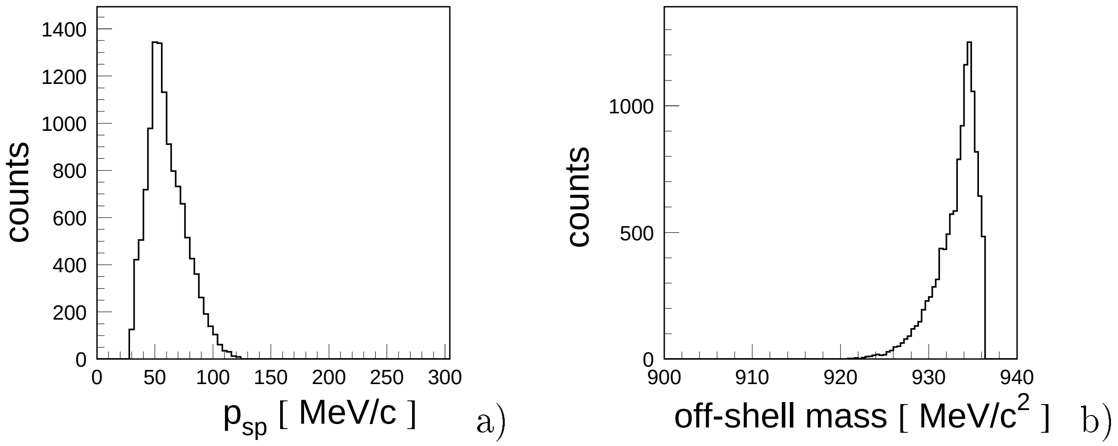

FIGURE 6. (a) The momentum distribution of the spectator protons which were registered in coincidence with the forward scattered neutron and proton. (b) Spectrum of the off-shell mass of the interacting neutron, provided that all nucleons outgoing from the $pd \to p_{sp}pn\eta'$ reaction have been measured at the COSY-11 detection system.

Both, the position of the spectator detector and the proton beam momentum were optimized such that most of the registered events have an excess energy in the range between 0 MeV and 25 MeV. This is the range for which the total cross section of the $pp \to pp\eta'$ has bean studied at COSY-11 [35]. Increasing the beam momentum we generally shift the maximum from Figure 4a to larger values, but simultaneously installing the spectator detector behind the target (see Figure 5), such that the spectator proton is moving opposite to the proton beam, the excess energy is decreasing, since the neutron is escaping the beam proton. Positioning of the tagger detector behind the target reduces also drastically its irradiation. The distribution of the excess energy for events registered under the chosen geometry is shown in Figure 7a. In the first approximation it reflects the dependence of the COSY-11 acceptance on the excess energy. Figure 7b depicts the difference between the generated and reconstructed excess energy. The standard deviation of the obtained resolution amounts to 2 MeV, and is due to the finite dimension of the beam and target and the granulation of the spectator detector. In this simulations the distance between the beam and the detector was adjusted to be 5 cm as an optimum regarding both the coverage of the solid angle and the angular resolution. However, the accuracy of the excess energy reconstruction may be improved significantly if needed, since the scattering chamber allows for the installation of spectator detectors at a distance of 10 cm from the beam.

Apart from the excess energy, in order to identify the reaction it is necessary to determine the momentum vectors of the registered protons and neutrons. Proton momenta will be reconstructed by tracking back the proton trajectory to the target point, and the neutron momenta will be determined from the time of flight between the target and neutron detector and the angle defined by the middle of the hit segment. The granulation of the neutron detector allows to determine the horizontal position with an accuracy of ± 4.5 cm. For the time resolution of one segment (11 scintillation and 11 lead plates) a conservative value of 0.5 ns (standard deviation) was assumed.

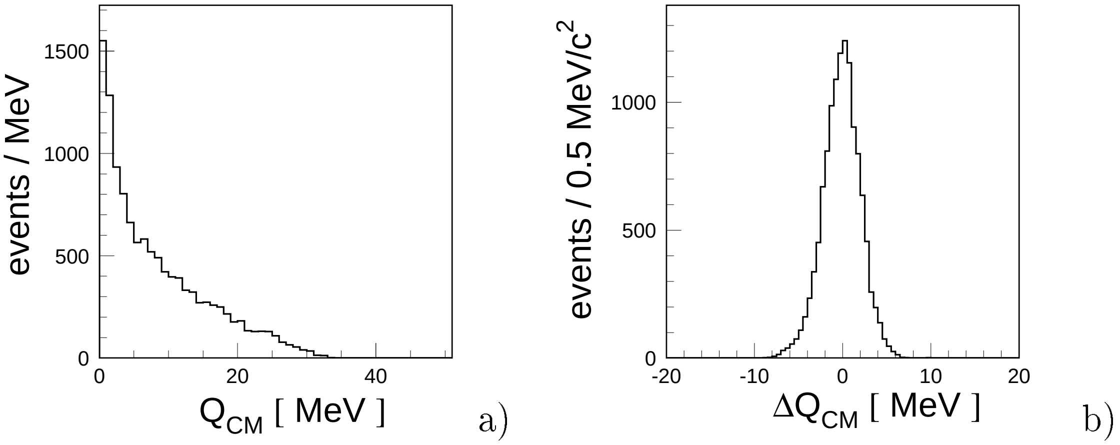

FIGURE 7. (a) Distributions of the excess energy Q_{CM} for the quasi-free $pn \to pn\eta'$ reaction as measured with the COSY-11 detection system at a beam momentum of 3.350 GeV/c. The shape corresponds roughly to the energy dependence of the detection efficiency. Figure shows the number of reconstructed events per 1 MeV bin out of the 5 10^6 events generated in the target. (b) Difference between the generated and reconstructed excess energy. Calculations were performed assuming a target diameter of 0.9 cm [66], and standard deviations of 0.2 cm and 0.4 cm for the horizontal and vertical beam spread, respectively. The applied values correspond to a realistic estimation of the beam parameters based on the data from previous COSY-11 experiments. The spectator detector modules were positioned behind the target, five centimeters from the beam.

The missing mass spectrum, reconstructed from events for which signals from the spectator detector as well as the forward scattered protons and neutrons were registered, is shown in Figure 8. The obtained mass resolution amouts to 7.6 MeV (FWHM) which is only 3 times the resolution of the measurements for the $pp \to pp\eta'$ reaction at an excess energy of 23.6 MeV.

Assuming a luminosity of $3 \cdot 10^{30}\ cm^{-2}s^{-1}$, and taking into account i) the detection efficiency which decreases with excess energy as shown in Figure 7a and ii) the energy dependence of the total cross section as determined for the $pp \to pp\eta'$ reaction, we calculate the number of quasi-free $pn \to pn\eta'$ events which will be measured per day. The calculation can be performed modulo the absolute cross section which in the one extreme scenario should be equal to the cross section of the $pp \to pp\eta'$ reaction, and in the other extreme case should be enhanced by factor of about 6.5, as discussed in the previous sections.

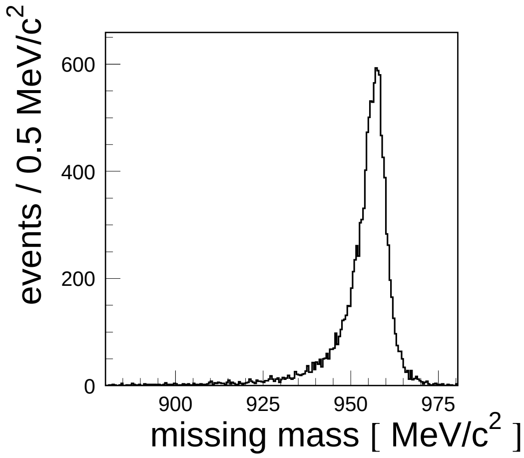

FIGURE 8. The missing mass distribution as reconstructed from the generated events under the described assumptions of the time and position resolution of the COSY-11 detectors.

The estimation results in 30 and 195 measured and reconstructed events per day for the extreme scenarios.

The energy dependence of the total cross section is predominantly determined by the nucleon-nucleon final state interaction, which approximately has the same influence for the η and η' production. Thus, the observation that the excitation function for the $pp \rightarrow pp\eta$ – and $pn \rightarrow pn\eta$ reaction is approximately the same justifies our assumption of the cross section dependence for the estimation of the counting rate.

Taking into account that the expected background from many pion production will be at least as large as it was in the case of the measurement of the $pp \rightarrow pp\eta'$ reaction at the highest measured excess energy of Q = 23.6 MeV [35], (background / signal $\approx$ 6) it is needed to measure at least 1000 events in order to get rid of the statistical fluctuation of the background.

For measuring 1000 quasi-free $pn \rightarrow pn\eta'$ events 5 days or 5 weeks will be needed depending on the production mechanism.

Presently, we would like to ask **at first for one week of COSY beam time** at the end of this year in order to test the functioning of the system by a) a three days measurement of the quasi-free production of the η meson and b) a three days measurement of the $pn \rightarrow pn\eta'$ production in order to estimate the real experimental background and the time needed to realize the proposed investigations.

REFERENCES

1. G.R Kalbfleisch et al., Phys. Rev. Lett. **12** (1964) 527.
2. M. Goldberg et al., Phys. Rev. Lett. **12** (1964) 546.
3. F.J. Gilman, R. Kauffman, Phys. Rev. **D 36** (1987), 2761,
   see also Errata: Phys. Rev. **D 37** (1988) 3348.
4. A. Bramon, R. Escribano, M.D. Scadron, Eur. Phys. J. **C 7** (1999) 271.
5. D.J. Griffiths, *Introduction to Elementary Particles*,
   John Wiley & Sons, Inc. New York 1987
6. J.L. Rosner, Phys. Rev. **D 27** (1983) 1101.
7. M.R. Pennington, DTP-90/68,
   Proceedings of the Oxford Conference, September 1990
8. M. D. Scadron, *Advanced Quantum Theory*, Springer-Verlag Berlin Heidelberg, 1991
9. B. Diekmann, Phys. Rep. **159** (1988) 99.
10. J.F. Donoghue, H. Gomm, Phys. Lett. **121B** (1983) 49.
11. F. Lenz, Nucl. Phys. **B 279** (1987) 119.
12. S.D. Bass, S. Wetzel, W.Weise, Nucl. Phys. **A 686** (2001) 429.
13. E. Kou, Phys. Rev. **D 63** (2001) 054027.
14. H.J. Lipkin, Phys. Lett. **B 67** (1977) 65.
15. M. R. Ahmady, E. Kou, e-Print Archive: hep-ph/9903335.
16. F. Araki, M. Musakhanov, H. Toki, Phys. Rev. **D 59** (1999) 037501.
17. B. Tseng, Phys. Lett. **B 446** (1999) 125.
18. H. J. Lipkin, Phys. Lett. **B 494** (2000) 248.
19. H.-Y. Cheng, B. Tseng, Chin. J. Phys. **39** (2001) 28.
20. S. D. Bass, Phys. Lett. **B 463** (1999) 286.
21. A. Ali, A.Ya Parkhomenko, e-Print Archive: hep-ph/0012212.
22. P. Ball, J.-M. Frère, M. Tytgat, Phys. Lett. **B 365** (1996) 367.
23. T. Muta, M.-Z. Yang, e-Print Archive: hep-ph/9902275.
24. E. Kawai, Phys. Lett. **B 124** (1983) 262.
25. C.P. Jessop et al., Phys. Rev. **D 58** (1998) 052002.
26. G. Brandenburg et al., Phys. Rev. Lett. **75** (1995) 3804.
27. D. Du, Y. Yang, G. Zhu, Phys. Rev. **D 59** (1999) 014007.
28. H. Calén et al., Phys. Lett. **B 366** (1996) 39.
29. H. Calén et al., Phys. Rev. Lett. **79** (1997) 2642.
30. A. M. Bergdolt et al., Phys. Rev. **D 48** (1993) R2969.
31. E. Chiavassa et al., Phys. Lett. **B 322** (1994) 270.
32. F. Hibou et al., Phys. Lett. **B 438** (1998) 41.
33. F. Balestra et al., Phys. Lett. **B 491** (2000) 29.
34. J. Smyrski et al., Phys. Lett. **B 474** (2000) 182.
35. P. Moskal et al., Phys. Lett. **B 474** (2000) 416.
36. P. Moskal et al., Phys. Rev. Lett. **80** (1998) 3202.
37. K. Nakayama et al., Phys. Rev. **C 61** (1999) 024001.
38. C. Wilkin, e-Print Archive: nucl-th/9810047.
39. J. Haidenbauer, Ch. Hanhart, J. Speth, Acta Phys. Pol. **B 27** (1996) 2893.
40. C. J. Horowitz, H. O. Meyer, D. K. Griegel, Phys. Rev. **C 49** (1994) 1337.

41. R. Plötzke et al., Phys. Lett. **B 444** (1998) 555.
42. Q. Zhao, e-Print Archive: nucl-th/0011070.
43. B. Borasoy, Eur. Phys. J. **A 9** (2000) 95.
44. G. 't Hooft, Phys. Rev. Lett. **37** (1976) 8.
45. D. Lehmann, Eur. Phys. J. **A 4** (1999) 327.
46. M. R. Ahmady, V. Elias, E. Kou, Phys. Rev. **D 57** (1998) 7034.
47. P. Moskal et al., AIP Conf. Proc. **512** (2000) 65.
48. P. Moskal et al., Phys. Lett. **B 482** (2000) 356.
49. V. Baru et al., Eur. Phys. J. **A 6** (1999) 445.
50. E. Hernández, E. Oset, Phys. Lett. **B 350** (1995) 158.
51. G. Fäldt, C. Wilkin, Z. Phys. **A 357** (1997) 241.
52. J.-F. Germond, C. Wilkin, Nucl. Phys. **A 518** (1990) 308.
53. J.M. Laget, F. Wellers, J. F. Lecolley, Phys. Lett. **B 257** (1991) 254.
54. A. Moalem et al., Nucl. Phys. **A 600** (1996) 445.
55. N. Nikolaev, CosyNews **No. 3** May 1998, Published by the Forschungszentrum Jülich in Cooperation with CANU, the COSY User Organisation of the Universities.
56. S. D. Bass, private communication
57. H. Calén et al., Phys. Rev. **C 58** (1998) 2667.
58. H. Calén et al., Phys. Lett. **B 458** (1999) 190.
59. S. D. Bass, e-Print Archive: hep-ph/0006348.
60. E. Chiavassa et al., Phys. Lett. **B 337** (1994) 192.
61. M. Lacombe et al., Phys. Lett. **101B** (1981) 139.
62. S. Häggström, Ph.D. thesis,
Uppsala University, Acta Universitatis Upsaliensis 13 (1997)
63. M. Lacombe et al., Phys. Rev. **C21** (1980) 861.
64. J. Bacelar et al., COSY Proposal#83.2
65. S. Brauksiepe et al., Nucl. Instr. and Meth. in Phys. Res. **A 376** (1996) 397.
66. H. Dombrowski et al., Nucl. Instr. & Meth. in Phys. Res. **A 386** (1997) 228.