Study of the isospin dependence of the η' production in the collision of nucleons

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Abstract. According to the quark model, the masses of η and η' mesons should be almost equal. However, the empirical values of these masses differ by more than the factor of two. Similarly, though the almost the same quark-antiquark content, the total cross section for the creation of these mesons close to the kinematical thresholds in the $pp \to ppX$ reaction differs significantly. Using the COSY-11 detection setup we intend to determine whether this difference will also be so significant in the case of the production of these mesons in the proton-neutron scattering. Our main aim is the determination of the excitation function of the total cross section for the $pn \to pn\eta'$ reaction near the kinematical threshold. The comparison of the $pp \to pp\eta'$ and $pn \to pn\eta'$ total cross sections will allow to learn about the production of the η' meson in the channels of isospin I = 0 and I = 1 and to investigate aspects of the gluonium component of the η' meson.

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INTRODUCTION

Despite the fact that the η' meson was observed fourty years ago, its structure is still not known. According to the quark model, η and η' mesons can be described as the mixture of the singlet and octet states of the SU(3) - flavour pseudoscalar meson nonet. Within the one mixing angle scheme, a small mixing angle ($\Theta = -15.5^0$) implies that the masses of η and η' mesons should be almost equal. However, the empirical values of these masses differ by more than the factor of two.

At present there is also not much known about the relative contribution of the possible reaction mechanisms of the production of the η' meson. It is expected that the η' meson can be produced through heavy meson exchange, through the excitation of an intermediate resonance or via emission from the virtual meson [1]. However it is not possible to judge about the mechanism responsible for the η' meson production only from the total cross section of the $pp \to pp\eta'$ reaction [2]. Therefore one has to investigate the η' production in both, proton-proton and proton-neutron scattering. A comparison of the close–to–threshold total cross section for the η' production in both the $pp \to pp\eta'$ and $pn \to pn\eta'$ reaction constitutes a tool not only to investigate the production of the η' meson in channels of isospin I = 1 and I = 0 but also may provide – as suggested in reference [3, 4, 5] – insight into the flavour-singlet (perhaps also into gluonium) content of the η' meson and the relevance of quark-gluon or hadronic degrees of freedom in the creation process.

Since the quark structure of η and η' mesons is very similar, in case of the dominant

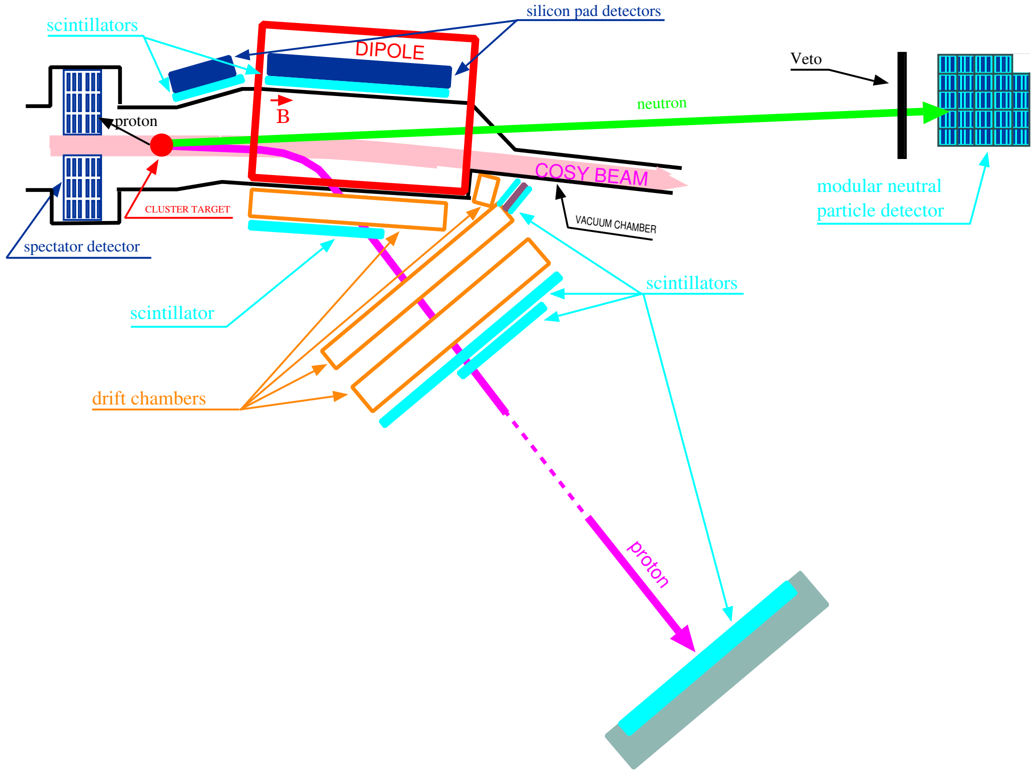

FIGURE 1. Schematic view of the COSY–11 detection setup. For more details the interested reader is referred to [11, 12]

isovector meson exchange – by the analogy to the η meson production – we can expect that the ratio $R_{\eta'}$ should be about 6.5 [6]. If however η' meson is produced via its flavour-blind gluonium component from the colour-singlet glue excited in the interaction region the ratio should approach unity after corrections for the initial and final state interactions. The close–to–threshold excitation function for the $pp \rightarrow pp\eta'$ reaction has already been determined [7, 8, 9, 10], whereas the total cross section for the η' meson production in the proton-neutron interaction is still unknown.

EXPERIMENTAL METHOD

In August 2004 –for the first time– using the COSY–11 facility we have conducted a measurement of the η' meson production in the proton-neutron collision.
A quasi-free $pn \rightarrow pnX$ reactions were induced by a proton beam in a deuteron target since pure neutron targets do not exist. For the data analysis the proton from the deuteron is considered as a spectator which does not interact with the bombarding proton, but escapes untouched and hits the detector carrying the Fermi momentum possessed at the time of the reaction. The experiment is based on the registration of all outgoing nucleons from the $pd \rightarrow p_{sp}pnX$ reaction. The COSY–11 detection setup is schematically depicted in figure 1. Protons are measured in two drift chambers and scintillator de-

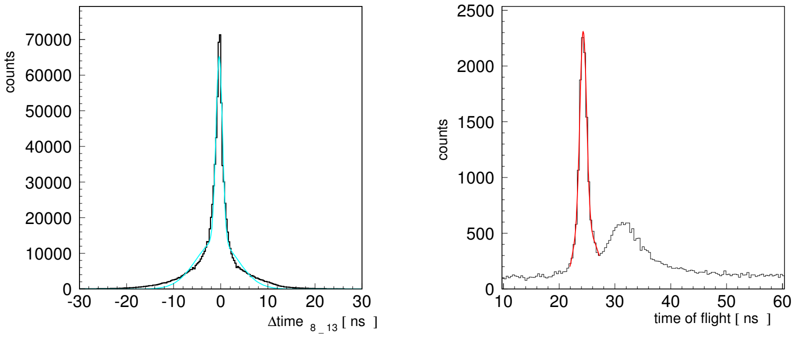

FIGURE 2. (left) Distribution of the time difference between 8^{th} and 13^{th} module of the neutron detector as determined after the calibration. **(right)** Time-of-flight distribution between the target and the neutron detector as obtained after time walk correction under condition that in coincidence with neutral particle also two charged particles were identified.

tectors [11, 13], neutrons are registered in the neutral particle detector [14]. Protons considered as a spectators are measured by the dedicated silicon-pad detector [15, 16]. Application of the missing mass technique allows to identify events with the creation of the meson under investigation and the total energy available for the quasi-free proton-neutron reaction can be calculated for each event from the momenta of the spectator and beam protons.

timing calibration of the neutral particle detector

The neutral particle detector at the COSY–11 facility is built out of 24 modules and delivers information about the time at which the registered neutron or gamma quanta induced correspondingly a hadronic or electromagnetic reaction. This information together with the time of the reaction allows to calculate the time-of-flight between the target and the neutron detector and to determine the absolute momentum of registered paricles, provided that it could have been identified [17]. The experimental precision of the missing mass determination of the $pn \to pn\eta'$ reaction [18, 19] strongly rely on the accuracy of the reconstruction of the momentum of neutrons therefore the time calibration of the neutron detector has to be done with high precision.

In order to establish relative time offsets for all single detection units, distribution of time differences between neighbouring modules were derived from experimental data. The values of the relative time offsets were adjusted such that time differences obtained from experimental data and from simulation equals to each other for each pair of detection unit. Figure 2 (left) shows example of experimental distribution of time difference as determined after the calibration.

Before the general time offset of the neutron detector was determined, the influence of the time walk effect was inspected.

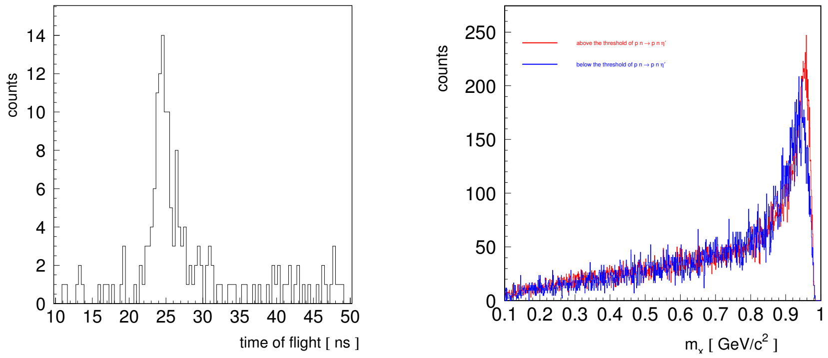

FIGURE 3. **(left)** Time-of-flight distribution between the target and the neutron detector obtained assuming that in coincidence with neutral particle also proton and deuteron were identified based on signals from drift chambers and scintillator hodoscopes, (after correction for time walk) **(right)** Missing mass spectra of the $pn \to pn\eta'$ process determined for the excess energies larger and smaller than zero

The time walk effect is caused by variations in the amplitude and risetime of the incoming signals. For example, two signals differing in pulse hight but exactly coincident in time may trigger the discriminator at different times. An offline correction can be applied to minimize this effect. The function used for offline time-walk correction was $t_c = t_m - \alpha + \beta(\frac{1}{\sqrt{ADC^{up}}} + \frac{1}{\sqrt{ADC^{dw}}})$, where t_c and t_m are corrected and measured time, α and β are coefficient determined by data, ADC^{up} and ADC^{dw} denote the measured signals in upper and lower part of the detector module. The aplication of the time walk correction allowed to improve the time resolution (σ) from 1.2 ns to 0.6 ns. It is worth to note that this is the overall accuracy resulting from the time resolution of the neutron and S1 detector and the accuracy of the momentum reconstruction in the magnetic field.

A general time offset of the neutron counter was established with respect to the S1 detector. For this purpose events with two tracks in the drift chambers and a simultaneous signal in the neutron detector have been selected. Figure 2 (right) presents the time-of-flight distribution – for neutral particles – measured between the target and the neutral particle detector. The spectrum was obtained under the condition that in coincidence with a signal in the neutral particle two charged particles were registered in the drift chambers. A clear signal originating from the gamma rays is seen over a broad enhancement from neutrons. This histogram shows that discrimination between signals originating from neutrons and gamma quanta can be done by a cut on the time of flight. In order to establish the general time offset the $pd \to pdX$ reaction have been used. For this reaction, due to the baryon number conservation there is only one possible source of a signal in a neutron detector, namely a gamma quantum, which originate from the decay of eg. π^0 mesons in the target. Thus, the calibration is based on the measurement of the proton, deuteron in drift chambers and scintillators, and gamma quanta in the neutral particle detector. Knowing the distance between the target and a module in the neutral particle detector which gave the signal as a first one, one can adjust the general time offset between this detector and the S1 counter. The time of the reaction in the target can be calculated from the times when proton and deuteron crossed the S1 scintillator and from their reconstructed momenta and trajectories. Figure 3 (left) presents experimental distribution of the time-of-flight between the target and neutron detector with the requirement that two charged particles were registered and that one of them was identified as a proton and the other as a deuteron. As expected, in this spectrum only a signal from the gamma quanta is seen.

missing mass of the $pn \rightarrow pnX$ reaction

Due to the smaller efficiency and lower resolution for the registration of the quasi-free $pn \rightarrow pn$ *meson* reaction in comparison to the measurements of the proton-proton reactions, the elaboration of the data encounters problems of low statistics. However, one can extract the number of registered $pn \rightarrow pn$ *meson* events from the missing mass distribution provided that the contribution of the continuous spectrum originting from the multi-pion production can be disentangled from the signal resulting from the production of the investigated meson [20]. This can be done by comparison of the missing mass distribution for the negative values of Q, when only pions may be created, and the missing mass distribution for Q larger than zero. In case of the positive values of Q a signal from the η' meson is expected on the top of the multi-pion mass distribution. In order to derive a signal of the η' meson from a missing mass spectrum for positive Q value, one has to subtract from this spectrum a missing mass distribution determined for negative Q after the shift of the latter to the kinematical limit and normalization at the very low mass values where no events from the η' meson are expected. Example of application of this method [20, 21] in the analysis of the quasi-free $pn \rightarrow pn\eta'$ reaction is shown in the figure 3 (right) where missing mass spectra of the $pn \rightarrow pn\eta'$ process determined for the excess energies larger (red line) and smaller than zero (blue line) is presented.

At present the analysis aiming for establishing the excitation function for the $pn \rightarrow pn\eta'$ reaction is in progress and will deliver the values for the total cross section in the excess energy range between 0 and 20 MeV.

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