

STUDY OF THE NEAR THRESHOLD TOTAL
CROSS-SECTIONS FOR THE QUASI-FREE $pn \rightarrow pn\eta'$
REACTION WITH THE COSY-11 DETECTOR*

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The measurement of the quasi-free production of the η' meson has been carried out at the COSY-11 detection setup using a proton beam and a deuteron cluster target. The energy dependence of the cross-section is extracted using a fixed proton beam momentum of $p_{\text{beam}} = 3.35 \text{ GeV}/c$ and exploiting the Fermi momenta of nucleons inside deuterons. The data cover a range of centre-of-mass excess energies from 0 to 24 MeV. Due to the low statistics at the present stage only upper limits for the cross-sections could be extracted. In this article we focus on the functioning and efficiency determination of the neutron detector.

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1. Introduction

In August 2004 — for the first time — using the COSY-11 [1] facility we have conducted a measurement of the η' meson production in the proton–neutron collision [2]. The aim of the experiment is the determination of the total cross-section of the $pn \rightarrow pn\eta'$ reaction near the kinematical threshold. We expect that the comparison of the $pp \rightarrow pp\eta'$ [3] and $pn \rightarrow pn\eta'$ total cross-sections will help to understand the production of the η' meson in different isospin channels and to investigate aspects of the gluonium component of this meson. In the framework of the quark model the η' meson is predominantly a flavour-singlet combination of quark–antiquark pairs, and it is expected to mix with purely gluonic states. Therefore, additionally to the production mechanisms associated with meson exchange [4, 5] it is also

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possible that the η' meson is produced from excited glue in the interaction region of the colliding nucleons, which couple to the η' meson directly via its gluonic component or through its SU(3)-flavour-singlet admixture [6, 7].

2. Experimental method

In order to investigate the isospin dependence of the meson production in hadronic interactions [8], the COSY-11 facility has been extended by a neutral-particle-detector. The measurement of the η' meson production in the proton-neutron collision [2] has been conducted using a proton beam of the Cooler Synchrotron COSY [9] and a cluster jet deuteron target [10]. More details concerning functioning of the particular detectors and method of the measurement of the quasi-free reaction can be found in references [1, 2, 11, 12]. In this article we will concentrate on the neutral particle detector [13–15] which has been designed to deliver the time at which the registered neutron or gamma quantum induced a hadronic or electromagnetic reaction, respectively. This information combined with the time of the reaction at the target place — deduced using other detectors — enables to calculate the time-of-flight between the target and the neutron detector and to determine the absolute momentum of registered particles, provided that they could have been identified.

The neutron detector consists of 24 modules. Each module is built out of eleven plates of scintillator material with dimensions of $240 \text{ mm} \times 90 \text{ mm} \times 4 \text{ mm}$ interlaced with eleven plates of lead with the same dimensions. The scintillators are read out at both edges of the module via light guides — made of plexiglass — whose shape changes from rectangular to cylindrical, in order to accumulate the produced light on the circular photocathode of a photomultiplier. The neutron detector is positioned at a distance of 7.36 m from the target with the configuration of modules schematically depicted in Fig. 1. The detector covers the neutron laboratory angular range of $\pm 1.84^\circ$ in x and $\pm 1.1^\circ$ in y direction.

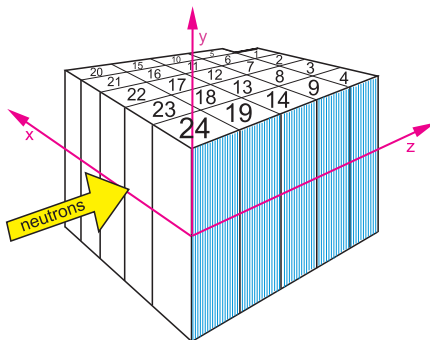


Fig. 1. Configuration of the detection units.

Fig. 2 (left) shows the distribution of the time-of-flight for all detection units. One can see a clear enhancement of events originating from gamma quanta. As expected from the known absorption coefficients [16], gamma quanta are predominantly registered in the first row of the detector whereas interactions points of neutrons are distributed more homogeneously.

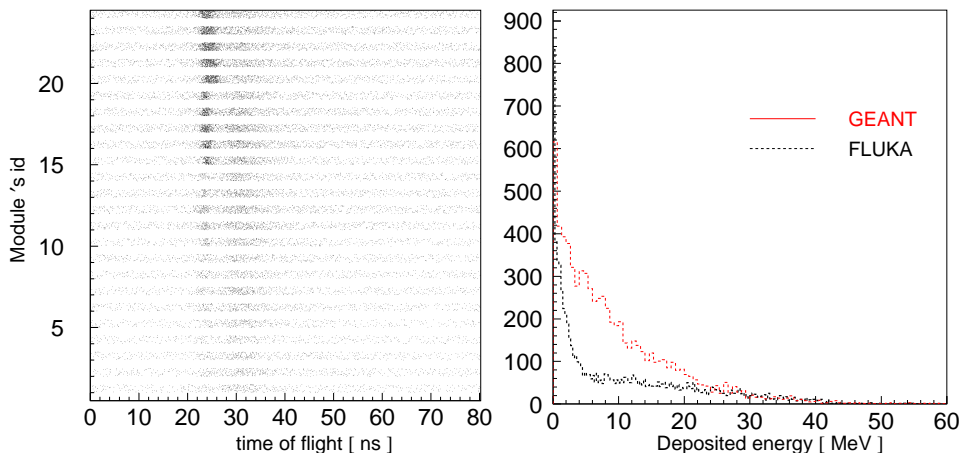


Fig. 2. Left: Time-of-flight determined between the target and the neutral particle detector for all detector modules. Right: Total energy deposited in scintillator layers of the neutral particle detector for neutrons impinging on the detector with kinetic energy equal to 300 MeV from simulations using FLUKA-2008 (dashed line) and GEANT-3 (dotted line) packages.

The efficiency of the COSY-11 neutral particle detector — which is an important factor for determining the absolute values of cross-sections — was determined using two independent simulation programs. One of these programs is based on the GEANT-3 (GEometry ANd Tracking) code [17] used for simulation of the hadronic cascades induced in matter by neutrons. In the other program the FLUKA¹ (FLUktuierende KAskade) simulation package is used [18, 19].

The comparison of the simulated distributions of the total deposited energy in the neutron detector using FLUKA-2008 and the GEANT-3 packages, is presented in Fig. 2. The simulation was performed for neutrons with kinetic energy equal to 300 MeV. As can be seen, the range of deposited energy is the same for both cases, however, GEANT simulations yield on the average higher energy response of the neutron detector. The efficiency of the neutron detector is given by the ratio of the number of generated neutrons to the number of events, for which the energy deposited in the scintillator

¹ The simulations were performed with the new 2008 version.

material was larger than the threshold value in at least one of 24 detection units. The calculated efficiency as a function of the kinetic energy of neutrons is shown in Fig. 3 (left). In this figure open squares denote results obtained using the GEANT-3 package, and the outcome of simulations using the FLUKA-2008 is presented as black circles.

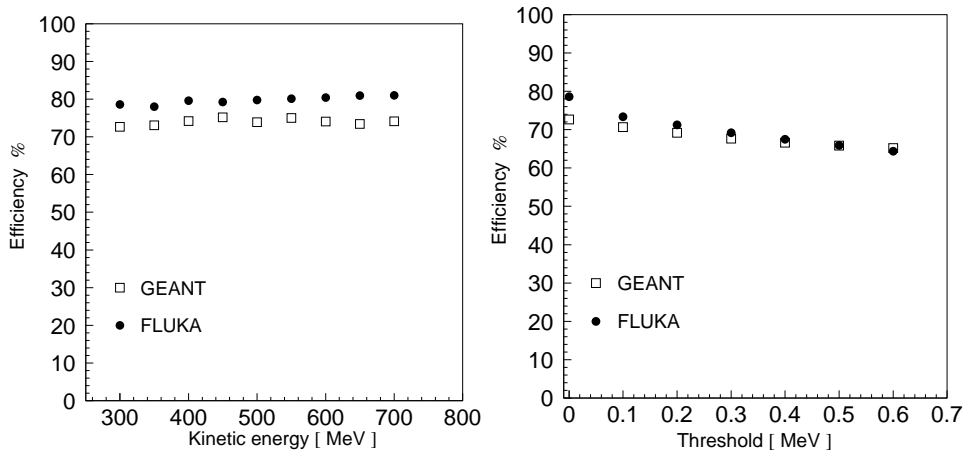


Fig. 3. Left: The efficiency distribution as a function of the kinetic energy of neutrons determined for a threshold of 0 MeV. Right: Relation between the threshold value and the efficiency for neutrons with energy of 300 MeV.

The kinetic energy of neutrons from the $pn \rightarrow pn\eta'$ reaction varies from 300 MeV up to 700 MeV for the 3.35 GeV/c beam momentum, and as can be inspected from Fig. 3 (left) the efficiency is fairly constant in this range. It is worth to stress that two independent simulation tools leads to fairly good ($\pm 3\%$) agreement for the values of the efficiency in the energy range relevant for the studies of the $pn \rightarrow pn\eta'$ reaction.

We have also conducted studies of the efficiency dependency on the threshold. In the experiment the threshold was set to about 0.1 MeV and therefore we scanned the values from 0 up to 0.6 MeV. The result is presented in Fig. 3 (right). For both the GEANT and FLUKA-2008 simulations the values of the efficiency change by about 10% over the scanned threshold range of 0.6 MeV.

2.1. Estimation of the total cross-section

Having all outgoing nucleons from $pn \rightarrow pn\eta'$ reaction registered, we apply the missing mass technique in order to identify the η' meson. 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. Therefore, the excess energy range for $Q \geq 0$ has been divided only into four intervals of 8 MeV width. For each interval we have calculated the missing mass. Next, from events with negative Q value the corresponding background missing mass spectrum was constructed, shifted to the kinematical limit and normalized to the experimental distribution at low mass values where no events of the η' meson production are expected. A detailed description of the method used for the background subtraction can be found in a dedicated article [20]. After subtracting missing mass distributions for the negative values of Q from spectra for Q values larger than 0 — due to the very low signal-to-background ratio — at the present stage of the data analysis, the signal from the η' meson was found to be statistically insignificant.

Nevertheless, having the luminosity — established from the number of the quasi-free proton–proton elastic scattering events [21] — and the detection efficiency of the COSY-11 system we have estimated upper limits of the total cross-section for the quasi-free $pn \rightarrow pn\eta'$ reaction. The preliminary result is shown in Fig. 4.

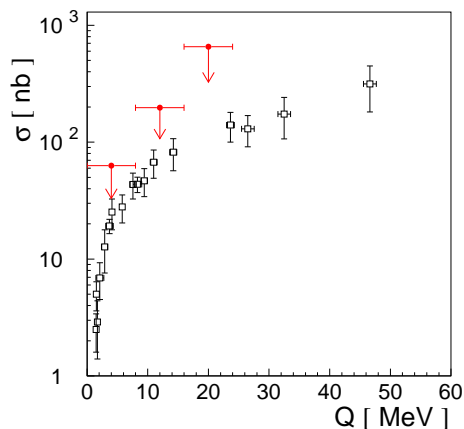


Fig. 4. Total cross-sections for the $pp \rightarrow pp\eta'$ reaction as a function of the excess energy (open symbols). Upper limit for the total cross-section for the $pn \rightarrow pn\eta'$ reaction as a function of the excess energy (closed symbols).

3. Perspectives

As already mentioned based on the $pp \rightarrow pp\eta'$ reaction channel only it is not possible to determine the reaction mechanism responsible for the η' production. To put more constraints on the theoretical models [4, 5] and to learn more about the structure of the η' meson [6, 7] we began investigations

aiming at the determination of the dependence of the η' meson production on the isospin of the colliding nucleons. After the measurement of the $pn \rightarrow pn\eta'$ reaction, we have extended our experimental studies to a pure isospin zero state of the interacting nucleons by the measurement of the quasi-free $pn \rightarrow d\eta'$ reaction. This experiment was conducted using a proton beam with a momentum of 3.365 GeV/c and a deuteron target. Assuming that the ratio of the cross-sections for the $pn \rightarrow d\eta'$ and $pp \rightarrow pp\eta'$ reactions will be at the same order as the ratio already established [22] for the $pn \rightarrow d\eta$ and $pp \rightarrow pp\eta$ reactions we expect to identify about 1000 $pn \rightarrow d\eta'$ events in the available data sample [23].

An additional outcome of this measurement will be an increase of the statistics for the $pn \rightarrow pn\eta'$ channel and a consistency check of the obtained results.

Together with the previous results on $pp \rightarrow pp\eta'$ and $pn \rightarrow pn\eta'$ we would then complete the study of the η' meson production cross-section in nucleon–nucleon collisions. The results obtained in different isospin channels can then be compared with theoretical models for the production of mesons. This will reduce significantly the ambiguities of such models and will lead to a better understanding of the production mechanism of the η' meson in nucleon–nucleon collisions. The result will be also of importance in rate estimates for studying the η' meson decays with the WASA-at-COSY facility [24, 25].

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