

# Production of $\eta$ and $\eta'$ mesons via the quasi-free proton-neutron interaction

P. Moskal<sup>1\*</sup>, H.-H. Adam<sup>†</sup>, A. Budzanowski<sup>\*\*</sup>, R. Czyżykiewicz<sup>\*</sup>,  
D. Grzonka<sup>\*</sup>, M. Janusz<sup>‡</sup>, L. Jarczyk<sup>‡</sup>, T. Johansson<sup>§</sup>, B. Kamys<sup>‡</sup>,  
A. Khoukaz<sup>†</sup>, K. Kilian<sup>\*</sup>, P. Kowina<sup>\*</sup>, W. Oelert<sup>\*</sup>, C. Piskor-Ignatowicz<sup>‡</sup>,  
J. Przerwa<sup>‡</sup>, T. Rożek<sup>\*</sup>, R. Santo<sup>†</sup>, G. Schepers<sup>\*</sup>, T. Sefzick<sup>\*</sup>,  
M. Siemaszko<sup>‡</sup>, J. Smyrski<sup>‡</sup>, A. Strzałkowski<sup>‡</sup>, A. Täschner<sup>†</sup>, P. Winter<sup>\*</sup>,  
M. Wolke<sup>2\*</sup>, P. Wüstner<sup>¶</sup> and W. Zipper<sup>||</sup>

<sup>\*</sup>*IKP, Forschungszentrum Jülich, D-52425 Jülich, Germany*

<sup>†</sup>*IKP, Westfälische Wilhelms-Universität, D-48149 Münster, Germany*

<sup>\*\*</sup>*Institute of Nuclear Physics, PL-31-342 Cracow, Poland*

<sup>‡</sup>*M. Smoluchowski Institute of Physics, Jagellonian University, PL-30-059 Cracow, Poland*

<sup>§</sup>*Uppsala University, S-75121 Uppsala, Sweden*

<sup>¶</sup>*ZEL, Forschungszentrum Jülich, D-52425 Jülich, Germany*

<sup>||</sup>*Institute of Physics, University of Silesia, PL-40-007 Katowice, Poland*

**Abstract.** A comparison of the close-to-threshold total cross sections for the  $\eta'$  meson production in both the  $pp \rightarrow pp\eta'$  and  $pn \rightarrow pn\eta'$  reactions should provide insight into the flavour-singlet (perhaps also into gluonium) content of the  $\eta'$  meson and the relevance of quark-gluon or hadronic degrees of freedom in the creation process. The excitation function for the reaction  $pp \rightarrow pp\eta'$  has been already established. At present, experimental investigations of the quasi-free  $pn \rightarrow pnX$  reactions are carried out at the COSY-11 facility using a beam of stochastically cooled protons and the deuteron cluster target. A method of measurement and preliminary results from the test experiments of the  $pn \rightarrow pn\eta$  reaction are presented in this report.

## INTRODUCTION

Close-to-threshold production of  $\eta$  and  $\eta'$  mesons in the nucleon-nucleon interaction requires a large momentum transfer between the nucleons and occur at distances in the order of  $\sim 0.3$  fm. This implies that the quark-gluon degrees of freedom may play a significant role in the production dynamics of these mesons. Therefore, additionally to the mechanisms associated with meson exchanges it is possible that the  $\eta'$  meson is created from excited glue in the interaction region of the colliding nucleons [1, 2], which couple to the  $\eta'$  meson directly via its gluonic component or through its SU(3)-flavour-singlet admixture. The production through the colour-singlet object as suggested in reference [1] is isospin independent and should lead to the same production yield of the  $\eta'$  meson in the  $pn \rightarrow pn\eta'$  and  $pp \rightarrow pp\eta'$  reactions after correcting for the final

---

<sup>1</sup> email: p.moskal@fz-juelich.de

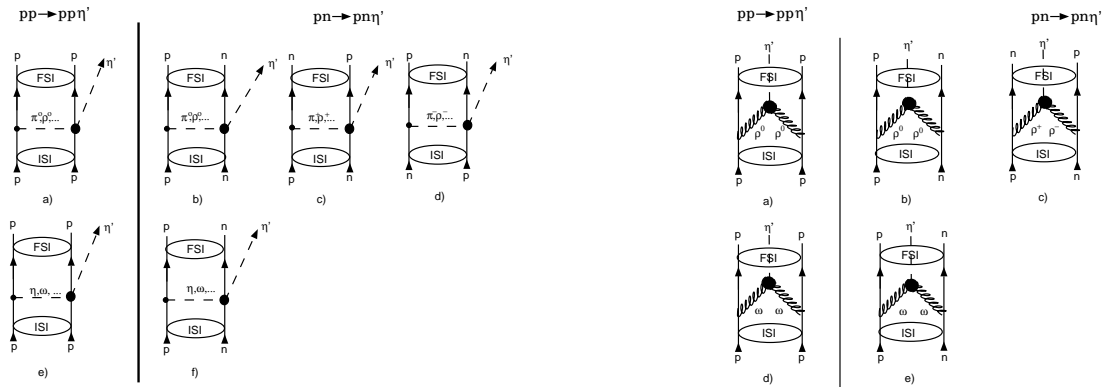
<sup>2</sup> present address: The Svedberg Laboratory, Thumbergsvägen 5A, Box 533, S-75121 Uppsala, Sweden.

and initial state interaction between the nucleons.

Investigations of the  $\eta$ -meson production in collisions of nucleons allowed to conclude that, close to the kinematical threshold, the creation of  $\eta$  meson from isospin  $I = 0$  exceeds the production with  $I = 1$  by about a factor of 12. This was derived from the measured ratio of the total cross sections for the reactions  $pn \rightarrow pn\eta$  and  $pp \rightarrow pp\eta$  ( $R_\eta = \frac{\sigma(pn \rightarrow pn\eta)}{\sigma(pp \rightarrow pp\eta)}$ ), which was determined to be  $R_\eta \approx 6.5$  in the excess energy range between 16 MeV and 109 MeV [3]. The large difference of the total cross section between the isospin channels suggests the dominance of isovector meson ( $\pi$  and  $\rho$ ) exchange in the creation of  $\eta$  in nucleon-nucleon collisions [4, 3].

Since the quark structure of  $\eta$  and  $\eta'$  mesons is very similar we can – by analogy to the  $\eta$  meson production – expect that in the case of dominant isovector meson exchange the ratio  $R_{\eta'}$  should also be about 6.5. If, however, the  $\eta'$  meson was produced via its flavour-blind gluonic component from the colour-singlet glue excited in the interaction region, the ratio  $R_{\eta'}$  should approach unity after corrections for the interactions between the participating baryons.

Figure 1 demonstrates qualitatively the fact that the production of mesons in the proton-neutron collisions is more probable than in the proton-proton interaction if it is driven by the isovector meson exchanges only. This is because in the case of the proton-neutron collisions there are always more possibilities to realise the exchange or fusion of the isovector mesons than in the case of the reaction of protons.



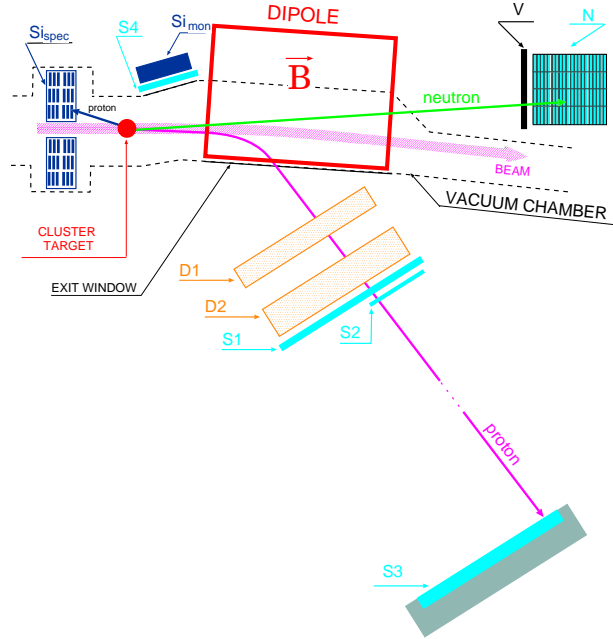
**FIGURE 1.** (left) Example of diagrams with the isovector and isoscalar meson exchange leading to the creation of the meson  $\eta'$  in the proton-proton and proton-neutron collisions. (right) Fusion of the virtual  $\omega$  and  $\rho$  mesons emitted from the colliding nucleons.

The close-to-threshold excitation function for the  $pp \rightarrow pp\eta'$  reaction has been already determined [5, 6, 7, 8] whereas the total cross section for the  $\eta'$  meson production in the proton-neutron interaction remains unknown. As a first step towards the determination of the value of  $R_{\eta'}$  the feasibility of the measurement of the  $pn \rightarrow pn\eta'$  reaction by means of the COSY-11 facility was studied using a Monte-Carlo method [9, 10]. As a second step, a test experiment of the  $pn \rightarrow pn\eta$  reaction – suspected to have by at least a factor of 30 larger cross section than the one for the  $pn \rightarrow pn\eta'$  reaction – was performed. In this test measurement, using a beam of protons and a deuteron cluster target, we have proven the ability of the COSY-11 facility to study the quasi-free creation of mesons via the  $pn \rightarrow pnX$  reaction. Appraisals of simulations and preliminary results of the measurements of the quasi-free  $pn \rightarrow pn\eta$  reaction performed using the newly

extended COSY-11 facility [9, 10] will be presented in the next section.

## TEST MEASUREMENT OF THE $PN \rightarrow PN\eta$ REACTION

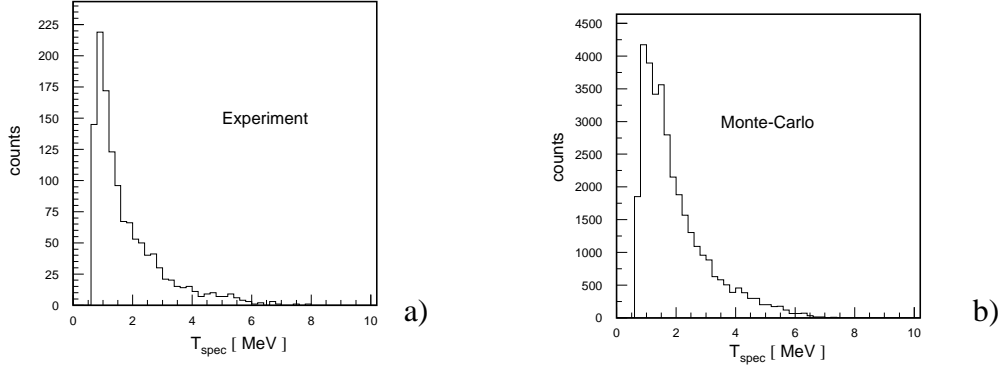
As a general commissioning of the extended COSY-11 facility to investigate quasi-free  $pn \rightarrow pnX$  reactions, we have performed a measurement of the  $pn \rightarrow pn\eta$  process at a beam momentum of 2.075 GeV/c. The experiment, carried out in June 2002, had been preceded by the installation of a spectator [11] and neutron detectors, and by a series of thorough simulations performed in order to determine the best conditions for measuring quasi-free  $pn \rightarrow pn\eta$  and  $pn \rightarrow pn\eta'$  reactions [9, 10]. Figure 2 presents the COSY-11 detection facility with superimposed tracks of protons and neutron originating from the quasi-free  $pn \rightarrow pnX$  reaction induced by a proton beam [12] impinging on a deuteron target [13]. The identification of the  $pn \rightarrow pn\eta$  reaction is based on the measurement of the four-momentum vectors of the outgoing nucleons and the  $\eta$  meson is identified via the missing mass technique. The slow proton stopped in the first layer of the position sensitive silicon detector ( $Si_{spec}$ ) is, in the analysis, considered as a spectator without interaction with the bombarding particle and it is moving with the Fermi momentum as possessed at the moment of the collision.



**FIGURE 2.** Schematic view of the COSY-11 detection setup [14]. Only detectors needed for the measurements of the reaction  $pd \rightarrow p_{sp}pn\eta(\eta')$  are shown.

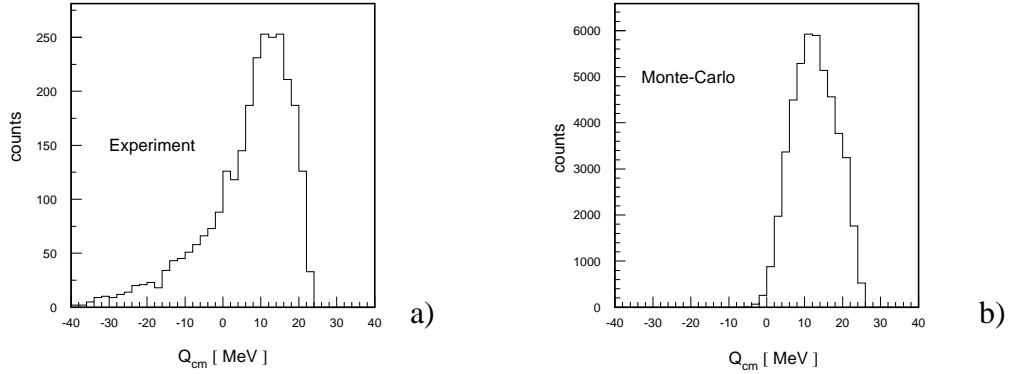
D1, D2 denote the drift chambers; S1, S2, S3, S4 and V the scintillation detectors; N the neutron detector and  $Si_{mon}$  and  $Si_{spec}$  silicon strip detectors to detect elastically scattered and spectator protons, respectively.

From the measurement of the momentum vector of the spectator proton  $\vec{p}_{sp}$  one can infer the momentum vector of the struck neutron  $\vec{p}_n = -\vec{p}_{sp}$  at the time of the reaction and hence calculate the total energy of the colliding nucleons for each event. In the



**FIGURE 3.** Distributions of the kinetic energy of the spectator protons. (a) Experiment, (b) Monte-Carlo simulations taking into account the acceptance of the COSY-11 detection system and an analytical parametrization of the deuteron wave function [15] calculated from the PARIS potential [16].

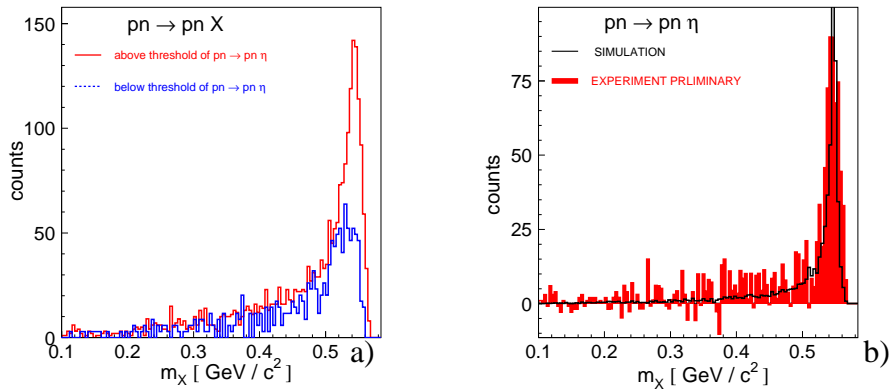
approximation that the struck neutron is treated as a free particle we can assume that the matrix element for quasi-free meson production off a bound neutron is identical to that for the free  $pn \rightarrow pn\text{Meson}$  reaction<sup>3</sup>. In figures 3a and 3b the measured and expected distribution of the kinetic energy of the spectator proton is presented. Though still very rough energy calibration of the detector units one recognizes a substantial similarity in the shape of both distributions.



**FIGURE 4.** Distributions of the excess energy  $Q_{CM}$  for the quasi-free  $pn \rightarrow pnX$  reaction, determined with respect to the  $pn\eta$  threshold. (a) Experiment. (b) Simulation.

Figure 4 shows spectra of the excess energy in respect to the  $pn\eta$  system as obtained in the experiment (4a) and the simulation (4b) for the  $pn \rightarrow pn\eta$  reaction. The remarkable difference between the distributions comes from the fact that in reality additionally to the  $pn \rightarrow pn\eta$  reaction also the multi-pion production is registered. The  $\eta$  and multi-pion production cannot be distinguished from each other on the event-by-event basis by

<sup>3</sup> For more comprehensive discussion of this issue the reader is referred to reference [17]



**FIGURE 5.** Missing mass spectra as obtained during the June'02 run:  
a) Event distribution for  $Q < 0$  (black line) and for  $Q > 0$  (gray line).  
b) Histogram represents the difference between number of events above and below threshold for the  $pn \rightarrow pn\eta$  reaction, and the line corresponds to the Monte-Carlo simulation.

means of the missing mass technique. However, we can determine the number of the registered  $pn \rightarrow pn\eta$  reactions from the multi-pion background comparing the missing mass distributions for  $Q$  values larger and smaller than zero. Knowing that negative values of  $Q$  can only be assigned to the multi-pion events we can derive the shape of the missing mass distribution corresponding to these events. This is shown as the solid line in figure 5. A thorough evaluation of the background is in progress, however, rough comparison of events for positive and negative  $Q$  yields the promising results with a clear signal from the  $pn \rightarrow pn\eta$  reactions, as can be deduced by inspection of figures 5a and 5b.

## REFERENCES

1. S. D. Bass, Phys. Lett. **B 463** (1999) 286.
2. S. D. Bass, e-Print Archive: hep-ph/0006348.
3. H. Calén et al., Phys. Rev. **C 58** (1998) 2667.
4. G. Faldt, T. Johansson, C. Wilkin, Phys. Scripta **T 99** (2002) 146.
5. P. Moskal et al., Phys. Rev. Lett. **80** (1998) 3202.
6. P. Moskal et al., Phys. Lett. **B 474** (2000) 416.
7. F. Hibou et al., Phys. Lett. **B 438** (1998) 41.
8. F. Balestra et al., Phys. Lett. **B 491** (2000) 29.
9. P. Moskal, Schriften des FZ-Jülich: Matter & Material **11** (2002) 27; e-Print Archive: nucl-ex/0110001.
10. R. Czyżykiewicz, Diploma Thesis, Jagellonian University (2002), Berichte des FZ-Jülich, Jül-4017.
11. R. Bilger et al., Nucl. Instr. & Meth. **A 457** (2001) 64.
12. D. Prasuhn et al., Nucl. Instr. & Meth. **A 441** (2000) 167.
13. H. Dombrowski et al., Nucl. Instr. & Meth. **A 386** (1997) 228.
14. S. Brauksiepe et al., Nucl. Instr. & Meth. **A 376** (1996) 397.
15. M. Lacombe et al., Phys. Lett. **101B** (1981) 139.
16. M. Lacombe et al., Phys. Rev. **C 21** (1980) 861.
17. P. Moskal, M. Wolke, A. Khoukaz, W. Oelert, Prog. Part. Nucl. Phys. **49** (2002) 1, hep-ph/0208002.