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Isospin symmetry violation, meson production and η-nucleus interaction studies

B J ROY[1], V JHA[1], A CHATTERJEE[1] and H MACHNER[2],
for GEM Collaboration
[1]Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai 400 085, India
[2]Institut für Kernphysik, Forschungszentrum, Jülich 52425, Germany
E-mail: bjroy@apsara.barc.ernet.in

Abstract. We have studied isospin symmetry violation in nuclear reactions by measuring simultaneously the cross-section of the following two reactions $p + d \rightarrow {}^3\text{H}\ \pi^+$ and $p + d \rightarrow {}^3\text{He}\ \pi^0$. The experiment was perfomed at the cooler synchrotron accelerator COSY, Jülich at several beam energies close to the corresponding η production threshold. We also have ongoing programmes on η-nucleus final-state interaction studies via $p+{}^6\text{Li} \rightarrow {}^7\text{Be} +\eta$ reactions, high resolution search for dibaryonic resonances and lambda-proton final state interaction studies. The experimental details and results obtained so far are presented here.

Keywords. Meson production; meson–nucleus interaction; charge symmetry.

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1. Introduction

The charge symmetry breaking (CSB) of strong interaction is one of the interesting problems of nuclear and particle physics. At the quark level this symmetry breaking is believed to be associated with the mass difference between the up- and down-quarks. In the pionic sector, the charge symmetry violation is responsible for the mixing of π^0 and η mesons and also that of ρ^0 and ω [1]. One experimental possibility to investigate isospin symmetry violation in the pseudoscalar meson sector is by comparing the cross-section of the two reactions $p + d \rightarrow {}^3\text{H}\ \pi^+$ and $p + d \rightarrow {}^3\text{He}\ \pi^0$. In particular, the mixing angle between π^0 and η can be determined from the ratio

$$R = \frac{\mathrm{d}\sigma/\mathrm{d}\Omega(pd \rightarrow {}^3\text{H}\,\pi^+)}{\mathrm{d}\sigma/\mathrm{d}\Omega(pd \rightarrow {}^3\text{He}\,\pi^0)} \qquad (1)$$

which in turn determines the mass difference between the up- and down-quarks (for more details see ref. [2] and references therein).

Currently there are extensive experimental and theoretical efforts devoted for achieving a better understanding of the η-nucleus interaction. Theoretical calculations indicate a strong possibility for the existence of a new type of nuclear matter, the η-mesic nucleus, caused by the strong interaction between the η-meson and a nucleus. One of the interesting aspects that can be investigated by studying η-nucleus interaction is the behaviour of $N^*(1535)$ resonance in nuclear matter. Due to the large mass of η-meson (547 MeV), this $S11$ resonance is very close to η-N threshold. The resonance is also very broad with $\Gamma \sim 150$ MeV covering the whole low energy region of η-nucleon interaction. The η-nucleon interaction at low energies where S-wave dominates can be considered as a series of formation and decay of this resonance inside the nucleus as explained in ref. [3]. Such a mechanism will allow one to study medium modifications of $N^*(1535)$ resonance. Final state interaction effects are the only source of information about the η-meson interaction with nucleus. Since the meson factories cannot produce η-meson beam, the η-meson particles are available for investigations only as products of certain nuclear reactions where they appear as final state particles.

In this contribution an overview of some of the GEM experiments are presented. More details of the subject presented here can be found in the contributions of H Machner in this proceedings.

2. Experimental set-up

The cooler synchrotron accelerator (COSY) at Jülich delivers proton beam of energies up to 2.5 GeV. The accelerator system [4] consists of a cyclotron JULIC as injector and a synchrotron to accelerate the beam with the possibilities to cool the beam. The floor plan of the accelerator complex is shown in figure 1. The area marked as 'Big Karl' in figure 1 is the place where our GEM experiments are carried out.

The GEM detector set-up (figure 2) consists of germanium wall and magnetic spectrograph Big Karl. The reaction products that are emitted at 0° are momentum analysed by the Big Karl and are detected in the focal plane. The focal plane is equipped with a stack of two multiwire drift chambers (MWDC) followed by two layers of scintillator hodoscopes $\sim$4 m apart. The time-of-flight information between the two hodoscope layers is useful to identify and select the particles of interest. The detectors are described elaborately in refs [4,5]. Some parts of the focal plane detection system were modified to suit the need of different experiments which will be discussed later.

3. Reactions

3.1 *Charge symmetry breaking in nuclear reactions*

A dedicated detection system was used to measure simultaneously the two reactions $p+d \to {}^3\mathrm{H}\,\pi^+$ and $p+d \to {}^3\mathrm{He}\,\pi^0$. The experiment was performed at COSY, Jülich using extracted proton beams of momenta 1.56, 1.57, 1.571, 1.59 and 1.7 GeV/c.

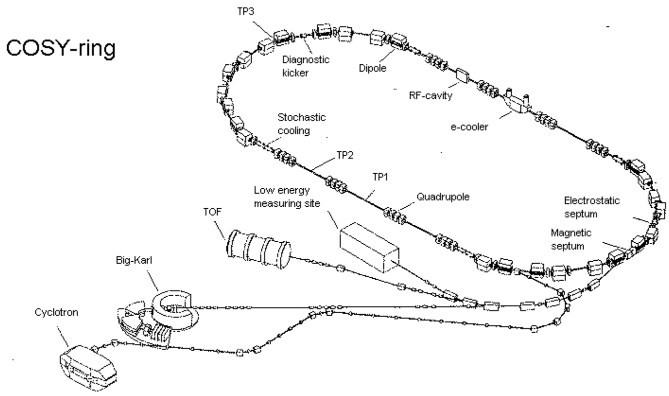

Figure 1. The floor plan of the COSY accelerator complex. JULIC is the injector cyclotron. The external target stations are the TOF (time-of-flight facility) and the Big Karl (magnetic spectrograph). The GEM experiments are done at the Big Karl area. In addition to external target stations several experiments are being done inside the ring which are not shown here.

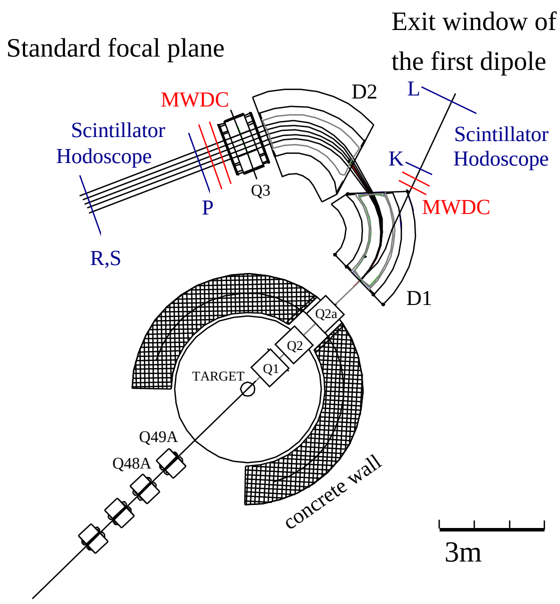

Figure 2. COSY external target station with the magnetic spectrograph Big Karl (the GEM experimental area).

Typical beam intensity was 5×10^8 protons/s. The target was liquid deuterium. The ^{3}He particles were detected at the normal focal plane whereas tritons were measured at the exit of the dipole D1 (figure 2). The simultaneous detection minimises various systematical errors thereby increasing the sensitivity of the measurement. Crucial

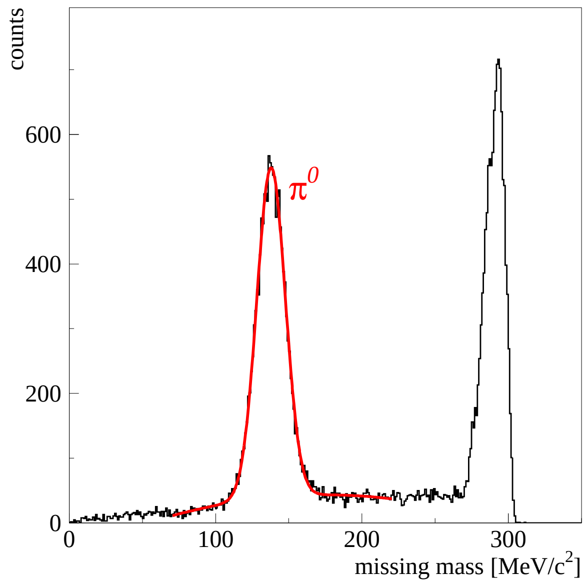

Figure 3. Missing mass spectrum of the $pp \rightarrow {}^3\text{He}\,\pi^0$ reaction. The pions are clearly visible. The second peak on the right-hand side arises due to multi-pion background.

point was the relative acceptance determination between the two detection system. The relative acceptance determination was performed using $pp \rightarrow d\pi^+$ reaction at a beam momentum of 1.206 GeV/c. Simultaneous detection of deuterons and pions in these two detection systems simulate exactly the conditions for ^{3}H and ^{3}He detection. The relative acceptance measurement was also performed based on the equality of the centre of mass cross-sections for deuterons emitted at 0° and 180°. In order to improve the background to an acceptable level, a non-zero beam incidence angle on the target was introduced. This was done with the help of a special dipole magnet mounted close to the target. More details of the experimental procedure can be found in ref. [6].

The ^{3}He events from $pd \rightarrow {}^3\text{He}\,\pi^0$ were identified from the missing mass spectrum (figure 3) whereas tritons from $pd \rightarrow {}^3\text{H}\,\pi^+$ were identified from the time-of-flight spectrum (figure 4). A total systematical error (including all possible systematical uncertainties) was estimated to be 9% for ^{3}He cross-section values and 13.5% for ^{3}H cross-section values. It is to be mentioned that the systematical errors influence absolute values of the cross-section but get cancelled in the relative value of the ratio of cross-sections. More details of the results are presented and discussed in the contribution of H Machner in this proceedings.

3.2 *η-Nucleus final state interaction studies*

To continue our efforts in understanding the η-nucleus interaction we planned to study, in addition to η-mesic nuclei searches [7,8], the reaction $p\,{}^6\text{Li} \rightarrow {}^7\text{Be}\,\eta$ at an

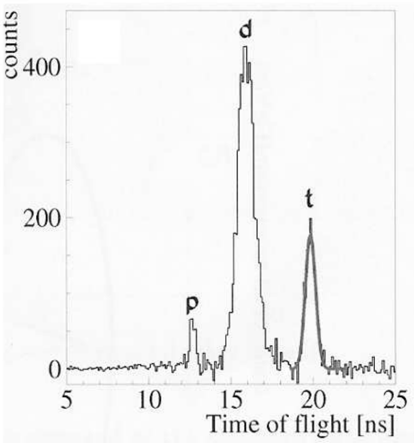

Figure 4. Background subtracted time-of-flight spectrum. Events correspond to triton production in $pd \to {}^3\mathrm{H}\,\pi^+$ are well-separated and clearly identified.

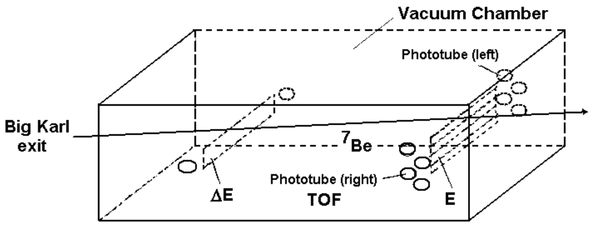

Figure 5. Schematic diagram of the Big Karl exit detector set-up used for η-nucleus final state interaction studies.

incident energy ($T_p = 662.5$ MeV) close to the reaction threshold. The ^{6}Li target was selected mainly because it is the lightest solid target that can be prepared. An earlier study [9] on this reaction was at an excess energy of 19 MeV corresponding to incident proton kinetic energy of 683 MeV. A total of only eight events were detected of which three were estimated to be associated with the background. The estimated centre of mass cross-section is 4.6±3.8 nb/sr. The above number includes the sum of ^{7}Be states up to 10 MeV excitation energy. Clearly high-quality and high-statistics data are needed. An experiment has been performed at the COSY accelerator, Jülich using the existing facilities. The reaction product (^{7}Be) was detected by the magnetic spectrograph Big Karl. The identification of $p\,^6\mathrm{Li} \to {}^7\mathrm{Be}\,\eta$ events would then follow from the re-construction of invariant mass of the unobserved η particles. The Big Karl is an ideal tool for such measurements. The Big Karl has a very good momentum resolution, allowing us the possibility of separating various excited states of the final nucleus. It is well-known, from many previous measurements, that the Big Karl spectrometer is an ideal tool for heavy recoil measurements. It was also expected that the detection of such heavy recoil nucleus with Big Karl can be achieved almost free of background. However, the existing multiwire drift chambers were not suitable for the detection of such strongly ionising particles. They were replaced by a new set of detectors (figure 5).

The new detector set-up consists of thin plastic scintillators in the form of a long bar. Two such layers of scintillators (thickness = 0.5 and 5 mm for the first and second layers respectively) were placed 80 cm apart for ΔE–E particle identification and time-of-flight information. The whole assembly was mounted inside a newly developed large size vacuum chamber and was positioned in the focal plane of the Big Karl. The reaction products were detected and identified by this detector set-up. Various particles were separated in the energy vs. time-of-flight spectrum (figure 6). The identification was based on simulation results. Though a good particle separation was achieved, position resolution was not sufficient enough for identification of the η events. In order to enhance the sensitivity of the measurement, two multiwire avalanche counters have been constructed to be mounted inside the same vacuum chamber just before the scintillator bars. The multiwire avalanche counter, having a very thin window and operates in low pressure, is designed to have enhanced position resolution. A test measurement was performed with this set-up and more measurements are in progress.

3.3 *Dibaryonic resonances search and* Λ-*p final state interaction studies*

One of the interesting open problems of intermediate energy physics is the question of the existence or non-existence of dibaryonic resonances. QCD-inspired models predict dibaryons. However, all experimental efforts so far have failed to identify them. A possible reason could be that the experimental resolutions and/or statistical accuracies were not sufficient. The predicted $S = -1$ dibaryon at 2.109 GeV with quantum numbers $L = 1, S = 0, J_p = 1^-, I = 1/2$ is expected to be narrow ($\Gamma \sim 100$ keV) and is located between ΛN and ΣN thresholds [10]. A high-resolution experiment at COSY by the HIRES Collaboration [11] has been planned to search for this $S = -1$ dibaryonic resonance using the high-resolution magnetic

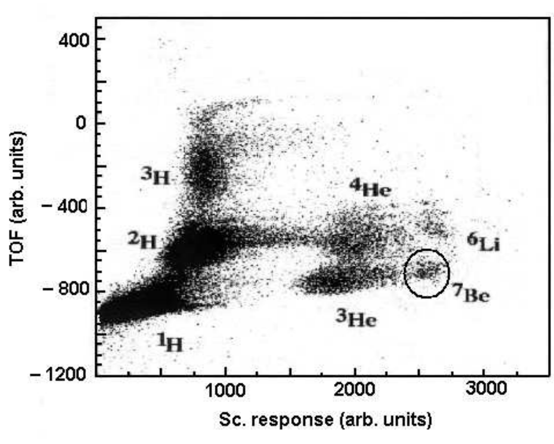

Figure 6. Time-of-flight vs. energy spectrum from the scintillator bars (preliminary results). See text for details.

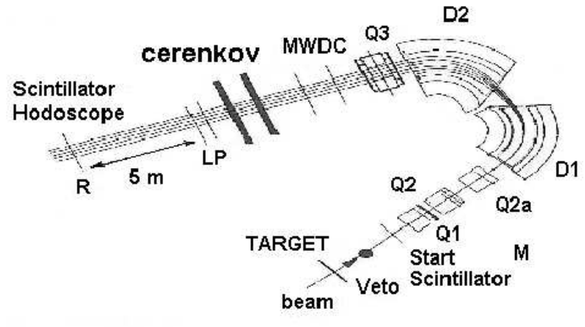

Figure 7. Experimental set-up for dibaryonic resonance search.

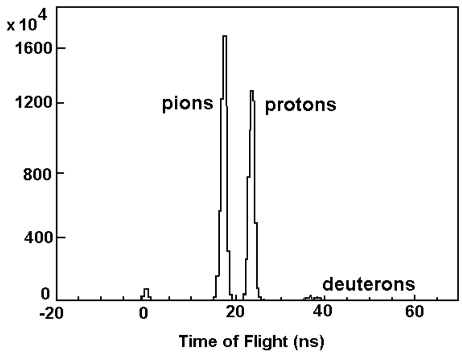

Figure 8. Time-of-flight spectrum at the focal plane without any gate from the Cerenkov counter. Protons and pions are separated clearly.

spectrometer Big Karl. In the same experimental set-up (figure 7), by changing the Big Karl momentum setting, the Λp production close to threshold can also be studied.

The experiment is an inclusive measurement of kaons from $p + p \to K^+ + X$ and the identification of dibaryons is based on the missing mass information of the unobserved particle X. With the high-resolution ($\Delta P/P \sim 10^{-4}$) Big Karl spectrometer, a missing mass resolution of ∼350 keV is expected to be achieved which is far better than earlier measurements. While kaons are well-separated in time-of-flight from the background (scattered protons), the separation of pions and kaons is crucial. To achieve this, two threshold Cerenkov detectors made of silica aerogel (refractive index $n = 1.05$) are constructed and used to filter out pions. The Cerenkov counter has a large sensitive area ($70 \times 8 \times 8$ cm^3) necessary to cover the Big Karl focal plane dimension. The results from an exploratory run are shown in figures 8–10. With the Cerenkov counters, good pion suppression is achieved and kaons are clearly visible (see figures 8 and 9). Data close to threshold (figure 10) deviate significantly from the phase-space calculations and indicate a strong final state interaction between Λ-p. Also observed is the absence of any narrow dibaryons at the predicted mass (figure 10). High statistics measurements are in progress.

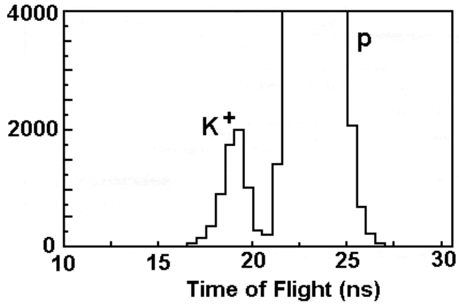

Figure 9. Same as figure 8 but gated with the Cerenkov detector. Pions are suppressed and kaons are clearly visible.

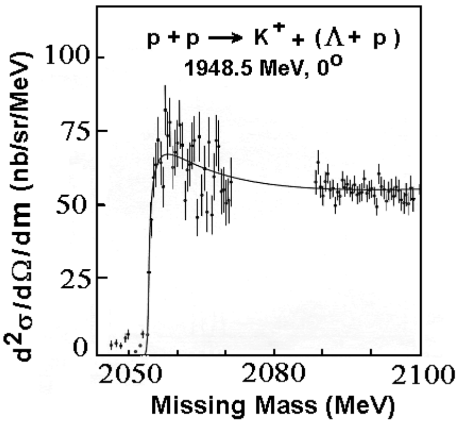

Figure 10. Missing mass spectrum of the reaction $pp \rightarrow K^+ + X, X = \Lambda p$ generated from the detected kaons (preliminary results of the HIRES experiment). Big Karl was set at two different momenta in order to collect data near Λ-p threshold and at the expected dibaryonic resonance. The soild line is a fit to the data.

4. Summary

Experimental studies of charge symmetry violation in meson production and interaction with nuclei have been/are being carried out by the GEM Collaboration at the multi-GeV hadron facility COSY, Jülich. An overview of various recent experiments including the ongoing ones have been presented here.

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