ISSN 1330–0016
CODEN FIZBE7

MODIFICATIONS OF DELTA IN NUCLEAR MEDIUM

DAMIR BOSNAR and MIHAEL MAKEK
for the A1 collaboration at MAMI

Department of Physics, Faculty of Science, P.O. Box 331, HR-10 002 Zagreb, Croatia

Received 10 December 2003; Accepted 30 August 2004
Online 14 November 2004

In the experiments at the Mainz Microtron, MAMI, Δ^0 particles in the electron scattering reactions $^{12}\mathrm{C}\,(\mathrm{e},\mathrm{e}'\Delta^0)\,^{11}\mathrm{C}$ have been produced in nuclear medium. The three high-resolution magnetic spectrometers of the A1 collaboration have been used in triple coincidence measurements $^{12}\mathrm{C}\,(\mathrm{e},\mathrm{e}'\mathrm{p}\,\pi^-)\,^{11}\mathrm{C}$. Indications for substantial changes of delta properties in the nuclear medium have been obtained. Because of low statistics, these results cannot yet be taken as conclusive. A new setup for measurements at MAMI with silicon detectors for proton detection, which subtend larger solid angle, is described.

PACS numbers: 14.20.-c, 25.30.Dh,Fj UDC 539.12
Keywords: Δ^0 particles in nuclear medium, electron scattering reaction,

1. Introduction

Hadrons are composite objects consisting of quarks and gluons that occupy some volume in space. When packed close together, e.g. in the nucleus, one would expect that their properties would change due to mutual interactions and influences. Surprisingly, there is no conclusive experimental evidence of such changes. Because of that, experimental investigations of hadron properites in the nuclear medium are among the most interesting in hadron physics. One line of these investigations is the production of hadrons in nuclei in scattering reactions. In the past, several experiments, using hadron probes, have reported hints of changes of hadron properties in the nuclear medium. But, they all suffered either from low statistics or their overall resolution was not sufficient to provide conclusive evidence of such changes. For a summary of previous experiments see, e.g., Ref. [1].

In the nineties, the invention of electron accelerators with continuous electron beams made possible the investigations with electromagnetic probes. The electromagnetic interactions are theoretically well described and suitable choices of scattering reactions in investigations of hadron production in the nuclear medium can give some answers about their properties and possible changes. The A1-collaboration [2] at MAMI has been using electron scattering on the nucleus and nuclei to explore their properties [3]. And electron scattering on the ^{12}C nuclei has been used to produce delta particles and to explore their properties in nuclear medium [1]. Prior to this measurement, only one exclusive delta-electroproduction experiment at and above delta production energies has been done [4].

In the next section, a short description of the beam properties of MAMI will be given, the third section is devoted to the description of the magnetic spectrometers and additional detectors of the A1-collaboration, the fourth section describes the choice of kinematics, and last section will give an overview of the obtained results and plans for future measurements.

2. *Electron accelerator MAMI*

The electron accelerator MAMI, Mainz microtron, is located at the campus of the Johannes Gutenberg University in Mainz, Germany. It is an electron accelerator with a 100% duty factor, and consists of an injector linac followed by a cascade of three microtrons. It delivers a continues electron beam with the maximum energy of 885 MeV, and the maximum current of about 100 μA. A polarized electron beam is available as well, with the maximum polarization of 80% and the maximum current of about 15 μA [5]. The energy of the outgoing beam has fluctuations of less than 10^{-6}, and in any mode of operation, MAMI is characterized by its very high stability and reliability. The upgrading of the accelerator is currently being undertaken. The existing third stage of the microtron will be used as the input to the double sided-microtron. After this upgrade, which will be completed in 2005, the maximum electron energy will be 1.5 GeV. The ongoing activities will be continued at these higher energies and with the production of the strangeness in the nuclei new possibilities will be opened.

3. *Three magnetic spectrometers of the A1-collaboration and additional detectors*

The A1 collaboration at MAMI has built three high-resolution magnetic spectrometers [6]. The magnetic spectrometers, named A, B, C, have solid angles of 28 msr, 5.6 msr and 28 msr, respectively. They can detect electrons, pions, protons and other charged particles with the maximum momentum 665 MeV/c, 810 MeV/c, and 490 MeV/c, and have acceptance of 20%, 15%, 25%, respectively. Detector packages in all three spectrometers are built in the same way and consist of two double-planes of the vertical drift chambers (VDCs), two layers (3 mm and 10 mm thick) of the scintillator counters and the Cherenkov counter. In the spectrometer A, a proton polarimeter [7] can be put in place of the Cherenkov counter. It can determine the polarization of protons detected in the spectrometer A. In addition, the spectormeter B can be taken out of the plane to the extend of 10°. The magnetic spectrometers provide information regarding the momentum of the outgoing charged particles with a resolution better than 10^{-4}, the angles of the outgoing charged particles with a resolution better than 3 mrad at the target, and information regarding the type of charged particles. Single measurements, as well as double and triple coincidence measurements are possible. Software packages including hardware control, data acquistion, and data analysis have been developed [8]. For specific measurements, additional detectors can be used together with the magnetic spectrometers. E.g., a neutron detector consisting of a wall of scintillation detetectors for neutron detection has been used in investigations of the nucleon-nucleon correlations in the nucleus. A neutron polarimeter for neutron detection and determination of their polarization has been used in the measurements of the neutron electric form factor [9]. The forth magnetic spectrometer, named short orbit spectrometer, has recently been completed and succesfully tested [10]. It will be used to detect charged pions right above the treshold of pion production. In the future investigations of the hadron properties in the nuclear medium, a telescope made of silicium detectors, described below, will be used for proton detection.

4. Kinematics

We have investigated properties of delta particles produced in the electron scattering reactions $^{12}\mathrm{C}\,(\mathrm{e},\mathrm{e}'\Delta^0)\,^{11}\mathrm{C}$. We have measured $^{12}\mathrm{C}\,(\mathrm{e},\mathrm{e}'\mathrm{p}\,\pi^-)\,^{11}\mathrm{C}$ and we have detected protons and pions, produced in the decay of delta particles, with the magnetic spectrometers A and C, respectively, along with scattered electrons in the spectrometer B. Delta particles in these reactions can be produced in two different ways, which can be separated kinematically. The first possibility is the so-called quasi free-production. Delta is produced on a neutron which is knocked out of the ^{12}C nucleus, while the rest of the nucleus does not participate in this reaction. This delta takes all the momentum of a virtual photon, and the pion and the proton produced in the delta decay are boosted in its direction. The second possibility is the so-called bound delta production. Delta is produced on a neutron which remains bound in ^{12}C nucleus, and the whole $^{12}\mathrm{C}_\Delta$ nucleus takes the momentum of a virtual photon. The pion and the proton produced in the delta decay are emitted into the back-to-back direction in the rest frame of the Δ particle. The produced proton and pion are not so much boosted in the virtual photon direction, in the second case as compared to the first case, due to the mass ratio of the Δ and ^{12}C nucleus.

In order to determine the corresponding kinematical regions, Monte Carlo simulations of these reactions have been performed [1]. Using these simulations, kinematics in which the bound delta production can clearly be separated from the quasi-free delta production has been selected, and a series of measurements for various kinematics has been performed [1,11]. In this report, we will show the results of the measurements for a kinematical setting in the bound delta production region (see Table 1).

TABLE 1. Kinematical setting in the bound delta region.

E_{e} (MeV)	$\theta_{\mathrm{e'}}$	q^2 (GeV/c)^2	p_{p} (MeV/c)	θ_{p}	p_π (MeV/c)	θ_π	N_{events}
855	18°	−0.047	222.0	90.8°	203.7	63.3°	252

5. *Results of the measurements and discussion*

Since we have detected e′, p and π^- in the reaction $^{12}\mathrm{C}\,(\mathrm{e},\mathrm{e'p}\,\pi^-)\,^{11}\mathrm{C}$, we can determine their 4-momenta and calculate the missing mass of the reaction, which corresponds to the mass of residual ^{11}C

$$M_{\mathrm{miss}} = \sqrt{(\omega + M(^{12}\mathrm{C}) - E_{\mathrm{p}} - E_\pi)^2 - (\vec{q} - \vec{p}_{\mathrm{p}} - \vec{p}_\pi)^2}\,, \tag{1}$$

where E_{p}, E_π and $\vec{p}_{\mathrm{p}}$, $\vec{p}_\pi$ are the energies and momenta of the proton and the pion respectively, ω and $\vec{q}$ are the energy and momentum of the virtual photon and $M(^{12}\mathrm{C})$ is the mass of the ^{12}C nucleus. In the analysis, we have concentrated on the reactions in which the residual ^{11}C nuclei have remained in the ground state, $M_{\mathrm{miss}} = M(^{11}\mathrm{C}_{\mathrm{g.s.}})$, and which could be separated form the excited states. The excellent overall resolution achieved in the measurements provided a reconstruction of various physical quantities needed to study the delta production and its properties in the nucleus. One of the most interesting is the excitation energy spectrum of the $^{12}\mathrm{C}_\Delta$ nucleus, $\hat{\omega} = W - M(^{12}\mathrm{C})$, where W is the invariant total mass.

In the previous measurements [1] of the bound delta kinematics, two peaks with the widths of several MeV in the spectrum of the $\hat{\omega}$ have been noticed at the energies of 282 and 296 MeV (see Fig. 5 in Ref. [1]). These peaks have been interpreted as a substantial change of delta properties in the nuclear medium, in particular of the width of the delta particle, and a simple model has explained observed energies of the peaks. Later on, a better quantitative theoretical justification has been developed [12].

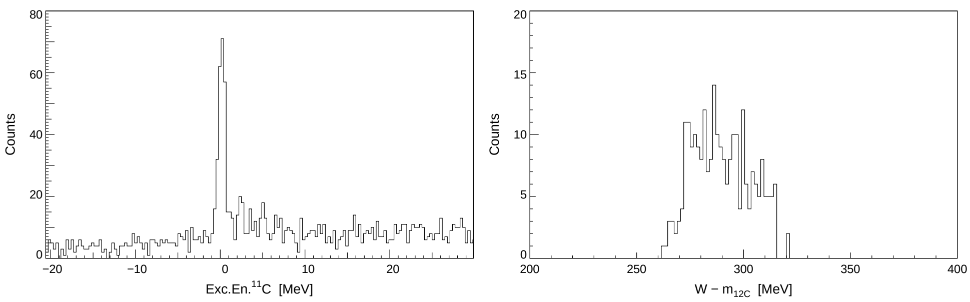

Fig. 1. Energy spectrum of residual ^{11}C *nucleus obtained from* $M_{\mathrm{miss}} - M(^{11}\mathrm{C})$*, left, and excitation energies* $\hat{\omega}$ *of the* $^{12}\mathrm{C}_\Delta$ *nucleus, right, after a cut on the ground state of* ^{11}C.

In order to explore the properties of the delta particle in the nuclear medium in more detail, and to determine the width of the delta particle in nuclear medium, a dedicated measurement for only one selected kinematics in the bound delta production region (see Table 1) has been performed. As in previous measurements, an excellent resolution of excitation energies of the residual ^{11}C nucleus has been achieved, as is shown in Fig. 1, left. This spectrum has been obtained after the cut on the timing in the three spectrometers, which selects the triple coincidence events. The cut around zero in this histogram selects events in which the ^{11}C was left in the ground state. However, previously obsereved peaks at the 282 and 296 MeV in the excitation energies $\hat{\omega}$ of the $^{12}C_{\Delta}$ were not clearly observed in this measurement, Fig. 1, right. No hardware or software problem has been detected in this measurement, and the question of possible changes of the delta properties in the nuclear medium remains open.

One serious difficulty encountered in these triple coincidence measurements is low statistics caused by small solid angles of the magnetic spectrometers, as can be seen from the last column of Table 1, which shows the total number of good events after all cuts. To collect higher statistics, one possibility is to do very long measurements, or to enlarge the available solid angles of the detectors. In order to further examine properties of delta particles in the nuclear medium, we have adopted the second approach.

6. *Future measurements*

In our future measurements, we intend to use a telescope made of silicon detectors for proton detection and the magnetic spectrometer A (28 msr) for the detection of electrons, instead of the previously used spectrometer B (5.6 msr). The spectrometer C (28 msr) will be used, as previously, for the detection of pions. The telescope made of silicon detectors consists of double-sided strip detector, 300 μm thick, with dimensions 24×24 mm^2 with the strip pitch 1 mm wide (detector type BB2 from Micron Semiconductor [13]). The strips on the opposite sides of the detector are at 90° and that provides angular information in both θ and ϕ directions. Behind the strip detector there are 5 silicon detectors, (MSX09 detectors from the same producer) each 1 mm thick and with dimensions 30×30 mm^2. The combination of these detectors will provide a good angle and energy information of detected protons together with the $\Delta E - E$ information necessary for particle separation. The detectors will be placed in the scattering chamber at the distance of 8.2 cm from the target and at this distance they will subtend the solid angle of 90 msr (see Fig. 2).

The described telescope made of silicon detectors for proton detection, in conjuction with the magnetic spectrometers should provide a satisfactory overall resolution, and due to a larger solid angle, improved statistics.

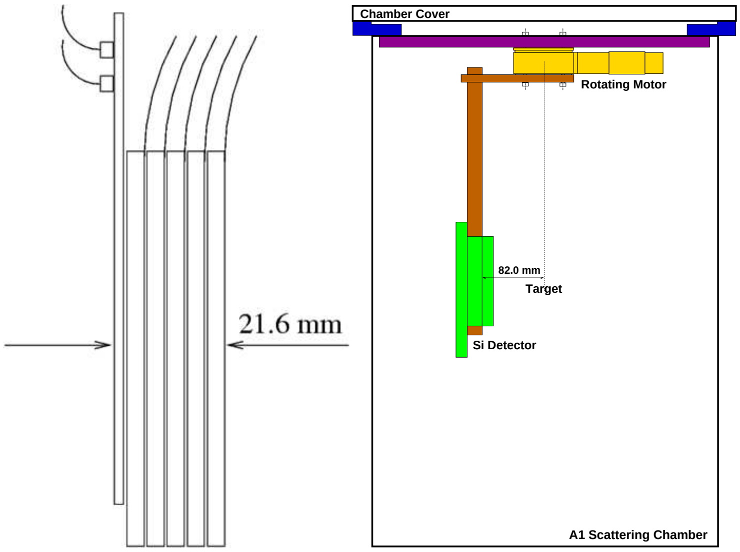

Fig. 2. Telescope of the BB2 and five MSX09 detectors, left; Holder of the telescope of silicon detectors with the rotating motor in the A1-scattering chamber, right.

References

[1] P. Bartsch et al., Eur. Phys. J. A **4** (1999) 209.

[2] wwwa1.kph.uni-mainz.de/A1

[3] wwwa1.kph.uni-mainz.de/A1/publications

[4] L. Elouadrhiri et al., Phys. Rev. C **50** (1994) R2266.

[5] K. Aulenbacher et al., Nucl. Instr. Meth. A **391** (1997) 498.

[6] K. I. Blomqvist et al., Nulc. Instr. Meth. A **403** (1998) 263.

[7] Th. Pospischil et al., Nucl. Instr. Meth. A **483** (2002) 713.

[8] M. O. Distler et al., *Proc. 12th IEEE Real Time Congress on Nuclear and Plasma Sciences*, Valencia, June 2001.

[9] M. Seimetz, *Messung des elektrischen Formfaktors des Neutrons bei $Q^2 = 0.3$ and 0.6* $(\mathrm{GeV}/c)^2$, Ph.D. thesis, Mainz University (2003).

[10] M. Ding, Ph.D. thesis, Mainz University, in preparation.

[11] A. Wagner, Ph.D. thesis, Mainz University, in prepartion.

[12] Th. Walcher, Phys. Rev. C **62** (2001) 064605.

[13] www.micronsemiconductor.co.uk

PROMJENE SVOJSTAVA DELTA U NUKLEARNOJ SREDINI

U eksperimentima s mikrotronom u Mainzu, MAMI, proizvodili smo u nuklearnoj sredini čestice Δ^0 reakcijom $^{12}\mathrm{C}\,(\mathrm{e},\mathrm{e}'\Delta^0)\,^{11}\mathrm{C}$. U okviru suradnje A1, rabili smo tri magnetska spektrometra visokog razlučivanja za trosudesna mjerenja $^{12}\mathrm{C}\,(\mathrm{e},\mathrm{e}'\mathrm{p}\,\pi^-)\,^{11}\mathrm{C}$. Podaci ukazuju na promjene svojstava delta čestica u nuklearnoj sredini. Zbog slabe statistike, ti se ishodi još ne mogu smatrati konačnima. Opisuje se i nov mjerni sustav za detekciju protona sastavljen od silicijskih detektora koji zahvaća veći prostorni kut.