Available online at www.sciencedirect.com
ScienceDirect
PHYSICS LETTERS B
Physics Letters B 656 (2007) 38–44
www.elsevier.com/locate/physletb

Study of nuclear correlation effects via $^{12}C(\vec{p},\vec{n})^{12}N(g.s., 1^+)$ at 296 MeV

T. Wakasa [a,*], M. Dozono [a], E. Ihara [a], S. Asaji [a], K. Fujita [b], K. Hatanaka [b], M. Ichimura [c], T. Ishida [d], T. Kaneda [b], H. Matsubara [b], Y. Nagasue [a], T. Noro [a], Y. Sakemi [d], Y. Shimizu [e], H. Takeda [a], Y. Tameshige [b], A. Tamii [b], Y. Yamada [a]

[a] *Department of Physics, Kyushu University, Fukuoka 812-8581, Japan*
[b] *Research Center for Nuclear Physics, Osaka University, Osaka 567-0047, Japan*
[c] *Faculty of Computer and Information Sciences, Hosei University, Tokyo 184-8584, Japan*
[d] *Cyclotron and Radioisotope Center, Tohoku University, Miyagi 980-8578, Japan*
[e] *Center for Nuclear Study, The University of Tokyo, Tokyo 133-0033, Japan*

Received 21 August 2007; received in revised form 7 October 2007; accepted 8 October 2007

Available online 13 October 2007

Editor: D.F. Geesaman

Abstract

We report measurements of the cross section and a complete set of polarization observables for the Gamow–Teller $^{12}C(\vec{p},\vec{n})^{12}N(g.s., 1^+)$ reaction at a bombarding energy of 296 MeV. The data are compared with distorted wave impulse approximation calculations employing transition form factors normalized to reproduce the observed beta-decay ft value. The cross section is significantly under-predicted by the calculations at momentum transfers $q \gtrsim 0.5\ \mathrm{fm}^{-1}$. The discrepancy is partly resolved by considering the non-locality of the nuclear mean field. However, the calculations still under-predict the cross section at large momentum transfers of $q \simeq 1.6\ \mathrm{fm}^{-1}$. We also performed calculations employing random phase approximation response functions and found that the observed enhancement can be attributed in part to pionic correlations in nuclei.

PACS: 24.70.+s; 25.40.Kv; 27.20.+n

Keywords: Nuclear correlation; Gamow–Teller 1^+ state; Polarization transfer measurement

The prediction of pion condensation [1] has prompted extensive experimental and theoretical studies of nuclear spin–isospin correlations. Pion condensation is expected to occur in cool neutron stars (NS) such as 3C58 [2] because pion condensation can accelerate the cooling of NS [3]. It is believed that pion condensation does not occur in normal nuclei; however, precursor phenomena may be observed even in normal nuclei if they are in the proximity of the critical point of the phase transition. The first proposal for possible evidence of a precursor was enhancement of the M1 cross section in proton inelastic scattering [4,5]. However, this prediction was not supported by measurements of $^{12}C(p,p')^{12}C(1^+, T=1)$ [6,7]. A possible reason for the absence of the precursor may be that the M1 cross section involves both pionic (spin-longitudinal) and rho-mesonic (spin-transverse) transitions and that the contribution from the rho-mesonic transition might mask the pionic effect.

A further possible source of evidence of a precursor was proposed by Alberico et al. [8–11]. They calculated the pionic and rho-mesonic response functions, R_L and R_T, in the quasielastic scattering (QES) region. Their results showed significant enhancement in R_L/R_T due to nuclear spin–isospin correlations. Great effort has been made [12] to extract the spin response functions R_L and R_T experimentally in $(\vec{p},\vec{p}')$ scatterings [13–17] and $(\vec{p},\vec{n})$ reactions [18–22] at intermediate energies. None of the observed ratios show evidence of the theoretically expected enhancement. The fact that the rho-mesonic response R_T is equally important in determining the ratio R_L/R_T means that the pionic enhancement may be masked by the contribution from the rho-mesonic component. Recent analysis of QES data shows pionic enhancement in the

* Corresponding author.
E-mail address: wakasa@phys.kyushu-u.ac.jp (T. Wakasa).

0370-2693/$ – see front matter
doi:10.1016/j.physletb.2007.10.017

spin-longitudinal cross section that well represents R_L, suggesting that the lack of enhancement in R_L/R_T is due to the rho-mesonic component [23]. It should be noted that pionic enhancement has been also observed in the pure pionic excitation of $^{16}O(p,p')^{16}O(0^-, T=1)$ scattering at $T_p = 295$ MeV [24].

Recent progress in the development of high intensity polarized ion sources and high efficiency neutron polarimeters has enabled the measurement of a complete set of polarization observables for the $^{12}C(\vec{p},\vec{n})^{12}N(g.s., 1^+)$ reaction at large momentum transfers covering the critical momentum $q \simeq 1.7$ fm^{-1} of pion condensation. This Gamow–Teller (GT) transition is the isobaric analog to the M1 excitation of $^{12}C(p,p')^{12}C(1^+, T=1)$ scattering. In addition, the (p,n) reaction is free from isospin mixing effects. Thus, it is very interesting to study nuclear correlation effects in this reaction by separating the cross section into pionic and rho-mesonic components with polarization observables. Furthermore, distorted wave impulse approximation (DWIA) calculations for finite nuclei employing nuclear correlations with continuum random phase approximation (RPA) are available.

In this Letter, we present the measurement of the cross section and a complete set of polarization observables for the $^{12}C(\vec{p},\vec{n})^{12}N(g.s., 1^+)$ reaction. An incident beam energy of 296 MeV is used. This is one of the best energies to study GT transitions since the spin excitations including GT transitions are dominant in the (p,n) reaction near 300 MeV [25]. Furthermore, distortion effects become minimum around this incident energy. This allows us to extract nuclear structure information reliably by the (p,n) reaction, such as the nuclear correlation effects. We compare our results with DWIA calculations. Possible evidence of nuclear correlations is observed in the comparison between the experimental and theoretical results. We also compare our data with DWIA calculations employing RPA response functions including the Δ isobar in order to assess the nuclear correlation effects quantitatively.

The data were obtained with a neutron time-of-flight (NTOF) system [26] with a neutron detector and polarimeter NPOL3 system [27] at the Research Center for Nuclear Physics, Osaka University. The NTOF system consists of a beam-swinger dipole magnet, a neutron spin-rotation (NSR) magnet, and a 100-m tunnel. The beam polarization was continuously monitored using two $\vec{p}+p$ scattering polarimeters; its typical magnitude was about 0.70. The beam energy was determined to be 296 ± 1 MeV from the kinematic energy shift between two peaks from $^7Li(p,n)^7Be(g.s. + 0.43$ MeV) and $^{12}C(p,n)^{12}N(g.s.)$. In the beam-swinger system, a beam with a typical current of 500 nA was incident on a self-supporting ^{nat}C (98.9% ^{12}C) target with a thickness of 89 mg/cm^2. Neutrons from the target passed through the NSR magnet and were measured by the NPOL3 system in the 100-m TOF tunnel with a resolution of about 500 keV FWHM. The neutron detection efficiency of NPOL3 was determined to be 0.025 ± 0.002 using $^7Li(p,n)^7Be(g.s. + 0.43$ MeV) at 0°, whose cross section is known for $T_p = 80$–795 MeV [28]. The neutron polarimetry of NPOL3 was calibrated using $^{12}C(\vec{p},\vec{n})^{12}N(g.s.)$ at 0° [27]. The effective analyzing power $A_{y;\mathrm{eff}}$ of NPOL3 was determined to be $A_{y;\mathrm{eff}} = 0.151 \pm 0.007 \pm 0.004$, where the first and second uncertainties are statistical and systematic uncertainties, respectively.

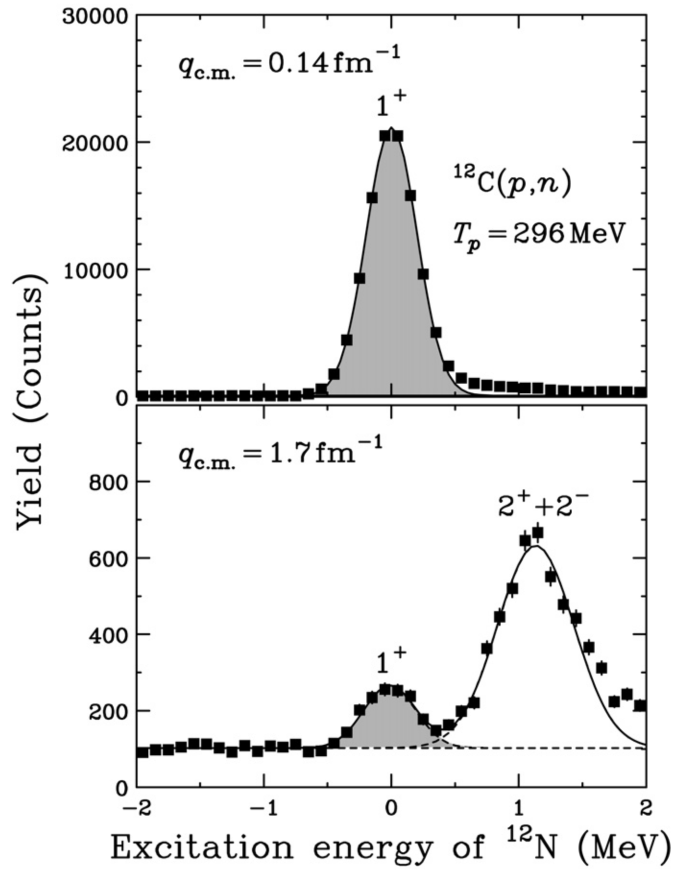

Fig. 1. Excitation energy spectra for $^{12}C(p,n)^{12}N$ at $T_p = 296$ MeV and $q = 0.14$ fm^{-1} (upper panel) and $q = 1.7$ fm^{-1} (lower panel). The dashed curves and straight dashed line represent fits to the individual peaks and background, respectively. The solid curve shows the sum of the peak fitting.

Fig. 1 shows the excitation energy spectra of $^{12}C(p,n)^{12}N$ for momentum transfers $q = 0.14$ fm^{-1} and 1.7 fm^{-1}. The GT 1^+ state at $E_x = 0$ MeV (ground state) forms a pronounced peak for $q = 0.14$ fm^{-1}, though it is not fully resolved from the neighboring states for $q = 1.7$ fm^{-1}. Therefore, we performed peak fitting for $E_x \leqslant 1.5$ MeV to extract the yield of the 1^+ state. The first and second excited states with $J^\pi = 2^+$ and 2^- at $E_x = 0.96$ and 1.19 MeV [29] were considered in the peak fitting and were assumed to form a single peak because the present energy resolution could not resolve these two peaks. The continuum background from wrap-around and $^{13}C(p,n)$ events is also considered in the peak fitting. The dashed curves in Fig. 1 represent the fits to the individual peaks, while the straight dashed line and solid curve represent the background and the sum of the peak fitting, respectively. The peak fittings at all momentum transfers were satisfactory for extracting the 1^+ yield.

The differential cross section for $^{12}C(p,n)^{12}N(g.s., 1^+)$ at $T_p = 296$ MeV is shown in the upper panel of Fig. 2. The data for the analyzing power were also measured and the results are displayed in the lower panel. The momentum-transfer dependence was measured in the range $q = 0.1$–2.2 fm^{-1}, covering