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Possibility to Employ Nucleon Pickup Cross Sections to Look into Nucleon Momentum Distributions in Nuclei

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In order to extract the nucleon momentum distribution in the nucleus, a new method that utilizes nucleon pickup cross sections has been tested. In a simple model, measured one-nucleon pickup cross sections for ^{16}O at 100 − 300 MeV/nucleon are consistent with a nucleon momentum distribution with a long tail at high momentum part, which is similar to those kind of tails often discussed in relation to short-range correlations or tensor interactions in nuclei.

KEYWORDS: nucleon momentum distribution, short-range correlation

1. Introduction

Nucleon momentum distributions have been often discussed in relation to the nucleon spatial distribution or in other words to the existence of halo structure. Since the momentum distribution reflects the Fourier transform of spatial wave function, for example, a tail-like behavior of the halo spatial wave function at the peripheral part corresponds to a narrow width of the momentum distribution, which has been often observed in the momentum distribution of the projectile fragment. On the other hand, the outer part of the nucleon momentum distribution depends on the correlations at small distances, where the short-range correlations in the nuclear force or the tensor interactions are considered to play important roles [1]. As there are not so much experimental information so far on the outer part of nucleon momentum distribution in nuclei other than that from electron scattering [2], it is valuable to develop different new methods to obtain such information. Along this direction, exclusive measurements of neutron pickup cross sections for proton beams have been recently carried out to reveal the importance of tensor correlations in interpreting the data [3, 4].

In the present study, with a relatively simple and easy experimental condition, we tried to investigate the possibility of extracting the information of outer part of nucleon momentum distribution by inclusive measurements of nucleon pickup cross sections using heavy-ion beams at a few 100 MeV/nucleon. If we consider the momentum matching between the transferred nucleon states before and after the pickup, the pickup cross section may be assumed to be determined by the overlap product of the nucleon momentum distributions before and after the pickup. When the beam energy is large, the momentum distance between the centers of two distributions before and after the pickup becomes so large, which leads to a very small overlap resulting a small pickup cross section. If the nucleon momentum distribution has a long tail originating from the short-range correlations or the tensor force, the cross section would be much larger by orders of magnitude than that without a tail.

2. Experiment

Primary beams of ^{16}O with various energies between 100 – 300 MeV/nucleon were provided by HIMAC heavy ion synchrotron at National Institute of Radiological Sciences, Japan. One-nucleon pickup cross sections for the primary beams on Be targets, ^{9}Be(^{16}O, ^{17}F) and ^{9}Be(^{16}O, ^{17}O), were measured. Reaction products ^{17}F and ^{17}O were identified and counted through the fragment separator SB2 [2] by use of the $B\rho - TOF - \Delta E$ method. The TOF information was obtained by two thin plastic scintillators set at F1 and F2. ΔE was taken with a 500 μm thick Si detector located at F2. A schematic drawing of the experimental setup is shown in Fig. 1. Longitudinal distributions of fragment momentum were measured by sweeping magnetic fields of the separator. The angular acceptance of the separator was also measured, which is more than 90 % at 300 MeV/nucleon and ~ 50 % at 120 MeV/nucleon. The primary beam intensity was $10^7 - 10^9$ depending on beam energy (~ 2×10^9 at 300 MeV/nucleon), which was monitored by the secondary emission monitor placed just before the target. From the integration of measured longitudinal momentum distribution with the correction of angular acceptance, the pickup cross section was deduced.

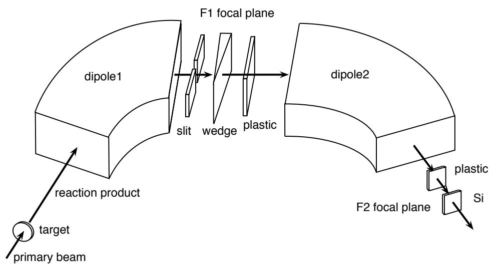

Fig. 1. Schematic drawing of the experimental setup.

3. Result and Discussion

Figure 2 shows longitudinal momentum distributions (differential cross sections $d\sigma/dp$) measured at several beam energies. Horizontal axis Δp is defined as the difference of the beam momentum from that with the primary-beam velocity. The energy losses in the Be target and the wedge degrader are appropriately corrected. The total one-proton pickup cross sections are obtained by integrating these spectra with the correction of the angular acceptance.

The deduced one-proton pickup cross sections σ_{+1p} (preliminary) are plotted in Fig. 3 by closed circles for ^{9}Be(^{16}O, ^{17}F) channel. These cross sections show a rapidly decreasing tendency with increasing energy. In order to look into this behavior, we made an estimation of the decrease assuming that σ_{+1p} is proportional to the overlap integral of nucleon momentum distributions in projectile and target.

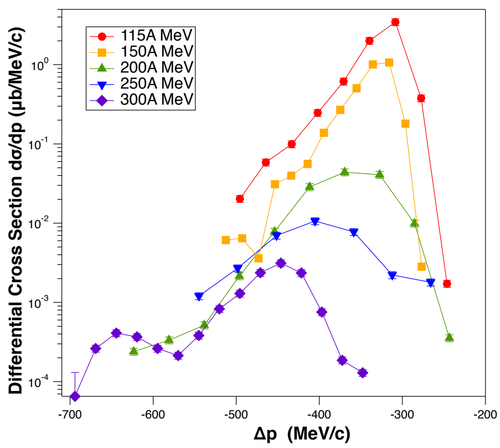

Fig. 2. Measured differential cross sections $d\sigma/dp$ plotted as a function of longitudinal momentum.

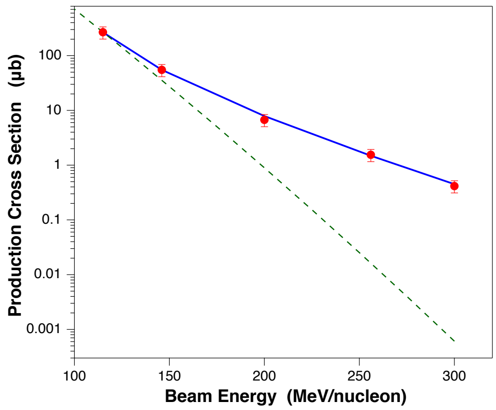

Fig. 3. Measured one-proton pickup cross sections (closed circles) plotted as a function of beam energy. Dashed curve shows a simple model calculation assuming Gaussian for nucleon momentum distribution in the nucleus. Solid curve : similar best-fit model calculation with (Gaussian + exponential tail)-type momentum distribution.

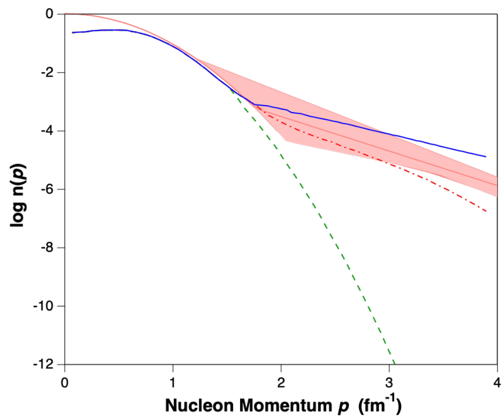

Fig. 4. Deduced nucleon momentum distribution (shaded area) using a simple reaction model with a functional shape of (Gaussian + exponential tail). Dashed curve : harmonic oscillator model prediction, dash-dotted curve : with only tensor correlations included, and solid curve : both tensor and short-range correlations included [1].

Dashed curve in Fig. 3 shows this estimation assuming a Gaussian momentum distribution with the Goldhaber model width [6] normalized at 115 MeV/nucleon. At the largest energy of 300 MeV/nucleon, σ_{+1p} show a large enhancement by three orders of magnitude compared to this estimation. On the other hand, a nucleon momentum distribution that has an exponential tail can explain this energy dependence with the same assumption of the relation $\sigma_{+1p} \propto$ (overlap integral). In this case, the amplitude and the slope of the exponential tail are free parameters to be extracted from the experimental data. From the energy dependence of σ_{+1p}, a rough estimate of the nucleon momentum distribution up to ~ 4 fm^{-1} was deduced as shown by the shaded area in Fig. 4. The thin solid curve indicates the best-fit one which corresponds to the solid curve in Fig. 3. In Fig. 4, the present result is compared with a phenomenological model calculation in which harmonic oscillator model only (dashed curve), including tensor correlations (dash-dotted curve), and including both tensor and short-range correlations (thick solid curve), are used. The gross shape and tail part in the present result is consistent with these calculations including these tensor and short-range correlations though there is a degree of freedom in the normalization of the present result. In order to make a detailed discussion, the present data should be compared with realistic and elaborate theoretical calculations.

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