First systematic measurement of cluster knockout reaction with ^{40}Ca

R. Tsuji,[*1,*2] J. Zenihiro,[*1] J. Tanaka,[*3] Y. Kubota,[*2] Y. Chazono,[*2] K. Higuchi,[*2,*4] T. Sugiyama,[*2,*4] M. Dozono,[*1] Y. Hijikata,[*1,*2] S. Ogio,[*1] T. Yano,[*1] Y. Maeda,[*5] Y. Matsuda,[*6] Z. H. Yang,[*7] S. Huang,[*7] D. S. Ahn,[*8] S. Kim,[*8] S. Ota,[*3] N. Kobayashi,[*3] T. Kawabata,[*9] T. Furuno,[*9] D. Beaumel,[*10] S. Franchoo,[*10] S. Kawase,[*11] K. Miki,[*12] M. Mitsui,[*5] N. Yamasaki,[*6] F. Saito,[*6] S. Umemoto,[*6] Q. Li,[*7] Z. Du,[*7] J. Bian,[*7] C. Liu,[*7] K. Kawata,[*3] J. Cai,[*13,*3] F. Furukawa,[*3] H. Shibakita,[*9] Y. Li,[*2] and T. Uesaka[*2] for the ONOKORO Collaboration

Spontaneous light cluster formations such as d, t, ^{3}He, and ^{4}He in the low-density region of heavy nuclei and infinite nuclear matter are predicted by recent relativistic mean-field theory.[1,2] Thus, we launched the "ONOKORO" project to study the light cluster formation using quasi-free proton-induced cluster knockout reaction ((p,pX) reaction ($X = d$, t, ^{3}He, ^{4}He)) at 200–400 MeV/nucleon.[3] The recent reaction theories can explain (p,pX) reactions including the fragile clusters such as d, t, and ^{3}He.[4,5]

As the first measurement in the ONOKORO project, we measured the (p,pX) reaction ($X = d$, t, ^{3}He, ^{4}He) from about 10 mg/cm^2-thick ^{40}Ca target using 230 MeV proton beam at the Research Center for Nuclear Physics, Osaka University. ^{40}Ca is doubly magic and intermediate-mass nuclei that reliable calculations such as AMD are available.[4] The angles and energies of scattered protons and knocked-out clusters were measured with Grand Raiden (GR) spectrometer and Large Acceptance Spectrometer (LAS) simultaneously. For the verification of the angular distribution of the triple differential cross sections calculated by the reaction theory which describes the (p,pX) reactions of the fragile clusters, the data at several scattering angles of $(p,pd)/(p,pt)$ were taken.[5] The configuration of the scattering angle in the center-of-mass system is in Table 1.

Table 1. Scatterimg angle in the center-of-mass system.

cluster	d	t	^{3}He	^{4}He
$\theta_{\rm cm}$ (deg)	50, 60, 70, 75	50, 60, 70	70	80

The (p,pX) reaction in normal kinematics satisfies the following energy conservation law.

$$S_X = T_{\rm in} - T_p - T_X - T_R \quad (1)$$

S_X is the separation energy of the cluster, $T_{\rm in}$ is the proton incident energy, and T_p, T_X, and T_R are the energies of scattered protons, knocked-out clusters, and the residual nuclei. T_p and T_X have the kinematical correlation, because T_R is smaller than the other terms relatively in the recoil-less condition. Figure 1 shows the x positions at the focal plane of GR and LAS spectrometers which correspond to the momentums and energies of the scattered protons and knocked-out clusters. Each locus in Fig. 1 corresponds to the kinematical correlation for different separation energies S_X.

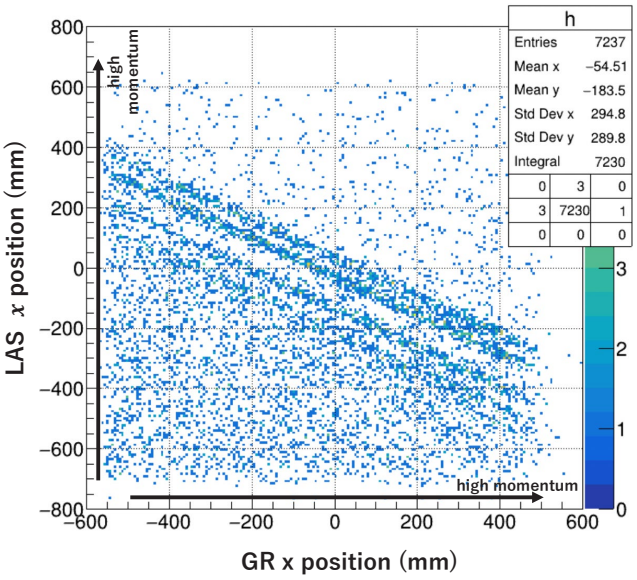

Fig. 1. Momentum correlation of ^{40}Ca (p,pd) at $\theta_{\rm cm} = 60°$.

The kinematical correlations of (p,pX) reactions from ^{40}Ca were also confirmed for other clusters. The analysis to get the separation energy spectrum and the triple differential cross section is ongoing.

*1 Department of Physics, Kyoto University
*2 RIKEN Nishina Center
*3 Research Center for Nuclear Physics (RCNP), Osaka University
*4 Department of Physics, Saitama University
*5 Department of Physics, Miyazaki University
*6 Department of Physics, Konan University
*7 Department of Physics, Peking University
*8 CENS, Institute for Basic Science
*9 Department of Physics, Osaka University
*10 IJCLab
*11 Department of Physics, Kyushu University
*12 Department of Physics, Tohoku University
*13 Institute for Modern Physics

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