Probing dilute nuclear density by antiproton-nucleus scattering†

K. Makiguchi,*1 W. Horiuchi,*1 and A. Kohama*2

Nuclear density distributions are the basic properties of atomic nuclei. Traditionally, the charge density distributions have been measured using electron-nucleus scattering. Hadronic probes have been used to study matter density distributions, especially via proton-nucleus scattering. Recently, we proposed a practical approach to extract the nuclear surface diffuseness of unstable nuclei using proton-nucleus elastic scattering differential cross sections.1,2) As a natural extension of the previous study, we investigated antiproton-nucleus scattering because it could provide a different sensitivity to the nuclear structure than the proton probe because the antiproton-nucleon (pN) total cross sections are typically 3–4 times larger than those of NN at incident energies varying from a few hundreds to thousands MeV.

High-energy antiproton-nucleus reactions can be efficiently described by the Glauber model.3) The total reaction and elastic scattering cross sections can be obtained by evaluating the optical phase-shift function e^iμ(b) as a function of the impact parameter vector b. In optical limit approximation, we have iμ(b) = −∫ ρ_N(r)Γ_{NN}(b−s)·dr, where r = (s, z) with z denoting the beam direction, nucleon (N) one-body density ρ_N(r), and antinucleon-nucleon NN profile function Γ_{NN}(b). The parameters of the profile function were determined to reproduce the pN and p-12C cross-section data. The validity of the present model is demonstrated in Fig. 1. The theoretical cross sections were significantly consistent with the experimental data without any adjustable parameter using harmonic-oscillator type density distributions that reproduce the observed charge radii.

We found that strong absorption occurs even beyond the nuclear radius owing to the large pN elementary cross sections, resulting in strong sensitivity in the nuclear tail. This sensitivity is quantified by taking an example of a possible halo nucleus 31F, which is located at the fluorine dripline; however, the antiproton scattering on unstable nuclei is still not feasible. According to the investigations in Ref. 4) the shell gap between 0f7/2 and 1p3/2 orbits is essential and the dominance of the (1p3/2)2 configuration forms the halo structure in 31F. We considered these density distributions of 31F with (1p3/2)2 (halo) and (0f7/2)2 (nonhalo) dominance from Ref. 4) and calculated the ratio of the total reaction cross sections of antiproton and proton scattering. Figure 2 displays the ratios of 31F as a function of incident energy. The ratios of 29F with harmonic-oscillator type density distributions are also plotted for comparison. 31F with the halo tail yielded the largest ratios, while the nonhalo density produced almost the same behavior as 29F, which demonstrates the advantage of antiproton scattering in the analysis of dilute density distribution.

Fig. 1. Elastic scattering differential cross sections for antiproton-nucleus scattering at 180 MeV/nucleon adopted from the original paper.

Fig. 2. Ratio of total reaction cross sections of 29,31F for antiproton and proton scattering as a function of the incident energy adopted from the original paper.

References

† Condensed from the article in Phys. Rev. C 102, 034614 (2020)
*1 Department of Physics, Hokkaido University
*2 RIKEN Nishina Center