Probing dilute nuclear density by antiproton-nucleus scattering[†]

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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 ($\bar{p}N$) 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 $e^{i\chi(\boldsymbol{b})}$ as a function of the impact parameter vector $\boldsymbol{b}$. In optical limit approximation, we have $i\chi(\boldsymbol{b}) = -\int \rho_N(\boldsymbol{r})\Gamma_{\bar{N}N}(\boldsymbol{b}-\boldsymbol{s})\,d\boldsymbol{r}$, where $\boldsymbol{r} = (\boldsymbol{s}, z)$ with z denoting the beam direction, nucleon (N) one-body density $\rho_N(\boldsymbol{r})$, and antinucleon-nucleon $\bar{N}N$ profile function $\Gamma_{\bar{N}N}(\boldsymbol{b})$. The parameters of the profile function were determined to reproduce the $\bar{p}N$ and $\bar{p}$-^{12}C 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.

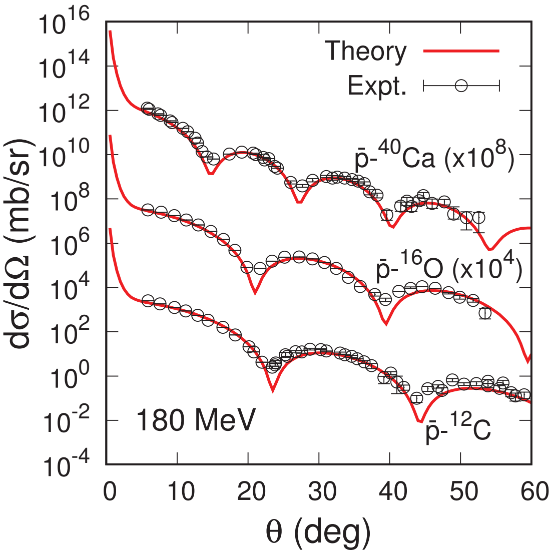

Fig. 1. Elastic scattering differential cross sections for antiproton-nucleus scattering at 180 MeV/nucleon adopted from the original paper.

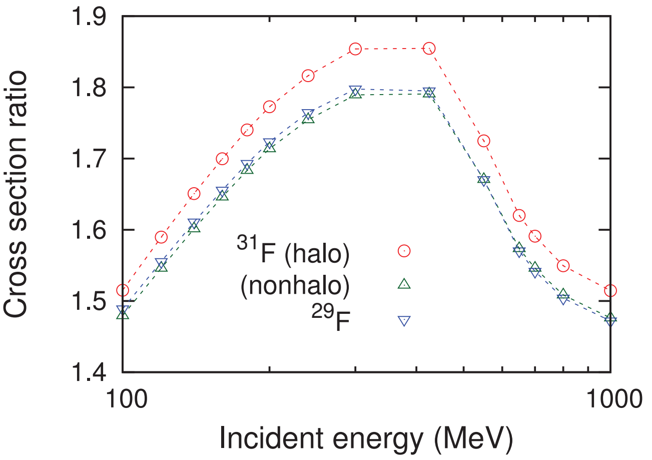

Fig. 2. Ratio of total reaction cross sections of ^{29,31}F for antiproton and proton scattering as a function of the incident energy adopted from the original paper.

We found that strong absorption occurs even beyond the nuclear radius owing to the large $\bar{p}N$ elementary cross sections, resulting in strong sensitivity in the nuclear tail. This sensitivity is quantified by taking an example of a possible halo nucleus ^{31}F, 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 $0f_{7/2}$ and $1p_{3/2}$ orbits is essential and the dominance of the $(1p_{3/2})^2$ configuration forms the halo structure in ^{31}F. We considered these density distributions of ^{31}F with $(1p_{3/2})^2$ (halo) and $(0f_{7/2})^2$ (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 ^{31}F as a function of incident energy. The ratios of ^{29}F with harmonic-oscillator type density distributions are also plotted for comparison. ^{31}F with the halo tail yielded the largest ratios, while the nonhalo density produced almost the same behavior as ^{29}F, *which demonstrates the advantage of antiproton scattering in the analysis of dilute density distribution.*

References

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