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Investigation of nuclear matter distribution of the neutron-rich He isotopes by proton elastic scattering at intermediate energies

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Abstract. Absolute differential cross-sections for elastic p^6He and p^8He scattering were measured in inverse kinematics with secondary beams. In order to supplement data taken for small-angle scattering, differential cross-sections for higher momentum transfer were measured using liquid hydrogen target. Both data sets were analyzed together. They have permitted to deduce the radial shape of the nuclear matter distributions and the root-mean-square radii with the help of Glauber theory. In addition to a phenomenological analysis, used already in the previous work, a model-independent analysis with a help of a Sum-Of-Gaussians (SOG) method has been performed. The experimental $p^{6,8}$He elastic scattering cross-sections have also been compared with the predictions from various theoretical nuclear models.

PACS. 21.10.Gv Mass and neutron distributions – 24.50.+g Direct reactions – 25.10.+s Nuclear reactions involving few-nucleon systems – 25.40.Cm Elastic proton scattering

1 Introduction

The study of neutron-rich light nuclei near the drip line has attracted much attention as they exhibit a particular nuclear structure, namely an extended distribution (so-called halo) of the valence neutrons surrounding a compact core. Elastic proton scattering at intermediate energies is known as a suitable technique for exploring the nuclear matter distributions in the stable nuclei. It was successfully applied at GSI also for the radioactive nuclei ^{6,8}He [1,2] and ^{8,9,11}Li [3] with beam energies close to 700 MeV/u in inverse kinematics. The method has been proven to be very effective for measuring the differential cross-sections and deriving the nuclear matter distributions in the halo nuclei, such as ^{6}He, ^{8}He and ^{11}Li, with the aid of the Glauber multiple scattering theory.

2 Motivation and experimental method

Previous measurements performed in the small momentum transfer region have yielded valuable information on the nuclear sizes and radial structure of the overall nuclear matter density distributions. A high-pressure hydrogen-filled ionization chamber was used as the target and the detector for the recoiling protons. Theoretical estimations have shown that in case of higher momentum transfer the experimental data more sensitively probe the density of the inner part of the nuclei and thus generally improves the accuracy of the total matter distribution [4]. Recently, a novel experimental approach has been accomplished with the aim to deduce the differential $p^{6,8}$He cross-sections at a higher momentum transfer close to the first diffraction minimum. The major difference with respect to the previous experiments was that instead of the active gaseous target a liquid hydrogen target was used, combined with a proton recoil detector [5].

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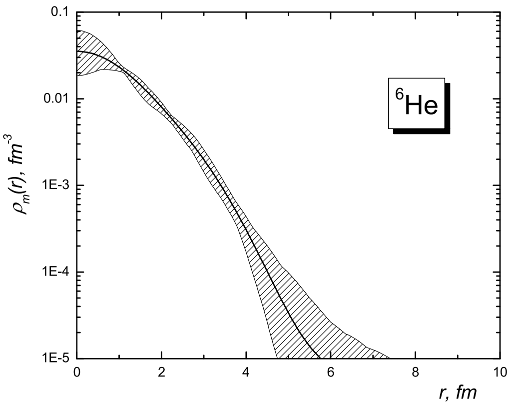

Fig. 1. Nuclear matter density distribution deduced from the experimental cross-section for ^{6}He using a Sum-Of-Gaussians method. The shaded area represents the resulting error band.

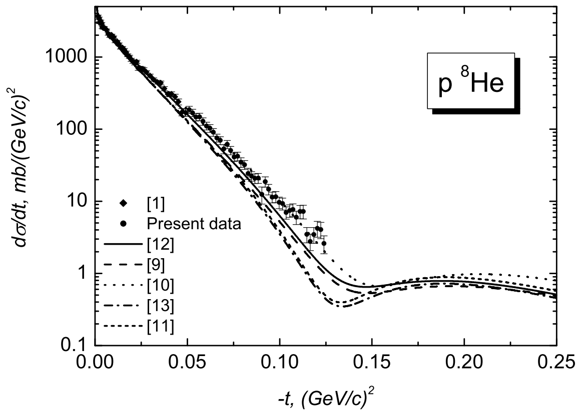

Fig. 2. Experimental differential cross-section $\mathrm{d}\sigma/\mathrm{d}t$ *versus* the four momentum transfer squared $-t$ for p^8He and comparison with calculations based on predictions of various theoretical models for the nuclear matter density.

3 Analysis and results

The differential cross-sections obtained in both experiments have been evaluated using several phenomenological parameterizations for the nuclear matter distribution. Details of this part of the analysis are described in [2]. In addition, a model-independent analysis with the help of a Sum-Of-Gaussians (SOG) method has been performed, which is a standard method for the investigation of nuclear charge distributions from electron scattering data [6]. Figure 1 shows, as an example, the radial shape of the total nuclear matter distribution in ^{6}He derived from the SOG analysis. The deduced values of the nuclear matter radii R_{m} of ^{6}He 2.37(5) fm and ^{8}He 2.49(4) fm are consistent with the results of the phenomenological analysis and confirm the existence of an extended neutron halo in these nuclei. The nuclear charge radius of ^{6}He has been recently measured for the first time using the method of isotope shift based on laser spectroscopy technique [7]. It was found to be 2.054(14) fm, and the corresponding value for the point-proton radius is 1.912(18) fm. The obtained value is in good agreement with the present value of $R_{\mathrm{core}} = 1.97(9)$ fm (expected when assuming to have an α-particle core + 2n halo structure) that assures the consistency of both measurements. The analysis of the experimental cross-sections confirms the structure of ^{6}He as a three-body system. The core size of ^{8}He has been found to be $R_{\mathrm{core}} = 1.86(8)$ fm and within the phenomenological approach, the nuclear matter density has been parameterized as an α-particle core and four valence neutrons and a ^{6}He core and two valence neutrons. Both parameterizations permit the same quality description of the experimental cross-sections. A possible explanation is that a ground state of ^{8}He is a mixture of these two configurations. This fact is supported by the analysis of the inelastic scattering of ^{8}He on protons, measured also in the present experiment [8].

Precise data on the differential cross-sections may provide a sensitive test for theoretical predictions on nuclear matter density distributions. Density distributions obtained from various theoretical approaches: relativistic mean field calculations [9], microscopic cluster model using the refined resonating group method [10], microscopic quantum Monte Carlo calculations [11], variational Monte Carlo [12], Fermionic Molecular Dynamics [13]. The cross-sections $\mathrm{d}\sigma/\mathrm{d}t$ for $p^{6,8}$He elastic scattering have been calculated using nuclear matter density distributions. Figure 2 shows the comparison of the data with the latest calculations for ^{8}He. The best agreement has been obtained using densities from [10] and [12]. A similar comparison has been also made for p^6He. In this case the best agreement between the experimental data and theory was archived with densities from [11] and [13].

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