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S. NEUMAIER et al

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Gesellschaft für Schwerionenforschung mbH
Postfach 11 05 52 · D-64220 Darmstadt · Germany

Study of the Nucleon Density Distribution of ^6He and ^8He by Proton Elastic Scattering in Inverse Kinematics *

S. Neumaier [a], G.D. Alkhazov [c], M.N. Andronenko [c], T. Beha [b], K-H. Behr [b], A. Brünle [b], K. Burkhard [b], A.V. Dobrovolsky [c], P .Egelhof [b], C. Fischer [b], G.E. Gavrilov [c], H. Geissel [b], V.I. Iatsoura [c], H. Irnich [b], A.V. Khanzadeev [c], G.A. Korolev [c], A.A. Lobodenko [c], P. Lorenzen [a], G. Münzenberg [b], M. Mutterer [a], F. Nickel [b], W. Schwab [b], D.M. Seliverstov [c], P. Singer [a], T. Suzuki [b], J.P. Theobald [a], N.A. Timofeev [c], A.A. Vorobyov [c]

[a] Institut für Kernphysik, TH-Darmstadt, 64289 Darmstadt, Germany
[b] Gesellschaft für Schwerionenforschung, 64220 Darmstadt, Germany
[c] Petersburg Nuclear Physics Institute, 188350 Gatchina, Russia

Abstract

Nuclear matter distributions of the neutron-rich nuclei ^6He and ^8He were studied via proton-nucleus scattering in inverse kinematics using the recoil detector IKAR. The differential cross sections for p^4He, p^6He and p^8He elastic scattering were measured with an uncertainty of $\pm$ 2% for the absolute normalization for proton recoil energies from 1 to 20 MeV. The experimental techniques and the data analysis are described and first Glauber calculations presented. Data analysis is still in progress so only preliminary results are given.

1. INTRODUCTION

One of the most exciting events in nuclear structure physics in recent years was the discovery of light neutron-rich nuclei near or at the neutron drip line to reveal an extended neutron distribution surrounding the nuclear core. Clear evidence for this neutron halo was obtained for ^{11}Li and ^{14}Be and a less pronounced neutron skin for $^{6,8}He$ and ^{12}Be (see recent review articles [1,2]). Although the existence of an extended neutron distribution in these nuclei is now a solidly established fact, the applied methods seem to be incapable of assigning accurate values for the nuclear matter radii involved.

Protons with energies of 700 MeV to 1000 MeV as probes have proved to be a well suited method to study nuclear density distributions of stable nuclei, because at these high energies elastic proton-nucleus scattering can be described accurately by the diffractive multiple scattering theory which relates the measured cross sections to the nuclear matter radii of interest in a rather unambiguous way [3]. This method can also be applied to study unstable nuclei by measuring proton elastic scattering in inverse kinematics using radioactive beams and proton targets. Furthermore, theoretical estimates show that proton scattering in the region of small momentum transfer is especially sensitive to the extension of halo structures [4].

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2. EXPERIMENT

2.1 Experimental Setup

The experiment on elastic proton scattering was performed at the heavy ion synchrotron (SIS) of GSI Darmstadt using secondary ^{4,6,8}He beams from the fragment separator (FRS), at incident kinetic energies of 699 MeV/u, 717 MeV/u, and 674 MeV/u, respectively. Beam particles are interacting with protons inside the high-pressure hydrogen filled ionization chamber IKAR [5] which serves simultaneously as gas target and detector. This recoil proton detector IKAR was developed at the Petersburg Nuclear Physics Institute (PNPI,Gatchina). It operates at 10 bar pressure and consists of 6 Frisch-gridded ionization chambers with electrodes arranged perpendicular to the beam direction (Fig. 1). Signals from the various electrodes of IKAR were registered by using flash-type ADCs. Use of a tracking detector for the forward particles consisting of 4 multiwire proportional chambers has permitted a simultaneous measurement of the scattering angle Θ_S of the incident particle. Furthermore a set of scintillation counters was used to identify the incident particles eventwise in mass and charge via TOF and dE/dx. During a measuring period of two weeks about $4 \cdot 10^4$ elastic scattering events were recorded for ^{6}He and ^{8}He each. The differential cross section for ^{4}He was also measured with about $5 \cdot 10^3$ events total to test the experimental method and the data normalization.

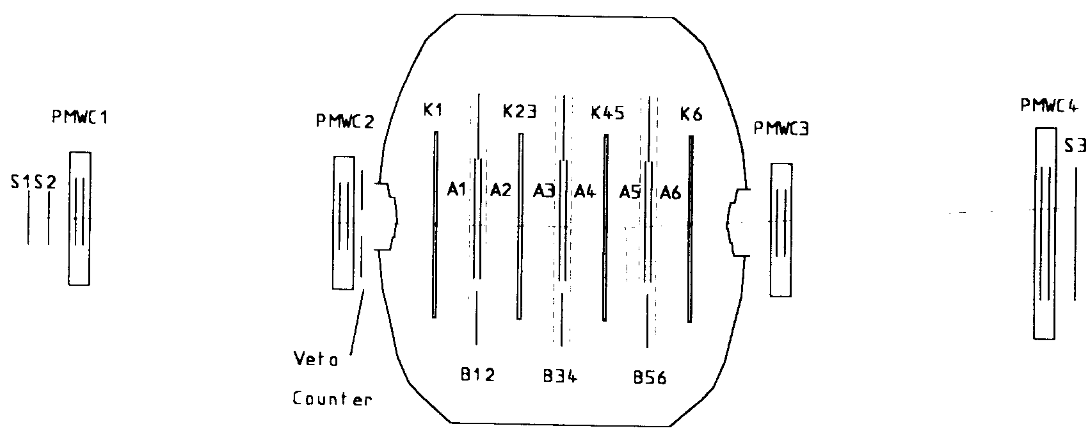

Fig. 1. Schematical view of the experimental setup. The center part shows the hydrogen filled ionization chamber IKAR which serves simultaneously as a gas target and detector system for recoil protons. Four proportional multiwire chambers (PMWC 1- 4) determine the scattering angle of the projectile. A series of scintillation counters (S1 - S3) was used for particle identification.

2.2 Data Analysis

The techniques of data registration by flash-ADCs allows a detailed off-line analysis of the various parameters of the ionization chamber signals. A computing algorithm was developed to determine precisely the energy T_R of recoil protons, or their energy loss ΔT_R in case they leave the active volume, and to reconstruct the interaction vertex in the grid-cathode space as well as the projection of the track of recoil protons on the beam axis. The energy calibration was performed by analyzing signals from ^{241}Am α-sources implanted on to several cathodes and grids of IKAR. The pulse length of the anode signals due to the energy loss of the beam particles determines the effective target thickness. To correct for background events the correlation of the proton recoil energies measured in IKAR with the values evaluated from the scattering angle Θ_S of the incident projectile was studied.

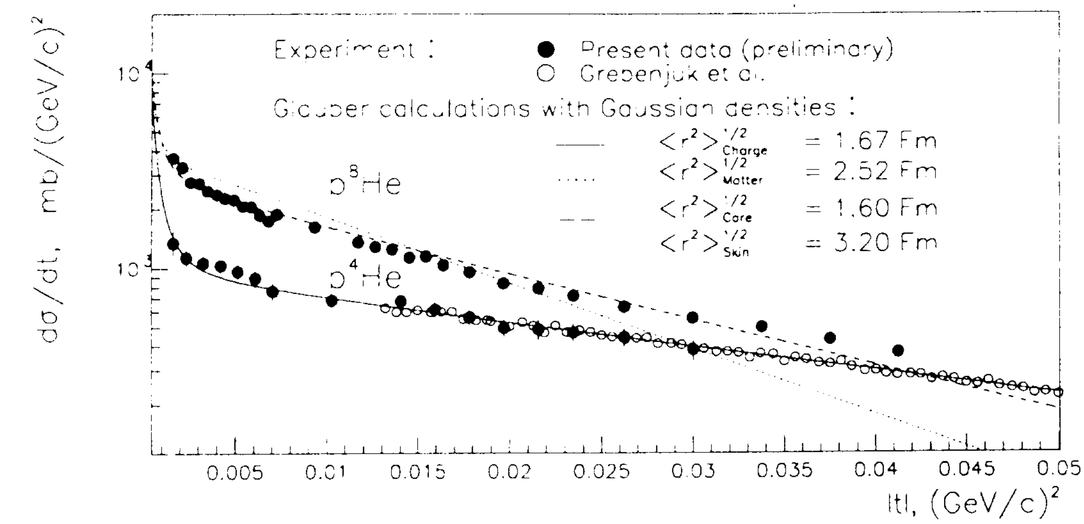

Fig. 2. Absolute differential cross section *dσ/dt* versus the four momentum transfer squared $|t|$ for p^{4}He and p^{8}He elastic scattering (full dots) measured in the present experiment. Open dots show the result of an earlier measurement of p^{4}He scattering which was performed in direct kinematics with a proton beam [6]. Plotted lines are obtained by calculations using the Glauber multiple scattering theory. The assumptions made for the nuclear density distributions are also listed in the figure (for details see text).

3. PRELIMINARY RESULTS

Data analysis is still in progress, so only preliminary results are available. Figure 2 summarizes the differential cross sections deduced for ^{4}He and ^{8}He (full dots). The absolute values *dσ/dt* are plotted versus the four momentum transfer squared $|t|$. For the ^{4}He data an excellent overall agreement for the absolute values, as well as for the $|t|$-dependence of the cross section with data by Grebenjuk et al. [6] is attained. These data were measured earlier in direct kinematics using the IKAR chamber operated with helium as counting gas (open dots). The favorable situation of higher energies of recoil particles in the case of inverse kinematics has allowed to supplement these experimental data in the region of low momentum transfer.

In fig. 2, the measured data are compared with the cross sections calculated using the Glauber multiple scattering theory [7]. Only the scalar parts of the *pp* and *pn* scattering amplitudes were taken into account. In these calculations the nuclear matter distributions were parametrized by one or a sum of two Gaussians with the cited values for the root mean square radii $r_{rms} = \langle r^2 \rangle^{1/2}$ as fixed parameters. The p^4He cross section is well described over the whole measured range of momentum transfer, the calculations being performed with a single Gaussian distribution and a nuclear matter radius for ^4He which corresponds to the nuclear charge radius r_{rms} = 1.67 fm determined from electron scattering [8].

For p^8He scattering a reasonable description of the data is obtained by using a nuclear matter distribution which is parametrized by 2 Gaussians with a value of r_{rms} = 1.67 fm for core nucleons and r_{rms} = 3.2 fm for skin neutrons, combining to an average r_{rms} (^8He) = 2.52 fm. This has to be compared with values of 2.52 fm [9] and 2.70 fm [10] deduced previously with the aid of a Glauber-type analysis [11] of the measured total reaction cross sections for 700 MeV/u nuclei of ^8He interacting with various targets [12]. As it is seen from fig. 2, the assumption of a nuclear density distribution using a single Gaussian (with r_{rms}(^8He) = 2.52 fm) fails to describe the measured differential cross section. This is a convincing indication for an extended nuclear matter skin in ^8He. A more detailed theoretical analysis in order to deduce the rms-radii of core and skin by fitting the present data is in progress.

4. SUMMARY

Medium energy elastic proton scattering on exotic nuclei in inverse kinematics has been shown to be a powerful tool to provide information on nuclear density distributions. The recoil detector IKAR is well suited to perform such measurements. The experimental method was tested with proton scattering on ^4He. The present status of analysis confirms the existence of a neutron skin in ^8He. Data analysis for p^6He scattering and more detailed theoretical calculations are in progress. Further measurements with radioactive beams of neutron-rich lithium and beryllium isotopes using the same experimental techniques are in preparation.

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