Halo studies with high-energy (20 GeV) proton scattering

M. Tomaselli[1,2], L.C. Liu[3], S. Fritzsche[4], T. Kühl[2]
[1] TU Darmstadt, [2] GSI Darmstadt,[3] Los Alamos National Laboratory, [4] Univ. Kassel

Proton-nucleus elastic scattering at intermediate energies was applied for the first time at GSI to extract nuclear matter and charge radii from neutron-rich light nuclei by the IKAR collaboration [1]. One of the outstanding results is the discovery of a pronounced neutron halo in the matter distribution of neutron rich nucleus, such as ^{11}Li. A recent analysis of the p-^{6}Li scattering experiments [2] has further shown that extended matter distribution characterizes also nuclei with neutron-proton excess. Theoretical calculations of the 2n-halo structure have so far mainly been performed in the framework of the *Borromean* three-ring approximation which was firstly introduced to investigate the halo structure of ^{11}Li. In that approximation the valence neutrons interact among themselves via neutron-neutron interaction while leaving the reference (core) nucleus in its ground state. In other words, the interaction between the valence- and core-clusters, which is responsible for the dynamics of nuclear core polarization, is neglected under the assumption that the halo (long-tailed) neutrons are weakly bound. We report in this contribution on the effects of the halo structure on high-energy p-^{6}Li elastic differential cross sections. We have calculated the ground-state matter distribution of ^{6}Li by using the Boson Dynamic-Correlation Model (BDCM) [3] which describes the structure of open-shell even-even nuclei in terms of valence as well as core clusters. In the BDCM, the energy levels, magnetic moments, matter and charge distributions, and other nuclear observables are all calculated in a model basis that is the self-consistent solution of the dynamic equations. In contrast to the Hartree-Fock (HF) approach, the BDCM includes a coupling between the core and the valence particles. This coupling modifies the HF description and polarizes the core via particle-hole excitations ($2\hbar\omega$). At the same time, the valence particles become *dressed* by the complex excitations of the core. From a HF point-of-view, these *dressed* particles correspond to a particular solution of an expanded, nonlinear HF Hamiltonian. The calculated r.m.s. radius of the ^{6}Li matter distribution [4] is found in good agreement with those extracted from recent p-^{6}Li elastic scattering experiments performed in inverse kinematics at 0.7 GeV/u [2]. Because the elastic diffraction peak can only provide information about the r.m.s. radius, we propose to study the halo aspect of the predicted matter distribution by using large momentum transfers which can be obtained in the scattering of protons having energies of tens of GeV. The use of such high-energy protons has several advantages: (a) the large momentum transfers needed to reveal the details of the nuclear structure which can be derived from the scattering at very small angles ($\theta < 4^o$ at 20 GeV), for which eikonal model and Glauber model can be employed with confidence; and (b) in this large-momentum transfer region the Coulomb amplitude is negligibly small and, hence, the nuclear structure effect are not masked by the Coulomb interaction. In Fig. 1-left, we compare the halo matter density distribution of ^{6}Li given by the BDCM with that derived from the electron scattering experiment performed at limited momentum transfers (q$\leq$ 0.35 GeV/c). On the right-hand side we can see that the BDCM distribution has an extended nuclear tail while the electron-experiment one does not. In Fig. 1-right, we compare the p-^{6}Li elastic differential cross sections given by the above two matter-density distributions which have similar r.m.s. radii but very different nuclear tails. We see that both distributions give differential cross sections that are very close to each other at momentum transfers $q < 0.3$ GeV/c. However, the first diffraction minimum due to the presence of the halo occurs at $q \simeq 0.38$ GeV/c while that of the non-halo distribution is at $q \simeq 0.47$ GeV/c. Furthermore, the differential cross sections at the second maximum differ by two orders of magnitude. We have thus demonstrated, through the example of ^{6}Li, that high-energy protons represent an ideal tool for probing nuclear halo structure and constitutes a stringent test for nuclear models in the sense that a good nuclear model must be able to reproduce simultaneously the experimental energy levels and the scattering cross sections up to large momentum transfers. Protons of 20 GeV are readily available at several facilities, such as Brookhaven National Laboratory and the new GSI project.

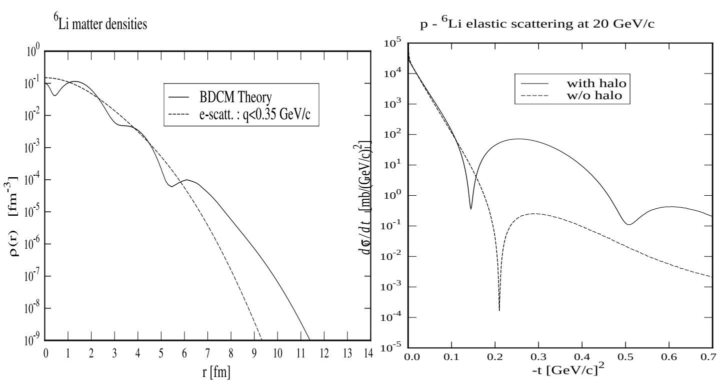

Figure 1: Left: Calculated (BDCM) halo density of ^{6}Li [3] compared with the density derived from electron scattering experiment measured up to q=0.35 GeV/c. Right: Predicted proton-^{6}Li elastic scattering differential cross sections at 20 GeV for the densities with and without halo.

[1] S.R. Neumaier *et al.*, Nucl. Phys. **A712**, 247 (2002); G.D. Alkhazov *et al.*, Nucl. Phys. **A712**, 269 (2002). [2] A.V. Dobrowolsky *et al.*, Nuclear Physics at Border Lines (NPB) 2001, G. Fazio, G. Giardina, F. Hanappe, G. Imme' and N. Rowley, World Scientific, ISBN 981-02-4778-8, 336 (2002). [3] M. Tomaselli *et al.*, Phys. Rev. **C62**, 67305 (2000); M. Tomaselli, L.C. Liu, T. Kühl *et al.*, PRC submitted for publication. [4] M. Tomaselli, T. Kühl, W. Nörtershäuser *et al.* Can. J. Phys. **80**, 1347 (2002).