Quasi-elastic Scattering of a Secondary ^{6}He Beam on a ^{9}Be Target at 25MeV/Nucleon*

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The quasi-elastic scattering of a secondary ^{6}He beam (25 MeV/n) on a ^{9}Be target has been measured for the first time with the application of a sophisticated tracking detector system. The angular distribution is reported. A phenomenological optical potential is obtained by fitting the experimental data, which encourages more accurate experimental measurements.

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Nuclear reactions using secondary radioactive beams have opened a new possibility for studying the structure of exotic nuclei far away from the β-decay stability line. Neutron halos and skins have been discovered in several neutron-rich nuclei such as ^{11}Li and ^{6}He through the measurements of the interaction cross sections[1] and the momentum distributions of the projectile fragments.[2] The density distributions of these nuclei were determined from the energy and the target mass dependence of the interaction cross section.[3] In recent years there have been more and more measurements of the angular distributions in order to further understand the characteristics of the skin and halo nuclei.[4] Here we report on the measurements of the differential cross sections of ^{6}He+^{9}Be quasi-elastic scattering. These data are expected to provide a more detailed view of the structure of the neutron skin as well as the optical models.

The experiment was performed with a radioactive ion beam line[5] (RIBLL) that was built up at the Heavy Ion Research Facility (HIRFL) in Lanzhou. The secondary beam of ^{6}He was produced by fragmentation of a 50 MeV/n ^{13}C primary beam, provided by HIRFL, on a 3000 μm thick ^{9}Be production target and separated by the RIBLL. The resulting beam of ^{6}He had an average energy of 25 MeV/n. The purity of ^{6}He was about 48%, mixed with 30% ^{9}Be, 21% ^{4}He and a minority of others. The intensity of the secondary beams was about 2000 pps. After various cuts, the ^{6}He particle rate incident on the target was only 100 pps on average.

The momentum acceptance of the RIBLL was approximately 5%, leading to a beam spot that was about 100 mm in the horizontal direction and 70 mm in the perpendicular direction. In order to achieve the required angular resolution, we used a detection system that may reconstruct the track of each incident particle, as well as each scattered particle. A schematic view of the experimental set-up is shown in Fig. 1. The upstream detection system consisted of two plastic scintillators (T1 and T2) and two low-pressure multiwire proportional chambers[6] (LPMWPC1 and LPMWPC2). An incident particle was identified by its time-of-flight between T1 and T2 and its energy loss was in T2. Then the incident angle and position were determined by the LPMWPCs. The latter had a position resolution smaller than 1 mm in the x- or y-directions, an active area of $70 \times 70\,\mathrm{mm}^2$ and a detection efficiency for He isotopes higher than 95%. The ^{9}Be target of 200 μm thickness and $30 \times 30\,\mathrm{mm}^2$ effective area was set down to the stream of LPMWPCs. Six telescopes (Tel1–6) (each of which consisted of a position sensitive silicon detector (PSSD)), a large-area Si detector and a CsI scintillation detector were installed on both sides of the beam line covering the angles of 8° – 19°, 26° – 37° to 42° – 55° in the laboratory system. Scattered particles were identified by the $\Delta E - E$ technique, an example of which is shown in Fig. 2. The PSSD position resolution is 2.6 mm in both the x- and y-directions.[7] The geometrical efficiency of the system was determined by a Monte Carlo simulation that takes into account the beam profiles and the geometry of the telescopes.

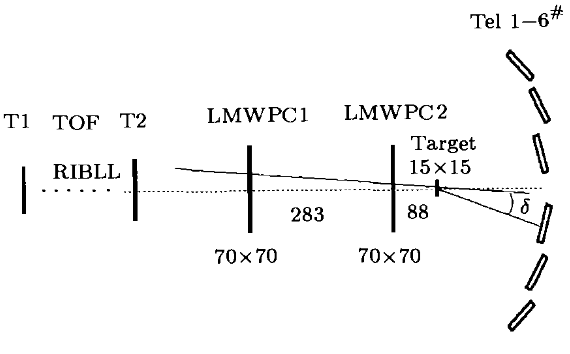

Fig. 1. Experimental set-up of the system.

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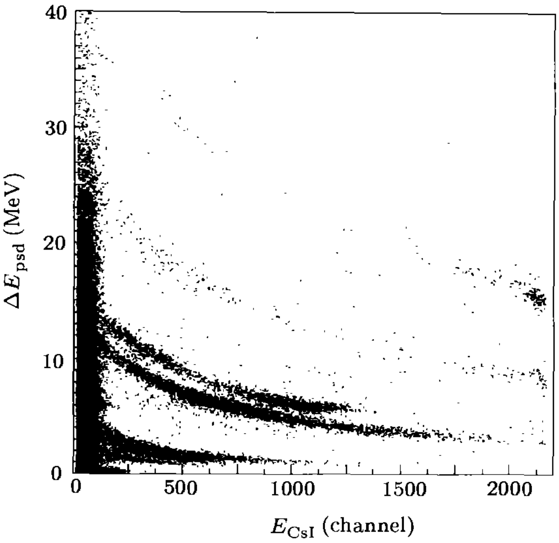

Fig. 2. Two-dimensional plot ($\Delta E_{\rm psd}$ versus $E_{\rm CsI}$) obtained with Tel3.

The analysis of trajectories consisted of a few steps. Firstly, the incident particle direction was determined as the straight line passing through the two LPMWPCs and tracked on to the target. Secondly, the direction of the scattered particle was determined as the straight line passing through the point of impact of the incident beam on the target and the position at PSSD. Thirdly, the scattering angle which was the angle between the above-defined incident and outgoing directions was calculated. The position resolutions and calibrations of the various detectors led to an error of the cm scattering angle in the forward direction not exceeding ±4°. The determination of the number of incident particles depended on the application of the scalars of LPMWPCs.[6]

Angular distributions for quasi-elastic scattering of ^{6}He from a ^{9}Be target measured in the present experiment are shown in Fig. 3. The indicated error bars are statistical only. The flattening of the structure of the angular distribution was a result of the use of a thick target, the limited angular resolution and the lack of separation between elastic and inelastic scattering.

The analysis of the scattering angular distribution was carried out in the framework of the conventional optical model by using the standard Woods–Saxon potential

$$U(r) = V_{\rm Coul}(r) - Vf_V(r) - {\rm i}Wf_W(r) \qquad (1)$$

where $f_V(r) = 1/(1+\exp[(r-R_V)/a_V])$ and $f_W(r) = 1/(1+\exp[(r-R_W)/a_W])$ with $R_V = r_V A_T^{1/3}$, $R_W = r_W A_T^{1/3}$, and $V_{\rm Coul}$ was the Coulomb potential of the uniformly charged sphere. The potential parameters V, W, r_V, r_W, a_V and a_W were adjusted to fit the experimental data. The results obtained are $V = 44.18\,{\rm MeV}$, $W = 39.76\,{\rm MeV}$, $r_V = 2.528\,{\rm fm}$, $r_W = 1.261\,{\rm fm}$, $a_V = 1.334\,{\rm fm}$, $a_W = 0.3114\,{\rm fm}$. The calculation is also shown in Fig. 3.

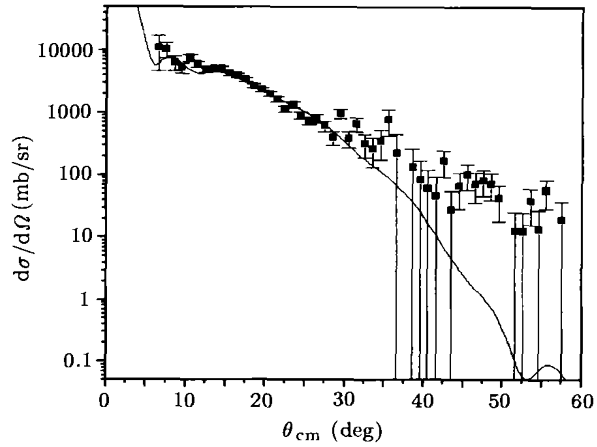

Fig. 3. Experimental data of angular distribution (squares) and optical model calculations (solid line) of ^{6}He elastic scattering.

In view of the optical potential parameters, relatively large r_V and a_V are necessary to reach the large cross section at small angles. This anomaly effect might be related to the exotic structure of ^{6}He.[8] Still, it is too early to draw any conclusion due to the lack of accuracy of the experimental data. In particular, data at smaller angles with high angular and statistical accuracy are needed to determine the real part of the optical potential. It is clear that the current results encourage more experimental effort to measure the angular distributions of the scattering and reaction of exotic nuclei.

In summary, we have developed a sophisticated detection system and have applied it, for the first time, to measure the elastic-scattering cross sections of unstable nuclei ^{6}He on a ^{9}Be target. Optical potentials were obtained by fitting the experimental data, which encourages more accurate and more complete measurements.

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