Measurement of Total Reaction Cross Section for Neutron-Rich Nucleus ^{11}Li on ^{28}Si Target at Medium Energy*

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Abstract The neutron-rich nucleus ^{11}Li is separated by the radioactive ion beam line RIBLL at HIRFL from the breakup of 50MeV/u ^{13}C on Be target. The total reaction cross sections for ^{11}Li at energies range from 25 to 45MeV/u on Si target have been measured by using the transmission method. The experimental data at high and low energies can be fitted well by Glauber model using two Gauss density distribution. The matter radius of ^{11}Li was also deduced.

Key words Glauber model, transmission method, total reaction cross section

1 Introduction

The nucleus near the drip line can be produced by radioactive ion beam equipments, so that research region was expanded along the isospin degree of freedom. The N/Z ratio for nuclei around the β stability line is between 1.0 to 1.5, while the single nucleon separation energy is about 6—8MeV and the radius is expressed to proportional to $A^{1/3}$. On the other hand for unstable nuclei, N/Z radio is between 0.6 to 4, single nucleon separation energy is 0—4MeV, and the matter distribution may be dispersed. This provides new opportunity for the study of nuclear structure.

In 1985, the interaction cross sections of some radioactive nuclei at high energies were measured by Tanihata at LBL. The interaction cross section of ^{11}Li show an exotic enhancement, which corresponds to the disperse neutron distribution of ^{11}Li, called neutron halo[1]. After this experiment many more halo nucleus were found, such as ^{6}He, ^{11}Be, ^{14}Be, ^{17}B, ^{19}B, ^{19}C etc. The proton halo nucleus ^{8}B was also identified. Experiments show that at medium energies the total reaction cross section is more sensitive to the tail region of nuclear matter distribution than that at high energies. The parameters of the nuclear matter distributions, including the root mean square (rms) radii, can be deduced from reaction cross section at different energies. The information about the exotic property of the nuclear structure could then be

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explored.

The ^{11}Li is treated as ^{9}Li+2n structure based on the analysis of the interaction cross section measured by the early experiments. The rms radii was deduced from this high energy data. Since the reaction cross section at medium energy is more sensitive to the tail region of the nuclear matter distribution, it is better to carry on experiment at medium energies to prove the nuclear radii for ^{11}Li.

We report here the total reaction cross section of ^{11}Li on Si target at 25—45MeV/u measured at the Radioactive Ion Beam Line in Lanzhou (RIBLL). The nuclear matter distribution as well as it's rms radii was deduced from the present experimental data together with the high energy experimental data through the Glauber model analysis.

2 Experimental setup and detection methods

The experiment was carried out at the RIBLL[2, 3]. The primary beams of ^{13}C at 60MeV/u with an intensity up to 50enA were produced by the Heavy Ion Research Facility in Lanzhou (HIRFL), bombarding a primary target of 4mm thick Be. The different type of ions can be separated by 1mm wedge degrader and magnetic rigidity of RIBLL.

Figure 1 shows the schematic view of experiment setup. The starting and stopping time of flight of particles were taken from the timing detector at T1, T2 of RIBLL. Each detector consists of a plastic scintillation film with ellipsoid focus on electron photomultiplier tube[4]. The time resolution of the detector is less than 200 ps. A collimator with 8mm diameter was placed at T2 to limit the beam spot on the following particle telescope. The telescope detector consists of seven Si semiconductor detectors and one CsI(Tl) stopping detector. The semiconductors had thickness of 1000, 700, 2000, 1000, 1000, 2000, 700μm, respectively, and effective area 150mm^2. The CsI(Tl) had thickness of 10mm and effective area 70mm×70mm. In addition, in front of the telescope detector a position sensitive Si detector (PSD) was used to provide position of incident particles. The detector had thickness 325μm and effective area 45mm×45mm.

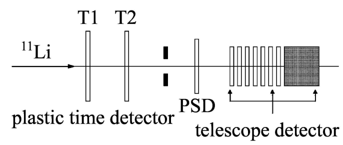

Fig. 1. Schematic view of the detection setup.

The incoming ^{11}Li particles passing through Si semiconductor detectors were stopped by CsI detector. Each of the frontal 6 Si detectors provided the ΔE signal and also played the role of the secondary Si target, for the following detectors in the telescope. The emergent particles were identified by ΔE-E method. The energy resolution of Si detector is less than 1%. The experimental data were saved in computer, and then analyzed offline.

3 Data analysis

Transmission method, also called beam attenuation method is independent of theoretic models. The total reaction cross section is expressed as:

$$\sigma_{\mathrm{R}} = \frac{1}{N_{\mathrm{t}}} \ln\left(\frac{N_0}{N_1}\right) , \qquad (1)$$

Where N_{t} is area particle density of the target, N_0 incident number of particles, and N_1 the remaining number of particles in the beam leaving the target. The total reaction cross section can be obtained by accurate measurement of the incoming and outgoing number of ^{11}Li particles before and after each layer of the Si target.

The incoming ^{11}Li can be selected by ΔE-TOF method. The ΔE_1-TOF spectrum of the incoming particles is showed in Fig. 2, in which ^{11}Li can be clearly selected and the number N_0 can be obtained. Similarly the outgoing particles N_1 without reaction can be obtained from the ΔE_2-E spectrum. This way the total reaction cross sections for 6 layers of Si target can be deduced. The experimental results are shown in Table 1. The errors include systematic error, statistic error and error from the way to select the outgoing particles. The systematic error is 2.9%, statistic error is negligible and other error is about 1.0%.

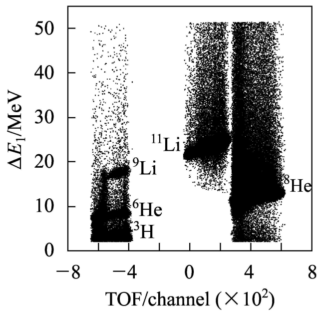

Fig. 2. ΔE_1-TOF spectrum for incoming particles.

Table 1. Measured $\sigma_{\rm t}$ for ^{11}Li on Si target.

$E_{\rm in}/({\rm MeV\cdot u^{-1}})$	$\sigma_{\rm t}$/mb
41.1±1.1	2276±95
39.2±0.8	2314±95
36.0±2.4	2362±95
32.3±1.3	2424±100
29.6±1.4	2450±100
25.0±3.2	2483±100

The theoretical calculation was carried out by the so called modified Glauber model[5—8]. The input of the model includes the matter distribution of the project and the target. The rms radius is defined by:

$$\langle r^2\rangle^{\frac{1}{2}}=\frac{\left(4\pi\int\limits_0^{+\infty}\rho(r)r^4{\rm d}r\right)^{\frac{1}{2}}}{\sqrt{A}}. \qquad (2)$$

We adopt the double- Gaussian distribution for ^{11}Li nucleus. By fitting the experimental data at high and medium energies, the proton and neutron distributions are obtained and are showed in Fig. 3. The rms radii of ^{11}Li is then deduced as (3.10±0.18)fm, which is in coincident with other results, such as 3.12(16)fm from Refs. [1,9], 3.53(6)fm from Refs. [10, 11] and 3.71(20)fm from Ref. [12].

The experiment data, including the data of the present experiment, data from Warner's experiment[13] and data at high energies are plotted in Fig. 4 together with Glauber model calculation. The calculation is in very good agreement with the experimental data. The obtained neutron matter distribution of ^{11}Li is a very dispersed one interpreted as a halo structure.

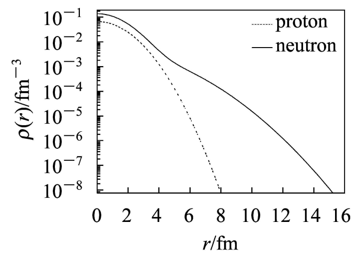

Fig. 3. Neutron and proton distributions for ^{11}Li.

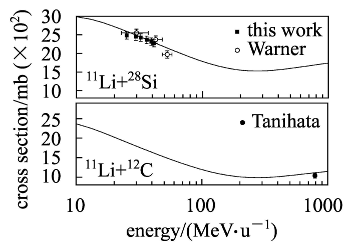

Fig. 4. Measured total reaction cross sections (dots) of the ^{11}Li on C target as a function of the incident energy together with the prediction of Glauber model (solid line).

4 Discussion

The total reaction cross section of ^{11}Li on Si target was measured at medium energies, and analyzed by Glauber model calculations together with data at high energies. The obtained ^{11}Li rms radius is (3.10±0.18)fm as deduced from the two Gaussian function distribution of the matter density.

The nuclear matter distribution of ^{11}Li is a very dispersed one, in consistent with a ^{9}Li+2n halo structure. The obtained rms radius for ^{11}Li is more reliable by simultaneously fitting the experimental data at different energies, compared to the previous results obtained for only one specific energy.

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中能区丰中子核^{11}Li的反应总截面的测量*

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摘要 利用HIRFL提供的50MeV/u的^{13}C束流轰击Be靶, 通过RIBLL选择出放射性核素^{11}Li. 实验采用透射法测量了25—45MeV/u的^{11}Li在^{28}Si靶上的反应总截面. 采用双参数Gauss密度分布形式, 利用Glauber模型很好地拟合了高能和中能区的^{11}Li实验数据, 并从密度分布中提取了核的物质均方根半径.

关键词 Glauber模型 透射法 反应总截面

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