CPC(HEP & NP), 2010, **34**(9): 1469–1471 Chinese Physics C Vol. 34, No. 9, Sep., 2010

A revisit to the neutron skin thickness of neutron-rich nuclei in the statistical abrasion ablation model *

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Abstract The cross sections of the fragments produced in the projectile fragmentation reactions of the even calcium isotopes from A=36 to A=52 are calculated using the statistical abrasion ablation model. The neutron skin thickness are studied by investigating the fragments isotopic cross section distributions. The neutron-skin thicknesses of the calcium isotopes have a good linear correlation to the peak positions of their fragment isotopic cross section distributions. The correlation between the neutron skin thickness and the neutron density distributions of ^{48}Ca is investigated by introducing a parameter to adjust the diffuseness parameter in the fermi-type density distribution.

Key words neutron rich nucleus, neutron skin thickness, projectile fragmentation

PACS 25.70.Mn, 21.65.Cd

1 Introduction

The operation of the new generation of radioactive nuclear beam (RNB) facilities, which are located in RIKEN, FAIR, CSR and FRIB, etc., will greatly promote the research in the properties of the very neutron/proton asymmetric nuclei. The new generation of RNB facilities provide more kinds and better quality of RNB in the laboratory. This make the production of more neutron-rich and proton-rich nuclei become easier and push the drip lines further from the β-stability line [1, 2]. Neutron-rich nucleus will form a neutron skin structure. The neutron skin thickness is defined as the difference between the neutron and proton RMS radii: $\delta_{\rm np} \equiv <r_{\rm n}^2>^{1/2} - <r_{\rm p}^2>^{1/2})$. $\delta_{\rm np}$ depends on the balance between various aspects of the nuclear force. The actual proton and neutron density distributions are determined by the balance between the isospin asymmetry and Coulomb force. It is found that $\delta_{\rm np}$ is related to a constraint on the EOS of neutron. This constraint is important for extrapolating the EOS to a high density case, and thereby finding its use for the properties of neutron stars [3–6].

There are some methods used to determine the neutron skin thickness of a neutron-rich nucleus [5–14]. In a previous work [7], it is found that the neutron skin thickness of the neutron-rich nucleus has a good linear correlation to the neutron-removal cross section ($\sigma_{\rm nabr}$) in the projectile fragmentation reactions at the intermediate energy within the framework of the statistical abrasion ablation (SAA) model. It is suggested to use $\sigma_{\rm nabr}$ as an experimental observable to extract the neutron skin thickness of the neutron-rich nucleus. In a recent work [8], it is suggest to use neutron/proton ratio of nucleon emissions as a probe of neutron skin in framework of the Isospin-Dependent Quantum Molecular Dynamics (IQMD) model. These effort to combine the experimental observable to $\delta_{\rm np}$ of the neutron-rich nucleus is helpful to study the neutron distribution of neutron-rich nucleus. It is found that isospin effect in the projectile fragmentation of asymmetric neutron-rich matter will influence the fragment isotopic cross section distributions [15–17]. In this article, the correlation between $\delta_{\rm np}$ of the calcium isotopes and the isospin effect in the fragment isotopic cross section distributions of their

Received 19 January 2010

* Supported by National Science Foundation of China (10905017, 10775168), Shanghai Development Foundation for Science and Technology (06QA14062), Program for Innovative Research Team (in Science and Technology) in University of Henan Province, China (2010IRTSTHN002) and the State Key Program of Basic Research of China (2007CB815004)

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projectile fragmentation will be studied.

2 The calculations

Using the SAA model [15–20], the fragments produced in the 80 A MeV odd calcium isotopes $^{36-52}$Ca+^{12}C projectile fragmentation are calculated. In the calculation, the free space nucleus-nucleus cross sections [21] and the Fermi-type density distributions [7, 22] are adopted:

$$\rho_i(r)=\frac{\rho_i^0}{1+\exp\left(\dfrac{r-C_i}{f_i t_i/4.4}\right)}, i=\mathrm{n},\mathrm{p}, \tag{1}$$

where f_i is a parameter added to adjust the diffuseness parameters. In the calculations, f_i is kept to be 1 and the density distributions are just the well known Fermi-type density distribution [22]. δ_{np} for each projectile nucleus is calculated as the distributions in Eq. (1).

3 Results and discussion

After plotting the cross sections of the fragments as the function of their mass number A, the fragments isotopic cross section distributions are fitted using the Gaussian function. The peak positions of the fragment isotopic cross section are obtained. When investigating the correlation between the peak position and the charge numbers of the fragments (Z_{frag}), a good linear correlation between the peak position and Z_{frag} are found, as can be seen in Fig. 1. The linear correlations between the peak positions and Z_{frag} are fitted by the linear function $y=a+b\times x$ and the slopes b and the intercepts a are obtained.

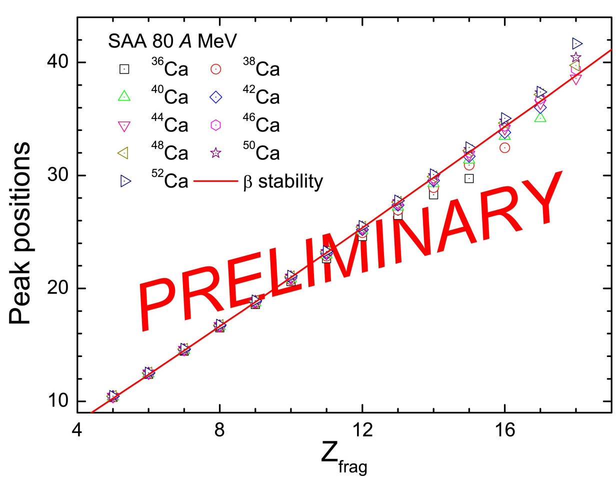

Fig. 1. (color online). The correlation between the peak positions of the fragment isotopic cross section distributions and the Z_{frag}.

When studying the correlation between the slopes b and δ_{np} of the projectile nuclei, as can be seen in Fig. 2, it is found that the correlation between b and δ_{np} of these calcium isotopes is linear. The result of linear fit is $y=2.1639(\pm0.0017)+1.2179(\pm0.0483)\cdot x$, with an adjusted R-square 0.9919. In Fig. 2, the error bars are from the results of linear fit.

The linear correlation between b and δ_{np} help us to think if we can extract δ_{np} from b. But it is not clear wether b is sensitive to the change of neutron density distribution. To understand this, following the method in Ref. [7], we change f_i in Eq. (1) to change the diffuseness of neutron density distribution and hence the neutron skin thickness.

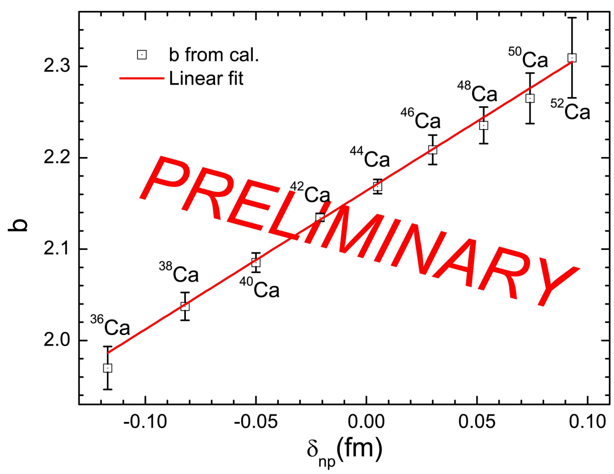

Fig. 2. (color online). The correlation between b and the neutron skin thickness (δ_{np}) of projectile nuclei.

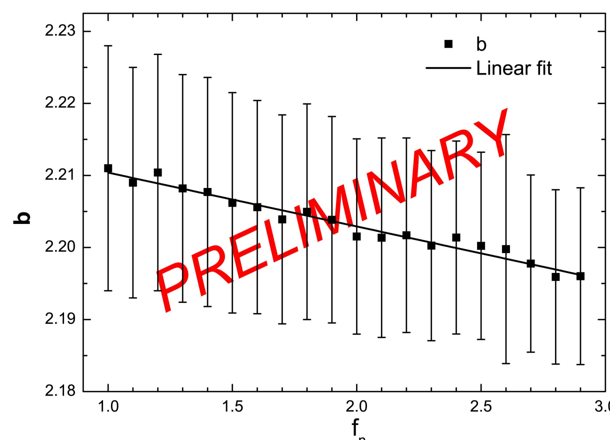

Fig. 3. (color online). The correlation between b and f_{n} of the neutron density distribution of ^{48}Ca. The line is the result of linear fit.

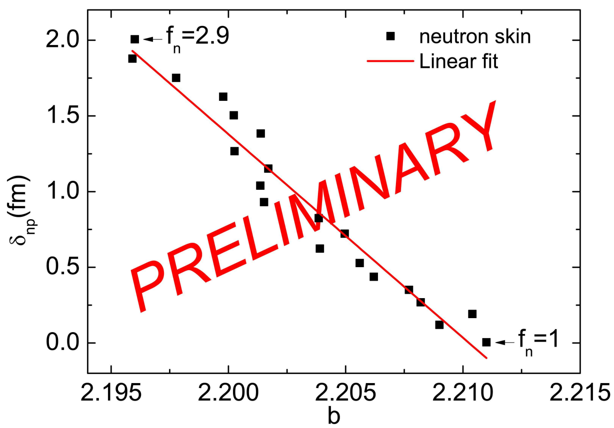

Fig. 4. (color online). The correlation between b and $f_{\rm n}$ of the neutron density distribution of ^{48}Ca. The line is the result of linear fit.

The correlation between b and $f_{\rm n}$ of ^{48}Ca is plotted in Fig. 3. b decreases slowly as $f_{\rm n}$ increases. The result of linear fit is $y = 2.2179(\pm0.0007) - 0.00747(\pm0.0003)\cdot x$. To see if b is sensitive to the change of $f_{\rm n}$, we plotted the correlation between b and $f_{\rm n}$ in Fig. 4. When $f_{\rm n}$ is increased from 1 to 2.9, b decreases almost linearly. The result of linear fit is $y=297.036(\pm15.611)-134.389(\pm7.085)\cdot x$. But the difference between b from $f_{\rm n}$=1.0 to $f_{\rm n}$=2.9 is not very big.

4 Summary

The fragments isotopic cross section distributions of even $^{36-52}$Ca projectile fragmentation is analyzed. The peak positions have a good linear correlation to $Z_{\rm frag}$. The fitted slopes between the peak positions and $Z_{\rm frag}$ are found to have good linear correlation to $\delta_{\rm np}$ of the projectile nuclei. To see if b is sensitive to $\delta_{\rm np}$, we change a parameter $f_{\rm n}$ to adjust the diffuseness parameter of the neutron density distribution of ^{48}Ca. b is found to decrease slowly as $f_{\rm n}$ increases.

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