Isospin effect of projectile fragment yields*

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Abstract Isospin asymmetry is very important in the nuclear equation of state (EOS), isotope yield from the projectile fragments can give information of the reaction process. In this paper projectile fragment yields are measured in the collision ^{36,40}Ar+^{64}Ni at incident energy 50 MeV/u with different isospin asymmetry project ^{36,40}Ar, data analysis, particle identification and event selection are described. Isotope yields are compared in these two reactions, and are also compared with the empirical parametrization of fragmentation cross-section calculated by EPAX.

Key words isospin, projectile fragment yields

PACS 25.70.-z, 25.70.Mn, 29.85.Fj

1 Introduction

Isospin degree plays an important role in the nuclear reaction, particularly recent years with the collisions induced by exotic radioactive beam or very isospin asymmetry system, isospin effect were paid much attention for reaction products. For the isospin asymmetry nuclei, the symmetry energy term in the equation of state (EOS) becomes more important than in the collisions induced by nuclei near the stable line. Isospin composition observation of reaction products is one common used method, isospin effect of products can give us much information in the reaction process[1—3].

Projectile fragmentation is an simple reaction process, which can give us direct information of the dynamical isospin transportation. Recently isoscaling phenomena reveals that in two isospin different reaction systems, their isotope yield ratio shows exponential function of proton number Z and neutron number N, which can be expressed in an simple mode[4, 5]:

Received 8 July 2008

* Supported by National Natural Science Foundation of China (10405033, 10505026), Knowledge Innovation Project of Chinese Academy of Sciences (KJXC3-SYW-N2), Major State Basic Research Development Program in China (2007CB815004) and National Defense Scientific Innovation Foundation of Chinese Academy of Sciences (CXJJ-216)

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$$R_{21}(Z,N)=\frac{Y_2(N,Z)}{Y_1(Z,N)}=C\exp(\alpha N+\beta Z) \quad (1)$$

where α and β are two scaling parameters and C is an overall normalization constant. This scaling behavior has been observed in a very broad range of reactions[6—15] and theoretical calculations[16—28].

We aim to investigate the projectile fragmentation process with isospin different projects, to study the isospin effect of isotope yield dependence on incident project isospin, and the difference of isoscaling behavior between light fragments and heavy fragments.

2 Experimental setup

The fragmentation experiments were carried out using the Separate Sector Cyclotron (SSC, K=450) at Heavy Ion Research Facility of Lanzhou (HIRFL) in Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS). Primary beams ^{36}Ar,^{40}Ar isotopes with incident energy 50 MeV/nucleon were produced, and target we used is isotope target ^{64}Ni with thickness of 0.89 mg/cm^2 foil. Emitted fragments were collected and identified using Radioactive Ion Beam Line in Lanzhou (RIBLL) [29] as a separator. Fig. 1 shows the experimental setup and RIBLL fragments separator. RIBLL was designed to be a double achromatic anti-symmetry spectrometer with a total length of 35 m, it has three focal points (F0, F2 and F4) and two focal planes (F1, F3). And it consists of four large dipoles, and each dipole has a radius of 3 m and a bending angle of 57.3°. Maximum magnetic rigidity of the whole system is 4.2 Tm with an accuracy $\Delta B\rho/B\rho<6\times10^{-4}$. A detailed description of the RIBLL can be found in Ref. [29]. The momentum opening, dp/p, was limited by using a slit in the dispersive image of spectrometer (labeled in F1). For both target ^{36,40}Ar, several magnetic rigidities were set.

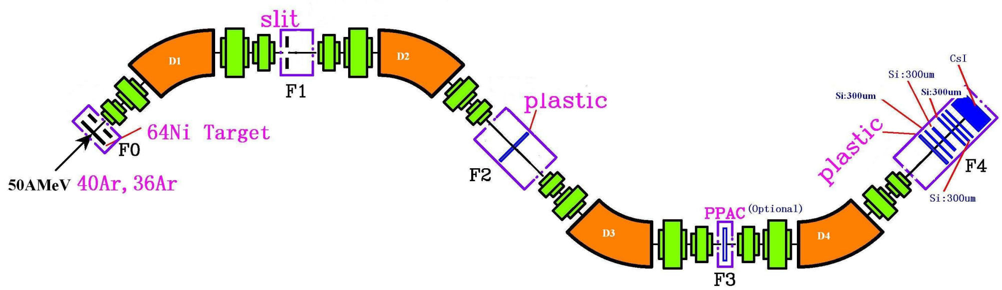

Fig. 1. RIBLL fragments separator and experimental setup. Focal points are F0, F2 and F4, focal planes are F1 and F3 respectively. target is placed in F0, slit is located in F1. Two plastic time detectors are placed in F2 and F4 respectively. The ΔE detector is put in F4 after the plastic time detector.

All fragments produced in our study were fully stripped of electrons. Hence they could be identified using the $B\rho$-TOF-ΔE method, on an event-by-event basis. The magnetic rigidity $B\rho$ was determined from the magnetic setting of RIBLL fragment separator. Time of Flight (ToF) was measured with plastic scintillator (SCIN) placed at F2 and F4 respectively, only the second half of RIBLL was used to measure the ToF. Energy loss ΔE was measured by a 300 μm thickness silicon detector with sensitive area of 5 cm × 5 cm located in the Focal point F4 after SCIN, both SCINs and silicons are shown in Fig. 1. Position sensitive Parallel Plate Avalanche Counters (PPAC) in F3 was put to monitor particles transmiting through the F3 center in experiment. Three 300 μm silicon detectors were put in F4 after the plastic time detector, the fist one was used to generate a ΔE signal, others were used to collect paticle residue energy. After silicons, a crystal CSI detector was placed to stop all the particle and total energy.

Fragments identification (PID) and calibration are done by special isotope series of A/Z = 2 with magnetic setting $B\rho$ = 2.27 Tm and some special isotopes with same A/Z values. A typical raw experimental particle identification pattern is shown in Fig. 2, the example provided is for the ^{36}Ar+^{64}Ni reaction at $B\rho$=2.355 Tm. We can see a clear separation of individual group events. The nearly vertical line located near ToF channel 160 ns is the line of fragments with N = Z. Calibrated PID spectra of fragment charge number Z vs neutron excess N-Z was shown in Fig. 3, all fragments are clearly separated in all our experiments.

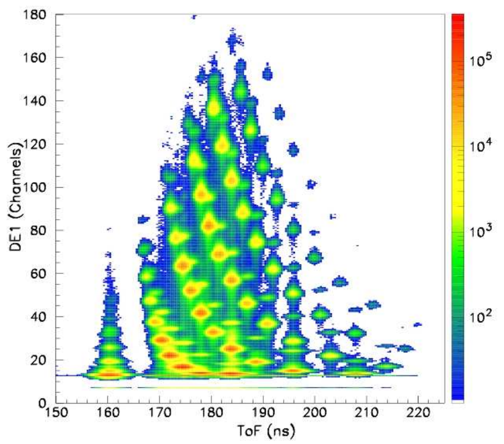

Fig. 2. Raw particle identification spectrum for ^{36}Ar+^{64}Ni reaction at $B\rho=2.355$ Tm.

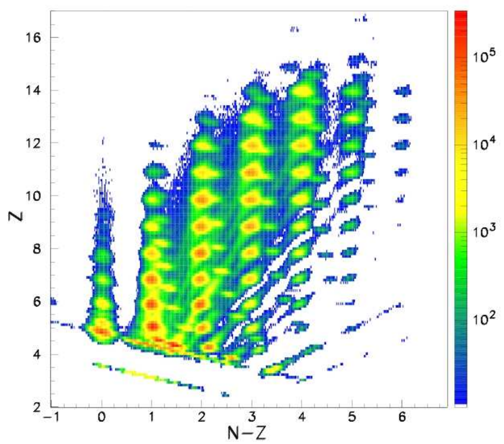

Fig. 3. Calibrated particle identification spectrum for ^{36}Ar +^{64} Ni reaction at $B\rho$ = 2.355 Tm.

3 Isotope yields and comparison with EPAX

There are many background events in particle identification profiles Fig. 2 and Fig. 3, especially in ^{40}Ar +^{64} Ni reaction, where a lots scattering events are detected as well as many primary beam scattering events. Thus several windows are created in event selection process to choose the real event, including windows in $Z\%(N-Z)$ scattering figure of Fig. 3, and windows on 2-dimensional $\Delta E1\%\Delta E2$ scattering figure. In Fig. 4 relative isotope yields are printed for magnetic rigidity setting $B\rho=2.325$ Tm in two reactions ^{36,40}Ar+^{64}Ni, slit in F1 for this magnetic rigidity setting along horizontal direction is ±5 cm, corresponding to momentum acceptance $\Delta p/p=0.49\%$, slit in F1 along vertical direction is set to its maximum values ±40 cm. Isotope yield comparison in two reactions are plotted in Fig. 4, isotopes are labels on the frame, from light fragments B to heavy elements Al, the symbol representation and the EPAX predictions are demonstrated in figure bottom. Isotope yields in two reactions show difference clearly, proton-rich isotopes in proton-rich project reaction have higher yields than proton-deficient project reaction, while neutron-rich isotopes in neutron-rich project reaction have higher yields than neutron-deficient project reaction.

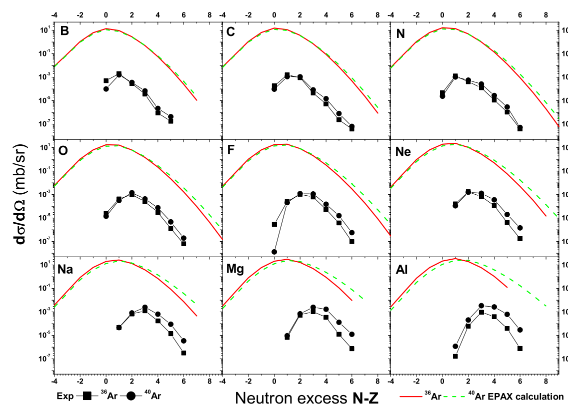

Fig. 4. Isotope yield comparison in two reactions ^{36,40}Ar+^{64}Ni at magnetic rigidity $B\rho=$ 2.325 Tm and EPAX predictions, the symbol representations are defined in the figure bottom as well as the EPAX predictions.

EPAX is an empirical parametrization of fragmentation cross sections calculation program, its basic characteristics, formula and parameter description can be found in Refs. [30, 31]. In Fig. 4 solid and dash lines are projectile fragmentation product cross section calculated with EPAX without considering the RIBLL transmission rate. In general EPAX can describe the fragmentation of medium-to heavy-mass projectiles, nucleon-pickup cross sections are not included, thus it does not calculate pickup cross-sections and the description of the light fragments (with $A<0.5A_{\rm P}$) are generally not as good as the predictions for fragments near the projectiles because light fragments may be produced in more central collisions from other reaction mechanism such as multifragmentation. In our calculation without considering RIBLL transmission rate, both experiment and EPAX prediction show isospin dependent isotope cross sections, though the predict cross section by EPAX are much larger than measured ones. Magnetic rigidity and slit settings cut most of the fragments yield to narrow momentum range, thus RIBLL transmission rate should be considered, which will correct measured isotope cross section. We also need to consider the absolute cross section normalization, angular distribution correction before we make a reasonable comparison with EPAX.

Some of our authors acknowledge staffs of HIRFL accelerator for providing ^{36,40}*Ar beams in our experiment.*

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