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Detector system for the angular distribution measurement of $^{12}C + {}^{12}C$ elastic scattering at 200–400*A* MeV

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ABSTRACT

To obtain the angular distributions of $^{12}C + {}^{12}C$ elastic scatterings with the incident energies of 200–400*A* MeV for the study of three-body forces, a detector system was constructed at second Radioactive Ion Beam Line in Lanzhou (RIBLL2) of Institute of Modern Physics (IMP). This system was composed of five plastic scintillation detectors with two read-outs for each detector, a Multi Wire Proportional Chamber (MWPC) and a 4×4 CsI(Tl) array. The ^{12}C beam with the incident energy of 200*A* MeV on a natural carbon target was used to test this detector system. It is found that the plastic scintillation detector can give the good energy loss (ΔE) and time of flight (TOF) signals, it can also reflect the position information of scattered ^{12}C events. MWPC can precisely provide the trajectories of scattered particles. This system has a very good particle identification ability and can clearly distinguish the scattered ^{12}C particles from the fragments. It can be used for the study of the three-body forces effect for high energy heavy-ion scattering.

1. Introduction

The role of three-body force in complex nuclear systems is one of the key issues not only in nuclear physics but also in nuclear astrophysics relevant to high-density nuclear matter in neutron stars and supernova explosions [1]. The binding energy per nucleon (16 MeV) for nuclear matter at the saturation density $\rho_0 \approx 0.17\ \mathrm{fm}^{-3}$ cannot be reproduced if only two-body nucleon–nucleon (NN) interactions are taken into account [1]. To obtain an acceptable saturation curve and incompressibility, the contributions of three-body force must be considered. This demonstrates that the three-body force is important in high-density nuclear matter. The three-body force is expected to show repulsive effects at high-density region.

Elastic scattering is one of the general nuclear reactions induced by nucleons and composite-nucleus projectiles impinging on different target nuclei. This reaction has provided valuable information about nuclear many-body dynamics. Recently, it has become possible to accurately describe the elastic scattering of a nucleon off a nucleus for a wide range of beam energies using the single-folding model with effective NN interactions. For example, the folding model potential with complex G-matrix interactions was used to describe proton elastic scattering with energies up to 400 MeV [2–6]. Optical potentials below 100 MeV are attractive and change to repulsive when the beam energy increases. This is a reflection of the hard core in the NN interactions. In heavy-ion scattering, a similar situation is expected from the double-folding model (DFM) based on the complex G-matrix interaction. In high energy heavy-ion collisions, the densities of the projectile and target nuclei overlap while collision, thus the density may be much higher than the normal density. Therefore, the G-matrix would be modified depending on the density.

Recently, Furumoto et al. developed a folding model with complex G-matrix interaction, called the CEG07 [6], derived from the ESC04 (Extended-Soft-Core) model [7,8] with additional three-body force which is composed of three-body attraction (TBA) and three-body repulsion (TBR). They applied the DFM to high energy heavy-ion scattering at $E/A = 100$–400 MeV [9] and to the evaluation of the global optical potentials of nucleus–nucleus systems, including neutron- and proton-rich nuclei in the energy range of up to 400*A* MeV. It is shown that the diffraction oscillation

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changes drastically with increasing incident energy. The angular distributions thus provide a means to distinguish the different contributions of three-body force.

However, the above mentioned studies were conducted without any experimental data. A serial of experiments aims to confirm the effects of three-body force in heavy-ion collisions at high energies. The elastic and inelastic angular distributions of $^{12}C + {}^{12}C$ scattering with an incident energy of 100*A* MeV have been determined using the ring cyclotron in Research Center for Nuclear Physics (RCNP) at Osaka University [10]. The differential cross sections of the ground state ($0_1{}^+$), various excited states including the 4.44 MeV ($2_1{}^+$) state, and the sum of the 7.65 MeV ($0_2{}^+$) state, the 9.64 MeV ($3_1{}^-$) state and the simultaneous excitation to 4.44 MeV, were precisely obtained. The present data have shown clearly the importance of repulsive three-body force in high energy heavy-ion collisions. It thus experimentally provides the first discussion of the three-body force. At higher incident energies (200*A*–400*A* MeV), the experiment may be able to provide clearer experimental grounds for the discrimination of interaction models and important roles of three-body force.

The angular distributions of $^{12}C + {}^{12}C$ elastic scatterings with the incident energies of 200–400*A* MeV will be measured in near future. The angular distributions will cover 1.0–5.0° in laboratory frame with an angular resolution of 0.2°. The detector system was tested at the second Radioactive Ion Beam Line in Lanzhou (RIBLL2) of Institute of Modern Physics (IMP) with an incident energy of 200*A* MeV.

2. Experimental setup

To obtain the angular distribution of elastic scattering, the particle identification method, position sensitive detector and energy measurement detector have to be used. Therefore, in this experiment the detector system consists of five plastic scintillation detectors with two read-outs for each detector, a multi wire proportional chamber (MWPC) and a 4×4 CsI(Tl) array. The schematic view of the detector system used is shown in Fig. 1. The ^{12}C beams with the incident energy of 200*A* MeV hit on a strip natural carbon target with a width of 5 mm and a thickness of 2 mm, which is placed in the small target chamber. Then the scattered particles go through a vacuum scattering chamber with a length of 2 m which connects with the small target chamber. When the scattered particles go out the scattering chamber, they enter into the atmosphere. At the exit of scattering chamber (T1) two plastic scintillation detectors with two read-outs for each one are paralleled. At T2 which is about 1 m downstream of T1, three plastic scintillation detectors with two read-outs for each one are paralleled. The thicknesses of the plastic scintillators (EJ200) are 3 mm and 5 mm for T1 and T2 detectors, respectively. The MWPC before and close to three plastic scintillation detectors is used to give the position information of scattered particles. It is composed of *X* plane (horizontal position), *Y* plane (vertical position), and *U* plane with 45° tilted with respect to *X* and *Y* planes. The span between every two wires is 2 mm for *X* and *Y* planes. After three plastic scintillation detectors, an array of CsI(Tl) crystals with 4×4 matrix was used as E detector to stop the scattered ^{12}C particles. The volume of each crystal is $70 \times 70 \times 250$ (t) mm^3 and the thickness is enough to stop the 400*A* MeV ^{12}C particles. The ID number of each crystal during the experiment is shown in lower and right part of Fig. 1. The primary ^{12}C beam after target was transported to the beam dump. The diameter of the beam pipe is made as small as possible based on the beam size in order to make the angular range larger. The plastic scintillation detectors at T1 (T11 and T12) and T2 (T21, T22 and T23) were placed downstream of target with distances of 2 m and 3 m, respectively, and cover the same scattering angles, respectively. The time of flight (TOF) and deposited energy (ΔE) can be obtained through the time and energy information of the plastic scintillation detectors. The correlation between TOF and ΔE can be obtained. Different combinations of plastic scintillation detectors can be used for the trigger signal of data acquisition system at different angular ranges to obtain enough statistics.

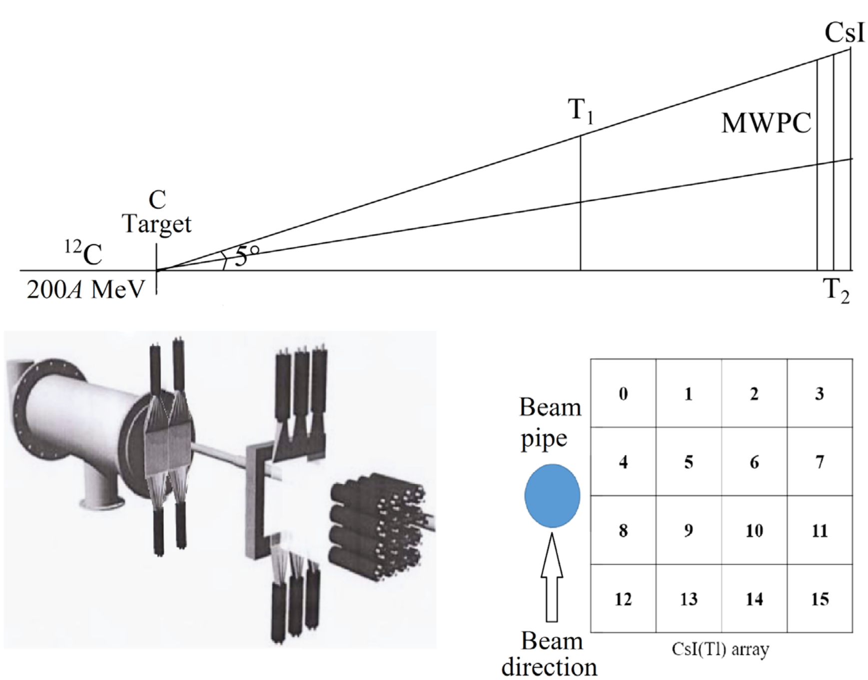

Fig. 1. Schematic view of the detector system used in the testing experiment. The upper part shows the detector setups. The lower and left part represents the configuration of detector system. The lower and right part shows the schematic view of 4×4 CsI(Tl) array. The geometry of the plastic scintillation detectors at T1 and T2 are 100 mm (horizontal) $\times$ 200 mm (vertical) and 100 mm (horizontal) $\times$ 300 mm (vertical), respectively. The MWPC is about 320 mm $\times$ 320 mm.