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LIGHT FRAGMENTS PRODUCTION AND ISOSPIN DEPENDENCES IN Sn+Ni AND Sn+Al CENTRAL COLLISIONS AT 25 MeV/A AND 35 MeV/A FROM REVERSE/ISOSPIN EXPERIMENTS*

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This paper presents the physical analysis results for the following reactions: ^{124}Sn+^{64}Ni, ^{124}Sn+^{27}Al, ^{124}Sn+^{58}Ni at 35 MeV/A and 25 MeV/A. The main goal of this studies was to find observables sensitive to isospin effects and to present the similarities/differences between the systems characterised by various charge asymmetry factor, defined as $I = (N-Z)/A$. Theoretical simulations based on the Quantum Molecular Dynamics (QMD) model have been performed in order to compare them with the results of the analysis of experimental data. The first phase of the reaction was carried out with the code CHIMERA [1]. The sequential decay of hot fragments was simulated by the code COOLER [2]. The conclusions are as follows: there are observables sensitive to the isospin of the system, such as the Light Charged Particles (LCP) emission and their sensitivity is demonstrated more prominently in the analysis of central collisions at 35 MeV/A. The theoretical calculations do not reproduce these relations well.

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1. Introduction

The data were collected in two experimental campaigns REVERSE 2000 and ISOSPIN 2003 in Istituto Nazionale di Fisica Nucleare, Laboratorio Nazionale del Sud (INFN–LNS) in Catania (Italy). The aim of the project was to explore the behaviour of the nuclear matter EOS by studying heavy ion collisions at intermediate energies and the influence of the isospin degree of freedom on the reaction mechanism. The investigated systems are very interesting from the isospin dependences point of view since the charge asymmetry factor $I = (N - Z)/A$ accounts 0.170 for ^{124}Sn+^{64}Ni, 0.165 for ^{124}Sn+^{27}Al and 0.142 for ^{124}Sn + ^{58}Ni. If the isospin does not influence the reaction mechanism, similar results for systems ^{124}Sn + ^{64}Ni and ^{124}Sn + ^{58}Ni might be expected, since there are no reasons to observe the differences from the kinematical point of view. However, if similar results will be noticed for ^{124}Sn + ^{64}Ni and ^{124}Sn+^{27}Al, it may be explained as the influence of the isospin degree of freedom on the reaction mechanism, since the charge asymmetry factors of these systems are almost equal.

2. The experimental set up

Heavy ion studies at intermediate energies require experimental devices with particular features and performances. Charged fragments produced in reactions from REVERSE/ISOSPIN projects were detected in the 4π multidetector CHIMERA (Charged Heavy Ion Mass and Energy Resolving Array), placed in the INFN–LNS in Catania (Italy). It is a set of 1192 $\Delta E - E$ telescopes arranged in 35 rings in a cylindrical geometry along the beam axis direction. The forward part of the device, covering the polar angles from

1° to 30° is made of 688 modules, assembled in 18 rings, grouped in couples and supported by 9 wheels, centred on the beam axis. The second block, covering the polar angle from 30° to 176° is made of 504 modules, grouped in 17 rings, assembled in such a way, to compose a sphere of 40 cm in radius. The target is placed in the middle of the sphere. Every telescope consists of thin a silicon detector and a caesium-iodide crystal CsI(Tl), coupled to a photodiode. For more details see [3–5].

3. The selection of central collisions

It is well known, that the impact parameter is an immeasurable observable in the experiment hence the observable related to the impact parameter (known as the impact parameter estimator) must be determined. In Fig. 1 the relation predicted for $^{124}\mathrm{Sn}+^{64}\mathrm{Ni}$ at 35 MeV/A by QMD model, between the impact parameter and several impact parameter estimators (the heaviest fragment velocity Fig. 1(a), the total transverse energy Fig. 1(b), multiplicity Fig. 1(c)) is presented. It is clearly visible that chosen impact parameter estimators are strongly corelated with the violence of the collision. The observed reaction characteristics are very similar in these three sorting procedures. The results presented in this paper are relative to the $V_{Z_{\mathrm{MAX}}}^{\mathrm{CM}}/V_p^{\mathrm{CM}}$ estimator, which demonstrates the best sensitivity to the impact parameter. The next step of our analysis was to determine the respective ranges of the chosen impact parameter estimator, in which the collision may be considered as peripheral, semi-peripheral or central, what is shown in Fig. 2. The most violent collisions would be selected under condition: $V_{Z_{\mathrm{MAX}}}^{\mathrm{CM}}/V_p^{\mathrm{CM}} \leq 0.4$.

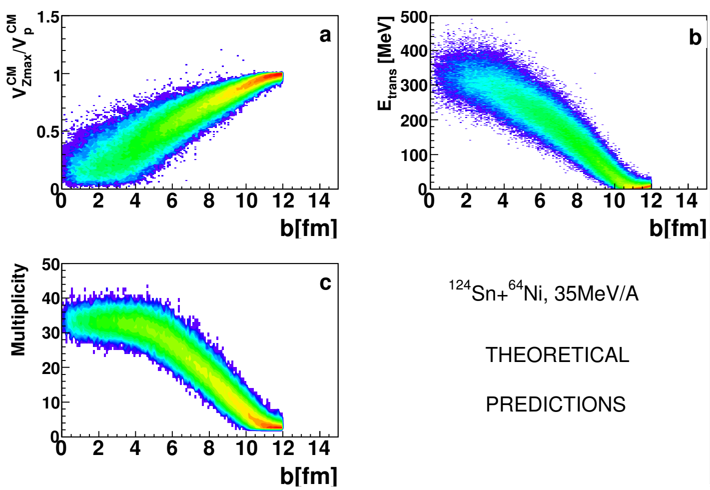

Fig. 1. The relation between the impact parameter and chosen impact parameter estimators predicted by theoretical model for $^{124}\mathrm{Sn}+^{64}\mathrm{Ni}$ at 35 MeV/A.

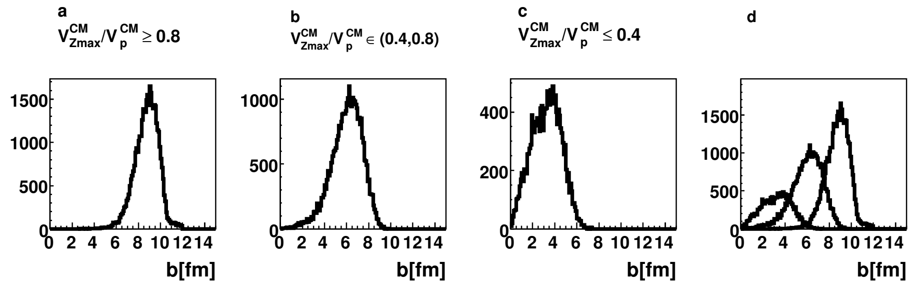

Fig. 2. Impact parameter distribution in three bins of normalised the heaviest fragment velocity in CM frame (chosen impact parameter estimator). CHIMERA+COOLER predictions filtered by experimental conditions for $^{124}\mathrm{Sn} + ^{64}\mathrm{Ni}$ at 35 MeV/A.

Nevertheless according to the simulations, events selected under this condition would be characterised by the impact parameter up to 6 fm (Fig. 2(c)). Hence, we applied the following method: for events, which fulfilled the condition: $V_{Z_{\mathrm{MAX}}}^{\mathrm{CM}}/V_p^{\mathrm{CM}} \leq 0.4$, the random number was generated in the range from 0 to 6 according to predefined distribution shown in Fig. 2(c). This generated value will be considered as reconstructed impact parameter b_{rec} and events with $b_{\mathrm{rec}} \leq 3$, would be treated as central collisions in our further studies. With the use of this method we assigned the impact parameter to all experimental events, even to those for which $V_{Z_{\mathrm{MAX}}}^{\mathrm{CM}}/V_p^{\mathrm{CM}} \geq 0.8$ and $V_{Z_{\mathrm{MAX}}}^{\mathrm{CM}}/V_p^{\mathrm{CM}} \in (0.4, 0.8)$, by generating the random numbers according to respective distributions shown in Fig. 2(a) and 2(b). For each system, the particular theoretical impact parameter distributions were generated separately.

4. The isospin dependences

The isospin dependences were studied in the simple, experimental observables, *i.e.* the angular distributions of light fragments emitted in central collisions, as shown in Fig. 3. The left panels represent the results of experimental data analysis and the right ones the theoretical simulations. In the experiment, similarities in fragment yields are especially visible between $^{124}\mathrm{Sn} + ^{64}\mathrm{Ni}$ and $^{124}\mathrm{Sn}+^{27}\mathrm{Al}$ systems at 35 MeV/A. It is noteworthy that these systems are characterised by a similar value of the charge asymmetry factor. It indicates that the fragments production depends more on the isospin of the system than on its size. Theoretical simulations in turn point to the similarities between $^{124}\mathrm{Sn} + ^{64}\mathrm{Ni}$ and $^{124}\mathrm{Sn} + ^{58}\mathrm{Ni}$. The emission of particles in central collisions at 25 MeV/A does not demonstrate any isospin dependences and is well described by the model. The contribution to the presented observables originates from all emission sources, *i.e.*, Projectile Like

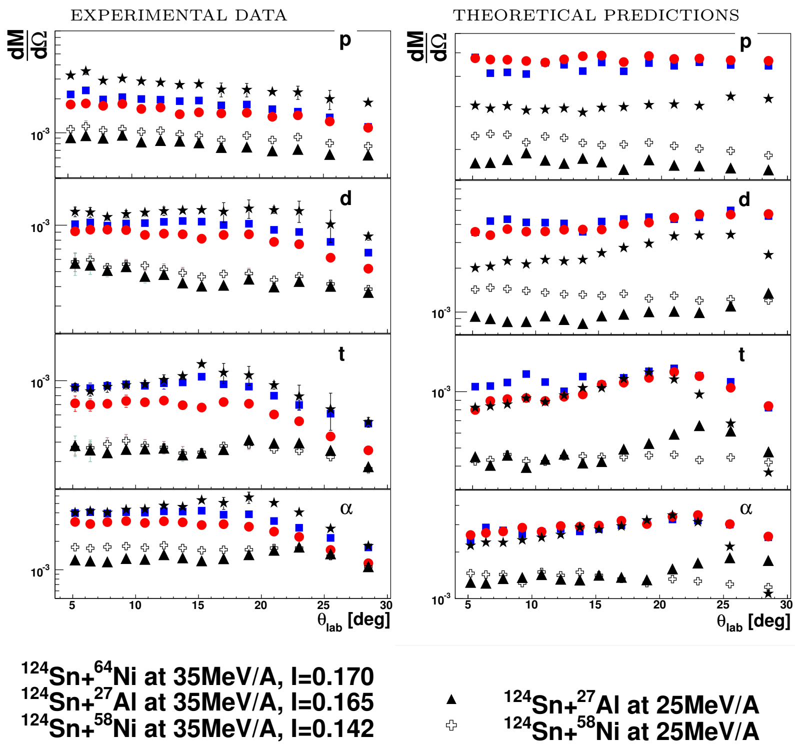

Fig. 3. Angular distributions of emitted LCPs in central collisions, experimental data (left panels), theoretical predictions (right panels).

Fragment source (PLF), Target Like Fragment source (TLF) and Nucleon–Nucleon source (NN), known also as Intermediate Velocity Source (IVS). Hence, we focused on the analysis of the central collisions and the isospin dependences present in the properties of the emission sources. Assuming the fragment contribution from three emission sources, the moving source fit was done on observed LCPs energy spectra, which provided four source parameters: multiplicity, temperature, velocity and Coulomb barrier. The procedure allowed us to compare the source properties of systems. In Fig. 4 the multiplicities of proton, deuteron, tritons and α particles from the NN source are plotted as a function of the charge asymmetry factor $(N - Z/A)$ of the system. The upper panels of Fig. 4 represent the results of experimental data analysis. Visible proportional relation between the emission of light fragments emitted from NN source and the isospin of the system is observed. The bottom panels of Fig. 4 present the theoretical predictions. According to the simulations, the emission of LCPs from the NN source only depends on the size of the system.

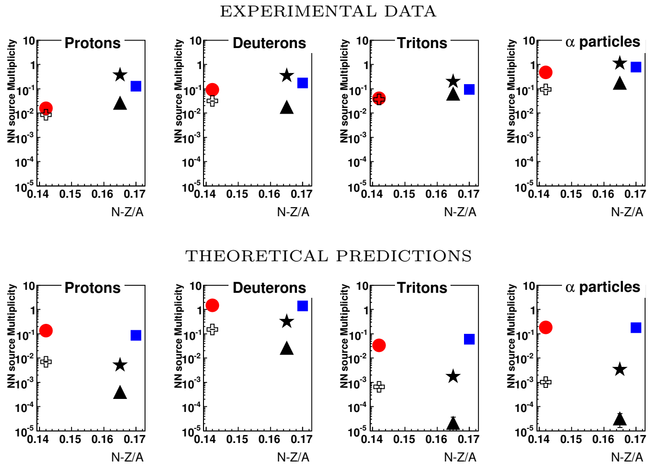

Fig. 4. Multiplicity of LCPs from NN source plotted as a function of charge asymmetry factor $(N - Z/A)$ of the system, top panels: experimental data, bottom panels: theoretical calculations. The explanation of used markers: see Fig. 3.

5. Conclusions

The analysis of LCPs production and isospin dependences of ^{124}Sn + ^{64}Ni, ^{124}Sn + ^{58}Ni, ^{124}Sn+^{27}Al at 35 MeV/A and 25 MeV/A collisions have been investigated. The main goal of this studies was to find the observables sensitive to the isospin of the system, which can be represented by the charge asymmetry factor $I = (N - Z)/A$ of the system. The isospin effects were demonstrated in the observables, such as the angular distribution of light particles emitted in central collisions at 35 MeV/A and LCPs emission from the NN source. The theoretical calculations do not reconstruct the isospin relations correctly. This indicates that as yet the isospin effects may not be interpreted properly in used approaches.

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