RECONSTRUCTION OF PRIMARY FRAGMENTS OF HEAVY ION COLLISIONS AT INTERMEDIATE ENERGIES*

K. Gąsior

University of Silesia, Institute of Physics
Uniwersytecka 4, 40-007 Katowice, Poland

(Received December 17, 2013)

For intermediate energies in the range of 20–100 MeV/A, multifragmentation is the one of the nuclear mechanisms which determine variety of reaction products. Moreover, emission of secondary fragments is strongly dependent on excitation energy of hot nuclear sources. As a results of heavy ion collisions at intermediate energies, high excited nuclear matter is produced. Time evolution of such system is a very dynamic process, so experimental detection of primary nuclear fragments is impossible at this stage. De-excitation of this matter, through the secondary decays produces a variety of stable fragments which can be measured in the experiments. This phenomenon causes that information about the original nucleus from which are formed secondary particles can be lost. We propose a reconstruction procedure based on correlations between intermediate mass fragments and multiplicities of light particles like: n, p, d, t, ^{3}He, ^{4}He. Secondary products of heavy ion reaction have been obtained by predictions given by the GEMINI model. A combination of theoretical knowledge with experimental data, especially information about secondary fragments and average excitation energy, allows to obtain a reaction products formed directly after heavy ion collision.

DOI:10.5506/APhysPolB.45.443
PACS numbers: 25.70.Pq

1. Introduction

The reaction mechanism of heavy ion collision strongly depends on the incident energy. For intermediate energies (20–100 MeV/A), multifragmentation [1] is a process describing dynamical and statistical behaviour of nuclear matter during reaction. That kind of the reaction mechanism can be represented by the participant–spectator model. A collision of projectile nucleus with stationary target leads to creating the areas directly taking part

* Presented at the XXXIII Mazurian Lakes Conference on Physics, Piaski, Poland, September 1–7, 2013.

in the reaction (participant) and those that are free (spectator). From the participant area there are emitted excited primary fragments of reaction.

Time evolution of such system is a very dynamic process thus the fragments formed on the early stage of the nuclear reaction are slightly different than these emitted later. Directly after collision there are produced primary fragments that cannot be detected in a real experiments. Since the nuclear matter is excited and very unstable, de-excitation process causes forming the final products of reaction that can be measured.

This phenomena losses information about the primary fragments. Therefore, it became interesting to create a procedure based mainly on the secondary products of reaction, to reconstruct the origin nucleus.

2. QMD and GEMINI model simulations of reaction

Simulation of ^{40}Ar+^{124}Sn reaction at incident energy equals 47 MeV$/A$ was based on the QMD [2–4] and GEMINI [5] models, for primary and secondary fragments, respectively.

As a results of the simulation, a wide range of isotopic and energetic distribution of reaction products is received. Since the fragments are excited, de-excitation process leads to forming a stable secondary nucleus. The visible differences between predictions obtained form the QMD and GEMINI models shows Fig. 1. Dynamics of heavy ion reaction causes increasing the number of light particles with charge $Z = 1, 2, 3$ and in a bit heavier nucleus at the damage of projectile-like and target-like fragments.

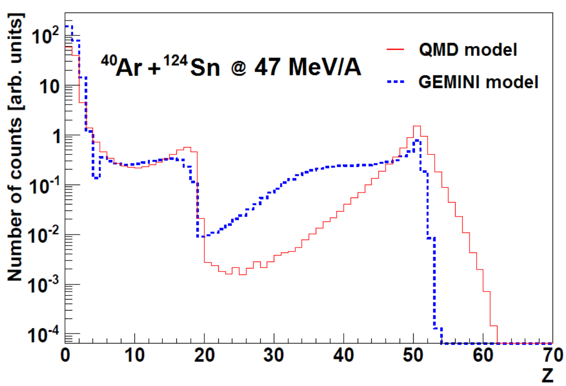

Fig. 1. Comparison between primary (QMD model — solid line) and secondary (GEMINI — dotted line) fragments of heavy ion reaction for ^{40}Ar+^{124}Sn at 47 MeV$/A$.

Evidently, it can be seen in the isotopic distribution presented in Fig. 2. The isotopic distributions obtained from GEMINI model are narrower and shifted towards neutron-poorer nucleus than the QMD model predictions.

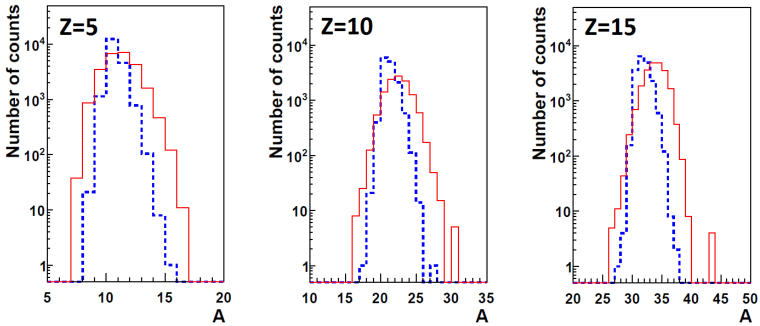

Fig. 2. Isotopic distribution from the QMD (solid line) and GEMINI (dotted line) models.

The time of QMD model calculations provides information about the evolution of the excitation energy of the reaction products at the selected point of time. When the time reaction increases, the value of excitation energy decreases (Fig. 3). The further reaction process depends on the

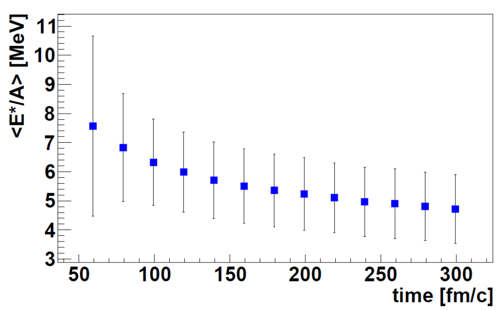

Fig. 3. Time dependence of average excitation energy per nucleon for intermediate mass fragments. Statistical errors are defined as the standard deviation from a particular distributions.

excitation energy of the primary fragments. The higher energy of selected nucleus, the more lighter particles are produced by the secondary decays. To a detailed analysis were subjected whole isotopes of intermediate mass fragments in a range: $3 \leq Z^*_{\mathrm{IMF}} \leq 20$, for which the mean value of excitation energy per nucleon equals: 4.72 ± 1.33 MeV. Distribution of the excitation energy per nucleon of intermediate mass fragments is presented in Fig. 4. According to the excitation energy per nucleon, in the range of 0.5–4.5 MeV, for selected nucleus, results of de-excitation process were presented in Fig. 5.

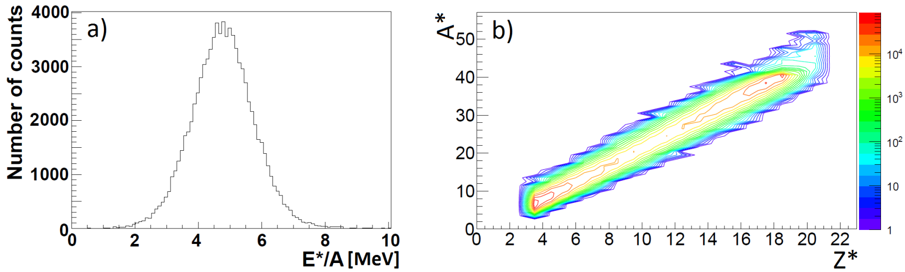

Fig. 4. Distribution of (a) the excitation energy per nucleon of the intermediate mass fragments, (b) mass *versus* charge of selected primary fragments, generated by the QMD model for the reaction time: $t = 300$ fm$/c$.

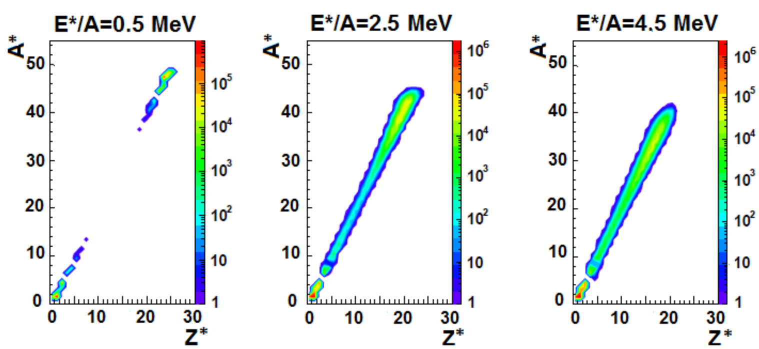

Fig. 5. De-excitation of the primary nucleus $Z^* = 25$, $A^* = 49$ for different excitation energy per nucleon in the range of 0.5–4.5 MeV.

3. Multiplicity of light particles

The reconstruction procedure is based on the decays of primary fragments on the intermediate mass fragments (IMF) and correlated with them by the multiplicities of light particles (LP) like: n, p, d, t, ^{3}He, ^{4}He. Simulations of de-excitation of primary fragments obtained from the GEMINI model include different channels of secondary decays. Thus for each nucleus, it is possible to create a database of light particles multiplicity. This analysis assumes the value of excitation energy per nucleon close to this obtained from the QMD model simulation of reaction for intermediate mass fragments, equals 4.5 MeV. Value of the average excitation energy per nucleon, for selected reaction, can be evaluated by experimental data or, as in this case, from the QMD model simulation.

It is worth stressing that the Gaussian fit of multiplicity distribution allows for more independence of reconstruction method of preparation procedure. On the basis of the mean of the Gaussian function and the width of the distributions, in dependence on the value of the average excitation energy per nucleon, a special database will be developed which makes the procedure universal. The values of Gaussian fit parameters (mean and sigma) are presented in Table I.

TABLE I

Example Gaussian fit parameters of light particles multiplicity distributions. The Gaussian fit parameters are used to define the scope and shape of light particles multiplicity. The errors of mean and sigma values are not more than 10%.

Light particle	Mean	Sigma
n	4.341	1.349
p	1.898	0.961
d	1.009	1.085
t	0.768	1.023
^{3}He	0.584	0.912
^{4}He	0.932	1.204

4. Reconstruction procedure

The proposed procedure associates together theoretical and experimental knowledge. The reconstruction formula (Eq. (1)) includes masses and charges of secondary particles: intermediate mass fragments (IMF) and light particles ($i = n$, p, d, t, ^{3}He, ^{4}He) with an appropriate contribution of their multiplicities w_i coefficient [6]. The w_i coefficient is taken from the Gaussian

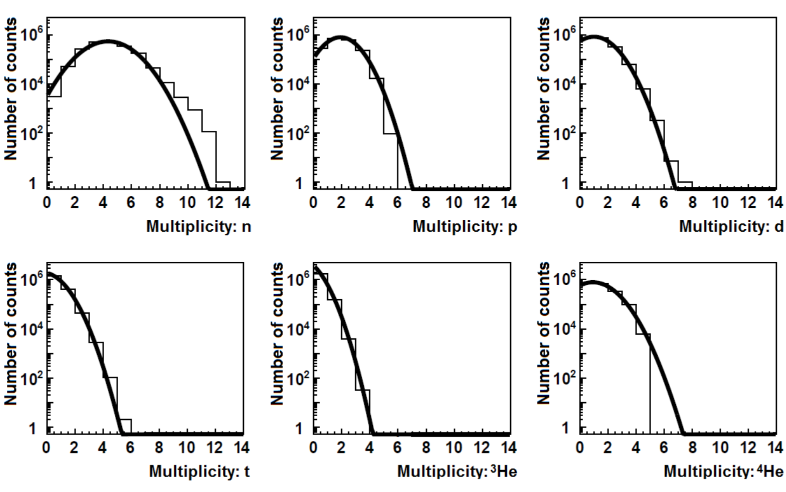

Fig. 6. The Gaussian fit of the light particles (LP): n, p, d, t, ^{3}He, ^{4}He corresponding with second decays of nucleus: $Z = 10$, $A = 20$, $E^*/A = 4.5$ MeV.

fitting function to the distributions of light particles multiplicities, shown in Fig. 6

$$\begin{cases} Z^* = Z_{\mathrm{IMF}} + \sum\limits_i w_i Z_i \\ A^* = A_{\mathrm{IMF}} + \sum\limits_i w_i A_i \end{cases} . \tag{1}$$

Reconstructing quantitatively nucleus produced in the reaction ^{40}Ar+^{124}Sn at 47 MeV/A, it is possible to obtain a whole group of particles. It has been shown in Fig. 7.

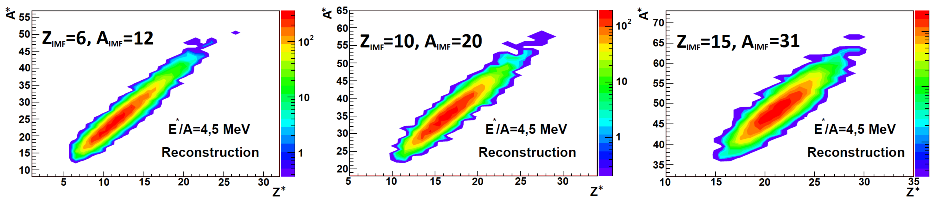

Fig. 7. Group of particles reconstructed from a particular secondary nucleus.

For every available intermediate mass fragments, reconstruction procedure was applied. Therefore, it has become possible to reconstruct and compare distribution of primary fragments received from a two-way procedure. Results of this analysis are presented in Fig. 8.

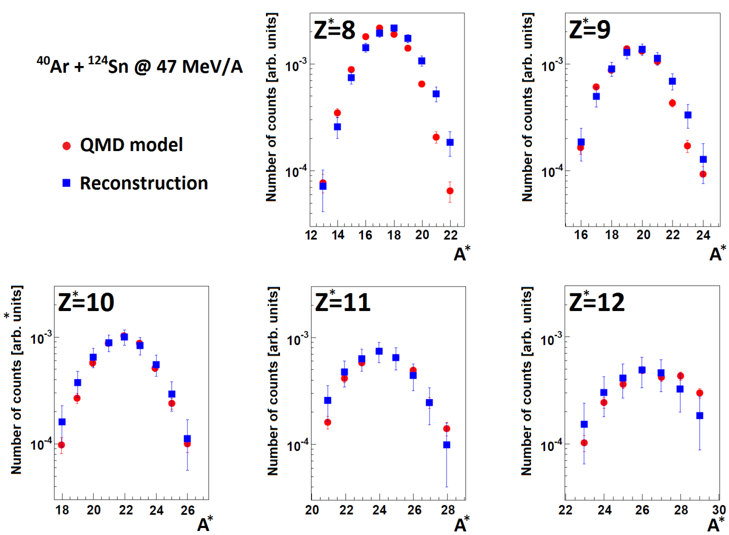

Fig. 8. Comparison of isotopic distribution of the primary fragments obtained from the reconstruction procedure (squares) and QMD model (dots). The vertical bars correspond to the statistical errors.

5. Conclusion

In this paper, reconstruction procedure of primary fragments formed after heavy ion collision was presented.

As was shown, data obtained from reconstruction procedure give promising results. A very good compatibility of the reconstructed data with the QMD model confirms the main assumptions of the procedure, therefore the analysis can be performed.

Although the data are consistent, some solutions need improvements. Further investigation requires the range of isotopes choice to create database of light particles multiplicity. Furthermore, the normalization process of the primary fragments distributions and method of estimation of the systematic errors have to be subjected to a detailed analysis.

REFERENCES

[1] J. Hubele *et al.*, *Phys. Rev.* **C46**, R1577 (1992).
[2] J. Aichelin, H. Stocker, *Phys. Lett.* **B176**, 14 (1986).
[3] C. Hartnack *et al.*, *Nucl. Phys.* **A495**, 303c (1989).
[4] J. Łukasik, Z. Majka, *Acta Phys. Pol. B* **24**, 1959 (1993).
[5] R. Charity *et al.*, *Nucl. Phys.* **A483**, 371 (1988).
[6] M.R.D. Rodrigues *et al.*, *Phys. Rev.* **C88**, 034605 (2013).