Coalescence and Chemical Equilibrium in Multifragmentation at Intermediate Energies

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The light particle emission which occurs during violent collisions of two heavy nuclei carries essential information on the early dynamics and on the degree of equilibration at each stage of the reaction. The coalescence model gives us a way to exploit the early particle emission (nucleons and light clusters) in order to obtain specific information on the reaction dynamics and on the thermal evolution of multifragmenting systems produced in central collisions. For example, the size (the density) of the interaction region can be studied as a function of the surface velocity of the emitted light particles which is related to the evolution time of the system [1].

A large number of experiments was done using the Tamu Nimrod detector. The list of the studied system is presented in figure 1. In this figure, the systems are classified using their expected residual excitation energy and masses after preequilibrium emission.

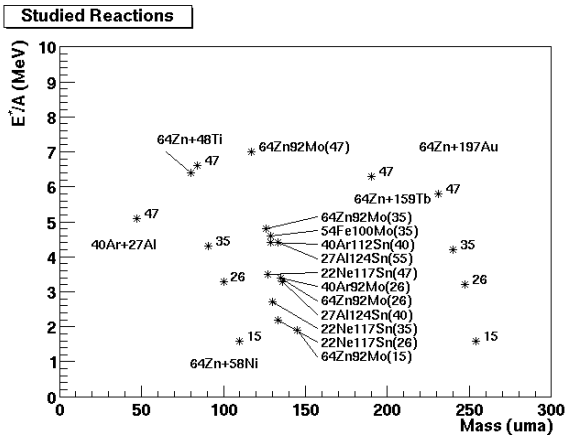

Figure 1: Studied reactions during the Nimrod experiments.

The calibration of the detectors is presently being improved for Z=1 (see other report of the same collaboration). Here we present some preliminary results temperatures and chemical equilibrium in Ar(40 AMeV)+Sn reaction.

The more violent collisions were selected as shown in Figure 2 by selection of high multiplicity (neutron and charged particle) events.

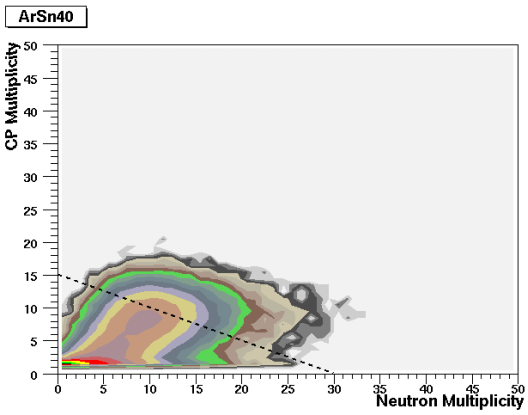

Figure 3: Charged particle multiplicity as a function of the neutron multiplicity. The dashed line shows the selection for the central events.

This figure shows the charged particles measured with the Nimrod charged particle array as a function of the neutron multiplicity extracted from the neutron ball. The low multiplicity region can be associated with a larger impact parameters and the highest multiplicities, with the high excitation energies associated with the more central events. In a first approach, we can select the most violent events by taking into account only the 10% largest multiplicities (above the dashed line in the figure).

With this selection, Figure 3 shows the evolution of three isobaric ratios as a function of the surface velocity, at 40 degrees in the laboratory frame.

In the top of Figure 3, these ratios are relatively similar for the largest surface velocities but their behavior changes dramatically when the velocity becomes lower. This discrepancy for the lowest velocities (and thus for the later stage of the reaction) is related to the mixing of two different processes. In fact, at the late stage of the reaction, the contribution of the secondary emission from the target-like fragment becomes important especially for the neutrons largely favored in an evaporation process. To open the surface velocity windows

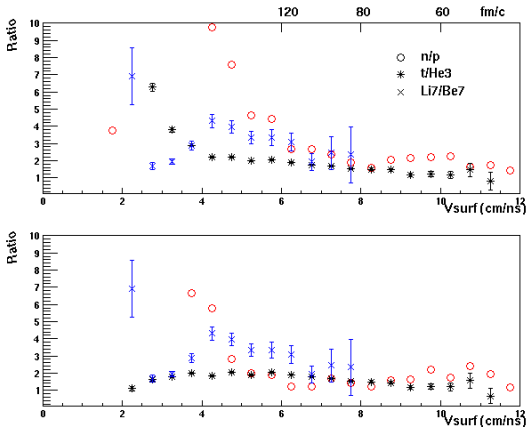

Figure 2: n/p, t/he3 and ^{7}Li/^{7}Be ratios as a function of the surface velocity. The top shows the ratios without TLF correction. The bottom depicts ratios after removing TLF contribution.

for the observation of earlier stage, the contribution from the TLF must be removed. This was done using a multisource fit in order to extract the different contributions (Target-Like Fragment source, Projectile-Like Fragment source and Nucleon-Nucleon source) [1]. The bottom of Figure 3 shows the results after the TLF correction. Even after correction, for the velocities lower than 5 cm/ns, some part of the large TLF contribution appears to remain. We consider this velocity as a lower limit for observing the pre-thermalization component.

The time scale at the top of the figure was extracted from QMD model calculations of the time dependance of the light particle energies. The QMD model indicates that the thermal equilibrium is reached ~100 fm/c. Which correspond to surface velocities in the range 6 to 8 cm/ns. In Figure 4 the ratios in this velocity range are shown before the TLF correction (triangles) and after correction (empty circles).

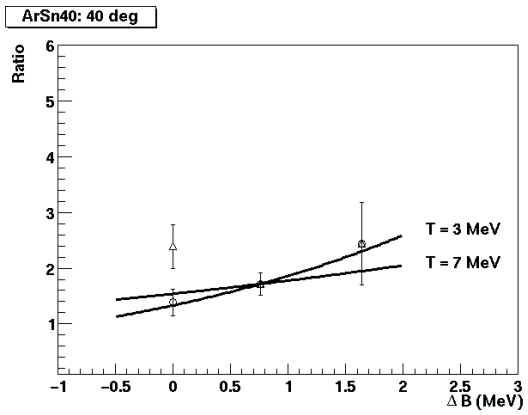

Figure 4: Comparison of the isobaric ratios as a function of the difference in the binding energy (see text for details).

These ratios are compared with two lines associated to the values of these ratios, normalized to the t/he3 ratio, as a function of the different binding energies like expected in case of chemical equilibrium and that, for a temperature of 3 and 7 MeV. The results are strongly dependent in the quality of the source fit analysis which needs to be improved. Also, the statistics for to the ^{7}Li-^{7}Be ratio will be improved by a factor of 2 or three when all the detectors of this ring will be taken into account. Finally, we will also take into account the Coulomb correction, proposed in references [2] and [3]. In this way we hope to have a valid check of chemical equilibration.

The Albergo temperatures were extracted for three different systems (see Figure 5).

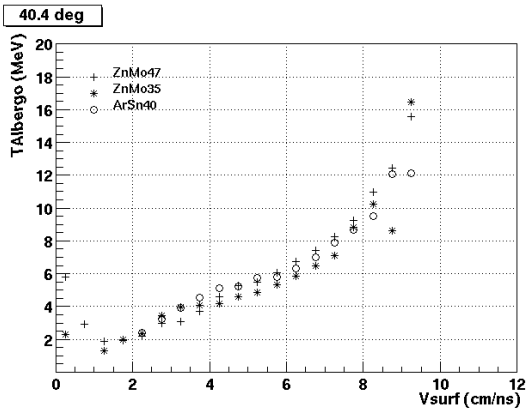

Figure 5: Albergo temperatures as a function of the surface velocity.

The behavior of the temperature is in qualitative agreement with a cooling system. Quantitatively, we have to be careful in interpreting this result for the earliest stage of the reaction, at high velocities, where the thermal equilibrium is probably not achieved. For the lowest velocities, the validity of the TLF correction must be checked.

References

[1] K. Hagel *et al.*, Phys. Rev. C **62** (2000).
[2] J. Toke *et al.*, Phys. Rev. C **63** (2001).
[3] S. Shlomo *et al.*, Phys. Rev. C **55** (1996).