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# Isospin influence on the intermediate-Mass Fragments production at low energy

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**Summary.** — The reactions $^{78}$Kr + $^{40}$Ca and $^{86}$Kr + $^{48}$Ca realized at 10 $A$MeV, have been studied in Catania at LNS with the $4\pi$ multidetector CHIMERA. For these systems, we have already studied the fusion-evaporation and fission-like processes. Now we will present a study of the break-up of the Projectile-Like Fragment (PLF) into two fragments, following more violent deep-inelastic collision. A selection method has been developed, in order to discriminate PLF break-up from events due to other mechanisms, fusion-fission–like processes, which populate the same region of the phase-space. A preference for PLF aligned break-up, along the direction of the PLF-TLF separation axis with the light fragment emitted in the backward part, has been evidenced, suggesting dynamical-nonequilibrium effects. The isospin is expected to play a crucial role in the onset of this process; a comparison between the neutron-rich $^{86}$Kr + $^{48}$Ca system and neutron-poor $^{78}$Kr + $^{40}$Ca one will be presented.

## 1. – Introduction

Heavy-ion–induced reactions with stable and radioactive beams are a powerful tool to investigate the behavior of nuclear matter under different stress conditions.

Depending on the energy domain, where the collisions are realized, it is possible to observe different reaction mechanisms; in particular we are interested to the processes involved in the so-called low-energy regime where $E/A \leq 15\,A$MeV. This energy domain is characterized by the competition between the Compound Nucleus formation and its

 

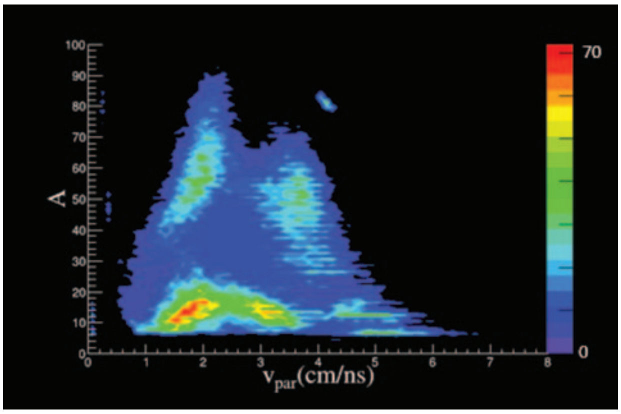


Fig. 1. – Correlation between the fragment mass and parallel velocity of the reaction products in events with 3 IMFs well detected and identified.

consequent de-excitations through fusion-fission and fusion-evaporation, and other binary processes like quasi-elastic scattering and deep inelastic collisions.

These reaction mechanisms populate a wide range of mass region from the light charged particles up to fission fragments and evaporation residues with the Intermediate-Mass Fragments (IMF) ($Z \leq 3$) in between. The reaction mechanisms responsible of the IMF production are: fission-like processes and the damped deep inelastic collision followed by projectile-like break-up. Because of the low energy, events due to these processes populate the same region of the phase-space, thus in order for distinguishing between the projectile-like break-up and fission-like processes, a careful selection method has been developed.

We have already studied the fusion-evaporation and fission-like processes in the reactions $^{78}$Kr + $^{40}$Ca and $^{86}$Kr + $^{48}$Ca at 10 $A$MeV [1-3] with the $4\pi$ multidetector CHIMERA [4-6]. For details about the IMF production through fission-like processes we refer to ref. [1]. The main results of this previous analysis put in evidence that the neutron enrichment seems to discourage the fission-like processes. Now we will present the results relative to the analysis of projectile-like break-up events. In previous experiments performed at higher energy from the CHIMERA group, an evident influence of the isospin on the nature of the break-up of the PLF is observed [7-9] so we expected that also at low energy the isospin should play a crucial role.

## 2. – Selection method and results

In the reactions $^{78}$Kr + $^{40}$Ca and $^{86}$Kr + $^{48}$Ca at 10 $A$MeV we have analyzed only events with three IMF, well detected and identified, fig. 1 shows, for this class of events, the correlation between the fragment mass and parallel velocity of the reaction products.

Different reaction mechanisms populate this plot: the break-up of the slow fission fragment from the compound nucleus, the break-up of the fast fission fragment from the compound nucleus and the break-up of the PLF.

After its formation the compound nucleus could decay though fission and then the slow fission fragment can break-up into two fragments. As shown in fig. 2 at the end of this process we have three bodies: the fast fragment emitted in the fission of the compound nucleus ($F_1$) and the two fragments produced in the break-up of the slow

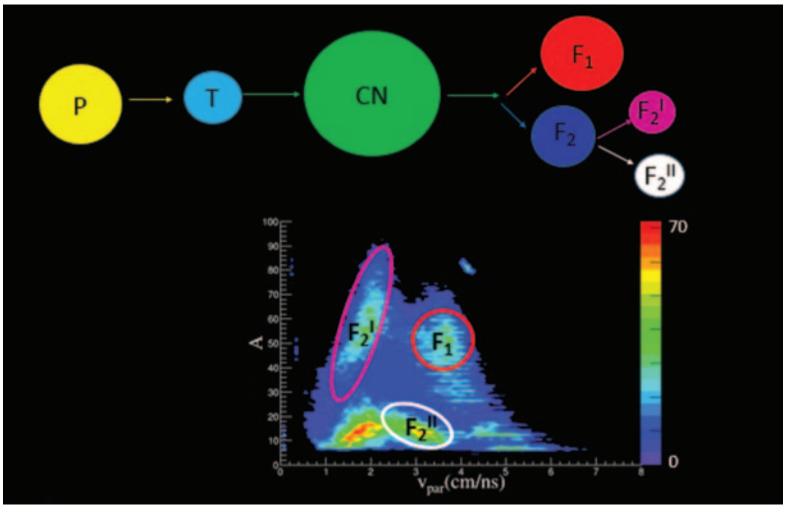


Fig. 2. – Schematic representation of the break-up of the slow fragment produced in the fission of the compound nucleus, and localization of the fragments produced in the mass *vs.* parallel velocity plot in events with 3 IMFs well detected and identified.

fission fragment ($F_2^I$ and $F_2^{II}$), for threshold reasons, in the kinematical solution where the lighter fragment is forward emitted.

If after the fission of the compound nucleus the fast fragment produced breaks up into two fragments, at the end, as shown in fig. 3, we will observe: the slow fragment emitted in the fission of the compound nucleus ($F_2$) and the two fragments produced in the break-up of the fast fission fragment ($F_1^I$ and $F_1^{II}$), with the lighter fragment backward or forward emitted.

The last reaction mechanisms, which is the process that we are interested in, is the break-up of the projectile. These events are originated from a a two-step mechanism, compatible with the hypothesis of a binary deep inelastic interaction, followed by the further fission-like decay of the PLF (fig. 4). The three bodies produced in this reaction

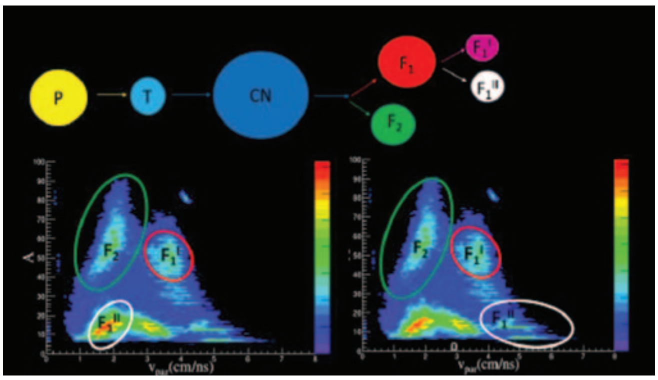


Fig. 3. – Schematic view of the break-up of the fast fragment produced in the fission of the compound nucleus, and localization of the fragments produced in the mass *vs.* parallel velocity plot in events with 3 IMFs well detected and identified.

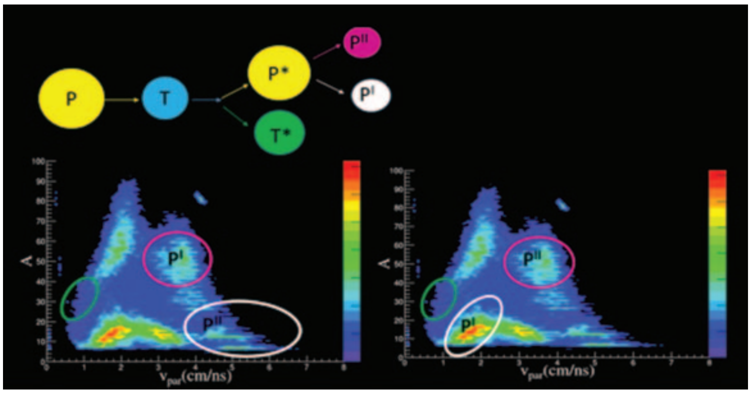


Fig. 4. – Schematic view of the break-up of the PLF and localization of the fragments produced in the mass *vs.* parallel velocity plot in events with 3 IMFs well detected and identified.

are: a part of the Target-Like Fragment (TLF) ($T^*$) and the two fragments coming from the break-up of the PLF ($P^I$ and $P^{II}$), with the lighter fragment backward or forward emitted.

So, as it is possible to observe in fig. 5, the reconstructed source of each combination of two fragments produced in events with 3 IMFs well detected and identified is the slow fragment emitted in the fission of the compound nucleus ($F_2$) or the PLF ($P^*$) or the fast fission fragment ($F_1$). In order to be sure to take into account only events due the PLF break-up we required that the reconstructed source of two fragments is $(P^*)^*/(F_1)$ and that the third fragment does not belong to the slow branch of fission from the compound nucleus.

The pictures shown until now regard the $^{78}$Kr + $^{40}$Ca system, but similar results have been obtained for the $^{86}$Kr + $^{48}$Ca system, so the same logic has been applied in the selection method for this system. The correlation between the mass and the parallel velocity of the fragments produced int the PLF break-up selected as previously explained, is shown in fig. 6 on the left for $^{78}$Kr + $^{40}$Ca and on the right for the $^{86}$Kr + $^{48}$Ca system.

Very important information about the nature of the break-up process could be extracted from the angular distribution in the PLF reference frame. The main signature

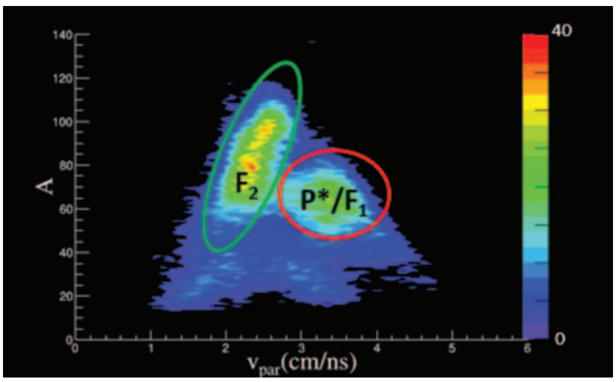


Fig. 5. – The mass *vs.* parallel velocity plot of the reconstructed source of each combination of two fragments in events with 3 IMFs well detected and identified.

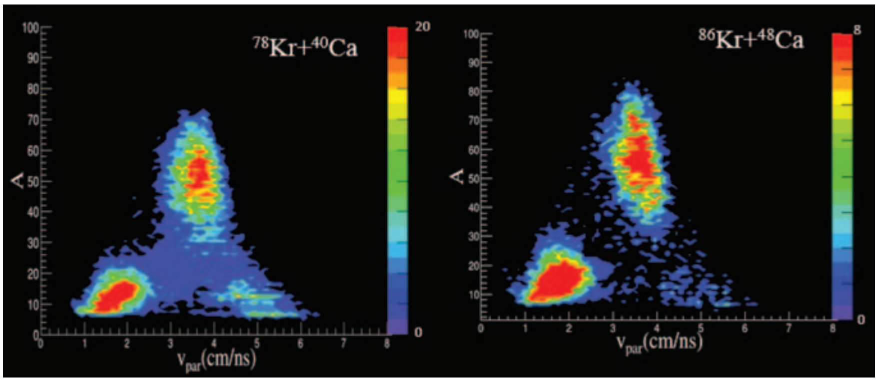


Fig. 6. – The mass *vs.* parallel velocity plot for the PLF break-up on the left for the $^{78}$Kr + $^{40}$Ca and on the right for the $^{86}$Kr + $^{48}$Ca system.

of a dynamical break-up is the alignment of the break-up axis with the separation direction of the two primary fragments (PLF and TLF), with the lighter breakup fragment backward emitted. The aligned break-up demonstrates the persistence of the memory of the previous deep inelastic step and in particular of the direction of the separation axis between PLF and TLF.

A very nice observable, that allows to disentangle between statistical and dynamical break-up, is the cosine of $\theta$ proximity. The proximity angle is defined as the angle between the separation axis between PLF and TLF and the break-up axis oriented from the light to the high fragment. The distributions in $\theta$ proximity for different asymmetry parameters, $A_H/A_L$, when the reconstructed PLF is in anticoincidence with the slow fission, obtained for $^{78}$Kr + $^{40}$Ca and $^{86}$Kr + $^{48}$Ca are peaked around 1, as is possible to observe in fig. 7. this suggests a preferential emission direction and thus a dynamical break-up, these dynamical effects seem to be more pronounced for the neutron-rich system, in agreement with the results obtained in previous experiments performed at higher energy by the CHIMERA group.

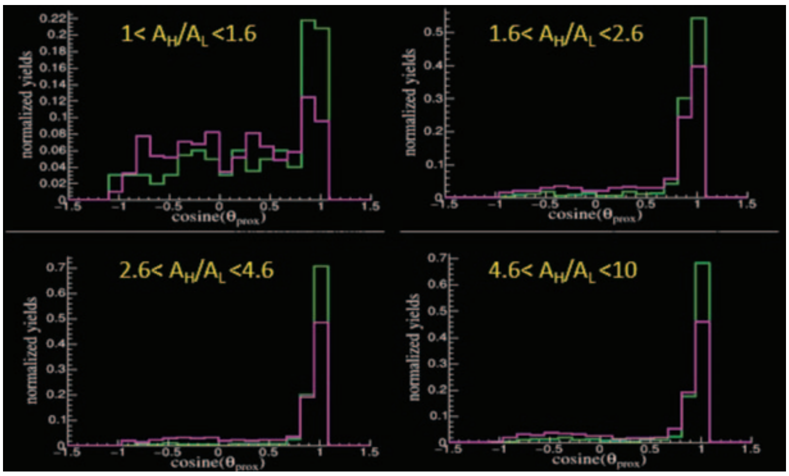


Fig. 7. – Distribution in cosine of $\theta$ proximity for the two studied systems for different asymmetry parameters.

In order to be sure that this effect was not due to some error in our procedure and selection, we have done the distribution when the reconstructed source is F1, in coincidence with the slow fission fragment, and we have obtained a flat distribution as is expected in the case of statistical break-up.

## 3. – Conclusions

The preliminary results of the analysis relative to the PLF break-up in the reactions $^{78}$Kr+$^{40}$Ca and $^{86}$Kr+$^{48}$Ca have been presented. A selection method has been developed, in order to discriminate PLF break-up from events due to other mechanisms, fusion-fission–like processes, which populate the same region of the phase-space. A preference for PLF aligned break-up, along the direction of the PLF-TLF separation axis with the light fragment emitted in the backward part, has been evidenced, suggesting dynamical-nonequilibrium effects. The results seem to put in evidence that the dynamical effects are more pronounced for the reaction $^{86}$Kr + $^{48}$Ca, with respect to the $^{78}$Kr + $^{40}$Ca one, for the different asymmetry parameters, in agreement with the results obtained at higher energy

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