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DOMINANCE OF DEEP INELASTIC BINARY PROCESSES IN SYMMETRIC NUCLEUS-NUCLEUS COLLISIONS from 25 to 75 MeV/u

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ABSTRACT

Reaction mechanisms in symmetrical nucleus-nucleus collisions have been studied with the 4π device Indra. It turns out that deep inelastic collisions represent a dominant part of the reaction cross section and that quite large excitation energies (exceeding 10 MeV/u) are reached in these collisions.

1. Introduction

Several mechanisms are observed in low energy heavy ion induced reactions (below 15 MeV/u). For light systems, fusion is observed in central collisions whereas deep inelastic processes are observed for peripheral ones. The critical angular momentum associated with the transition from fusion to deep inelastic collisions is related to the disappearance of a pocket in the sudden potential describing the collision [1]. For heavy systems for which the product Z_1Z_2 of the atomic numbers of the initial partners exceeds 2500, the initial relative potential is repulsive for any relative distance and fusion is impossible. In these cases, only deep inelastic processes are observed [2].

When increasing the bombarding energy from 15 to 40 MeV/u, fusion is still observed for light systems. However, two features are observed : fusion is more and more incomplete, and the corresponding cross section seems to vanish [3]. Preequilibrium emission is responsible for the first feature. Concerning the vanishing of the fusion cross section, several interpretations have been propound : the maximum energy sustainable by a hot nucleus has been discussed in ref. 4-5, whereas the opening of new decay channels is considered in references 6-7. In references 8 and 9, it has been concluded that the major part the reaction cross section corresponds to deep inelastic collisions, even for light systems. Similar conclusions have been given in reference 10. In references 8-9, deep inelastic mechanisms have been recognized from the coincident detection of the final residues of the quasi-projectile and quasi-target nuclei. In reference 10, the initial quasi-projectile has been reconstructed from its decay products but nothing was obtained for the slow quasi-target partner because of thresholds effects.

To day, it is possible to go further on this question because new low threshold 4π devices are able to detect both quasi-projectile and quasi-target decay products. It is what we did for the symmetrical systems Ar+KCl and Xe+Sn from 25 to 74 MeV/u. In this contribution, we show that deep inelastic processes are indeed quite dominant for these symmetrical reactions.

2. Event selection

The experiment has been performed at Ganil with Indra [11]. Any event for which more than 3 modules fired in coincidence were registered. The first step of the analysis consisted in asking for a complete detection : more than 80% of the available total charge and linear momentum were required. We have tested that such a selection eliminates most peripheral and semi-peripheral collisions for which the quasi-projectile or/and quasi-target could be missed in the forward beam hole or because of thresholds effects. Conversely, we have tested that most violent collisions have been preserved by this selection.

3. The dominant role of two source events

The dominance of two sources reactions has been observed from this experiment both for the Ar/KCl and Xe+Sn systems. Our purpose in this section is to establish this feature. A first indication can be obtained from figure 1 in which two $V_{//}$ - Z plots are shown : for each event, one has diagonalized the momentum tensor in order to extract the main axis ; $V_{//}$ is the velocity component on this main axis for each IMF ($Z \geq 3$) of the event. Z is the corresponding charge. In figure 1-a, any IMF has been considered. In figure 1-b only the two heaviest ones have been retained. It turns out that most of the considered products can be attributed to one forward source (projectile- like fragment) and a backward one (target-like fragment). The two arrows indicate the initial projectile and target velocities in the center of mass frame. The relative velocities between the selected projectile-like and target-like sources correspond to some dissipation since most peripheral collisions have been eliminated by the "complete event" requirement explained in section 2. However, they are generally much larger than the expected values for coulomb repulsion (about 2.5 cm/ns) and only few events can result from a fusion nucleus decay (their cross section is about 80 mbarns for the Xe+Sn system at 50 MeV/u).

Hence it is justified to reconstruct the initial projectile and target-like products. We did it by attributing the various IMF of a given event to the projectile-like or target-like sources. The mathematical method which has been used to optimize this sharing consists in the search for the maximum value of the thrust :

$$T = \frac{|\Sigma \vec{p}_i| + |\Sigma \vec{p}_j|}{\Sigma |\vec{p}_k|}$$

In the numerator, each summation includes IMF which have been attributed to a definite source. The denominator is simply a scaling factor. In figure 2 we have plotted some characteristics of the reconstructed sources : their relative velocity versus the rotation angle of the di-nuclear source system. One gets what is generally labelled a Wilcynski plot at lower bombarding energy.

Such a behaviour has been obtained whatever the bombarding energy and for both studied systems : Ar+KCl form 32 to 74 MeV/u and Xe+Sn from 25 to 52 MeV/u. Deep inelastic collisions are quite dominant at and above 30 MeV/u for symmetrical systems. For the lightest system (Ar+KCl), this result is different from the known behaviour at lower bombarding energy.

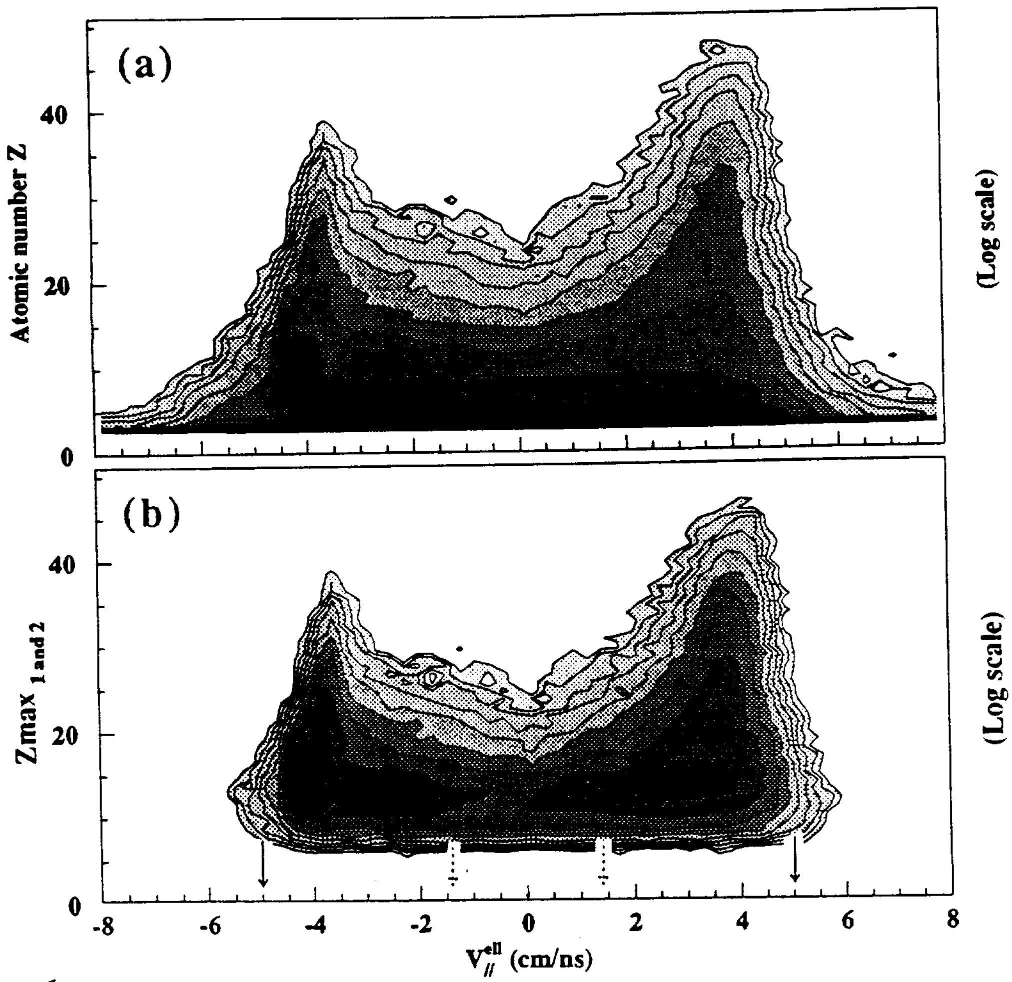

Figure 1

$V_{//}$ - Z plots for various IMF belonging to "complete events" (see section 2) for the Xe+Sn system at 50 MeV/u. In part (a) of the figure any IMF has been retained. In part (b), only the two heaviest of a given event are retained. Most events exhibit a two source behaviour and only few of them can correspond to fusion.

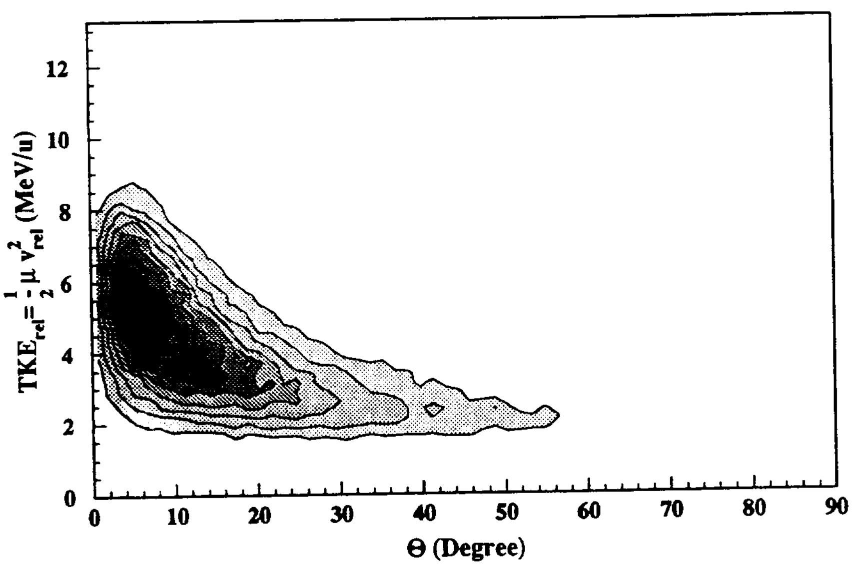

Figure 2

Correlation between the relative velocity (in MeV/u unit) of the reconstructed primary sources and the rotation angle of the di-nuclear source system for the 50 MeV/u Xe+Sn system.

In the deep inelastic picture, the dissipated energy is related to the relative velocity of reconstructed sources. Hence, we have sorted events according to this quantity, and we have tested that the coincident light charged particle behaviour was coherent with a sequential emission from these sources. Figure 3 is an exemple for the Ar+KCl system at 74 MeV/u. We have selected relative velocities between reconstructed sources which correspond to a dissipated energy range of 6-8 MeV/u. The arrows indicate the source velocities. It turns out that coincident alpha particles exhibit the behaviour expected for sequential decay. This coherence strongly supports the validity of the thrust method.

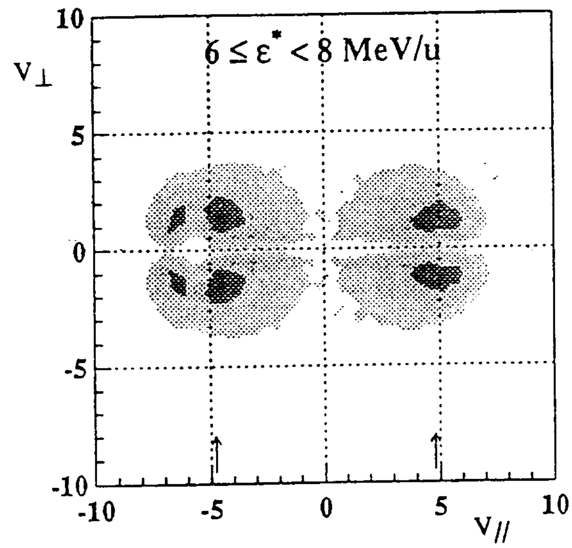

Figure 3
$V_\perp$ - $V_{//}$ plot of alpha particles for the system Ar+KCl at 74 MeV/u. We have selected events corresponding to a dissipated energy of 6-8 MeV/u.

Very large excitation energy values can be reached in these deep inelastic collisions. It is shown in figure 4 that values exceeding 10 MeV/u are obtained with a sizeable cross section at 50 MeV/u bombarding energy, whatever the total mass of the system is. One may of course ask questions about uncertainties on dissipated energies due to pre-equilibrium emission. Simulations indicate that they do not exceed 10%, which is confirmed from an analysis of figure 5. We have plotted is this figure the evolution of particle multiplicities with dissipated energies. Note that the observed correlation is quite meaningful since these two quantities are independant observables. It turns out that superimposed curves are obtained for various bombarding energies ranging from 25 to 75 MeV/u. Such a coherence between various bombarding energy results would not be observed if pre-equilibrium effects were sizeable : indeed in such a case, 74 MeV/u data would be much more affected that 32 MeV/u ones.

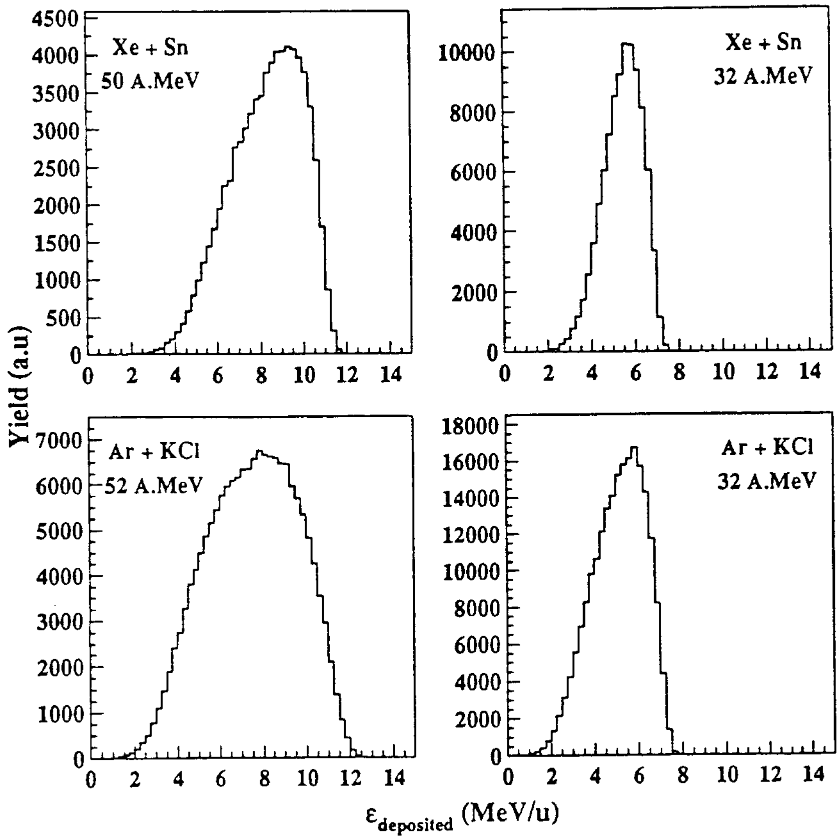

Figure 4

Dissipated energy distributions extracted for several systems at various bombarding energies. The results are independent of the total available mass.

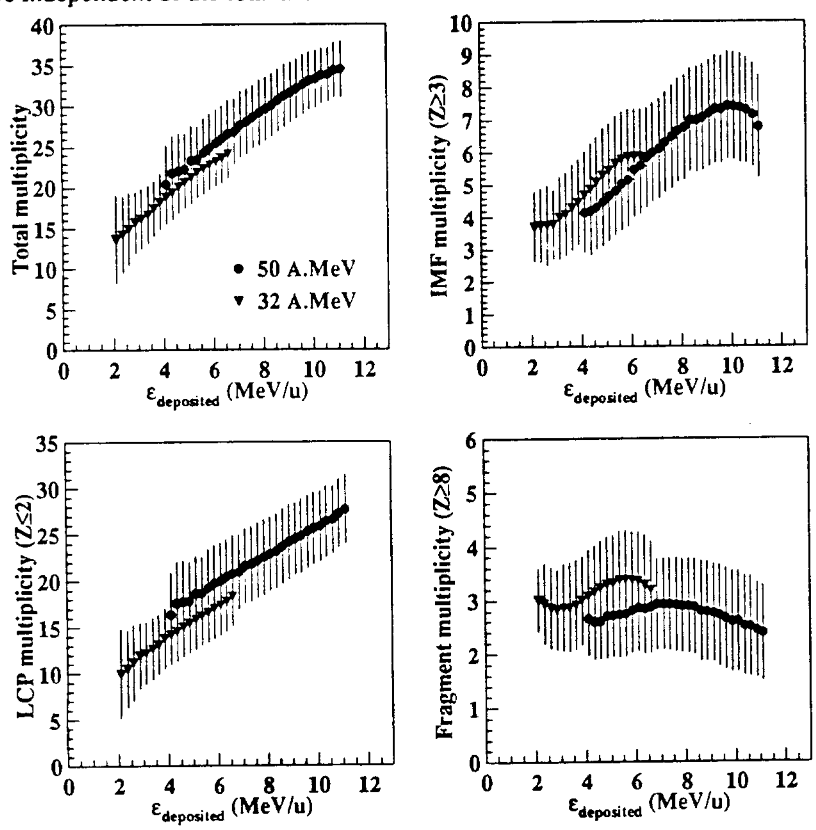

Figure 5

Correlations between light charged particle multiplicities and the dissipated energy extracted as described in the text for the Xe+Sn system at 32 and 50 MeV/u.

4. Conclusion

In this contribution, we have shown that deep inelastic collisions play a dominant role for symmetric nucleus collisions up to 75 MeV/u. Excitation energies ranging from less than 1 MeV/u to more than 10 MeV/u are reached with sizeable cross sections. Fusion nuclei (if any) represent a cross section of about 80 mbarns (for Xe+Sn at 50 MeV/u) and other results indicate a continuous evolution between deep inelastic like and fusion like events. The source reconstruction procedure discussed in this paper make possible a detailed study of hot nuclei decay on a wide range of excitation energy.

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