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In medium fragment break-up of projectile in $^{58}\text{Ar}+^{36}\text{Ni}$ central collisions

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Abstract. Latest results concerning the study of central collisions in $^{36}\text{Ar}+^{58}\text{Ni}$ reactions, carried out by using the INDRA 4π detector at the GANIL are presented. Reaction mechanisms involved in very central collisions for such asymmetric system and their evolution as function of incident energy are studied, from 32 to 95 AMeV, suggesting an in-medium “break-up” process of the projectile where the presence of nuclear transparency plays an important role. Such a process, leading to forward emission of fragments and lights particles in the laboratory frame, is found to be more and more relevant at high energies, when the contribution from quasi-fusion processes vanishes. Evidences of emissions from an excited quasi-target (QT*), moving along the beam direction with velocity rising with incident energy under the dragging effect of the in-medium “crumbling” of the projectile are highlighted.

1. Introduction

At intermediate incident energy very central collisions can lead to the formation of a unique source, characterized by excitation energies comparable with the nucleons’ binding energy. This system can meet several decay modes depending on its angular momentum, its density, its excitation energy. Nevertheless, the formation of such a composite excited system in central collisions is subjected to some conditions strictly related to the nuclear stopping, that governs the amount of energy dissipated in the reaction [1].

In the present work we focus on very central collisions (between 0 and 0.3 reduced impact parameter) in $^{36}\text{Ar}+^{58}\text{Ni}$ reactions and, after highlighting the not occurrence of single source formation at the highest energies, even in most violent collisions, we concentrate the analysis on the projectile fragmentation and target de-excitation separately. The projectile products, appearing like an anisotropic “crumble” of fragments and light particles, provide interesting evidences about an in-medium fragmentation process that become dominant above 45/50 AMeV, reflecting the strong interplay between mean-field (nuclear degrees of freedom) and n-n collisions (nucleonic degrees of freedom) played in the intermediate energy range [3].

2. Event selection and characterization

We study the so called “complete” events, where the total detected charge and total pseudo-momentum are above 75% of the values they have in the entrance channel of the reaction.

Since we are interested in central collisions, a gate is applied on the global variable $E_{\text{t1,2}}$, namely the total transverse energy of light particles ($Z=1,2$) and concentrate our analysis on collisions with reduced impact parameter $b_{\text{red}} < 0.3$.

When the centrality gate is applied most contributions from peripheral events are strongly suppressed and a significant emission at mid-velocity ($v_{\text{par}} \approx v_{\text{CM}}$) is observed for fragments with charges greater



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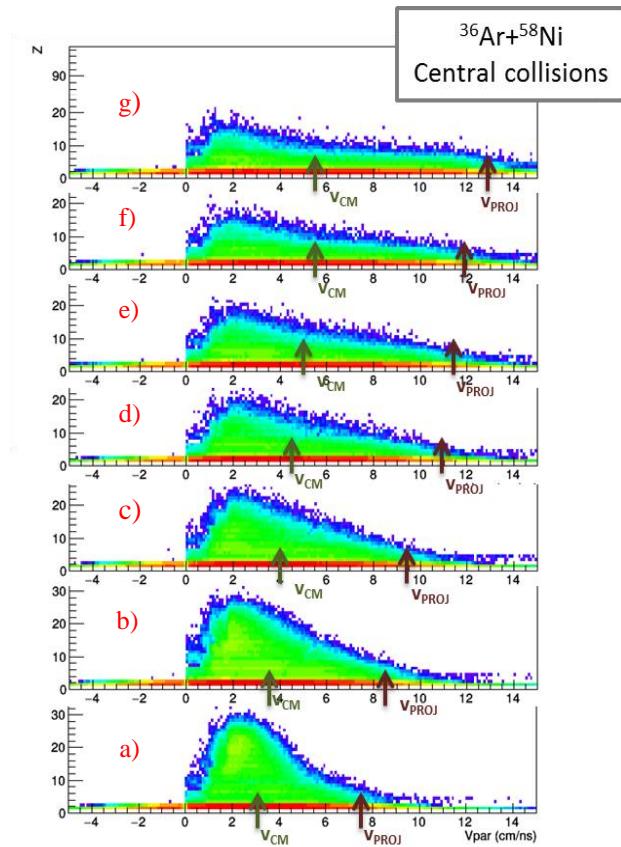


Figure 2.1 v_{par} -Z correlations at all the E_{inc} range (32, 40, 52, 63, 74, 84, 95 AMeV)

exit the interaction region with parallel velocity values from $v_{par}=v_{CM}$ to about $v_{par}=v_{proj}$. Such results are consistent with a sort of projectile *crumble* breakup occurring in a semi-transparent medium.

Furthermore, an emission of fragments with a large range of charges ($1 < Z < Z_{target}$) and parallel velocities centred at low values, approximately $v_{par} = 1-2$ cm/ns, is observed. Such observations can be associated (see next Section 2.1) to emissions from the excited quasi-target (QT*).

2.1. Reconstruction and characterization of QT and QP sources

In order to better characterize the observed reaction mechanism, we reconstruct the total QT and QP charges by summing the charges of all particles and fragments with v_{par} values lower and greater, respectively, than the center of mass velocity of the reaction: $Z_{QT,QP} = \sum_{(v < v_{CM}, v \geq v_{CM})} Z_v$

Such reconstruction of the QP and QT sources allows us to also determine their center of mass velocities, shown on fig. 2.1.1.

The v_{CM}^{targ} ranges from 1.9 cm/ns at 42 AMeV to 2.2 cm/ns at 92 AMeV, indicating a sort of gluing and dragging of the target along the beam direction by the projectile crumbling, that become more violent with increasing of beam energy.

Finally, in order to extract some information about the decay mechanism of the QT in coincidence with the in-medium projectile breakup we study the kinetic energy spectra of alpha particles emitted by the QT and measured in its centre of mass reference frame

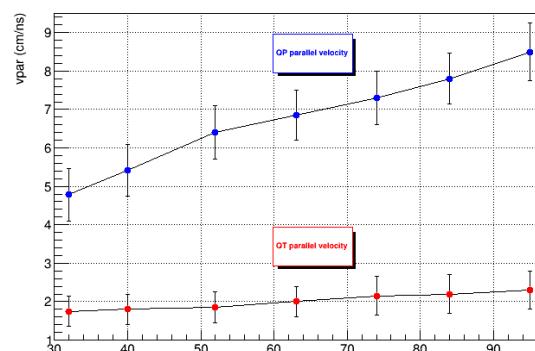


Figura 2.1.1 Center of mass velocity for reconstructed QT (red points) and QP (blue points).

than the charges of the two colliding nuclei at 32 and 45 AMeV (panel a) and b) in fig. 2.1). Such events may correspond to fusion-like process, with a subsequent emission of fragments and light particles through evaporation and multi-fragmentation of a compact source.

Such process becomes less significant and eventually disappears at higher beam energies, indicating a less significant contribution from stopping processes in central collisions. Mechanisms related to transparency phenomena are visible on fig. 2.1 where the v_{par} -Z correlations at all the E_{inc} range is shown: the projectile completely loses its identity after the collision (no QP remnants centered at projectile velocity is observed), undergoing a multiple breakup into fragments with charges from $Z=1$ to about $Z=10-15$ (depending on the beam energy).

But, in contrast to what happens at relativistic energies, the reaction products do not show a peak at the projectile velocity, being spread along the v_{par} axis: this aspect seems to suggest that the projectile breakup occurs inside the projectile-target interaction region, where the decay products slow down by dissipating a variable portion of their kinetic energy and then

exit the interaction region with parallel velocity values that can span a wide range extending from $v_{par}=v_{CM}$ to about $v_{par}=v_{proj}$.

Such results are consistent with a sort of projectile *crumble* breakup occurring in a semi-transparent medium.

Furthermore, an emission of fragments with a large range of charges ($1 < Z < Z_{target}$) and parallel velocities centred at low values, approximately $v_{par} = 1-2$ cm/ns, is observed. Such observations can be associated (see next Section 2.1) to emissions from the excited quasi-target (QT*).

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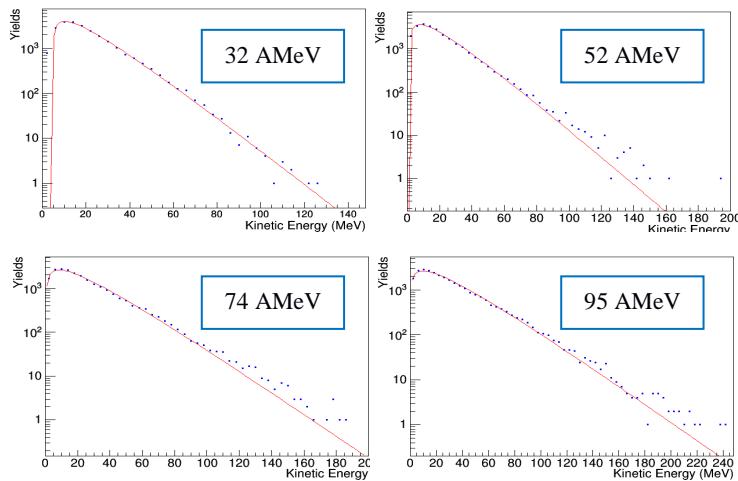


Figure 2.1.2 Energy spectra of alpha particle at 90° in the QT reference fram: solid red lines refer to Maxwellian best-fit.

(fig. 2.1.2). The solid red lines refer to Maxwellian best-fits. To avoid contaminations by other non-QT sources only alpha at 90° in the center of mass of the reconstructed target are selected.

A good agreement between fits and data is observed, indicating that alpha particles are mostly evaporated from the excited target, and temperatures extracted from these fits have values ranging from 11 to 17 MeV.

3. Conclusions and perspectives

The evolution of the reaction mechanisms in central $^{36}\text{Ar}+^{58}\text{Ni}$ collisions at $E/A=32-95$ MeV is studied. The identification of evaporative processes and dynamic multifragmentation and the characterization of fragments emitting sources, together with the study of the kinematics and energy spectra of reaction products emitted in very central collisions, allowed us to isolate a reaction mechanism not yet studied in such kind of reactions, and related to nuclear transparency: a fast “in medium” fragmentation of the projectile that occurs and become dominant with increasing of beam energy in the most violent collisions, where the nuclear stopping saturates (at about 45/50 AMeV) [2]. This mechanisms shows features of a process out of equilibrium, where the mass asymmetry between projectile and target nuclei plays likely an important role. We refer to such phenomenon as an “in-medium crumbling” of the projectile, i.e. a fragmentation of the projectile within the nuclear medium constituted by the whole colliding system in the overlap region. In-medium produced fragments travel through the interaction region and, while quickly escaping from it, they seem to drag the excited quasi-target along the beam direction. The latter finally undergoes an evaporative de-excitation, as it is suggested by the Maxwellian shape kinetic energy spectra of alpha particles in the QT reference frame.

In order to further explore the nature of such reaction mechanism and crumbling breakup phenomenon, it would be important to understand what parameters may favor its observation, namely the total mass of the system and its charge and isospin asymmetry. For this purpose investigations on system with the same mass but different N/Z ratio, or systems with a different mass asymmetry are in progress.

References

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