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# Comparison of fragment partitions produced in peripheral and central collisions.

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FOR THE INDRA AND ALADIN COLLABORATIONS.

a) IPN Orsay; b) GANIL

## Abstract

Ensembles of single-source events, produced in peripheral and central collisions and corresponding respectively to quasi-projectile and quasi-fusion sources, are analyzed. After selections on fragment kinematic properties, excitation energies of the sources are derived using the calorimetric method and the mean behaviour of fragments of the two ensembles are compared. Differences observed in their partitions, especially the charge asymmetry, can be related to collective energy deposited in the systems during the collisions.

## Introduction

Heavy-ion collisions at intermediate energies give access with good detection efficiency to two kind of multifragmenting sources: Quasi-Fusion (QF) sources produced in central collisions and Quasi-Projectile (QP) sources produced in peripheral collisions. Open questions are: how do the hot sources produced explore the phase diagram after their formation? How the trajectories in this phase diagram influence the de-excitation properties? For central collisions, experimental results [1] show that radial collective energy is present in addition to thermal pressure during the multifragmentation process. This presence of radial collective energy is the consequence of the compression/expansion cycle where the hot system passes through before its

multifragmentation. In the following, we shall present briefly experimental data and event selections. In a second part, a method to extract expansion energy in QP sources will be presented and their trajectories in the phase diagram will be deduced. The third part will be devoted to a comparison of fragment partitions from QP and QF sources. Finally we shall conclude and draw some outlooks.

## 1 Selection of event ensembles.

Data collected by the multidetector INDRA are used. For central collisions, we chose the Xe+Sn reaction at five bombarding energies (25, 32, 39, 45 and 50 MeV/A) performed at GANIL and for peripheral collisions the Au+Au reaction at 80 MeV/A performed at GSI. These two systems are close in size (ratio of about 1.3) and the chosen bombarding energies give a sufficient overlap in excitation energy. For both central and peripheral collisions, we only keep correctly detected and measured events which have a total detected charge greater than 80% of the system charge. Well characterized events are obtained for QF sources using flow angle selection [2] and we propose a new method of selection for QP sources [3]. In both cases fragments are defined as products with charge greater or equal to 5.

### 1.1 QF sources selection

The kinetic energy tensor is computed event by event in the centre of mass of the reaction. This global variable, provides information such as the flow angle ( $\theta_{flow}$ ) which characterizes the event main axis with respect to the beam direction. Events with  $\theta_{flow} > 60^\circ$  are kept for the five bombarding energies.

### 1.2 QP sources selection

A new selection is proposed [3] to select events with all fragments associated to the de-excitation of QP sources. The goal of that selection is to remove events which contain emissions from the participant zone which populate the same velocity space region than QP sources; indeed such emissions can blur the QP de-excitation pictures. The selection is based on a compactness criterion in the velocity space of fragments. The dedicated variable called VarDyn combines two observables (eq.1). The first one is the reconstructed velocity of the sources ( $\beta_{qp}$ ) in the centre of mass of the reaction. It provides information on the dissipation of collisions. More dissipative is the collision

lower is the  $\beta_{qp}$  value, which tends asymptotically to zero for central collisions. The second observable is the mean relative velocity between fragments ( $\beta_{rel}$ ) which is a measure of the compactness of QP events in velocity space. If one or several fragments come from the mid-rapidity (MR) region, we expect larger values than in the case where all secondary fragments are localized around the reconstructed velocity sources. The VarDyn observable is defined as the ratio between these two observables. Well defined QP sources are selected asking for the compactness criterion :  $\text{VarDyn}=\beta_{qp}/\beta_{rel}>1.5$ . Events with fragments in the MR region and the most dissipative collisions are thus rejected.

$$\beta_{rel} = \frac{2}{M_{frag}(M_{frag}-1)} \sum_{i<j}^{M_{frag}} |\vec{\beta}_i - \vec{\beta}_j| \quad \beta_{qp} = \left| \sum_i^{M_{frag}} \frac{\vec{p}_i}{E_i} \right| \quad (1)$$

$$\beta_{rel}^{(N)} = \frac{\beta_{rel}}{\sqrt{\langle Z \rangle (Z_s - \langle Z \rangle)}} \quad (2)$$

### 1.3 Choice of excitation energy as control parameter.

To compare the two sets of events corresponding to QP and QF sources, we use the excitation energy ( $E^*$ ) obtained with a calorimetric procedure. This procedure consists in an event by event total energy balance. The same algorithm and the same hypotheses on parameters are used for both QP and QF sources [3]. Then we deduce excitation energies and sizes of the reconstructed sources ( $Z_s$ ). A common  $E^*$  range between 4 and 12 MeV/A is populated by the two types of sources for which a size ratio of about 1.2-1.3 is deduced.

## 2 Radial collective energy in peripheral collisions - comparison to central collisions.

To obtain experimental information on collective radial energy in QP sources, we use the  $\beta_{rel}$  observable (previously defined in eq.1) and calibrate it using QF data from central collisions. However to take into account Coulomb and size effects we normalize  $\beta_{rel}$  with a term which takes into account both effects through the mean Coulomb energy seen by the average fragment charge of each event due to the other ones. As we are dealing with velocities we take the root square of this factor and obtain the normalized relative velocity  $\beta_{rel}^{(N)}$  (eq.2). At  $E^* \sim 5$  MeV/A, which corresponds to

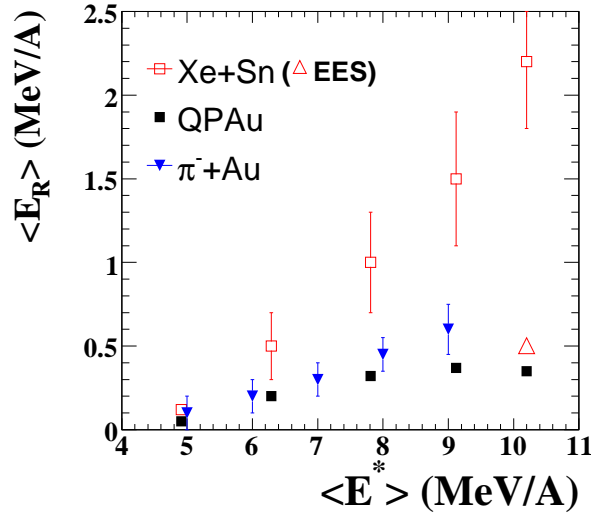


Figure 1:

the QF event ensemble of Xe+Sn at 25 MeV/A incident energy, normalized relative velocities are similar for QF and QP sources. When  $E^*$  increases, the increase of  $\beta_{rel}^{(N)}$  is stronger for QF sources. At  $E^* \sim 10$  MeV/A, which corresponds to QF events from Xe+Sn at 50 MeV/A, the mean value of the normalized relative velocity for QF sources is twice the value of QP ones. To link this observation with the amount of collective radial energy in sources, we have made a calibration of  $\beta_{rel}^{(N)}$  using four published values of collective radial energy for central collisions [1]. These values are obtained for the same Xe+Sn reactions from 32 to 50 MeV/A using a statistical model (SMM) where the collective radial energy is a free parameter and can be tuned to reproduce experimental kinetic energies. This calibration allows us to obtain an estimate of the collective energy for Xe+Sn at 25 MeV/A and for the five corresponding excitation energy values for QP sources. Figure 1 summarizes all the values of radial collective energies as a function of excitation energy. We have also added other experimental values obtained in the study of the multifragmentation of gold induced by hadrons ( $\pi^-$ ) by the ISIS collaboration [4]. In this type of reactions, a collective radial energy only due to thermal pressure is expected. For central collisions (open squares), we observe a strong correlation between excitation energy and ra-

dial collective energy whereas for QP sources (full squares), the trend is close to ISIS values, which indicates that the main part of the radial collective energy is due to thermal pressure. For the three types of reactions, we see that the onset of collective radial energy is localized around  $E^*=5$  MeV/A. Concerning the contribution to radial collective energy coming from thermal pressure for QF sources, a calculation with the EES model [7] for a source at around  $E^*=10$  MeV/A gives a value of 0.5 MeV/A (open triangles) which in the same range that the radial collective energy estimated in both QP sources (full squares) and ISIS data (full triangles). This coherence indicates a general property of nuclei : the relation between thermal pressure and thermal energy independently of the formation process.

For sources produced in peripheral collisions, the friction/abrasion process provides sources with thermal pressure only. Such sources, starting from normal density, directly enter the low density region without an intermediate step in the high density region as it is the case for central collisions. These two types of sources provide a good opportunity to track possible influences of different trajectories in the phase diagram on the fragment partitions.

### 3 Comparison of fragment partitions.

For a given excitation energy, the total charge bound in fragments ( $Z_{frag}$ ) scales with source charge ( $Z_s$ ) for both QP and QF sources. To see how the bound charge is shared among the fragments, we start comparing the charge of the biggest fragment,  $Z_1$ , in each event. Many thermostistical studies [5] indicate that  $Z_1$  is a good candidate as order parameter of phase transition in hot nuclei. We observe that its mean value is governed by excitation energy and largely independent of source sizes and production mode, which is not the case if we look to  $Z_1$  fluctuations. Indeed, on the excitation energy range studied, trends are similar but  $Z_1$  fluctuations for QP sources are larger and in good agreement with systematics reported in [6].

To go further, we propose to study the behaviour of the  $A_Z$  observable (eq.4) that we name the generalized asymmetry. It summarizes information on fragment charge partition independently of the fragment multiplicities which largely differ for QP and QF sources. The main result, comparing the behaviour of  $A_Z$ , is that partitions from QP sources are more asymmetric than those from QF sources. Since, the charge bound in fragments ( $Z_{frag}$ ) scales with the size of the source ( $Z_{source}$ ) and the mean charge of the biggest

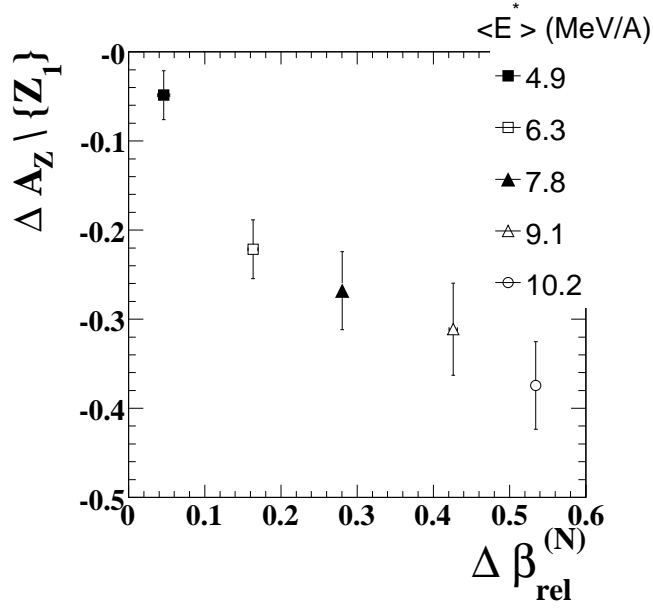


Figure 2:

fragment  $Z_1$  is quasi independent of the different sources, one must consider a possible bias due to the specificity of the largest fragment. To do that we can now take the fragment partition but without the biggest fragment in the calculation of the generalized asymmetry that we call  $A_Z \setminus \{Z_1\}$ . The effect still remains, which confirms the difference between QP and QF sources as far as charge partitions are concerned.

$$A_Z = \frac{1}{\sqrt{M_{frag} - 1}} \frac{\sigma_Z}{\langle Z \rangle} \quad (3)$$

$$\Delta O = \frac{\langle O \rangle^{Xe+Sn} - \langle O \rangle^{QPAu}}{\langle O \rangle^{QPAu}} \Big|_{E^*} \quad (4)$$

## Conclusions and outlooks.

In this work, we have used two event ensembles provided by heavy-ion collisions in the intermediate energy domain, Quasi-Fusion and Quasi-Projectile sources, to deepen our knowledge of multifragmentation. If the general behaviour of multifragmentation (total charge bound in fragments, charge of

the biggest fragment in each event) is governed by the excitation energy deposited into the sources, differences at a given excitation energy have been observed in both the kinematic properties and partitions of fragments for the two types of sources. Using previous estimates of radial collective energy in central collisions, a calibration of the normalized relative velocity for fragments  $\beta_{rel}^{(N)}$  was made. Extracted radial collective energy values for QP sources are found much lower than those of QF sources and in good agreement with data from multifragmentation reactions induced by hadrons. Such low values are compatible with radial collective energies only produced by thermal pressure. Fragment charge partitions of the two types of sources show differences in the fragmentation degree ( $A_Z$  observable) or in the charge fluctuations of the largest fragment ( $\sigma_{Z_1}$ ). To go further and link differences in trajectories in the phase diagram and partitions, we propose to study the correlation between dynamic and static observables. We define the relative difference ( $\Delta O$ ) between the mean values of a given observable  $O$  for QP and QF sources (eq.4). Taking as reference the QP ones (radial collective thermal energy only), one can obtain an estimate of compression/expansion effects for QF sources. We calculate this relative difference for  $A_Z \setminus \{Z_1\}$  and  $\beta_{rel}^{(N)}$  observables and for the five common excitation energy of sources. As preliminary result, fig.2 shows a strong correlation which indeed indicates that radial collective expansion is responsible for more symmetric fragment partitions in multifragmentation of QF sources.

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