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First applications of the HIPSE event generator

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Abstract

The predictions of an event generator, HIPSE (Heavy-Ion Phase-Space Exploration), dedicated to the description of nuclear collisions in the intermediate energy range, are compared with experimental data collected by the INDRA and INDRA-ALADIN collaborations. Special emphasis is put on the kinematical characteristics of fragments and light particles at all impact parameters for the system Xe+Sn between 25 and 80 MeV/u.

1. Introduction

In view of the complexity of the processes occuring during nuclear reactions, a dedicated phenomenological model has been developed and compared with experimental data obtained within the INDRA and INDRA-ALADIN collaborations. Details concerning the description of the model may be found in [1, 2]. In order to test and validate the assumptions of the model and to put contraints on the free parameters of the generator, comparisons between the model and the experiment have been performed for the system Xe+Sn from 25 to 80 MeV/u bombarding energy [3, 4, 5, 6, 7, 8].

2. Brief presentation of the experimental data

In order to test the model at various impact parameters, three different cuts have been applied both to the data and to the simulation. These cuts, more and more severe, tend to sample more and more central collisions.

(a) Minimum bias events: these are events where at least 10% of the total charge and total linear momentum along the beam axis (for charged particles) have been detected. The largest part of the total cross section is thus considered.

(b) 'Complete' events: the second selection of the data has been performed using the completeness criterium that has been mostly used by the INDRA collaboration. It requires that at least 80% of the total charge and total linear momentum (for charged particles) be detected. This is a necessary condition to perform an event by event analysis, in particular for the study of mid-central and central collisions for which fragmentation is a dominant decay mechanism.

(c) Complete 'central' events: in addition to the preceding completeness criterium, a sorting is applied by means of an additional global variable. A momentum tensor analysis is developped. The diagonalization of the tensor gives three eigen-values on which several sorting variables may be defined. Here, we have used the flow angle θ_{flow} that corresponds to the angle between the main axis of the tensor and the beam axis. It is generally expected that large values of the flow angles correspond to more violent collisions and thus select smaller impact parameters. In the following, we consider events for which we have $\theta_{flow} > 30°$ [4, 9].

In order to evaluate the degrees of centrality for each selection, we show on Fig .1 the impact parameter distributions given by the simulation associated with the three selections in the 50 MeV/u case. Note that the results of the calculation have been filtered with help of the software filter of the INDRA detector. As expected, the selection (**a**) is associated with the full range of impact parameters up to the grazing angle, although there, the geometrical acceptance of the INDRA detector is limited and thus reduces strongly the number of events. The completeness criterium (**b**) induces

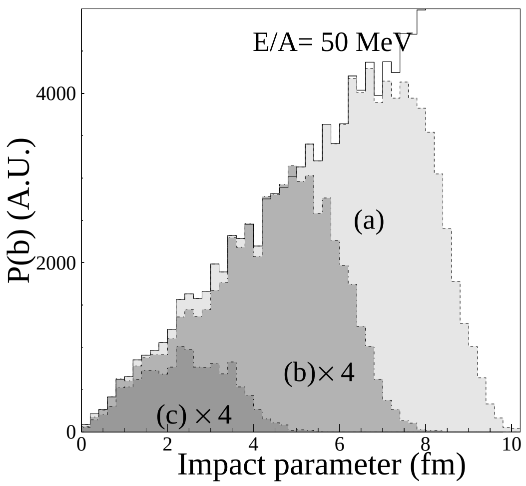

Figure 1: Impact parameter distributions for the reaction ^{129}Xe+^{120}Sn at 50 MeV/A as given by the model filtered by the INDRA filter software. Unfilled histogram: all simulated events. Other histograms are labelled according to the selection discussed in the text. Note that, in cases (**b**) and (**c**), the distributions have been multiplied by a factor 4

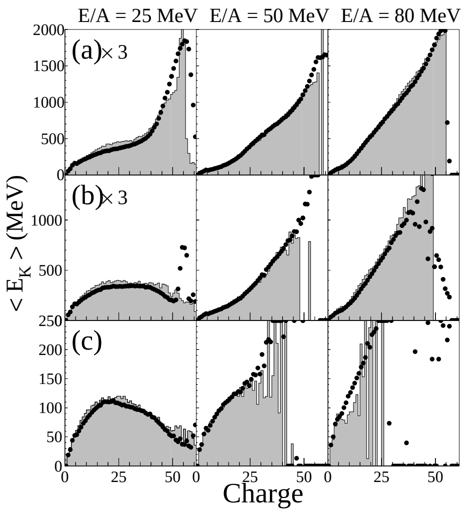

Figure 2: Mean kinetic energy in the center of mass as a function of the charge Z: experimental data (black points), simulated data (filled histograms). Reactions are indicated on top of each panel. Selections are **(a)**, **(b)** and **(c)** respectively from top to bottom.

a rather strong reduction factor in the event acceptance and is dominated by mid-peripheral collisions. The last selection (**c**) is, as expected, associated with the most central collisions.

3. Atomic number and kinetic energy distributions

To address the kinematics of the reaction, we show in Fig. 2 the mean center-of-mass kinetic energy of the fragments as a function of the atomic number Z. The experimental data (black points) are directly compared with the results of the calculation (solid line) after filtering. Different beam energies (25, 50 and 80 MeV/u) and selections (**a**), (**b**) and (**c**) are presented. The kinetic energy distribution is nicely reproduced over the whole atomic number range and for all selections. Note that a quite remarkable agreement is reached for light fragments. These latter originate both from the initial partition at freeze-out and from the secondary de-excitation of heavier species. A closer look at the velocity of light fragments shows the competition between these two production modes.

Selection **(a)** is dominated by peripheral collisions, the kinetic energy of heavy fragments ($Z \geq 20$) thus corresponds essentially to the Quasi Target (QT) and Quasi Projectile (QP) dynamics after de-excitation. At 25 MeV/u, small deviations for atomic number near 20 is due to an over-estimate of the QP fission process. In our calculation, it appears that the mean kinetic energy is sensitive to the initial nucleon exchange as well as to the hardness of the potential. However, the dependance on the parameters is much less important as far more central collisions are concerned.

At low incident energy, the phase of re-aggregation is important because the relative velocity between the nascent fragments may not be large enough to overcome the nuclear potential. At hight energy, the phase of re-aggregation is less effective and, as such, the reaction ressembles very much the 'pure' participant-spectator picture. Note that, without the possible strong chemical reorganisation during the first instants of the reaction (phase of re-aggregation), it is not possible to properly describe the fusion-evaporation process at low energy. Indeed, values of α_a (corresponding to the hardness of potential) and x_{tr} (the rate collective energy and the deformation needed in statistical approaches is taken into account naturally by the persistence of the entrance channel.

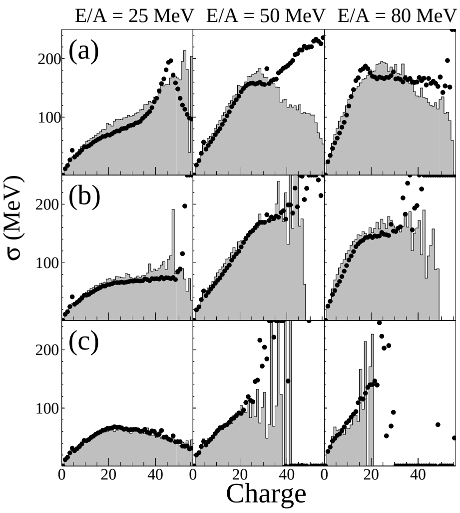

Figure 3: Width of kinetic energy in the center of mass distribution as a function of the charge Z: experimental data (black points), simulated data (filled histograms). Reactions are indicated on top of each panel. Selections are **(a)**, **(b)** and **(c)** respectively from top to bottom.

of exchange of nucleons between the target and the projectile) have been mainly adjusted to reproduce Fig. 2.

For central collisions (**a**), the main effect explaining the kinetic energies is the coupling of the intrinsic motion of the nucleons with the relative velocity between the two partners of the reaction.

To go further, Fig. 3 shows the width σ of the fragment kinetic energy distribution as a function of the atomic number Z. As in the previous figure, different selections and beam energies are presented, and again a good agreement between the data and the model is obtained. For central collisions, where the multifragmentation process is dominant, the kinetic energy and angular distributions keep a strong memory of the entrance channel. Our results underline the importance of the relative momentum between the two partner of the reaction as well as the role of the impact parameter mixing. The main effects explaining the width of kinetic energy distribution at the end of the process is the intrinsic motion of the nucleon (Fermi distribution) because of the frozen density approximation assumed in the model. In our picture, the origin of kinetic energy fluctuations is to a large extent non-thermal. Note that both the

4. Light particles and mid-rapidity emission

Fig. 4 shows the light charged particle mean multiplicity and the associated variance per event from protons to alpha's. Here again, a good agreement is achieved. Experimentally, light particles are produced either in the early instants of the collision (pre-equilibrium emission) (see for instance [10]), or by evaporation of "sources" on longer time scales.

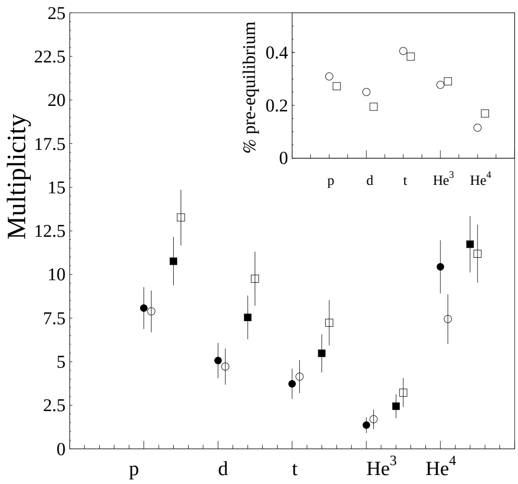

Figure 4: Mean multiplicity per event and the associated variance (error bars) for light particles for Xe+Sn at 50 MeV/u (circles) and 80 MeV/u (squares). Black points: experimental data. Open points: HIPSE data. In the insert, we have reported the percentage of pre-equilibrium emission for each species.

This is also the case in the HIPSE generator. In particular, the evaporation by excited fragments is considered in the de-excitation/propagation phase. A particular interest may be found in the determination of the rate of pre-equilibrium emission. An example of the percentage of pre-equilibrium emission given by the simulation is shown in Fig. 4. At least, thirty percent of the total light particles is emitted in the early instant of the reaction: those are particles which are present in the partition at freeze-out. A large part of these particles result from early nucleon-nucleon collisions. In particular, particules emitted earlier are located near mid-rapidity. Without taking account nucleon-nucleon collisions, it is not possible to reproduce such an effect. The percentage of nucleon-nucleon collisions (a free parameter in our model) has thus been mainly adjusted by considering the correlation between the kinetic energy and the emission angle (not shown here).

In view of the general agreement of the HIPSE model with the data, the model appears to be a valuable tool for detailed analysis such as calorimetry, thermometry or isoscaling studies.

5. Conclusions

First comparisons between the HIPSE event generator and INDRA data have been presented in order to test and validate the assumptions of the model. Considering the kinematical characteristics of the fragments, we have shown that the collective motion finds its origin both in the intrinsic motion of the nucleon and in the relative momentum between the two partners of the reaction suggesting a fragmentation process with a strong memory of the entrance channel. Moreover, the model gives informations on the phase space explored during the collision as for example pre-equilibrium emission. It also allows a direct access of the partition at freeze-out (in terms of excitation energy, angular momentum, impact parameter...) before secondary decay.

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