Determination of initial conditions of projectile fragmentation from transport model calculations

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Projectile fragmentation is a practical tool for producing radioactive ion beams in the laboratory and remains a very active field of research both experimentally and theoretically. In recent years we proposed a model for projectile fragmentation [1] which could successfully explain different experimental observables. In initial stage of the reaction, depending upon the impact parameter projectile like fragments (PLF) of different masses are produced and its excitation is often characterized by a temperature at freeze-out condition. The main limitations of this model are (i) PLF size is calculated from straightline geometry and (ii) temperature profile is parameterized with the help of experimental data. In this work we have determined the PLF mass and its excitation directly from transport model based on Boltzmann-Uehling-Uhlenbeck (BUU) calculation [2, 3].

To start the transport model calculation the ground state energy and the corresponding phase space density of the projectile and target nuclei are calculated by Thomas-Fermi (TF) method. The mean field potential energy density is [3]

$$u(\rho(\vec{r})) = \frac{A}{2}\rho^2(\vec{r}) + \frac{B}{\sigma+1}\rho^{\sigma+1}(\vec{r}) + \frac{1}{2}\rho(\vec{r})\int d^3r' v(\vec{r},\vec{r'})\rho(\vec{r'}) \qquad (1)$$

where,

$$v(\vec{r},\vec{r'}) = V_0\frac{e^{-|\vec{r}-\vec{r'}|/a}}{|\vec{r}-\vec{r'}|/a} \qquad (2)$$

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We choose to do ^{58}Ni on ^{9}Be reaction with beam energy 140MeV/n (MSU experiment). The transport calculation is done by test particle method (N_{test} =100) in a $25\times25\times33 fm^3$ box in the projectile frame. In addition to original velocities (calculated by TF method), the target test particles are boosted with the beam velocity in the negative z-direction. Positions and momenta of the test particles were updated every $\Delta t = 0.3 fm/c$ (Vlasov propagation) by the equations

$$\vec{r}_i(t+\delta t) = \vec{r}_i(t) + \Delta t\frac{\vec{p}_i}{m} \qquad (3)$$

$$\vec{p}_i(t+\delta t) = \vec{p}_i(t) - \Delta t\nabla u(\vec{r},t) + C \qquad (4)$$

where C represents the contribution of nucleon-nucleon collision to change the momenta of test particles (see App. B. of [2]). Now we exemplify our method for ^{58}Ni on ^{9}Be at impact parameter b=4 fm. Fig. 1 shows variation of $\rho_z(z)$ {$=\sum_{x,y}\sum_{i=1}^{AN_{test}} S(\vec{r}_\alpha - \vec{r}_i)$,

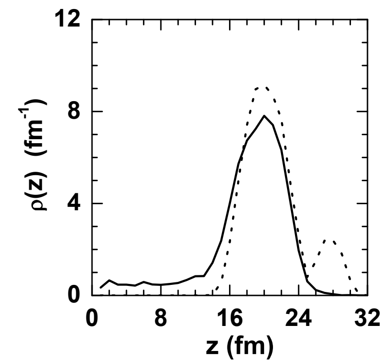

FIG. 1: $\rho_z(z)$ variation with z at t=0 fm/c (dashed line) and 50 fm/c (solid line) for $b = 4$fm.

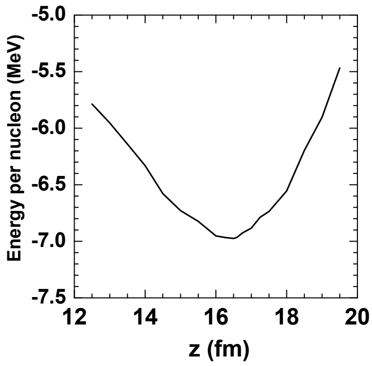

FIG. 2: Energy per nucleon of the test particles remains right side of the separation (z) for $b = 4$ fm studied at $t = 50$ fm/c.

see [3] for details} as a function of z at t=0 (when the the nuclei start to approach each other) and at t=50 fm/c (when ^{9}Be has traversed the original ^{58}Ni). In order to identify the PLF and to determine it's mass and excited state energy we need to specify which test particles belong to the PLF and which to the rest (participant and target spectators). At t=50 fm/c, let us consider constructing a wall at z=0 and pulling the wall to the right. As we pull we leave out the test particles to the left of the wall. With the test particles to the right of the wall we compute the number of nucleons and the total energy per nucleon. The number of particles goes down and initially the energy per nucleon will go down also as we are leaving out the target spectators first and then the participants. At some point we enter the PLF and if we pull a bit further we are cutting off part of the PLF giving it a non-optimum shape. So the energy per nucleon will rise. The situation is shown in Fig. 2. The point which produces this minimum is a reference point. The test particles to the right are taken to belong to PLF. The entire calculation is repeated at each impact parameter. Fig. 3.a shows the variation of PLF mass with impact parameter calculated from this method and its comparison with earlier used geometrical method result[1].

Our second aim is to determine the excitation of the PLF. Hence, we again use the TF method for a spherical (ground state) nucleus having mass equal to the PLF mass. Subtracting the ground state energy from excited state energy the excitation is obtained. Knowing the mass number and the excitation we use the canonical thermodynamic model [4] to deduce the temperature. Fig.3.b shows the comparison between the temperature profile obtained from this calculation and that used in [1].

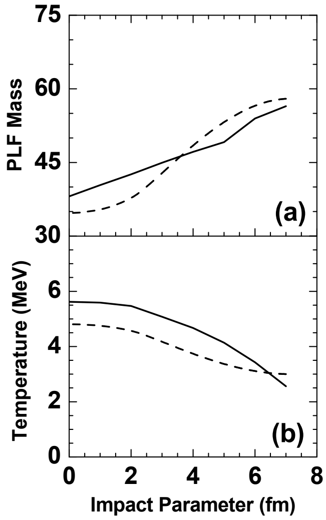

FIG. 3: (a) PLF mass and (b) Temperature profile obtained from BUU model calculation (solid lines) compared with earlier results [1] (dotted lines).

Hence we can conclude that, we successfully determine the PLF mass and temperature profile from transport model calculations without any adjustable parameters.

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