2 - 23 Fragment Charge Dependence of Transverse Flow in Heavy-ion Collisions at Intermediate Energy

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In our present study, the heavy-ion reactions of $^{40}Ca + ^{40}Ca$, $^{48}Ca + ^{48}Ca$ at 35 AMeV have been simulated by AMD(Antisymmetrized Molecular Dynamics Model) and CoMD-II(Constrained Molecular Dynamics Model-II), allowing us to avoid the risk of model dependence and obtain the general properties of transverse flow, by comparing comparing the transverse flow extracted from both AMD and CoMD models.

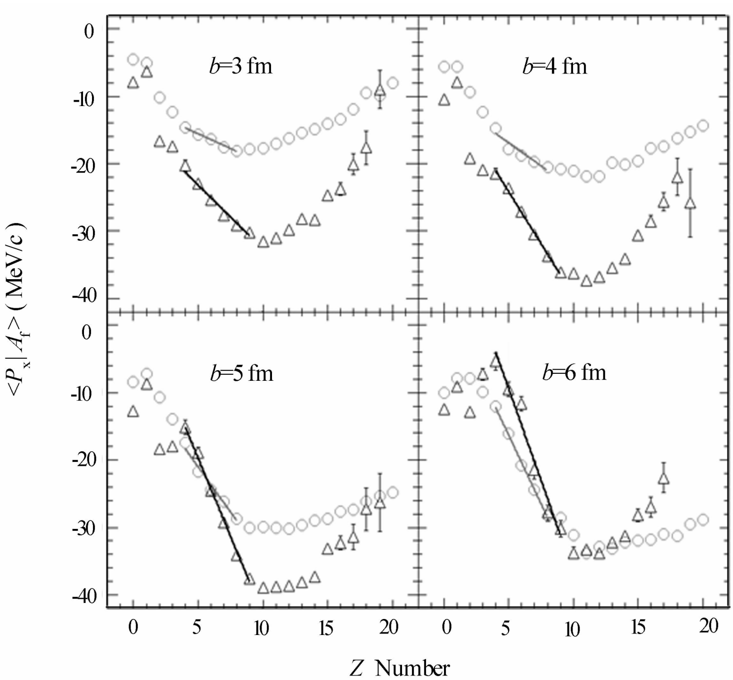

Fig. 1 The transverse flow extracted from AMD+GEMINI(△) and CoMD(○) in the reactions, $^{40}Ca + ^{40}Ca$ at 35 AMeV with b=3, 4, 5, 6 fm, as a function of Z number. —from the linear fitting, and the fitting regions are $4<Z<9$ for AMD+GEMINI and $4<Z<8$ for CoMD.

Transverse flow from both AMD and CoMD simulationsare fitted with a linear function, $<P_x/A_f> = k \cdot Z + C0$. In order to give the physical interpretation of k, the transverse flow from both AMD+GEMINI and CoMD with discrete b=3, 4, 5, 6 fm is plotted in Fig. 1 as a function of Z where Z is extended up to 20, and the transverse flow from small IMFs is linearly fitted. The result in Fig. 1 exhibits a significantly larger transverse flow for all the fragments from AMD+GEMINI with b=3, 4, 5 fm, and that is consistent with Z. Kohley's simulation result from AMD+GEMINI and CoMD simulation[1]. This enhancement of transverse flow from AMD, relative to that from CoMD, is mainly due to the softer symmetry energy and weaker NN cross section used in AMD calculation which can directly affect the generation of flow, but this enhancement becomes weaker and weaker as b increases until the flow from two models equal with b= 6 fm. Without considering model-dependent effect, the flow from both AMD+GEMINI and CoMD gives the same trend, linearly increasing for IMFs(almost $4<Z<9$) and gently decreasing for heavy chargeparticles(HCPs)(almost $10<Z<20$) with the increase of Z number. Since our focus is on the slope k, here we will explain the linear decrease first. The linear decrease, for IMFs, is mainly attributed to the isotropic thermal motion superimposed upon collective motion during the dynamical evolution. As we know, transverse flow is generated at the early stage, when a compressed deformed overlapped region is formed. Then the compressed nuclear matter releases the compressive energies by expanding in the phase space. The process to release energies is also a process to distribute nucleons in both coordinate space and momentum space. So during the period of expansion, collective motion(flow) and cluster-like structures emerge. If ignoring thermal motion, single nucleons and clusters with a certain number of nucleons will move together with similar velocities, driven by the collective flow. But as we know, the nuclear reaction system has temperature so thermal motion really exists, and for a cluster with A nucleons, the velocity of the thermal motion is proportional to $(1/A)^{1/2}$ for a given temperature. That indicates the larger the cluster is, the more weakly the flow is influenced by the thermal motion, so that the transverse flow for the heavier IMFs will keep the initial flow more. Whereas due to the thermal motion, the transverse momentum distribution of free nucleons and lighter IMFs tend to be more isotropic so smaller transverse flow is obtained. In order to remove the effect of "initial state" caused by b selection and model difference on transverse flow, the fitting parameter k is divided by the initial flow value, which is supposed to be the maximum value of the transverse flow for each case. After this normalization, k_{red} should be a constant, if the temperatures of the overlapped region are almost the same for different b. Here thereduced slopes k_{red} from AMD+GEMINI and CoMD calculation with b=3, 4, 5, 6 fm are presented as a function of b in Fig. 2. k_{red} from both cases appears with the same increasing trend as a function of b in Fig. 2. That may be attributed to the limitation of the local thermal equilibrium around the mid-rapidity region. The compression in the early stage makes the overlapped region hot, and with the help of NN collisions the heat can be conducted from the non-overlapped region. Thus in this case, the larger NN cross section, larger overlapped region and longer touching time will allow the equilibrium easy to be achieved. But with the increase of b, the overlapped region becomes smaller and the touching time becomes shorter, so it becomes more difficult to pass the heat to non-overlapped region by collision. Thus, a temperature gradient is generated between $Y_{red}=0$ to $|Y_{red}|=1$. While lighter fragments all just prefer to being emitted around the mid-rapidity region. That indicates the transverse flow for heavier IMFs will be reduced more by the thermal motion, relative to that from heavier ones. So k_{red} shows a increasing trend as a function of b. Similarly, the enhancement of k_{red} from AMD+ GEMINI, rather than that from CoMD, can be interpreted that the region around $Y_{red}=0$ $(-0.5<Y_{red}<0.5)$ is easier and closer to establish thermal equilibrium in the mid-peripheral collisions because of the greater NN cross section used in CoMD calculation.

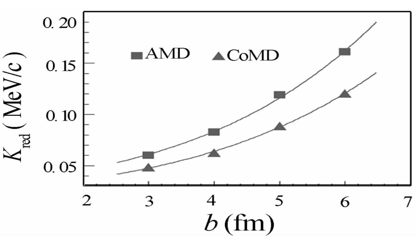

Fig. 2 The reduced slope from the fitting of transverse flow extracted from AMD+GEMINI(■) and CoMD(▲) in the reactions, $^{40}Ca+^{40}Ca$ at 35 AMeV with b=3, 4, 5, 6 fm, as a function of impact parameter b. —for guiding the eyes.

Additionally, due to the relative isotropic pre-equilibrium emission, neutrons and LCPs($Z<4$) shows obviously small transverse flow in Fig. 1. Furthermore, HCPs mainly decay from projectile-like fragments(PLFs) and target-like(TLFs) and in rapidity spectrum, PLFs and TLFs are always sitting closed to $Y_{red}=1$, so that means little longitudinal momentum is transformed into transverse momentum by the attractive mean field. But even so, since the longitudinal momentum of smaller PLFs and TLFs is much easier to turn into transverse momentum, for lighter HCPs, larger transverse flow should be extracted, relative to heavier ones. Thus, a gentlydecreasing trend isexhibited with the increase of Z HCPs. Especially the trend tends to be flatter when b increases in Fig. 1, because of the weaker attractive force produced in the smaller overlapped region.

Reference

[1] Z. Kohley, et al., Phys. Rev., C85(2012)064605.