SIDEWARD PEAK OF INTERMEDIATE MASS FRAGMENTS IN HIGH ENERGY PROTON INDUCED REACTIONS

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We study the sideward enhanced IMF emission mechanism by using a combined framework of a transport model (JAM/MF) and a newly developed Non-Equilibrium Percolation (NEP) model. We find that the sideward enhancement may emerge if the fragmentation takes place within a short time scale around 20 fm/*c*. Within this short time period, the un-heated part of the residual nucleus is kept to have doughnut shape, then the Coulomb repulsion from this shape strengthens the sideward emission of IMFs.

1 Introduction

Multifragment formation from excited nuclei formed in heavy-ion collisions has attracted much attention in these decades in relation to the nuclear matter properties.[1] The central question here — Is it statistical or dynamical ? — is, unfortunately, not completely solved yet. One of the problems is the non-trivial role of strong collective flow, which makes it difficult to relate fragment formations and the nuclear matter properties directly.

In proton induced reactions, flow effects are expected to be much smaller, and purely statistical fragmentation may emerge. Actually, fragment mass and energy distributions [2,3] are well explained in statistical models provided that well-established dynamical effects are properly included.

However, the angular distribution of Intermediate Mass Fragments (IMFs) seems to contradict to a statistical picture. As the incident energy increases, the IMF angular distribution grows from forward to sideward peaked in the laboratory frame.[2,3,4] When an equilibrated residual nucleus moving forward breaks up into fragments isotropically or with in-plane enhancement in its rest frame, the laboratory angular distribution should be forward peaked.

In this work, we investigate the non-equilibrium dynamical effects, such as the non-spherical nuclear formation,[5] which causes the sideward enhanced IMF emission in high energy proton induced reactions.

2 Non-Equilibrium Percolation Model and Calculated Results

For a description of fragment formation in high-energy ($E_p \gtrsim$ 10 GeV) proton induced reactions, there are three important ingredients to be included in the model — hadronic cascade, mean field evolution, and fragmentation. For the dynamical evolution part, we have applied a transport model, JAM/MF, which is an extended version of the hadron-string cascade model JAM [6] including the mean field parameterized recently.[7] Fragment formation processes are analyzed based on the phase space information of JAM/MF by using a newly developed Non-Equilibrium Percolation (NEP) model.[8]

In NEP, we utilize the nucleon phase space variables at the switching time $t = t_{sw}$ in JAM/MF as the initial condition. All the nucleon pairs in the residual nuclei are first connected by bonds, and the bond breaking probabilities are determined by using the total excitation energy, bond lengths, and the local excitation. As shown in the upper panel of Fig. 1, fragment mass distribution does not strongly depend on the switching time, and the characteristic U-shape curve of the experimental mass distribution [4] is well reproduced as in the standard percolation models.[9]

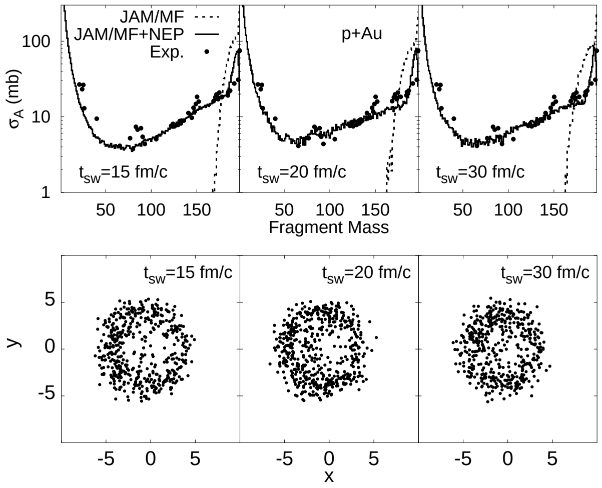

Figure 1. Upper: Switching time dependence of calculated fragment mass distributions in p(12 GeV) + Au reaction in comparison with the experimental data of p(11.5 GeV) + Au reaction. Lower: Switching time dependence of calculated IMF ($6 \leq Z \leq 20$) formation point (x, y) distribution in central ($b < 3$ fm) p(12 GeV) + Au reaction. We overlay IMF formation points in 5000 simulation events.

However, IMF formation point distribution does depend on the switching time. We find in the lower panel of Fig. 1 that IMFs ($6 \leq Z \leq 20$) are calculated to be formed mainly in the doughnut shaped region in central events for fast fragmentation. Along the leading proton path, a large part of nucleons collide with the leading proton or secondary cascade particles. Since they have large kinetic energies, they increase the bond breaking probability. As a result, the IMF formation is suppressed along the leading proton path.

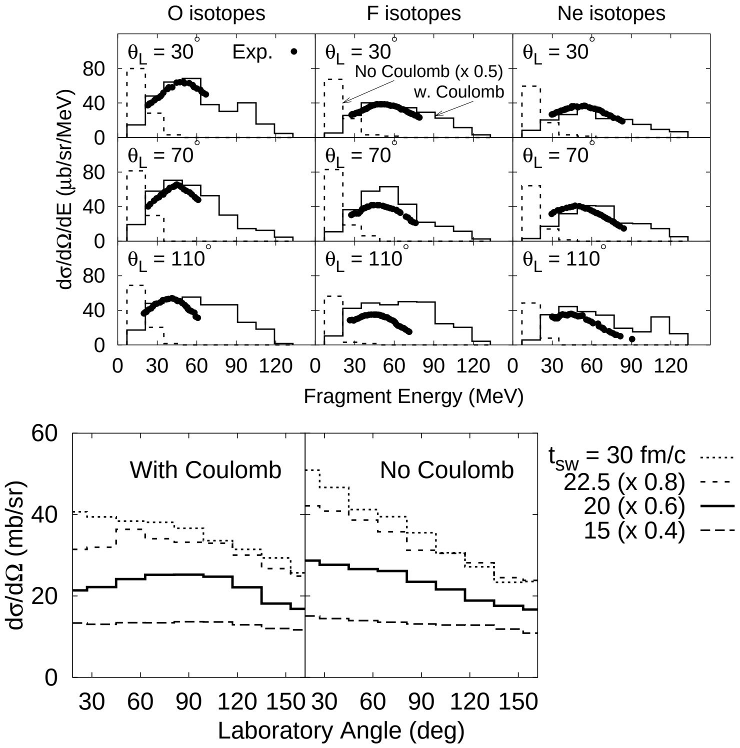

Figure 2. Upper: Calculated kinetic energy distributions of O, F and Ne isotopes at laboratory emission angles of 30, 70, and 110 degrees produced in p(12 GeV)+Au reaction in comparison with the experimental data. Lower: Calculated switching time dependence of the IMF angular distribution with (left) and without (right) Coulomb expansion.

After fragments being produced, they are pushed and accelerated by the Coulomb repulsion, and this Coulomb potential is the main source of IMF energies as shown in the upper panel of Fig. 2. The calculated results after

Coulomb expansion well reproduce the qualitative behavior of data.[2]

This Coulomb push plays an important role on the IMF angular distribution as well. When the starting configuration is not spherical but doughnut shaped, the Coulomb repulsion pushes fragments mainly in sideways. As a result, when the fragmentation time scale is short $t_{sw} \lesssim 25$ fm/c, the Coulomb repulsion modifies the angular distribution from forward peaked to sideward peaked (Lower panel of Fig. 2).

3 Summary

In this paper, we have analyzed the mechanism of sideward enhanced IMF emission by using a transport model (JAM/MF) followed by a new version of percolation model, which takes account of non-uniform nucleon spatial distribution and the local excitation in the residual nucleus (NEP).[8] We find that IMF angular distribution can be sideward peaked, if IMFs are formed within a short time scale around 20 fm/c, due to the combined effects of doughnut shaped IMF formation point distribution and the Coulomb repulsion.

Understanding of the incident energy dependence of the IMF angular distribution and the mechanism of fast fragmentation in dynamical models would be remaining interesting problems.

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