Unified Description of Nuclear Stopping in Central Heavy-ion Collision from 10A MeV to 1.2A GeV

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The detailed analysis of wide excitation function of nuclear stopping has been studied within a transport model, Isospin-dependent Quantum Molecular Dynamics model (IQMD) and an overall good agreement with the INDRA and FOPI experimental data has been achieved. It is found that mean value of isotropy in central Heavy-Ion Collision (HIC) reaches a minimum near Fermi energy and approaches a maximum around 300 - 400A MeV. This suggests that, in statistical average, the equilibration is far from being reached even in central HIC especially near Fermi energy. A hierarchy in stopping of fragments, which favors heavy fragments to penetrate, provides a robust restriction on the global trend of nuclear stopping and could serve as a probe for nuclear equation of state.

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I. INTRODUCTION

The equation of state (EOS) of nuclear matter and its transport mechanisms are the focus of Heavy-ion Collisions (HIC) during the past three decades 1-8. Before the early 1980s, hydrodynamics approaches based on the local equilibration postulate were provided to extract the EOS information from experimental observables 9. The discovery of collective flow seems to confirm these approaches and their corresponding equilibration conditions. With the development of microscopic transport theories, it is found that the local equilibration postulate is not indispensable. Actually, near Fermi energy, both statistical and dynamical models which are based on very different, even contradictory mechanisms can predict the same multifragmentation phenomenon 10.

During central HIC process, the nuclear stopping governs most of the dissipated energy and constrains the different reaction mechanisms at different incident energies. It can provide the information on the EOS, nucleon-nucleon (N-N) cross section and the degree of the equilibration reached in HIC 11–20. Recently, INDRA and ALADIN Collaborations investigated event-by-event nuclear stopping in central HIC at intermediate energies by 4π multidetector 12. In the experiment 12, a striking minimal stopping at 40A MeV (Fermi energy) for Xe+Sn system was observed. These experimental results are potential to provide important information about the properties of the nuclear matter and help to find out critical clues for the whole dynamical process during HIC. In previous comparison between experimental results and one isospin-dependent Quantum Molecular Dynamics model (IQMD) simulations 13, a significant difference between them is observed. In the experiment 12, below 70A MeV, they show the experimental data far below the IQMD simulation results and argued that IQMD model overpredicts nuclear stopping power at low energy. However, before comparing the experimental results quantitatively with that of transport model, two important ingredients should be carefully considered. One is the difference between nucleon phase space (the momentum and positions ensemble of all nucleons) and fragment phase space (the momentum and positions ensemble of all fragments) in IQMD, and the other is the criterion of the centrality in the experiment. After considering these two ingredients, we find that the nuclear stopping could be served as a potential probe for determining the nuclear EOS.

This article is organized as following: After introducing some details on IQMD model in Sec.II, two ingredients are reconsidered in Sec.III: one is the difference between nucleon phase space and fragment phase space and the other is the impact parameter mixing. Then we compare the simulation results of IQMD with INDRA’s experiments near Fermi energy as well as FOPI’s at higher energy in Sec.IV. Summary and conclusions are given in Sec.V.

II. ISOSPIN DEPENDENT QUANTUM MOLECULAR DYNAMICS (IQMD) MODEL

The Quantum Molecular Dynamics (QMD) 21 model, is a n-body theory, to predict the behavior of HIC at intermediate energies on an event by event basis. The IQMD 22,23 model, as inheriting from the QMD model, considers the isospin effects at various aspects: different density distribution for neutron and proton, the asymmetry potential term in mean field, experimental cross-section for nucleon-nucleon ($\sigma_{np}$ $\approx$ 3$\sigma_{pp}$, $\sigma_{pp}$ = $\sigma_{nn}$) and Pauli-blocking for neutron and proton separately. Just like in QMD, each nucleon wave function is represented
as a Gaussian form in IQMFD, which defined as:

\[ \phi_i(\vec{r}, t) = \frac{1}{(2\pi L)^{3/4}} \exp\left[-\frac{(\vec{r} - \vec{r}_i(t))^2}{4L}\right] \exp\left[-\frac{i\vec{p} \cdot \vec{p}_i(t)}{\hbar}\right]. \]  

(1)

Here \( L \) is the width parameter for the Gaussian wave-packet, which is found to be dependent on the size of the reacting system, to constrain the stability of system. We use \( L = 2.16 \text{ fm}^2 \) for Xe+Sn system. The \( \vec{r}_i(t) \) and \( \vec{p}_i(t) \) are the position and momentum coordinates of nucleon. Performing variation method, equations of the time evolution of the mean position \( \vec{r}_i(t) \) and momentum \( \vec{p}_i(t) \) are found to be well known Hamilton equations of motion:

\[ \dot{\vec{r}}_i = \frac{-\partial(H)}{\partial\vec{p}_i} \quad \text{and} \quad \dot{\vec{p}}_i = \frac{\partial(H)}{\partial\vec{r}_i}, \]  

(2)

where \( \langle H \rangle \) is the Hamiltonian of the system. So now the problem is to calculate the Hamiltonian of the system.

After applying the Wigner transformation to the single nucleon wave function, one can get Wigner distribution function to describe a single nucleon density in phase space defined as:

\[ f_i(\vec{r}, \vec{p}, t) = \frac{1}{\pi^3 h^3} \exp\left[-(\vec{r} - \vec{r}_i(t))^2/\pi^2 h^2\right] \exp\left[-(\vec{p} - \vec{p}_i(t))^2/2\hbar^2\right], \]  

(3)

and the total density of the system is the sum over all the nucleons.

Then we can get total Hamiltonian in IQMFD model:

\[ \langle H \rangle = \langle T \rangle + \langle V \rangle, \]  

(4)

where the meanfield part is

\[ \langle V \rangle = \frac{1}{2} \sum_i \sum_{j \neq i} \int f_i(\vec{r}, \vec{p}, t) V^{ij} f_j(\vec{r}', \vec{p}', t) d\vec{r} d\vec{r}' d\vec{p} d\vec{p}'. \]  

(5)

In QMFD model, the two-body potential interaction contains the Coulomb interaction and the real part of the G-Matrix. The later one can be divided into three parts: the contact Skyrme-type interaction, a finite range Yukawa-potential, and a momentum dependent part. Mathematically, the two-body potential interaction can be written as:

\[ V^{ij} = G^{ij} + V_{Coul}^{ij} \]

\[ = V_{\text{Skyrme}}^{ij} + V_{\text{Yuk}}^{ij} + V_{\text{ndi}}^{ij} + V_{\text{Coul}}^{ij} \]

\[ = t_1 \delta(\vec{x}_i - \vec{x}_j) + t_2 \delta(\vec{x}_i - \vec{x}_j) \rho^{-1}(\vec{x}_i) + \]

\[ t_3 \exp\left[-(\vec{x}_i - \vec{x}_j) / \mu\right] + \]

\[ t_4 \ln^2(1 + t_5 (\vec{p}_i - \vec{p}_j)^2) \delta(\vec{x}_i - \vec{x}_j) + Z_i Z_j e^2 / |\vec{x}_i - \vec{x}_j|, \]

(6)

where \( Z \) is the charge of the baryon, \( t_1...t_5 \) and \( \mu \) are the parameters to fit the real part of G-matrix and the properties of nuclei. For IQMFD model, one additional part, the symmetry potential \( V_{\text{sym}}^{ij} \), is added to take into account the isospin effects. The total potential in IQMFD is then written as:

\[ V^{ij} = V_{\text{Skyrme}}^{ij} + V_{\text{Yuk}}^{ij} + V_{\text{ndi}}^{ij} + V_{\text{Coul}}^{ij} + V_{\text{sym}}^{ij}, \]  

(7)

where the symmetry potential

\[ V_{\text{sym}}^{ij} = t_6 \frac{1}{\rho_0} T_3 \delta(\vec{r}_i - \vec{r}_j), \]  

(8)

with \( t_6 = 100 \text{ MeV} \) for fitting the Bethe-Weizsäcker mass formula, \( T_3 \) is the isospin third projection and \( \rho_0 \) is the nuclear saturation density \((0.16 \text{ fm}^{-3})\).

We focus on the Skyrme potential, the momentum dependent potential, due to their special connection to nuclear EOS.

One can fulfill the calculation for Skyrme potential and momentum dependent in Eq. (4) by introducing the interaction density,

\[ \rho_{\text{int}}(\vec{r}_i) = \frac{1}{4 \pi L^{3/2}} \sum_j e^{-((\vec{r}_i - \vec{r}_j)^2)/(4L)}, \]  

(9)

The momentum dependent potential, which may be optional in QMFD and IQMFD, is parameterized with the experimental data, can be written as

\[ U_{\text{ndi}} = \delta \cdot \ln^2 \left( \epsilon \cdot (\Delta \rho)^2 + 1 \right) \cdot (\rho_{\text{int}} / \rho_0), \]  

(10)

where \( \delta = 1.57 \text{ MeV} \) and \( \epsilon = 500 \left(\text{GeV}/c\right)^{-2} \) are taken from the measured energy dependence of the proton-nucleus optical potential \[24\] and \( \rho_{\text{int}} = \sum \rho_{\text{int}}(\vec{r}_i) \).

The Skyrme potential is

\[ U^{\text{Sky}} = \alpha \left( \rho_{\text{int}} / \rho_0 \right) + \beta \left( \rho_{\text{int}} / \rho_0 \right)^\gamma, \]  

(11)

where \( \alpha, \beta \) and \( \gamma \) are the Skyrme parameters, which connect tightly with the EOS of bulk nuclear matter. After fitting the minimum binding energy and the compressibility at the saturation density, one can get the parameters. The nuclear compressibility, which is the second derivative of the energy at the minimum with respect to the density is expressed as:

\[ \kappa = 9 \rho^2 \frac{\partial^2}{\partial \rho^2} \left( \frac{E}{A} \right). \]  

(12)

\( \kappa = 200 \text{ MeV} \) means soft EOS, while \( \kappa = 380 \text{ MeV} \) is for hard EOS. Please see Table I the Skyrme sets of parameters for different EOS.

The other terms can be also calculated by applying the convolution of the interaction with the Wigner distribution function. After all the potential terms are determined, one can solve the equations of motion of the baryons. For the mesons, only Coulomb force is considered.

For the collisions, IQMFD uses the experimental cross-section which tell the isospin effects and nuclear medium
nucleon phase space at intermediate energy, where the nucleon phase space. While, in previous IQMD simulation by Liu. collisions and get excited to become free. In this case, the dominant role and most of nucleons suffer violent col-

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Fermi motion dominates over the others. In this case, the correlation effects to all orders and deals with fragmenta-

One definition is the energy-based isotropy ratio \( R_E \),

\[
R_E = \frac{\sum |E_{ti}|}{2 \sum |E_{li}|},
\]

where \( E_{ti}(E_{li}) \) is the c.m. transverse (parallel) kinetic energy and the sum runs over all products event by event.

One can expect \( R_E = 1 \) for isotropy or full stopping, \( R_E < 1 \) for partial transparency, and \( R_E > 1 \) for super stopping. Another definition is \( R_p \),

\[
R_p = \frac{2 \sum |p_{ti}|}{\pi \sum |p_{li}|},
\]

where momenta are used instead of energies. However, they are actually the different forms of physics realization of classical Maxwell distribution assumption.

At low energy, two-body collision between nucleons is suppressed by Pauli-blocking greatly and the mean field governs the HIC process. At freeze-out stage, the motion of a large portion of nucleons is limited in certain fragments, in which Fermi motion dominates over the others. While, at higher energy, two-body collision comes to play the dominant role and most of nucleons suffer violent collisions and get excited to become free. In this case, the fragment phase space tends to get closer to the nucleon phase space. While, in previous IQMD simulation by Liu et al. [13], the nuclear stopping was investigated from nucleon phase space at intermediate energy, where the isotropic Fermi motion still plays a great role. In comparison with the experimental data of the stopping, the fragment phase space should be applied at intermediate energy within IQMD model rather than nucleon phase space.

In Fig. 1, we show the results of stopping defined as the ratio of transverse momenta to parallel momenta \( R_p \), in nucleon phase space and fragment phase space, respectively. The scaled impact parameter, \( b_{red} \) is adopted, with \( b_{max} = 1.12(A_t^{1/3} + A_p^{1/3}) \) fm, where \( A_p \) and \( A_t \) are the mass of projectile and target, respectively. Apparently, stopping calculated in nucleon phase space reaches almost the saturated value, just like Liu’s situation [13]. While, in the case of fragment phase space, stopping become far below the saturated value and get closer to the experimental value. It underlies that, at low incident energy, nuclear stopping obtained from fragment phase space is more sensitive as compared to the nucleon phase space and tends to fill the gap between theory and experiments. At higher incident energy (above 100 A MeV), the difference between stopping presented in nucleon phase space and fragment space in IQMD, tends to get smaller. However, a minimum stopping with value 0.70 at about 55 A MeV is shown in IQMD, compared that with value 0.68 at 40 A MeV in experiment. This difference may come from the different criteria of centrality between IQMD and experiment.

To avoid autocorrelations, total charged particle multiplicity \( N_{ch} \) in the experiment [12] is chosen as the criterion of the centrality. However, the largest \( N_{ch} \) does not mean the highest centrality, due to event-by-event fluctuation. On one hand, \( N_{ch} \) gets saturated at certain centrality and then central and near central HIC provide similar \( N_{ch} \). On the other hand, due to the dynamical

| \( \alpha \) (MeV) | \( \beta \) (MeV) | \( \gamma \) | \( \delta \) (MeV) | \( \varepsilon \) (\( \alpha^2 \) GeV/V) |
|-----------|-------|--|---------|---------|
| S         | -356  | 303| 1.17    | ----    |
| SM        | -390  | 320| 1.14    | 1.57    | 500    |
| H         | -124  | 71 | 2.00    | ----    |
| HM        | -130  | 59 | 2.09    | 1.57    | 500    |

TABLE I: Parameter sets for the nuclear equation of state used in the QMD model. S and H refer to the soft (compressibility \( \kappa =200 \) MeV) and hard equations of state (compressibility \( \kappa =380 \) MeV), \( M \) refers to the inclusion of momentum dependent interaction. The results are taken from [22].

FIG. 1: (Color online) Comparison between experimental stopping values [12] (black points) and predictions of IQMD calculation in nucleon phase space (red open circle) and fragment phase space (blue up triangle) for central \(^{129}\text{Xe} + ^{120}\text{Sn}\) collision. Two lines are for guiding the eyes. IQMD adopts the hard EOS and \( b_{red} < 0.1 \).
fluctuation, \( N_{ch} \) at certain centrality presents a broad distribution. Thus, the HIC at different centralities may share the same \( N_{ch} \) with a great chance. Hence, if \( N_{ch} \) is adopted for the criterion of the centrality, it is expected that the impact parameters will suffer a great mixing and cover a wide range, which will decrease the stopping power and increase the fluctuation of the HIC system greatly.

We now use IQMD model to elucidate the impact parameter mixing situation. In the experiment \[12\], a typical cross-section of 50 mb for the most total charged particle multiplicity is taken for all HIC systems. Within the IQMD model, we calculate the mean \( N_{ch} \) and its width at head-on collision (\( b_{red} = 0 \)). Then, low limit is set as the mean \( N_{ch} \) with its half width off. In Fig. 2(a), IQMD model reproduces well the experimental results of INDRA and ALADIN Collaborations \[12\], except giving a little higher \( N_{ch} \) (note that the experimental filter is not used in the present calculation). The red dash line at \( N_{ch} = 44 \) is the low limit for central collision in IQMD which is comparable with \( N_{ch} = 36 \) in experiment. In Fig. 2(b), a mean value of stopping (\( R_E \)) around 0.6–0.7 is observed in the exact central collision, which has a decreasing trend with the increase of impact parameter. When the cut \( N_{ch} = 44 \) is applied, there is a broad distribution of impact parameter in Fig. 2(d), and a lower mean value of stopping about 0.56 with a width about 0.42 in Fig. 2(c), which is comparable with that a mean value 0.56 with a width 0.47 in experiment \[12\]. In this context, better criterion of centrality should be provided to reduce the probability of impact parameter mixing at low energy.

IV. RESULTS AND DISCUSSIONS

Taking the above two key ingredients into account, we can compare the experimental results with those of IQMD quantitatively. To have a broad view of the nuclear stopping, a systematic simulation of \( ^{129}\text{Xe} + ^{120}\text{Sn} \) is made in very central HIC (\( b_{ired} < 0.15 \)) from 10 A MeV to 1.2 A GeV to cover most of the intermediate energy range, where our results can be compared with the recent INDRA and FOPI data \[11, 17\].

It should be noted that related but different definitions of stopping are adopted by INDRA \[12\] and FOPI \[11, 17\] Collaborations, respectively. The event-by-event stopping (event level) defined as the ratio of transverse to parallel kinetic energies is adopted by INDRA and ALADIN Collaborations (i.e. \( R_E \)). While, the ratio of the variances of the transverse to that of longitudinal rapidity distribution of fragment (fragment level) is taken in the case of FOPI experiment

\[
\text{varl}_{tl} = \frac{(\Delta y_{tl})^2}{(\Delta y_{tl})^2}.
\]

Despite this, they are the same in spirit to show the global stopping power of central HIC. When a full stopping (likely to be in equilibration) is reached, both \( R_E \) and \( \text{varl}_{tl} \) are required with a value of unit.

Now we compare our results with INDRA experiment. The central (\( b_{ired} < 0.15 \)) collision of \( ^{129}\text{Xe} + ^{120}\text{Sn} \), at incident energy 50 A MeV is taken as an example. The time evolution of the stopping (defined in \( R_E \)) for various EOS are shown in Fig. 3 The stopping for different EOS presents the same trend. The stopping rises up at the early compression stage, drops down at the following expansion stage and becomes stable after the system.
reaches the freeze-out. This is consistent with the results from works of [12] and [14], which are in nucleon phase space. However, the stopping power shows EOS dependence. The hard EOS shows higher stopping than the soft EOS, during the whole time evolution. This is due to the hard EOS nuclear matter is harder to be compressed than the soft one. When compressed from the longitudinal direction, the hard EOS nuclear matter will squeeze out more than the soft one, through the transverse expansion. The momentum dependent force decreases the stopping power of the system, this may result from its repulsive nature and increasing in mean free path [22]. At this incident energy, the INDRA experimental result seems to support the soft EOS.

It may be pointed out that here the time adopted in IQMD for the freeze-out stage is 200 fm/c. At low incident energy case, the heavy fragments may still stay at an exciting state, which would deexcite themselves by emitting free nucleons, LCP and gamma rays at the later stage. Basing on this consideration, some hybrid models, a dynamical one followed by a statistical one, come into the play, such as AMD + GEMINI [25, 27] and HIPSE + SIMON [28] etc. They do fit the experimental fragment distribution very well. At the same time, the deexcitation procedure may also extend both transverse and longitudinal width of rapidity of the final fragments, which smears the original stopping at fragment level. Especially, at higher excitation stage will also emit free nucleons or LCPs, which will increase the isotropy of the system. This might be very serious for lower energy (≤ 40 A MeV) case due to more heavy fragments are left. As a compensation, the freeze-out time is delayed from 200 fm/c to 300 fm/c (or even later), but no great changes happen, except for the IMF raise their stopping value a little higher. For higher energy (≥ 100 A MeV), since there exists very few heavy fragments, it is not necessary to evolve the system with such a long time or deexcite the system with a statistical process [29].

Fig. 4 shows the excitation function of the mean value of \( R_E \) and its width \( \sigma_{R_E} \) for \(^{129}\text{Xe} + ^{120}\text{Sn} \) by using different EOS. In Fig. 4(a), the soft EOS with the compressibility of \( \kappa = 200 \) MeV is taken to show the distribution of \( R_E \) with incident energies. In Fig. 4(b) and (c), the mean \( R_E \) and its width \( \sigma_{R_E} \) show the same trends, consistent with the experimental results [12]. Scaled by 0.75, the width of stopping in the experiment of INDRA is compared with the simulation results. The broader widths in experiment could come from the impact parameter mixing, as we have discussed in Sec. II. For all the considered energy range, the hard EOS with \( \kappa = 380 \) MeV shows stronger stopping than the soft EOS. The EOS with momentum dependent interaction (MDI) [24] tends to decrease the stopping at energy below 500 A MeV. While the weight of MDI tends to vanish above 500 A MeV. Near the Fermi energy, we also observe a minimum of stopping with its minimal width for all EOS. The EOS with MDI favors more penetration and consumes less energy to reach the minimal stopping. The present experimental results seem to favor the soft EOS around Fermi energy. This also consists with recent conclusion on the soft hadronic matter basing on Kaon spectrum analysis at higher energy [6, 7]. At 300 - 400 A MeV, a maximum of stopping accompanied by its maximal width is seen for all EOS. This is comparable to the recent experimental results of FOPI collaboration [11, 17, 19].

The smaller size collision system \(^{58}\text{Ni} + ^{58}\text{Ni} \) is also investigated to see the stopping behavior and similar behaviors are found in comparison with the case of \(^{129}\text{Xe} + ^{120}\text{Sn} \), except for \(^{58}\text{Ni} + ^{58}\text{Ni} \) shows lower stopping power. It may be noticed again, the INDRA data seems to support the soft EOS case. (Fig. 5(b))

Fig. 5(a) displays the atomic number (Z) hierarchy of the degree of stopping at fragment level at different incident energies. From small fragment Z = 1 with stopping value 0.7 – 0.9 to intermediate one Z = 10 with 0.1 – 0.2,
indicating that the stopping power drops quickly as $Z$ of the fragment increases. Similar trend has been experimentally observed for central $^{129}\text{Xe} + ^{120}\text{Sn}$ collisions. Four energy points, namely 40, 100, 300 and 1200$A$ MeV are investigated. (a) and (c) shows $Z$-dependent stopping at fragment level and the yield of fragments (scaled by $Z=1$), respectively. (b) and (d) displays bi-dimensional distributions of transverse and longitudinal rapidity for different fragments at 40$A$ MeV, respectively.

It is highly expected that the hierarchy would help to determine nuclear EOS. Fig. 7 shows $Z$-dependent stopping for four different energies with different EOS in IQMD. The hard EOS case shows higher stopping at fragment level than the soft EOS one, and the MDI always makes it easy for the fragments to penetrate. At lower energy (150 $A$ MeV in Fig. 7(b)), the EOS without MDI agrees with FOPI data [11] much better ($\text{Xe}+\text{CsI}$ are similar system as $\text{Xe}+\text{Sn}$). On the contrary, at higher energy (Fig. 7(c) and (d)), to reproduce experimental data, the weight of MDI should be increased. More information could be extracted once more experimental data are provided to low down the statistical fluctuation. In addition, at energy near Fermi energy as shown in Fig. 7(a), it does deserve performing experiment to obtain $Z$-dependent stopping, which is important to understand the minimal stopping at event level at Fermi energy as well as constrain the EOS.

The atomic number dependence of stopping observable $\text{var}t_{l}$ for fragments emitted in central $^{129}\text{Xe} + ^{120}\text{Sn}$ collisions. Open symbols represent our calculations with different EOS and solid symbols with error bar denote the available experimental data [11]: (a) 45$A$ MeV (no experimental data available yet); (b) 150$A$ MeV; (c) 250$A$ MeV; (d) 400$A$ MeV.
less collision history than those inside. Thus, they would keep their original direction and compose the final heavy residues.

In very central HIC, the incident energy dependence of stopping can be understood in a unified structure based on Pauli-blocking, mean field and N-N collision. At intermediate energy, two-body collision between nucleons always increases the dissipation of the HIC system and tends to favor more isotropy. While, Pauli-blocking suppresses N-N collision at low energy, and mean field forms collective motion. This picture shows incident energy dependence. Below Fermi energy, the HIC system has enough time to reach an equilibration state because of the slow process of the reaction. Near Fermi energy, N-N collision is suppressed by Pauli-blocking greatly and nucleons tend to keep their original moving state and have an entrance effect. Meanwhile, mean field dominates HIC, and clusters are then favored. Above Fermi energy, two-body collision between nucleons comes to play the dominant role and reach their maximal effect at 300 - 400 A MeV. While, at higher energy, the mean free path of nucleon increases because of the smaller N-N cross section, thus most of nucleons will pass through with each other.

V. SUMMARY AND CONCLUSIONS

In summary, we successfully describe, for the first time, the wide-range excitation function of nuclear stopping from 10A MeV to 1.2A GeV with a transport model IQMD. A minimum of nuclear stopping value near Fermi energy and a maximum at about 300.4 MeV in very central HIC match the INDRA and FOPI data very well. The former indicates that in statistical average, equilibration state is far from being reached near Fermi energy even in very central HIC. Meanwhile, the hierarchy of stopping observable together with the yields of fragments, provides us a decomposition way to understand the whole stopping excitation function. Around Fermi energy, the soft EOS seems the best, while at energy from 250 to 400 A MeV, the role of MDI becomes important. In addition, it is also highly expected that the isospin which has been regarded to reach its equilibration the fastest at the early HIC process might also get a great penetrating in very central HIC near Fermi energy.

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