Theoretical uncertainties on the extraction of in-medium NN cross sections by different Pauli blocking algorithms

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ABSTRACT: Three typical Pauli blocking algorithms in quantum molecular dynamics type models are investigated in the nuclear matter, the nucleus, and heavy ion collisions. In nuclear matter, the blocking ratios obtained with the three algorithms are underestimated by 13%-25% compared to the corresponding analytical values. For a finite nucleus, spurious collisions occur around the surface of the nucleus owing to the defects of the Pauli blocking algorithms. In the simulations of heavy ion collisions, the uncertainty of stopping power arising from the different Pauli blocking algorithms is less than 5%.

I. INTRODUCTION

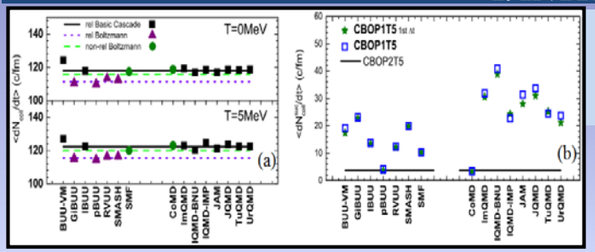

FIG.1 Attempted (a) and successful (b) collision rates [Ying-Xun Zhang, et al, PRC, 97, 034625 (2018)]

Currently, the different treatments of **Pauli blocking** is one of the reasons why the observed differences was found in the reaction path and corresponding results.

II. PAULI BLOCKING AND IN-MEDIUM NN CROSS

A. Pauli blocking algorithms

The probability $P_\tau(p_i')$ of the final state p_i' being occupied by other particles is:

1) $P_\tau(p_i') = 4\sum_{j\in\tau(j\neq i)}^{A} \exp\left(-\frac{(\vec{r}_i-\vec{r}_j)^2}{2{\sigma_r}^2} - \frac{(\vec{p}_i'-\vec{p}_j)^2}{2{\sigma_p}^2}\right)$ (PB-Wigner)

2) $P_\tau(p_i') = \frac{1}{2}\sum_{j\in\tau(j\neq i)}^{A} \exp\left(-\frac{(\vec{r}_i-\vec{r}_j)^2}{4{\sigma_r}^2} - \frac{(\vec{p}_i'-\vec{p}_j)^2}{4{\sigma_p}^2}\right)$ (PB-Husimi)

3) $P_\tau(p_i') = \sum_{j\in\tau(j\neq i)}^{A}({O_{ij}}^{(x)}/\frac{4}{3}\pi {R_x}^3)({O_{ij}}^{(p)}/\frac{4}{3}\pi {R_p}^3)$ (PB-HSP)

where, ${O_{ij}}^{(x)}$ (${O_{ij}}^{(p)}$) is the volume of the overlap region of hard spheres with the radius $R_x(R_p)$ of nucleons i and j in coordinate (momentum) space.

B. In-medium NN cross sections

The in-medium *NN* cross-section in the ImQMD model is:

$\sigma_{\rm QMD}^{\rm med} = (1+\eta(E_{\rm beam})\rho/\rho_0)\sigma^{\rm free}$

where, $E_{\rm beam}$ is the energy of incident beam.

III. RESULTS AND DISCUSSION

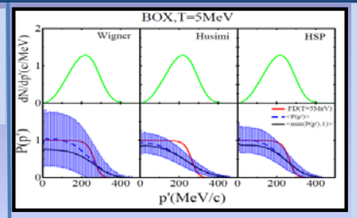

FIG.2 The distributions of momentum and occupation probabilities

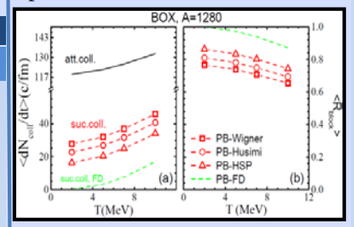

FIG.3 (a) Attempted and successful collision rates; (b) Pauli blocking ratios

In nuclear matter:
The three Pauli blocking algorithms underestimate the Pauli blocking probability in the lower momentum region and overestimate the blocking probability in the high momentum.

In nuclear matter:
To obtain the same successful collision rate from the Pauli blocking algorithms adopted in QMD and from the analytical Pauli blocking, $\sigma_{\rm QMD}^{\rm med}$ **is smaller than its true values, i.e.** $\sigma_{\rm QMD}^{\rm med} < \sigma^{\rm med}$.

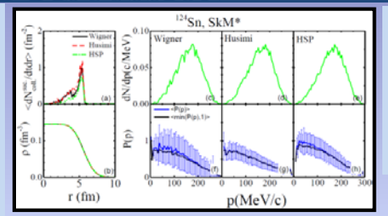

FIG.4 The distributions of successful collision rates, density, momentum and occupation probabilities

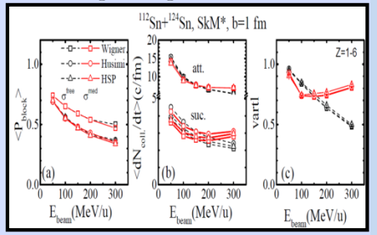

FIG.5 (a) Pauli blocking ratios; (b) attempted and successful collision rates; (c) stopping power

In finite nuclei:
The most of the successful NN collisions occur at the surface of the nucleus.

In HICs:
The uncertainty of stopping power arising from the different Pauli blocking algorithms is less than 5%.

The in-medium correction on NN is necessary and depends on the beam energy.

Ⅳ. Summary

1) In nuclear matter, all three algorithms underestimate the Pauli blocking ratio by 13%-25% at $T \leq 10$ MeV, which may lead to the extracted in-medium cross sections from QMD type models being smaller than the true in-medium cross sections.
2) In a finite nucleus, the spurious collision mainly occurs around the surface of the finite nucleus.
3) In HICs, the uncertainties of stopping power with different Pauli blocking are less than 5%. In order to produce the behaviors of the *varl* increasing with beam energy, a strong enhancement of in-medium *NN* cross sections is needed.
4) A refined Pauli blocking algorithm must be developed in the future for obtaining the true values of in-medium cross sections by comparing the HIC data with the transport model calculations.