# Nuclear Stopping, Flow and In-Medium Cross Sections

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Intermediate energy heavy ion collisions (HIC) provide usefull information about the high density behavior of the nuclear equation of state (EoS), which is very uncertain from nuclear matter models. However, such studies are a difficult topic, since the compression phase takes place in the early stage of a HIC where non-equilibrium phenomena govern the collision dynamics. The degree of compression is thereby stronlgy connected with the degree of equilibration and, therefore, non-equilibrium effects have to be considered on the level of the effective interaction [1]. This topic has been extensively investigated [1,2]. Furthermore, the compression and equilibration are influenced by 2-body scattering and thus by the stopping properties of the system [3]. It is also expected that in-medium properties of nucleon-nucleon (NN) cross sections can be studied in HIC.

We report here first results of transport calculations of HIC with in-medium modificated total and differential NN cross sections $\sigma$. The density and energy dependence of $\sigma$ is taken from a microscopic DBHF model [4] which has been used for the nuclear mean field. Fig. 1 shows the in-medium properties of np and pp cross sections used here. The case $k_F = 0$ corresponds to free 2-body scattering. Generally the in-medium cross sections are reduced due to the Pauli blocking which appears in the Bethe-Salpeter equation of the DBHF model for intermadiate states [4]. For very high energies ($E_{lab} > 0.4\ GeV$) the cross sections approach the free values.

We have analyzed central and peripheral $Au + Au$ collisions at SIS energies up to 1 $GeV$ per nucleon, where all important inelastic channels have been considered in the transport calculations (for details see [2]). Fig 2 shows the energy dependence of the scaled directed flow defined by $p_x^{dir}/(p_{proj}/A)$ where $p_x^{dir} = \sum sign(y)p_x/A$ (y is the scaled longitudinal rapidity) and the degree of stopping in terms of the observable *vartl*, the ratio of the variances of the transverse to that of the longitudinal rapidity distributions [5] (experimental data were available only for $p_x^{dir}$). It is seen that the directed flow is maximal between 0.4 and 0.6 $AGeV$. Calculations with in-medium cross sections reduce the flow due to the reduction of the effective cross sections compared to the free ones and improving the comparison with the data. The correlation with the stopping properties indicates, furthermore, that the system is more *transparent* when using effective cross sections, i.e. the stopping power is less pronounced which decreases the degree of equilibration. Recent experiments [5] support this interpretation.

In conclusion, collective flow and stopping properties of nuclear matter in HIC are a promising tool to investigate hot and dense hadronic matter with respect to their medium modifications in nucleonic enviroment. Correlation effects of flow and stopping allow to investigate the still unknown high density behavior of the nuclear mean field and the NN cross section of in-medium scattering. Our results favorize a moderate density dependence of the EoS (not discussed here) and a relatively strong reduction of effective cross sections in medium.

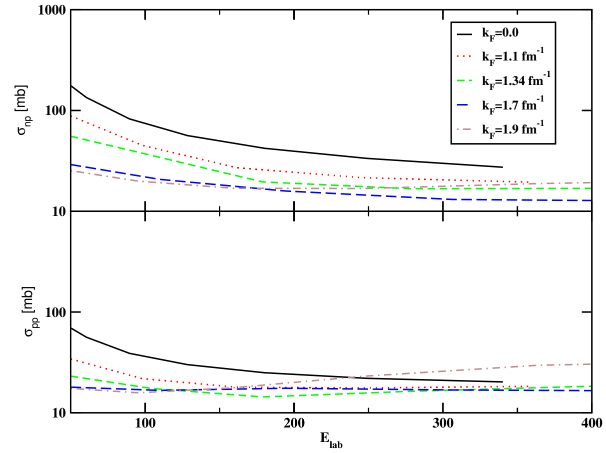


Fig. 1: Symmetry energy $E_{sym}$ vs. baryon density $\rho$ for three different model explained in the text.

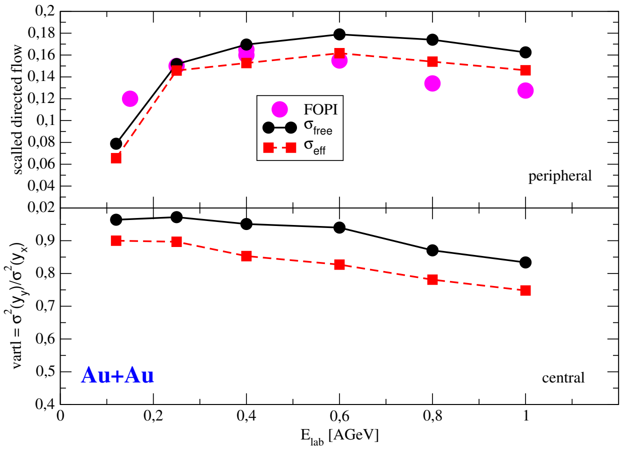


Fig. 2: Proton-neutron directed flow $F^{pn}$ (top) and elliptic flow $v_2$ (bottom) at midrapidity ($|\Delta Y| < 0.3$) vs. normalized rapidity $y_{cm}^{(0)}$ and transverse momentum $p_t^{(0)}$, respectively, for $^{132}Sn(1.5AGeV) + {}^{132}Sn$ semi-central reactions ($b = 6\ fm$).

## References

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