Energy Dependence of Nuclear Stopping at SIS Energies

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The idea of studying nuclear stopping phenomena via the 'isospin-mixing' method was introduced by Bass *et al.* [1]. This method utilizes collisions of nuclei that have the same mass, but different N/Z ratios ($^{96}_{44}$Ru and $^{96}_{40}$Zr in this analysis). It allows to extract informations on nuclear stopping directly from experimental data without resorting to the model comparison. We employed this idea at beam energies of $400A$ and $1528A$ MeV, and the $400A$ MeV results were recently published [2, 3]. In this contribution, we present preliminary $1528A$ MeV data. Together with lower energy data this allows for the first time the beam energy dependence of the nuclear stopping power obtained with the 'isospin-mixing' method.

We first present the ratio of differential rapidity distributions for the two mixed systems (distinguished by exchanging projectile and target): $R_p = N_y^{RuZr}/N_y^{ZrRu}$, where N_y^i is the proton yield in the detector acceptance at a given rapidity for Ru + Zr with $i = RuZr$ and for Zr + Ru with $i = ZrRu$, etc. This ratio behaves differently as a function of rapidity for different stopping scenarios - it raises (positive slope) for partial transparency, and falls (negative slope) for full local stopping as assumed in ideal fluid hydrodynamic scenarios ('rebound'). If full mixing of isospin has been achieved in the collision, R_p is expected to be flat as a function of rapidity. The left panel of Fig. 1 shows the experimental data at $400A$ MeV, which is qualitatively in agreement with the 'transparency' scenario for central collisions as R_p increases with the normalized rapidity $y^{(0)} = y/y_{cm} - 1$ with y_{cm} the c.m. rapidity. In the middle panel of Fig. 1, we show the rapidity dependence of the R_Z variable, $R_Z = (2N_y^i - N_y^{ZrZr} - N_y^{RuRu})/(N_y^{ZrZr} - N_y^{RuRu})$. This observable was designed to assess the differential rapidity distribution for protons relative to that of the corresponding 'calibrating' symmetric systems [2]. Note that R_Z takes $+1$ for $i = ZrZr$ and -1 for $i = RuRu$ in backward hemisphere in c.m. In the case of full equilibrium in a mixed reaction, R_Z would be equal to zero. Two solid lines in the figure ($R_Z = \pm 0.437y^{(0)}$) describe an average of both measurements and can be used to deconvolute the overall measured proton rapidity distribution for Ru + Ru into separated components for the projectile and for the target nucleons as shown in the right panel of Fig. 1. For each rapidity bin, the numbers of projectile and target nucleons can be obtained as $N_{projectile} = 0.5(1+0.437y^{(0)})N$ and $N_{target} = 0.5(1 - 0.437y^{(0)})N$, respectively. After deconvolution a shift between the two deduced rapidity distributions emerges, clearly demonstrating incomplete mixing of nucleons.

The preliminary results at $1528A$ MeV are presented in Fig. 2. In the left panel the R_p values are shown together with $400A$ MeV results. The R_p variable is steeper at $1528A$ MeV, which manifests more transparency at higher beam energy. This trend was already predicted by IQMD sometime ago [1], but the model fails to quantitatively describe the rapidity dependence of R_p at $1528A$ MeV. In the middle panel the R_Z variables for both isospin asymmetric systems are shown. Two solid lines represent the linear fit functions ($R_Z = \pm 0.856y^{(0)}$) to an average of both measurements. The deconvolution of the proton rapidity distribution into the projectile and target components in the right panel of Fig. 2 shows a larger transparency effect at higher beam energy. To be more quantitative, the nuclear mixing variable $M_{pr} = (N_f - N_b)/(N_f + N_b)$, where N_f is the number of projectile nucleons emitted forward and N_b backward in c.m., is estimated. If nuclei are more transparent, the parameter M_{pr} should be larger. M_{pr} at $1528A$ MeV is ~ 0.41 which is about a factor of two larger than that at $400A$ MeV (~ 0.21).

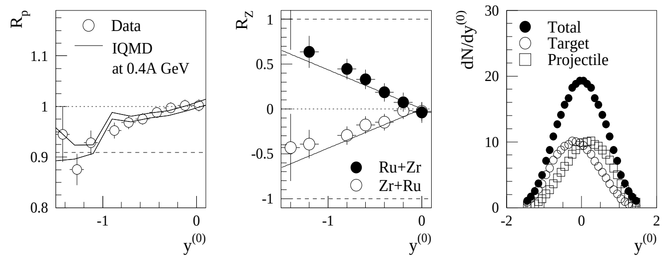

Figure 1: (Left) Comparison of the variable R_p with the IQMD calculation [4]. Solid lines are the limits estimated by IQMD with hard EoS and momentum-dependent interaction, IQMD(HM), for free NN cross section. (Middle) The parameter R_Z for both isospin asymmetric collisions Ru + Zr (solid circles) and Zr + Ru (open circles). (Right) The projectile (open squares) and target (open circles) components of protons determined by the unfolding procedure described in the text. All data points are for the impact parameter (b_{IQMD}) of 0.9 ± 0.6 fm estimated by the IQMD(HM) calculation at $400A$ MeV.

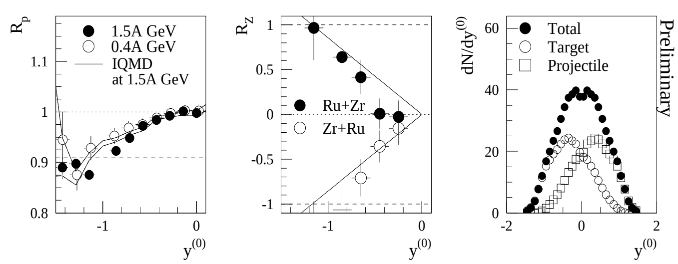

Figure 2: The same as Fig. 1, but for preliminary $1528A$ MeV data. The collision centrality is for the geometric impact parameter less than 2 fm determined by the total multiplicity.

References

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