Baryon stopping and mean rapidity-loss at FAIR energy

Needia Sharma, Joydeep Thakur and Amitabha Mukhopadhyay*
Department of Physics, University of North Bengal, Siliguri-734013, West Bengal, India

One of the main objectives of studying a high-energy collision between two heavy nuclei is the unique opportunity that it provides to examine a thermally and/or chemically equilibrated hadronic/partonic matter under extreme thermodynamic conditions. If the collision energy is moderately high, as the case will be at the Facility for Antiproton and Ion Research (FAIR), the colliding nuclei would try to stop each other, and the participating nucleons are squeezed very hard within a very small volume ($\sim 10^3\,\mathrm{fm}^3$). The kinetic energy lost by the incoming nuclei is used up to create new particles, and to generate their thermal energies and collective flow. The consequence of this energy loss is reflected as a loss in the mean rapidity of the final state baryons. The mean rapidity loss in the center-of-mass (CM) frame can be calculated by using the following equation [1],

$$\delta y = y_b - \frac{2}{N_{\mathrm{part}}} \int_0^{y_b} y \frac{dN_{B-\overline{B}}}{dy} dy \qquad (1)$$

Here y_b is the rapidity of incoming beam, N_{part} is the number of participating nucleons, and $\frac{dN_{B-\overline{B}}}{dy}$ is the rapidity density of net baryons, i.e., the difference between the number of baryons and antibaryons, chosen mainly to count the leading baryons and avoid counting the created baryons [2]. The beam rapidity (y_b) in CM frame is,

$$y_b = \ln(\sqrt{s_{\mathrm{NN}}}/m_p) \qquad (2)$$

Here m_p is the mass of a proton and $\sqrt{s_{\mathrm{NN}}}$ is the nucleon-nucleon (NN) CM energy. In the CM system y_b is the maximum rapidity that an outgoing particle can have after the collision. It is possible only in the case of fully transparent collisions or zero stopping when the collision energy is really very high, like that in the top RHIC or LHC energies. Baryon stopping can be measured from the rapidity distributions of net-protons. If antiproton production is negligibly small, net-proton rapidity distribution may be approximated to that of protons. We may then calculate the percentage of stopped protons at ($\mid y \mid < 0.5$) at a particular energy as [3],

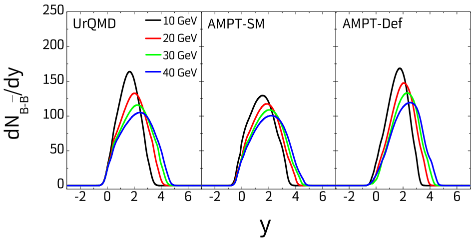

FIG. 1: The rapidity distribution of net-baryons for $(0-10)\%$ central collisions.

$$N^{\mathrm{protons}}_{\mathrm{stopped}} = \left\{ \int_{-0.5}^{0.5} \frac{dN}{dy} dy \Bigg/ \int_{-y_b}^{y_b} \frac{dN}{dy} dy \right\} \qquad (3)$$

In order to study the baryon stopping in the upcoming Compressed Baryonic Matter (CBM) experiment to be held at FAIR, we have analyzed a set of simulated data on ^{197}Au+^{197}Au collisions using the ultra-relativistic quantum molecular dynamics, UrQMD (v-3.4) [4] and a muti-phase transport, AMPT (v-2.26t9b) model [5] in its string melting (SM) and default (Def) versions at four different incident beam energies, $E_{\mathrm{lab}} = 10A$, $20A$, $30A$ and $40A$ GeV. According to Landau's hydrodynamic model [6, 7], the rapidity distribution of net-baryons follows a Gaussian-like behavior as shown in FIG. 1. It is observed that with an increase in the beam

---

[*] Electronic address: `amitabha_62@rediffmail.com`

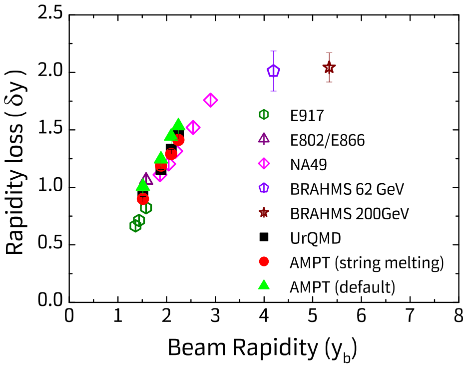

FIG. 2: Rapidity loss as a function of y_b.

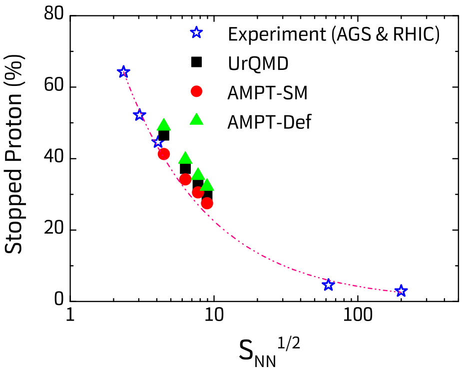

FIG. 3: Percentage of stopped protons as a function of $\sqrt{s_{\rm NN}}$.

energy, the height of rapidity distribution of net baryons decreases and the distribution becomes wider. This is expected because a collision becomes more transparent at higher collision energy. Therefore, with increasing beam energy the baryon production at higher rapidity increases, which leads to a decrease in the same at mid-rapidity. We expect that at FAIR energies baryon production will be dominated by stopped protons [7]. We have calculated the average rapidity loss (δy) using Eq. (1) at different beam energies in the CM frame and plotted them as a function of y_b in FIG. 2. Our simulation results obtained from the transport models are in good agreement with different experimental results as shown in FIG. 2. It is found that the fractional rapidity loss $\delta y/y_b \approx 0.5$ at AGS, which rises to $\gtrsim 0.6$ at SPS or FAIR (simulation), and then to drop below 0.4 at RHIC. Further to quantify baryon stopping, we have estimated the percentage of stopped protons at $(\mid y \mid < 0.5)$ at different collision energies by using Eq. (3). FIG. 3 shows the energy dependence of percentage of stopped protons in different experiments [3] along with our simulation results for the $(0-5)\%$ central collisions. The STAR experimental data points are fitted with a parametric equation like, $N^{\rm protons}_{\rm stopped} = A\exp[-B\ln(\sqrt{s_{\rm NN}/s_0})]$, where $\sqrt{s_0} = 1$ GeV, and the values of fit parameters are $A = 118.89 \pm 6.18$ and $B = 0.72 \pm 0.05$ [3]. Similar kind of variation is reproduced in our simulation study. In summary, we conclude that our simulation study on baryon stopping using microscopic transport models reproduces more or less similar results as those obtained from different experiments in the AGS to the RHIC range. AMPT-SM prediction in this regard is perhaps slightly better than either the UrQMD or AMPT-Def.

References

[1] I. C. Arsene, I. G. Bearden *et al.*, Phys. Lett. B **677**, 267-271 (2009).

[2] F. Videbaek and O. Hansen, Phys. Rev. C **52**, 2684, (1995).

[3] D. Thakur, S. Jakhar, P. Garg, R. Sahoo, Phys. Rev. C **95**, 044903 (2017).

[4] S. A. Bass et al., Prog. Part. Nucl. Phys. 41, 255 (1998).

[5] Z. -W. Lin, C. M. Ko, B. -A. Li, B. Zhang, and S. Pal, Phys. Rev. C 72, 064901 (2005).

[6] S. Z. Belensky and L. D. Landau, Usp. Fiz. Nauk. 56, 309 (1955).

[7] P. Sahoo, P. Pareek, S. K. Tiwari, and R. Sahoo, Phys. Rev. C **99**, 044906 (2019).