Correlation between elliptical flow and nuclear stopping around the transition energy in mid rapidity zone

Dhanpat Sharma* and Suneel Kumar
Department of Physics and Astrophysics
Central University of Haryana, Mahendergarh, 123031, India

1. Introduction

The study of heavy ion (HI) physics primarily seeks to explore the behavior of nuclear matter under extreme conditions, with a focus on the nuclear equation of state (NEOS). In heavy ion collisions (HIC), the mid-rapidity zone, characterized by high density, experiences significant nuclear stopping and various type of anisotropic flow. Anisotropic flow arises due to pressure anisotropy generated in non-central collisions and is often represented through Fourier expansion [1].

$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n\phi) \qquad (1)$$

where v_n represents the harmonic coefficients andϕ is the azimuthal angle. Elliptic flow, second harmonic coefficient, plays a particularly important role in intermediate-energy HI collisions, shedding light on the interplay between the nucleonic mean field and nucleon-nucleon (n-n) collisions. The sign of elliptic flow offers insight into nucleon dynamics, distinguishing between in-plane and out-of-plane flow. The energy at which elliptic flow vanishes, known as transition energy, is influenced by factors such as system mass and charge asymmetry.

HI collisions lead to the thermalization of nuclear matter, governed by both Pauli blocking and binary collisions. This thermalization is closely linked to nuclear stopping. Two central factors nucleonic mean field and nucleon-nucleon scattering cross-section are considered equally important in reaction dynamics. Our focus is on the second harmonic coefficient, elliptic flow, and its relationship with nuclear stopping around the transition energy.

*Electronic address: dhanpatsharma95@gmail.com

2. The model

In this work IQMD [2] model frame work has been adopted to simulate the $^{197}_{79}Au$+$^{197}_{79}Au$ reaction. IQMD model work in three step.

Initialization

Each nucleon represented by the Gaussian wave packet and occupies volume h^3 which is distributed in a sphere of radius $R = 1.12A^{1/3}$.

$$f_i(\mathbf{r},\mathbf{p},t) = \frac{1}{\pi^3\hbar^3}\, e^{-(\mathbf{r}-\mathbf{r_i}(t))^2 \frac{2}{L}}\, e^{-(\mathbf{p}-\mathbf{p_i}(t))^2 \frac{L}{2\hbar^2}}. \qquad (2)$$

Propagation

In IQMD model, hadrons propagate using the Hamilton equations of motion :

$$\frac{dr_i}{dt} = \frac{d\langle\ H\ \rangle}{dp_i}\ ;\ \frac{dp_i}{dt} = -\frac{d\langle\ H\ \rangle}{dr_i}, \qquad (3)$$

n-n collision

The last step is dubbed as n-n collisions in which two nucleons are supposed to be collide to each other if the distance between their centroids is less than $\sqrt{\frac{\sigma_{tot}}{\pi}}$

3. Result and Discussion

Left panel of the Fig. 1 shows the variation of $\langle V_2\rangle$ with scaled impact pa- rameter at 50 MeV/nucleon and 400 MeV/nucleon. At 50 MeV/nucleons (Fig. 1(a)), Pauli blocking plays dominating role. In the absence of high pressure gradient, longitudinal energy mainly dissipate into rotational energy of the system and due to this, nucleons can not attain high transverse energy with in a certain angle with the reaction plane. Below the semi-peripheral

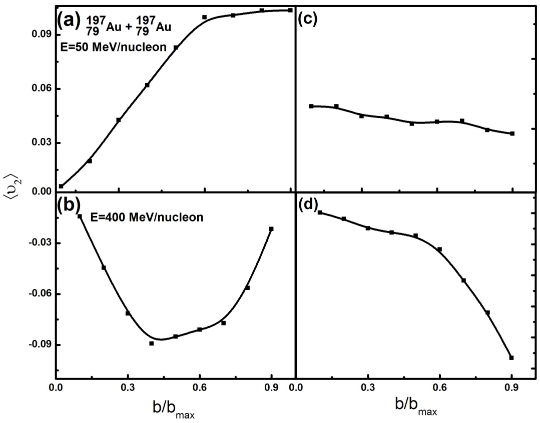

FIG. 1: Variation of elliptical flow $\langle V_2 \rangle$ and nuclear stopping $\langle R_P \rangle$ as a function of scaled impact parameter in mid rapidity range at 50 MeV/nucleon and 400 MeV/nucleon.

impact parameter, magnitude of $\langle V_2 \rangle$ is increasing positively due to more in-plane emission. And above this impact parameter, due to very small overlapping region, system does not get enough energy to rotate. Thats why, slope of $\langle V_2 \rangle$ decreases. Whereas, at 400 MeV/nucleon (Fig 1 (b)), it can be clearly seen that the magnitude of $\langle V_2 \rangle$ is negative which confirms the squeeze-out effect of the nucleons. This negative value of elliptical flow means that out-of-plane component of transverse momentum is much stronger than the in-plane component. This is because, reaction dynamics are influenced by the n-n collisions at 400 MeV/nucleon. Maximum squeeze- out emission takes place from semi central to semi-peripheral collisions and it is due to maximum energy transfer takes place from participant region to spectator region.

Right panel of the Fig. 1 shows the variation of nuclear stopping with scaled impact parameter for the nucleons at 50 MeV/nucleon and 400 MeV/nucleon. At 50 MeV/nucleon (Fig 1(c)), nuclear stopping decreases slowly with impact parameter At low incident energy interactions among the nucleons are attractive this might be due to dominance of nuclear mean field which leads to fragment

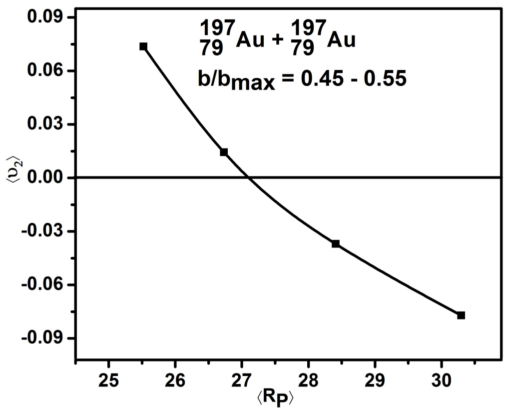

FIG. 2: Correlation between elliptical flow ($\langle V_2 \rangle$) and nuclear stopping ($\langle R_P \rangle$) aound transition energy.

phase space and hence strong role of Pauli blocking. At 400 MeV/nucleon (Fig 1(d)) going toward higher impact parameter, nuclear stopping first decreases very slowly and then above the semi-peripheral collisions, it decreases very rapidly because dissipation of longitudinal energy is very less due to very small overlapping region.

In Fig. 2, a inverse correlation has been observed between $\langle V_2 \rangle$ and $\langle R_P \rangle$ at $\hat{b}$=0.45-0.55 for $^{197}_{79}Au +^{197}_{79} Au$ reaction with increase in incident energies at 200 fm/c.

Acknowledgments

Authors are very thankful to the Prof. R. K. Puri for providing the IQMD code.

References

[1] Voloshin S & Zhang Y J. Phys. C 70 665 (1996).
[2] Hartnack C et al. Eur. Phys. J. A 1 151 (1998).
[3] Sharma D & Kumar, Journal of Physics G: Nuclear and Particle Physics 51 055102. (2023).