Dependence of anisotropic flow of net-protons on particlization model for various nuclear equation of state

Sumit Kumar Kundu[1],* Yoshini Bailung[1], Sudhir Pandurang Rode[2], Partha Pratim Bhaduri[3], and Ankhi Roy[1]
[1] *Department of Physics, School of Basic Sciences,*
Indian Institute of Technology Indore, Indore 453552 India
[2] *Veksler and Baldin Laboratory of High Energy Physics,*
Joint Institute for Nuclear Research Dubna, Moscow region, 141980 Russia and
[3] *Variable Energy Cyclotron Centre, HBNI,*
1/AF Bidhan Nagar, Kolkata 700064, India

Introduction

Relativistic heavy-ion collision experiments are conducted to explore the phase diagram in different regions of strongly interacting matter, expressed in terms of temperature (T) and baryon chemical potential (μ_B). By varying the beam energy, hot and dense QCD matter can be produced over a wide range of temperatures and densities. Upcoming experiments at accelerator facilities such as FAIR and NICA are being built to decode the QCD phase structure at moderate temperatures and high net baryon densities, by colliding heavy-ions in the energy range $\sqrt{s_{NN}}$ = 2.7–11 GeV. Prior to the commissioning of the experiments, it might be useful to carry out phenomenological studies based on theoretical models to gain insight about the properties of the dense baryonic medium, expected to be produced in this energy regime.

Previously, in [1], different variants of the ultra-relativistic quantum molecular dynamics (UrQMD) model [2], namely the pure transport(cascade) mode and the hybrid mode have been compared for Au–Au collision in mid-central (corresponds to approximately 10-40% central) region for the beam energy range E_{lab} = 1A-158A GeV. In this study, the impact of different particlization prescriptions available in UrQMD have been examined, and the results are compared to the available experimental measurements.

Model Description

The UrQMD model combines a transport approach with a (3+1)d hydrodynamical evolution for a good description of the produced hot QCD matter in heavy-ion collisions. The hybrid picture offers different configurations via three different equations of state (EoS) . i) The hadron gas (HG) EoS, which has underlying degrees of freedom similar to the pure transport approach, and proceeds via the evolution of a non-interacting 'gas' of hadrons without any phase transition. ii) The Bag Model EoS has an inbuilt first-order deconfinement phase transition from hadronic phase to a quark-gluon plasma (QGP) anticipated at finite baryon densities. iii) The chiral + deconfinement EoS refers to the employment of both chiral and deconfinement phase transitions, the latter being a smooth cross-over transition for all finite values of μ_B.

The default freezeout scenario in UrQMD proceeds in a gradual transition where the hydrodynamic cells are mapped into particle degrees of freedom according to the Cooper-Frye prescription; this scenario is termed as Gradual Freezeout (GF) which leads to a particlization via rapidity independent transition temperature without artificial time dilation effects. The hybrid mode offers employment of two other freezeout scenarios. i) In Isochronous Freezeout (ICF) the hydrodynamics fields are particlized on an isochronous hypersurface. ii) The Iso-Energy Freezeout (IEF) recipe is based on the hottest region during freeze-out, which coincides with mid-rapidities for low beam energies.

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*Electronic address: `phd1701151005@iiti.ac.in`

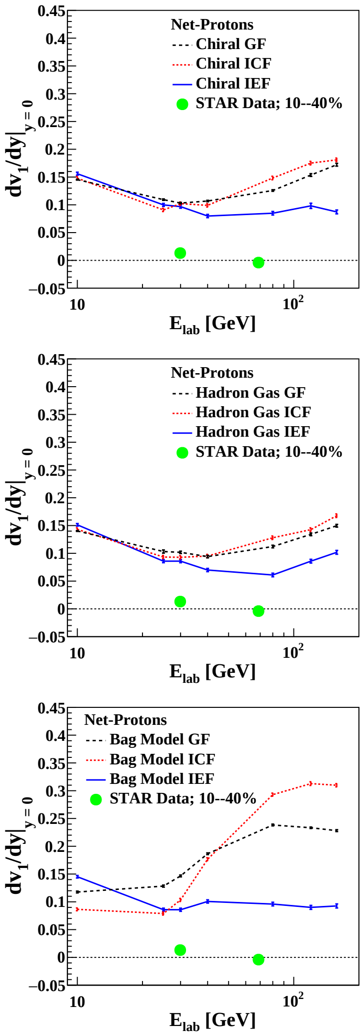

FIG. 1: Slope of directed flow of net protons as a function of beam energy at midrapidity for different hydrodynamic and freezeout modes of UrQMD for noncentral (b = 5-9 fm) Au–Au collisions with STAR experimental measurements [3].

Results

In this section, the results of our study are discussed and interpreted. To test the sensitivity of different EoS and freeze-out modes which imply different possible evolution scenarios of the produced fireball, we choose direct flow (v_1) of net-proton as our observable. Clearly, from Fig. 1, it is evident that the slope of directed flow (dv_1/dy) of net-proton at mid-rapidity show sensitivity to different freeze-out scenarios. These results are confronted by STAR experimental measurements in 10–40% Au–Au collisions [3]. Interestingly, similar sort of splitting of dv_1/dy around $E_{\rm lab}$ = 30-40 AGeV is seen as our previous study [1]. Moreover, except in case of Bag Model EoS, dv_1/dy shows similar trend and less sensitivity to GF and ICF in other two EoS cases. The slope of directed flow of net-proton for IEF has lesser magnitude at higher beam energies for all EoS and seem to be closer to the experimental measurements. Furthermore, it can be seen that below 30 AGeV, dv_1/dy show almost no sensitivity which we believe is a no surprise since the hydrodynamic evolution is unlikely to be switched on at these energies [4] and thus, no freezeout criteria is applied. More work using these different freezeout criteria is foreseen. For instance, other flow coefficient studied in [1] can further be investigated using different freezeout modes. In particular, the reduced curvature of rapidity spectra of net protons at midrapidity is worth the further investigation.

Acknowledgments

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References

[1] S. K. Kundu, Y. Bailung, S. P. Rode, P. P. Bhaduri and A. Roy, Phys. Rev. C **104** (2021) no.2, 024907

[2] S. A. Bass, M. Belkacem, M. Bleicher, M. Brandstetter, L. Bravina, C. Ernst, L. Gerland, M. Hofmann, S. Hofmann and J. Konopka, *et al.* Prog. Part. Nucl. Phys. **41** (1998), 255-369

[3] L. Adamczyk *et al.* [STAR], Phys. Rev. Lett. **112** (2014) no.16, 162301

[4] S. P. Rode, P. P. Bhaduri and A. Roy, Eur. Phys. J. A **55** (2019) no.11, 216