Concluding remarks

This thesis is based on a simulation study of some bulk properties and collective flow of charged hadrons coming out of AB collisions. Event generators like the UrQMD and AMPT (default and string melting) are used to build up AB event samples at incident beam energies that are typically expected from the SIS-100/300 accelerator(s) at the Facility for Anti-proton and Ion Research (FAIR). Though we have examined the incident beam energy dependence and system size dependence of some features of collective flow by using different collision systems, our study mainly focuses on the Au+Au interaction at $E_{\rm lab} = 30A$ GeV. Near this energy value we expect significant baryon stopping, comparable values of baryon and meson density in the final hadronic states, and an enhanced production of strangeness. Monte-Carlo Glauber model has been used to determine the initial geometry and centrality of the collisions. In this concluding section, we have summarized the major observations of our study, and have tried to identify the future scope of this kind of simulation based analysis. We believe that our investigation is going to set a good reference baseline for the experimental results on collective flow expected from the CBM-FAIR project.

We have observed a longitudinal scaling in the η-distributions of charged hadrons, and when their average transverse momentum is studied as functions of η. While the integrated yield per participant pair obtained from the UrQMD generated events follows a power law dependence on $N_{\rm part}$, that from the AMPT remains almost uniformly distributed. The UrQMD results in this regard are consistent with the prediction of a wounded nucleon model. A mass dependent flattening of the p_T-spectra confirms the presence of collectivity (radial flow) in the medium produced in AB collisions.

Collective fluid-like behaviour of hadronic matter produced under extreme thermodynamic conditions is explored from the Fourier decomposition of anisotropic azimuthal distributions of the final state particles. Particularly, the elliptic flow coefficient v_2 is of utmost importance, which allows us to examine the evolution of early stages of a high-energy AB collision. Elliptical anisotropy is found to be maximum in the mid-central and central events generated by the AMPT in its string melting configuration. The triangular flow parameter v_3 on the other hand, is very little dependent on the collision centrality, and the UrQMD model does not produce any triangular flow at all. It should be remembered that v_3 is generated only from the initial geometric fluctuations. Through out our investigation we have taken care of the initial state fluctuations, and noticed that the proper quantification of geometrical anisotropy present in the overlapping part of the colliding nuclei, is made by a participant eccentricity $\varepsilon_{\rm part}$ and not by the nuclear eccentricity $\varepsilon_{\rm std}$. We do not notice any unusual (exotic) behaviour of the flow parameters with regard to their dependences on $N_{\rm part}$, p_T or η. Rather multiplicity scaling effects are found when flow parameters are measured against particle density. In conformity with the hydrodynamic prediction, transport model simulations also preserve the mass ordering of hadrons, however a constituent quark number scaling is observed only in the string melting mode of AMPT. AMPT (string melting) also turns out to be most suitable candidate to reproduce the experimental flow results in Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ GeV available from the STAR experiment, which naively manifests the role of partonic interactions/dof even at lower beam energies. High precision CBM data are expected to shed further light on these issues.

The matter formed in an AB collision at RHIC and LHC, is thermalized within a very short time and expands collectively thereafter almost like a perfect fluid with very small value of shear viscosity over entropy (η/s). Higher partonic cross section, a parameter that can be tuned in the AMPT (string melting) model, corresponds to a lower specific viscosity (η/s). A combined analysis of v_2 and v_3 and their relative strength is believed to be capable of providing useful information related to the specific viscosity of the fireball medium. A higher partonic cross section turns out to be more efficient in transforming the initial anisotropy, either geometric or fluctuating in nature, to the final state momentum anisotropy. Triangular flow appears to be more sensitive to the partonic cross section or the specific viscosity of the medium. In contrast to the LHC results we find a strong pseudorapidity dependence of v_2 and v_3, which in our case can be attributed to the highest particle densities in the central pseudorapidity region. Moreover these observations reveals the effect of higher amount of baryon stopping expected at the FAIR energies.

We have explored the effects of hadron multiplicities, multiple rescattering and collision geometry on the collective behaviour of final state hadrons produced in small (Si+Si and Ni+Ni), medium (In+In) and large (Au+Au) sized systems at $E_{\rm lab} = 30A$ GeV. We do not notice any significant change in the properties (except differences in magnitude) of the fireball medium although the system size varies considerably. When geometric effects are scaled out, v_2 appears to be independent of the system size, an observation that manifests that within the framework of the models used, the rescattering mechanism is similar in different colliding systems. An entropy driven soft hadron production appears to be the main reason behind most of these observations. Moreover, $\varepsilon_{\mathrm{part}}$ once again turns out to be the more appropriate choice to measure geometric anisotropy.

Besides the azimuthal distribution of particle numbers and the Fourier (flow) coefficients estimated thereof, we have also investigated the azimuthal distribution of transverse or radial velocity (v_T). For a non-ideal viscous fluid, as the case may be at FAIR conditions, the shear tension is expected to be proportional to the gradient of the radial velocity along the azimuthal direction, which again is related to the anisotropy in the radial velocity distribution. We have presented the azimuthal distribution of total transverse velocity, and after removing the influence of multiplicity that of the mean transverse velocity. We observe that the dominant contribution to the final state asymmetry is coming from the multiplicity distribution and only a small fraction of it is due to the kinematic reason. Gross features of the anisotropy parameter v_2 corresponding to the transverse velocity, are similar to that measured from usual azimuthal distributions of charged hadrons, i.e., highest in mid-central collisions and linearly dependent on p_T. The azimuthally integrated value of the radial flow is maximum for the most central collisions. This observation can be explained in terms of more energy being deposited by the colliding nuclei in central AB collisions which subsequently gives rise to more radial pressure. Our simulated results are consistent with those obtained from the RHIC and LHC experiments, and do not require any new dynamics for their interpretation.

We have employed an event shape variable, called the transverse sphericity, particularly to understand the dynamics of particle production mechanism and collective flow of hadronic matter in AB collisions at $E_{\mathrm{lab}} = 30A$ GeV. The AMPT (string melting) generated events are classified into isotropic and jetty categories. The jetty events are rare (less than one in ten min. bias events) at the energy considered, but on several occasions they behave quite differently from the isotropic or minimum bias events, and the differences can not be attributed either to geometric or multiplicity reasons. We observe a crossing in the p_T-spectra of charged hadrons in the jetty and isotropic events, and the crossing point depends on the hadron mass involved. Considerable differences in the average p_T and v_2 values are observed for these two event categories. The jetty events produce significantly higher amount of elliptic flow.

In spite of the fact that a thorough simulation based analysis has been performed using microscopic transport models, we believe that until the experimental data from CBM-FAIR become available there is enough scope to further extend this kind of investigation. Firstly, one can perform a parameter scan of the models that are already used, and/or use other event generators based on transport and statistical models to compare with the present set of results. It would be quite worthwhile to see the results of a more detailed analysis, as the minimum bias event samples are segregated with respect to different hadron species and for event subsamples belonging to different event shape categories. Significant differences observed in the average transverse momentum and elliptic flow parameter values, and a hadron mass dependence of the crossing point in the p_T-spectra of hadrons, are indeed quite prospective issues in this regard. Further analysis can also be made to extract the freeze-out parameters like the chemical potential, to examine the cluster properties and to study the correlations and event-by-event fluctuations of conserved quantities. Effects of non-flow correlations is another area that has not been fully explored in this investigation.