Abstract

We present first results from a hydro-Boltzmann hybrid approach to heavy ion reactions from GSI-SIS to BNL-RHIC energies. Event-by-event fluctuations are directly taken into account via the non-equilibrium initial conditions generated by the microscopic UrQMD model. After the (3+1)-dimensional hydrodynamic evolution, the freezeout procedure is performed via the Cooper-Frye formula and a subsequent hadronic cascade calculation using again UrQMD to incorporate important final state effects.

For the results presented here we have used an equation of state for a free hadron gas without any phase transition. All hadrons with masses up to \( \sim 2 \) GeV are taken into account as in the UrQMD model. This serves as the baseline calculation for further studies with other equations of state.

Freezeout

The hydrodynamic evolution is stopped, if the energy density drops below twice the ground state energy density \( (T \sim 800 \text{MeV}/fm^3) \) in all cells. This criterium corresponds to a T-isochronous freezeout configuration where the phase transition is expected. The freezeout is performed via the Cooper-Frye formula

$$f_{\mathbf{p}}(x,p) = \frac{1}{\sqrt{2\pi m^3}} \exp \left( -\frac{m^2}{2m^2 p^4} \right)$$

where \( f_{\mathbf{p}} \) are the boosted Fermi or Bose distributions corresponding to the respective particle species. Since we are dealing with a constant time/asynchronous freezeout the normal vector on the hypersurface is \( \mathbf{n}^\tau = \left( \frac{\mathbf{p}}{E} \right) \). For the fermions and strange mesons the chemical potentials for baryon number and strangeness are taken into account. Figure 2 shows the distribution of energy in the cells at freezeout with respect to temperature and baryon-chemical potential at \( E_{\text{lab}} = 40 \) A GeV.

Results

Let us compare results from the UrQMD-hydro approach to the pure UrQMD cascade calculation. Both models are at this point purely hadronic and without any phase transition, but still very different in the assumptions for the underlying dynamics.

For the particle multiplicity (see Figure 3) from the AGS to the SPS energy regime are surprisingly similar. It seems that e.g. for the pion yield it does not matter if one employs the hadronic transport model with infinite mean free path and all the resonance and string dynamics or the relativistic one fluid model to describe the dynamics of the dense and hot phase of the heavy ion reaction. On the contrary, all strange particles are enhanced in the hydro+UrQMD approach due to the local equilibration. They are produced following the thermal distributions at the freezeout and do not interact much further in the hadronic cascade.

![Graph showing multiplicity comparison](image)

Figure 4: Rapidity and transverse mass spectra for \( \pi^- \) in Au+Au/Pb+Pb collisions at \( E_{\text{lab}} = 40 \) A GeV are surprisingly similar in both approaches as well (see Figure 4). Only at the highest SPS energy the hydro+UrQMD shows more stopping and a flatter transverse mass distribution.

![Graph showing rapidity and transverse mass spectra comparison](image)

Figure 5: Excitation function of \( |y^-| \) - \( j^- \) values for pions at midrapidity \( |y| = 0.5 \) in Au+Au (Pb+Pb) collisions from \( E_{\text{lab}} = 2 \) GeV to \( 200 \) GeV. UrQMD+Hydro calculations are depicted with full lines, while UrQMD-2.3 calculations are depicted with dotted lines. The corresponding experimental data (NA49) are depicted with symbols.

The excitation function for the mean value of the transverse mass of pions which is proportional to the temperature of the system is very different in the two calculations. The nonequilibrium UrQMD approach shows a softening of the equation of state in the region where the phase transition is expected because of the excited resonances while the hadron gas hydro calculation just raised as a function of the energy.

Acknowledgements

We are grateful to the Center for Scientific Computing (CCS) at Frankfurt for the computing resources. The authors thank Dirk Rischke for providing the HI-hydro code and Horst Stöcker for fruitful discussions. H. Petersen thanks the Deutsche Telekom Stiftung for the scholarship and the Helmholtz Research School on Quark Matter Studies for support. This work was supported by GSI and BMWF.

References