

First results from a hydro+Boltzmann approach

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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 process is performed via the Cooper-Frye formula and a subsequent hadronic cascade calculation using again UrQMD to incorporate important final state effects.

We show results for the multiplicities of different particle species in the energy range from $E_{\text{lab}} = 2$ AGeV to $E_{\text{lab}} = 160$ AGeV and compare them to previous pure UrQMD calculations and the available experimental data. The rapidity and transverse mass spectra for pions in the SPS regime are investigated in more detail. Furthermore, the excitation function of the mean transverse mass of pions is shown.

Initial State

The Ultra-relativistic Quantum Molecular Dynamics Model is used to calculate the initial state of a heavy ion collision for the hydrodynamical evolution [1]. This has been done to account for the non-equilibrium in the very early stage of the collision. In this configuration the effect of event-by-event fluctuations of the initial state is naturally included. Since many details of the UrQMD model are not relevant for the present calculation we refer the interested reader to [2, 3] for the details of the UrQMD model. The coupling between the UrQMD initial state and the hydrodynamical evolution happens when the two Lorentz-contracted nuclei have passed through each other. The initial time to begin with the hydro evolution is calculated via Eqn. 1 (and is assumed to be at least 1 fm/c). This assures that (essentially) all initial baryon-baryon scatterings have proceeded and that the energy deposition has taken place.

$$t_{\text{start}} = \frac{2R}{\gamma v} = \frac{2R}{\sqrt{\gamma^2 - 1}} = 2R \sqrt{\frac{2m_N}{E_{\text{lab}}}} \quad (1)$$

where R is the radius of the nucleus, m_N is the nucleon mass and E_{lab} is the kinetic beam energy.

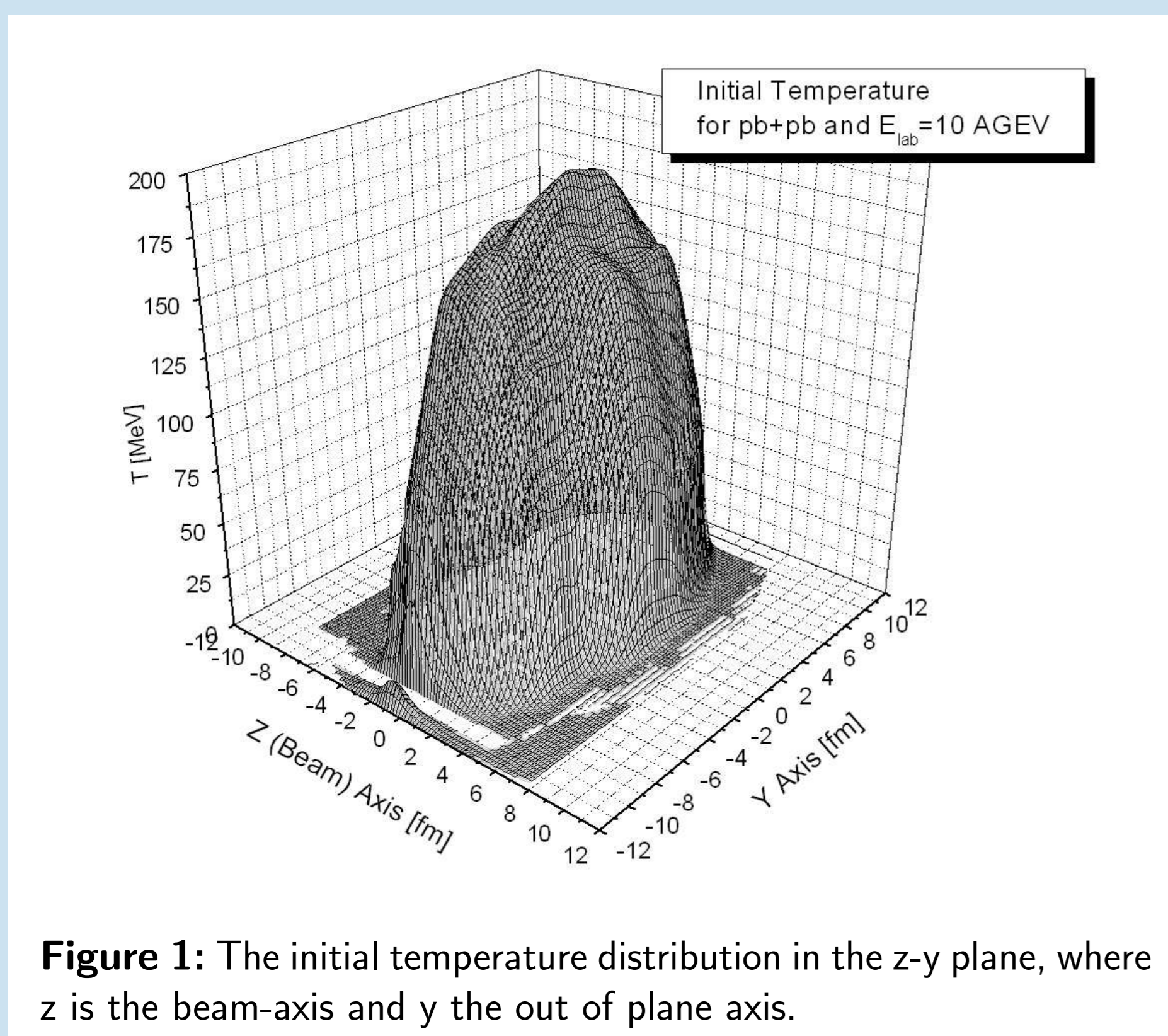


Figure 1: The initial temperature distribution in the z-y plane, where z is the beam-axis and y the out of plane axis.

To allow for a consistent and numerically stable mapping of the 'point like' particles from UrQMD to the 3-dimensional spatial-grid with a cell size of $(0.2\text{fm})^3$, each hadron is represented by a Gaussian with a finite width. I.e. each particle is described by a three-dimensional Gaussian distribution of its total energy, momentum (in x-, y-, and z-direction) and baryon number density. The width of these Gaussians is chosen to be $\sigma = 1$ fm. To account for the Lorentz-contraction of the nuclei in the longitudinal direction, a gamma-factor (in longitudinal direction) is included. The resulting distribution function, e.g. for the energy density, then reads:

$$\epsilon_{\text{cf}}(x, y, z) = N \exp \frac{(x - x_p)^2 + (y - y_p)^2 + (\gamma_z(z - z_p))^2}{2\sigma^2}, \quad (2)$$

where $N = (\frac{1}{2\pi})^{\frac{3}{2}} \frac{\gamma_z}{\sigma^3} E_{\text{cf}}$ provides the proper normalisation, ϵ_{cf} and E_{cf} are the energy density and total energy of the particle in the computational frame, while (x_p, y_p, z_p) is the position vector of the particle. Summing over all single particle distribution functions leads to distributions of energy, momentum and baryon number densities in each cell. As an example, Figure 1 shows the initial temperature distribution obtained for $E_{\text{lab}} = 10$ AGeV.

(3+1)d hydrodynamical evolution

Ideal relativistic one fluid dynamics is based on the conservation of the energy-momentum tensor and the net baryon number current. In our case, the full (3+1) dimensional hydrodynamical evolution is performed using the SHASTA algorithm [4, 5]. The equation of state is needed as an additional input to calculate the pressure, temperature and chemical potential corresponding to the energy and the baryon number densities.

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 ~ 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 five times the ground state energy density (i.e. $\sim 730 \text{ MeV}/\text{fm}^3$) in all cells. This criterium corresponds to a $T-\mu_B$ -configuration where the phase transition is expected. The freezeout is performed via the Cooper-Frye formula

$$E \frac{dN}{d^3p} = \int_{\sigma} f(x, p) p^{\mu} d\sigma_{\mu} \quad (3)$$

where $f(x, p)$ are the boosted Fermi or Bose distributions corresponding to the respective particle species. Since we are dealing with a constant time/isochronous freezeout the normal vector on the hypersurface is $d\sigma_{\mu} = (d^3x, 0)$. 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 baryo-chemical potential at $E_{\text{lab}} = 40$ AGeV.

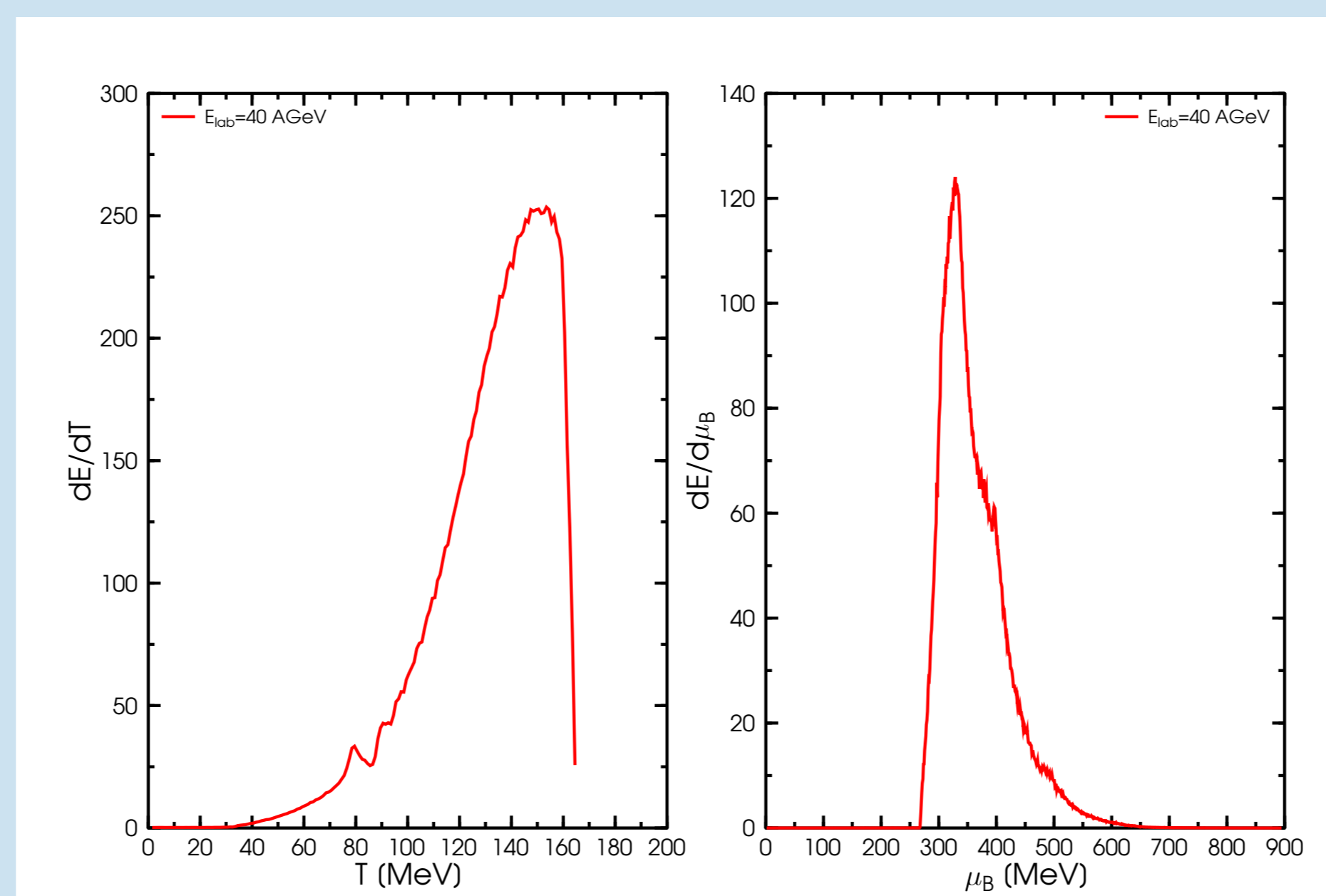


Figure 2: Distribution of the energy in the cells at freezeout at $E_{\text{lab}} = 40$ AGeV.

The particles are distributed on the grid until the initial net baryon number is reached. Strangeness and charge are also conserved in each event separately, energy conservation is fulfilled for the mean values averaged over several events. The particle vector information is then transferred back to the UrQMD model, where rescatterings and the final decays are performed using the hadronic cascade.

Results

Let us compare results from the UrQMD+hydro hybrid 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.

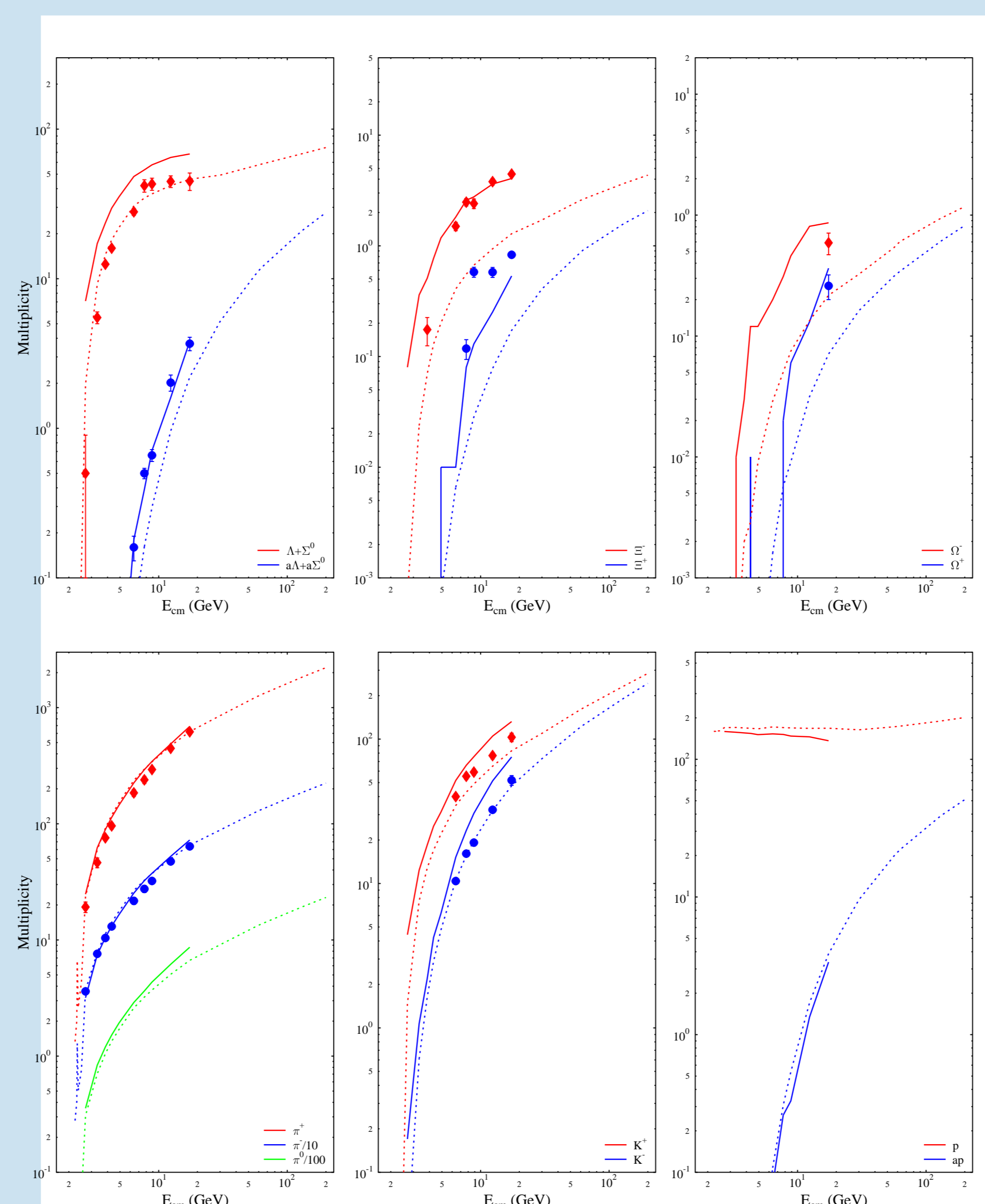


Figure 3: Excitation function of particle multiplicities (4π) in Au+Au/Pb+Pb collisions from $E_{\text{lab}} = 2$ AGeV to $\sqrt{s_{NN}} = 200$ GeV. UrQMD+Hydro calculations are depicted with full lines, while UrQMD-2.3 calculations are depicted with dotted lines. The corresponding data from different experiments (E895, E866 and NA49) are depicted with symbols.

The results for the particle multiplicities (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 ideal 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 equilibrium. They are produced following the thermal distributions at the freezeout and do not interact much further in the hadronic cascade.

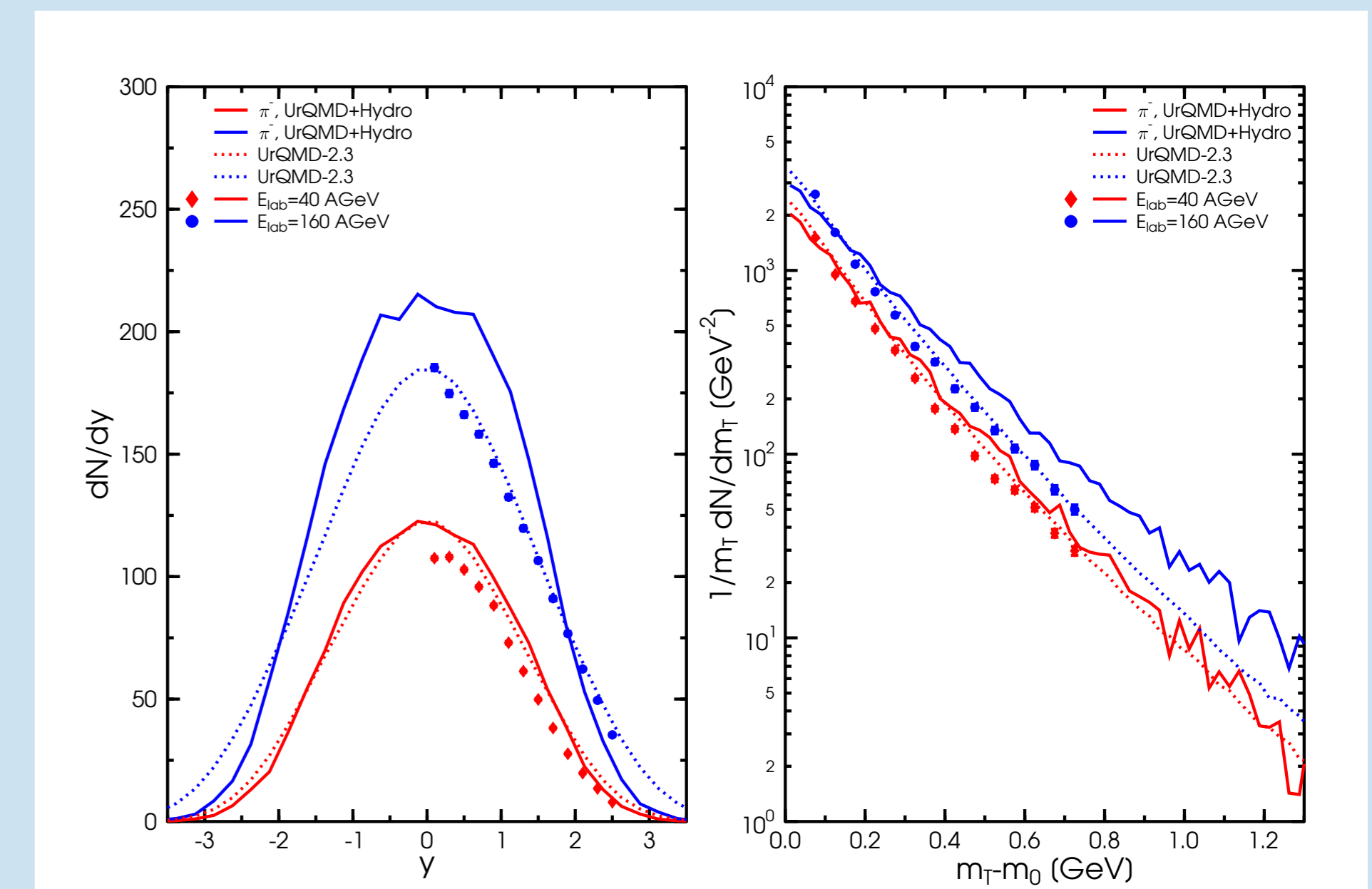


Figure 4: Rapidity and transverse mass spectra for π^- in Au+Au/Pb+Pb collisions at $E_{\text{lab}} = 40$ AGeV and $E_{\text{lab}} = 160$ AGeV. UrQMD+Hydro calculations are depicted with full lines, while UrQMD-2.3 calculations are depicted with dotted lines. The corresponding experimental data (NA49) are depicted with symbols.

The rapidity and the transverse mass spectra for π^- at $E_{\text{lab}} = 40$ AGeV 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.

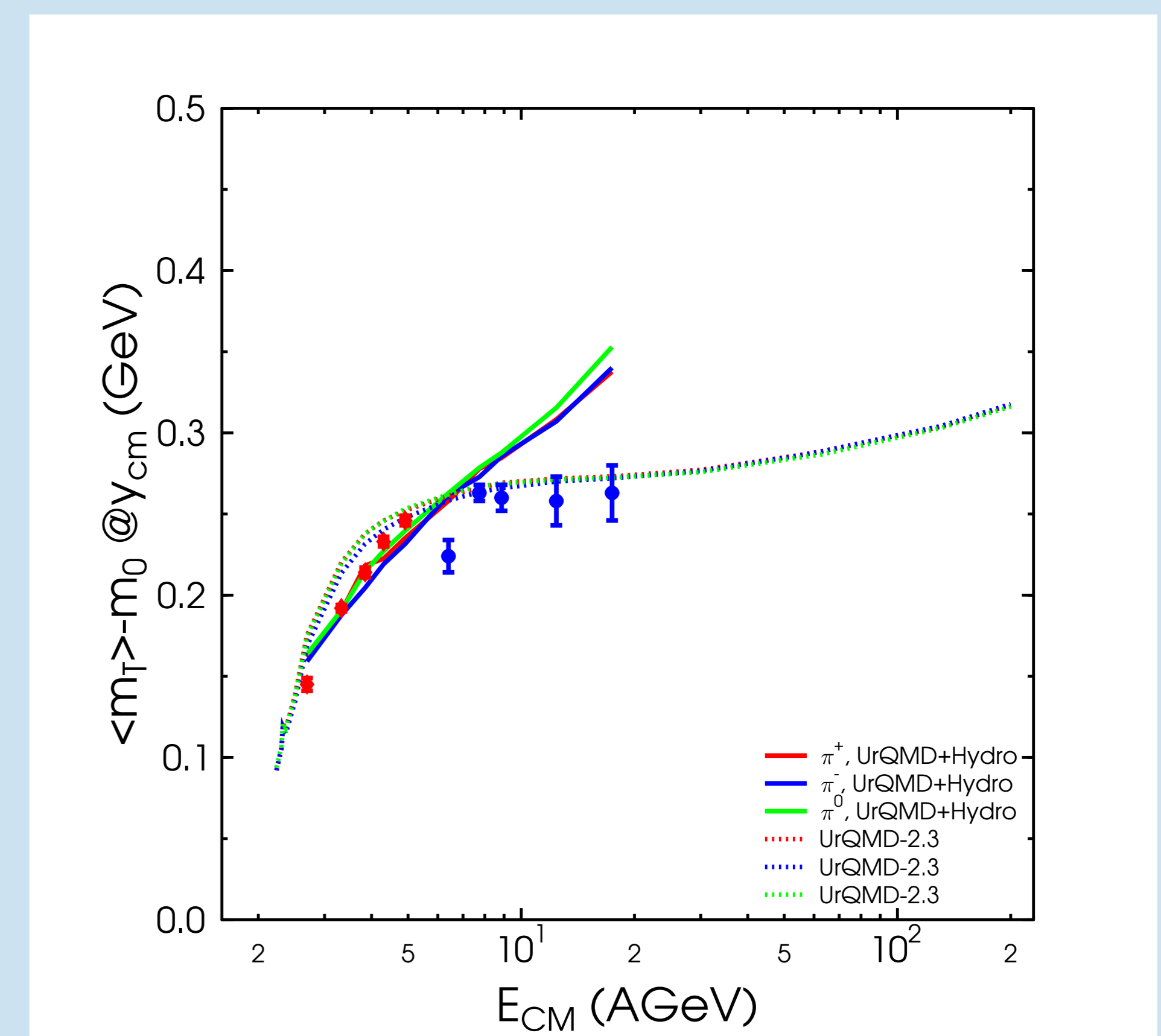


Figure 5: Excitation function of $\langle m_T \rangle - m_0$ values for pions at midrapidity ($|y| < 0.5$) in Au+Au/Pb+Pb collisions from $E_{\text{lab}} = 2$ AGeV to $\sqrt{s_{NN}} = 200$ GeV. UrQMD+Hydro calculations are depicted with full lines, while UrQMD-2.3 calculations are depicted with dotted lines. The corresponding data from different experiments (E895, E866 and 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 raises as a function of the energy.

Acknowledgements

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References

- [1] J. Steinheimer, M. Bleicher, H. Petersen, S. Schramm, H. Stöcker and D. Zschiesche, arXiv:0710.0332 [nucl-th].
- [2] S. A. Bass *et al.*, Prog. Part. Nucl. Phys. **41** (1998) 225
- [3] M. Bleicher *et al.*, J. Phys. G **25** (1999) 1859
- [4] D. H. Rischke, S. Bernard and J. A. Maruhn, Nucl. Phys. A **595** (1995) 346
- [5] D. H. Rischke, Y. Pursun and J. A. Maruhn, Nucl. Phys. A **595** (1995) 383 [Erratum-ibid. A **596** (1996) 717]