# Three-Fluid Simulations of Relativistic Heavy-Ion Collisions


Yu.B. Ivanov[1,2], E.G. Nikonov[1,3], W. Nörenberg[1], V.N. Russkikh[1,2], and V.D. Toneev[1,3]

[1]GSI, Darmstadt; [2]Kurchatov Institute, Moscow; [3]Joint Institute for Nuclear Research, Dubna


Probing Equation of State (EoS) of QCD matter in relativistic heavy-ion collisions is still a fascinating problem inspiring new experimental projects [1]. Hydrodynamic models have an advantage that they directly address EoS of hot and dense nuclear matter, which is of prime interest for this domain of physics. We have developed 3D 3-fluid relativistic hydrodynamic model [2, 3] for simulating heavy-ion collisions at incident energies from few to about 200 A·GeV. The model involves possibility to use various EoS including those with deconfinement phase transition of different orders.

A specific feature of the dynamic 3-fluid description is a finite stopping power resulting in a counter-streaming regime of leading baryon-rich matter. This counter-streaming behavior is supported by experimental rapidity distributions in nucleus–nucleus collisions and simulated by introducing the multi–fluid concept. The basic idea of a 3-fluid approximation to heavy-ion collisions is that at each space-time point $x = (t, \mathbf{x})$ the distribution function of baryon-rich matter, can be represented by a sum of two distinct contributions $f_b(x,p) = f_p(x,p)+f_t(x,p)$, initially associated with constituent nucleons of the projectile (p) and target (t) nuclei. During their mutual friction these fluids radiate mesons, gluons, quark-antiquark pairs, etc., depending on the EoS phase, which form a third baryon-free (i.e. with zero net baryonic charge) fluid in the mid-rapidity region. Thus, in addition to the two baryon-rich fluids (specifying 2-fluid models), a new model incorporates this "fireball" fluid which is treated on equal footing with the baryon-rich ones. Its evolution is delayed due to a formation time $\tau$, during which the baryon-free fluid neither thermalizes nor interacts with the baryon-rich fluids. After formation it thermalizes and starts to interact with the baryon-rich fluids. Mutual friction forces between different fluids are estimated, based on available experimental hadronic cross sections, and then tuned to reproduce the observed stopping power in nucleus-nucleus collisions. Details of this extension of the model can be found in [2].

In our hydrodynamic model we simulate the whole process of the reaction, i.e. from the formation of a hot and dense nuclear system to its subsequent decay. This is in distinction to numerous hydrodynamic simulations, which treat only the expansion stage of a fireball formed in the course of the reaction, while the initial state of this dense and hot nuclear system is constructed from either kinetic simulations or more general albeit model-dependent assumptions. The set of hydrodynamic equations is solved numerically using the particle-in-cell method.

It is found that for $\tau = 0$ the interaction with baryon-rich fluids strongly affects the baryon-free fluid. However, at reasonable finite formation time, $\tau \simeq 1$ fm/c, the effect of this interaction turns out to be substantially reduced although still noticeable. Baryonic observables are only slightly affected by the interaction with the baryon-free fluid [2].

As an example, Fig.1 presents proton rapidity spectra for $Au + Au$ collisions at incident energies $E_0$ =6, 8, and 10.5 $A \cdot GeV$. These preliminary calculations were performed for two EoS's [3]. The impact parameters $b$ relevant to each set of data were determined by a fraction of the total reaction cross section, corresponding to this set. One can see that evolution of the spectra shape with changing the impact parameter is reproduced reasonably well for all considered energies. However, the rapidity spectra prove to be quite insensitive to the EoS used.

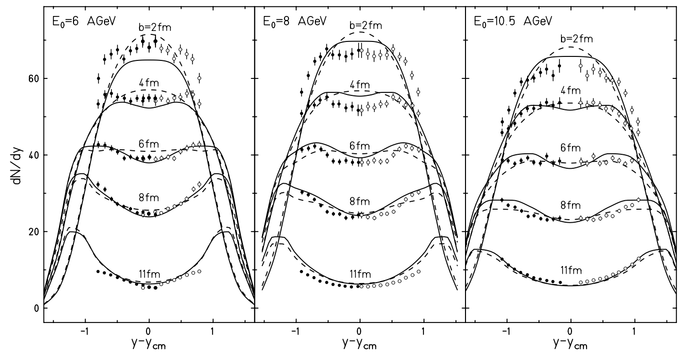


Figure 1: Proton rapidity spectra from $Au + Au$ collisions at three bombarding energies $E_0$ and different impact parameters $b$ (given in fm). Solid and dashed lines are calculated for the hadron gas EoS and mixed phase EoS with crossover phase transition, respectively. Experimental points are from [4].

Unfortunately, in spite of reasonable reproduction of observable proton rapidity spectra in the wide range of bombarding energies and centrality parameters we are unable to favor any of considered EoS's. Careful analysis of more delicate characteristics, like excitation functions for directed and elliptic flows, transverse temperature and strangeness abundance, as well as dilepton production, is needed. This work is in progress now.

## References


[1] Conceptual Design Report *" An International Accelerator Facility for Beams of Ions and Antiprotons"*, http://www.gsi.de/GSI-Future/cdr/ .

[2] V.N. Russkikh, Yu.B. Ivanov, E.G. Nikonov, W. Nörenberg and V.D. Toneev, Phys. Atom. Nucl. **67** (2004) 199.

[3] V.D. Toneev, Yu.B. Ivanov, E.G. Nikonov, W. Nörenberg and V.N. Russkikh, Proc. of XII Int. Conf. on Selected Problems of Modern Physics, Dubna, June 8-11, 2003, [nucl-th/0309008].

[4] E917 Collaboration, Phys. Rev. Lett. **86** (2001) 1970.