Parameterizing smooth viscous fluid dynamics with a viscous blast wave

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We have studied how well viscous blast waves represent simulations of high energy nuclear collisions using relativistic viscous fluid dynamics. Previously we had introduced a blast wave with shear viscous corrections [1]. This blast wave ansatz extends the range of applicability to larger momenta, into a region beyond strict kinetic equilibrium. The blast wave fits are sensitive to the ratio of shear viscosity to entropy density η/s of hadronic matter at freeze-out. As reported previously one can use viscous blast wave fits to extract the specific shear viscosity of hadron matter as a function of temperature [1].

To further support our conclusions we have carried out this follow-up study. We have run many instances of viscous fluid dynamic simulations of nuclear collisions with η/s and the freeze-out temperature T_{fo} as parameters, sampling a region in the $\eta/s - T_{\mathrm{fo}}$-plane consistent with expectations in real collisions. Subsequently we have extracted η/s and T_{fo} by Bayesian analysis from the computed identified hadron spectra and elliptic flow using our viscous blast wave ansatz. We find that the fitted values of η/s are mostly consistent with the "true" values of η/s used in the fluid dynamic simulations. On the other hand the fitted freeze-out temperatures are only consistent with "true" values at lower temperatures (more central collisions), but they underpredict the "true" values for peripheral collisions by as much as 15 MeV. We have carefully assigned uncertainties to the fitted values which allow for a notion of consistency between points. The analysis was carried out for Au+Au collisions at energies of 200 GeV at the Relativistic Heavy Ion Collider (RHIC) and for Pb+Pb collisions with 5.02 TeV at the Large Hadron Collider (LHC).

We have parameterized maps M from "true" to fitted blast wave values of η/s and T_{fo} to quantify the systematic deviations of raw fit values. Fig. 1 shows an example of several points in the $\eta/s - T_{\mathrm{fo}}$-plane for Au+Au collisions, together with raw blast wave fits including uncertainty estimates, and the points obtained from the parameterized map for Au+Au applied to the "true" values. The maps M can be inverted and applied to the raw blast wave fit values to obtain corrected fit values which are very close to the "true" values used in fluid dynamics. In extension, raw values of η/s and T_{fo} obtained in blast wave fits from data can be corrected by applying the appropriate inverse maps. The corrected blast wave fit values can be surmised to be closer to the real values.

This correction has been applied to the raw values of η/s and T_{fo} extracted from experimental data in [1] as reported previously. Beyond this immediate application our study points to the possibility that blast wave fits, which are intuitive and numerically cheap tools of data analysis, can be made much more reliable by systematically studying and removing biases introduced by the simplifying assumptions made. The results of this study have been submitted for publication [2].

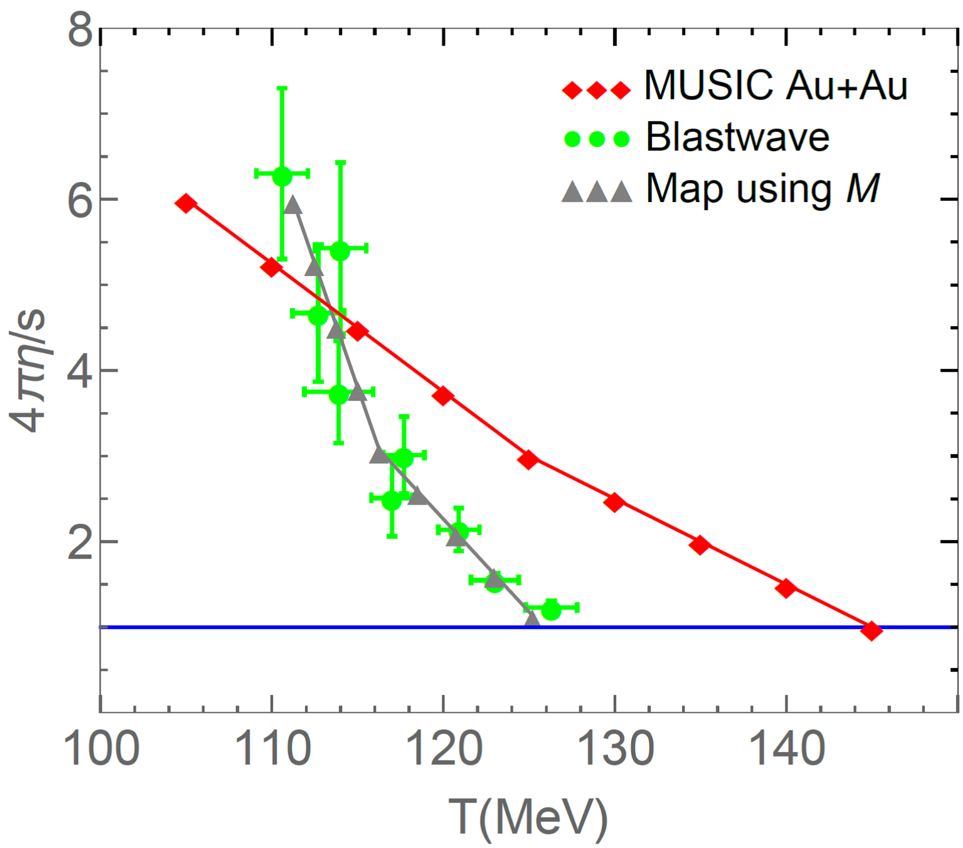

Fig. 1. Points in a plane spanned by specific shear viscosity η/s and freeze-out temperature used for viscous fluid dynamic simulations of Au+Au collisions at RHIC (red diamonds), the same parameters extracted from viscous blast wave fits of identified hadron spectra and elliptic flow calculated with these simulations (green circles), and parameterized map M applied to the original values (grey triangles). Lines are included to guide the eye.

[1] Z. Yang and R.J. Fries, arXiv:1807.03410.

[2] Z. Yang and R.J. Fries, arXiv:2007.11777.