MUSIC with the UrQMD Afterburner

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Abstract

As RHIC is entering the precision measurement era and the LHC is producing a copious amount of new data, the role of 3+1D event-by-event viscous hydrodynamics is more important than ever to understand the bulk data as well as providing the background for hard probes. For more meaningful comparison with the experimental data, it is also important that hydrodynamics be coupled to the hadronic afterburner. In this proceeding we report on preliminary results of coupling MUSIC with UrQMD.

1. Introduction

Full understanding of Quark-Gluon Plasma (QGP) in relativistic heavy ion collisions requires a wide range of theoretical tool sets. There is little doubt that the initial condition of the nuclei before the collision as well as the gluon dynamics right after the collision is governed by classical Yang-Mills dynamics [1, 2]. Less than 1 fm/c after the collision, the system reaches the local equilibrium stage and hydrodynamic expansion begins. How the system reaches the local equilibrium state so quickly is still hotly debated, but progress is being made [3]. In the initial stage of the hydrodynamic expansion, the system is in the QGP phase. This phase is so dense that hydrodynamics must be valid. As the system expands and cools, it enters the hadronic phase. On the one hand, this system should still admit a hydrodynamic description via the hadronic equation of state. On the other hand, as the system becomes more dilute, hadronic kinetic theory models should become more accurate. Therefore, there should be a range of temperatures where both descriptions are valid. This enables us to switch from one description to another within a range of temperature slightly below the critical temperature. In this short proceeding, we report on our effort to deal with this transition between the hydrodynamics phase and the hadronic kinetic theory phase by coupling 3+1D event-by-event viscous hydrodynamics (MUSIC) and a hadronic quantum molecular dynamics model (UrQMD). The initial Glasma phase and its coupling to the hydrodynamic phase is dealt with in Refs.[1][2].

2. 3+1D Event-by-Event Viscous Hydrodynamics

Hydrodynamics was first applied to particle collisions by Belenkij and Landau in 1956 [4]. In more recent times, boost-invariant 2+1D ideal hydrodynamics have enjoyed much success in heavy ion phenomenology [5][6]. Detailed data from RHIC experiments, however, eventually made it clear that it is necessary to go beyond the 2+1D ideal hydrodynamic with smooth averaged initial conditions. For instance, the surprisingly large triangular flow [7][8][9] can never
Figure 1: The momentum distribution of RHIC and the LHC 5% most central collisions compared to the MUSIC+UrQMD calculations. RHIC result is based on 10,000 events (100 UrQMD events on each of 100 hydro events) events and LHC result is based on 1,000 events (10 UrQMD events on each of 100 hydro events). For RHIC, the results of pure MUSIC events are also shown.

Figure 2: The $p_T$ dependent $v_2$ from RHIC and the LHC in the 10−20% centrality class compared to the MUSIC and MUSIC+UrQMD calculations. RHIC result is based on 10,000 events (100 UrQMD events on each of 100 hydro events) events and LHC result is based on 1,000 events (10 UrQMD events on each of 100 hydro events).

be reproduced in this way. More recent efforts have improved this by including non-zero shear viscosity [10, 11], 3+1D dynamics [12, 13], and fluctuating initial conditions [14, 15, 16]. However, none of the above mentioned studies implements all three improvements over the 2+1D ideal hydrodynamics. Only recently, the first implementation of 3+1D event-by-event viscous hydrodynamics was made by 3 of the present authors [17, 18, 19].

Our implementation of hydrodynamics (named MUSIC) uses the hyperbolic $\tau-\eta$ coordinate system without assuming invariance in $\eta$. The viscous tensor $\pi^{\mu\nu}$ is calculated by using a variant of the Israel-Stewart formalism [20]. The algorithm chosen to solve the system of hyperbolic equations is the Kurganov and Tadmor algorithm in the semi-discrete form [21] together with Heun’s method. This implementation is relatively simple yet very stable. Glauber approximation provides fluctuating initial conditions for the energy density. For the equation of state, the lattice based parameterization “s95p-v1” from [22] is the default option although other options are also available. When freezing out at about $T = 140$ MeV without the afterburner, the Cooper-Frye formula is used to get the final state hadronic spectrum with the full resonance decays adapted from Heinz and Kolb’s 2-D scheme. This Cooper-Frye procedure includes the viscous correction [23].
3. UrQMD Afterburner

UrQMD (Ultrarelativistic Quantum Molecular Dynamics) is a hadronic kinetic theory model that has been very successful in describing heavy ion collisions up to the RHIC energy [24, 25]. Recently, H. Petersen et al has updated the UrQMD code to include hydrodynamics [26] and made it publicly available. The hydrodynamics included in the original version (UrQMD v. 3.3p1) is a 3+1D ideal hydrodynamic simulation in the Cartesian coordinate system with the simple freeze-out surface determined at a constant $t$. MUSIC on the other hand uses the hyperbolic coordinate system and generates a fairly complicated iso-thermal freeze-out surface. We have implemented an interface between these two systems fully taking into account the freeze-out hypersurface directions. (See also Ref.[27] for an exact freeze-out-surface finding algorithm.) One missing ingredient is the viscous correction of the thermal distribution when it is sampled for the subsequent UrQMD run. This will be implemented in the near future although the viscous correction is not expected to be large at around $T = 170$ MeV for moderate values of $p_T$ [23]. In this work, we present our preliminary results with previously tuned values of the hydrodynamics parameters. More complete analysis including hydro parameter dependencies will be reported elsewhere.

4. Results and Summary

Three main results are shown in Figures 1 and 2. For RHIC, we have 10,000 events in each centrality bin generated by running 100 UrQMD events on each of 100 viscous MUSIC events. For the LHC, we have 1,000 events in each centrality bin generated by 10 UrQMD events on each of 100 viscous MUSIC events. The transition to UrQMD was made at $T_{tr} = 170$ MeV. The two panels in Figure 1 show proof of principle results. The RHIC $p_T$ spectra for $\pi^{-}$, $K^{-}$ and $\bar{p}$ are reasonably well produced for the $0 - 5$% centrality bin. For all 3 species, the description of the data is either improved over or of about the same quality as the pure hydrodynamics results. In the second panel, our calculations are compared with the ALICE data shown in this conference [28]. It should be emphasized here that the calculation was done before the data were shown.

For $v_2(p_T)$ in Figure 2 the $\bar{p}$ result is much improved with the afterburner at RHIC. This may be due to the better description of finite baryon mean free path in UrQMD compared to
hydrodynamics. For the LHC, one may argue that the afterburner improves the description a little, but the statistical error at this point is too big to say that definitely. Calculations with afterburner lead to larger $v_3(p_T)$ in general. However, this needs more careful study to quantify.

In summary, we have reported our preliminary results on coupling MUSIC to the UrQMD afterburner. Encouragingly, changes from the pure hydrodynamics cases seem to go in the right direction. In near future, we plan to (i) improve our statistics up to 10 times, (ii) include the effect of $\delta f$ at the transition, and (iii) slightly re-tune hydrodynamics parameters such as the viscosity for better experimental fit. These further studies will be reported elsewhere.

Acknowledgments

CG, SJ and SR are supported by the Natural Sciences and Engineering Research Council of Canada. BPS is supported under DOE Contract No.DE-AC02-98CH10886 and acknowledges support from a BNL Lab Directed Research and Development grant. BPS gratefully acknowledges a Goldhaber Distinguished Fellowship from Brookhaven Science Associates. We greatly appreciate computer time on the Guillimin cluster at the CLUMEQ HPC centre, a part of Compute Canada HPC facilities where bulk of these calculations were carried out. We also thank H. Petersen and P. Huovinen for helpful discussions.

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