MUSIC and MARTINI with a Hadronic Afterburner

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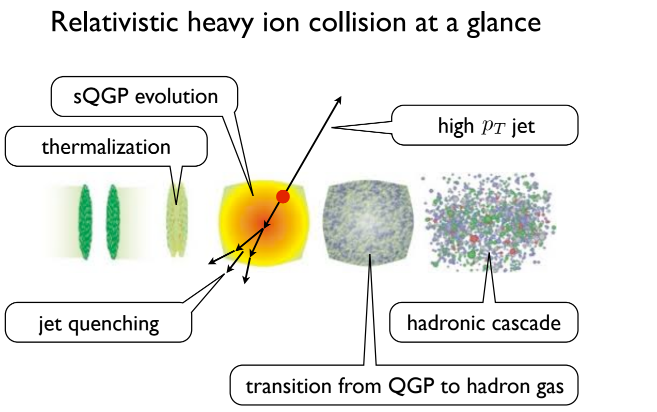
ABSTRACT

We present our improved event generator for heavy ion collisions which combines MUSIC, MARTINI and UrQMD. It includes hydrodynamic medium evolution (MUSIC) starting from IP-Glasma or MC-Glauber initial conditions, jet production and propagation through the evolving medium (MARTINI), and the final hadronic interactions of the bulk and jet particles (UrQMD). The result is generation of full events for relativistic heavy ion collisions consistently including both the soft and hard physics of each event.

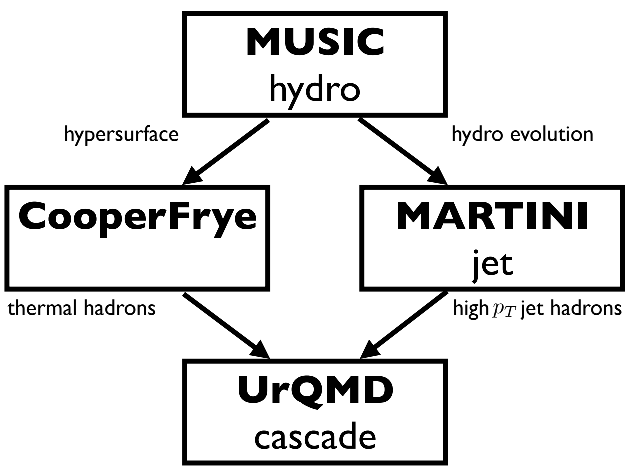
In this work, we will present our first results on jet quenching, nuclear modification and effects on v_2 and v_3. These calculations will be compared to the RHIC and LHC data and implications for future work will be discussed.

Introduction



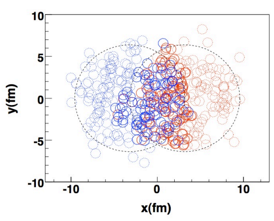
We present the recently developed event generator that takes MUSIC hydro, MARTINI jet and UrQMD cascade into account. In the following sections, we will explain each part of our event generator and show first results comparing with experimental data from RHIC and LHC.

Model Overview



Model – Initial Conditions

We consider two types of initial condition — MC-Gluaber and IP-Glasma.

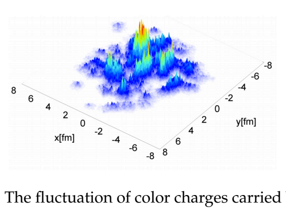


PHOBOS MC-Glauber
(arXiv:0805.4411)

The Monte-Carlo Glauber samples positions of nucleons of colliding nuclei according to a Wood-Saxon distribution.

$$\rho_A(r) = \frac{\rho_0}{1+\exp[(r-R)/d]} \tag{1}$$

We put Gaussian energy deposit for each participant and binary collision.



In the IP-Glasma picture [1], partons with high x provide color sources for classical Yang-Mills fields. The color gauge field in terms of the path-orderd Wilson line is given by

$$A^i(\mathbf{x}_\perp) = \frac{i}{g} V(\mathbf{x}_\perp)\partial_i V^\dagger(\mathbf{x}_\perp) \tag{2}$$

$$V(\mathbf{x}_\perp) = P\exp\left[-ig\int dx^- \frac{\rho(x^-,\mathbf{x}_\perp)}{\nabla_T^2+m^2}\right] \tag{3}$$

The fluctuation of color charges carried by high-x partons in nuclei are described as

$$\langle \rho^a(x^-,\mathbf{x}_\perp)\rho^b(y^-,\mathbf{y}_\perp)\rangle = g^2\mu_A^2(\mathbf{x}_\perp)\delta^{ab}\delta(x^- - y^-)\,\delta^{(2)}(\mathbf{x}_\perp - \mathbf{y}_\perp) \tag{4}$$

where $g^2\mu$ depends on the transverse position inside the nucleus. These fluctuations are not present in the MC-Glauber model.

Model – MUSIC Hydro

MUSIC [2][3][4] solves $3+1$D viscous hydrodynamic equations.

$$\partial_\mu T^{\mu\nu}(t,x) = 0 \tag{5}$$

The energy momentum tensor is decomposed as a sum of ideal part with local thermal equilibrium and shear viscous correction $\pi^{\mu\nu}$. The evolution of $\pi^{\mu\nu}$ is given by

$$\Delta^\mu_\alpha\Delta^\nu_\beta u^\sigma\partial_\sigma\pi^{\alpha\beta} = -\frac{1}{\tau_\pi}(\pi^{\mu\nu} - S^{\mu\nu}) - \frac{4}{3}\pi^{\mu\nu}(\partial_\alpha u^\alpha) \tag{6}$$

where $S^{\mu\nu}$ is the first order Navier-Stokes shear viscous tensor.
This provides a 3-dimensional isothermal hypersurface and hydro evolution history which are used in the event generator.

Model – Cooper-Frye Sampling

We sample hadrons from the freeze-out hypersurface Σ according to the Cooper-Frye formula [5]

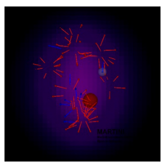
$$\frac{dN}{d^3\mathbf{p}} = g\int_\Sigma f(x,p)\,\frac{p^\mu d^3\Sigma_\mu}{E_\mathbf{p}}\,. \tag{7}$$

where $f(x,p)$ is the Boltzmann distribution function. We have a deviation δf from the thermal distribution f_0 due to the viscous correction to the energy-momentum tensor. In this work we used the quadratic ansatz and δf is given as

$$\delta f = \frac{1}{2}f_0(1\pm f_0)\frac{\pi_{\mu\nu}p^\mu p^\nu}{(\epsilon+P)T^2}\,. \tag{8}$$

We assume a grand canonical ensemble where particles are sampled independently.

Model – MARTINI Jet

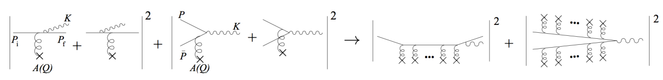


MARTINI [6] is a modular algorithm to compute energy loss of jet partons moving through QGP medium.
PYTHIA is used to sample initial hard collisions and perform the final fragmentation. Computation of radiative and elastic jet energy loss is based on the McGill-AMY formalism.

Model – McGill-AMY Formalism

Radiative Energy Loss

AMY [7] is a formalism to compute the energy loss of hard partons propagating in a hot QCD medium. Beginning with the relation between the photon (or gluon) production rate and the current-current correlator, it sums over all possible diagrams to take the LPM effect into account.



Collisional Energy Loss

The $2\to2$ processes of hard partons and thermal partons are combined with the radiative processes in [8][9]. The collisional energy loss rate is computed from a convolution of Boltzmann distribution functions and $2\to2$ scattering matrix elements. The differential energy loss dE/dt has a logarithmic dependence on E.

$$\left.\frac{dE}{dt}\right|_{ab} = C_{ab}\pi\alpha_s^2T^2\left[\ln\frac{ET}{m_g^2} + D_{ab}\right] \tag{9}$$

where C_{ab} and D_{ab} are constants that depend on which kind of partons are interacting.

Model – UrQMD Cascade

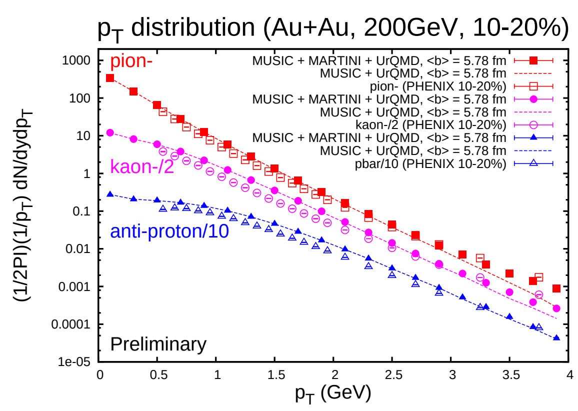
UrQMD (Ultra-relativistic Quantum Molecular Dynamics) [10] is a transport model which solves Boltzmann's transport equation

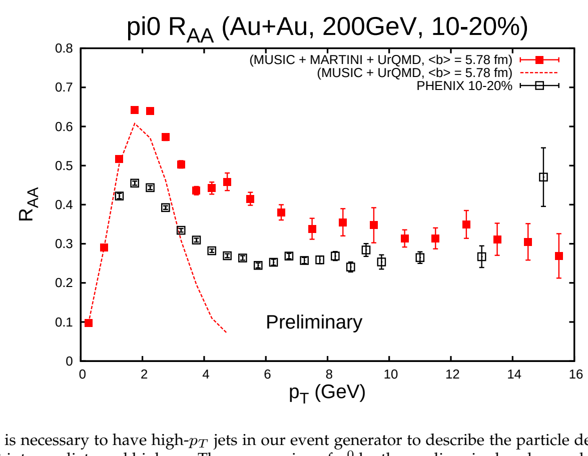
$$p^\mu\frac{\partial f}{\partial x^\mu}(t,\mathbf{x},\mathbf{p}) = \mathcal{C}[f] \tag{10}$$

by performing scattering and decay in an N-body system. UrQMD includes 55 baryon species and 32 meson species with masses up to 2.25 GeV.
The cross sections and decay rates that enter UrQMD are based on the experimental data.

Results – p_T Spectra

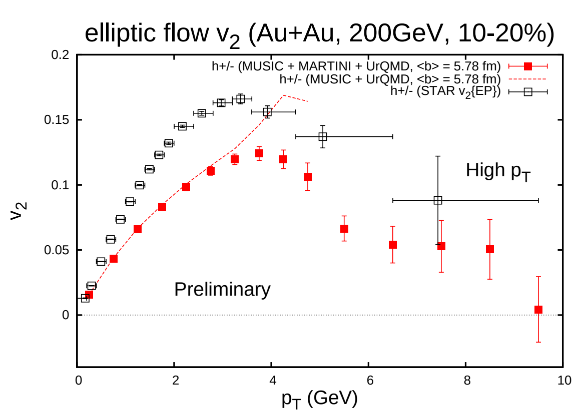
Au+Au $\sqrt{s_{NN}} = 200$ GeV with MC-Glauber



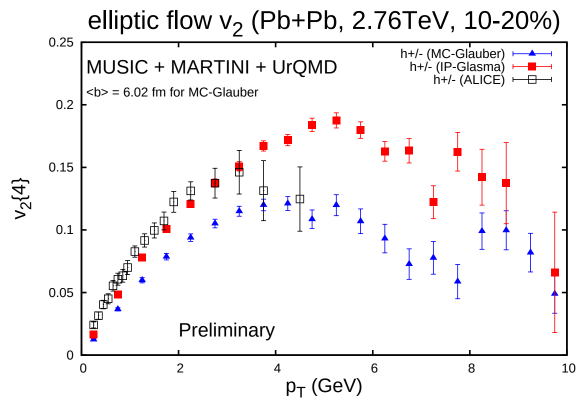


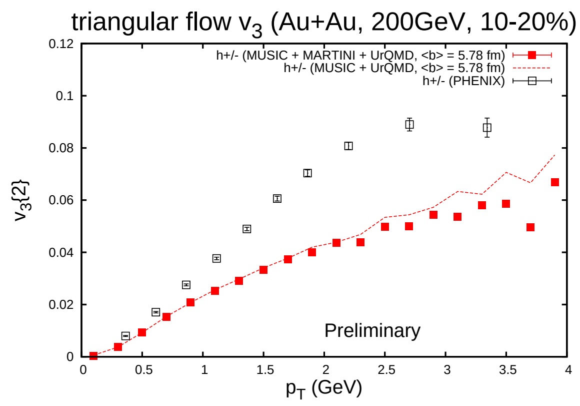
It is necessary to have high-p_T jets in our event generator to describe the particle distribution at intermediate and high p_T. The suppression of π^0 by the medium is also observed.
The mismatch between our calculation and the experimental data implies that the jet energy loss is stronger than our assumption where we set $\alpha_s = 0.3$. Also, as we are considering quadratic dependence of δf on the momenta, it strongly favors higher p_T. In terms of the relaxation time, it may take shorter to equilibrate.

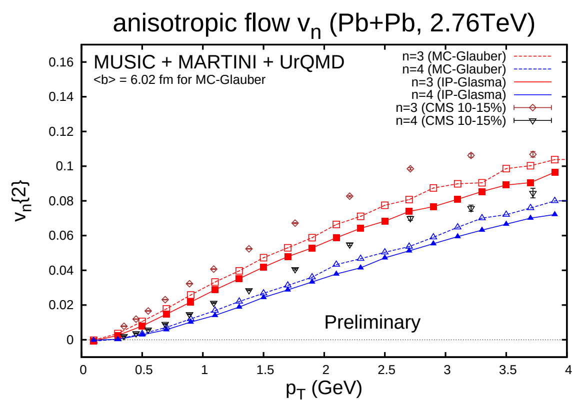
Results – Azimuthal Anisotropy



Results – Azimuthal Anisotropy (Continued)



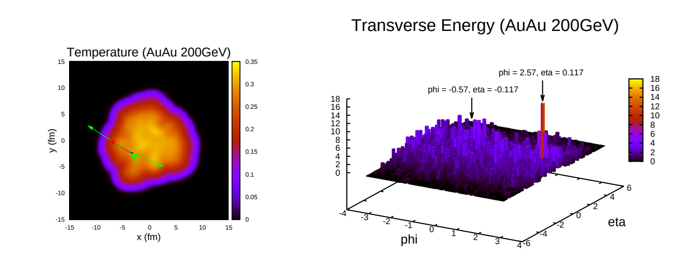




We can see the shear effect between low-p_T and high-p_T particles as well as the azimuthal anisotropy of high-p_T particles generated by the medium.
In addition to shifting the spectra to higher p_T the viscous correction δf affects the azimuthal anisotropy. Since the δf allows particles to have higher p_T, their anisotropic flows can be smeared in spite of anisotropic flow velocity.

Results – Jet Quenching

Au+Au $\sqrt{s_{NN}} = 200$ GeV with MC-Glauber



High-p_T jets are produced (**left**) and they experience energy loss inside the medium.
This is shown in the transverse energy distribution (**right**) where one of the back-to-back jets is diffused.

Conclusion

We developed an event generator which incorporates both of low-p_T and high-p_T physics involved in a relativistic heavy ion collision.
Addition of MARTINI jet energy loss algorithm on top of MUSIC+UrQMD allows us to reproduce important features of high-p_T jets from hard processes. It is also essential in taking the interaction among particles in the intermediate momentum regime into account.
Future works include understanding the depedence on the viscous correction to the Boltzmann distribution function, finding the better way to determine centrality and tuning the model to reach better agreement with the experimental data.

References

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