Initial angular momentum in high energy nuclear collisions

R.J. Fries, G. Chen, and S. Somanathan

The study of the effects of angular momentum in high energy nuclear collisions has intensified recently after the STAR collaboration reported non-vanishing polarization measured for Lambda baryons in collisions at the Relativistic Heavy Ion Collider (RHIC). The polarization effect decreases with beam energy and is compatible with zero within current error bars at top RHIC energies. In a recent study [1] we looked at the high energy limit of nuclear collisions, where color glass condensate (CGC) is expected to be the correct effective theory for the early phase of the collision. In the analytic framework developed by some of us with Kapusta and Li [2] it is possible to recursively solve the Yang-Mills equations for the initial gluon field, and to calculate event averages over color charge distributions in the framework of the McLerran-Venugopalan model.

We have studied the relativistic angular momentum tensor $M^{\mu\nu\lambda}$ calculated from the energy momentum tensor $T^{\mu\nu}$ of the initial classical gluon field. Since the setup is boost-invariant, a good approximation around midrapidity at the highest energies, we calculate $dL_2/d\eta$ and estimate it to be ~ $R_A Q_S^{-3} \varepsilon_0$ at a time ~ $1/Q_S$ at midrapidity. Here R_A is the nuclear radius, Q_S is the saturation scale, and ε_0 is the average initial energy density. The energy flow in the gluon field carrying this angular momentum is shown in Fig. 1 in the reaction plane (orthogonal to the y-axis). The nuclei after the collision are moving to the right in the upper half-plane and to the left in the lower half-plane, the vortex visible in Fig. 1 is

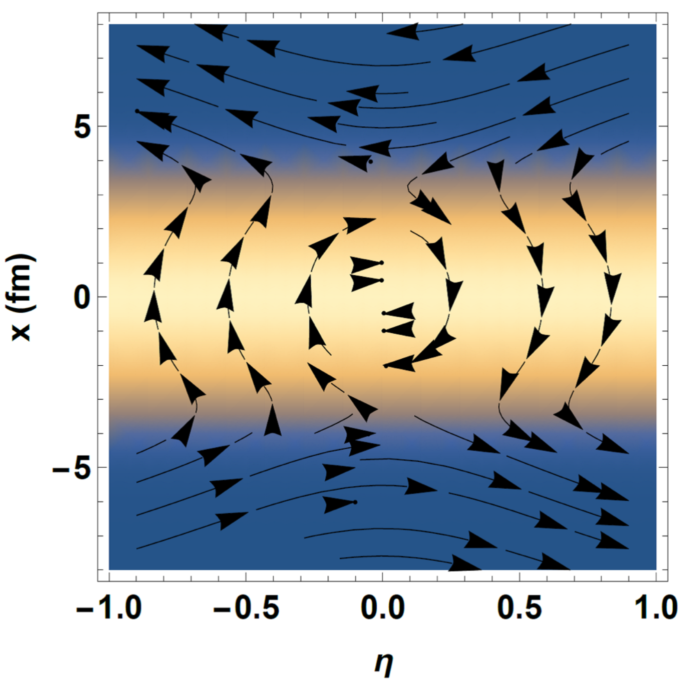

FIG. 1. Energy flow components (T^{01}, T^{03}) of the initial gluon field contributing to local angular momentum around midrapidity in the reaction plane of Pb+Pb collisions at time τ = 0.25 fm/c. Flow not contributing to angular momentum (for example radial flow) is subtracted for clarity. Background shading shows the initial energy density in the reaction plane.Figure taken from Ref. [1].

thus aligned with the primordial angular momentum of the colliding nuclei. Note that energy flow not contributing to angular momentum is not shown. To be more precise, only rapidity-odd contributions of the flow T^{01} in x-direction (directed energy flow), and rapidity even contributions of the flow T^{03} in z-direction (longitudinal shear flow) contribute and are shown.

We further discuss the procedure to match results from the initial classical Yang-Mills phase to ideal and viscous fluid dynamics, with conservation laws for energy, momentum and angular momentum as guiding principles. We argue that dissipative stress calculated from the Yang-Mills phase has to be included when initializing fluid dynamics, or basic conservation laws are violated.

We find that in the fluid phase the angular momentum is initially carried by a longitudinal shear flow, i.e. an imbalance of longitudinal flow velocity between two sides of the reaction plane. This event-averaged picture will receive modifications when event-by-event fluctuations are taken into account. Angular momentum is also carried by the initial shear stress tensor. In a boost-invariant picture there is no rotational component to the flow field. Both the shear stress and longitudinal shear flow tend to dissipate in viscous fluid dynamics, leading to overall suppressed local angular momentum at midrapidity. This is consistent with the observation that particle polarization and directed flow at midrapidity decrease with increasing beam energy and increasing boost-invariance of the system.

[1] R.J. Fries, G. Chen, and S. Somanathan, Phys. Rev. C (Submitted);e-Print: arXiv:1705.10779 [nucl-th].
[2] G. Chen, R.J. Fries, J.I. Kapusta, and Y. Li, Phys.Rev. C **92**, 064912 (2015).