A study of vorticity formation in high energy nuclear collisions

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Introduction

Vorticity in peripheral collisions[1, 2, 3]) provides information about the (mean) hydrodynamic initial conditions and it is related to the onset of peculiar physics in the plasma at high temperature, such as the chiral vortical effect [4]. It has been shown that vorticity gives rise to polarization of particles in the final state, so that e.g. a baryon polarization can be used to detect it [5, 6]. In relativistic hydrodynamics, one can define several vorticities:

- Kinematic vorticity: \( \omega_{\text{kin}} = \frac{1}{2} (\partial u_x - \partial u_y) \)
- T-vorticity: \( \Omega_{\text{t}} = \frac{1}{2} \left[ \partial (u_x u_t) - \partial (u_y u_t) \right] \)
- Thermal vorticity: \( \omega_{\text{th}} = \frac{1}{2} \left[ \partial (\beta_x \beta_t) - \partial (\beta_y \beta_t) \right] \)

Each having peculiar features.

Particularly,

- for an ideal uncharged fluid, T-vorticity vanishes if it vanishes in the initial state, unlike kinematic and thermal vorticity,
- thermal vorticity is constant at full thermodynamical equilibrium and in local thermodynamical equilibrium drives particle polarization.

Modeling of the initial conditions

We have studied vorticity formation with our ECHO-QGP 3+1 D code [7] implementing relativistic dissipative hydrodynamics in the Israel-Stewart formulation with minimal Bjorken initial conditions (i.e. with \( u^\beta = 0^\beta = y^\beta = 0 \)) and with an initial energy density \( \varepsilon(x, y, \eta) \) modified with a function \( f(\eta) \), being \( \eta \) the longitudinal Bjorken coordinate, such as to have a finite angular momentum \[8, 9].

Validation of the code used for this study

To validate the core routines of our ECHO-QGP code, we performed a numerical simulation of a Bjorken conformal flow with an azimuthally symmetric radial expansion and we compared the results with the semi-analytic solutions that extend to the viscous case [13, 14] the solutions previously found by Galuber and Yarom [11, 12] in the unviscid case.

Sensitivity to \( \eta/s \)

The free parameters have been chosen following ref. [9], where they were adjusted to reproduce the data in Au-Au collisions at \( \sqrt{s_{NN}} = 200 \) GeV. The values of \( \eta_s \) and \( \eta/s \) have been chosen to obtain (qualitatively) the best agreement between our calculated pion \( \eta/s \) and the measured directed flow for charged particles in the central rapidity region by the STAR collaboration [10].

Results on thermal vorticity and polarization

The relation between the polarization vector of a spin 1/2 particle and thermal vorticity is [5]:

\[ \eta(p) = \frac{1}{8m} \int d^3 p \, n(p) \left( \frac{m}{p} \right) \eta \left( \frac{\gamma m}{p} \right) \]

But the polarization vector which is measurable is the one in the decaying particle rest frame:

\[ \Pi_0 = \Pi - \frac{p}{(m + p)} \eta \]

References


ECHO-QGP is freely distributed under the terms of the GPLv2 license and can be downloaded from: http://theory.infn.it/echoqqp/ For more informations, please contact Gabriele Inghirami at inghirami@fias.uni-frankfurt.de

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