Local spin polarization and helicity polarization in hydrodynamic approaches

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Abstract

We study local spin polarization and helicity polarization at 200 GeV in the relativistic hydrodynamic model. We present the local spin polarization and helicity polarization contributed from thermal vorticity (thermal), shear viscous tensor (shear), and the fluid acceleration (accT). It is found that the total local spin polarization can be very sensitive to the equation of states. We also find that the local helicity polarization induced by thermal vorticity dominates over other contributions. Our studies also provide a baseline for the future investigation on local parity violation through the correlations of helicity polarization.

Introduction

Recently, the effects of shear viscous tensor on the local spin polarization’s azimuthal dependence were studied and found to be important to solve the “Spin sign Puzzle”. Recently, Helicity-helicity (polarization) correlations is proposed to extract the signal of local-parity violation. Therefore, it is essential to study the helicity polarization without an axial chemical potential from hydrodynamic as a baseline for the future analysis.

Theoretical Framework

We can calculate the spin polarization of hyperons via the modified Cooper-Frye formula:

\[ S^h(p) = \frac{\int d\Sigma \cdot \mathbf{p} f_{\mathbf{p}}(p, X)}{2m_X \int d\Sigma \cdot N(p, X)}. \]

Axial currents can be decomposed as

\[ J^a = J^a_{\text{thermal}} + J^a_{\text{shear}} + J^a_{\text{accT}} + J^a_{\text{chemical}} + J^a_{\text{fluid}}, \]

where they are related to:

- **Thermal vorticity**
  \[ J^a_{\text{thermal}} = \frac{1}{4} \mathbf{\epsilon} \rho \mathbf{\epsilon} \partial_t \mathbf{u} \cdot \mathbf{T}. \]

- **Shear viscous tensor**
  \[ J^a_{\text{shear}} = -\frac{1}{2(1+p)} \mathbf{\epsilon} \rho \mathbf{\epsilon} \partial_t \mathbf{u} \rho \mathbf{u} \cdot \mathbf{D}. \]

- **Fluid acceleration**
  \[ J^a_{\text{accT}} = -\frac{1}{2T} \mathbf{\epsilon} \rho \mathbf{\epsilon} \partial_t (\rho \mathbf{u} \cdot \mathbf{T}). \]

Similarly, the helicity polarization can also induced by these term

\[ S^h = \mathbf{\tilde{p}} \cdot \mathbf{S} = \mathbf{\tilde{p}} \cdot \mathbf{S}^x + \mathbf{\tilde{p}} \cdot \mathbf{S}^y + \mathbf{\tilde{p}} \cdot \mathbf{S}^z, \]

In particular, we can further decompose the helicity polarization induced by thermal vorticity as two part:

\[ S^h_{\text{Th}}(\mathbf{p}) = \int d\Sigma \rho \frac{F_{\mathbf{p} \times \mathbf{D}}}{T} \mathbf{D} \cdot \mathbf{\nabla} \mathbf{T}, \]

\[ S^h_{\text{Th}}(\mathbf{p}) = \int d\Sigma \rho \frac{F_{\mathbf{p} \times \mathbf{\omega}}}{T} \mathbf{\omega}, \]

which are associated with the temperature gradient and vorticity, respectively.

Results

Eos: sp95-pec total: black, opposite to experiments qualitatively
- YC, Shi Pu, Di-Lun Yang, Phys. Rev. C 104.064901

Eos: wb2014 total: black consistent with experiments qualitatively

Summary

- **Shear induced Local spin polarization**
  - Shear induced polarization always give a “correct” sign
  - Total local polarization is very sensitive to EoS.
  - The local spin polarization is still an open question. We still need to study spin hydrodynamics and quantum kinetic theory with collisions.

- **Helicity polarization**
  - provide the baseline for the future investigation
  - help us to distinguish the local spin polarization contributed by thermal vorticity
  - we may extract the magnitude of local fluid vorticity by helicity polarization