Local Spin Polarization in 200 GeV Au+Au and 2.76 TeV Pb+Pb Collisions

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Abstract

We calculated the azimuthal angle dependence of the local spin polarization of hyperons in 200 GeV Au+Au and 2.76 TeV Pb+Pb collisions in the framework of the (3+1)D viscous hydrodynamic model CLVisc with AMPT initial conditions encoding initial orbital angular momenta. We find that the azimuthal angle dependence of the hyperon polarization strongly depends on the choice of the spin chemical potential $\Omega_{\mu\nu}$. With $\Omega_{\mu\nu}$ chosen to be proportional to the temperature vorticity, our simulation shows coincidental results with the recent measurements at RHIC.

Keywords: Heavy-ion collision, Local spin polarization, Spin chemical potential, Temperature vorticity

Introduction. Recently the global polarization of $\Lambda$ (including $\bar{\Lambda}$) hyperons in non-central heavy-ion collisions has been observed \cite{1}. This indicates that the huge orbital angular momentum (OAM) of colliding nuclei is distributed into the hot and dense medium through the spin-orbit coupling \cite{2, 3}. The spin-orbit coupling in parton-parton collisions can be converted to the spin-vorticity coupling through ensemble average over initial momenta in a fluid with a shear flow velocity \cite{4}. Then the vorticity field leads to the local hadron polarization along the vorticity direction \cite{5, 6}. Several theoretical approaches have been developed to study the global and local polarization in heavy ion collisions based on the assumption that the spin degree of freedom is in local equilibrium in which the thermal vorticity is involved \cite{5, 6, 7, 8, 9, 10, 11, 12}.

The global polarization effect in the OAM direction can be well understood by the hydrodynamic and transport models \cite{13, 14, 15, 16}. However these models are based on the thermal vorticity and the spin equilibrium assumption and cannot reproduce the data for longitudinal polarization: actually there is a sign difference between the data and these model calculations \cite{17, 18, 19}. It worth mentioning that the longitudinal polarization can be described by the the chiral kinetic theory \cite{20}, which is for massless fermions instead of massive fermions in the realistic situation.

The assumption that the spin is in a global equilibrium is not always justified, so the thermal vorticity may not be the right quantity for the spin chemical potential. In this work, we test different types of spin chemical potentials $\Omega_{\mu\nu}$ and calculate the corresponding local polarization of hyperons. We use the (3+1)D
vorticities are considered, where \( \lambda \) is the polar angle of the daughter proton in the \( \Lambda \) hyperon’s rest frame, \( \alpha_H \) is the hyperon decay parameter (\( \alpha_\Lambda = \alpha_{\bar{\Lambda}} = 0.642 \pm 0.013 \) for \( \Lambda \) and \( \bar{\Lambda} \)), \( \mathcal{P}_z \) is the longitudinal component of Eq. (8).

For Au+Au collisions at \( \sqrt{s_{NN}} = 200 \) GeV and 20\% - 50\% centrality, the longitudinal polarization from four types of vorticities as functions of azimuthal angles in momentum space are shown in Fig. 1.

For Pb+Pb collisions at \( \sqrt{s_{NN}} = 2.76 \) TeV and 10\% - 60\% centrality, the polarization in the beam direction and in the OAM direction for four types of vorticities are shown in Fig. 2 and 3 respectively.

In summary, we find that the experimental data of the longitudinal polarization in Au+Au collisions at 200 GeV can be described quite well by the T-vorticity. For Pb+Pb collisions at 2.76 TeV, the longitudinal polarization also has a periodic structure but is smaller than 200 GeV. The magnitude of the polarization in the direction of the global OAM is consistent with the decreasing trend in the STAR measurement [1].

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Fig. 1. The azimuthal angle dependence of longitudinal polarization in Au+Au collisions at 200 GeV and 20% – 50% centrality. In our simulation we choose the rapidity range $Y \in [-1, 1]$. The left panel shows the longitudinal polarization for four types of vorticities and the transverse momentum range $p_T \in [0, 2.0]$ GeV, while the right panel shows the dependence of the polarization with the $T$-vorticity on different transverse momentum ranges.

Fig. 2. The azimuthal angle dependence of longitudinal polarization in Pb+Pb collisions at 2.76 TeV and 10% – 60% centrality. In our simulation we choose the rapidity range $Y \in [-1, 1]$. The left panel shows the longitudinal polarization for four types of vorticities and the transverse momentum range $p_T \in [0, 3.0]$ GeV, while the right panel shows the dependence of the polarization with the $T$-vorticity on different transverse momentum ranges.

Fig. 3. The azimuthal angle dependence of the polarization in the direction of the global OAM in Pb+Pb collisions at 2.76 TeV and 10% – 60% centrality. In our simulation we choose the rapidity range $Y \in [-1, 1]$ and $p_T \in [0, 3]$ GeV.
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