Investigating the local polarization of Λ and $\bar{\Lambda}$ hyperons at relativistic energies

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I. INTRODUCTION

The global and local polarization measurements of Λ and $\bar{\Lambda}$ hyperons by STAR and ALICE Collaborations creates an intriguing interest to investigate the source of particle polarization in heavy-ion collisions [1–7]. Recent studies reveal that the transverse component of the vorticity field is responsible for the global spin polarization of Λ hyperons. In contrast, the longitudinal component of the vorticity field accounts for the local (or longitudinal) polarization. In non-central heavy-ion collisions, the inhomogeneous expansion of the fireball creates an anisotropic flow in the transverse plane, indicating a quadrupole pattern of the longitudinal vorticity along the beam direction, which is responsible for the local polarization of Λ-hyperons. In this study, we explore the centrality and transverse momentum ($p_{\rm T}$) dependence of elliptic flow-induced local polarization for Λ and $\bar{\Lambda}$ hyperons in Au+Au and Pb+Pb collisions at $\sqrt{s_{NN}} = 200$ GeV and 5.02 TeV, respectively using ECHO-QGP and EPOS4 as hydrodynamic and AMPT as transport models [3].

II. FORMALISM

The mean spin vector of a spin-1/2 particle at leading order in thermal vorticity is given by [3];

$$S^{\mu}(p) = -\frac{1}{8m}\epsilon^{\mu\rho\sigma\tau}p_{\tau}\frac{\int_{\Sigma} d\Sigma_{\lambda}p^{\lambda}\, n_F(1-n_F)\bar{\omega}_{\rho\sigma}}{\int_{\Sigma} d\Sigma_{\lambda}p^{\lambda}\, n_F}, \tag{1}$$

where $\bar{\omega}$ is the thermal vorticity, and is given by;

$$\bar{\omega}_{\mu\nu} = -\frac{1}{2}(\partial_{\mu}\beta_{\nu} - \partial_{\nu}\beta_{\mu}) \tag{2}$$

where, $\beta^{\mu} = \frac{u^{\mu}}{T}$, u^{μ} is the four-velocity vector, and T is the temperature. $n_F = 1/[\exp{(\beta.p - \sum_j \mu_j q_j/T)} + 1]$ is the Fermi-Dirac distribution function.

Using the equation of motion of an ideal uncharged fluid, Eq. 1 can be written as

$$S^{\mu}(p) = -\frac{1}{4m}\epsilon^{\mu\rho\sigma\tau}p_{\tau}\frac{\int_{\Sigma} d\Sigma_{\lambda}p^{\lambda}\, A_{\rho}\beta_{\sigma}n_F(1-n_F)}{\int_{\Sigma} d\Sigma_{\lambda}p^{\lambda}\, n_F}, \tag{3}$$

Solving Eq. 3 at ρ =0, we have

$$S_z(\mathbf{p}_T, Y=0) = \frac{dT}{d\tau}\frac{1}{mT}v_2(p_{\rm T})\sin 2\phi \tag{4}$$

The detailed derivation of Eq. 4 is presented in Ref. [3]. In the rest frame of the particle, the longitudinal polarization vector P_z^* can be obtained from S_z^*, and is given as

$$P_z^* = 2S_z^* \tag{5}$$

III. RESULTS AND DISCUSSION

The left and right panel of Fig. 1 shows P_z as a function of centrality and $p_{\rm T}$, respectively. The centrality dependence of P_z is estimated in the $p_{\rm T}$ range $0.15 < p_{\rm T} < 3.0$ GeV/c and the $p_{\rm T}$ dependence of P_z is studied for (30-50)% centrality bin, in accordance to the ALICE measurement. The left panel of Fig. 1 shows the magnitude of longitudinal polarization increases with collision centrality. However, ECHO-QGP predicts a slightly decreasing trend towards peripheral collisions. Similarly, the right panel of Fig. 1 shows the longitudinal polarization increases for $p_{\rm T} \lesssim 2.0$ GeV/c and decreases towards $p_{\rm T} \gtrsim 2.0$ GeV/c for ECHO-QGP model. While, for AMPT, P_z increases with $p_{\rm T}$. The observed increase in polarization observable in mid-central can be attributed to the rising contributions of elliptic flow

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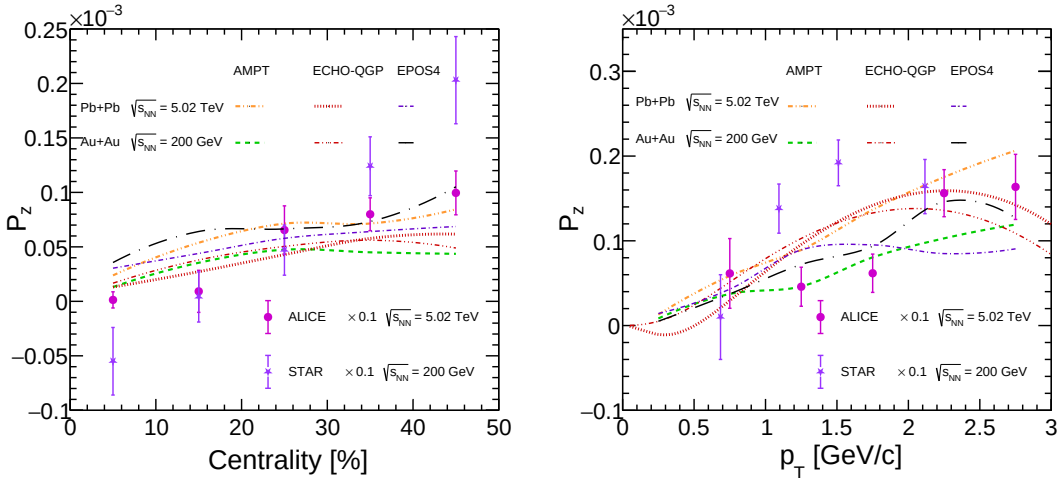

FIG. 1. The longitudinal component of Λ and $\bar{\Lambda}$ polarization (P_z) as a function of collision centrality obtained from ECHO-QGP, EPOS4, and AMPT model simulation for $\sqrt{s_{NN}}$ = 5.02 TeV and $\sqrt{s_{NN}}$ = 200 GeV in Pb+Pb and Au+Au collisions, respectively [3]. The obtained results are compared with STAR and ALICE measurements, taken from Ref. [1] and [2], respectively.

in mid central collisions. The trend of longitudinal polarization with centrality for EPOS4 is the same as AMPT, although theoretical modelling of these two models are different. The AMPT and EPSO4 results show the $\sqrt{s_{NN}}$ dependence for P_z of Λ and $\bar{\Lambda}$. However, $\sqrt{s_{NN}}$ dependence of P_z for Λ and $\bar{\Lambda}$ hyperons in ECHO-QGP are inconclusive.

The small variations between the hydrodynamic and transport models arises due to different evolution and hadronization processes considered in these models. Here, we have also observed that the magnitude of the collision center of the mass-energy dependence of elliptic flow-induced polarization along the beam direction is weak as compared to the global spin polarization.

IV. SUMMARY

All these models predict a maximum longitudinal polarization in mid-central collisions around 30-50 % centrality at $p_{\rm T} \approx$ 2.0 - 3.0 GeV/c. These findings on longitudinal polarization advocate the existence of a thermal medium in non-central heavy-ion collisions. Our findings are in qualitative agreement with corresponding experimental data at the RHIC and LHC energies.

A. Reference

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