Hyperon polarization in heavy ion collisions at STAR

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Abstract.
In these proceedings, we present the measurements of global polarization for Λ, $\bar{\Lambda}$ with the high-statistics data collected by the STAR experiment for isobar (Ru+Ru, Zr+Zr) collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6, 27 GeV. These measurements allow us to study possible magnetic field driven effects through the polarization difference between Λ and $\bar{\Lambda}$ and system size dependence of global polarization. Furthermore, we present the first measurements of Λ, $\bar{\Lambda}$ hyperon local polarization in isobar collisions at $\sqrt{s_{NN}}$= 200 GeV and Au+Au collisions at $\sqrt{s_{NN}}$= 19.6, 27 GeV. Comparisons with previous measurements in Au+Au and Pb+Pb collisions at RHIC and LHC provide important insights into the collision system size and energy dependence of the vorticities. The local polarization measurements at lower beam energies can probe the predicted baryonic spin hall effect in a dense baryonic environment in heavy-ion collisions.

1 Introduction

In non-central heavy-ion collisions, the produced system has large orbital angular momentum and may have a strong vortical structure, which leads to the global spin polarization of hyperons through the spin-orbital interaction [1]. Due to the nature of the weak decay, Λ hyperon's polarization can be determined through the angular distribution of decay daughter proton in parent's rest frame.

In these proceedings, we report Λ, $\bar{\Lambda}$ global and local polarization as a function of centrality in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6, 27 GeV and Ru+Ru, Zr+Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV, using the data collected by STAR experiment.

2 Global polarization results

In the STAR experiment, the global polarization is determined by $P_\Lambda = \frac{8}{\alpha\pi}\frac{1}{A^0}\frac{<\sin(\Psi_1-\phi^*_{\rm p})>}{\rm Res(\Psi_1)}$ where α is the decay parameter, A^0 is the acceptance correction factor, ϕ^*_p is the decay proton azimuthal angle in Λs rest fame. Res(Ψ_1) is the first-order event plane resolution, can be determined by Zero Degree Calorimeters with Shower Maximum Detectors (ZDC SMD). $\Lambda(\bar{\Lambda})$ hyperons have been reconstructed through the decay channel: $\Lambda \to \pi^- + p$ ($\bar{\Lambda} \to \pi^+ + \bar{p}$).

Global polarization has been observed for Λ and $\bar{\Lambda}$ hyperons in Au+Au collisions from $\sqrt{s_{\rm NN}}$ = 3 to 200 GeV by the STAR experiment [2, 3]. The possible splitting between Λ

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and $\bar{\Lambda}$ global polarization, expected from the magnetic field[3], is not statistically significant with the data collected in the beam energy scan I (BES-I) program. The STAR collaboration recently acquired about 10 times statistics at $\sqrt{s_{\rm NN}}$ = 19.6 and 27 GeV from BES-II compared to BES-I. Results of Λ ($\bar{\Lambda}$) global polarization as a function of collision centrality is found to increase monotonically. The polarization splitting $P_{\bar{\Lambda}} - P_{\Lambda}$ = -0.018 ± 0.127(stat.) ± 0.024(syst.)% at 19.6 GeV, $P_{\bar{\Lambda}} - P_{\Lambda}$ = 0.109 ± 0.118(stat.) ± 0.022(syst.)% at 27 GeV, integrated over 20-50% centrality, is not statistically significant from BES-II[4].

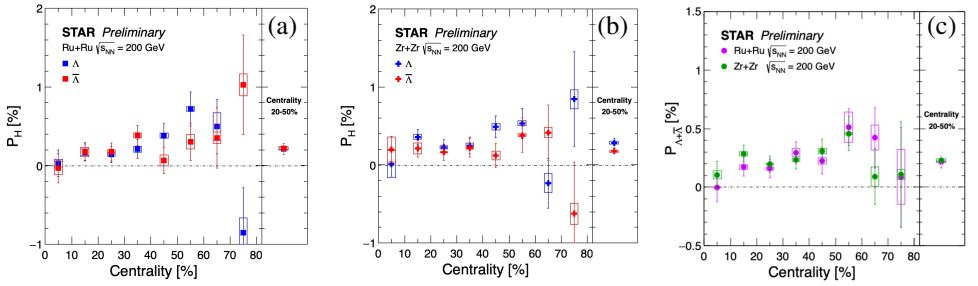

Figure 1: Global polarization of Λ and $\bar{\Lambda}$ as a function of centrality in Ru+Ru(a), Zr+Zr(b) collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. Panel (c) shows Λ+$\bar{\Lambda}$ global polarization results in isobar collisions. Open boxes and vertical lines represent systematic and statistical uncertainties.

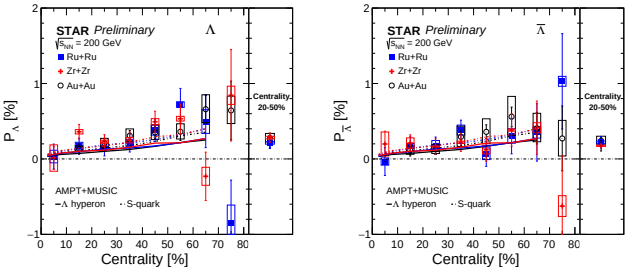

Figure 2: Λ(left) and $\bar{\Lambda}$(right) global polarization as a function of centrality in Ru+Ru, Zr+Zr, and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV.

Figure 1 (a) and (b) show Λ and $\bar{\Lambda}$ global polarization $P_{\Lambda,\bar{\Lambda}}$ as a function of centrality in Ru+Ru and Zr+Zr collisions. The polarization increase from central to peripheral collisions. In order to achieve a better precision in polarization splitting, we also combine measurements in 20-50% centrality results. No significant difference between Λ and $\bar{\Lambda}$ global polarization in Ru+Ru and Zr+Zr collisions is observed. It indicates that there is no magnetic field driven effects on the hyperon polarization within present statistical precision. Figure 1 (c) shows Λ+$\bar{\Lambda}$ global polarization $P_{\Lambda+\bar{\Lambda}}$ as a function of centrality in Ru+Ru and Zr+Zr collisions. The results are consistent in each centrality between Ru+Ru and Zr+Zr collisions.

Figure 2 shows Λ and $\bar{\Lambda}$ global polarization comparison between isobar and Au+Au collisions. The results are consistent for the whole centrality range, indicating there is no obvious collision system size dependence. The hydrodynamic model calculation from Λ polarization scenario and *s*-quark polarization scenario are consistent with the experiment data[5].

3 Local polarization results

STAR has measured the local polarization with respect to the second-order event plane in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV [6]. The local polarization $\langle \cos\theta^*_{\rm p} \rangle$ as a function of

azimuthal angle relative to the second-order event plane shows a sine modulation, as expected from quadrupole structure of vorticity along the beam direction. The second and third-order event planes are determined by the Time Projection Chamber detector (TPC).

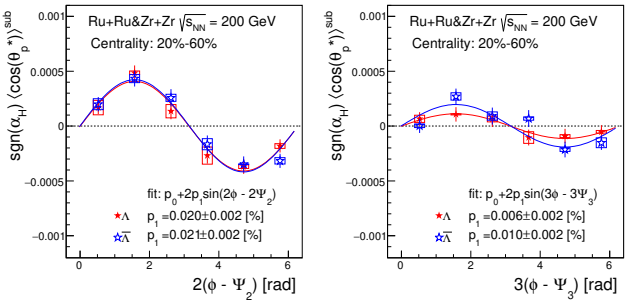

Figure 3: Local polarization $\langle\cos\theta_p^*\rangle$ of Λ and $\bar{\Lambda}$ hyperons as a function of azimuthal angle ϕ relative to the second and third-order event plane in isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV[7].

Figure 3 shows $\langle\cos\theta_p^*\rangle$ of Λ and $\bar{\Lambda}$ hyperons as a function of azimuthal angle ϕ relative to the second-order event plane Ψ_2(left) and third-order event plane Ψ_3(right) for $20\% - 60\%$ centrality, respectively. The solid lines are the fits to the results with $p_0 + 2p_1\sin(n\phi - n\Psi_n)$. The left panel in figure 3 shows a clear sine modulation in polarization signal, as expected from quadrupole structure of vorticity along the beam direction. The pattern in isobar collisions is similar to that in Au+Au with better statistical significance. Figure 3 (right) shows the first measurements of $\langle\cos\theta_p^*\rangle$ with respect to the third-order event plane Ψ_3. The results also show a sine modulation for both Λ and $\bar{\Lambda}$, indicating triangular flow driven polarization[7].

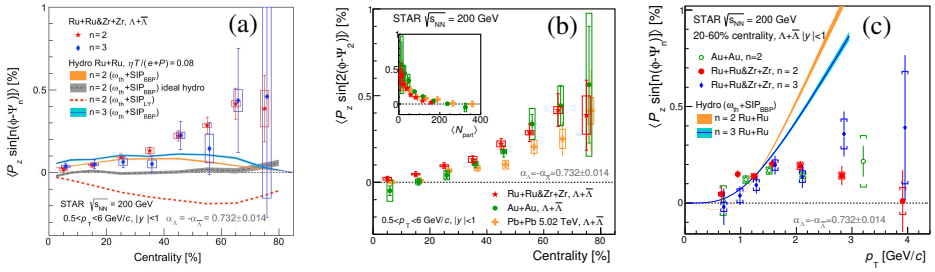

Figure 4: (a): the local polarization w.r.t 2nd(3rd) event plane of $\Lambda+\bar{\Lambda}$ as a function of the collision centrality in isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV. (b): the comparison of the second Fourier sine coeffcient of $\Lambda+\bar{\Lambda}$ local polarization among isobar, Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and Pb+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. (c): local polarization w.r.t 2nd(3rd) event plane of $\Lambda+\bar{\Lambda}$ as a function of transverse momentum. [7]

Figure 4 (a) presents the comparison of centrality dependence of magnitude of $\Lambda+\bar{\Lambda}$ local polarization with respect to second and third Fourier sine coefficients. The results from second order event planes is consistent with expected increase in elliptic flow magnitude towards peripheral collisions. The results from third order also increases from central to peripheral collisions. However, there is no significant difference between the second-order and third-order local polarization within measurement uncertainties.

Figure 4 (b) shows the $\Lambda+\bar{\Lambda}$ local polarization with respect to the second-order event plane as a function of the collision centrality in isobar, Au+Au, and Pb+Pb collisions. A hint of system size dependence has been observed when comparing isobar and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, while the energy dependence is not obvious between $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions and $\sqrt{s_{NN}}$ = 5.02 TeV Pb+Pb collisions.

The local polarization relative to both event planes are plotted as a function of hyperons transverse momentum in Figure 4 (c). Results show that p_T dependence of the polarization is indeed similar to that of elliptic (v_2) and triangular (v_3) flow.

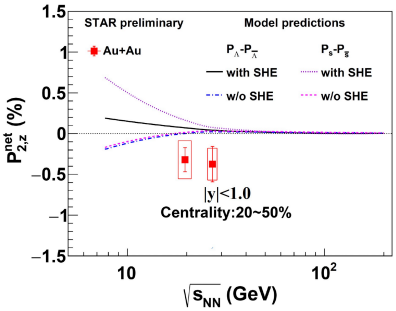

Figure 5: Net local polarization as a function of collision energy.

Figure 5 presents the net local polarization of Λ and $\bar{\Lambda}$, an observable designed to probe the baryonic Spin Hall effect (SHE)[5], in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6 and 27 GeV using data from BES-II. The present measurement of net local polarization does not have the precision to conclude on the scenario of SHE at the measured energies. Measurements at lower energies, where SHE signal is anticipated, are currently in progress.

4 Summary

The global and local polarization of Λ and $\bar{\Lambda}$ have been measured in isobar (Ru+Ru, Zr+Zr) collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV and Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6 and 27 GeV. The global polarization of Λ and $\bar{\Lambda}$ are consistent, indicating that the magnetic field effects on global polarization are not observed within current statistical limitation. The global polarization is consistent across collisions with different system sizes, Ru+Ru, Zr+Zr, and Au+Au at same collision centrality and beam energy. Significant local polarization signals with respect to the second-order and third-order event plane are observed in isobar collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. A slight hint of collision system size dependence has been observed, while energy dependence is not obvious. An observable of net local polarization, proposed to probe the baryonic Spin Hall effect, is measured in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 19.6 and 27 GeV. The present measurement of net local polarization does not have the precision to conclude on the scenario of SHE at the measured energies. Global and local polarization studies at other BES-II energies are underway.

Acknowledgements

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