

Measurements of global and local spin polarization of hyperons in Au+Au collisions at RHIC-STAR

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Abstract. Vortical structure created in heavy ion collision leads to the polarization of hyperons phenomenon, which can be used as a probe to study the spin degree of freedom. RHIC Beam Energy Scan II program offers a good opportunity to study the hyperon polarization over the wide energy regime. In these proceedings, we report measurements of the global polarization of Λ , $\bar{\Lambda}$, Ξ^\pm and Ω^\pm at $\sqrt{s_{NN}} = 7.7 - 27$ GeV in Au+Au collisions from BES-II. The global hyperons polarization of all hyperons decrease as collision energy increases. Additionally, we report the second harmonics of local Λ , $\bar{\Lambda}$ polarization and their difference at $\sqrt{s_{NN}} = 7.7 - 27$ GeV, which can be used to probe the baryonic spin Hall effect. These measurements provide valuable insights into the spin dynamics within the QCD medium produced in heavy ion collisions.

1 Introduction

In non-central heavy ion collisions, substantial angular momentum is generated, resulting in significant vorticity and the spin polarization of particles with finite spin along the system angular momentum [1–3], this phenomenon is global polarization. In experiment, weak-decayed hyperons can serve as a probe to extract the polarization information due to its "self-analysing" property [5], decayed daughter baryon tends to be emitted along the parent hyperon spin direction. Global polarization study can probe the vortical characteristics of the medium and serve as a tool for exploring the nuclear matter equation of state in heavy ion collisions. This phenomenon has been observed in STAR BES-I program, showing the first evidence of fluid vorticity in heavy ion collisions [7].

Additionally, anisotropic flow can produce local vorticities in both in-plane (z) and out-of-plane (y) directions, leading to local hyperon polarization [2, 4]. The second harmonic of local spin polarization (P_{2z}) and their difference, are predicted to be a sensitive probe for the baryonic spin Hall effect driven by gradients in baryon chemical potential [6]. Local polarization along the beam direction has also been observed in STAR at $\sqrt{s_{NN}} = 200$ GeV [8].

2 Results and discussion

In experiment, global hyperon (for example, Λ) polarization can be determined by

$$P_\Lambda = \frac{8}{\pi\alpha_\Lambda} \frac{1}{R_1} \langle \sin(\Psi_1 - \phi_p^*) \rangle \quad (1)$$

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where α_Λ is the Λ hyperon decay parameter, Ψ_1 is the 1st order event plane angle, R_1 is the 1st order event plane resolution, ϕ_p^* is the decayed proton azimuthal direction in the parent hyperon rest frame.

Local hyperon polarization can be determined by

$$P_{2,z} = \frac{\langle \cos \theta_p^* \sin(2\phi_\Lambda - 2\Psi_2) \rangle}{R_2 \alpha_\Lambda \langle (\cos \theta_p^*)^2 \rangle}, \quad P_{2,z}^{net} = P_{2,z}^\Lambda - P_{2,z}^{\bar{\Lambda}} \quad (2)$$

where θ_p^* is the decayed proton polar angle in Λ rest frame, Ψ_2 is the 2nd order event plane and R_2 is the 2nd order event plane resolution.

2.1 Global Λ polarization

The global polarization of Λ and $\bar{\Lambda}$, measured by the RHIC-STAR experiment during the BES-II program, is shown in the left panel of Fig. 1. P_Λ and $P_{\bar{\Lambda}}$ results show that polarization decreases with increasing beam energy. Compared with the BES-I results, the BES-II measurements are consistent within uncertainties, with the statistical error bars reduced by a factor of nine. Systematic uncertainties arise from hyperon decay parameter, background contribution, hyperon reconstruction selection criteria [9]. $P_{\bar{\Lambda}} - P_\Lambda$ measurements, as shown in the right panel, indicate no significant splitting between polarization of Λ and $\bar{\Lambda}$ within uncertainties. These results place an upper limit on the late-stage magnetic field of $B \lesssim 10^{13}$ T.

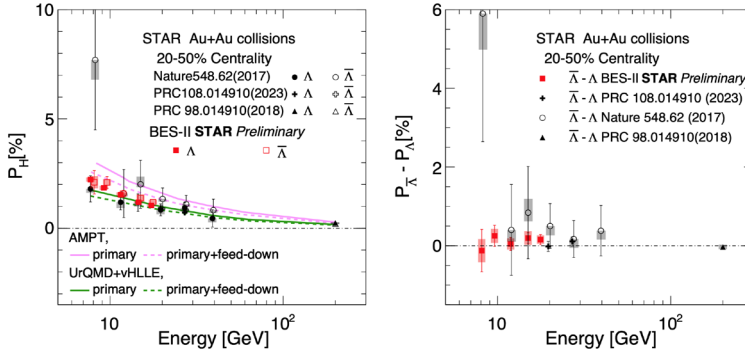


Figure 1. Global polarization of Λ and $\bar{\Lambda}$ hyperon (left panel) and their difference (right panel) as function of collision energy in Au+Au collisions.

2.2 Global Ξ and Ω polarization

Ξ^- and Ω^- hyperons decay via $\Xi^- \rightarrow \Lambda + \pi^-$ and $\Omega^- \rightarrow \Lambda + K^-$, followed by a subsequent decay $\Lambda \rightarrow p + \pi^-$. This decay chain allows the global polarization of Ξ^- and Ω^- to be determined using two independent methods. The direct method is based on angular distribution measurement of daughter Λ in the parent hyperon rest frame, while the indirect method uses daughter Λ global polarization combined with a spin transfer factor [2]. As shown in Fig. 2 (left panel), the global polarization of the Ξ^- hyperon determined by both methods is consistent within uncertainties. Ξ and Λ global polarization show no significant difference within uncertainty. Ω hyperon global polarization cannot be calculated reliably using the direct method due to the small decay parameter, $\alpha_\Omega = 0.0157 \pm 0.0021$. Consequently, the Ω

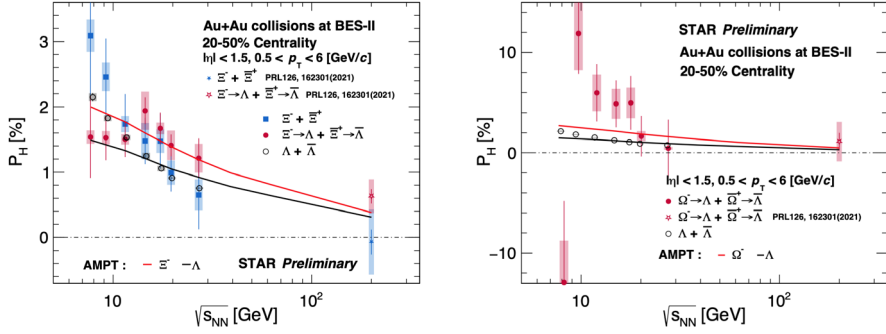


Figure 2. Ξ (Left panel) and Ω (right panel) hyperon global polarization as function of collision energy in Au+Au collisions. Blue markers are for direct method, red markers are for spin transfer method.

polarization is determined exclusively via the spin transfer method. As shown in Fig. 2 (right panel), the global Ω polarization is larger than that of the Λ hyperon, though the difference is not statistically significant. Furthermore, both Ξ and Ω global polarizations exhibit the same energy dependence, a trend qualitatively reproduced by AMPT model predictions.

2.3 Local Λ polarization and spin Hall effect

The measurement of local polarization $P_{2,z}$ of Λ and $\bar{\Lambda}$, as well as their difference, is motivated by the predicted baryonic spin Hall effect. Local polarization of Λ and $\bar{\Lambda}$ are measured in RHIC-STAR BES-II program, with the results shown in Fig. 3. In the left panel, within uncertainty no strong energy dependence of Λ and $\bar{\Lambda}$ $P_{2,z}$ is observed. Fig. 4 presents the net local polarization in the z direction. A simultaneous model fit to both global and local polarization is necessary to clarify the behavior of local polarization and to assess possible contributions from the baryonic spin Hall effect.

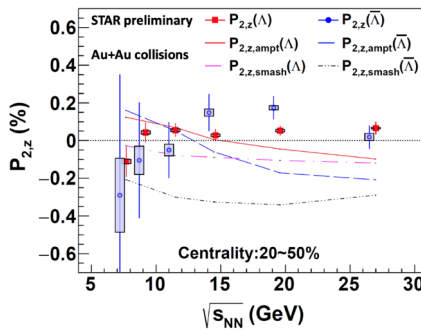


Figure 3. Local polarization of Λ and $\bar{\Lambda}$ $P_{2,z}$ as function of collision energy in Au+Au collisions.

3 Summary

In summary, the global spin polarization of Λ, Ξ, Ω hyperons is measured in Au+Au collisions at 7.7, 9.2, 11.5, 14.6, 19.6, and 27 GeV from the RHIC-STAR BES-II program. The

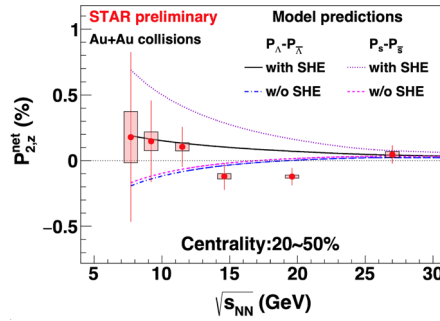


Figure 4. Net local polarization of Λ and $\bar{\Lambda}$ $P_{2,z}$ as function of collision energy in Au+Au collisions.

global polarization of Λ , Ξ , Ω exhibits a similar beam energy dependence. This presents the first measurement of non-zero global polarization for Ξ and Ω at BES-II energies. Within uncertainty, no splitting is observed between global polarization of Λ and $\bar{\Lambda}$. Measurements of $P_{2,z}$ for Λ and $\bar{\Lambda}$ in the RHIC-STAR BES-II program show no strong energy dependence, and a simultaneous model fit to global and local polarization is needed to clarify their behavior and potential contributions from the baryonic spin Hall effect.

Acknowledgements

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