Centrality dependence of hyperon global polarization in Au+Au collisions at RHIC

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Abstract. We present the centrality dependence of Λ and ¯Λ hyperon global polarization in Au+Au collisions at √s_{NN} = 62 GeV and 200 GeV measured with the STAR detector at RHIC. Within the precision of the measurement, we observe no centrality dependence of Λ and ¯Λ hyperon global polarization and within our acceptance it is consistent with zero. Different sources of systematic uncertainties (feed down effects, spin precession) are discussed and estimated. The obtained upper limit, |P_{Λ, ¯Λ}| ≤ 0.02, is compared to theoretical predictions discussed recently in literatures.

1. Introduction

The system created in non-central relativistic nucleus-nucleus collisions possesses large orbital angular momentum. One of the most interesting and important phenomena predicted to occur in such a system is global polarization of the system [1, 2, 3]. This phenomenon manifests itself in the polarization of produced secondary particles along the direction of the system’s angular momentum. Measurement of global polarization may provide valuable insight into the evolution of the system, the mechanism for hadronization, and the origin of hadronic spin preferences. The orbital angular momentum of the system may be transformed into a preference in global spin orientation of particles by spin-orbit coupling at various stages of the system evolution. This can happen at the partonic level, while the system evolves as an ensemble of deconfined polarized quarks. Polarization of hadrons produced secondarily could also be acquired via hadron re-scattering at a later hadronic stage. An example of transformation from system orbital momentum to the global polarization of produced ρ-mesons, which is due to the pion re-scattering, is discussed in [2]. One specific scenario for the spin-orbit transformation via the polarized quark phase is discussed in [1]. There, it is argued that parton interactions in non-central relativistic nucleus-nucleus collisions lead first to the global polarization of the produced quarks. The magnitude for this global quark polarization at RHIC (Relativistic Heavy Ion Collider) energies was estimated to be as high as thirty percent. Assuming that the strange and non-strange quark polarizations (P_s and P_q, respectively) are equal, in the particular case of the ‘exclusive’ parton recombination scenario [1], the global polarization P_H for Λ, Σ, and Ξ hyperons appears
to be similar to that for quarks: \( P_H = P_q \approx 0.3 \). Recently more realistic calculations \(^4\) of the global quark polarization were performed within a model based on the HTL (Hard Thermal Loop) gluon propagator. The resulting hyperon polarization was predicted to be in the range from \(-0.03\) to \(0.15\), depending on the temperature of the QGP formed.

In this paper we present the centrality dependence of \( \Lambda \) and \( \bar{\Lambda} \) hyperon global polarization in \( \text{Au+Au} \) collisions at \( \sqrt{s_{NN}}=62 \) and 200 GeV measured with the STAR (Solenoidal Tracker At RHIC) detector.

2. Global polarization of hyperons

In the hyperon global polarization measurement we use the observable derived in \( ^5 \) \( ^6 \):

\[
P_H = \frac{8}{\pi \alpha_H} \langle \sin (\phi_p^* - \Psi_{RP}) \rangle .
\]

(1)

where \( P_H \) is the hyperon global polarization, \( \Psi_{RP} \) is the reaction plane angle, and \( \alpha_H \) is the hyperon decay parameter. \( \phi_p^* \) is the azimuthal angle of the 3-momentum of hyperon’s decay product, measured in hyperon’s rest frame. Angle brackets in this equation denote an average over the solid angle of the hyperon’s decay product 3-momentum in the hyperon’s rest frame and over all directions of the system orbital momentum \( L \), or, in other words, over all possible orientations of the reaction plane. Note that in Eq. 1 perfect detector acceptance is assumed. A detailed study \( ^7 \) of detector acceptance effects shows that related systematic uncertainty is less than 20%.

The hyperon reconstruction procedure used in this analysis is similar to that in \( ^8 \) \( ^9 \) \( ^10 \). \( \Lambda \) and \( \bar{\Lambda} \) particles were reconstructed from their weak decay topology, \( \Lambda \rightarrow p\pi^- \) and \( \bar{\Lambda} \rightarrow \bar{p}\pi^+ \), using charged tracks measured in the STAR main TPC (Time Projection Chamber) \( ^11 \). The corresponding decay parameter is \( \alpha_{\Lambda} = -\alpha_{\bar{\Lambda}} = 0.642 \pm 0.013 \) \(^12\). In this analysis hyperon candidates with invariant mass within the window \( 1.11 < m_{\Lambda,\bar{\Lambda}} < 1.12 \) GeV/\( c^2 \) are used. The statistics for \( \bar{\Lambda} \)-hyperons is smaller than that for \( \Lambda \)-hyperons by 40\% (20\%) for \( \text{Au+Au} \) collisions at \( \sqrt{s_{NN}}=62 \) GeV (200 GeV). The background contribution is estimated by fitting the invariant mass distribution with the sum of a Gaussian and a 3rd-order polynomial function, and is found to be less than 8\%.

Collision centrality was defined using the total charged particle multiplicity within a pseudorapidity window of \( |\eta| < 0.5 \). The charged particle multiplicity distribution was divided into nine centrality bins (classes): 0-5\% (most central collisions), 5-10\%, 10-20\%, 20-30\%, 30-40\%, 40-50\%, 50-60\%, 60-70\%, and 70-80\% of the total hadronic inelastic cross section for \( \text{Au+Au} \) collisions.

The reaction plane angle in Eq. 1 is estimated by calculating the so-called event plane flow vector \( Q_{EP} \). This implies the necessity to correct the final results by the reaction plane resolution \( R_{EP} \) \(^13\) \(^14\) \(^15\). The global polarization measurement requires the knowledge of the direction of the system orbital momentum \( L \), hence, of the first-order event plane vector. In this paper, the first-order event plane vector was determined from two STAR Forward TPCs \(^16\), which span a pseudorapidity region...
2.7 < |\eta| < 3.9. Charged particle tracks with transverse momentum 0.15 < p_t < 2.0 GeV are used to define the event plane vector. It was found in this analysis that the event plane vector defined with the particles measured in the Forward TPCs is reliable within the centrality region 0-80% for Au+Au collisions at \( \sqrt{s_{NN}} = 62 \) GeV. With higher multiplicity at \( \sqrt{s_{NN}} = 200 \) GeV, saturation effects in the Forward TPCs for the most central collisions become evident, and the estimated reaction plane angle is unreliable. Due to this effect, the centrality region used for the \( \Lambda (\bar{\Lambda}) \) hyperon global polarization measurement in Au+Au collisions at \( \sqrt{s_{NN}} = 200 \) GeV is limited to 20-70%.

The measured hyperons consist of primordial \( \Lambda (\bar{\Lambda}) \) and feed down from multiply strange hyperons (\( \Xi^0 \) and \( \Omega \)) and \( \Sigma^0 \) decays, and also from short-lived resonances decaying via strong interactions. Under the assumption that the global polarization has the same value for \( \Lambda \) and \( \Sigma^0 \) [1], we estimate the relative contribution from \( \Sigma^0 \) to the extracted global polarization of the \( \Lambda \) hyperons to be \( \leq 30\% \). This estimate takes into account an average polarization transfer from \( \Sigma^0 \) to \( \Lambda \) of \(-1/3\) [17, 18] (this value can be affected by non-uniform acceptance of the daughter \( \Lambda \)). It furthermore allows for the \( \Sigma^0/\Lambda \) production ratio to be 2-3 times higher for Au+Au collisions than the value (15%) measured [19] for d+Au. Based on the results [20], the contribution of feed-downs from multiply strange hyperons (\( \Xi, \Omega \)) is estimated to be less than 15%. The effect of feed-downs to \( \Lambda (\bar{\Lambda}) \) from strongly decaying resonances has not been measured with the STAR detector. Calculations from a string fragmentation model [21] suggest that in pp collisions the fraction of direct hyperons is about 27% for \( \Lambda \) and 15% for \( \bar{\Lambda} \), respectively. The global polarization measurement could also conceivably be affected by hyperon spin precession in the strong magnetic field within the TPC. The effect of the spin precession on the global polarization measurements is found to be negligible. The overall relative uncertainty in the \( \Lambda (\bar{\Lambda}) \) hyperon global polarization measurement due to detector effects is estimated to be less than a factor of 2.

Results of the measurement for the \( \Lambda \) global polarization as a function of centrality have been presented in [3]. Figure 1 presents the \( \Lambda \) and \( \bar{\Lambda} \) hyperon global polarization as a function of centrality given as a fraction of the total inelastic hadronic cross section. Black circles show the result of the measurement for Au+Au collisions at \( \sqrt{s_{NN}} = 200 \) GeV. Red squares indicate the result of a similar measurement for Au+Au collisions at \( \sqrt{s_{NN}} = 62 \) GeV. Within uncertainties we observe no centrality-dependence of the \( \Lambda \) and \( \bar{\Lambda} \) global polarization and the obtained results are consistent with zero.

3. Conclusion

The \( \Lambda \) and \( \bar{\Lambda} \) hyperon global polarization as a function of centrality has been measured in Au+Au collisions at center of mass energies \( \sqrt{s_{NN}} = 62 \) and 200 GeV with the STAR detector at RHIC. Within uncertainties we observe no centrality-dependence of \( \Lambda \) and \( \bar{\Lambda} \) global polarization. Combining results of this measurement and those from [3], an upper limit of \( |P_{\Lambda,\bar{\Lambda}}| \leq 0.02 \) for the global polarization of \( \Lambda \) and \( \bar{\Lambda} \) hyperons within
Figure 1. (Color online) Global polarization of $\Lambda$ (left) and $\bar{\Lambda}$ (right) hyperons as a function of centrality given as fraction of the total inelastic hadronic cross section. Black circles show the results for Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV (centrality region 20-70%) and red squares indicate the results for Au+Au collisions at $\sqrt{s_{NN}}=62$ GeV (centrality region 0-80%). Only statistical errors are shown.

STAR’s acceptance is obtained. The obtained upper limit is far below the few tens of percent values discussed in [1], but it falls within the predicted region from the more realistic calculations [4] based on the HTL (Hard Thermal Loop) model.