Global polarization of Ξ hyperons in Au+Au collisions from the STAR experiment

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The hot and dense matter produced in non-central heavy-ion collisions possess a large initial orbital angular momentum. This initial orbital angular momentum leads to global polarization of final state hadrons, which could be measured via parity violating weak decays of hyperons. The STAR experiment observed non-zero Λ global polarization. A large amount of new data provide opportunities to measure multistrange hyperon polarization. It could be important input for hydrodynamic studies of the system. In this proceedings, we report results of Ξ hyperon global polarization ($P_{\Xi^- + \bar{\Xi}^+}$) measurement for Au+Au collisions at $\sqrt{s_{NN}}$ = 27, 54.4 and 200 GeV.

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Introduction

The quark-gluon plasma - hot-dense matter produced in relativistic heavy-ion collisions - has been an object of interest from the very beginning of its discovery. Experimental observations at RHIC and the LHC with sophisticated theoretical studies obtained information about nearly prefect liquid nature of the QGP [1].

Relativistic hydrodynamics predicts that QGP possess large vorticity in non-central collisions. It manifests itself in polarization of produced particles along the direction of its vorticity. One can obtain polarization of hyperons from its parity violating weak decay properties [2, 3].

In the hyperon decays the angular distribution of daughter baryons in the parent hyperon rest frame is given by:

$$\frac{dN}{d\cos\theta^*} \propto 1 + \alpha_H P_H \cos\theta^*, \tag{1}$$

α_H is the hyperon decay parameter, P_H is the hyperon polarization, $\cos\theta^*$ is the angle between the polarization vector and daughter baryon momentum in the hyperon rest frame [4].

Global polarization value can be obtained by measuring daughter baryon's momentum projection on initial angular momentum direction. One can measure it in respect to reaction plane (which is defined by the beam direction and impact parameter vector):

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$$P_H = \frac{8}{\pi\alpha_H}\frac{\langle\sin\left(\Psi_1^{obs} - \phi^*_{daughter}\right)\rangle}{Res(\Psi_1)}, \quad (2)$$

where $\phi^*_{daughter}$ is the azimuthal angle of the daughter baryon in the parent hyperon rest frame, $Res(\Psi_1)$ is event plane resolution. Decay parameter values are $\alpha_\Lambda = 0.732\pm0.014$, $\alpha_{\bar{\Lambda}} = -0.758\pm0.010$, $\alpha_{\Xi^-} = -\alpha_{\bar{\Xi}^+} = -0.401\pm 0.010$ [5].

Global polarization of Λ hyperons was measured by the STAR for collision energies $\sqrt{s_{NN}} = 3-200$ GeV [6–8] and were described successfully by transport and hydrodynamic model calculations. Multistrange hyperon's global polarization measurements could possibly achieve goal of understanding the nature of vorticity [9].

Λ hyperons are reconstructed via its decay $\Lambda \to p+\pi^-$, and for Ξ hyperons decay channel $\Xi^- \to \Lambda + \pi^-$ is analyzed. This cascade decay provides opportunity to measure its global polarization in two separate ways. One can use Equation 2 directly measuring angle of daughter Λ decaying from Ξ. Additionally, a fraction of Ξ global polarization could transfer into its daughter Λ polarization with transfer factor $C_{\Xi^-\Lambda} = 0.932$ and global polarization of Ξ hyperons could be measured by examining its daughter Λ global polarization [10–12].

In this proceedings we report on the measurements of the global polarization of $\Xi^- + \bar{\Xi}^+$ hyperons in Au+Au collisions at $\sqrt{s_{NN}} = 27$, 54.4 and 200 GeV and compare it to that of $\Lambda + \bar{\Lambda}$.

Data analysis

Data of Au+Au collissions at $\sqrt{s_{NN}} = 27$ and 54.4 GeV collected by STAR experiment was used for this analysis. STAR features cylindrical geometry detector for high-multiplicity collisions [13]. Events with collision vertex within 70 cm from the center of Time-Projection Chamber (TPC) and with vertex position within 2 cm from the beam line in the transverse plane were analyzed. All events had to pass minimum-bias trigger.

Tracks of charged particles were measured in TPC [14] within a pseudorapidity range $|\eta| < 1$ and with full azimuthal acceptance. Tracks with momentum > 0.15 GeV$/c$ were identified via ionization energy losses, dE/dx, and by their squared mass obtained by TOF [15] and were used for hyperon reconstruction.

From all charged-particle tracks with number of associated ionization hits in TPC more than 15 and momentum magnitude $P > 0.15$ GeV/c, protons and pions were selected. Λ hyperons were reconstructed via topology of its decay $\Lambda \to p + \pi^-$ ($\bar{\Lambda} \to \bar{p} + \pi^+$) with quality assurance selections: distance of closest approach (DCA) between charged daughter particles and primary vertex position, DCA between primary vertex position and reconstructed Λ trajectory, DCA between daughter p and π^- trajectories, decay length of

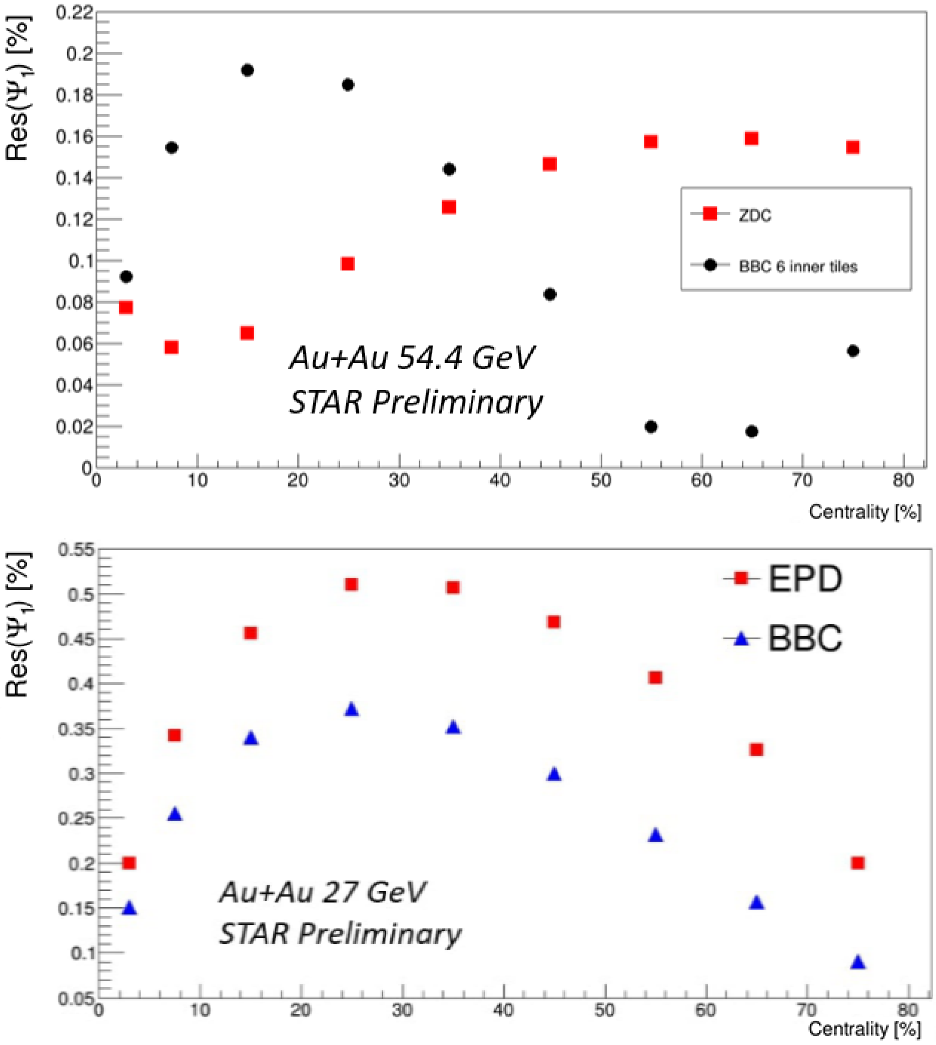

Fig. 1. Resolution of the first order event-plane at $\sqrt{s_{NN}} = 27$ and 54.4 GeV.

reconstructed Λ. After that the same procedure was performed for decay $\Xi^- \to \Lambda + \pi$ ($\bar{\Xi}^+ \to \bar{\Lambda} + \pi^+$).

The collision centrality (overlapping between colliding nuclei) was determined based on the measured multiplicity of charged tracks within midrapidity region. Centrality and trigger efficiency were obtained by fitting it to a Monte Carlo Glauber simulation.

For event plane reconstruction EPD [16] ($2.1 < \eta < 5.1$) and BBC [17] ($3.3 < \eta < 5.1$) were used separately for $\sqrt{s_{NN}} = 27$ GeV, ZDC [18] ($\eta > 5.2$) and BBC for $\sqrt{s_{NN}} = 54.4$ GeV collision energy. The first-order event plane of the spectator particles was used as a proxy for reaction plane.

Global polarization calculations with respect to event plane should take into account event plane resolution. Resolution was calculated via two-subevent method, with the usage of East (forward rapidity) and West (backward rapidity) detectors in combination.

Following Equation 2, $\langle \sin(\Psi_1 - \phi^*_{daughter}) \rangle$ should be measured. To detach signal of real hyperons from combinatoric pairs of its daughter candi-

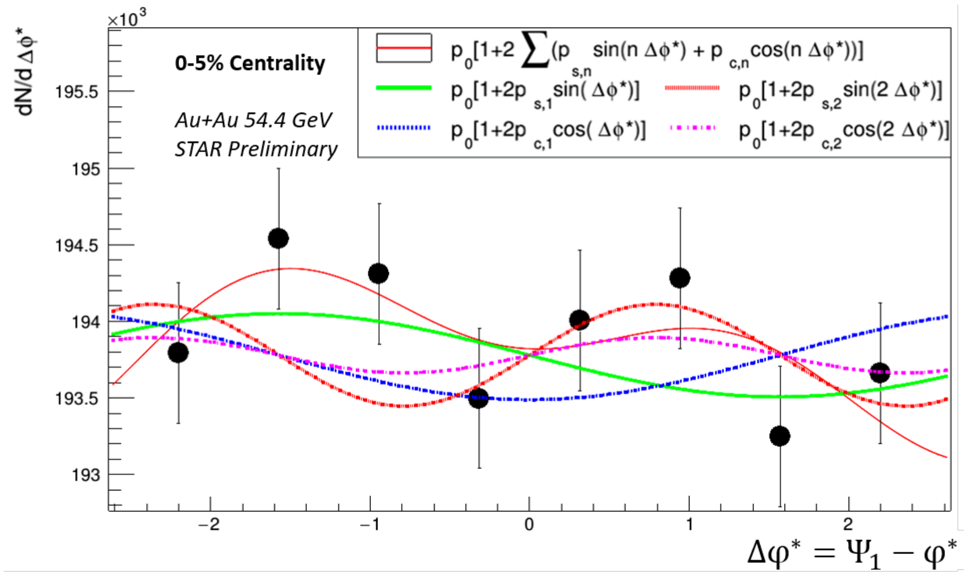

Fig. 2. Event-plane method for global polarization value extraction.

dates, so-called "event-plane method" was used. This method consists in measuring number of hyperons as a function of $(\Psi_1 - \phi^*_{daughter})$, and then fitting it with Fourier function to obtain the sine coefficient $\langle \sin(\Psi_1 - \phi^*_{daughter}) \rangle$. Example of such a fit is presented in Figure 2.

Following the Equation 2, by taking detector event-plane resolution into account, observable global polarization value can be calculated. Track efficiency correction was not applied due to negligible effect.

Acceptance correction, proposed in previous measurements of Λ global polarization, was applied [7]. Finite detector acceptance leads to small dependence of Equation 2 from $p^*_{daughter}$. For this reason it can be rewritten as:

$$\frac{8}{\pi \alpha_H} \langle \sin(\phi^*_b - \Psi_{RP}) \rangle = \frac{4}{\pi} \overline{\sin \theta^*_b} P_H(p^H_t, \eta^H) = A_0(p^H_t, \eta^H) P_H(p^H_t, \eta^H), \quad (3)$$

where $A_0(p^H_t, \eta^H) = \frac{4}{\pi} \overline{\sin \theta^*_b}$ is correction factor depending on p^H_t, η^H and collision centrality.

Results

Figure 3 represents global polarization of $\Lambda + \bar{\Lambda}$ and $\Xi^- + \bar{\Xi}^+$ hyperons as a function of collision energy for the centrality bin 20-50% (20-80% for $\Xi^- + \bar{\Xi}^+$ at $\sqrt{s_{NN}} = 200$ GeV due to smaller signal). The results of this analysis are shown together with $\sqrt{s_{NN}} = 7.7$-200 GeV Λ global polarization studies, preliminary results for new datasets at $\sqrt{s_{NN}} = 27$ and 54.4 GeV and thr first $\sqrt{s_{NN}}$ =200 GeV study of Ξ global polarization. Theoretical curves obtained in AMPT [19] model are shown together with the experimental results.

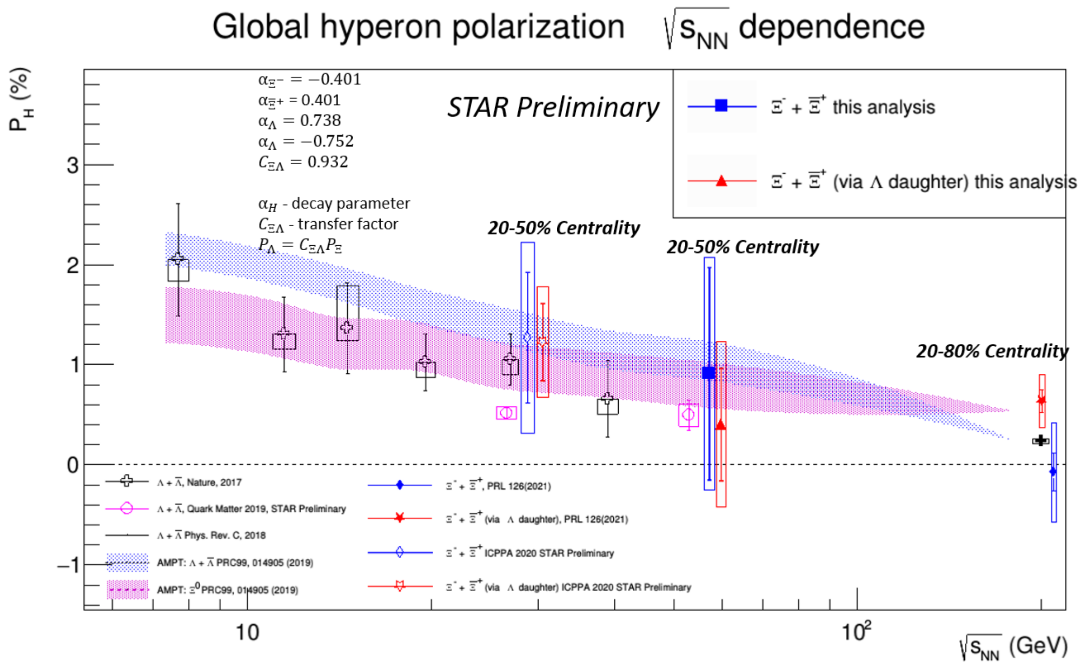

Fig. 3. Global polarization of hyperons collision energy dependence.

Global polarization was measured for Ξ hyperons directly via the angle of daughter Λ and via its Λ daughter decays. Both measurements are consistent within given large uncertainties.

Experimental trend for Ξ global polarization is consistent with theoretical AMPT calculations. Within uncertainties it is also consistent with Λ global polarization which means that further measurements with higher statistics and better event plane resolution are needed to measure any possible difference between these results.

Summary

We present the first results of global polarization measurements for $\Xi^- + \bar{\Xi}^+$ in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV for 20-50% collision centrality measured directly via the angle of daughter Λ and via its transfer to Λ daughter global polarization. Results stay within experimental trend and consistent with theoretical predictions within uncertainties.

REFERENCES

1. *Voloshin S.A., Poskanzer A.M., Snellings R.* Collective phenomena in non-central nuclear collisions. — 2008. — arXiv:0809.2949 [nucl-ex].

2. *Liang Z.T., Wang X.N.* Globally Polarized Quark-Gluon Plasma in Noncentral $A+A$ Collisions // Phys. Rev.

Lett. — 2005. — Mar. — V. 94. — P. 102301. — URL: https://link.aps.org/doi/10.1103/PhysRevLett.94.102301.

3. *Voloshin S.A.* Polarized secondary particles in unpolarized high energy hadron-hadron collisions? — 2004. — arXiv:nucl-th/0410089.

4. *Voloshin S.A., Niida T.* Ultrarelativistic nuclear collisions: Direction of spectator flow // Phys. Rev. C. — 2016. — Aug. — V. 94. — P. 021901. — URL: https://link.aps.org/doi/10.1103/PhysRevC.94.021901.

5. *Zyla P.A. et al.* [Particle Data Group Collaboration] Review of Particle Physics // Progress of Theoretical and Experimental Physics. — 2020. — 08. — V. 2020, no. 8. — 083C01 https://academic.oup.com/ptep/article-pdf/2020/8/083C01/34673722/ptaa104.pdf.

6. *Abelev B.I., Aggarwal M.M., Ahammed Z., Anderson B.D., Arkhipkin D., Averichev G.S., Bai Y., Balewski J., Barannikova O., Barnby L.S., et al.*. Global polarization measurement in Au+Au collisions // Physical Review C. — 2007. — Aug. — V. 76, no. 2. — URL: http://dx.doi.org/10.1103/PhysRevC.76.024915.

7. *Adamczyk L., et al.*. Global Lambda hyperon polarization in nuclear collisions // Nature. — 2017. — Aug. — V. 548, no. 7665. — P. 62–65. — URL: http://dx.doi.org/10.1038/nature23004.

8. *Abdallah M.S. et al.* [STAR Collaboration] Global Λ-hyperon polarization in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 3$ GeV. — 2021. — 7. — arXiv:2108.00044.

9. *Adam J. et al.* [STAR Collaboration Collaboration] Global Polarization of Ξ and Ω Hyperons in Au + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV // Phys. Rev. Lett. — 2021. — Apr. — V. 126. — P. 162301. — URL: https://link.aps.org/doi/10.1103/PhysRevLett.126.162301.

10. *Lee T.D., Yang C.N.* General Partial Wave Analysis of the Decay of a Hyperon of Spin $\frac{1}{2}$ // Phys. Rev. — 1957. — Dec. — V. 108. — P. 1645–1647. — URL: https://link.aps.org/doi/10.1103/PhysRev.108.1645.

11. *Huang M. et al.* [HyperCP Collaboration] New Measurement of $\Xi^- \to \Lambda\pi^-$ Decay Parameters // Phys. Rev. Lett. — 2004. — Jun. — V. 93. — P. 011802. — URL: https://link.aps.org/doi/10.1103/PhysRevLett.93.011802.

12. *Luk K.B., Diehl H.T., Duryea J., Guglielmo G., Heller K., Ho P.M., James C., Johns K., Longo M.J., Rameika R., et al.*. Search for DirectCPViolation in Nonleptonic Decays of Charged Ξ and Λ Hyperons // Physical Review Letters. — 2000. — Dec. — V. 85, no. 23. — P. 4860–4863. — URL: http://dx.doi.org/10.1103/PhysRevLett.85.4860.

13. *Anerella M., et al.*. The RHIC magnet system // Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. — 2003. — V. 499, no. 2. — P. 280 – 315. — The Relativistic Heavy Ion Collider Project: RHIC and its Detectors URL: http://www.sciencedirect.com/science/article/pii/S016890020201940X.

14. *Anderson M., Berkovitz J., Betts W., Bossingham R., Bieser F., Brown R., Burks M., Calderón de la Barca Sánchez M., Cebra D., Cherney M., et al.*. The STAR time projection chamber: a unique tool for studying high multiplicity events at RHIC // Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. — 2003. — Mar. — V. 499, no. 2-3. — P. 659–678. — URL: http://dx.doi.org/10.1016/S0168-9002(02)01964-2.

15. *Llope W.* Multigap RPCs in the STAR experiment at RHIC // Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. — 2012. — V. 661. — P. S110–S113. — X. Workshop on Resistive Plate Chambers and Related Detectors (RPC 2010) URL: https://www.sciencedirect.com/science/article/pii/S0168900210017006.

16. *Adams J., Ewigleben A., Garrett S., He W., Huang T., Jacobs P., Ju X., Lisa M., Lomnitz M., Pak R., et al.*. The STAR event plane detector // Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. — 2020. — Jul. — V. 968. — P. 163970. — URL: http://dx.doi.org/10.1016/j.nima.2020.163970.

17. *Whitten C.A. et al.* [STAR Collaboration] The beam-beam counter: A local polarimeter at STAR // AIP Conf. Proc. — 2008. — V. 980, no. 1. — P. 390–396.

18. *Xu Y.F., Chen J.H., Ma Y.G., Tang A.H., Xu Z.B., Zhu Y.H.* Physics performance of the STAR zero degree calorimeter at relativistic heavy ion collider // Nucl. Sci. Tech. — 2016. — V. 27, no. 6. — P. 126.

19. *Wei D.X., Deng W.T., Huang X.G.* Thermal vorticity and spin polarization in heavy-ion collisions // Phys. Rev. C. — 2019. — Jan. — V. 99. — P. 014905. — URL: https://link.aps.org/doi/10.1103/PhysRevC.99.014905.