Experimental discovery of global polarization of Λ and \( \bar{\Lambda} \) hyperons in the STAR experiment \cite{1} \cite{2} gave us evidence of existence of a new class of collective phenomena in heavy-ion collisions. The global polarization of hyperons is well described within the thermodynamic approach based on hadronic degrees of freedom \cite{3} \cite{4}. This was demonstrated by implementation of this approach into various hydrodynamical \cite{5} \cite{6} \cite{7} \cite{8} \cite{9} \cite{10} \cite{11} models of heavy-ion collisions. This thermodynamic approach is not without its problems, see recent review \cite{12}. One of them, concerning the global polarization incorporated into the model of the three-fluid dynamics. Centrality dependence of the polarization is studied. It is predicted that the polarization reaches a maximum or a plateau (depending on the equation of state and centrality) at \( \sqrt{s_{NN}} \approx 3 \) GeV.

At present, experiments at lower collision energies than those of the Beam Energy Scan (BES) program at the Relativistic Heavy Ion Collider (RHIC) are in progress: STAR fixed target (FXT) program \cite{23} at RHIC and HADES \cite{24} at GSI Helmholtzzentrum für Schwerionenforschung. Also new facilities for heavy-ion collisions are under construction, which are designed for collider regimes, Nuclotron-based Ion Collider Facility (NICA) in Dubna \cite{25}, and for fixed-target experiments, the Baryonic Matter at Nuclotron (BM@N) \cite{26} in Dubna \cite{26} \cite{27}, the Facility for Antiproton and Ion Research (FAIR) in Darmstadt \cite{28}, and High Intensity heavy-ion Accelerator Facility (HIAF) in Huizhou, China \cite{29}. The energy ranges for the Au beams are \( \sqrt{s_{NN}} = 3 - 7.2 \) GeV for STAR-FXT, \( \sqrt{s_{NN}} = 2.3 - 2.6 \) GeV for HADES, \( \sqrt{s_{NN}} = 2.3 - 3.5 \) GeV for BM@N, \( \sqrt{s_{NN}} = 2.3 - 4 \) GeV for HIAF, \( \sqrt{s_{NN}} = 2.7 - 4.9 \) GeV for FAIR, and \( \sqrt{s_{NN}} = 4 - 11 \) GeV for NICA.

The NICA and BES-RHIC energy ranges overlap. Therefore, all above mentioned calculations of the global polarization \cite{0} \cite{17} \cite{21} \cite{22} involved the high-energy end of the NICA range. Even some works dedicated to the polarization at NICA and FAIR energies \cite{7} \cite{16} in fact considered the upper end of this range that overlaps with BES-RHIC energies. Predictions of the global polarization in the actual NICA range were done in Refs. \cite{9} \cite{11} \cite{21} \cite{22}. The first estimates at even lower energies but in terms of vorticity were recently reported in Ref. \cite{30}. All the estimates agree with that the global polarization (vorticity \cite{30}) rises with the collision energy decrease. Ref. \cite{30} predicts that the maximum vorticity is reached at \( \sqrt{s_{NN}} \approx 3 \) GeV and then it decreases with decreasing collision energy.

In this paper, predictions for the global polarization of \( \Lambda \) hyperons at HADES–NICA energies are made, based on the thermodynamic approach \cite{3} \cite{4}. Simulations are performed within the model of the three-fluid dynamics (3FD) \cite{31}. The 3FD model takes into account nonequilibrium at the early stage of nuclear collisions. This nonequilibrium stage is modeled by means of two counterstreaming baryon-rich fluids. Newly produced particles, dominantly populating the midrapidity region, are attributed to a fireball fluid. These fluids are governed by conventional hydrodynamic equations coupled by friction terms in the right-hand sides of the Euler equations. Calculations are done with three different equations of state (EoS’s): a purely hadronic EoS \cite{32} and two versions of the EoS with the deconfinement transition \cite{33}, i.e. a first-order phase transition (1PT) and a crossover one. The physical input of the present 3FD calculations is described in Ref. \cite{34}.

In Fig. 1 the global polarization of \( \Lambda \) hyperons in \( \text{Au}+\text{Au} \) collisions at different centralities, i.e. impact parameters \( b = 2, 4, 6 \) and 8 fm, is presented in the collision-energy range extended to the low energies. The STAR data \cite{1} are also displayed to connect the low-energy predictions with the data available at BES-RHIC. The impact parameter \( b = 8 \) fm roughly complies with the STAR centrality selection of 20–50\% \cite{1}. Glauber simulations of Ref. \cite{35} were used to relate the experimental centrality and the mean impact parameter. In the 3FD model, the colliding nuclei have a shape of sharp spheres without the

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1 In fact, the BM@N is already in operation, but the planned beams of really heavy ions with high luminosity will be achieved only in future.

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Global \( \Lambda \) polarization in moderately relativistic nuclear collisions

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Predictions for the global polarization of \( \Lambda \) hyperons in Au+Au collisions at moderately relativistic collision energies, \( 2.4 \leq \sqrt{s_{NN}} \leq 11 \) GeV, are made. These are based on the thermodynamic approach to the global polarization incorporated into the model of the three-fluid dynamics. Centrality dependence of the polarization is studied. It is predicted that the polarization reaches a maximum or a plateau (depending on the equation of state and centrality) at \( \sqrt{s_{NN}} \approx 3 \) GeV.
The global polarization in Fig. 1 is calculated precisely in the same way as it is described in Ref. [11]. It is related to the midrapidity region $|y_h| \leq 0.5$, where rapidity range is calculated based on hydrodynamical velocities. This constraint roughly simulates the STAR acceptance in terms of pseudorapidity $|\eta| < 1$. Of course, the acceptance in different experiments may be different, the STAR acceptance is implemented just for definiteness. The above constraint means that at the freeze-out instant the polarization is averaged over the central region of colliding nuclei confined by the condition $|y_h| \leq 0.5$. As this condition is related to a certain choice of spatial width of this central region, its rapidity width $\Delta y_h$ slightly depends on the collision energy, centrality ($b$) and EoS, such that $\Delta y_h/2 \approx 0.5$, see Fig. 2. As seen, $\Delta y_h$ is not exactly equal to 0.5, e.g., it is 0.45 at $\sqrt{s_{NN}} = 2.42$ GeV. For details of this calculation, please, refer to Ref. [11]. The failure of the hadronic EoS at $\sqrt{s_{NN}} > 8$ GeV is discussed in Ref. [11] in detail. To avoid this discussion that is irrelevant to the low energies considered here, the hadronic-EoS results are displayed only below the energy of 8 GeV.

As seen from Fig. 1, the global polarization increases with the collision energy decrease. Depending on the EoS, it reaches values of 6–8% at $\sqrt{s_{NN}} = 2.7$ GeV at $b = 8$ fm. At $\sqrt{s_{NN}} \approx 3$ GeV this increase slows down or even a maximum is reached, again depending on the EoS and centrality. This is in agreement with findings in Ref. [30]. Note the the decrease of the global polarization with the energy rise was predicted in Ref. [37] long before the first experimental results. That prediction was based on the chiral vortical effect.

The global polarization predicted by the crossover and 1PT EoS’s is very similar at $\sqrt{s_{NN}} > 3$ GeV, while at $\sqrt{s_{NN}} < 3$ GeV the predictions differ. Predictions of the hadronic EoS slightly differ from two above even at 3$< \sqrt{s_{NN}} < 7$ GeV. The reason is that the hadronic sectors of the crossover, 1PT and hadronic EoS’s are similar but not identical. Therefore, the difference between results of different EoS’s characterizes uncertainty of the present prediction. The sensitivity to these small differences in the EoS increases at $\sqrt{s_{NN}} < 3$ GeV.

In the present calculation the same freeze-out for all species is used. As a result the $\Lambda$ polarization turned out to be very close to the $\Lambda$ one, therefore it is not presented here. Earlier freeze-out of $\Lambda$’s partially solves the problem of the $\Lambda$–$\bar{\Lambda}$ splitting [17], but not at the lowest BES-RHIC energy of 7.7 GeV.

Feed-down contribution to the $\Lambda$ polarization due to decays of higher mass hyperons is not taken into account in the present estimate. This feed-down can reduce the polarization by about 10–15%, as demonstrated in Refs. 6, 6, 18, 35, albeit at higher collision energies. Although, this feed-down effect is definitely less than the uncertainty due to the EoS at $\sqrt{s_{NN}} < 3$ GeV.

To summarize, based on the 3FD model, predictions for the $\Lambda$ global polarization in Au+Au collisions in current and upcoming experiments at moderately relativistic energies, $2.4 \leq \sqrt{s_{NN}} \leq 11$ GeV, are made. It is predicted that the polarization reaches a maximum or a plateau (depending on the EoS and centrality) at $\sqrt{s_{NN}} \approx 3$ GeV. Of course, not all related aspects were considered in this short paper, e.g. the rapidity-acceptance dependence of the global polarization, applicability of the thermodynamic approach to nuclear col-
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