Evaluation Report on Project Renewal Proposal for JINR Participation in the STAR Experiment at RHIC (2027–2029)

1. OVERVIEW

The proposal presents a request for renewal of JINR participation in the STAR experiment at RHIC for the period 2027–2029. The project is focused on the analysis of high-statistics data collected during recent RHIC runs (2022–2026), with emphasis on the Beam Energy Scan (BES-II) program, as well as Hot QCD, Cold QCD, and spin physics.

The scientific objectives are well aligned with the overarching goals of contemporary relativistic heavy-ion physics, including:

- Mapping the QCD phase diagram and searching for the critical point,
- Studying the properties and microstructure of the quark-gluon plasma (QGP),
- Investigating spin-dependent phenomena and nucleon structure,
- Providing essential input for future experiments at NICA and the Electron-Ion Collider (EIC).

The proposal demonstrates strong continuity with previous work and positions the JINR group to play an important role in extracting physics results from the final STAR datasets.

2. SUMMARY OF ACHIEVEMENTS (2024–2026)

The JINR group has demonstrated substantial and diverse scientific activity during the previous period. Key achievements include:

- **QCD Phase Structure and Critical Point Search:** Analysis of net-proton cumulant ratios (C_4/C_2) has revealed statistically significant deviations in the region $\sqrt{s_{NN}} \sim 19$ GeV, contributing to the global effort to identify signatures of the critical point.
- **Strangeness Production and Particle Spectra:** Systematic studies of strange hadron production (including Ξ and Ω baryons) and extension of spectra to higher rapidities provide important constraints on hadronization mechanisms and medium properties.
- **Nuclear Modification and Jet Quenching:** Measurements of the nuclear modification factor R_{CP} have been extended to higher transverse momenta. The observed suppression at intermediate energies and discrepancies with transport and hybrid models highlight the need for improved theoretical understanding.
- **Femtoscopy and Space–Time Evolution:** Comprehensive femtoscopic analyses, including pion and kaon correlations, have yielded detailed information on source sizes and dynamics. The identification of Coulomb and residual interaction effects at low energies is particularly noteworthy.
- **Thermodynamic and Statistical Analyses:** Extraction of freeze-out parameters using Blast-Wave and Tsallis-based approaches provides systematic insight into the evolution of the system across BES energies.
- **Resonance and Rare Probe Studies:** Reconstruction of ϕ meson spectra across systems and energies, including first measurements in $p+p$ at 500 GeV, opens avenues for future spin-alignment studies.
- **Methodological Developments:** Innovative work on machine learning for particle identification and exploratory studies using fractal analysis and scaling approaches demonstrate methodological breadth.
- **Computational Contributions:** The group has contributed to data processing, simulation, and preparation for future high-statistics experiments at NICA.

Overall, the achievements reflect a strong and sustained contribution to the STAR physics program, with particular strengths in femtoscopy, fluctuation observables, and particle production studies.

3. ASSESSMENT OF PROPOSED WORK (2027–2029)

The proposed research program is scientifically well-motivated and timely. The primary focus on completing the analysis of BES-II and recent high-statistics datasets is both necessary and of high impact.

3.1 Hot QCD Physics

The proposal addresses key open questions regarding:

- Transport properties of the QGP (e.g., η/s, ζ/s),
- Initial-state fluctuations and three-dimensional structure,
- Vorticity and spin polarization,
- Higher-order susceptibilities and phase transition signatures.

These topics are central to the RHIC scientific mission and will benefit significantly from the available datasets and upgraded detector capabilities.

3.2 Cold QCD and Spin Physics

The planned measurements of spin asymmetries, Sivers functions, and transversity distributions are highly relevant for understanding nucleon structure and provide essential input for the future EIC program.

3.3 Connection to NICA and Future Facilities

The proposal demonstrates a clear and important connection to the NICA/MPD program. In particular:

- Transfer of analysis expertise,
- Preparation for high-statistics data processing,
- Proposed fixed-target studies at the Nuclotron addressing cold nuclear matter effects.

This continuity significantly enhances the long-term scientific value of the project.

3.4 Feasibility

The proposed work is realistic and feasible, given:

- The availability of high-quality datasets,
- The demonstrated experience of the group,
- The planned use of JINR computing resources.

4. STRENGTHS

- Strong and diverse scientific output in the previous period,
- Access to unique and high-quality experimental data,
- Expertise in key analysis areas (femtoscopy, fluctuations, spectra),
- Clear relevance to major international programs (RHIC, NICA, EIC),
- Good integration of experimental, phenomenological, and computational efforts.

5. POINTS FOR IMPROVEMENT

While the proposal is strong overall, the following aspects could be improved:

- Greater prioritization of key physics goals would enhance clarity,
- More explicit identification of flagship deliverables (e.g., specific observables or publications),
- Clearer articulation of JINR leadership roles within the STAR collaboration,
- Stronger integration of theoretical interpretation in some analysis areas.

These points, however, do not detract significantly from the overall quality and feasibility of the project.

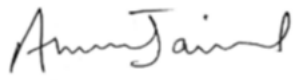
6. CONCLUSION AND RECOMMENDATION

The proposal presents a comprehensive and scientifically valuable program that builds upon a strong record of achievements. The planned work is timely, feasible, and well aligned with the strategic directions of relativistic heavy-ion physics and future experimental facilities.

The project renewal is strongly recommended for approval, with high priority.

The continued participation of the JINR group in the STAR experiment will ensure:

- Maximization of the scientific output from existing RHIC datasets,
- Significant contributions to the understanding of QCD matter under extreme conditions,
- Effective preparation for future experiments at NICA and EIC.



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