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A Novel Deep Learning Method for Detecting Nucleon-Nucleon Correlations

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This study investigates the impact of nucleon-nucleon correlations on heavy-ion collisions using the hadronic transport model SMASH in $\sqrt{s_{\rm NN}} = 3$ GeV ^{197}Au+^{197}Au collisions. We developed an innovative Monte Carlo sampling method that incorporates both single-nucleon distributions and nucleon-nucleon correlations. By comparing three initial nuclear configurations –a standard Woods-Saxon distribution (un-corr), hard-sphere repulsion (step corr), and ab initio nucleon-nucleon correlations (nn-corr) –we revealed minimal differences in traditional observables except for ultra-central collisions. When distinguishing between un-corr and nn-corr configurations, conventional attention-based point cloud networks and multi-event mixing classifiers failed (accuracy ˜50\%). To resolve this, we developed a novel deep learning architecture integrating multi-event statistics and high-dimensional latent space feature correlations, achieving 60\% overall classification accuracy, which improved to 70\% for central collisions. This method enables the extraction of subtle nuclear structure signals through statistical analysis in high-dimensional latent space, offering a new paradigm for studying initial-state nuclear properties and quark-gluon plasma characteristics in heavy-ion collisions. It overcomes the limitations of traditional single-event analysis in detecting subtle initial-state differences.

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