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Neural network study of the impact of nuclear structures in heavy ion collisions

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Understanding the nuclear structure in heavy-ion collisions is essential, as it critically influences final state observables. However, characterizing the structure of heavy nuclei in high-energy collisions remains challenging. Current simulation methods for modeling final state events based on initial state data are highly reliant on model parameters, requiring extensive tuning and adjustment. To simplify nuclear structure estimation and minimize model parameter dependencies, we propose a novel approach of using a state-of-the-art neural network architecture that maps final state observables directly with initial nuclear structure characteristics. We train this model with $^{238}U +^{238} U$ ($\sqrt{s_{NN}} = 193$ GeV) and $^{129}Xe +^{129} Xe$ ($\sqrt{s_{NN}} = 5.44$ TeV) collision data to ensure model robustness across system sizes and collision energies. This allows us to extract quantitative information on nuclear deformation from event-by-event correlations of final state observables, effectively minimizing parameter influence. Our study leverages various three-particle and four-particle correlations, alongside their combinations, to train the models, analyze error distribution patterns, and identify the most effective observables for accurate and precise nuclear deformation estimation. We found that prediction accuracy strongly depends on the type of nuclear deformation used to train the models, with accuracy ranging from $90\% - 100\%$, depending on the specific deformation parameters. The results also reveal that flow-transverse momentum correlation plays the leading role. The method developed in this study aims to advance our understanding of the initial state in heavy-ion collisions, potentially providing a robust framework for probing nuclear structures with reduced computational constraints.

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