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A Centrality-independent Framework for Revealing Genuine Higher-Order Cumulants in Heavy-Ion Collisions

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We propose a novel centrality definition-independent method for analyzing higher-order cumulants, specifically addressing the challenge of volume fluctuations that dominate in low-energy heavy-ion collisions. This method reconstructs particle number distributions using the Edgeworth expansion, with parameters optimized via a combination of differential evolution algorithm and Bayesian inference. Its effectiveness is validated using UrQMD model simulations and benchmarked against traditional approaches, including centrality definitions based on particle multiplicity. Our results show that the proposed framework yields cumulant patterns consistent with those obtained using number of participant nucleon (N_{part}) based centrality observables, while eliminating the conventional reliance on centrality determination. This consistency confirms the method's ability to extract genuine physical signals, thereby paving the way for probing the intrinsic thermodynamic properties of the produced medium through event-by-event fluctuations.

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