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Probing the Origin of Finite $V_{2\Delta}$ in Low-Multiplicity pp Collisions using string shoving model

Content

Recent ALICE measurements of ultra-long-range azimuthal correlations ($|\Delta\eta| > 5$) in low-multiplicity pp collisions at $\sqrt{s}$ = 13~TeV ($\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta < 7$) have revealed significant discrepancies with both hydrodynamic and Color Glass Condensate estimations, challenging the traditional picture of collective behavior in small systems. In this work, we perform a systematic investigation of the origin of finite second-order two-particle correlation coefficients $V_{2\Delta}$ in the low-multiplicity regime using the PYTHIA8 event generator with the string-shoving mechanism, where repulsive interactions between overlapping color strings generate collective-like effects without invoking a thermalized medium. We employ the template-fit method to extract $V_{2\Delta}$ while subtracting non-flow contributions. Crucially, we compare three different event activity estimators, namely, mid-rapidity charged-particle multiplicity N_{ch}, the number of multiparton interactions N_{mpi}, and the recently proposed event-shape observable flattenicity $(1-\rho_{\mathrm{nch}})$. Our results reveal a counter-intuitive finding: the strongest ultra-long-range azimuthal correlations arise not in high-multiplicity events, but in events with low $N_{\mathrm{mpi}} \approx 1$ (dijet-dominated events), where the anisotropic geometry of a few overlapping strings and beam remnants enables efficient string shoving. The correlation strength diminishes with increasing N_{mpi} due to geometric cancellation and dilution effects. We demonstrate that the traditional N_{ch}-based event classification introduces a significant bias, mixing isotropic MPI-rich events with jet-dominated topologies, which artificially suppresses the extracted $V_{2\Delta}$ and worsens the apparent failure of the model. In contrast, flattenicity — which quantifies global event topology — selects cleaner correlation structures with reduced hard-process bias and reveals the built-in saturation mechanism of the string-shoving model. Furthermore, we show that the low-multiplicity templates used for non-flow subtraction already contain intrinsic flow-like correlations from string shoving, leading to oversubtraction in higher activity classes. Our findings support a picture of gradual onset of collectivity, where initial-state string-shoving effects dominate in low-multiplicity pp collisions, while final-state hydrodynamic collective expansion becomes increasingly relevant at high multiplicities. This work strongly advocates for moving beyond N_{ch}-based analyses toward global, topology-sensitive estimators like flattenicity for unbiased interpretation of collective phenomena in small collision systems.

Summary

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