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Multimodal Fragmentation: The High-Energy Portal to Exotic Matter

The rapidly evolving landscape of exotic hadrons is opening a new frontier in our understanding of strongly interacting matter. Recent experimental discoveries of tetraquark and pentaquark candidates have established an increasingly rich spectrum of multiquark states, while their microscopic nature remains largely unresolved. Competing pictures include compact multiquark configurations, diquark-based structures, and hadronic molecular interpretations. In this context, high-energy production can provide information complementary to spectroscopy, turning fragmentation observables into potential probes of the mechanisms through which exotic matter is formed. We present recent developments toward a multimodal fragmentation description of exotic hadrons, in which different production mechanisms and structural configurations are consistently incorporated within a common QCD framework. Particular emphasis is placed on all-heavy and hidden-heavy tetraquarks, where complementary NRQCD-based and structure-sensitive fragmentation inputs provide a natural laboratory for connecting microscopic hypotheses with collider phenomenology. The resulting fragmentation functions are evolved across energy scales through threshold-aware heavy-flavor evolution, enabling precision studies at present and future high-energy facilities. This approach promotes exotic-hadron production from a rate-prediction problem to a structural probe, establishing a novel interface between hadron spectroscopy, heavy-flavor dynamics, and precision QCD. We finally discuss how this program can be extended to a broader spectrum of multiquark states, including pentaquarks, and how future collider measurements could exploit multimodal fragmentation patterns to investigate the internal organization of exotic matter.

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