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Search for the QCD Critical Endpoint at a Temperature of 108 MeV

Determining the location of the Quantum Chromodynamics (QCD) critical endpoint (CEP) is a central goal in high-energy nuclear physics. Direct lattice QCD simulations are hindered by the sign problem at finite baryon chemical potential (μ_B), necessitating indirect approaches. Recent first-principles lattice investigations, particularly those analyzing Lee-Yang edge singularities from simulations at imaginary μ_B, suggest the CEP is located at a low temperature, around $T_c^{CEP} \approx 110$ MeV [1]. A significant caveat, however, is that these results are obtained by extrapolating from data generated at higher temperatures (T $gtrsim120$ MeV). Intriguingly, predictions from independent theoretical frameworks, such as the Functional Renormalization Group (FRG) [2], Dyson-Schwinger Equations (DSE) [3], and AdS/CFT [4], also point towards a CEP in a similar low-temperature domain. While this broad agreement is encouraging, the reliance of current lattice predictions on extrapolation highlights the urgent need for direct simulations within the target critical region.

In our study, we present the first direct lattice QCD investigation of the QCD critical endpoint (CEP) at a low temperature of $T \approx$ 108 MeV, using (2+1)-flavor HISQ ensembles at imaginary baryon chemical potential μ_B. Baryon-number fluctuations up to fourth order are excellently described by a hadron resonance gas (HRG), indicating negligible residual interactions. A model-independent search for Lee–Yang singularities via multi-point Padé approximants finds no evidence of criticality in the complex μ_B plane. Fits with a critical ansatz, used solely as a diagnostic, flag at most a marginal window around $\mu_B \simeq 420$–750 MeV—no stronger than the false-positive baseline calibrated on analytic HRG mock data. Moreover, this potential signal is not manifested in the higher-order susceptibility ratios (e.g., χ_6^B/χ_2^B), which serve as the most sensitive probes measurable with reasonable precision in current experiments. Together, these results demonstrate smooth, analytic thermodynamics at this temperature; consequently, at the beam energies corresponding to $T \approx$ 108 MeV—i.e., $\sqrt{s_{NN}} \approx 5$ GeV—experimental observables should reflect HRG (hadronic-phase) thermodynamics rather than critical behavior.

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