Extracting the Speed of Sound in Au+Au Collisions across the RHIC Beam Energy Scan

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The speed of sound, c_s, reflects the thermodynamic properties of the quark–gluon plasma produced in relativistic heavy-ion collisions. In ultracentral collisions, recent studies have conjectured that c_s^2 can be extracted from the logarithmic dependence of the mean transverse momentum, $\langle p_T \rangle$, on the charged-particle multiplicity, $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ [1]. Measurements from CMS and ALICE have demonstrated the feasibility of this approach at the LHC and highlighted its sensitivity to the choice of centrality estimator [2, 3]. We present STAR Beam Energy Scan results for Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$, 54.4, and 27 GeV. The choice and tuning of the centrality estimator used in the conventional logarithmic-slope analysis are guided by a recently proposed framework for event-by-event fluctuations [4, 5]. This approach aims to better control residual initial-state fluctuations in the ultracentral region. Preliminary results for c_s^2 at these collision energies, together with their temperature dependence and comparisons with lattice-QCD calculations, will be presented.

References

[1] F. G. Gardim, G. Giacalone, M. Luzum, and J.-Y. Ollitrault, "Thermodynamics of hot strong-interaction matter from ultrarelativistic nuclear collisions," *Nature Physics* **16**, 615–619 (2020). doi:10.1038/s41567-020-0846-4.

[2] CMS Collaboration, "Probing thermodynamic properties of proton-lead collision systems via multiplicity dependence of average transverse momentum at the LHC," CMS Physics Analysis Summary CMS-PAS-HIN-25-001 (2025).

[3] ALICE Collaboration, "Study of $\langle p_{\mathrm{T}} \rangle$ and its higher moments, and extraction of the speed of sound in Pb–Pb collisions with ALICE," *Journal of High Energy Physics* **2025**, 076 (2025). doi:10.1007/JHEP11(2025)076.

[4] G. Nijs and W. van der Schee, "Ultracentral heavy ion collisions, transverse momentum and the equation of state," arXiv:2312.04623 [nucl-th] (2023).

[5] Y.-S. Mu, J.-A. Sun, L. Yan, and X.-G. Huang, "Extracting the Speed of Sound in Heavy-Ion Collisions: A Study of Quantum-Initiated Fluctuations and Thermalization," arXiv:2501.02777 [nucl-th] (2025).