Contribution ID: **49**

Type: **Poster**

The Effect of Acausality on Bayesian Analyses of Heavy-Ion Collisions

Tuesday, March 11, 2025 6:04 PM (2 minutes)

Hydrodynamic models have been instrumental in uncovering the properties of quark-gluon plasma (QGP) in relativistic heavy-ion collisions, providing an effective framework to describe the system's evolution. However, their validity is challenged in scenarios where causality is violated, as such violations undermine their ability to represent the underlying relativistic quantum field theory accurately. Non-linear causality conditions offer a rigorous criterion for identifying these regimes, which arise in modern hydrodynamic simulations during the early stages of the system's evolution.

In this study, we explore the consequences of enforcing causality constraints on Bayesian analyses used to infer QGP properties. Our results demonstrate that while causality violations typically involve a small fraction of the system's energy, imposing strict causal limits leads to significant changes in the inferred initial conditions and the preferred values of QGP transport properties. Notably, our findings reveal a marked reduction in the bulk viscosity, underscoring the sensitivity of QGP parameter estimates to early-time non-equilibrium dynamics.

These insights highlight the critical importance of incorporating causality constraints into hydrodynamic models to enhance the reliability of QGP property extraction and deepen our understanding of strongly interacting matter governed by quantum chromodynamics (QCD).

Based on: arXiv:2409.17127 or Phys.Rev.C 110 (2024) 6, 064904.

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Session Classification: Poster session