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Studying nuclear matter under extreme conditions using supercomputing

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The study of the Quark-Gluon Plasma (QGP) –the most extreme state of nuclear matter produced in relativistic heavy-ion collisions –has seen great progress in recent years, owing to advances in theoretical understanding, better experimental facilities, as well as the increase in computational resources available in modern High-Performance Computing (HPC) facilities. This talk will describe the crucial role HPC resources have played constraining long- and short-range QGP properties, while providing an outlook for future progress.

Long-range properties of the QGP fluid itself, such as its viscosity, have been constrained using low-energy hadrons measured at the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory and the Large Hadron Collider at CÉRN [1]. The data from RHIC and LHC is also used to constrain short-range properties of the QGP, which are probed by studying how high-energy jets propagate through the QGP. Recently, the transverse momentum diffusion coefficient associated with jet-medium interactions has been constrained using a vast ensemble of data [2]. For both sets of QGP transport coefficients, large-scale HPC allocations deployed for Bayesian model-to-data comparisons were necessary. The next generation of Bayesian analysis will attempt to simultaneously constrain short- and long-range QGP transport coefficients, requiring an even greater effort from the nuclear physics community. Indeed, this endeavor will require larger involvement from computational/data physicists as well as significant HPC allocations. This increased participation of computational/data physicists in modern nuclear physics is a recognized need by the wider nuclear research community [3], and I will discuss potential interdisciplinary progress that can be made.

[1] D. Everett et al., Phys. Rev. Lett. 126 (2021) 24, 242301
[2] R. Ehlers et al., arXiv:2408.08247
[3] A. Boehnlein et al., arXiv:2501.00905

Keyword-1

Quark-Gluon Plasma

Keyword-2

High Performance Computing

Keyword-3

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