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Elucidating QGP at finite baryon density with (3+1)D Bayesian analysis at the RHIC Beam Energy Scan program

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We present a systematic Bayesian analysis of Quark-Gluon Plasma (QGP) properties at finite baryon density using measurements of Au+Au collisions at the RHIC Beam Energy Scan program. The theoretical model simulates event-by-event (3+1)D dynamics of relativistic heavy-ion collisions with the state-of-the-art hybrid hydrodynamics and hadronic transport theory. We analyze the model's 20-dimensional posterior distributions obtained using three Gaussian Process emulators with different accuracy and demonstrate the essential role of training an accurate model emulator in the Bayesian analysis [1]. Our analysis provides robust constraints on the Quark-Gluon Plasma's transport properties and various aspects of (3+1)D relativistic nuclear dynamics using heavy-ion measurements from 7.7 to 200 GeV [2]. By running full model simulations with a few parameter sets sampled from the posterior distribution, we make timely predictions for pT differential observables, anisotropic flow rapidity decorrelation, and flow observables in O+O collisions with systematic theory uncertainties, which can be compared with the upcoming measurements from the STAR Collaboration. Finally, we highlight a detailed experimental design analysis to elucidate how individual experimental observables constrain different model parameters, providing valuable physics insights into the phenomenological model for heavy-ion collisions.

[1] H. Roch, S. A. Jahan and C. Shen, "Model emulation and closure tests for (3+1)D relativistic heavy-ion collisions,"Phys. Rev. C 110, no.4, 044904 (2024)
[2] S. A. Jahan, H. Roch and C. Shen, "Bayesian analysis of (3+1)D relativistic nuclear dynamics with the RHIC beam energy scan data,"arXiv:2408.00537 [nucl-th]

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