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Differentiable reconstruction of the AdS/QCD Warp Factor

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Holographic QCD models describe strongly interacting matter through a five-dimensional gravitational background. In Einstein–Maxwell–Dilaton models, the warp factor A(z) deforms the AdS metric and affects QCD thermodynamics, the phase structure, and heavy-meson spectra. Such models are commonly calibrated using lattice-QCD data [1, 2] in contrast with employment on the experimental data.

In this work, we develop a differentiable-programming framework for the inverse reconstruction of the warp factor in AdS/QCD using PyTorch [3]. We consider parameterized families of phenomenological ansatz, in particular combinations of logarithms of polynomials. Their parameters are optimized with gradient-based methods, in particular Adam [4] and L-BFGS-B [5], while automatic differentiation provides gradients through the numerical pipeline without finite-difference approximations.

For each parameter set, we construct the holographic background and calculate the phase-transition curve in the temperature–baryon-chemical-potential coordinates. Its deviation from the chemical freeze-out line defines the thermodynamic loss; the method is tested using both an analytic freeze-out parameterization and experimental data from the relativistic nucleus-nucleus collisions [6]. Heavy-meson masses are calculated following [7] using the aforementioned ansatz'. The constraints on the meson masses are included through gaussian process emulator differentiable surrogate [8] that approximate the dependence of meson masses on the background parameters. The total loss combines information on the thermodynamics and meson spectroscopy along with regularization on the critical endpoint (CEP) position to achieve smooth and physically admissible warp factors. The procedure reconstructs families of warp factors compatible with chemical-freeze-out and spectroscopic constraints, allowing us to assess the stability and non-uniqueness of the inverse problem.

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Primary author(s) : KOMLEVA, Anna (MIPT (NRU)); Mr. ALKIN, Andrey (MIPT (NRU)); SVETLICHNYI, Aleksandr (INR RAS, MIPT(NRU))

Presenter(s) : KOMLEVA, Anna (MIPT (NRU))

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