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Towards Real-Time Observables from First Principles: Correlators in 3+1D Yang-Mills Theory

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Real-time quantum field theories remain challenging due to the severity of the numerical sign problem. In this work, we successfully apply the complex Langevin (CL) method to SU(2) Yang-Mills theory in 3+1 dimensions. By introducing an anisotropic kernel, we stabilize simulations for real-time evolutions beyond the inverse temperature, enabling the first ab initio computations of unequal-time correlation functions in this setting. We verify consistency relations among propagators, observe time-translation invariance, and achieve agreement with Monte Carlo results in thermal equilibrium. Strikingly, our approach allows an independent verification of the fluctuation-dissipation relation for the integrated magnetic energy correlator. These results represent significant progress toward extracting real-time observables, such as transport coefficients, from non-Abelian gauge theories within a first-principles framework.

Authors: BOGUSLAVSKI, Kirill (TU Wien (AT)); HOTZY, Paul (TU Wien); MÜLLER, David I. (TU Wien)

Presenter: BOGUSLAVSKI, Kirill (TU Wien (AT))

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