Contribution ID: **92** Type: **not specified**

QCD at nonzero temperature and density

Friday, 7 August 2020 17:40 (20 minutes)

Replica evolution of classical field is proposed as an approximate simulator of real-time quantum field dynamics at finite temperatures. We consider N classical field configurations $(\phi_{tx}, \pi_{tx}(\tau = 0, 1, \cdots N-1)$, dubbed as replicas, which interact with each other via the τ-derivative terms and evolve with the classical equation of motion. The τ-derivative terms in the Hamiltonian, $\xi^2 \sum_x (\phi_{x+\hat{\tau}} - \phi_x)^2/2$, correspond to the kinetic part of the Euclidean action in the imaginary time formalism of the finite temperature quantum field theory by regarding the replica index τ as the imaginary time index.Thus the replica evolution is technically the same as the molecular dynamics part of the hybrid Monte-Carlo sampling. The partition function of replicas at temperature ξ is proven to be proportional to that in quantum field theory at temperature $T = \xi/N$. At the same time, the time dependence of the replica-index average of field variables is described by the classical equation of motion when the fluctuations are small. We examine the statistical and dynamical properties of the ϕ^4 theory in the 4+1 spacetime dimensions. We note that the Rayleigh-Jeans divergence in the classical field can be removed in replica evolution with $N \geq 2$ by including the mass counterterm. We also find that the thermal mass obtained from the unequal time correlation function at zero momentum grows as a function of the coupling as in the perturbative estimate in the small coupling region. Hence the replica evolution, the classical field theory with improved quantum statistical property, would be a candidate to represent the real-time evolution of quantum field.

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Session Classification: QCD at nonzero Temperature and Density

Track Classification: QCD at nonzero Temperature and Density