Hessisches Kompetenzzentrum
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Topological Susceptibility at High Temperatures from Lattice Quantum Chromodynamics II

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Project Term
2023 - 2024

Clusters
Lichtenberg II Cluster Darmstadt

Additional Software
MILC QCD

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Introduction

Two unsolved problems in the standard model of particle physics are the strong *CP*-problem and the nature of dark matter. The former puzzle manifests itself in the vanishing of the electric dipole moment of the neutron, while the latter problem appears since the motion of objects on large astronomical scales hints at the existence of an unknown kind of matter that only interacts with ordinary matter via gravity. Both puzzles are solved simultaneously by the Peccei-Quinn mechanism which introduces a hypothetical particle, the QCD axion. As this particle would influence the evolution of the early universe, its mass $m_a(T)$ in the range 1.5 to $7T_c$ needs to be understood where T_c is the QCD phase transition temperature. The mass at these temperatures is proportional to the square root of the topological susceptibility $\chi^2(T)$. As the nature of topology in QCD is inherently non-perturbative, Lattice QCD has been proven to be a reliable tool to study it. So far, the topological susceptibility has been studied either indirectly in full Lattice QCD or directly in pure gauge Lattice QCD, ignoring fermions. This works aims to extend the latter study to full QCD. The main hurdle to measure the topological susceptibility at high temperatures is the fact that topological configurations are strongly suppressed in this regime, leading to insufficient statistics.

Methods

We use Lattice QCD to investigate the topological nature of unquenched high-temperature QCD incorporating HISQ fermions

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up to the charm quark. Lattice QCD is based on the path integral approach to quantum field theory, requiring integrals at every point in space-time. Discretizing space-time into a lattice then allows for numerical Monte Carlo integration. To get physically meaningful results, the considered lattices need to be sufficiently fine, demanding high computational effort and parallelization. For Lattice QCD, four-dimensional field configurations are generated subsequently. As hinted at before, the algorithm struggles to give a statistically significant amount of topological configurations. Therefore, the number of topological configurations is artificially increased by reweighting, using an accept-reject step in terms of some combination of topological charge and peak action density. This picks up so-called dislocations, which are the "stepping stones" to topological configurations. As the lattice configurations are noisy, some cleanup using gradient flow is performed before measuring the aforementioned observables.

Results

We found the appropriate way to combine the topological charge and peak action density to properly pick up the dislocations as efficiently as possible. In particular, for small dislocations, we discovered that the peak action density is the more sensitive observable. Furthermore, we developed an easy and reliable scheme to determine how much gradient flow to use. We also found that the improved Lüscher-Weisz style definitions of gradient flow and peak action density make picking up the dislocations easier. Also, investigations to measure the size of an instanton on the lattice have been performed.

Discussion

The above methods have been proven to be very successful on a small lattice and the lowest considered temperature in the sense that the topological sector can be reached from the non-topological one efficiently. The measurements will have to be extended to larger lattices and higher temperatures to complete our studies. Furthermore, the determination of the instanton radius needs to be improved as the so far investigated methods are not reliable yet.

Last Update: 2024-11-18 14:42