The 38th International Symposium on Lattice Field Theory

LATTICE 21

JULY 26-30 2021, ZOOM/GATHER@MIT

Contribution ID: **424** Type: **Oral presentation**

Particle density probability distribution function and center symmetry breaking in finite density lattice gauge theories

Tuesday, 27 July 2021 22:30 (15 minutes)

We study the nature of the phase transition at high temperature and high density in lattice gauge theories by focusing on the probability distribution function, which represents the probability of appearance of particle density in a heat bath. The probability distribution function is obtained by constructing a canonical partition function by fixing the number of particles from the grand partition function. However, if the Z(3) center symmetry, which is important for understanding the finite temperature phase transition of SU(3) lattice gauge theory, is strictly maintained on a finite lattice, the probability distribution function is always zero, except when the number of particles is a multiple of 3. For U(1) gauge theory, this problem is more extreme. The center symmetry makes it impossible for a charged state to exist.

In this study, we discuss the solution to this problem, and at the same time, propose a method of avoiding the sign problem, which is an important problem in the finite density lattice gauge theory, by the center symmetry. This problem is essentially the same as the problem that the expectation value of the Polyakov loop is always zero when calculating with finite volume, as long as the center symmetry is not broken. In the U(1) lattice gauge theory, when the fermion mass is heavy, numerical simulations are actually performed, and it is demonstrated that the calculation of the probability distribution function at a finite density is possible using the method proposed in this study. Furthermore, the application of this method to QCD is discussed.

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Session Classification: QCD at nonzero Temperature and Density

Track Classification: QCD at nonzero Temperature and Density