PROCEEDINGS OF SCIENCE

Lattice study of the gluon plasma via center vortex mechanism

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We study the equation of state of the gluon plasma in center vortex mechanism by using a quenched $SU(2)$ lattice simulation. The free energy above T_c is significantly affected by center vortices. This implies that the magnetic degrees of freedom provide a non-perturbative effect to the constitution of the high-temperature gluon medium.

Xth Quark Confinement and the Hadron Spectrum,
October 8-12, 2012
TUM Campus Garching, Munich, Germany

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1. Introduction

The quark-gluon plasma (QGP) has been successfully produced in the facilities of the heavy-ion collision experiments (RHIC and LHC). This new matter is a strongly-interacting plasma, to which one can not apply the weakly-couping perturbation. A question on what mode in quantum chromodynamics (QCD) above T_c causes such strong interaction is still an unsolved issue.

We focus on a singularity of magnetic degrees of freedom, which arises in the thermal perturbation theory of QCD [1]. The magnetic gluon propagator in the zero-momentum limit diverges if the magnetic mass vanishes. It is shown by the lattice simulation that the non-perturbative magnetic mass is not zero [2]. Moreover, peculiar non-perturbative phenomena such as a spatial Wilson-loop and a color-Coulomb instantaneous force in the deconfining phase can be described by the magnetic scaling $\sim g^2(T)T$ [3, 4].

In those cases, the magnetic and/or spatial components may be linked to some (infrared-singular) confining objects. In the point of view of the topological defect the magnetic monopole and/or vortex may play an important role for a spatial (magnetic) confinement. It has been studied that the center vortex mechanism also holds well over hot Yang-Mills theory [5]; as a result, the hot-glue energy-momentum tensor is largely affected [6]. Furthermore, the numerical simulations show that the vortices in the hot medium deform the shape of the magnetic gluon propagator, particularly in the limit $\vec{p} = 0$ [7]. It is concluded that the magnetic mode should be treated as a non-perturbative object above T_c comparing with an electric gluon, which usually produces a screened potential with a color-Debye mass.

Here we report the lattice study of the gluon plasma in terms of the center-vortex degrees of freedom by using an $SU(2)$ quenched-lattice calculation. In particular, we investigate the equation of state (EOS) at high temperature, because the many lattice computations show inconsistency between the Stefan-Boltman (SB) limit and those numerical values.

We here employ direct maximal center projection (MCP) [8], so as to identify center vortex on the lattice. The removal technique of vortices from the original lattice is also used [9]. The lattice calculations show that non-zero string tension as well as the chiral condensation are lost after the vortex removal [8, 9].

The pressure (EOS) of the plasma state on the lattice can be calculated via the plaquette expectation value with the lattice coupling β as $\frac{p}{T^4}\Big|_{\beta_0}^{\beta} = \int_{\beta_0}^{\beta} d\beta' \Delta S$, where $T = 1/(N_t a)$ and $\Delta S = N_t^4\left(\langle S\rangle_T - \langle S\rangle_0\right)$, and $< S_T >$ and $< S_0 >$ are the expectation values on the anti-symmetric and symmetric lattices.

2. Results

The left and center figures of Fig. 1 show numerical results of ΔS as a function of β. One can see that after the removal of the vortices from the original lattices, the enhancement of ΔS in the deconfinement phase becomes larger. The whole behavior that depends on the β is similar; that is, as the temperature increases, ΔS decreases as the same as the data estimated by the normal configurations. However, ΔS with no center vortex at high temperature regions falls into a negative value and seem to have relatively large volume dependence. In the right figure, we additionally

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plot the pressure after integrating ΔS with β. It is found that the pressure without vortices is greatly enhanced comparing to the case of the normal lattice.

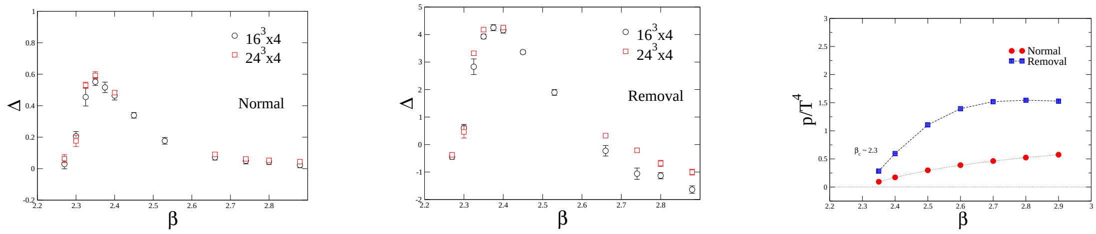

Figure 1: (Preliminary numerical data) The left and center figures show ΔS as a function of β, which is calculated by the normal and the removal (of center vortices) configurations. The lattice sizes plotted are $16^3 \times 4$ (black circle) and $24^3 \times 4$ (red square) and $\beta_c \approx 2.3$. The right figure displays the pressure on the lattice $16^3 \times 4$; the circular symbols correspond to the data with vortices, while the squares are computed by the vortex-free configuration.

3. Summary

We study the equation of state of the gluon plasma in terms of the center vortices by using the $SU(2)$ lattice simulation. Our (preliminary) numerical calculations seem to show the large contributions coming from the center vortices as a topological defect. In order to obtain a conclusive result, we have to discuss the difference of the statistics between the topological vortices and the degrees of freedom of gluons, and also investigate the volume dependence at the higher temperature regions.

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