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有限温度量子色力学のダイナミクス

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To understand the state of matter at very high temperature and/or density, such as in the early universe, inside the neutron star, and in the heavy ion collision etc., it is crucial to know the Equation of State (EoS) of Quantum Chromo Dynamics (QCD), the fundamental theory of strong interactions. The ultimate goal of our project is to determine the EoS in the continuum by numerical simulations on the basis of lattice QCD with the Wilson-type quark action. For this, we are employing the energy–momentum tensor (EMT) and other physical quantities defined by the gradient flow (GF) and the Small Flow-$t$ime eXpansion (SFtX) method. We summarize achievements we made so far by utilizing the present and past JHPCN (and other) computational resources.

In this poster, we present the results for the $N_f = 2+1$ QCD with physical quark masses [Kanaya–Baba–Suzuki–Ejiri–Kitazawa–H.S.–Taniguchi–Umeda, PoS LATTICE2019, 088 (2019) and ongoing study]. We use gauge field configurations generated by non-perturbatively $O(a)$-improved Wilson quark action and the RG improved Iwasaki gauge action. The lattice spacing is fixed to $a0.09\,\mathrm{fm}$. $T = 0$ configurations are PACS-CS configuration on a $32^3 \times 64$ lattice. $T > 0$ configurations are WHOT-QCD configurations ($32^3 \times N_t$, $N_t = 4, 5, \ldots, 18$) and our own configurations.

EoS obtained by SFtX method (preliminary):

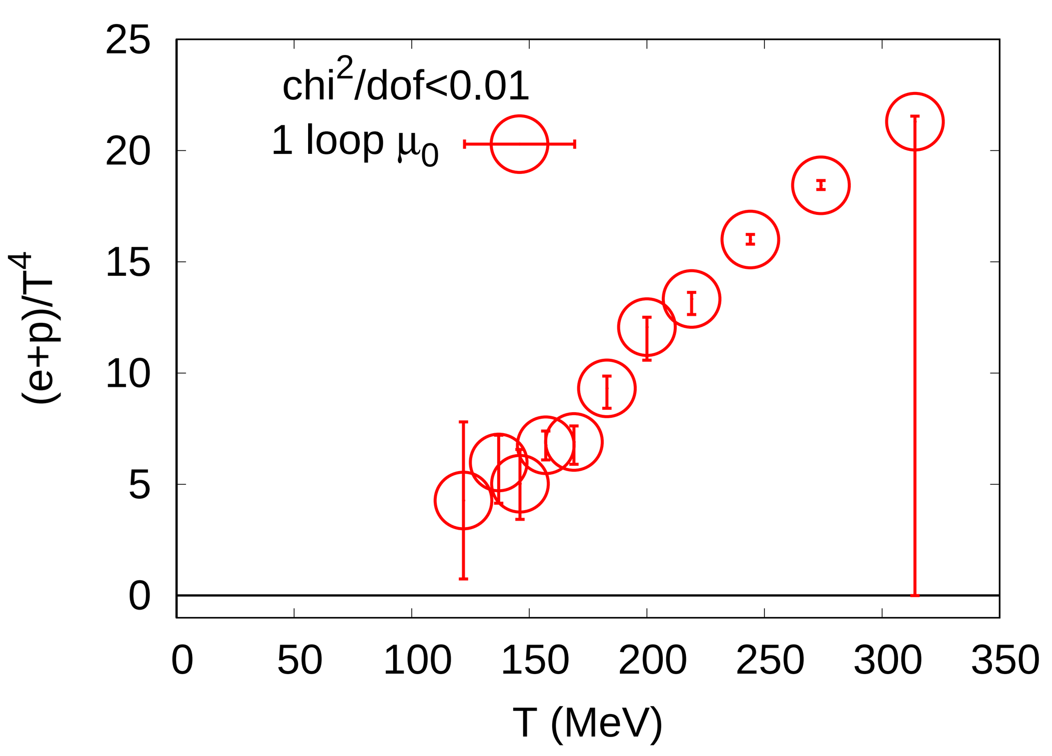

Figure: Entropy density $(\epsilon + p)/T^4$ as function of temperature T

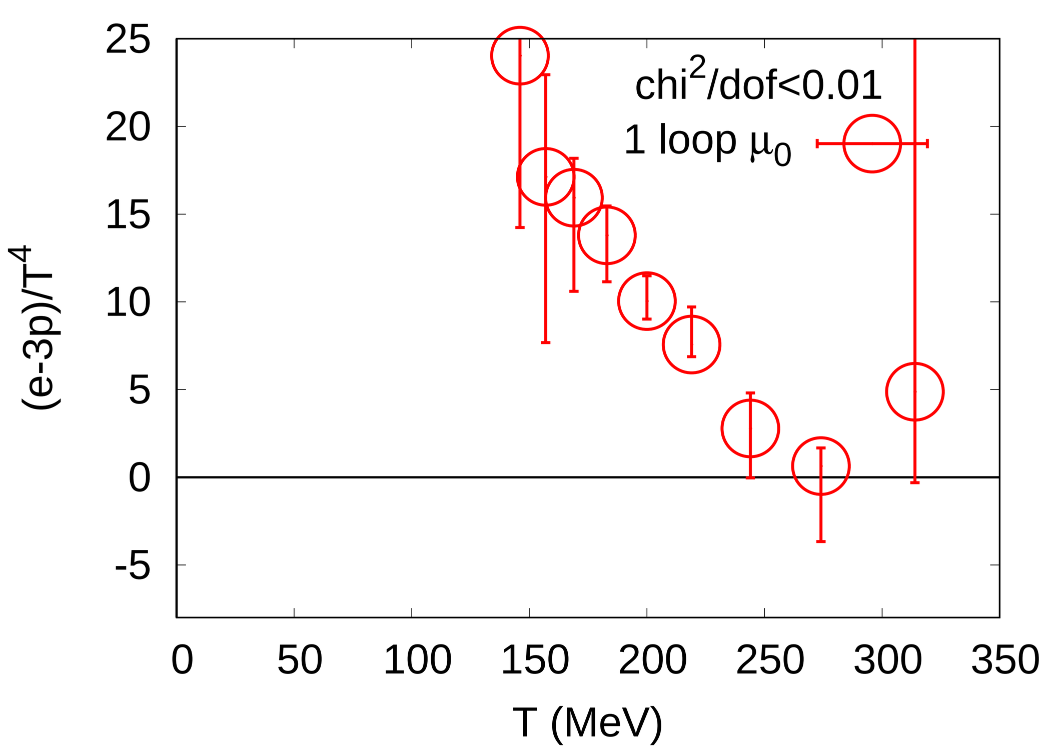

Figure: Trace anomaly $(\epsilon - 3p)/T^4$ as function of temperature T

Disconnected chiral susceptibility (preliminary):

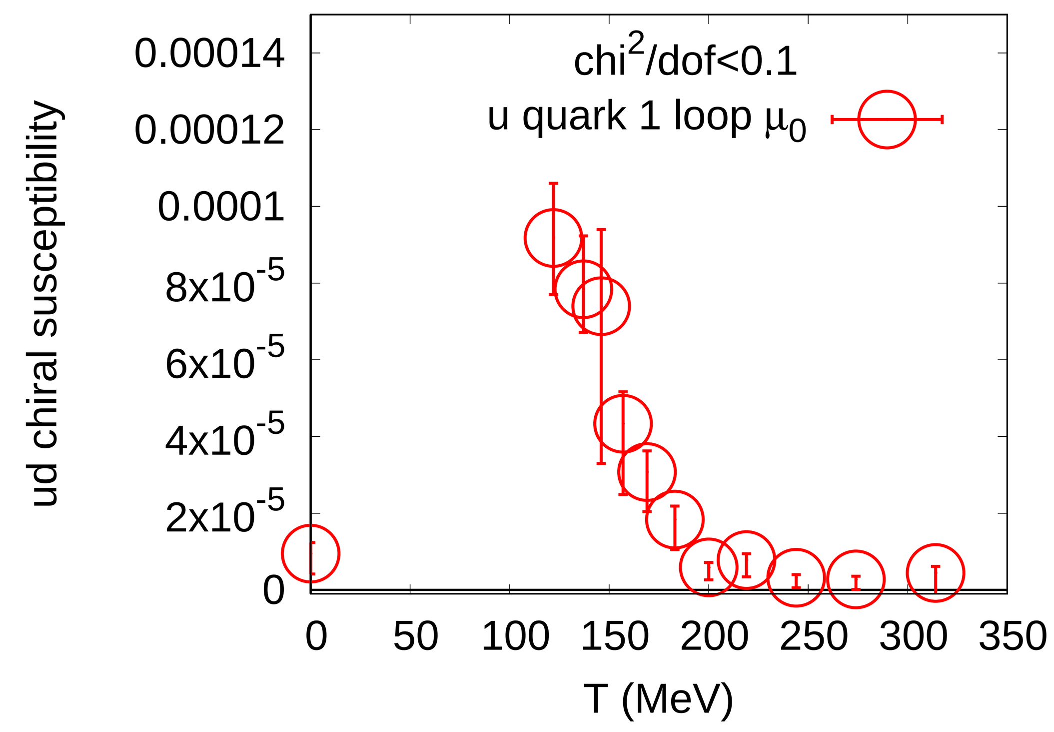

Figure: Disconnected chiral susceptibility of the ud quarks (in the $\overline{\mathrm{MS}}$-scheme at $\mu = 2\,\mathrm{GeV}$ in GeV^6)

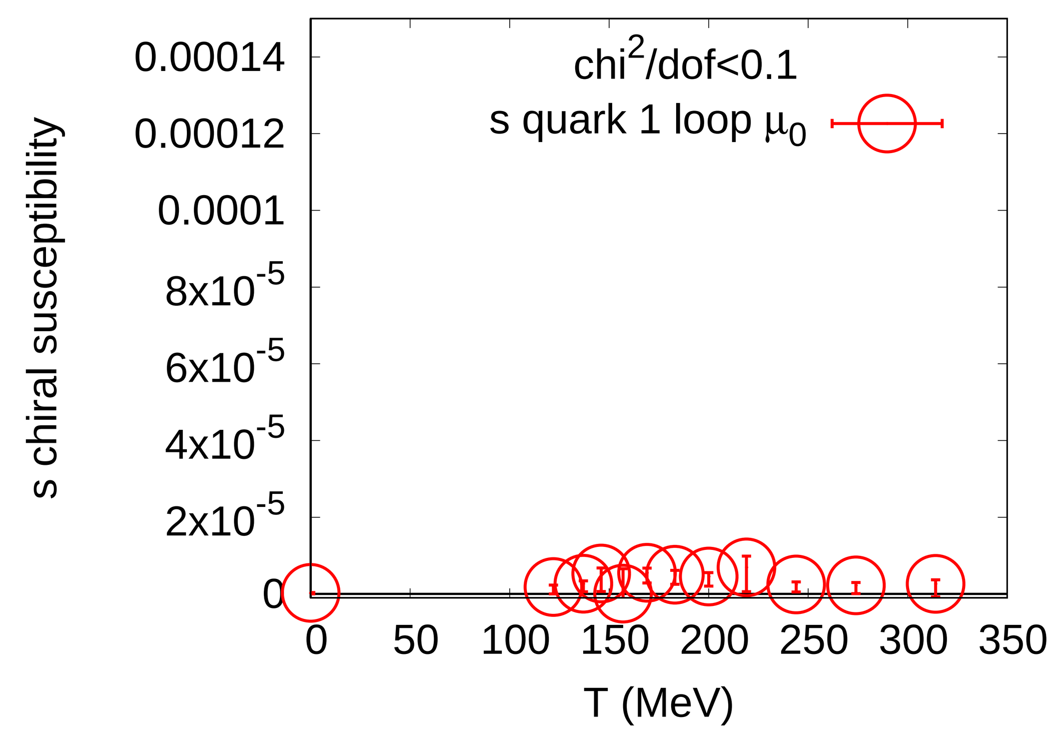

Figure: Disconnected chiral susceptibility of the s quark (in the $\overline{\mathrm{MS}}$-scheme at $\mu = 2\,\mathrm{GeV}$ in GeV^6)

To reduce the statistical error in the results at $T = 122\,\mathrm{MeV}$, a temperature close to the pseudo-critical temperature, we accumulated 213 new gauge configuration on a lattice $32^3 \times 18$ by using a JHPCN computational resources allocated to us in the fiscal year 2019 ($64 \cdot 9$ node · month CPU time of ITO subsystem A at Research Institute for Information Technology, Kyushu University).

We are now computing various physical quantities by using these newly-obtained gauge configurations.

This fiscal year, $40,000$ node · hour CPU time of ITO subsystem A at Research Institute for Information Technology, Kyushu University, was allocated to us from the JHPCN project.

We are now generating new QCD gauge field configurations with physical quark masses at finite temperatures to use the PACS10 configurations [Ishikawa–Ishizuka–Kuramashi–Nakamura–Namekawa–Taniguchi–Ukita–Yamazaki–Yoshié, PRD 99, 014504 (2019)] with the lattice spacing $a = 0.08\,\mathrm{fm}$ on a 128^4 lattice as zero temperature gauge configurations.

By using 64 nodes of the ITO subsystem A, by the hybrid Monte-Carlo method, we are now generating gauge field configurations on a $48^3 \times 12$ lattice with the lattice spacing $a = 0.08\,\mathrm{fm}$; this setup corresponds to the temperature $206\,\mathrm{MeV}$.

As the following Monte-Carlo history of the plaquette variable indicates we are still far way from the thermal equilibrium (i.e., the gauge configurations are not yet distributed according to the desired Boltzmann weight). It seems that at least additional one month is needed to achieve the thermal equilibrium.

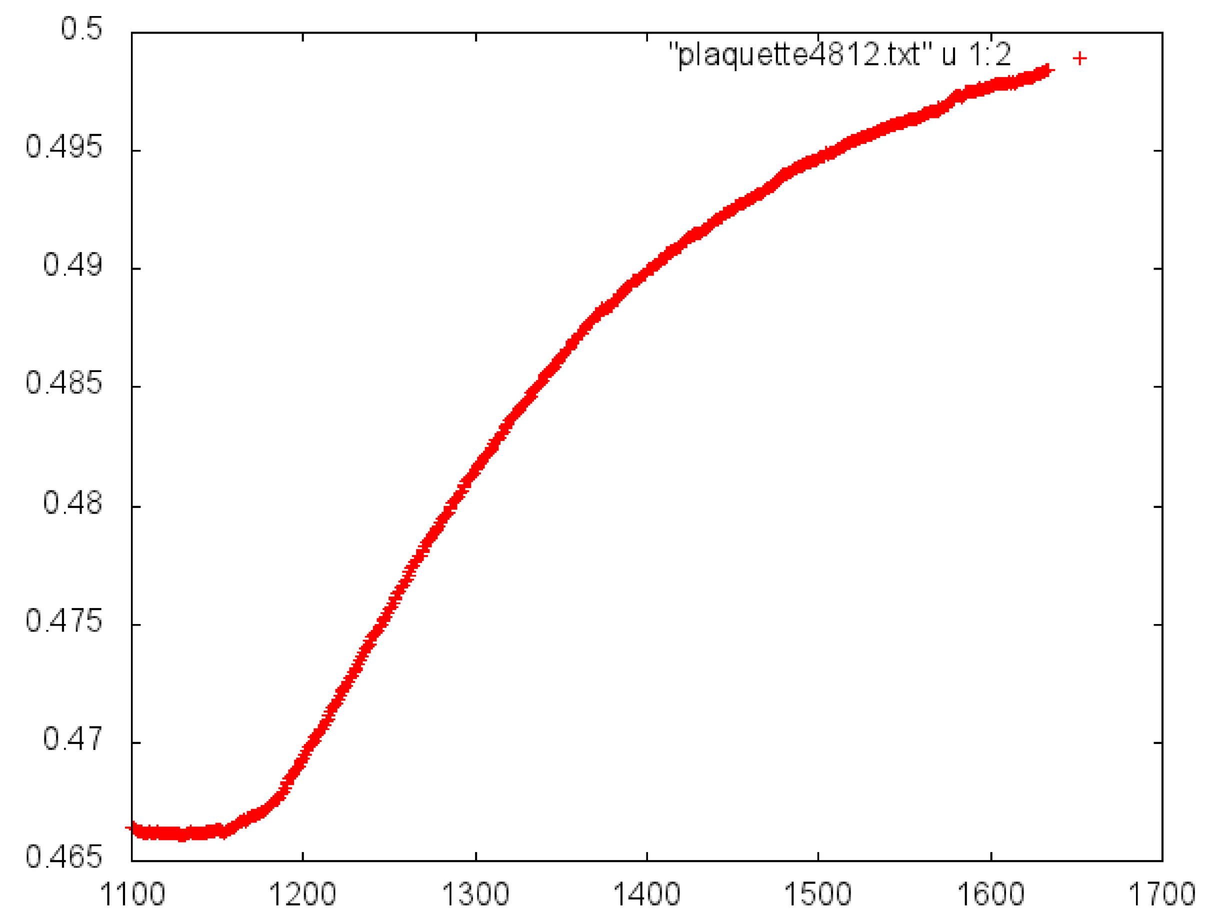

Figure: Monte-Carlo history of the plaquette variable