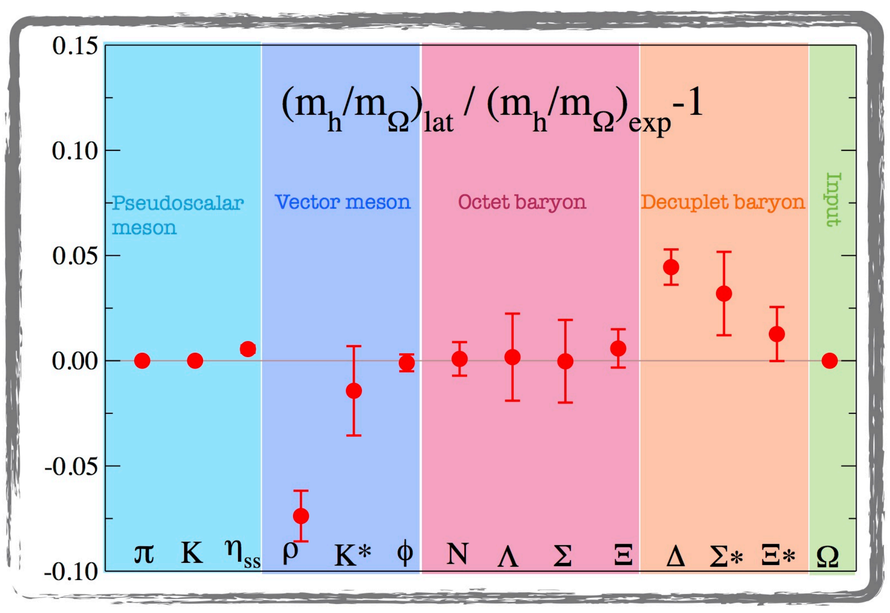
Research in Particle Physics

2+1 flavor QCD at Physical Point

Hadrons are the constituents of atomic nuclei. The computation of their mass spectrum from the quantum chromodynamics (QCD), the fundamental theory of strong interaction described by quarks and gluons, has been a principal subject in particle physics.

After quenched simulation, in which dynamical quarks are neglected, and a succeeding 2 flavor QCD simulation with dynamical up and down quarks by the CP-PACS computer, those studies were extended to 2+1 flavor QCD by incorporating the dynamical strange quark, though the degenerate up-down quark mass was much heavier than the physical value of 3 MeV (physical point). On the PACS-CS and T2K computers, we have succeeded in reaching the physical point by a reweighting technique utilizing the simulated data at the up-down quark mass of 4 MeV. This calculation is followed by $(8\ \mathrm{fm})^3$ volume simulation on the K computer. The left figure presents relative difference of the light hadron spectrum from the experiment at the physical point. In the figure the inputs are only the pion, kaon, and omega baryon masses to determine the up-down and strange quark masses, and the lattice cutoff, respectively. Our results at the physical point show good agreement with the experiment albeit errors are still not quite small for some of the hadrons.

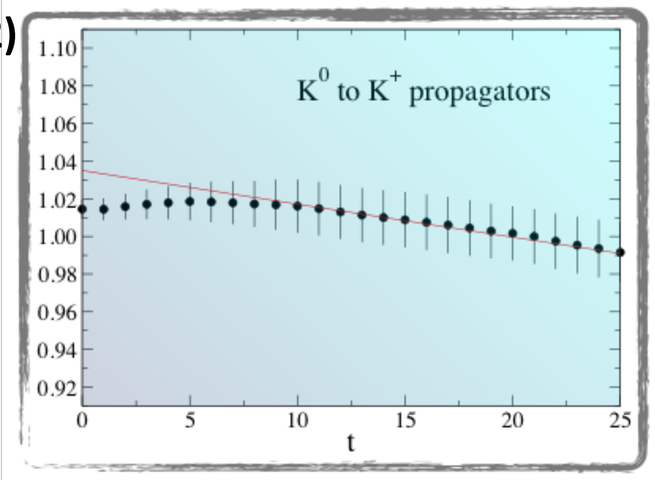
(1)



In nature, the masses for up and down quarks and also their electric charges are different. Their effects are observed in mass splittings among isospin multiplets of light hadrons, e.g., m^{K^0}-$m^{K^\pm}$. Thus, we have embarked on 1+1+1 flavor QCD+QED simulation at the physical point incorporating the isospin breaking effects. The right figure plots the ratio of K^0 to $K^\pm$ propagators to detect their mass difference. Our results (black symbol) show a good consistency with the expected slope from the experimental value of m^{K^0} -$m^{K^\pm}$ (red line).

[PACS-CS Collaborations: Phys. Rev. D81, 074503 (2010); S. Aoki et al., Phys. Rev. D86, 034507 (2012); K.-I. Ishikawa et al., https://arxiv.org/abs/1511.09222]

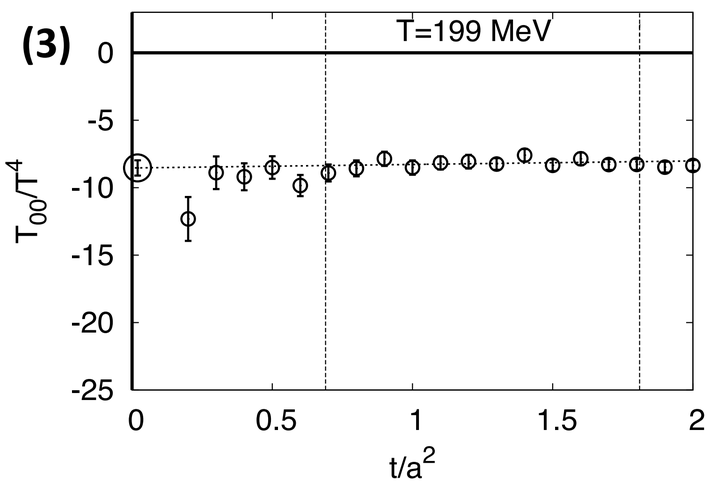
(2)



Direct calculation of energy-momentum tensor for Quantum Chromodynamics

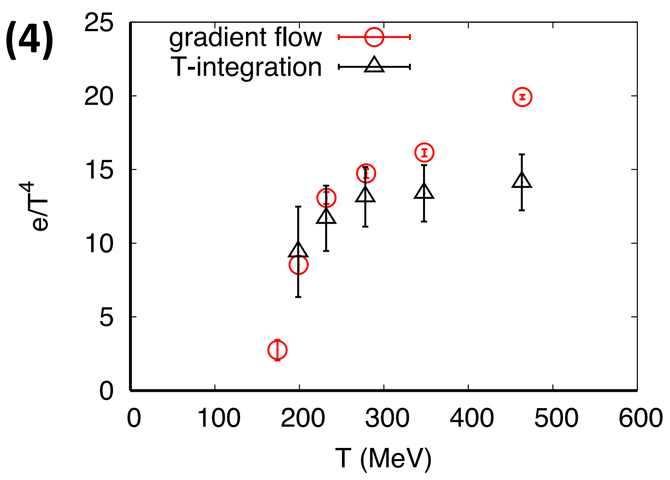
Energy-momentum tensor (EMT) is a generator of the translation and is one of the most essential quantity in physics. Lattice simulation is the only method to evaluate a quark and gluon contribution to EMT from the first principle. However it is not straightforward to be studied on the lattice due to the explicit violation of the translation symmetry.

(3)

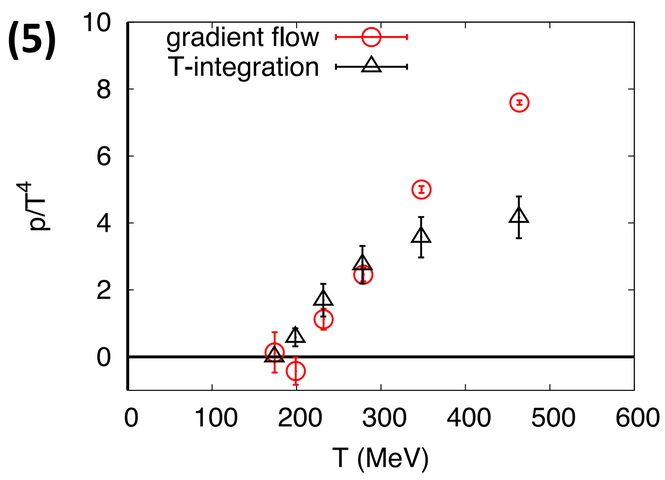


Recently a new method was proposed to calculate EMT by applying gradient flow equation. In the process of the gradient flow the violation of symmetry is smeared and the EMT becomes renormalized automatically. Conversion to the proper EMT operator related to the symmetry is performed by taking zero flow time limit (fig3).We applied the method to 2+1 flavor QCD for the first time and calculated the simplest ingredient; energy density (fig4) and pressure (fig5) as a first step. The result shows a good agreement with the conventional method at $T \leq 300$ MeV with considerably improved statistical error.

(4)



(5)



An important future direction of this study is a calculation of correlation functions of EMT at the physical point, which is under way using the HA-PACS and the COMA.

[Y. Taniguchi et al., https://arxiv.org/abs/1609.01417]