Research in Particle Physics

2+1 flavor QCD at Physical Point on very large lattices (master-field simulations)

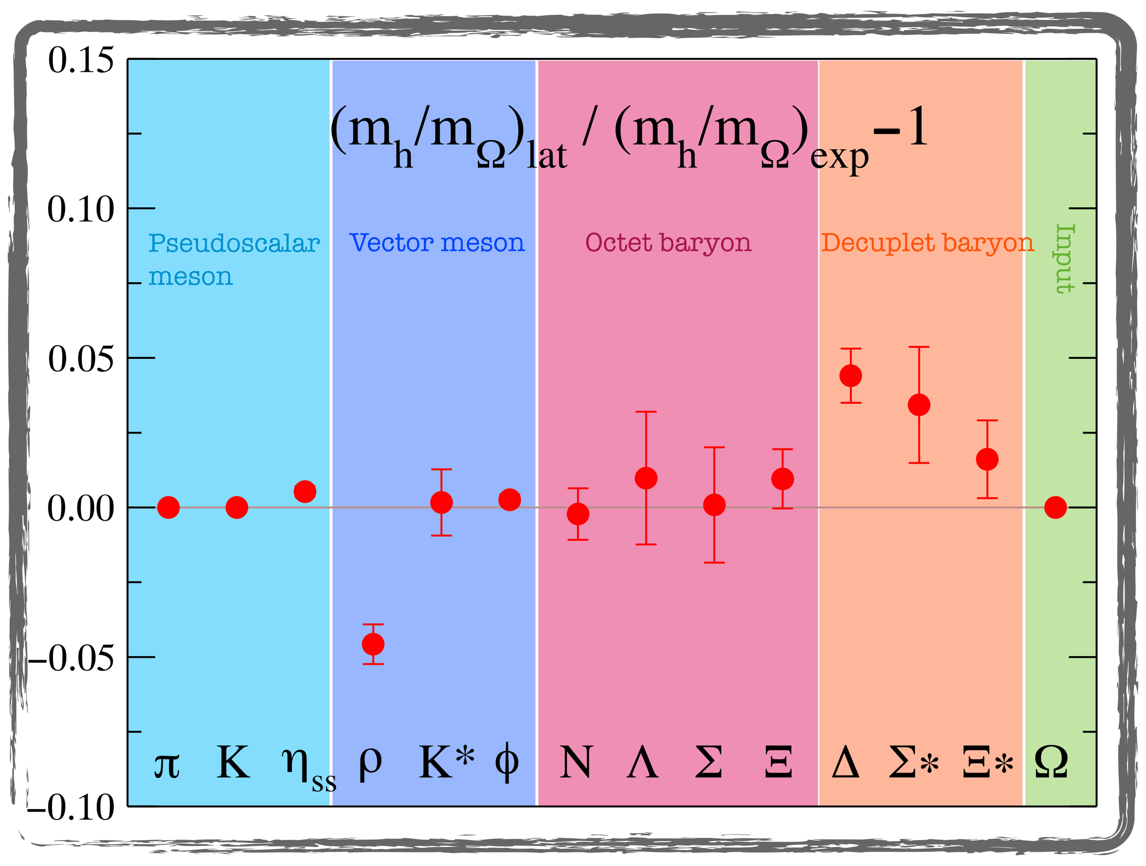

Fig1, K.-I. Ishikawa et. al., https://arxiv.org/abs/1511.09222

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 and a succeeding 2 flavor QCD simulation by the CP-PACS, 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. On the PACS-CS and T2K computers, we have succeeded in reaching the physical point by a reweighting technique. This calculation is followed by a larger volume simulation on the K computer. Fig. 1 presents relative difference of the light hadron spectrum from the experiment. 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.

Our current project is aiming to control and remove systematic errors due to the previous simulations on a finite volume with a finite lattice spacing. We are performing so called master-field simulations on very larger $(10\text{fm})^4$ volume with several lattice spacings using the Oakforest-PACS computer which ranks in the 3rd position in the HPCG benchmark and in the 6th position in the TOP500 list at SC16. Fig. 2 shows a comparison of pseudoscalar decay constants, f_π and f_K, on $(10\text{fm})^4$ and $(5\text{fm})^4$. We detect 0.66% and 0.25% finite volume effect on f_π and f_K, respectively. The effect is very small but negligible to compare the corresponding experiments. Now, we can control and remove the finite volume effect completely by using the master-field simulations.

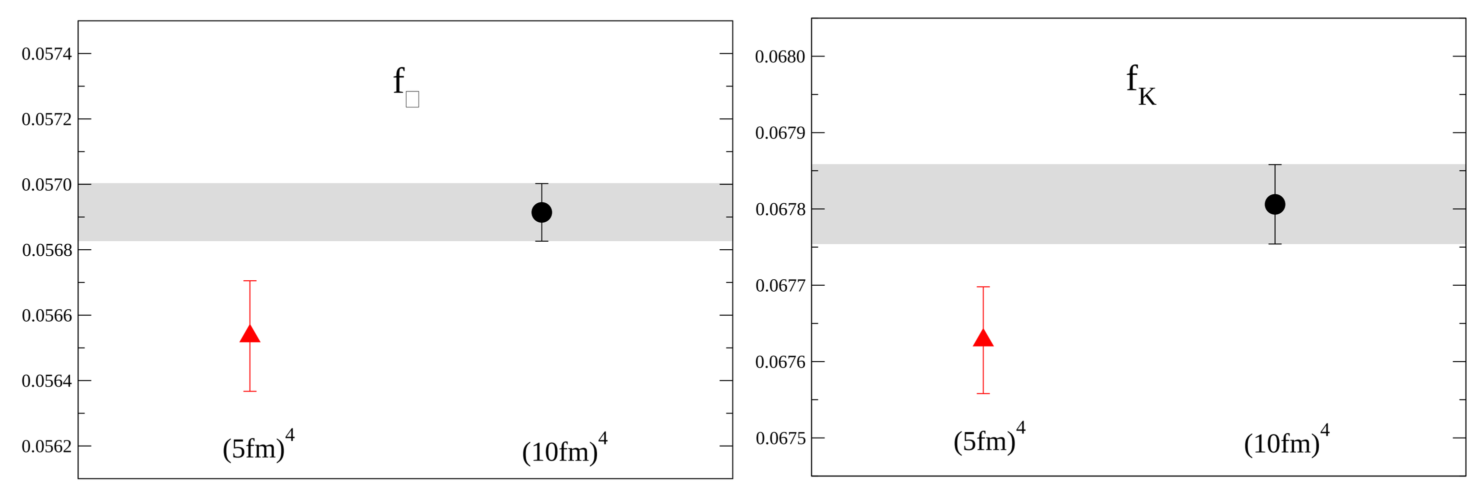

Fig2, K.-I. Ishikawa et. al., https://arxiv.org/abs/1807.06237

Energy-momentum tensor in 2+1 flavor QCD using gradient flow

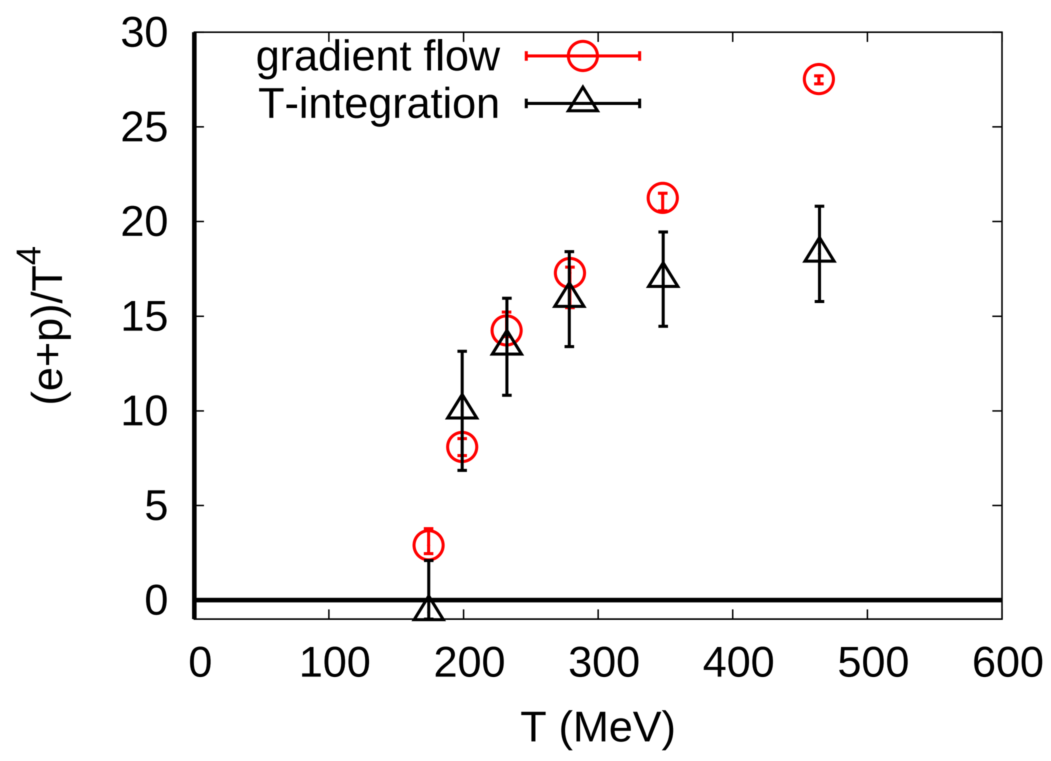

Fig. 3, Y. Taniguchi et. al., Phys. Rev. D 96, no. 1, 014509 (2017)

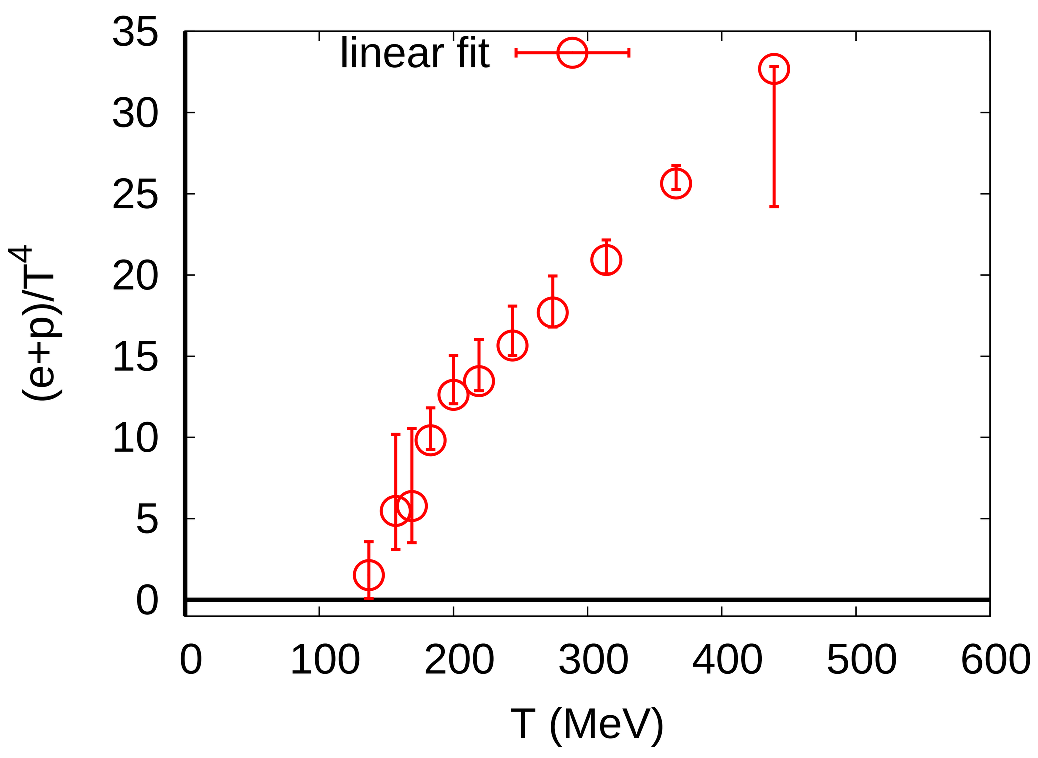

Fig. 4, K. Kanaya et. al., EPJ Web of Conference, 175, 07023, pp.1-8

The energy-momentum tensor is a fundamental observable in physics. It is the source of the gravity. Its diagonal elements contain the energy density and the pressure, while its off-diagonal elements represent the stress. In order to calculate the energy-momentum tensor on the lattice, we need to perform a complicated non-perturbative renormalization due to violation of the translational invariance on the lattice. For this purpose we adopt the gradient flow as a renormalization scheme proposed by H. Suzuki. We are making the first systematic application of the method to QCD with dynamical quarks.

Fig. 3 shows the entropy density as a function of temperature. The degenerate u and d quark mass is heavier than experiment in this plot. Red symbols are our new results using the gradient flow method. Black symbols are our old results using a conventional method. Both agree well with each other off the shaded region in which lattice artifact is considered to be large.
Fig. 4 is the same as Fig. 3 but the ud quark mass is set to its physical value.