Research in Particle Physics

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

Hadrons are the constituents of atomic nuclei. Computing the mass spectrum of hadrons from first principles of the quantum chromodynamics (QCD), the fundamental theory of strong interaction described by quarks and gluons, is a principal subject in particle physics.

After quenched and succeeding 2 flavor QCD simulations 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 one. On the PACS-CS and the T2K computers, we have succeeded in reaching the physical point. This calculation is followed by a larger volume simulation on the K computer.

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 $(10fm)^4$ volume with several lattice spacings using the Oakforest-PACS.

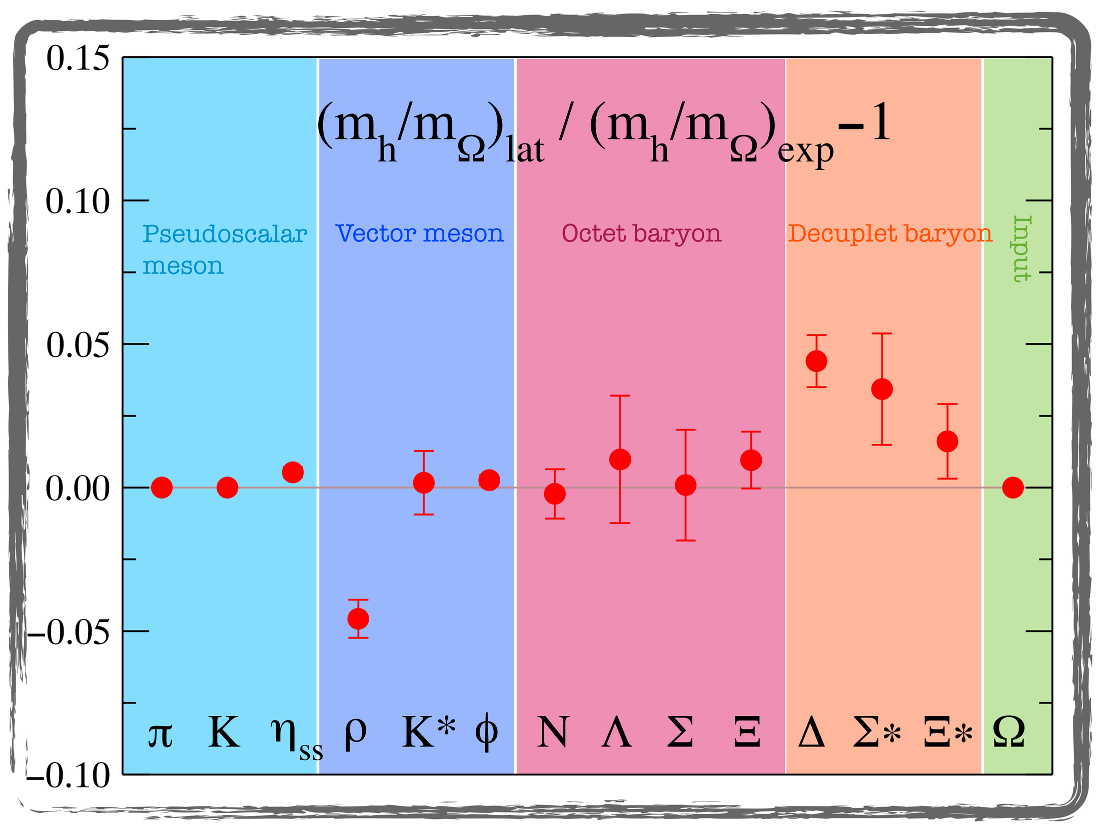

Fig1a:
Relative difference of the light hadron spectrum from the experiment. Inputs are only the pion, kaon, and omega baryon masses to determine the up-down and strange quark masses, and the lattice cutoff, respectively. Our results show good agreement with the experiment albeit errors are still not quite small for some of the hadrons.
[K.-I. Ishikawa et al., https://arxiv.org/abs/1511.09222]

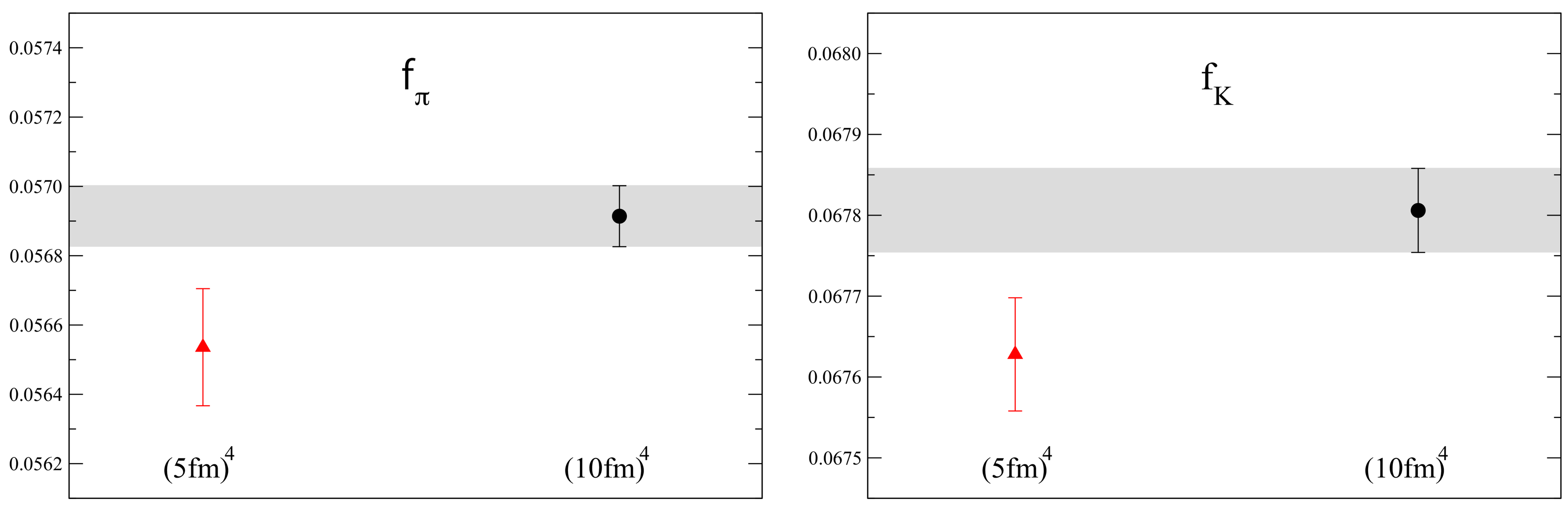

Fig. 1b:
A comparison of pseudoscalar decay constants, f_π and f_K, on $(10fm)^4$ and $(5fm)^4$. We detect 0.66% and 0.26% finite volume effect on f_π and f_K, respectively. The effect is very small and negligible to compare the corresponding experiments. Now, we can control and remove the finite volume effect completely by using the master-field simulations.
[K.-I. Ishikawa et al., Phys. Rev. D 99, 014504]

Exploring QCD phase diagram

Investigating the phase structure of QCD at non-zero temperature and density is very important to understand properties of strongly interacting matters under extreme conditions. It is known that the order of the phase transition depends on the mass and the number of flavors of quarks and there should be so-called critical endlines, lines of second order phase transitions, in certain space of quark masses as shown in Fig. 2a.

To determine the shape of the critical endline in the small quark mass region we are carrying out lattice QCD simulations at finite temperature with 2+1 as well as 3 degenerate quark flavors on Cygnus and Oakforest-PACS. Fig. 2b shows our recent estimation of the critical pion mass in 3 flavor QCD in the continuum limit including a new calculation with the temporal lattice extent of 12, where the new result gives a smaller upper bound than that of our previous calculation.

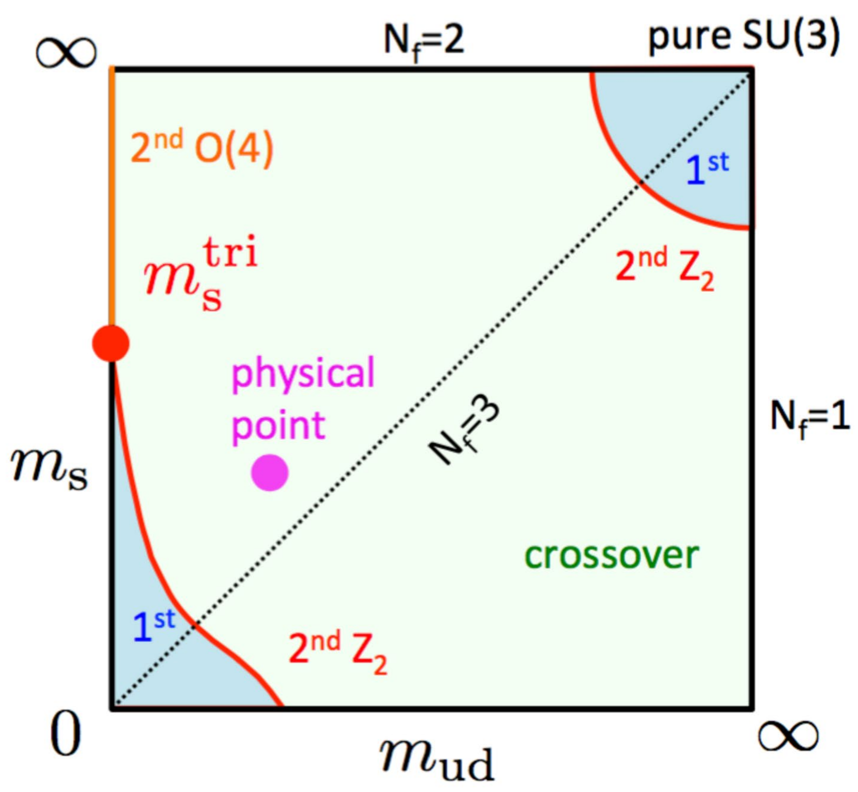

Fig. 2a:
Expected quark mass dependence of the order of the QCD phase transition. Our goal is to determine the shape of the critical endline shown as a red curve in the lower-left corner.

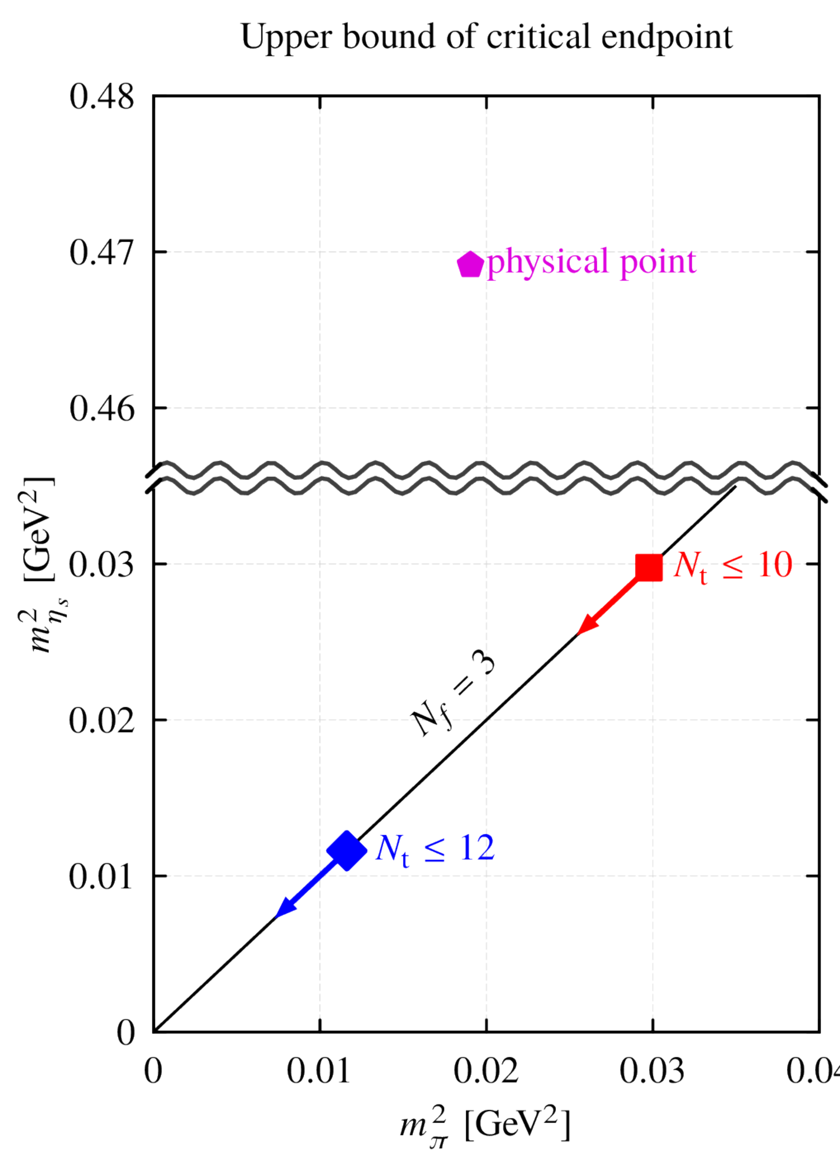

Fig. 2b:
Our recent estimation of the critical pion mass, $m_{\pi,E}$, in 3 flavor QCD. The continuum extrapolation including new data sets with the temporal extent of 12 gives an upper bound $m_{\pi,E} \lesssim 110$ MeV.
[Y. Kuramashi et al., Phys. Rev. D 101, 054509]