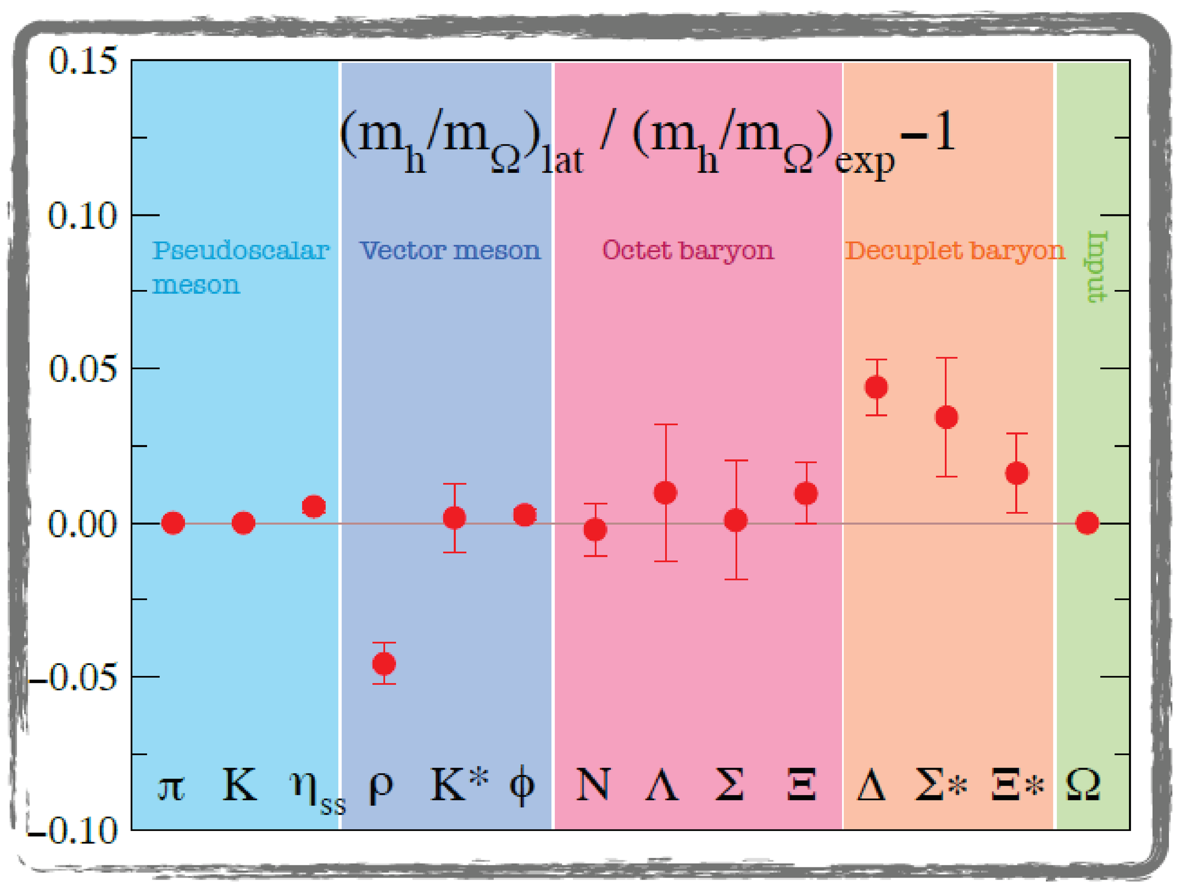
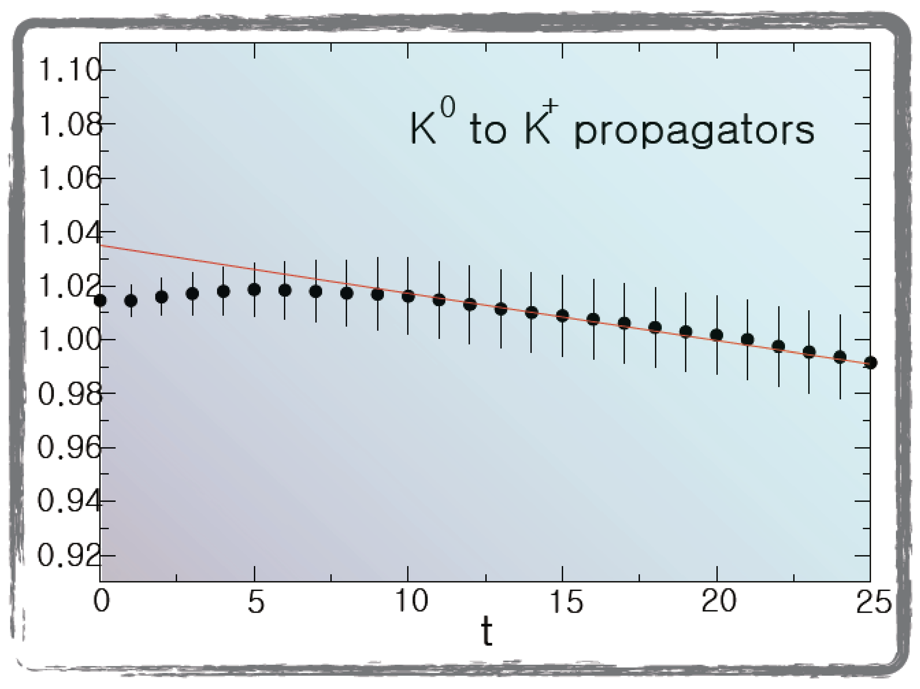
2+1 flavor QCD at Physical Point

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, 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 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.

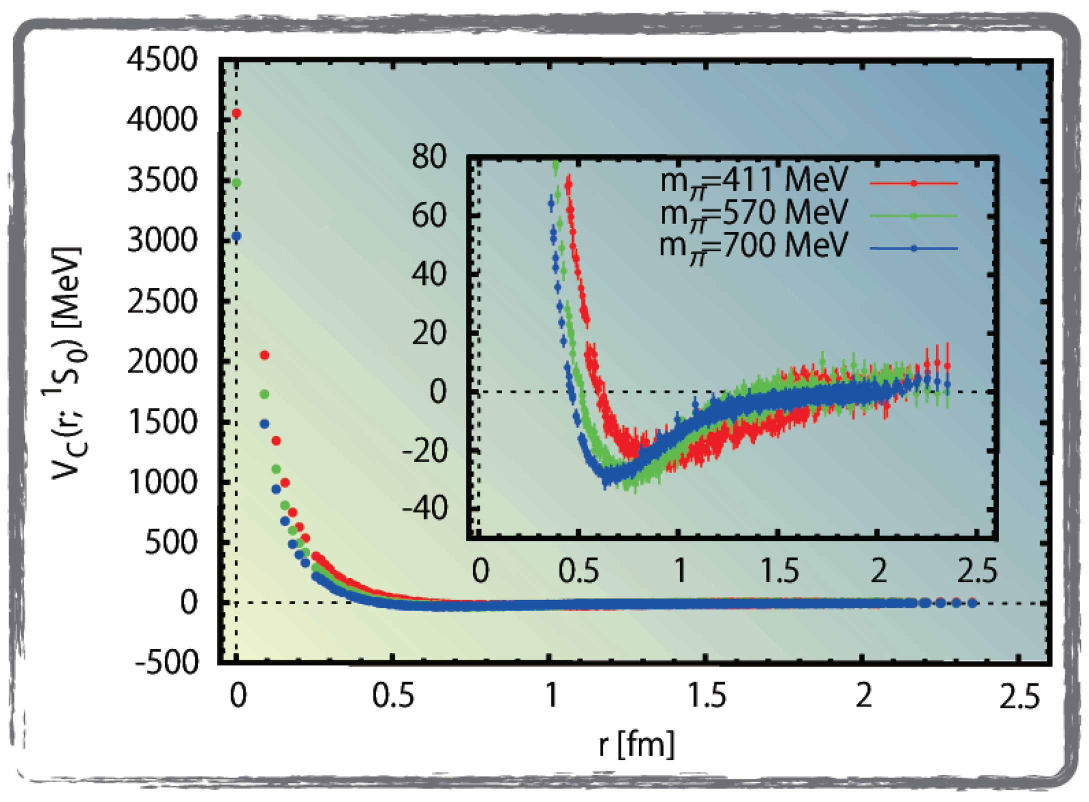
In nature, the masses for up and down quarks and also their electric charges are different. Their effects are observed in mass splittings among isospin multiplets of light hadrons, e.g., m_{K^0}-$m_{K^\pm}$. Thus, we have embarked on 1+1+1 flavor QCD+QED simulation at the physical point incorporating 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).



Nuclear force from Quantum Chromodynamics

Nuclear force originates from strong interaction, though it has been difficult to understand it from the fundamental theory of strong interaction due to high complexities of QCD.

We have succeeded, for the first time, in calculating the nuclear force directly from the first principle calculation of QCD using the quenched approximation. Extending our first study in 2007, we studied the 2+1 flavor QCD and obtained the nuclear force as shown in the right figure, which is the central force in the spin-0 state at the three, different quark masses. The global shape of the nuclear force is in good agreement with phenomenological one, which has tail at the long distance and repulsive core in short range.



An important future direction of this study is a calculation at the physical point, which is under way using the HA-PACS and the K computer. We are also trying a diffrent approach to reproduce the binding energy of atomic nuclei directly from QCD.