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.

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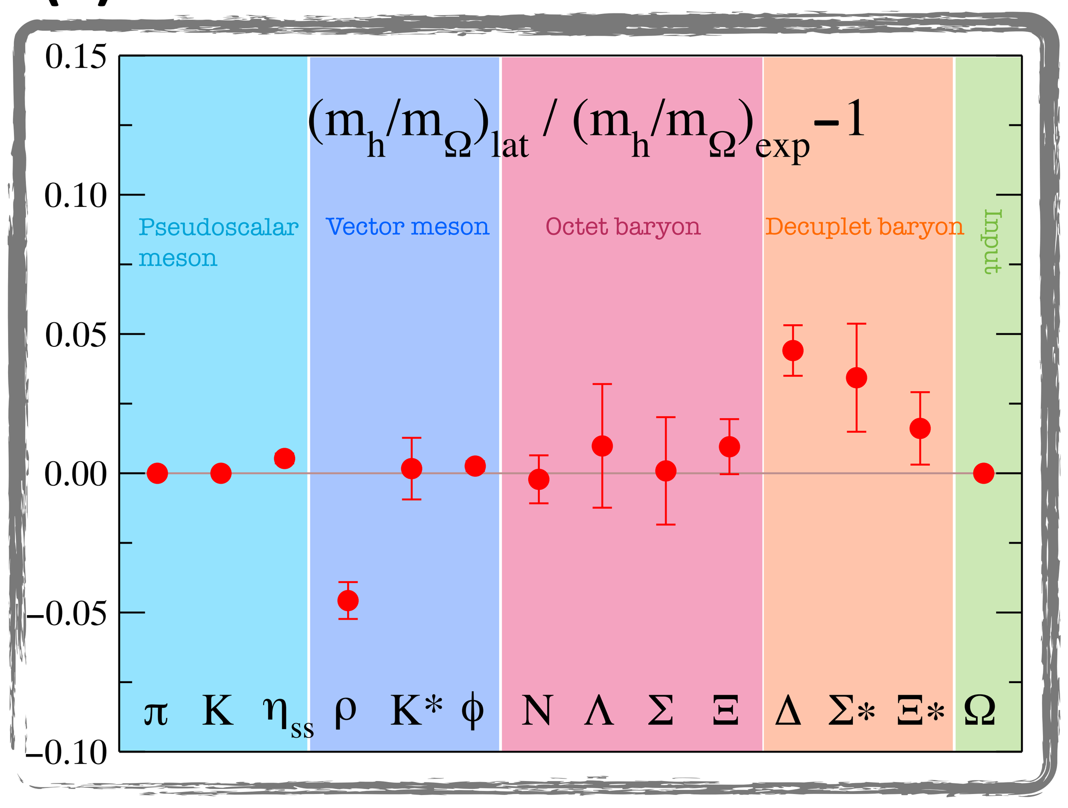
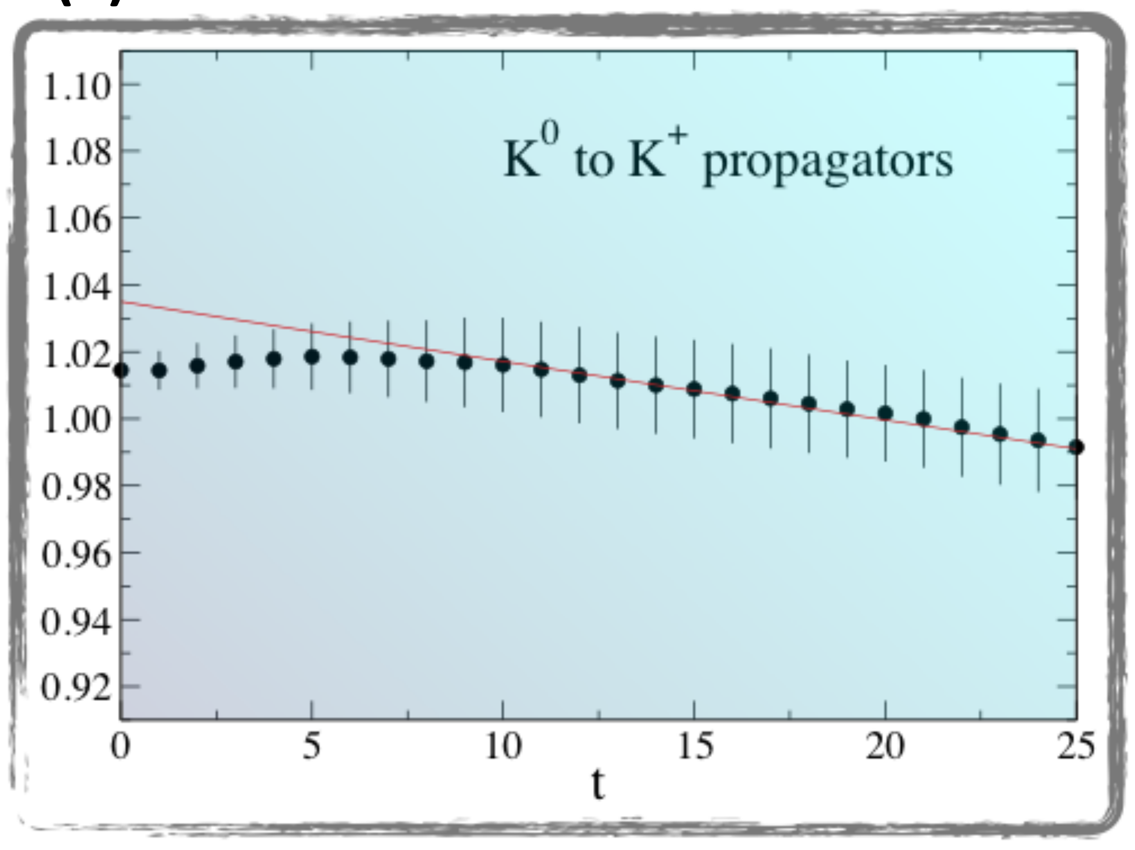


After quenched simulation, in which dynamical quarks are neglected, and a succeeding 2 flavor QCD simulation with dynamical up and down quarks by the CP-PACS, those studies were extended to 2+1 flavor QCD by incorporating the dynamical strange quark, though the degenerate up-down quark mass was much 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).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 the simulations on larger volumes 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.

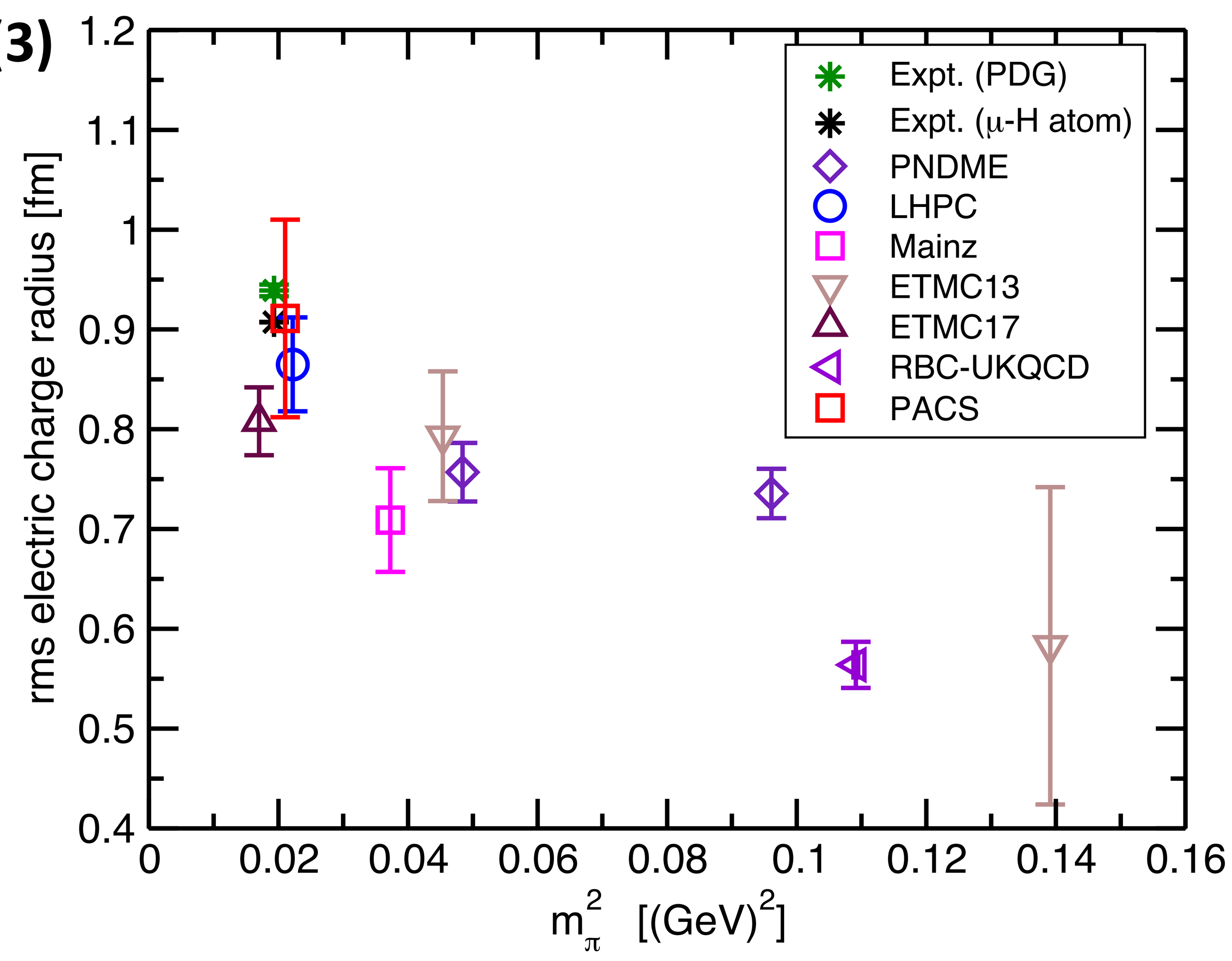
(2)



Proton radius problem

Proton radius problem is one of urgent problems to be solved in particle physics. The charge radius of the proton is different in the two experiments using the elastic electron scattering and the muonic hydrogen atom, which are expressed by the black and green stars, respectively, in the figure of the isovector charge radius (Fig.3): the difference of the charge radius between the proton and neutron.

(3)



We (PACS Collaboration) tackles this problem using lattice QCD calculation. The current purpose, however, is to reproduce the experimental values, because the charge radius at larger pion mass than the physical one is significantly smaller than the experiments. Towards this purpose, we calculate the isovector charge radius in 2+1 flavor QCD at almost physical point on a large volume, where the spatial extent is 8.1 fm, using several computing resources including COMA and Oakforest-PACS.

Our result of the charge radius is plotted by the red square in Fig.3. Since the statistical error of our result is large, at present we cannot conclude which experiment is preferable from the lattice QCD calculation. One of important future works is to reduce the statistical error. Another important future work is to include the QED and isospin breaking effects. We attempt these calculations using Oakforest-PACS.

[N. Tsukamoto et al. for PACS Collaboration, https://arxiv.org/abs/1710.10782]