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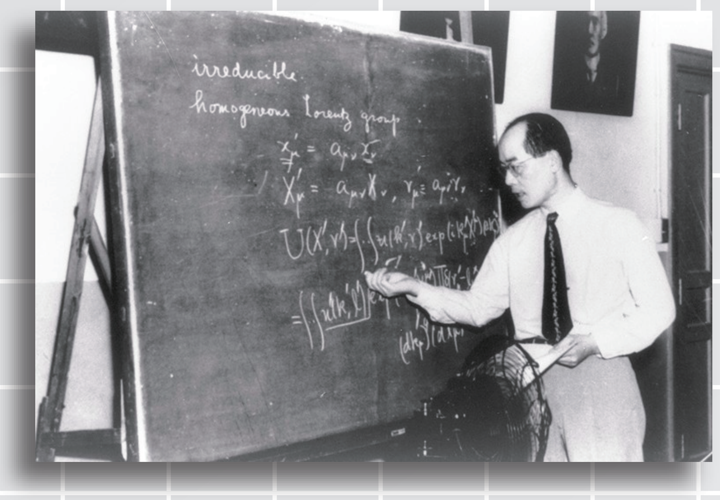
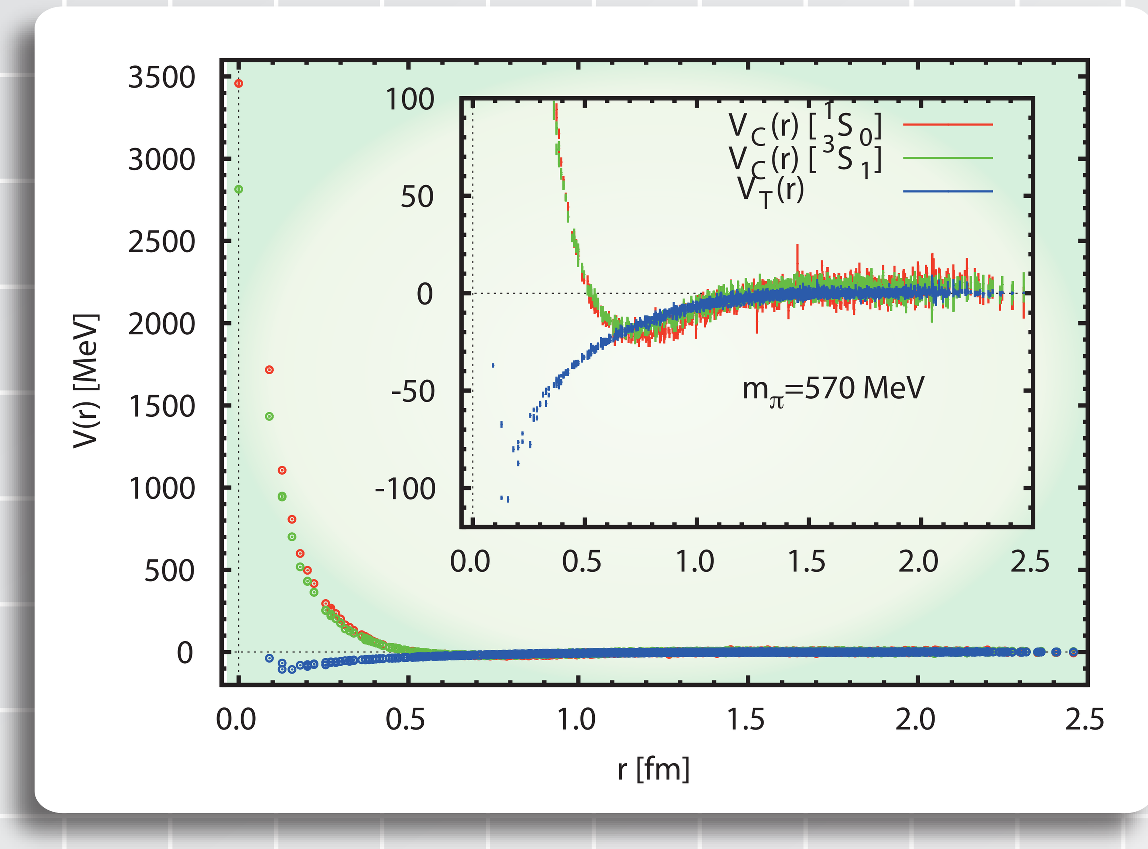
Research in Particle Physics (2)

Nuclear force from lattice QCD



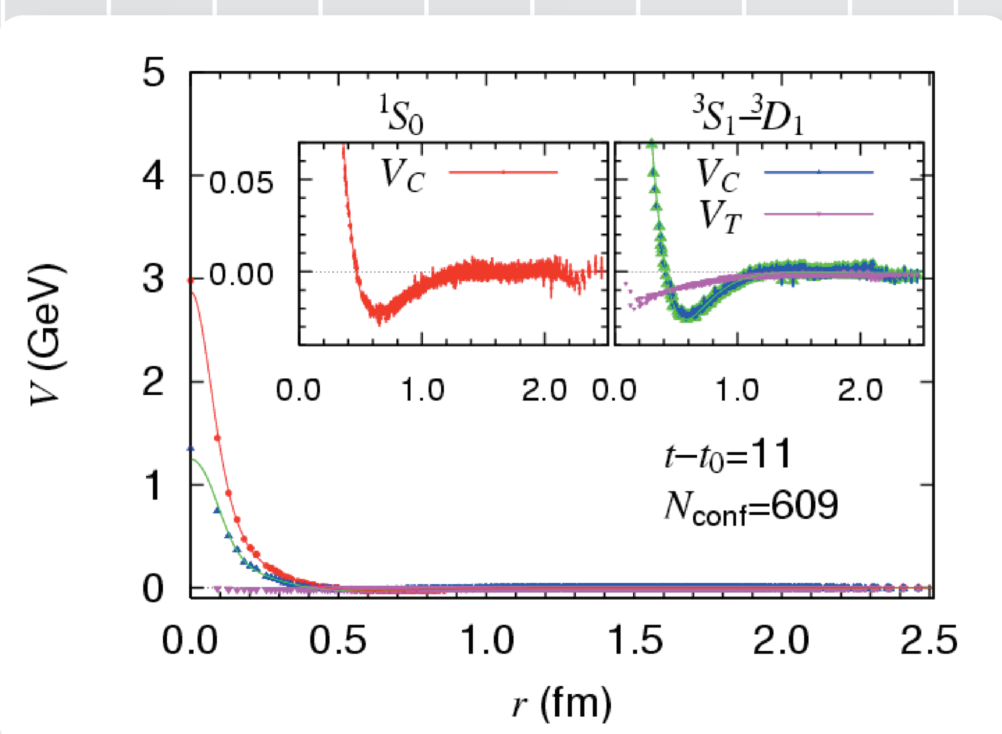
In 1935, Yukawa theoretically introduced π mesons to account for the nuclear force among protons and neutrons inside nuclei. Later it was found that the protons, neutrons and π mesons are all composed of more fundamental quarks. Due to high complexities of QCD, which governs the dynamics of quarks, however, it has been difficult to reproduce the nuclear force from quarks.

In 2007, we have succeeded, for the first time, in unraveling the the nuclear force directly from lattice QCD: In the quenched approximation, we reproduced not only the Yukawa's force at long distances but also the strong repulsive core at short distances. The repulsive core was speculated from the nucleon experiment and is considered to be essential for the stability of the matter.



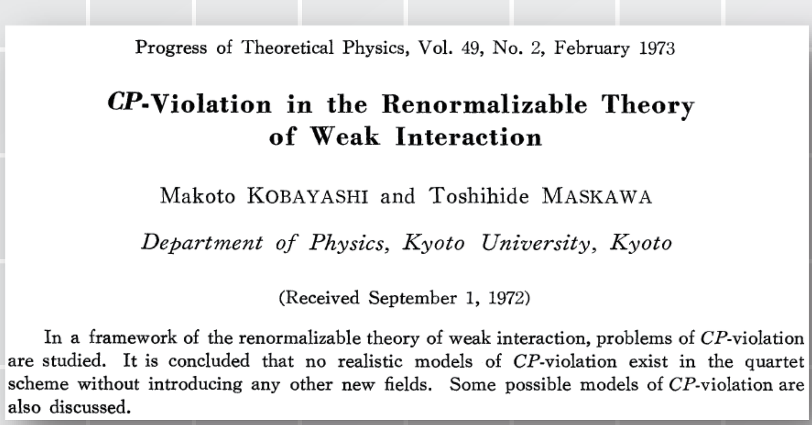
After this study, we removed the quenched approximation by using gauge configurations with 2+1 flavors of dynamical quarks by the PACS-CS Collaboration, and extended to include the tensor part of the potential. The right figure shows the nuclear potential. [red: central force potential for spin 0 states, green: central force potential for spin 1 states, blue: tensor potential for spin 1 states]. We observe that the tensor potential seems to have no repulsive core.

Hyperon force from lattice QCD



Nucleon is made of three light (u or d) quarks, while hyperon contains at least one s quark. The hyperon-nucleon potentials are only a little known experimentally due to the short life time of hyperons. The left figure represents our result for the potentials between Lambda (one of hyperons) and nucleon [red: central potentials for spin 0, blue: that for spin 1, magenta: the tensor potential]. We notice that the spin dependence of the central potential between Lambda and nucleon is larger than that of nucleon-nucleon, and that the tensor potential is much shallower than that between nucleons.

Electroweak mixing matrix


Progress of Theoretical Physics, Vol. 49, No. 2, February 1973

CP-Violation in the Renormalizable Theory of Weak Interaction

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In a framework of the renormalizable theory of weak interaction, problems of CP-violation are studied. It is concluded that no realistic models of CP-violation exist in the quartet scheme without introducing any other new fields. Some possible models of CP-violation are also discussed.

In 1978, Kobayashi and Maskawa constructed the fundamental theory of quark mixing and CP violation. The Nobel Prize in Physics 2008 was awarded for their prediction of the CP violation which is considered to be a source of the asymmetry between matter and anti-matter in the universe.

Calculation of QCD effects on the lattice is indispensable for precise determination of the CKM matrix elements, the key parameters of the Kobayashi-Maskawa theory,. We have calculated the decay constants of D and D_s mesons with 2+1 flavors of dynamical quarks (right figure), with which two CKM matrix elements are estimated to be

$$|V_{cd}| = 0.207(2)(9) + O(g^2 a),$$
$$|V_{cs}| = 0.98(2)(3) + O(g^2 a)$$

This enables us determination of fundamental parameters in the nature without phenomenological assumptions.