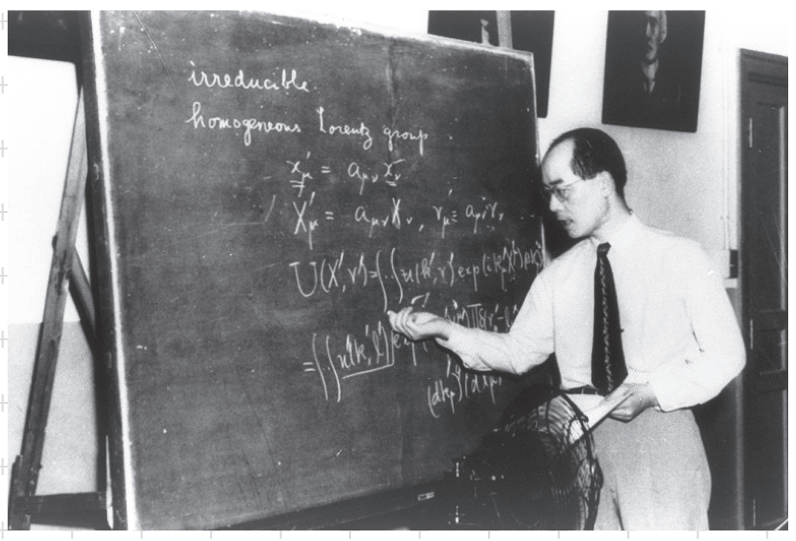
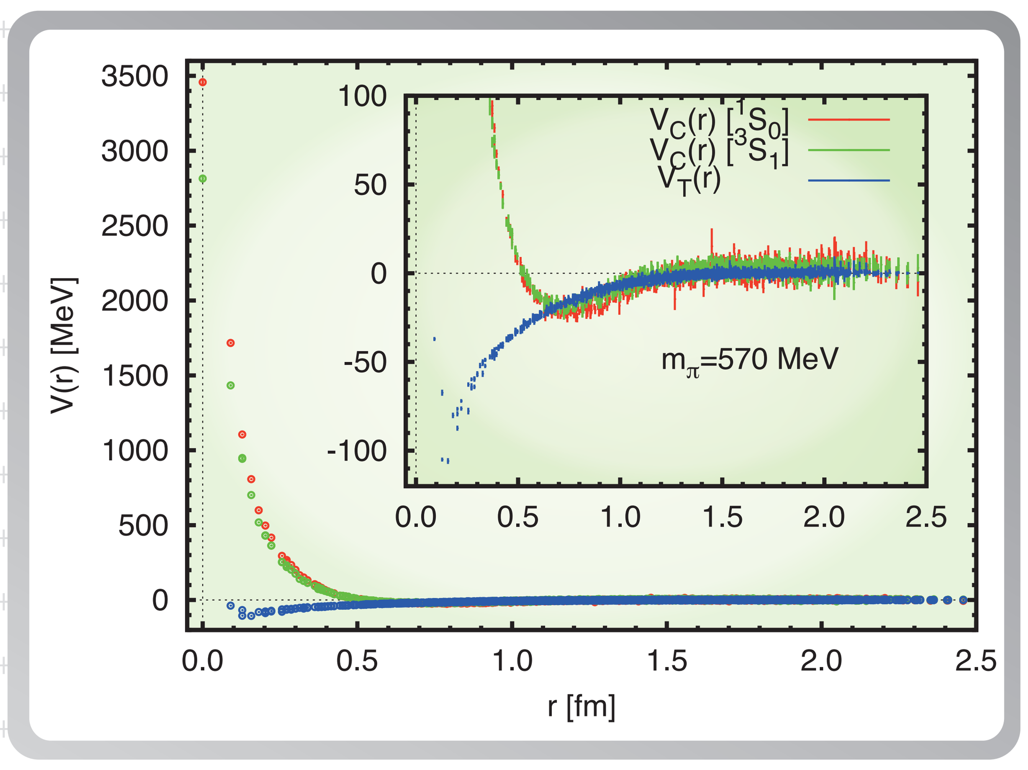
Research in Particle Physics (2)

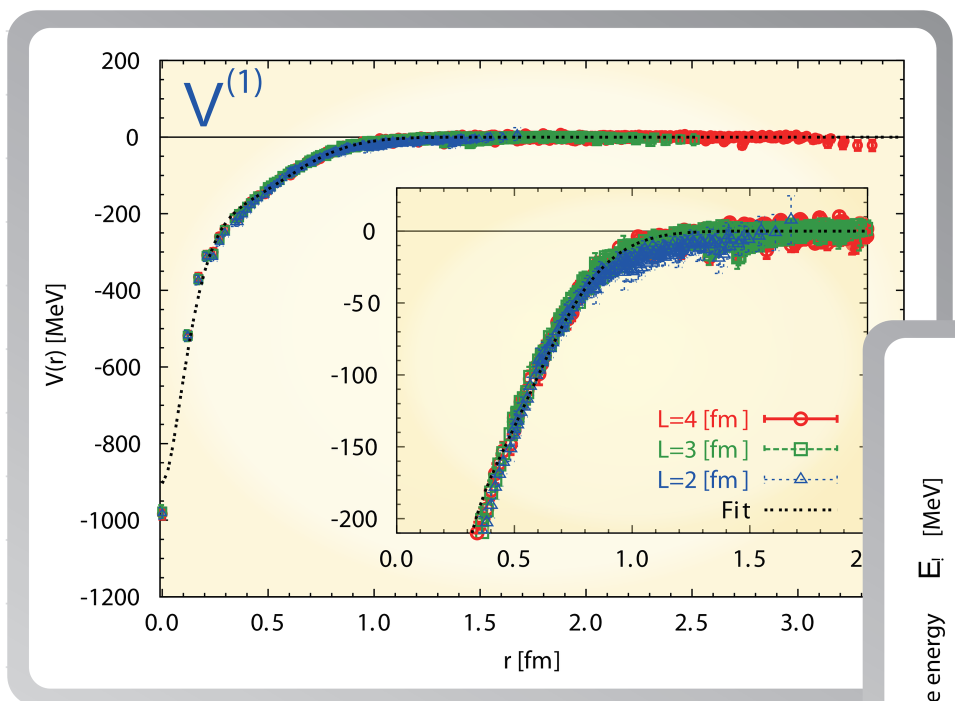
Nuclear Force Directly from Quarks

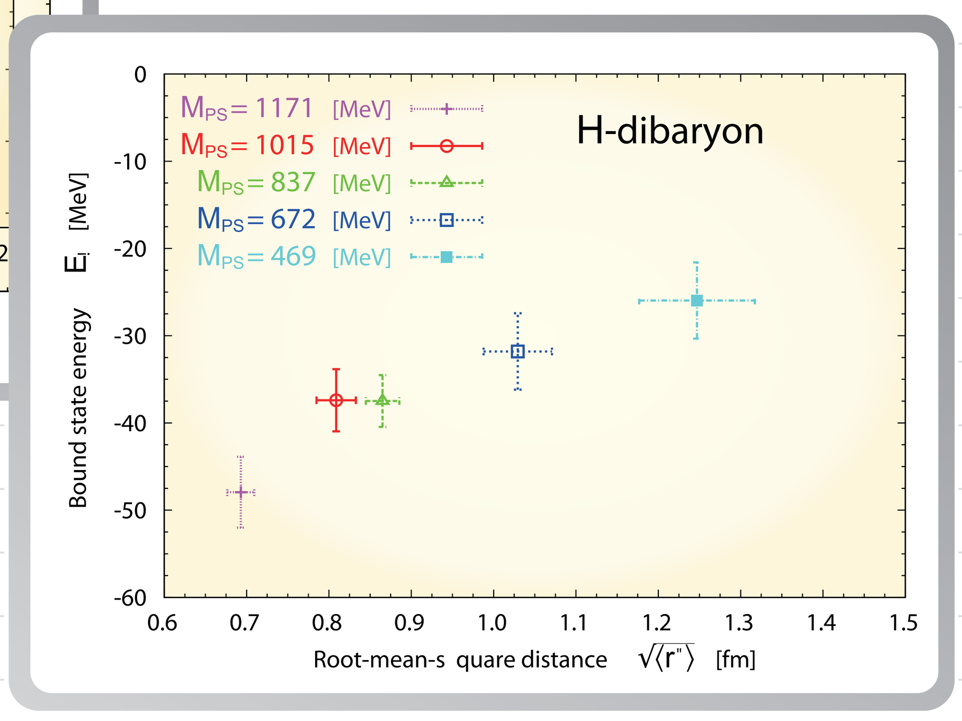


In 1935, Hideki Yukawa theoretically introduced π mesons to account for nuclear force among protons and neutrons inside nuclei. Later it was found that the proton, the neutron and the π meson are all composed of more fundamental quarks. Due to high complexities of QCD, which governs the dynamics of quarks,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

We have succeeded, for the first time, in unraveling the nuclear force directly from lattice QCD. Extending our first study in 2007 using the quenched approximation, we studied the 2+1 flavor QCD and reproduced not only the Yukawa's force at long distances but also the strong repulsive core at short distances, as shown in the right figure [red: central force potential for spin 0 states, green: central force pot ential for spin 1 states, blue: tensor potential for spin 1 states]. Our calculation predicts absence of the repulsive core in the tensor potential.



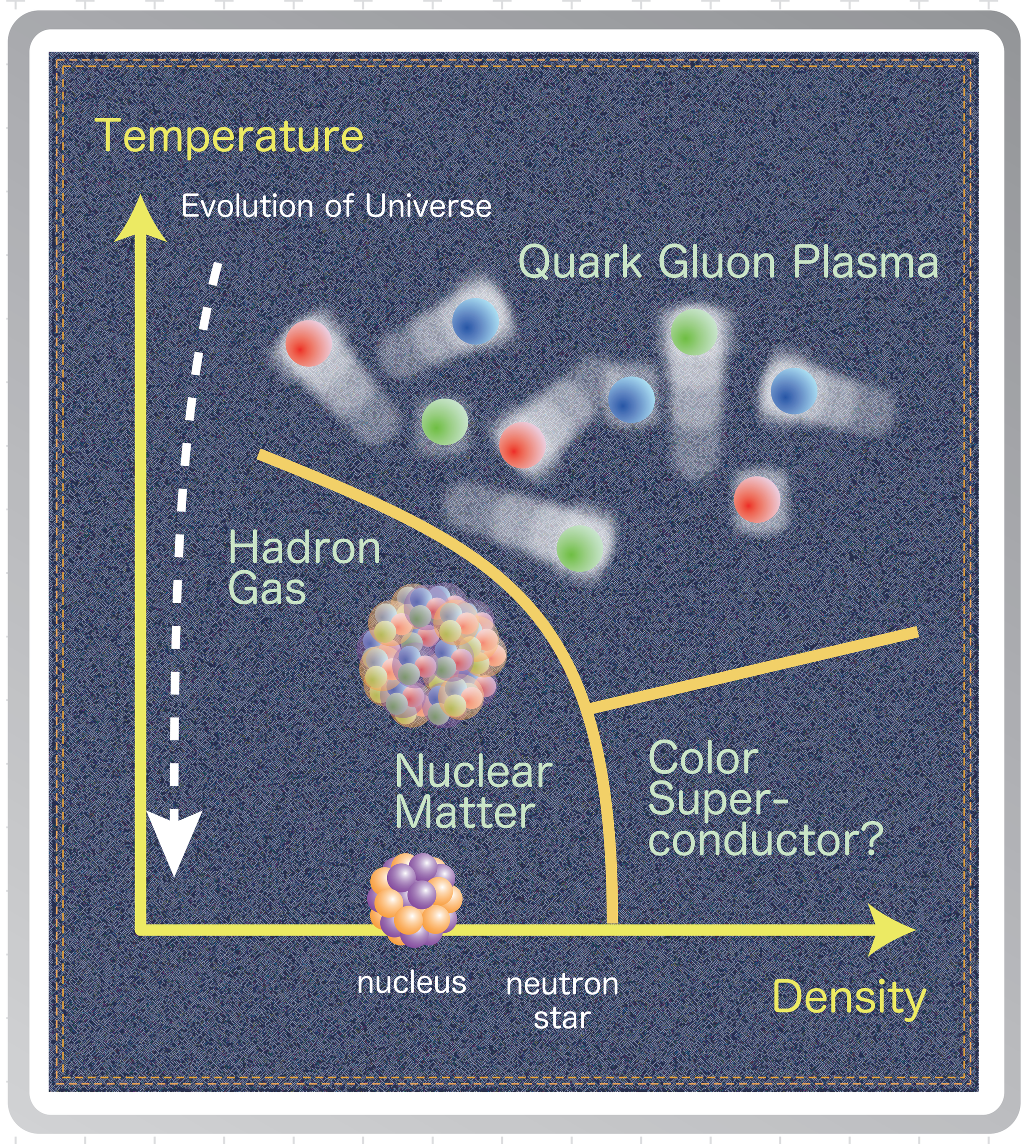




As an application of our method, the flavor-singlet 6 quark state, called H-dibaryon, is studied in flavor SU (3) limit of lattice QCD. The left figure shows that the flavor-singlet potential is insensitive to the spatial lattice extension L.

This potential leads to a bound H-dibaryon with the binding energy of 25-50 MeV, as shown in the right figure, where its size and binding energy are plotted at five different values of the pseudo-scalar meson mass.

Quark matter in extreme conditions



At temperatures higher than about 10^{12} K and/or at densities several times higher than nuclei, quarks are expected to form a variety of new states of matter that the humanbeing has never experienced. Clarification of their nature is important in understanding the nucleosynthesis in early Universe.

We are studying thermodynamic properties of quark matter using improved Wilson quarks, with which a solid continuum limit exists. The right figure shows the first results of energy density and pressure in the high-temperature phase, obtained with 2+1 flavors of dynamical Wilson quarks.