Division of Particle Physics

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In nature, there are four basic forces: gravity, electromagnetism, the weak force, and the strong force. The strong force makes stars shine and holds together the nuclei in the various molecules that form our bodies. It acts on quarks, which are the smallest constituent particles (elementary particles) of matter, causing a characteristic phenomenon called "confinement" due to non-perturbative effects. In experiments, only the bound state of multiple quarks (called "hadrons") is observed—not individual quarks. Therefore, a non-perturbative method is needed to study the strong force. Lattice quantum chromodynamics (QCD) involves the application of the theory of QCD to a discretized lattice of four-dimensional space–time—consisting of the three dimensions of space and one dimension of time—and can be used to quantitatively examine the 10^{-15} m world of strong forces on the basis of first principles using supercomputers.

Research Topics

- Precise calculation of the hadron mass spectrum
- Precise determination of the fundamental parameters of QCD (coupling constants and quark masses)
- Understanding the internal structure of hadrons
- Composition of light nuclei with quarks as degrees of freedom
- Study of QCD-based interactions between hadrons
- Understanding the phase structure of QCD, including the ultrahigh-temperature state (early universe) and high-density state (inside the neutron star)
- Application of tensor renormalization group to relativistic quantum field theory

Latest Accomplishments

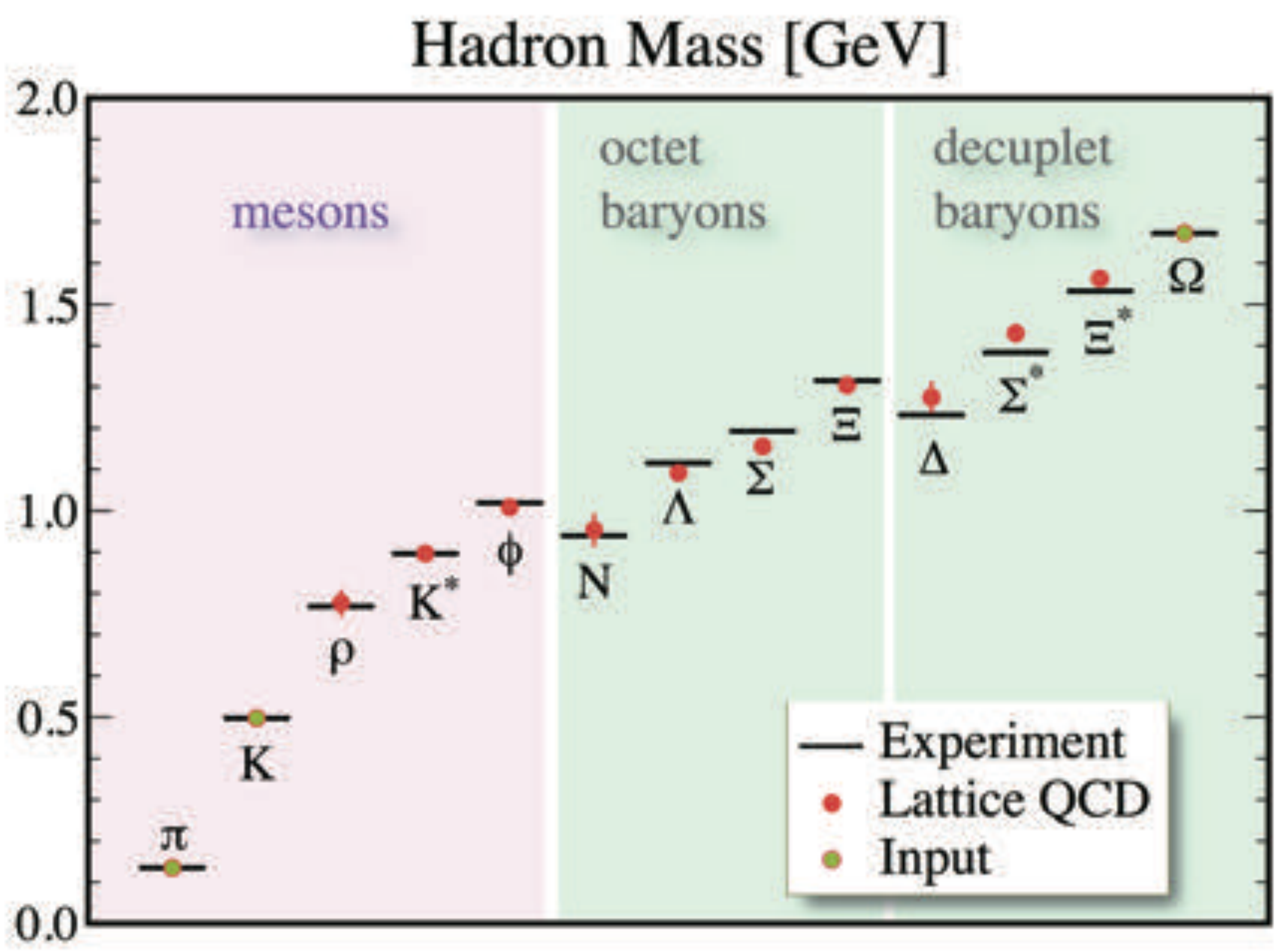

Fig.1 Hadron masses with lattice QCD in comparison with experimental values

Recent improvements in algorithms and computer performance have made it possible to perform physical point calculations (calculations using the quark masses in nature), which has been a goal for many years. Thus, lattice QD calculations are entering an era where precision calculation error levels are improving from 10% to 1%. Figure 1 shows the hadronic mass calculated via lattice QCD. Although this report was published in 2009, the calculation nearly reproduces the experimental value. Since then, lattice QCD calculations have made progress, and we now approach an era in which we can strive for a new type of physics based on small deviations between experimental values and theoretical calculations. For example, in Figure 2, we compare the theoretical calculation (with error symbols) and experimental values (light blue vertical band) of a physical parameter called $|V_{us}|$ using lattice QCD. Because the discrepancy between the two is evidence of an unknown physical phenomenon, it is important to evaluate this discrepancy through further precise calculations in the future.

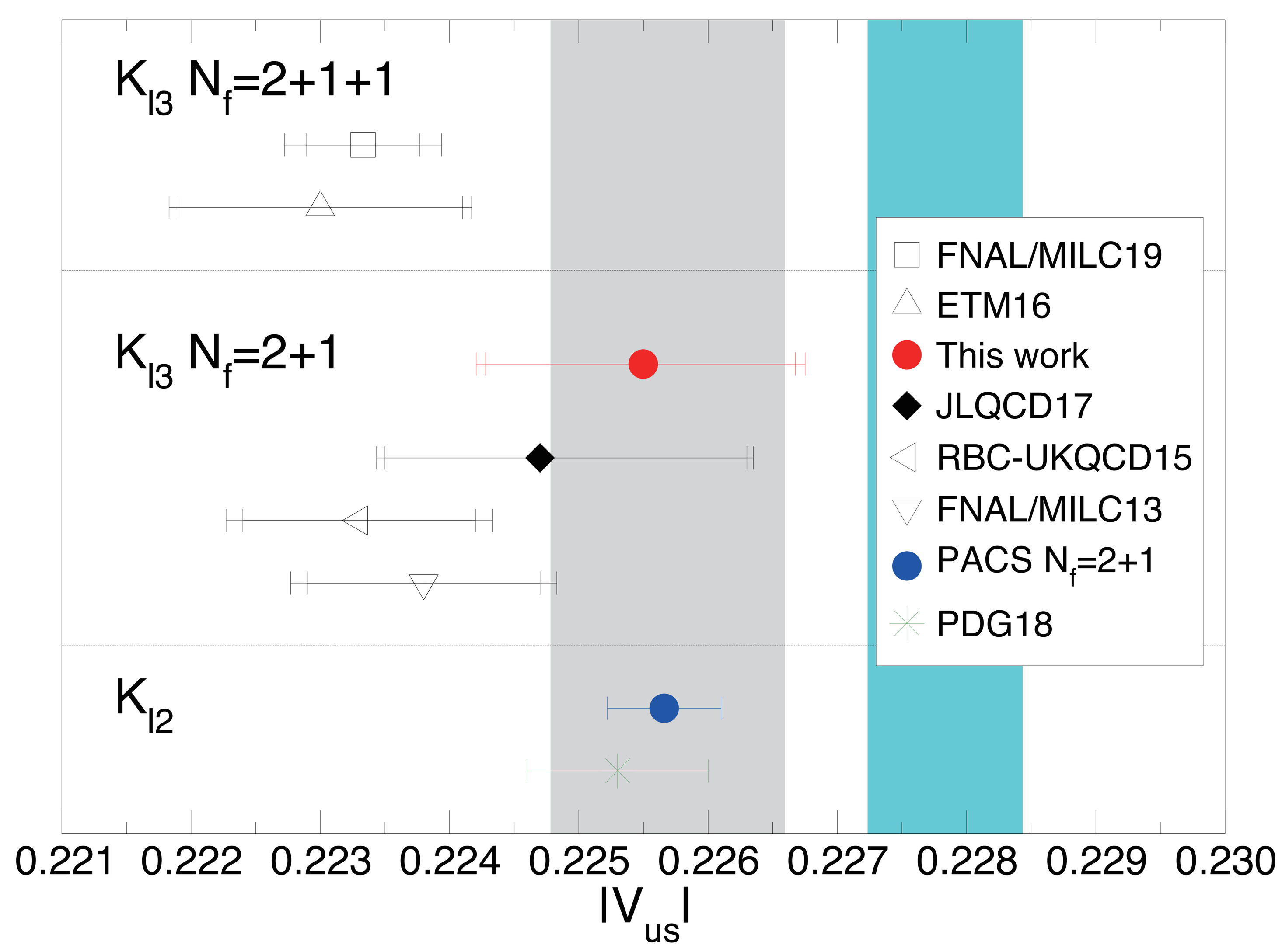

Fig.2 Comparison between lattice QCD calculation and experimental data (light blue vertical band). The red and blue circles represent the results of our group's calculations.