The Sigma Meson in Lattice QCD

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In the low-energy region, the sigma meson plays an important role for the chiral symmetry breaking of QCD. Despite its importance, the experimental identification of the light scalar meson is a long standing puzzle and the σ had disappeared from the list of Particle Data Group (PDG) for over 20 years. But, the scenes around the σ are changing recently; re-analyses of π-π scattering phase shift strongly suggest the existence of the $I = 0$ and $J^{PC} = 0^{++}$ meson and significant contributions of the σ in the decay channels of heavy particles such as D$\rightarrow \pi\pi\pi$ are reported [1, 2]. The σ may reveal itself also in $\Upsilon(3S) \rightarrow \Upsilon\pi\pi$ channel[3]. In 1996 PDG, "f_0(400-1200) or σ" appeared bellow 1 GeV mass region. In the 2002 edition, it appears as "f_0(600) or σ" and as the 105th branch of the D$^+$ decay, "D $\rightarrow \sigma + \pi$ " is cited [4]. Now it is an important task of the lattice calculation to confirm the properties of the σ meson based on QCD.

In quenched QCD, DeTar and Kogut first measured the σ meson screening mass in a lattice simulation [5], Alfold and Jaffe discussed the possible light scalar mesons as $\bar{q}^2q^2$ states [6], and masses and mixing of $q\bar{q}$ states and a glueball have been investigated by Lee and Weingarten [7]. However, as we have already reported in the previous proceedings [8], the connected and disconnected diagrams give almost the same amount of the contributions, indicating that the dynamical quark effect seems to be essential in the calculation.

McNeile and Michael computed the mixed iso-singlet scalar masses of $q\bar{q}$ and glueball states in two kinds of situation, i.e, with and without the dynamical quark effects [9]. We focus our attention to explore whether the σ meson exists below 1 GeV in this work. Based on the quite similar motivation, Prelovsek presented the calculation of the quenched scalar meson correlator with the domain wall fermions, where the disconnected diagram is taken into account effectively through an approximate formula based on the chiral perturbation theory [10].

As for the σ meson, we adopt the operator as

$$\sigma(x) \equiv \sum_{c=1}^{3}\sum_{\alpha=1}^{4} \frac{\bar{u}_\alpha^c(x)u_\alpha^c(x) + \bar{d}_\alpha^c(x)d_\alpha^c(x)}{\sqrt{2}} \ , \tag{1}$$

where u and d are the u-quark and d-quark Dirac spinors, respectively. The indices c and α denote color and Dirac spinor indices, respectively. Quantum numbers of the operator are $I = 0$ and $J^P = 0^+$. Because our simulation is full QCD, any kind of the state which has the same quantum number can contribute to the correlation as a virtual state.

We calculate the σ propagator in the full QCD by using the Hybrid Monte Carlo (HMC) algorithm, in order to take the dynamical quarks which are important to estimate the disconnected diagrams of the σ propagator. We use the Z_2 noise method to calculate the disconnected diagrams. The 500 or 1000 random Z_2 numbers are generated. The two-flavor Wilson fermion system is simulated on the $8^3 \times 16$ lattice.

After 500 trajectories are updated in the quenched QCD, we start to update the configuration in the full QCD by using HMC algorithm. More than 500 trajectories by HMC are spent for thermalization. The σ propagators are calculated on a configuration in every 10 trajectories.

Based on ref.[11], A coupling constant β is set to 4.8 ($a = 0.197(2)$ fm, $\kappa_c = 0.19286(14)$) and three values of the hopping parameter, $\kappa = 0.1846$, 0.1874 and 0.1891 are assayed. The simulations with larger hopping parameters give us clearer signals. Though our simulation is still far from the chiral limit and no decay channel is yet open, our preliminary results obtained with still a relatively low statics indicate the existence of the light σ meson with the mass in almost the same order as that of the ρ meson[12].

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References

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