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Effects of dynamical sea-quarks on quark and gluon propagators

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Abstract. We present an unquenched calculation of the quark propagator in Landau gauge with 2+1 flavors of dynamical quarks. We study the scaling behavior of the quark propagator in full QCD on two lattices with different lattice spacings and similar physical volume. We use configurations generated with an improved staggered ("Asqtad") action by the MILC collaboration.

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Due to the difficulties of simulating dynamical fermions, most of the QCD simulations in the past were done in the quenched approximation, that is, ignoring the dynamics of sea quarks. In the quenched approximation the determinant of the Dirac operator is replaced by a constant. This would be reasonable if quarks were very heavy, but as they are not, this approximation results in uncontrolled systematic errors that can be as large as 30% [1].

Computing resources now available are powerful enough to treat up, down and strange quarks dynamically. In particular there has been a great deal of progress using the staggered formalism for lattice fermions. We have calculated the gluon and quark propagator in Landau gauge using configurations generated by the MILC collaboration [2, 3] available from the Gauge Connection `http://www.qcd-dmz.nersc.gov`.

The MILC configurations were generated with the $\mathcal{O}(a^2)$ one-loop Symanzik-improved Lüscher–Weisz gauge action. The dynamical configurations use the Asqtad quark action, an $\mathcal{O}(a^2)$ Symanzik-improved staggered fermion action. First results for the gluon propagator and quark propagator in full QCD were published in Ref. [4] and Ref. [5] respectively. We here extend those results by using a finer lattice. As well as being interesting in themselves, the study of the propagators is proving to be a fruitful area of interaction between lattice gauge theory and Dyson-Schwinger equations. See, for example, Refs. [6, 7].

Effects of dynamical sea-quarks

First we discuss the gluon dressing function, $q^2D(q)$, where $D(q) = \langle A(q)A(-q)\rangle$, is the gluon propagator. The addition of dynamical quarks to the gauge fields produces a

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TABLE 1. Lattice parameters used in this study. The dynamical configurations each have two degenerate light quarks (up/down) and a heavier quark (strange).

Dimensions	β	a	**Bare Quark Mass**	**#Config**
$28^3 \times 96$	7.09	0.090 fm	14.0 MeV, 67.8 MeV	108
$28^3 \times 96$	7.11	0.090 fm	27.1 MeV, 67.8 MeV	110
$20^3 \times 64$	6.76	0.125 fm	15.7 MeV, 78.9 MeV	203
$20^3 \times 64$	6.79	0.125 fm	31.5 MeV, 78.9 MeV	249
$20^3 \times 64$	6.81	0.125 fm	47.3 MeV, 78.9 MeV	268
$20^3 \times 64$	6.83	0.125 fm	63.1 MeV, 78.9 MeV	318

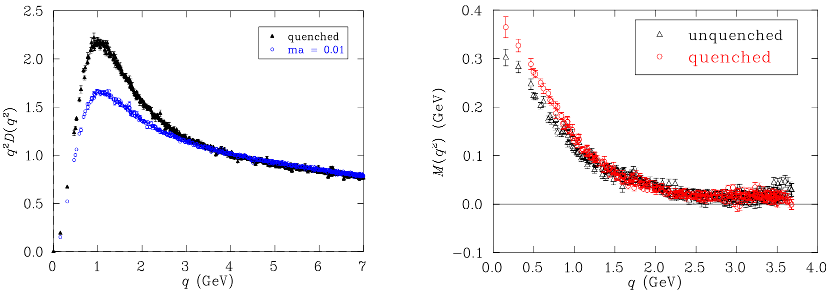

FIGURE 1. The gluon dressing function in Landau gauge is left. Full triangles correspond to the quenched calculation, while open circles correspond to 2+1 flavor QCD. As the lattice spacing and volume are the same, the difference between the two results is entirely due to the presence of quark loops. Right is the comparison of the unquenched (full QCD) and quenched quark propagator for non-zero quark mass. The mass function for the unquenched dynamical-fermion propagator has been interpolated so that it agrees with the quenched mass function for $ma = 0.01$ at the renormalization point, $q = 3$ GeV. For the unquenched propagator this corresponds to a bare quark mass of $ma = 0.0087$.

clearly visible effect in the dressing function in the region of the infrared hump. Unquenching results in a reduction of around 30% at 1 GeV. The qualitative features of the propagator – enhancement of the intermediate infrared momenta followed by suppression in the deep infrared – are, however, unchanged. Spectral positivity is violated in full QCD just as in the quenched theory, something that will be discussed in more detail in an upcoming publication.

On the right-hand side of Fig. 1 we compare both quenched and dynamical data for the quark mass function. For the comparison, we select a bare quark mass for the quenched case ($ma = 0.01$) and interpolate the dynamical mass function so that it agrees with the quenched result at the renormalization point, $q = 3$ GeV. The quark propagator is not strongly altered by the presence of sea quarks. The dynamical mass generation is somewhat supressed, the quark mass function at zero four-momentum being reduced by about 20% in the chiral limit. For a given bare quark mass, the running mass is larger in full QCD than in quenched QCD. The wavefunction renormalization function, Z, is

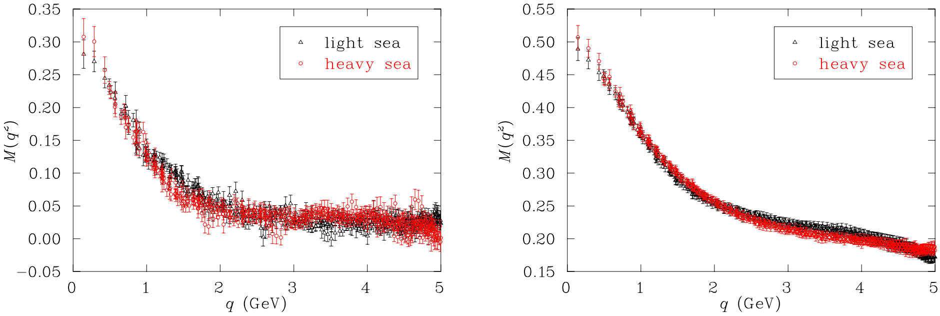

FIGURE 2. The unquenched quark mass function for the two different values of the light sea quark mass on the fine lattice (14.0 MeV and 27.1 MeV). The valence quark masses are $m = 14.0$ MeV (left) and $m = 135.6.$ MeV (right), the lightest and heaviest in our current sample respectively.

insensitive to changes in the bare quark mass for the cases studied here.

In Fig. 2 the valence quark mass is held fixed while the sea quark mass changes. Clearly the dependence over this small range of sea quark masses is weak. Unfortunately we only have two dynamical sets to compare, and for the lightest valence quark the data are rather noisy. We have studied the scaling behavior of quark propagator by working on two lattices with different lattice spacing but similar physical volume. We compared the wave-function renormalization function $Z(q^2)$ and mass function $M(q^2)$ for two lattices in Ref. [8]. The quark propagators are in excellent agreement,showing no observable dependence on the lattice spacing.

These results reflect the fact that quenched QCD is in some sense, “maximally non-abelian.” The quark loops compete with the self-interacting gauge field, screening the color charge and weakening – but by no means overcoming – confinement and chiral symmetry breaking. Furthermore, we find good scaling behavior for Asqtad fermions at a lattice spacing of $a = 0.125$ fm.

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