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SEA QUARK MATRIX ELEMENTS AND FLAVOR SINGLET SPECTROSCOPY ON THE LATTICE [a]

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I summarize the results of three recent lattice studies which use stochastic estimator techniques in order to investigate the flavor singlet dynamics in QCD. These include a measurement of the pion-nucleon σ-term, the computation of the flavor singlet axial coupling constant of the nucleon and a determination of flavor singlet meson screening lengths in finite temperature QCD.

1 Introduction

For many years, technical difficulties have prevented lattice gauge theorists from addressing questions related to the spectroscopy of flavor singlet mesons or the contribution of sea quarks to hadronic matrix elements. Fortunately, our recent computations [1,2,3] as well as those of other groups [4,5] show that this situation is currently changing. In this talk, I would like to present the results obtained so far and discuss the challenges which lie ahead. Three main points are emphasized: 1) Stochastic estimator techniques provide reliable tools to attack this kind of problems [6]. 2) Although the current studies remain relatively crude, they give results which are in good qualitative agreement with experiment or phenomenological expectations. 3) Measurements involving disconnected quark loops can be very sensitive to lattice artifacts and a full quantitative study will require the use of improved action and operators.

2 The pion-nucleon σ-term

It is well known that the value of the pion-nucleon σ-term can be extracted from pion-nucleon scattering experiments. However the measurement occurs at a non-zero value of the momentum transfer, namely at $q^2 = 2m_\pi^2$, whereas

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the physically interesting quantity is $\sigma_{\pi N}$ at $q^2 = 0$ (in particular, one has $\sigma_{\pi N}(q^2 = 0) = m_q \frac{\partial M_N}{\partial m_q}$). The question of the extrapolation to $q^2 = 0$ is therefore a rather important one. In general, one appeals to chiral perturbation theory at this stage and one finds that in this context $\sigma_{\pi N}(q^2 = 2m_\pi^2) =$ 60 MeV implies a zero momentum transfer value of $\sigma_{\pi N}(q^2 = 0) = 45$ MeV. Interestingly, on the lattice, the full scalar form factor of the nucleon can be computed and this procedure can therefore be tested. What we find is that the scalar form factor is harder than expected. In particular, one finds a difference of only 7 MeV instead of 15 MeV between the above two values of q^2. The difference between χPT and the lattice comes from the fact that χPT includes only the multi-pion exchange contributions and may miss the contributions of higher resonances in the short range part of the form factor. In our computation, we find evidence for these in the connected part of the scalar form factor whereas the disconnected part is mostly consistent with 2 pion exchange (see ref. [1] for details). Finally, on the lattice one can of course work directly at $q^2 = 0$ (i.e. revert the order of limits so that $q^2 \to 0$ before $m_q \to 0$). Both procedures give results which are consitent within errors and of the order of $\sigma_{\pi N} = 53$MeV.

3 The flavor singlet axial coupling constant of the nucleon

The problem of the "proton spin crisis" has attracted much attention in recent years. In it's simplest form, the question which is being asked is: what is the fraction of the spin of the nucleon which is carried by the spin of the quarks? This fraction is defined as:

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s \qquad \text{where} \qquad 2M_N \Delta q \; s_\mu = \langle N \uparrow | \; \bar{q}\gamma_\mu\gamma_5 q \; | \; N \uparrow \rangle$$

and s_μ is the polarization vector of the nucleon ($s_\mu^2 = 1$). In order to measure $\Delta\Sigma$ on the lattice, we therefore have to compute the matrix element of the axial vector current in a polarized nucleon. Our calculation was carried out on a lattice of size $16^3 \times 24$ at $\beta = 6.0$ in quenched QCD and gives the following results[2]. The sea quarks are found to be negatively polarized and give contributions which are essentially identical for u,d and s (i.e. the dependance in m_{sea} is very weak): $\Delta u_{sea} = \Delta d_{sea} = \Delta s = -0.12 \pm 0.01$. Putting these results together with the connected contributions, one finds $\Delta\Sigma = 0.25 \pm 0.12$ which agrees well with the current experimental "world average" ($\Delta\Sigma = 0.31 \pm 0.07$).

4 $U_A(1)$ at finite temperature

We have measured flavor singlet meson screening masses in finite temperature QCD. Our main motivation for this study is to investigate the breaking of the $U_A(1)$ symmetry by the axial anomaly in a finite temperature setting. In particular, we are interested in the transition between the low temperature regime where the η' gets its mass as a consequence of the axial anomaly to the high temperature regime where instantons form a very dilute gas and $U_A(1)$ is "effectively restored". At the same time, we want to see the relation between this and the chiral symmetry restoring phase transition. For this study we used the staggered fermion formulation which has the advantage of preserving a continuous subgroup of the full chiral symmetry group. Considering 2 quark flavors for simplicity, we compute the screening masses in 4 channels corresponding to the $\vec{\pi}$, σ, $\vec{\delta}$ and η' mesons. Chiral symmetry restoration will then be signaled by $m_{\vec{\pi}} = m_\sigma$ and $m_{\vec{\delta}} = m_{\eta'}$, whereas $U_A(1)$ restoration would imply: $m_\sigma = m_{\eta'}$ and $m_{\vec{\pi}} = m_{\vec{\delta}}$. Our main results are the following: We have performed the first[b] measurement of the scalar flavor singlet meson (σ) screening mass and have shown that it becomes light close to the transition. Above the phase transition, we find that at the value of the quark mass currently used (ma=0.00625) the $U_A(1)$ symmetry breaking is of the same order as the explicit breaking of chiral symmetry. We also find that in the high temperature phase, the disconnected part of flavor singlet correlators are saturated by the low lying fermionic modes and can in general be interpreted in terms of topological activity in the QCD vacuum[3].

5 Reducing the lattice artifacts

We have found that the details of the above computation are affected by artefacts associated with the finiteness of the lattice spacing a. These artefacts follow from the imperfectness of our "fixes" to the fermion doubling problem when $a \neq 0$ and therefore take slightly different forms whether we use Wilson fermions (section 2 and 3) or Kogut-Susskind fermions (section 4). For Wilson fermions, the problem is that doublers have masses of order $1/a$ and therefore only decouple in the continuum limit. When studying strange quarks on current lattices ($m_s a \simeq 0.1$) we have a situation where the lightest doubler is only ten times heavier than the particle we are interested in. This will inevitably create lattice artifacts in closed quark loops. In [7], we used trian-

[b] Earlier measurements which appeared in the literature considered only the connected part of the σ propagator and therefore should be reinterpreted as representing the $\vec{\delta}$ (scalar flavor triplet)

gle diagrams (i.e. lowest order disconnected contributions) to estimate these errors and proposed ma dependant correction factors to be used in Wilson fermion measurements of sea quark matrix elements. Since these correction factors are relatively large, the use of improved action and operators appears highly desirable in future simulations of this type (A first step in this direction was taken in [7] where it was shown that the 2-link Hamber-Wu action leads to smaller lattice artifacts in the triangle diagram). For staggered fermions, the remaining lattice artifacts are associated with flavor symmetry breaking. In our study of the $U_A(1)$ symmetry, the most damaging aspect of this problem is the zero-mode shift phenomenon studied by Smit and Vink [8], namely the fact that the Atiyah-Singer index theorem is not exactly satisfied on the lattice. The result is that configurations with non-zero topology often do not contribute to fermionic correlators as much as they should in the limit $m_q \to 0$ (because of the abscence of appropriate zero-mode(s).) This problem has been partly documented in [3] and improved action which would partially correct it are currently under study [9].

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