SU(2) Glueballs, diquarks and mesons in dense matter

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We present preliminary results from a high statistics study of 2-color QCD at low temperature and non-zero baryon density. The simulations are carried out on a $6^3 \times 12$ lattice and use a standard hybrid molecular dynamics algorithm for staggered fermions for two values of quark mass. Observables include glueball correlators evaluated via a multi-step smearing procedure as well as scalar and vector mesons and diquarks.

1. Motivation

The SU(2) QCD lattice theory has been recently reconsidered as a good starting point in order to get some insight into QCD phenomena at chemical potential $\mu$ and temperature different from zero. The main difficulty of the complex action once $\mu \neq 0$ is avoided adopting the color SU(2) group as in this case the determinant is real and standard hybrid Monte Carlo simulations are possible. As a general reference see \cite{1}.

In the following we discuss the scalar gluonic correlators constructed by the smearing technique \cite{2} in order to excite glueballs and compare their behavior with that of scalar mesons as a function of baryon density. The study of the pattern of chiral symmetry in the vector fermionic sector and of vector condensation signals is also addressed.

2. The simulation

The simulations were performed on $6^3 \times 12$ lattice using a standard hybrid molecular dynamics algorithm for staggered fermions \cite{3} at $\beta = 1.3$ for two quark masses: $m = 0.05$ and $m = 0.07$ and four values of the chemical potential: $\mu = 0.0, 0.2, 0.4, 0.6$. We performed 400000 steps saving configurations every 10 steps. We also performed 30000 steps for $m = 0.07$ and $\mu = 0.25, 0.30, 0.32, 0.35, 0.90$.

The glueball correlation functions have been obtained using the smearing procedure \cite{2} trying six values of the smearing weight: $w = 0.025, 0.05, 0.07, 0.1, 0.2, 0.3$ repeated recursively 1, 2, 3, 4 times (smearing steps). Our analysis is in progress and the data shown in the following are to be considered preliminary, more details will be given in \cite{4}. See ref. \cite{5} for recent result on glueballs at finite temperature. In Figs. 1 and 2 we show the good fluctuation reduction obtained by the smearing procedure; the glueball correlators and masses are plotted at $\mu \neq 0$ as a function of a combined smearing variable (steps times weight). The value of masses are obtained as logarithm of the glueball correlation ratios at different distances.

The general features of the results are monitored by the behavior of the particle number matrix element $\langle \bar{\psi} \gamma_0 \psi \rangle$ and of the chiral condensate $\langle \bar{\psi} \psi \rangle$ as a function of the chemical potential $\mu$. We find a clear signal of phase transitions at $\mu_c = 0.25$ for $m = 0.05$, and $\mu_c = 0.3$ for $m = 0.07$ in agreement with \cite{4}.

In Fig. 3 we show the behavior of the chiral susceptibility for the $\rho$ and the $A_1$ as a function
of $\mu$. After the phase transition the two states become degenerate, consistently with a vanishing chiral condensate. However, the behavior of our staggered propagators at finite density is different from the free-like one observed at high temperature, confirming the observations of [6].

The trend of Fig. 3 suggests that the $\rho$ becomes heavier, while the $A_1$ becomes lighter with density. The propagator themselves do not show any dramatic change, but, again their behavior suggests an heavier $\rho$ in the dense phase. Note that a recent study with Wilson fermions [7] reports instead a lighter $\rho$ in the medium. As spectrum’s qualitative features might well depend on the mass range, and on lattice artifacts, more work is needed before drawing general conclusions on the behavior of vector mesons in dense matter.

The vector diquark correlators do not show any hint of the predicted vector condensation [8], but the saturation effects might well hide this phenomenon (the $\rho$ mass at zero chemical potential was estimated to be $m_\rho \simeq 1.8$, hence the threshold $\mu_v = m_\rho/2$ is well inside the saturation region).

A sample of the results for the scalar sector is given in Fig. 4: the lower diagram shows the propagators, normalised to their zero distance value, for the pion, sigma, and scalar glueball in the normal phase; the pion (the Goldstone meson) is the lightest particle. In the superfluid phase (upper diagram) the sigma meson and the pion are degenerate, and heavier than the glueball. In addition, by contrasting lower and upper diagram we note that the glueball is lighter in the medium.

3. Summary

It is possible to measure glueball states at $\mu \neq 0$. The smearing procedure [2], already tested
in the theory with $\mu = 0$, increases very much the signal. The correlators at high density show the usual behavior.

In the vector sector we see the expected $\rho - A_1$ degeneracy at high density and we find a behavior clearly different from the high temperature one. The $\rho$ appears to be heavier in dense matter, at least for $m_q = 0.07$.

We find a different level ordering in the scalar sector after the phase transition: from $m_\pi < m_\sigma \sim m_{G^{00+}}$ at $\mu = 0.0$ to $m_{G^{00+}} < m_\sigma \sim m_\pi$ at $\mu = 0.4$.

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