Auxiliary field Monte-Carlo study of the QCD phase diagram at strong coupling

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in collaboration with
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Work in progress

- QCD phase diagram → HIC, Early Universe, Compact Stars, ...
- Lattice QCD at finite density
  → Taylor expansion, Imaginary $\mu$, Canonical, Reweighting, Fugacity expansion, Strong Coupling Lattice QCD, ...
- SC-LQCD study of phase diagram
  - Mean Field (Strong Coupling Limit, Finite Coupling Correction, ..)
  - Monomer-Dimer-Polymer simulation (Fromm, Unger, de Forcrand)
  - Auxiliary Field Monte-Carlo (present work)
Strong Coupling Lattice QCD

Pure YM

YM+Quarks (MF)

YM+Q+Fluc. (MDP) (SCL(1/g^2=0))

Kawamoto ('80), Kawamoto, Smit ('81), Damagaard, Hochberg, Kawamoto ('85), Bilic, Karsch, Redlich ('92), Fukushima ('03); Nishida ('03), Kawamoto, Miura, AO, Ohnuma ('07).

Miura, Nakano, AO, Kawamoto ('09)
Nakano, Miura, AO ('10)

Mutter, Karsch ('89), de Forcrand, Fromm ('10), de Forcrand, Unger ('11)

Challenge: YM+Q+Fluc.+Finite Coupling Effects

de Forcrand, Fromm, Langelage, Miura, Philipsen, Unger ('11), AO, Nakano, Ichihara (in prep.)

Ohnishi @ NTFL (Feb. 17, 2012)
**Auxiliary Field MC in SC-LQCD**

- Strong coupling expansion in the strong coupling limit \((1/g^2=0)\)
- \(1/d\) expansion + link integral
- Bosonization (Extended Hubbard-Stratonovich transf.)
- Monte-Carlo Integral over Auxiliary Fields \((\sigma_{MC})\)

\[
S_{\text{eff}} = \frac{L^3 N}{4 N_c g^2} \sum_{k, f_M(k) > 0} f_M(k) \left[ \sigma_k^* \sigma_k + \pi_k^* \pi_k \right] - \sum_x \log R(x)
\]

\[
R(x) = X_N(x)^3 - 2 X_N(x) + 2 \cosh(3 N \tau \mu) \quad \text{(local Fermion determinant)}
\]

\[
X_N = 2 \cosh \left[ \arcsinh \left( \frac{d \sigma}{2 N_c + m_0} \right) \right] \quad \text{(for const. } \sigma, \pi \text{)}
\]

- \(X_N(x)\) = easily calculated from \(\sigma(x)\) and \(\pi(x)\) (complex).
- Imaginary part \((\pi)\) involves \(\varepsilon_x \rightarrow \) Phase cancellation for low \(k\).
- Sign problem is less severe at larger \(\mu\).
- Extension to Finite Coupling is straightforward.

\[\varepsilon=1\] \[\varepsilon=-1\]
Phase diagram

σMC results of phase diagram

- Sign problem is weak in small lattice.
- PhDF & Fromm & Unger results are confirmed qualitatively!

Come to my talk Next Week