Chiral and deconfinement transitions in strong coupling lattice QCD with finite coupling and Polyakov loop effects *

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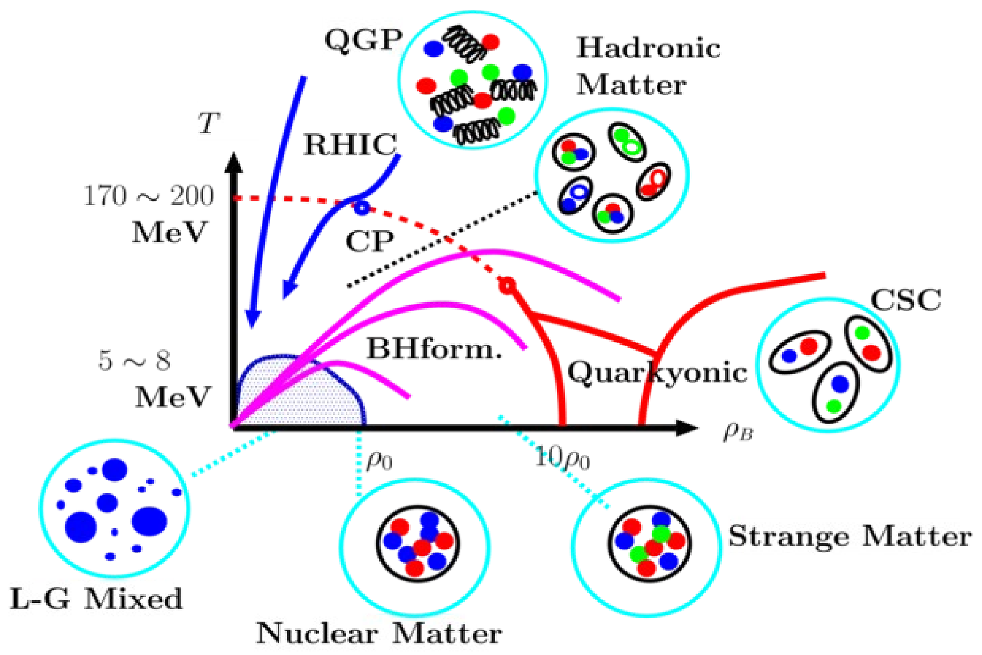
Introduction

- **QCD phase diagram is of great interest !**
  - **Transition at high T → Lattice MC, RHIC, LHC**
  - **High μ transition has rich physics**
    → Various phases, CEP, Astrophysical applications, …



- **Approaches to Dense QCD Matter**
  - **Perturbative QCD → Applicable only to high T or μ**
  - **Lattice QCD → Sign Problem**
  - **Eff. Models (NJL [1], PNJL [2], PQM [3], …)**
    →Model & Par. deps.
  - ***Strong Coupling Lattice QCD***
    - **Strong coupling expansion & U_j integral**
      → Sign problem is weak and applicable to large μ region !
    - **Successes in pure Yang-Mills [4],**
      Chiral transitions [5], Deconf. transitions [6,7].
- **No work on self-consistent description of chiral and deconf. transitions with finite coupling effects based on SC-LQCD.**

> ***We develop SC-LQCD framework including both Finite Coupling & Polyakov loop effects Polyakov loop extended SC-LQCD (P-SC-LQCD), and discuss chiral and deconf. transitions.***

Polyakov loop extended Strong Coupling Lattice QCD

- **Lattice action → Eff. potential**
  - **Strong coupling ($1/g^2$) expansion**
    (NNLO in with quarks [8], LO in Polyakov loop [6,7])
  - **Large dimensional (1/d) expansion (LO)**
  - **Mean Field Approx. (static and constant aux. fields)**

Lattice QCD action
S_{LQCD} (χ, χ^{bar}, U_0, U_j)

↓ ***$1/g^2$ expansion and U_j integral***

Eff. action
S_{eff} (χ, χ^{bar}, U_0)

↓ ***Bosonization [9]***

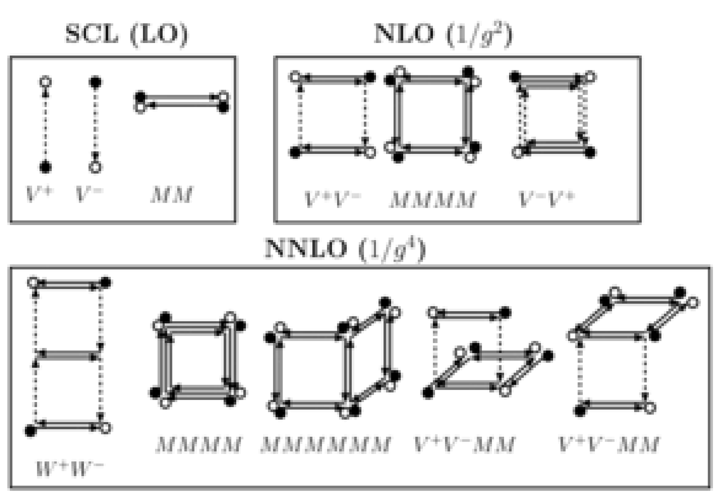
Eff. action (bi-linear in χ)
S_{eff} (χ, χ^{bar}, U_0, σ, ℓ, $ℓ^{bar}$, ω, ...)

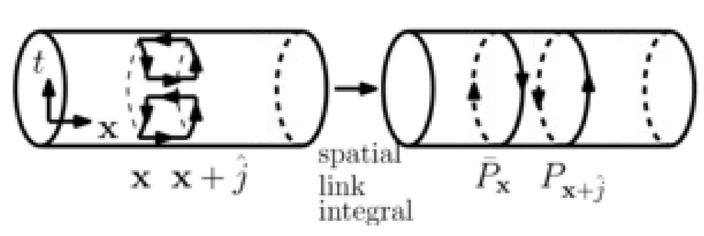
↓ ***quark det. (& U_0 integral)***

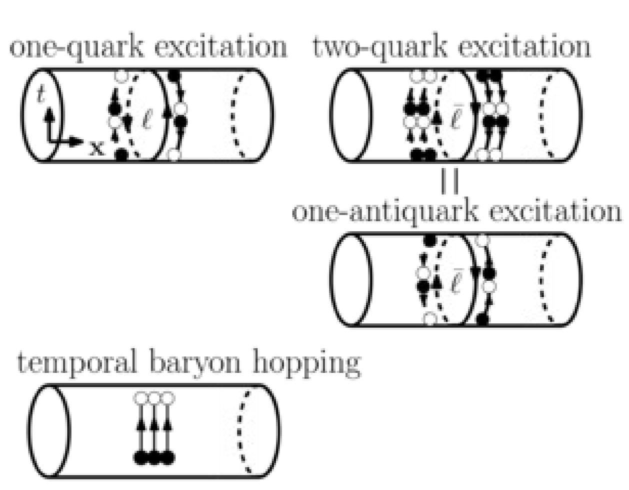
Eff. potential
F_{eff} (σ, ℓ, $ℓ^{bar}$, ω, ...)

↓ ***Min. Search***

Equilibrium
σ(T, μ), ℓ(T, μ), ...







- **Eff. Potential (in Haar measure method)**

$$F_{\text{eff}}=F_q(\Phi;\mu,T)+U_g(l,\bar{l};T)+F_{\text{eff}}^{(X)}(\Phi)$$

$$F_q=-N_cE_q-T\log R(E_q-\tilde{\mu},N_cl,N_c\bar{l})-T\log R(E_q+\tilde{\mu},N_c\bar{l},N_cl)$$

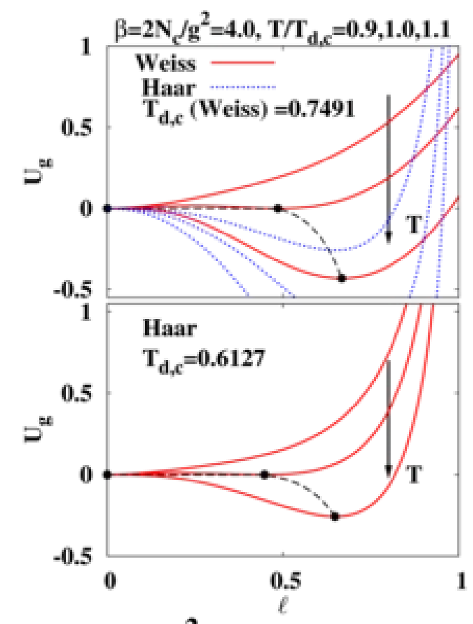
$$R(x,L,\bar{L})=1+L\exp(-x/T)+\bar{L}\exp(-2x/T)+\exp(-3x/T)$$

$$U_g=-2T\beta_P\bar{l}l-T\log\left[1-6\bar{l}l+4(l^3+\bar{l}^3)-3(\bar{l}l)^3\right]$$

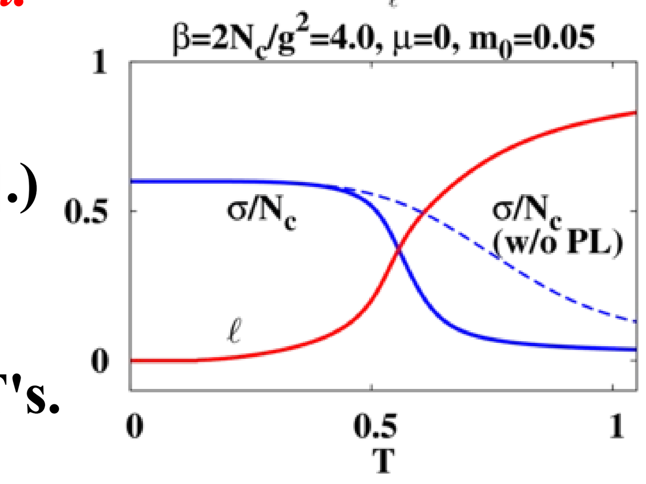
*** T.Z.Nakano, K. Miura, A. Ohnishi, [arXiv:1009.1518]**

Chiral and Deconf. Transitions in P-SC-LQCD

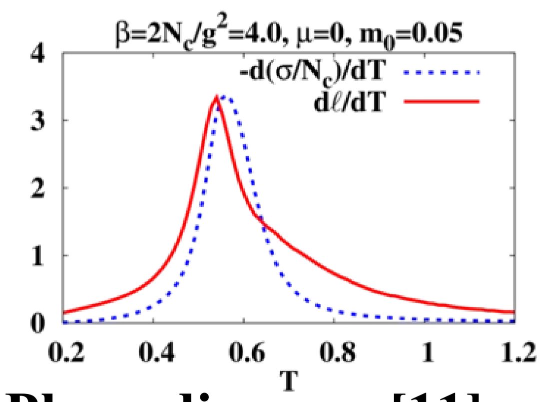
- **Effective Potential of the Polyakov loop**
  - **Haar measure method [6]**
    → log(Haar measure) as the potential
    (No U_0 integral)
  - **Bosonization method [7]**
    → Perform U_0 integral after bosonization
    (Weiss mean field approximation)

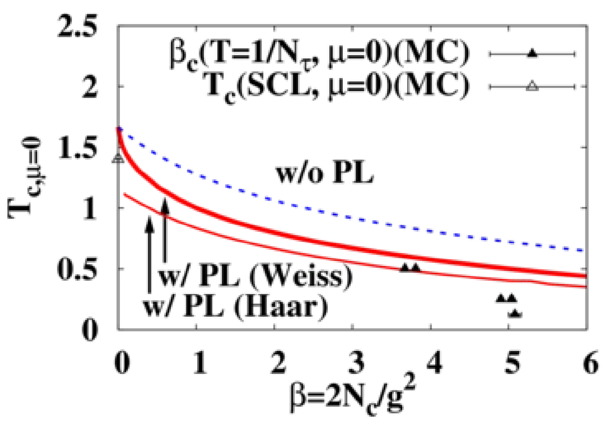


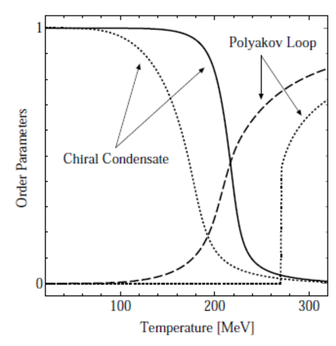
- **Chiral cond. and Polyakov loop (μ=0)**
  - **Chiral and Deconf. transition correlate !**
  - ***SC-LQCD w/o PL: quarks are confined.***
    → PL promote quarks to deconfine !
    (cf. Quarks are *not* confined in NJL
    → PL *confines* quarks in PNJL [2].)
  - **T_c is suppressed by PL**



- **Transition Temperature at μ=0**
  - **-dσ/dT, dℓ/dT are peaked at similar T's.**
  - **Improved from SC-LQCD w/o PL.**
  - **Quantitatively, not bad for β < 4 in T_c (β_c) [10]**

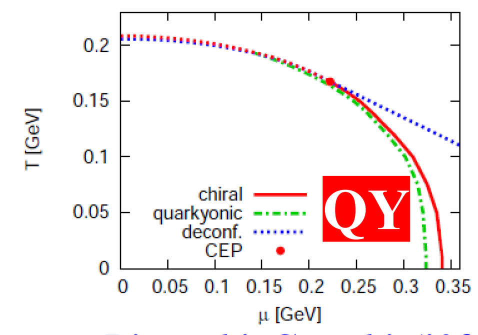




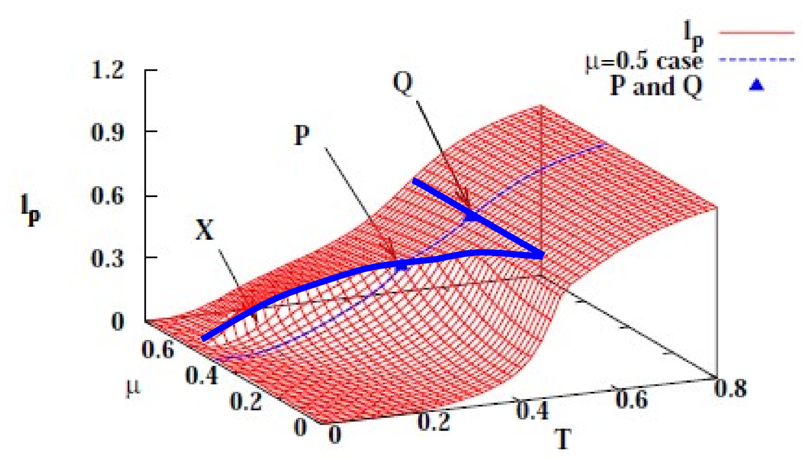


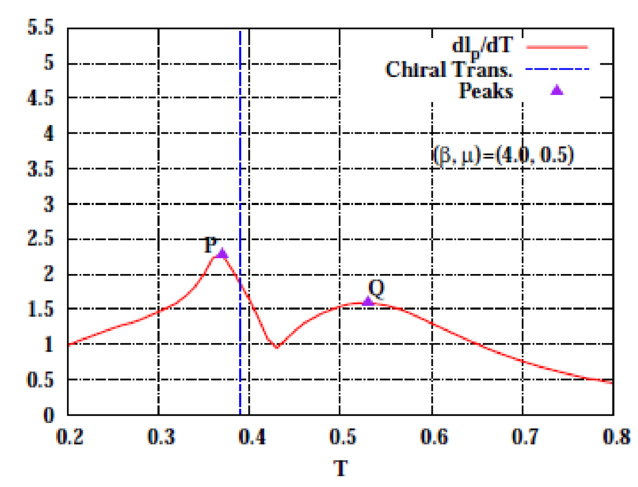
Fukushima ('04)

- **Phase diagram [11]**
  - **Separated chiral & deconf. boundaries at finite μ**
    → Quarkyonic matter [12]
    would be measurable from two peak structure of dℓ/dT !



McLerran, Pisarski, Sasaki ('09)





Summary

- **SC-LQCD framework is extended to include finite coupling and Polyakov loop effects (P-SC-LQCD).**
  - **Two order parameters (chiral cond. & Polyakov loop) are included on the same footing based on QCD.**
  - **Mixed strong coupling expansion orders.**
    → Double expansion in fermionic and pure YM parts.
- **Chiral & Deconf. transitions are discussed in P-SC-LQCD.**
  - **Chiral transition temperature is suppressed by Polyakov loop in P-SC-LQCD.**
  - **MC results on chiral transition T are roughly reproduced for $\beta_g = 2N_c/g^2 \leq 4$.**
  - **The existence of Quarkyonic matter is supported, and may be measurable via the behavior of the Polyakov loop.**
- **Future works**
  - **Improvement: $1/g^2$, 1/d, mean field, staggered fermions.**
  - **Model construction based on P-SC-LQCD.**

[1] Y. Nambu, G. Jona-Lasinio, PR122('61)345; T.Hatsuda, T. Kunihiro, PRep247('94) 221. [2] K.Fukushima, PLB591('04)277; S.Roessner, C.Ratti, W.Weise, PRD75('07) 034007. [3] B.J. Schaefer, J.M.Pawlowski, J.Wambach, PRD76('07)074023;V.Skokov, B.Friman, E. Nakano, K.Redlich, B.J. Schaefer, PRD82('10)034029. [4] K.G.Wilson, PRD10('74)2445; G. Munster, NPB180('81),23. [5] N. Kawamoto, J. Smit, NPB192('81) 100; P.H.Damgaard, N. Kawamoto, K. Shigemoto, PRL53('84)2211. [6] E.M.Ilgenfritz, J. Kripfganz, ZPC29('85) 79; A.Gocksch, M.Ogilvie, PRD31('85)877. [7]J.B.Kogut, M.Snow, M.Stone, NPB200('82) 2311. [8] T.Z.Nakano, K.Miura, AO, PTP123('10)825. [9] K.Miura, T.Z.Nakano, AO, N.Kawamoto, PRD80('09)074034; K.Miura, T.Z.Nakano, AO, PTP122('09)1045. [10] Ph. de Forcrand, M. Fromm, PRL104('10)112005; S.A. Gottlieb et al. PRD35('87)3972; M. D'Elia, M.P.Lombardo, PRD67('03)014505; Z.Fodor, S.D.Katz, JHEP03('02)014; R. Gavai et al.[MT(c) Collab.], PLB241('90)567. [11] K. Miura, T.Z.Nakano, AO, N.Kawamoto, PoS(Lat10)202. [12] L.McLerran, R.D.Pisarski, NPA796('07)83; Y.Hidaka, L.McLerran, R.D.Pisarski, NPA808('08)117.