Explanation for baryon mass puzzle in strong coupling lattice QCD

K. Miura, N. Kawamoto, and A. Ohnishi

YITP

7/15(Tue), 2008, Talk at Lattice Conference 2008

References

- Miura, Kawamoto, and Ohnishi, to appear in PTP. Suppl.
- Miura and Ohnishi, arXiv:0806.3357 [nucl-th].
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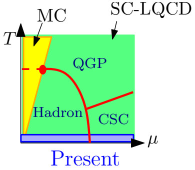
SC-LQCD



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2. No sign problem.
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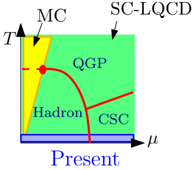

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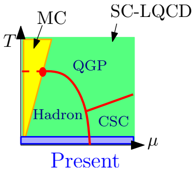

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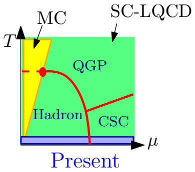

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Baryon Mass Puzzle (Forcrand,Kim ('07))

- **Naive Estimate:** $N_c \mu_c \sim M_B$

Damgaard,Kawamoto,Shigemoto ('85)

- **In Real World:** $N_c \mu_c > M_B$
- **SC-LQCD:** $N_c \mu_c < M_B$, $(c.f.\ (N_c \mu_c,\ M_B) \simeq (1.7 - 1.8,\ 3.0)$ in SC-LQCD)
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Baryon Mass Puzzle=Discrepancy between SC-LQCD results and Naive estimates

Questions

- What's the origin of the *Baryon Mass Puzzle* in the strong coupling limit?
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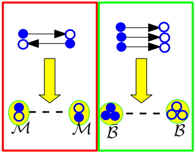
Outline of Analyses (SCLim case)

$$Z = \int_{\chi,\bar{\chi},U_0,U_j} \exp[-S_F^{(\tau)} - S_F^{(s)} - \cancel{S_G}]$$

$\bar{\chi} \xrightarrow{e^{\mu}U_0} \chi$ $\quad$ $\bar{\chi} \xrightarrow{U_j} \chi$ $\quad$ $1/g^2$

Link $(\mathbf{U_0},\ \mathbf{U_j})$integral

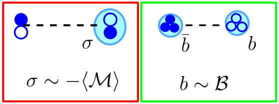


$$Z = \exp[-S_{eff}[\mu, \underline{\mathcal{M}_x \mathcal{M}_{x+\hat{\nu}}},\ \underline{\bar{\mathcal{B}}_x \mathcal{B}_{x+\hat{\nu}}}]$$

Consider the Next to Leading of $1/d$ expansion (Kluberg-Stern,Morel,Petersson,('83))

Mean field approximation

$\int \mathcal{D}[\chi,\bar{\chi}]$



$$S_{eff}[\mu,\sigma,b,\bar{b}] \xrightarrow{\int \mathcal{D}[\mathbf{b},\bar{\mathbf{b}}]} \mathcal{F}_{eff}(\mu,\sigma)$$

Pole search of $(b,\bar{b})$

minimum search

$$M_B(\bar{\sigma}) \xleftarrow{\text{input}} \bar{\sigma}(\mu)$$

Effective Potential & Baryon Mass

- **Effective potential**

$$\mathcal{F}_{eff}(\mu,\sigma) = \frac{N_c}{d+1}\sigma^2 - \sum_{\mathbf{p}} \begin{cases} E_B(\mathbf{p},\sigma) & (E_B \geq N_c\mu) \\ N_c\mu & (E_B \leq N_c\mu) \end{cases} \tag{1}$$

The baryon loop effects are explicitly evaluated and we obtained an "Upgraded Version" of the previous work (Damgaard,Kawamoto and Shigemoto ('85))

- **Baryon excitation energy**

$$E_B(\mathbf{p},\sigma) = \sinh^{-1}\left[\sqrt{\sum_j \sin^2 p_j + 16(\sigma+m_0)^{2N_c}}\right] \tag{2}$$

$$\rightarrow M_B(\sigma) \quad (\text{ignoring } p_j) \tag{3}$$

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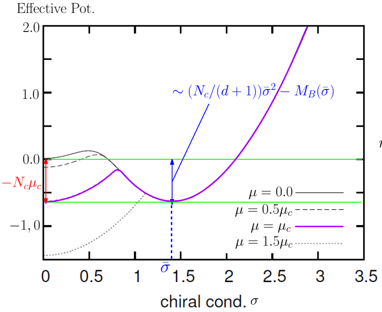
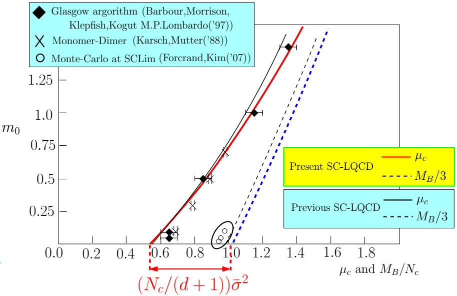
Origin of Baryon Mass Puzzle in SCLim.





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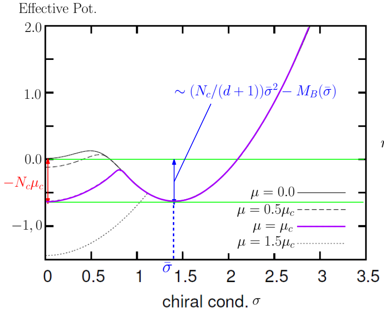

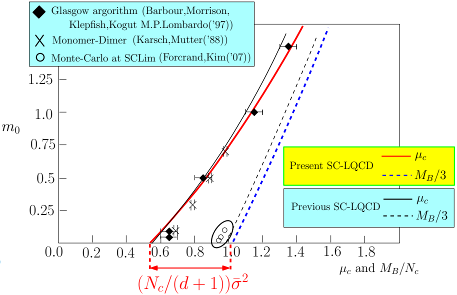

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Fermion mass puzzle in SCLim

Fermion mass puzzle

- Similarly we encounter the quark mass puzzle at the finite T treatment ($m_q > \mu_c$).
- Thus the fermion ($\ni$ baryon) mass puzzle may be the artifact of the strong coupling limit. It is natural to consider that the strong coupling expansion can solve this problem.
- We have found that the plaquette effect leads to the dynamical shift of the chemical potential ($\mu \rightarrow \tilde{\mu}$) in the finite T treatment (*c.f.* Today Poster A (Miura) Wed. 14:50-15:10 (Ohnishi)). Its apprication to the baryon mass puzzule is quite interesting.

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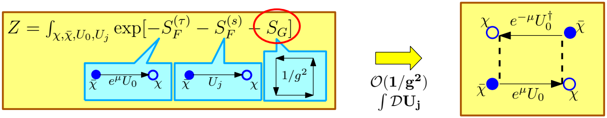

- **New kind of mean field**

$$\phi_\tau = -\frac{1}{2}\langle e^{\mu}\bar{\chi}_x U_{0,x}\chi_{x+\hat{0}} + e^{-\mu}(h.c.)\rangle \tag{6}$$

- **Dynamical shift of μ**

$$\mu \to \tilde{\mu} = \mu - \frac{d}{(N_c g)^2}\phi_\tau \tag{7}$$

- **Stationary condition of $\mathcal{F}_{\text{eff}}(\mu, \sigma, \phi_\tau)$**

$$\phi_\tau = \rho_q(\sigma) \quad \text{(quark density)} \tag{8}$$

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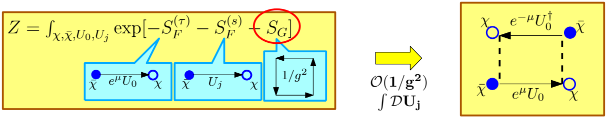

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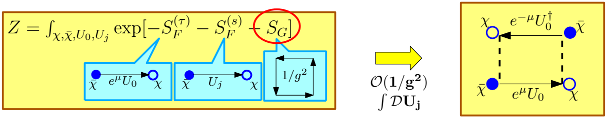

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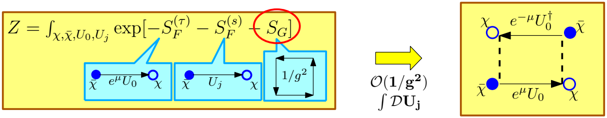

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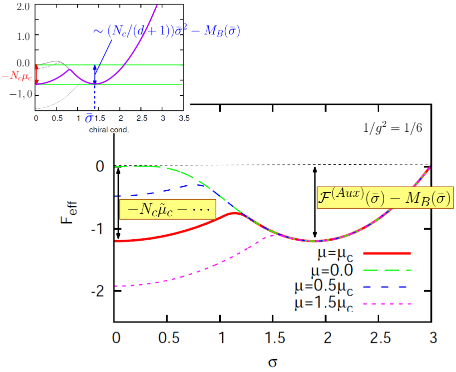
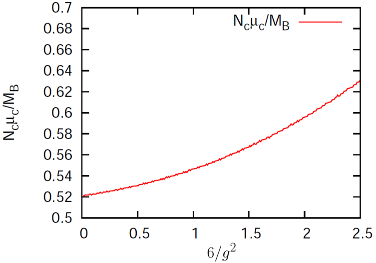
Relation between M_B and $N_c\mu_c$ with Finite $1/g^2$





$$-N_c\tilde{\mu}_c - \cdots = \mathcal{F}^{(Aux)}(\bar{\sigma}) - M_B(\bar{\sigma}) \tag{9}$$

$$\tilde{\mu}_c = \mu_c - \frac{d}{(N_c g)^2} N_c \tag{10}$$

Summary

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- We attacked the *Baryon Mass Puzzle* by utilizing the strong coupling lattice QCD.
- We precisely investigated the baryon loop effects in the strong coupling limit, and found that the existence of chiral condensates at the vacuum led to the *Baryon Mass Puzzle*.
- We demonstrated that the *Vector Meson-like Field* which came from Plaquette could modify the relation between M_B and $N_c\mu_c$, but it was not enough to solve the *Baryon Mass Puzzle*.

Future works

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- Complete solution of the Baryon Mass Puzzle?
- Reasonable density property in SC-LQCD?
- Sign problem?