# 格子QCDの強結合展開に基づく NNLOにおける有効ポテンシャルの評価

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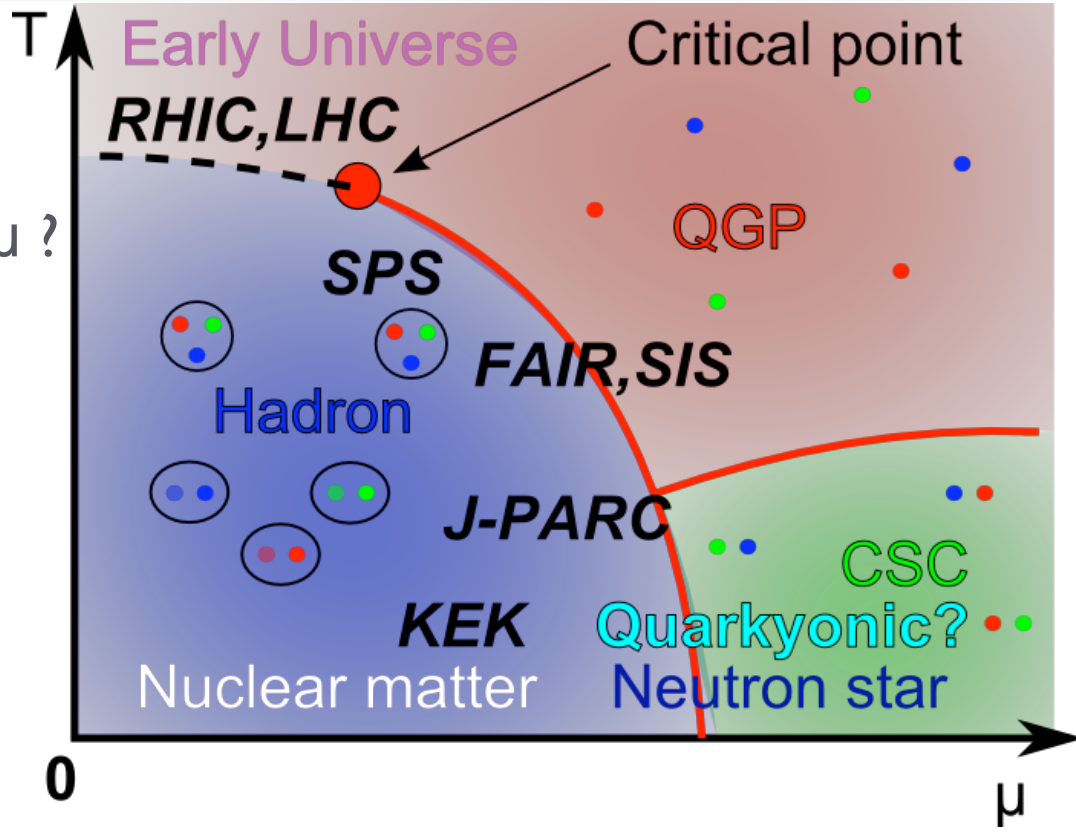
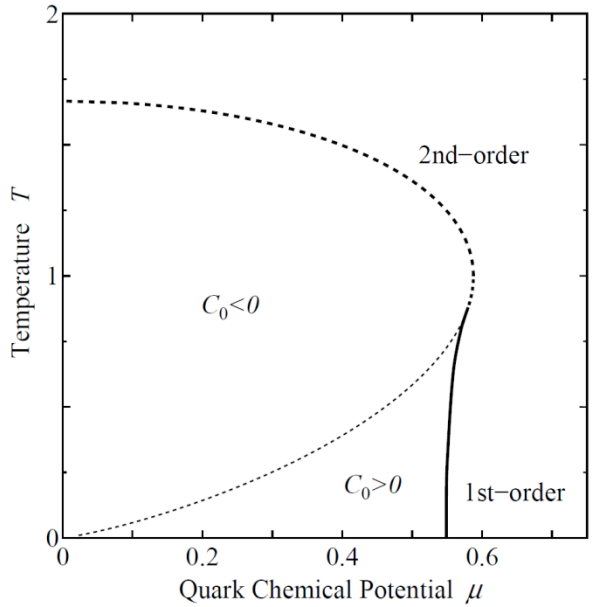
- QCD phase diagram
  - Where is the critical point ?
  - What phase appear in high μ ?

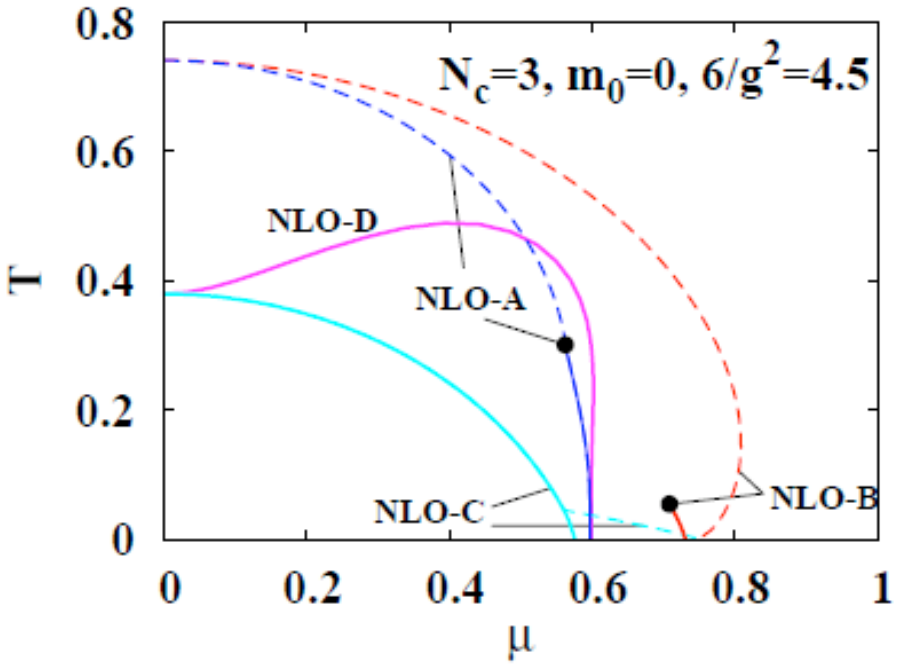


# 格子QCDの強結合展開

- $1/g^2$ expansion
- Sign problem can be weakened or avoided ⇔ MC simulations
- SCL➔NLO➔NNLO




K. Fukushima (2004)



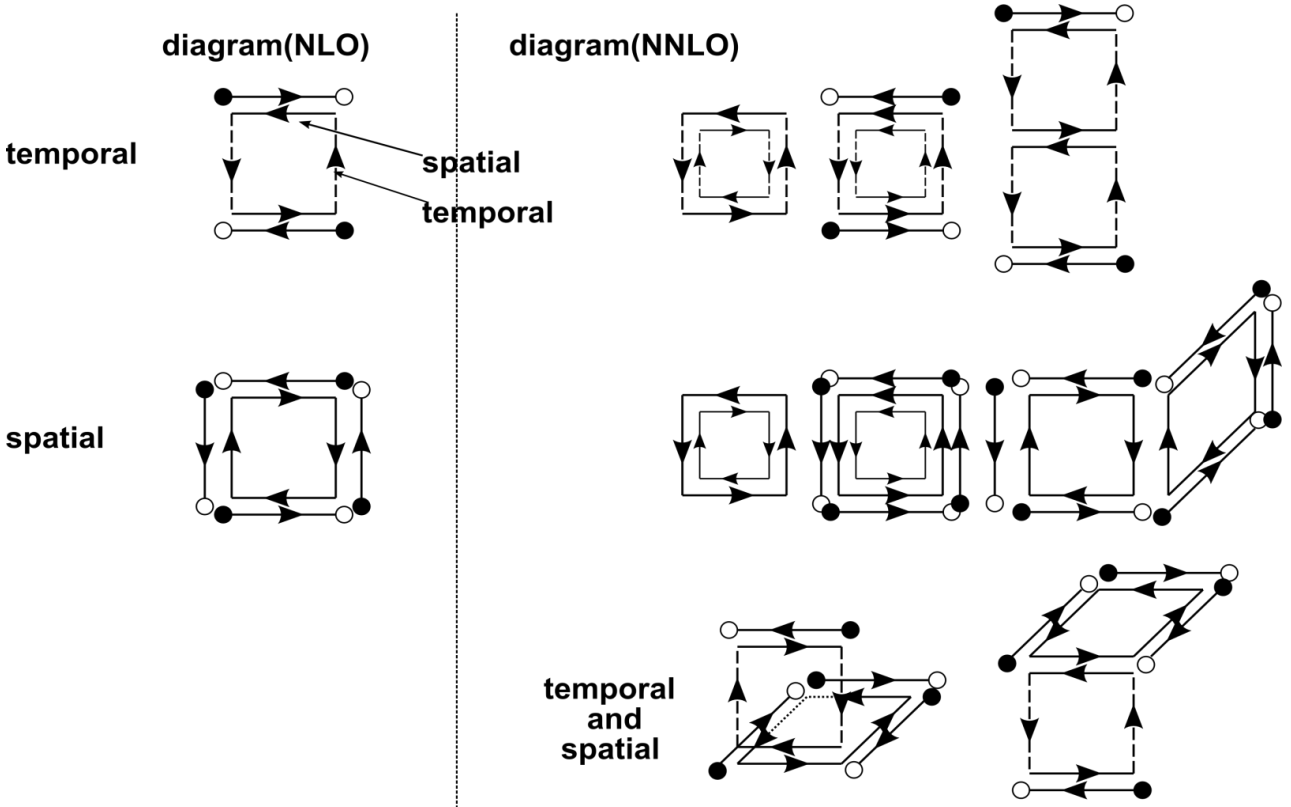

K. Miura, T. Z. N and A.Ohnishi (2009)

- Finite T, μ全体を網羅したQCD phase diagram

  ➔NNLO($1/g^4$)までの寄与を考慮した有効ポテンシャルを求める。

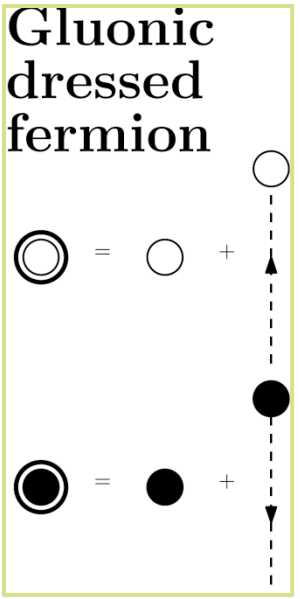
# Diagram(NNLO;$1/g^4$)

- Systematicにdiagramsを評価。
  - NLO➔1つのプラケット, NNLO➔2つのプラケット
  - プラケット(□)にフェルミオン(●→○, ○ ← ● )をはりあわせる。



# 有効ポテンシャル(NNLO;$1/g^4$)

- NLO, NNLOの効果➔SCLの形に繰りこむことができる。
  - Modification of $m_q$, μ and $Z_\chi$ ,and a gluonic dressed fermion
- Chiral condensate(σ)とquark number density($\omega_\tau$)の関数
  - Muti-order parameters




auxiliary fields　quark sector

Effective potential

$$\mathcal{F}_{eff}(\sigma,\omega_\tau;T,\mu)=\mathcal{F}^{(X)}_{eff}(\sigma,\omega_\tau)+\mathcal{V}_q(m_q;\tilde{\mu},T)-N_c\log Z_\chi$$

Effective potential ( auxiliary fields )

$$\mathcal{F}^{(X)}_{eff}=\frac{1}{2}\tilde{b}_\sigma\sigma^2+\frac{1}{2}\beta_s\sigma^4+2\beta_{ss}\sigma^6+\frac{1}{2}(\beta_t+2\beta_{ts}\sigma^2)(\varphi_\tau^2-\omega_\tau^2)$$
$$+\beta_{\tau\tau}(4(Z_\chi m_q)^2(\varphi_\tau^2-\omega_\tau^2)-4Z_\chi m_q\varphi_\tau\sigma+\sigma^2)+\beta_{\tau s}\sigma^2(\varphi_\tau^2-\omega_\tau^2)$$

Modification of $m_q$, $\tilde{\mu}$, $Z_\chi$

quark mass

$$m_q=\frac{\tilde{b}_\sigma\sigma+m_0+2\beta_{\tau\tau}\sigma}{(1+4\beta_{\tau\tau}\varphi_\tau)Z_\chi}$$

shift of chemical potential

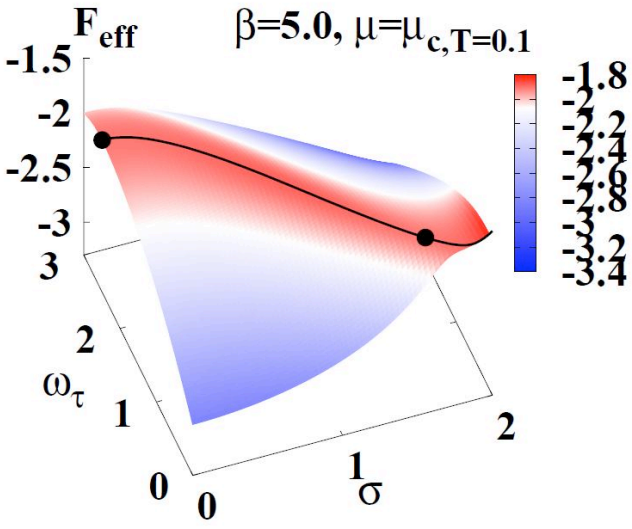
$$\tilde{\mu}=\mu-\log\sqrt{Z_+/Z_-}$$

wave function renormalization factor

$$Z_\chi=\sqrt{Z_+Z_-}$$

where

$$Z_\pm=1+(\beta_\tau+2\beta_{\tau s}\sigma^2)(\varphi_\tau\pm\omega_\tau)+4\beta_{\tau\tau}Z_\chi m_q(2Z_\chi m_q(\varphi_\tau\pm\omega_\tau)-\sigma)$$
$$\tilde{b}_\sigma=b_\sigma+2\beta_s\sigma^2+6\beta_{ss}\sigma^4+2\beta_{\tau s}(\varphi_\tau^2-\omega_\tau^2)$$



# Results: $T_c$, $\mu_c$, QCD phase diagram and CP

- $T_{c,,\mu=0}$ ,$\mu_{c,T=0}$ → ≒NLO
- CP → sensitive to NNLO effects
- Partially chiral restored phase が存在