Quark Propagators at the confinement and deconfinement phases

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Main Results

* Quark propagators have negative norm contributions at confinement phase.
* This feature remains at deconfinement phase.

Introduction

Quark propagator

→ Quark confinement

→ Chiral symmetry breaking

Quark propagators relate to two phase transitions in QCD.

Quark confinement

Pole mass, Asymptotic state

Chiral symmetry breaking

Order parameter: $\langle \psi(0)\bar{\psi}(x) \rangle_{x \to 0}$

Introduction2

At finite temperature

low	high
Quark : confined	Quark : deconfined
Chiral symmetry : breaking	Chiral symmetry : restored

How do behaviors of quark propagators change?

Do quark propagators have no pole at confinement phase and one or some pole(s) at deconfinement?

Formulation

Quark propagator

$$G(x,y) = \langle \psi(x)\bar{\psi}(y)\rangle = \langle W^{-1}(x,y;U)\rangle$$

$$S_f = \sum_{x,y} \bar{\psi}(x) W(x,y;U) \psi(y)$$

in our calculations, Clover fermion

Time-time correlation function

$$G(x_4 - y_4) = \langle \psi(x_4)\bar{\psi}(y_4)\rangle = \sum_{\vec{x},\vec{y}} \langle W^{-1}(x,y;U)\rangle$$

when $\vec{p} = 0$

$$G(t) = G_4(t)\gamma_4 + G_s(t)$$

Formulation2

Time-time correlation function(One pole case)

$$G(t) = \frac{Z_1}{2V\cosh(m\beta/2)}\left[\cosh(m(t-\beta/2))\gamma_4 - \sinh(m(t-\beta/2))\right]$$

Effective mass

$$\frac{G_4(t)}{G_4(t+1)} = \frac{\cosh(m(t-\beta/2))}{\cosh(m(t+1-\beta/2))}$$

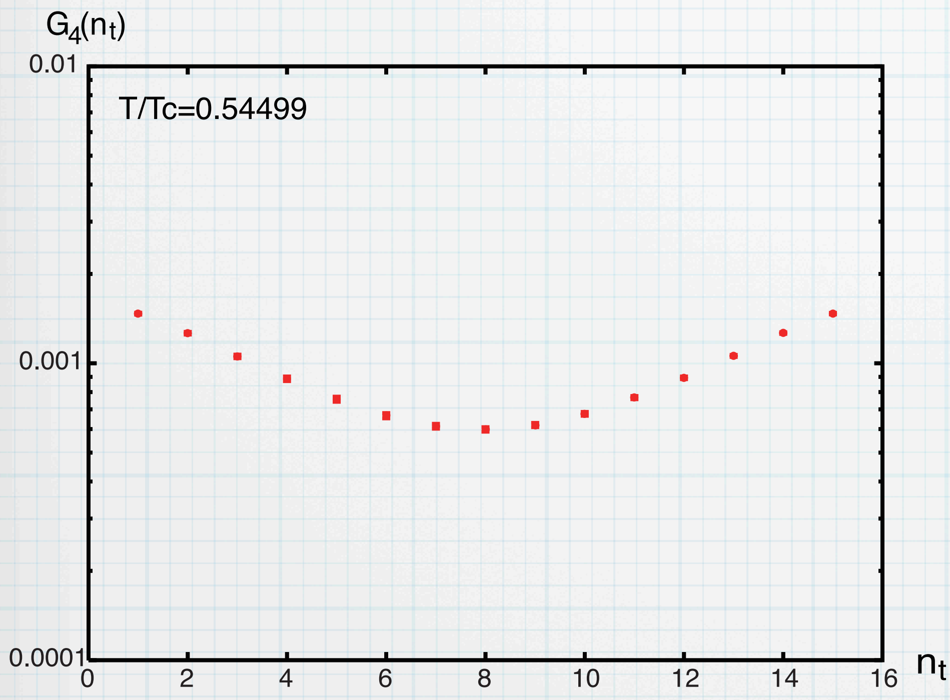
$$\frac{G_s(t)}{G_s(t+1)} = \frac{\sinh(m(t-\beta/2))}{\sinh(m(t+1-\beta/2))}$$

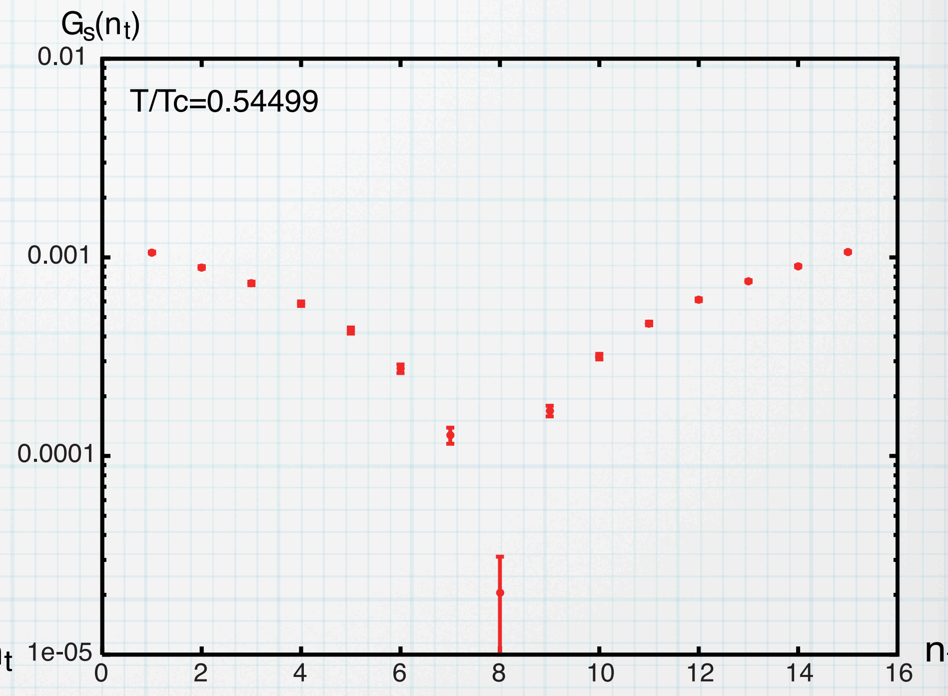
Numerical Conditions

* Quenched approximation
* Plaq. gauge action + Wilson fermions with Clover
* Gauge Fixing : Landau Gauge
* Thermalization : 1000
* Sweeps between measurements : 1000
* # of Configuration : 20 - 50
* beta = 6.10, kappa = 0.1345559, 0.1353591
* beta = 6.25, kappa = 0.1346226, 0.1352633
* Confinement phase : Nt = 16, Ns = 24, 32
* Deconfinement phase : Nt = 8, Ns = 24, 32

Numerical Result 1

Time-time correlation function at confinement phase

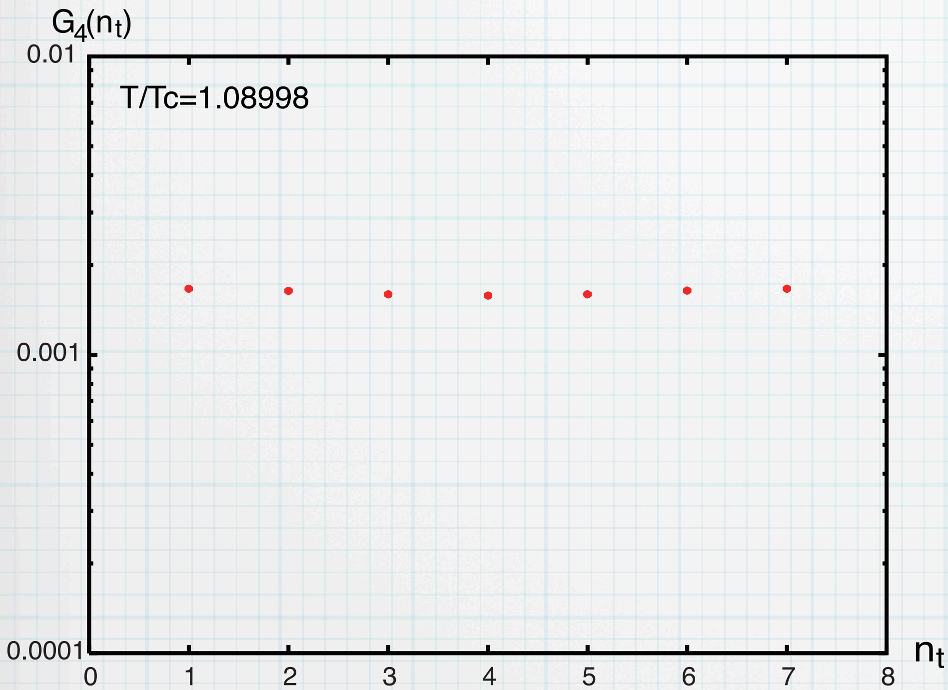


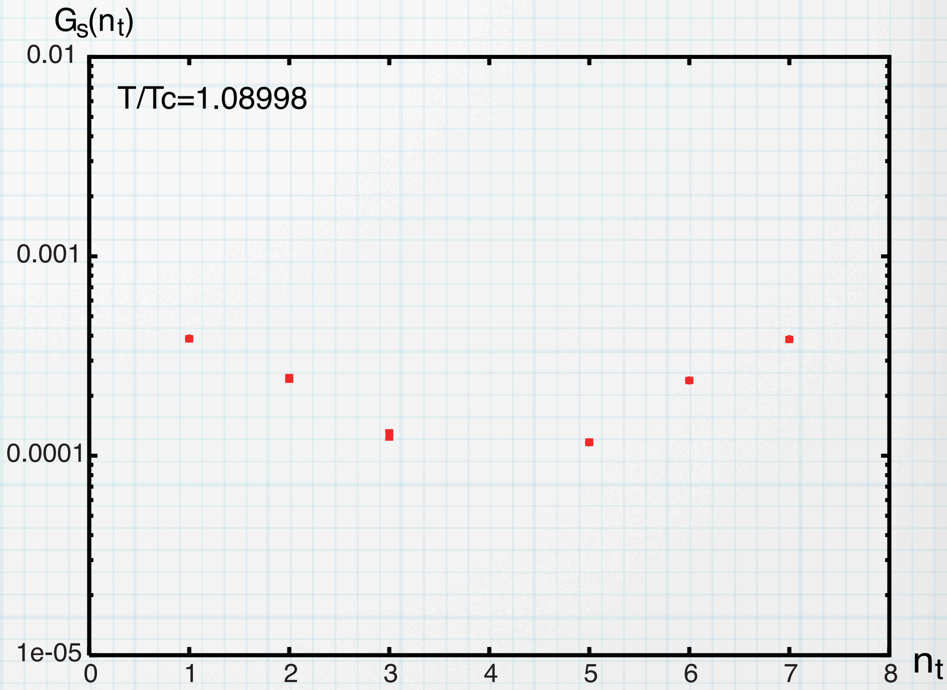


- beta = 6.10, kappa = 0.1345559
- Nt = 16, Ns = 24

Numerical Result 2

Time-time correlation function at deconfinement phase

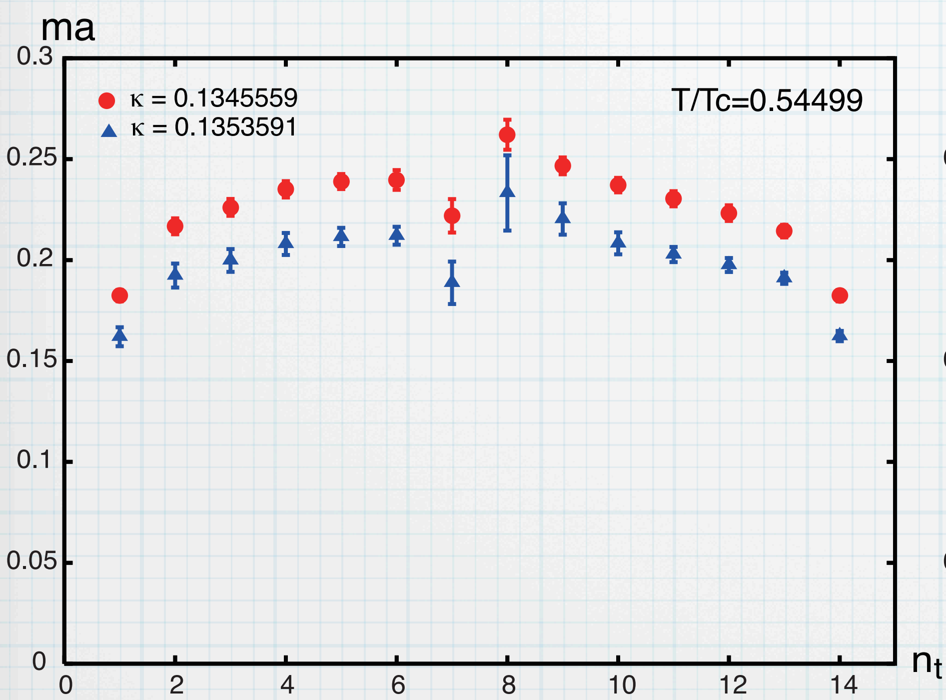


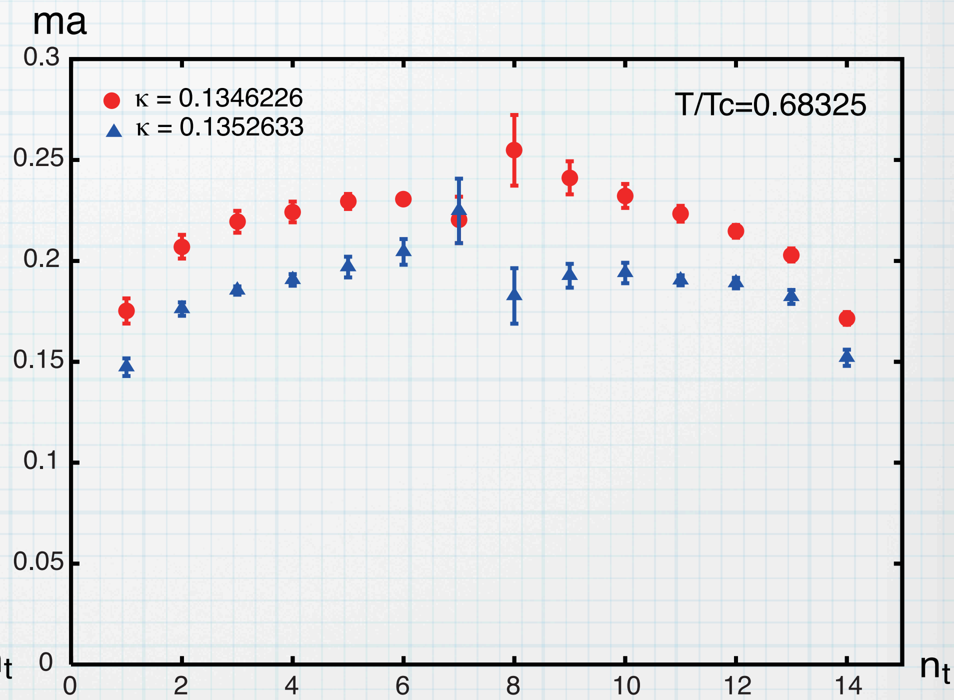


- beta = 6.10, kappa = 0.1345559
- Nt =8, Ns = 24

Numerical Result 3

Effective mass at confinement phase





- beta = 6.10
- Nt = 16, Ns = 24

- beta = 6.25
- Nt = 16, Ns = 24

For details

$$G(t) = \rho_1 e^{-m_1 t} + \rho_2 e^{-m_2 t} \qquad (m_1 < m_2)$$

$$m_{\text{eff}} = \ln \frac{G(t)}{G(t+1)} = \ln \frac{\rho_1 e^{-m_1 t}}{\rho_1 e^{-m_1 (t+1)}} = m_1 \qquad (t \to \infty)$$

$$m'_{\text{eff}} = \ln \frac{G(t)}{G(t+1)} = \ln \frac{\rho_1 e^{-m_1 t} + \rho_2 e^{-m_2 t}}{\rho_1 e^{-m_1 (t+1)} + \rho_2 e^{-m_2 (t+1)}}$$

$$= m_1 + \ln \frac{1 + \frac{\rho_2}{\rho_1} e^{-(m_2 - m_1)t}}{1 + \frac{\rho_2}{\rho_1} e^{-(m_2 - m_1)(t+1)}} \qquad (t \to 0)$$

$$\frac{\rho_2}{\rho_1} > 0 \;\Rightarrow\; \frac{1 + \frac{\rho_2}{\rho_1} e^{-(m_2 - m_1)t}}{1 + \frac{\rho_2}{\rho_1} e^{-(m_2 - m_1)(t+1)}} > 1 \;\Rightarrow\; m_{\text{eff}} < m'_{\text{eff}}$$

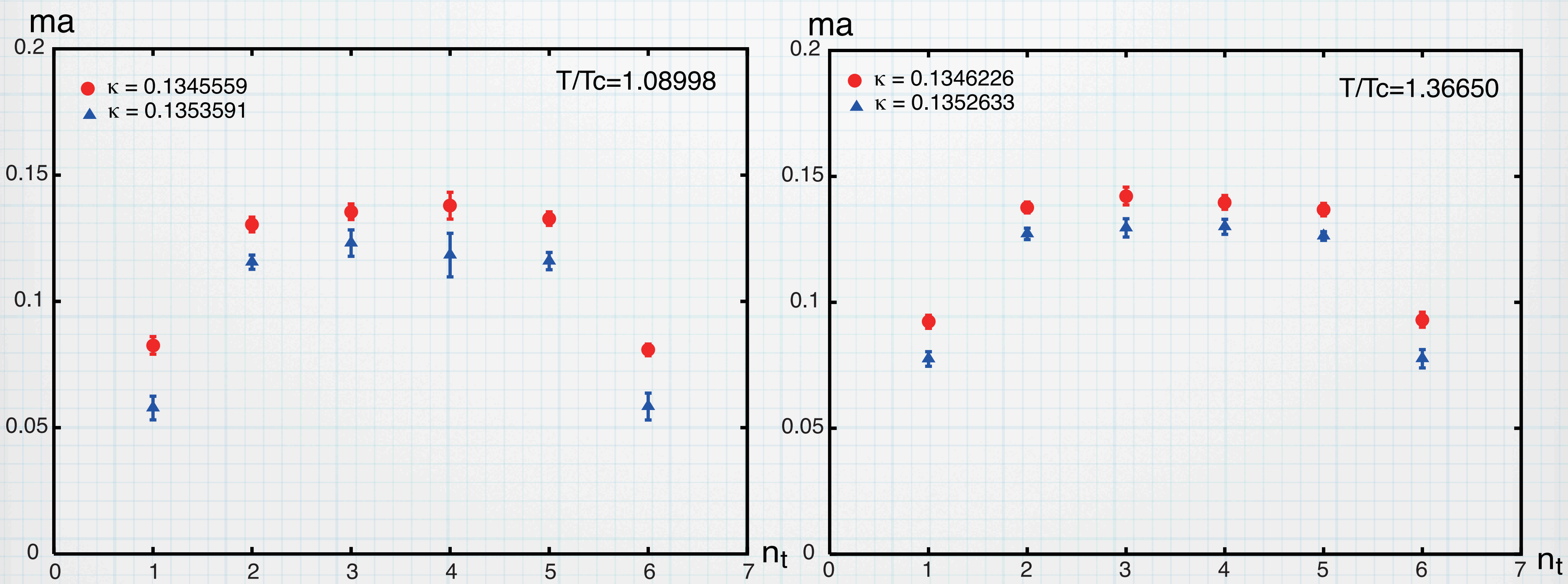
$$\frac{\rho_2}{\rho_1} < 0 \;\Rightarrow\; \frac{1 + \frac{\rho_2}{\rho_1} e^{-(m_2 - m_1)t}}{1 + \frac{\rho_2}{\rho_1} e^{-(m_2 - m_1)(t+1)}} < 1 \;\Rightarrow\; m_{\text{eff}} > m'_{\text{eff}}$$

namely *violation of positivity*. If a certain degree of freedom has negative norm contributions in its propagator, it cannot describe a physical asymptotic state, *i.e.* there is no Källén–Lehmann spectral representation for its propagator.

R. Alkofer, W. Detmold, C. S. Fischer, P. Maris, Phys.Rev. D70 (2004) 014014.

Numerical Result 4

Effective mass at denfinement phase

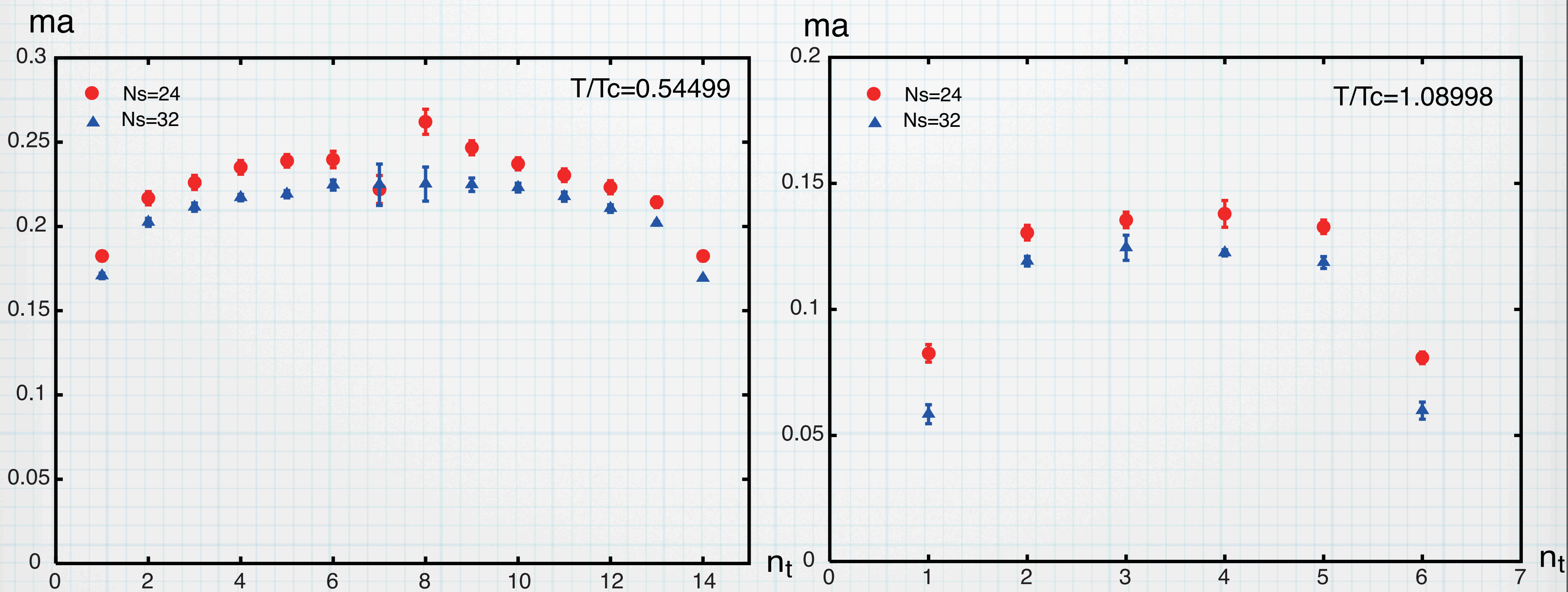


- beta = 6.10
- Nt = 8, Ns = 24

- beta = 6.25
- Nt =8, Ns = 24

Numerical Result 5

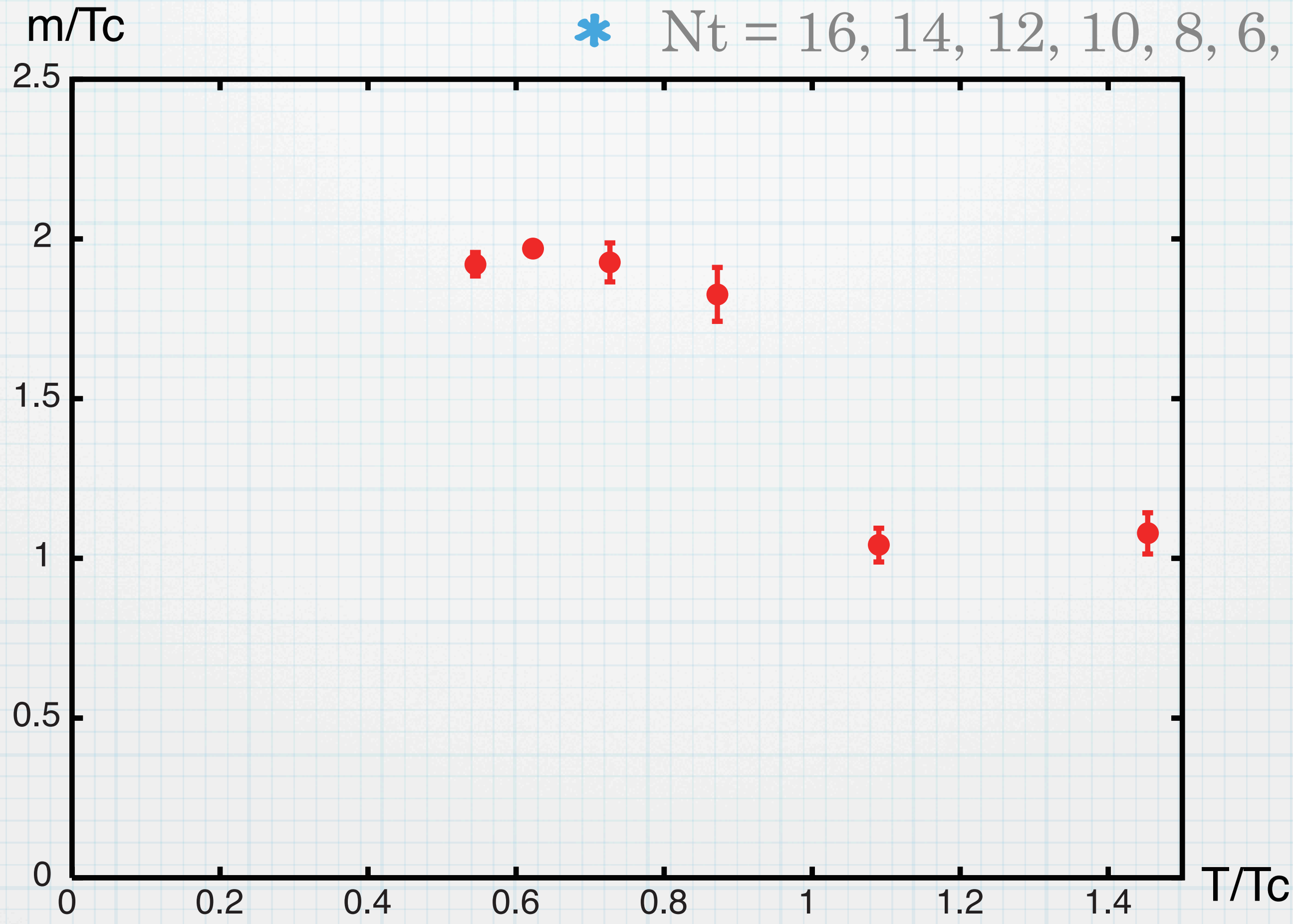
Volume dependence of effective mass



- beta = 6.10, kappa = 0.1345559

Numerical Result 6

Temperature dependence of quark mass



- Nt = 16, 14, 12, 10, 8, 6, Ns = 32
- beta = 6.10, kappa = 0.1345559

Summary

* Effective mass shows that quark propagators include negative norm state.
* This feature remains at deconfinement phase.
* We can not fit the scalar part of time-time correlation functions.
* These behavior do not depend quark mass or spatial volume.
* Effective mass at confinement phase twice larger than it at deconfinement phase.