Exploring for a light composite scalar in eight flavor QCD

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Outline

- **Introduction**
- **Lattice calculation**
- **Result**
- **Summary**

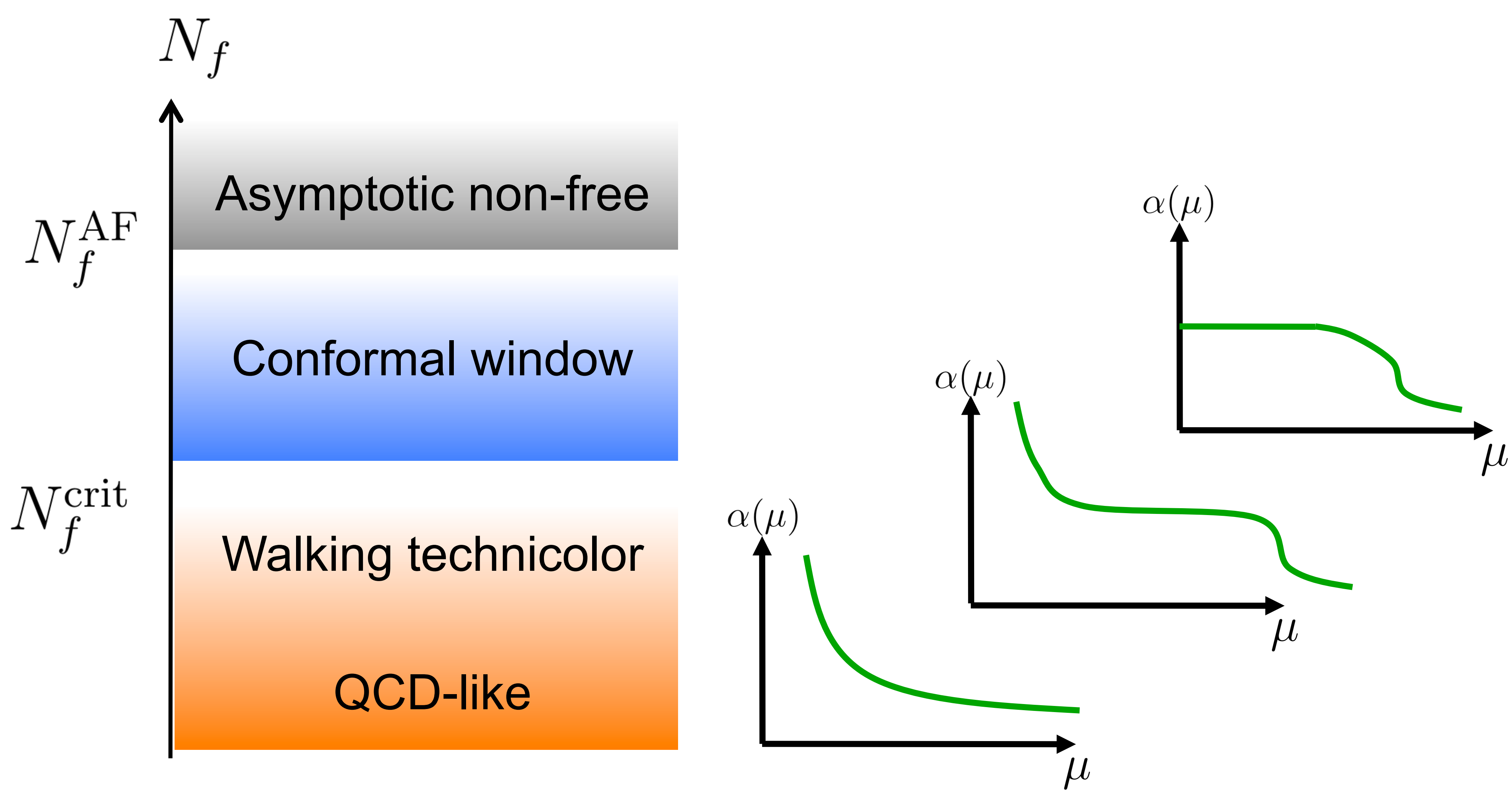
Introduction

"Higgs boson"

- Higgs like particle (126 GeV) has been found at LHC.
- Consistent with the Standard Model Higgs. But true nature is so far unknown.
- Many candidates for beyond the SM.

  one interesting possibility

  – **(walking) technicolor**
    - "Higgs" = dilaton (pNGB) due to breaking of the approximate scale invariance



Nf=8 QCD is a candidate of walking gauge theory

From the previous talk given by K. Nagai, we found

- ChPT-like behavior of pion mass and decay constant in small mass region (mf ≦ 0.04)
  -> consistent with chiral broken phase

- hyperscaling behavior in mf ≧ 0.04 with large anomalous dimension
  -> showing the approximate scale invariance

It is important to investigate the mass of a flavor singlet scalar (0++), since it can be regarded as a techni-dilaton (Higgs in the SM), which is a pseudo Nambu-Goldstone boson of the spontaneous scale symmetry.

c.f.

In the conformal phase, flavor singlet scalar can be light due to the infrared conformality. [Miransky, '96]

For the flavor singlet scalar in Nf=12 QCD [arXiv1305.6001, latKMI],

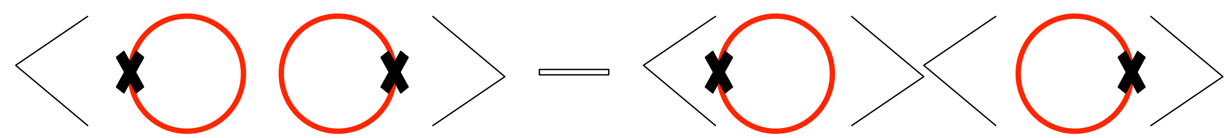
talks by E. Rinaldi and T. Yamazaki.

Lattice calculation
of
flavor singlet scalar

Flavor singlet scalar from fermion bilinear operator

$$C_\sigma(t) = \langle \sum_i^{N_f} \bar{\psi}_i\psi_i(t) \sum_j^{N_f} \bar{\psi}_j\psi_j(0)\rangle = N_f(-C(t) + N_f D(t))$$

$$\mathcal{O}_F(t) \equiv \bar{\psi}_i\psi_i(t), \qquad D(t) = \langle \mathcal{O}_F(t)\mathcal{O}_F(0)\rangle - \langle \mathcal{O}_F(t)\rangle\langle \mathcal{O}_F(0)\rangle$$



<u>Staggered fermion case</u>

- Scalar interpolating operator can couple to two states of

$$(\mathbf{1} \otimes \mathbf{1}) \ \& \ (\gamma_4\gamma_5 \otimes \xi_4\xi_5)$$

  - 0+(non-singlet scalar) : $C(2t)_+ \rightarrow a_0(\text{continuum limit})$
  - 0-(scPion) : $C(2t)_- \rightarrow \text{scPion (continuum limit)}$

$$C_\pm(2t) \equiv 2C(2t) \pm C(2t+1) \pm C(2t-1)$$

- Flavor singlet scalar can be evaluated with disconnected diagram.

$$C_\sigma(2t) = -C_+(2t) + 2D_+(2t)$$

<u>(8 flavor) = 2 × (one staggered fermion)</u>

Calculation of disconnected diagrams

- Measurement of Random source propagator

$$D\phi(x) = \eta(x_0), \qquad \langle \eta(x)\eta^\dagger(y)\rangle = \delta_{x,y}$$

for this noise vector, we use stochastic gaussian sources.

- Noise reduction technique for staggered fermion

(use of Ward-Takahashi identity[Kilcup-Sharpe, '87, Venkataraman-Kilcup '97])

simple method : $D^{-1}(x,y) = \langle \eta^\dagger(x)\phi(y)\rangle$

noise reduction method: $D^{-1}(x,y) = \langle m_f \phi(x)\phi^\dagger(y)\rangle$
(|x-y| =even)

O(10) times efficient in computational cost

This was already applied to Nf=12 QCD scalar measurements
at strong coupling region[Jin-Mawhinney; PoS 2011]
and at hyperscaling region [LatKMI, 2013]. Details -> talk by T. Yamazaki

Simulation setup

- SU(3), Nf=8

- HISQ (staggered) fermion
and tree level Symanzik gauge action

Volume (= L^3 x T)
- L =18, T=24
- L =24, T=32
- L =30, T=40

Bare coupling constant ($\beta = \frac{6}{g^2}$)
- beta=3.8

bare quark mass
- mf= 0.02-0.1,
  (5 masses)

- high statistics (shown in table)

L	T	mf	#confs
18	24	0.04	5600
		0.06	9000
		0.08	7500
		0.10	8500
24	32	0.04	3400
		0.06	14000
		0.08	3600
30	40	0.02	7900

- Use of 64 noise sources for each gauge configuration

Lattice results of Scalar in Nf=8

- All results are preliminary.

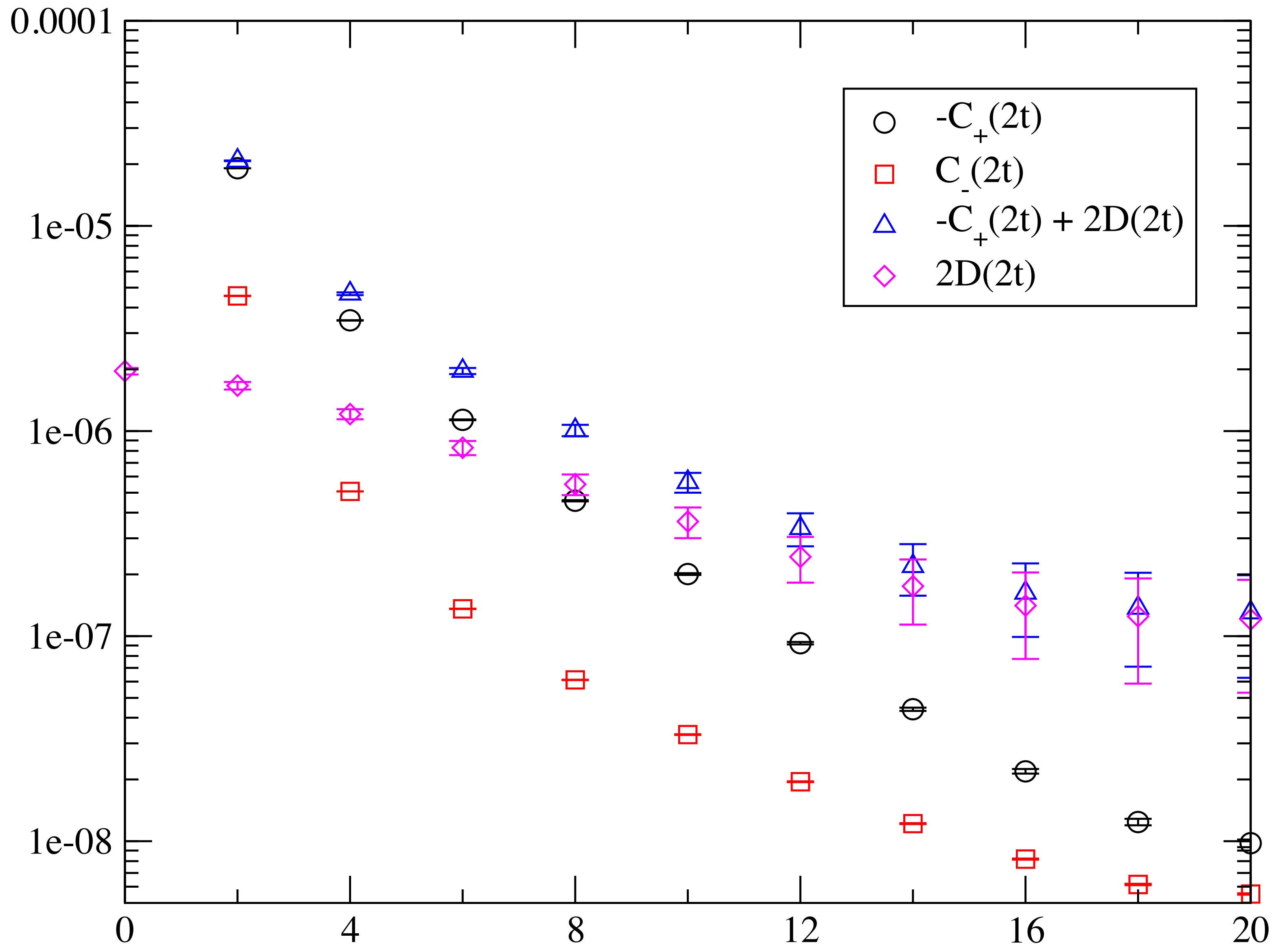
scalar correlator, L=30, T=40, β=3.8, mf=0.02

$$0^+(a_0)\ : C_+(2t) = 2C(2t) + C(2t+1) + C(2t-1)$$

$$0^-(\mathrm{scPion})\ : C_-(2t) = 2C(2t) - C(2t+1) - C(2t-1)$$

$$0^+(\sigma)\ : C_\sigma(2t) = -C_+(2t) + 2D_+(2t)$$ ←Full singlet scalar correlator

$$0^+\ : 2D_+(2t)$$ ←Disconnected part of singlet scalar correlator

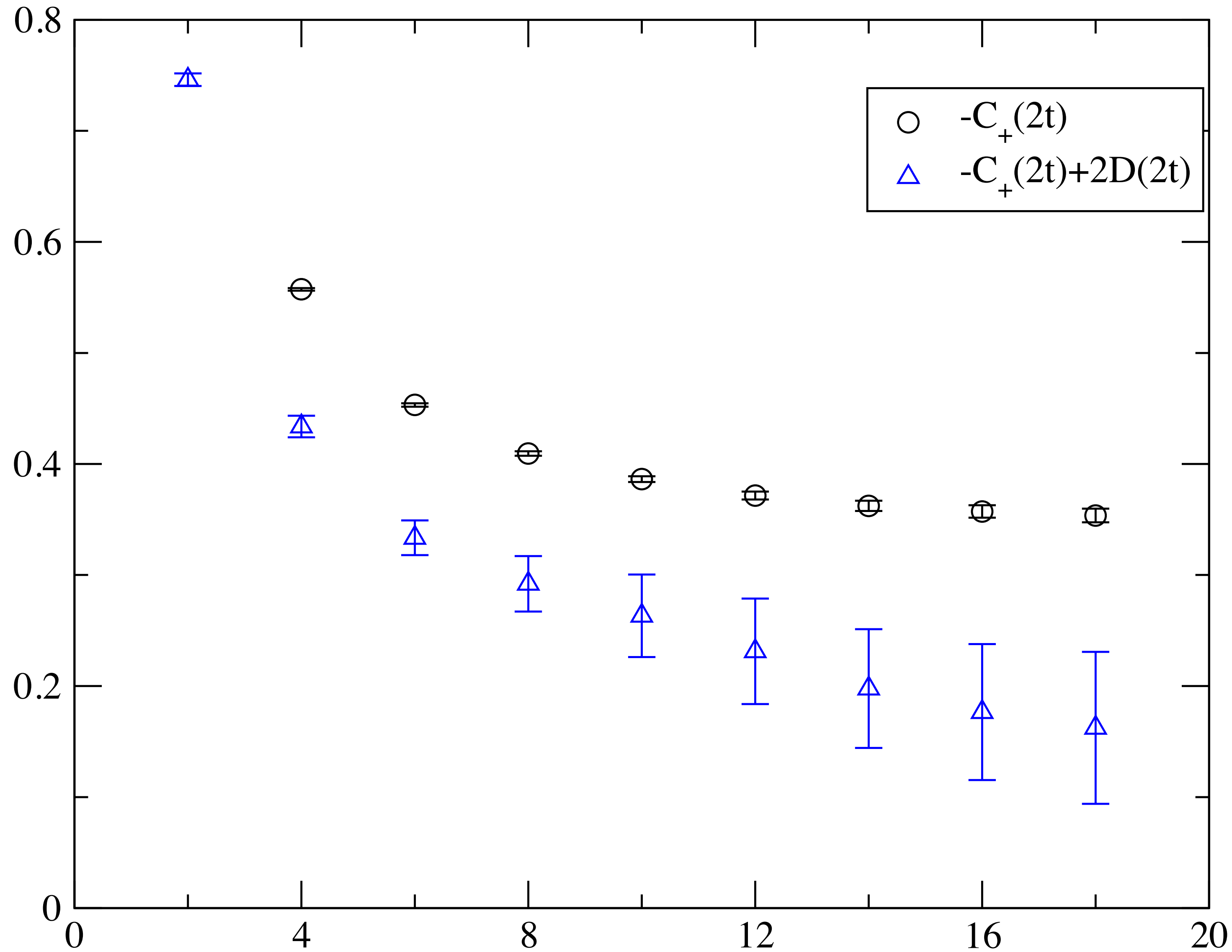


D(2t) dominates full scalar correlator at large time separation.

scalar effective mass , L=30, T=40, β=3.8, mf=0.02

$$0^+(a_0)\ :C_+(2t) \to A_{a_0} e^{-m_{a_0} 2t}$$

$$0^+(\sigma)\ :C_\sigma(2t) = -C_+(2t) + 2D_+(2t) \to A_\sigma e^{-m_\sigma 2t}$$



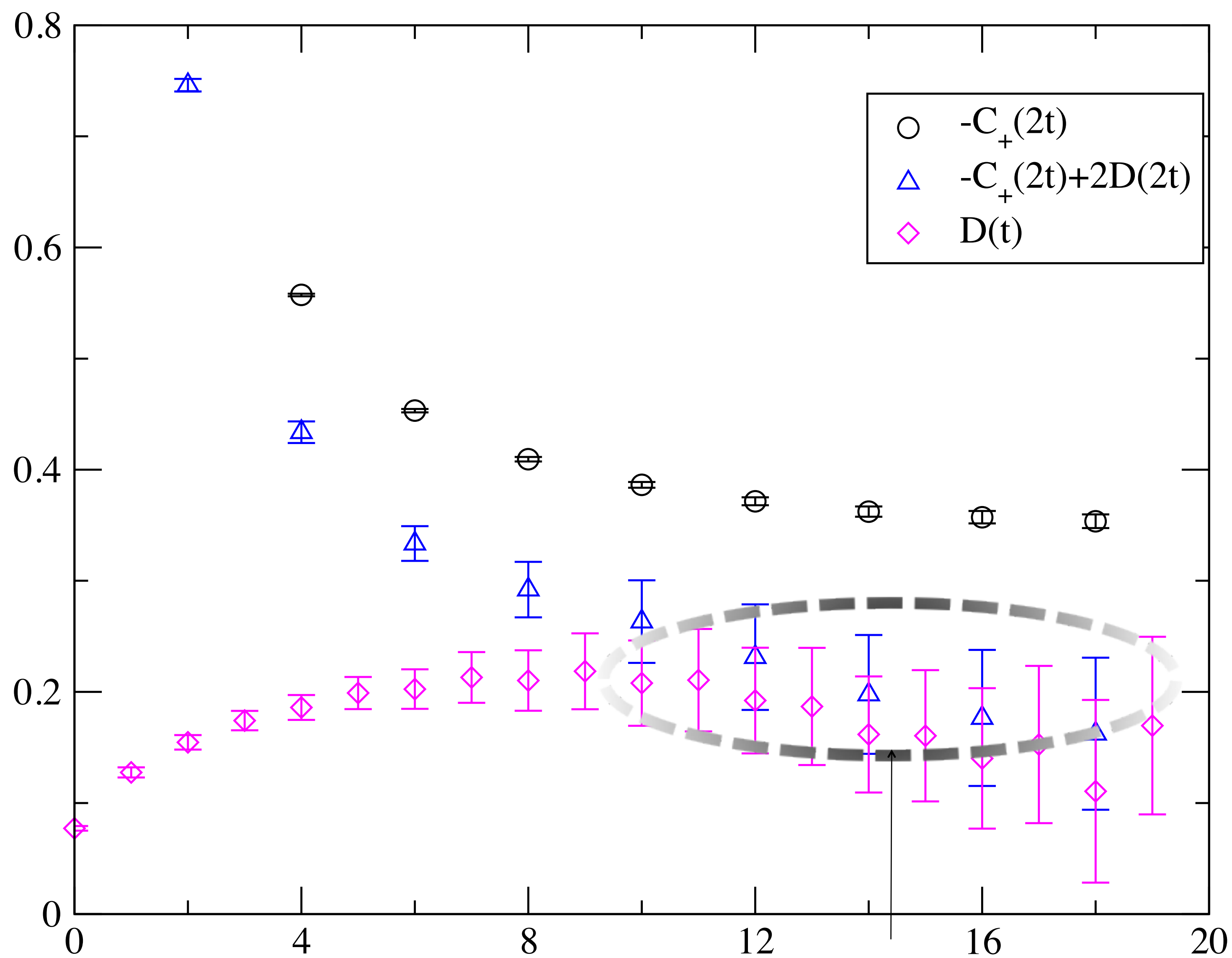
singlet scalar mass < non-singlet scalar

scalar effective mass , L=30, T=40, β=3.8, mf=0.02

$$0^+(a_0) : C_+(2t) \rightarrow A_{a_0} e^{-m_{a_0} 2t}$$

$$0^+(\sigma) : C_\sigma(2t) = -C_+(2t) + 2D_+(2t) \rightarrow A_\sigma e^{-m_\sigma 2t}$$

$$D(t) = A_\sigma e^{-m_\sigma t} + A_{a_0} e^{-m_{a_0} t} \rightarrow A'_\sigma e^{-m_\sigma t} \ (\text{if } m_\sigma < m_{a_0})$$



- No zigzag behavior in D(t) thanks to good taste symmetry of HISQ
- Disconnected correlator gives same effective mass as full correlator at large t.

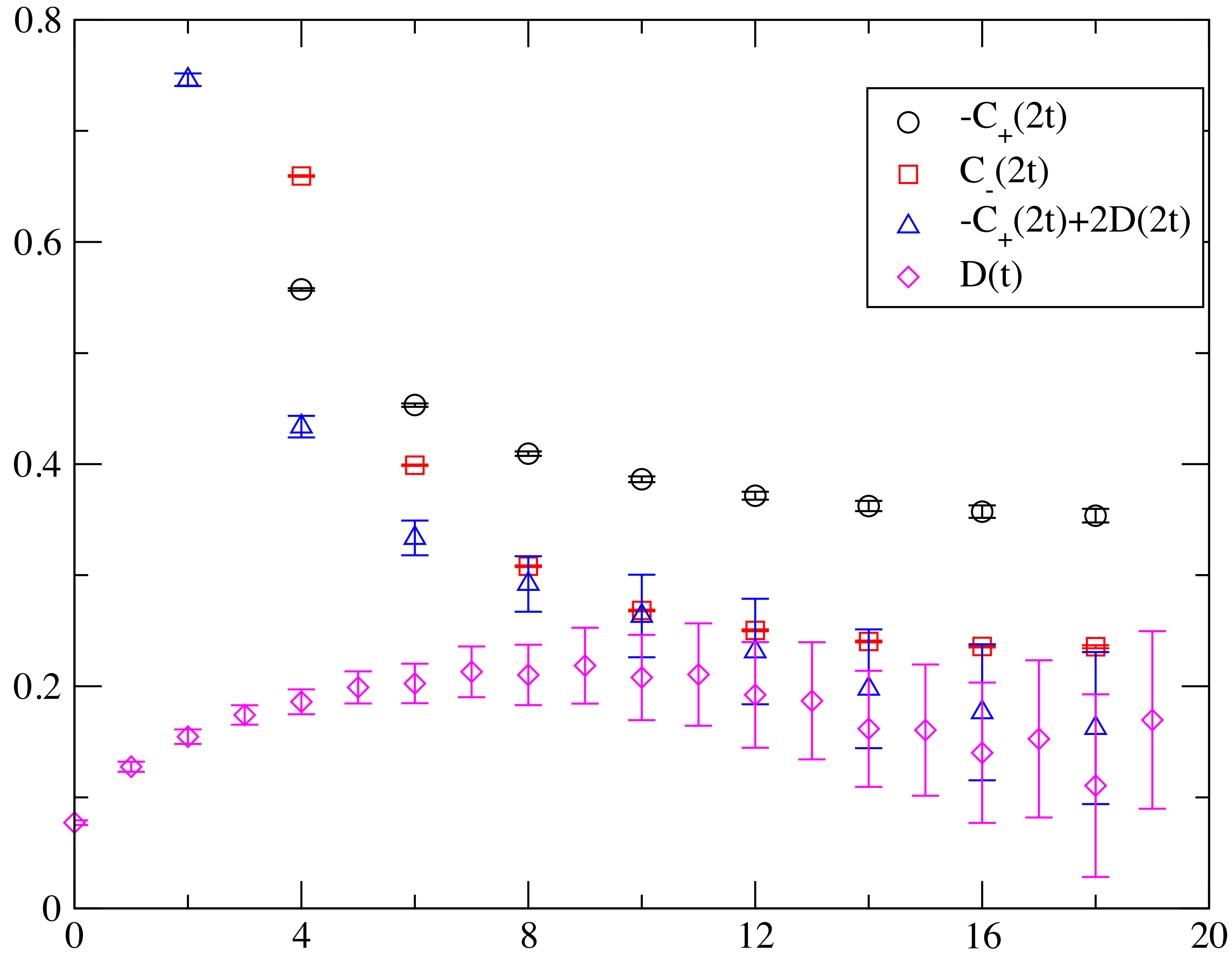
scalar effective mass , L=30, T=40, β=3.8, mf=0.02

$$0^+(a_0)\ :C_+(2t) \to A_{a_0} e^{-m_{a_0} 2t}$$

$$0^+(\sigma)\ :C_\sigma(2t) = -C_+(2t) + 2D_+(2t) \to A_\sigma e^{-m_\sigma 2t}$$

$$D(t) = A_\sigma e^{-m_\sigma t} + A_{a_0} e^{-m_{a_0} t} \to A'_\sigma e^{-m_\sigma t}\ (\text{if } m_\sigma < m_{a_0})$$

$$0^-(\text{scPion}) : C_-(2t) \to A_{\pi_{sc}} e^{-m_{\pi_{sc}} 2t}$$



- scPion mass ~ flavor singlet scalar mass

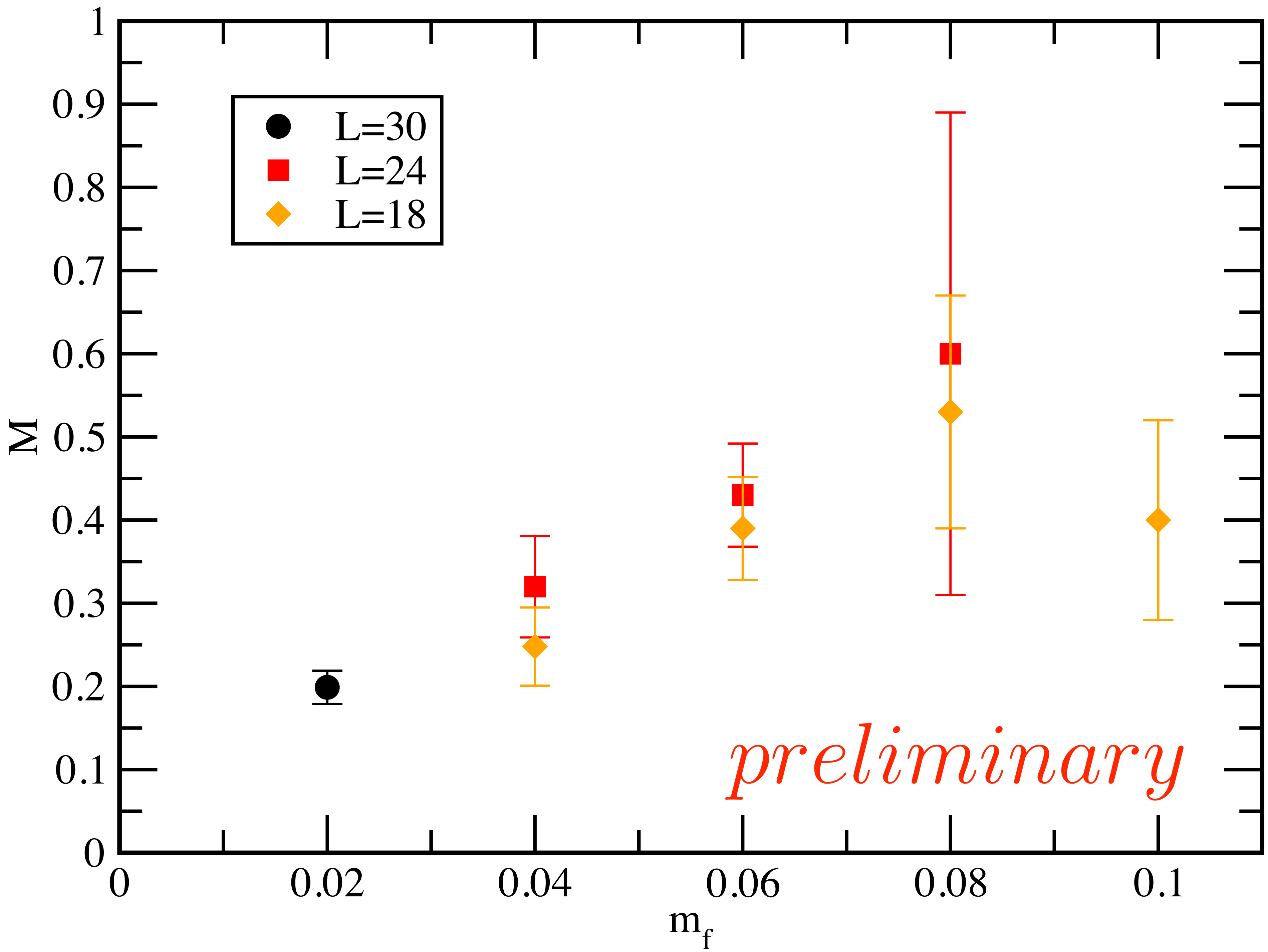
Fit analysis

- We can extract the mass from the disconnected diagrams D(2t), whose ground state mass corresponds to the mass of a flavor singlet scalar.
- Fit range for each parameter is shown below.

volume	mass	fit range
L=30,T=40	m=0.02	[6-20]
L=24,T=32	m=0.04	[6-16]
L=24,T=32	m=0.06	[6-14]
L=18,T=24	m=0.04	[6-12]
L=18,T=24	m=0.06	[6-12]
L=18,T=24	m=0.08	[6-12]
L=18,T=24	m=0.10	[6-12]

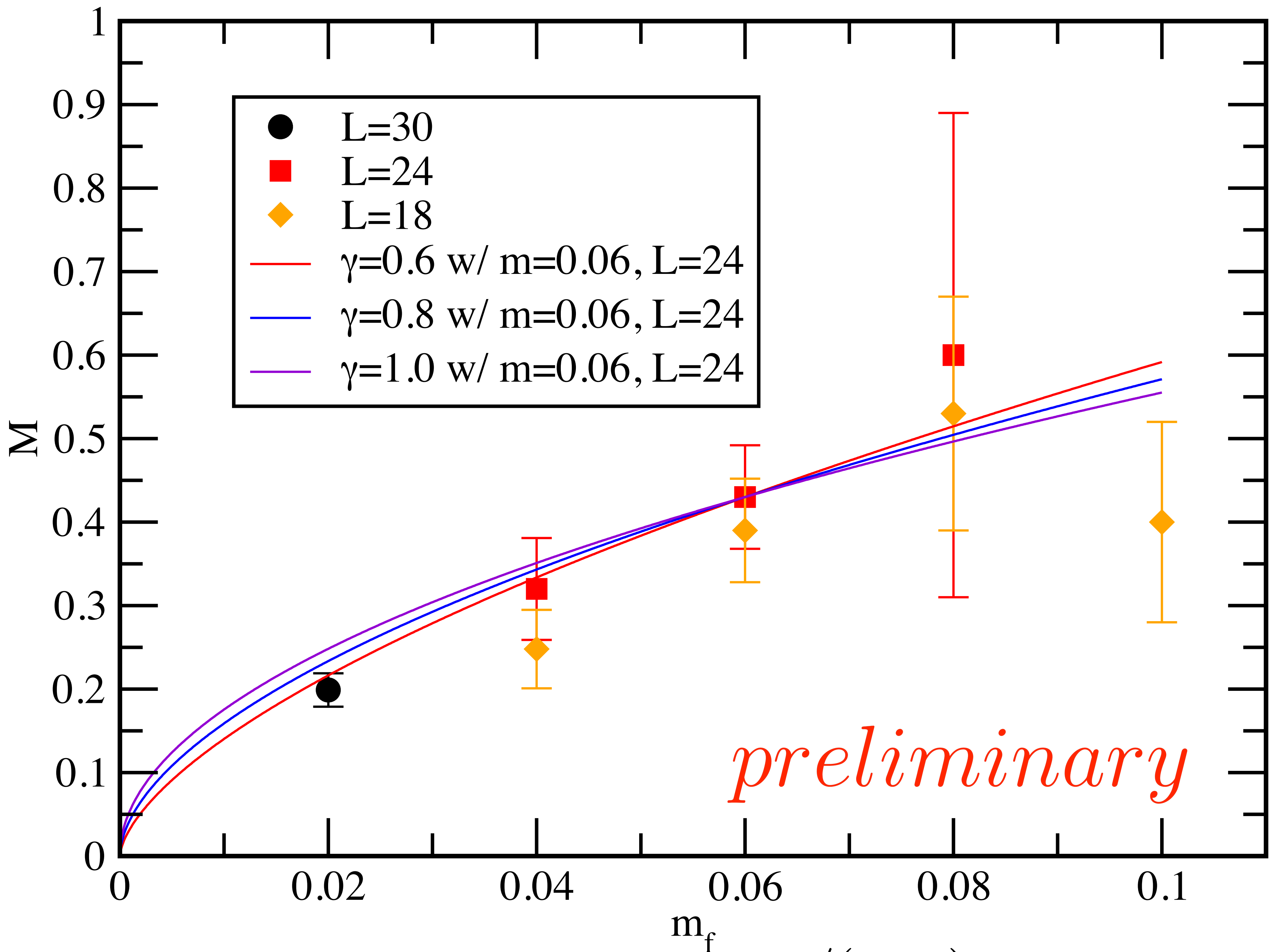
(t_min =6 fixed)

Fit result of flavor singlet scalar meson mass



- Statistical error only.
- Fermion mass dependence is observed.
- No visible finite volume effect (L=18 and 24 are consistent for m>0.04).

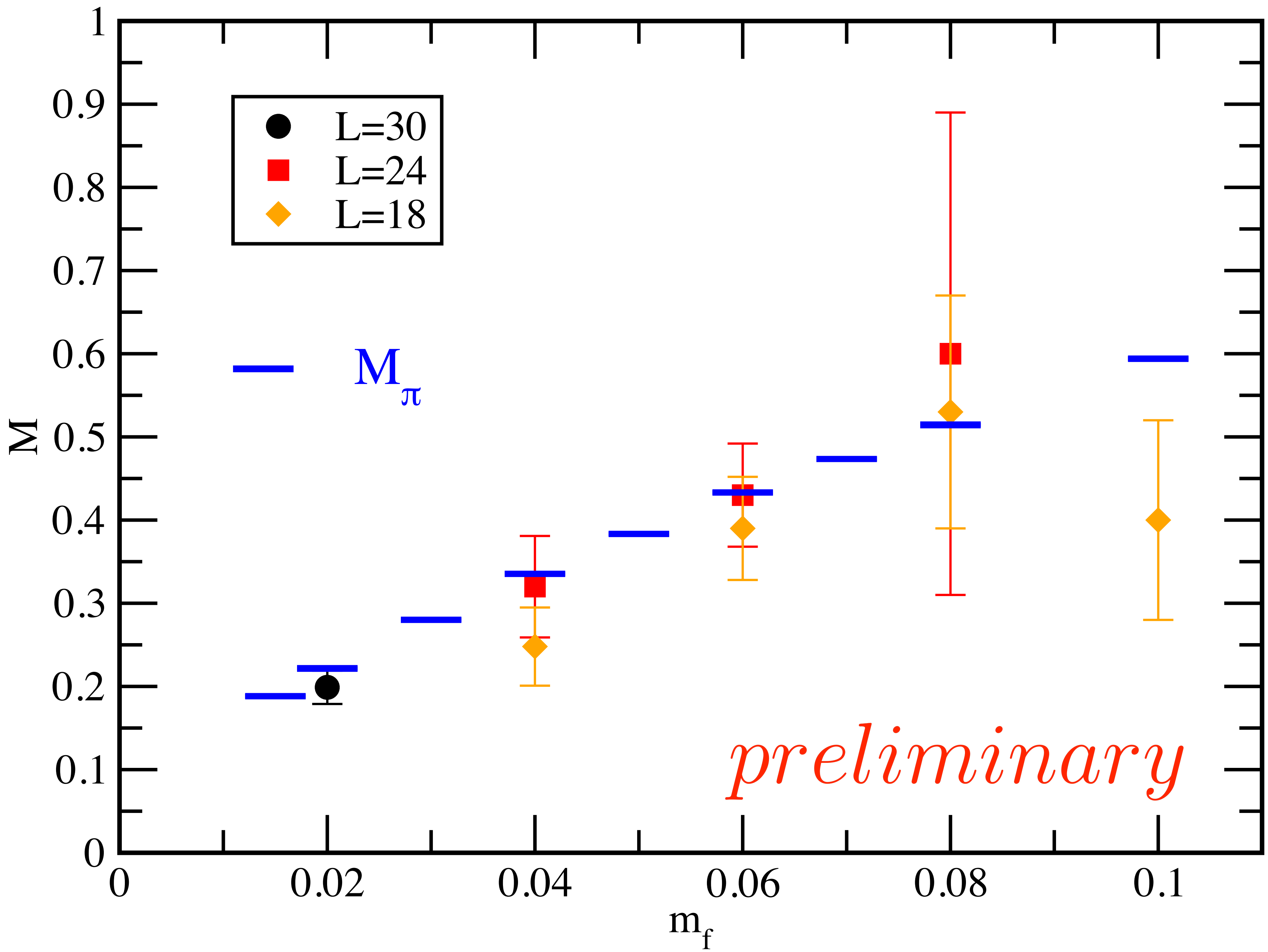
Hyperscaling curve



$$m_\sigma = C m_f^{1/(1+\gamma)}$$

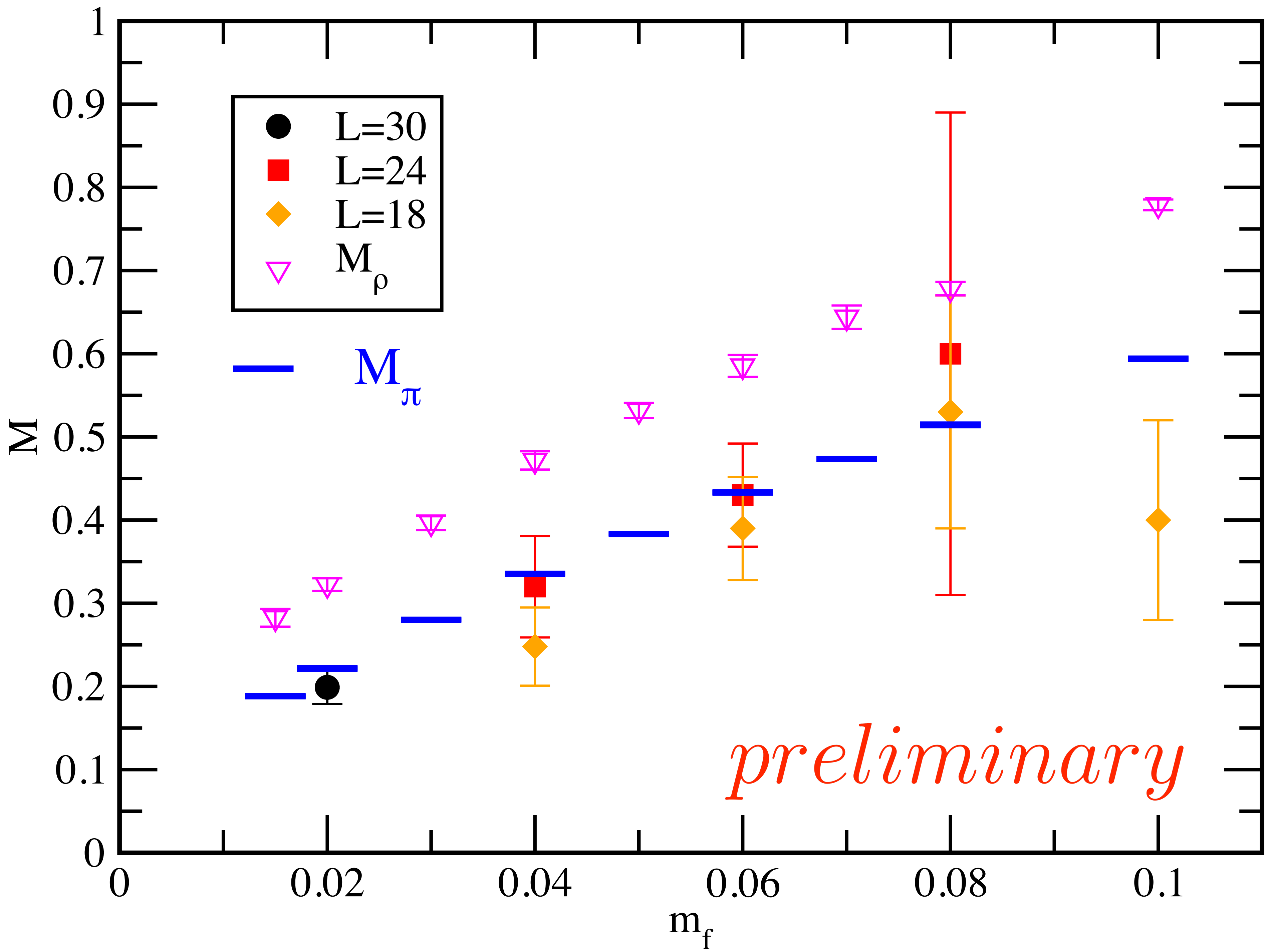
- It seems to be consistent with hyperscaling (γ=0.6-1.0) for larger mass region.
- We need more statistics and different mass data for careful hyperscaling analysis.

Comparison with NG-boson mass



- **Scalar(0++) is as light as NG-pion.**

Comparison with vector meson mass

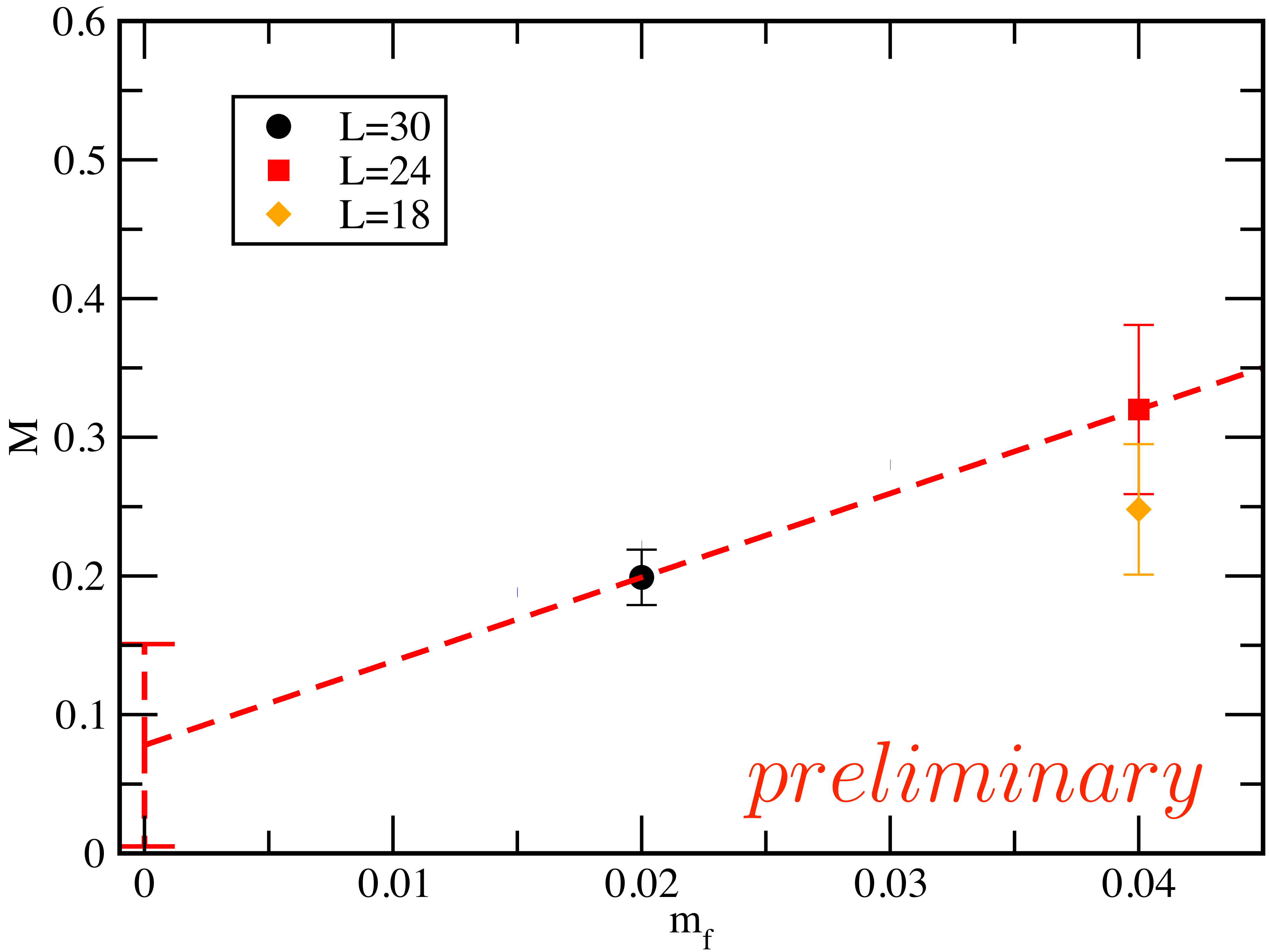


- **rho mass > flavor singlet scalar mass**

chiral limit extrapolation

To estimate the scalar mass in the chiral limit,
we carry out the chiral extrapolation with polynomial fit,
since we observed the ChPT-like behavior for m_π, F_π and
m_ρ in smaller fermion mass region ($m_f \leqq 0.04$).
[K. Nagai talk, LatKMI, PRD87(2013)]

Simple estimate of the scalar mass in the chiral limit

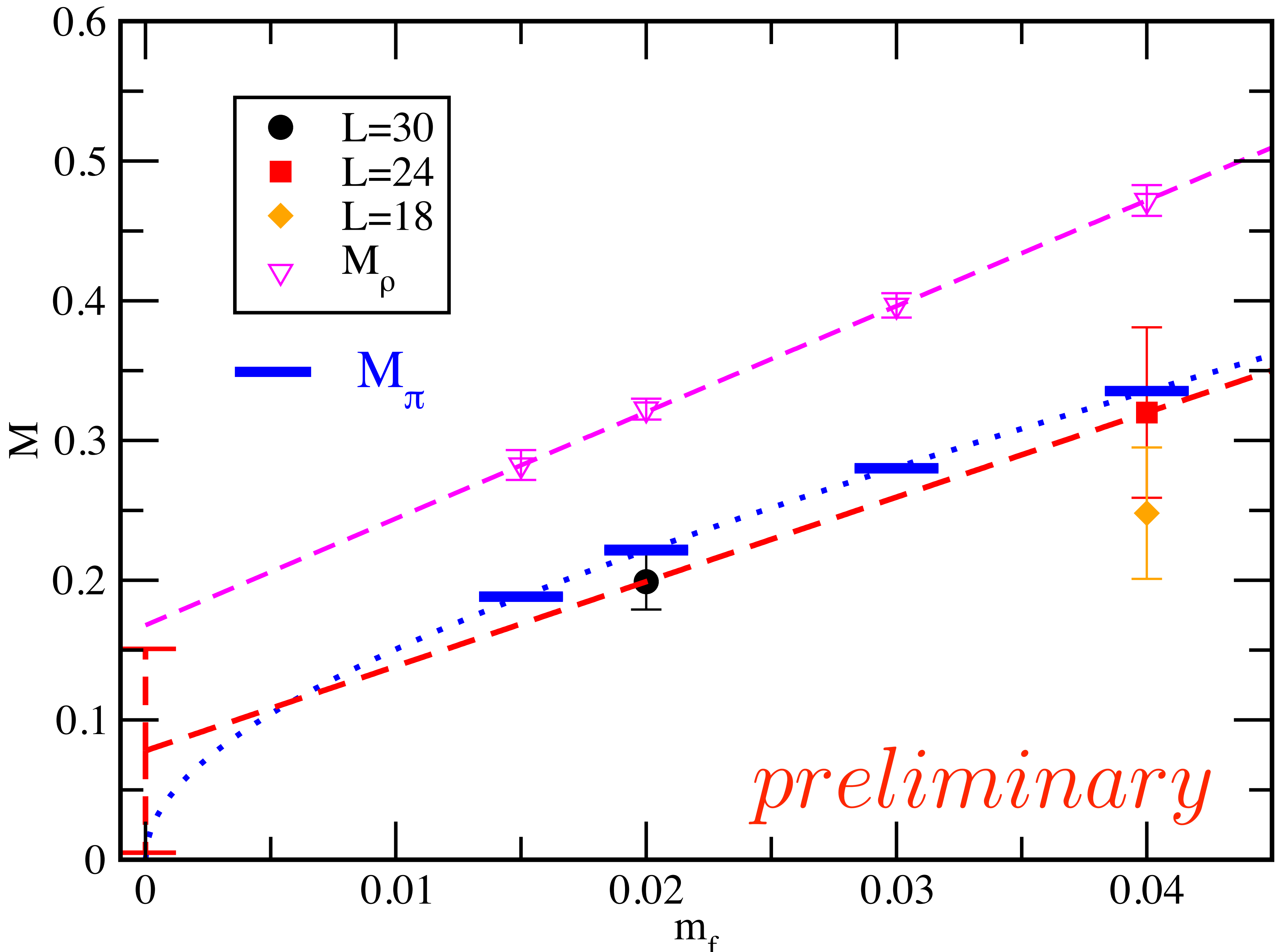


$$m_\sigma = c_0 + c_1 m_f$$

2pt linear extrapolation

fit data: mf=0.02, L=30 and mf=0.04, L=24

Chiral extrapolation for other spectra(same as previous talk by K. Nagai)

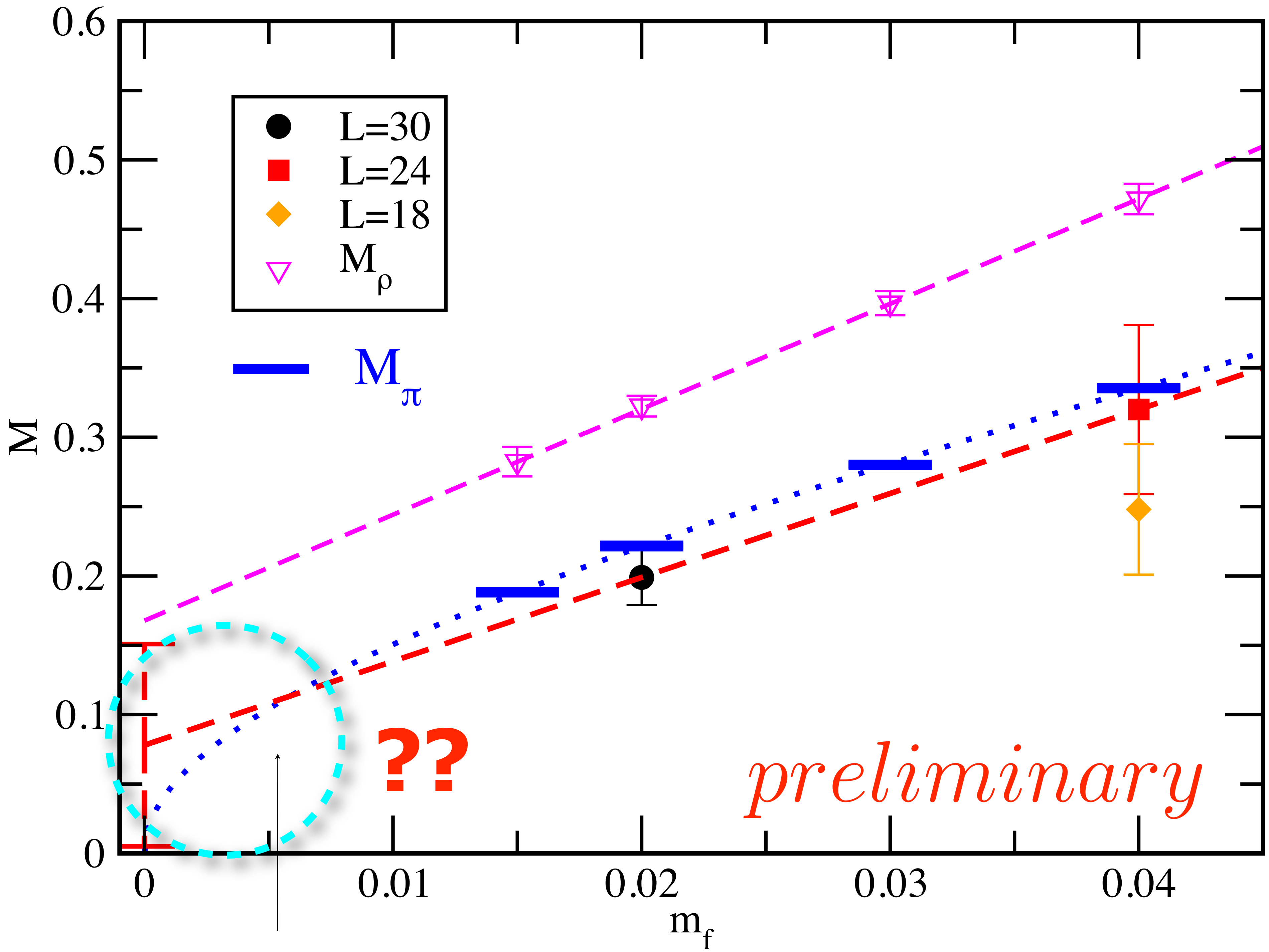


fit data

$$m_\pi^2 = c_1 m_f + c_2 m_f^2$$ mf: 0.015- 0.04 (4 points)

$$m_\rho = c_0 + c_1 m_f + c_1 m_f^2$$ mf: 0.015- 0.04 (4 points)

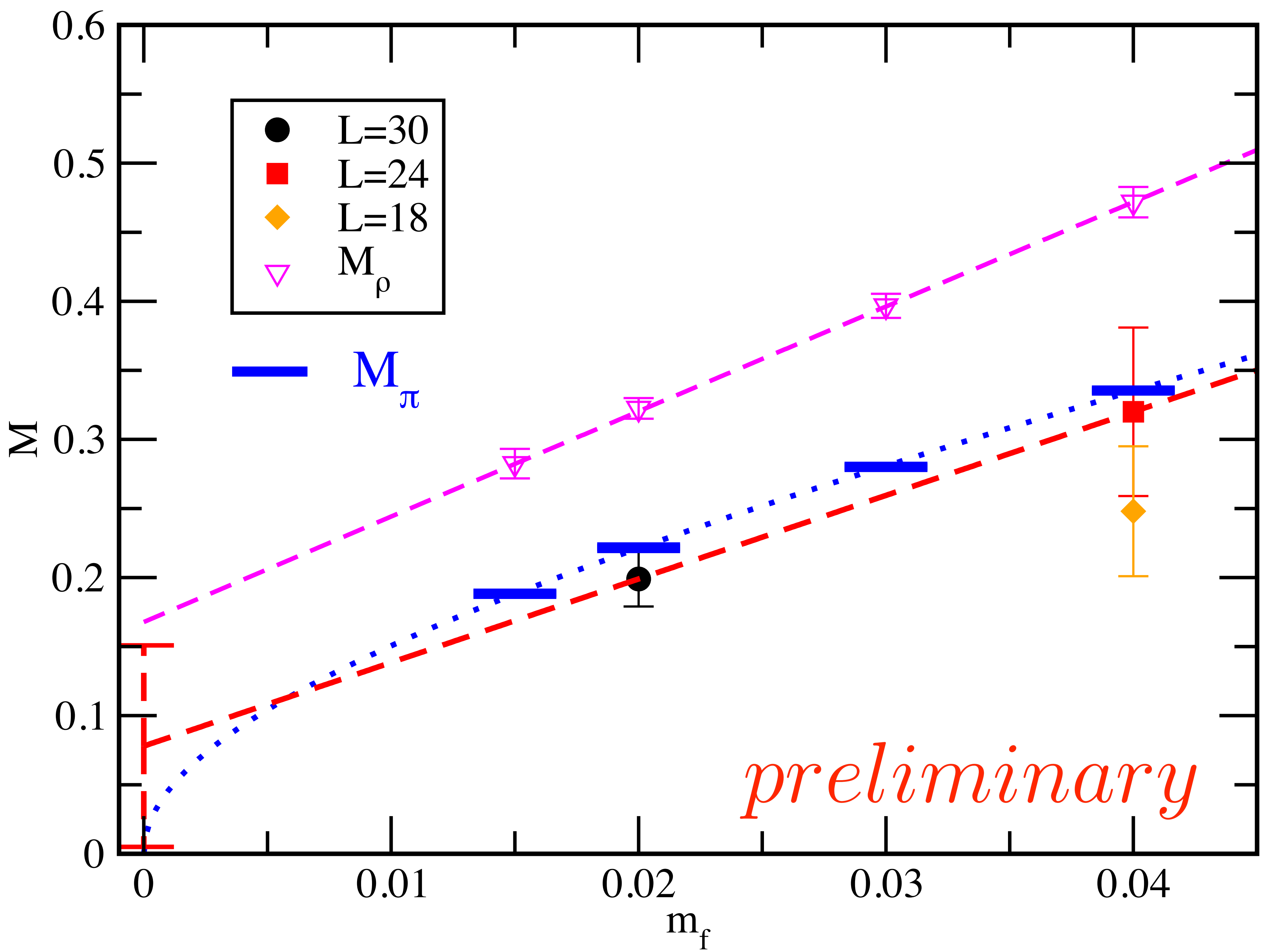
Chiral limit extrapolation (ChPT-like fit)



There is a possibility of crossing phenomena of two curves for pion and scalar very near the chiral limit in the case of the chiral broken phase.

Direct check → Future work!!

Chiral limit extrapolation (ChPT-like fit)



In the chiral limit $\frac{m_\sigma}{F_\pi/\sqrt{2}} = 3.6(3.3)$ $\frac{m_\sigma}{m_\rho} = 0.5(5)$

2013年7月29日月曜日

Summary

•Many flavor SU(3) gauge theory is being investigated.
•In this talk, We focus on the Nf=8 case.

•We measure the flavor singlet scalar mass.
Using the noise reduction technique with high statistics(O(10000)),
we obtain a good signal of fermion bilinear operator and good plateau from disconnected diagrams.

The resulting mass for flavor singlet scalar is as light as pion.
The situation is different from usual lattice QCD (Nf=2,2+1) results.

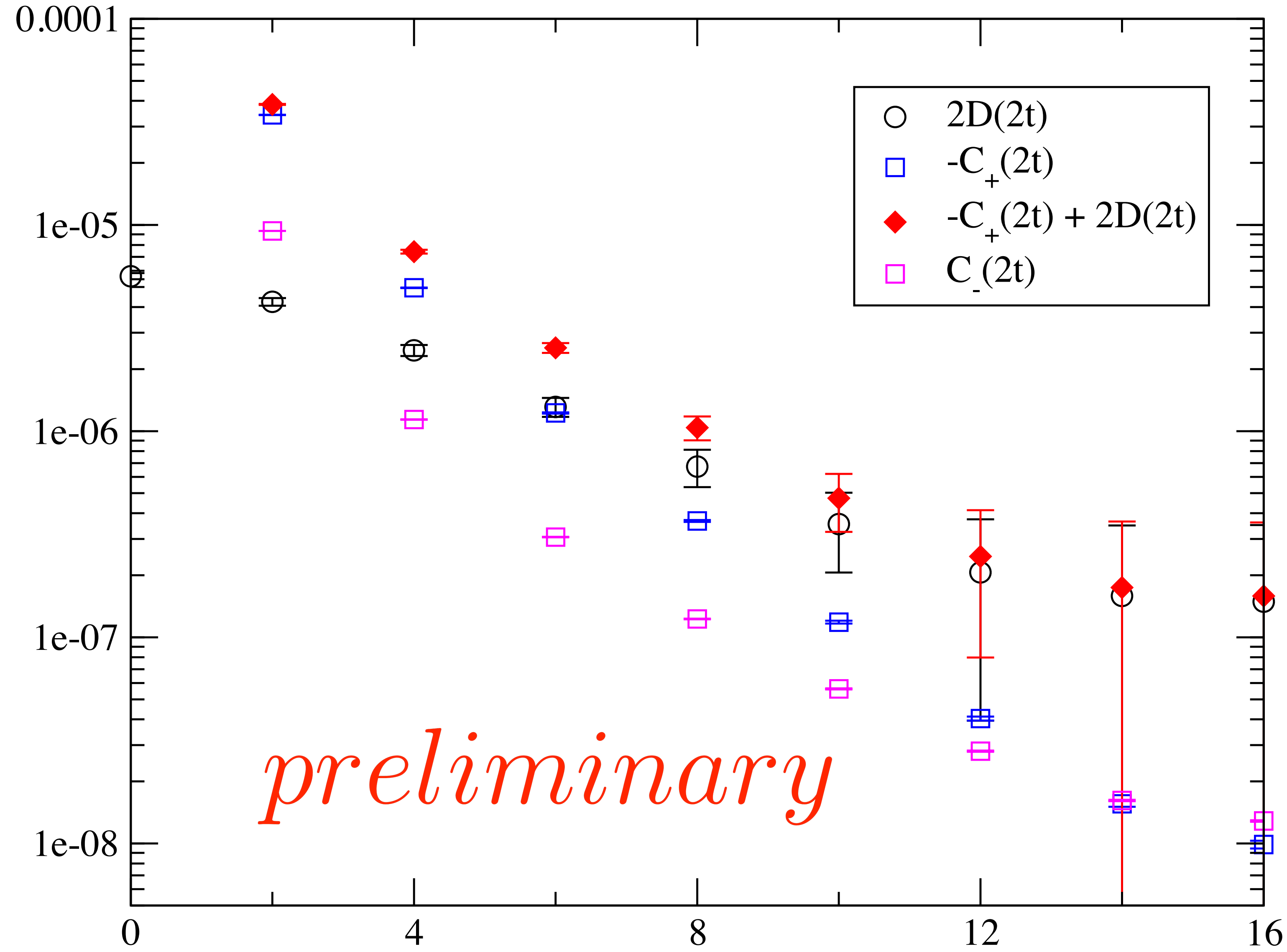
We estimate the chiral limit mass by simple polynomial fit.
In the chiral limit, $m_\sigma/(F_\pi/\sqrt{2})=3.6(3.3)$. (statistical error only)
It is a good candidate of the walking technicolor model.

Future work
Comparison with the mass from gluonic operator and operator mixing effect.
More statistics and lighter fermion mass data are needed
for further study.

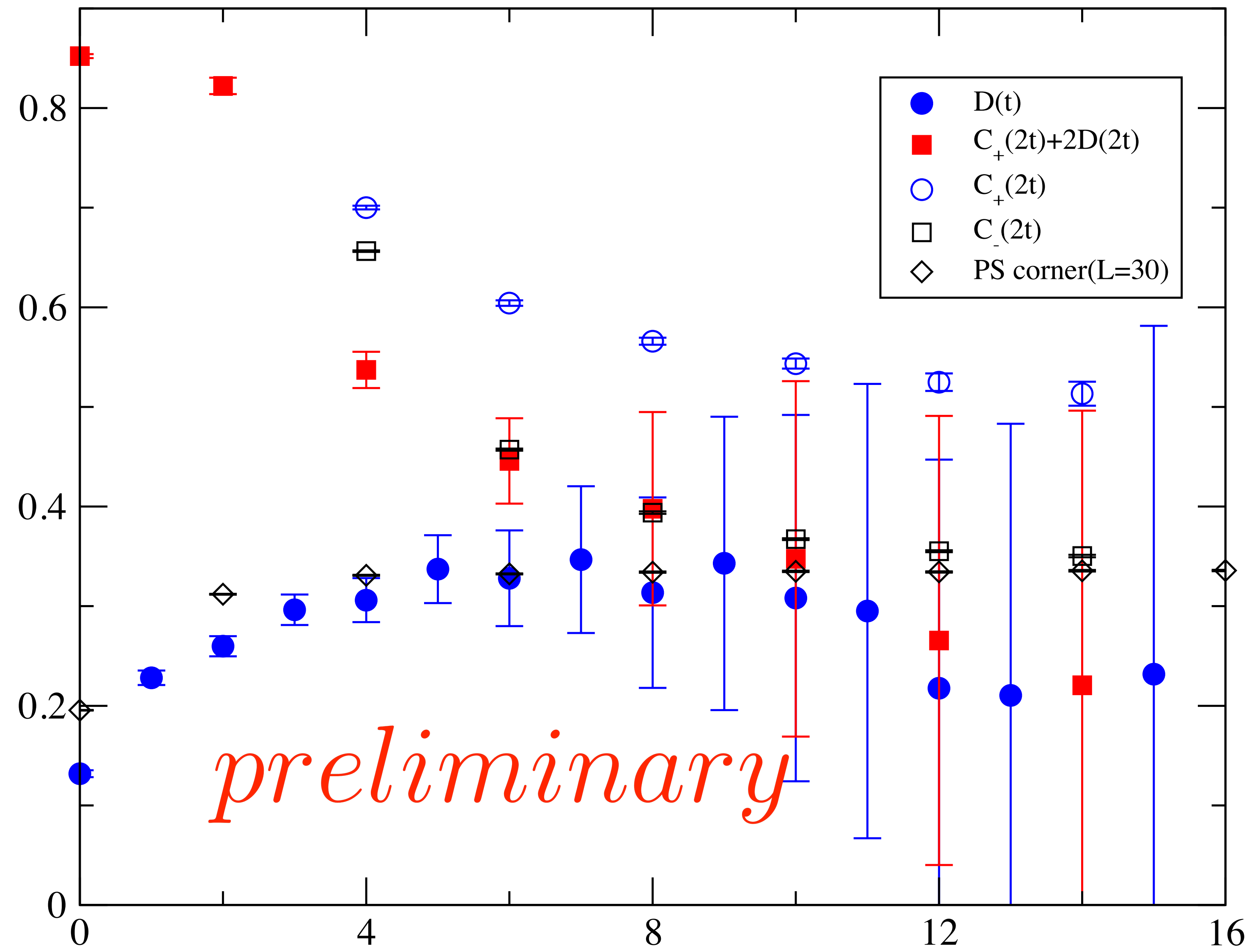
END
Thank you

Backup slide

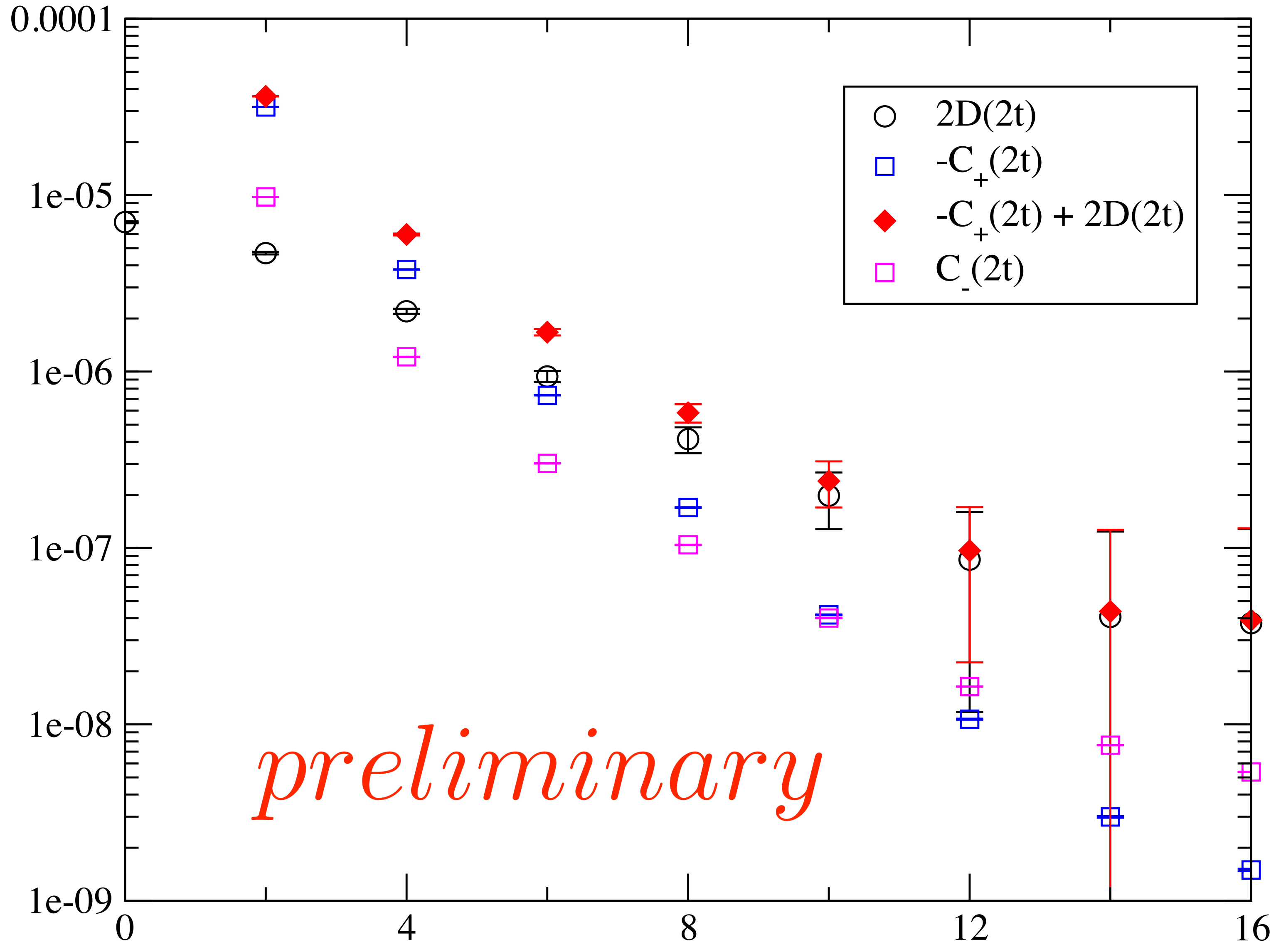
Nf=8, L=24, m=0.04, #conf=3400



Nf=8, L=24, m=0.04, #conf=3400



Nf=8, L=24, m=0.06, #conf=14000



Nf=8, L=24, m=0.06, #conf=14000