Exploring for a light composite scalar in many flavor QCD

Hiroshi Ohki

KMI, Nagoya University

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References:
Phys.Rev. D86 (2012) 054506,
Phys. Rev. D87, 094511 , arXiv:1302.6859 [hep-lat].
arXiv:1305.6006 [hep-lat]
(LatKMI collaboration)

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 is

  Dynamical breaking of electroweak symmetry

  -> composite Higgs

  – **(walking) technicolor**

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

Origin of the electroweak symmetry breaking

- **Technicolor** **(dynamical symmetry breaking model, alternative to Higgs mechanism in SM)**

Electroweak symmetry breaking

-> techni-fermion Q condensation (scale up of QCD)

(c.f. Chiral symmetry breaking in QCD)
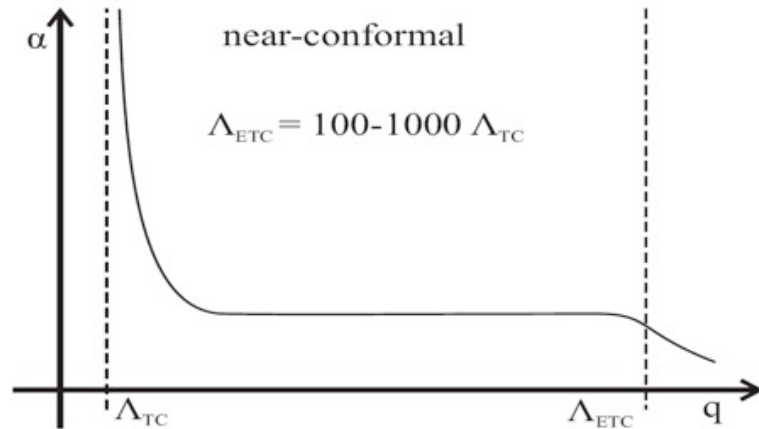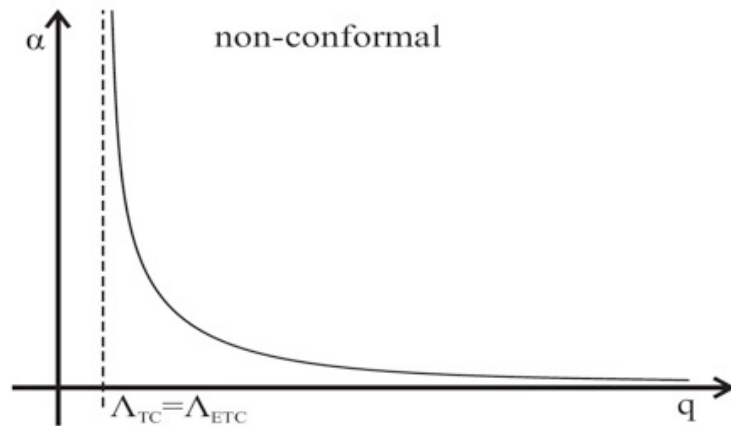
a new strong interaction

Ex. $SU(N)_{TC} \times SU(3)_{color} \times SU(2)_L \times U(1)_Y$

$$\langle \bar{Q}Q \rangle = \Lambda_{TC}^3 \qquad \Lambda_{TC} \sim 250 \text{ GeV}$$

Technicolor model

- Flavor problem -> ETC origin non-renormalizable operators
  give a realistic flavor structure
 FCNC problem need to be resolved.

- EW precision measurement
e.g. S-parameter could be small near conformal phase.
    or negative contribution by ETC induced operator

- **Existence of a light composite scalar (126 GeV) !!**

walking (conformal) dynamics

$$\langle \bar{Q}Q \rangle_{ETC} = \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d(\ln \mu)\gamma(\alpha(\mu)) \right) \langle \bar{Q}Q \rangle_{TC}$$

QCD like $\qquad \alpha(\mu) \propto \dfrac{1}{\ln \mu} \qquad \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d(\ln \mu)\gamma(\alpha(\mu)) \right) = \ln\left(\dfrac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma}$

Conformal $\qquad \gamma \sim \mathcal{O}(1) \qquad \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d(\ln \mu)\gamma(\alpha(\mu)) \right) = \left(\dfrac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma(\alpha^*)}$

- "Higgs" = pseudo Nambu-Goldstone boson
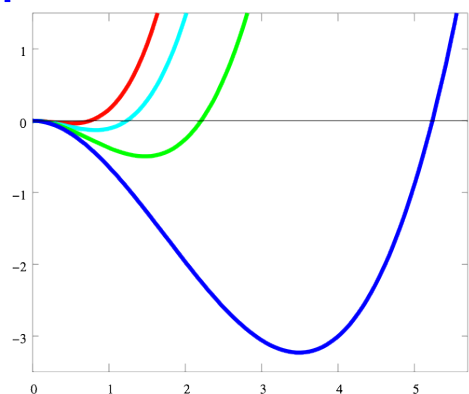 - breaking of the approximate scale invariance (dilaton)
    [Yamawaki-Bando-Matumoto]

Candidate of near-conformal gauge theory → **Large Nf QCD**

2-loop running coupling in large Nf QCD

$$\boxed{\text{RGE}} \quad \mu \frac{d}{d\mu}\alpha(\mu) = \beta(\alpha) = -b\,\alpha^2(\mu) - c\,\alpha^3(\mu)$$

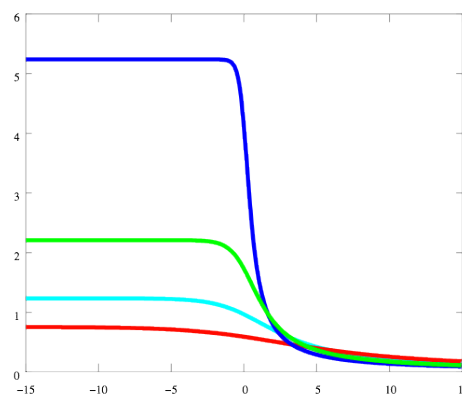| $(N_c = 3)$	$N_f < 8.05$	$8.05 < N_f < 16.5$	$16.5 < N_f$
$b = \frac{1}{6\pi}(33 - 2N_f)$	$+$	$+$	$-$
$c = \frac{1}{12\pi^2}(153 - 19N_f)$	$+$	$-$	$-$

$\beta(\alpha)$

$\alpha(\mu)$

$N_f = 9$
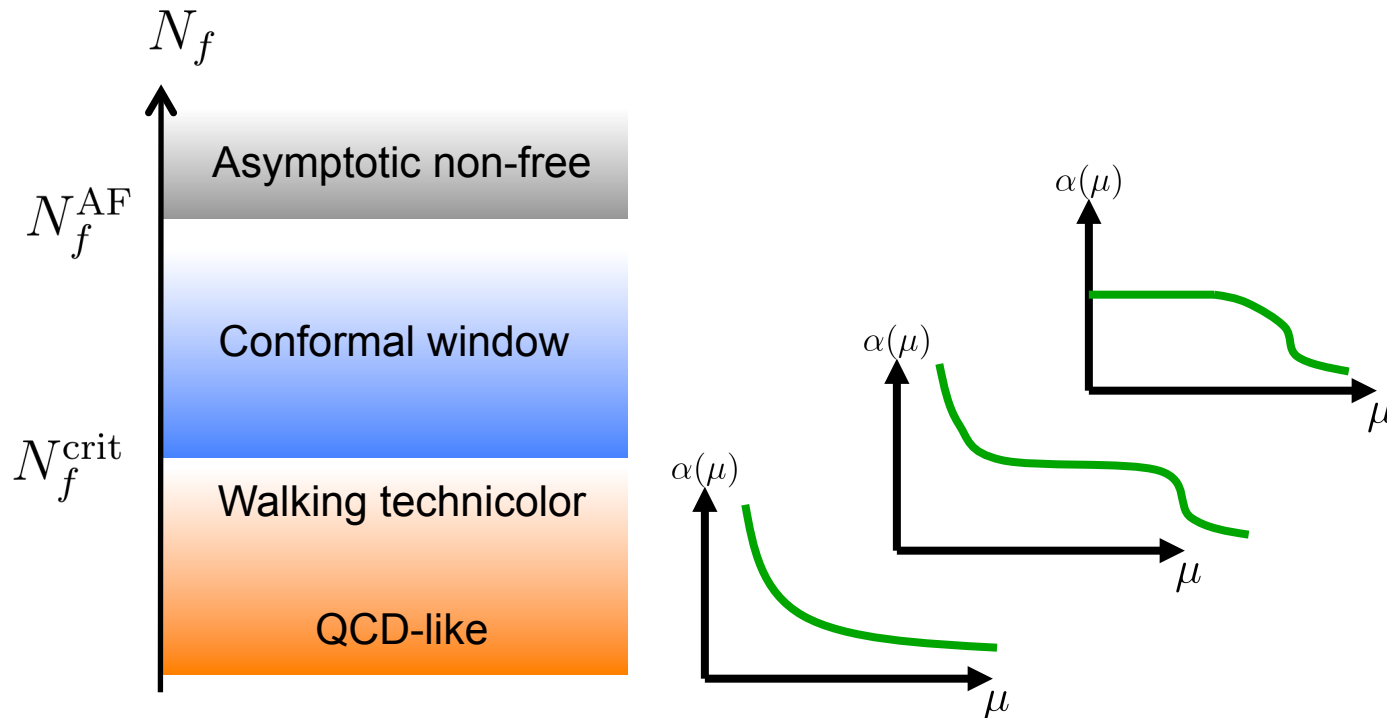$N_f = 10$
$N_f = 11$
$N_f = 12$

α

$\log \frac{\mu}{\Lambda}$

IR fixed point at

$$\alpha_* = -b/c$$

Walking (conformal) behavior : non-perturbative gauge dynamics

Large Nf QCD: benchmark test of walking dynamics

• Walking technicolor (WTC) could be realized just below conformal window.
• What the value of the anomalous dimensions? Preferable value of γ is order 1.
• Rich hadron structures may be observed (LHC).

Lattice!!

Large Nf QCD on the Lattice

[LatKMI collaboration]
Yasumichi Aoki, Tatsumi Aoyama, Masafumi Kurachi,
Toshihide Maskawa, Kei-ichi Nagai, Kohtaroh Miura, Hiroshi
Ohki, Enrico Rinaldi, Akihiro Shibata, KoichiYamawaki,
TakeshiYamazaki

SU(3) with fundamental fermions

Our goals:
* Understand the flavor dependence of the theory
* Find the conformal window
* Find the walking regime and investigate scalar mass and the anomalous dimension

Our current status (lattice):
* Nf=16: likely conformal
* Nf=12: consistent with IR conformal
* Nf=8: studies suggests walking behavior
* Nf=4: chiral broken and enhancement of chiral condensate

Nf=8 and 12 are good candidates of walking (near-conformal) technicolor model

simulation setup

- **SU(3), Nf= 8, 12 flavor**

- use of improved staggered action
  - to get nearly continuum results from non-zero lattice spacing
  - to reduce flavor violation for good SU(N) chiral symmetry
  - bound to $N_f=4\,n$

- use tree level Symanzik gauge action

- **Nf=8** : $\beta=6/g^2=3.8$, V=L^{3}xT: L/T=3/4; L=18, 24, 30, $0.02\leqq m_f\leqq0.1$
- **Nf=12 :** $\beta=6/g^2=4.0$, V=L^{3}xT: L/T=3/4; L=18, 24, 30, $0.05\leqq m_f\leqq0.1$

- **Statistics ~ more than 5000 trajectories**

Lattice simulations

Scalar spectrum ← a flavor singlet fermion bilinear operator

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

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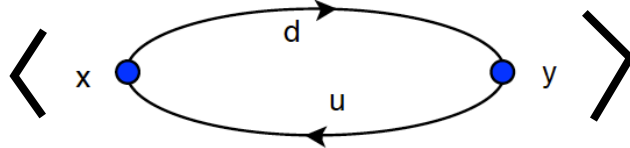
flavor singlet scalar measurement

- huge number of configurations

- consistency check by the measurement of 0++ glueball correlator.
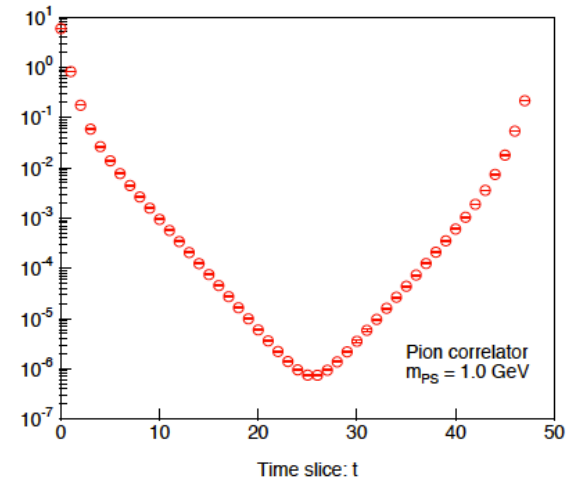
Review : lattice correlation function

case: two-point correlation function for pseudo-scalar

$$P(t) = \sum_x \bar{u}(\vec{x}, t)\gamma_5 d(\vec{x}, t)$$

$$\langle 0|P(t)P^\dagger(0)|0\rangle = \sum_n \langle 0|P(0)|\pi_n\rangle\langle\pi_n|P^\dagger(0)|0\rangle e^{-E_{\pi_n}t}$$

$$\sim |\langle 0|P(0)|\pi\rangle|^2 e^{-m_\pi t} \quad (t \to \infty)$$

$$G \propto \cosh\left[M\left(t - \frac{T}{2}\right)\right]$$

Pion correlator
$m_{PS} = 1.0$ GeV

Time slice: t

case: flavor-singlet scalar scalar

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

$$\mathcal{O}_F(t) \equiv \bar{\psi}_i\psi_i(t), \qquad D(t) = \langle\mathcal{O}_F(t)\mathcal{O}_F(0)\rangle - \langle\mathcal{O}_F(t)\rangle\langle\mathcal{O}_F(0)\rangle$$
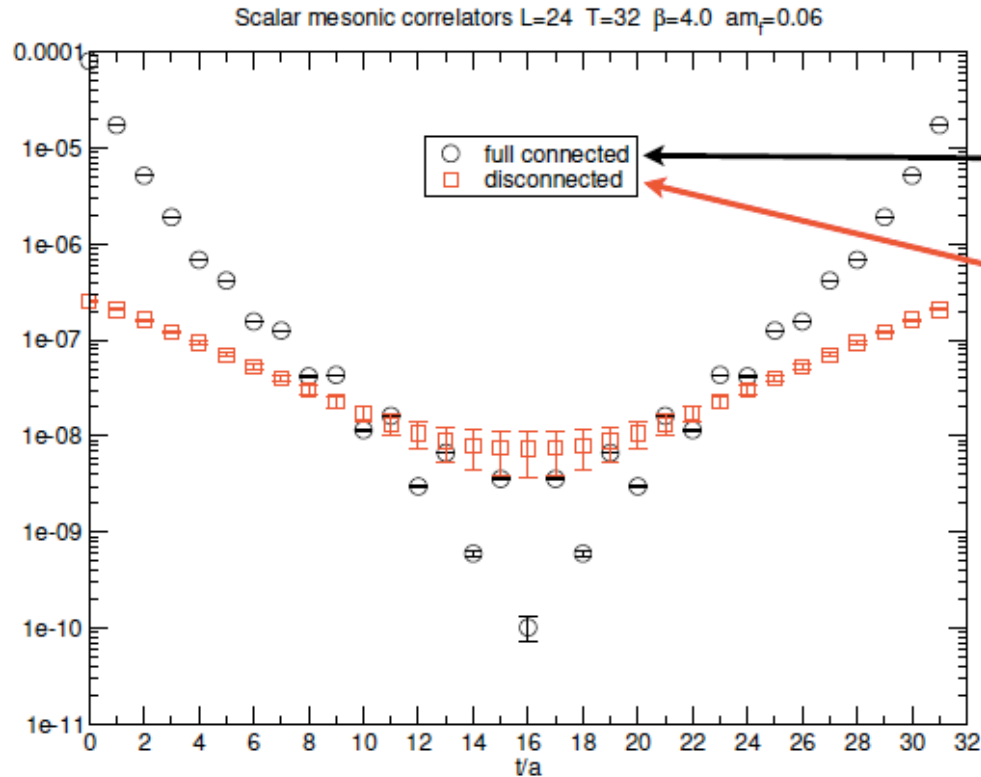
Full correlator consists of connected and (vacuum-subtracted) disconnected diagrams. In general, disconnected diagram is very noisy.

Example
[Nf=12, V=24^3 x 32, m=0.06]

Scalar mesonic correlators L=24 T=32 β=4.0 am$_f$=0.06

$$\left\langle \bigcirc \right\rangle = -C(t)$$

$$\left\langle \bigcirc \bigcirc \right\rangle - \left\langle \bigcirc \right\rangle^2$$

- connected and disconnected correlator measured on 14000 configurations

- 64 stochastic gaussian sources used for the disconnected piece on each configuration

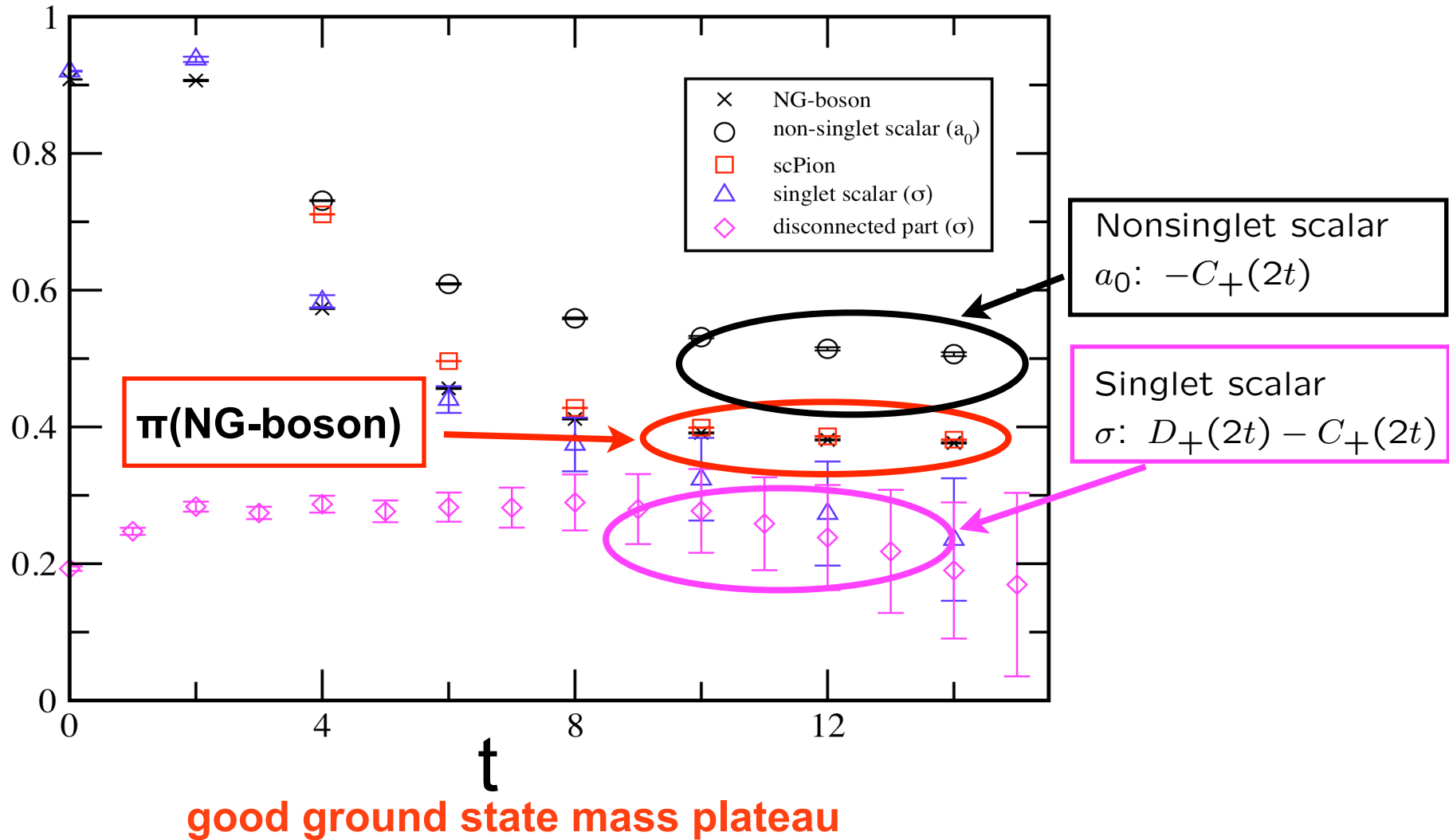- 2 stochastic gaussian sources used for the connected piece on each configuration

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

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

$$\left\langle \bigcirc \bigcirc \right\rangle - \left\langle \bigcirc \right\rangle \left\langle \bigcirc \right\rangle$$

Effective mass (mf=0.06, L=24)

$$m_{\text{eff}}(t) = \log(C_H(t)/C_H(t+1)) \xrightarrow{t \gg 1} m_H$$


Legend:
- × NG-boson
- ○ non-singlet scalar (a_0)
- □ scPion
- △ singlet scalar (σ)
- ◇ disconnected part (σ)

π(NG-boson)

Nonsinglet scalar
a_0: $-C_+(2t)$

Singlet scalar
σ: $D_+(2t) - C_+(2t)$

good ground state mass plateau

Result (Nf=12)

$L^3 \times T$	m_f	N_{cfgs}
$24^3 \times 32$	0.05	11000
$24^3 \times 32$	0.06	14000
$24^3 \times 32$	0.08	15000
$24^3 \times 32$	0.10	9000
$30^3 \times 40$	0.05	10000
$30^3 \times 40$	0.06	15000
$30^3 \times 40$	0.08	15000
$30^3 \times 40$	0.10	4000
$36^3 \times 48$	0.05	5000
$36^3 \times 48$	0.06	6000

Results: Nf=12 summary
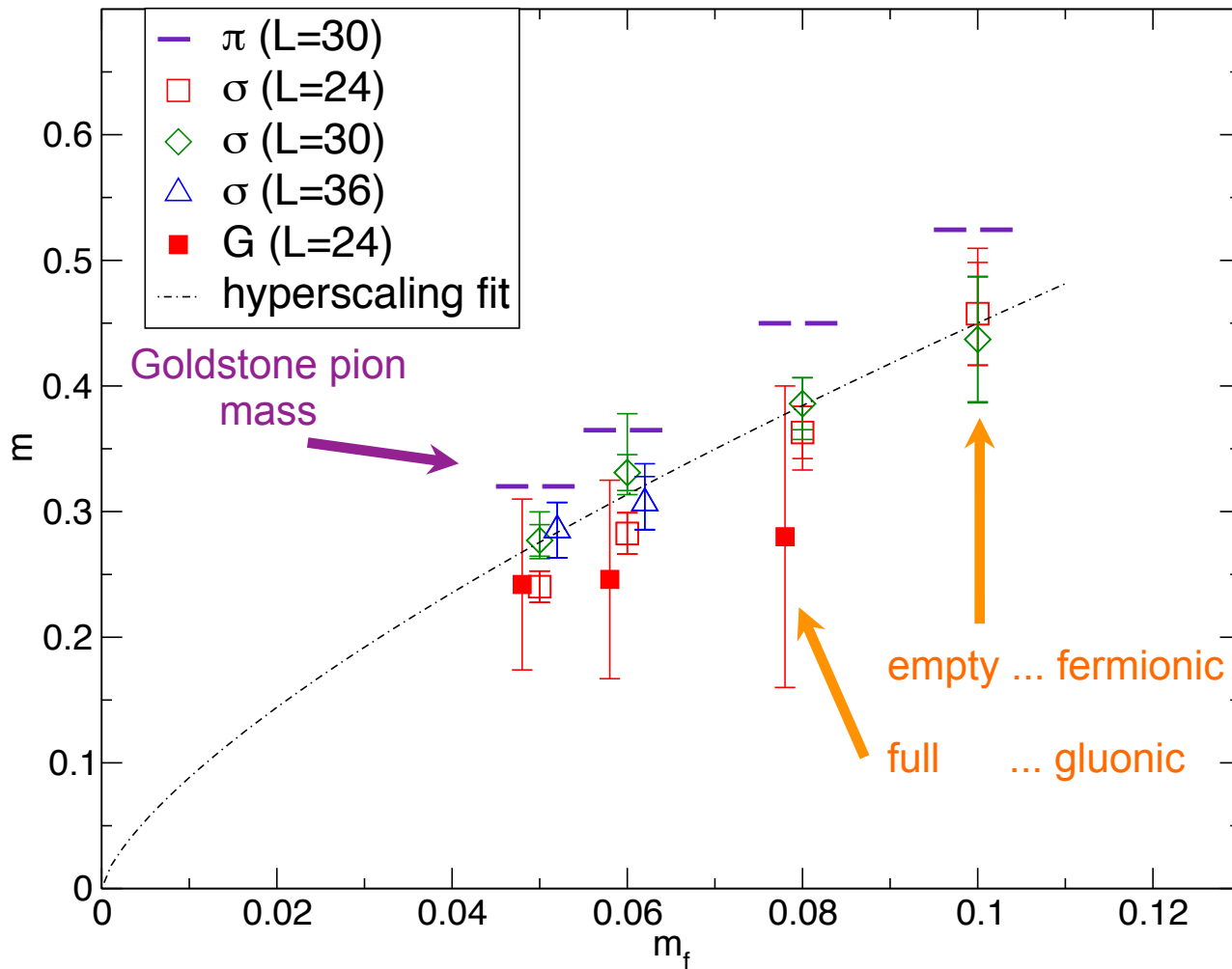
Result (Nf=8)
[very preliminary]

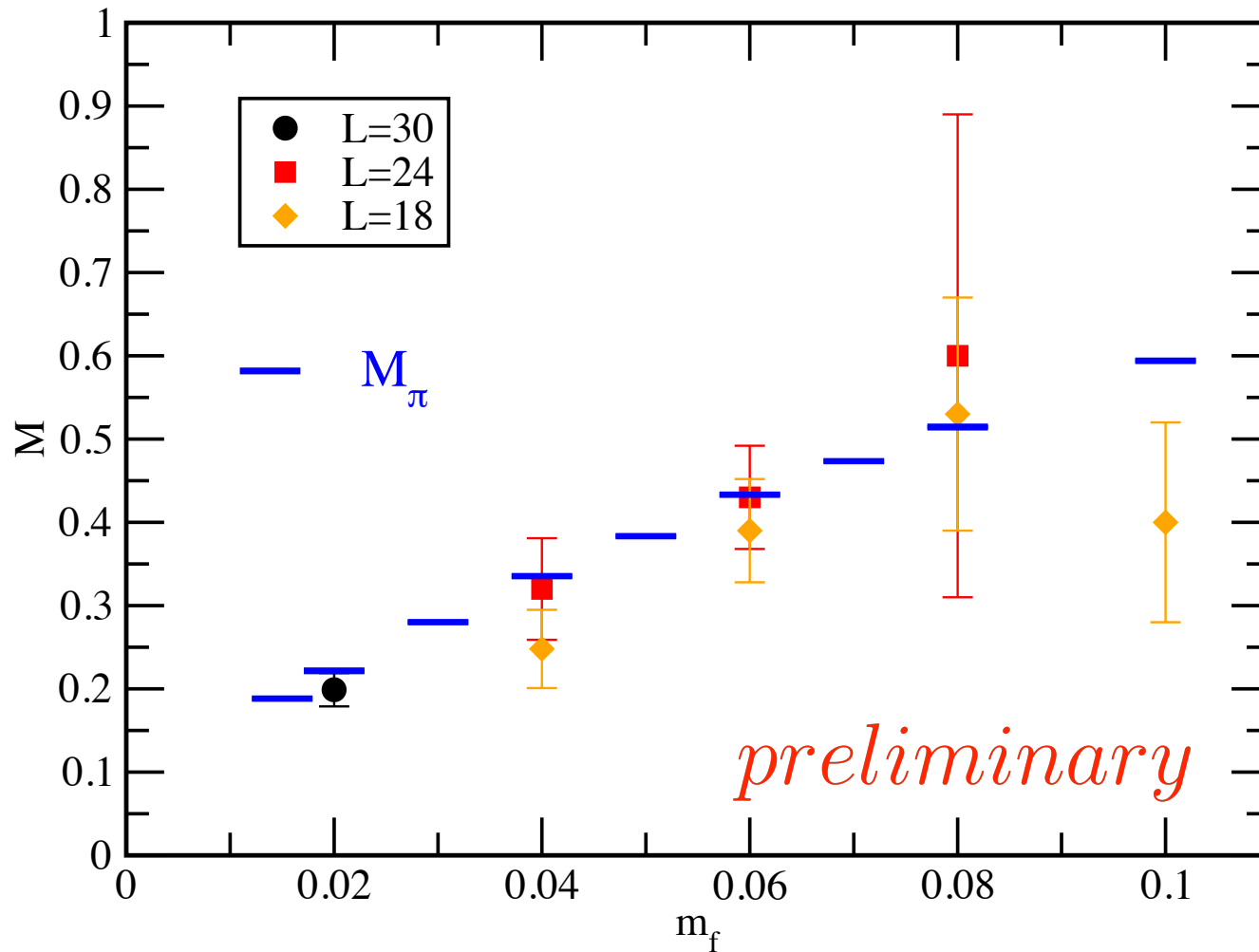| L	T	mf	#confs
18	24	0.04	5600
		0.06	9000
		0.08	7500
		0.10	8500
24	32	0.04	3400
		0.06	14000
		0.08	3600
30	40	0.02	7900

Result of flavor singlet scalar meson mass [Nf=8]
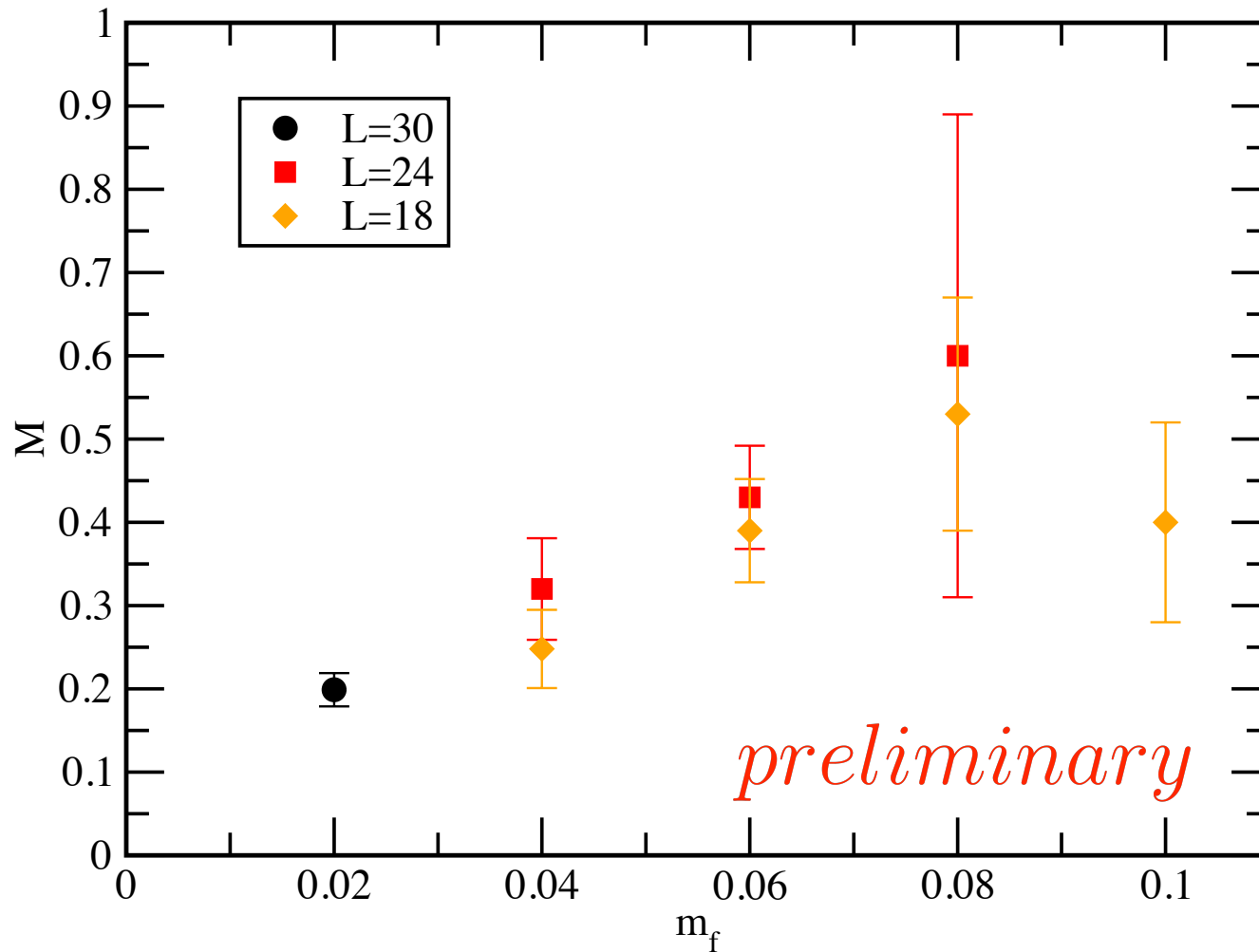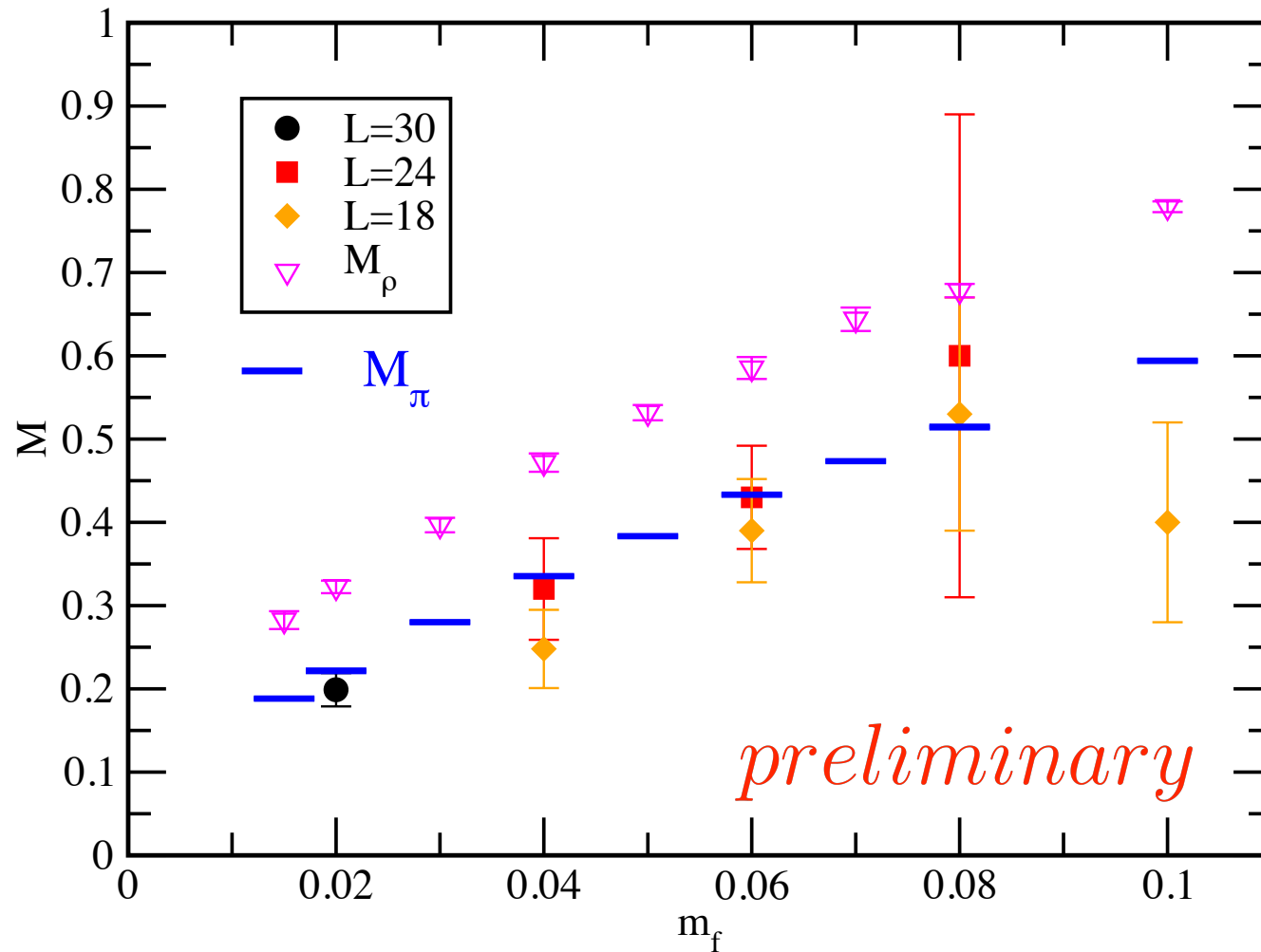
- Statistical error only.
- Fermion mass dependence is observed.
- No visible finite volume effect (L=18 and 24 are consistent for m>0.04).

Comparison with NG-boson mass [Nf=8]

- **Scalar(0++) is as light as NG-pion.**
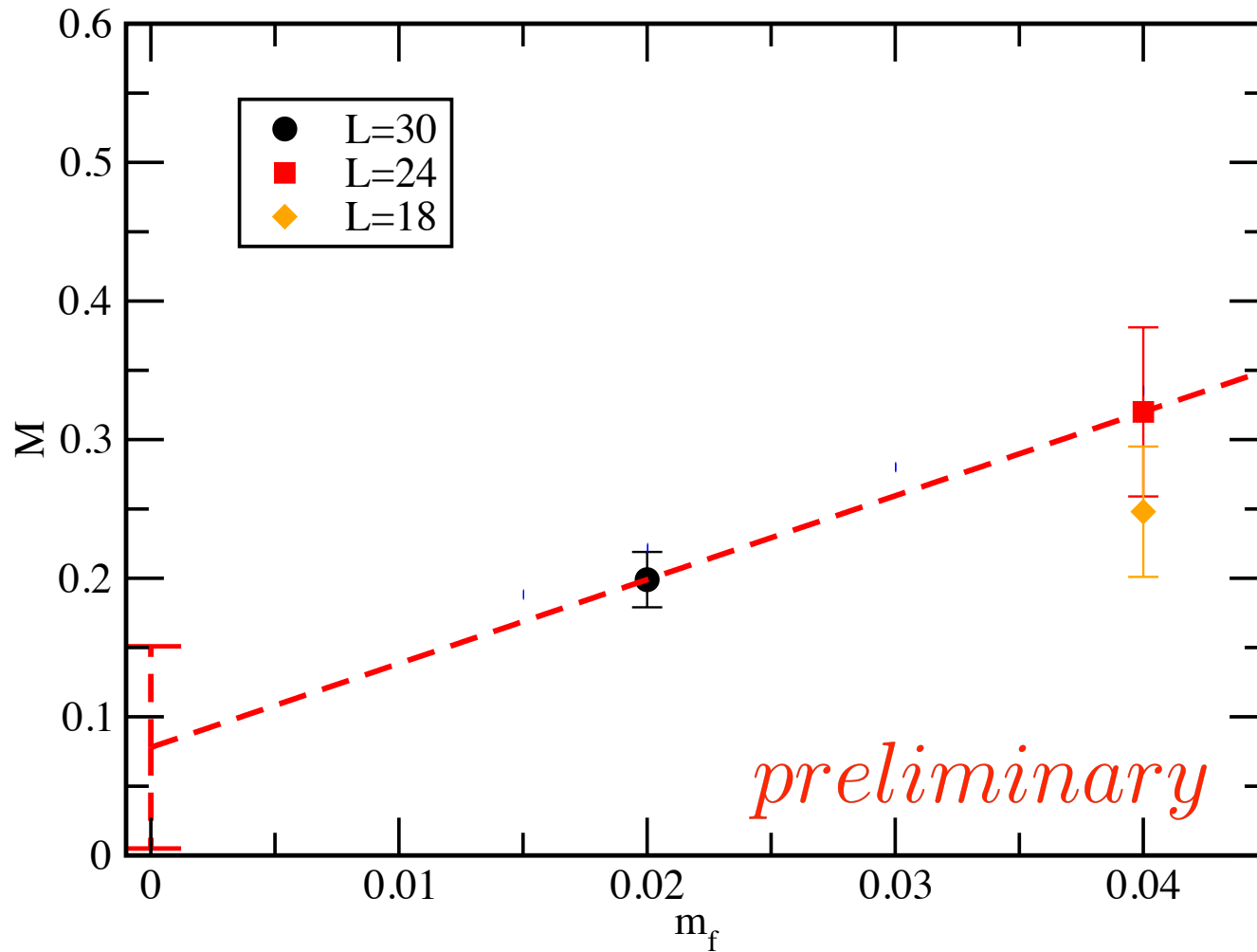
Comparison with vector meson mass [Nf=8]

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.

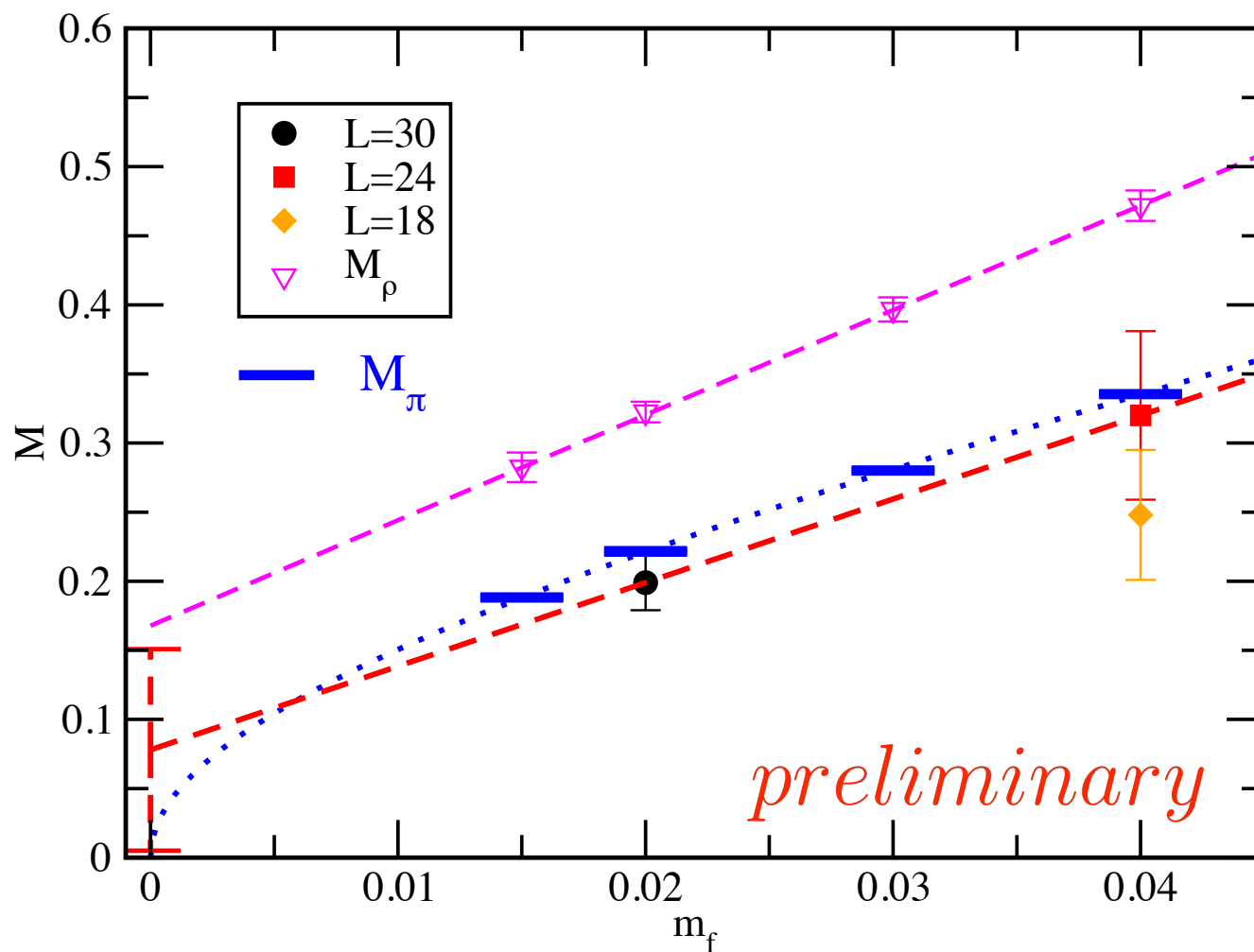Simple estimate of the scalar mass in the chiral limit

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

2pt linear extrapolation

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

Chiral limit extrapolation (ChPT-like fit)

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

Summary

Summary

•Many flavor SU(3) gauge theory is being investigated.
•In this talk, We focus on the Nf=8 and 12 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 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 (many things to do)
careful study of chiral limit extrapolation, discritization errors, finite volume effects,
study of decay width (dilaton decay constant),
consistency check of the LHC results
Comparison with Nf=4 QCD

END
Thank you