Lattice study of flavor-singlet scalar in large N_f QCD

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(LatKMI Collaboration)

Refs. $N_f = 12$: Phys. Rev. Lett. 111(2013)162001
$N_f = 8$: arXiv:1309.0711 (Lattice2013 Proceedings) + Update

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  - Recent studies in our project
  - Difficulty of calculation
  - Flavor-singlet scalar in $N_f = 12$ QCD
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Recent study of LatKMI Collaboration

PRD86(2012)054506; PRD87(2013)094511

Search for candidate of walking technicolor from lattice calculation

$N_f = 4$ QCD: Spontaneous chiral symmetry breaking

$N_f = 12$ QCD: Consistent with conformal phase
[Talk: Aoki and Ohki]

$N_f = 8$ QCD may be candidate of Walking technicolor
[Talk: Aoki and Nagai]

- Spontaneous chiral symmetry breaking
  $F_\pi \neq 0$ and $F_\pi/m_\pi \to \infty$ towards $m_f \to 0$
- Slow running (walking) coupling in wide scale range
  Different behaviors of F_π in light and middle m_f
- Large anomalous mass dimension $\gamma^* \sim 1$ in walking region
  $\gamma = 0.62$–0.97: Hyperscaling-like behavior in middle m_f
- Light composite scalar $\Leftarrow$ Important to check!

Calculation of flavor-singlet scalar in (approximate) conformal theory

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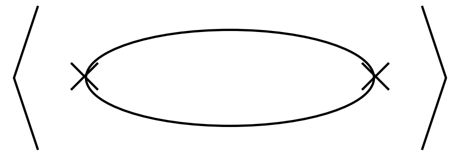
Calculation of flavor-singlet scalar in (approximate) conformal theory

Difficulty of flavor-singlet scalar meson

- Flavor non-singlet scalar meson $S_{NS}(t) = \sum_{\vec{x}} \overline{\psi}_a(\vec{x},t)\psi_b(\vec{x},t) \ (a \neq b)$

$\langle 0|S_{NS}(t)S^{\dagger}_{NS}(0)|0\rangle \quad =$  $= -C(t)$

c.f. m_π, F_π from non-singlet pseudoscalar

Calc. cost: $O(100)$ configurations $\times$ $O(1)$ $D^{-1}[U](x,y)$

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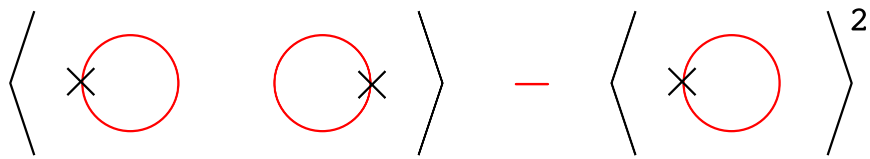
$\langle 0|S(t)S^{\dagger}(0)|0\rangle \quad = -C(t) + (N_f/4)D(t)$ (disconnected)

$D(t) =$ 

Much harder but essential for flavor-singlet

Calc. cost: $O(10000)$ configurations $\times$ $O(100)$ $D^{-1}[U](x,x)$

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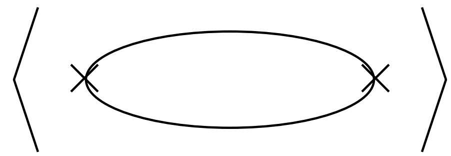
$\langle 0|S_{NS}(t)S^{\dagger}_{NS}(0)|0\rangle \quad =$  $= -C(t)$

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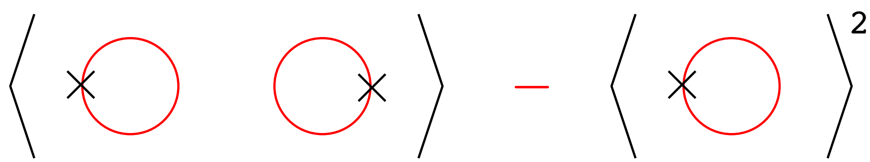
$D(t) =$ 

Much harder but essential for flavor-singlet

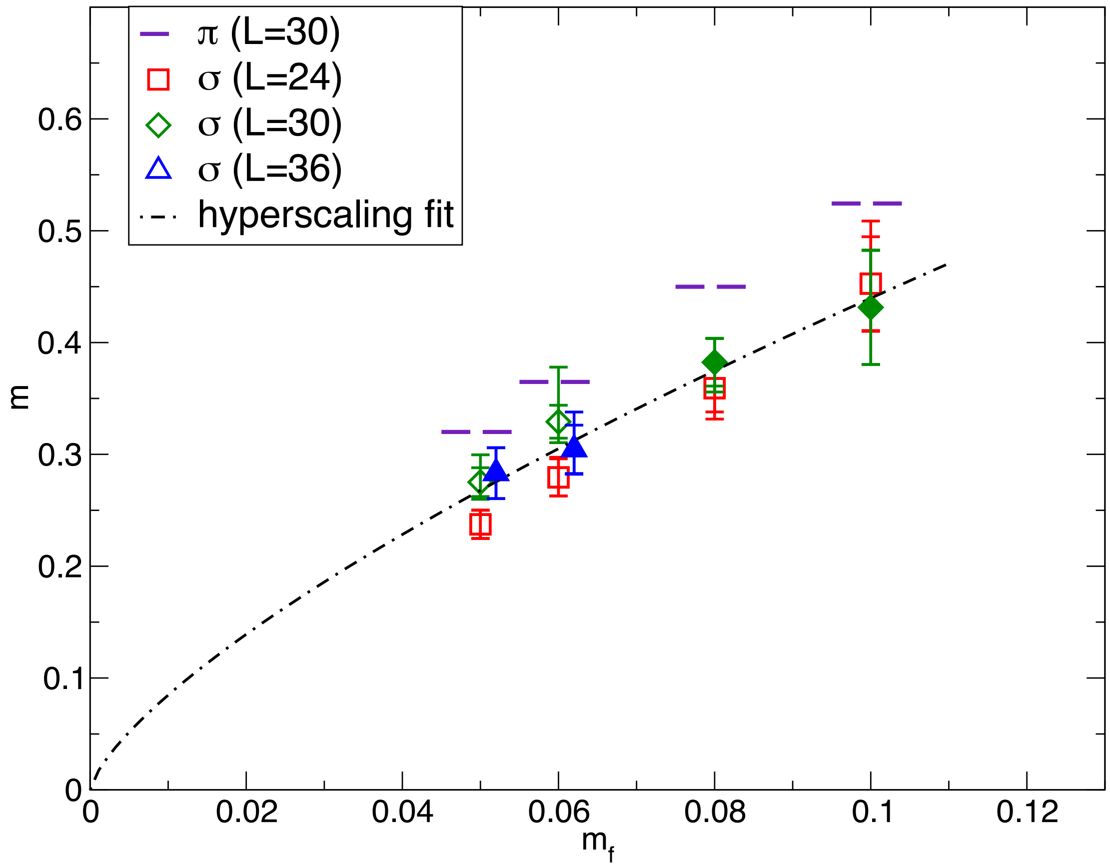
Calc. cost: $O(10000)$ configurations $\times$ $O(10)$ $D^{-1}[U](x,x)$

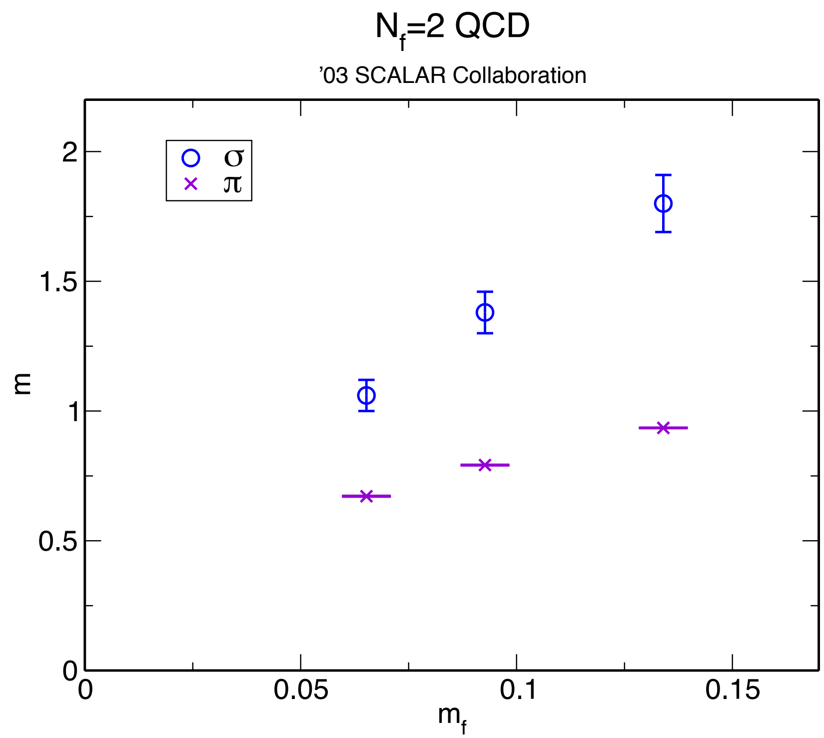
Noise reduction method

'97 Venkataraman and Kilcup

Flavor-singlet scalar mass m_σ in $N_f = 12$

Phys. Rev. Lett. 111(2013)162001 [Talk: Aoki and Ohki]





Lighter than π in all m_f: Much different from usual QCD

Conformal symmetry may make σ light

Encouraging result for walking technicolor

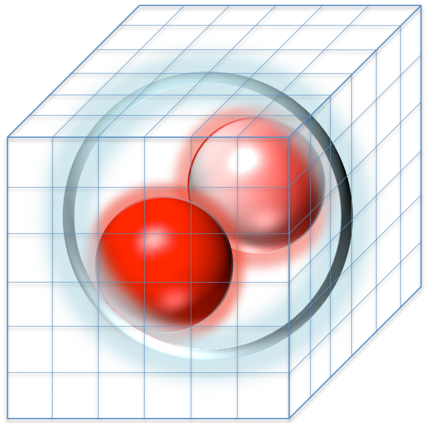
Flavor-singlet scalar in $N_f = 8$ QCD

$N_f = 8$ QCD may be candidate of walking theory; PRD87(2013)094511

[Talk: Aoki and Nagai]

If flavor-singlet scalar is light

$\rightarrow$ Possibility of composite Higgs (technidilaton)



Required conditon to explain $m_{\text{Higgs}}/v_{\text{EW}} \sim 0.5$

$$m_\sigma/F \sim 1 \text{ in } m_f = 0 \text{ limit}$$

c.f. usual QCD $m_\sigma/F \sim$ 4–5

Purpose

1. Different from usual QCD?
2. Estimate m_σ/F in $m_f = 0$ limit

Flavor-singlet scalar in $N_f = 8$ QCD

report of preliminary results arXiv:1309.0711

May be candidate of walking theory; PRD87(2013)094511

Simulation parameters

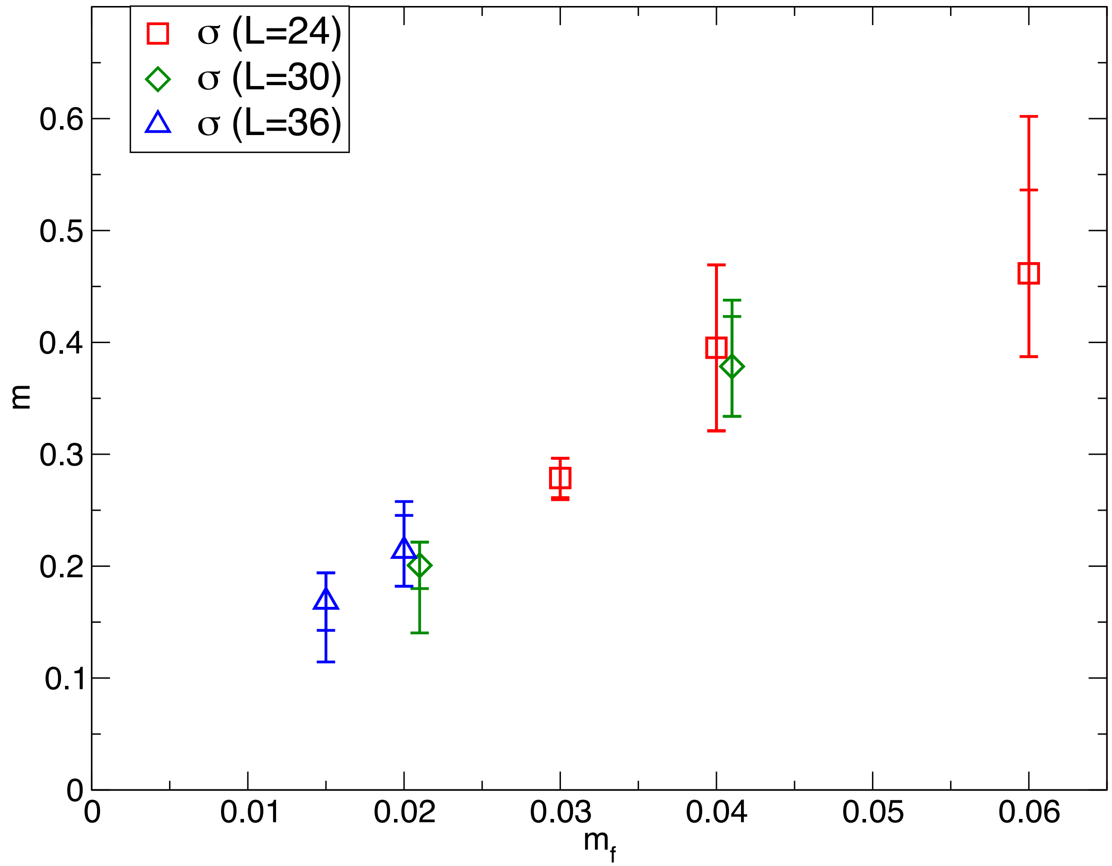
- Common setup: HISQ/Tree action
  calculation of m_σ
- $\beta = 3.8$ same as spectrum study
- Huge number of configurations
- Five m_f for chiral extrapolation
- Noise reduction method with $N_r = 64$

L, T	m_f	confs
24,32	0.03	27400
	0.04	5500
	0.06	18000
30,40	0.02	8000
	0.04	12600
36,48	0.02	2900
	0.015	2900

All results are preliminary.

Machines: φ at KMI, CX400 at Nagoya Univ.,
CX400 and HA8000 at Kyushu Univ.

Flavor-singlet scalar mass m_σ in $N_f = 8$

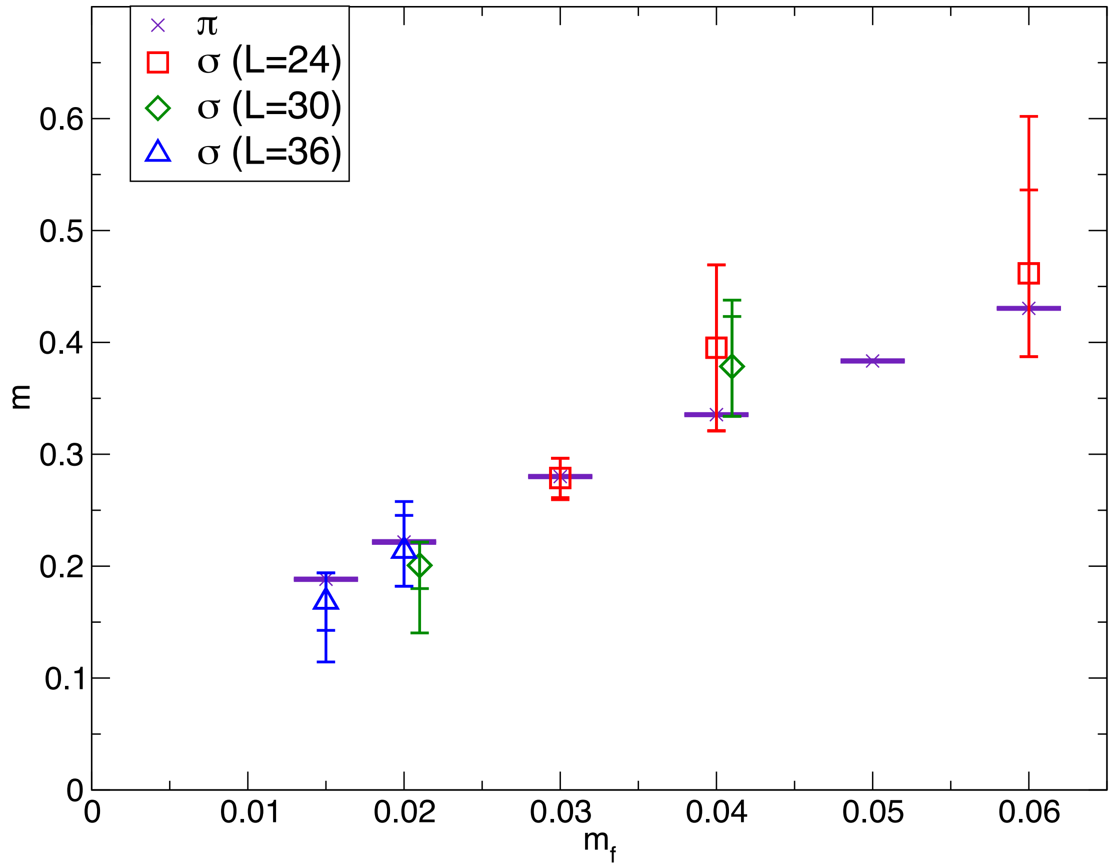


Reasonable signals with statistical error $< 20\%$

Systematic error from fit range dependence of m_σ

Finite volume effect seems under control

Flavor-singlet scalar mass m_σ in $N_f = 8$



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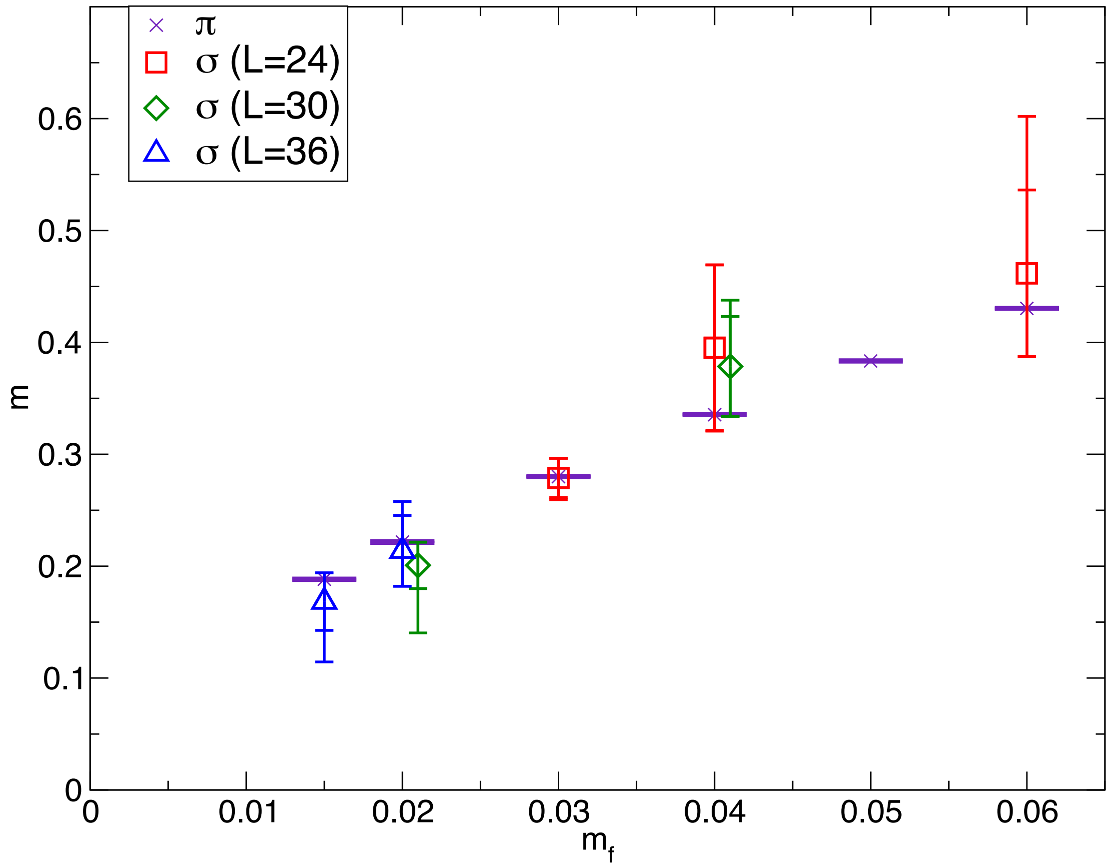
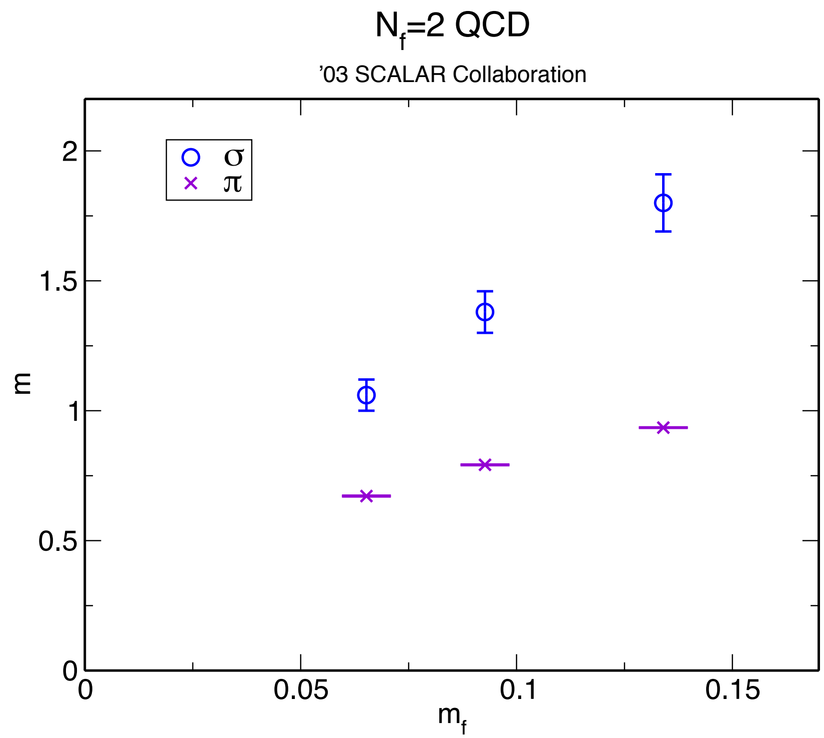
$m_\sigma \sim m_\pi$ in all m_f

Flavor-singlet scalar mass m_σ in $N_f = 8$



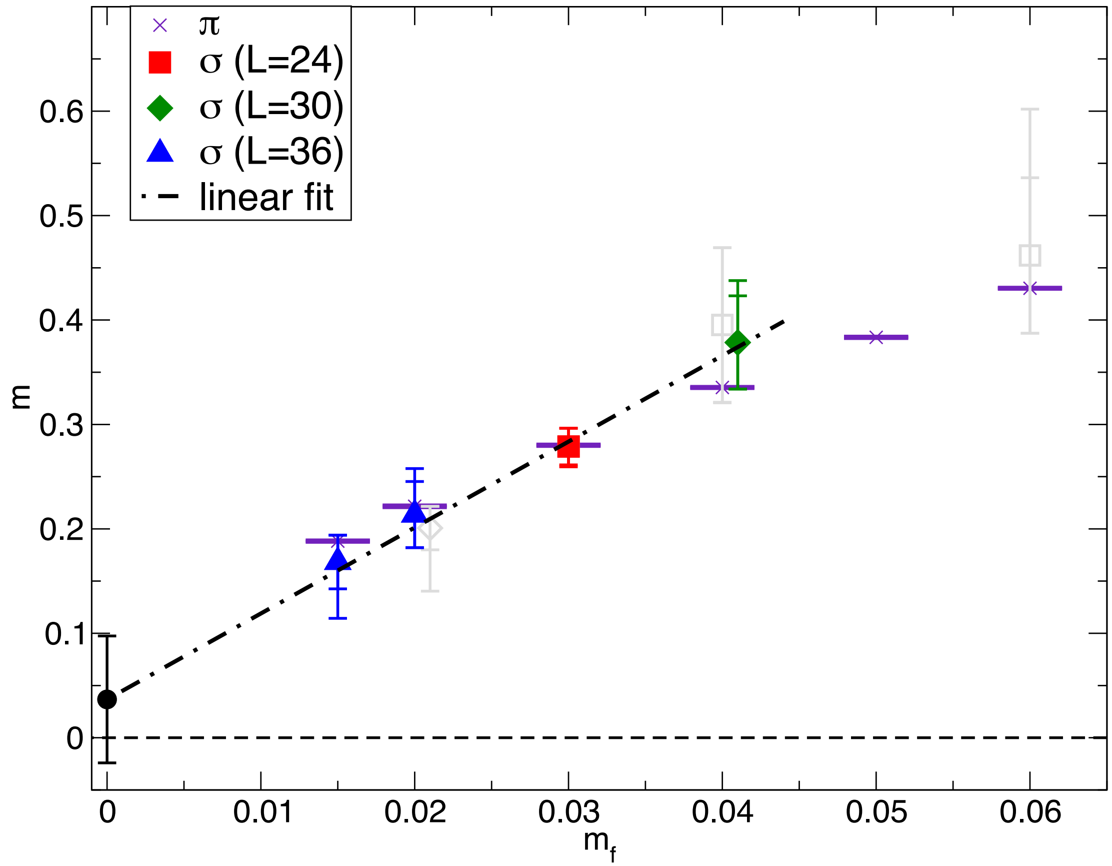


Reasonable signals with statistical error $< 20\%$

Systematic error from fit range dependence of m_σ

$m_\sigma \sim m_\pi$ in all m_f, much different from $N_f = 2$ QCD

Chiral extrapolation (1) in $N_f = 8$



$$m_\sigma = m_0 + A m_f\text{: } m_0 = 0.038(61) \rightarrow \frac{m_\sigma}{F} = 1.7(2.8)$$

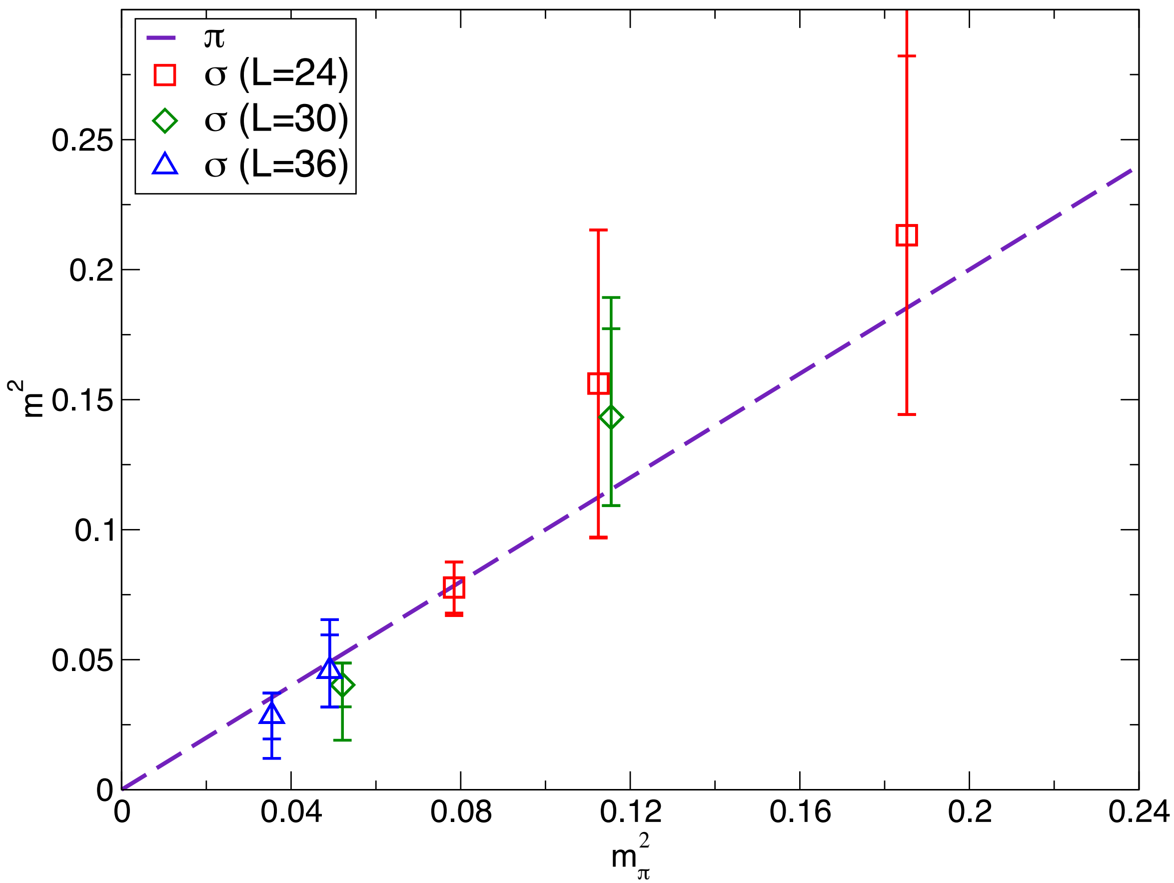
$F = 0.0219(7)$ PRD87(2013)094511

c.f.) 1 family model: $m_{\text{Higgs}} = 210(340)$ GeV

Chiral extrapolation (2) in $N_f = 8$

ChPT with scale symmetry breaking '13 Matsuzaki and Yamawaki

$$m_\sigma^2 = m_0^2 + C \cdot m_\pi^2 + (\text{chiral log of } m_\pi)$$



$$m_\sigma \sim m_\pi \to C \sim 1$$

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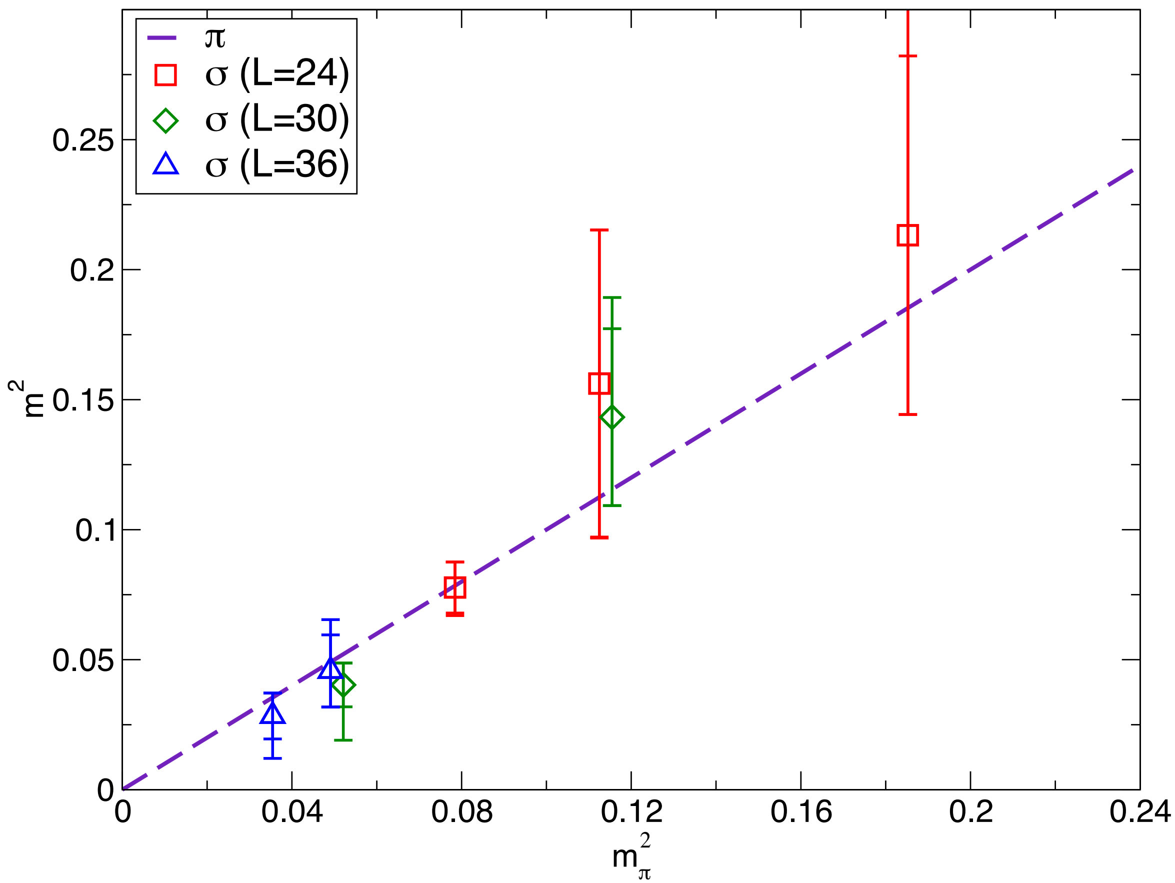

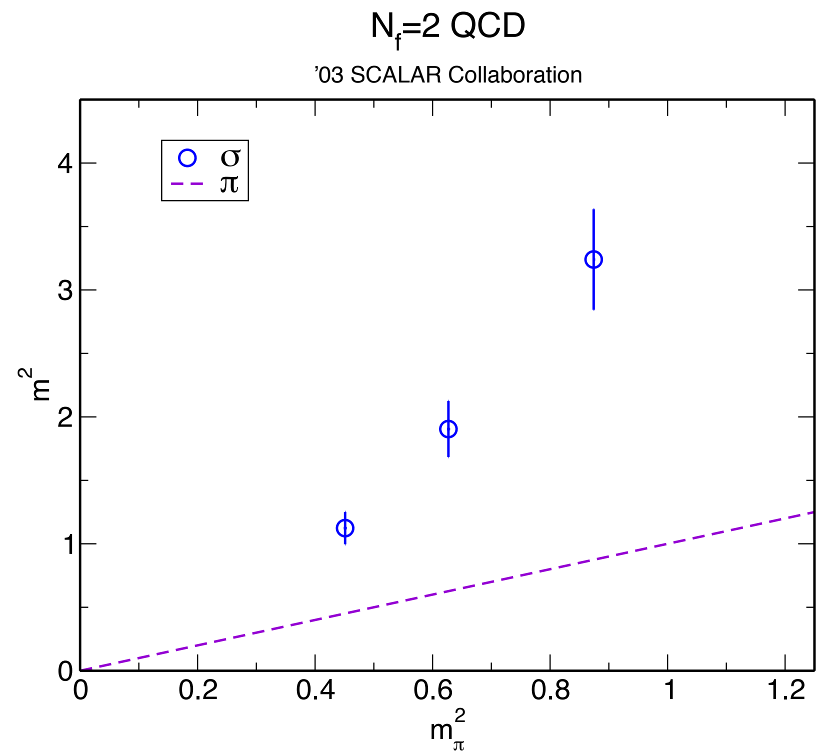

$m_\sigma \sim m_\pi \to C \sim 1$: different from $N_f = 2$ QCD

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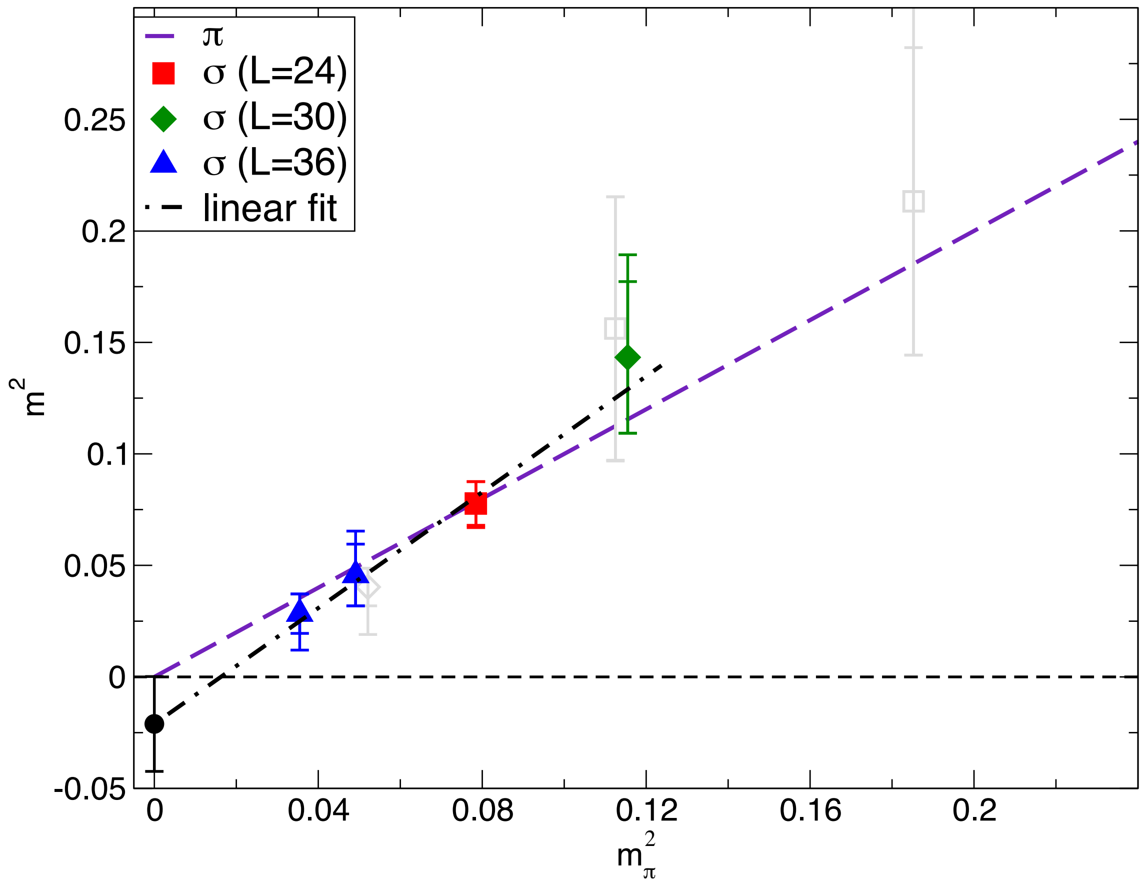

$m_0^2 < 0$: data not in $m_\sigma > m_\pi$ region

Need data at smaller m_f where $m_\sigma > m_\pi$ as in usual QCD

$N_f = 8$ chiral broken phase [Talk: Aoki and Nagai]

Summary

Flavor-singlet scalar is important in walking technicolor theory.
Difficult due to huge noise in lattice simulation
$\Rightarrow$ Noise reduction method and large N_{conf} $O(10000)$

Results of $N_f = 12$ QCD (consistent with conformal phase)
- $m_\sigma < m_\pi$; much different from small N_f QCD
- Conformal symmetry may make σ light

Results of $N_f = 8$ QCD (may be candidate of walking technicolor)
- $m_\sigma \sim m_\pi$; much different from small N_f QCD
- Might be reflection of approximate conformal symmetry
- Need more data at smaller m_f for chiral extrapolation
  Linear chiral extrapolation : $m_\sigma/F = 1.7(2.8)$

Possibility of light composite Higgs $m_{\text{Higgs}} \sim v_{EW}$
(technidilaton)

Future work:

Smaller m_f data for more reliable chiral extrapolation