Behavior of the S parameter in the crossover region between walking and QCD-like regimes of an $SU(N)$ gauge theory

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Refs.

M. Kurachi and R. Shrock, hep-ph/0605290

M. Kurachi and R. Shrock, Phys. Rev. D74:056003 (2006)

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Outline

1. Introduction

2. Large -N_f QCD

3. Methods

4. Numerical results

5. Summary

Introduction

Possible scenarios for EWSB

- With fundamental Higgs $\cdots\cdots$ SM, etc.
- Without fundamental Higgs
  - Perturbative $\cdots\cdots\cdots\cdot$ Higgsless models, etc.
  - Non-perturbative $\cdots\cdots$ Technicolor models, etc.

Introduction

Possible scenarios for EWSB

- With fundamental Higgs $\cdots\cdots$ SM, etc.
- Without fundamental Higgs
  - Perturbative $\cdots\cdots\cdots$ Higgsless models, etc.
  - Non-perturbative $\cdots\cdots$ Technicolor models, etc.

The last one is the least hypothetical

We know dynamical symmetry breaking actually occurs in the real world (i.e., chiral symmetry breaking in QCD)

The S parameter in Technicolor models

- Perturbative calculations are not reliable

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We can use the knowledge of QCD if we assume

that technicolor is a just a scaled-up version of QCD

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- Phenomenological difficulties...

Possibly large contribution to the S parameter

from the strong dynamics

(EW precision measurements require $S \sim O(0.1)$)

We investigate the large flavor $SU(N)$ gauge theory

as an example of Non-QCD-like dynamics

What is the large flavor $SU(N)$ gauge theory?

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$SU(N)$ gauge theory with an arbitrary

number (N_f) of massless fermions

(Note : "large flavor" here does not mean $N_f \to \infty$)

Here, we take $N = 3$ for concreteness,

so we call it the large -N_f QCD

What is interesting about the large N_f QCD?

Existence of the IR fixed point makes

the theory quite different from QCD

- Walking behavior of the running coupling

  (which is nice for solving the FCNC problem
  and providing large enough fermion masses)

- Chiral restoration

Two-loop running coupling in the large -N_f QCD

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

$(N_c = 3)$	$N_f < 8$	$8 < N_f < 16.5$	$16.5 < N_f$
$b = \frac{1}{6\pi}(33 - 2N_f)$	$+$	$+$	$-$
$c = \frac{1}{12\pi^2}(153 - 19N_f)$	$+$	$-$	$-$

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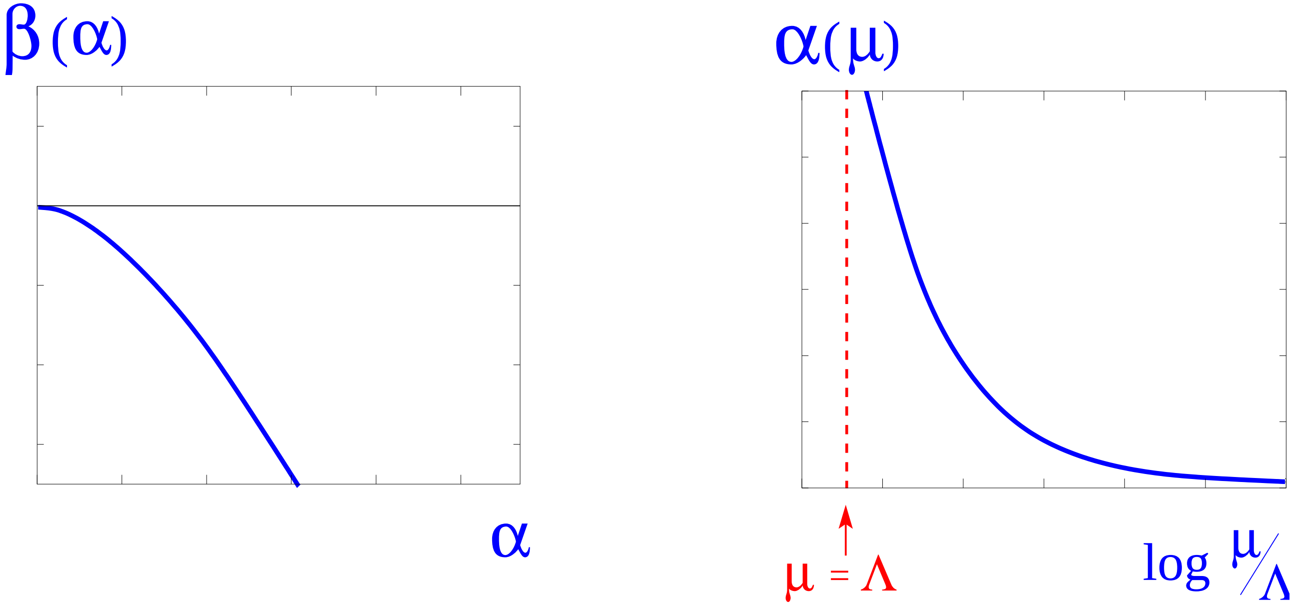

$$N_f < 8$$

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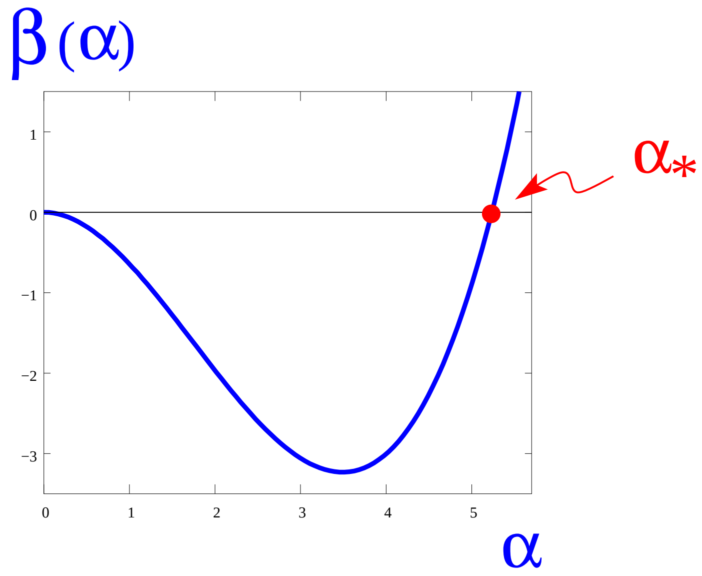

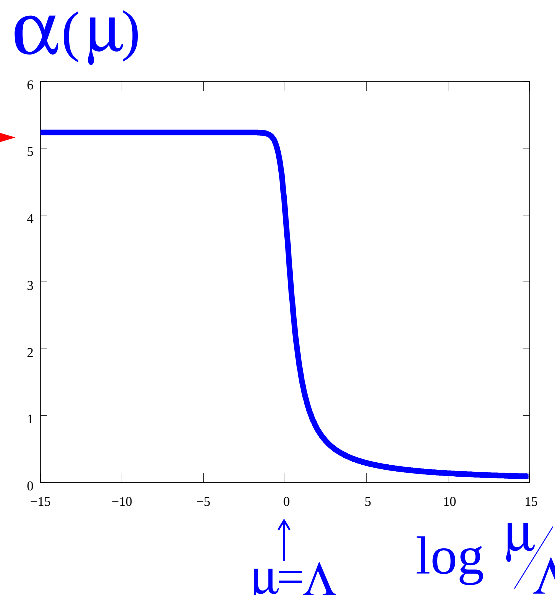

$$8 < N_f < 16.5 \quad (\alpha_* = -b/c)$$

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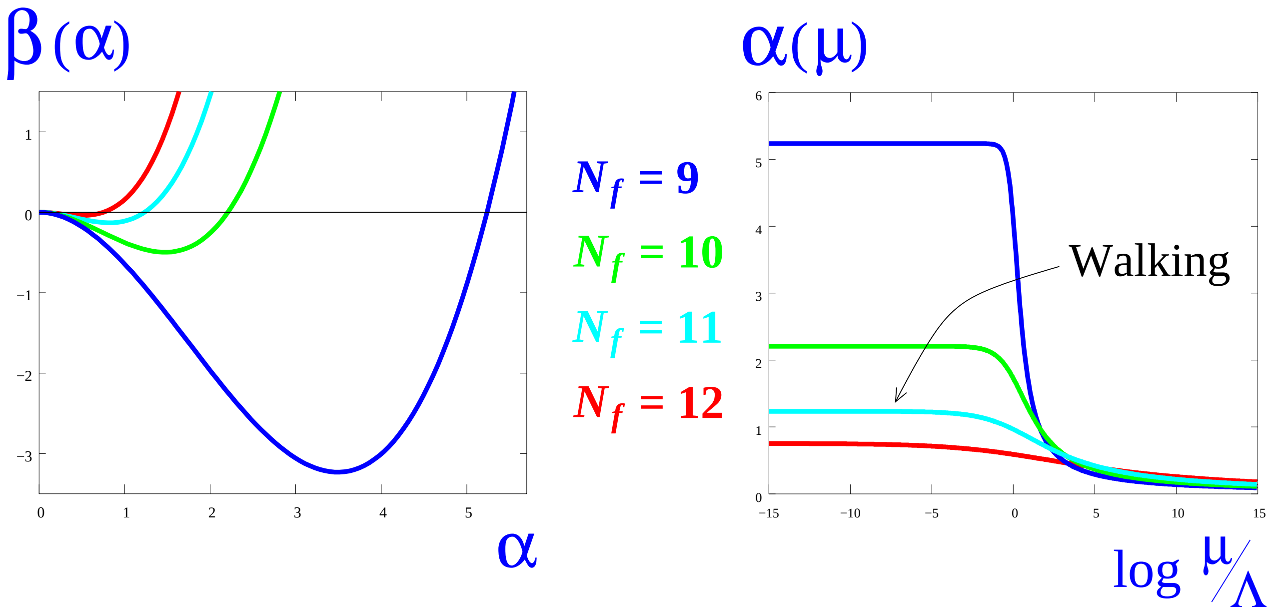

Chiral restoration at $N_f = N_f^{\rm cr} \simeq 12$ $(\alpha_* = \alpha_{\rm cr} = \pi/4)$

What is interesting about the large N_f QCD?

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- Walking behavior of the running coupling
- Chiral restoration

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Contribution to the S parameter might

be small compared to the QCD-like theory

How to calculate the S parameter

$$\hat{S} \equiv \frac{S}{(N_f/2)} = -4\pi \frac{d}{dq_E^2} \left[\Pi_{VV}(q_E^2) - \Pi_{AA}(q_E^2) \right] \Big|_{q_E^2=0}$$

- Current-current correlator Π_{JJ} :

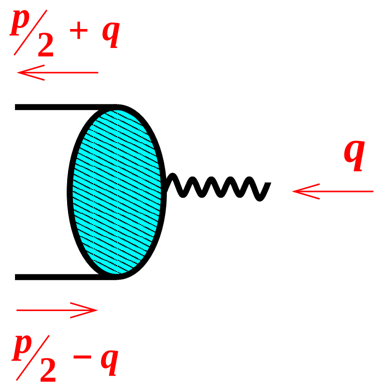
$$\delta^{ab} \left(\frac{q_\mu q_\nu}{q^2} - g_{\mu\nu} \right) \Pi_{JJ}(q^2) = i \int d^4x \; e^{iqx} \; \langle 0 | T J_\mu^a(x) J_\nu^b(0) | 0 \rangle$$

$$J_\mu^a(x) = \begin{cases} V_\mu^a(x) = \bar{\psi}(x) \frac{\lambda^a}{2} \gamma_\mu \psi(x), \\ A_\mu^a(x) = \bar{\psi}(x) \frac{\lambda^a}{2} \gamma_\mu \gamma_5 \psi(x), \end{cases}$$

How to calculate the current correlators

We need

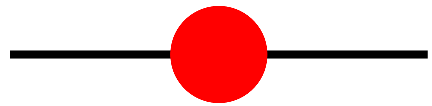
- the three point vertex function $\chi^{(J)}_{\alpha\beta}$:



$$\delta^j_i \left(\frac{\lambda^a}{2}\right)^{f'}_{f} \int \frac{d^4p}{(2\pi)^4} e^{-ipr} \chi^{(J)}_{\alpha\beta}(p;q,\epsilon)$$

$$= \epsilon^\mu \int d^4x e^{iqx} \langle 0|T\ \psi_{\alpha i f}(r/2)\ \bar{\psi}^{jf'}_{\beta}(-r/2)\ J^a_\mu(x)\ |0\rangle$$

- and the full fermion propagator :



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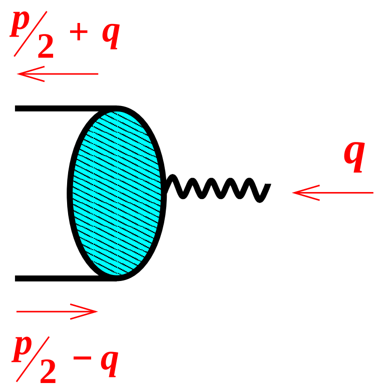

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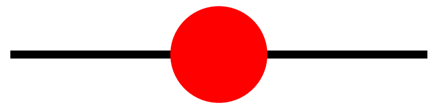
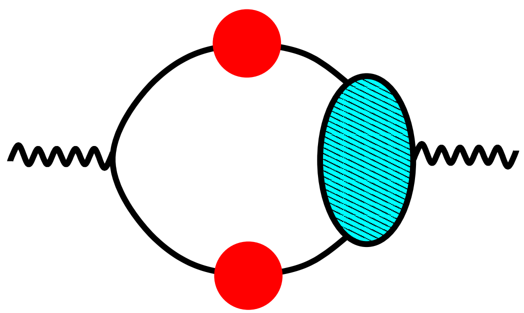




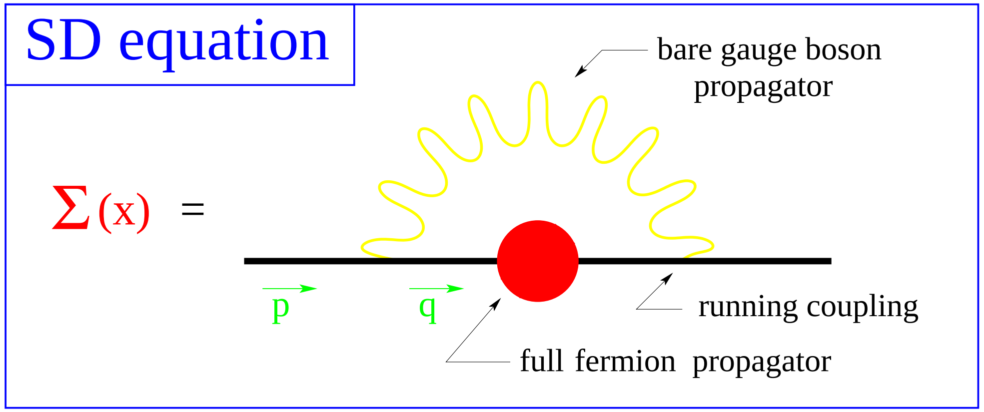
$\Pi_{JJ}(q_E^2)$

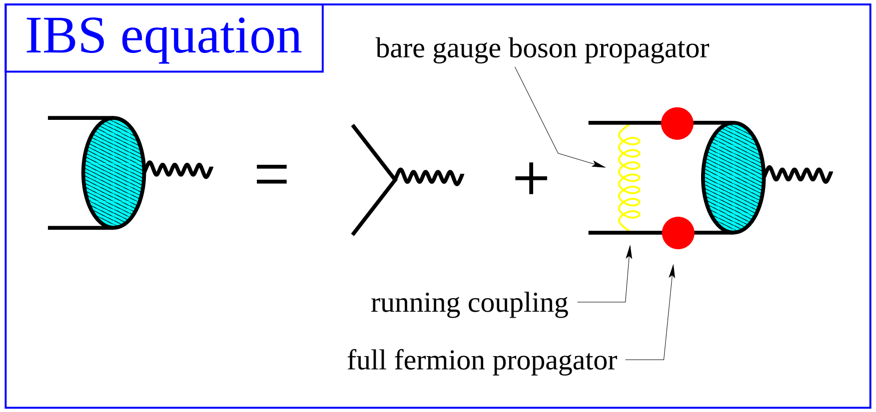
How to calculate the three-point vertex

We numerically solve the inhomogeneous BS equation

and the SD equation simultaneously

with the improved ladder approximation





Numerical Result

We calculate the S parameter of the large N_f QCD in the range from $N_f \simeq 10$ $(\alpha_* \simeq 1.8)$ to

$$N_f \simeq N_f^{\rm crit} \simeq 12 \ (\alpha_* \simeq 0.9)$$

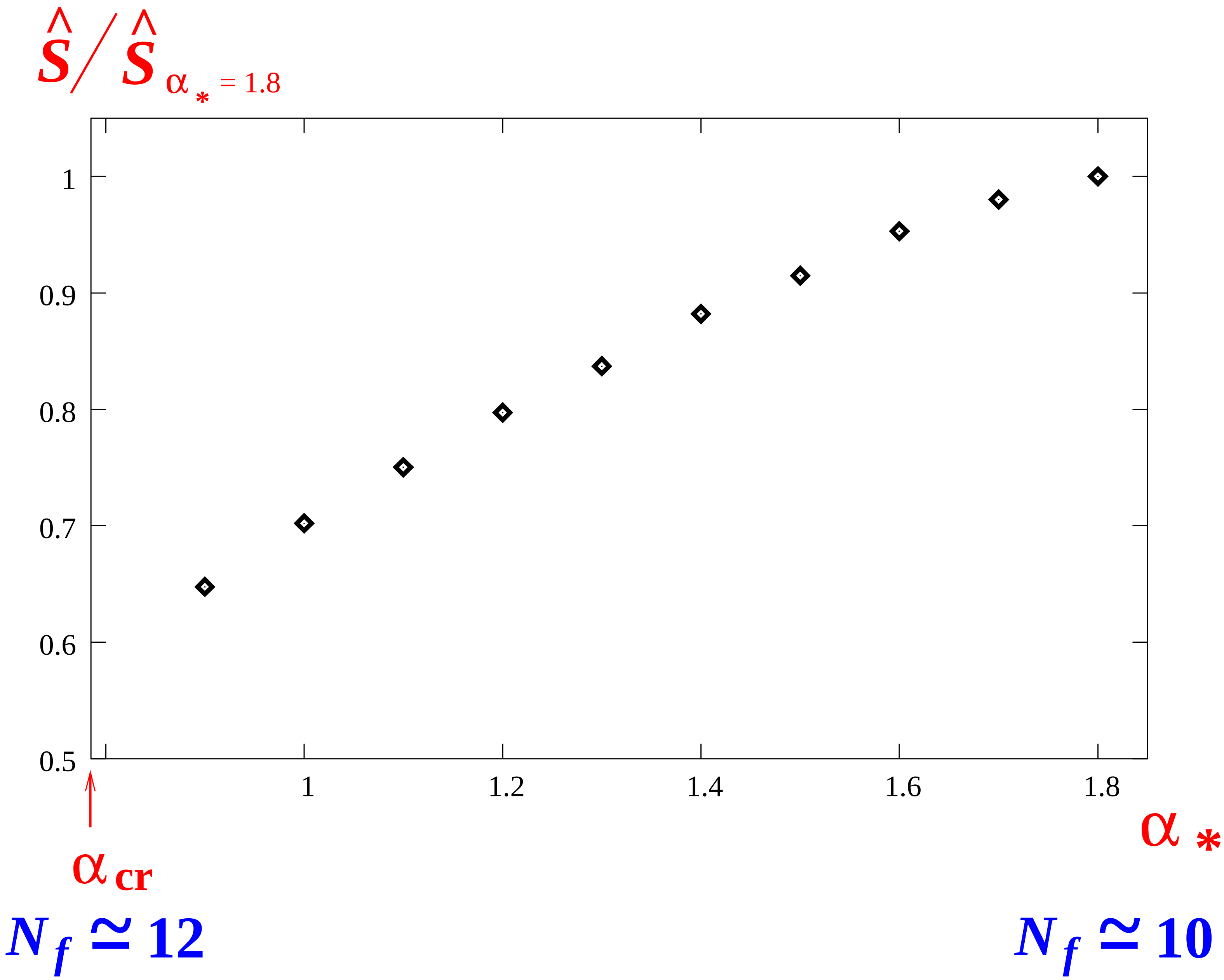
- $N_f \simeq N_f^{\rm crit} \simeq 12$: Walking regime $(\Sigma/\Lambda \ll 1)$

  $\Longrightarrow$ The scale relevant for the determination of physical quantities is near the IR fixed point

- $N_f \simeq 10$: QCD-like regime $(\Sigma/\Lambda \simeq 0.2)$

  $\Longrightarrow$ The scale relevant for the determination of physical quantities is farther from the IR fixed point

Numerical Result



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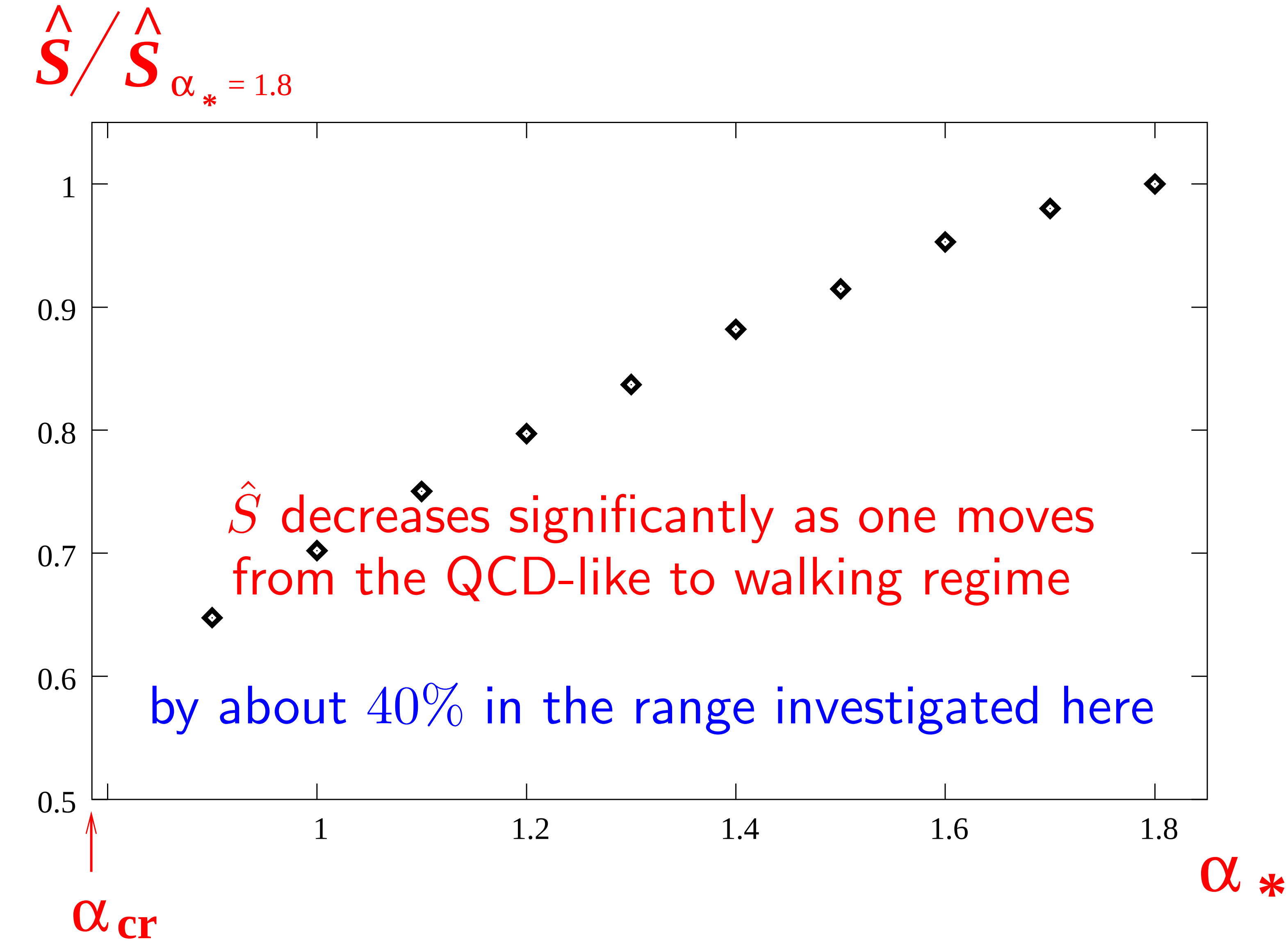

$\hat{S}$ decreases significantly as one moves from the QCD-like to walking regime

by about 40% in the range investigated here

$N_f \simeq 12$ $N_f \simeq 10$

Summary

- We calculated the S parameter in the large N_f QCD by solving the SD and IBS equations with the improved ladder approximation
- We found that contribution from ladder diagrams to $\hat{S}$ decreases significantly as one moves from the QCD-like to walking regime
- This results motivate us to do further investigations of walking gauge theories as candidates for the origin of the EWSB