Conformal fixed point of SU(3) gauge theory with 12 fundamental massless fermions

arXiv:1109.5806 [hep-lat] and work in progress

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Lattice Meets Experiment 2011: Beyond the Standard Model, 2011/10/15 @ FermiLab

collaborators

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Numerical simulation was carried out on
NEC SX-8 and SR16000 in YITP, Kyoto
NEC SX-8 in RCNP, Osaka
SR11000 and BlueGene in KEK
100 GPUs in Taiwan

Summary of our work

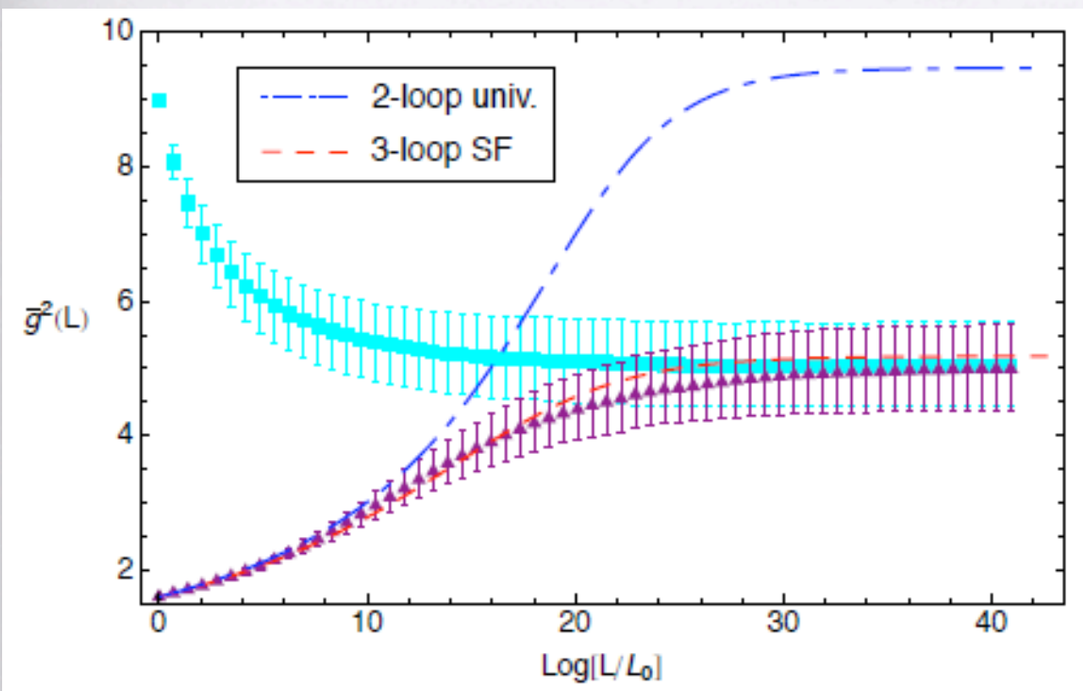
- Study SU(3) gauge theory coupled with 12 massless fundamental fermions
- Measured the running coupling constant in Twisted Polykov loop scheme and found an IR fixed point
- Derived the universal quantities around the fixed point
  - critical exponent of the beta fn.
  - mass anomalous dimension

Running coupling

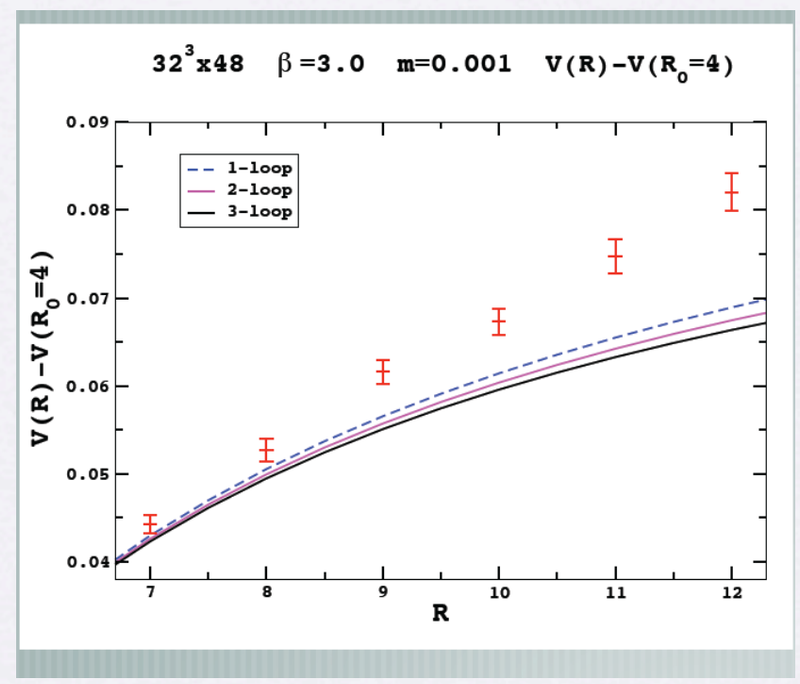
Present status on the study of IR behavior in the case of SU(3) Nf=12

Running coupling constant

Appelquist et al. (SF scheme)
Phys.Rev.D79:076010,2009



Fodor et al. (potential scheme)
PoS LAT2009:055,2009,
talk at Lattice2010



Plot: Slide of K.Holland's talk at Lattice2010

The existence of the fixed point should be scheme independent.

Our result

arXiv:1109.5806 [hep-lat]

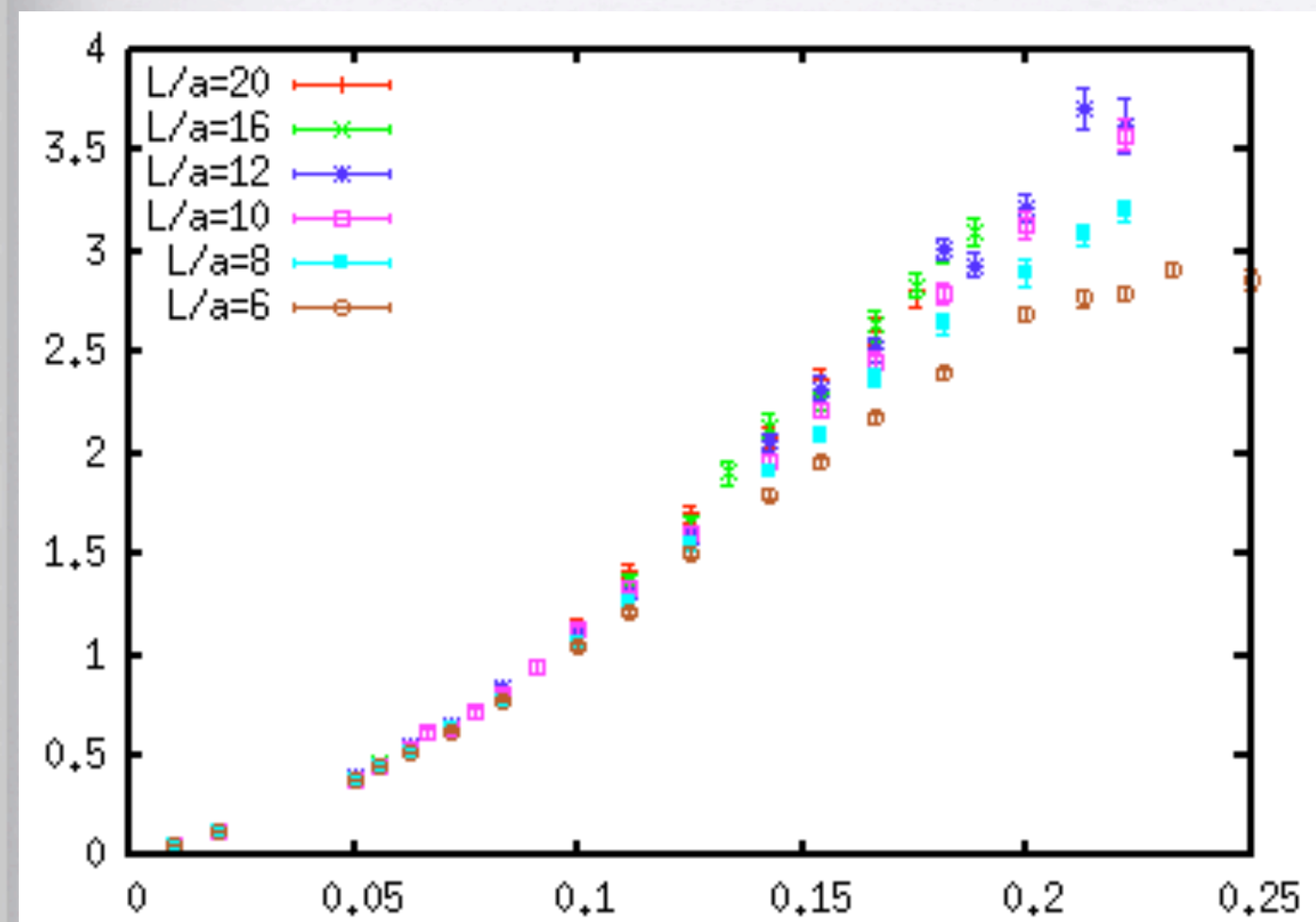
Twisted Polyakov loop scheme
(No O(a) error)

$$g_{TP}^2 = \frac{1}{k}\frac{\langle \sum_{y,z} P_1(y,z,L/2a) P_1(0,0,0)^* \rangle}{\langle \sum_{x,y} P_3(x,y,L/2a) P_3(0,0,0)^* \rangle}$$

Consider O(a^2) error in taking continuum limit

Raw data in TPL scheme

$g^2_{TPL}(\beta, L/a)$



$1/\beta (= g_0^2/6)$

2-3 % statistical error.

# of Trj is 8,000- 897,000.

Fitting fn. for beta interpolation

$$g^2_{TPL}(\beta, L/a) = \frac{6}{\beta} + \sum_{j=1}^{N} \frac{C_j(L/a)}{\beta^{j+1}}$$

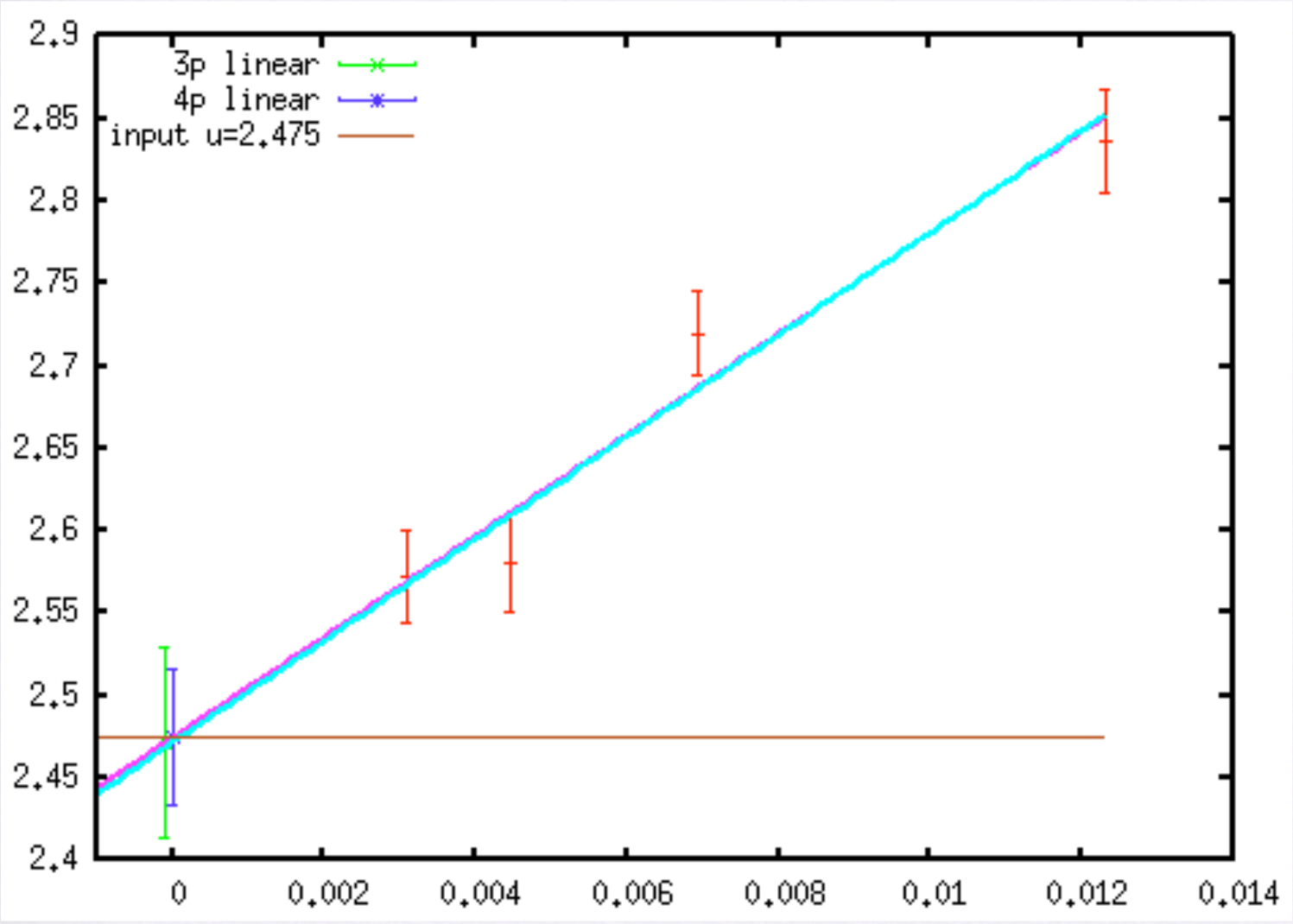
s=1.5 step scaling

L/a=6 -> L/a=9
L/a=8 -> L/a=12
L/a=10 -> L/a=15
L/a=12 -> L/a=18

For L/a = 9, 15 and 18,
we estimate values of g2 for a given β
by the linear interpolation in (a/L)2.

Continuum extrapolation on TPL scheme

$\Sigma(g^2(L), L/a; s)$



$(a/L)^2$

s=1.5 step scaling

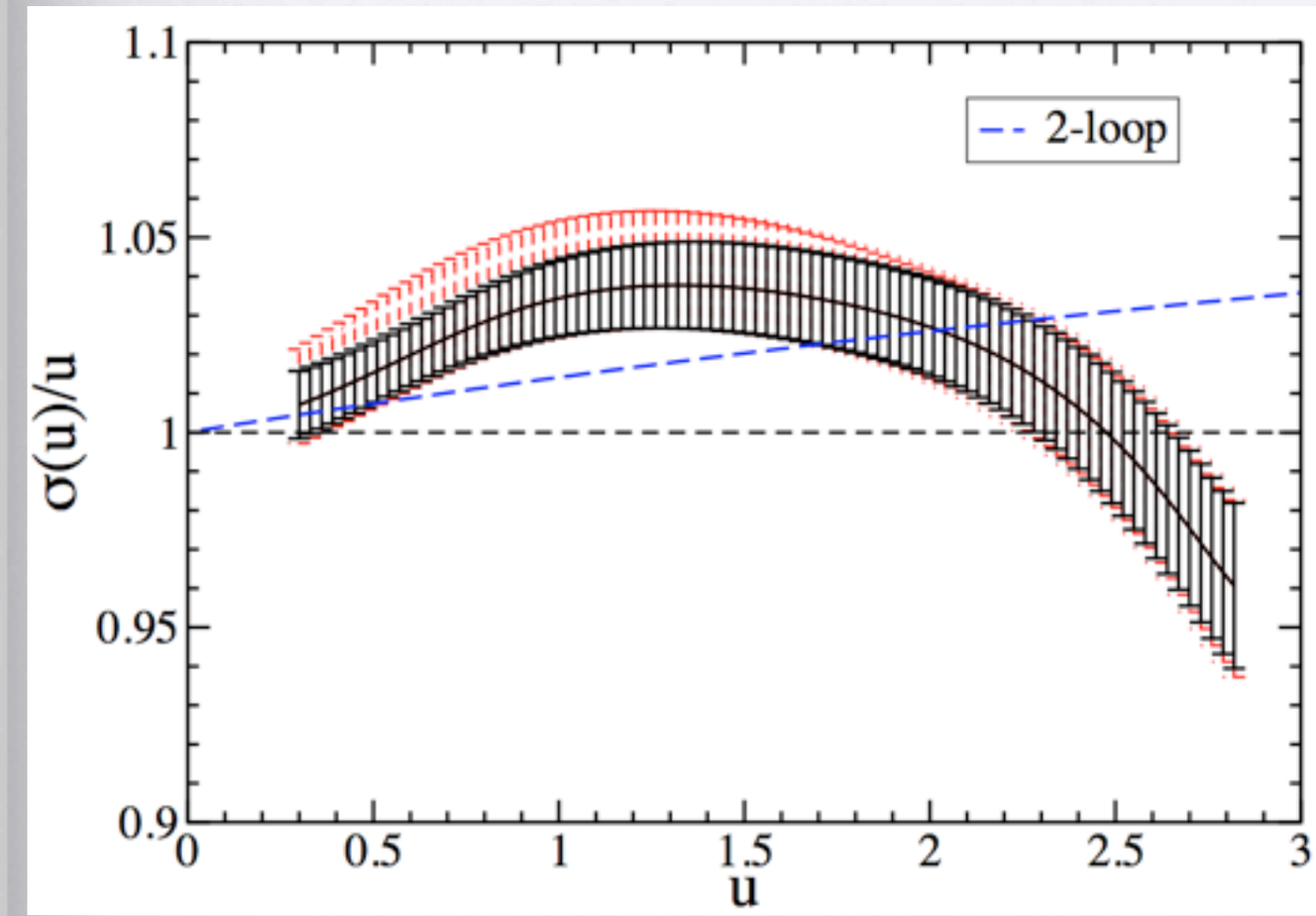
L/a=6 -> L/a=9
L/a=8 -> L/a=12
L/a=10 -> L/a=15
L/a=12 -> L/a=18

2 loop prediction in this region is

$\sigma(u = 2.48) \sim 2.54$

The systematic error is small in the strong coupling region.

Growth ratio of TPL coupling



TPL coupling shows the IR fixed point at

$$g^{2*} = 2.48 \pm 0.18(stat.)^{+0.07}_{-0.08}(sys.)$$

Around the fixed point, the beta fn. can be approximated by the linear fn.

$$\beta(g^2) \sim \gamma_g^*(g^{2*} - g^2)$$

Our result

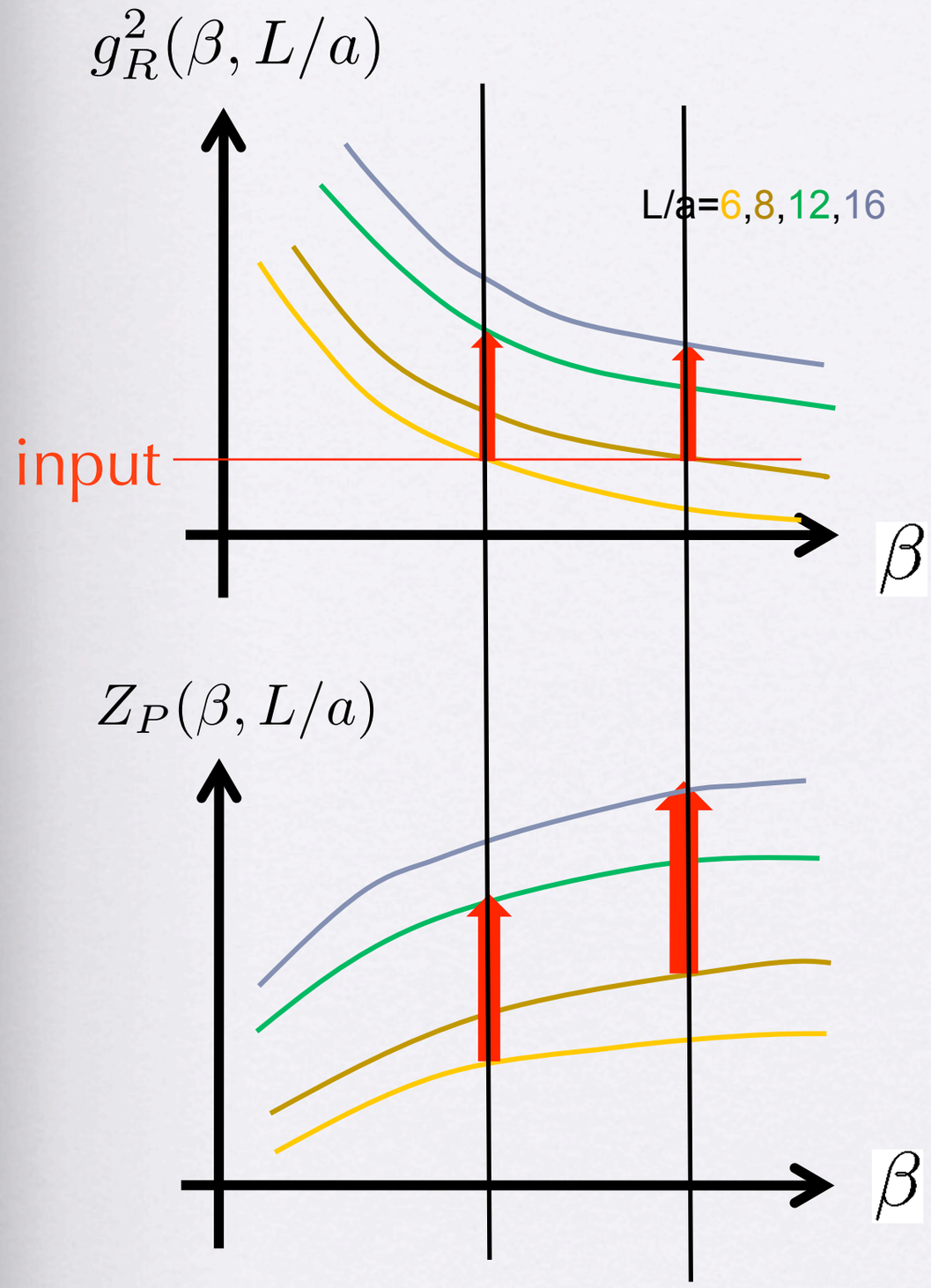
$$\gamma_g^* = 0.52^{+0.27}_{-0.24}$$

SF scheme	2 loop at $g^{2*} = 9.4$	4 loop (MS bar)
$\gamma_g^* = 0.13 \pm 0.03$	$\gamma_g^* = 0.36$	$\gamma_g^* = 0.28$

Anomalous dimension

—Preliminary result—

A new scheme of the mass anomalous dimension



PCAC relation in QCD

$$\partial^\mu (A_R)_\mu = 2mP_R$$
$$= 2(Z_m \cdot m_0)(Z_m^{-1} \cdot P_0)$$

Measure the correlator of psuedo scalar op.

$$C_P(t) = \sum_x \langle P(t,x)P(0,0)\rangle$$

Renormalization condition

$$C_R(t) \equiv C_P^{tree}(t)$$

Definition of Z factor

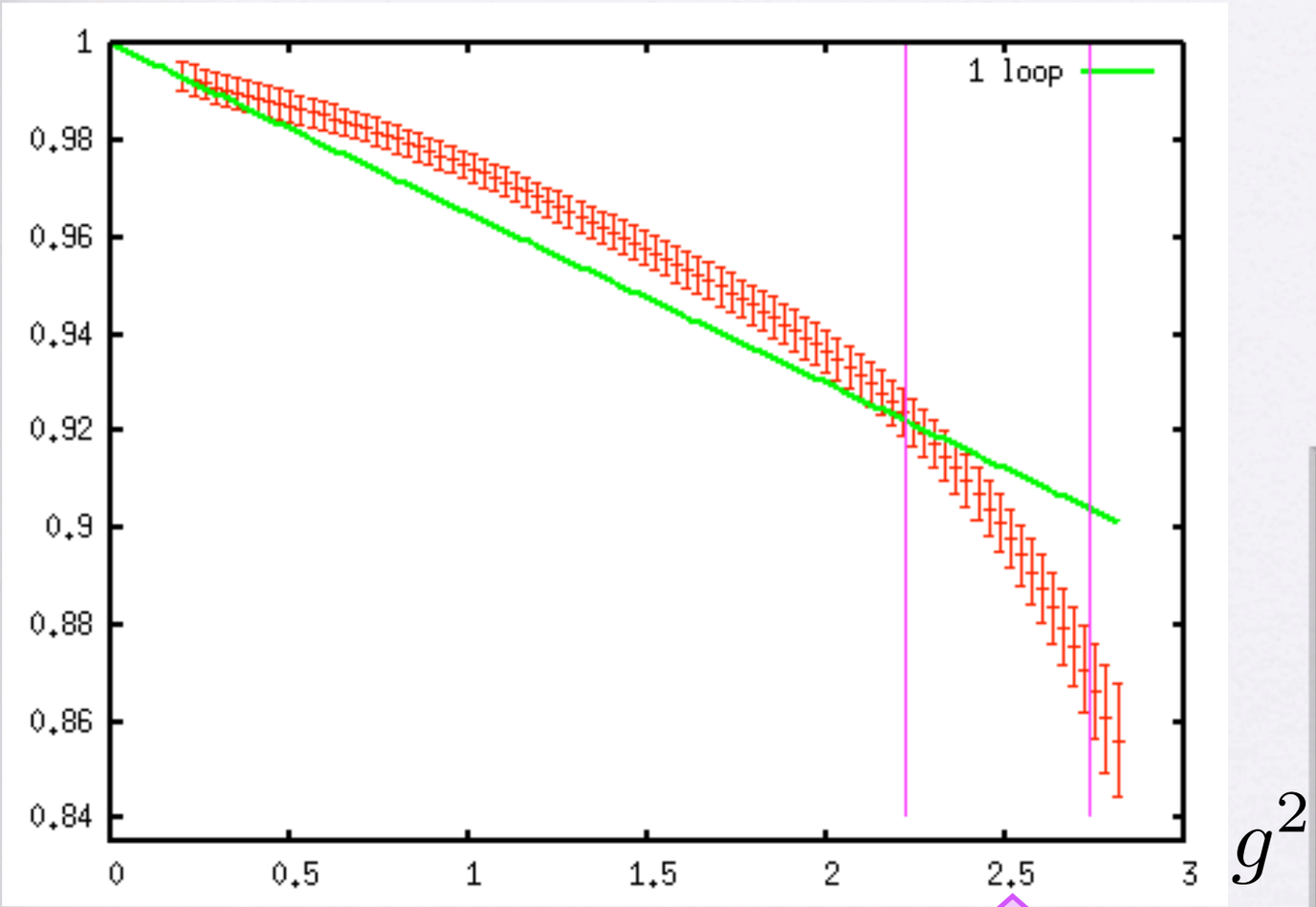
$$\boxed{Z_P(g_0) \equiv \sqrt{\frac{C_P^{tree}(t)}{C_P(t)}}}$$ at fixed t

Scaling function

$$\sigma_P(g^2, s) = \lim_{a\to 0} \left.\frac{Z_P(g_o, a/sL)}{Z_P(g_0, a/L)}\right|_{g^2=const}$$

Preliminary results

$\sigma_P(g^2)$



$$g^{2*} = 2.48 \pm 0.18(stat.)^{+0.07}_{-0.08}(sys.)$$

At the fixed point,

$$\gamma^* = -\frac{\ln(\sigma_P)}{\ln(s)}$$

$$0.11 \leq \gamma^*_m \leq 0.22$$

Perturbative results

2loop	3loop	4loop
0.773	0.312	0.253

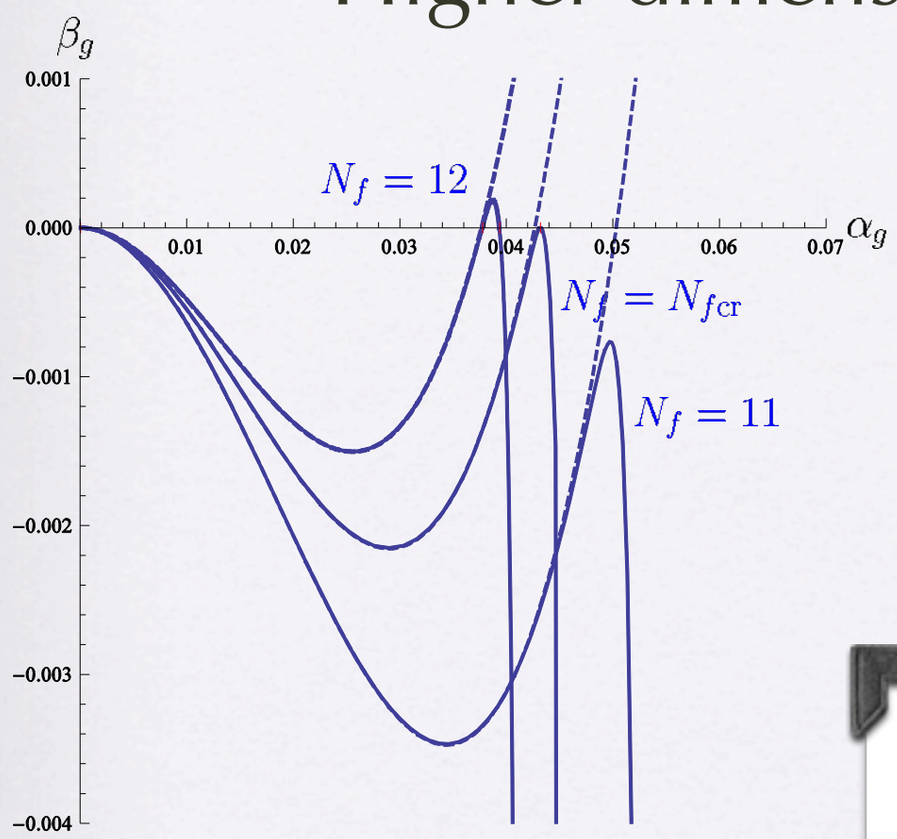
T.A.Ryttov and R.Shrock, Phys.Rev.D83,056011 (2011)

Lattice results

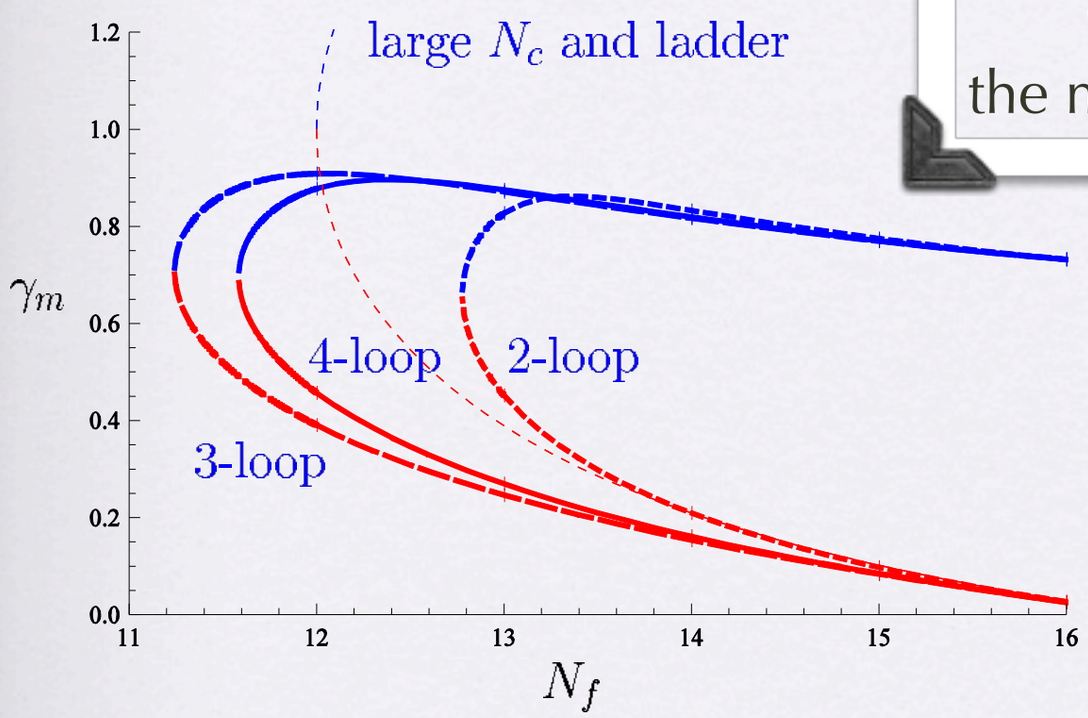
0.403(13) : T. Appelquist et al, Phys.Rev.D84:054501,2011.

0.47-0.58 : KMI group

Higher dimensional operator's effect



4-loop



Y. Kusafuka and H. Terao, [arXiv:1104.3606 [hep-ph]]
H. Fukano and F. Sannino, Phys.Rev.D82:035021,2010.

4 loop YM beta fn + 4 fermi interaction within ERG analysis

$$\gamma_m^* \sim 0.45$$

Around the nontrivial fixed point, higher dimensional op. might be large effect.

the lower bound of Nf becomes large,
the mass anomalous dimension becomes large.

Plots: Slide of Kusafuka's talk at JPS meeting, Sep 2011

Conclusion and Discussion

Is there IR fixed point in SU(3) Nf=12 theory?

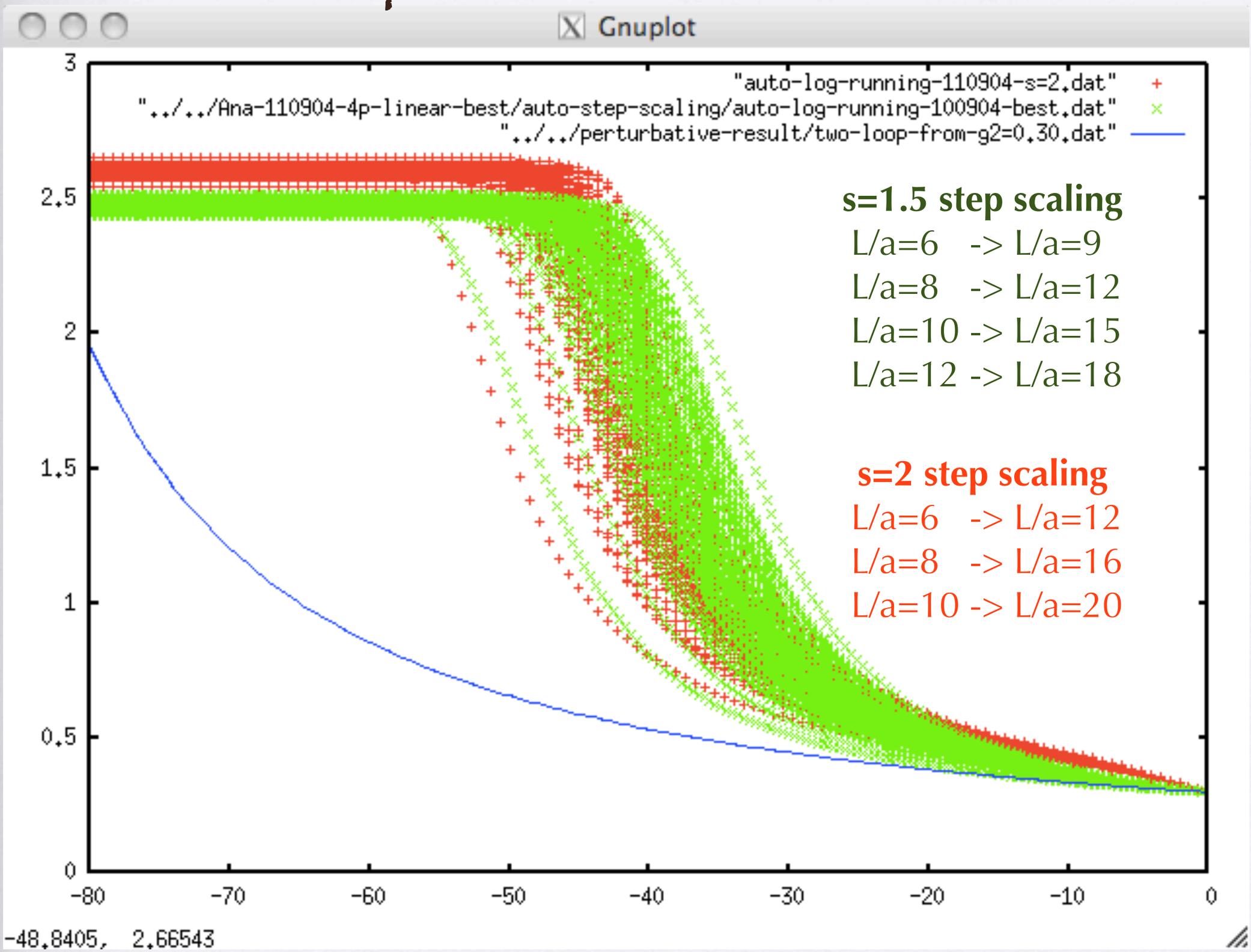
Appelquist group :YES (SF scheme g^2*~5, gamma_g =0.10-0.16)
Fodor group : NO (Potential scheme)
A. Hasenfratz :YES (MonteCalro RG, bare step scaling)
Our group :YES (TPL scheme g^2*~2.5, gamma_g=0.28-0.79)
The critical exponent is not consistent with each other

Chiral condensate

Fodor group : chiral symmetry is broken (huge lattice size and low beta region)
Columbia U group : chiral symmetry is broken
Appelquist group : the same data can be fitted by conformal hypothesis

Anomalous dimension for psuedo-scalar operator

Appelquist group : gamma*= 0.403(13) using conformal hypothesis with mass deformation
KMI group : gamma*~0.47-0.58
Our group : gamma*~0.11-0.22 by directly measurement

Lattice precise data will give phenomenological and theoretical information around nontrivial fixed point in near future.

comparison s=1.5 with s=2