Higgs compositeness in Sp(2N) gauge theory - part IV: Two-flavor Sp(4) gauge theory

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Lattice2017

✤ Model

Sp(4) gauge theory with 2 Dirac fermions in fundamental representation

$$\mathcal{L} = -\frac{1}{4} F^a_{\mu\nu} F_{a\mu\nu} + \bar{u}(i\gamma^\mu D_\mu - m)u + \bar{d}(i\gamma^\mu D_\mu - m)d$$

Global symmetry: SU(4) $\xrightarrow{\textbf{broken}}$ *Sp*(4)

$\langle \bar{u}u + \bar{d}d \rangle \neq 0$ at chiral limit

$\langle \bar{u}u + \bar{d}d \rangle \neq 0,\ m\bar{u}u,\ m\bar{d}d$ at non-zero mass

☞ ***5 Goldstone bosons***

UV theory of SO(6)/SO(5) **composite Higgs** models

J. Barnard, T. Gherghetta, T. S. Ray (2014)

Low energy EFT ⇨ Particle phenomenology

[B. Lucini's Talk @ Mon. 16:40]

✤ Field contents and observables

Field contents of the low-energy EFT (chiral PT & HLS)

Label	Operator	Meson	J^P
PS	$\overline{u}\gamma_5 d$	π	0^-
V	$\overline{u}\gamma_\mu d$	ρ	1^-
AV	$\overline{u}\gamma_5\gamma_\mu d$	a_1	1^+

Observables: **masses** and **decay constants**

Massless limit: 6 low-energy constants cannot be fixed

various quark masses

Leading order(LO): 7 low-energy constants ***at least two values of m_0***

Next-to-leading order(NLO): 12 low-energy constants

at least three values of m_0

✤ Masses and decay constants

Parametrization of meson two-point correlation functions

$$\langle 0|\bar{u}\gamma_5 d(t)\bar{u}\gamma_5 d(0)|0\rangle = -\frac{G_{\pi_1}^2}{V m_{\pi_1}} e^{-m_{\pi_1} t},$$

$$\langle 0|\bar{u}\gamma_\mu d(t)\bar{u}\gamma_\mu d(0)|0\rangle = -\frac{m_\rho f_\rho^2}{V} e^{-m_\rho t},$$

$$\langle 0|\bar{u}\gamma_\mu\gamma_5 d(t)\bar{u}\gamma_\mu\gamma_5 d(0)|0\rangle = -\frac{m_{a1} f_{a1}^2}{V} e^{-m_{a1} t}.$$

Meson decay constants

$$\langle 0|\bar{u}\gamma_\mu\gamma_5 d|\pi_1\rangle = i f_{\pi_1} p_\mu, \quad \langle 0|\bar{u}\gamma_\mu d|V\rangle = i f_\rho m_\rho \epsilon_\mu, \quad \langle 0|\bar{u}\gamma_\mu\gamma_5 d|A\rangle = i f_{a1} m_{a1} \epsilon_\mu.$$

For the pseudo-GB, use PCAC relation

$$f_\pi = \frac{2 m_{pcac}}{m_\pi^2} G_\pi, \quad m_{pcac} = \frac{\partial_t \langle 0|\bar{u}\gamma_0\gamma_5 d(t)\bar{u}\gamma_5 d(0)|0\rangle}{2\langle 0|\bar{u}\gamma_5 d(t)\bar{u}\gamma_5 d(0)|0\rangle}$$

✤ Simulation details

Gauge configurations: *pure Sp(4) using HB* & *dynamical Sp(4) using HMC*

[D. Vadacchino's Talk @ Mon. 17:00] **[E. Bennett's Talk @ Mon. 17:20]**

~200 configurations for each ensemble

HiRep code modified by encoding Sp(4) gauge group and resymplectization

Del Debbio, Patella, Pica (2010)

Thermalization time is determined by monitoring Plaquette values.

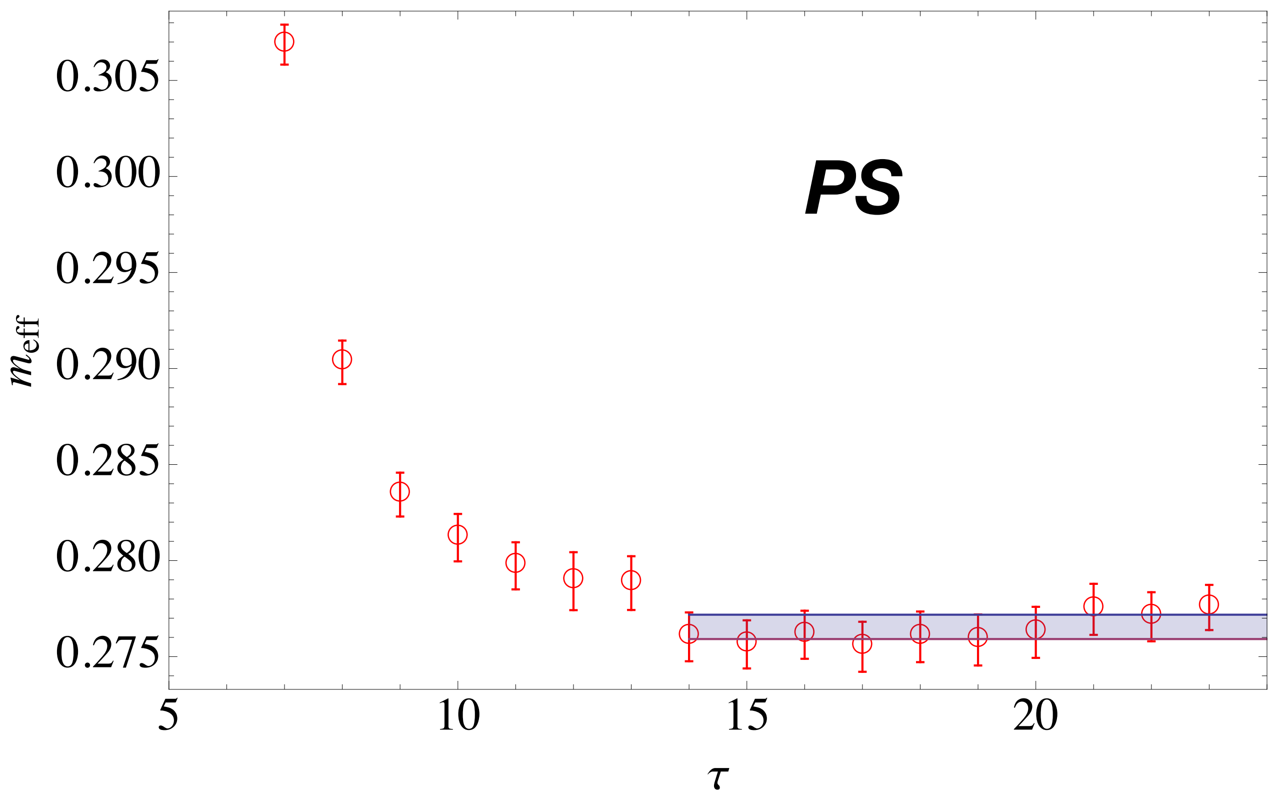
Two adjacent configurations are separated by roughly one autocorrelation time(12~32 trajectories).

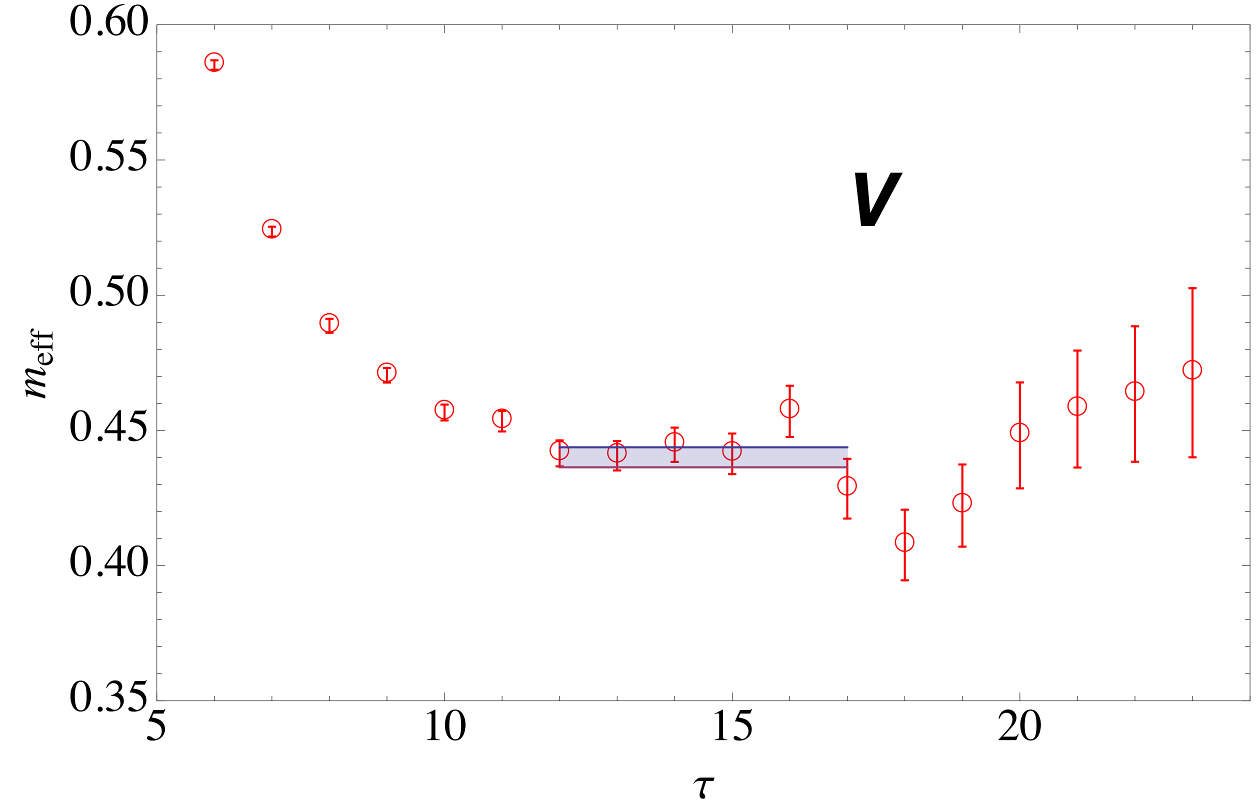
Coarse lattices

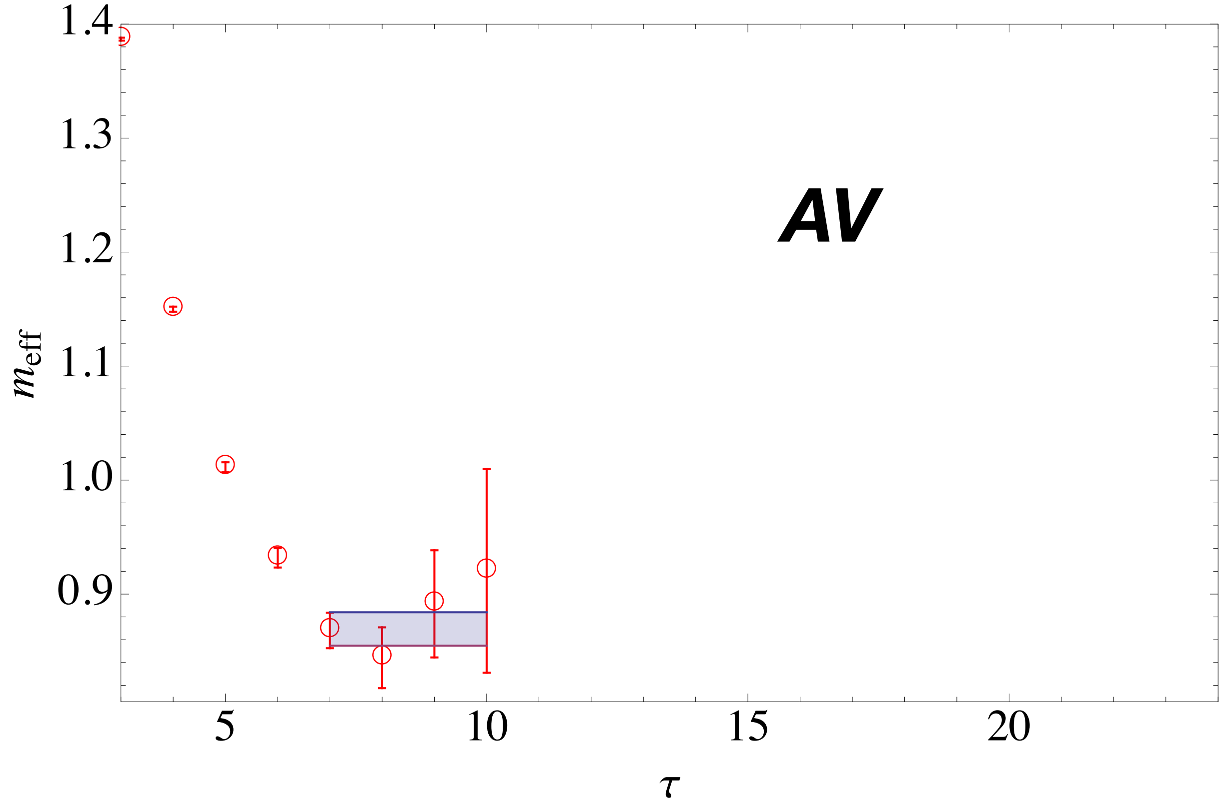
Quenched case: $\beta = 7.62$, $m_0 = -0.7 \sim -0.82$ on 48×16^3, 48×24^3

Dynamical case: $\beta = 6.9$, $m_0 = -0.89 \sim -0.92$ on 32×16^3

✤ Numerical results: Quenched case

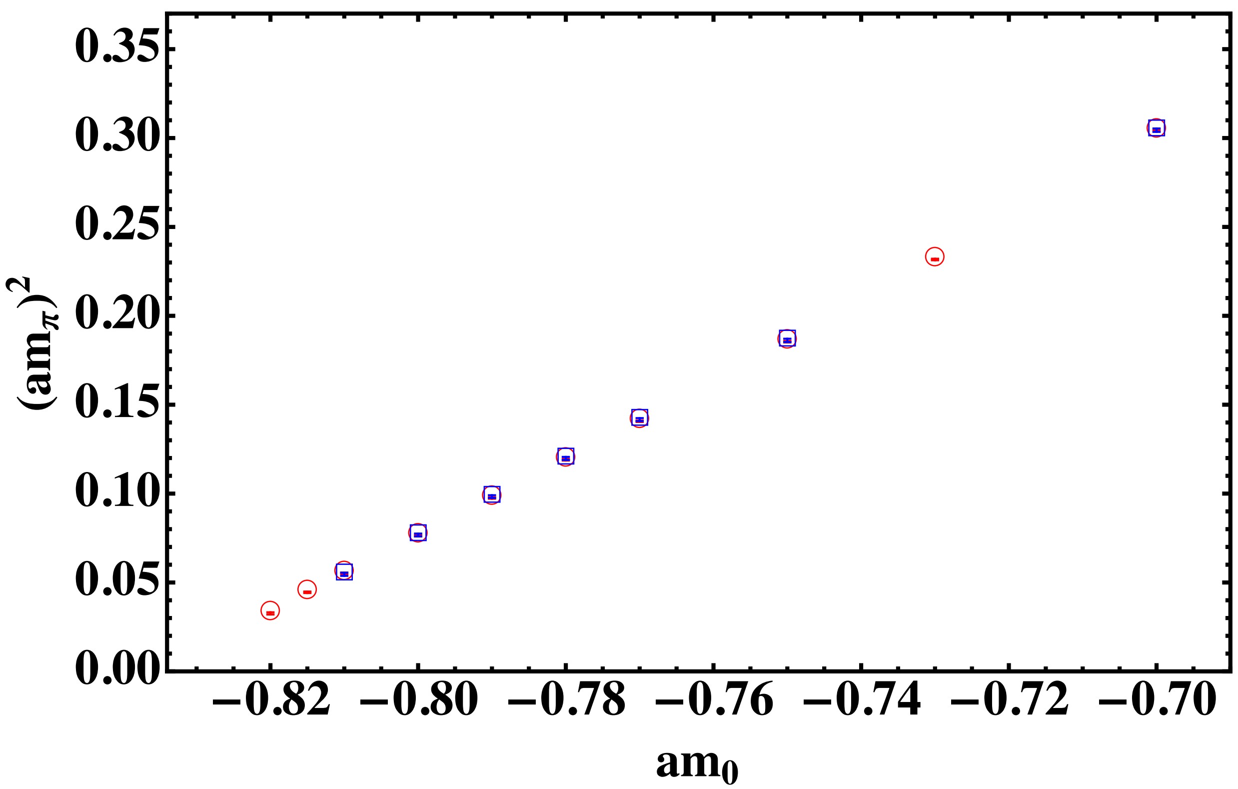


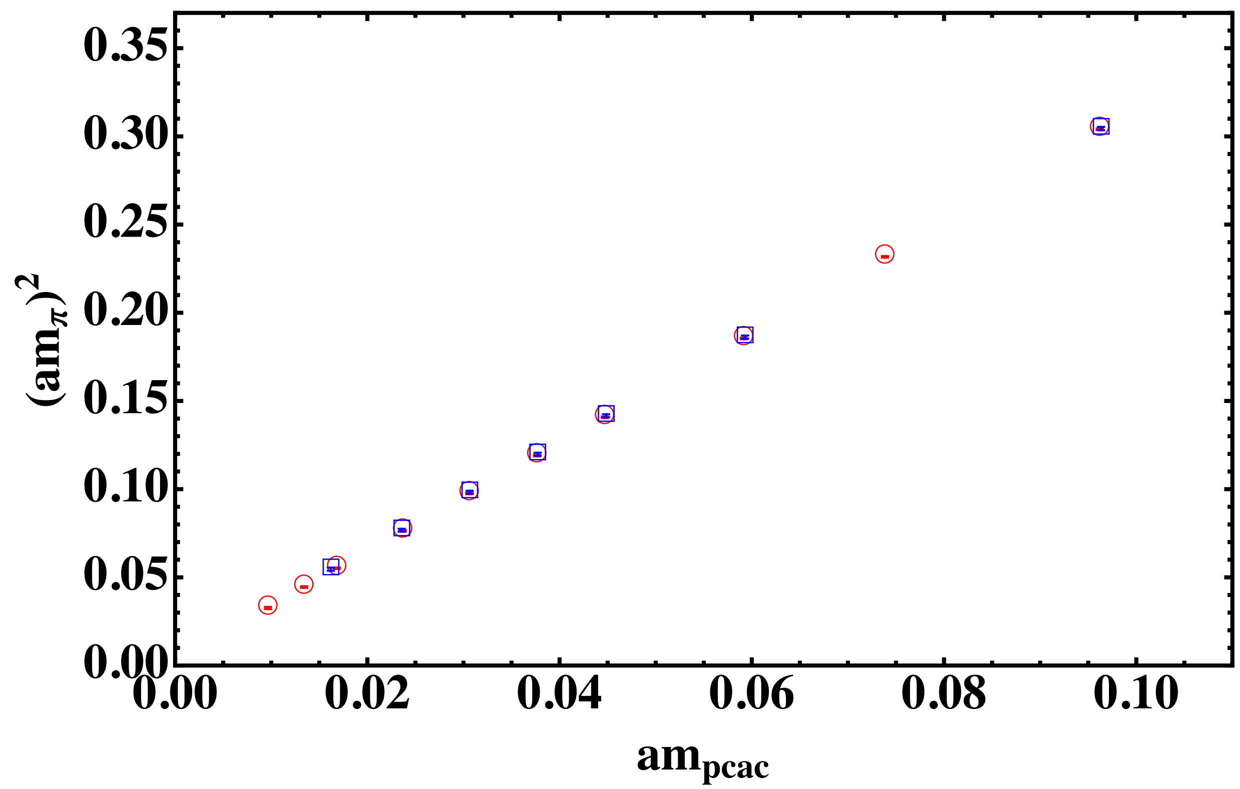


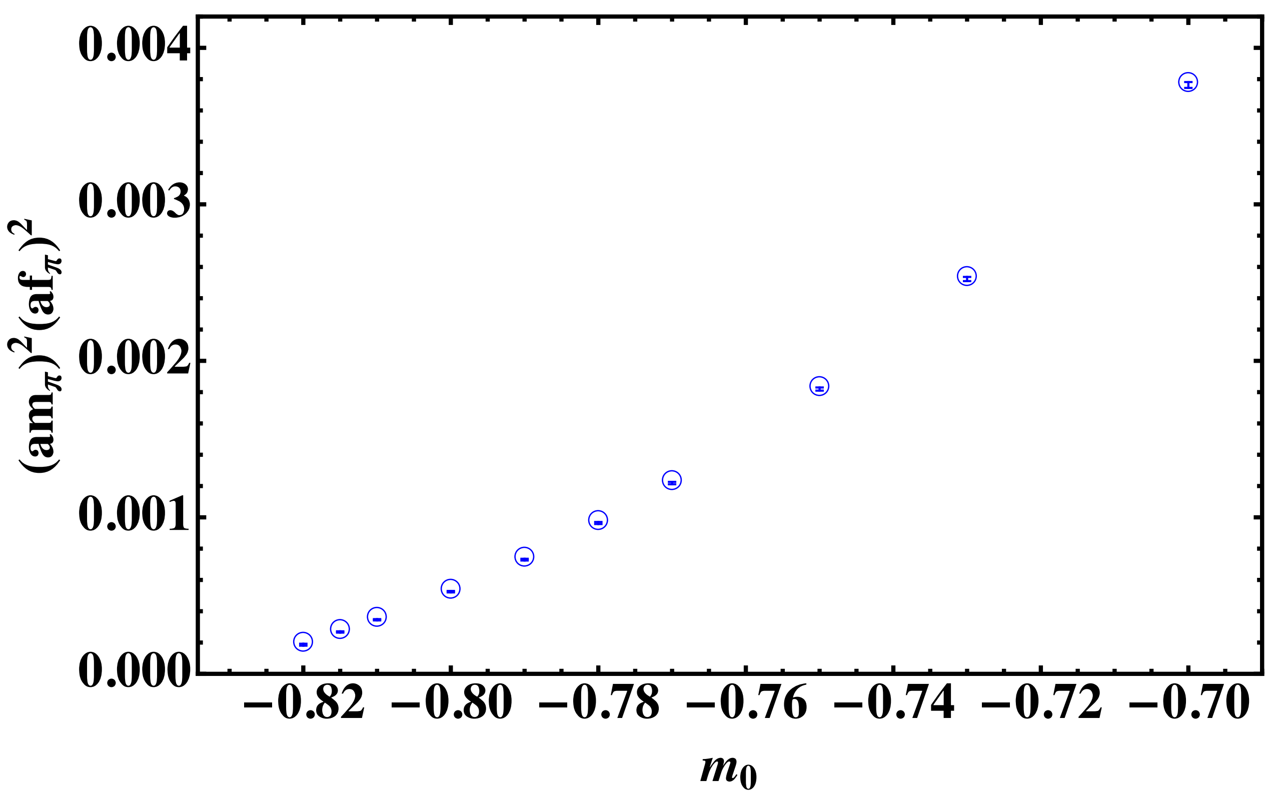


Effective mass plots
(m_0=-8.0, 48x24^3)

✤ Numerical results: Quenched case







***Blue square*: 48x16³**

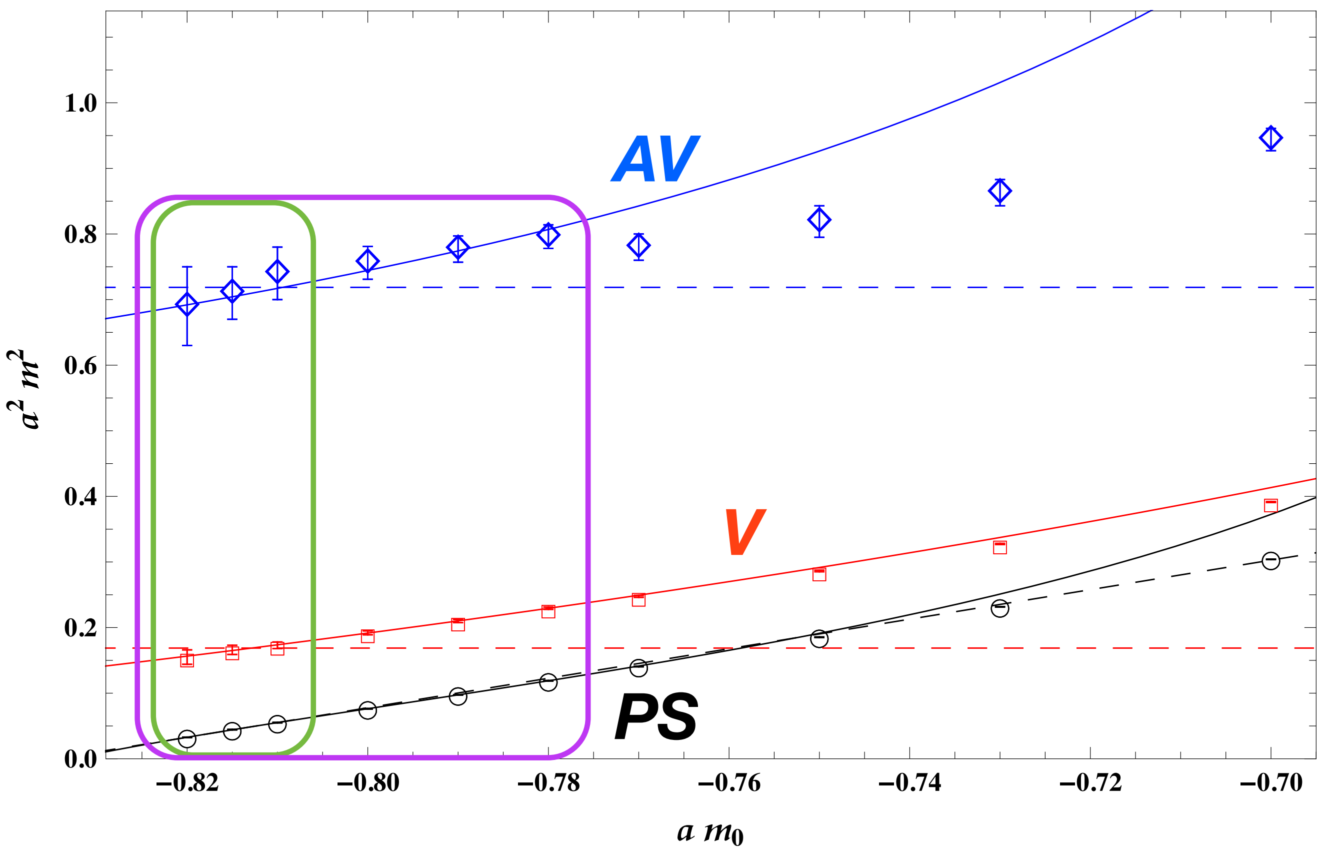
***Red circle*: 48x24³**

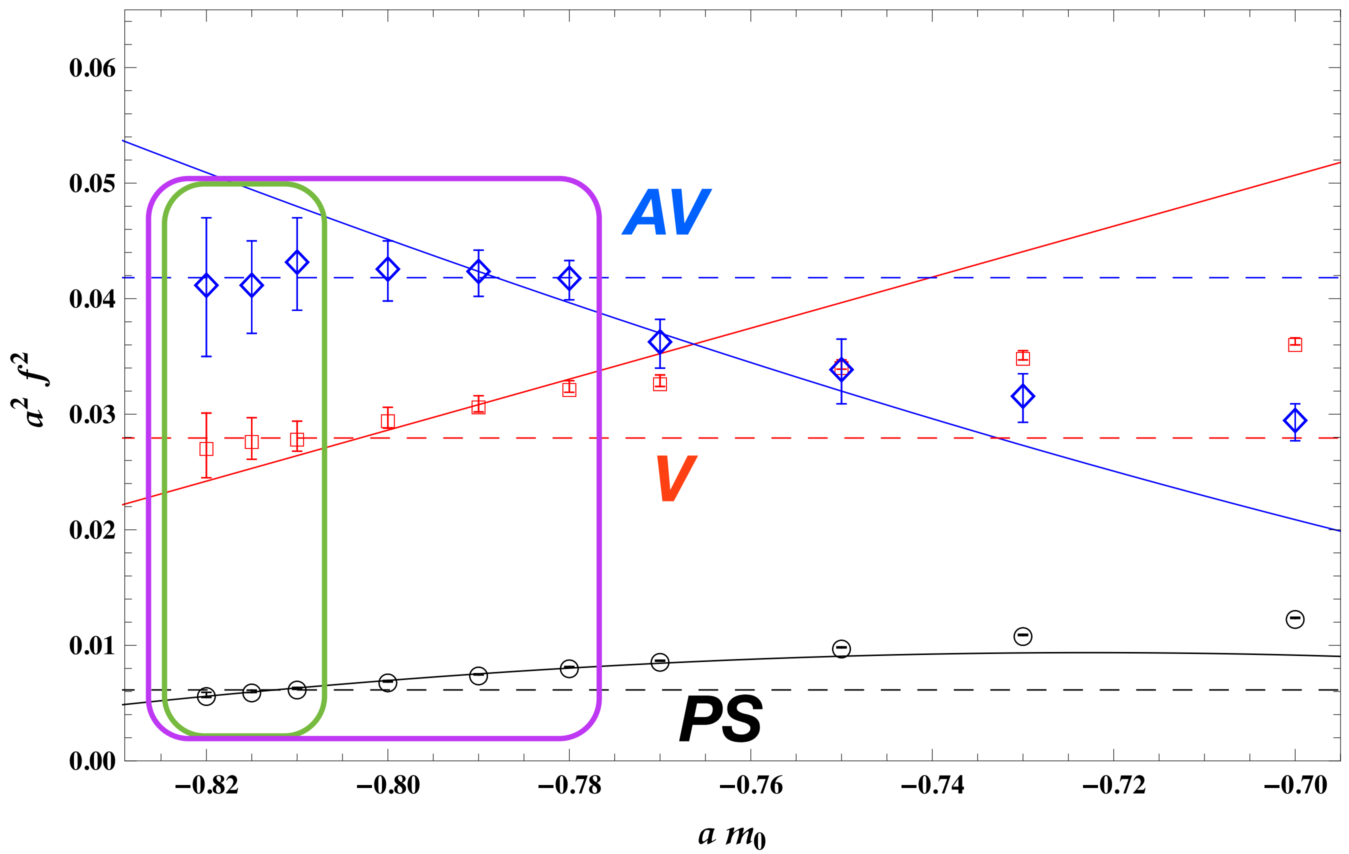
NLO GMOR relation

$$m_\pi^2 f_\pi^2 = mv^3 + m^2 v_5^2$$

✤ Numerical results: Quenched case

Global EFT fit(uncorrelated)





Dashed line: LO EFT - use three lightest points(8 free parameters)

$$\chi^2/N_{d.o.f} \simeq 1.15$$

Solid line: NLO EFT - use six lightest points(13 free parameters)

$$\chi^2/N_{d.o.f} \simeq 1.2$$

✤ Discussion

What do we learn from this exercise?

Unitarity ✓ ***checked***

GMOR relation ✓ ***checked***

rho-pi-pi coupling * $g_{\rho\pi\pi} \sim -8$

* Predict the width of rho-meson & compare with direct measurement

vector meson mass $m_\rho / f_\pi \sim 5$

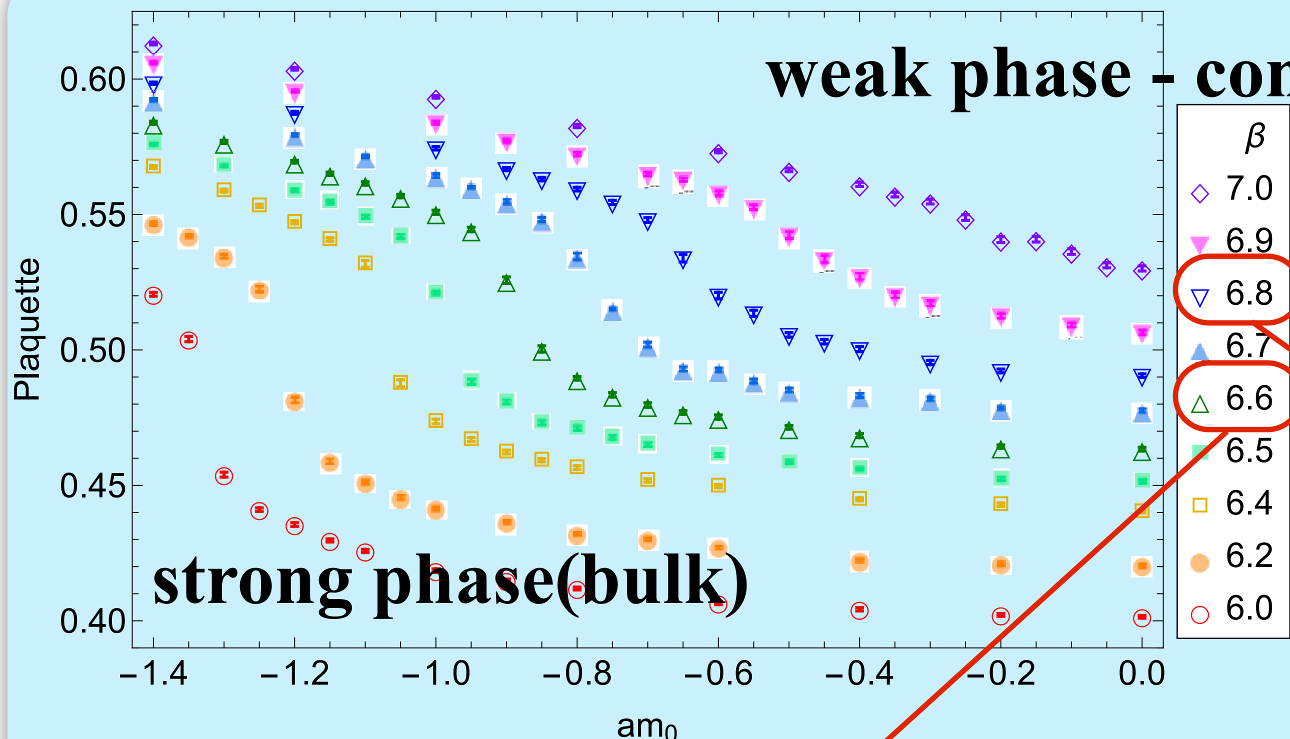
Peskin-Takeuchi S-parameter ** $S \simeq 0.1$

** By using this underlying model as a TC model, not a composite Higgs model

Investigation of lattice systematics is working in progress.

- Correlated fit to determine LECs with errors
- One-loop perturbative matching between lattice and continuum
- Finite lattice spacing effects

✤ Toward dynamical simulation: phase space



weak phase - connected to continuum

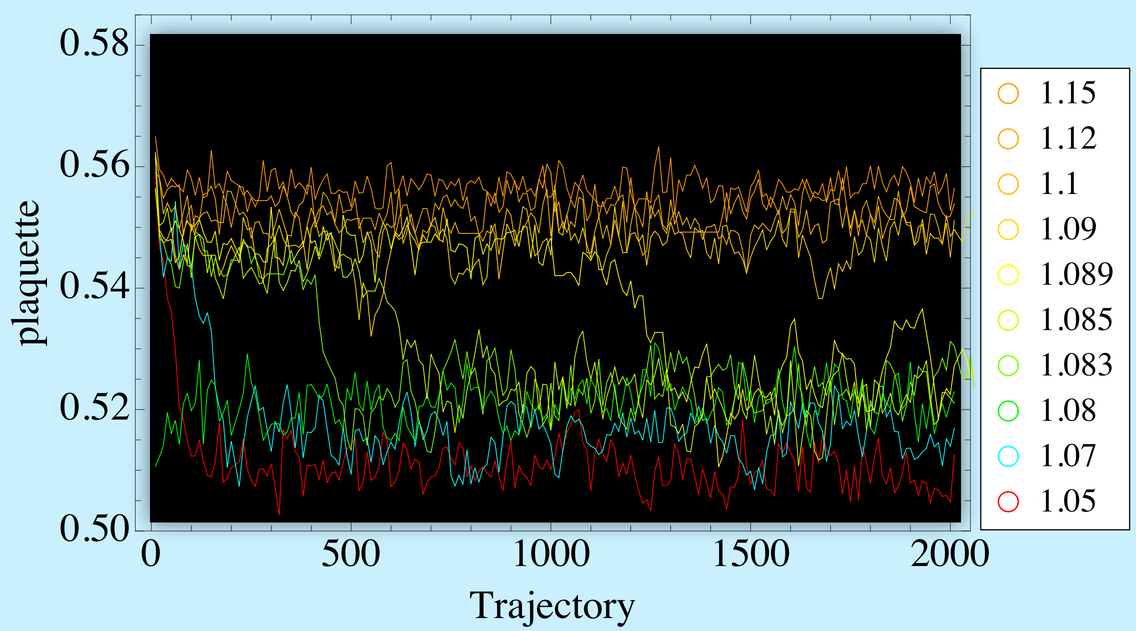
$\beta \gtrsim 6.8$

strong phase(bulk)

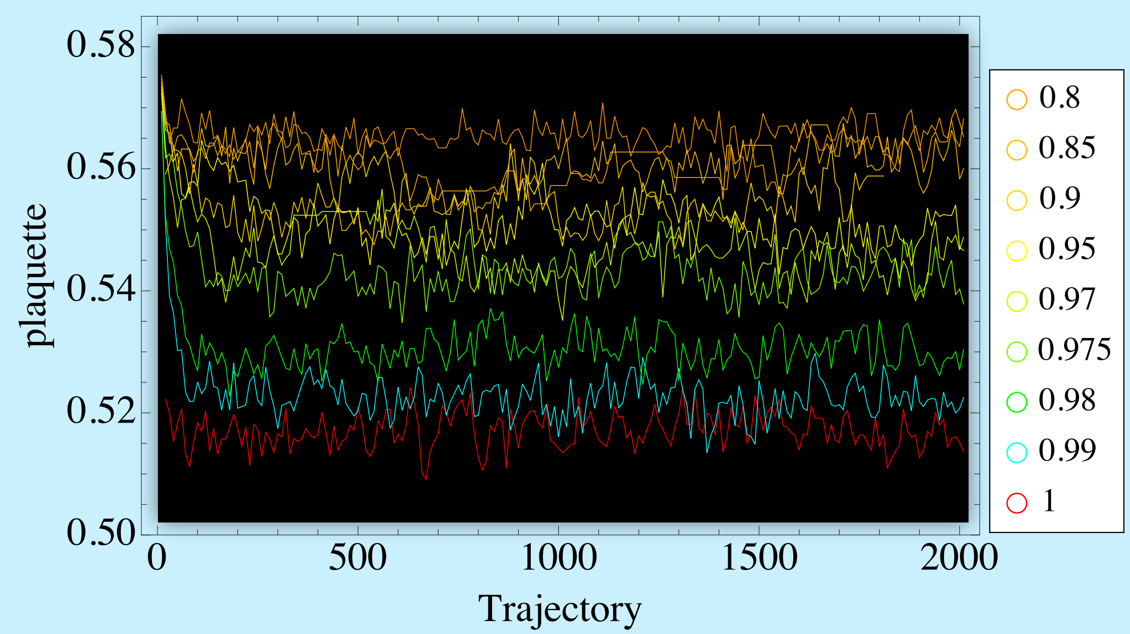
Mass scan: small lattice (4^4)

Trajectories: larger lattice (8^4)

metastability (first order bulk transition)



crossover



✤ Toward dynamical simulation: phase space

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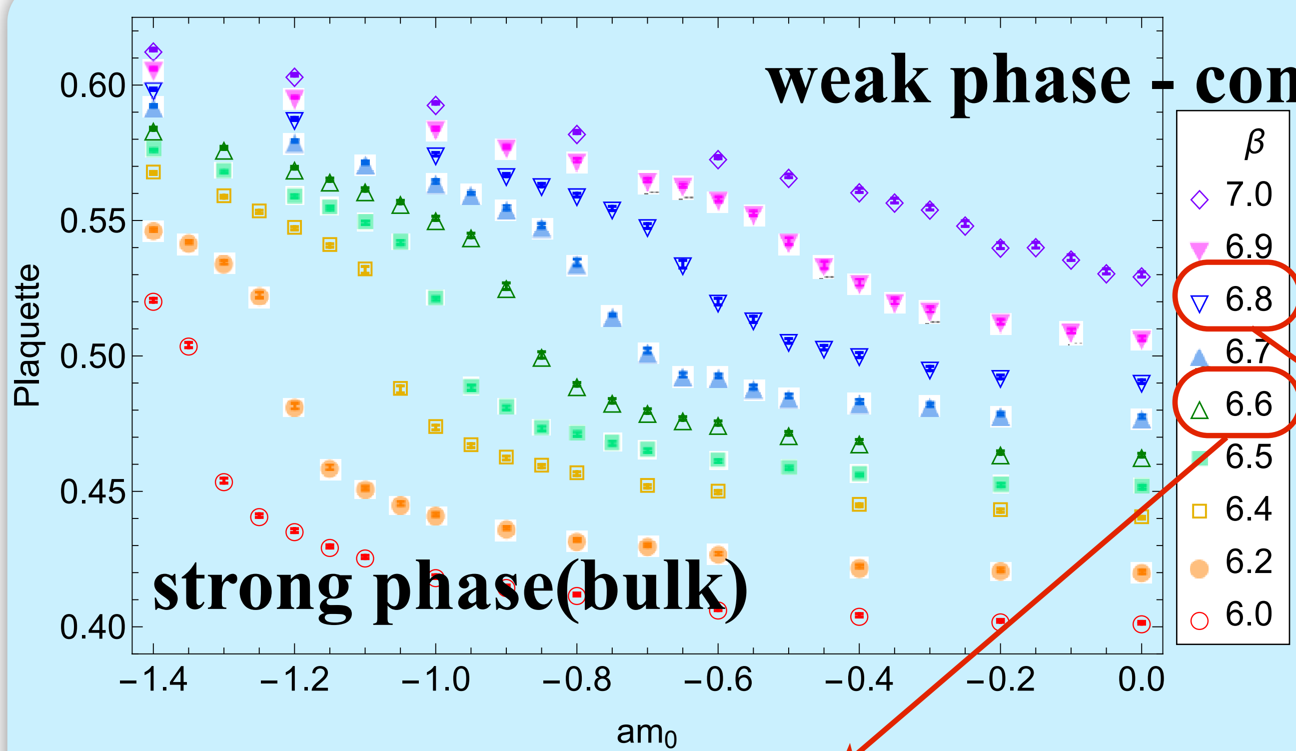
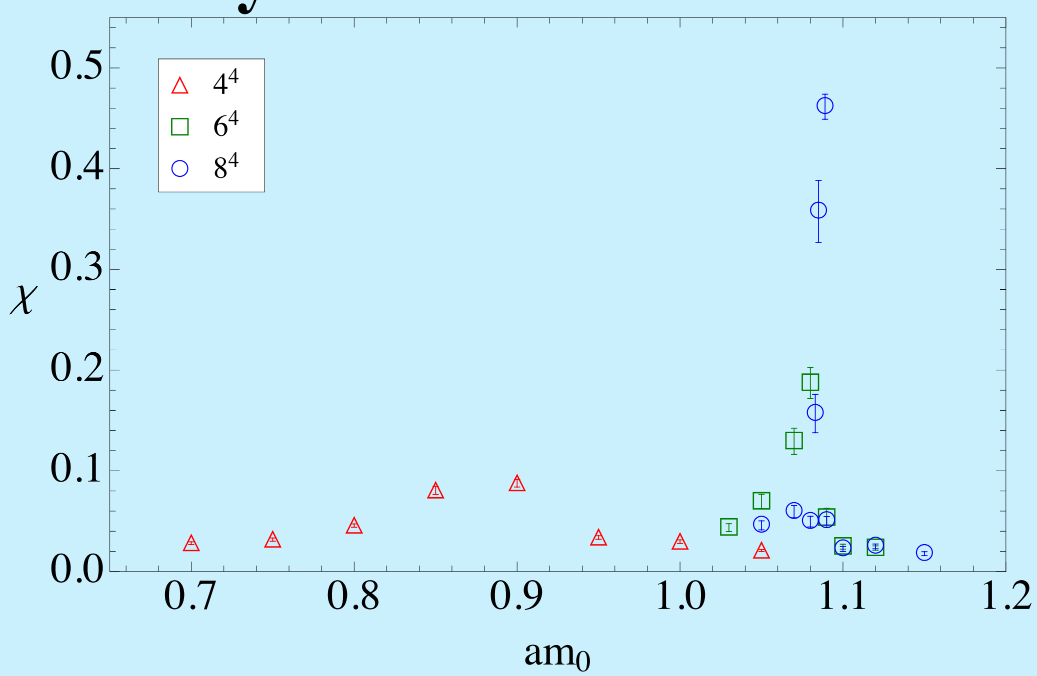


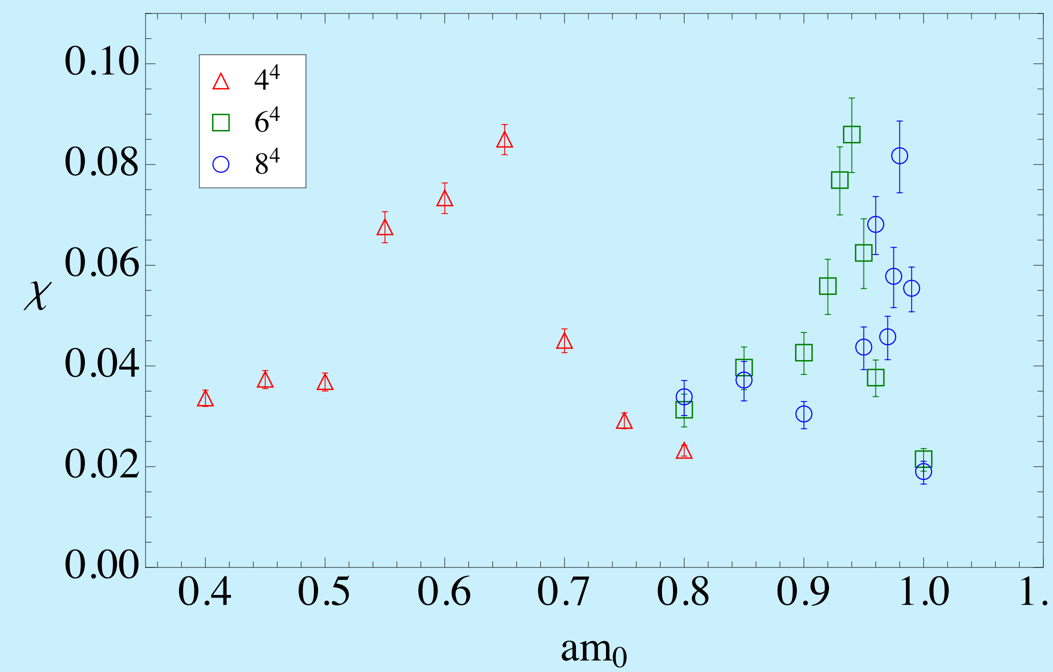
strong phase(bulk)

Plaq. susceptibility: larger lattice (8^4)

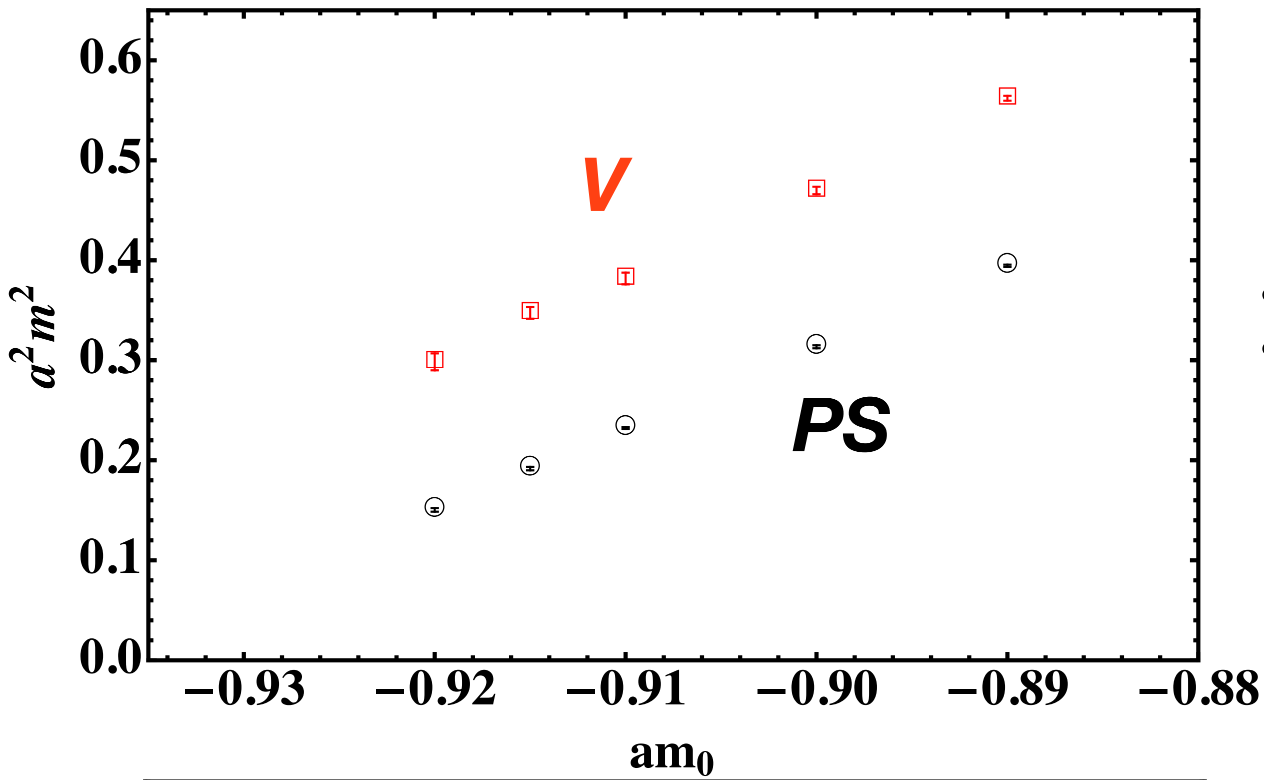
scales by L^4 - first order bulk transition

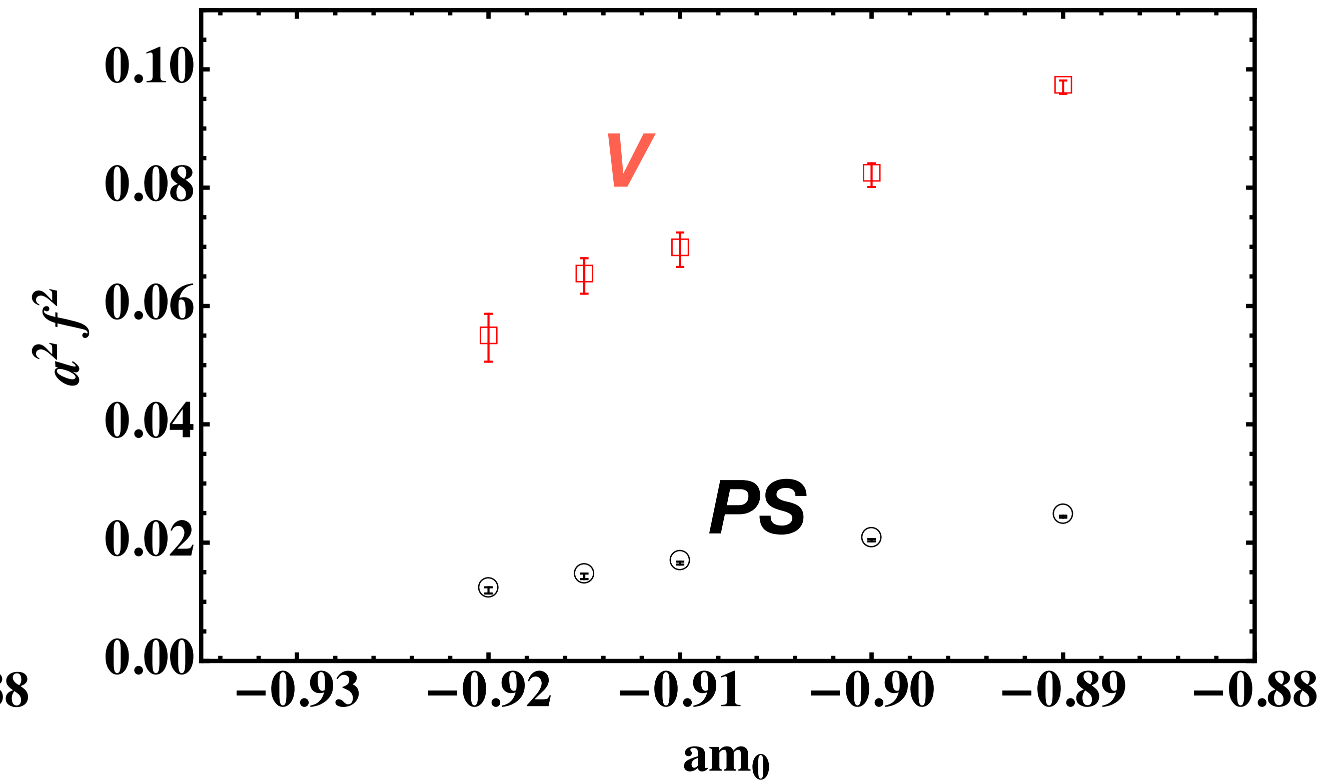
crossover

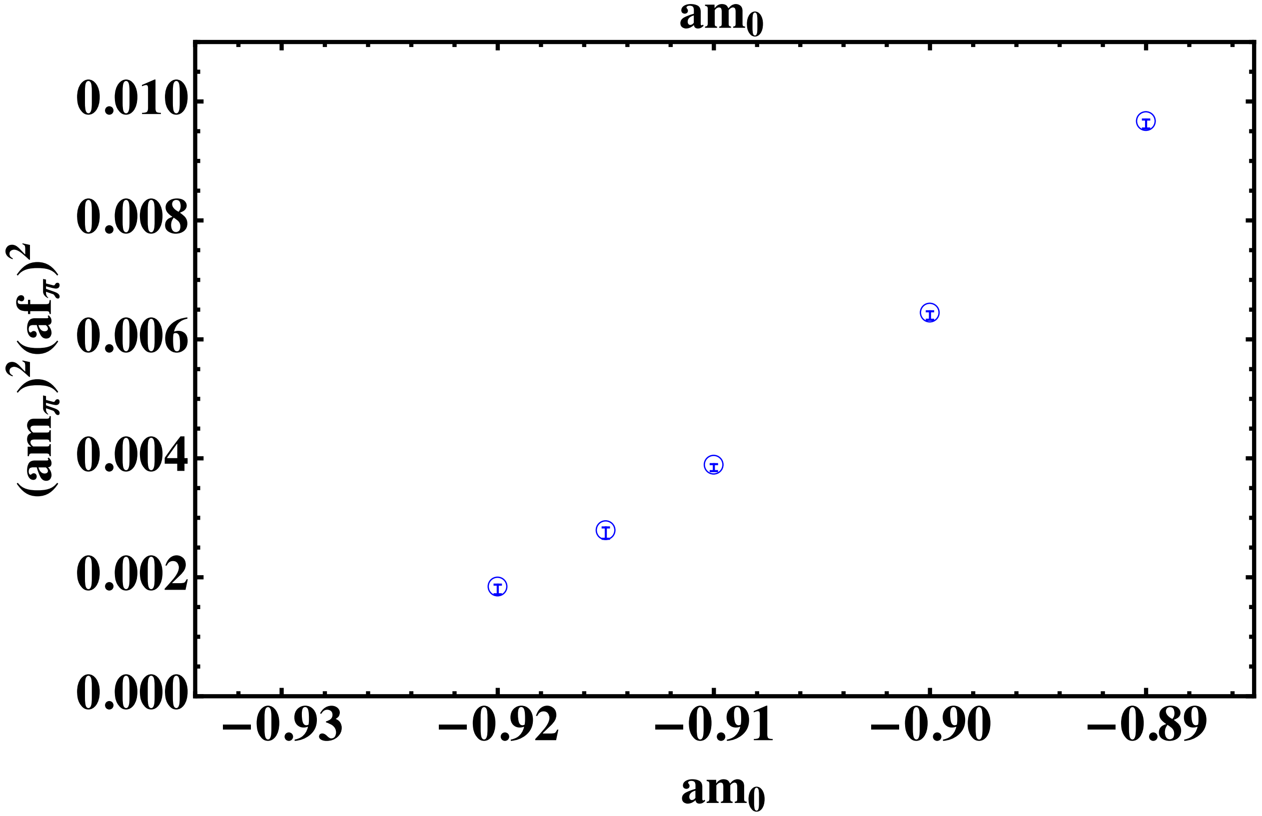




✤ Numerical results: dynamical case $\beta = 6.9$







NLO GMOR relation

$$m_\pi^2 f_\pi^2 = m v^3 + m^2 v_5^2$$

✤ Conclusion & Outlook

Conclusion

- Sp(4) lattice gauge theory has successfully been implemented.
- Our low-energy EFT including π, ρ, a_1 captures the qualitative features of the quenched simulation results.
- Lattice bulk phase space has been explored.

Ready to explore new territory: Two-flavor Sp(4)

Things to do

Quenched case

- One-loop perturbative matching between lattice and continuum
- Scale setting using Wilson Flow
- Investigate finite lattice spacing & finite quark mass effects

Dynamical case

- Generate more ensembles & Repeat the analysis

Discuss the physics of two-flavor Sp(4)

Thank you for your attention!
Enjoy the night tour at Alhambra!