Symmetric Mass Generation in gauge-fermion systems

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Mass Generation

Spontaneous symmetry breaking:

- chiral symmetry breaks
  $\longrightarrow$ massless Goldstone bosons
- bilinear condensate $\langle\bar{\psi}\psi\rangle \neq 0$
- non-Goldstone states are gapped
- 't Hooft anomaly matching OK

Symmetric mass generation:

- no symmetry breaking
  $\longrightarrow$ no massless Goldstones
- bilinear condensate $\langle\bar{\psi}\psi\rangle = 0$,$\langle\psi\psi\psi\psi\rangle \neq 0$
- all bound states are gapped
- 't Hooft anomalies must cancel

SMG is a new paradigm / phase
though we have seen it in lattice simulations: e.g.

-AH, Neuhaus,*Phys.Lett.B* 220 (1989) 435-440, Lee et al,....
-Cheng,AH,Schaich,*Phys.Rev.D* 85 (2012) 094509

Is SMG only a lattice artifact ? Not always.

Symmetric Mass Generation

SMG in the continuum is possible if

- all ’t Hooft anomalies (continuous and discrete) cancel $\longrightarrow$ 8 Dirac fermions
- some 4-fermion interaction triggers a 4-fermion condensate

Two candidates :

- ❖ SU(3) gauge + $N_f = 8$ massless Dirac fermions
- ❖ SU(2) gauge + $N_f = 4$ massless Dirac fermions

(Strong gauge-fermion interactions can lead to 4-fermion condensate)

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- A.H. *PRD* 106 (2022) 1, 014513
- LSD collaboration - O. Witzel’s talk

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  - N. Butt, S. Catterall, A.H.

(Strong gauge-fermion interactions can lead to 4-fermion condensate)

Summary/Conclusion

In numerical simulations (with staggered fermions)

- SU(3) gauge + $N_f = 8$
- SU(2) gauge + $N_f = 4$

look very similar:

- weak coupling phase that appears conformal
  - chirally symmetric
  - show conformal hyperscaling

- strong coupling phase that is SMG with
  - chirally symmetric
  - gapped spectrum

- the phase transition is continuous
  $\rightarrow$ $\exists$ continuum limit and RG β function

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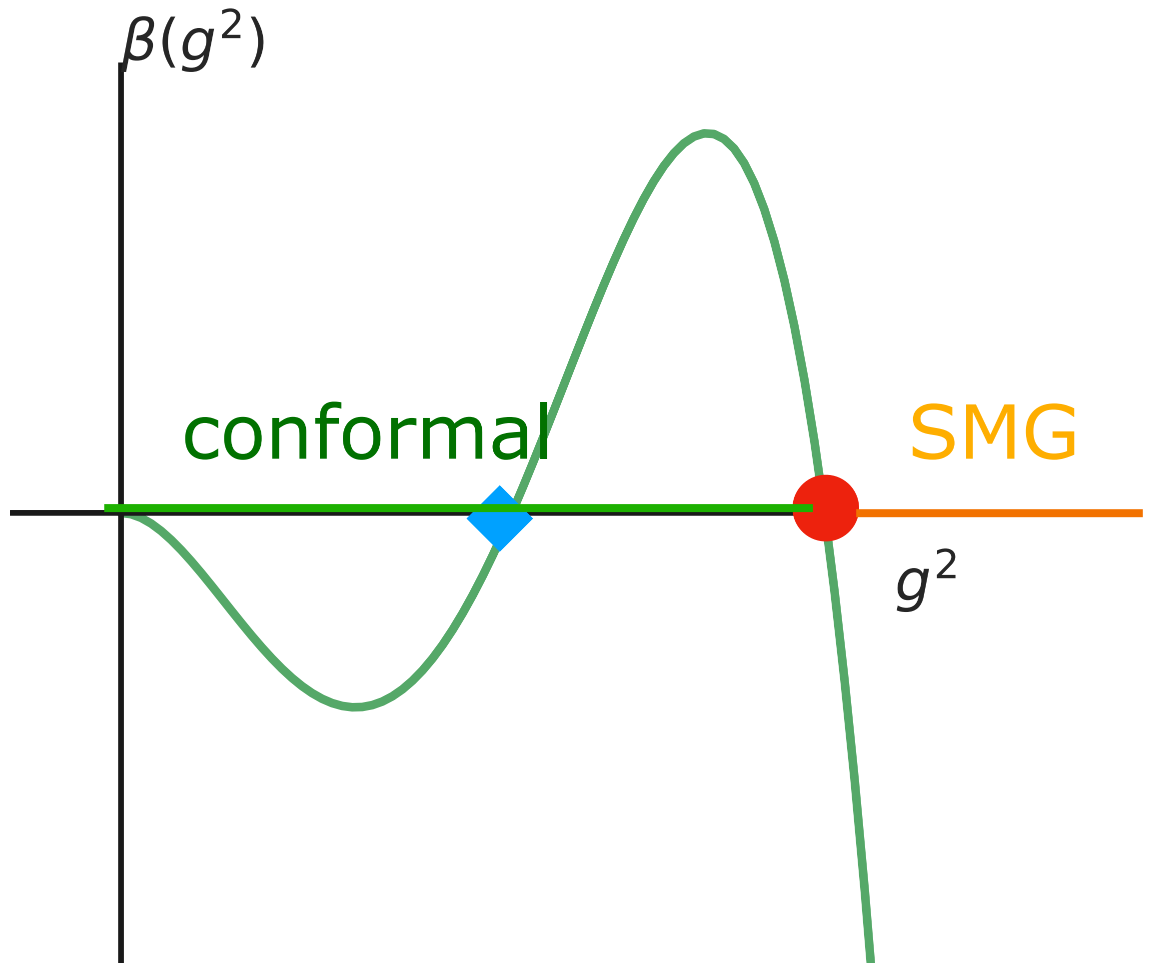

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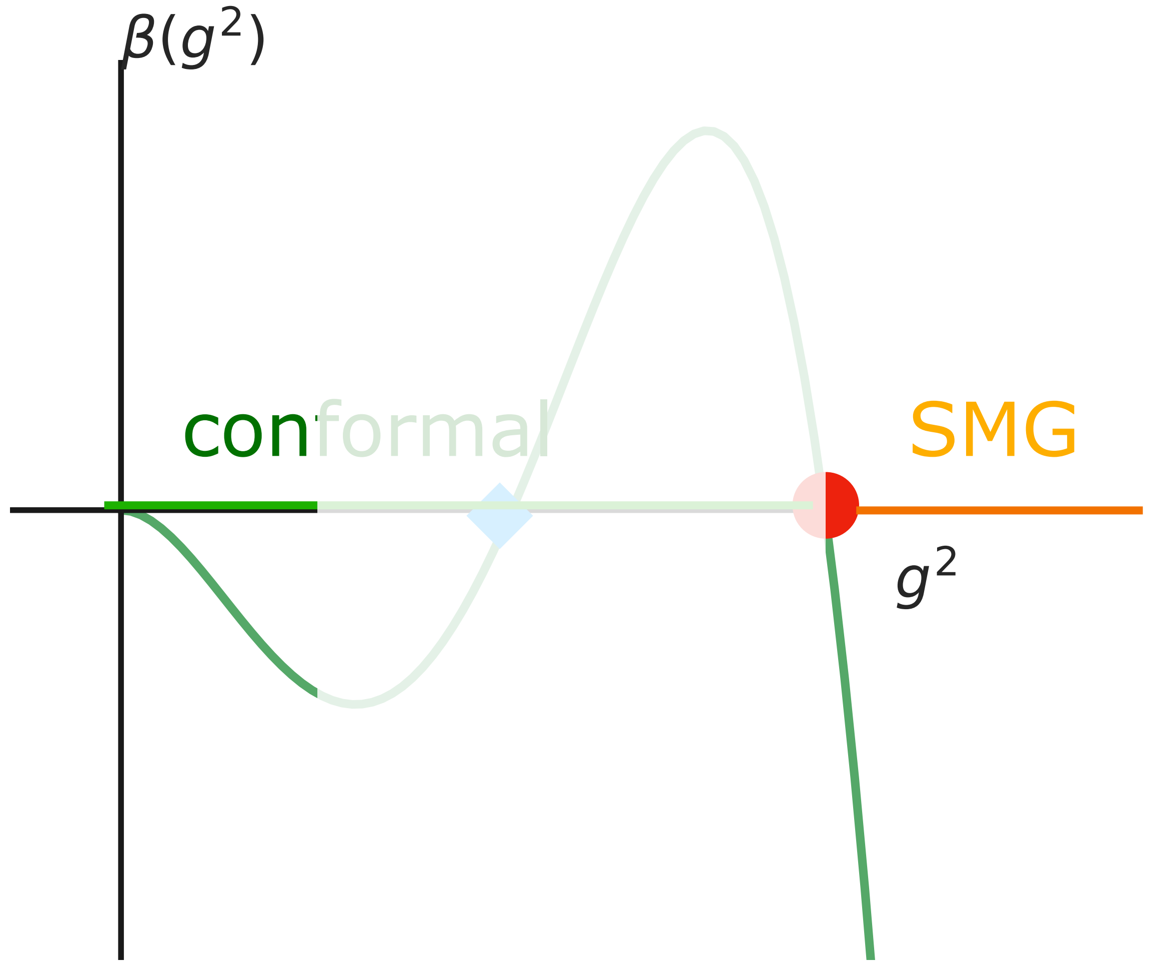

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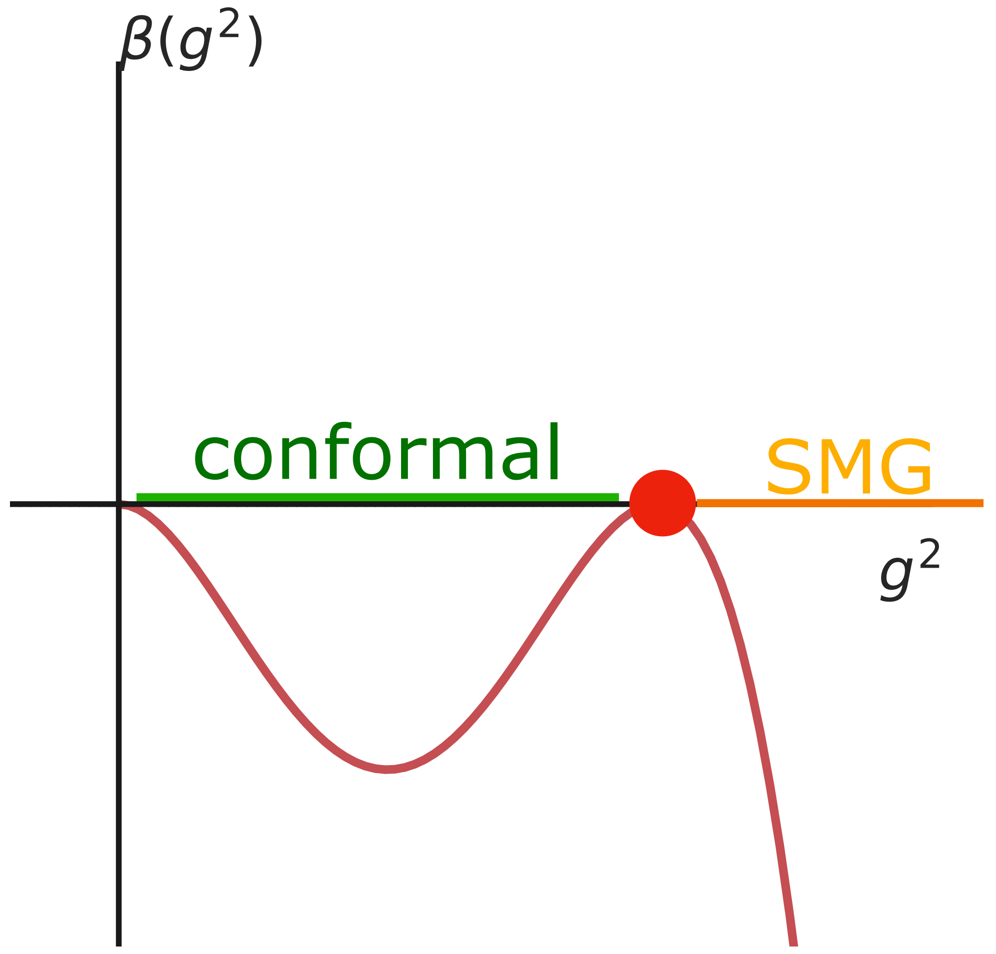
- (could be 'walking': fixed point merger leads to the opening of the conformal window)



Simulation details

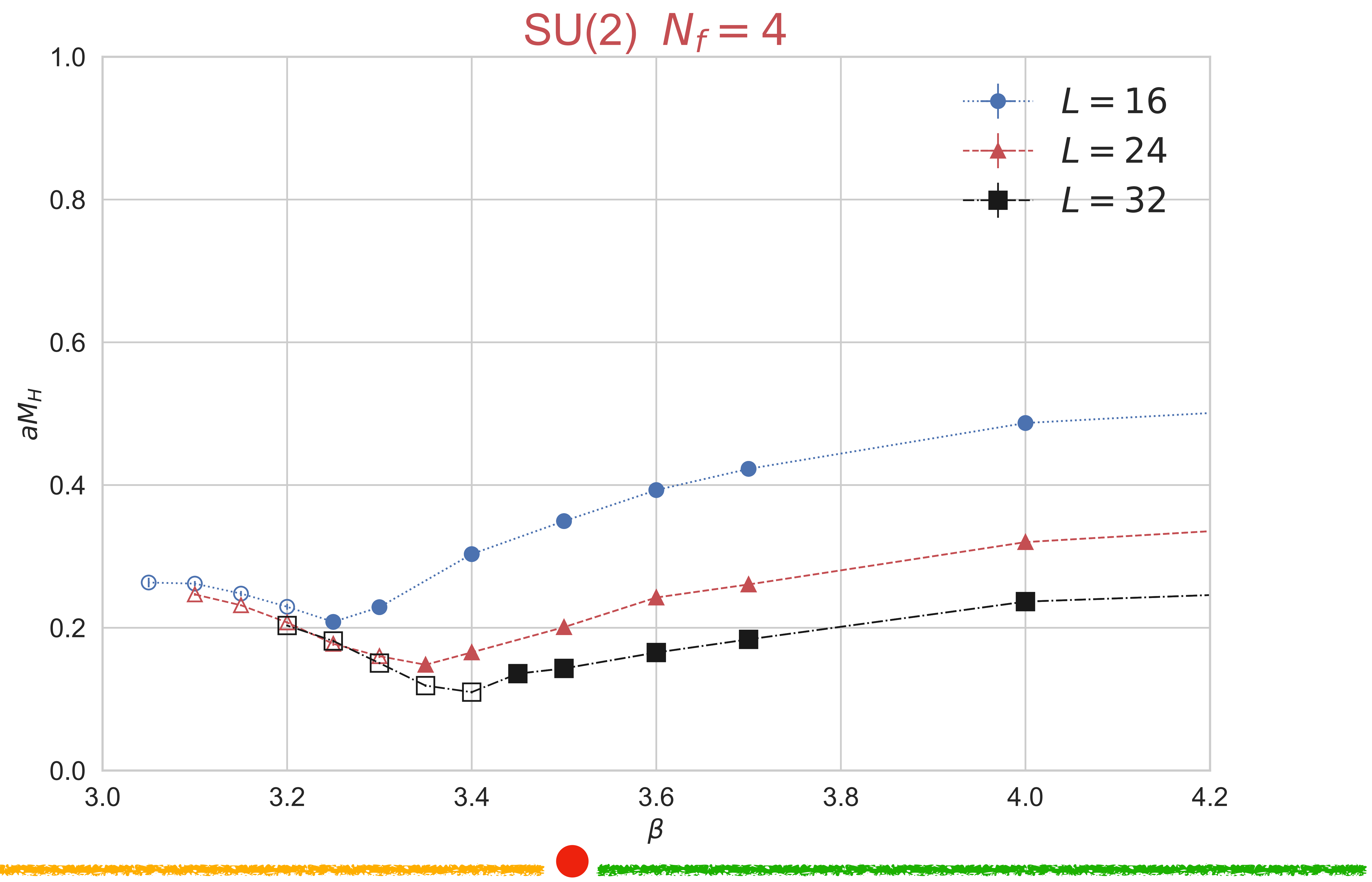
Numerical simulations for both actions are

- nHYP smeared massless staggered fermions
- PV improved gauge action: 8 PV bosons per fermion, $am_{PV} = 0.75$
- HMC update: QEX code
  - https://github.com/jcosborn/qex
  - https://github.com/ctpeterson/qex_staghmc

- Measurements: hadron spectrum, gradient flow, Dirac eigenmodes:
  - QLUA
  - QEX
  - MILC-variant : https://github.com/daschaich/KS_nHYP_FA

Hadron spectrum - SU(2) + $N_f = 4$

Mass of would-be Goldstone pion



volume independent
"gapped" phase

1/L volume scaling
conformal phase

Hadron spectrum

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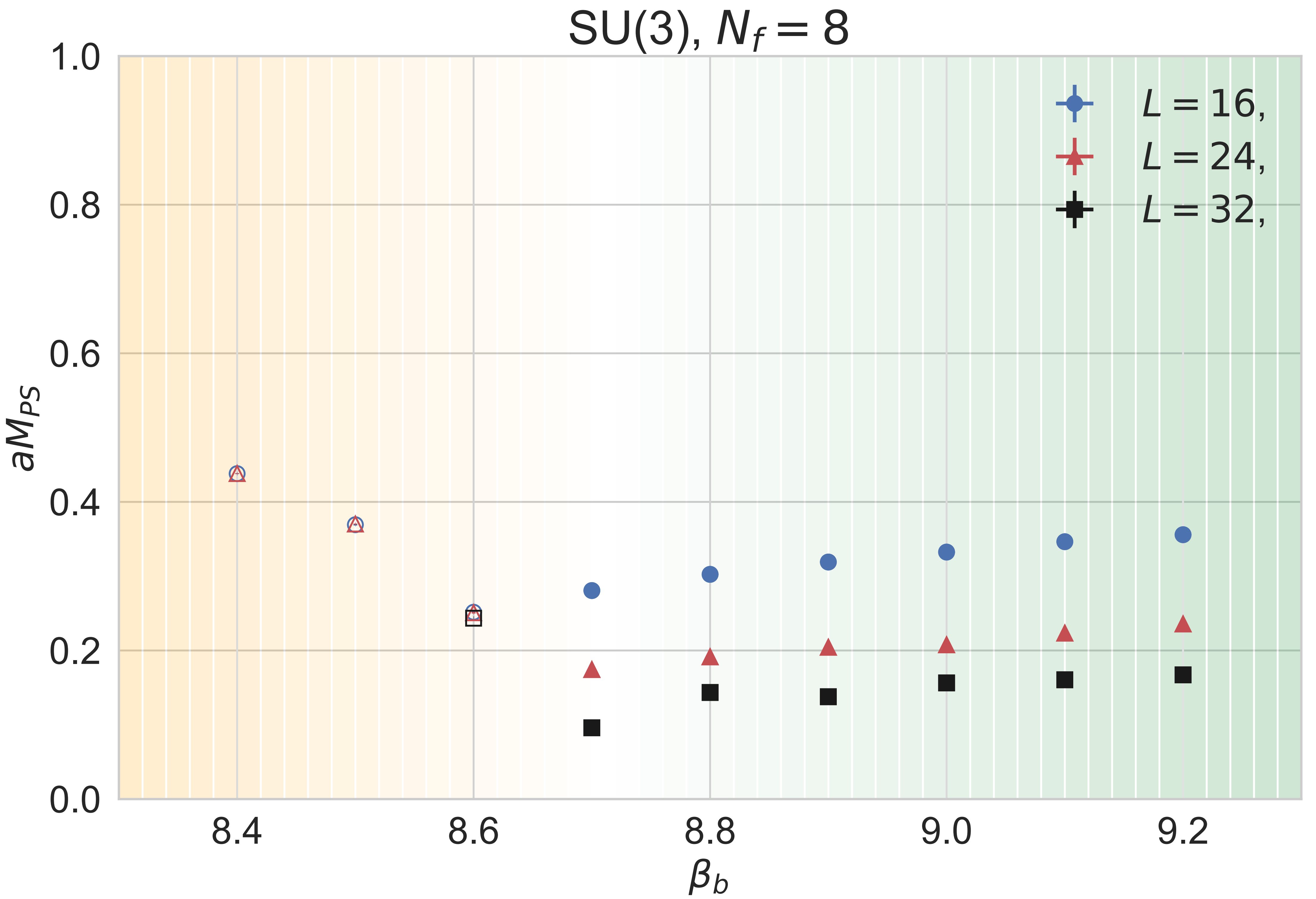

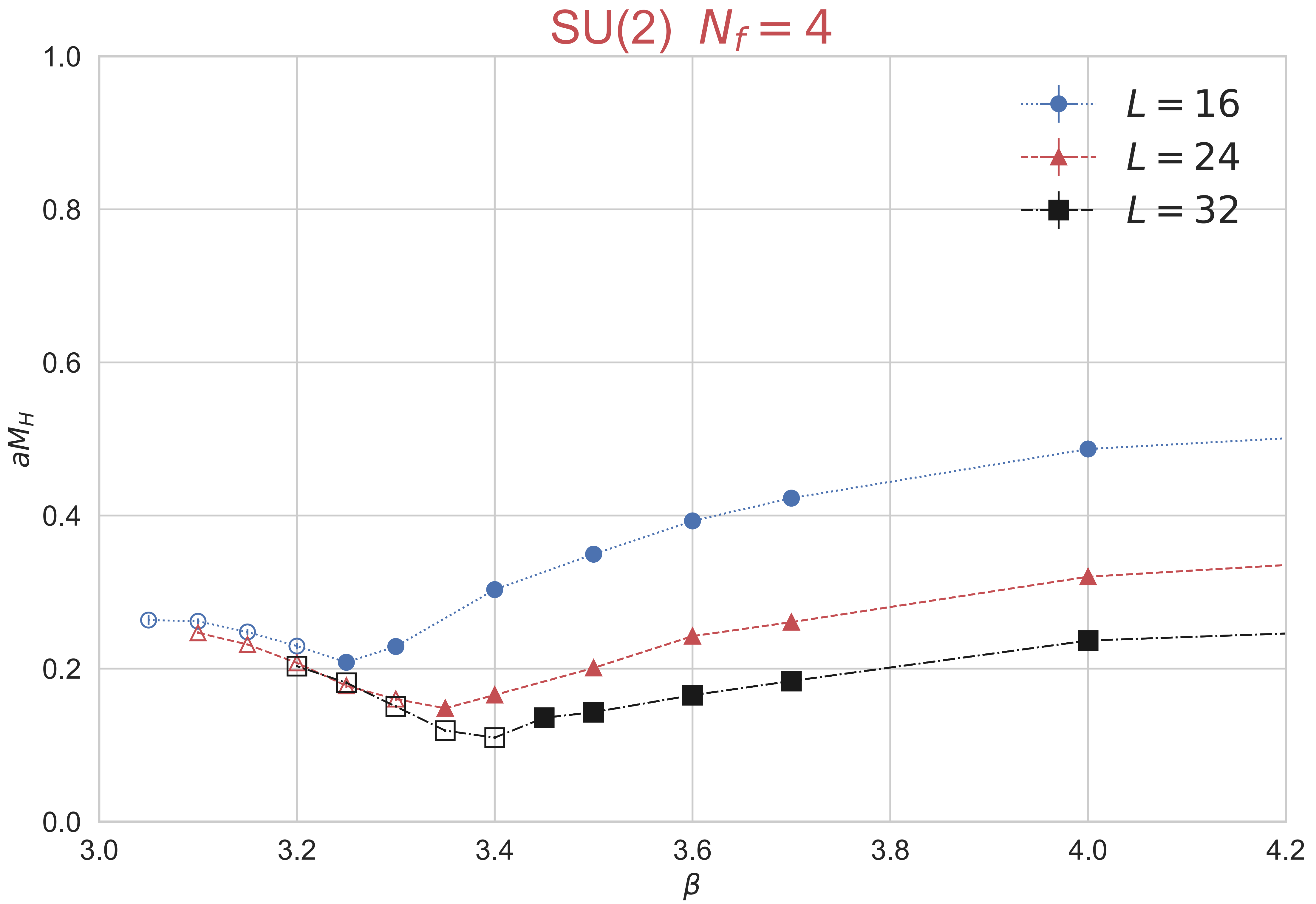

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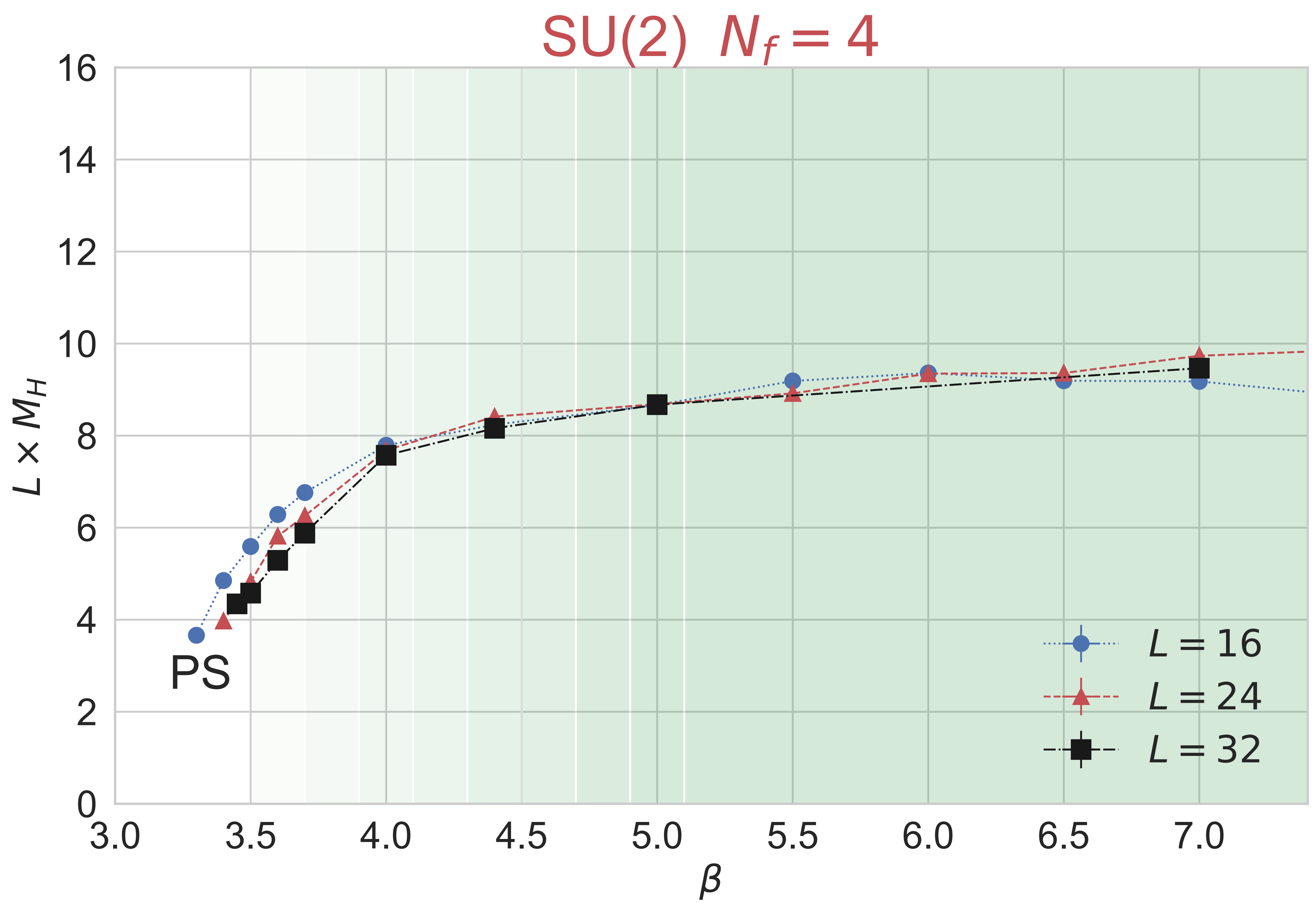
Weak coupling shows $M_{PS}L \approx$ const conformal scaling



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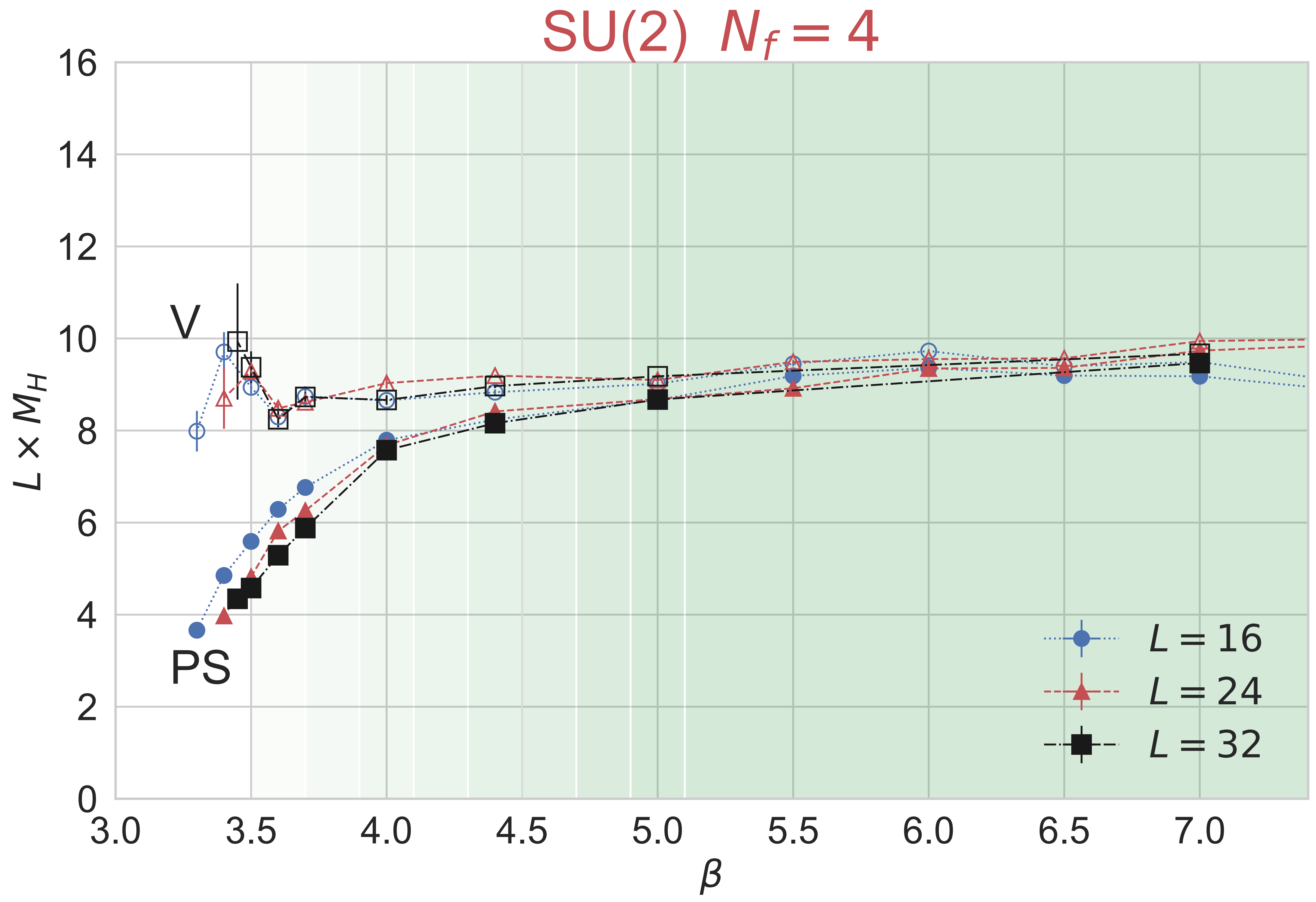


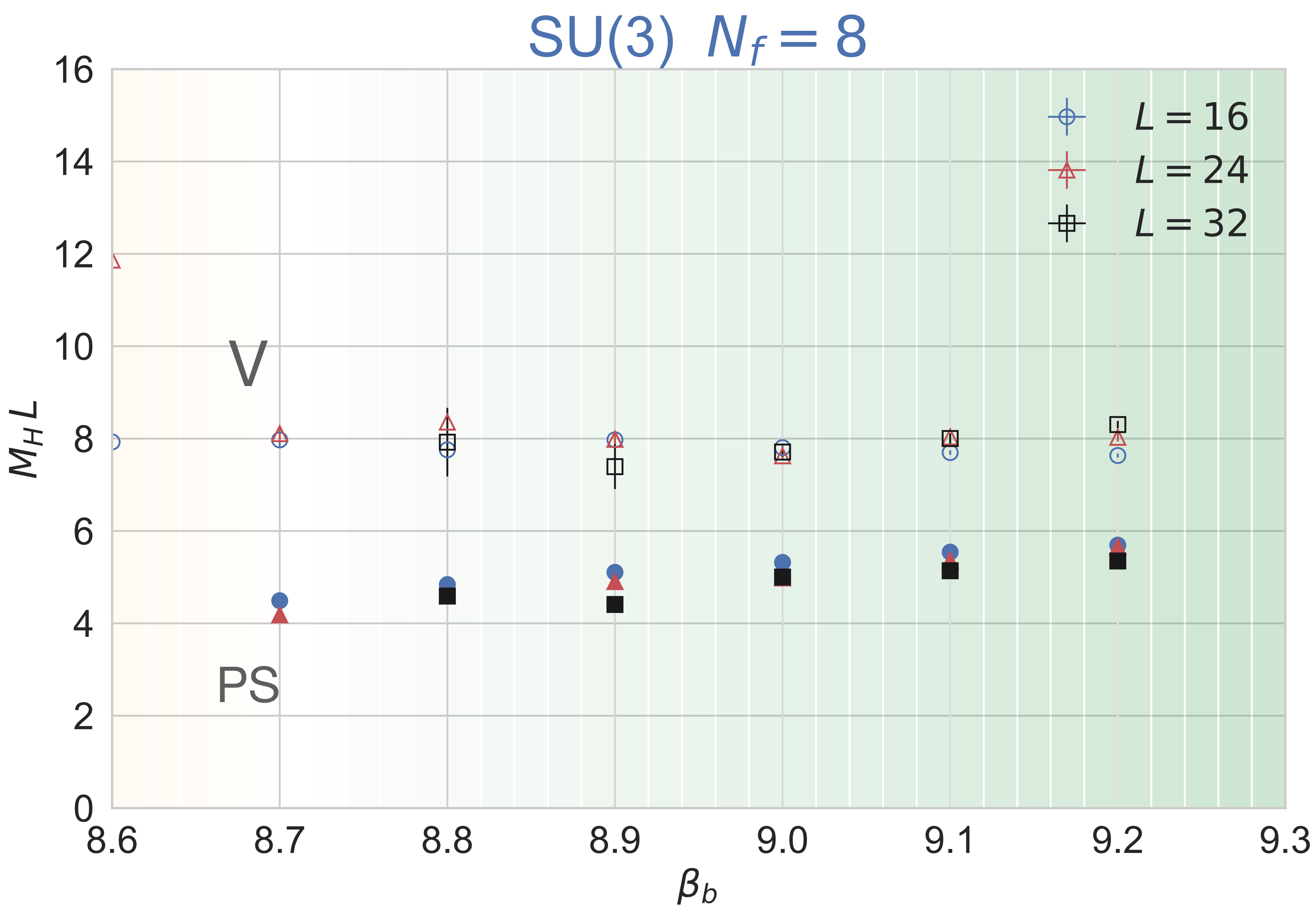
1/L volume scaling
conformal phase

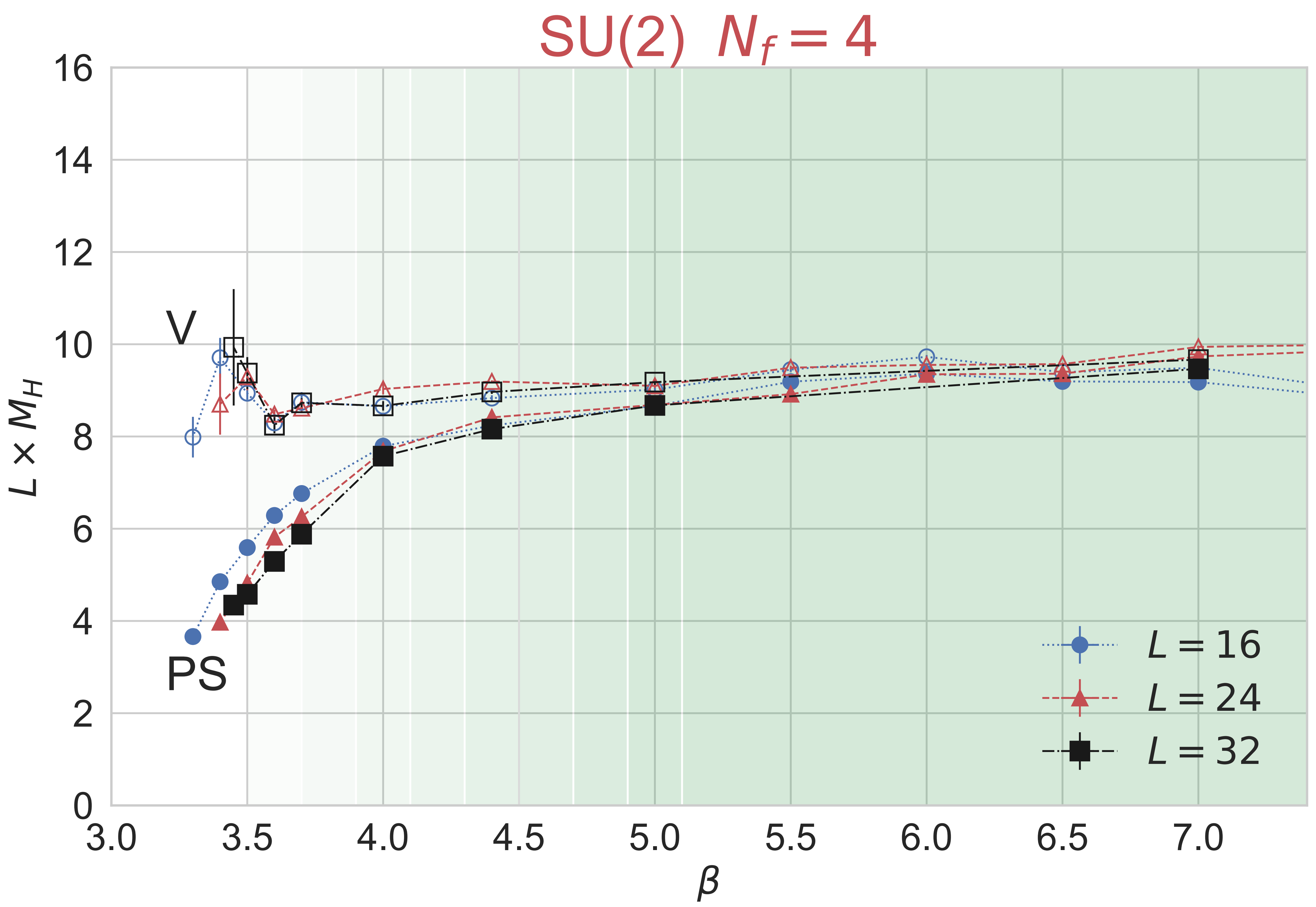
The vector shows the same 1/L conformal scaling

This is not epsilon regime

Hadron spectrum

Weak coupling shows $M_{PS}L \approx$ const conformal scaling

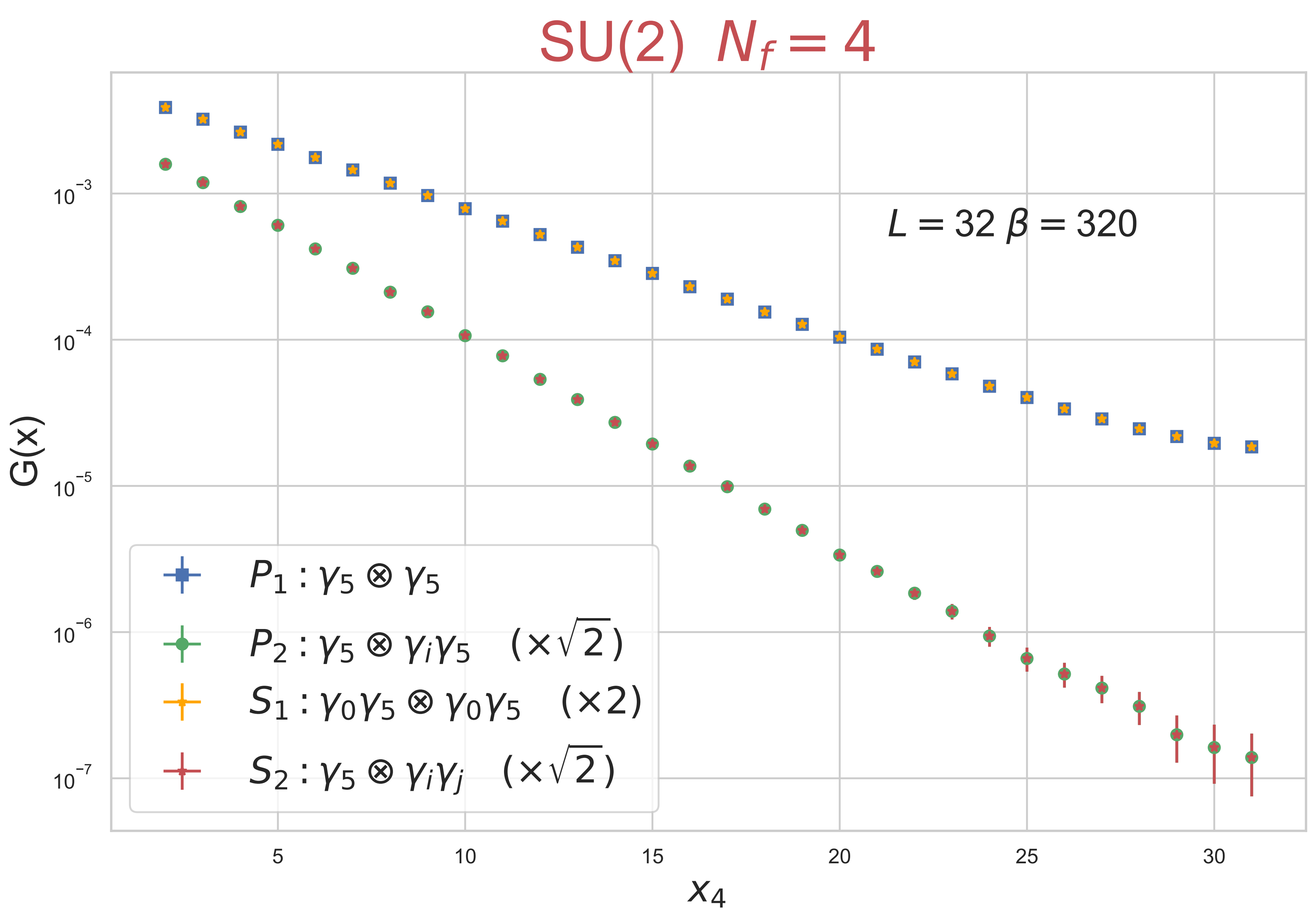




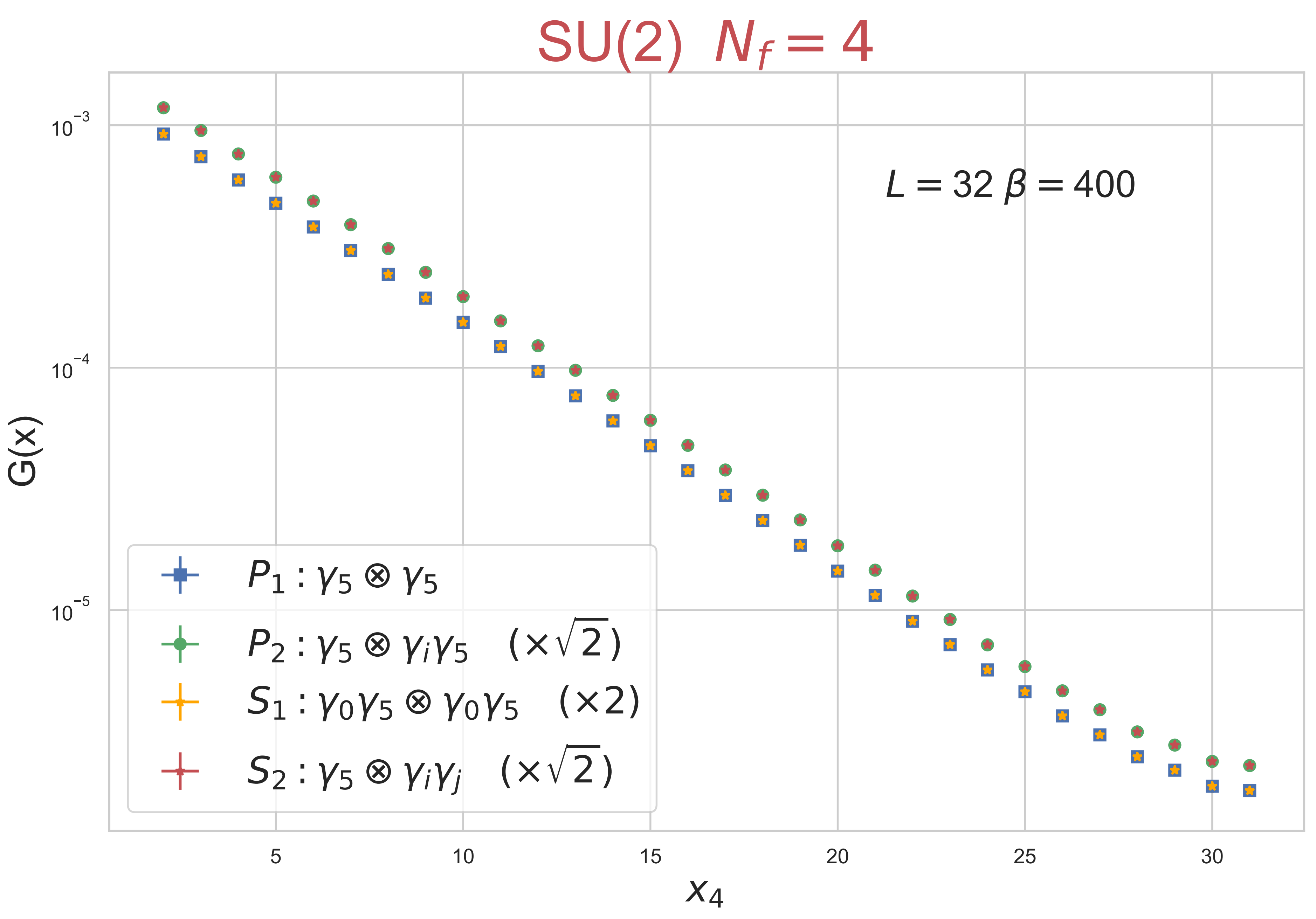
1/L volume scaling
conformal phase

Chiral symmetry- SU(2) + $N_f = 4$

Parity partner correlators are identical in both phases



SMG phase



weak coupling phase

Order of the phase transition / FSS :

Finite size scaling/curve collapse analysis:

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Scaling near the critical point $g \to g^*$

$\mathcal{O}$: dimensionless operator

$$\mathcal{O}(g, L) = f\left(L/\xi\right)$$

- ξ: correlation length at g
- $f(x = L/\xi)$ unique curve, independent of L

- 2nd order scaling: $\xi \propto |g - g_*|^{-\nu}$,
  - 1st order scaling: like 2nd order but $\nu = 1/d = 0.25$

- BKT or walking scaling: if $\beta(g^2) \sim (g^2 - g_*^2)^2 \;\to\; \xi \propto e^{\zeta/|g-g_*|}$

Find the exponents and g_* by standard curve-collapse analysis ;

Order of the phase transition / FSS :

Observable $\mathcal{O}$:

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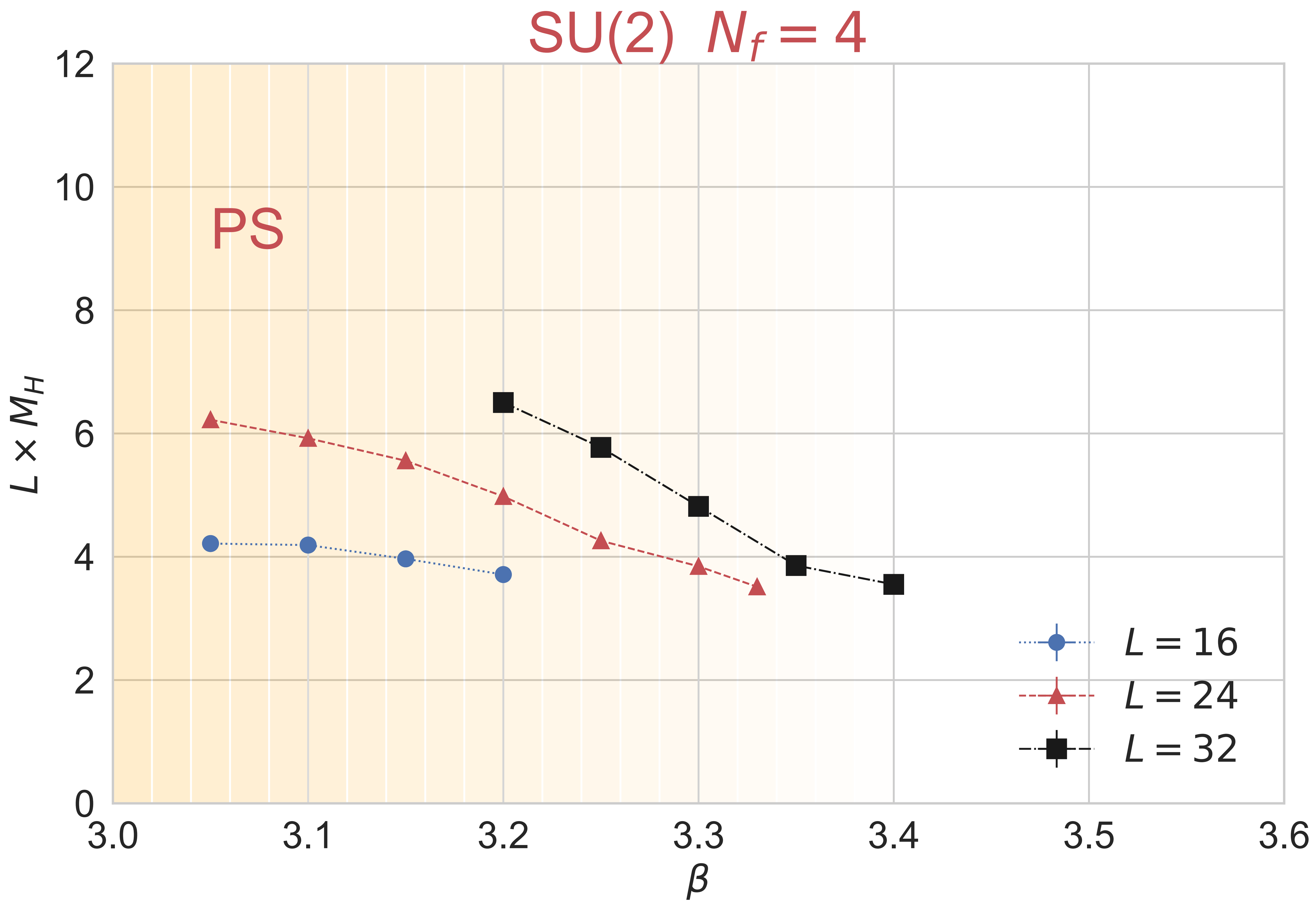
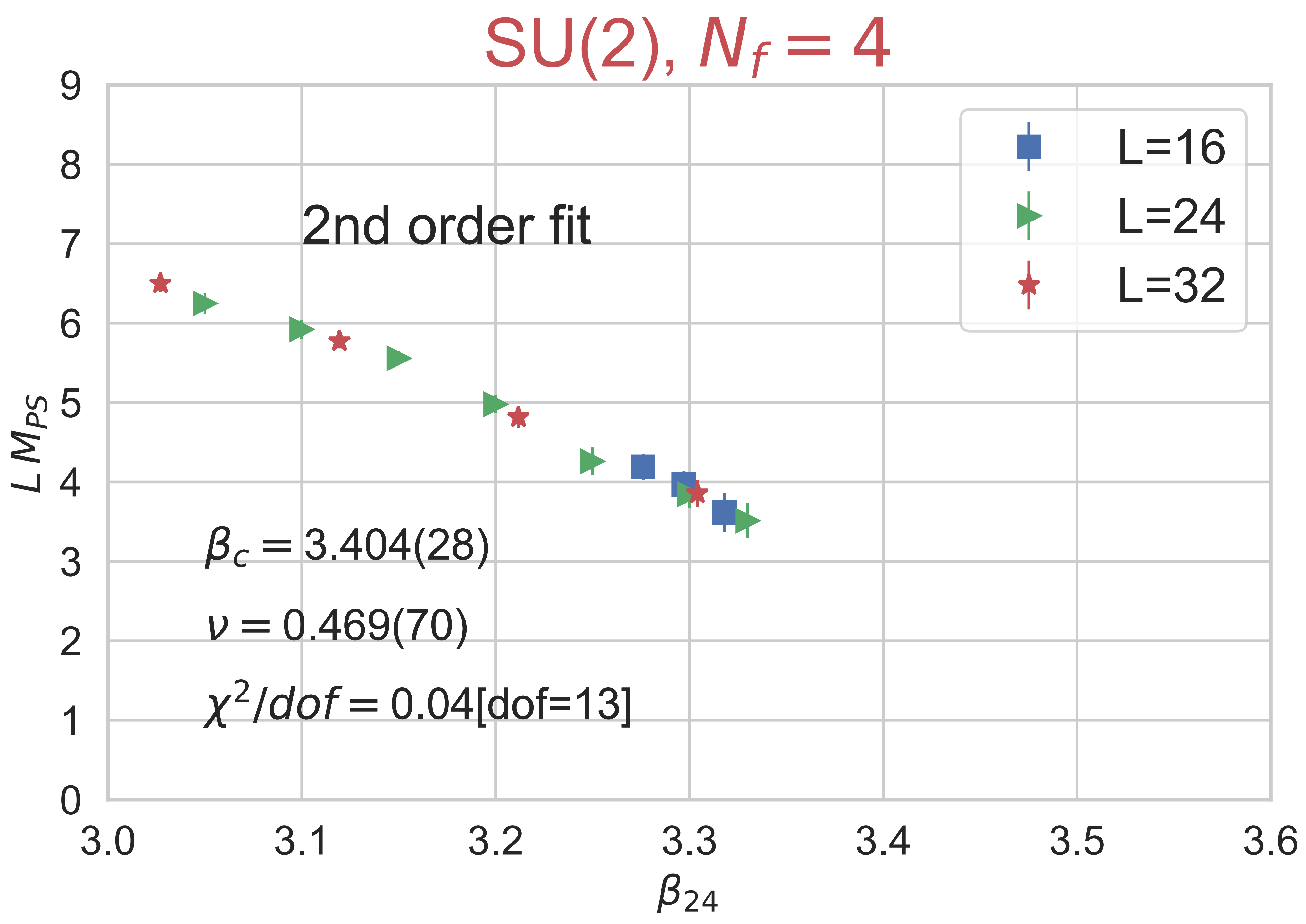
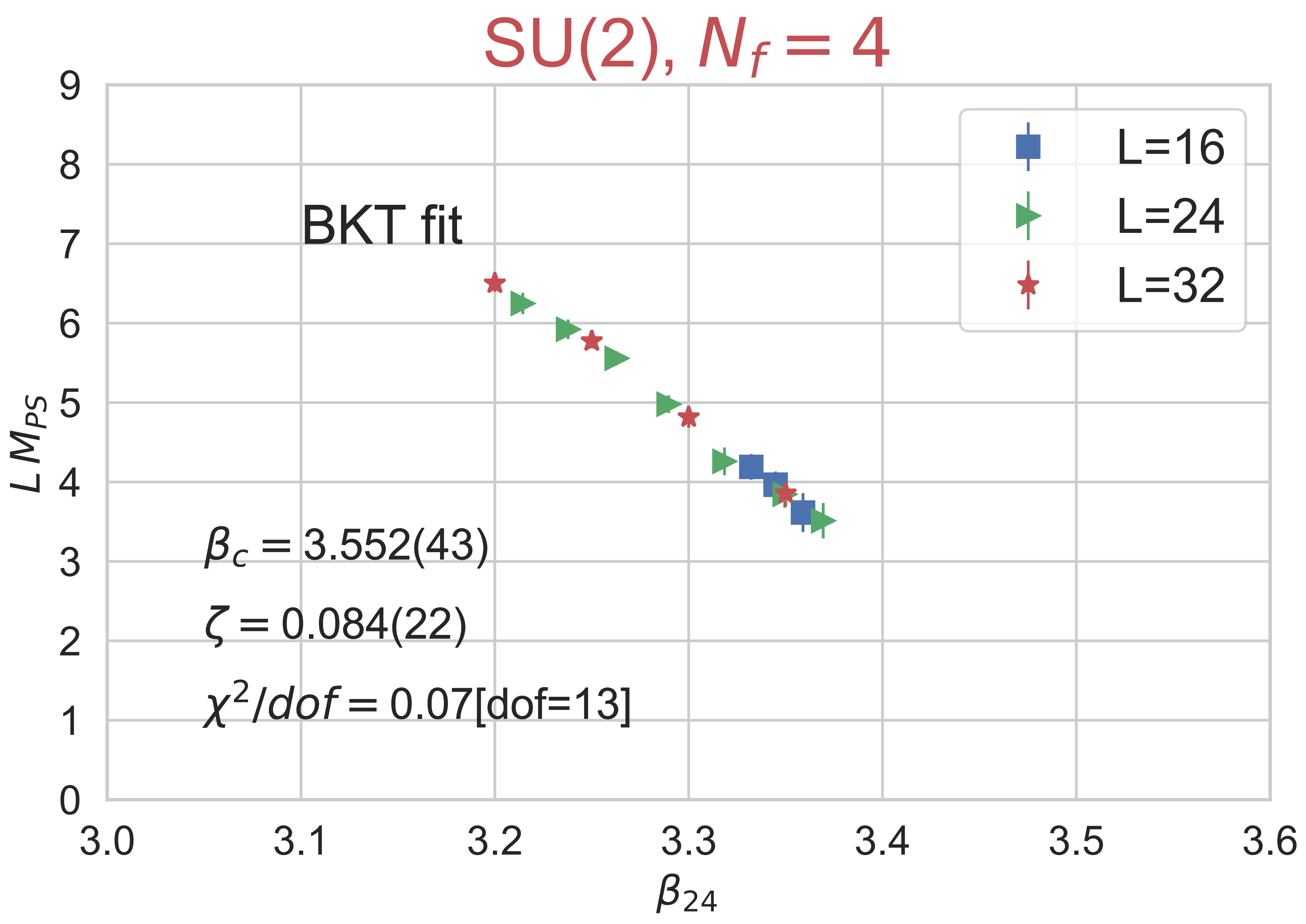
- Finite volume gradient flow (GF) coupling: $g^2_{GF}(g,L;t) = \mathcal{N} t^2 \langle E(t) \rangle_{g,L}$, $t/L^2 = c/8$
- Spectral mass: $L\,M_{PS}$



FSS/ Order of the phase transition - SU(2) + $N_f = 4$





- Both 2nd order and BKT fits show good curve collapse
  $\nu \approx 0.5$ is not consistent with first order transition
- FSS does not (yet) distinguish 2nd order and BKT

Summary/Conclusion

Symmetric Mass Generation:

- is a new paradigm - we do not yet know all its applications
- lattice simulations often show SMG phase, but with first order transitions

Systems that are anomaly-free can have continuum limit / continuous phase transition

- SU(3) gauge + $N_f = 8$
- SU(2) gauge + $N_f = 4$

Lattice simulations are ongoing; suggest both systems

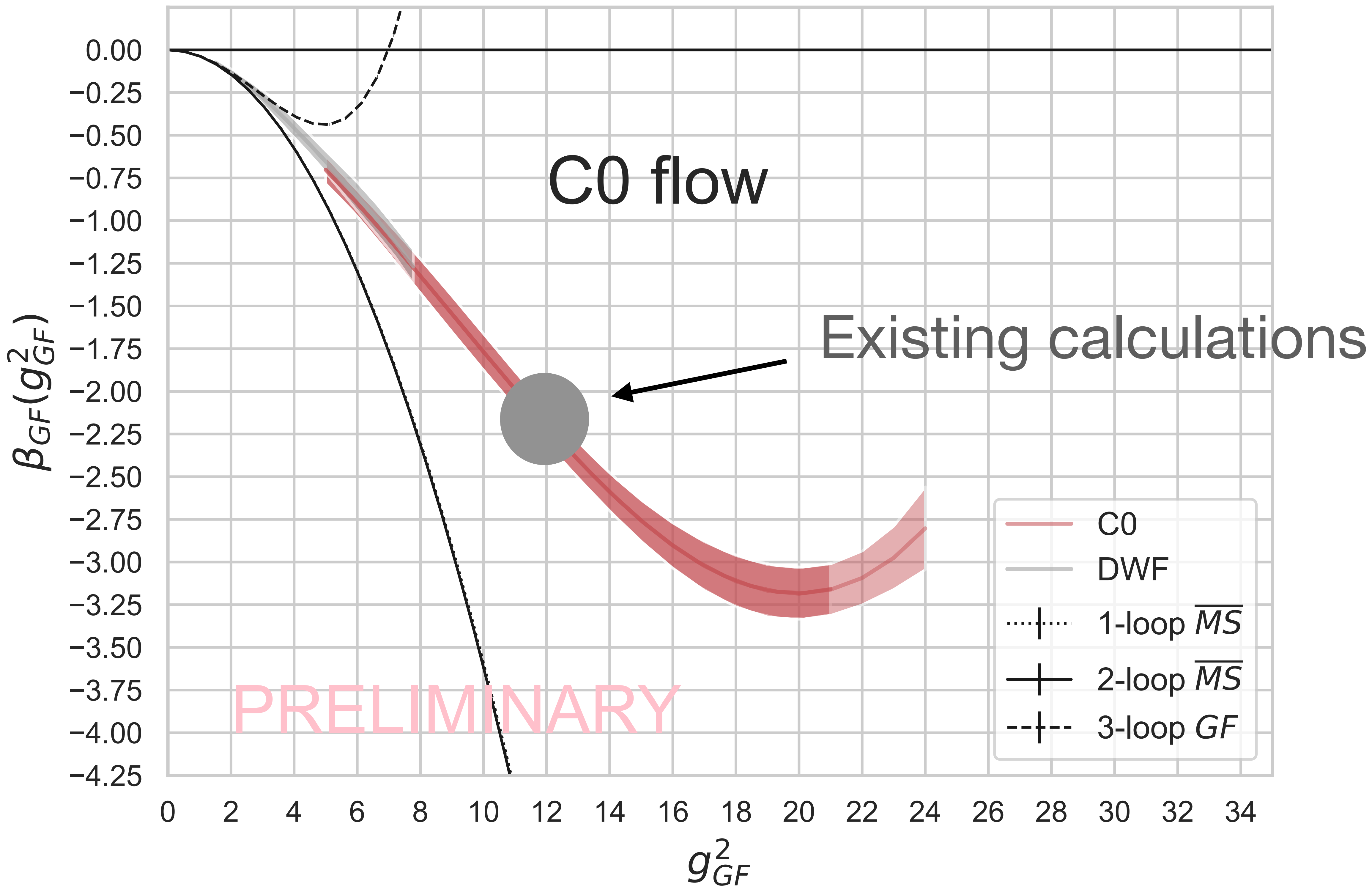
- exhibit conformal and SMG phases
- continuous phase transition

More details about SU(3) gauge + $N_f = 8$ in next talk by O. Witzel

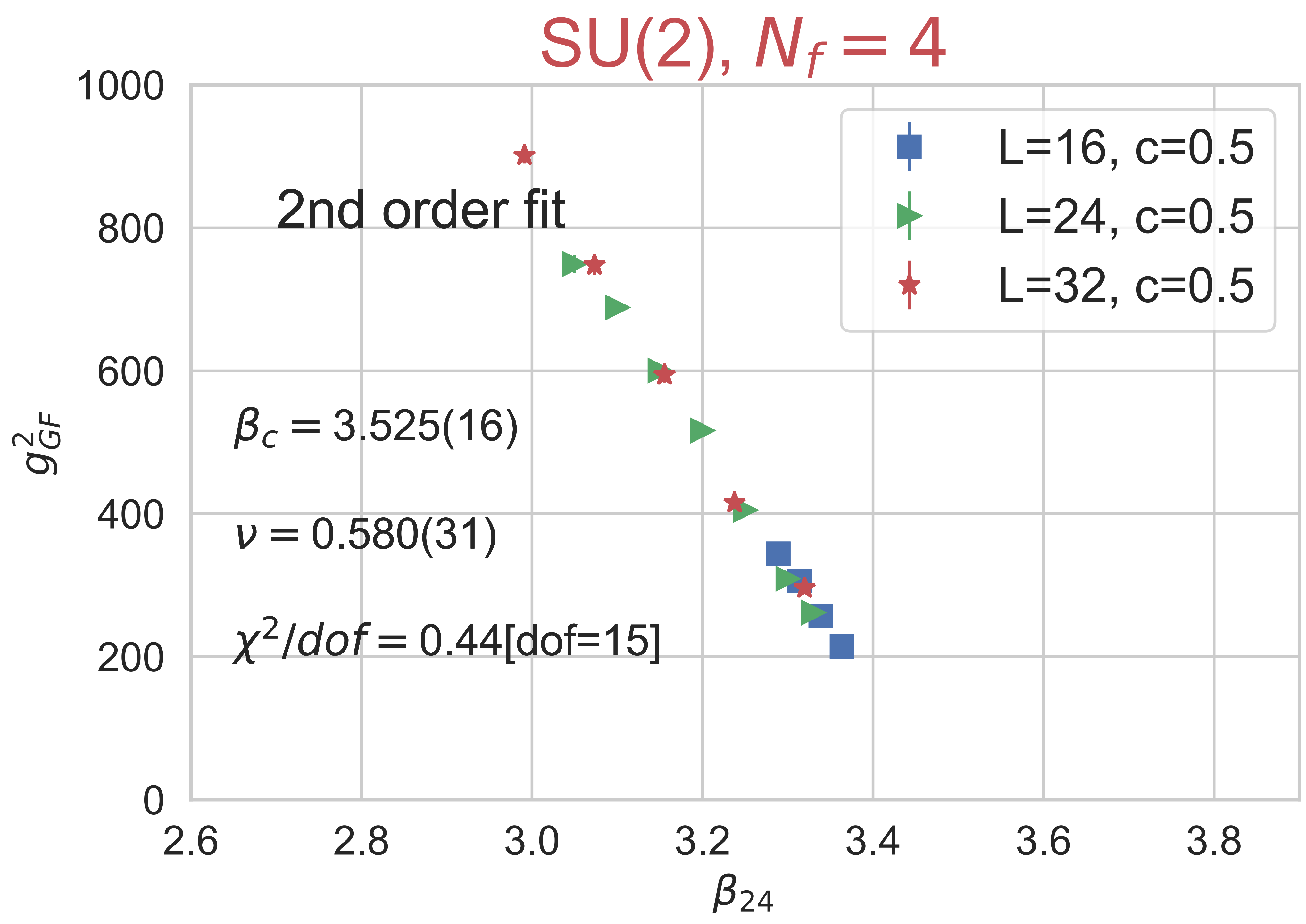
EXTRA SLIDES

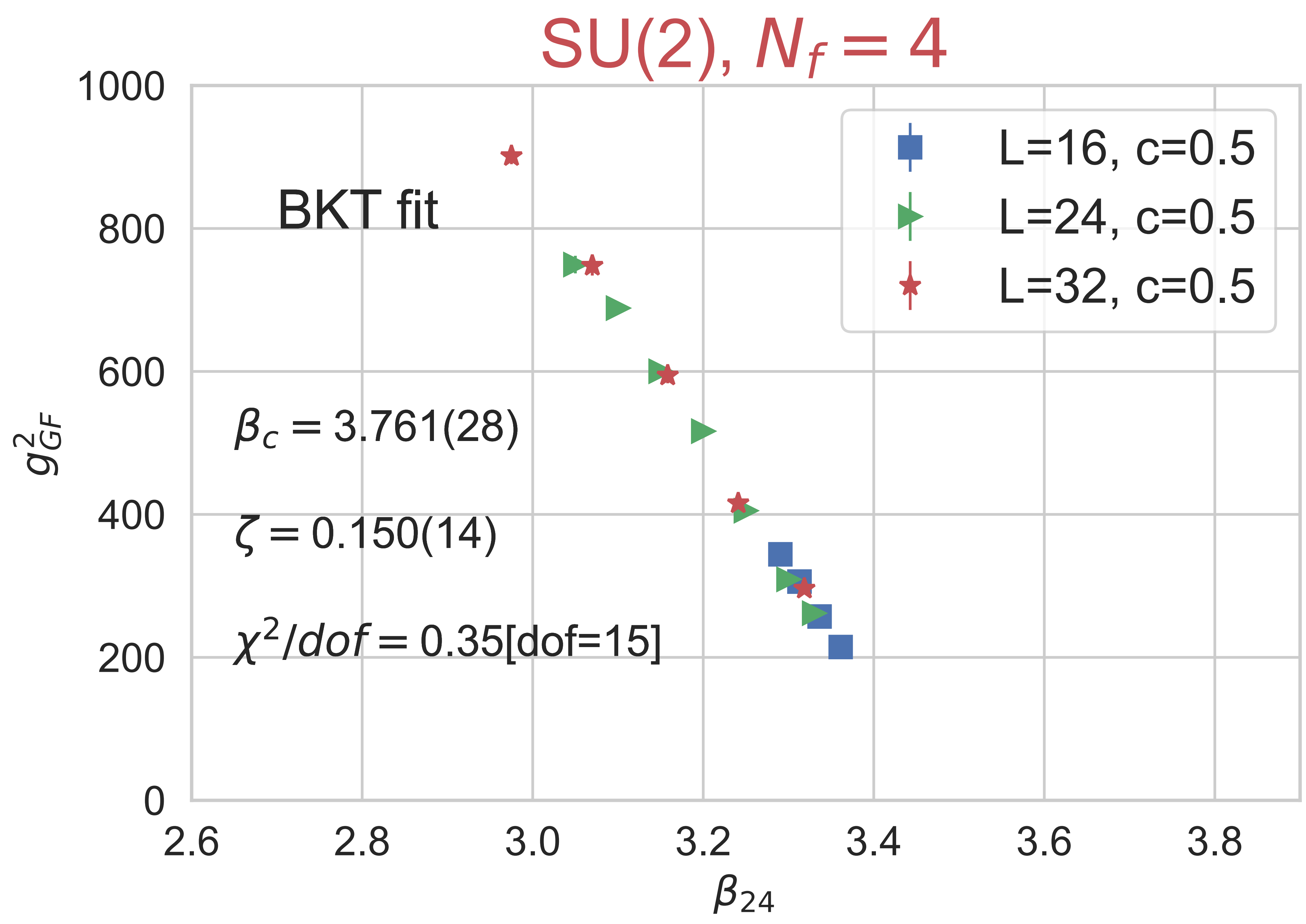
SU(3) + $N_f = 8$ β function

Cutoff effects due to topology limit the range where $\beta(g^2)$ can be reliably evaluated



FSS/ Order of the phase transition - SU(2) + $N_f = 4$





Use GF coupling $g^2(c = 0.5)$

Both 2nd order and BKT fits show excellent curve collapse

$\nu \approx 0.5$ is not consistent with first order transition