Investigating SU(3) with $N_f = 8$ fundamental fermions at strong renormalized coupling

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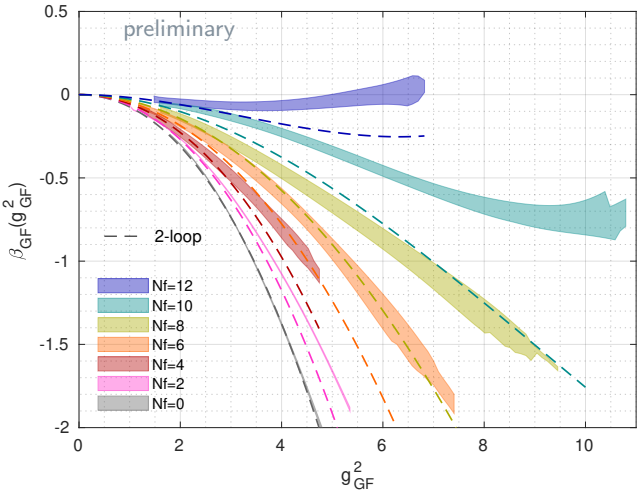
41st Lattice Conference
Liverpool, United Kingdom · August 02, 2024

Landscape of SU(3)

- Plot: Lattice 2023

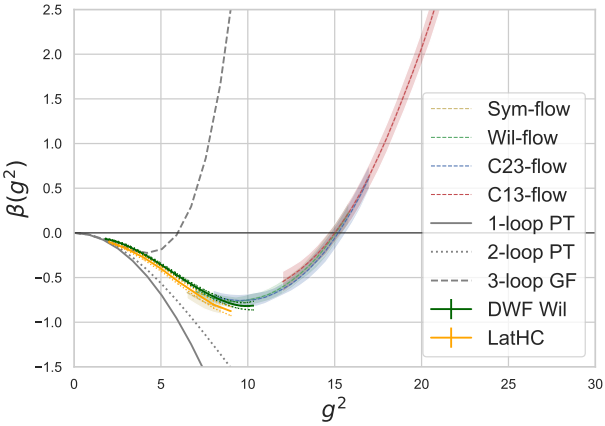


- Simulations with stout-smeared Möbius DWF and Symanzik gauge action
- Systematic effects for $N_f = 10$ likely underestimated
- Reach in g^2 limited by 1st order bulk phase transition (lattice artifact)
  $\rightarrow N_f = 12$ Sign of IRFP
  $\rightarrow N_f = 10$ likely turning around
- Qualitative behavior captured by 2-loop PT prediction
- 3-loop GF prediction tracks nonperturbative result longer, but than turns away showing different qualitative behavior

[Harlander, Neumann JHEP06(2016)161]

$N_f = 10$ at strong coupling

[Hasenfratz, Neil, Shamir, Svetitsky, OW PRD 108 (2023) L071503]

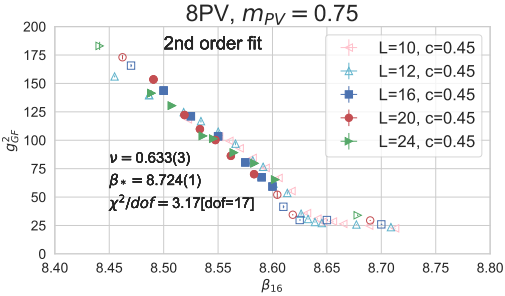


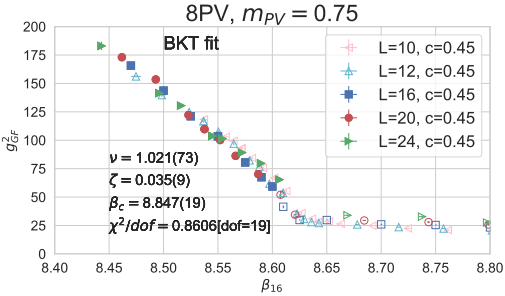
- Simulating $N_f = 10$ with Wilson fermions and additional Pauli-Villars fields allows simulations at much stronger coupling
- Clear IRFP
  - → $N_f = 10$ is conformal
  - → Confirms $N_f = 12$ is conformal
- What is the nature of $N_f = 8$?
- Where is the sill of the conformal window?

Continuous β function for $N_f = 8$ at strong coupling

- Work in progress by Hasenfratz, Peterson
- nHYP-smeared staggered fermions with additional Pauli-Villars fields
  fundamental gauge action with adjoint term
- Reaching $g^2 \sim 24$
  $\rightarrow \beta$ function may be turning, but no sign of a fixed point
  $\rightarrow$ Simulations troubled by large topological artifacts in the gradient flow
  $\rightarrow$ Close to a phase transition?

Signs that $N_f = 8$ is special [Hasenfratz PRD 106 (2022) 014513]





- Finite size scaling

  2^{nd} order: $g^2(\beta; L; c) = f^{(c)}_{\text{2nd}}\left((\beta/\beta_* - 1)\, L^{1/\nu}\right)$ BKT: $g^2(\beta; L; c) = f^{(c)}_{\text{BKT}}\left(L \exp\left(-\zeta|\beta/\beta_* - 1|^{-\nu}\right)\right)$

- BKT fit preferred for these (small volume) data

Simulations

- nHYP-smeared staggered fermions
- Additional Pauli-Villars fields
- Plaquette gauge action with adjoint term

- Volume $16^3 \times 32$, $24^3 \times 64$, $32^3 \times 64$, $48^3 \times 96$
- $\beta_b = 8.10, 8.20, 8.30, 8.40, 8.50, 8.60, 8.70, 8.80, 8.90, 9.10, 9.20, 9.30, 9.50$

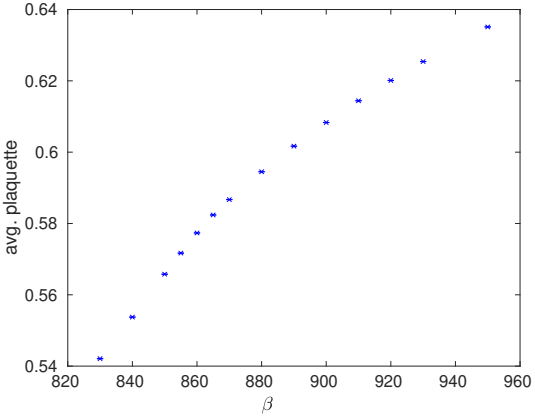
  $\rightarrow$ Simulations cross from weak coupling to symmetric mass generation (SMG) phase

  [Hasenfratz PRD 106 (2022) 014513]

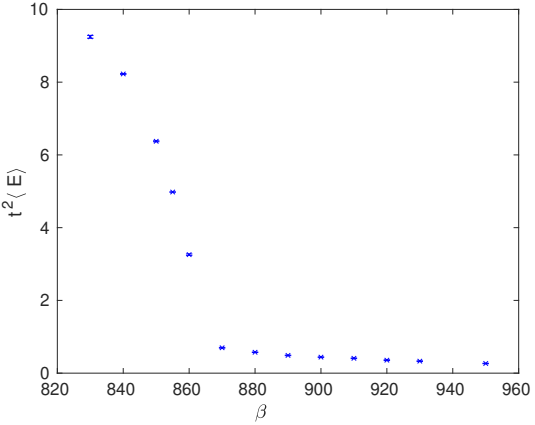
- HMC: QEX (Osborn, Jin, Peterson)
- Spectrum: MILC (DeTar et al., ..., Schaich, Hasenfratz)
- Gauge flow: QLUA (Pochinsky et al.)

$24^3 \times 64$ ensembles

- Average plaquette



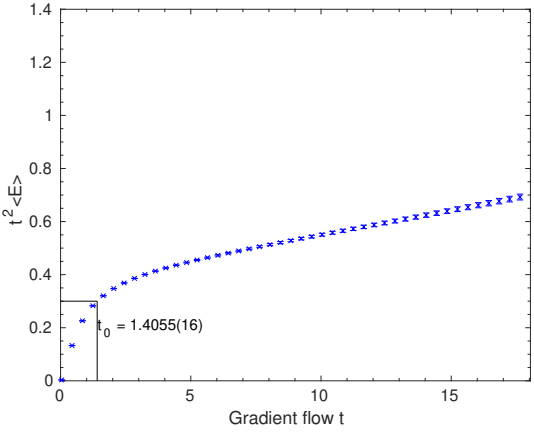
- $t^2\langle E(t)\rangle$ at $t = L^2/32 = 18$



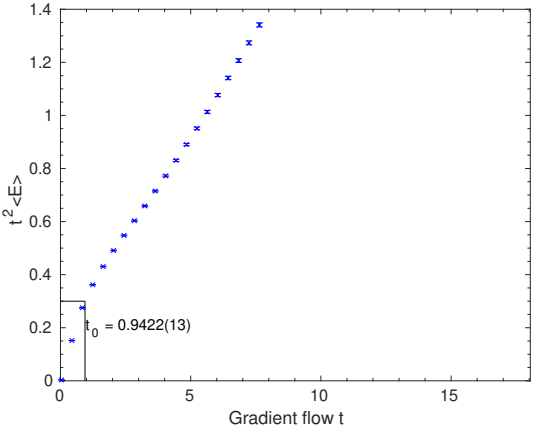
- Something interesting is happening

$t^2\langle E(t)\rangle$ vs. t

- $\beta_b = 8.70$

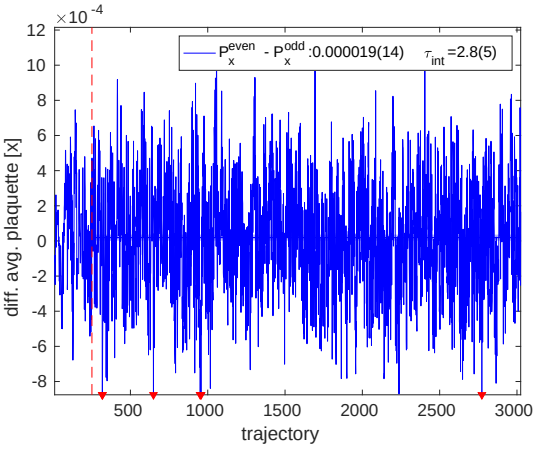


- $\beta_b = 8.60$



Broken symmetry between even and odd sites

- $\beta_b = 8.70$



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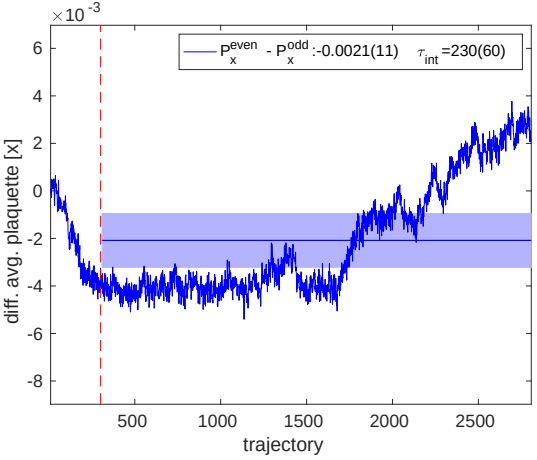

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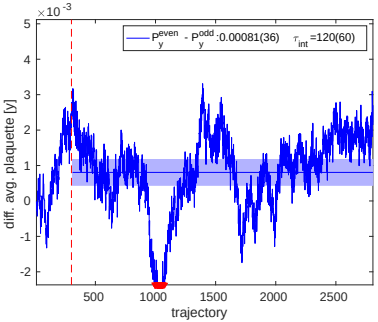
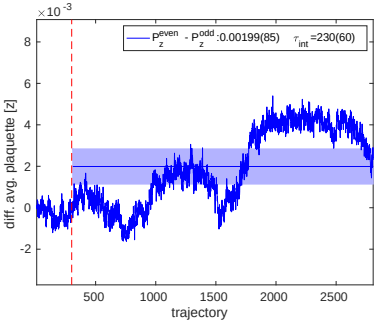
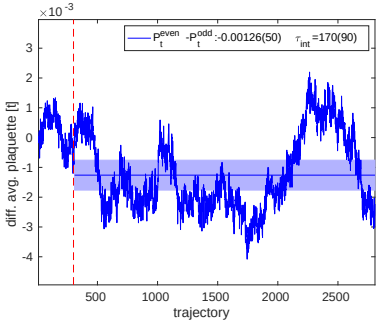
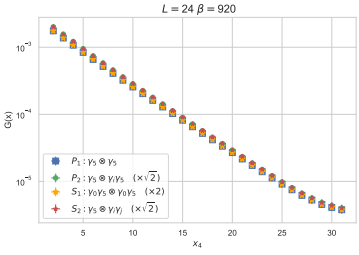






Pseudoscalar correlator

- Weak coupling
  $\beta_b = 9.20$ (conformal)



- Degenerate pseudoscalar and scalar (parity doubling)
- No taste splitting

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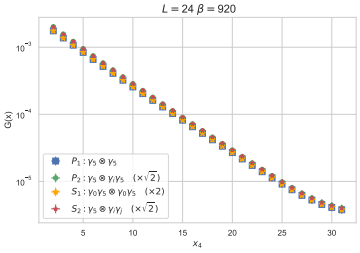

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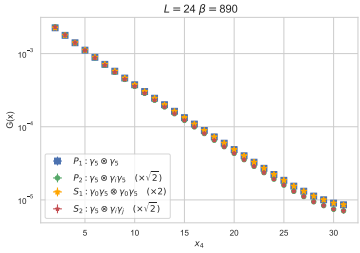

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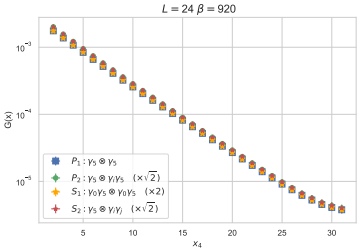

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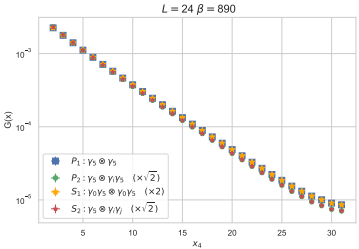
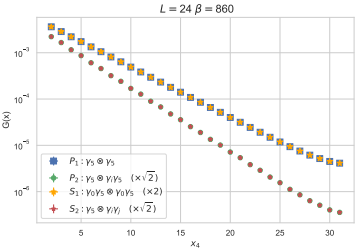


- Degenerate pseudoscalar and scalar (parity doubling)

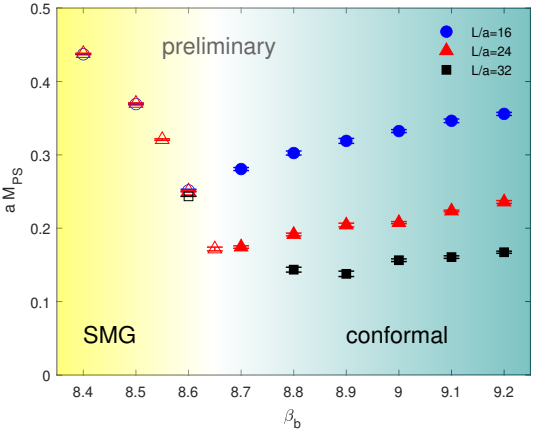
- Strong coupling
  $\beta_b = 8.60$ (SMG)



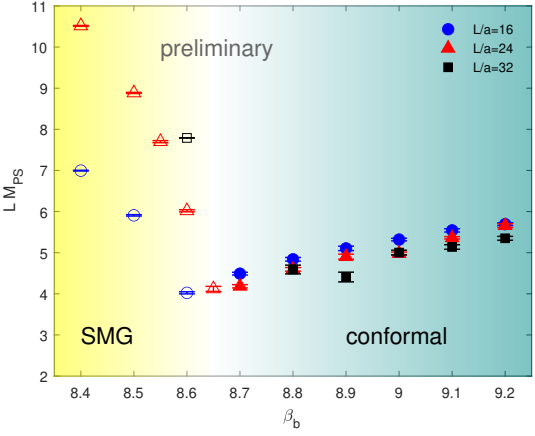
- Degenerate pseudoscalar and scalar (parity doubling)
- No chiral symmetry breaking

Pseudoscalar correlator

- aM_{PS}



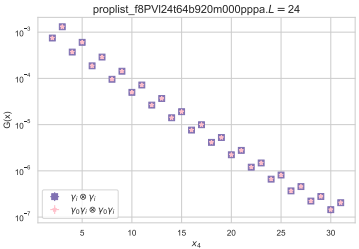
- LM_{PS}



- Conformal scaling for $\beta_b > 8.6$

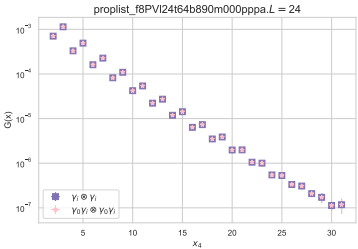
Vector correlator

- Weak coupling
  $\beta_b = 9.20$ (conformal)



- Degenerate vector and axial (parity doubling)

- $\beta_b = 8.90$



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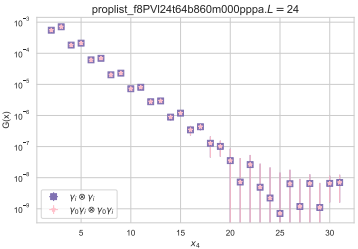

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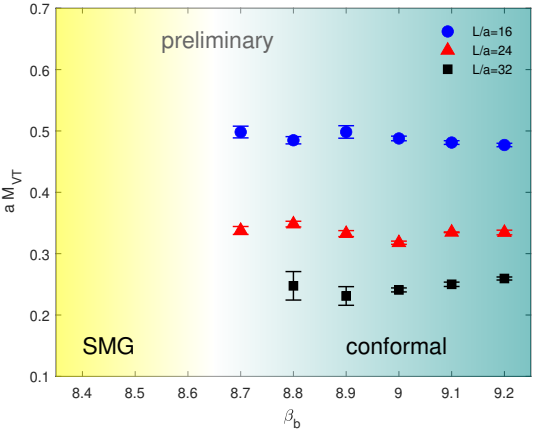
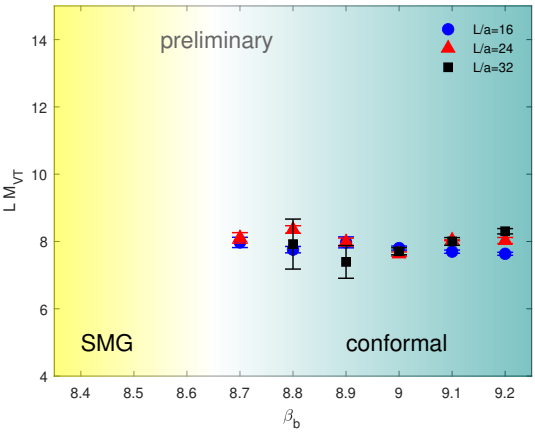
- No chiral symmetry breaking

Vector correlator

- aM_{VT}

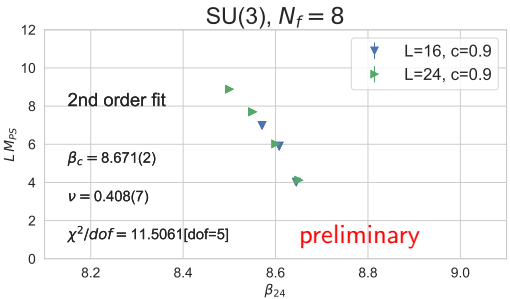


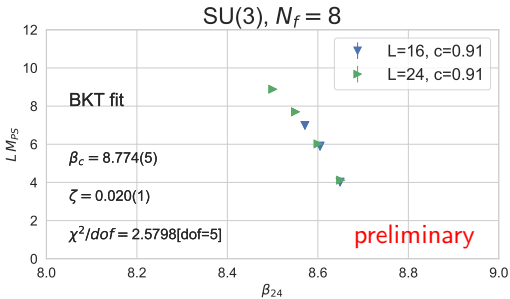
- LM_{VT}



- Conformal scaling for $\beta_b > 8.6$

Outlook: finite size scaling





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Summary

- Large scale simulations to test SU(3) with $N_f = 8$ fundamental flavors at strong coupling using additional Pauli-Villars fields
- Preliminary findings support picture of a conformal and an SMG phase
  $\rightarrow$ No chiral symmetry breaking
- Further simulations on larger volumes needed/planned

Acknowledgment

- Special thanks to Amitoj Singh and his team at Jefferson Lab for granting us access and early science time on the new 24s cluster