Nc=2 lattice gauge theories with fundamental and adjoint Wilson fermions

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14-19 July 2010, Lattice 2010, Villasimius, Italy

Motivation

Study of phase structure of SU(N) gauge theories

- *Search for conformal window: possible alternative to Standard Model Higgs sector*
- Fundamental/adjoint (or higher) representations
- At zero and finite temperature

- SU(2) theories:
  - Conformal behavior is expected with less #flavor
  - Nf=2 adjoint fermions: ''Minimal Walking technicolor''

Lattice: Catterall and Sannino (2007), Catteral et al (2008)
Del Debbio et al. (2008), Bursa et al. (2010)
Hietanen, Rummukainen, Tuominen (2009)

Our approach

Use of overlap fermion

- Exact chiral symmetry
- Epsilon regime to explore chiral symmetry breaking

- For locality of overlap operator,
  - Wilson-Dirac kernel must have gap (mobility edge)

    ⇔ Out of Aoki phase (Golterman and Shamir, 2003)

  — Motivation of this work

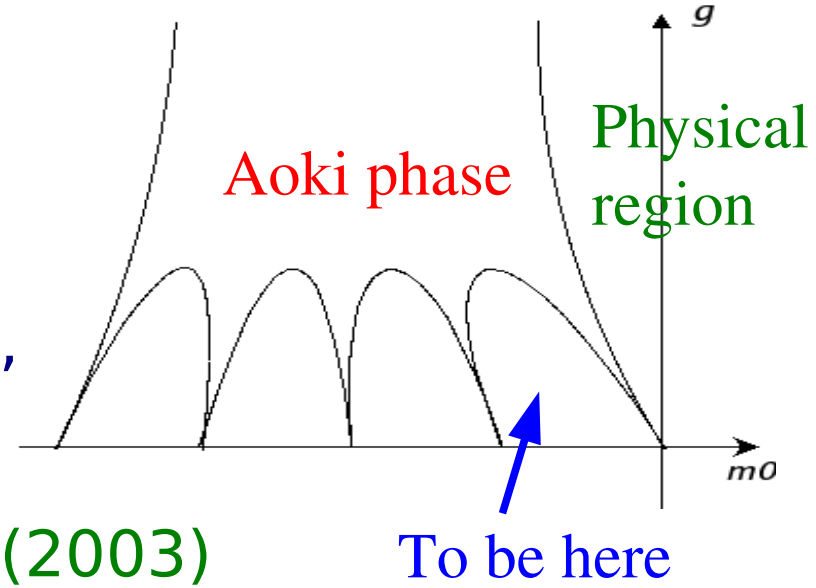
Present work:

- SU(2) gauge theories with Nf=2 fundamental and adjoint Wilson fermions (+twisted mass ghost)
  - *Investigation of Aoki phase*
  - Preparation to overlap simulations
  - Exercise to probe conformal behaviors

Aoki phase

Flavor-parity broken phase of Wilson-Dirac operator

- Proposed by Aoki, 1984
- Numerical evidence
- Chiral Lagrangian analysis
  (Sharpe and Singleton, 1998)



- As the kernel of overlap operator,
  to be in between fingers
- Conjecture of Golterman-Shamir (2003)
  - Eigenmodes of H_W is local below ''mobilty edge''
  - Aoki phase is characterized by vanishing mobility edge

Aoki phase

Results in QCD: Around 1st 'finger',

- 1st order phase transition at high β

  e.g. Ilgenfritz et al. (2004); Farchioni et al. (2005)

- 1st order transition is also observed at strong coupling

  e.g., JLQCD Collaboration (2005); Nagai et al. (2009)

  - Dynamics may differ from high β region

In present work,

- Wide range of bare quark mass of Wilson-Dirac operator is explored
- Not only 1st 'finger', 2nd 'finger' is also investigated
  - Number of light d.o.f. different from 1st finger

Lattice setup

SU(2) Iwasaki gauge + Nf=2 fundamental or adjoint Wilson fermions (+ twisted mass ghost)

- Fermoins introduced as topology fixing term

Vranas, 2000, Fukaya, 2006, JLQCD, 2006

$$\det\left(\frac{H_W^2}{H_W^2+\mu^2}\right) = \int \mathcal{D}\chi^\dagger \mathcal{D}\chi \exp[-S_E]$$

- Twisted mass ghost cancels high frequency effect:
  — not expected to change low energy dynamics

In the following, we focus on the adjoint case

- Lattice: 8^3x16, β =0.90
- Similar behavior is observed for fundamental fermions

— All results are very preliminary —

Analysis procedure

Observed quantities:

- Meson correlators
  - PS and V meson masses, PCAC quark mass
- Static quark potential
  - Fundamental static quark
- Spectrum of Wilson-Dirac operator (in progress)
  - Locality
- Spectrum of overlap-Dirac operator (in progress)
  - Chiral condensate
  - Comparison with Random Matrix Theory

Meson correlator

- PS meson correlator:

$$\Gamma(x,y) = \langle \pi_+(x)\pi_-(y)\rangle \qquad \pi_\pm(x) = i\bar{\psi}(x)\gamma_5\tau_\pm\psi(x)$$

from propagators with twisted mass

$$S_q = [D_W - im_1\tau_3\gamma_5]^{-1}$$

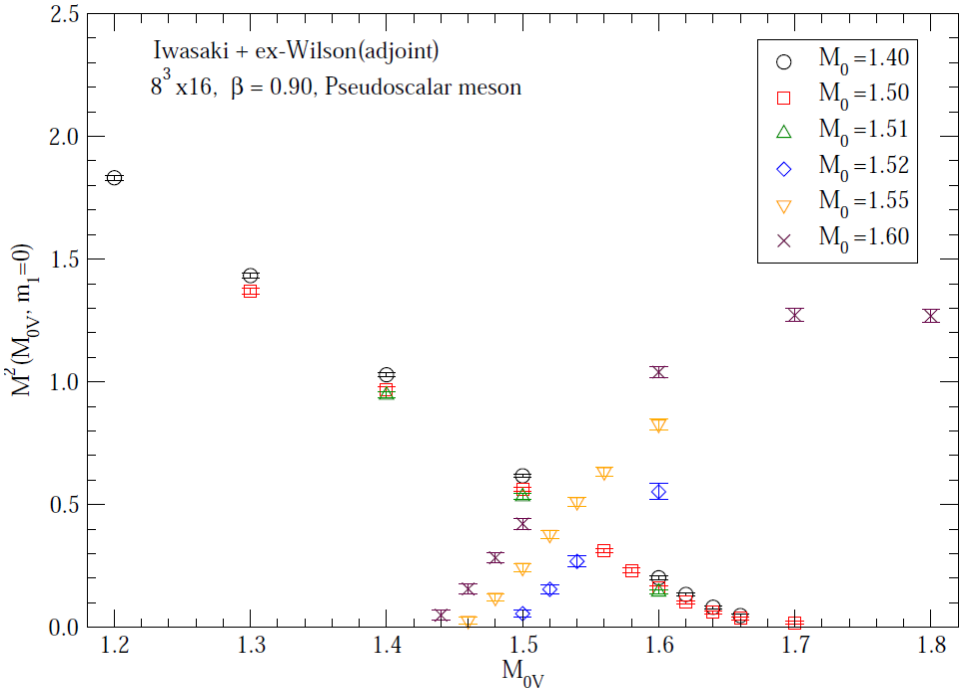
  - Meson mass is extracted from exponential fit
  - Linearly extrapolated to m_1=0 with smallest 3 points
- Vanishing charged pion mass = Aoki phase
- Vector meson mass, PCAC quark mass are also measured

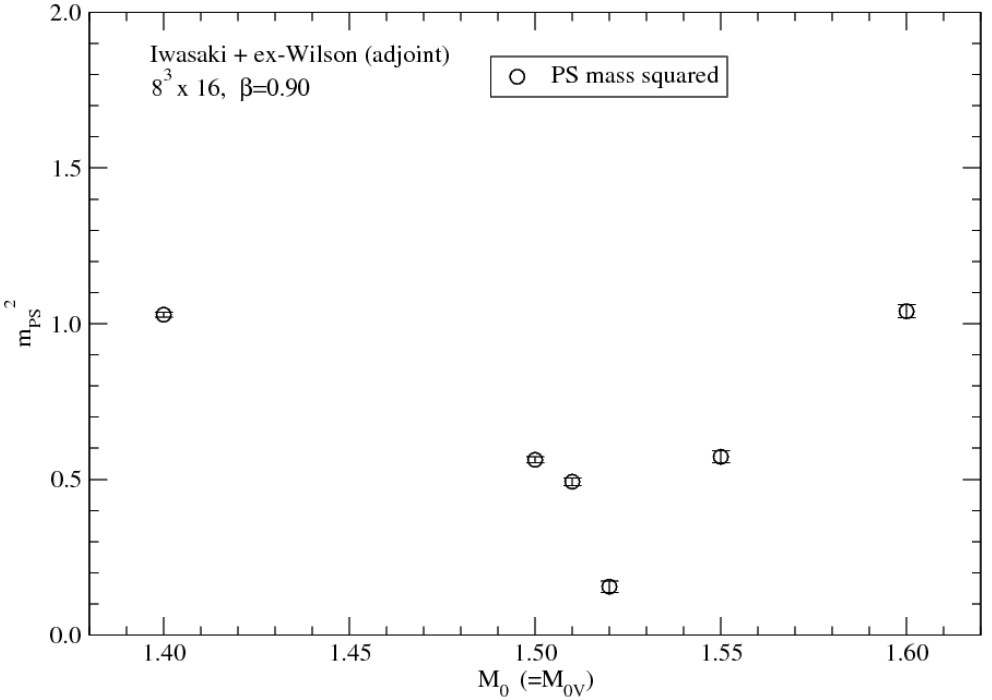
PS meson mass around 1st finger

PS meson mass vs M_{0V} (valence) around 1st 'finger'

- Partially quenched data: sign of slope suddenly changes
- Valence=sea data shows cusp-like structure

- Consisten with 1st order phase transition





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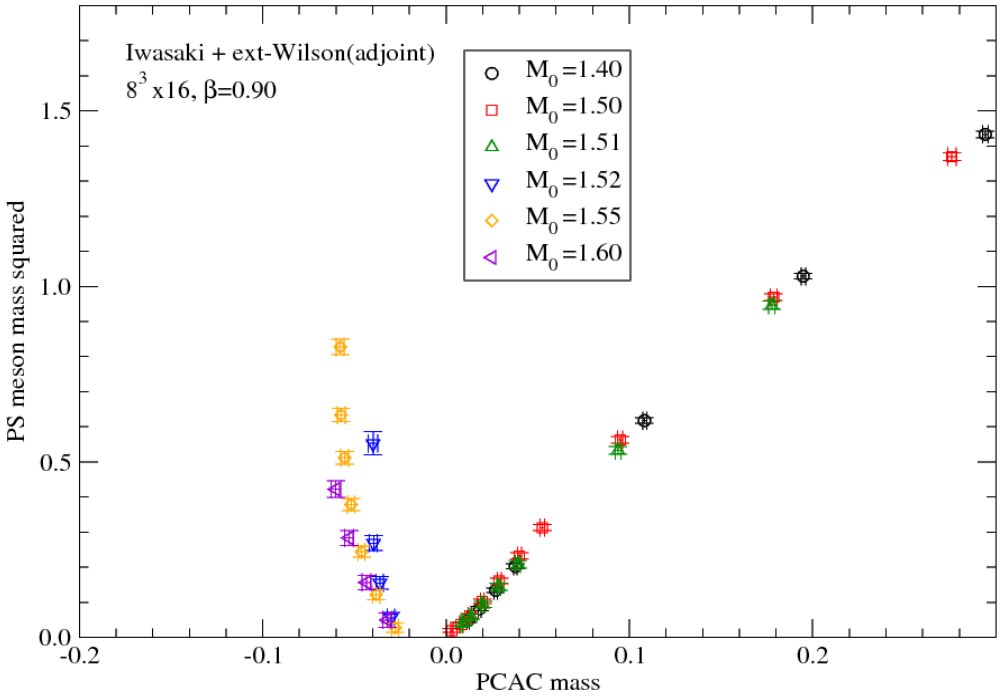
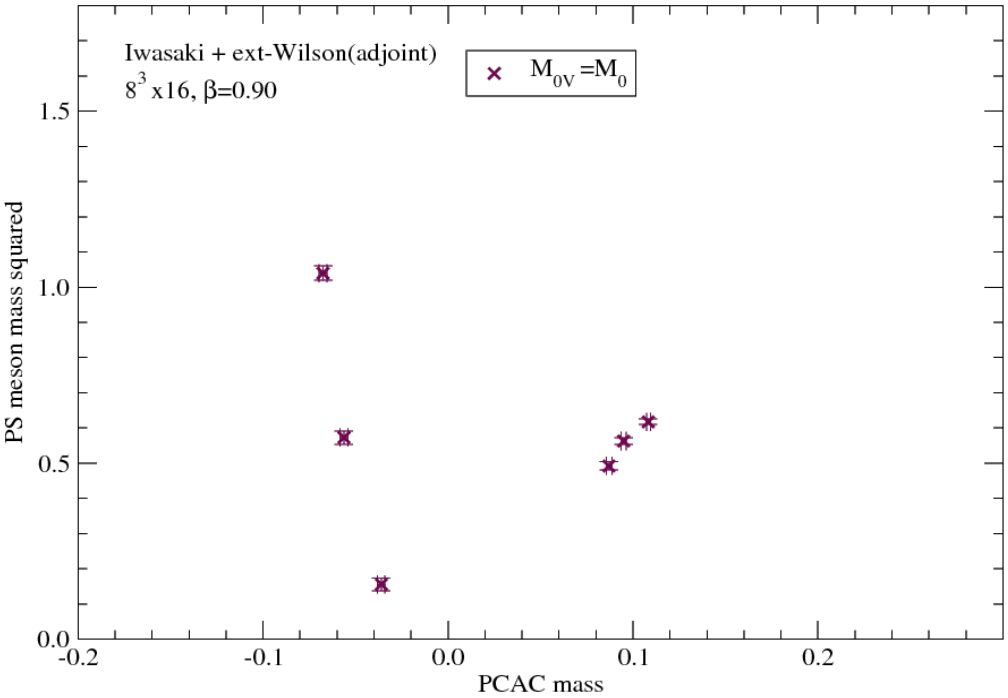
PS meson mass vs PCAC mass

- $M_0 \leq 1.51$: Positive PCAC mass
  - Partially quenched data shows $m_{PS}{}^2 \propto m_q$
  - Not enough light
- $M_0 \geq 1.52$: Negative PCAC mass
  - M_0=1.52 corresponds to our lightest case





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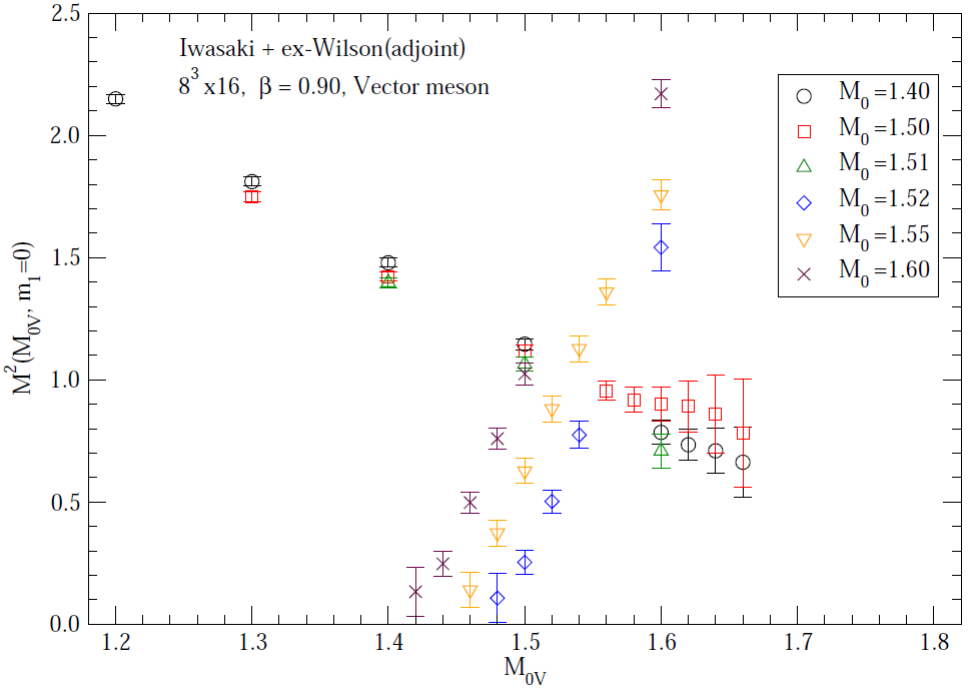
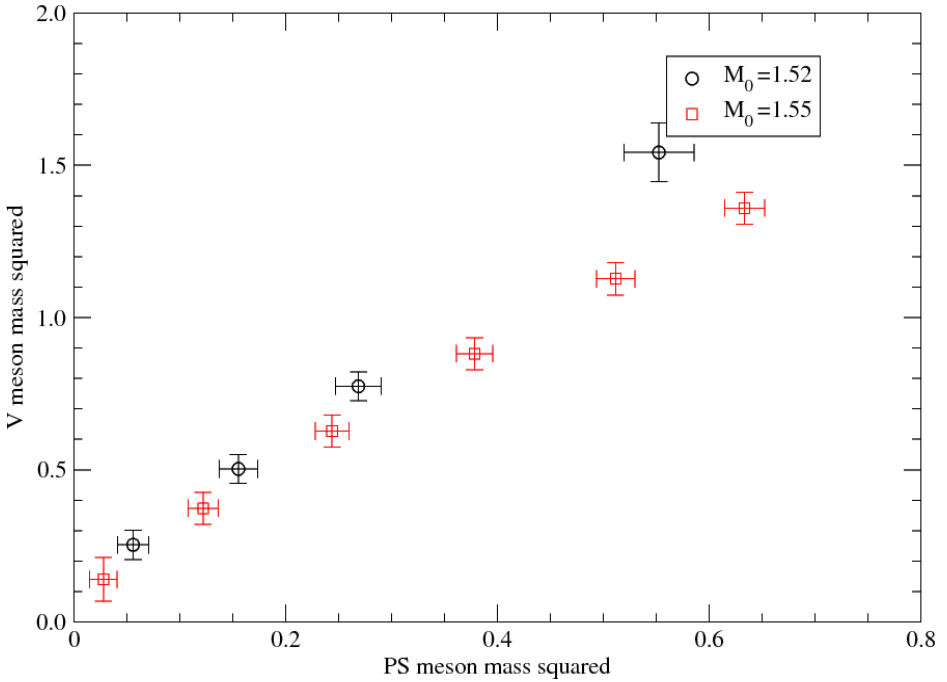
Vector meson mass

- M_0 below transition: QCD-like behavior
- M_0 above transition: m_V/m_{PS} seems to be const.
  - Consistent with signature of near-conformal





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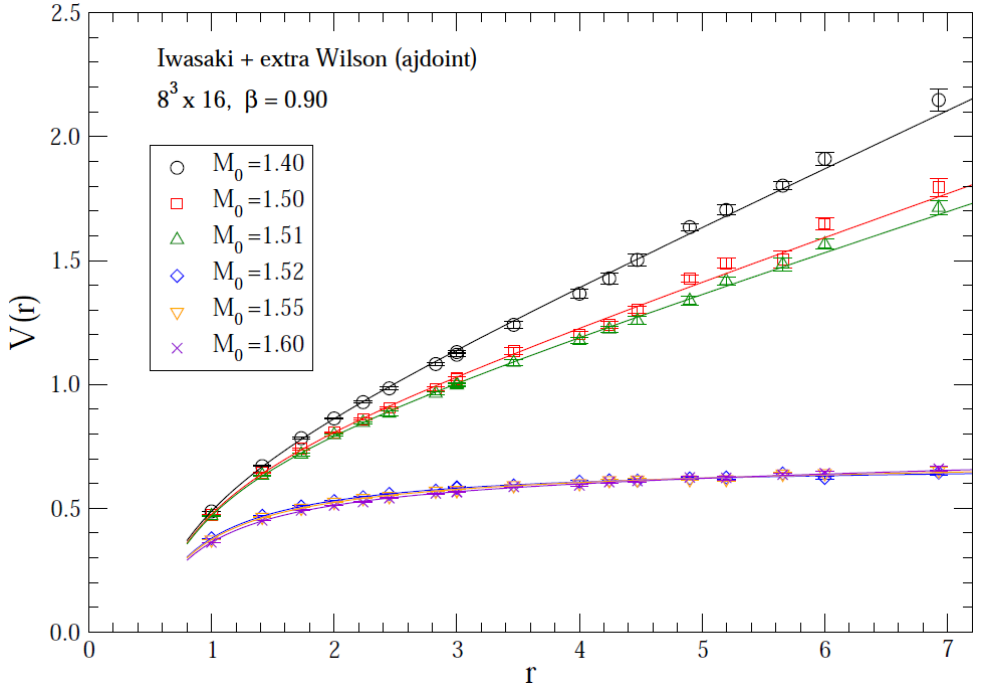
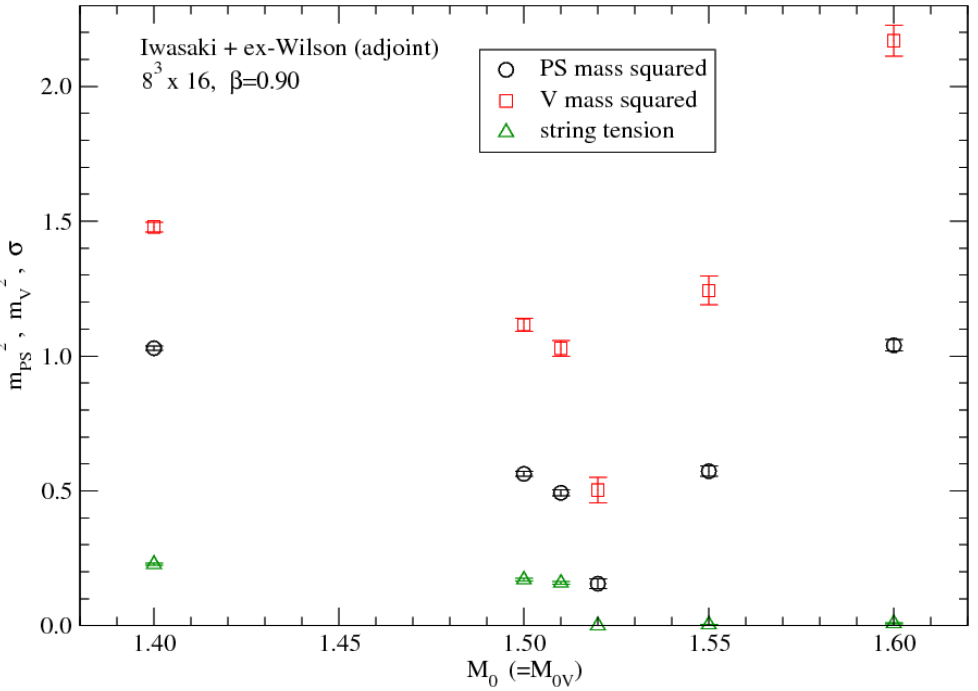
Static potential

- Static potential in fundamental repr.
  - $M_0 \leq 1.51$: QCD-like confining potential

    Cf: at M_0=1.40, $\alpha(r_0)$~0.2fm [r_0=0.5fm: just a guide]
  - At M_0 =1.52, string tension is consistent with zero

    Consistent with conformal phase
  - At $M_0 \geq 1.55$, tiny string tension





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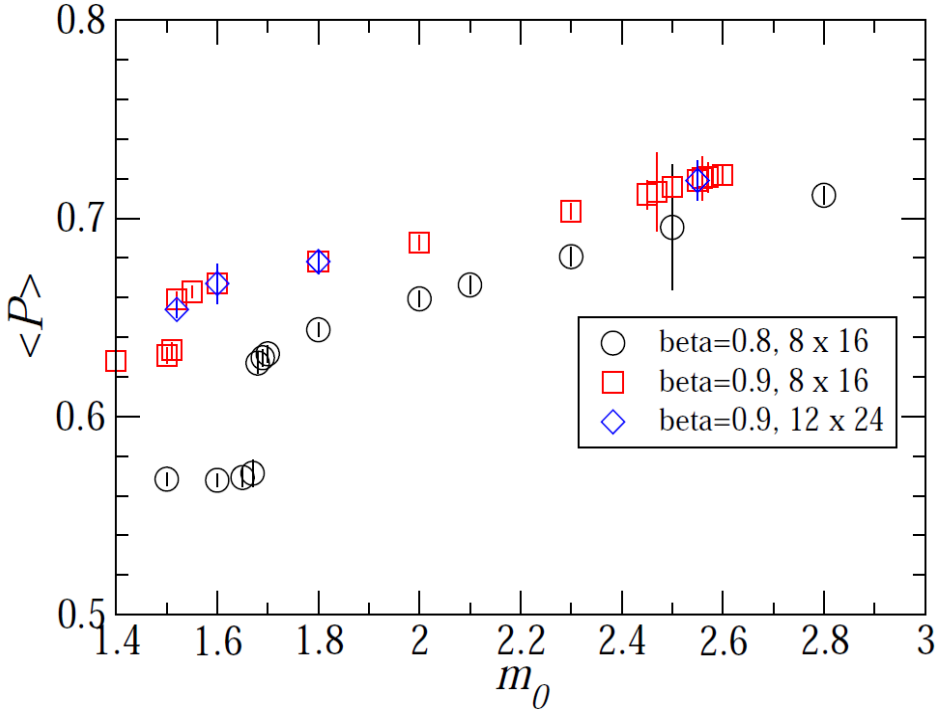
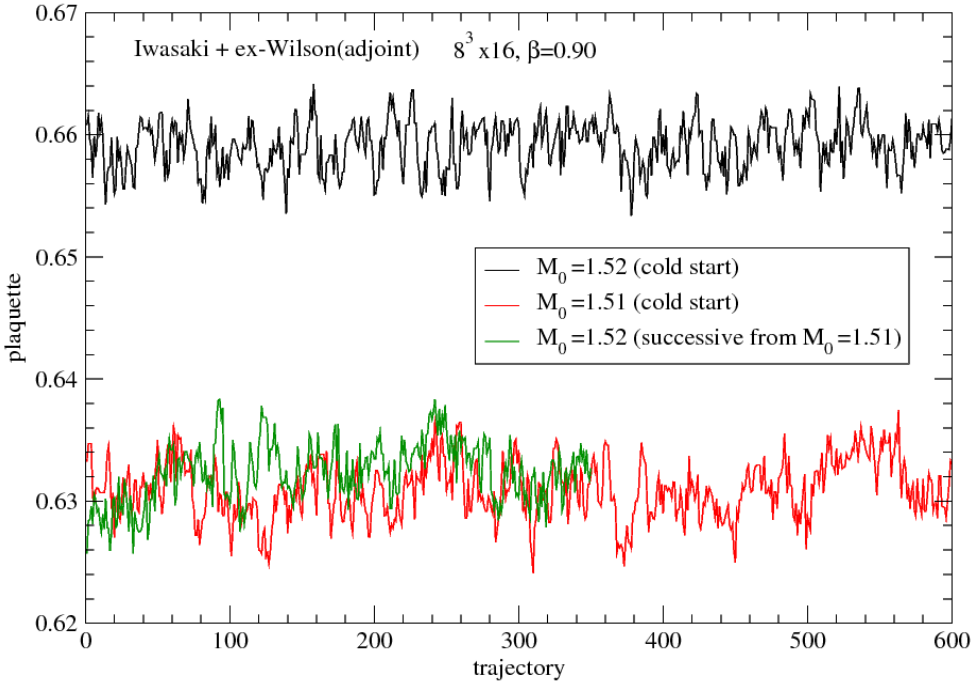
Plaquette

- 2-state signal
  - Update for M_0=1.52 with hot(M_0=1.51) and cold initial configs. exhibit different plaquette values
  - Supports 1st order phase transition





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Discussion

Result at β=0.90 around 1st finger:

- 1st order phase transition (No Aoki phase)
- At M_0=1.52 (m_q<0, smallest $|m_q|$) near-conformal behavior
  - V/PS meson mass ratio
  - Static potential
  - Increasing M_0 would wash out conformal behavior
- In positive m_q resion, quark mass is not enough light

Conjectuire: while light quark mass region is near-conformal, difficult to observe due to 1st order phase transition.

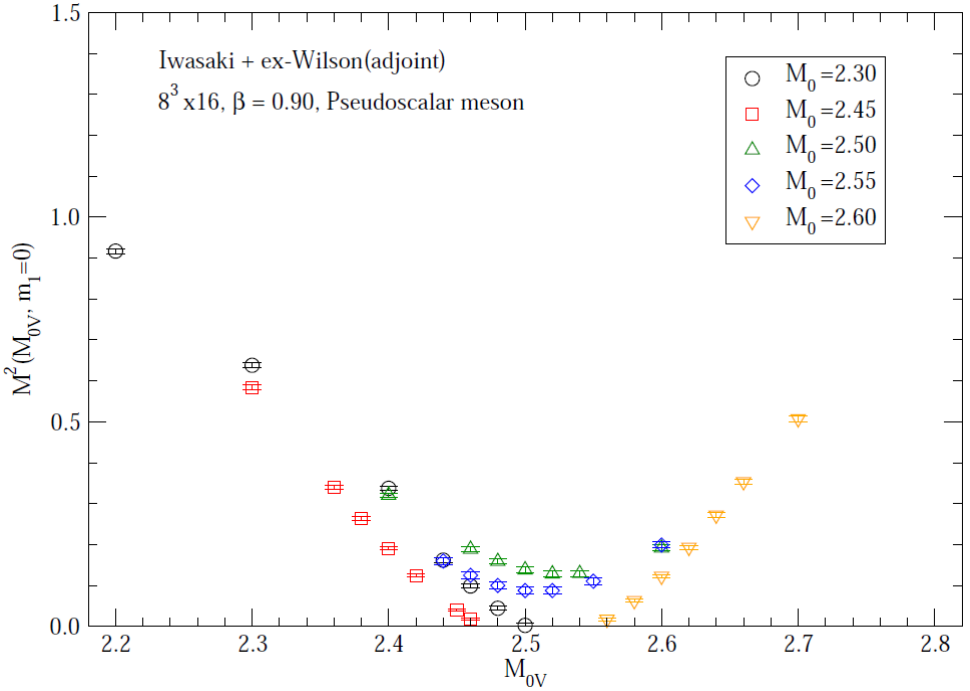
To confirm this scenario,

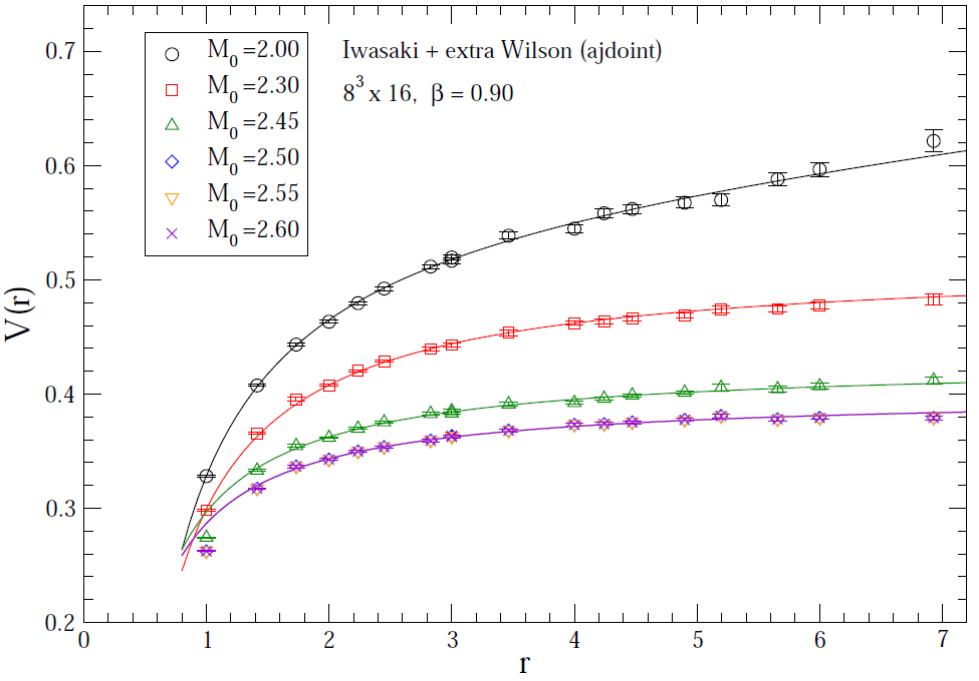
- At larger β, small m_q should be explored: conformal-like behavior should be observed

Around 2nd finger

- Light d.o.f is 8 instead of 2 around 1st finger
- PS meson mass vs M_{0V}
  - Consistent with 2nd order phase transition?
  - Existence of Aoki phase?
- Static potential exhibits no string tension $2.3 \leq M_0 \leq 2.6$

More detailed study is in progress





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Conclusion and outlook

We are exploring phase structure of SU(2) gauge theories with Nf=2 Wilson fermions

Result for adjoint fermions:

- Structure around 1st and 2nd fingers
- Conformal-like behavior is observed for small PCAC mass region around 1st finger

Works in progress:

- Fundamental fermions
- Extension to larger lattice sizes and other β values
- Spectrum of Wilson and overlap Dirac operator

Outlook

- Dynamical overlap fermions
- Finite temperature