Study of the finite-temperature physics of a lattice SU(4) gauge BSM model.

Venkitesh Ayyar [1] Thomas Degrand [1] Daniel Hackett [1] William Jay [1] Ethan Neil [1,3] Benjamin Svetitsky [2] Yigal Shamir [2].

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Mon, June 19, Lattice 2017, Granada, Spain

Work supported by grants from the DOE.

Computational work done using resources provided by Fermilab and local Janus cluster.

Motivation

- Study of SU(4) gauge theory with fermions in multiple representations in (3+1)D.
- Interesting in the context of partial compositeness[1,2](W. Jay's talk).
- Looking for confinement and chiral transitions.
- Can have different transitions for each representation.

[1] D. B. Kaplan and H. Georgi, Phys. Lett. B 136, 183 (1984).
[2] G. Ferretti, JHEP 06 (2014), 142.

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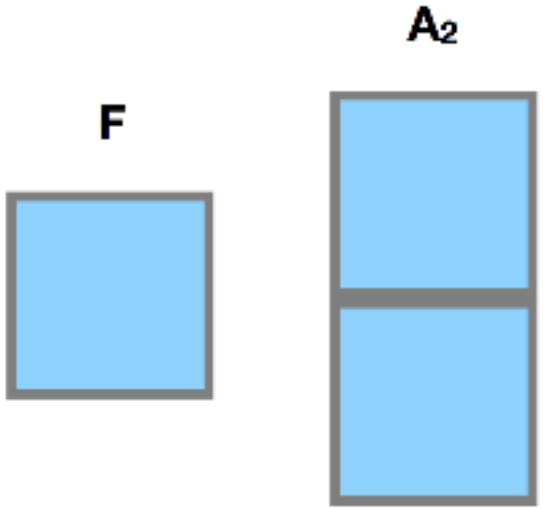
Model details

- SU(4) gauge theory.
- NDS action[3](nHYP Dislocation Suppression).
- Clover improved Wilson fermions.
- 2 flavors of fermions in the fundamental representation(F).
- 2 flavors of fermions in two-index anti-symmetric representation (A_2)
- 3D bare parameter space : β, κ_4, κ_6.
- Finite temperature study.



[3]DeGrand, Shamir, Svetitsky 2014

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Types of transitions (... for this talk)

Confinement transition

- Low temperatures $\rightarrow$ color singlets. No individual quarks.
- High temperatures $\rightarrow$ Individual quarks can exist.
- Transition line moves with N_t.

Bulk Transition

- Unphysical lattice transition.
- Transition line at fixed bare parameters is independent of N_t.

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Polyakov loop expectation value

In pure gauge theory

- $\langle P \rangle$ order parameter for SSB of centre symmetry Z(4).
- Confined $\implies \langle P \rangle = 0$.
- Deconfined, $\implies \langle P \rangle \neq 0$.

Full multi-rep theory

- F fermions break Z(4) completely.
- A_2 fermions break Z(4) to Z(2).
- Pseudo-order parameter.
- $\langle P \rangle = e^{-\beta F}$
- $P^F \equiv e^{-\text{Free energy}}$ of F quark.
- Similarly, can define $P^{A_2} \equiv e^{-\text{Free energy}}$ of A_2 quark.
- Can look at confinement-deconfinement for each representation.

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Flow anisotropy

- Wilson flow observable $\langle t^2 E(t) \rangle$ can be used to diagnose the phase[4].
- $\langle t^2 E(t) \rangle = \langle t^2 E_{ss}(t) \rangle + \langle t^2 E_{st}(t) \rangle$
- Spatial and temporal values deviate in deconfined phase.
- In previous work, $t^2 \langle E_{ss}(t) - E_{st}(t) \rangle$.
- We use $\langle \frac{E_{ss}(t)}{E_{st}(t)} \rangle - 1$.

[4] S. Datta, S. Gupta, and A. Lytle, Phys. Rev. D94, 094502 (2016); M. Wandelt, F. Knechtli, and M. Gunther, JHEP 10, 061 (2016)

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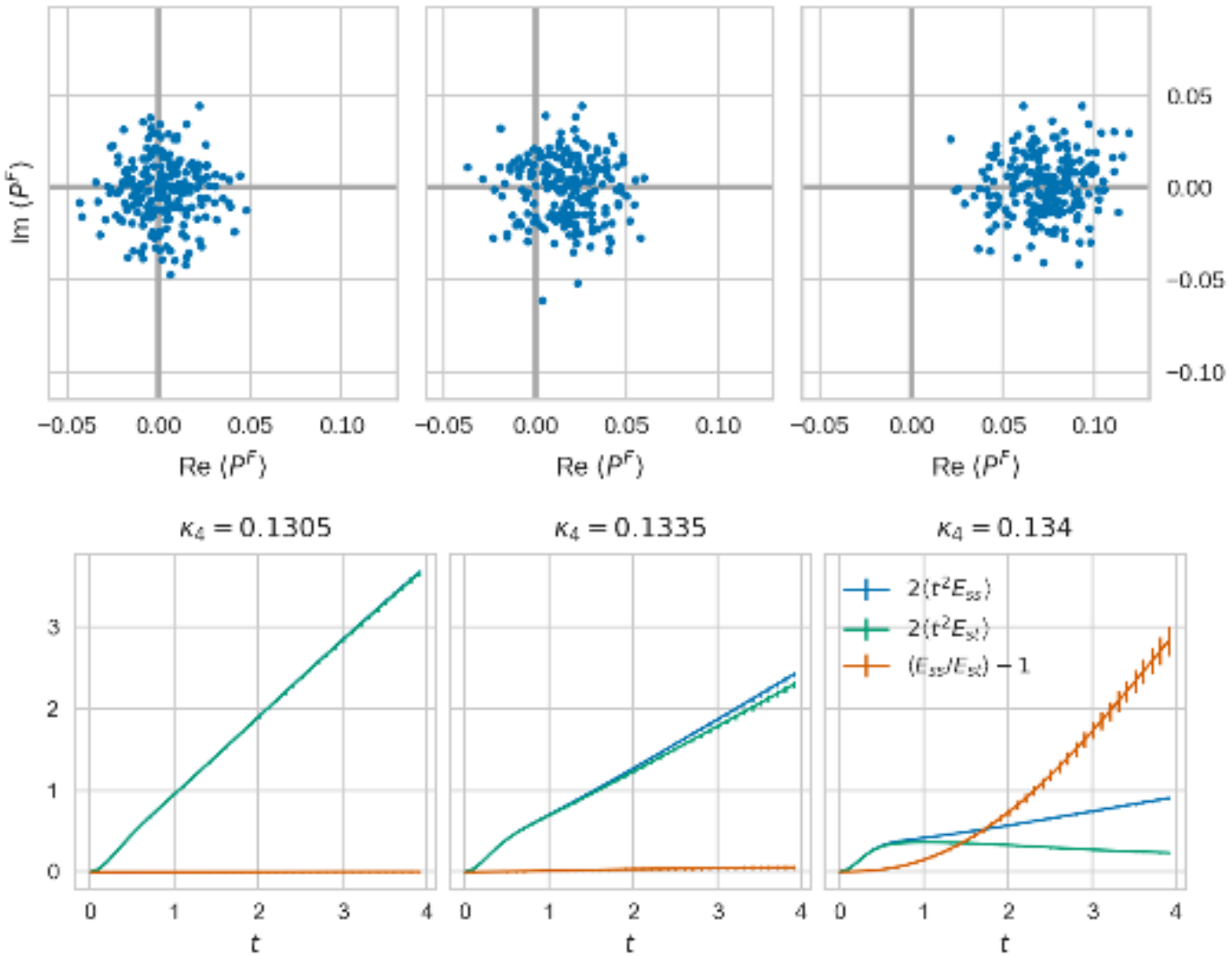
Im $\langle P^F \rangle$
0.05
0.00
−0.05
−0.10
−0.05 0.00 0.05 0.10
Re $\langle P^F \rangle$
$\kappa_4 = 0.1305$
$\kappa_4 = 0.1335$
$\kappa_4 = 0.134$
$2\langle t^2 E_{ss} \rangle$
$2\langle t^2 E_{st} \rangle$
$\langle E_{ss}/E_{st} \rangle - 1$
0 1 2 3 4
t

Lattice simulation details

- Finite temperature study.
- Lattice sizes $12^3 \times 6$ and $16^3 \times 8$.

- Both diagnostics (PL and flow) are consistent.
- Empirically determine a cut to distinguish confined and deconfined phases
- For Polyakov loop, the variance of $arg(P) < 1.0$.
- 30-200 independent configs for each ensemble.
- Around 500 ensembles.

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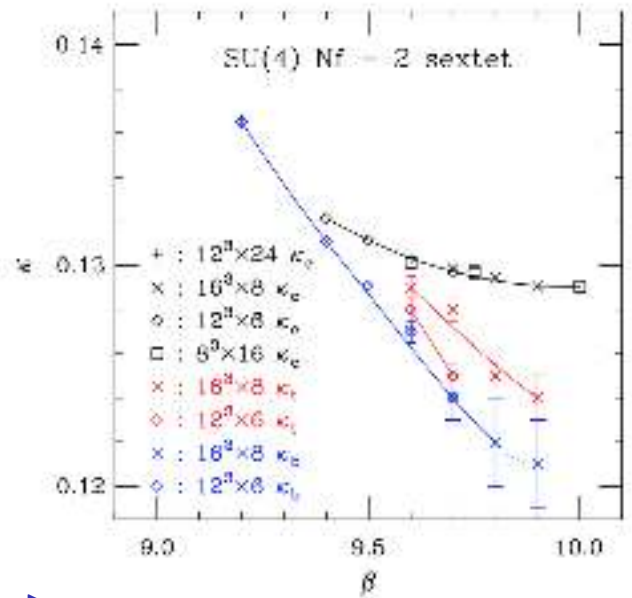
Sextet-only limit

Previous work[5] with A_2 fermions (different action)



- Bulk transition followed by
- Confinement transition
- $\kappa_{critical}$.

[5] T. DeGrand, Y. Liu, E. Neil, Y. Shamir, B. Svetitsky, PRD 91, (2015).

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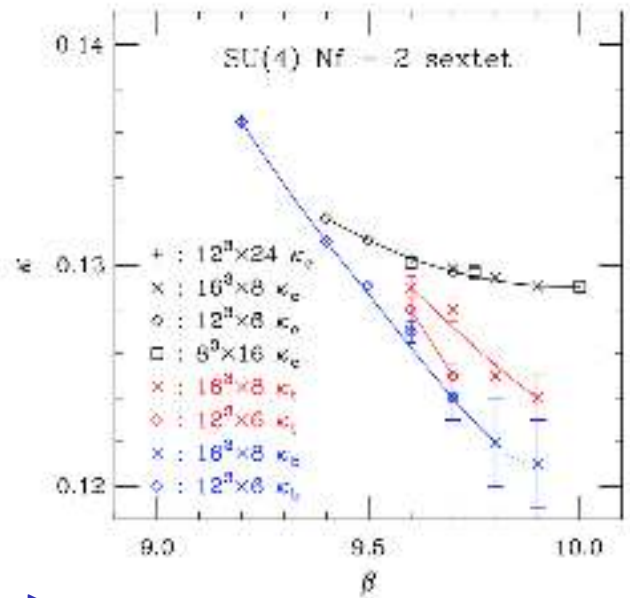
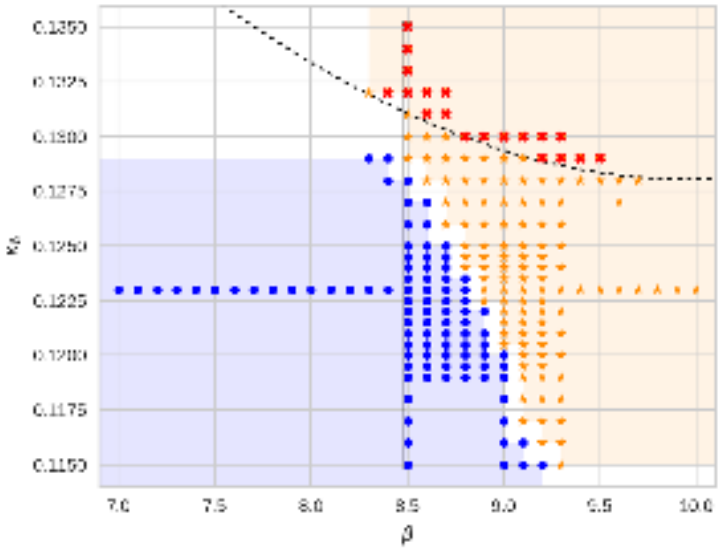


- Bulk transition followed by
- Confinement transition
- $\kappa_{critical}$.

NDS action in the A_2-only limit. ($12^3 \times 6 lattice$)



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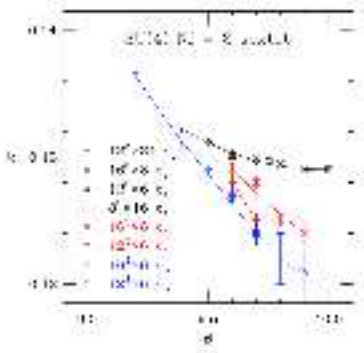
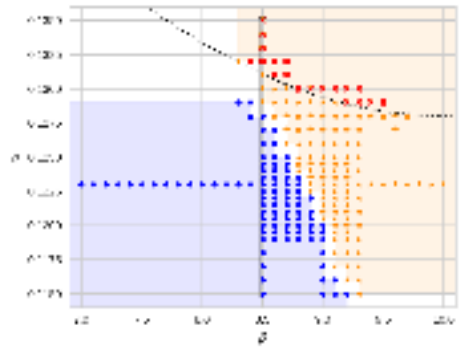
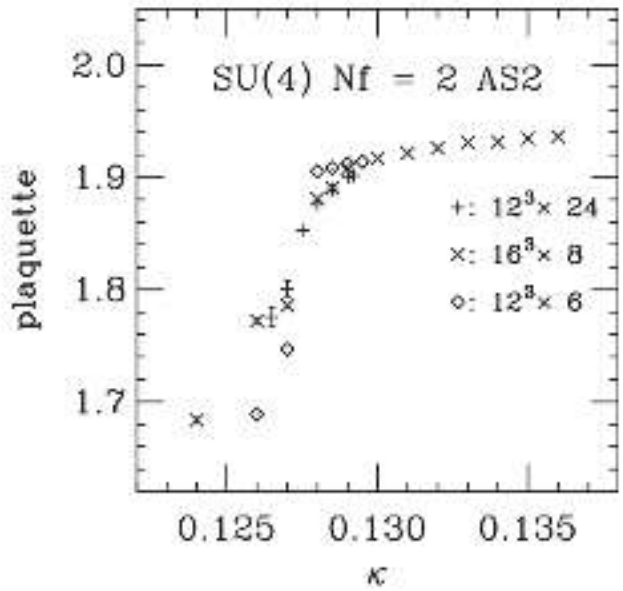
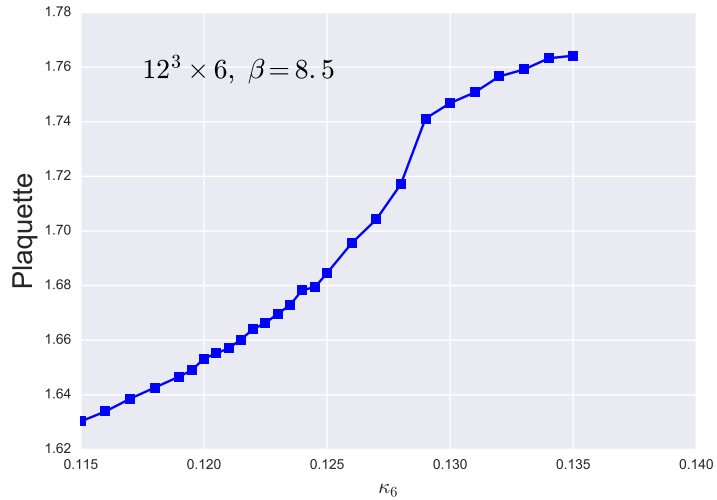




$\beta = 9.6$





No Bulk transition in region of interest with NDS action.

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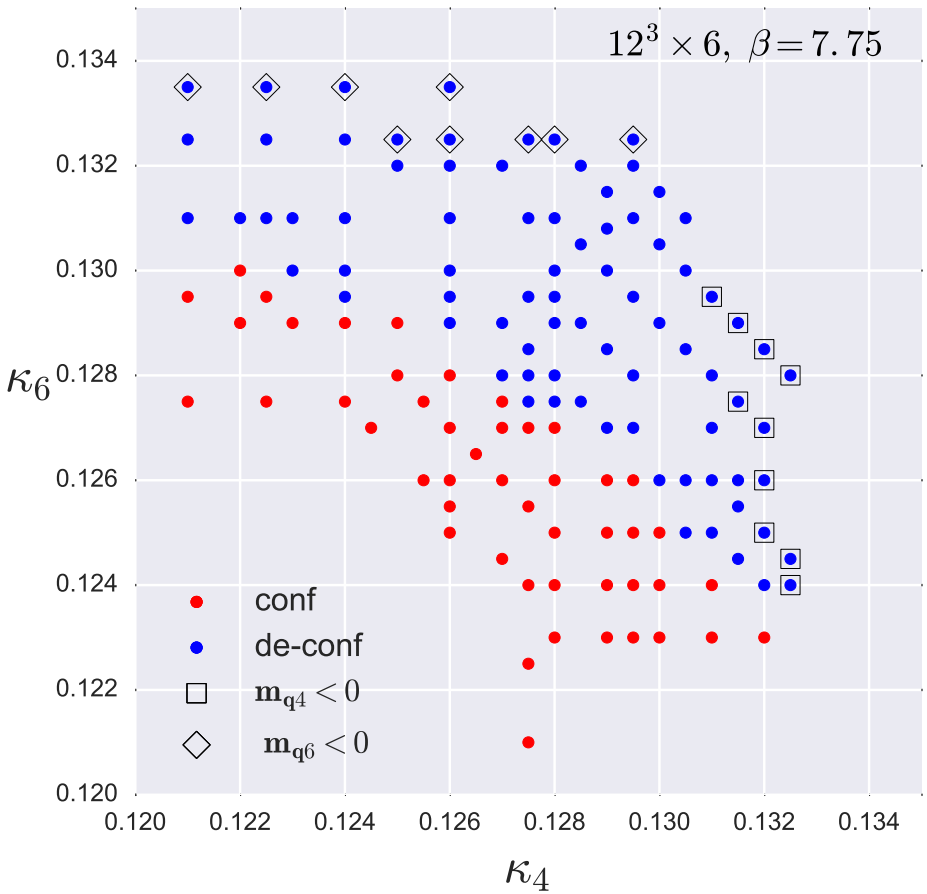
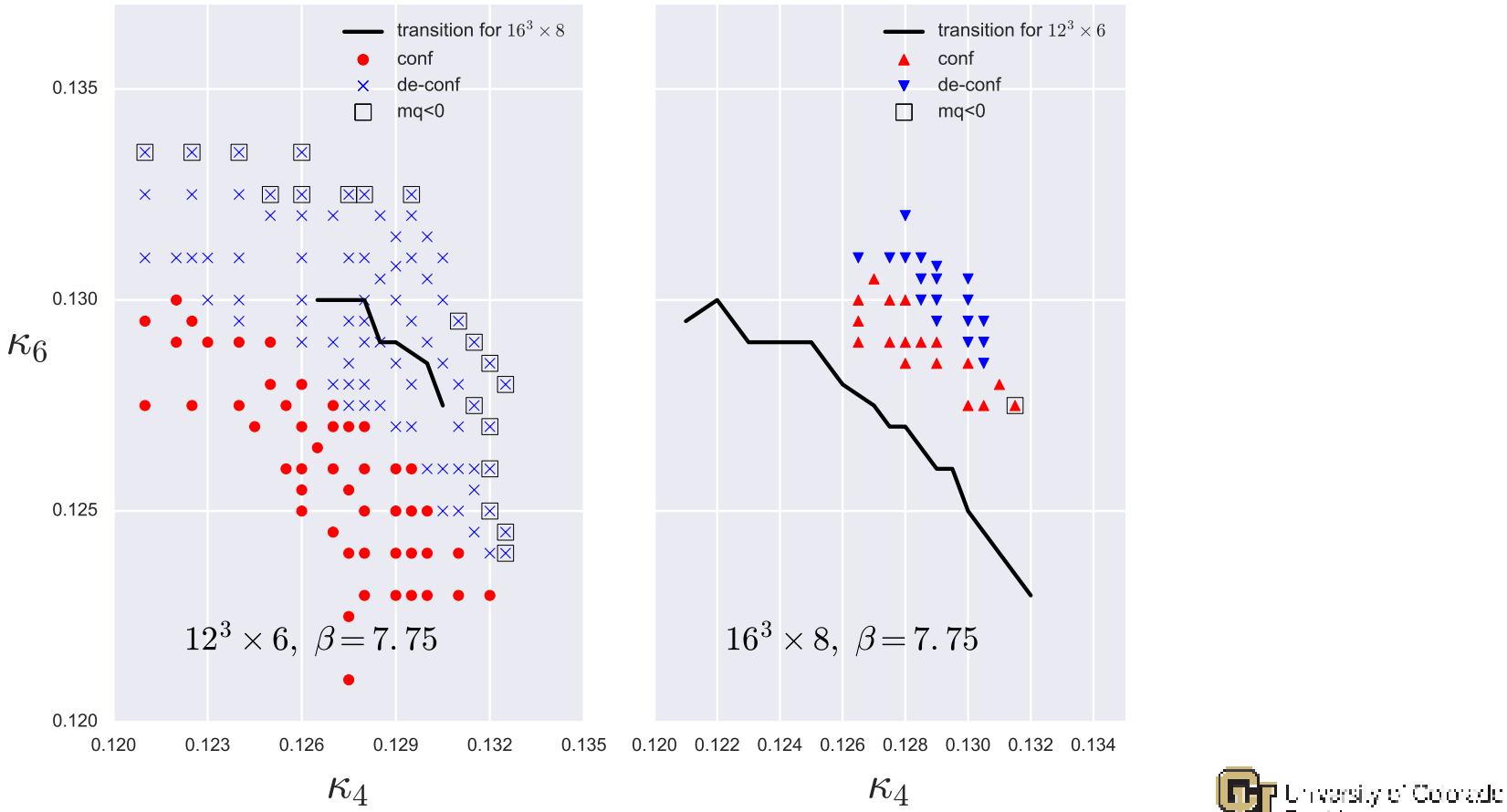
Phase diagram

Simulation with both representations:



Variation with temperature

- Curve shifts to the right as temperature $T = \frac{1}{aN_t}$ decreases.



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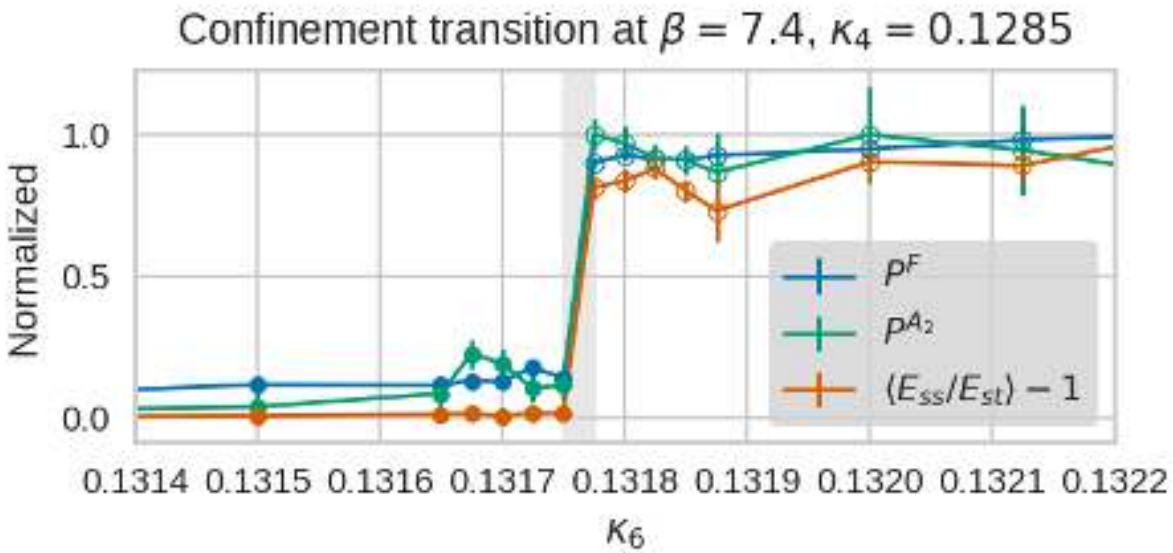
No phase separation for different reps

- Polyakov loop for F and A_2 at fixed β and κ_4.
- All observables respond simultaneously.
- Same in entire parameter space.
- Single transition.
- Transition seems first order.



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Conclusions

- Finite temperature study of SU(4) gauge theory with 2 fermion reps.
- NDS action helps avoid the bulk transition.
- Confinement transitions for both reps coincide.
- Chiral transition for both reps? (D. Hackett's talk)

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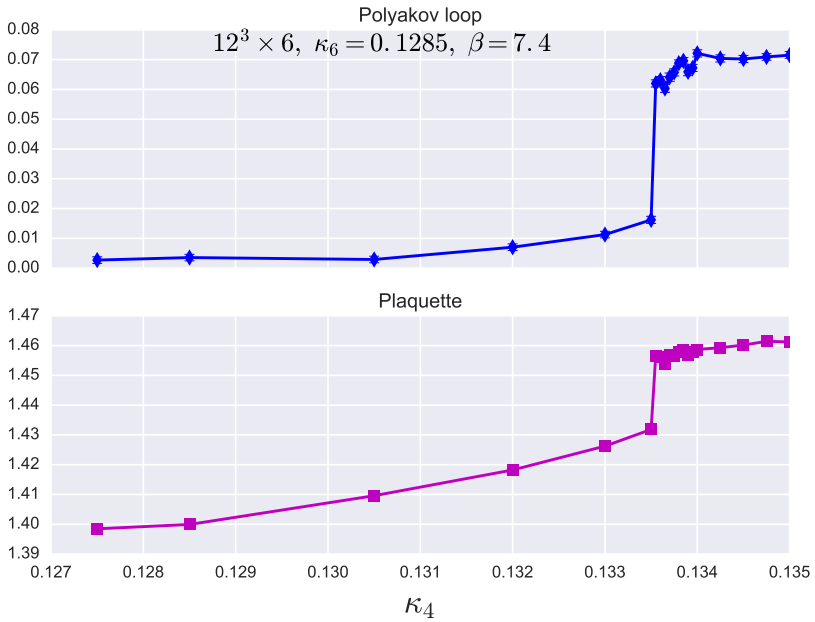
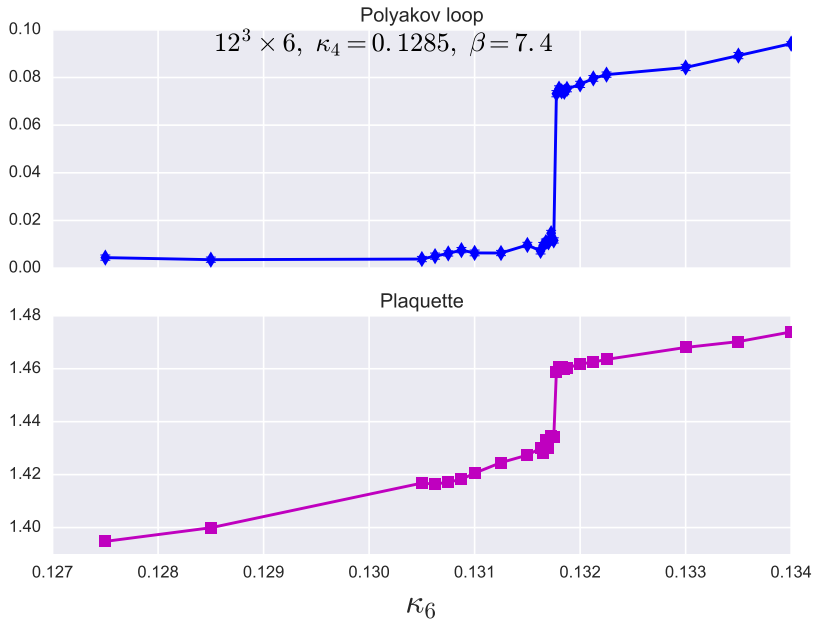
THANK YOU

Order of transition





- Polyakov loop and Plaquette discontinuous $\Longrightarrow$ 1^{st} order confinement transition.

Higher-rep Polyakov loop

- $\Omega^F_x = \prod_t U^F_{x,t}$
- $P^F = Tr\Omega^F$

- $\Omega^{A_2}_x = \prod_t U^{A_2}_{x,t}$
- $P^{A_2} = Tr\Omega^{A_2}$

- $U^{A_2} = \frac{1}{2}\left[U^F_{ij}U^F_{kl} - U^F_{il}U^F_{kj}\right]$
- $P^{A_2} = \frac{1}{2}\left[\left(Tr\Omega^F\right)^2 - Tr(\Omega^F)^2\right]$

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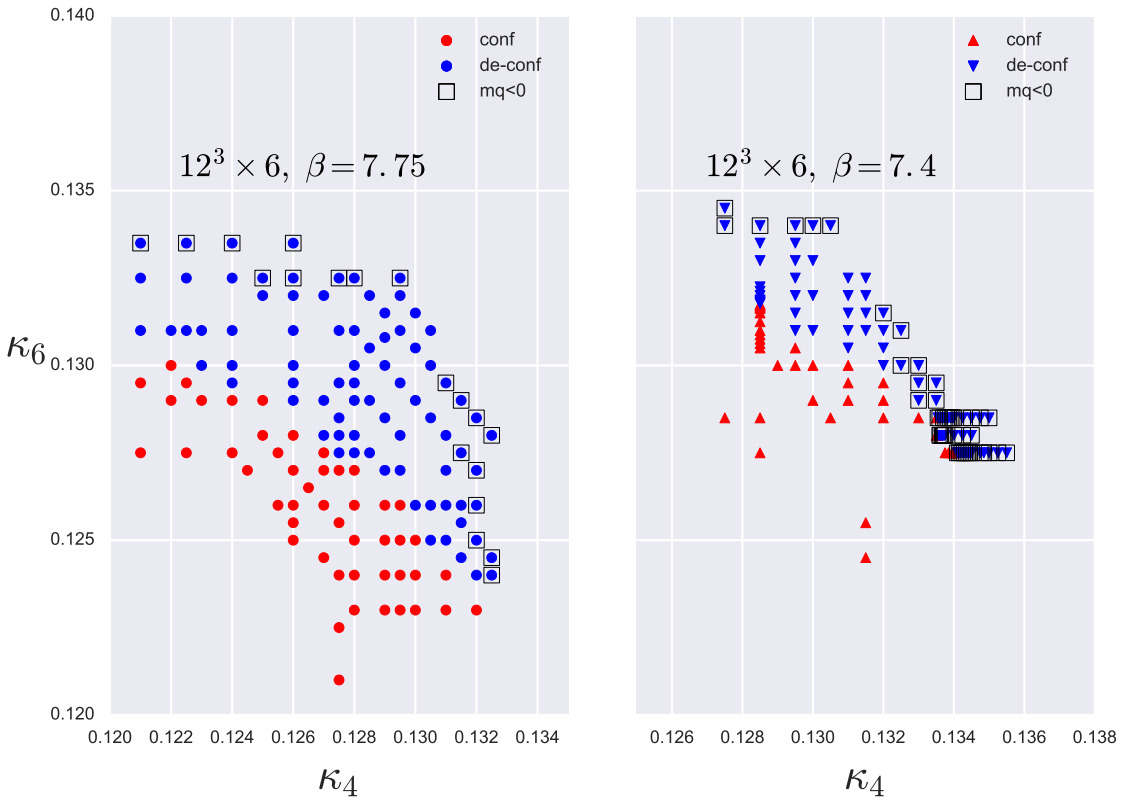
Comparison for $\beta = 7.75$ and $\beta = 7.4$.

- Curve shifts to the right.



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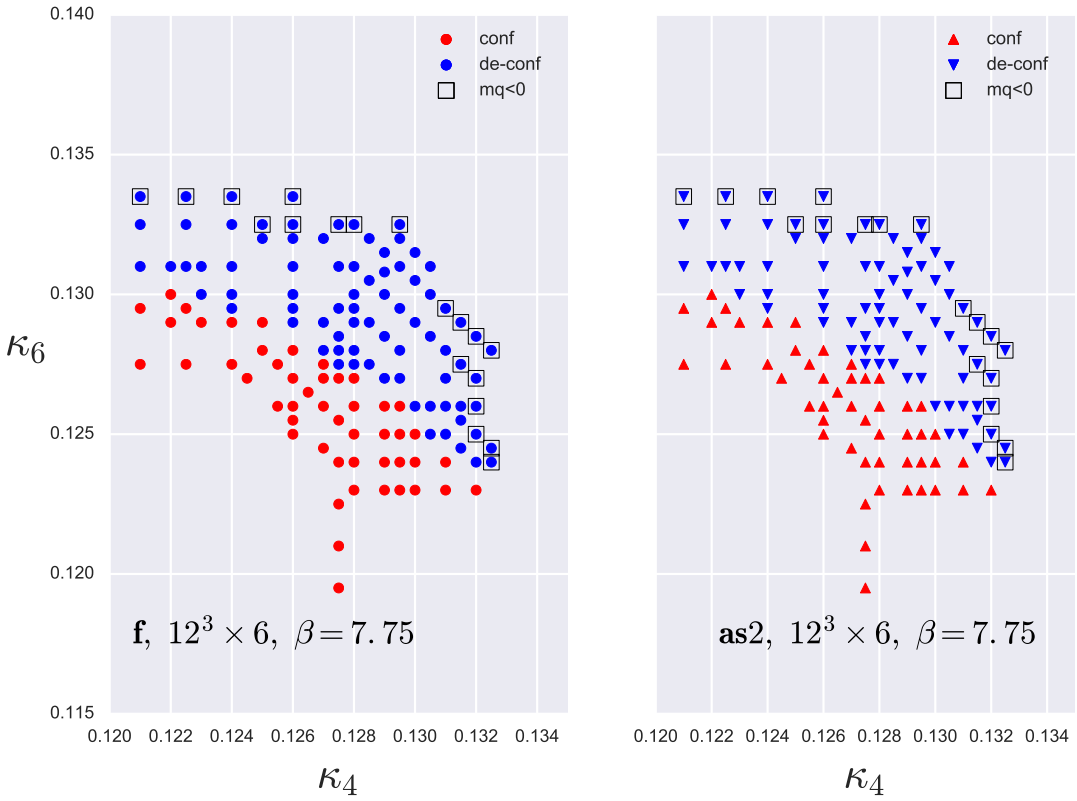
Phase diagram comparison

- Comparing the confinement transition for F vs A_2.
- Both transitions co-incide.