Exploring the phases of QCD with many flavors

Xiao-Yong Jin

RIKEN Advanced Institute for Computational Science

New Horizons for Lattice Computations with Chiral Fermions

with Robert Mawhinney (Columbia University)

Introduction

- Detailed data in:
  - My dissertation (2011):
    http://academiccommons.columbia.edu/catalog/ac:137844
  - Lattice conference proceedings (2008-2011).

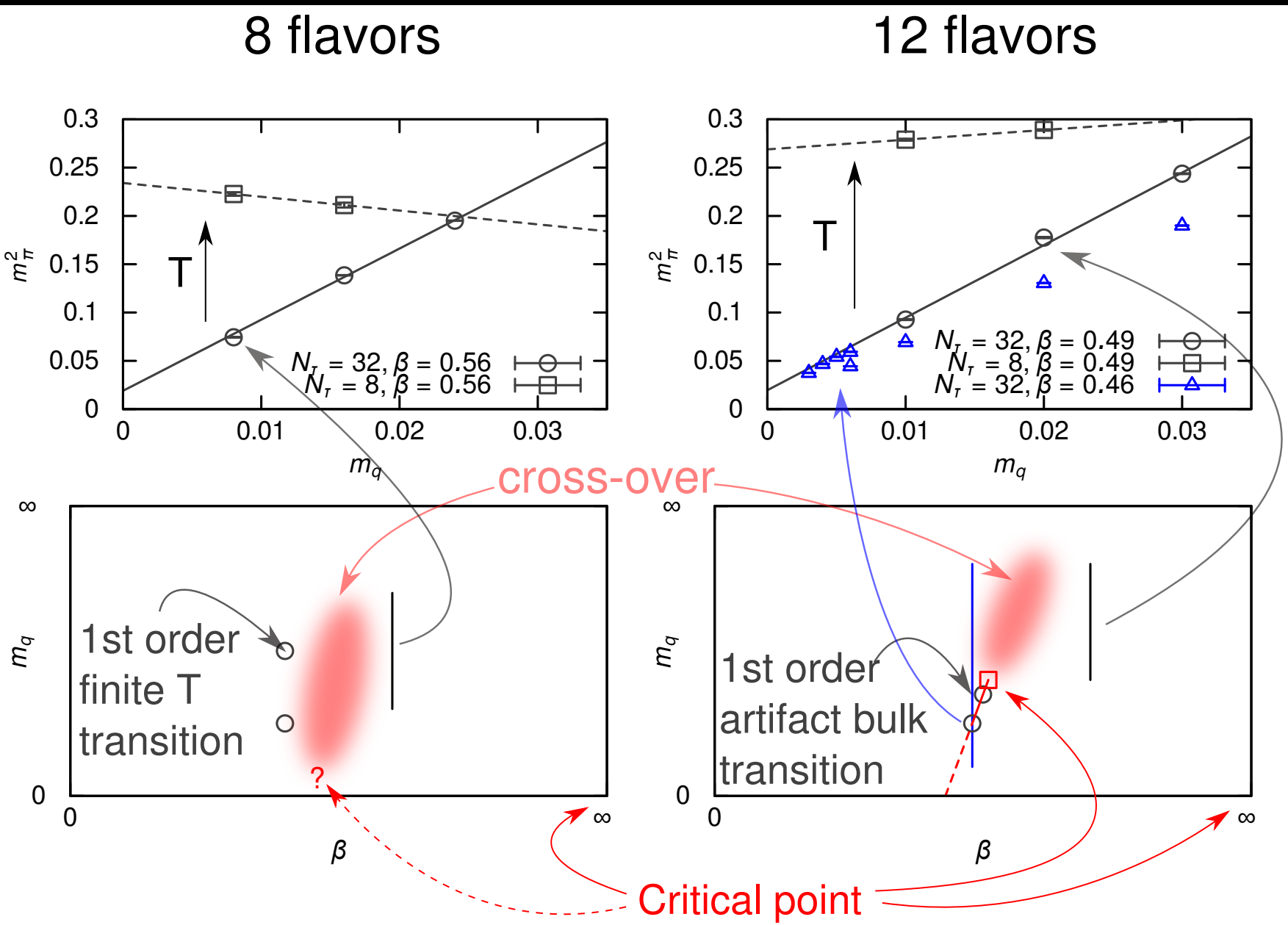
- Goal: Identify the phase (walking or conformal or ...)
  - Hadronic observables from zero temperature simulations, including meson propagators and masses, π decay constant, Quark potential and string tension...
  - Zero temperature and finite temperature
  - DBW2 gauge with naïve staggered fermion action

To see the whole picture

The subject of this talk

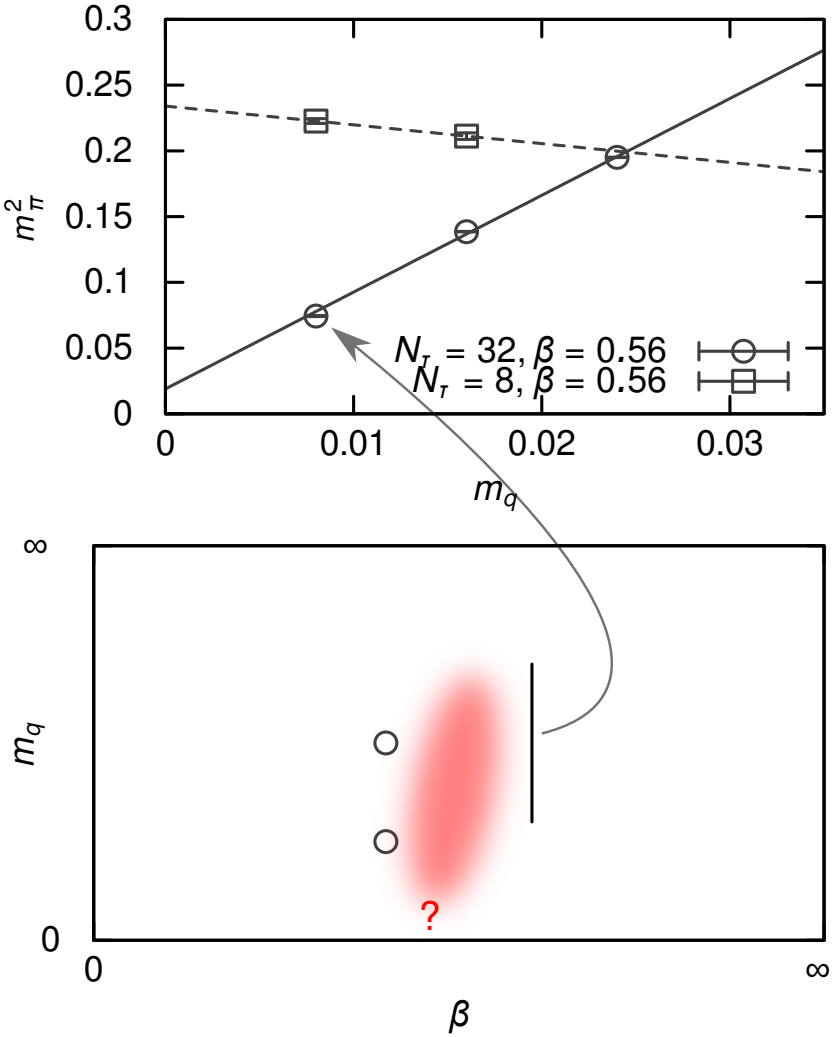
- Understand the direct implication of our data
- Carefully speculate about our blind spots

Summary of data

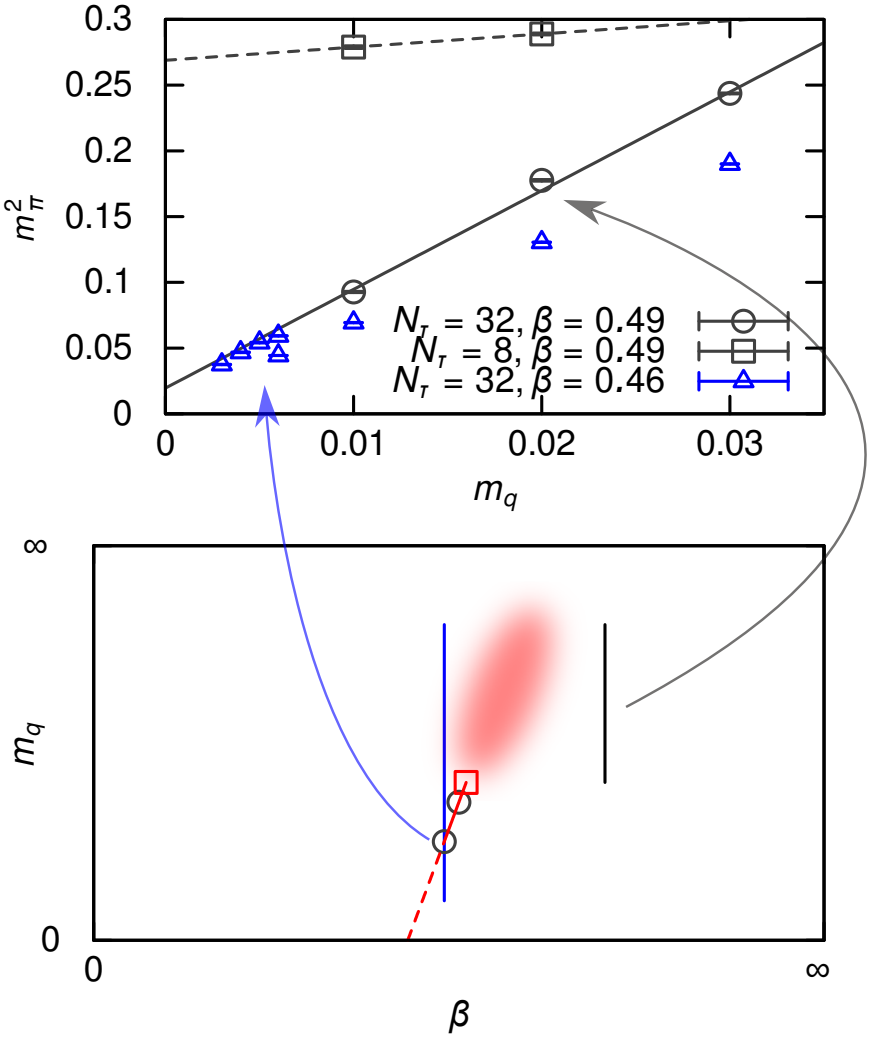


Zero temperature simulations

8 flavors

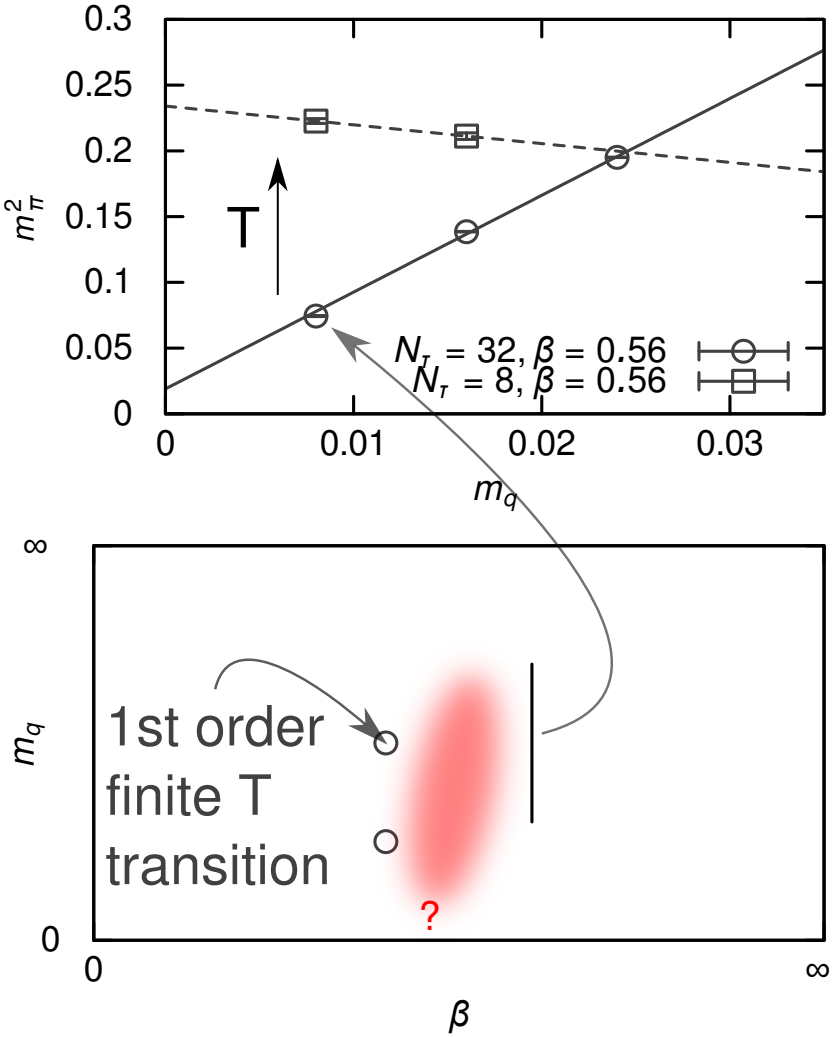


12 flavors

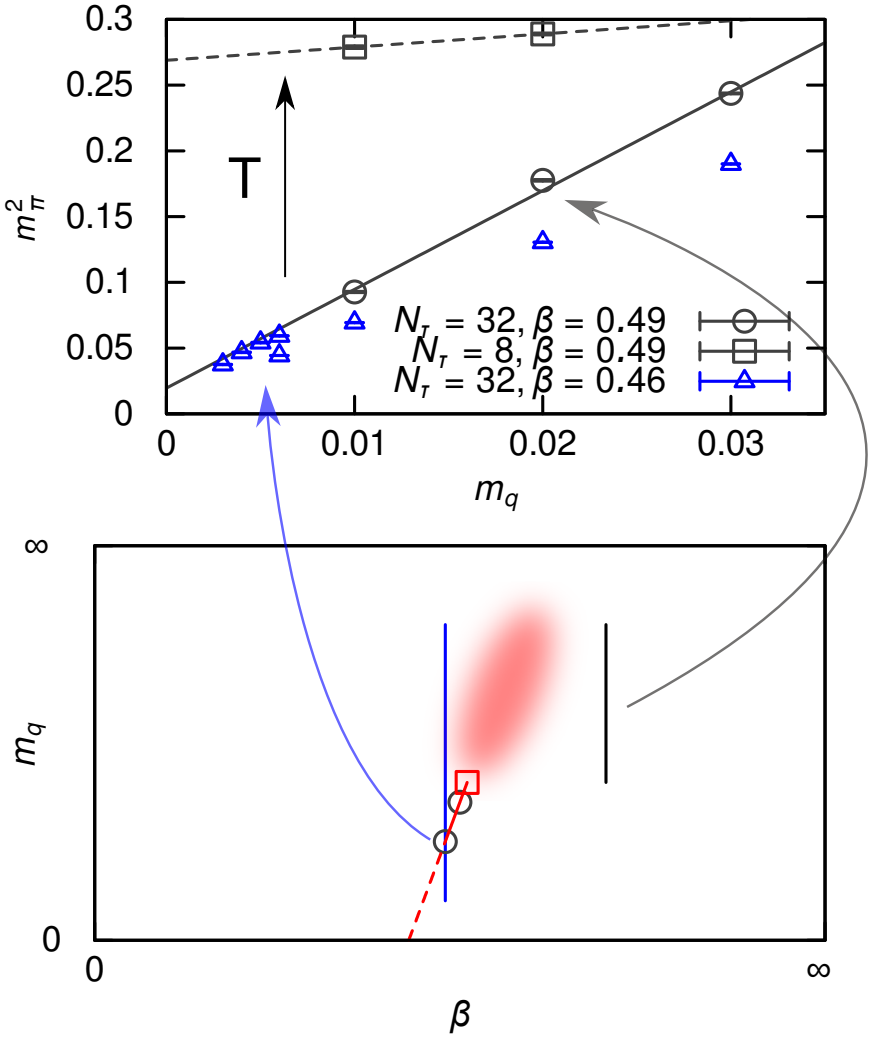


Finite temperature

8 flavors

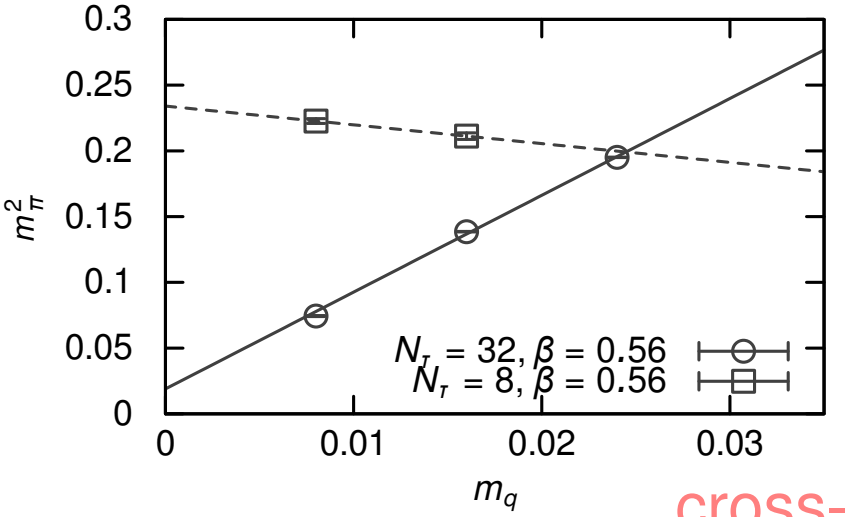


12 flavors

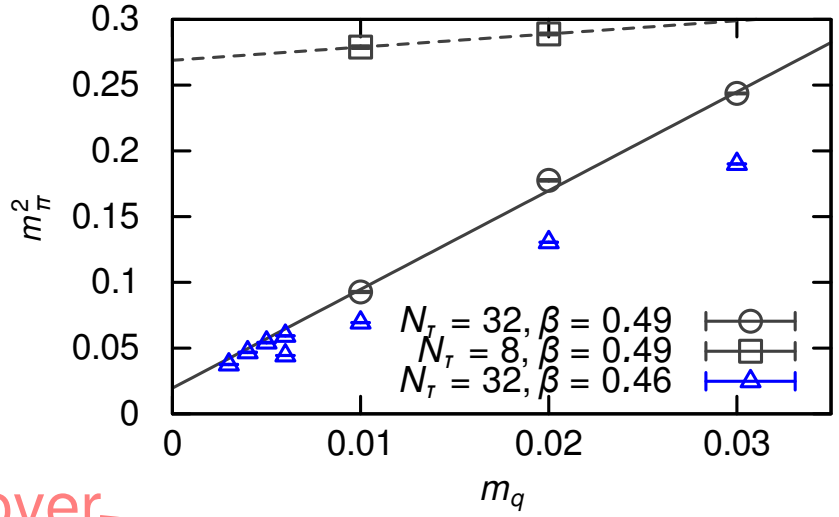


The bulk transition

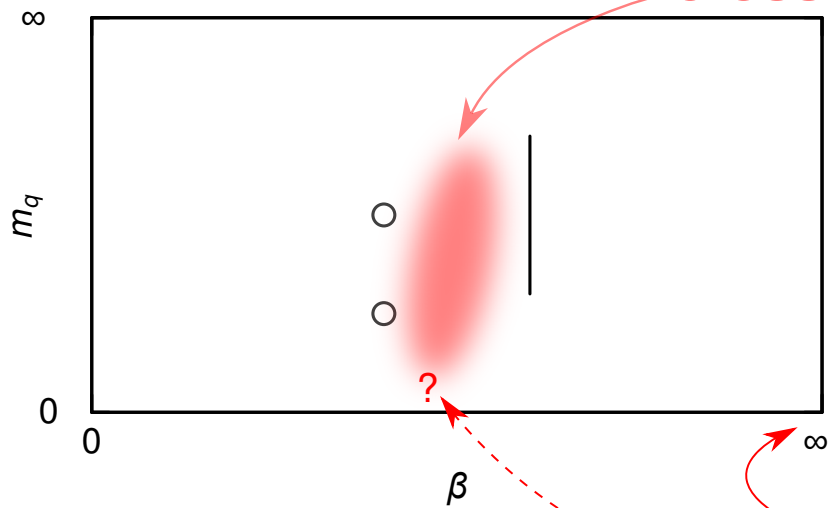
8 flavors

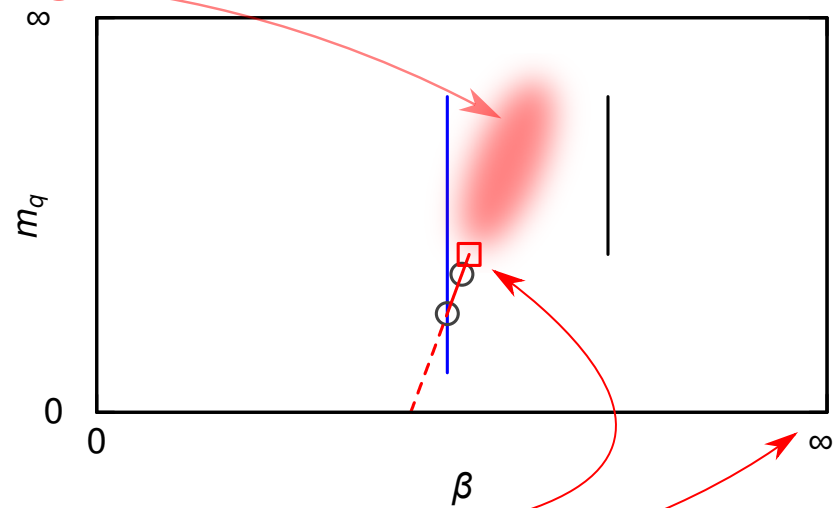


12 flavors



cross-over



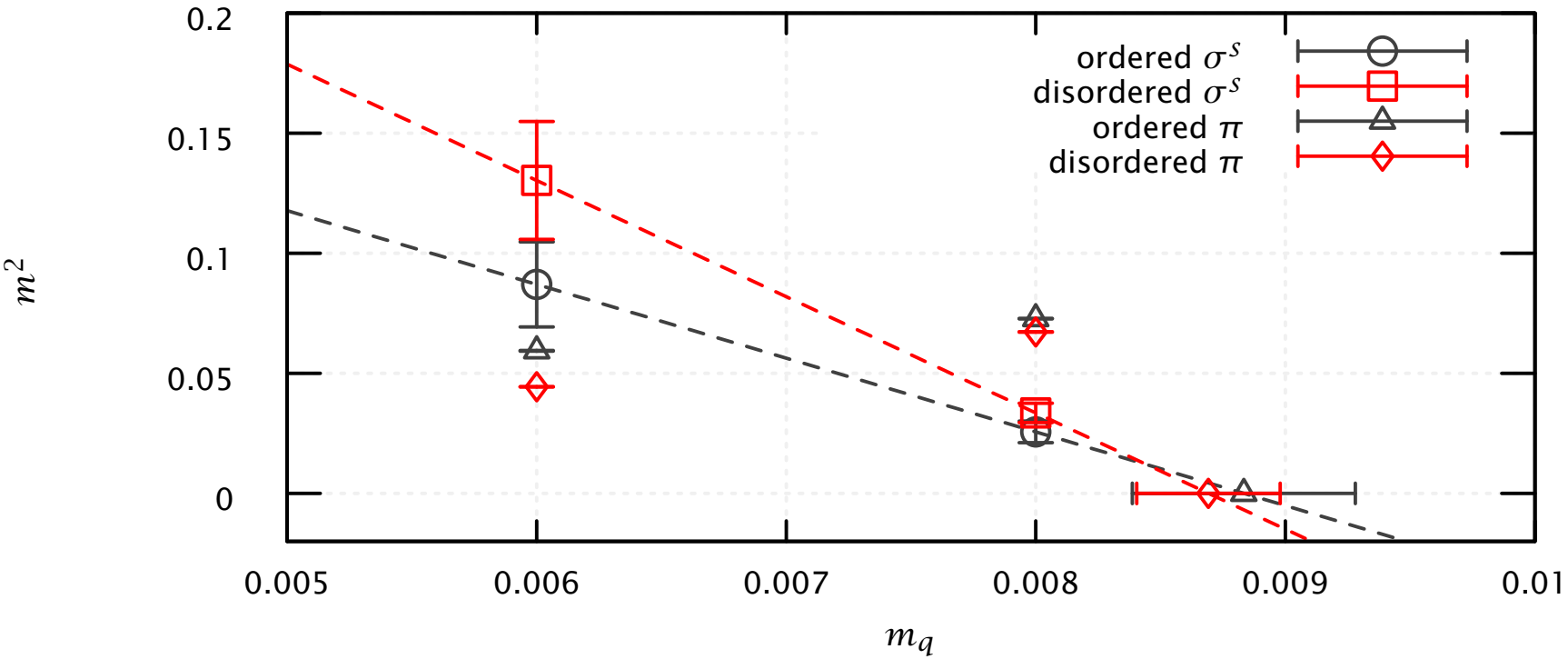


Critical point

The bulk transition

- 8 flavors:
  - Bulk transition appears (strengthens) when simple plaquette action is used instead of DBW2.
- 12 flavors:
  - Volume independent $\longrightarrow$ finite temperature effect less likely.
  - For most channels, the difference in particle masses on the two sides of the bulk transition become smaller and vanish when quark mass is increased.
  - The scalar singlet is found to be special.

Scalar singlet meson



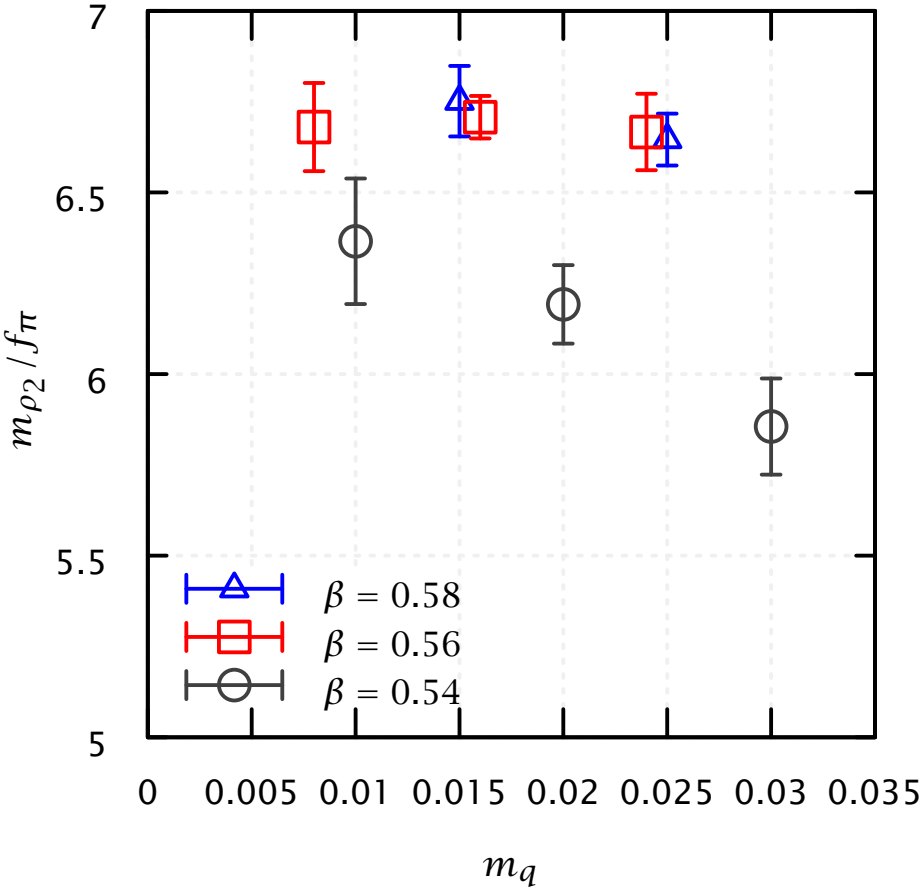
- The scalar singlet meson becomes lighter along the 1st order bulk transition line approaching the 2nd order critical end point.
- Critical exponent is consistent with Ginzburg-Landau theory.
- Continuum limit of the lattice theory at second order critical point is likely a free scalar field theory.

Consequences of a light scalar singlet meson

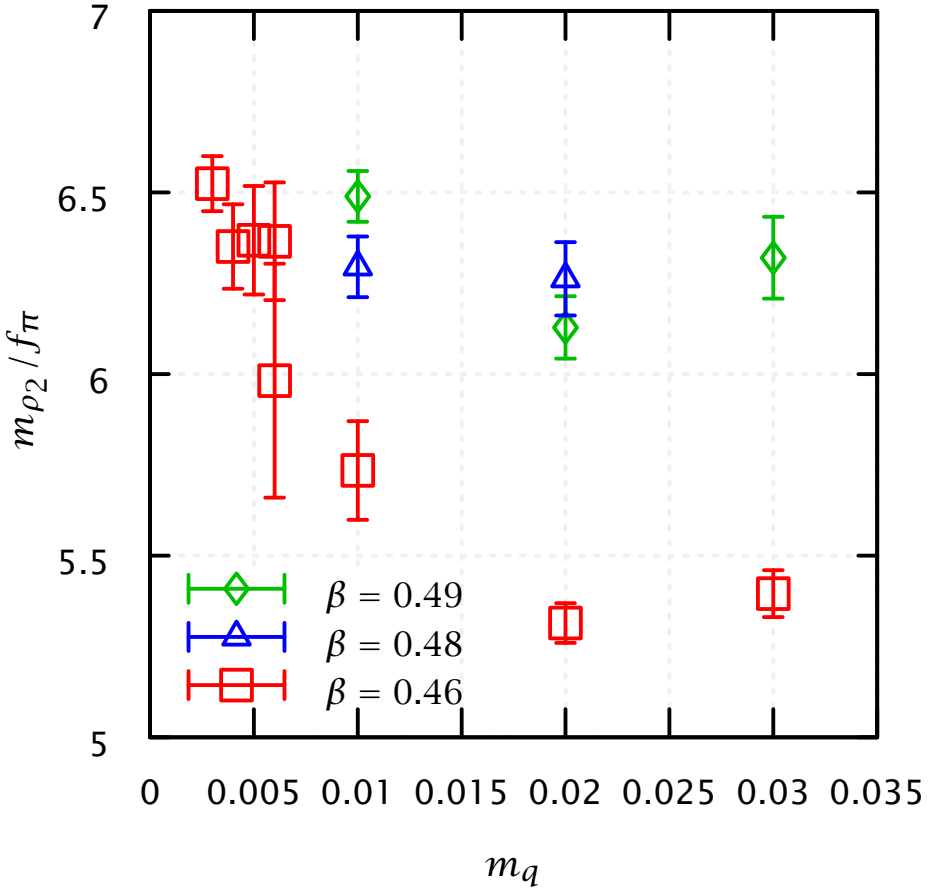
Chiral perturbation theory is not applicable.

Scaling of m_{ρ_2}/f_π versus quark mass

8 flavors



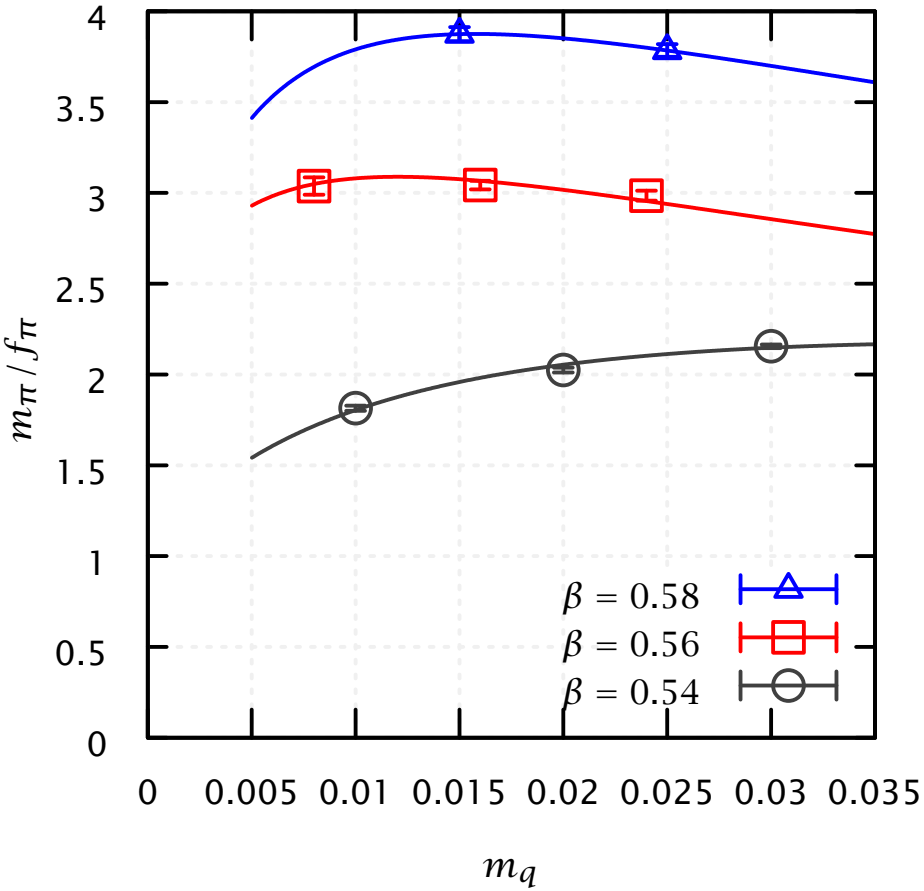
12 flavors



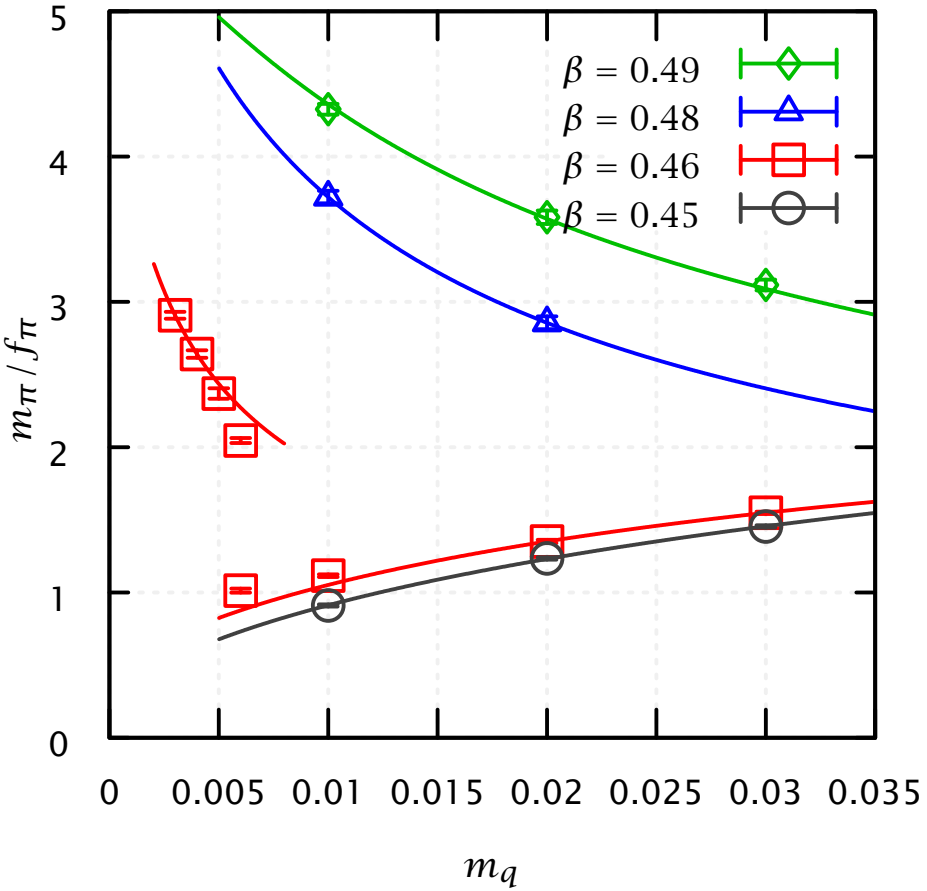
- Approaches to a constant at weak couplings
- Other ratios behave the same, except for pion masses

Scaling of m_π / f_π versus quark mass

8 flavors



12 flavors



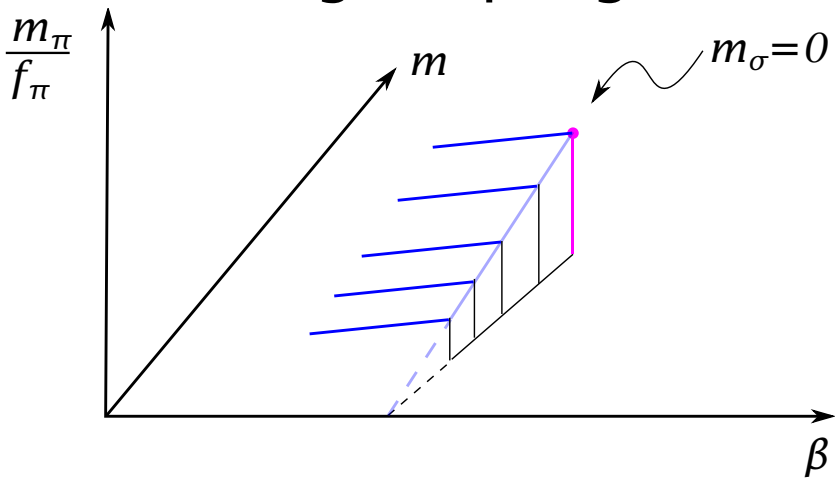
Warnings:

- Backward flow of constant m_π / f_π in weaker couplings.
- Misleading conclusions at large m_q.

The flow of constant physics (m_π / f_π)

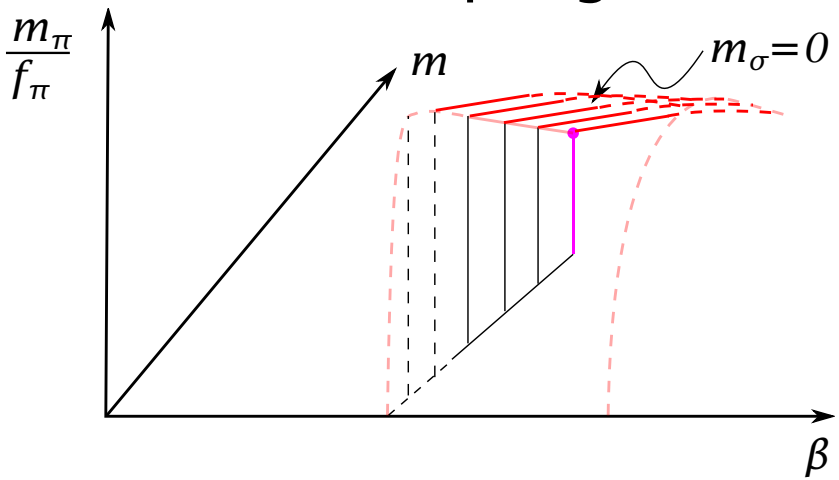
A sketch of m_π / f_π surface parameterized by m and β.

Strong coupling side



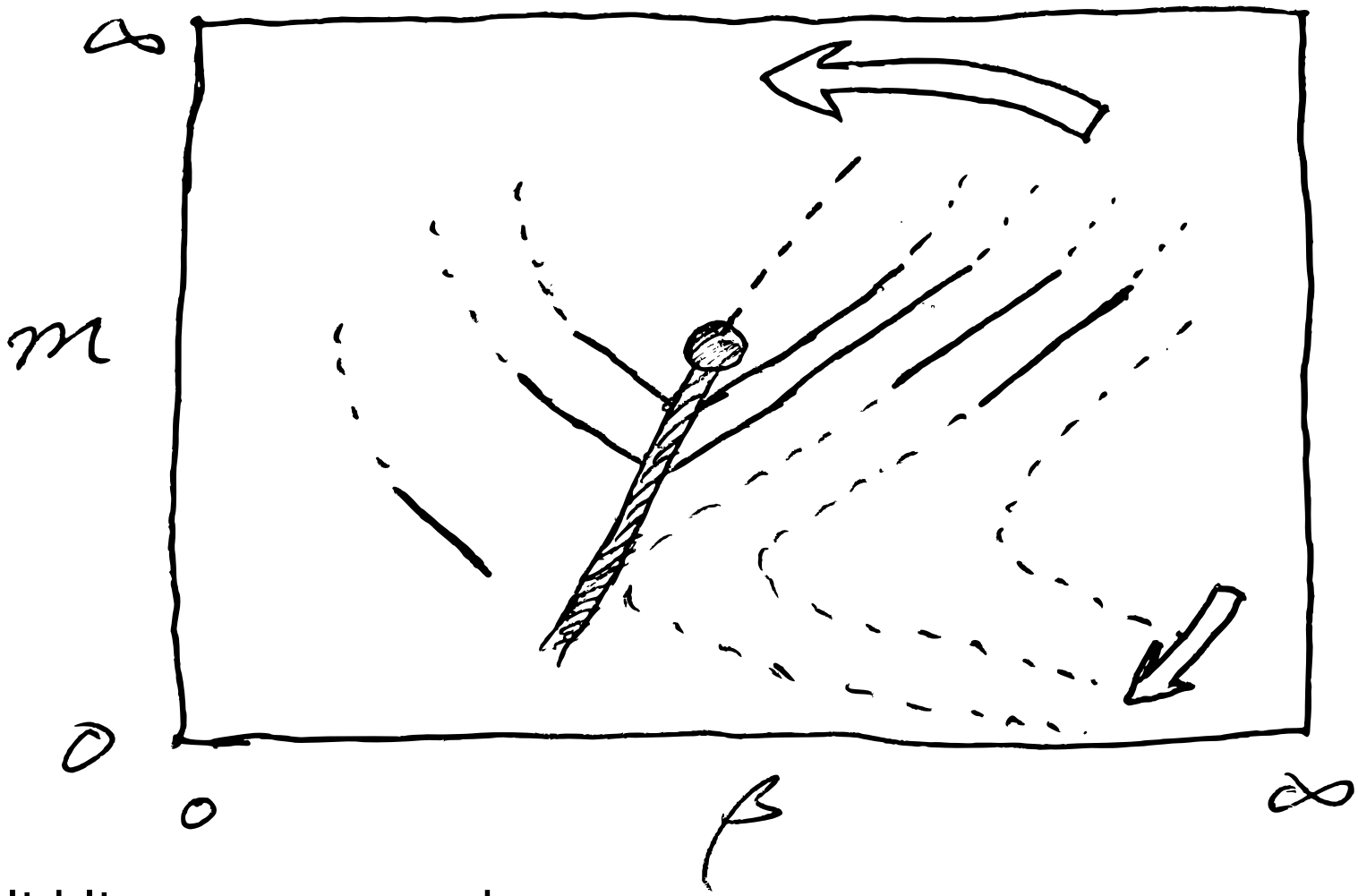
Same as QCD except the $\beta \to \infty$ cannot be reached, because the bulk transition blocks the way.

Weak coupling side



Comparing with 8-flavor data, we conjecture that only when m_q is much smaller and β is much larger than the bulk transition, can we recover QCD behavior.

Conjectured lines of constant physics (m_π / f_π)



- Solid lines represent data.
- Dashed lines are our conjecture.
- Arrows denotes the direction of m_π / f_π going smaller.

Conclusion

- Our data show:
  - 12-flavor has an additional critical point where scalar correlation length diverges.
  - 12-flavor show the same behavior as 8-flavor at larger m_q.
- We conjecture:
  - Possible bulk transition with 8-flavor at smaller m_q.
  - For 12 flavors, much smaller m_q and/or much weaker coupling is required to move away from the additional critical point and recover the physics at $\beta \to \infty$.