Exploring Many Flavor QCD with Wilson Fermion

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in collaboration with

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Introduction

- Many Flavor QCD [MFQCD]

  ⇔ Dynamical Electroweak symmetry breaking, *i.e.* Technicolor

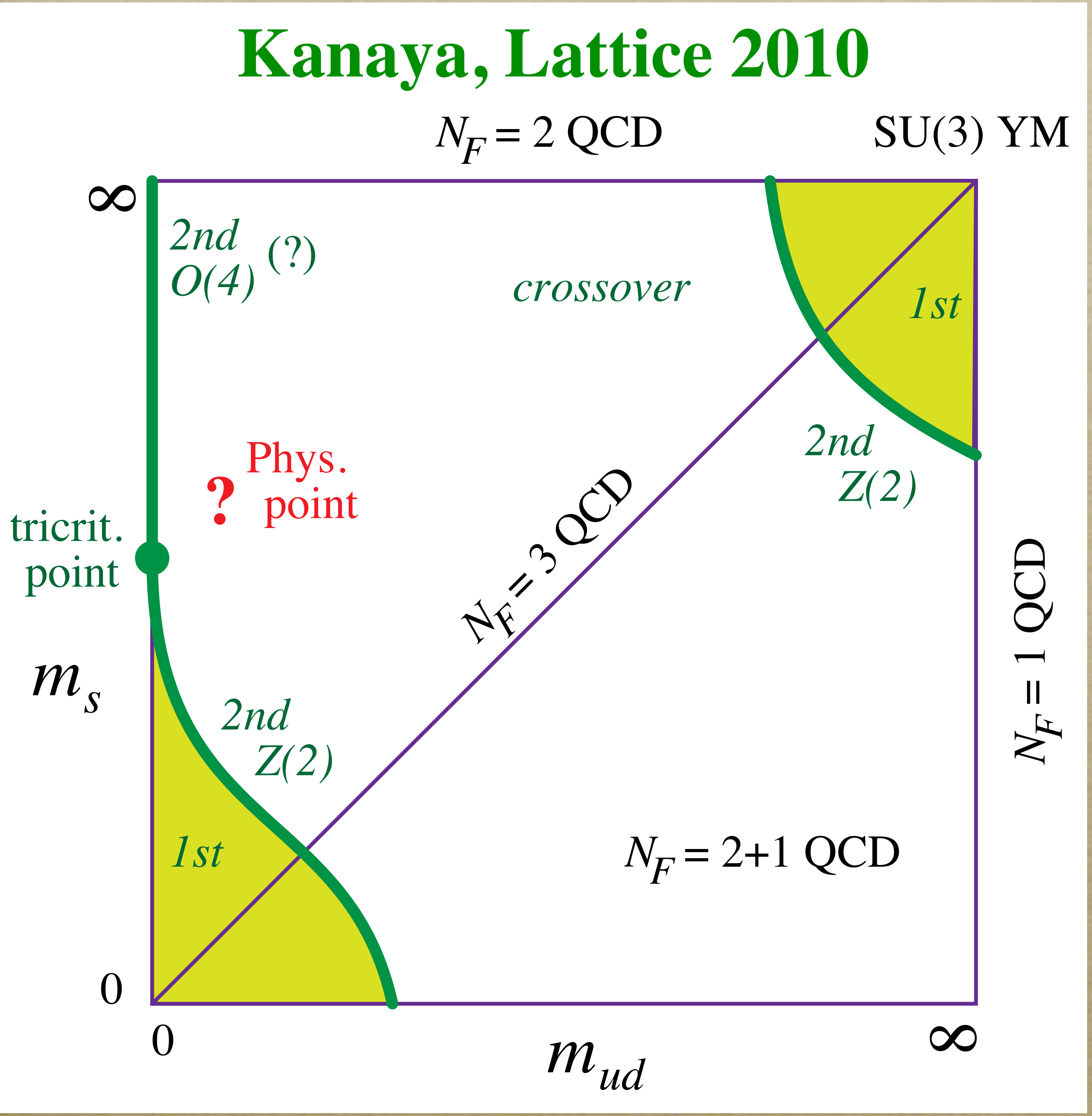
- The thermodynamical properties of MFQCD, especially its nature of the chiral phase transition, is important from the viewpoint of EW baryogenesis within TC.

  Appelquist, Schwetz and Selipsky, PRD52, 4741 (1995);
  Kikukawa, Kohda and Yasuda, PRD77 (2008) 015014

- We study MFQCD at finite temperature.
- Progress report is given.

Columbia plot

Brown, Butler, Chen, Christ, Dong, Schaffer, Unger, and Vaccarino (90), N.H. Christ, Z. Dong (92) and N.H. Christ(92)



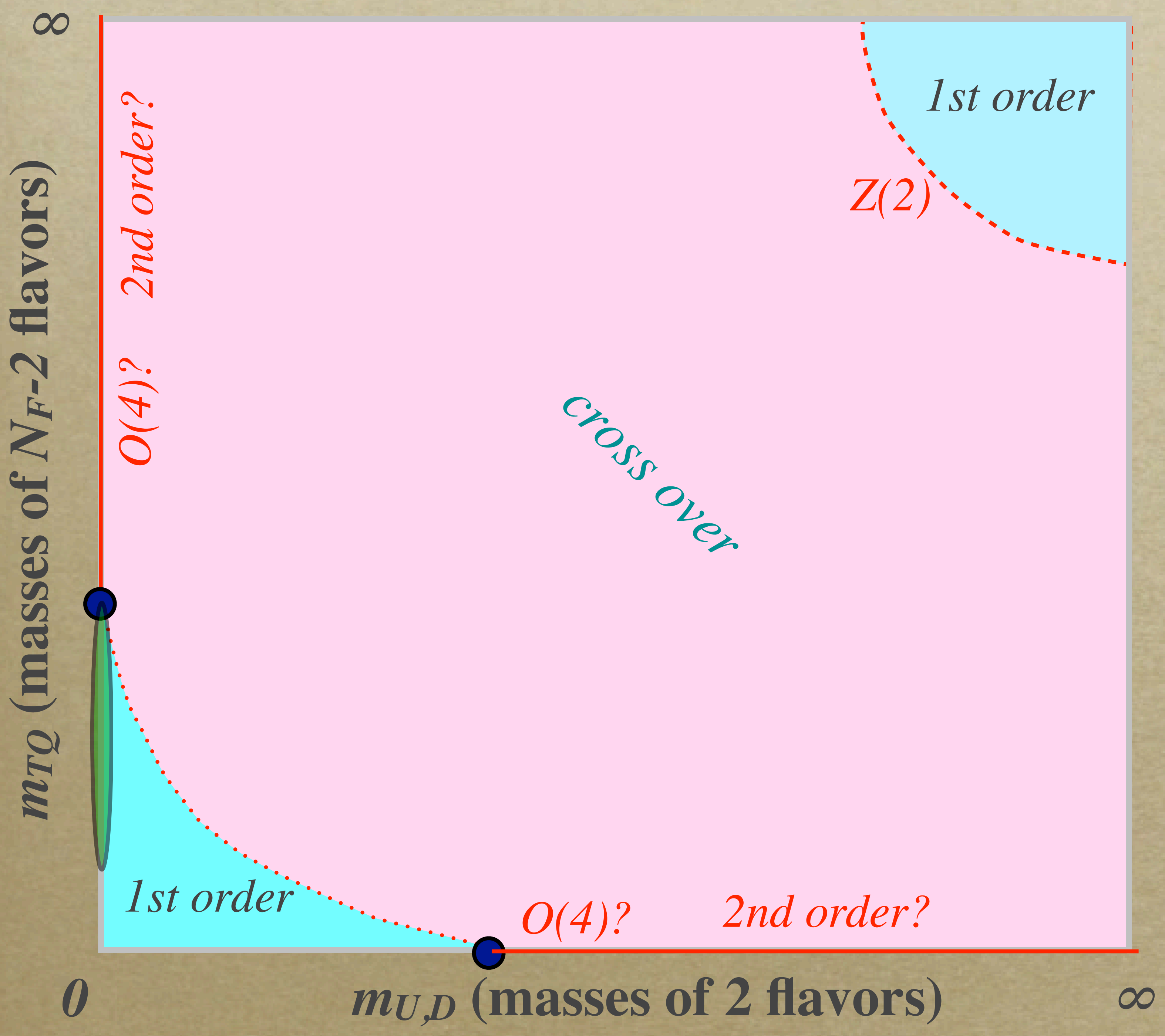
When $N_F \geqq 3$, Chiral Phase Transition is 1st order.

Pisarski and Wilczek, PRD 29, 338 (1984) and more?

How does this plot for MFQCD look like?

$N_F = 4$ ($< N_F^{crit}$)

[2 flavors of N_F are exact massless.]



In TC, 2 of N_F must be exact massless.

$N_F^{crit} > 4$ is assumed.

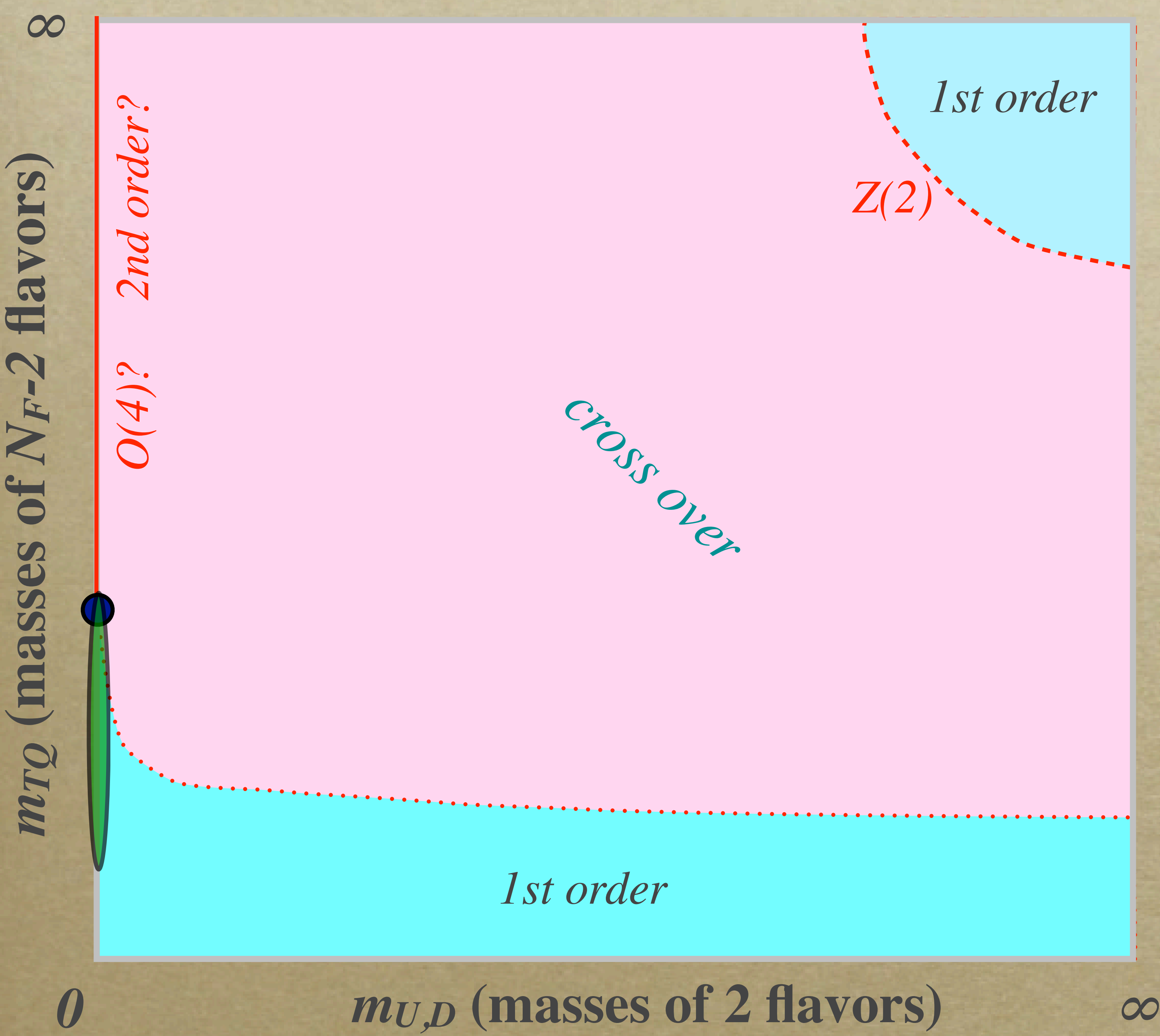
Symmetric under reflection wrt diagonal line.

Running of g^2 is not slow enough.

Less interesting.

$5 \leqq N_F < N_F^{crit}$

[2 flavors of N_F are exact massless.]



1st order persists to $m_{U,D} = \infty$ for small m_{TQ}.

Slow running and large γ_m is expected at some value of N_F.

For TC model containing EW baryogenesis, important to identify the location of the 1st order region.

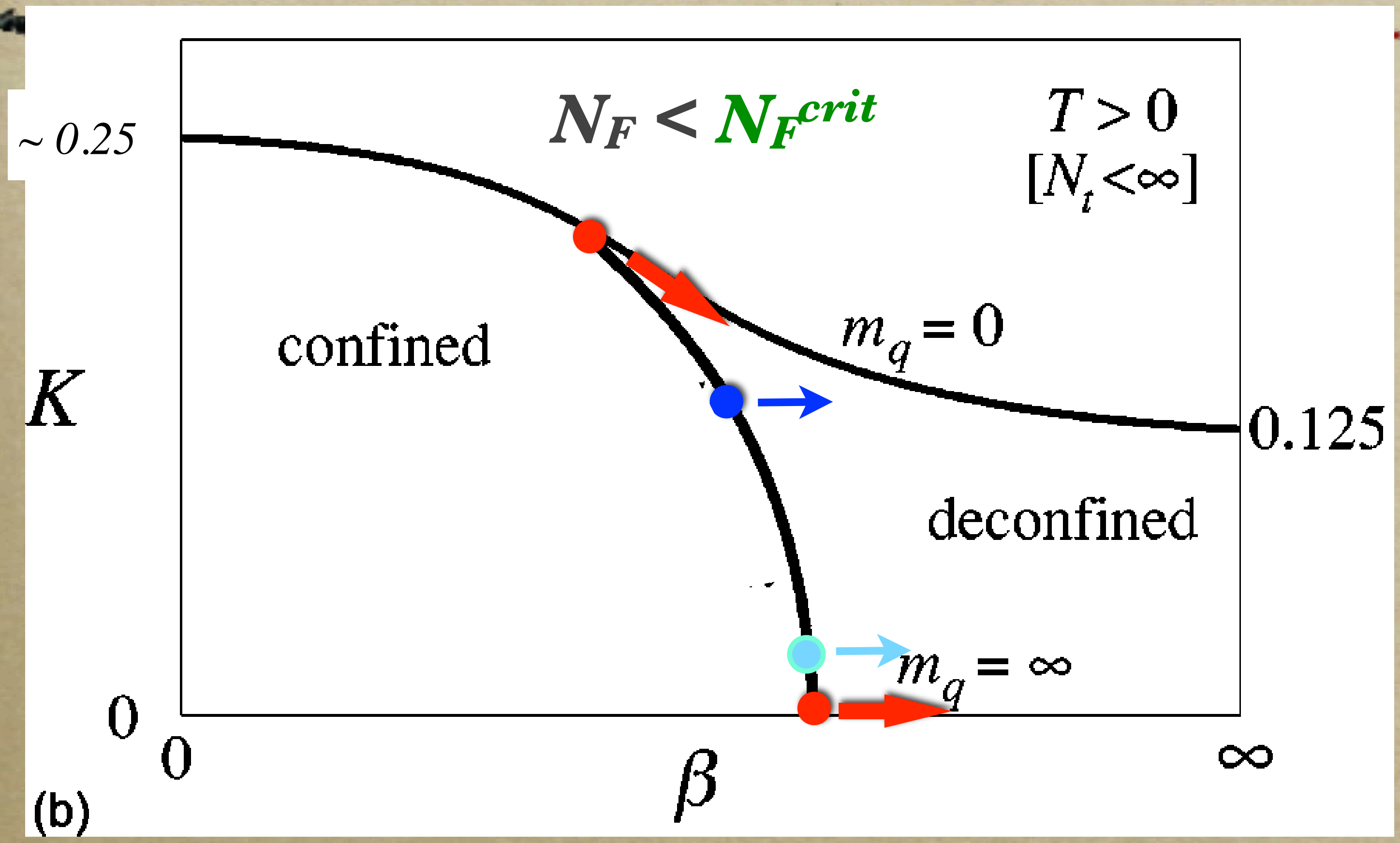
Appelquist, Schwetz and Selipsky, PRD52, 4741 (1995).
Kikukawa, Kohda and Yasuda, PRD77 (2008) 015014

Phenomenologically interesting!

Strategy: overview

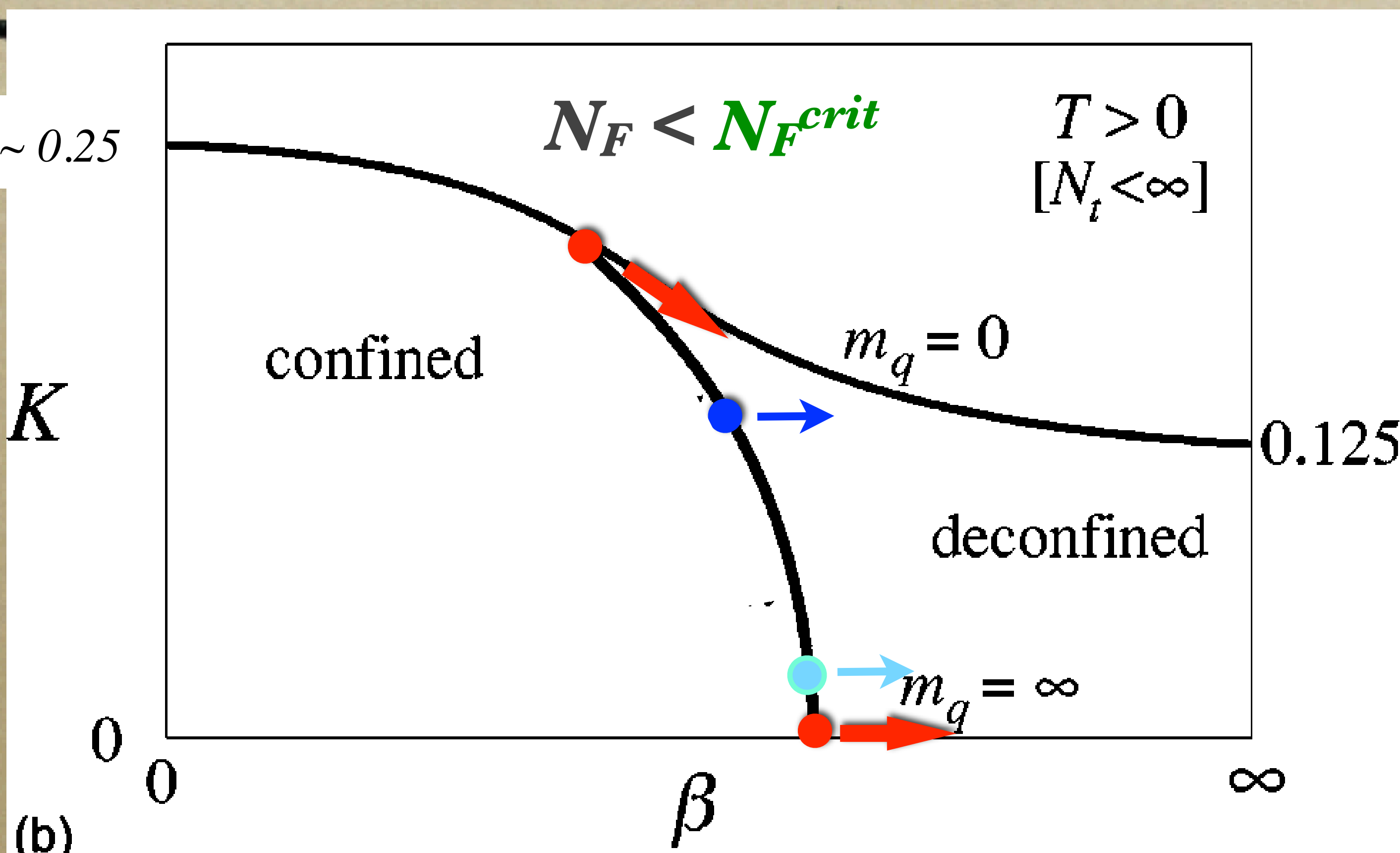
- In this exploratory study, we employ the standard Wilson plaquette gauge action and the plain Wilson Fermion to explore the Wilson Phase Diagram [β-K plane].
- The parameters:
  - $V = N_S^3 \times N_T$ = {8^3 x 4, 8^3 x 8, 16^3 x 8}
  - SU(3) gauge theory with {4, 6, 10} degenerate flavors
- The β-K plane is scanned and <P> and <|L|> are measured at each (β,K) to identify the phase.

Wilson Phase diagram for confining theory ($N_F < N_F^{crit}$) Iwasaki *et al. (91,04)*



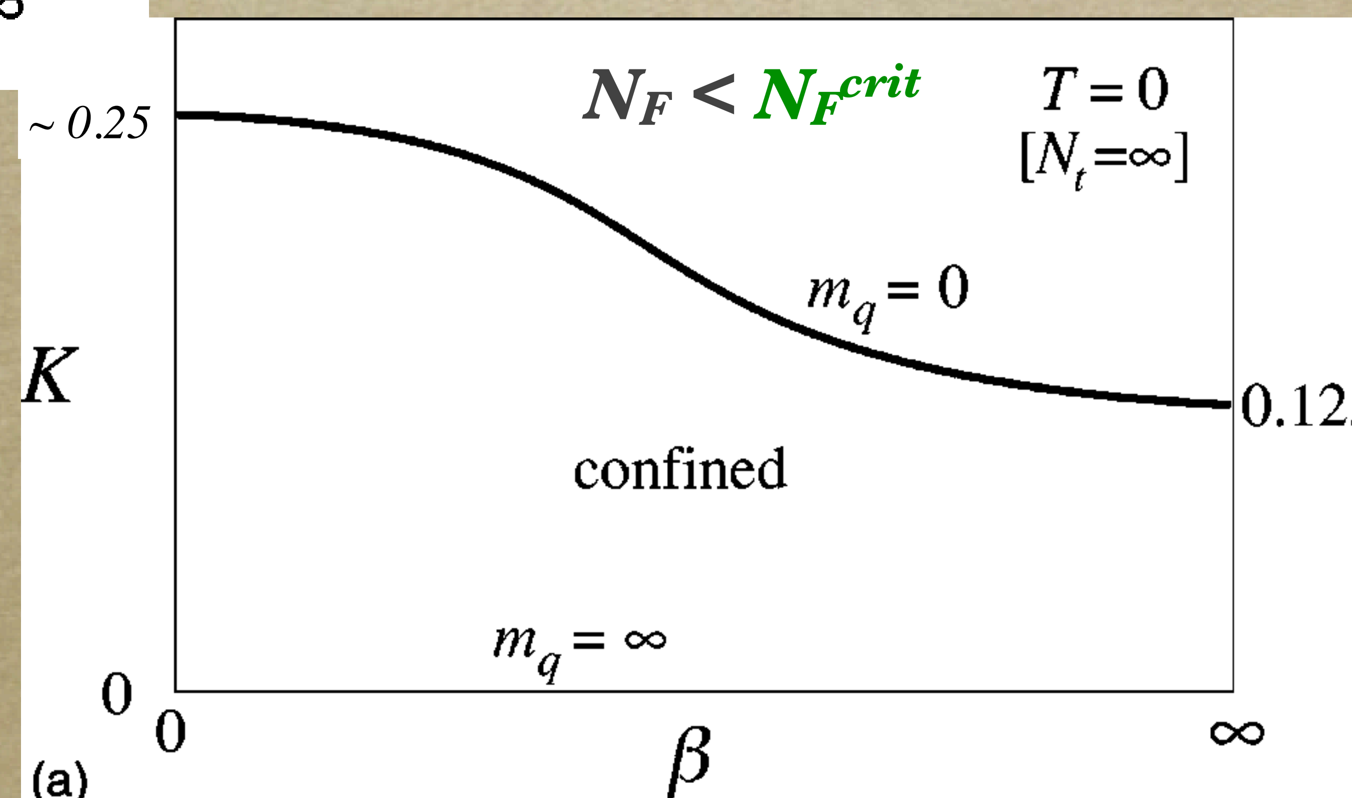
If the theory is confining, the transition line moves to the right as N_T increases.

Wilson Phase diagram for confining theory ($N_F < N_F^{crit}$) Iwasaki *et al.* (91,04)



If the theory is confining, the transition line moves to the right as N_T increases.

Eventually, in the large N_T limit, the whole region is covered by confining phase.

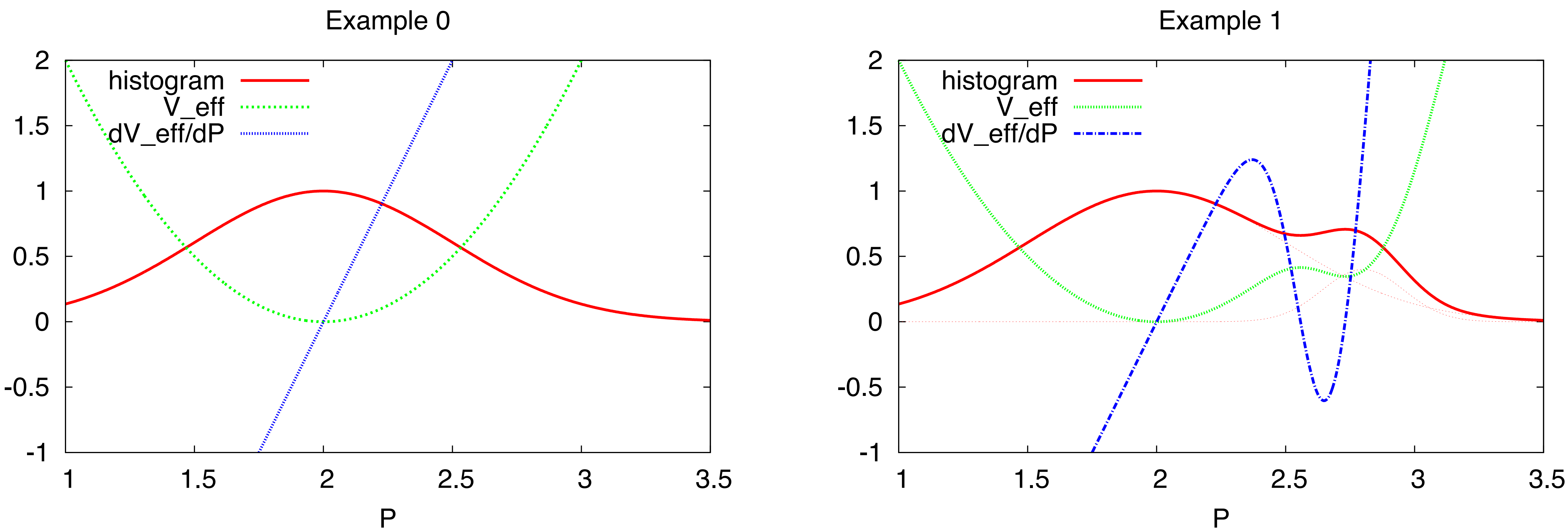


Strategy: details

- ✓ By scanning β-K plain, find **the critical endpoint around m_q=0** (not around mq=∞).
- ✓ See whether **the endpoint** moves to the right or not while changing N_T.
- ✓ β_{CP} = β @ critical endpoint

Finding Critical Endpoint: Histogram Method and Re-weighting

Saito et al, [WHOT-QCD], PRD84, 054502 (2011); S. Ejiri, Phys. Rev. D 77, 014508 (2008)



$$
\begin{aligned}
w(P';\beta,\kappa) &= \int \mathcal{D}U\mathcal{D}\psi\mathcal{D}\bar{\psi}\,\delta(P'-P[U])\,e^{-S_f-S_g} \\
&= \int \mathcal{D}U\mathcal{D}\psi\mathcal{D}\bar{\psi}\,\delta(P'-P[U])\,\left[\det M(\kappa)\right]^{N_F} e^{6\beta N_V P[U]} \\
&= e^{6\beta N_V P'} \int \mathcal{D}U\mathcal{D}\psi\mathcal{D}\bar{\psi}\,\delta(P'-P[U])\,\left[\det M(\kappa)\right]^{N_F}.
\end{aligned}
$$

$$
V_{\rm eff}(P';\beta,\kappa) = -\ln\Big(w(P';\beta,\kappa)\Big)
$$

$$
\frac{dV_{\rm eff}(P;\beta,\kappa)}{dP} = \frac{dV_{\rm eff}(P;\beta_0,\kappa)}{dP} - 6\,(\beta-\beta_0)\,N_V
$$

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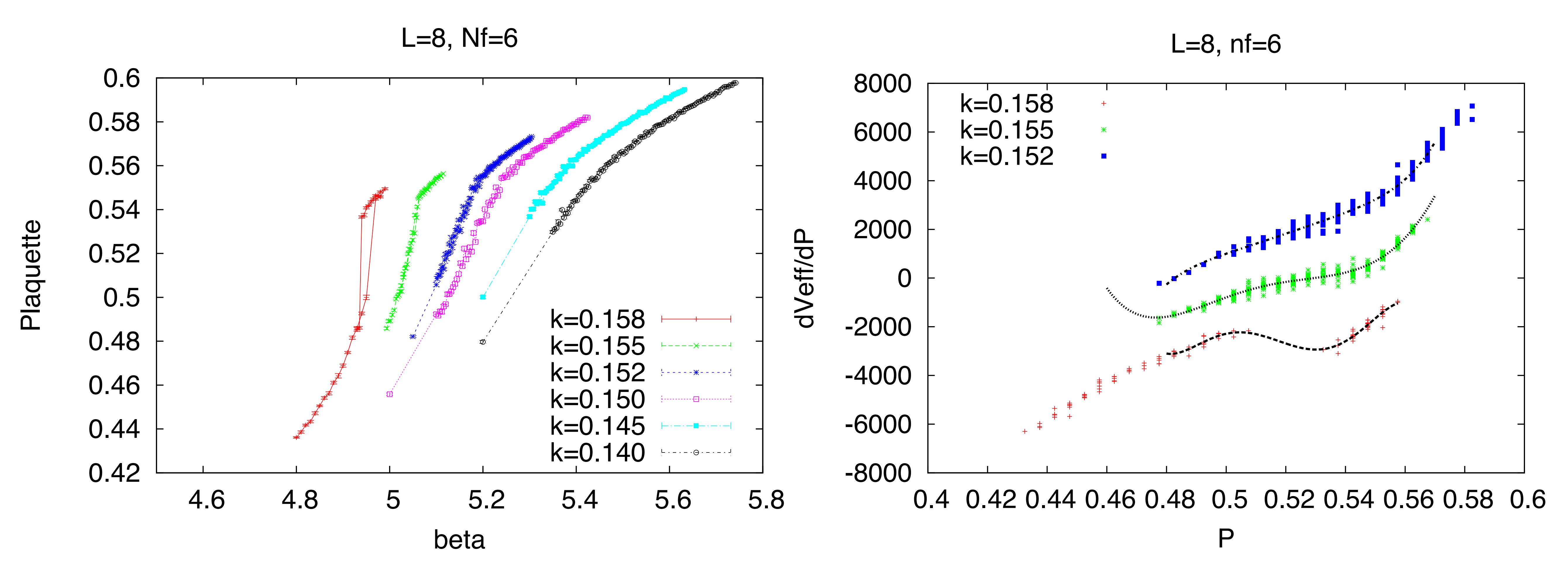
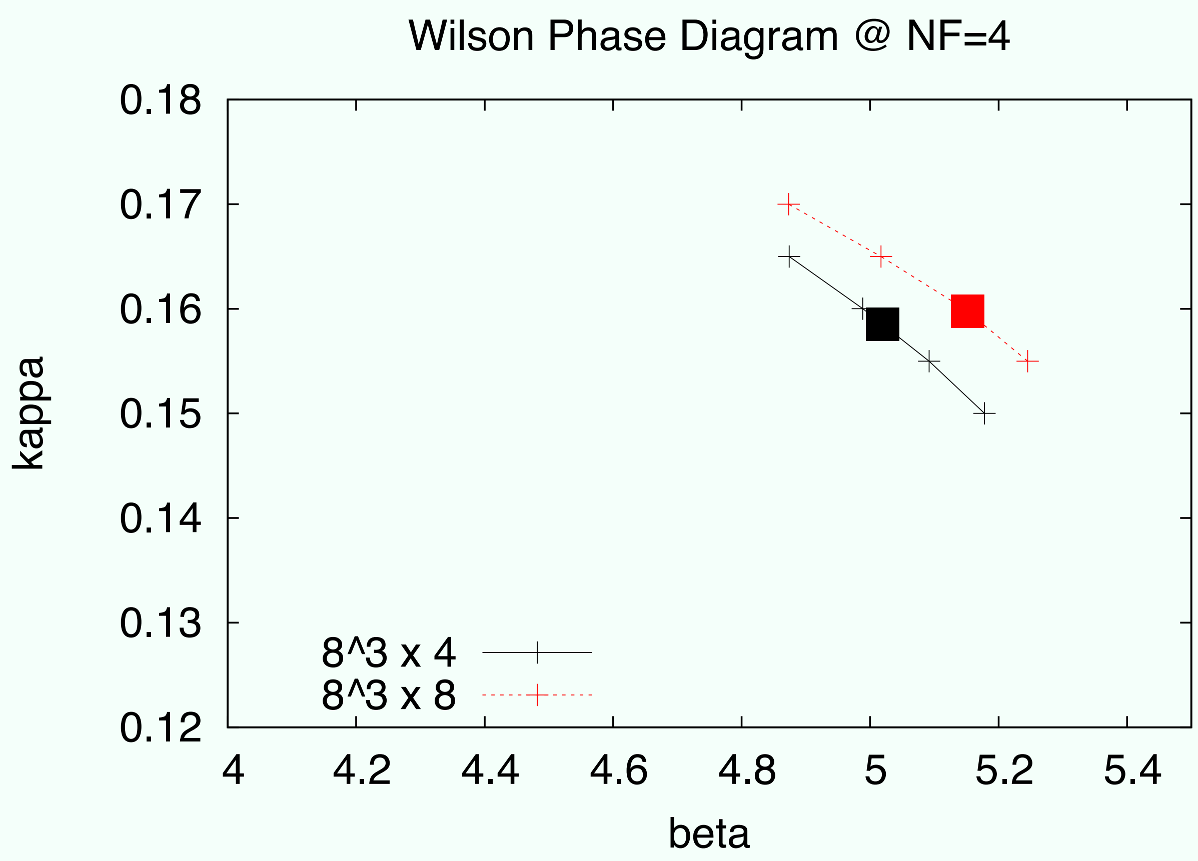
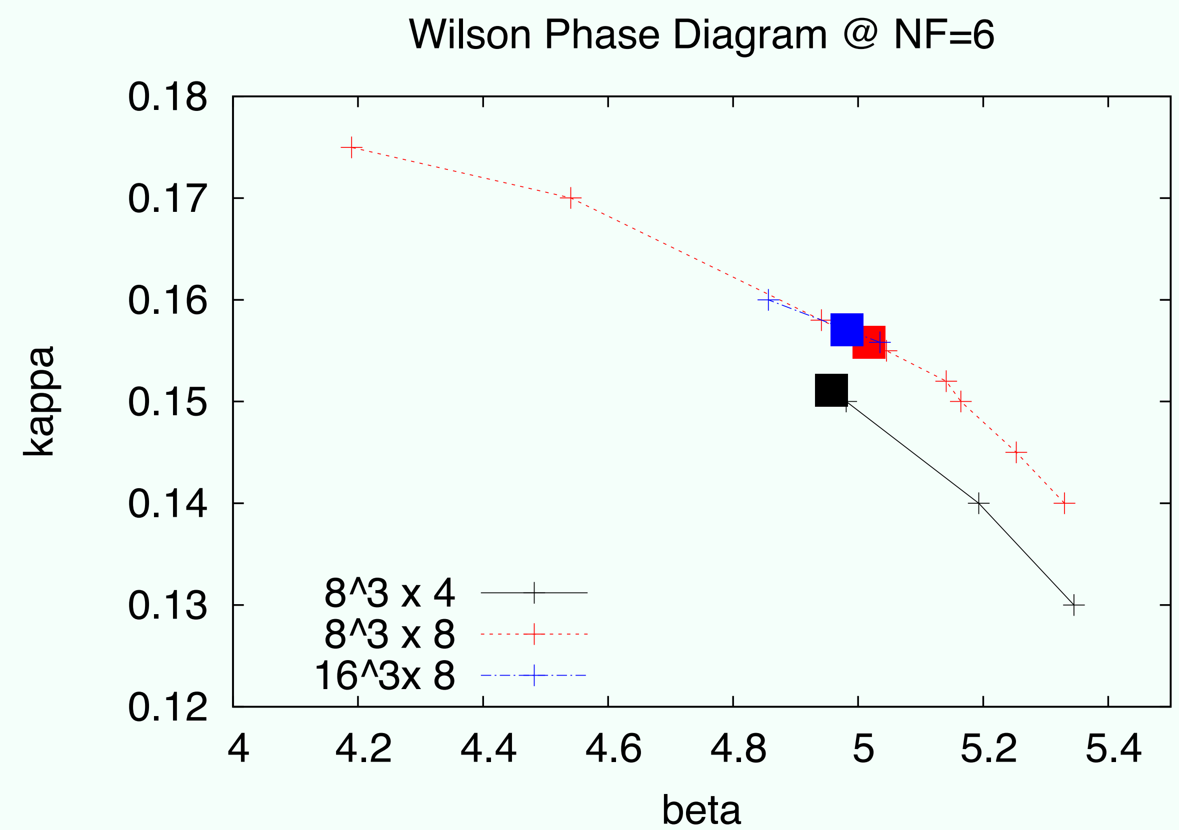


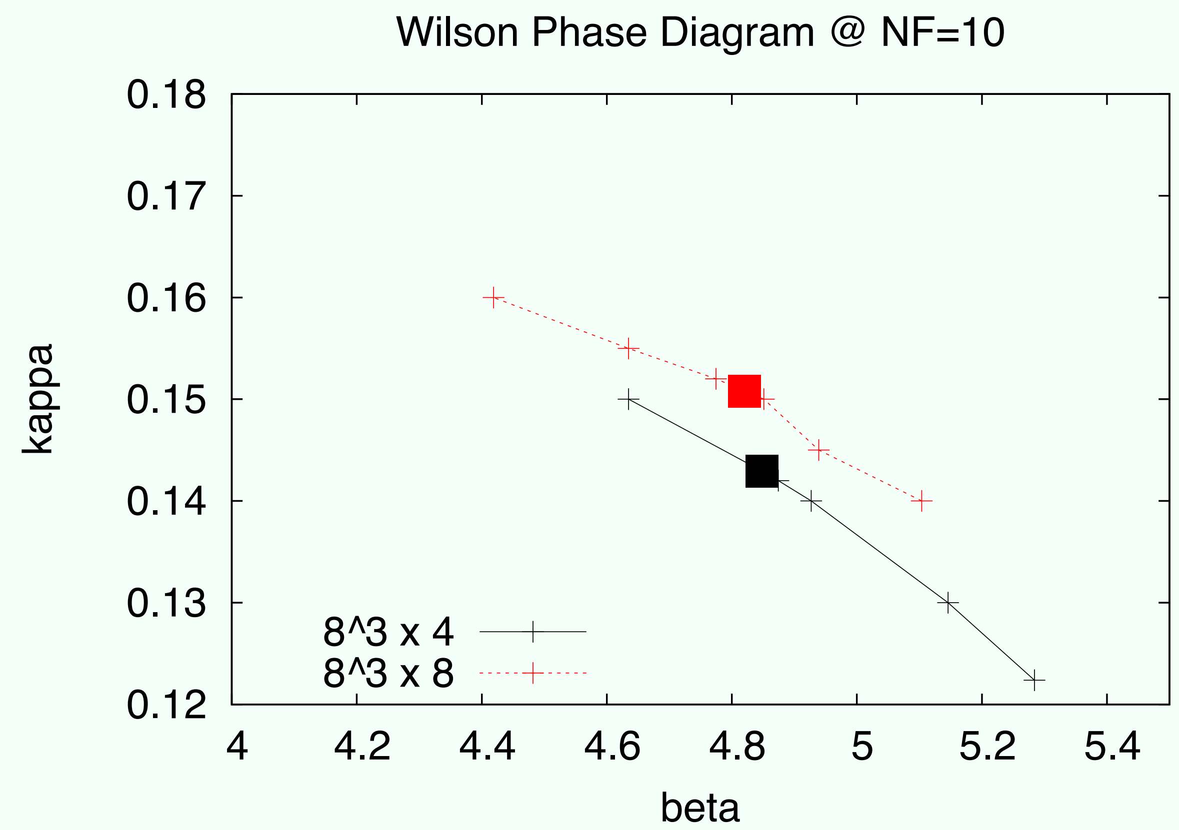
From dV_{eff}/dP, β_{cp} at each K can be determined.

N_T dependence of β_{cp}



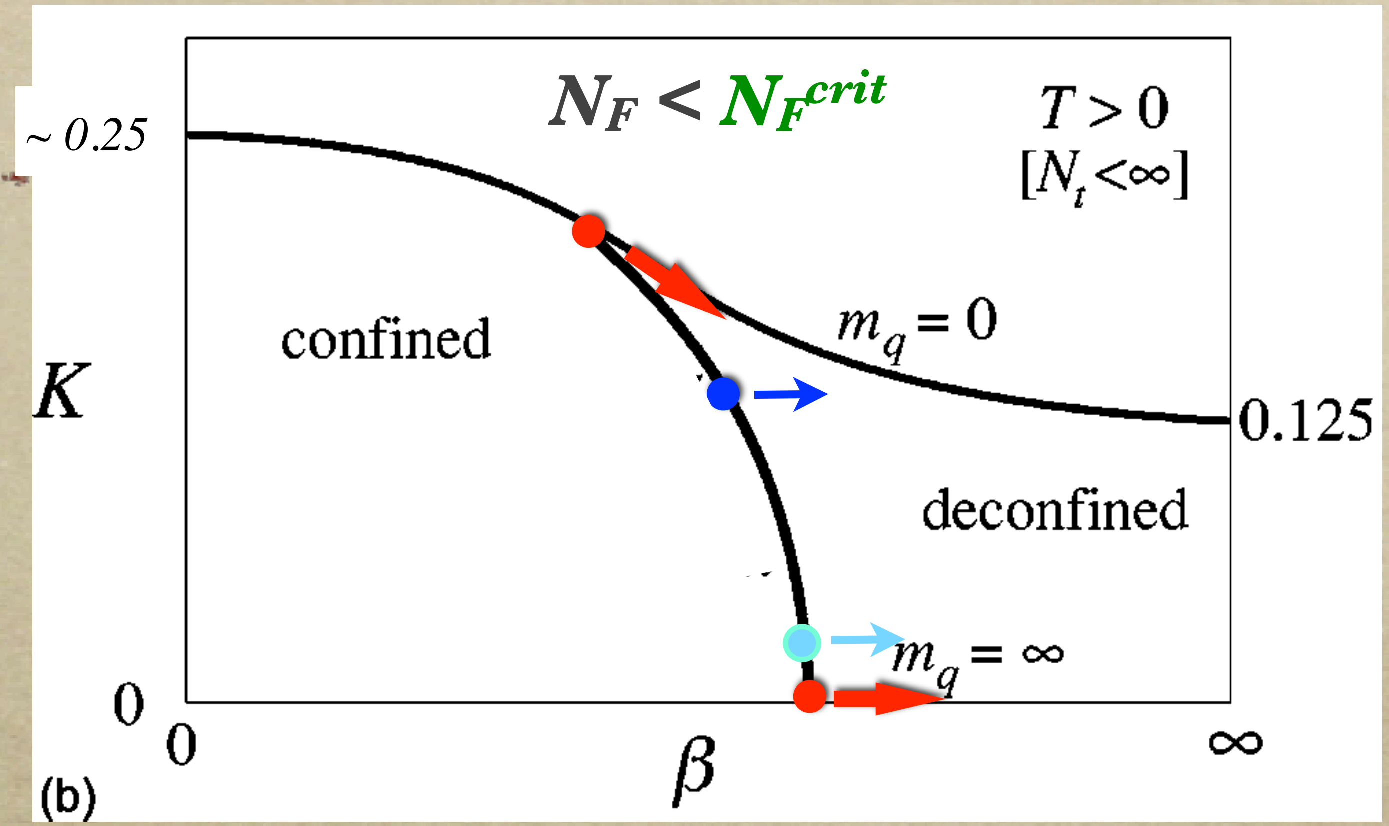


- Endpoint moves to the right for N_F =4.
- The direction of the shift is unclear for N_F =6 and 10.
  Large N_T data necessary

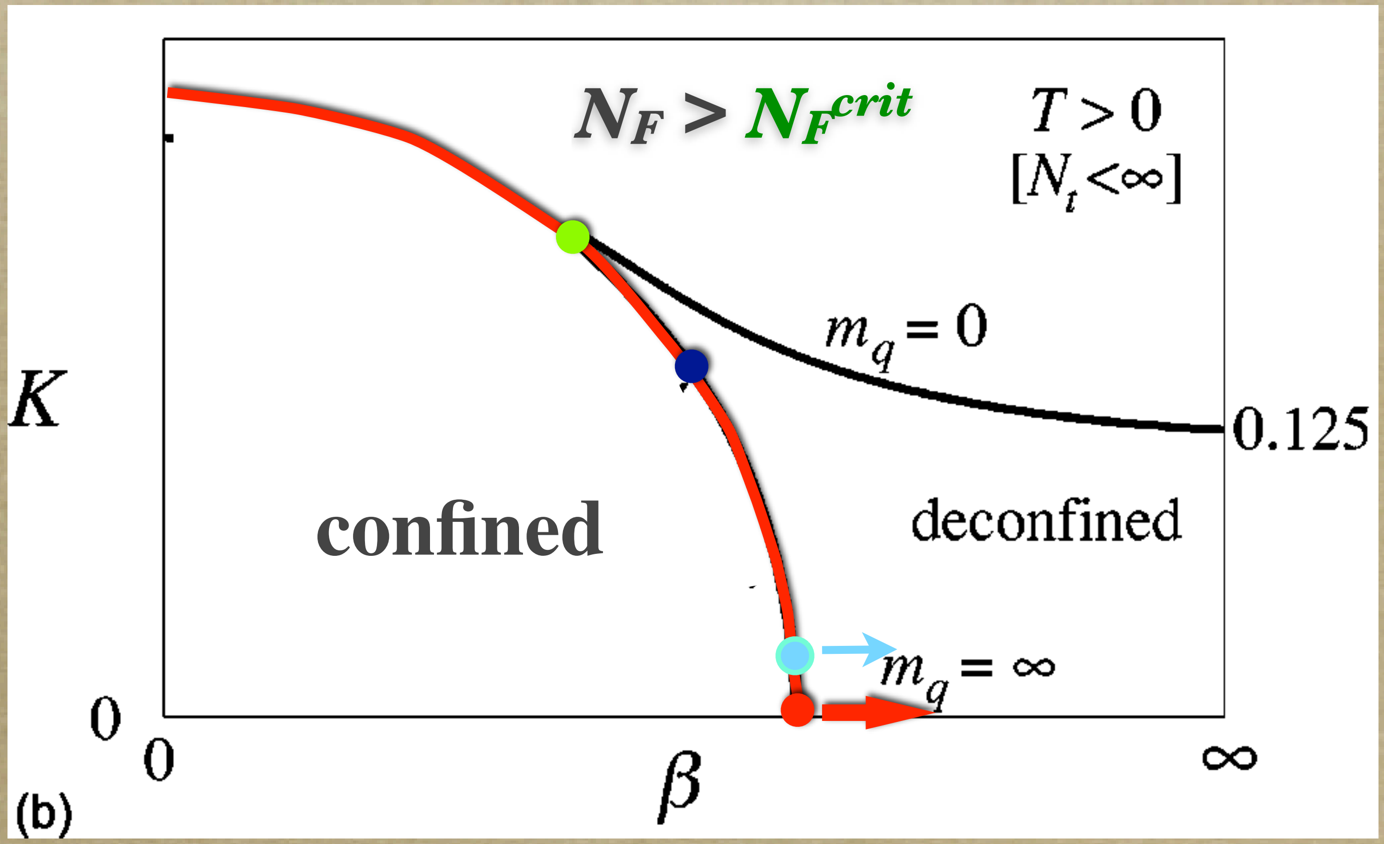


Possible interpretation

- The endpoint moving to the right:
  The 1st order chiral transition may persist in the continuum limit. Theory is confining and consistent with Pisarski & Wilczek.



- The endpoint not moving to the right:
  Two possibilities in the continuum limit:
  1. Theory is confining, but no 1st order region, inconsistent with P & W.
  2. Chiral transition does not occur. Theory is conformal.

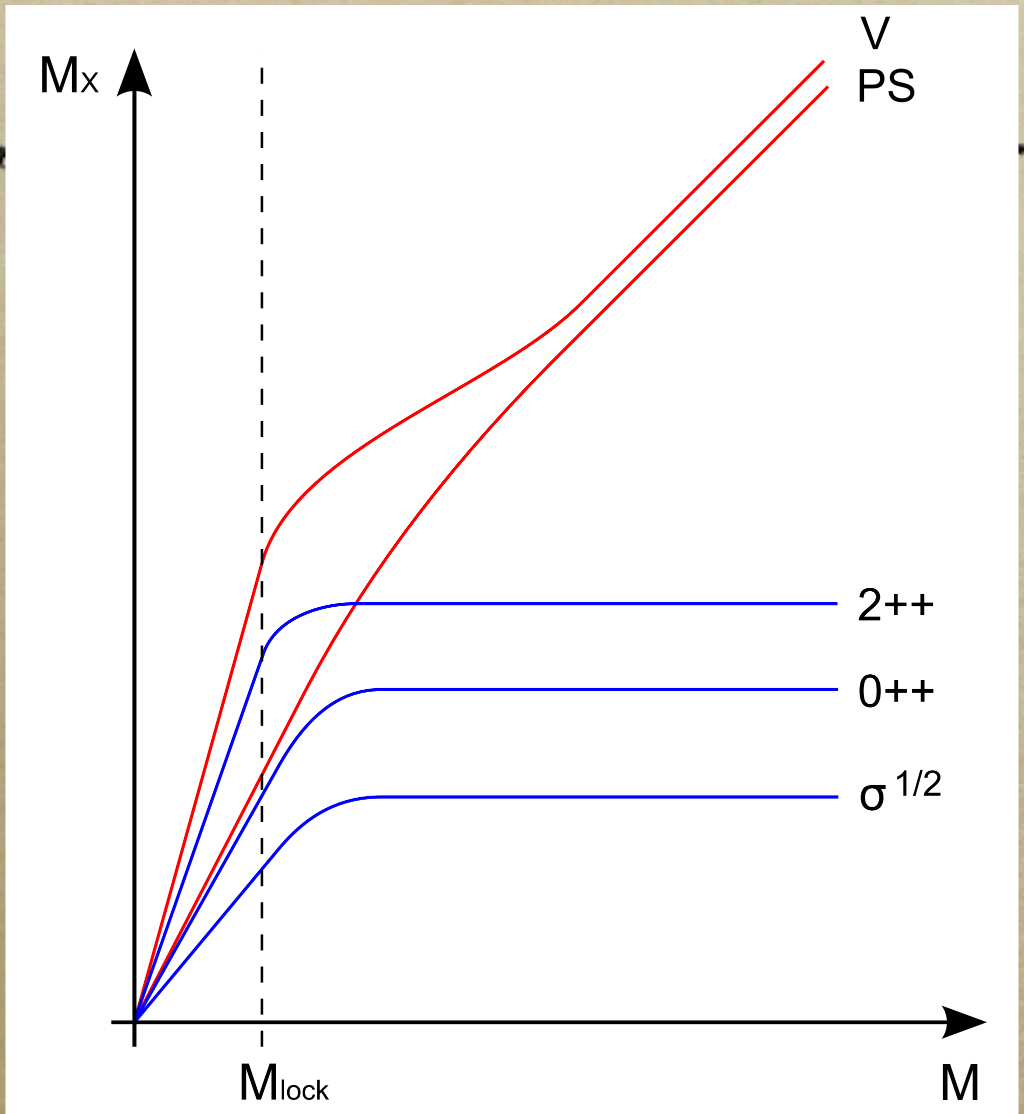


Summary

- ✓ Establishing Columbia plot for Many Flavor QCD clarifies phenomenologically interesting region.
- ✓ We employ Wilson fermion to study the thermodynamical properties of Many Flavor QCD by scanning the β-K plane.
- ✓ Method tracing the critical endpoint looks feasible.
- ✓ Method may be used to fix the conformal window.

Backup Slides

Spectrum in Conformal Window

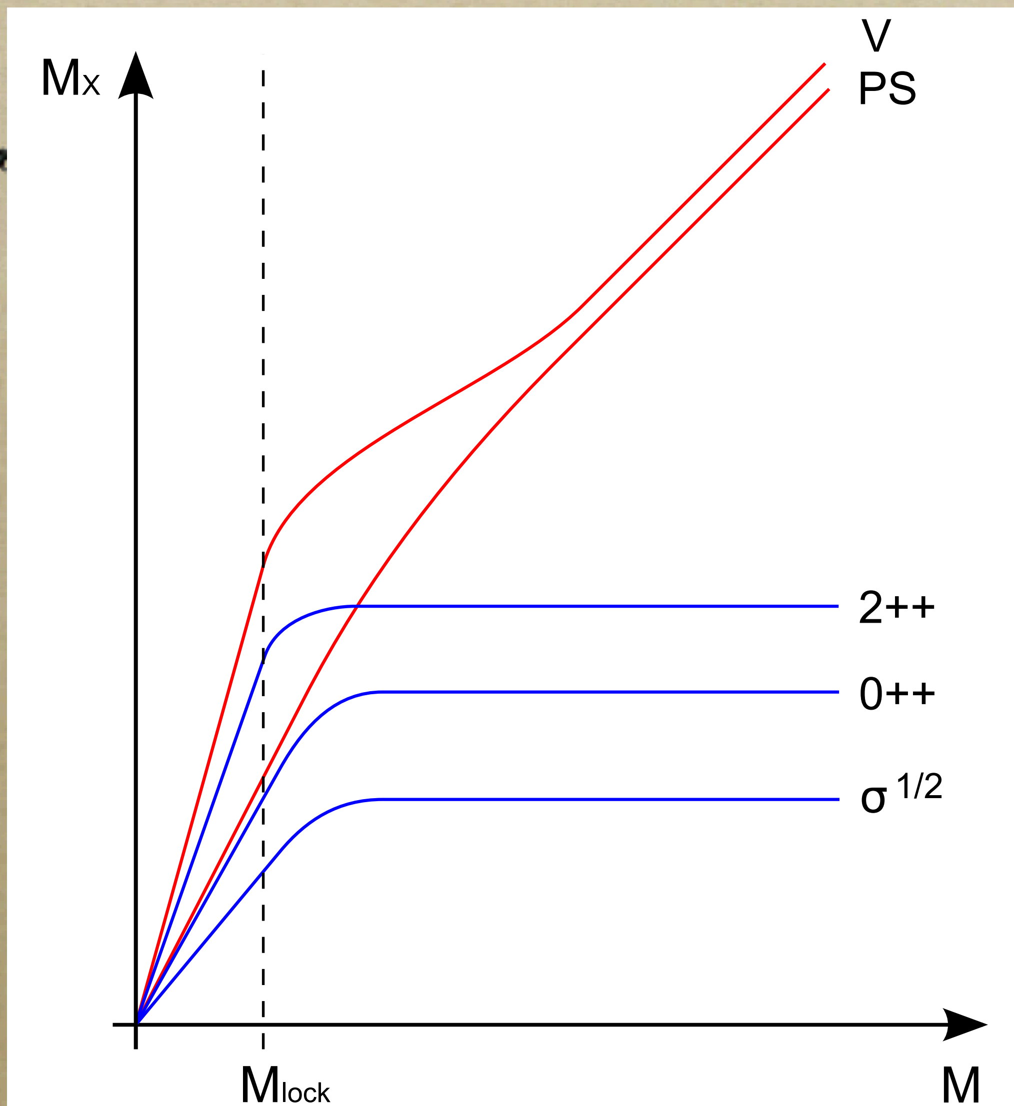


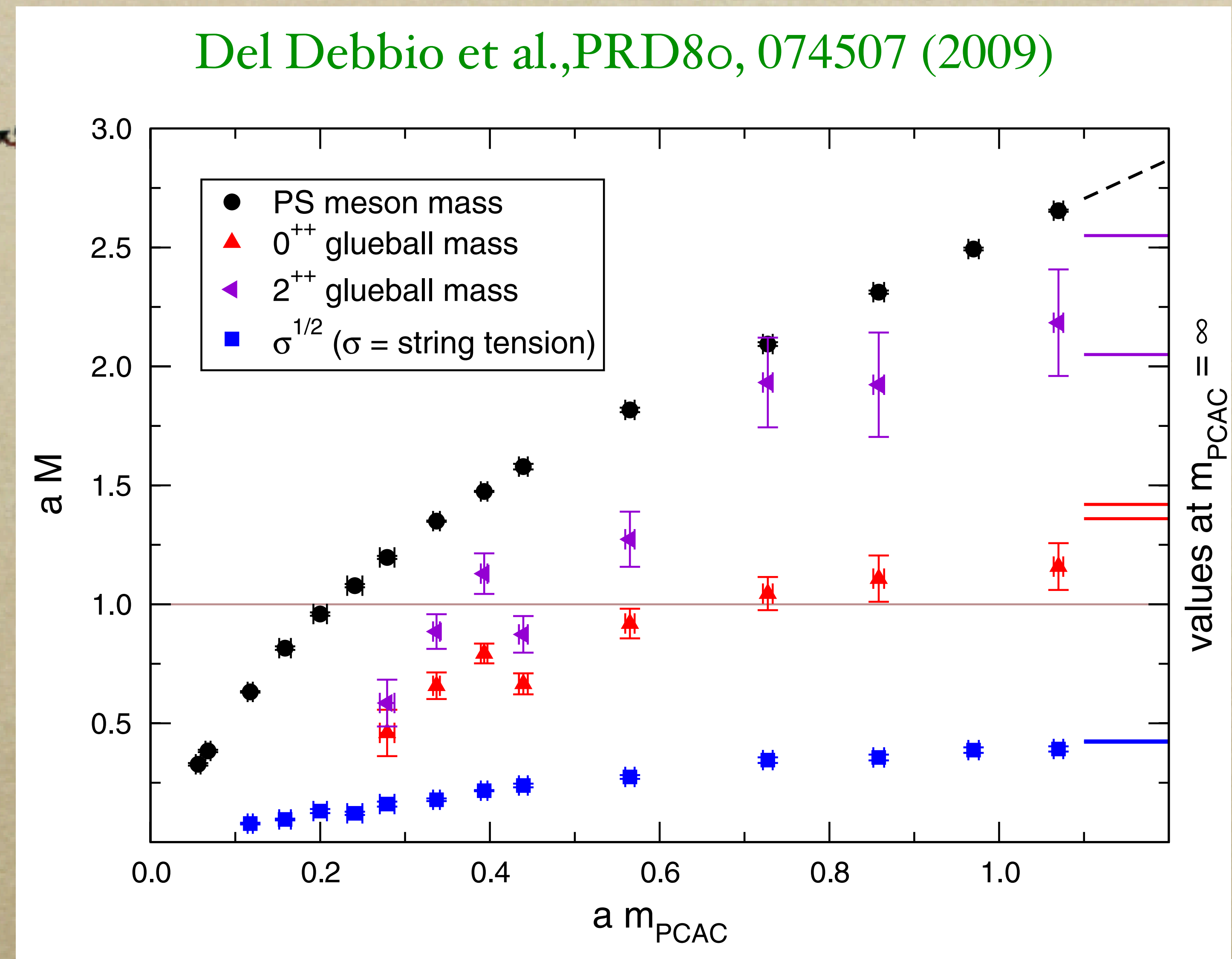
- In the massless limit, everything including **σ** vanish.

➡ Dynamical scale Λ vanishes in contrast to QCD.

- Like **confining** except for the small mass region.
- **Lattice calc. seems to reproduce the expected spectrum.**

Spectrum in Conformal Window





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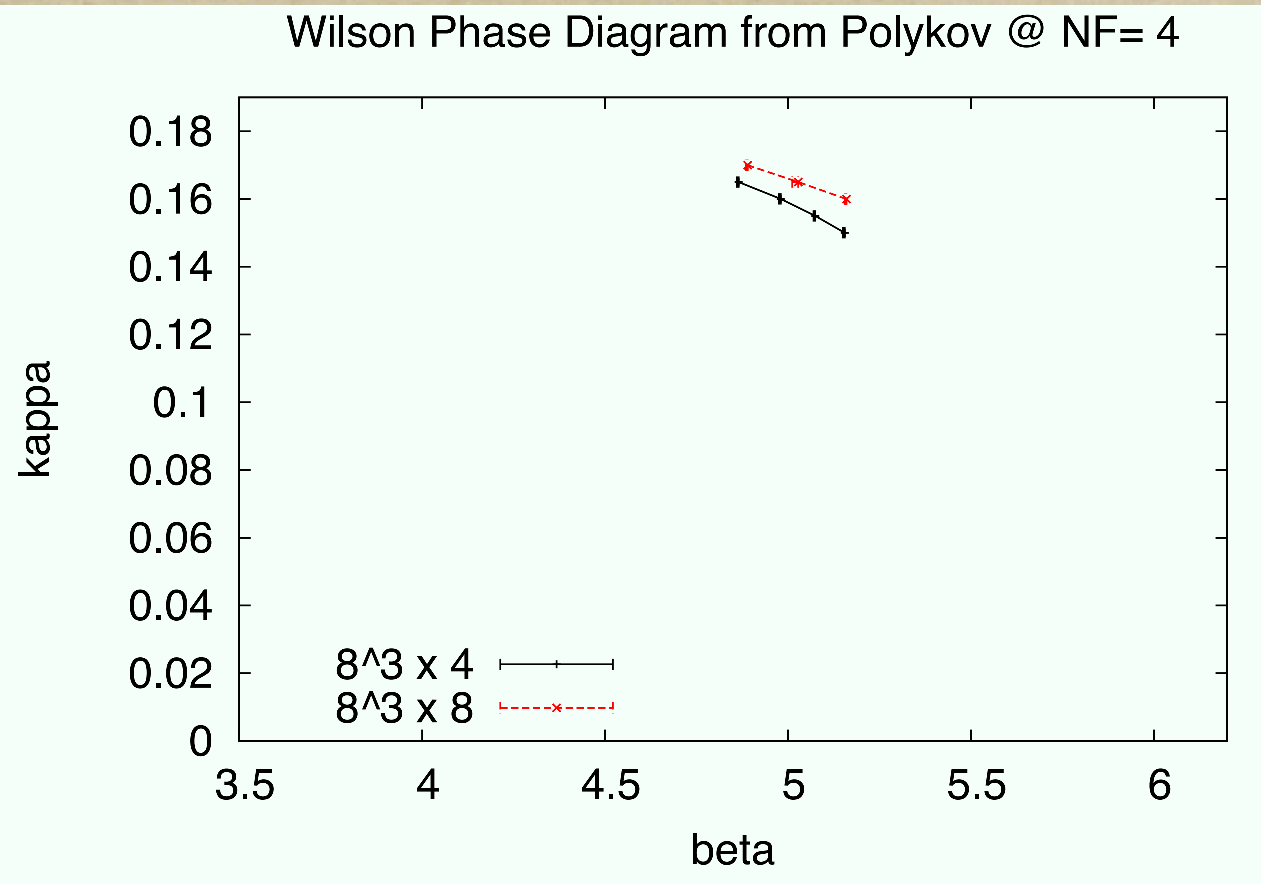
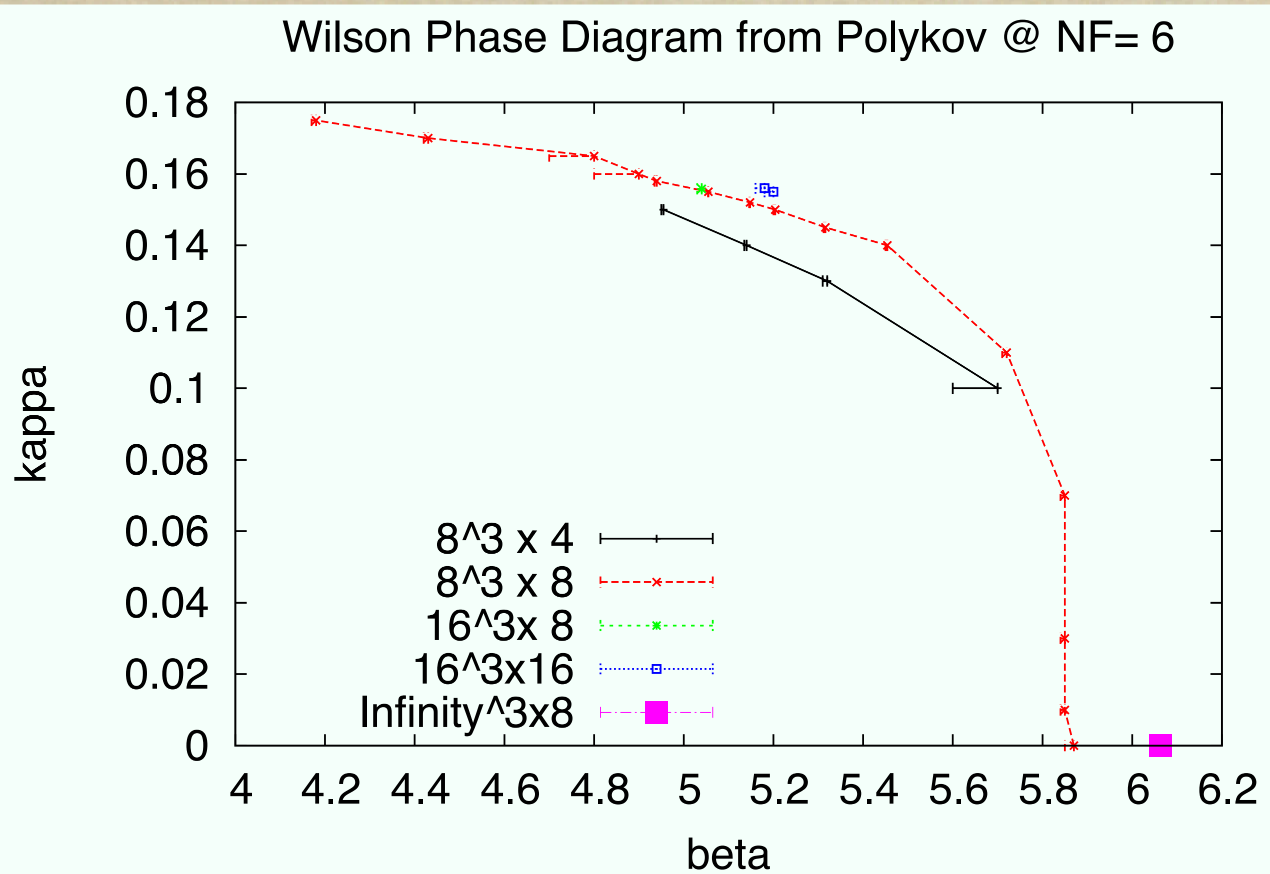
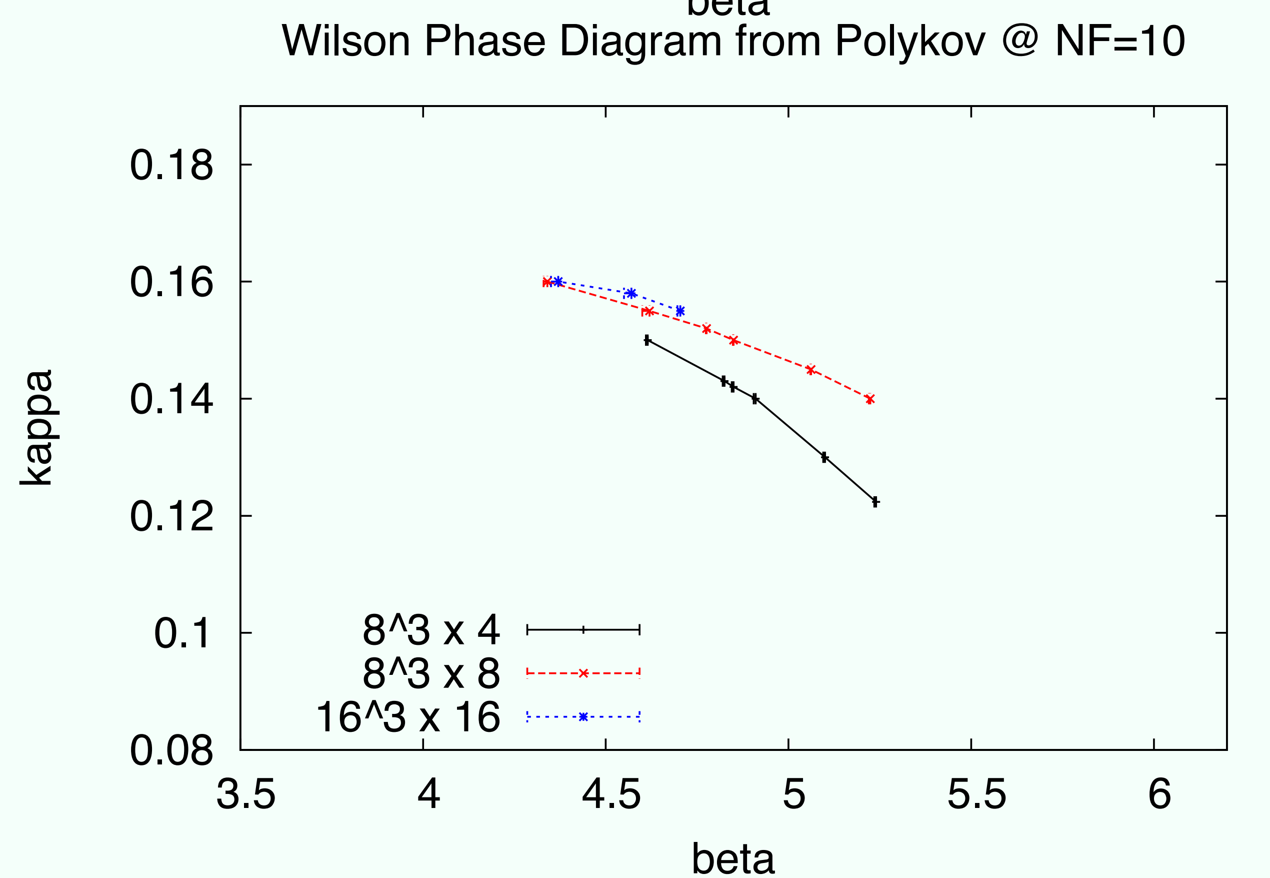
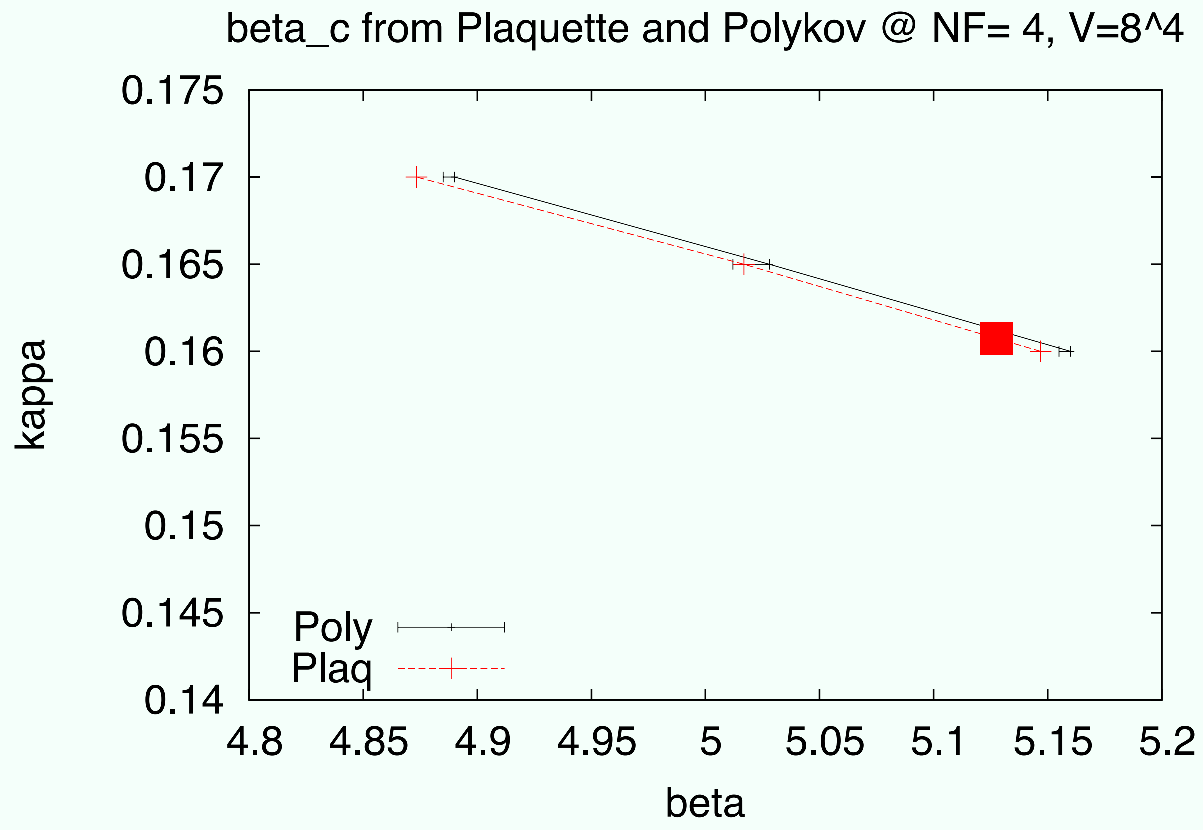
β_c from Polyakov loop

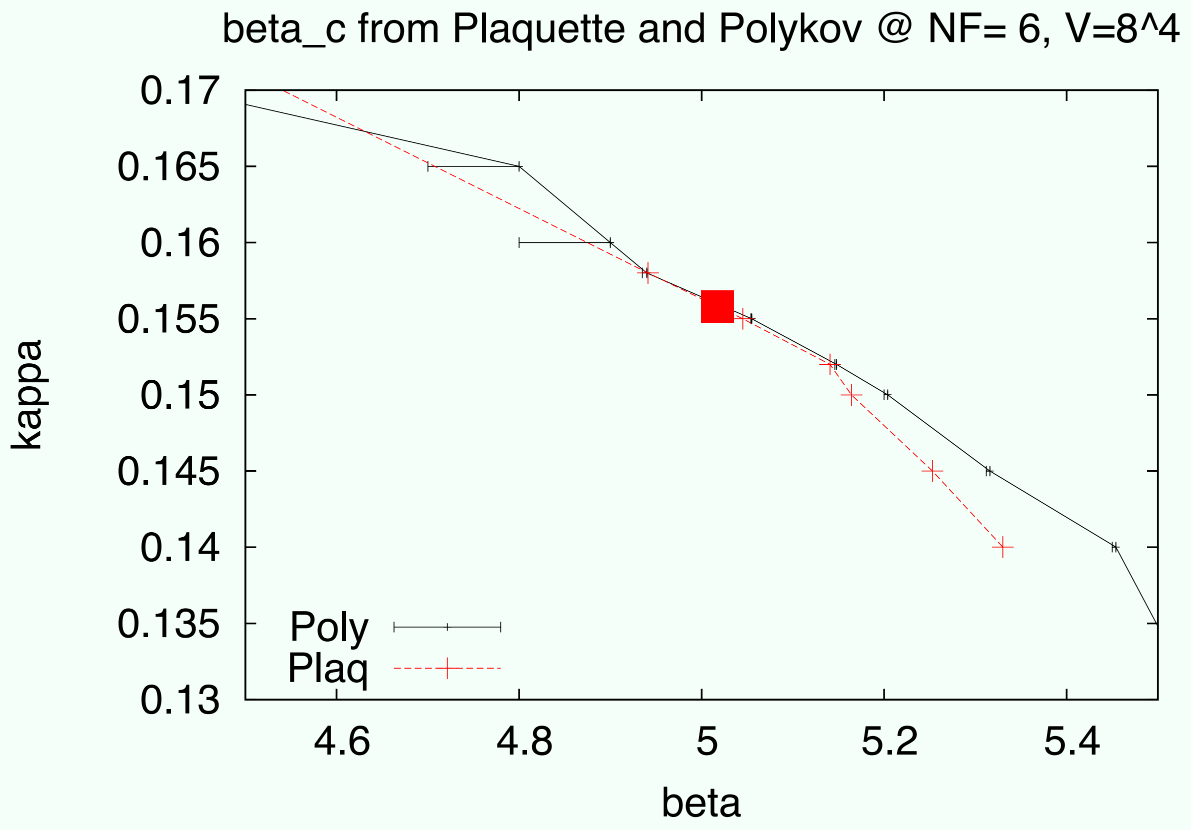




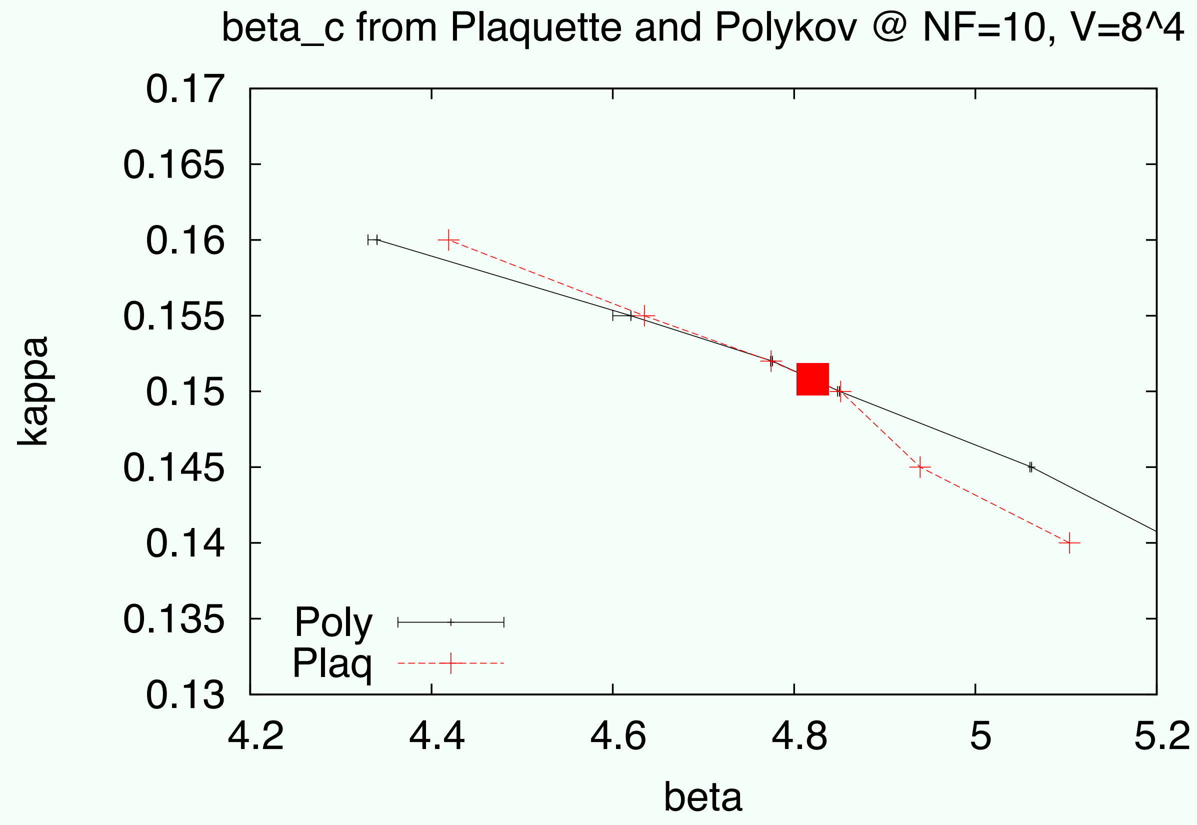


Comparison of Plaq. and Polyakov

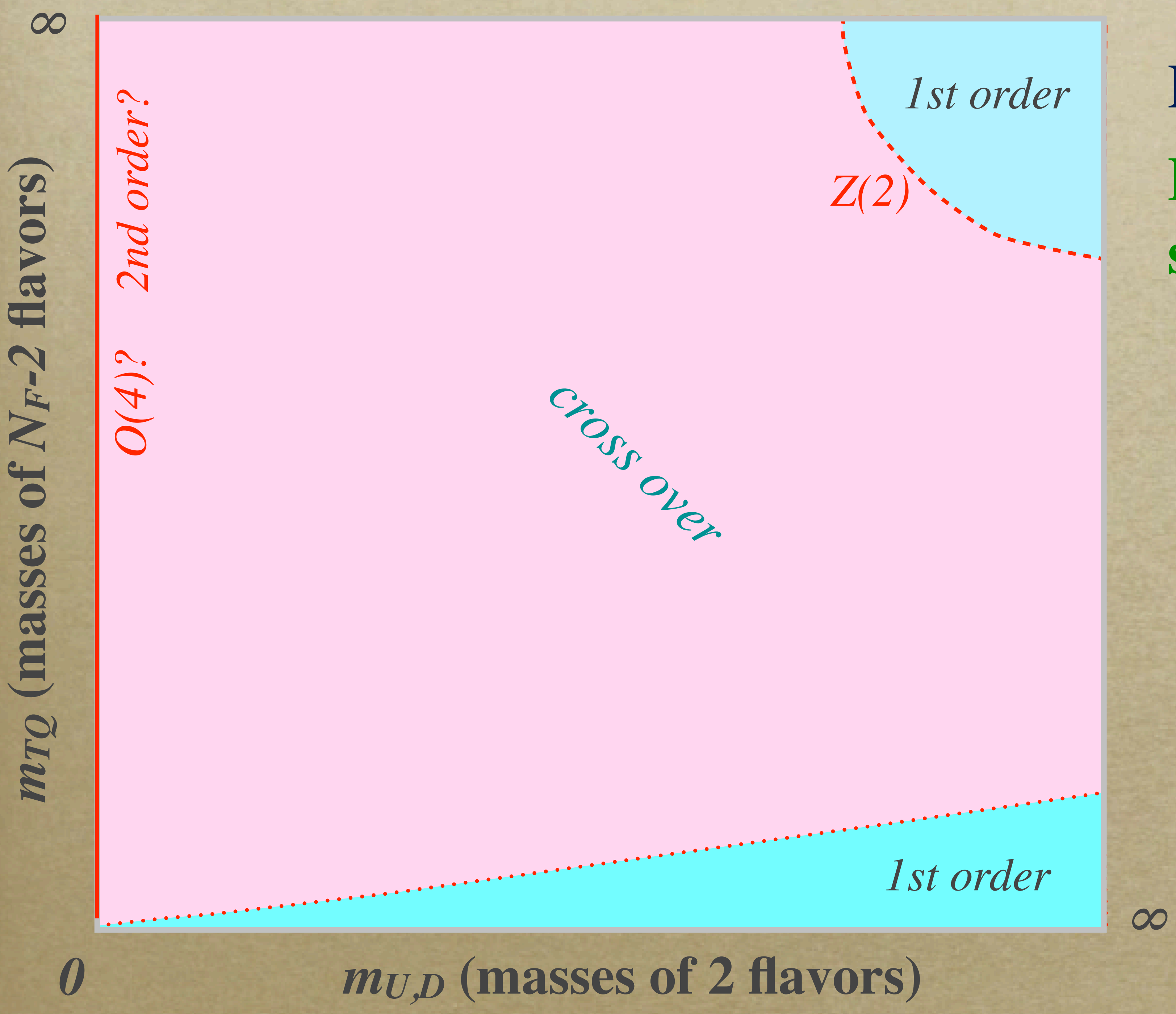




- Two lines are on top of each other in the 1st order region.
- In the other region, they deviate.



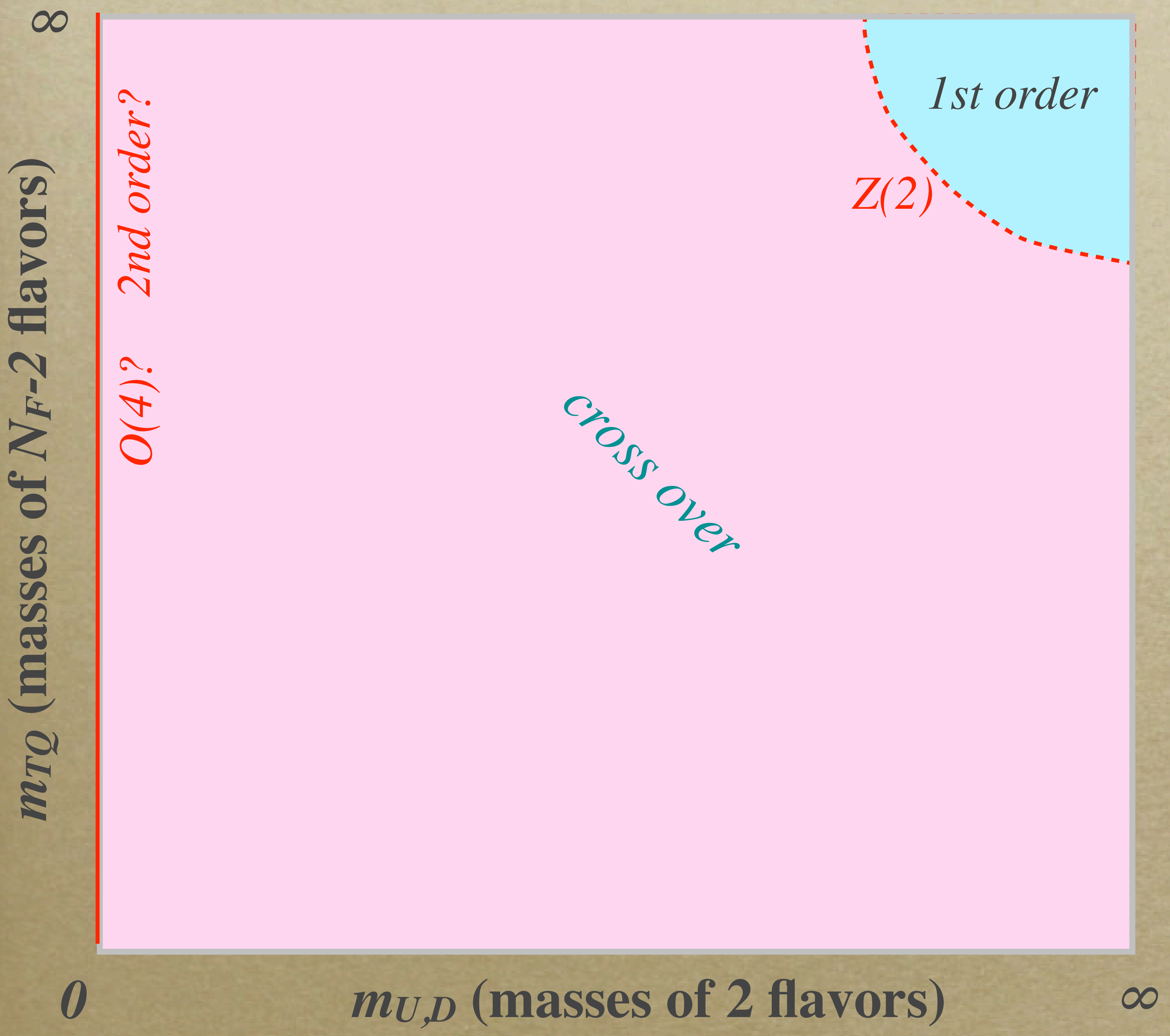
N_F - 2< N_F^{crit} < N_F (Speculation)



If this is the case,

EW baryogenesis within TC seems difficult.

$N_F^{crit} < N_F - 2 < N_F$ (Speculation)



If this is the case, not interesting.

Critical Beta in the quenched approximation

Iwasaki, et al., PRD46(1992)4657:
$\beta c(Nt=4,K=0)=5.69254(24)$
$\beta c(Nt=6,K=0)=5.89405(51)$

Boyd, et al., NPB469(1996) 419:
$\beta c(Nt= 4,K=0) = 5.6925\ (2)$
$\beta c(Nt= 6,K=0) = 5.8941\ (5)$
$\beta c(Nt= 8,K=0) = 6.0625$
$\beta c(Nt=12,K=0) = 6.3384$