university of groningen

faculty of mathematics and natural sciences

probing the conformal window on the lattice

Tiago Nunes da Silva

XQCD 2013 – Bern, CH

probing the conformal window on the lattice *(with fundamental fermions)*

Tiago Nunes da Silva

university of groningen
faculty of mathematics and natural sciences

FOM

XQCD 2013 – Bern, CH

Is there an IR fixed point in SU(3) Nf=12 theory?

Ishikawa, Iwasaki, Nakayama, Yoshie (phase structure, correlation fn.)

Appelquist, Fleming, Neil, M.Lin, Schaich (running coupling, mass spectrum)

Deuzeman, Lombardo, Pallante, Miura, da Silva (finite temperature)

Cheng, A. Hasenfratz, Petropoulos, Schaich (MCRG, phase structure, Dirac eigenmodes)

DeGrand (mass spectrum)

LatKMI (mass spectrum)

D.Lin, Ogawa, Ohki, Shintani (running coupling)

Fodor, Holland, Kuti, Nogradi, Schroeder, (running coupling, phase structure, spectrum)

Jin and Mawhinney (phase structure)

Slide adapted from E. Itou

our collaboration

A. Deuzeman, University of Bern, Switzerland
M.P. Lombardo, INFN, Italy
K. Miura, Nagoya University, Japan
T. Nunes da Silva, University of Groningen, The Netherlands
E. Pallante, University of Groningen, The Netherlands

outline

- background
- the pre-conformal regime
- the conformal window

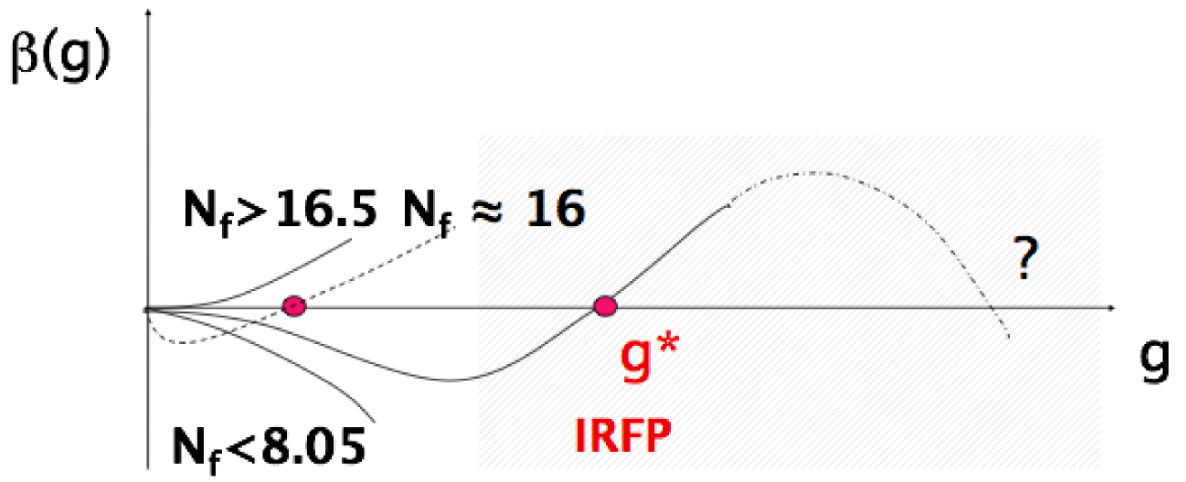
outline

- background
- the pre-conformal regime
- inside the conformal window

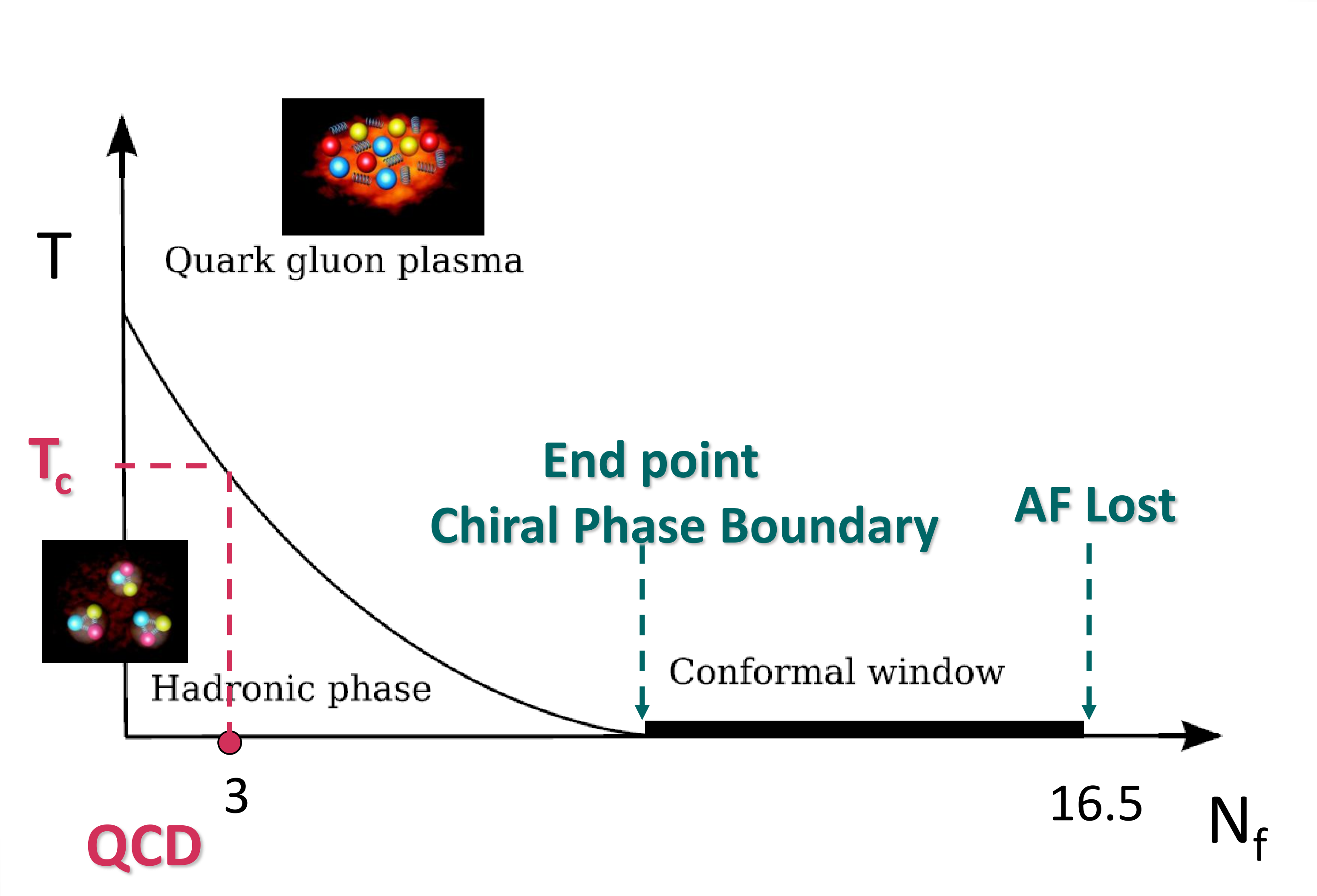
beta function and conformality

$$\beta(g) = -b_0 g^3 - b_1 g^5 + (\ldots)$$

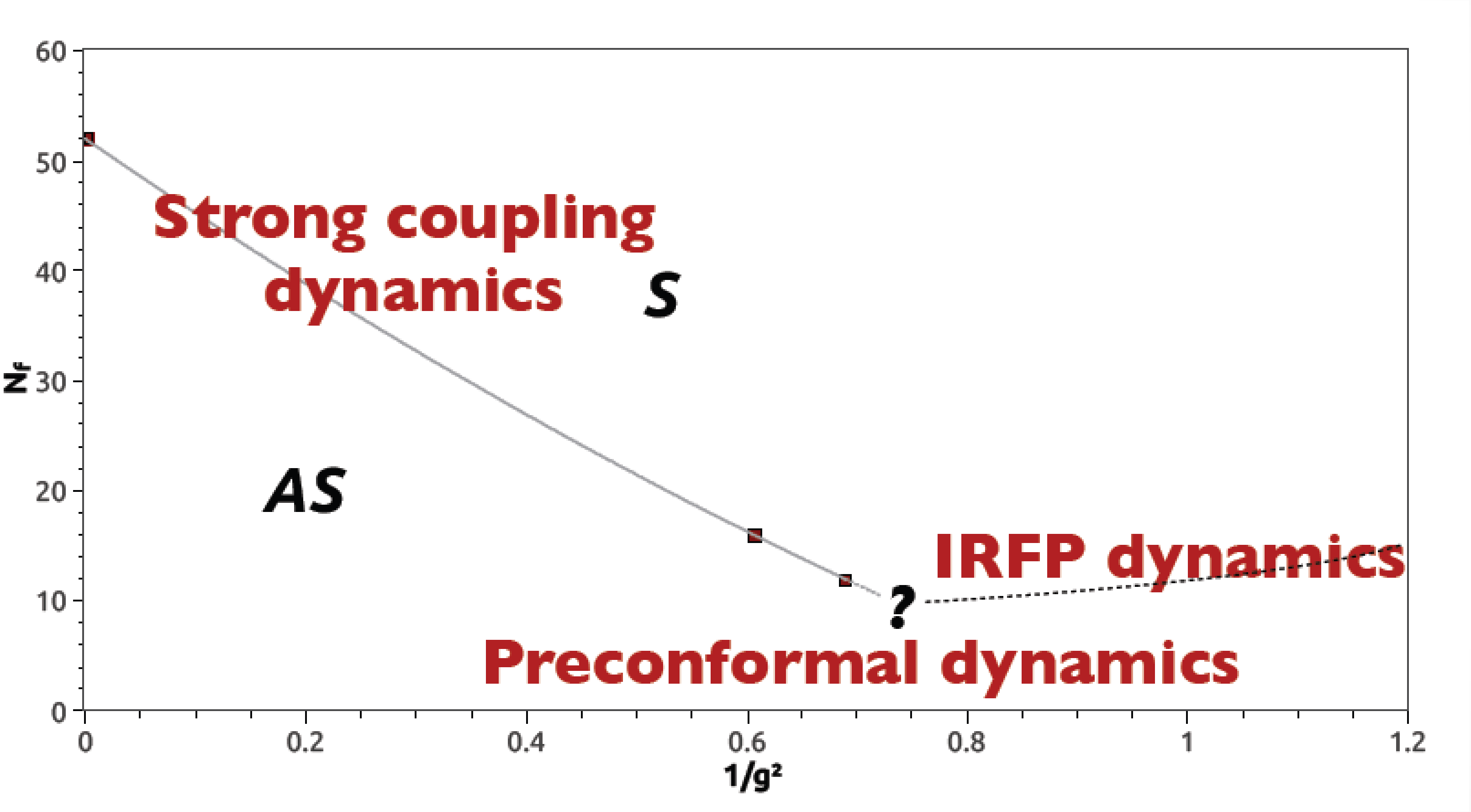
$$b_0 = \frac{1}{16\pi^2}\left(11 - 2\frac{N_f}{3}\right), \qquad b_1 = \frac{1}{(16\pi^2)^2}\left(102 - 38\frac{N_f}{3}\right)$$



the T-N_f phase diagram



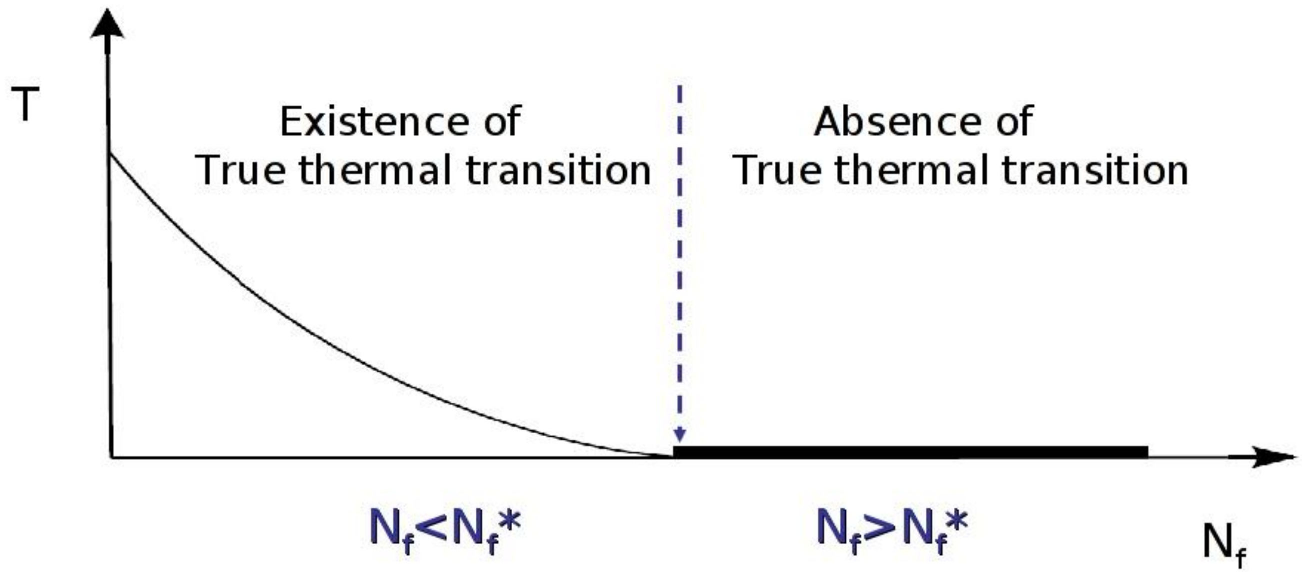
the $N_f - 1/g$ phase diagram



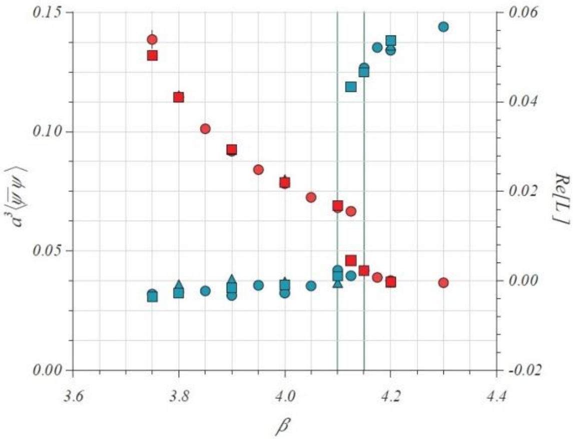
outline

- background
- the pre-conformal regime
- the conformal window

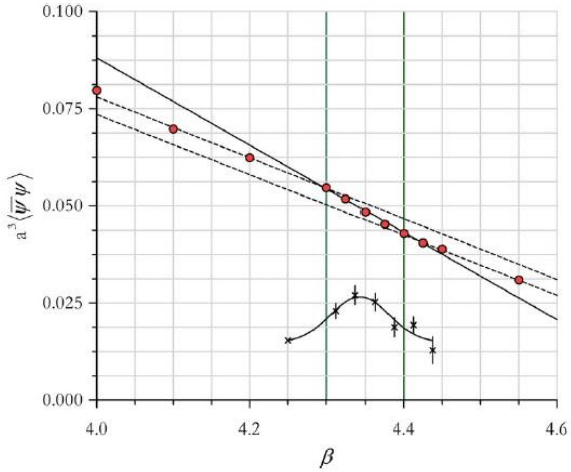
hunting a thermal transition



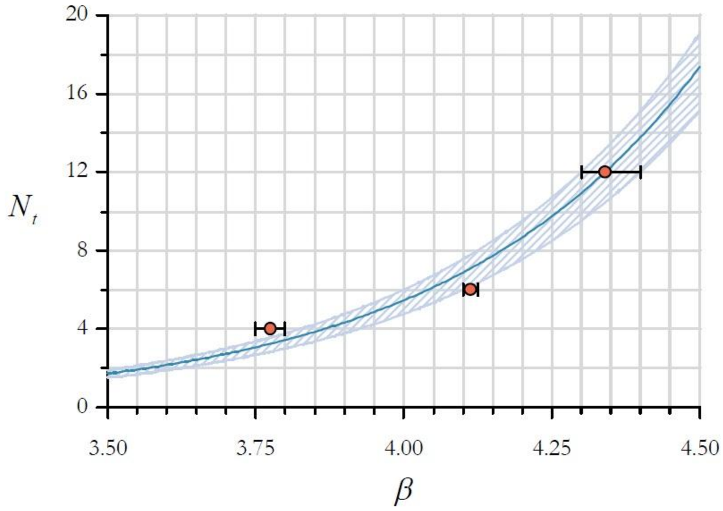
a thermal transition with $N_f = 8$



$N_t = 6$

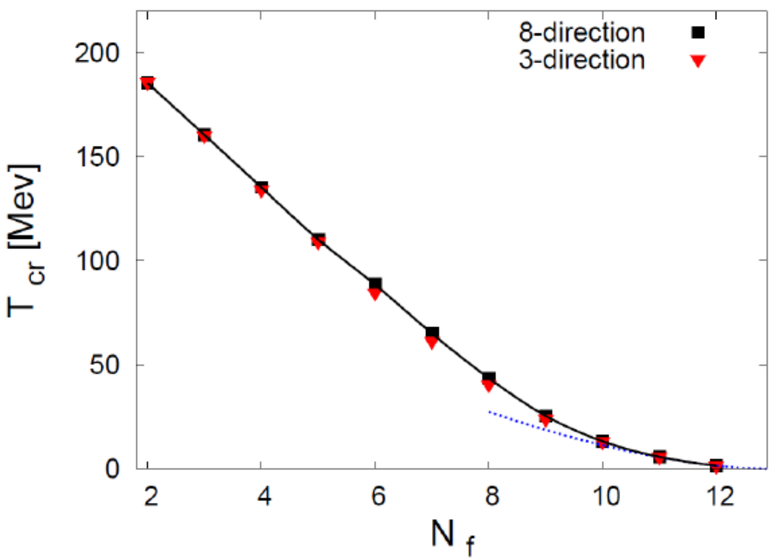


$N_t = 12$



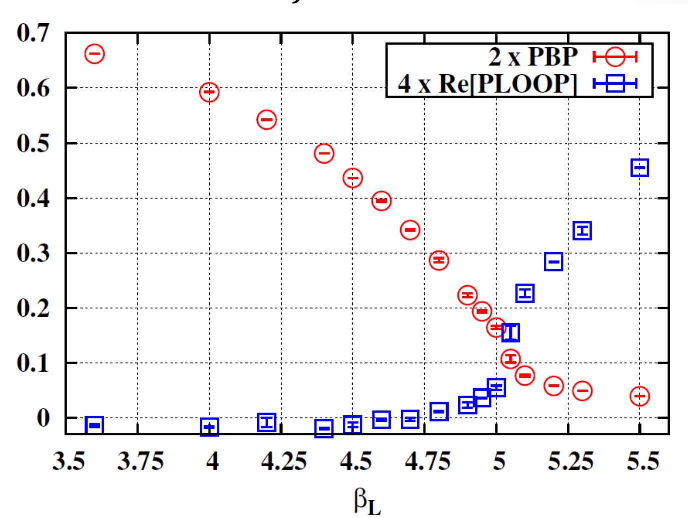
A. Deuzeman, E. Pallante and M.P. Lombardo;
Phys.Lett.B670 (2008)

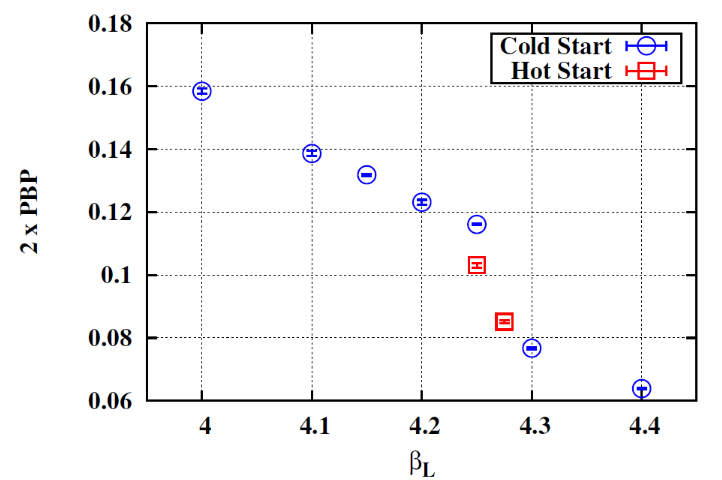
opening the conformal window



J. Braun, H. Gies; JHEP 0606 024 (2006)

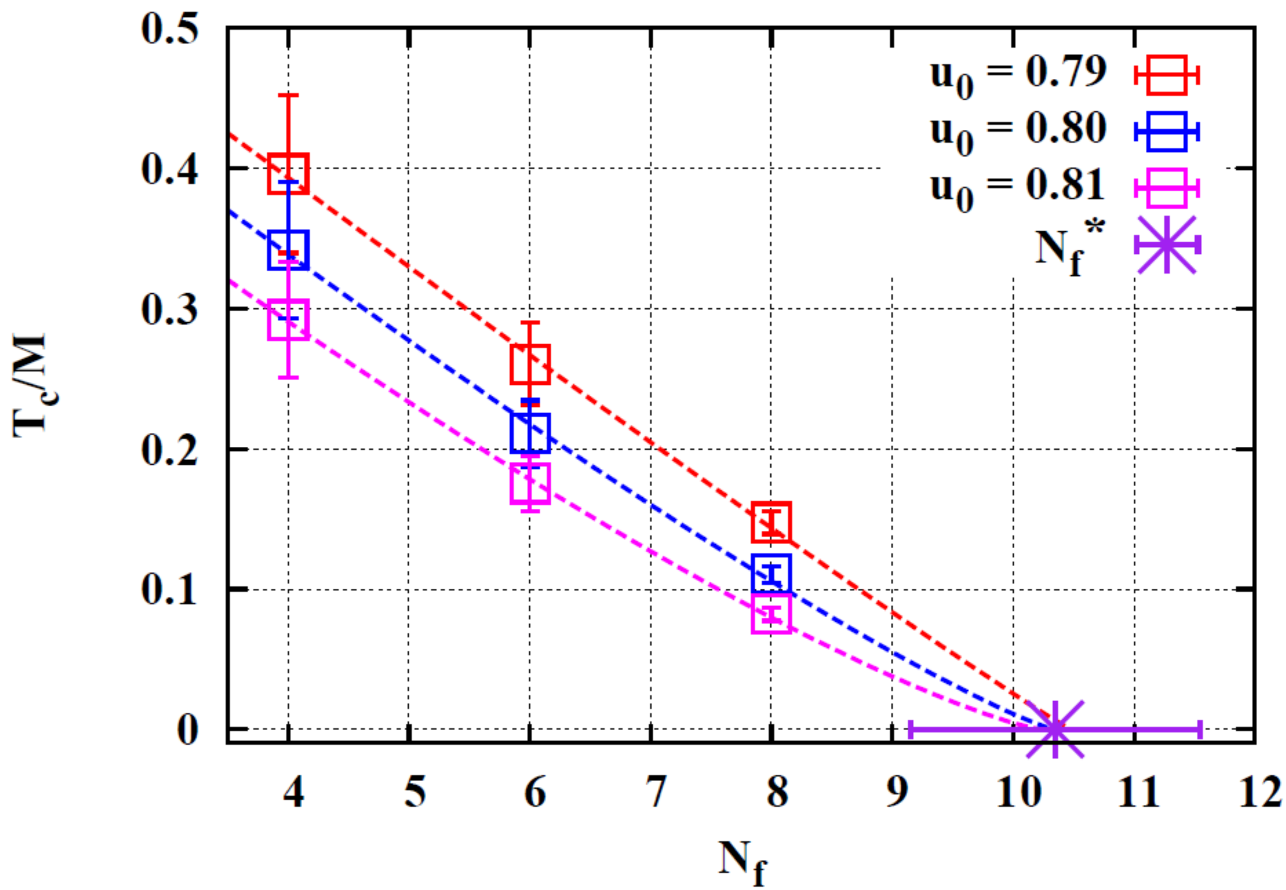
$N_f = 6$





$N_f = 8$

opening the conformal window



$N_f^C = 10.4 \pm 1.2$

Nuclear Physics B, 871 (2013)

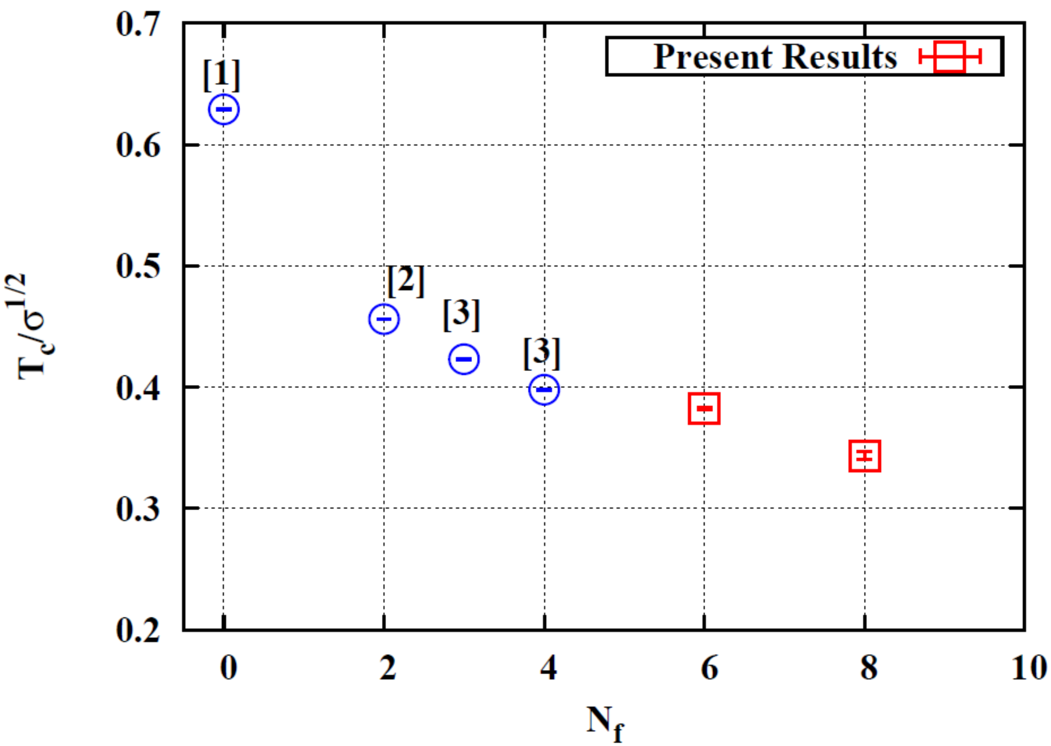
opening the conformal window

- We would like to find a direct evidence of the singularity that opens the CW from $\left({}^{T_C}/_{M}\right)\left(N_f^*\right) = 0$, where M is an UV scale that should disentangle the behavior in the IR.

- In the work above it was calculate at the plaquette scale with the help of the two-loop beta function.

- How can we define the UV scale directly from lattice measurements, without using perturbation theory ?

work in progress: $T_c/\sqrt{\sigma}$



[1]E. Laermann, Nucl.Phys.B, (1996)

[2] F. Karsch and E. Laermann, Nucl.Phys.B, (2001)

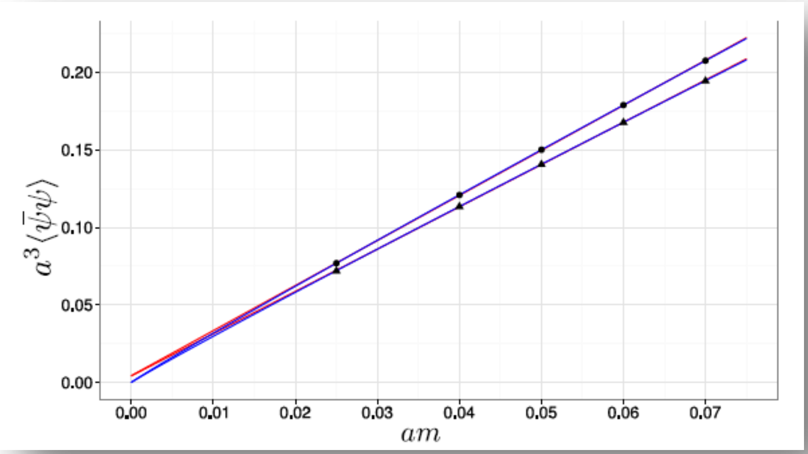
[3] Engels, Nucl.Phys.B, (1997)

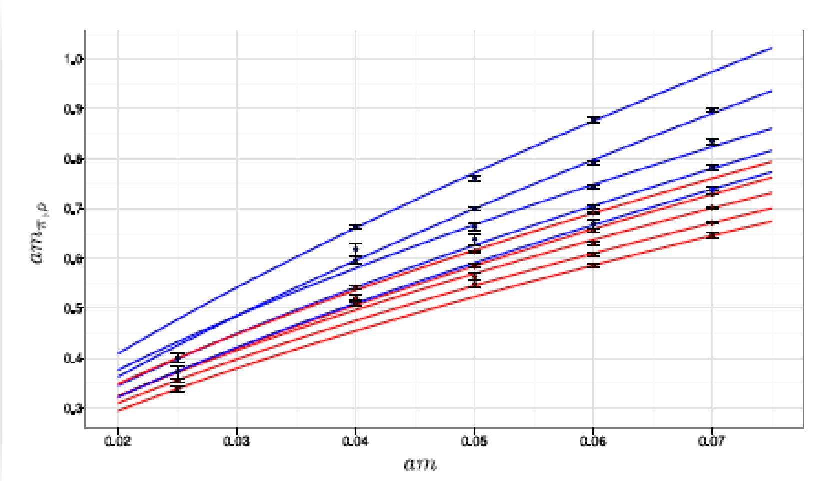
Quantity serves as input for model building in Gauge/Gravity duality models. See, e.g., Gursoy et. al. arXiv:1006.5461

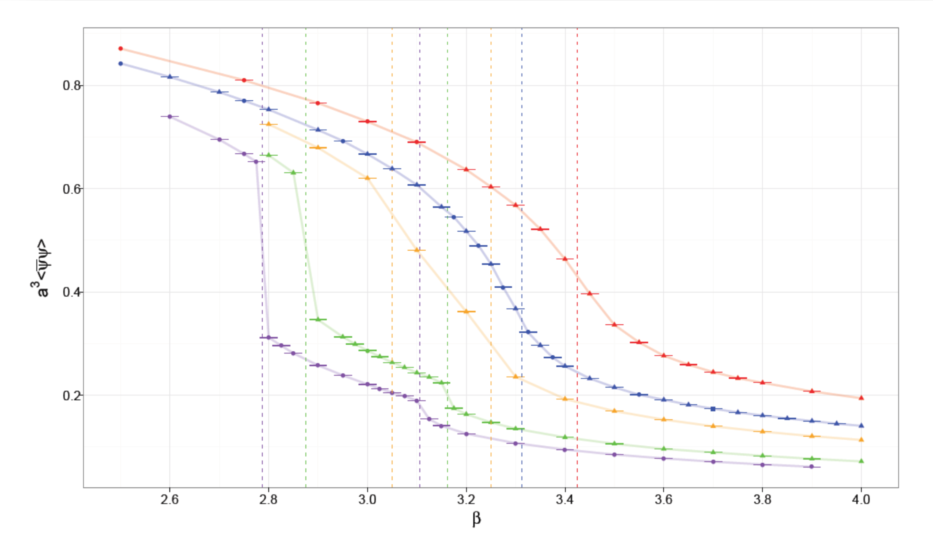
outline

- background
- the pre-conformal regime
- the conformal window

evidences of conformality





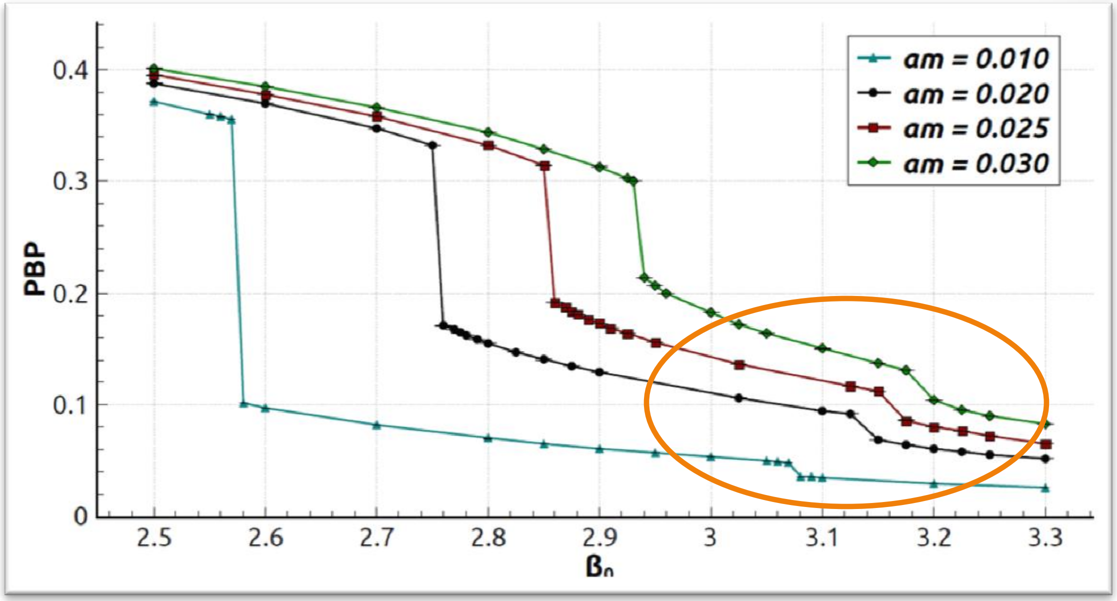


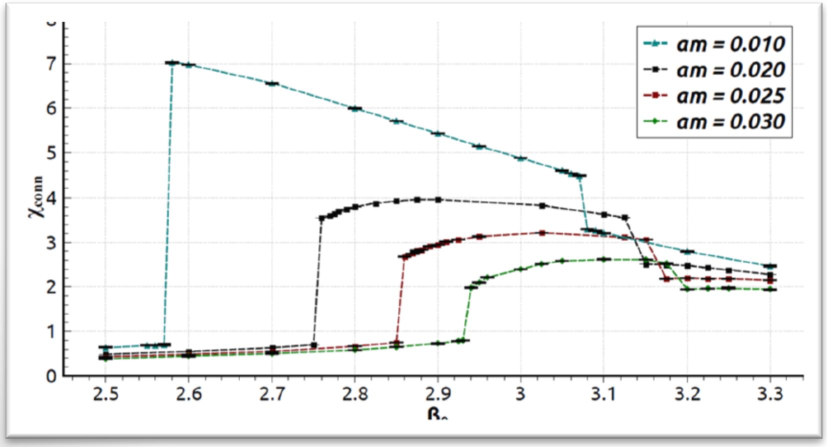
Phys.Rev.D82 (2010)

a tale of two jumps

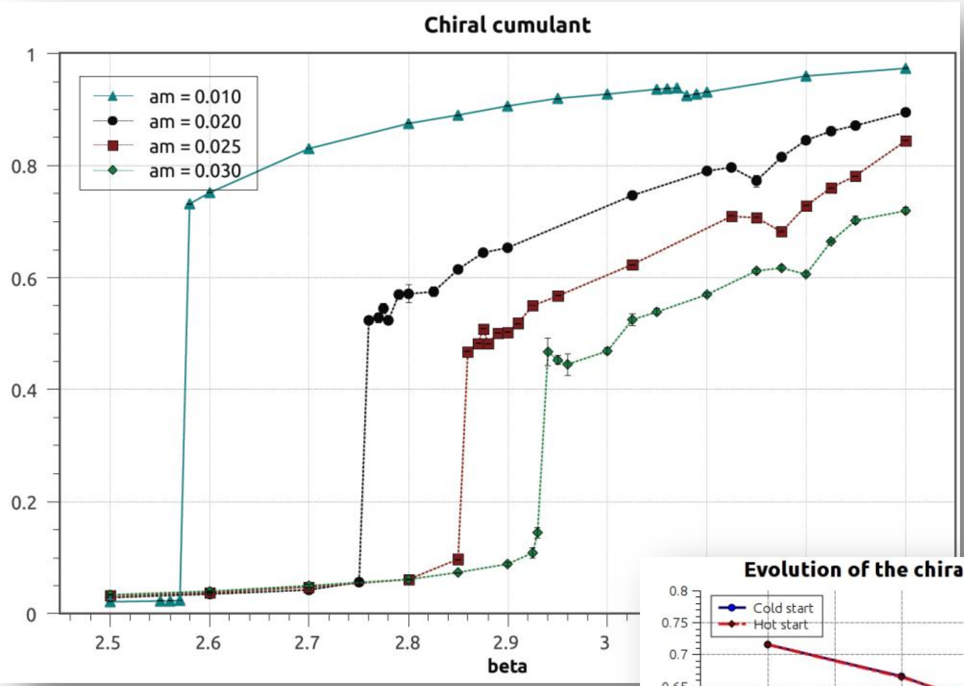
SU(3) with $N_f = 12$ fundamental flavors

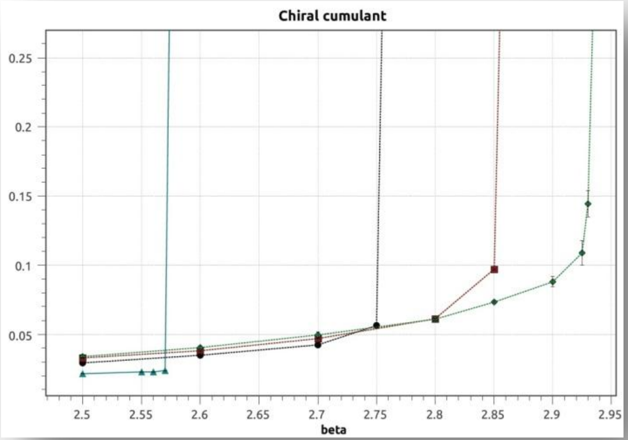
Tree level Symanzik + Naik improved action

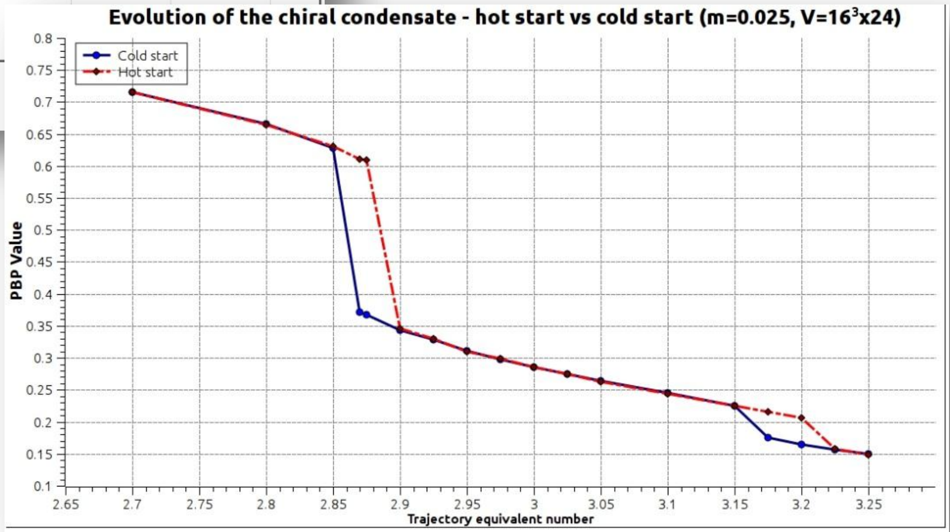




a game of symmetries



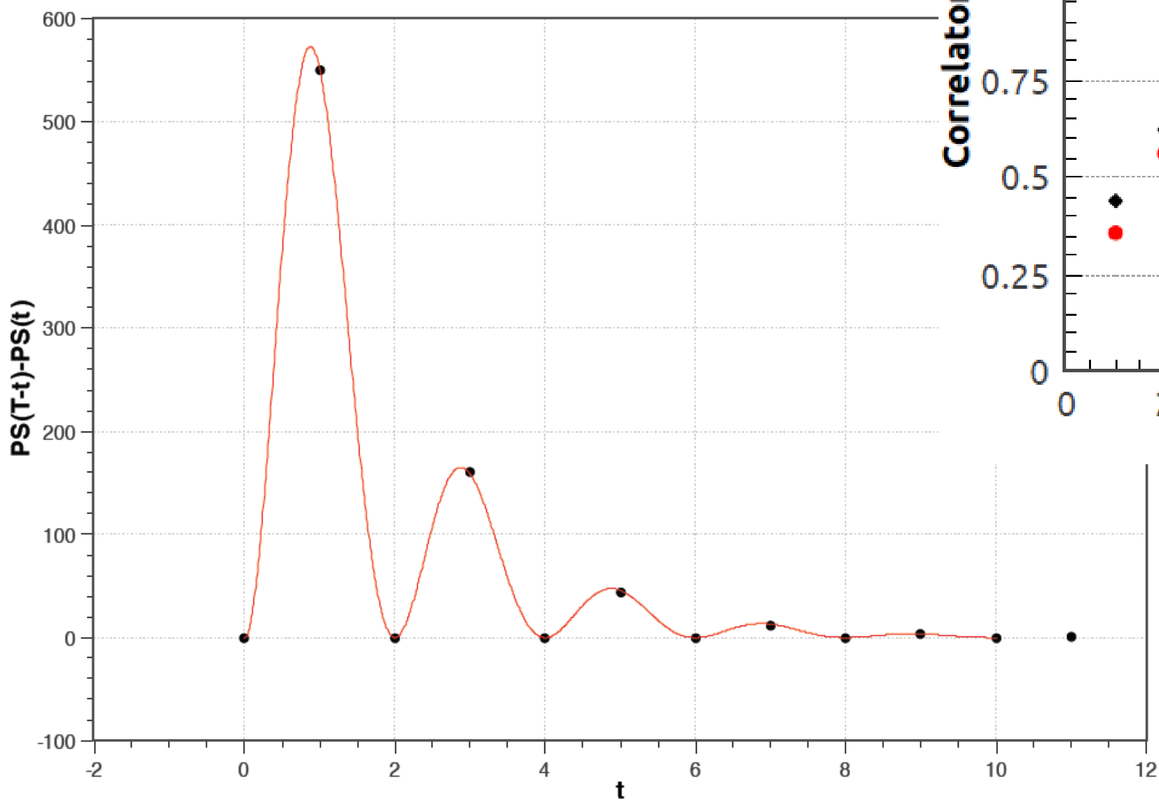


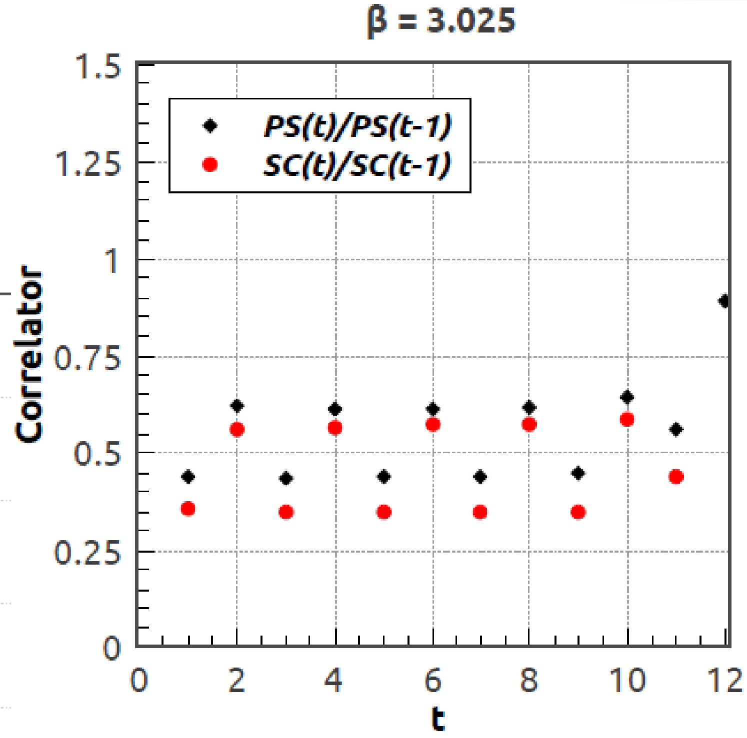


$$R = \frac{\frac{\partial(\langle\bar{q}q\rangle)}{\partial m}}{\frac{\langle\bar{q}q\rangle}{m}} = \frac{\chi_\sigma}{\chi_\pi}$$

signatures of the exotic phase

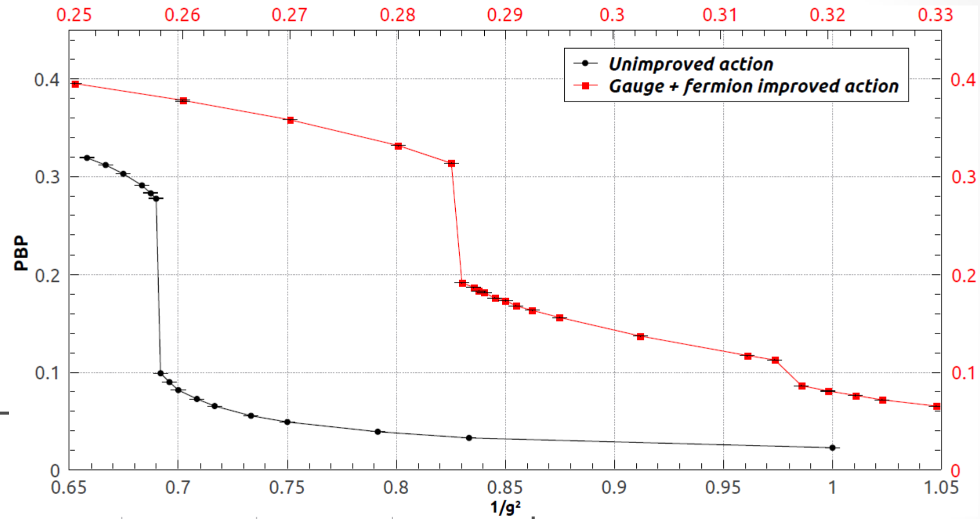
$$Asym \propto C(1-(-1)^t)(e^{-mt} - e^{-m(T-t)})$$

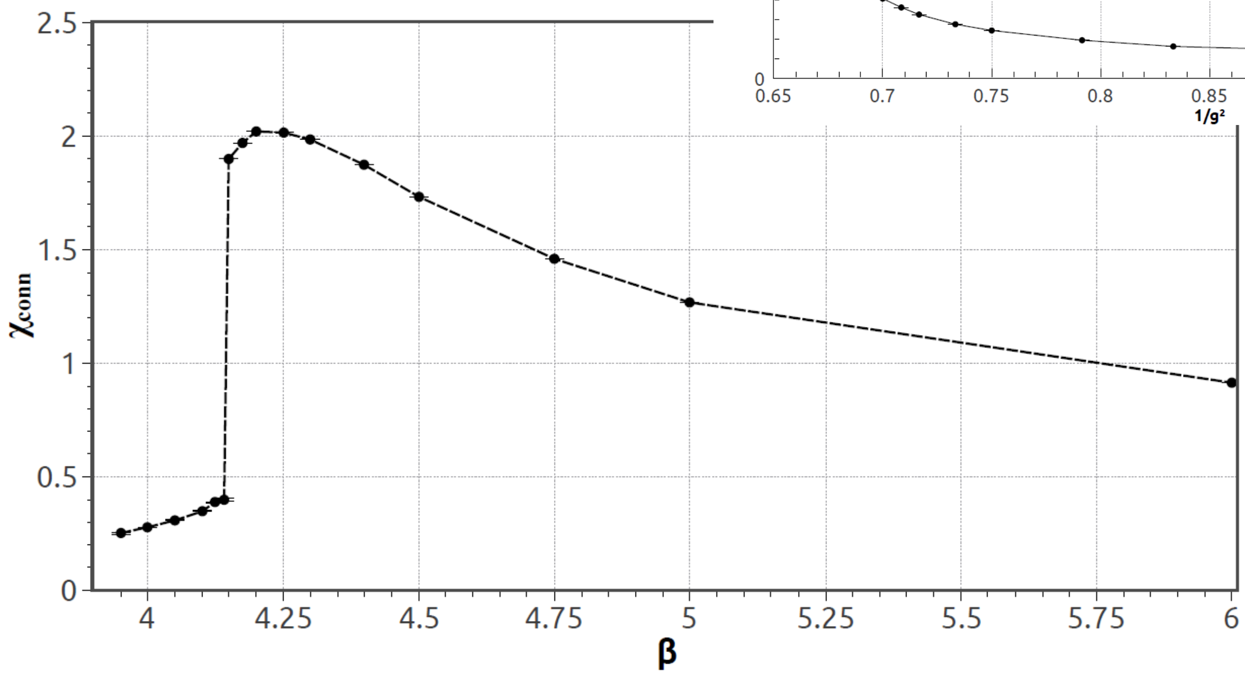




effect of improvement I

Second jump disappears with an unimproved action!





effect of improvement

- The Transfer matrix of a Symanzik improved lattice gauge action is no longer Hermitean. (Luscher, Weisz 1984).

- The appearance of complex eigenvalues opens up the possibility of the emergence of new phases.

- Where and how these phases appear will depend on the specifics of the improvement being used.

effect of improvement II

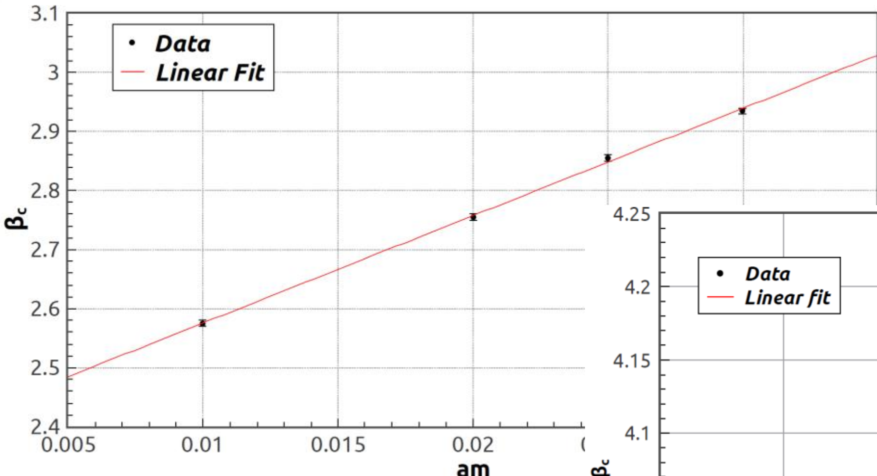
- In our specific case, the exotic phase will appear as a consequence of the competition between nearest and third nearest interactions introduced by Naik improvement.

- But this is a general feature of improved theories at strong coupling and such exotics may be observed by other groups using different actions (e.g. maybe the S^4 broken phase observed by A. Hasenfratz et al.).

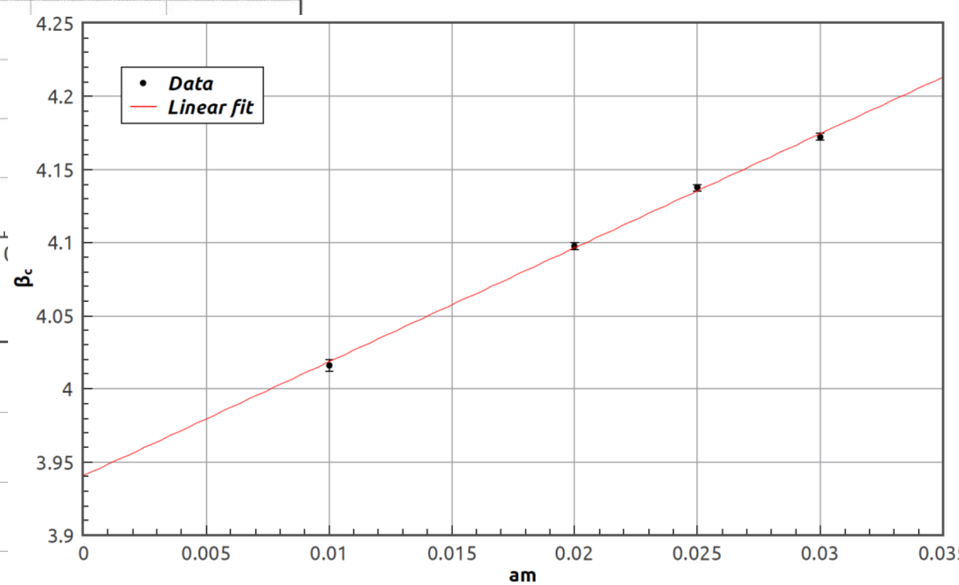
- Since our studies on chiral symmetry restoration were carried at weaker couplings these results are not affected by this exotic.

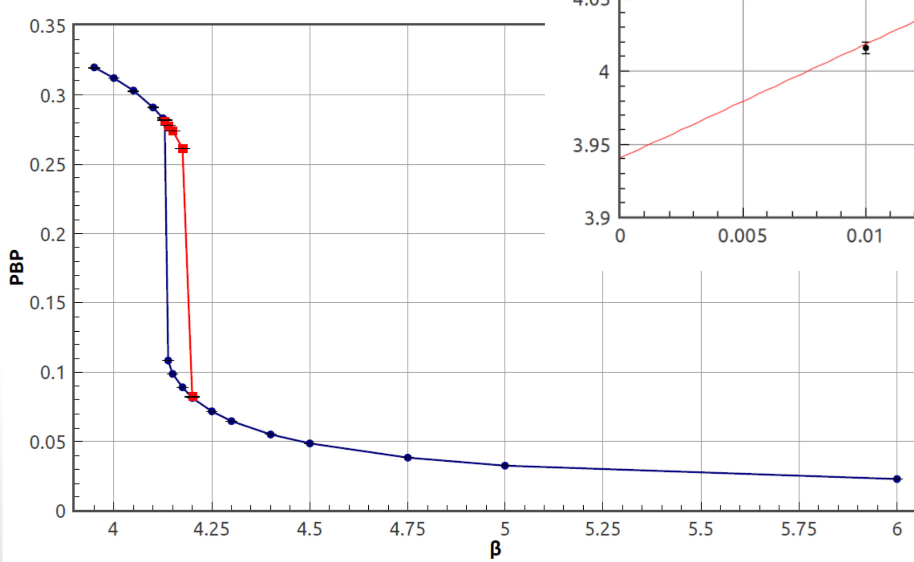
order of the transition

gauge + fermion improved action



naive action





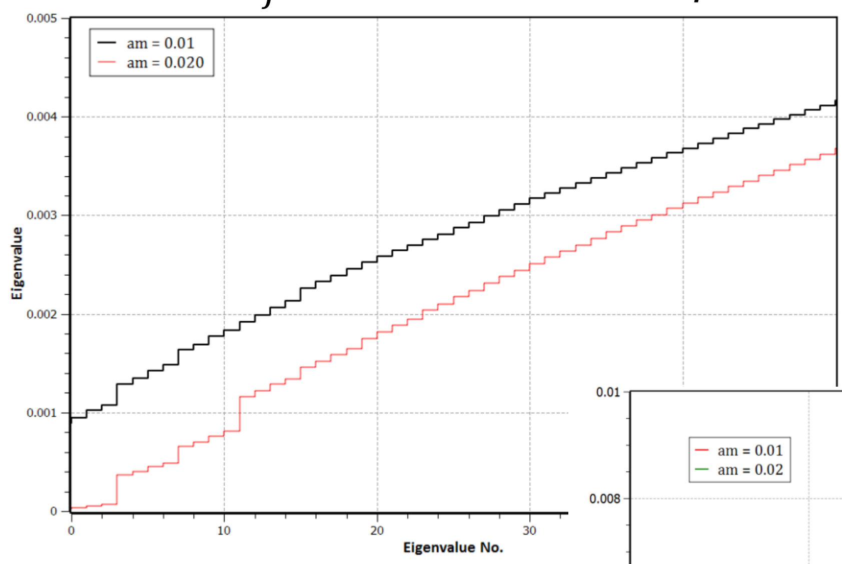
work in progress

- New ensembles with $N_f = 12, 16$ at volumes up to 32x32 are under study.

- Study of the eigenvalues and update on the study of the spectrum.

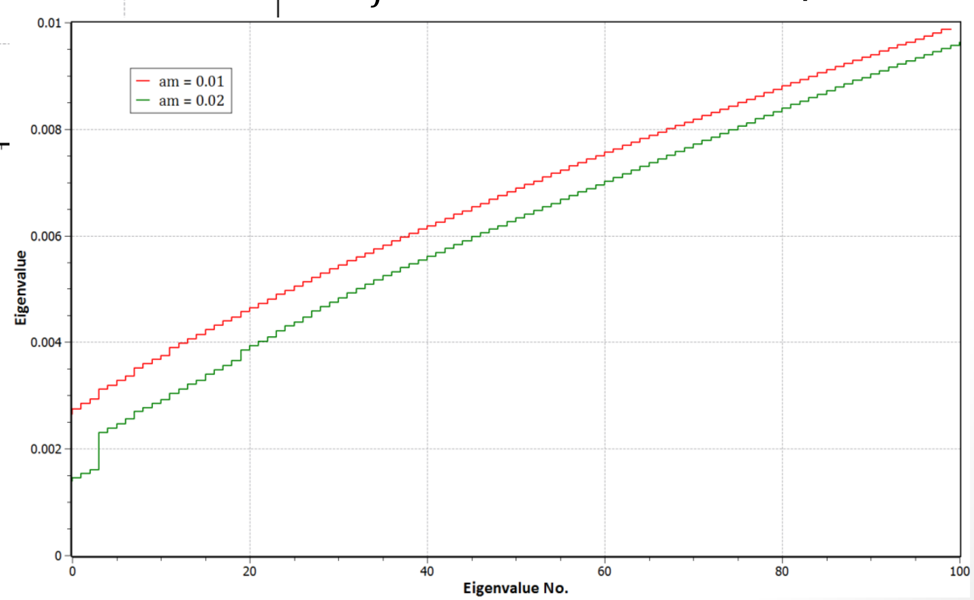
work in progress: mass dependence of eigenvalues

$N_f = 12, V = 32 \times 32, \beta = 3.900$

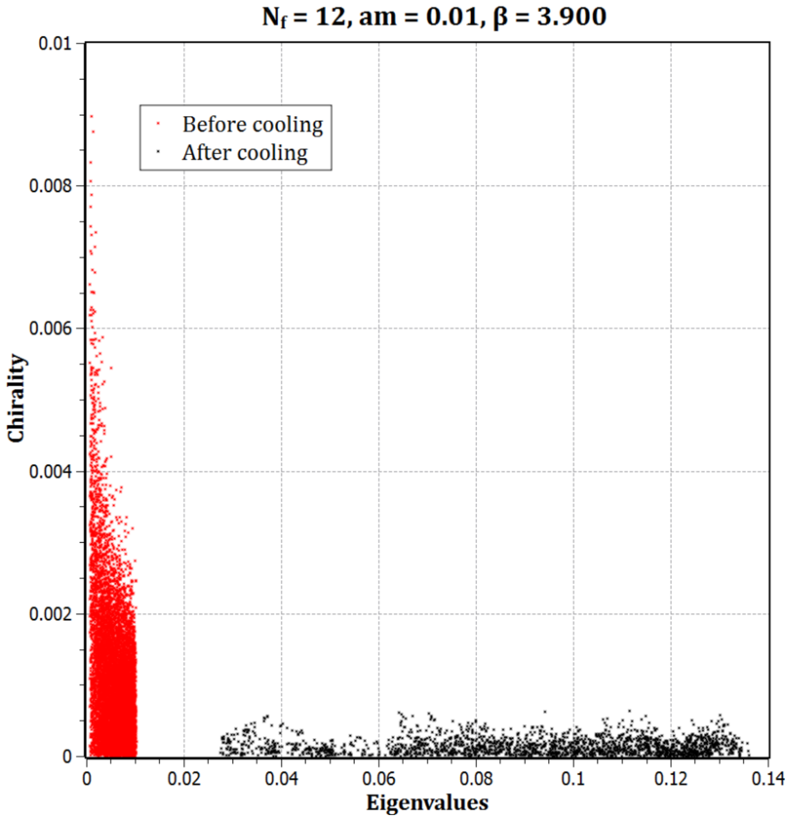


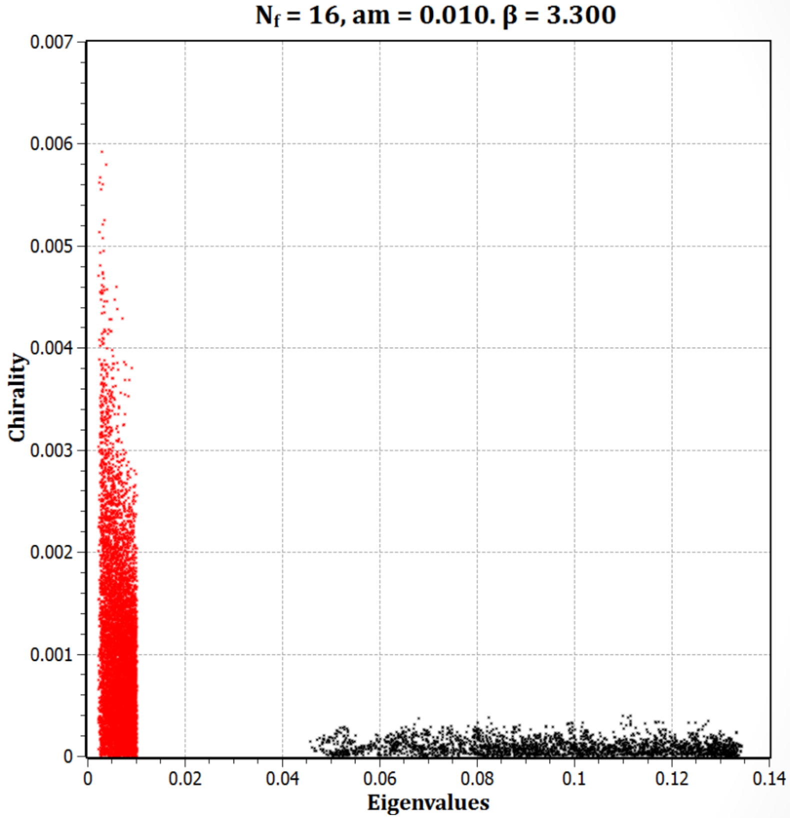
No zero modes!

$N_f = 16, V = 32 \times 32, \beta = 3.300$



work in progress: chirality





Smearing pushes eigenvalues to higher values and suppresses chirality

mass ratios

QCD :

$m_\pi \propto \sqrt{m_q}$

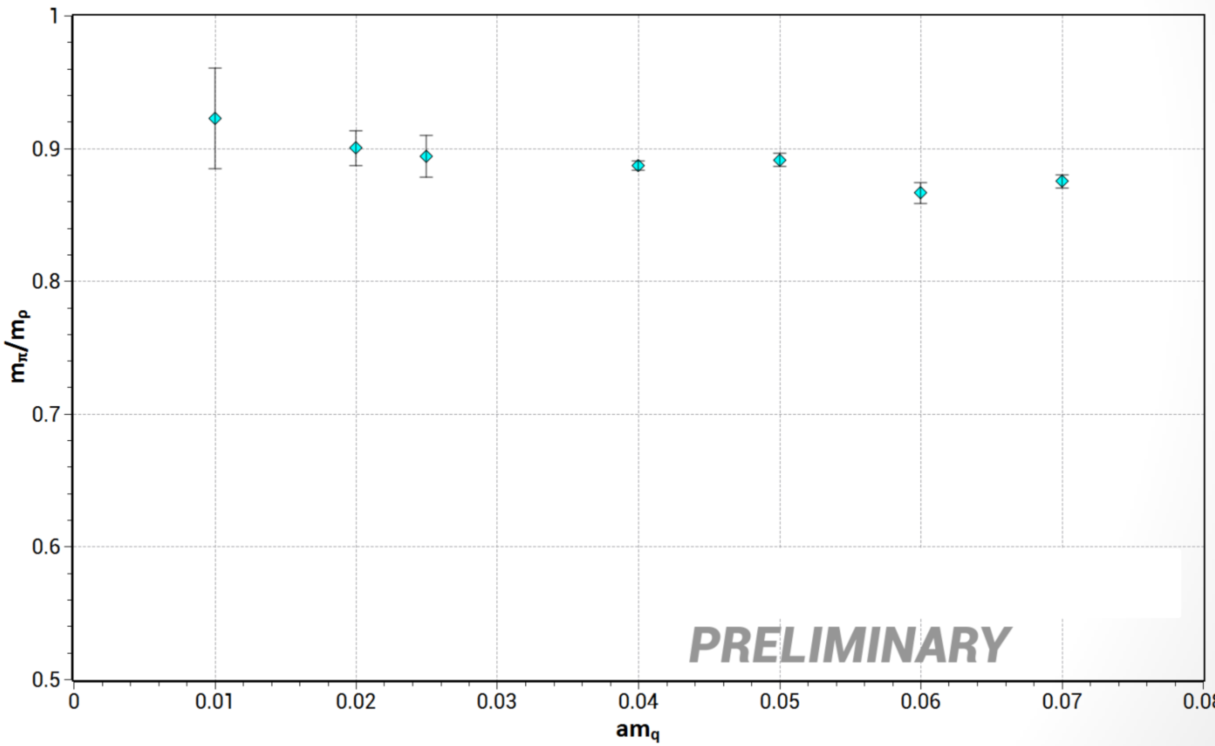
$m_\rho \propto m_0 + bm$

$\frac{m_\pi}{m_\rho} \propto \sqrt{m_q}$

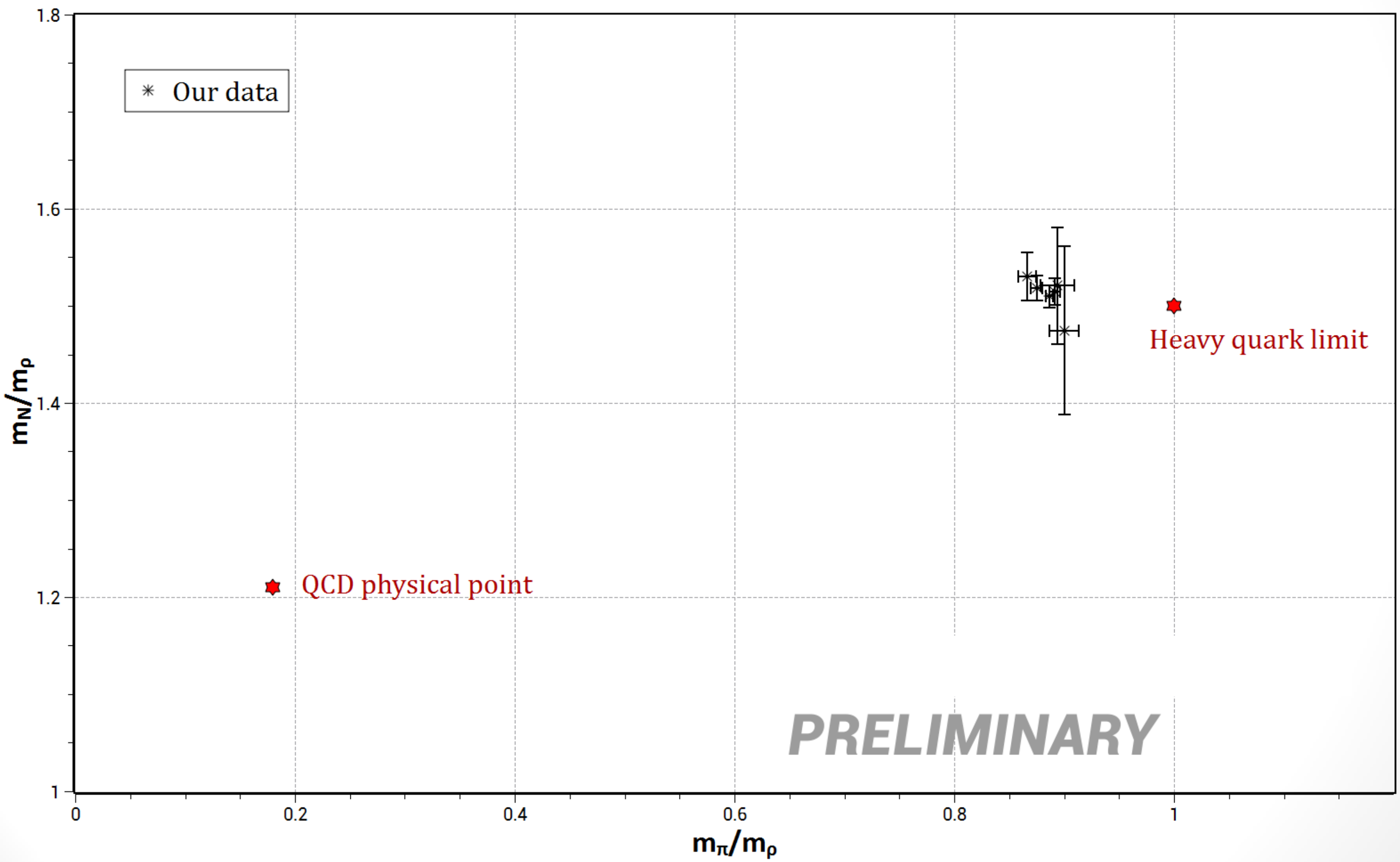
Conformal:

$m_\pi \,\&\, m_\rho \propto m^\alpha$

$\frac{m_\pi}{m_\rho} \approx 1$



the Edinburgh plot



conclusions and outlook

- Our results are consistent with an conformal window opening below $N_f = 12$.
- Improved lattice theories might develop exotic phases at strong coupling
- Final analysis on the way -> stay tuned!
- Thank you!

backup – CPB scaling

$$k_{\mathrm{SB}} \propto k_0\, \theta(N_f^{\mathrm{cr}} - N_f)\, |N_f^{\mathrm{cr}} - N_f|^{-1/\Theta} \exp\left(- \frac{\pi}{2\epsilon\sqrt{\alpha |N_f^{\mathrm{cr}} - N_f|}} \right)$$

power-law
(due to running coupling)

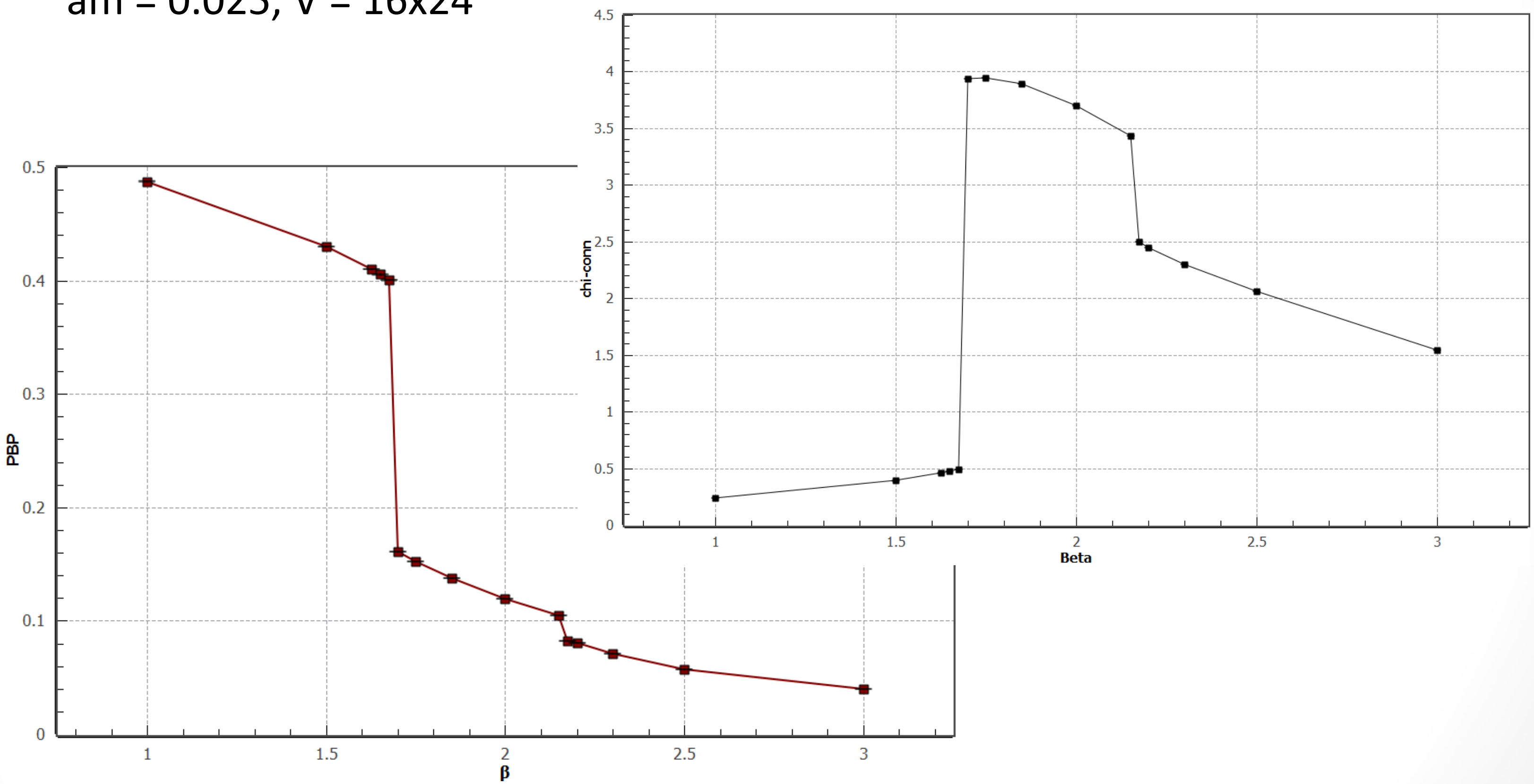
exponential-law
(Miransky-KBT scaling)

$\bar{\psi}\psi$,T_c

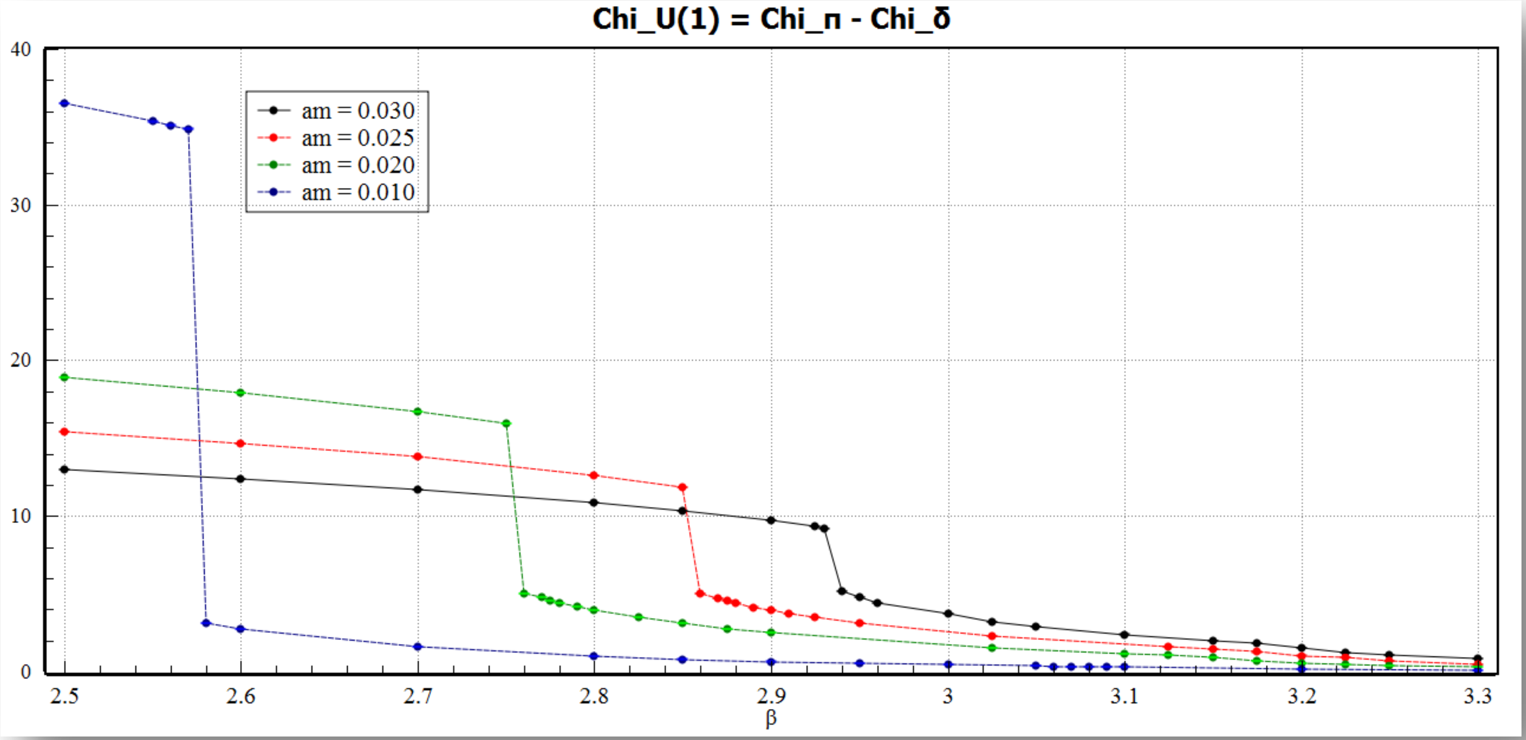
$$\beta(g^2) = -\Theta(g^2 - g_\star^2) + \ldots \quad \Theta < 0$$

backup – bulk $N_f = 16$

SU(3) with $N_f = 16$,
am = 0.025, V = 16x24



backup – chi_U(1)



backup - improvement

- Consider the free lattice fermion propagator:

$$S_F(p)^{-1} = \sum_\mu i\gamma_\mu \left(\frac{9}{8} \sin p_\mu - \frac{1}{24} \sin 3p_\mu \right)$$

- Contributions from the interacting theory can modify the coefficients of each sine term.

- In particular, a change in the sign of the second term will induce imaginary poles and ghosts and signal the emergence of the exotic phase.

backup - improvement

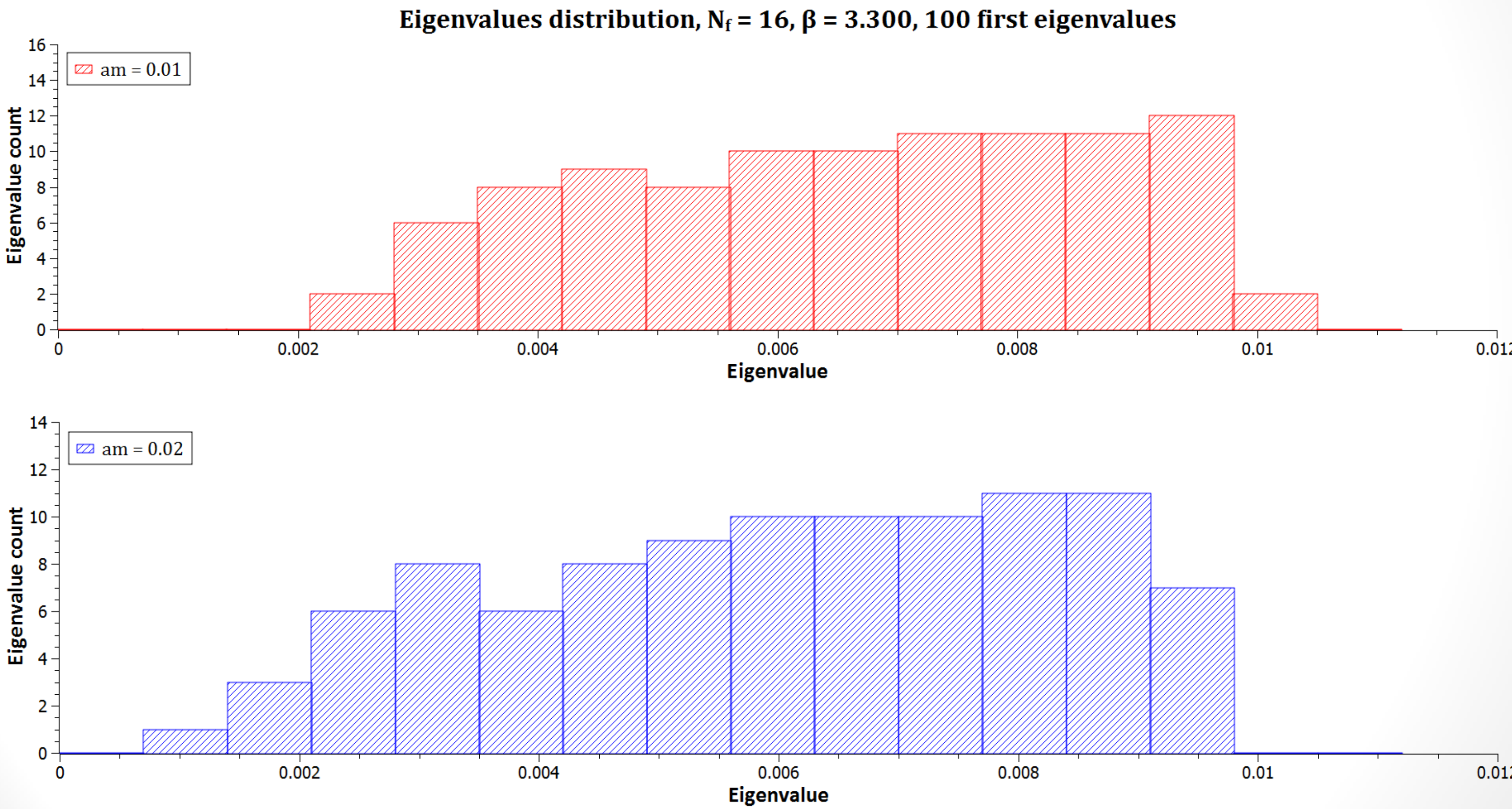
- Baryon number density will receive contributions from nearest and third nearest interactions:

$$n(\mu) = \frac{d}{d\mu} \log Z(\mu) = n_1(\mu) + n_3(\mu)$$

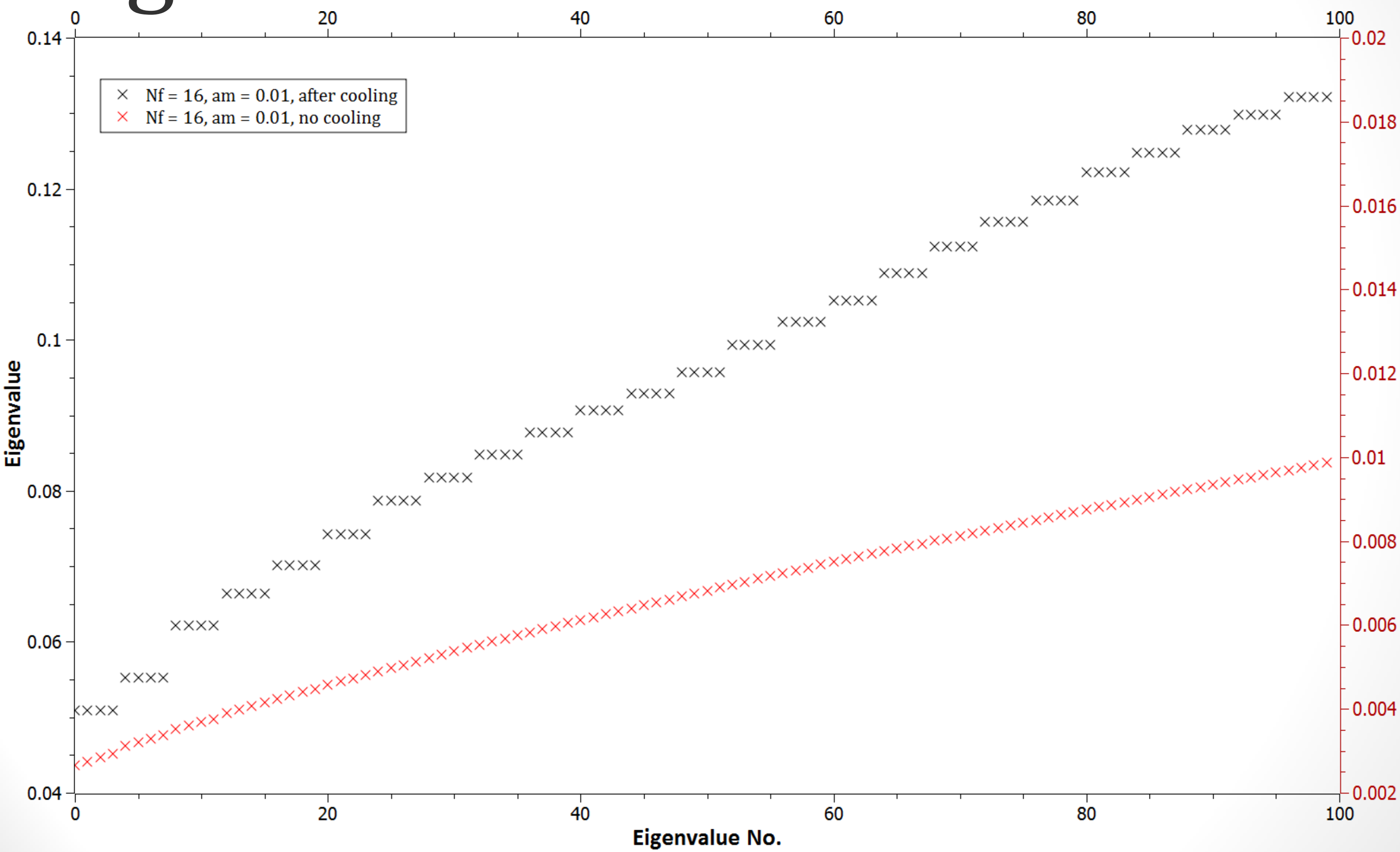
- Baryon number conservation at $\mu = 0$ can be realized with $n_1 = n_3 = 0$ or with $n_1 = -n_3 \neq 0$.

- At strong coupling, when third nearest interactions become relevant, the second realization is possible. A non-zero value of $n_1(\mu)$ allows for both an oscillation term in the PS correlator and the time asymmetry in all correlators.

backup I – eigenvalue distribution



backup II – cooling effect on eigenvalues



backup - relation to chiral condensate