QCD thermodynamics with two-flavours of Wilson fermions on large lattices

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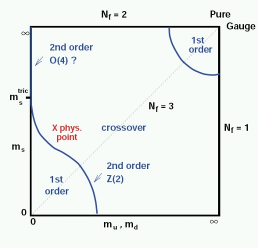
Contents

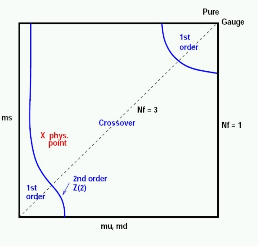
1. Motivation:

The $N_f = 2$ chiral transition

The $N_f = 2$ chiral transition – Scenarios

Two possible scenarios:





2nd order transition
– $O(4)$ universality

1st order transition

The $N_f = 2$ chiral transition – A challenging case

- Quark mass must be close enough to the chiral limit to show the right scaling behavior.

  $\Rightarrow$ Necessary $m_\pi \leq$300 MeV at least

- Discretisation effects can be expected to be severe for finite T simulations. (See long time discrepancy between staggered results)

  $\Rightarrow$ Use $N_t \geq 12 - 16$ for Wilson fermions.

  [Philipsen and Zeidlewicz (2010), arXiv:0812.1177]

- Control finite size effects.

  $\Rightarrow$ Use several volumes with idealy $N_s/N_t \geq 3$.

To disentangle causes for violations of critical scaling:

$\Rightarrow$ **Need to separate different systematic effects!**

The $N_f = 2$ chiral transition – Status

- **$N_f = 2$ Staggered fermions:**
  Some studies, but all with $N_t \leq 6$ [e.g. Bonati *et al* arXiv:0901.3231]
  $\Rightarrow$ Contradictory results: $O(2)/O(4)$ ruled out by newer studies.
  Trustworthy for the task at hand? (Rooting? Taste breaking? ...)
- **Twisted mass Wilson fermions:** [tmft arXiv:1102.4530]
  $N_t \leq 12$ and $m_\pi \gtrsim 300$ MeV
  $\Rightarrow$ not conclusive – $O(4)$ scenario more likely
- **$\mathcal{O}(a)$-improved Wilson fermions:** [QCDSF/DIK arXiv:1102.4461]
  $N_t \leq 14$ and 1 at $m_\pi = 200$ MeV, others $m_\pi \gtrsim 350$ MeV
  $\Rightarrow$ not conclusive – points towards $O(4)$
- **Domain wall fermions:** [HotQCD arXiv:1205.3535]
  $N_t = 8$, $V = 16^3$, single quark mass, $m_\pi = 200$ MeV
- **$N_f = 2 + 1$ staggered:** [HotQCD arXiv:1111.17.10]
  Signs for $O(2)$ scaling already for physical strange quark masses.

$\Rightarrow$ **Picture is not conclusive!**

2. Simulation setup

Action and scale setting

Action: Non-perturbatively $\mathcal{O}(a)$-improved Wilson fermions
Wilson plaquette gauge action

Algorithms: deflation accelerated DD-HMC [Lüscher (2004-2005), e.g. hep-lat/0509125]
MP-HMC with DFL-SAP-GCR solver
[Marinkovic and Schäfer (2010), arXiv:1011.0911]

$\Rightarrow$ Good scaling properties with volume and quark masses.

Scale setting: r_0 in the chiral limit as determined by CLS
[Donnellan *et al*, arXiv:1012.3037; Fritzsch *et al*, arXiv:1205.5380]

Mass scale: PCAC mass converted to $\overline{\text{MS}}$ scheme
[ALPHA, hep-lat/0507035]

Pion masses: Conversion via continuum χPT [B.B., A. Jüttner, H. Wittig, to be published]

Renormalisation: Interpolation of ALPHA results as used within CLS.

Temperature scan setup

Basic strategy:

- Use $N_t = 16$ for all scans.
- Use 3 different volumes: 32^3, 48^3 and 64^3
  (enables a finite volume scaling study; control FS effects)
- at least 3 different pion masses below $m_\pi \leq$300 MeV
  (ideally even below the physical point)
- We scan in β:
  - First attempts: keep κ fixed
    $\Rightarrow$ Quark mass changes along the scan
    (is problematic for Wilson fermions at small quark masses)
  - Now: Keep renormalised quark mass fixed!
    $\Rightarrow$ Line of constant physics (LCP)
    (conceptually much cleaner)

Observables

Chiral transition:

- Chiral condensate $\langle\bar{\psi}\psi\rangle$ (subtracted and bare)
  Order parameter of the transition in the chiral limit.
  (Problematic due to additive and multiplicative renormalisation)
- Screening masses in various channels
  Sensitive to chiral symmetry restoration.

Deconfinement:

- Polyakov loop L
  Order parameter of the transition in the pure gauge limit.
- Quark number susceptibility χ_q
  Measures the net number of quarks.

In addition: Associated susceptibilities and Binder cumulants.

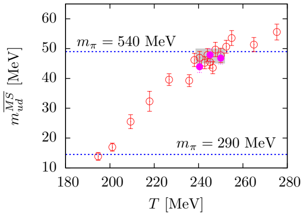
3. Status and strategy adjustment

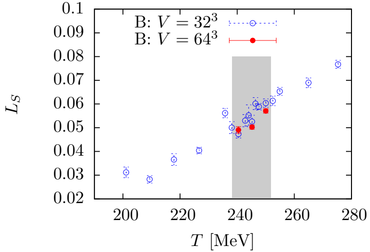
β-scans at fixed κ

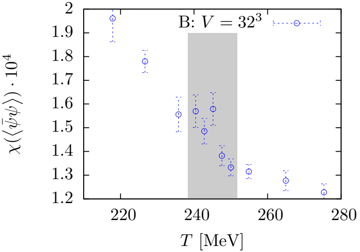
So far two $N_t = 16$ scans:

- **B**: $\kappa = 0.136500$ (Test scan)
  $m_\pi \approx 540$ MeV at T_C
- **C**: $\kappa = 0.136575$
  $m_\pi \approx 290$ MeV at estimated T_C

Two volumes: 32^3 and 64^3







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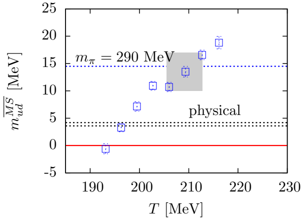
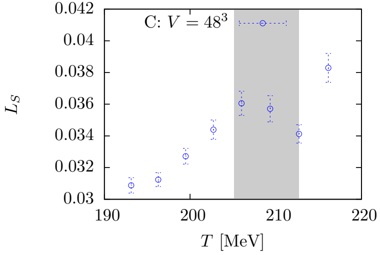
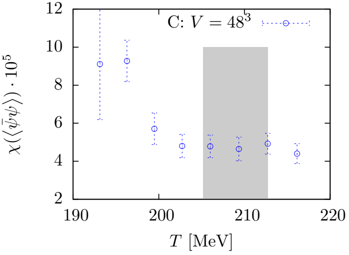
One volume: 48^3







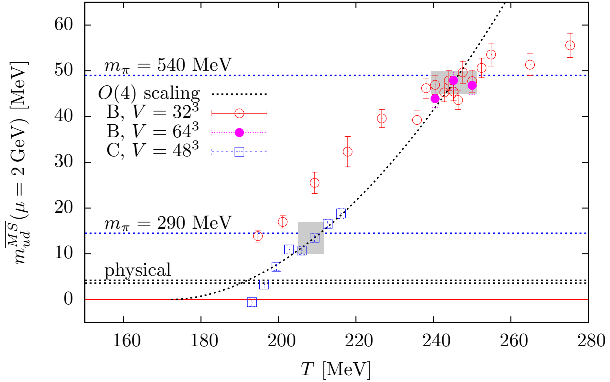
β-scans at fixed κ

Looks good at first!

But as usual:

The devil is in the details!!!

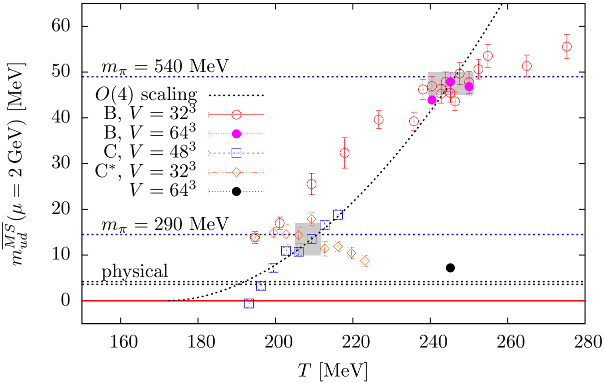
Scaling and simulations in the chiral regime



Curve: $T_C(m_q) = T_C(0)\left(1 + C\, m_q^{1/(\delta\beta)}\right) \quad \Leftarrow \quad$ (naive $O(4)$ scaling)

Scanning along lines of constant physics

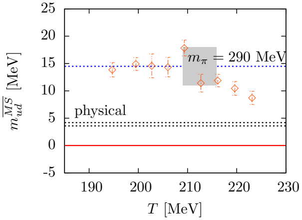
Change the setup: ⇒ **Scan along LCPs**



(LCP not perfect above $T = 210$ MeV due to recent updates on $T = 0$ results)

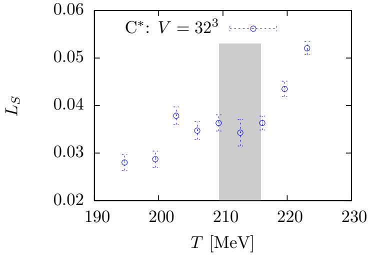
β-scans at LCP

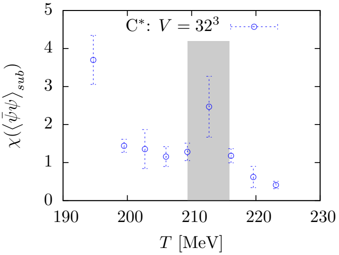
- **C***: LCP at $m_\pi \approx$290 MeV



Preliminary results!

(Statistic: ~3000 MD-units
— approx. 10–30%)





4. Screening masses and chiral symmetry restoration

Screening masses and chiral symmetry

Channels for screening masses:

scalar (isovector)	–	S	vector	–	V
pseudoscalar	–	P	axial vector	–	A

Interesting symmetries: (for us)

- $V \xleftrightarrow{SU_A(2)} A$
- $S \xleftrightarrow{SU_A(2)} P$

Degeneracy signals chiral symmetry restoration!

[see e.g.: Cheng *et al*, arXiv:1010.1216; HotQCD, arXiv:1205.3535]

β-scans at LCP

- **C***: LCP at $m_\pi \approx$290 MeV

Preliminary results!

(Statistic: ∼3000 MD-units
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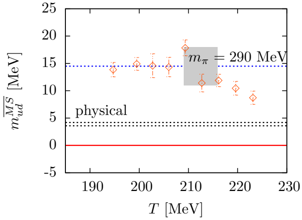

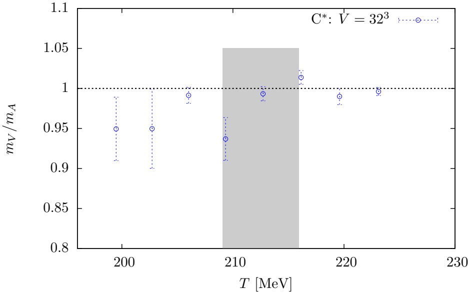

β-scans at LCP

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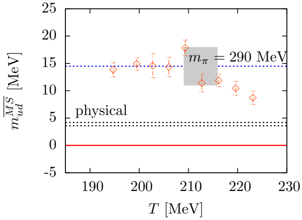
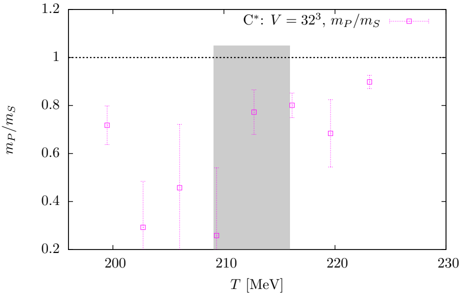




5. Spectral representation of correlation functions

Temporal vector and axial vector correlation functions

[for an overview see e.g.: Ding *et al*, arXiv:1012.4963]

Temporal vector and axial vector correlation functions (at zero momentum) obey the spectral representation

$$G_H(t, T) = \int_0^\infty \frac{d\omega}{2\pi} \, \rho_H(\omega, T) \, \frac{\cosh(\omega \, [t - 1/(2T)])}{\cosh(\omega/(2T))} \; .$$

The associated spectral function ρ_H encodes information about plasma properties.
(electrical conductivity, thermal dilepton rate, ...)

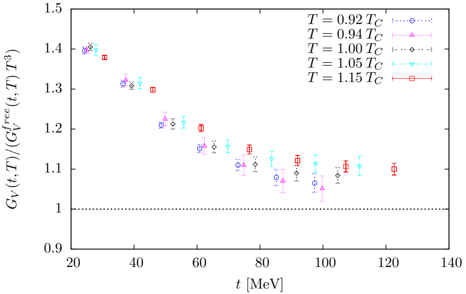
Difficult to extract:

- Needs to be very close to the continuum ($N_t \geq 16$ at least).
- Sufficient control over finite size effects.

Our 16×64^3 lattices might be at the lower border of what is necessary to be able to extract information.

Results on G_V and G_A along the LCP

Normalised by the free continuum correlation function.



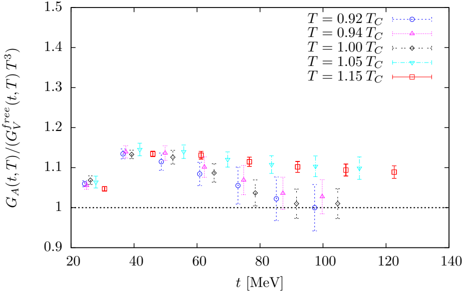
See a flattening for $T > T_C$.

$\Rightarrow$ Appearance of transport properties.

(Encoded e.g. in the slope around $t = T/2$)

Results on G_V and G_A along the LCP

Normalised by the free continuum correlation function.



Similar behavior as in the vector case (at large t).

G_V and G_A move closer together for large t above T_C.

$\Rightarrow$ Chiral symmetry restoration!

Conclusions and perspectives

- The finite temperature project in Mainz aims to extract the order of the $N_f = 2$ chiral transition with controlled systematics using lattices of size 16×32^3, 16×48^3 and 16×64^3.
- We have readjusted our strategy and started to perform scans along lines of constant physics with $m_\pi \leq 300$ MeV.
- We measure screening masses in different channels to investigate the chiral symmetry restoration pattern and the strength of the $U_A(1)$-anomaly.
- In addition, we are interested in quantities that are related to plasma properties.
- I presented first results for vector correlators on large lattices with dynamical fermions that might allow to extract information about the associated spectral function.
- Simulation with yet lighter quarks are planned for the next year ...

Thank you for your attention!