On the strength of the QCD crossover at small chemical potentials

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Introduction

The QCD transition at $\mu_B = 0$ was shown to be a crossover using finite volume scaling on continuum extrapolated lattice results in Ref. [1].

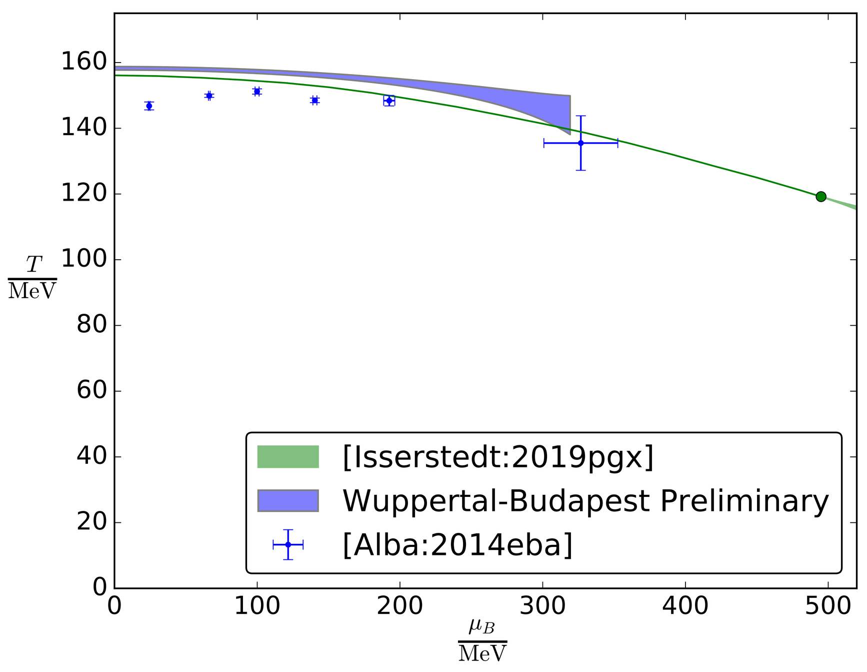
For the temperature for the chiral transition one has found 150-160 MeV, depending on the observable [2, 3, 4, 5].

This temperature has a mild chemical potential dependence

$$T(\mu_B) = T_c\left(1 - \kappa_2\left(\frac{\mu_B}{T}\right)^2 + ...\right)$$

with $\kappa_2 = 0.015(2)$ [6, 7, 8, 9].

This plot shows the Wuppertal-Budapest group's preliminary result on the transition line.



I. Chiral observables

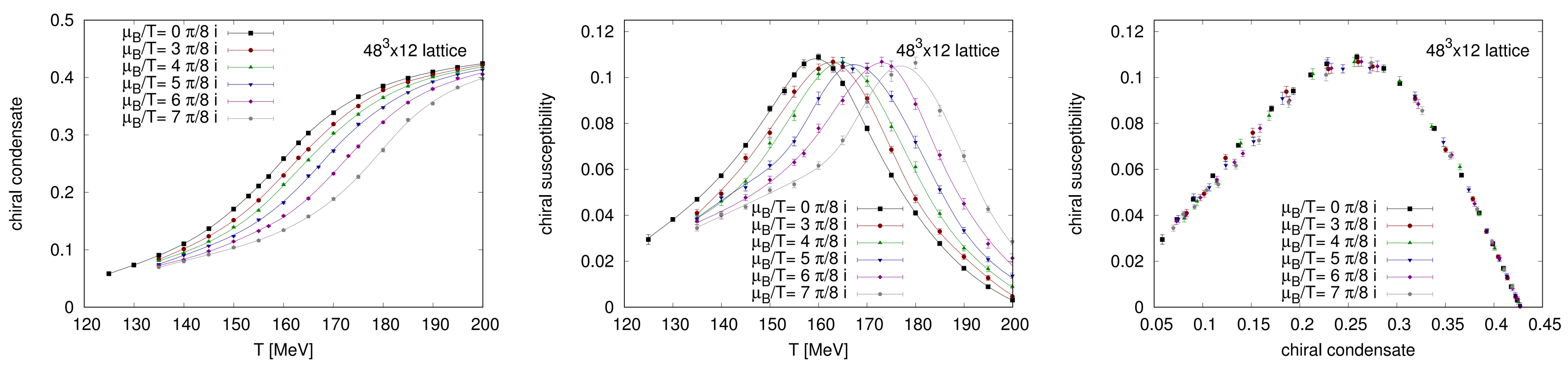
The chiral condensate works as an order parameter of the chiral transition. Our renormalized condensate is understood relative to $T = 0$.

$$\langle\bar\psi\psi\rangle_R = -N_f\left[\langle\bar\psi\psi\rangle_T - \langle\bar\psi\psi\rangle_0\right]\frac{m}{X^4} \tag{1}$$

The susceptibility peaks at the transition temperature.

$$\chi_R^{\bar\psi\psi} = -N_f\left[\chi_T^{\bar\psi\psi} - \chi_0^{\bar\psi\psi}\right]\frac{m^2}{X^4} \tag{2}$$

Here m is the light quark and X the pion mass.

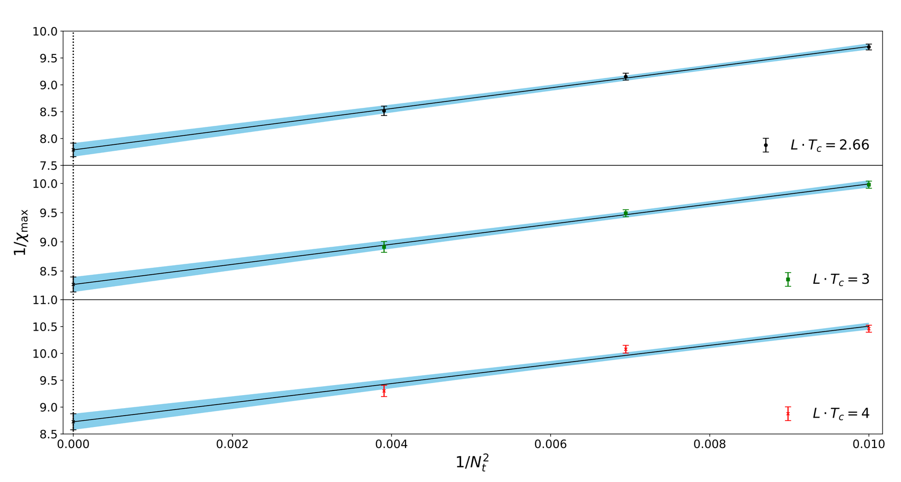


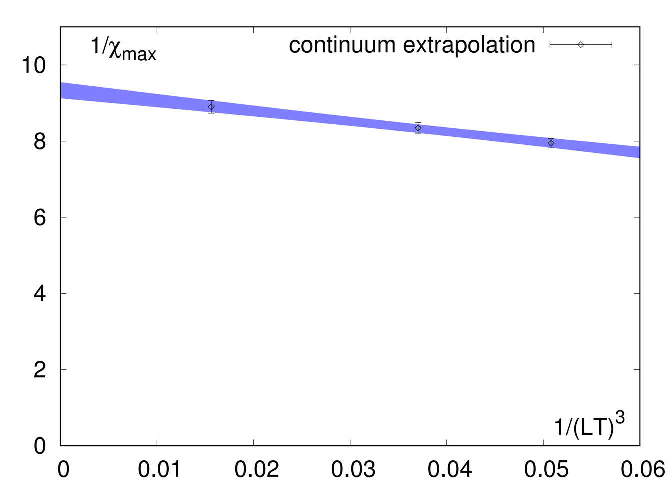
II. Crossover at $\mu = 0$

We reproduce the result of Ref. [1] on finer lattices $N_\tau = 16, 12$ and 10. Analysis procedure to obtain T_c:

1) Continuum extrapolation of $\chi^{-1}_{\max}$ at fixed physical volume

2) Finite volume scaling of the continuum $\chi^{-1}_{\max}$, with $LT_c \in \{2.67, 3, 4\}$





We determine the transition temperature in the infinite volume limit from the L dependence of the peak position of the chiral susceptibility.

$$T = a + \frac{b}{(LT_c)^3} + \frac{c}{N_t^2} + \frac{d}{(L\cdot T_c)^3 N_t^2} \tag{3}$$

1) The maximum of $\chi(\langle\bar\psi\psi\rangle)$ is located $\longrightarrow \langle\bar\psi\psi\rangle_c$

2) T_c is the solution of the equation: $\langle\bar\psi\psi\rangle(T) = \langle\bar\psi\psi\rangle_c$

We find: 159.7±0.6 MeV at $LT \to \infty$

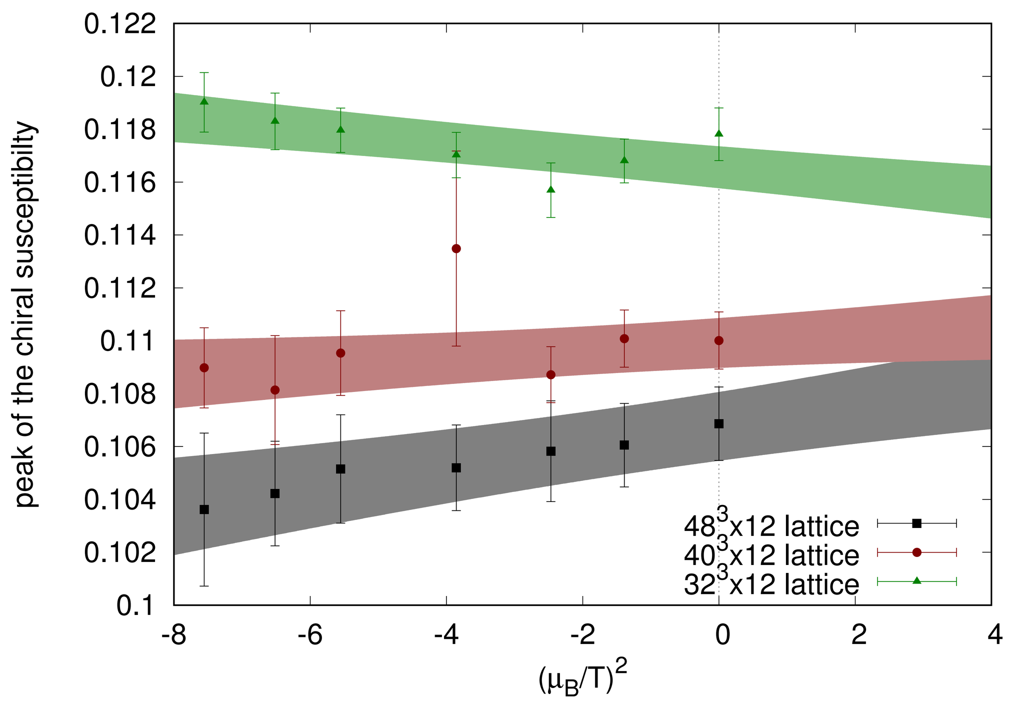
[systematics of isospin symmetry breaking is not included].

See also: 156.5±1.5 MeV at $LT = 4$ [9] and 157±4 MeV at $LT = 3$ [3].

III. Finite volume scaling at imaginary μ_B

At finite μ_B direct simulations are prohibited by the sign problem. At imaginary μ_B (i.e. $\mu_B^2 < 0$) there is no sign problem. We attempt an analytical continuation from imaginary to real μ_B.

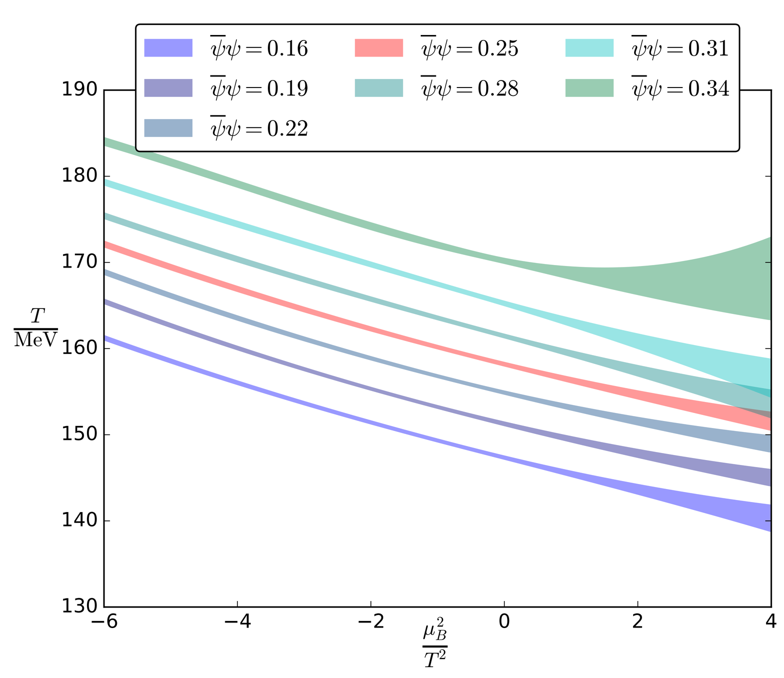
Using a finite lattice resolution $N_\tau = 12$ we calculated the $\chi_{\max}$ in three volumes in a broad range of imaginary chemical potentials.

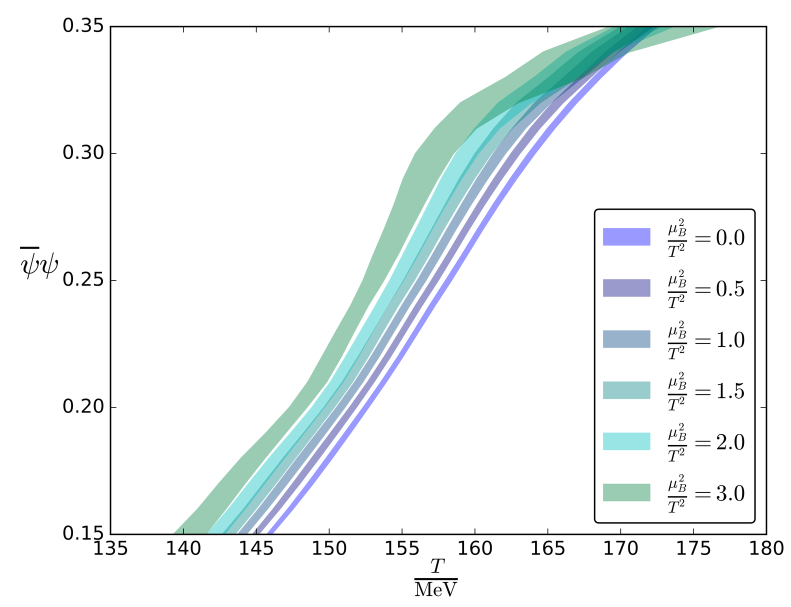


The volume dependence of $\chi_{\max}$ changes slowly with the chemical potential. The strength of the transition rises very weakly with μ_B.

IV. Extrapolation of the condensate

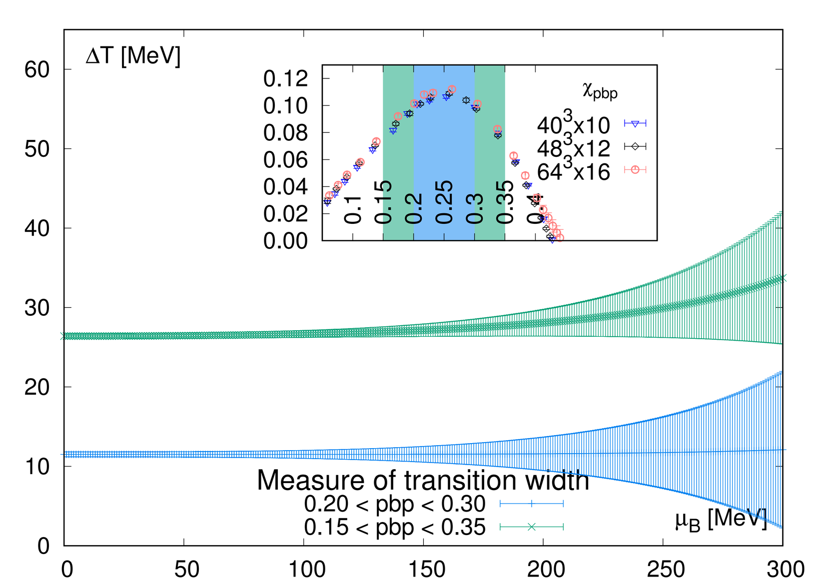
We continuum extrapolated the chiral condensate and extrapolated to real chemical potential. Technically, we calculated the temperatures for each $(\mu_B/T)^2$ where a certain value of the condensate is taken. E.g. near T_c we have $\langle\bar\psi\psi\rangle \approx 0.25$.





The increase of the slope of the condensate is not significant.

V. Width of the transition at finite μ_B



We define a measure for the width of the transition: the temperature difference between a high and a low value of the condensate (two choices are shown). The width is then extrapolated (both in μ_B and continuum). The width of the transition is constant up to $\mu_B \lesssim 200$ MeV.

References

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