Phase Diagram of QCD with HYP Staggered Fermions

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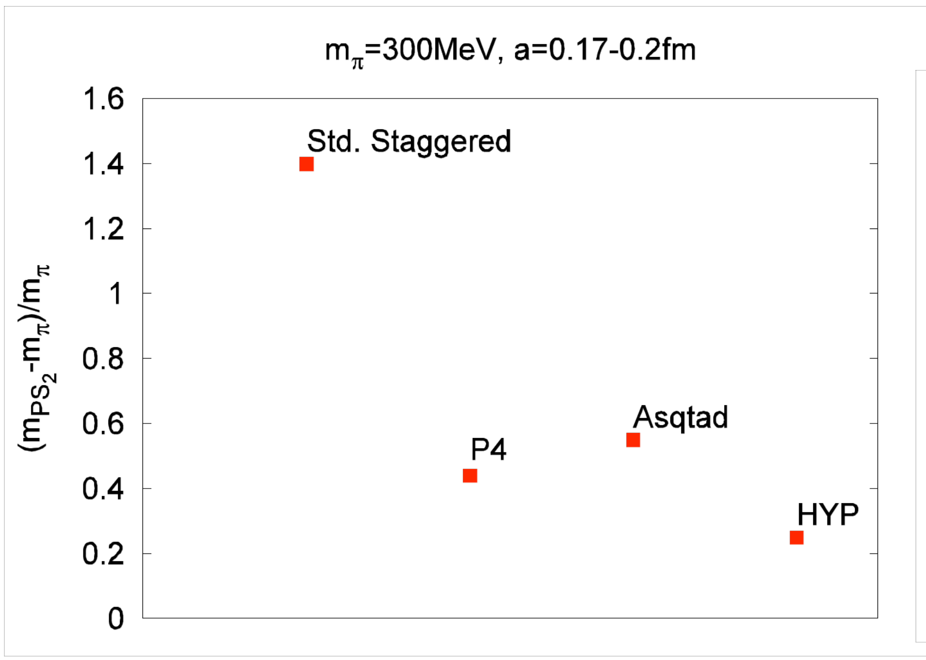
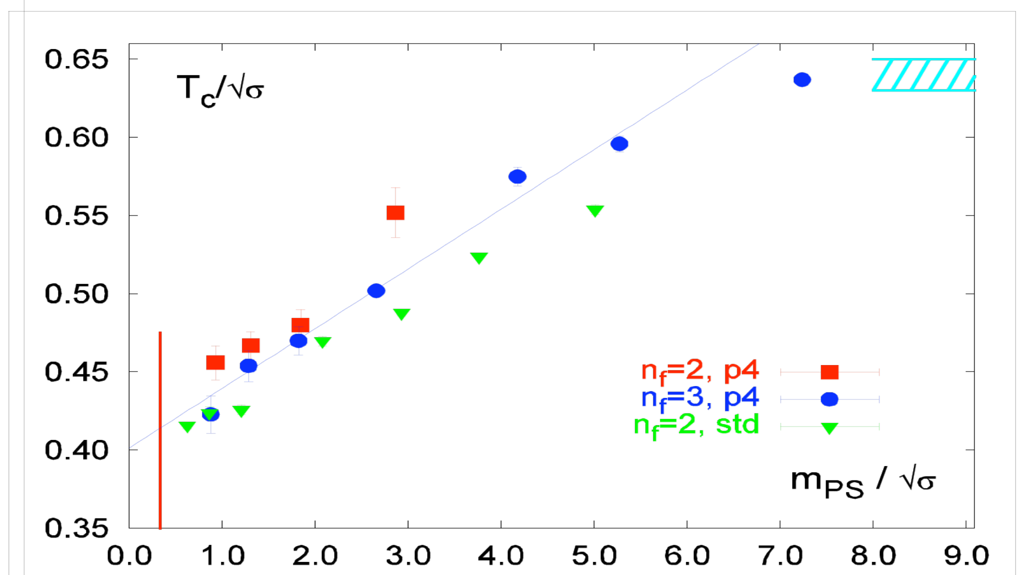
What is the nature of the transition to the deco fined phase of QCD for the physical values of the quark masses and what is value of the corresponding temperature ?

Problems: flavor symmetry breaking $SU(3)_V \times SU(3)_A \to U(1) \times SU(3)_A$

quark mass dependence of the properties of the transition





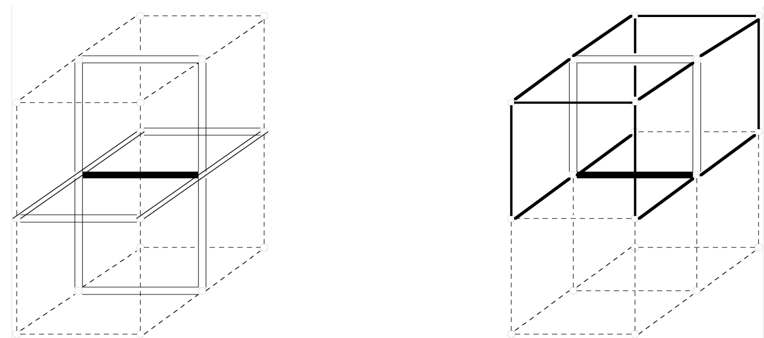
Staggered HYP Action

$$S = -\beta \sum_P \frac{1}{3} \mathrm{Re}\, Tr U_p + \sum_x m \bar{\psi}_x \psi_x + \frac{1}{2} \sum_{x,\mu} \eta_\mu(x) \left(\bar{\psi}_x U_\mu^{fat}(x) \psi_{x+\mu} - \bar{\psi}_x U_\mu^{fat+}(x) \psi_{x-\mu} \right)$$

$$\beta = 6 / g^2$$

$$U_\mu^{fat}(x) = \mathrm{Proj}_{SU(3)} \Big\{ a_i U_\mu(x) + b_i \sum_{\pm\nu \neq \mu} \bar{V}_\nu(x) \bar{V}_\mu(x+\nu) \bar{V}_\nu^{+}(x+\mu) \Big\},$$

$$V_\mu(x) = U_\mu(x), \quad U_\mu^{APE}(x)$$



Because of SU(3) projection the widely used R-algorithm is not applicable → partial stochastic Metropolis: HB and OR update with pure gauge action in small sub-volumes + global Acc/Reject step with fermion action.

Simulation costs increase at most as m^{-1} compared to $m^{-2.5}$ increase for the R-algorithm

Simulation parameters

Simulations were done on $N_\sigma^3 \times N_\tau$ lattices for $\beta = [4.2 : 5.7]$

$$N_\tau = 4, \quad N_\sigma = 6,\ 8,\ 12$$

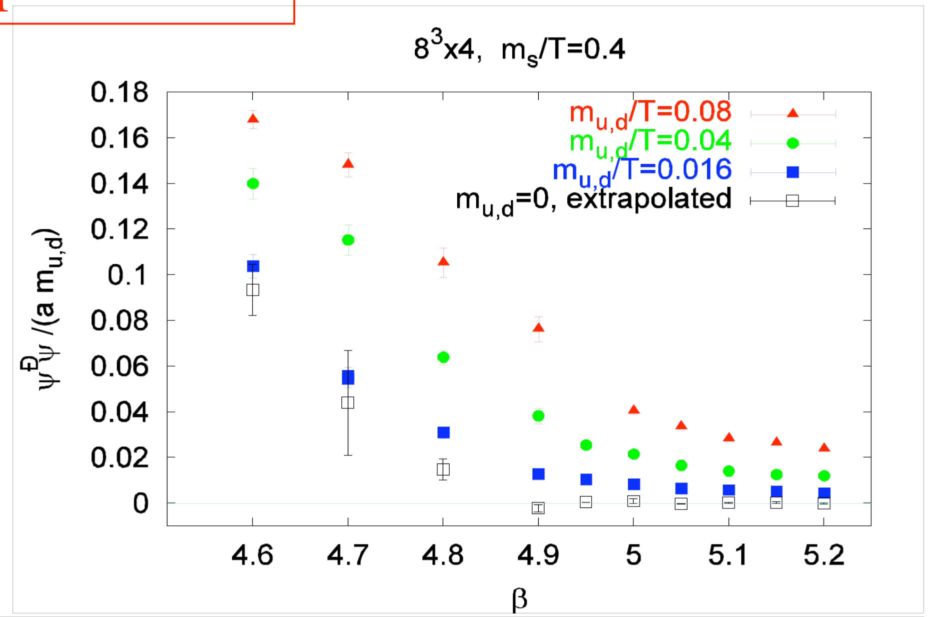
$$N_\tau = 6, \quad N_\sigma = 8,\ 10$$

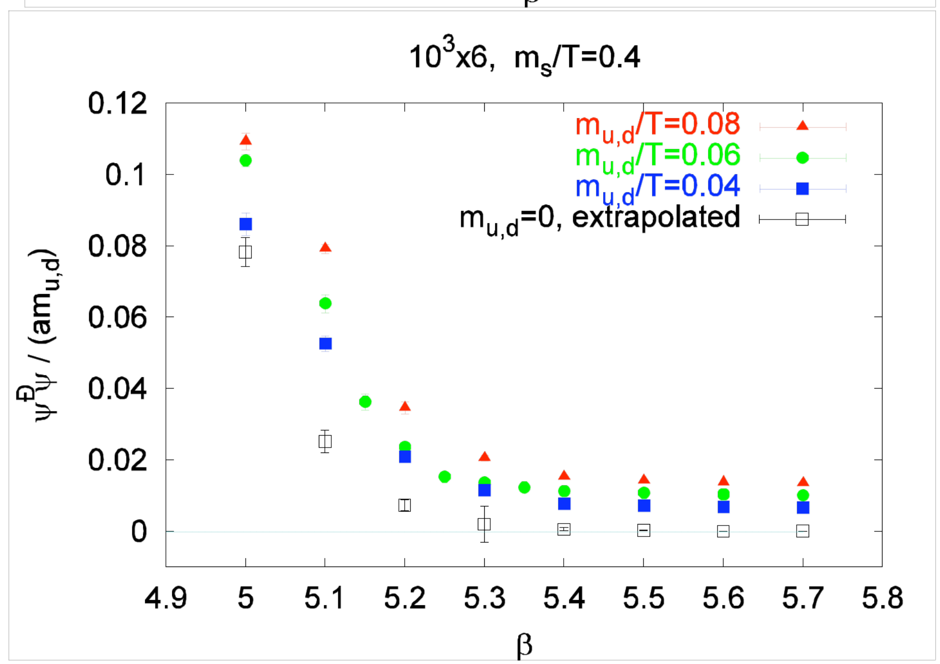
$$m_s / T = 0.4 \approx m_s^{phys} / T;$$

$$m_{u,d} / T = 0.08,\ 0.06,\ 0.04,\ 0.016$$

$$m_{u,d} = 0.016T \approx m_{u,d}^{phys}$$

The system in the deconfined phase for $\beta > 4.9$, $N_\tau = 4$ and for $\beta > 5.3$, $N_\tau = 6$





Setting the scale

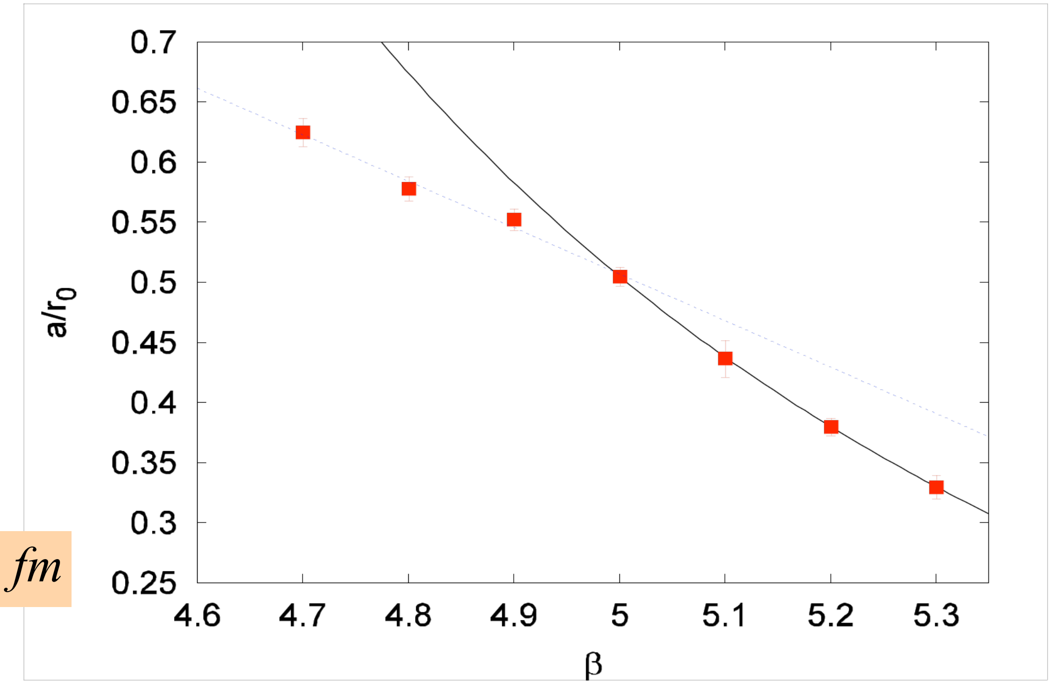
The lattice spacing is set by the Sommer scale r_0 defined as

$$\left. \frac{dV(r)}{dr} \right|_{r=r_0} = 1.65$$

$$a / r_0 = c_0 \, R(\square) \cdot (1 + c_2 \, R^2(\square))$$

2-loop beta function

from the MILC collaboration： $r_0 = 0.467(11)\, fm$



$\square = 5.0$ $\quad \frac{m_{\square ss}}{m_{\square}} = 0.615 \square 0.620 \pm 0.006$

$$m_{\square} = 423(7)\text{MeV}, \; m_{\square} / m_{\square} = 0.454(17)$$
$$m_{\square} = 302(5)\text{MeV}, \; m_{\square} / m_{\square} = 0.365(11)$$

$\Rightarrow$ $m_{\square} \square 130\text{MeV}$

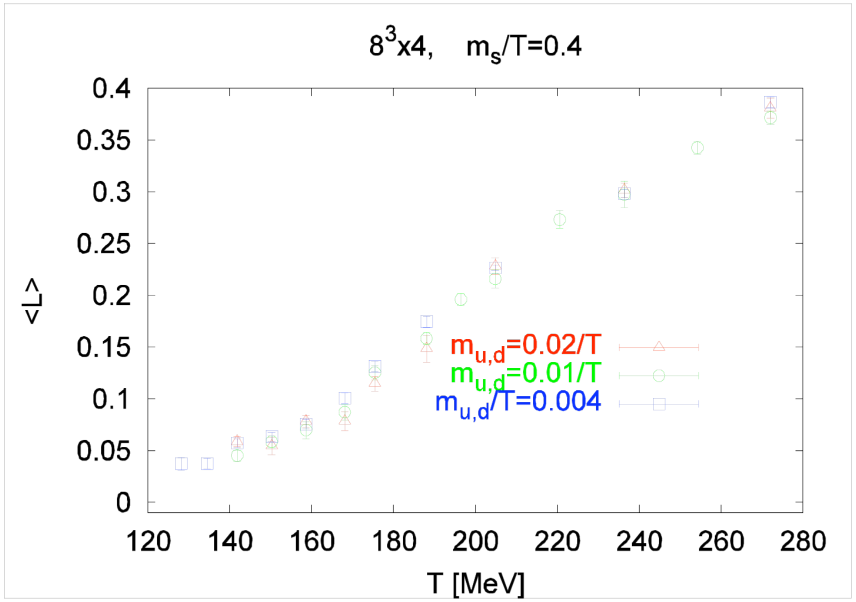
$for \;\; m_{u,d} / T = 0.0016$

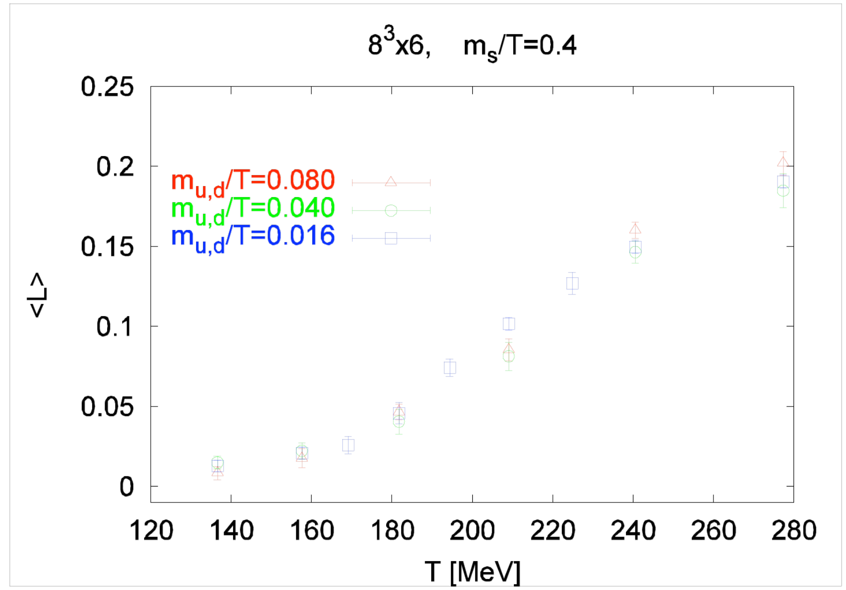
$\square = 5.2$ $\quad \frac{m_{\square ss}}{m_{\square}} = 0.613 \square 0.637 \pm 0.007$

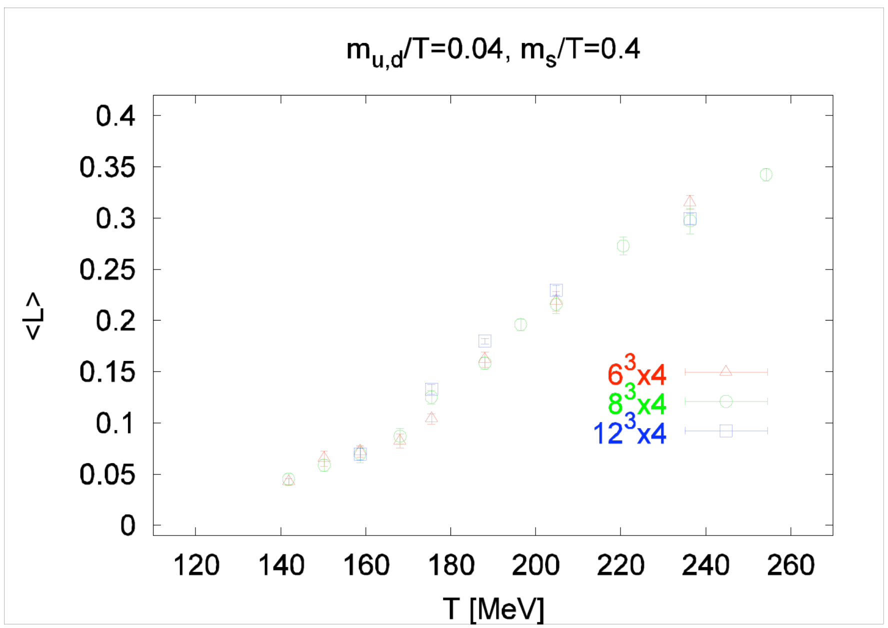
$$m_{\square} = 458(18)\text{MeV}, \; m_{\square} / m_{\square} = 0.470(33)$$
$$m_{\square} = 335(13)\text{MeV}, \; m_{\square} / m_{\square} = 0.390(16)$$

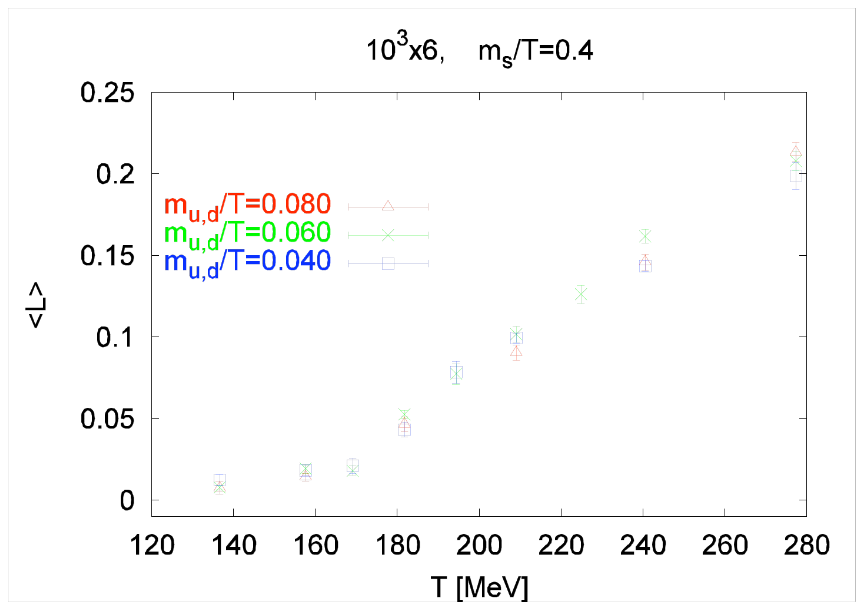
$\Rightarrow$ $m_{\square} \square 150\text{MeV}$

Polyakov loops

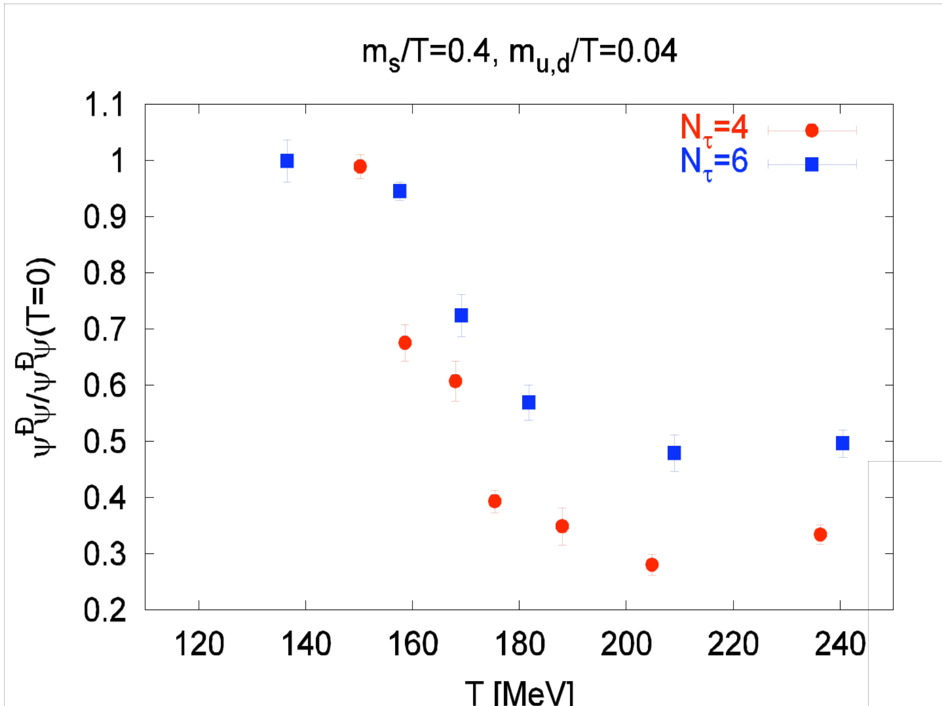




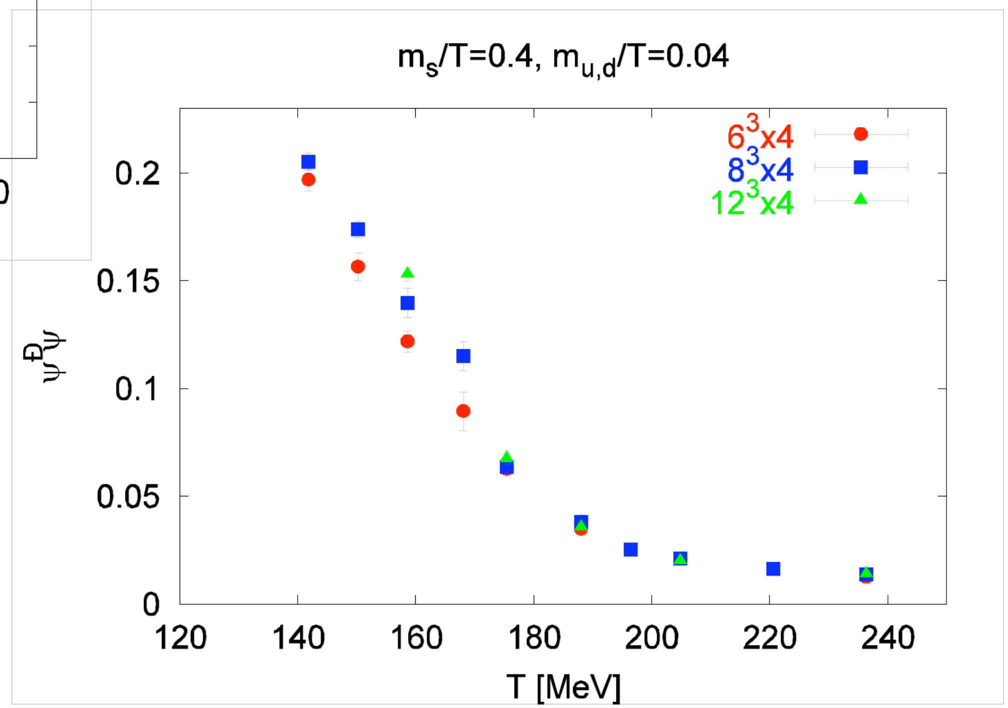




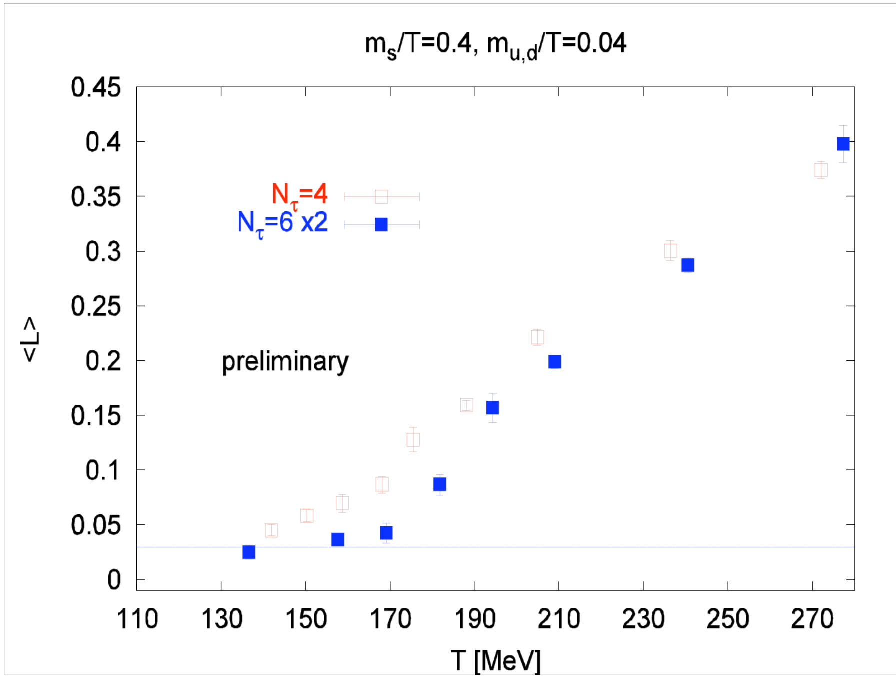
T-dependence of the chiral condensate



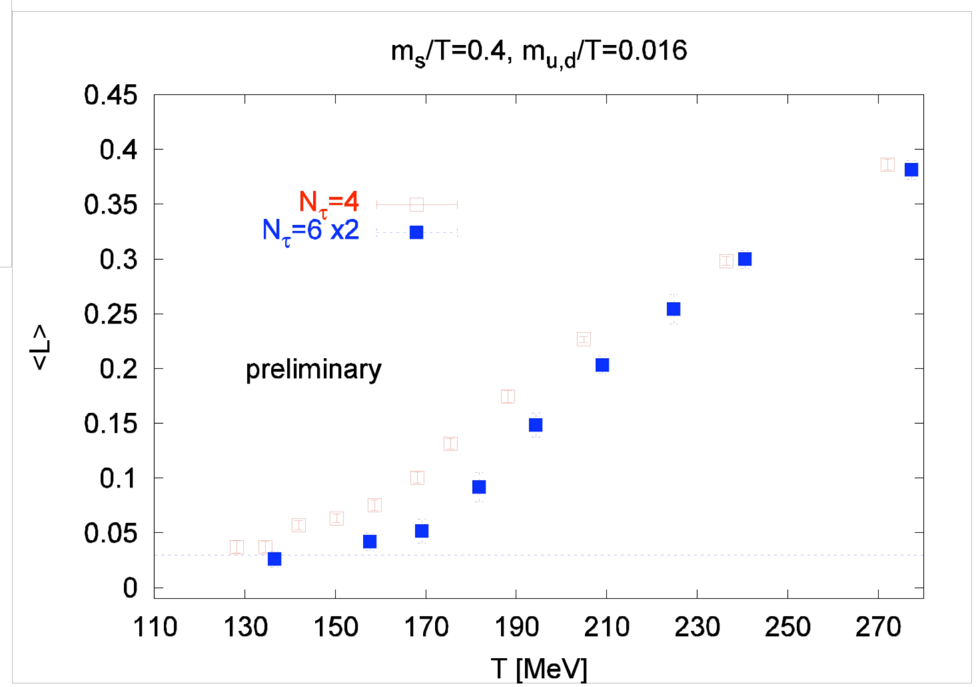
$m_{u,d} / T = 0.04$ □ $m_{□}$ □ 215 MeV



T-dependence of the Polyakov loops at different lattice spacing



$m_\pi \approx 215-235$ MeV



$m_\pi \approx 130-150$ MeV

Conclusion and outlook

- The deconfinement transition have been studied in 2+1 flavor QCD with very small u,d-quark masses down to the physical values and two different lattice spacings $N_\tau = 4, 6$

- No phase transition was found but only a quite smooth crossover around $T_{tr} = 175 - 185\,\text{MeV}$, weak mass dependence for $m_\pi \sim 300$ MeV

In comparison the Bielefeld group gets : $T_c = (177 \pm 0.09 \mp 0.01)$ MeV

(in the chiral limit, 2 flavor)

- Future prospect: keeping the quark masses constant in physical units rather than in lattice units; extension to finite chemical potential using the re-weighting with exact determinant evaluation and location of the end-point in (T, μ) plane.