Polyakov Loop Susceptibility and Correlators in the Chiral Limit

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CRC–TR 211 Strong-interaction matter under extreme conditions

The untraced Polyakov loop

$$L_{\vec{x}} = \prod_{\tau} U_4(\vec{x}, \tau)$$

is related to the color-averaged free energy of a quark-antiquark pair[1]

$$F_{q\bar{q}}(r, T) = -T \log \left\langle \frac{1}{9} \operatorname{tr} L_{\vec{x}} \operatorname{tr} L^{\dagger}_{\vec{y}} \right\rangle \qquad r = |\vec{x} - \vec{y}|.$$

Of interest to us will be color-singlet free energy[2]

$$F_1(r, T) = -T \log \left\langle \frac{1}{3} \operatorname{tr} L_{\vec{x}} L^{\dagger}_{\vec{y}} \right\rangle,$$

which is not a gauge invariant quantity.

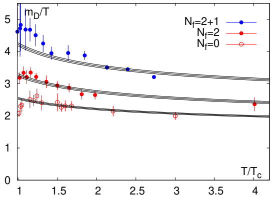
[1] L. D. McLerran and B. Svetitsky, Phys. Rev. D, 24.2, 450–460 (1981).
[2] S. Nadkarni, Phys. Rev. D, 34.12, 3904–3911 (1986).

Debye mass m_D

- $r_D = 1/m_D$ characterizes distance at which in-medium modifications of quark-antiquark interaction dominate (color screening).
- Can extract m_D from large r behavior of F_1:

$$F_1(r,T) \sim \frac{\alpha(T)}{r} e^{-r\, m_D(T)} + C$$

- m_D dependence on T and N_f can be seen, e.g. in lattice simulations[3].



QUESTION: How does m_D depend on m_ℓ?

[3] O. Kaczmarek, PoS(CPOD07), 043 (2008).

Deconfinement criteria

The Polyakov loop,

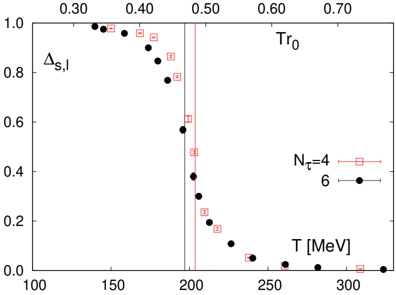
$$P = \frac{1}{N_s^3} \sum_{\vec{x}} \frac{1}{N_c} \operatorname{tr} L_{\vec{x}},$$

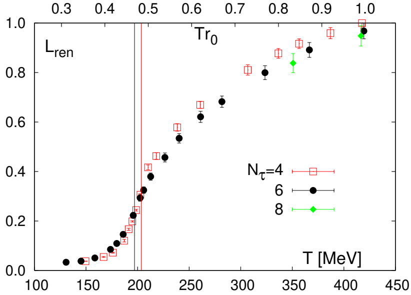
m_D, and deconfinement are all related.

- For quenched QCD

  $$\chi = N_s^3 \left(\langle |P|^2 \rangle - \langle |P| \rangle^2 \right)$$

  peaks near T_c, where $\mathbb{Z}_3$ is spontaneously broken.
- Corresponds to an inflection point in P.
- Finite quark mass breaks $\mathbb{Z}_3$ explicitly.
- Nevertheless at large quark mass some remnant seemed to remain.
- Tempting to associate χ peak with hadron melting in dynamical QCD.

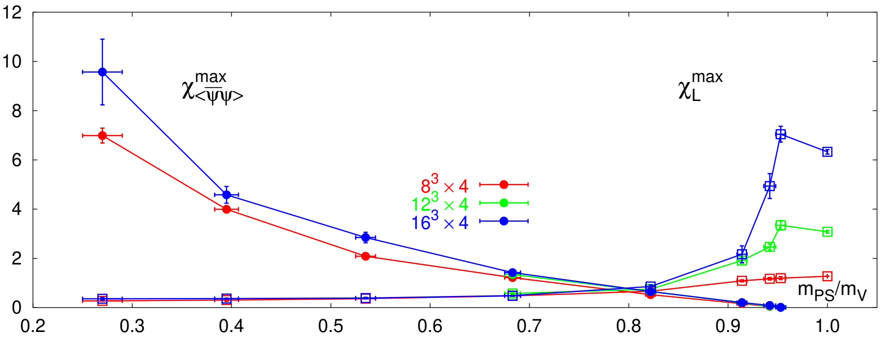




- Past studies have shown order parameter inflection points to appear at similar temperatures[4] however...

[4] M. Cheng et al., Phys. Rev. D, 77.1, 014511 (2008).

Deconfinement criteria



- ...the heights of susceptibility maxima have been known for some time to depend strongly on the quark mass[5].

QUESTION: Does it make sense to associate Polyakov susceptibility with hadron melting, especially as $m_\ell \to 0$?

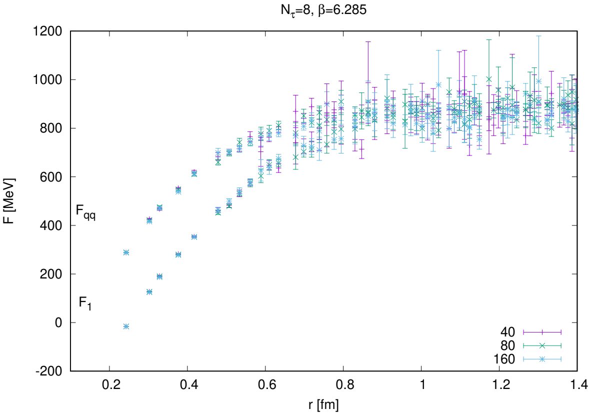
[5] F. Karsch, Lectures on Quark Matter, 583, 209–249 (2002).

Set up and statistics

- $N_f = 2+1$ with HISQ action
- $N_\tau = 8$ and 12
- $N_s/N_\tau \geq 3$
- m_s fixed to its physical value
- m_s/m_ℓ varies from 27 to 160
- T in the vicinity of chiral transition temperature
- Set scale with r_1[6]
- F_{qq} and F_1 measurements in Coulomb gauge
- Renormalize by matching F_1 to zero temperature potential[7]
- Roughly 3000 to 20000 depending on the parameters

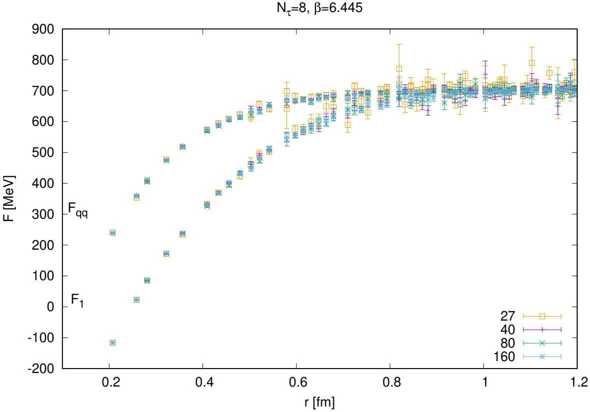
[6] C. Bernard, PoS(Lattice 2010), 074 (2011).
[7] O Kaczmarek et al., Phys. Lett. B, 543.1-2, 41–47 (2002).

Preliminary results: Free energies



$T \approx 141$ MeV

Preliminary results: Free energies

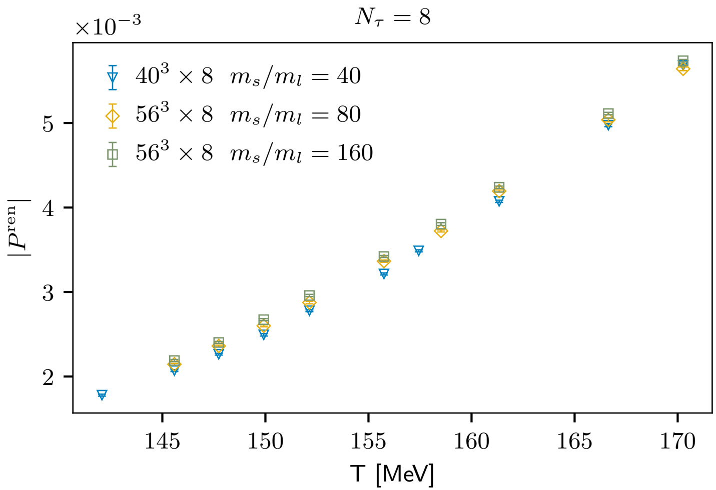


$T \approx 166$ MeV

CONCLUSION: No dependence of m_D on m_ℓ noticeable.

FUTURE: Precise determination of m_D. (Gradient flow?)

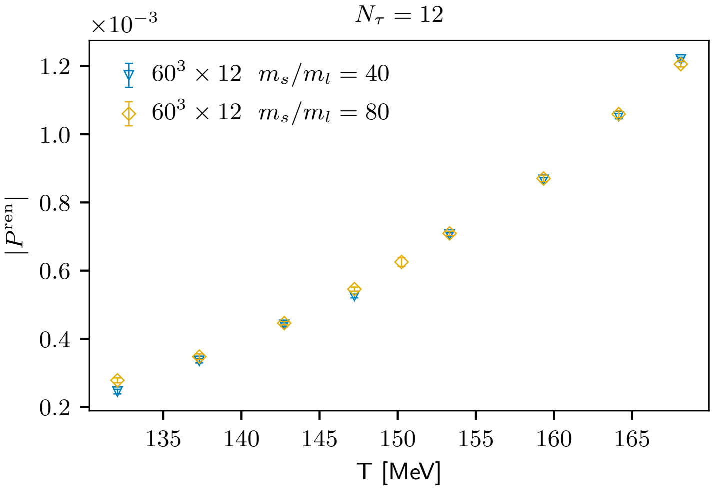
Preliminary results: Polyakov loop



$T_{pc}^{40} \approx 158$ MeV, $T_{pc}^{80} \approx 154$ MeV, $T_{pc}^{160} \approx 151$ MeV

No inflection point

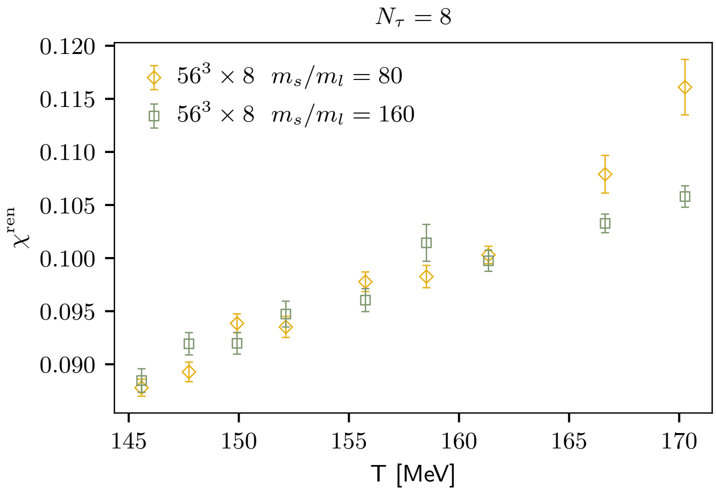
Preliminary results: Polyakov loop



$T_{pc}^{40} \approx 156$ MeV, $\quad T_{pc}^{80} \approx 149$ MeV

No inflection point

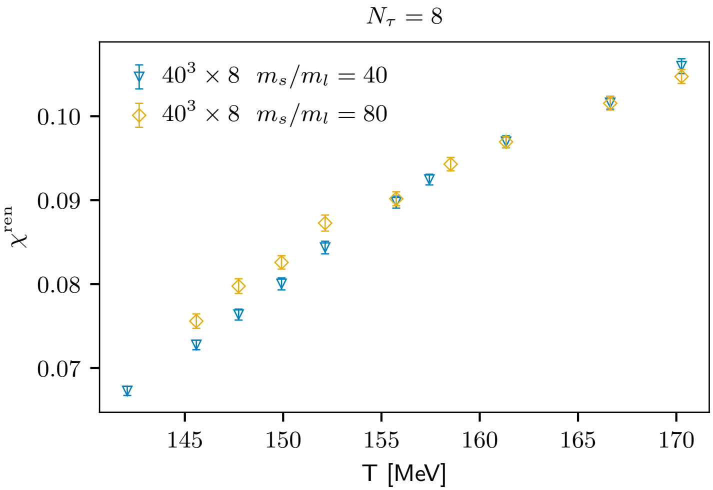
Preliminary results: Polyakov susceptibility



$T_{pc}^{80} \approx 154$ MeV, $\quad T_{pc}^{160} \approx 151$ MeV

No peak

Preliminary results: Polyakov susceptibility



$T_{pc}^{40} \approx 158$ MeV, $\quad T_{pc}^{80} \approx 154$ MeV

CONCLUSION: No drastic change in P^{ren} near chiral T_{pc}.

Summary and outlook

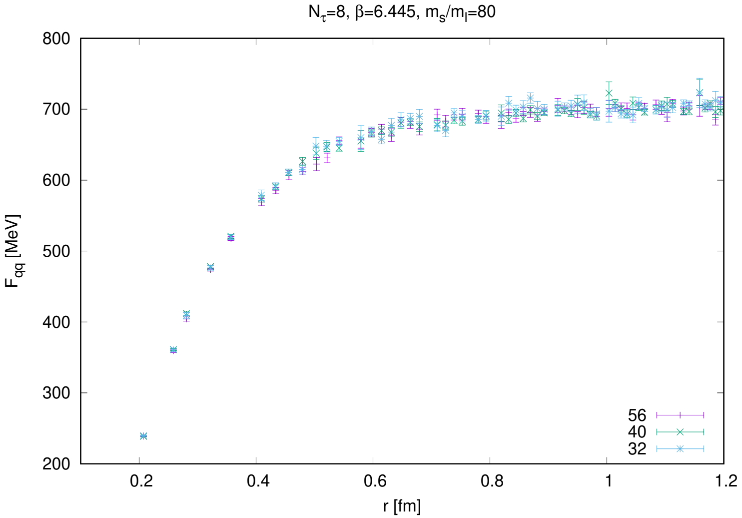
- Does m_D change with m_ℓ?
  - Preliminary results suggest no dependence within our statistics.
  - Working toward numerical determination of m_D.
  - May use gradient flow to smooth UV fluctuations.
- χ as a probe for hadron melting?
  - Does not coincide with T_{pc} from chiral susceptibility.
  - Results at other parameter combinations still forthcoming...
  - ...in particular points at $m_s/m_l = 27$ and 20.

Thank you!

Additional details: current statistics

$N_s^3 \times N_\tau$	m_s/m_ℓ	approx. N_{conf}/run
$24^3 \times 8$	40	20 000
$32^3 \times 8$	27	6 000
	80	10 000
$40^3 \times 8$	40	10 000
	80	6 000
$42^3 \times 12$	40	10 000
$48^3 \times 12$	80	6 000
$56^3 \times 8$	160	3 000
	80	3 000
$60^3 \times 12$	40	6 000
	80	3 000

Additional details: N_s dependence of F_{qq}



Additional details: a dependence of F_{qq}

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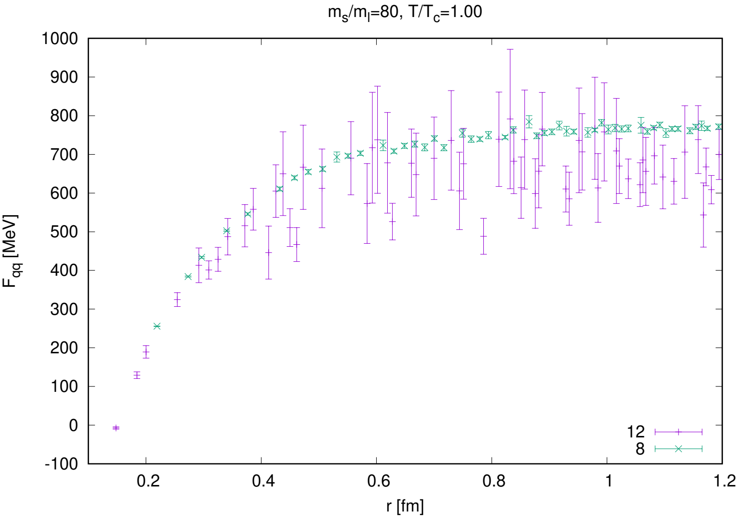
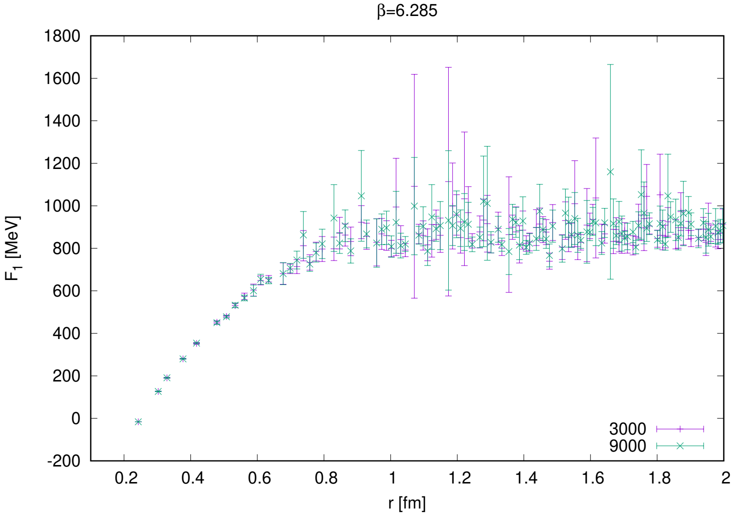
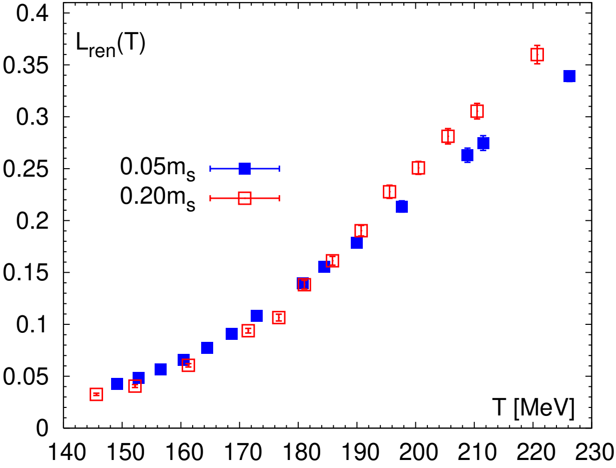


Additional details: θ_{gf} dependence of F_1





Taken from a HISQ study[8];

[8] A. Bazavov et al., Phys. Rev. D, 85.5 (2012).