# Screening masses and static quark free energy at non-zero baryon density from Lattice QCD

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M.Andreoli[1], C.Bonati[1], M.D'Elia[1], M.Mesiti[2], F.Negro[1], *A.Rucci*[1†] and F.Sanfilippo[3]

[1] *Department of Physics of University of Pisa and INFN Pisa, Italy*
[2] *Academy of advanced computing, Swansea University, UK* [3] *INFN Roma Tre, Italy*
[†] *Poster author email address: andrea.rucci@pi.infn.it*

## Introduction

At high temperatures, the interaction between static color charges can be used to probe the screening effects in the Quark-Gluon Plasma (QGP) which are the basis of interesting phenomenology such as dissociation of heavy quark bound states. In our work we studied the effects of a non-zero baryon chemical potential on the screening masses and on the static quark free energy by means of Lattice QCD simulations on a $N_f$=2+1 theory [*].

## Gauge-invariant screening masses

Screening masses of QCD can be extracted from the long-distance behaviour of suitable gauge-invariant correlators of the Polyakov loop $L$ [1,2,3]. At zero chemical potential

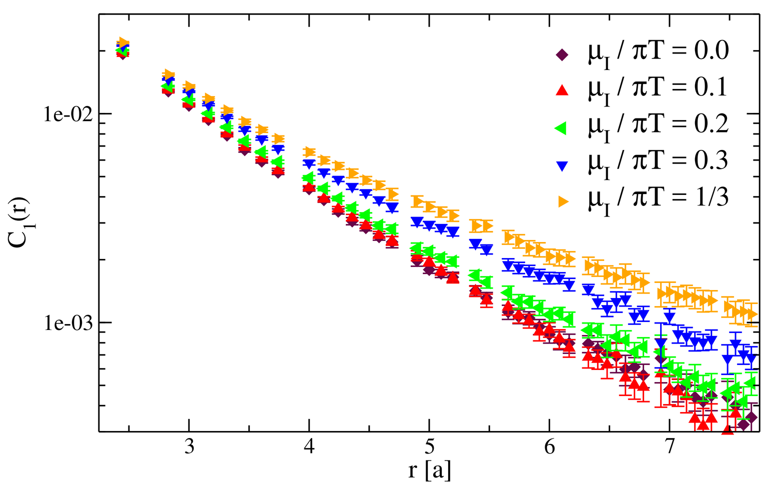
$$C_{M^+}(\mathbf{r},T) = \langle \mathrm{TrRe}L(\mathbf{0})\mathrm{TrRe}L(\mathbf{r})\rangle - \langle \mathrm{TrRe}L\rangle^2 \sim exp(-m_M r)/r$$
$$C_{E^-}(\mathbf{r},T) = \langle \mathrm{TrIm}L(\mathbf{0})\mathrm{TrIm}L(\mathbf{r})\rangle - \langle \mathrm{TrIm}L\rangle^2 \sim exp(-m_E r)/r$$

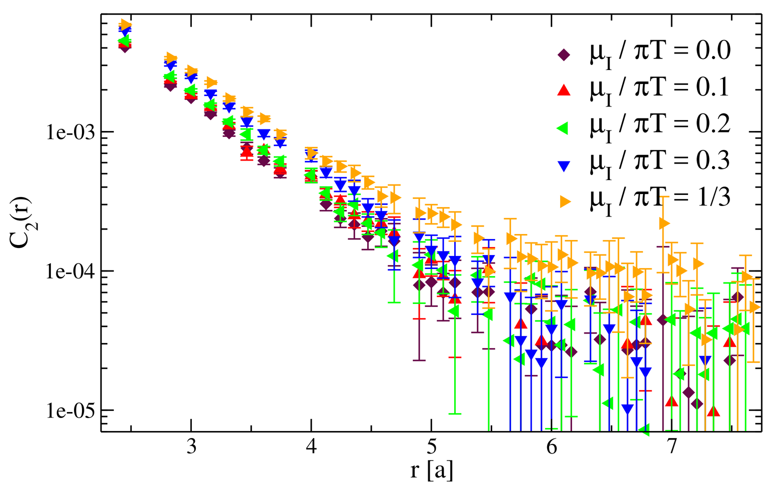
belong separately to the chromo-magnetic and -electric sectors. When $\mu_B > 0$, charge-conjugation symmetry is broken and true physical modes are obtained by diagonalizing the matrix

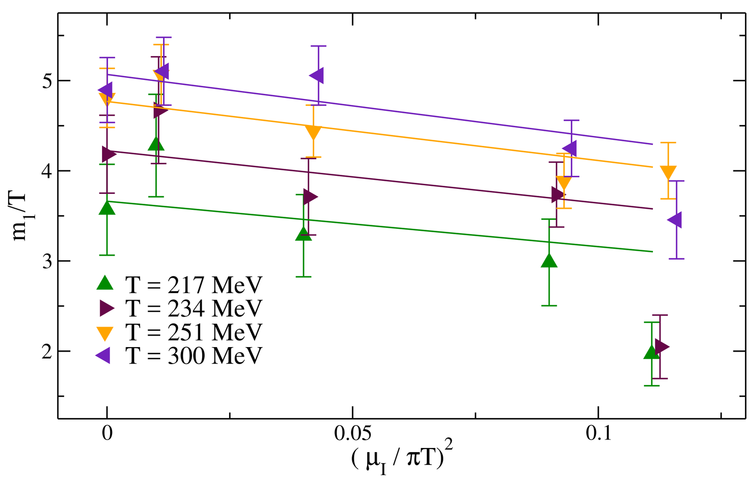
$$\begin{pmatrix} C_{M^+}(\mathbf{r}) & C_X(\mathbf{r}) \\ C_X(\mathbf{r}) & C_{E^-}(\mathbf{r}) \end{pmatrix}$$

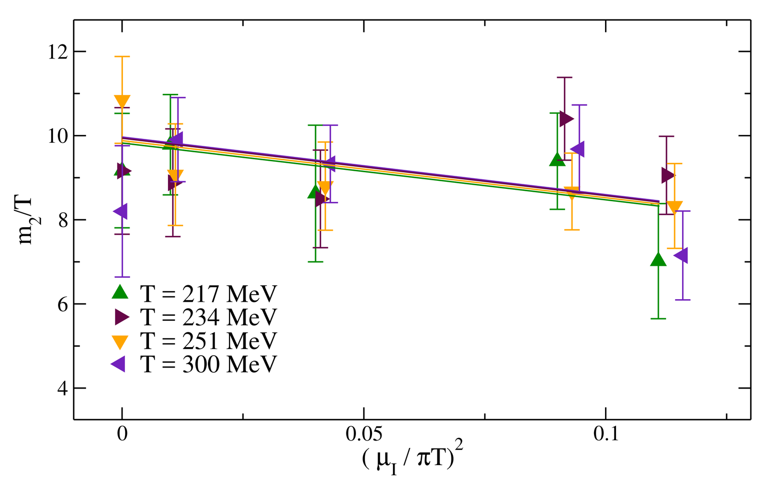
where $C_X(\mathbf{r})$ is a mixed correlator. New screening masses $m_1$ and $m_2$ are defined from the large $\mathbf{r}$ decrease of the eigenvalues $C_{1,2}(\mathbf{r})$ with the ansatz $C_{1,2}(\mathbf{r}) \sim \exp(-m_{1,2}r)/r$.

The correlators obtained on a $32^3 \times 8$ lattice at $T \simeq 217$ MeV and the QCD screening masses for several values of $T$ and $\mu_I/T$ are reported




In the range of temperatures and baryon density explored, our data suggests that

- The correlator $C_X$ signals the presence of a mixing at $\mu_B > 0$
- Magnetic and electric correlators mix and share the same long-distance behaviour dominated by the largest mass
- Eigenvalues $C_1$ and $C_2$ determine two new well-distinct masses $m_1$ and $m_2$
- Masses are described by

$$\frac{m_{1,2}(\mu_B,T)}{T} = a_{1,2}(T)\left[1 + b_{1,2}\left(\frac{\mu_B}{3\pi T}\right)^2\right]$$

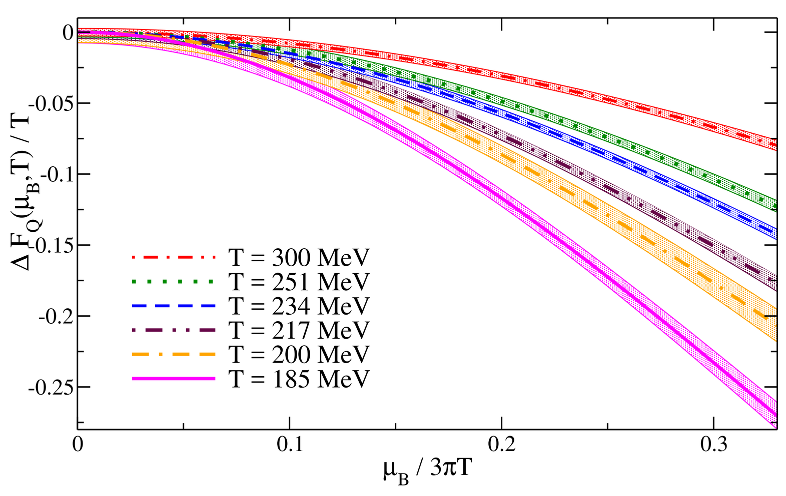
## Static quark free energy

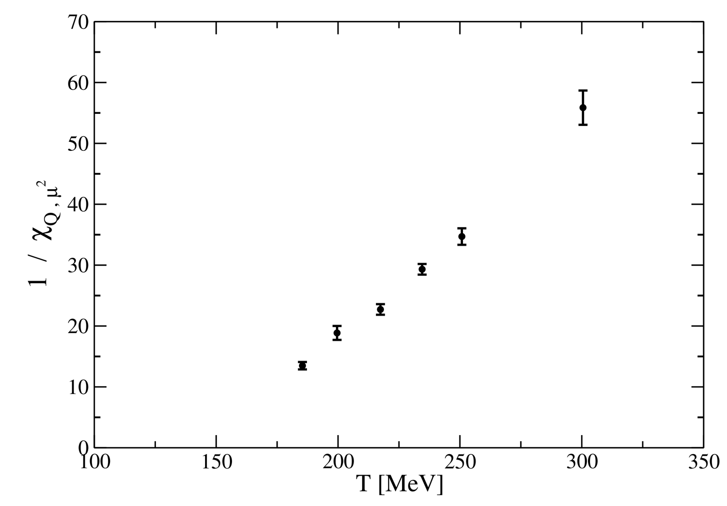
The free energy $F_Q$ of an heavy quark in the thermal medium is related to the Polyakov loop $L$ by $F_Q = -T\log|\langle \mathrm{Tr}L\rangle|$ [4]. We computed the renormalized ratio

$$\frac{|\langle \mathrm{Tr}L\rangle(T,\mu_B)|^2}{|\langle \mathrm{Tr}L\rangle(T,0)|^2} = \exp\left(-2\frac{\Delta F_Q(T,\mu_B)}{T}\right) = 1 - \chi_{Q,\mu_B^2}\left(\frac{\mu_B}{T}\right)^2 + \mathcal{O}\left((\mu_B/T)^4\right)$$

where $\Delta F_Q(T,\mu_B) = F_Q(T,\mu_B) - F_Q(T,0)$ and extracted the quadratic coefficient $\chi_{Q,\mu_B^2}$.

The results of $\Delta F_Q$ and the curvature $\chi_{Q,\mu_B^2}$ obtained on a $32^3 \times 8$ lattice are shown




- The free energy is a decreasing function of $\mu_B$ which enhances deconfinement
- In the small baryon density range, the shape is quadratic
- The coefficient $\chi_{Q,\mu_B^2}$ increases as the critical temperature is reached, signaling the deconfinement

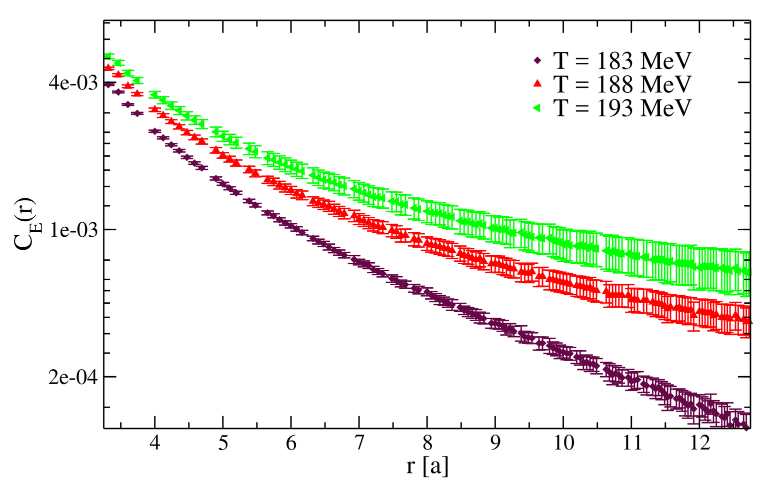
## The case of the Roberge-Weiss point

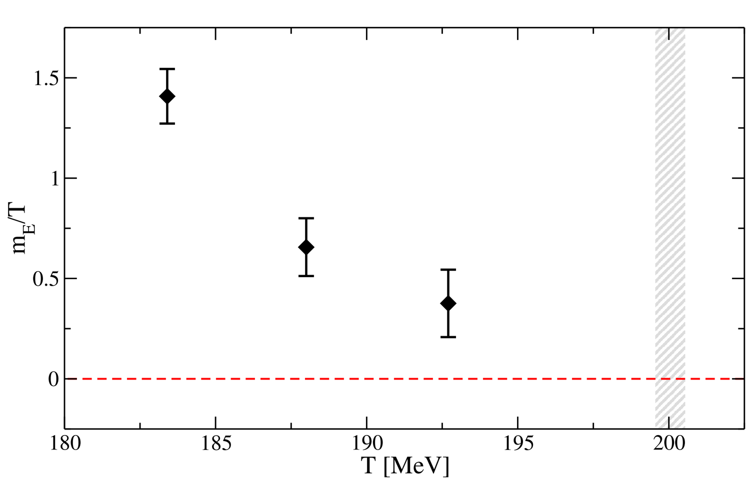
Imaginary chemical potential makes the partition function of the system periodic with period

$$\mu_I/T = \pi(2k+1)/3 \qquad k = 0, \pm 1, \dots$$

so that charge-conjugation is recovered at low temperatures but spontaneously broken above $T_{RW} \sim$200 MeV, the Roberge-Weiss endpoint [*]. In our work we investigated the behaviour of the screening masses near this point.

Color-electric correlator and mass computed on a $40^3 \times 10$ lattice at $\mu_I/T = \pi$ at $T \lesssim T_{RW}$ are shown




- Definitions of color-electric and -magnetic masses are recovered with inverted hierarchy
- Significant growth of $C_{E^-}$ due the Roberge-Weiss transition whose order parameter is ImTr$L$

## References

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**[*] This work: Phys. Rev. D97, 054515 (2018) [arXiv:1712.09996]**