Confinement/deconfinement phase transition in dense medium

V. G. Bornyakov[1,2,3], V. V. Braguta[1,2,3,4], E.-M. Ilgenfritz[4], A. Yu. Kotov[2,4,*], A. V. Molochkov[3], A. A. Nikolaev[2]

[1]IHEP NRC "Kurchatov Institute", Protvino, 142281 Russia
[2]ITEP NRC "Kurchatov Institute", Moscow, 117218 Russia
[3]FEFU, School of Biomedicine, Vladivostok, 690950 Russia
[4]JINR, BLTP, Dubna, 141980 Russia
*kotov@itep.ru

Abstract

We present the results of the study of dense lattice $SU(2)$ QCD at zero temperature. We reach very large baryon density (up to quark chemical potential $\mu_q > 2000$ MeV). In the region $\mu_q \sim 1000$ MeV we observe for the first time the confinement/deconfinement transition which manifests itself in a rising of the Polyakov loop and vanishing of the string tension. After the deconfinement at $\mu_q > 1000$ MeV we observe a monotonous decrease of the spatial string tension which ends up with its vanishing at $\mu_q > 2000$ MeV. From this observation we draw the conclusion that the confinement/deconfinement transition at finite density and zero temperature is quite different from that at finite temperature and zero density. Our results indicate that in very dense matter the quark-gluon plasma is similar to a weakly interacting gas of quarks and gluons without magnetic screening mass in the system, sharply different from a quark-gluon plasma at large temperature.

In QC$_2$D there is no sign problem,
but (for large values of μ) this theory is very similar to the real QC$_3$D [1, 2]!

Simulation parameters

- Lattice size: mainly 32^4, some data at $32^3 \times 48$
- Staggered fermions with rooting
- Two flavors of dynamical quarks
- Improved gauge action
- $a = 0.044$ fm
- $m_\pi = 740(40)$ MeV

Deconfinement in dense medium

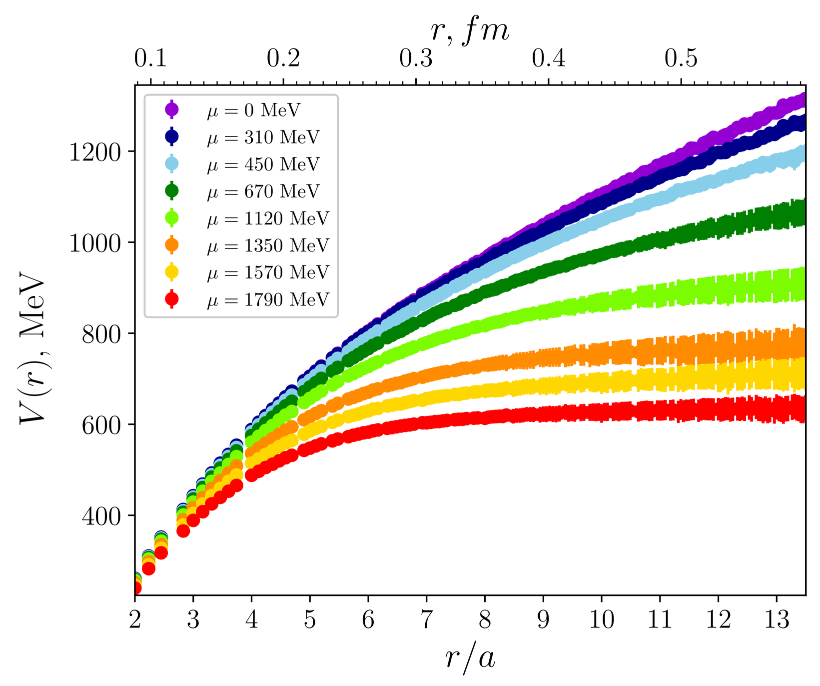

Figure 1: *The interaction potential $V(r)$ between a static quark-antiquark pair.*

The interaction potential can be well described by

- the Cornell potential: $V(r) = A + \frac{B}{r} + \sigma r$ for $\mu \leq 1100$ MeV
- the Debye potential: $V(r) = A + \frac{B}{r} e^{-m_D r}$ for $\mu \geq 1300$ MeV

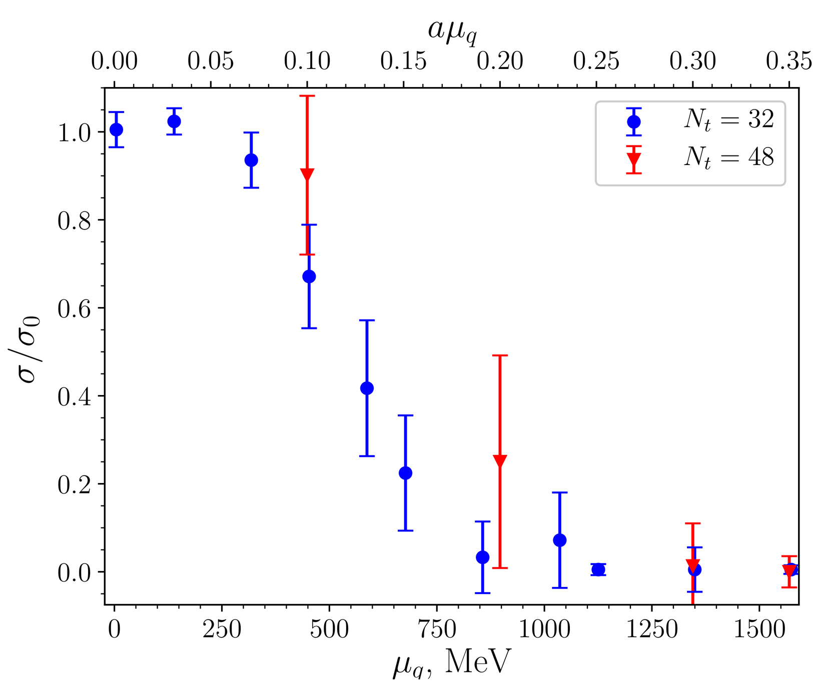

Figure 2: *The string tension σ divided by the string tension σ_0 at $\mu = 0$ as a function of quark chemical potential. Blue points correspond to lattice size 32^4, red points represent data at lattice size $32^3 \times 48$.*

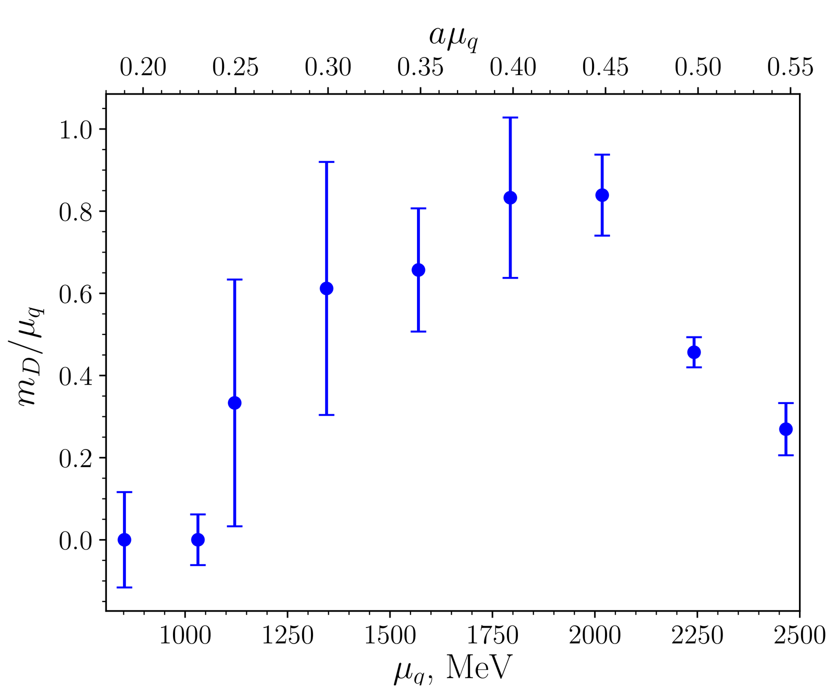

Figure 3: *Debye mass (divided by μ_q) from the $V_{\overline{Q}Q}$ fit as a function of μ_q.*

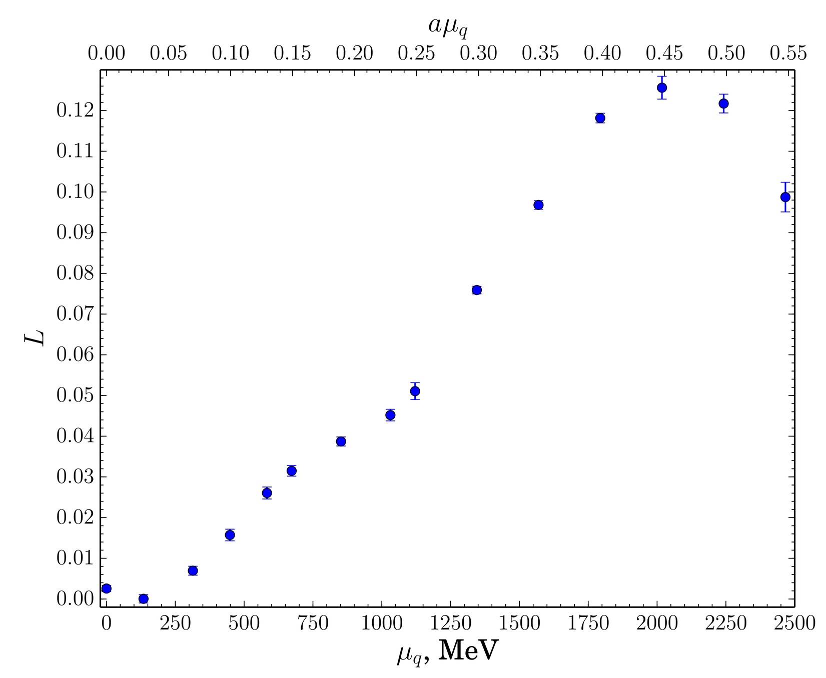

Figure 4: *Polyakov loop as a function of the quark chemical potential.*

The spatial string tension is extracted from spatial Wilson loops. It characterizes the properties of the medium. In the deconfinement phase at $\mu_q = 0$ and large T the spatial string tension is nonzero (nonperturbative effects). Contrary, at zero $T = 0$ and $\mu \neq 0$ we see that it start to decrease at the phase transition and at $\mu_q \approx 2$ GeV becomes zero.

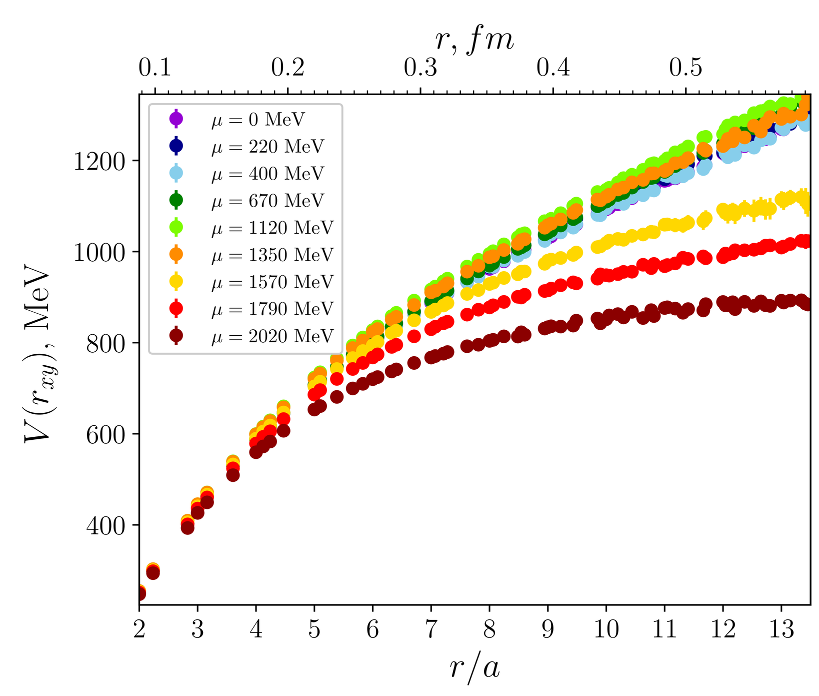

Figure 5: *The spatial string tension σ divided by the string tension σ_0 at $\mu = 0$ as a function of quark chemical potential.*

Fermionic observables

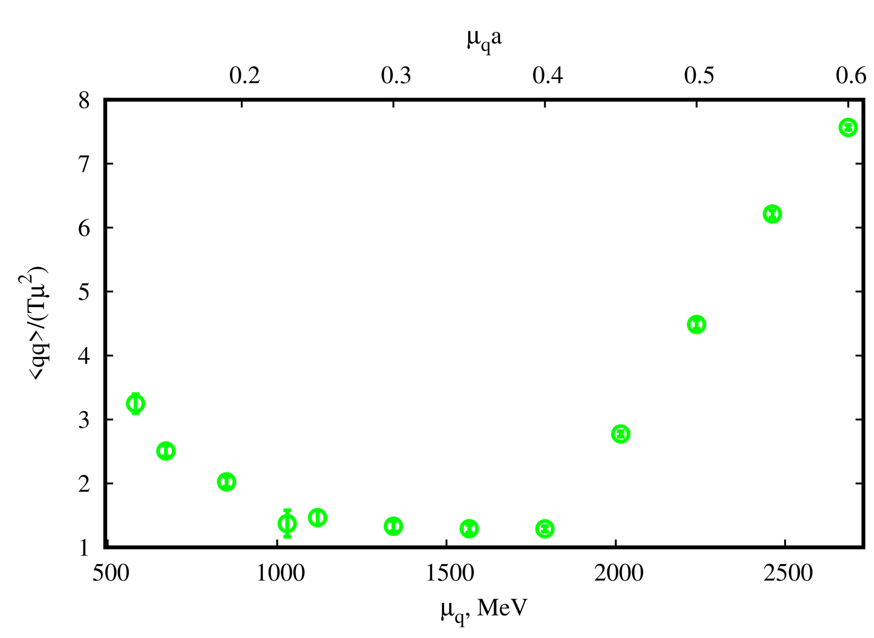

Figure 6: *The diquark condensate normalized by $T\mu^2$.*

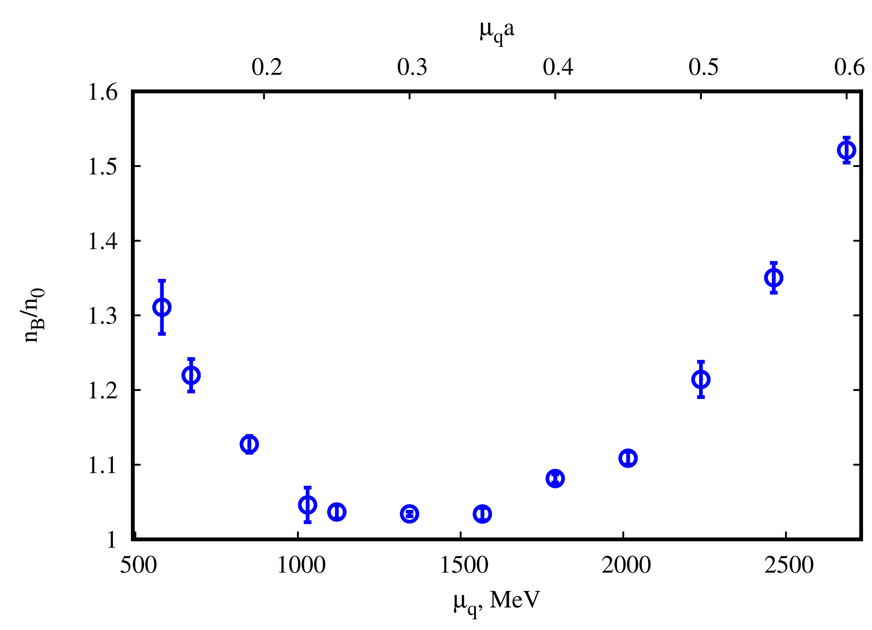

Figure 7: *Quark number density normalized by the density of free continuous quarks $n_q^{(0)} = (4^3_q)/(3\pi^2)$.*

Both diquark condensate and baryon density indicate the formation of Fermi sphere and diquark condensation on its surface.

Topological susceptibility

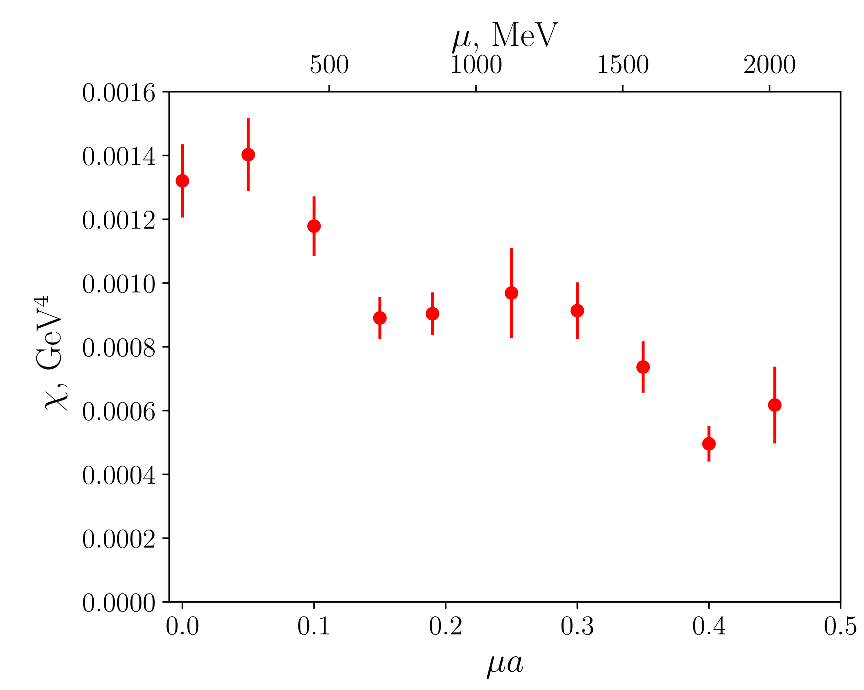

Figure 8: *Topological susceptibility as a function of quark chemical potential.*

Conclusion

- The first observation of confinement/deconfinement transition in two-color QCD.
- Difficult to determine critical chemical potential $\mu_q \sim 1000$ MeV.
- Deconfinement at large density is different from the finite temperature deconfinement
- Quark-gluon plasma at large density is perturbative (gas of quarks and gluons)

References

[1] V. G. Bornyakov, V. V. Braguta, E.-M. Ilgenfritz, A. Y. Kotov, A. V. Molochkov and A. A. Nikolaev, JHEP **1803**, 161 (2018) doi:10.1007/JHEP03(2018)161 [arXiv:1711.01869 [hep-lat]].

[2] V. V. Braguta, E.-M. Ilgenfritz, A. Y. Kotov, A. V. Molochkov and A. A. Nikolaev, Phys. Rev. D **94**, no. 11, 114510 (2016) doi:10.1103/PhysRevD.94.114510 [arXiv:1605.04090 [hep-lat]].