Lattice study of dense SU(2) QCD
Part II

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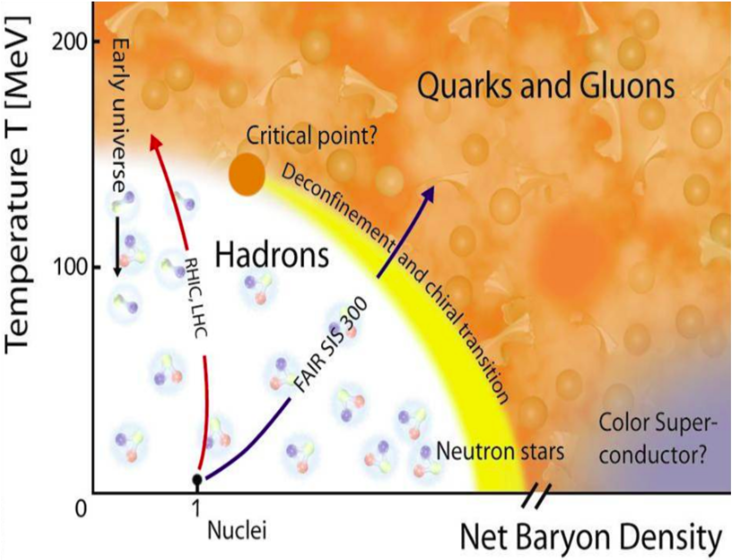
Outline:

- The phase diagram at low and moderate density
- **Large density: Deconfinement in dense medium**

QCD phase diagram

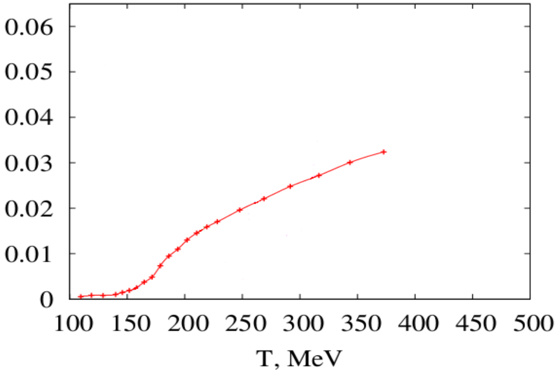


Details of the simulation (new study):

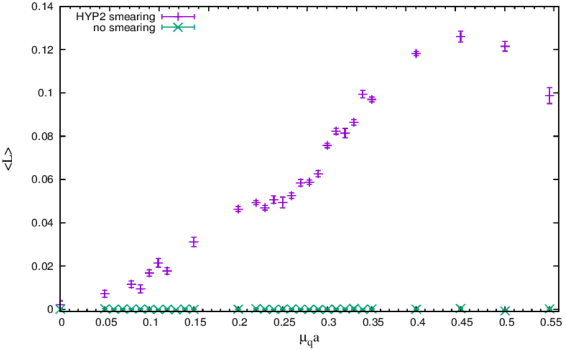
- Tree-level improved gauge action
- $a = 0.044$ fm   previous study: $a = 0.11$ fm
  $\Rightarrow$ **closer to continuum limit**
  one can reach larger density without lattice artifacts
- $m_\pi = 740(40)$ MeV
  new study: $m_\pi L_s \simeq 5$ previous study: $m_\pi L_s \simeq 3$
  $\Rightarrow$ **Smaller final volume effects**
- Lattices
  - $32^3 \times 32$ ($T \simeq 0$)
  - $32^3 \times 24$ ($T \simeq 186$ MeV)
  - $32^3 \times 16$ ($T \simeq 280$ MeV)
  - $32^3 \times 8$ ($T \simeq 560$ MeV)
- Fixed λ parameter

Preliminary results!

Polyakov loop ($\mu = 0$)



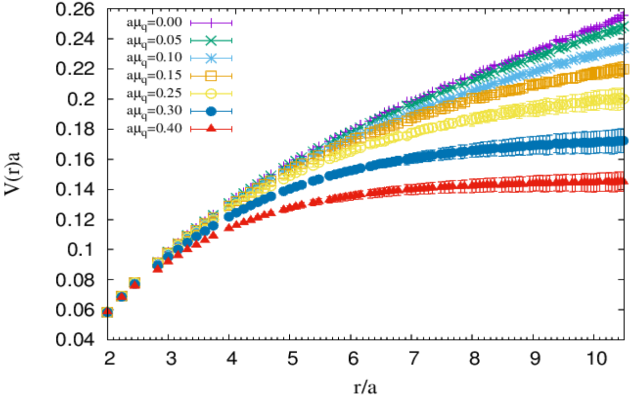
Polyakov loop



Rich physics?

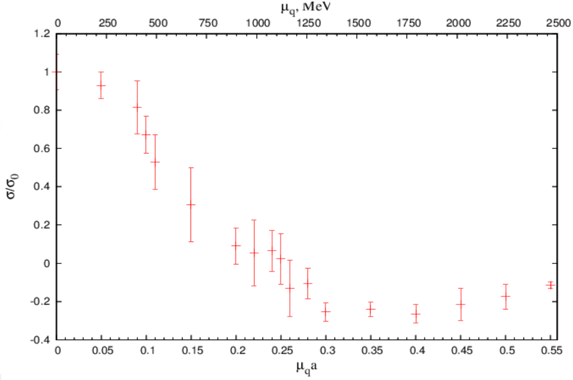
- Critical chemical potential $a\mu \sim 0.25$ (1100 MeV)
- At least one extremum in $< L >$

Potential between static quark-antiquark pair



We observe deconfinement in dense medium!

String tension



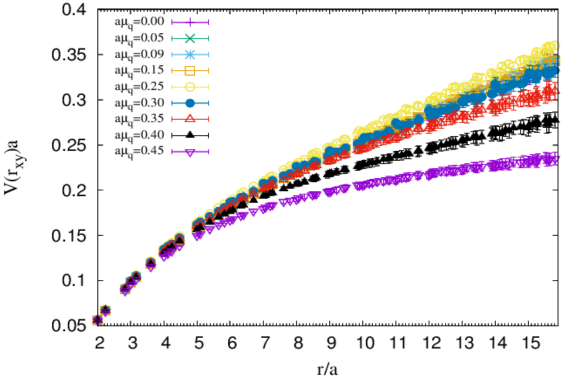
- Fit by the Cornell potential: $V(r) = A + \frac{B}{r} + \sigma r$

Debye screening

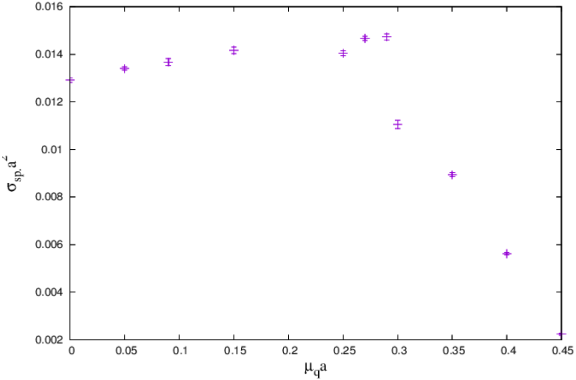
$a\mu_q$	μ_q, MeV	B	$m_D a$	χ^2/dof
0.00	0.00	0.5307(89)	-0.1091(48)	10.689
0.05	135.14	0.4532(72)	-0.0380(46)	5.178
0.08	216.22	0.458(10)	0.0324(65)	3.889
0.09	243.25	0.4712(97)	0.0127(61)	3.316
0.10	270.27	0.4249(76)	0.0628(51)	2.753
0.15	405.41	0.474(13)	0.2355(81)	1.218
0.20	540.55	0.542(21)	0.390(12)	2.666
0.25	675.68	0.4662(89)	0.3645(56)	0.246
0.30	810.82	0.638(18)	0.6411(88)	0.316
0.35	945.96	0.641(21)	0.764(10)	0.135
0.40	1081.1	0.590(19)	0.8479(98)	0.153
0.45	1216.23	0.404(15)	0.742(11)	0.033
0.50	1351.37	0.2851(92)	0.5847(94)	0.047

- Debye potential $V(r) = A + \frac{B}{r} e^{-m_D r}$
- The Debye potential fit is good for the $a\mu \geq 0.25$

Spatial potential $V(r)$



Spatial string tension



- Deconfinement at $a\mu > 0.25 - 0.3$?

Conclusion:

- We observe deconfinement in dense medium
- Difficult to determine critical chemical potential
  - Polyakov loop $a\mu \sim 0.25$
  - From string tension $a\mu \sim 0.25$
  - From Debye screening $a\mu \geq 0.25$
  - From spatial string tension $a\mu \geq 0.25 - 0.3$
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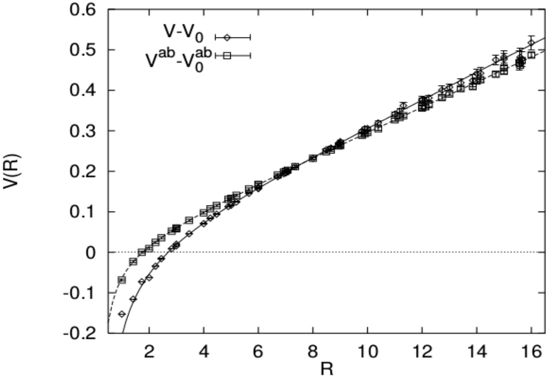
We are going to study **Abelian Monopoles**

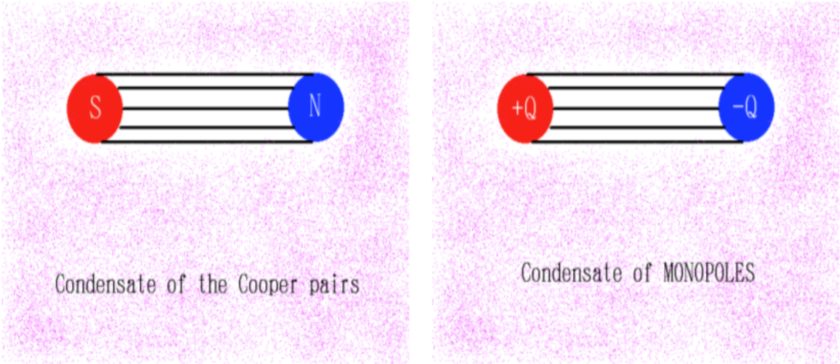
Maximal Abelian gauge

- SU(2) QCD
  $\hat{A} = A_1\hat{\sigma}_1 + A_2\hat{\sigma}_2 + A_3\hat{\sigma}_3$, $\sigma_{1,2,3}$–Pauli matrices
- Choose $\hat{A}$ maximally diagonal:
  $\max_\Omega R(A^\Omega)$, $\quad R(A) = -\int d^4x(A_1^2 + A_2^2)$
- $\Omega_0 = diag(e^{-i\alpha(x)}, e^{i\alpha(x)})$ does not change $R(A)$
- Gauge transformation: $A_\pm \to e^{\pm 2i\alpha} A_\pm$ $(A_\pm = A_1 \pm iA_2)$,
  $A_3 \to A_3 - \frac{1}{g}\partial\alpha$
- Substitute $\hat{A} \to A_3$
- Instead of the $SU(2)$ we study $U(1)$
- In $U(1)$ monopoles can be defined

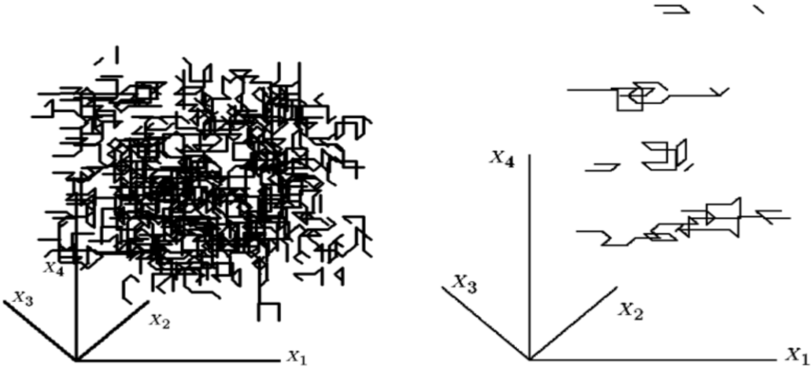
Abelian dominance



Model of dual superconductor



Condensation of monopoles

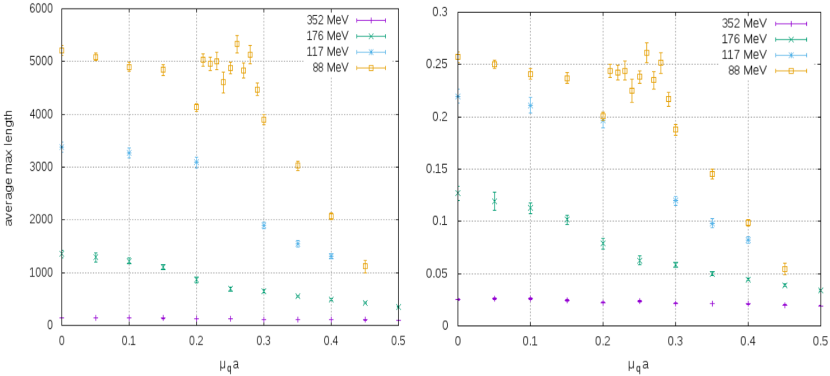


Basic facts about Abelian monopoles:

- Percolation cluster (confinement/deconfinement transition)
- Small monopole loops (virtual particles)
- Wrapped monopole trajectories (real particles)
- Wrapped monopoles at high temperature are connected with spatial string tension ($\sqrt{\sigma}_s \sim \rho_{mon}^{1/3}$)

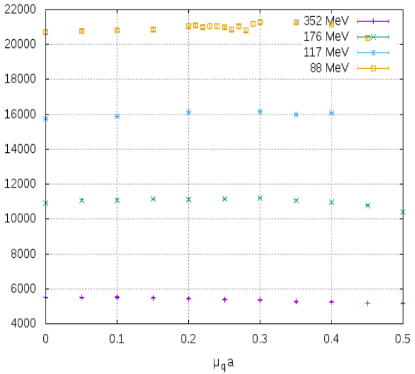
One can use Abelian monopoles to study confinement/deconfinement transition

The length of percolation cluster



- Percolation cluster disappears in the region $a\mu \in (0.2, 0.3)$
- Deconfinement transition $a\mu \in (0.2, 0.3)$

Total length of nonpercolation clusters

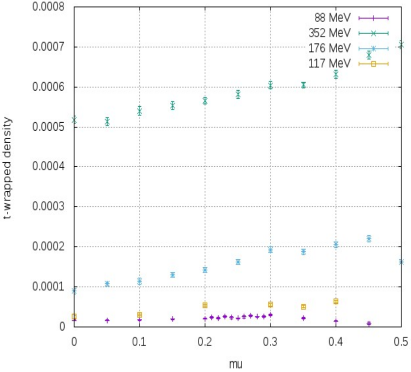


- Total length is practically insensitive to the value of chemical potential
- Physics at small distances does not feel density

Magnetic screening mass

- In perturbative QCD there is no magnetic screening mass
- There is nonperturbative magnetic screening mass at high temperature ($m_M \sim g^2 T$)
- One can expect that there is no magnetic mass in dense medium (D. T. Son, Phys. Rev. D59, 094019)
- The question of (non)existence of magnetic mass is important
  - $m_M \neq 0$: $\quad \Delta \sim \Lambda \exp\left(-\frac{3\pi^2\Lambda^2}{2\mu^2 g^2}\right)$
  - $m_M = 0$: $\quad \Delta \sim \mu g^{-5} \exp\left(-\frac{3\pi^2}{\sqrt{2}g}\right)$

Density of wrapped cluster



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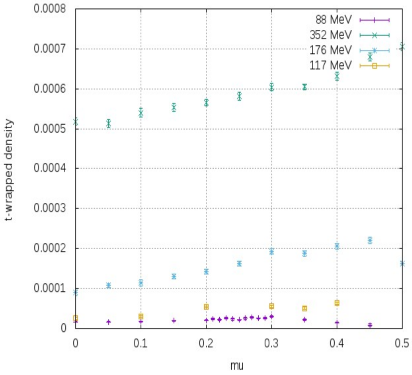

- Density of wrapped clusters rises (Why?)

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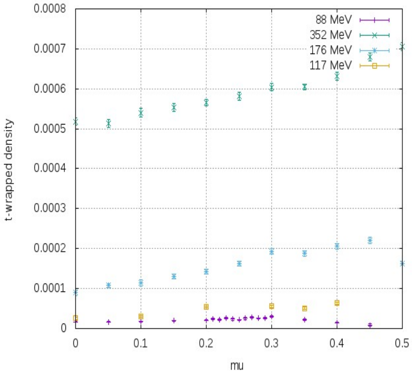

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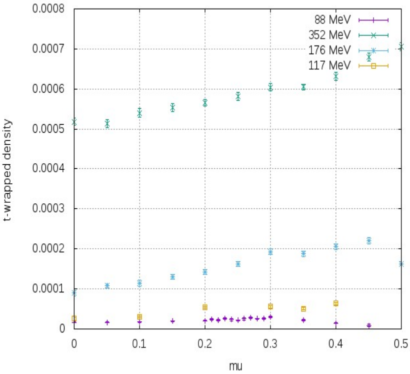

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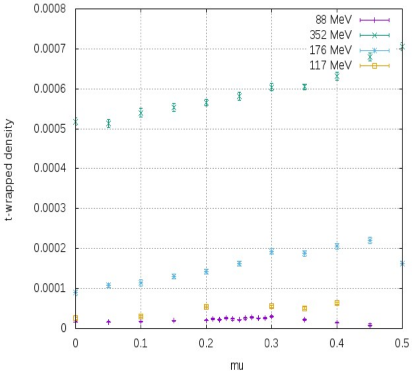

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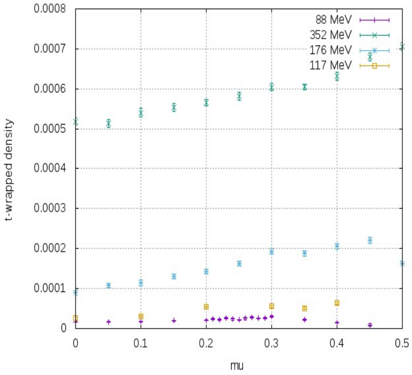

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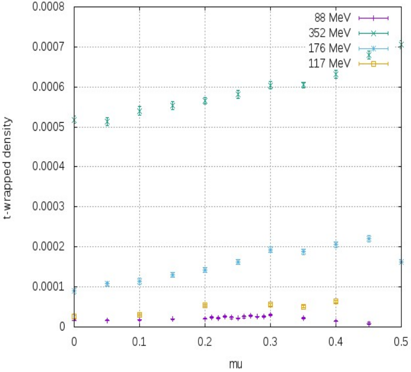

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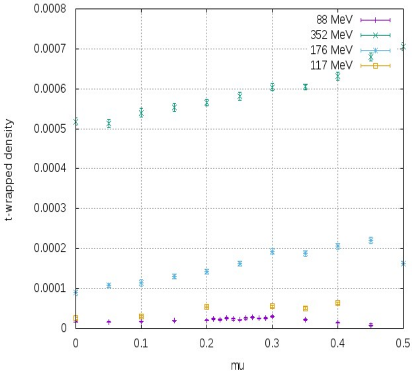

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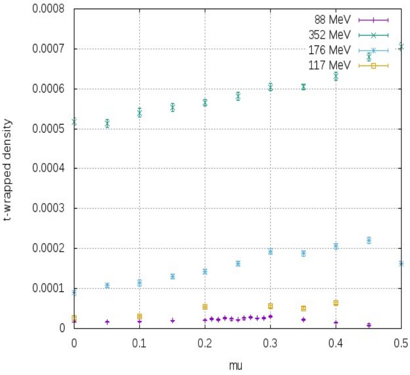

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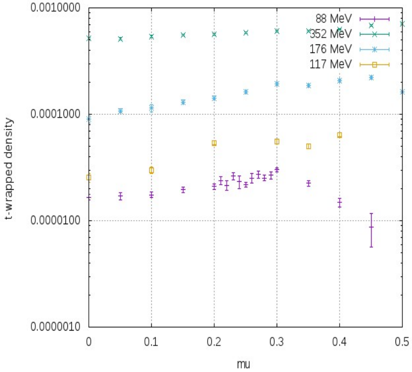
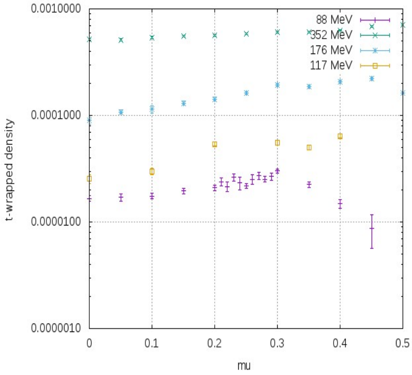
- There is **no magnetic mass in dense medium!**
- Why density rises? $m_M^2 = c_1 (g^2 T)^2 \to m_M^2 = c_1 (g^2(\mu) T)^2$
- **Rise of density is connected with asymptotic freedom**

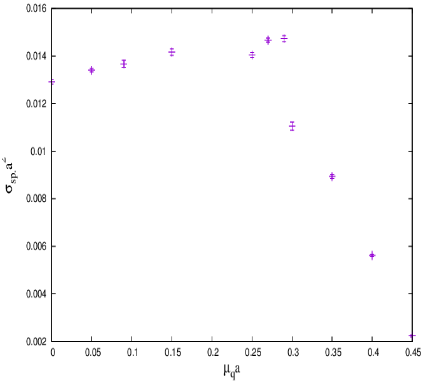
Density of wrapped cluster (log scale)



- Manifistation of the deconfinement in the region $a\mu \sim 0.3$
- Decrease of the monopole density for $a\mu \geq 0.3$
- No magnetic screening mass, but there is electric screening mass $m_E^2 = c_3(g\mu)^2$
- One can expect that monopole trajectories become more static

Density of wrapped cluster (log scale)





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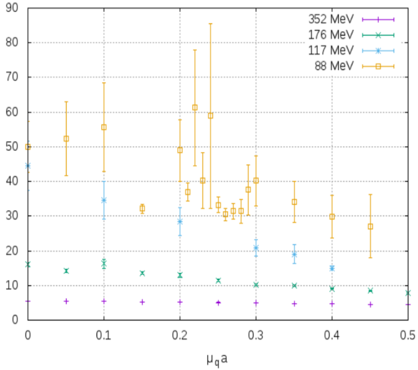
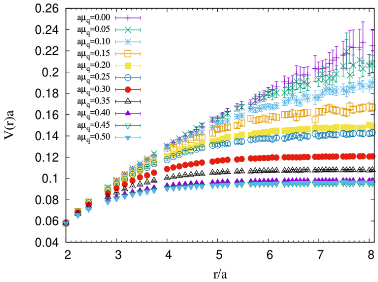
The ratio $\frac{L}{L_4}$

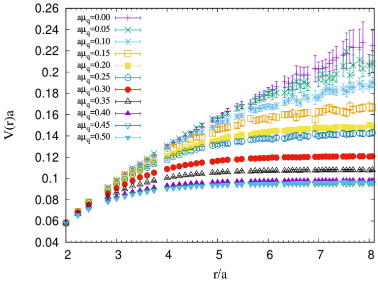


- Monopole trajectories become more static



Conclusion:

- We observe few manifestations of deconfinement in the region $a\mu \in (0.2, 0.3)$
  - Disappearence of percolation cluster
  - Density of wrapped clusters
- Confirmation of zero magnetic screening mass



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Confirmation confinement/deconfinement transition in dense medium!