Magnetic monopoles in high temperature QCD

Nucl. Phys. B 799 (2008), 241

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GGI workshop, Florence

Outline

Motivation

Abelian magnetic monopoles are candidates for explaining color confinement within the dual superconducting model of the QCD vacuum (confinement is induced by the breaking of a magnetic $U(1)$ symmetry via monopole condensation).

The magnetic component is supposed to be relevant (Chernodub & Zakharov '06, Liao & Shuryak '06) in explaining the physical properties of the Quark Gluon Plasma phase (above the transition).

It has been identified (Chernodub & Zakharov '06) with abelian magnetic monopoles "evaporating" from the condensate at $T > T_c$.

The Abelian Projection

How can we get abelian monopoles from a non abelian theory such as QCD?

- First we fix a gauge that leaves a $U(1)$ residual symmetry: in the Maximal Abelian Gauge we maximize $F_{\mathrm{MAG}} = \sum_{\mu,x} \mathrm{Re}\,\mathrm{tr}\left[U_\mu(x)\sigma_3 U_\mu^\dagger(x)\,\sigma_3\right]$
- Then we take the diagonal part of the links (Abelian Projection)

Possible dependence of the abelian observables on the gauge fixed prior the projection!!!

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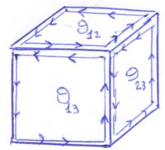
De Grand-Toussaint



De Grand elementary cube (in 3D)

On abelian projected configurations monopole currents are defined as
$m_\mu = \frac{1}{2\pi}\varepsilon_{\mu\nu\rho\sigma}\hat{\partial}_\nu\overline{\theta}_{\rho\sigma}$
where $\overline{\theta}_{\rho\sigma}$ is the compactified part of the abelian plaquette phase (De Grand & Toussaint '80).

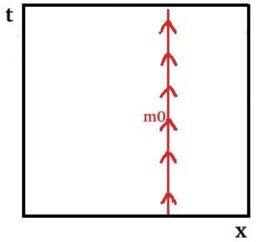
- Quantization of charge
- Closure of monopole currents: $\hat{\partial}_\mu m_\mu = 0$

The thermal monopole density

At $T < T_c$ magnetic currents are virtual;
At $T > T_c$ currents and monopoles become real (magnetic currents percolate in temporal direction).

Real particle = wrapped trajectory on the compact t direction (Chernodub & Zakharov '07).

$$\rho = \frac{\sum_{\vec{x}} \left| N_{wrap}(m_0(\vec{x},t)) \right|}{V_s}$$
$$m_0(\vec{x},t) = \text{magnetic trajectory in time direction}$$



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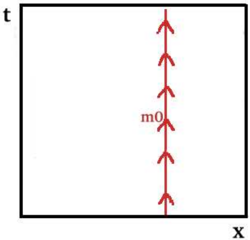

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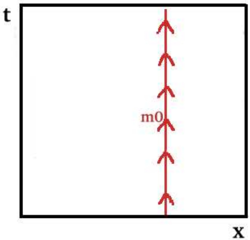

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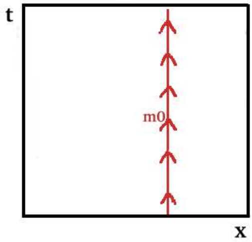


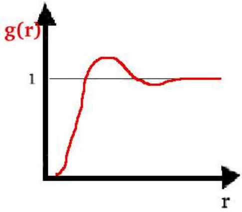
The monopole-(anti)monopole correlation function

$$g(r) = \frac{<\rho(0)\rho(r)>}{<\rho><\rho>} \quad \text{(monopole-monopole)}$$

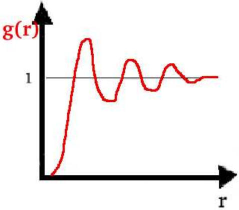
$$g(r) = \frac{<\rho^+(0)\rho^-(r)>}{<\rho^+><\rho^->} \quad \text{(monopole-antimonopole)}$$

$$g(r) = 1$$

g(r)-free gas



g(r)-liquid



g(r)-solid

- $g(r) = 1 \Rightarrow$ no interaction
- If the interaction potential $V(r)$ is weak we can extract it through $g(r) = exp(-V(r)/T)$.

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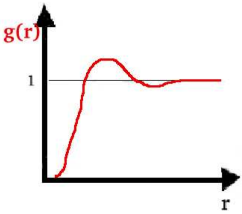

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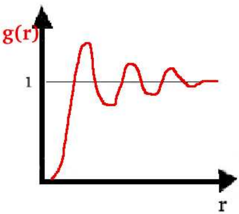

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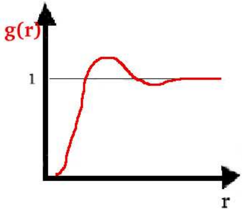

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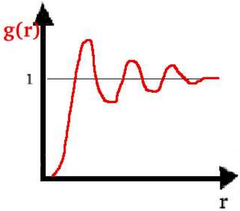

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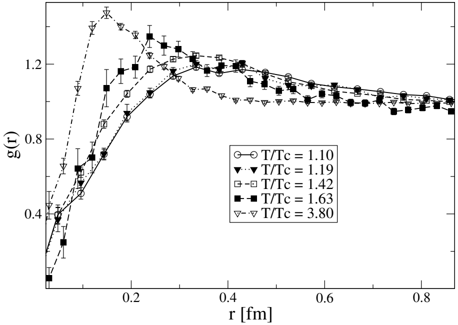

- Fit with screened Coulomb $V(r) = \alpha_M e^{-r/\lambda}/r$, $\lambda \sim 0.2$ fm;
- Liquid-like structure!!
  Stronger α_M coupling at high T (Liao & Shuryak '07);
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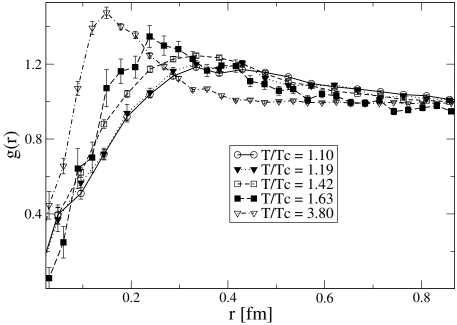

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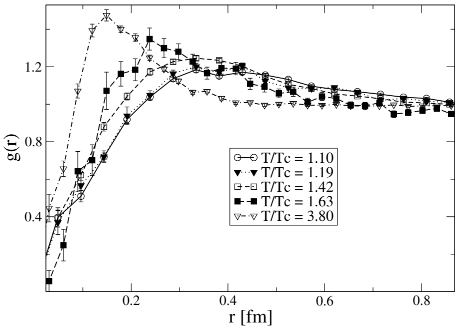

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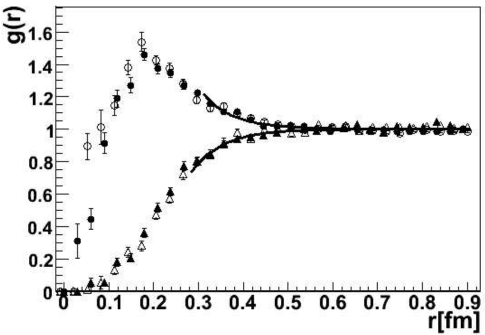

Monopole-monopole (triangles) Vs. Monopole-antimonopole (circles) at different β's

- Monopoles repel monopoles and attract antimonopoles;
- The scaling is good.

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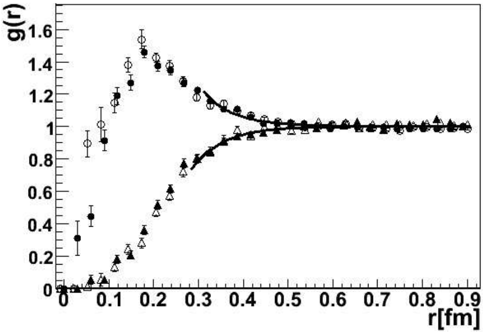

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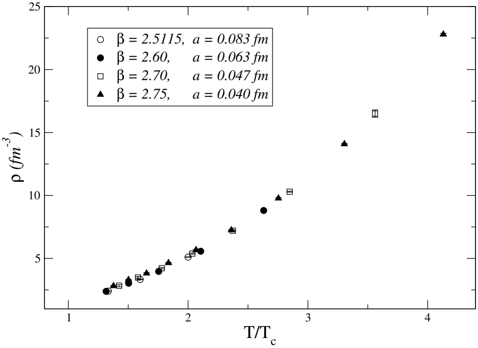

Monopole density (with MAG)

- $\rho \neq \frac{\zeta(3)}{\pi^2} T^3$ (free particles) $\Rightarrow$ interactions are important!!!
  Nice fit with $\rho \sim T^3/(\log(T/\Lambda_{eff}))^\alpha$ with $\alpha \sim 2 - 3$
- Good scaling (all data lay on the same physical curve).

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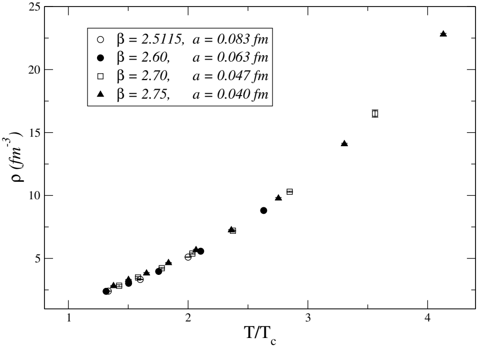

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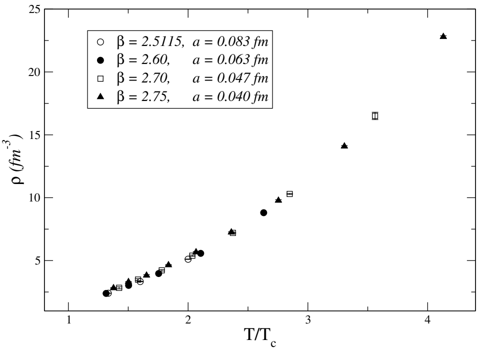

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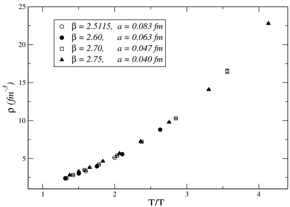
The gauge dependence problem

- In the Landau gauge, defined by maximizing $F_L = \sum_{\mu,x} \mathrm{Re}\,\mathrm{tr}\ U_\mu(x)$ before the Abelian projection, the monopole density is compatible with zero.

The Gribov ambiguity



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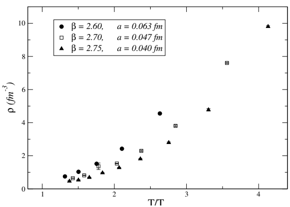

Monopole density (Landau preconditioning + MAG)

Within the same MAG gauge we start the gauge fixing iterative algorithm from a Landau gauged configuration: the density is now different and the scaling is lost. We are on a different local maximum of F_{MAG}.

A similar behavior was observed for vortices in center dominance studies (Bornyakov et al. '96, Kovacs & Tomboulis '99, Greensite et al. '01)

Summary

- We measured the density of thermal monopoles in the deconfined phase. An interacting behavior is observed, as $\rho \not\propto T^3$ (precisely $\rho \sim T^3/(\log(T/\Lambda_{eff}))^\alpha$ with $\alpha \sim 2$, even 3 at high T)
- We observed the monopole-(anti)monopole correlation function. A liquid-like behavior is observed.
- A very good physical scaling is observed for monopoles obtained with the standard Maximal Abelian Gauge;
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