String breaking, monopoles and the photon propagator in the 3D Abelian Higgs Model

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The mechanism of confinement in 3D $U(1)$ gauge theory is known to be due to monopoles [1]. Increasing the temperature in $2+1$ dimensions [2] as well as coupling the model to matter fields [3] destroys the confinement property. In view of the monopole mechanism of confinement in QCD [4] it might be interesting to study in the Abelian model how this is reflected in terms of string breaking. One might wonder whether, with matter fields included, this effect is accompanied by monopole binding in neutral clusters [5], analogous to what has been observed in the finite temperature case [2]. Deconfinement should also be signalled by a change of the gauge boson propagator, analogous to the finite temperature deconfinement of pure 3D $U(1)$ theory [6]. We have studied these questions in the 3D $U(1)$ Abelian Higgs model on the lattice. In this case the propagator should change from a form characteristic for a confining theory to a conventional Yukawa-type massive propagator due to the onset of the Higgs mechanism [7].

In order to study string breaking we have restricted ourselves to a Higgs model with fixed $|\varphi| = 1$ in the unitary gauge described by the action

$$S[\theta] = -\beta \sum_P \cos\theta_P - \kappa \sum_l \cos\theta_l \,. \tag{1}$$

We have considered the model varying κ at fixed $\beta = 2$. Instead of a usual phase transition there is a crossover causing the breakdown of confinement. We have localized it by means of the susceptibility of the hopping term. The crossover is accompanied by a sudden rise of the fraction of neutral clusters among the monopoles, mainly in the form of dipoles (see Fig. 1). Notice the volume independence of the susceptibility peak.

The potential between external charges has been extracted from the Polyakov loop correlator $\langle P(\mathbf{0}) P^*(\boldsymbol{R})\rangle = \exp\left(-LV(R)\right)$, with L being the linear size of the lattice. It has been parametrized in the form

$$e^{-LV^{\rm fit}(R)} = C_0 \Big[\sin^2\eta + \cos^2\eta\, \frac{\cosh(\sigma L(L/2-R))}{\cosh(\sigma L^2/2)}\Big] \cdot \exp\Big\{\gamma L \Big[\Delta_2^{-1}(R) - \Delta_2^{-1}(0)\Big]\Big\} \,. \tag{2}$$

Here Δ_2^{-1} is the inverse lattice Laplacian in two dimensions, and non-vanishing γ should mimick the presence of a Coulomb-like term. The R independent $\sin^2\eta$ term plays the

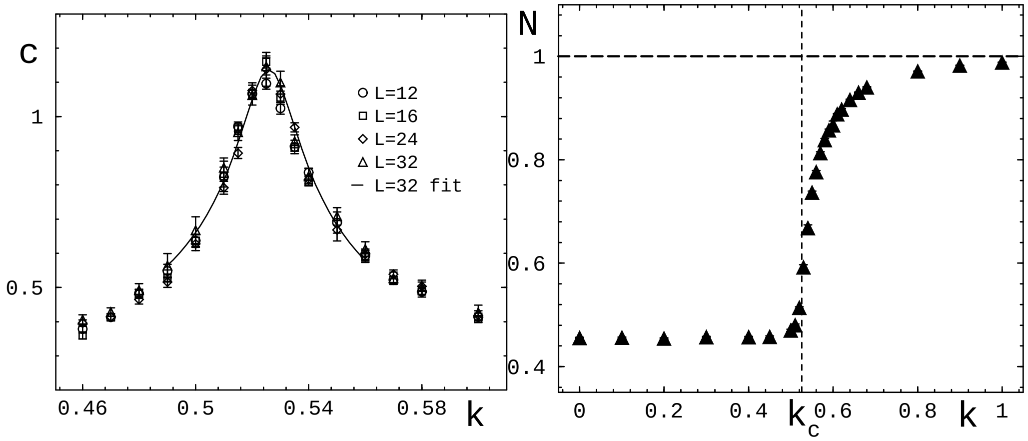

Figure 1: The hopping term susceptibility (left) and the fraction of neutral monopole clusters (right) as functions of κ.

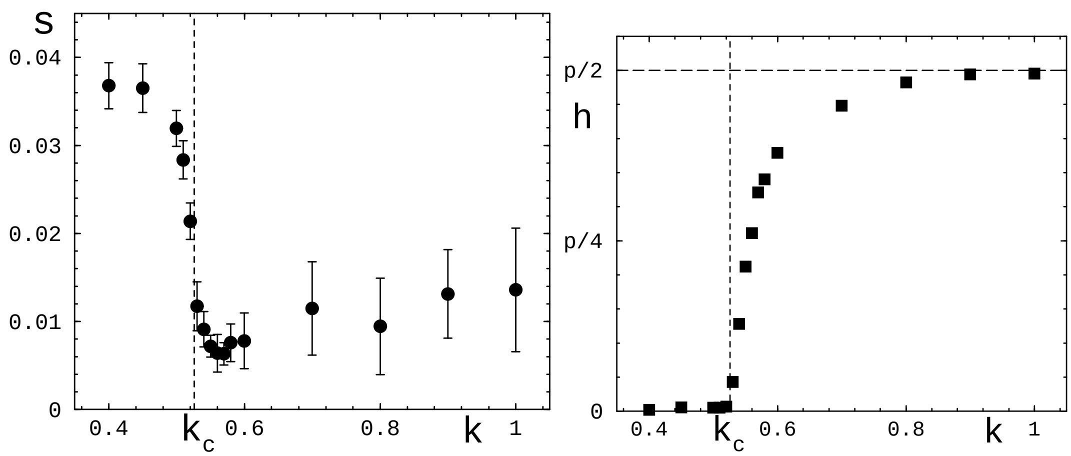

Figure 2: The effective string tension (left) and the breaking angle η (right) as functions of κ.

role of an order parameter describing the onset of deconfinement. The effective string tension σ as well as the breaking angle η have been found to change exactly at the crossover (see Fig. 2).

For the propagator study we have abandoned the unitary gauge and have performed gauge-fixing of the Monte Carlo gauge fields to the Landau gauge. In the confinement region the photon propagator is well described by the generic form suggested by Refs. [6],

$$D(p^2) = \frac{Z\ m^{2\alpha}}{\beta\ \left(p^{2(1+\alpha)} + m^{2(1+\alpha)}\right)} + C \qquad (3)$$

with non-vanishing mass m and anomalous dimension α. When the Abelian field is decomposed into monopole and regular part one can define the propagator of the latter (see Fig. 3), characterized by $\alpha = 0$ and some mass m_{reg} vanishing in the confinement region.

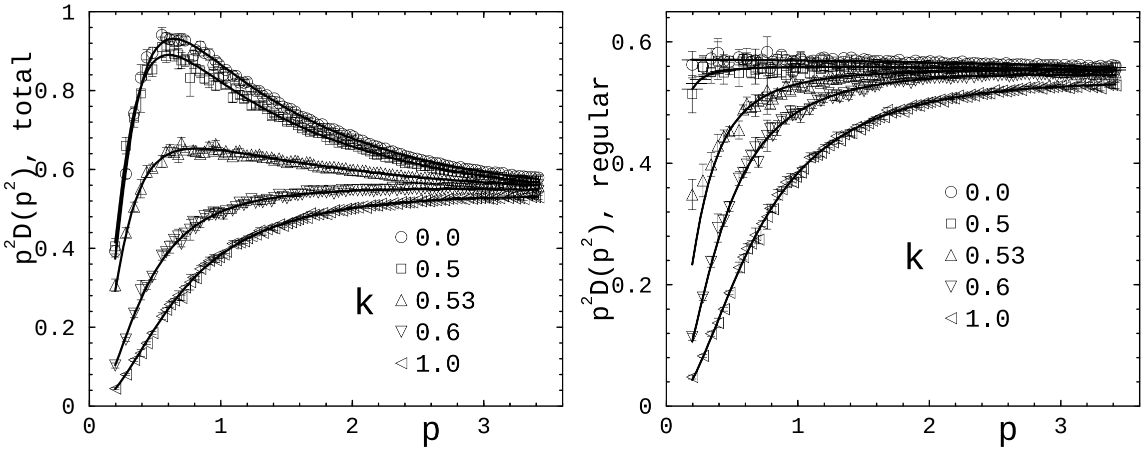

Figure 3: Momentum dependence of the total propagator (left) and of the regular part (right) and the fits for various κ.

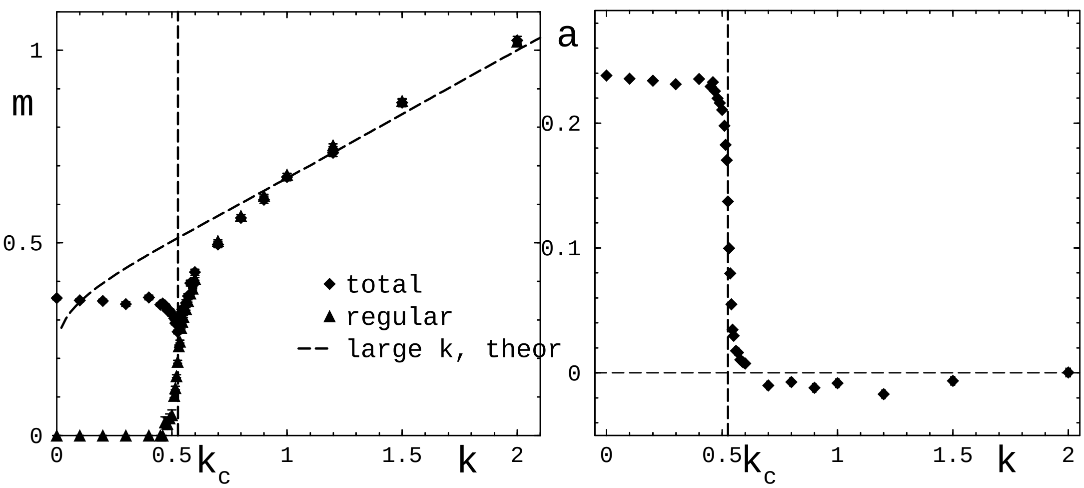

Figure 4: fit parameters of the propagators as functions of κ: the masses m and $m_{\rm reg}$ (left) with the large-κ prediction for $m_{\rm reg}$ and the anomalous dimension α (right).

At the crossover the photon mass changes its character from typical for the confining region to a conventional Higgs-generated mass $m_{\rm reg}$ while the anomalous dimension α drops to zero (see Fig. 4).

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