

Spatial confinement and thermal deconfinement in the 3D Gross–Neveu model

F.C. Khanna^{a,b}, A.P.C. Malbouisson^c, J.M.C. Malbouisson^{a,d,*}, H. Queiroz^d,
T.M. Rocha-Filho^e, A.E. Santana^e, J.C. da Silva^f

^a Theoretical Physics Institute, University of Alberta, Edmonton, Alberta T6G 2J1, Canada

^b TRIUMF, Vancouver, British Columbia V6T 2A3, Canada

^c Centro Brasileiro de Pesquisas Físicas/MCT, 22290-180 Rio de Janeiro, RJ, Brazil

^d Instituto de Física, Universidade Federal da Bahia, 40210-340 Salvador, BA, Brazil

^e Instituto de Física, Universidade de Brasília, 70910-900 Brasília, DF, Brazil

^f Centro Federal de Educação Tecnológica da Bahia, 40000-900 Salvador, BA, Brazil

Received 17 April 2005; accepted 8 August 2005

Available online 18 August 2005

Editor: L. Alvarez-Gaumé

Abstract

We study the N -component $(2 + 1)$ -dimensional Gross–Neveu model bounded between two parallel planes separated by a distance L at finite temperature T . From the four-point function, we obtain a closed expression for the large- N effective coupling constant $g = g(L, T, \lambda)$. Different behavior depending on the magnitude of the fixed coupling constant λ is found to lead to a “critical” value λ_c . If $\lambda < \lambda_c$, only short-distance and/or high-temperature “asymptotic freedom” ($g \rightarrow 0$) is found. For $\lambda \geq \lambda_c$, and low enough T , one also observes a divergence in g as $L \rightarrow L_c$, suggesting that fermions become spatially confined, an effect which is destroyed by raising the temperature. We find a confining length, $L_c \simeq 1.61$ fm, that is close to the proton charge diameter ($\simeq 1.74$ fm) and a “deconfining” temperature, $\simeq 138$ MeV, which is comparable to the estimated value of the deconfining temperature (≈ 200 MeV) for hadrons.

© 2005 Elsevier B.V. All rights reserved.

PACS: 11.10.Kk; 11.10.Wx

Keywords: Gross–Neveu model; Four-point function; Spatial confinement; Thermal deconfinement

* Corresponding author.

E-mail addresses: khanna@phys.ualberta.ca (F.C. Khanna), adolfo@cbpf.br (A.P.C. Malbouisson), jmalbouie@ufba.br (J.M.C. Malbouisson), hebe@fis.ufba.br (H. Queiroz), marciano@fis.unb.br (T.M. Rocha-Filho), asantana@fis.unb.br (A.E. Santana), jcsilva@cefetba.br (J.C. da Silva).

Effective models in quantum field theories have been employed over the last decades in trials to obtain clues about the behavior of strongly interacting particles. Among them, the Gross–Neveu model [1], dealing with the four-fermion contact interaction, has been analyzed at finite temperature as an effective model for QCD and for superconducting systems (see, for instance, Refs. [2,3]). Calculation of the effective potential of the ϕ^4 theory at finite temperature has also been performed [4].

Recently, we have studied the N -component tridimensional Gross–Neveu model at zero temperature, bounded between two parallel planes [5]. A closed expression was derived for the large- N effective coupling constant $g(L, \lambda)$ as a function of the distance L between the planes. From this result, the behavior of $g(L, \lambda)$ depending on the magnitude of the free space fixed coupling constant λ was found, such that for small λ ($\lambda < \lambda_c$), $g(L \rightarrow 0, \lambda) \rightarrow 0$; we refer to this property by saying that the model presents “asymptotic freedom” at short distances. On the other hand, for large enough values of λ ($\lambda > \lambda_c$) we found that $g(L \rightarrow L_c, \lambda) \rightarrow \infty$, implying that both spatial confinement (the system being bounded within the length L_c) and short distance asymptotic freedom are simultaneously present. In this context, the analysis of the effect of temperature is crucial, since it affects the confinement properties. The main objective of the present Letter is to study the spatial confinement and thermal deconfinement properties of the Gross–Neveu model.

We recall that even though it is perturbatively non-renormalizable for dimensions $D > 2$, the massive Gross–Neveu model in Euclidean three-dimensional (3D) space has been shown to exist and has been explicitly constructed in the large N [6]. A decisive physical point that brings consistency to this derivation is a theoretical result [7] supporting the idea that perturbatively non-renormalizable models do exist and have a physical meaning. For the $N = 1$ case, some operators can be made more relevant in the low energy region if the fermionic field is minimally coupled to the Chern–Simons field [8,9].

We consider the N -component 3D massive Gross–Neveu model, in the large- N limit, compactified along the imaginary-time axis and also along one of the spatial directions. From a physical point of view, in terms of a generalized Matsubara formalism [10], the model is intended to describe fermions bounded between two parallel planes, a distance L apart from one another and in thermal equilibrium with a reservoir at temperature $T = \beta^{-1}$. From the four-point function, we define an effective renormalized coupling constant $g(L, \beta, \lambda)$ in the large- N limit, which presents different behavior with L and β if the fixed coupling constant λ is below or above some “critical” value λ_c : high- T and short-distance asymptotic freedom, if $\lambda < \lambda_c$; with $\lambda \geq \lambda_c$, we obtain simultaneously asymptotic freedom and spatial confinement, for low enough temperatures. As the temperature is increased, a deconfining transition occurs. This is the first time, to our knowledge, that such an analytical calculation has been performed for an effective ab initio model.

Considering the Gross–Neveu model as an effective theory for the strong interaction between quarks and taking the constituent quark mass ($m \approx 350$ MeV) as the fermion mass, we find a confining length of 1.61 fm which is close to the proton charge diameter of ≈ 1.74 fm. Also, the temperature destroying the confinement, 138 MeV, is comparable to the estimated deconfinement temperature for hadrons (≈ 200 MeV).

A central ingredient in our approach is the topological nature of the Matsubara imaginary-time formalism. To calculate the partition function in a quantum field theory, the Matsubara prescription is equivalent to a path-integral approach on $R^{D-1} \times S^1$, where S^1 is a circle of circumference $\beta = 1/T$. As a consequence the Matsubara formalism can be thought, in a generalized way, as a mechanism to deal also with spatial constraints in a field theory model. In this situation, for consistency, the fields fulfill periodic (anti-periodic) boundary conditions for bosons (fermions). We infer from this discussion that we are justified to consider in this Letter the Matsubara mechanism as a path-integral formalism on $R^{D-2} \times S^1 \times S^1$ to deal simultaneously with temperature effects and spatial constraints. These ideas have been applied in different physical situations: for spontaneous symmetry breaking in the compactified ϕ^4 model [10,11]; for second-order phase transitions in films, wires and grains [12]; for the Casimir effect for bosons [13] and for fermions in a box [14]; and, in particular, for the Gross–Neveu model at zero temperature [5]. It is worth emphasizing that for the fermionic field, the boundary (anti-periodic) conditions coincide with the physical bag-model conditions [5,15,16].

Download English Version:

<https://daneshyari.com/en/article/9860918>

Download Persian Version:

<https://daneshyari.com/article/9860918>

[Daneshyari.com](https://daneshyari.com)