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ENDPOINT OF THE 4-D FINITE TEMPERATURE ELECTROWEAK PHASE TRANSITION

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Abstract

We determine the endpoint of the four-dimensional hot electroweak phase transition (SU(2)-Higgs model). The Monte-Carlo analysis is done on lattices with temporal extention of $L_t = 2$. Our results show that the electroweak phase transition is of first order for $m_H < 76.9 \pm 0.4$ GeV. At this endpoint the phase transition is of second order and only a rapid cross-over can be seen above it.

1. Introduction

The understanding of the observed baryon asymmetry of the universe needs a quantitative description of the electroweak phase transition (EWPT) [3]. It is known that the perturbative description of the EWPT breaks down for the physically allowed Higgs-boson masses (e.g. $m_H > 78$ GeV) [4]. Physical quantities (e.g. surface tension between the high and the low temperature phases, latent heat) obtain $\mathcal{O}(100\%)$ corrections in different orders of the perturbation theory.

* talk presented at the RESCEU'97 meeting, November 1997, Tokyo

In order to understand these nonperturbative phenomena a systematically controllable technique by lattice Monte-Carlo simulations is used. Since merely the bosonic sector is responsible for the bad perturbative features (due to infrared problems) the simulations are done without fermions. The first results dedicated to this questions were obtained on four-dimensional lattices [5]. Soon after another approach was initiated, namely simulations of the reduced model in three dimensions [6]. The latter contains two steps. The first one is a perturbative reduction of the original four-dimensional model to a three-dimensional one by integrating out the heavy degrees of freedom. The second step is the nonperturbative analysis of the three-dimensional model on the lattice, which is less CPU-time consuming than the Monte-Carlo simulation of the four-dimensional model. The comparison of the results obtained by the two techniques is not only a useful cross-check on the perturbative reduction procedure but also a necessity. The reason is that the fermions must be included perturbatively anyhow and the comparison tells us a lot about this perturbative step. In the recent years exhaustive studies have been carried out both in the four- [7] and in the three-dimensional [8] sectors of the problem. These works determined several cosmologically important quantities such as the critical temperature (T_c), interface tension (σ) and latent heat ($\Delta\epsilon$).

2. Study of the endpoint by the Lee-Yang zeros

Previous works show that the strength of the first order EWPT gets weaker as the mass of the Higgs-boson increases. Actually the line of the first order phase transition, separating the symmetric and broken phases on the $m_H - T_c$ plane has an endpoint, $m_{H,c}$. There are several direct and indirect evidences for that. In four dimension at $m_H \approx 80$ GeV the EWPT turned out to be extremely weak, even consistent with the no phase transition scenario on the 1.5-sigma level [9]. Three-dimensional results show that for $m_H > 95$ GeV no first order phase transition exists [10] and more specifically that the endpoint is: $m_{H,c} \approx 67$ GeV [11]. In this letter we present the analysis of the endpoint on four dimensional lattices. We study the thermodynamical limit of the first Lee-Yang zeros of the partition function. In order to get rid of the finite lattice spacing effects a careful extrapolation to the continuum limit should be performed.

We study the four-dimensional SU(2)-Higgs lattice model on asymmetric lattices, i.e. lattices with different spacings in temporal (a_t) and spatial (a_s) directions. Equal lattice spacings are used in the three spatial directions ($a_i = a_s$, $i = 1,2,3$). The asymmetry of the lattice spacings is given by the asymmetry factor $\xi = a_s/a_t$. The different lattice spacings can be ensured by different coupling strengths in the action for time-like and space-like directions

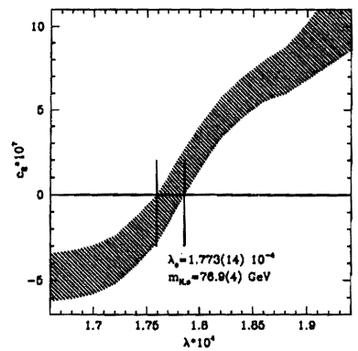

Fig. 1. The 1-sigma region for c_2 as a function of λ.

[12]. Details of the simulation techniques can be found in [7].

We have performed our simulations on $V = 2 \cdot L_s^3$ type four-dimensional lattices with asymmetry parameter of $a_s/a_t = 3.919$. We had 8 different lattices, each of them had approximatly a twice as large lattice-volume as the previous one. The smallest lattice was $V = 2{\cdot}5^3$ and the largest one was $V = 2{\cdot}24^3$. We collected quite a large statistics and the Ferrenberg-Swendsen reweighting [14] was used to obtain information in the vicinity of a simualtion point. Having determined the endpoint λ_c we determine the $T = 0$ quantities (renormalized masses and couplings) on $V = 64{\cdot}16{\cdot}8^2$, where $L_t = 64$. The determination of the endpoint of the finite temperature EWPT, thus a characteristic feature of the phase diagram, is done by the use of the Lee-Yang zeros of the partition function $\mathcal{Z}$ [13]. We analytically continue $\mathcal{Z}$ to complex values of κ by reweighting the available data. Denoting κ_0 the lowest zero of $\mathcal{Z}$, i.e. the zero closest to the real axis, one expects in the vicinity of the endpoint the scaling law $\mathrm{Im}(\kappa_0) = c_1(\lambda)V^{-\nu} + c_2(\lambda)$. In order to pin down the endpoint we are looking for a λ value for which c_2 vanishes. Again, the change in λ has been done by reweighting.

Figure 1 contains our results. As it can be seen for large values of λ (above $1.787 \cdot 10^{-4}$) the whole one-sigma region for c_2 is positive. This is a clear signal for a rapid cross-over, without any first order phase transition. For smaller values of λ the allowed region for c_2 is negative indicating a first order phase transition (as we have pointed out in the previous paragraph c_2 should actually vanish in the thermodynamical limit; however, for a finite lattice negative values appear).

The endpoint of the finite temperature electroweak phase transition is at

$\lambda_c = 1.773 \pm 0.014 \cdot 10^{-4}$. Determining the zero temperature quantitites one obtains $m_{H,c} = 76.9 \pm 0.4$ GeV for the corresponding Higgs-boson mass.

3. Discussion

In this paper we have determined the endpoint of the finite temperature electroweak phase transition. We have used $L_t = 2$ temporal extension on lattices with asymmetric lattice spacings: $a_s/a_t = 3.919$. The endpoint is given by $\lambda_c = 1.773 \pm 0.014 \cdot 10^{-4}$. Below this scalar self-coupling the phase transition is of first order. Above this value no phase transition can be observed, only a rapid cross-over occurs. The corresponding physical value of the Higgs-boson mass is $m_{H,c} = 76.9 \pm 0.4$ GeV. Since our temporal extension is rather small ($L_t = 2$) and our lattice spacing asymmtery is quite large (≈ 4) we plan to study the endpoint on finer lattices.

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4. References

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