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MSSM electroweak baryogenesis and flavour mixing in transport equations

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Abstract

We make use of the formalism of [T. Konstandin, et al., hep-ph/0410135], and calculate the chargino-mediated baryogenesis in the Minimal Supersymmetric Standard Model. The formalism makes use of a gradient expansion of the Kadanoff–Baym equations for mixing fermions. For illustrative purposes, we first discuss the semiclassical transport equations for mixing bosons in a space–time-dependent Higgs background. To calculate the baryon asymmetry, we solve a standard set of diffusion equations, according to which the chargino asymmetry is transported to the top sector, where it biases sphaleron transitions. At the end we make a qualitative and quantitative comparison of our results with the existing work. We find that the production of the baryon asymmetry of the universe by CP-violating currents in the chargino sector is strongly constrained by measurements of electric dipole moments.

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1. Introduction

Electroweak baryogenesis [2] is an effective framework for explaining the baryon asymmetry of the universe (BAU). The most appealing feature of this mechanism lies in the fact that the

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relevant physics will soon be explored by experiments, most notably by LHC at CERN and by the new generation of electric dipole measurements.

It has been realized that the scenario of electroweak baryogenesis depends on extensions of the Standard Model (SM), since two mandatory conditions are not met in the SM. The first reason is that CP-violation in the SM is marginal, such that the observed magnitude of baryon asymmetry cannot be explained. Secondly, the electroweak phase transition in the SM is a crossover [3,4], leading to a too weak departure from equilibrium to be viable for baryogenesis.

The Minimal Supersymmetric Standard Model (MSSM) instead has all the necessary ingredients. CP violation is enhanced by adding phases to the parameters in the soft supersymmetry breaking sector, which contribute to the chargino mass matrix. Furthermore, the additional bosonic degrees of freedom can lead to a strong first-order phase transition as, e.g., in the light stop scenario [5,6].

These considerations indicate that the MSSM has the potential of explaining the observed BAU via electroweak baryogenesis. However, a formalism that determines the baryon asymmetry has to incorporate several features. Clearly, the formalism has to reflect the quantum nature of the involved particles, for CP violation is a purely quantum effect. In addition, since the sphaleron processes are only operative in the unbroken phase, the CP-violating particle densities have to be transported away from the wall into the unbroken phase to lead to a net baryon density. A formalism that can handle both of these aspects is given by the Kadanoff–Baym equations, which are in turn derived from the out-of-equilibrium Schwinger–Dyson equations.

Early approaches that aimed to determine CP-violating densities and have not attempted to derive transport equations from first principles have been based on the dispersion relation of the quasi-particles [7–11] deduced with the WKB method. For a recent resurrection of the method see [12].

In [13,14] it was suggested that an important contribution is given by mixing effects of the quasi-particles in the wall rather than from the dispersion relations in the case of a nearly degenerate mass matrix. However, in the work [13,14] transport equations are not derived in a first principle approach either, but the current continuity equation is used to determine CP-violating contributions to the Green functions in a perturbative approach, which are subsequently inserted as sources into classical diffusion equations derived in [16]. These classical diffusion equations neglect oscillations of the off-diagonal elements of the Green function that are important for a proper treatment of CP violation.

Starting from the Kadanoff–Baym equations, the authors of [17,18] have derived the CP-violating semiclassical force in kinetic transport equations, which appears in fermionic kinetic equation at second order in derivatives. Initially, this was done for the one fermion flavour case [17] and then subsequently generalized to the diagonal part of the multiflavour case [18].

Recently, this formalism was advanced to include mixing fermions [1]. The formalism provides an accurate description of the dynamics in the thick wall regime, which applies to particles, whose de Broglie wave length is much shorter than the thickness of the phase boundary (bubble wall), formally $\partial_x \ll k$.

One conclusion of the work [1] is that two features of the transport equations are not captured by the procedure used in [13,14]. Firstly, the densities that are off-diagonal in the mass eigenbasis of the system will perform oscillations analogously to neutrino oscillations. This effect suppresses the transport of the CP-violating sources, especially if the mass spectrum in the chargino sector is far from degeneracy. Secondly, while Refs. [13,14] used a phenomenological prescription (Fick's law) to introduce the CP-violating sources into the diffusion transport equa-