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論文題目:
Studies on Electroweak Phase Transition Signatures:
A Bridge Between Cosmological and Collider Phenomenology
（電弱相転移の特性に関する理論的研究：宇宙現象と加速器現象の架け橋）

論文要旨

One of the biggest issues plaguing modern physics is the observed value of the Baryon Asymmetry of the Universe. One of the most promising mechanisms to explain the observed Baryon Asymmetry of the Universe is Electroweak Baryogenesis. For Electroweak Baryogenesis to be successful, there must have occurred in the early universe a Strongly First Order Electroweak Phase Transition. In order for the Electroweak Phase Transition to be First Order, the sphaleron decoupling condition must be satisfied. The sphaleron decoupling condition requires large deviations in the Higgs triple self-coupling. The Higgs triple self-coupling measurements at colliders can thus be used to probe the nature of the Electroweak phase transition. Furthermore, first order cosmological phase transitions are capable of generating gravitational waves and even, in certain circumstances, primordial black holes. In extended scalar models, the main effects leading to these phenomena are the non-decoupling effects originating from loop correction from the new degrees of freedom. The Standard Model Effective Field Theory is not appropriate to describe non-decoupling effects, while the Higgs Effective Field Theory lacks predictive power. In order to consistently describe the non-decoupling effects from new physics in a model independent framework, the nearly-aligned Higgs Effective Field Theory must be used.

In this thesis, various topic on the Standard Model phenomenology, extended Higgs models, and cosmology of the electroweak phase transition are reviewed. The nearlyaligned Higgs Effective Field Theory, it's validity, and it's effectiveness in describing non-decoupling effects is also reviewed in detail. Then, a new observable is proposed as a probe for the nature of the Electroweak phase transition, the Higgs di-photon effective coupling. Towards this objective, the nearly-aligned Higgs Effective Field Theory is extended for the first time into it's sub-leading order, chiral dimension 4, Lagrangian. This is necessary since, in the chiral formalism, loop induced interactions, like the Higgs di-photon, are only described by Lagrangians of this order. Furthermore, several classes of models are chosen as benchmark models for our analysis using the effective theory.

The non-decoupling effects on the Higgs di-photon couplings are analysed, and it's importance once again proven. It was found that in models with charged scalars, large values of the Higgs triple self-coupling become easily constrained by Higgs di-photon measurements, unless the new physics scale is high enough. Then, an analysis of signatures of the electroweak phase transition is performed for the benchmark models mentioned above. The sphaleron decoupling condition is taken into account, together with the phase transition completion condition, and perturbative unitarity. Various observables are analysed, such as the Higgs triple self-coupling, the Higgs di-photon coupling, gravitational waves, and primordial black holes. Besides corroborating the necessity of a large Higgs triple self-coupling, it is shown that models with charged scalars also necessitate large deviations on the Higgs di-photon coupling.

This thesis closes with discussions on the usage of future measurements to probe the nature of the Electroweak phase transition. First, an hypothetical scenario of Higgs di-photon coupling measurement at the HL-LHC is considered. In this scenario, it is shown how such measurements can be used to give tangible predictions on subsequent measurements of the Higgs triple self-coupling, in order to produce a Strongly First Order Electroweak Phase Transition. Secondly, hypothetical scenarios of Higgs triple self-coupling measurements at the HL-LHC and the various stages of the ILC are considered. It is shown that such measurements at the HL-LHC and the first and second stages of the ILC are incapable of decisively determining the nature of the electroweak phase transition by themselves. Even the last stage of the ILC is shown to only determine that the electroweak phase transition is first order, or that it is not first order, in some very fine-tuned circumstances. It is also shown that joining these measurements of the Higgs triple self-coupling, with the ones from the Higgs di-photon, can solve this issue and decisively determine the nature of the Electroweak phase transition in the future. This further motivates the use of the Higgs di-photon as a complementary probe of the nature of the Electroweak phase transition.