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【学位論文内容の要旨】

In 2012, a new boson was discovered with the mass 126GeV at the Large Hadron Collider (LHC). After that, the spin of this boson turned out to be zero. It was confirmed that this boson couples to many of the standard model (SM) particles. Consequently, the new particle was identified to be a Higgs boson, which plays a role of triggering spontaneous breaking of the electroweak gauge symmetry and generating masses of elementary particles. Furthermore, its coupling strength to the other particles seems to be consistent with the prediction in the SM within the error of the current data. Therefore, the SM was found to be a very successful model even with including the Higgs sector.

However, none of the researchers believes that the SM is a fundamental theory of particle physics. In the SM, only Electromagnetic Force and Weak Force are unified to Electroweak Force at the energy scale above 100GeV, which is written as a quantum gauge field theory with the gauge symmetry $SU(2)_L \times U(1)_Y$. On the other hand, Strong Force is described as an independent gauge theory with $SU(3)_C$, the quantum chromodynamics. Consequently, the gauge structure of the SM is given by $SU(3)_C \times SU(2)_L \times U(1)_Y$. From the viewpoint of the history of unification of law in physics, the SM is nothing but a low energy effective theory of a more fundamental theory such as the grand unified theory (GUT), in which the gauge structure in the SM is derived from a more simple structure such as SU(5), SO(10), and so on.

Another reason why the SM is not a fundamental theory arises from its Higgs sector. As the Higgs field is the order parameter of electroweak gauge symmetry breaking, it must be a scalar field. It has been known that the introduction of such a scalar field into a gauge field theory is problematic, yielding quadratic ultraviolet divergences in the radiative correction to the mass of the Higgs boson. Renormalization of these quadratic divergences bring a serious problem of huge fine tuning, so-called the hierarchy problem. Clearly, a new physics model beyond the SM is necessary at the TeV scale, in which the quadratic divergences are canceled and the hierarchy problem disappears.

Introduction of supersymmetry (SUSY) at the TeV scale is a charming idea. SUSY is the symmetry between bosons and fermions. The quadratic divergences from a bosonic loop contribution and from a fermion loop contribution are canceled with each other in SUSY theories. Supersymmetric extensions of the SM have been extensively investigated for previous three decades. The minimal supersymmetric standard model (MSSM) predicts a set of new particles at the TeV scale, SUSY partner particles of the

SM ones. In addition, the Higgs sector is predicted to be composed of two Higgs doublets in the MSSM, in which the mass of the SM-like Higgs boson is preferred to be less than about 120 GeV without large fine tuning. The recent LHC results that the mass of the Higgs boson is 126 GeV and that no other new particles has not been found yet seem to indicate the tension between the MSSM and the hierarchy problem. Some extended models from the MSSM are also investigated to relax this tension. In the next-to-minimal supersymmetric standard model (NMSSM), the mass of the Higgs boson can be greater than that in the MSSM, and the experiment value of the Higgs boson mass may be explained easier.

SUSY-GUTs are attractive, because the hierarchy problem disappears and the gauge couplings are unified with better accuracy as compared to the GUT without SUSY. The unification scale is typically 10^{16}GeV. SUSY-GUTs also have a new fine-tuning problem. In these models, there is the mass splitting between the color triplet and $SU(2)_L$ doublet Higgs fields, which arises from common multiplet. This is so-called the doublet-triplet splitting problems. In general, it is very difficult to test models of GUTs at the collider experiments. The GUT scale is typically $O(10^{16})$ GeV that is inferred from gauge coupling unification scale. Due to the decoupling theorem, it is difficult to test GUTs at the electroweak scale. Usually, tests of GUTs rely on checking relations among parameters of new particles by flavor experiments indirectly.

In this thesis, we discuss a new type of GUTs, the supersymmetric grand unified theory with the Hosotani mechanism (SGGHU). This model was proposed to solve the doublet-triplet problem. This model predicts the existence of adjoint chiral superfields whose quantum numbers are equal to the gauge bosons in the standard model and masses are at the supersymmetric breaking scale, namely at the TeV scale. The Higgs sector is extended with additional $SU(2)_L$ triplet and singlet chiral multiplets. Therefore, properties of particles in the Higgs sector are different from the standard model and other models. In this thesis, phenomenological analyses of the SGGHU, especially the mass spectrum of the particles in the model and the coupling constants of the Higgs sector. We calculate deviations in coupling constants of the standard model-like Higgs boson and the mass spectrum of the additional Higgs bosons. We find that our model is distinguishable from the others by precision measurements of these couplings and masses of the additional Higgs bosons. We show the testability of our model at the collider experiments such as the luminosity up-graded Large Hadron Collider and the International Linear Collider.

【論文審査の結果の要旨】

当審査委員会は上記申請論文を査読し、2014年１月２７日の本審査会と学位論文公聴会（オーラルディフェンス）で精緻な質疑応答を行なった結果、申請者には博士（理学）の学位を受けるに十分な当該専門分野の学識と研究業績があると認め、合格と判定した。以下に審査結果概要を示す。

本論文では、素粒子の相互作用（電弱相互作用、強い相互作用）を統一的に理解するために考案された数々の大統一理論の中のある種の理論（大ゲージ・ヒッグス超対称統一模型）が、素粒子の質量起源を担うとされるヒッグス粒子の物理に影響を与えることに注目し、将来実験でのヒッグス粒子の性質の詳細測定によって、大統一理論を加速器実験で検証するという可能性を、世界で始めて議論している。

大統一理論は、力の統一が実験で到達できるエネルギー領域（１０００ギガ電子ボルト）より遥かに高いエネルギー（１０の１６ギガ電子ボルト程度）で実現する。その結果、加速器での検証はその効果が小さすぎて絶望視されていた。この為、陽子崩壊という理論が予言する希少な現象を捉える努力がなされているが証拠は発見されていない。

大ゲージヒッグス超対称統一理論では、対称性の自発的破れではなく細谷機構と呼ばれるメカニズムで大統一対称性を破る。この理論の特徴として、非常に軽い（テラ電子ボルト程度の質量の）スカラー場が複数現れる。そのためヒッグスセクターはアイソスピン2重項場に加え１重項場や３重項場を含む。谷口裕幸氏はこの性質に注目し、この理論を将来の加速器実験で検証できるのではないかと考えた。

谷口氏はこの理論を深く理解し、理論に現れる拡張ヒッグスセクターの性質を詳しく調べた。大統一のエネルギー領域で様々な場の結合定数が同じ値を持つことからスタートして、低エネルギーでの諸物理量の大きさを理論計算した。実験で到達できるテラ電子ボルトのエネルギー領域に現れる複数のヒッグス粒子の質量を持ち得るかを計算し、またヒッグス場とクォークやレプトンとの結合定数を計算した。得られた標準理論からのズレは数パーセントであるが、計画中の国際線形加速器（ILC）では結合定数をパーセントレベルで測定できる為、ILCでこの理論を検証できる可能性があると結論した。

本論文を審査した結果、研究内容の専門性と独創性に関して異論は出ず、公聴会でも素粒子理論の高度な専門知識に基づく内容を解りやすく説明するなどのプレゼンテーションを行なうことができた。これを受けて審査委員全員で審議した結果として、申請者は学位を受けるに十分であると認め、本審査および最終試験ともに合格と判定した。