Synopsis

Standard Model(SM) is a gauge theory invariant under $SU(3)_c \times SU(2)_L \times U(1)_Y$. The interaction is mediated by eight gluons of the strong interaction sector and the four gauge bosons $W^{\pm}, Z^0$ and γ of the electroweak sector. In nature $SU(2)_L \times U(1)_Y$ symmetry is broken and so $SU(3)_c \times U(1)_{em}$ symmetry is preserved at low energy. The most popular method to induce this symmetry breaking is to assume the existence of a complex doublet higgs field, which upon acquiring vacuum expectation value breaks the electroweak symmetry. Out of the four real degrees of freedom of the complex doublet three get absorbed by the gauge bosons of electroweak sector as longitudinal degrees of freedom and hence three gauge bosons become massive. The fourth degree of freedom is expected to be detected by the experiment. From LEP searches the present lower bound on its mass is 63 GeV[1].

In SM left handed fields transform as doublets and right handed fields as singlets of the $SU(2)_L$ group. On the other hand quarks transform as triplets and leptons transform as singlets of the $SU(3)_c$ group. The right handed neutrino is not included in SM to render the neutrino absolutely massless. Hence there are fifteen fermions per generation. There exists three generations making a total of fortyfive fermions. Out of all these fermions the top quark is yet to be discovered by direct experimental search though there are a number of indirect (theoretical as well as experimental) evidences of the existence of the Top quark. At the Fermilab Tevatron the Top quark decays which are allowed by SM are studied. The present lower bound on the mass of the top quark is 108 GeV from CDF collaboration and about 10 GeV less from the D0 collaboration[2].

In spite of great experimental successes the Standard Model cannot be given the status of a complete theory and there is strong motivation for the study of the physics beyond the Standard Model. In this thesis we have concentrated on GUTS and supersymmetric GUTS as studies beyond the Standard Model. GUTS offer the possibility of a simple but unified description of strong and electroweak interactions. Typically in these models all the interactions arise out of a single Lagrangian which is locally invariant under the gauge transformations of a single simple lie group called the unification group. The fermions are put into some irreducible representation of the GUT group. A large spectrum of GUTS are proposed in the literature which can be classified by the unification group. All these theoretically very attractive models have at least one common prediction namely the decay of proton.

This thesis looks at the constraints on unification theories vis-a-vis the recent experimental results coming from high LEP results. The work may be subdivided into three broad classes. First part deals with comparing the experimental results with the predictions of the known models of unification. The second part deals with a new paradigm of GUT namely the low energy unification. In the third part we look at the predictions that one may obtain from the study of the evolution of the yukawa couplings in supersymmetric GUTS.

We have shown that the stringent bounds placed on the weak mixing angle from a recent analysis of measurements at LEP rule out any possibility of the survival of Left-Right symmetry at low energies in Grand Unified Theories and partially unified theories. The lowest mass scale to which the left-right symmetry survives is 10^9 GeV. This scale is driven up even higher with the inclusion of the higgs contributions to beta functions, and also in the supersymmetric versions of the theories[3].

Recently it has been shown that using the precise values of the weak mixing angle and the strong coupling constant at weak scale an unique intersection point of the strong weak and hypercharge couplings is not obtained in one step unification assuming only SM at low energy and with one higgs doublet. Furthermore it has also been shown that the criterion of unique intersection of the couplings at the unification scale is satisfied in the minimal supersymmetric standard model, predicting an unification scale around 10^{16} GeV and the supersymmetry scale around 1 TeV[4]. In this context we consider the modification of the minimal $SU(5)$ lagrangian due to higher dimensional operators, arising from quantum gravity effects or from spontaneous compactification of extra dimensions in Kaluza-Klein theories. Due to the presence of these operators the strong weak and hypercharge couplings do not meet at all at the unification scale, M_U, and the magnitude of the mismatch are directly related to the couplings of the higher dimensional operator. In particular, we consider five and six dimensional operators and show that large range of values of couplings of these operators are compatible with the latest values of the weak mixing angle and the strong coupling constant derived from LEP. Experimental constraints on M_U coming from proton lifetime is also satisfied[5]. We have also studied the nonterturbarive unification scenario first proposed by Maiani Parisi and Petronzio[10] in the context of the LEP data. We see that the supersymmetric version of the theory with five fermion generations is still consistent with the LEP data though the nonsupersymmetric version is ruled out.

Recently a new paradigm of GUT has evolved with an interesting possibility that unification is achieved at a low scale which means the absence of the big desert while at the same time the experimental constraints including that of the proton lifetime remain satisfied[6]. A GUT model based on $SU(15)$ or $SU(16)$ offers such a possibility. We have studied the possibility of achieving low unification scale GUT models based on $SU(16)$[7]. Baryon number symmetry being an explicit local gauge symmetry the gauge boson mediated proton decay is absent. We have considered in detail a number of breaking chains and the higgs representations giving rise to the desired symmetry breaking, and identified one chain giving low energy unification. These higgs field representations are constructed in such a way that higgs mediated proton decay is absent. At the end we have indicated the very rich low energy physics obtainable from these models which includes quark-lepton ununified symmetry and chiral color symmetry. Phenomenological implications of these low energy groups are also studied.

The $SU(15)$ GUT model was already existing in the literature when we started working on such model building exercises. Our result [8]is that when one includes the higgs field contributions in the beta functions and assume the well known extended survival hypothesis, it rules out the symmetry breaking chains which exist in the literature. On the other hand it predicts new phenomenologically more interesting symmetry breaking chains.

Supersymmetry offers a very interesting theoretical possibility which places fermions and bosons at an equal footing via its symmetry transformations laws. Though supersymmetry itself can solve the problem of gauge hierarchy it is nevertheless an interesting proposition to endow the $SU(15)$ GUT model with supersymmetric transformation laws and see the consequences. This is simply because supersymmetry is a rich symmetry and nature seems to use all the symmetries available to her. We have considered the supersymmetric version of the $SU(15)$ GUT[9] and applied the constraints coming from the LEP experiments. We have attempted to ask the question that if supersymmetry is discovered in near future how is it going to affect the new paradigm of low energy unification of the $SU(15)$ GUT. We find that the low energy unification with $SU(15)$ in the supersymmetric framework is not allowed. Most of the symmetry breaking chains do not allow for low energy unification, and a few symmetry breaking chains which low energy unification fail to satisfy the perturbative unification constraint (coupling constant less than unity). Hence the signals of the existence of supersymmetry in future colliders will rule out the possibility of low energy unification.

The perfect unification of gauge couplings[4] around the scale 2×10^{16} GeV in the presence of supersymmetry above the TeV range is often considered as a serious hint about the existence

of supersymmetry in nature. We have considered the evolutions of the yukawa couplings of the Minimal Supersymmetric Standard Model (MSSM) assuming that there is an underlying perturbative theory upto the scale of unification of the gauge couplings (M_U). Demanding that the Top quark yukawa coupling has to remain perturbative upto the scale M_U we have calculated the upper bound of the top quark yukawa coupling at the low energy scale. This in turn gives a lower bound on the quantity $tan\beta$ of MSSM which is defined as the ratio of the vacuum expectation values of the higgs fields that couples to the top quark to that which couples to the down quark. Such bound on the value of $tan\beta$ is expected to influence the search of higgs bosons in the MSSM [11] [12]. Numerically this bound is very similar to the bound obtained from the fixed point solution of the top quark Yukawa coupling.
In summary in the first part we have considered the presently available experimental data and worked out some of its consequences in the context of unified models. In the second part we have done some model building exercises which avoids the hierarchy problem and does not suffer from fast proton decay. At the end we have studied the evolution of yukawa couplings in the context of supersymmetric GUTS and have given lower bound on the parameter $tan\beta$ of the MSSM.

References

[1] G. Giacomelli, P. Giacomelli, CERN Preprint, CERN-PPE/93-107, (1993) D. Decamp et al, Aleph Collaboration, Phys Rep, **216**, (1992), 253. These references also summarize the search of the higgs bosons expected in supersymmetric extensions of the model.
For higgs searches in the presence of a broken global U(1) symmetry see for example B. Brahmachari, A.S. Joshipura, S.D. Rindani, D. P. Roy and K. Sridhar. Tata Institute preprint TIFR-TH-93/26. (to appear in Phys. Rev. D)

[2] R. Berbieri, Summary talk given at Recontres de Moriond on Electroweak Interactions and Unified Theories, Les Arcs, France. March 1993, CERN Preprint, CERN-TH-6863/93, (1993)

[3] B. Brahmachari, U. Sarkar and K. Sridhar, Phys. Lett. **B 273** (1992), 105

[4] U. Amaldi, W. de Boer and H. Furstenau, Phys. Lett. **B 260** (1991), 447
F. Anselmo, L. Ciforelli, A. Zichichi, CERN Preprint, CERN-PPE/92-123, (1992).

[5] B. Brahmachari, P.K. Patra, U. Sarkar and K. Sridhar, Mod Phys Lett **A8** (1993), 1487.

[6] P.H. Frampton and B.H Lee. Phys. Rev. Lett **64** (1990) 619.

[7] B. Brahmachari; Phys. Rev. **D 48**, (1993), 1266

[8] B. Brahmachari,R.B. Mann, U. Sarkar and T.G Steele, Phys. Rev. **D 45** (1992) 2467.

[9] B. Brahmachari, U. Sarkar, Phys. Lett. **B 303** (1993), 260

[10] B. Brahmachari, U. Sarkar, K. Sridhar, Mod Phys Lett, **A8** (1993), 3349

[11] B. Brahmachari, Preprint, Preprint PRL-TH-93/15, (1993)

[12] B. Brahmachari and P. Roy, Preprint PRL-TH-93/17, (1993)