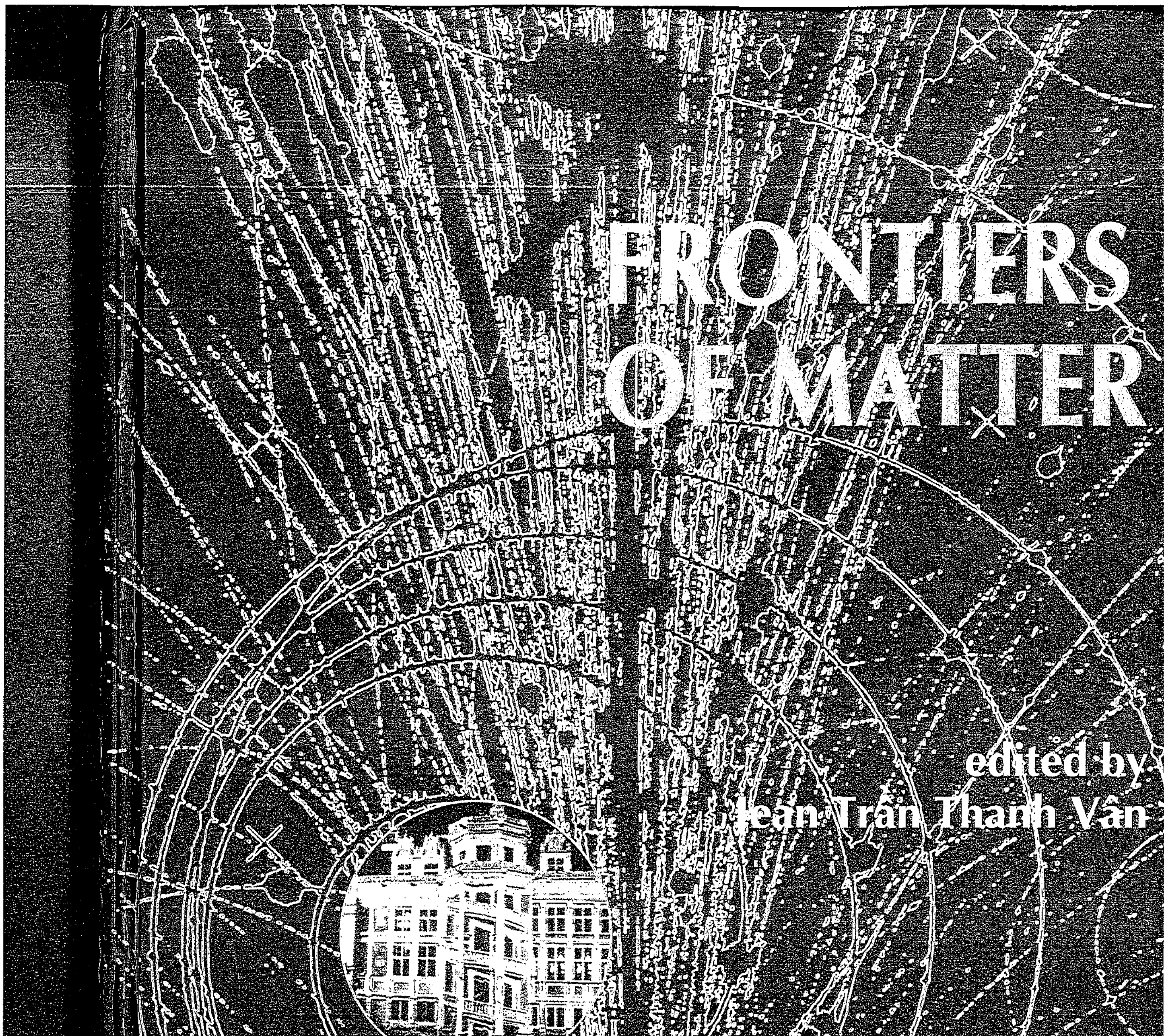
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LOW ENERGY UNIFICATION: PHENOMENOLOGICAL VIABILITY AND ITS IMPLICATIONS

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We investigate the required changes in the MSSM β-functions in order to achieve intermediate scale unification, working in the traditional logarithmic running of the gauge couplings. A string unified model with the required extra matter is presented. Assuming also a compactification scale (and the appearance of KK states), we check the viability of intermediate scale GUT unification.

1 Introduction

It was recently proposed [1,2,3], that in the weakly-coupled Type I string vacua the string scale can naturally lie in some intermediate energy, 10^{10-13}GeV, which happens to be the geometrical mean of the Planck scale, M_P, and weak scale, M_W (i.e. $M_{string} \sim \sqrt{M_W M_P} \sim 10^{11}$GeV). It is a rather interesting fact that the possibility of intermediate scale unification was also shown to appear in the context of Type IIB theories [4]. This scenario has the advantage that this intermediate scale does not need the power-like running of the gauge couplings in order to achieve unification.

In this talk we would like to investigate the changes that the MSSM β-functions should suffer in order to achieve gauge coupling unification at 10^{10-13}GeV. We further determine the extra matter fields which make gauge couplings merge at an intermediate energy and show that such spectra may appear in the context of specific string unified models which can in principle avoid fast proton decay. Finally, we address the same questions assuming Kaluza-Klein massive states above a compactification scale M_C.

2 Renormalization Group Analysis

In this section we will explore the possibility of modifying the MSSM β-functions in order to implement the intermediate scale unification scenario. We begin by writing down the (one-loop) running of the gauge couplings

$$\frac{1}{\alpha_i(M)} = \frac{1}{\alpha_U} + \frac{\beta_i}{2\pi}\log\frac{M_U}{M_{SB}} + \frac{\beta_i^{NS}}{2\pi}\log\frac{M_{SB}}{M}, \qquad i = 1, 2, 3 \tag{1}$$

where M_U is the unification scale and M_{SB} is the SUSY breaking scale and we have of course $M_U > M_{SB} > M$. In the equation above, we have assumed that i) the three gauge couplings unify at M_U ($\alpha_i(M_U) = \alpha_U$), ii) extra matter, possibly remnants of a GUT, appears in the region between M_U and M_{SB}: $\beta_i = \beta_i^S + \delta\beta_i$, where $\beta_i^S = (33/5, 1, -3)$ is the MSSM β functions, and

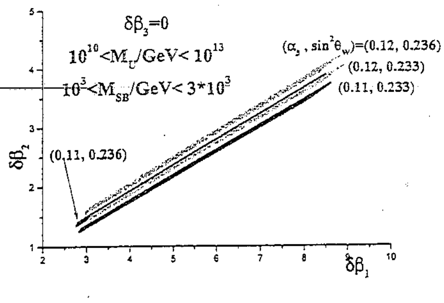

Figure 1: The allowed region of the $(\delta\beta_1, \delta\beta_2)$ space for four different $(\alpha_3, sin^2\theta_W)$ pairs.

iii) in the region between M_{SB} and M_Z we have the (non-SUSY) SM (although with two higgs instead of one) and the corresponding $\beta_i^{NS} = (4.2, -3, -7)$ functions.

By choosing $M \equiv M_Z$ in (1), we can solve the system of these three equations with respect to (M_U, M_{SB}, α_U) as functions of the $\delta\beta_i$'s, taking the values of $\alpha_i(M_Z)$ from experiment.

$$
\begin{aligned}
t_{SB} &= \frac{\delta\beta_{jk}(2\pi\delta(\alpha^{-1})_{ji} + \delta\beta_{ji}^{NS} t_Z) - \delta\beta_{ji}(2\pi\delta(\alpha^{-1})_{jk} + \delta\beta_{jk}^{NS} t_Z)}{-\delta\beta_{ji}(\delta\beta_{jk}^{NS} - \delta\beta_{jk}) + \delta\beta_{jk}(\delta\beta_{ji}^{NS} - \delta\beta_{ji})} \\
t_U &= \frac{2\pi\delta(\alpha^{-1})_{ji} + \delta\beta_{ji}^{NS} t_Z - (\delta\beta_{ji}^{NS} - \delta\beta_{ji}) t_{SB}}{\delta\beta_{ji}} \\
\frac{1}{\alpha_U} &= \frac{1}{\alpha_i} - \frac{\beta_i^{NS}}{2\pi}(t_{SB} - t_Z) - \frac{\beta_i}{2\pi}(t_U - t_{SB}) \qquad (2)
\end{aligned}
$$

where $t_{SB,U,Z}$ is the logarithm of the corresponding scales, $\delta p_{ij} = p_j - p_i$ and i, j, k should be different. It is obvious that t_U, t_{SB} and α_U depend only on the differences of β_i's. Therefore, if a certain solution (t_U, t_{SB}, α_U) is obtained by using specific values for $(\delta\beta_1, \delta\beta_2, \delta\beta_3)$, the same solution is obtained for $(\delta\beta_1 + c, \delta\beta_2 + c, \delta\beta_3 + c)$ where c is an arbitrary constant.

In Fig.1 we plot the acceptable values of $(\delta\beta_1, \delta\beta_2)$ for $\delta\beta_3 = 0$, demanding the unification scale to be in the region $(10^{10} - 10^{13})$GeV while the SUSY breaking scale is in the region $(1-3)10^3$GeV. The four "lines" correspond to the four indicated combinations of $(\alpha_3(M_Z), s_W^2\theta(M_Z))$. Translating the "lines" by an amount c in both directions, the corresponding figure for $\delta\beta_3 = c$ appears.

Let us try to find the acceptable values for a specific GUT model, namely the $SU(4) \times SU(2)_L \times SU(2)_R$. In this case, we assume that the breaking to the standard model occurs directly at the string scale, so that the gauge couplings g_L, g_R, g_4 attain a common value g_U. The massless spectrum of the string model – in addition to the three families and the standard higgs fields – leaves some extra matter fields which change the MSSM β-functions. Taking into account these remnants and the extra constraints of the specific GUT model (requiring even number of these extra states), only the following 3 points are acceptable in all the region allowed by the constraints on $sin^2\theta_W(M_Z)$ and $\alpha_3(M_Z)$ having put earlier (keeping $\delta\beta_3 = 0$)

$$(\delta\beta_1, \delta\beta_2, \delta\beta_3) = (4, 2, 0), \quad (6.5, 3, 0), \quad (8.5, 4, 0)$$

Of course, several possible sets of the extra states can generate the above changes in the β-functions.

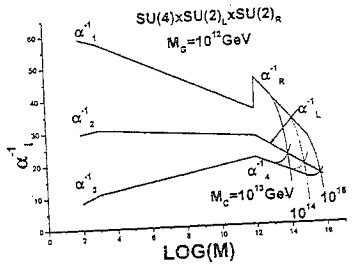

Figure 2: The running of the gauge couplings for the case of the $SU(4) \times SU(2)_L \times SU(2)_R$ GUT model.

3 Inclusion of KK-states

Here we assume the existence of a compactification scale M_C (smaller than the would be unification scale if M_C had not existed) above which KK-excitations are considered. Although the tower of the massive KK-states dictates a power law running of the gauge couplings, we use the successful approximation of incorporating the massive KK-states with masses less than the running scale, working therefore with the conventional logarithmic running[6].

In ref (6) it was stated that in the MSSM, whatever the chosen M_C is, unification of the gauge couplings always occurs. This statement can be generalized in the form that: if i) There exists an energy scale M_U where the coupling constants α_i's unify, assuming conventional logarithmic running (no–compactification scenario) and ii) The ratio of the differences of the β–functions β_{ij}^{KK} (above the compactification scale M_C) to the corresponding difference β^{ij} (below the compactification scale M_C) is the same for all $\{ij\}$ combinations, then it can be shown[7] that the gauge couplings do unify, whatever energy scale we choose as a compactification scale M_C, above which the massive KK-states contribute to the running. MSSM with the standard matter content, while only gauge bosons and higgs acquire KK-states, satisfies with a good approximation these two requirements. Therefore, with any chosen $M_C \lesssim 10^{16}$GeV, gauge coupling unification is ensured.

Working in the $SU(4) \times SU(2)_L \times SU(2)_R$ GUT model, we find numerous matter content above the GUT scale M_G (which is taken to be in the intermediate region $\sim 10^{12}$GeV) and several possibilities for the states acquiring (or not) KK-states (above M_C), where the β-functions obey the condition in order to achieve gauge coupling unification whatever the compactification scale is. In Fig.2, we show the running of the gauge couplings for three different compactification scales and for a specific matter content, while we have chosen the GUT scale to be 10^{12}GeV.

Concluding, we have checked the possibility of intermediate scale (10^{10-13} GeV) gauge coupling unification, using the traditional logarithmic running, i.e. without incorporating the power-law dependence on the scale coming from the Kaluza-Klein tower of states. We have showed that this kind of unification can be achieved with small changes of the β-functions of the MSSM gauge couplings, which can be attributed to matter remnants of superstring models. We have applied the above to the successful $SU(4) \times SU(2)_L \times SU(2)_R$ model (which is safe against proton decay even in this intermediate scale), and found the necessary extra massless matter and higgs fields needed. Finally, incorporating KK-states, we have shown that there exist numerous cases of massless spectra (which can be derived from the superstring), implying naturally intermediate scale unification.

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