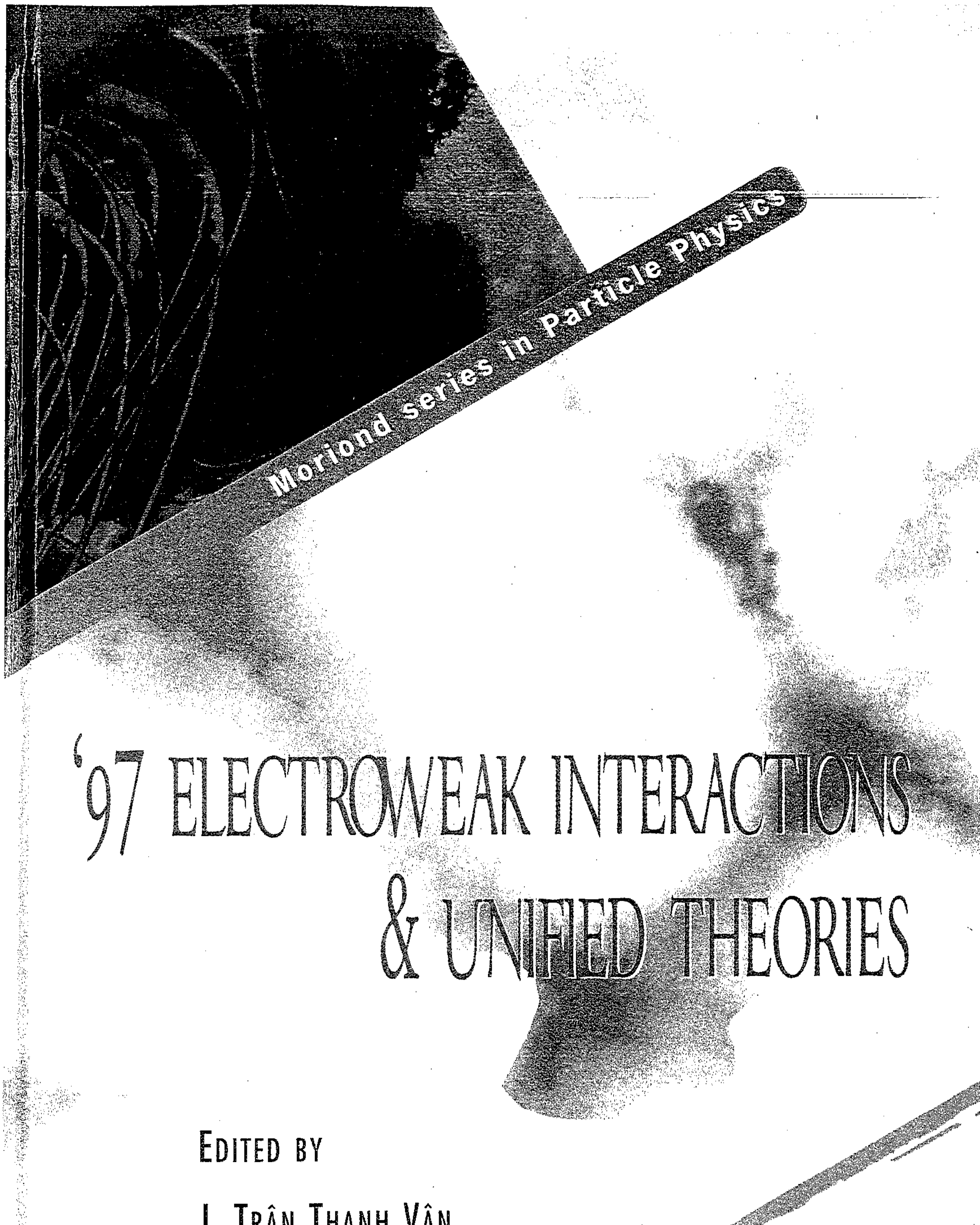

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EDITIONS

Stringy Constraints on Effective Supergravity Models[†]

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Abstract

The constraints from duality invariance on effective supergravity models with intermediate gauge symmetry are analysed. Some examples are presented where the intermediate gauge symmetry breaks down to the standard gauge group radiatively. Finally, the Higgs mixing term coefficient in the scalar potential is calculated, in a model independent approach, where new contributions depending on the modular weights of the Higgs superfields are included.

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Effective supergravity models from strings have drawn particular attention. Several string symmetries which remain in the effective field theory may be used to constrain a number of arbitrary parameters and in particular the form of the Kähler function, the superpotential terms and the initial values of the scalar masses. In this talk I will describe the constraints imposed by the duality invariance on a general class of models based on the standard gauge group. I will also consider unified models with intermediate gauge symmetries which can be derived from strings.

The general form of the gauge invariant Kähler function is [1]

$$G(z,\bar{z}) = \mathcal{K}(z,\bar{z}) + log|\,\mathcal{W}(z)\,|^2 \tag{1}$$

where $\mathcal{K}(z,\bar{z})$ is the Kähler potential and $\mathcal{W}$ is the superpotential. Denoting $z = (\Phi, Q)$, where Φ stands for the dilaton field S and other moduli T_i while Q for the chiral superfields and assuming a general factorizable form of the Kähler potential, at tree level we can write

$$\begin{aligned} \mathcal{K}_t(\Phi,\bar{\Phi}) &= -log(S+\bar{S}) - \Sigma_n h_n log(T_n+\bar{T}_n) + Z_{\bar{i}j}(T,\bar{T})\bar{Q}_{\bar{i}}Q_j \\ &\quad + (\frac{1}{2}\mathcal{M}_{ij}(T,\bar{T})Q_iQ_j + cc) + log|\mathcal{W}|^2 \\ \mathcal{W} &= k_0 + \frac{1}{3}\lambda_{ijk}(\Phi)Q_iQ_jQ_k + \frac{1}{2}\mu_{ij}(\Phi)Q_iQ_j + \cdots \end{aligned} \tag{2}$$

where k_0 is a model dependent constant [2] and $\{\cdots\}$ stand for possible non-renormalizable contributions. Terms bilinear in the fields Q_i refer in fact to an effective higgs mixing term [3, 4].

Under modular symmetries the moduli T_i, the matter fields Q_i and the superpotential $\mathcal{W}$ transform in the following way:

$$T_i \rightarrow \frac{aT_i - ib}{icT_i + d}, \quad Q_i \rightarrow \delta_{ij}Q_i\prod_n t_n^{-q_i^n}, \quad \mathcal{W} \rightarrow \prod_n t_n^{-h_n}\mathcal{W} \tag{3}$$

where we have introduced the notation $t_n = icT_n + d_n$, while q_i is the modular weight of the corresponding matter field Q_i. Assuming invariance of the μ parameter under the symmetries of the string we end up with the following relation between the modular weights:

$$\prod_l t_l^{h_l} = \prod_m t_m^{q_2^m}\prod_n t_n^{q_1^n} \tag{4}$$

If we further impose the cosmological constant constraint and simplify our approach assuming a single modulus T and a Higgs mixing term $\mu H_1 H_2$ in the superpotential, we get the simple relation $q_1 + q_2 = h = 3$. Such a relation could be helpfull since modular weights govern the initial conditions for the scalar masses $m_{H_1}^2$ and $m_{H_2}^2$ and could in principle trigger a radiative symmetry breaking at a lower scale.

It is well known that using only the MSSM spectrum, unification of the gauge couplings occurs naturally at $M_U \sim 10^{16}GeV$ i.e. almost two orders lower than the string scale. This is rather suggestive for the existence of an Intermediate Gauge Symmetry (IGS). Models with IGS have appeared in a string context [5]. In what follows, it will be assumed that there is at least one pair of higgs fields, $H_{1,2}$, having the required group properties, and obtaining large vacuum expectation values (vevs) which break the intermediate gauge group down to the MSSM symmetry. We will also perform our computation in the context of only one modulus T and the dilaton field S.

With respect to the fields $z_I \equiv (S, T, H_1, H_2)$, the scalar potential $V(z)$ is given by

$$V(z) = e^{G(z)}\left(G_I G^{-1}_{I\bar{J}} G_J - 3\right) + |\,D\,|^2 \tag{5}$$

where $|D|^2$ are the D-terms and G_I is the derivative of G with respect to the field z_I. In oder now to examine in detail the properties of the scalar potential, we need the specific knowledge of the superpotential. However, for illustrative purposes, let us collect only terms independent of $|\mathcal{W}|^2$. In terms of the unrenormalized field vevs $v_i =< H_i >$ we obtain, at the minimum[6],

$$V_0 = e^{<G>}\{3 - (\frac{h^2}{Q^2} + \frac{v_1^2}{T^{q_1}} + \frac{v_2^2}{T^{q_2}})\}, \text{ where } \quad Q^2 = h + q_1\frac{|v_1|^2}{T^{q_1}} + q_2\frac{|v_2|^2}{T^{q_2}} \text{ and } \quad v_i =< H_i > \quad (6)$$

Eq(6) determines the two vevs $v_{1,2}$ of the IGS breaking higgs fields. Assuming that the potential at the minimum is zero and equal renormalised vevs (so that the flatness of the effective potential is ensured), we can express the vev as a function of h and the sum $q_1 + q_2 \equiv q$. For h close to 3 and the additional constraint $q = 3$, we can get a sensible result of vev$\sim 10^{-2}M_{str}$. The terms dropped out of the potential could allow for a wider range of q and h giving vev in the desired region.

In the following, we would like to examine the possibility of breaking the IGS radiatively, pretty much the same way as this happens in the MSSM We will take as an example the $SU(4) \times SU(2) \times SU(2)$ model[7]. The breaking of this symmetry is realized at a high scale with the introduction of a higgs pair belonging to $H + \bar{H} = (4,1,2) + (\bar{4},1,2)$ representations. The SM symmetry breaking occurs due to the presence of the two standard doublet higgs fields which are found in the $h = (1,2,2)$ representation of the original symmetry of the model. The gauge invariant tree level superpotential which is of relevance to our discussion here is [7]

$$\mathcal{W} \;=\; \lambda_1 F_L \bar{F}_R h + \lambda_2 \bar{F}_R H \phi_i + \lambda_3 H D D + \lambda_4 \bar{H}\bar{H} D \qquad (7)$$

where $F_L = (4,2,1)$, $\bar{F}_R = (\bar{4},1,2)$, $D = (6,1,1)$ and ϕ_i are gauge singlet fields. Using now the known RGEs for the scalar masses and the Yukawa couplings we can check the possibility of one of the mass-squared parameters to turn negative. Of course the initial values at the M_{str} scale are needed. After rescaling to obtain correct normalized fields, while assuming zero cosmological constant, we get for the Higgs mass parameters the relation $m^2_{H_i} = m^2_{3/2}(1 + q_i)$, $\quad i = 1,2$, where $m_{3/2}$ is the gravitino mass. Obviously, the initial conditions of the two higgs fields depend crucially on the modular weights $q_{1,2}$ which are in general not equal to each other. Assuming large initial values for the Yukawa couplings $\lambda_{3,4} \sim \mathcal{O}(1)$, we show in Fig.1 the two higgs mass - parameters as a function of the scale $\log_{10} M$. It can be seen that $m^2_{H_2}$ turns negative at a scale $M_X \sim 10^{14} - 2 \times 10^{15} GeV$, depending on the choice of the two modular weights. This scale is not far from the conventional unification scale M_U. All other soft squared mass parameters are positive at that scale. From these figures we conclude that the IGS symmetry can break down radiatively naturally, provided that the two modular weights are different in order to create a hierarchy for the two higgs mass parameters at M_{str}.

A way to avoid an unacceptable Peccei-Quinn symmetry in the MSSM, is to introduce a mixing term $\mu H_1 H_2$ [8, 3] where the mass parameter μ should be of the order of the electroweak scale. Nevertheless, the introduction of an explicit μ-term in the theory generates a new hierarchy problem, since one has to introduce a new scale in the theory. In the context of the $N = 1$ effective supergravity theories it is possible to obtain an induced higgs mixing term [9, 10] due to the effects of a hidden sector.

We evaluate, in a general framework of supergravity theory with generic stringy features, the $H_1 H_2$ mixing term in the scalar potential. Using (2) and (5), the (leading part of the) coefficient of the $H_1 H_2$ term is given by[11]

$$m_{3/2}\{1 - \tilde{q} - \mathrm{Re}T(\partial_T - \partial_{\bar{T}})\}\,\mu_{sim}(T,\bar{T}), \qquad (8)$$

$$\text{where} \quad \tilde{q} \;=\; \frac{q_1 + q_2}{2}, \quad \mu_{sim}(T,\bar{T}) \equiv \frac{\mu_{12}}{c} + \mathcal{M}_{12}, \quad \text{and} \quad c = e^{-<K>/2} m_{3/2} \qquad (9)$$

Now, if we consider the case where μ (we are suppressing the subscript "12") is a constant whilst $\mathcal{M}(T, \bar{T})$ has a scaling property under the T and $\bar{T}$ derivatives [9], which makes the derivative terms in (8) to vanish, the formula takes the simple form

$$(1 - \tilde{q})(e^{<\mathcal{K}>/2}\mu + m_{3/2}\mathcal{M}) \tag{10}$$

We should point out here, that under the above assumptions we can see from (10) that there exists a possibility where the presence of the higgs mixing term $\mathcal{M}$ in the Kähler function does not imply an effective μ-term in the low energy potential, namely when $q_1 + q_2 = 2$. In fact, this is the case of a class of string models obtained in the (2,2) compactifications of the heterotic superstring.

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Figure 1