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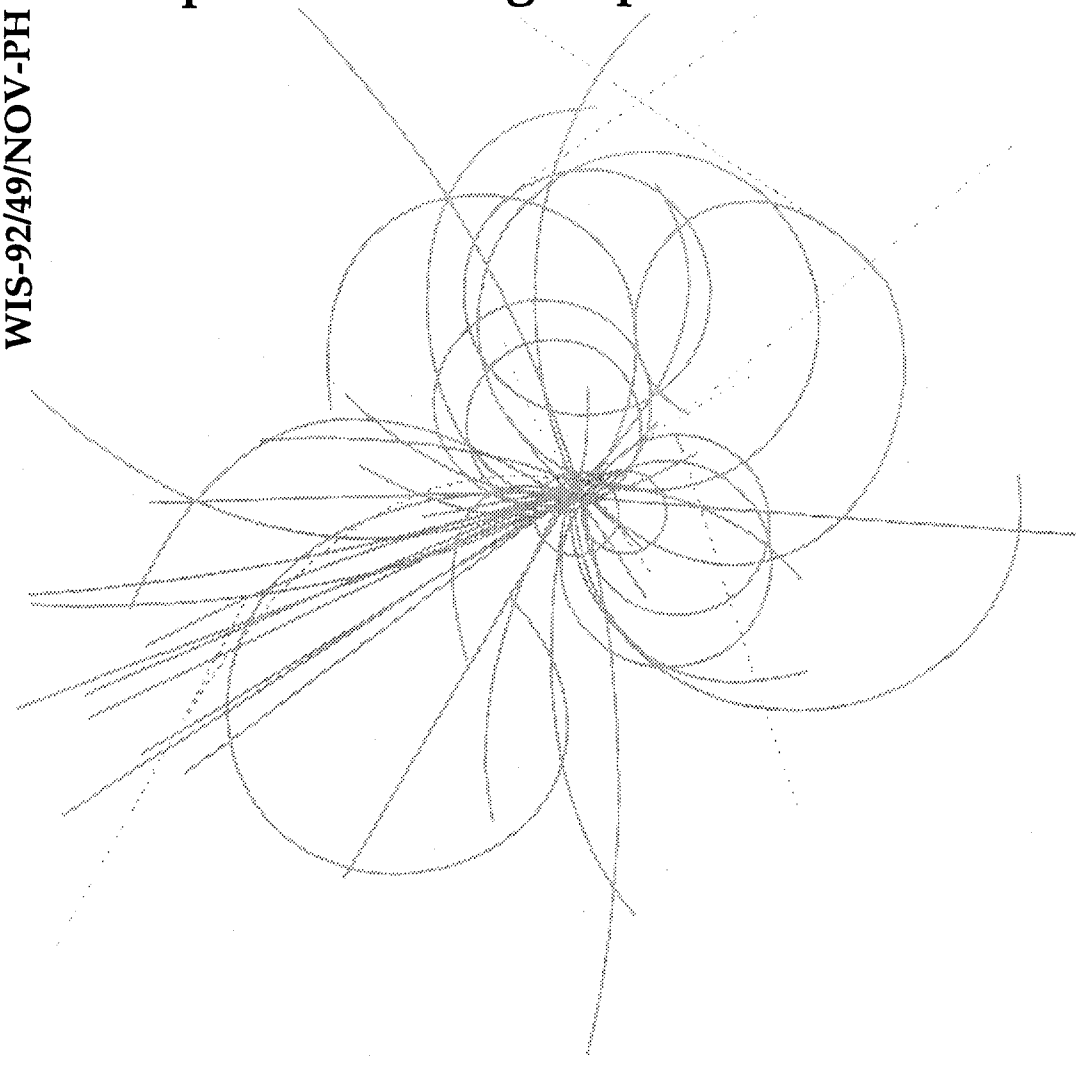

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June 1992

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June 1992

* Invited talk presented at the XV International Warsaw Meeting on Elementary Particle Physics, Kazimierz, Poland, 25–29 May 1992. This work was supported in part by a Feinberg School Fellowship and by the Superconducting Super Collider Laboratory, which is operated by the Universities Research Association, Inc., under Contract No. DE-AC35-89ER40486.

WIS-92/49/NOV-PH
SSCL-preprint-123
June 15, 1992

Superstring Derived Standard-like Models and the Top Quark Mass Hierarchy*

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ABSTRACT

I propose that the large mass splitting between the top and bottom quarks is a signature of a class of superstring derived standard-like models. In these models only $+\frac{2}{3}$ charged quarks obtain a trilevel mass term. Mass terms for the lighter quarks and leptons are obtained from higher order terms in the superpotential. These models contain an "anomalous" $U(1)$ gauge symmetry. Application of the Dine–Seiberg–Witten mechanism cancels the anomaly leaves a cubic level mass term only for the top quark.

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* *Invited talk presented at the XV international Warsaw meeting on elementary particle physics, Kazimierz, Poland, 25-29 May 1992.*

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One of the unresolved puzzles of the Standard–Model is the mass splitting between the top quark and the lighter quarks and leptons. Especially difficult to understand within the context of the Standard–Model is the big splitting in the heaviest generation. Possible extensions to the Standard Model are Grand Unified Theories. Although the main prediction of GUTs, proton decay, has not yet been observed, calculations of $\sin^2\theta_W$ and of the mass ratio $\frac{m_b}{m_\tau}$ support their validity. In spite of these GUTs successes, an understanding of the mass splitting between the top quark and the lighter quarks and leptons is still lacking. The next level in which such an understanding may be developed is in the context of superstring theory.

In this talk I show how the mass splitting between the top quark and the rest of the quarks and leptons is explained in a class of superstring derived standard–like models [2,1]. The splitting is achieved by the following mechanism. At the trilinear level of the superpotential only $+\frac{2}{3}$ charged quarks obtain a nonvanishing Yukawa coupling, while the remaining quarks and leptons obtain their mass terms from nonrenormalizable terms. I demonstrate how this mechanism is realized in two superstring derived standard–like models [2,1]. In these models only $+\frac{2}{3}$ charged quarks obtain trilinear mass terms while non vanishing mass terms for $-\frac{1}{3}$ charged quarks and for charged leptons appear at the quartic level [1] or quintic level [2]. The models contain an anomalous $U(1)$ symmetry. Application of the Dine–Seiberg–Witten mechanism [3] to cancel the anomaly leaves a trilevel mass term only for the top quark. The bottom and tau lepton mass terms are obtained from the higher order terms. The $SO(10)$ singlet fields in these terms obtain a non vanishing VEV by the application of the Dine–Seiberg–Witten mechanism. Thus, these terms become effective trilinear mass terms with a suppression factor of $\left(\frac{\langle\Phi\rangle}{M_{pl}}\right)^n$, where $n = 1$ or 2. In the standard–like models, a close connection may exist between the top quark mass hierarchy and the requirement of a supersymmetric vacuum at the Planck scale. The only models which admit a supersymmetric solution to the F and D constraints are models in which only $+\frac{2}{3}$ charged quarks obtain a cubic level mass term. In the model of Ref. [1] I calculate the relevant quartic order coefficients and show that after the application of the Dine–Seiberg–Witten mechanism, the bottom Yukawa coupling is suppressed by a factor of $\frac{1}{8}$ relative to the top quark Yukawa coupling.

The superstring models are constructed in the four dimensional free fermionic formulation [4]. The standard–like models are spanned by a basis of eight vectors. The first five vectors in the basis $\{1, S, b_1, b_2, b_3\}$ consist of the NAHE set [5,6], which is common to all the realistic constructions in the free fermionic formulation [5,7,8,2,1]. This set was first constructed by Nanopoulos, Antoniadis, Hagelin and Ellis in the construction of the flipped $SU(5)$ (*nahe*=pretty, in Hebrew). The vectors b_1, b_2 and b_3 of the NAHE set perform several functions. First, they give rise to the chiral generations, second they split the hidden and observable

sectors and finally they determine the chirality of the massless generations. The NAHE set generates an $N = 1$ supersymmetry with $SO(10) \times E_8 \times SO(6)^3$ gauge symmetry. The sectors b_1, b_2 and b_3 each gives rise to two copies of massless chiral fields in $(16,4,1,1) + (16,\bar{4},1,1)$ representations (one for each $SO(6)$). In the standard–like models three additional vectors α, β and γ, are needed to reduce the number of chiral generations to three generations. At the same time these additional vectors break the three horizontal $SO(6)$ symmetries to $U(1)^3 \times U(1)^3$. In the free fermionic models a close connection exist between the breaking of the horizontal symmetries and the reduction of the number of generations to three chiral generations. It can be argued that in the free fermionic constructions three generations is the most natural number of generations [6].

The model of Ref. [7] leads to the following non vanishing trilevel mass terms from the sectors b_1, b_2 and b_3: $\{(u^c_{L_1} Q_1 \bar{h}_1 + N^c_{L_1} L_1 \bar{h}_1 + d^c_{L_2} Q_2 h_2 + e^c_{L_2} L_2 h_2 + e^c_{L_3} L_3 h_3 + d^c_{L_3} Q_3 h_3)$, where a common normalization factor $\sqrt{2}g$ is assumed. This model produce cubic level Yukawa couplings to the $+\frac{2}{3}$ charged quark from the b_1 sector and to the $-\frac{1}{3}$ charged quarks from the sectors b_2 and b_3. The boundary conditions of the real fermions in the vector γ, determine the non vanishing Yukawa couplings for the states from a given sector b_1, b_2 or b_3. If $|\gamma(U(1)_{\ell_{j+3}}) - \gamma(U(1)_{r_{j+3}})| = 0$ $(j = 1,2,3)$, trilevel mass terms are possible only for $-\frac{1}{3}$ type quarks while if $|\gamma(U(1)_{\ell_{j+3}}) - \gamma(U(1)_{r_{j+3}})| = 1$, trilevel mass terms are possible only for $+\frac{2}{3}$ type quarks. Therefore the model of Ref. [7] produce cubic mass terms for all three heaviest generation states. However, this model, and in more general, all the models of this kind, do not admit supersymmetric solutions to the F and D flatness constraints. On the other hand in the models of Refs. [1,2] only $+\frac{2}{3}$ charged quarks obtain a cubic level mass term and do admit F and D flat solutions.

in these models the bottom quark and tau leptons mass terms are obtained from higher order terms. In model [1] from the quartic order terms,

$$W_4 = \{d^c_{L_1} Q_1 h'_{45} \Phi_1 + e^c_{L_1} L_1 h'_{45} \Phi_1 + d^c_{L_2} Q_2 h'_{45} \bar{\Phi}_2 + e^c_{L_2} L_2 h'_{45} \bar{\Phi}_2\}, \qquad (1)$$

and in model [2] from the quintic order terms,

$$W_5 = \{d^c_{L_1} Q_1 h_{45} \Phi^-_1 \xi_2 + e^c_{L_1} L_1 h_{45} \Phi^+_1 \xi_2 + d^c_{L_2} Q_2 h_{45} \Phi^-_2 \xi_1 + e^c_{L_2} L_2 h_{45} \bar{\Phi}^-_2 \xi_1\}. \quad (2)$$

In model [1] the effective bottom quark Yukawa coupling was calculated in Ref.[1]. The $SO(10)$ singlet in Eq.(1) acquires a VEV of the order of $\frac{1}{10} M_{Pl}$, resulting in

a suppression of λ_b relative to λ_t by

$$\frac{\lambda_b}{\lambda_t} = \frac{0.35g^3}{g\sqrt{2}} \sim \frac{1}{8}, \tag{3}$$

where $g \sim \frac{1}{\sqrt{2}}$ is the gauge coupling at the unification scale. In model [2] we can estimate the suppression factor to be the square of this value. By running the RGEs, from the unification scale down to the top and bottom masses, we can estimate the top quark mass,

$$m_t \sim (140 - 180)GeV \qquad \tan\beta \sim (5 - 15). \tag{4}$$

I would like to emphasize that the proposed mechanism for the top–bottom mass hierarchy, is unique to the choice of the observable gauge group in the standard–like models. For example, from the talk of John Rizos [9], we learn that in the superstring derived flipped $SU(5)$ [5] $\lambda_t = \lambda_b = \lambda_\tau$ at the unification scale. Therefore, λ_b is not suppressed relative to λ_t. In this case one has to resort to rather large values of $\tan\beta$, to obtain the correct top–bottom mass relation.

To conclude I summarize the present level reached by the superstring derived standard–like models. We identified a class of viable superstring models with the following properties: 1. Three and only three generations of chiral fermions. There are no extra generations and mirror generations which presumably get massive at a very large scale. 2. The gauge group is $SU(3)_C \times SU(2)_L \times U(1)_{B-L} \times U(1)_{T_{3R}} \times U(1)^n \times$ *hidden*. n reduces to one or zero after application of the Dine–Seiberg–Witten (DSW) mechanism. The $U(1)_{Z'} = \frac{1}{2}U(1)_{B-L} - \frac{2}{3}U(1)_{T_{3R}}$ combination may be broken at the Planck scale, by the DSW mechanism. If it remains unbroken down to low energies, it results in a gauged mechanism to suppress proton decay from dimension four operators. 3. There are enough scalar doublets and singlets to break the symmetry in a realistic way and to generate realistic fermion mass hierarchy. 4. Proton decay from dimension four and dimension five operators is suppressed due to gauged $U(1)$ symmetries. 5. These models suggest an explanation for the top-bottom mass hierarchy. The top quark gets a trilevel mass term, the mass terms for the bottom quark and for the lighter quarks and leptons are obtained from higher order terms. The top–bottom mass hierarchy is correlated with the requirement of a supersymmetric vacuum at the Planck scale.

ACKNOWLEDGMENT

This work is supported in part by a Feinberg School Fellowship. I would like to thank the SSC laboratory for its hospitality while part of this work was conducted.

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