INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392 - I

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SCHOOL ON
NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

SUPERSTRINGS IMPLICATIONS TO PARTICLE PHYSICS & COSMOLOGY (3)

by

D. V. Nanopoulos
U.W. - Madison
U. S. A

SUPERSTRING IMPLICATIONS TO PARTICLE PHYSICS/COSMOLOGY

D.V. Nanopoulos

UW- Madison

U.S.A.

ICTP

3-5/5/88

SCHOOL ON NON-ACCEL. PHYSICS.

1) I. Antoniadis, J. Ellis, J. Hagelin and D.V.N. (AEHN)$_{I}$

Phys. Lett. 194B (1987) 231

2) B. Campbell, J. Ellis, J. Hagelin, D.V.N. and R. Ticciati

Phys. Lett. 198B (1987) 200

(CEHNT)

(3) I. Antoniadis, J. Ellis, J. Hagelin and D.V.N. (AEHN)$_{II}$

MAD/TH/87-30

(or) SLAC-PUB-4499 X

(or) CERN-TH-4931 ✓

(4) I. Antoniadis, J. Ellis, J. Hagelin and D.V.N (AEHN)$_{III}$

MAD/TH/88-10

(or) CERN-TH-5005/88

(5) J. Ellis, J. Hagelin, S. Kelley and D.V.N (EHKN)

MAD/TH/88-8

(or) CERN-TH-4990/88

After 20 years !

$$S'_{4\text{-}D} = -\frac{1}{2}\int d^2\sigma \Big(\sum_{\mu=0}^{3} \partial_\alpha X^\mu \partial^\alpha X_\mu - 2\psi_+^\mu \partial_- \psi_{\mu +} - 2\,(\chi_+^i \partial_- \chi_+^i) - 2\sum_{1}^{44} \lambda_-^A \partial_+ \lambda_-^A \Big)$$

$i = 1, \cdots 18$

- (X^μ, ψ^μ) : $SO(3,1)$ vectors; Inter. Symm. Singlets $\rightsquigarrow$ (SUPER) SPACE-TIME ✓

•• $\chi_+^i \equiv (\chi^I, y^I, \omega^I)$ with $(\chi^I, y^I, \omega^I) \sim \underline{3}$ of $SU(2)^I$ ✓

$i = 1 \cdots 18$; $I = 1 \cdots 6$

λ_-^A; $A = 1 \cdots 44$ $\rightsquigarrow$ Intern. Symmetries

$\therefore$ ALWAYS $\boxed{D=4}$!!!

(e.g: If all λ_-^A same B.C treatment $\rightsquigarrow SO(44) \longrightarrow \cdots$)

- These "new" Sm theories consistent... at the same level of the $D=10$ heterotic string ✓

•• "New" $\rightsquigarrow$ (?) still "very simple" ✓

••• $D=4$ not unique (?) : same story: $\forall\ D \leq 10$!

"PHYSICS" (?)

STRAIGHT SU(5)

① Stand. Model Reps: $(3,2):\begin{pmatrix}u\\d\end{pmatrix}_L$; u^c_L ; d^c_L : $(\bar{3},1)$

$(1,2):\begin{pmatrix}\nu\\e\end{pmatrix}_L$; e^c_L $\nu^c_L(?)$: $(1,1)$

② SU(5) : $\bar{5} = (\bar{3},1) + (1,2)$ → unique : $\begin{pmatrix}\nu\\e\end{pmatrix}_L$

$10 = (3,2) + (\bar{3},1) + (1,1)$

$(3,2)$ → unique: $\begin{pmatrix}u\\d\end{pmatrix}_L$

but $(\bar{3},1)$: u^c or d^c (?) but $\boxed{\text{if } \operatorname{Tr} Q = 0}$ (Charge Quantiz)

! $\boxed{\text{DICHOTOMY}}$!

$d^c \in \bar{5}$: $\operatorname{Tr}(Q)_5 = 0$ ✓

and thus $u^c \in 10$ (G-G)

③ $SU(5) \xrightarrow[\langle 24\rangle]{M_X} SU(3)_c \times SU(2)_L \times U(1)_Y \xrightarrow[\langle 5\rangle]{M_W} SU(3)_c \times U(1)_{E.M.}$

$\langle 24\rangle$: $\begin{pmatrix}1&&&&\\&1&&&\\&&1&&\\&&&-3/2&\\&&&&-3/2\end{pmatrix}$

One of MANY other Choises

MANY Mines: COSMOLOG. PROBLEMS !

(UNIVERSE → WRONG PHASE ...)

$\langle 5\rangle$: $\begin{pmatrix}H_1\\H_2\\H_3\\ \hline H^+\\H^0\end{pmatrix}$

H_1, H_2, H_3 → $M_{H_3} \gtrsim 10^{12}$ GeV ↑ PROTON DECAY!

H^+, H^0 → Stand. model Higgs $m_{H^0} \sim O(M_W)$

GAUGE HIERARCHY PROBLEM!

④ If ∃ neutrino masses/oscill. ... → INTRODUCE $\nu^c_L \sim (1,1)$ [illegible]

→ SEE-SAW MECHANISM: $\begin{pmatrix}0 & m\\ m & M\end{pmatrix}$ ... AD-HOC ...

G-N
B
DKN

FLIPPED SU(5) : (5̄)∩X(5)∩5

① Take the other way : $\bar{f} = \begin{pmatrix} u^c \\ u^c \\ u^c \\ \nu \\ e \end{pmatrix}$; $F = \begin{pmatrix} 0 & d^c & -d^c & d & u \\ -d^c & 0 & d^c & d & u \\ d^c & -d^c & 0 & d & u \\ -d & -d & -d & 0 & \nu^c \\ -u & -u & -u & -\nu^c & 0 \end{pmatrix}$;

ℓ^c.

$\therefore$ $u \leftrightarrow d$

$u^c \leftrightarrow d^c$

$\nu \leftrightarrow e$

$\nu^c \leftrightarrow e^c$

NECESSITY! ($m_\nu \neq 0$ ..) (?)

Now: $\mathrm{Tr}\, Q \neq 0$ cause $Q \in SU(5) \times U(1)$ (NOT (SEMI)SIMPLE)

$(U(1)) \leftrightarrow U(1)_Y$

- No problem with charge quantization if

$SU(5) \times U(1) \underbrace{\subset}_{\text{(possible!)}} SO(10), E_6, \ldots$ [PRIMORDIALLY !]

(AEHN)$_I$

② $$SU(5) \times U(1) \xrightarrow[\langle 10 \rangle_H]{M_X} SU(3)_c \times SU(2)_L \times U(1)_Y \xrightarrow[\langle 5 \rangle_h]{M_W} SU(3)_c \times U(1)_{E.M.}$$

$\langle 10 \rangle_H \to \langle \text{"}\tilde{\nu}^c_H\text{"} \rangle \neq 0$

- "UNIQUE VACUUM" $\to$ NO COSMOL. PROBLEMS

$\langle 5 \rangle_h \to \begin{pmatrix} h_1 \\ h_2 \\ h_3 \\ h^+ \\ h^0 \end{pmatrix}$ as before

BUT

.. * Small Rep: Antisymm. tensor (ψ^{ij}) *

$\exists$ $10_H 10_H 5_h$ Coupling

$\langle 10_H \rangle 10_H 5_h$

$\exists (\bar{3},1)$ $\exists (3,1)$

$\nexists (1,2)$

NATURAL DOUBLET-TRIPLET SPLITTING !!!

(3) Particle Content. (AEHN)$_I$

$SO(10)$

F_i $(\underline{10}, 1/2)$

$\bar{f}_i$ $(\bar{\underline{5}}, -3/2)$; i = generation index: i.e. 1, 2, 3. $(\underline{16})$

ℓ^c_i $(\underline{1}, 5/2)$

H_1 $(\underline{10}, 1/2)$; $\bar{H}_1$ $(\bar{\underline{10}}, -1/2)$: "Heavy Higgs" (part of $\underline{16}$ + $\bar{\underline{16}}$)

h_1 $(5, -1)$; $\bar{h}_1$ $(\bar{5}, 1)$: "light Higgs" $(\underline{10})$

ϕ_m $(1, 0)$: $m = 1, 2, 3, 4$ $(\underline{1})$

$(N_g + 1)$

Most general superpotential consistent with $SU(5) \times U(1) \otimes Z_2 \, (H_1 \to -H_1)$

$$W = \lambda_1^{ij} F_i F_j h_1 + \lambda_2^{ij} F_i \bar{f}_j \bar{h}_1 + \lambda_3^{ij} \bar{f}_i \ell^c_j h_1 + \lambda_4 H_1 H_1 h_1 + \lambda_5 \bar{H}_1 \bar{H}_1 \bar{h}_1$$

$$+ \lambda_6^{im} F_i \bar{H}_1 \phi_m + \lambda_7^{m} h_1 \bar{h}_1 \phi_m + \lambda_8^{mnp} \phi_m \phi_n \phi_p$$

(4)

Physics.

λ_1 : masses to $Q=-1/3$ quarks

λ_2 : masses to $Q=2/3$ quarks and $Q=0$ leptons

$m_{u_i} = m_{\nu_i}$!!! UPS !!! ~ (see λ_6 !)

λ_3 : masses to $Q=-1$ leptons

[$m_{Q=-1/3} = m_{Q=-1} \Big|_{M_X}$ not automatic !]

λ_4, λ_5: Natural 3-2 splitting.

λ_6 : Natural See-Saw Mechanism à la G-N

$$(\nu_i, \nu_j^c, \varphi_m) \begin{pmatrix} 0 & m_u^{ij} & 0 \\ m_u^{ij} & 0 & \lambda_6 \langle H_1 \rangle \\ 0 & \lambda_6 \langle H_1 \rangle & \otimes \end{pmatrix} \begin{pmatrix} \nu_i \\ \nu_j^c \\ \varphi_m \end{pmatrix}$$

3 "massless" neutrinos ⊕ 3 Superheavy (M_X) Dirac neutrinos

∴ Resolves the $m_u = m_\nu$ Problem !

λ_7: Provides h-$\bar{h}$ mixing necessary at low energies...

λ_8: Important for "breaking" details...

∴ ★ CONSISTENT (SUGRA) GUT MODEL: $\sin^2\theta_W$; M_X; Proton-decay ✓
★ ECONOMICAL
★ AESTHETICALLY APPEALING

Radiative breaking at both scales... ✓

Comments.

1) $S \rightsquigarrow$ guarantees $\exists$ space-time SUSY
($\mathcal{H}_S \ni$ gravitino)

$S, b_1, b_2 \rightsquigarrow$ $N=1$ space-time SUSY

2) $\{1, S, b_1, b_2, b_3\} \rightsquigarrow SO(10) \times SO(6)^3$
with $((16, 4, 1, 1) + (16, \bar{4}, 1, 1)) \times 3$
massless chiral fields

3) $b_4, b_5, \alpha \rightsquigarrow$ $SO(6)^3 \longrightarrow \boxed{U(1)^3}$
$SO(10) \longrightarrow \boxed{SU(5) \times U(1)}$ YES !

b_4, b_5: break rank
α: Unitary groups $[\rightarrow \bar{\psi}^{1\to 5}]$

4) $\underline{A} \rightsquigarrow$. dependence of $G(A)$ "Hidden group"
.. $\nexists$ massless states $\sim$ non-trivially under "observable" and "hidden" group

$$\therefore \quad \boxed{G \equiv [SU(5) \times U(1)] \times \underbrace{U(1)^3}_{\text{"unique"}}}$$

Particle Content

MASSLESS MODES

$F_i \equiv (10, 1/2)_i$

$\bar{F}_i \equiv (\bar{5}, -3/2)_i$; $i \equiv$ generation index: 1, 2, 3

$\ell^c_i \equiv (1, 5/2)_i$

$U(1)^3$: $(1/2, 0, 0)$ $(0, 1/2, 0)$ $(0, 0, -1/2)$

$H_1 \equiv (10, 1/2)_{1/2, 0, 0}$; $\bar{H}_1 \equiv (\bar{\cdots})$

$H_2 \equiv (10, 1/2)_{0, 1/2, 0}$; $\bar{H}_2 \equiv (\bar{\cdots})$

$h_j \equiv (5, -1)_j$; $j \equiv$ 1, 2, 3 ; $\bar{h}_j \equiv (\bar{\ })$

$(-1, 0, 0)$ $(0, -1, 0)$ $(0, 0, 1)$

$h_{12} \equiv (5, -1)_{1/2, 1/2, 0}$; $\bar{h}_{12} \equiv (\bar{5}, +1)_{-1/2, -1/2, 0}$

$\phi_{23} \equiv (1, 0)_{0, 1, 1}$

$\phi_{13} \equiv (1, 0)_{1, 0, 1}$; $\bar{\phi}_{ij} \equiv (\bar{\ })$ [redacted] $i, j = 1, 2, 3$ $i < j$.

$\phi_{12} \equiv (1, 0)_{1, -1, 0}$

MASSIVE MODES

$H_{12} \equiv (10, 1/2)_{-1/2, 1, 0}$

$H_{13} \equiv (10, 1/2)_{-1/2, 0, -1}$; $\oplus$ $\overline{\text{particles}}$

$H_5 \equiv (10, 1/2)_{-1, -1/2, 0}$

$\chi \equiv (1, 0)_{-1/2, 1/2, 0}$

$\Phi \equiv (1, 0)_{0, 1/2, 1/2}$

Most general $\underset{\text{Renorm.}}{\overset{\text{trilinear}}{\times}}$ Superpotential consistent with $SU(5)\times(U(1))^4$

$$W_R = \lambda_1 (F_1F_1h_1,\ F_2F_2h_2,\ F_3F_3h_3) + \lambda_2 (F_1\bar{f}_2\bar{h}_{12},\ F_2\bar{f}_1\bar{h}_{12})$$
$$+ \lambda_3 (\bar{f}_1 l^c_1 h_1,\ \bar{f}_2 l^c_2 h_2,\ \bar{f}_3 l^c_3 h_3) + \lambda_4 (H_1H_1h_1,\ H_2H_2h_2)$$
$$+ \lambda_5 (\bar{H}_1\bar{H}_1\bar{h}_1,\ \bar{H}_2\bar{H}_2\bar{h}_2)$$
$$+ \lambda_7 (h_1\bar{h}_2\varphi_{12},\ h_1\bar{h}_3\varphi_{13},\ h_2\bar{h}_3\varphi_{23},\ \bar{h}_1h_2\bar{\varphi}_{12},\ \bar{h}_1h_3\bar{\varphi}_{13},\ \bar{h}_2h_3\bar{\varphi}_{23})$$
$$+ \lambda_8 (\varphi_{12}\varphi_{23}\bar{\varphi}_{13},\ \bar{\varphi}_{12}\bar{\varphi}_{23}\varphi_{13})$$

Comments

1) a priori: $F_i H_i h_i$; $H_1 \bar{f}_2 \bar{h}_{12}$; $H_2 \bar{f}_1 \bar{h}_{12}$

BUT forbidden by a generalized R-parity: $\boxed{\overset{(-)}{H}_{1,2} \rightarrow -(\overset{(-)}{H}_{1,2})}$

¡ DYNAMICS ! $\rightsquigarrow$

i) $N=1$ $d=4$ SUGRA : $\exists\ U(1) \rightsquigarrow \exists$ R-parity BFNS (1982)

ii) Automatic Symmetry of massless modes of Sm — GFV (1987)

iii) Even if R-parity was not there $\rightsquigarrow \exists$ basis for the fields $\rightsquigarrow$ W_R as written above !!

2) $\exists$ $U(1)$"ANOMALOUS" $\rightsquigarrow$ field theory O.K if broken at M_{PL} BFN (1982)

"automat." breaking $\sim M_{PL}$ $\longleftarrow$ string theory : proven O.K DSW (1987)

I Gauge Symmetry breaking

Look for flat directions :

(1) $W_R \ni \lambda_8$ terms : F-, D- flat directions $\rightsquigarrow \overset{(-)}{\Phi}_{ij} \rightsquigarrow$

$$\rightsquigarrow \quad \langle \Phi_{23} \rangle = \langle \bar{\Phi}_{23} \rangle \equiv V_{23} \neq 0 \quad \text{or} \quad V_{12} \quad \text{or} \quad V_{13}$$

Notice: if $V_{12} \neq 0 \rightsquigarrow h_1, \bar{h}_2 \rightsquigarrow$ massive ($\sim M$) $\rightarrow$ λ_4, λ_5: useless ! $\rightsquigarrow$

take $\boxed{V_{23} \neq 0}$ ($V_{13} \neq 0 \rightarrow$ equivalent physics: $\exists$ 1<->2 symmetry)

i) $\overset{(-)}{h}_2, \overset{(-)}{h}_3 \rightsquigarrow \mathcal{O}(M)$

ii) $\overset{(-)}{\Phi}_{12}, \overset{(-)}{\Phi}_{13} \rightsquigarrow \mathcal{O}(M)$

OUT FROM THE "LIGHT" $\mathcal{O}(M_W)$ SPECTRUM !!!

$$\therefore \quad \langle \overset{(-)}{\Phi}_{23} \rangle \equiv V_{23} = \mathcal{O}(M) \quad \text{O.K} \ \checkmark$$

(2) $W_R \ni \lambda_{4,5}$ terms : F-, D- flat directions $\rightsquigarrow \overset{(-)}{H}_{1,2}$

$$\rightsquigarrow \quad \langle H_1 \rangle = \langle \bar{H}_1 \rangle = V_1 \neq 0$$
$$\langle H_2 \rangle = \langle \bar{H}_2 \rangle = V_2 \neq 0 \quad \text{O.K} \ \checkmark$$

$$\therefore \quad SU(5) \times U(1)^4 \xrightarrow[M]{\star\ \text{"UNIQUELY"}\ \star \ \text{broken}} SU(3)_c \times SU(2)_L \times U(1)_Y$$

$$\left(\begin{array}{lll} U(1)_1 + U(1)_2 - U(1)_3 & \rightsquigarrow \text{"anomalous"} & \rightsquigarrow \text{autom. broken} \\ U(1)_2 + U(1)_3 & \rightsquigarrow & \langle \Phi_{23} \rangle \\ U(1) + U(1)_1 & \rightsquigarrow & \langle \text{"}H_1\text{"} \rangle \\ U(1) + U(1)_2 & \rightsquigarrow & \langle \text{"}H_2\text{"} \rangle \end{array}\right)$$

Radiative breaking available (EHKN)

$$\frac{M}{M_{Pl}} \sim 10^{-2 \pm 1}$$

(EHKN)

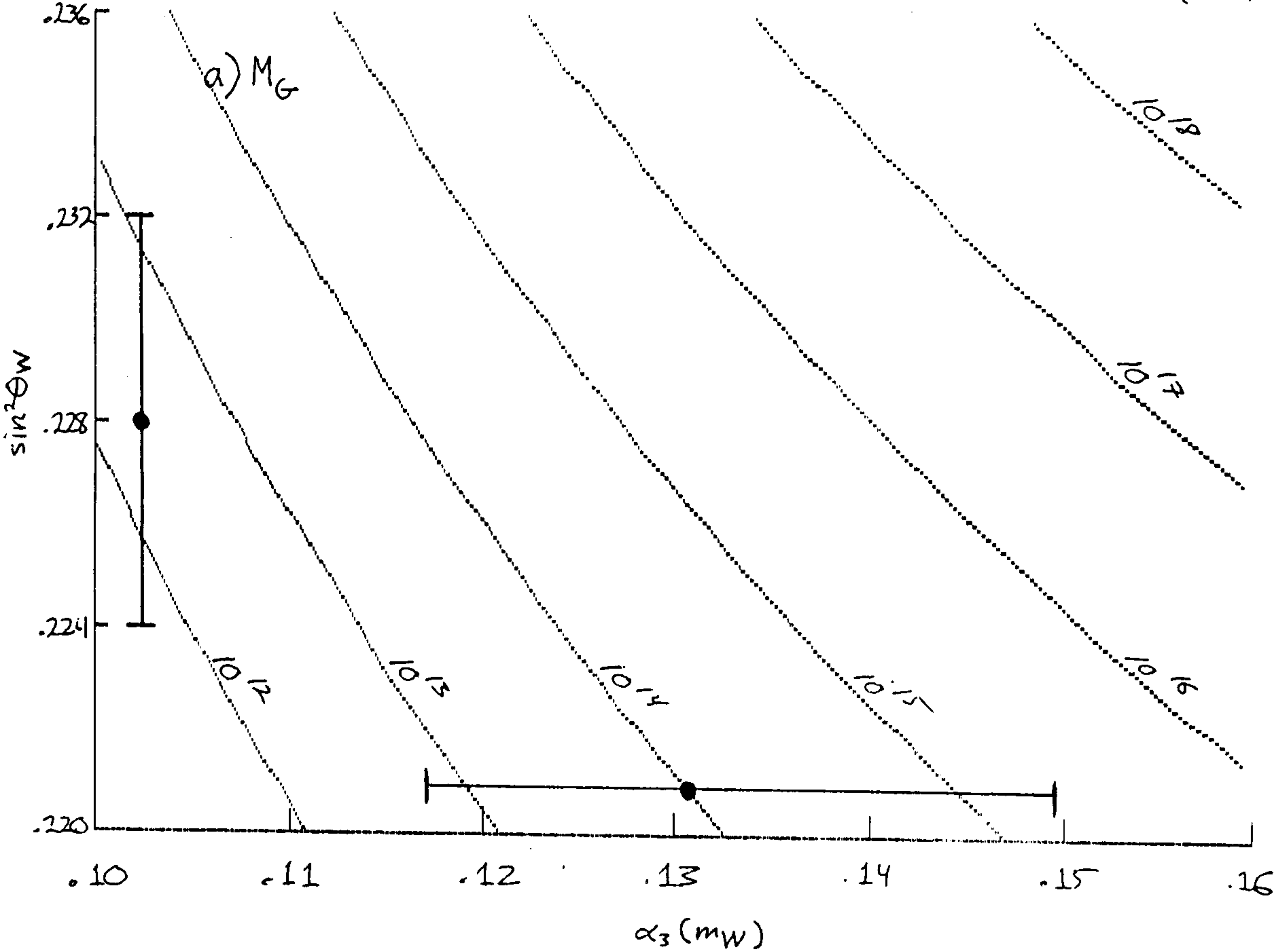
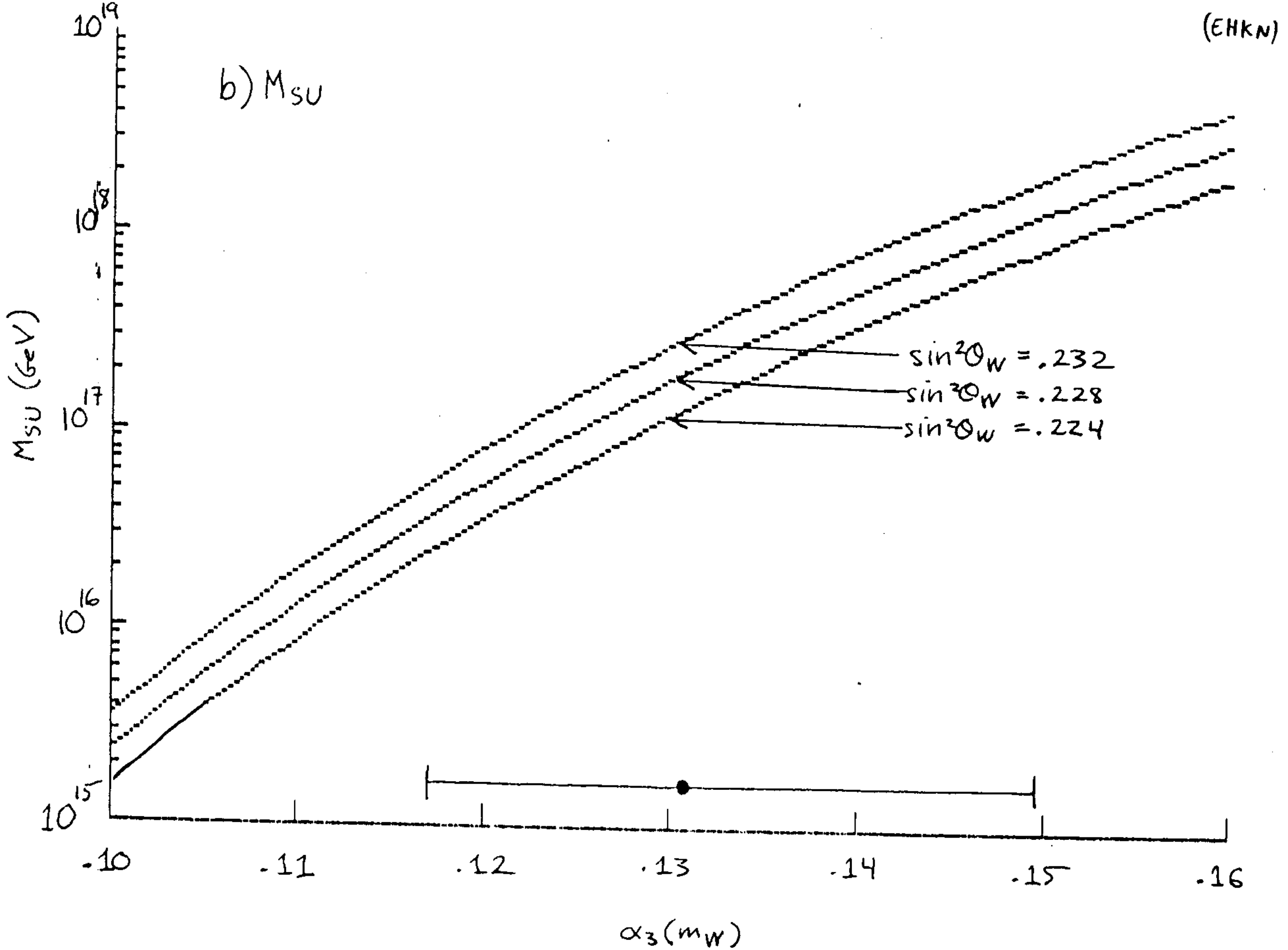


FIGURE 2a



(EHKN)
b) M_{SU}
M_{SU} (GeV)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
$\sin^2\theta_W = .232$
$\sin^2\theta_W = .228$
$\sin^2\theta_W = .224$
.10
.11
.12
.13
.14
.15
.16
$\alpha_3(m_W)$

FIGURE 2b

(3) W_R $\longrightarrow$ F-, D- flat directions $\rightsquigarrow$ $\overset{(-)}{h}_1$; $\overset{(-)}{h}_{12}$ $\rightsquigarrow$

$$\rightsquigarrow \quad \begin{array}{l} \langle h_1 \rangle = v_1 \neq 0 \\ \langle \bar{h}_{12} \rangle = \bar{v}_{12} \neq 0 \end{array} \quad \rightsquigarrow O(M_W)$$

$$\therefore \quad SU(3)_C \times SU(2)_L \times U(1)_Y \xrightarrow[M_W]{\text{Broken}} SU(3)_C \times U(1)_{E\text{-}M}$$

Radiative breaking available (EHKN)

$$\frac{M_W}{M_{Pl}} \sim 10^{-16} \left(\approx e^{-1/\alpha_t} \right)$$

$\therefore$ GAUGE SYMMETRY BREAKING ✓✓

- Recently it has been "proven" (ABK) that the ABOVE flat directions of W_R ($\equiv$ trilinear superpotential) SHOULD remain flat in the presence of non-renormalizable (Sum massive modes) terms. ✓✓ [FLATNESS THEOREM]

✓ Gauge symmetry breaking pattern: VALID

✓✓ "Selection Rule" for allowable non-renormal. terms

(EHKN)

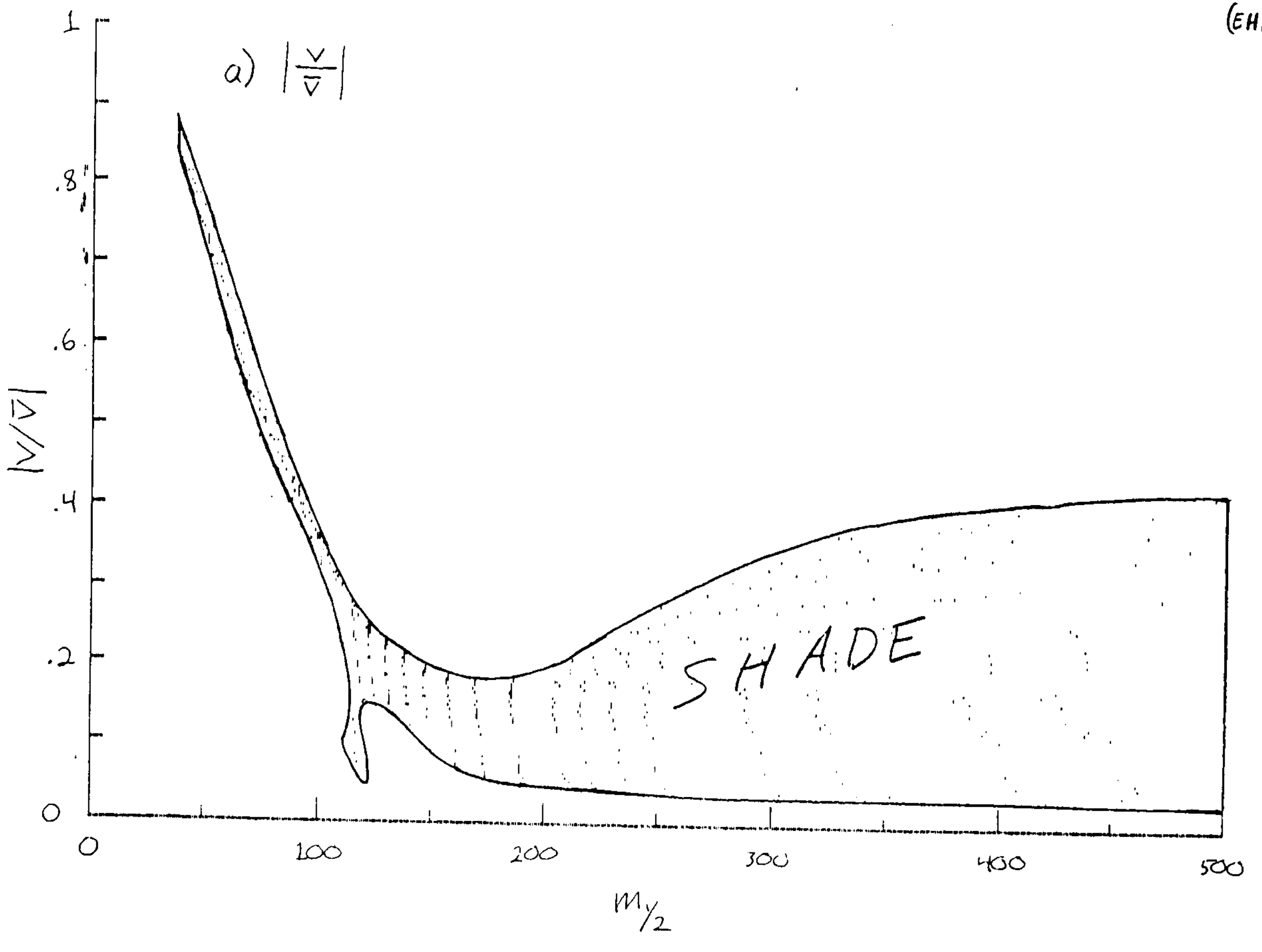


FIGURE 6a

(EHKN)

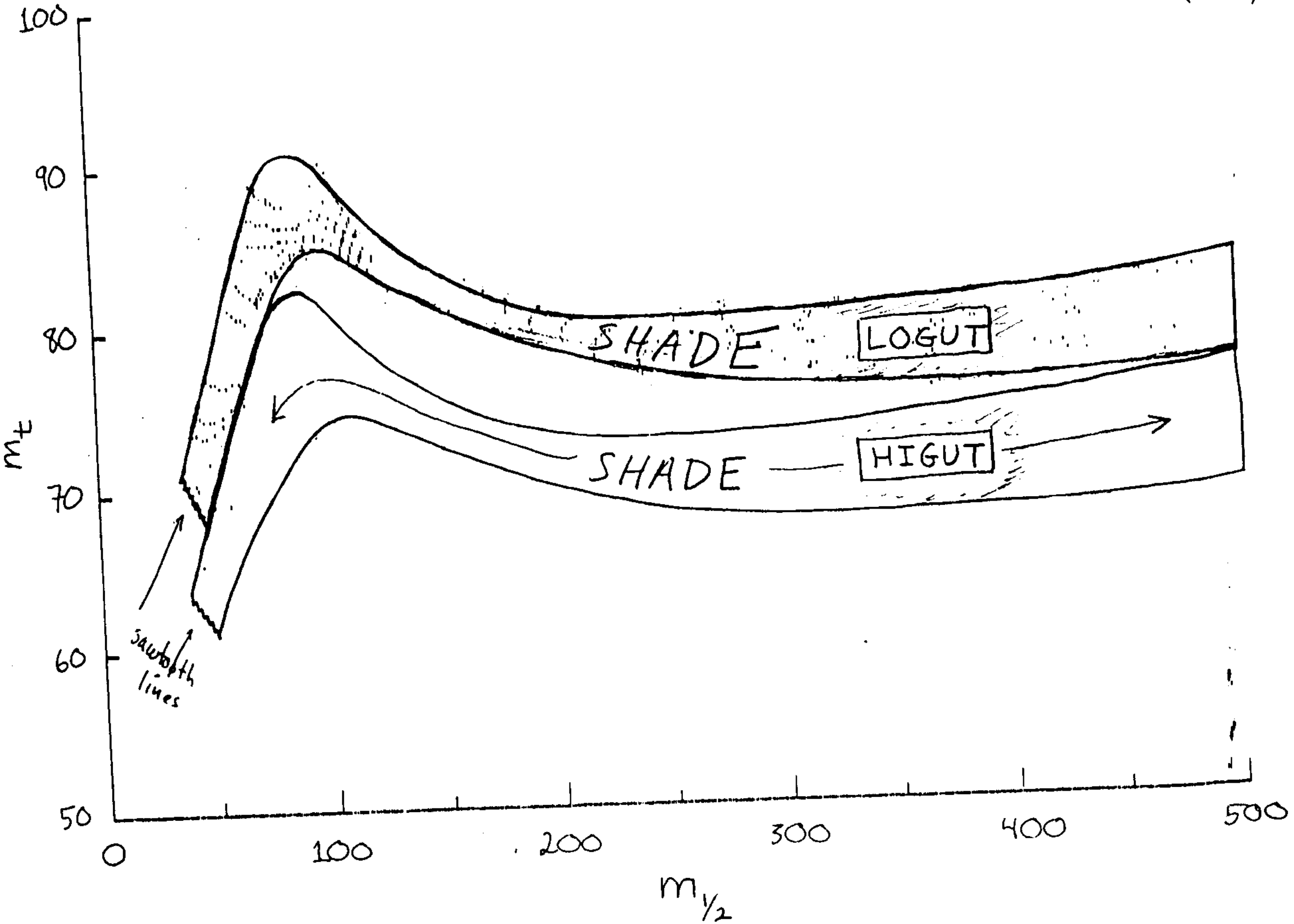


FIGURE 7

(EHKN)

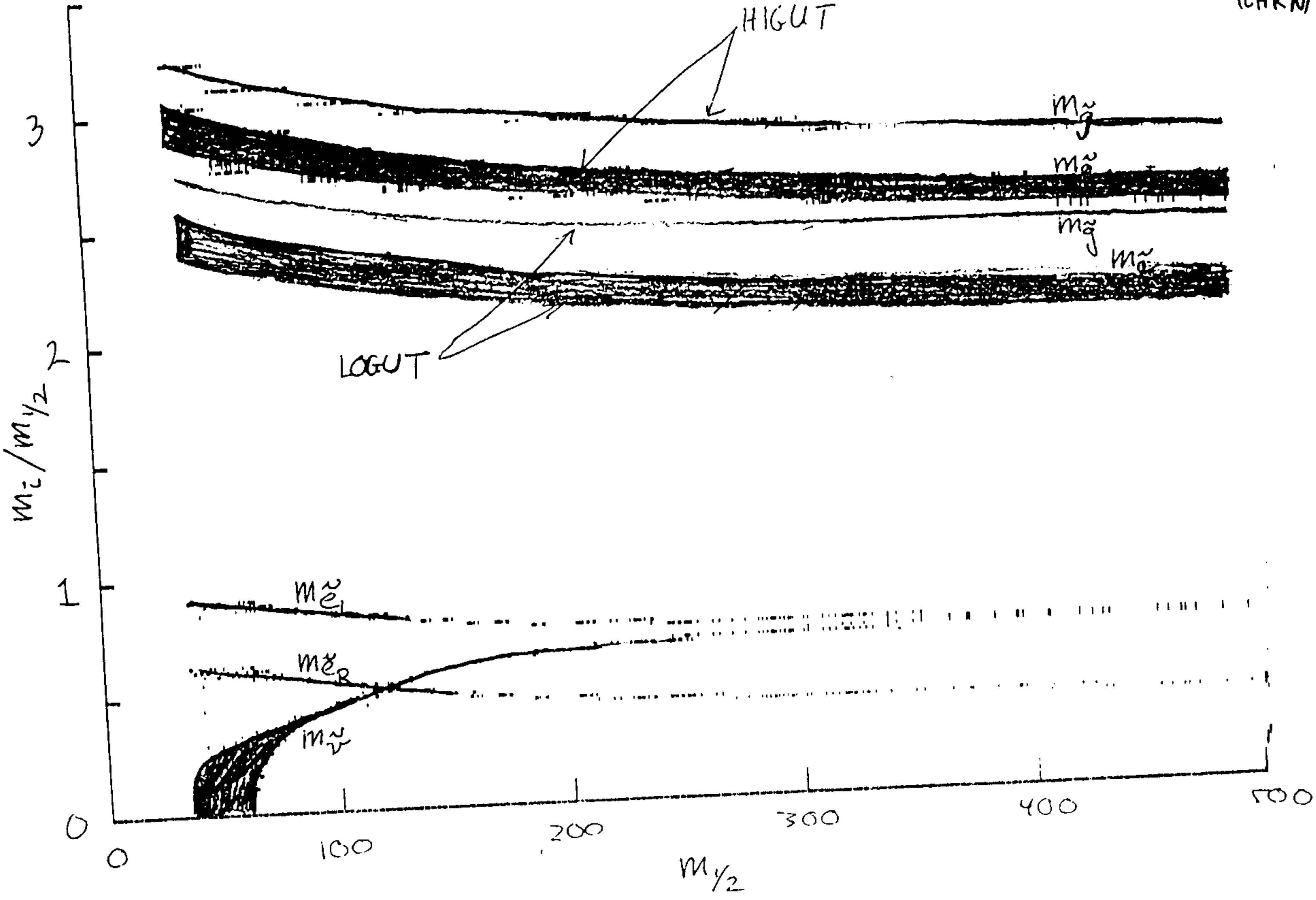


FIGURE 8

(II) Hierarchical Fermion Masses

(1) $W_R^{1,2,3} = \lambda_1 F_1 F_1 h_1 + \lambda_2 (F_1 \bar{f}_2 \bar{h}_{12}, F_2 \bar{f}_1 \bar{h}_{12}) + \lambda_3 (\bar{f}_1 \ell_1^c h_1)$

NOT VERY HELPFUL !

TRY NON-RENORM. TERMS CONSISTENT WITH: (i) $SU(5) \times U(1)^4$ gauge Inv

(ii) R-parity

(iii) "Flatness" select. rule

[Integrate out ~~s~~ massive modes]

[LOWEST NON-TRIVIAL ORDER]

(2)

$$W^1_{NR} = \lambda_{11} (F_1 F_2 h_1)(H_1 \bar{H}_2) + \lambda_{12} (F_2 F_2 h_1)(H_1 \bar{H}_2)^2 + \lambda_{13} (F_3 F_3 h_1) \cdot (H_1 \bar{H}_2)^2 \varphi_{23}$$

$$W^2_{NR} = \lambda_{21} (F_1 \bar{f}_1 \bar{h}_{12})(\bar{H}_1 H_2) + \lambda_{22} (F_2 \bar{f}_2 \bar{h}_{12})(\bar{H}_2 H_1) + \lambda_{23} (F_3 \bar{f}_3 \bar{h}_{12})(H_1 \bar{H}_2) \cdot \varphi_{23}$$

$$W^3_{NR} = \lambda_{31} (\bar{f}_1 \ell_2^c h_1)(\bar{H}_2 H_1) + \lambda_{32} (\bar{f}_2 \ell_1^c h_1)(H_1 \bar{H}_2) + \lambda_{33} (\bar{f}_2 \ell_2^c h_1)(H_1 \bar{H}_2)^2 + \lambda_{34} (\bar{f}_3 \ell_3^c h_1)(H_1 \bar{H}_2)^2 \varphi_{23}$$

$$M_D = \langle h_1 \rangle \begin{array}{c|c} \begin{array}{ccc} b & s & d \\ F_1 & F_2 & F_3 \end{array} & \\ \hline \begin{pmatrix} \text{"}\lambda_1\text{"} & & \\ & & \\ & & \end{pmatrix} & \begin{array}{l} F_1 \to b^c \\ F_2 \to s^c \\ F_3 \to d^c \end{array} \end{array}$$
$(-1/3)$

- $\dfrac{\langle h_1 \rangle}{\langle \bar{h}_{12} \rangle} \sim \dfrac{1}{5}$ (EHKN) $\rightsquigarrow$ (DYNAMICAL)

(i) $m_{t,c} > m_{b,\tau}$ ✓

(ii) $m_{t,b,\tau,c} \gg m_{s,\mu,u,d,e}$ ✓

$$M_U = \langle \bar{h}_{12} \rangle \begin{array}{c|c} \begin{array}{ccc} t & c & u \\ F_1 & F_2 & F_3 \end{array} & \\ \hline \begin{pmatrix} & \text{"}\lambda_2\text{"} & \\ \text{"}\lambda_2\text{"} & & \\ & & \end{pmatrix} & \begin{array}{l} \bar{f}_1 \to t^c \\ \bar{f}_2 \to c^c \\ \bar{f}_3 \to u^c \end{array} \end{array}$$
$(2/3)$

$$M_L = \langle h_1 \rangle \begin{array}{c|c} \begin{array}{ccc} \tau & \mu & e \\ \bar{f}_1 & \bar{f}_2 & \bar{f}_3 \end{array} & \\ \hline \begin{pmatrix} \text{"}\lambda_3\text{"} & & \\ & & \\ & & \end{pmatrix} & \begin{array}{l} l_1^c \to \tau \\ l_2^c \to \mu \\ l_3^c \to e \end{array} \end{array}$$
(-1)

Residual of SO(10) symm.

$\text{"}\lambda_1\text{"} = \text{"}\lambda_3\text{"}\big|_M$

E-G: P.L. B88 (1979) 315

N-S: P.L. B124 (1983) 37

$\lambda_{11} V_1 V_2$

$\lambda_{11} V_1 V_2$ $\lambda_{12} V_1^2 V_2^2$

$\lambda_{13} V_1^2 V_2^2 V_{23}$

$\lambda_{21} V_1 V_2$

$\lambda_{22} V_1 V_2$

$\lambda_{23} V_1 V_2 V_{23}$

$\lambda_{31} V_1 V_2$

$\lambda_{32} V_1 V_2$ $\lambda_{33} V_1^2 V_2^2$

$\lambda_{34} V_1^2 V_2^2 V_{23}$

.. λ's $\sim \mathcal{O}(1) \rightarrow$ [AEFNT]

... $\frac{V_{1,2}}{M_{Pl}} \sim 10^{-2\pm 1}$

.... $\frac{\langle h_1, \bar{h}_{12} \rangle}{M_{Pl}} \sim 10^{-16}$

(DYNAMICALLY !)

$\downarrow$

WE DERIVE

$\downarrow$

- HIERAR. FERMION SPECTRUM ✓

.. $m_b \simeq m_\tau |_M$ ✓
$m_s \simeq m_\mu |_M$
$m_d \neq m_e |_M$ ✓

... $\theta_{1,2,3;\delta} \neq 0$ ✓

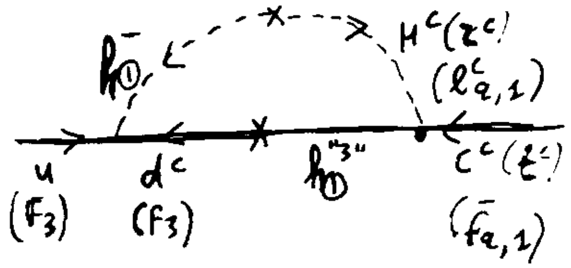
⋮

- $\exists$ $U(1)^3$ (local) gauge symmetry CRUCIAL !
  $\downarrow$ "FAMILY GROUP"

.. In S'um $\nexists$ global (continu.) symm. (BD)

• $\exists$ discrete symmetry P_3: $M_3 \to -M_3$ respected by all interaction terms in Low-Energy Effective theory

★ BUT ★



(G. Leontaris
CERN Preprint
TH-4986 (1988)

$\lambda^{q} \dfrac{m_s}{\langle \bar{h}_{12} \rangle}$
$\lambda^{q\prime}(\cdots)$

$\lambda^{q} \dfrac{m_s}{\langle \bar{h}_{12} \rangle} \lambda^{q\prime}(\cdot)$

Neutrino Mass Matrix

(1) $\nexists$ λ_6-terms $\in W_R$!

$(F_1 H_2 \chi \quad F_2 \bar{H}_1 \bar{\chi})$

(2) $$W^6_{NR} = \lambda_{611}(F_1\bar{H}_1)^2 + \lambda_{612}(F_1\bar{H}_1)(F_2\bar{H}_2) + \lambda_{621}(F_1\bar{H}_2)(F_2\bar{H}_1)$$

$$+ \lambda_{622}(F_2\bar{H}_2)^2 + \lambda_{623}(F_3\bar{f}_3 h_{12})(H_1\bar{H}_2)\varphi_{23} + \lambda_{633}(F_3\bar{H}_2)^2\varphi_{23}$$

$(F_3\bar{H}_2\varphi)$

e.t.c…

• $$(\nu_1, \nu_1^c, \nu_2^c, \nu_2)\begin{pmatrix} 0 & 0 & \lambda_2\bar{v}_{12} & 0 \\ 0 & \lambda_{611}V_2^2 & (\lambda_{612}+\lambda_{621})\cdot V_1V_2 & \lambda_2\bar{v}_{12} \\ \lambda_2\bar{v}_{12} & (\,''\,) & \lambda_{622}V_1^2 & 0 \\ 0 & \lambda_2\bar{v}_{12} & 0 & 0\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_1^c \\ \nu_2^c \\ \nu_2\end{pmatrix}$$

(NOVEL)

$\exists$ two eigenstates of mass $\sim \lambda V_{1,2}^2$ ✓

and $\exists$ $\underset{\boxed{(\nu_\tau, \nu_\mu)}}{''}$ $''$ $\sim \dfrac{\lambda\,\bar{v}_{12}^2}{V_{1,2}^2} \sim \boxed{\mathcal{O}(eV)}$!!!

•• $$(\nu_3, \nu_3^c)\begin{pmatrix} 0 & \lambda_{23}\bar{v}_{12}V_1V_2V_{23} \\ \lambda_{23}\bar{v}_{12}V_1V_2V_{23} & \lambda_{633}V_2^2V_{23}\end{pmatrix}\begin{pmatrix}\nu_3 \\ \nu_3^c\end{pmatrix}$$

$\exists$ 1-eigenstate of mass $\sim \lambda V_2^2 V_{23}$ ✓

and $\exists$ $\underset{\boxed{(\nu_e)}}{''}$ $''$ $\sim \lambda\,\bar{v}_{12}^2 V_1^2 V_{23} \sim \boxed{\mathcal{O}(10^{-8}eV)}$!!!

(III) HIGGS DOUBLET-TRIPLET SPLITTING

(1) $$W_R^{4,5,7} = \lambda_4 \left(H_1 H_1 h_1 ,\ H_2 H_2 h_2 \right) + \lambda_5 \left(\bar{H}_1 \bar{H}_1 \bar{h}_1 ,\ \bar{H}_2 \bar{H}_2 \bar{h}_2 \right) + \lambda_7 \left(h_2 \bar{h}_3 \varphi_{23} ,\ \bar{h}_2 h_3 \bar{\varphi}_{23} \right)$$

(2) $$W_{NR}^{4,5} = \lambda_{4122} \left(H_1 H_2 h_2 \right)\left(\bar{H}_1 H_2 \right) + \lambda_{4123} \left(H_1 H_2 h_3 \right)\left(\bar{H}_1 H_2 \bar{\varphi}_{23} \right) + (\text{"Conjugate" terms})$$

$$W_{NR}^{"4,5"} = \lambda_{H\phi} \lambda_{\bar{H}\phi}\, \varepsilon^{\alpha\beta\gamma\delta\varepsilon} H_{1\alpha\beta} h_{\phi\gamma}\, \varepsilon_{\alpha'\beta'\gamma'\delta\varepsilon} \bar{H}_1^{\alpha'\beta'} \bar{h}_{\phi}^{\gamma'}$$

with $H\phi \equiv H_{12}$; $h_\phi \equiv h_2$ $\quad \exists\ \lambda_{H12} H_1 H_{12} h_2 + \text{"c.c"}$ ✓

H_{13} ; $h_\phi \equiv h_3$ $\quad \exists\ \lambda_{H13} H_1 H_{13} h_3 + \text{"c.c"}$

H_5 ; $h_\phi \equiv h_{12}$ $\quad \exists\ \lambda_{H5} H_1 H_5 h_{12} + \text{"c.c"}$

(Colour) Triplet mass matrix

$$\left(h_1, h_2, h_3, h_{12}, \bar{H}_1, \bar{H}_2 \right)
\begin{pmatrix}
\cdot & \cdot & \cdot & \cdot & \lambda_4 V_1 & \cdot \\
\cdot & \lambda_{H1}\lambda_{\bar{H}1} V_1^2 & \lambda_7 V_{23} & \cdot & \lambda_{4122} V_2^2 V_1 & \lambda_4 V_2 \\
\cdot & \lambda_7 V_{23} & \lambda_{H13}\lambda_{\bar{H}13} V_1^2 & \cdot & \lambda_{4123} V_2^2 V_1 V_{23} & \lambda_{4123} V_1^2 V_2 V_{23} \\
\cdot & \cdot & \cdot & \lambda_{H5}\lambda_{\bar{H}5} V_1^2 & \cdot & \cdot \\
\lambda_5 V_1 & \lambda_{5122} V_2^2 V_1 & \lambda_{5123} V_2^2 V_1 V_{23} & \cdot & \cdot & \cdot \\
\cdot & \lambda_5 V_2 & \lambda_{5123} V_1^2 V_2 V_{23} & \cdot & \cdot & \cdot
\end{pmatrix}
\begin{pmatrix} \bar{h}_1 \\ \bar{h}_2 \\ \bar{h}_3 \\ \bar{h}_{12} \\ H_1 \\ H_2 \end{pmatrix}$$

$\therefore$ ALL UN-WANTED HIGGS TRIPLETS : $M_{"3"} \ggg M_W$ ✓

(IV) h-$\bar{h}$ MIXING.

- h_1; $\bar{h}_{12}$ the ones available for Electroweak-breaking

(1) $W_R^7 \not\ni$ relevant $h_1 \bar{h}_{12}$ mixing term

(2) $W_{NR}^{"7"} \ni (\bar{H}H)^m (\Phi_{23})^n h_{1,12} \bar{h}_{1,12}$, $m+n \geq 4$

because of "Flatness" selection rule !

$\mathcal{O}(M_W)\, h_{1,12} \bar{h}_{1,12}$ ✓

.. In our scheme $\lambda_1^b \sim \lambda_2^t \rightsquigarrow$

$\langle h_1 \rangle \neq 0$ independent of the existence of $h_1 \bar{h}_{12}$ mixing

(In sharp contrast to conventional SUSY GUTs !)

RECAP

$\exists$ 4-D String Model $\rightsquigarrow$ effective F.T: FLIPPED $SU(5)\times U(1)$ GUT with following properties:

- It is reduced (by radiative breaking) to $SU(3)_c\times SU(2)_L\times U(1)_Y$ at $M \rightsquigarrow$ Dyn. determ: $\frac{M}{M_{Pl}} \sim 10^{-2\pm 1}$

$$SU(3)_c\times SU(2)_L\times U(1) \xrightarrow[M_W]{\text{RADIAT.}} SU(3)_c\times U(1)_{E.M}$$

$$\frac{M_W}{M_{Pl}} \sim 10^{-16} \quad \text{(dynam. determ)}$$

Hierarchical quark/lepton mass matrices; $\theta_1 \theta_2 \theta_3 \delta \neq 0$

Elegant/Natural Higgs doublet-triplet splitting

- Novel (acceptable) see-saw mechanism for ν_L

Cosmologically acceptable:

i) $\nexists$ late phase transition, $\nexists$ overproduction of entropy (to dilute everything)

ii) $\exists$ sufficient Baryon asymmetry

iii) $\exists$ (flipped) Dark Matter

$\vdots$