SEESAW IN SO(10) AND SPLIT SUSY

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(JSI, LJUBLJANA, SLOVENIA)

FLAVOUR IN THE ERA OF THE LHC, CERN 05

WORK DONE WITH

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WE WILL CONSIDER

THE YUKAWA STRUCTURE IN SO(10)

I.E.

HOW ARE M_U, M_D, M_E, M_N

FERMION MASSES & MIXINGS

CONSTRAINED BY SO(10)

WE WILL ASSUME:

(1) ONLY SO(10)

NO FLAVOUR SYMMETRY

(2) RENORMALIZABILITY

- NEED IT FOR PREDICTIONS
- NOT SO CRAZY:

$$W = \frac{c}{M_{Pe}} QQQL \qquad (16_F^4)$$

$c \lesssim 10^{-7}$ PHENOMENOLOGICAL CONSTRAINT

THE MOST GENERAL YUKAWA

$$\mathcal{L}_Y = 16_F^T \left(10_H Y_{10} + 120_H Y_{120} + 126_H Y_{126} \right) 16_F$$

3 X 3 MATRICES

$$Y_{10,126}^T = + Y_{10,126}$$

$$Y_{120}^T = - Y_{120}$$

FROM SO(10)

THE MOST GENERAL CASE

NOT RESTRICTIVE:

TRY TO MODEL SIMPLE,

MINIMAL SUBCASES

126 <

(1) BREAKS RANK OF SO(10)

(2) GIVES MASS TO $\nu_{R,L}$ (MAJORANA)

(3) CORRECTS LIGHT FERMION MASSES

THE BEST STUDIED GUT MODEL:

$10_H + 126_H$ IN SUSY

MODEL 1

CLARK, KUO, NAKAGAWA
LAZARIDES, SHAFI, WETTERICH
BABU, MOHAPATRA

→ REALISTIC 3 GENERATION SPECTRUM

BERTOLINI, MALINSKY, OŚ
BABU, MACESANU, 05

→ PREDICTION: $|U_{e3}| \geq 0.1$

GOH, MOHAPATRA, NG, 03

→ IF TYPE II SEESAW DOMINATES, SIMPLE CONNECTION:

(b-τ) UNIFICATION ⟺ LARGE θ_{ATM}

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AMON ILAKOVAC (NEXT TALK)

IS 126_H REALLY NECESSARY ?

(1) <u>RANK OF SO(10):</u>

$126_H \longrightarrow 16_H$

$SO(10)$
$\downarrow$
$SU(2)_L \times SU(2)_R \times SU(4)_C$
$\downarrow \langle 16_H \rangle$
SM

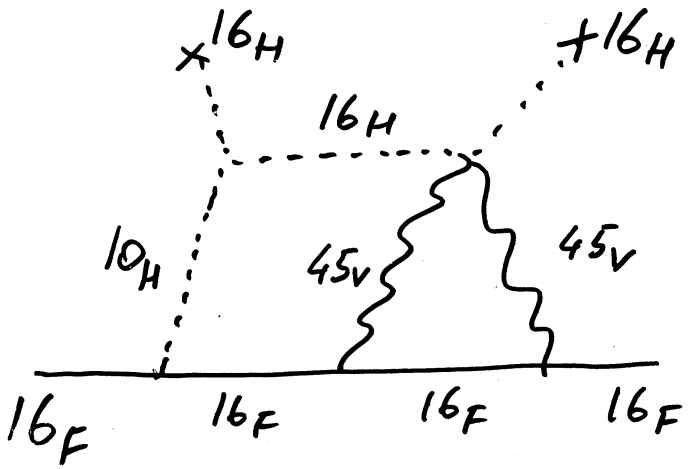
$\langle 16_H \rangle = M_R$

(IN THE $(1,2,\bar{4})$ DIRECTION

(2) <u>M_{ν_R} MASS:</u>

NO 126_H, AT TREE ORDER $M_{\nu_R} = 0$

WITTEN'S IDEA (80):



$$M_{\nu_R} \simeq \left(\frac{\alpha'}{\pi}\right)^2 \frac{M_R^2}{M_{GUT}} Y_{10}$$

WHEN IS IT VALID?

NONSUSY: DIFFICULT,

WITHOUT FINE-TUNING $M_R \ll M_{GUT}$

FOR SUCCESSFUL GAUGE UNIFICATION

$\Rightarrow$ M_{VR} TOO SUPPRESSED, BUT...

SUSY: NO, FOR LOW-ENERGY

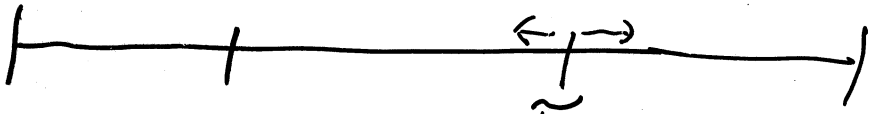
SUSY BREAKING,

$M_{VR} \propto m_{SUSY}$

SPLIT SUSY:

(ARKANI-HAMED, DIMOPOULOS, GIUDICE, ROMANINO, 04)

$\tilde{m} = ?$



M_Z GAUGINOS HIGGSINOS (~ TeV) $\tilde{m}$ (SFERMIONS) M_{GUT}

YES, IF $\tilde{m} \simeq M_{GUT}$

(BAJC, SENJANOVIĆ, 04)

(3) LIGHT FERMION MASSES :

WITTEN'S MODEL TOO SIMPLE

ONLY ONE HIGGS : 10_H

ALL MATRICES $\propto Y_{10}$ (DIAGONAL)

$\Rightarrow$ NO MIXINGS

ADD ANOTHER HIGGS : 120_H

Y_{120} ANTISYMMETRIC

$$M_D = M_0 + M_2$$

$$M_U = c_0 M_0 + c_2 M_2$$

$$M_E = M_0 + c_3 M_2$$

$$M_{\nu_D} = c_0 M_0 + c_4 M_2$$

MODEL 2

$M_0 \propto Y_{10}$ SYMMETRIC

$M_2 \propto Y_{120}$ ANTISYMMETRIC

$c_0 \in \mathbb{R}$ $\quad c_{2,3,4} \in \mathbb{C}$

NEUTRINO:

$$M_{\nu_R} = c_R M_0$$ (WITTEN)

$$M_N = -M_{\nu_D}^T M_{\nu_R}^{-1} M_{\nu_D}$$

STUDY FIRST THE 2^{ND} AND 3^{RD} GENERATIONS ONLY:

$$M_0 = \begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix}$$

$$M_2 = \begin{pmatrix} 0 & i\alpha \\ -i\alpha & 0 \end{pmatrix}$$

$c_0, a, b \in \mathbb{R} \quad (a, b > 0)$

$\alpha, c_2, c_3, c_4 \in \mathbb{C}$

ONLY 4 REAL PARAMETERS FROM YUKAWA SECTOR (a, b, α)

BUT 7 REAL PARAMETERS FROM HIGGS SECTOR (c_0, c_2, c_3, c_4)

IN THE APPROXIMATION $(m_c, m_s, m_\mu = 0)$

$$M_D = \begin{pmatrix} a & -i\sqrt{ab} \\ i\sqrt{ab} & b \end{pmatrix}$$

$$M_E = M_D \qquad M_U = c_0 M_D$$

$\Downarrow$ $\qquad$ $\Downarrow$

(1) $\boxed{m_\tau = m_b}$ $\qquad$ (2) $\boxed{\theta_q = 0}$

THE CHARGED LEPTON MIXING ANGLE:

$$\tan(2\theta_E) = \frac{2\sqrt{ab}}{b-a}$$

$$M_N = -M_{\nu_D}^T M_{\nu_R}^{-1} M_{\nu_R} \propto \begin{pmatrix} a & 0 \\ 0 & b \end{pmatrix} \Rightarrow \theta_N = 0$$

$$\theta_{ATM} = \theta_E - \theta_N = \theta_E$$

$\Downarrow$

(3) $\boxed{\theta_{ATM} \text{ MAXIMAL} \Leftrightarrow \text{NEUTRINO DEGENERATE}}$

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WITTEN + 10_H + 120_H

(1) COUNTEREXAMPLE TO THE COMMON BELIEF THAT IN SO(10) GUTS V MASSES HIERARCHICAL

(2) θ_q SMALL BECAUSE EQUAL TO THE DIFFERENCE OF TWO LARGE ANGLES

(3) θ_ℓ LARGE BECAUSE IT FAILS TO CANCEL (M_N DIAGONAL)

(4) B-L UNIFICATION AUTOMATIC (IN SPITE OF 120_H)
UNUSUAL: CONNECTED TO THE SMALL 2ND GENERATION CHARGED FERMION MASSES

OPEN QUESTIONS AND PROBLEMS

→ B-L UNIFICATION (SMALL $\tan\beta$)

→ HOW SMALL CAN BE $\tilde{m}$?

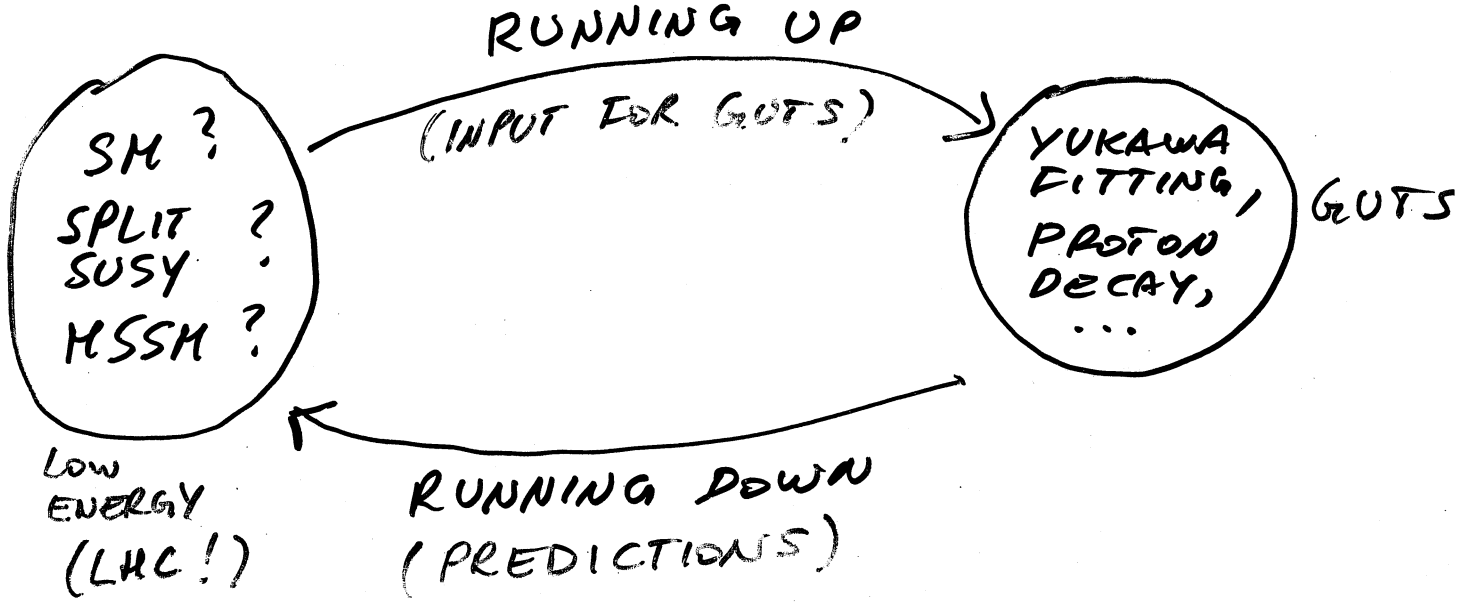
→ **3 GENERATIONS** CASE TO BE STUDIED IN DETAIL

BAJC, NEHEVŠEK, SENJANOVIĆ (WORK IN PROGRESS)

→ CONTRIBUTIONS OF Y_{120} TO WITTEN'S DIAGRAM

→ **MORE AMBITIOUS**:

CAN YUKAWA STRUCTURE IN GUTS TELL US SOMETHING ABOUT THE LOW-ENERGY SPECTRUM?



PREDICTIONS FOR LOW-ENERGY PHYSICS
(TESTS FOR LHC ?)

MODEL 1 $(10_H + 126_H)$

- LOW ENERGY ($\sim O(TeV)$) SUSY
- $|U_{e3}| \gtrsim 0.1$

MODEL 2 $(10_H + 120_H)$

- GAUGINO, HIGGSINO IN $O(TeV)$ REGION
- SMALL $\tan\beta$ (< 1)
- INDICATION FOR DEGENERATE NEUTRINO

WHAT IF NOTHING BEYOND SM IS FOUND AT LHC?
DON'T WORRY:

MODEL 3 $(120_H + 126_H)$

- SM

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IN ALL THESE MODELS $\not{CP}$ PHASES PREDICTABLE