

THE MINIMAL $SO(10)$ GUT

BORUT BAJC

(JSI, LJUBLJANA, SLOVENIA)

- FLAVOUR IN THE
ERA OF LHC (2)

- CERN 06

WORK DONE WITH

~~XXXX~~

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MINIMALITY :

THEORY WITH THE MINIMAL
ASSUMPTIONS & PARAMETERS

→ MAXIMAL PREDICTIVITY

NOT NECESSARILY THE
SIMPLEST ONE !

EX.:

$SU(5)$ IS THE SIMPLEST GUT

NOT THE MINIMAL

(NEUTRINO !)

ASSUMPTIONS (WORKING HYPOTHESIS)

- ONLY GUT SYMMETRY - $SO(10)$

NO FLAVOUR

NO SINGLET

- ONLY RENORMALIZABLE OPERATORS

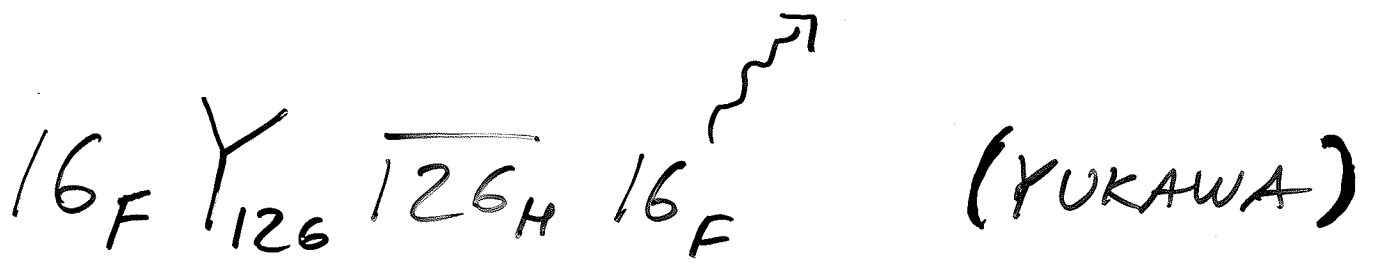
- LOW ENERGY SUSY

IN SUSY LARGE $\langle \overline{126}_H \rangle \sim M_{\nu_R}$

MUST BE CANCELED IN D-TERMS BY 126_H



$(2, 1, 4) + (1, 2, \bar{4})$



3x3 MATRIX IN GENERATION SPACE

$(1, 3, 10)$ MASS TO ν_R

PATI-SALAM DECOMPOSITION

$(2, 2, 15)$ MASS TO CHARGED FERMIONS

$(3, 1, \bar{10})$ MASS TO ν_L

$SU(2)_L \times SU(2)_R \times SU(4)_C$
C $SO(10)$

ANOTHER REASON TO USE 126_H : ^⑤

$\langle (1, 3, 10) \rangle \neq 0$ HAS $B-L = 2$



R-PARITY UNBROKEN AT
HIGH ENERGY

MOHAPATRA, 86
FONT, IBAÑEZ, QUEVEDO, 89
MARTIN, 92

$$R = (-1)^{3(B-L)}$$

IT REMAINS UNBROKEN ALSO
AT LOW ENERGY

AULAKH, BENAKLI, SENJANOVIĆ, 97
AULAKH, MELFO, SENJANOVIĆ, 98
AULAKH, MELFO, RAŠIN, SENJANOVIĆ, 99

$\overline{126}_H$:

$$\langle (2, 2, 15) \rangle \implies M_E = -3 M_D$$

GOOD FOR 2ND GEN.

$$u_\mu \approx -3 u_s$$

BAD FOR 1ST, 3RD GEN.

NEED FOR 10_H :

\swarrow
 $(2, 2, 1) + \dots$

$$\langle (2, 2, 1) \rangle \implies M_E = M_D$$

GOOD FOR 3RD GEN.

$$u_\tau \approx u_b$$

BAD FOR 1ST, 2ND GEN.

COMBINATION OF 10_H AND $\overline{126}_H$
COULD BE REALISTIC ?

- LAZARIDES, SHAFI, WETTERICH, 81
- BABU, MOHAPATRA, 92

$$M_D = \nu_{10}^d Y_{10} + \nu_{126}^d Y_{126} \quad (7)$$

$$M_U = \nu_{10}^u Y_{10} + \nu_{126}^u Y_{126}$$

$$M_E = \nu_{10}^d Y_{10} - 3 \nu_{126}^d Y_{126}$$

$$M_{\nu_D} = \nu_{10}^u Y_{10} - 3 \nu_{126}^u Y_{126}$$

ONLY 10_H : $M_D = M_E$

ONLY $\overline{126}_H$: $-3 M_D = M_E$

-3 DUE TO $\langle (2, 2, 15) \rangle \propto \begin{pmatrix} 1 \\ 1 \\ -3 \end{pmatrix}$

NEUTRINO:

$$M_{\nu_R} = \nu_R Y_{126}$$

$$\nu_R = \langle (1, 3, 10) \rangle$$

$$M_{\nu_L} = \nu_L Y_{126}$$

$$\nu_L = \langle (3, 1, \overline{10}) \rangle$$

$$M_N = \underbrace{M_{\nu_D}^T M_{\nu_R}^{-1} M_{\nu_D}}_{\text{TYPE I SEESAW}} + \underbrace{M_{\nu_L}}_{\text{TYPE II SEESAW}}$$

FIRST ATTEMPTS USED ONLY TYPE I

BABU, MOHAPATRA, 92

ODA, TAKASUGI, TANAKA, YOSHIMURA, 98

MATSUDA, KOIDE, FUKUYAMA, NISHIURA, 01

FUKUYAMA, OKADA, 02

NOT VERY SUCCESSFUL

IF ASSUME ONLY TYPE II

$$M_N \propto M_{\nu_L} \propto M_D - M_E$$

- 2ND + 3RD GENERATIONS ($m_2 \ll m_3$)

- ASSUME SMALL MIXING ANGLES IN CHARGED SECTOR

$$M_N \propto \begin{pmatrix} \epsilon & \epsilon \\ \epsilon & m_b - m_\tau \end{pmatrix}$$

IN TYPE II SEESAW LARGE ATMOSPHERIC ANGLE CONNECTED WITH B-TAU UNIFICATION

BAJC, SENJANOVIĆ, VISSANI, 01, 02

SEVERAL ANALYSIS PERFORMED

GOH, MOHAPATRA, NG, 03, 03

DUTTA, KIMURA, MOHAPATRA, 04, 04

BASC, SENJANOVIĆ, VISSANI, 04

GOH, MOHAPATRA, NASRI, 04

BERTOLINI, FRIGERIO, MALINSKY, 04

RESULT :

THE YUKAWA SECTOR

$$16_F \left(10_H Y_{10} + \overline{126}_H Y_{126} \right) 16_F$$

IS REALISTIC BOTH

IN TYPE I

BERTOLINI, MALINSKY, 05

BABU, MACESANU, 05

AND TYPE II

SEE-SAW

WHAT ABOUT THE HIGGS SECTOR?

$$10_H + 126_H + \overline{126}_H$$

- NOT ENOUGH TO BREAK

$$SO(10) \rightarrow SM$$

- NOT ENOUGH TO FINE-TUNE

THE DOUBLET - TRIPLET SPLITTING

$$W_H = M_{10} 10_H^2 + M_{126} \overline{126}_H \cdot 126_H$$

$\begin{matrix} \downarrow \\ (2, 2, 1) \end{matrix}$
 $\begin{matrix} \downarrow \\ (2, 2, 15) \end{matrix}$
 $\begin{matrix} \downarrow \\ (2, 2, 15) \end{matrix}$

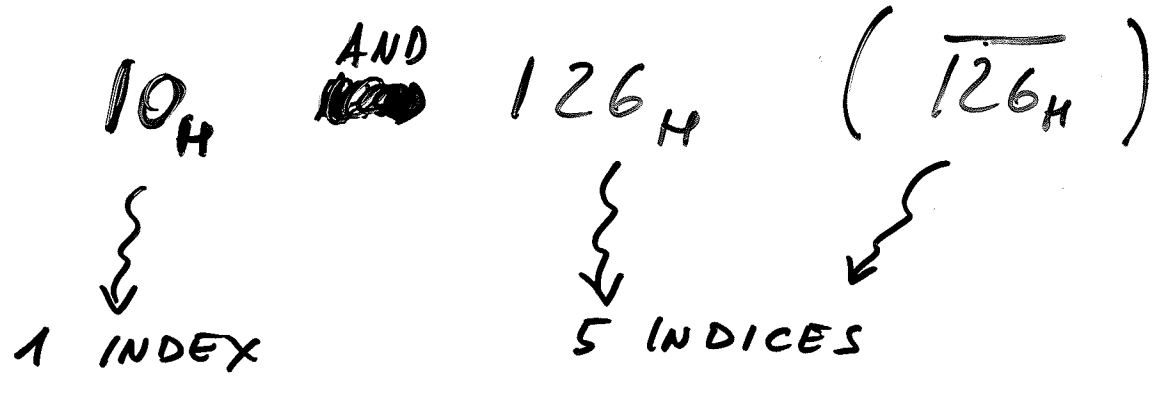
THE DOUBLETS D, \bar{D} :

$$(\bar{D}_{10}, \bar{D}_{126}, \bar{D}_{\overline{126}}) \begin{pmatrix} M_{10} & \odot & \odot \\ \odot & 0 & M_{126} \\ \odot & M_{126} & 0 \end{pmatrix} \begin{pmatrix} D_{10} \\ D_{126} \\ D_{\overline{126}} \end{pmatrix}$$

TO GET

$$\det M_{\text{DOUBLETS}} = 0 \quad (\text{MSSM HIGGS!})$$

ONE NEEDS TO MIX



\nwarrow \nearrow
 CONNECTED BY

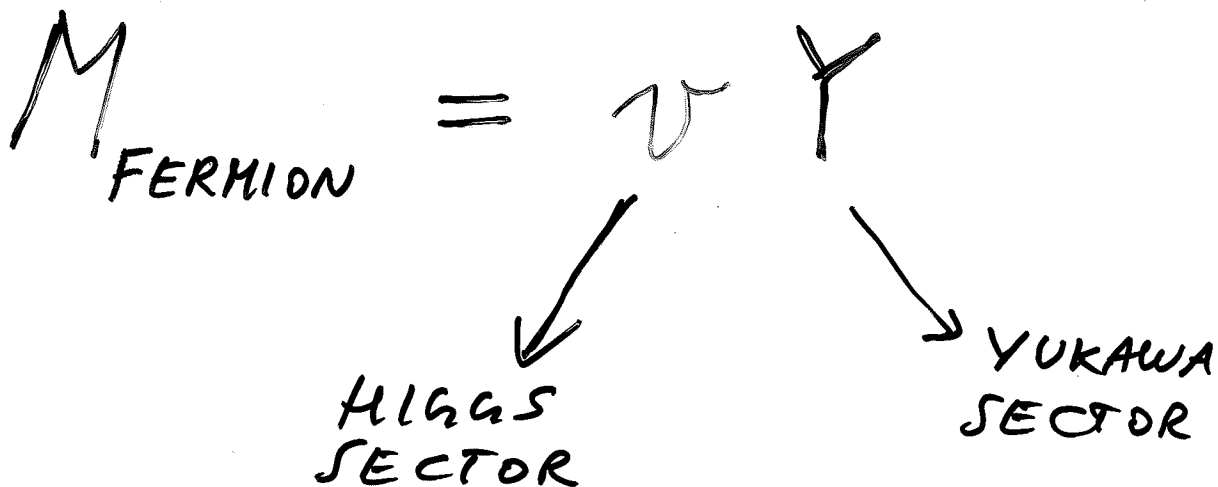
$210_H \rightsquigarrow 4 \text{ INDICES}$
 \parallel

- (1, 1, 1)
- +
- (1, 1, 15)
- +
- (1, 3, 15)
- +
- (2, 2, 10)
- +
- (2, 2, $\overline{10}$)
- +
- ...

TOGETHER WITH
 $126_H + \overline{126}_H$
 BREAK
 $SO(10) \rightarrow SM$
 OTHER DOUBLETS

SO FAR THE FITTING OF
YUKAWA SECTOR HAS BEEN
DONE WITHOUT ASSUMING
HIGGS SECTOR

WHY SHOULD IT MATTER?



THE ν VEVS DETERMINED BY
THE HIGGS SECTOR PARAMETERS

→ TYPE II SEE-SAW ONLY UNLIKELY
BASJ, HELFO, SENIANDVIĆ, VISSANI, 05

→ TYPE I SEE-SAW ONLY UNLIKELY
AULAKH, GARG, 05

MORE DETAILS :

FROM $SO(10)$ RELATIONS AT M_{GUT} :

$$M_U = \alpha M_D + \beta M_E$$

$$\frac{\alpha}{\beta} = f(x)$$

ONLY ONE
PARAMETER

$$x \in \mathbb{C}$$

FITTING M_U, M_D, M_E

\Rightarrow DETERMINES x

(BUT SOLUTION DEPENDENT!)

THE SAME x WILL ENTER
THE NEUTRINO MASS FORMULA

CONCENTRATE ON TYPE II SEESAW :

TYPICALLY $M_N \sim \frac{v^2}{M_{GUT}}$

TOO SMALL (FOR 3RD GENERATION)

MORE PRECISELY:

$$M_N \approx \frac{v (M_D - M_E)}{\sqrt{|\eta|} h(x) m_T(x)}$$

FROM

$$\eta \begin{matrix} \overline{126}_H \\ 126_H \\ 210_H \end{matrix}$$

↑ SAME X AS BEFORE!

M_N ENHANCED IF

- (a) $\eta \rightarrow 0$
- (b) $h(x) \rightarrow 0$
- (c) $m_T(x) \rightarrow 0$

VERY UNLIKELY !

IMPLIES

- EITHER LIGHT MULTIPLETS (SPOILS UNIFICATION)
- OR X THAT DO NOT FIT CHARGED FERMIONS

MORE WORK NEEDED!

CONCLUSIONS

① MINIMAL RENORMALIZABLE $SO(10)$

$$= 3 * 16_F + 10_H + 126_H + \overline{126}_H + 210_H :$$

ONLY 26 PARAMETERS (+ SUSY)

② GOOD CHANCES TO DESCRIBE
LOW-ENERGY SPECTRUM, MIXINGS, PHASE

③ POSSIBLE PROBLEMS INCLUDING
HIGGS SECTOR CONSTRAINTS

④ PREDICTIONS :

- $|U_{e3}| > 0.1$, ALL PHASES

- NEUTRINOS HIERARCHICAL

- LOW-ENERGY SUSY WITH

EXACT R-PARITY (LSP!)

→ SEARCH FOR OTHER SOLUTIONS

→ MIXED TYPE I + II SEESAW

OTHER CHECKS:

PROTON DECAY (SOFT TERMS!)

LEE, MOHAPATRA, 94
 GOH, MOHAPATRA, NASRI, NG, 03
 FUKUYAMA, ILAKOVAC, KIKUCHI,
 MELJANAC, OKADA, 04, 04
 DUTTA, HIKURA, MOHAPATRA, 04

LEPTOGENESIS (CORRECT PREDICTIONS)

BABU, MACESANU, 05

SO(10) GROUP THEORY (SPECTRUM)

HE, MELJANAC, 89
 LEE, 94
 AULAKH, GIRDHAR, 02
 FUKUYAMA, ILAKOVAC, KIKUCHI,
 MELJANAC, OKADA, 04
 BAJC, MELFO, SENJANOVIC, VISSANI, 04

RGE + THRESHOLDS (LARGE CORRECTIONS)

AULAKH, GIRDHAR, 04

LFV

(SOFT TERMS!)

ILAKOVAC (FLAVOUR LHC 1)