

Title: Explorations in Particle Theory (PHYS 646) - Lecture 13

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Abstract:

Local SUSY is SUSY in supergravity -

- SUGRA multiplet contains new auxiliary fields

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- D.W. = c

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SUGRA is SUGRA in supergravity -

- SUGRA multi contains new auxiliary fields, F_g . These acquire
VEVs when $\langle F_g \rangle \neq 0$

- $D_i W = \dots / M_P^2$, F-terms of superfields Φ_i are \propto to $D_i W$

- $V_F = \dots \left\{ \frac{F_j K_j^{-1}}{M_P^2} - 3 |W|^2 / M_P^2 \right\}$

\Rightarrow new feature

SUSY is SUSY in supergravity -

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$$- V_F = e^{K/M_P^2} \left\{ F_i F_j K_{ij}^{-1} - 3|W|^2 / M_P^2 \right\}$$

↻ new feature

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$$- V_F = e^{\frac{K}{M_P^2}} \left\{ F_i F_j K_{ij}^{-1} - 3 \frac{|W|^2}{M_P^2} \right\}$$

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Super-Higgs

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The MSSM

4 Spectrum: $N=1$ ~~2~~ ³ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

M

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (4 fermion, scalar).

$(4R)$

Spectrum: $N=1$ ~~2D~~ Superfields (41 fermion, scalar).

4 $P_L \overline{(U_R)} = \overline{U_R}$

Spectrum: $N=1$ $\mathcal{N}=4$ Superfields (41 fermion, scalar).

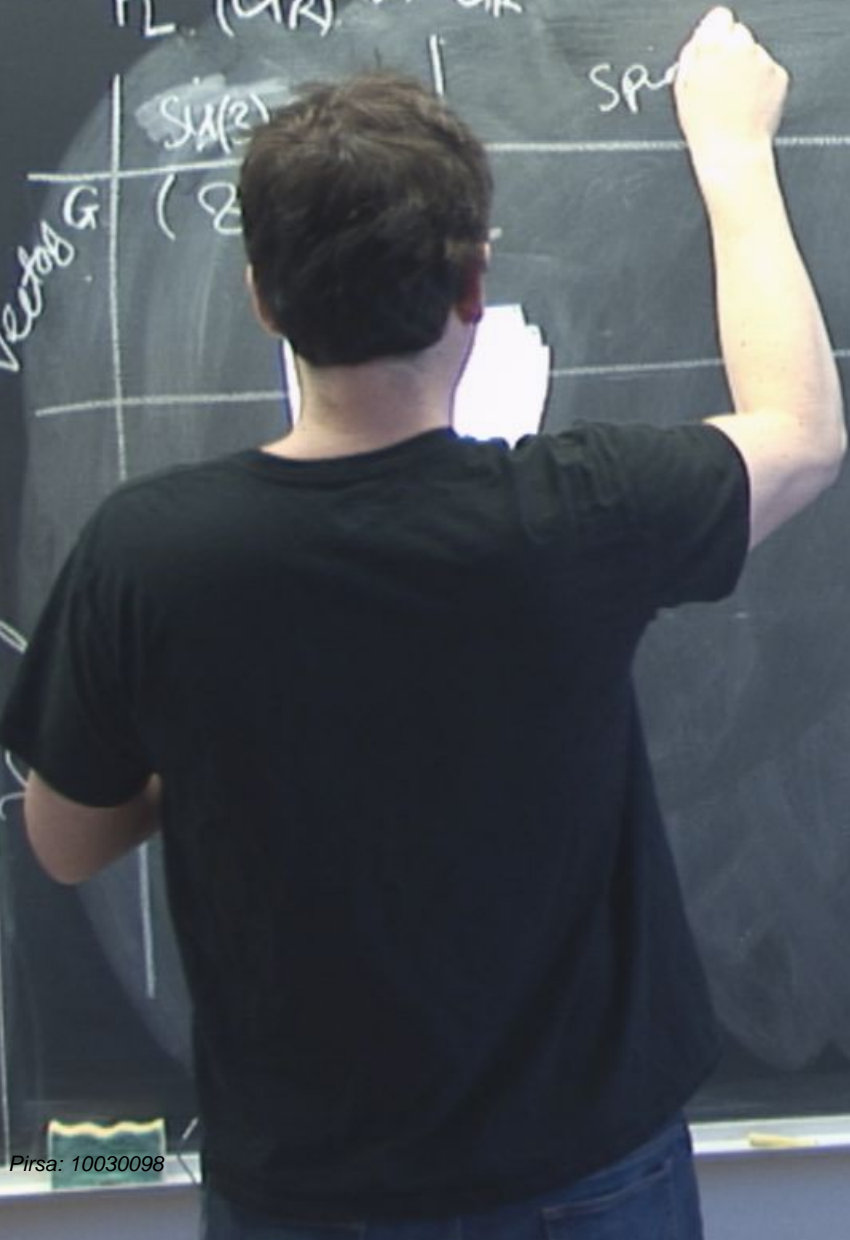
$$P_L(\overline{U_R}) = \overline{U_R}$$

Vector

$SU(2)$

(8)

Spin



Spectrum: $N=1$ $\mathcal{N}=1$ superfields (41 fermion, scalar).

$P_L(\overline{U_R}) = \overline{U_R}$

	$su(3)$	$su(2)$	$u(1)$	
G	8	1	0	
				fermion
				\bar{g}
				boson
				g

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$P_L \overline{(U_R)} = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	
Vector	8	1	0	
				fermion
				boson
				\tilde{g}
				g

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$P_L(\overline{U_R}) = \overline{U_R}$

		$SU(3) \times SU(2) \times U(1)$			fermion	boson
Vector	G	(8	1	0)	gluino \tilde{g}	g
	W	(1	3	0)	wino \tilde{w}	W
$\mathcal{N}=1$						

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

Vector	$SU(3) \times SU(2) \times U(1)$			fermion		boson
	G	W	B			
G	(8	1	0)	gluino	$\overline{15} \overline{3} \overline{1/3}$	$15 \overline{3} \overline{1/3}$
W	(1	3	0)	wino	$\overline{3} \overline{3} \overline{0}$	$3 \overline{3} \overline{0}$
B	(1	1	0)	bino	$\overline{1} \overline{1} \overline{0}$	$1 \overline{1} \overline{0}$

$\mathcal{N}=1$

Spectrum: $N=1$ ^{real} Superfields (41 fermion, scalar).

$P_L(U_R) = U_R$

Vector	$SU(3) \times SU(2) \times U(1)$			fermion $s = 1/2$		boson	
	G	W	B	quino	gluino	g	W
G	(8	1	0)				
W	(1	3	0)	wino			
B	(1	1	0)	bino			

} spin 1

real

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$			
Vector					fermion $s = 1/2$	boson
G	(8	1	0)	gluino	\bar{b}	g
W	(1	3	0)	wino	b	W
B	(1	1	0)	bino	\bar{b}	B
Q	(3	2	$1/6$)			} spin 1

$\mathcal{N}=1$

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$P_L(\overline{U_R}) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$		fermion $s = 1/2$	boson
Vector G	(8	1	0)	quino	\overline{q}	g
W	(1	3	0)	wino	\overline{W}	W
B	(1	1	0)	bino	\overline{b}	B
$Q_{1/2}$	(3	2	$1/6$)		$\begin{pmatrix} u \\ d \end{pmatrix}_L$	

} spin 1

$\mathcal{N}=1$



Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$		
Vector					
G	(8	1	0)	gluino	\tilde{g}
W	(1	3	0)	wino	\tilde{W}
B	(1	1	0)	bino	\tilde{B}
Q	(3	2	$\frac{1}{6}$)		$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$

fermion
 $s = \frac{1}{2}$

boson

$\left. \begin{matrix} \tilde{g} \\ \tilde{W} \\ \tilde{B} \end{matrix} \right\} \text{spin } 1$

$\mathcal{N}=1$

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$				
Vector	G	(8	1	0)	gluino	\overline{g}	g
	W	(1	3	0)	wino	\overline{W}	W
	B	(1	1	0)	bino	\overline{B}	B
Chiral	Q	(3	2	$\frac{1}{6}$)		$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_R$
	L						

fermion
 $s = \frac{1}{2}$

boson

g
 W
 B } spin 1

Chiral

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (H, fermion, scalar).

$P_L(U_R) = U_R$

	$SU(3)$	$SU(2)$	$U(1)$					
Vector	G	(8	1	0)	gluino	\tilde{g}	boson	$\left. \begin{matrix} \tilde{g} \\ W \\ B \end{matrix} \right\} \text{spin } 1$
	W	(1	3	0)	wino	\tilde{W}		
	B	(1	1	0)	bino	\tilde{B}		
Chiral	Q	(3	2	$\frac{1}{6}$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix}_L \equiv \tilde{Q}_L$		

Chiral

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ χ_{real} Superfields (41 fermion, scalar).

$$P_L \overline{(U_R)} = \overline{U_R}$$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$		boson	
G	(8	1	0)	gluino	\tilde{g}	\tilde{g}	} spin 1
W	(1	3	0)	wino	\tilde{W}	\tilde{W}	
B	(1	1	0)	bino	\tilde{b}	\tilde{B}	
Q_L	(3	2	$1/6$)		$\begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$\begin{pmatrix} \tilde{u}_L \\ \tilde{d}_L \end{pmatrix} \equiv \tilde{Q}_L$	

χ_{real}

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (41 fermion, scalar).

$$P_L(U_R) = \overline{U_R}$$

	$SU(3)$	$SU(2)$	$U(1)$		
Vector					
G	(8	1	0)	gluino	\tilde{g}
W	(1	3	0)	wino	\tilde{W}
B	(1	1	0)	bino	\tilde{b}
\tilde{Q}_i	(3	2	$\frac{1}{6}$)	$\begin{pmatrix} u \\ d \end{pmatrix}_L$	$\begin{pmatrix} \tilde{u} \\ \tilde{d} \end{pmatrix}_L \equiv \tilde{Q}_L$
\tilde{L}_i	(1	2	$-\frac{1}{2}$)		

fermion
 $s = \frac{1}{2}$

boson

\tilde{g}
 \tilde{W}
 \tilde{B} } spin 1

family
 $i \in \{1, 2, 3\}$

$\mathcal{N}=1$

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

family
 $\in \{1, 2, 3\}$

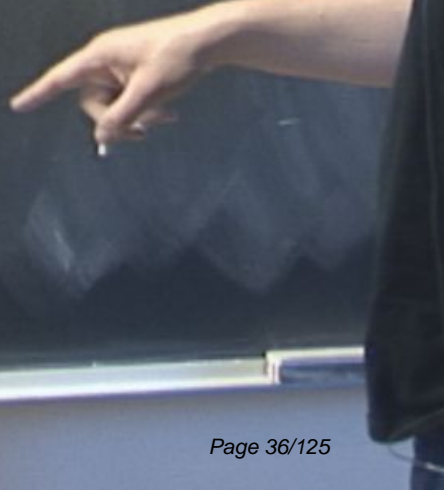
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Vector
 G
 W
 B

Spectrum: $N=1$ χ_{real} Superfields (41 fermion, scalar).
 $P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
G	(8	(1	0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	0)	wino \tilde{W}	\tilde{W}
B	(1	(1	0)	bino \tilde{b}	\tilde{B}
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_i$
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}$

spin 1



would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

family
 $\in \{1, 2, 3\}$

3rd

Spectrum: $N=1$ 3rd Superfields (41 fermion, scalar).

$$P_L(U_R) = \overline{U_R}$$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	1	0)	gluino \tilde{g}	g
W	(1	3	0)	wino \tilde{W}	w
B	(1	1	0)	bino \tilde{b}	B
Q_i	(3	2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_{Li}$
L_i	(1	2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}$

g, w, B } spin 1

$\tilde{u}_i, \tilde{d}_i, \tilde{\nu}_i, \tilde{e}_i$

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ χ_{real} Superfields (41 fermion, scalar).

$P_L \overline{(U_R)} = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	1	0)	gluino \tilde{g}	g
W	(1	3	0)	wino \tilde{W}	W
B	(1	1	0)	bino \tilde{b}	B
Q_i	(3	2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_i$
L_i	(1	2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix} \equiv \tilde{L}_i$

spin 1

family
 $\in \{1, 2, 3\}$

χ_{real}

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

family
 $\in \{1, 2, 3\}$

Spectrum: $N=1$ χ_{real} Superfields (41 fermion, scalars).

$$P_L (U_R) = \overline{U_R}$$

Vector	$SU(3)$	$SU(2)$	$U(1)$
G	(8	(1	0)
W	(1	(3	0)
B	(1	(1	0)
Q_i	(3	(2	$1/6$)
L_i	(1	(2	$-1/2$)
U_i	(3	(1	$-2/3$)

fermion
 $s = 1/2$

quino \tilde{q}
 wino \tilde{W}
 bino \tilde{B}
 $\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$
 $\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$
 $\overline{U_{Ri}}$

boson

\tilde{g}
 \tilde{W}
 \tilde{B}
 $\left. \begin{matrix} \tilde{g} \\ \tilde{W} \\ \tilde{B} \end{matrix} \right\} \text{spin } 1$
 $\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} = \tilde{Q}_{Li}$
 $\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L = \tilde{L}_i$
 U_i

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ χ_{real} superfields (4 fermion, scalar).

$P_L (U_R) = \overline{U_R}$

Vector	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
G	(8	(1	0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	0)	wino \tilde{W}	\tilde{W}
B	(1	(1	0)	bino \tilde{b}	\tilde{B}
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_i$
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_{L} \equiv \tilde{L}_i$
U_{Ri}	(3	(1	$-2/3$)	$\overline{U_{Ri}}$	\tilde{U}_{Ri}^*

family
 $i \in \{1, 2, 3\}$

χ_{real}

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ χ ra Superfields (4 fermion, scalar).

$P_L (U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} = \tilde{Q}_i$
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L = \tilde{L}_i$
U_i	(3	(1	$-2/3$)	$\overline{U_{Ri}}$	\tilde{U}_{Ri}^*
d_{iR}	(3	(1	$1/3$)	$\overline{D_{Ri}}$	\tilde{D}_{Ri}

family
 $\in \{1, 2, 3\}$

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ ~~chiral~~ superfields (4 fermion, scalar).

$$P_L(U_R) = \overline{U_R}$$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$		boson	
Vector							
G	(8	(1	(0)	gluino	\tilde{g}	g	} spin 1
W	(1	(3	(0)	wino	\tilde{W}	W	
B	(1	(1	(0)	bino	\tilde{B}	B	
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_i$	
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_{L} \equiv \tilde{L}_i$	
U_{iR}	(3	(1	($-2/3$)	$\overline{U_{iR}}$	\tilde{U}_{iR}	\tilde{U}_{iR}^*	
d_{iR}	(3	(1	($1/3$)	$\overline{d_{iR}}$	\tilde{d}_{iR}	\tilde{d}_{iR}^*	
e_{iR}	(1	(1	(-1)	$\overline{e_{iR}}$	\tilde{e}_{iR}	\tilde{e}_{iR}^*	

family
 $i \in \{1, 2, 3\}$

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ χ ra Superfields (41 fermion, scalar).

$P_L (U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{B}	\tilde{B}
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_{Li}$
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L \equiv \tilde{L}_i$
u_{Ri}	(3	(1	$-2/3$)	$\overline{U_{Ri}}$	\tilde{u}_{Ri}^*
d_{Ri}	(3	(1	$1/3$)	$\overline{d_{Ri}}$	\tilde{d}_{Ri}^*
e_{Ri}	(1	(1	(-1)	$\overline{e_{Ri}}$	\tilde{e}_{Ri}^*

family
 $\in \{1, 2, 3\}$

spin 0

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ χ ra^l Superfields (41 fermion, scalar).

$$P_L(U_R) = \overline{U_R}$$

Vector	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$		boson	
G	(8	(1	(0)	quino	\tilde{q}	g	} spin 1
W	(1	(3	(0)	wino	\tilde{W}	w	
B	(1	(1	(0)	bino	\tilde{b}	B	
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix}_L \equiv \tilde{Q}_i$	} spin 0	
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L \equiv \tilde{L}_i$		
u_{Ri}	(3	(1	$-2/3$)	$\overline{u_{Ri}}$	\tilde{u}_{Ri}^*		
d_{Ri}	(3	(1	$1/3$)	$\overline{d_{Ri}}$	\tilde{d}_{Ri}^*		
e_{Ri}	(1	(1	(-1)	$\overline{e_{Ri}}$	\tilde{e}_{Ri}^*		

family
 $\in \{1, 2, 3\}$

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ $\mathcal{N}=1$ superfields (41 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	(1	(0)	gluino \tilde{g}	g
W	(1	(3	(0)	wino \tilde{W}	W
B	(1	(1	(0)	bino \tilde{b}	B
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_{Li}$
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L \equiv \tilde{L}_i$
U_{Ri}	(3	(1	($-2/3$)	$\overline{U_{Ri}}$	\tilde{U}_{Ri}^*
d_{Ri}	(3	(1	($1/3$)	$\overline{d_{Ri}}$	\tilde{d}_{Ri}^*
e_{Ri}	(1	(1	(-1)	$\overline{e_{Ri}}$	\tilde{e}_{Ri}^*

family
 $i \in \{1, 2, 3\}$

spin 0.

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ χ ra¹ Superfields (41 fermion, scalar).

$P_L (U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector					
G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
					$\left. \begin{matrix} \tilde{g} \\ \tilde{W} \\ \tilde{B} \end{matrix} \right\} \text{spin } 1$
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_{Li}$
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_{L}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L \equiv \tilde{L}_i$
U_{Ri}	(3	(1	($-2/3$)	$\overline{U_{Ri}}$	\tilde{U}_{Ri}^*
d_{Ri}	(3	(1	($1/3$)	$\overline{d_{Ri}}$	\tilde{d}_{Ri}^*
e_{Ri}	(1	(1	(1)	$\overline{e_{Ri}}$	\tilde{e}_{Ri}^*
H_2	(1	(2	($1/2$)		

family
 $\in \{1, 2, 3\}$

spin 0

would
 $\sim (100 \text{ GeV})^4$
 observation
 rich

Spectrum: $N=1$ ~~2~~ superfields (41 fermion, scalar).

$$P_L(U_R) = \overline{U_R}$$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_{L_i}$
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L \equiv \tilde{L}_i$
U_{R_i}	(3	(1	$-2/3$)	$\overline{U_{R_i}}$	$\overline{U_{R_i}^*}$
d_{R_i}	(3	(1	$1/3$)	$\overline{d_{R_i}}$	$\overline{d_{R_i}^*}$
e_{R_i}	(1	(1	(-1)	$\overline{e_{R_i}}$	$\overline{e_{R_i}^*}$
H_2	(1	(2	$1/2$)	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$

family
 $\in \{1, 2, 3\}$

spin 0

would
 $\sim (100 \text{ GeV})^4$
 observation
 is ch

Spectrum: $N=1$ ~~chiral~~ superfields (4 fermion, scalar).

$$P_L(U_R) = \overline{U_R}$$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_i$
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix}_L \equiv \tilde{L}_i$
U_{iR}	(3	(1	$-2/3$)	$\overline{U_{iR}}$	\tilde{U}_{iR}^*
d_{iR}	(3	(1	$1/3$)	$\overline{d_{iR}}$	\tilde{d}_{iR}^*
e_{iR}	(1	(1	(-1)	$\overline{e_{iR}}$	\tilde{e}_{iR}^*
H_2	(1	(2	$1/2$)	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$

family
 $\in \{1, 2, 3\}$

spin 0

Spectrum: $N=1$ chiral superfields (4 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector					
G	(8	(1	(0)	gluino	g
W	(1	(3	(0)	wino	W
B	(1	(1	(0)	bino	B
					} spin 1
family $\in \{1, 2, 3\}$					
chiral					
Q_i	(3	(2	(1/6)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L \equiv \tilde{Q}_L^i$
L_i	(1	(2	(-1/2)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L \equiv \tilde{L}_i$
U_{iR}	(3	(1	(-2/3)	$\overline{U_{iR}}$	U_{iR}^*
d_{iR}	(3	(1	(1/3)	$\overline{d_{iR}}$	d_{iR}^*
e_{iR}	(1	(1	(-1)	$\overline{e_{iR}}$	e_{iR}^*
H_2	(1	(2	(1/2)	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$

spin 0

Spectrum: $N=1$ chiral superfields (4 fermion, scalar).

$P_L(U_R) = U_R$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector					
G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
				} dark matter	} spin
Chiral					
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L = Q_L^i$
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L = L^i$
U_{iR}	(3	(1	($-2/3$)	U_{iR}	U_{iR}^*
D_{iR}	(3	(1	($1/3$)	d_{iR}	d_{iR}^*
E_{iR}	(1	(1	(-1)	e_{iR}	e_{iR}^*
H_2	(1	(2	($1/2$)	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$

family $i \in \{1, 2, 3\}$

chiral
anom
cancel.

Spectrum: $N=1$ ~~real~~ Superfields (4 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector					
G	(8	(1	(0)	gluino \tilde{g}	g
W	(1	(3	(0)	wino \tilde{W}	W
B	(1	(1	(0)	bino \tilde{b}	B
				} dark and	} spin 1
Family $\in \{1, 2, 3\}$					
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L \equiv \tilde{Q}_L^i$
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L \equiv \tilde{L}_i$
U_{Ri}	(3	(1	($-2/3$)	$\overline{U_{Ri}}$	U_{Ri}^*
d_{Ri}	(3	(1	($1/3$)	$\overline{d_{Ri}}$	d_{Ri}^*
e_{Ri}	(1	(1	(-1)	$\overline{e_{Ri}}$	e_{Ri}^*
				$\begin{pmatrix} H_u^+ \\ H_0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_u^+ \\ H_0 \\ H_2^- \end{pmatrix}$
H_2	(1	(2	($1/2$)		

real
anom
cancel
 χ_3

spin 0

Spectrum: $N=1$ χ raL Superfields (4L fermion, scalar).

$$P_L(U_R) = U_R$$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector G	(8	(1	(0)	gluino \tilde{g}	g
W	(1	(3	(0)	wino \tilde{W}	W
B	(1	(1	(0)	bino \tilde{b}	B
Q_i	(3	(2	$1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_i$
L_i	(1	(2	$-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix} \equiv \tilde{L}_i$
U_{Ri}	(3	(1	$-2/3$)	U_{Ri}	U_{Ri}^*
d_{Ri}	(3	(1	$1/3$)	d_{Ri}	d_{Ri}^*
e_{Ri}	(1	(1	(-1)	e_{Ri}	e_{Ri}^*
H_2	(1	(2	$+1/2$)	$\begin{pmatrix} H_1 \\ H_2 \end{pmatrix}$	
H_1	(1	(2	$-1/2$)		

family $\in \{1, 2, 3\}$

dark
and

χ raL
anom
cancel
 χ_3

spin 0

Spectrum: $N=1$ χ raL Superfields (41 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector					
G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
				$\left. \begin{matrix} \tilde{g} \\ \tilde{W} \\ \tilde{b} \end{matrix} \right\} \text{dark matter}$	$\left. \begin{matrix} \tilde{g} \\ \tilde{W} \\ \tilde{B} \end{matrix} \right\} \text{spin 1}$
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}$	$\begin{pmatrix} \tilde{u}_i \\ \tilde{d}_i \end{pmatrix} \equiv \tilde{Q}_i$
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}$	$\begin{pmatrix} \tilde{\nu}_i \\ \tilde{e}_i \end{pmatrix} \equiv \tilde{L}_i$
χ raL U_i	(3	(1	($-2/3$)	\overline{U}_i	\tilde{U}_i^*
χ raL d_i	(3	(1	($1/3$)	\overline{d}_i	\tilde{d}_i^*
χ raL e_i	(1	(1	(-1)	\overline{e}_i	\tilde{e}_i^*
H_2	(1	(2	($1/2$)	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$
H_1	(1	(2	($-1/2$)	$\begin{pmatrix} H_1^0 \\ H_2^+ \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_1^0 \\ H_2^+ \\ H_2^- \end{pmatrix}$

family $\in \{1, 2, 3\}$

χ raL anom. cancels $\times 3$

spin 0

Spectrum: $N=1$ $\mathcal{N}=1$ Superfields (4 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector					
G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{W}	\tilde{W}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
				} dark and	
family $\in \{1,2,3\}$					
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L$	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}_L \equiv \tilde{Q}_i$
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L$	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}_L \equiv L_i$
U_{iR}	(3	(1	($-2/3$)	U_{iR}	U_{iR}^*
d_{iR}	(3	(1	($1/3$)	d_{iR}	d_{iR}^*
e_{iR}	(1	(1	(-1)	e_{iR}	e_{iR}^*
H_2	(1	(2	($1/2$)	$\begin{pmatrix} H_2^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_2^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$
H_1	(1	(2	($-1/2$)	$\begin{pmatrix} H_1^+ \\ H_1^0 \\ H_1^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_1^0 \\ H_1^- \end{pmatrix}$

$\mathcal{N}=1$
anom
cancel
 χ_3

spin 0

Spectrum: $N=1$ χ ra Superfields (4 fermion, scalar).

$P_L(U_R) = \overline{U_R}$

	$SU(3)$	$SU(2)$	$U(1)$	fermion $s = 1/2$	boson
Vector					
G	(8	(1	(0)	gluino \tilde{g}	\tilde{g}
W	(1	(3	(0)	wino \tilde{w}	\tilde{w}
B	(1	(1	(0)	bino \tilde{b}	\tilde{B}
					spin 1
family $i \in \{1, 2, 3\}$					
Q_i	(3	(2	($1/6$)	$\begin{pmatrix} u_i \\ d_i \end{pmatrix}$	$\begin{pmatrix} u_i \\ d_i \end{pmatrix} \equiv \tilde{Q}_i$
L_i	(1	(2	($-1/2$)	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix}$	$\begin{pmatrix} \nu_i \\ e_i \end{pmatrix} \equiv \tilde{L}_i$
U_i	(3	(1	($-2/3$)	U_i	U_i^*
d_i	(3	(1	($1/3$)	d_i	d_i^*
e_i	(1	(1	(-1)	e_i	e_i^*
H_2	(1	(2	($+1/2$)	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_2^0 \\ H_2^- \end{pmatrix}$
H_1	(1	(2	($-1/2$)	$\begin{pmatrix} H_1^+ \\ H_1^0 \\ H_1^- \end{pmatrix}$	$\begin{pmatrix} H_1^+ \\ H_1^0 \\ H_1^- \end{pmatrix}$

dark and

χ ra anom. cancels χ_3

spin 0

2 Higgs bos.

Superpotential

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$
 c, j, k family $1 \rightarrow 3$

$W \supset (u)_{ij} Q_i H_2 \bar{U}_j$

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$
 c, j, k family $1 \rightarrow 3$

$$W_{\text{MSSM}}^{\text{RP}} = (Y_u)_{ij} Q_i H_2 \bar{U}_{Rj}$$

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$
 c, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

$$W_{RP} = (Y_u)_{ij} Q_i H_2 \bar{U}_{Rj}$$

Superpotential.

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

$$W_{\text{MSSM}} = (Y_u)_{ij} Q_i^a H_2^b \bar{U}_{Rj} \epsilon_{ab}$$

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$
 i, j, k family $1 \rightarrow 3$

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$
 c, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$
$$2 \times 2 = 3 \oplus 1$$

$$W_{MSSM} = (Y_u)_{ij} Q_i^{ac} H_2^b \bar{U}_{Rj\alpha} \epsilon_{ab}$$

Superpotential.

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

$$W_{\text{MSSM}} = (Y_u)_{ij} Q_i^{\text{acc } b} H_2 \bar{U}_{Rj\alpha} \epsilon_{ab}$$

x, y, z $SU(3)_c$ $1 \rightarrow 3$

a, b $SU(2)_L$ $1 \rightarrow 2$

c, j, k family $1 \rightarrow 3$

Superpotential.

$$3 \otimes \bar{3} = 8 \oplus 1$$
$$2 \times 2 = 3 \oplus 1$$

$$W_{\text{MSSM}} = (Y_u)_{ij} Q_i^{\text{acc } b} \bar{U}_{Rj\alpha} \epsilon_{ab}$$

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$
 i, j, k family $1 \rightarrow 3$

Superpotential

x, y, z $SU(3)_c$ $1 \rightarrow 3$

a, b $SU(2)_L$ $1 \rightarrow 2$

c, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

IR_p

$$M_{SSM} = (Y_u)_{ij} Q_i H_2 \bar{U}_{Rj} \epsilon_{ab}$$

matrix of dimensionless coupling const.

Superpotential

x, y, z $SU(3)_c$ $1 \rightarrow 3$

a, b $SU(2)_L$ $1 \rightarrow 2$

c, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

matrix of dimensionless coupling constants

W_{RP}

$$W_{MSSM} = (Y_u)_{ij} Q_i^a H_2^b \bar{U}_{Rj\alpha} \epsilon_{ab}$$

$$+ (Y_D)_{ij} Q_i^a H_1^b \bar{D}_{Rj\alpha} \epsilon_{ab}$$

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$

a, b $SU(2)_L$ $1 \rightarrow 2$

c, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

matrix of dimensionless coupling const.

$$W_{MSSM} = (Y_U)_{ij} Q_i^a H_2^b \bar{U}_{Rj} \epsilon_{ab}$$

$$+ (Y_D)_{ij} Q_i^a H_1^b \bar{D}_{Rj} \epsilon_{ab}$$

$$+ (Y_E)_{ij} L_i^a H_1^b \bar{E}_{Rj} \epsilon_{ab}$$

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$

a, b $SU(2)_L$ $1 \rightarrow 2$

c, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

matrix of dimensionless coupling const.

$$W_{MSSM} = (Y_U)_{ij} Q_i^a H_2^b \bar{U}_{Rj} \epsilon_{ab}.$$

$$+ (Y_D)_{ij} Q_i^a H_1^b \bar{D}_{Rj} \epsilon_{ab}$$

$$+ (Y_E)_{ij} L_i^a H_1^b \bar{E}_{Rj} \epsilon_{ab}$$

$$+ \mu H_1^a H_2^b \epsilon_{ab}$$

Superpotential

x, y, z $SU(3)_c$ $1 \rightarrow 3$

a, b $SU(2)_L$ $1 \rightarrow 2$

c, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

matrix of dimensionless coupling const.

$$W_{MSSM} = (Y_U)_{ij} Q_i^a H_2^b \bar{U}_{Rj} \epsilon_{ab} +$$

$$+ (Y_D)_{ij} Q_i^a H_1^b \bar{D}_{Rj} \epsilon_{ab} +$$

$$+ (Y_E)_{ij} L_i^a H_1^b \bar{E}_{Rj} \epsilon_{ab} +$$

$$+ \mu [H_1^a H_2^b \epsilon_{ab} - E_M] = 1.$$

Superpotential

x, y, z $SU(3)_c$ $1 \rightarrow 3$

a, b $SU(2)_L$ $1 \rightarrow 2$

i, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

matrix of dimensionless coupling const.

$$W_{MSSM} = (Y_U)_{ij} Q_i^a H_2^b \bar{U}_{Rj}^c \epsilon_{abc} + (Y_D)_{ij} Q_i^a H_1^b \bar{d}_{Rj}^c \epsilon_{abc} + (Y_E)_{ij} L_i^a H_1^b \bar{e}_{Rj}^c \epsilon_{abc} + \mu H_1^a H_2^b \epsilon_{abc} \rightarrow [E_M] = 1$$

Y_U, Y_D, Y_E are Yukawa couplings

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$

i, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

$$W_{MSSM} = (Y_U)_{ij} Q_i^{ax} H_2^b \bar{U}_{Rjx} \epsilon_{ab}$$

Y_U, Y_D, Y_E are Yukawa

$$+ (Y_D)_{ij} Q_i^{ax} H_1^b \bar{d}_{Rjx} \epsilon_{ab}$$

$$+ (Y_E)_{ij} L_i^a H_1^b \bar{e}_{Rj} \epsilon_{ab}$$

$$+ (\mu H_1^a H_2^b \epsilon_{ab} \rightarrow E_M) = 1.$$

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

i, j, k family $1 \rightarrow 3$

ϵ matrix of dimensionless coupling const. s. ar

$$W_{MSSM} = (Y_u)_{ij} Q_i^{ax} H_2^b \bar{U}_{Rjx} \epsilon_{ab}.$$

Y_u, Y_D, Y_E are Yukawa couplings

$$+ (Y_D)_{ij} Q_i^{ax} H_1^b \bar{d}_{Rjx} \epsilon_{ab}$$

$$+ (Y_E)_{ij} L_i^a H_1^b \bar{e}_{Rj} \epsilon_{ab}$$

$$+ (\mu H_1^a H_2^b \epsilon_{ab} \rightarrow E_\mu) = 1.$$

family $i \in \{1, 2, 3\}$

To begin with, quarks + leptons are massless

Superpotential

x, y, z $SU(3)_c$ $1 \rightarrow 3$
 a, b $SU(2)_L$ $1 \rightarrow 2$

i, j, k family $1 \rightarrow 3$

$$3 \otimes \bar{3} = 8 \oplus 1$$

$$2 \times 2 = 3 \oplus 1$$

W_{RP}

$$W_{MSSM} = (Y_u)_{ij} Q_i^{abc} H_2^b \bar{U}_{Rj}^a \epsilon_{ab} +$$

matrix of dimensionless coupling const. a

Y_u, Y_D, Y_E are
 "Yukawa couplings"

$$+ (Y_D)_{ij} Q_i^{abc} H_1^b \bar{d}_{Rj}^a \epsilon_{ab} +$$

$$+ (Y_E)_{ij} L_i^a H_1^b \bar{e}_{Rj} \epsilon_{ab} +$$

$$+ (\mu H_1^a H_2^b \epsilon_{ab} \rightarrow E_\mu) = 1.$$

family $i \in \{1, 2, 3\}$

To begin with, quarks + leptons are massless

Superpotential.

x, y, z $SU(3)_c$ $1 \rightarrow 3$
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To begin with, quarks + leptons are massless

$$\rightarrow (Y_u)_{ij} [u_L^x H_2^0 \overline{u_R^j} - d_L^x H_2^+ \overline{\chi_{kj}^x}]$$

$$\rightarrow (Y_u)_{ij} [u_L^i H_2^0 \bar{u}_R^j - d_L^i H_2^+ \bar{\nu}_R^j]$$

Higgs mech. $\therefore \langle H_2^0 \rangle = v_2, \quad \langle H_1^0 \rangle = v_1$

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$$M_Z^2 = (g_1^2 + g_2^2) \frac{(v_1^2 + v_2^2)}{4}$$

g_1, g_2 are $U(1), SU(2)_L$ gauge couplings resp.

$$\rightarrow (Y_u)_{ij} [u_L^i H_2^0 \bar{u}_R^j]_x - d_L^i H_2^+ \bar{u}_R^j x$$

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Higgs mech. $\therefore \langle H_2^0 \rangle = v_2, \quad \langle H_1^0 \rangle = v_1$

$[v_1]$

$$M_Z^2 = (g_1^2 + g_2^2) \frac{(v_1^2 + v_2^2)}{4} \Rightarrow v_1^2 + v_2^2 = 246^2$$

g_1, g_2 are $U(1), SU(2)_L$ gauge couplings resp.

$$H_2^0 = v_2 + h_2^0, \quad H_1^0 = v_1 + h_1^0$$

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Higgs mech. $\therefore \langle H_2^0 \rangle = v_2, \quad \langle H_1^0 \rangle = v_1$

$$M_Z^2 = (g_1^2 + g_2^2) \frac{(v_1^2 + v_2^2)}{4} \Rightarrow v_1^2 + v_2^2 = (246 \text{ GeV})^2 \quad [v_i] = 1$$

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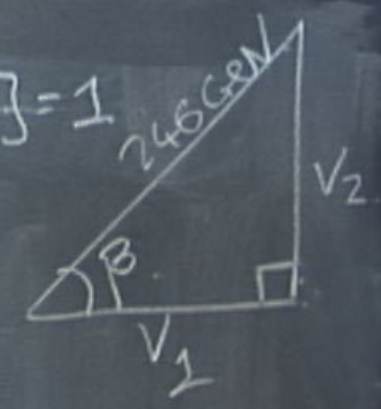
$$\rightarrow (Y_u)_{ij} [u_L^i H_2^0 \bar{u}_R^j]_x - d_L^i H_2^+ \bar{\nu}_R^j x$$

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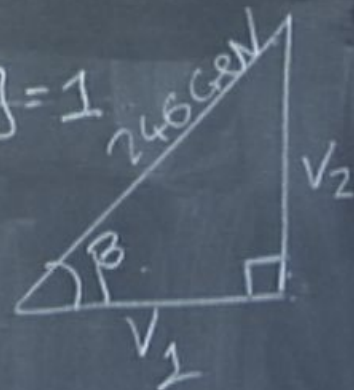
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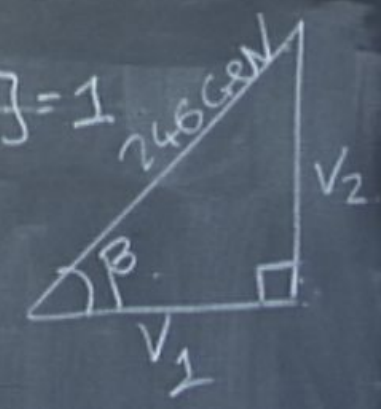
$$\tan \beta = \frac{v_2}{v_1}$$

$$\rightarrow (Y_u)_{ij} \left[u_{Li}^x H_2^0 \overline{u_{Rj}^x} - d_L^x H_2^+ \overline{u_{Rj}^x} \right]$$

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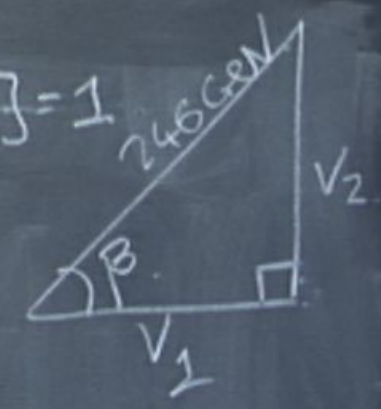
hence w/o $(Y_u)_{ij} \left[u_{Li}^x v_2 \overline{u_{Rj}^x} + u_{Li}^x h_2^0 \overline{u_{Rj}^x} + \dots \right]$

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 Z doublets = 8 R.d.o.f. - 3 eaten = 5



$$\rightarrow (Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_{Lj}^x H_2^+ \bar{u}_{Rj}^x]$$

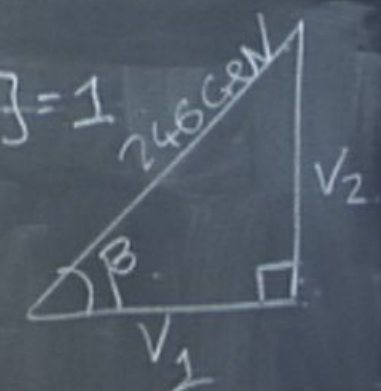
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$$\tan \beta = \frac{v_2}{v_1}$$

hence w/o $(Y_u)_{ij} [u_{Li}^x v_2 \bar{u}_{Rj}^x + u_{Li}^x h_2^0 \bar{u}_{Rj}^x + \dots]$

2 C doublets = 8 R.d.o.f. - 3 'eaten' = 5 physical Higgs:

- h_1^0
- H^0
- A^0
- H^+, H^-

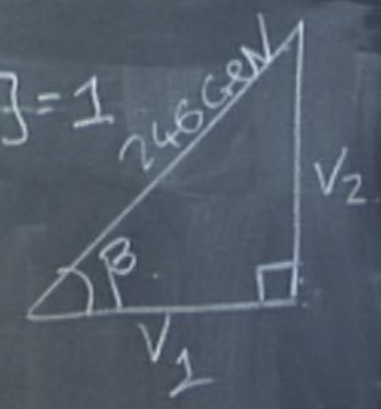
$$\rightarrow (Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_L^x H_2^+ \bar{u}_{Rj}^x]$$

Higgs mech. $\therefore \langle H_2^0 \rangle = v_2, \quad \langle H_1^0 \rangle = v_1$

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2 C doublets = 8 R d.o.f. - 3 'eaten' = 5 physical Higgs:

- h_1^0 CP+
- H_1^0
- A^0 -CP-
- H^+, H^-

$$\rightarrow (Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_{Lj}^x H_2^+ \bar{u}_{Ri}^x]$$

Higgs mech. : $\langle H_2^0 \rangle = v_2$ $\langle H_1^0 \rangle = v_1$

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$$[v_i] = 1$$

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$$H_2^0 = v_2 + h_2^0, \quad H_1^0 = v_1 + h_1^0$$



hence w/o $(Y_u)_{ij} [u_{Li}^x v_2 \bar{u}_{Rj}^x + u_{Li}^x \bar{u}_{Rj}^x + \dots]$

2 C doublets = 8 R.d.o.f. - 3 'eaten' = 5 physical Higgs

- H^0
- A^0
- H^\pm

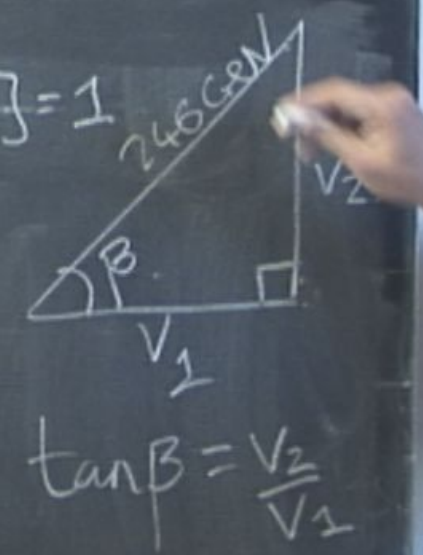
$$\rightarrow (Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_{Lj}^x H_2^+ \bar{u}_{Rj}^x]$$

Higgs mech. $\therefore \langle H_2^0 \rangle = v_2, \quad \langle H_1^0 \rangle = v_1$

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g_1, g_2 are $U(1), SU(2)$ gauge couplings resp.

$$H_2^0 = v_2 + h_2^0, \quad H_1^0 = v_1 + h_1^0$$



hence w/o $(Y_u)_{ij} [u_{Li}^x (v_2 \bar{u}_{Rj}^x + u_{Li}^x h_2^0 \bar{u}_{Rj}^x) - \dots]$

2 C doublets = 8 R.d.o.f. - 3 'eaten' = 5 physical Higgs

- h_1^0 CP+
- H_1^0
- A^0 CP-
- H^+, H^-

$$\rightarrow (Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_{Lj}^x H_2^+ \bar{u}_{Rj}^x]$$

$$M_{ij}^{\sim} \frac{\partial^2 W}{\partial \phi_i \partial \phi_j}$$

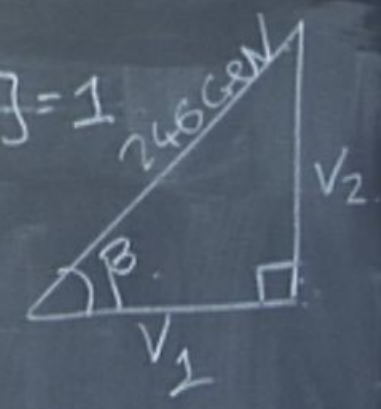
Higgs mech. : $\langle H_2^0 \rangle = v_2, \quad \langle H_1^0 \rangle = v_1$

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g_1, g_2 are $U(1)$, $SU(2)$ gauge couplings resp.

$$H_2^0 = v_2 + h_2^0, \quad H_1^0 = v_1 + h_1^0$$



$$\tan \beta = \frac{v_2}{v_1}$$

hence $W \supset (Y_u)_{ij} [u_{Li}^x (v_2 \bar{u}_{Rj}^x + u_{Li}^x h_2^0 \bar{u}_{Rj}^x) + \dots]$

2 doublets = 8 R.d.o.f. - 3 eaten = 5 physical Higgs

- h_1^0 CP+
- H_1^0
- A^0 CP-
- H^+, H^-

$(Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_{Lj}^x H_2^+ \bar{u}_{Rj}^x]$

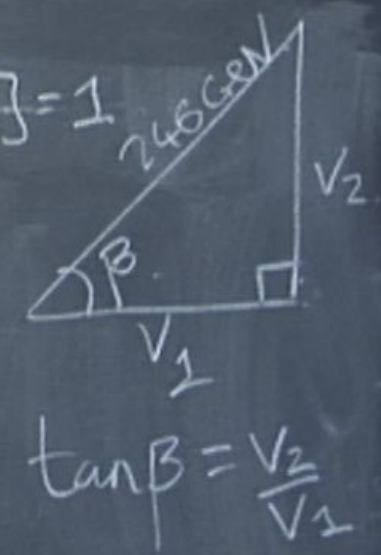
 $M_{ij} = \frac{\partial^2 W}{\partial \phi_i \partial \phi_j}$

Higgs mech. : $\langle H_2^0 \rangle = v_2$ $\langle H_1^0 \rangle = v_1$

$M_Z^2 = (g_1^2 + g_2^2) \frac{(v_1^2 + v_2^2)}{4} \Rightarrow v_1^2 + v_2^2 = (246 \text{ GeV})^2$

g_1, g_2 are $U(1)$, $SU(2)$ gauge couplings resp.

$H_2^0 = v_2 + h_2^0$, $H_1^0 = v_1 + h_1^0$

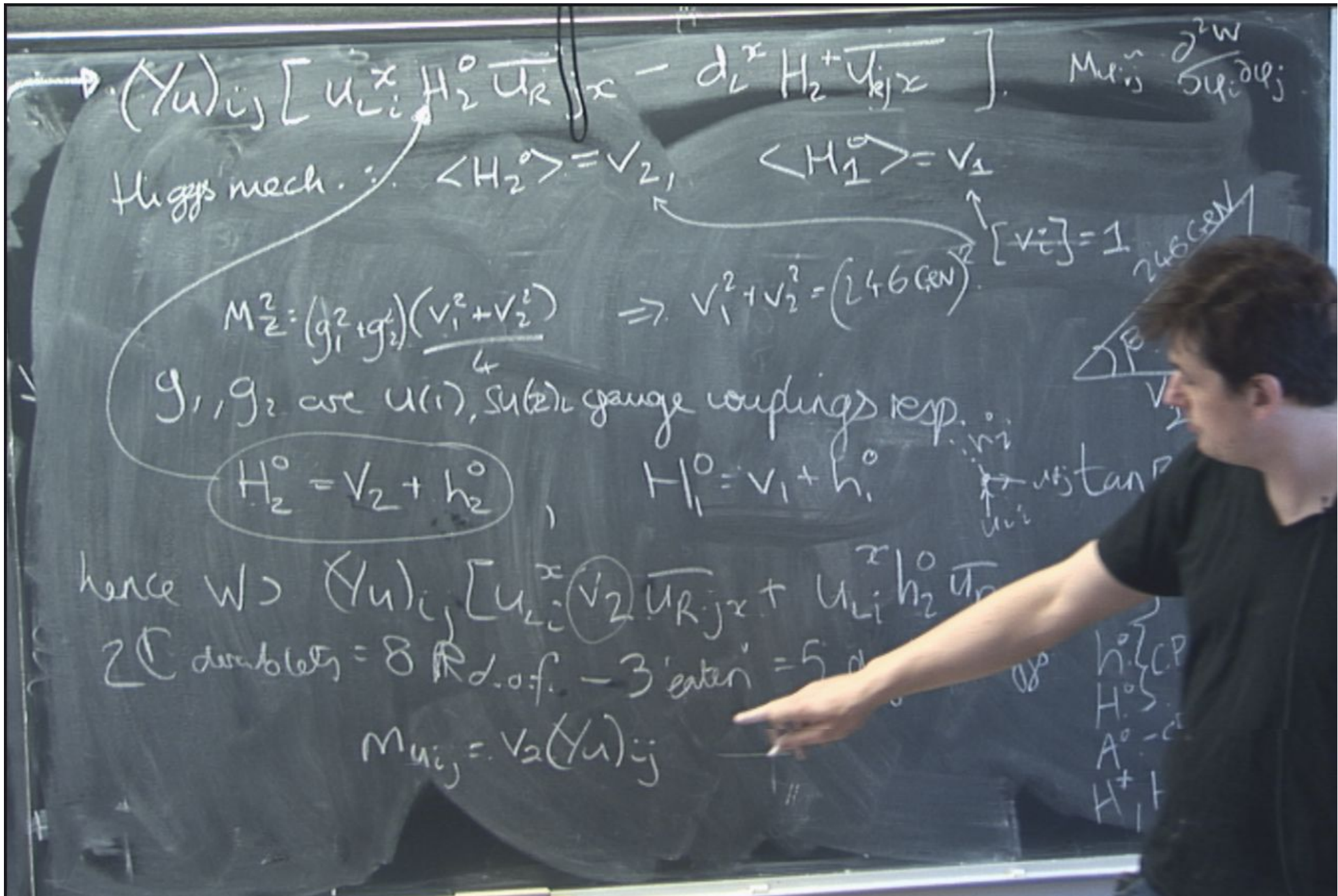


hence $W \supset (Y_u)_{ij} [u_{Li}^x (v_2 \bar{u}_{Rj}^x + u_{Li}^x h_2^0 \bar{u}_{Rj}^x + \dots)]$

2×3 doublets = 8 R.d.o.f. - 3 eaten = 5 physical Higgs

$M_{uij} = v_2 (Y_u)_{ij}$

- h_1^0 CP +
- H_2^0
- A^0 CP -
- H^+, H^-



$$M_{ij} = \frac{\partial^2 W}{\partial \phi_i \partial \phi_j}$$

$$(Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_L^x H_2^+ \bar{u}_{Rj}^x]$$

Higgs mech. : $\langle H_2^0 \rangle = v_2$ $\langle H_1^0 \rangle = v_1$

$$M_Z^2 = (g_1^2 + g_2^2) \frac{(v_1^2 + v_2^2)}{4}$$

$$\Rightarrow v_1^2 + v_2^2 = (246 \text{ GeV})^2$$

$$[v_i] = 1 \quad 246 \text{ GeV}$$

g_1, g_2 are $U(1)$, $SU(2)$ gauge couplings resp.

$$H_2^0 = v_2 + h_2^0, \quad H_1^0 = v_1 + h_1^0$$

hence $W \supset (Y_u)_{ij} [u_{Li}^x (v_2 \bar{u}_{Rj}^x + u_{Li}^x h_2^0 \bar{u}_{Rj}^x)$

$2 \times (\text{doublets}) = 8 \text{ R.d.o.f.} - 3 \text{ 'eaten'} = 5 \text{ d.o.f.}$

$$M_{u_{ij}} = v_2 (Y_u)_{ij}$$

- h_1^0 LCP
- H^0 S
- A^0 -CP
- H^\pm T

$(Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_L^x H_2^+ \bar{u}_{Rj}^x]$

Higgs mech. $\therefore \langle H_2^0 \rangle = v_2, \quad \langle H_1^0 \rangle = v_1$

$M_Z^2 = (g_1^2 + g_2^2) \frac{(v_1^2 + v_2^2)}{4} \Rightarrow v_1^2 + v_2^2 = (246 \text{ GeV})^2$

g_1, g_2 are $U(1)$, $SU(2)$ gauge couplings resp.

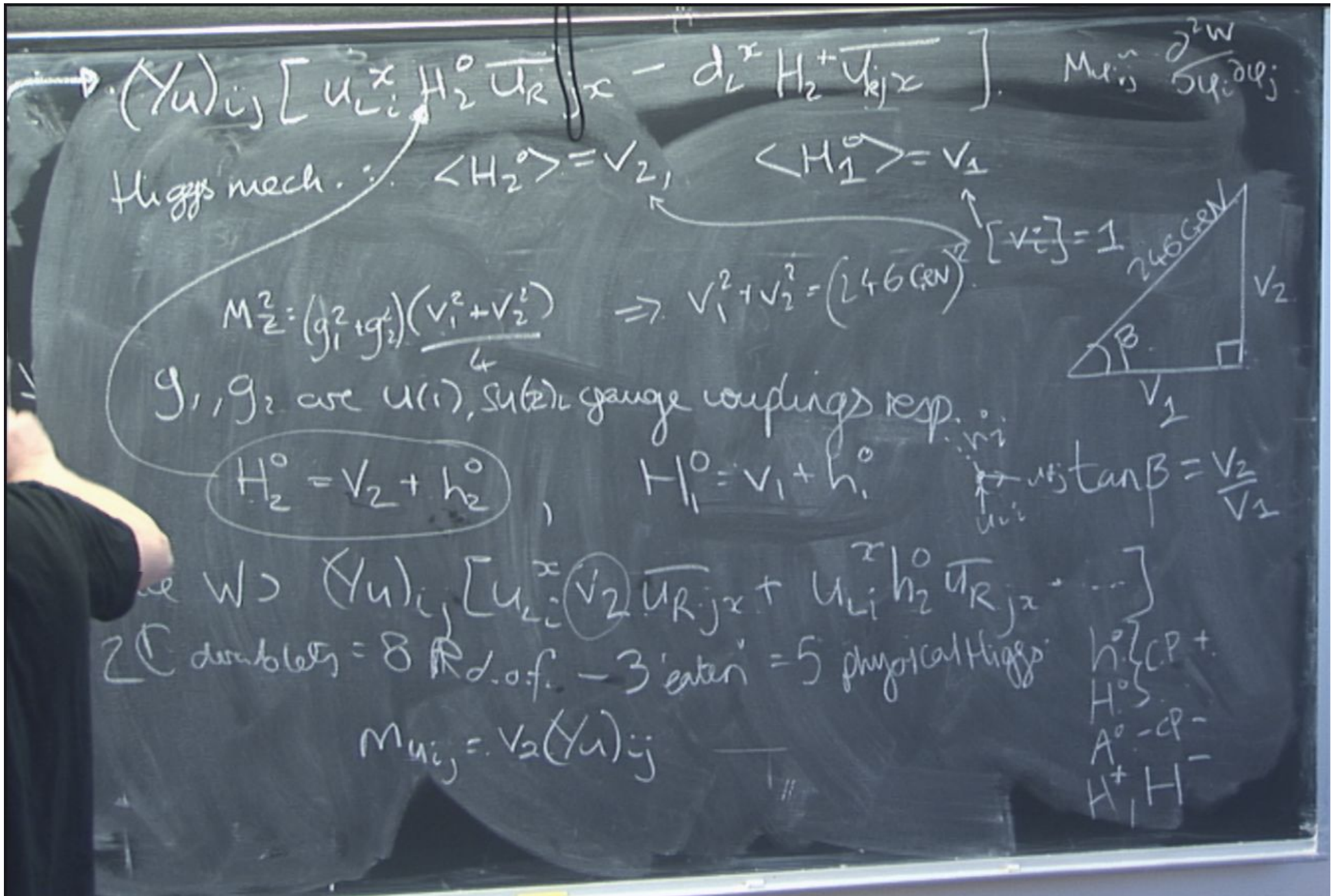
$H_2^0 = v_2 + h_2^0, \quad H_1^0 = v_1 + h_1^0$

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$2 \text{ (doublets)} = 8 \text{ R.d.o.f.} - 3 \text{ 'eaten'} = 5 \text{ physical Higgs}$

$M_{u_{ij}} = v_2 (Y_u)_{ij}$

$M_{u_{ij}} \sim \frac{\partial^2 W}{\partial u_{Li} \partial u_{Rj}}$
 $\tan \beta = \frac{v_2}{v_1}$



$$M_{ij} = \frac{\partial^2 W}{\partial \phi_i \partial \phi_j}$$

$$(Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_L^x H_2^+ \bar{u}_{Rj}^x]$$

Higgs mech. : $\langle H_2^0 \rangle = v_2$ $\langle H_1^0 \rangle = v_1$

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2 doublets = 8 R.d.o.f. - 3 eaten = 5 physical Higgs

$$M_{uij} = v_2 (Y_u)_{ij}$$

- h_1^0 CP +
- H_1^0 S
- A^0 CP -
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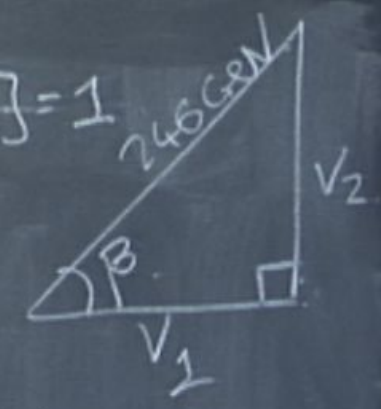
$(Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_{Lj}^x H_2^+ \bar{u}_{Rj}^x]$

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$2 \text{ (doublets)} = 8 \text{ R.d.o.f.} - 3 \text{ 'eaten'} = 5 \text{ physical Higgs:}$

- h^0 CP+
- H^0
- A^0 CP-
- H^+, H^-

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NB!! In SM, we'd add a \mathcal{L} term $\int \bar{Q}_L H_2^+ dR \gamma_n^{th.c}$

NB!! In SM, we'd add a \mathcal{L} term $\int \bar{Q}_L(H_2)^+ Q_R Y_n + h.c.$

, but In SUSY, G is holomorphic: $W \supset \bar{Q}_L H_2$

NB!! In SM, we'd add a \mathcal{L} term $\mathcal{L} \supset \bar{Q}_L (H_2)^+ \mathcal{D}_R \gamma_5 + \text{h.c.}$

, but In SUSY, \mathcal{W} is holomorphic: $\mathcal{W} \supset \bar{Q}_L H_2^+ \mathcal{D}_R \gamma_0$

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would break SUSY explicitly! It's not allowed...

this is

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this is another reason for an additional Higgs doublet with opposite Y .

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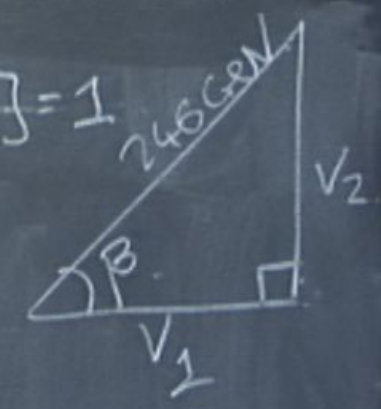
$(Y_u)_{ij} [u_{Li}^x H_2^0 \bar{u}_{Rj}^x - d_{Lj}^x H_2^+ \bar{u}_{ki}^x]$

 $M_{ij} = \frac{\partial^2 W}{\partial \phi_i \partial \phi_j}$

Higgs mech. : $\langle H_2^0 \rangle = v_2$ $\langle H_1^0 \rangle = v_1$

$M_Z^2 = (g_1^2 + g_2^2) \frac{(v_1^2 + v_2^2)}{4} \Rightarrow v_1^2 + v_2^2 = (246 \text{ GeV})^2$

g_1, g_2 are $U(1)$, $SU(2)$ gauge couplings resp.



$H_2^0 = v_2 + h_2^0$ $H_1^0 = v_1 + h_1^0$

$\tan \beta = \frac{v_2}{v_1}$

hence $W \supset (Y_u)_{ij} [u_{Li}^x (v_2 \bar{u}_{Rj}^x + u_{Li}^x h_2^0 \bar{u}_{Rj}^x + \dots)]$

$2 \times (\text{doublets}) = 8 \text{ R.d.o.f.} - 3 \text{ 'eaten'} = 5 \text{ physical Higgs}$

$M_{uij} = v_2 (Y_u)_{ij}$

- h^0 CP+
- H^0 S
- A^0 CP-
- H^+, H^-

NB!! In SM, we'd add a \mathcal{L} term $\int \bar{Q}_L (H_2)^+ d_R$

but In SUSY, \mathcal{W} is holomorphic: $\mathcal{W} \supset \bar{Q}_L H_2^+ d_R Y_D$
would break SUSY explicitly! It's not allowed
this is another reason for an additional Higgs doublet
with opposite Y .

$$(M_E)_{ij} = \frac{v(Y_E)_{ij}}{v}, \quad (M_D)_{ij} = v(Y_D)_{ij}.$$

NB11 In SM, we'd add a \mathcal{L} term $\int \bar{Q}_L (H_2)^+ \mathcal{D}_R \gamma_5 + h.c.$

but In SUSY, \mathcal{W} is holomorphic: $\mathcal{W} \supset \bar{Q}_L H_2^+ \mathcal{D}_R \gamma_5$ would break SUSY explicitly! It's not allowed...

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$$(M_E)_{ij} = \frac{v(E)}{f} \gamma_{ij}, \quad (M_D)_{ij} = v(D) \gamma_{ij}$$

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$$\downarrow (M_E)_{ij} = \frac{v_i(Y_E)_{ij}}{1}, \quad (M_D)_{ij} = v_i(Y_D)_{ij}$$

μ -term gives a mass to Higgs bosons and Higgsinos

NB!! In SM, we'd add a \mathcal{L} term $\int \bar{Q}_L (H_2)^+ \mathcal{D}_R \gamma_5 + \text{h.c.}$

but In SUSY, \mathcal{W} is holomorphic: $\mathcal{W} \supset \bar{Q}_L H_2^+ \mathcal{D}_R \gamma_5$ would break SUSY explicitly! It's not allowed...

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$$\begin{aligned} (M_E)_{ij} &= \frac{v_i(Y_E)_{ij}}{1} & (M_D)_{ij} &= v_i(Y_D)_{ij} \end{aligned}$$

μ -term gives a mass to Higgs bosons and Higgsinos
All terms in $\mathcal{W}_{\text{MSSM}}$

NB!! In SM, we'd add a \mathcal{L} term $\int \bar{Q}_L (H_2)^+ \mathcal{D}_R \gamma_5 + h.c.$

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$$\downarrow (M_E)_{ij} = \frac{v_u(Y_E)_{ij}}{1}, \quad (M_D)_{ij} = v_u(Y_D)_{ij}.$$

\mathcal{M} -term gives a mass to Higgs bosons and Higgsinos
All terms in \mathcal{W}_{MSSM} conserve B, L .

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 is another reason for an additional Higgs doublet with opposite Y .

$$(M_E)_{ij} = \frac{v(Y_E)_{ij}}{1}, \quad (M_D)_{ij} = v(Y_D)_{ij}$$

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 All terms in \mathcal{W}_{MSSM} conserve B, L .

quarks $B = 1/3$

leptons $L = 1$

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this is another reason for an additional Higgs doublet with opposite Y .

$$\downarrow (M_E)_{ij} = \frac{V(E)}{f} \gamma_{ij}, \quad (M_D)_{ij} = v_H (Y_D)_{ij}$$

μ -term gives a mass to Higgs bosons and higgsinos

All terms in \mathcal{W}_{MSSM} conserve B, L .

quarks $B = 1/3$

leptons $L = 1$

$$W/P = \frac{\lambda_{ijk}}{2} L_i^a L_j^b E_{Rk} \Sigma_{ab} + \lambda'_{ijk} L_i^a Q_j^b D_{Rk} \Sigma_{ab}$$

$$\begin{aligned}
 W/P &= \frac{\lambda_{ijk}}{2} L_i^a L_j^b \overline{E_{Rk}} \Sigma_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D_{Rk}} \Sigma_{ab} \\
 &+ \frac{\lambda''_{ijk}}{2} \overline{U_{Ri}}^x \overline{U_{Rj}}^y \overline{D_{Rk}}^z \Sigma_{xyz}
 \end{aligned}$$



$$\begin{aligned}
 W_{RP} = & \frac{\lambda_{ijk}}{2} L_i^a L_j^b \overline{E_{Rk}} \epsilon_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D_{Rk}} \epsilon_{ab} \\
 & + \frac{\lambda''_{ijk}}{2} \overline{U_{Ri}^x} \overline{U_{Rj}^y} \overline{D_{Rk}^z} \epsilon_{xyz} + K_i L_i^a H_2^b \epsilon_{ab}
 \end{aligned}$$

$$\begin{aligned}
 W/P &= \left[\frac{\lambda_{ijk}}{2} L_i L_j \overline{E_{Rk}} \right] \epsilon_{ab} + \lambda'_{ijk} L_i Q_j \overline{D_{Rk}} \epsilon_{ab} \\
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 &\quad \downarrow \text{rotate } L
 \end{aligned}$$

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 &\qquad \qquad \qquad \downarrow \\
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 \end{aligned}$$

If one has both ~~B~~ and ~~X~~ interactions, one tends to get

$$\begin{aligned}
 W_{RP} = & \left[\frac{\lambda_{ijk}}{2} L_i^a L_j^b \overline{E_{Rk}} \right] \epsilon_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D_{Rk}} \epsilon_{ab} \\
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 \end{aligned}$$

\swarrow ~~\otimes~~ \searrow

\uparrow rotate L

If one has both ~~\otimes~~ and ~~\otimes~~ interactions, one tends to predict proton decay

$$\begin{aligned}
 W_{RP} = & \left[\frac{\lambda_{ijk}}{2} L_i^a L_j^b \overline{E_{Rk}} \right] \Sigma_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D_{Rk}} \Sigma_{ab} \\
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 \end{aligned}$$

$\underbrace{\hspace{10em}}_{\text{X}}$
 \downarrow violate L

If one has both ~~B~~ and ~~X~~ interactions, one tends to predict proton decay $\tau_p > 10^{35}$ years.

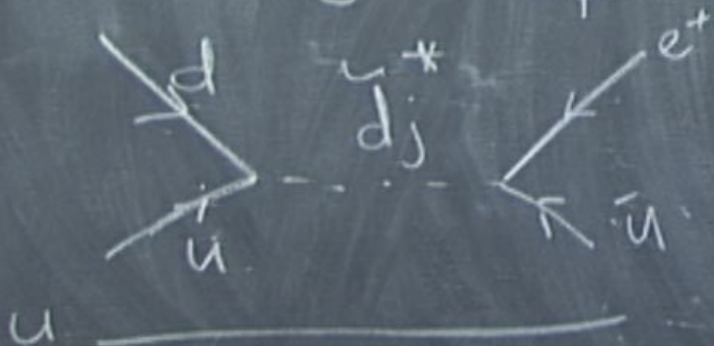
$$\begin{aligned}
 W_{\cancel{P}} = & \left[\frac{\lambda'_{ijk}}{2} L_i^a L_j^b \bar{E}_{Rk} \right] \Sigma_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \bar{D}_{Rk} \Sigma_{ab} \\
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 & \quad \quad \quad \downarrow \\
 & \quad \quad \quad \text{rotate } L
 \end{aligned}$$

If one has both \cancel{B} and \cancel{X} interactions, one tends to predict proton decay $\tau_p > 10^{35}$ years.

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 W_{RP} = & \left[\frac{\lambda'_{ijk}}{2} L_i^a L_j^b \overline{E_{Rk}} \right] \epsilon_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D_{Rk}} \epsilon_{ab} \\
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 \end{aligned}$$

\downarrow state L

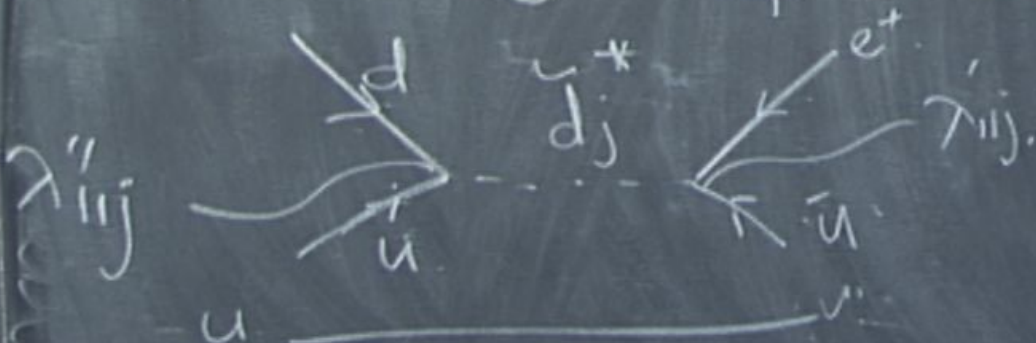
If one has both ~~B~~ and ~~X~~ interactions, predict
 proton decay $\tau_p > 10^{35}$ years



$$\begin{aligned}
 W_{RP} = & \left[\frac{\lambda_{ijk}}{2} L_i^a L_j^b \overline{E_{Rk}} \right] \epsilon_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D_{Rk}} \epsilon_{ab} \\
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 \end{aligned}$$

$\underbrace{\hspace{10em}}_{\text{B}}$
 $\underbrace{\hspace{10em}}_{\text{X}}$
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 \end{aligned}$$

If one has both ~~B~~ and ~~X~~ interactions, one tends to
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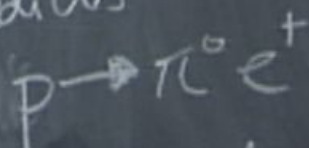
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 \end{aligned}$$

~~⊗~~ ↑ ν date L

If one has both ~~⊗~~ and ~~⊗~~ interactions, one tends to predict proton decay

$$\tau_p > 10^{35} \text{ years}$$

predicts.



decay rate predicted is $\sim 0(1 \text{ sec})$



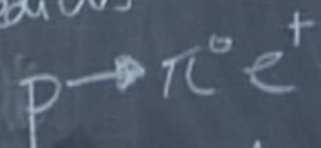
$$\begin{aligned}
 W_{RP} = & \left[\frac{\lambda'_{ijk}}{2} L_i^a L_j^b \overline{E_{Rk}} \right] \epsilon_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D_{Rk}} \epsilon_{ab} \\
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 \end{aligned}$$

~~⊗~~ ↑ rotate L

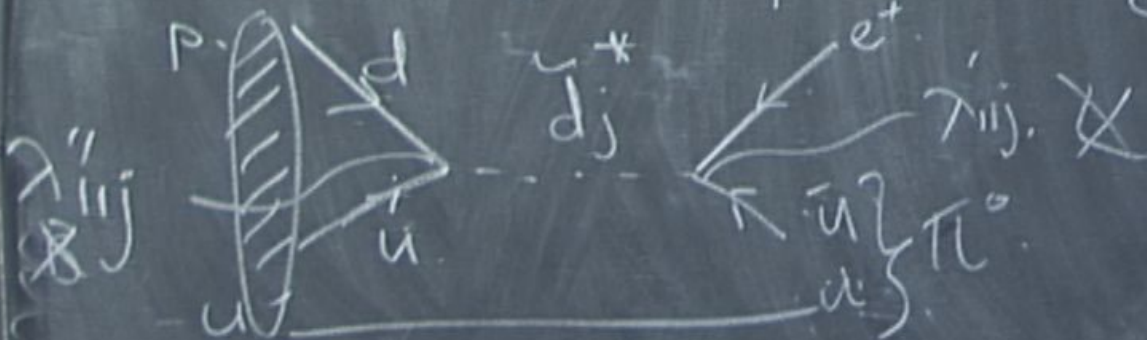
If one has both ~~⊗~~ and ~~⊗~~ interactions, one tends to predict proton decay

$$T_p > 10^{35} \text{ years}$$

predicts.



decay rate predicted $\sim 10^{11} \text{ sec}^{-1}$



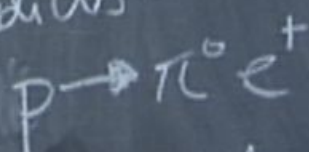
$$\begin{aligned}
 W_{RP} = & \left[\frac{\lambda'_{ijk}}{2} L_i^a L_j^b \overline{E}_{Rk} \right] \epsilon_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \overline{D}_{Rk} \epsilon_{ab} \\
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 \end{aligned}$$

↑
vitate!

If one has both ~~B~~ and ~~X~~ interactions, one tends to predict proton decay

$$\tau_p > 10^{35} \text{ years}$$

predicts.



decay rate predicted is 0!



\mathbb{Z}_2 multiplicity $R_p = (-1)^{3(B-L)+2S}$ spin

R parity bans all terms in W_{RP} !

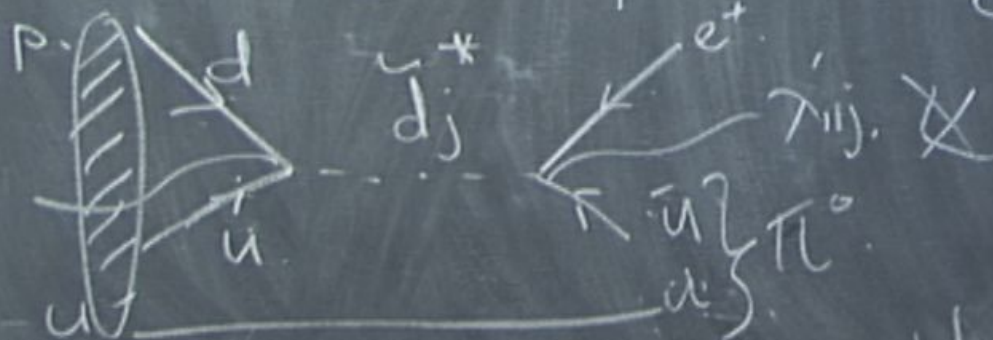
$$\begin{aligned}
 W_{RP} = & \left[\frac{\lambda_{ijk}}{2} L_i^a L_j^b \bar{E}_{Rk} \right] \epsilon_{ab} + \lambda'_{ijk} L_i^a Q_j^{bx} \bar{D}_{Rk} \epsilon_{ab} \\
 & + \frac{\lambda''_{ijk}}{2} \bar{U}_{Ri}^x \bar{U}_{Rj}^y \bar{D}_{Rk}^z \epsilon_{xyz} + K_i L_i^a H_2^b \epsilon_{ab}
 \end{aligned}$$

~~B~~ ~~X~~

↑
rotate L

If one has both ~~B~~ and ~~X~~ interactions, one tends to predict proton decay

$$\tau_p > 10^{35} \text{ years}$$



predicts.

$$p \rightarrow \pi^0 e^+$$

decay rate predicted $\sim 10^{11} \text{ sec}^{-1}$

Z_2 multiplicity \rightarrow R parity bans all terms in W_{RP} !
 $R_p = (-1)^{3(B-L)+2S}$
 spin