Portorož, April 14 2011

Aspects of SO(10) unification with extended matter sector

Michal Malinský
AHEP group, IFIC of CSIC/University of Valencia

based on
PRD83 (2011) 035002 & 035018 + work in progress

in collaboration with

Stefano Bertolini (SISSA), Luca DiLuzio (SISSA), Martin Heinze (KTH Stockholm), Martin Hirsch (IFIC), Laslo Reichert (IFIC) and others

Extra matter in GUTs

... requires a **very good** motivation...

- undoes matter unification a la SO(10)

- incomplete SU(5) multiplets in the desert alter the running

  can be welcome but requires finetunning

- pushes the unified gauge coupling up

  speeds up proton decay, can spoil calculability

- does not like to be testable

  rather at higher scales (running), vector-like

Extra matter in GUTs

... requires a **very good** motivation...

- The Georgi-Glashow SU(5) model fails due to:

  - no unification

  - no neutrino masses

Extra matter in GUTs

... requires a **very good** motivation...

- The Georgi-Glashow SU(5) model fails due to:

  - no unification

  - no neutrino masses

- Georgi-Glashow SU(5) + 24 of matter: B. Bajc & G. Senjanović 2007

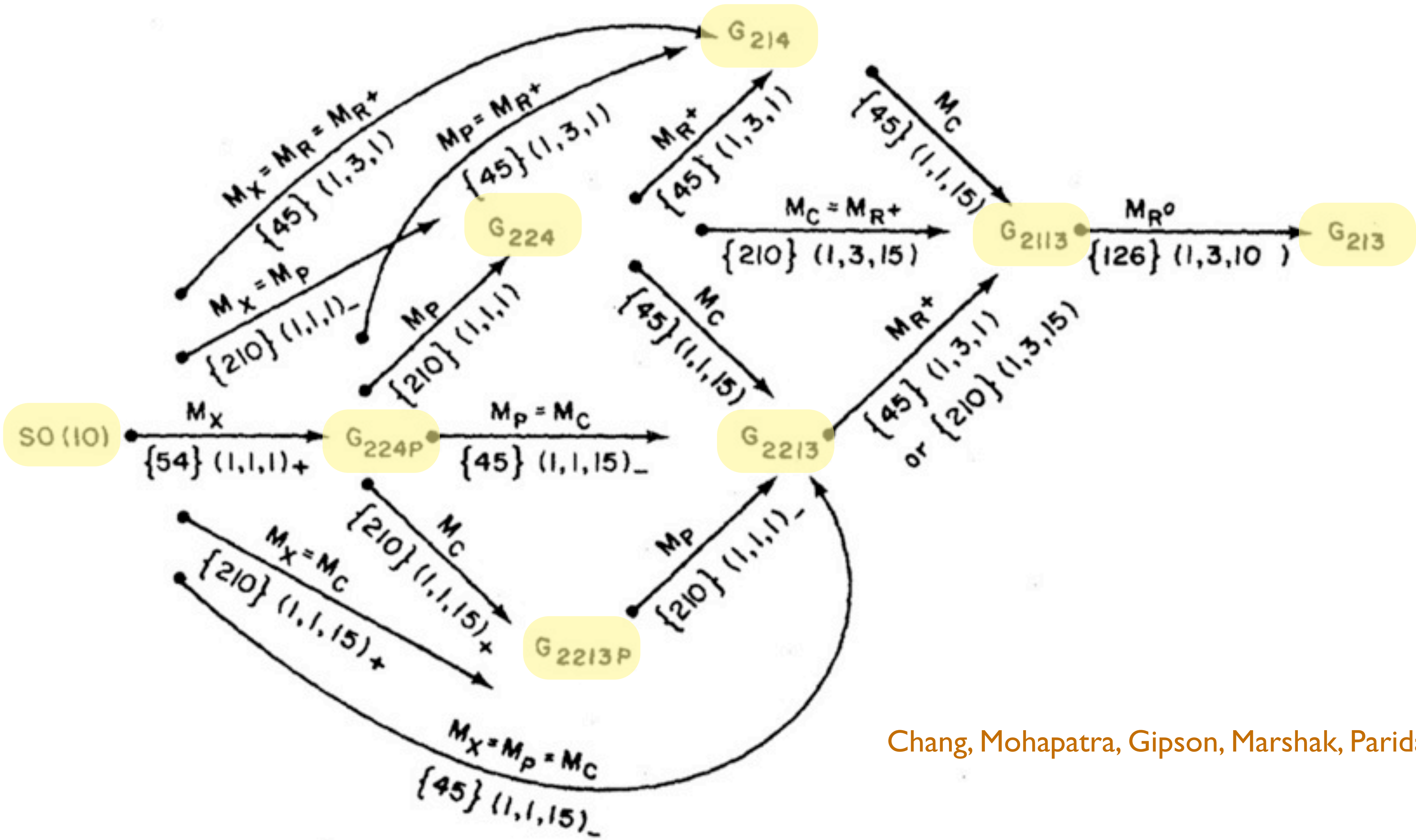
  - 24 of SU(5) contains the type-I singlet + type-III triplet

  - the triplet cures unification if at the TeV scale! => testable seesaw

Extra matter in GUTs

- Extra matter in SO(10) ? - unification is easier

  - neutrino masses essentially automate



Chang, Mohapatra, Gipson, Marshak, Parida 1985

Extra matter in SO(10)

... requires a **good** motivation...

Extra matter in SO(10)

... requires a **good** motivation...

SO(10) Higgs sector can be unloaded !

- Part I: Extra matter changes the effective Yukawa flavour structure
- Part II: Extra matter amplifies the SSB power of Higgs multiplets (via flipping)

Part I

The flavour aspects

Extra matter in SO(10)

- Matter in 16 only: 16 x16 = 10 + 126 + 120

  - 126* mandatory for neutrinos at renormalizable level

  - extra 126 necessary in SUSY

  - other IRREPs needed for the SO(10) breaking and doublet mixing

Minimal SUSY SO(10): 10+126+126*+210+...

Extra matter in SO(10)

- Matter in 16 only: $16 \times 16 = 10 + 126 + 120$

  - 126* mandatory for neutrinos at renormalizable level

  - extra 126 necessary in SUSY

  - other IRREPs needed for the SO(10) breaking and doublet mixing

  Minimal SUSY SO(10): 10+126+126*+210+...

- Extra matter, e.g., in 10: $16 \times 10 = 16^* + 144$, $10 \times 10 = 1 + 45 + 54$

  - down quarks and charged leptons "remixed"

  - a type-II triplet in 54 for neutrinos

  - doublets mixed via <16> which is there anyway to break $SU(2)_R \times U(1)_{B-L}$

  With extra matter: 10+16+16*+45+54...

Extra matter in SO(10)

$$16_F = \overset{L_L}{(1,2,-1)} \oplus \overset{D^c_L}{(\overline{3},1,+2/3)} \oplus \overset{Q_L}{(3,2,+1/3)} \oplus \overset{U^c_L}{(\overline{3},1,-4/3)} \oplus \overset{N^c_L}{(1,1,0)} \oplus \overset{E^c_L}{(1,1,+2)}$$

$$10_F = \overset{\Lambda_L}{(1,2,-1)} \oplus \overset{\Delta^c_L}{(\overline{3},1,+2/3)} \oplus \overset{\Lambda^c_L}{(1,2,+1)} \oplus \overset{\Delta_L}{(3,1,-2/3)}$$

Extra matter in SO(10)

$$16_F = \overset{L_L}{(1,2,-1)} \oplus \overset{D^c_L}{(\overline{3},1,+2/3)} \oplus \overset{Q_L}{(3,2,+1/3)} \oplus \overset{U^c_L}{(\overline{3},1,-4/3)} \oplus \overset{N^c_L}{(1,1,0)} \oplus \overset{E^c_L}{(1,1,+2)}$$

$$10_F = \overset{\Lambda_L}{(1,2,-1)} \oplus \overset{\Delta^c_L}{(\overline{3},1,+2/3)} \oplus \overset{\Lambda^c_L}{(1,2,+1)} \oplus \overset{\Delta_L}{(3,1,-2/3)}$$

Extra matter in SO(10)

$$16_F = \overset{L_L}{(1,2,-1)} \oplus \overset{D^c_L}{(\overline{3},1,+2/3)} \oplus \overset{Q_L}{(3,2,+1/3)} \oplus \overset{U^c_L}{(\overline{3},1,-4/3)} \oplus \overset{N^c_L}{(1,1,0)} \oplus \overset{E^c_L}{(1,1,+2)}$$

$$10_F = \overset{\Lambda_L}{(1,2,-1)} \oplus \overset{\Delta^c_L}{(\overline{3},1,+2/3)} \oplus \overset{\Lambda^c_L}{(1,2,+1)} \oplus \overset{\Delta_L}{(3,1,-2/3)}$$

- A toy model:

$$W_Y = Y_{10} 16_F 16_F 10_H + F 16_F 10_F 16_H + \lambda 10_F 10_F 54_H + M_{10} 10_F 10_F$$

- down quarks and charged lepton mass matrices:

M_d	D^c_L	Δ^c_L
D_L	$Y_{10} v_d^{10}$	$-F v_d^{16}$
Δ_L	$F V^{16}$	$M_{10} - \lambda V^{54}$

M_l	E^c_L	Λ^c_L
E_L	$Y_{10} v_d^{10}$	$F V^{16}$
Λ_L	$-F v_d^{16}$	$M_{10} + \frac{3}{2}\lambda V^{54}$

Extra matter in SO(10)

$$16_F = \overset{L_L}{(1,2,-1)} \oplus \overset{D_L^c}{(\overline{3},1,+2/3)} \oplus \overset{Q_L}{(3,2,+1/3)} \oplus \overset{U_L^c}{(\overline{3},1,-4/3)} \oplus \overset{N_L^c}{(1,1,0)} \oplus \overset{E_L^c}{(1,1,+2)}$$

$$10_F = \overset{\Lambda_L}{(1,2,-1)} \oplus \overset{\Delta_L^c}{(\overline{3},1,+2/3)} \oplus \overset{\Lambda_L^c}{(1,2,+1)} \oplus \overset{\Delta_L}{(3,1,-2/3)}$$

- A toy model:

$$W_Y = Y_{10} 16_F 16_F 10_H + F 16_F 10_F 16_H + \lambda 10_F 10_F 54_H + M_{10} 10_F 10_F$$

- down quarks and charged lepton mass matrices:

M_d	D_L^c	Δ_L^c
D_L	$Y_{10} v_d^{10}$	$-F v_d^{16}$
Δ_L	$F V^{16}$	$M_{10} - \lambda V^{54}$

M_l	E_L^c	Λ_L^c
E_L	$Y_{10} v_d^{10}$	$F V^{16}$
Λ_L	$-F v_d^{16}$	$M_{10} + \frac{3}{2}\lambda V^{54}$

- the triplet part of the neutrino mass matrix is calculable, some nice features...

A naturaly large atmospheric mixing (one 10 active, 2nd and 3rd generation only):

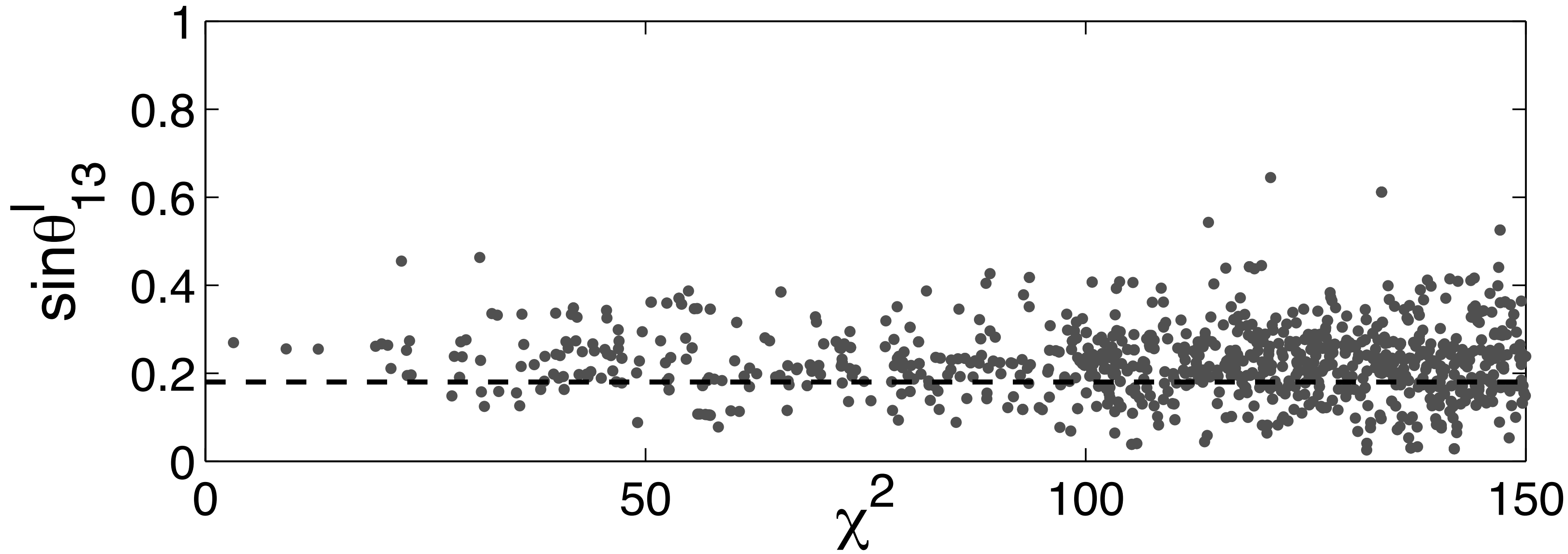
$$\tan 2\theta_{23}^{\nu} \approx 2 \frac{y_b |V_{cb}|}{y_s \left| 1 - \left(\frac{y_b}{y_s} |V_{cb}| \right)^2 \right|}$$

Extra matter in SO(10)

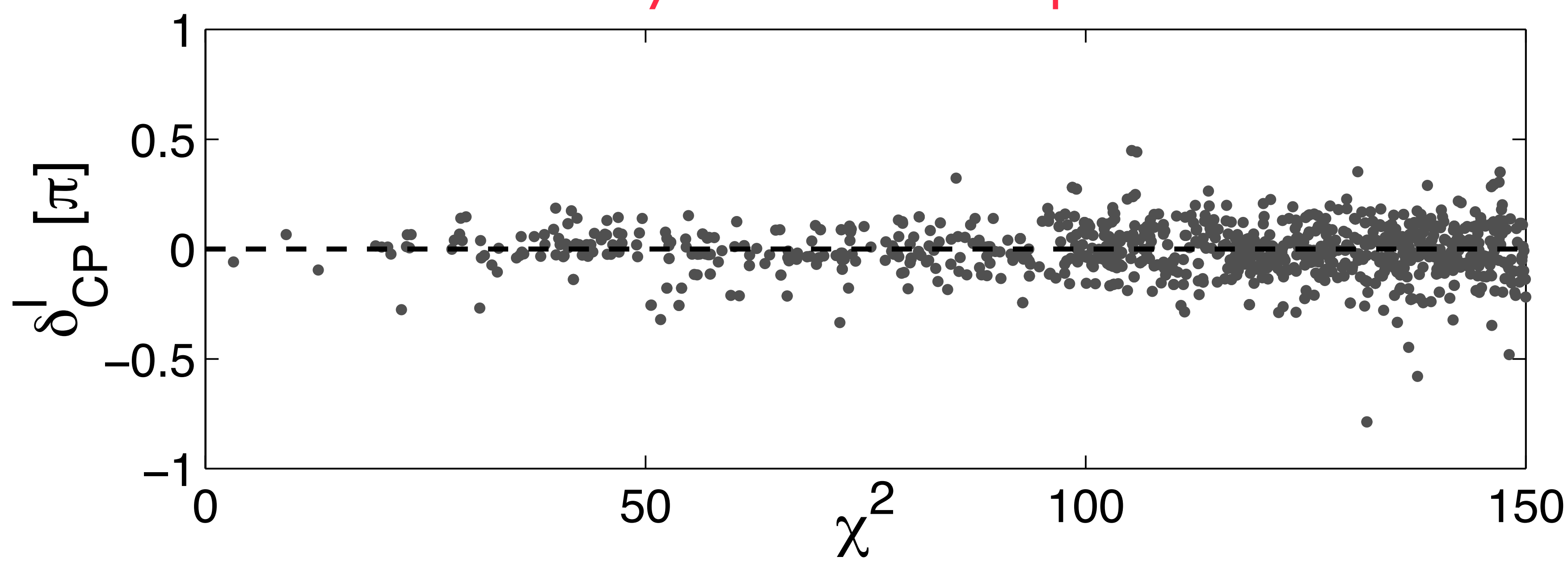
- There are even two genuine predictions in the type-II dominated regime:

A relatively "large" reactor mixing angle

M.Heinze, MM, 2011



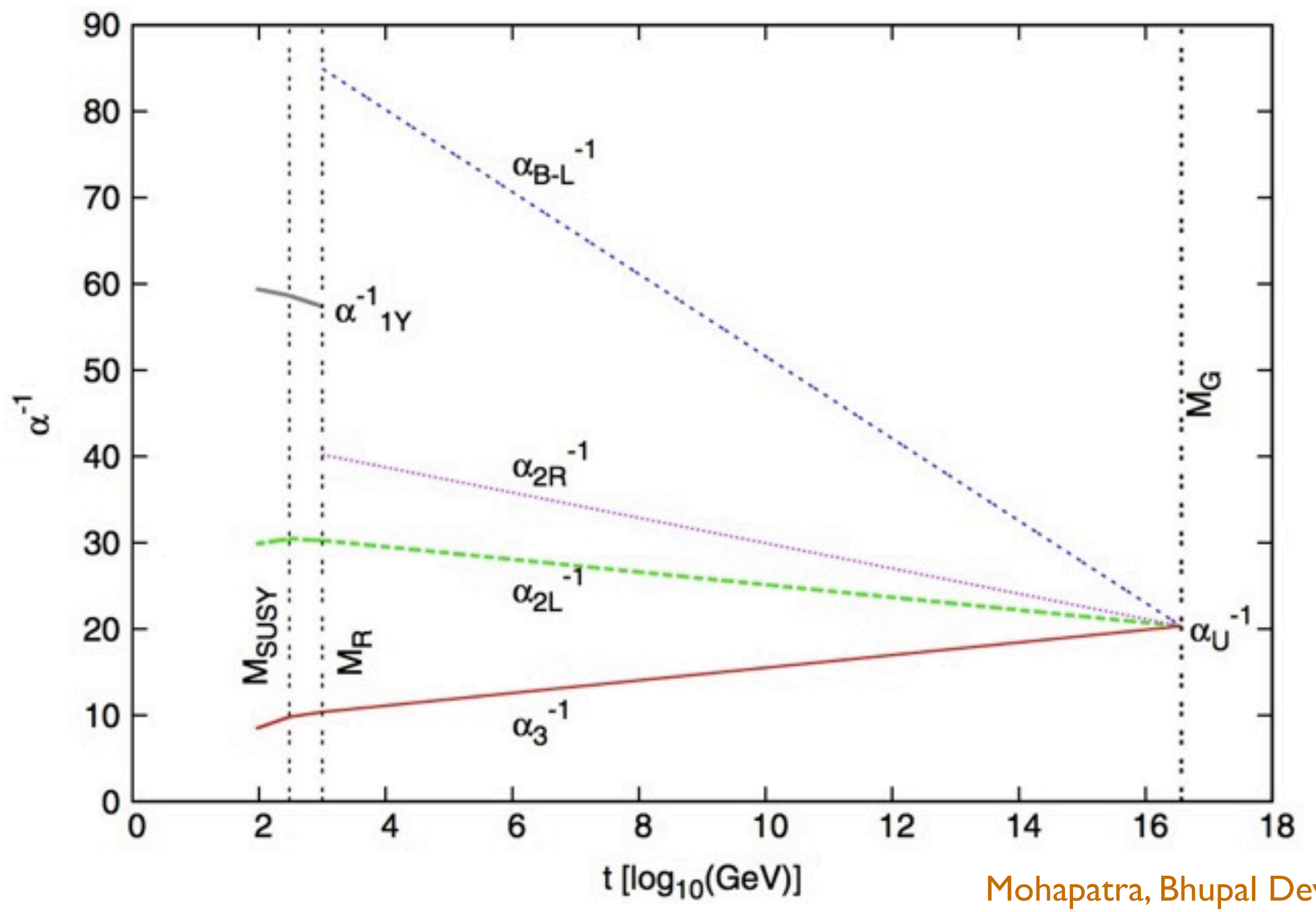
A very small Dirac CP phase



Extra matter in SO(10)

- Remarkably, this game can be played at almost any scale, perhaps even very low!

  - with extra light color states $SU(2)_R \times U(1)_{B-L}$ can be low even in SO(10)
  - indeed, the QCD gauge coupling **must be** slowed down in such a case



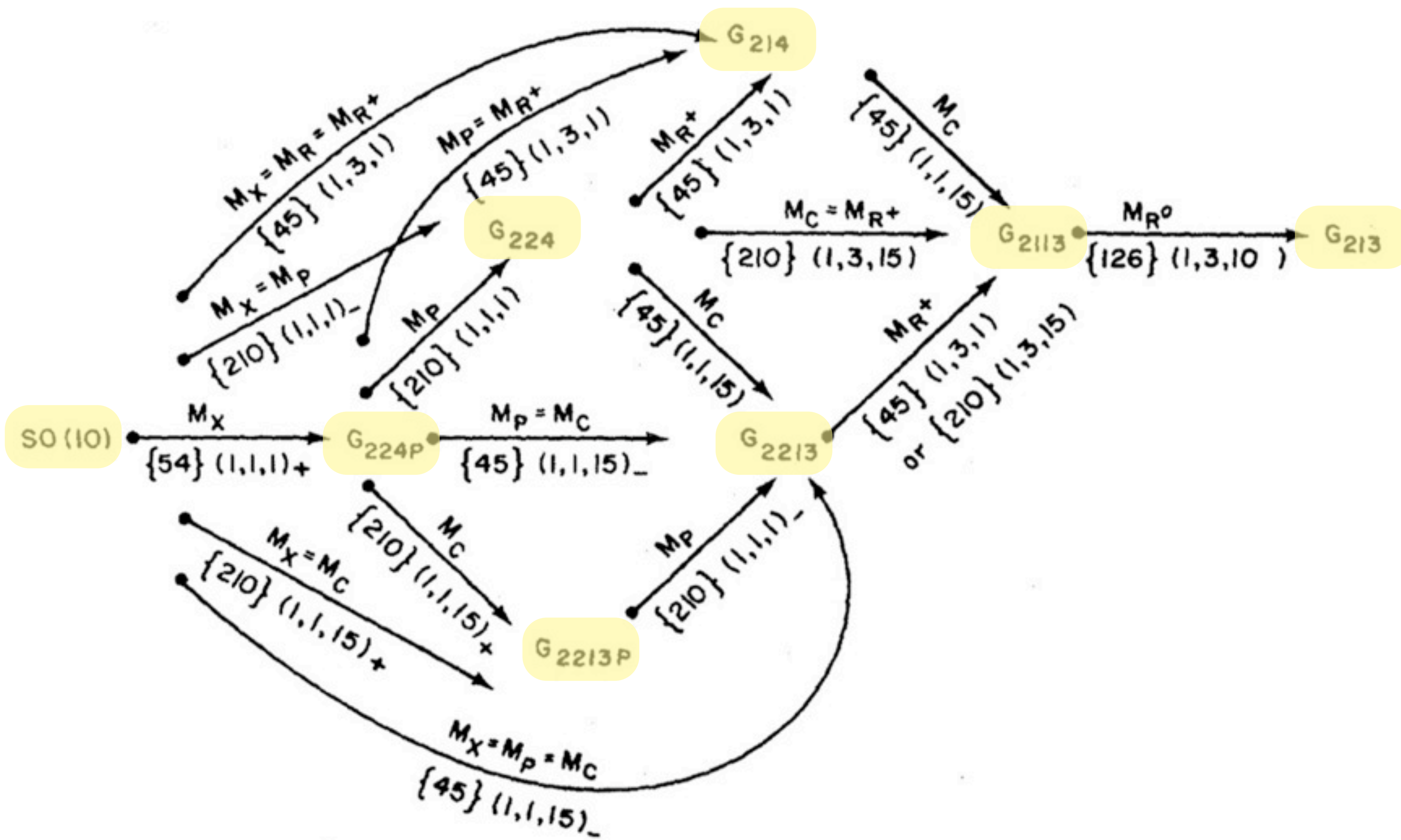
Mohapatra, Bhupal Dev, 2010

Part II

The power of Higgses

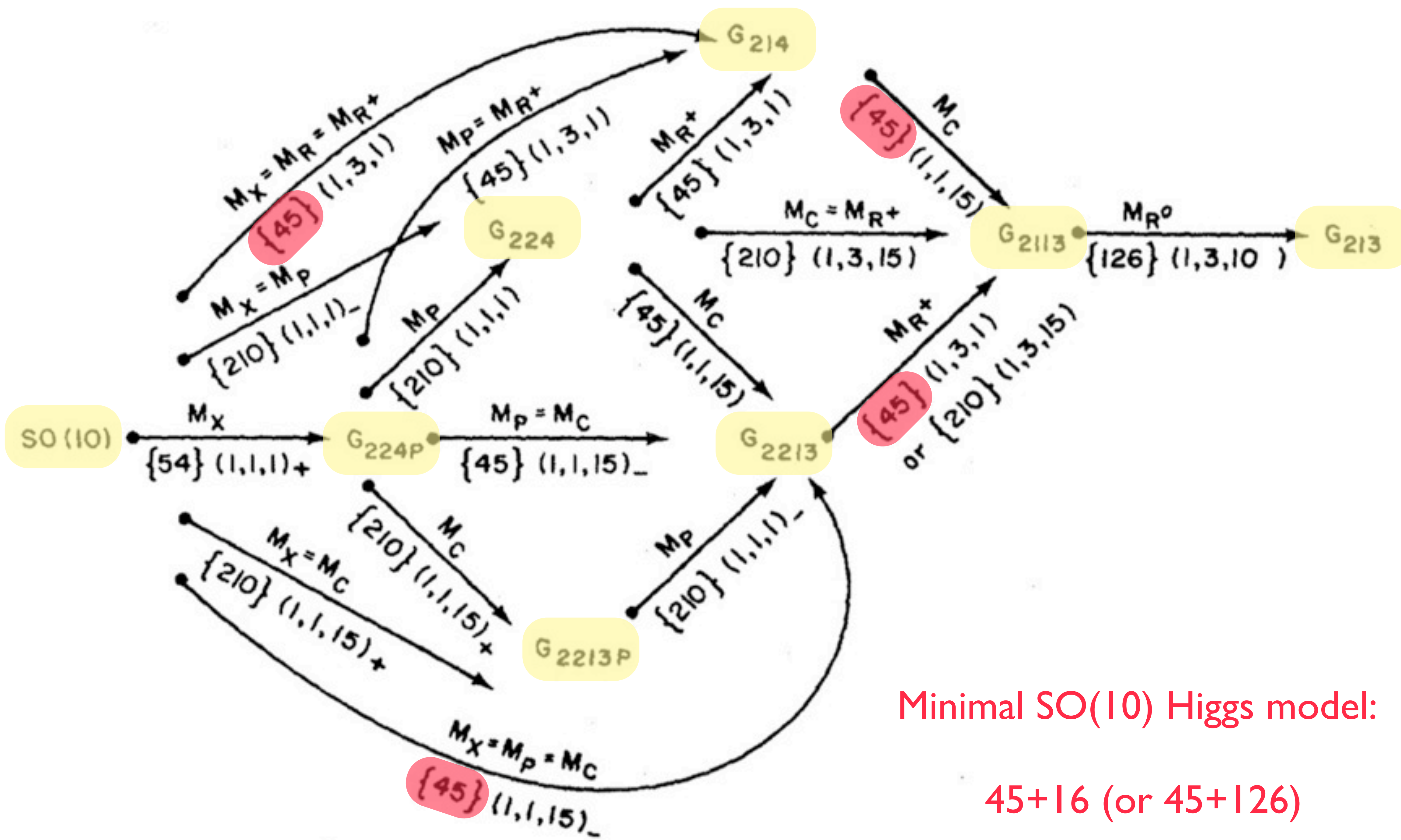
SO(10) symmetry breaking in minimal models

- Breaking SO(10) down to the SM in a “most economical” way:



SO(10) symmetry breaking in minimal models

- Breaking SO(10) down to the SM in a "most economical" way:



Minimal SO(10) Higgs model:

45+16 (or 45+126)

SU(5) lock in the minimal SUSY SO(10) Higgs model

- One SU(5)-preserving SM singlet in 16, two different SM singlets in 45:

$$\langle 45_H \rangle = \begin{pmatrix} \omega_Y & & & & \\ & \omega_Y & & & \\ & & \omega_Y & & \\ & & & \omega_R & \\ & & & & \omega_R \end{pmatrix} \otimes \tau_2$$

$\omega_R = 0 \quad SO(10) \to SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

$\omega_Y = 0 \quad SO(10) \to SU(4)_C \otimes SU(2)_L \otimes U(1)_R$

$\omega_R = \pm\omega_Y \quad SO(10) \to SU(5) \otimes U(1)$

SU(5) lock in the minimal SUSY SO(10) Higgs model

- One SU(5)-preserving SM singlet in 16, two different SM singlets in 45:

$$\langle 45_H \rangle = \begin{pmatrix} \omega_Y & & & & \\ & \omega_Y & & & \\ & & \omega_Y & & \\ & & & \omega_R & \\ & & & & \omega_R \end{pmatrix} \otimes \tau_2$$

$\omega_R = 0$ $\quad SO(10) \to SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

$\omega_Y = 0$ $\quad SO(10) \to SU(4)_C \otimes SU(2)_L \otimes U(1)_R$

$\omega_R = \pm\omega_Y$ $\quad SO(10) \to SU(5) \otimes U(1)$

- The Higgs superpotential:

$$W \ni M_{16}\overline{16}_H 16_H + M_{45}\mathrm{Tr}\, 45_H^2 + \lambda \overline{16}_H 45_H 16_H + \ldots$$

- SUSY below the GUT scale:

$$F_{\langle 45_H \rangle} = 0 \text{ requires } \langle 45_H \rangle \propto \langle \overline{16}_H \rangle \langle 16_H \rangle$$

SU(5) lock in the minimal SUSY SO(10) Higgs model

- One SU(5)-preserving SM singlet in 16, two different SM singlets in 45:

$$\langle 45_H \rangle = \begin{pmatrix} \omega_Y & & & & \\ & \omega_Y & & & \\ & & \omega_Y & & \\ & & & \omega_R & \\ & & & & \omega_R \end{pmatrix} \otimes \tau_2$$

$\omega_R = 0$ $\quad SO(10) \to SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$

$\omega_Y = 0$ $\quad SO(10) \to SU(4)_C \otimes SU(2)_L \otimes U(1)_R$

$\omega_R = \pm\omega_Y$ $\quad SO(10) \to SU(5) \otimes U(1)$

- The Higgs superpotential:

$$W \ni M_{16}\overline{16}_H 16_H + M_{45}\,\mathrm{Tr}\,45_H^2 + \lambda \overline{16}_H 45_H 16_H + \ldots$$

- SUSY below the GUT scale:

$F_{\langle 45_H \rangle} = 0$ requires $\langle 45_H \rangle \propto \langle \overline{16}_H \rangle \langle 16_H \rangle$ SU(5) remains unbroken!

Realistic renormalizable SUSY SO(10) Higgs models need more than 45+16 (or 45+126)

SU(5) lock in the minimal non-SUSY SO(10) Higgs model

Remarkably, there is a similar SU(5) lock even without supersymmetry!

- Tachyons in the scalar spectrum unless $\frac{1}{2} \leq |\omega_Y/\omega_R| \leq 2$

$$
\begin{aligned}
m^2_{(8,1,0)} &= 2a_2(\omega_R - \omega_Y)(\omega_R + 2\omega_Y) \\
m^2_{(1,3,0)} &= 2a_2(\omega_Y - \omega_R)(\omega_Y + 2\omega_R)
\end{aligned}
$$

Only the SU(5)-like vacuum allowed ! Yasue, Ma & co., Buccella & co. in 1980's

SU(5) lock in the minimal non-SUSY SO(10) Higgs model

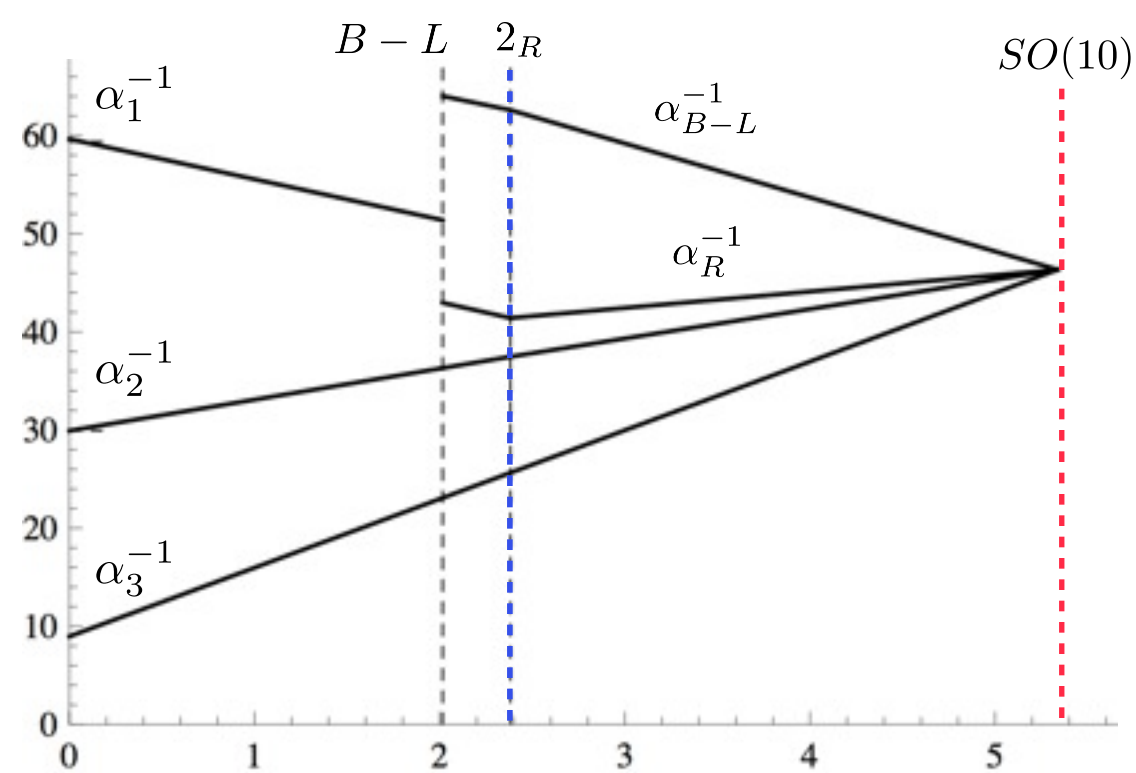
Remarkably, there is a similar SU(5) lock even without supersymmetry!

- Tachyons in the scalar spectrum unless $\frac{1}{2} \leq |\omega_Y/\omega_R| \leq 2$

$$m^2_{(8,1,0)} = 2a_2(\omega_R - \omega_Y)(\omega_R + 2\omega_Y)$$
$$m^2_{(1,3,0)} = 2a_2(\omega_Y - \omega_R)(\omega_Y + 2\omega_R)$$

Only the SU(5)-like vacuum allowed ! Yasue, Ma & co., Buccella & co. in 1980's

- Typical "multi-stage" breaking pattern $SO(10) \to SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \to \text{SM}$



SU(5) lock in the minimal non-SUSY SO(10) Higgs model

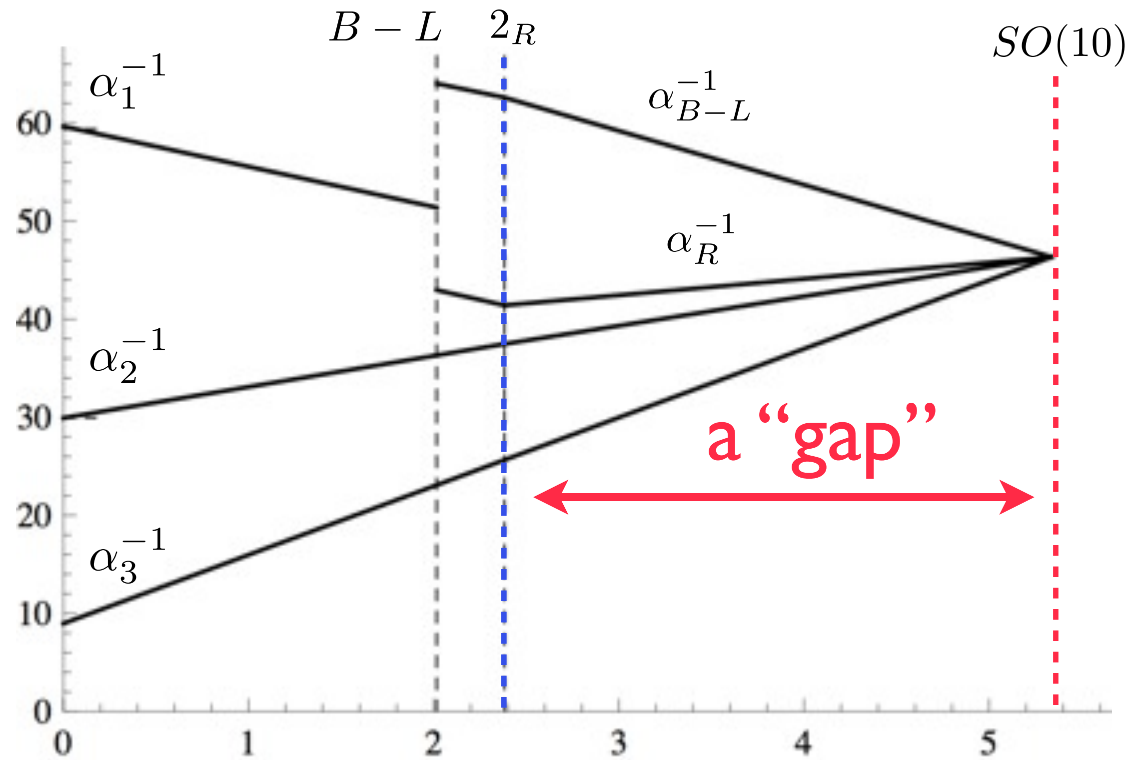
Remarkably, there is a similar SU(5) lock even without supersymmetry!

- Tachyons in the scalar spectrum unless $\frac{1}{2} \leq |\omega_Y/\omega_R| \leq 2$

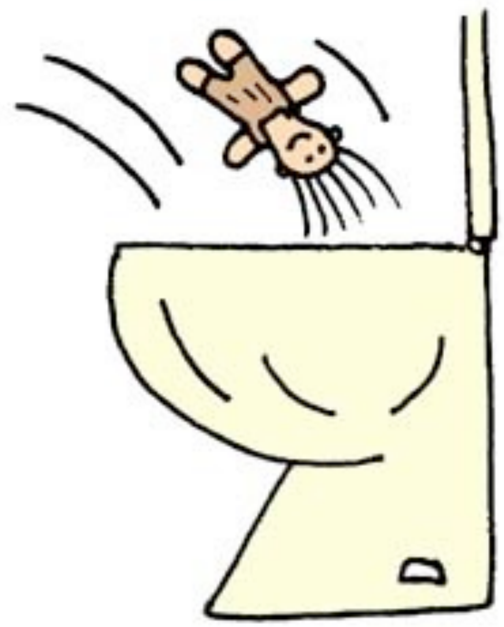
$$m^2_{(8,1,0)} = 2a_2(\omega_R - \omega_Y)(\omega_R + 2\omega_Y)$$
$$m^2_{(1,3,0)} = 2a_2(\omega_Y - \omega_R)(\omega_Y + 2\omega_R)$$

Only the SU(5)-like vacuum allowed ! Yasue, Ma & co., Buccella & co. in 1980's

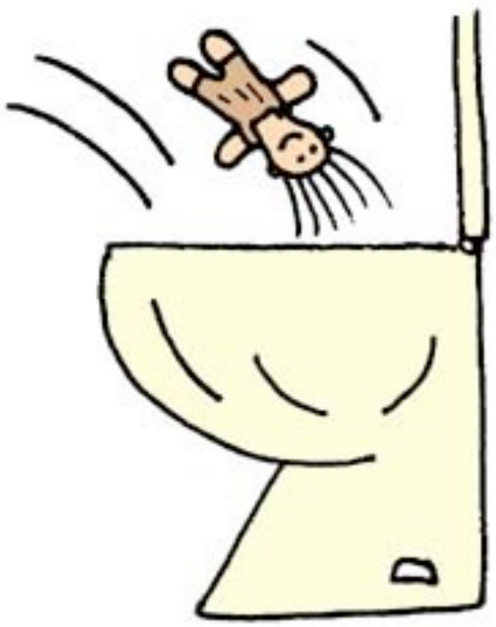
- Typical "multi-stage" breaking pattern $SO(10) \to SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \to \text{SM}$



SU(5) lock in the minimal non-SUSY SO(10) Higgs model

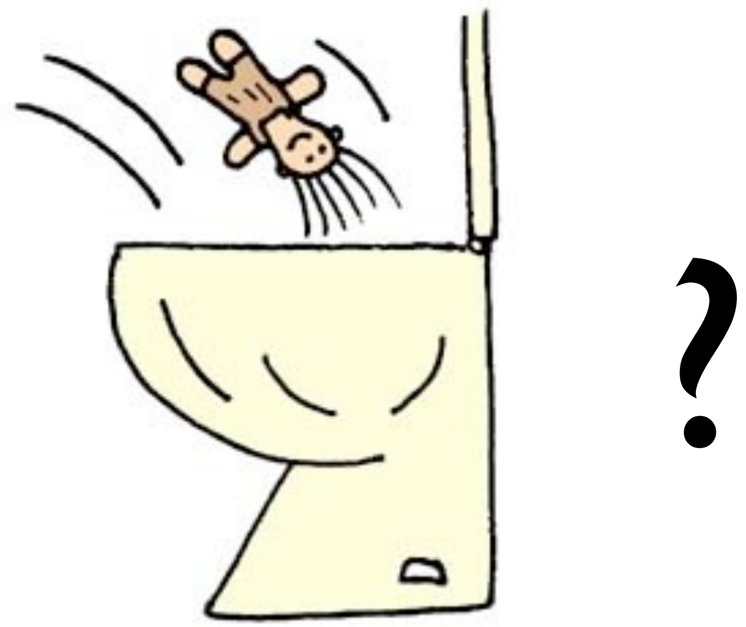


SU(5) lock in the minimal non-SUSY SO(10) Higgs model



?

SU(5) lock in the minimal non-SUSY SO(10) Higgs model



- Second Weinberg's law of progress in particle physics:

"Do not trust arguments based on the lowest order of perturbation theory!"

S.Weinberg , "Why RG is a good thing"
in "Asymptotic Realm of Physics", MIT press 1983

A quantum salvation of the minimal non-SUSY SO(10)

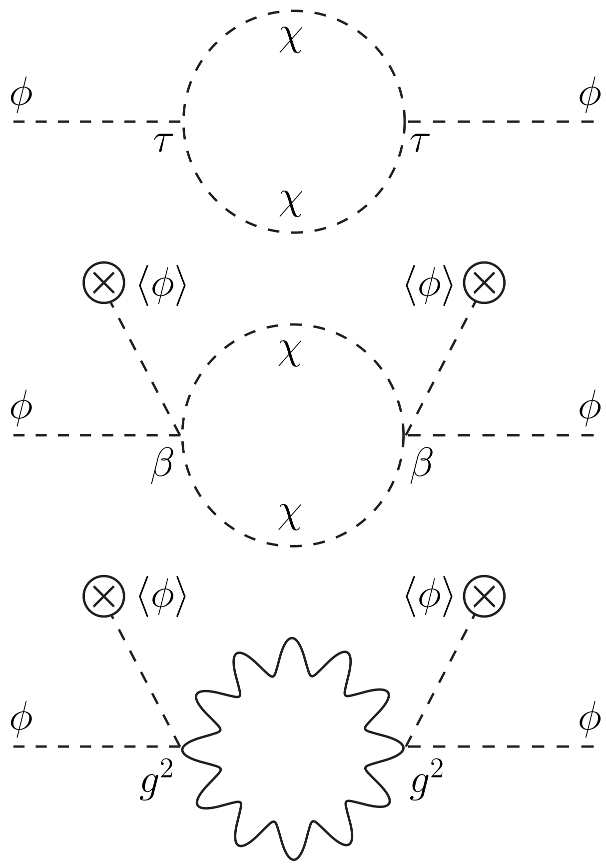
S.Bertolini, L.DiLuzio, MM, Phys. Rev. D 81, 035015 (2010)

- We have performed a one-loop analysis of the minimal SO(10) vacuum

  - Coleman-Weinberg effective potential minimization:

$$\Delta m^2_{(1,3,0)} = \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(2\omega_R^2 - \omega_R\omega_Y + 2\omega_Y^2) + g^4\left(16\omega_R^2 + \omega_Y\omega_R + 19\omega_Y^2\right)\right] + \text{logs}\,,$$

$$\Delta m^2_{(8,1,0)} = \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(\omega_R^2 - \omega_R\omega_Y + 3\omega_Y^2) + g^4\left(13\omega_R^2 + \omega_Y\omega_R + 22\omega_Y^2\right)\right] + \text{logs}\,,$$



A quantum salvation of the minimal non-SUSY SO(10)

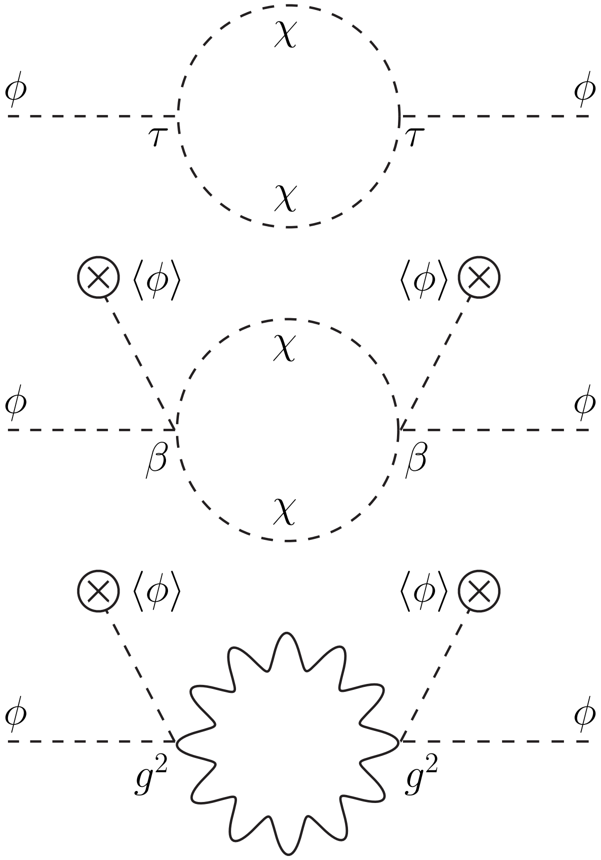
S.Bertolini, L.DiLuzio, MM, Phys. Rev. D 81, 035015 (2010)

- We have performed a one-loop analysis of the minimal SO(10) vacuum

- Coleman-Weinberg effective potential minimization:

$$\Delta m^2_{(1,3,0)} = \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(2\omega_R^2 - \omega_R\omega_Y + 2\omega_Y^2) + g^4\left(16\omega_R^2 + \omega_Y\omega_R + 19\omega_Y^2\right)\right] + \text{logs}\,,$$

$$\Delta m^2_{(8,1,0)} = \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(\omega_R^2 - \omega_R\omega_Y + 3\omega_Y^2) + g^4\left(13\omega_R^2 + \omega_Y\omega_R + 22\omega_Y^2\right)\right] + \text{logs}\,,$$



- radiative corrections to PGB masses non-trivial & large

- compete with the tree-level parts for $a_2 \lesssim \mathcal{O}(10^{-1})\beta, \tau$

NO TACHYONS even in the $\omega_R \gg \omega_Y$ or $\omega_Y \gg \omega_R$ regimes !

The gap is supported at the quantum level !

Can we unlock the minimal SO(10) Higgs model in SUSY?

- Going wild? (non-renormalizable?)

  - neutrinos OK within a non-renormalizable seesaw

  - SU(5) lock of SUSY SO(10) with 16+45 can be broken via non-ren. operators

- Drawbacks of non-renormalizable SO(10) breaking

  - large GUT-scale thresholds

  - proton decay issues due to a postponed SU(5) breakdown

Can we unlock the minimal SO(10) Higgs model in SUSY?

- Indeed, the trick is to add extra matter ...

Can we unlock the minimal SO(10) Higgs model in SUSY?

- Indeed, the trick is to add extra matter ...

???

Can we unlock the minimal SO(10) Higgs model in SUSY?

- Indeed, the trick is to add extra matter ...

???

Extra matter in three 10's provides the freedom to flip SO(10) !

S.Barr 1982, Nanopoulos 1984

- Flipping = extra U(1) gauge factor admixed into the SM hypercharge

  - flipped SU(5): doublet-triplet splitting, monopoles, proton decay...

The minimal flipped SUSY SO(10) Higgs model

- Minimal flipped SUSY SO(10) Higgs model S.Bertolini, L.DiLuzio, MM, 2011

  - hypercharge: $Y=-\frac{1}{5}Y_5-\frac{1}{20}Z+\frac{1}{4}X$ of $SU(5)\otimes U(1)_Z\otimes U(1)_X$

The minimal flipped SUSY SO(10) Higgs model

- Minimal flipped SUSY SO(10) Higgs model — S.Bertolini, L.DiLuzio, MM, 2011

  - hypercharge: $Y=-\frac{1}{5}Y_5-\frac{1}{20}Z+\frac{1}{4}X$ of $\underbrace{SU(5)\otimes U(1)_Z}_{SO(10)}\otimes U(1)_X$

The minimal flipped SUSY SO(10) Higgs model

- Minimal flipped SUSY SO(10) Higgs model S.Bertolini, L.DiLuzio, MM, 2011

  - hypercharge: $Y=-\frac{1}{5}Y_5-\frac{1}{20}Z+\frac{1}{4}X$ of $\underbrace{SU(5)\otimes U(1)_Z}_{SO(10)}\otimes U(1)_X$

  - SM singlets reshuffled:

Standard → The spinorial 16 ← Flipped

$SU(5)$	
$SO(10)$	$SO(10)_f$
$(\bar{3},1;+\frac{1}{3})_{\bar{5}}$	$(\bar{3},1;+\frac{1}{3})_{\bar{5}}$
$(1,2;-\frac{1}{2})_{\bar{5}}$	$(1,2;+\frac{1}{2})_{\bar{5}}$
$(3,2;+\frac{1}{6})_{10}$	$(3,2;+\frac{1}{6})_{10}$
$(\bar{3},1;-\frac{2}{3})_{10}$	$(\bar{3},1;+\frac{1}{3})_{10}$
$(1,1;+1)_{10}$	$\mathbf{(1,1;0)_{10}}$
$\mathbf{(1,1;0)_{1}}$	$\mathbf{(1,1;0)_{1}}$

Standard → The adjoint 45 ← Flipped

$SU(5)$	
$SO(10)$	$SO(10)_f$
$\mathbf{(1,1;0)_{1}}$	$\mathbf{(1,1;0)_{1}}$
$\mathbf{(1,1;0)_{24}}$	$\mathbf{(1,1;0)_{24}}$
$(8,1;0)_{24}$	$(8,1;0)_{24}$
$(3,2;-\frac{5}{6})_{24}$	$(3,2;+\frac{1}{6})_{24}$
$(\bar{3},2;+\frac{5}{6})_{24}$	$(\bar{3},2;-\frac{1}{6})_{24}$
$(1,3;0)_{24}$	$(1,3;0)_{24}$
$(3,2;+\frac{1}{6})_{10}$	$(3,2;+\frac{1}{6})_{10}$
$(\bar{3},1;-\frac{2}{3})_{10}$	$(\bar{3},1;+\frac{1}{3})_{10}$
$(1,1;+1)_{10}$	$\mathbf{(1,1;0)_{10}}$
$(\bar{3},2;-\frac{1}{6})_{\overline{10}}$	$(\bar{3},2;-\frac{1}{6})_{\overline{10}}$
$(3,1;+\frac{2}{3})_{\overline{10}}$	$(3,1;-\frac{1}{3})_{\overline{10}}$
$(1,1;-1)_{\overline{10}}$	$\mathbf{(1,1;0)_{\overline{10}}}$

The minimal flipped SUSY SO(10) Higgs model

- Minimal flipped SUSY SO(10) Higgs model — S.Bertolini, L.DiLuzio, MM, 2011
  - hypercharge: $Y = -\frac{1}{5}Y_5 - \frac{1}{20}Z + \frac{1}{4}X$ of $\underbrace{SU(5)\otimes U(1)_Z}_{SO(10)} \otimes U(1)_X$
  - SM singlets reshuffled:

The spinorial 16 (Standard ↘ SO(10), Flipped ↙ $SO(10)_f$)

$SU(5)$	
$SO(10)$	$SO(10)_f$
$(\bar{3}, 1; +\frac{1}{3})_{\bar{5}}$	$(\bar{3}, 1; +\frac{1}{3})_{\bar{5}}$
$(1, 2; -\frac{1}{2})_{\bar{5}}$	$(1, 2; +\frac{1}{2})_{\bar{5}}$
$(3, 2; +\frac{1}{6})_{10}$	$(3, 2; +\frac{1}{6})_{10}$
$(\bar{3}, 1; -\frac{2}{3})_{10}$	$(\bar{3}, 1; +\frac{1}{3})_{10}$
$(1, 1; +1)_{10}$	$\mathbf{(1, 1; 0)_{10}}$
$\mathbf{(1, 1; 0)_{1}}$	$\mathbf{(1, 1; 0)_{1}}$

The adjoint 45 (Standard ↘ SO(10), Flipped ↙ $SO(10)_f$)

$SU(5)$	
$SO(10)$	$SO(10)_f$
$\mathbf{(1, 1; 0)_{1}}$	$\mathbf{(1, 1; 0)_{1}}$
$\mathbf{(1, 1; 0)_{24}}$	$\mathbf{(1, 1; 0)_{24}}$
$(8, 1; 0)_{24}$	$(8, 1; 0)_{24}$
$(3, 2; -\frac{5}{6})_{24}$	$(3, 2; +\frac{1}{6})_{24}$
$(\bar{3}, 2; +\frac{5}{6})_{24}$	$(\bar{3}, 2; -\frac{1}{6})_{24}$
$(1, 3; 0)_{24}$	$(1, 3; 0)_{24}$
$(3, 2; +\frac{1}{6})_{10}$	$(3, 2; +\frac{1}{6})_{10}$
$(\bar{3}, 1; -\frac{2}{3})_{10}$	$(\bar{3}, 1; +\frac{1}{3})_{10}$
$(1, 1; +1)_{10}$	$\mathbf{(1, 1; 0)_{10}}$
$(\bar{3}, 2; -\frac{1}{6})_{\overline{10}}$	$(\bar{3}, 2; -\frac{1}{6})_{\overline{10}}$
$(3, 1; +\frac{2}{3})_{\overline{10}}$	$(3, 1; -\frac{1}{3})_{\overline{10}}$
$(1, 1; -1)_{\overline{10}}$	$\mathbf{(1, 1; 0)_{\overline{10}}}$

Symmetry-breaking power enhanced!

The minimal flipped SUSY SO(10) Higgs model

- Minimal flipped SUSY SO(10) Higgs model — S.Bertolini, L.DiLuzio, MM, 2011

	Standard $SO(10)$		Flipped $SO(10) \otimes U(1)$	
Higgs superfields	R	NR	R	NR
$16 \oplus \overline{16}$	$SO(10)$	$SU(5)$	$SO(10) \otimes U(1)$	$SU(5) \otimes U(1)$
$2 \times (16 \oplus \overline{16})$	$SO(10)$	$SU(5)$	$SO(10) \otimes U(1)$	SM
$45 \oplus 16 \oplus \overline{16}$	$SU(5)$	SM	$SU(5) \otimes U(1)$	SM $\otimes U(1)$
$45 \oplus 2 \times (16 \oplus \overline{16})$	$SU(5)$	SM	**SM**	SM

The minimal flipped SUSY SO(10) Higgs model

- Minimal flipped SUSY SO(10) Higgs model   S.Bertolini, L.DiLuzio, MM, 2011

	Standard $SO(10)$		Flipped $SO(10)\otimes U(1)$	
Higgs superfields	R	NR	R	NR
$16 \oplus \overline{16}$	$SO(10)$	$SU(5)$	$SO(10)\otimes U(1)$	$SU(5)\otimes U(1)$
$2\times(16 \oplus \overline{16})$	$SO(10)$	$SU(5)$	$SO(10)\otimes U(1)$	SM
$45 \oplus 16 \oplus \overline{16}$	$SU(5)$	SM	$SU(5)\otimes U(1)$	$\text{SM}\otimes U(1)$
$45 \oplus 2\times(16 \oplus \overline{16})$	$SU(5)$	SM	**SM**	SM

$$45 \oplus 2\times(16 \oplus \overline{16})$$

- the SU(5) lock broken at the renormalizable level

- thresholds under control

- breaking at 10^{16} GeV OK for d=5 seesaw

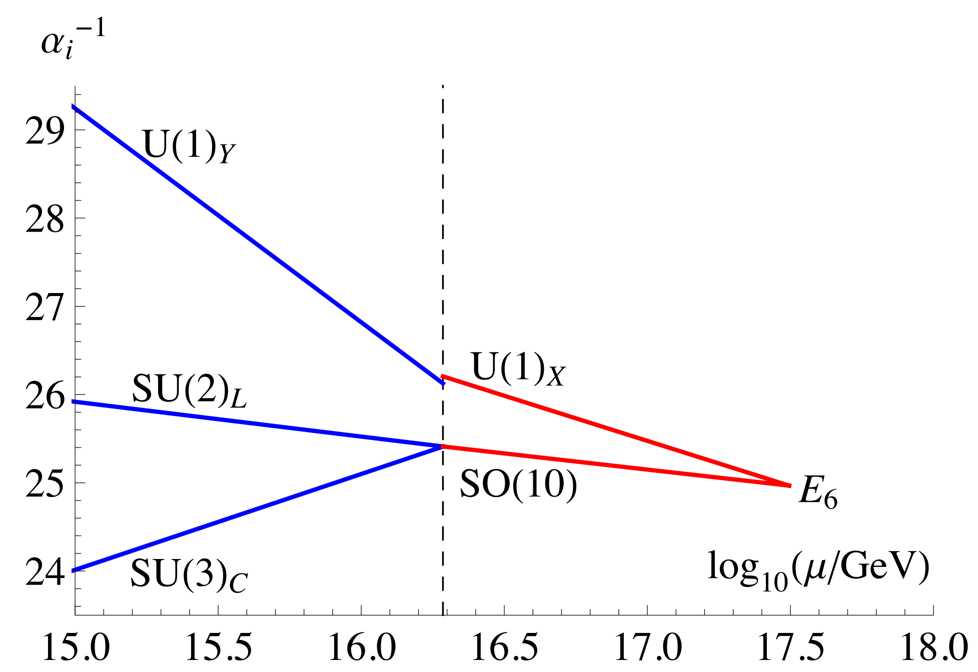
The minimal flipped SUSY SO(10) Higgs model

- Minimal flipped SUSY SO(10) Higgs model   S.Bertolini, L.DiLuzio, MM, 2011

	Standard $SO(10)$		Flipped $SO(10)\otimes U(1)$	
Higgs superfields	R	NR	R	NR
$16\oplus\overline{16}$	$SO(10)$	$SU(5)$	$SO(10)\otimes U(1)$	$SU(5)\otimes U(1)$
$2\times(16\oplus\overline{16})$	$SO(10)$	$SU(5)$	$SO(10)\otimes U(1)$	SM
$45\oplus16\oplus\overline{16}$	$SU(5)$	SM	$SU(5)\otimes U(1)$	$\mathrm{SM}\otimes U(1)$
$45\oplus2\times(16\oplus\overline{16})$	$SU(5)$	SM	**SM**	SM

$$45\oplus 2\times(16\oplus\overline{16})$$

- the SU(5) lock broken at the renormalizable level
- thresholds under control
- breaking at 10^{16} GeV OK for d=5 seesaw
- E6 re-unification available at 10^{17} GeV



Thanks for your kind attention!