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Twin-Unified $SU(5) \times SU(5)'$ GUT

And Phenomenology

(Skype talk)

arXiv: 1403.0025 [hep-ph]

UNICOS-2014

(Chandigarh, India, May 13-15, 2014)

Outline

- Intro / Motivations : Problems & Puzzles of SM
  - Neutrino masses & mixings
  - Higgs vacuum stability – "λ_h -problem"
  - Charge quantization, three gauge couplings …

→ New Physics

- SU(5)xSU(5)' GUT with D2 "parity"

  Model, symm. breaking pattern

- Implications & Phenomenology
  - Coupling unification, composite leptons,
  - fermion (including neutrino) masses,
  - Nucleon stability …
- Summary

Evidences for New Physics (Beyond SM):

Atmospheric & Solar Neutrino 'scales'

$$\Delta m^2_{\rm atm} = 2.4 \cdot 10^{-3} {\rm eV}^2$$

$$\Delta m^2_{\rm sol} = 7.9 \cdot 10^{-5} {\rm eV}^2$$

- **Origin of these scales and mixings?**

Unexplained in SM $\leftarrow \ \mathbf{m}_\nu \lesssim \mathbf{10^{-4}}\ \mathrm{eV}$

Without New Physics

$$m_\nu \sim \frac{M^2_{EW}}{M_{Pl}}$$

Neutrino Data

global 3ν oscillation analysis

Parameter	Best fit	1σ range
$\delta m^2/10^{-5}$ eV^2 (NH or IH)	7.54	7.32 – 7.80
$\sin^2\theta_{12}/10^{-1}$ (NH or IH)	3.07	2.91 – 3.25
$\Delta m^2/10^{-3}$ eV^2 (NH)	2.43	2.33 – 2.49
$\Delta m^2/10^{-3}$ eV^2 (IH)	2.42	2.31 – 2.49
$\sin^2\theta_{13}/10^{-2}$ (NH)	2.41	2.16 – 2.66
$\sin^2\theta_{13}/10^{-2}$ (IH)	2.44	
$\sin^2\theta_{23}/10^{-1}$ (NH)	3.86	
$\sin^2\theta_{23}/10^{-1}$ (IH)	3.92	
δ/π (NH)	1.08	
δ/π (IH)	1.09	

← **Fogli et al.** [1205.5254]

Schwetz et al. →

parameter	best fit $\pm1\sigma$
Δm^2_{21} $[10^{-5}\mathrm{eV}^2]$	$7.59^{+0.20}_{-0.18}$
Δm^2_{31} $[10^{-3}\mathrm{eV}^2]$	$2.50^{+0.09}_{-0.16}$ $-(2.40^{+0.08}_{-0.09})$
$\sin^2\theta_{12}$	$0.312^{+0.017}_{-0.015}$
$\sin^2\theta_{23}$	$0.52^{+0.06}_{-0.07}$ 0.52 ± 0.06
$\sin^2\theta_{13}$	$0.013^{+0.007}_{-0.005}$ $0.016^{+0.008}_{-0.006}$
δ	$\left(-0.61^{+0.75}_{-0.65}\right)\pi$ $\left(-0.41^{+0.65}_{-0.70}\right)\pi$

Shortcomings of SM:

SM Interactions : $SU(3)_C \times SU(2)_L \times U(1)_Y$ □ (8 gluons) + (3 + 1 EW Bosons)

$$\begin{pmatrix} u \\ d \end{pmatrix} = q(3, 2, -1/3) \qquad u^c(\bar{3}, 1, 4/3) \qquad d^c(\bar{3}, 1, -2/3)$$

$$\begin{pmatrix} \nu \\ e \end{pmatrix} = l(1, \bar{2}, 1) \qquad e^c(1, 1, -2)$$

Fractional $U(1)_Y$ charges – how $Q_p = -Q_e$?

Three gauge couplings: $\alpha_3, \alpha_2, \alpha_1$

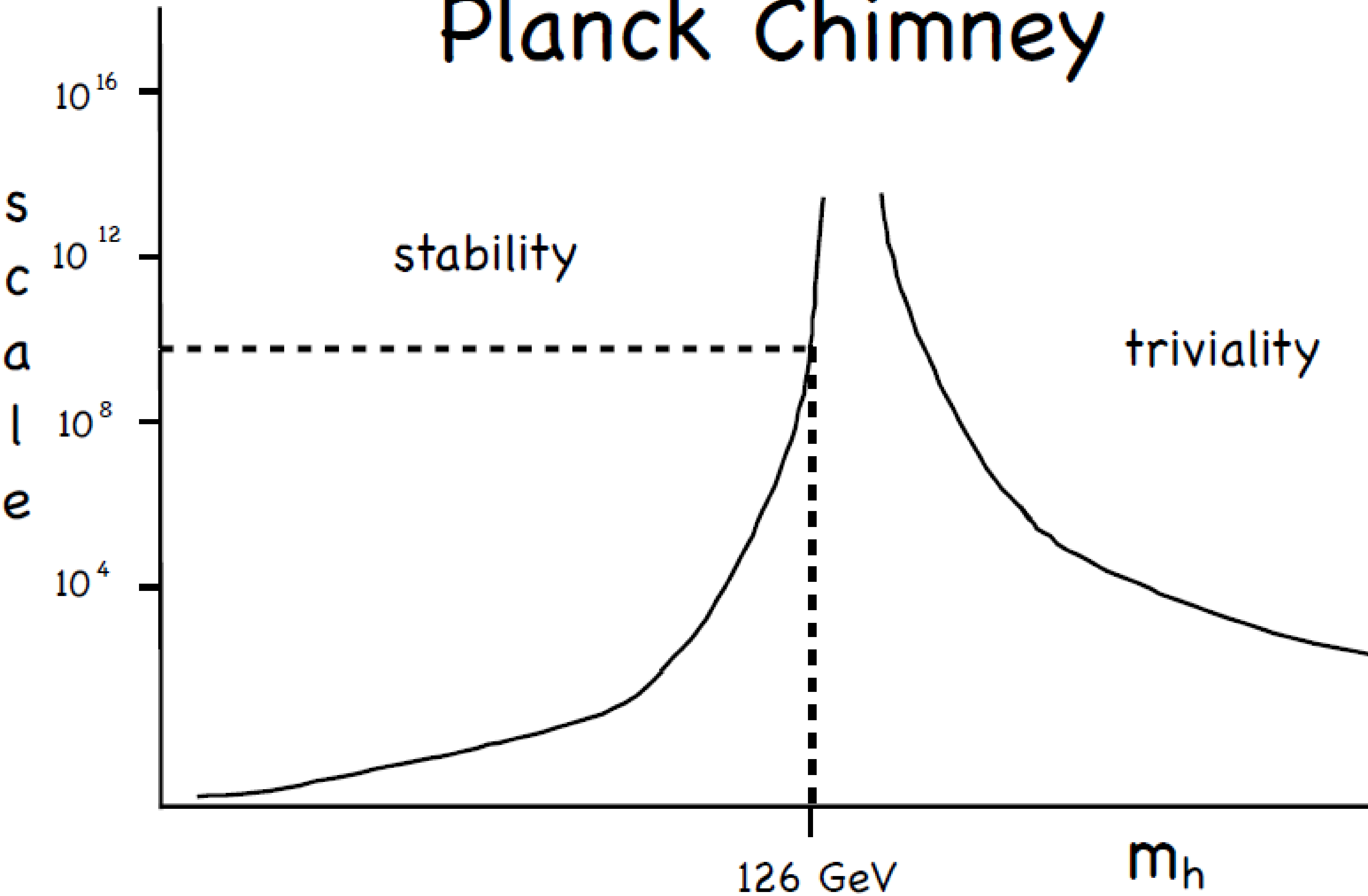
$$\text{Breaking: } SU(3)_C \times SU(2)_L \times U(1)_Y \xrightarrow{\langle H \rangle} SU(3)_C \times U(1)_{em}$$

LHC Discovery - $M_h \approx 125\ GeV$

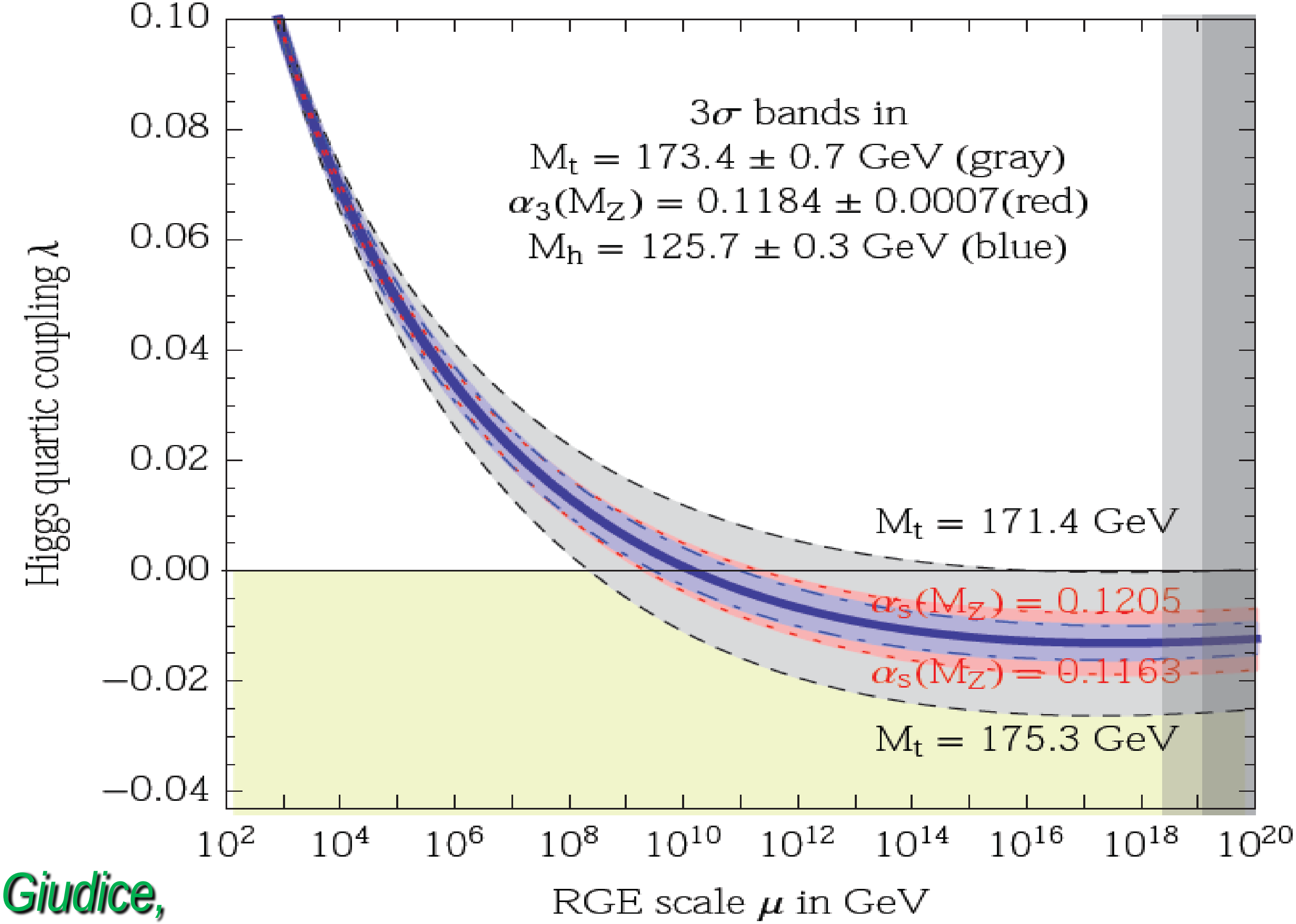
Why/how it is light? –Gauge Hierarchy Problem

From P. Ramond's talk at ISOUPS-20013

Planck Chimney

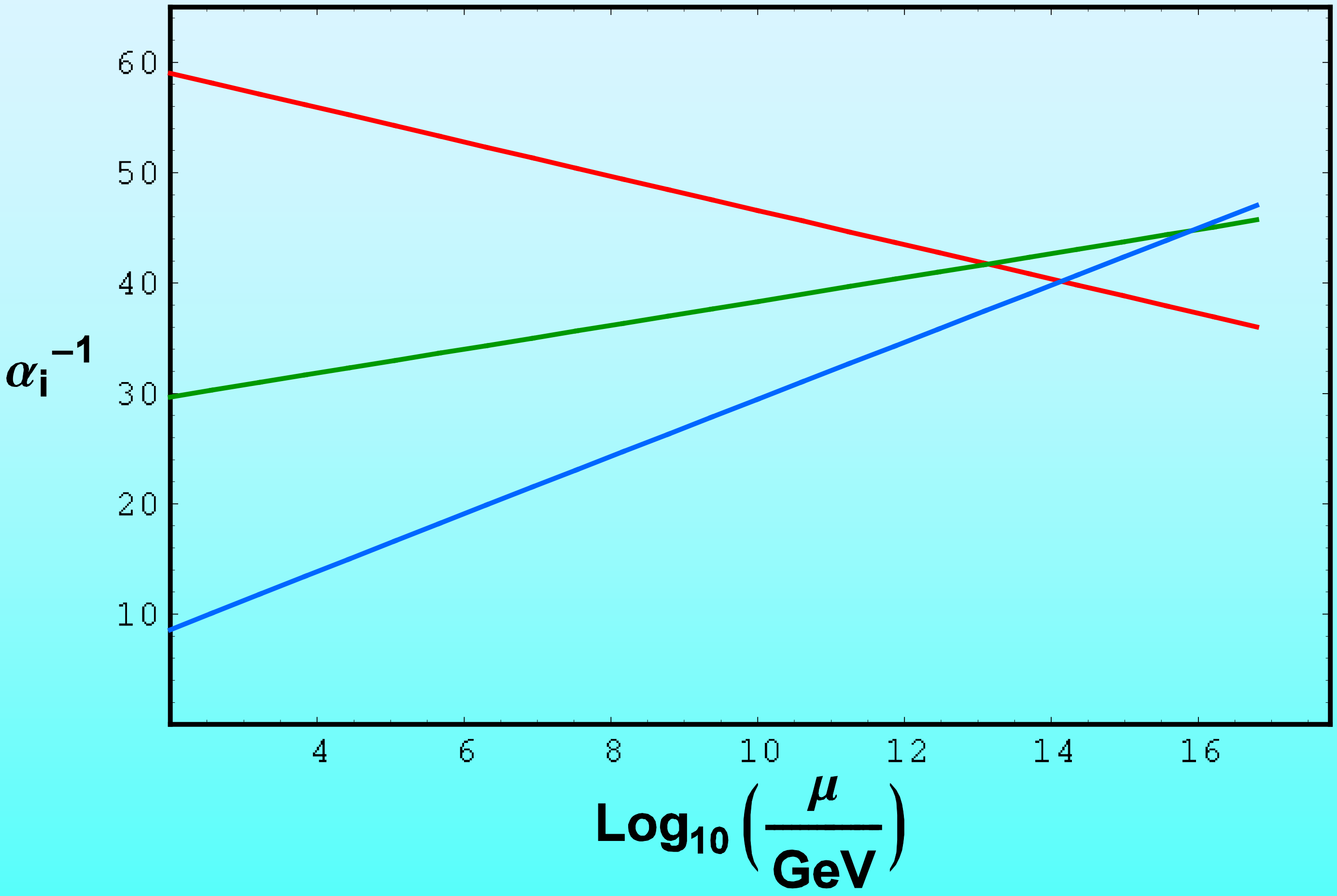


$$V = -\frac{1}{2}m^2|H|^2 + \lambda|H|^4$$

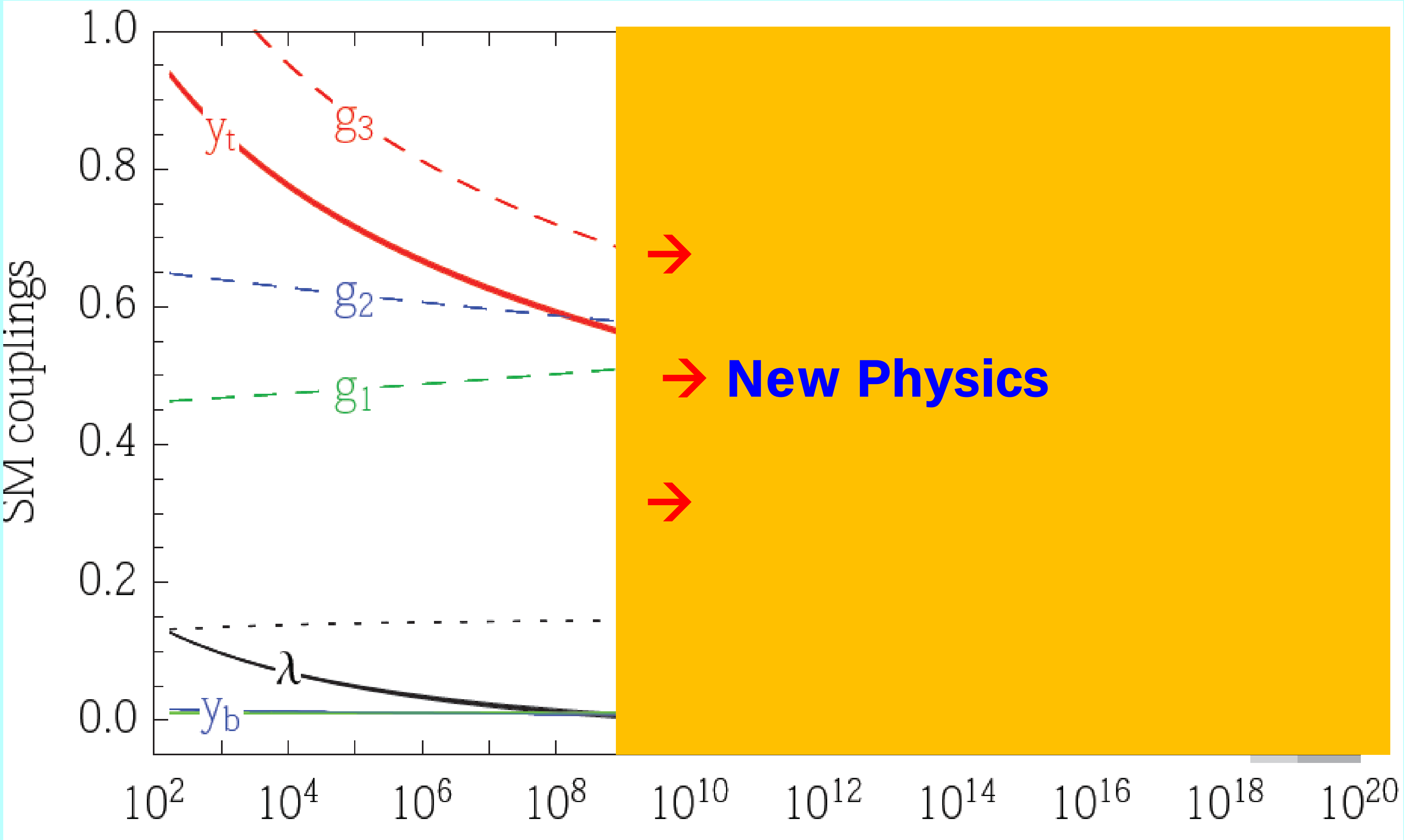


Buttazzo, Degrassi, Giardino, Giudice, Sala, Salvio, Strumia, arX: 1307.3536

SM Gauge Couplings' Running



SM



Good idea – New Physics (?)

Some extension of SM is required

&

Would be nice to have simultaneous resolution

Of these problems.

New physics below $\sim 10^{10}\ GeV$

GUT is still tempting…

Simplest (minimal) SU(5) GUT do not give all this...

GUT Model – "Twinification"

$$G_{GUT} = SU(5) \times SU(5)' \times D_2$$

D_2 → single coupling: $g_5 = {g'}_5$

Breaking: $G_{GUT} \to G_{SM} = SU(3)_c \times SU(2)_w \times U(1)_Y$ must happen

Symmetry breaking:

Scalars: $H(5,1)\ ,\quad \Sigma(24,1)\ ,\qquad H'(1,5)\ ,\quad \Sigma'(1,24)$

$$\Phi \sim (5,\bar{5}) \qquad\qquad D_2 : \quad \Phi \leftrightarrow \Phi^\dagger$$

Symmetry breaking: 1st stage

$$V_{H\Sigma} = -M_\Sigma^2\,\mathrm{tr}\Sigma^2 + \lambda_1(\,\mathrm{tr}\Sigma^2)^2 + \lambda_2\,\mathrm{tr}\Sigma^4 + H^\dagger\left(M_H^2 - h_1\Sigma^2 + h_2\,\mathrm{tr}\Sigma^2\right)H$$

$$V_{H'\Sigma'} = -M_\Sigma^2\,\mathrm{tr}\Sigma'^2 + \lambda_1(\,\mathrm{tr}\Sigma'^2)^2 + \lambda_2\,\mathrm{tr}\Sigma'^4 + H'^\dagger\left(M_H^2 - h_1\Sigma'^2 + h_2\,\mathrm{tr}\Sigma'^2\right)H'$$

$$V_{mix} = \lambda(\,\mathrm{tr}\Sigma^2)(\,\mathrm{tr}\Sigma'^2) + \tilde{h}\left(H^\dagger H\,\mathrm{tr}\Sigma'^2 + H'^\dagger H'\,\mathrm{tr}\Sigma^2\right) + \hat{h}(H^\dagger H)(H'^\dagger H')$$

there is minima with:

$$\langle\Sigma\rangle = v_\Sigma \mathrm{Diag}\,(2,2,2,-3,-3)\ , \qquad \langle H\rangle = 0$$

$$v_\Sigma^2 = \frac{M_\Sigma^2}{2(30\lambda_1 + 7\lambda_2)}$$

$$\langle\Sigma'\rangle = 0\ , \qquad \langle H'\rangle = 0$$

[can be small, non-zero. Open option..]

$$SU(5)\times SU(5)'\times D_2 \to SU(3)\times SU(2)\times U(1)\times SU(5)'$$

Scalar spectrum:

With tunning: $M_H^2 = 3v_\Sigma^2(3h_1 - 10h_2)$

$$M_h = 0 \ , \quad M_T^2 = 5h_1 v_\Sigma^2 > 0 \ , \ (\text{with} \ \ h_1 > 0)$$

$$M_{H'}^2 = M_H^2 + \tilde{h}\langle \,\mathrm{tr}\Sigma^2\rangle = M_H^2 + 30\tilde{h}v_\Sigma^2 > 0$$

$$M_{\Sigma'}^2 = -M_\Sigma^2 + \lambda\langle \,\mathrm{tr}\Sigma^2\rangle = -M_\Sigma^2 + 30\lambda v_\Sigma^2 > 0$$

Sym. Breaking channel is justified

Symmetry breaking: 2nd stage

$$\langle\Phi\rangle = v_I \cdot \mathrm{Diag}\,(x,\ x,\ x,\ 1,\ 1)$$

$$SU(5) \times SU(5)' \to SU(3) \times SU(2) \times U(1)$$

Interesting and viable selection:

$$x = 0\ , \quad \langle\Phi\rangle = v_I \cdot \mathrm{Diag}\,(0,\ 0,\ 0,\ 1,\ 1)$$

$$SU(5) \times SU(5)' \to SU(3) \times SU(3)' \times SU(2) \times U(1)$$

1st + 2nd stages →

$$SU(5) \times SU(5)' \to SU(3)_c \times SU(2)_w \times U(1)_Y \times SU(3)'$$

Identification of interactions and couplings:

$$SU(5) \times SU(5)' \to SU(3)_c \times SU(2)_w \times U(1)_Y \times SU(3)'$$

$$SU(3)_c \equiv SU(3) \subset SU(5) \ , \qquad SU(3)' \subset SU(5)' \qquad \longrightarrow g_c = g_3$$

$$SU(2)_w = \mathrm{Diag}\,[SU(2) \times SU(2)'] \qquad \longrightarrow \text{at } \mu = M_I : \quad \frac{1}{g_w^2} = \frac{1}{g_2^2} + \frac{1}{g'^2_5}$$

$$U(1)_Y = \mathrm{Diag}\,[U(1) \times U(1)'] \qquad \longrightarrow \text{at } \mu = M_I : \quad \frac{1}{g_Y^2} = \frac{1}{g_1^2} + \frac{1}{g'^2_5}$$

Gives successful gauge coupling unification

RG Equations

$$\alpha_{5'}^{-1}(M_G) = \alpha_{5'}^{-1}(M_I) - \frac{b_{5'}}{2\pi}\ln\frac{M_G}{M_I}$$

$$\alpha_3^{-1}(M_G) = \alpha_c^{-1}(M_Z) - \frac{\bar{b}_c}{2\pi}\ln\frac{M_I}{M_Z} - \frac{b_3}{2\pi}\ln\frac{M_G}{M_I}$$

$$\alpha_2^{-1}(M_G) = \alpha_w^{-1}(M_Z) - \frac{\bar{b}_w}{2\pi}\ln\frac{M_I}{M_Z} - \frac{b_2}{2\pi}\ln\frac{M_G}{M_I} - \alpha_{5'}^{-1}(M_I)$$

$$\alpha_1^{-1}(M_G) = \alpha_Y^{-1}(M_Z) - \frac{\bar{b}_Y}{2\pi}\ln\frac{M_I}{M_Z} - \frac{b_1}{2\pi}\ln\frac{M_G}{M_I} - \alpha_{5'}^{-1}(M_I)$$

Unif. Conditions: $\alpha_1^{-1}(M_G) = \alpha_2^{-1}(M_G) = \alpha_3^{-1}(M_G) = \alpha_{5'}^{-1}(M_G)$

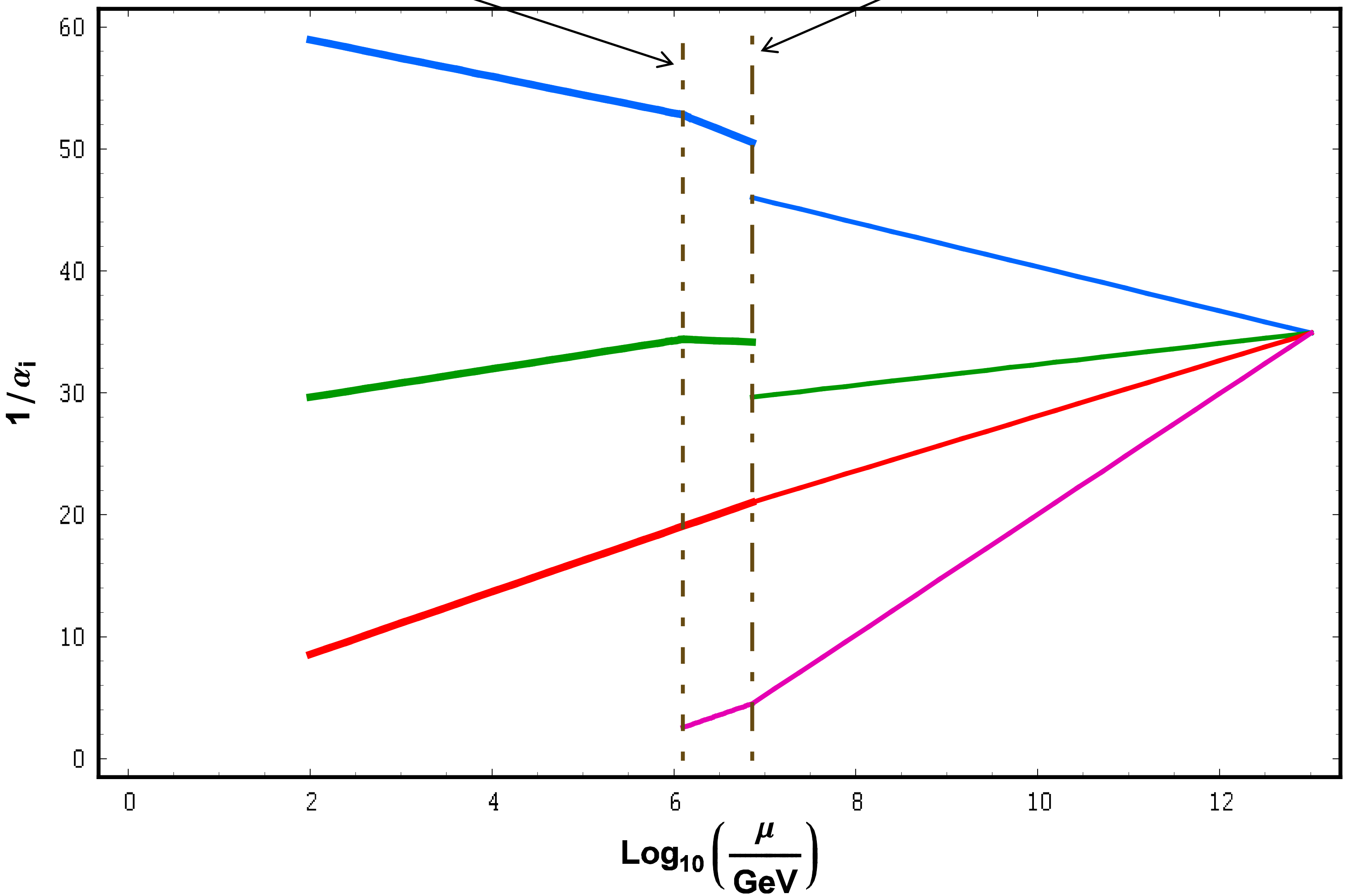
→ Can be calculated: $\{M_I,\ M_G,\ \alpha_G,\ \alpha_{5'}(M_I)\}$

$\langle \Sigma' \rangle = 0$

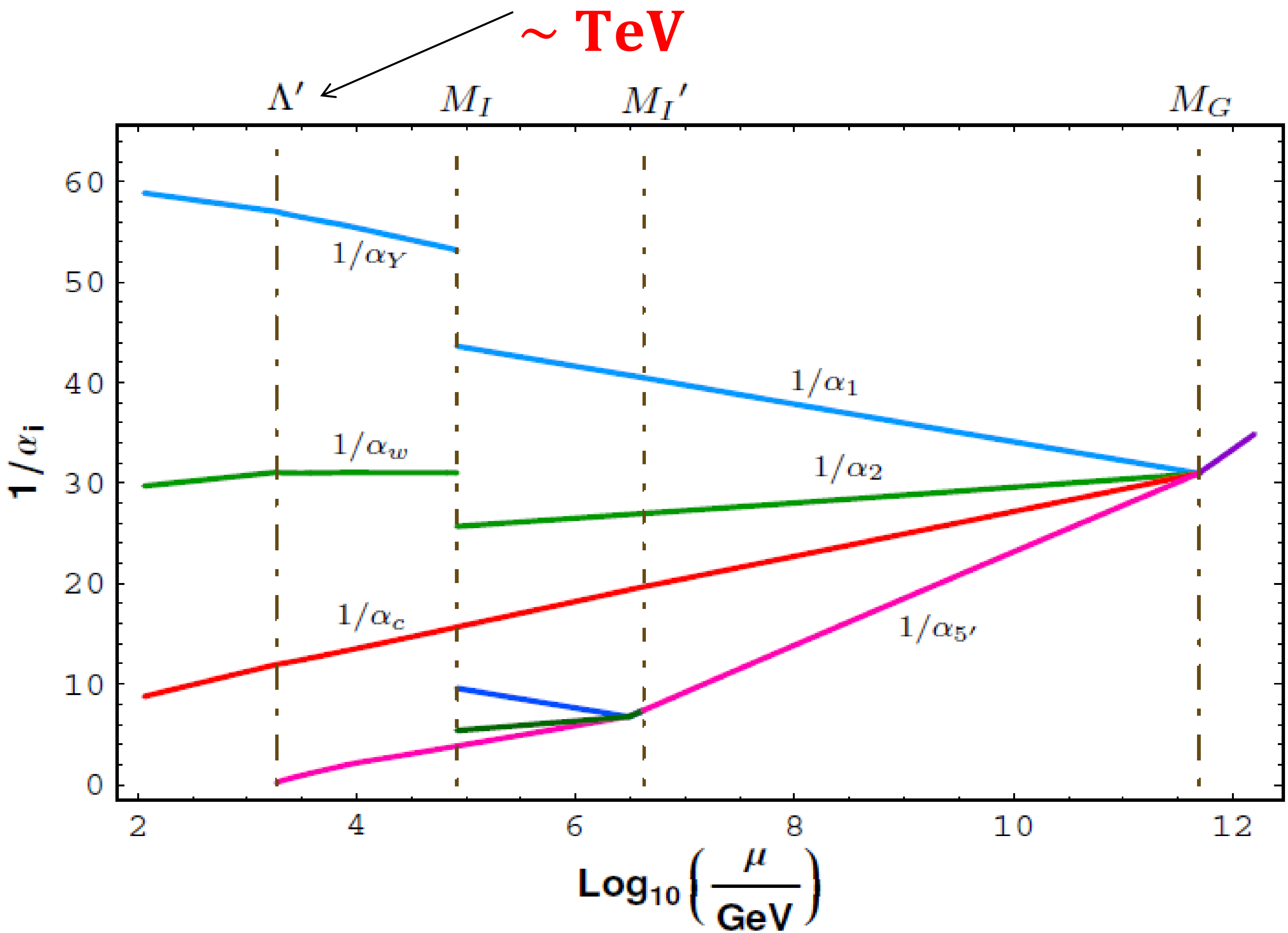
$M_{GUT} \cong 10^{13}\ GeV$

$\Lambda' \approx 10^6\ GeV$

$M_I \approx 7 \cdot 10^6\ GeV$



$M_I < \langle \Sigma' \rangle < M_{GUT}$ (Phenom. Interesting!)



Spectrum for $M_I < \langle \Sigma' \rangle < M_{GUT}$

M_a	GeV	M_a	GeV	M_a	GeV	M_a	GeV
$M^{(1)}_{\hat{l}l}$	$7.54 \cdot 10^4$	$M^{(2)}_{e^c\hat{e}^c}$	$7.54 \cdot 10^4$	$M_{D'}$	$4.16 \cdot 10^6$	$M_{TD'}$	$3.92 \cdot 10^6$
$M^{(2)}_{\hat{l}l}$	$7.54 \cdot 10^4$	$M^{(3)}_{e^c\hat{e}^c}$	$1.2 \cdot 10^5$	$M_{TT'}$	1874.7	$M_{\Sigma'_{8'}}$	9277
$M^{(3)}_{\hat{l}l}$	$1.2 \cdot 10^5$	Λ'	1851	$M_{DD'}$	$8.25 \cdot 10^4$	$M_{\Sigma'_{3'}}$	$2M_{\Sigma'_{8'}}$
$M^{(1)}_{e^c\hat{e}^c}$	$7.54 \cdot 10^4$	$M_{T_{H'}}$	1851	$M_{DT'}$	8250	$M_{\Sigma'_{1'}}$	$4.16 \cdot 10^6$

$M_{X'}$	$2.08 \cdot 10^6$
M_{T_H}	$5 \cdot 10^{11}$

M_X	$4.95 \cdot 10^{11}$
M_Σ	$5 \cdot 10^{11}$

Matter Sector

$\mathbf{SU(5)} \times \mathbf{SU(5)}'$ Matter:

$$3 \times [\Psi(10,1) + F(\bar{5},1)] \;, \qquad 3 \times [\Psi'(1,\bar{10}) + F'(1,5)]$$

$$D_2 \;: \qquad \Psi \rightleftarrows \overline{\Psi'} \equiv (\Psi')^\dagger \;, \quad \mathbf{F} \rightleftarrows \overline{F'} \equiv (F')^\dagger$$

$$\Psi = \{q, u^c, e^c\} \;, \qquad F = \{l, d^c\}$$

$$\Psi' = \{\hat{q}, \hat{u}^c, \hat{e}^c\} \;, \qquad F' = \{\hat{l}, \hat{d}^c\}$$ ← Extra Matter

$SU(3)_c \times SU(2)_w \times U(1)_Y \times SU(3)'$ Transformations:

$$q \sim (3, 2, -\frac{1}{\sqrt{60}}, 1)\ , \quad u^c \sim (\bar{3}, 1, \frac{4}{\sqrt{60}}, 1)\ , \quad e^c \sim (1, 1, -\frac{6}{\sqrt{60}}, 1)$$

$$l \sim (1, 2, \frac{3}{\sqrt{60}}, 1)\ , \qquad d^c \sim (\bar{3}, 1, -\frac{2}{\sqrt{60}}, 1)\ ,$$

$$\hat{q} \sim (1, 2, \frac{1}{\sqrt{60}}, \bar{3}')\ , \quad \hat{u}^c \sim (1, 1, -\frac{4}{\sqrt{60}}, 3')\ , \quad \hat{e}^c \sim (1, 1, \frac{6}{\sqrt{60}}, 1)$$

$$\hat{l} \sim (1, 2, -\frac{3}{\sqrt{60}}, 1)\ , \qquad \hat{d}^c \sim (1, 1, \frac{2}{\sqrt{60}}, 3')\ .$$

Non-trivial under SM..

Yukawa Couplings

$$\mathcal{L}_Y + \mathcal{L}_{Y'} + \mathcal{L}_Y^{mix}$$

$$\mathcal{L}_Y = \sum_{n=0} C^{(n)}_{\Psi\Psi} \left(\frac{\Sigma}{M_*}\right)^n \Psi\Psi H + \sum_{n=0} C^{(n)}_{\Psi F} \left(\frac{\Sigma}{M_*}\right)^n \Psi \mathbf{F} H^\dagger + \text{h.c.}$$

$$\mathcal{L}_{Y'} = \sum_{n=0} C^{(n)*}_{\Psi\Psi} \left(\frac{\Sigma'}{M_*}\right)^n \Psi'\Psi' H'^\dagger + \sum_{n=0} C^{(n)*}_{\Psi F} \left(\frac{\Sigma'}{M_*}\right)^n \Psi' \mathbf{F}' H' + \text{h.c}$$

$$\mathcal{L}_Y^{mix} = \lambda_{FF'} F \Phi F' + \lambda_{FF'} \overline{F'} \Phi^\dagger \overline{F} + \frac{\lambda_{\Psi\Psi'}}{M} \Psi (\Phi^\dagger)^2 \Psi' + \frac{\lambda_{\Psi\Psi'}}{M} \overline{\Psi'} \Phi^2 \overline{\Psi} \ ,$$

Quark Masses

$$\mathcal{L}_Y \to q^T Y_U u^c h + q^T Y_D d^c h^\dagger + e^{cT} Y_{e^c l} l h^\dagger + \text{h.c.} + \cdots$$

‘Lepton’ Decoupling

$$\mathcal{L}_Y^{mix} \to \hat{l}^T M_{\hat{l}l} l + e^{cT} M_{e^c \hat{e}^c} \hat{e}^c + \text{h.c.}$$

SM Leptons can emerge as composites...

Composite Leptons

- SU(3)′ confines at Λ' scale.
  SU(3)′ color-less B′-baryons & M′ mesons formed

- $\hat{l}$ & $\hat{e}$ do not participate in confinment

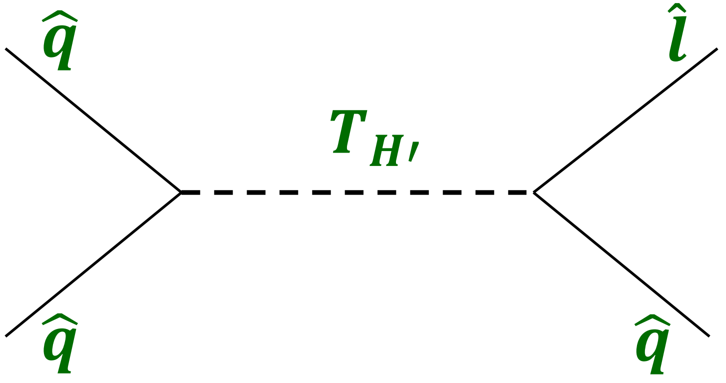
- Chiral QCD′ [SU(2)xU(1) unbroken]

- t′ Hooft anomaly matching

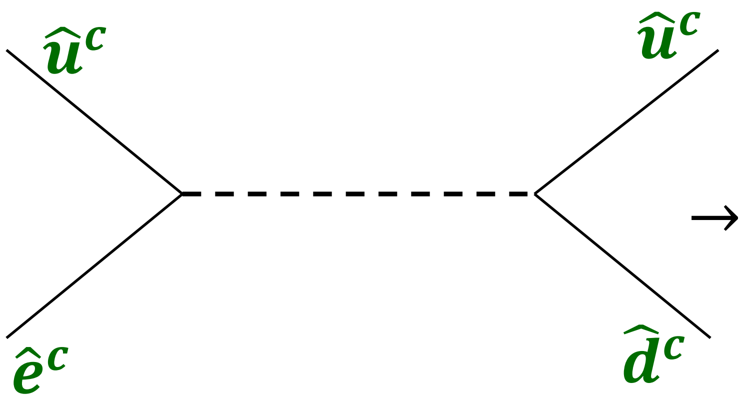
→ B′ baryons must have same anomalies as $\hat{q}, \hat{u}^c$ and $\hat{d}^c$
i.e. local/global anomalies.

Charged Lepton Yukawas

Can be generated within the model (without extension!):

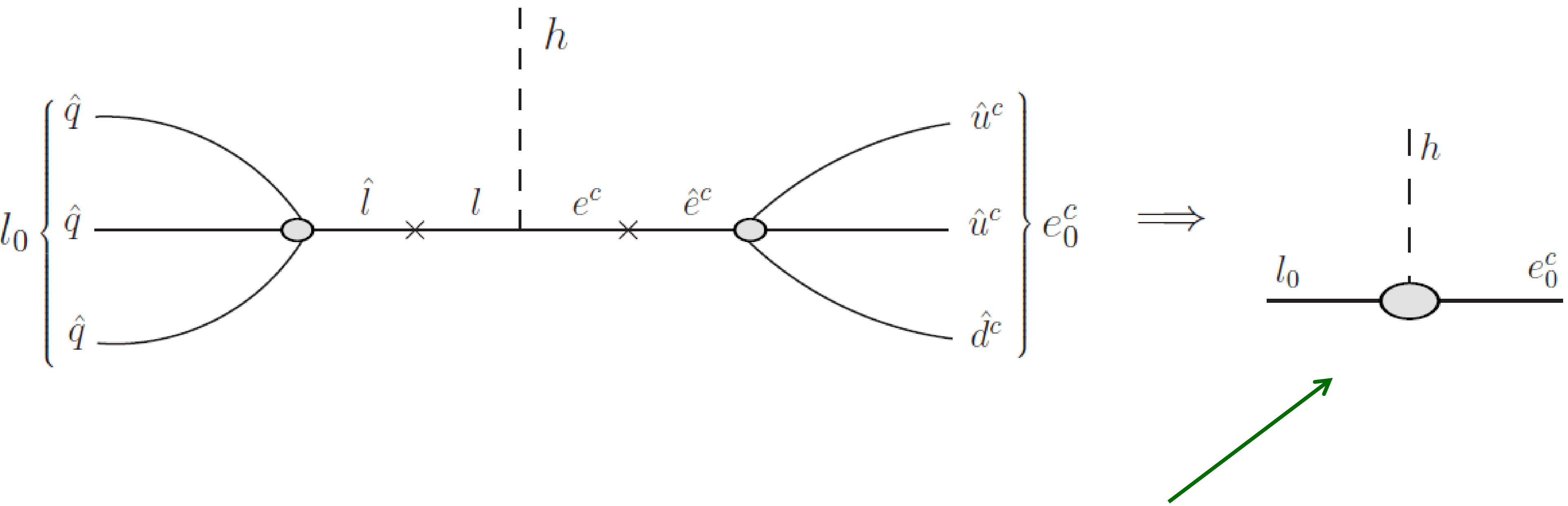


$$\rightarrow \frac{1}{(M_{T_{H'}})^2}(\hat{q}\,\hat{q})(\hat{q}\,\hat{l}) \sim \frac{(\Lambda')^3}{(M_{T_{H'}})^2}\,\hat{l}\,l_0$$



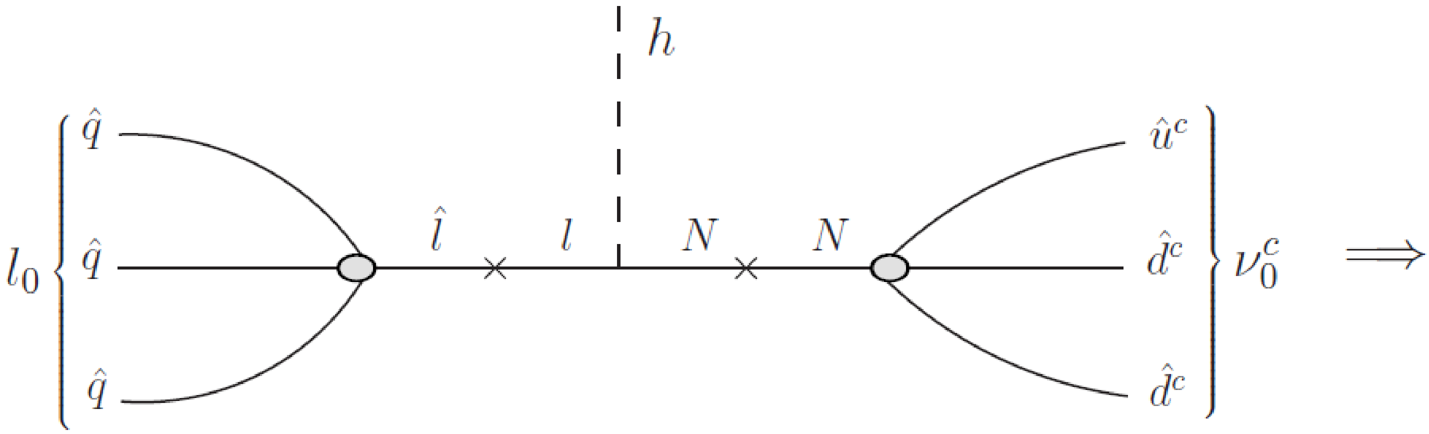
$$\rightarrow \frac{1}{(M_{T_{H'}})^2}(\hat{u}^c\hat{e}^c)(\hat{u}^c\hat{d}^c) \sim \frac{(\Lambda')^3}{(M_{T_{H'}})^2}\,\hat{e}^c\,{e^c}_0$$

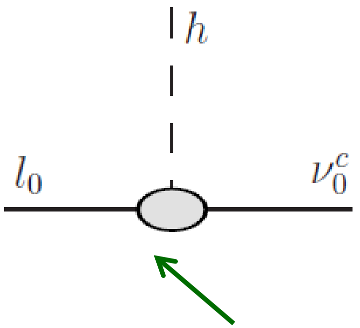
Charged Lepton Yukawas



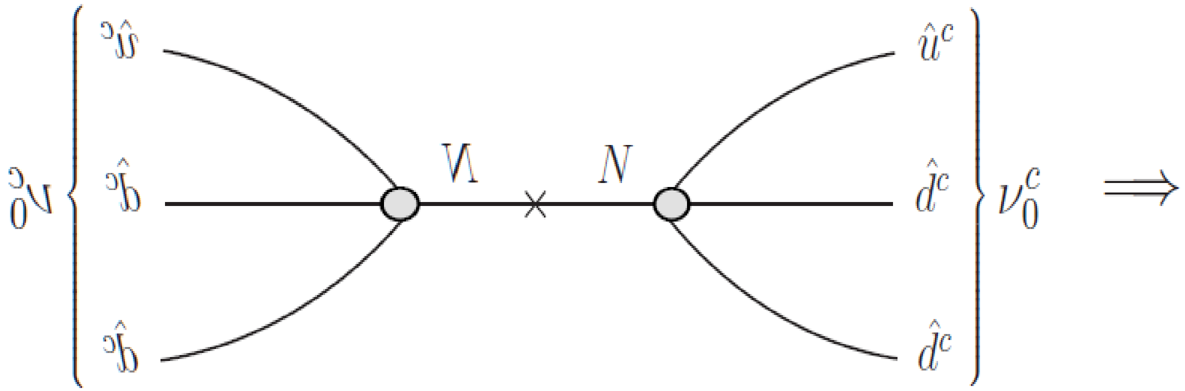
$$l_0^T Y_E e_0^c h^\dagger + \text{h.c.}$$

Neutrino Masses/couplings





$$l_0^T Y_\nu \nu_0^c h$$



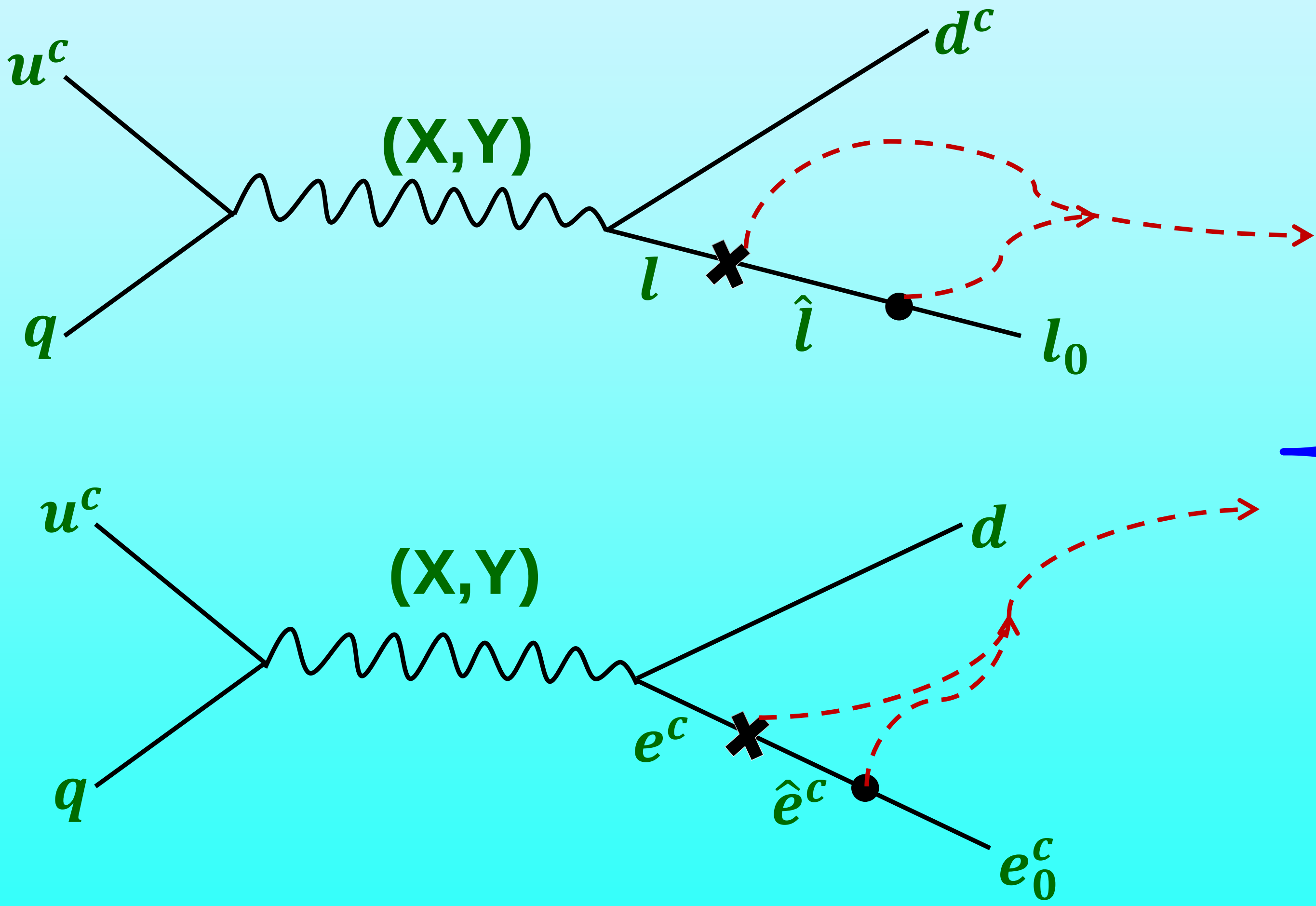
$$-\frac{1}{2}\nu_0^{cT} M_{\nu^c} \nu_0^c$$

Scenarios: a) Dirac Neutr. (with sterile)
b) Majorana (with see-saw)
c) Hybrid → a)+b)

Nucleon Stability

$M_{GUT} \sim 5 \cdot 10^{11}$ GeV,

but nucleon stability can be *achieved:*



Free parameters allowing suppression

B-violating d=6 operators

$$\mathcal{O}_{d6}^{(e^c)} = \frac{g_X^2}{M_X^2}\mathcal{C}_{\alpha\beta}^{(e^c)}(\overline{u^c}\gamma_\mu u)(\overline{e^c_\alpha}\gamma^\mu d_\beta) \ , \qquad \mathcal{O}_{d6}^{(e)} = \frac{g_X^2}{M_X^2}\mathcal{C}_{\alpha\beta}^{(e)}(\overline{u^c}\gamma_\mu u)(\overline{d^c}_\beta\gamma^\mu e_\alpha)$$

$$\mathcal{O}_{d6}^{(\nu)} = \frac{g_X^2}{M_X^2}\mathcal{C}_{\alpha\beta\gamma}^{(\nu)}(\overline{u^c}\gamma_\mu d_\alpha)(\overline{d^c}_\beta\gamma^\mu \nu_\gamma)$$

$$\mathcal{C}_{\alpha\beta}^{(e^c)} = \mathcal{U}_{11}(\mathcal{R}P_1^* V_{CKM})_{\alpha\beta} + (\mathcal{U}P_1^* V_{CKM})_{1\beta}(\mathcal{R})_{\alpha 1}$$

$$\mathcal{C}_{\alpha\beta}^{(e)} = \mathcal{U}_{11}\mathcal{L}_{\beta\alpha} \ , \qquad \mathcal{C}_{\alpha\beta\gamma}^{(\nu)} = (\mathcal{U}P_1^* V_{CKM})_{1\alpha}\mathcal{L}_{\beta\gamma} \ .$$

Definitions: $R_u^\dagger L_u^* \equiv \mathcal{U} \ , \quad R_d^\dagger \frac{1}{M_{\hat{l}l}}\hat{\mu} L_e^* \equiv \mathcal{L} \ , \quad R_e^\dagger \tilde{\mu}^* \frac{1}{M^*_{e^c\hat{e}^c}} L_u^* \equiv \mathcal{R}$

We can use freedom in $\mathcal{U}$, $\mathcal{L}$, $\mathcal{R}$ to suppress nucleon decay..

Ex.: Selection:

$$\mathcal{U}_{11} = 0, \quad \mathcal{L} = \begin{pmatrix} \epsilon_1 & \epsilon_2 & \epsilon_3 \\ \times & \times & \times \\ \times & \times & \times \end{pmatrix}, \quad \mathcal{R} = \begin{pmatrix} 0 & \times & \times \\ 0 & \times & \times \\ \times & \times & \times \end{pmatrix}$$

$$\sqrt{|\epsilon_1|^2 + |\epsilon_3|^2 + |\epsilon_3|^2} \lesssim 4.8 \cdot 10^{-6} \quad (\mathcal{U} P_1^* V_{CKM})_{11} = 0$$

→ **We get:** $\tau\ (p \to \bar{\nu} K^+) \lesssim 5.9 \cdot 10^{33}$ yrs.

More natural: $|\mathrm{Det}(\mathcal{R})| \lesssim 10^{-2} \quad |\mathrm{Det}(\mathcal{L})| \gtrsim 10^{-6}$

+ Yukawa sector constaint→: $\sqrt{|\epsilon_1|^2 + |\epsilon_3|^2 + |\epsilon_3|^2} \gtrsim \sqrt{3} \cdot 10^{-6}$

→ **We get:** $\tau(p \to \bar{\nu} K^+) \lesssim 5 \cdot 10^{34}$ yrs.

Testable in a future…

Other operators (induced by T_H):

$$\frac{1}{M_{T_H}^2}(q^T C_{qq} q)(q^T C_{ql} l)$$

$$\frac{1}{M_{T_H}^2}(u^c C_{u^c e^c} e^c)(u^c C_{u^c d^c} d^c)$$

$$\frac{1}{M_{T_H}^2}(q^T C_{qq} q)(q^T C_{ql} \frac{1}{M_{\hat{l}l}} \hat{\mu} l_0)$$

$$\frac{1}{M_{T_H}^2}(u^c C_{u^c e^c} \frac{1}{M_{e^c \hat{e}^c}^T} \tilde{\mu}^T e_0^c)(u^c C_{u^c d^c} d^c)$$

Can be also adequately suppressed

(due to many free couplings)

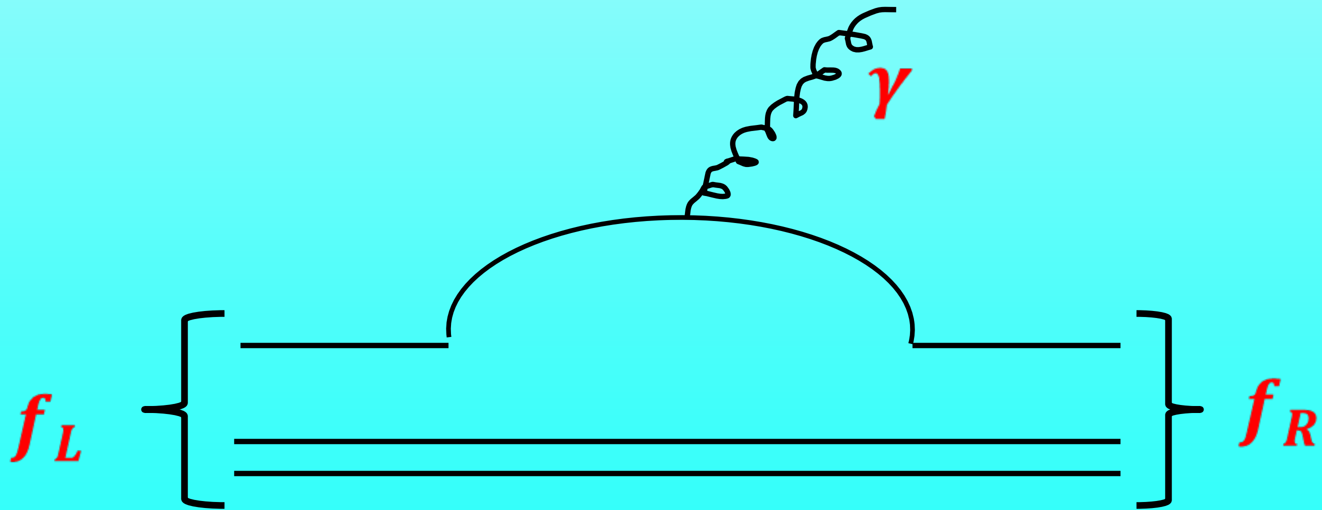
Some other constraints / implications

Compositeness→

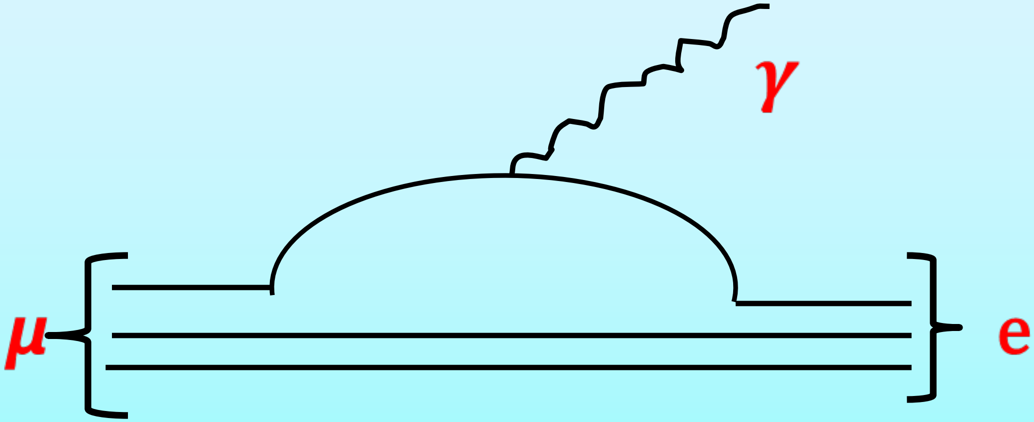
Contribution to anom. magn. Moments

(Barbieri, Maiani'1980
Brodsky, Drell, 1980)

$$\Delta a_f / a_f \sim \left(\frac{m_f}{\Lambda'}\right)^2 \qquad \to \Lambda' > \sim \mathbf{TeV}$$



LFV Rare Decays: $\mu \to e\gamma$



$$(1,2) \sim m_f \left(\frac{1}{\Lambda'}\right)^2 \lambda_{12}$$

Very model dependent →
no real constraint on Λ' (if $\lambda_{12} \to 0$)

Higgs Vacuum Stability - 'λ_h -problem'

Within SM (1-loop):

$$16\pi^2 \frac{d}{dt}\lambda_h = 12\lambda_h^2 + 12\lambda_h\lambda_t^2 - 12\lambda_t^4 - \frac{3}{2}\lambda_h(3g_2^2 + g_1^2) + \frac{3}{16}\left(2g_2^4 + (g_2^2 + g_1^2)^2\right)$$

$$16\pi^2 \frac{d}{dt}\lambda_t = \frac{9}{2}\lambda_t^3 - \lambda_t\left(\frac{17}{20}g_1^2 + \frac{9}{4}g_2^2 + 8g_3^2\right)$$

Within presented GUT, new physics around ~ few TeV

Higgs Vacuum Stability - 'λ_h -problem'

New quartic interactions:

$$V_{H\Phi} = \frac{\lambda_{1H\Phi}}{\sqrt{25}}(H^\dagger H)(\Phi^\dagger \Phi) + \frac{\lambda_{2H\Phi}}{\sqrt{10}}(\Phi^\dagger H)(\Phi H^\dagger)$$

$$16\pi^2 \frac{d}{dt}\lambda_h = 12\lambda_h^2 + 12\lambda_h\lambda_t^2 - 12\lambda_t^4 + 6(\lambda_{1H\Phi})^2 + 12(\lambda_{2H\Phi})^2 + \cdots$$

Can easily solve the problem.

Complete & detailed study is required..

Summary

- SU(5)xSU(5)' GUT – "Twinification" was presented

- Obtained:

  Realistic GUT model with interesting implications:

  - Successful gauge coupling unification,
  - composite leptons & sterile/RH neutrinos
  - fermion (including neutrino) masses,
  - Nucleon stability

Higgs vacuum stability
and collider signatures } need further studies

Thank You

Backup: Compositeness & Anomaly matching

Chiral sym. of SU(3)' sector:

$$G_f^{(6)} = SU(6)_L \times SU(6)_R \times U(1)_{B'}$$

$$\hat{q}_\alpha = (\hat{u}, \hat{d})_\alpha \sim (6_L, 1, \frac{1}{3}) \ , \qquad \hat{q}^c_\alpha = (\hat{u}^c, \hat{d}^c)_\alpha \sim (1, 6_R, -\frac{1}{3})$$

Condenstates:

$$\langle 6_L 6_L T^\dagger_{H'} \rangle = \langle \hat{u}\hat{d}T^\dagger_{H'} \rangle \sim \Lambda', \qquad \langle 6_R 6_R T_{H'} \rangle = \langle \hat{u}^c \hat{d}^c T_{H'} \rangle \sim \Lambda'$$

→ Induce breaking:

$$SU(6)_L \to SU(4)_L \times SU(2)'_L \equiv G_L^{(4,2)}, \qquad SU(6)_R \to SU(4)_R \times SU(2)'_R \equiv G_R^{(4,2)}$$

$$6_L = (4,1)_L + (1,2)_L$$

Composites:

$$(4',1)_{L,R} \subset [(4,1)_{L,R}]^3$$

$$(1,2')_{L,R} \subset [(1,2)_{L,R}]^3$$

$(4',1)_{L,R}$ and $(1,2')_{L,R}$ = 3 lepton families +3 RHN/sterile neutrinos

& All anomalies match (i.e. initial and composite states have same anomalies)