UNIFICATION WITHOUT SUPERSYMMETRY: WHERE DO WE STAND?

Planck 2011 - Lisboa, 1st June 2011

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Based on
Phys. Rev. D81 (2010) 035015 + Work in progress

THE GRAND UNIFICATION PROGRAM

Potential understanding of our low-energy world

- Charge quantization
- Rationale for the SM quantum numbers
- Handle on flavor and neutrino masses

Intrinsic predictivity of new phenomena

- Matter instability
- GUT Monopoles

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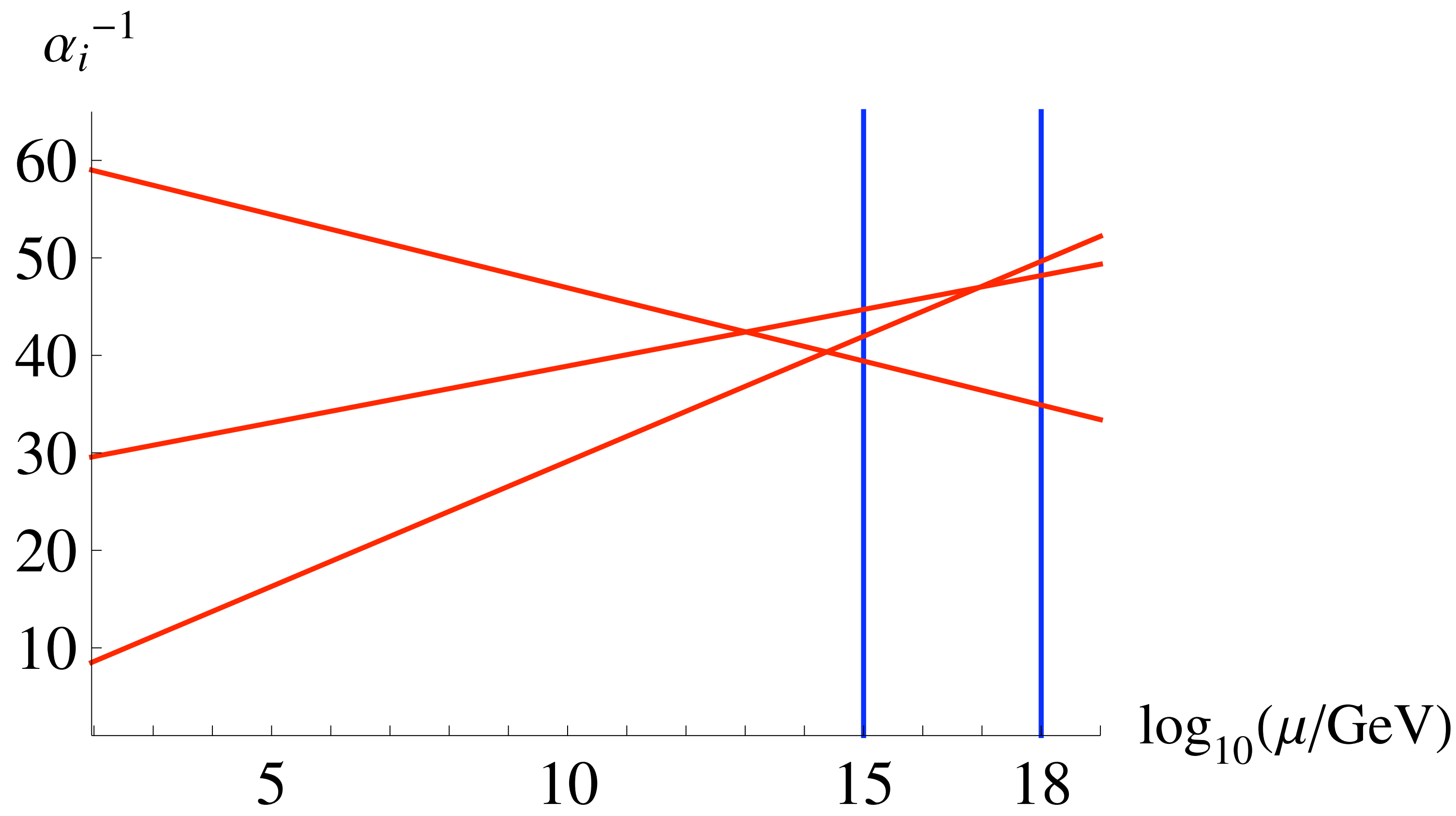

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- Minimal SUSY SU(5): proton decay close to the experimental bound

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- SO(10) GUTs usually score better than SU(5) models
  - More predictive in the Yukawa sector (SM matter + RH neutinos into 3 16_F's)
  - Natural relief from the tensions with the simplest SU(5) models

INTERMEDIATE SCALES IN THE NON-SUSY SO(10)

The unification ansatz predicts the existence of intermediate scales in the range $10^{10\div 14}$ GeV

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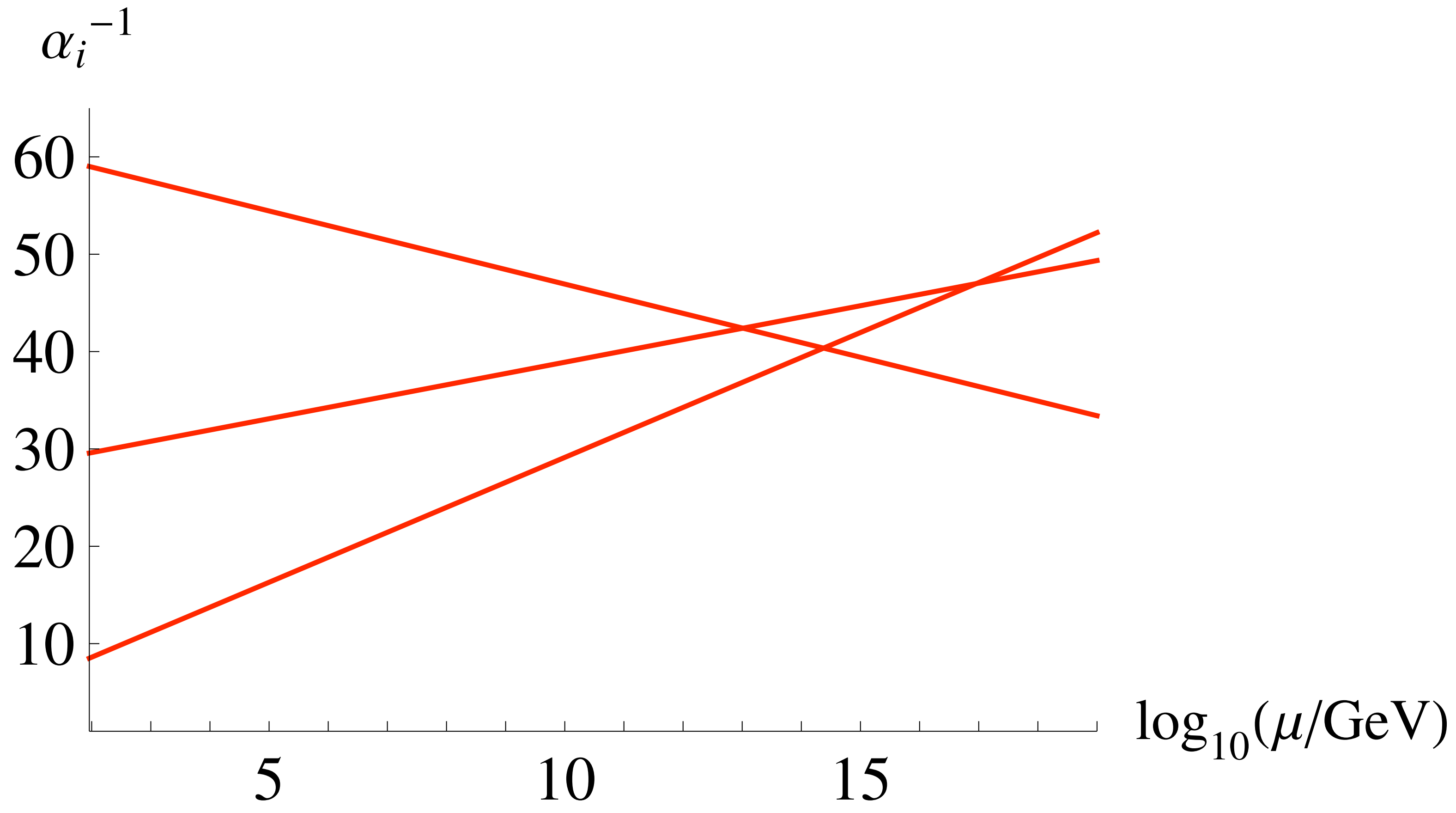

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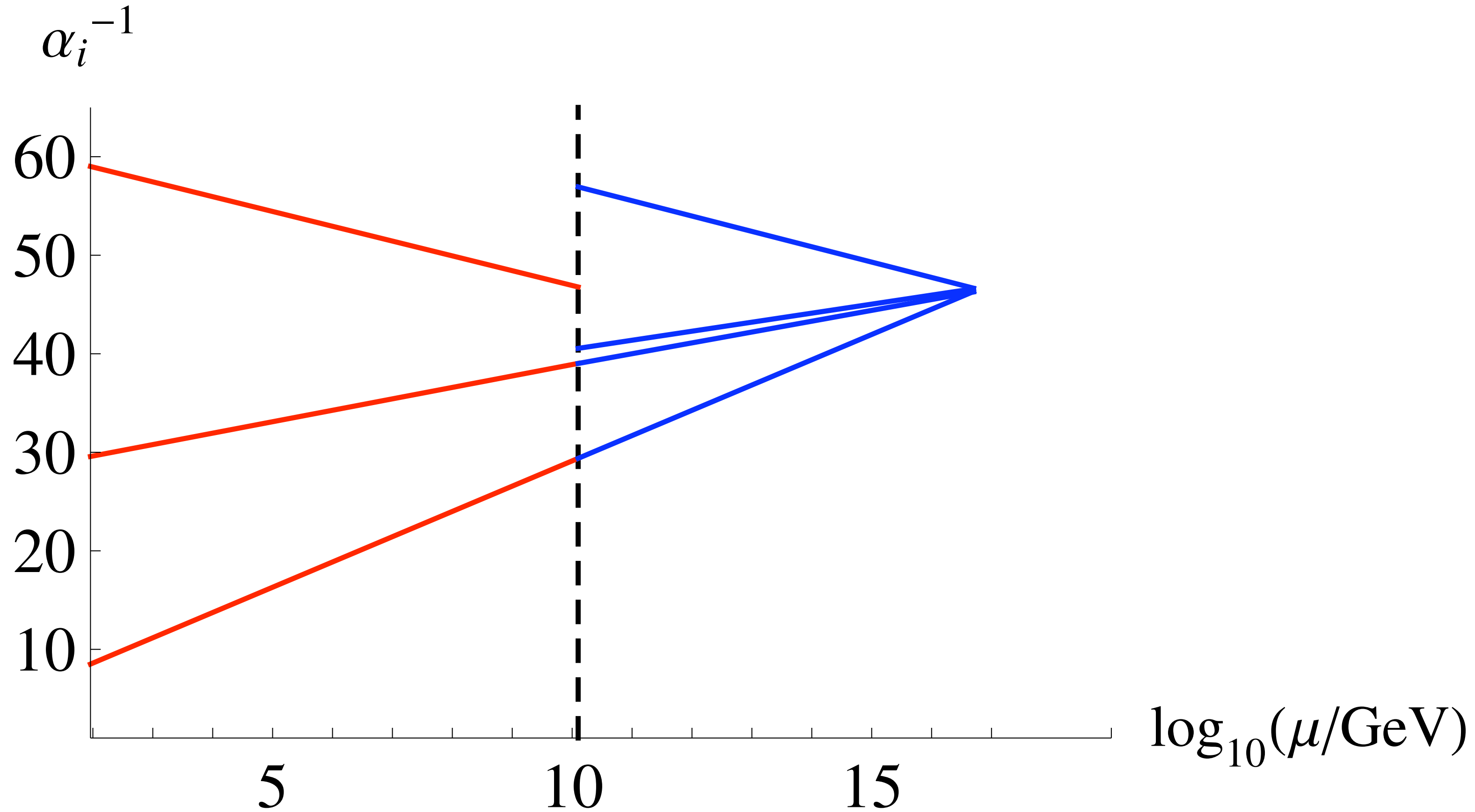
$$SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \longleftarrow SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L} \longleftarrow SO(10)$$



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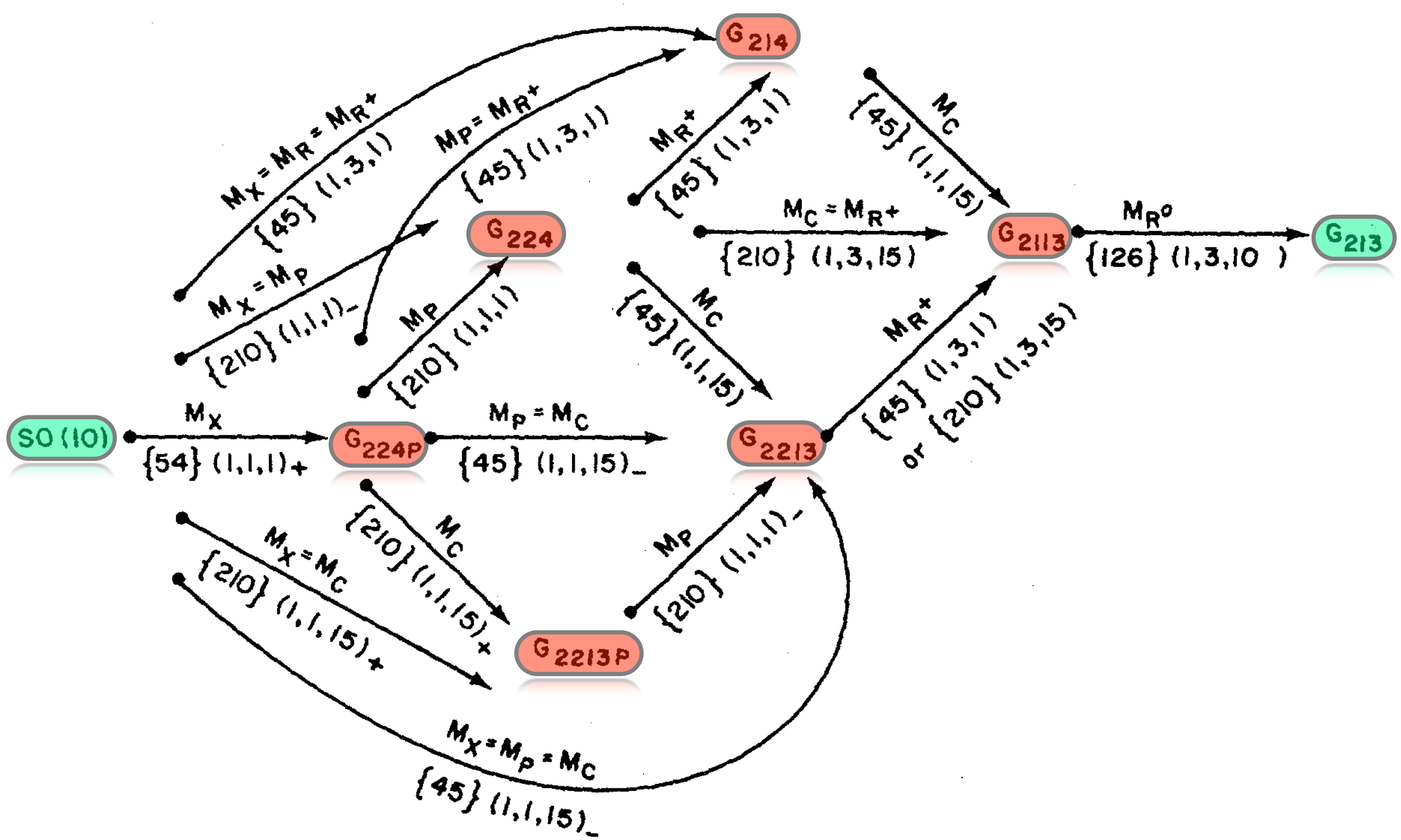

[Chang, Mohapatra, Gipson, Marshak, Parida (1985)]

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NO GO ⁉

The dynamics of the Higgs sector does not support gauge coupling unification

[Yasuè (1981), Anastaze, Derendinger, Buccella (1983), Babu, Ma (1985)]

THE LOCKING STATES

$45_H \oplus 16_H$ potential analysed long ago [Buccella, Ruegg, Savoy (1980)]

$$V_0 = V_{45_H} + V_{16_H} + V_{45_H 16_H}$$

$$V_{45_H} = -\mu^2 \, \mathrm{Tr}\, 45_H^2 + a_1 \, (\mathrm{Tr}\, 45_H^2)^2 + a_2 \, \mathrm{Tr}\, 45_H^4$$

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From the positivity of the scalar states (1,3,0) and (8,1,0) $\subset 45_H$

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$$M^2(1,3,0) = 2a_2(\omega_{B-L} - \omega_R)(\omega_{B-L} + 2\omega_R)$$

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$$\Longrightarrow \quad a_2 < 0\,, \qquad -2 < \omega_{B-L}/\omega_R < -\tfrac{1}{2}$$

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Gauge unification requires an hierarchy between ω_{B-L} and ω_R !

A TREE LEVEL ACCIDENT

Global symmetries of the potential in the limit $a_2 = \lambda_2 = \beta = \tau = 0$

$$V_{\text{moduli}} = -\mu^2 \,\mathrm{Tr}\, 45_H^2 + a_1 \,(\mathrm{Tr}\, 45_H^2)^2 - \nu^2\, 16_H^\dagger 16_H + \lambda_1\, (16_H^\dagger 16_H)^2 + \alpha\, (16_H^\dagger 16_H) \mathrm{Tr}\, 45_H^2$$

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$$\left.\begin{array}{l} O(45) \otimes O(32) \xrightarrow[\langle 16_H \rangle]{\langle 45_H \rangle} O(44) \otimes O(31) \implies 44 + 31 = 75 \text{ GB} \\ \qquad SO(10) \xrightarrow[\langle 16_H \rangle]{\langle 45_H \rangle} SM \implies 33 \text{ WGB} \end{array}\right\} \; 75 - 33 = 42 \text{ PGB}$$

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- The states (1,3,0) and (8,1,0) belong to this set of PGB
- The absence of the terms λ_2 β and τ is just a tree level accident !
- Nothing prevents these couplings from entering at the quantum level !

Explicit computation of the one-loop PGB masses with Effective-Potential methods

$$M^2(1,3,0) = 2a_2(\omega_{B-L} - \omega_R)(\omega_{B-L} + 2\omega_R) + \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(2\omega_R^2 - \omega_R\omega_{B-L} + 2\omega_{B-L}^2) + g^4\left(16\omega_R^2 + \omega_{B-L}\omega_R + 19\omega_{B-L}^2\right)\right] + \text{Log's}\,(\mu)$$

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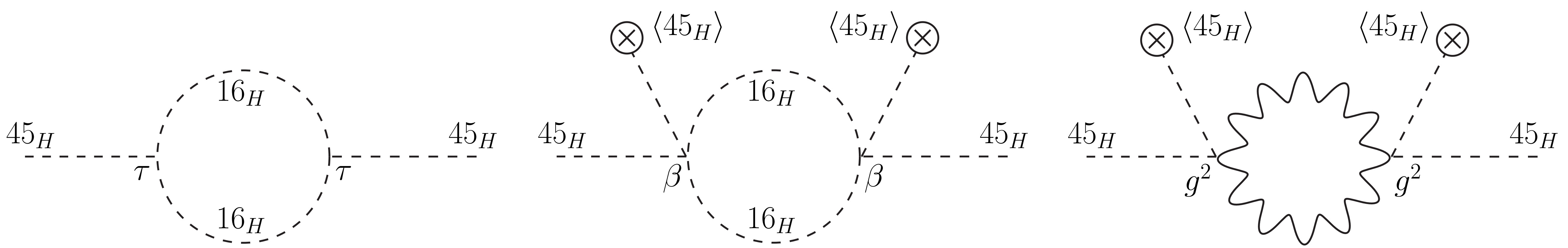

ONE LOOP PGB MASSES: RESULTS

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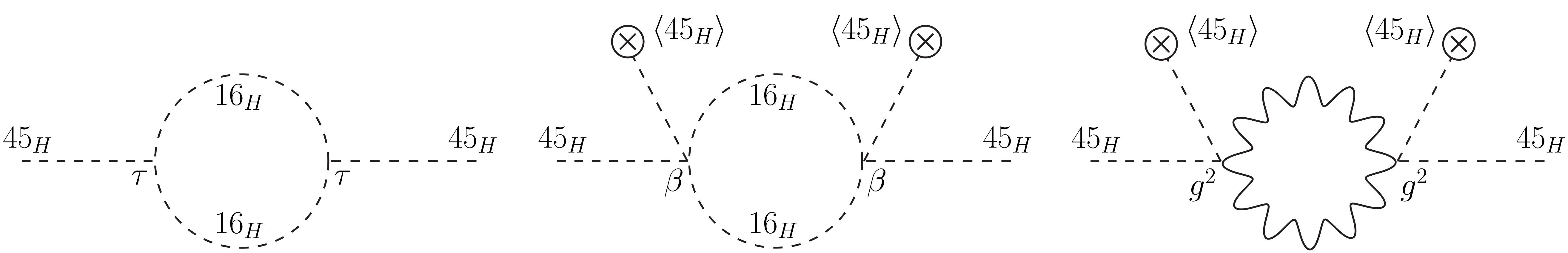

- For $|a_2|<10^{-2}$ the phenomenological vacua open up at the quantum level !
- Inherent to all the non-SUSY SO(10) models with a dominant $<45_H>$

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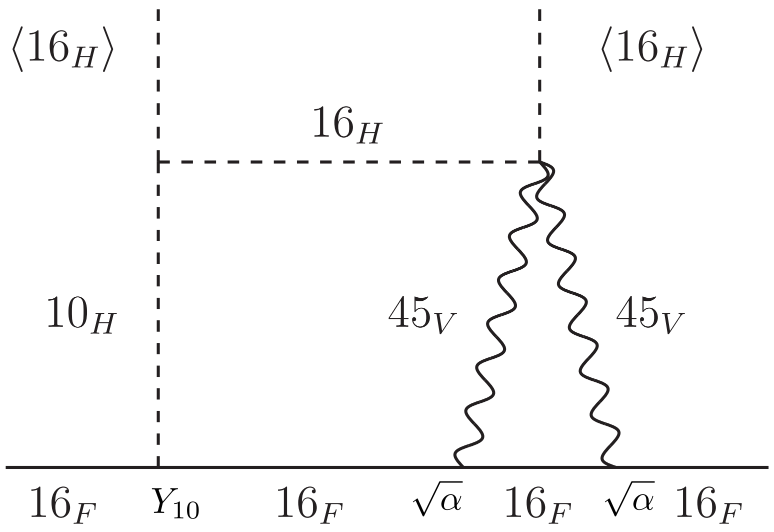

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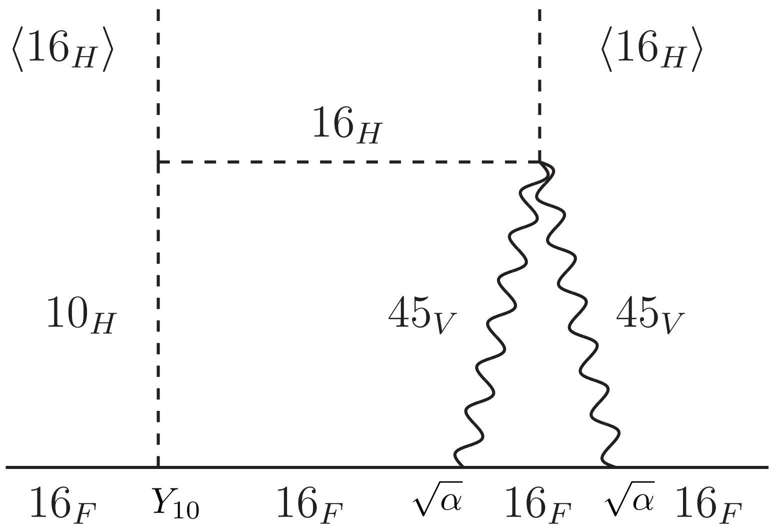

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Without SUSY it is natural to consider a 126_H in place of 16_H

- RH neutrino mass scale much better: $\quad M_R \sim Y_{126} \; M_{B-L} \; \subset \; Y_{126} \; 16_F 16_F 126^*_H$
- Renormalizable Yukawa sector potentially predictive

[Babu, Mohapatra (1993); Bajc, Melfo, Senjanovic, Vissani (2005); Joshipura, Patel (2011)]

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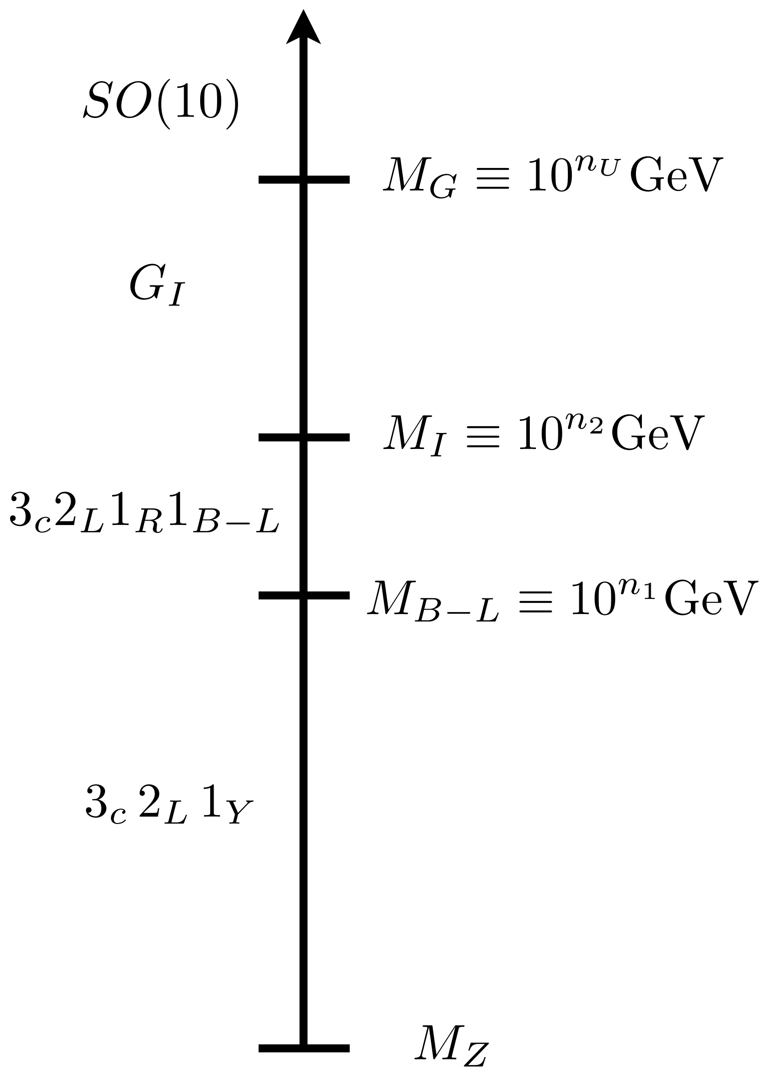
- If compatible

  - Compute the proton decay branching ratios ...

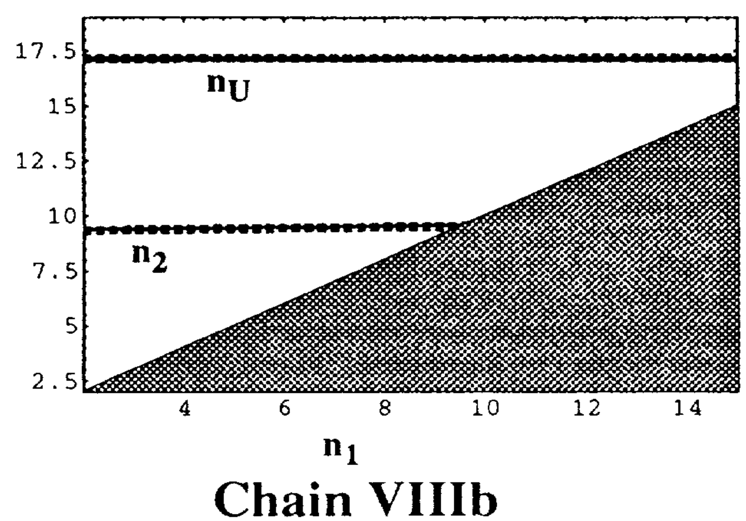
BACKUP SLIDES

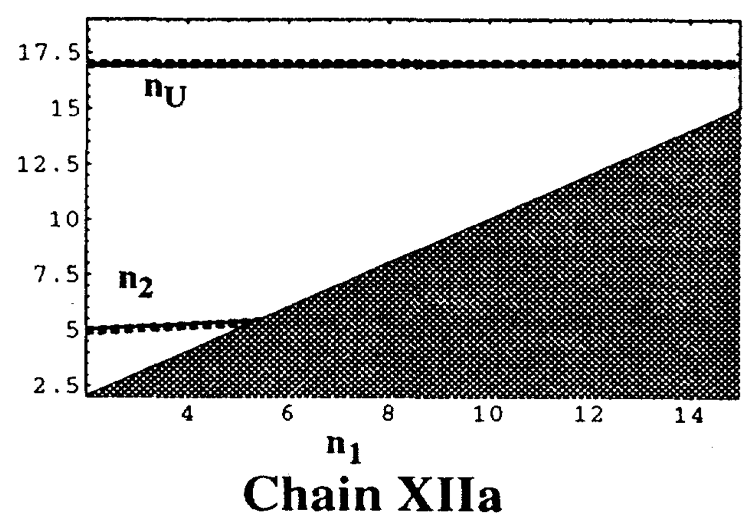
IMPACT OF THE TWO-LOOP ANALYSIS

- U(1) mixing makes M_{B-L} essentially free (upper bound given by M_I)
- Two-loop effects tend to raise M_I and lower M_G
- Sharp disagreement for chain XIIa: M_I is raised by 5 orders of magnitude !

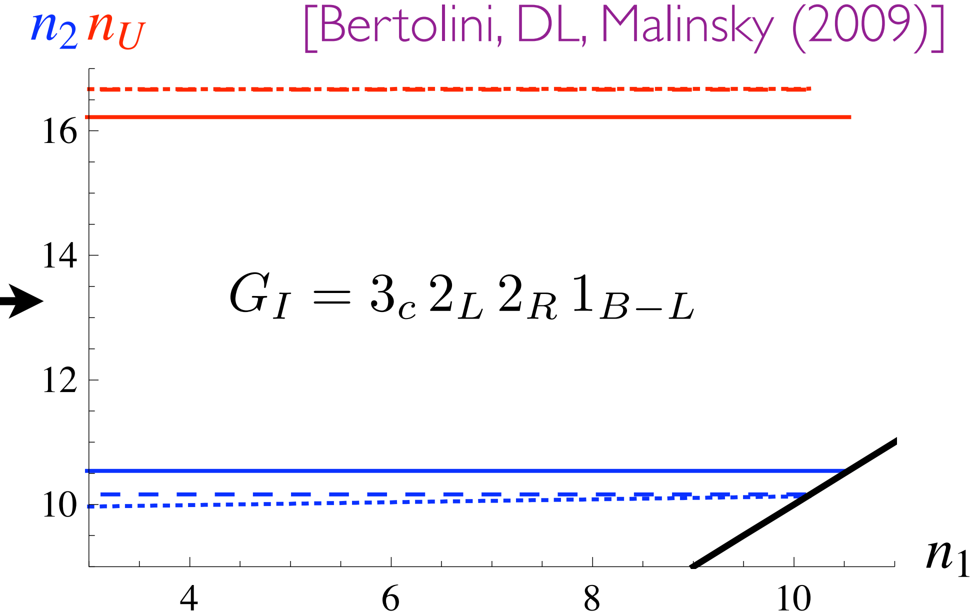


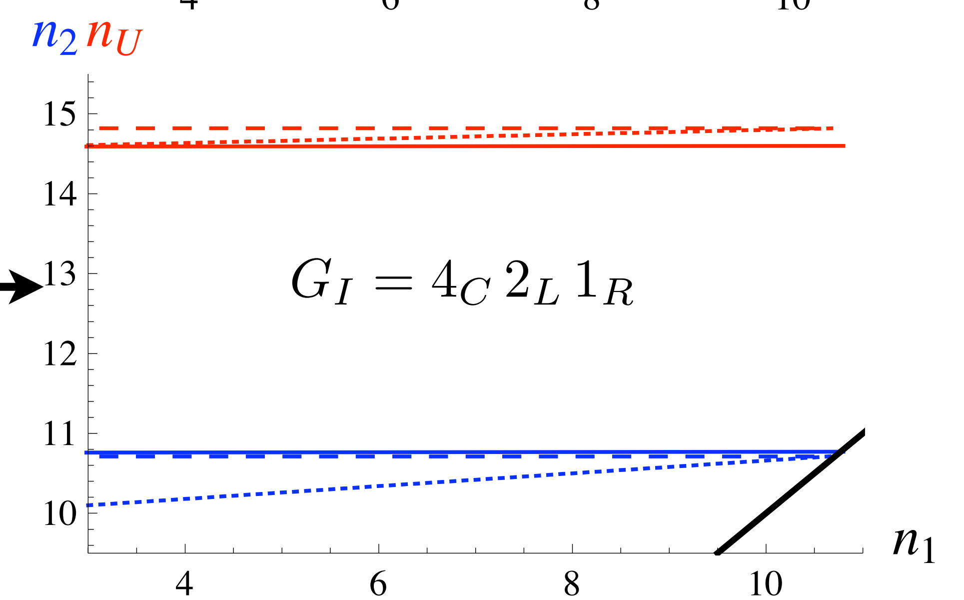
[Deshpande, Keith, Pal (1993)]





[Bertolini, DL, Malinsky (2009)]





SO(10) AS A THEORY OF FERMION MASSES AND MIXINGS

Renormalizable Yukawa sector with $10_H \oplus 126_H$

- SO(10) Yukawa

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

$$10_H = (1,2,2) + (6,1,1)$$

$$126^*_H = (15,2,2) + (10,1,3) + (\overline{10},3,1) + (6,1,1)$$

- Effective mass sum rule

$$M_u = \langle 1,2,2\rangle^u_{10} Y_{10} + \langle 15,2,2\rangle^u_{126} Y_{126}$$

$$M_d = \langle 1,2,2\rangle^d_{10} Y_{10} + \langle 15,2,2\rangle^d_{126} Y_{126}$$

$$M_e = \langle 1,2,2\rangle^d_{10} Y_{10} - 3\,\langle 15,2,2\rangle^d_{126} Y_{126}$$

$$\left.\begin{aligned} M_D &= \langle 1,2,2\rangle^u_{10} Y_{10} - 3\,\langle 15,2,2\rangle^u_{126} Y_{126} \\ M_R &= \langle 10,1,3\rangle Y_{126} \\ M_L &= \langle \overline{10},3,1\rangle Y_{126} \end{aligned}\right\} \quad \mathcal{M}_\nu = M_L - M_D M_R^{-1} M_D^T$$