Theory and Experiment in High Energy Physics workshop, Prague, October 3 2024

Leptogenesis in unified models

Michal Malinský

IPNP, Charles University in Prague

based on: MM, V. Miřátský, R. Fonseca, M. Zdráhal, Phys.Rev.D110, 015030 (2024)

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Does it make sense?

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BARYOGENESIS WITHOUT GRAND UNIFICATION

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and Deutsches Elektronen-Synchrotron DESY, D-2000 Hamburg, Fed Rep Germany

Received 8 March 1986

A mechanism is pointed out to generate cosmological baryon number excess without resorting to grand unified theories The lepton number excess originating from Majorana mass terms may transform into the baryon number excess through the unsuppressed baryon number violation of electroweak processes at high temperatures

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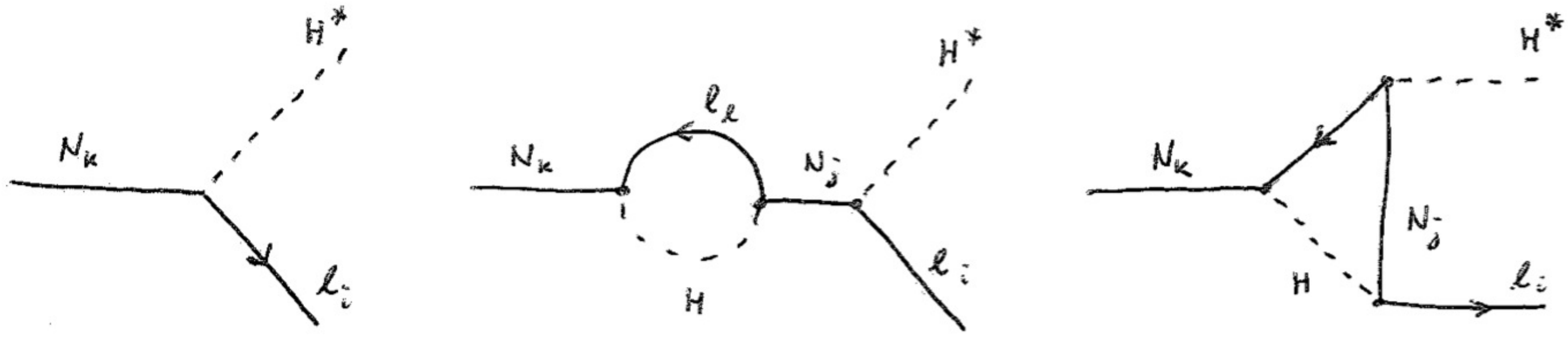
$$\varepsilon_i = \frac{\sum_\alpha [\Gamma(N_i \to l_\alpha H) - \Gamma(N_i \to \bar{l}_\alpha H^*)]}{\sum_\alpha [\Gamma(N_i \to l_\alpha H) + \Gamma(N_i \to \bar{l}_\alpha H^*)]}$$



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Cassas-Ibarra: $Y_N = \frac{1}{v}\sqrt{M}R\sqrt{m}V$

J.A. Casas and A. Ibarra, Nucl. Phys. B 618, 171 (2001)

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NB Davidson-Ibarra $|\varepsilon_1| \leq \frac{3}{16\pi}\frac{M_1(m_3 - m_1)}{v^2}$ valid only for hierarchical RHNs

S. Davidson and A. Ibarra, Phys. Lett. B535, 25 (2002)

2) No need to be sorry for perturb. B violation along with F-Y

(unifications are truly LG - friendly)

- RHN are often a must, other options (e.g. scalar SU(2) triplet)
- their mass scale is typically constrained
- the flavour structure is also constrained

} calculability, testability (?)

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Minimal SO(10):

$$M_u = Y_{10} v_u^{10} + Y_{126} v_u^{126}$$
$$M_d = Y_{10} v_d^{10} + Y_{126} v_d^{126} \qquad M_R = Y_{126} \langle \Delta_R^0 \rangle$$
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Extra constraints from B-asymmetry **may** have a great discrimination power!

3) In (G)UTs LG often dominates over the inherent high-scale BG

(symmetries and scales matter a lot!)

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- fast OOE B-L violating interactions needed ⬅ sphalerons wash out B+L !!!

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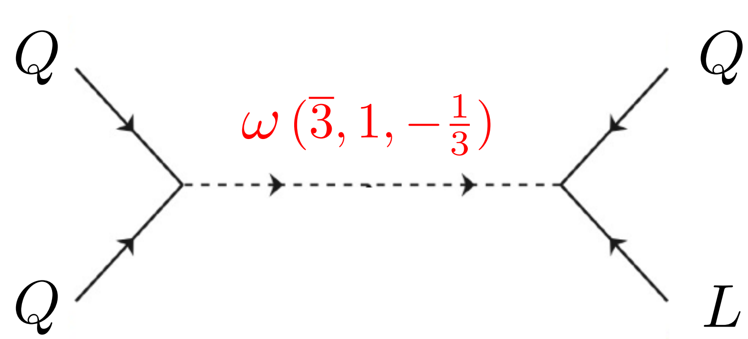
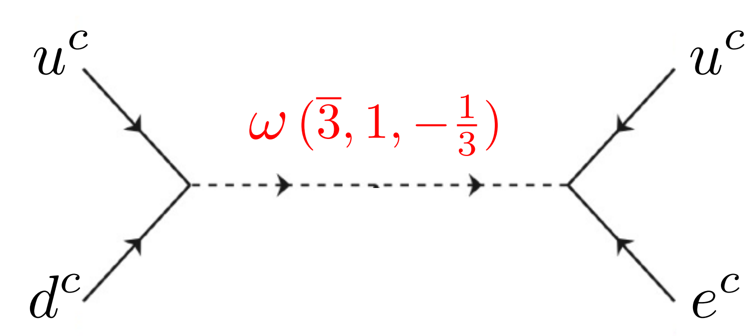
SU(5) à la Georgi & Glashow:

H. Georgi and S. L. Glashow, Phys. Rev. Lett., 32 (1974) 438–441

$$5_H \ni (3,1,+\tfrac{1}{3})$$
$$24_H \ni (8,1,0) \oplus (1,0,0)$$
$$24_G \ni (3,2,\tfrac{5}{6}) \oplus (\overline{3},2,-\tfrac{5}{6})$$

All interactions are B-L conserving!





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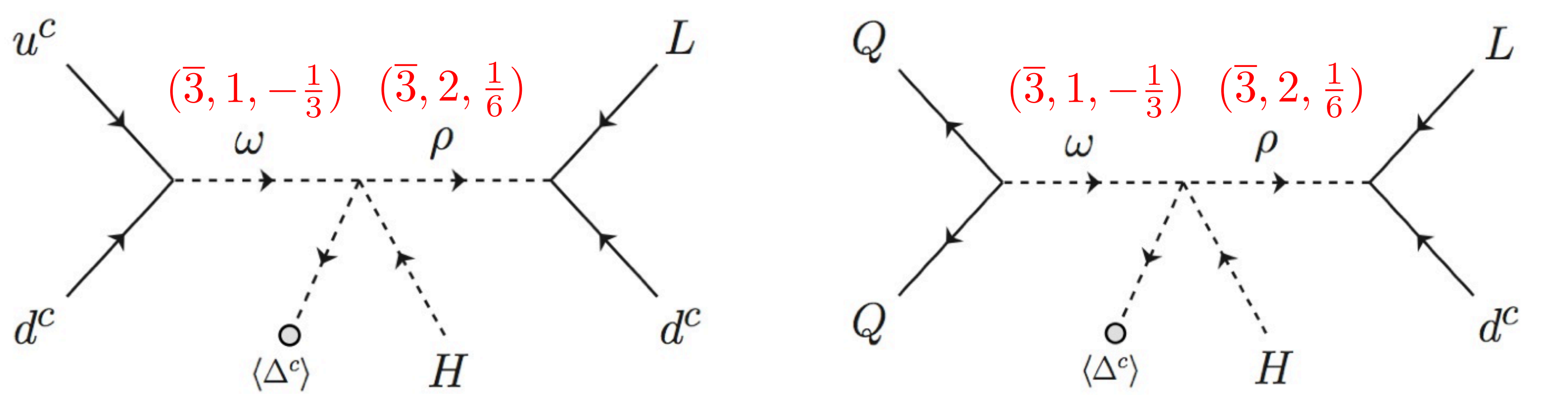
SO(10) GUTs: B-L is a part of the gauge group & spontaneously broken!



See e.g. K.S. Babu & R.N. Mohapatra Phys.Rev.D 86 (2012) 035018

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$$\Gamma(\omega \to qqH) \neq \Gamma(\omega^* \to \bar{q}\bar{q}H^*)$$

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There is still a good case for leptogenesis in SO(10)-like (G)UTs:

- ~10^{13} GeV bound on triplet masses (p-stability), **way above the D-I limit**
- the *B* - *L* / RHN mass scale therein is often well below that [minimal SO(10)]

Outline

Minimal flipped SU(5) UT

- LG is the leading source of baryon asymmetry (M_R two loops below M_G)
- the extra constraint from η_B has a profound impact on its predictivity

Minimal SO(10) GUT

- old-time flavour fits (nontrivial) are surprisingly compatible with η_B
- B-L scale can be determined without ever looking at gauge unification

Leptogenesis in the minimal flipped SU(5)

based on :

MM, V. Miřátský, R. Fonseca, M. Zdráhal, PRD110, 015030 (2024)

D. Harries, MM, M. Zdráhal, PRD 98, 095015 (2018)

C. Arbelaez Rodriguez, H. Kolešová, MM PRD 89, 055003 (2014)

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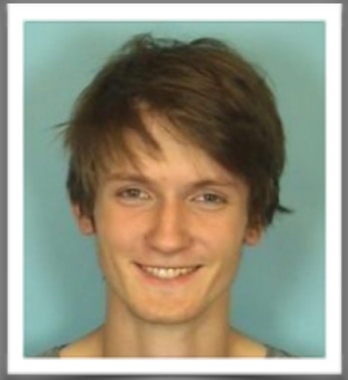
starring :



Václav Miřátský

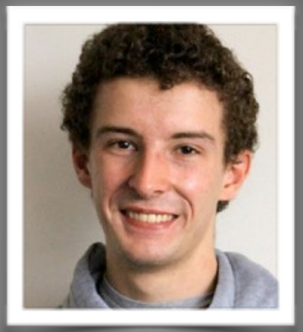
Renato Fonseca

Martin Zdráhal

co-starring :

C. Arbelaez Rodriguez

H. Kolešová



D. Harries

Flipped SU(5) one-minute course

SO(10) ⊃ SU(5) x U(1)Z

Matter: $16_M \ni (10,+1)_M \oplus (\overline{5},-3)_M \oplus (1,+5)_M$

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2 possible Y_{SM} assignments:

Standard: $Y = T_{24}$ $\qquad u^c, Q, e^c \qquad d^c, L \qquad \nu^c$

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Symmetry breaking:

$16_H \ni (10,+1)_H$ — SU(5) x U(1) to the SM

$10_H \ni (5,-2)_H$ — SM to the QCD x QED

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Gauge sector: $45_G \ni (24,0)_G \oplus (1,0)_G \ni (3,2,-\frac{1}{6})_G + h.c.$ X',Y'

BLNV nucleon decays in flipped SU(5) - one U_ν rules them all

$\Gamma(p \to \pi^0 \ell^+_\alpha)$	$\Gamma(p \to \pi^+ \overline{\nu})$	$\Gamma(n \to \pi^- \ell^+_\alpha)$	$\Gamma(n \to \pi^0 \overline{\nu})$
$\Gamma(p \to K^0 \ell^+_\alpha)$	$\Gamma(p \to K^+ \overline{\nu})$	$\Gamma(n \to K^- \ell^+_\alpha)$	$\Gamma(n \to K^0 \overline{\nu})$
$\Gamma(p \to \eta\, \ell^+_\alpha)$			$\Gamma(n \to \eta\, \overline{\nu})$

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Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

Charged mesons:
(no flavour ambiguity!)

$$\Gamma(p \to K^+ \overline{\nu}) = 0$$

$$\Gamma(p \to \pi^+ \overline{\nu}) = \left(\frac{g_G}{M_G}\right)^4 \frac{m_p}{8\pi f_\pi^2} A_L^2 |\alpha|^2 (1 + D + F)^2$$

BLNV nucleon decays in flipped SU(5) - one U_ν rules them all

$\Gamma(p\to\pi^0\ell^+_\alpha)$	$\Gamma(p\to\pi^+\overline{\nu})$	$\Gamma(n\to\pi^-\ell^+_\alpha)$	$\Gamma(n\to\pi^0\overline{\nu})$
$\Gamma(p\to K^0\ell^+_\alpha)$	$\Gamma(p\to K^+\overline{\nu})$	$\Gamma(n\to K^-\ell^+_\alpha)$	$\Gamma(n\to K^0\overline{\nu})$
$\Gamma(p\to\eta\,\ell^+_\alpha)$			$\Gamma(n\to\eta\,\overline{\nu})$

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Neutral mesons:

$$\Gamma(p\to\pi^0\ell^+_\alpha)=\frac{1}{2}\Gamma(p\to\pi^+\overline{\nu})|(V_{CKM})_{11}|^2|(V_{PMNS}U_\nu)_{\alpha 1}|^2$$

$$m_\nu=U_\nu^T D_\nu U_\nu$$

Constraining U_ν yields **constraints for ALL 2-body BNV channels!!!**

RH neutrino masses in the flipped SU(5)

Tree level: $10_M Y_{50} 10_M \langle 50_H \rangle$ OK in principle but overkill

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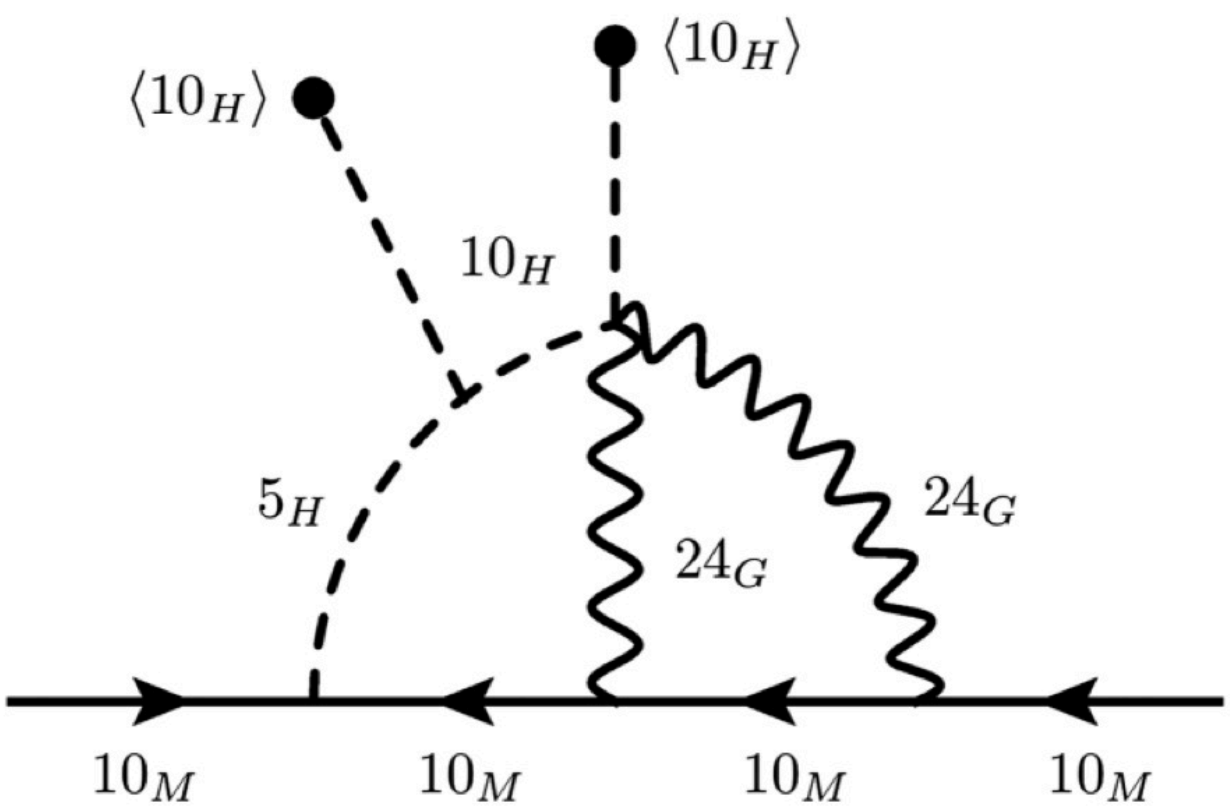
"Witten's loop" option: C. Arbelaez-Rodriguez, H. Kolešová, MM PRD89



The Witten's loop

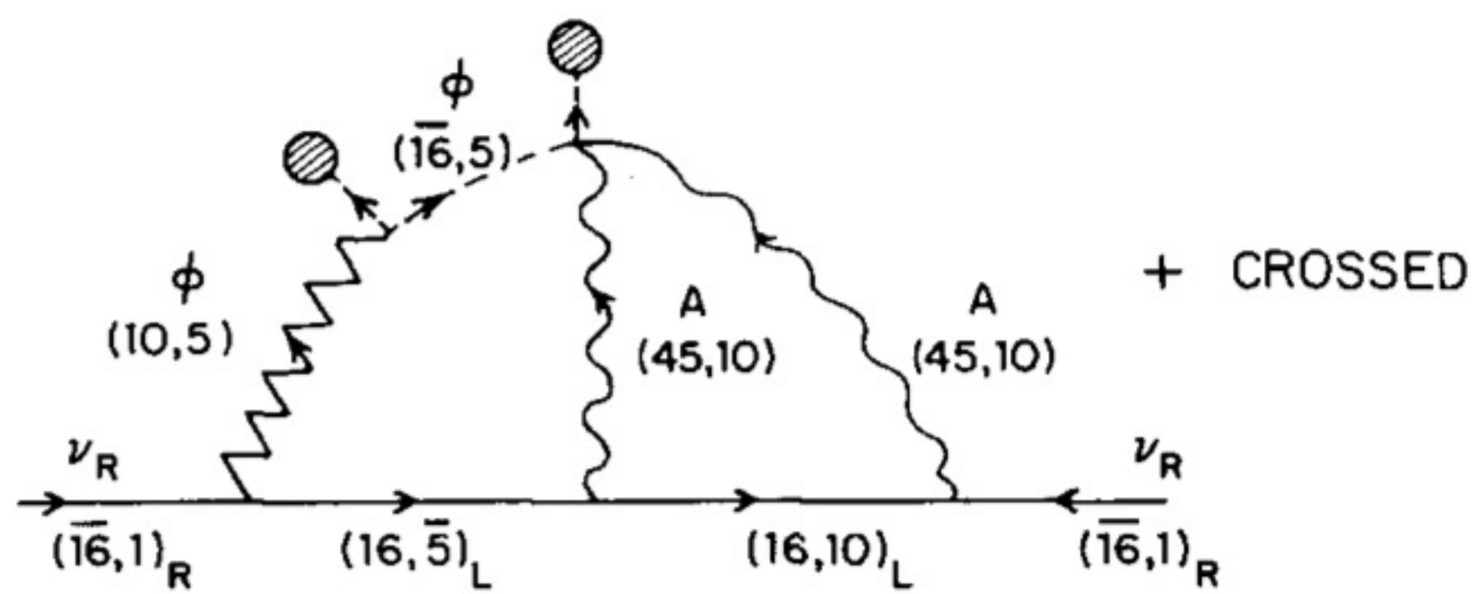
NEUTRINO MASSES IN THE MINIMAL O(10) THEORY ☆

Phys. Lett. B91 (1980) 81

Edward WITTEN [1]
Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138, USA

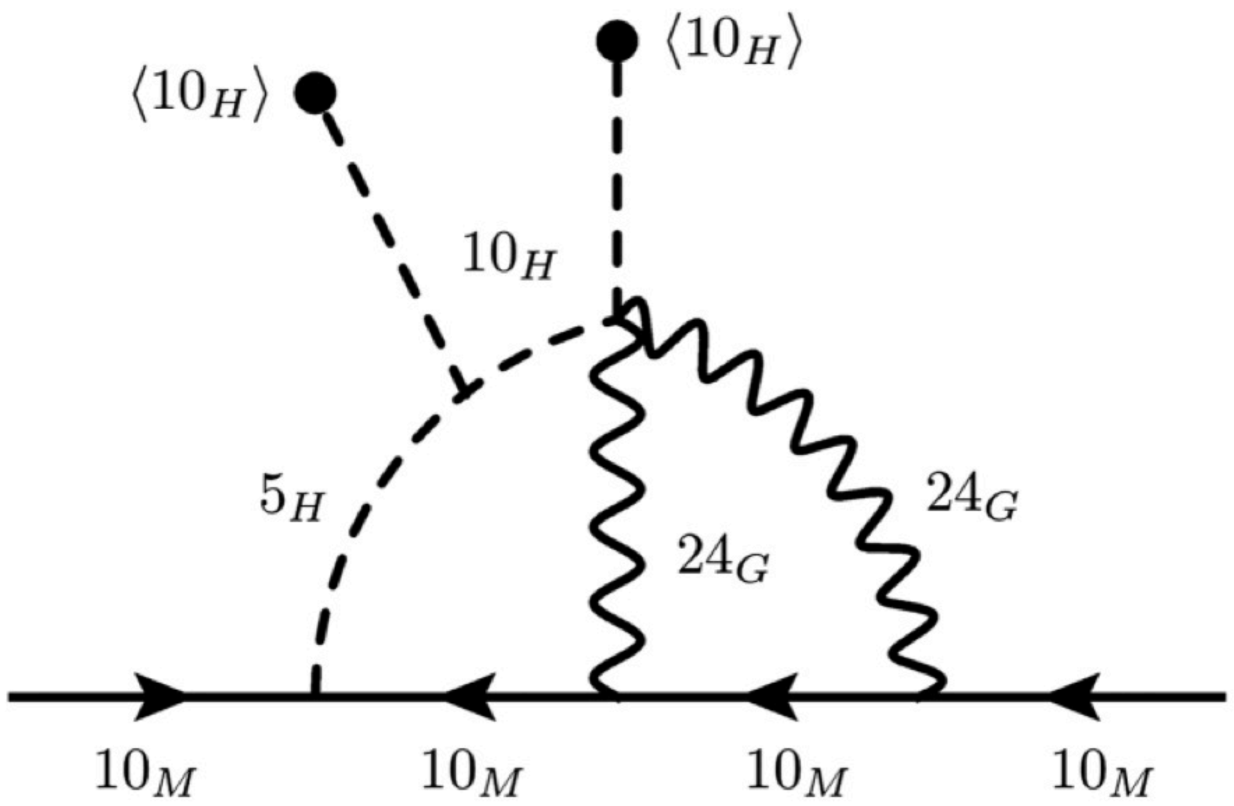
Received 6 December 1979

Neutrino masses are discussed in the context of the O(10) grand unified theory. In the "minimal" form of this theory, with minimal Higgs and fermion content, the right-handed neutrinos acquire masses at the two loop level. The left-handed neutrino masses are correspondingly *larger* by a factor roughly $(\alpha/\pi)^{-2}$ than they would be if the right-handed neutrino could acquire mass at the tree level. In the simplest form of this theory, the neutrino mass matrix is proportional to the up quark mass matrix, and the neutrino mixing angles equal the usual Cabibbo angles. The neutrino masses will be roughly in the range $10^{0\pm2}$ eV depending on the strength of O(10) symmetry breaking, and on certain unknown ratios of masses and couplings of superheavy particles.



Witten's mechanism in the minimal flipped SU(5)

Flipped SU(5) Witten's loop anatomy: C. Arbelaez-Rodriguez, H. Kolešová, MM PRD89



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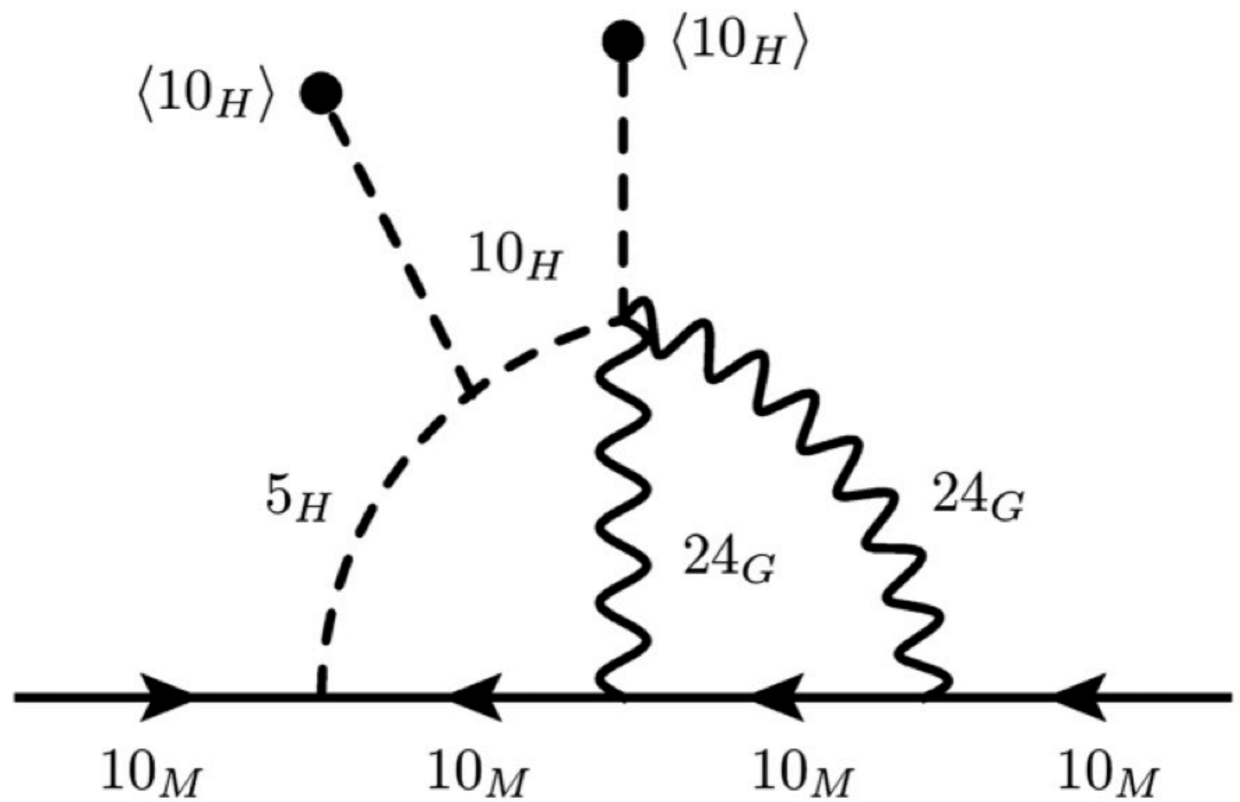

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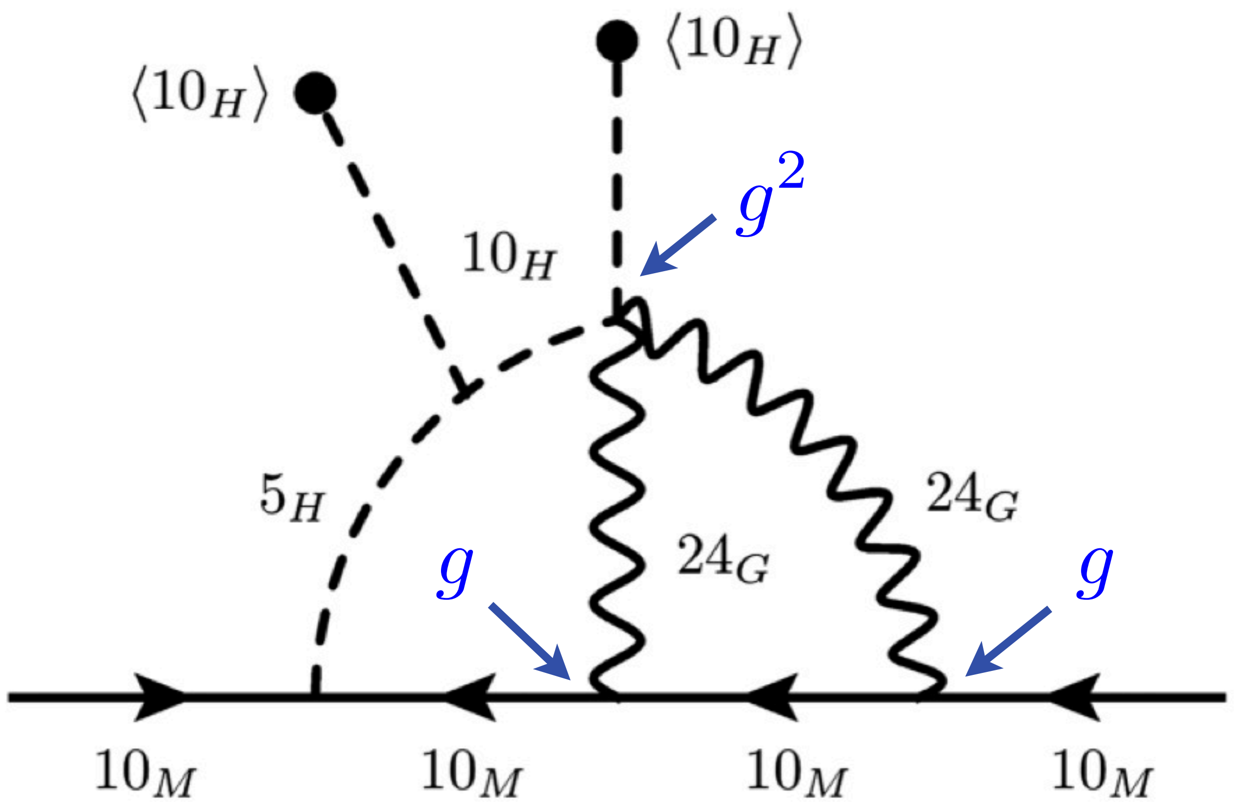

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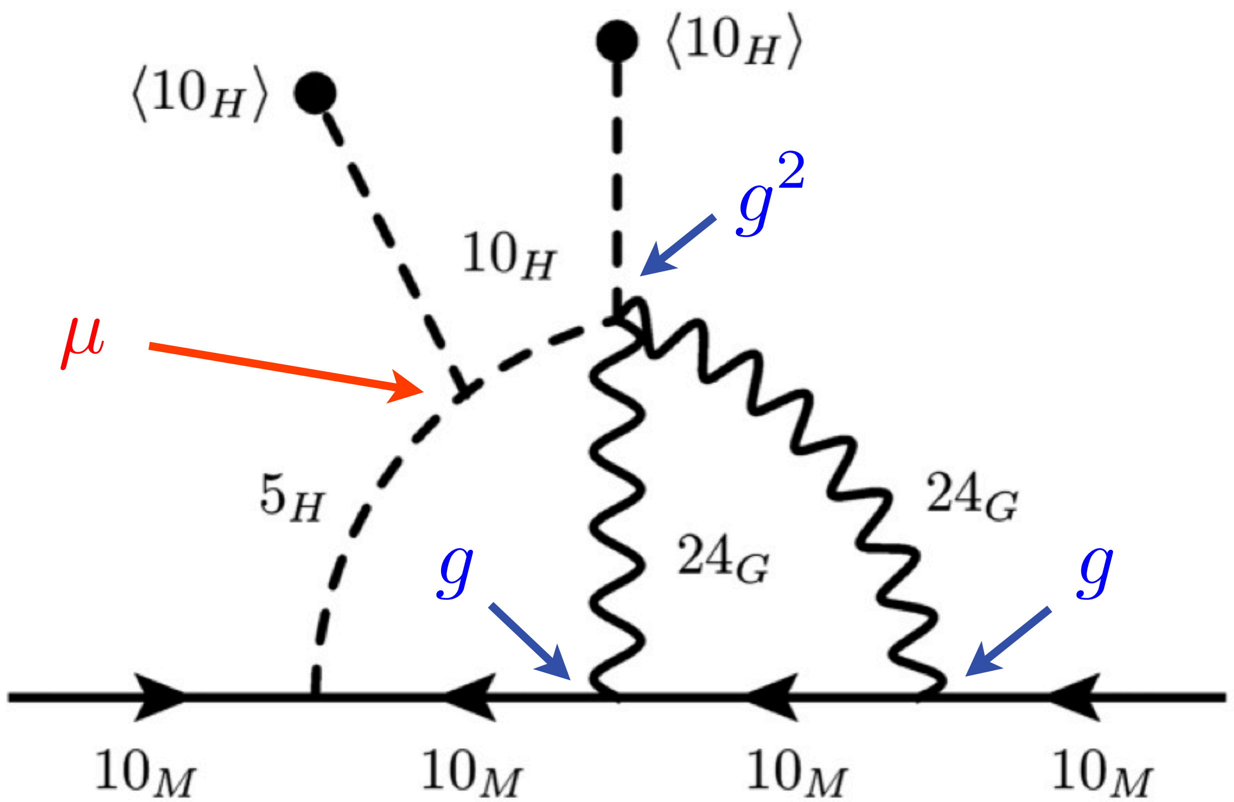

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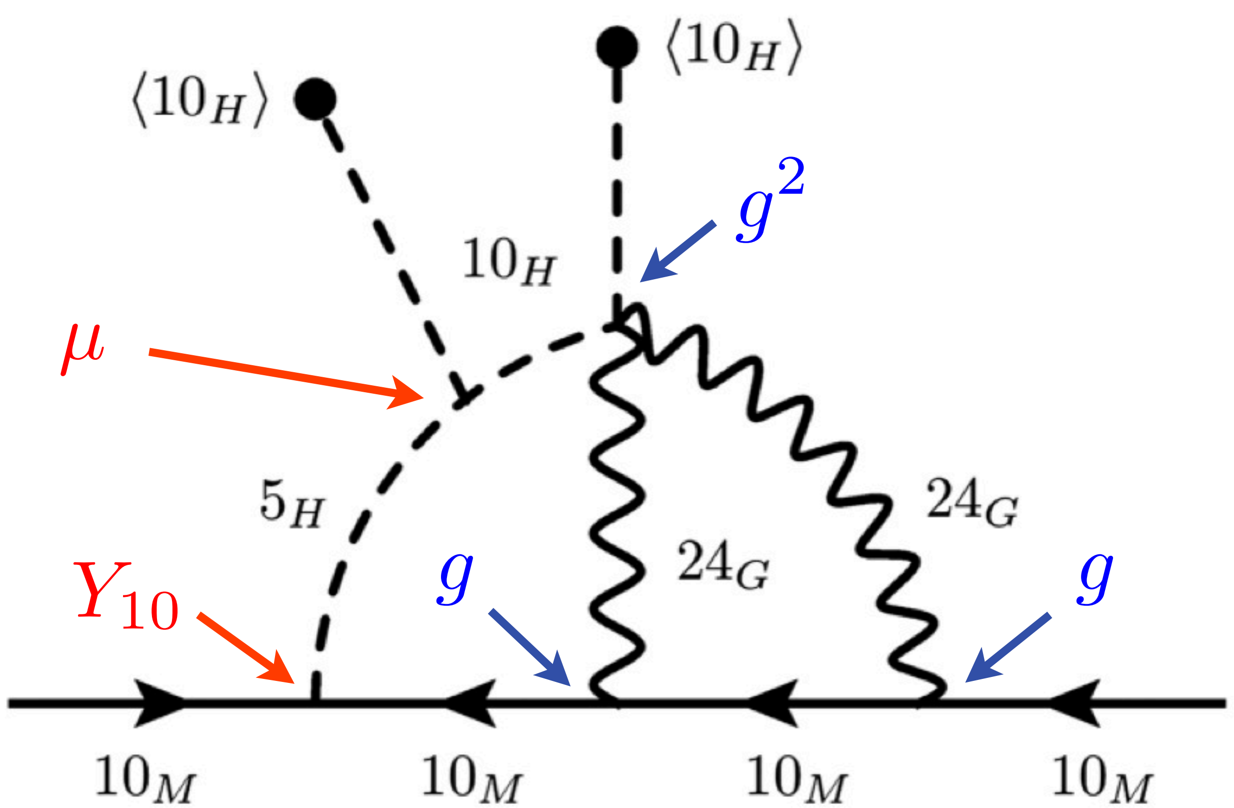
$$10_M Y_{10} 10_M 5_H$$



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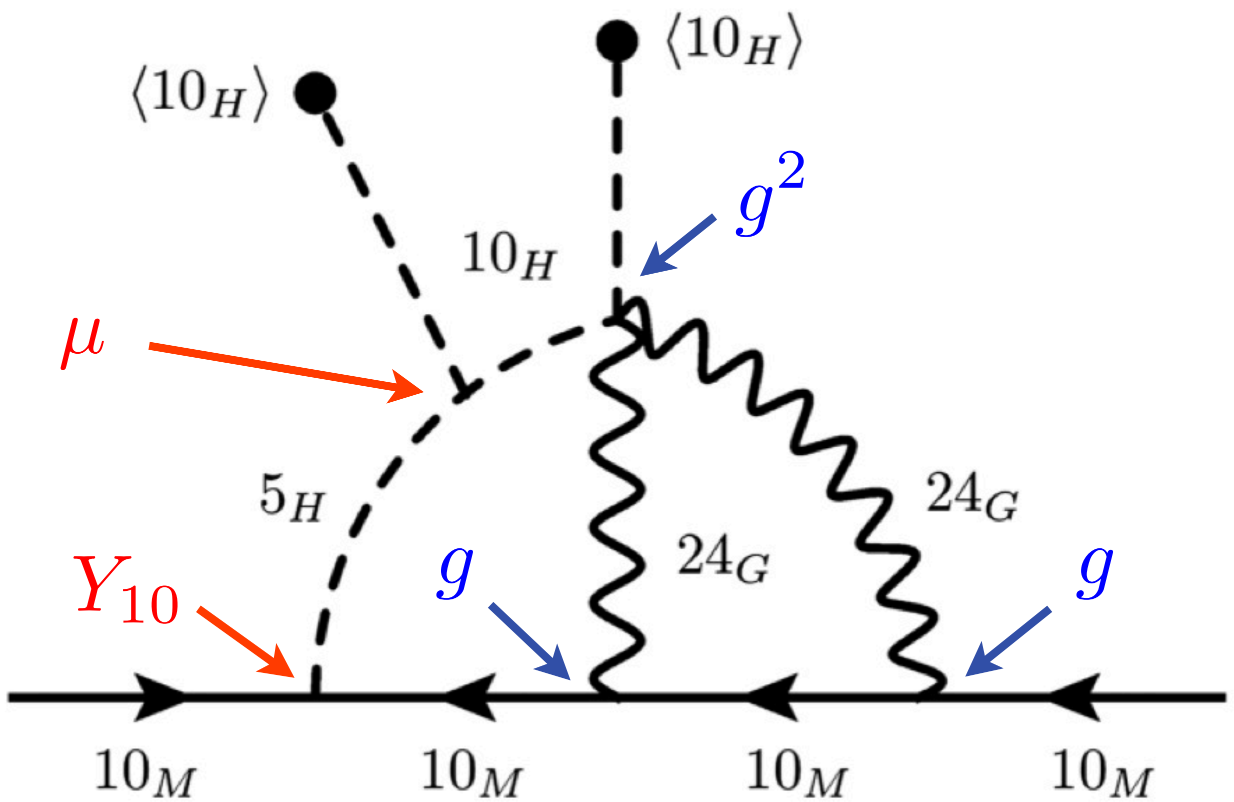

$$M_M = \frac{1}{(16\pi^2)^2} g^4 \mu\, Y_{10} \frac{\langle 10_H \rangle^2}{M_X^2}$$

NB first mention of this in the flipped SU(5) context : Leontaris, Vergados, PLB 258 (1991)

Witten's mechanism in the minimal flipped SU(5)

Flipped SU(5) Witten's loop anatomy: C. Arbelaez-Rodriguez, H. Kolešová, MM PRD89

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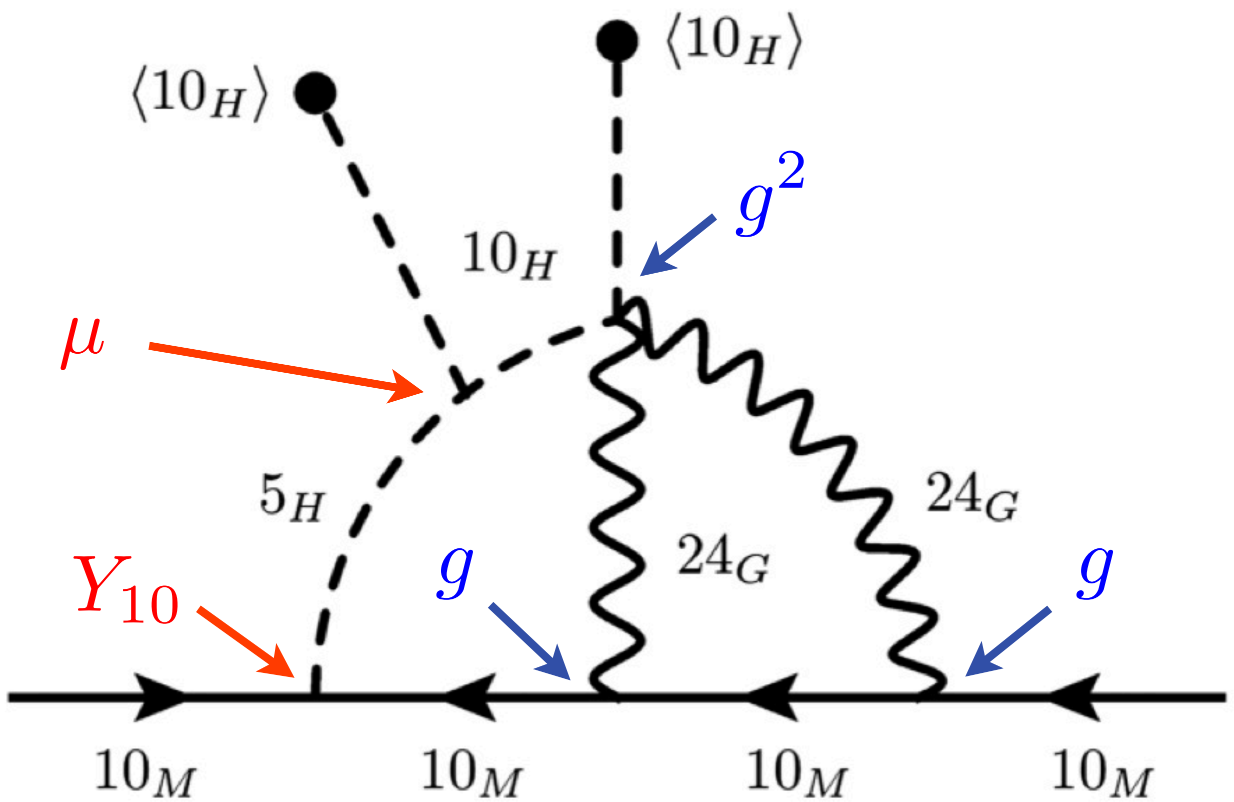

$$M_M = \frac{1}{(16\pi^2)^2} g^4 \mu\, Y_{10} \frac{\langle 10_H \rangle^2}{M_X^2} K(\ldots)$$

O(1) factor depending on the details of the heavy spectrum

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Seesaw - the key to phenomenology

$$D_u U_\nu^\dagger D_\nu^{-1} U_\nu^* D_u = M_M$$

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U_ν structure is strongly constrained !

D_ν^{-1} looks like $\begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix}$ GeV^{-1} $\quad D_u \sim \begin{pmatrix} 10^{-3} & 0 & 0 \\ 0 & 10^{0} & 0 \\ 0 & 0 & 10^{2} \end{pmatrix}$ GeV

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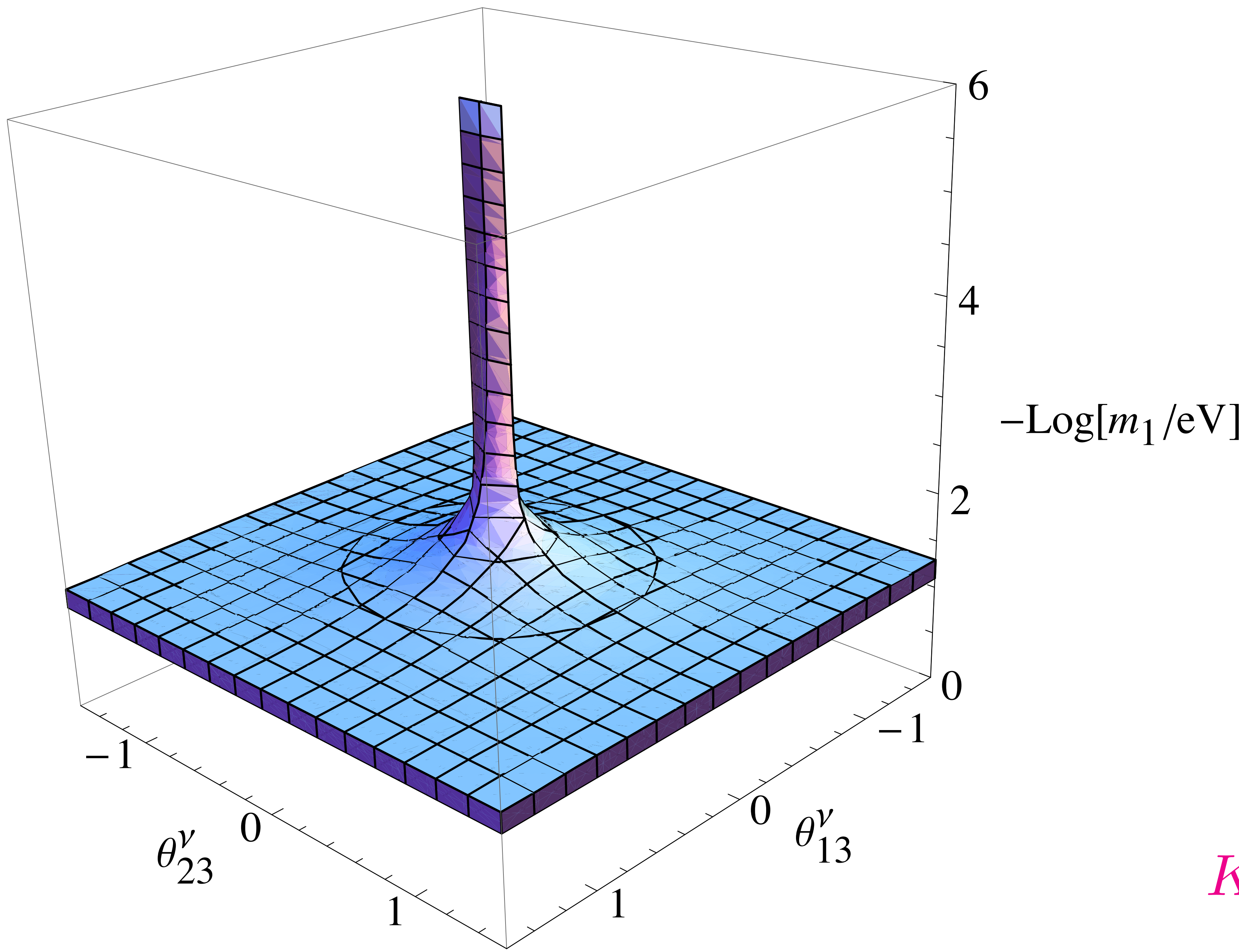
Severity of these constraints depends on the lightest neutrino mass…

The parameter space (m_1, U_ν)

U_ν angular behaviour:



$K = 1$

The parameter space (m_1, U_ν)

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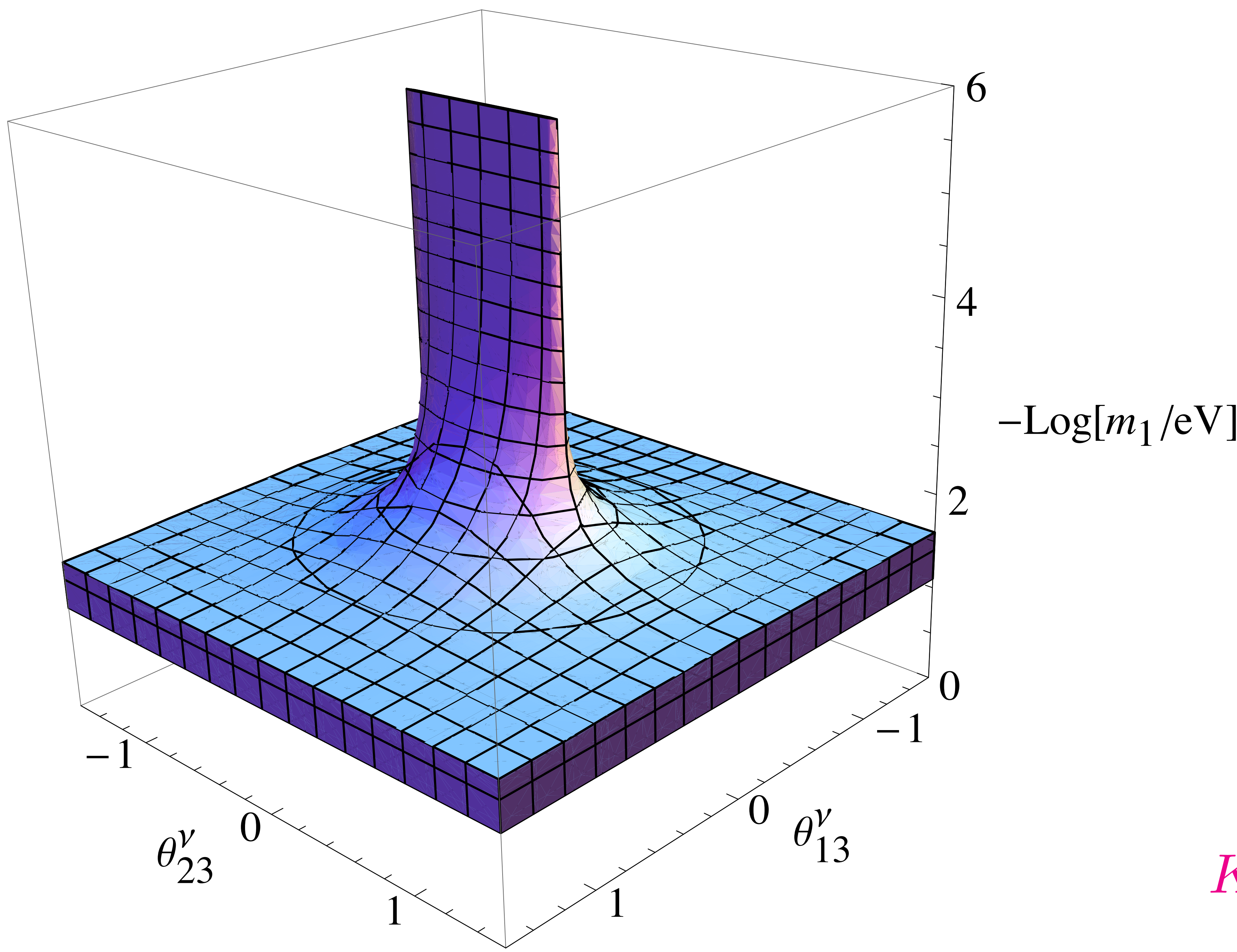
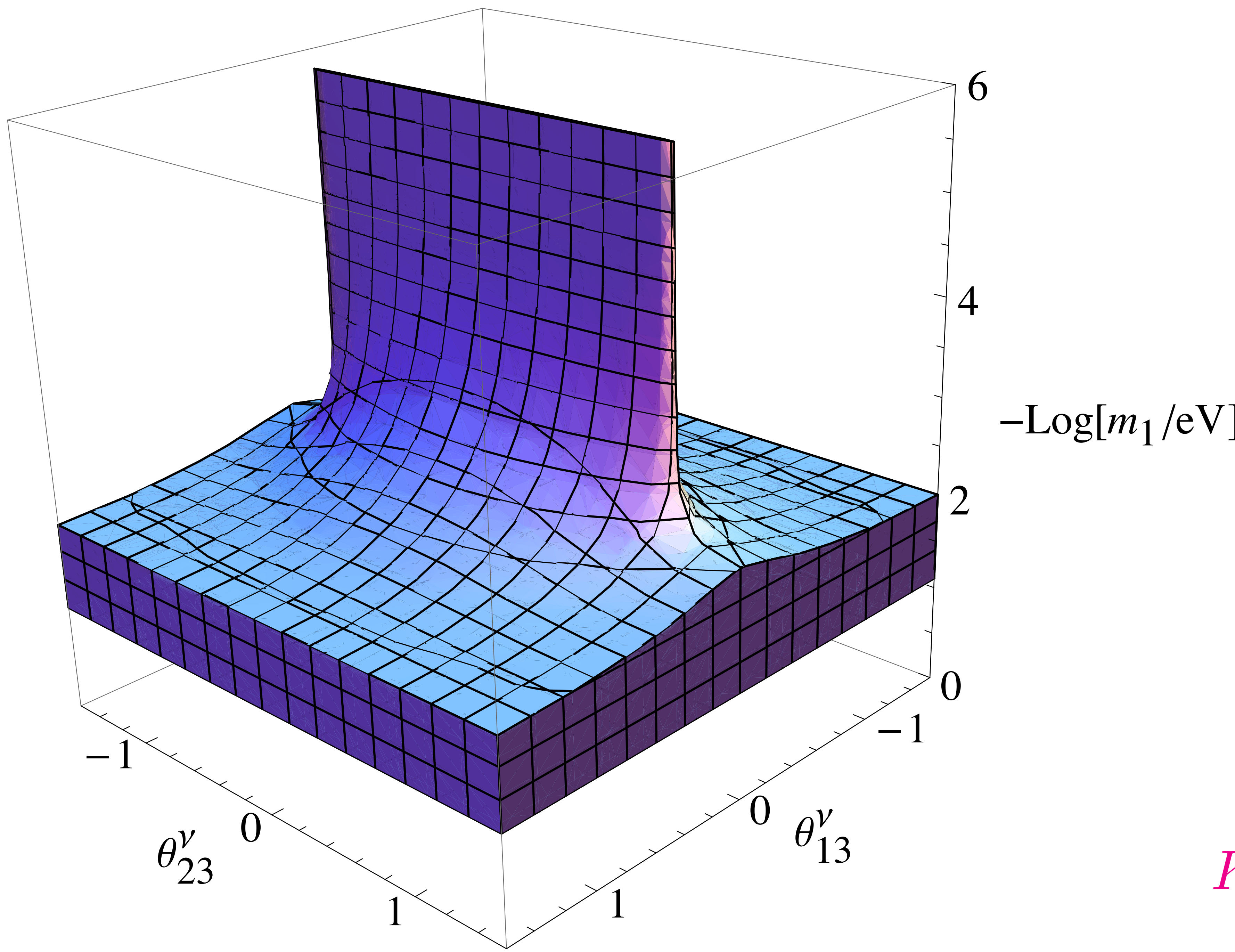


$K = 2$

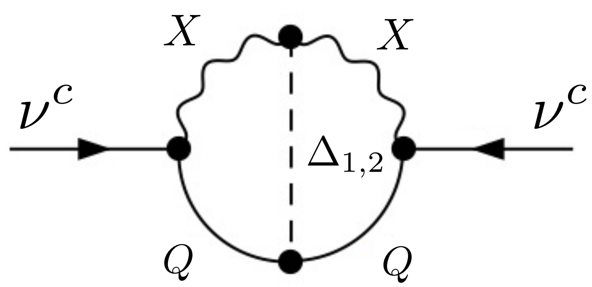
U_ν angular behaviour:

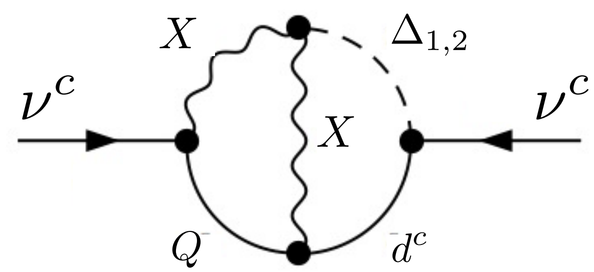


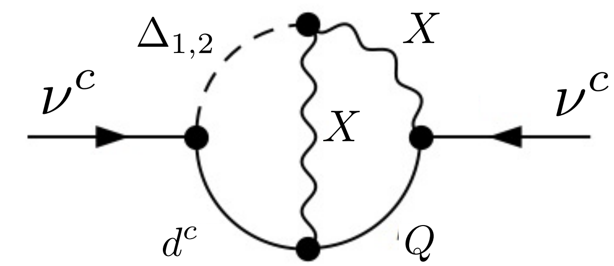
$K = 5$

D. Harries, MM, M. Zdráhal, PRD 98, 095015 (2018)

$$M_M = \Sigma_{\text{1-loop}}(0) + \ldots$$







UV divergences (dim. reg.):

$$-\frac{M_\Delta^4}{4M_X^4\varepsilon^2} - \frac{3M_\Delta^4}{4M_X^4\varepsilon} + \frac{M_\Delta^4 \log\left(M_\Delta^2\right)}{2M_X^4\varepsilon} + \frac{3}{2\varepsilon}$$

Exactly cancel among the three topologies

$$M_M \lesssim 10^{-2} M_X \times 10^{-1} \times 3 \sum_{i=1,2} (U_\Delta)_{i1} (U_\Delta^*)_{i2}\, I\left(\frac{m_{\Delta_i}^2}{m_X^2}\right)$$

NB. Zero-momentum two-loop integrals: M.J.G. Veltman, J. Van der Bij, Nucl. Phys. B231, 205 (1984)

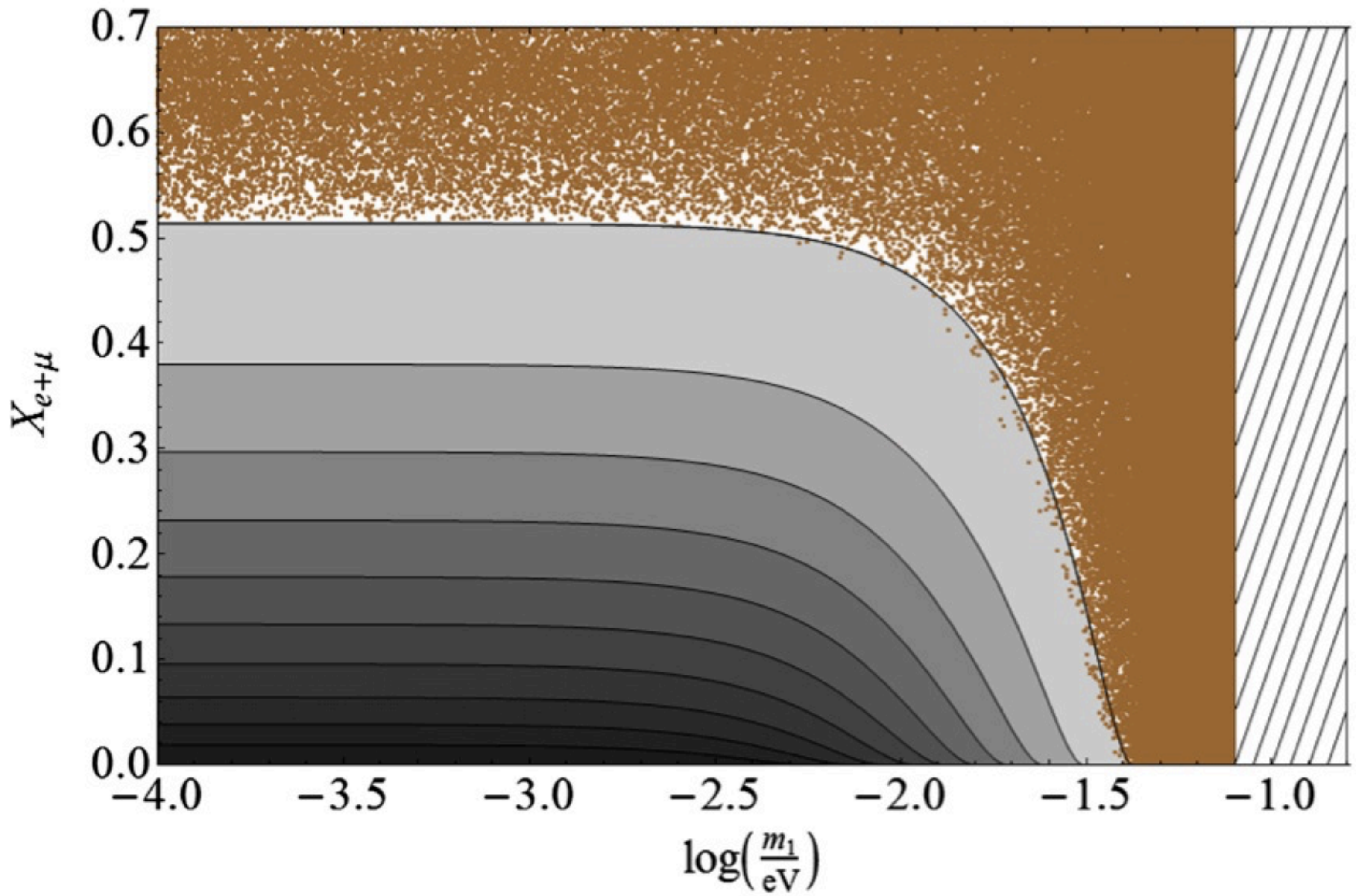
U_ν features in proton decay rates

Unlikely to have both $\Gamma(p \to \pi^0 e^+)$ and $\Gamma(p \to \pi^0 \mu^+)$ arbitrarily suppressed

(in the "small" m_1 regime)

K

growing



C.Arbelaez-Rodriguez, H.Kolešová, MM, PRD89

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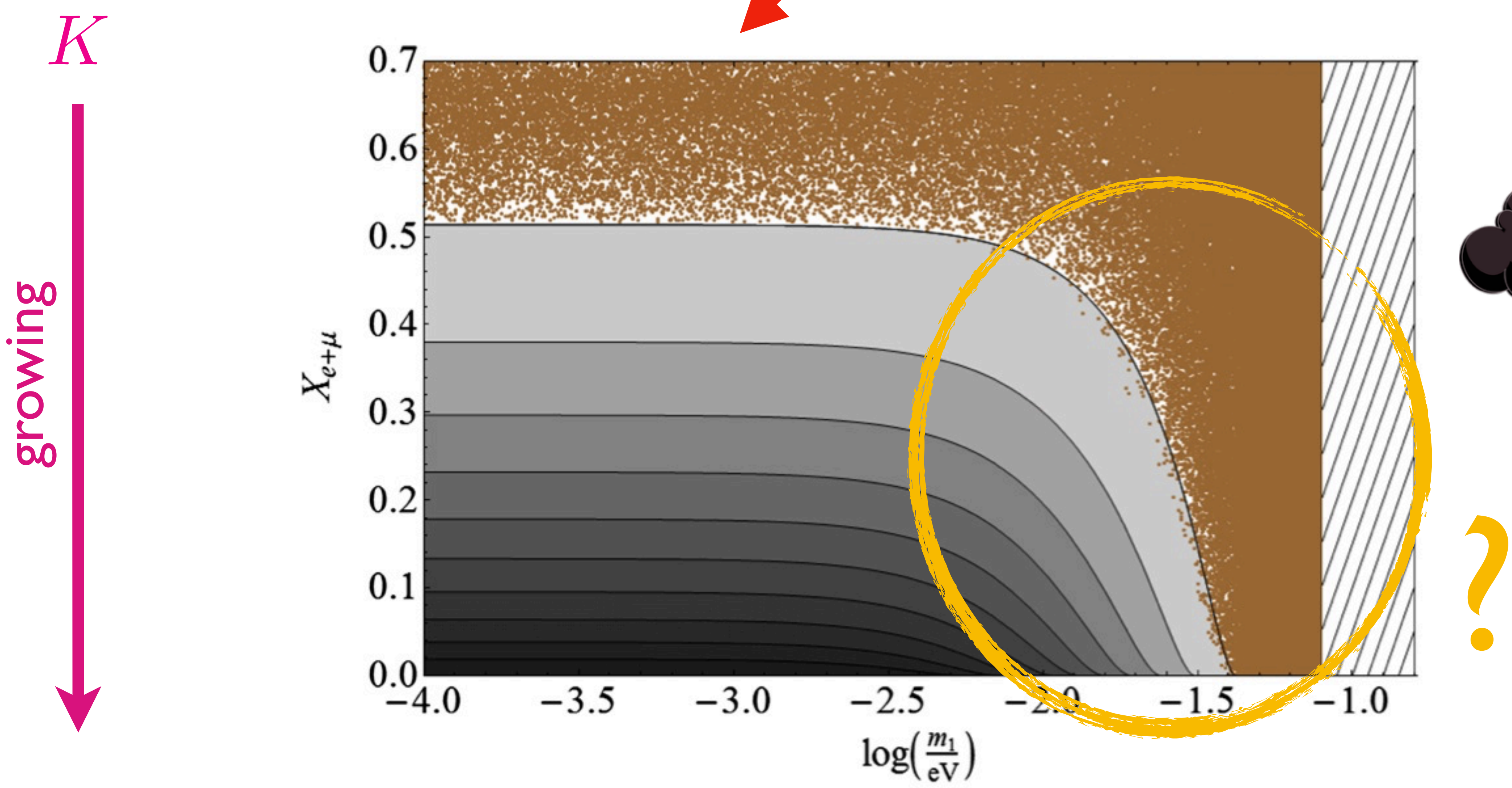

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The "large" m_1 regime?

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- RHN spectrum tends to be hierarchical and suppressed - out of Davidson-Ibarra mode!

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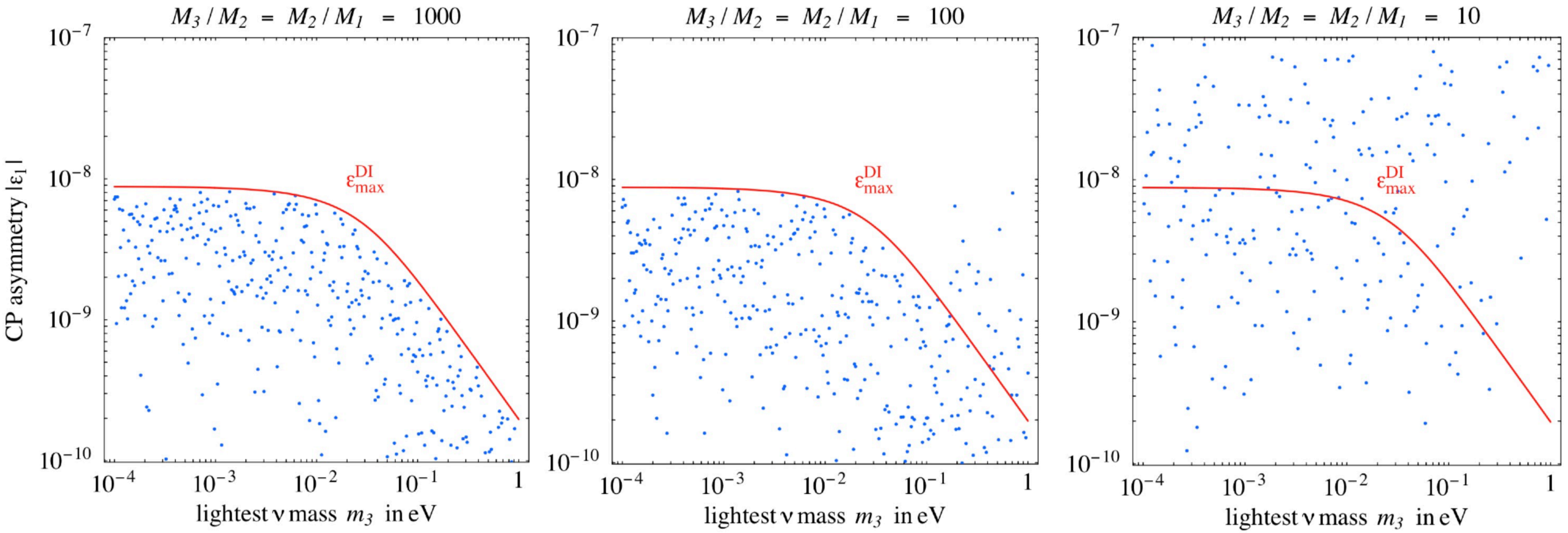

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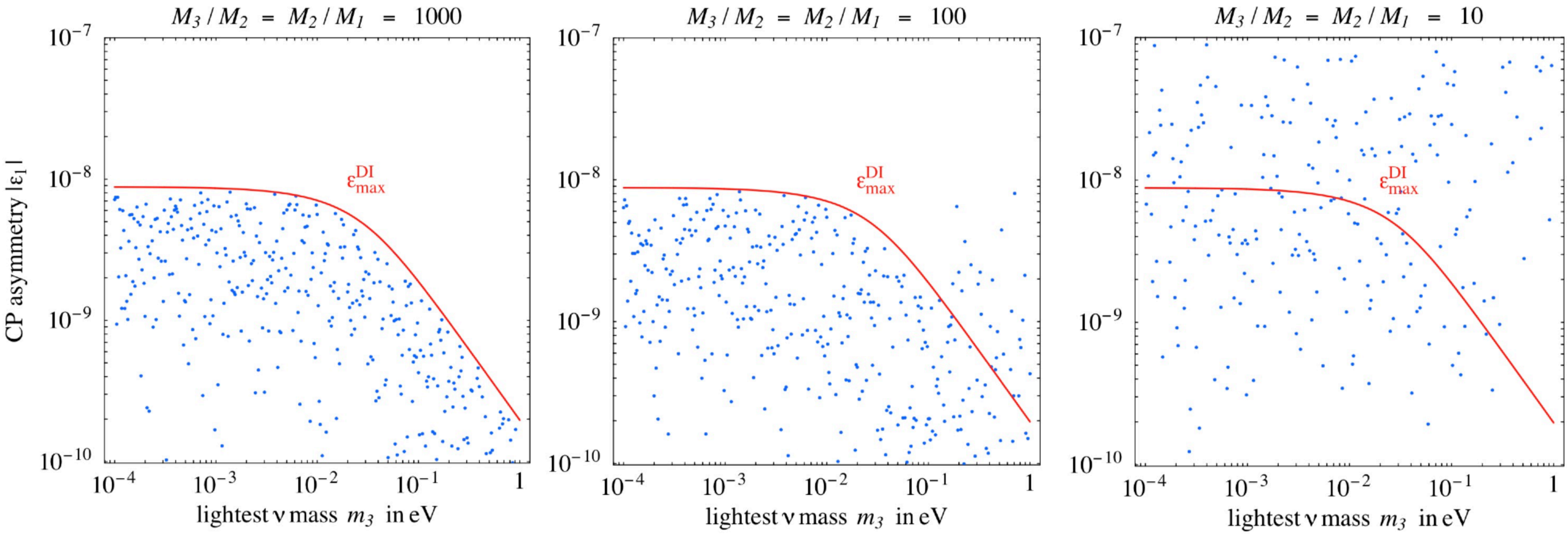

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- Again, U_ν can not be arbitrary ➔ **further constraints on BLNV rates (?)**

Thermal leptogenesis in the minimal flipped SU(5) à la Witten

Detailed numerical analysis MM, V. Miřátský, R. Fonseca, M. Zdráhal, PRD110, 015030 (2024)

using ULYSSES A. Granelli, K.Moffat, Y.F. Perez-Gonzalez, H. Schulz, J. Turner, Comput.Phys.Commun. 262 (2021)

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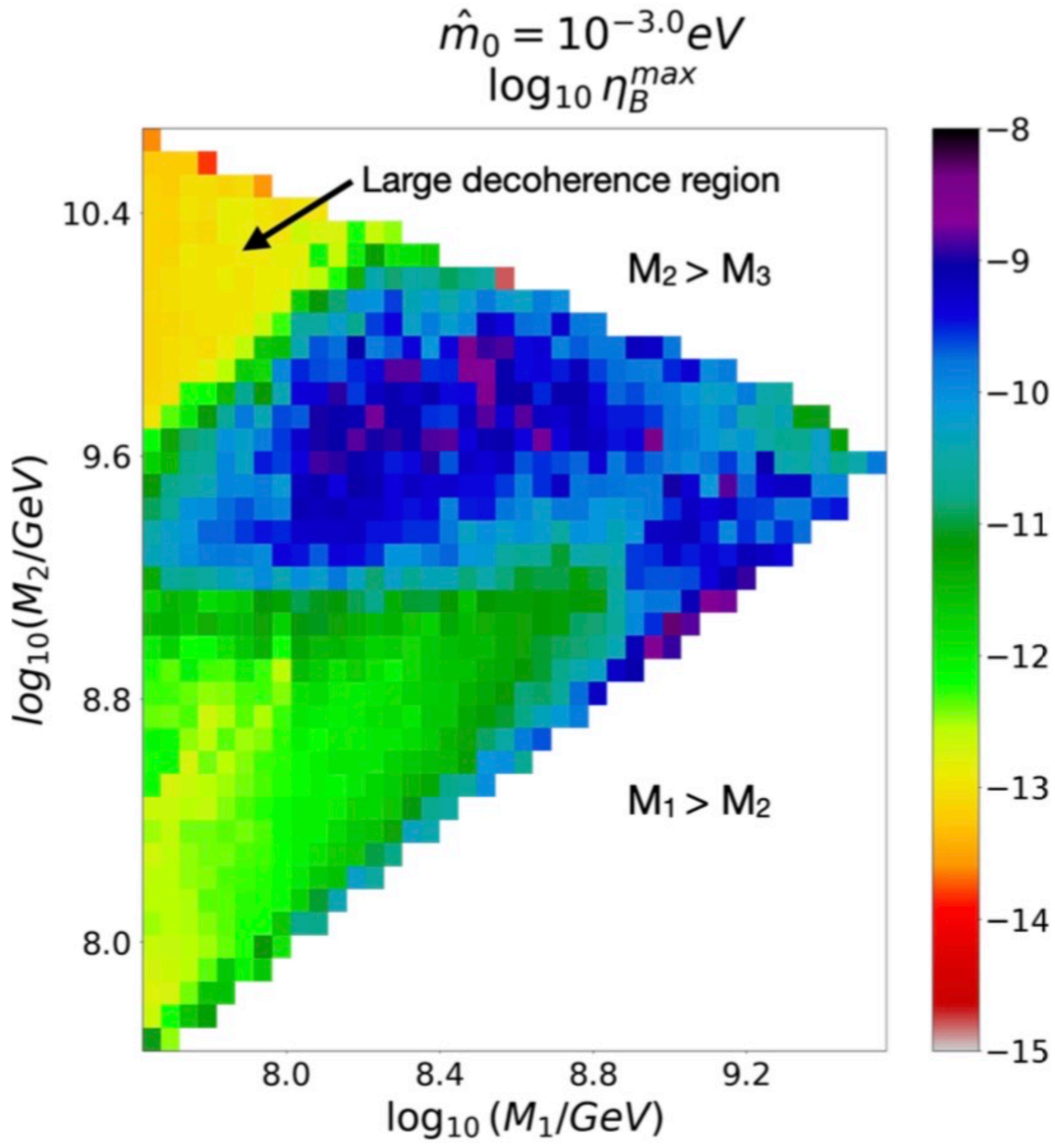

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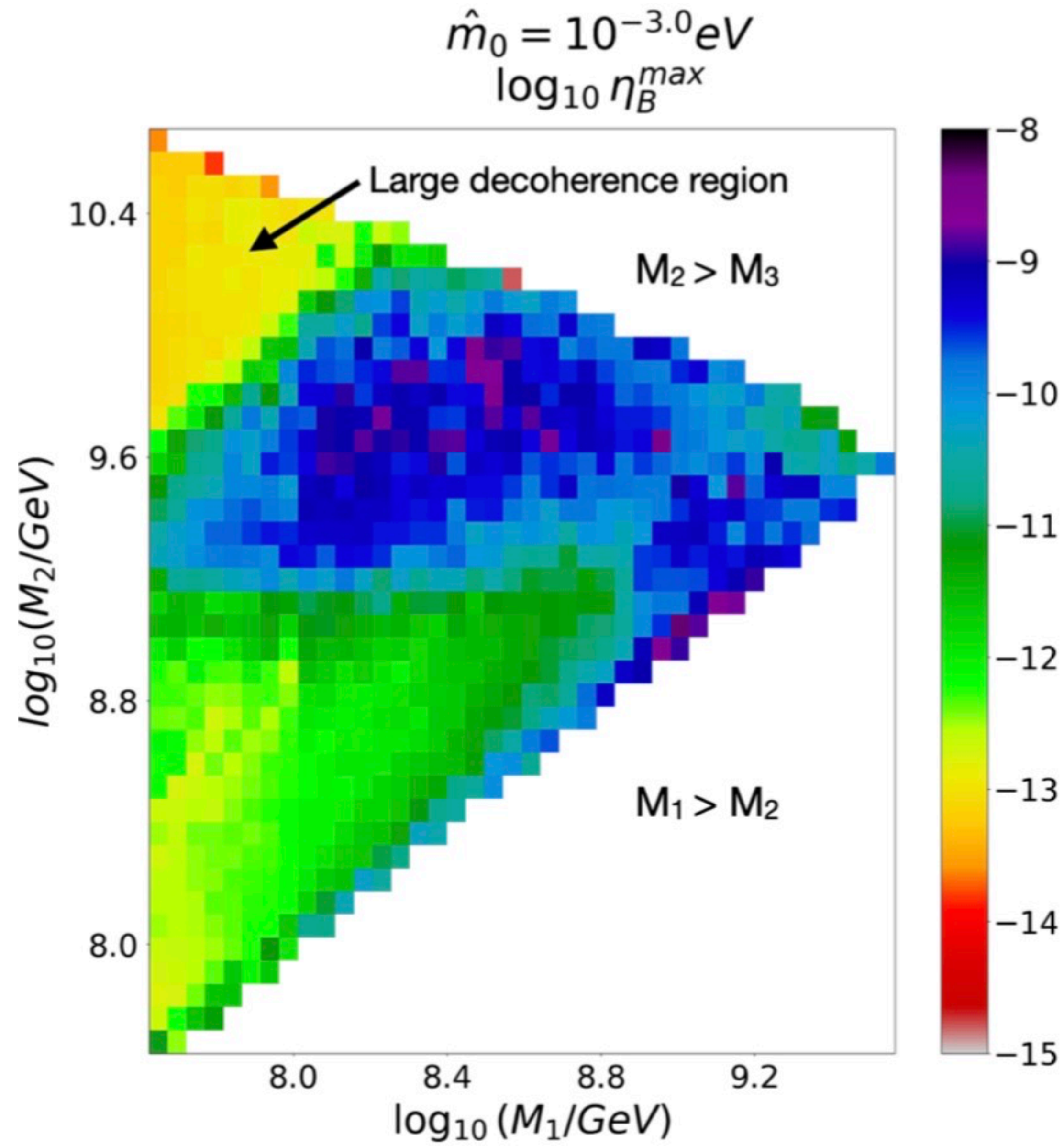

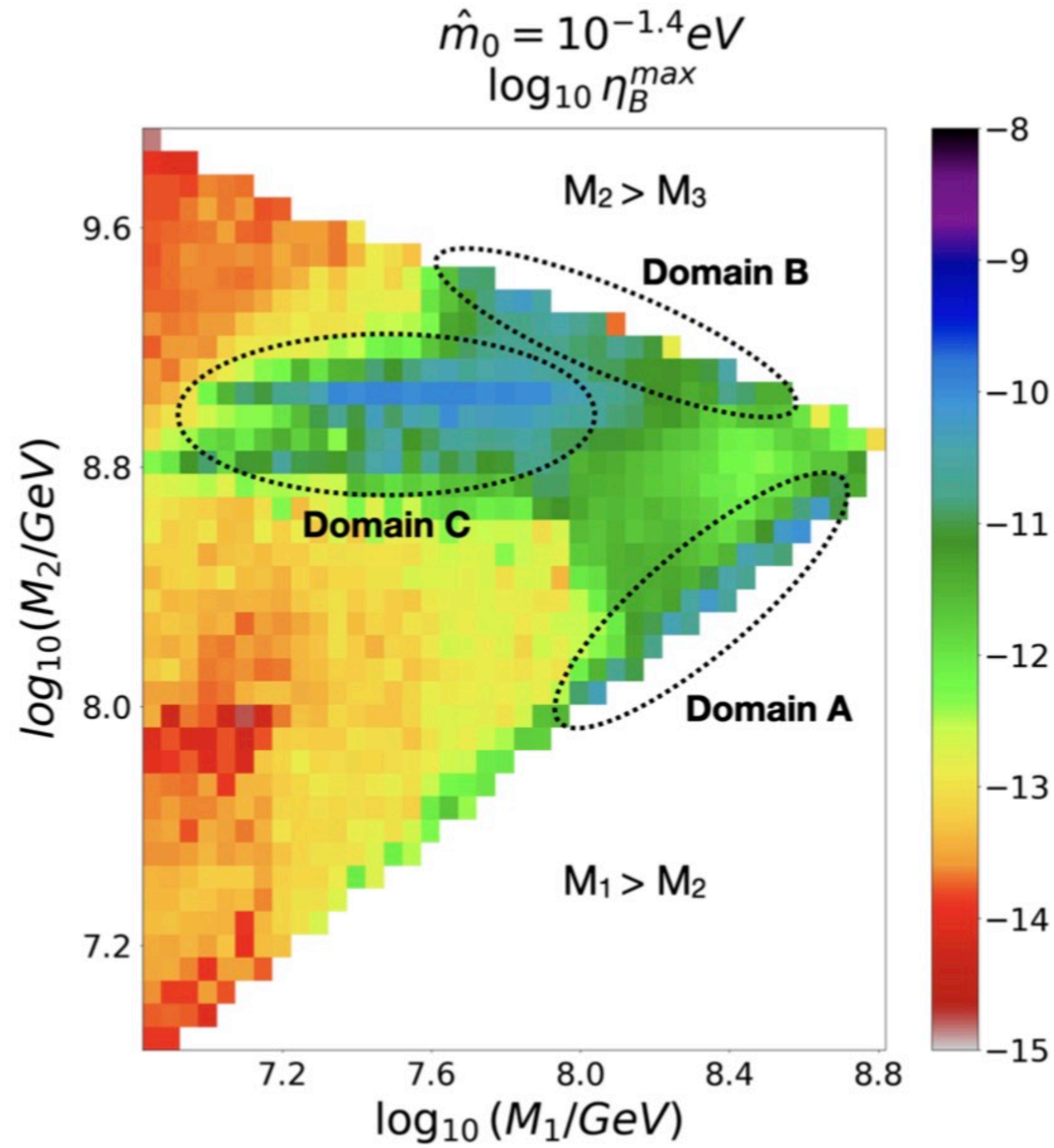

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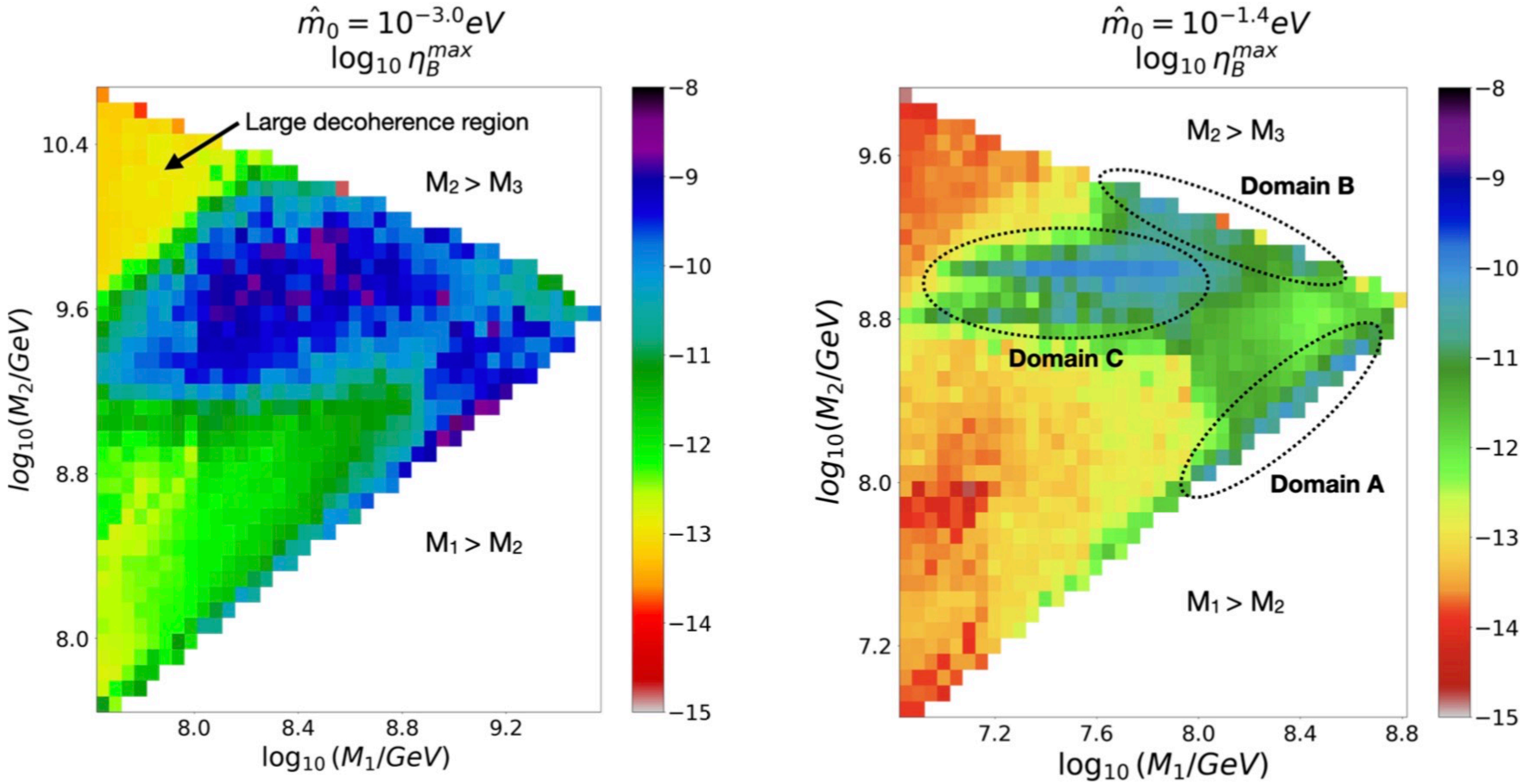

No-go for "large" $m_1 > 10^{-1.5}$ eV! No signal in KATRIN, BR($p \to \pi^0 \mu^+$)<0.09

Leptogenesis in the minimal SO(10)

based on :

K. Jarkovská, MM, V. Susič, PRD 108, 055003 (2023)
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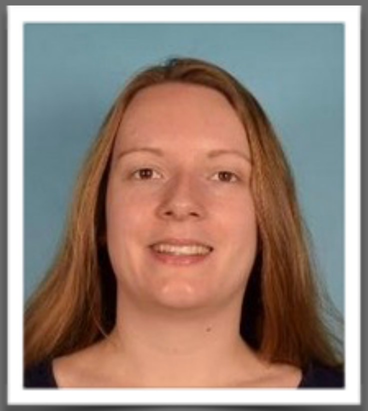
starring :

Vasja Susič

Dominik Starý

co-starring :



Kateřina Jarkovská

Timon Mede

SO(10) broken by 45

The minimal potentially realistic & calculable SO(10) GUT

SO(10) broken by 45 Why?

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GUT scale is difficult to determine: $\mathcal{L} \ni \frac{\kappa}{\Lambda} F^{\mu\nu} \langle \Phi \rangle F_{\mu\nu}$

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The 45 breaking is **very** special: $\mathcal{L} \ni \frac{\kappa}{\Lambda} F^{\mu\nu} \langle 45 \rangle F_{\mu\nu} = 0$

$$(45 \otimes 45)_{sym} = 54 \oplus 210 \oplus 770$$

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Minimal renormalizable model scalar sector: **45+126+10**

$$M_u = Y_{10} v_u^{10} + Y_{126} v_u^{126}$$
$$M_d = Y_{10} v_d^{10} + Y_{126} v_d^{126}$$
$$M_l = Y_{10} v_d^{10} - 3 Y_{126} v_d^{126}$$
$$M_\nu^D = Y_{10} v_u^{10} - 3 Y_{126} v_u^{126}$$

$$M_R = Y_{126} \langle \Delta_R^0 \rangle$$
$$m_\nu^{II} \propto Y_{126} \langle \Delta_L^0 \rangle$$

Minimal SO(10) Yukawa sector fits

19 parameters (6 compact) , 3+3+4 (quarks) + 3+2+3 (leptons) masses+mixings!!!

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Many attempts…

T. Ohlsson, M. Pernow, JHEP 06 (2019) 085
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A. S. Joshipura and K. M. Patel, Phys. Rev. D 83, 095002 (2011)

… and others

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… and others

Our toolchain: REAP + MixingParameterTools, differential evolution, …

Minimal SO(10) Yukawa sector fits

Best fit point:

Observable	Fit	Pull
m_u [MeV]	1.23	-7.24×10^{-3}
m_c [GeV]	0.632	0.686
m_t [GeV]	167.3	-0.593
m_d [MeV]	2.46	-1.08
m_s [MeV]	54.92	0.381
m_b [GeV]	2.841	0.0851
$\sin\theta_{12}^{\mathrm{CKM}}$	0.2250	-0.0363
$\sin\theta_{13}^{\mathrm{CKM}}/10^{-3}$	3.69	-0.148
$\sin\theta_{23}^{\mathrm{CKM}}/10^{-2}$	4.161	-0.276
δ_{CKM}	1.147	0.379
Δm_{21}^2 $[10^{-5}\mathrm{eV}^2]$	7.54	0.613
Δm_{31}^2 $[10^{-3}\mathrm{eV}^2]$	2.502	-0.315
m_e [MeV]	0.4843	0.253
m_μ [GeV]	0.1021	0.285
m_τ [GeV]	1.727	-0.117
$\sin^2\theta_{12}^{\mathrm{PMNS}}$	0.311	0.696
$\sin^2\theta_{13}^{\mathrm{PMNS}}/10^{-2}$	2.138	-1.10
$\sin^2\theta_{23}^{\mathrm{PMNS}}$	0.432	-1.48
χ^2	–	6.93 !!!

Minimal SO(10) flavour-related “predictions”

Very preliminary, sorry for the missing estimates of uncertainties - TBD

Observable	Prediction
$\log \eta_B$	-10.47
m_1 [meV]	4.21
m_2 [meV]	9.65
m_3 [meV]	50.2
M_1 [GeV]	1.01×10^{10}
M_2 [GeV]	2.12×10^{11}
M_3 [GeV]	9.68×10^{11}
δ_{CP}	4.64
ϕ_1	5.16
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See also V.S. Mummidi, K. Patel, JHEP 12 (2021) 042

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in the right ballpark!

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N_1-dominated TLG!

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large Dirac CP phase!

See also V.S. Mummidi, K. Patel, JHEP 12 (2021) 042

A curiosity:

determination of the B-L scale
without ever looking at gauge unification constraints(!)

Reason:
Heavy thresholds (a.k.a. scalar spectrum)
are largely out of control even in the minimal SO(10)

The minimal SO(10) Higgs model

Scalar potential: $V = V_{45} + V_{126} + V_{\rm mix}$

$$V_{45} = -\frac{\mu^2}{2}(\phi\phi)_0 + \frac{a_0}{4}(\phi\phi)_0(\phi\phi)_0 + \frac{a_2}{4}(\phi\phi)_2(\phi\phi)_2\,,$$

$$\begin{aligned} V_{126} = & -\frac{\nu^2}{5!}(\Sigma\Sigma^*)_0 \\ & + \frac{\lambda_0}{(5!)^2}(\Sigma\Sigma^*)_0(\Sigma\Sigma^*)_0 + \frac{\lambda_2}{(4!)^2}(\Sigma\Sigma^*)_2(\Sigma\Sigma^*)_2 \\ & + \frac{\lambda_4}{(3!)^2(2!)^2}(\Sigma\Sigma^*)_4(\Sigma\Sigma^*)_4 + \frac{\lambda_4'}{(3!)^2}(\Sigma\Sigma^*)_{4'}(\Sigma\Sigma^*)_{4'} \\ & + \frac{\eta_2}{(4!)^2}(\Sigma\Sigma)_2(\Sigma\Sigma)_2 + \frac{\eta_2^*}{(4!)^2}(\Sigma^*\Sigma^*)_2(\Sigma^*\Sigma^*)_2\,, \end{aligned}$$

$$\begin{aligned} V_{\rm mix} = & \frac{i\tau}{4!}(\phi)_2(\Sigma\Sigma^*)_2 + \frac{\alpha}{2\cdot 5!}(\phi\phi)_0(\Sigma\Sigma^*)_0 \\ & + \frac{\beta_4}{4\cdot 3!}(\phi\phi)_4(\Sigma\Sigma^*)_4 + \frac{\beta_4'}{3!}(\phi\phi)_{4'}(\Sigma\Sigma^*)_{4'} \\ & + \frac{\gamma_2}{4!}(\phi\phi)_2(\Sigma\Sigma)_2 + \frac{\gamma_2^*}{4!}(\phi\phi)_2(\Sigma^*\Sigma^*)_2\,. \end{aligned}$$

$$(\phi\phi)_0(\phi\phi)_0 \equiv \phi_{ij}\phi_{ij}\phi_{kl}\phi_{kl}$$

$$(\phi\phi)_2(\phi\phi)_2 \equiv \phi_{ij}\phi_{ik}\phi_{lj}\phi_{lk}$$

$$(\phi\phi)_0 \equiv \phi_{ij}\phi_{ij}\,,\quad (\Sigma\Sigma^*)_0 \equiv \Sigma_{ijklm}\Sigma^*_{ijklm}$$

$$(\Sigma\Sigma^*)_0(\Sigma\Sigma^*)_0 \equiv \Sigma_{ijklm}\Sigma^*_{ijklm}\Sigma_{nopqr}\Sigma^*_{nopqr}$$

$$(\Sigma\Sigma^*)_2(\Sigma\Sigma^*)_2 \equiv \Sigma_{ijklm}\Sigma^*_{ijkln}\Sigma_{opqrm}\Sigma^*_{opqrn}$$

$$(\Sigma\Sigma^*)_4(\Sigma\Sigma^*)_4 \equiv \Sigma_{ijklm}\Sigma^*_{ijkno}\Sigma_{pqrlm}\Sigma^*_{pqrno}$$

$$(\Sigma\Sigma^*)_{4'}(\Sigma\Sigma^*)_{4'} \equiv \Sigma_{ijklm}\Sigma^*_{ijkno}\Sigma_{pqrln}\Sigma^*_{pqrmo}$$

$$(\Sigma\Sigma)_2(\Sigma\Sigma)_2 \equiv \Sigma_{ijklm}\Sigma_{ijkln}\Sigma_{opqrm}\Sigma_{opqrn}$$

$$(\phi)_2(\Sigma\Sigma^*)_2 \equiv \phi_{ij}\Sigma_{klmni}\Sigma^*_{klmnj}$$

$$(\phi\phi)_0(\Sigma\Sigma^*)_0 \equiv \phi_{ij}\phi_{ij}\Sigma_{klmno}\Sigma^*_{klmno}$$

$$(\phi\phi)_4(\Sigma\Sigma^*)_4 \equiv \phi_{ij}\phi_{kl}\Sigma_{mnoij}\Sigma^*_{mnokl}$$

$$(\phi\phi)_{4'}(\Sigma\Sigma^*)_{4'} \equiv \phi_{ij}\phi_{kl}\Sigma_{mnoik}\Sigma^*_{mnojl}$$

$$(\phi\phi)_2(\Sigma\Sigma)_2 \equiv \phi_{ij}\phi_{ik}\Sigma_{lmnoj}\Sigma_{lmnok}$$

$$(\phi\phi)_2(\Sigma^*\Sigma^*)_2 \equiv \phi_{ij}\phi_{ik}\Sigma^*_{lmnoj}\Sigma^*_{lmnok}$$

The minimal SO(10) Higgs ~~model~~ nightmare

Scalar potential: $V = V_{45} + V_{126} + V_{\rm mix}$

$$V_{45} = -\frac{\mu^2}{2}(\phi\phi)_0 + \frac{a_0}{4}(\phi\phi)_0(\phi\phi)_0 + \frac{a_2}{4}(\phi\phi)_2(\phi\phi)_2\,,$$

$$\begin{aligned} V_{126} = &-\frac{\nu^2}{5!}(\Sigma\Sigma^*)_0 \\ &+ \frac{\lambda_0}{(5!)^2}(\Sigma\Sigma^*)_0(\Sigma\Sigma^*)_0 + \frac{\lambda_2}{(4!)^2}(\Sigma\Sigma^*)_2(\Sigma\Sigma^*)_2 \\ &+ \frac{\lambda_4}{(3!)^2(2!)^2}(\Sigma\Sigma^*)_4(\Sigma\Sigma^*)_4 + \frac{\lambda'_4}{(3!)^2}(\Sigma\Sigma^*)_{4'}(\Sigma\Sigma^*)_{4'} \\ &+ \frac{\eta_2}{(4!)^2}(\Sigma\Sigma)_2(\Sigma\Sigma)_2 + \frac{\eta_2^*}{(4!)^2}(\Sigma^*\Sigma^*)_2(\Sigma^*\Sigma^*)_2\,, \end{aligned}$$

$$\begin{aligned} V_{\rm mix} = &\frac{i\tau}{4!}(\phi)_2(\Sigma\Sigma^*)_2 + \frac{\alpha}{2\cdot 5!}(\phi\phi)_0(\Sigma\Sigma^*)_0 \\ &+ \frac{\beta_4}{4\cdot 3!}(\phi\phi)_4(\Sigma\Sigma^*)_4 + \frac{\beta'_4}{3!}(\phi\phi)_{4'}(\Sigma\Sigma^*)_{4'} \\ &+ \frac{\gamma_2}{4!}(\phi\phi)_2(\Sigma\Sigma)_2 + \frac{\gamma_2^*}{4!}(\phi\phi)_2(\Sigma^*\Sigma^*)_2\,. \end{aligned}$$

$$(\phi\phi)_0(\phi\phi)_0 \equiv \phi_{ij}\phi_{ij}\phi_{kl}\phi_{kl}$$

$$(\phi\phi)_2(\phi\phi)_2 \equiv \phi_{ij}\phi_{ik}\phi_{lj}\phi_{lk}$$

$$(\phi\phi)_0 \equiv \phi_{ij}\phi_{ij}\,, \quad (\Sigma\Sigma^*)_0 \equiv \Sigma_{ijklm}\Sigma^*_{ijklm}$$

$$(\Sigma\Sigma^*)_0(\Sigma\Sigma^*)_0 \equiv \Sigma_{ijklm}\Sigma^*_{ijklm}\Sigma_{nopqr}\Sigma^*_{nopqr}$$

$$(\Sigma\Sigma^*)_2(\Sigma\Sigma^*)_2 \equiv \Sigma_{ijklm}\Sigma^*_{ijkln}\Sigma_{opqrm}\Sigma^*_{opqrn}$$

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The minimal SO(10) ~~Higgs model~~ nightmare

Tree-level scalar spectrum contains tachyons…

The minimal SO(10) ~~Higgs model~~ nightmare

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

$$\langle 45 \rangle = \begin{pmatrix} \omega_{BL} & & & & \\ & \omega_{BL} & & & \\ & & \omega_{BL} & & \\ & & & \omega_R & \\ & & & & \omega_R \end{pmatrix} \otimes \sigma_2$$

Yasuè 1981, Anastaze, Derendinger, Buccella 1983, Babu, Ma 1985

flipped-SU(5)-like vacua only!

The minimal SO(10) Higgs ~~model~~ nightmare

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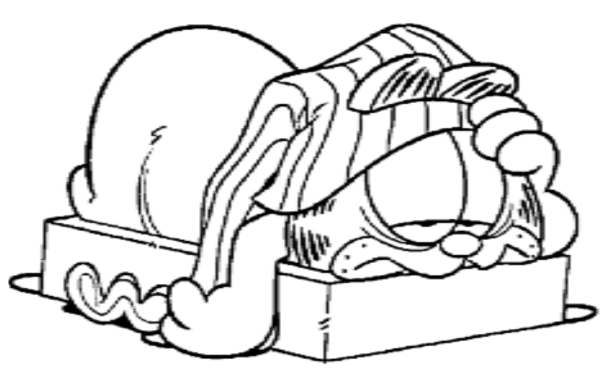
???



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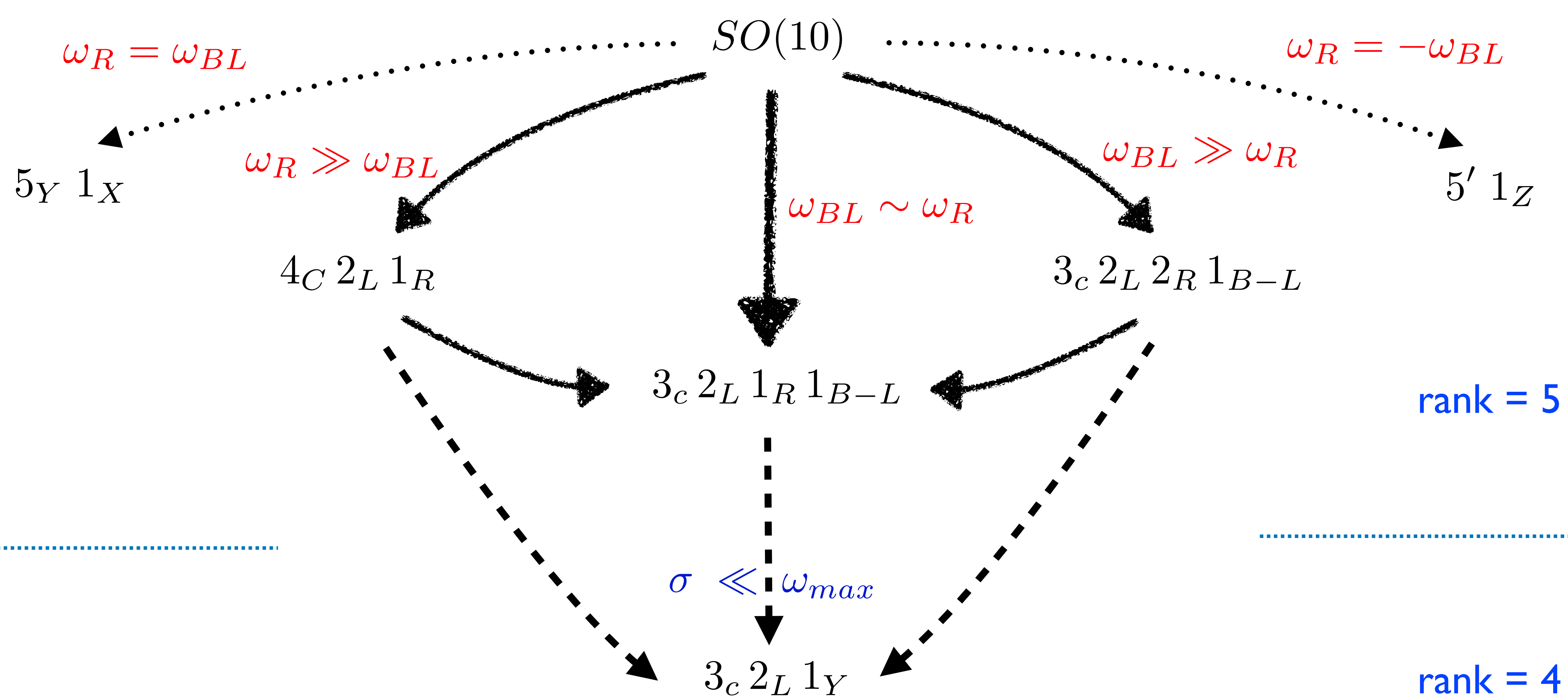
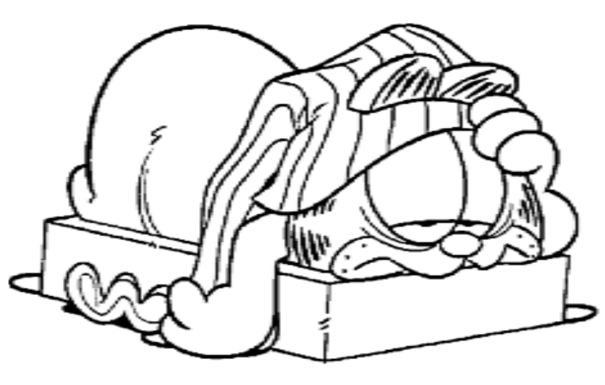
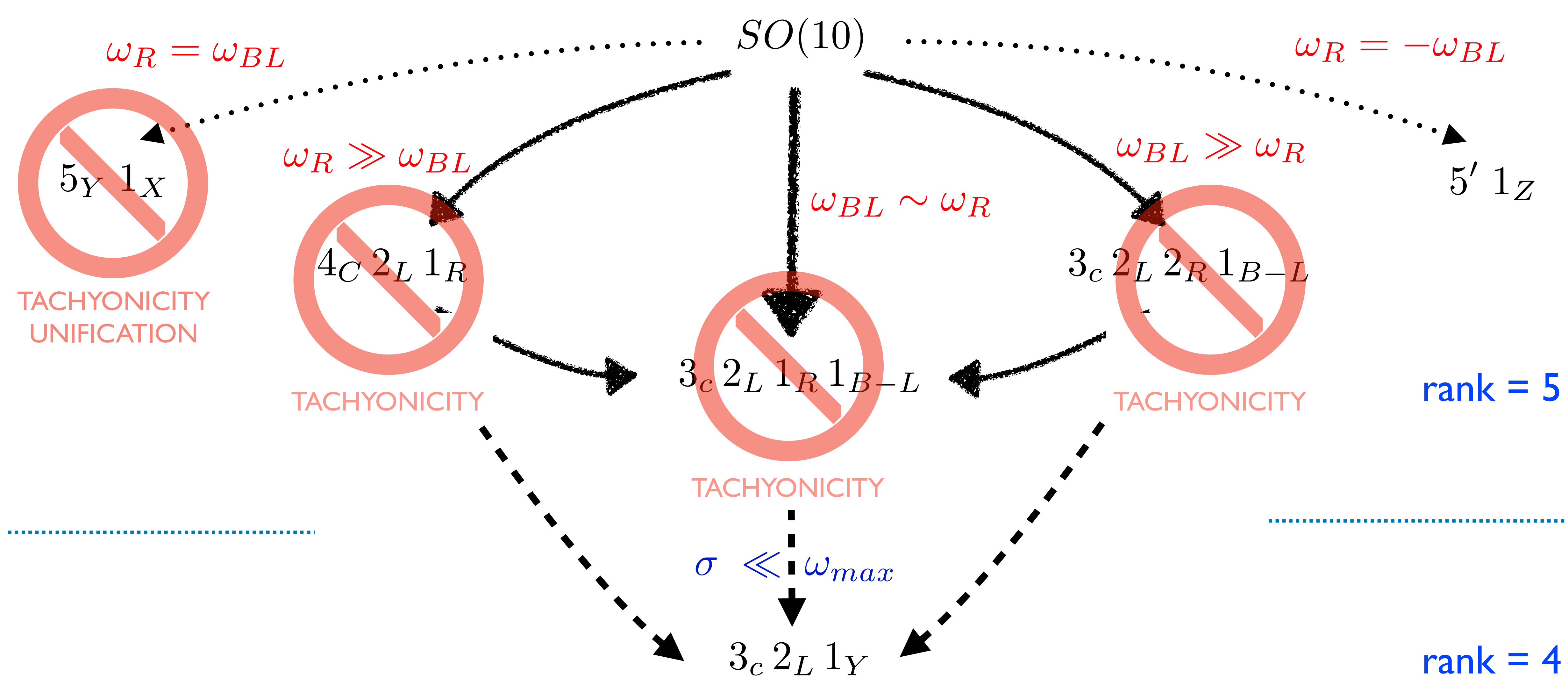
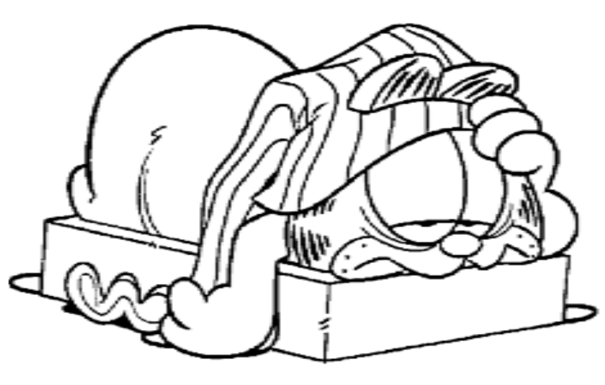


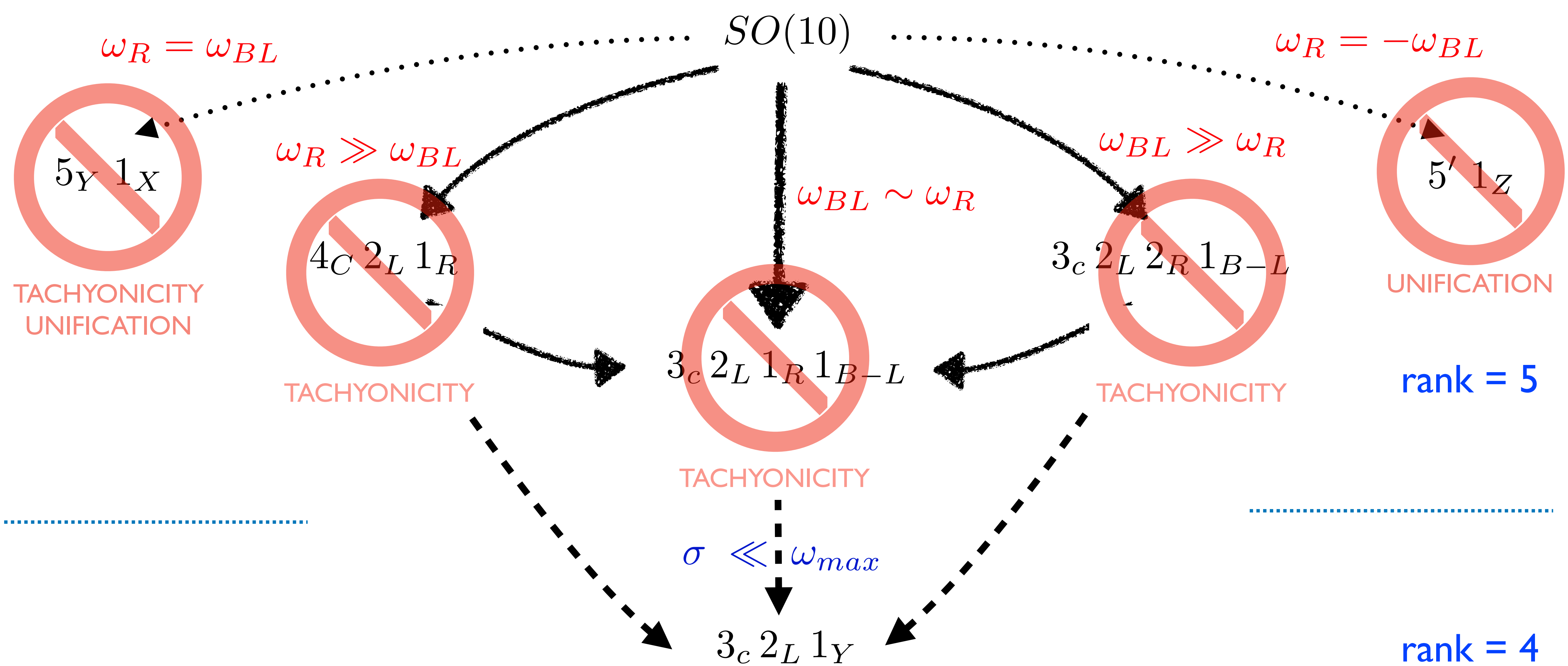


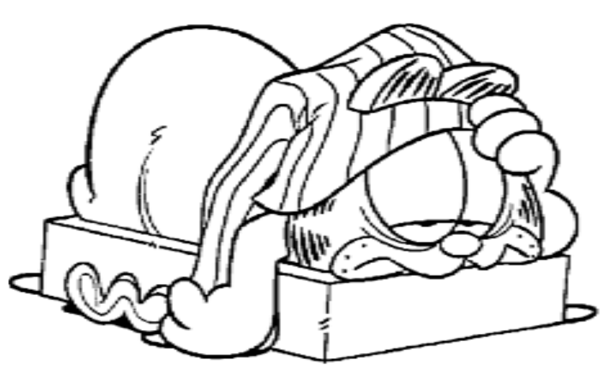
The minimal SO(10) Higgs ~~model~~ nightmare





The minimal SO(10) ~~Higgs model~~ nightmare





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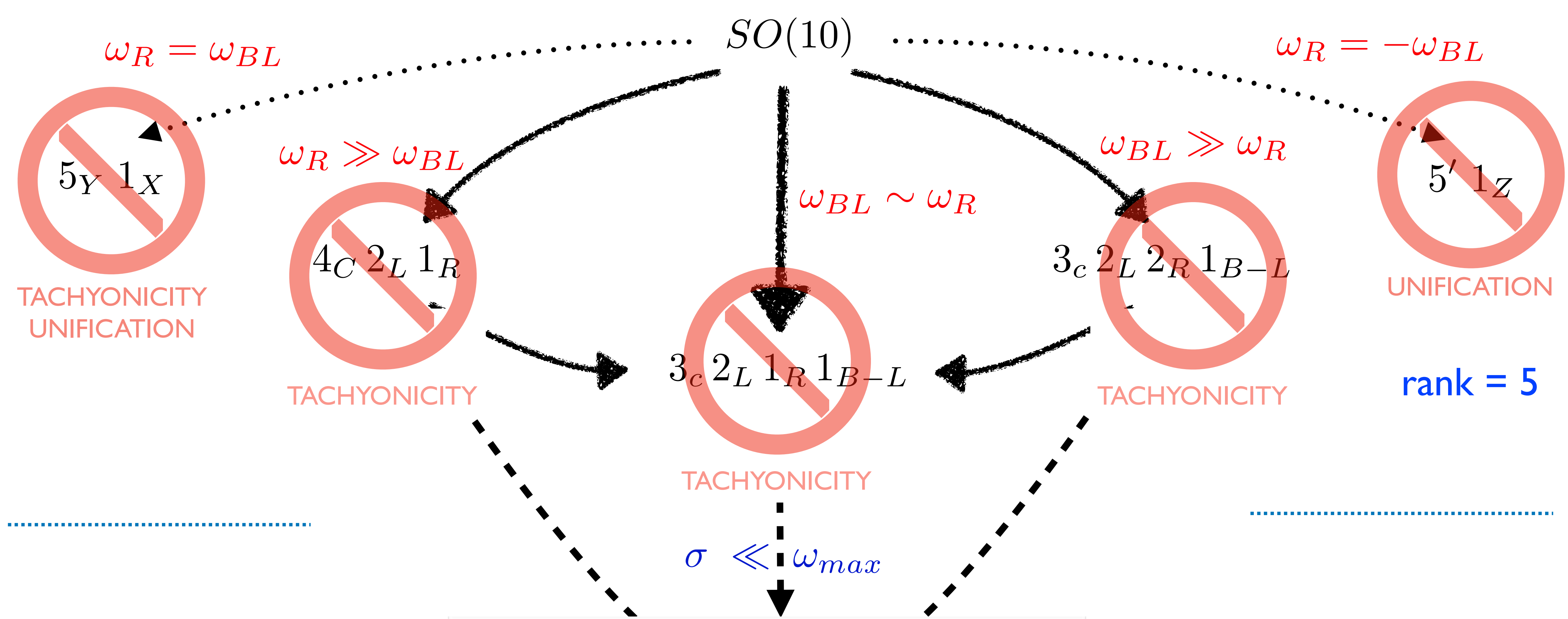

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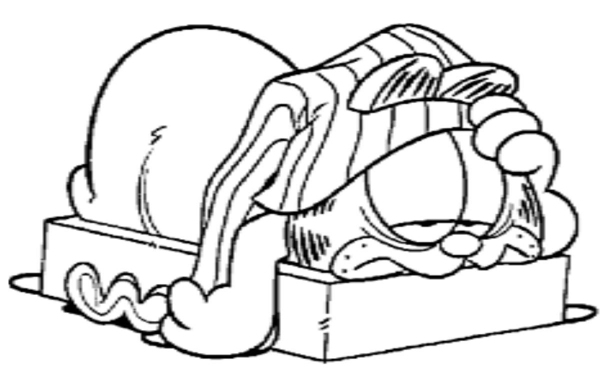

"Never trust arguments based on the lowest order of perturbative expansion!"

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

The minimal quantum SO(10) Higgs ~~model~~ nightmare

S. Bertolini, L. Di Luzio, MM, PRD 81, 035015 (2010)

Radiative corrections can change the situation completely!

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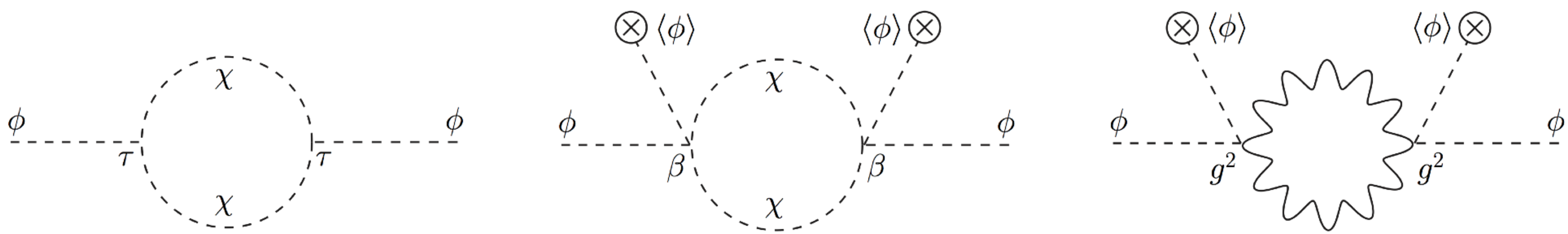

$$\Delta m^2_{(1,3,0)} = \frac{1}{4\pi^2}\left[\tau^2 + \beta^2(2\omega_R^2 - \omega_R\omega_Y + 2\omega_Y^2) + g^4\left(16\omega_R^2 + \omega_Y\omega_R + 19\omega_Y^2\right)\right] + \text{logs}\,,$$

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

See also L. Gráf, H. Kolešová, MM, T. Mede, V. Susič PRD 95, 075007 (2017)

The minimal quantum SO(10) Higgs ~~model~~ super-nightmare

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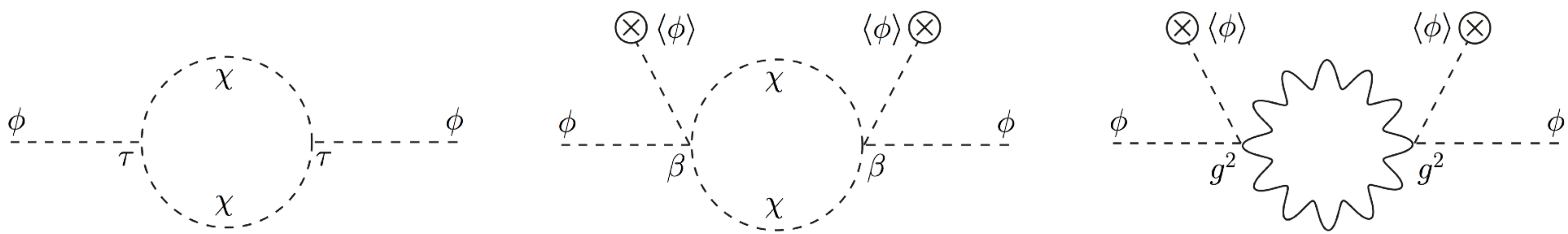

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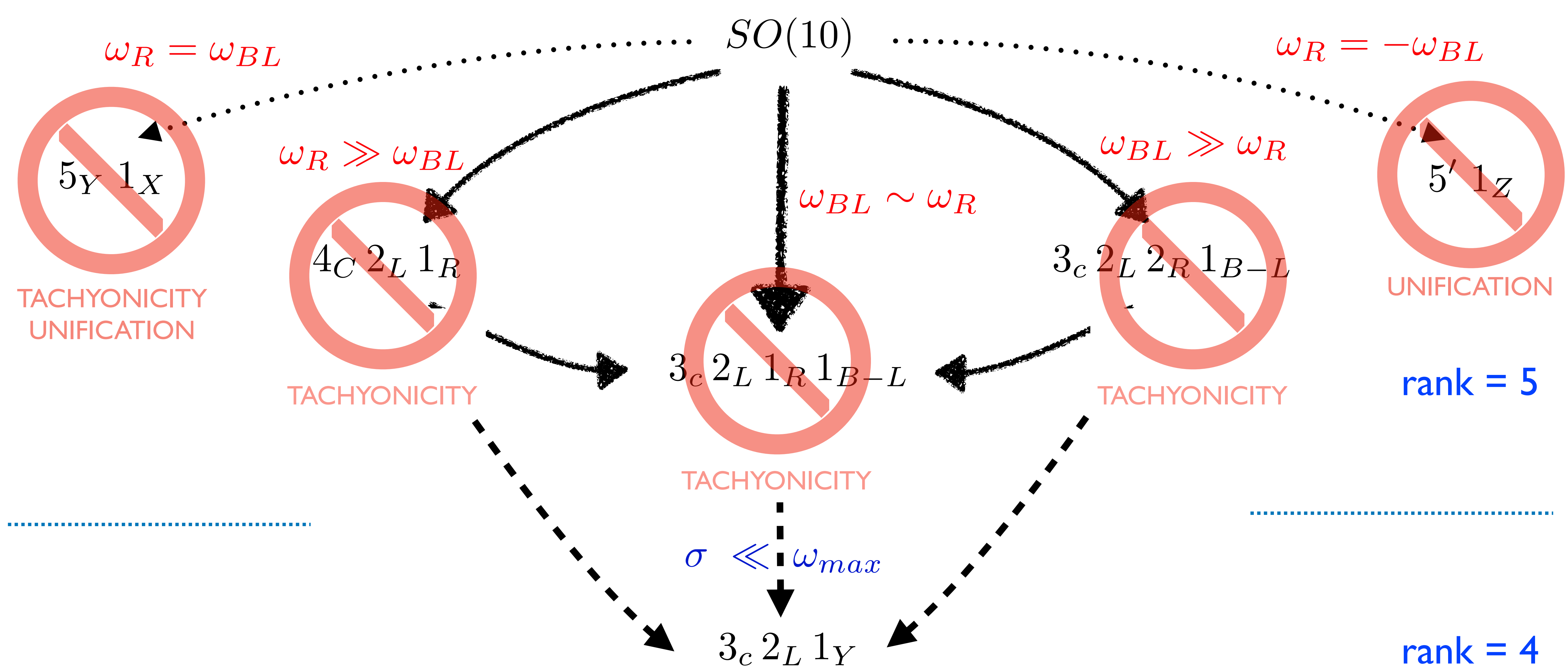
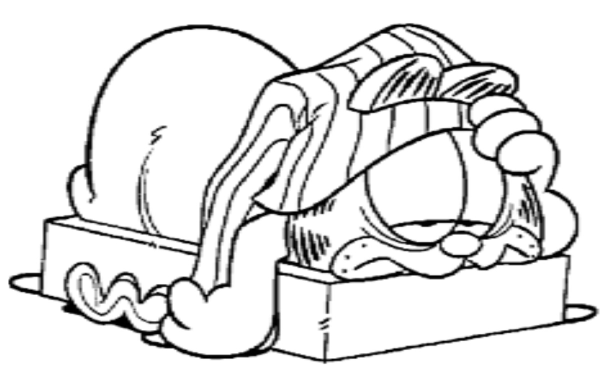
The minimal quantum SO(10) Higgs model breaking landscape





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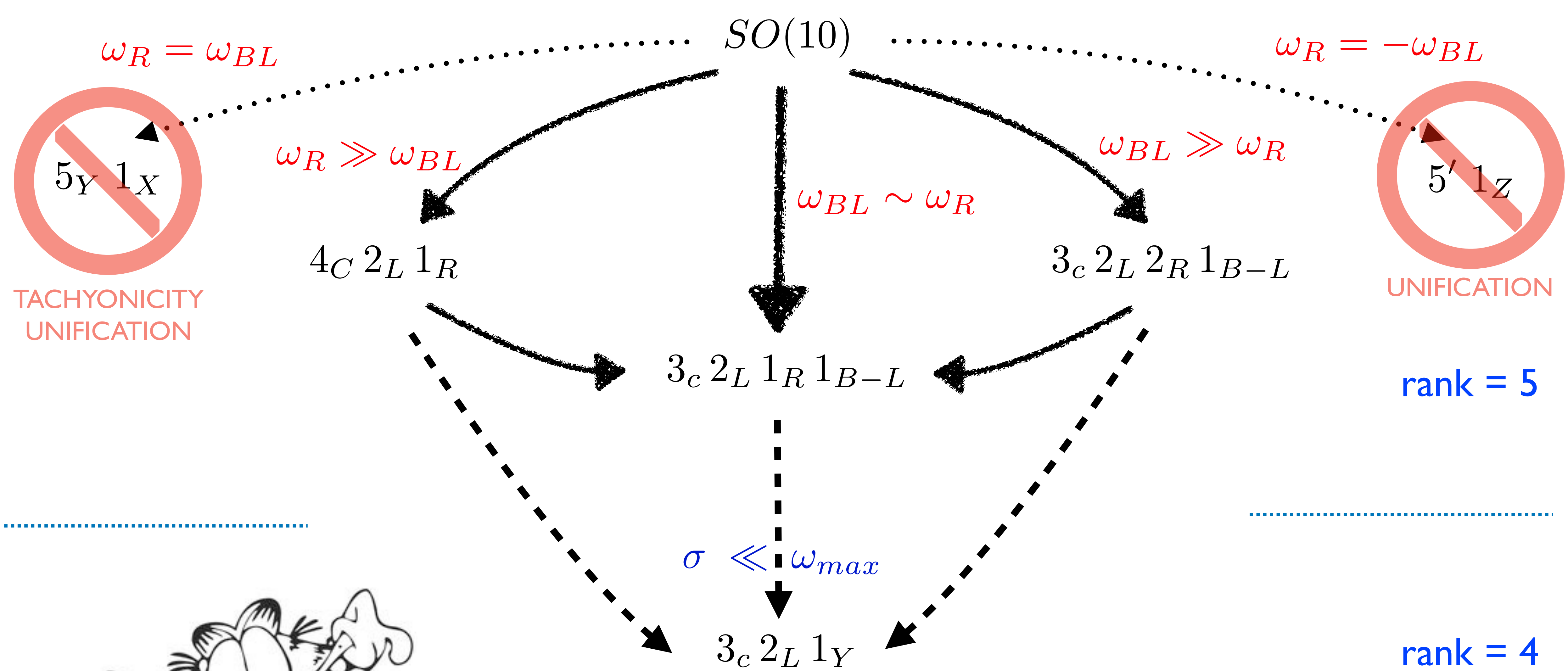

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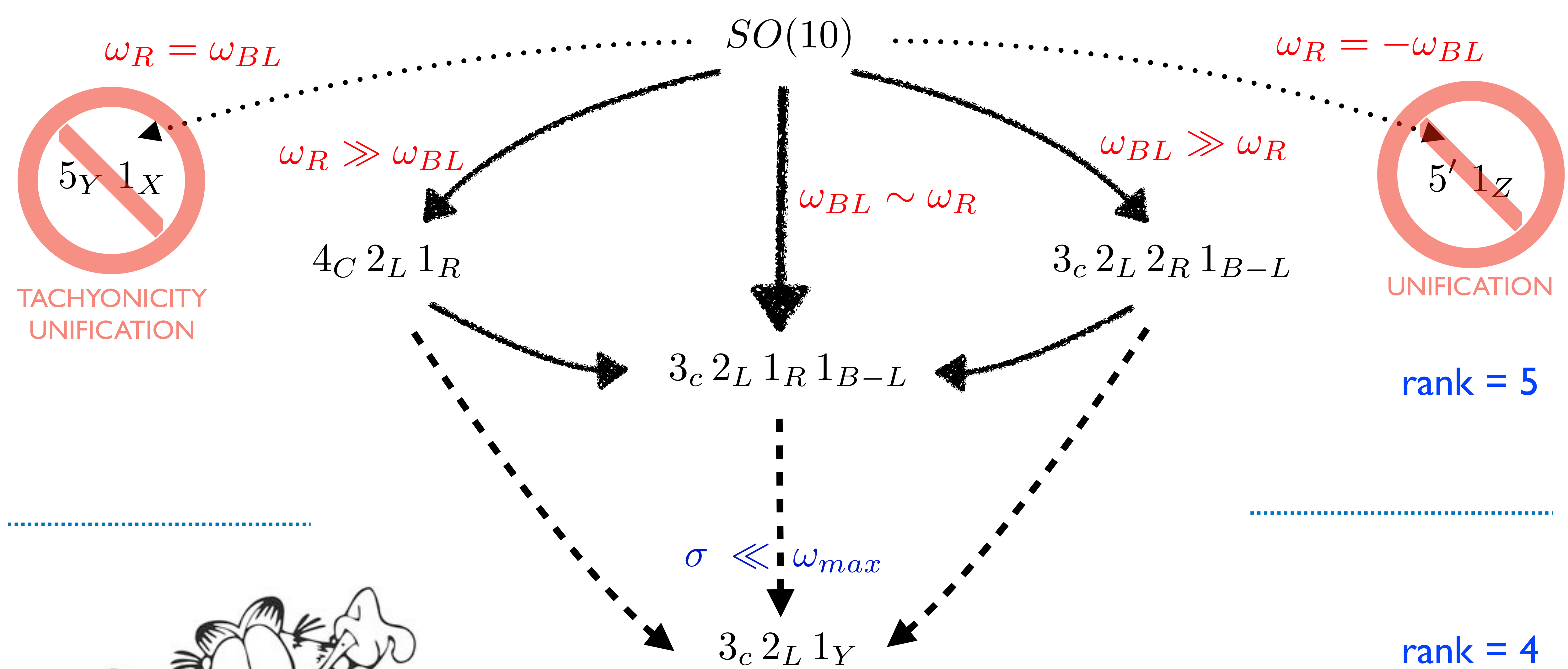

Beware! $\dfrac{\omega_R \omega_{BL}}{|\sigma|^2}$ all over the place!

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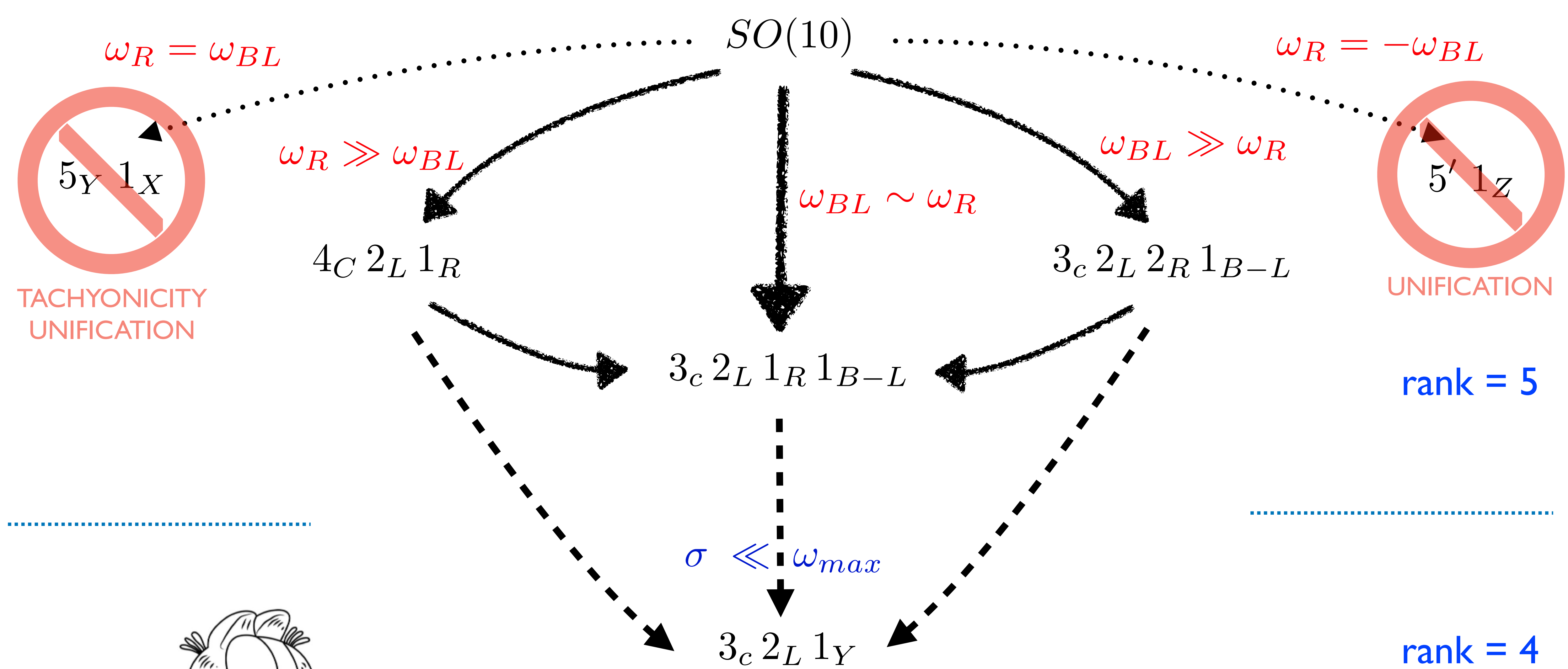

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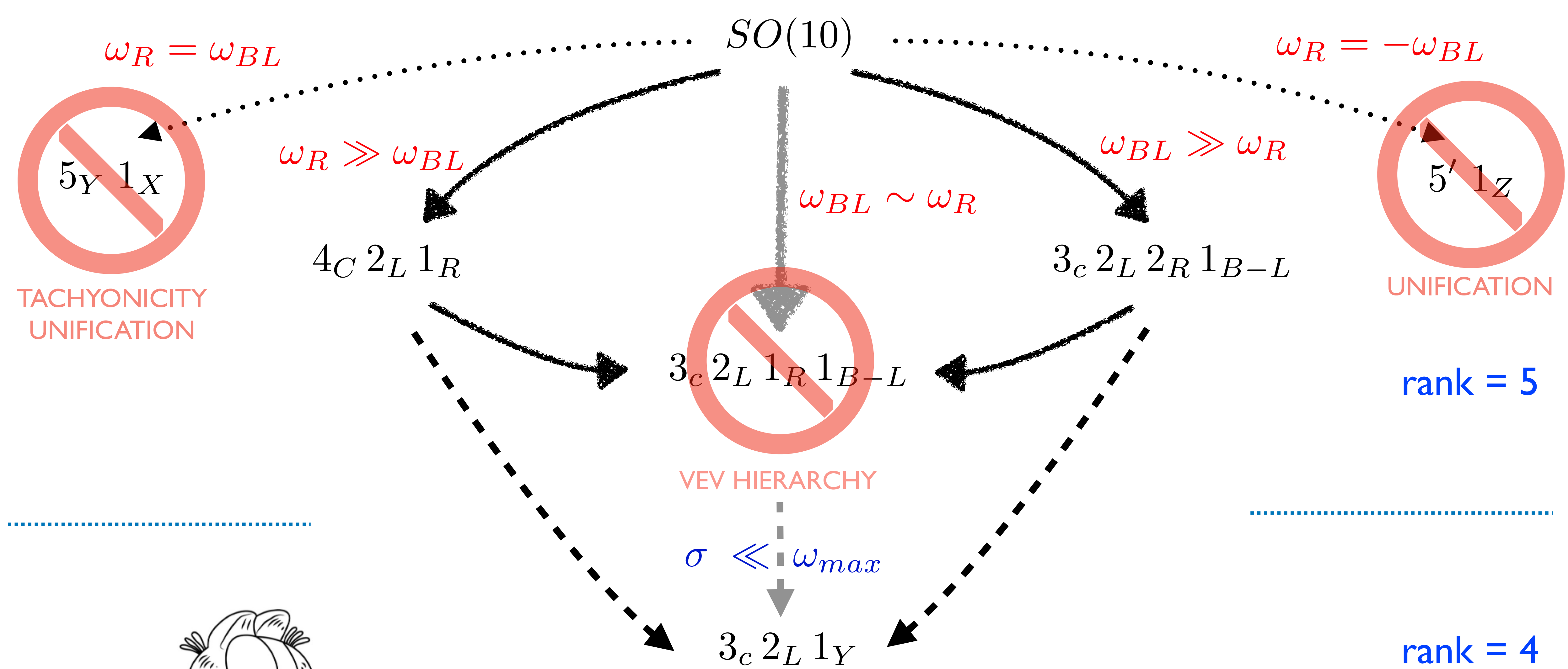

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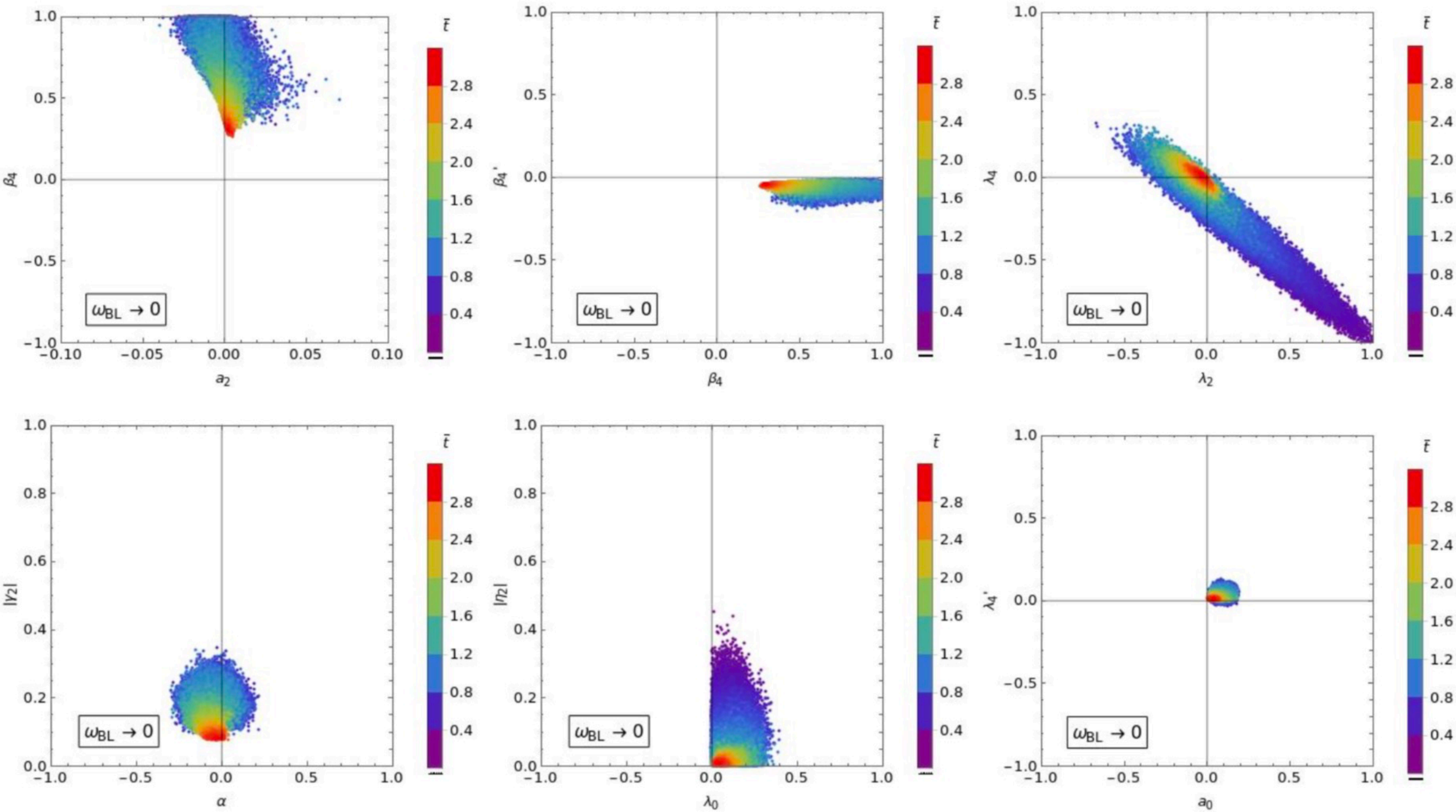
The scalar sector of the model is non-perturbative :-(

$SO(10) \to 4_C 2_L 1_R \to \mathrm{SM}$

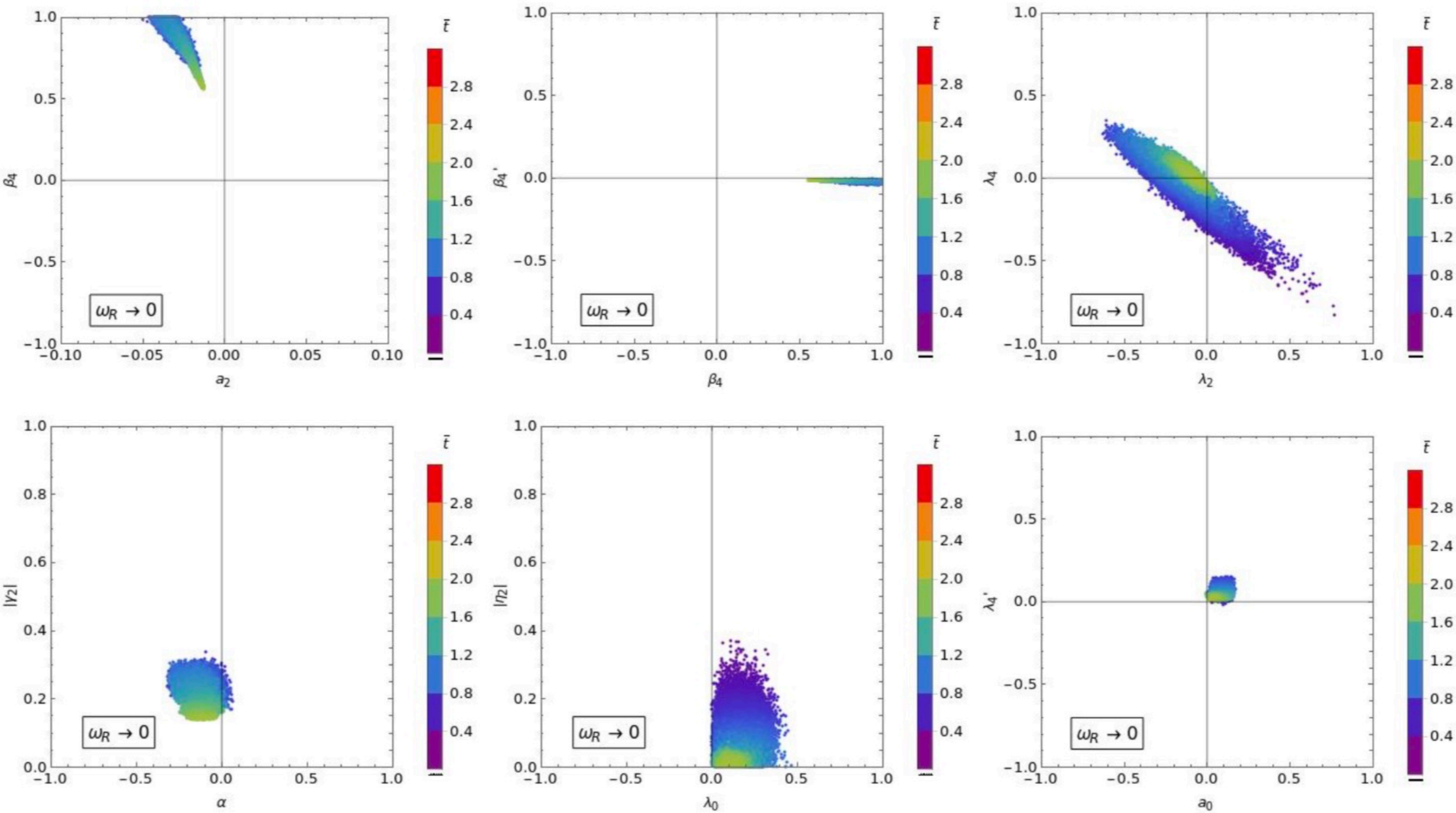
K. Jarkovská, MM, T. Mede, V. Susič, PRD 105, 095003 (2022)



The scalar sector of the model is non-perturbative :-(

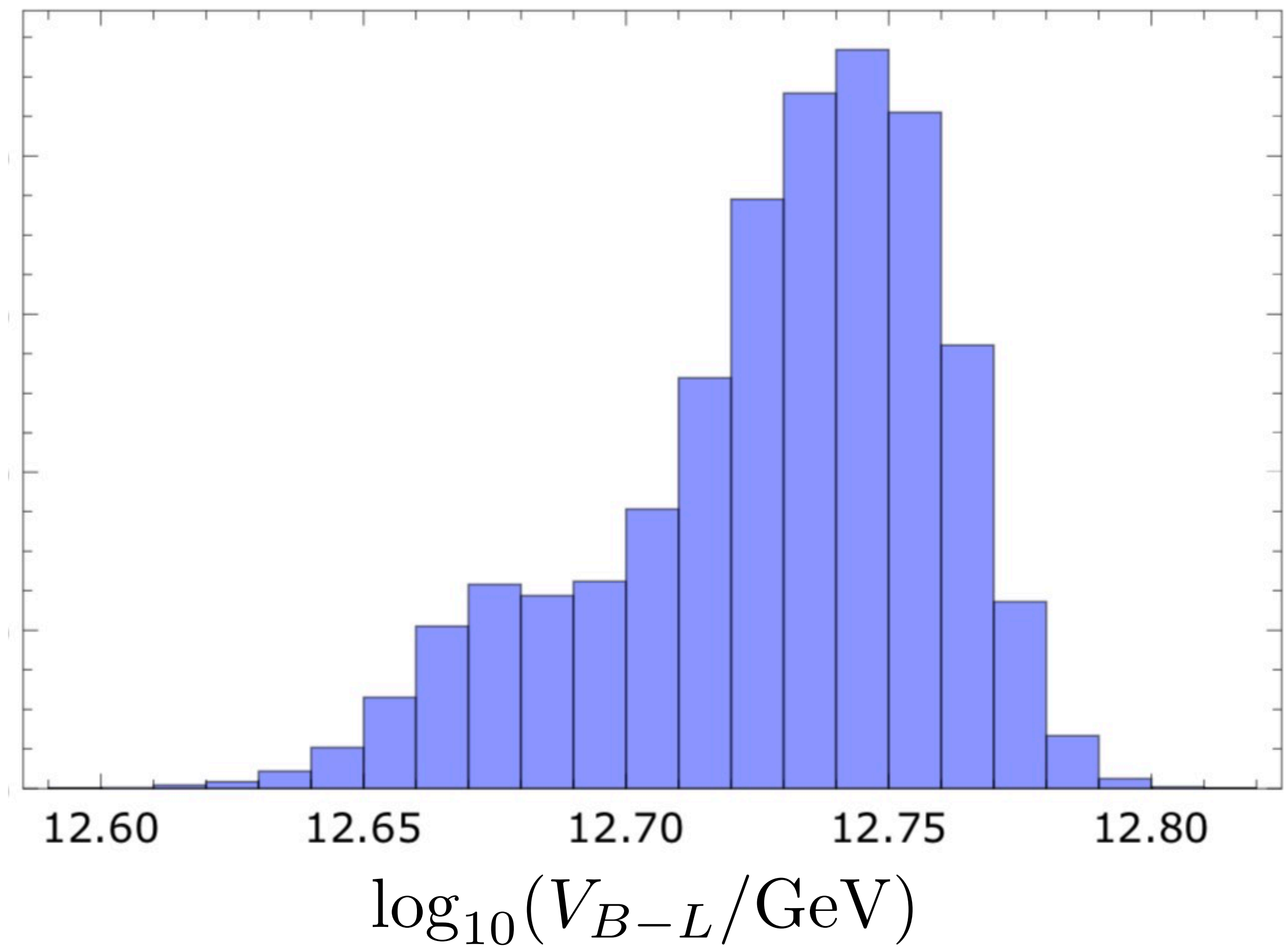
$SO(10) \to 3_c 2_L 2_R 1_{B-L} \to \mathrm{SM}$

K. Jarkovská, MM, T. Mede, V. Susič, PRD 105, 095003 (2022)



B-L scale in the minimal SO(10) from LG & flavour only (!!!)

LG constricts B-L into a very narrow region



Very preliminary, research in progress (R.I.P.)

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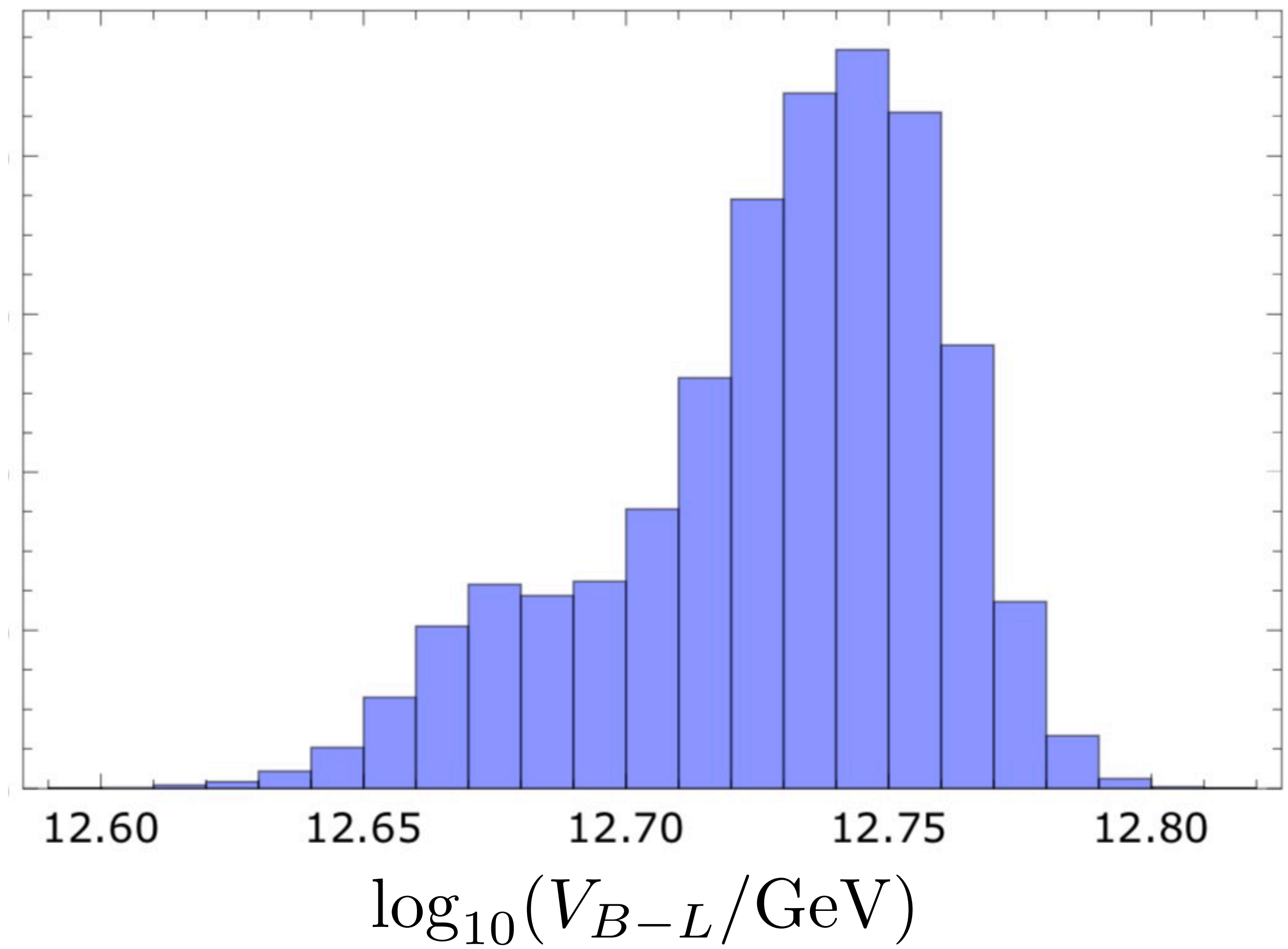

Very preliminary, research in progress (R.I.P.)

Exactly where gauge unification in non-SUSY SO(10) needs it !

Take home messages

1) It makes perfect sense to look at leptogenesis even in models featuring rich enough dynamics for baryogenesis to proceed in the "direct mode"

2) Baryon asymmetry may be a very good discriminator, especially if the flavour structure of such models happens to be strongly constrained

Thanks for your attention!