Hirschfest, Valencia, January 24 2024

The minimally flipped "you-know-what"

Michal Malinský

IPNP, Charles University in Prague

based on arXiv:2312.08357 [hep-ph]

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The minimally flipped leptogenesis

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… and at some point Martin got rather depressed about it :-)

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PHYSICAL REVIEW D **75,** 011701(R) (2007)

Thermal leptogenesis in extended supersymmetric seesaw model

M. Hirsch* and J. W. F. Valle†

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Physical Research Laboratory, Ahmedabad 380 009, India

(Received 10 August 2006; published 29 January 2007)

We consider an extended supersymmetric SO(10) seesaw model with only doublet Higgs scalars, in which neutrino masses are suppressed by the scale of *D*-parity violation. Leptogenesis can occur at the TeV scale through the decay of a singlet Σ, thereby avoiding the gravitino crisis. Washout of the asymmetry can be effectively suppressed by the absence of direct couplings of Σ to leptons.

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A bit of HEP-centric etymology & a pictogram

Leptogenesis

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Lep togenesis

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LEP togenesis

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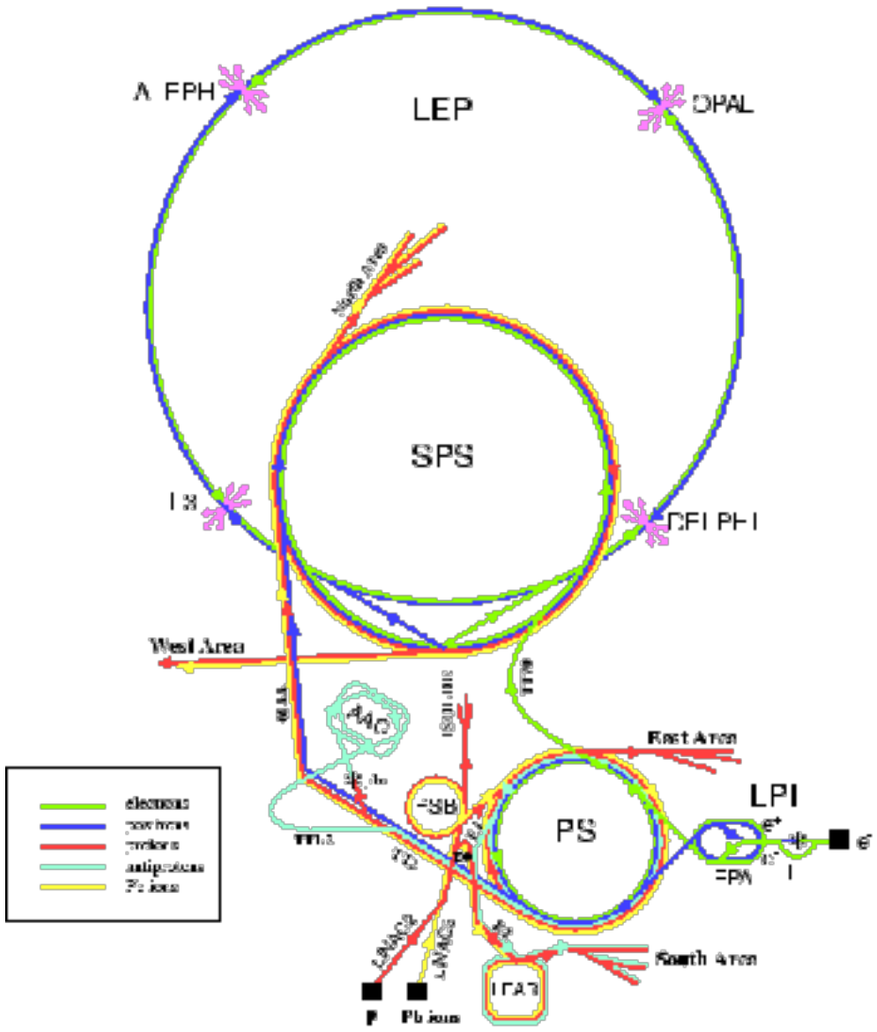

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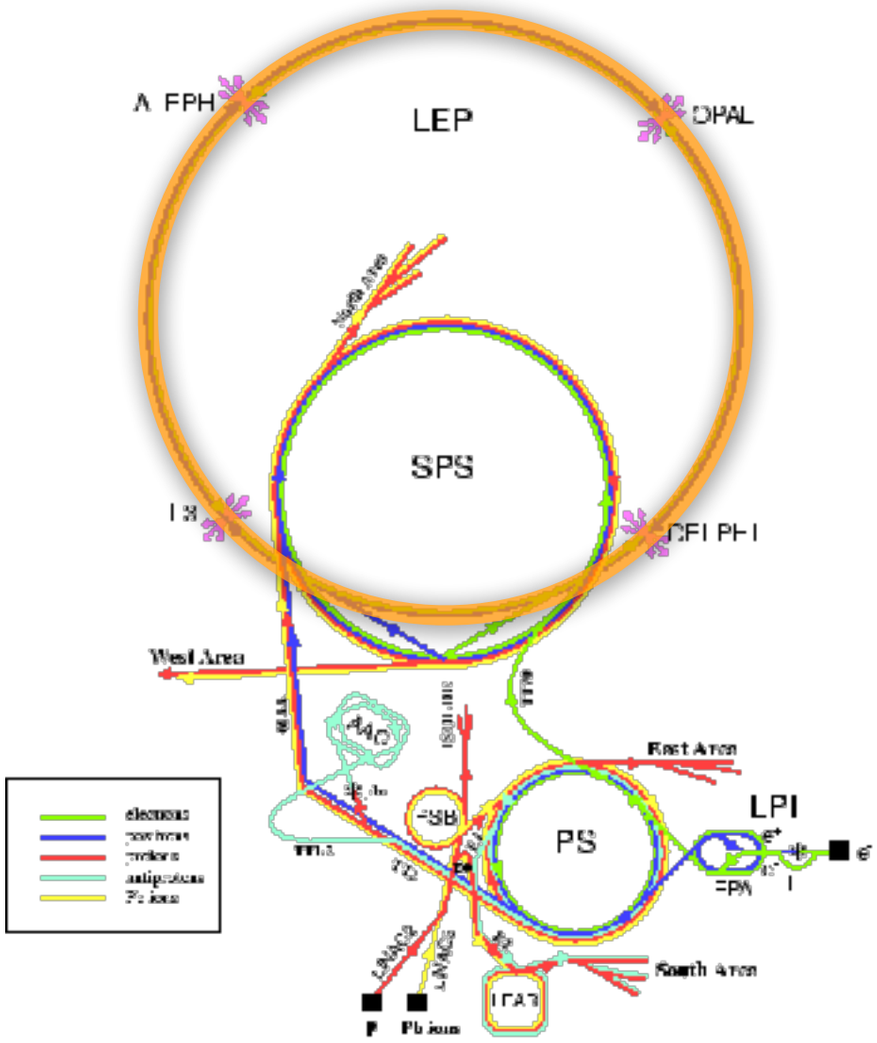

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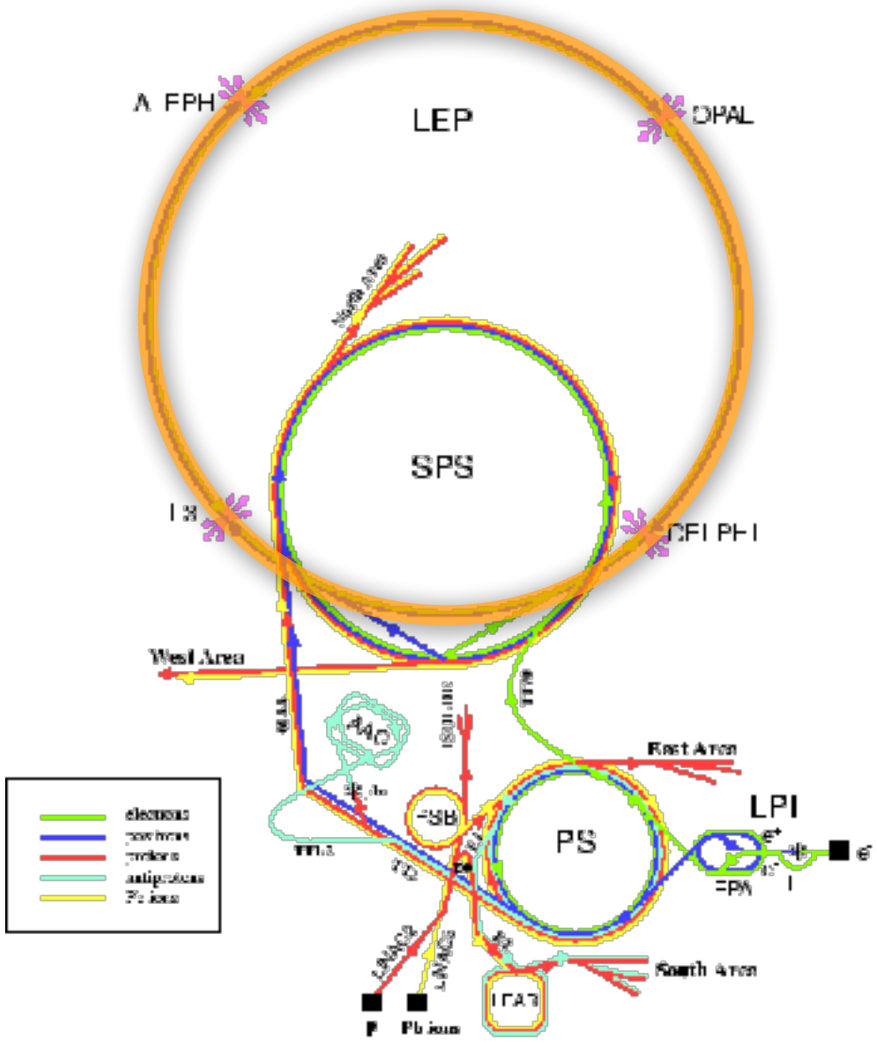

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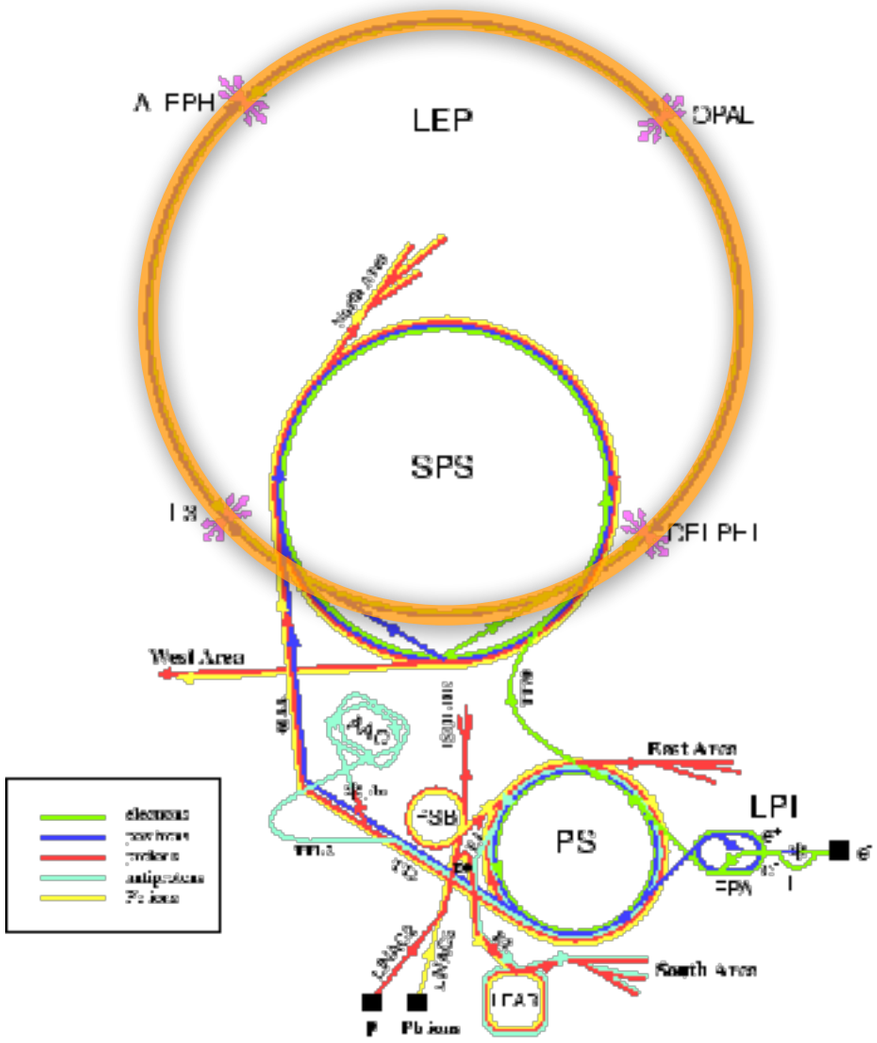

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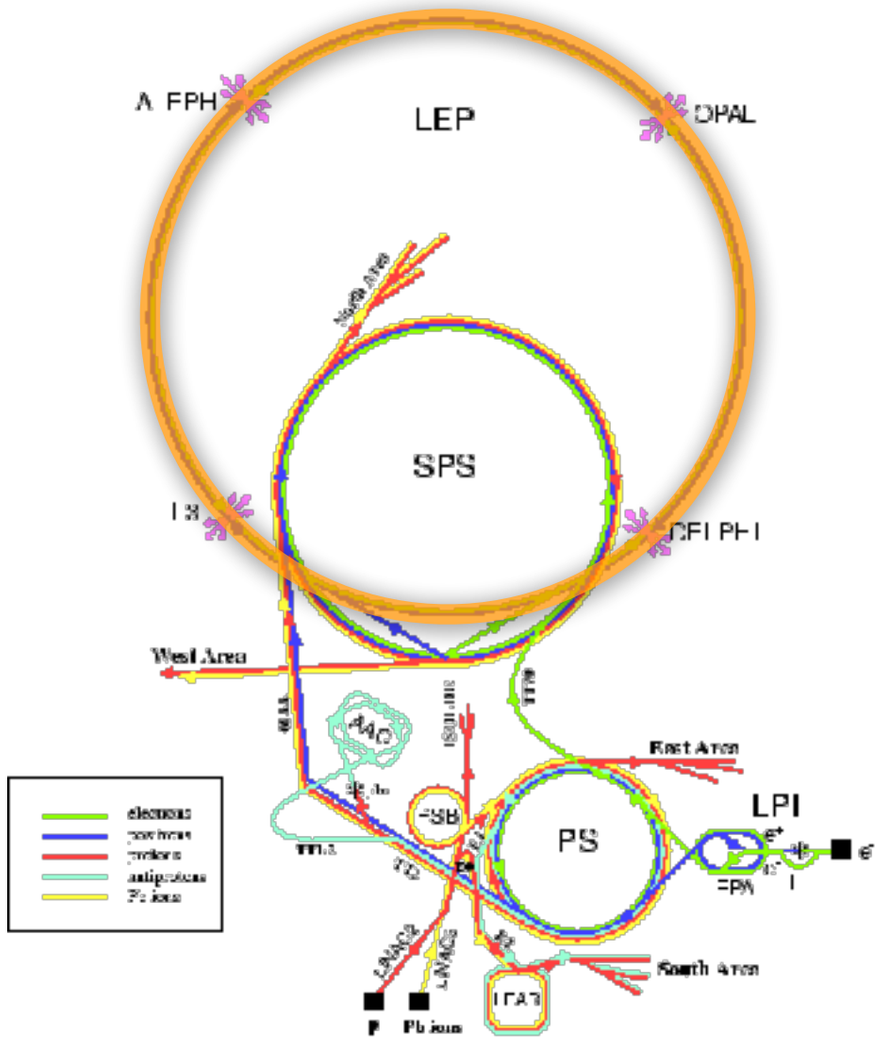

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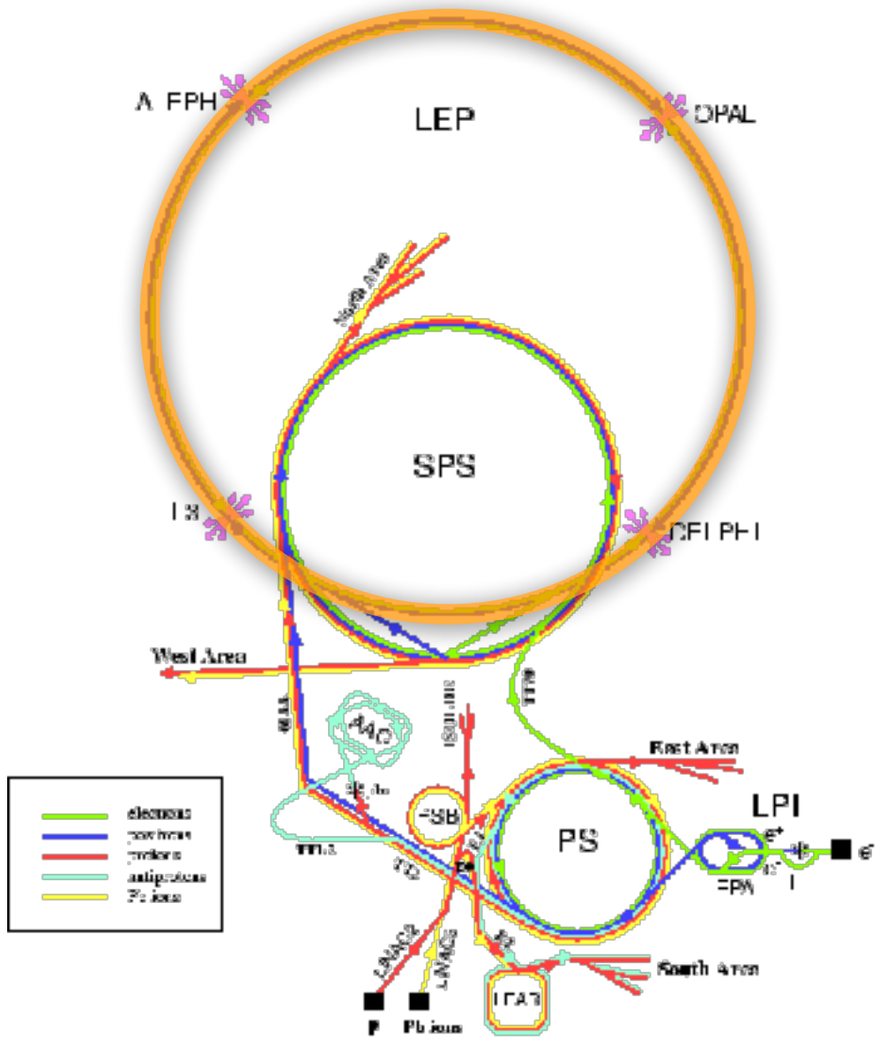

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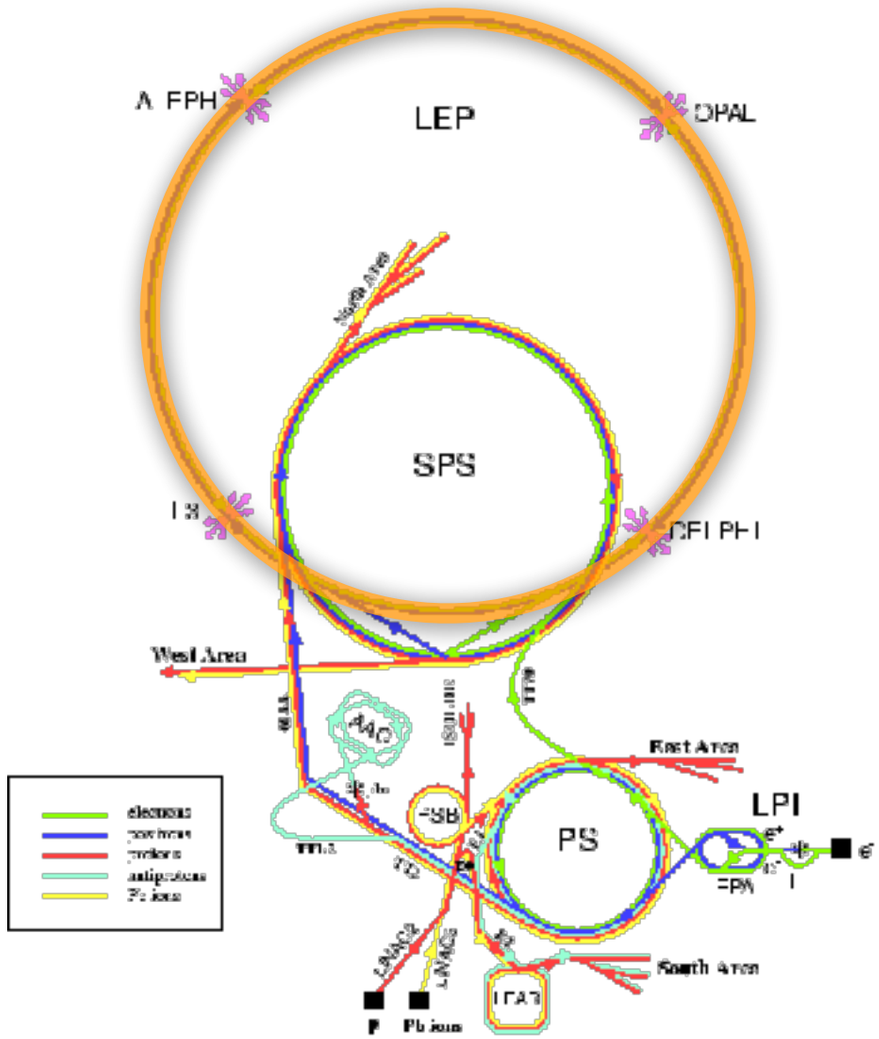

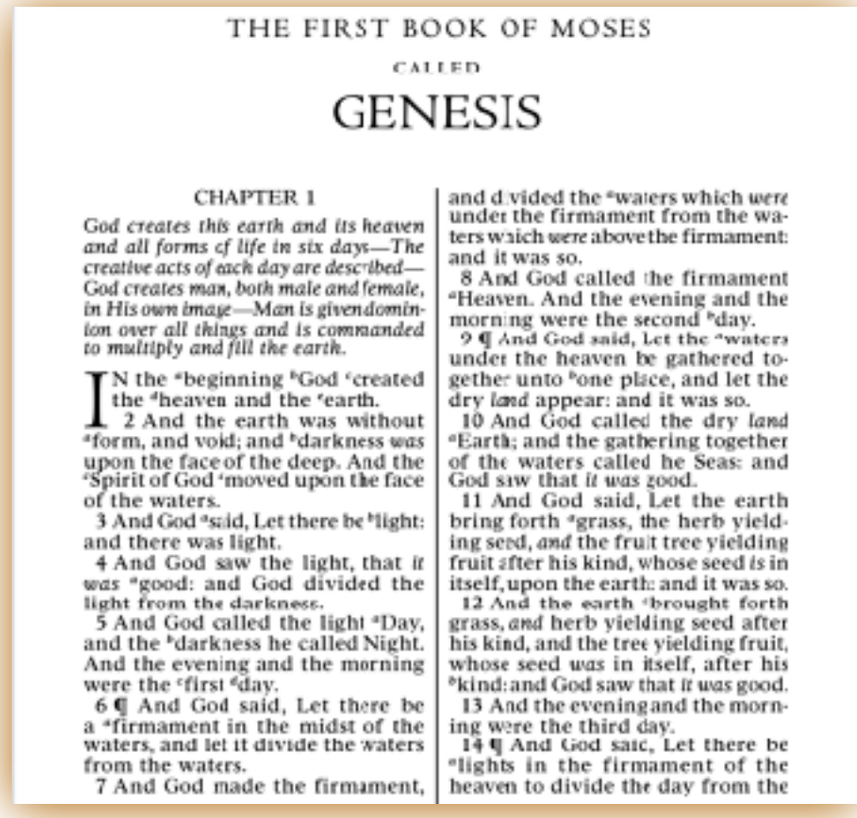

THE FIRST BOOK OF MOSES

CALLED

GENESIS

CHAPTER 1

God creates this earth and its heaven and all forms of life in six days—The creative acts of each day are described—God creates man, both male and female, in His own image—Man is given dominion over all things and is commanded to multiply and fill the earth.

IN the [a]beginning [b]God [c]created the [d]heaven and the [e]earth.
2 And the earth was without [a]form, and void; and [b]darkness *was* upon the face of the deep. And the [c]Spirit of God [d]moved upon the face of the waters.
3 And God [a]said, Let there be [b]light: and there was light.
4 And God saw the light, that *it* was [a]good: and God divided the light from the darkness.
5 And God called the light [a]Day, and the [b]darkness he called Night. And the evening and the morning were the [c]first [d]day.
6 ¶ And God said, Let there be a [a]firmament in the midst of the waters, and let it divide the waters from the waters.
7 And God made the firmament, and divided the [a]waters which *were* under the firmament from the waters which *were* above the firmament: and it was so.
8 And God called the firmament [a]Heaven. And the evening and the morning were the second [b]day.
9 ¶ And God said, Let the [a]waters under the heaven be gathered together unto [b]one place, and let the dry *land* appear: and it was so.
10 And God called the dry *land* [a]Earth; and the gathering together of the waters called he Seas: and God saw that *it* was good.
11 And God said, Let the earth bring forth [a]grass, the herb yielding seed, *and* the fruit tree yielding fruit after his kind, whose seed *is* in itself, upon the earth: and it was so.
12 And the earth [a]brought forth grass, *and* herb yielding seed after his kind, and the tree yielding fruit, whose seed *was* in itself, after his [b]kind: and God saw that *it was* good.
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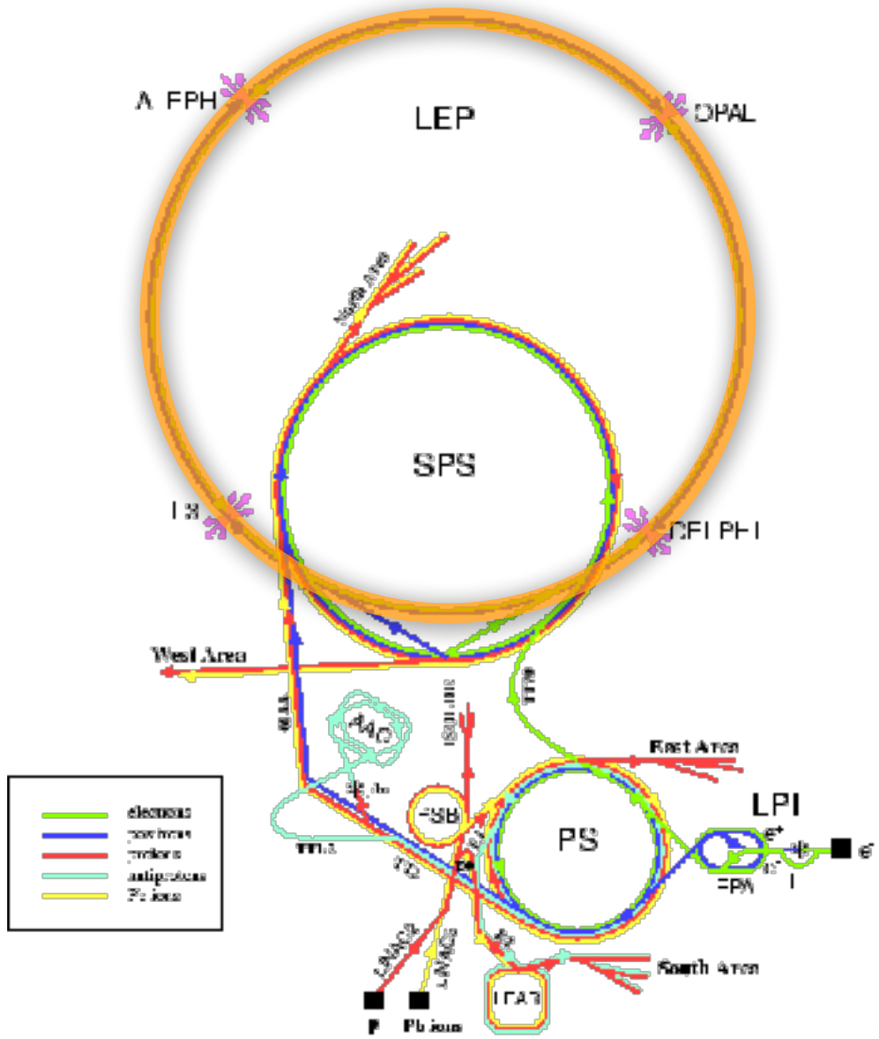

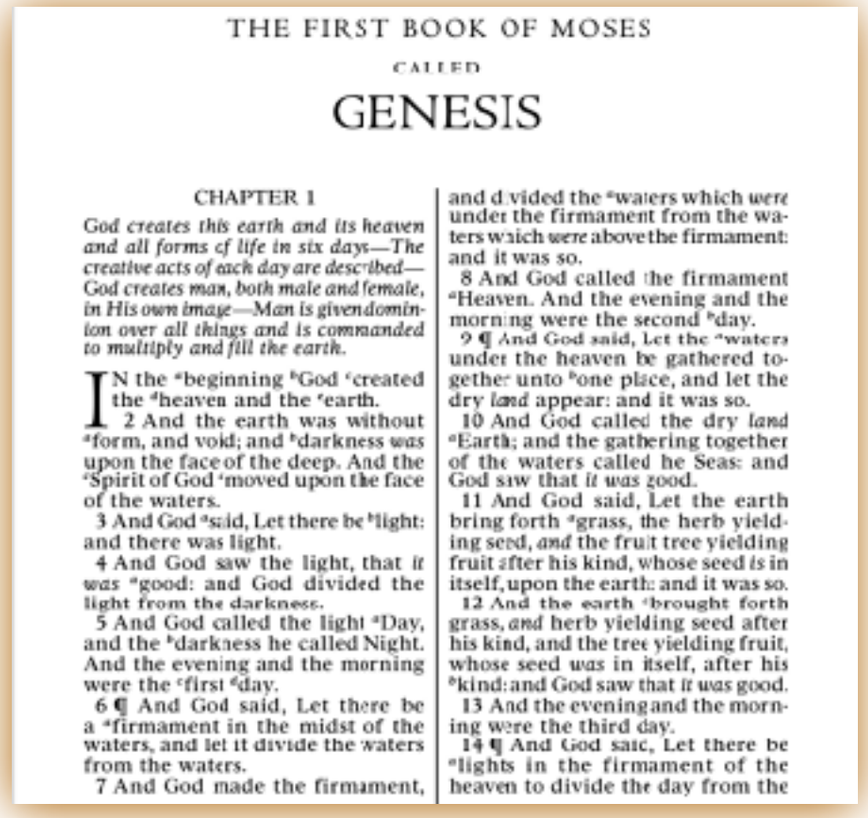

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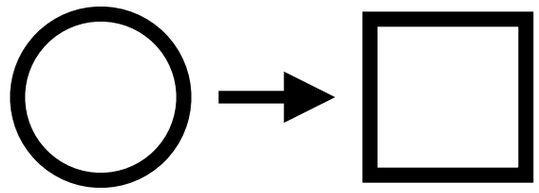

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η_B may turn into a strong discriminator if further constraints on Yukawas and/or neutrino spectral shape are at place (top-down)

Take-home message

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The minimal unified model with flipped hypercharge assignment is a perfect illustration of this!

Hirschfest, Valencia, January 24 2024

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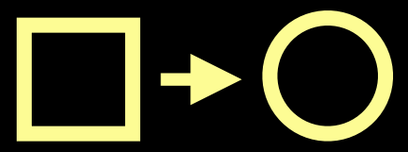
The minimal 

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The minimal □→○

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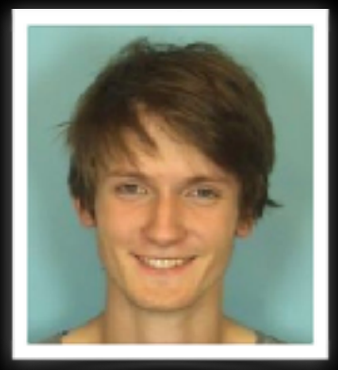
starring :



Václav Miřátský

Renato Fonseca

Martin Zdráhal

co-starring :

C. Arbelaez Rodriguez

H. Kolešová

D. Harries

based on arXiv:2312.08357 [hep-ph] , Phys.Rev. D98, 095015 (2018) and Phys.Rev. D89, 055003 (2014)

Flipped SU(5) one-minute crash 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:

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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_V rules them all

$\Gamma(p \to \pi^0 \ell_\alpha^+)$	$\Gamma(p \to \pi^+ \overline{\nu})$	$\Gamma(n \to \pi^- \ell_\alpha^+)$	$\Gamma(n \to \pi^0 \overline{\nu})$
$\Gamma(p \to K^0 \ell_\alpha^+)$	$\Gamma(p \to K^+ \overline{\nu})$	$\Gamma(n \to K^- \ell_\alpha^+)$	$\Gamma(n \to K^0 \overline{\nu})$
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Nath, Fileviez-Perez, Phys.Rept.441

Charged mesons:
(no flavour ambiguity!)

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

Dorsner, Fileviez-Perez, PLB605

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

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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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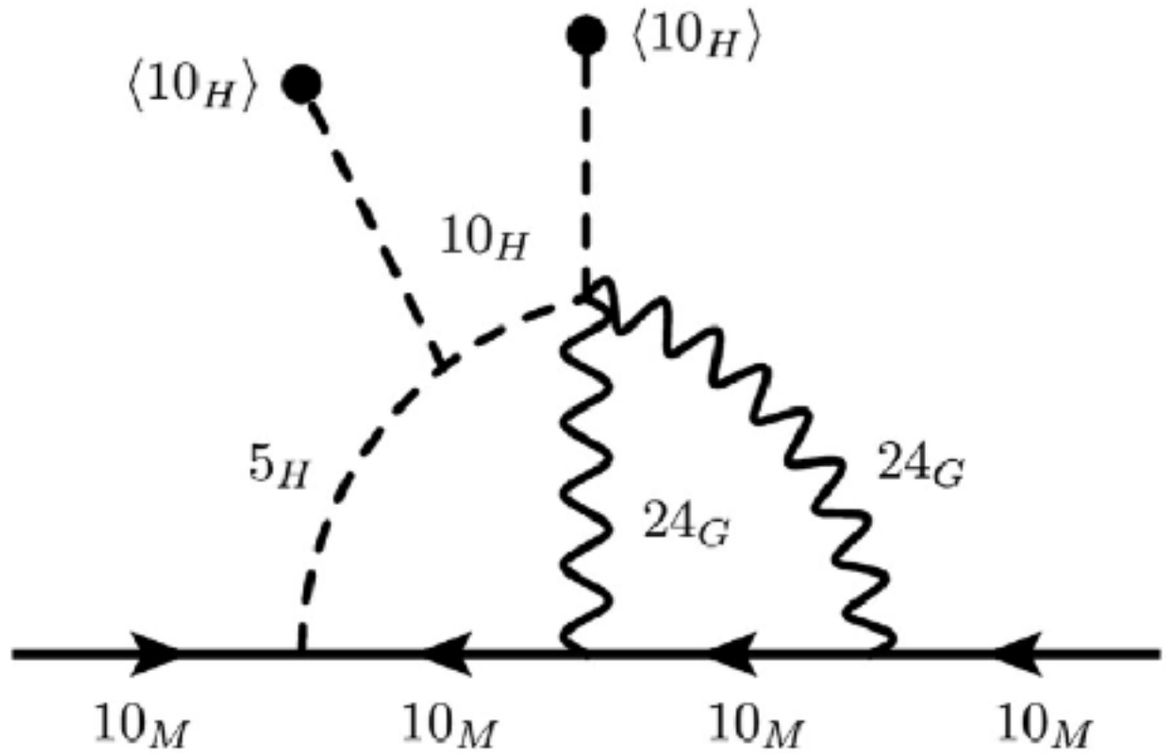
Witten's loop option: C. Arbelaez-Rodriguez, H. Kolešová, MM PRD89 (2014)



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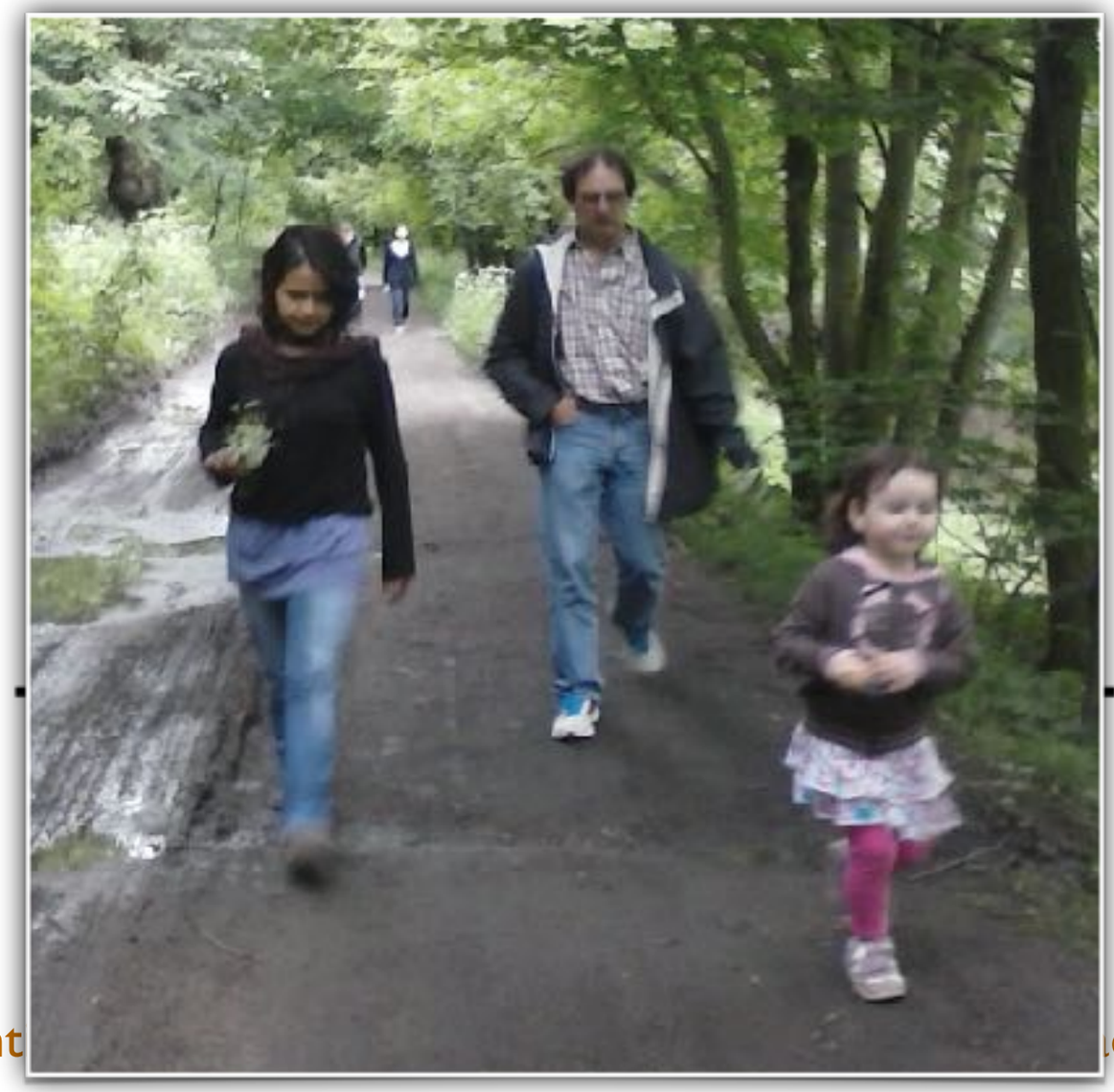

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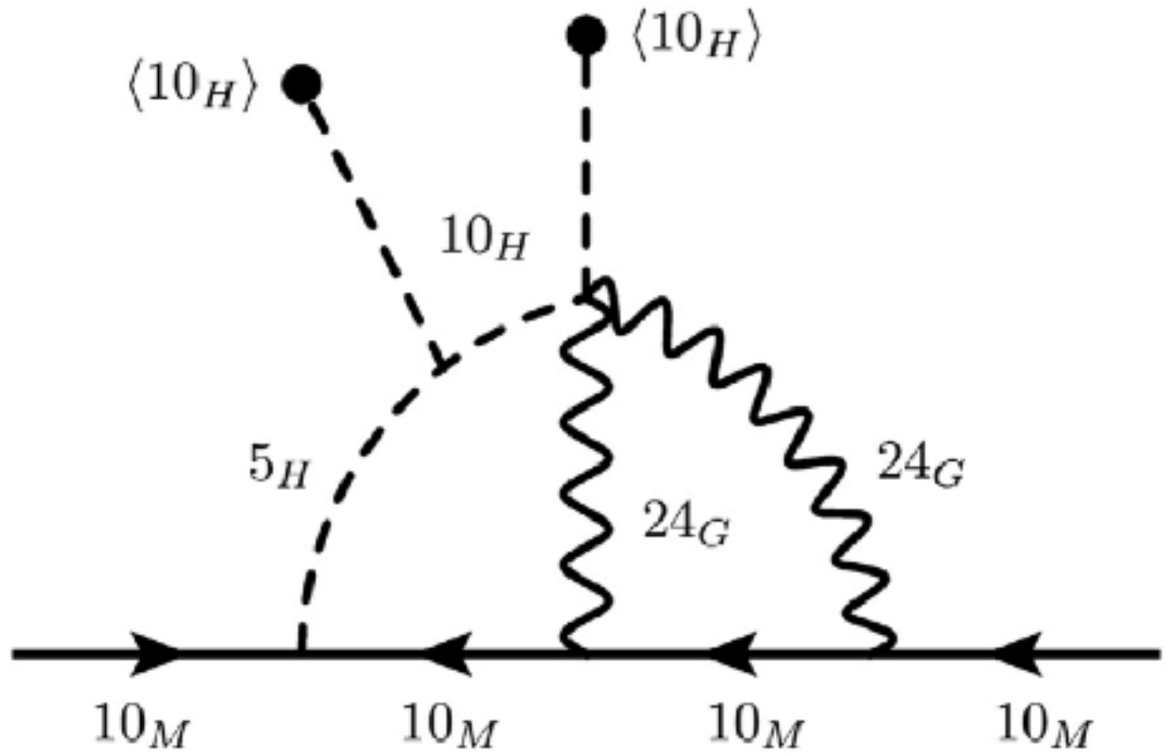

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The Witten's loop

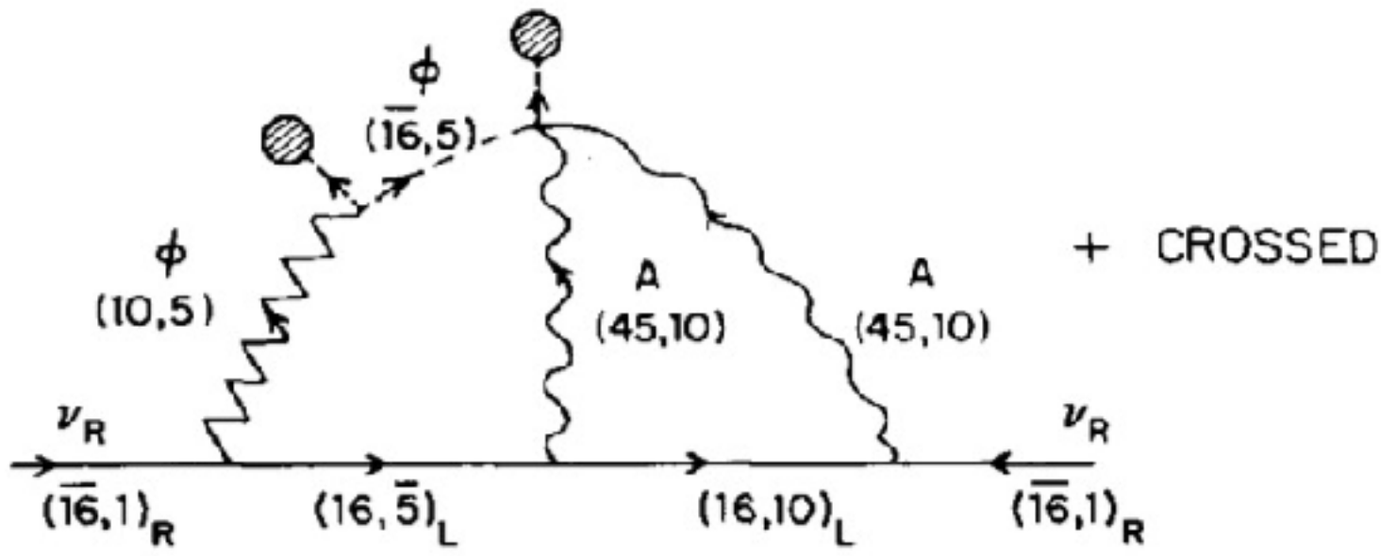
NEUTRINO MASSES IN THE MINIMAL O(10) THEORY ☆

Phys. Lett. B91 (1980) 81

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

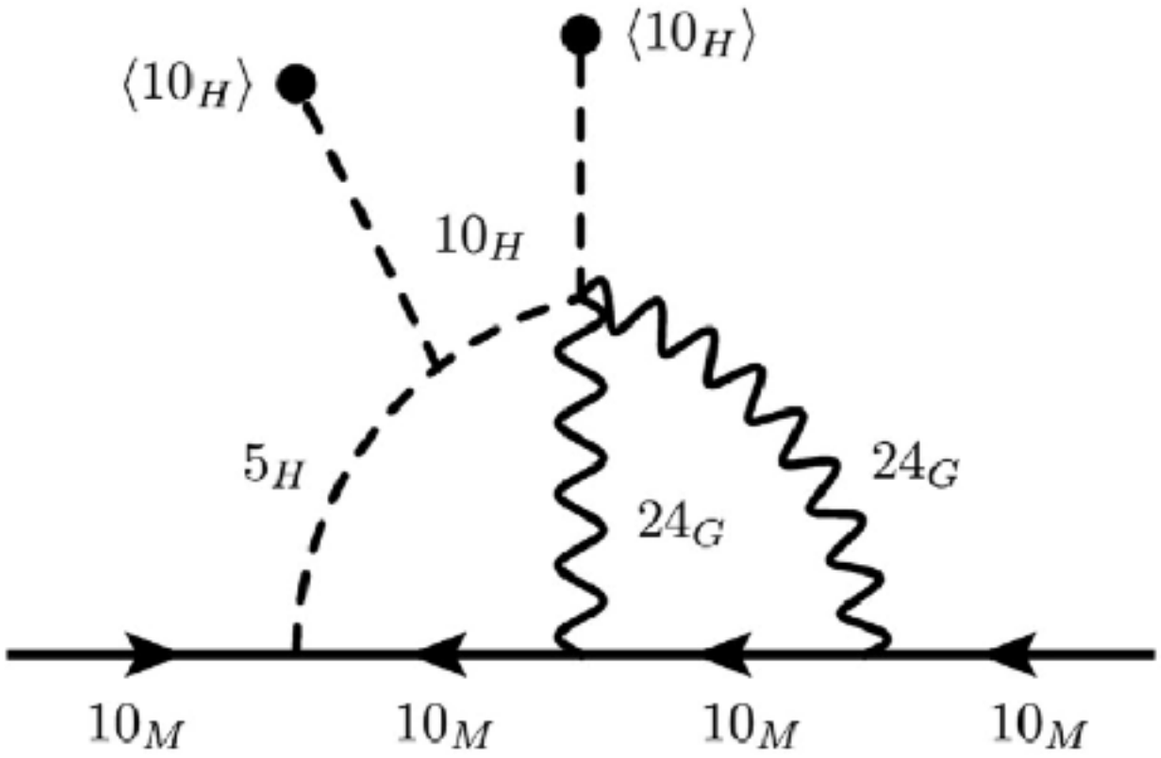
Received 6 December 1979

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(2014)



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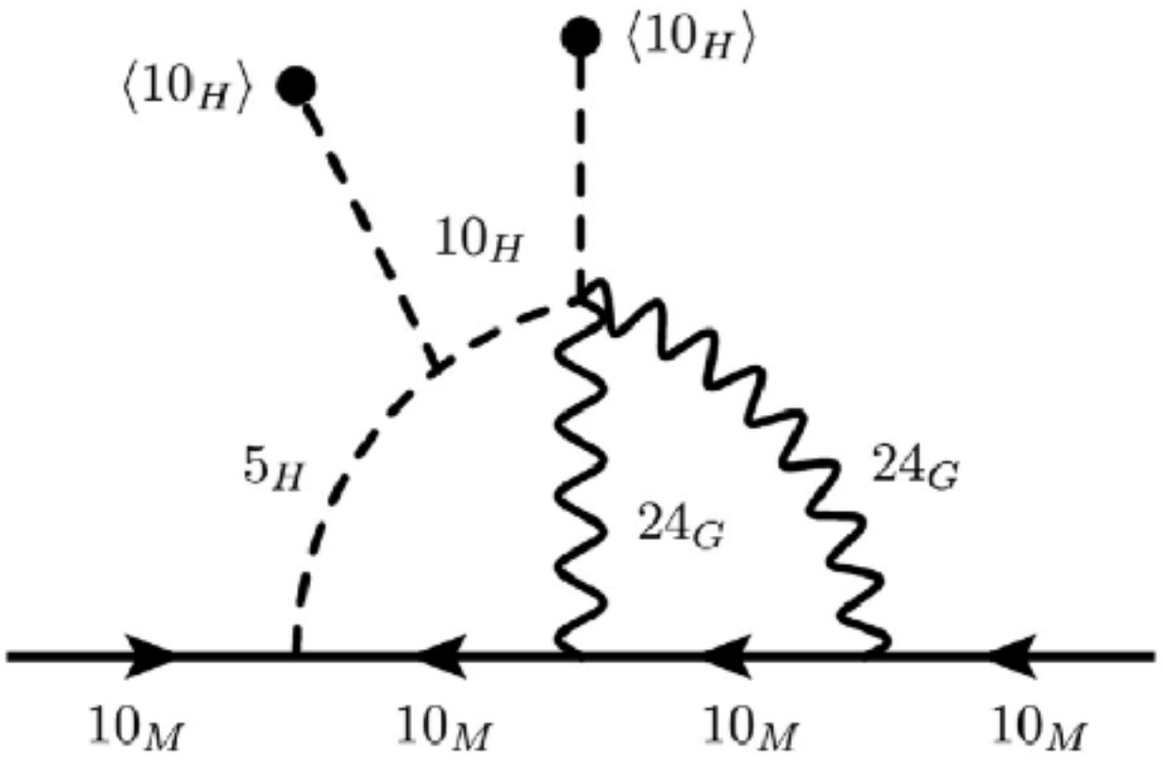
Flipped SU(5) Witten's loop anatomy: C. Arbelaez-Rodriguez, H. Kolešová, MM PRD89(2014)



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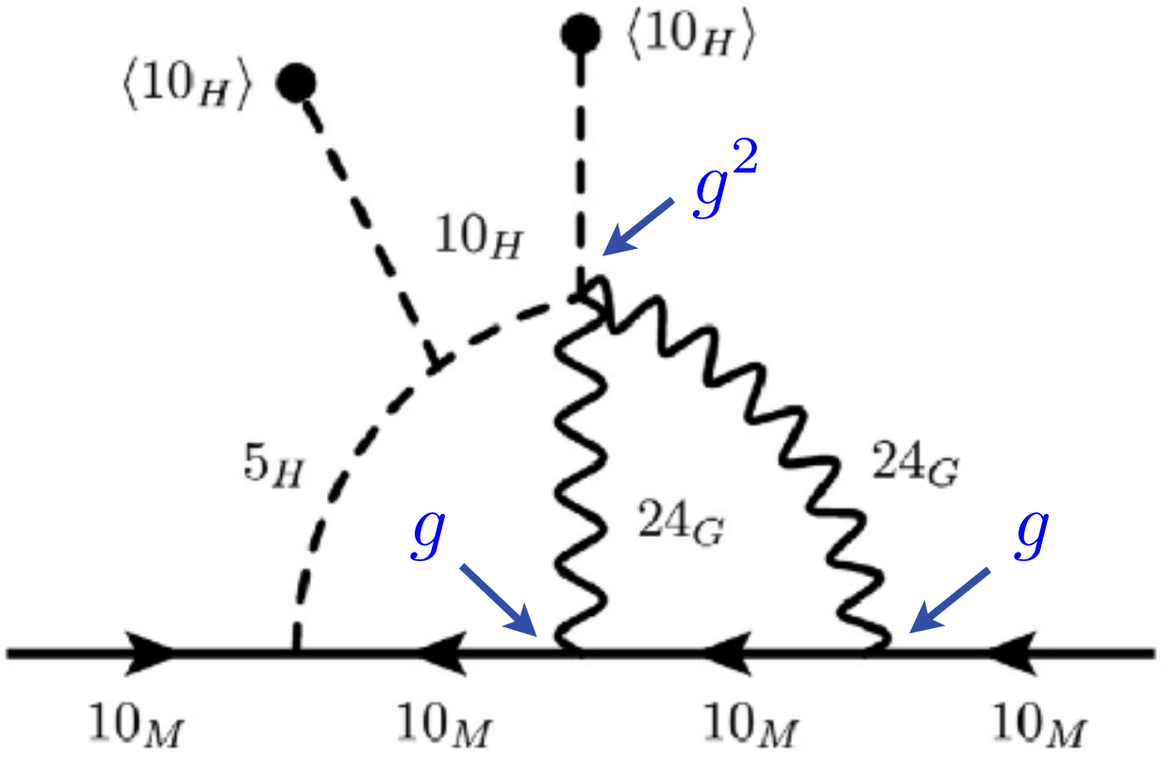

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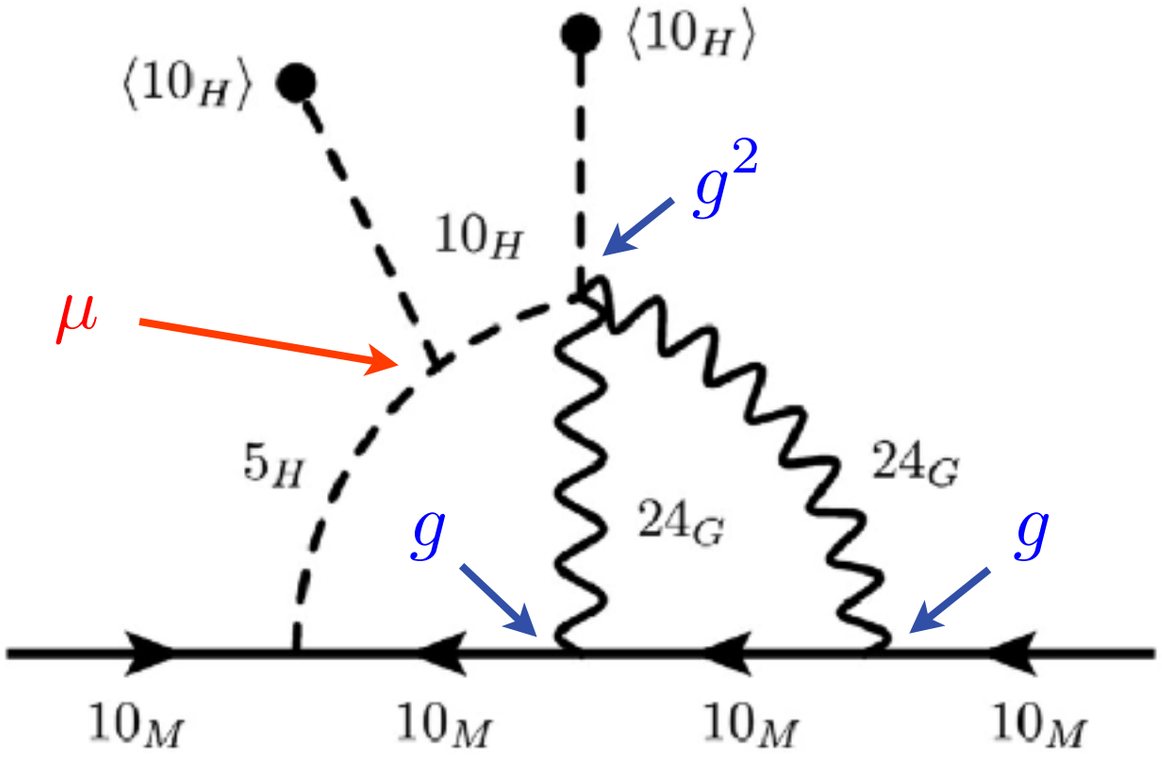

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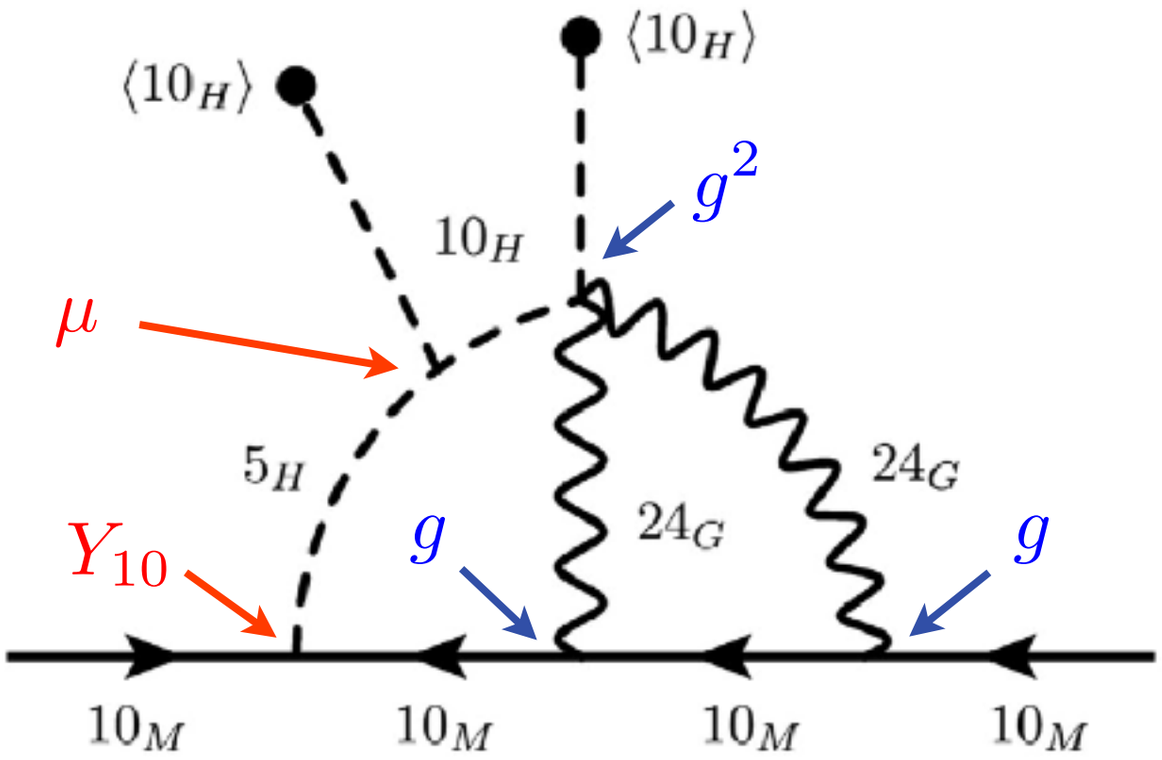

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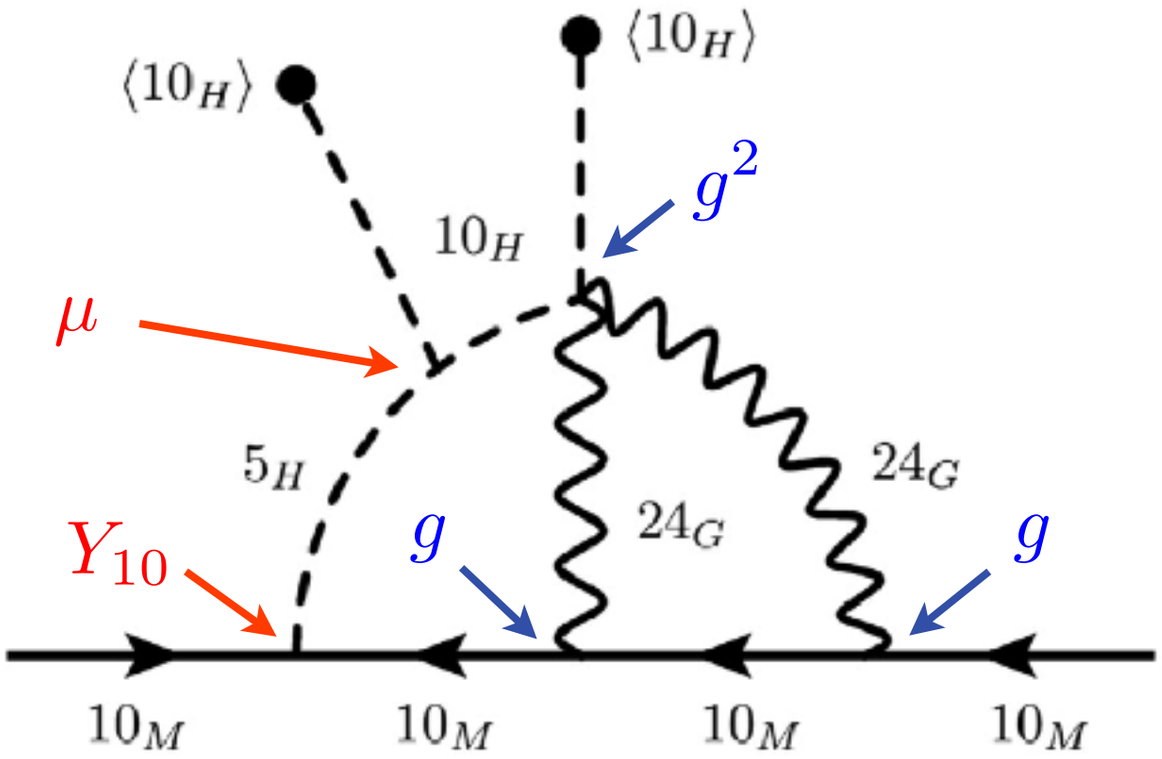

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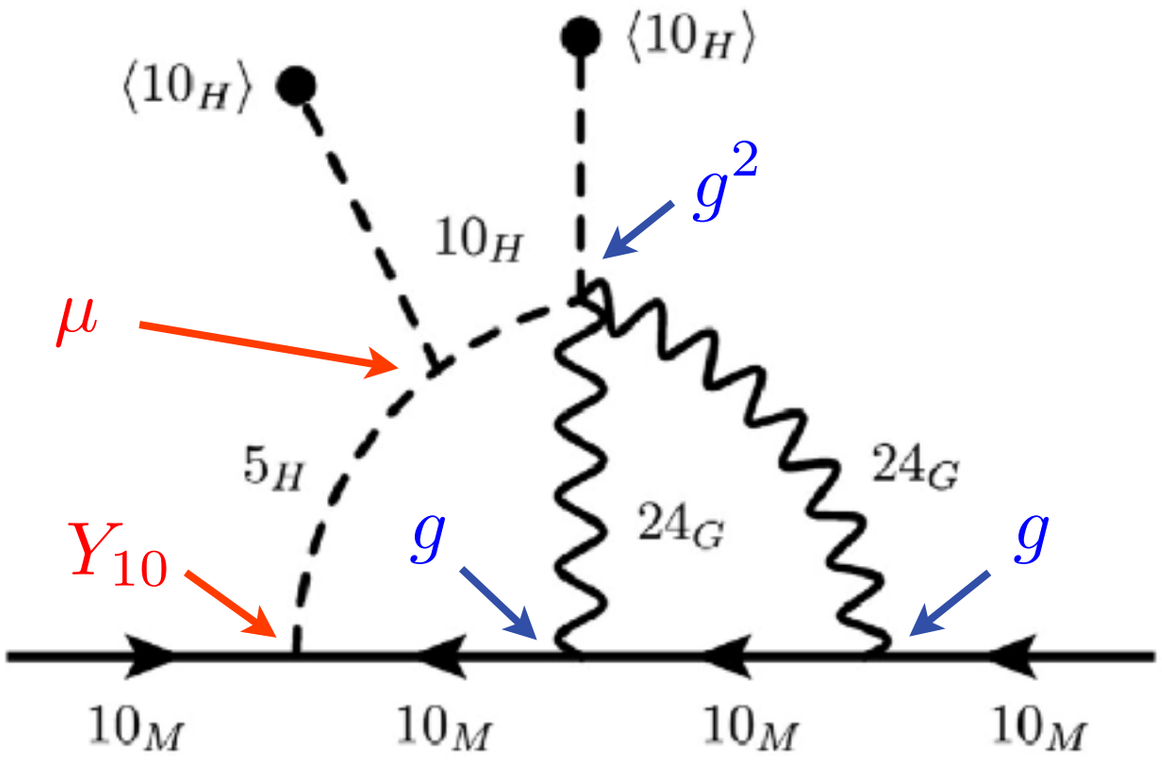

$$M_M = \frac{1}{(16\pi^2)^2} g^4 \mu\, Y_{10} \frac{\langle 10_H \rangle^2}{M_X^2} K(\ldots)$$

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

Seesaw formula - the key to phenomenology

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

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Perturbativity, non-tachyonicity of the spectrum:

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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} $\qquad D_u \sim \begin{pmatrix} 10^{-3} & 0 & 0 \\ 0 & 10^{0} & 0 \\ 0 & 0 & 10^{2} \end{pmatrix}$ GeV

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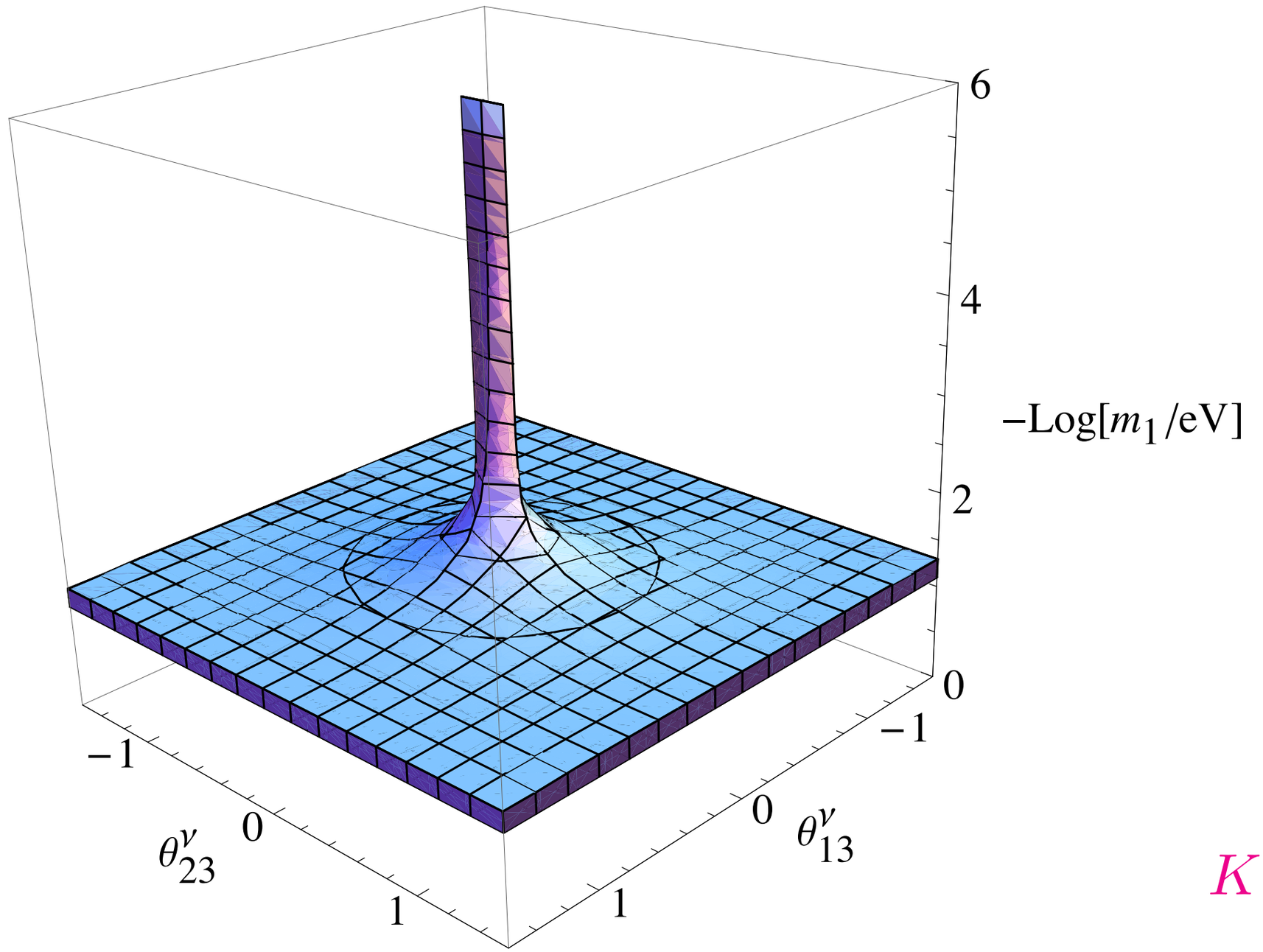
Severity of these constraints depends on U_ν and the lightest neutrino mass m_1…

The parameter space (m_1, U_ν)

C.Arbelaez-Rodriguez, H.Kolešová, MM, PRD89 (2014)

U_ν angular behaviour:



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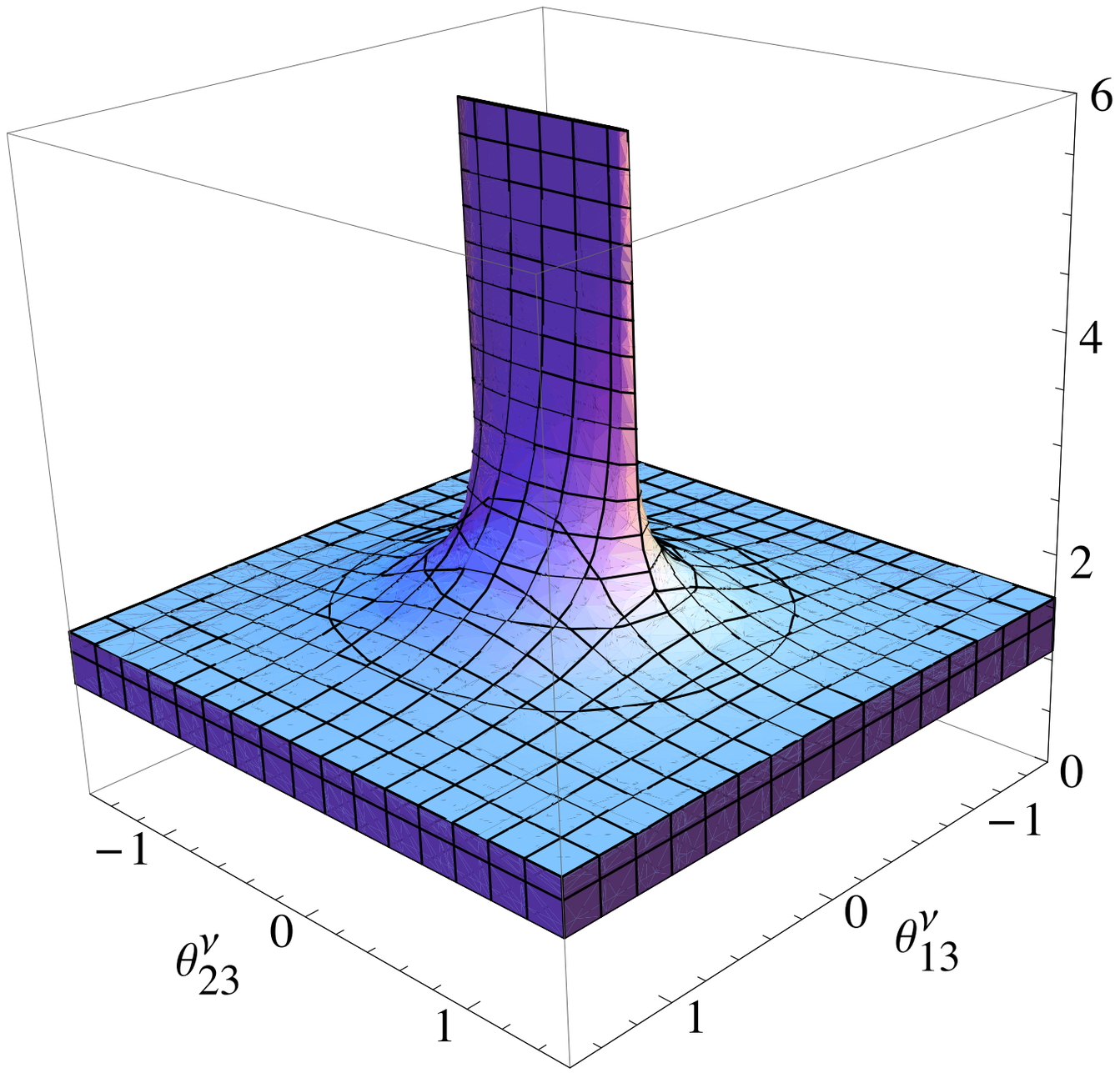

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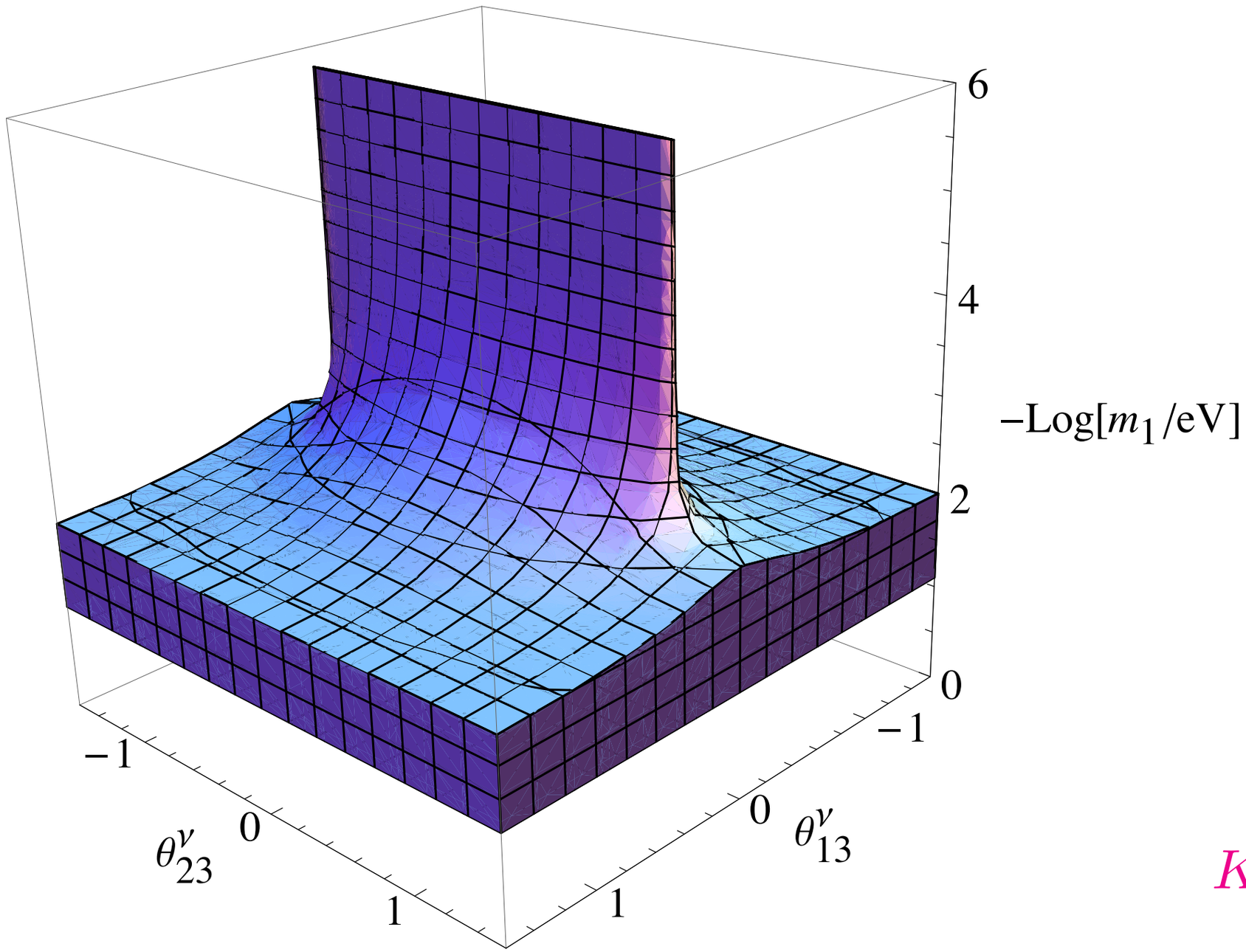

$K = 5$

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

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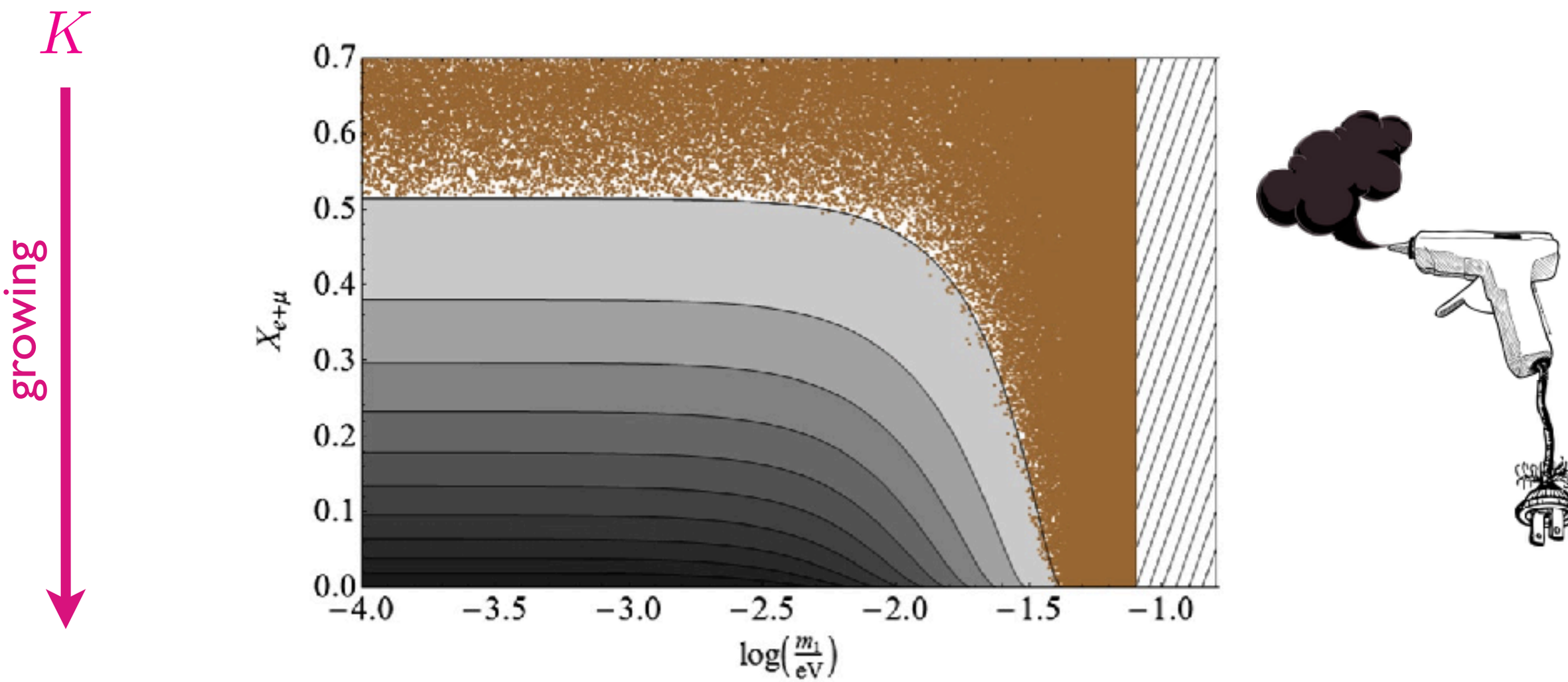

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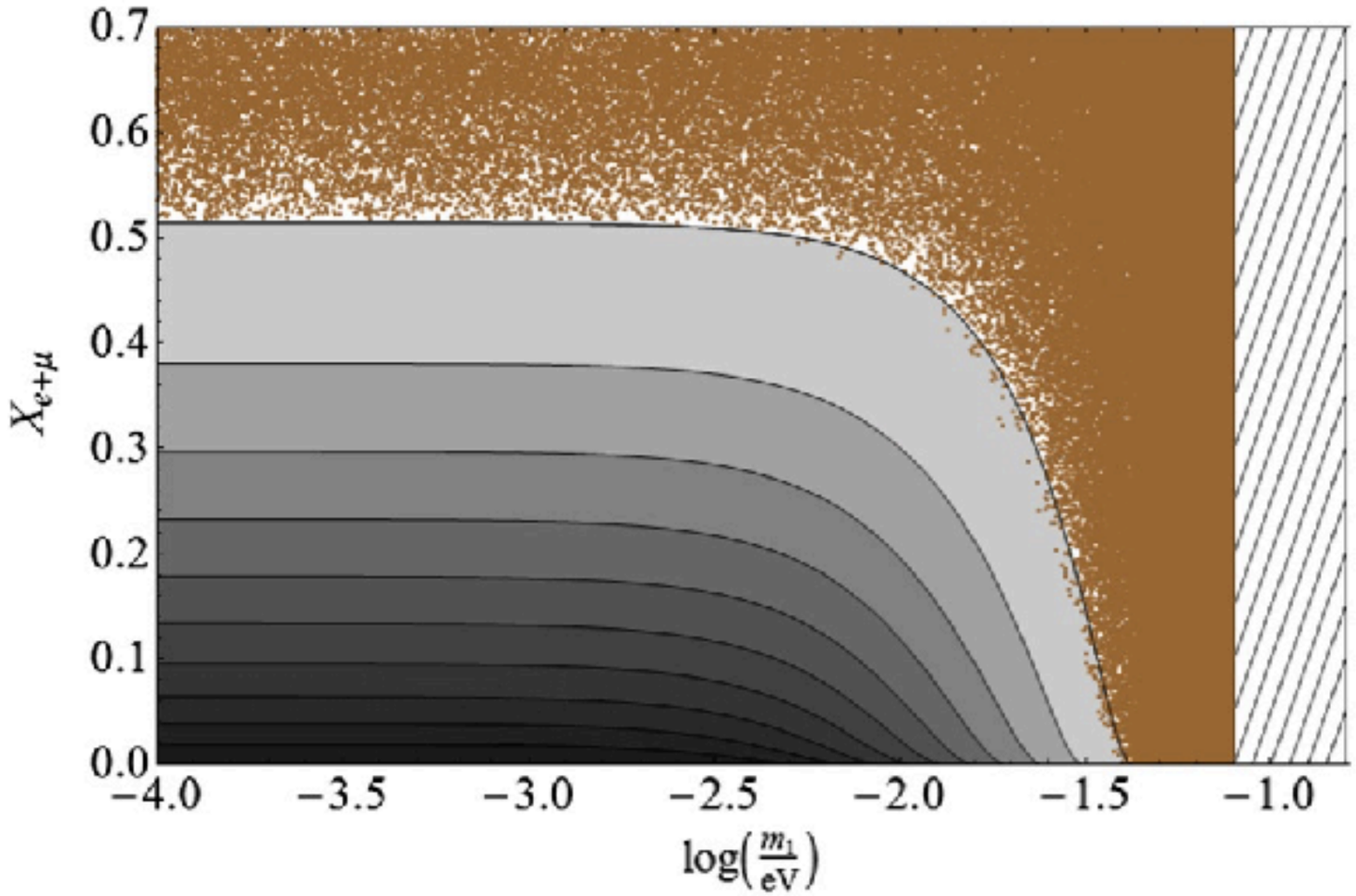

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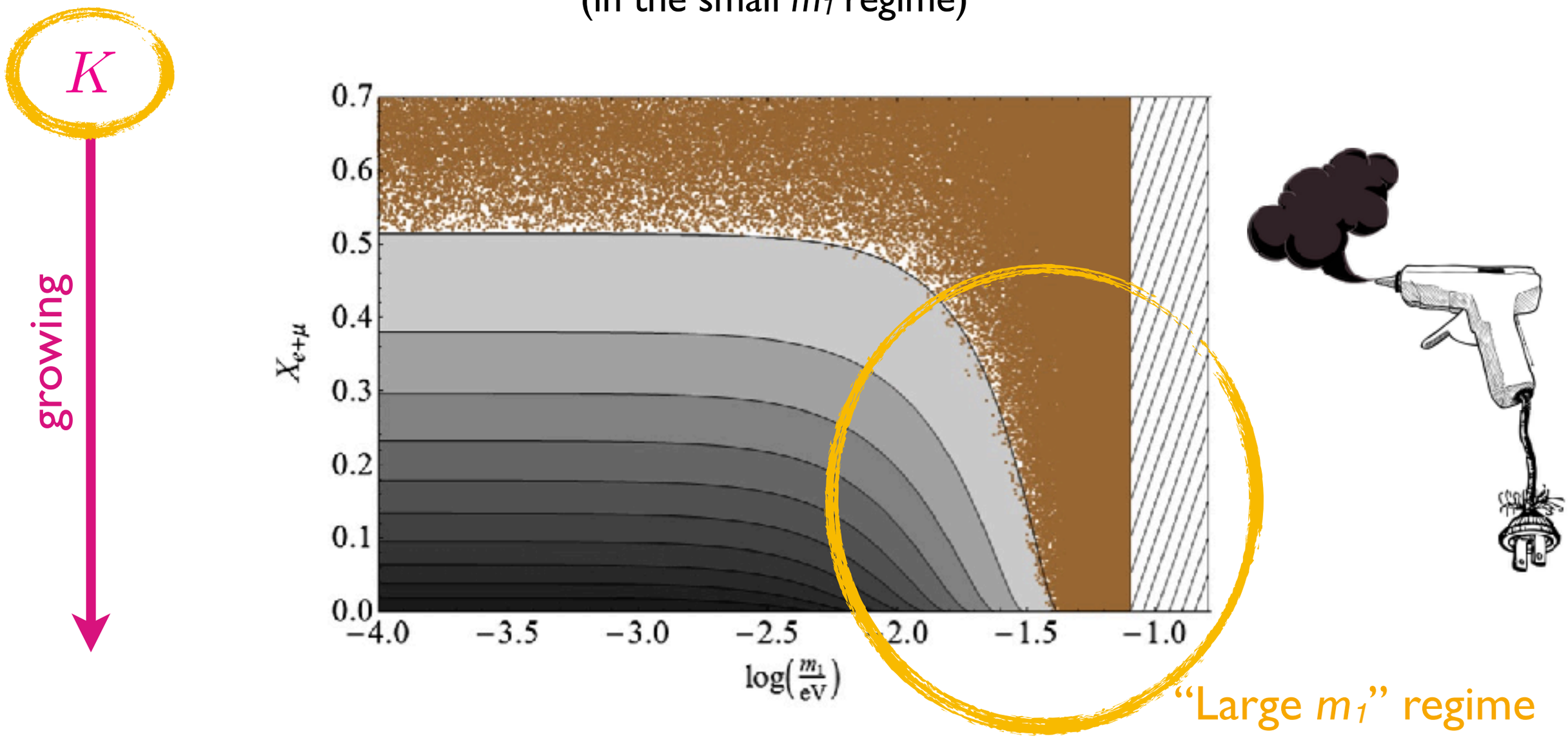


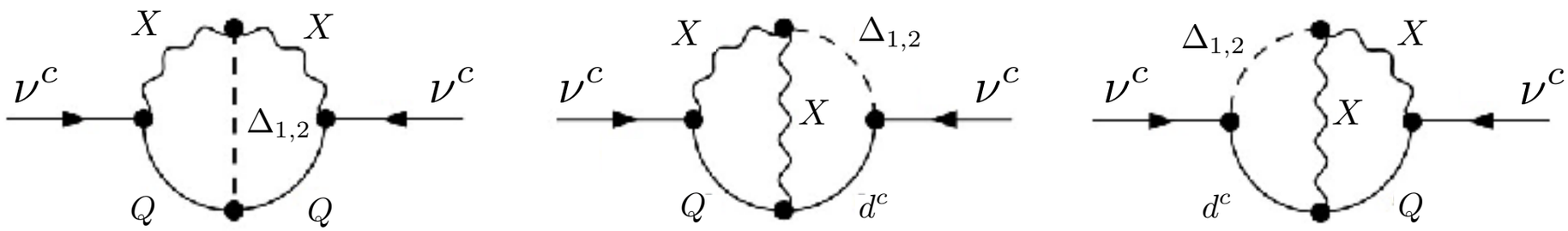
C.Arbelaez-Rodriguez, H.Kolešová, MM, PRD89 (2014)

K ?

D. Harries, MM, M. Zdráhal PRD98 (2018)

Broken phase massive PE, unitary gauge:

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



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

- Each graph is UV divergent but no d=4 counterterm - Σ(0) must be finite

UV divergences (d. 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

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

How about the "large m_1" regime?

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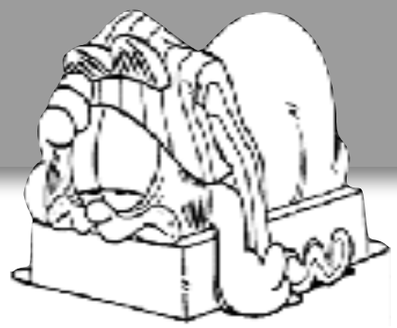

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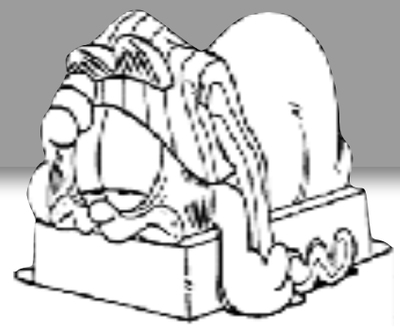

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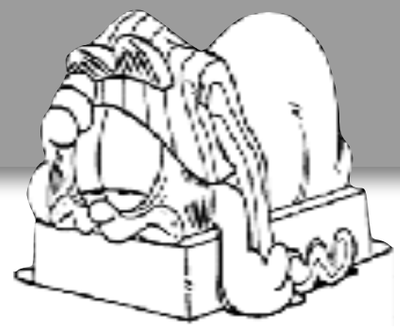

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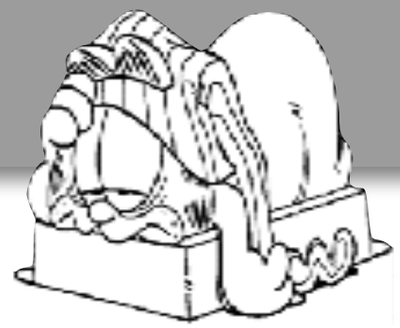

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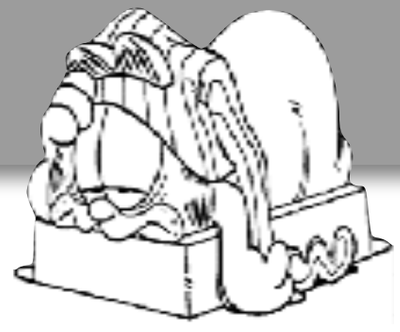

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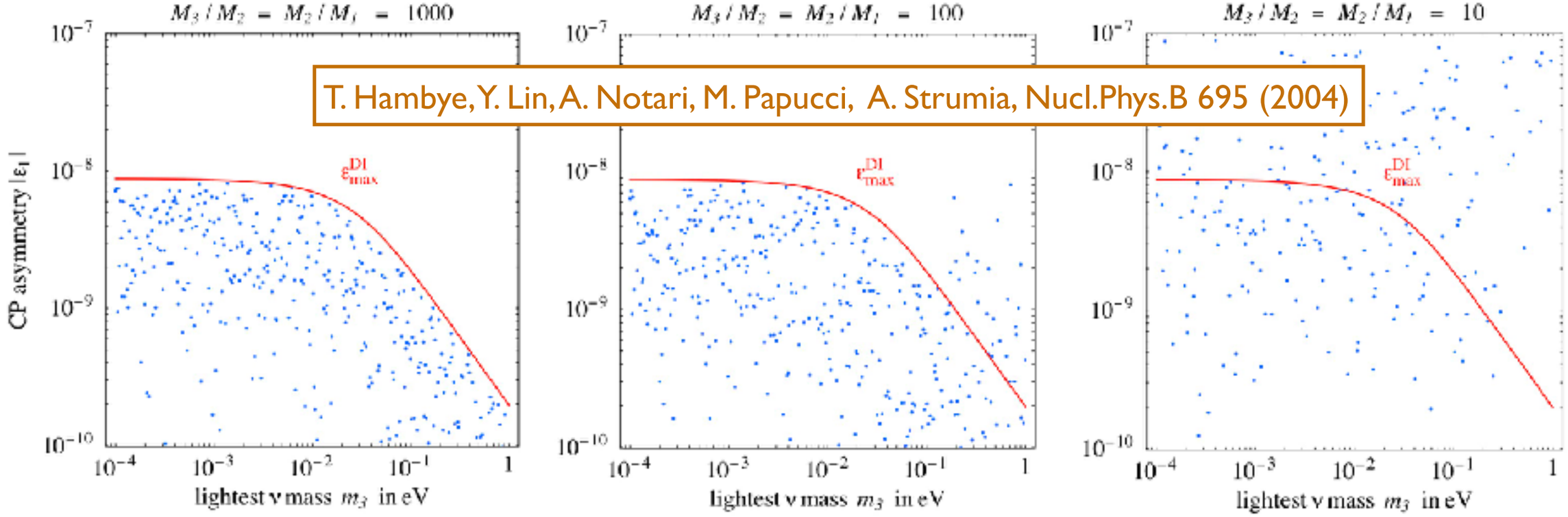
D-I limit can be cheated quite easily…

T. Hambye, Y. Lin, A. Notari, M. Papucci, A. Strumia, Nucl.Phys.B 695 (2004)



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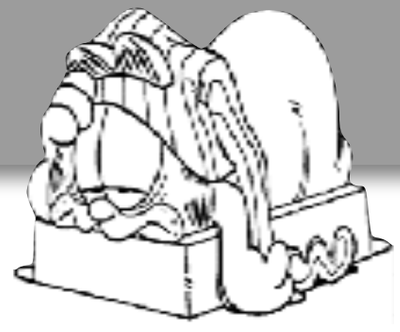

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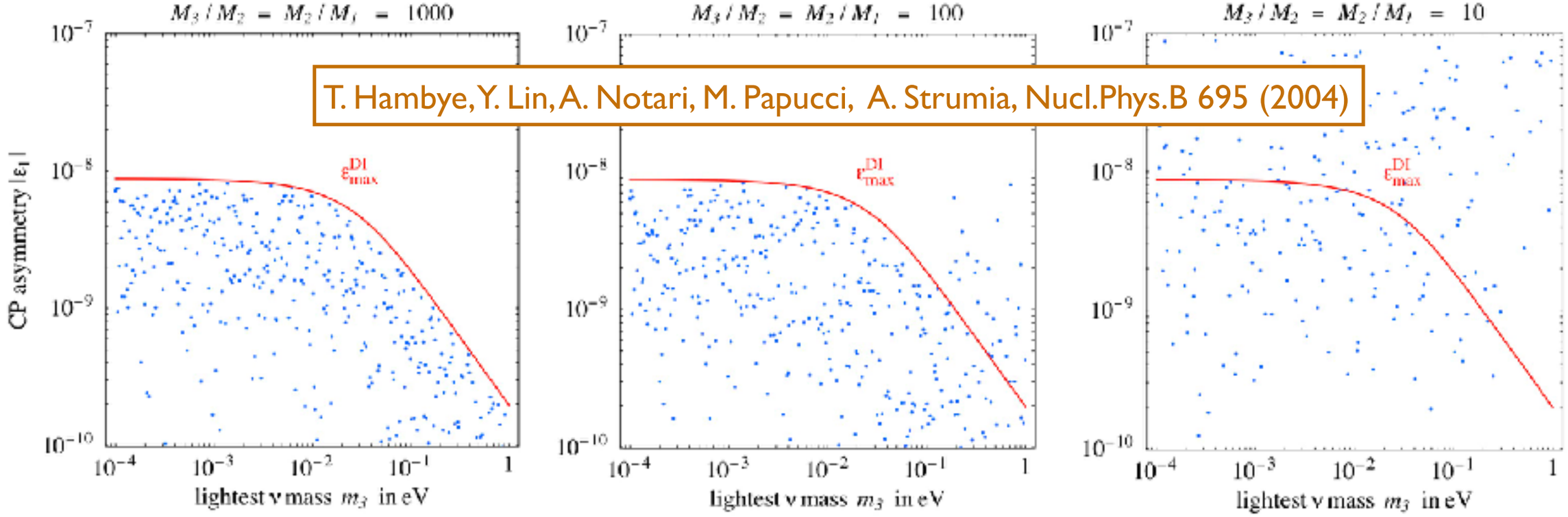
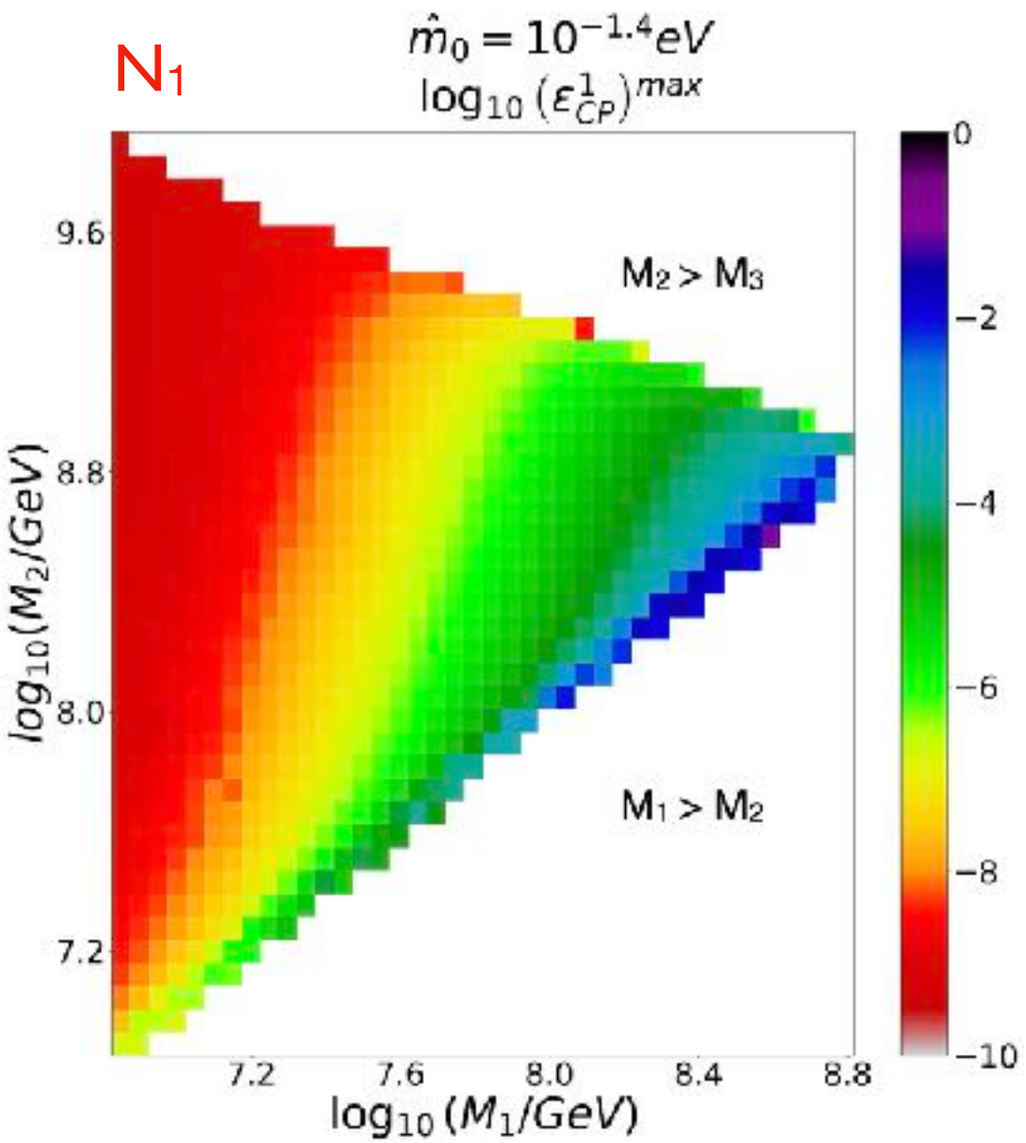


- U_ν may need to be special though → **further constraints on BLNV rates (?)**

Thermal ○→□ in the minimal flipped SU(5) à la Witten

"Large m_1" regime : CP asymmetries OK, washout typically large



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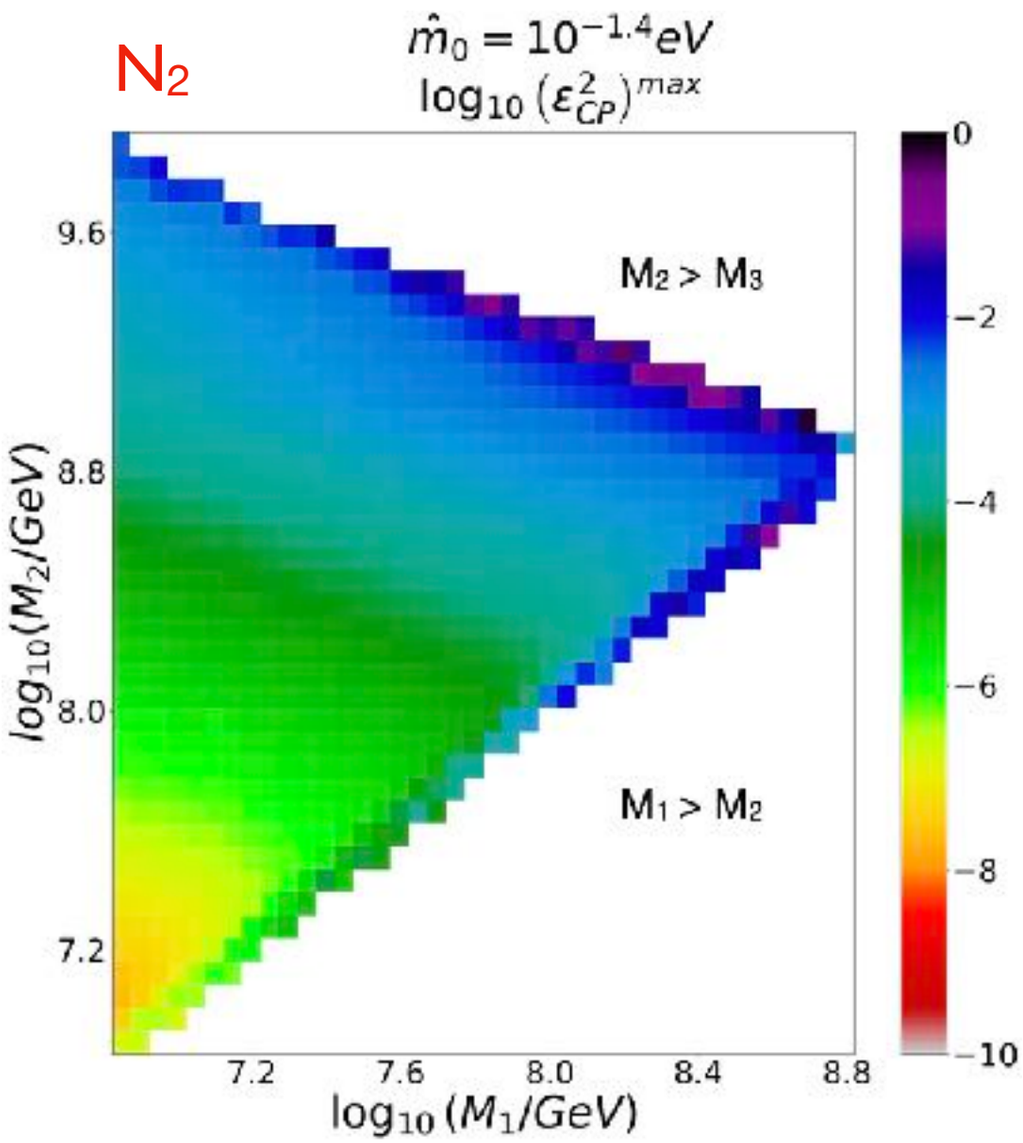

Miřátský, Fonseca, Zdráhal, MM, arXiv:2312.08357

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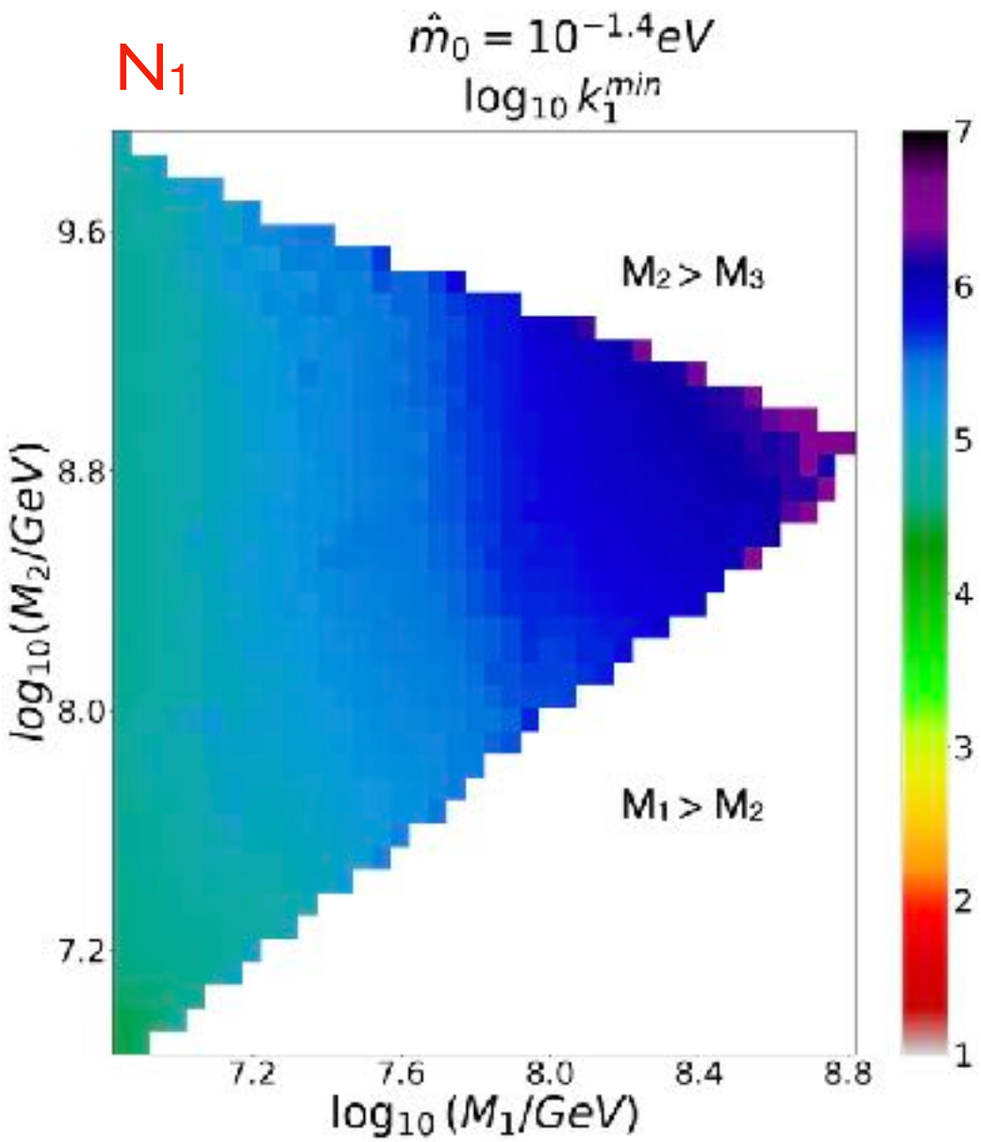
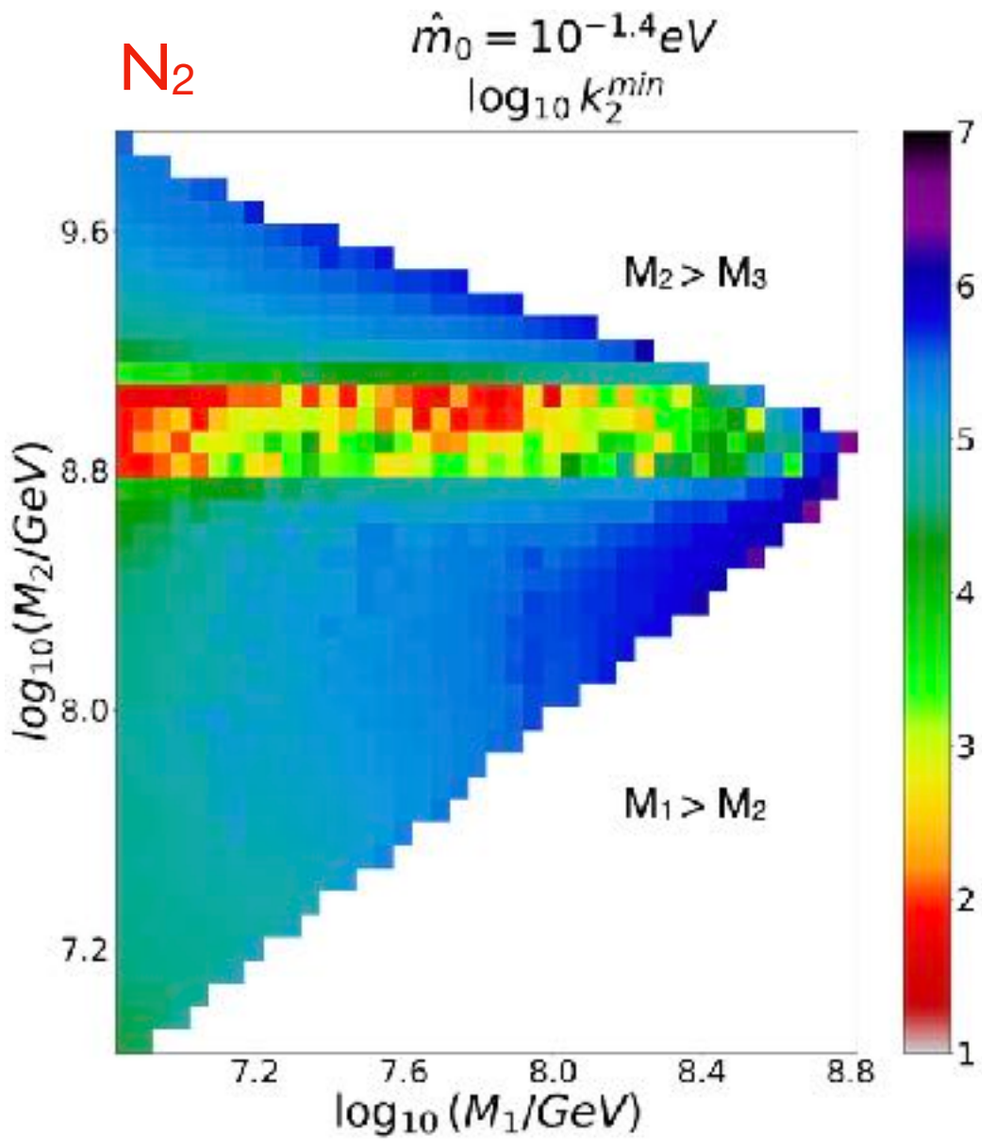


Washout



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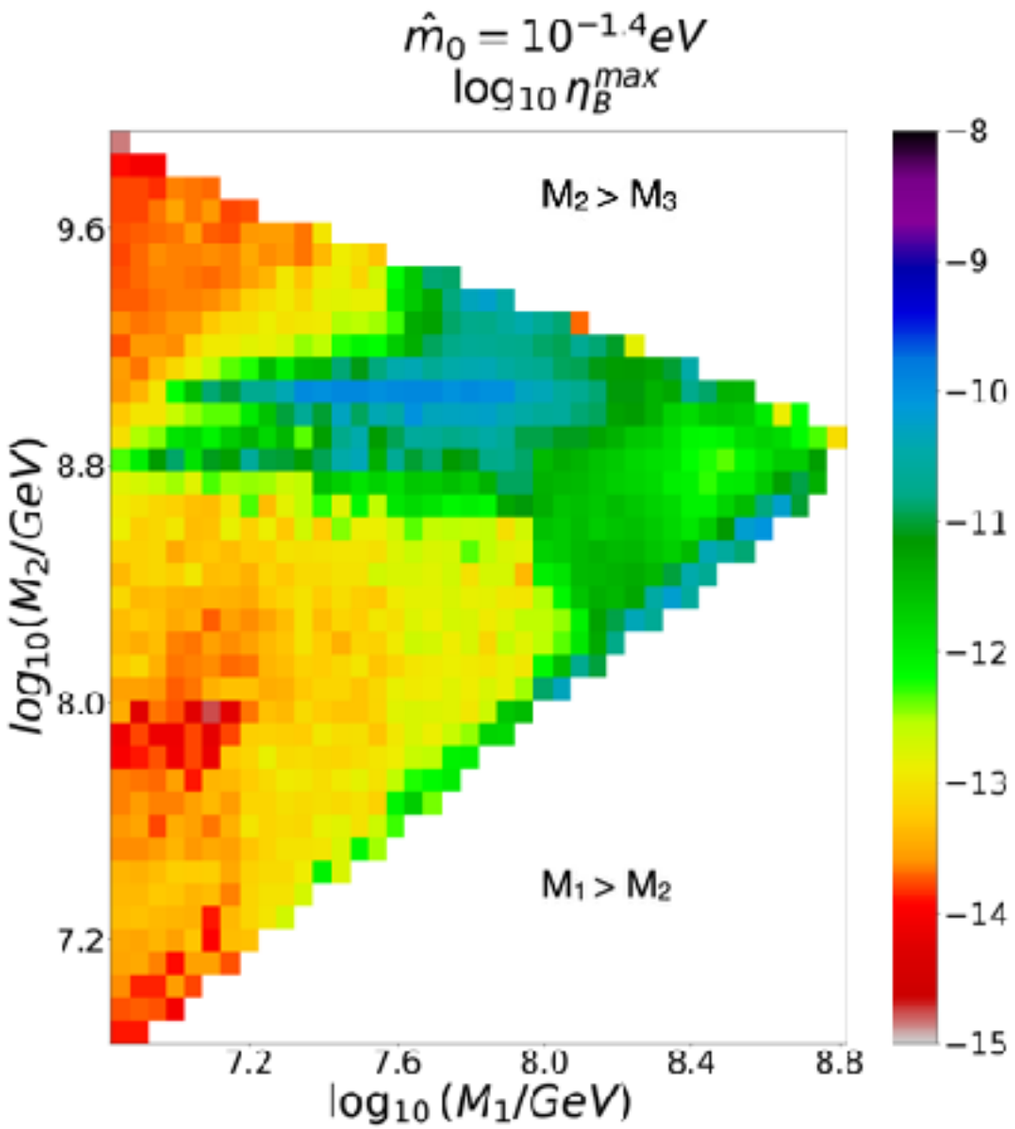

Detailed numerical analysis (ULYSSES)

A. Granelli et al., Comput.Phys.Commun. 262 (2021)

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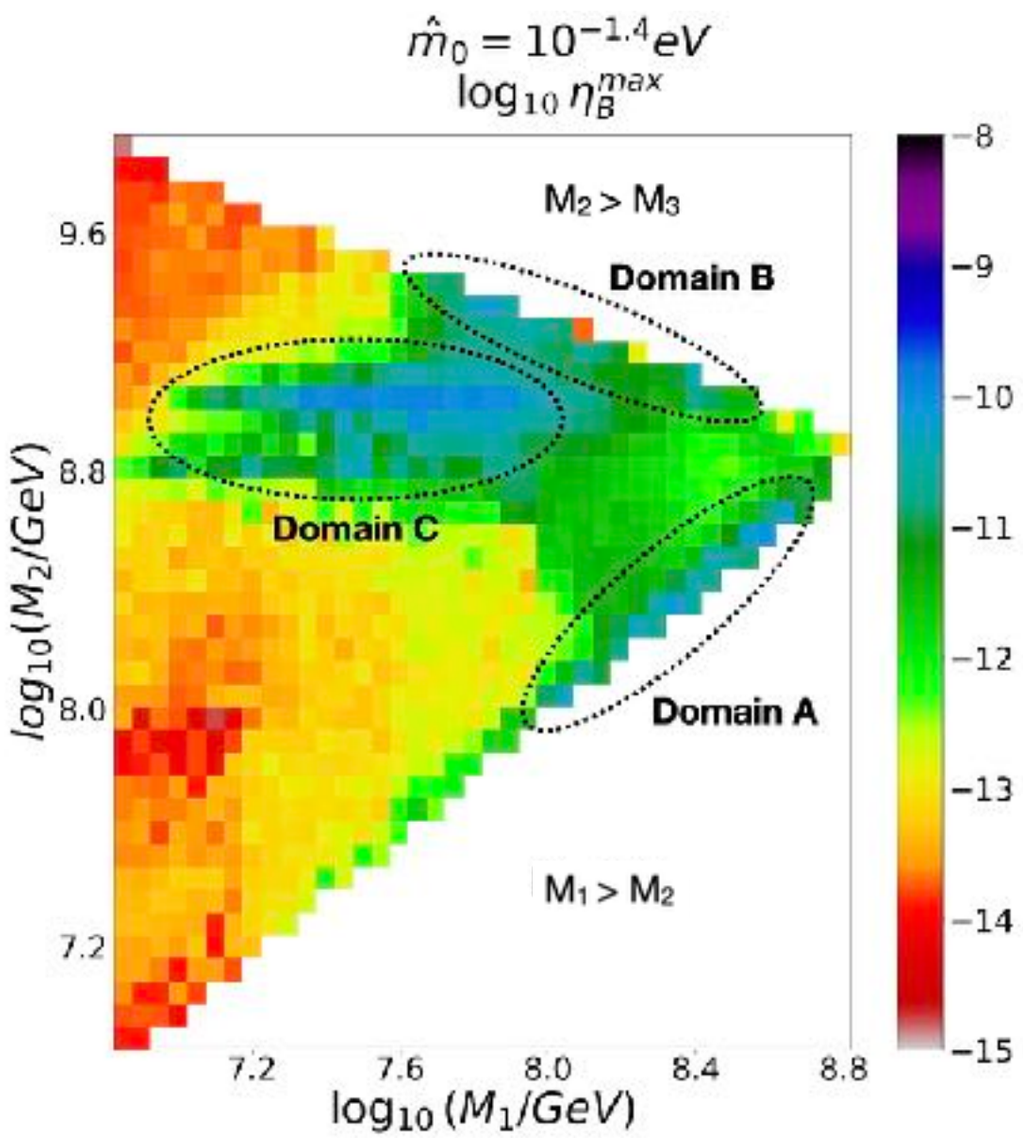

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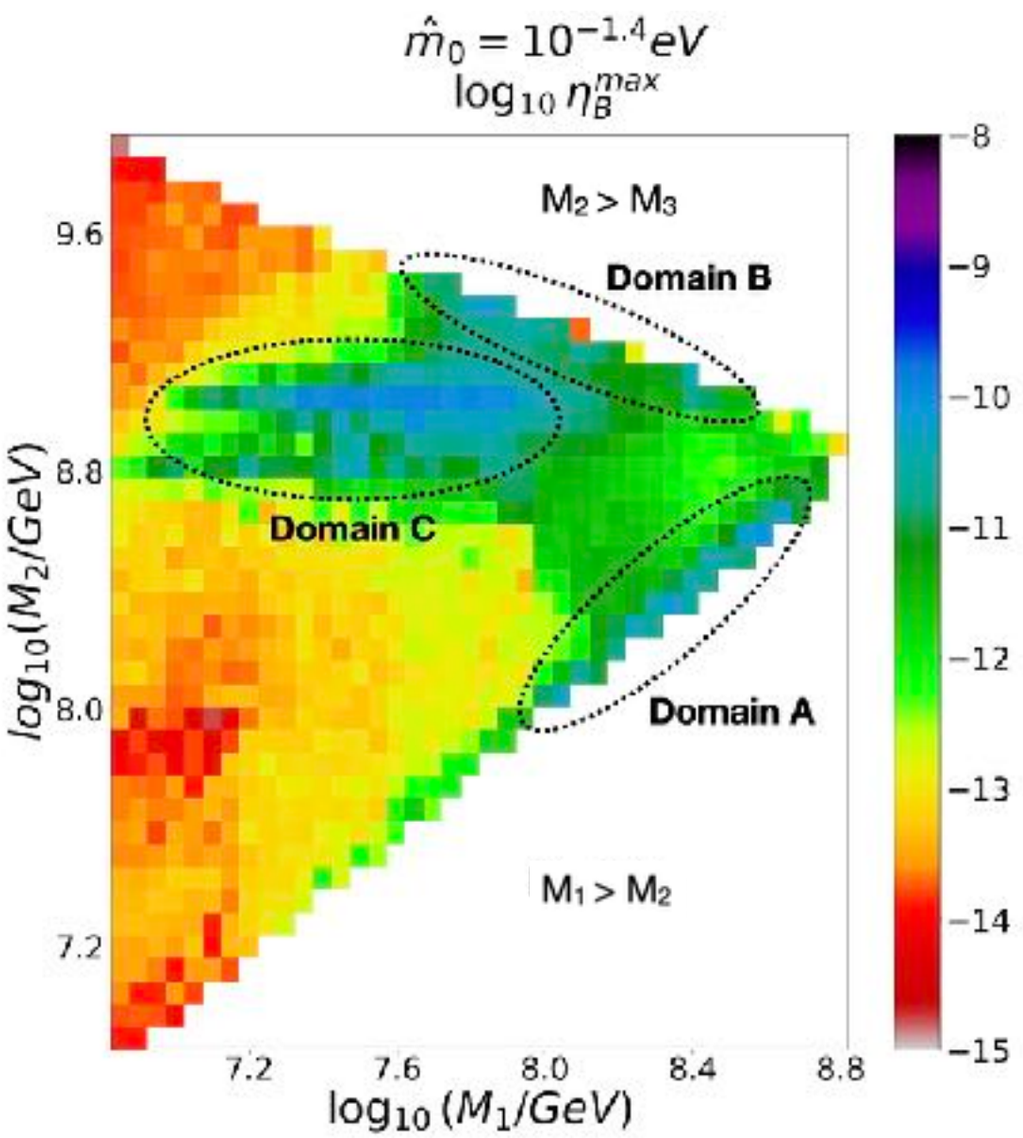

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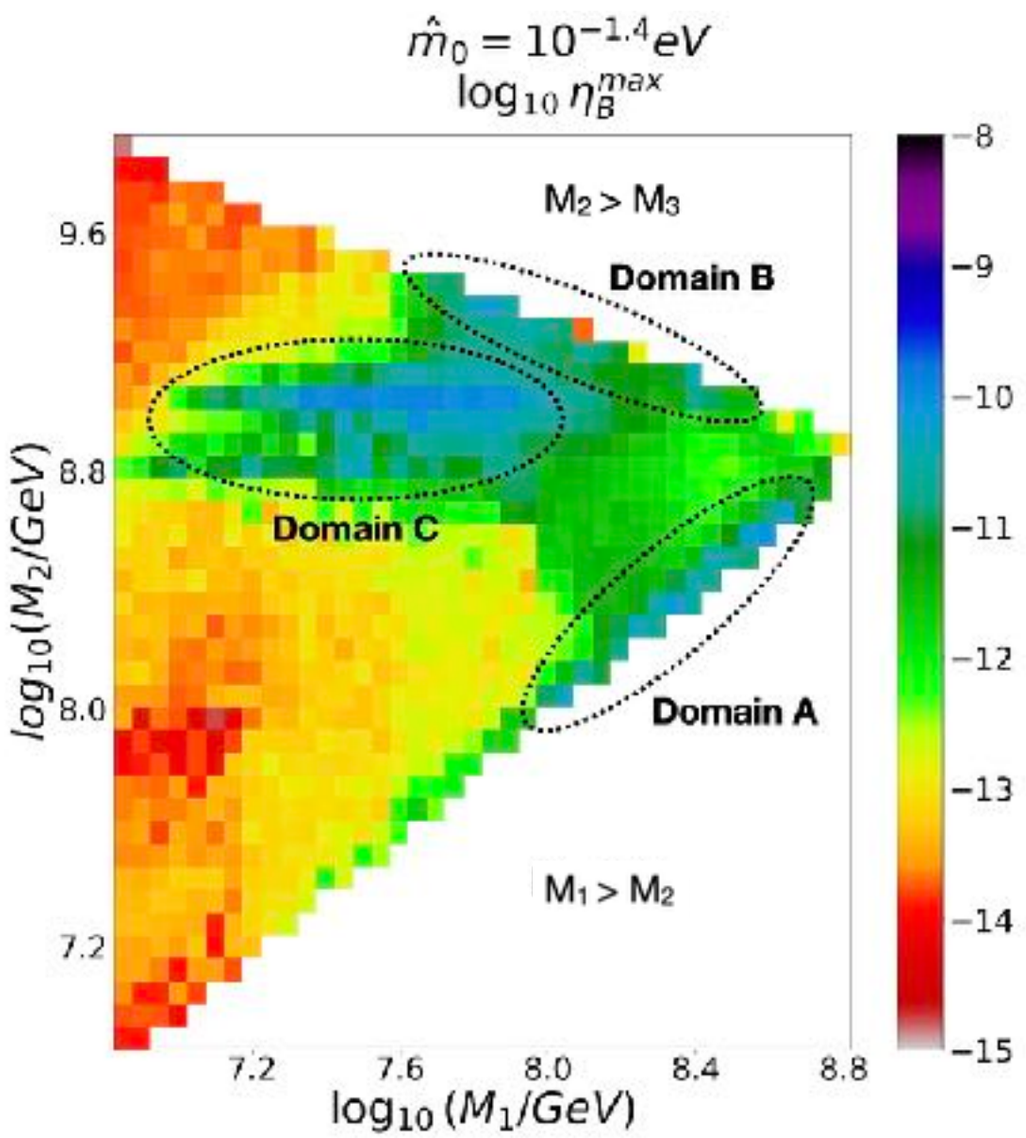

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No signal in KATRIN

Miřátský, Fonseca, Zdráhal, MM, arXiv:2312.08357

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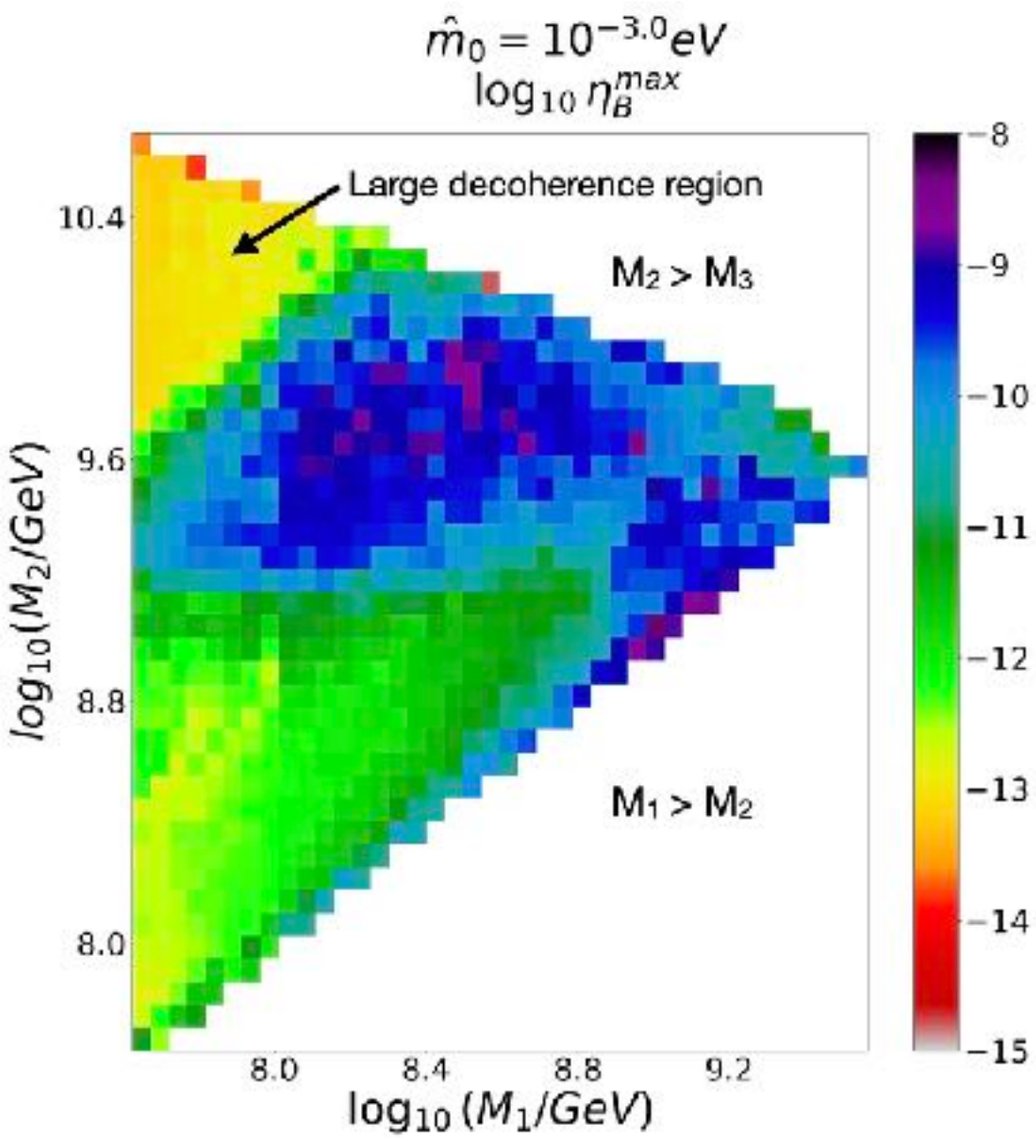

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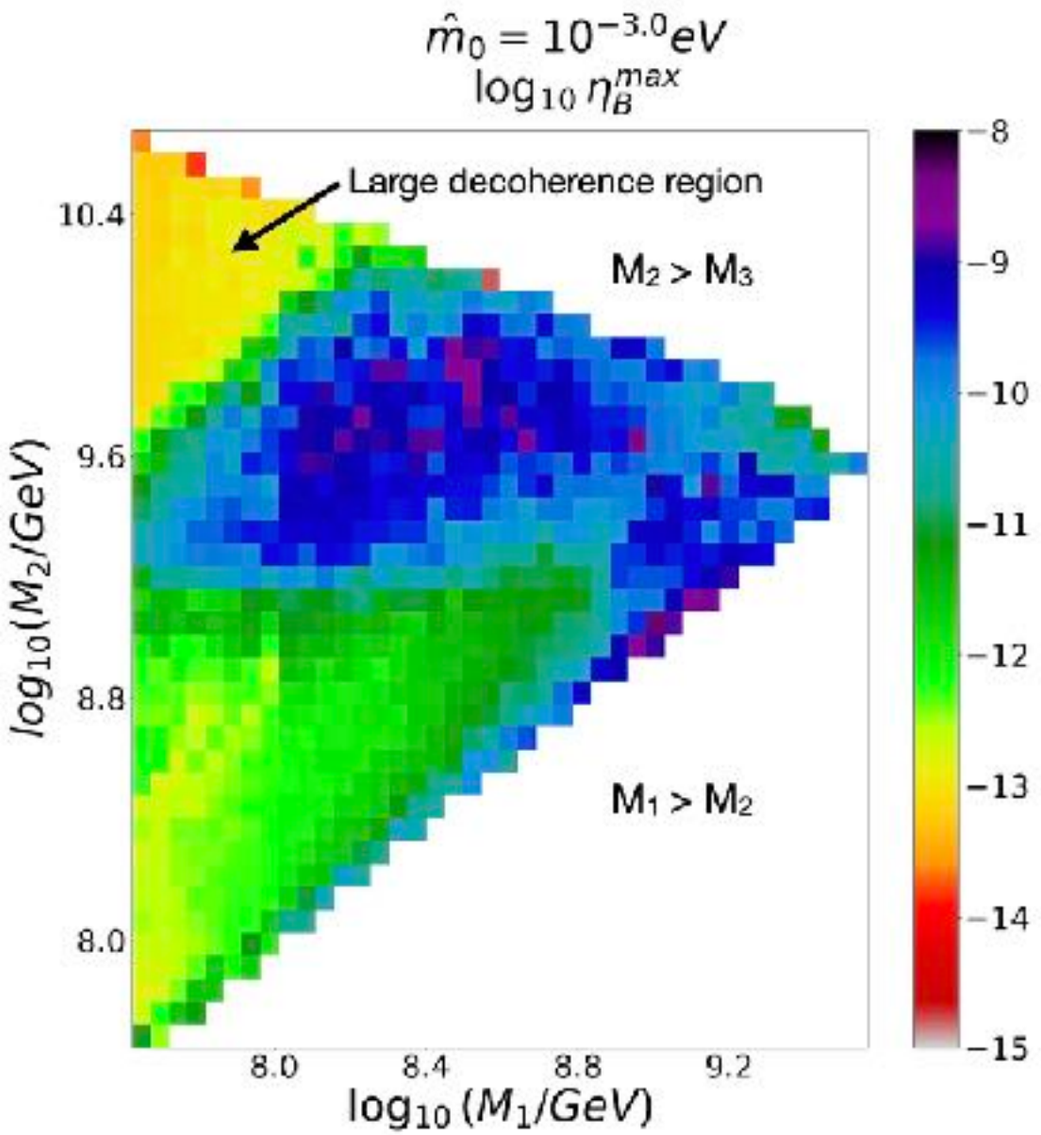
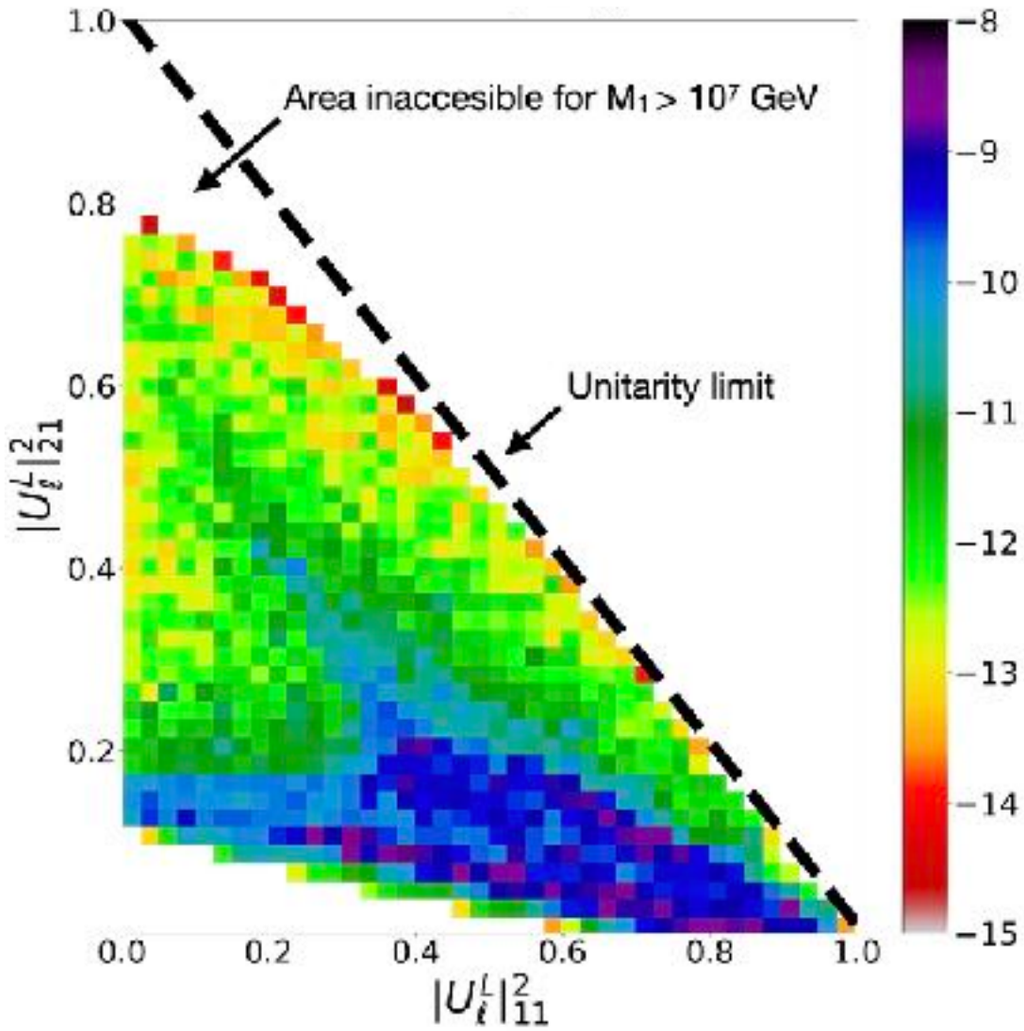


Further constraints on p-decay!



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