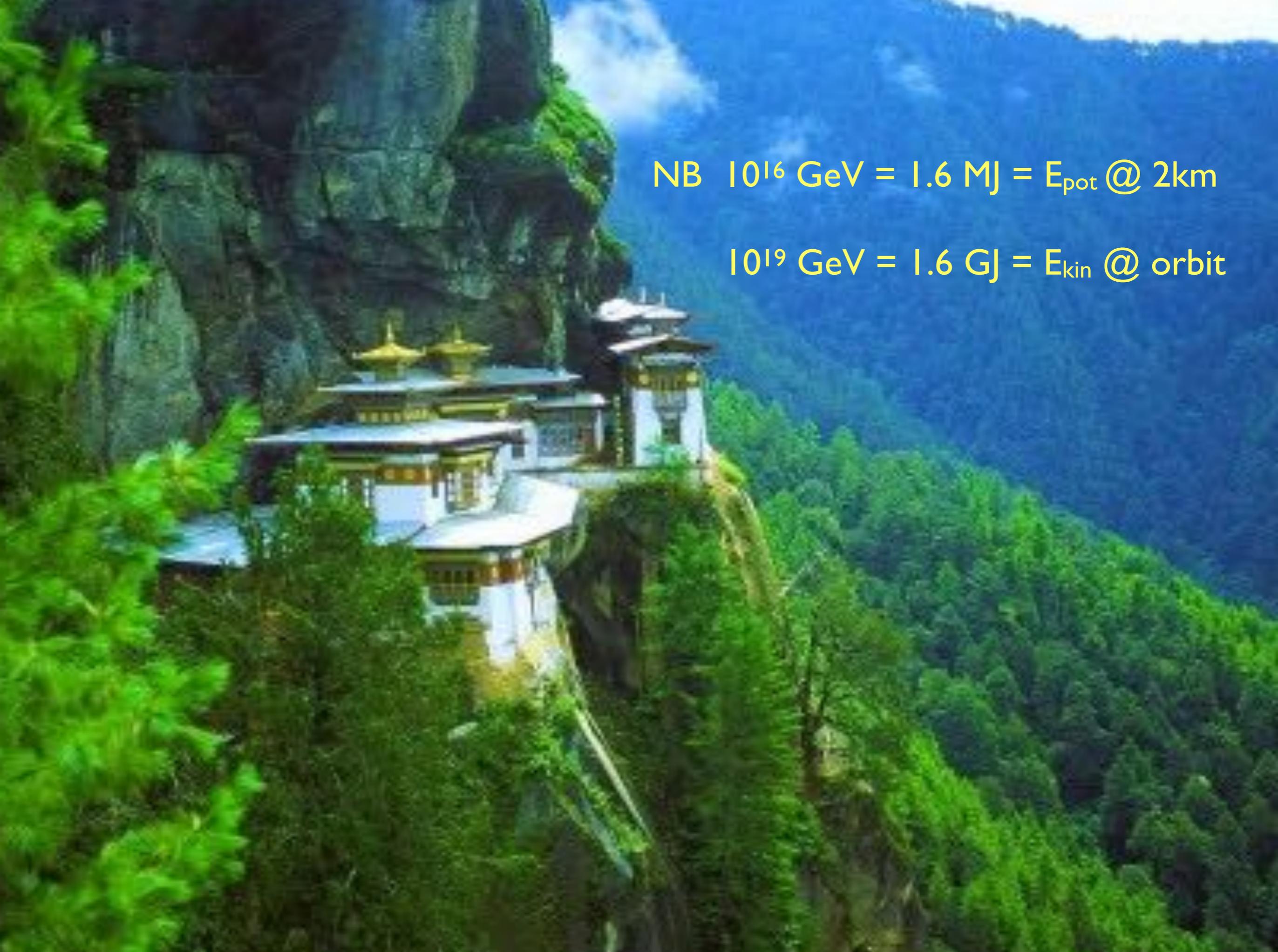


NB  $10^{16}$  GeV = 1.6 MJ =  $E_{\text{pot}}$  @ 2km



NB  $10^{16}$  GeV = 1.6 MJ =  $E_{\text{pot}}$  @ 2km

$10^{19}$  GeV = 1.6 GJ =  $E_{\text{kin}}$  @ orbit

Portorož, April 14 2023



# Leptogenesis in the flipped $SU(5)$ à la Witten

Michal Malinský

**(R.I.P.)**

IPNP, Charles University in Prague

Portorož, April 14 2023



# Leptogenesis in the flipped $SU(5)$ à la Witten

(R.I.P.)

Michal Malinský

IPNP, Charles University in Prague

starring :



Václav Miřátský



Renato Fonseca



Martin Zdráhal

Portorož, April 14 2023



# Leptogenesis in the flipped $SU(5)$ à la Witten

**(R.I.P.)**

Michal Malinský

IPNP, Charles University in Prague

starring :



Václav Miřátský

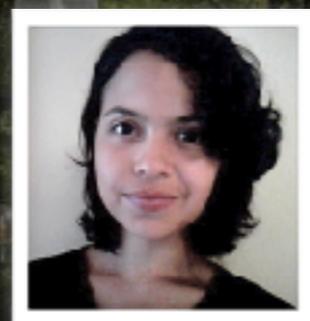


Renato Fonseca

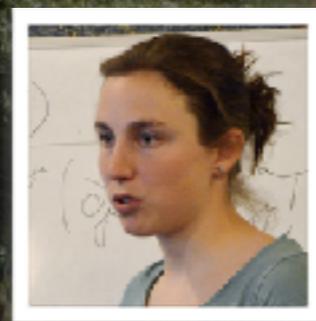


Martin Zdráhal

co-starring :



C. Arbelaez Rodriguez



H. Kolešová



D. Harries

# (Trivial) take-home message

In the vanilla (bottom-up) RHN leptogenesis (almost) anything is possible,  
the correct  $\eta_B$  is attainable in many different regimes

$\eta_B$  may turn into a very strong discriminator if further constraints  
on Yukawas / neutrino spectral shape are imposed (top-down)

# Flipped SU(5) | min crash course

$$SO(10) \supset SU(5) \times U(1)_Z$$

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

# Flipped SU(5) | min crash course

$$SO(10) \supset SU(5) \times U(1)_Z$$

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

2 possible  $Y_{SM}$  assignments:

$$\text{Standard: } Y = T_{24}$$

$$u^c, Q, e^c$$

$$d^c, L$$

$$\nu^c$$



# Flipped SU(5) | min crash course

$$SO(10) \supset SU(5) \times U(1)_Z$$

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

2 possible  $Y_{SM}$  assignments:

$$\text{Standard: } Y = T_{24}$$

$$u^c, Q, e^c$$

$$d^c, L$$

$$\nu^c$$

$$M_u = M_u^T$$
$$M_\ell = M_d^T$$

# Flipped SU(5) | min crash course

$$SO(10) \supset SU(5) \times U(1)_Z$$

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

2 possible  $Y_{SM}$  assignments:

Standard:  $Y = T_{24}$

**Flipped:**  $Y = \frac{1}{5}(Z - T_{24})$

$$\begin{array}{c} u^c, Q, e^c \\ \downarrow \\ d^c, Q, \nu^c \end{array}$$

$$\begin{array}{c} d^c, L \\ \downarrow \\ u^c, L \end{array}$$

$$\begin{array}{c} \nu^c \\ \downarrow \\ e^c \end{array}$$

$$\begin{array}{l} M_u = M_u^T \\ M_\ell = M_d^T \end{array}$$

# Flipped SU(5) | min crash course

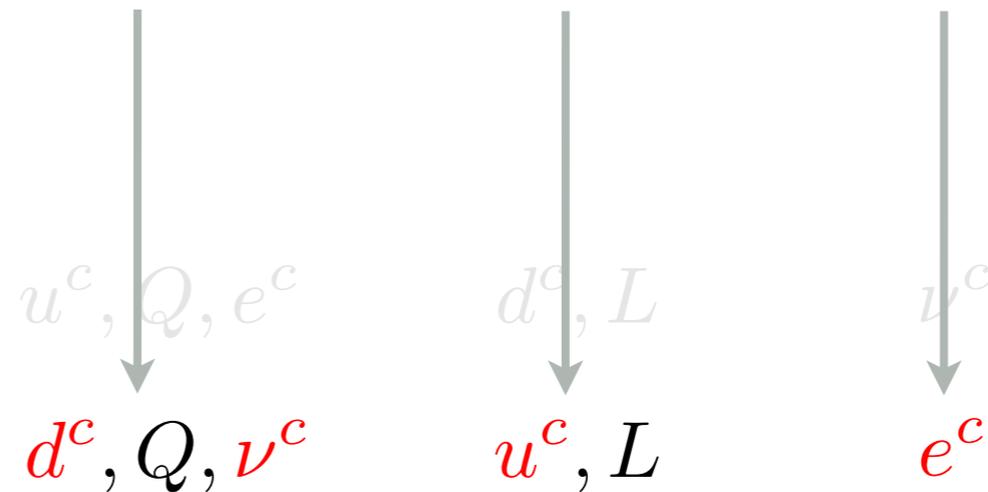
$$SO(10) \supset SU(5) \times U(1)_Z$$

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

2 possible  $Y_{SM}$  assignments:

Standard:  $Y = T_{24}$

**Flipped:**  $Y = \frac{1}{5}(Z - T_{24})$



$$M_u = M_u^T$$

$$M_d = M_d^T$$

$$M_\nu = M_u^T$$

# Flipped SU(5) | min crash course

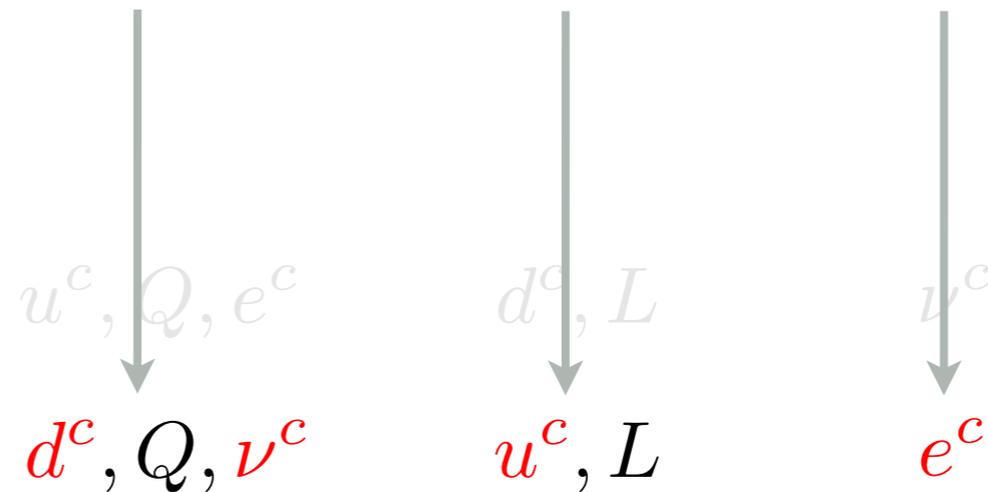
$$SO(10) \supset SU(5) \times U(1)_Z$$

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

2 possible  $Y_{SM}$  assignments:

Standard:  $Y = T_{24}$

**Flipped:**  $Y = \frac{1}{5}(Z - T_{24})$



$$M_u = M_u^T$$

$$M_d = M_d^T$$

$$M_\nu = M_u^T$$

**Symmetry breaking:**  $16_H \ni (10, +1)_H$   
 $10_H \ni (5, -2)_H$

SU(5) x U(1) to the SM  
 SM to the QCD x QED

# Flipped SU(5) | min crash course

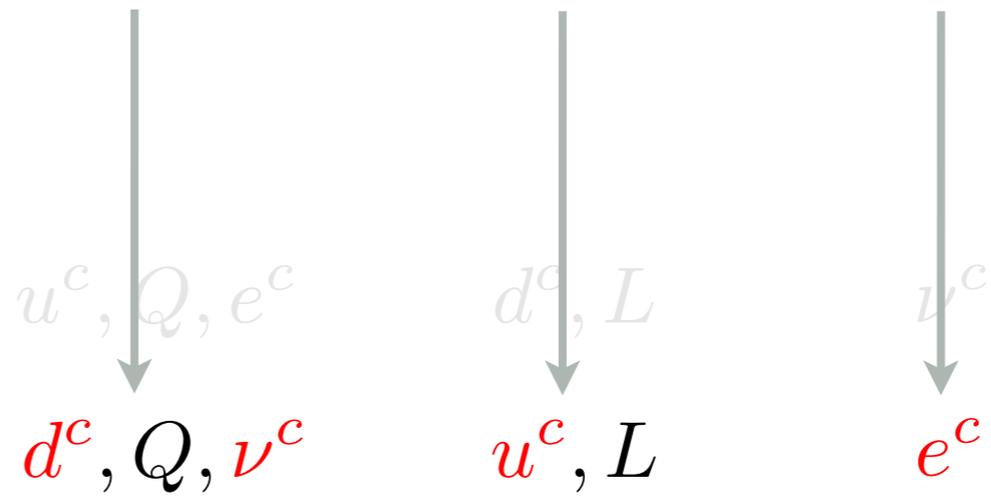
$$SO(10) \supset SU(5) \times U(1)_Z$$

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

2 possible  $Y_{SM}$  assignments:

Standard:  $Y = T_{24}$

**Flipped:**  $Y = \frac{1}{5}(Z - T_{24})$



$$M_u = M_u^T$$

$$M_d = M_d^T$$

$$M_\nu = M_u^T$$

**Symmetry breaking:**  $16_H \ni (10, +1)_H$   $SU(5) \times U(1)$  to the SM  
 $10_H \ni (5, -2)_H$  SM to the QCD  $\times$  QED

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

# BLNV nucleon decays in flipped SU(5) - one $U_\nu$ rules them all

$$\begin{array}{cccc} \Gamma(p \rightarrow \pi^0 \ell_\alpha^+) & \Gamma(p \rightarrow \pi^+ \bar{\nu}) & \Gamma(n \rightarrow \pi^- \ell_\alpha^+) & \Gamma(n \rightarrow \pi^0 \bar{\nu}) \\ \Gamma(p \rightarrow K^0 \ell_\alpha^+) & \Gamma(p \rightarrow K^+ \bar{\nu}) & \Gamma(n \rightarrow K^- \ell_\alpha^+) & \Gamma(n \rightarrow K^0 \bar{\nu}) \\ \Gamma(p \rightarrow \eta \ell_\alpha^+) & & & \Gamma(n \rightarrow \eta \bar{\nu}) \end{array}$$

# BLNV nucleon decays in flipped SU(5) - one $U_\nu$ rules them all

|   |   |   |   |
|---|---|---|---|
| $\Gamma(p \rightarrow \pi^0 \ell_\alpha^+)$ | $\Gamma(p \rightarrow \pi^+ \bar{\nu})$ | $\Gamma(n \rightarrow \pi^- \ell_\alpha^+)$ | $\Gamma(n \rightarrow \pi^0 \bar{\nu})$ |
| $\Gamma(p \rightarrow K^0 \ell_\alpha^+)$   | $\Gamma(p \rightarrow K^+ \bar{\nu})$   | $\Gamma(n \rightarrow K^- \ell_\alpha^+)$   | $\Gamma(n \rightarrow K^0 \bar{\nu})$   |
| $\Gamma(p \rightarrow \eta \ell_\alpha^+)$  |   |   | $\Gamma(n \rightarrow \eta \bar{\nu})$  |

**Charged mesons:**  
(no flavour ambiguity!)

$$\Gamma(p \rightarrow K^+ \bar{\nu}) = 0$$

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

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

# BLNV nucleon decays in flipped SU(5) - one $U_\nu$ rules them all

$$\Gamma(p \rightarrow \pi^0 \ell_\alpha^+)$$

$$\Gamma(p \rightarrow \pi^+ \bar{\nu})$$

$$\Gamma(n \rightarrow \pi^- \ell_\alpha^+)$$

$$\Gamma(n \rightarrow \pi^0 \bar{\nu})$$

$$\Gamma(p \rightarrow K^0 \ell_\alpha^+)$$

$$\Gamma(p \rightarrow K^+ \bar{\nu})$$

$$\Gamma(n \rightarrow K^- \ell_\alpha^+)$$

$$\Gamma(n \rightarrow K^0 \bar{\nu})$$

$$\Gamma(p \rightarrow \eta \ell_\alpha^+)$$

$$\Gamma(n \rightarrow \eta \bar{\nu})$$

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

**Charged mesons:**  
(no flavour ambiguity!)

$$\Gamma(p \rightarrow K^+ \bar{\nu}) = 0$$

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

**Neutral mesons:**

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

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

Constraining  $U_\nu$  yields **constraints for ALL 2-body BNV channels!!!**

# RH neutrino masses in the flipped SU(5)

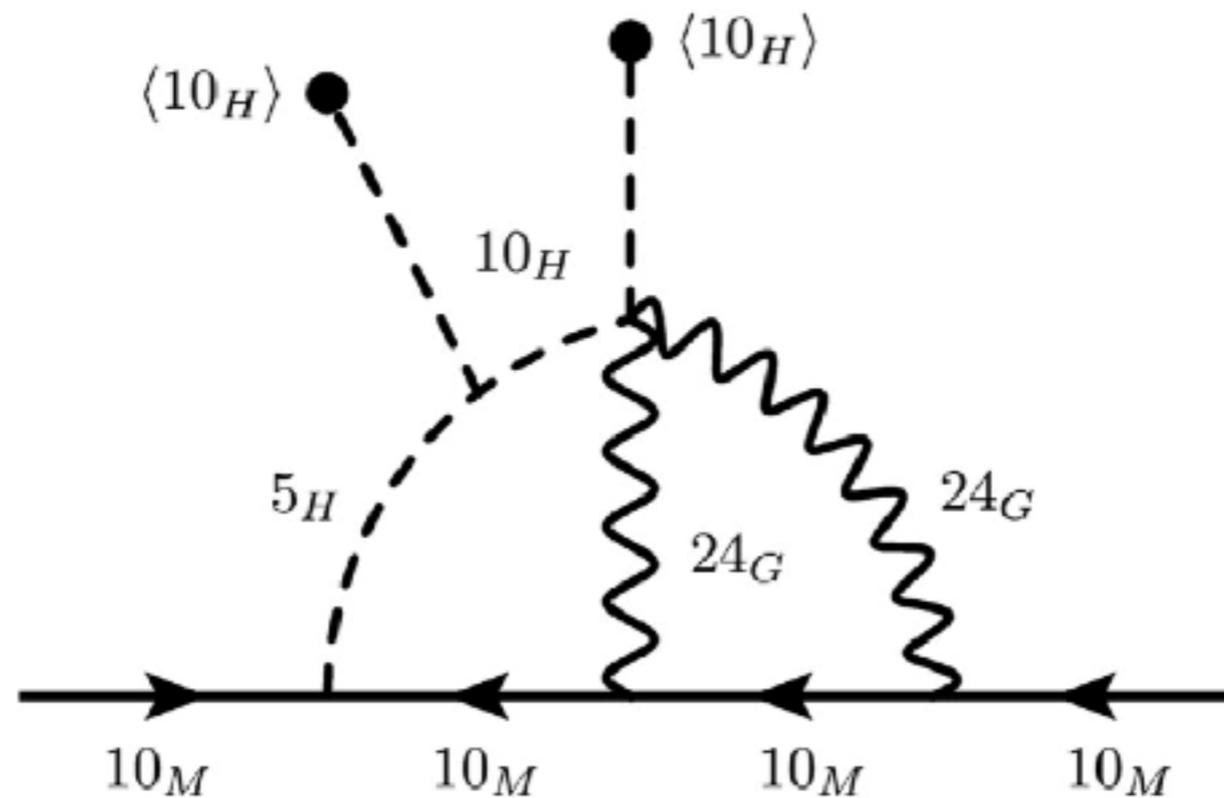
Tree level:  $10_M Y_{50} 10_M \langle 50_H \rangle$       OK in principle but overkill

# 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

Witten's loop option:

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



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

# The Witten's loop

## NEUTRINO MASSES IN THE MINIMAL O(10) THEORY <sup>☆</sup>

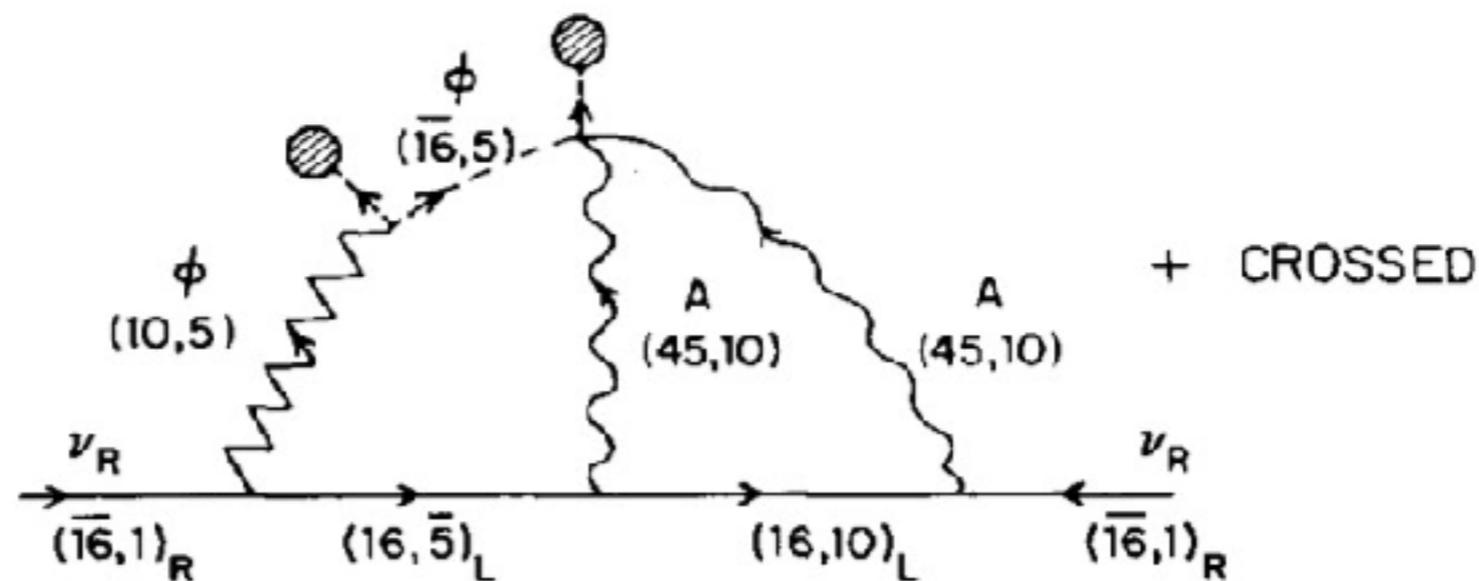
Phys. Lett. B91 (1980) 81

Edward WITTEN <sup>1</sup>

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  $10^{0\pm 2}$  eV depending on the strength of O(10) symmetry breaking, and on certain unknown ratios of masses and couplings of superheavy particles.

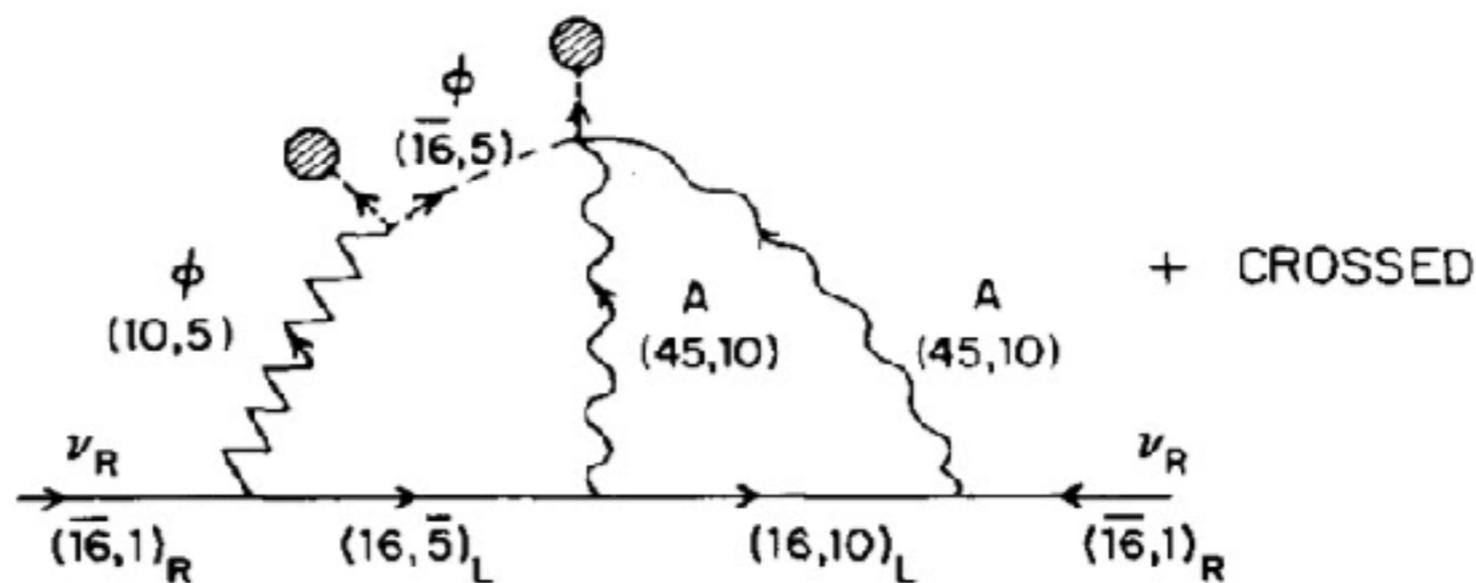


# The Witten's loop

Not many true applications though!

**Early 1980's:** no need for a hierarchy of scales (seesaw vs. GUT)  
stability issues in the minimal SO(10) scenario

cf. talk by Vasja Susič



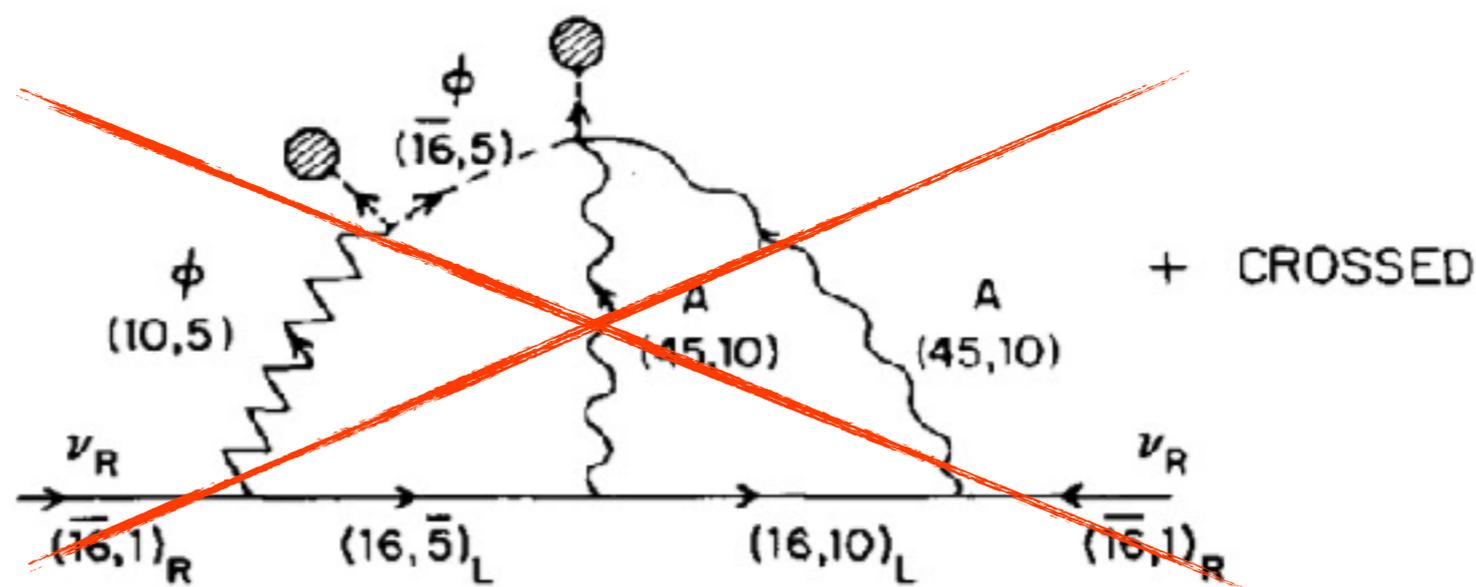
# The Witten's loop

Not many true applications though!

**Early 1980's:** no need for a hierarchy of scales (seesaw vs. GUT)  
stability issues in the minimal SO(10) scenario

cf. talk by Vasja Susič

**Mid 1980's:** paradigm shift towards TeV-scale SUSY, loops killed



# The Witten's loop

Not many true applications though!

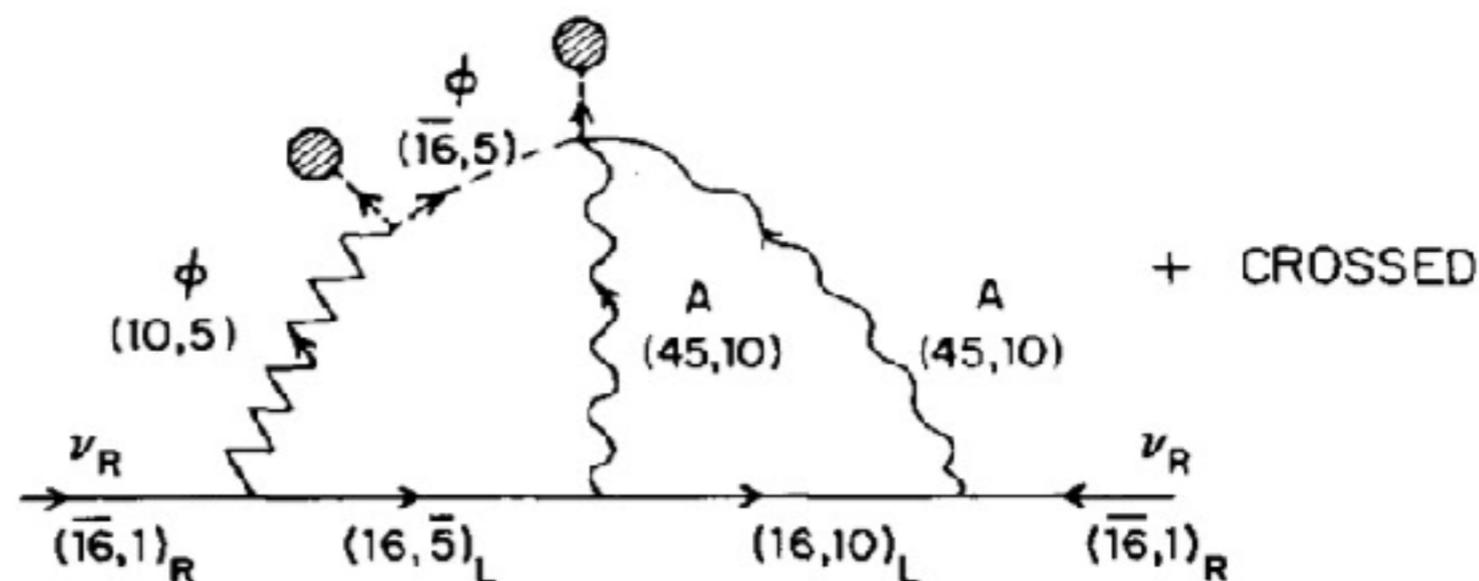
**Early 1980's:** no need for a hierarchy of scales (seesaw vs. GUT)  
stability issues in the minimal SO(10) scenario

cf. talk by Vasja Susič

**Mid 1980's:** paradigm shift towards TeV-scale SUSY, loops killed

**Few exceptions:** super-split supersymmetry - scalars at the GUT scale

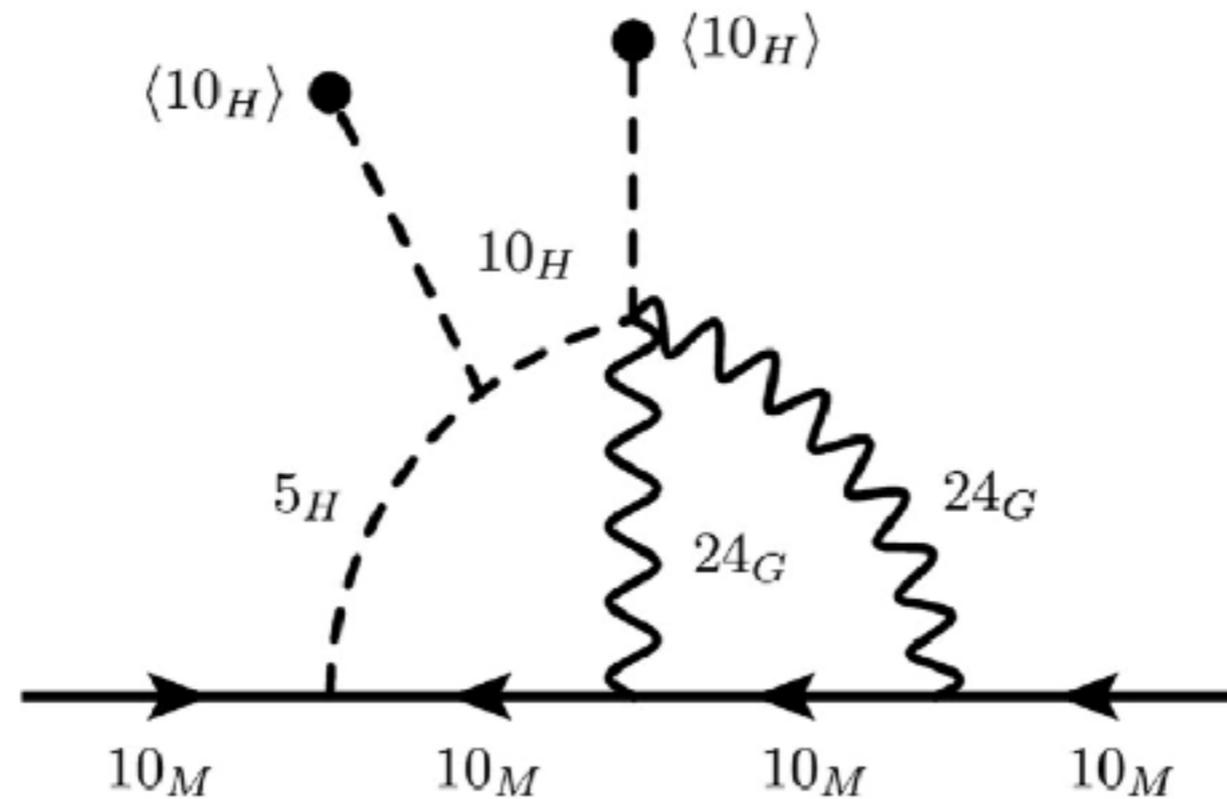
Bajc, Senjanovic, Phys. Lett.B610 (2005) 80



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

Flipped SU(5) Witten's loop anatomy:

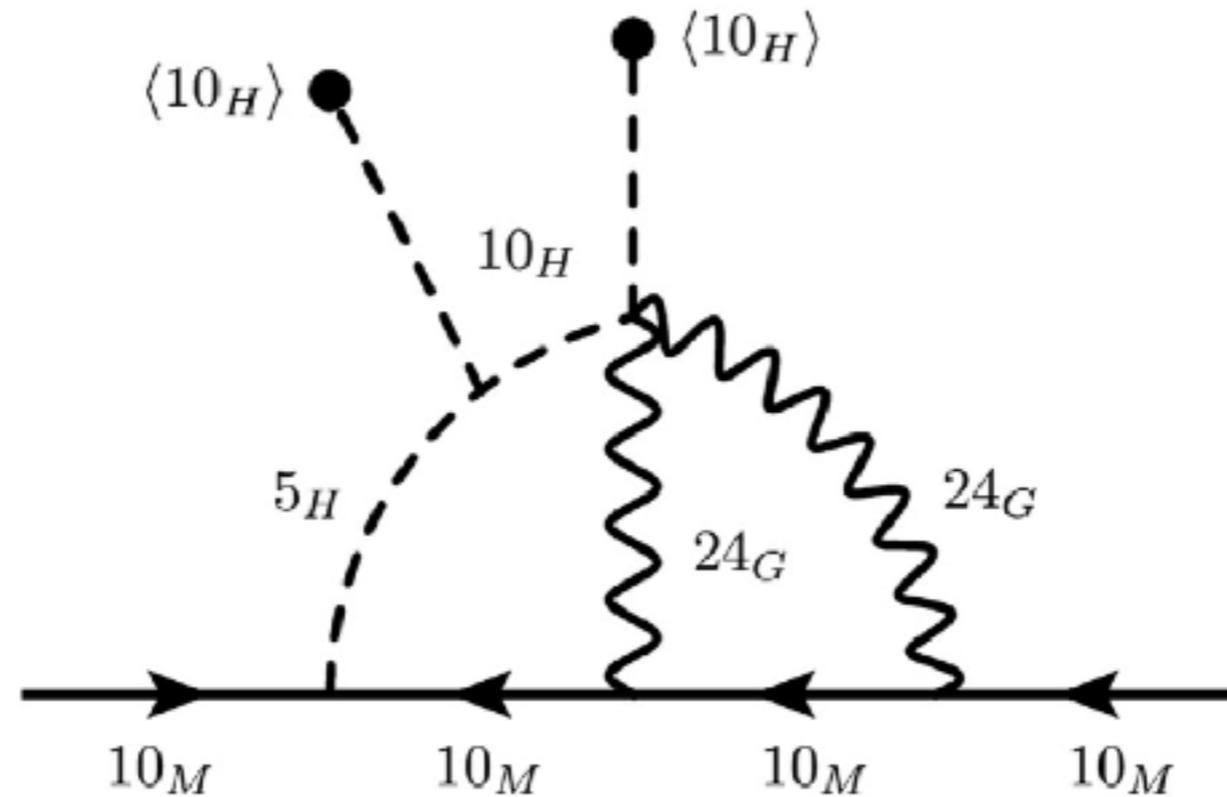
C.Arbelaez-Rodriguez, H. Kolečová, MM PRD89



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

Flipped SU(5) Witten's loop anatomy:

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

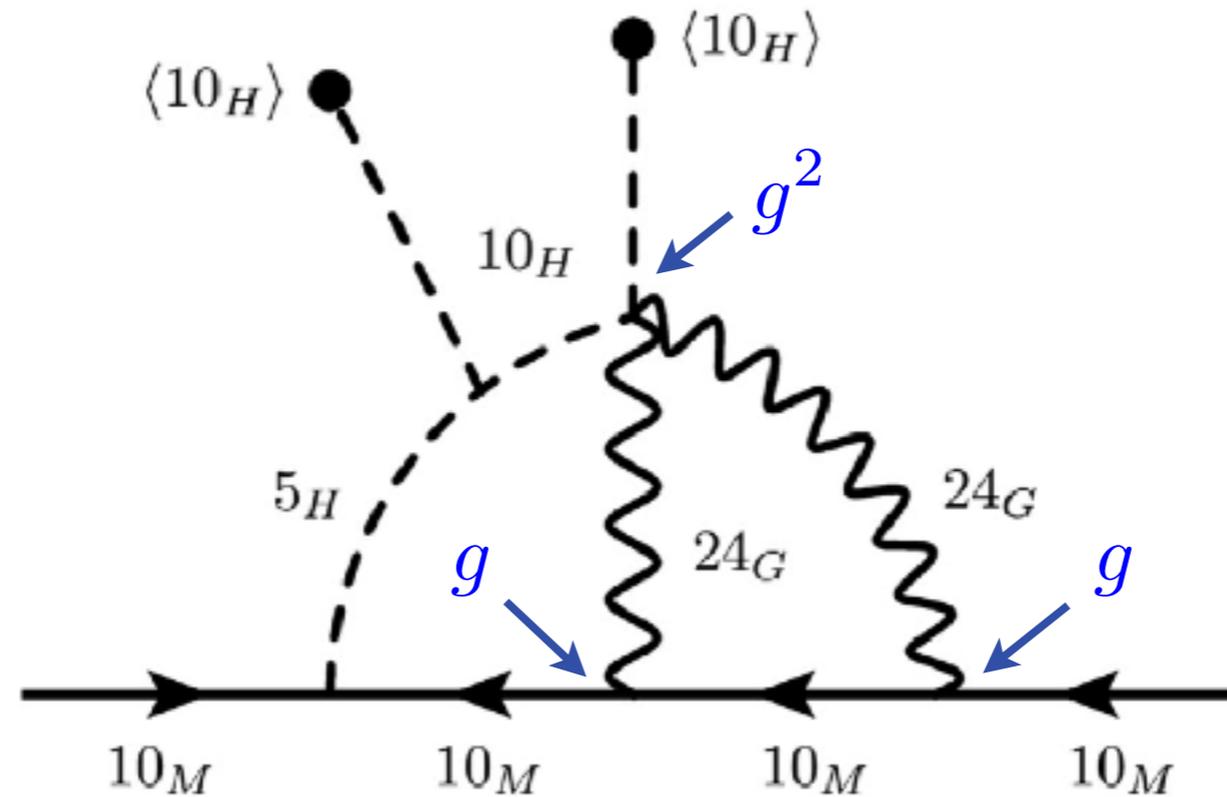


$$M_M = \frac{1}{(16\pi^2)^2}$$

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

Flipped SU(5) Witten's loop anatomy:

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



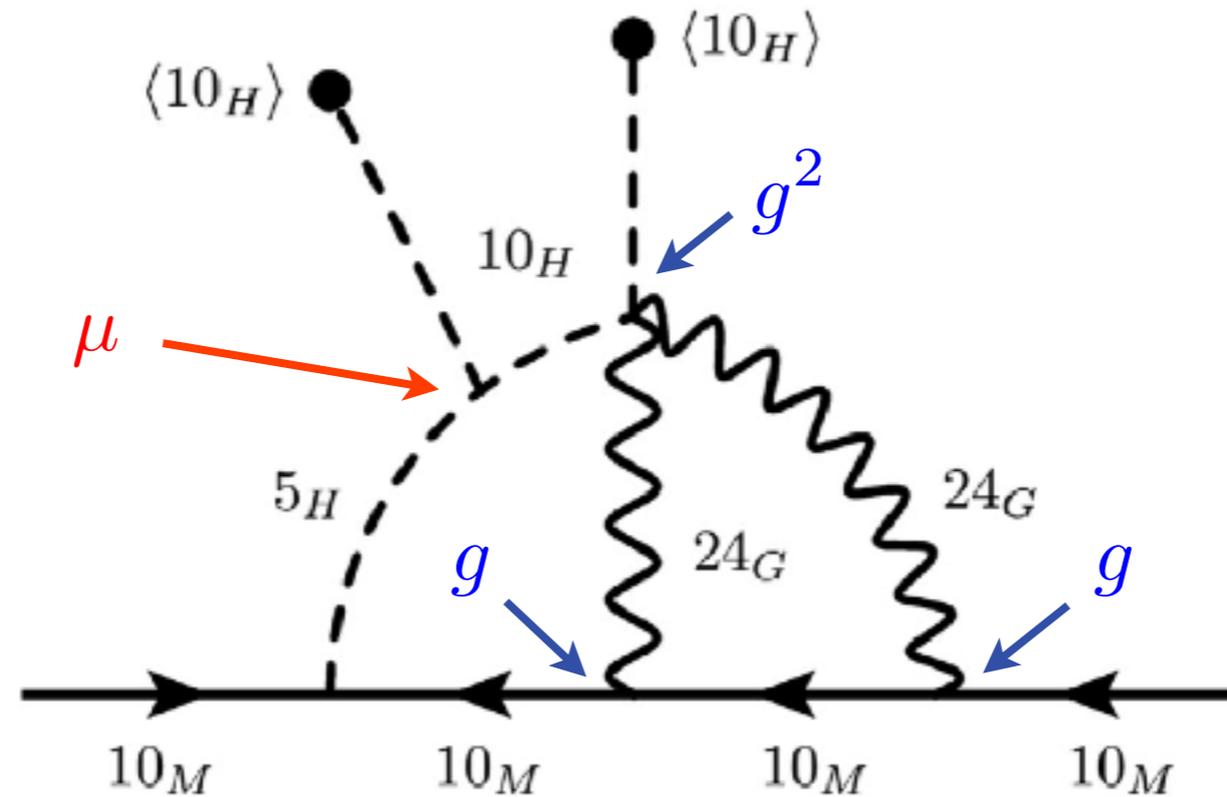
$$M_M = \frac{1}{(16\pi^2)^2} g^4$$

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

Flipped SU(5) Witten's loop anatomy:

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

$$\mu 5_H 10_H 10_H$$



$$M_M = \frac{1}{(16\pi^2)^2} g^4 \mu$$

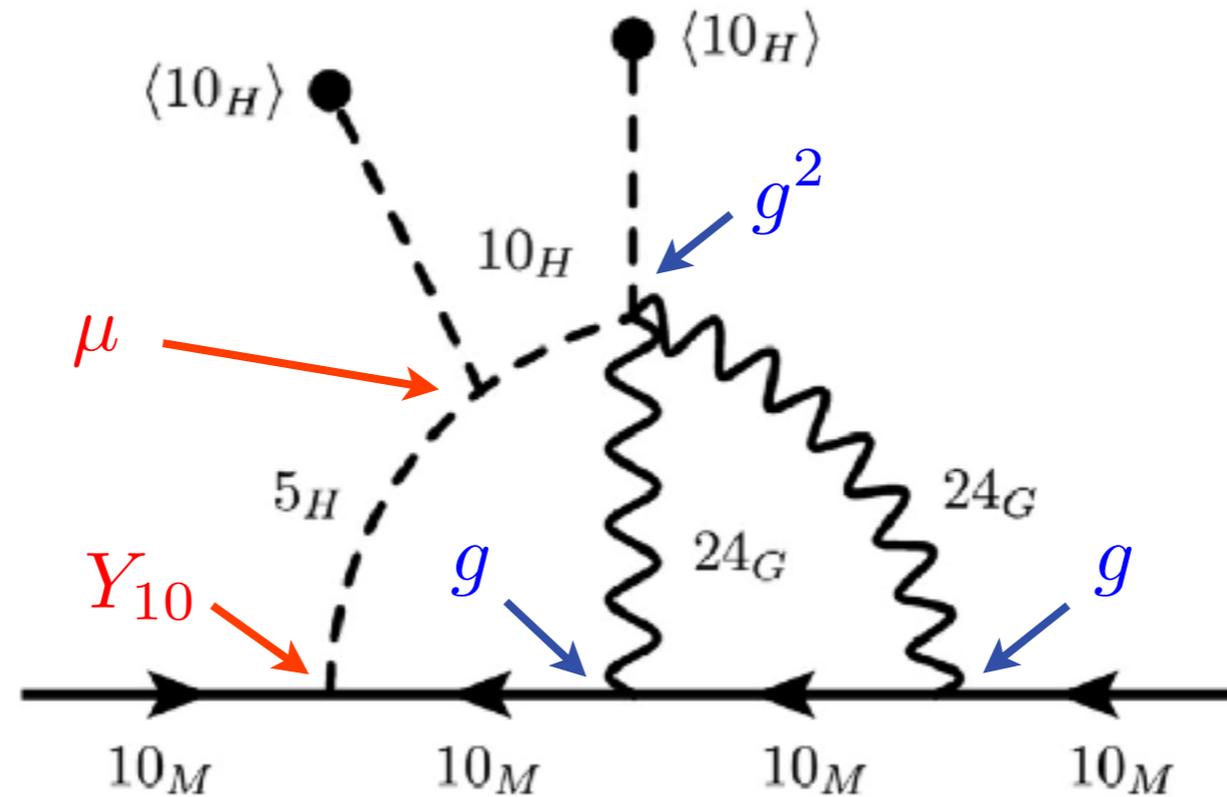
# Witten's mechanism in the minimal flipped SU(5)

Flipped SU(5) Witten's loop anatomy:

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

$\mu$   $5_H$   $10_H$   $10_H$

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



$$M_M = \frac{1}{(16\pi^2)^2} g^4 \mu Y_{10}$$

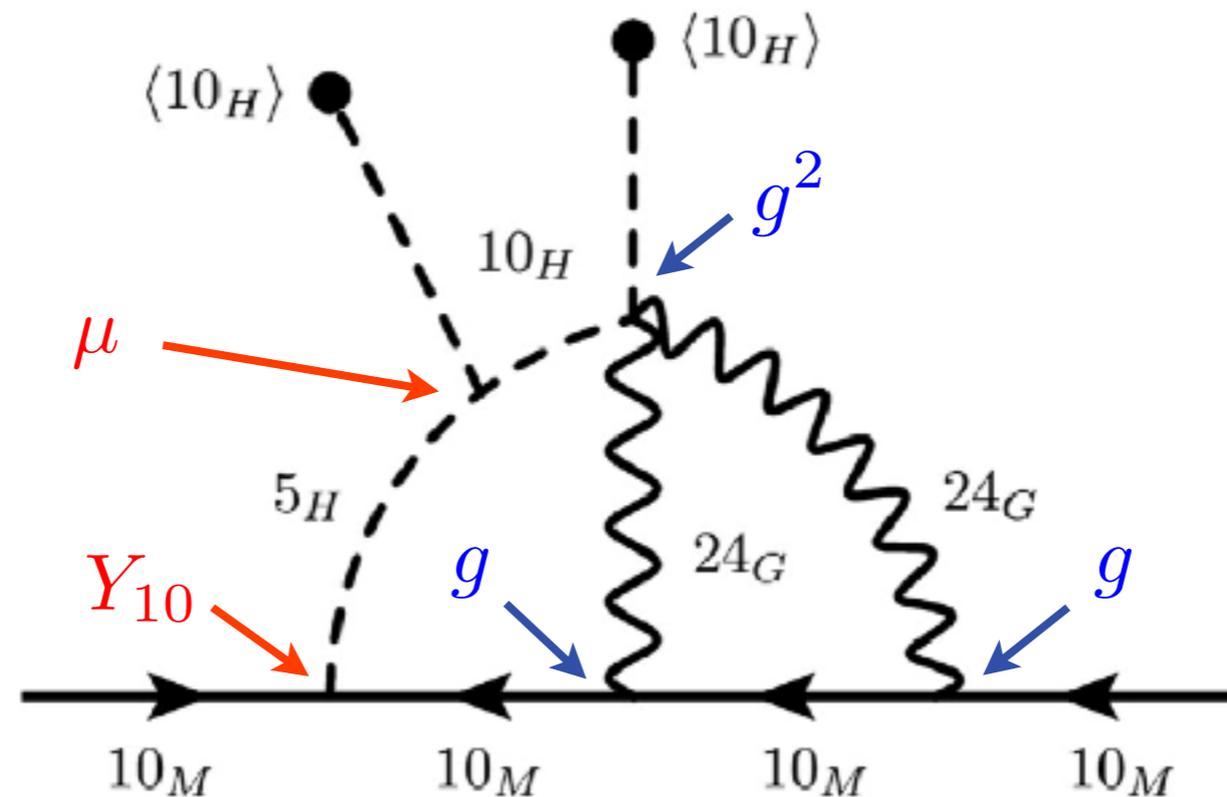
# Witten's mechanism in the minimal flipped SU(5)

Flipped SU(5) Witten's loop anatomy:

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

$\mu 5_H 10_H 10_H$

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

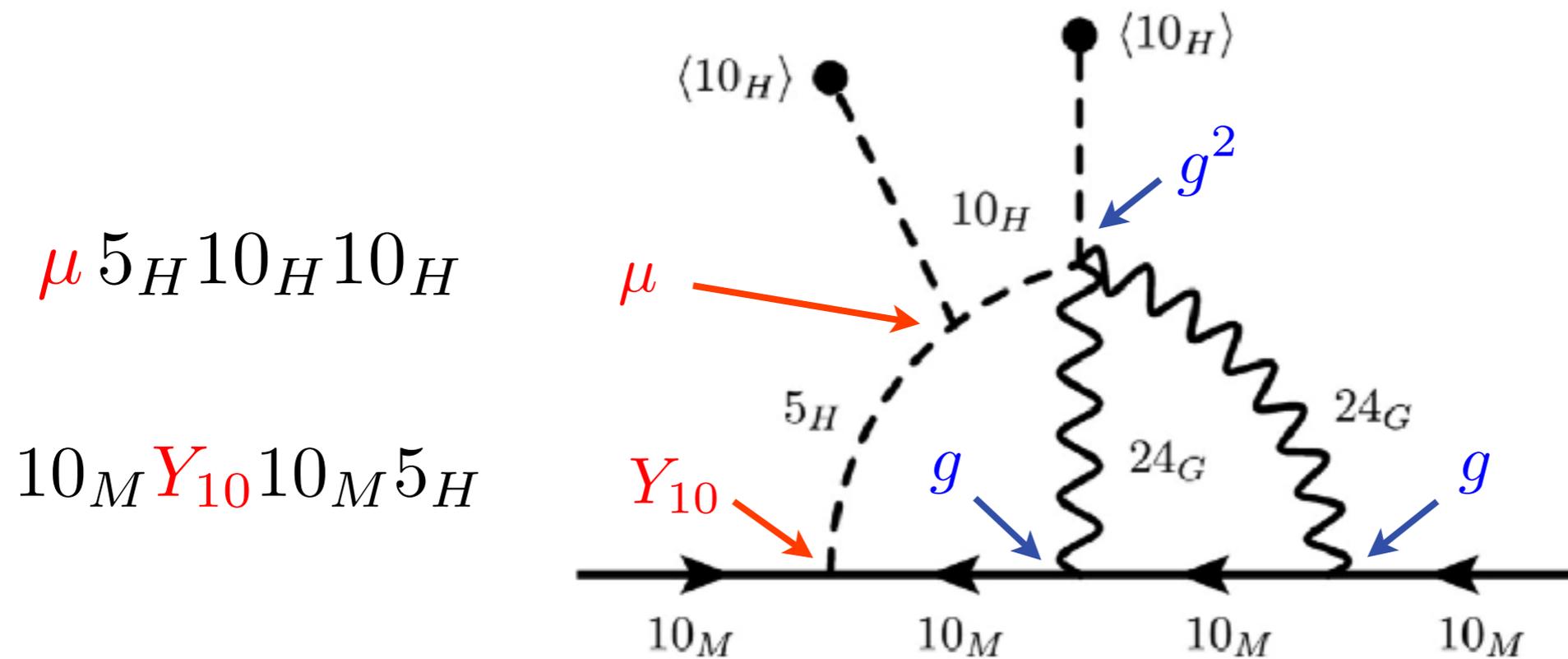


$$M_M = \frac{1}{(16\pi^2)^2} g^4 \mu Y_{10} \frac{\langle 10_H \rangle^2}{M_X^2}$$

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

Flipped SU(5) Witten's loop anatomy:

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



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

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

# Seesaw - the key to phenomenology

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

# Seesaw - the key to phenomenology

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

Perturbativity, non-tachyonicity of the spectrum:

Witten's loop structure



$$\left| D_u U_\nu^\dagger D_\nu^{-1} U_\nu^* D_u \right| \lesssim K(\dots) \times 10^{-2} M_X$$

# Seesaw - the key to phenomenology

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

Perturbativity, non-tachyonicity of the spectrum:

Witten's loop structure

$$\left| D_u U_\nu^\dagger D_\nu^{-1} U_\nu^* D_u \right| \lesssim K(\dots) \times \boxed{10^{-2} M_X} \sim 10^{14} \text{ GeV}$$

# Seesaw - the key to phenomenology

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

Witten's loop structure

Perturbativity, non-tachyonicity of the spectrum:

$$|D_u U_\nu^\dagger D_\nu^{-1} U_\nu^* D_u| \lesssim K(\dots) \times \boxed{10^{-2} M_X} \sim 10^{14} \text{ GeV}$$

**$U_\nu$  structure is strongly constrained !**

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

# Seesaw - the key to phenomenology

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

Witten's loop structure

Perturbativity, non-tachyonicity of the spectrum:

$$\left| D_u U_\nu^\dagger D_\nu^{-1} U_\nu^* D_u \right| \lesssim K(\dots) \times \boxed{10^{-2} M_X} \sim 10^{14} \text{ GeV}$$

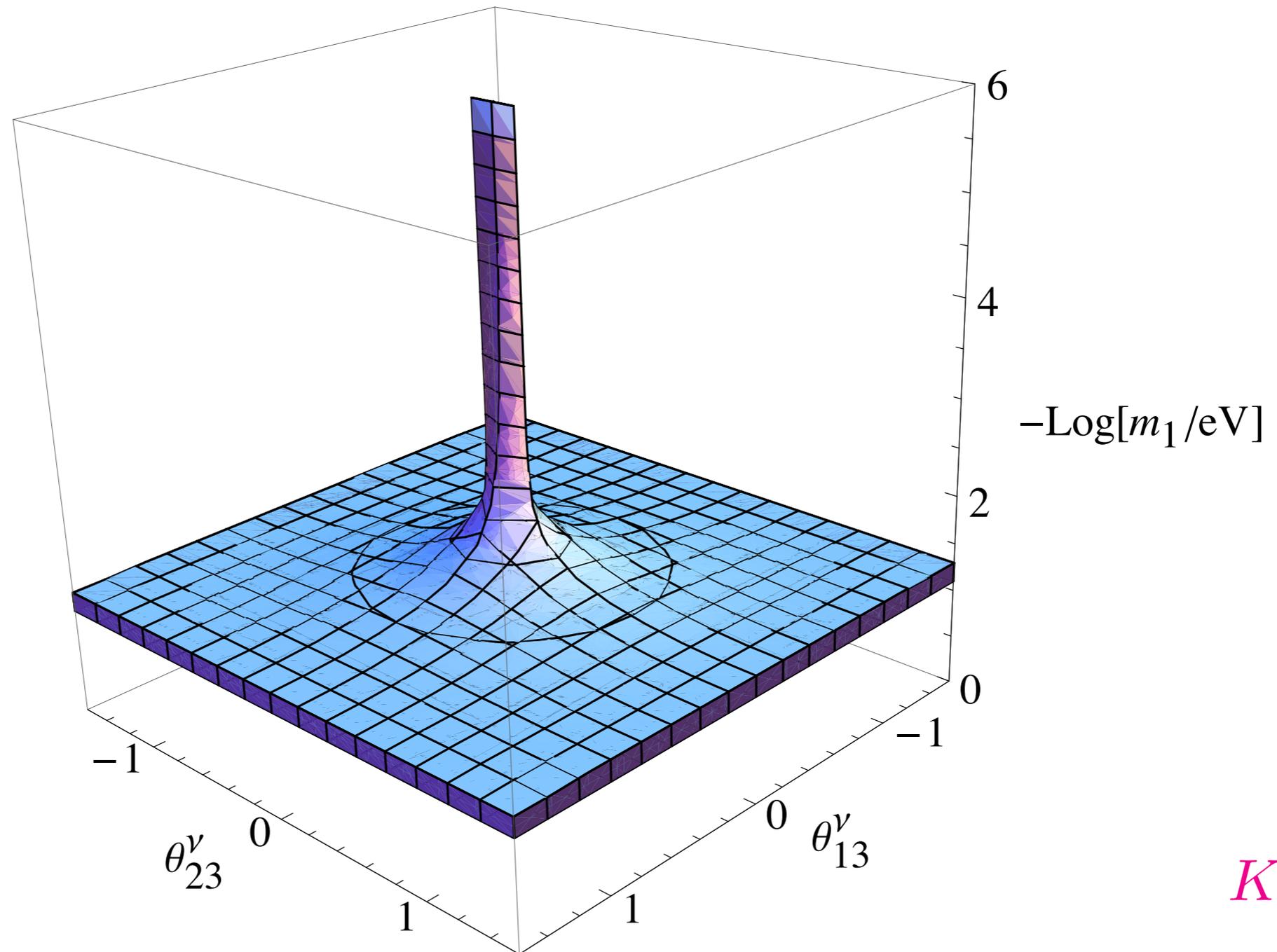
**$U_\nu$  structure is strongly constrained !**

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

Severity of this depends on the lightest neutrino mass...

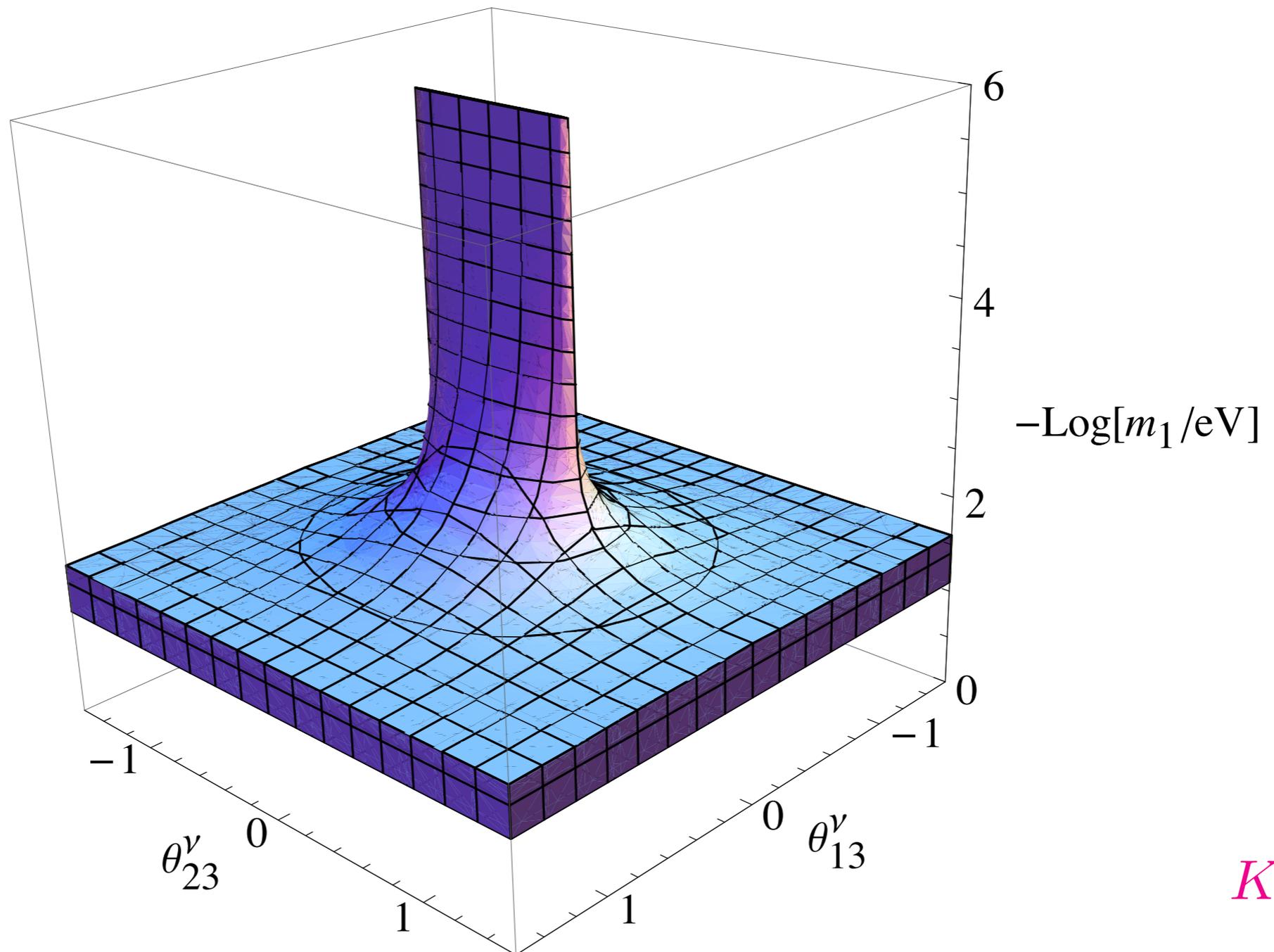
# The parameter space $(m_1, U_\nu)$

$U_\nu$  angular behaviour:



# The parameter space $(m_1, U_\nu)$

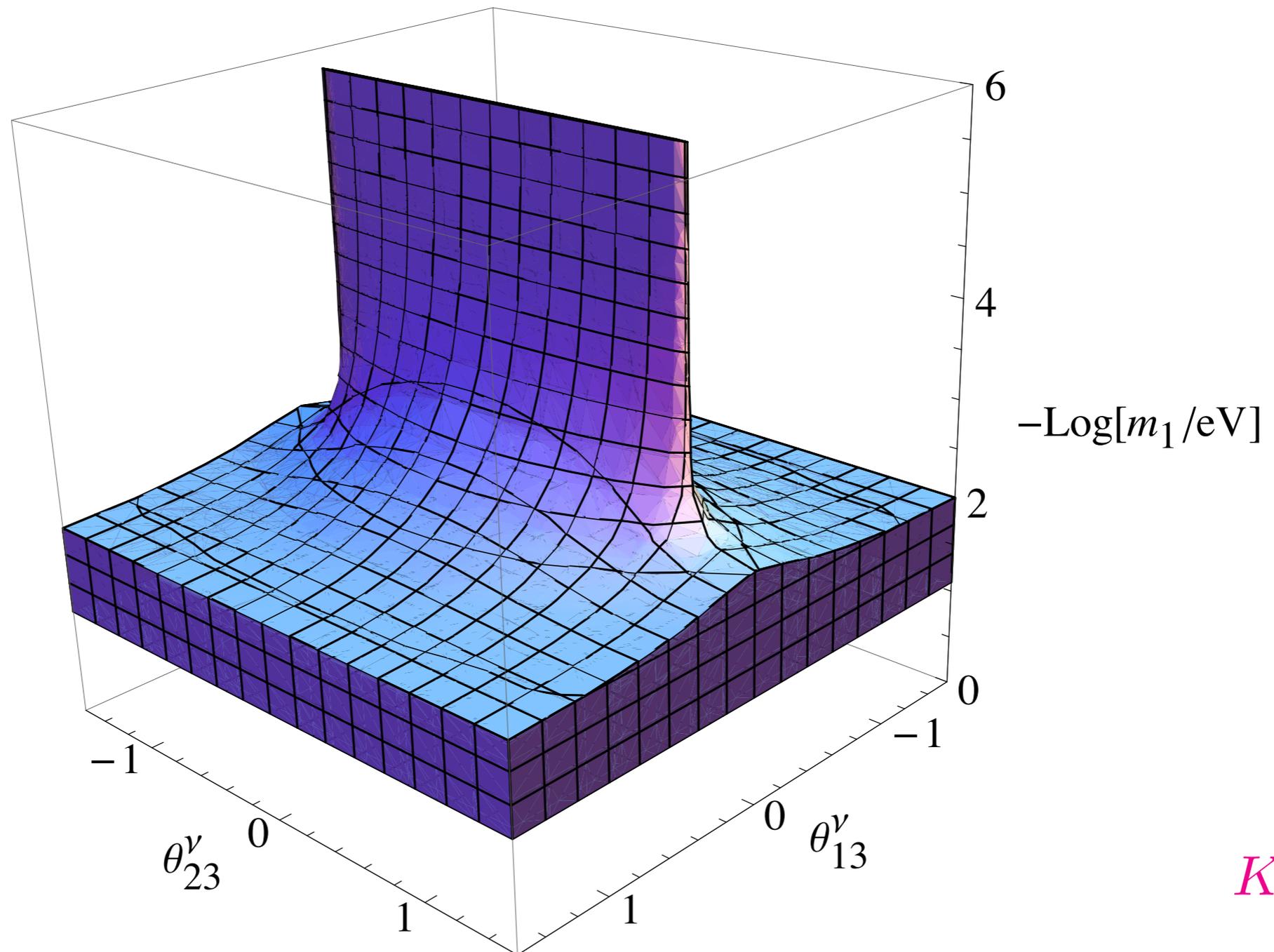
$U_\nu$  angular behaviour:



$K = 2$

# The parameter space $(m_1, U_\nu)$

$U_\nu$  angular behaviour:

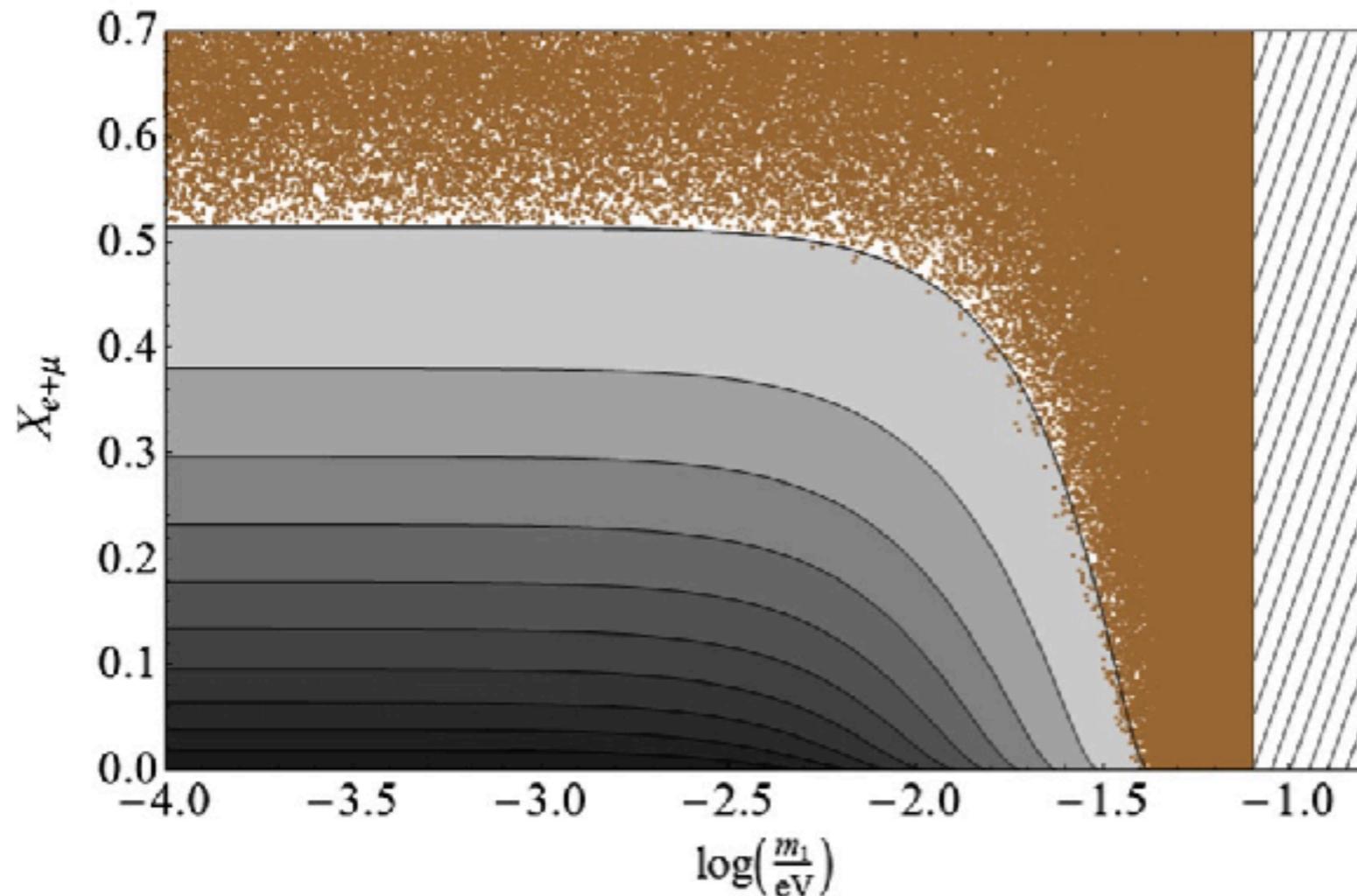


$K = 5$

# $U_\nu$ features in proton decay rates

Unlikely to have both  $\Gamma(p \rightarrow \pi^0 e^+)$  and  $\Gamma(p \rightarrow \pi^0 \mu^+)$  arbitrarily suppressed  
(in the small  $m_1$  regime)

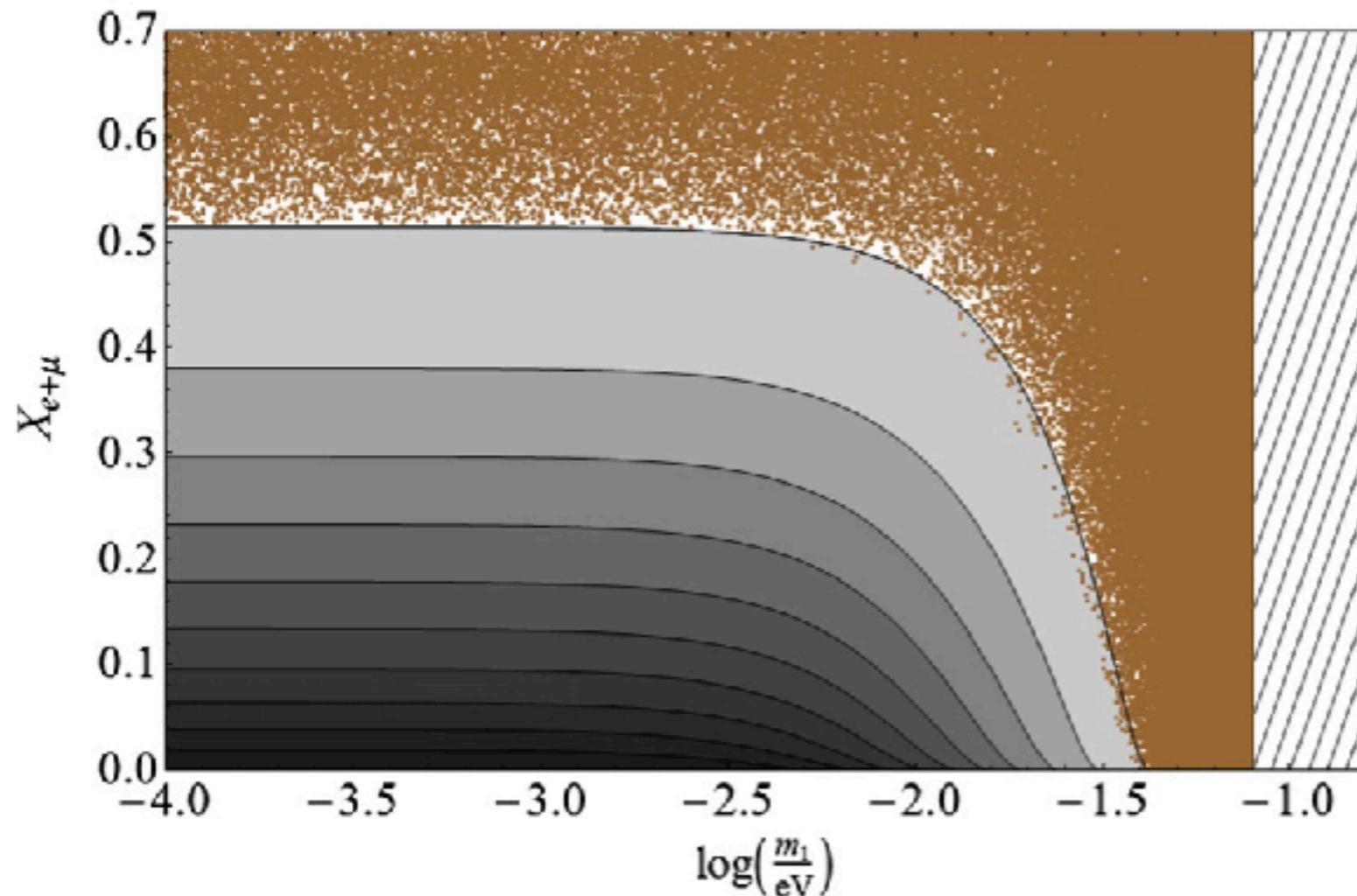
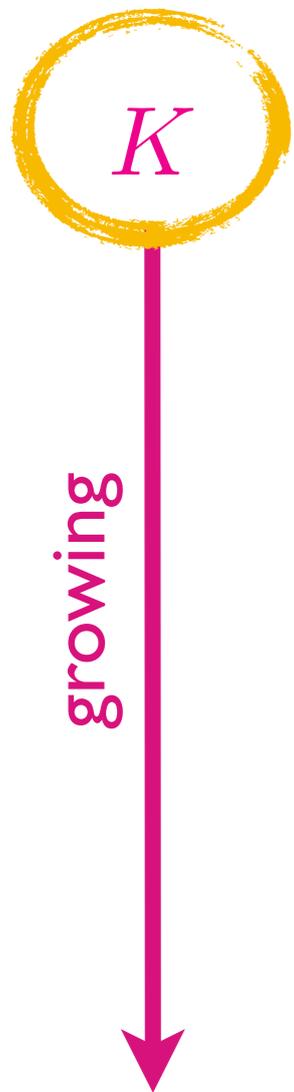
$K$   
growing  
↓



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

# $U_\nu$ features in proton decay rates

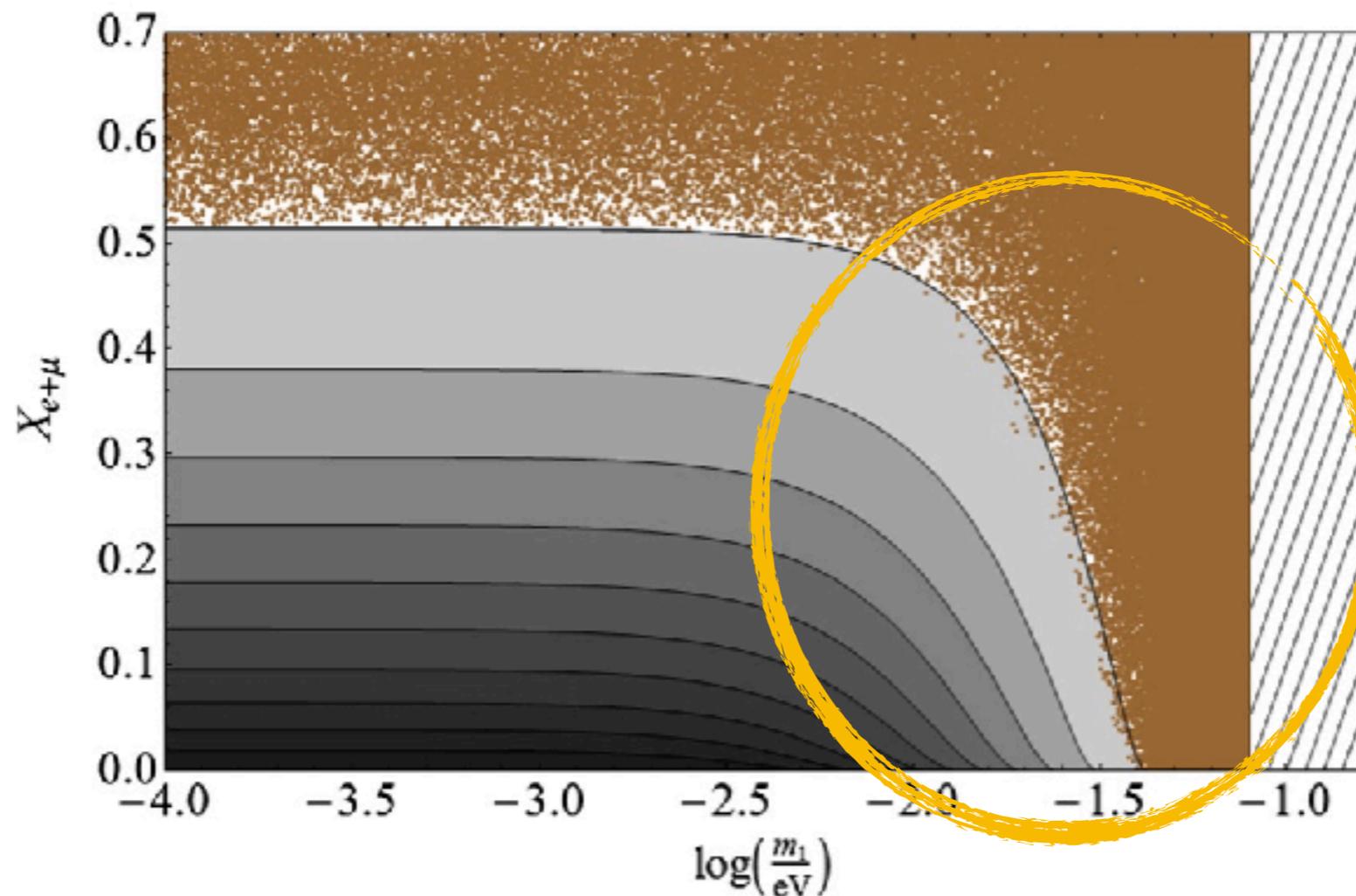
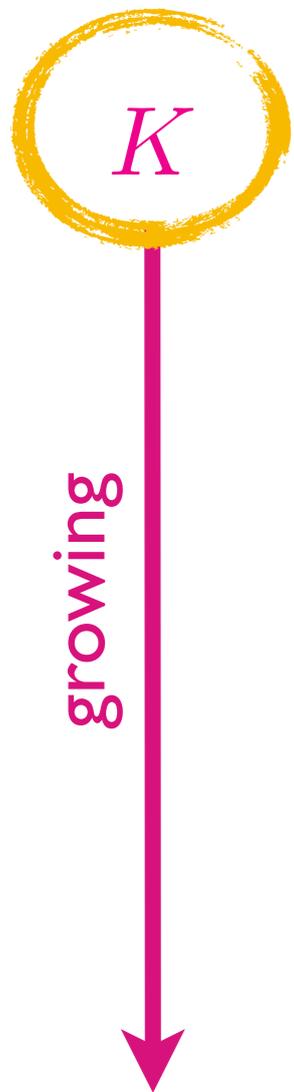
Unlikely to have both  $\Gamma(p \rightarrow \pi^0 e^+)$  and  $\Gamma(p \rightarrow \pi^0 \mu^+)$  arbitrarily suppressed  
(in the small  $m_1$  regime)



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

# $U_\nu$ features in proton decay rates

Unlikely to have both  $\Gamma(p \rightarrow \pi^0 e^+)$  and  $\Gamma(p \rightarrow \pi^0 \mu^+)$  arbitrarily suppressed  
(in the small  $m_1$  regime)



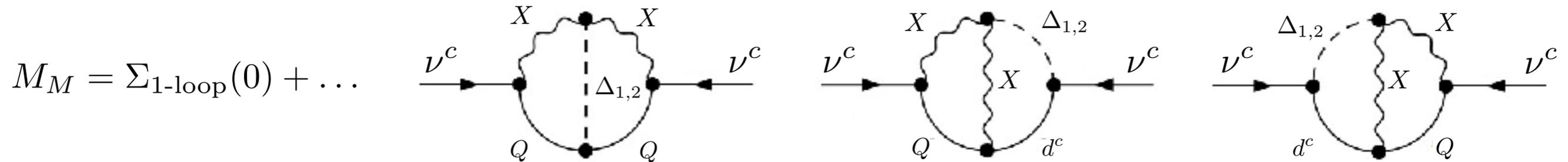
C.Arbelaez-Rodriguez, H.Kolešová, MM, PRD89

# How about $K$ ?



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

Broken phase massive PE, unitary gauge:



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 -  $\Sigma(0)$  must be finite

UV divergences (d. reg.):

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

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?

Thermal leptogenesis may be non-trivial (if ever possible) here

# How about the “large” $m_1$ regime?

Thermal leptogenesis may be non-trivial (if ever possible) here

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

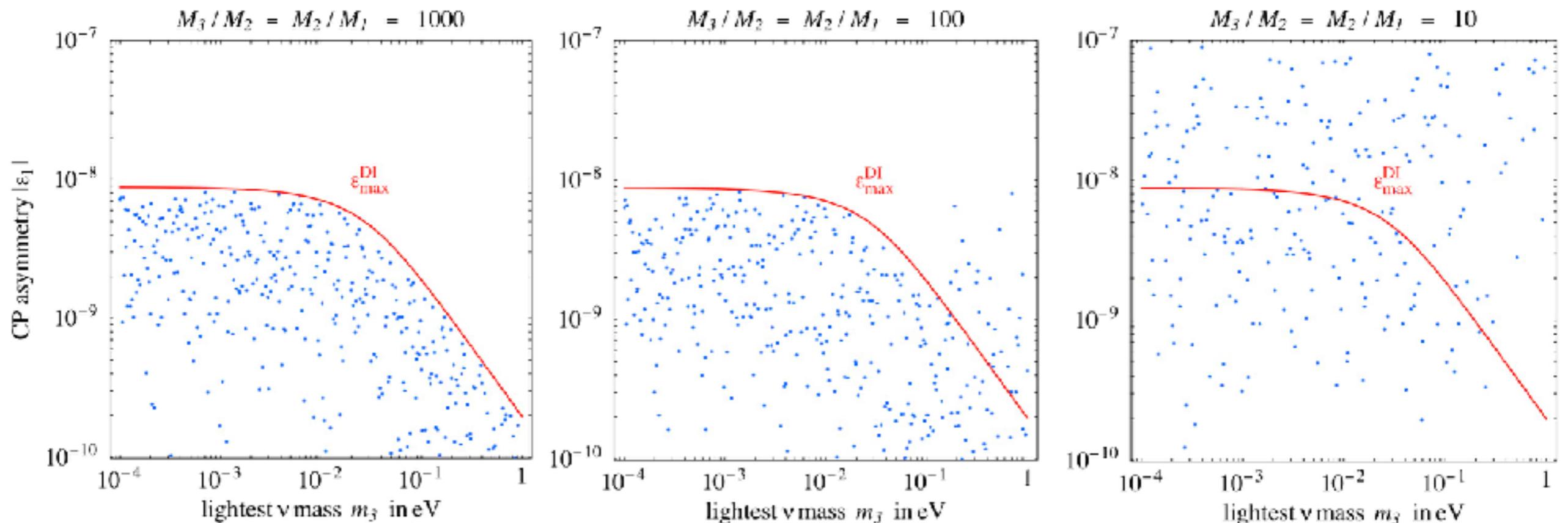
- RHN spectrum tends to be hierarchical and suppressed - **conflict with Davidson-Ibarra?**

# How about the “large” $m_1$ regime?

Thermal leptogenesis may be non-trivial (if ever possible) here

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

- RHN spectrum tends to be hierarchical and suppressed - **conflict with Davidson-Ibarra?**



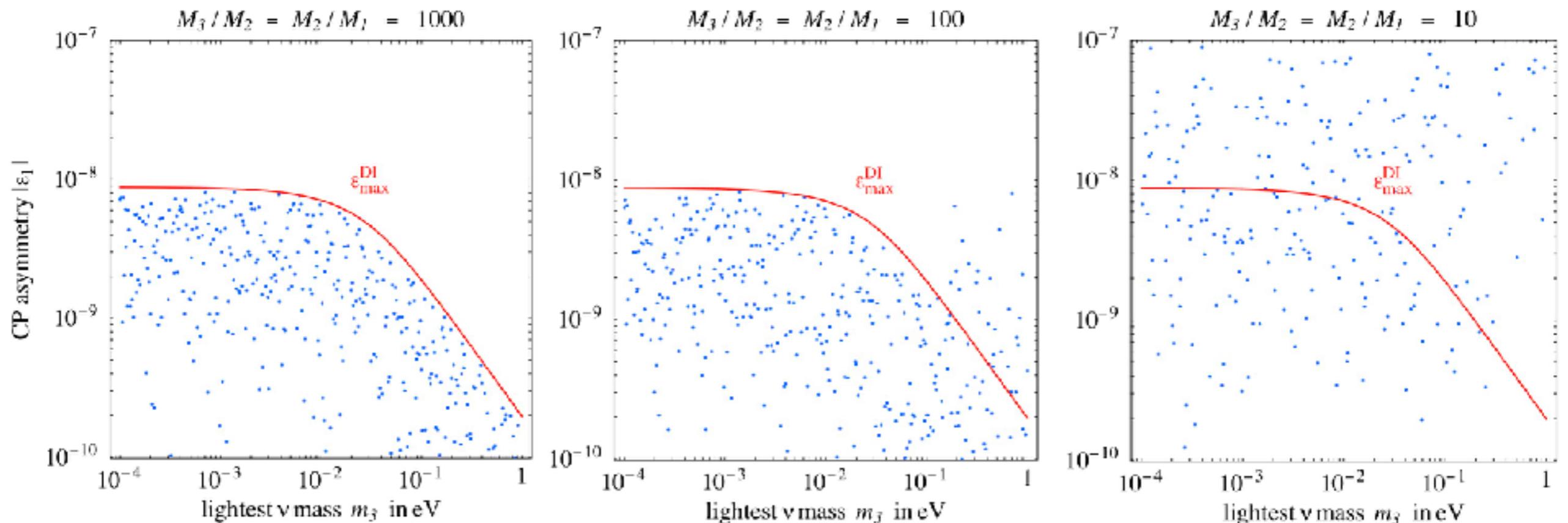
T. Hambye, Y. Lin, A. Notari, M. Papucci, A. Strumia, Nucl.Phys.B 695 (2004)

# How about the “large” $m_1$ regime?

Thermal leptogenesis may be non-trivial (if ever possible) here

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

- RHN spectrum tends to be hierarchical and suppressed - **conflict with Davidson-Ibarra?**



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

- Again,  $U_\nu$  can not be arbitrary => **further constraints on BLNV rates (?)**

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

Detailed numerical analysis (ULYSSES) MM, V. Miřátský, R. Fonseca, M. Zdráhal, in preparation

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

VERY PRELIMINARY

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

Detailed numerical analysis (ULYSSES) MM, V. Miřátský, R. Fonseca, M. Zdráhal, in preparation

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

## Summary:

### 1) “large” $m_1$ (quasi-degenerate) regime:

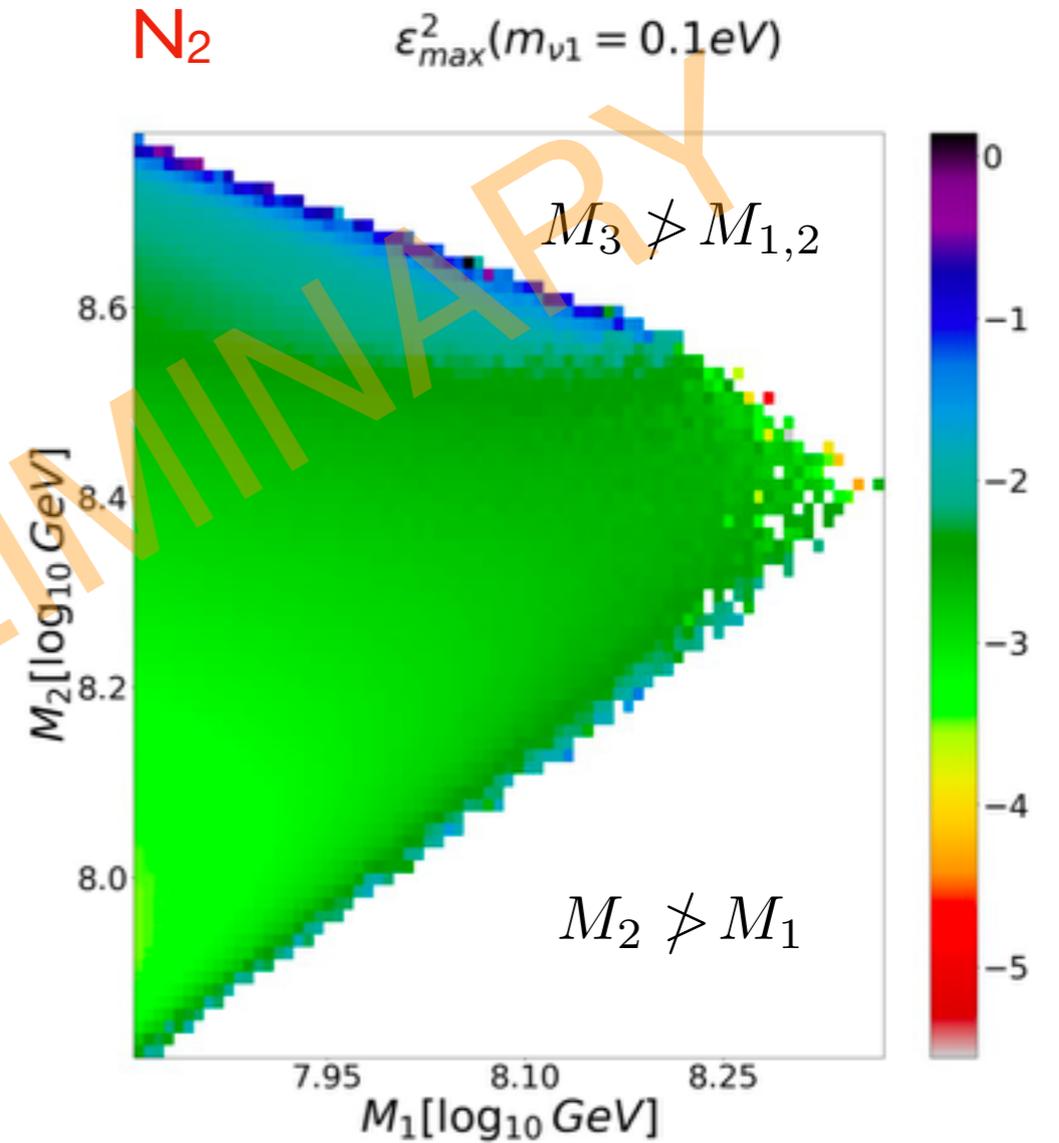
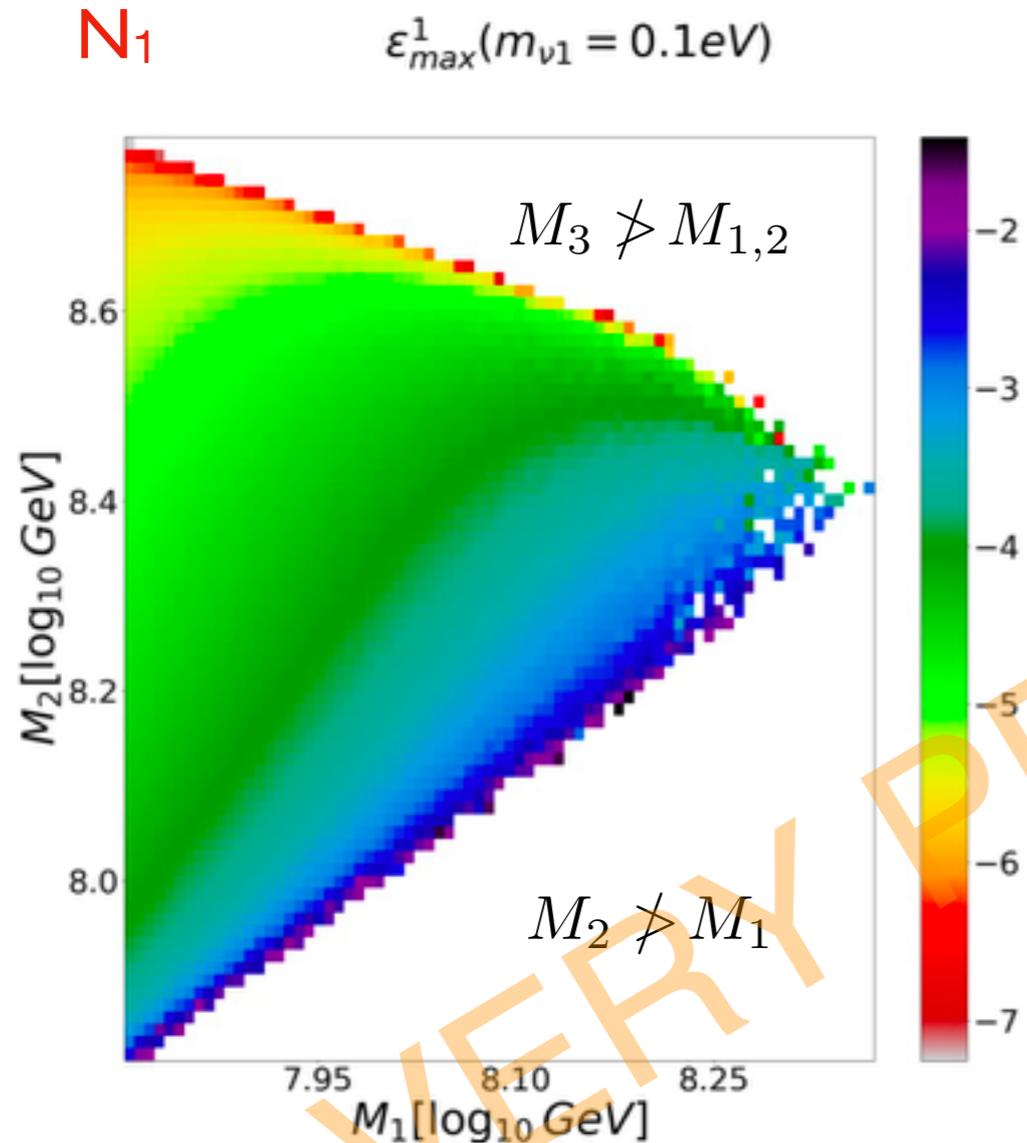
- no obstacle to avoiding Davidson-Ibarra limit for CP asymmetries
- no way to get the right  $\eta_B$  from  $N_1$  OOE decays though - washout too large
- $N_2$ -dominated regime possible but yield insufficient

VERY PRELIMINARY

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

CP asymmetries (“large”  $m_1$  regime):

MM, V. Miřátský, R. Fonseca, M. Zdráhal  
in preparation

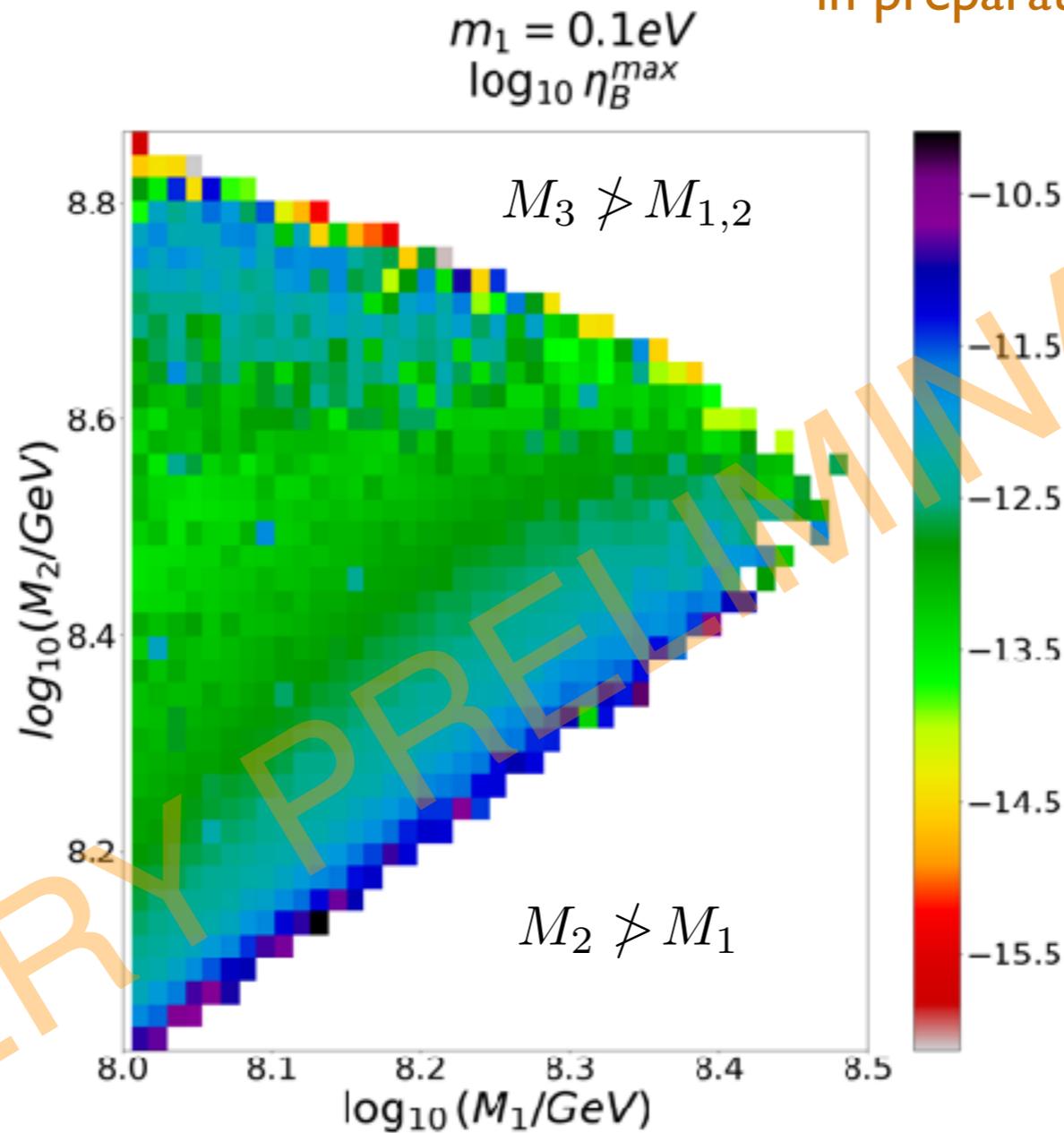


$M_1 M_2 M_3 \sim \tilde{m}_u^2 \tilde{m}_c^2 \tilde{m}_t^2 / m_1^3$  in quasi-degenerate regime

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

B-asymmetry (“large”  $m_1$  regime):

MM, V. Miřátský, R. Fonseca, M. Zdráhal  
in preparation



**Not a single good point found for “large”  $m_1$  (several tens of millions generated)!**

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

Detailed numerical analysis (ULYSSES) MM, V. Miřátský, R. Fonseca, M. Zdráhal, in preparation

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

## Summary:

### 1) “large” $m_1$ (quasi-degenerate) regime:

- no obstacle to avoiding Davidson-Ibarra limit for CP asymmetries
- no way to get the right  $\eta_B$  from  $N_1$  OOE decays though - washout too large
- $N_2$ -dominated regime possible but yield insufficient

**Upper limit on the absolute neutrino mass scale => testability !**

VERY PRELIMINARY

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

Detailed numerical analysis (ULYSSES) MM, V. Miřátský, R. Fonseca, M. Zdráhal, in preparation

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

## Summary:

### 1) “large” $m_1$ (quasi-degenerate) regime:

- no obstacle to avoiding Davidson-Ibarra limit for CP asymmetries
- no way to get the right  $\eta_B$  from  $N_1$  OOE decays though - washout too large
- $N_2$ -dominated regime possible but yield insufficient

**Upper limit on the absolute neutrino mass scale => testability !**

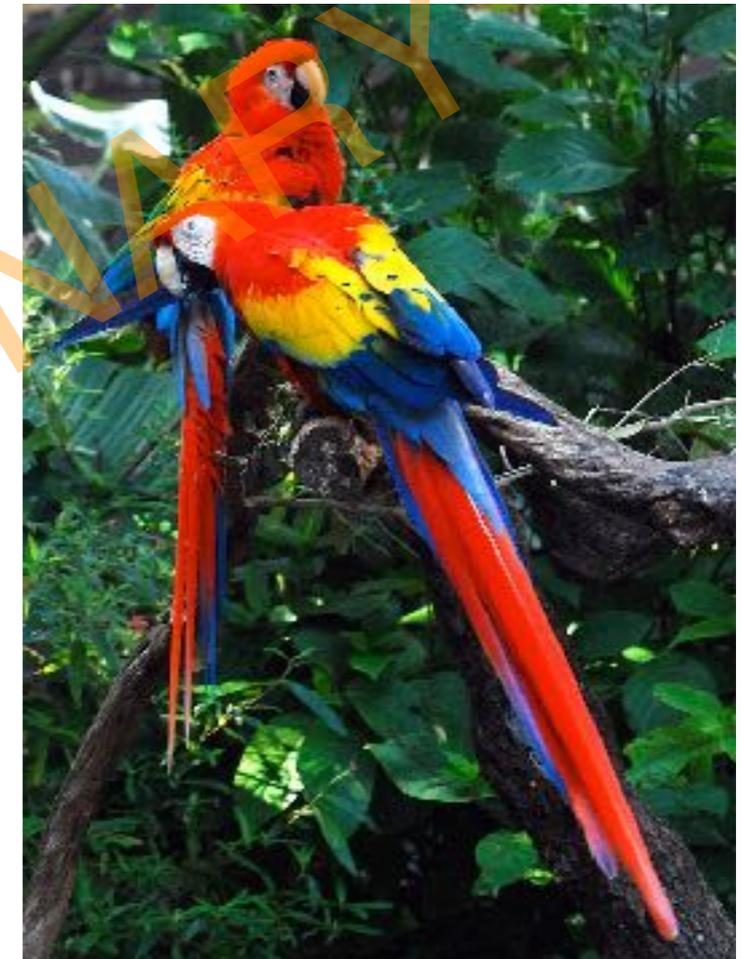
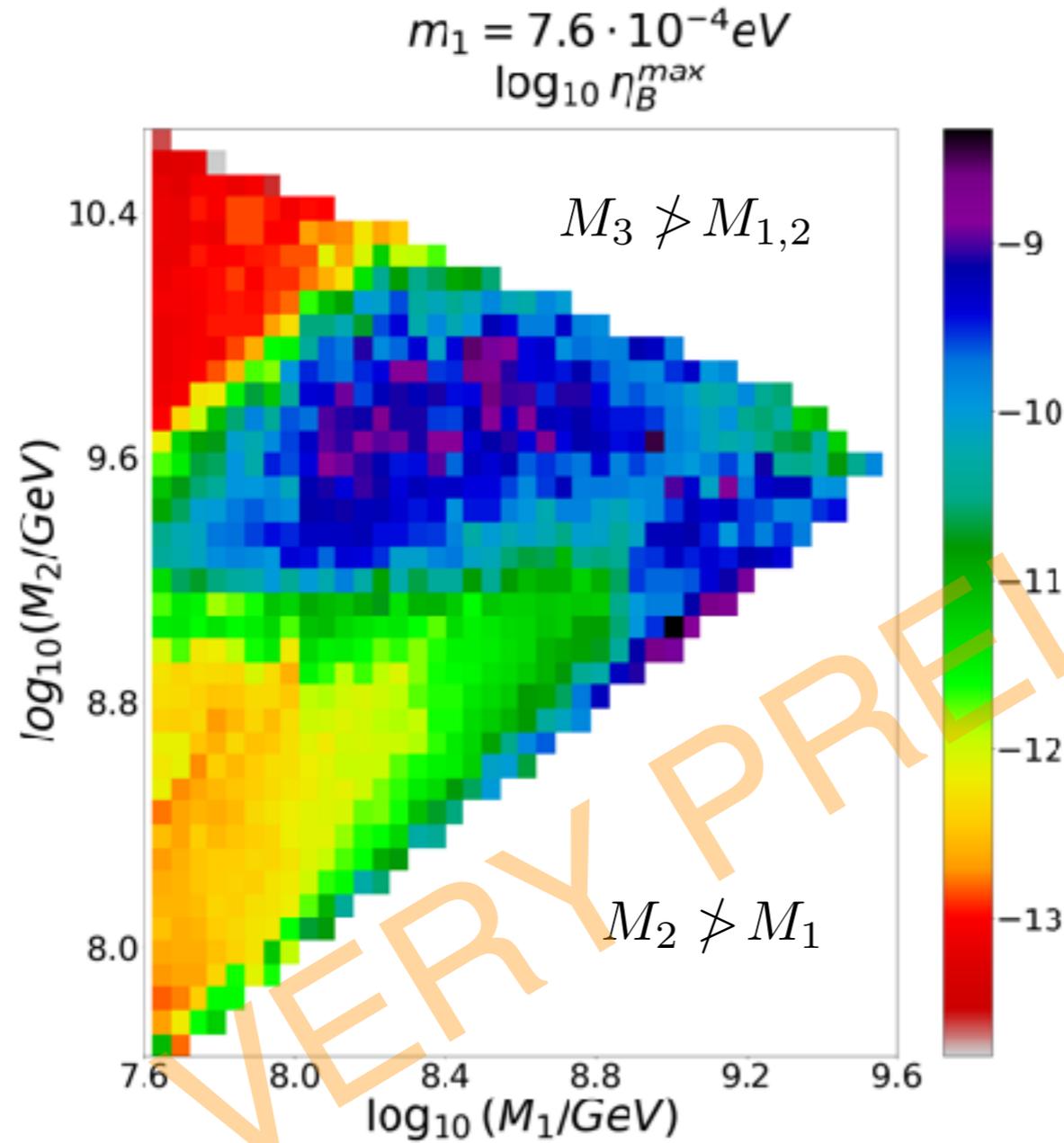
### 2) “small” $m_1$ ( $< 0.01$ eV, hierarchical neutrinos) regime:

- $N_1$  washout can be suppressed enough in small PS domains
- $N_2$ -regime “optically dominant”, decoherence effects important

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

B-asymmetry (hierarchical regime):

MM, V. Miřátský, R. Fonseca, M. Zdráhal  
in preparation



$M_1 \sim M_2$

Leptogenesis leaves open just those parts of the parameter space  
where interesting features in p-decay are expected!

Thanks for your kind attention!

A scenic view of a coastal town, likely Portorož, featuring multi-story buildings with balconies, a prominent tall cypress tree, and a clear blue sky. The foreground shows a street with parked cars and streetlights.

Thanks for your kind attention!

Thanks to the organisers for the great Portorož 2023!

Horse time!

