FLASY'14, Brighton, June 21 2014

Abelian Higgs models

Michal Malinský

Institute of Particle and Nuclear Physics, Charles University in Prague

FLASY'14, Brighton, June 21 2014

Witten's loop in the flipped SU(5) UT

Michal Malinský

Institute of Particle and Nuclear Physics, Charles University in Prague

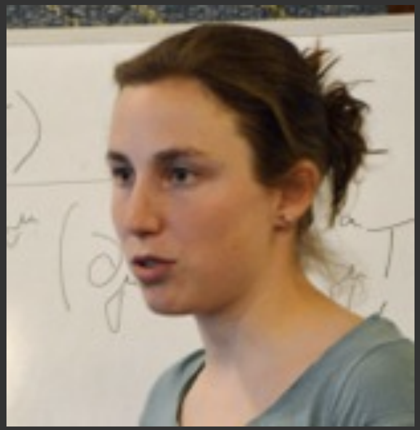
FLASY'14, Brighton, June 21 2014

Witten's loop in the flipped SU(5) UT

Michal Malinský

Institute of Particle and Nuclear Physics, Charles University in Prague

in collaboration with



Helena Šediváková (IPNP Prague)

Carolina Arbelaez Rodriguez (IST Lisbon/AHEP Valencia)

Loop-induced (RH) Majorana neutrino masses in a non-SUSY unification

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

“The Higgs mass suffers from large radiative corrections!”

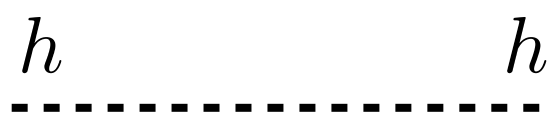
The standard (wrong) argument:

$\Gamma_{hh} \propto$

$p^2 - m_H^2$

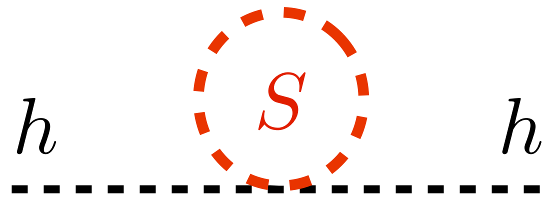
The standard (wrong) argument:

$\Gamma_{hh} \propto$



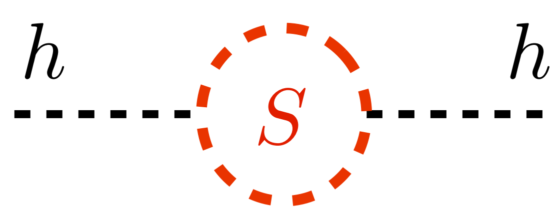
$$p^2 - m_H^2$$

$+$



$$\frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right)$$

$+$

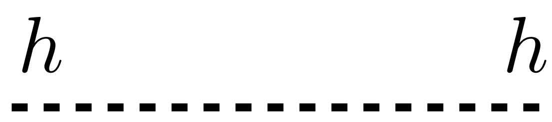


$$\frac{1}{16\pi^2} v^2 \left(C_{UV} - \int_0^1 \mathrm{d}x \log \frac{M_S^2 - x(1-x)p^2}{\mu^2} \right)$$

$+\ldots$

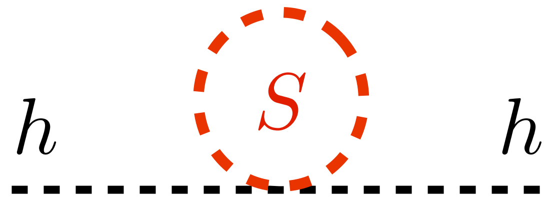
The standard (wrong) argument:

$\Gamma_{hh} \propto$



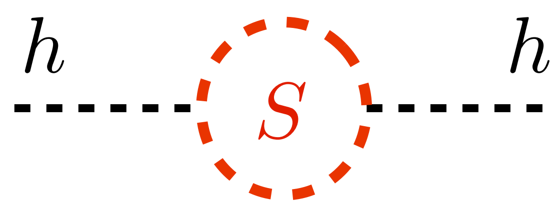
$$p^2 - m_H^2$$

$+$



$$\frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right)$$

$+$



$$\frac{1}{16\pi^2} v^2 \left(C_{UV} - \int_0^1 \mathrm{d}x \log \frac{M_S^2 - x(1-x)p^2}{\mu^2} \right)$$

$+ \ldots$

For large M_S^2 the root shifts enormously...

$$m_H^2 \to m_H^2 + \frac{1}{16\pi^2} M_S^2 \left(1 - \log \frac{M_S^2}{\mu^2} \right) + \ldots$$

so the tree-level mass must be carefully readjusted order by order...

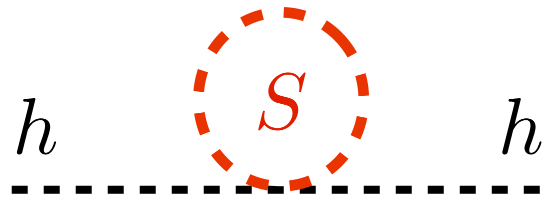
The “hierarchy problem”

The standard (wrong) argument:

$\Gamma_{hh} \propto$

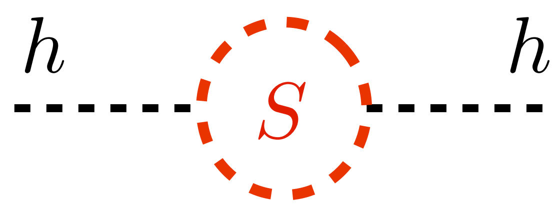
$$p^2 - m_H^2$$

$+$



$$\frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right)$$

$+$



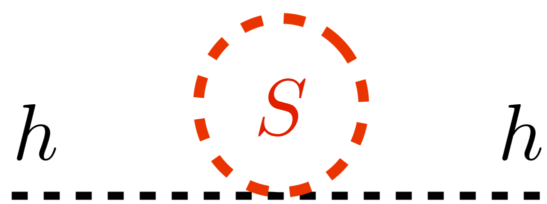
$$\frac{1}{16\pi^2} v^2 \left(C_{UV} - \int_0^1 \mathrm{d}x \log \frac{M_S^2 - x(1-x)p^2}{\mu^2} \right)$$

The standard (wrong) argument:

$\Gamma_{hh} \propto$

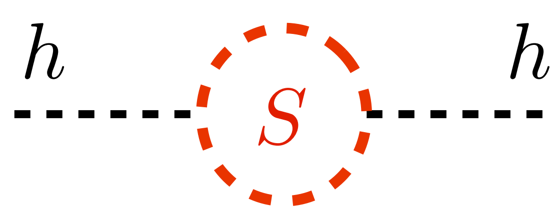
$$p^2 - m_H^2$$

$+$



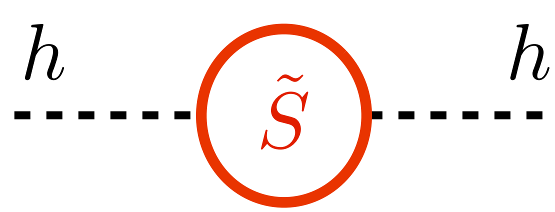
$$\frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right)$$

$+$



$$\frac{1}{16\pi^2} v^2 \left(C_{UV} - \int_0^1 dx \log \frac{M_S^2 - x(1-x)p^2}{\mu^2} \right)$$

SUSY: $+$



$$-\frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 - \int_0^1 dx \log \frac{M_S^2 - x(1-x)p^2}{\mu^2} \right) + p^2 \text{ terms}$$

$+ \dots$

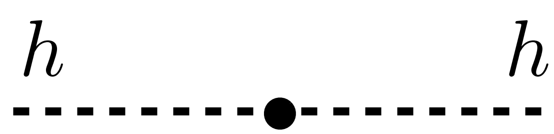
The shift of the root is small even for large M_S^2

"The hierarchy is stabilized by SUSY near M_Z"

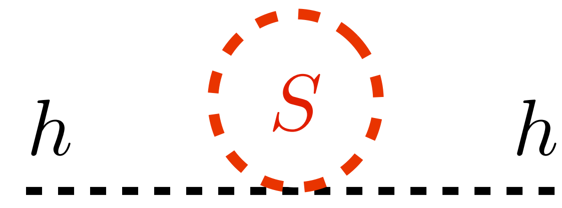
“The Higgs mass suffers from large radiative corrections!”

The devil is in detail:

$\Gamma_{hh} \propto$



$+$



$+ \ldots$

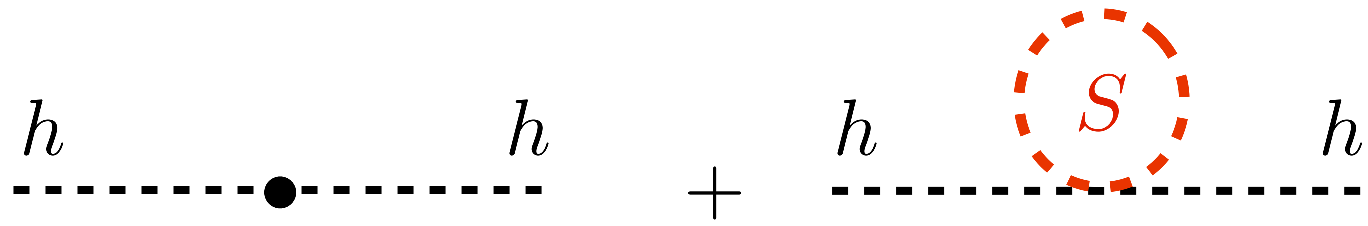
$$p^2 - m_H^2$$

$$\frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right)$$

“The Higgs mass suffers from large radiative corrections!”

The devil is in detail:

$\Gamma_{hh} \propto$



$+ \dots$

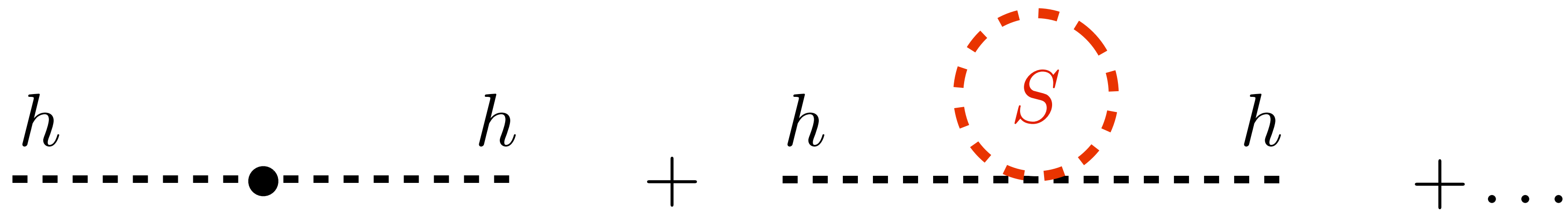
$$p^2 - m_H^2 \qquad + \qquad \frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right)$$

The root is **not the physical mass** ! **Mind the one-point function**

Perturbation theory contrived unless one-point function vanishes

"The Higgs mass suffers from large radiative corrections!"

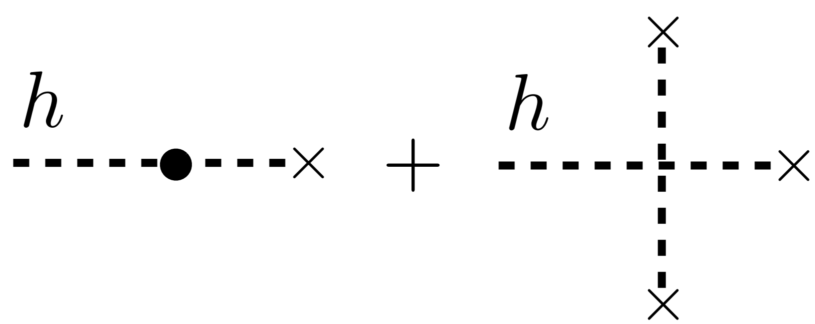
The devil is in detail:

$\Gamma_{hh} \propto$ 

$$p^2 - m_H^2 \qquad \frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right)$$

The root is **not the physical mass** ! **Mind the one-point function**

Perturbation theory contrived unless one-point function vanishes

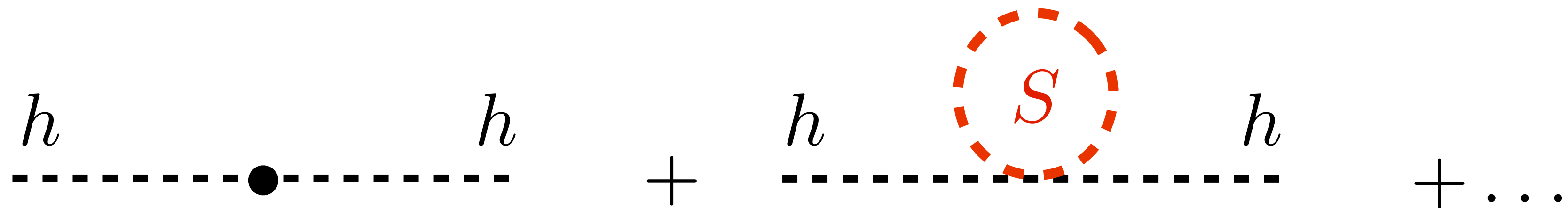
$\Gamma_h \propto$ 

$$m_H^2 v \qquad \lambda v^3$$

"The Higgs mass suffers from large radiative corrections!"

The devil is in detail:

$$\Gamma_{hh} \propto$$

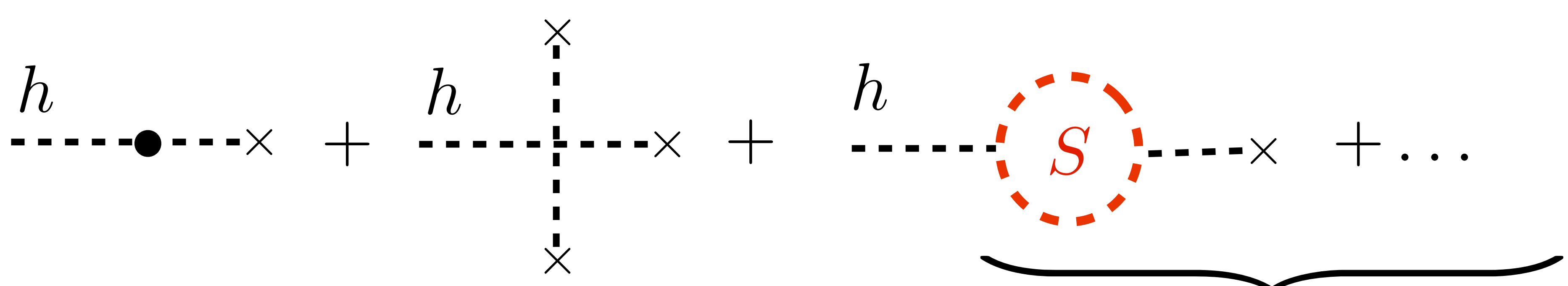


$$p^2 - m_H^2 \qquad + \qquad \frac{1}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right) \qquad + \ldots$$

The root is **not the physical mass** ! **Mind the one-point function**

Perturbation theory contrived unless one-point function vanishes

$$\Gamma_h \propto$$



$$m_H^2 v \qquad + \qquad \lambda v^3 \qquad + \qquad \frac{v}{16\pi^2} M_S^2 \left(C_{UV} - 1 + \log \frac{M_S^2}{\mu^2} \right) \qquad + \ldots$$

No need to be sorry about loops...

In the **true quantum vacuum** the polynomial M_S^2 -dependence drops out.

The poor Higgs is in the same shape like anybody else in the SM...

“Higgs anti-discrimination act”

Full one-loop effective potential level approach: MM, EPJ C73 (2013) 2415

No need to be sorry about loops...

In the **true quantum vacuum** the polynomial M_S^2 -dependence drops out.

The poor Higgs is in the same shape like anybody else in the SM...

“Higgs anti-discrimination act”

Who cares? Do you mind getting rid of the UV divergences?

Correlations among observables (= **physics**) **perfectly stable!**

Full one-loop effective potential level approach: MM, EPJ C73 (2013) 2415

Outline

Loop-induced (RH) Majorana neutrino masses in a non-SUSY unification

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

The Witten's loop

NEUTRINO MASSES IN THE MINIMAL O(10) THEORY ☆

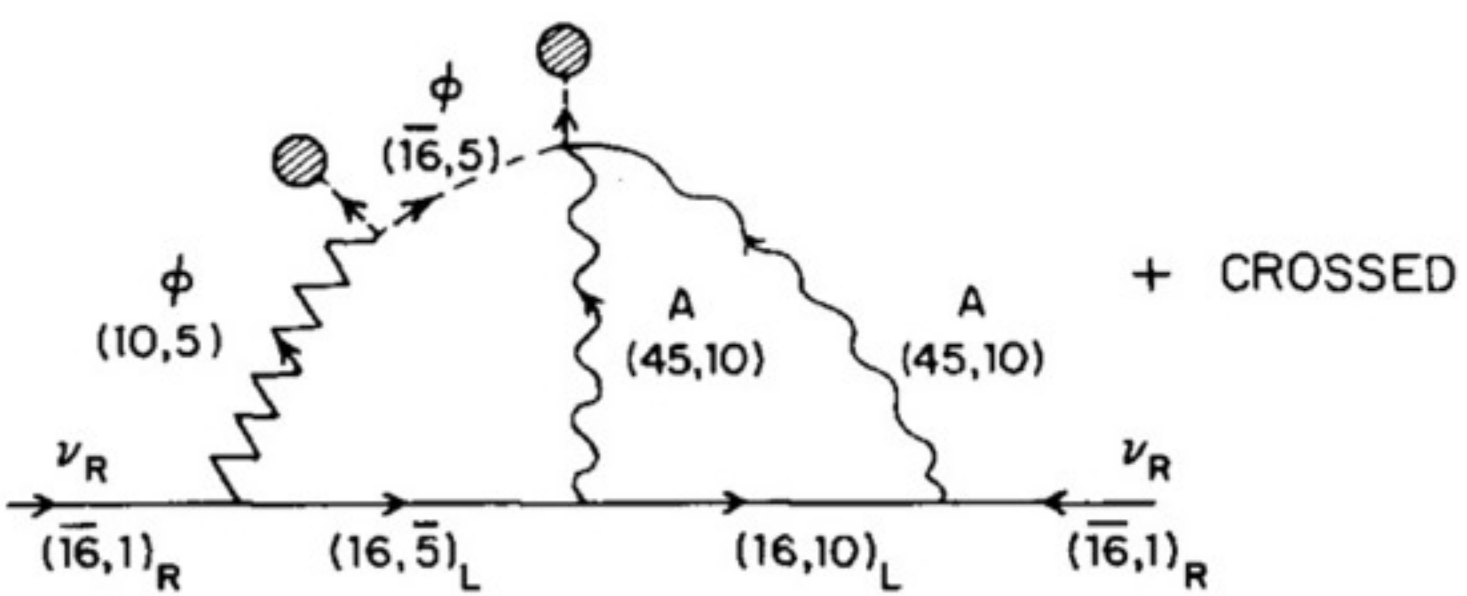
Phys. Lett. B91 (1980) 81

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.



The Witten's loop

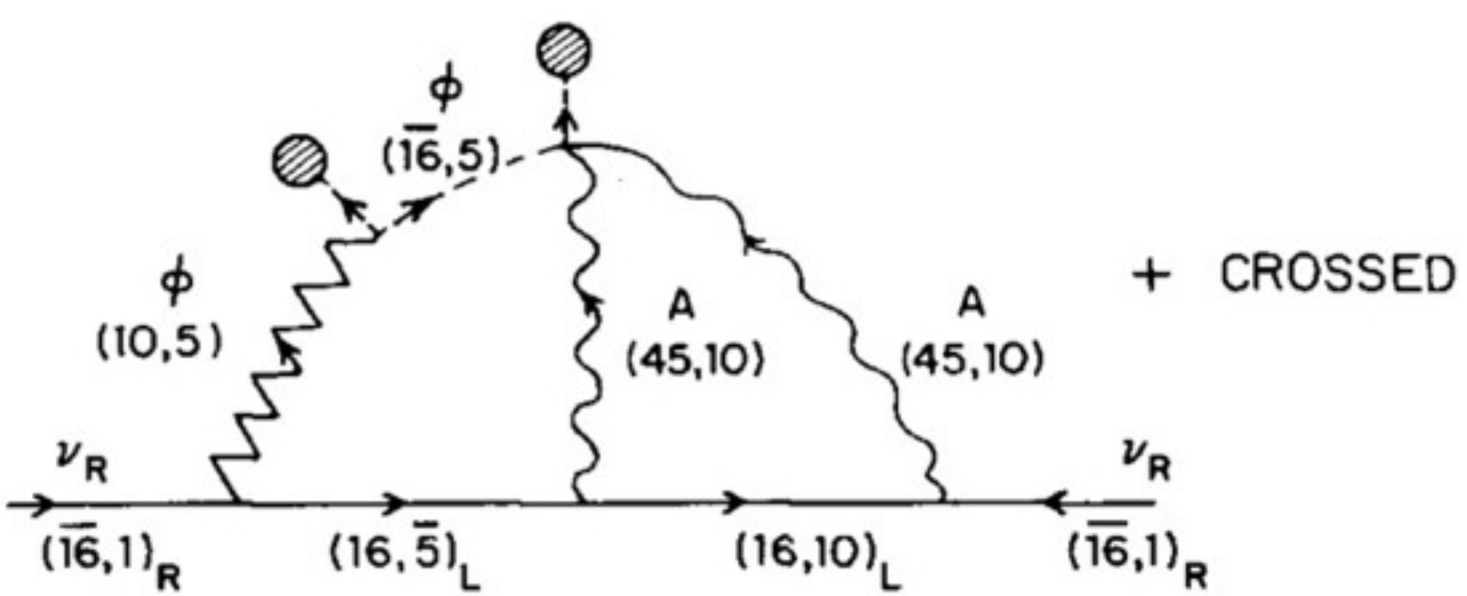
NEUTRINO MASSES IN THE MINIMAL O(10) THEORY ☆

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.



The Witten's loop

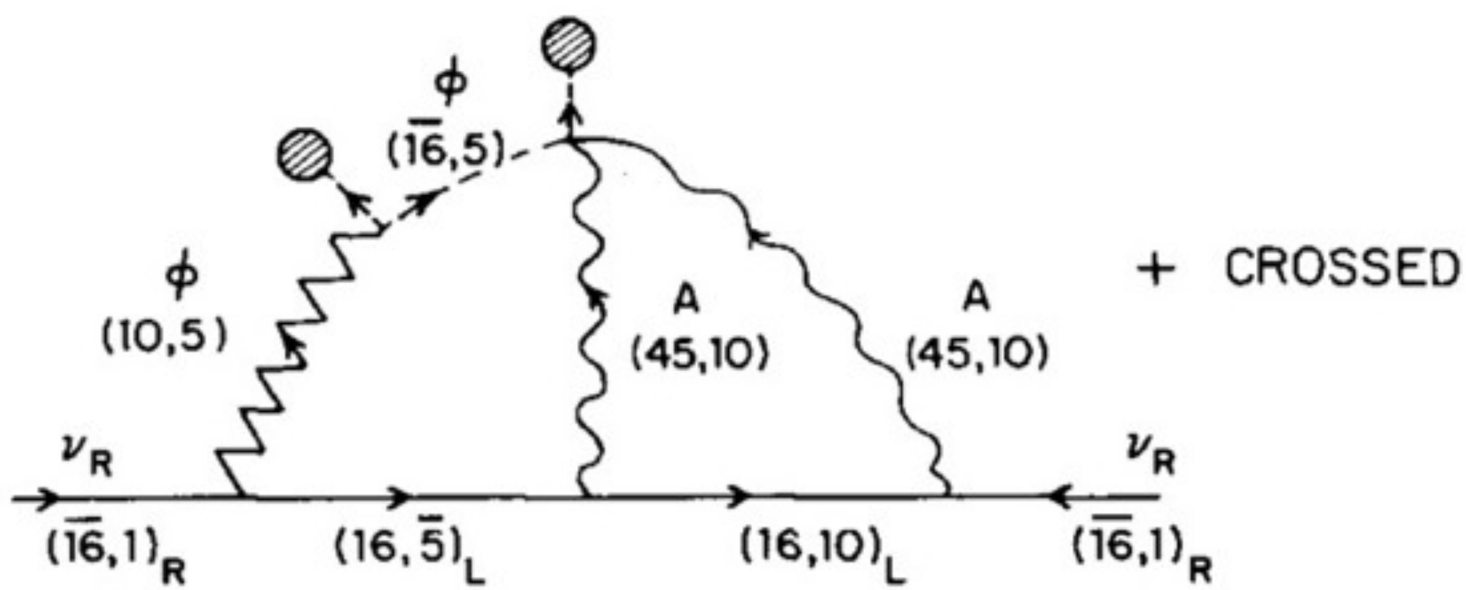
NEUTRINO MASSES IN THE MINIMAL O(10) THEORY ☆

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.



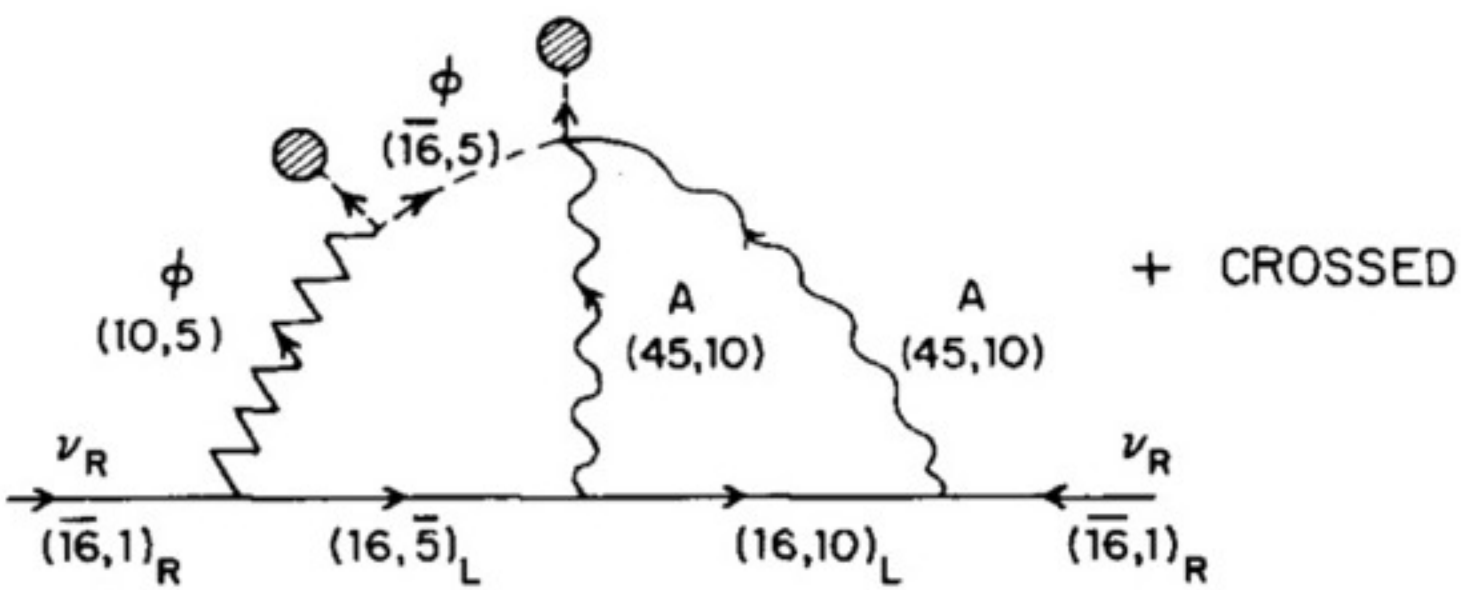
The Witten's loop

- the structure is unique:

  need to mimic 126_H (5-index tensor) with fields coupled to 16_M

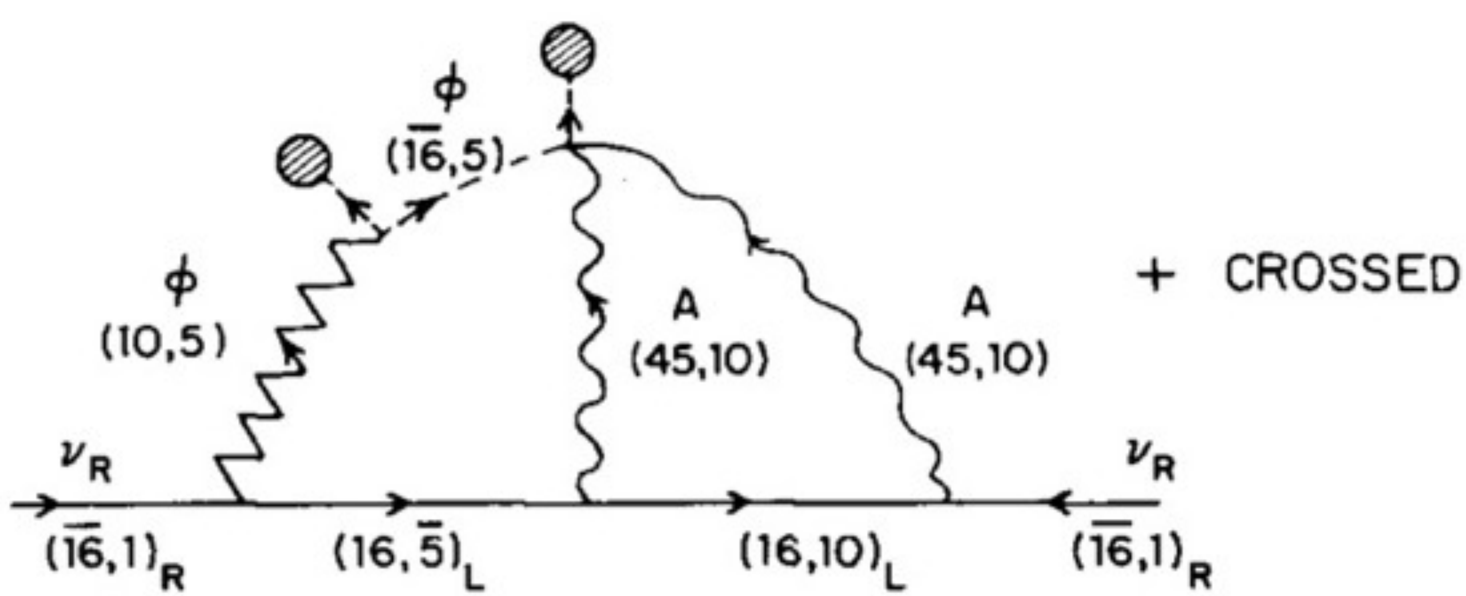
  these are 10_H and 45_G with 1 and 2 indices, respectively

$10_H \times 45_G \times 45_G$



The Witten's loop

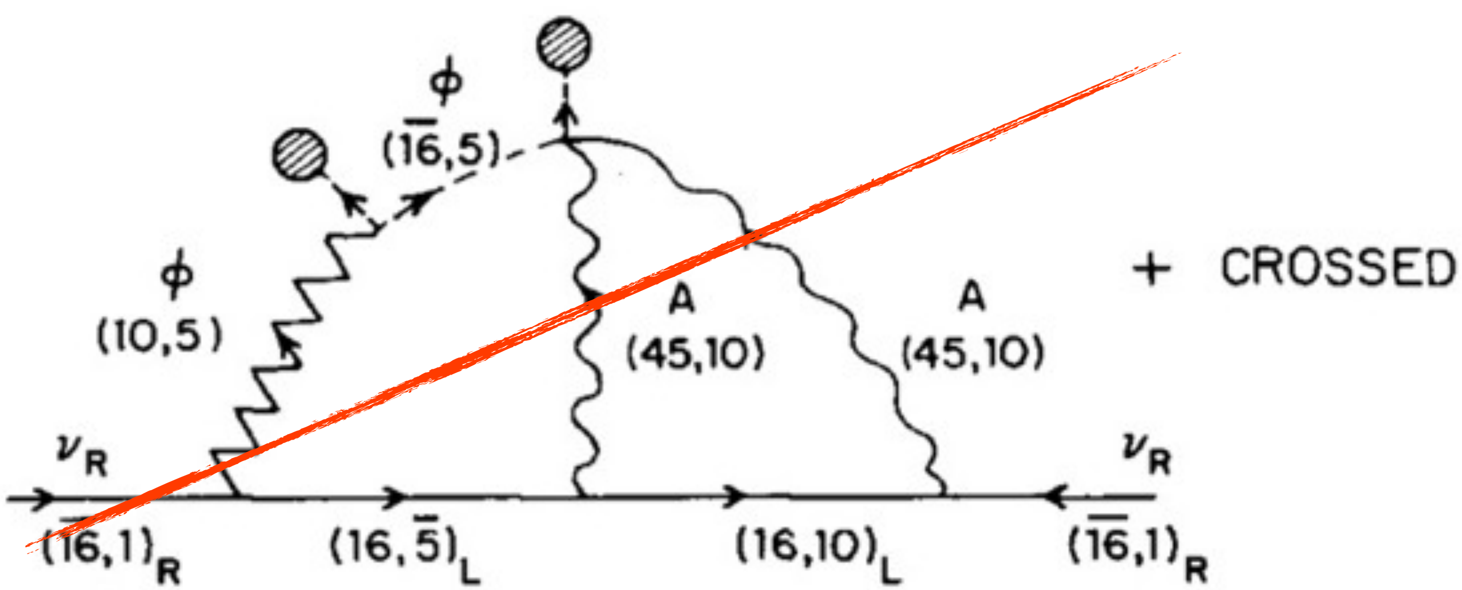
Not many real applications though!



The Witten's loop

Not many real applications though!

1980: Not much known about the scales **=> not needed**



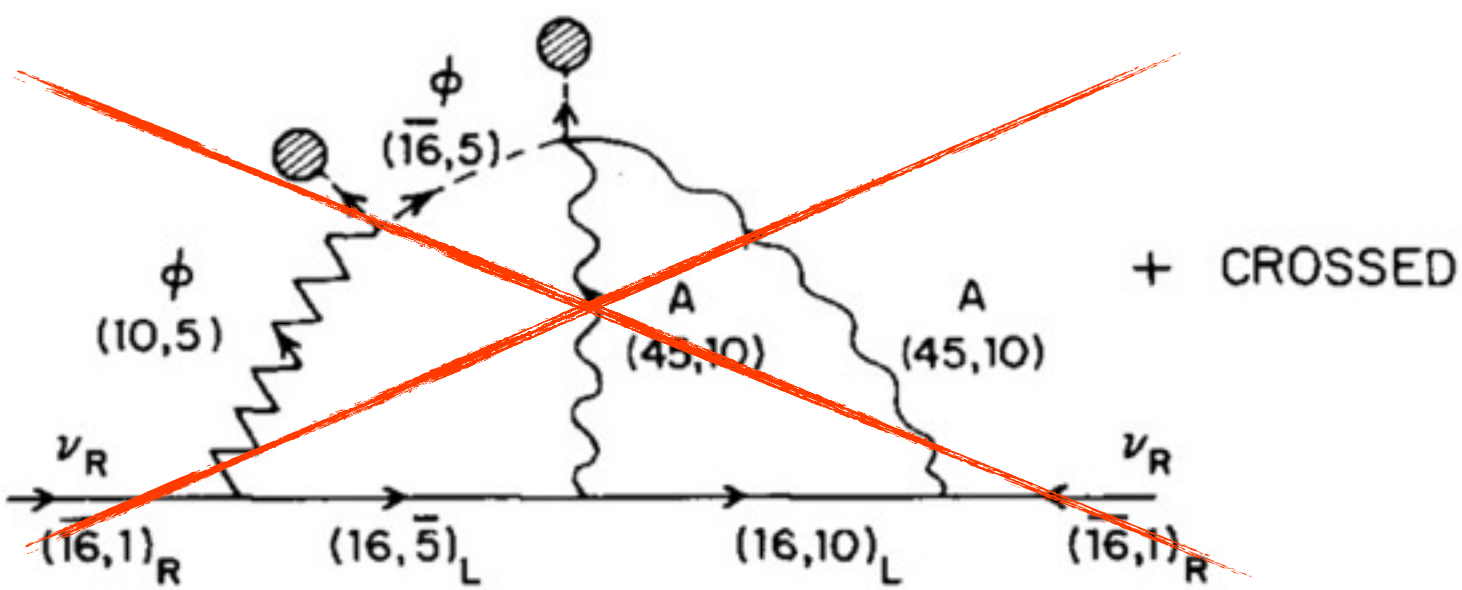
The Witten's loop

Not many real applications though!

1980: Not much known about the scales **=> not needed**

mid 1980's: one-step unification failure

TeV-scale SUSY "came to rescue" **=> no point**



The Witten's loop

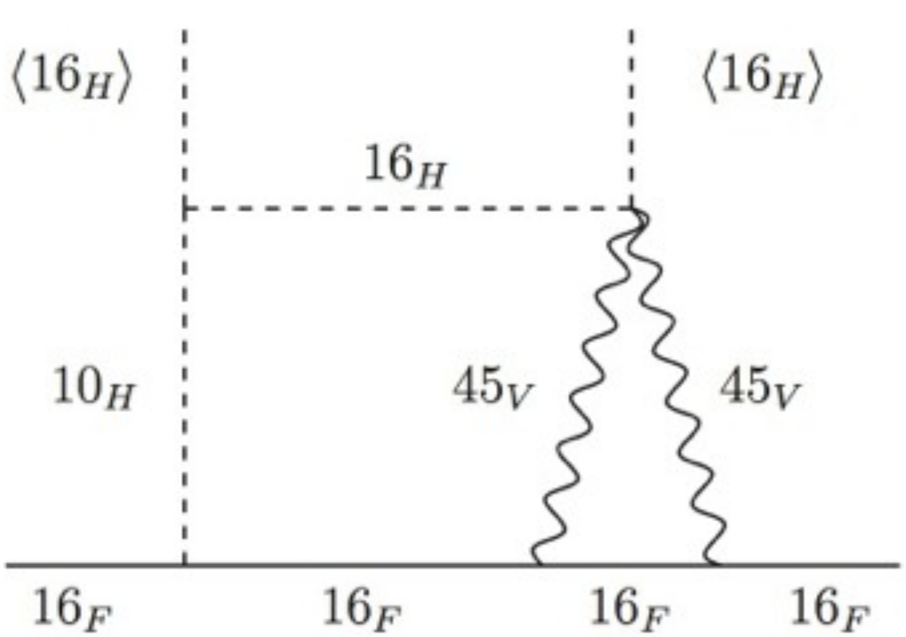
The Witten's loop

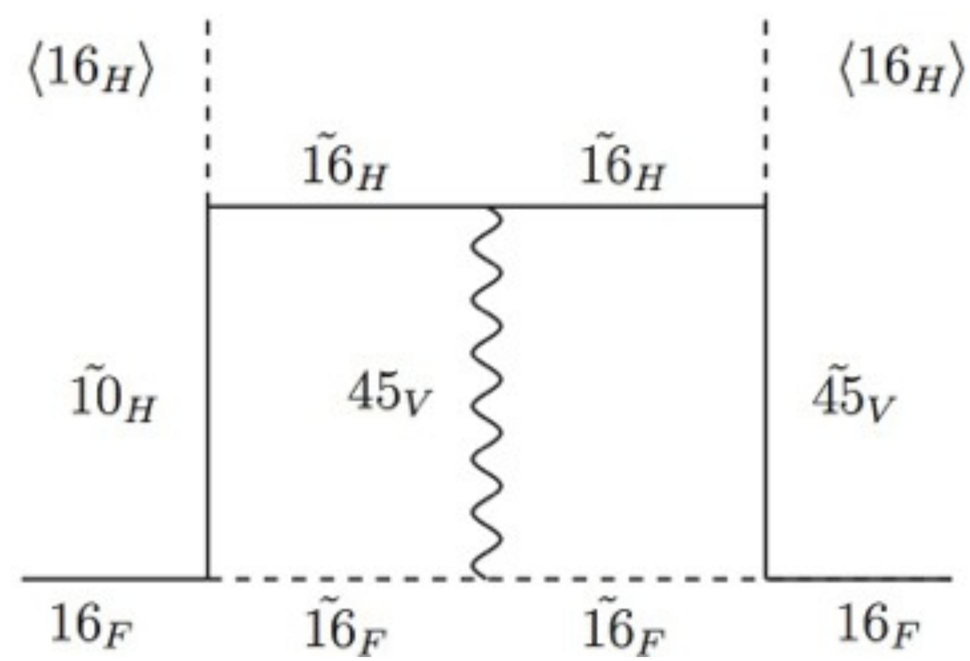
Extremely split SUSY: SUSY scalars at the GUT scale

one-step unification

loops not killed by SUSY

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





Towards the core of the Witten's loop

Other solutions to the "loop / scale / unification" issue?

Towards the core of the Witten's loop

Other solutions to the "loop / scale / unification" issue?

non-SUSY GUTs do also unify

however, this is not one-step which lowers the critical VEV

Towards the core of the Witten's loop

Other solutions to the "loop / scale / unification" issue?

non-SUSY GUTs do also unify

however, this is not one-step which lowers the critical VEV

need more freedom in running than that in SO(10)

retain testability

Towards the core of the Witten's loop

Witten's loop in the flipped SU(5) unification

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Flipped SU(5) basics

Flipped SU(5) basics

SO(10) $\supset$ SU(5) x U(1)z

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

2 possible hypercharge assignments:

Standard:	$Y = T_{24}$	u^c, Q, e^c	d^c, L	ν^c
Flipped:	$Y = \frac{1}{5}(Z - T_{24})$	d^c, Q, ν^c	u^c, L	e^c

Flipped SU(5) basics

SO(10) ⊃ SU(5) x U(1)z

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

2 possible hypercharge assignments:

Standard:	$Y = T_{24}$	u^c, Q, e^c	d^c, L	ν^c
Flipped:	$Y = \frac{1}{5}(Z - T_{24})$	d^c, Q, ν^c	u^c, L	e^c

Symmetry breaking:

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

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

Gauge sector: $45_G \ni \quad (24,0)_G \oplus (1,0)_G$

Flipped SU(5) basics

SO(10) ⊃ SU(5) x U(1)Z

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

2 possible hypercharge assignments:

Standard:	$Y = T_{24}$	u^c, Q, e^c	d^c, L	ν^c
Flipped:	$Y = \frac{1}{5}(Z - T_{24})$	d^c, Q, ν^c	u^c, L	e^c

Symmetry breaking:

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

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

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

Flipped SU(5) basics

Flipped SU(5) basics

- unification is not "Grand", just SU(3) x SU(2)

VEV of (10,+1) = Witten's VEV = mass of the X',Y' bosons

running is well under control ($F_{\mu\nu}\langle H\rangle F^{\mu\nu}/M_{Pl}$ absent)

- monopoles absent

$$
\begin{aligned}
&\pi_2(SU(5)\otimes U(1)/SU(3)\otimes SU(2)\otimes U(1))\\
&=\pi_2(SU(5)/SU(3)\otimes SU(2))\\
&=\pi_1(SU(3)\otimes SU(2))=0
\end{aligned}
$$

Flipped SU(5) basics

Flavour structure: rather different from the "standard" SU(5)

$$\mathcal{L} \ni Y_{10} 10_M 10_M 5_H + Y_{\overline{5}} 10_M \overline{5}_M 5^*_H + Y_1 \overline{5}_M 1_M 5_H + h.c.$$

Flipped SU(5) basics

Flavour structure: rather different from the "standard" SU(5)

$$\mathcal{L} \ni Y_{10} 10_M 10_M 5_H + Y_{\overline{5}} 10_M \overline{5}_M 5_H^* + Y_1 \overline{5}_M 1_M 5_H + h.c.$$

$$M_u = {M_\nu^D}^T \propto Y_{\overline{5}}$$

$$M_d = M_d^T \propto Y_{10} \qquad M_e \propto Y_1 \ \text{arbitrary}$$

+ down-quark - charged lepton degeneracy gone

Flipped SU(5) basics

Flavour structure: rather different from the "standard" SU(5)

$$\mathcal{L} \ni Y_{10} 10_M 10_M 5_H + Y_{\overline{5}} 10_M \overline{5}_M 5_H^* + Y_1 \overline{5}_M 1_M 5_H + h.c.$$

$$M_u = M_\nu^{D\,T} \propto Y_{\overline{5}} \qquad M_\nu^M = 0$$

$$M_d = M_d^T \propto Y_{10} \qquad M_e \propto Y_1 \ \text{arbitrary}$$

+ down-quark - charged lepton degeneracy gone

- neutrinos massive, but heavy & Dirac

50_H usually included to generate RH neutrino masses @ tree level...

The strategy

We use the Witten's loop to generate

RH Majorana masses in the flipped SU(5) unification

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

The strategy

We use the Witten's loop to generate

RH Majorana masses in the flipped SU(5) unification

&

use lepton flavour to learn about p-decay

or vice versa

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Proton decay in SU(5)

Standard SU(5)

$(3,2,-5/6)_G$

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

$$\overline{u^c}Q\overline{e^c}Q,^{(I)}\ \overline{u^c}Q\overline{d^c}L^{(II)}$$

Proton decay in SU(5)

Standard SU(5)

(3,2,-5/6)G

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

$$\overline{u^c}Q\overline{e^c}Q,^{(I)}\ \overline{u^c}Q\overline{d^c}L^{(II)}$$

I: $$\left[(U^\dagger_{u^c}U_u)_{11}(U^\dagger_{e^c}U_d)_{ab}+(U^\dagger_{u^c}U_d)_{1b}(U^\dagger_{e^c}U_u)_{a1}\right]\overline{u^c_{L(1)}}\gamma_\mu u_{L(1)}\overline{e^c_{L(a)}}\gamma_\mu d_{Lb}$$

neutral meson

II: $$\left[(U^\dagger_{u^c}U_u)_{11}(U^\dagger_{d^c}U_e)_{ab}\right]\overline{u^c_{L(1)}}\gamma_\mu u_{L(1)}\overline{d^c_{L(a)}}\gamma_\mu e_{Lb}-\left[(U^\dagger_{u^c}U_d)_{1a}(U^\dagger_{d^c}U_\nu)_{bc}\right]\overline{u^c_{L(1)}}\gamma_\mu d_{L(a)}\overline{d^c_{L(b)}}\gamma_\mu \nu_{Lc}$$

neutral meson

charged meson

Proton decay in SU(5)

Standard SU(5)

$(3,2,-5/6)_G$

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

$$\overline{u^c}Q\overline{e^c}Q,^{(I)}\ \overline{u^c}Q\overline{d^c}L^{(II)}$$

I: $$\left[(U_{u^c}^\dagger U_u)_{11}(U_{e^c}^\dagger U_d)_{ab} + (U_{u^c}^\dagger U_d)_{1b}(U_{e^c}^\dagger U_u)_{a1}\right]\overline{u^c_{L(1)}}\gamma_\mu u_{L(1)}\overline{e^c_{L(a)}}\gamma_\mu d_{Lb}$$

neutral meson

II: $$\left[(U_{u^c}^\dagger U_u)_{11}(U_{d^c}^\dagger U_e)_{ab}\right]\overline{u^c_{L(1)}}\gamma_\mu u_{L(1)}\overline{d^c_{L(a)}}\gamma_\mu e_{Lb} - \left[(U_{u^c}^\dagger U_d)_{1a}(U_{d^c}^\dagger U_\nu)_{bc}\right]\overline{u^c_{L(1)}}\gamma_\mu d_{L(a)}\overline{d^c_{L(b)}}\gamma_\mu \nu_{Lc}$$

neutral meson — charged meson

$$\Gamma(p\to K^+\overline{\nu}) = F_1|(V_{CKM})_{11}|^2 + F_2|(V_{CKM})_{12}|^2 C$$

$$\Gamma(p\to \pi^+\overline{\nu}) = F_3|(V_{CKM})_{11}|^2 C$$

SU(5) may be tested by looking at the charged meson final states

Proton decay in the flipped SU(5)

Flipped SU(5)

(3,2,1/6)$_G$

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

$$\overline{d^c}Q\overline{u^c}L,^{(III)}\ \overline{d^c}Q\overline{\nu^c}Q^{(IV)}$$

Proton decay in the flipped SU(5)

Flipped SU(5)

$(3,2,1/6)_G$

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

$$\overline{d^c}Q\overline{u^c}L,^{(III)}\ \overline{d^c}Q\overline{\nu^c}Q^{(IV)}$$

III: $-\left[(U^\dagger_{d^c}U_u)_{a1}(U^\dagger_{u^c}U_e)_{1b}\right]\overline{u^c_{L(1)}}\gamma_\mu u_{L(1)}\overline{d^c_{L(a)}}\gamma_\mu e_{Lb}+\left[(U^\dagger_{d^c}U_d)_{ba}(U^\dagger_{u^c}U_\nu)_{1c}\right]\overline{u^c_{L(1)}}\gamma_\mu d_{L(a)}\overline{d^c_{L(b)}}\gamma_\mu \nu_{Lc}$

neutral meson — charged meson

IV: $\left[(U^\dagger_{d^c}U_u)_{a1}(U^\dagger_{\nu^c}U_d)_{bc}+(U^\dagger_{d^c}U_d)_{ac}(U^\dagger_{\nu^c}U_u)_{b1}\right]\overline{d^c_{L(a)}}\gamma_\mu u_{L(1)}\overline{\nu^c_{L(b)}}\gamma_\mu d_{Lc}$

charged meson

Proton decay in the flipped SU(5)

Flipped SU(5)

$(3,2,1/6)_G$

Nath, Fileviez-Perez, Phys.Rept.441

Dorsner, Fileviez-Perez, PLB605

$$\overline{d^c}Q\overline{u^c}L,^{(III)}\ \overline{d^c}Q\overline{\nu^c}Q^{(IV)}$$

III: $-\left[(U^\dagger_{d^c}U_u)_{a1}(U^\dagger_{u^c}U_e)_{1b}\right]\overline{u^c_{L(1)}}\gamma_\mu u_{L(1)}\overline{d^c_{L(a)}}\gamma_\mu e_{Lb}+\left[(U^\dagger_{d^c}U_d)_{ba}(U^\dagger_{u^c}U_\nu)_{1c}\right]\overline{u^c_{L(1)}}\gamma_\mu d_{L(a)}\overline{d^c_{L(b)}}\gamma_\mu \nu_{Lc}$

neutral meson — charged meson

IV: $\left[(U^\dagger_{d^c}U_u)_{a1}(U^\dagger_{\nu^c}U_d)_{bc}+(U^\dagger_{d^c}U_d)_{ac}(U^\dagger_{\nu^c}U_u)_{b1}\right]\overline{d^c_{L(a)}}\gamma_\mu u_{L(1)}\overline{\nu^c_{L(b)}}\gamma_\mu d_{Lc}$

charged meson

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

$$\Gamma(p\to \pi^+\overline{\nu})=\tilde{F}_1 C$$

$$\frac{\Gamma(p\to K^0\ell^+)}{\Gamma(p\to \pi^0\ell^+)}=\frac{\tilde{F}_2}{\tilde{F}_1}\frac{|(V_{CKM})_{12}|^2}{|(V_{CKM})_{11}|^2}$$

There is a clear feature in the charged mesons and in the **ratio** of the neutral...

Proton decay in the flipped SU(5)

The central formula:

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

Proton decay in the flipped SU(5)

The central formula:

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

If we knew U_ν we would have **prediction** for ALL BNV channels!!!

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

Proton decay in the flipped SU(5)

The central formula:

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

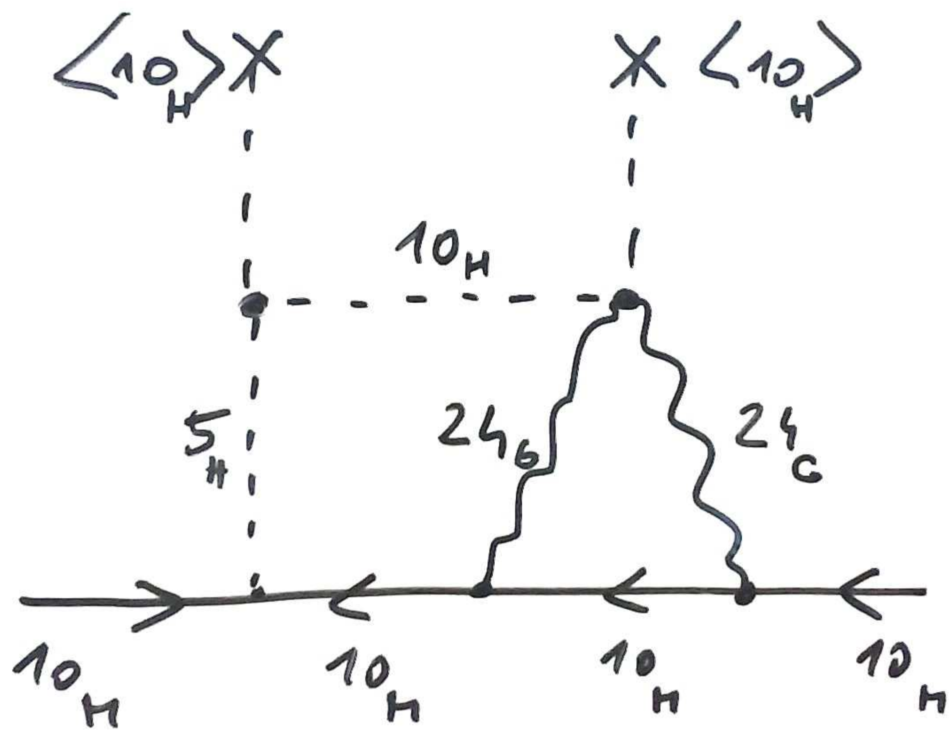
If we knew U_ν we would have **prediction** for ALL BNV channels!!!

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

There are constraints on U_ν in the Witten's loop scenario !!!

Nothing like that if the RH neutrino mass is due to 50_H ...

Witten's loop anatomy in the flipped SU(5)

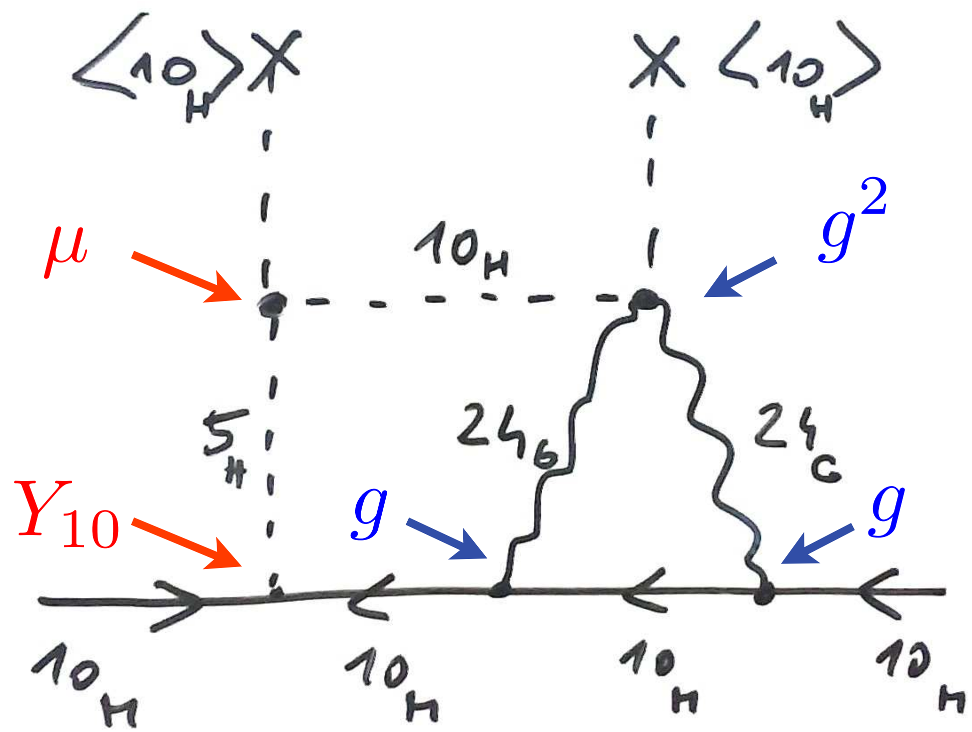


C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop anatomy in the flipped SU(5)

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

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

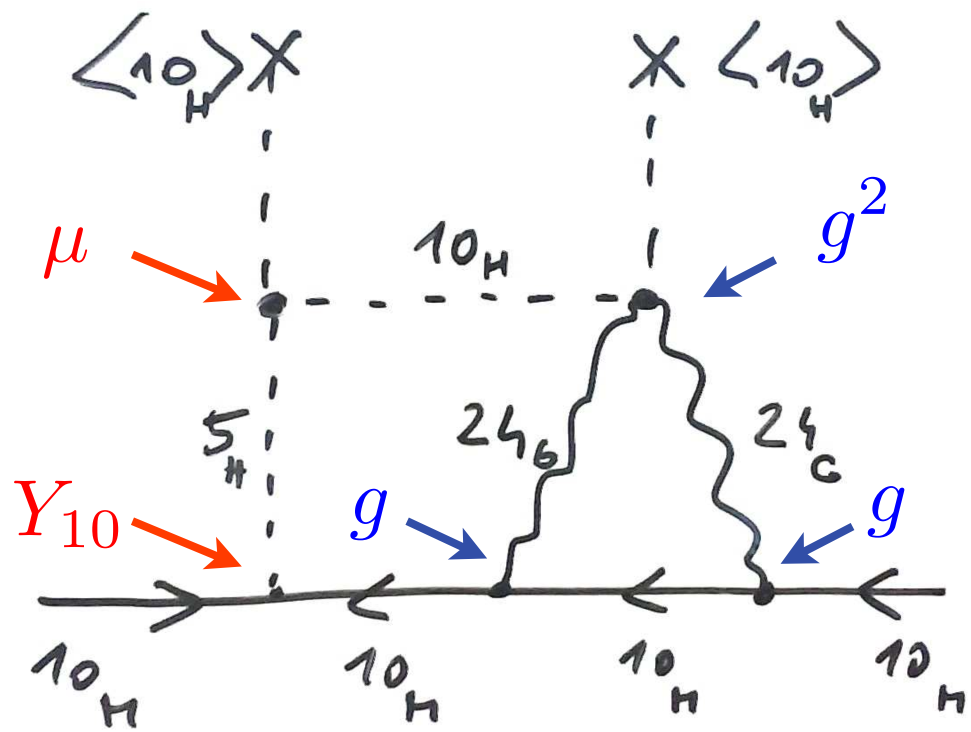


C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop anatomy in the flipped SU(5)

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

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



$$M_\nu^M = \left(\frac{1}{16\pi^2}\right)^2 g^4\, Y_{10}\, \mu \frac{\langle 10_H \rangle^2}{M_G^2} K(\ldots)$$

$K(\ldots)$ is an O(1) factor depending on the details of the heavy spectrum

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop anatomy in the flipped SU(5)

The U_ν matrix kicks in via seesaw (using $M_u = M_\nu^{D^T}$) :

$$D_U U_\nu^\dagger D_\nu^{-1}(m_1, ...) U_\nu^* D_U = \left(\frac{1}{16\pi^2}\right)^2 g^4\, Y_{10}\, \mu \frac{\langle 10_H \rangle^2}{M_G^2} K(...)$$

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop in the perturbative & stable regime

Y_{10} and μ are constrained from perturbativity + SM vacuum stability

$$D_U U_\nu^\dagger D_\nu^{-1}(m_1, \ldots) U_\nu^* D_U = \left(\frac{1}{16\pi^2}\right)^2 g^4\, Y_{10}\, \mu \frac{\langle 10_H \rangle^2}{M_G^2} K(\ldots)$$

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop in the perturbative & stable regime

Y_{10} and μ are constrained from perturbativity + SM vacuum stability

$$D_U U_\nu^\dagger D_\nu^{-1}(m_1,...)U_\nu^* D_U \leq \left(\frac{1}{16\pi^2}\right) g^4 \frac{\langle 10_H \rangle^3}{M_G^2} K(...)$$

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop in the perturbative & stable regime

Y_{10} and μ are constrained from perturbativity + SM vacuum stability

$$D_U U_\nu^\dagger D_\nu^{-1}(m_1,...)U_\nu^* D_U \leq \overbrace{\left(\frac{1}{16\pi^2}\right) g^4 \frac{\langle 10_H\rangle^3}{M_G^2}}^{\sim 10^{14}\text{ GeV}} K(...)$$

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop in the perturbative & stable regime

Y_{10} and μ are constrained from perturbativity + SM vacuum stability

$$D_U U_\nu^\dagger D_\nu^{-1}(m_1,\ldots)U_\nu^* D_U \leq \overbrace{\left(\frac{1}{16\pi^2}\right) g^4 \frac{\langle 10_H\rangle^3}{M_G^2}}^{\sim 10^{14}\ \mathrm{GeV}} K(\ldots)$$

LHS: $\sim \begin{pmatrix} 10^4 & 0 & 0 \\ 0 & 5\times 10^8 & 0 \\ 0 & 0 & 5\times 10^{13} \end{pmatrix}$ GeV

for $U_\nu = 1$ and $m_1 = 8 \times 10^{-2}$ eV
(assuming normal hierarchy)

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop in the perturbative & stable regime

Y_{10} and μ are constrained from perturbativity + SM vacuum stability

$$D_U U_\nu^\dagger D_\nu^{-1}(m_1,\ldots)U_\nu^* D_U \leq \overbrace{\left(\frac{1}{16\pi^2}\right) g^4 \frac{\langle 10_H \rangle^3}{M_G^2}}^{\sim 10^{14}\,\mathrm{GeV}} K(\ldots)$$

LHS: $\sim \begin{pmatrix} 10^4 & 0 & 0 \\ 0 & 5\times 10^8 & 0 \\ 0 & 0 & 5\times 10^{13} \end{pmatrix}$ GeV

for $U_\nu = 1$ and $m_1 = 8 \times 10^{-2}$ eV (assuming normal hierarchy)

Beware of U_ν as D_ν^{-1} itself looks like $\begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix}$ GeV^{-1} !!!

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Witten's loop in the perturbative & stable regime

Y_{10} and μ are constrained from perturbativity + SM vacuum stability

$$D_U U_\nu^\dagger D_\nu^{-1}(m_1,\ldots)U_\nu^* D_U \leq \overbrace{\left(\frac{1}{16\pi^2}\right) g^4 \frac{\langle 10_H\rangle^3}{M_G^2}}^{\sim 10^{14}\ \mathrm{GeV}} K(\ldots)$$

LHS: $\sim \begin{pmatrix} 10^4 & 0 & 0 \\ 0 & 5\times 10^8 & 0 \\ 0 & 0 & 5\times 10^{13} \end{pmatrix}$ GeV

for $U_\nu = 1$ and $m_1 = 8 \times 10^{-2}$ eV (assuming normal hierarchy)

Beware of U_ν as D_ν^{-1} itself looks like $\begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix}$ GeV^{-1} !!!

Only some U_ν's can provide a consistent flavour fit...

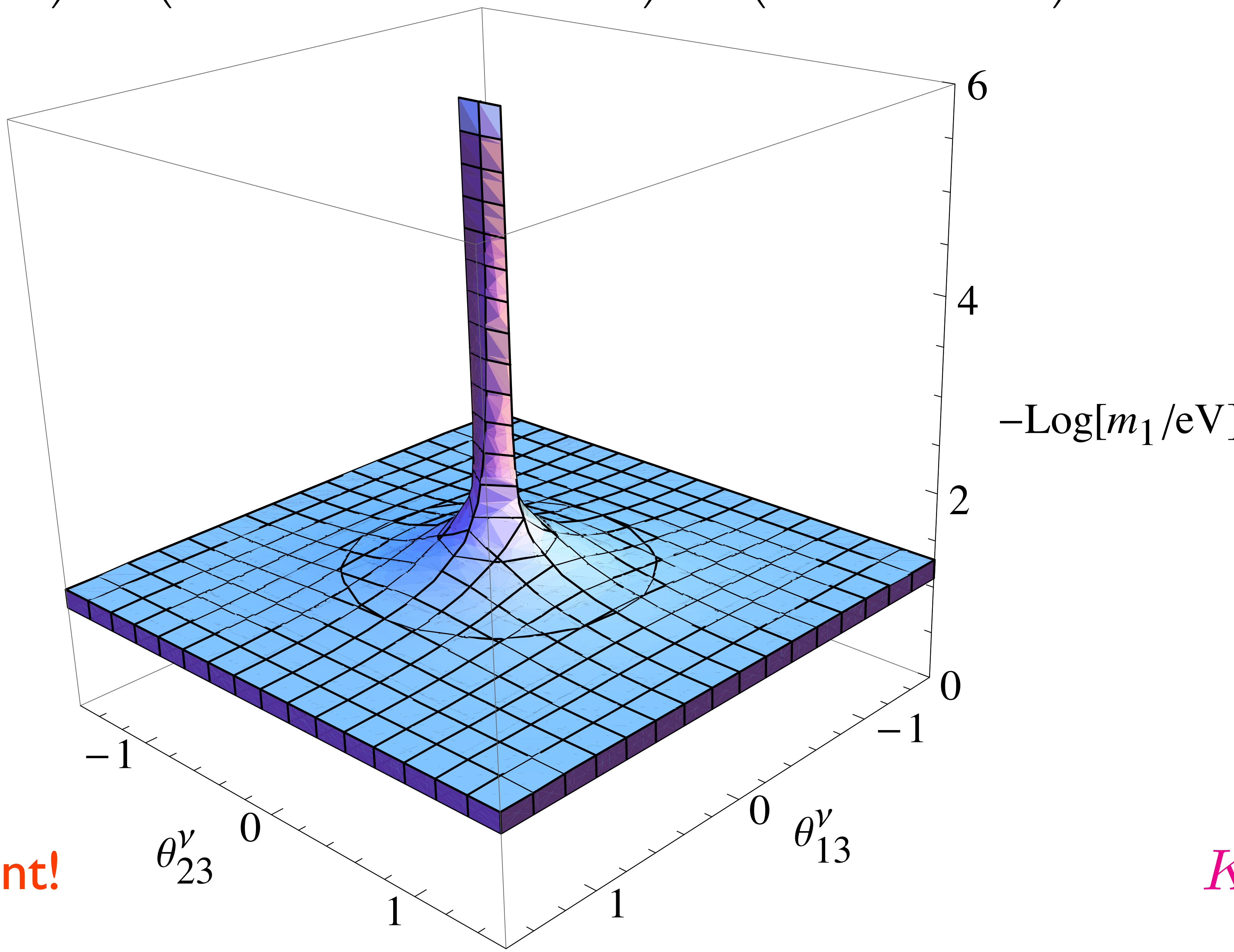
C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Only some U_ν's allowed!

$$\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} U_\nu^\dagger \begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix} U_\nu^* \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} \leq 10^{14}\mathrm{GeV}^2 K$$

Only some U$_\nu$'s allowed!

$$\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} U_\nu^\dagger \begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix} U_\nu^* \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} \leq 10^{14}\mathrm{GeV}^2 K$$

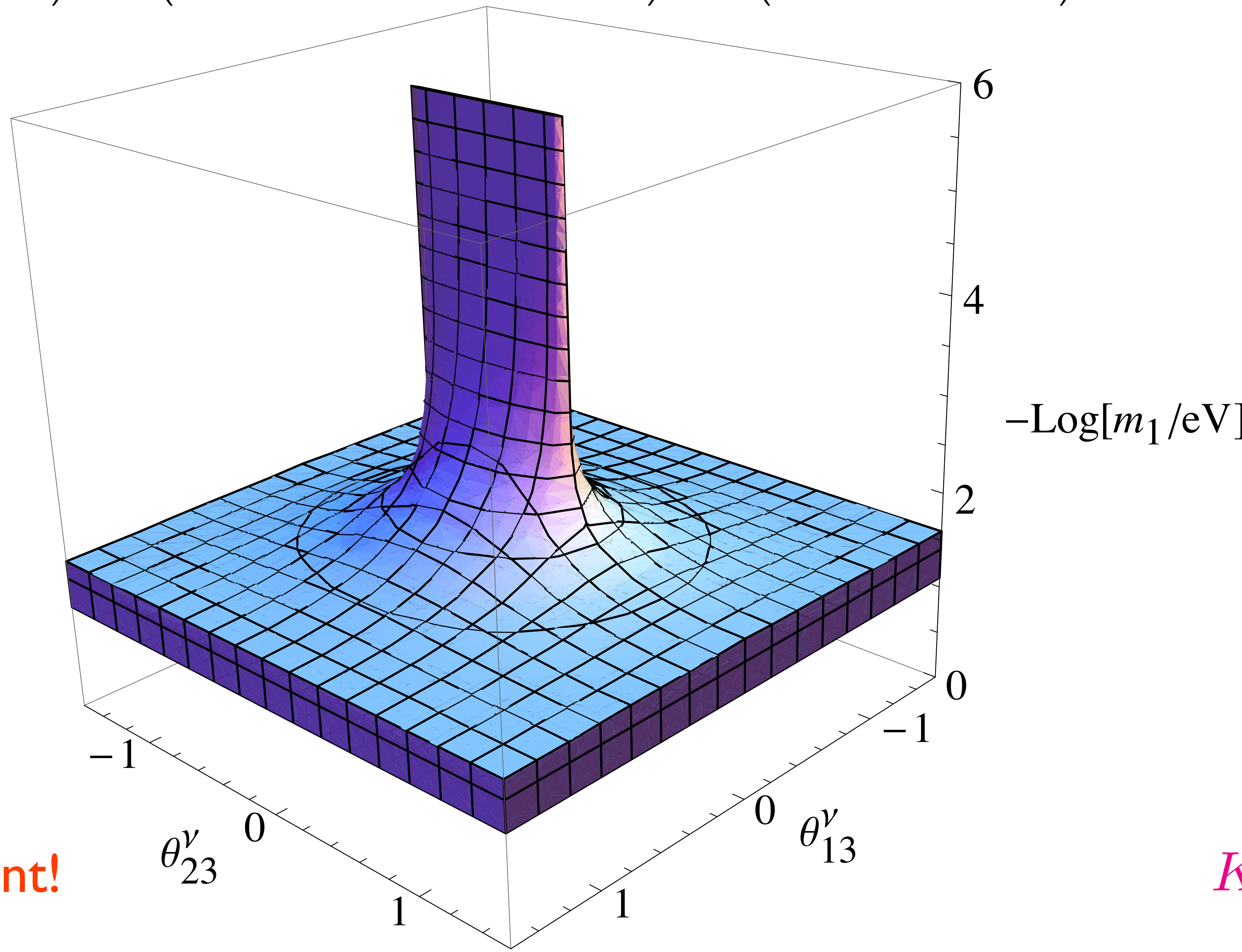


θ_{12}-independent!

$K = 1$

Only some U$_\nu$'s allowed!

$$\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} U_\nu^\dagger \begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix} U_\nu^* \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} \leq 10^{14}\mathrm{GeV}^2 K$$

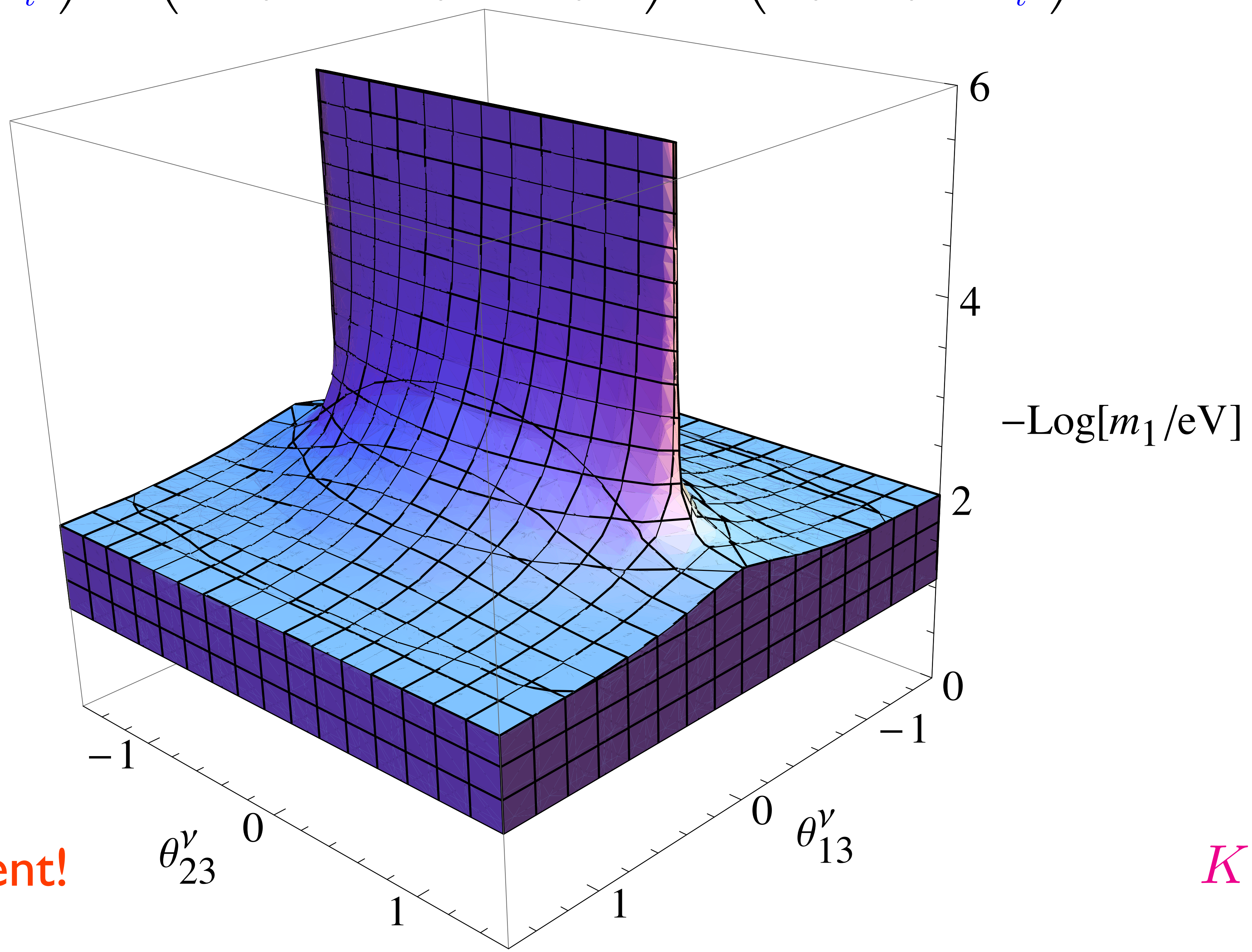


θ_{12}-independent!

$K = 2$

Only some U$_\nu$'s allowed!

$$\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} U_\nu^\dagger \begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix} U_\nu^* \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} \leq 10^{14}\mathrm{GeV}^2 K$$

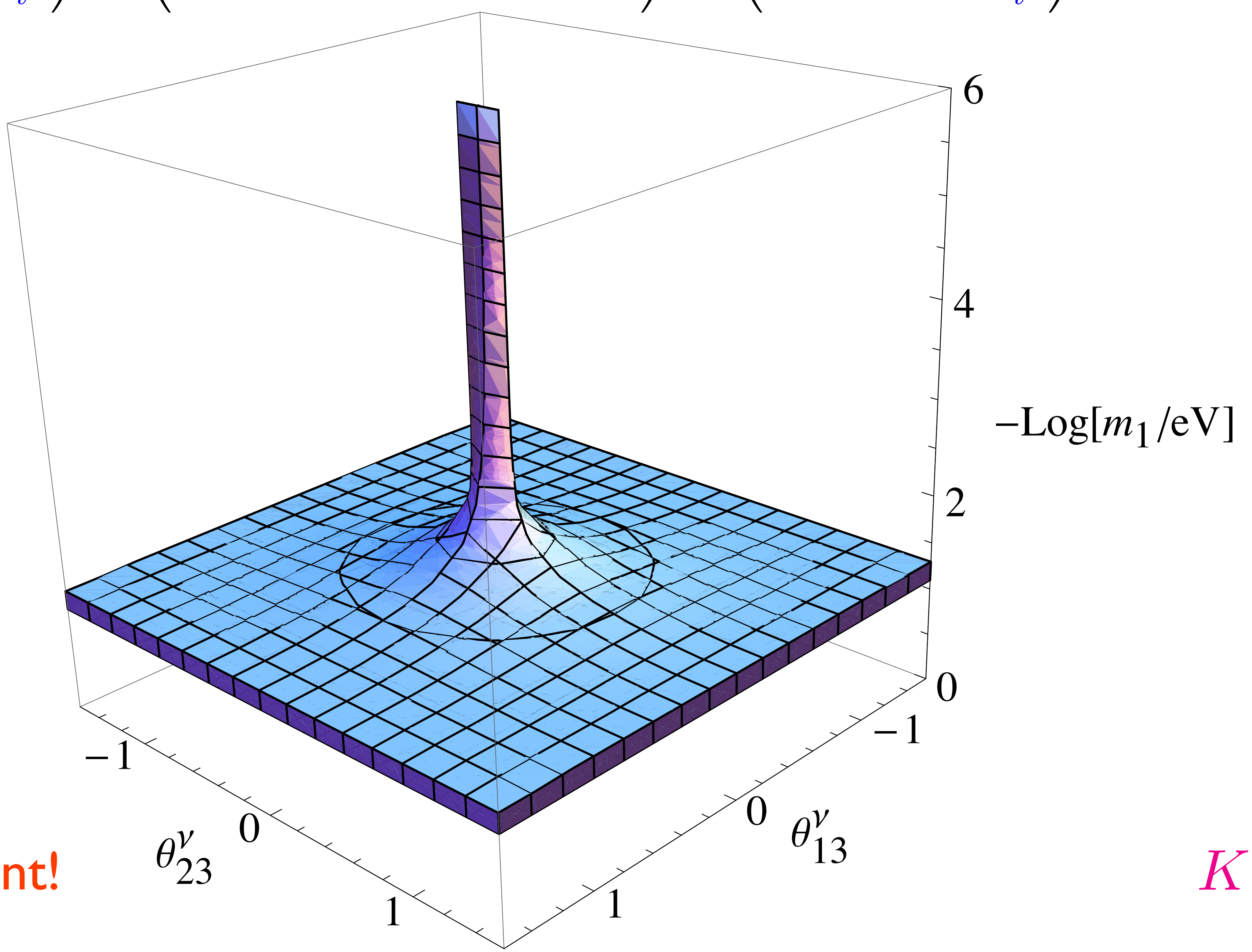


θ_{12}-independent!

$K = 5$

Only some U$_\nu$'s allowed!

$$\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} U_\nu^\dagger \begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix} U_\nu^* \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} \leq 10^{14}\mathrm{GeV}^2 K$$

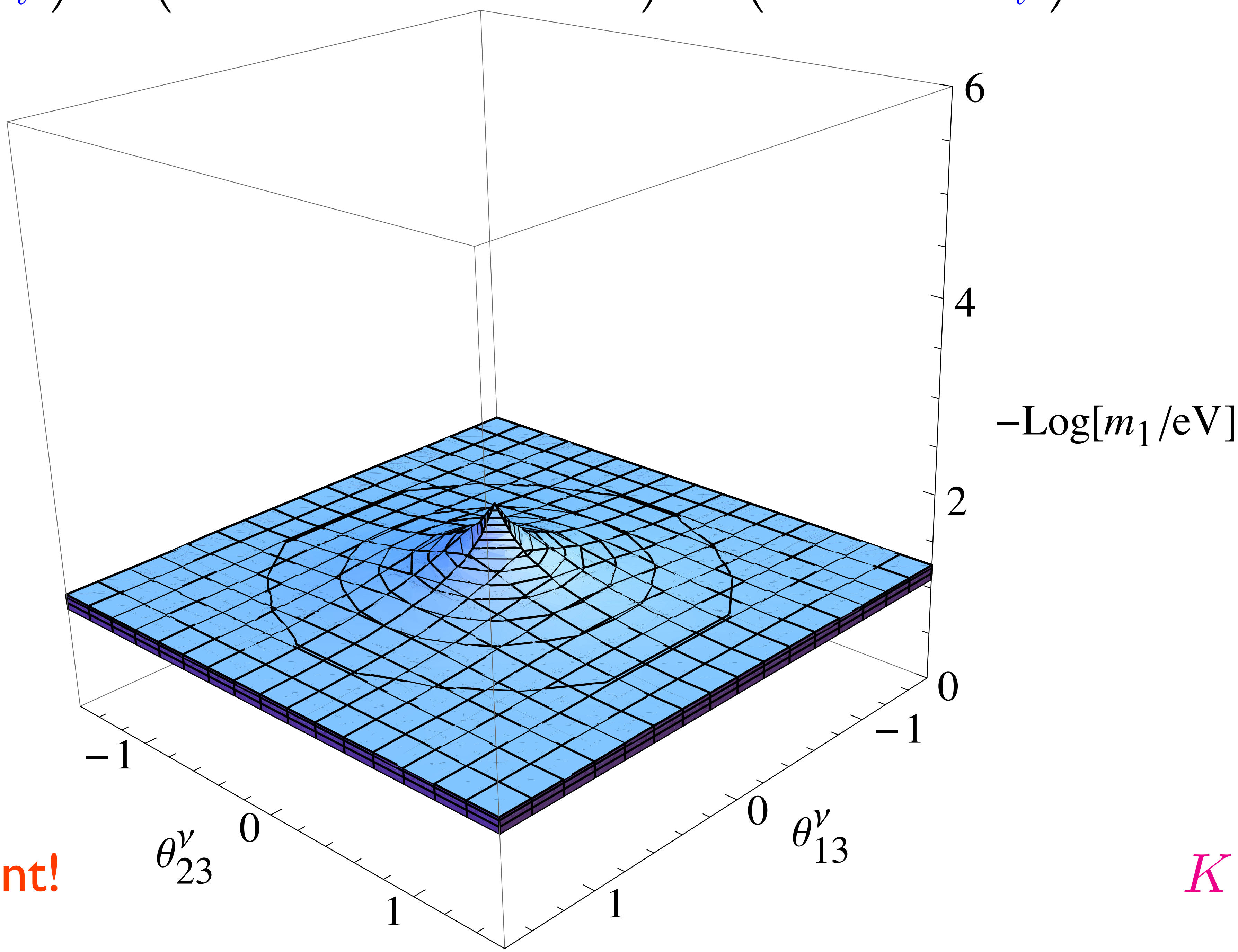


θ_{12}-independent!

$K = 1$

Only some U$_\nu$'s allowed!

$$\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} U_\nu^\dagger \begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix} U_\nu^* \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} \leq 10^{14}\mathrm{GeV}^2 K$$

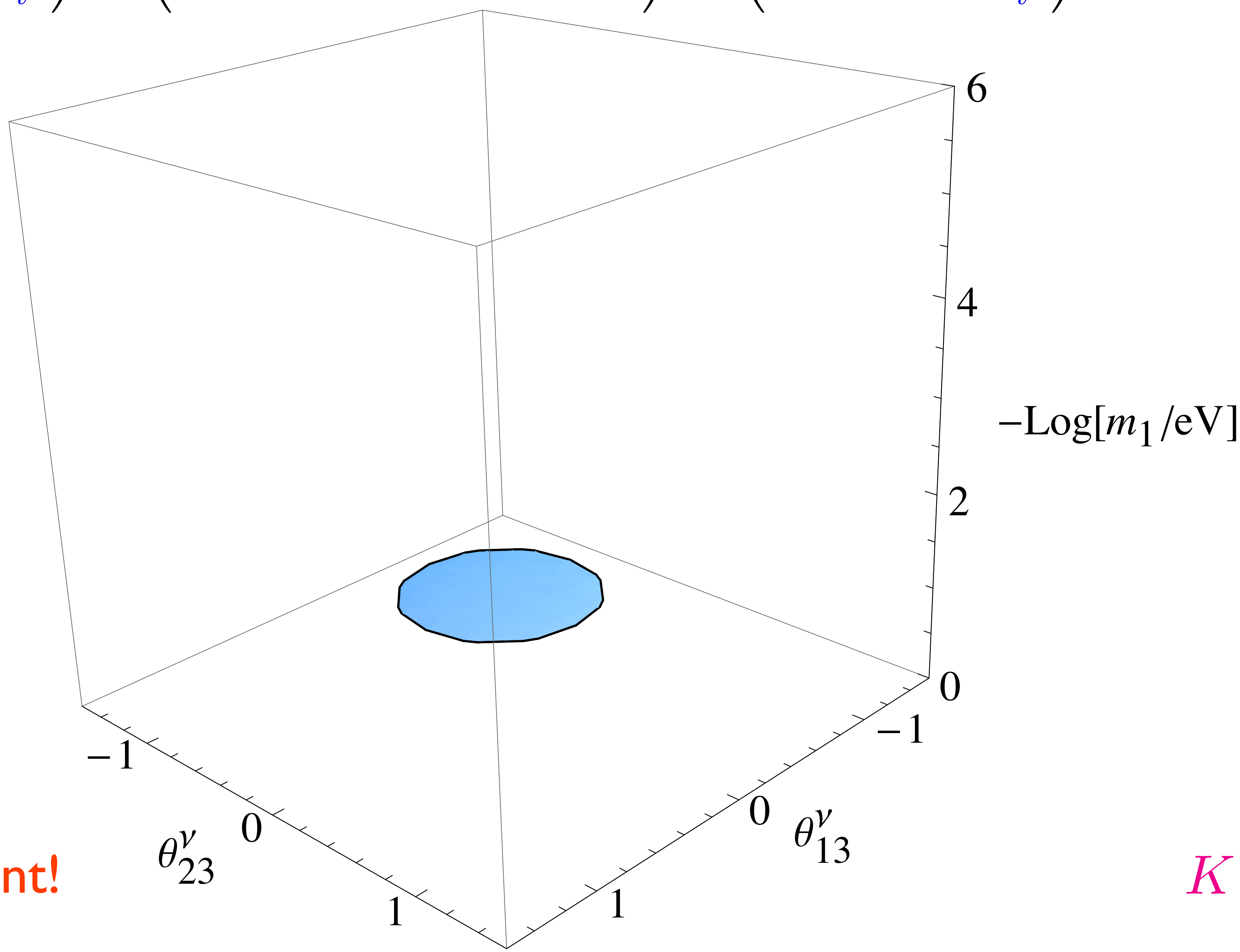


θ$_{12}$-independent!

$K = 0.9$

Only some U_ν's allowed!

$$\begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} U_\nu^\dagger \begin{pmatrix} 10^{10-\infty} & 0 & 0 \\ 0 & 10^{10-11} & 0 \\ 0 & 0 & 10^{10} \end{pmatrix} U_\nu^* \begin{pmatrix} m_u & 0 & 0 \\ 0 & m_c & 0 \\ 0 & 0 & m_t \end{pmatrix} \leq 10^{14}\text{GeV}^2 K$$



θ_{12}-independent!

$K = 0.5$

Proton decay to neutral mesons+charged leptons

To be superimposed over the observable(s) of interest ...

$$\Gamma(p \to \pi^0 e^+) + \Gamma(p \to \pi^0 \mu^+)$$

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

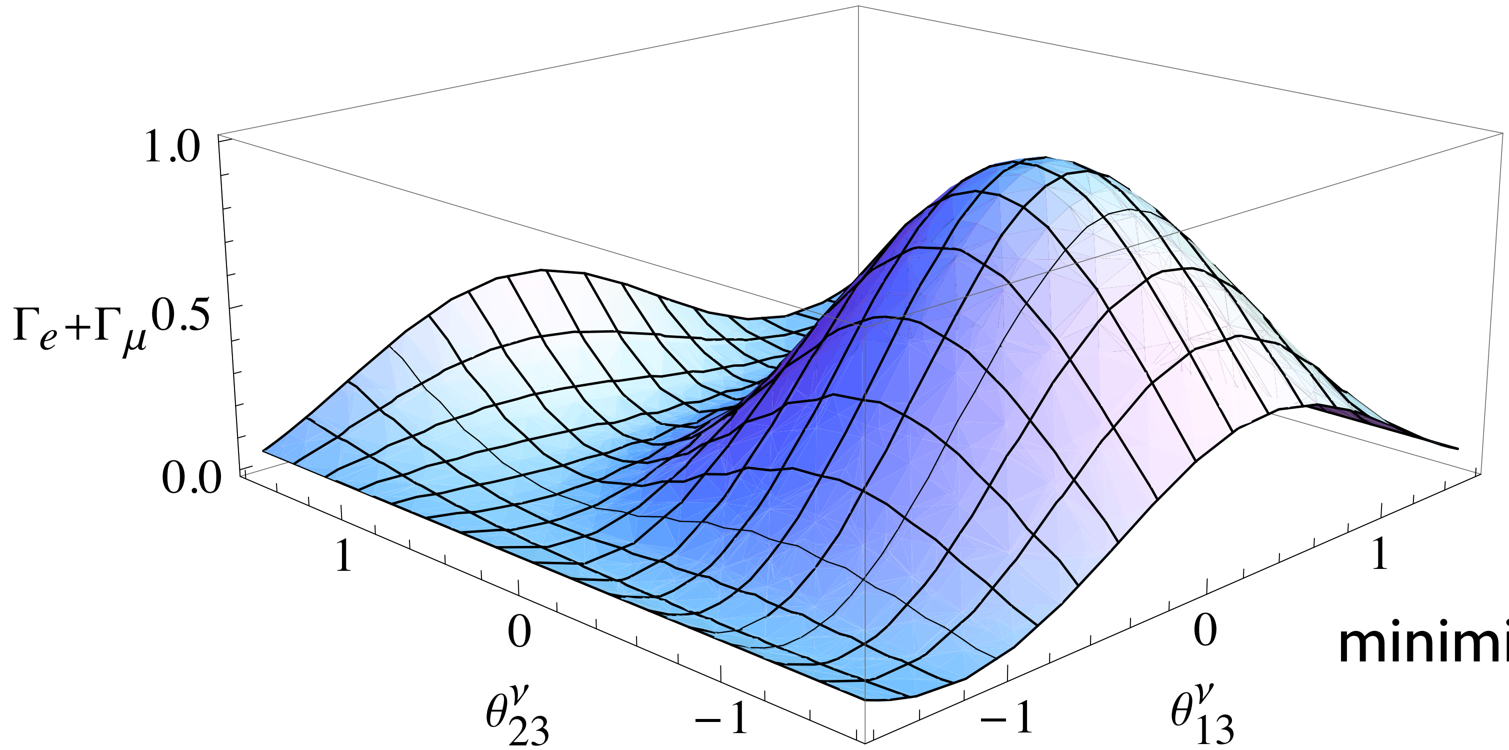
Proton decay to neutral mesons+charged leptons

To be superimposed over the observable(s) of interest ...

$\Gamma(p \to \pi^0 e^+) + \Gamma(p \to \pi^0 \mu^+)$

the minima of the sum of the BNV matrix elements

$$\Gamma(p \to \pi^0 \ell_\alpha^+) \propto |(V_{PMNS} U_\nu)_{\alpha 1}|^2$$

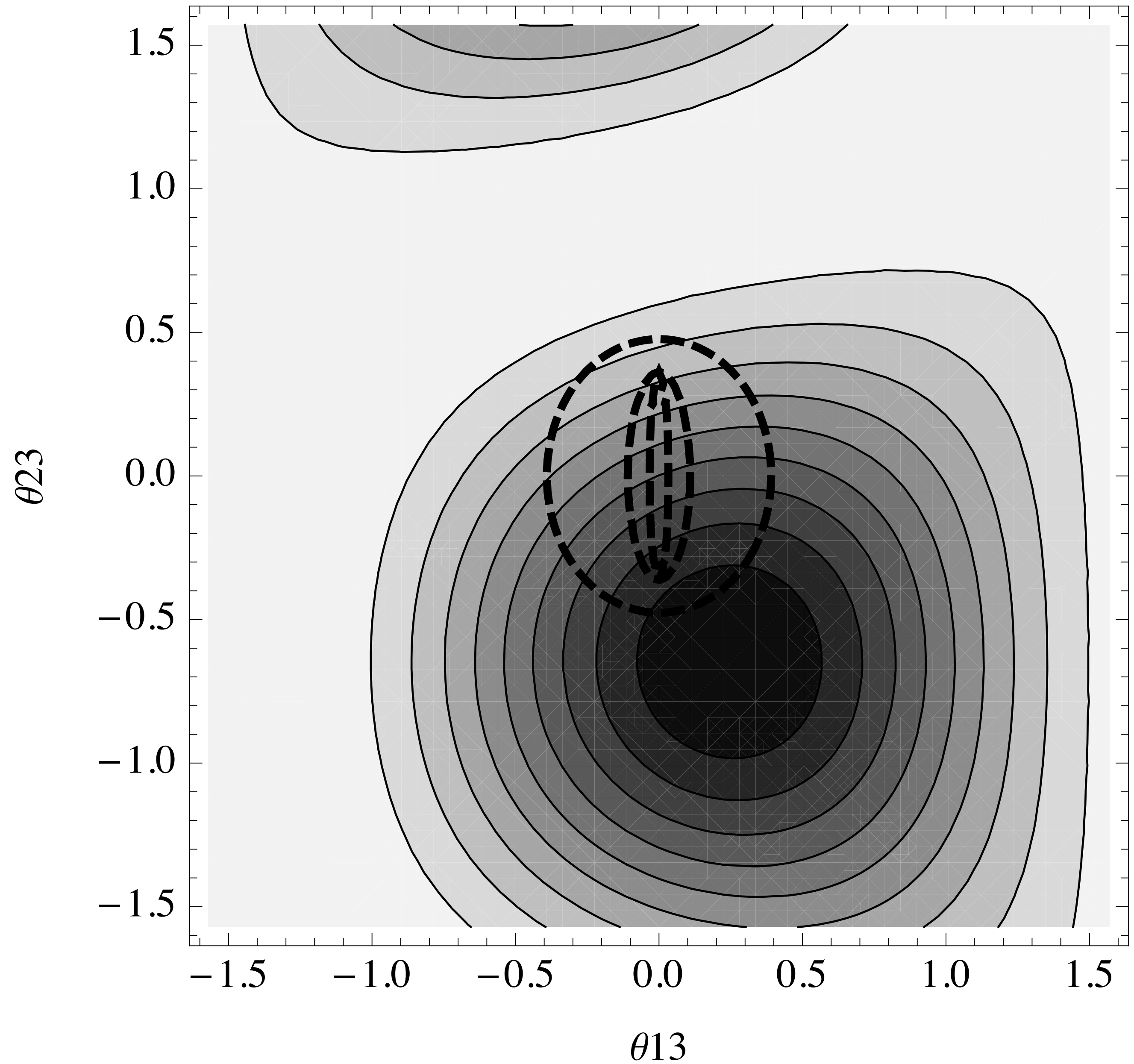


minimization w.r.t. θ_{12} analytic

C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Proton decay to neutral mesons+charged leptons

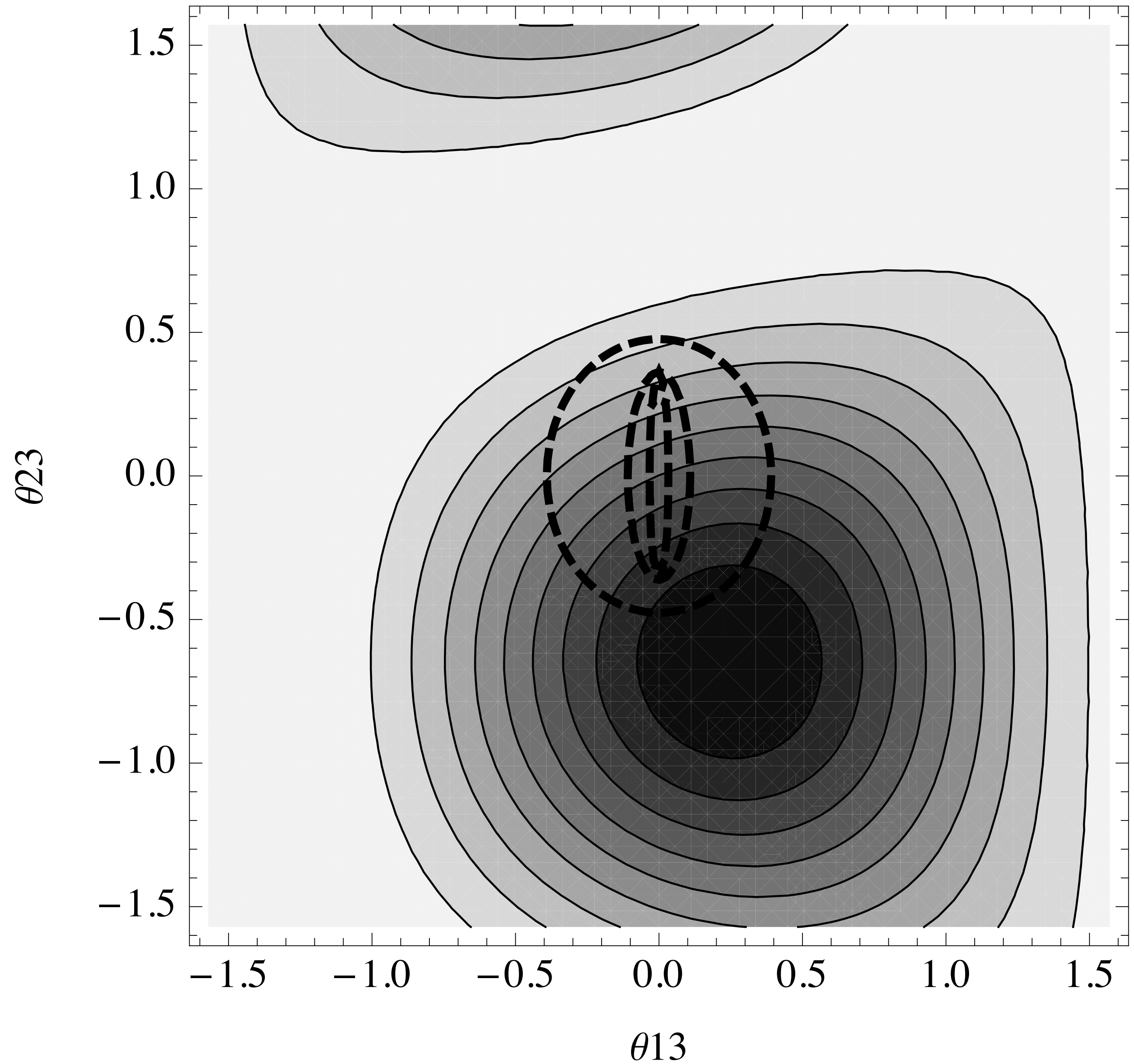
Superimposing the two: $\Gamma(p \to \pi^0 e^+) + \Gamma(p \to \pi^0 \mu^+)$ in the perturbative mode



C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Proton decay to neutral mesons+charged leptons

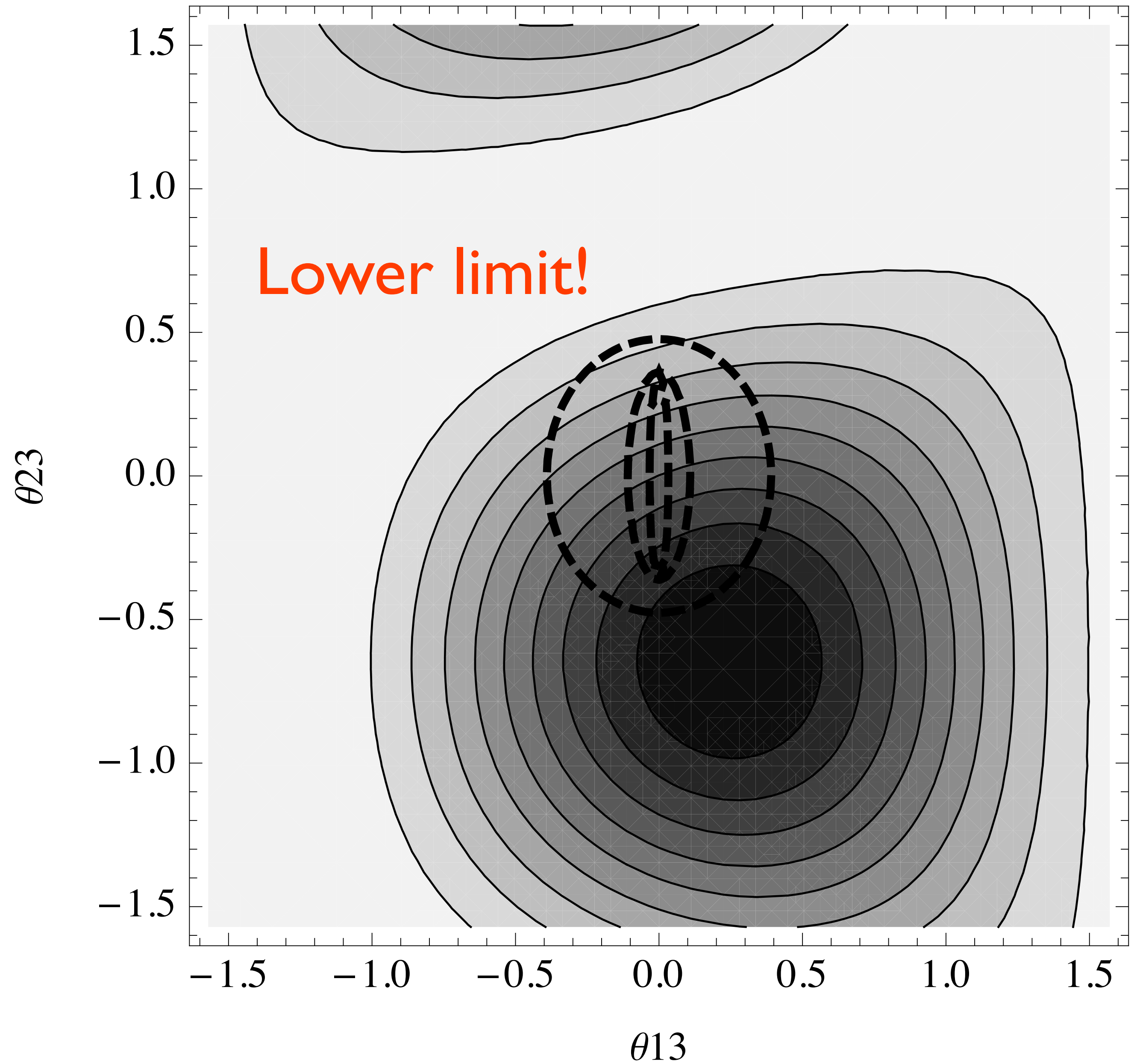
Superimposing the two: $\Gamma(p \to \pi^0 e^+) + \Gamma(p \to \pi^0 \mu^+)$ in the perturbative mode



C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Proton decay to neutral mesons+charged leptons

Superimposing the two: $\Gamma(p \to \pi^0 e^+) + \Gamma(p \to \pi^0 \mu^+)$ in the perturbative mode



C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

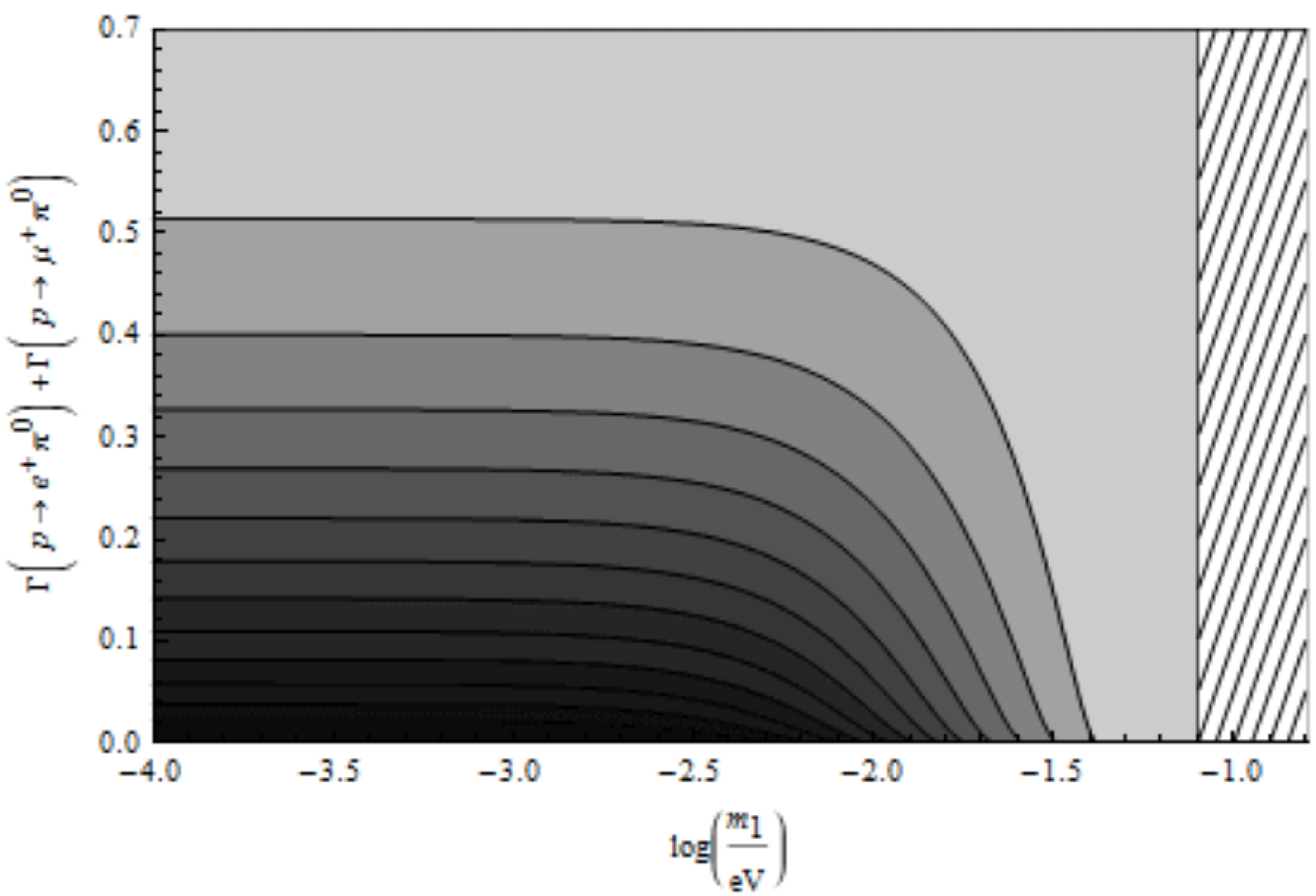
Proton decay to neutral mesons+charged leptons

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

$K = 1$

$K = 2$

$K = 3$



C. Arbelaez Rodriguez, H. Kolešová, MM, PRD89, 055003 (2014)

Conclusions / outlook

Flavour structure of the LFV/LNV operators is great fun.

Do not forget about the flavour structure of the d=6 BNV!

Thanks for your kind attention!