
Weak Gravity Conjecture constraints on the SM and Beyond

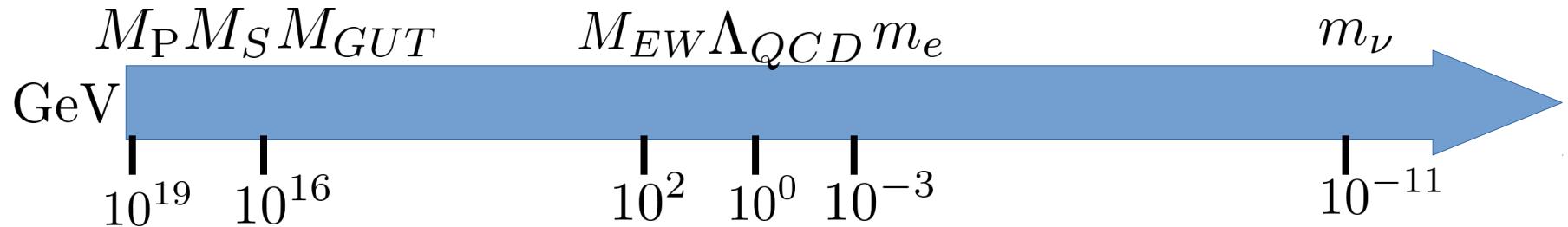
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Ibanez, M-L, Valenzuela [1706.05392] Ibanez, M-L, Valenzuela [1707.05811] } JHEP 1711 (2017) 066

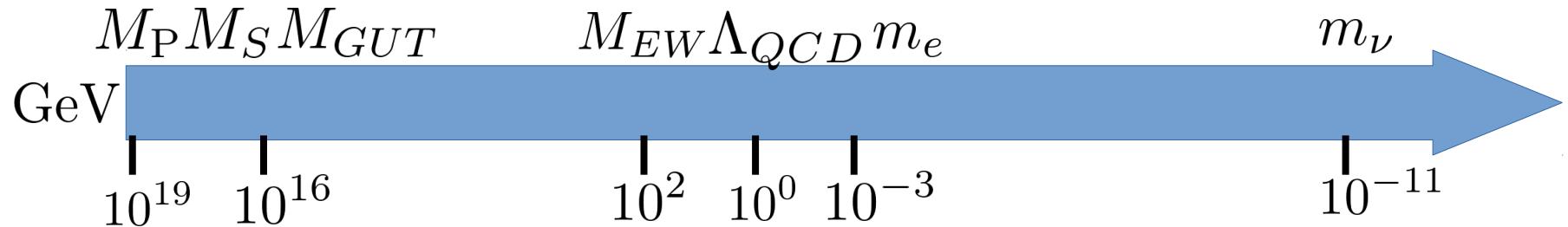
Introduction



Naturalness problems:

- Cosmological constant
- EW hierarchy problem

Introduction

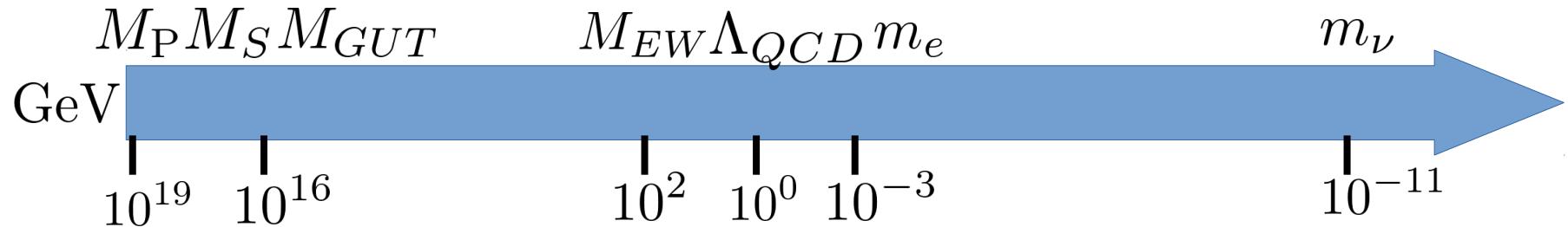


Naturalness problems:

- Cosmological constant
- EW hierarchy problem → LHC



Introduction



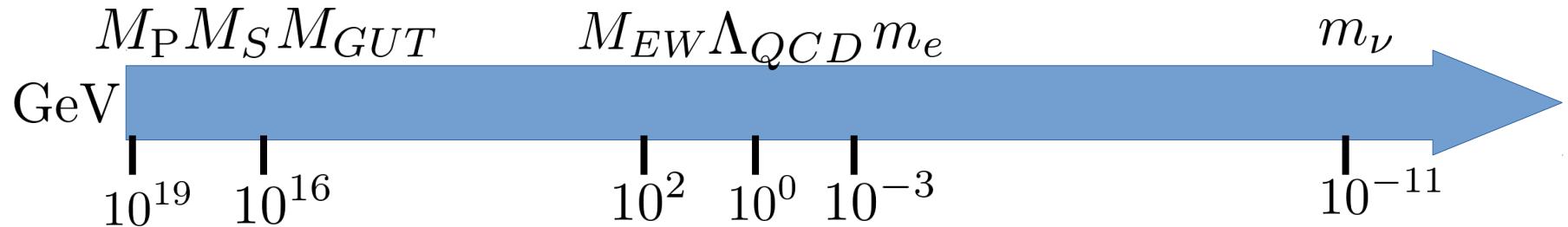
Naturalness problems:

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† Yet, so far...

Introduction



Naturalness problems:

- Cosmological constant
- EW hierarchy problem → LHC

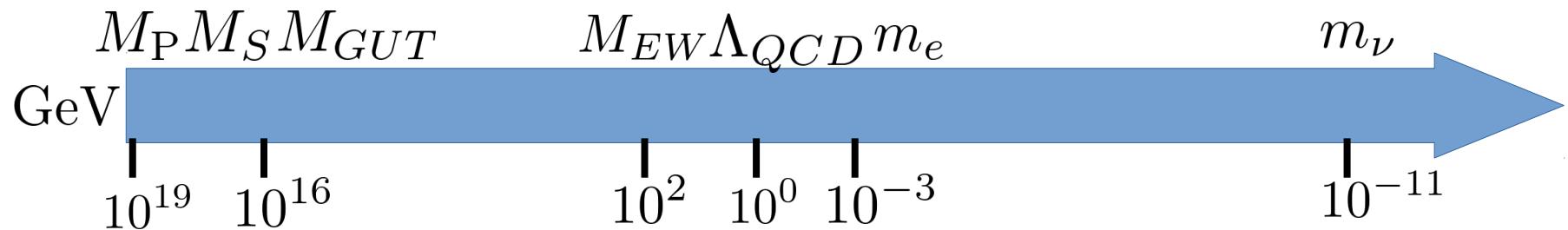
Numerical Coincidence:

$$m_\nu \sim 10^{-2} \text{ eV}$$
$$\Lambda \sim (0.24 \cdot 10^{-2} \text{ eV})^4$$



$$m_\nu \sim \Lambda^{1/4}$$

Introduction



Absence of New Physics forces us to think differently
about the guiding principles of HEP

- Maybe the UV structure is telling us how the IR should behave
- Quantum Gravity Constraints

Quantum Gravity Constraints

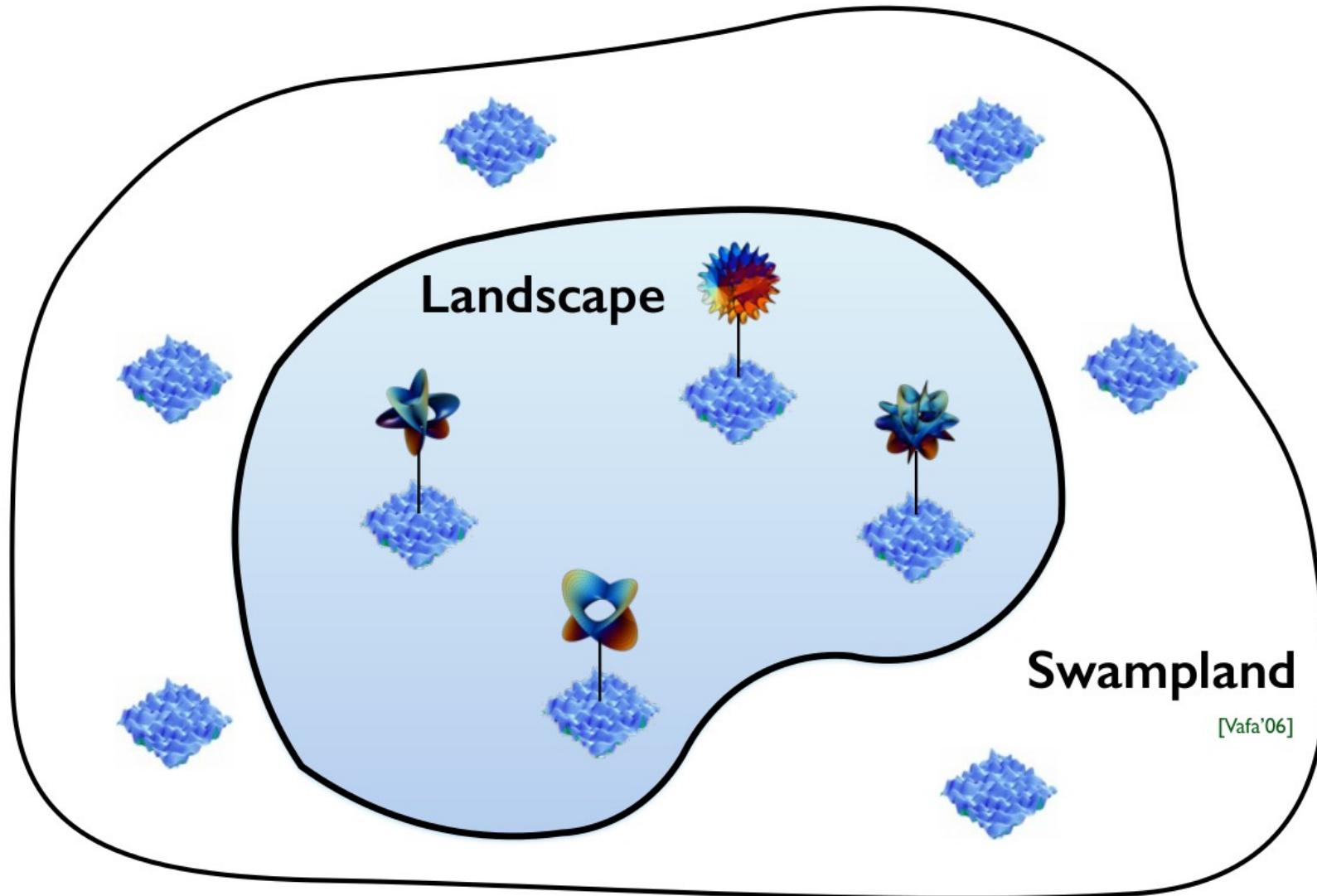
Not everything is possible within String Theory/Quantum Gravity

Quantum Gravity Constraints

Not everything is possible within String Theory/Quantum Gravity

- Not every effective theory can be embedded in QG:
Swampland!! [\[Vafa '06\]](#)

Quantum Gravity Constraints



Picture by Irene Valenzuela

Quantum Gravity Conjectures

Guiding principles to build an effective theory consistent with QG

- Common features of the string landscape, model building failures, black hole arguments.
- Absence of global symmetries [Banks-Dison '88]
- Completeness hypothesis [Horowitz, Strominger, Seiberg...]
[Polchinski '03]
- Weak Gravity Conjecture [Arkani-Hamed et al. '06]
- Swampland constraints about the moduli space [Ooguri-Vafa '06]

These conjectures could have a significant impact
on low energy physics!!

Weak Gravity Conjecture [Arkani-Hamed et al '06]

In theories of QG with a p-form gauge field, there must be an electrically charged object with charge Q and tension T such that:

$$T \leq M_p^2 Q$$

In order to allow for extremal black holes to decay (remnants).

Gravity must be always weaker than any other interaction

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- Sharpened version of the WGC: [Ooguri - Vafa '16]
 - Non-SUSY AdS vacua cannot be consistent with QG
 - It also applies to lower dimensional vacua
 - The AdS vacua must be stable

Weak Gravity Conjecture [Arkani-Hamed et al '06]

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Non-SUSY AdS vacua cannot be consistent with QG

SM compactifications should be also consistent with QG

Compactifications of the SM to 3D

Standard Model + Gravity on S^1 :

[Arkani-Hamed et al. '07]

[Arnold-Fornal-Wise '10]

$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} + \text{Casimir Energy}$$

One-loop corrections: $e^{-2\pi m R}$, $m \gg 1/R$

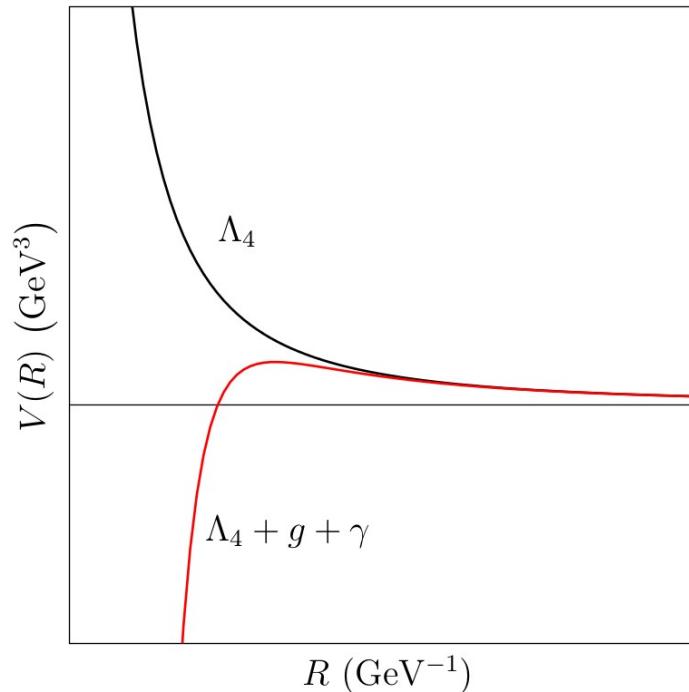
Depending on the light mass spectra and the c.c. we could get AdS vacua!!

Looking at the whole spectrum one can find inconsistencies that can be solved assuming SUSY for instance [Gonzalo, Herráez, Ibáñez '18]

Compactifications of the SM to 3D

Standard Model + Gravity on S^1 :

$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} - 4 \left(\frac{r^3}{720\pi R^6} \right)$$



Compactifications of the SM to 3D

Standard Model + Gravity on S^1 :

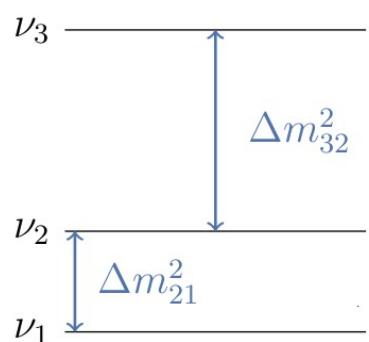
$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} - 4 \left(\frac{r^3}{720\pi R^6} \right) + \sum_i (2\pi R)(-1)^{s_i} n_i \rho_i(R)$$

Compactifications of the SM to 3D

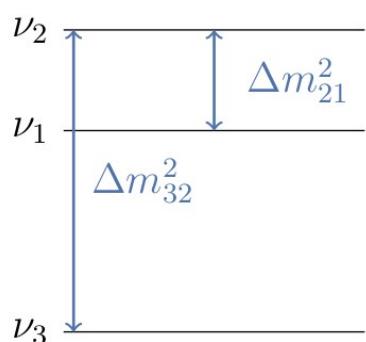
Standard Model + Gravity on S^1 :

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Normal
Hierarchy



Inverted
Hierarchy



$$\Delta m_{21}^2 = (7.53 \pm 0.18) \cdot 10^{-5} \text{ eV}^2$$

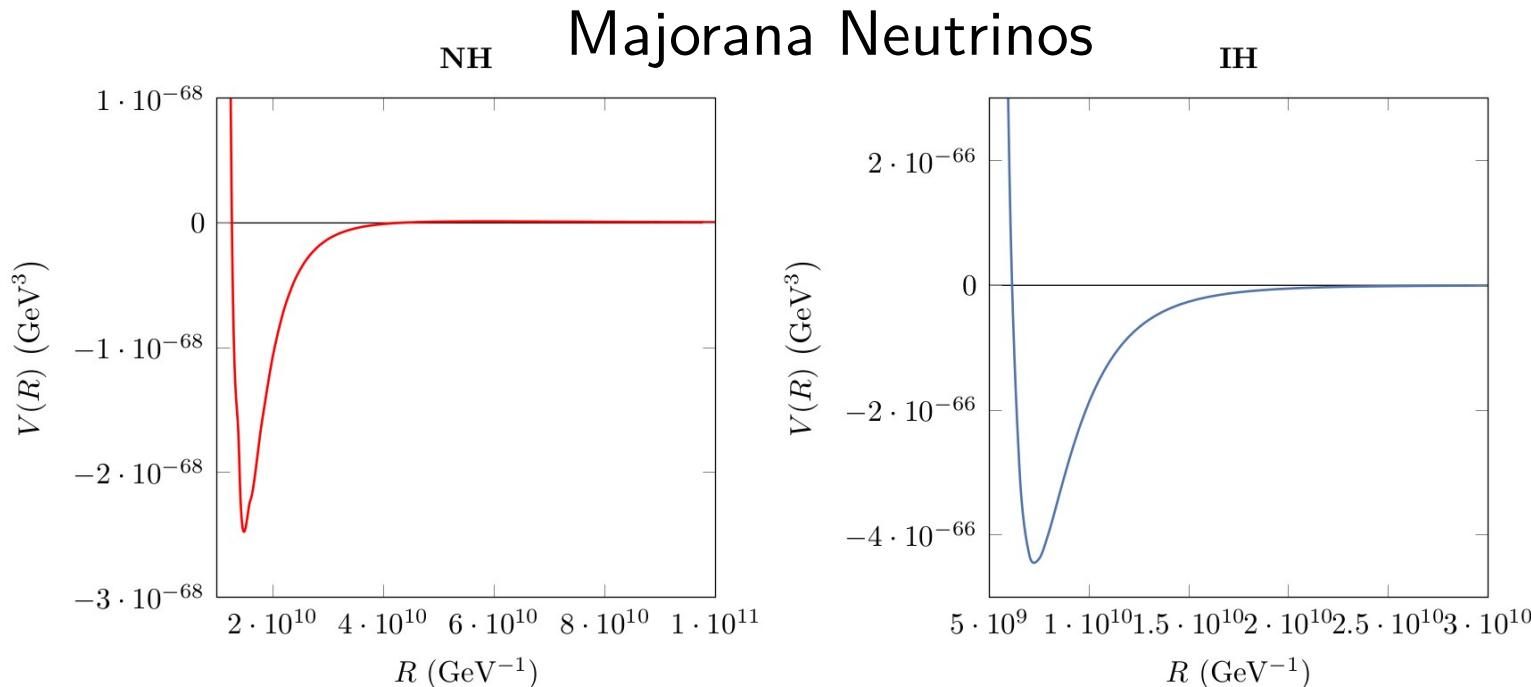
$$\Delta m_{32}^2 = (2.44 \pm 0.06) \cdot 10^{-3} \text{ eV}^2 \text{ (NH)}$$

$$\Delta m_{32}^2 = (2.51 \pm 0.06) \cdot 10^{-3} \text{ eV}^2 \text{ (IH)}$$

Compactifications of the SM to 3D

Standard Model + Gravity on S^1 :

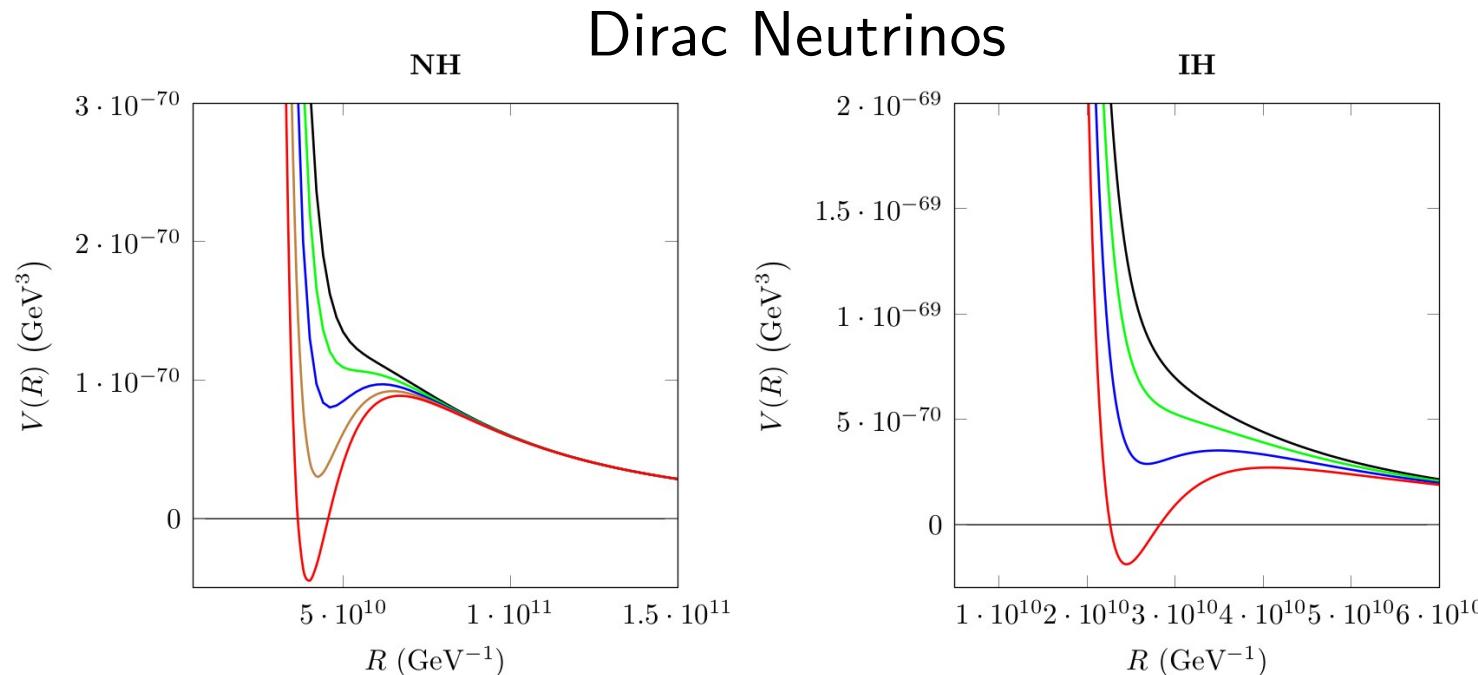
$$V(R) \simeq \frac{2\pi r^3 \Lambda_4}{R^2} - 4 \left(\frac{r^3}{720\pi R^6} \right) + \sum_i (2\pi R)(-1)^{s_i} n_i \rho_i(R)$$



Compactifications of the SM to 3D

Standard Model + Gravity on S^1 :

$$V(R) \sim \frac{2\pi r^3 \Lambda_4}{R^2} - 4 \left(\frac{r^3}{720\pi R^6} \right) + \sum_i (2\pi R)(-1)^{s_i} n_i \rho_i(R)$$



Constraints on neutrino masses

Majorana Neutrinos

AdS vacuum for any value of m_ν  RULED OUT!

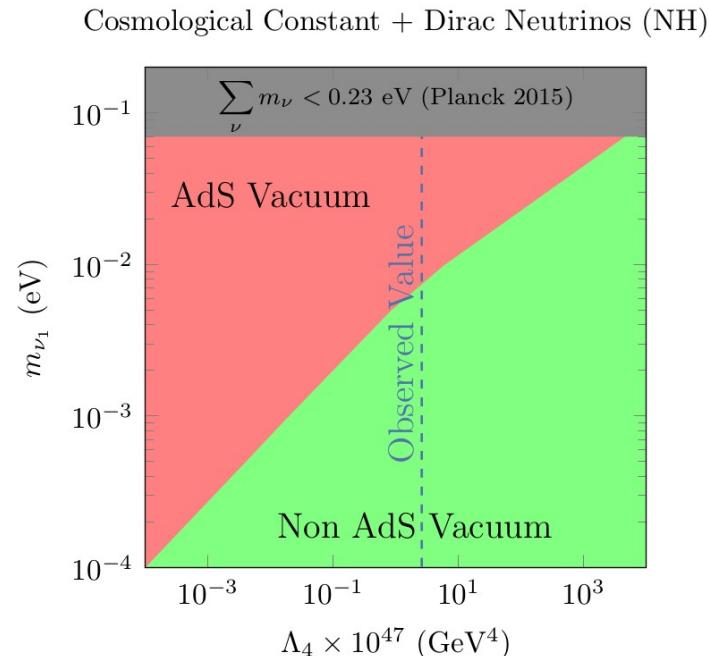
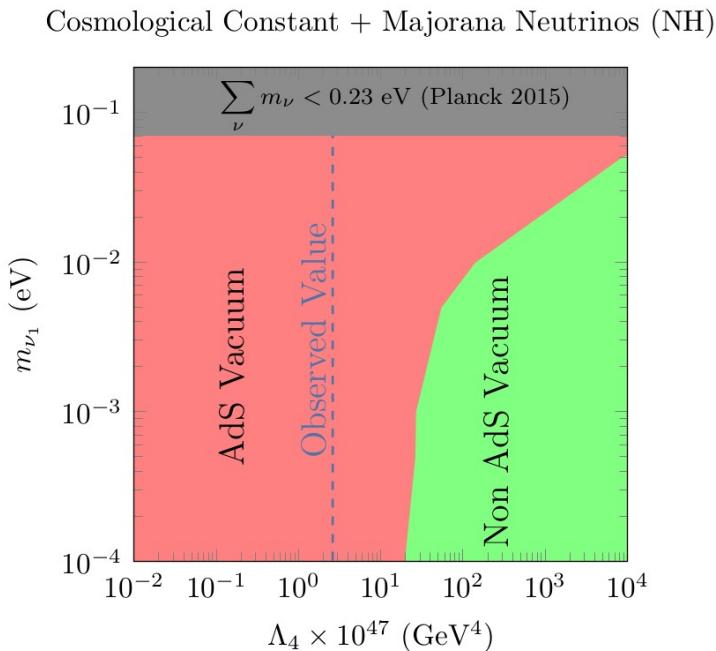
Dirac Neutrinos

		NH	IH
No	vacuum	$m_{\nu_1} < 6.7 \text{ meV}$	$m_{\nu_3} < 2.1 \text{ meV}$
dS ₃	vacuum	$6.7 \text{ meV} < m_{\nu_1} < 7.7 \text{ meV}$	$2.1 \text{ meV} < m_{\nu_3} < 2.56 \text{ meV}$
AdS ₃	vacuum	$m_{\nu_1} > 7.7 \text{ meV}$	$m_{\nu_3} > 2.56 \text{ meV}$

$m_{\nu_1} < 7.7 \text{ meV}$ (NH)

$m_{\nu_3} < 2.56 \text{ meV}$ (IH)

Lower bound on the Cosmological Constant



$$\Lambda_4 \geq \frac{a(n_f)30(\sum m_i^2)^2 - b(n_f, m_i)\sum m_i^4}{384\pi^2}$$

$$a(n_f)$$

$$b(n_f, m_i)$$

$$= 0.184(0.009)$$

$$= 5.72(0.29)$$

Majorana (Dirac)

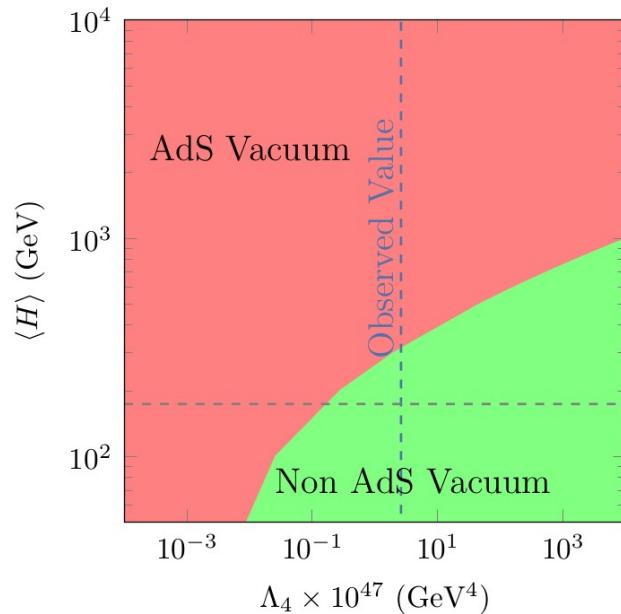
First argument to have $\Lambda_4 \neq 0$, not based on Cosmology

Upper bound on the EW scale

Majorana Neutrinos

$$\langle H \rangle \lesssim \frac{\sqrt{2}}{Y_{\nu_1}} \sqrt{M \Lambda^{1/4}}$$

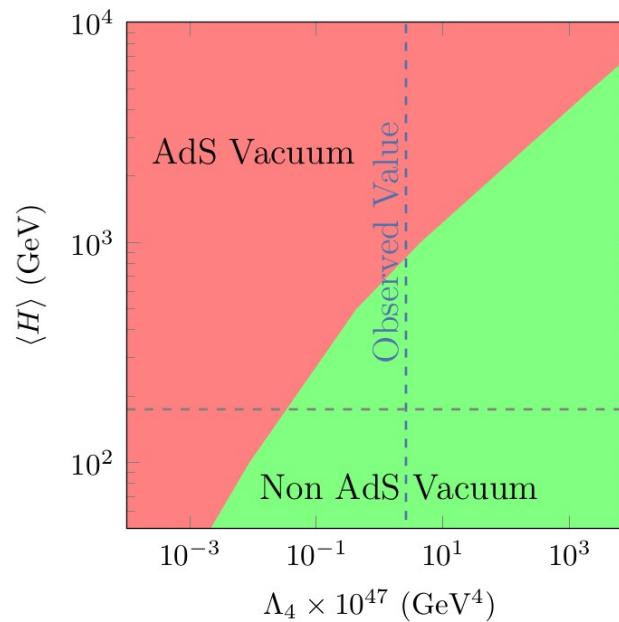
Majorana Neutrinos (NH)



Dirac Neutrinos

$$\langle H \rangle \lesssim 1.6 \frac{\Lambda^{1/4}}{Y_{\nu_1}}$$

Dirac Neutrinos (NH)



$$M = 10^{10} \text{ GeV}, Y_\nu = 10^{-3} \quad m_\chi = 1 \text{ meV}$$

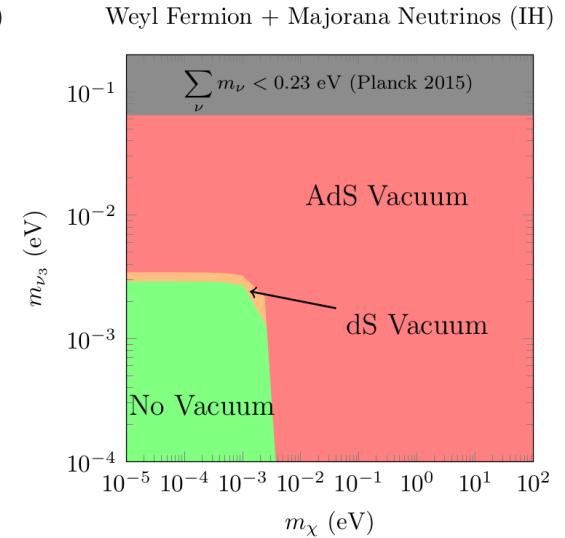
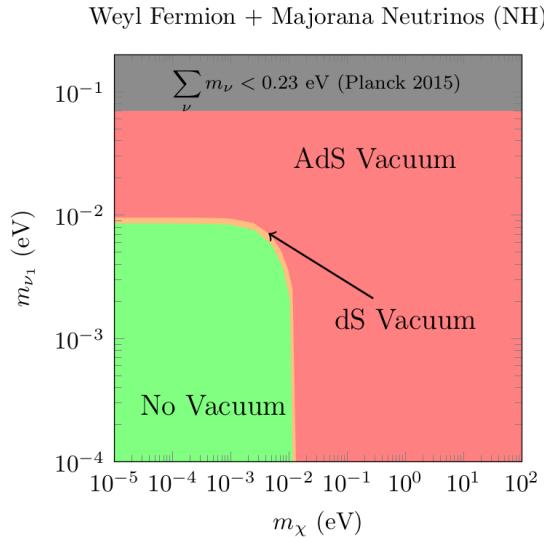
$$Y_\nu = 10^{-14}$$

Parameters leading to a higher EW scale: Inconsistency with quantum gravity

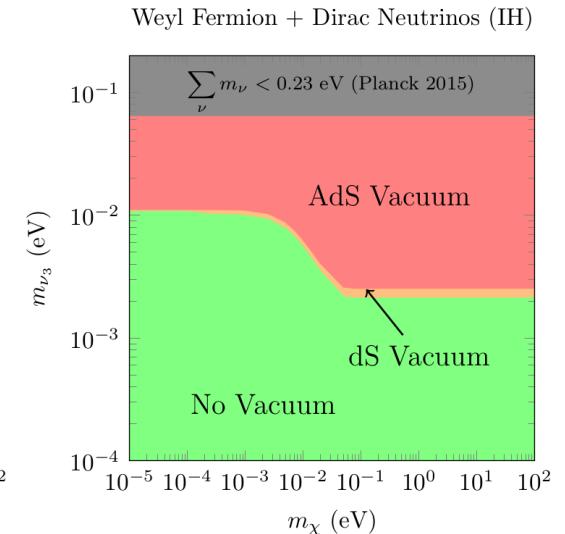
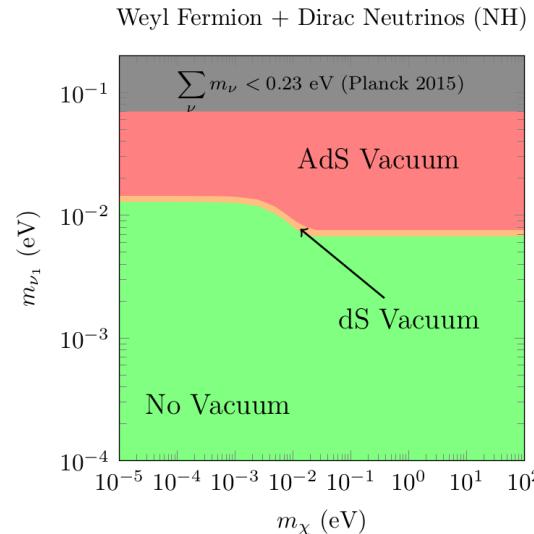
There is also a lower bound: $\langle H \rangle \geq \Lambda_{QCD}$ [Gonzalo, Ibáñez '18]

BSM Physics : Weyl Fermion

Majorana Neutrinos

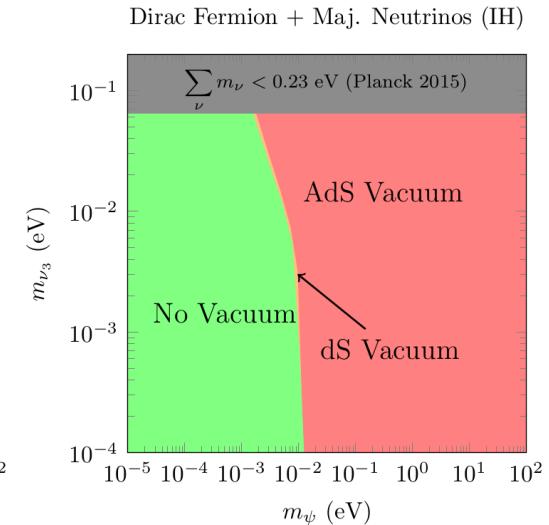
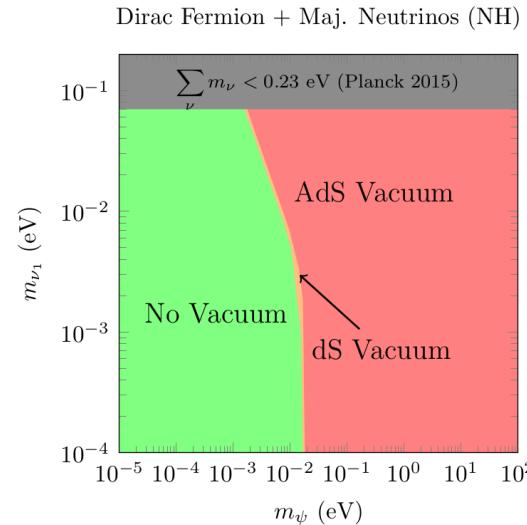


Dirac Neutrinos

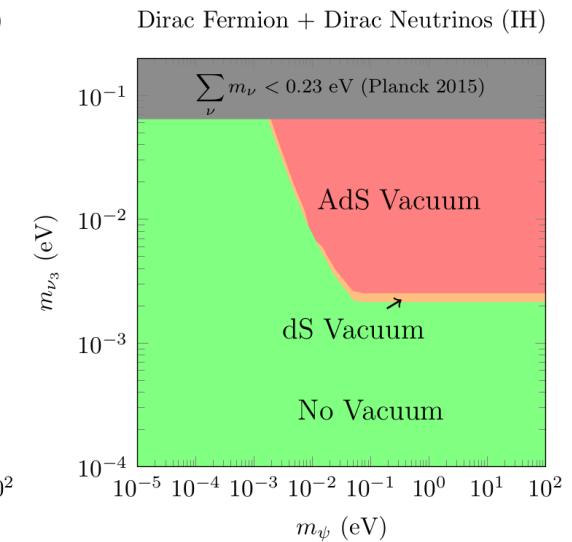
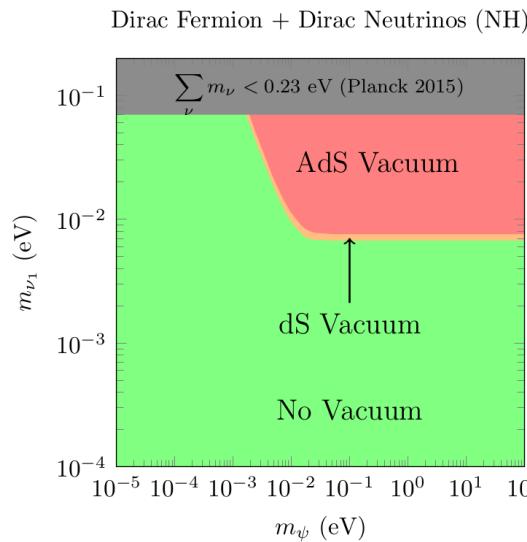


BSM Physics : Dirac Fermion

Majorana Neutrinos



Dirac Neutrinos

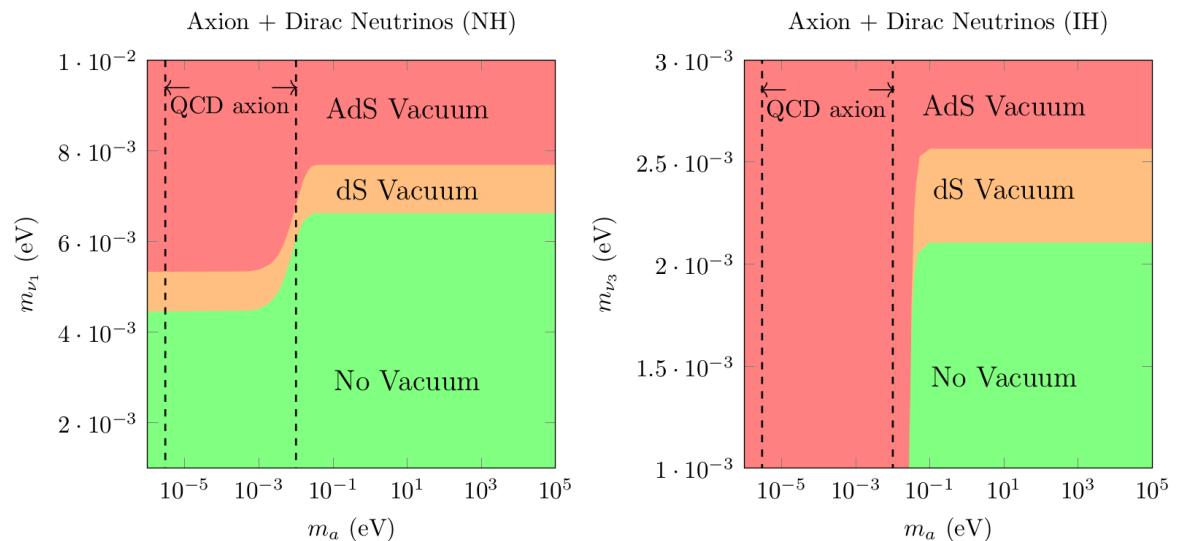


BSM Physics : Axion

Majorana Neutrinos

The presence of the axion makes the AdS vacuum deeper

Dirac Neutrinos



Conclusions

- Not every effective theory can be embedded into QG
(QG conjectures)
- Consistency with QG implies constraints low energy physics
- AdS Instability Conjecture + stability of 3D SM vacua:
 - Lower bound on the cosmological constant and upper bound on neutrino masses
 - Upper bound on the EW scale in terms of the c.c.