Weak gravity conjecture, Multiple point principle and SM landscape

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People used to think

- If (Energy) $\ll M_P$, effect of gravity is decoupled.
- Model building below Planck scale is independent from gravity (SM, beyond SM).

People used to think

- This might not true.

- Gravity may say something about low energy model building. [Vafa '05]

Motivation

- Test conjectures about quantum gravity

  by SM physics.

- Conjecture1: Weak Gravity Conjecture

  Gravity is weakest force.

  All non-SUSY AdS vacua are unstable.

- Conjecture2: Multiple Point criticality Principle

  The parameters of the theory are tuned so that

  many vacua are degenerate in energy.

Talk Plan

1. Conjectures
2. Standard Model on M_4
3. Standard Model on $M_3 \times S^1$

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[Arkani-Hamed, Motl, Nicolis, Vafa ‘06]

Weak gravity conjecture(WGC)

- Conjecture:

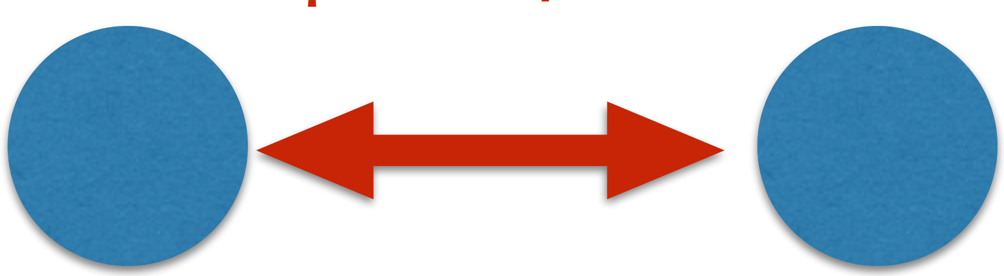
  Gravity is weakest force.

- q: gauge charge.

  WGC requires

  (gauge force) ≧ (gravity force)

$q \geqq m/M_P$



q, m

[Ooguri, Vafa '16]

Non-SUSY AdS conjecture

- Conjecture1:

Motivation: It is unnatural that non-BPS state saturates WGC under quantum correction.

Except for BPS state, gravity is strictly weakest force.

Implication of conjecture1.

All non-SUSY AdS vacua supported by flux are unstable.

- Conjecture2: All non-SUSY AdS vacua are unstable.

Motivation: (All known construction from M/string theory, AdS is supported by some flux.) + (Conjecture1)

[Froggatt, Nielsen ’95][Bennett ‘96]

Multiple point principle(MPP)

- Conjecture:

  The parameters of the theory are tuned so that many vacua are degenerate in energy.

- Possible principle to extract predictions from vast landscape.

Motivation of MPP

	Statical mechanics	QFT
micro-canonical	$\Omega(E) = \sum_n \delta(H_n - E)$	?
	Equivalent in thermodynamic limit	
canonical	$Z(\beta) = \sum_n e^{-\beta H_n}$	$Z(\{\lambda\}) = \int [d\varphi]\, e^{-S(\{\lambda\})[\varphi]}$

In statical mechanics, micro-canonical ensemble is fundamental.
First, E(extensive variable) is given, and T(intensive variable) appears as a result.

Motivation of MPP

Statical mechanics

QFT

micro-canonical $\Omega(E) = \sum_n \delta(H_n - E)$

$$\int [d\varphi]\, e^{-S_{\mathrm{extra}}}\, \delta\left(\int d^4x\, \varphi^2 - I_2\right)$$

Proposal in [Froggatt, Nielsen '95]

Equivalent in
thermodynamic limit

canonical $Z(\beta) = \sum_n e^{-\beta H_n}$

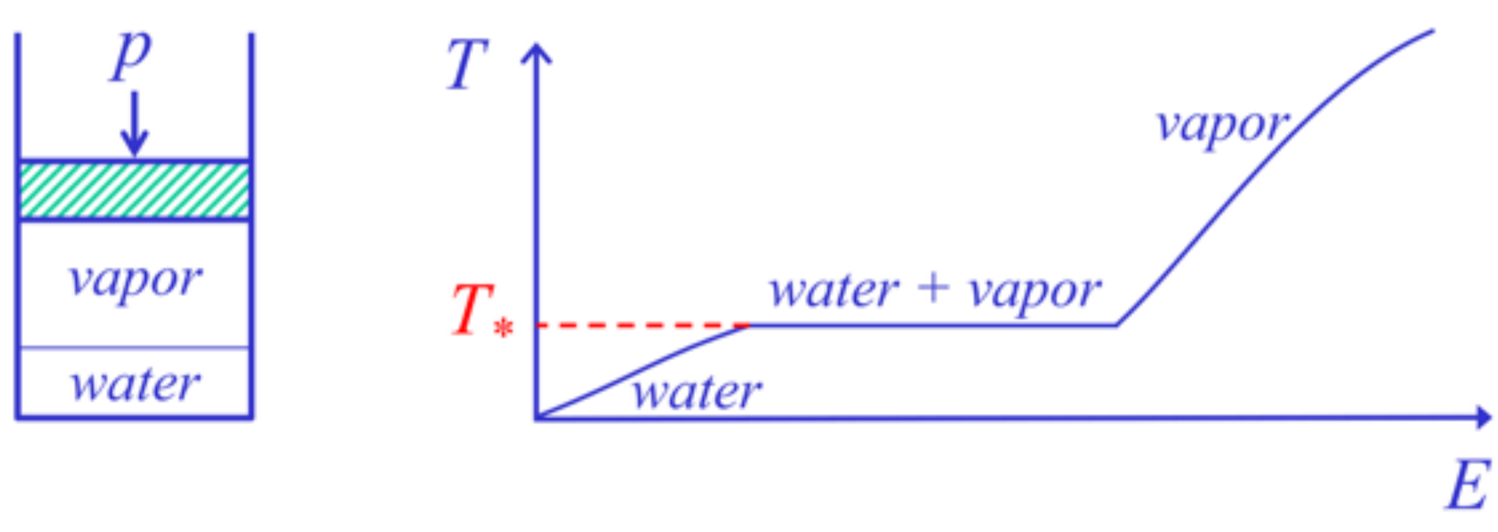
$$Z(\{\lambda\}) = \int [d\varphi]\, e^{-S(\{\lambda\})[\varphi]}$$

Correspondence:
T↔coupling(intensive variable),
E ↔$\int \phi^2$ (extensive variable).

Coexisting phase

- Add heat to water under constant pressure.

- Point: For wide range of E, the temperature T is tuned to be boiling point T_*.



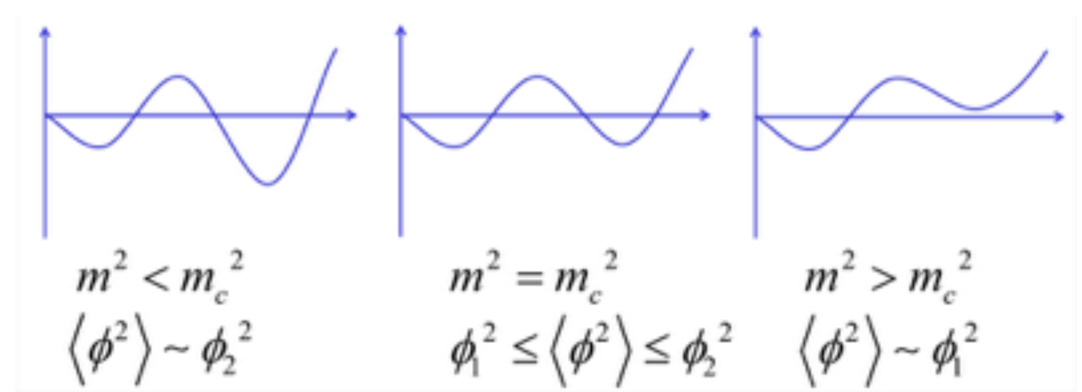
QFT version

- Inspired by micro-canonical ensemble, we fix I_{2}.

$$\int [d\varphi]\, e^{-S_{\rm extra}}\, \delta\Big(\int d^4x\, \varphi^2 - I_2 \Big)$$

- Taking natural value $I_2 = O(V_4 M_P^2)$, the constraint is realized as an average between two vacuum.

- To maintain coexisting phase, vacua should be degenerate.



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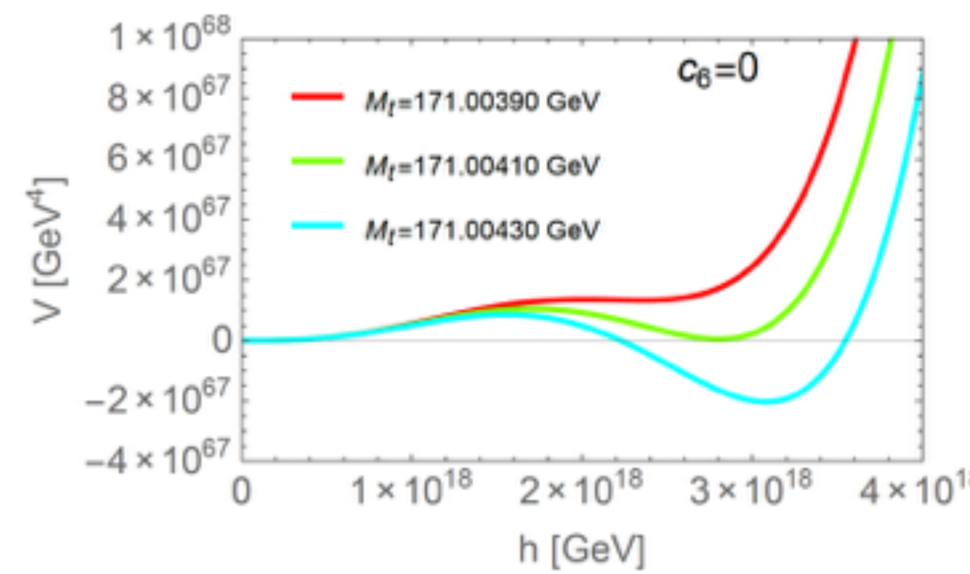
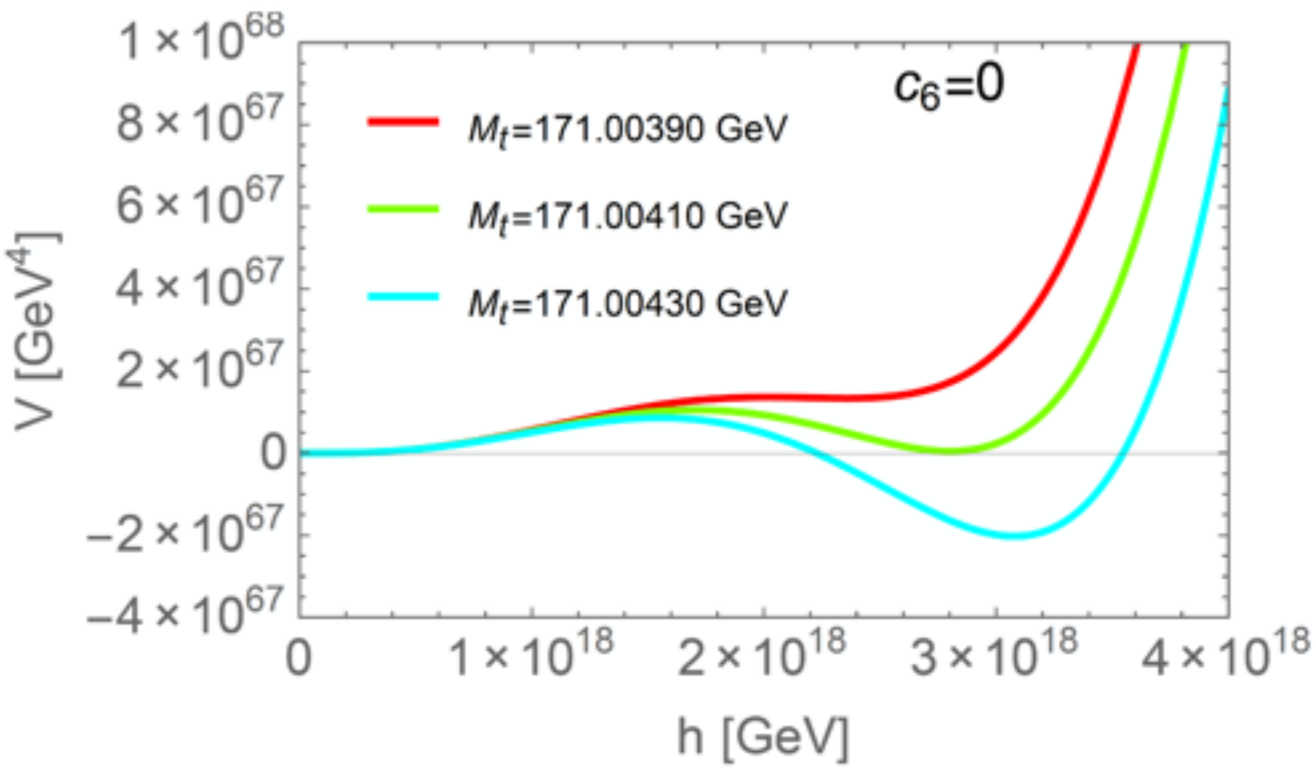
AdS vacuum in SM

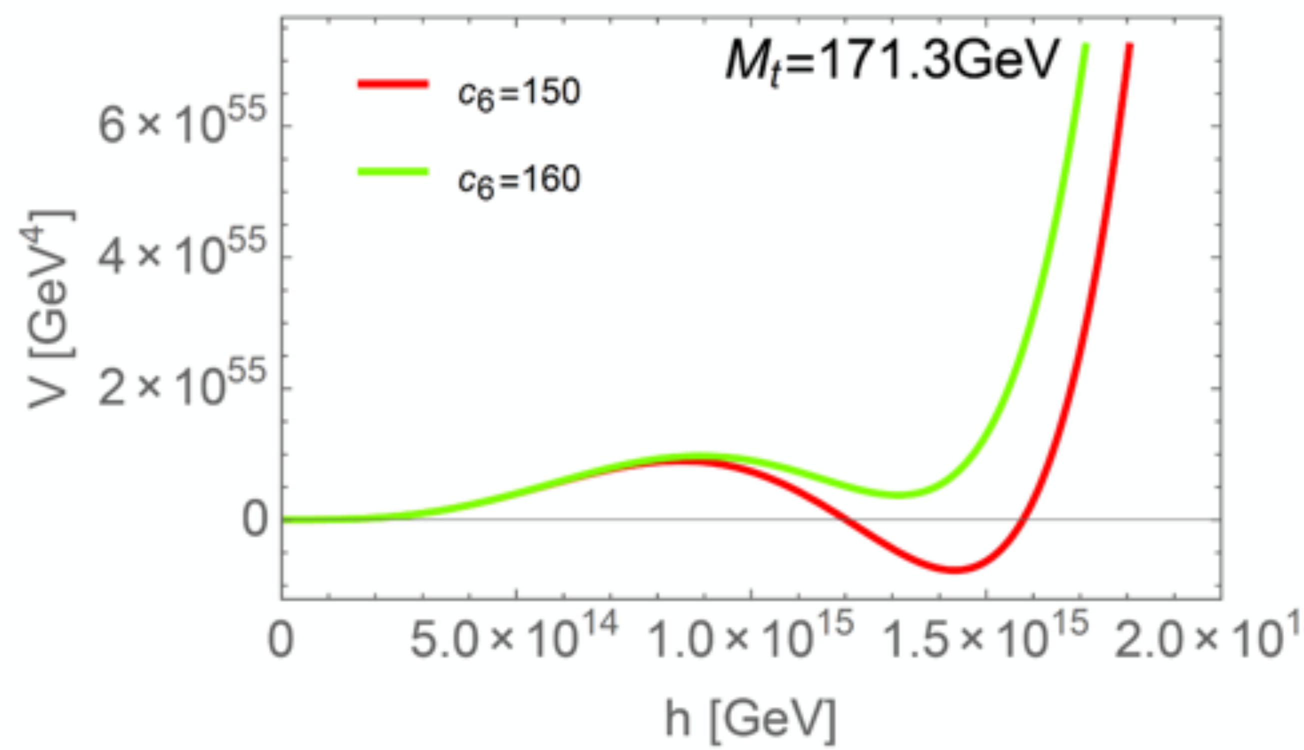
- 4d SM Higgs potential can have AdS_4 minimum, depending on M_t, M_H and higher dim. operator

[Degrassi et. al. '12, …]



SM Higgs potential





Application of WGC

Depending on M_t , M_H and higher-dim operators, high scale AdS vacuum appears.
WGC can constrain top & Higgs mass. [YH, Shiu '17]

Application of MPP

Requiring the degenerate vacua, the predictions on M_H, M_t are obtained.
The correct M_H was predicted 20 years ago. [Froggatt, Nielsen '95]

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S^1 compactification of SM

[Arkani-Hamed, Dubovsky, Nicolis, Villadoro '07]

potential for radion L

$$\frac{L_0^2}{(2\pi L)^2}\left\{\Lambda_4 - \frac{1}{180L^4(2\pi)^4} - \sum_i 2V_{S^1}^{(1)}\left(L, M_{\nu_i}, \frac{1-z}{2}\right)\right\}$$

One-loop effective potential (Casimir energy)

$$V_{S^1}^{(1)} = (-1)^{2s_p+1}\frac{n_p}{2}\sum_{n=-\infty}^{\infty}\frac{1}{2\pi L}\int\frac{d^3k}{(2\pi)^3}\log\left(k_0^2+k_1^2+k_2^2+M^2+\frac{(n+\theta)^2}{L^2}\right)$$

S^1 compactification of SM

[Arkani-Hamed, Dubovsky, Nicolis, Villadoro '07]

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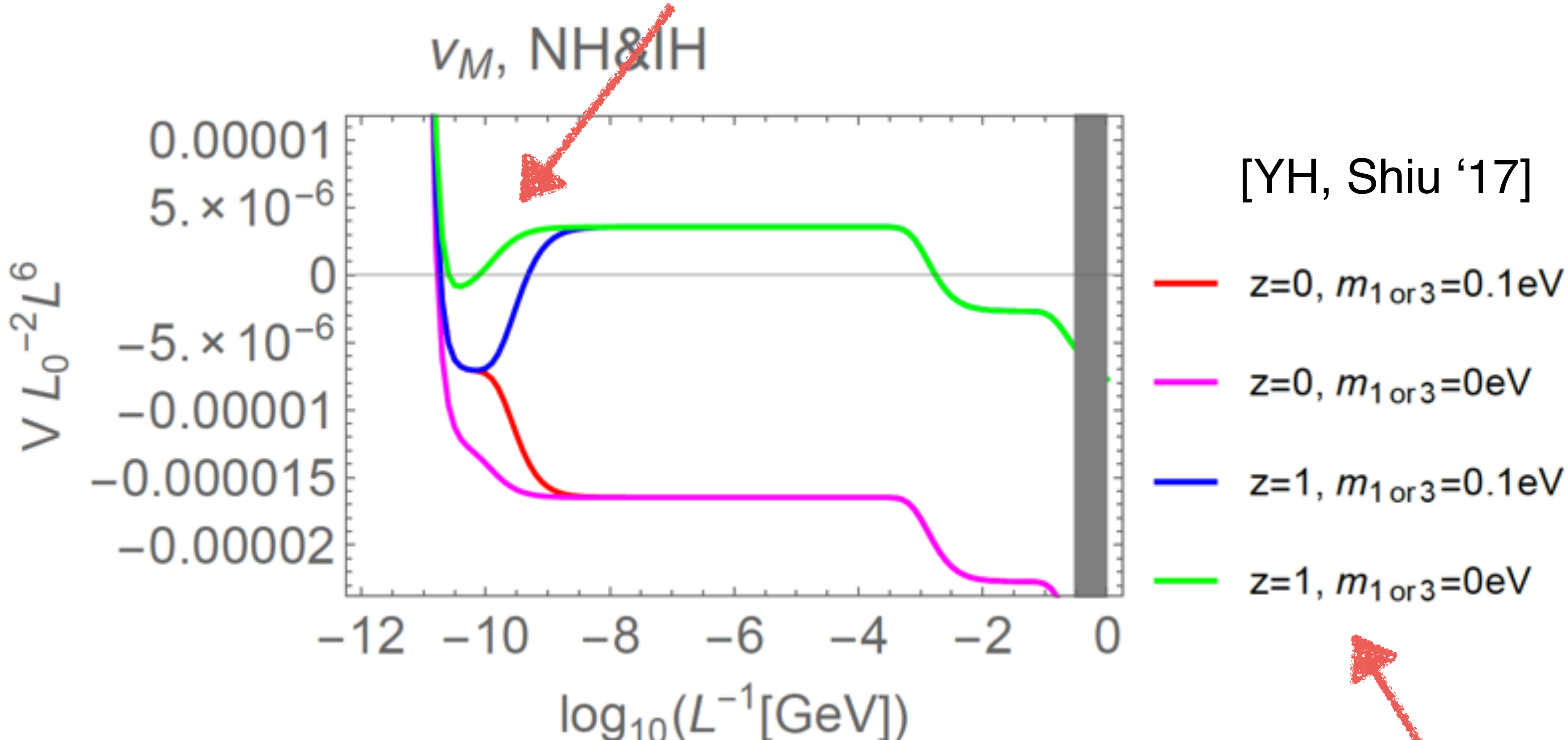
vacuum around neutrino mass scale



[YH, Shiu '17]

[See also Ooguri Vafa '16, Ibanez et. al. '17]

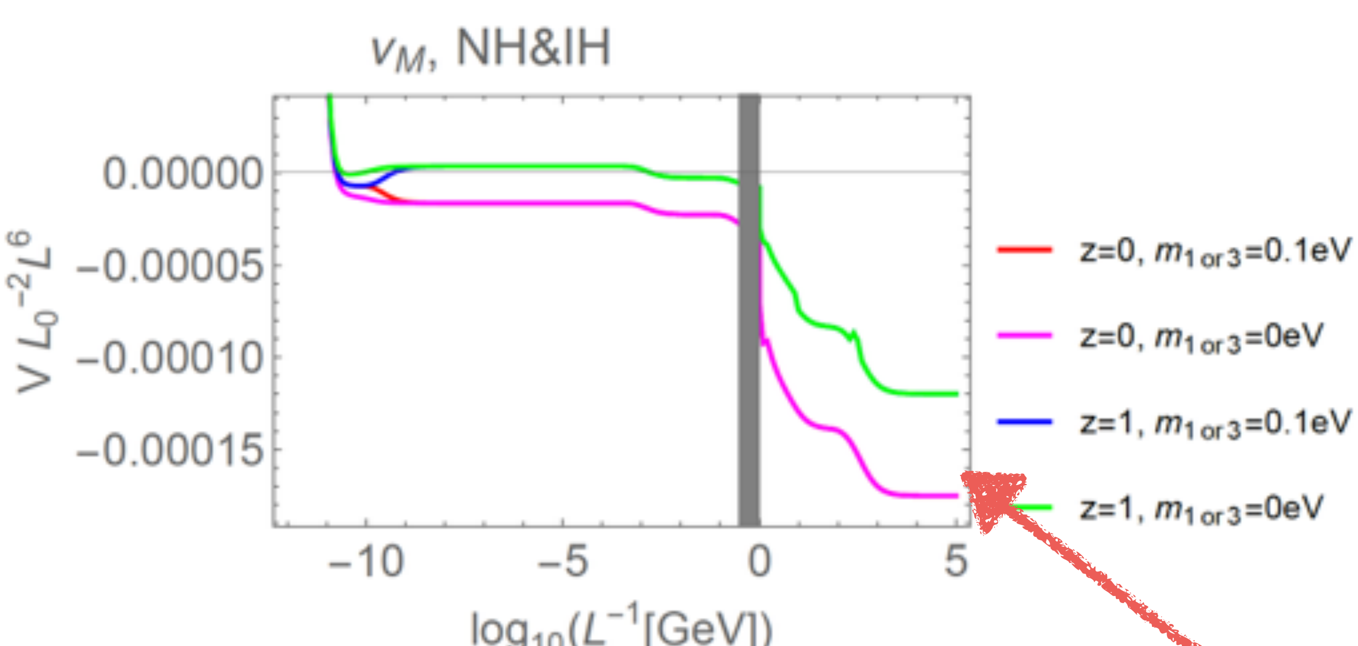
bc & mass of v

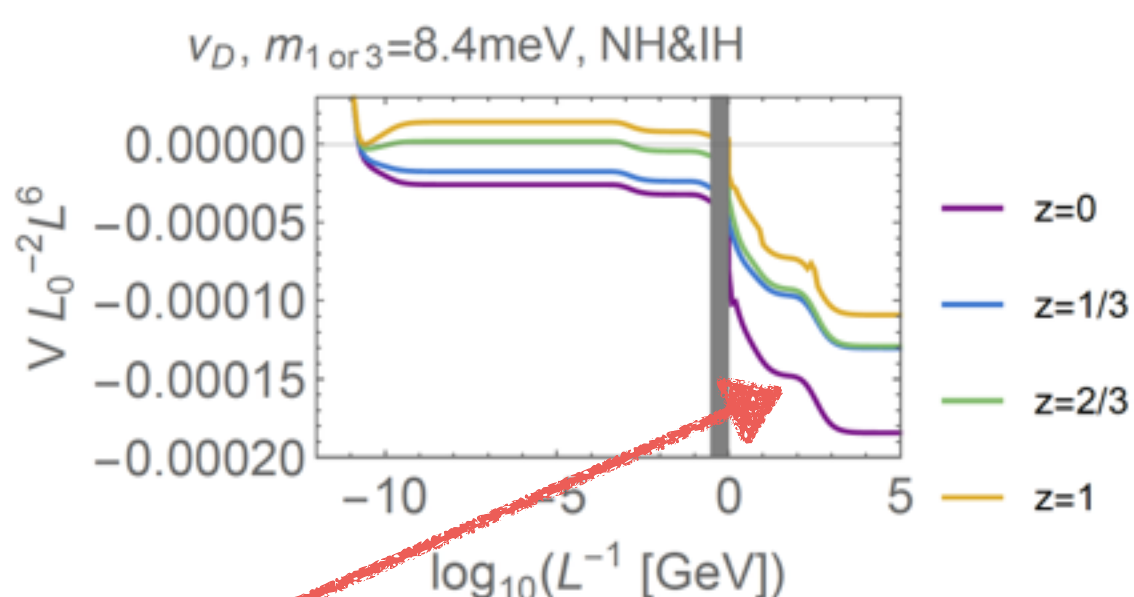
Application of WGC

[YH, Shiu '17]

- Neutrino vacuum can be AdS, but it is likely to decay non-perturbatively.

- Consistent with the conjecture.



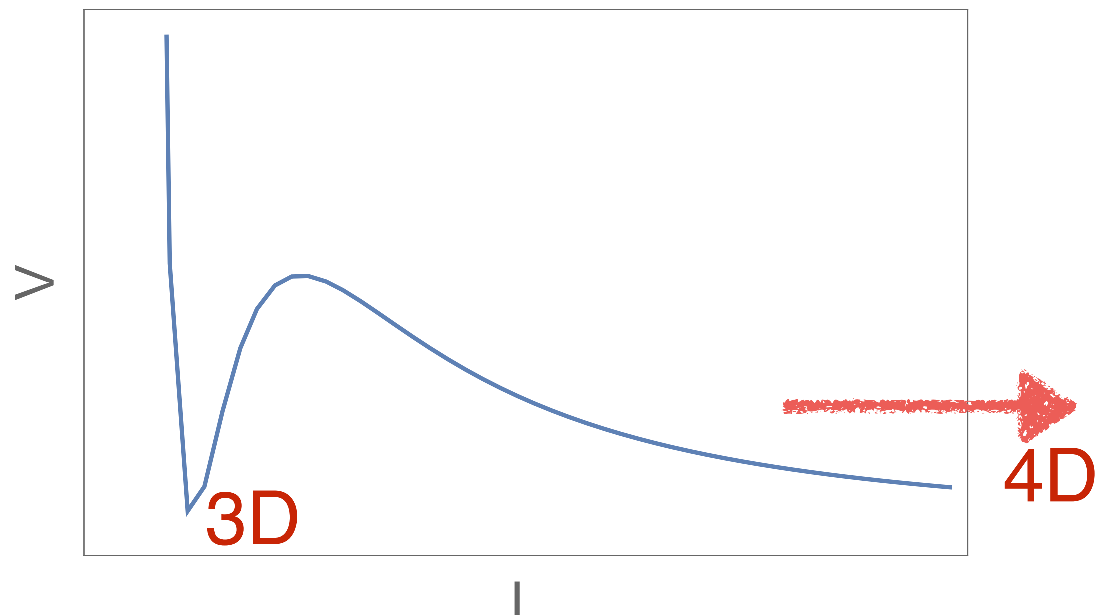


Runaway behavior for small radius

Application of MPP

[YH, Shiu '17]

- We may consider the degeneracy between 3D and 4D vacua.

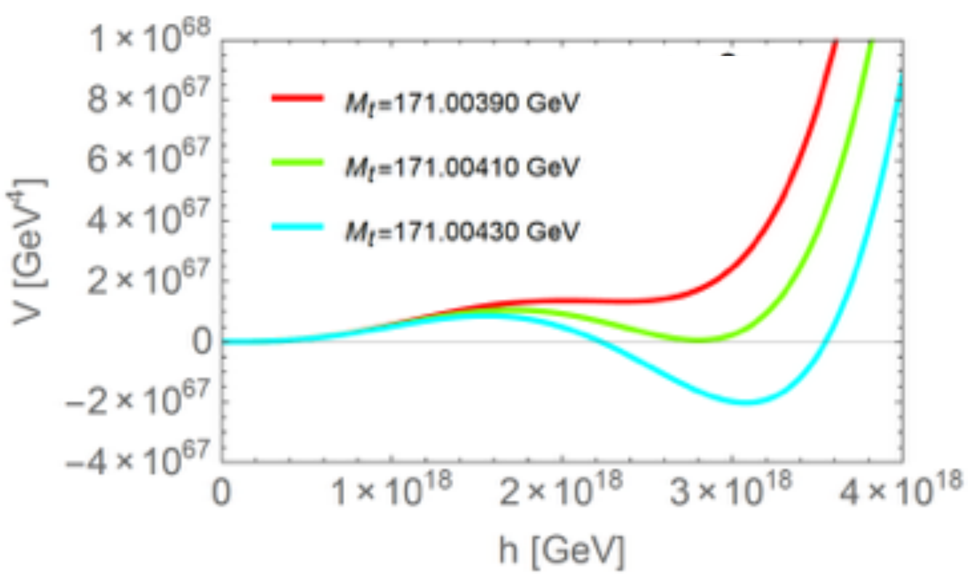


- Predicted neutrino mass is $m_{\nu,\mathrm{lightest}} = O(1\text{-}10)\,\mathrm{meV}$, and neutrino is Dirac.

Summary

- Conjecture1: Weak Gravity Conjecture

Related to Stability of the electroweak vacuum.



- Conjecture2: Multiple Point criticality Principle

Prediction:

Neutrino is Dirac, and $m_{\nu,\text{lightest}}$ = O(1-10)meV.

Backup

Quantum gravity & SM physics

- Motivation: Test of conjectures about quantum gravity by SM physics.

- Conjecture1: Weak Gravity Conjecture

  Gravity is weakest force. [Arkani-Hamed, Motl, Nicolis, Vafa '06]

  Non-SUSY AdS vacua are unstable.(sharpened ver.) [Ooguri, Vafa '16]

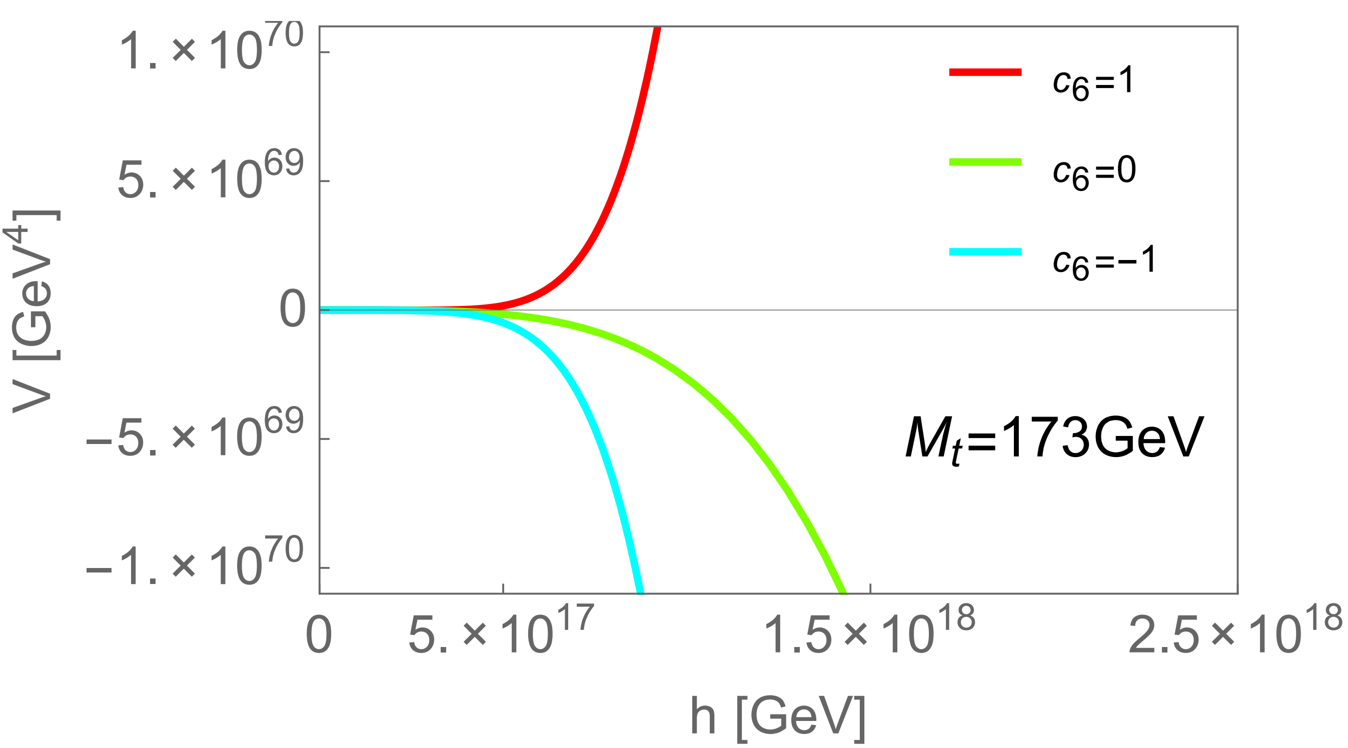
- Conjecture2: Multiple Point criticality Principle

  The parameters of the theory are tuned so that many vacua are degenerate in energy. [Froggatt, Nielsen '95]

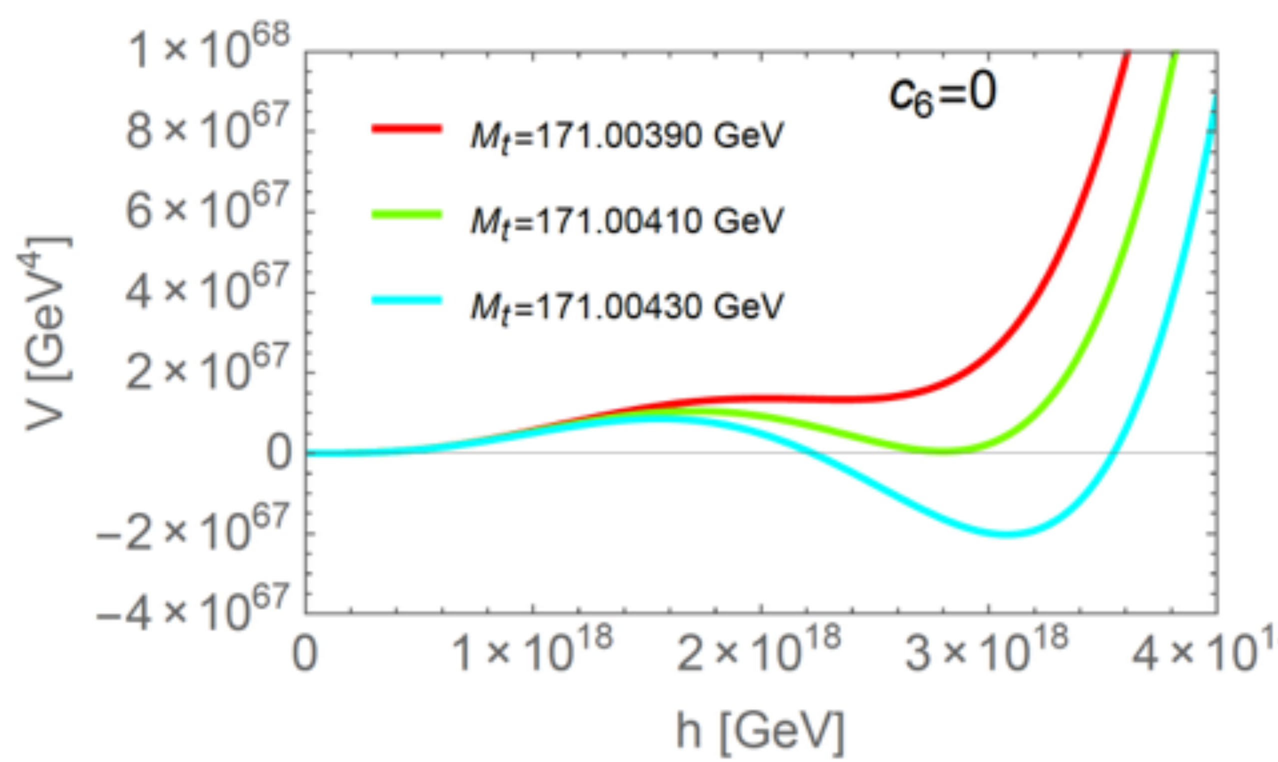
Test1: Higgs potentials

[Degrassi et. al. '12, …]

central value M_t=173GeV & c_6=0,
EW vacuum is metastable.



smaller $M_t \lesssim$ 171GeV,
EW vacuum is absolutely stable.



$\lambda<0$ for h > 10^{10}GeV .

Requiring the degenerate vacua, the predictions on M_H, M_t are obtained.
The correct M_H was predicted 20 years ago. [Froggatt, Nielsen '95]

Test2: S^1 compactification of SM

[Arkani-Hamed, Dubovsky, Nicolis, Villadoro '07]

potential for radion L

$$\frac{L_0^2}{(2\pi L)^2}\left\{\Lambda_4 - \frac{1}{180L^4(2\pi)^4} - \sum_i 2V_{S^1}^{(1)}\left(L, M_{\nu_i}, \frac{1-z}{2}\right)\right\}$$

d.o.f.

γ +graviton: 4

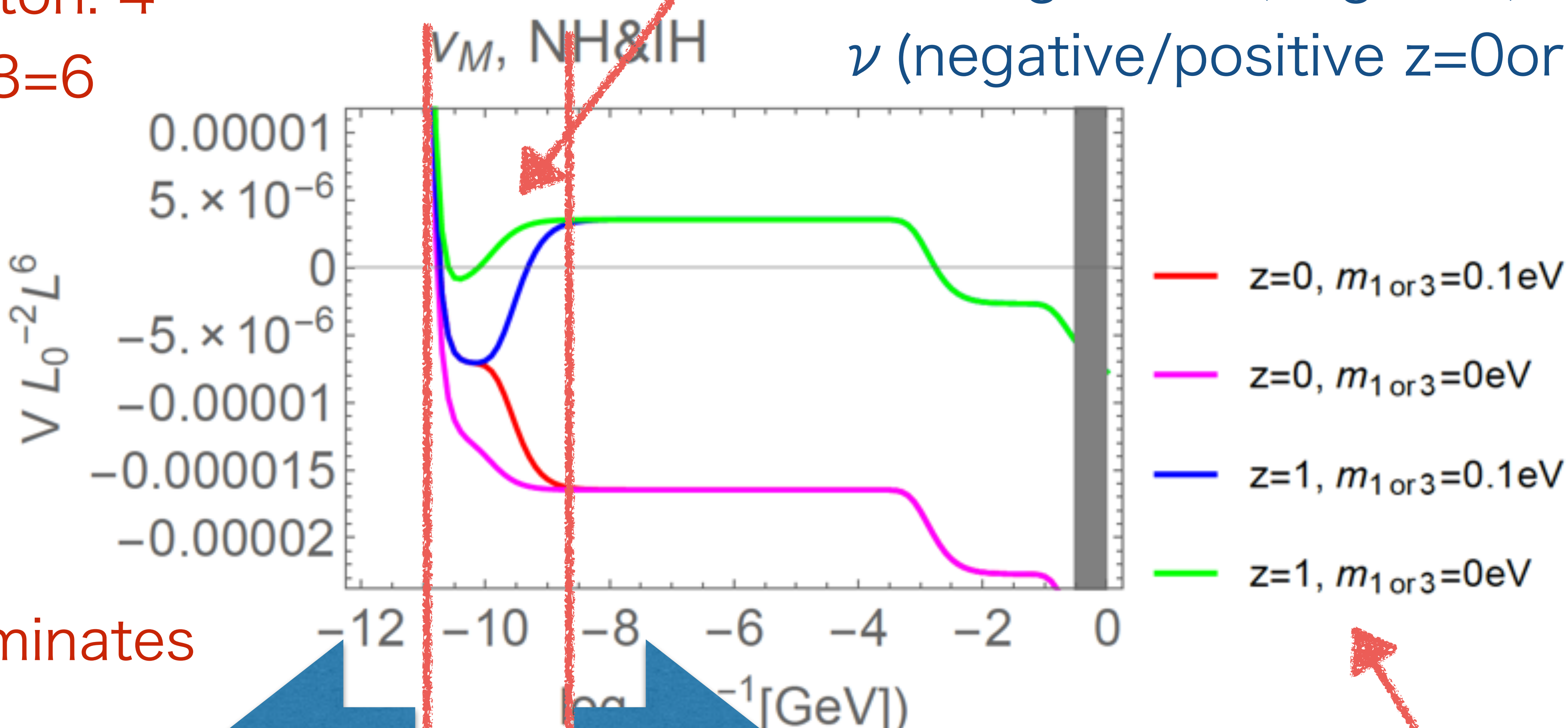
ν: 2×3=6

balance among

Λ4(positive)

γ +graviton(negative)

ν (negative/positive z=0or1)



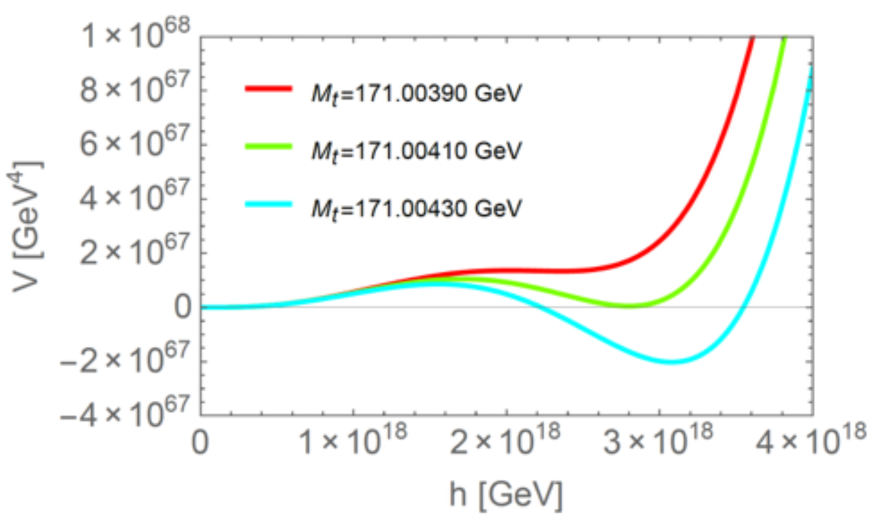
cc dominates

ν dominates

bc & mass of v

Summary

- SM Higgs potential and SM landscape are good place to test various conjectures.



- Multiple Point criticality Principle predicts Neutrino is Dirac, and $m_{\nu,\mathrm{lightest}}$ = O(1-10)meV.

AdS vacuum in SM on S^1

- potential for radion field.

  There is AdS_3 minimum.

bc & mass of ν