(No) Eternal Inflation, and Precision Higgs Physics

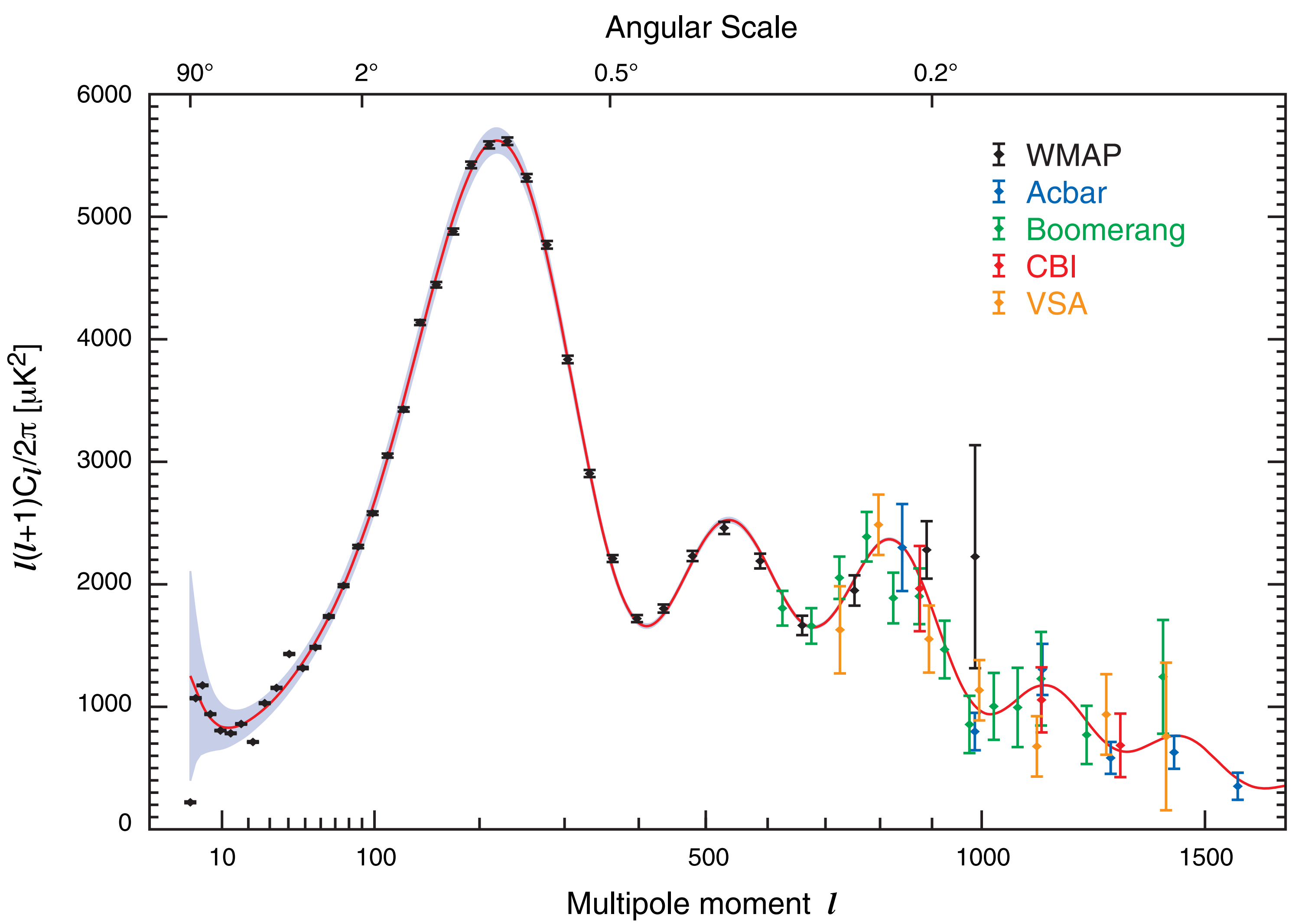
(A possibility to tell about
the destiny of our Universe at the ILC)

N. Arkani-Hamed, S. Dubovsky, L. Senatore, G. Villadoro,
JHEP 0803:075, 2008

Outline

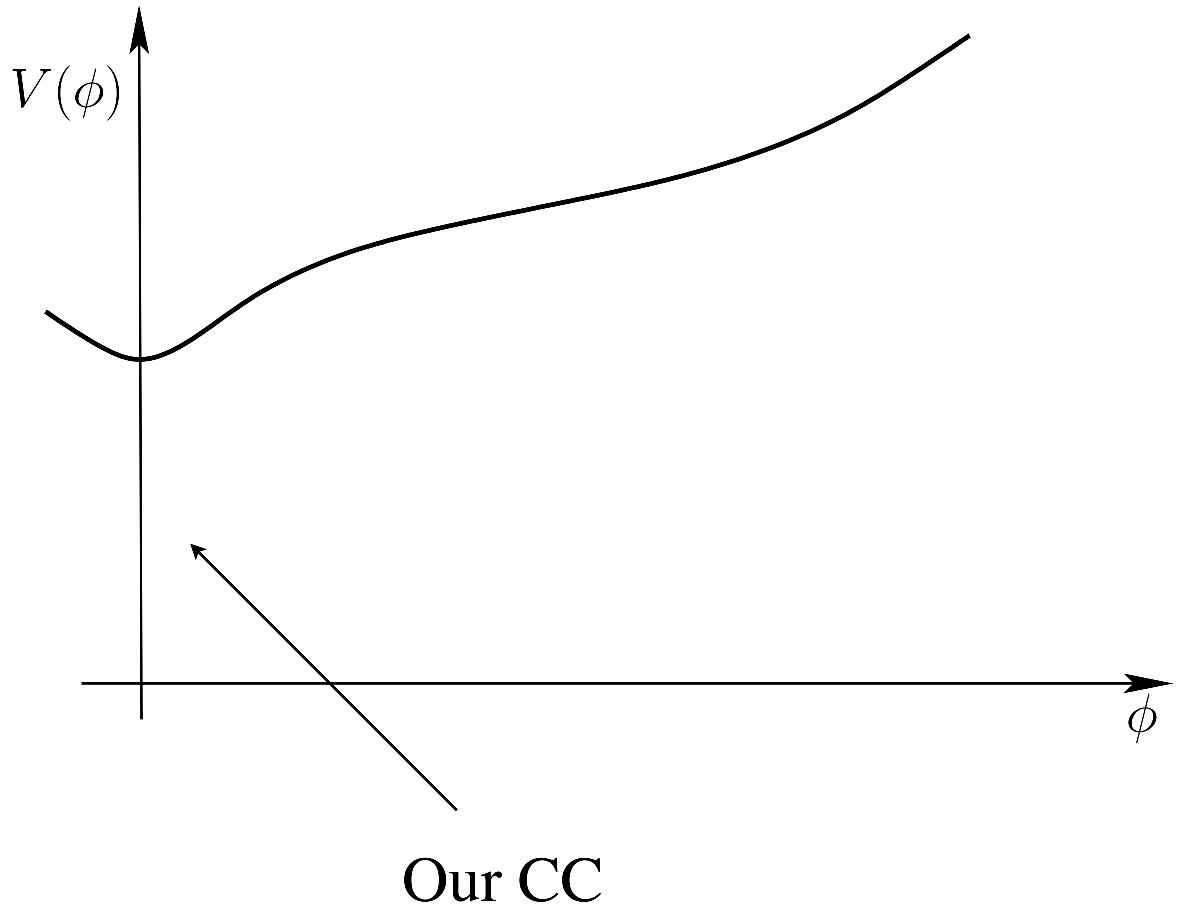
- The Universe is Accelerating (Inflating)
- Probably due to the Energy of our Vacuum
- For light Higgs our vacuum can be unstable
- Depending on the mass
  - The Phase of Acceleration will terminate
  - The Phase of Acceleration will last forever
- We have chances to discover this at ILC with precision measurements

From Cosmology:



- The universe is accelerating $a \sim e^{Ht}$
- ~ it seems there is a small Vacuum Energy (this is a remarkable discovery)

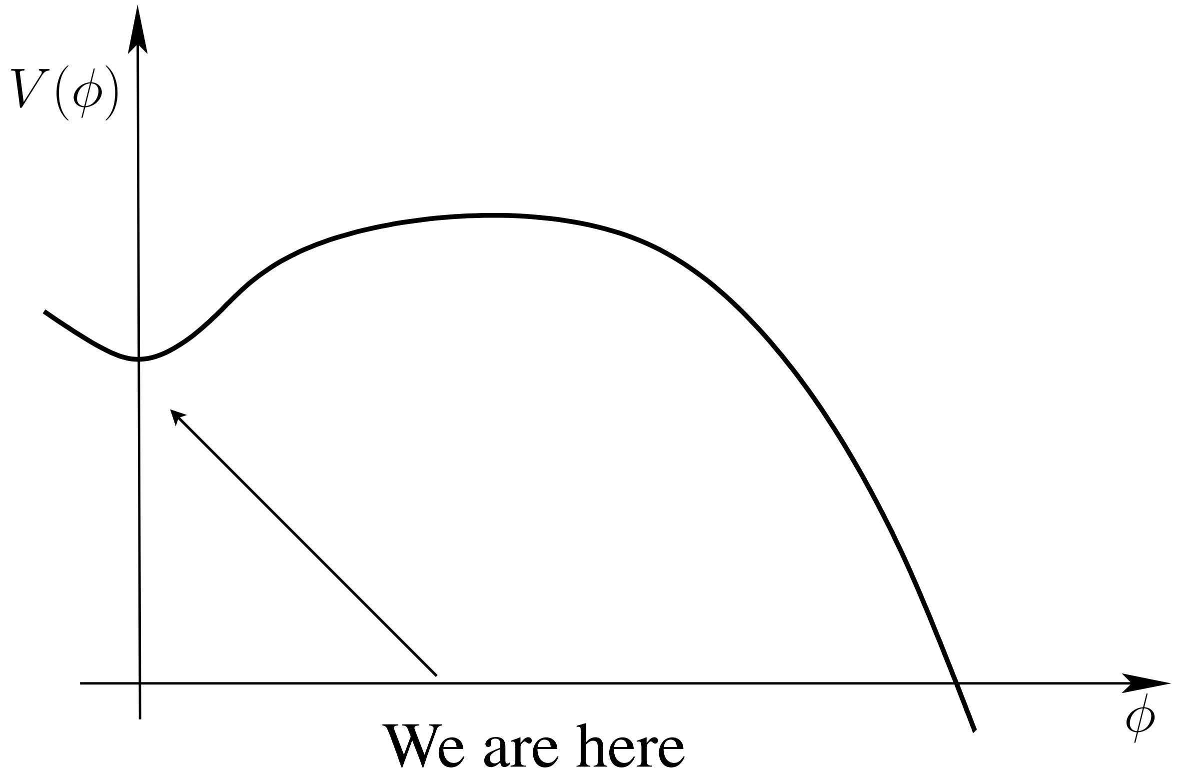
The Potential for Every Scalar has a Non-Zero Energy Minimum



Absolute (stable) vacuum

$$a \sim e^{Ht}$$

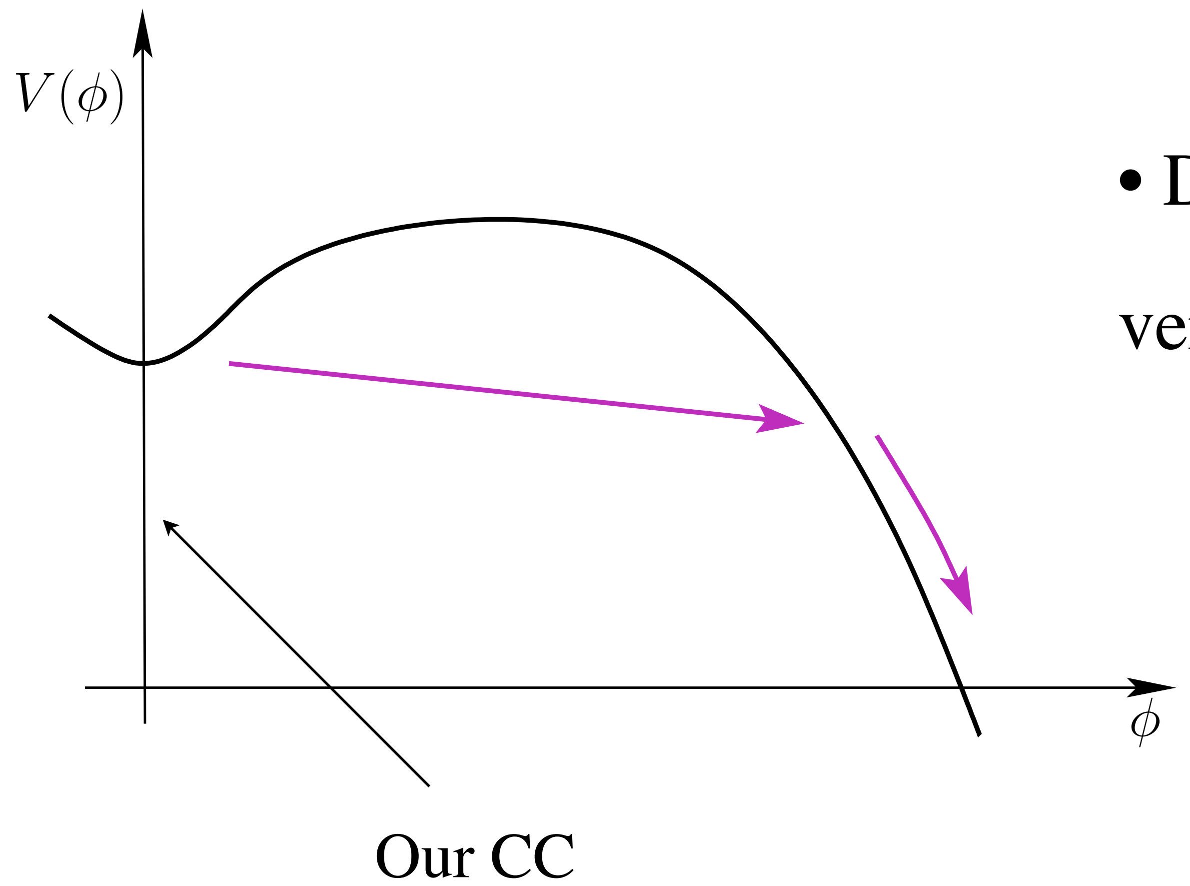
$$H \sim V(\phi_{\text{min}})^{1/2}$$



More likely: no stable positive energy minimum

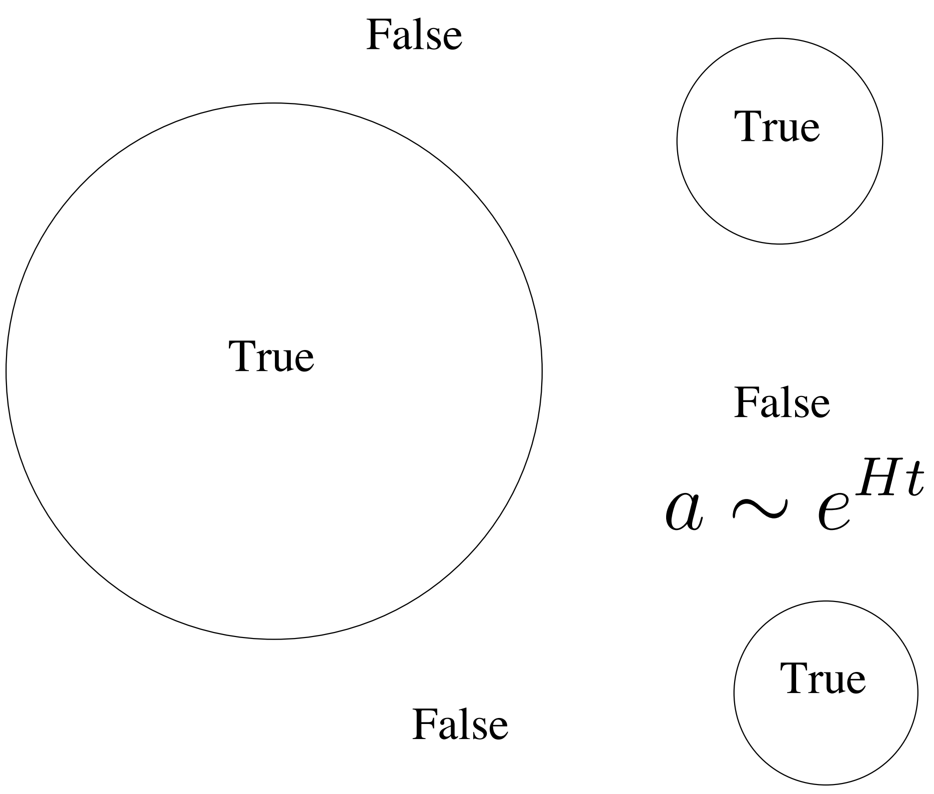
$\Rightarrow$ False (unstable) vacuum

Quantum Mechanical Instability



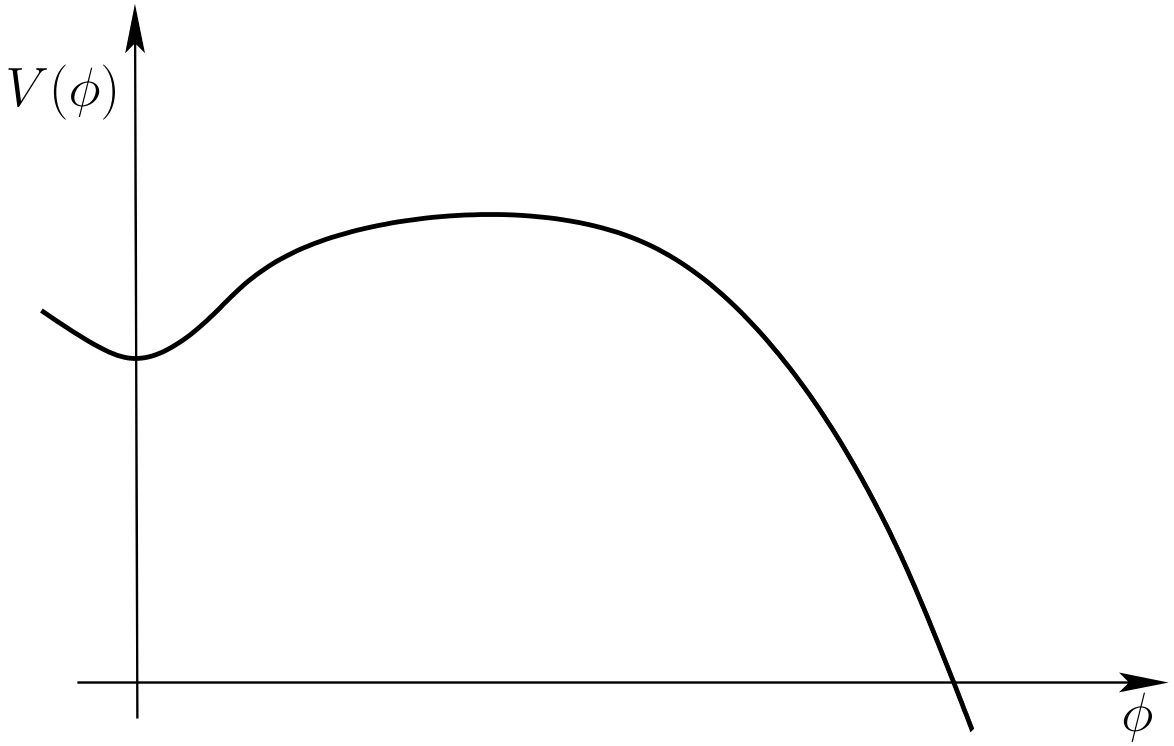
• Decay rate per unit time and unit volume is very small $\Gamma \sim e^{-\frac{1}{|\lambda|}}$

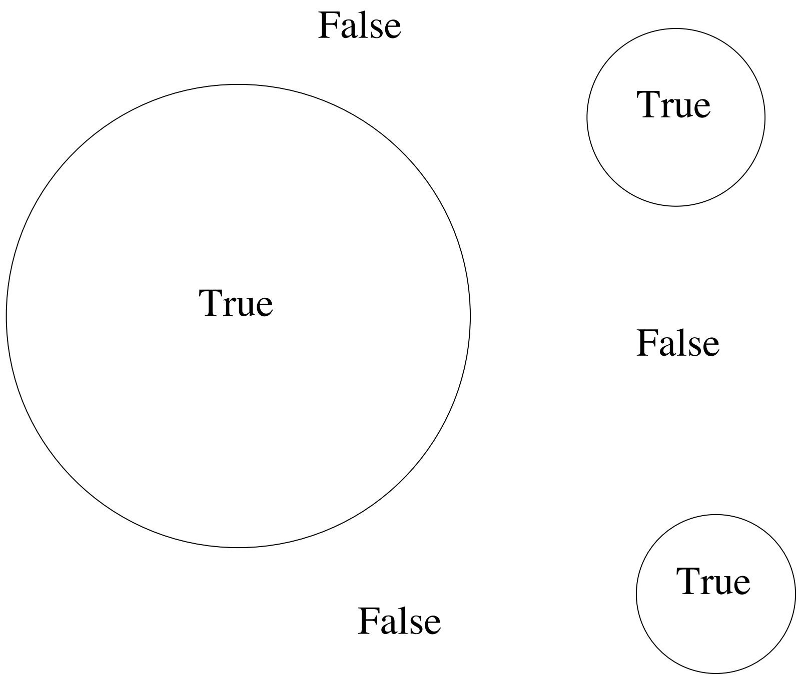
• Every decay produces a true-vacuum bubble that expands in a false-vacuum expanding see



Coleman **PRD 15, 1977**
Callan and Coleman **PRD 16, 1977**

Two Qualitative Regimes and a Phase Transition





- Decay rate: $\Gamma \sim e^{-\frac{1}{|\lambda|}}$

- Small Decay Rate: expansion of false vacuum wins over expansion of bubbles:

Bubble do not meet $\Longrightarrow$ Eternal Expansion (Eternal Inflation)

- Large Decay Rate: bubble production is so fast that they eat all the false vacuum

The acceleration ceases.

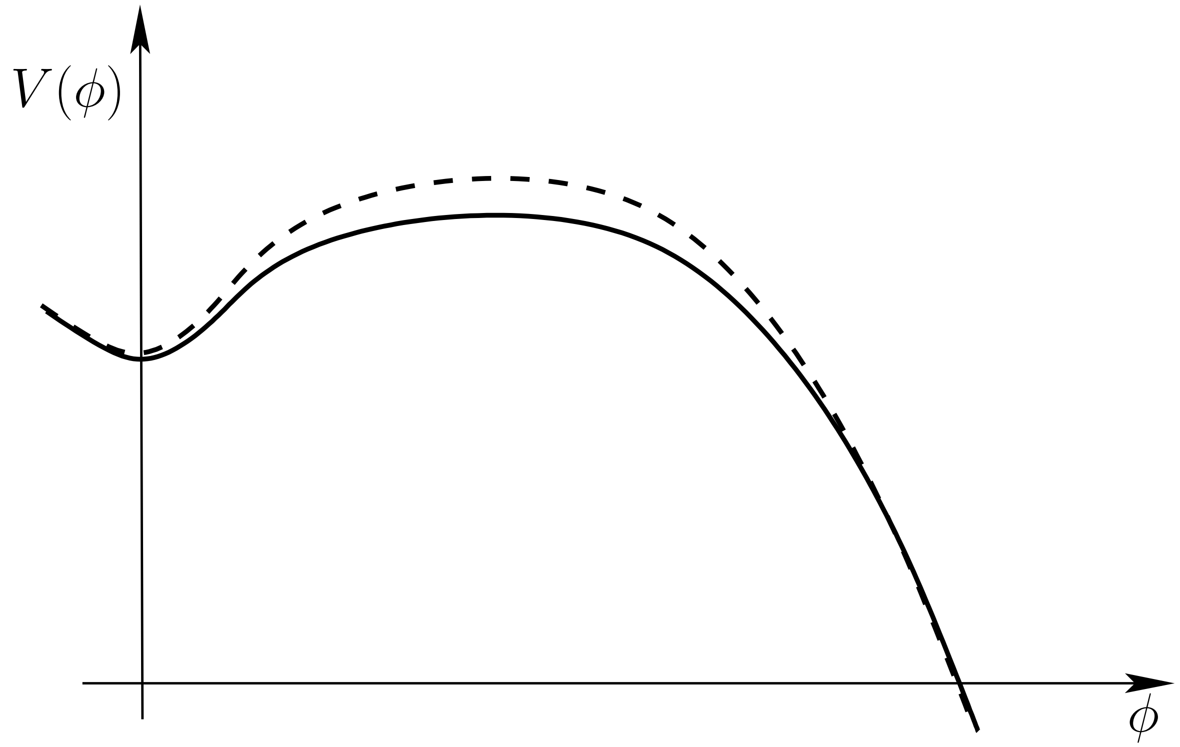
- The distinction is sharp (A Phase Transition)

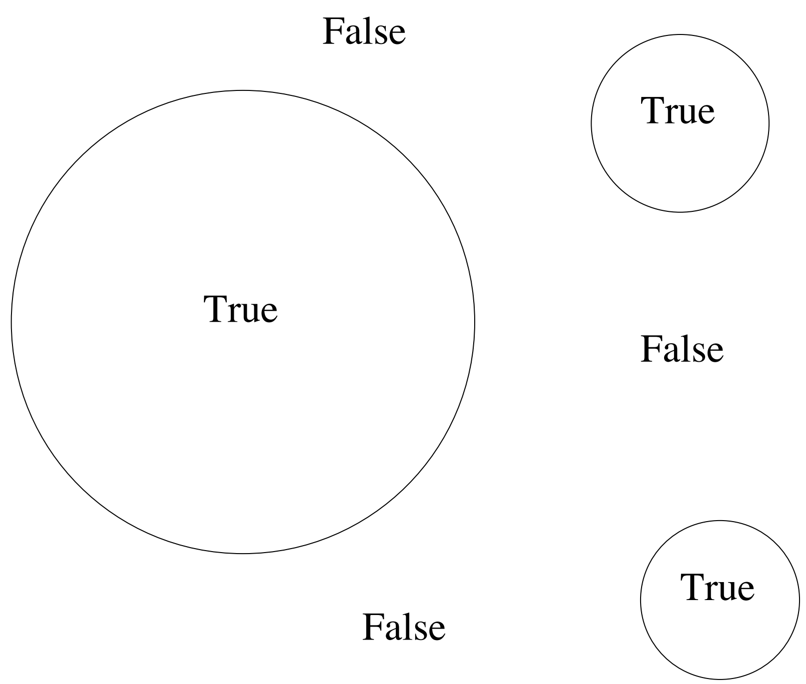
$$V_{\text{infl}} = V_0\, e^{3H_\Lambda t} e^{-\Gamma\, \widehat{\text{Vol}}_4(t)} \quad \Longrightarrow \quad \Gamma / H_\Lambda^4 < 9/4\pi \qquad \text{Sharp!}$$

$$\widehat{\text{Vol}}_4 \sim t/H_\Lambda^3$$

A. Guth and E. J. Weinberg
Nucl. Phys. B 212 (1983)

Two Qualitative Regimes and a Phase Transition





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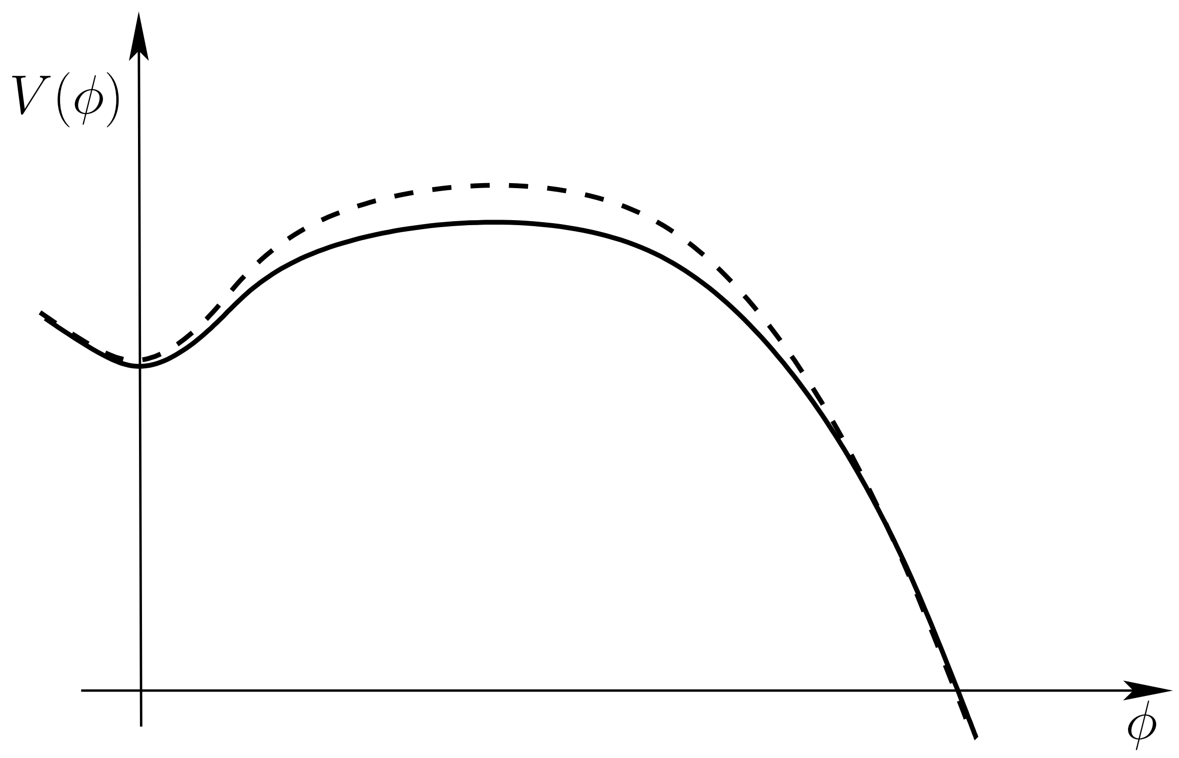
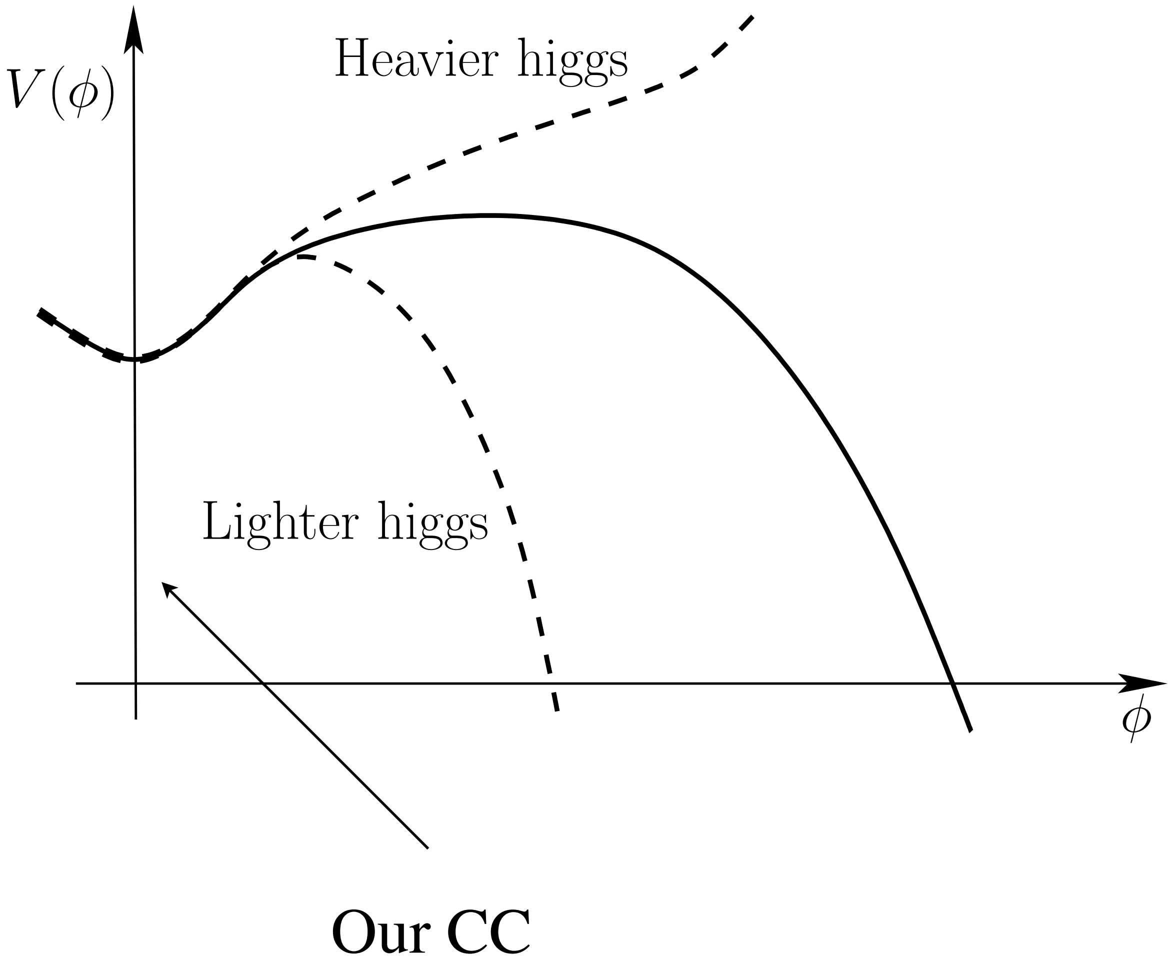
This applies to the potential of all the scalar fields we have:
it applies to the Higgs potential

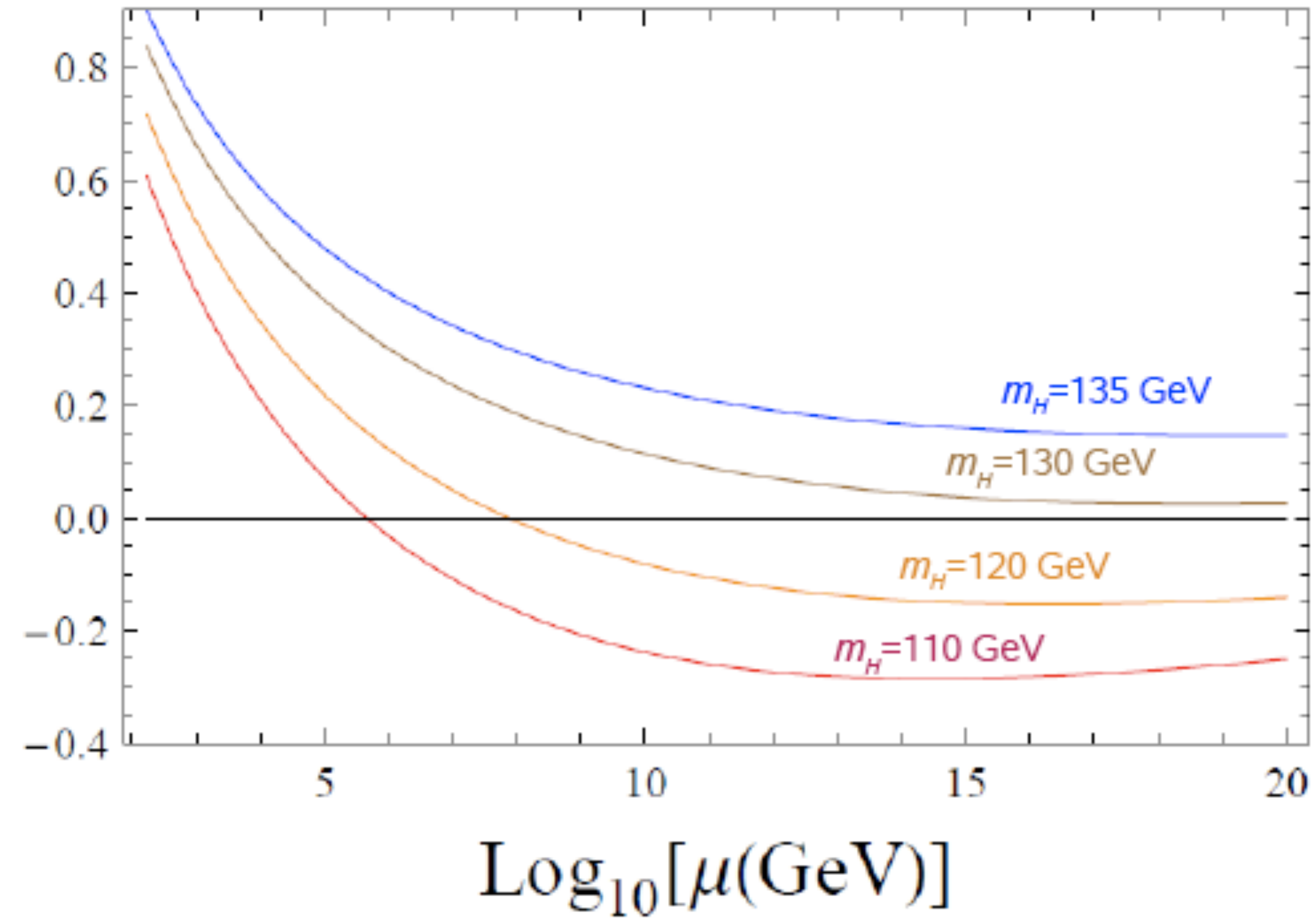


Metastability of the Standard Model

If SM holds up to some very high energy:

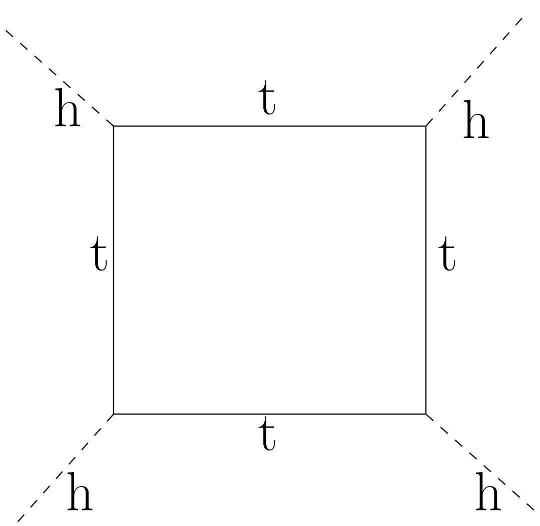
A light higgs $\Longrightarrow$ metastability of SM $\quad \Gamma \sim e^{-\frac{1}{|\lambda|}}$ $\qquad m_h \sim \lambda(v)^{1/2} v$



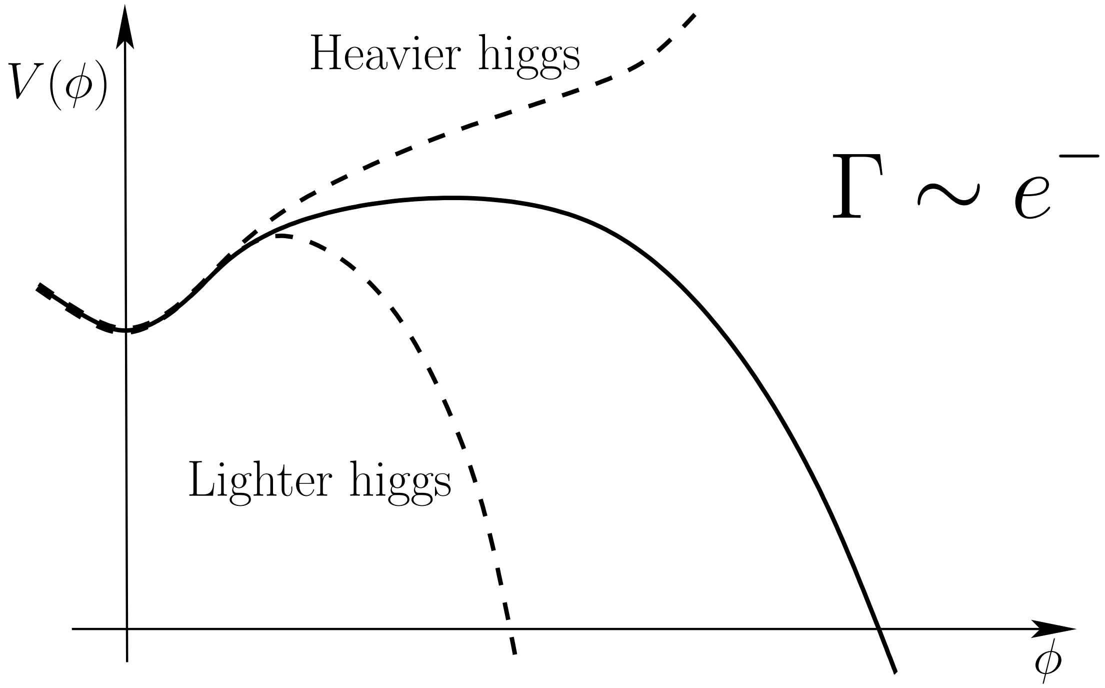


The Renormalization group running drives the quartic coupling negative

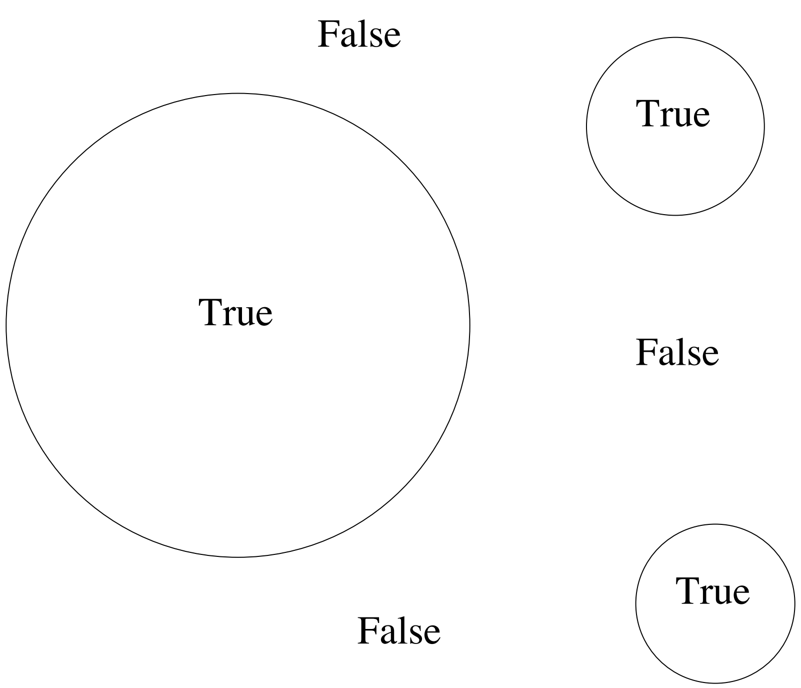
$$V(\phi) \sim m^2\phi^2 + \lambda(\phi)\phi^4$$



A Particle Physics Signature



$$\Gamma \sim e^{-\frac{1}{|\lambda|}}$$



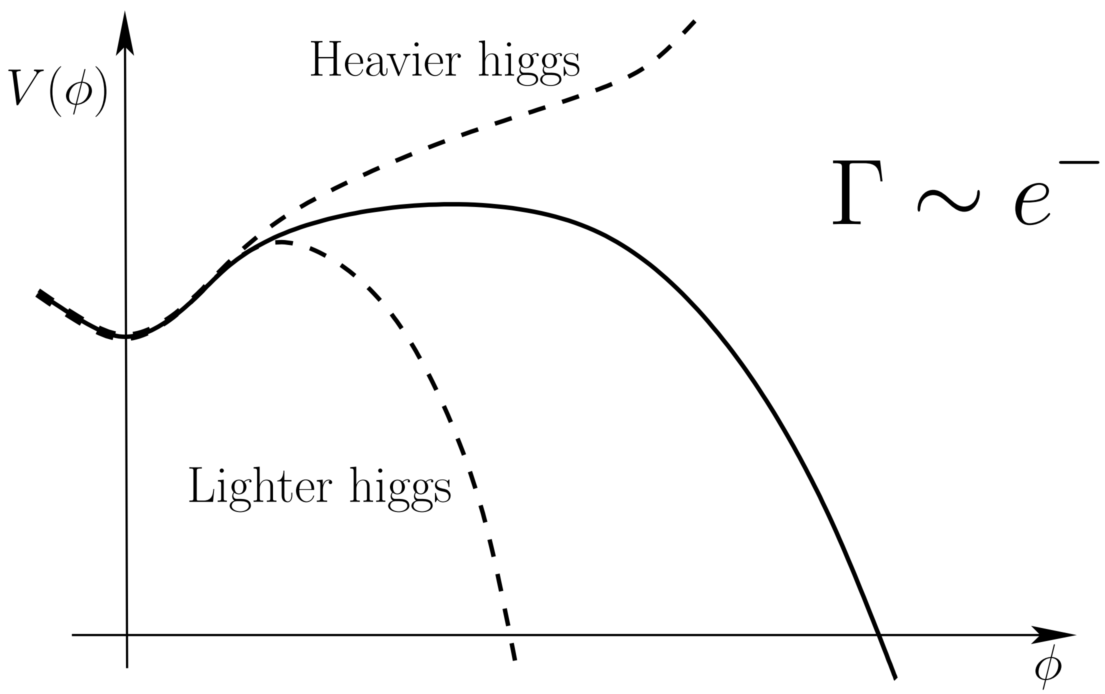
- No eternally inflating $\Longleftrightarrow$ $\Gamma/H_\Lambda^4 > 9/(4\pi)$: the standard model channel is fast enough if:

$$m_H(\text{GeV}) < 110.7 + 4.1\frac{m_t(\text{GeV}) - 173.1}{1.3} - 2.5\frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\text{th}}$$

This is a sharp number.

- Errors come from the running for many energy scales:
  - m_t from Tevatron
  - α_s from PDG
- Assumption: Standard Model holds up to high energies (10^{16} GeV)

But we should not have already decayed



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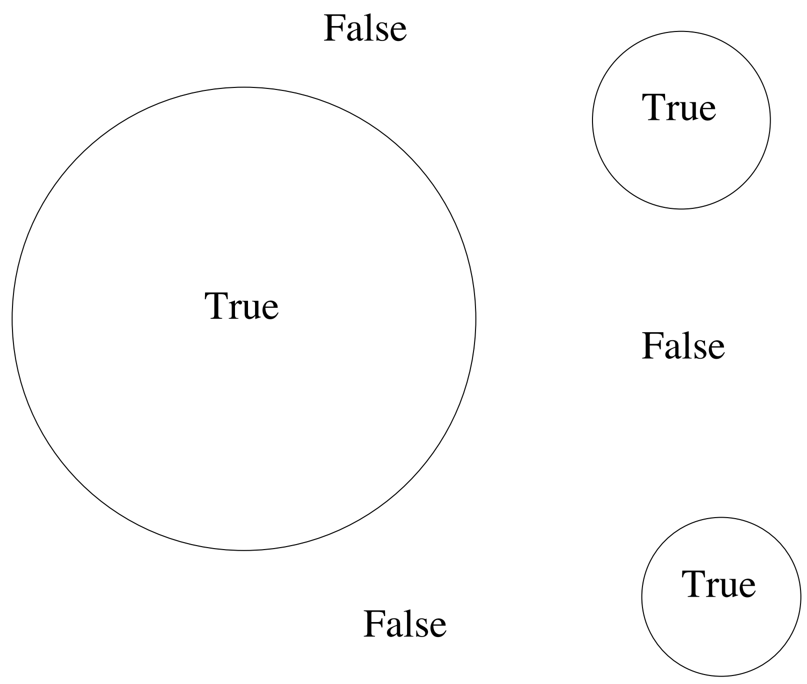


- Requirement that we have not yet decayed (at 95% C.L.)

$$m_H(\mathrm{GeV}) > 110.5 + 4.1\frac{m_t(\mathrm{GeV}) - 173.1}{1.3} - 2.5\frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\mathrm{th}}$$

This is a not-sharp but reasonable number.

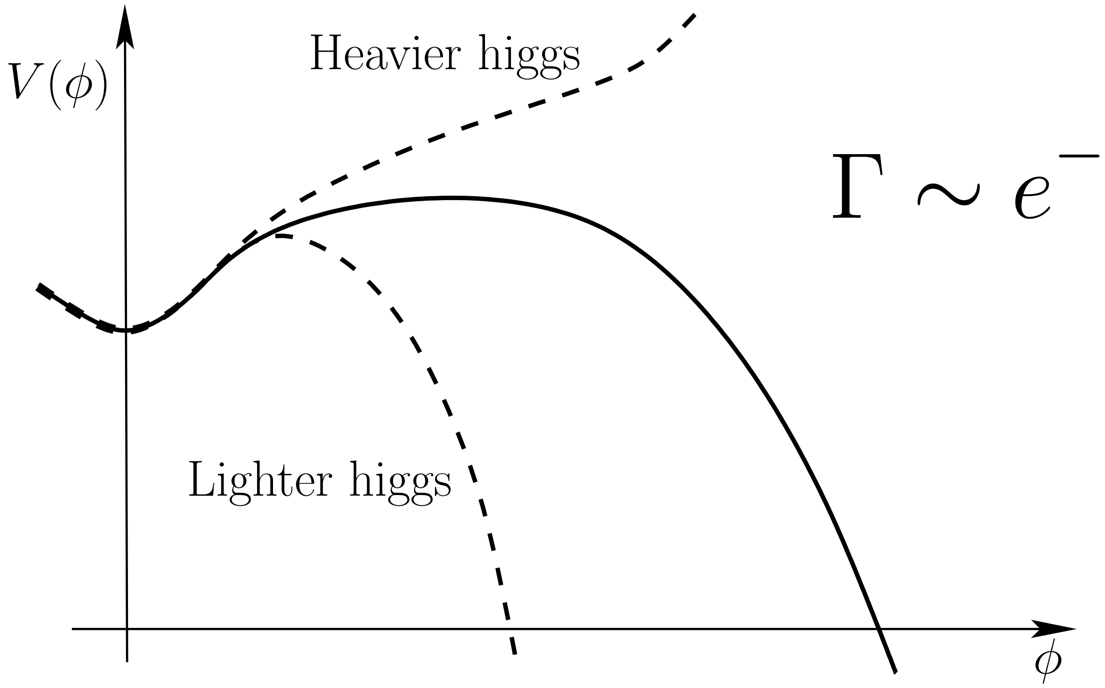
Kransikov, Maiani, Cabibbo, Parisi, Petronzio, Hung, Linde, Sher, Altarelli, Isidori, Strumia, Casas, Ispinosa, Quiros,...., Giudice, Riotto.... (**‘78-’08**)

- No eternally inflating:

$$m_H(\mathrm{GeV}) < 110.7 + 4.1\frac{m_t(\mathrm{GeV}) - 173.1}{1.3} - 2.5\frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\mathrm{th}}$$

- A tiny window!: $\Delta m_H \sim 0.2\ \mathrm{GeV}$

A tiny window



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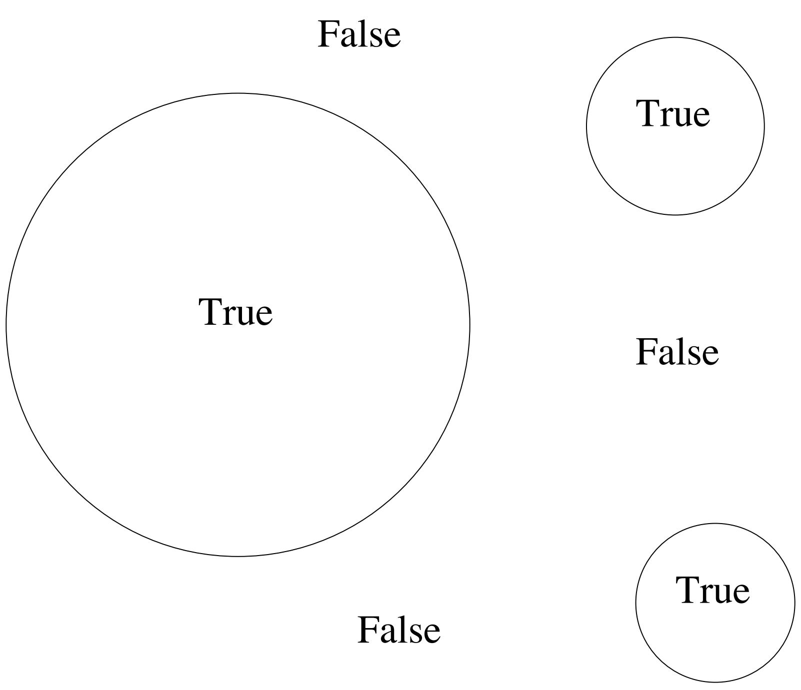
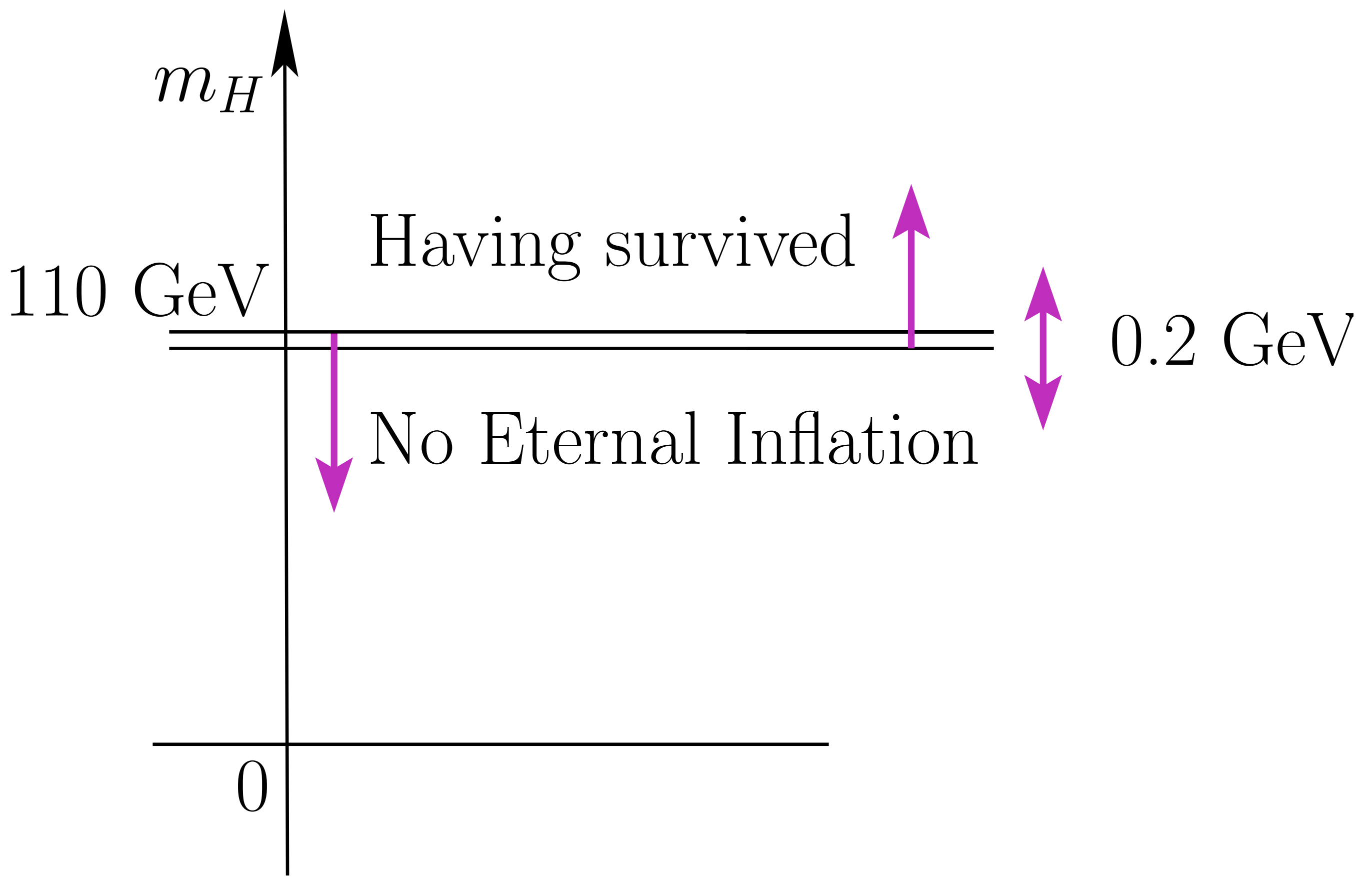




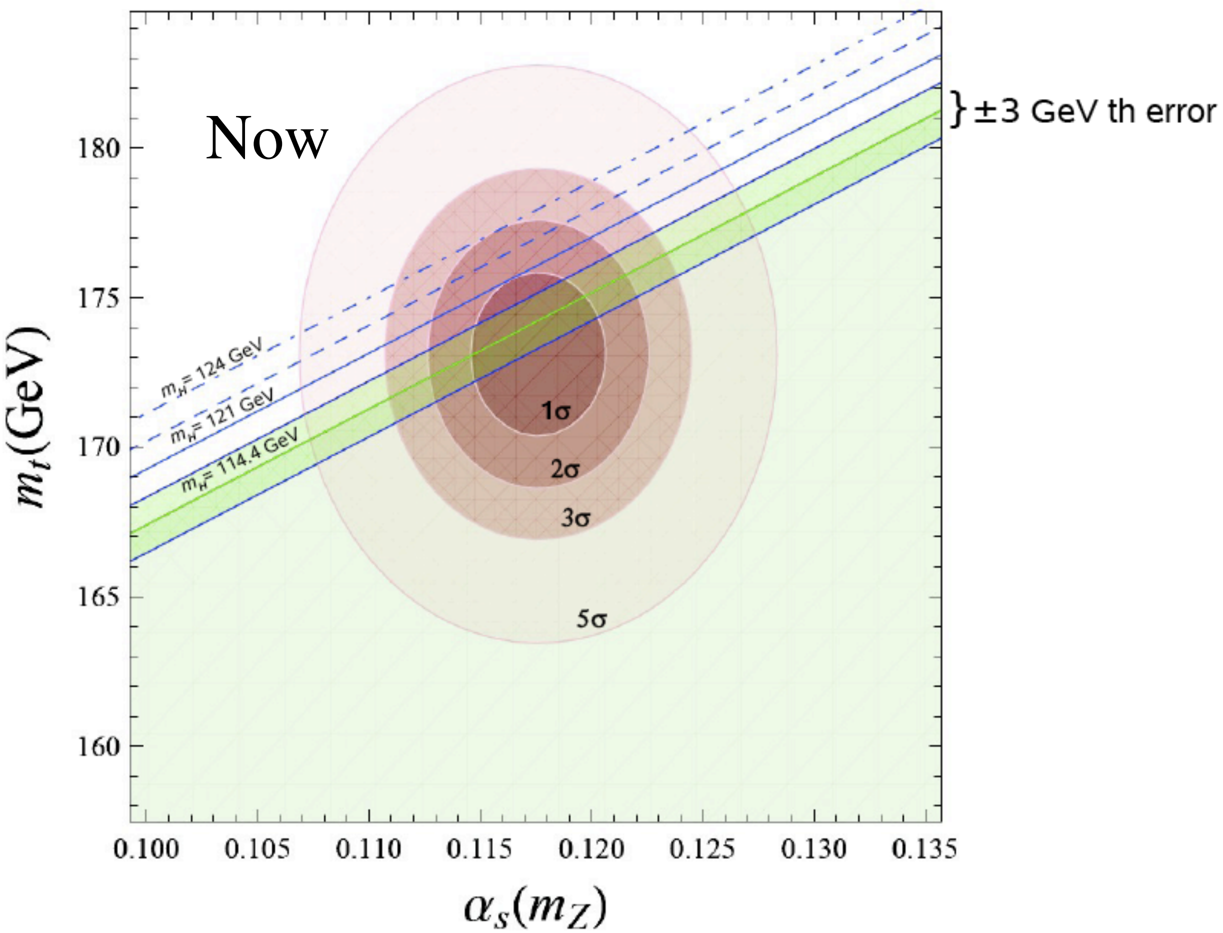
- Window small: $\Gamma \sim H \sim H_\Lambda$
- If we find only the higgs at LHC, and
- and we find it to be in this tiny window,
- $\Longrightarrow$ believe the assumption of SM up to high energies
- Learn about destiny of our Universe
- Learn about Quantum Gravity

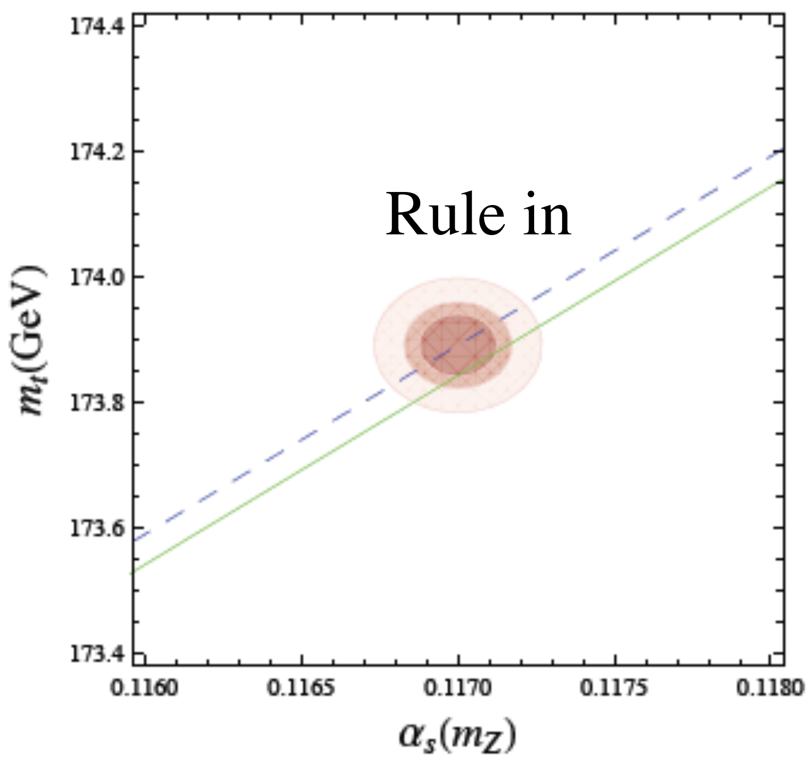
(scenario theoretically motivated)

Can we do it? Yes we can

- Now: $m_H(\text{GeV}) < 110.7 + 4.1\frac{m_t(\text{GeV}) - 173.1}{1.3} - 2.5\frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\text{th}}$
- After LHC:

$$m_t(\text{GeV}) > 174.4 + 0.3 \times (m_H(\text{GeV}) - 115) + 0.8 \times \frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 1_{\text{th}}$$

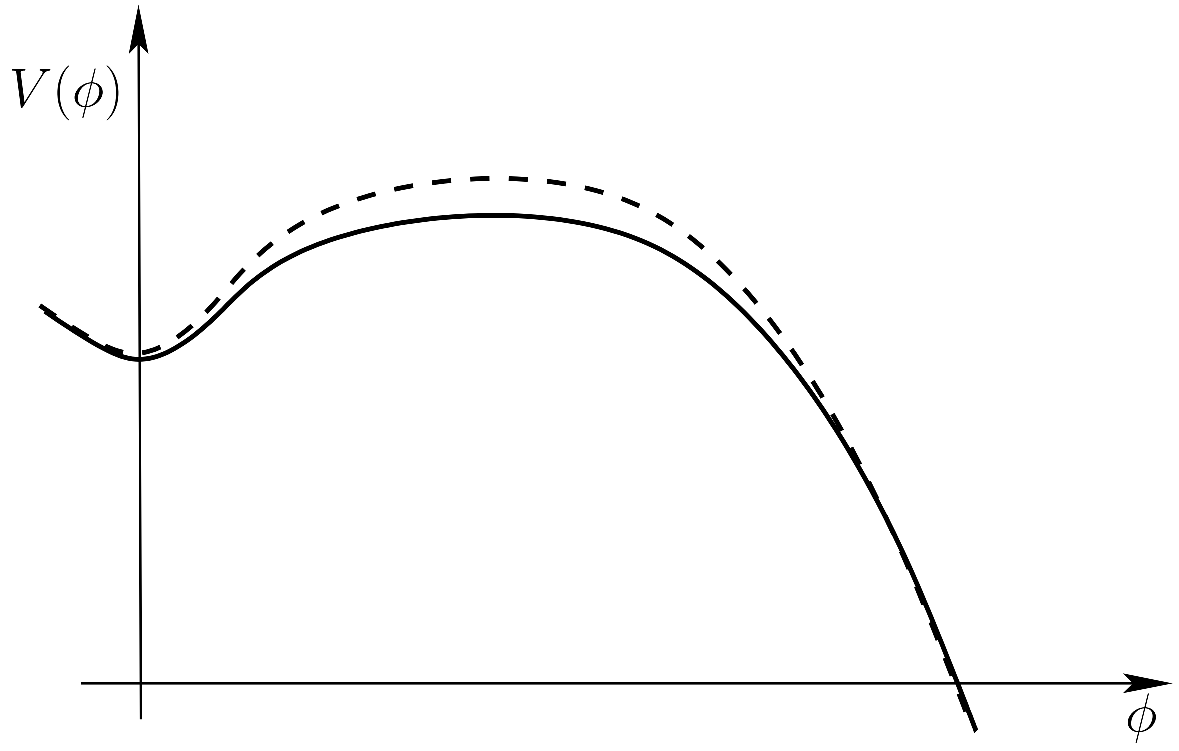




- Theory:
  - Now: $\mathcal{O}(\alpha_s^3)$ $\mathcal{O}(\alpha_W^2)$
  - Need: $\mathcal{O}(\alpha_s^5), \mathcal{O}(\alpha_w^3)$
- Experiment:
  - Now: $\Delta m_h \lesssim ?$, $\Delta m_t \lesssim 1.4$ GeV, $\frac{\Delta\alpha_s}{\alpha_s} \lesssim 1.7\%$
  - Need: $\Delta m_h \lesssim 100$ MeV, $\Delta m_t \lesssim 70$ MeV, $\frac{\Delta\alpha_s}{\alpha_s} \lesssim 0.14\%$

LHC ↗ ILC ↗ Lattice ILC, LHC? ↑

All of this was assuming
we find only the Higgs at LHC.
What if, if we find SUSY?



Metastability of SUSY vacua

• Depending on the size of the soft terms, there are MSSM vacua with energy lower than our vacuum

Kusnko, Langacher, Segre
PRD 54, 2996

$$3 \lesssim \frac{A_t^2 + 3\mu^2}{m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2} \lesssim 7.5 \quad \Longrightarrow$$

Stability

Survival limit

No Eternal Inflation condition:

$$A_t^2 + 3\mu^2 \simeq 7.5 \left(m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 \right)$$

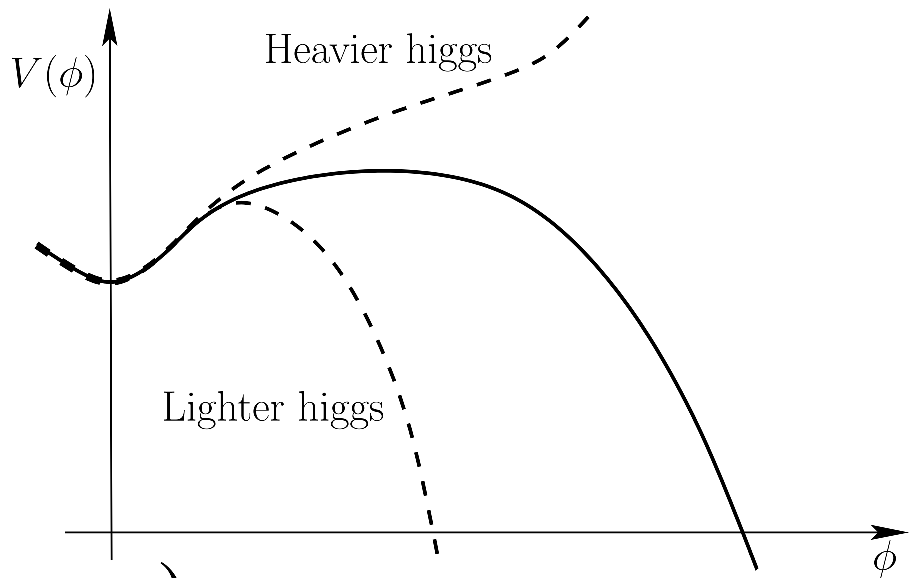
• Good: everything at the TeV scale: no need to assume anything about high energy physics

• Good: can get some evidences from LHC

• ~Bad: couplings are difficult to measure

Conclusions

- Even in the 'nightmare scenario' with only the Higgs at LHC
  - Sharp Phase Transition to Eternal Inflation $\Longrightarrow$
    - A sharp value of the Higgs mass

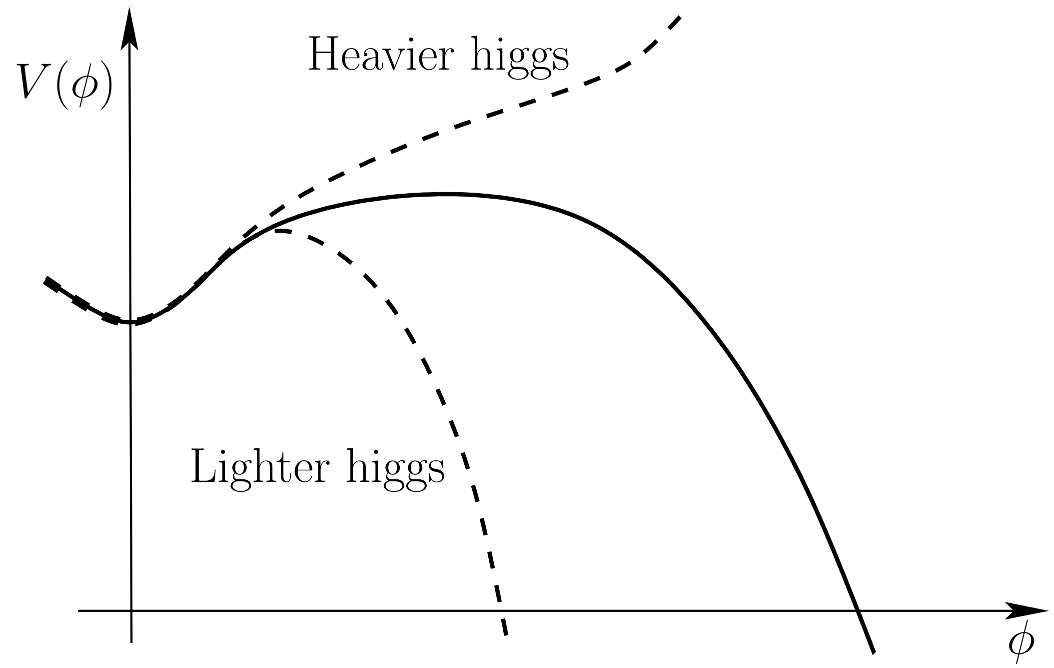


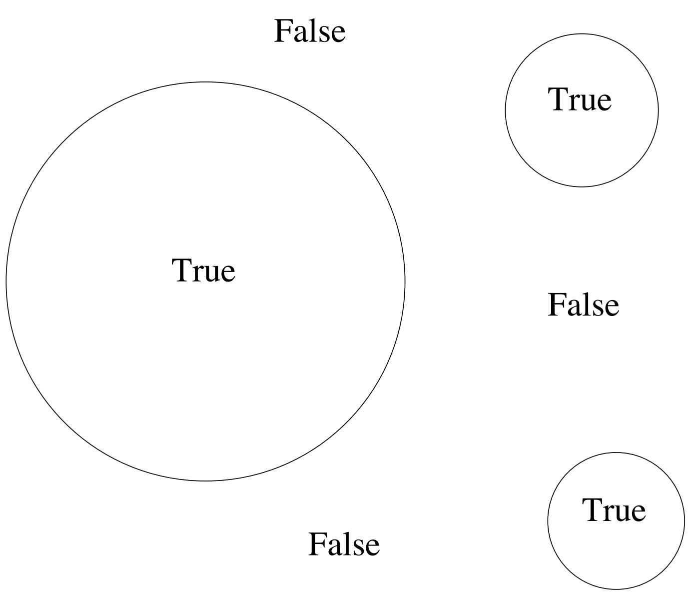
- If verified:
    - Learn about our Future (and that we will decay soon)
    - Learn about Eternal Inflation and Quantum Gravity

At ILC!

- Possibilities even with Physics BSM

A “No Eternal Inflation” Principle?





If (~ and only if) LHC verifies this scenario:

- No dS Space with Gravity
  - Quantum Gravity $\Longrightarrow$ No local Observables: S matrix $\Longrightarrow$ No dS space
  - With GR: Coleman de-Luccia minimum rate $e^{-S_{\rm dS}}$ $\Longrightarrow$ Metastable Minimum
- $\Longrightarrow$ dS only Metastable
  - Naively Truly Metastable dS is ok with S-matrix
  - Problem with S-matrix with Eternal
- $\Longrightarrow$ A “No Eternal Inflation” principle