

Revisiting Affleck-Dine Leptogenesis with light sleptons

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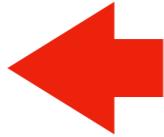
Based on JCAP 07 (2023) 003 [hep-ph 2304.05614]
Kazuki Enomoto, Koichi Hamaguchi, Kohei Kamada, and JW

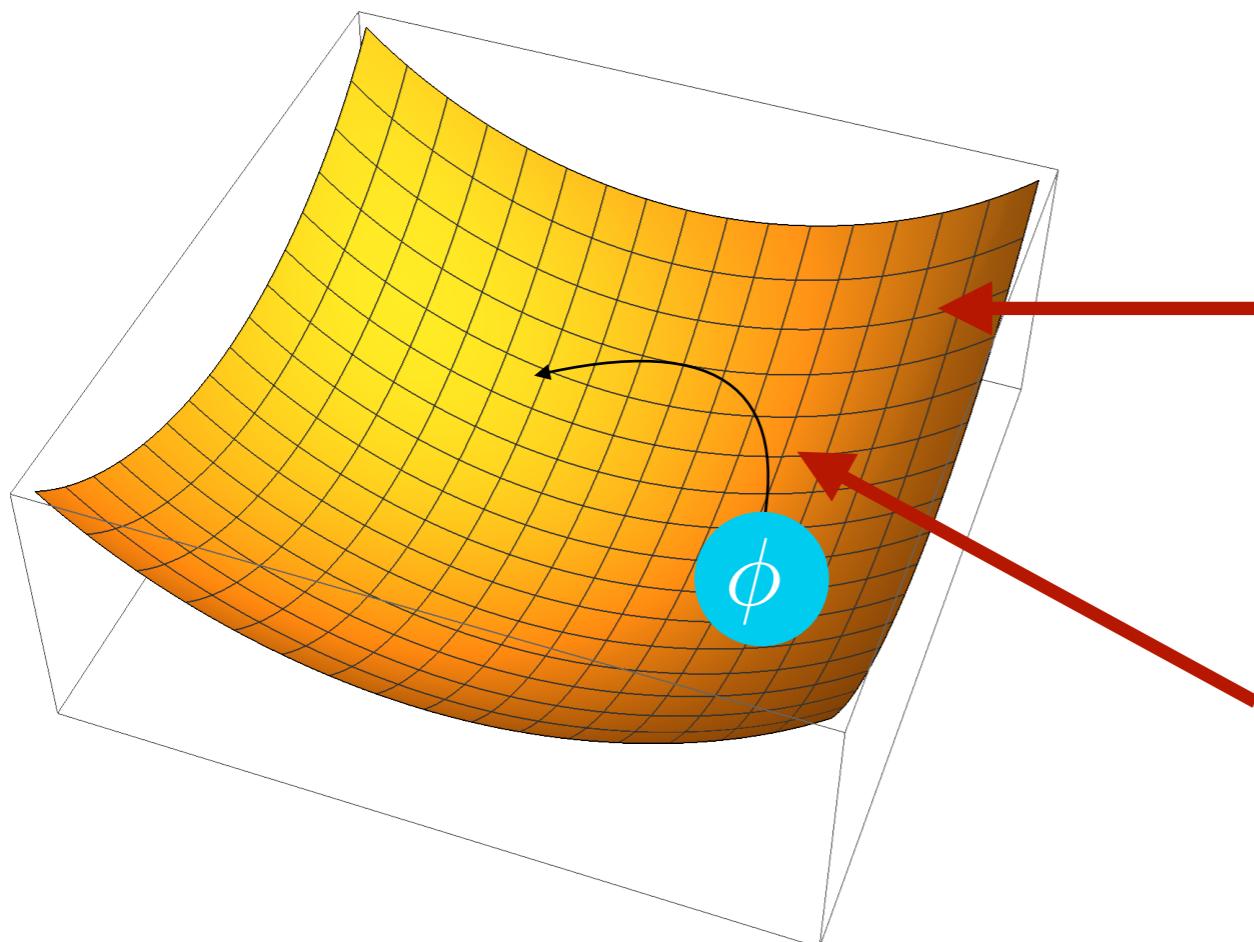
Affleck-Dine Leptogenesis

I. Affleck and M. Dine, Nucl. Phys. B **249**, 361 (1985).

H. Murayama and T. Yanagida, Phys.Lett.B **322**, 349-354 (1994)

M. Dine, L. Randall and S. D. Thomas, Nucl. Phys. B **458**, 291 (1996).

ϕ : Complex scalar field
(which has L number)  e.g. Slepton & Higgs



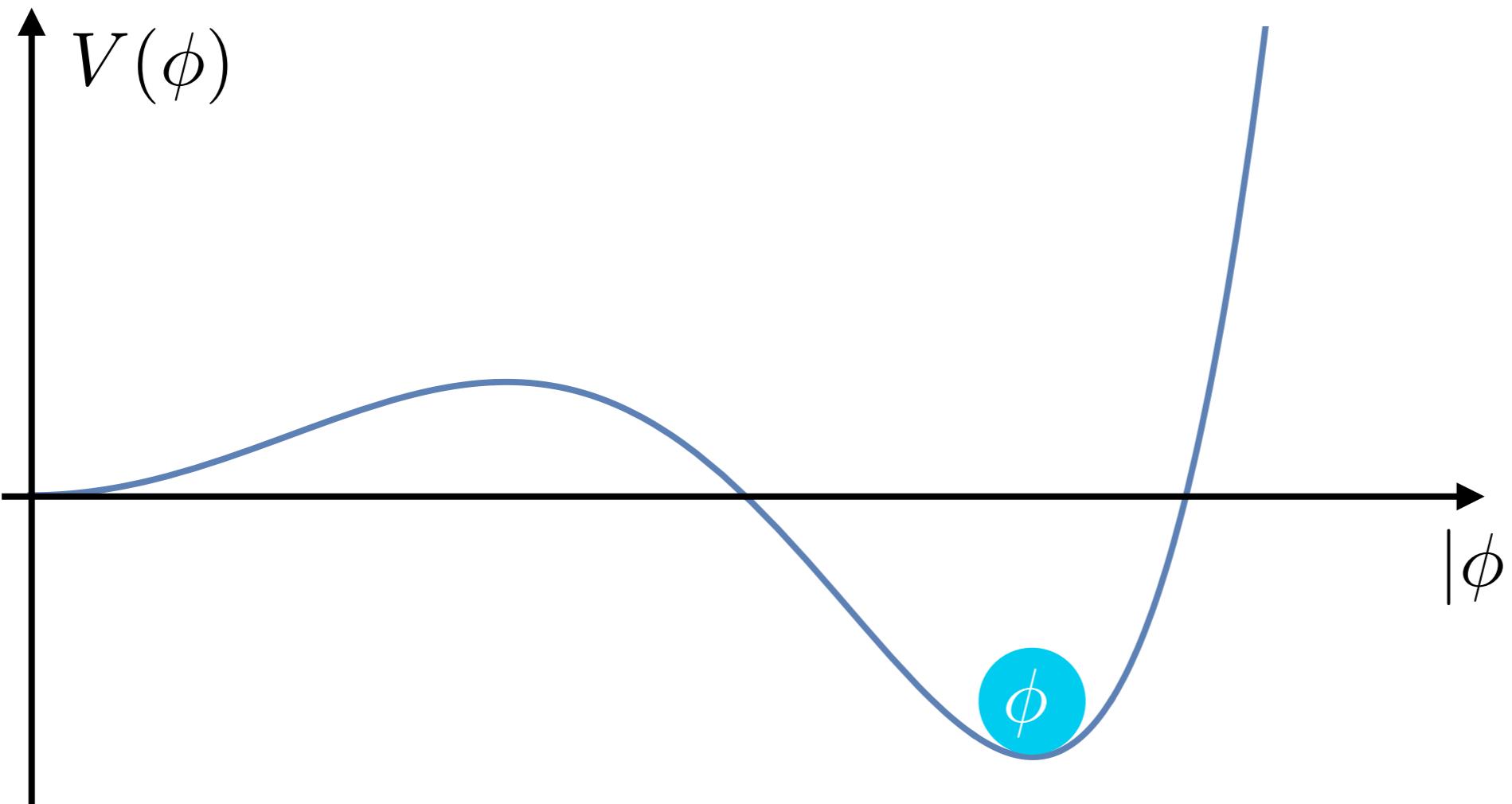
Sakharov's 3 conditions

A.D. Sakharov, Ah. Eksp. Teor. Piz. Pis'ma **5**, 32 (1967)

\cancel{C}, \cancel{CP}
 $B - L$ violation

Out of equilibrium

Problem in ADLG



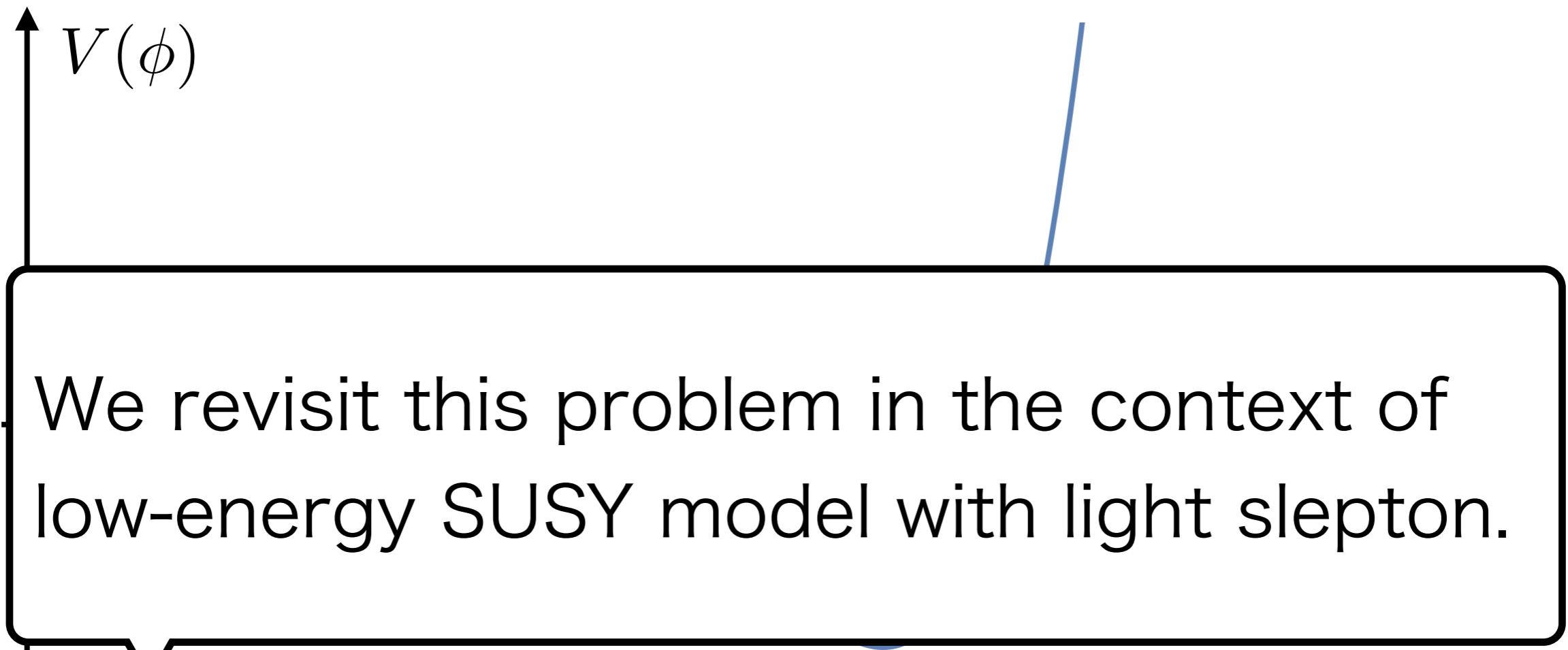
If $m_L \ll m_{3/2}$, the potential has an unwanted vacuum which may spoil ADLG scenario.

This problem has been discussed in AMSB model.

M. Kawasaki, T. Watari, and T. Yanagida, Phys.Rev.D 63 083510 (2001)

M. Kawasaki and K. Nakayama JCAP 02 002 (2007)

Problem in ADLG



If $m_L \ll m_{3/2}$, the potential has an unwanted vacuum which may spoil ADLG scenario.

This problem has been discussed in AMSB model.

Outline

- ✓ Introduction
- ▶ Light slepton mass in ADLG
- ▶ CBV problem
- ▶ Summary

Why slepton?

- ▶ LH_u flat direction

H. Murayama and T. Yanagida, Phys.Lett.B 322 349-354 (1994)

$$\tilde{L} = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi \\ 0 \end{pmatrix}, \quad H_u = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \phi \end{pmatrix}.$$

ϕ : Complex scalar field which has L number

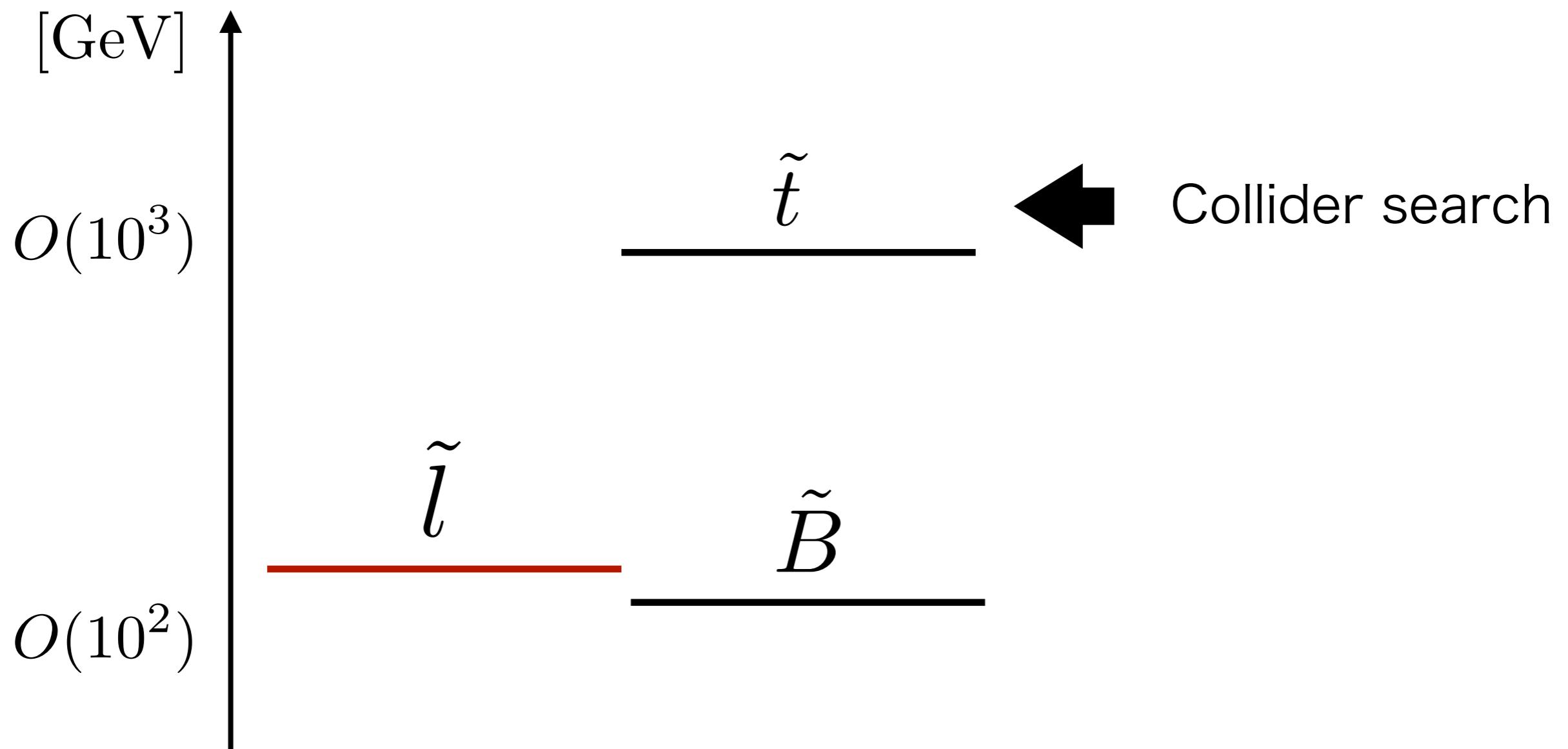
- ▶ Weinberg operator

$$W = \frac{1}{2M} (LH_u)^2 = \frac{1}{8M} \phi^4$$

→ $m_\nu = \frac{v_u^2}{M} \simeq 3 \times 10^{-9} \text{eV} \times \left(\frac{M}{10^{22} \text{GeV}} \right)^{-1} \sin^2 \beta$

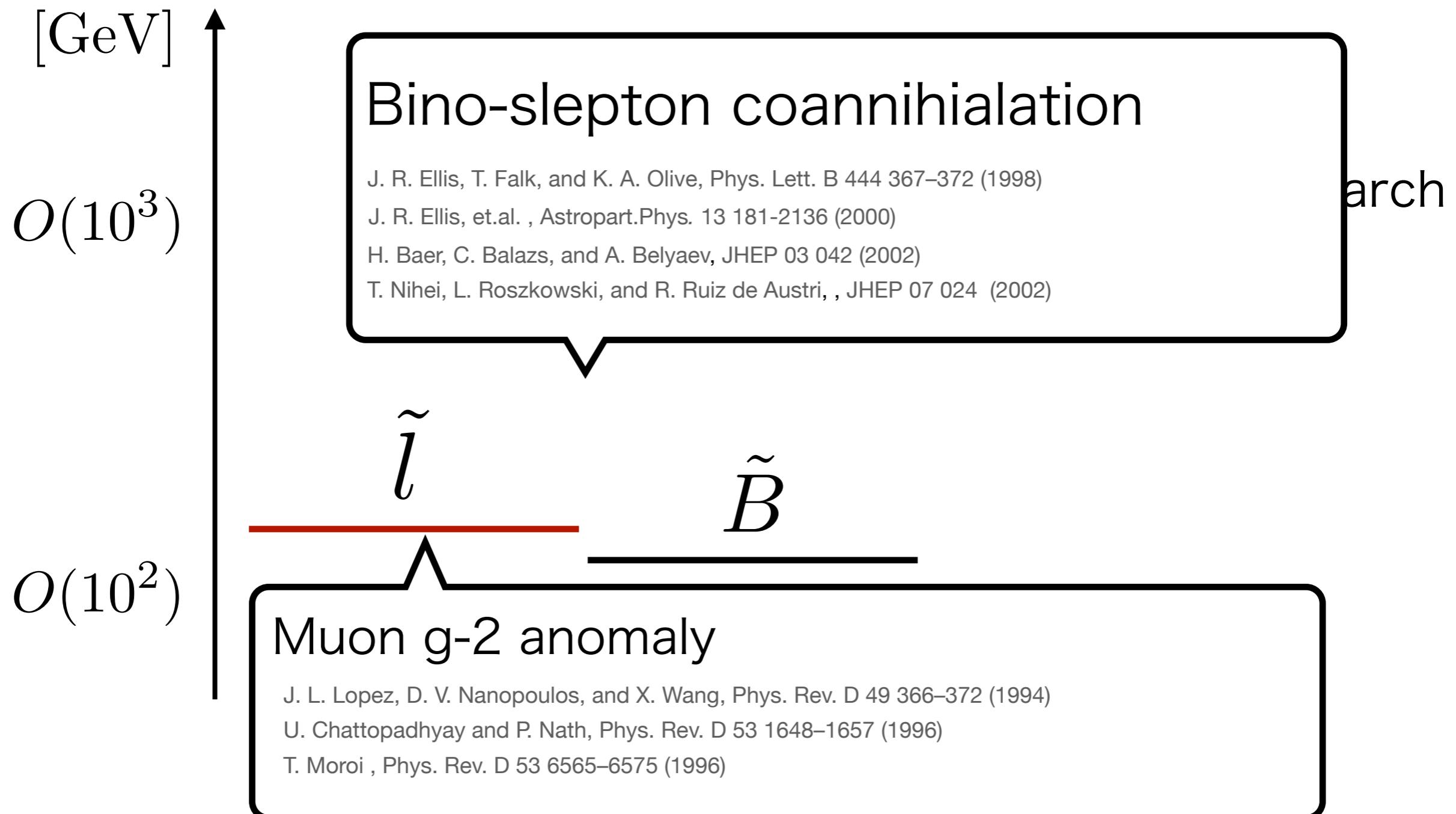
Light slepton

In the low-energy SUSY phenomenologies...



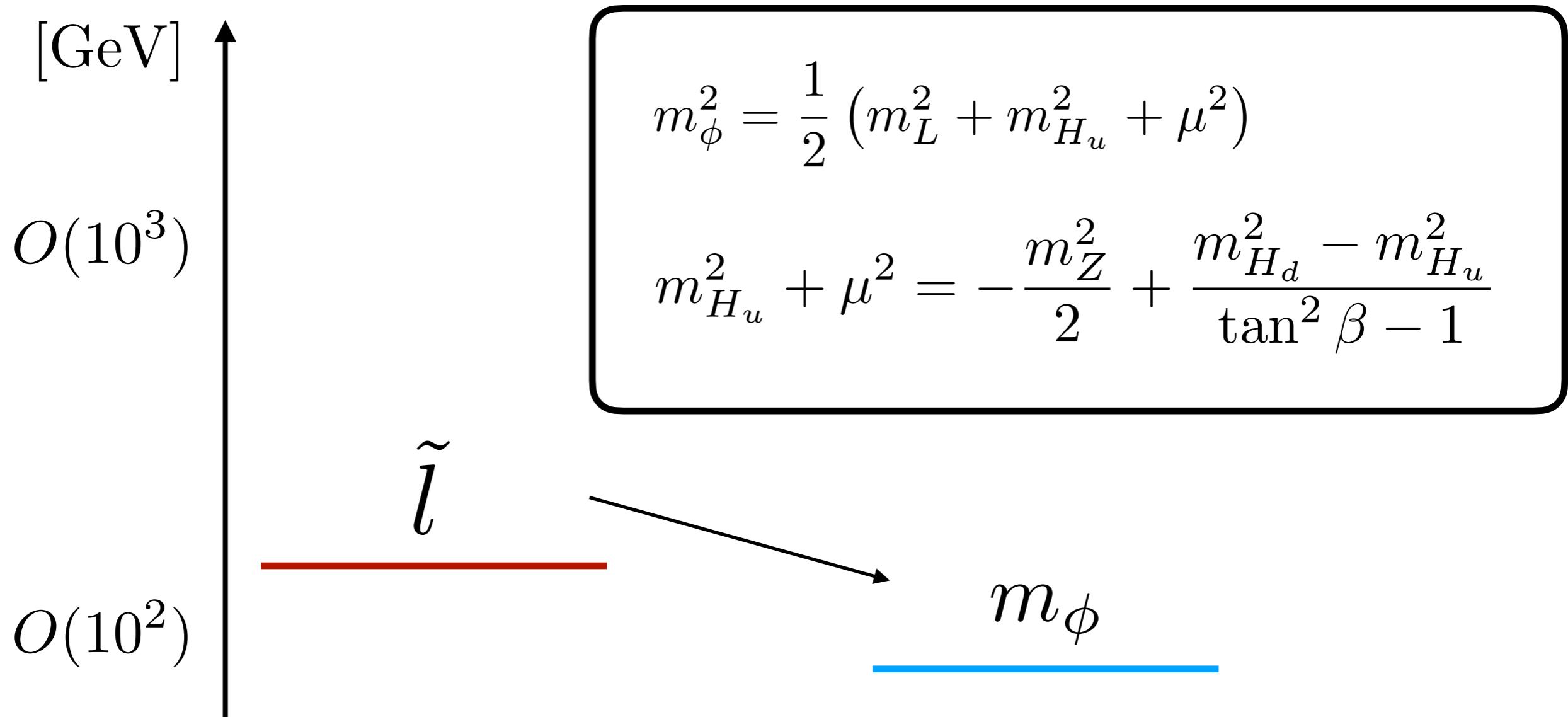
Light slepton

In the low-energy SUSY phenomenologies...



Light slepton

Light slepton leads to a light AD field.

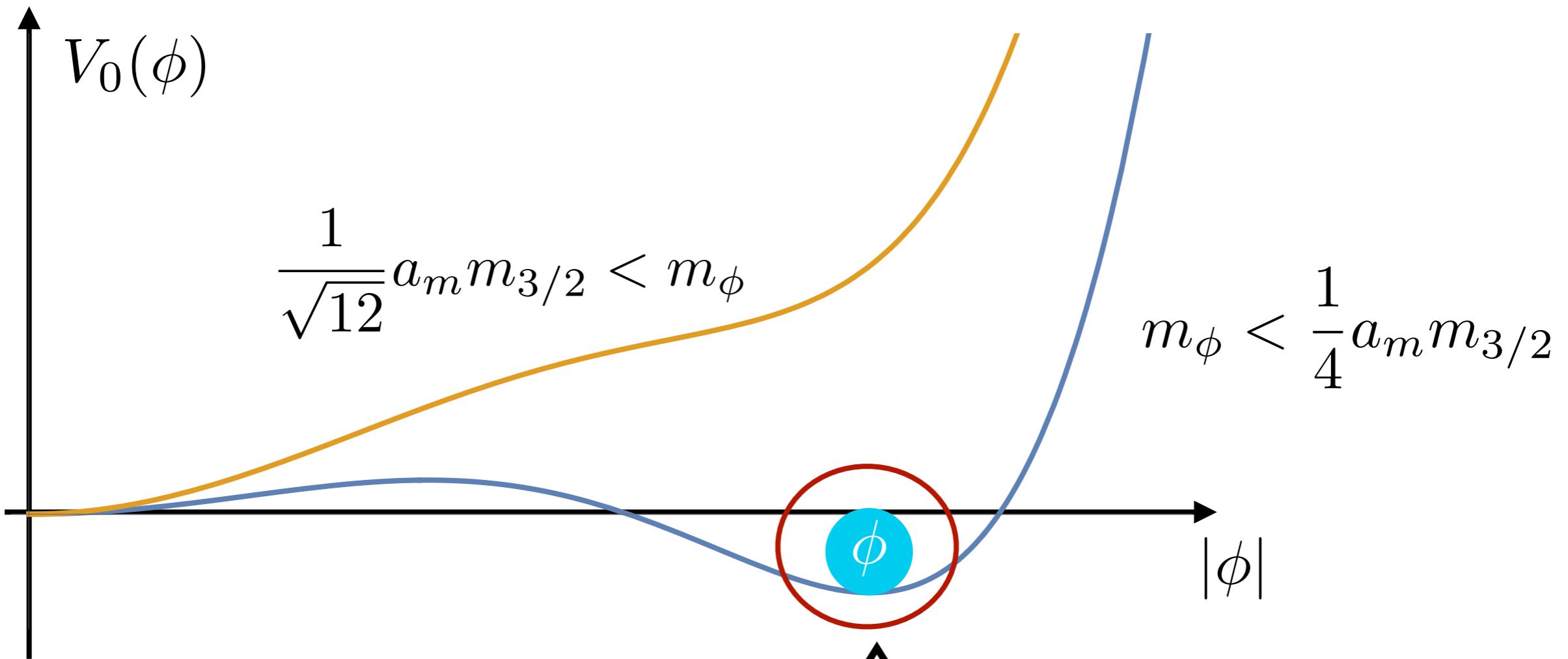


However, such a light AD field mass may cause unwanted charge-breaking vacuum (CBV).

Outline

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- ✓ Light slepton mass in ADLG
- CBV problem
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CBV problem in ADLG

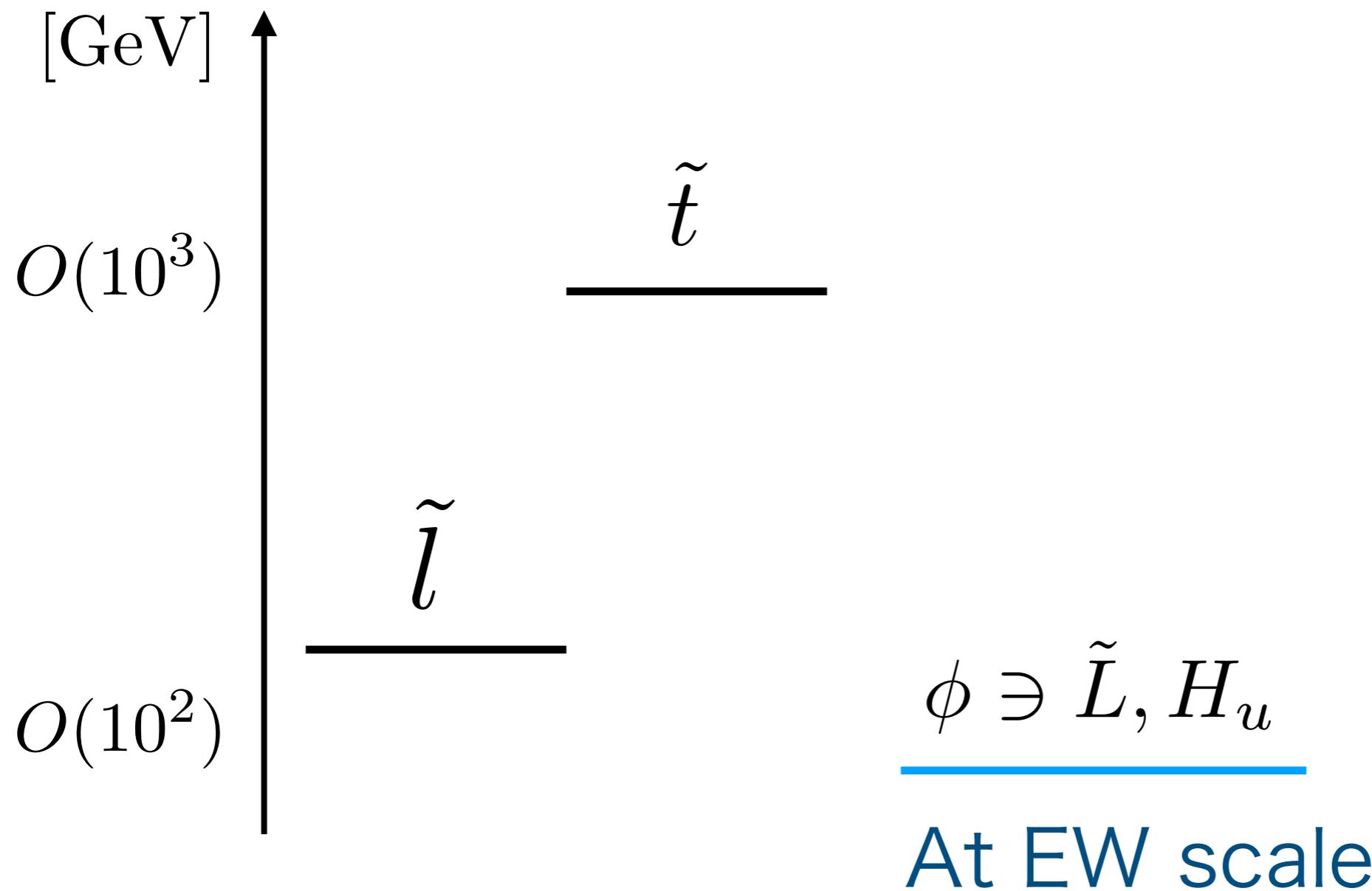


Existence of CBV is determined by effective potential

Quantum correction (running effect) &
Thermal correction are important

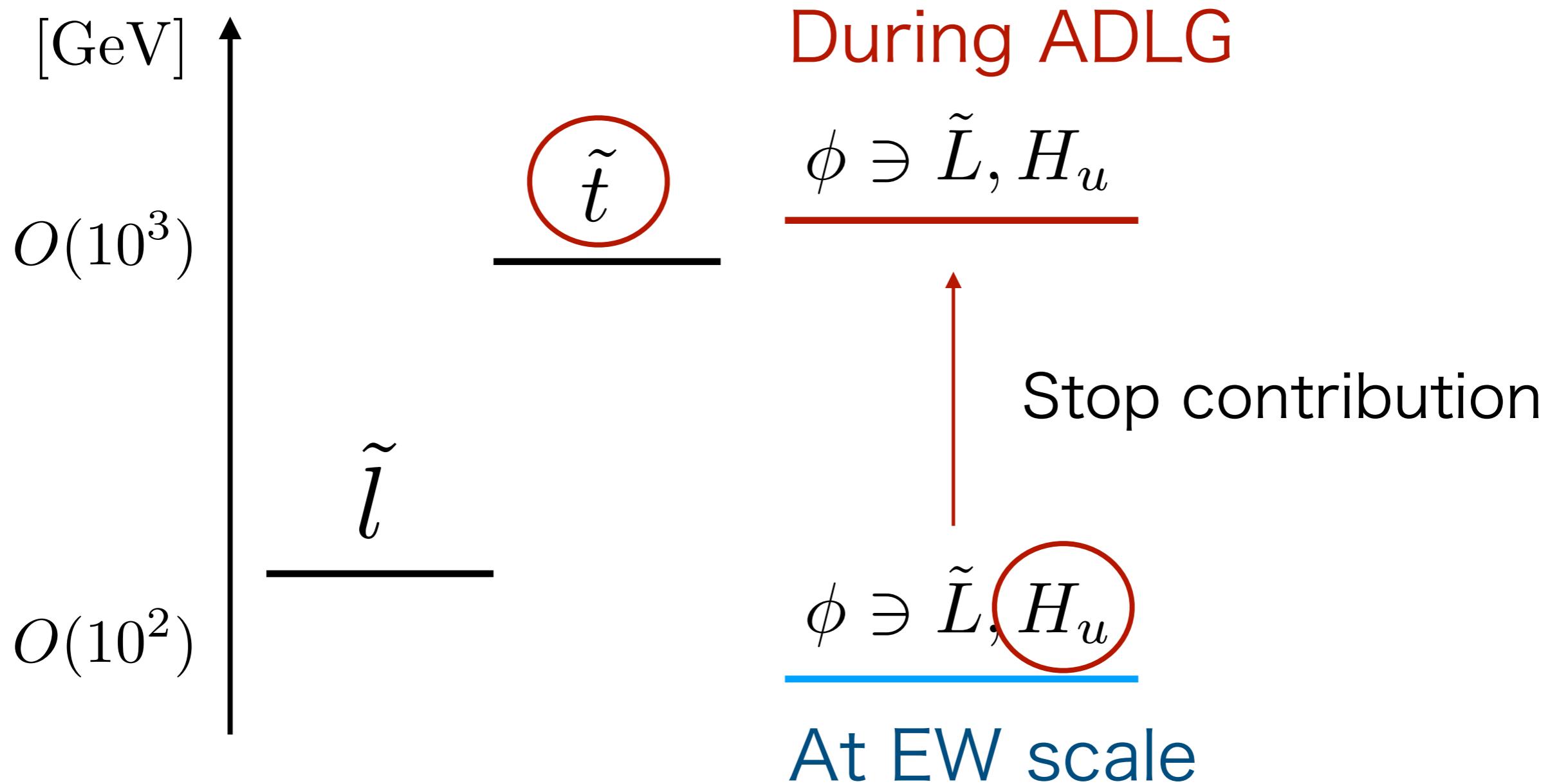
Running of AD field mass

Running effect of AD field mass is important!



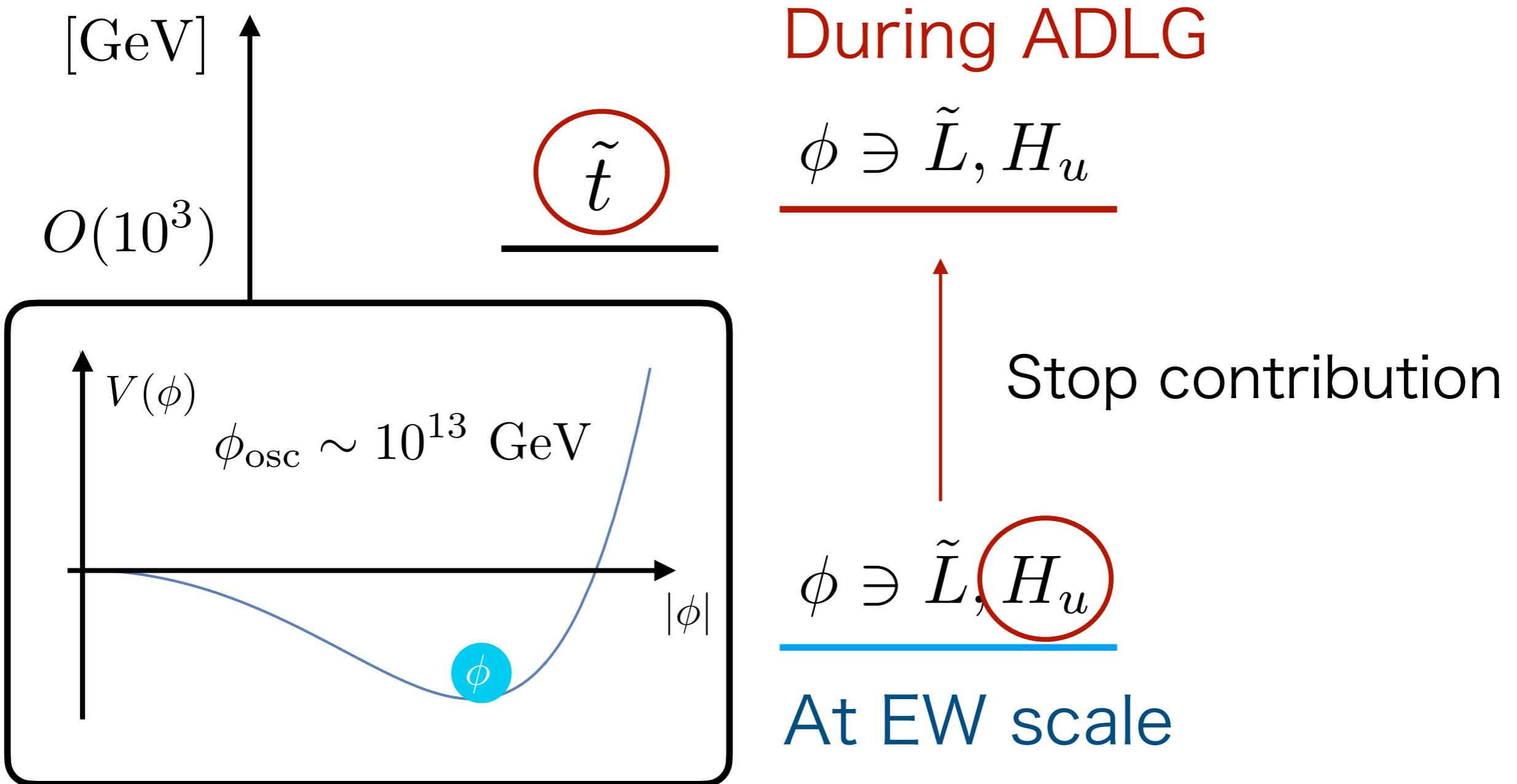
Running of AD field mass

Running effect of AD field mass is important!



Running of AD field mass

Running effect of AD field mass is important!



Running of AD field mass

Running effect is mainly coming from m_{H_u}

$$\frac{d}{d \ln Q} m_{H_u}^2 \sim \frac{1}{16\pi^2} 6|y_t|^2 (m_{Q_3}^2 + m_{u_3}^2) \quad \text{If } m_{H_u}^2 < m_{\tilde{t}}^2$$

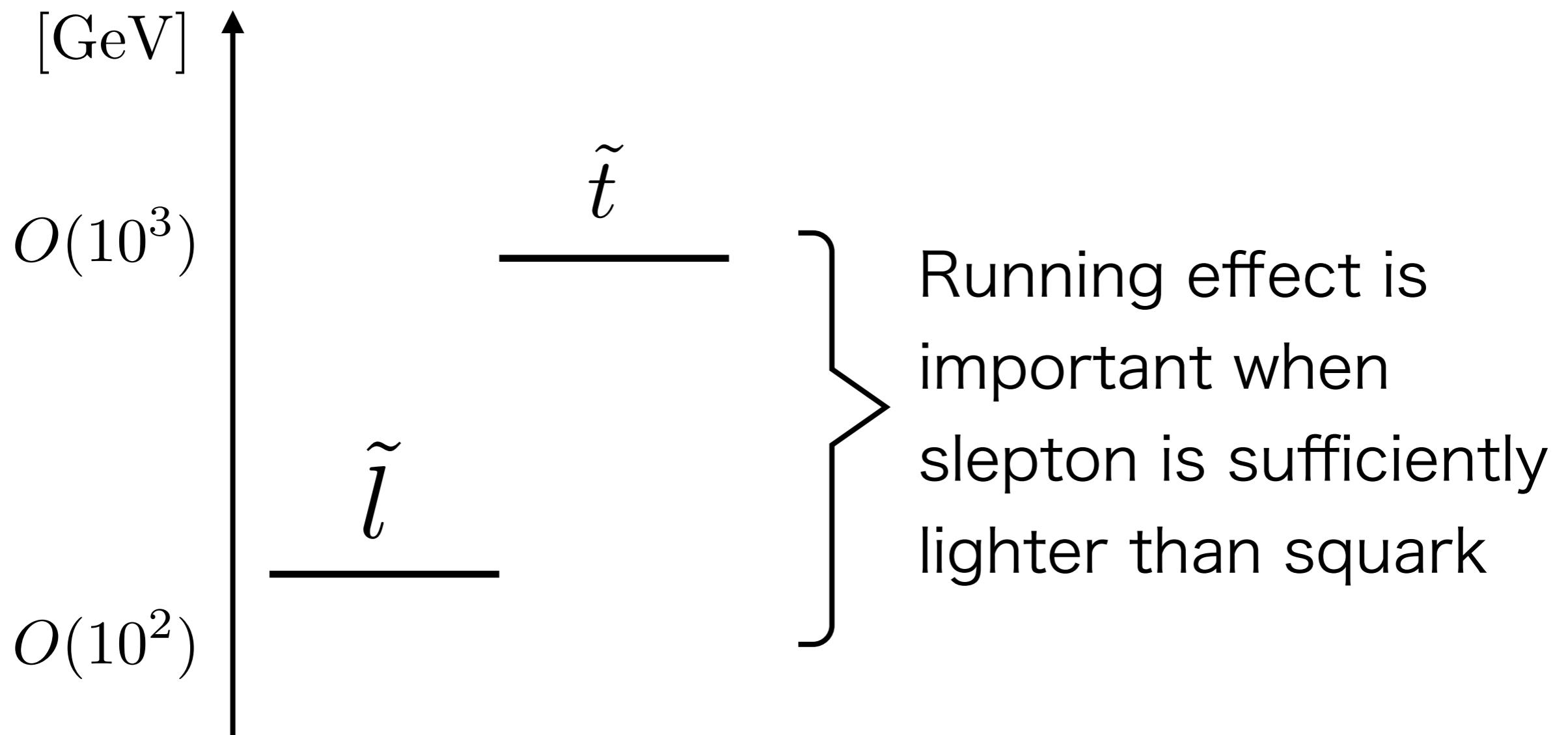


$$\begin{aligned} \delta m_\phi^2(\phi) &\simeq \frac{12|y_t|^2}{32\pi^2} m_{\tilde{t}}^2 \ln \left(\frac{\phi}{m_{\tilde{t}}} \right) \\ &\sim (3 \text{ TeV})^2 \left(\frac{m_{\tilde{t}}}{3 \text{ TeV}} \right)^2 \left(1 + \frac{1}{22} \ln \left(\frac{3 \text{ TeV}}{m_{\tilde{t}}} \frac{\phi}{10^{13} \text{ GeV}} \right) \right) \\ &> O(10^2) \text{ GeV} \end{aligned}$$

During ADLG

Running of AD field mass

The AD field mass running is important



Important in low-energy SUSY model

Thermal effect

In the early universe, we have

$$V_{\text{thermal}} \simeq \sum_{f_k |\phi| < T} c_k f_k^2 T^2 |\phi|^2 + a_g \alpha_3^2 T^4 \log \left(\frac{|\phi|^2}{T^2} \right)$$

Thermal mass & Thermal log term

R. Allahverdi, B. A. Campbell, and J. R. Ellis, Nucl. Phys. B 579 355–375 (2000)

A. Anisimov and M. Dine , Nucl.Phys.B 619 729-740 (2001)

Thermal potential can hide CBV during ADLG if reheating temperature is sufficiently high.

M. Kawasaki and K. Nakayama JCAP 02 002 (2007)

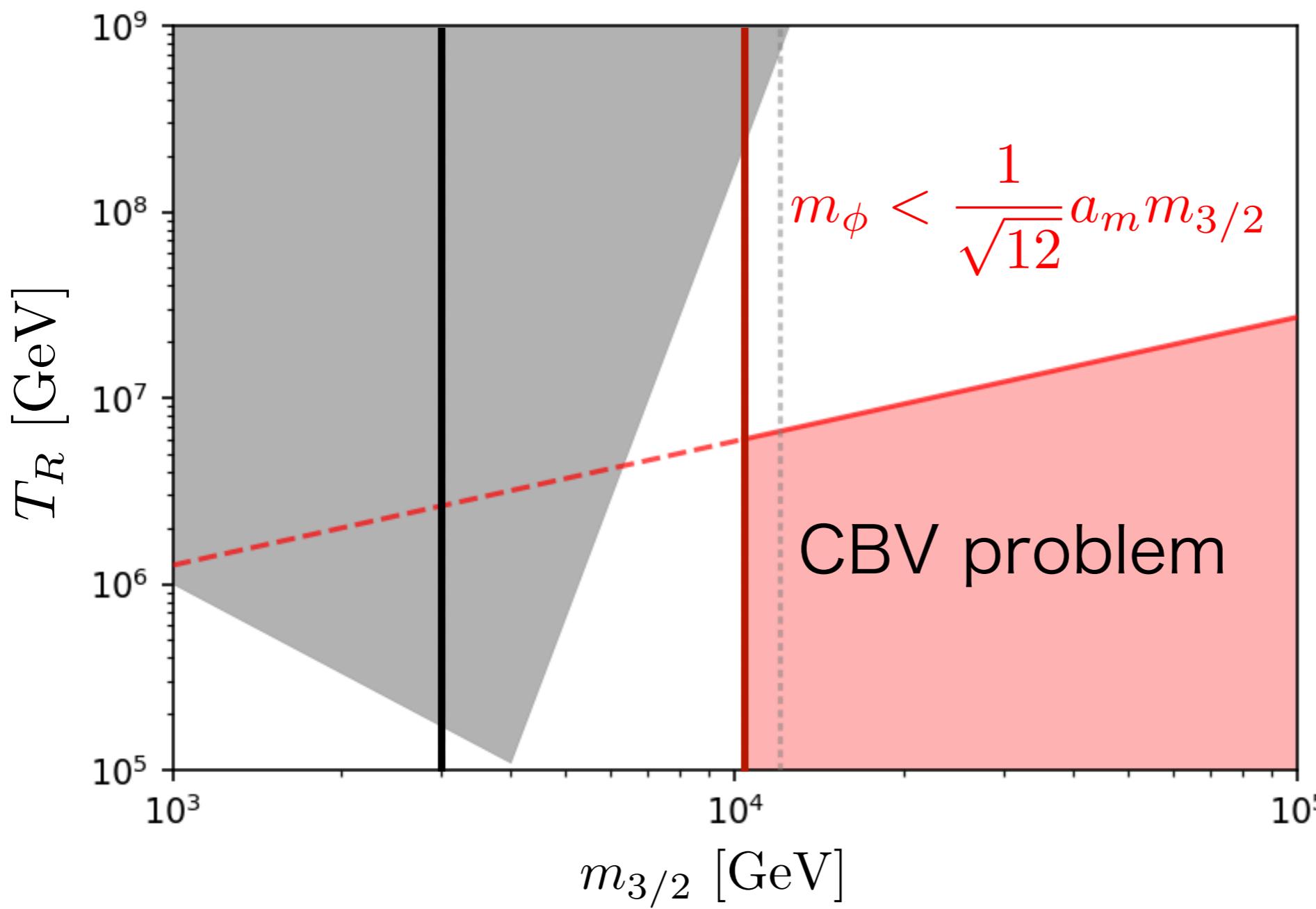
This effect is important when $a_m m_{3/2} > \sqrt{12} m_\phi \sim 10^4$ GeV in low-energy SUSY model

Result

$m_\phi \sim 3 \text{ TeV}$

High T_R is required

$$|V''_{\text{phase}}|_{H=H_{\text{osc}}} \lesssim H_{\text{osc}}^2$$



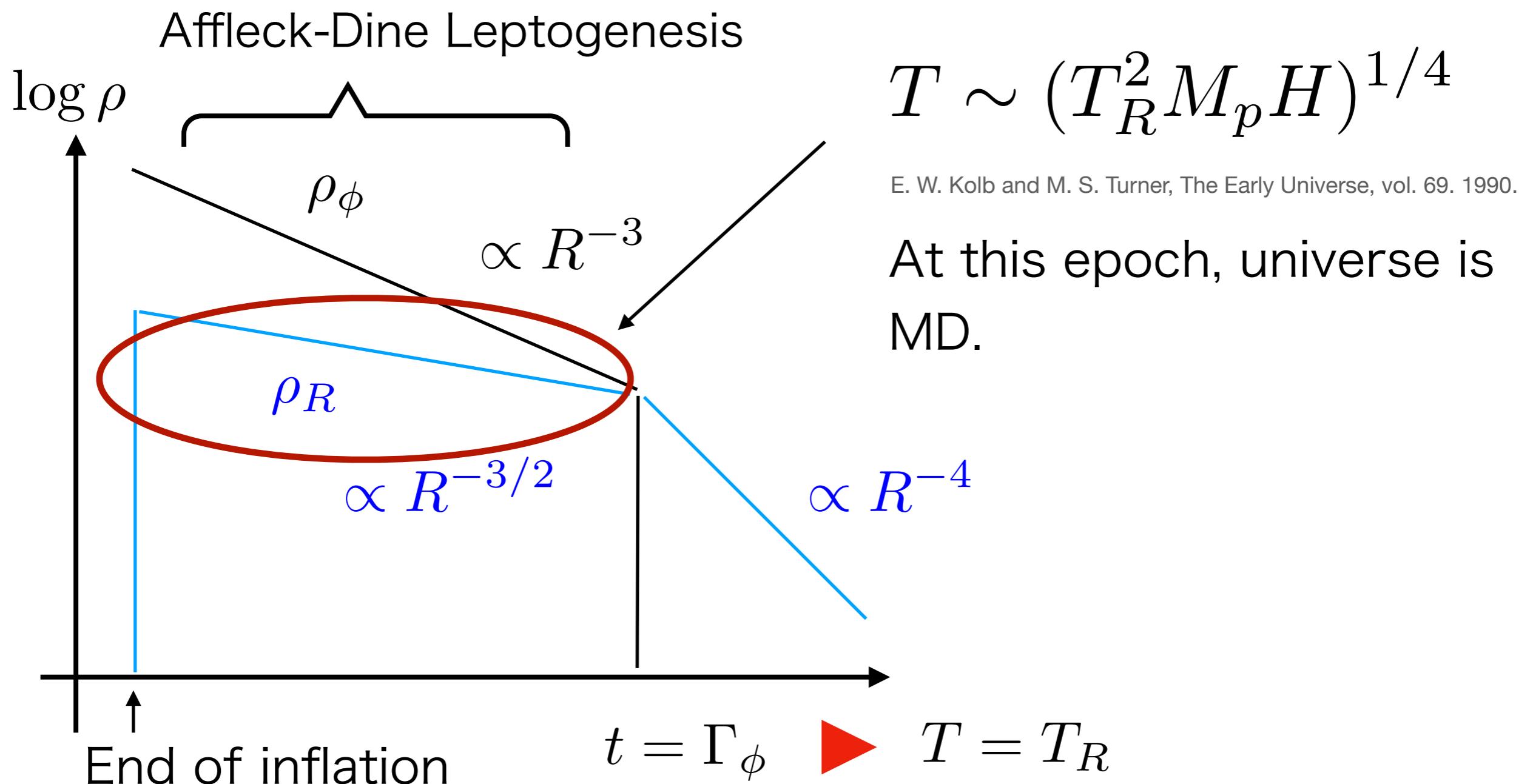
Summary

- ▶ Light AD field mass may cause charge-breaking vacuum (CBV). We revisit this problem in the context of low-energy SUSY phenomenology.
- ▶ We clarify that both thermal and quantum corrections are important for the disappearance of CBV.
- ▶ We also confirm that the correct baryon asymmetry can be produced while avoiding the cosmological gravitino problem

Backup

Inflaton oscillation epoch

After the end of inflation, inflaton oscillates for a while.



Baryon asymmetry

The net baryon-to-entropy ratio is fixed at reheating and can be estimated as

M. Fujii, K. Hamaguchi, and T. Yanagida, , Phys. Rev. D 63 123513 (2001)

$$\frac{n_B}{s} = \frac{2}{69} \delta_{\text{CP}} \frac{a_m m_{3/2} T_R}{H_{\text{osc}} M_p} \left(\frac{M}{M_p} \right)$$

where $\delta_{\text{CP}} \sim O(1)$

$$H_{\text{osc}}^2 \simeq m_\phi^2 + \sum_{f_k |\phi| < T} c_k f_k^2 T^2 + a_g \alpha_3^2 \frac{T^4}{|\phi|^2}$$

Running of gravitino A-term

The running effect of $a_m m_{3/2}$ is irrelevant.

S. Davidson, G. Isidori, and A. Strumia, Phys. Lett. B 646 100–104 (2007)

$$A_{ij}(\tilde{L}_i H_u)(\tilde{L}_j H_u) \rightarrow a_m \frac{m_{3/2} \phi^4}{8M}$$

$$\delta \hat{A}_{ij} \sim \frac{1}{(4\pi)^2} m_{\text{soft}} \ln \frac{M_{\text{pl}}}{\mu}$$

$$\hat{A}_{ij} := v^2 A_{ij}/m_{ij} \sim a_m m_{3/2}$$

Running of neutrino mass

Since RGE for each neutrino mass is proportional to the mass it self, running effect of the lightest neutrino mass is not important at the one loop level.

K. S. Babu, C. N. Leung, and J. T. Pantaleone, Phys. Lett. B 319 191–198 (1993)

P. H. Chankowski and Z. Pluciennik, Phys. Lett. B 316 312–317 (1993)

Mass shift from two loop effect is given by

$$\Delta m_{\nu 1} \sim 10^{-10} \text{ eV} \left(\frac{\tan \beta}{10} \right)^4$$

S. Davidson, G. Isidori, and A. Strumia, Phys. Lett. B 646 100–104 (2007)

Cf) $m_\nu = \frac{v_u^2}{M} \simeq 3 \times 10^{-9} \text{ eV} \times \left(\frac{M}{10^{22} \text{ GeV}} \right)^{-1} \sin^2 \beta$

Thermal log Q-ball

Q balls are formed when thermal log potential is dominant

$$V_{\text{thermal}} \simeq a_g \alpha_3^2 T^4 \log \left(\frac{|\phi|^2}{T^2} \right)$$

M. Kawasaki and K. Nakayama JCAP 02 002 (2007)
S. Kasuya and M. Kawasaki Phys. Rev. D 64, 123515 (2001)
T. Chiba, et.al., Phys. Rev. D 82, 103534 (2010).

However, charge of Q-balls are so small that they can not survive until temperature becomes lower than the electroweak scale in the case of LH_u flat direction.

M. Kawasaki and K. Nakayama JCAP 02 002 (2007)