dS self-organized criticality for the weak scale

Sunghoon Jung
Seoul National University

2107.02801 (PRR letter) with TaeHun Kim, and ongoing works

CAU workshop, Feb 2023

Overview

Take-home message:

"Early dS quantum effects may explain the near-criticality of our universe, in particular the near-critical weak scale."

1. Near-criticality of our Universe.
2. dS self-organized criticality: New beauty?
3. QCD quantum critical points for the weak scale
4. dS information problem

Near-criticality of our Universe

Two well-known long-time examples:

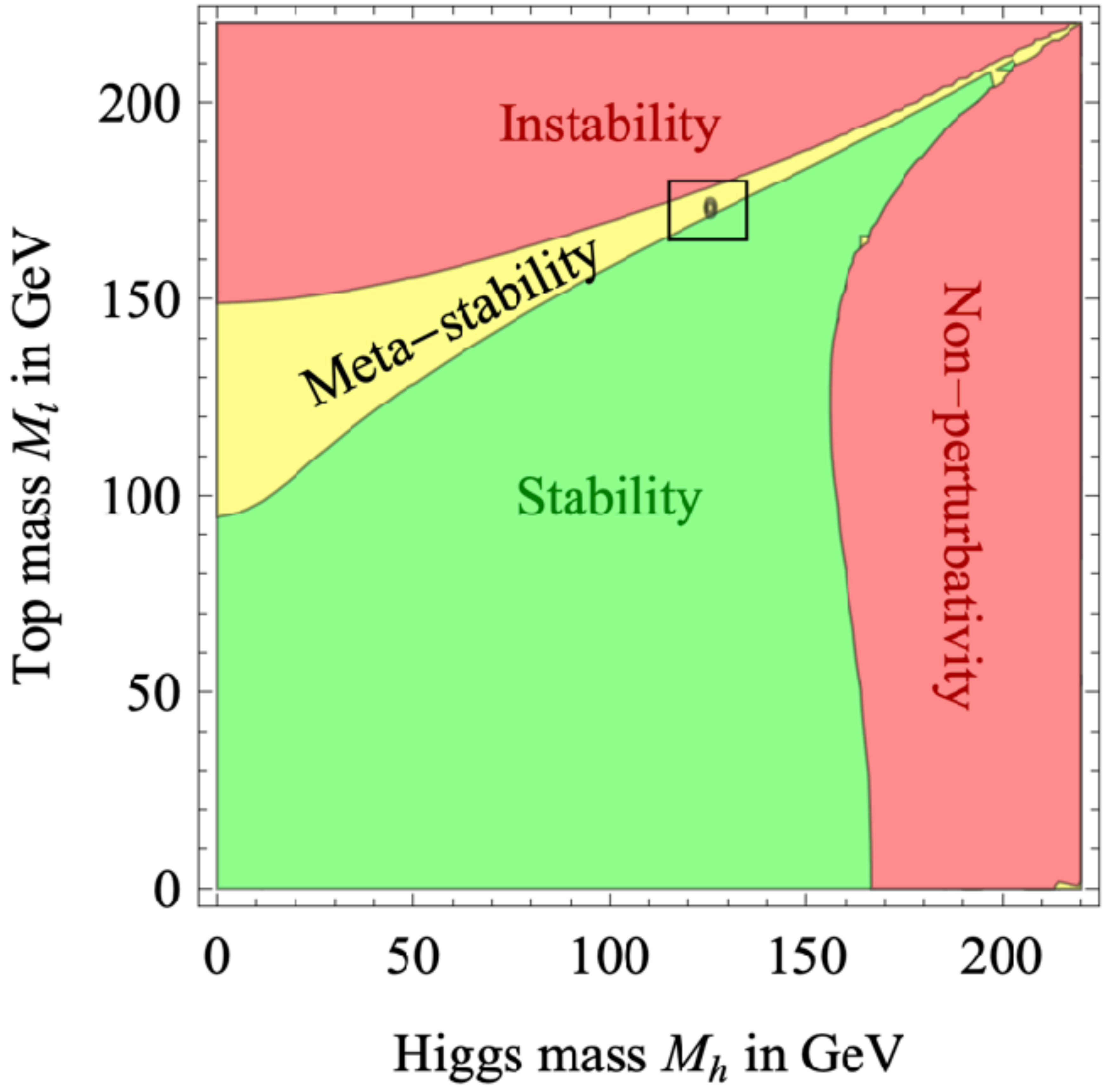
Higgs mass and c.c.

A new surprising case:

metastable EW vacuum with mh = 125 GeV.

Just a coincidence, or a new beauty?

(The question is not why they are so small, but why so close to some critical pts.)



Degrassi et al. (12,13)

Self-organized criticality

Examples in nature:

Sand piling,

1/f noise seems to be a result of a SOC,

Self-similar, fractal…

It's a statistical phenomenon.
Can such be realized for mh and cc?

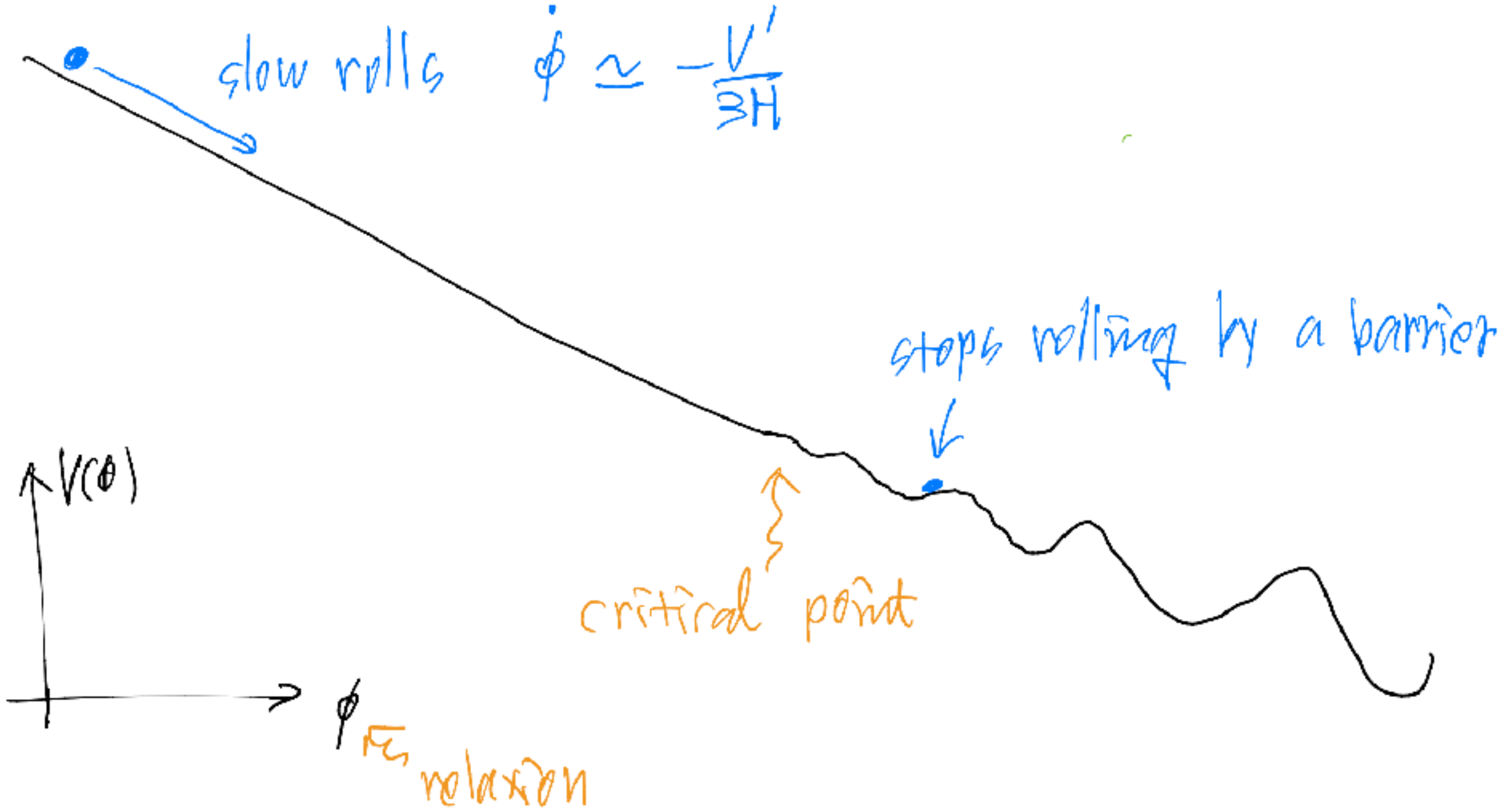
G.Giudice (08)
J.Khoury et al. (19, 20)
G.Giudce, M.Mccullough, T.You (21)

Prototype (classical) mechanism - relaxion

During inflation, a theory inevitably evolves toward a critical point, independent of initial conditions.

Relaxion's classical slow-roll sweeps a large range of field value, until it stops near a critical point.

The relaxion field value determines the value of the desired parameter — the Higgs vev, in our case.



P.W.Graham, D.Kaplan, S.Rajendran (15)

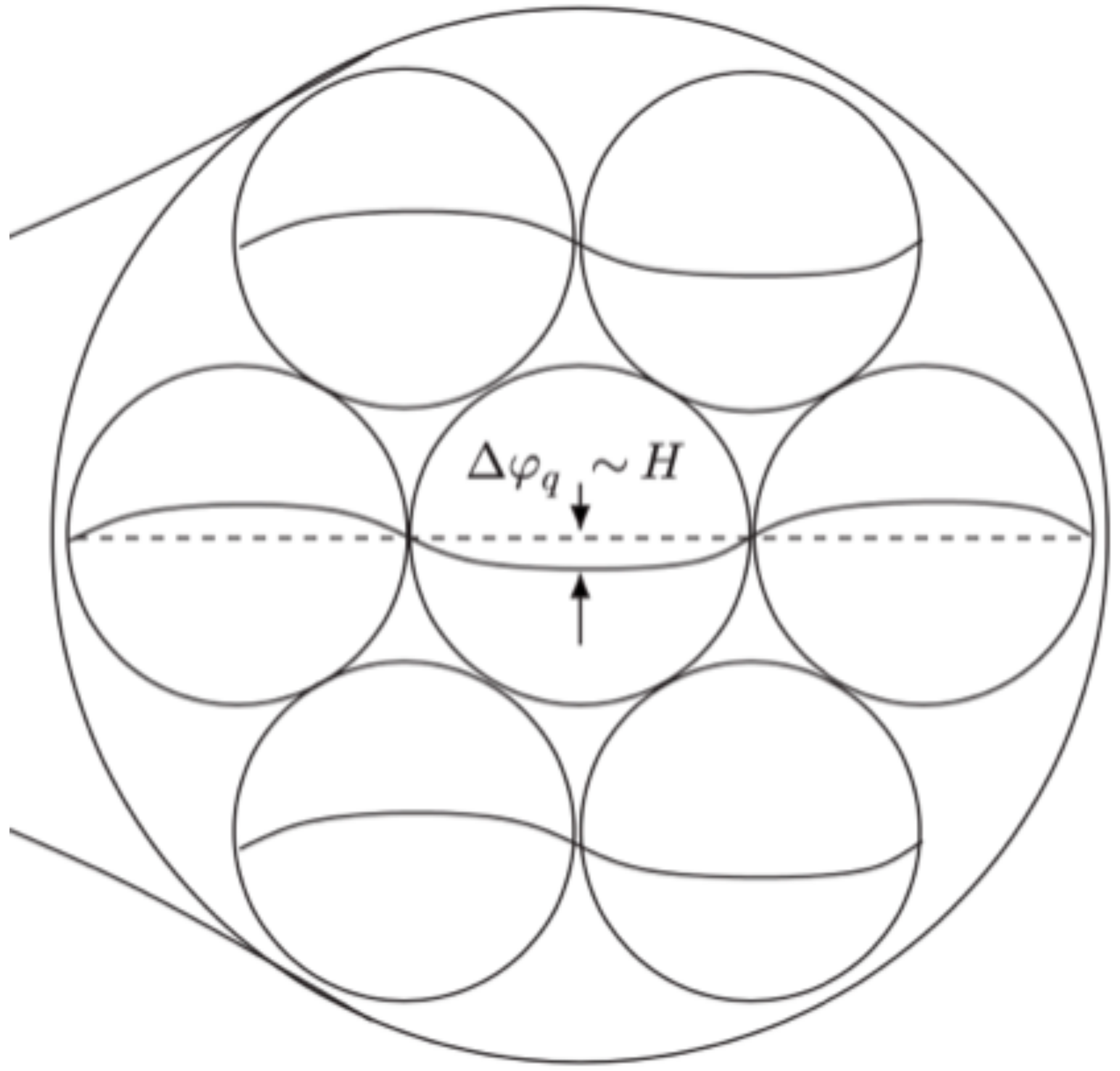
Quantum relaxation in dS

We study relaxation via dS quantum fluctuations.

Quantum effects are essentially diffusion, probabilistic.

Necessarily, we talk about the prob distribution
among Hubble patches — multiverse "ensemble".

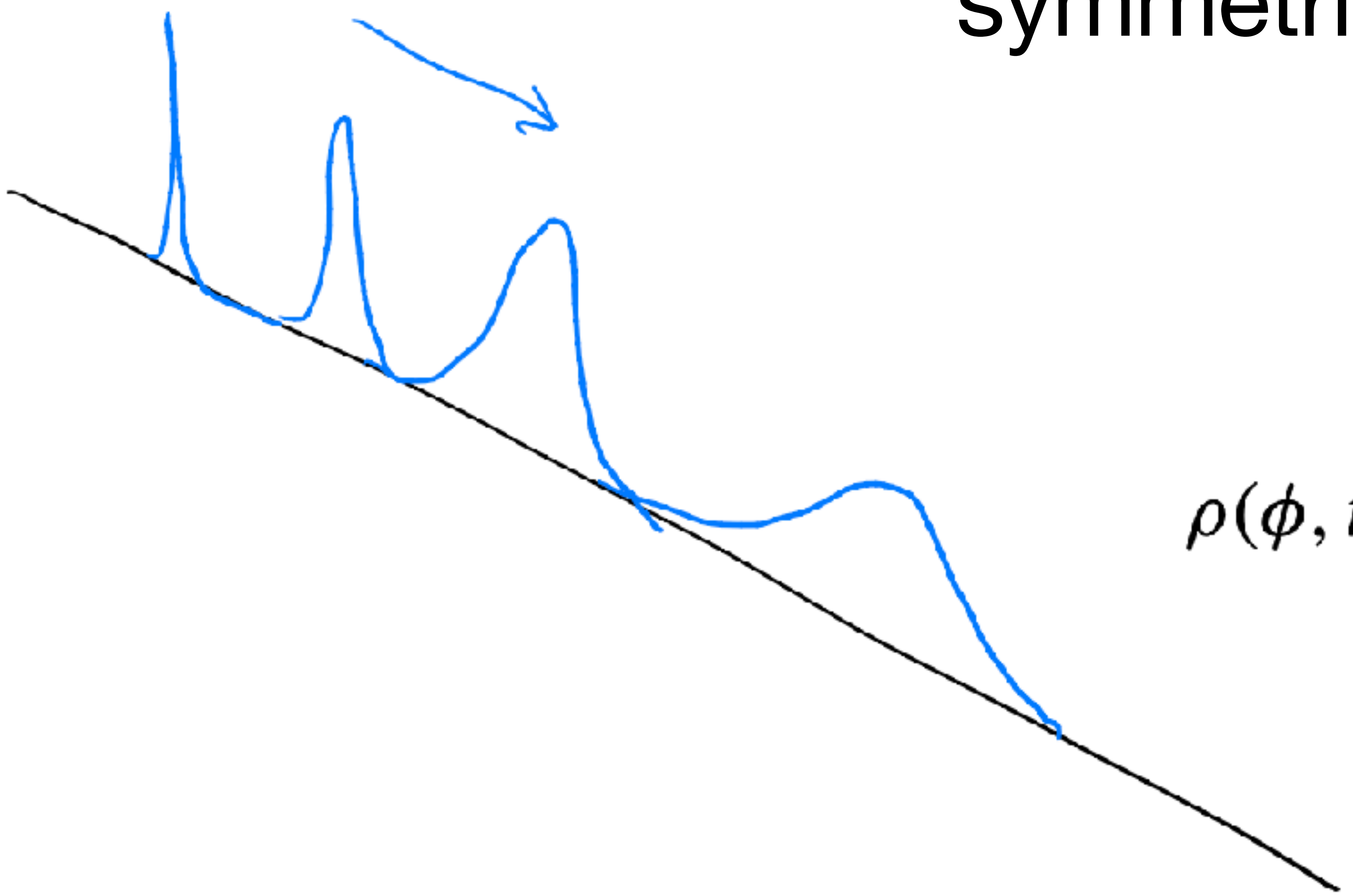
Quantum version can be
more widely applicable, stronger selection.

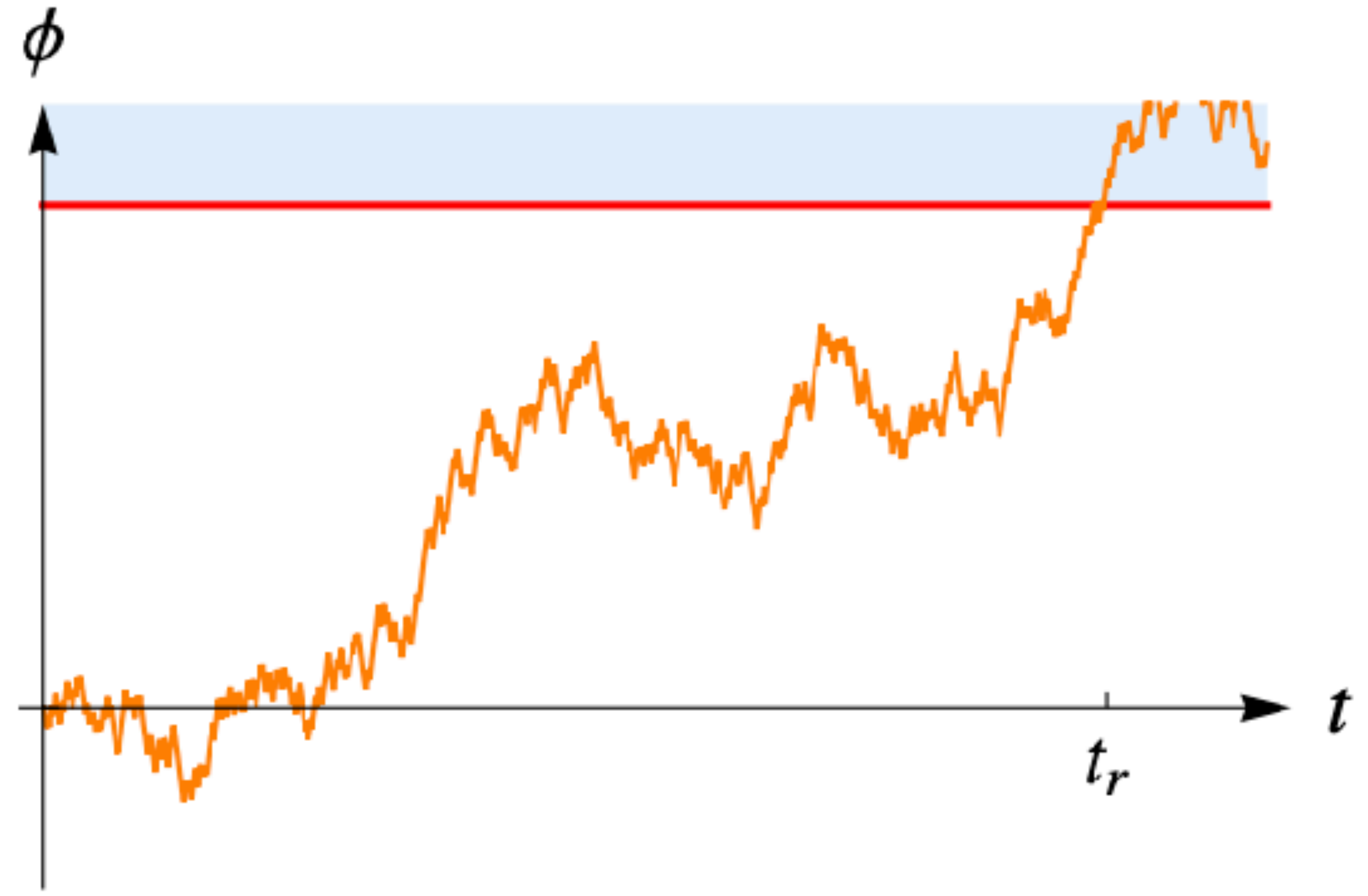


Usual evolution of Prob distribution

During inflation, scalar field values are subject to

(1) classical rolling ~ -V'/3H : always downward
(2) random walk ~ H/2pi : dS quantum origin, symmetric up or down

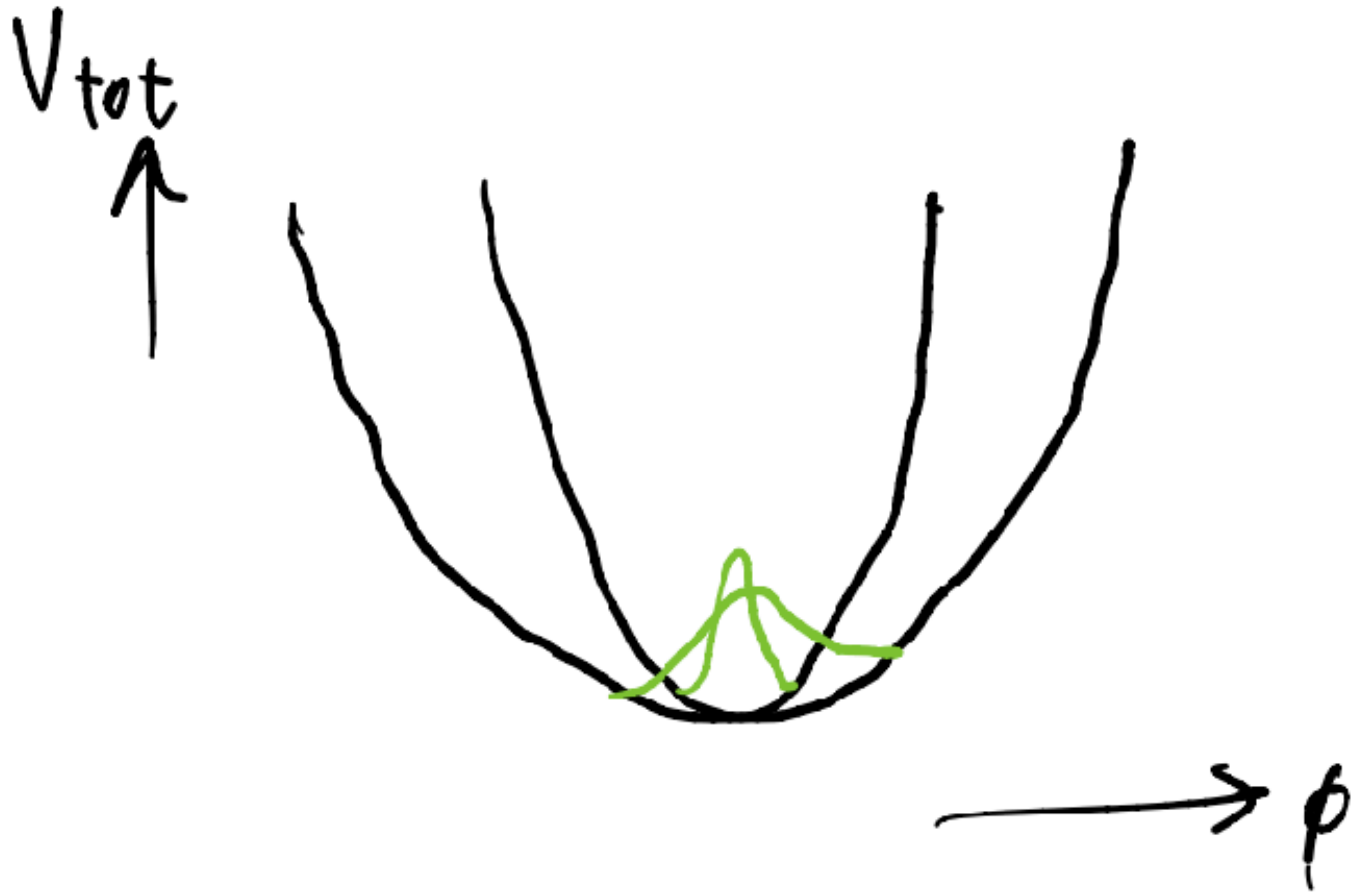




$$\rho(\phi, t) \propto \exp\left\{ \frac{-1}{2\sigma_\phi^2(t)} \left[\phi - \left(\phi_0 + \dot{\phi}_c t \qquad \right)\right]^2 \right\}$$

$$\dot{\phi}_c = -V'/3H \qquad \sigma_\phi^2(t) = \left(\frac{H}{2\pi}\right)^2 H t$$

Usual equilibrium near the bottom



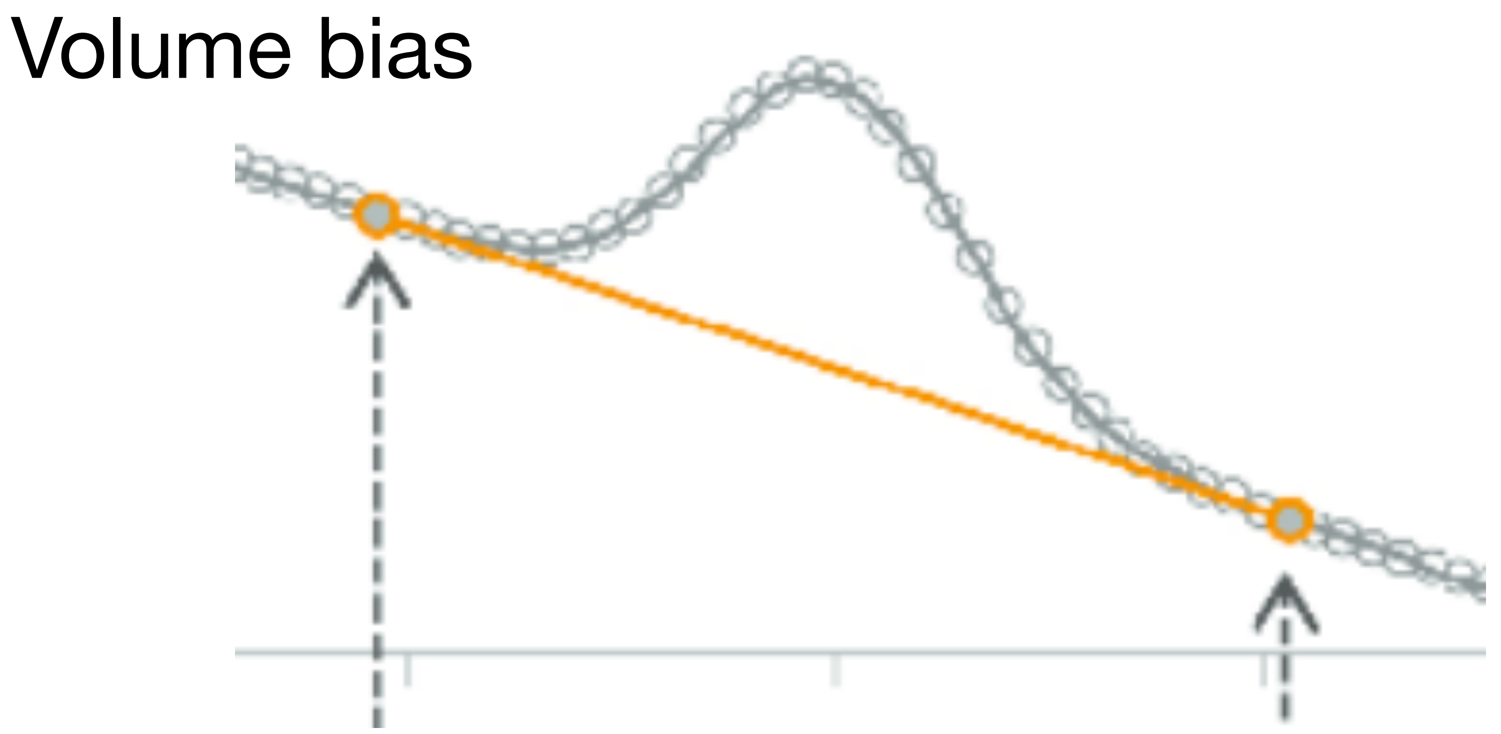
Equilibrium: Dispersion of the prob dist is balanced by steep classical rolling.

Usually, delta-function like at the minimum; the steeper the potential, the narrower the eq width.

Now, quantum surge upward, by volume bias

Prob distribution can climb up

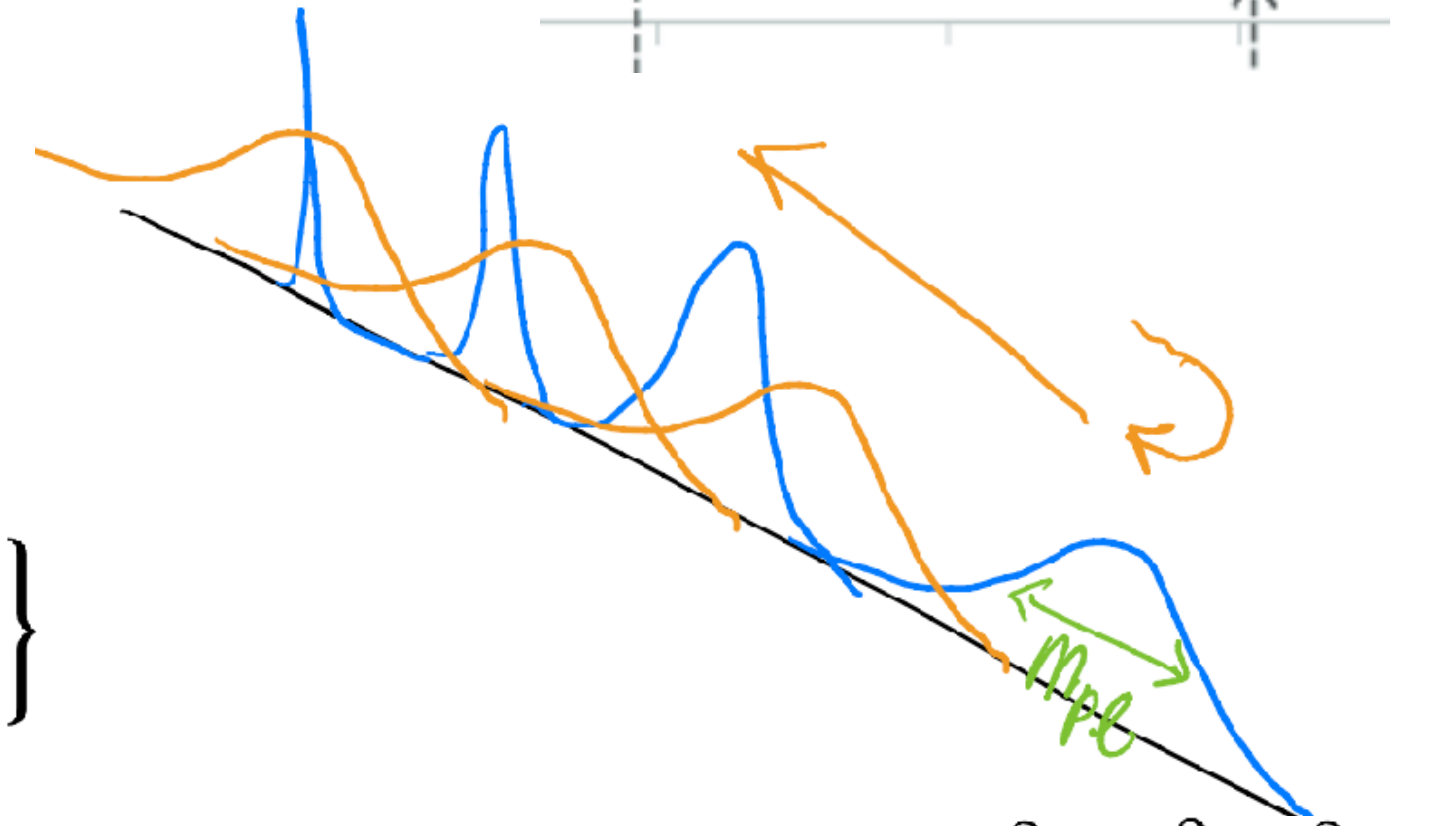
if volume bias upward > slow-roll downward.



Condition:

(1) broad width ~ Planckian

(2) the potential needs to be flat enough



$$\rho(\phi, t) \propto \exp\left\{\frac{-1}{2\sigma_\phi^2(t)}\left[\phi - \left(\phi_0 + \dot{\phi}_c t + \tfrac{3}{2}(\Delta H)'\sigma_\phi^2 t\right)\right]^2\right\}$$

$$\dot{\phi}_c = -V'/3H \qquad \sigma_\phi^2(t) = \left(\tfrac{H}{2\pi}\right)^2 Ht$$

starts to *climb up* the potential: $\sigma_\phi^2 \simeq \frac{2}{3}M_{\rm Pl}^2$

Where does it climb up to? Eq near a top

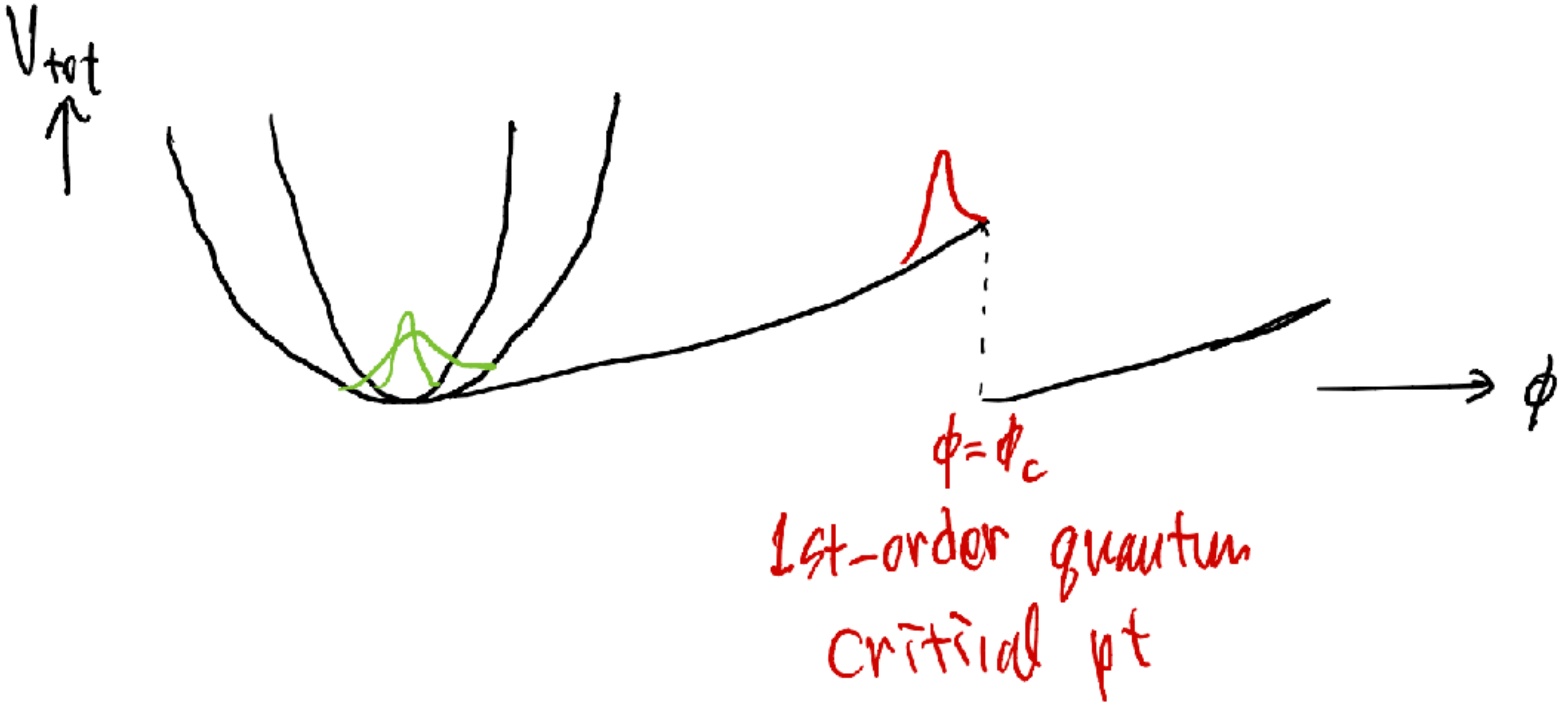
G.Giudce, M.Mccullough, T.You (21)

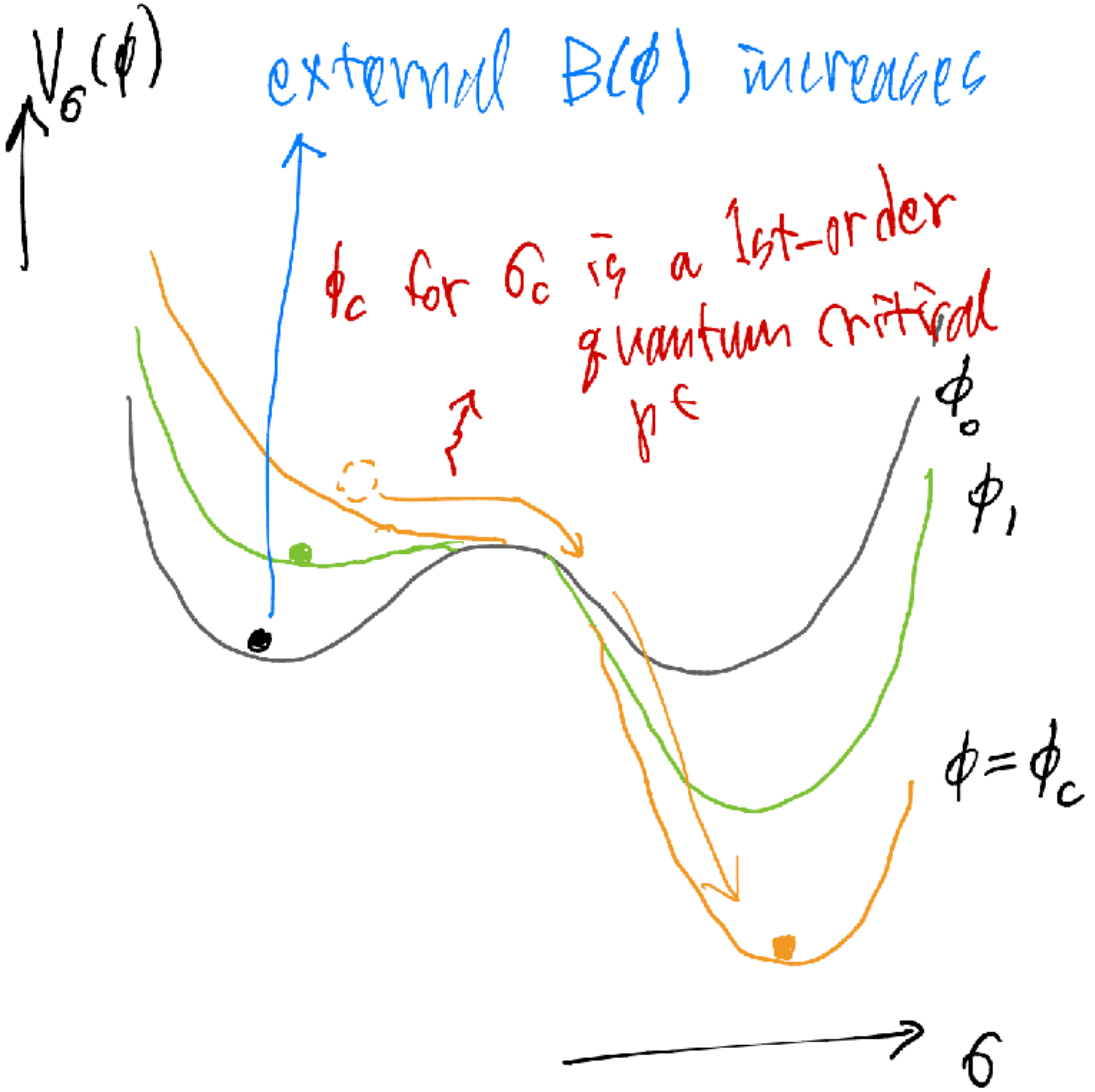
Equilibrium near the top (or a steep point) of a potential
— where Hubble rate is largest, hence the Hubble selection.

NB: The top essentially provides a repulsion force, hence eq away from the exact top.

NB: The flatter, the stronger quantum surge and narrower eq width — sharper selection.

Equilibrium near a top (quantum critical pt)



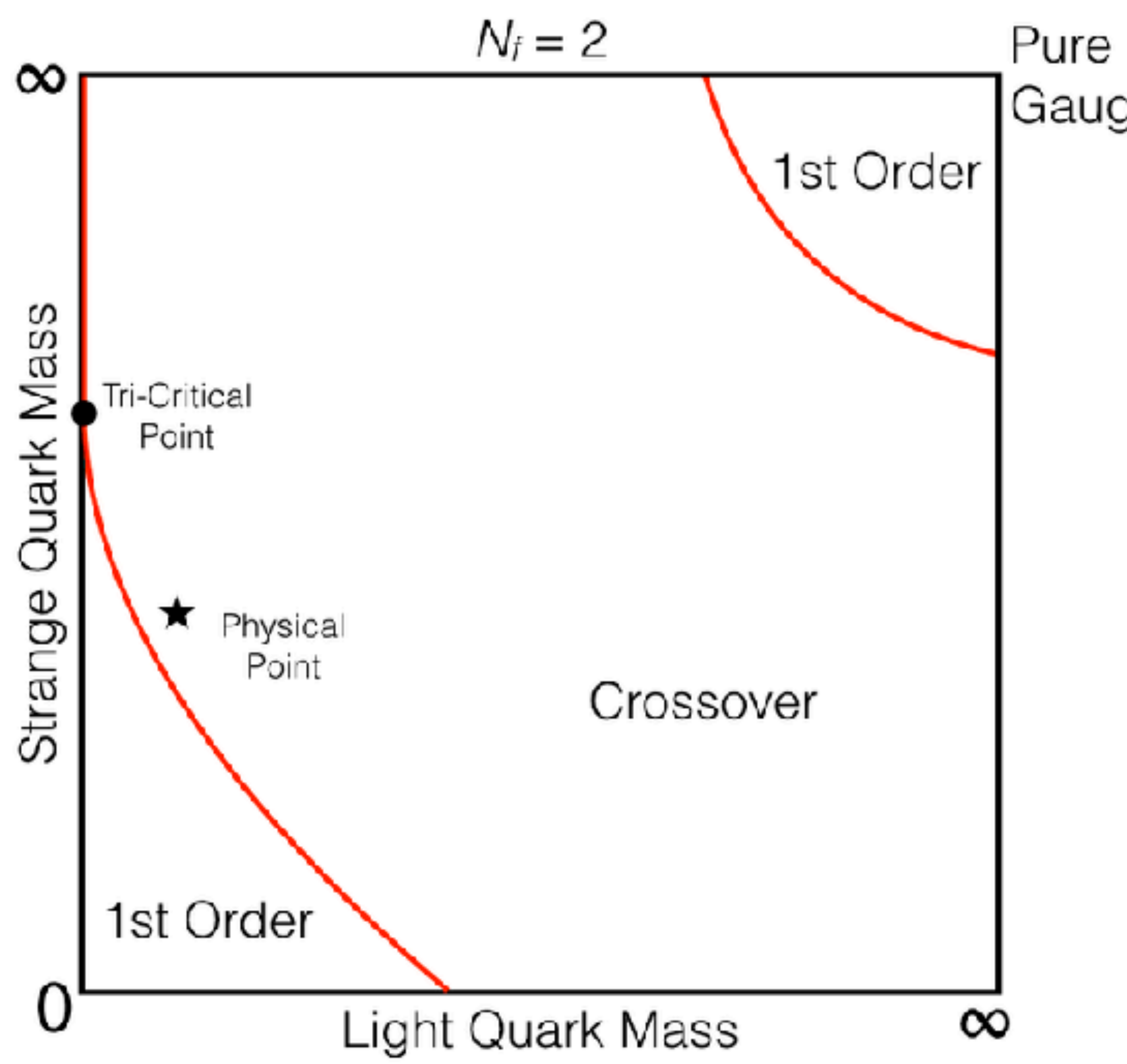


In particular, the top can be a
1st-order quantum critical point.

QCD quantum critical pts for the weak scale?

QCD chiral symmetry indeed exhibits a variety of phases depending on the Higgs vev (quark masses).

- The SM is thought to be near a critical line.
- Lam_QCD ~ v_EW maybe not a coincidence.
- The vev dependence of QCD phase structure is not well known yet,
  needs further study with lattice and holography.
- => We take a simplified pheno approach.



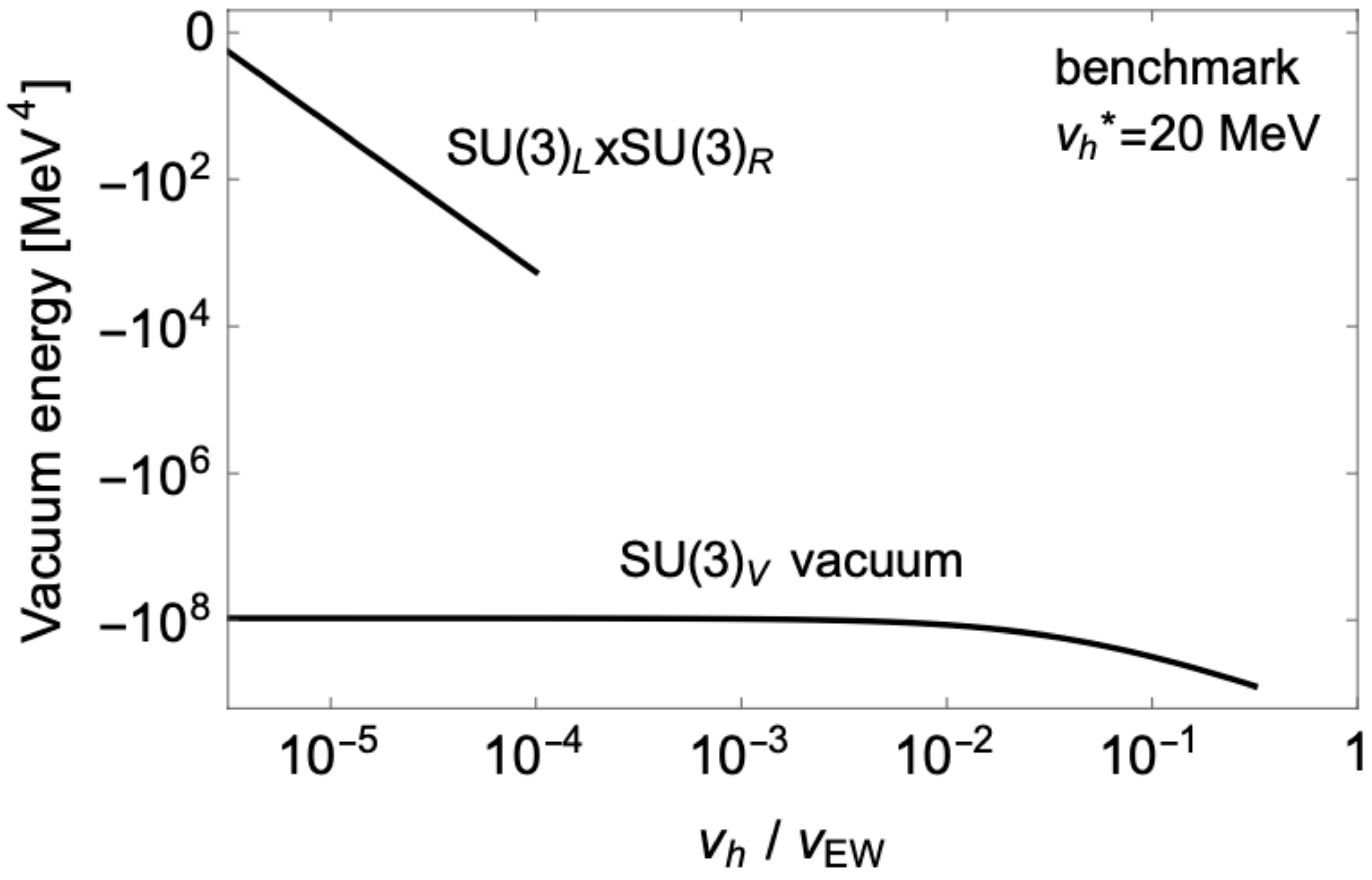
Linear Sigma Model of mesons

We use LSM of 3 quark flavors for a LO study. SU(3)L x SU(3)R.

$$V_\Sigma = \mu^2 \mathrm{Tr}[\Sigma\Sigma^\dagger] + \lambda_1 (\mathrm{Tr}[\Sigma\Sigma^\dagger])^2 + \lambda_2 \mathrm{Tr}[(\Sigma\Sigma^\dagger)^2]$$
$$-c(\det\Sigma + \det\Sigma^\dagger) - \mathrm{Tr}[\mathcal{H}(\Sigma + \Sigma^\dagger)]$$

SJ, T.Kim (21)

H is linear to the Higgs vev!

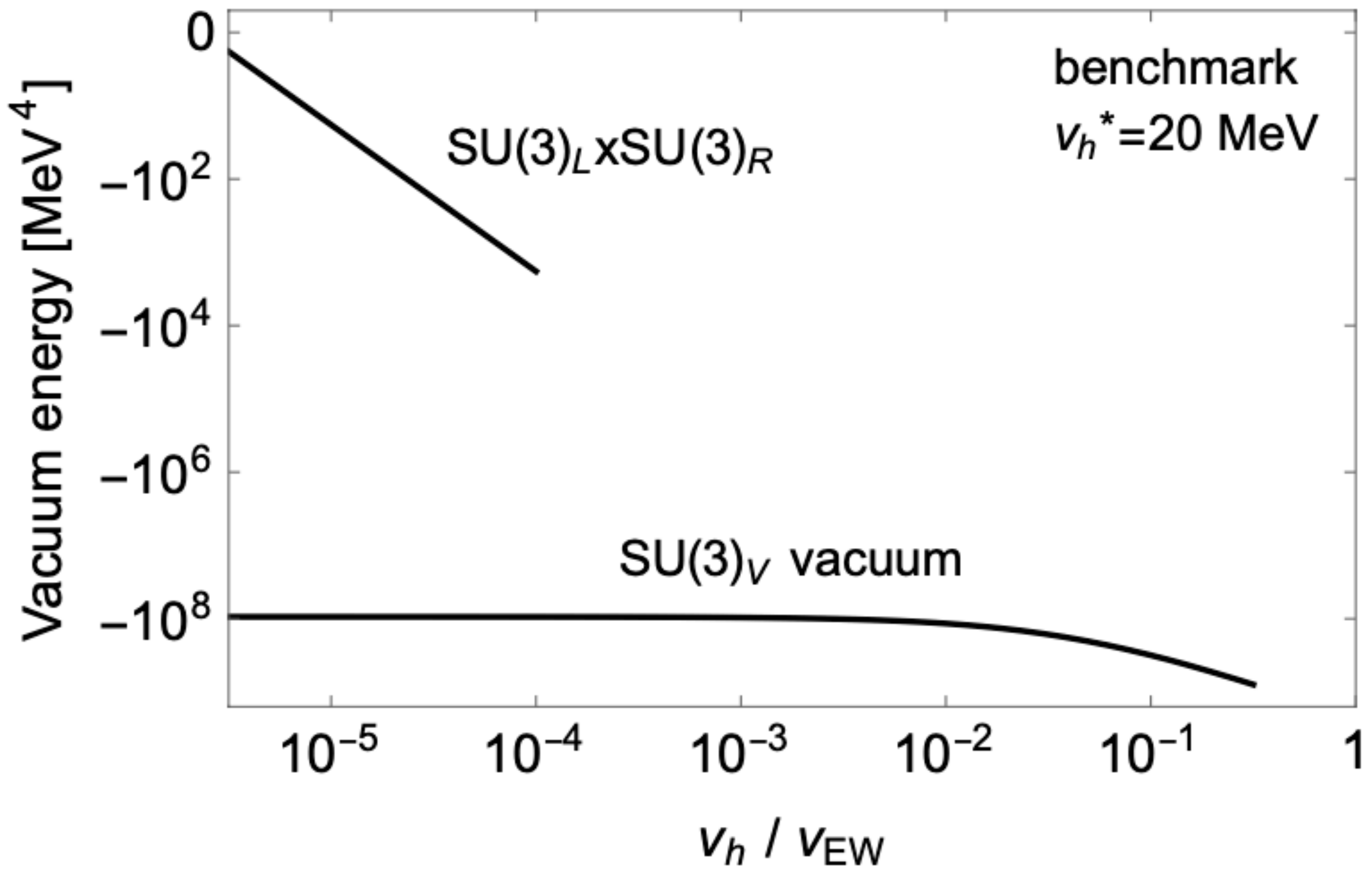


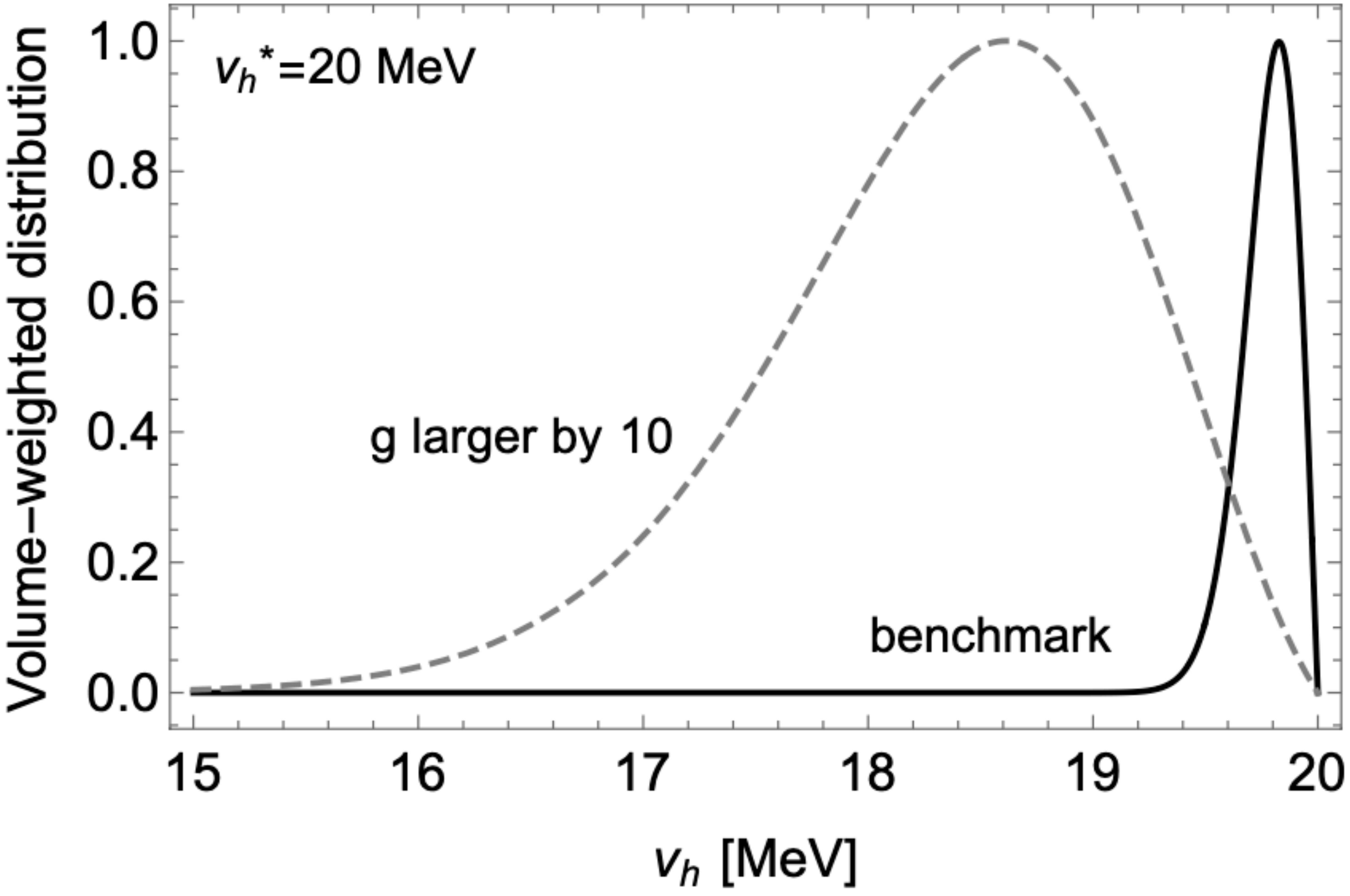
Three types of vacua: Y.Bai, B.Dobrescu (18)

- SU(3)v (QCD vacuum today)
- SU(3)L x SU(3)R
- SU(2)L x SU(2)R x U(1)v

Some of them can indeed co-exist —> 1st-order quantum criticality!

The weak scale is likely near QCD critical pts





SJ, T.Kim (21)

Summary

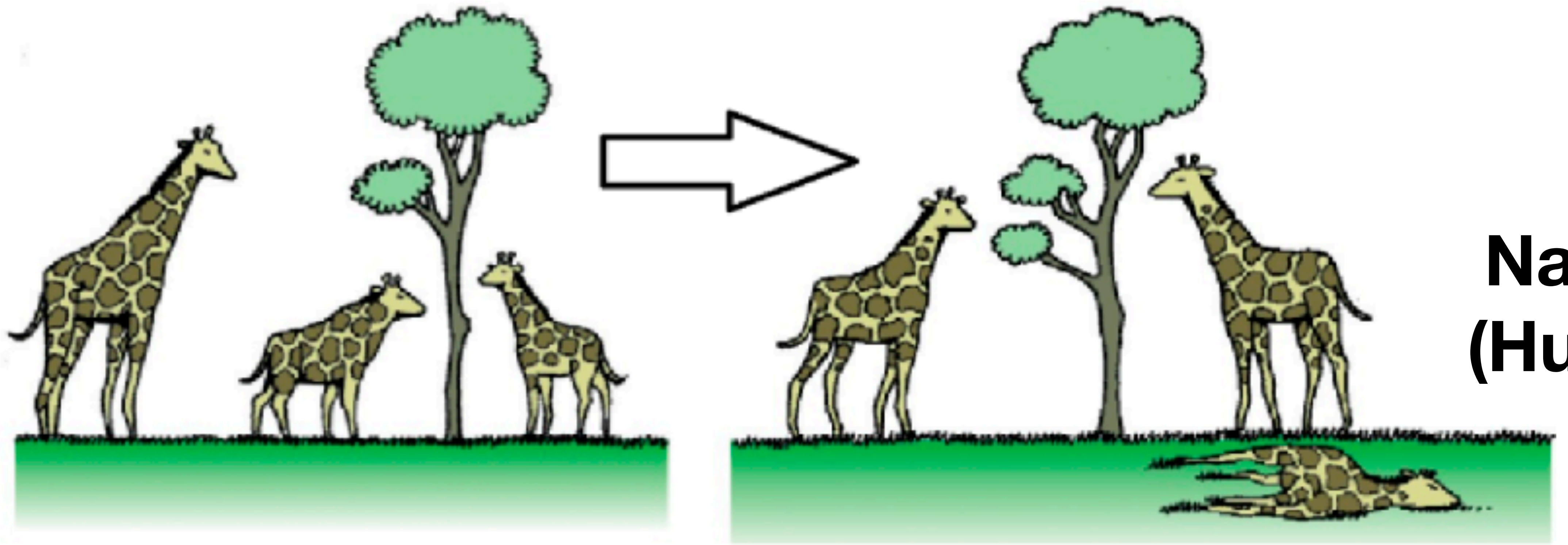
dS self-organized criticality : dS intrinsic quantum effects can drive universes toward a critical point, independently on initial conditions.

Apparent Higgs fine-tunings can indeed be due to dS SOC.

Hubble selection is analogous to Natural selection.

SOC requires long inflation, sensitive to quantum gravity.

mutations (quantum fluctuations)



Natural selection (Hubble selection)