



李政道研究所
TSUNG-DAO LEE INSTITUTE

Implications of Topological Field Configurations for Baryon Asymmetry and Dark Matter

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Tsung-Dao Lee Institute / Shanghai Jiao Tong University

In cooperation with Michael Ramsey-Musolf, Xu-Xiang Li, Lorenzo Sorbo,
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Dr. Tsung-Dao Lee and Shanghai

40th Anniversary of the Implementation of the Postdoctoral System in Shanghai

2025/9/25

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The nature of dark matter?

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$$B = C(B_{\text{ini}} - L_{\text{ini}})$$

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Be careful: The broken phase does NOT means out of equilibrium for baryon number violation (BNV).

BNV out of equilibrium criterion:

$$\text{BNV rate (T)} < \text{Hubble constant (T)}$$

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EWBG, in the broken phase, we might have BNV rate $>$ Hubble constant, which will erase all the baryon asymmetry.

A rigorous computation of BNV rate (sphaleron rate) in the broken phase is crucial.

The tradition condition

BNV out of equilibrium criterion:

$$\text{BNV rate (T)} < \text{Hubble constant (T)}$$

Why we cannot trust the $\frac{v_c}{T_c} > 1$ condition?

It comes from the traditional sphaleron rate computations:

$$\Gamma_{\text{BNV,sph}} \sim T^4 \kappa e^{-B v_c/T_c} \lesssim H, \quad \text{with } B \simeq 1.9$$

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Drawbacks:

- v_c is the minimal of V_{eff} , which is gauge dependent under the general R_ξ gauge. Different gauges might lead into different lower bound.
- The B is chosen as the SM value; while BSM can modify this value, especially in 2HDM, Georgi-Machacek, etc.
- The effect of zero modes and positive modes (κ) are not been consistently considered for BSM.

Gauge invariant rigorous sphaleron rate

BNV out of equilibrium criterion: $\text{BNV rate (T)} < \text{Hubble constant (T)}$

Our approach: sphaleron rate under 3D EFT for SM EFT (BSM are heavy to be integrated out).

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$$\Gamma_{\text{BNV,sph}}(x, y) \sim T^4 (\text{zero modes}(x, y)) e^{-f(x, y)}$$

$$x = \frac{\text{Higgs selfcoupling}_3}{\text{gauge coupling}_3^2} \quad y = \frac{\text{Higgs mass}_3^2}{\text{gauge coupling}_3^4}$$

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Zero modes are consistently considered.

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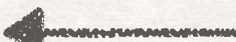
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$$\frac{v_c}{T_c} > 1$$

- v_c gauge dependent and fixed B 
- No consistent zero and positive modes 
- Condition immediately in the broken phase 

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- x, y are gauge invariant quantities under power counting (to g^4);
- Two-loop matching under 3D EFT
Zero modes are consistently considered.
- Quantitatively control of baryon washout in the broken phase.

New baryon number preservation condition

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BSM fields (different BSM parameters) will modify the values of x, y .

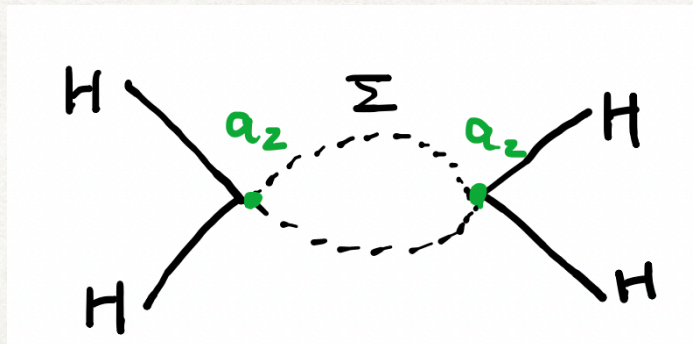
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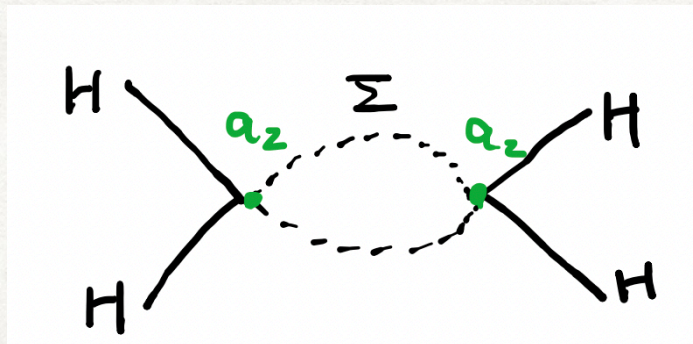
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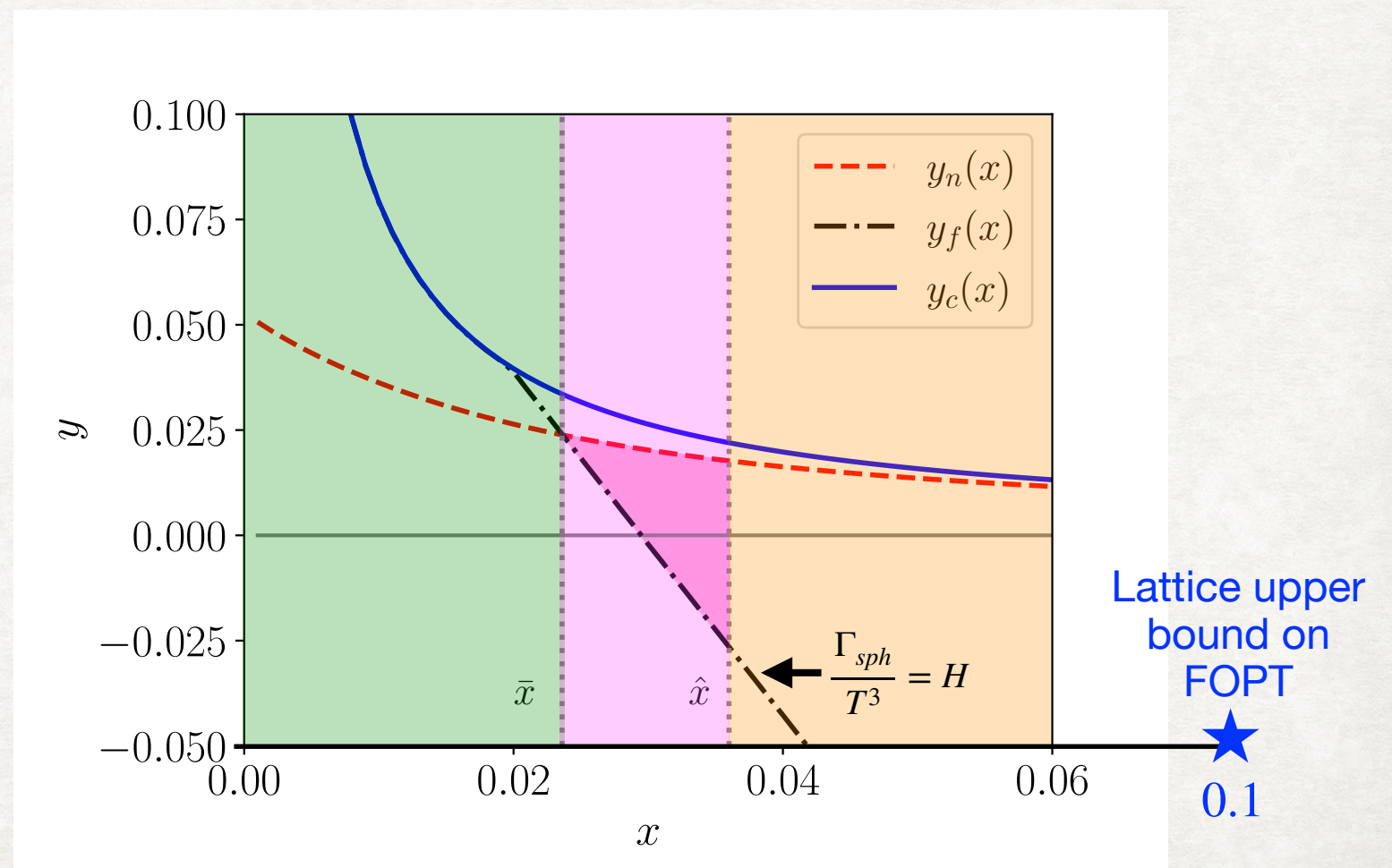
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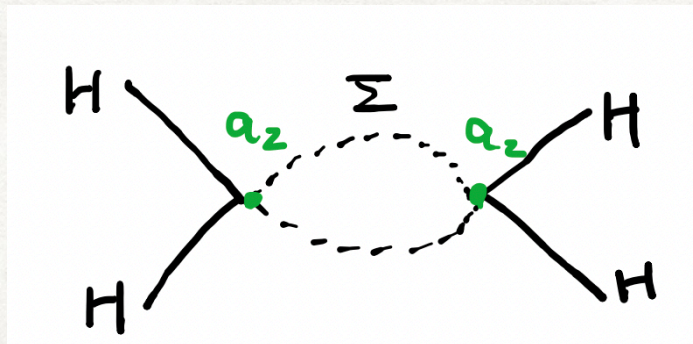
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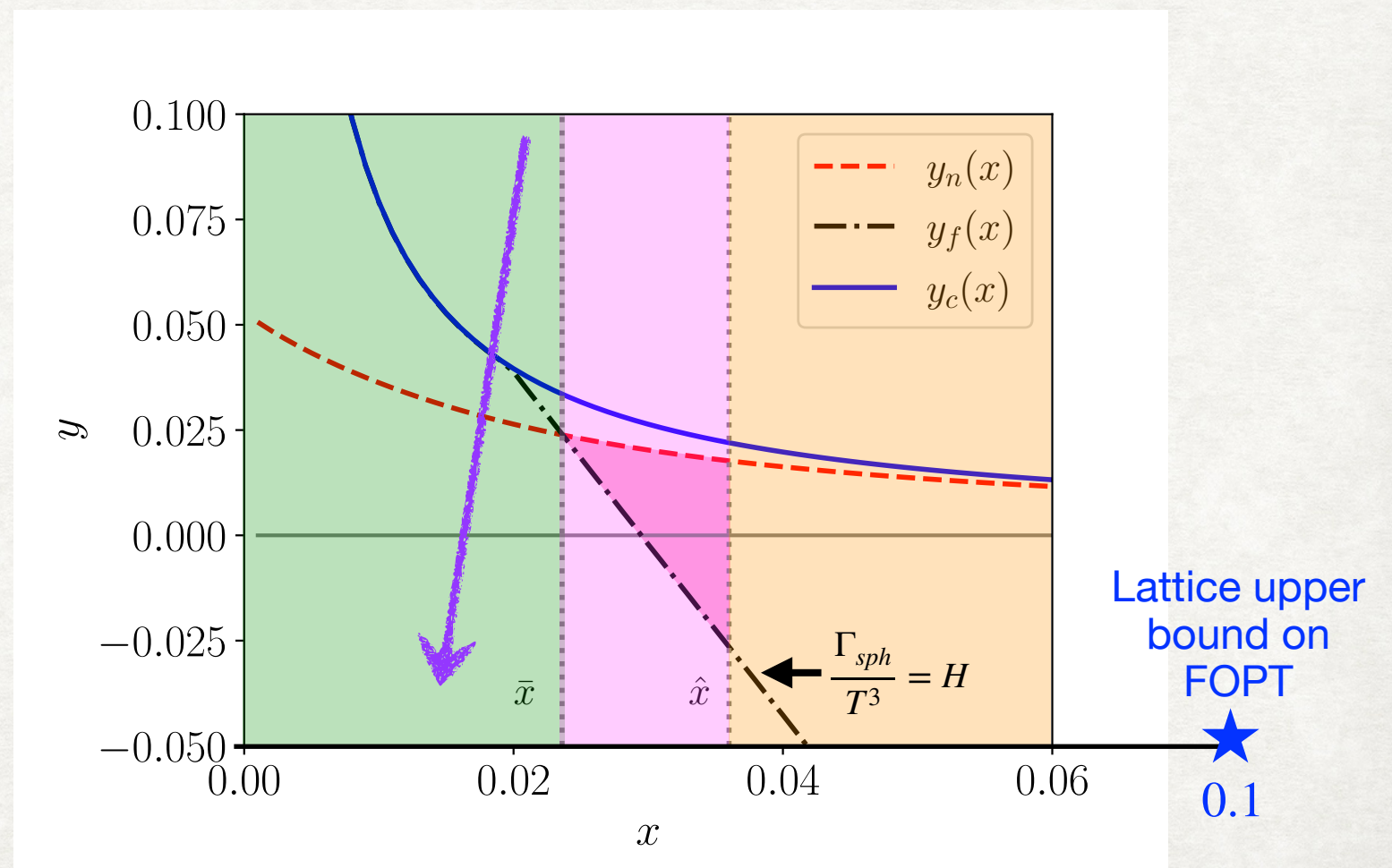
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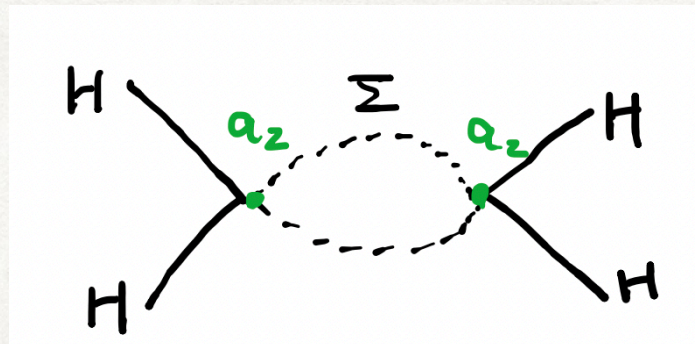
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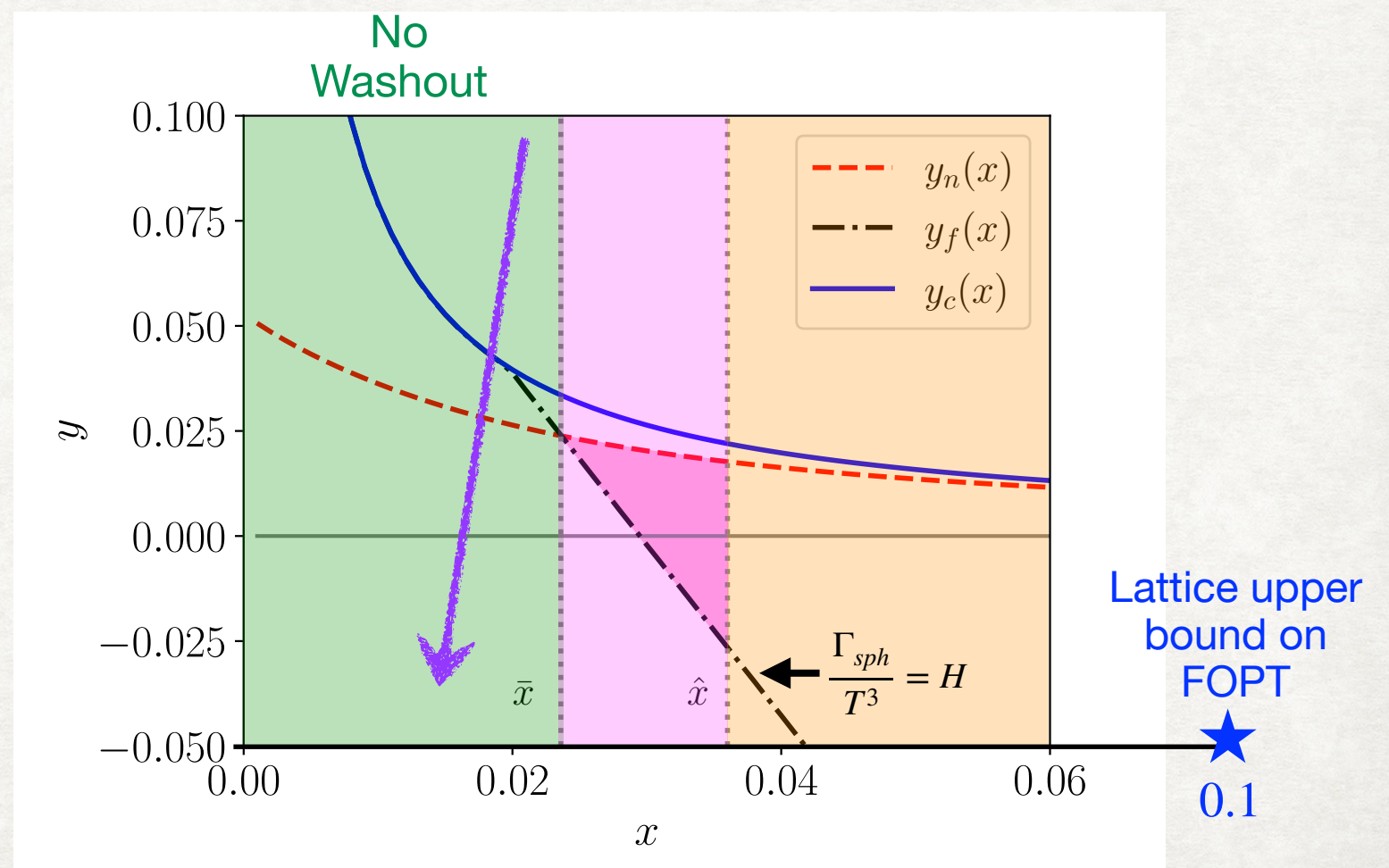
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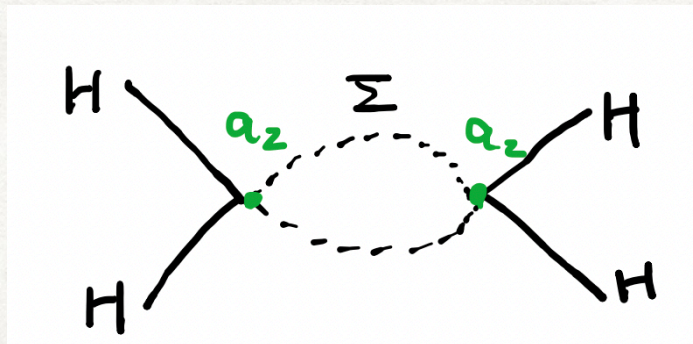
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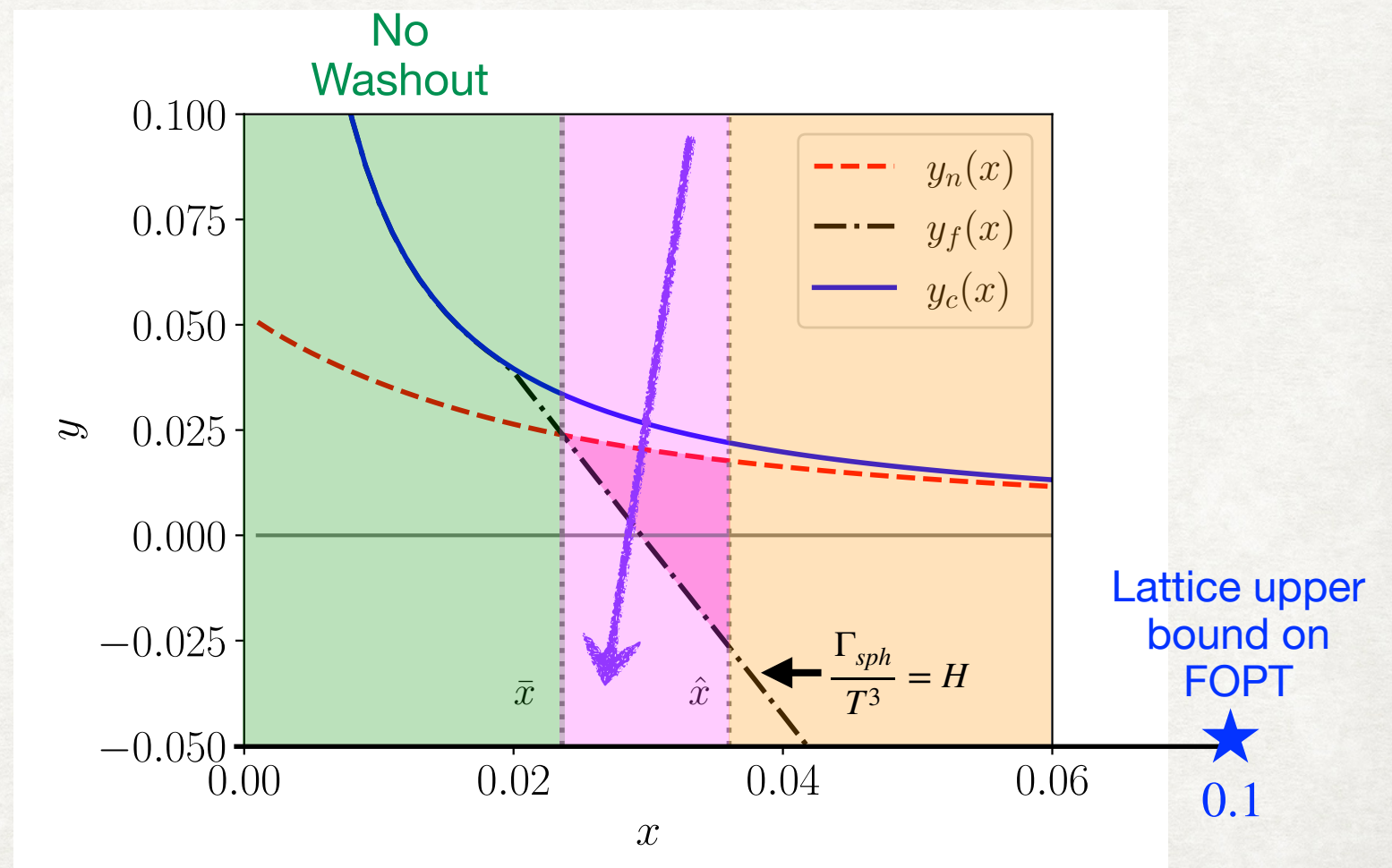
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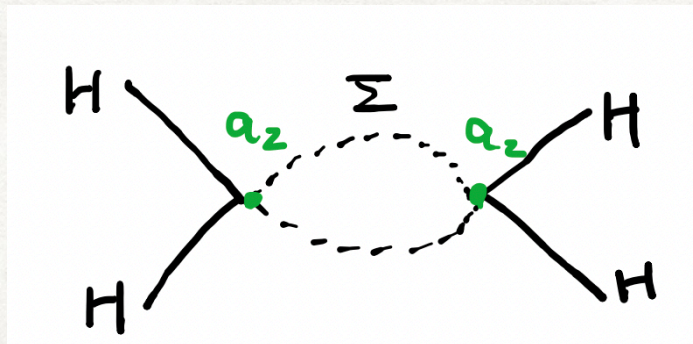
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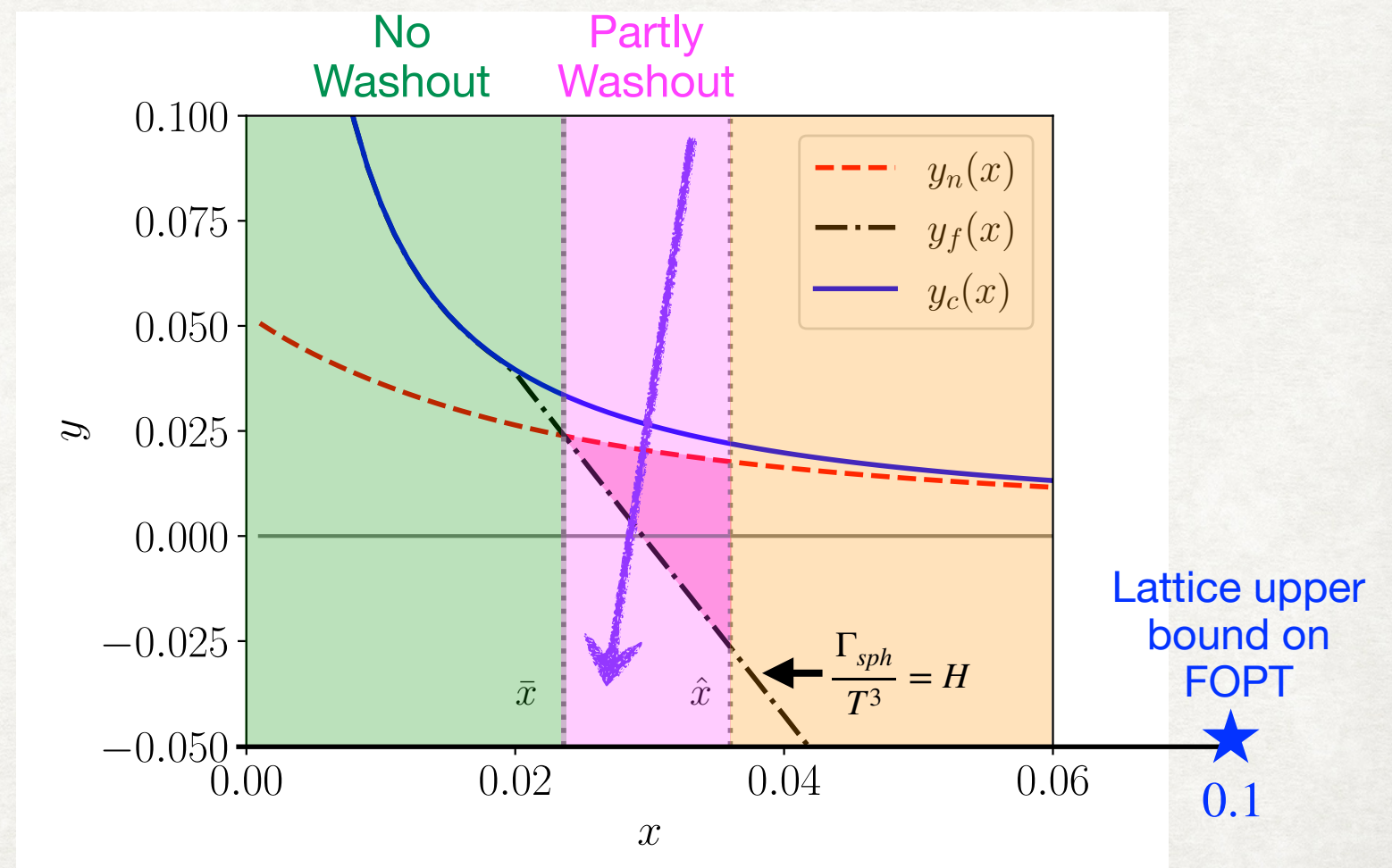
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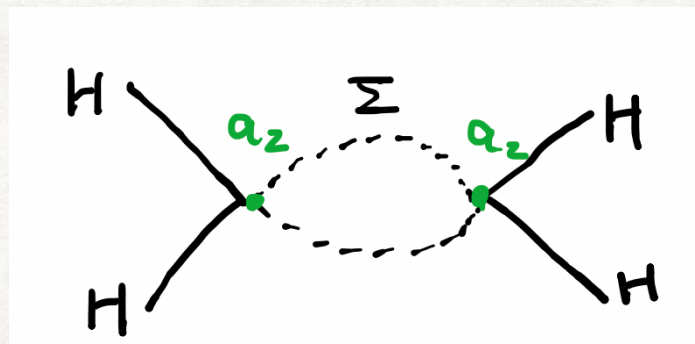
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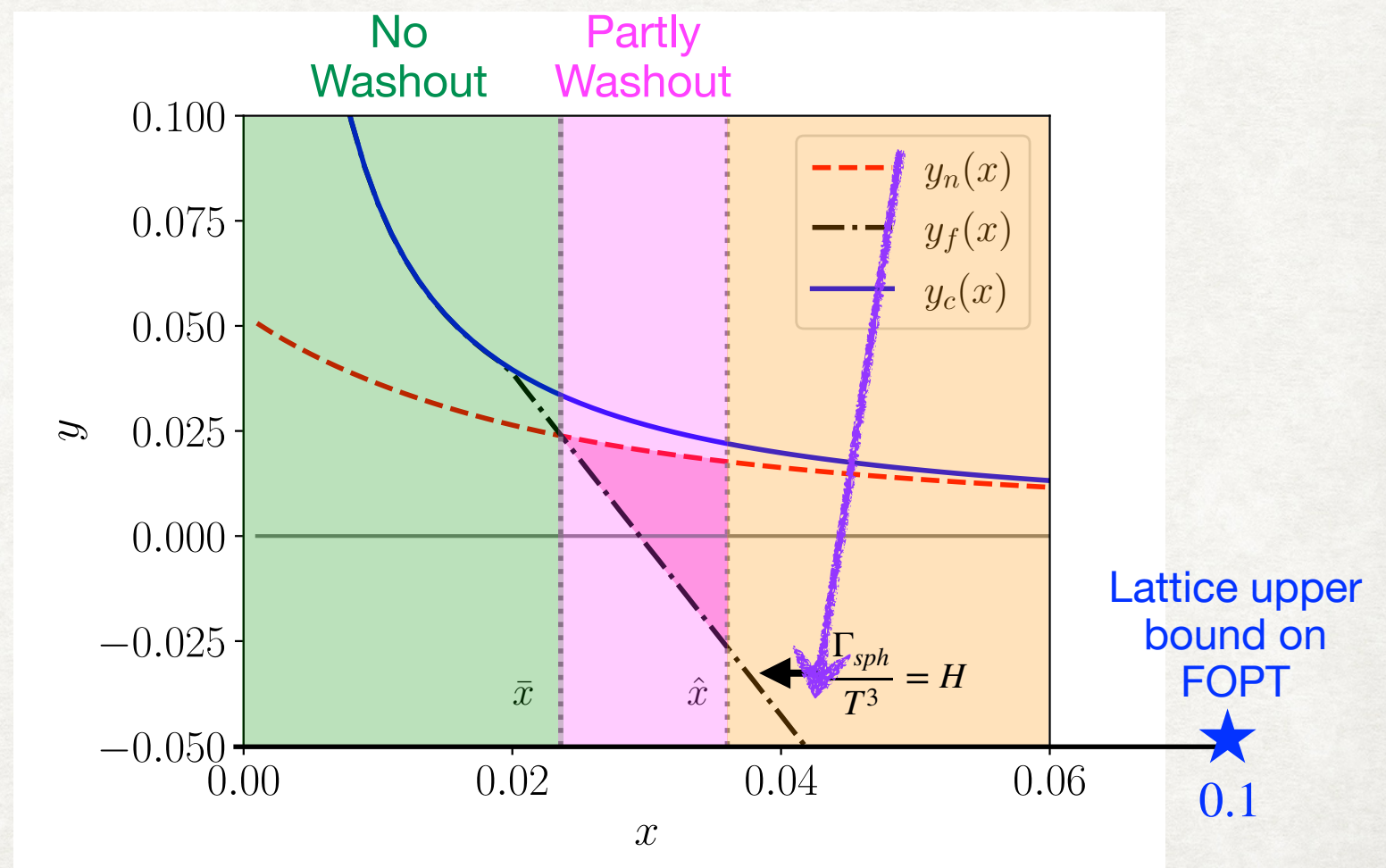
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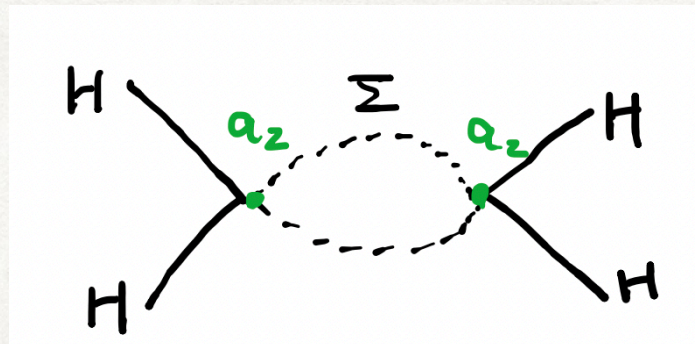
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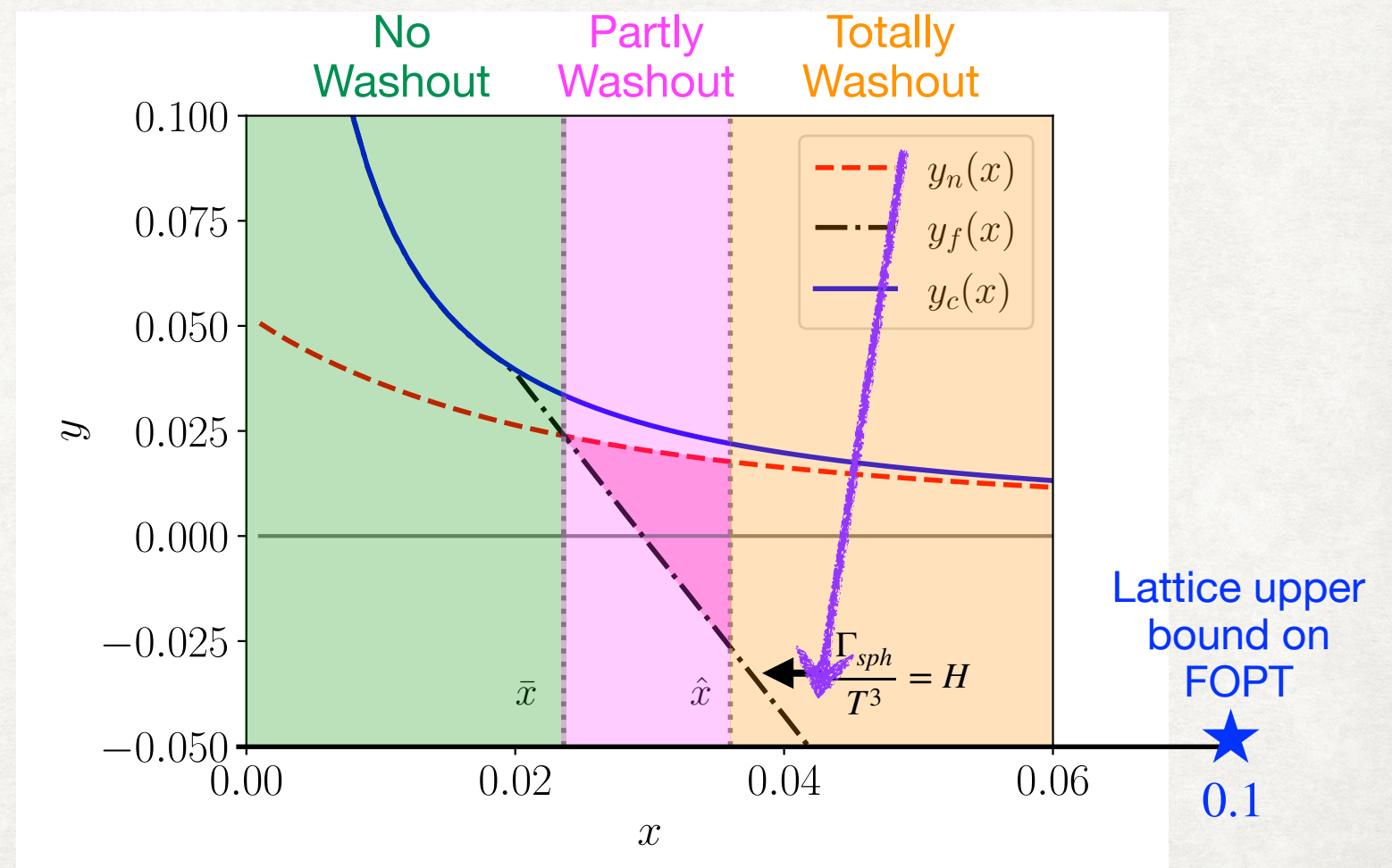
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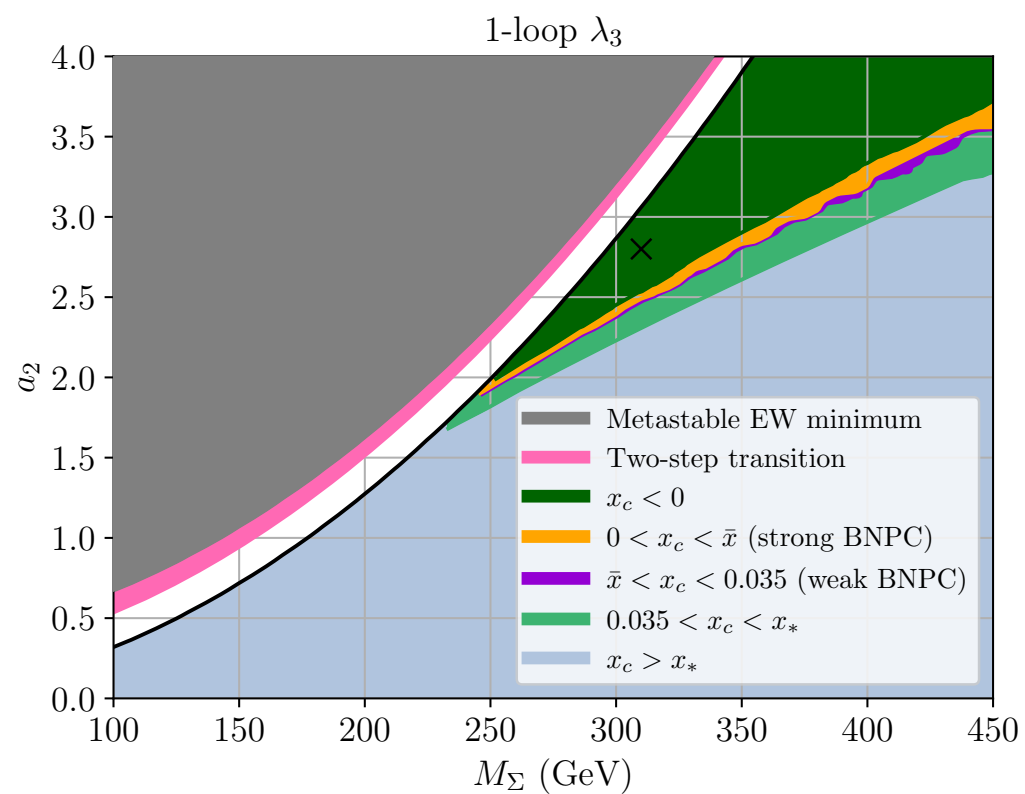
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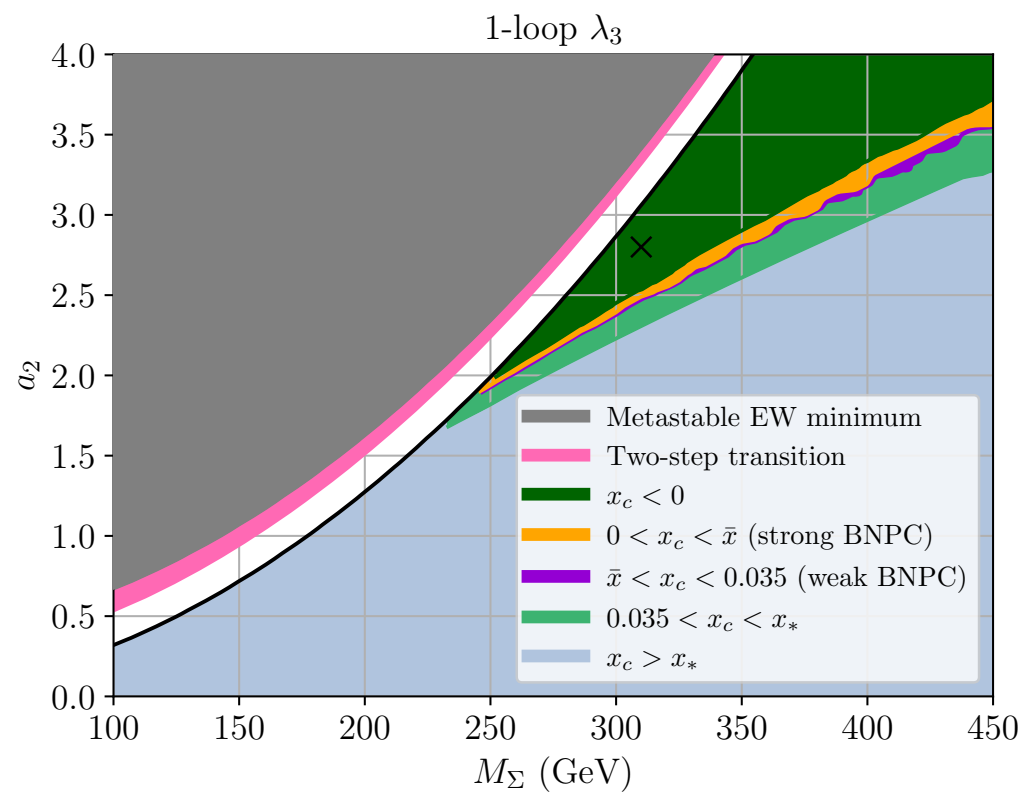
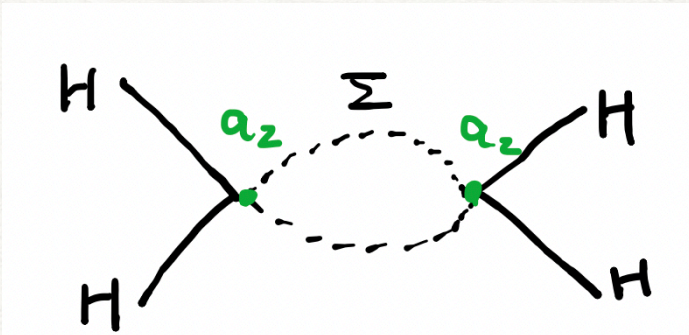
BSM applications: real triplet extension

a_2 : portal coupling between triplet (Σ) and Higgs (H)



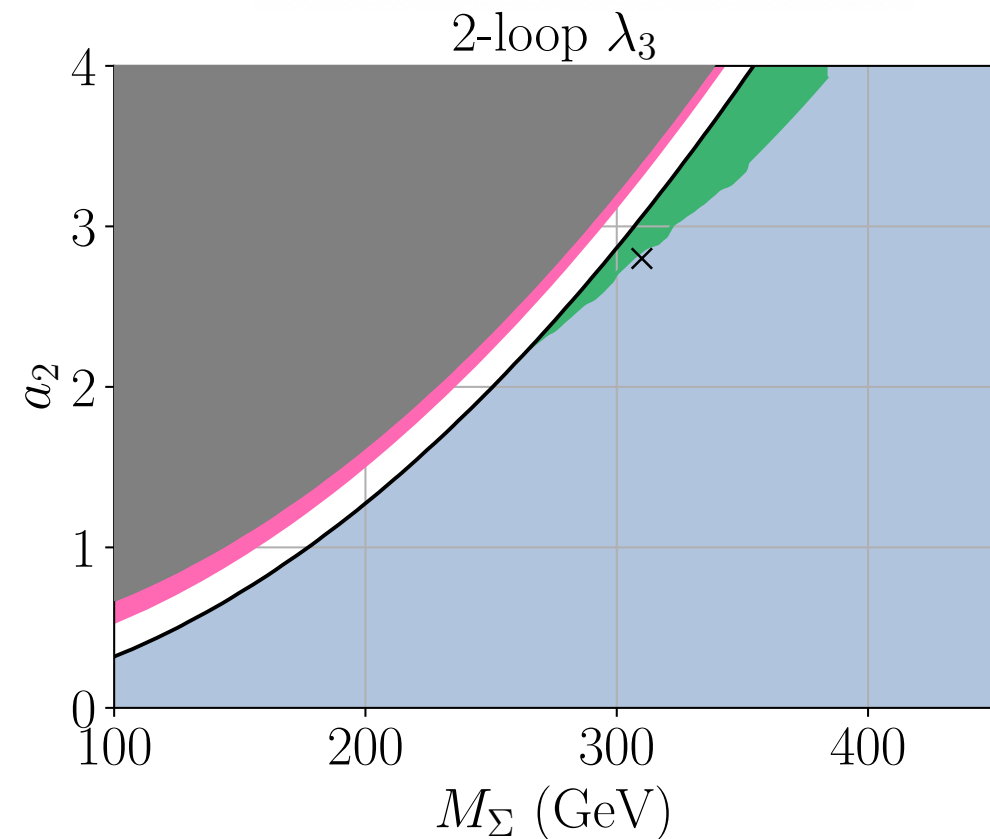
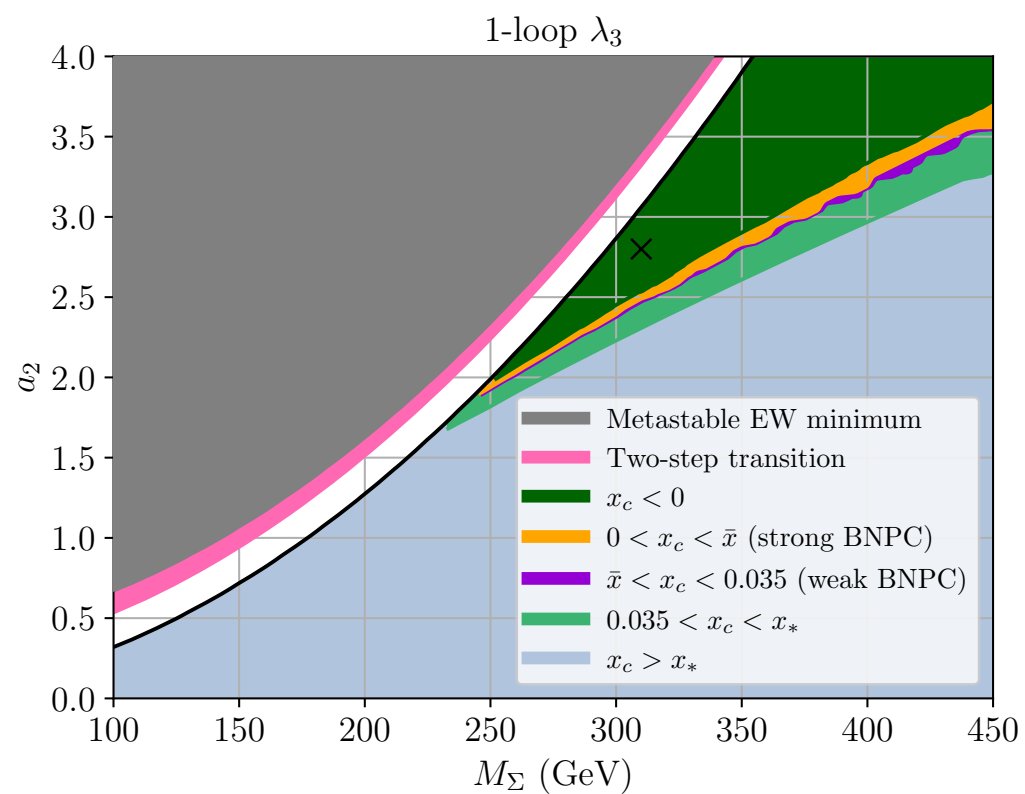
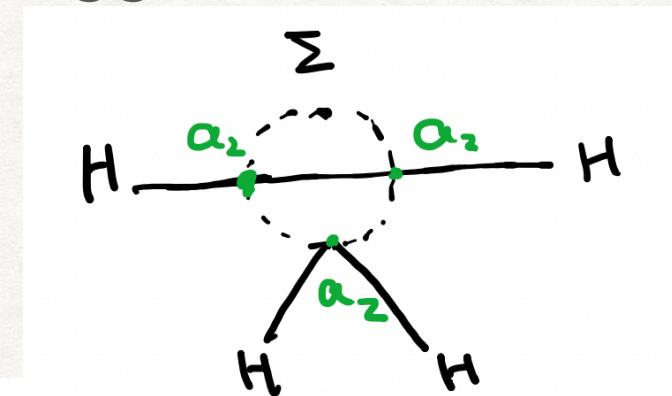
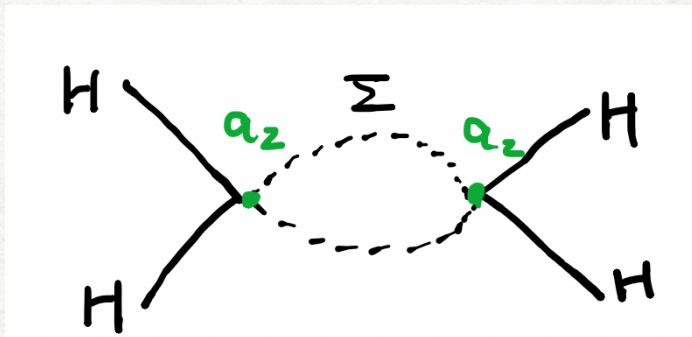
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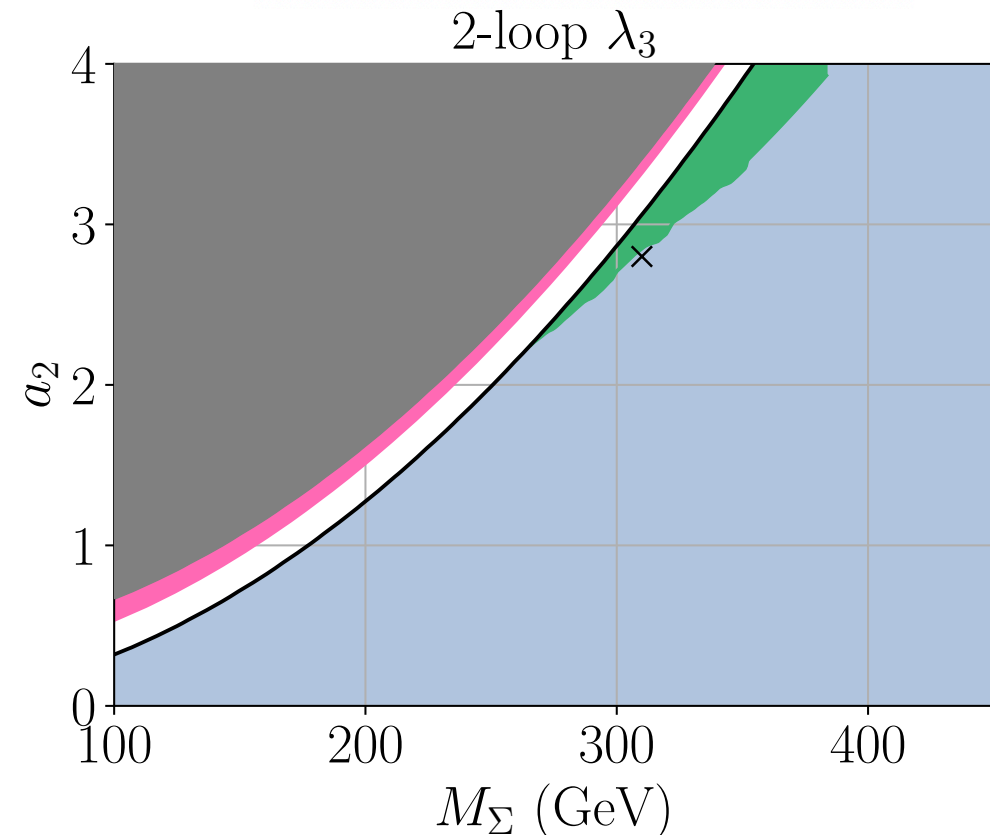
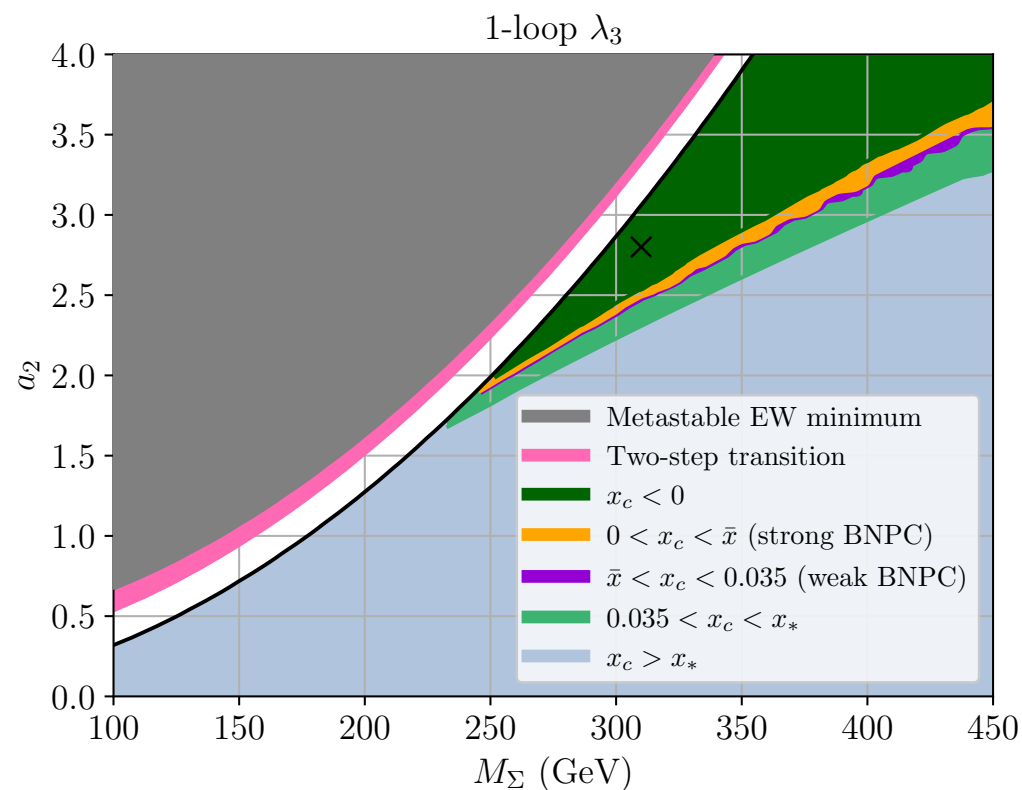
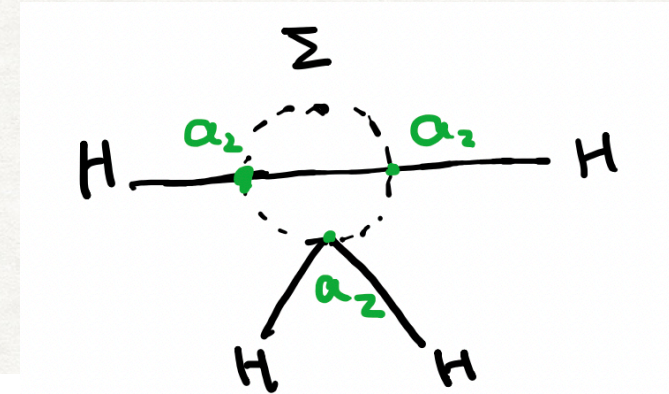
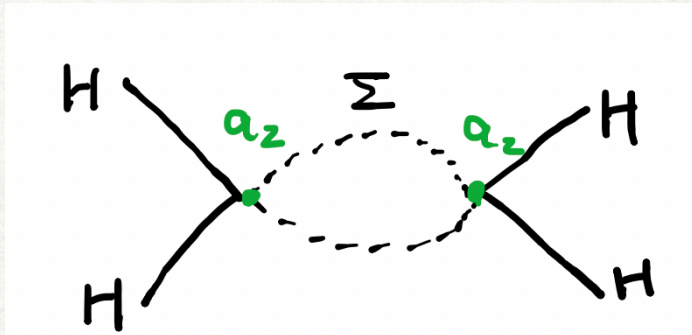
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At 1-loop level, there are (No, Partly, Totally) Washout regions.

At 2-loop level, region only with Totally Washout! (All parameters fails for EWBG).

Summary

- The topological field configurations play an important role to understand the baryon asymmetry and dark matter of our universe.
- A rigorous computation of sphaleron rate in the EW vacuum is crucial for electroweak baryogenesis.
- The traditional baryon number preservation (out of equilibrium) condition $v_c/T_c > 1$ is inaccurate and gauge-dependent. We propose new condition in the 3D $x - y$ panel, which is accurate and gauge independent.
- Two loop thermal corrections from the BSM fields are important to determine the properties of baryon washout and phase transition.