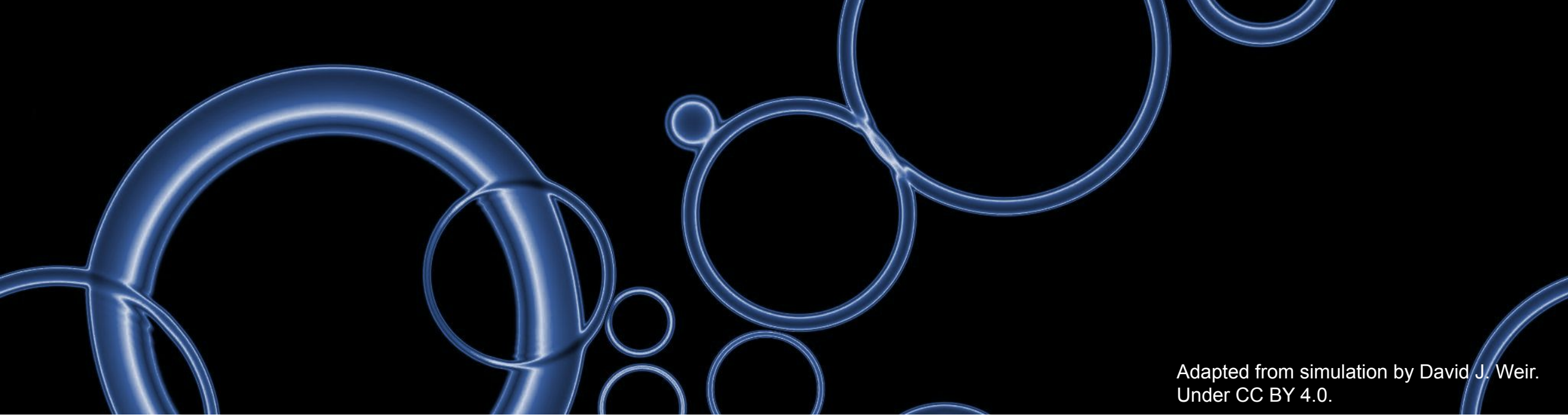


Hot news on the phase structure of the (SM)EFT

VAST 2026 · Universidad Complutense de Madrid | October 22nd 2026

Luis Gil (Universidad de Granada)

Based on:

M. Chala, M. C. Fiore and **LG** [2505.14335]

Funded by the European Union

European Research Council
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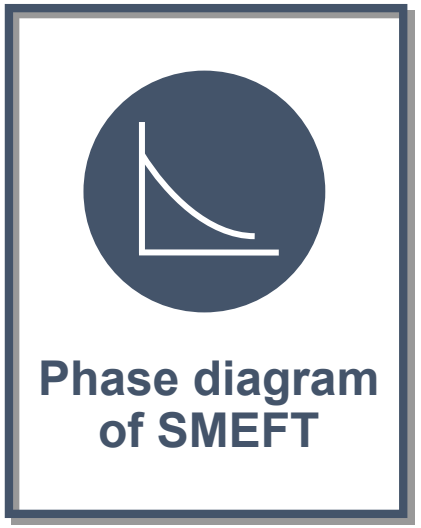
FTAE High Energy Theory

Junta de Andalucía

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Outline







3D EFT approach

IR problem of thermal field theory

[Laine, Vuorinen - 1701.01554]

- Thermal field theory in equilibrium = Euclidean QFT with periodic time:

$$\mathcal{Z}_{\rm th} = \mathrm{Tr}\left(e^{-\beta\mathcal{H}}\right) = \sum_q \langle q\ 0|e^{-\beta\mathcal{H}}|q\ 0\rangle = \mathcal{N}\int_{q(0)=q(-i\beta)} \mathcal{D}q \exp\left(-S_E\right)$$

- Fields decompose in tower of 3D **Matsubara modes** (~ Kaluza-Klein) with thermal masses:

Bosons: $\omega_n = 2\pi n T$

Fermions: $\omega_n' = 2\pi\left(n+\frac{1}{2}\right)T$

$$\int \frac{d^4P}{(2\pi)^4} f(P) \longrightarrow \sum\!\!\!\!\!\!\int_P f(\omega_n,\mathbf{p}) \equiv T\sum_{n\in\mathbb{Z}} \int \frac{d^3\mathbf{p}}{(2\pi)^3} f(\omega_n,\mathbf{p})$$

Sum-integrals

3D EFT approach

IR problem of thermal field theory

[Laine, Vuorinen - 1701.01554]

$$\oint\!\!\!\!\!\!\sum_{P} f(\omega_n, \mathbf{p}) \sim \int \frac{d^3\mathbf{p}}{(2\pi)^3} \int_{-\infty-i0^+}^{\infty-i0^+} \frac{d\omega}{2\pi} f(\omega, \mathbf{p}) n_{\mathrm{B}}(i\omega) \xrightarrow{T\gg E} \frac{T}{E^2}$$

Bosonic zero modes lead to IR divergences



3D EFT approach

IR problem of thermal field theory

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Bosonic zero modes lead to IR divergences

Even for weak coupling ($g^2 << \pi^2$) bosonic zero modes require **resummation.** Then:

- Perturbative expansion organized in **couplings**, not in loops
- Temporal gauge bosons get a perturbative **Debye mass:** $m_D \sim gT$
- Spatial gauge bosons get a **nonperturbative thermal mass:** $m_{NP} \sim g^2 T$ (Linde problem)

3D EFT approach

IR problem of thermal field theory

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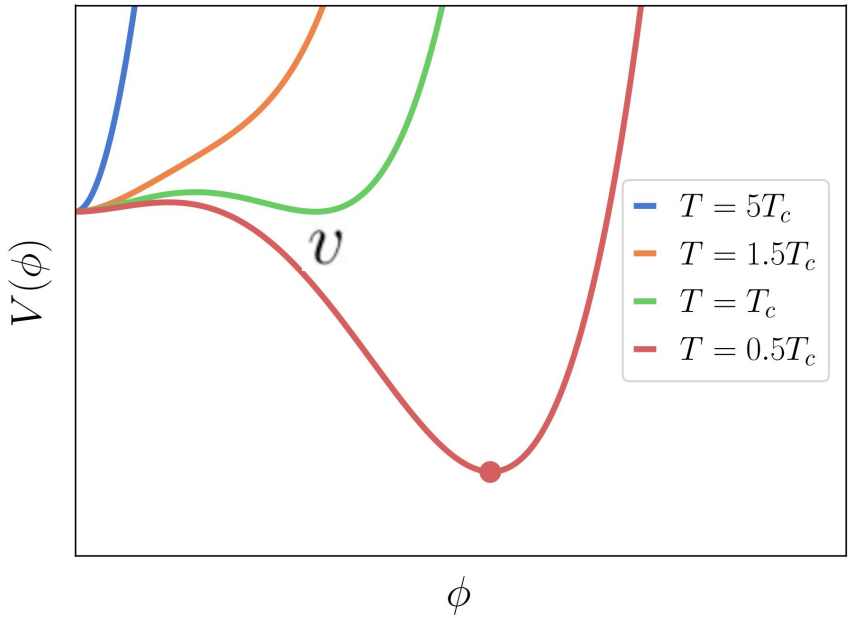
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Hierarchy of scales w.r.t. $m_{hard} \sim \pi T$ handled with **(3D) EFT for bosonic zero modes**

3D EFT approach

Application to EWPT

Also, **during a phase transition** the thermal mass of the Higgs is very small:

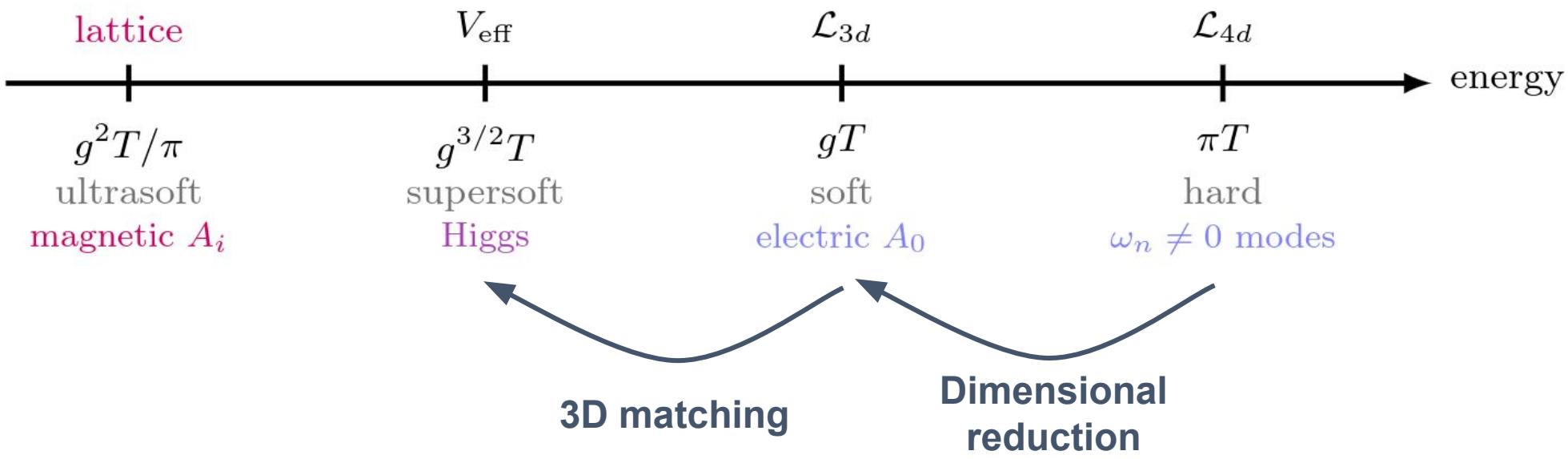


$$V_{\text{eff}}(v; T_c) = 0 \iff m^2(T) \approx -\mu^2 + \#g^2T^2 \approx 0$$
$$\implies m^2(T) \gtrsim g^2T^2$$

3D EFT approach

Application to EWPT

[Laine, Vuorinen - 1701.01554]



(*) Kindly stolen from P. Schicho's talk at GWPT'26



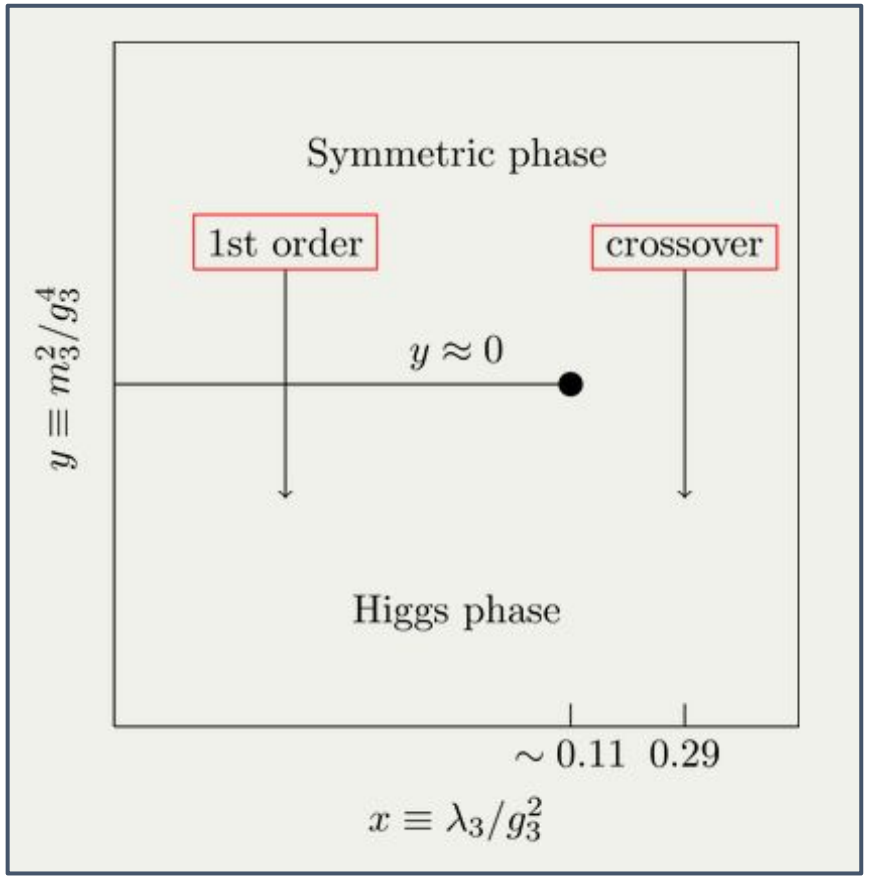
GOAL

Use high-T framework to study the phase diagram of the **SM(EFT)**

Phase diagram of the SMEFT

Higgs phase diagram

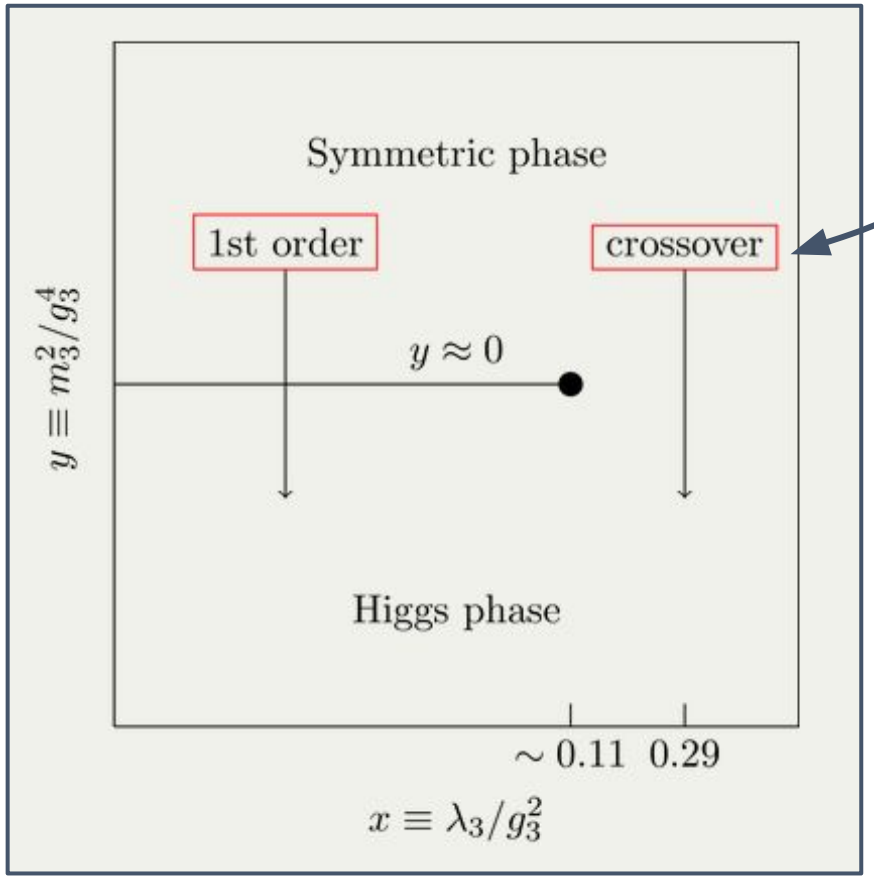
[Kajantie et al. - hep-ph/9605288]
[Gürtler et al. - hep-lat/9704013]
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Phase diagram of the SMEFT

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No electroweak first-order phase transition (FOPT) in **SM** :(

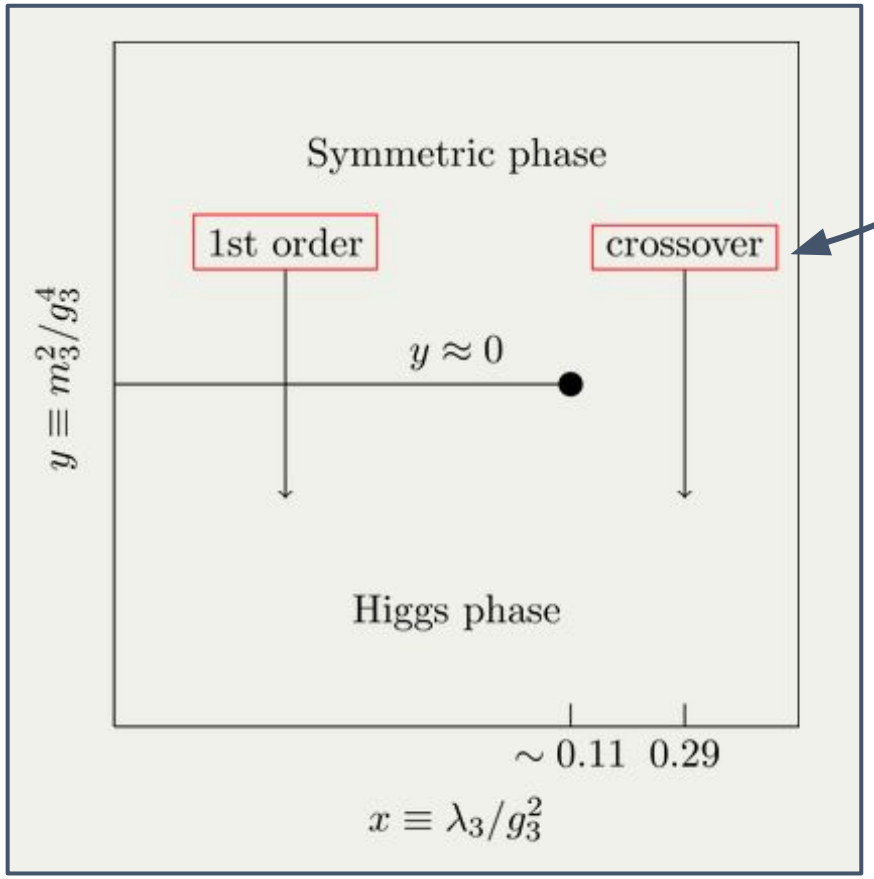
Many unknowns:

- What then caused baryogenesis?
- What BSM physics can trigger a FOPT?
- Can we expect to tell them apart through GWs?

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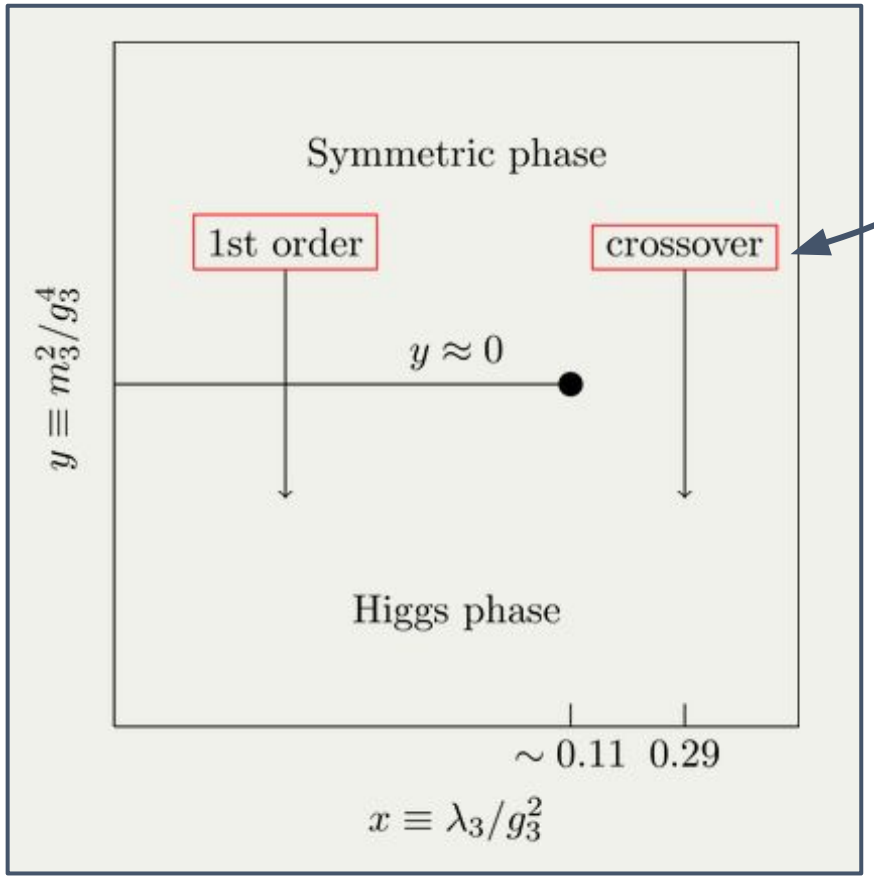
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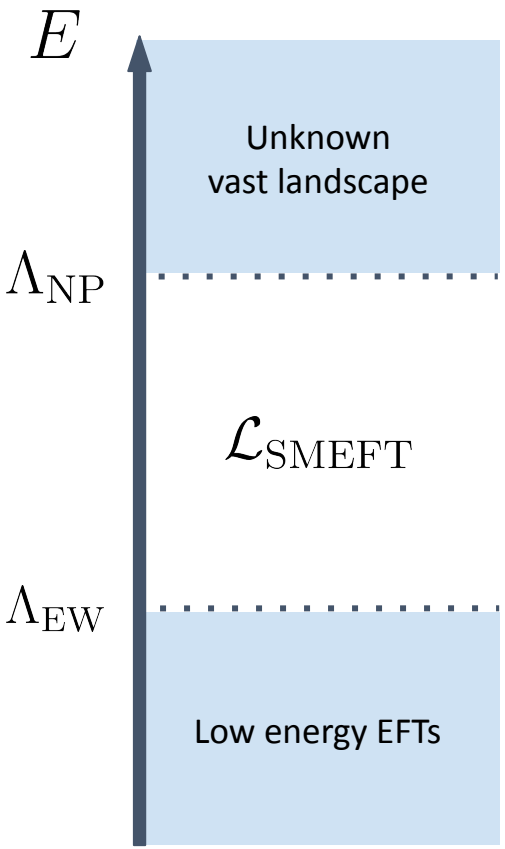
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→ **Let's take a look at the SMEFT!**

Phase diagram of the SMEFT

What is the SMEFT?

[Buchmuller, Wyler - NPB 268 (1986) 621-653]



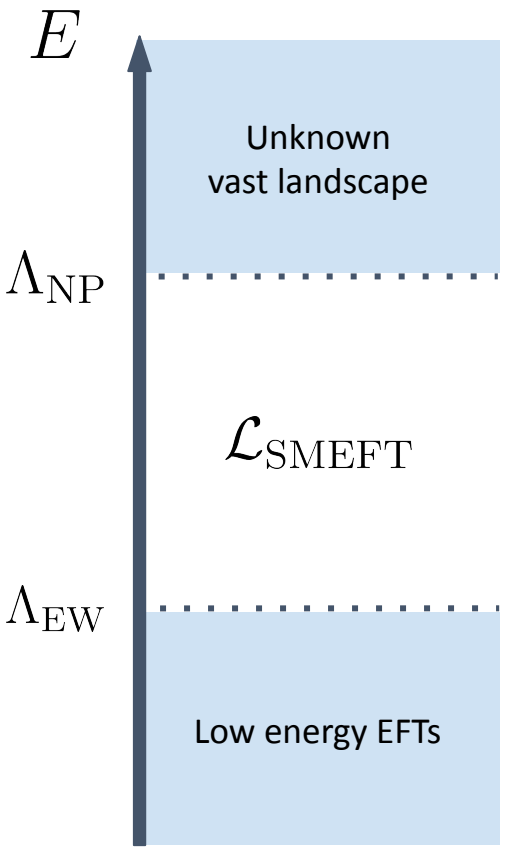
- **SMEFT** captures all heavier-than-$\Lambda_{\rm EW}$ physics as tower of effective operators

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_{\ell=0}^{\infty} \sum_{n=5}^{\infty} \sum_{k} \frac{c_{n,k}^{(\ell)}}{(4\pi)^{2\ell} \Lambda^{n-4}} \mathcal{O}_{n,k}$$

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PROS

- Whole classes of BSM models at once without new fields
- Universal framework to compare with experiments

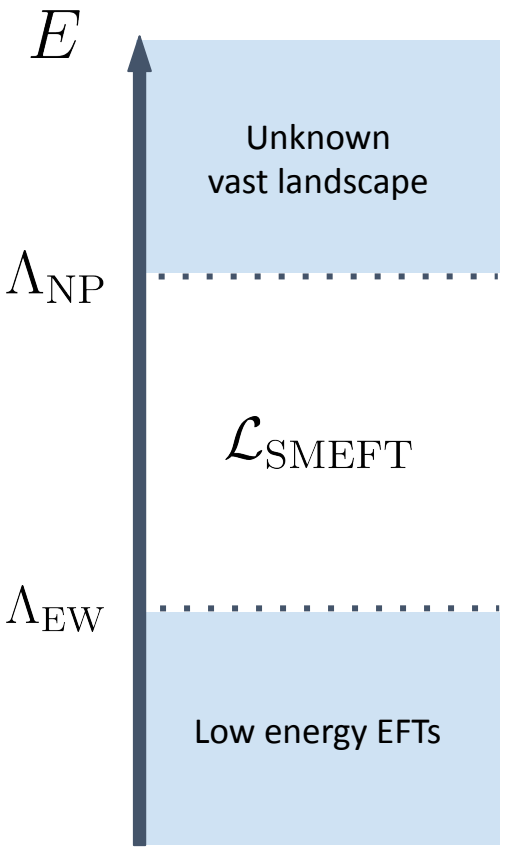
CONS

- No lighter-than-$\Lambda_{\rm EW}$ new physics
- Only Higgs phase transition

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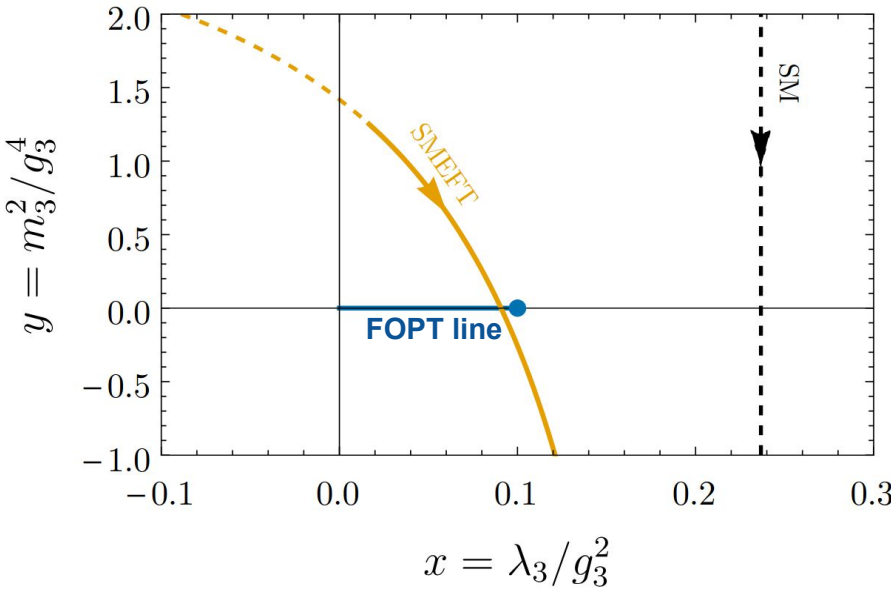
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$$x, y = f(c_i^{(\rm SM)}; T)$$

$$x', y' = f(c_i^{(\rm SMEFT)}; T)$$

Modify how potential evolves with T





Phase diagram of the SMEFT

Scanning its parameter space

DIMENSIONAL REDUCTION

At **T ~ 100 GeV,** a hierarchy of thermal scales allows us to construct a **bosonic 3D EFT** for thermal equilibrium.

SM-like theories reduce to:

$$\mathscr{L}_{3\mathrm{D}} = \frac{1}{4} W_{ij}^I W_{ij}^I + (D_i\phi)^\dagger (D_i\phi) + m_3^2 |\phi|^2 + \lambda_3 |\phi|^4$$

where now all couplings are **functions of T.**

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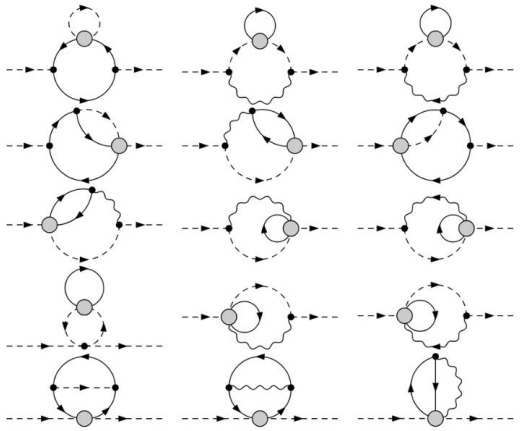
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Example: Two-loop matching of Higgs thermal mass

$$\Delta m_\phi^2 = \Big[-\frac{1}{4} c_\phi + \frac{47}{3} g_S^2 c_{\phi G} + \frac{1}{576} |Y_u|^2 \big(30 c_{\phi\Box} - 15 c_{\phi D} + 6 c_{\phi u} - 6 c_{\phi q}^{(1)} + 18 c_{\phi q}^{(3)} + 24 c_{qu}^{(1)} + 32 c_{qu}^{(8)} \big) + \frac{3}{64} \big(16 g_S c_{uG} Y_u^* - 3 c_{u\phi} Y_u^* + \text{h.c.} \big) \Big] T^4 \,,$$



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MATCHETE

Dimensional reduction of arbitrary theories (SMEFT too) at arbitrary EFT order

[Fuente-Martín et al. - 2604.21972]

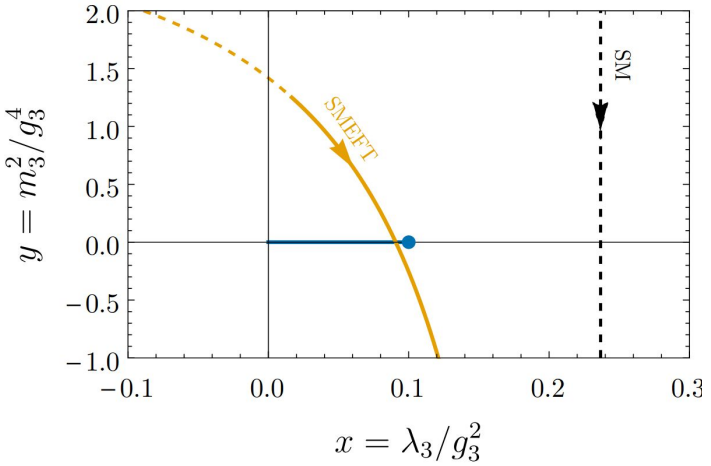
(*) Stay tuned for two-loops!

Phase diagram of the SMEFT

Scanning its parameter space

- Huge parameter space: **SMEFT @ dim-6** contains **59 independent operators (non B or L violating)**

- Which get us **closer to the FOPT line**?
  - Must make x smaller
  - Must be relatively unconstrained from collider data

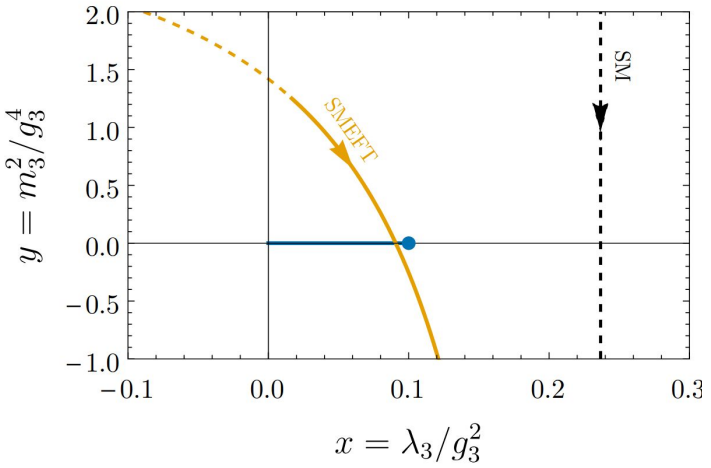


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$$\mathcal{O}_\phi \equiv (\phi^\dagger\phi)^3$$

[Camargo-Molina et al. - 2103.14022]

$$\mathcal{O}_{\phi\Box} \equiv (\phi^\dagger\phi)\Box(\phi^\dagger\phi)$$

$$\mathcal{O}_{t\phi} \equiv \bar{t}_L\tilde{\phi}t_R(\phi^\dagger\phi)$$

(Hot) new!



Phase diagram of the SMEFT

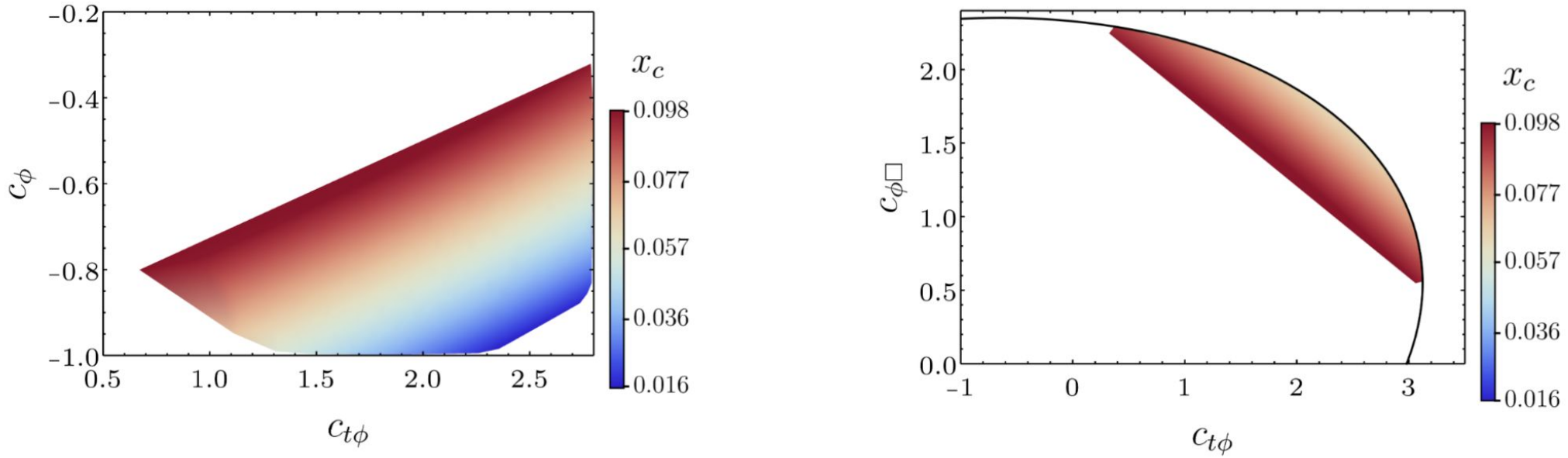
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Phase diagram of the SMEFT

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[Chala, Fiore, LG - 2507.16905]

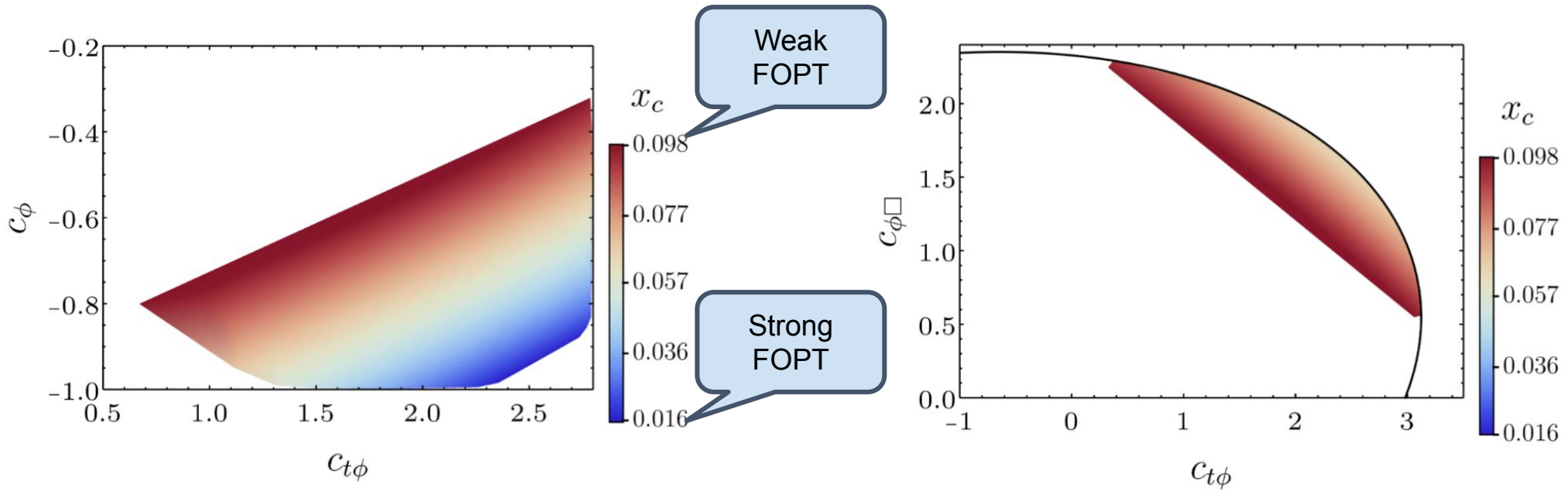


Figures: Regions of the parameter space (in TeV^{-2}) within collider bounds with a FOPT. In both panels, the non-appearing coefficient is set to zero.

Phase diagram of the SMEFT

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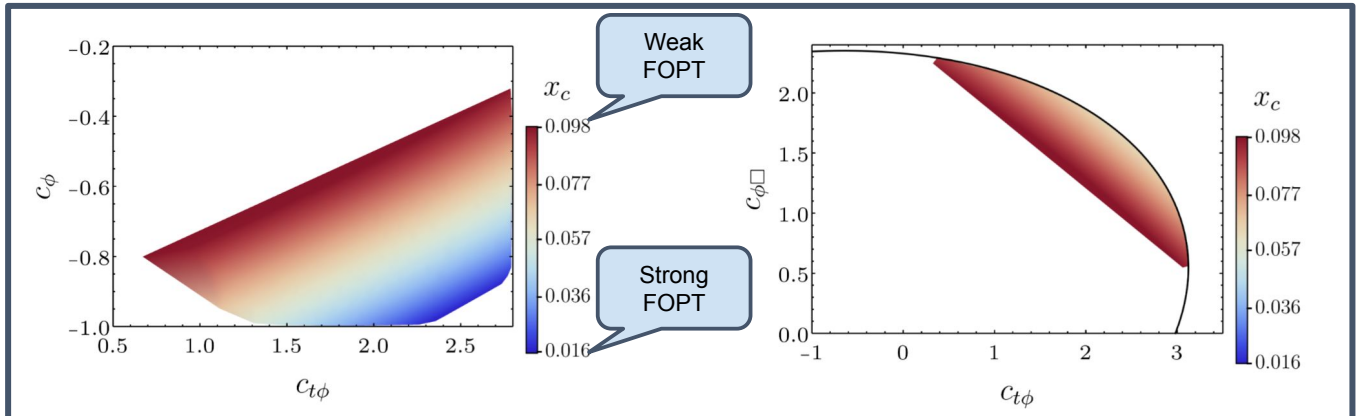


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Figures: Regions of the parameter space (in TeV^{-2}) within collider bounds with a FOPT. In both panels, the non-appearing WC is set to zero.

- FOPTs possible without direct modification of the Higgs potential **(with $c_\phi = 0$)**.

- Strong FOPTs **with joint contributions** of the three dim-6 operators, with all of them carrying **at most O(1) TeV^{-2} coefficients**.

Conclusions

- Computed, for the first time, the full O(g^4) high-temperature limit of the SMEFT.
- Explored new directions in its vast parameter space, constrained by collider bounds.
- Found that FOPTs are possible even without the sextic operator, but it is needed for strong FOPTs

  ⟶ BSM models that generate $\mathcal{O}_{t\phi} \equiv \bar{t}_L \tilde{\phi} t_R (\phi^\dagger \phi)$ at low energies worth checking too!

- Few works have addressed FOPTs in the SMEFT so far:

  [Camargo-Molina et al '22] [Camargo-Molina et al '24] [Chala, Guedes '25] [Chala, Fiore, LG '25]

What's left to do? 🔍

SMEFT @ O(g^6) Full nucleation study? HEFT? …