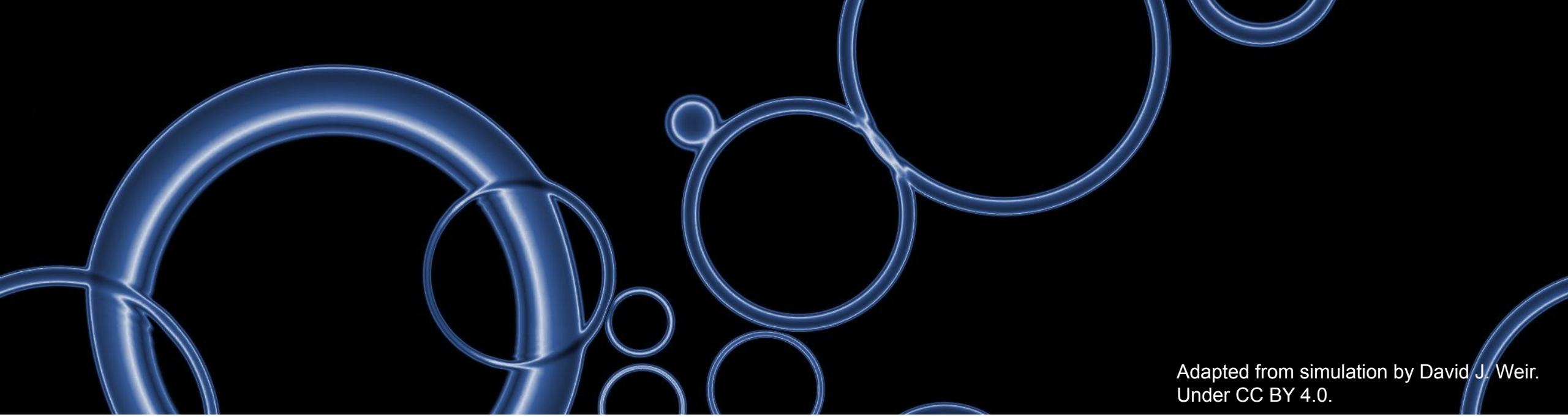


Hot news on the phase structure of the SMEFT

YOUNGST@RS - Shaping the Universe · MITP | January 27th 2026

Luis Gil (Universidad de Granada)

Based on:

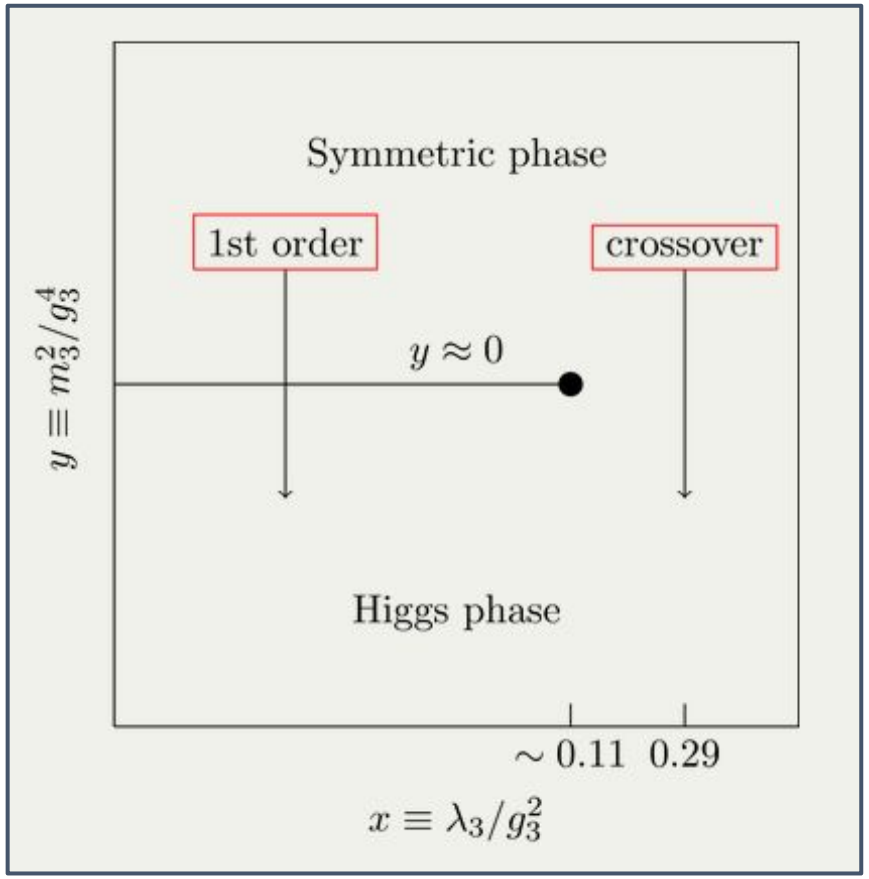
M. Chala, M. C. Fiore and **LG** [2505.14335]

FTAE High Energy Theory
Junta de Andalucía
GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Introduction

Higgs phase diagram

[Kajantie et al. - hep-ph/9605288]
[Gürtler et al. - hep-lat/9704013]
[Csikor et al. - hep-ph/9809291]



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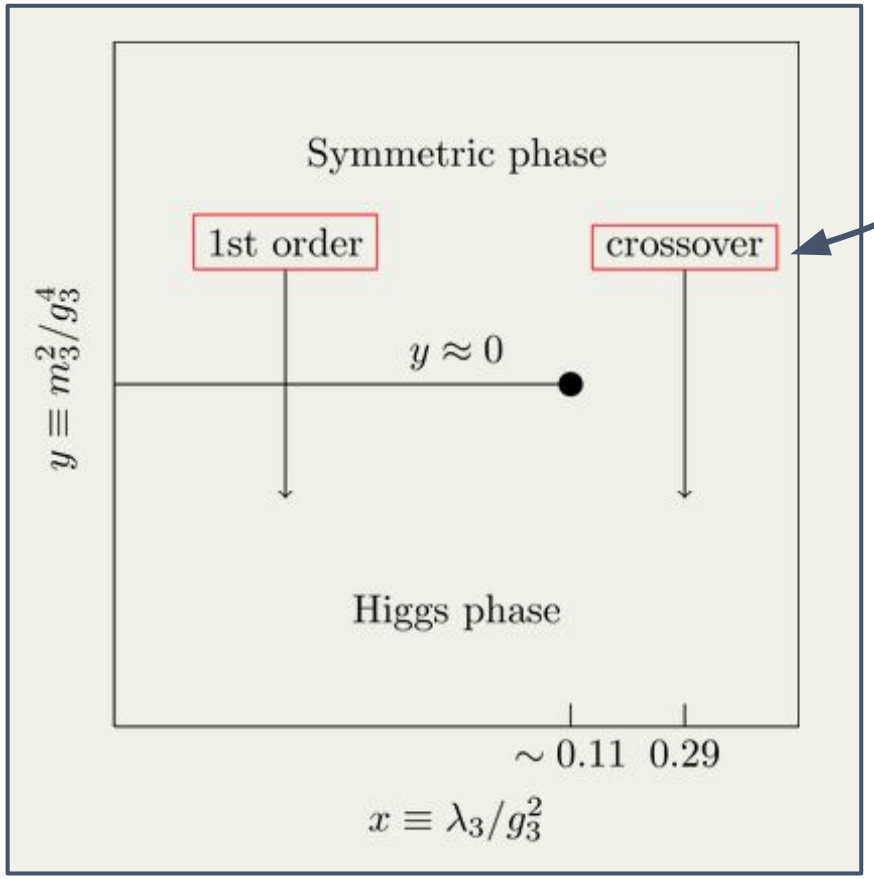

No electroweak first-order phase transition (FOPT) in **SM** :(

Many unknowns:

- What then caused baryogenesis?
- How can we know whether a FOPT really happened?
- What BSM physics can trigger a FOPT?

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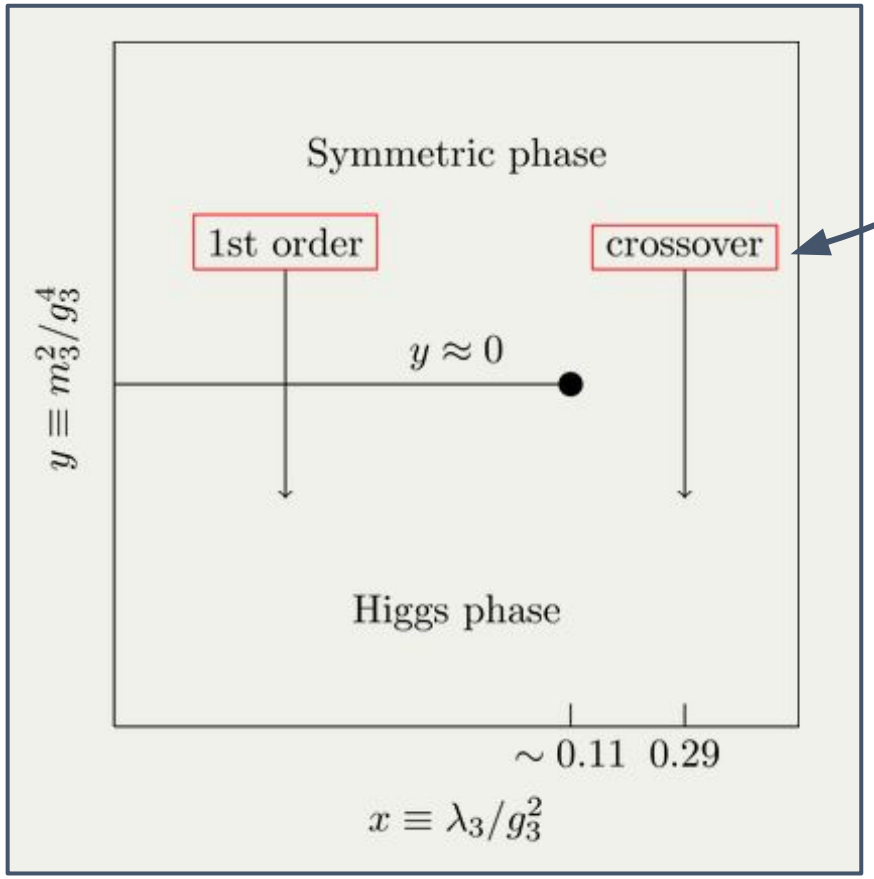

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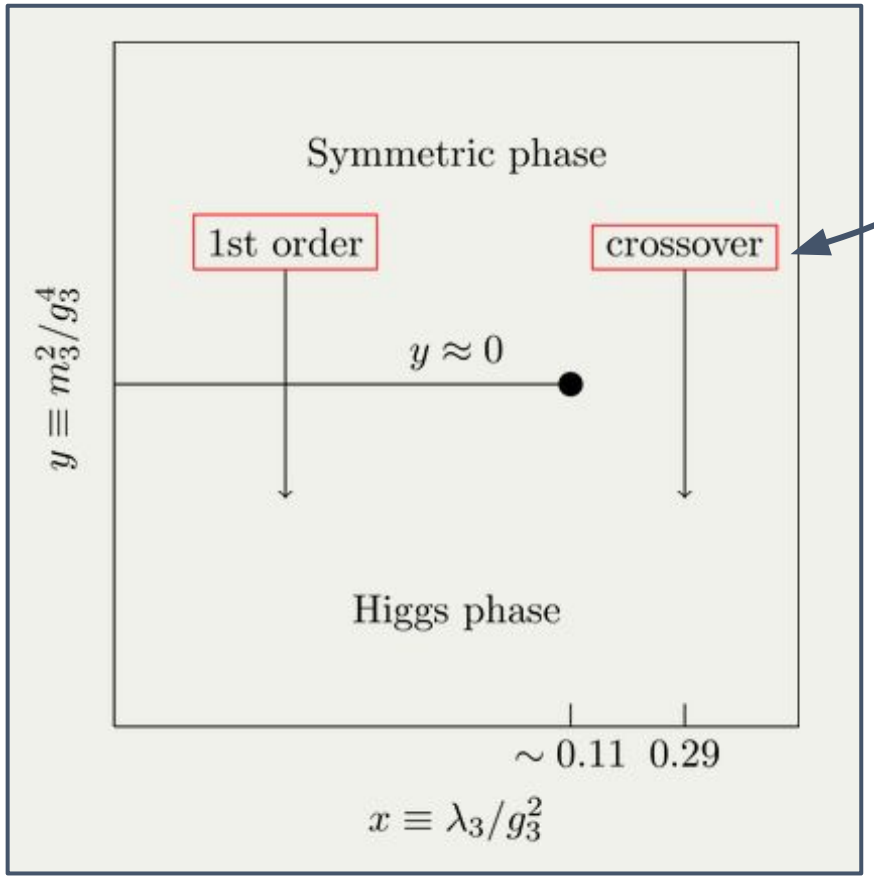

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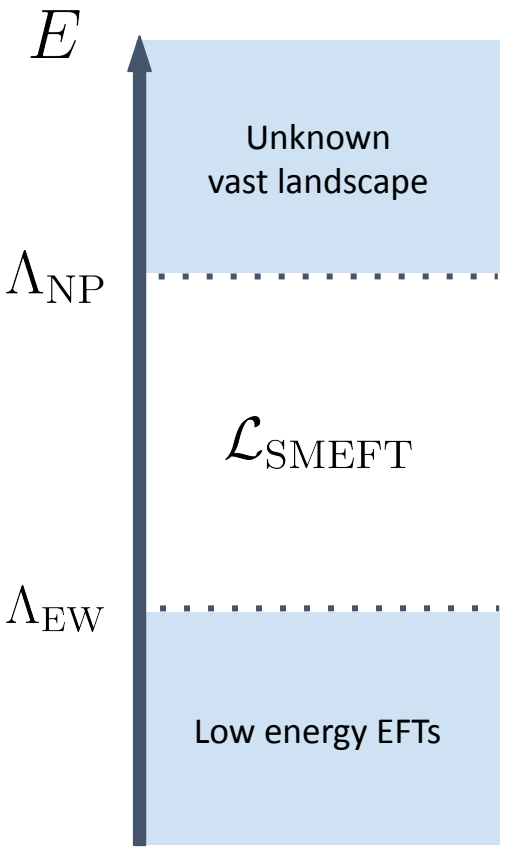
Let's take a look at the SMEFT!

Introduction

What is 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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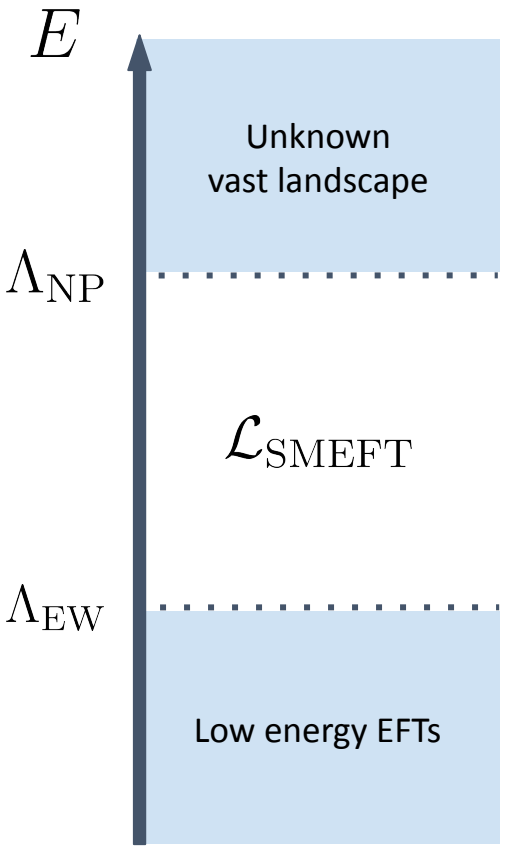

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PROS

- 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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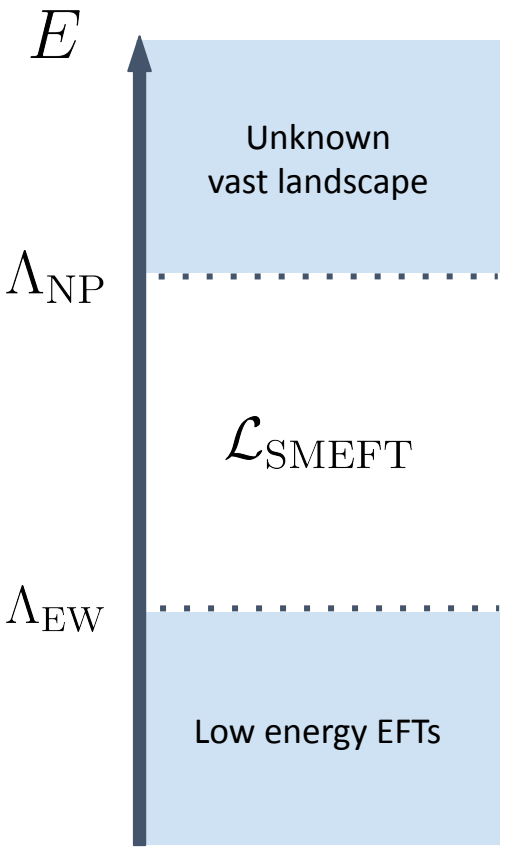

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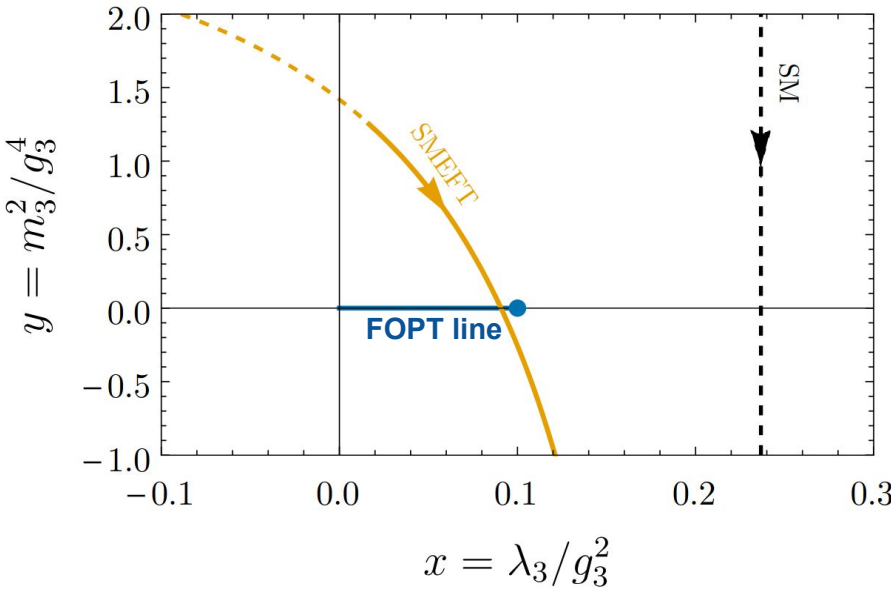
$$x, y = f(c_i^{(\rm SM)}; T)$$

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

Modify how potential evolves with T



Thermal field theory in equilibrium

Dimensional reduction

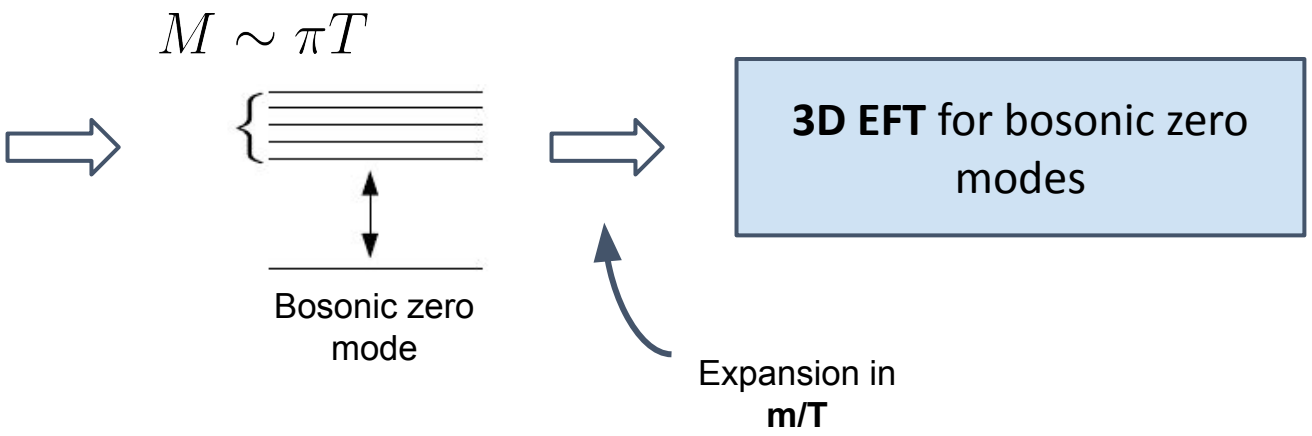
- **Generating functional** in thermal field theory (= Euclidean QFT with periodic time):

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

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

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

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



Thermal field theory in equilibrium

[Gould, Tenkanen - 2309.01672]

Thermal hierarchy of scales

$$\underbrace{\pi T}_{\text{hard}} \gg \underbrace{\left(\frac{g}{4\pi}\right)\pi T}_{\text{soft}} \gg \underbrace{\left(\frac{g}{4\pi}\right)^{3/2}\pi T}_{\text{softer}}$$

Finite-temperature
4D SMEFT

$$\Lambda_{\rm NP} \gg \pi T$$

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Integrate out heavy Matsubara modes

$$\Lambda_{\rm NP} \gg \pi T \qquad \pi T \gg \mu^2$$

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→ Dimensional reduction

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→ 3D matching

Integrate out temporal gauge bosons

$$m_{W_0}^2 \gg m_\phi^2$$

$$\Lambda_{\rm NP} \gg \pi T$$

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Finite-temperature **4D SMEFT**

Dimensional reduction

Integrate out heavy Matsubara modes

$\pi T \gg \mu^2$

3D matching

Integrate out temporal gauge bosons

$m_{W_0}^2 \gg m_\phi^2$

Lattice simulation of **3D SU(2) + Higgs**

[Gould et al. - 2205.07238]

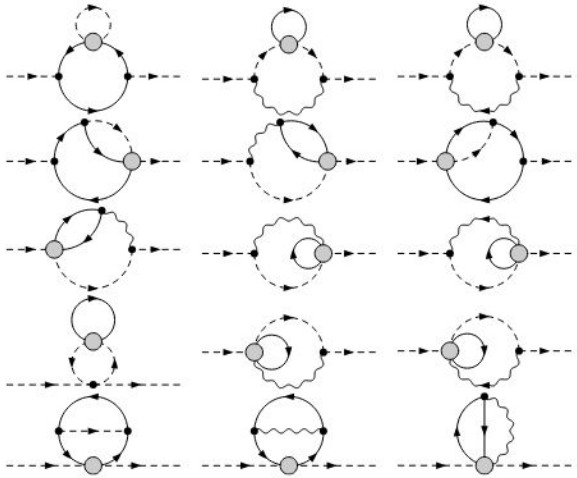
$\Lambda_{\rm NP} \gg \pi T$

High-T limit of SMEFT

From hard to softer scale

[Chala, Guedes - 2503.20016]

Ex: Two-loop SMEFT contributions to scalar effective mass.



$$\Delta m_\phi^2 = \Big[-\frac{1}{4} c_\phi + \frac{47}{3} g_S^2 c_{\phi G} + \frac{1}{576} |Y_u|^2 \big(30 c_{\phi\Box} - 15 c_{\phi D} + 6 c_{\phi u} - 6 c_{\phi q}^{(1)} + 18 c_{\phi q}^{(3)} + 24 c_{qu}^{(1)} + 32 c_{qu}^{(8)} \big) + \frac{3}{64} \big(16 g_S c_{uG} Y_u^* - 3 c_{u\phi} Y_u^* + \text{h.c.} \big) \Big] T^4 , \qquad (17)$$

1) Assign a **power counting** in powers of gauge coupling **g**

2) **Match** all 3D EFT Wilson coefficients to $O(g^4)$

$$\mathcal{L}_{3,\text{softer}} = \frac{1}{4} W_{ij}^I W_{ij}^I + (D_i\phi)^\dagger (D_i\phi) + m_3^2 |\phi|^2 + \lambda_3 |\phi|^4 + \mathcal{L}_{3,\text{softer}}^{(\text{dim-6})}$$

3) Compute parameters **x** and **y**

$$x \equiv \frac{m_3^2}{g_3^4} \qquad y \equiv \frac{\lambda_3^2}{g_3^2}$$

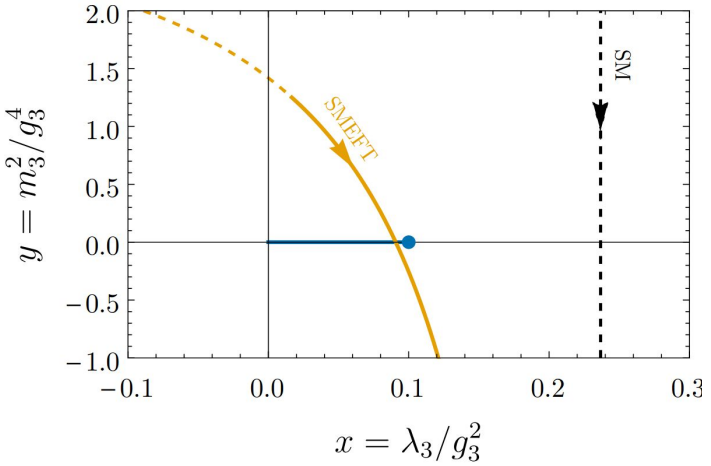
4) **Scan** SMEFT parameter space (compatible with colliders) [Giani et al. (SMEFiT) - 2302.06660]

High-T limit of SMEFT

Scanning the SMEFT

- 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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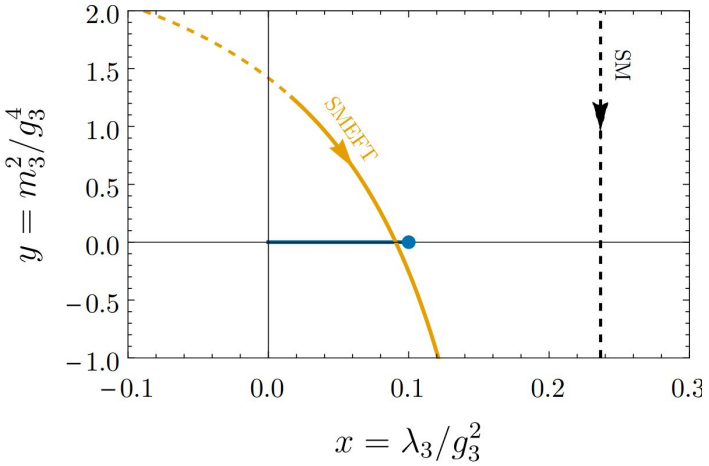

- We find the following candidates:

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

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

[Camargo-Molina et al. - 2103.14022]

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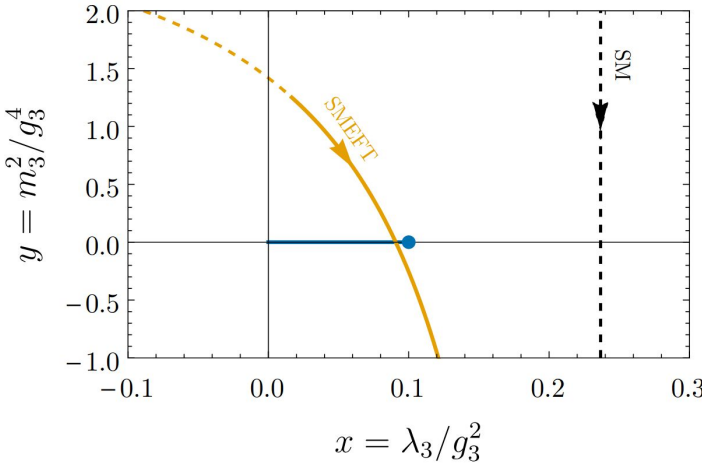

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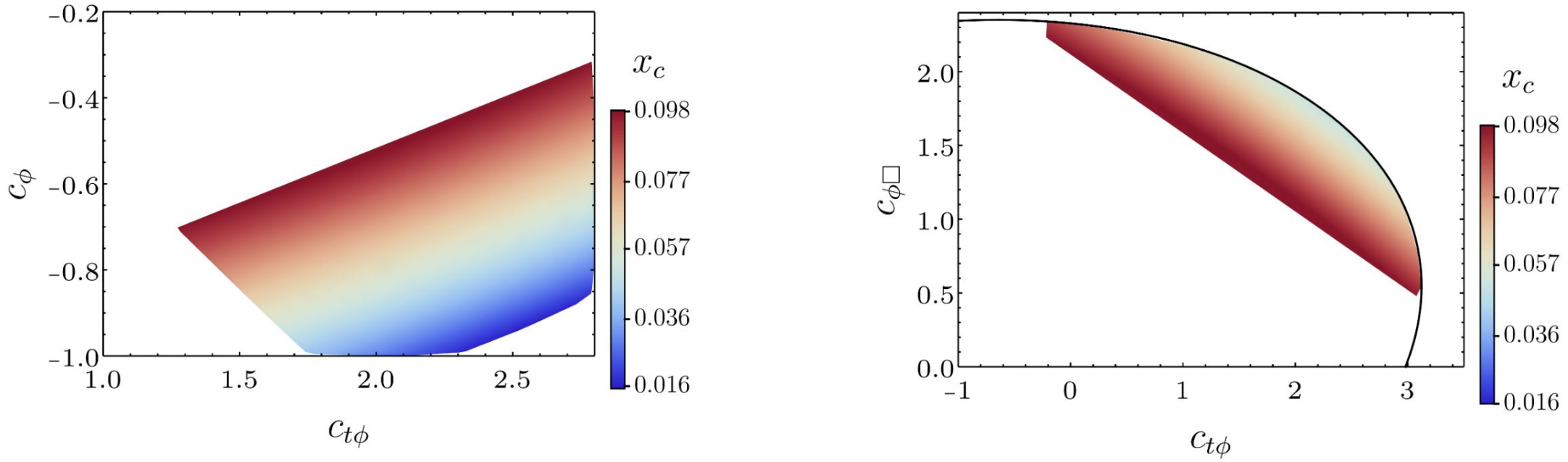
$$\mathcal{O}_{t\phi} \equiv \bar{t}_L\tilde{\phi}t_R(\phi^\dagger\phi)$$

(Hot) new!

Results

Modified phase diagram

[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 WC is set to zero.

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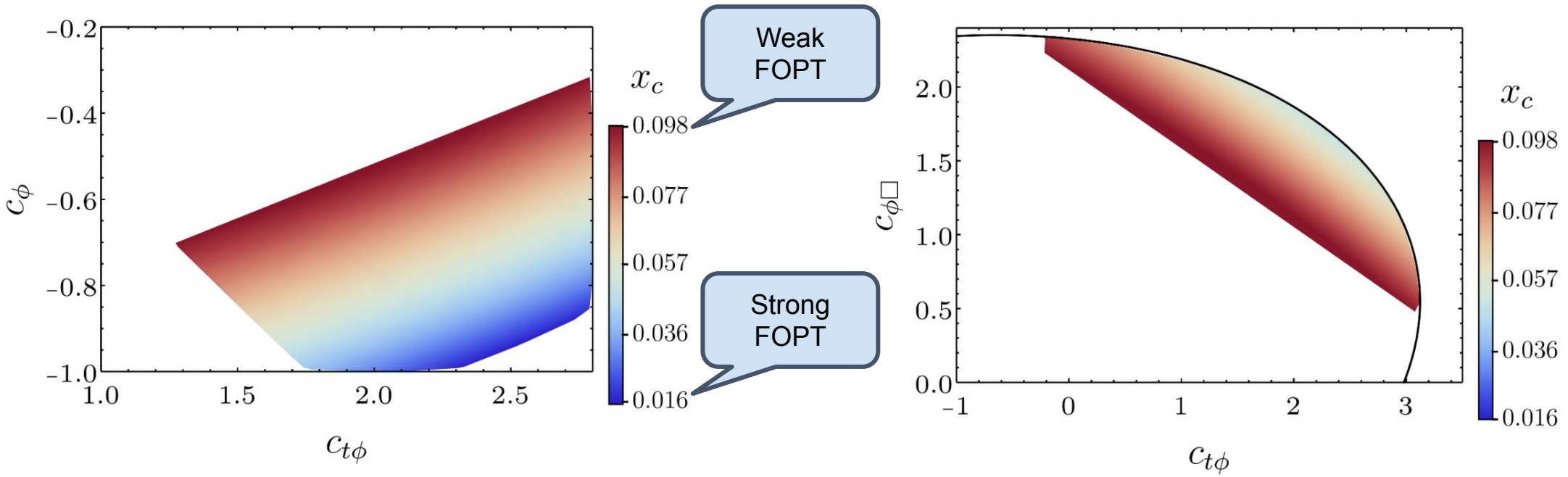

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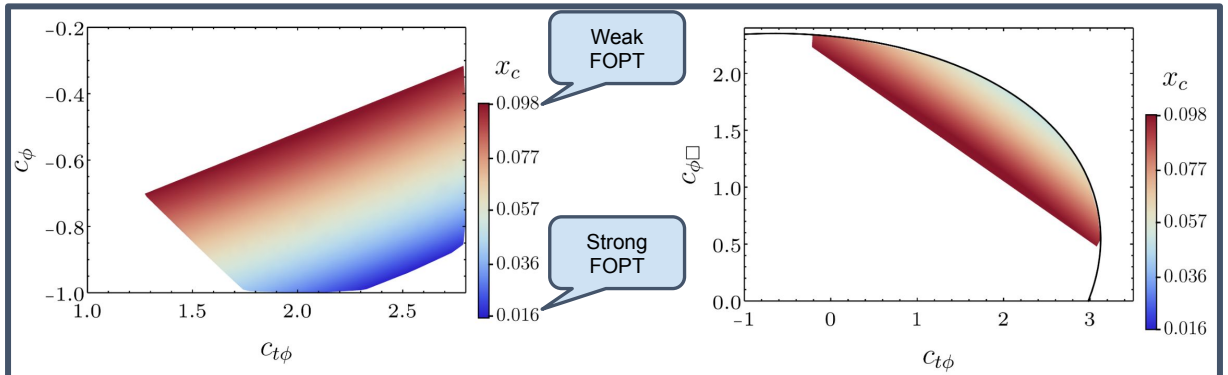


Figures: Regions of the parameter space (in TeV^{-2}) within collider bounds with a FOPT. In both panels, the non-appearing WC is set to zero.

- FOPTs possible without direct modification of the Higgs potential **(with $c_\phi = 0$)**.
- Strong FOPTs **with joint contributions** of the three dim-6 WCs, with all of them reasonably small **(at most O(1) TeV^{-2} values)**.
- **Two keys:** 1) include the relatively unconstrained $\mathcal{O}_{t\phi} \equiv \bar{t}_L \tilde{\phi} t_R (\phi^\dagger \phi)$
  2) two-loop matching for thermal masses

Conclusions

- Computed, for the first time, the full O(g⁴) 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]

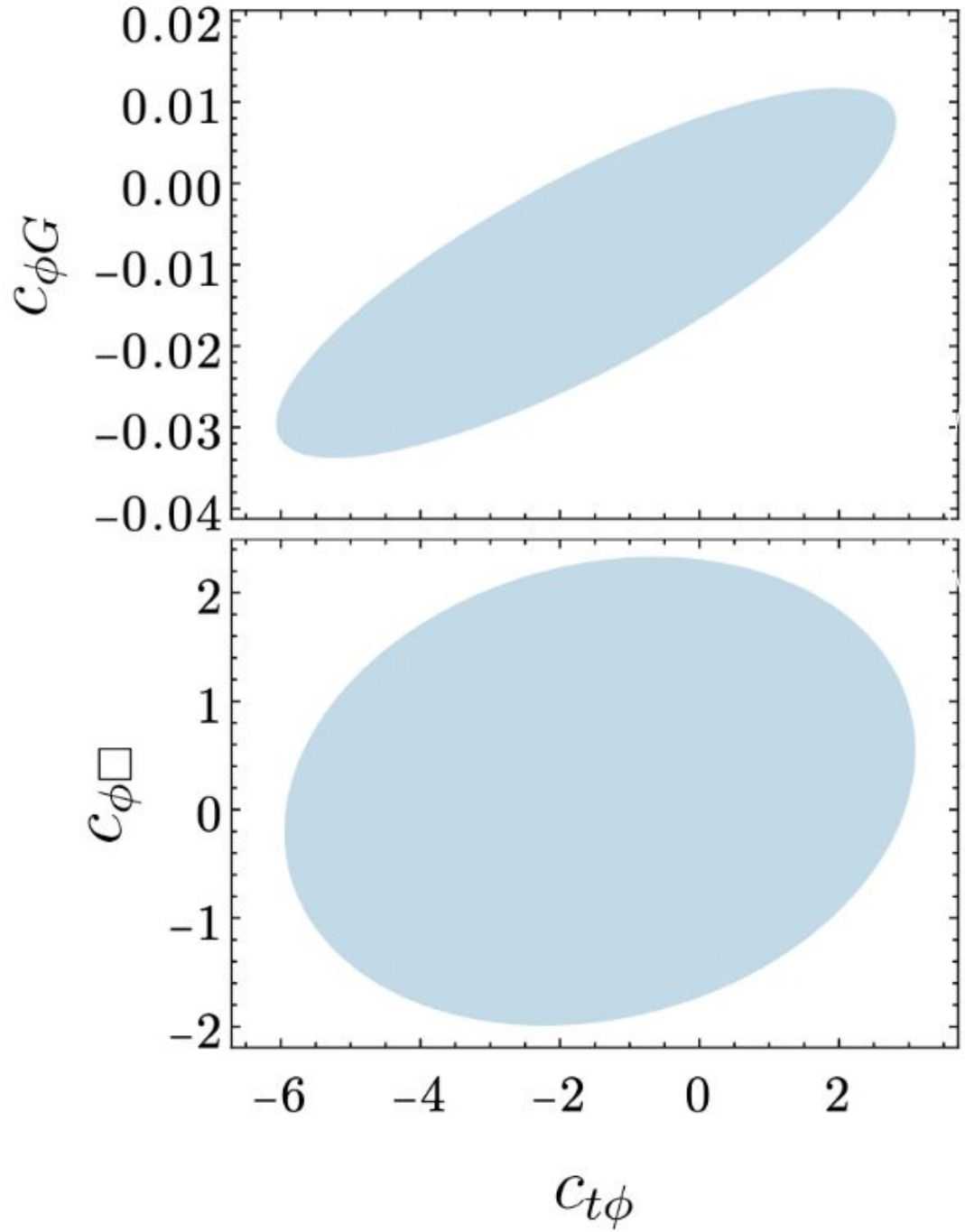
What's left to do? 🔍

Higher-dimensional operators in the 3D EFT? SMEFT @ dim-8? …

Thank you for your attention!

¡Gracias por vuestra atención!

$\mathcal{O}(g)$	c_{X^3}
$\mathcal{O}(g^2)$	$c_{X^2\phi^4}, c_{\phi^4 D^2}, c_{\psi^2 X\phi}, c_{\psi^2\phi^2}, c_{\psi^4}$
$\mathcal{O}(g^3)$	$c_{\psi^2\phi^3}$
$\mathcal{O}(g^4)$	c_{ϕ^6}


0.02
0.01
0.00
−0.01
−0.02
−0.03
−0.04
$c_{\phi G}$
2
1
0
−1
−2
$c_{\phi\Box}$
−6
−4
−2
0
2
$c_{t\phi}$