Crossing the desert: Towards predictions for SMEFT coefficients from Quantum Gravity

Abhishek Chikkaballi

National Center for Nuclear Research (NCBJ)

Warsaw, Poland

In collaboration with

Lydia Brenner, Astrid Eichhorn, Shouryya Ray

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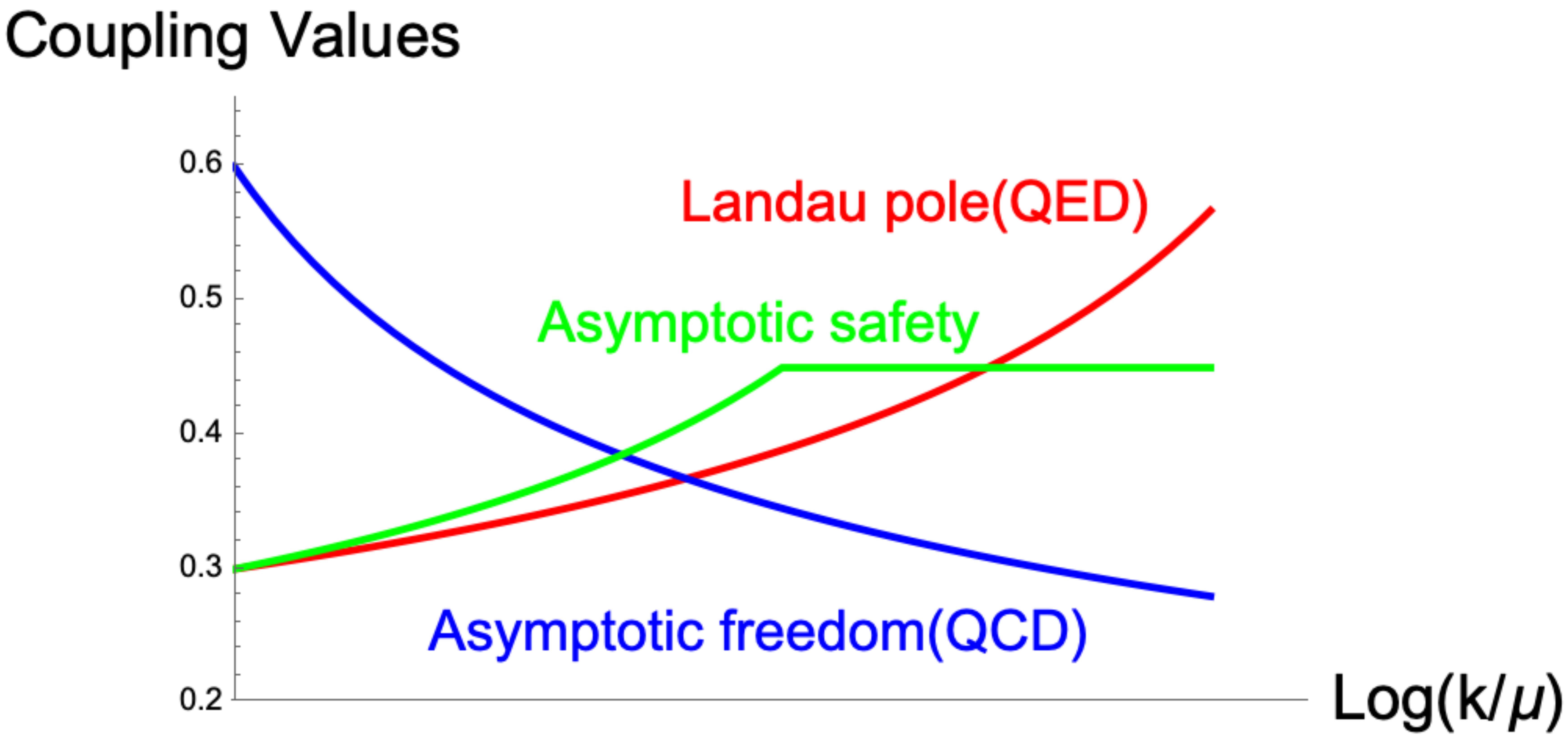
Asymptotic safety



UV complete theory: all the couplings approach a fixed point

$\Longrightarrow$ The theory can be extrapolated to infinitely large energy scales

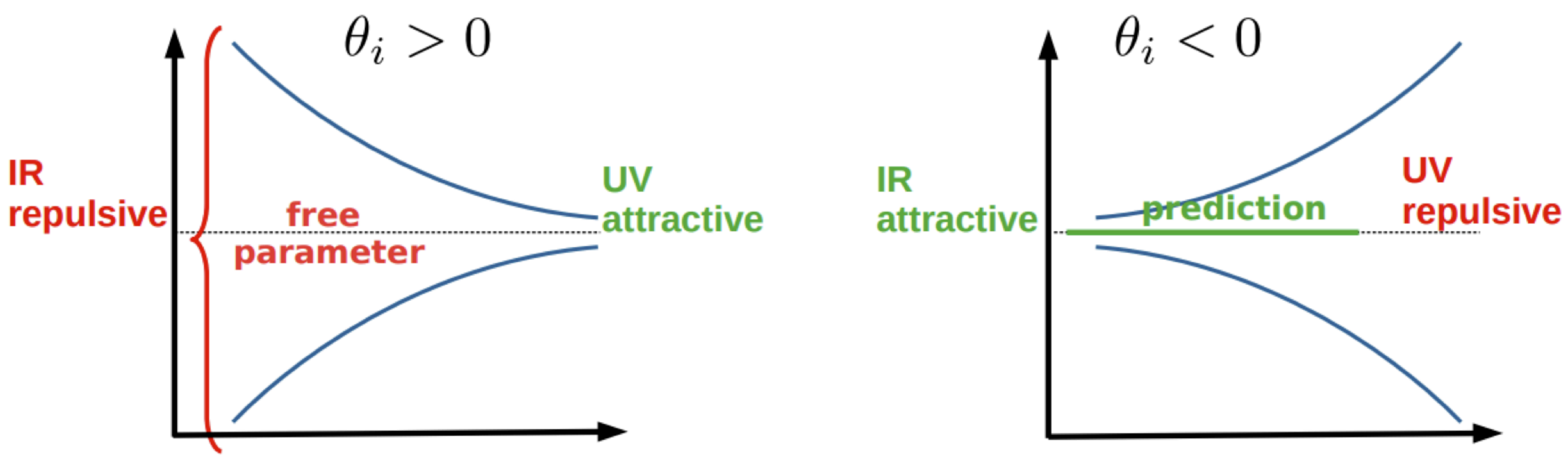
Predictions and free parameters

- Fixed point: where all the couplings stay constant with the changing scale

$$\beta_i(\{g_j\}) = 0$$

- Linearized flow near the fixed point

$$\text{Stability matrix: Stability matrix: } M_{ij} \equiv \left.\frac{\partial \beta_i}{\partial g_j}\right|_{\{g_i^*\}} \longrightarrow \{\theta_i\}\text{Critical exponents}$$



Relevant couplings are free parameters of the theory

Irrelevant couplings provide predictions

Asymptotically Safe Gravity (ASG)

Christiansen, Eichhorn '17, Christiansen *et al.* '17, Shaposhnikov, Wetterich '09, Oda, Yamada '15, Eichhorn, Held, Pawlowski '16, Wetterich, Yamada '16, Hamada, Yamada '17, Pawlowski *et al.* '18, Eichhorn, Versteegen '17, Eichhorn, Held '17-'18, Pastor-Gutiérrez, Pawlowski, Reichert '22, ...

Einstein-Hilbert action:

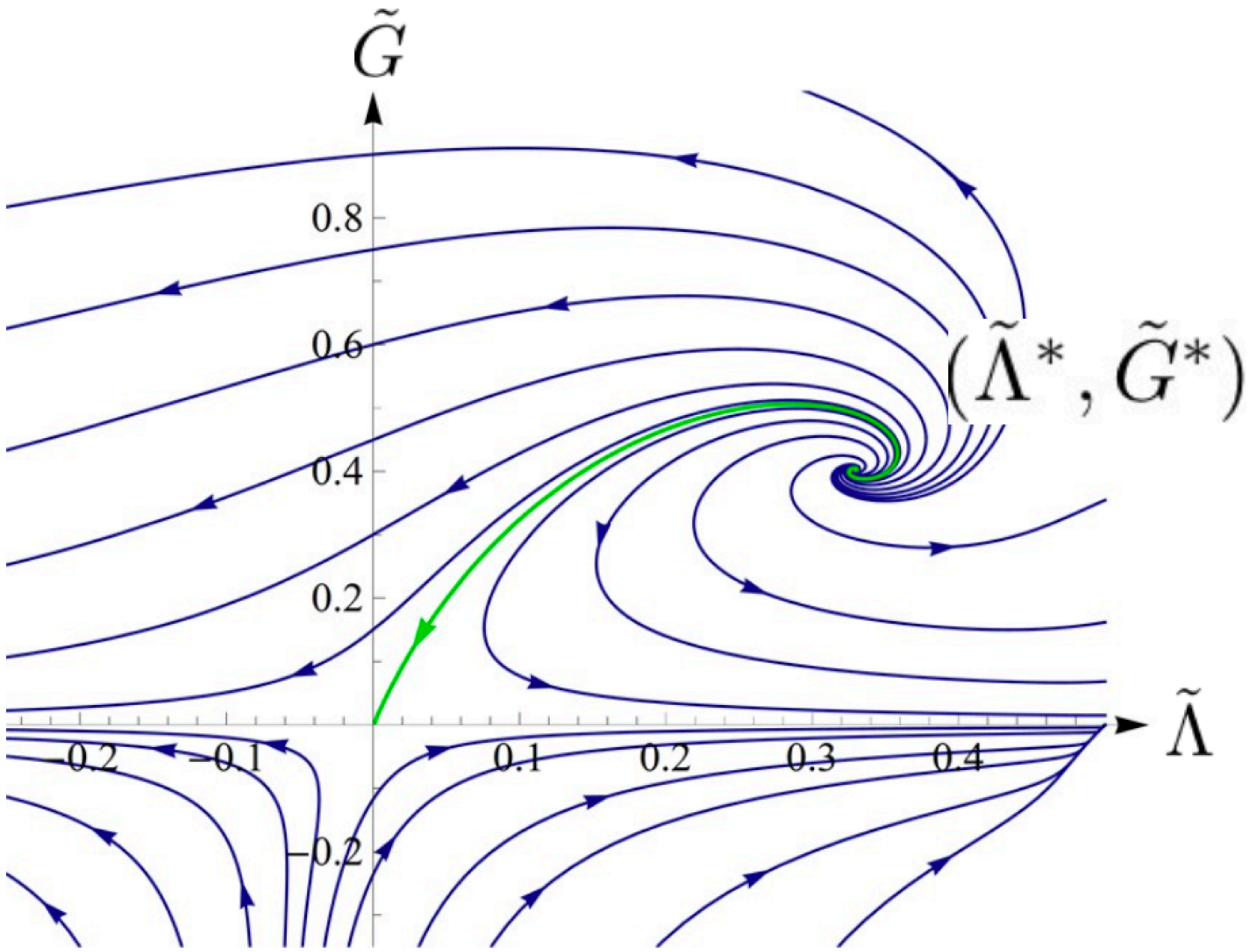
$$\Gamma_k = \frac{1}{16\,\pi\, G_N}\int d^4x\,\sqrt{g}(\Lambda - R)$$

$$\partial_t\Gamma_k = k\,\partial_k\Gamma_k = \frac{1}{2}\mathrm{STr}\left(\frac{k\,\partial_k R_k}{\Gamma^{(2)} + R_k}\right)$$

beta functions of gravitational couplings:

$$\frac{d\tilde{G}_N}{dt} = 0\;, \qquad \frac{d\tilde{\Lambda}}{dt} = 0$$

Reuter, Saueressig, hep-th/0110054



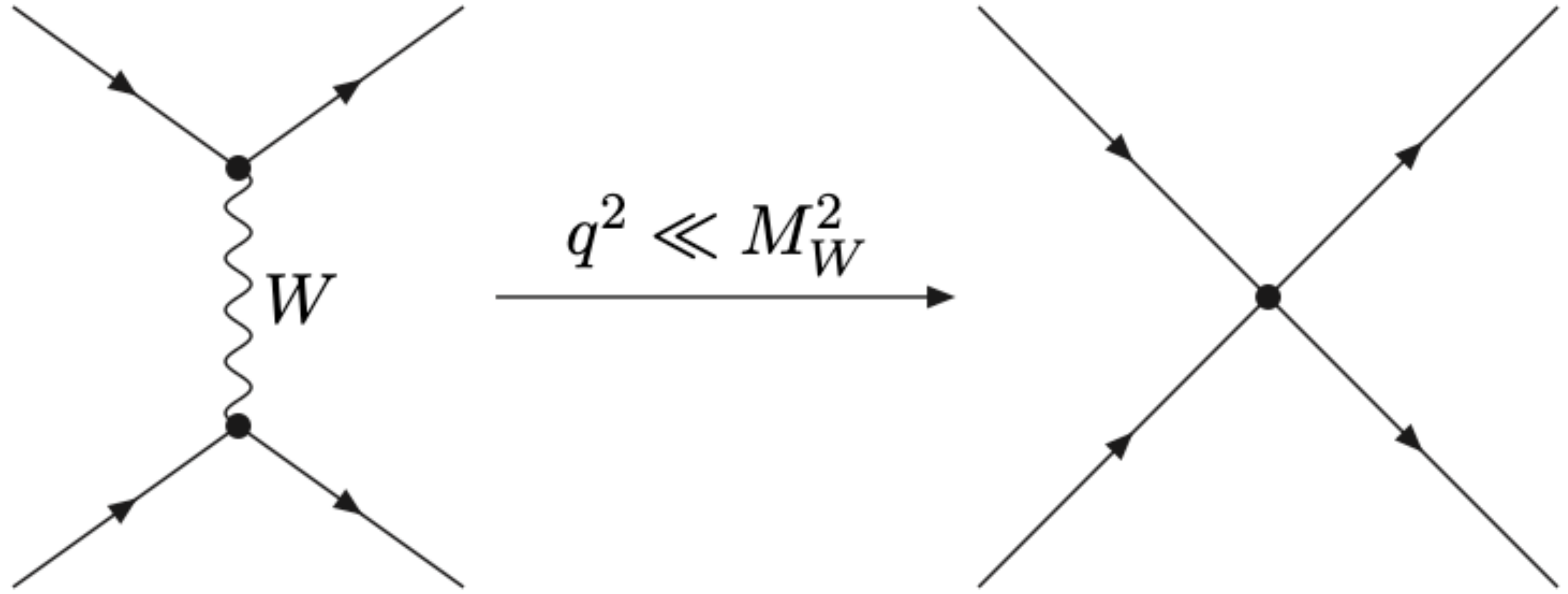
SMEFT

Effective Field Theory (EFT):

Things may appear simpler from a certain distance

A. Falkowski Eur. Phys. J. C (2023) 83:656

Example: Fermi theory



Buchmüller, Lüdeling hep-ph/0609174

Standard Model Effective Field Theory (SMEFT):

- Preserves SM gauge symmetry
- model-independent framework for characterizing experimental deviations

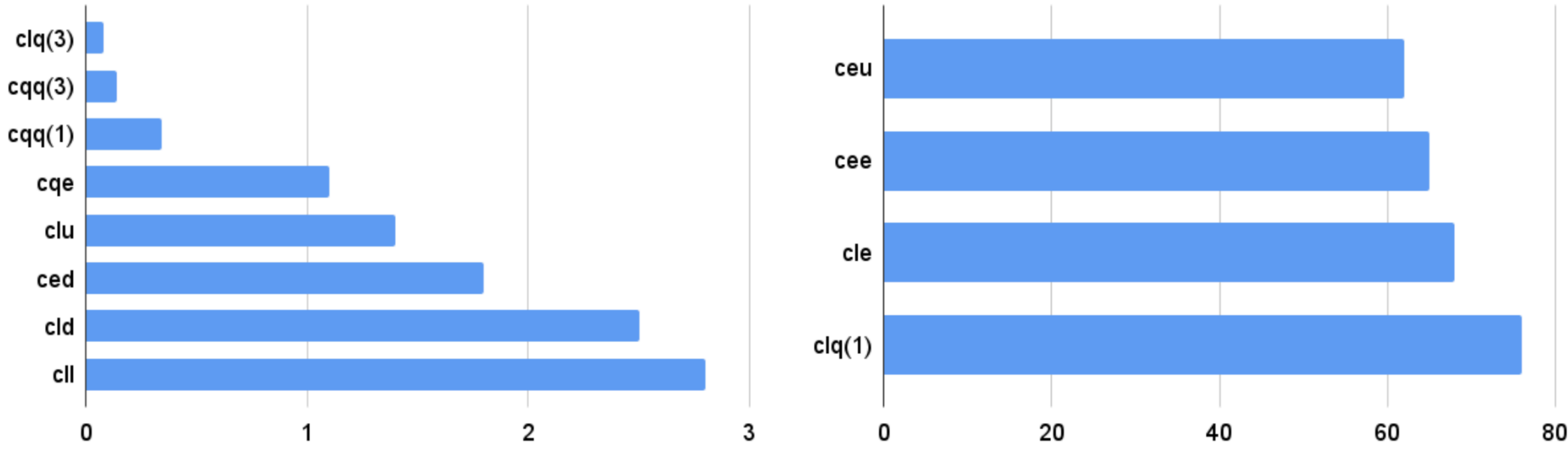
$$\mathscr{L}_{\text{EFT}} = \mathscr{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda_{\text{NP}}^2} \mathcal{O}_i^{(6)} + \sum_j \frac{c_j}{\Lambda_{\text{NP}}^4} \mathcal{O}_i^{(8)} + \ldots$$

$$\Lambda_{EW} \lesssim E \lesssim \Lambda_{NP}$$

SMEFT operator (dim-6)

c_i	Operator $(\bar{L}L)(\bar{L}L)$	c_i	Operator $(\bar{R}R)(\bar{R}R)$	c_i	Operator $(\bar{L}L)(\bar{R}R)$
c_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$	c_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$	c_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
$c_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$	c_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$	c_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
$c_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu \tau^I q_r)(\bar{q}_s\gamma^\mu \tau^I q_t)$	c_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$	c_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
$c_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$	c_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$	c_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$c_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu \tau^I l_r)(\bar{q}_s\gamma^\mu \tau^I q_t)$	c_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$	$c_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
		$c_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$	$c_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
		$c_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$	$c_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
				$c_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

Current experimental limits on four fermion SMEFT operators

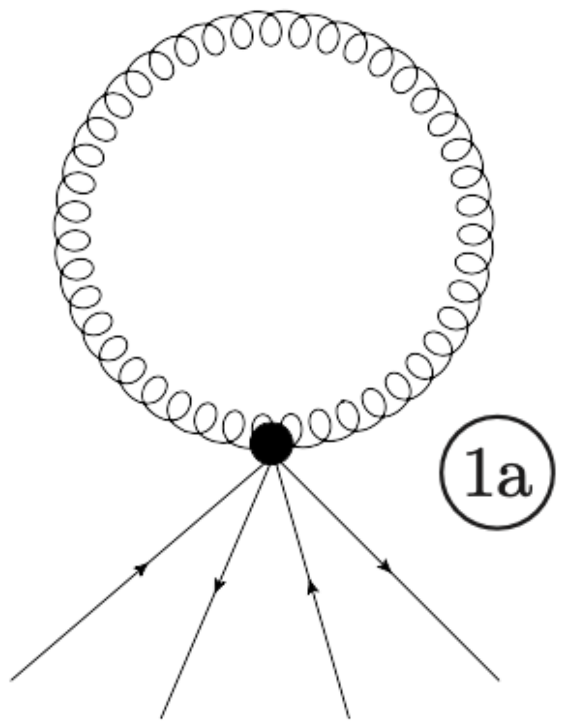


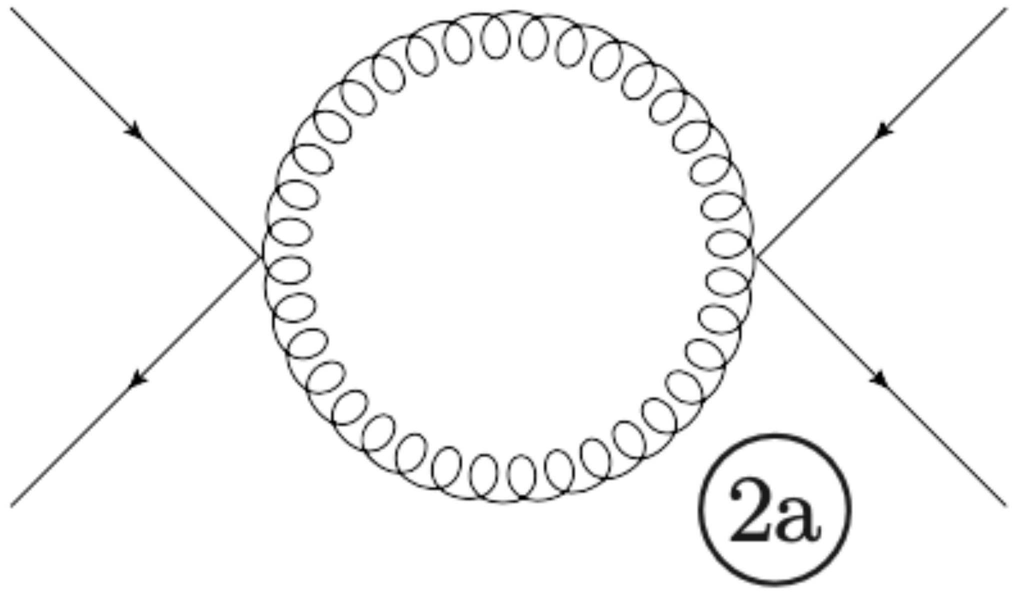
Toy model

$$S = \frac{1}{16\pi\bar{G}_{\rm N}}\int_x \sqrt{g}(2\bar{\Lambda} - R) + \int_x \sqrt{g}\bar{\psi}\gamma^\mu \nabla_\mu \psi + \int_x \sqrt{g}\left[\frac{\bar{\lambda}_+}{2}(\mathscr{V} + \mathscr{A}) + \frac{\bar{\lambda}_-}{2}(\mathscr{V} - \mathscr{A})\right]$$

Spacetime metric fluctuation $g_{\mu\nu} = \delta_{\mu\nu} + \sqrt{\bar{G}_{\rm N}}h_{\mu\nu}$

$$\mathscr{V} \pm \mathscr{A} = \left(\bar{\psi}\gamma_\mu\psi\right)^2 \mp \left(\bar{\psi}\gamma_\mu\gamma_5\psi\right)^2$$





Graviton induced interactions

Fierz-complete basis, $\mathrm{SU}(N_{\rm f})_{\rm L} \times \mathrm{SU}(N_{\rm f})_{\rm R}$

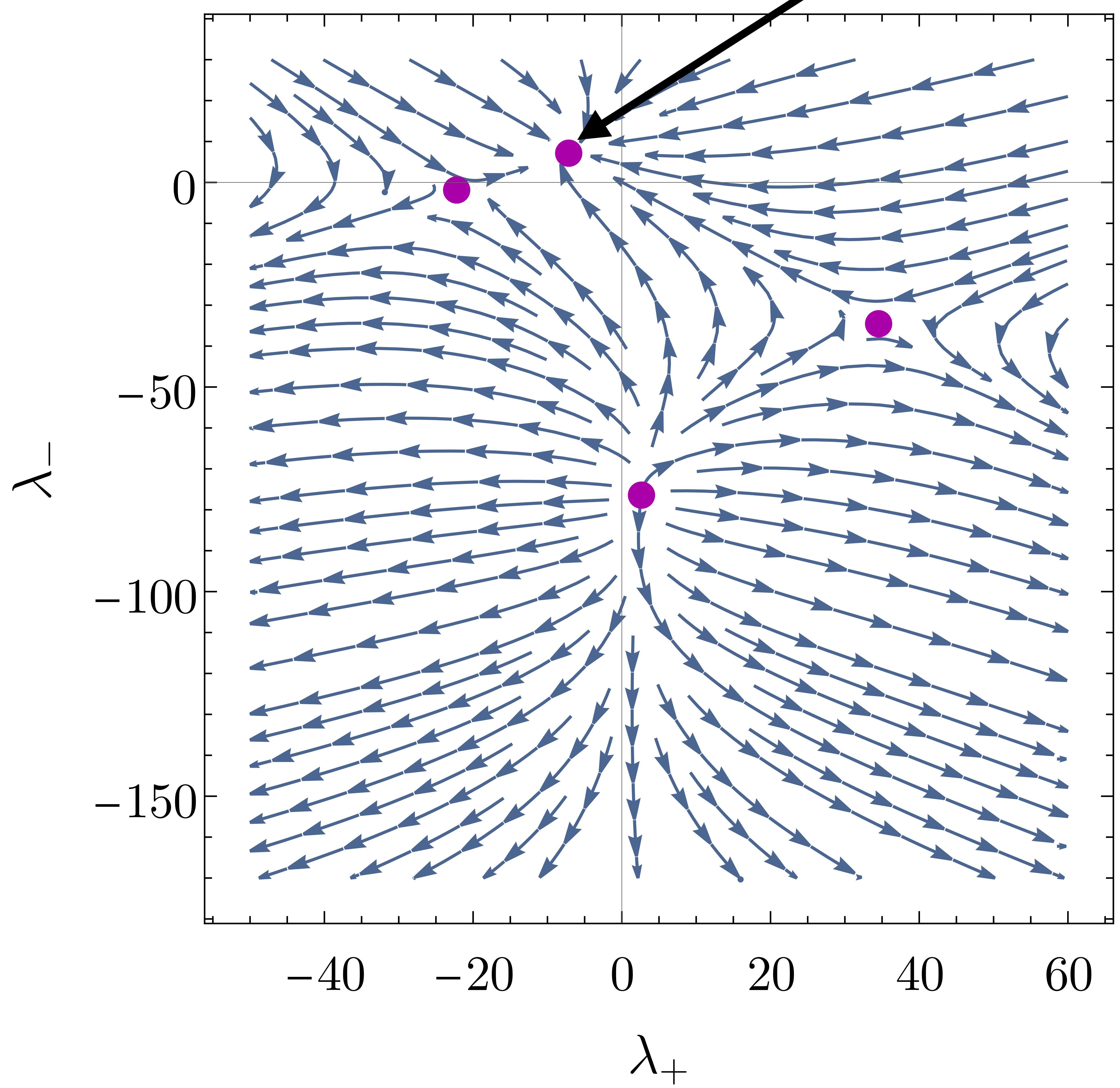
$$\frac{c_i}{M_{\rm Pl}^2} = \bar{\lambda}_- \qquad (i \in \{(\bar{L}L)(\bar{L}L), (\bar{R}R)(\bar{R}R)\})$$

$$\frac{c_i}{M_{\rm Pl}^2} = 2\bar{\lambda}_+ \qquad (i \in (\bar{L}L)(\bar{R}R))$$

Phase portrait

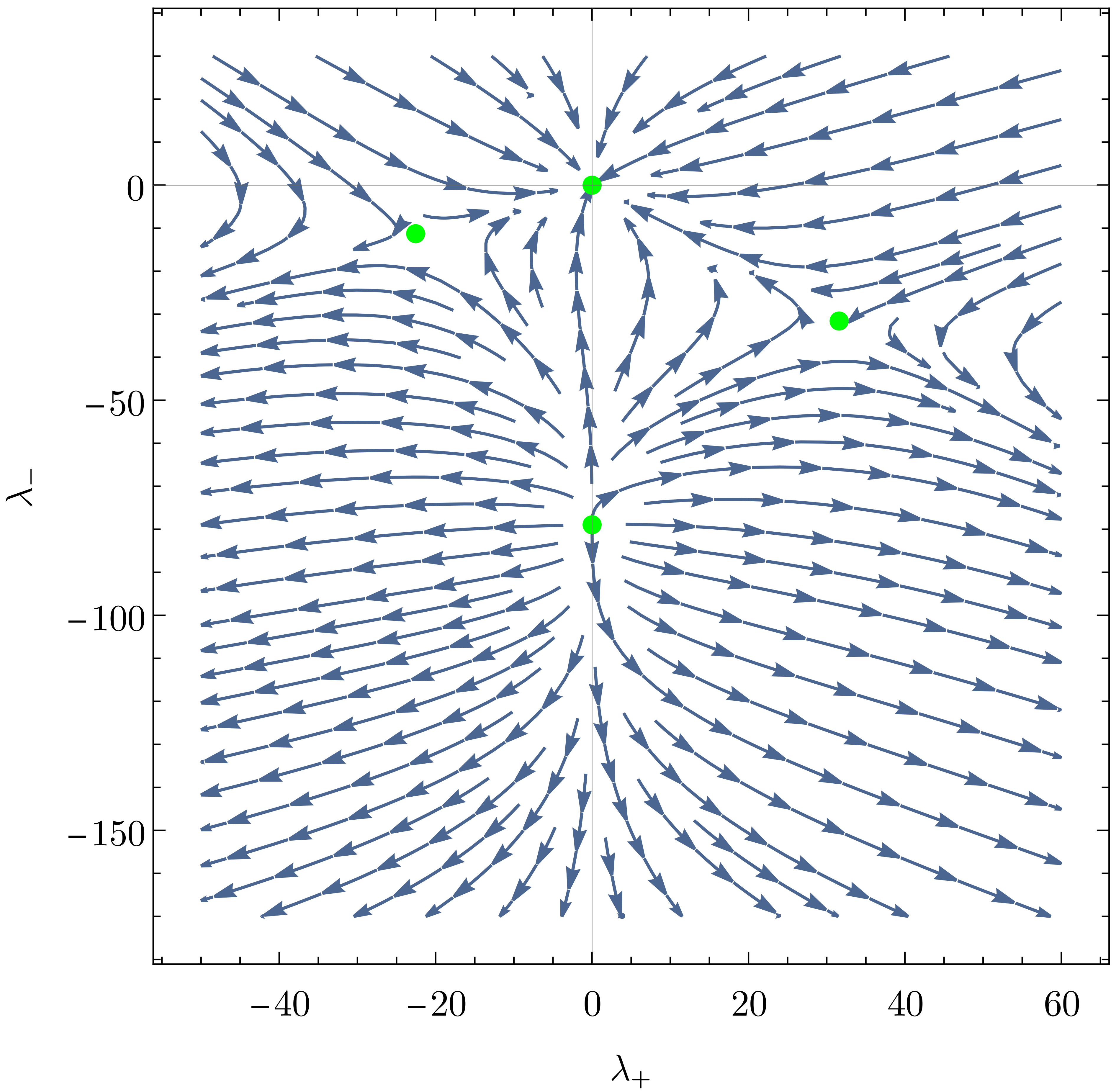
$$\beta_{\lambda_\pm} = 2\lambda_\pm + a^\pm \lambda_+ \lambda_- + b^\pm \lambda_\pm h_{ext} + c^\pm h_{ext}^2$$

sGFP ~ $c^\pm$



With gravity

Arrow points the flow from UV to IR



Without gravity

Case 1: Shifted Gaussian Fixed Point (sGFP)

$$\lambda_{\pm}(k > M_{\rm Pl}) = \lambda_{\pm,*}|_{\rm sGFP}$$

IR attractive $\Longrightarrow$ precise predictions $\lambda_{\pm}(k = M_{LHC})$

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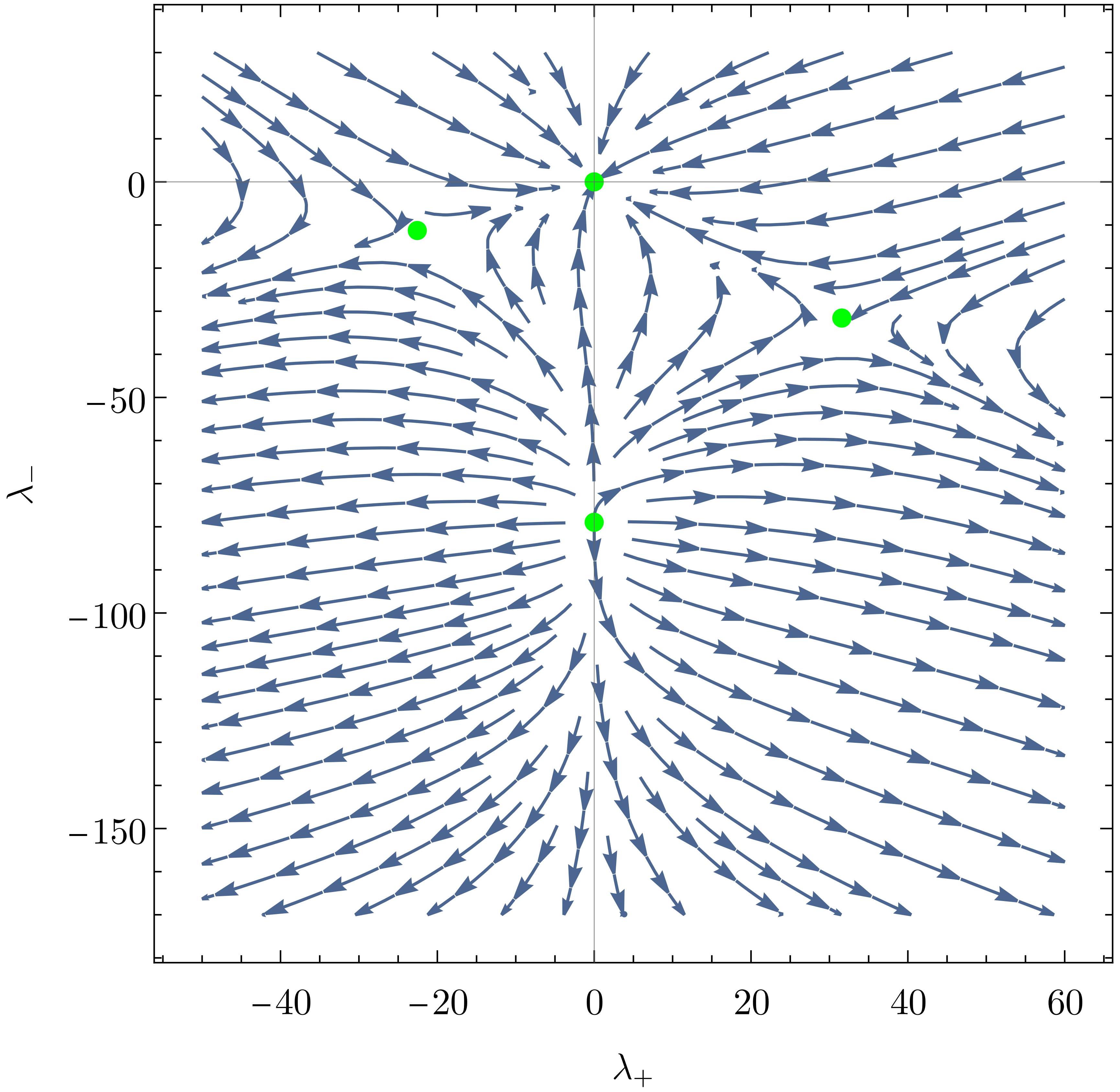
Systematic uncertainties in (G^*, Λ^*)



$\beta_{\lambda_{\pm}} \sim 2\lambda_{\pm} \Longrightarrow$ Wilson coefficients are Planck scale suppressed!

$$\left|\lambda_{\pm}(k = M_{\rm LHC})\right| \sim \left(\frac{M_{\rm LHC}}{M_{\rm Pl}}\right)^2$$

Case 2A: Classical scaling violation

Free parameter at Planck scale

$$|\lambda_{\pm}(k = M_{\rm Pl})| = \left(\frac{M_{\rm Pl}}{M_{\rm LHC}}\right)^{\delta}$$

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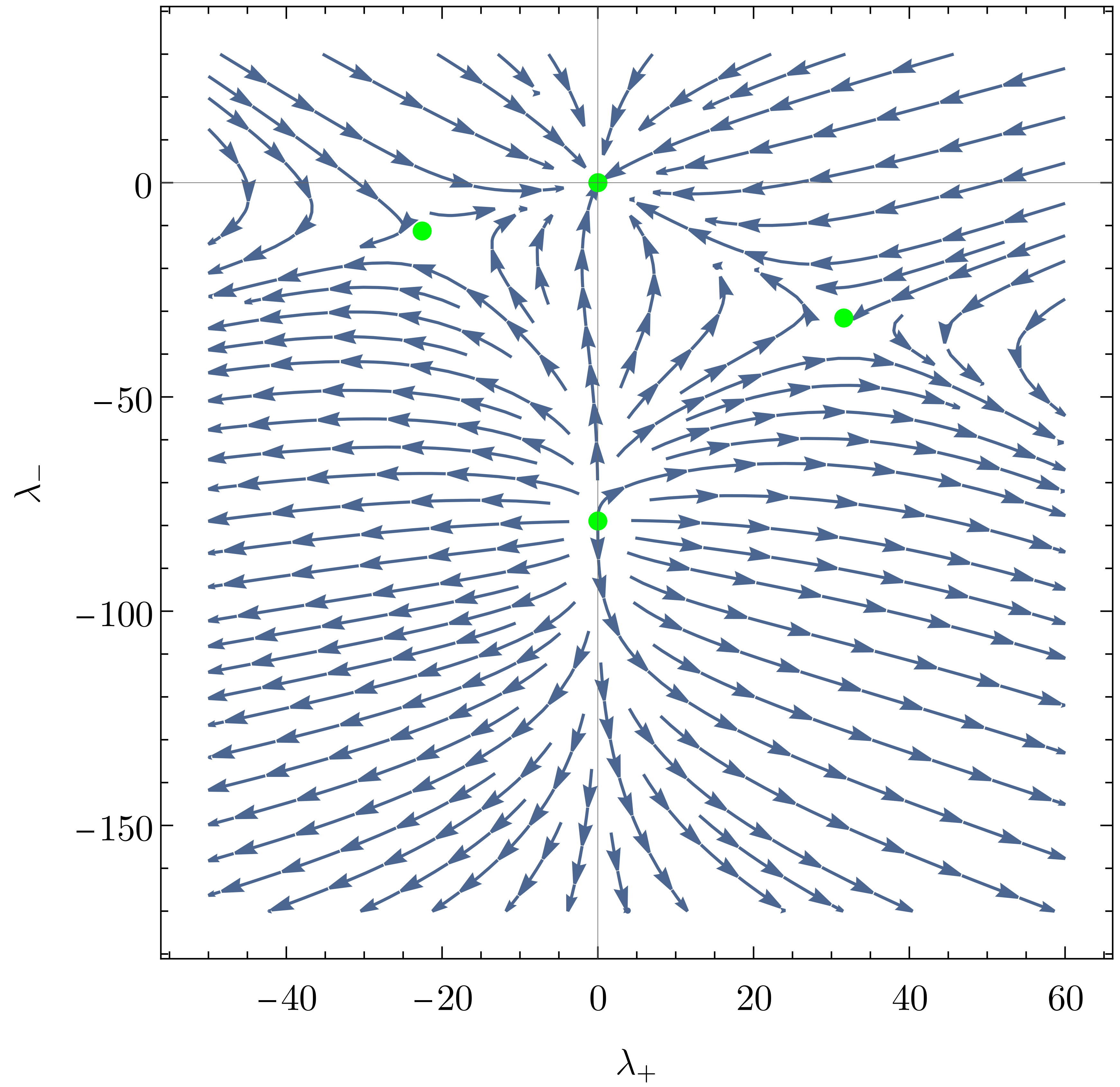

$$\lambda_{\pm}(k = M_{\rm LHC}) \approx \lambda_{\pm}(k = M_{\rm Pl})\left(M_{\rm LHC}/M_{\rm Pl}\right)^{2}$$

$$\sim \left(\frac{M_{\rm LHC}}{M_{\rm Pl}}\right)^{2-\delta}$$

Violation of naturalness expectation!

- Flow off to infinity in the IR
- Onset of chiral symmetry breaking close to Planck scale

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- **Case 2B: Suppressed by Effective New Physics scale $M_{\text{non-pert}}$**

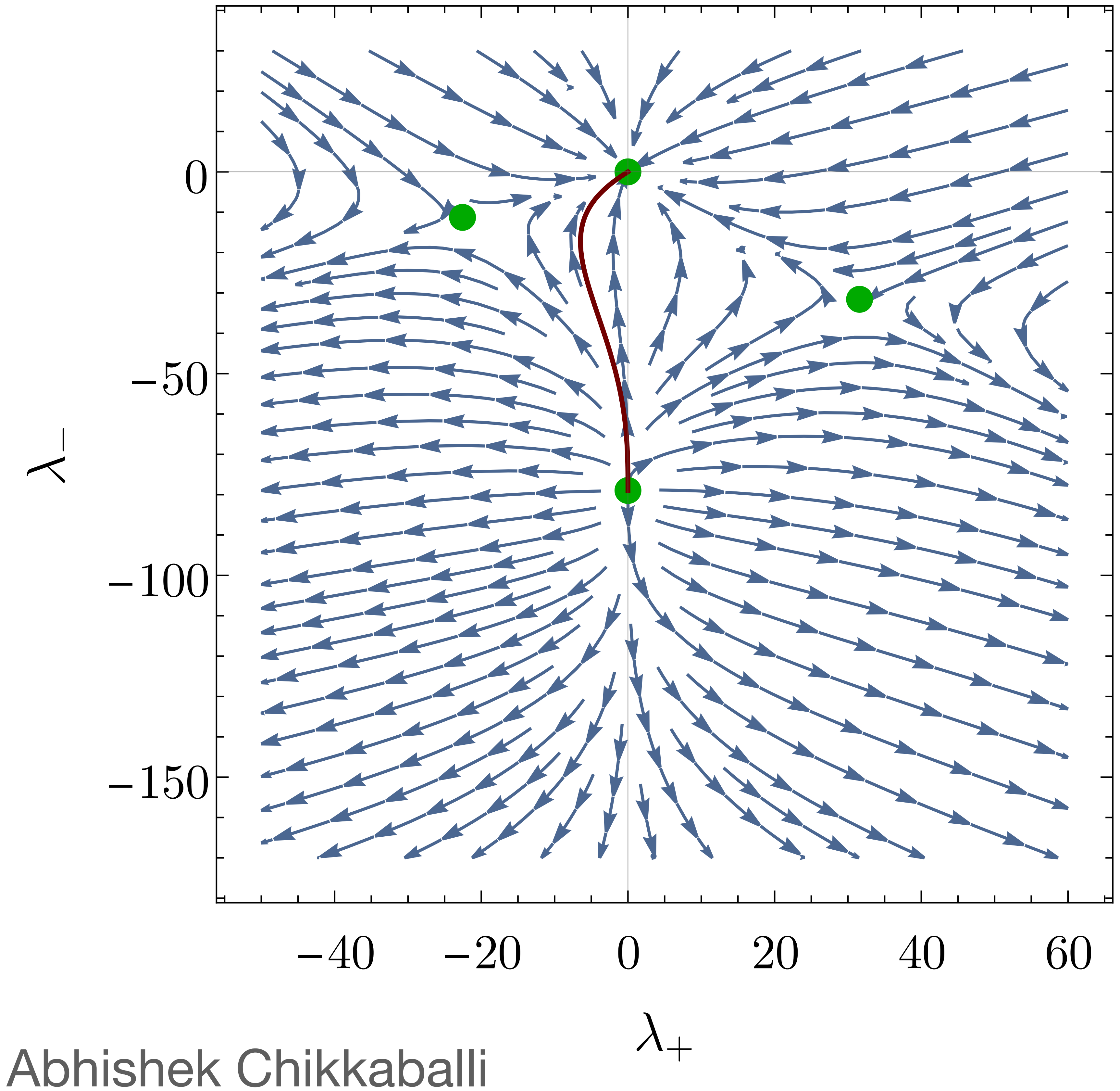
Effective $M_{\text{non-pert}}$ due to non-perturbative mechanism that generate sub-planckian fixed point

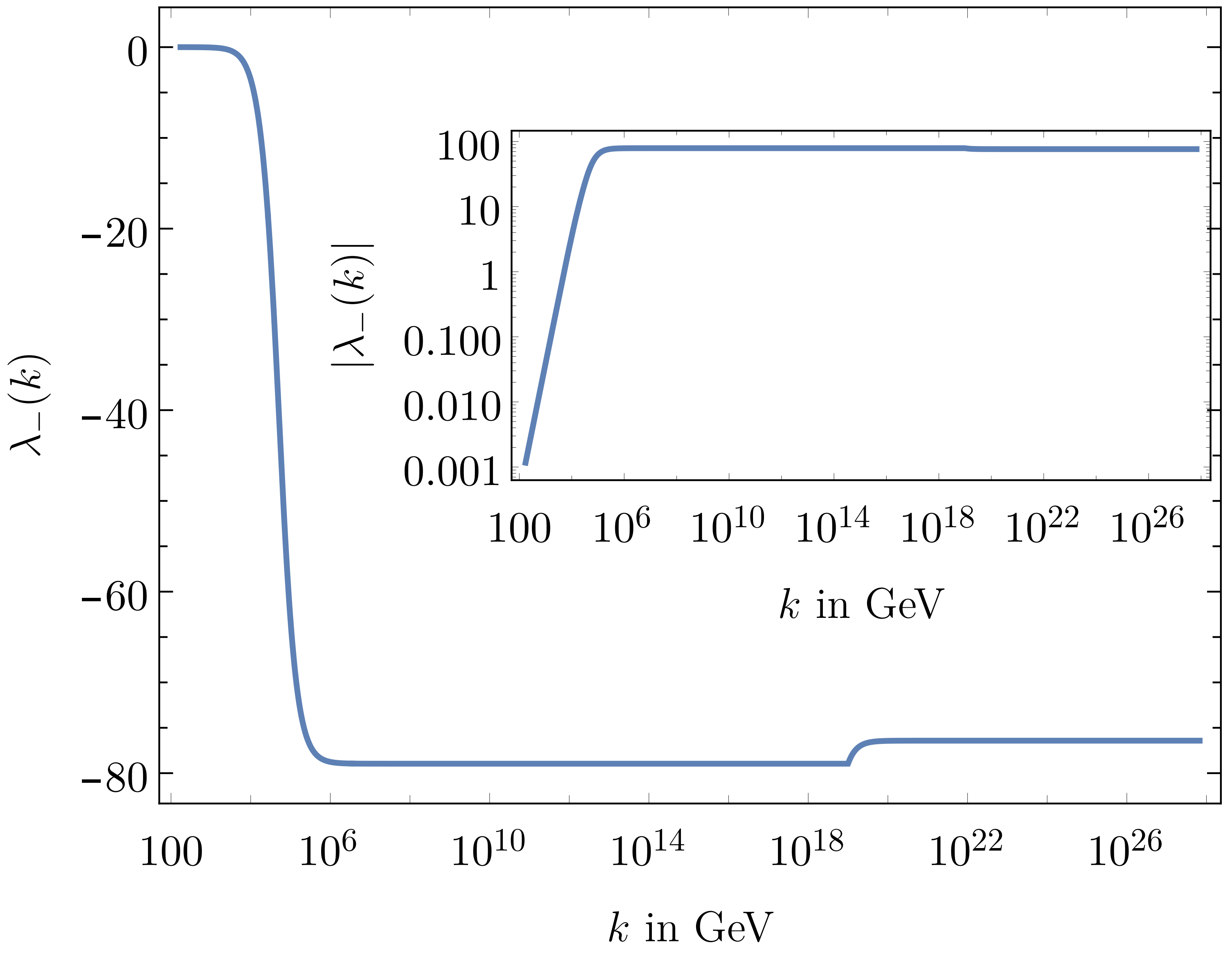
Free parameter at Planck scale

$$|\lambda_\pm(k = M_{\text{Pl}})| = \left(\frac{M_{\text{Pl}}}{M'_{\text{NP}}}\right)^2$$

$$\lambda_\pm(k = M_{\text{LHC}}) \approx \lambda_\pm(k = M_{\text{Pl}})\left(M_{\text{LHC}}/M_{\text{Pl}}\right)^2$$

$$\sim \left(\frac{M_{\text{LHC}}}{M'_{\text{NP}}}\right)^2$$





Conclusion

- ✦ In asymptotically safe gravity, SMEFT operators are expected to come with calculable values of their couplings at the Planck scale
- ✦ In the most conservative scenario, ASG contribution is unmeasurably small
- ✦ Existence of a non-perturbative fixed point at sub-Planckian scales generates new effective scale below the Planck scale

  $\Longrightarrow$ measurable value at the experimental scales

- ✦ Dimension-8 operators might not be negligible
- ✦ Traditional assumption that quantum gravity induces unmeasurably small Wilson coefficients is not always true