RG flows in non-perturbative Gauge-Higgs Unification

Nikos Irges, NTUA

Workshop on the Standard Model and Beyond, Corfu, 7 Sept. 2018

Based on

- **N.I. and F. Knechtli (NP B719, 121, 2005), F. Knechtli, B. Bunk and N.I. (LAT2005), N.I. and F. Knechtli (hep-lat/0604006), N.I. and F. Knechtli (NP B775, 283, 2007), N.I., F. Knechtli and M. Luz (JHEP 0708, 028), N.I., F. Knechtli and K. Yoneyama (NP B865, 541, 2012), N.I., F. Knechtli and K. Yoneyama (PL B722, 378, 2013), N. I. and F. Knechtli, JHEP 1406 (2014) 070, M. Alberti, N.I., F. Knechtli and G. Moir, JHEP 1509 (2015) 159**

- **N.I. and F. Koutroulis, NPB924 (2017) 178-278, hep-th 1804.06306 and work in progress**

- **N.I., PoS CORFU2016 (2016) 039, PoS CORFU2017 (2018) 080**

- **Work in progress with A. Chatziagapiou**

- The quantum Higgs mechanism in 4d
- The 5d model: NPGHU
- Towards an effective action

The Standard Model

$SU(3) \times SU(2) \times U(1)$
Quantum gauge fields coupled to fermionic matter and Higgs field(s) in a spontaneously broken EW symmetry phase in 4 space-time dimensions.

The Higgs sector has a naturalness issue that can be resolved by extra symmetry (susy, compositeness, 5d gauge symmetry, etc) or dynamically (e.g. simply by a low cut-off and/or by "weird" cancellations) or by a combination-correlation of both.
Behind its innocent perturbative nature, subtle non-perturbative effects may be hiding in the details (such as the origin of the relative sign in the Higgs potential):

$$V = -m_0^2 H^2 + \frac{\lambda_0}{6} H^4$$

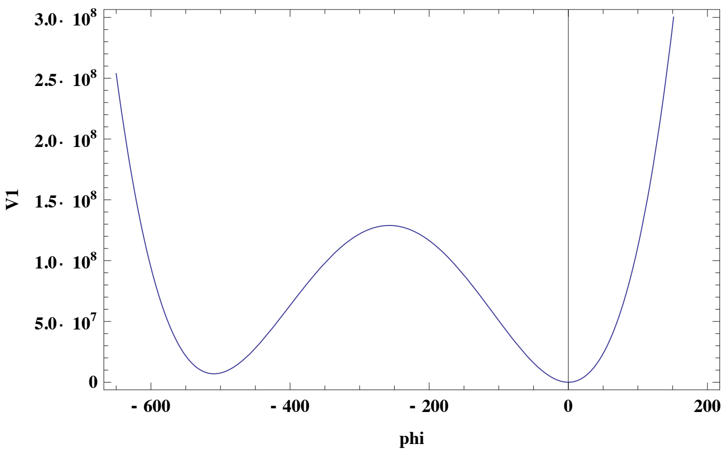
Let us look a bit closer at the Higgs mechanism in the simplest possible 4d context…

A toy model for the EW sector: the Abelian-Higgs model in 4d

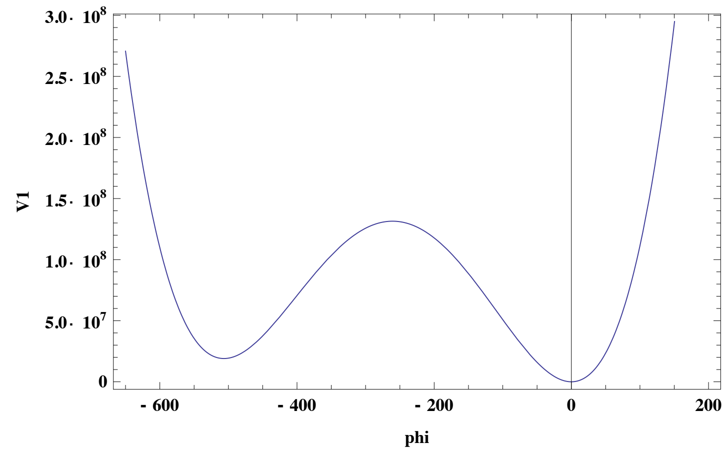
$$\mathcal{L}_{\rm AH} = -\frac{1}{4}F_{\mu\nu}^2 - \frac{1}{2\xi}\left(\partial_\mu A^\mu\right)^2 + |D_\mu H|^2 + m_0^2|H|^2 - \frac{\lambda_0}{6}|H|^4 + \text{const.}$$

Gauge invariant 1-loop AHiggs potential

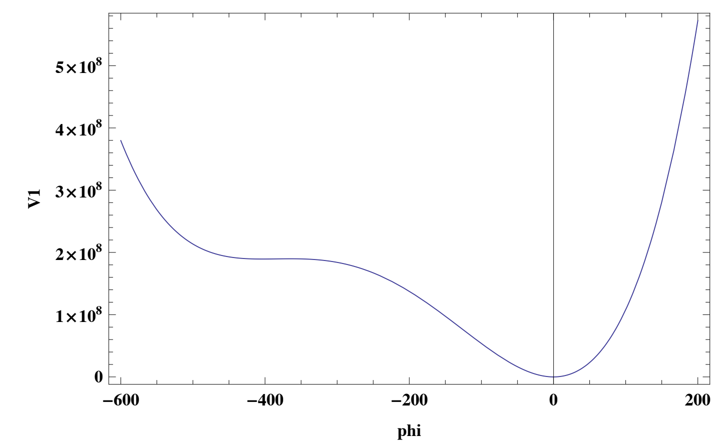
N.I. and F. Koutroulis, NPB924 (2017) 178-278



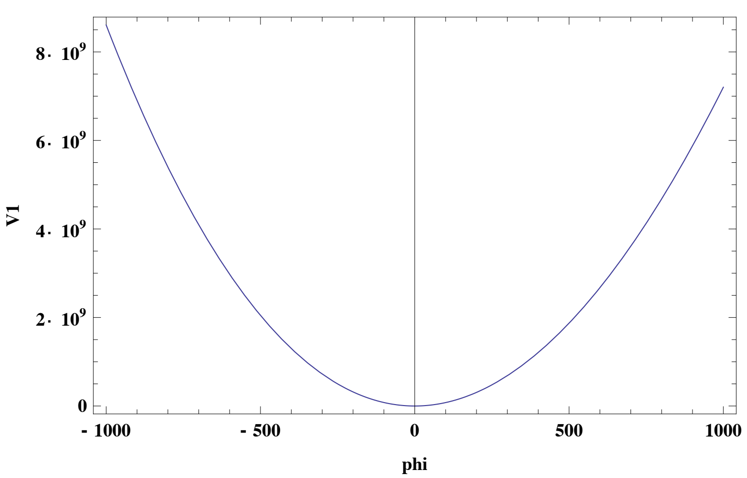
$125\ GeV$



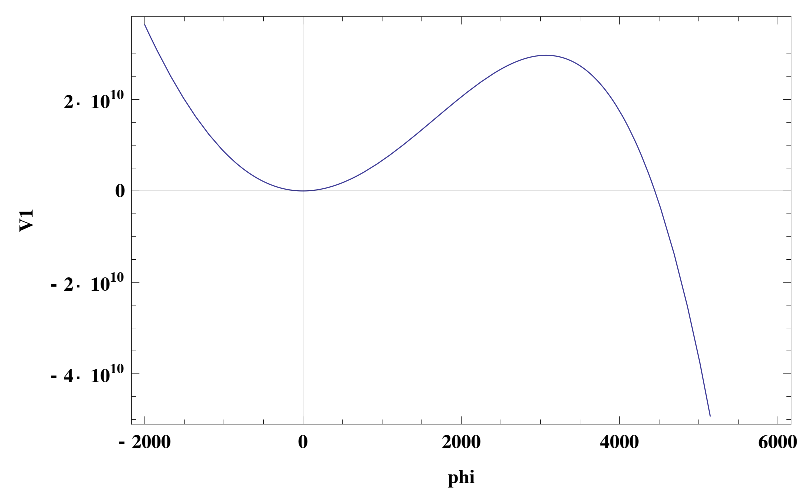
$10^{19}\ GeV$



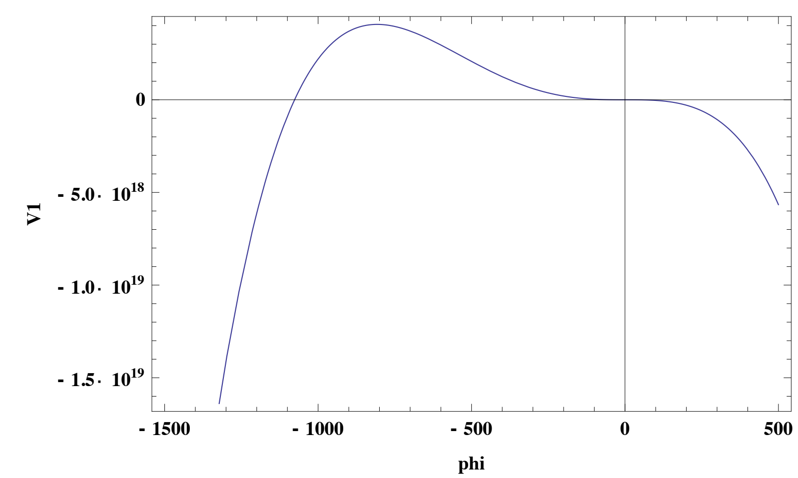
$10^{40}\ GeV$



$3 \cdot 10^{46}\ GeV$



$3.1 \cdot 10^{46}\ GeV$

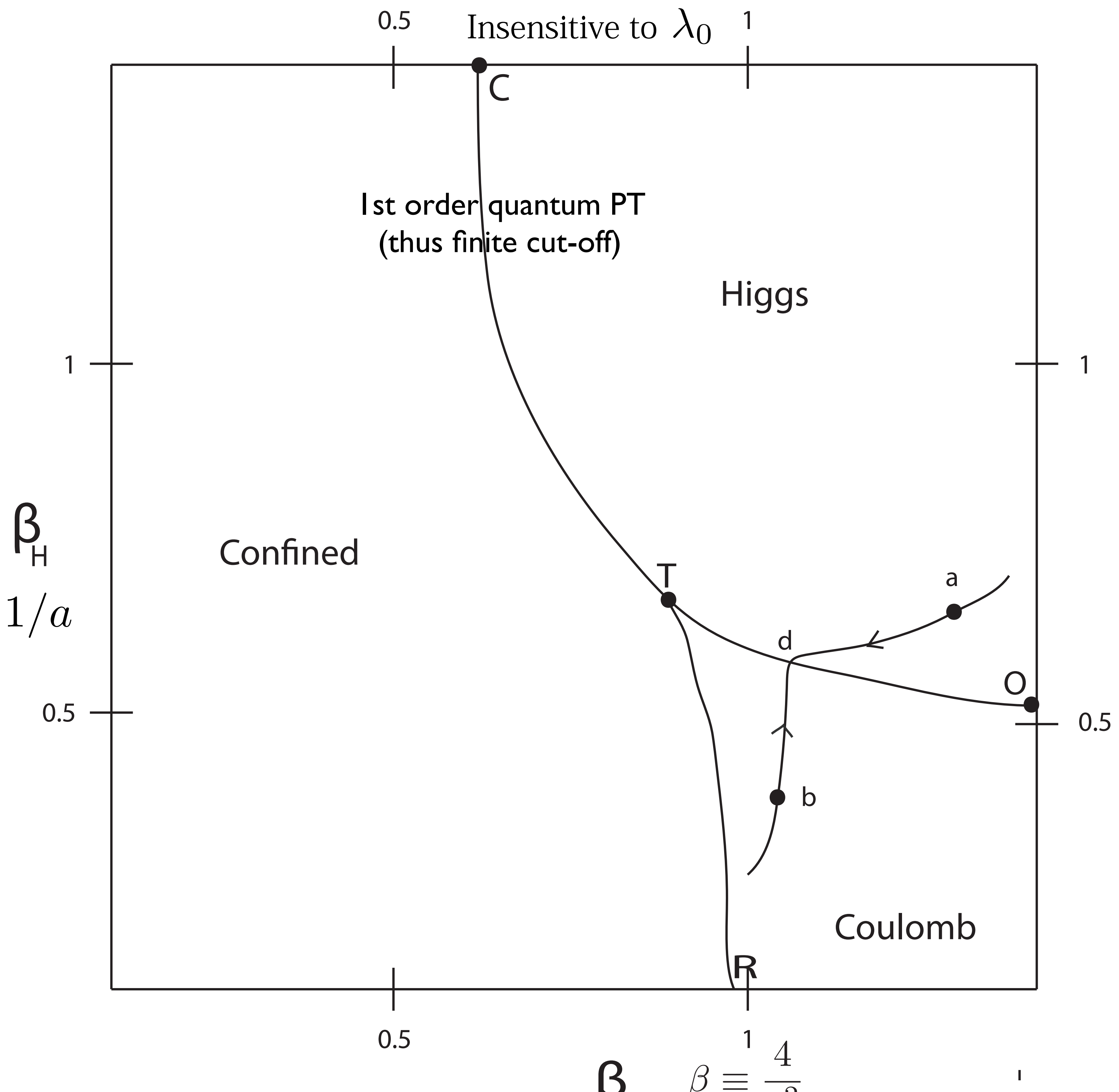


$4.3 \cdot 10^{49}\ GeV$

Instability scale   Non-perturbative domain   Landau Pole   Phase transition?

Phase diagram of the Abelian-Higgs model in 4d

Fradkin & Shenker (1979), Callaway & Carson (1982),
Evertz et al (1987), Khodayari (2016)

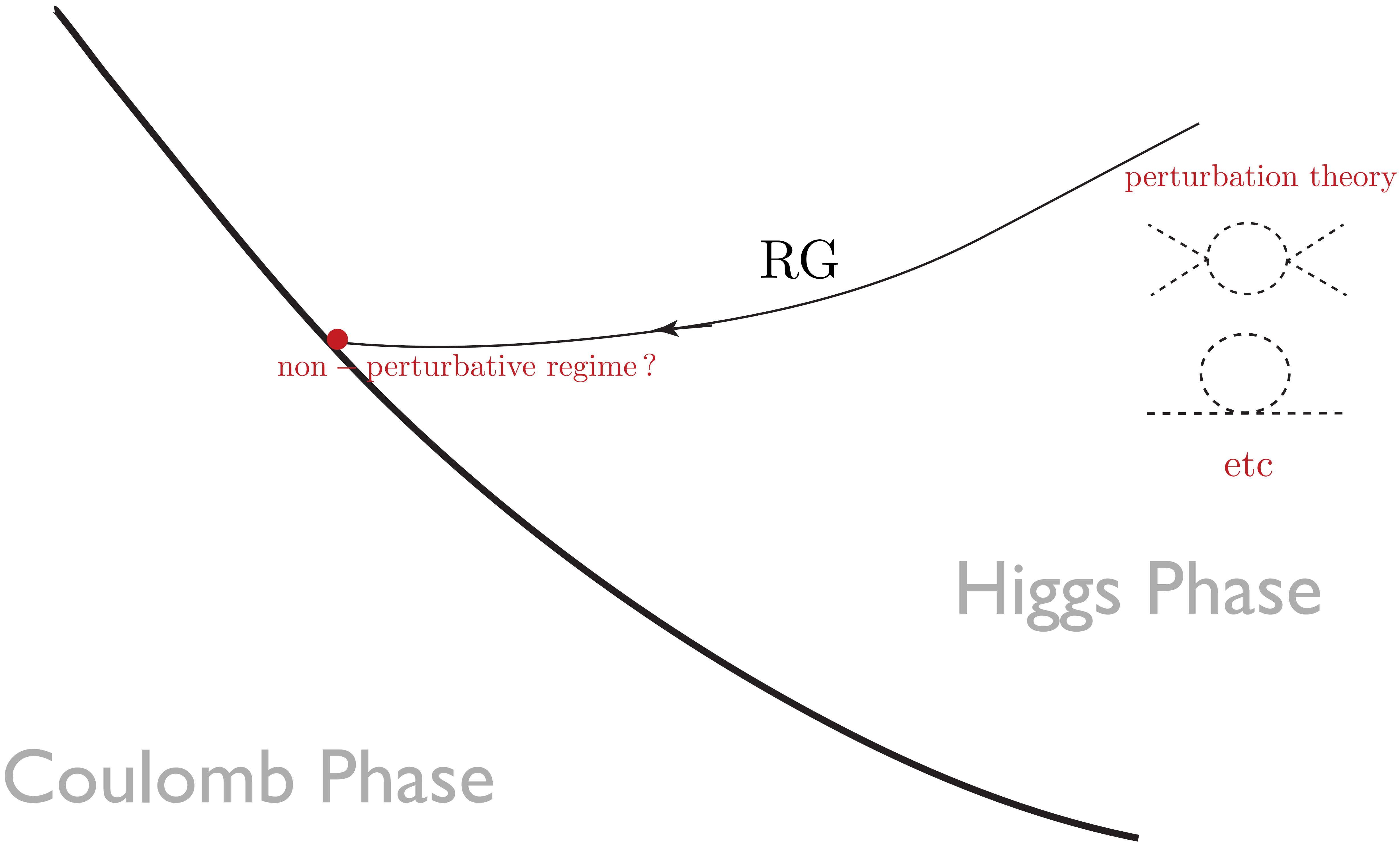


$$\beta_H \equiv \frac{v_0^2}{\Lambda^2}$$

$$\Lambda = \text{cutoff} \sim 1/a$$

$$\beta \equiv \frac{4}{g_0^2}$$

Zoom in


perturbation theory
RG
non − perturbative regime ?
etc
Higgs Phase
Coulomb Phase

Lesson from 4d:
If you want to generate a SM-like Higgs potential without putting it by hand, hope for a solution to the naturalness problem with the SM sitting on the brink of a "bulk" or "quantum" phase transition then find some UV completion without elementary scalars that possesses such phase transition and it has a (dimensionally reduced) Higgs phase.

Assume:

1. When the phase transition is approached along a physical trajectory on the phase diagram the system tends to become scale invariant.

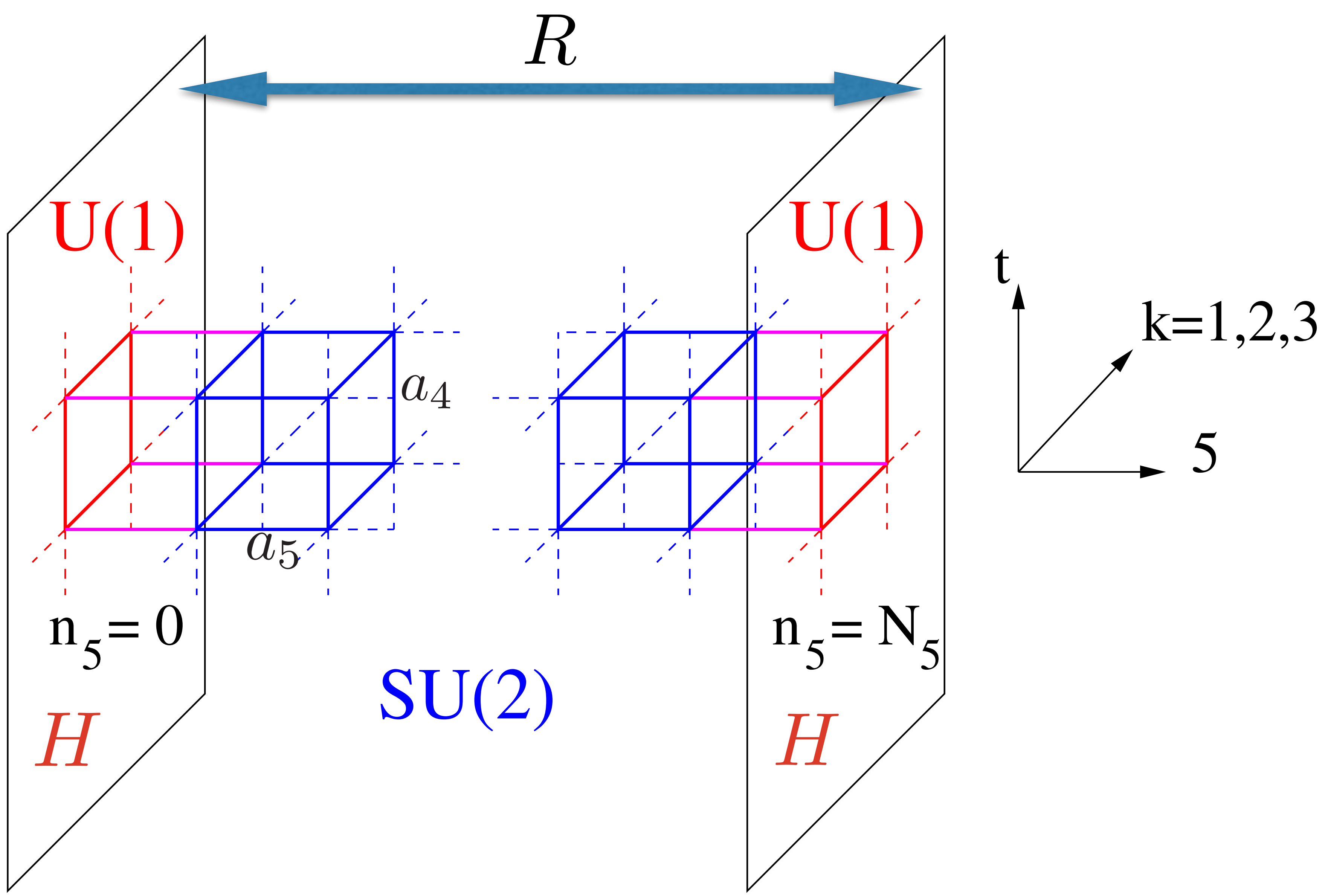
2. Phase transitions possess "shadows", meaning that when the nature of the system changes under the tuning of certain couplings, the new system has some memory of the physics that the original presence of the phase transition used to impose on it before the tuning took place.

Higher than 4d gauge theories with appropriate boundary conditions turn out to have these properties.

The 5d model

Let us consider now an anisotropic 5d SU(2) 'lattice orbifold'. On the boundaries we have the spectrum of a 4d SQED model U(1) + H + excited states. Classicaly the scalar potential vanishes.
Local and global symmetries are just 'right' so that all phases can be described in a gauge invariant way. We call this new version of GHU, "Non-Perturbative Gauge-Higgs Unification".

N. I., F. Knechtli (2005, 2007, 2014)



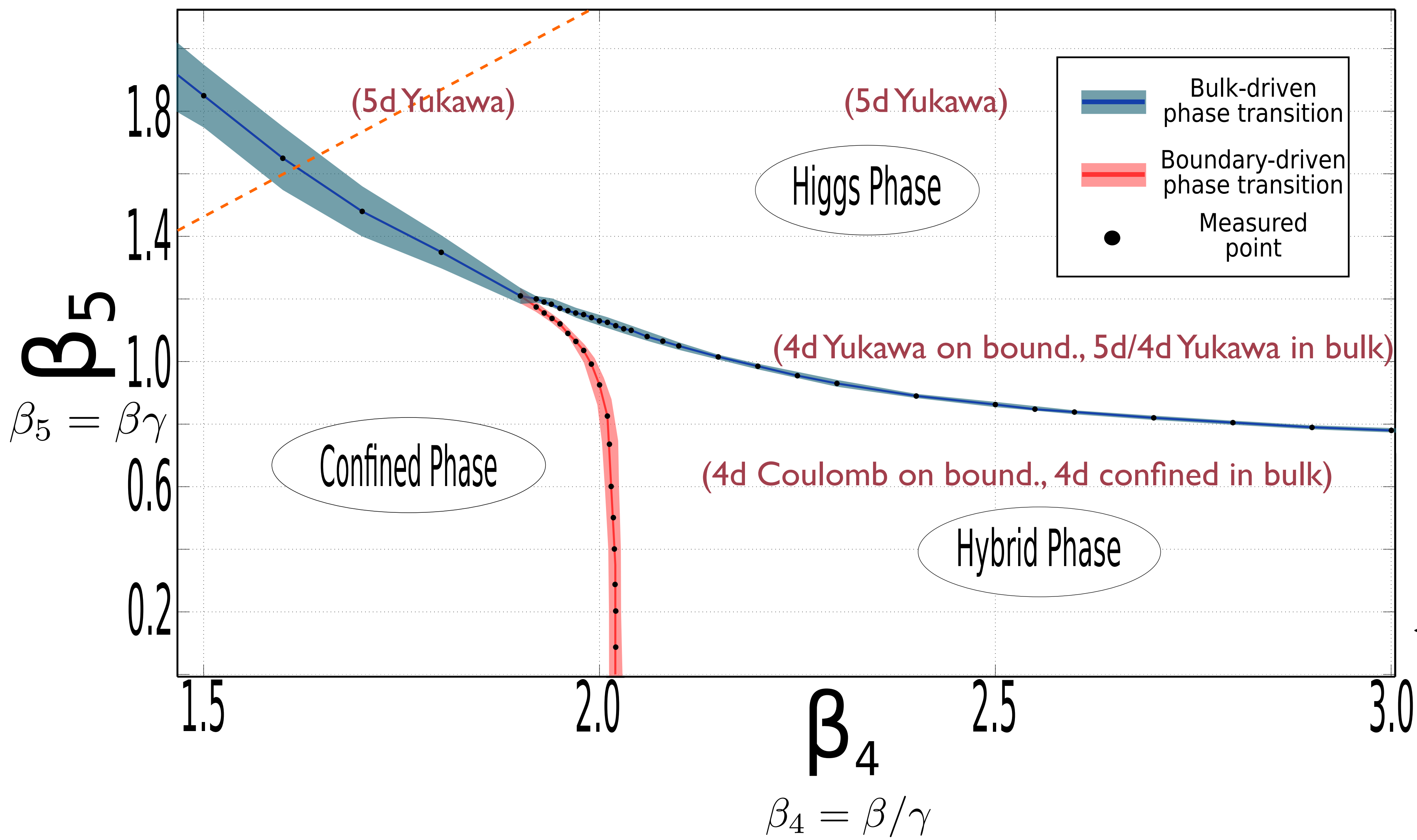
dimensionfull parameters: a_4, a_5, R, g_5

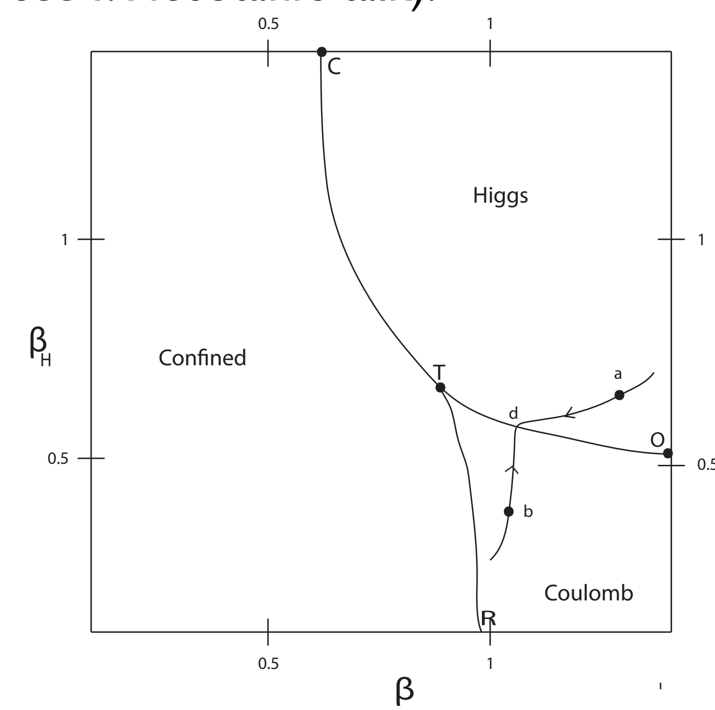
dimensionless parameters: $\beta = 4a_4^2/g_5^2 \;, \gamma = a_4/a_5 \;, N_5 = \pi R/a_5$

The phase diagram

G. Moir, M. Alberti, N. I., F. Knechtli (2015)

Non-perturbative dynamics:
I. Three Phases + dimensional reduction via localisation near the Higgs-Hybrid PT.
II. N5 dependence is weak and does not influence the existence of the Higgs phase.
III. No fermions.
So, it does not seem to be a non-perturbative Hosotani mechanism (for which see Y. Hosotani's talk).



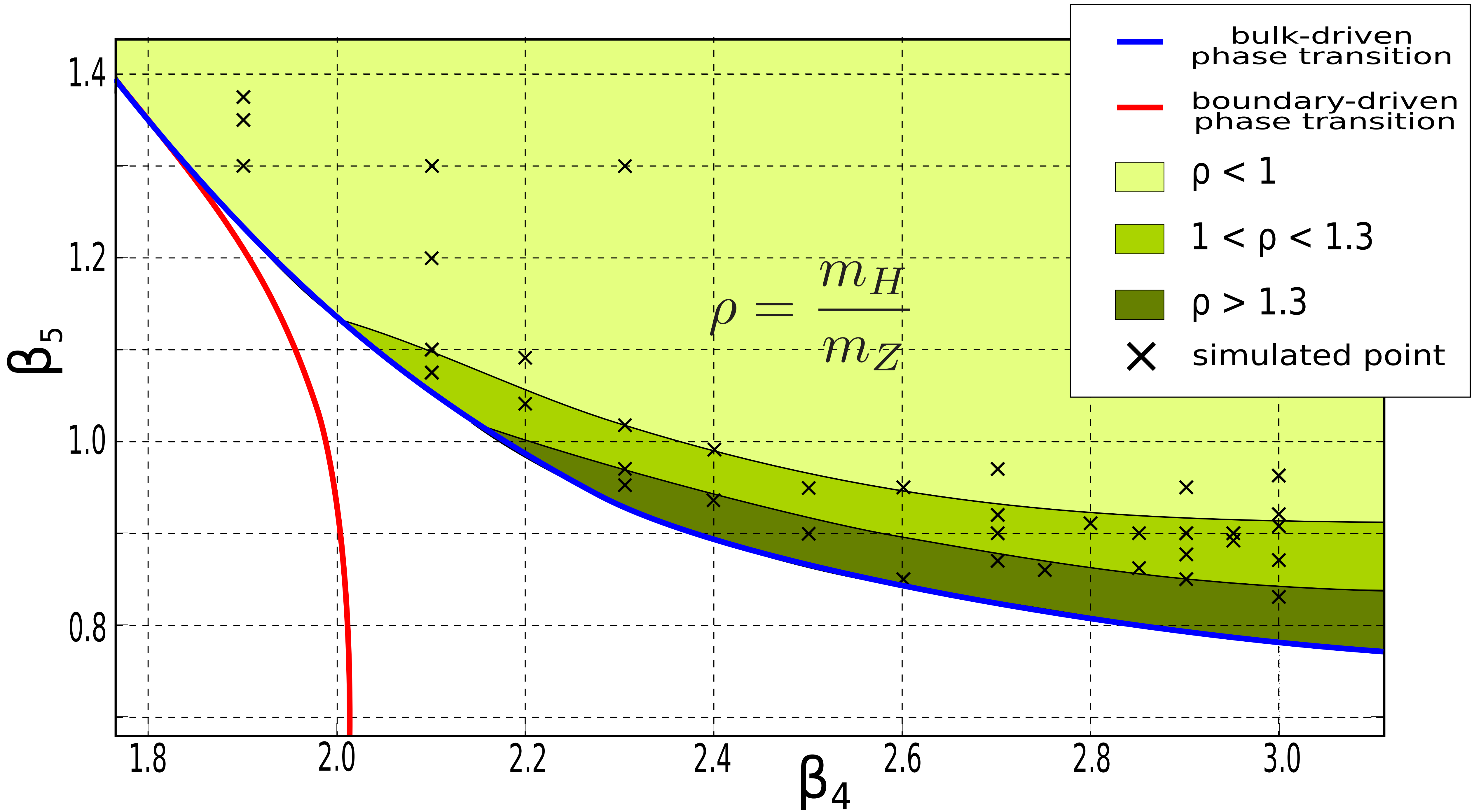


Note: this part of the phase diagram is reminiscent of the phase diagram of the (q=2) 4d Abelian-Higgs model, which is not unexpected since the two models have identical low lying spectra.

All phase transitions 1st order, effective theories must have a finite cut-off.

More NP dynamics:
Standard Model-like spectrum near the phase transition, precisely in the 4d Yukawa regime, where the 5d space breaks into an array of weakly interacting 4d planes.
The lattice spacing decreases as the PT is approached from either side.

G. Moir, M. Alberti, N. I., F. Knechtli (2015)

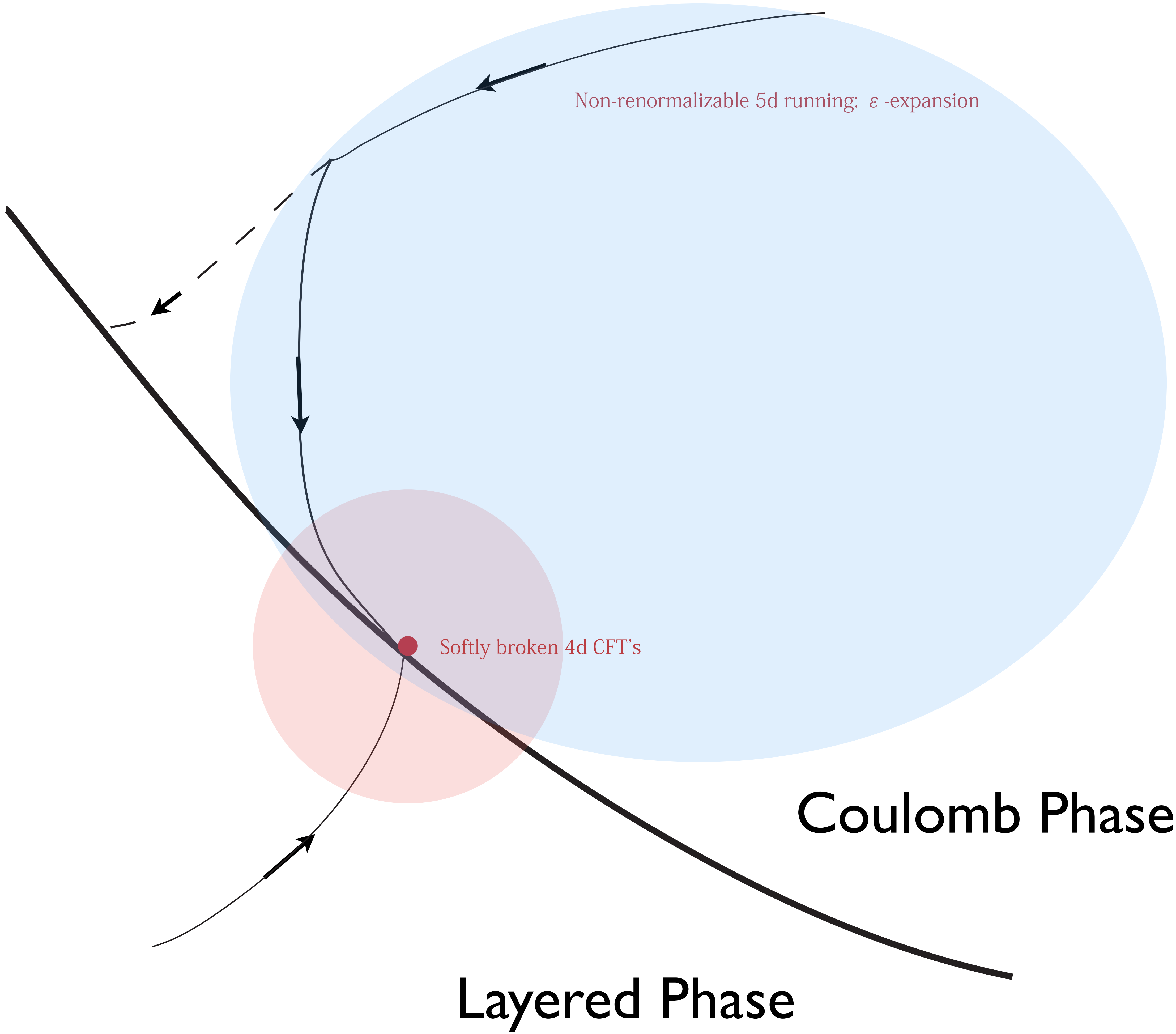


quantum + bosonic Higgs mechanism…no other such mechanism in 4 (or higher) dimensions to our knowledge…

Towards an effective action

To simplify things a bit, decouple the boundary from the bulk. This results in the loss of the Higgs phase in favour of the Coulomb phase and the Hybrid phase degenerating to a Layered phase. In this limit, the system can be described by a 4d boundary with a massless SQED on it and a 5d bulk with SU(2) symmetry. Near the PT the 5d bulk becomes "layered", i.e. decomposes into nearly independent 4d slices.
In fact, this is a natural limit when the full orbifold lattice action is expanded in small lattice spacings and the expansion is truncated to lowest non-trivial order.

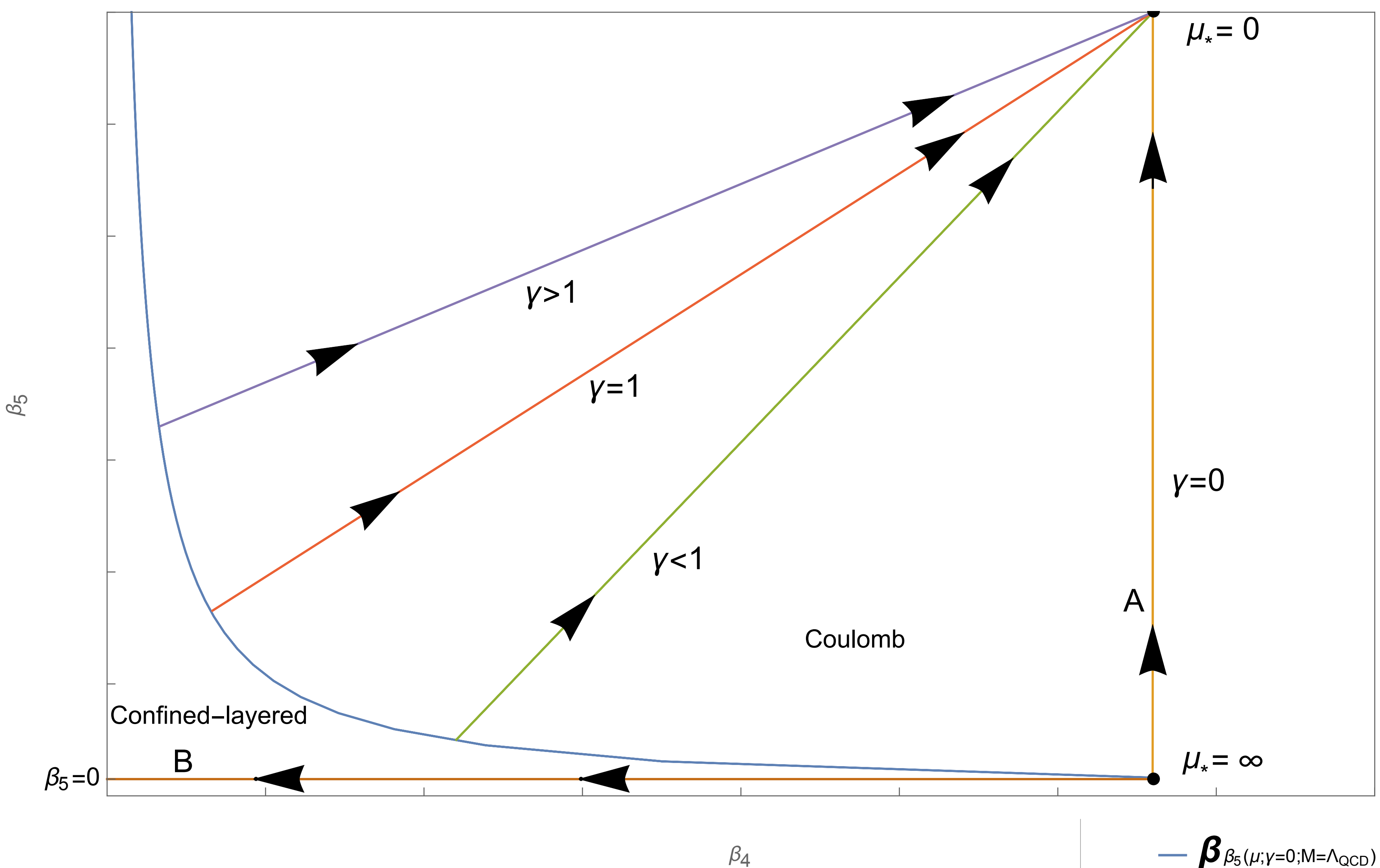
From a continuum QFT point of view the ε-expansion is one of the few available analytical tools. Alternatively, near the PT, one could describe the system via CFT techniques (by Assumptions I and II). Here we will concentrate on the QFT approach and come back to the CFT description another time.



Non-renormalizable 5d running: ε -expansion
Softly broken 4d CFT's
Coulomb Phase
Layered Phase

The ε-expansion

N. I., F. Koutroulis, arXiv:1804.06306



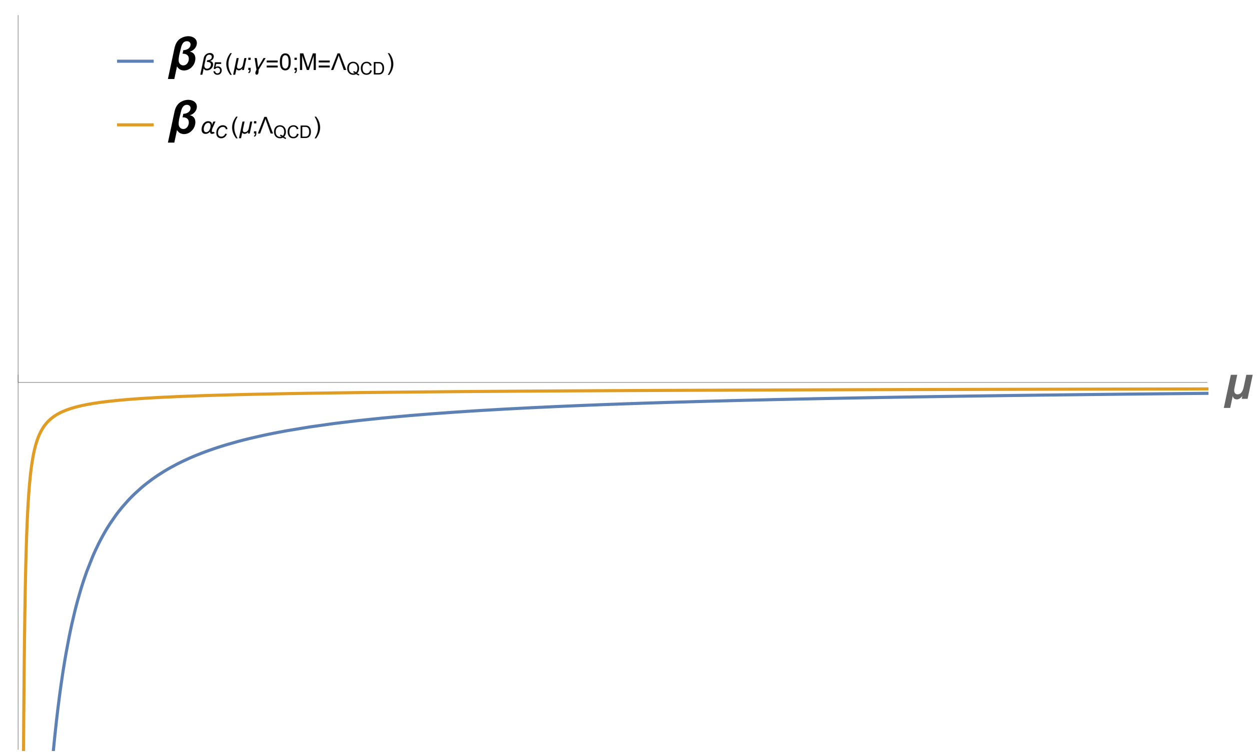
$$\alpha_5(\mu) = \frac{3N_C \varepsilon M^\varepsilon}{11\mathcal{C}_A \alpha_{5,M}(\mu^\varepsilon - M^\varepsilon) + 3N_C\varepsilon\mu^\varepsilon}\alpha_{5,M}$$

$$\beta_4(\mu) = \left(-\frac{11}{3\pi^2}\frac{f}{\gamma} + \beta_{4,M}\right)\frac{M}{\mu} + \frac{11}{3\pi^2}\frac{f}{\gamma}$$

$$\beta_5(\mu) = \left(-\frac{11}{3\pi^2}\gamma + \beta_{5,M}\right)\frac{M}{\mu} + \frac{11}{3\pi^2}\gamma$$

For the lines A and B, using Assumption 1, we can write:

$$\beta_5(\mu) = \beta_5(\Lambda_{\rm QCD})e^{-\frac{3\pi^2}{11}\beta_C(\mu)}$$



Conclusions and Outlook

- We presented a pure gauge 5d orbifold model that seems to realise Assumption 1.

- We computed RG flows in a limit where the boundary is decoupled from the bulk, using the ε-expansion. In this limit the system becomes blind to the Higgs mechanism. In order to recover the full non-perturbative physics, we presumably have to keep higher dimensional terms in the small lattice spacing expansion and repeat the calculation (work in progress with F. Koutroulis). This will check for instance Assumption 2.

- Physics around the PT must be also possible to describe with CFT techniques.

Thank you!