RG FLOWS IN *NON-PERTURBATIVE GAUGE-HIGGS UNIFICATION*: EFFECTIVE ACTION FOR THE *HIGGS PHASE NEAR THE QUANTUM PHASE TRANSITION*

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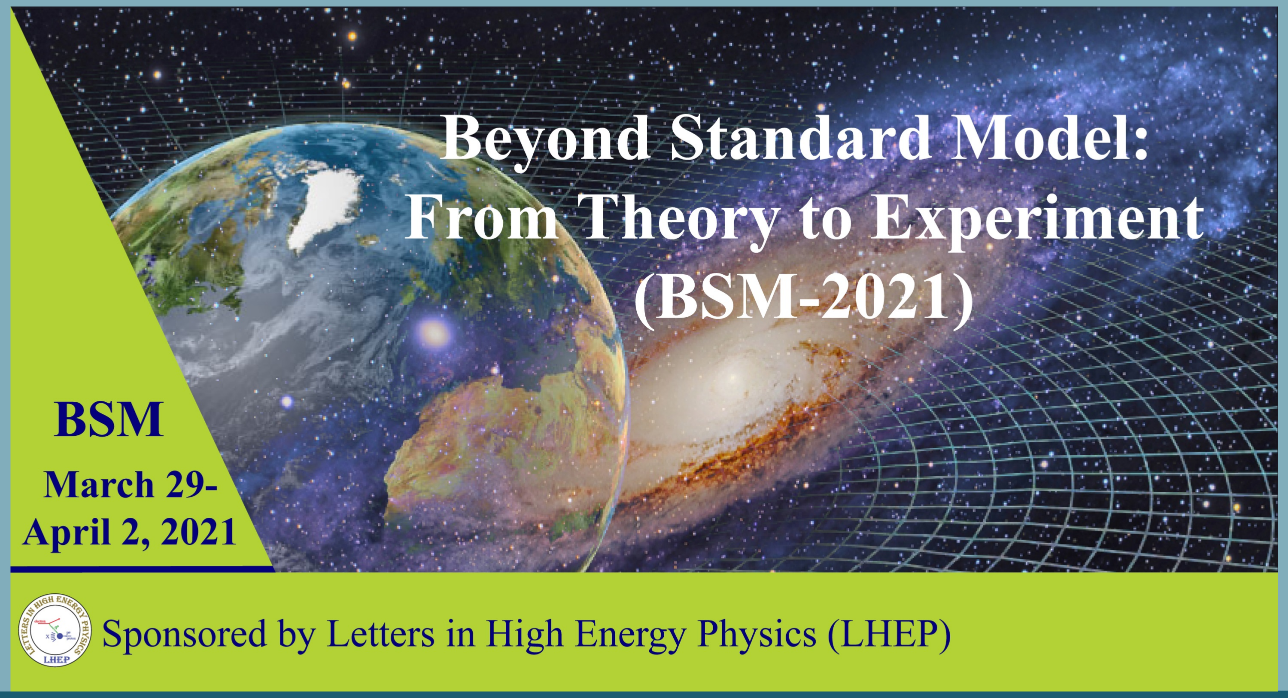
Based on: *Eur. Phys. J. C* ***81*** *(2021) 2, 187, Nikos Irges and F.K.*

01 April 2021

Beyond Standard Model: From Theory to Experiment (BSM - 2021)



CONTENTS

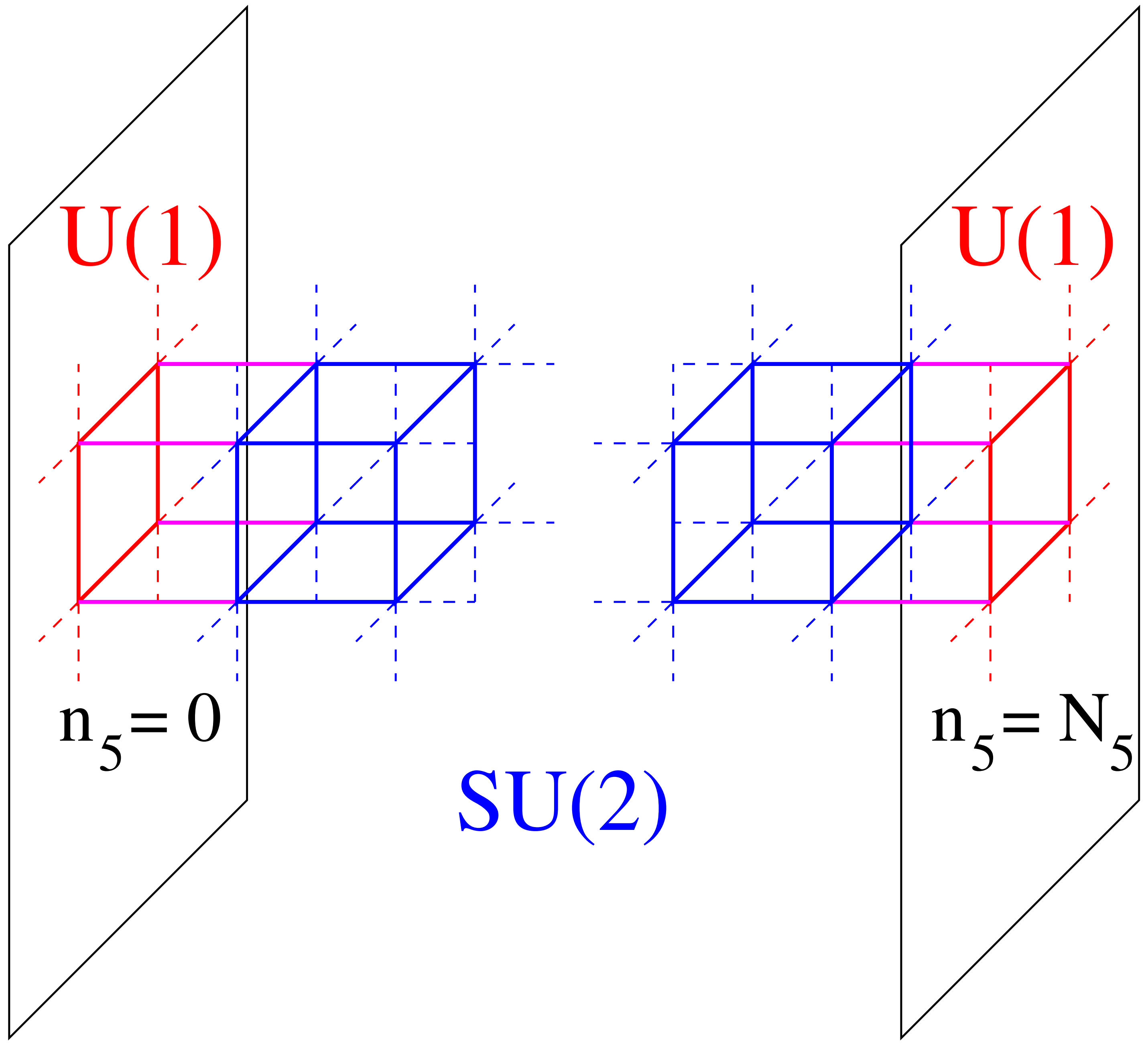
INTRO

- Ultimate goal is the proposal of a new approach to the Higgs-Hierarchy problem

- The Non-Perturbative Gauge-Higgs Unification (NPGHU) model:

  1. *An anisotropic, in fifth dimension, lattice with orbifold boundary conditions generating a 4d boundary*

  2. *A pure SU(2) gauge symmetry on the bulk. A U(1) gauge field coupled to a complex scalar survive on the boundary*



N. Irges and *F. Knechtli*, Nucl. Phys. B **719** (2005) 12
N. Irges and *F. Knechtli*, Nucl. Phys. B **775** (2007) 283
N. Irges, F. Knechtli and *K. Yoneyama*, Nucl. Phys. B **722** (2013) 378-383
M. Alberti, N. Irges, F. Knechtli and *G. Moir*, JHEP **09** (2015) 159
(After a lot of effort as you can see)

INTRO

- A non-perturbative spontaneous breaking of the gauge symmetry in infinite fifth dimension (Zero Temperature effect)

- Three crucial characteristics:

- Even though extra dimensional, no finite-temperature type potential. No compactification, no Kaluza-Klein states

A Higgs mechanism of quantum nature

- Pure bosonic nature of the Higgs mechanism. No need for fermions to trigger the mechanism

Not a GHU model → no Hosotani mechanism (quantum nature + fermions)

- There are not any polynomial terms in the classical (nor in the (quantum) effective) potential

Not a Coleman-Weinberg (CW) model (pure bosonic + classical nature potential)

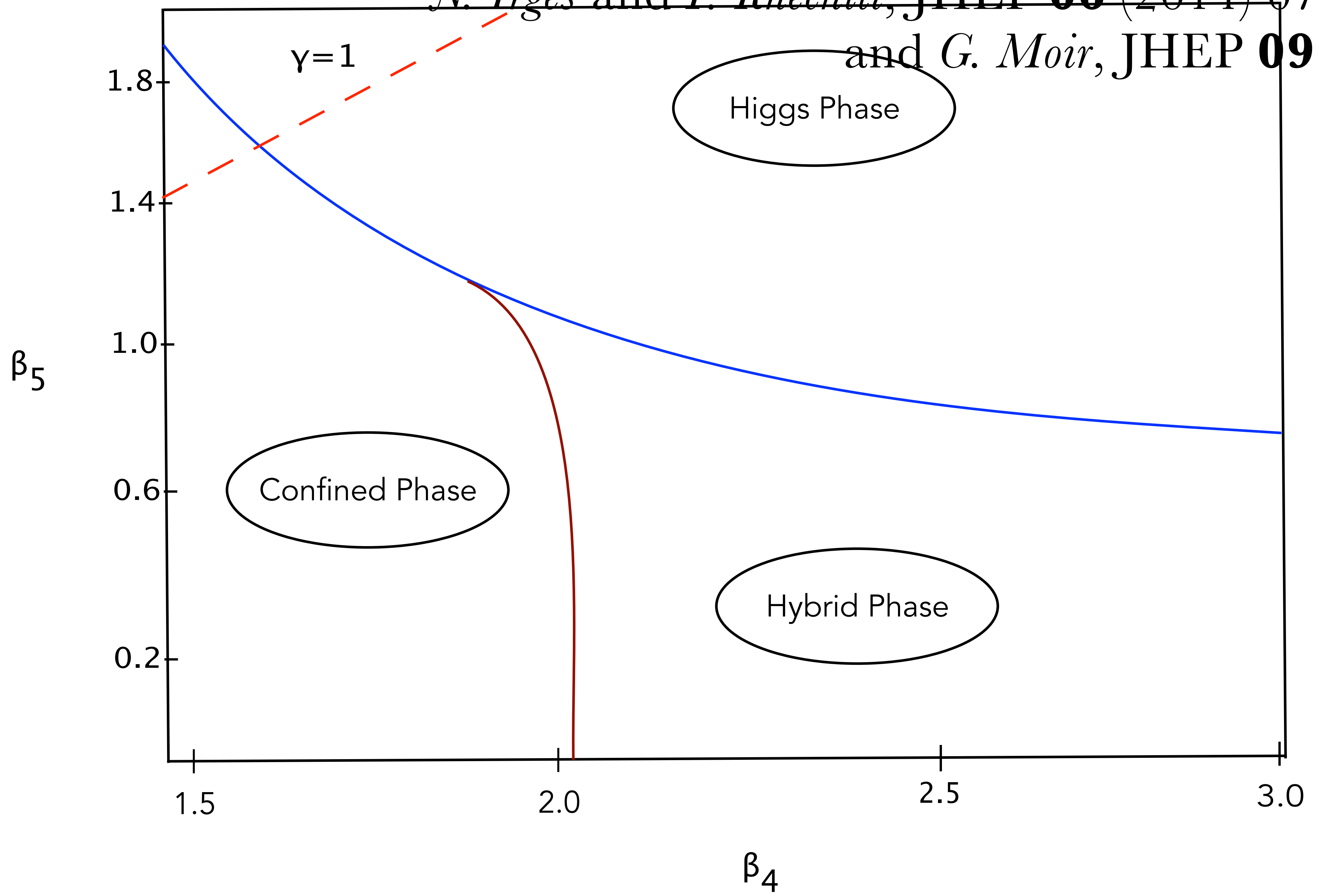
NPGHU model → Exhibits a pure quantum and bosonic spontaneous symmetry breaking mechanism

INTRO

- Gain: 1. *A non-perturbative (NP) new class of Higgs-type mechanisms*

  2. *The phase diagram of the lattice model exhibits a Higgs phase separated from two other phases by a1st order and "bulk" or "zero-temperature" or "quantum" phase transition:*

N. Irges and *F. Knechtli*, JHEP **06** (2014) 070; *M. Alberti, N. Irges, F. Knechtli* and *G. Moir*, JHEP **09** (2015) 159



The Phase Diagram of the anisotropic orbifold lattice.
N. Irges and *F. Knechtli*, JHEP 06 (2014) 070; *M. Alberti, N. Irges, F. Knechtli* and *G. Moir*, JHEP 09 (2015) 159

INTRO

- The 1st order phase transition implies that a hypothetical continuum effective potential should have a cut-off

- If it is low, it may give a possible resolution to the Higgs mass fine tuning problem

- Question 1: What about the continuum? Do the mentioned mechanism and its associated characteristics survive on the perturbative regime?

- Question 2: Is it possible this new class of Higgs-type mechanisms to give a realist scenario in accordance to our experimental facts, resolving the fine-tuning problem?

INTRO

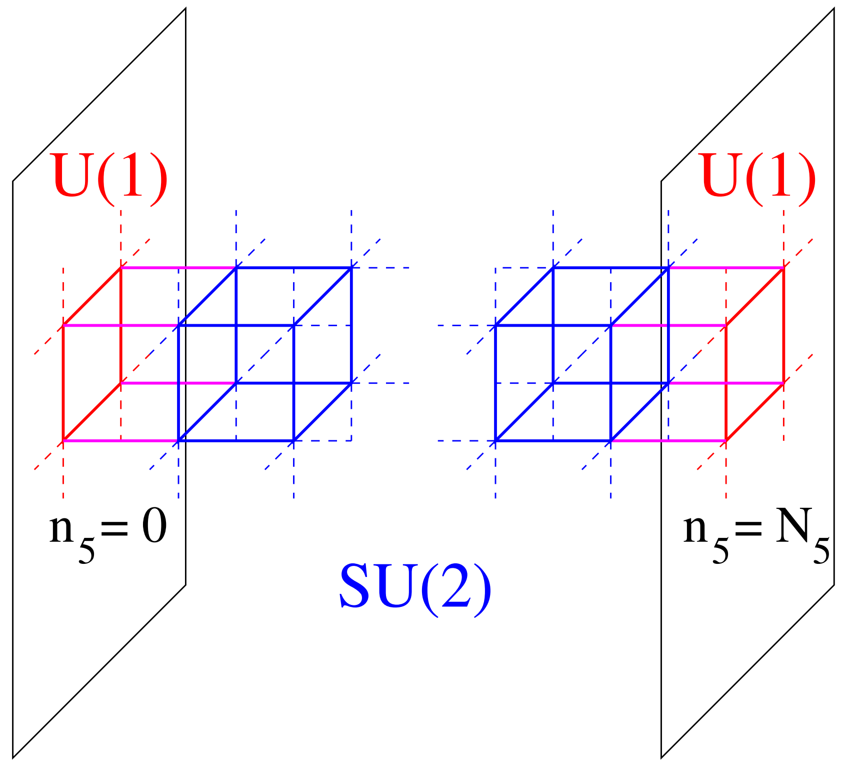
- Four crucial facts to keep in mind for the construction of the continuum action:
- Truncate at NLO including the dominant HDO (known as Symanzik's improvement*) which will unlock the physical properties of the Higgs phase

  Truncation at LO in lattice spacing expansion is not enough (*N. Irges and F.K.*, Nucl. Phys. B **937** (2018) 135-195)

- The boundary effective action, even though naively decoupled from the bulk, carries information of its 5d origin. This is hidden inside its *couplings*, the *anisotropy* and the constrained way that the RG flows can move on the phase diagram
- The Hybrid phase and the Higgs phase only near the Higgs-Hybrid phase transition are layered (Localization proved NP by N. Irges *et al*)
- Connect the lattice parameters (β_4, β_5 or β, γ which consist of a_4, a_5, g_5) with the continuum ones (μ, v, g_4). Use $\mu = \dfrac{F(\beta_4, \beta_5)}{a_4}$

**P. Weisz,* Nucl. Phys. B 212 (1983) 1-17; *M. Luscher, P. Weisz,* Commim. Math. Phys. 97 (1985) 59-77

QUANTIZATION WITH HDO



- What is the action to be quantized? Start from the lattice plaquette action $S^{\rm orb} = S^{\rm b-h} + S^{B}$

  The boundary action $S^{\rm b-h}$

$$S^{\rm b-h} = \frac{1}{2N}\sum_{n_\mu}\left[\frac{\beta_4}{2}\sum_{\mu<\nu}\mathrm{tr}\left\{1 - U^b_{\mu\nu}(n_\mu,0)\right\} + \beta_5\sum_{\mu}\mathrm{tr}\left\{1 - U^h_{\mu 5}(n_\mu,0)\right\}\right]$$

  The bulk action S^B

$$S^B = \frac{1}{2N}\sum_{n_\mu,n_5}\left[\beta_4\sum_{\mu<\nu}\mathrm{tr}\left\{1 - U_{\mu\nu}(n_\mu,n_5)\right\} + \beta_5\sum_{\mu}\mathrm{tr}\left\{1 - U_{\mu 5}(n_\mu,n_5)\right\}\right]$$

- The parameters of the model $\beta_4 = \frac{4a_5}{g_5^2} = \frac{4}{g_4^2}$, $\beta_5 = \frac{4a_4^2}{a_5 g_5^2} = \frac{4a_4^2}{a_5^2 g_4^2}$, $\gamma = \frac{a_4}{a_5}$, $g_4^2 = \frac{g_5^2}{a_5} = \frac{g_5^2}{a_4}\gamma$

- Expanding w.r.t the lattice spacings and truncate at NLO in the expansion

$$S^{\rm b-h} = \sum_{n_\mu} a_4^4 \sum_{\mu}\left[\sum_{\nu}\left(\frac{1}{4}F^3_{\mu\nu}F^3_{\mu\nu} + \frac{1}{16}a_4^2(\hat{\Delta}_\mu F^3_{\mu\nu})(\hat{\Delta}_\mu F^3_{\mu\nu})\right) + |\hat{D}_\mu\phi|^2 + \frac{a_4^2}{4}|\hat{D}_\mu\hat{D}_\mu\phi|^2\right]$$

- Consider the naive continuum limit and go to Minkowski space with metric $\eta_{\mu\nu} = (+,-,-,-)$ to get the boundary effective action

$$S^{\rm b-h} = \int d^4x\left[-\frac{1}{4}F^3_{\mu\nu}F^{3,\mu\nu} + |D_\mu\phi|^2 + \frac{c_\alpha^{(6)}}{2\mu^2}(\partial^\mu F^3_{\mu\nu})(\partial_\mu F^{3,\mu\nu}) - \frac{c_2^{(6)}}{\mu^2}|D^\mu D_\mu\phi|^2\right]$$

QUANTIZATION WITH HDO

- $A_M^{\mathbf{A}}$ is the bulk gauge field. $\mathbf{A} = 1,2,3$ denotes the adjoint index and $M = \mu,5$ the 5d Minkowski index

- $F_{\mu\nu}^3 = \partial_\mu A_\nu^3 - \partial_\nu A_\mu^3$ with A_μ^3 the gauge field and $\phi = \dfrac{A_5^1 + iA_5^2}{\sqrt{2}}$ the scalar field. $\mu, \nu \ldots$ denote the 4d Minkowski index

- $c_\alpha^{(6)}$ and $c_2^{(6)}$ are introduced for the HDO of the gauge and scalar field respectively absorbing the function $F(\beta_4, \beta_5)$ of $\mu = F(\beta_4, \beta_5)/a_4$

- Set $\mu^2 = \Lambda^2 \dfrac{\mu^2}{\Lambda^2}$ and absorb $\dfrac{\mu^2}{\Lambda^2}$ into the couplings. A cut-off for the Effective Field Theory (EFT) is introduced

- In this case Λ is not an external scale that must be introduced by hand. It is rather an internal scale, given by the value of the regulating scale at the phase transition, μ_*, where it assumes its maximum value. HDO are of quantum origin

N. Irges and F.K., Nucl. Phys. B **950** (2020) 114833

QUANTIZATION WITH HDO

- Expanding the gauge fixed action

$$
\begin{aligned}
S_0^{\mathrm{b-h}} \equiv \int d^4x \Bigg[& -\frac{1}{4}F^3_{\mu\nu,0}F_0^{3,\mu\nu} + \frac{1}{2\xi}A^3_{\mu,0}\partial^\mu\partial_\nu A_0^{3,\nu} - \bar{\phi}_0\Box\phi_0 - \frac{c^{(6)}_{\alpha,0}}{2\Lambda^2}F^3_{\mu\nu,0}\Box F_0^{3,\mu\nu} - \frac{c^{(6)}_{2,0}}{\Lambda^2}\bar{\phi}_0\Box^2\phi_0 - \bar{c}^3_0\Box c^3_0 \\
& + i g_0\sqrt{\gamma_0}A^3_{\mu,0}\left(\left\{\bar{\phi}_0\partial^\mu\phi_0 - \phi_0\partial^\mu\bar{\phi}_0\right\} + \frac{c^{(6)}_{2,0}}{\Lambda^2}\left\{\Box\bar{\phi}_0\partial^\mu\phi_0 - \Box\phi_0\partial^\mu\bar{\phi}_0\right\}\right) + g_0^2\gamma_0(A^3_{\mu,0})^2\bar{\phi}_0\phi_0 \\
& + g_0^2\gamma_0\left(\frac{c^{(6)}_{2,0}}{\Lambda^2}\left\{\phi_0\Box^2\bar{\phi}_0 + \bar{\phi}_0\Box^2\phi_0\right\} - \frac{c^{(6)}_{2,0}}{\Lambda^2}\partial^\mu(A^3_{\mu,0}\bar{\phi}_0)\partial_\mu(A_0^{3,\mu}\phi_0)\right) \\
& - \frac{i g_0^3\gamma_0^{3/2}c^{(6)}_{2,0}}{\Lambda^2}(A^3_{\rho,0})^2A^3_{\mu,0}\left(\bar{\phi}_0\partial^\mu\phi_0 - \phi_0\partial^\mu\bar{\phi}_0\right) - \frac{g_0^4\gamma_0^2c^{(6)}_{2,0}}{\Lambda^2}(A^3_{\rho,0})^4\bar{\phi}_0\phi_0\Bigg]
\end{aligned}
\quad , \; g^2 = \frac{g_5^2}{a_4}
$$

- To deal with the Ostrogradsky ghosts (O-ghosts) perform the most general field redefinition

$$\phi_0 \to \hat{\phi}_0 = \phi_0 + \frac{x}{\Lambda^2}D^2\phi_0 + \frac{y}{\Lambda^2}(\bar{\phi}_0\phi_0)\phi_0$$
$$A^3_{\mu,0} \to \hat{A}^3_{\mu,0} = A^3_{\mu,0} + \frac{x_\alpha}{\Lambda^2}(\eta_{\mu\rho}\Box - \partial_\mu\partial_\rho)A_0^{3,\rho}$$

- This introduces the Reparameterization ghosts (R-ghosts) which cancel the O-ghosts pole by pole at classical and quantum level

N. Irges and F.K., Phys. Rev. D 100, 065004 (2019)
N. Irges and F.K., Nucl. Phys. B **950** (2020) 114833

QUANTIZATION WITH HDO

- Fixing $x_\alpha = -c^{(6)}_{\alpha,0}$, $x = -\dfrac{c^{(6)}_{2,0}}{2}$ and $y = \dfrac{c^{(6)}_{1,0}}{8}$ gives the bare and redefined boundary action

$$
\begin{aligned}
S_0^{\rm b-h} &= \int d^4x \Bigg[-\frac{1}{4} F^3_{\mu\nu,0} F_0^{3,\mu\nu} + \frac{1}{2\xi} A^3_{\mu,0}\partial^\mu \partial_\nu A_0^{3,\nu} - \bar\phi_0 \Box \phi_0 - \frac{c^{(6)}_{1,0}}{4\Lambda^2}(\bar\phi_0\phi_0)\bar\phi_0\Box\phi_0 - \bar c_0^3 \Box c_0^3 \\
&+ i g_{4,0}\Big\{\eta_{\mu\rho} - \frac{\eta_{\mu\rho}\Box - \partial_\mu\partial_\rho}{\Lambda^2}\Big\} A_0^{3,\rho}\Big(\bar\phi_0\partial^\mu\phi_0 - \phi_0\partial^\mu\bar\phi_0\Big) + g^2_{4,0}(A^3_{\mu,0})^2\bar\phi_0\phi_0 \\
&+ \frac{g^2_{4,0}}{2\Lambda^2}\Big(A^3_{\mu,0}A^3_{\rho,0}\partial^\rho\bar\phi_0\partial^\mu\phi_0 + A^3_{\mu,0}\partial^\rho A^3_{\rho,0}\partial^\mu(\bar\phi_0\phi_0)\Big) - 2g^2_{4,0}\frac{A_0^{3,\mu}(\eta_{\mu\rho}\Box - \partial_\mu\partial_\rho)A_0^{3,\rho}}{\Lambda^2}\bar\phi_0\phi_0 \\
&+ i\frac{g_{4,0}\, c^{(6)}_{1,0}}{4\Lambda^2} A^3_{\mu,0}\bar\phi_0\phi_0\Big(\bar\phi_0\partial^\mu\phi_0 - \phi_0\partial^\mu\bar\phi_0\Big) + \frac{g^2_{4,0}\, c^{(6)}_{1,0}}{4\Lambda^2}(A^3_{\mu,0})^2(\bar\phi_0\phi_0)^2 \Bigg]
\end{aligned}
$$

- Now the boundary action is ghost-free and has developed a scalar quartic term $\bar\phi\phi\,\Box\,\bar\phi\phi$ (Recall that these HDO are of quantum nature)

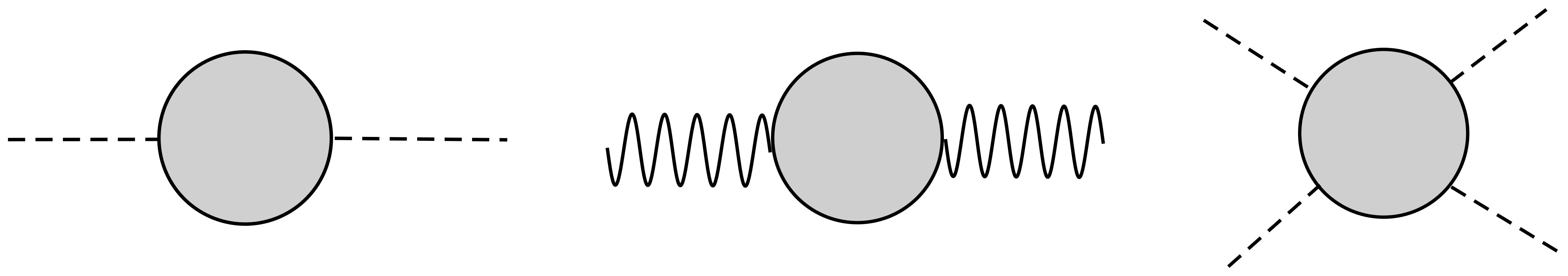
- One coupling in the beginning and two couplings, g_4 and the "quartic coupling" $c_1^{(6)}$ at the end. However is expected to be connected (`a la CW)

- The Feynman rules are straightforward but non-trivial due to the HDO. Ready for the 1-loop level, diagrammatic, renormalization

QUANTIZATION WITH HDO

- For the needed parameters g_4, $c_1^{(6)}$, ϕ and A^3_μ is enough (due to gauge invariance) to renormalize the propagators and the $\bar{\phi}\phi\,\Box\,\bar{\phi}\phi$- and $\bar{\phi}\phi A^3_\mu A^3_\nu$-vertices

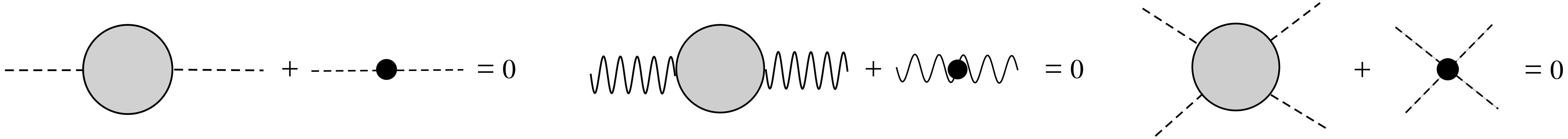
- The associated Feynman diagrams are a non-trivial version of the Scalar QED's ones



- The renormalization procedure suggests

$$g_{4,0} = (1+\delta_{g_4})g_4 \text{ or } \alpha_{4,0} = (1+\delta_{\alpha_4})\alpha_4 \text{ with } \alpha_4 = \frac{g_4^2}{16\pi^2} \qquad c_{1,0}^{(6)} = (1+\delta_{c_1^{(6)}})c_1^{(6)} \qquad \phi_0 = \sqrt{1+\delta_\phi}\,\phi \qquad A^3_{\mu,0} = \sqrt{1+\delta_A}\,A^3_\mu$$

- The renormalization conditions suggest



QUANTIZATION WITH HDO

- The countqerterms and the associated β-functions of the boundary action are fixed (the off-shell scheme $p_i^2 = \Lambda^2$ is used)

$$\delta_{g_4} = -\frac{1}{2}\delta A,\ \delta g_4 = \frac{1}{16\pi^2}\frac{g_4^3}{\varepsilon} \text{ or } \delta\alpha_4 = 2\frac{\alpha_4^2}{\varepsilon} \qquad \delta c_1^{(6)} = \frac{1}{16\pi^2}\frac{4(c_1^{(6)})^2 + 34g_4^4}{\varepsilon} \qquad \delta\phi = 0$$

$$\beta_{g_4} = \frac{g_4^3}{16\pi^2} \text{ or } \beta_{\alpha_4} = 2\alpha_4^2 \qquad \beta_{c_1^{(6)}} = \frac{4(c_1^{(6)})^2 + 34g_4^4}{16\pi^2}$$

- For completeness apply all the previous steps in the bulk lattice action to get its continuum version (5d Lee-Wick version**)

$$\mathcal{L}^B = -\frac{1}{4}F^A_{\mu\nu}F^{A,\mu\nu} + \frac{1}{16\Lambda^2}(D^\mu F^A_{\mu\nu})(D_\mu F^{A,\mu\nu}) - \frac{g_5}{24\Lambda^2} f_{ABC}F^A_{\mu\nu}F^B_{\nu\rho}F^C_{\rho\mu} + (\overline{D_\mu\Phi^A})(D^\mu\Phi^A) - \frac{1}{4\Lambda^2}(\overline{D^2\Phi^A})(D^2\Phi^A)$$

- The corresponding β-function of g_5 or of its auxiliary coupling $\alpha_5 = \frac{4g_5^2}{16\pi^2}\mu^{-\varepsilon}$ are straightforward in $d = 4 - \varepsilon$

$$\beta_{g_5\mu^{-\varepsilon/2}} = -\frac{\varepsilon}{2}g_5\mu^{-\varepsilon/2} - \frac{125}{6}\frac{g_5^3\mu^{-3\varepsilon/2}}{16\pi^2} \text{ or } \beta_{\alpha_5} = -\varepsilon\alpha_5 - \frac{125}{12}\alpha_5^2$$

***B. Grinstein, D. O'Connell and M. B. Wise*, Phys. Rev. D **77** (2008) 025012; *B. Grinstein and D. O'Connell*, Phys. Rev. D **78** (2008) 105005

THE HIGGS PHASE

- The desired Higgs phase is revealed when a CW procedure is followed

- The algorithm:

1. *Consider the 4d bare potential in momentum space*

2. *Construct the renormalized and improved effective potential using the scalar field as the running parameter and minimize it to find the non-trivial minimum*

3. *Find the relation between the couplings g_4, $c_1^{(6)}$ and then determine the scalar and gauge field masses and from those the scalar-to-gauge mass ratio*

- The improved 1-loop effective potential is of a CW type

$$V_{\text{imp.}}(c_1^{(6)}, \phi) = \frac{c_1^{(6)}}{4}(\bar{\phi}\phi)^2 + \left\{2(c_1^{(6)})^2 + 17g_4^4\right\}\frac{(\bar{\phi}\phi)^2}{64\pi^2}\left(\ln\frac{\bar{\phi}\phi}{v^2} - 3\right)$$

or using $\bar{\phi}\phi = \dfrac{(A_5^1)^2 + (A_5^2)^2}{2} \equiv \phi_r^2$

$$V_{\text{imp.}}(\phi_r) = \frac{c_1^{(6)}}{4}\phi_r^4 + \left\{2(c_1^{(6)})^2 + 17g_4^4\right\}\frac{\phi_r^4}{64\pi^2}\left(\ln\frac{\phi_r^2}{v^2} - 3\right)$$

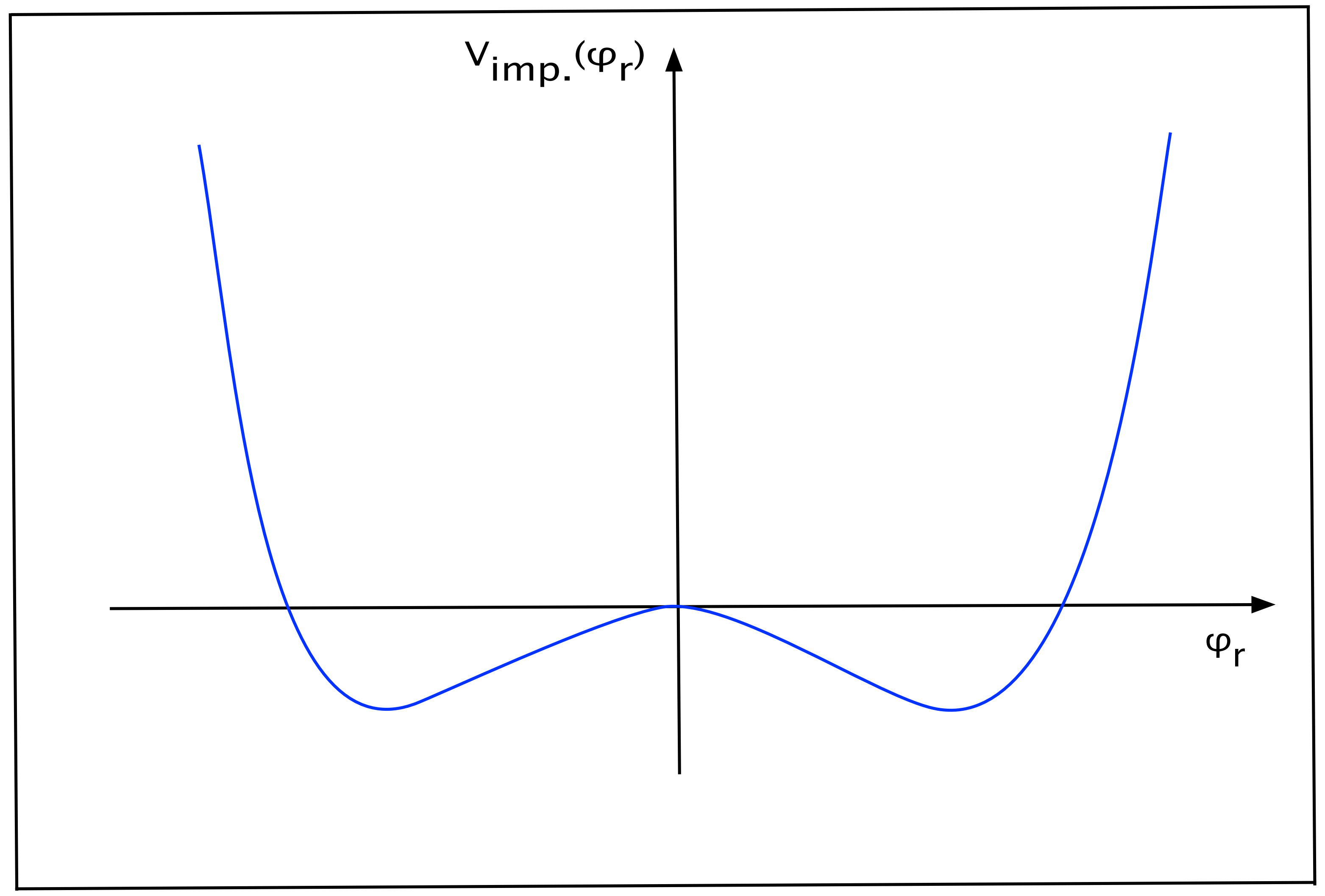
- The minimization suggests

$$\left.\frac{\partial V_{\text{imp.}}(\phi_r)}{\partial \phi_r}\right|_{\phi_r = v} = \frac{-(10(c_1^{(6)})^2 + 85g_4^4 - 32\pi^2 c_1^{(6)})v^3}{32\pi^2} = 0 \Rightarrow$$

$$c_1^{(6)} = \frac{85}{32\pi^2}g_4^4$$

THE HIGGS PHASE

- The expected connection between the couplings is achieved $\quad V_{\text{imp.}}(\phi_r) = \frac{17 g_4^4 \phi_r^4}{128\pi^2}\left(2\ln\frac{\phi_r^2}{v^2} - 1\right) + \mathcal{O}(g_4^8)$



The mexican hat potential $V_{\text{imp.}}(\phi_r)$

- The non-trivial vev ($<\phi_r> = v$) triggers the spontaneous breaking of the gauge symmetry $\phi_r = h + v$

$$m_h^2 \equiv \frac{\partial^2 V(h)}{\partial h^2}\Big|_{h=0} = \frac{210}{8\pi^2} g_4^4 v^2 \qquad m_{A_\mu^3}^2 = g_4^2 v^2 \equiv m_Z^2 \qquad \frac{m_h^2}{m_Z^2} \equiv \rho_{\text{bh}}^2 = \frac{210}{8\pi^2} g_4^2 \Rightarrow \rho_{\text{bh}} = \sqrt{\frac{210}{8\pi^2}}\, g_4 \simeq 1.64\, g_4$$

THE CONTINUUM PHASE DIAGRAM

- The needed ingredients:

  1. The RG evolution of the couplings in both phases

  2. The connection of β_4 and β_5 with the running gauge couplings of Higgs and Hybrid phase

  3. The value of the parameters on the phase transition denoted by *

The parameters

Higgs Phase	Hybrid Phase
$\alpha_4(\mu) = \dfrac{\alpha_{4,R}}{1 - \alpha_{4,R} \ln \frac{\mu^2}{m_R^2}}$	$\alpha_s(\mu) = \dfrac{c'_s}{\ln \frac{\mu}{\Lambda_s}}$ and $\Lambda_s = e^{-\frac{c'_s}{\alpha_{s,R}}} m_R$
$\mu = \exp\left[\dfrac{\alpha_4(\mu) - \alpha_{4,R}}{2\alpha_4(\mu)\,\alpha_{4,R}}\right] m_R$	$\mu = e^{\frac{c'_s}{\alpha_s(\mu)}} \Lambda_s$
$\beta_4(\mu) = \dfrac{1}{4\pi^2 \alpha_4(\mu)}$	$\beta_{4,s}(\mu) = \dfrac{1}{4\pi^2 \alpha_s(\mu)}$
$\beta_5(\mu) = \gamma^2(\mu)\beta_4(\mu)$	$\beta_{5,s}(\mu) = \gamma_s^2(\mu)\beta_{4,s}(\mu)$

THE CONTINUUM PHASE DIAGRAM

- On the Higgs-Hybrid phase transition $\mu = \mu_*$:

$$\alpha_4(\mu_*) = \alpha_s(\mu_*) = \alpha_* \qquad \mu_* = e^{\frac{c'_s}{1+2c'_s}\left[\frac{1}{\alpha_{4,R}}+\frac{2c'_s}{\alpha_{s,R}}\right]}\Lambda_s$$

$$\alpha_* = \frac{\alpha_{4,R}\,\alpha_{s,R}(1+2c'_s)}{\alpha_{s,R}+2c'_s\alpha_{4,R}} \qquad m_{h*} = \sqrt{\frac{210}{8\pi^2}}16\pi^2 v_*\alpha_*$$

- The above are controlled by four variables: $\alpha_{4,R}$, $\alpha_{s,R}$, v_*, and Λ_s ($c'_s = 3/125$)

- $\alpha_{s,R} = 0.014$ (SM's strong gauge coupling) and $\Lambda_s = m_p = 1000$ MeV (proton mass), fixed by physical motivation

- The first necessary condition for the validity of the effective action is the hierarchy of the scales

$$m_R < m_{h*} < \mu_*$$

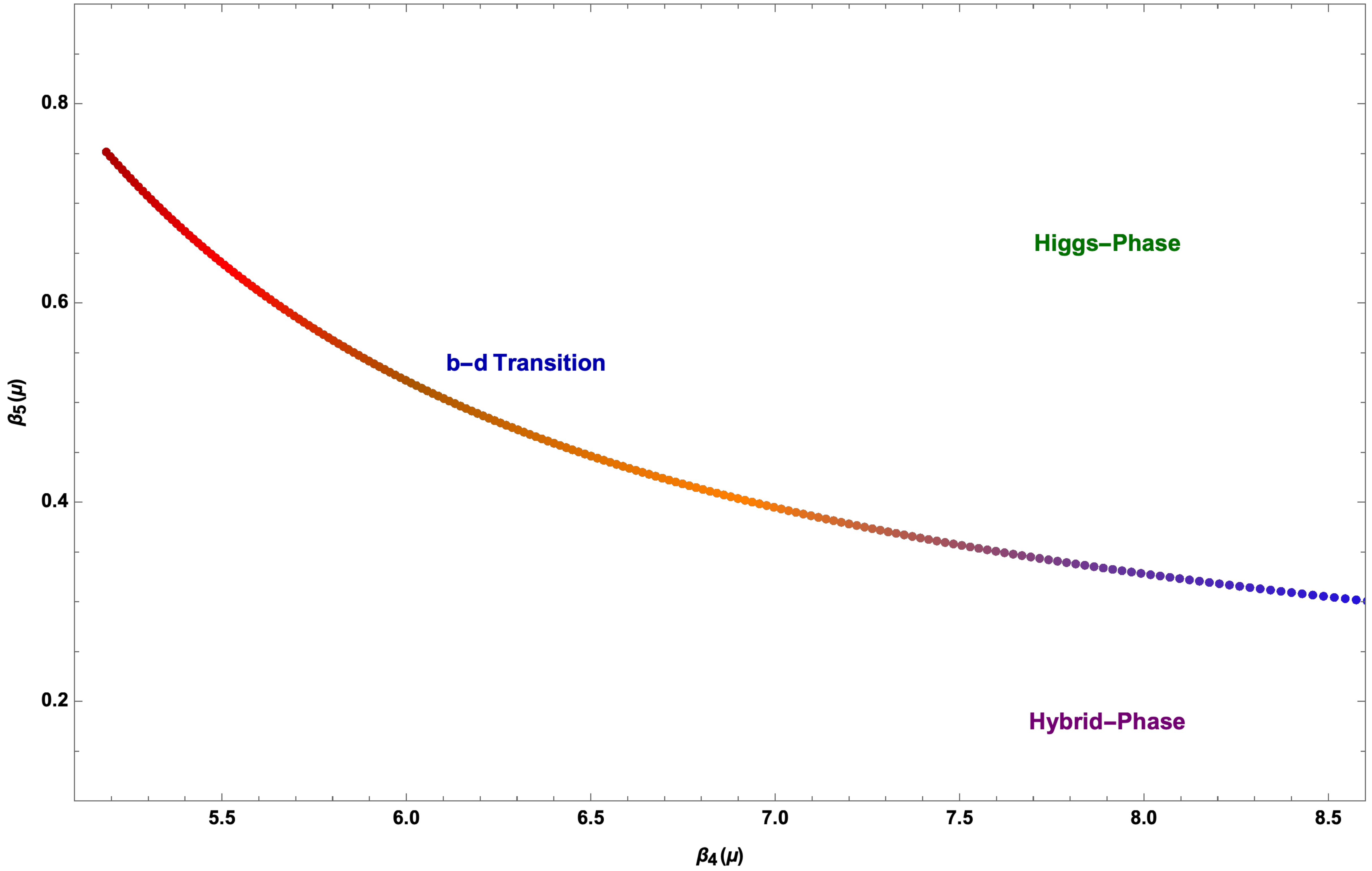
- The second necessary condition is to generate a SM-like spectrum

$$m_{h*} \simeq 125\,\text{GeV} \quad \text{and} \quad \rho_{\text{bh}} > 1$$

- Standard Model spectrum for $\alpha_{4,R} = 0.00435$ and $v_* = 108.2$ GeV $\longrightarrow$ $m_R = 5.55\,\text{GeV}$, $m_{h*} \approx 125.1\,\text{GeV}$, $\mu_* \approx 209\,\text{GeV}$ and $\rho_{\text{bh}} \approx 1.373$

THE CONTINUUM PHASE DIAGRAM

- Keep $\alpha_{s,R} = 0.014$, $\Lambda_s = 1000\,\text{MeV}$ and $v_* = 108.2\,\text{GeV}$. Vary $\alpha_{4,R} \rightarrow$ Varies $\mu_* \rightarrow$ different pair (β_{4*}, β_{5*})

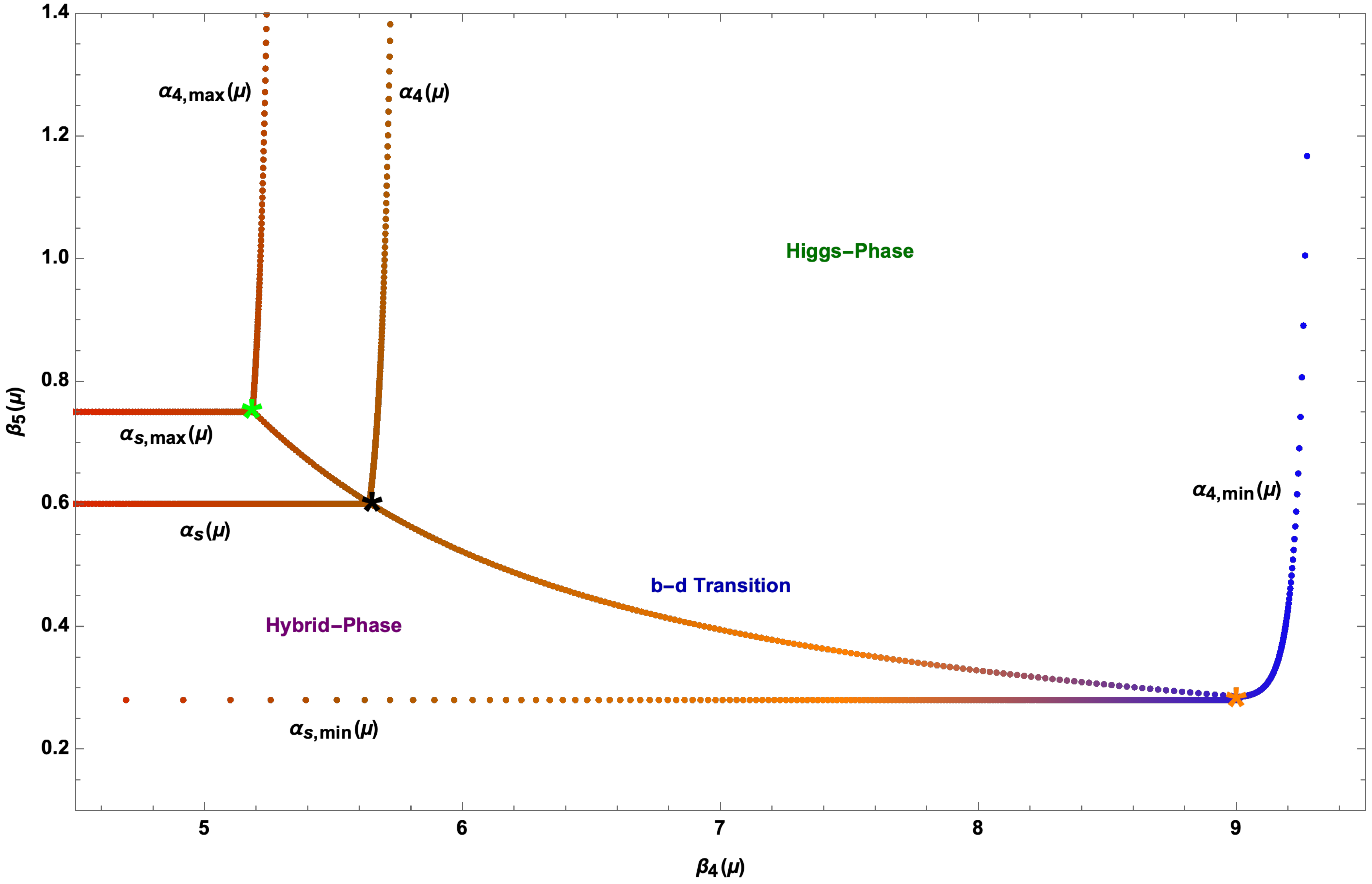


The perturbative phase diagram

THE CONTINUUM PHASE DIAGRAM

- The phase diagram and three RG flows: $\alpha_{4,R} \to$ $(\alpha_{4,R}^{\min} = 0.0027)$, $(\alpha_{4,R} = 0.00435)$, $(\alpha_{4,R}^{\max} = 0.00473)$

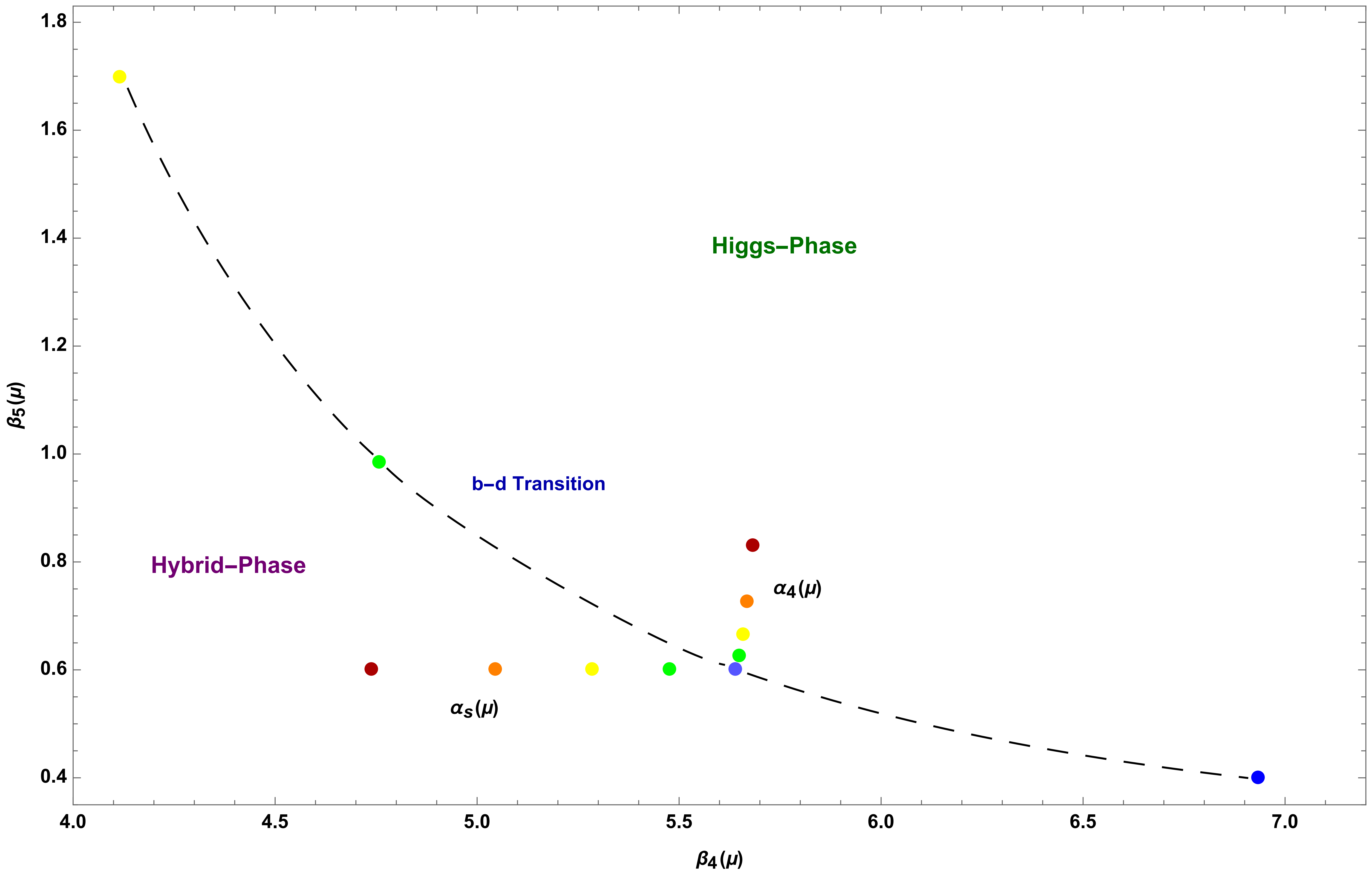
$(m_{h^*} \approx 78\,\mathrm{GeV}, \mu_* \approx 5123\ \mathrm{GeV})$ $(m_{h^*} \approx 125.1\,\mathrm{GeV}, \mu_* \approx 209\ \mathrm{GeV})$ $(m_{h^*} = \mu_* \approx 136.1\,\mathrm{GeV})$



The RG flows and the Phase transition

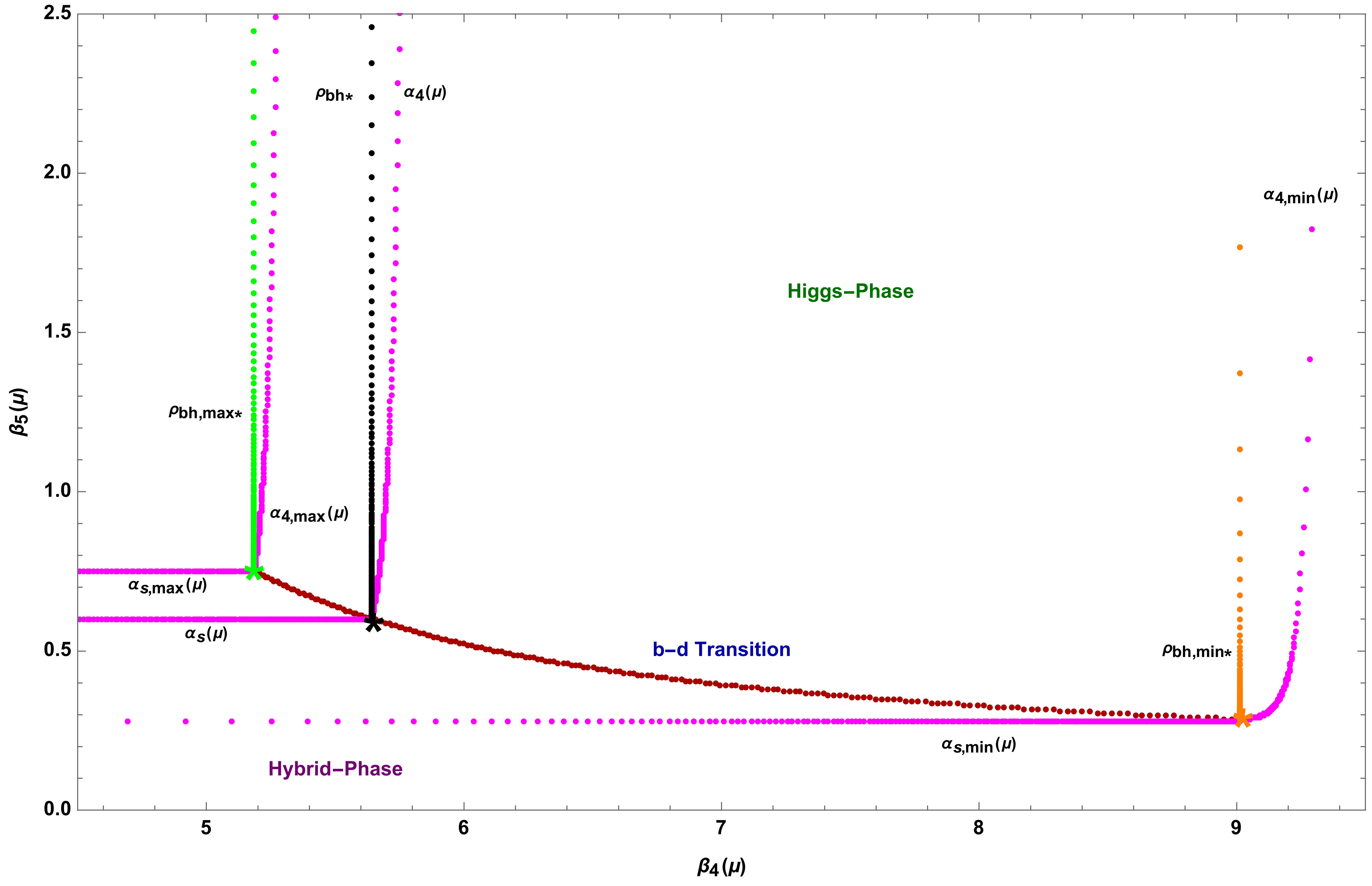
THE CONTINUUM PHASE DIAGRAM

- A zoomed version of the phase diagram



THE CONTINUUM PHASE DIAGRAM

- The Lines of Constant Physics



The Lines of Constant Physics (green, black and orange line) for the boundary-hybrid model in the Higgs phase. Along these lines the mass ratio and the scalar mass are kept fixed.

THE CONTINUUM PHASE DIAGRAM

- Numerical analysis shows that the fine tuning of an RG flow that respects the physical constraints is equal or less than $\mathcal{O}(10^2)$

Case 1: $\alpha_{s,R} \geq \mathcal{O}(10^{-1})$ only for $\alpha_{4,R} = 0.00435$ a realistic spectrum, however the 1st order phase transition below 2nd order phase transition

Case 2: $\alpha_{s,R} = \mathcal{O}(10^{-2})$ $(0.010 \leq \alpha_{s,R} \leq 0.098)$, only for $\alpha_{4,R} = 0.00435$ a realistic spectrum

Case 3: $\alpha_{s,R} \leq \mathcal{O}(10^{-3})$ a realistic spectrum for $\alpha_{4,R} \neq 0.00435$, however the the hierarchy condition is not respected

- Same arguments keeping $\alpha_{s,R} = 0.014$ and $\alpha_{4,R} = 0.00435$ fixed and varying Λ_s and v_*

- Then the fine tuning in the Higgs mass is very small

CONCLUSIONS

- The 1-loop effective action of an SU(2) gauge theory in five dimensions with boundary conditions that leave a U(1)-complex scalar theory on the boundary, located at the origin of a semi-infinite fifth dimension was constructed

- At perturbative level, the boundary theory is a version of the Coleman-Weinberg model where the quartic term is replaced by a dimension-6 derivative operator. A qualitatively similar to the CW model Higgs mechanism is at work but with different coefficients in the scalar mass and the β-functions that change things towards a more realistic direction

- Imposing on the effective action non-perturbative features known from the lattice, the system becomes highly constrained. The picture is that the model possesses a non-trivial phase diagram where the phases are separated by 1st order, quantum phase transitions located in the UV

- In order to use the model as a cartoon of a possible origin of the Standard Model Higgs sector, then it turns out that we have to sit on, or near the interface of the phase transition that separates the Higgs phase and a layered-type of phase, the Hybrid phase. There, dimensional reduction happens via localization in both phases and the effective action must be constructed with a dynamically generated finite cut-off but also with RG flows that are correlated below and above the phase transition

- Alternative resolution to the Higgs mass hierarchy problem: The fine tuning involved is about one part in a hundred and it is related to the choice of a ”physical RG flow” on the phase diagram while the dynamics do not allow a high cut-off for the effective action. Once such a physical RG flow is picked, there is very little fine tuning that takes place along it

- Several features of the model could be tested at Higgs-factories and future colliders

THANK YOU