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# *A PROFILE OF A HIGGS MECHANISM UNDER A UV AND QUANTUM, 1ST ORDER PHASE TRANSITION*

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### **CONTENTS**

• INTRODUCTION/MOTIVATION

• QUANTIZATION PROCEDURE AND THE ROLE OF HIGHER DIMENSIONAL OPERATORS (HDOs)

• THE HIGGS PHASE - THE HIGGS MECHANISM

• THE PHASE DIAGRAM OF THE BOUNDARY MODEL

• CONCLUSIONS

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

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

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

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



*N. Irges, F. Knechtli* and *K. Yoneyama*, Nucl. Phys. B **722** (2013) 378-383 k=1,2,3 *N. Irges* and *F. Knechtli,* Nucl. Phys. B **719** (2005) 12 *N. Irges* and *F. Knechtli*, Nucl. Phys. B **775** (2007) 283 *M. Alberti, N. Irges, F. Knechtli* and *G. Moir*, JHEP **09** (2015) 159 (*After a lot of effort as you can see*)

• Construction of a 4d continuum effective action for a 5d model originated by the lattice model of NPGHU (What is the motivation?)

• A: The model exhibits, non-perturbatively, spontaneous breaking of its gauge symmetry in infinite fifth dimension (*Zero Temperature* 

*effect*, *dimensional reduction through localization*):

• B: Three crucial characteristics:

*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

*1. Even though extra dimensional, no finite-temperature type potential. No compactification, no Kaluza-Klein states 2. Pure bosonic nature of the Higgs mechanism. No need for fermions to trigger the mechanism 3. There are not any polynomial terms (not a Coleman-Weinberg (CW) like model) in the classical (nor in the (quantum) effective) potential*

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

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

### • C: 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:* 



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

The Phase Diagram of the anisotropic orbifold lattice.

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:* 

orbifold action *S*orb defined in [2, 4] and reproduced in Appendix A:

• What is the action to be quantized? Start from the lattice plaquette action  $S^{\text{orb}} = S^{\text{b-h}} + S^B$ The boundary action *S*b−<sup>h</sup> of the nodes and *UMN* is the plaquette lying in the *MN* directions, with *M,N* = *µ,* 5. The  $\text{Equation 1: } \frac{1}{2}$  from the lattice plaquette action  $\text{S}^{\text{ref}} = \text{S}^{\text{ref}} + \text{S}^{\text{ref}}$ 

"

 $\overline{\phantom{a}}$ 

1

1

*a*2

#

#### **QUANTIZATION WITH HDO TIZA** " 4 DI tr **V** 1 *Uµ*⌫(*nµ, n*5) o  $\bf{H}$ 4 *g*2 *,* <sup>5</sup> = 4*a*<sup>2</sup> 4 *a*2 5*g*2

model 
$$
\beta_4 = \frac{4a_5}{g_5^2} = \frac{4}{g_4^2}, \beta_5 = \frac{4a_4^2}{a_5g_5^2} = \frac{4a_4^2}{a_5^2g_4^2}, \gamma = \frac{a_4}{a_5}, g_4^2 = \frac{g_5^2}{a_5} = \frac{g_5^2}{a_4}\gamma
$$

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

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

The bulk action  $S^B$ 

$$
S^B = \frac{1}{2N} \sum_{n_{\mu},n_{5}} \Biggl[ \beta_4 \sum_{\mu<\nu} {\rm tr}\,\Bigl\{1 - U_{\mu\nu}(n_{\mu},n_{5})\Bigr\} + \beta_5 \sum_{\mu} {\rm tr}\,\Bigl\{1 - U_{\mu 5}(n_{\mu},n_{5})\Bigr\} \Biggr]
$$

- The parameters of the model  $\beta_4 = \frac{4u_5}{g_5^2} = \frac{4}{g_4^2}$ ,  $\beta_5 = \frac{4u_4}{a_5g_5^2} = \frac{4u_4}{a_5^2g_4^2}$ ,  $\gamma = \frac{u_4}{a_5}$ ,  $\beta_4 =$  $4a_5$ *g*2 5 = 4 *g*2 4  $\beta_5 =$  $4a_4^2$  $a_5g_5^2$ =  $\text{model}$   $\beta_4 = \frac{10}{2} = \frac{1}{2}, \beta_5 = \frac{10}{2} = \frac{10}{2}, \gamma = \frac{10}{2}, \gamma = \frac{10}{2}, \beta_6 = \frac{10}{2} = \frac{10}{2}$  $85$   $84$   $4585$   $4584$   $45$   $4$   $4$ o model  $\beta = \frac{4a_5}{s} - \frac{4}{s} - \frac{4a_4^2}{s} - \frac{4a_4^2}{s} - \frac{a_4}{s} - \frac{a_4}{s^2} - \frac{85}{s^2} - \frac{85}{s^2}$
- Expanding w.r.t the lattice spacings and truncate at NLO in the expansion condition and the lattice section in the above actions in which the above actions are to be expansion ture that it is a set to separate the sum in the expansion in the expansion of the spacings and truncate at NLO in the expansion

*pM*. Moreover we move to Minkowski space with metric ⌘*µ*⌫ ⌘ (+*, , ,* ). These are standard

ntinuum limit and

 $\overline{\phantom{a}}$ 

 $\overline{\phantom{a}}$ 

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

!!<br>!!

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



where is a complex scalar field, *A*<sup>3</sup>

*<sup>µ</sup>* is the photon field and *F*<sup>3</sup>

 $P^2$  Start from the lattice plaquate costion  $S^{orb} - S^{b-h}$ ,  $S^B$ with  $g<sub>4</sub> a dimensionless derived coupling, defined in terms of the 5d gauge coupling, defined in terms of the 5d gauge coupling as  $g^2$$ 

*µ*⌫

= @*µA*<sup>3</sup>

⌫ @⌫*A*<sup>3</sup>

*<sup>µ</sup>*. The couplings

<sup>4</sup> <sup>=</sup>

; <sup>5</sup> = *.* (2.6)

## **QUANTIZATION WITH HDO**

•  $A_M^A$  is the bulk gauge field.  $A = 1,2,3$  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  $A_{\mu}^3$  the gauge field and  $\phi = \frac{A_5^1 + iA_5^2}{\sqrt{2}}$  the scalar field.  $\mu, \nu$ ... denote the 4d Minkowski index

- 
- Why NLO truncation?
- Set  $\Lambda^2 \equiv \Lambda^2(\mu)$  as a cut-off for the Effective Field Theory (EFT)

In this case  $\Lambda$  is not an external scale that must be introduced by hand. It is rather an internal scale, given by the value  $\bar{a}$ of the regulating scale at the phase transition, μ<sub>\*</sub>, where it assumes its maximum value. HDO are of quantum origin

• One more step, before renormalize diagrammatically at 1-loop order the boundary action and obtain its quantum effective version, is to

*Truncation at LO in lattice spacing expansion is not enough. It generates a 2nd order phase transition M. Irges and F.K.*, Nucl. Phys. B 937 (2018) 135-195 *enough. It generates a 2nd order phase transition* 

deal with the extra pole instability

 $rac{1}{2} + iA_5^2$  the scalar field.  $\mu, \nu$ ...

•  $c_{\alpha}^{(6)}$  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  $\mu = F(\beta_4, \beta_5)/a_4$ 

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



• Expanding the gauge fixed action  $S^{b-h}$  = Z  $d^4x$ 

• 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** on the boundary ¯*c*<sup>3</sup> , *c*3. In the latter case recall that the Faddeev-Popov ghosts are decoupled from the spectrum. Given the above, the gauge-fixed *S*b<sup>h</sup> reads

 $\sqrt{ }$ 

 $+$ 

• To deal with the Ostrogradsky ghosts (O-ghosts) perform the most general field redefinition + *ig*<sup>0</sup> <sup>p</sup>0*A*<sup>3</sup> *µ,*0 ¯0@*µ*<sup>0</sup> 0@*µ*¯<sup>0</sup> +

$$
\phi_0 \to \hat{\phi}_0 = \phi_0 + \frac{x}{\Lambda^2} D^2 \phi_0 + \frac{y}{\Lambda^2} (\bar{\phi}_0 \phi_0) \phi_0
$$
  

$$
A_{\mu,0}^3 \to \hat{A}_{\mu,0}^3 = A_{\mu,0}^3 + \frac{x_\alpha}{\Lambda^2} (\eta_{\mu\rho} \Box - \partial_\mu \partial_\rho) A_0^{3,\rho}
$$

[1], it is @*µA*<sup>3</sup>

*µ*. The same is true for the Faddeev-Popov ghosts which in the bulk are ¯*c<sup>A</sup>*

, *c<sup>A</sup>* and

*c*

(6)

$$
\int d^4x \left[ -\frac{1}{4} F_{\mu\nu}^3 F^{3,\mu\nu} - \frac{1}{2\xi} (\partial^{\mu} A_{\mu}^3)^2 + |D_{\mu}\phi|^2 \right]
$$
  

$$
\frac{c_{\alpha}^{(6)}}{2\Lambda^2} (\partial^{\mu} F_{\mu\nu}^3)(\partial_{\mu} F^{3,\mu\nu}) - \frac{c_2^{(6)}}{\Lambda^2} |D^{\mu} D_{\mu}\phi|^2 + \partial^{\mu} \bar{c}^3 \partial_{\mu} c^3 \right]
$$

er<br>  $\phi_{0}$ <sup> $\phi_{0}$ </sup>

- To deal with the Ostrogradsky ghosts (O-ghosts) perform the most general field redefinition
- This introduces the Reparameterization ghosts (R-ghosts) which cancel the O-ghosts pole by pole at classical and quantum level  $\frac{1}{2}$

 $2<sup>1</sup>$  $2<sup>†</sup>$ <sup>2</sup> ⇤<sup>2</sup> ¯0⇤20*c*¯

*S*b<sup>h</sup>

Int*,*<sup>0</sup> =

Z

*d*4*x*

s (O-gnosts*)* perform the most general field red

*ig*<sup>0</sup>



<sup>p</sup>0*A*<sup>3</sup>

n

¯0@*µ*<sup>0</sup> 0@*µ*¯<sup>0</sup>

o

+

*c*

2*,*0

n

⇤¯0@*µ*<sup>0</sup> ⇤0@*µ*¯<sup>0</sup>

o!

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

$$
\begin{array}{rcl}\n\text{Expanding the gauge fixed action} \\
\mathcal{S}_{0}^{b-h} & = & \int d^{4}x \left[ -\frac{1}{4}F_{\mu\nu,0}^{3}\bar{F}_{0}^{3,\mu\nu} + \frac{1}{2\xi}A_{\mu,0}^{3}\partial^{\mu}\partial_{\nu}A_{0}^{3,\nu} - \bar{\phi}_{0}\Box\phi_{0} - \frac{c_{\alpha,0}^{(6)}}{2\Lambda^{2}}F_{\mu\nu,0}^{3}\Box F_{0}^{3,\mu\nu} - \frac{c_{2,0}^{(6)}}{\Lambda^{2}}\bar{\phi}_{0}\Box^{2}\phi_{0} - \bar{c}_{0}^{3}\Box c_{0}^{3}\right] \\
& & + & ig_{0}\sqrt{\gamma_{0}}A_{\mu,0}^{3}\left(\left\{\bar{\phi}_{0}\partial^{\mu}\phi_{0} - \phi_{0}\partial^{\mu}\bar{\phi}_{0}\right\} + \frac{c_{2,0}^{(6)}}{\Lambda^{2}}\left\{\Box\bar{\phi}_{0}\partial^{\mu}\phi_{0} - \Box\phi_{0}\partial^{\mu}\bar{\phi}_{0}\right\}\right) + g_{0}^{2}\gamma_{0}(A_{\mu,0}^{3})^{2}\bar{\phi}_{0}\phi_{0} \\
& & + & g_{0}^{2}\gamma_{0}\left(\frac{c_{2,0}^{(6)}}{\Lambda^{2}}\left\{\phi_{0}\Box^{2}\bar{\phi}_{0} + \bar{\phi}_{0}\Box^{2}\phi_{0}\right\} - \frac{c_{2,0}^{(6)}}{\Lambda^{2}}\partial^{\mu}(A_{\mu,0}^{3}\bar{\phi}_{0})\partial_{\mu}(A_{0}^{3,\mu}\phi_{0})\right) \\
& & - \frac{ig_{0}^{3}\gamma_{0}^{3/2}c_{2,0}^{(6)}}{\Lambda^{2}}(A_{\rho,0}^{3})^{2}A_{\mu,0}^{3}\left(\bar{\phi}_{0}\partial^{\mu}\phi_{0} - \phi_{0}\partial^{\mu}\bar{\phi}_{0}\right) - \frac{g_{0}^{4}\gamma_{0}^{2}c_{2,0}^{(6)}}{\Lambda^{2}}(A_{\rho,0}^{3})^{4}\bar{\phi}_{0}\phi_{0}\right], \quad g^{2} = \frac{g_{5}^{2}}{a_{4}}\n\end{array}
$$

$$
\phi_0 \to \hat{\phi}_0 = \phi_0 + \frac{x}{\Lambda^2} D^2 \phi_0 + \frac{y}{\Lambda^2} (\bar{\phi}_0 \phi_0) \phi_0
$$

$$
A_{\mu,0}^3 \to \hat{A}_{\mu,0}^3 = A_{\mu,0}^3 + \frac{x_\alpha}{\Lambda^2} (\eta_{\mu\rho} \Box - \partial_\mu \partial_\rho) A_0^{3,\rho}
$$

### **QUANTIZATION WITH HDO**

<sup>2</sup>⇤<sup>2</sup> (@*µF*<sup>3</sup>

*<sup>µ</sup>*⌫)(@*µF*3*,µ*⌫) *<sup>c</sup>*

⇤<sup>2</sup> *<sup>|</sup>DµDµ<sup>|</sup>*

# $Q$ **UANTIZATION WITH HDO**

• Fixing  $x_\alpha = -c_{\alpha,0}^{(6)}$ ,  $x = -\frac{c_{2,0}}{2}$  and  $y = \frac{c_{1,0}}{8}$  gives the bare and redefined boundary action *a*<sub>,(0</sub>, *x* =  $-\frac{c_{2,0}^{(6)}}{2}$ 2,0  $\frac{2.0}{2}$  and  $y =$  $c_{1,0}^{(6)}$ 8  $c_{2,0}^{(6)}$   $c_{1,0}^{(6)}$   $c_{1,0}^{(6)}$   $c_{2,0}^{(6)}$   $\alpha = \frac{1}{2}$  and  $y = \frac{1}{8}$  $S_0^{\rm b-h}$  = z<br>Z  $d^4x$  $\sqrt{ }$  $-\frac{1}{4}$ 4  $F_{\mu\nu,0}^3 F_0^{3,\mu\nu} +$ 1  $2\xi$  $+$   $ig_{4,0}$  $\biggl\{ \eta_{\mu\rho} - \frac{\eta_{\mu\rho}\Box - \partial_\mu \partial_\rho \ }{\Lambda^2} \biggr\}$  $\Lambda^2$  $\left\} A_0^{3,\rho}$  $+ \frac{1}{2\Lambda^2} \left(A_{\mu,0}^3 A_{\rho,0}^3 \partial^\rho \phi_0 \partial^\mu \phi_0 + A_{\mu,0}^3 \partial^\rho A_{\rho,0}^3 \right)$  $g^2_{4,0}$  $2\Lambda^2$  $\sqrt{2}$  $A^3_{\mu,0} A^3_{\rho,0} \partial^\rho \bar{\phi}_0 \partial^\mu \phi_0 + A^3_\mu$  $\frac{g_{4,0}c_{1,0}^{(6)}}{a^{2}}A_{\mu}^{3}\sqrt{6}0^{d}$  $\frac{1}{2}$  $\frac{f_{4,0}}{2\lambda^2}$  ( **2**  $A_{\mu,0}A_{\rho,0}$ <sup>0</sup>  $\varphi$ <sub>0</sub>  $\varphi$ <sub>0</sub> +  $A_{\mu,0}$ <sup>0</sup> + *i g*4*,*<sup>0</sup> *c* (6)  $\frac{1}{4}\Lambda^2$   $A^3_{\mu,0}\bar{\phi}_0\phi_0$  $\sqrt{2}$ 

- nature)  $\frac{1}{10}$
- 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)  $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ arbitrary function and can be redefined to its original form. Another way to see this is the see this is that
- The Feynman rules are straightforward but non-trivial due to the HDO. Ready for the 1-loop level, diagrammatic, renormalization es are s

3*/*2

(6)

(6)

#

• 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  $\ddot{\cdot}$  is a dimensionless coupling which is understanding which is understanding which is used at  $\ddot{\cdot}$  $\gamma$  action is ghost-free and has developed a scalar quartic term  $\phi\phi\,\Box\,\phi\phi$  (Recall that these HDO ar is ghost-free and has developed a scalar quartic term  $\phi\phi\,\Box\,\phi\phi$  (Recall that these HDO are of  $\epsilon$ 

> be beginning and two couplings  $a$  and the "quartic coupling"  $c^{(6)}$  at the end However is expected  $\alpha$  beginning and two couplings  $\alpha$ , and the "quartic coupling"  $c^{(6)}$  at the end. However is expected to b

is that the former includes, after the field redefinition, the scalar quartic-like term ( $\alpha$ )  $\alpha$ 

↵*,*0, *x* = *c* <sup>2</sup>*,*0*/*2 and 2*y* = *c*

$$
\mu^{\nu} + \frac{1}{2\xi} A^{3}_{\mu,0} \partial^{\mu} \partial_{\nu} A^{3,\nu}_{0} - \bar{\phi}_{0} \Box \phi_{0} - \frac{c_{1,0}^{(6)}}{4\Lambda^{2}} (\bar{\phi}_{0} \phi_{0}) \bar{\phi}_{0} \Box \phi_{0} - \bar{c}_{0}^{3} \Box c_{0}^{3}
$$
\n
$$
\frac{\partial_{\mu} \partial_{\rho}}{\partial^{\mu} \partial^{\rho}} \Big\} A^{3,\rho}_{0} (\bar{\phi}_{0} \partial^{\mu} \phi_{0} - \phi_{0} \partial^{\mu} \bar{\phi}_{0}) + g_{4,0}^{2} (A^{3}_{\mu,0})^{2} \bar{\phi}_{0} \phi_{0}
$$
\n
$$
\partial^{\mu} \phi_{0} + A^{3}_{\mu,0} \partial^{\rho} A^{3}_{\rho,0} \partial^{\mu} (\bar{\phi}_{0} \phi_{0}) \Big) - 2g_{4,0}^{2} \frac{A^{3,\mu}_{0} (\eta_{\mu\rho} \Box - \partial_{\mu} \partial_{\rho}) A^{3,\rho}_{0}}{\Lambda^{2}} \bar{\phi}_{0} \phi_{0}
$$
\n
$$
(\bar{\phi}_{0} \partial^{\mu} \phi_{0} - \phi_{0} \partial^{\mu} \bar{\phi}_{0}) + \frac{g_{4,0}^{2} c_{1,0}^{(6)}}{4\Lambda^{2}} (A^{3}_{\mu,0})^{2} (\bar{\phi}_{0} \phi_{0})^{2} \Big]
$$

#### **QUANTIZATION WITH HDO**

• The renormalization procedure suggests

$$
g_{4,0} = (1 + \delta_{g_4})g_4
$$
 or  $\alpha_{4,0} = (1 + \delta_{\alpha_4})\alpha_4$  with  $\alpha_4 = \frac{g_4^2}{16\pi^2}$ 

$$
g_{4,0} = (1 + \delta_{g_4})g_4 \text{ or } \alpha_{4,0} = (1 + \delta_{\alpha_4})\alpha_4 \text{ with } \alpha_4 = \frac{g_4^2}{16\pi^2} \qquad c_{1,0}^{(6)} = (1 + \delta_{c_1^{(6)}})c_1^{(6)} \quad \phi_0 = \sqrt{1 + \delta_{\phi}}\phi \qquad A_{\mu,0}^3 = \sqrt{1 + \delta_A}A_{\mu}^3
$$
  
\nThe counterparts and the associated  $\beta$ -functions of the boundary action are fixed (the off-shell scheme  $p_i^2 = \Lambda^2$  is used)

*F <sup>A</sup> <sup>µ</sup>*⌫*F A,µ*⌫ + 5,  $\mu$  (5d Lee-Wi $\epsilon$  $Vick version$ 

 $\overline{\phantom{a}}$ 

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

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

• For completeness apply all the previous steps in the bulk lattice action to get its continuum version (5d Lee-Wick version) **P** For completeness apply all the previous steps in the bulk lattice action to get its continuously for  $\theta$ 

The above is a  $5$  version of the Lee-Wick gauge model  $\alpha$  and where we can extract the  $\alpha$ 

$$
\mathcal{L}^{B} = -\frac{1}{4} F_{\mu\nu}^{A} F^{A,\mu\nu} + \frac{1}{16\Lambda^{2}} (D^{\mu} F_{\mu\nu}^{A})(D_{\mu} F^{A,\mu\nu}) - \frac{g_{5}}{24\Lambda^{2}} f_{ABC} F_{\mu\nu}^{A} F_{\nu\rho}^{B} F_{\rho\mu}^{C} + (\overline{D_{\mu} \Phi^{A}})(D^{\mu} \Phi^{A}) - \frac{1}{4\Lambda^{2}} (\overline{D^{2} \Phi^{A}})(D^{2} \Phi^{A})
$$
\n
$$
\varepsilon_{\text{cav}} = \varepsilon_{\text{cav}}^{2} - \frac{125 g_{5}^{3} \mu^{-3\varepsilon/2}}{24\Lambda^{2}} \text{ or } \varepsilon_{\text{cav}}^{2} - \frac{125 g_{5}^{2}}{24\Lambda^{2}} \text{ or } \varepsilon_{\text{cav}}^{2}
$$

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

#

### **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 **Find** the non-trivial minimum and improved effective potential using the scalar field as the running parameter and minimize it to

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

The minimization suggests

rocedure is followed

@*c*

<sup>1</sup> (*t*)

1

1

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 scalarto-gauge mass ratio tings  $g_c$ ,  $c^{(6)}$  and then determine the scalar and gauge field masses and from those the scalar-

with respect to the scalar field the renormalized *V* (4), to finally arrive in momentum space at

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

factors. To see an example of the e2ee and the e2ee and the e2ee and the di⊄erent numerical factors, we proceed with the e2ee and the di⊄erent numerical factors, we proceed with the e2ee and the e2ee and the e2ee and the e

#### **dimension Eq. (D.7). Here the presence of the presence of the presence of the cross term is a cross term in the cross t** term between the quartic and gauge coupling exists due to the appearance of the anomalous dimension Equation Eq. (D.7). Here the presence of the presence of the cross term is not the cross term in the

term between the quartic and gauge coupling exists due to the appearance of the anomalous

 $S_{\rm eff}$  and  $\sigma$  the quartic coupling the  $\sigma$  the  $\sigma$  coupling the -function of Eq. (D.9). There, a cross  $\sigma$ 

term between the quartic and gauge coupling exists due to the appearance of the anomalous

- The desired Higgs phase is revealed when a CW procedure is followed evealed when a CW procedure is followed
- The algorithm:
- 1. *Consider the 4d bare potential in momentum space*  $T$   $C$  corresponding the  $Ad$  because potential is given  $m$  and  $m$  $\mathbf{f}_{\mathbf{a}}$ requisive and the tax our potential in the choice value.  $T_{\text{max}}$  the  $\Lambda$ <sup>d</sup> have potential in mean entered above.  $\mathbf{r}$

$$
\frac{(A_5^1)^2 + (A_5^2)^2}{2} \equiv \phi_r^2 \qquad V_{\text{imp.}}(\phi_r) = \frac{c_1^{(6)}}{4} \phi_r^4 + \left\{ 2(c_1^{(6)})^2 + 17g_4^4 \right\} \frac{\phi_r^4}{64\pi^2} \left( \ln \frac{\phi_r^2}{v^2} - 3 \right)
$$

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

(6)

- Construct the renormalized and improved effection
- 
- The improved 1-loop effective potential is of a CW type  $V_{\text{imp.}}(\phi_r) = \frac{c}{r}$  $\sqrt{G}$ 1 or using  $\bar{\phi}\phi =$  $(A_5^1)^2 + (A_5^2)^2$ 2  $\equiv \phi_r^2$  $\overline{Y}$   $(1)$  $\mathcal{C}$  $\overline{a}$  $\frac{c^{(6)}_1}{4} \phi$  $c_1^{(6)}$   $a_1^{(6)}$   $a_2^{(6)}$

(6)

The minimization suggests

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*   $\int$ e potential using the scalar field as the running parameter and minim: find the non-tribual minimum (6) renormalized and improved effective potential using the scalar field as the running parameter and min die the non-trivial minimum  $\ddot{\phantom{0}}$ using the scalar field as the running parameter and minimize it t

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*  to-gauge mass ratio the relation between the couplings  $g_{\lambda}$ ,  $c^{(6)}$  and then determine the scalar and gauge field masses and from those the scalar $to$  -gauge mass ratio

Notice the di↵erent with respect to CW numerical factor in the scalar mass. It arises due to the



• The non-trivial vev ( <  $\phi_r$  > = v) triggers the spontaneous breaking of the gauge symmetry  $\phi_r = h + v$  $\sum_{n=1}^{\infty}$ boson massacre

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

is the spontaneous breaking of the gauge symmetry  $\phi_r = h$  $\vdash$   $\nu$ 

 $\frac{1}{\sqrt{2}}$ 

r210

<sup>8</sup>⇡<sup>2</sup> *<sup>g</sup>*<sup>4</sup> ' <sup>1</sup>*.*<sup>64</sup> *<sup>g</sup>*<sup>4</sup> *.* (3.16)

In the last line we computed the numerical factor for later convenience. The corresponding

 $\mathbf{f}_{\text{max}}$ 

• Comparison with the CW case in the classical level • Comparison with the CW case in the classical level  $\sqrt{2}$ e classical level  $T_{\text{obs}}$ 

#### **THE HIGGS PHASE** <sup>8</sup>⇡<sup>2</sup> *<sup>g</sup>*<sup>4</sup> ' <sup>1</sup>*.*<sup>64</sup> *<sup>g</sup>*<sup>4</sup> *.* (3.16) **THE HIGGS PHASE THE HIGGS PHASE** THE MASSES IS ON THE SET ON THE SSB THAT THE SSB THROUGH RADIATIVE CONTINUES. IS NOT THE SSB THAT THE SSB THAT THE SSB

r210

$$
\rho_{\text{CW}} = \sqrt{\frac{\rho_{\text{CW}}}{\rho_{\text{CW}}}}
$$

 $\frac{1}{\sqrt{2}}$ 

for the Higgs self-coupling. Recall that *c*

(6)

or ↵4(*µ*) = ↵4*,R*

$$
g_4(\mu) = \frac{g_{4,R}}{\sqrt{1 - \frac{g_{4,R}^2}{16\pi^2} \ln \frac{\mu^2}{m_R^2}}} \quad \text{or} \quad \alpha_4(\mu) = \frac{\alpha_{4,R}}{1 - \alpha_{4,R} \ln \frac{\mu^2}{m_R^2}} \quad \text{and} \quad e(\mu) = \frac{e_R}{\sqrt{1 - \frac{e_R^2}{48\pi^2} \ln \frac{\mu^2}{M_R^2}}}
$$

<sup>1</sup> ' 0*.*13 close to the SM value

(6)

*<sup>g</sup>*4(*µ*) = *<sup>g</sup>*4*,R*

- The IR boundary conditions are  $m_R$ ,  $M_R$ ,  $g_4(m_R) = g_{4,R}$   $(\alpha_4(m_R) = \alpha_{4,R})$  and  $e(M_R) = e_R$ .  $\mathcal{U}$  some extremely large UV scale. A contraduction  $\mathcal{U}$  case with respect to the CW case. A crucial di4erence with respect to th conditions are  $m_R$ ,  $m_R$ ,  $\delta 4(m_R) = \delta 4R$ ,  $(m_4/m_R) = \alpha_{4,R}$  and  $c(m_R) = c_R$ . *<sup>e</sup>*(*µ*) = <sup>r</sup> re *m<sub>R</sub>*, *l R*  $R, M_R, g_4(n)$ *<sup>e</sup>*(*µ*) = <sup>r</sup>  $\frac{1}{2}$  are *R* are  $m_R$ ,  $M_R$
- The vev is fixed  $v \equiv v_*$  $\equiv \nu$ whether it can be identified more precisely. The identified more precisely. The identified more precisely. The<br>The identified more precisely. The identified more precisely. The identified more precisely. The identified mo

or ↵4(*µ*) = ↵4*,R*

(3.19)

equations 
$$
\mu \frac{dg_4(\mu)}{d\mu} = \beta_{g_4}
$$
 and  $\mu \frac{de(\mu)}{d\mu} = \beta_e$  with  $\beta_e = \frac{e^3}{48\pi^2}$ 

$$
\rho_{\rm CW} = \sqrt{\frac{3}{8\pi^2}} e \simeq 0.19 e \quad \text{and} \quad \lambda = \frac{33}{8\pi^2} e^4
$$

*µ*

*dµ*

= *g*<sup>4</sup> and *µ*

*dµ*

= *<sup>e</sup>* (3.18)

• The numerical difference originates from the higher derivative nature of the quartic coupling  $c_1^{(6)}$ , a crucial point for the model 1 ference originates from the higher derivative nature of the quartic coupling  $c_1^{\rm (6)}$ , a cruc .<br>an<sup>i</sup> • The numerical difference originates from the higher derivative nature of the quartic coupling  $c_1^{(6)}$ , a crucial point for the model  $\frac{1}{2}$  the higher deminitive persons of the guidations

 $\mathcal{L}_1$  plays the role of the scalar quartic coupling here scalar quartic coupling here scalar quartic coupling here scalar  $\mathcal{L}_2$ 

ons are 
$$
m_R
$$
,  $M_R$ ,  $g_4(m_R) = g_{4,R} (\alpha_4(m_R) = \alpha_{4,R})$  and  $e(M_R) = e_R$ .

*µ*

*dµ*

= *g*<sup>4</sup> and *µ*

• At quantum level the solution of the RG equations  $\mu$ *a*<sup>*i*</sup> *d g*4(*µ*) *dµ*  $d\overline{a_4(u)}$ **C** At quantum level the solution  $d_{\alpha}(\mu)$  $\bullet$  At quantum level the so

*dµ*

= *<sup>e</sup>* (3.18)

*g<sup>R</sup> R*) and *e*(*MR*) ⌘ *eR*. In order to locate the UV limit of the running in our case, recall first

*<sup>m</sup>*2(*<sup>V</sup>* ) ⌘ ⇢<sup>2</sup>

*CW* =

.<br>An is a strong stro

<sup>8</sup>⇡<sup>2</sup> *<sup>e</sup>*<sup>2</sup> )



### *REMARKS BEFORE THE PHASE DIAGRAM*

The effective boundary action is not completely decoupled from the 5d bulk

The RG flow in the Higgs phase is constrained from the one in the Hybrid phase

- -
	-

 $3.$  *A* matching of all physical observables is possible at the scale  $\mu_*$  where the running of  $g_s(\mu)$  and  $g_4(\mu)$  stops and it never reaches the continuum *limit so the model inherits a finite cut-off* 

• The Hybrid phase contains 4d slices with SU(2) gauge group in the bulk. 4d coupling  $g_s$  or  $\alpha_s = \frac{g_s^2}{16\pi^2}$  connected with  $\beta_{4,s}$  and =  $\frac{g_s^2}{16\pi^2}$  connected with  $\beta_{4,s}$  and  $\beta_{5,s}$ 1. *Dimensional reduction through localization when the Higgs-Hybrid phase transition (1st order, quantum) is approached. The entire Hybrid phase* 

*is layered in the fifth dimension*

2. *The bulk driven Higgs-Hybrid phase transition is approached simultaneously from either side when the system is driven towards the UV (proven NP) due to common μ*

### *dµ*

means that inside the entire Hybrid phase we see approximate 4d slices with *SU*(2) gauge group

couplings only, should be possible at the scale *µ*⇤. There, the running of *gs*(*µ*) stops and it never



↵4(*µ*) ↵4*,R*

= *c*

 $\overline{\phantom{0}}$ 

↵*s,R* ↵*s*(*µ*)

(4.12)

for the Higgs phase and

Hence,

for the Hybrid phase. Since we do not know how to compute *s*(*µ*), we can exploit localization:

#### **THE CONTINUUM PHASE DIAGRAM** 2↵4(*µ*⇤) ↵4*,R* ↵*s*(*µ*⇤)↵*s,R* **□ HE CON I INUUM PHASE DIAGE** = *c* 2↵⇤ ↵4*,R µ*⇤ = *e c* 0 *s* 1+2*c*0 *s* E. ↵4*,R* + <sup>2</sup>*<sup>c</sup>* 0 *s* ↵*s,R* ] ⇤*<sup>s</sup> .* (4.14)  $4.2$  Physics in the vicinity of the vicinity of the phase transition  $\mathbf{T}[\mathsf{H}]\mathsf{H}$  $\mathbf{F} = \mathbf{F} \mathbf{F} \mathbf{F}$  in the vicinity of the phase transition of the ph

• The second necessary condition is to generate a SM-like spectrum relevant RG equation, using the equation of Eq. (2.77) for  $\alpha$  is the equation of Eq. (2.77) for  $\alpha$ *n* and necessary condition is to generate a SM-like spectrum  $\mathcal{C}^{\mathbf{A}}$ *r*  $\mathcal{C}^{\mathbf{A}}$ *n*  $\mathcal{C}^{\mathbf{A}}$ <sup>n</sup>,  $\mathcal{C}^{\mathbf{A}}$ The condition is to generate a Sivillise spectrum The second necessary condition is to generate a SM-like spectrum

↵4(*µ*⇤) ↵4*,R*

↵*s,R* ↵*s*(*µ*⇤)

*c*

 $\frac{1}{2}$  ixed by  $\frac{1}{2}$  $12$  18 $20$  18 $20$  18 $20$  18 $20$  18 $20$  18 $20$  18 $20$  18 $20$  18 $20$  $\arg\, {\rm gauge\, coupling}$  and  $\Lambda_{\rm s}=m_{\rm p}=1000$  MeV (proton mass), fixed by physical motivation

point given by<sup>4</sup>

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

ne effective action is the hierarchy of the scales relevant RG equation, using the -function of Eq. (2.77) for " = 1 this time, yields ↵5(*µ*) = ↵5*,R*

↵5(*µ*) = ↵5*,R*

 $\tilde{\mathbf{f}}$  this, let us look at the way that the way that the bulk coupling runs, taking into account the HDO. T brandard rhouds speed and for  $\alpha_{4,R} = 0.00$  to and  $v_* = 10$  $\bullet$  Standard Model spectrum for  $\alpha_{\text{Lp}} = 0.00435$  and  $v_{\text{L}} = 108.2$  GeV

*,* (4.16)

↵⇤ ↵4*,R*

= *c*

0

↵*s,R* ↵⇤

1

$$
R(1 + 2c'_{s})
$$
  
- 2c'\_{s}\alpha\_{4,R}  

$$
m_{h*} = \sqrt{\frac{210}{8\pi^2}} 16\pi^2 v_{*}\alpha_{*}
$$

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

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

with ↵4(*µ*⇤) = ↵*s*(*µ*⇤) = ↵⇤, thereby the cut-o↵ implied by Eq. (4.10) being equal to

• On the Higgs-Hybrid phase transition  $\mu = \mu_*$ : On the Higgs 2↵4(*µ*⇤) ↵4*,R* <mark>l</mark>ybric *s*  $phase transition$  $\overline{a}$ with ↵4(*µ*⇤) = ↵*s*(*µ*⇤) = ↵⇤, thereby the cut-o↵ implied by Eq. (4.10) being equal to  $\frac{1}{2}$  phase transition  $y = y$ . in put scale of the arbitrary reference values  $\mu$ ,  $\mu$ , On the Higgs-Hybrid phase transition  $\mu = \mu_*$ :  $\alpha$  are ready to the numerical discussion and ask the sharper question of whether sharper question of whether  $\alpha$  $\text{C}_{11}$  and  $\text{HgS}_{9}$  rayond phase transition  $\mu - \mu *$ .

$$
\alpha_4(\mu_*) = \alpha_s(\mu_*) = \alpha_*
$$

$$
\alpha_* = \frac{\alpha_{4,R} \alpha_{s,R} (1 + 2c'_s)}{\alpha_{s,R} + 2c'_s \alpha_{4,R}}
$$

- The above are controlled by four variables:  $\alpha_{4,R}$ ,  $\alpha_{s,R}$ ,  $v_*$ , and  $\Lambda_s$  ( $c'_s = 3/125$ ) y four variables:  $\alpha_{4,R}$ ,  $\alpha_{s,R}$ ,  $\nu_*$ , and  $\Lambda_s$  ( $c_s = 3/125$ ) • The above are controlled by four variables:  $\alpha_{4,R}$ ,  $\alpha_{s,R}$ ,  $\nu_*$ , and  $\Lambda_s$  ( $c'_s = 3/125$ ) by four variables:  $\alpha_{4,R}, \alpha_{s,R}, v_*,$  and  $\Lambda_s$  ( $c_s' = 3/125$ )
	- $\alpha_{s,R} = 0.014$  (SM's strong gauge coupling) and  $\Lambda_s = m_p = 1000$  MeV (proton mass), fixed by physical motivation uge couping) and *i n*<sub>2</sub>*c*<sub>14</sub> *(SM*<sup>*s*</sup> strong gaught)  $\epsilon$  coupling) and  $\Lambda = m = 1000$  MeV  $14$  *(SM's strong gau*  $4$  (SM's strong gauge coupling) and  $\Lambda_s = m_p = 1000$  MeV (proto gauge coupling) and  $\Lambda_s = m_p = 1000$  MeV (protor
- The first necessary condition for the validity of the effective action is the hierarchy of the scales **i** ine first necessary condition for the validity of the effective action If we keep ⇤*<sup>s</sup>* fixed, the model is parametrized by the constants *x*, *y* and *v*⇤. A necessary active for the energy formation for the validity of the enective action is that the file If we keep ⇤*<sup>s</sup>* fixed, the model is parametrized by the constants *x*, *y* and *v*⇤. A necessary THE HISTREETS CONDITION FOR THE VANDRY OF THE CHECTIVE ACT

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

denoted before by an 'asterisk'.

condition *x<y*. Such a case is expected to be obeyed between a confined and a deconfined

condition  $\alpha$  condition  $\alpha$  case is expected to be obtained to be obtained and a confined and a deconfined and a decon

## **THE CONTINUUM PHASE DIAGRAM**





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#### **THE CONTINUUM PHASE DIAGRAM KREEPING FIXED IN FIXED FIXED. THE SIMULTANEOUS RESIDENCE REAL FIRST REAL FIRST REAL FIRST REAL FIRST REAL FIRST PIXE AND THE FIRST PIXE REAL FIRST PIXE AND THE ABOVE REAL FIRST PIXE AND THE FIRST PIXE REAL FIRST PIXE AND**

#### • A zoomed version of the phase diagram order phase transition is presented in Fig. 10 we are the phase transition in Fig. 10 we are the phase transition of the phase

to the phase diagram of Fig. 7. This is the reason why in the above examples we varied only *x*



# **THE CONTINUUM PHASE DIAGRAM**

phase transition

Case 2:  $\alpha_{s,R} = \mathcal{O}(10^{-2})$  (0.010 ≤  $\alpha_{s,R} \le 0.098$ ), only for  $\alpha_{4,R} = 0.00435$  a realistic spectrum Case 3:  $\alpha_{s,R} \leq O(10^{-3})$  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  $\Lambda_s$  and  $\nu_*$ Viable conditions for  $0.6$  GeV  $\leq \Lambda_{\rm s} \leq 16$  GeV and  $v_* = 108.2$  GeV
- 

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

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

• The relation  $\alpha_4(\mu_*) < \alpha_5(\mu_*)$  is true for Case 2. The system reaches the 1st order phase transition before the 2nd order one

Then the fine tuning in the Higgs mass is very small. The dynamics do not allow a high cut-off for the effective action



# **CONCLUSIONS**

• 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

• 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

- theory on the boundary, located at the origin of a semi-infinite fifth dimension was constructed
- the scalar mass and the  $\beta$ -functions that change things towards a more realistic direction
- in the UV
- generated finite cut-off but also with RG flows that are correlated below and above the phase transition
- 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

The 1-loop effective action of an  $SU(2)$  gauge theory in five dimensions with boundary conditions that leave a  $U(1)$ -complex scalar

• 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

• 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

# THANK YOU