Lines of Constant Physics in a 5-d Gauge-Higgs Unification Scenario

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24th July, 2016

Lattice 2016, Southampton

Motivation

The Standard Model's Higgs: Unknowns

- Quadratic sensitivity of Higgs mass to UV cut-off.
- Origin of potential responsible for spontaneous symmetry breaking.

Can we address these puzzles?

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The Extra-Dimensional Approach

- Higgs field is associated with the extra-dimensional components of the gauge field [Manton, 1979].
- Higgs potential is generated through quantum effects [Hosotani, 1983; ...].

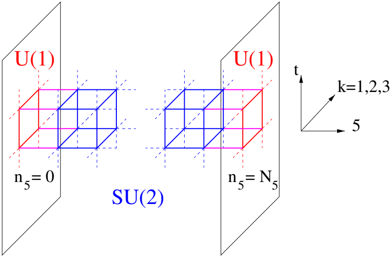
(see [Knechtli, Rinaldi, 2016] for a current review of lattice approaches/results)

Lattice Formulation

Wilson Gauge action:

$$S_W^{orb} = \frac{\beta_4}{2} \sum_{P_4} w \cdot \mathrm{tr}\,\{1 - P_4\} + \frac{\beta_5}{2} \sum_{P_5} \mathrm{tr}\,\{1 - P_5\}$$

$$w = \begin{cases} \frac{1}{2} & \text{plaquette on boundary} \\ 1 & \text{otherwise} \end{cases}$$



5-d Orbifold

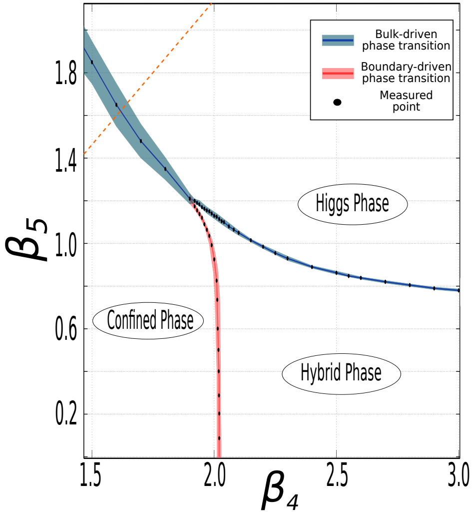
- The bare anisotropy is denoted by $\gamma = \sqrt{\beta_5/\beta_4} \equiv a_4/a_5$
- N_5 is the number of *links* in the fifth dimension
- The weight w is due to the orbifold boundary conditions.

Reminder

Requirements for a viable model

- ☐ it should reproduce the right physics.
- ☐ the fifth dimension should be “hidden”.
- ☐ the physics should be cut-off independent.

Phase Diagram



Notes

On the torus

- confined and Coulomb phase.

On the orbifold

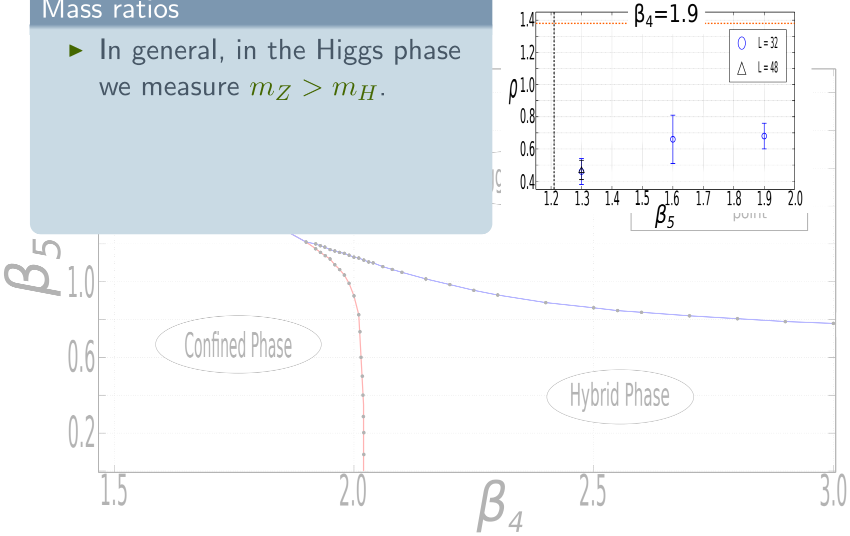
- One more phase: $U(1)$ gauge links deconfine separately.
- No compactification observed at $\gamma > 1$.
- Interesting physics is found at $\gamma < 1$.

Source [Alberti *et al.*, 2015]

Spectrum

Mass ratios

- In general, in the Higgs phase we measure $m_Z > m_H$.



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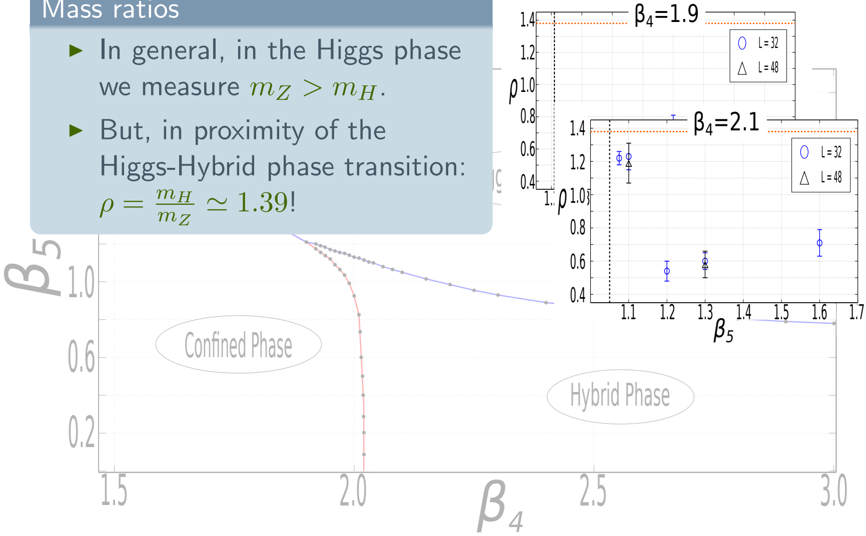
- In general, in the Higgs phase we measure $m_Z > m_H$.
- But, in proximity of the Higgs-Hybrid phase transition: $\rho = \frac{m_H}{m_Z} \simeq 1.39$!



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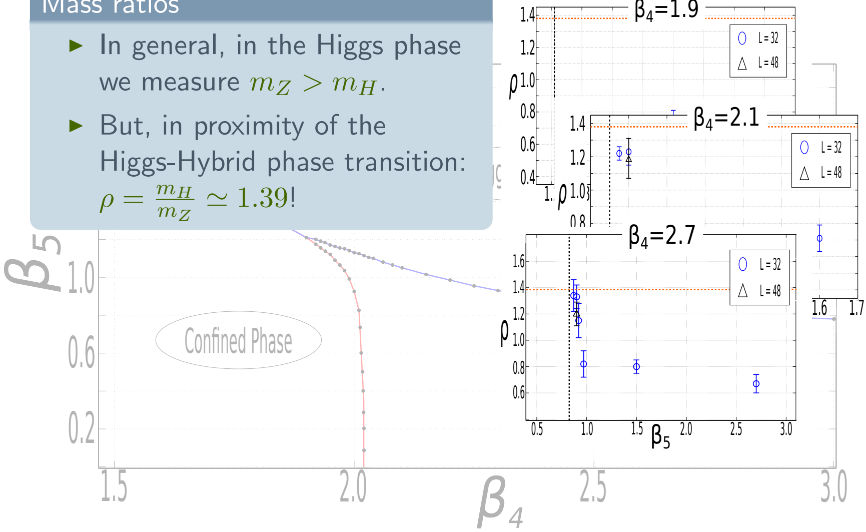

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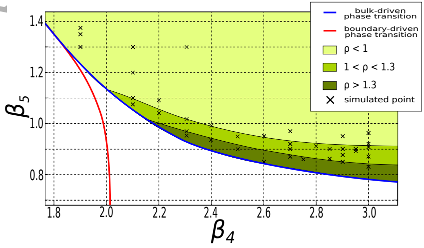
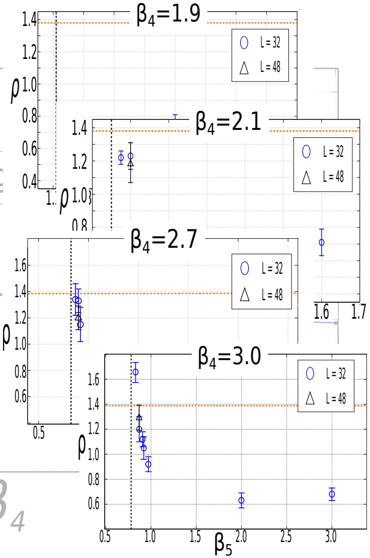


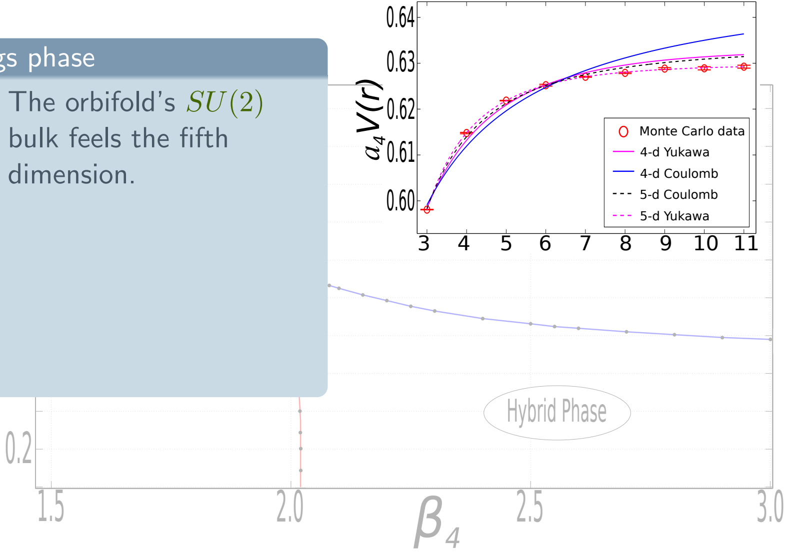


Source [Alberti *et al.*, 2015]

Dimensional Reduction

Higgs phase

- The orbifold's $SU(2)$ bulk feels the fifth dimension.

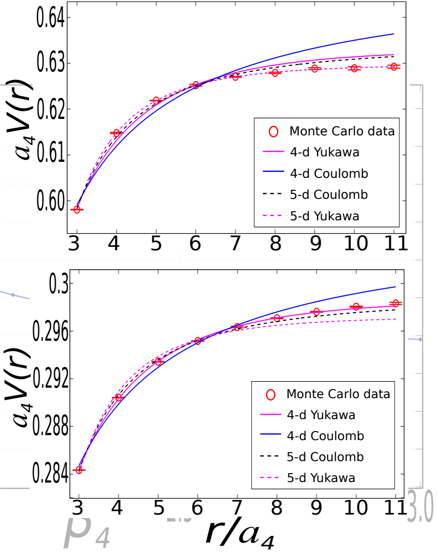


Dimensional Reduction

Higgs phase

- The orbifold's $SU(2)$ bulk feels the fifth dimension.
- But near the PT the boundary remains clearly four-dimensional

$\Rightarrow$ dimensional reduction via localization



Gauge-Higgs Unification

Gauge-Higgs Unification on the Orbifold

Does it work?

Requirements of a viable model

- ☑ it should reproduce the right physics.
- ☑ the fifth dimension should be "hidden".
- ☐ the physics should be cut-off independent.
  $\rightarrow$ Search for Lines of Constant Physics

Line of Constant Physics

Definition

a set of points (β_4, β_5, N_5) of which at least two independent physical quantities f_1, f_2 remain constant. For example we could choose

$$f_1 = \rho \equiv \frac{m_H}{m_Z}$$
$$f_2 = m_H R$$

and vary $a_4 m_H$ to make sure that the lattice spacing is changing along the line.

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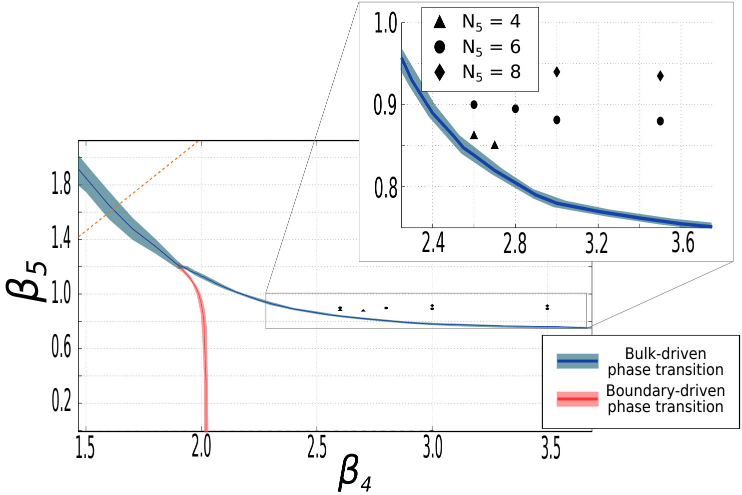
Construction

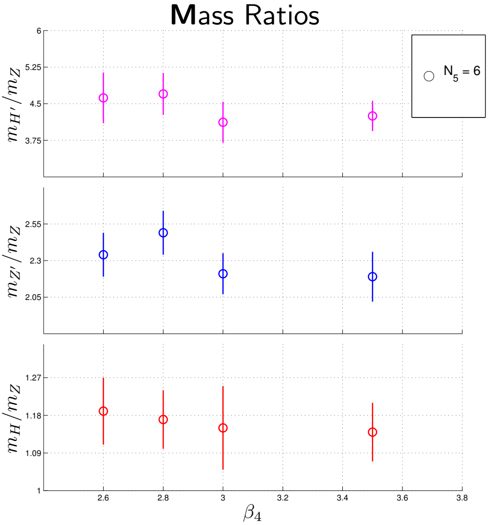
- As a first step, look for $\rho = const$ lines at various N_5 values.
- An LCP with $m_H \cdot R = const$ will intersect these lines in each N_5 plane.

LCP II

Search Region:



LCP III



$\rho \simeq 1.15$

Notes:

- Masses are extracted from solving the GEVP.
- β_5 (at fixed β_4) depends slightly on N_5.
- Errors are statistical.
- LCP could move a little with higher precision.

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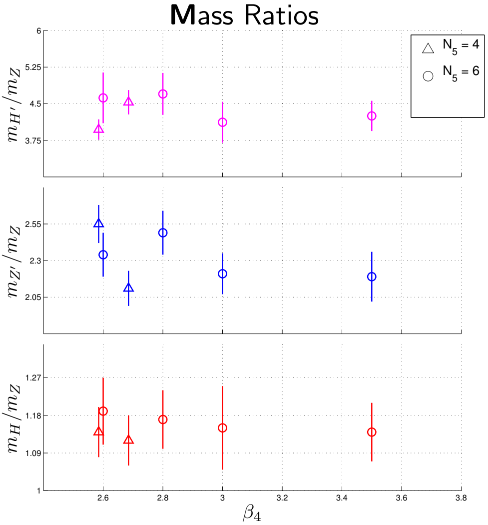

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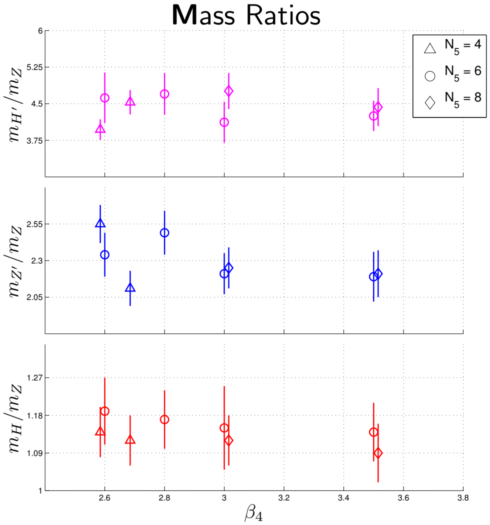

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LCP IV

Highlights

$\Rightarrow$ Despite non-renormalizability of the theory, scaling violations are excluded to a precision of ca. 10%.

"Physical" LCP exists (preliminary!)

N_5	β_4	β_5	$a_4 m_Z$	$\frac{m_H}{m_Z}$	$\frac{m_{Z'}}{m_Z}$	$\frac{m_{H'}}{m_Z}$
$N_5 = 4$	2.7	0.845	0.145(4)	1.47(10)	2.40(16)	4.14(20)
$N_5 = 6$	2.8	0.89	0.143(4)	1.42(9)	2.39(12)	4.98(36)

Conclusions and Outlook

Summary

- GHU on the orbifold addresses the problem of the Higgs' naturalness.
- It satisfies all the (basic) requisites: mass hierarchy, dimensional reduction, cut-off independence.
- It predicts excited states with masses $m_{Z'} \simeq 2.3 \cdot m_Z$ and $m_{H'} \simeq 4.3 \cdot m_Z$.

Outlook

- Short term: construct a standard model-like line of constant physics with $\rho = 1.39$.
- Long term: move to higher group to incorporate all the degrees of freedom of the standard model.

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Thank you for your attention!

References

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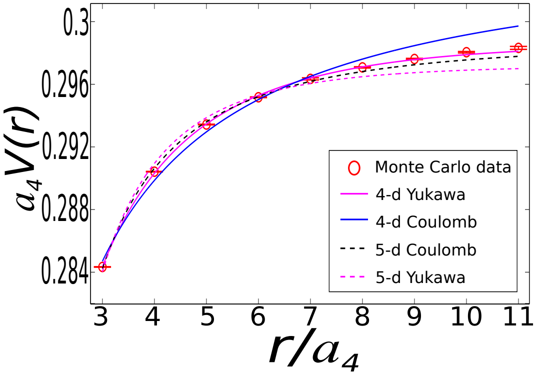
Static Potential



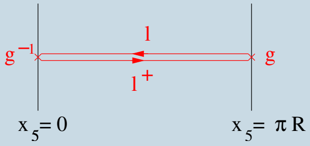
Dimension	Yukawa	Coulomb	Confining
4	$c_0 - c_1 \frac{e^{-m_Z r}}{r}$	$c_0 - \frac{c_1}{r}$	$c_0 + \sigma r - \frac{c_1}{r}$
5	$c_0 - c_1 \frac{K_1(m_Z r)}{r}$	$c_0 - \frac{c_1}{r^2}$	

Higgs Operators

Constructed from Polyakov Loops

Higgs d.o.f come from **Polyakov loops** in extra dimension

- $p = l\ g\ l^\dagger\ g^\dagger$
- $h = [p - p^\dagger, g]/(4N_5)$



Basis: $\mathcal{H} = \mathrm{tr}\,[hh^\dagger]$; $\mathcal{P} = \mathrm{tr}\,[p]$ (increase via smearing)

Constructed from vector operators

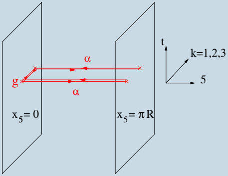
- several combinations give the correct quantum numbers: $tr(Z^2)$, $tr(Z)^2$, $tr(Z_j^2 Z_k^2)$ and $tr(Z_j^2)tr(Z_k^2)$.
- $tr(Z)^2$ found to have a good overlap with H'.

Z Operators

Z Boson Operators

Z boson d.o.f come from **vector** Polyakov loops

- $\mathcal{Z} = \mathrm{tr}\,[g\ \alpha\ U^\dagger\ \alpha]$
- $\mathcal{Z}' = \mathrm{tr}\,[g\ U\ l\ U^\dagger\ l^\dagger]$
- Order parameters for SSB



Orbifold BC

Reflection

The reflection operation acts on both the lattice points

$$\bar{n} \equiv \mathcal{R}n = (n_\mu, -n_5)$$

and the gauge links

$$\mathcal{R}U(n,\mu) = U(\bar{n},\mu)\,, \qquad \mathcal{R}U(n,5) = U^\dagger(\bar{n}-\hat{5},5)\ .$$

Group conjugation

Acts only on the gauge links

$$\mathcal{T}_g U(n,M) = g\ U(n,M)\ g^{-1}\ ,$$

with g^2 an element of the centre of $SU(2)$ (we choose $g = -i\sigma^3$)

LCP measurements

Masses at $\rho \simeq 1.15$

N_5	β_4	β_5	$a_4 m_Z$	$\frac{m_H}{m_Z}$	$\frac{m_{Z'}}{m_Z}$	$\frac{m_{H'}}{m_Z}$
$N_5 = 4$	2.6	0.862	0.149(4)	1.14(6)	2.55(13)	3.97(21)
	2.7	0.85	0.155(3)	1.11(6)	2.11(12)	4.50(25)
$N_5 = 6$	2.6	0.90	0.132(4)	1.19(8)	2.34(15)	4.62(52)
	2.8	0.895	0.136(6)	1.17(7)	2.49(15)	4.70(43)
	3.0	0.882	0.143(5)	1.15(10)	2.21(14)	4.12(42)
	3.5	0.88	0.137(5)	1.14(7)	2.19(17)	4.25(31)
$N_5 = 8$	3.0	0.936	0.132(4)	1.12(6)	2.25(14)	4.76(37)
	3.5	0.935	0.131(5)	1.09(7)	2.21(16)	4.43(39)