Fermion Mass Hierarchy in Grand Gauge-Higgs Unification with Localized Gauge Kinetic Terms

N. Maru[a,b] & Y. Yatagai[a] ([a]Osaka City University, [b]NITEP) @ HPNP2021

based on [N.Maru and Y.Yatagai, PTEP **2019**, 083B03(2019)] and [N.Maru and Y.Yatagai, EPJC **80** (2020)]

Introduction

- Gauge-Higgs unification solves the hierarchy problem
- The hierarchy problem was originally addressed in grand unification theory
- Therefore, the expansion of GHU to GUT is natural direction to explore

Model

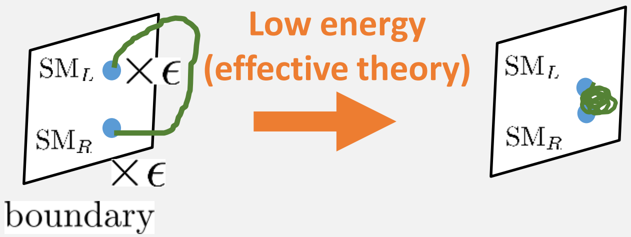
- 5D $SU(6)$ gauge theory on an S^1/Z_2 orbifold with localized gauge kinetic terms are considered

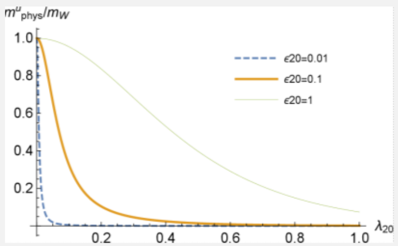
$$\mathcal{L} \supset \frac{1}{4}F^a_{MN}F^{a\,MN} + \delta(y)2\pi Rc_1\frac{1}{4}F^b_{\mu\nu}F^{b\,\mu\nu} + \delta(y-\pi R)2\pi Rc_2\frac{1}{4}F^c_{\mu\nu}F^{c\,\mu\nu}$$

- Orbifold breaking:

$$SU(6) \to SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_X$$

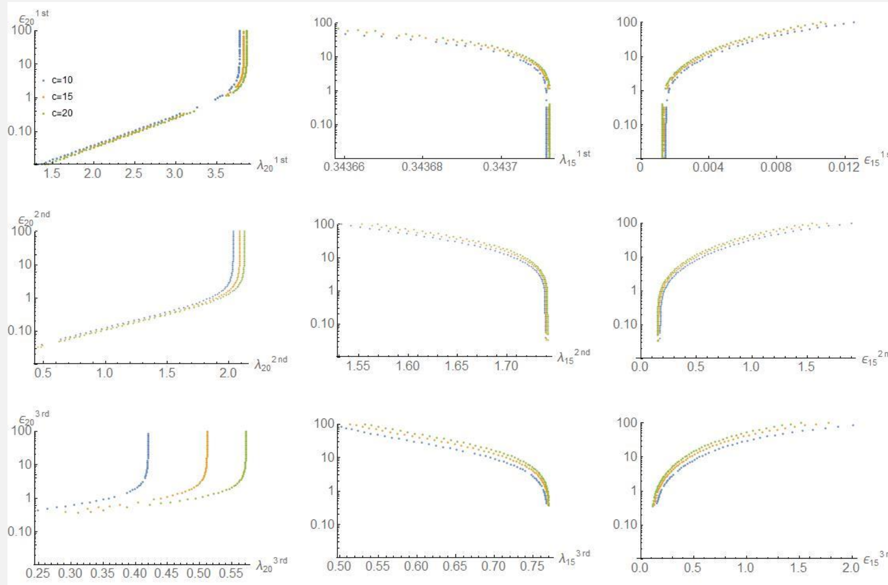
- SM fermions on one of the boundaries ($SU(5) \ni$ **10, 5, 1** rep)
- SM fermion masses are reproduced by introducing bulk fermions ($SU(6) \ni$ **20, 15, 6** rep)





Analysis

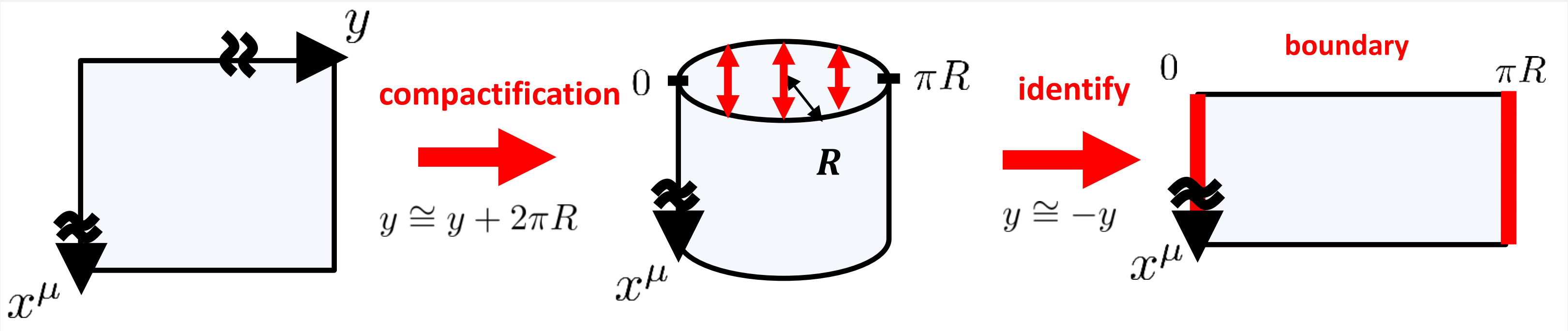
- Generated SM fermion mass is exponentially suppressed → fermion mass hierarchy is reproduced



- Top quark mass is reproduced by $c = c_1 + c_2 > 4$
- Higgs potential is generated by 1-loop effective potential
- Introducing the **15** rep or **6** rep extra bulk fermion reproduce electroweak symmetry breaking

backup 1

S^1/Z_2 orbifold



- Boundary condition :Dirichelt(+) or Neumann(-)

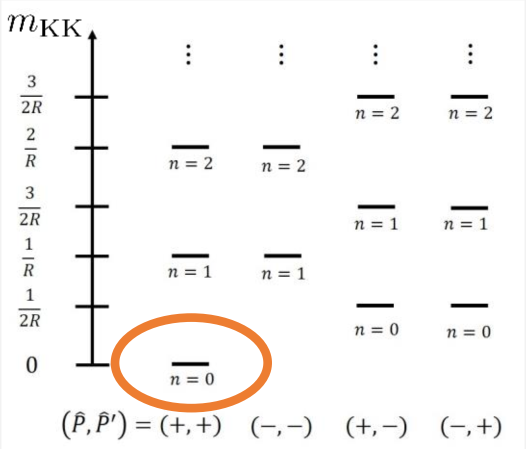
  ⇒extradimensional component of momentum

  becomes discretization

- In low energy effective theory,

  extradimensional component of momentum

  becomes Kaluza-Klein mass



Massless !

backup 2

Gauge sector

- Boundary condition Dirichelt(+) or Neumann(-)

$$A_\mu(y) = PA_\mu(-y)P^\dagger \qquad A_\mu(\pi R - y) = P' A_\mu(y - \pi R)P'^\dagger$$
$$A_y(y) = -PA_y(-y)P^\dagger \qquad A_y(\pi R - y) = -P' A_y(y - \pi R)P'^\dagger$$

$$P = \mathrm{diag}\,(+1,+1,+1,+1,+1,-1)\,,\, P' = \mathrm{diag}\,(+1,+1,-1,-1,-1,-1)$$

$$A_\mu = \left(\begin{array}{cc|ccc|c} (+,+) & (+,+) & (+,-) & (+,-) & (+,-) & (-,-) \\ (+,+) & (+,+) & (+,-) & (+,-) & (+,-) & (-,-) \\ \hline (+,-) & (+,-) & (+,+) & (+,+) & (+,+) & (-,+) \\ (+,-) & (+,-) & (+,+) & (+,+) & (+,+) & (-,+) \\ (+,-) & (+,-) & (+,+) & (+,+) & (+,+) & (-,+) \\ \hline (-,-) & (-,-) & (-,+) & (-,+) & (-,+) & (+,+) \end{array}\right)$$

$SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_X$

$$A_y = \left(\begin{array}{cc|ccc|c} (-,-) & (-,-) & (-,+) & (-,+) & (-,+) & (+,+) \\ (-,-) & (-,-) & (-,+) & (-,+) & (-,+) & (+,+) \\ \hline (-,+) & (-,+) & (-,-) & (-,-) & (-,-) & (+,-) \\ (-,+) & (-,+) & (-,-) & (-,-) & (-,-) & (+,-) \\ (-,+) & (-,+) & (-,-) & (-,-) & (-,-) & (+,-) \\ \hline (+,+) & (+,+) & (+,-) & (+,-) & (+,-) & (-,-) \end{array}\right)$$

Higgs

- Localized gauge kinetic terms

$$\mathcal{L} \supset \frac{1}{4}F^a_{MN}F^{a\,MN} + \delta(y)2\pi Rc_1\frac{1}{4}F^b_{\mu\nu}F^{b\,\mu\nu} + \delta(y-\pi R)2\pi Rc_2\frac{1}{4}F^c_{\mu\nu}F^{c\,\mu\nu}$$

- Localized terms deform the mass spectrum

$$m_W = \frac{\sin(\pi\alpha)}{\pi R\sqrt{1+c_1+c_2}} = 80.3\ \mathrm{GeV}$$
$$\Leftrightarrow R = R(\alpha, c_1+c_2)$$

Fermion sector

- Boundary condition

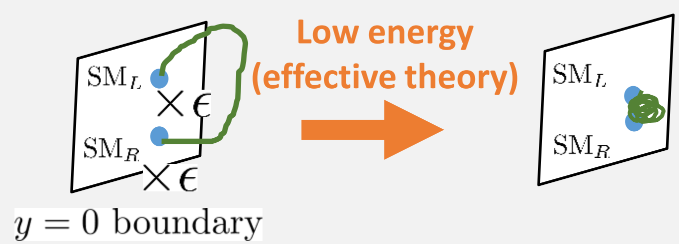
  ex) fundamental representation in $SU(3)$

$$\psi(y) = \eta_P P\gamma^5\psi(-y) \qquad \psi(\pi R - y) = \eta_{P'}P'\gamma^5\psi(y-\pi R)$$

$$\psi_L = \begin{pmatrix} (-\eta_P, -\eta_{P'}) \\ (-\eta_P, -\eta_{P'}) \\ (+\eta_P, +\eta_{P'}) \end{pmatrix} \qquad \psi_R = \begin{pmatrix} (+\eta_P, +\eta_{P'}) \\ (+\eta_P, +\eta_{P'}) \\ (-\eta_P, -\eta_{P'}) \end{pmatrix}$$

KK zero-mode with $(+,+)$ is chiral

- SM fermions are introduced as $SU(5)$ multiplet at $y=0$ boundary ($SU(5) \ni$ **10, 5, 1** rep)
- Bulk and mirror fermion are introduced for generating SM fermion masses ($SU(6) \ni$ **20, 15, 6** rep)



$$SU(5) \ni 10 = u_R \oplus q_L \oplus e_R,\ 5^* = d_R \oplus L_L,\ 1 = \nu_R$$
$$SU(6) \ni 20 = 10 \oplus 10^*,\ 15 = 10 \oplus 5,\ 6 = 5 \oplus 1$$