Gauge-Higgs unification in a RSI-1 space

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1. Introducción
    - RSI-1 model
    - Higgs mechanism

2. Towards the gauge-Higgs unification in a RSI-1 space
    - SU(2)

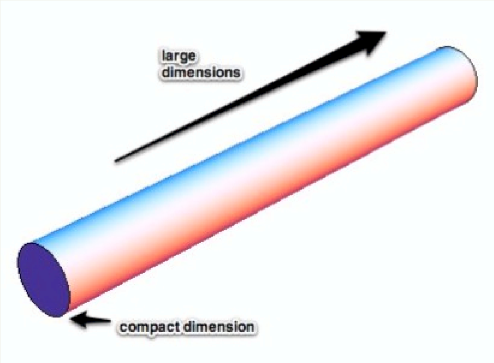
- Historically, the idea to consider our observable four dimensional (4D) universe as a subspace of a higher dimensional spacetime has a long tradition that goes back to the works of G. Nödstrom (*Phys. Z.* **15**, 504 (1914)), T. Kaluza (*Sitzungsber. Preuss. Akad. Wiss. Phys. Math.* **Kl. 1921**, 966 (1921)), and O. Klein (*Z. Phys.* **37**, 895 (1926)).
- Nowadays, there are two broad approaches one typically takes to address the possible consequences of extra dimensions in 4D physics. The top-down approach starts either from a fundamental theory or a low energy limit of it, for instance M/string theory, and upon compactification of the extra dimensions, one hopes to find an effective theory in 4D containing as much of the physics we know.
- In contrast, the bottom-up approach relies on “model building”, where the requirements of having the low energy spectrum and interactions of the known 4D physics put restrictions on properties such as the types of singularities, curvature, symmetries, etc., supported by the internal space.
- Following this approach, most attention has been devoted to high energy physics (see e.g. B. C. Allanach et al. hep-ph/0402295.,C. Csaki, arXiv:hep-ph/0404096. and references therein) and cosmology (see e.g. R. Maartens, *Living Rev. Relativity* **7**, 7 (2004), E. Elizalde, *J. Phys. A* **39**, 6299 (2006) and references therein).

Models with extra dimensions (ED)

- Compact dimensions

$\theta_j \in [0, 2\pi)$, $\eta_{\mu\nu} = \mathrm{diag}(1, -1, -1, -1)$

$$ds^2_{4+p} = \eta_{\mu\nu} dx^\mu dx^\nu - \sum_{j=1}^{p} R_j^2 d\theta_j^2$$

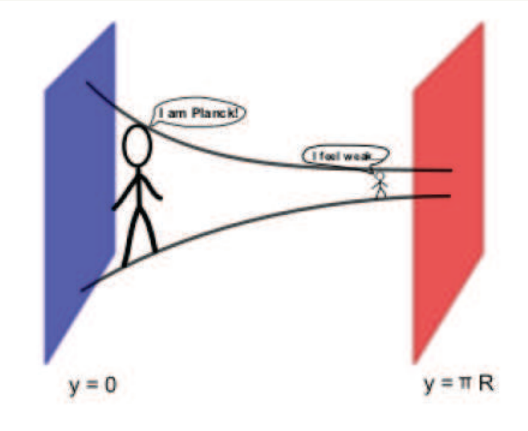


- Randall-Sundrum I

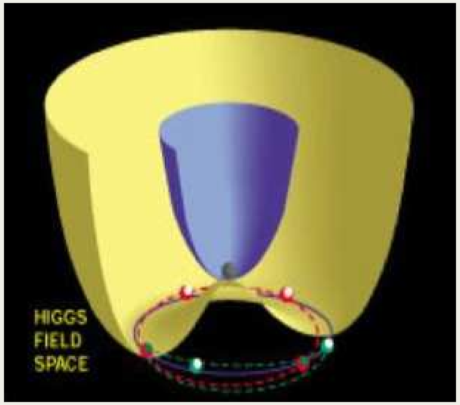
$$ds^2_5 = e^{-2\kappa|y|} \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$$

- Randall-Sundrum I-1 (RSI-1)

$$ds^2_6 = e^{-2\kappa|y|} \left(\eta_{\mu\nu} dx^\mu dx^\nu - R^2 d\theta^2\right) - dy^2$$



Higgs mechanism and ED



$$\mathcal{L} = (D_\mu \varphi)(D^\mu \varphi^*) + \mu^2 \varphi\varphi^* - \frac{1}{4}\lambda(\varphi\varphi^*)^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

$$D_\mu \varphi = (\partial_\mu + iqA_\mu)\varphi \qquad D_\mu \varphi^* = (\partial_\mu - iqA_\mu)\varphi^*$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$$

The Higgs particle has been discovered (?)

Open questions:

- Is there a principle governing the Higgs field?
- Which is the origin of the Higgs particle?

Gauge-Higgs unification scenarios

- It identifies the Higgs as a part of the gauge fields in higher dimensional theory
- The 4D Higgs field is unified with gauge fields
- The Higgs interactions are controlled by the gauge principle

SU(2) Gauge field in RSI-1

Metrics:

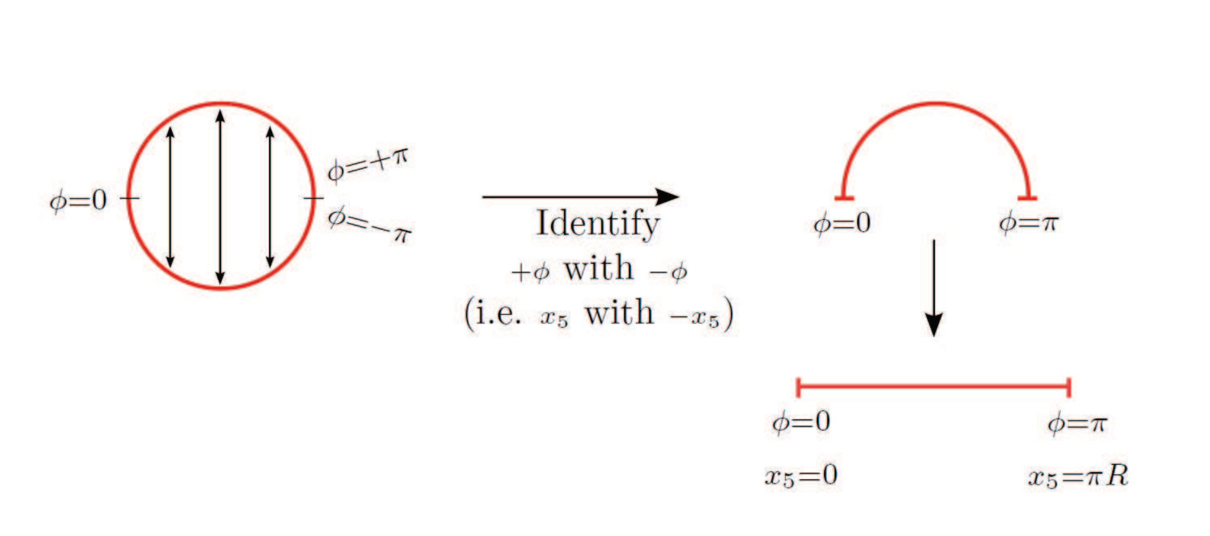
$$ds^2_{4+2} = e^{-2\kappa|y|}\left(\eta_{\mu\nu}dx^\mu dx^\nu - R^2 d\theta^2\right) - dy^2, \qquad g = \det g_{mn} = -e^{5\kappa|y|}R$$

Action:

$$S = -\frac{1}{2}\int d^4x dy R d\theta \sqrt{-g} Tr[(F^{(i)}_{mn}\frac{\sigma^i}{2})^2] = -\frac{1}{4}\int d^4x dy R d\theta \sqrt{-g}(F^{(i)}_{mn})^2$$

$$F^{(i)}_{mn} = \partial_m A^{(i)}_n - \partial_n A^{(i)}_m + q\epsilon^{ijk}A^{(j)}_m A^{(k)}_n, \qquad A_m = A^{(i)}_m \frac{\sigma^i}{2}, \qquad m, n = 0, 1, 2, 3, \theta, y$$

Orbifolding: $y \in [0, \pi r]$



$$\begin{pmatrix} A_\mu \\ A_\theta \\ A_y \end{pmatrix} (x, \theta, y_l - y) = P_l \begin{pmatrix} A_\mu \\ A_\theta \\ -A_y \end{pmatrix} (x, \theta, y_l + y) P_l, \qquad y_0 = 0, y_1 = \pi r$$

Consistency condition: $P_0 P_1 = U \in$ global SU(2)

We choose: $P_0 = P_1 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

Zero modes

$$A_{\mu,\theta} = \begin{pmatrix} A^{(3)}_{\mu,\theta} & 0 \\ 0 & -A^{(3)}_{\mu,\theta} \end{pmatrix} \qquad A_y = \begin{pmatrix} 0 & A^{(1)}_y - iA^{(2)}_y \\ A^{(1)}_y + iA^{(2)}_y & 0 \end{pmatrix}$$

We assume:

$$\begin{aligned} A^{(2)}_y &= 0 \\ A^{(i)}_\mu &= A^{(i)}_\mu(x) \\ A^{(3)}_\theta &\sim e^{2\kappa|y|} \end{aligned}$$

4D effective theory:

$$\begin{cases} F^{(1)}_{\mu\nu} = F^{(2)}_{\mu\nu} = F^{(1)}_{\mu\theta} = F^{(2)}_{\mu\theta} = 0 \\ F^{(3)}_{\mu\nu} = \partial_\mu A^{(3)}_\nu - \partial_\nu A^{(3)}_\mu \\ F^{(3)}_{\mu\theta} = \partial_\mu A^{(3)}_\theta \\ F^{(1)}_{\mu y} = \partial_\mu A^{(1)}_y ; F^{(2)}_{\mu y} = q A^{(3)}_\mu A^{(1)}_y ; F^{(3)}_{\mu y} = 0 \\ F^{(1)}_{\theta y} = 0 \\ F^{(2)}_{\theta y} = q A^{(3)}_\theta A^{(1)}_y \qquad \Rightarrow \qquad \mathcal{L} \sim -\frac{1}{4}\lambda(\varphi\varphi^*)^2 \\ F^{(3)}_{\theta y} = -\partial_y A^{(3)}_\theta \qquad \Rightarrow \qquad \mathcal{L} \sim \mu^2 \varphi\varphi^* \end{cases}$$

$$\mu^2 \sim \frac{e^{\kappa\pi r} - 1}{e^{4\kappa\pi r} - 1}$$

Conclusions

- Randall-Sundrum models extended with compact dimensions, can improve physical and mathematical behavior of the gauge-Higgs unification problem.
- The Higgs mass term is now obtained at the tree level.