Renormalization Group Running of Neutrino Parameters in Universal Extra Dimensions

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Outline

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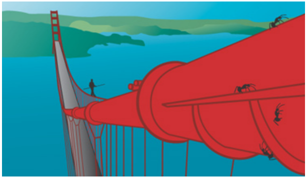
Universal Extra Dimensions

- Extra dimensions small, flat, and compactified.
- All SM fields propagate through the extra dimensions.
- Nice features: dark matter candidate and solution to hierarchy problem.



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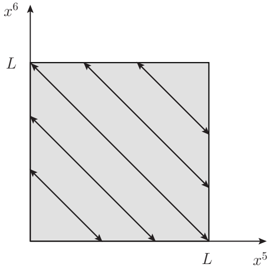
Compactification on the "Chiral square"



- Four-dimensional fermions (L/R) are chiral.
  Six-dimensional fermions have different chirality denoted $+/-$.
- Identification of points

$$
\begin{aligned}
(x^\mu, 0, y) &= (x^\mu, y, 0), \\
(x^\mu, L, y) &= (x^\mu, y, L).
\end{aligned}
$$

- Equivalent to T^2/Z_4-orbifold.
- Compactification radius:
  $R = L/\pi$, where $R^{-1} \sim 1$ TeV.

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Kaluza–Klein Decomposition

Kaluza–Klein decomposition (KK) of scalar field

$$\phi(x^\mu, x^4, x^5) = \frac{1}{L} \sum_{j,k} \phi^{(j,k)}(x^\mu) f^{(j,k)}(x^4, x^5),$$

j and k are called KK numbers and are integers. SM particles fulfill $j = 0, k = 0$ and $j \geq 1, k \geq 0$ otherwise. The four-dimensional field $\phi^{(j,k)}$ satisfy

$$\left(\partial_\mu \partial^\mu - M_0^2 - M_{j,k}^2\right) \phi^{(j,k)} = 0.$$

where $M_{j,k}^2 = \frac{j^2+k^2}{R^2}$. The field has an effective mass

$$M^2 = M_0^2 + M_{j,k}^2.$$

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Particle Content

Fermionic fields

- SM fermion content: $Q_{\mathrm{L}} = (u_{\mathrm{L}}, d_{\mathrm{L}})$, u_{R}, d_{R}, $L_{\mathrm{L}} = (\nu_{\mathrm{L}}, l_{\mathrm{L}})$, l_{R}
- UED fermion content: $Q_{+} = (u_{+}, d_{+})$, u_{-}, d_{-}, $L_{+} = (\nu_{+}, l_{+})$, l_{-}
- $\Psi_{+} = \Psi_{+\mathrm{L}} + \Psi_{+\mathrm{R}}$.
- A new tower of KK modes corresponding to each fermion

Gauge fields

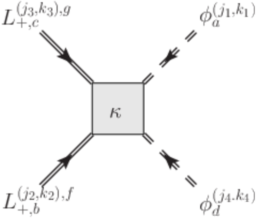
- Six-dimensional gauge field $A^{\alpha}(x^{\mu}, x^4, x^5) = (A^{\mu}, A^4, A^5)(x^{\nu}, x^4, x^5)$.
- KK decomposition
  - One gauge field corresponding to SM field
  - Two real, scalar fields without zero mode component

Effective Neutrino Mass Operator

- Weinberg operator, mass dimension = 5

$$\mathcal{L}_\kappa = -\frac{1}{8}\hat{\kappa}_{gf}(\overline{L_+^{C,g}}\varepsilon\tau^i L_+^f)(\phi^T\varepsilon\tau^i\phi) + \mathrm{h.c.}$$

- Can be realized through a seesaw mechanism



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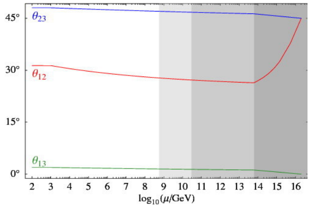
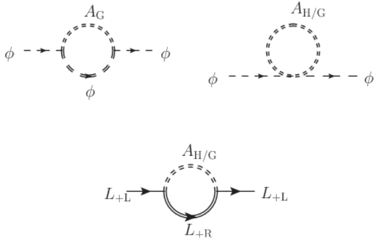
Renormalization Group Running

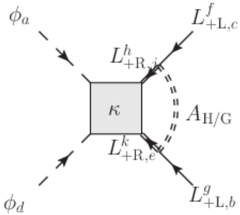
- Necessary to take RG running into account when studying physical parameters at high-energy scales.
- Higher dimensional models are generically non-renormalizable.
- Effective theory below energy cutoff Λ, UV completion above.



New Feynman diagrams in the UED model

The new diagrams contributing to the renormalization of the effective neutrino mass operator.





Beta Functions

The beta function for the effective neutrino operator is given by

$$\beta_\kappa = \beta_\kappa^{\mathrm{SM}} + s\beta_\kappa^{\mathrm{UED}},$$

where

$$\begin{aligned}
\beta_\kappa^{\mathrm{SM}} &= \frac{1}{16\pi^2}\left(2T\kappa + \lambda\kappa - \frac{3}{2}\kappa(Y_e^\dagger Y_e) - \frac{3}{2}(Y_e^\dagger Y_e)^T\kappa - 3g_2^2\kappa\right), \\
\beta_\kappa^{\mathrm{UED}} &= \frac{1}{16\pi^2}\left(4T\kappa + \lambda\kappa - \frac{3}{2}\kappa(Y_e^\dagger Y_e) - \frac{3}{2}(Y_e^\dagger Y_e)^T\kappa \right. \\
&\quad \left. - \frac{3}{2}g_1^2\kappa - \frac{5}{2}g_2^2\kappa\right).
\end{aligned}$$

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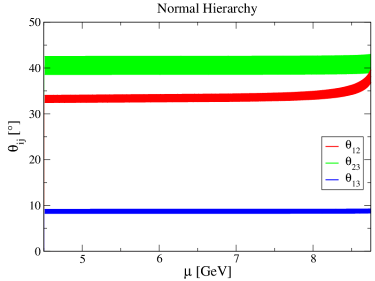
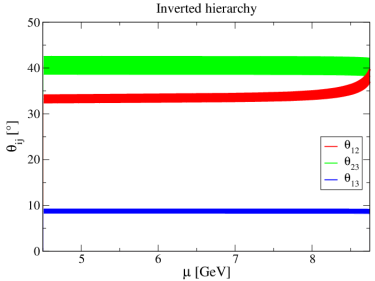
Results

Running of the neutrino mixing angles.





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Thank you for listening! Questions?

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