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J.Santiago, Ph D Thesis

Low Energy Constraints in Orbifold Models

Many models extending the Standard Model, in particular including gravity, require extra dimensions.

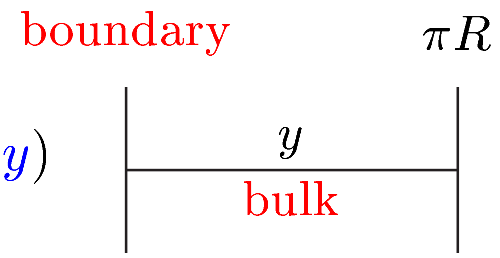
They are described by effective theories in $d > 4$ dimensions, non-renormalizable and valid up to some cut-off, typically the compactification scale M_c or the string scale M_s. In four dimensions these theories reduce to infinite towers of Kaluza-Klein states with the same quantum numbers as the observed fields. If M_c is not far from the TeV scale, they can manifest at colliders. Estimates are obtained assuming simple compactifications and are usually at tree-level. Loop corrections can change them drastically.

One can address many aspects: stability, symmetry breaking, . . . We will discuss low energy limits on Kaluza-Klein fermions and bosons in simple orbifold models, commenting on possible radiative correction effects.

Rubakov, hep-ph/0104152

Why orbifolds ?

$\frac{S^1}{Z_2}$ (identifying y and $-y$)



Simplest compactification allowing to implement chirality and get rid of unwanted massless modes.

$$\mathcal{L}(\phi) = \mathcal{L}_{\text{kin}}(\phi) + \mathcal{L}_{\text{int}}(\phi)$$

$$\phi(x, y) = \sum_n \phi^{(n)}(x) f_n(y)$$

$$\phi^{(n)} : m_n, \lambda_m, \ldots$$

$$\mathcal{L} = -\frac{1}{4}\int \mathrm{d}y\ [F^{MN}F_{MN}], \quad M,N = 0,1,2,3,4.$$

$$A_\mu(x,y) = \sum_{n=0}^{\infty} \frac{f_n(y)}{\sqrt{\pi R}} A_\mu^{(n)}(x) \sim \partial_\mu \text{ symmetric}$$

(Gauge $A_4 = 0$)

$$\begin{aligned}
\mathcal{L} &= -\frac{1}{4}\sum_{nm}\left\{\left[\int \mathrm{d}y\ \frac{f_n f_m}{\pi R}\right] F^{(n)\mu\nu}F^{(m)}_{\mu\nu}\right.\\
&\left.\quad + 2\left[\int \mathrm{d}y\ \frac{f_n \partial_y^2 f_m}{\pi R}\right] A^{(n)\mu}A^{(m)}_\mu\right\}\\
&= \sum_n \left[-\frac{1}{4}F^{(n)\mu\nu}F^{(n)}_{\mu\nu} + \frac{1}{2}m_n^2 A^{(n)\mu}A^{(n)}_\mu\right]
\end{aligned}$$

$$\begin{aligned}
\int_0^{\pi R}\mathrm{d}y\ \frac{f_n f_m}{\pi R} &= \delta_{nm}\\
\partial_y^2 f_n &= -m_n^2 f_n\\
\partial_y f_n|_{y=0,\pi R} &= 0
\end{aligned}$$

The solution is

$$f_n(y) = \sqrt{2-\delta_{n0}}\cos\left(\frac{ny}{R}\right), \quad n = 0,1,\ldots, \quad m_n = \frac{n}{R}$$

$$\begin{aligned}\mathcal{L}_{\text{gauge}} &= -\int \mathrm{d}y\; g_5 \bar{\Psi}\gamma^\mu A_\mu \Psi \\ &= -\sum_{nmr} \left[g^{LLV}_{nmr} \bar{\Psi}^{(n)}_L \gamma^\mu A^{(r)}_\mu \Psi^{(m)}_L + (L \to R) \right]\end{aligned}$$

$$g^{LLV}_{nmr} = \frac{g_5}{\sqrt{\pi R}} \int_0^{\pi R} \mathrm{d}y\; \frac{f^L_n f^L_m f^V_r}{\pi R} \quad \text{dimensionless}$$

$$\begin{aligned}\mathcal{L}_{\text{Yuk}} &= -\int \mathrm{d}y\; \left[\lambda_5 \bar{\Psi}\chi\phi + \text{h.c.} \right] \\ &= -\sum_{nmr} \left[\lambda^{\Psi\chi S}_{nmr} \bar{\Psi}^{(n)}_L \chi^{(m)}_R \phi^{(r)} \right. \\ &\qquad \left. + \lambda^{\chi\Psi S}_{mnr} \bar{\Psi}^{(n)}_R \chi^{(m)}_L \phi^{(r)} + \text{h.c.} \right]\end{aligned}$$

$$\lambda^{\Psi_1\Psi_2 S}_{nmr} = \frac{\lambda_5}{\sqrt{\pi R}} \int_0^{\pi R} \mathrm{d}y\; \frac{f^{\Psi_1 L}_n f^{\Psi_2 R}_m f^S_r}{\pi R} \quad \text{dimensionless}$$

$$\lambda_{nm} = \frac{\tilde{\lambda}_5}{\pi R} f^{\Psi L}_n(0) f^{\chi R}_m(0) \quad \text{Boundary Higgs}$$

Low Energy Constraints

Universal	$M_c > 300$ GeV	T parameter [1]
Brane interactions	$M_c > 4$ TeV	Z' tower [2]
Randall-Sundrum	$M_c > 10$ TeV	Precision data [3]
Fermion spreading	$M_c > 100$ TeV	FCNC [4]
Fermion multilocalization	$M_c > 80$ TeV $e^{-M/M_c} M_c \sim 300$ GeV	Precision and production data [5]

(1) Appelquist *et al.*, PRD64 (2001) 035002

(2) Rizzo, Wells, PRD61 (2000) 016007; Delgado *et al.*, JHEP 0001 (2000) 030

(3) Burdman, hep-ph/0205329

(4) Delgado *et al.*, JHEP 0001 (2000) 030

(5) del Aguila, Santiago, JHEP0203 (2002) 010

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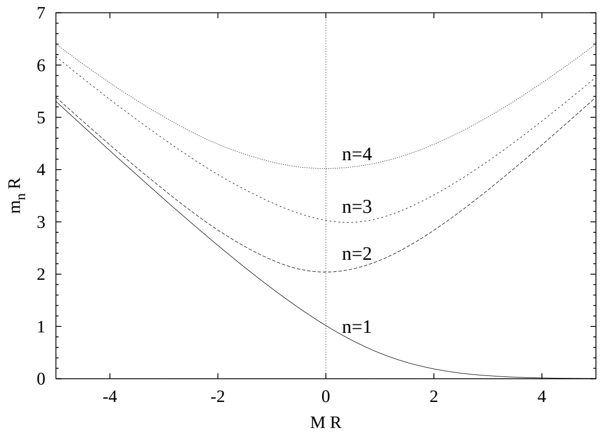
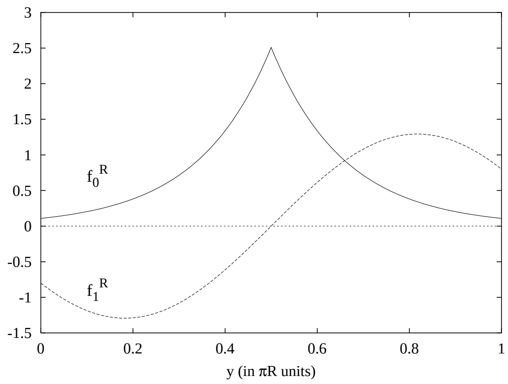
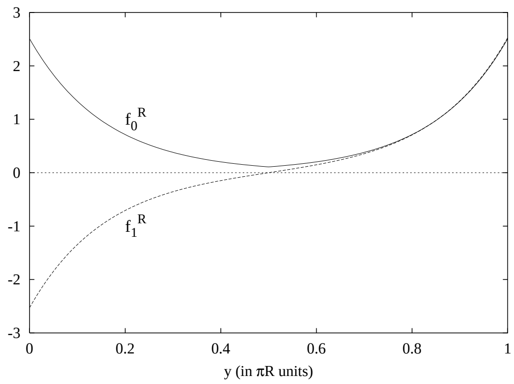
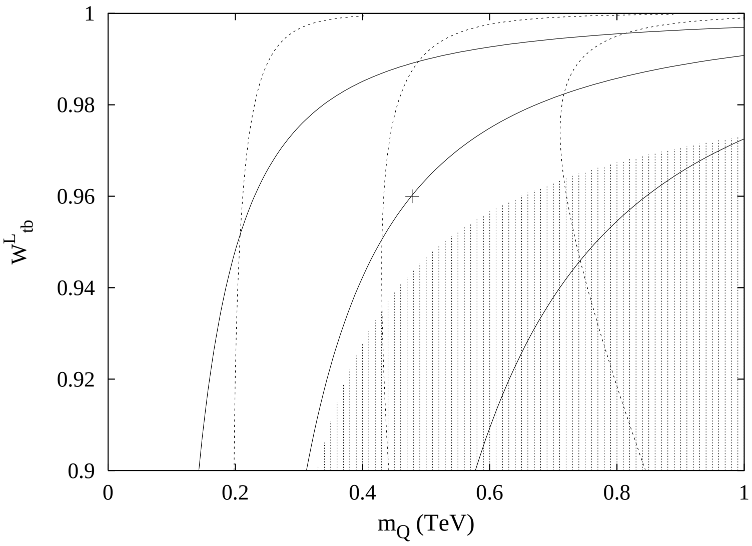






F. del Aguila and J. Santiago JHEP0203 (2002) 010



Top coupling and lightest vector-like quark mass as function of the intermediate brane position and the five dimensional mass. Solid (dotted) lines stand for fixed $\frac{a}{R}$ $(M_3^u R)$, from left to right 0.53, 0.51, 0.49 (5.55, 4.85, 4.5).

Fermion masses and mixing angles are reproduced with order one Yukawa couplings and $M \sim M_c \sim 85$ TeV, $W_{tb}^L = 0{,}96$ and $m_Q = 478$ GeV. Contributions to electroweak observables are within experimental errors.

M. Carena *et al.*, APPB 33 (2002) 2355

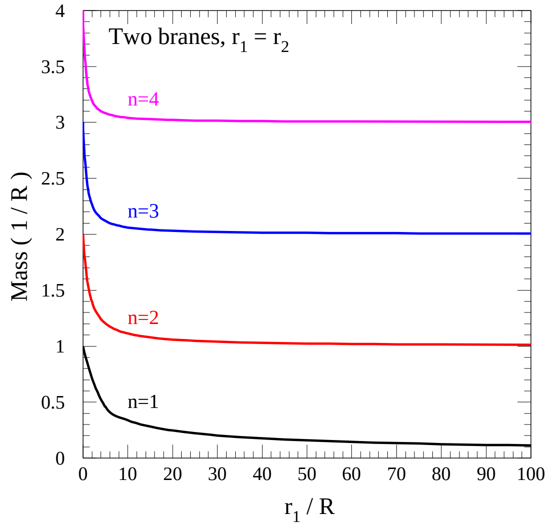
$$\begin{aligned}\mathcal{L} &= \int \mathrm{d}y \left\{ -\frac{1}{4} F^{MN} F_{MN} \right. \\ & \left. -\delta(y) \frac{r_1}{4} F^{\mu\nu} F_{\mu\nu} - \delta(y - \pi R) \frac{r_2}{4} F^{\mu\nu} F_{\mu\nu} \right\}\end{aligned}$$

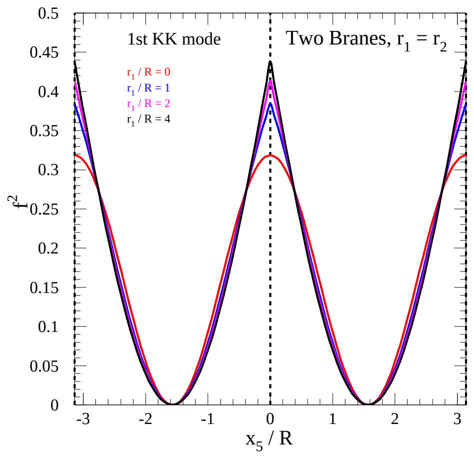
$$\left[\partial_y^2 + m_n^2 \left(1 + r_1 \delta(y) + r_2 \delta(y - \pi R)\right) \right] f_n = 0$$

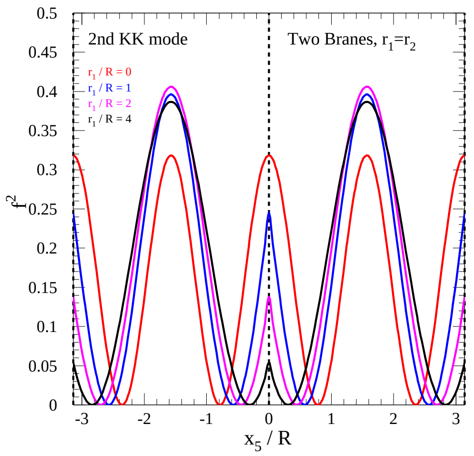
$$\begin{aligned} f_n(y) &= \mathcal{N}_n \cos(m_n y) - \frac{m_n r_1}{2} \sin(m_n y), \quad y \geq 0, \\ f_n(-y) &= f_n(y) \end{aligned}$$

$$(r_1 r_2 m_n^2 - 4) \tan(m_n \pi R) - 2(r_1 + r_2) m_n = 0$$

M. Carena *et al.*, APPB 33 (2002) 2355







Conclusions

- Despite the stringent bounds on M_c, their model dependence leaves still room for Kaluza-Klein effects at large colliders (*e.g.* fermion multi-localization).
- For example, if the top quark is multi-localized, a new quark of charge $\frac{2}{3}$ can exist with a mass of 400 GeV and a large mixing with the top quark.
- One-loop effects may stand for large corrections on the spectrum of Kaluza-Klein states.