Solving the Flavor Problem of Warped Extra Dimensions/Composite Higgs Models

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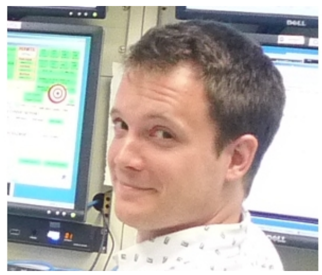


A mechanism is presented which brings theories with composite Higgs and partially composite quarks, described by warped extra dimensional theories, in agreement with all flavor constraints and a TeV New Physics scale. The possibility of extending these ideas to small N theories without a holographic dual is briefly elaborated on.

1 Introduction

It is a groundbreaking insight, that theories of warped extra dimensions with an infrared localized Higgs scalar are a dual description of large N composite Higgs models. These theories aim at explaining the hierarchy problem by introducing a composite scale in the TeV range. They typically have problems achieving this goal due to the accomodation of the large top mass, large corrections to electroweak precision observables, and sizable flavor changing neutral currents (FCNC). Promoting the Standard Model (SM) fermions to bulk fields puts into practice the concept of partial compositeness, rendering a heavy top feasable and suppressing FCNCs sufficiently in all but one observable, namely CP-violation in $K-\bar{K}$ mixing. The bounds from this observable are even more stringent than the ones coming from electroweak precision tests, pushing the composite scale, from now on denoted by $M_{\rm KK}$, by an order of magnitude. In this talk, I will present a mechanism, which mitigates these effects via a cancellation of the contributions from the exciations of the SM gluon, the Kaluza-Klein (KK) gluons, based on an extended strong interaction bulk gauge group[1]. In the dual theory this corresponds to a global symmetry of the composite sector and I will argue that such a mechanism would also ease the flavor problem of *small* N technicolor theories, which do not possess a holographic dual.

2 Solving the RS Flavor Problem

In the holographic description via a warped five dimensional Randall-Sundrum (RS) model with all SM fields in the bulk except for the Higgs, which is localized on the IR brane, the flavor problem can be parametrized through the contribution of the KK excitations of the gluon to

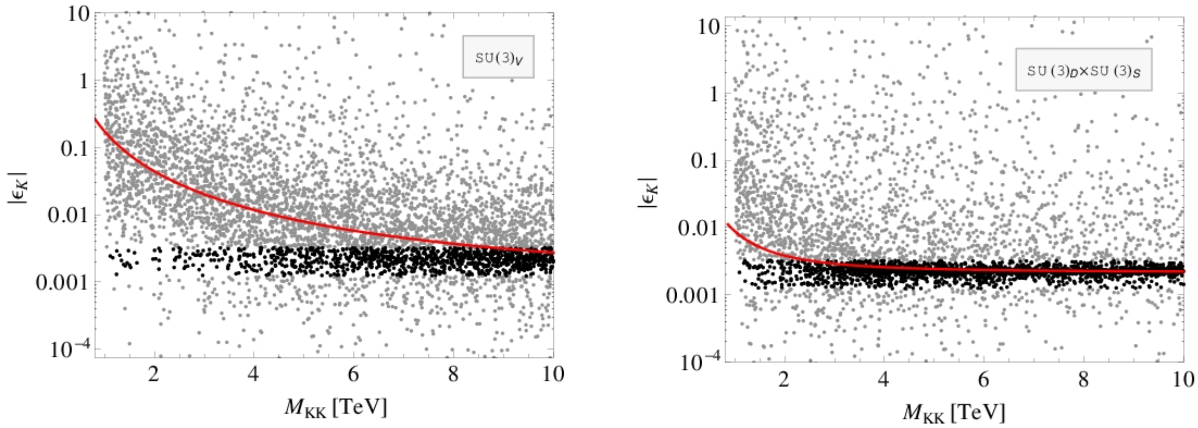


Figure 1: The CP-violating observable $|\epsilon_K|$ as a function of $M_{\rm KK}$ for the minimal RS model (left panel) and the model with a pseudo-axial gluon and $\tan\theta = 1, \xi = 1$ (right panel). The lines illustrate the decoupling behavior with $M_{\rm KK}$.

the CP violating quantity

$$\epsilon_K \sim \mathrm{Im}\,\langle K^0|\mathcal{H}_{\rm eff}^{\Delta S=2}|\bar{K}^0\rangle\,, \tag{1}$$

where the effective Hamiltonian for $K-\bar{K}$ mixing requires the operators

$$\begin{aligned} Q_1^{sd} &= (\bar{d}_L\gamma^\mu s_L)\,(\bar{d}_L\gamma_\mu s_L)\,, \qquad & Q_4^{sd} &= -\frac{1}{2}\,(\bar{d}_L^\alpha\gamma^\mu s_L^\beta)\,(\bar{d}_R^\beta\gamma_\mu s_R^\alpha) = (\bar{d}_R s_L)\,(\bar{d}_L s_R)\,, \\ \widetilde{Q}_1^{sd} &= (\bar{d}_R\gamma^\mu s_R)\,(\bar{d}_R\gamma_\mu s_R)\,, \qquad & Q_5^{sd} &= -\frac{1}{2}\,(\bar{d}_L\gamma^\mu s_L)\,(\bar{d}_R\gamma_\mu s_R) = (\bar{d}_R^\alpha s_L^\beta)\,(\bar{d}_L^\beta s_R^\alpha)\,, \end{aligned} \tag{2}$$

multiplied by Wilson coefficients $C_{1,4,5}$ and $\widetilde{C}_1$. In the SM, there are only loop-level contributions to Q_1^{sd}. In the minimal RS model all four Wilson coefficients receive contributions at tree level, but suppressed by a factor $g_s^2 L/M_{\rm KK}^2$, with $L \sim 36$ the *volume* of the extra dimension, times small flavor-changing couplings from KK gluon exchange [2]. Compared to the SM contribution, the suppression by the KK scale $M_{\rm KK} \sim$ few TeV roughly compensates the loop factor. However, the coefficients of the mixed chirality operators Q_4^{sd} and Q_5^{sd} are significantly enhanced by renormalization group running and large operator matrix elements, so that one obtains approximately

$$\langle K^0|\mathcal{H}_{\rm eff}^{\Delta S=2}|\bar{K}^0\rangle \propto C_1 + \widetilde{C}_1 + 115\left(C_4 + \frac{C_5}{3}\right). \tag{3}$$

As a consequence, New Physics contributions dominate over the SM and the composite scale is pushed to $M_{\rm KK} > 10$ TeV, if one does not want to introduce a fine-tuning of parameters of about 1%. This is the only observable, where FCNCs are not sufficiently suppressed by the RS-GIM mechanism, which is the 5D dual of the small mixings induced by the mostly elementary nature of light quarks. In the absence of the mixed chirality coefficients however, all flavor sectors can be brought in agreement with the experiment, without additional assumptions like minimal flavor violation (MFV).

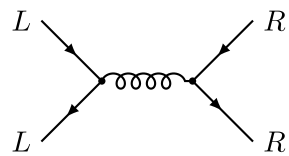
This observation motivates a solution to the RS flavor problem, which assumes that the new color charged composite states (or equivalently the gluon KK modes) do not contribute to the mixed chirality operators. To this end the strong-interaction gauge group in the bulk is extended to $SU(3)_D \times SU(3)_S$. The 5D color-octet gauge bosons G_μ^D and G_μ^S couple to $SU(2)_L$ quark doublets Q and singlets q with coupling strengths g_D and g_S, respectively:

$$\mathcal{L}_{\rm int} \ni g_D\,\bar{Q}\,G_\mu^D\gamma^\mu Q + g_S\,\bar{q}\,G_\mu^S\gamma^\mu q\,. \tag{4}$$

And this extended symmetry is broken by a suitable choice of boundary conditions (BCs) on the UV and IR branes, which give rise to the SM gluon, $g_\mu = G_\mu^D \cos\theta + G_\mu^S \sin\theta$, with $\tan\theta = g_D/g_S$, and the orthogonal combination $A_\mu = -G_\mu^D \sin\theta + G_\mu^S \cos\theta$, which will be refered to as *pseudo-axial gluon* (since it only couples axially for $\tan\theta = 1$), so that

$$\mathcal{L}_{\text{int}} \ni g_s \left(\bar{Q}\, g_\mu \gamma^\mu Q + \bar{q}\, g_\mu \gamma^\mu q \right) + g_s \left(-\tan\theta\, \bar{Q}\, A_\mu \gamma^\mu Q + \cot\theta\, \bar{q}\, A_\mu \gamma^\mu q \right), \tag{5}$$

where $g_s = \sqrt{g_D^2 + g_S^2}\, \sin\theta \cos\theta$ is fixed to be the strong interaction coupling constant. Given that in the 4D effective theory, the quark doublets will be decomposed in left-handed and the singlets into right handed quarks, one can see from (5), that the contributions of the gluon and the pseudo-axial gluon KK modes to the relevant mixed-chirality four quark operators,



will have opposite signs, independent of the mixing angle θ. If they also have the same size, a cancellation between the contributions of these resonances would take place.
The size of the contributions is given by the BCs for g_μ and A_μ, respectively. In order to have a zero mode, *i.e.* an elementary gluon gauge boson, g_μ need to have Neumann BCs on both branes. In the case of A_μ, the need of an extended Higgs sector, caused by the extended gauge group, which makes Yukawa terms couple quarks transforming under different $SU(3)$s, dictates the IR BCs, while experimental bounds enforce Dirichlet BCs on the UV brane. If the profiles $\chi_n(t)$ describe the KK wave functions along the extra dimension (t being the fifth coordinate), and m_n their respective masses, Neumann-Neumann BCs result in the sum over KK modes

$$\sum_{n\geq 1} \frac{\chi_n^{(g)}(t)\, \chi_n^{(g)}(t')}{m_n^2} = \frac{L}{4\pi M_{\text{KK}}^2} \left[t_<^2 - \frac{t^2}{L}\left(\frac{1}{2} - \ln t\right) - \frac{t'^2}{L}\left(\frac{1}{2} - \ln t'\right) + \frac{1}{2L^2} \right], \tag{6}$$

where only terms $\propto t_<^2 \equiv \min(t^2, t'^2)$ give rise to $\Delta F = 2$ transitions such as meson-antimeson mixing. The corresponding sum over KK states for the pseudo axial gluon gives

$$\sum_{n} \frac{\chi_n^{(A)}(t)\, \chi_n^{(A)}(t')}{m_n^2} = \frac{L}{4\pi M_{\text{KK}}^2} \left[t_<^2 - \xi \frac{L v^2}{2 M_{\text{KK}}^2}\, t^2 t'^2 \right], \tag{7}$$

where ξ is order one, but depends on the exact realization of the scalar sector. As a consequence, the dangerous $t_<^2$ terms cancel between the two sums and the new $t^2 t'^2$-term will only introduce further suppressed contributions. Therefore, the Wilson coefficients in (3) are of the order

$$C_1, \widetilde{C}_1 \sim \frac{v^2}{M_{\text{KK}}^2}, \qquad C_4, C_5 \sim \frac{v^4}{M_{\text{KK}}^4}. \tag{8}$$

A scatter plot showing 5000 parameter points illustrates the result in Figure 1. Points which do (not) fulfill the ϵ_K bound are colored black (light gray) and the M_{KK} scale at which the red line cuts into the black points roughly gives the New Physics scale in the respective model without finetuning.

3 More General Composite Higgs Models

In the dual theory, a bulk gauge symmetry translates to a global symmetry of the composite sector, where the residual symmetry group on the UV brane is weakly gauged by an elementary

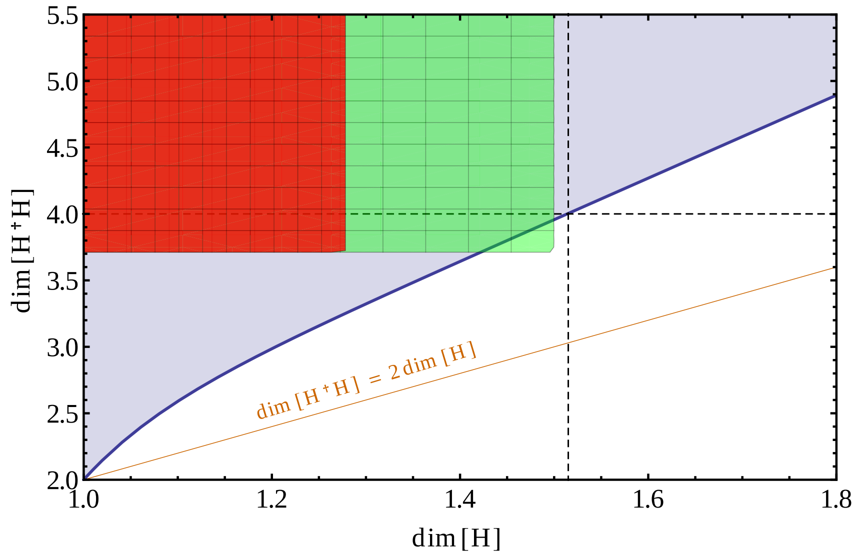


Figure 2: The scaling dimension of the operators H and $H^\dagger H$ in a 4D conformal theory with a global $SU(2)$ symmetry (see[4] for details). The excluded parameter space is shaded blue. Flavor constraints prefer the red region in minimal CTC, and the green region if left-right operators are forbidden.

gauge boson. The model introduced in this talk thus is the holographic dual of a composite sector which by a global symmetry does not admit mixed chirality operators with colored composites. This global symmetry is broken at the electroweak scale by the vacuum expectation value of the composite higgs as well as by mixing with the elementary sector, which only features an elementary gluon and no axigluon.

If such a symmetry can be succesfully implemented in an RS model, it may also be a possibility to resolve the flavor problem in a wider class of composite theories, which do not have a holographic dual. Especially small N theories with large anomalous dimensions, so called *partially gauged walking* or *conformal* technicolor theories (CTC) [3], which do not have composite quarks, but allow for the composite Higgs H to have a scaling dimension close to one, while the $H^\dagger H$ operator remains at most marginal, might be compatible with flavor constraints if they incorporate such a mechanism. Recent studies on the possible scaling dimensions in 4D conformal theories disfavor the region in which these models work without additional finetuning, shaded red in Figure 2, but a rough estimate shows that with the additional global symmetry one cuts back into the allowed parameter space, corresponding to the green shaded region (The bounds might be weaker than shown in Figure 2, since they tend to go down with additional symmetry in the composite sector, whereas the shown curve assumes an $SU(2)$, see [4] for details).

Acknowledgments

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