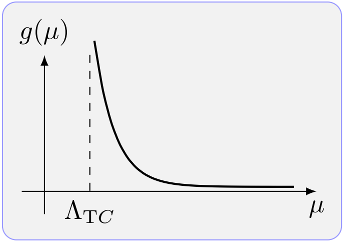
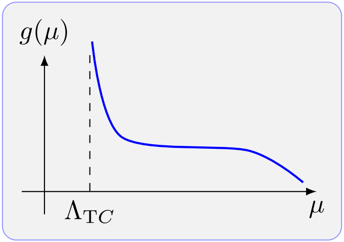
A Solution to the Flavor Problem of Warped Extra Dimensions

Martin Bauer



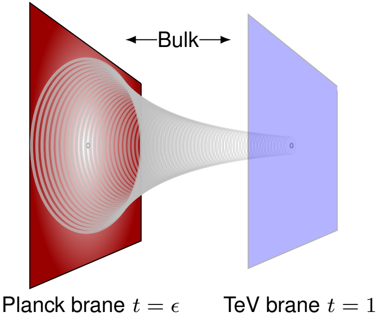


Warped Extra Dimensions Intro

- Compact Extra dimension

$$ds^2 = \frac{\epsilon^2}{t^2}\left(\eta_{\mu\nu}\, dx^\mu dx^\nu - \frac{1}{M_{\mathrm{KK}}^2} dt^2\right), \qquad \epsilon = \frac{\Lambda_{\mathrm{Weak}}}{\Lambda_{\mathrm{PL}}}$$

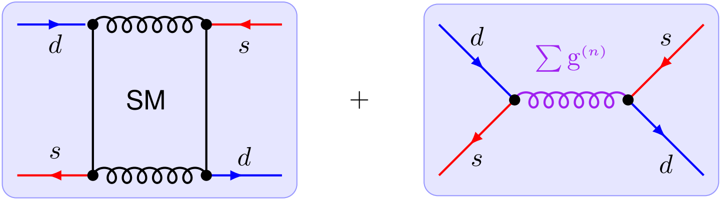
- All SM fields are 5D fields, except for the Higgs
- Solution to the Hierarchy problem
- Build-in suppression of FCNCs



The RS Flavor Problem

The RS-GIM mechanism is extremely effective, apart from one observable,

$$\epsilon_K = \frac{\kappa_\epsilon e^{i\phi_\epsilon}}{\sqrt{2}(\Delta m_K)_{\rm exp}} \, \mathrm{Im} \, \langle K^0 | \mathcal{H}_{\rm eff}^{\Delta S=2} | \bar{K}^0 \rangle \,,$$



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$$Q_{LL}^{sd} = (\bar{d}_L \gamma^\mu s_L) \, (\bar{d}_L \gamma_\mu s_L)$$

$$\widetilde{Q}_{LL}^{sd} = (\bar{d}_R \gamma^\mu s_R) \, (\bar{d}_R \gamma_\mu s_R)$$

$$\boxed{Q_{LR}^{sd} = -\tfrac{1}{2} (\bar{d}_R^\alpha \gamma^\mu s_R^\beta) \, (\bar{d}_L^\beta \gamma_\mu s_L^\alpha)}$$

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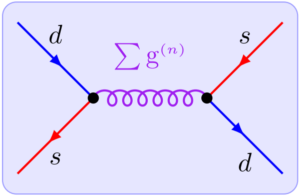

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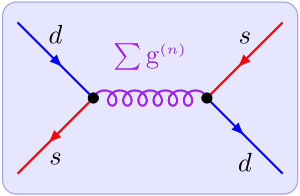

$$\langle K^0 | \mathcal{H}_{\rm RS}^{\Delta S=2} | \bar{K}^0 \rangle \propto C_{LL}^{\rm SM+RS} + \widetilde{C}_{LL}^{\rm RS} + 100 \left(\boxed{C_{LR}^{\rm RS}} + \tfrac{1}{N_C} C_{RL}^{\rm RS} \right)$$

Large chiral enhancement $\sim \left(\frac{m_K}{m_s + m_d} \right)^2$

RGE running
$3\,{\rm TeV} \to 2\,{\rm GeV}$

Solving the RS Flavor Problem

If we had a gauge boson which couples with opposite sign to left- and right-handed quarks, but with the same coupling strength as the KK gluons, we could evade the ϵ_K- constraint. Something like a 5D axigluon.

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Extend the strong bulk gauge group to $SU(3)_{\rm Doublet} \otimes SU(3)_{\rm Singlet}$

$$\mathcal{L}_{\rm int} \ni g_D \, \bar{Q} \, G^D_\mu \gamma^\mu Q + g_S \, \bar{q} \, G^S_\mu \, \gamma^\mu q$$

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and break it via boundary conditions into the gluon

$$g_\mu = G^D_\mu \cos\theta + G^S_\mu \sin\theta \qquad \text{with} \qquad \tan\theta = g_D/g_s$$

and the <u>axigluon</u> (only for $\tan\theta = 1$ it is a <u>pure</u> axigluon)

$$A_\mu = G^D_\mu \sin\theta - G^S_\mu \cos\theta$$

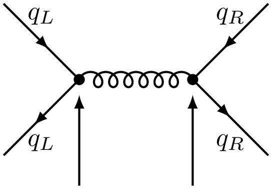
so that

$$\begin{aligned} \mathcal{L}_{\text{int}} \ni \; & g_s \left(\bar{Q} \, g_\mu \gamma^\mu Q + \bar{q} \, g_\mu \, \gamma^\mu q \right) \\ & + g_s \left(\boxed{\tan\theta} \; \bar{Q} \, A_\mu \gamma^\mu Q \boxed{- \cot\theta} \; \bar{q} \, A_\mu \, \gamma^\mu q \right) \end{aligned}$$

Solving the RS Flavor Problem

- Opposite sign

$C_{LR} \sim$



KK gluon: g_s g_s

KK axigluon: $g_s \tan\theta$ $-g_s \cot\theta$

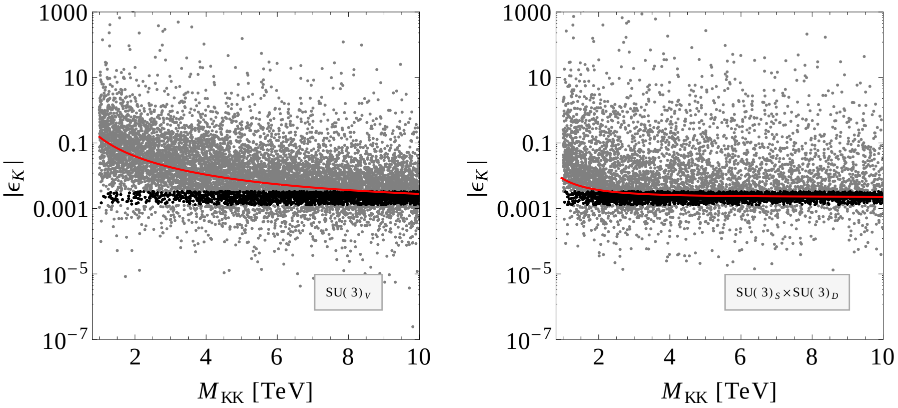
- Same size FCNCs : Set by boundary conditions

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

$$\sum_{n\geq 0} \frac{\chi_n^A(t)\,\chi_n^A(t')}{m_n^2} = \frac{L}{4\pi M_{\rm KK}^2}\left[A\,t_<^2 + B\,(t^2 + t'^2) + C\,t^2 t'^2 + D\right]$$

turns out: $A = 1$

Solving the RS Flavor Problem



$\Rightarrow$ Consistent model of flavor at the TeV scale!

[MB, Malm, Neubert PRL'11]

Beyond RS?

Is there a deeper reason?

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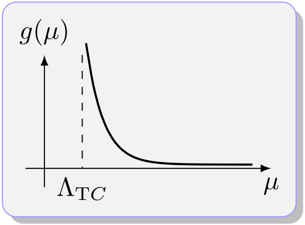
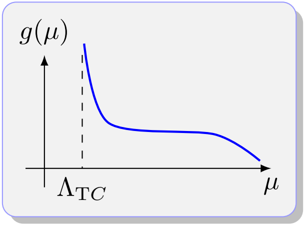
AdS	$\leftrightarrow$	(Large N) CFT
Gauge symmetry in the bulk	$\leftrightarrow$	Global symmetry in the Strongly coupled sector

Beyond RS?



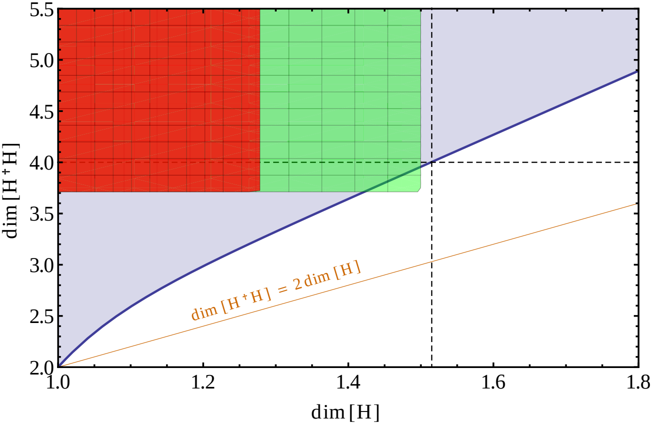
$\mu^2 H^\dagger H \qquad \dim\left[H^\dagger H\right] = 4$ ✓

$\frac{Y}{\Lambda^{\dim[H]-1}} \bar{Q} H t_R \qquad \dim\left[H\right] = 2$ ✗

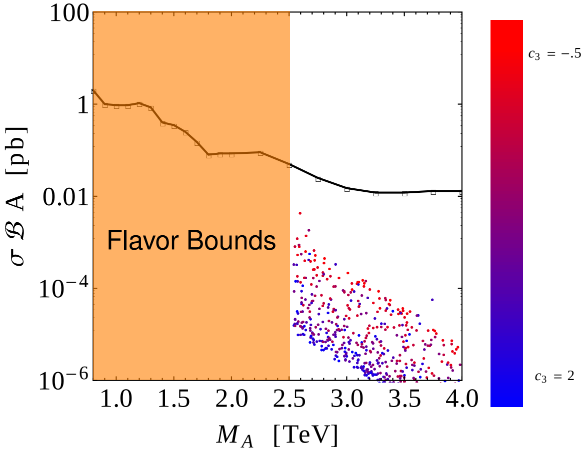


FCNCs: $\frac{c}{\Lambda^2}(\bar{s}d)(\bar{s}d)$

Beyond RS?

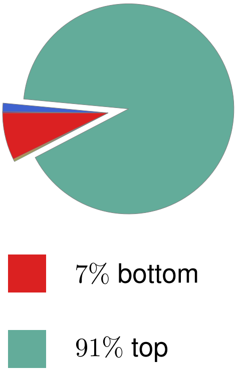


LHC Bounds: Dijet Bounds

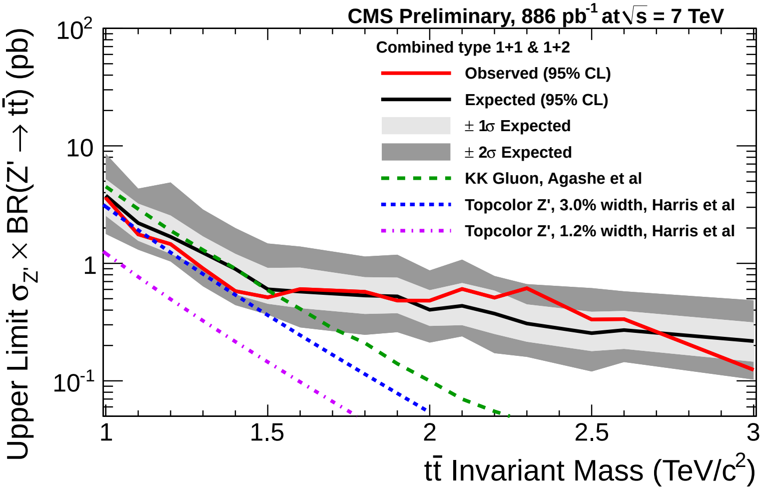


[ATLAS '11]

KK (Axi-)Gluon Branching Ratio:



LHC Bounds: $t\bar{t}$ Resonances



[CMS '11]