Radion flavor in Warped Extra Dimensions. [a]

by

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at

PHENO 2009, Madison, May 2009

[a] Based on **arXiv:0812.2489** *A.Azatov, M.T., L.Zhu*

Outline

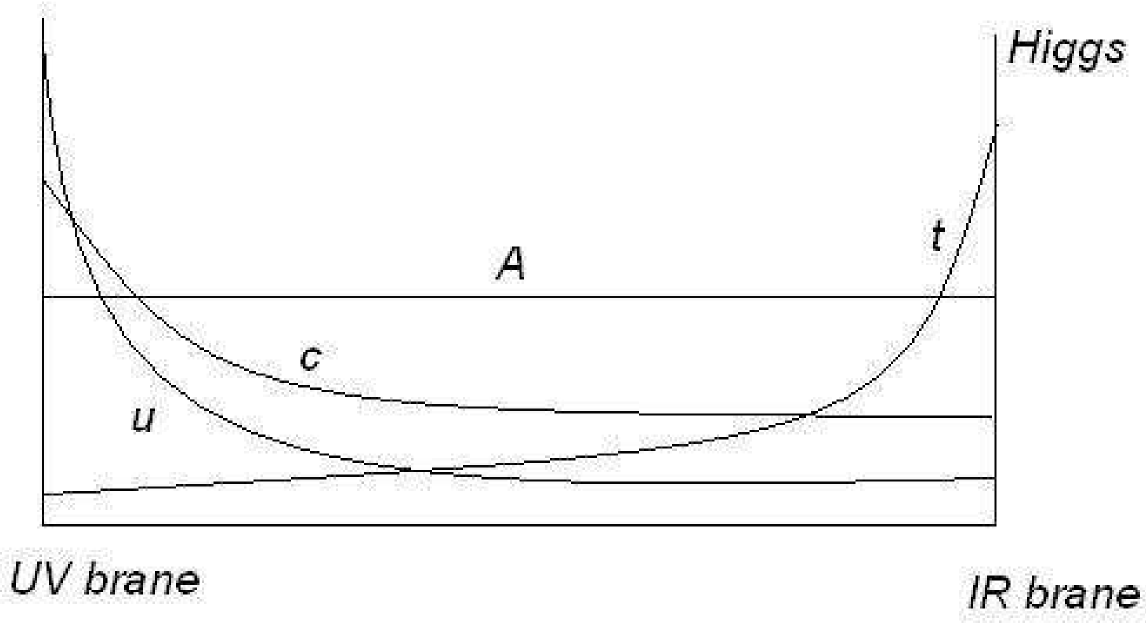
- Introduction
  - Flavor in RS
  - The radion in RS
- radion Flavor
- Conclusions

Introduction

- Warped Extra Dimensions: One compact extra dimension with warped geometry.

- Original setup: Two branes as boundaries and all SM fields on the TeV Brane $\rightarrow$ RS1.
  - Towers of KK gravitons
  - Radion graviscalar

- More recent setups: Two branes, Higgs field on TeV brane, SM fields in the "bulk".
  - Towers of KK gravitons
  - Towers of KK SM fields
  - Radion graviscalar



Flavor anarchy: masses and mixings from fermion localization

The Radion and its interactions

In the RS1 model [$Randall, Sundrum, ('98)$] the background metric g^{o}_{AB} is defined by

$$ds^2 \quad = \quad e^{-2\sigma}\eta_{\mu\nu}\, dx^\mu dx^\nu + dy^2 \quad = \quad \frac{R^2}{z^2}\left(\eta_{\mu\nu}\, dx^\mu dx^\nu + dz^2\right)$$

with $\sigma(y) = ky$ (and $R = 1/k$). Hierarchy created between the two boundaries at $y = 0$ and $y = \pi r_0$ $\quad (z = R$ and $z = R')$.

The linear metric perturbations $h_{AB}(x, y)$ can be reduced to

$$ds^2 = \left(e^{-2\sigma}\eta_{\mu\nu} + \left[e^{-2\sigma}h^{TT}_{\mu\nu}(x,y) - \eta_{\mu\nu}r(x)\right]\right) dx^\mu dx^\nu + \left(1 + 2e^{2\sigma}r(x)\right) dy^2$$

(the graviscalar $r(x)$ is massless. A stabilization mechanism providing it with mass is assumed for example[$Golberger, Wise ('99)$])

Ex. RS1 - Matter on the brane

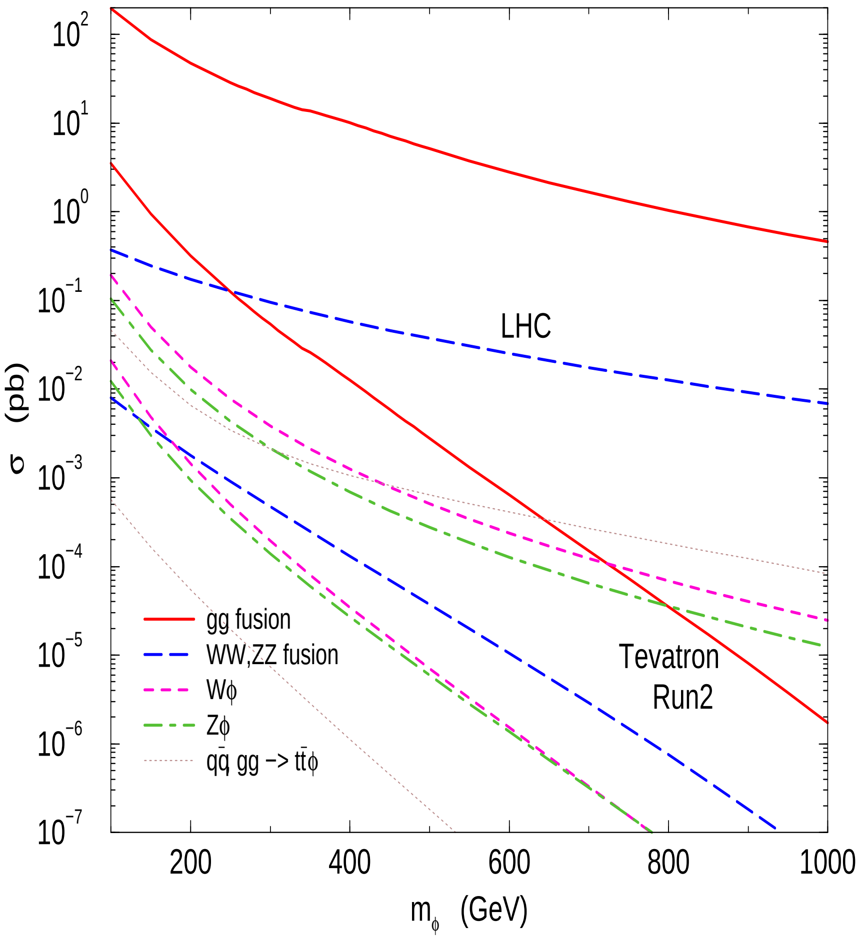
Higgs H

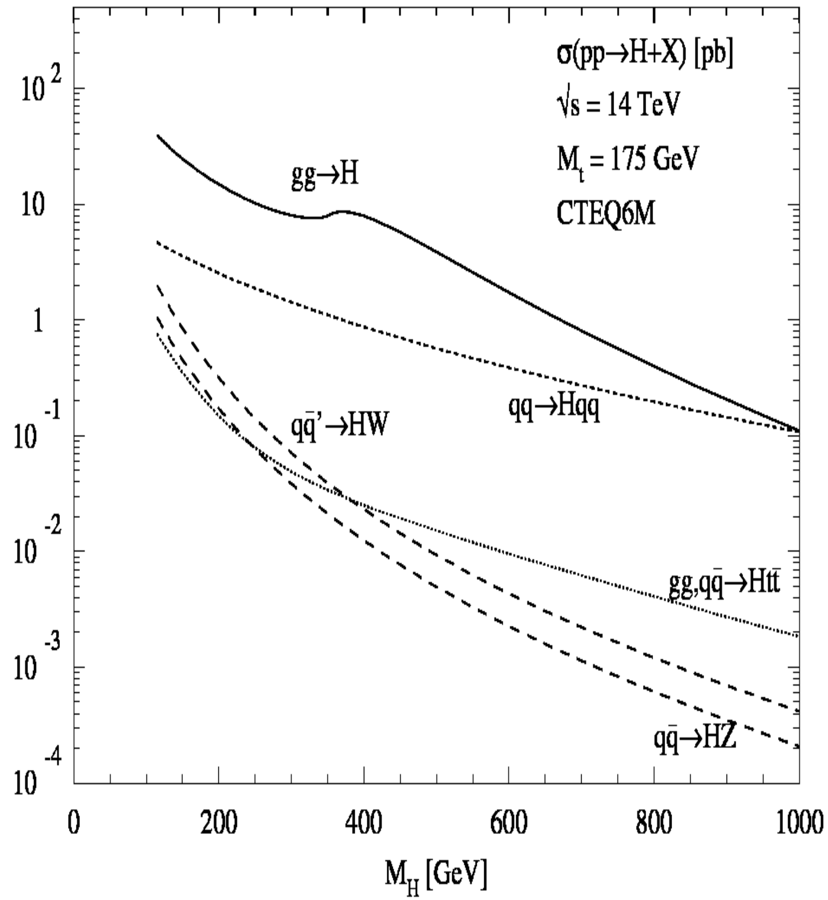
$$S_{int}(r) \;=\; \frac{1}{\Lambda_r}\int dx^4 T^{\mu}_{\mu}\,\phi_0(x)$$

Higgs-like couplings!

		Higgs
Gluon	$\frac{\alpha_s}{8\pi}\left[\sum_i F_{1/2}(\tau_i)/2 - b_3\right]\frac{\phi_0}{\Lambda_r}\,G_{\mu\nu}G^{\mu\nu}$	$\frac{\alpha_s}{8\pi}\left[\sum_i F_{1/2}(\tau_i)/2\right]\frac{H}{v}\,G_{\mu\nu}G^{\mu\nu}$
γ	$\frac{\alpha}{8\pi}\left[\sum_i e_i^2 N_c^i F_i(\tau_i) - (b_2 + b_Y)\right]\frac{\phi_0}{\Lambda_r}\,F_{\mu\nu}F^{\mu\nu}$	$\frac{\alpha}{8\pi}\left[\sum_i e_i^2 N_c^i F_i(\tau_i)\right]\frac{H}{v}\,F_{\mu\nu}F^{\mu\nu}$
W, Z	$\frac{\phi_0}{\Lambda_r}\,M_V^2 V^{\alpha}V_{\alpha}$	$\frac{H}{v}\,M_V^2 V^{\alpha}V_{\alpha}$
f	$\frac{\phi_0}{\Lambda_r}\,m_f\bar{f}f$	$\frac{H}{v}\,m_f\bar{f}f$

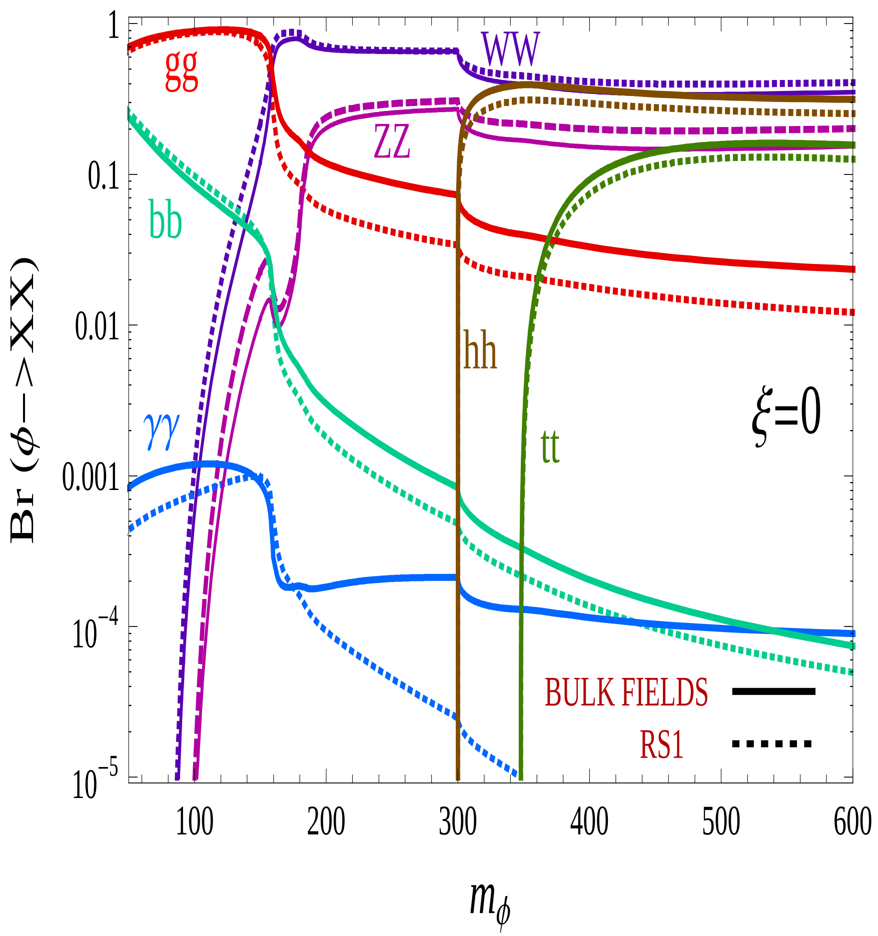
Radion Production vs. Higgs production



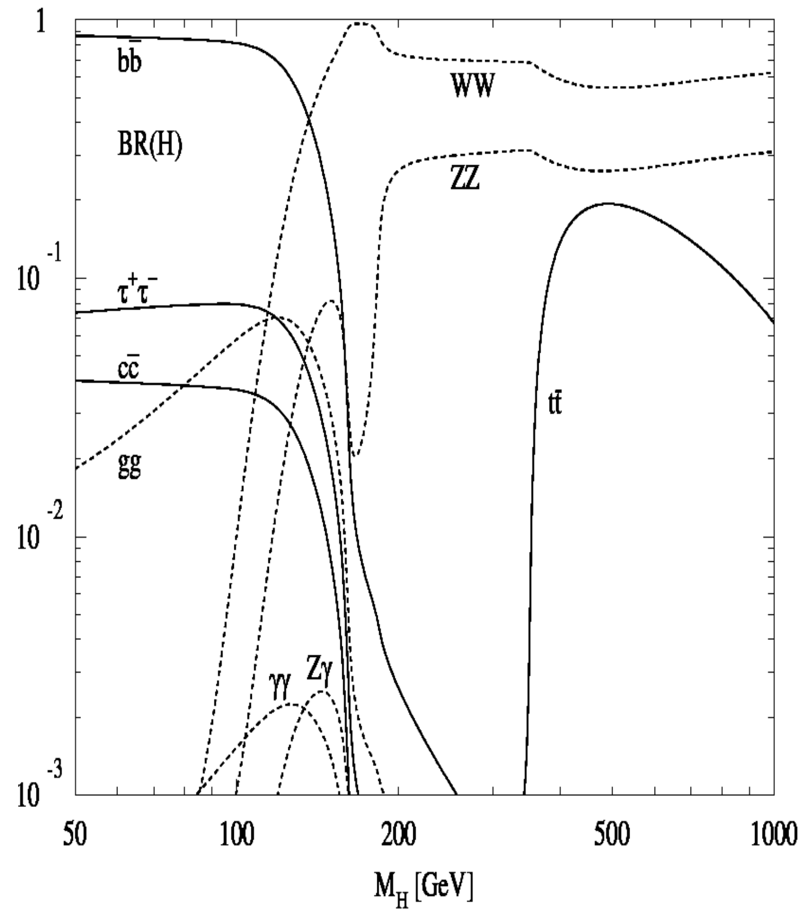


K.Cheung ('00)($\Lambda_\phi = 1$ TeV) (CMS TDR)

Radion Branchings vs. Higgs Branchings

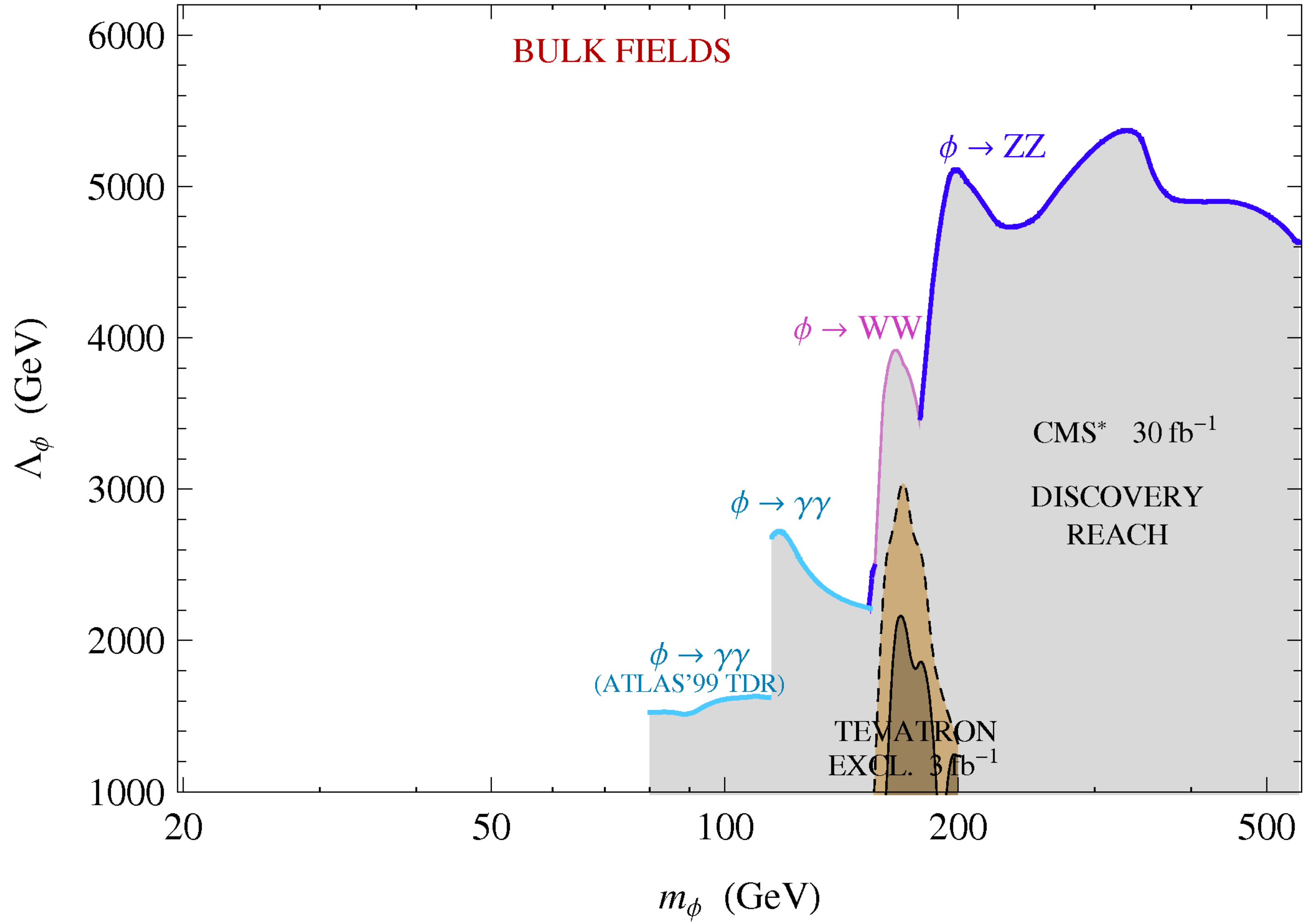


Branchings of the radion vs. its mass m_ϕ



Branchings of Higgs vs. its mass (from CMS TDR)

LHC REACH in $(m_\phi - \Lambda_\phi)$ (with Nobu Okada)



Radion couplings to 5D fermions

- 1 family of bulk fermions and a Brane Higgs: [Csaki,Hubisz,Lee(07)]

$$\frac{\phi_0}{\Lambda_r}(c_Q - c_U) m_u \bar{u} u$$

Computation slightly involved, but a way to understand it is look at R' dependance in fermion mass term:

$$m_f \sim Y v (R/R')^{c_Q - c_U - 1} \sim (1/R')^{c_Q - c_U}$$

Radion can be understood as perturbation in the interbrane distance L, or in $1/R'$ scale in the conformal frame. So we can write $\quad 1/R' \to 1/R' \ (1 + \phi/\Lambda_r)$

Then include it in mass term and expand linearly in the radion

$$(c_Q - c_U)\ \phi/\Lambda_r\ (1/R')^{c_Q - c_U} \Rightarrow (c_Q - c_U)\ \phi/\Lambda_r\ m_f$$

- We extend to 3 families and allow for bulk Higgs (localized towards IR brane) [A.Azatov, **M.T.**, L.Zhu (arXiv:0812.2489)]

$$\frac{\phi_0}{\Lambda_r}(c_Q^i - c_D^j)\ m_d^{ij}\ \bar{d}^i{}_L d_R^j + h.c$$

$$\frac{\phi_0}{\Lambda_r}\ \bar{\mathbf{d}}_{\mathbf{L}}(\mathbf{c_Q m_d} - \mathbf{m_d c_D})\mathbf{d_R}$$

where $\mathbf{m_d}$ is not in the diagonal physical basis and $\mathbf{c_{Q,D}}$ are diagonal matrices.

$c^i_{Q,D}$ are the fermion bulk parameters for UV fermions BUT

$|c^i_{Q,D}| = 1/2$ for IR fermions (and $c_Q > 0$ and $c_D < 0$).

$\Rightarrow$ **tree-level FCNC's!**

Diagonalize fermion mass matrix means here

$$\frac{\phi_0}{\Lambda_r}\ \bar{\mathbf{d}}_{\mathbf{L}}^{\mathbf{phys}}\left[(U^\dagger \mathbf{c_Q} U)\ \mathbf{m^d_{diag}} - \mathbf{m^d_{diag}}\ (W^\dagger \mathbf{c_D} W)\right]\quad \mathbf{d_R^{phys}}$$

In the physical basis we obtain the estimate:

$$\mathcal{L}_{HFV} = \frac{1}{\Lambda_r} a^d_{ij} \sqrt{m^d_i m^d_j} \;\; \phi_0 \bar{d}^i_L d^j_R \;\; + h.c.$$

$$a^d_{ij} \sim \begin{pmatrix} (c_{Q_1} - c_{D_1}) & (c_{Q_1} - c_{Q_2})\lambda\sqrt{\frac{m_s}{m_d}} & G(c_{Q_i})\lambda^3\sqrt{\frac{m_b}{m_d}} \\ (c_{D_1} - c_{D_2})\frac{1}{\lambda}\sqrt{\frac{m_d}{m_s}} & (c_{Q_2} - c_{D_2}) & (c_{Q_2} - \frac{1}{2})\lambda^2\sqrt{\frac{m_b}{m_s}} \\ F(c_{D_i})\frac{1}{\lambda^3}\sqrt{\frac{m_d}{m_b}} & (c_{D_2} - c_{D_3})\frac{1}{\lambda^2}\sqrt{\frac{m_s}{m_b}} & (\frac{1}{2} - c_{D_3}) \end{pmatrix}$$

where we have taken $c_{Q_3} = \frac{1}{2}$ (IR localized) and $\lambda \sim 0.22$.

F and G are $\mathcal{O}(.1)$ functions of the c_i's

$$\Rightarrow a_{ds} \sim a_{sd} \sim 0.06$$

Tree level RADION exchange will induce $s_L d_R s_R d_L$ with coefficient

$$C_4 = a_{ds} a_{sd} m_d m_s \frac{1}{m_\phi^2 \Lambda_r^2} \quad \Rightarrow K - \bar{K} \text{ mixing and } \epsilon_K \text{ put tight bounds}$$

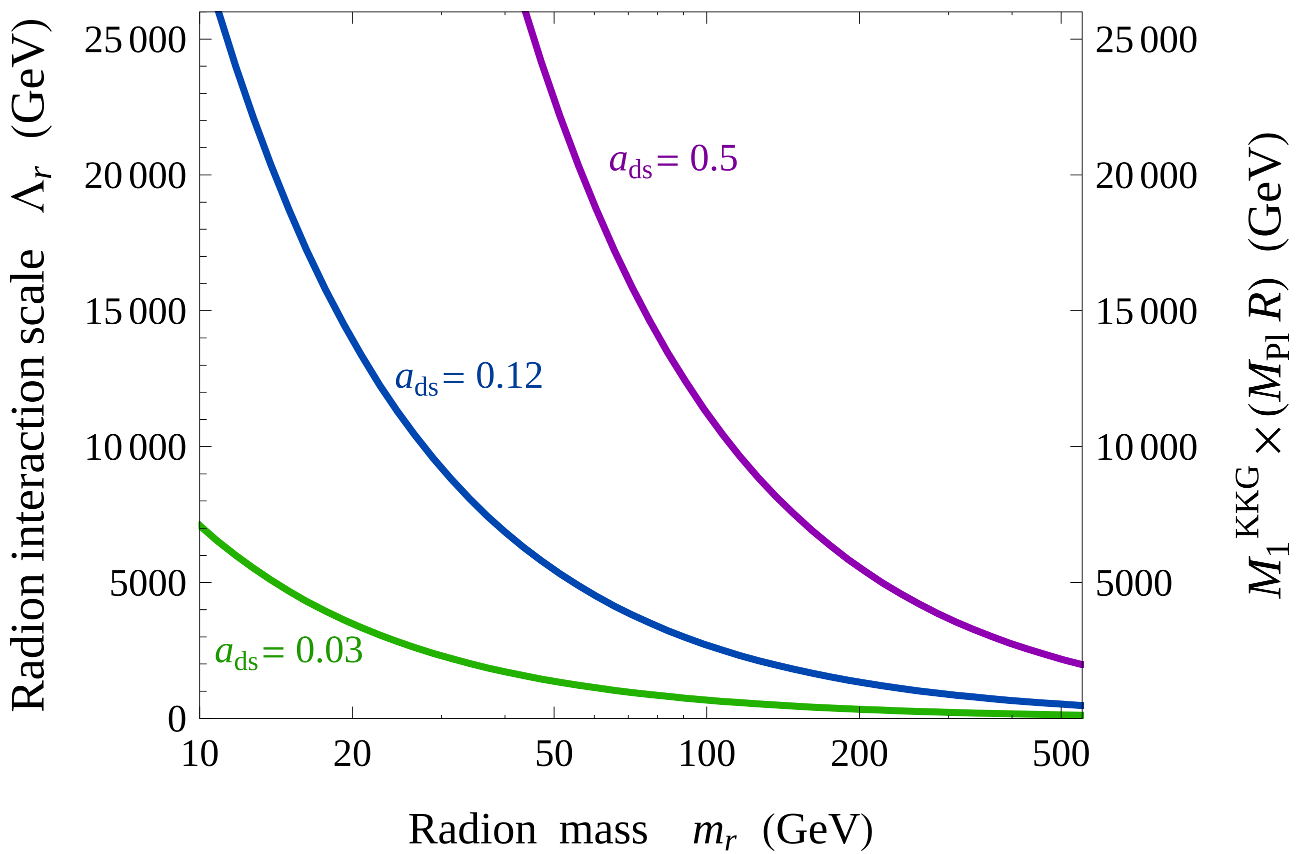


Figure 1: Bounds in $m_\phi - \Lambda_r$ plane from ϵ_K. Here we have called $a_{ds} \equiv \sqrt{|a_{ds} a_{sd}^*|}$. From [*A.Azatov*, **M.T.**, *L.Zhu* (arXiv:0812.2489)]

Outlook

Maybe LHC discovers one or two neutral scalars, and that's IT.

Is it a Higgs? (or a 2 Higgs doublet model?)
or is it an RS type scenario? (radion plus a Higgs?)

The Radion is Higgs-like but has special signatures:

- **Very narrow width**
- **Special production process**

and we have just seen that

- Probing the size of FV couplings important.
- Without flavor symmetry, $m_{radion} \gtrsim 20 - 50$ GeV
- Flavor at LHC? ($r \rightarrow$ t c ?)
- Higgs-radion mixing?