Flavor in the scalar sector of Warped Extra Dimensions [a]

by

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at

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[a]Based on **PRD80**:035016('09) *A.Azatov, M.T., L.Zhu*
PRD80:031701('09) *A.Azatov, M.T., L.Zhu*

Outline

- Introduction
- Flavor “Anarchy”
- Radion Pheno and Flavor
- Higgs FCNC’s
- Conclusions

Introduction

Warped Extra Dimension's double motivation

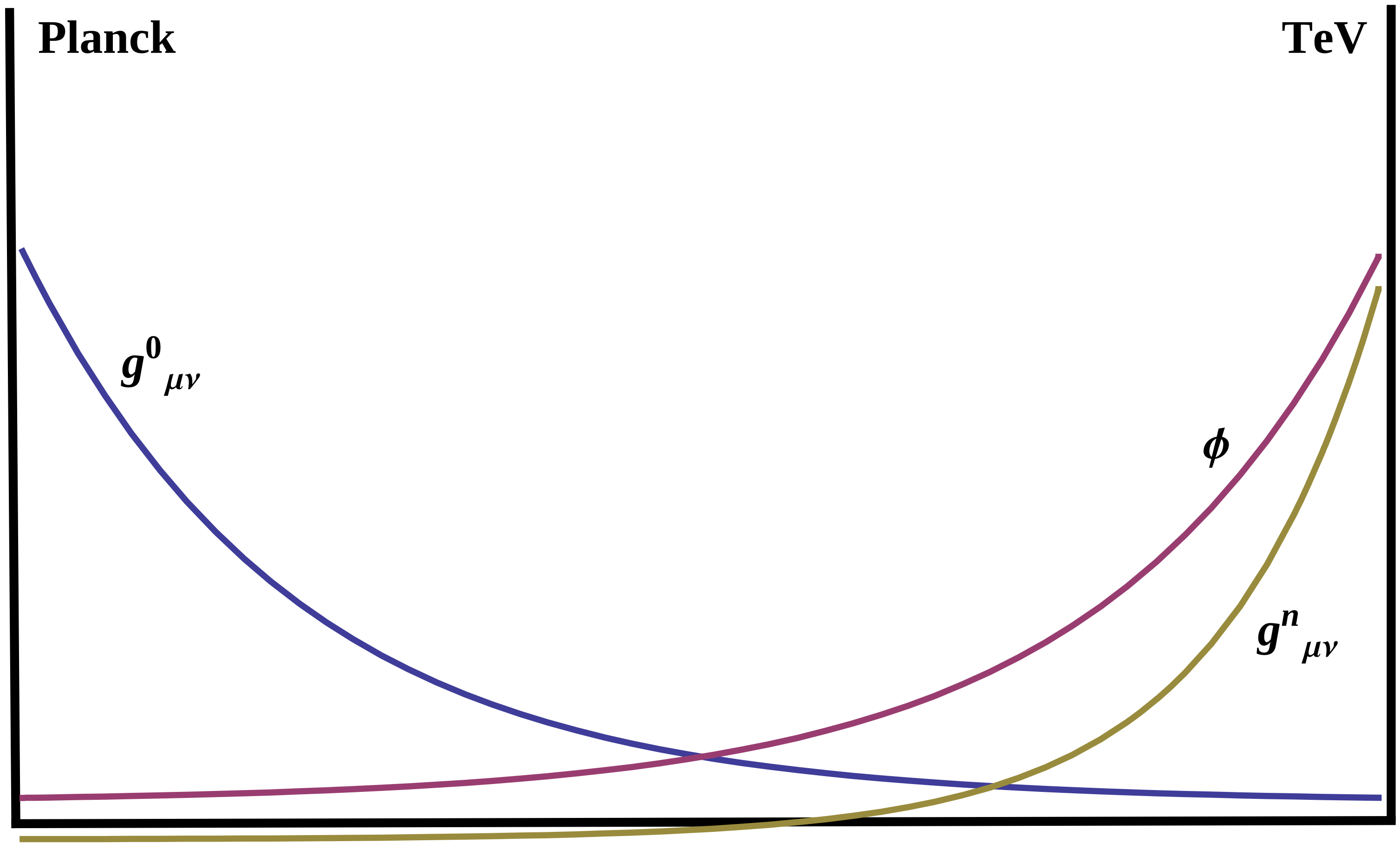
- Address Planck-TeV hierarchy [*Randall*,*Sundrum*](*RS*)
- Bulk SM with Fermion localization: Flavor hierarchies

[*Davoudiasl*,*Hewett*,*Rizzo*];[*Pomarol*,*Gherghetta*];[*Neubert*,*Grossman*];....

RS Metric Background : $ds^2 = e^{-2ky}\, \eta_{\mu\nu} dx^\mu dx^\nu - dy^2$

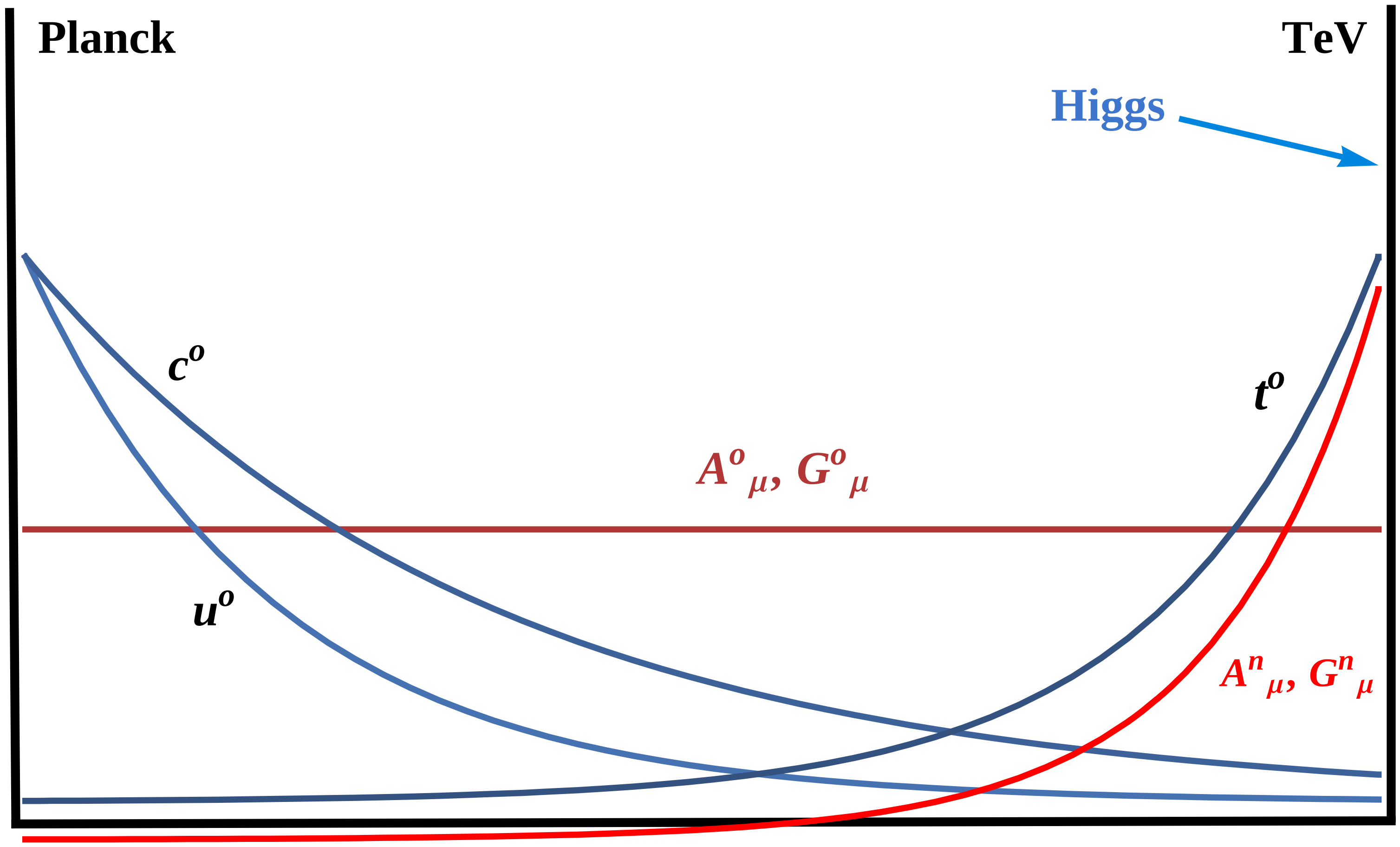
- Exponential factor "warps" down mass scales
- graviton localized near $y = 0$ Boundary (Planck or UV brane)
- Higgs localized near the other Boundary (TeV or IR brane)

Gravity Sector



RS Metric Background : $ds^2 = e^{-2ky}\,\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$

Matter in the Bulk



Precision Electroweak Constraints $M_{KK} > 3$ TeV

[Agashe,Delgado,May,Sundrum](03);[Agashe,Contino(06)]; [Carena,Ponton,Santiago,Wagner(06)(07)]

[Contino,DaRold,Pomarol(07)]..

Fermion localization: Flavor!

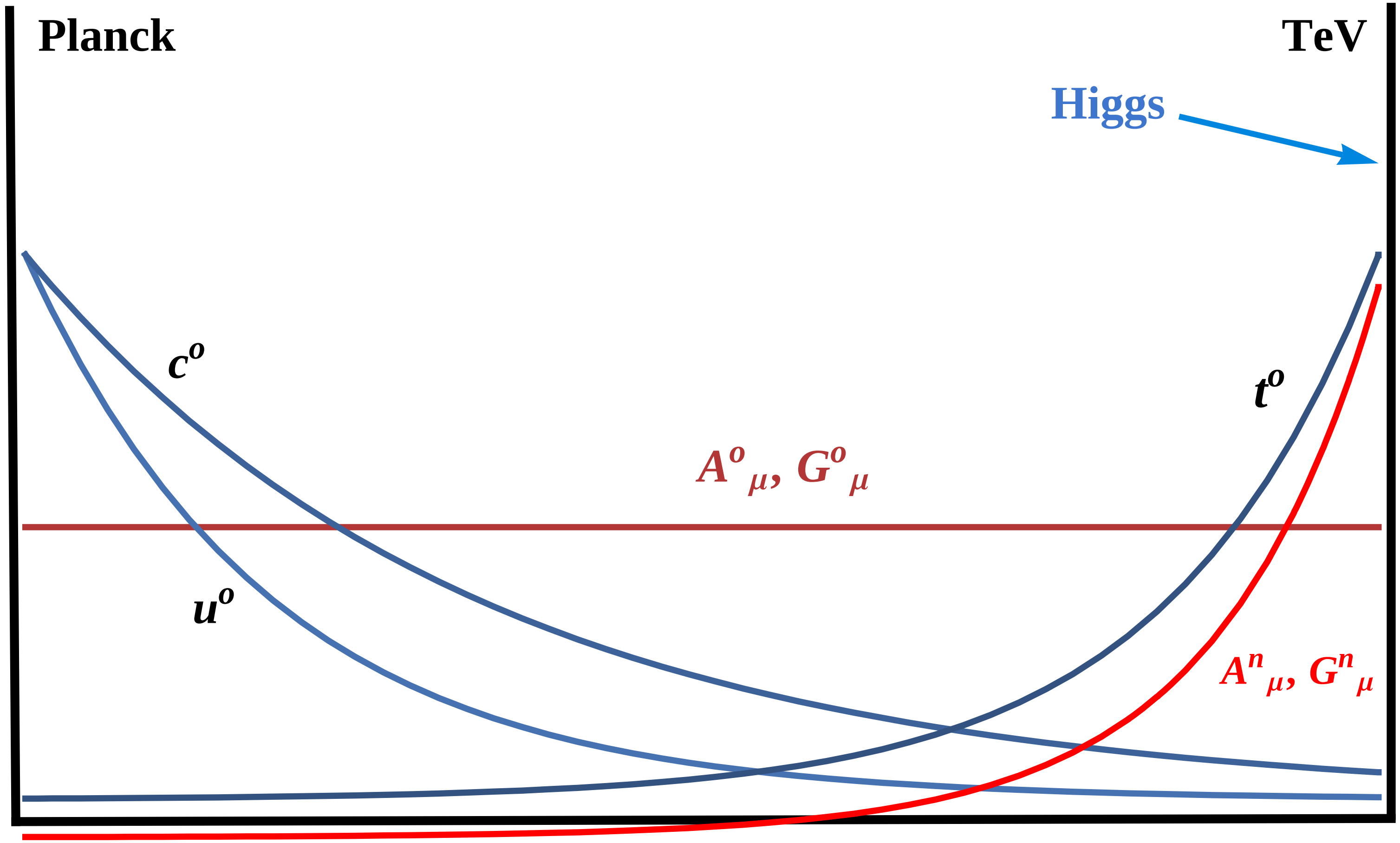
$$S = \int d^4x dy \sqrt{g} \Big[\frac{i}{2} \left(\bar{Q}\Gamma^A \mathcal{D}_A Q - D_A \bar{Q}\Gamma^A Q \right) + \frac{i}{2} \left(\bar{U}\Gamma^A \mathcal{D}_A U - \mathcal{D}_A \bar{U}\Gamma^A U \right)$$
$$+ c_Q \, k \, \bar{Q}Q - c_u \, k \, \bar{U}U \; + \; \left(Y \, \bar{Q}\mathcal{H}U + h.c. \right) \Big]$$

- Massless Fermion mode profiles

$$Q_L^0(y) \quad \propto \quad e^{(1/2 - c_Q)ky}$$
$$U_R^0(y) \quad \propto \quad e^{(1/2 - c_u)ky}$$

In flat ED, SEVERE flavor problem $M_{KK} > 100 - 5000$ TeV [*Delgado,Pomarol,Quiros*]

Much milder in Warped case $M_{KK} > 5 - 40$ TeV [Csaki,Falkowski,Weiler]; [Agashe,Azatov,Zhu]


Planck
TeV
Higgs
c^o
u^o
t^o
$A^o{}_\mu, G^o{}_\mu$
$A^n{}_\mu, G^n{}_\mu$

Flavor Anarchy

- Fermion profiles $\Psi_i(y) \propto e^{(1/2-c_i)ky}$
- Let $f_i = \Psi_i(y_{TeV})$ ($\equiv$ profile at the TeV brane)
- SMALL hierarchy in c_i's $\Rightarrow$ LARGE hierachy in f_i's
- Fermion mass matrix from $Y_{ij}\ HQ_iU_j$

$$\mathbf{m_{ij}} = \frac{v}{2}\, f_{Qi} Y_{ij} f_{uj}$$

- 5D Yukawa Y_{ij} anarchic and $\mathcal{O}(1)$

$\Rightarrow$ Mass matrices still hierachical

$$\mathbf{m_u} \sim \begin{pmatrix} f_{Q1}f_{u1} & f_{Q1}f_{u2} & f_{Q1}f_{u3} \\ f_{Q2}f_{u1} & f_{Q2}f_{u2} & f_{Q2}f_{u3} \\ f_{Q3}f_{u1} & f_{Q3}f_{u2} & f_{Q3}f_{u3} \end{pmatrix} \sim \begin{pmatrix} \epsilon^4 & \epsilon^3 & \epsilon^2 \\ \epsilon^3 & \epsilon^2 & \epsilon \\ \epsilon^2 & \epsilon & 1 \end{pmatrix}$$

- Diagonalize mass matrices:
$$U_{Q_u}\ \mathbf{m_u}\ W_u^\dagger \;=\; \mathbf{m_u^{diag}}$$
$$U_{Q_d}\ \mathbf{m_d}\ W_d^\dagger \;=\; \mathbf{m_d^{diag}}$$

- SM Fermion physical masses hierarchical $m_{u_i} \sim v\ f_{Q_i} f_{u_i}$

$$U_{Q_d}, U_{Q_u} \;\sim\; \begin{pmatrix} 1 & \frac{f_{Q1}}{f_{Q2}} & \frac{f_{Q1}}{f_{Q3}} \\ \frac{f_{Q1}}{f_{Q2}} & 1 & \frac{f_{Q2}}{f_{Q3}} \\ \frac{f_{Q1}}{f_{Q3}} & \frac{f_{Q2}}{f_{Q3}} & 1 \end{pmatrix}$$

$$W_u \sim \begin{pmatrix} 1 & \frac{f_{u1}}{f_{u2}} & \frac{f_{u1}}{f_{u3}} \\ \frac{f_{u1}}{f_{u2}} & 1 & \frac{f_{u2}}{f_{u3}} \\ \frac{f_{u1}}{f_{u3}} & \frac{f_{u2}}{f_{u3}} & 1 \end{pmatrix} \qquad W_d \sim \begin{pmatrix} 1 & \frac{f_{d1}}{f_{d2}} & \frac{f_{d1}}{f_{d3}} \\ \frac{f_{d1}}{f_{d2}} & 1 & \frac{f_{d2}}{f_{d3}} \\ \frac{f_{d1}}{f_{d3}} & \frac{f_{d2}}{f_{d3}} & 1 \end{pmatrix}$$

- SM CKM matrix

$$V_{CKM} = U^\dagger_{Q_u} U_{Q_d} = \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix} \Rightarrow \; U_{Q_u} \sim U_{Q_d} \sim \begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

$$W_u \sim \begin{pmatrix} 1 & \frac{m_u}{m_c}\frac{1}{\lambda} & \frac{m_u}{m_t}\frac{1}{\lambda^3} \\ \frac{m_u}{m_c}\frac{1}{\lambda} & 1 & \frac{m_c}{m_t}\frac{1}{\lambda^2} \\ \frac{m_u}{m_t}\frac{1}{\lambda^3} & \frac{m_c}{m_t}\frac{1}{\lambda^2} & 1 \end{pmatrix} \qquad W_d \sim \begin{pmatrix} 1 & \frac{m_d}{m_s}\frac{1}{\lambda} & \frac{m_d}{m_b}\frac{1}{\lambda^3} \\ \frac{m_d}{m_s}\frac{1}{\lambda} & 1 & \frac{m_s}{m_b}\frac{1}{\lambda^2} \\ \frac{m_d}{m_b}\frac{1}{\lambda^3} & \frac{m_s}{m_b}\frac{1}{\lambda^2} & 1 \end{pmatrix}$$

with $\lambda \sim .22$ cabibbo angle

The Radion and its interactions

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

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

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

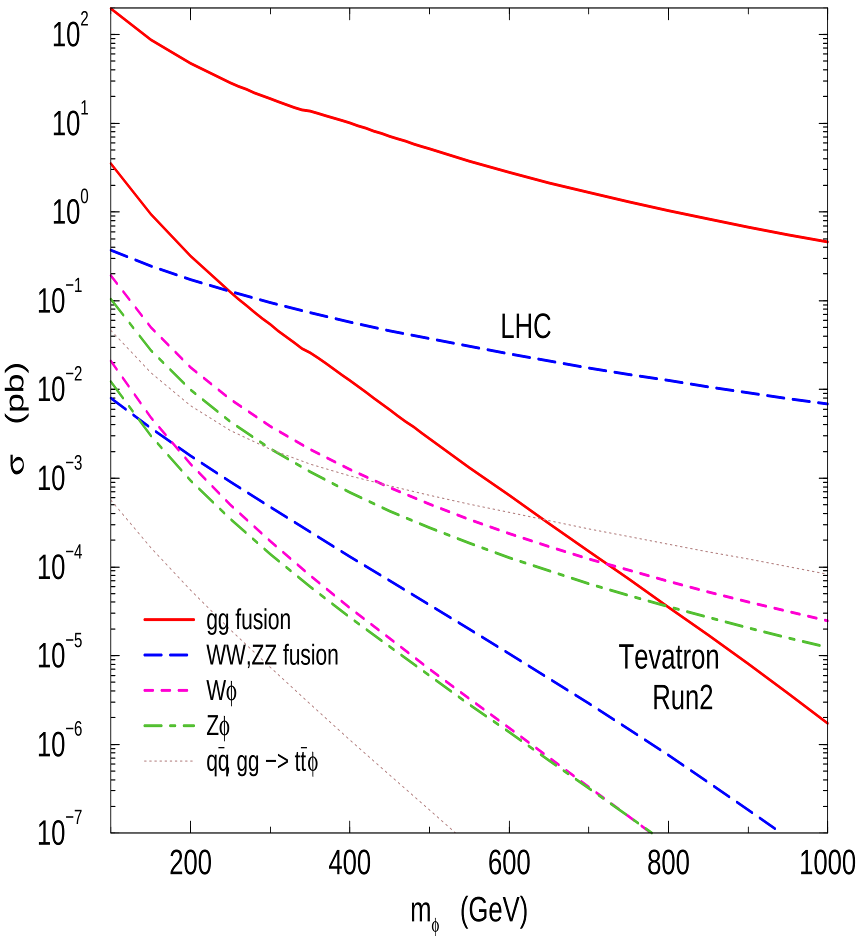
Higgs H

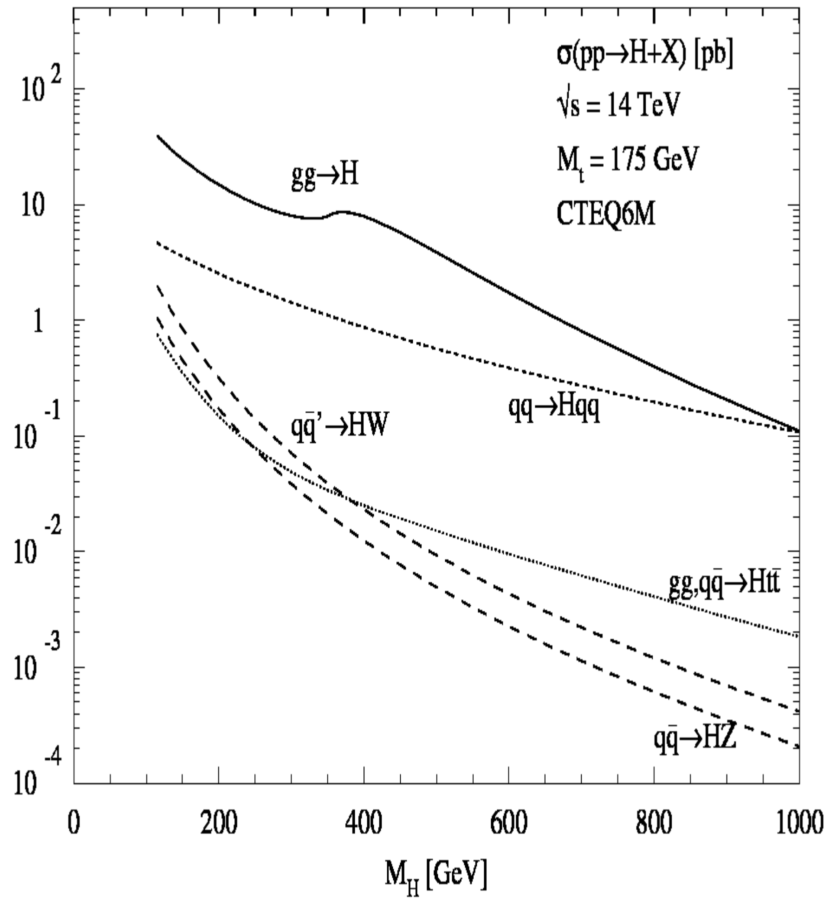
$$S_{int}(r) = \frac{1}{\Lambda_r}\int dx^4 T^{\mu}_{\mu}\, \phi_0(x)$$

Higgs-like couplings!

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	$\frac{\phi_0}{\Lambda_r} m_f \bar{f} f$	$\frac{H}{v} m_f \bar{f} f$

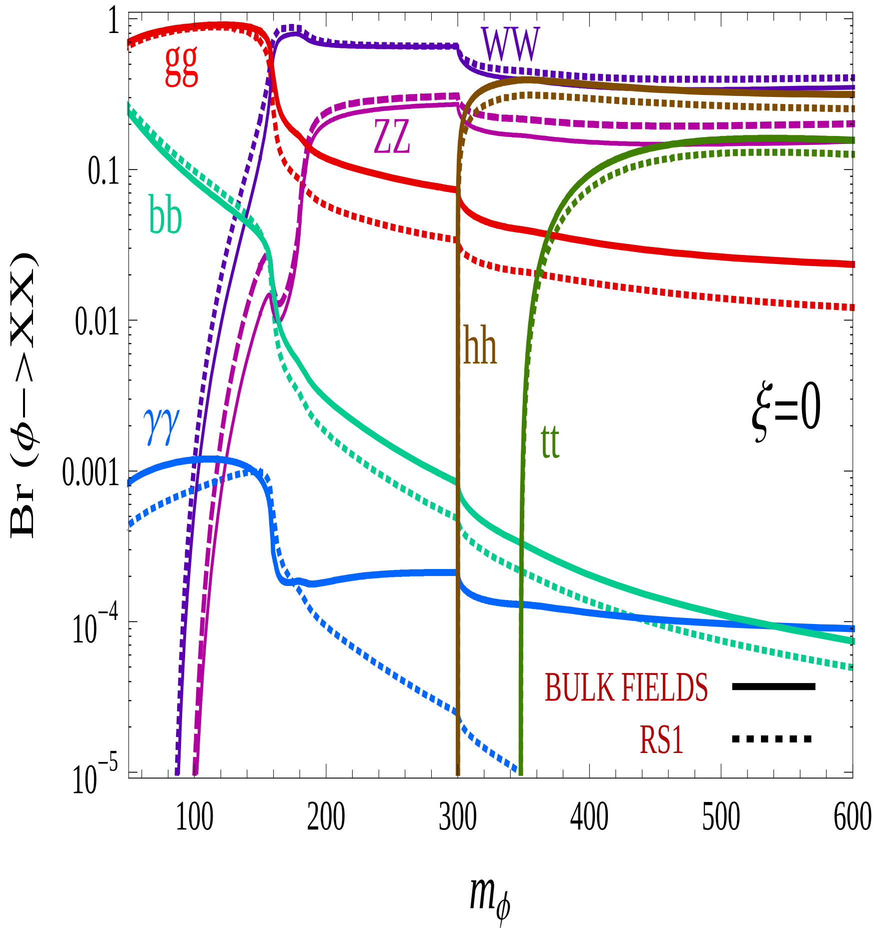
Radion Production vs. Higgs production

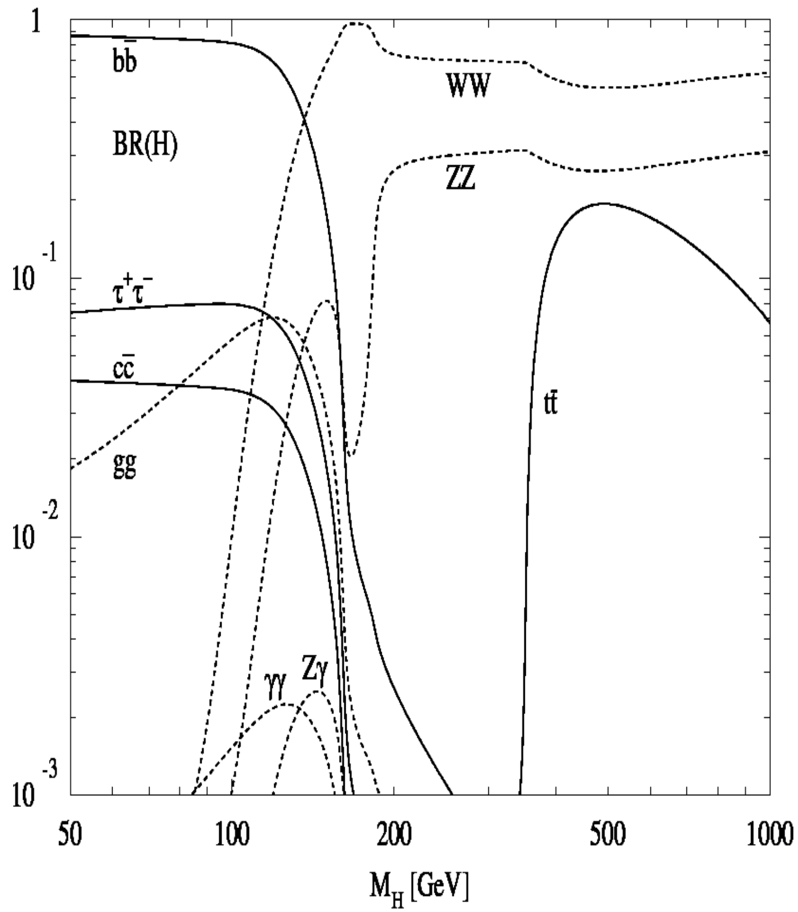




K.Cheung ('00)($\Lambda_\phi = 1$ TeV) (CMS TDR)

Radion Branchings vs. Higgs Branchings

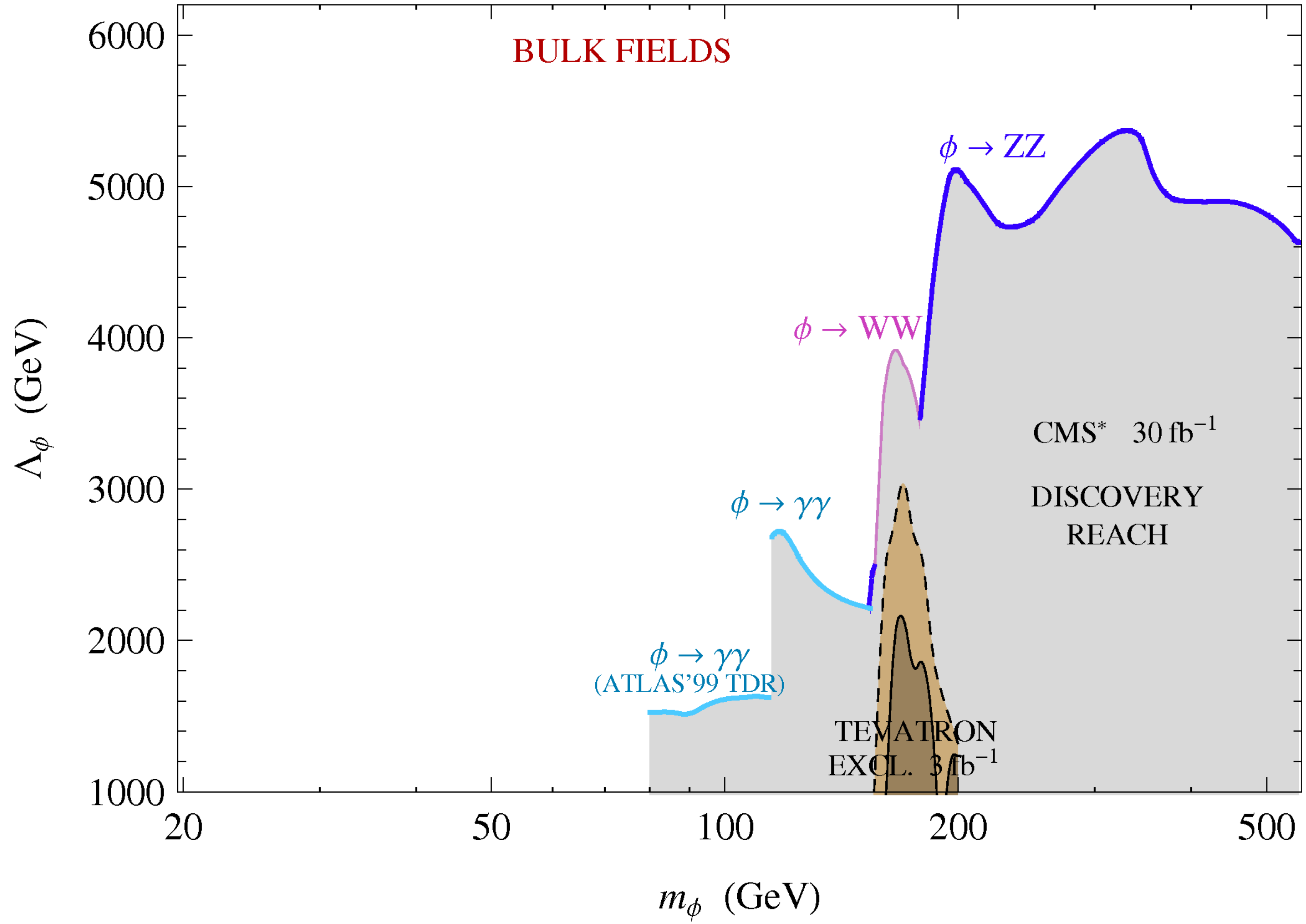




Branchings of the radion vs. its mass m_ϕ

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

LHC REACH in $(m_\phi - \Lambda_\phi)$



Radion couplings to 5D fermions

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

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

- 5D Computation involved. Simple exlanation, L dependence

$$m_u(L) \sim Yv(L)f_Q(L)f_u(L) \sim Yv(L)e^{(1-c_Q-c_U)kL} \sim m_o e^{-(c_U+c_Q)k}$$

- Radion can be understood as a fluctuation of the "radius" L.

$$k(L+\delta L) \to kL + \frac{\phi}{\Lambda_r}$$

The linear radion fluctuation in the mass term is

$$\begin{aligned} m_u(L+\delta L) &= m_u(kL) - \frac{\phi}{\Lambda_r}(c_U + c_Q)\ \ m_o e^{-(c_U+c_Q)kL} \\ &= m_u(kL) - \frac{\phi}{\Lambda_r}(c_U + c_Q)\ \ m_u \end{aligned}$$

- We extend to 3 families and allow for bulk Higgs (localized towards IR brane) *A.Azatov*,**M.T.**,*L.Zhu* PRD80;031701('09)

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

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

- $\mathbf{m_d}$ not in the diagonal physical basis;
- $\mathbf{c_{Q,D}}$ are NON-DEGENERATE diagonal matrices.

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

Diagonalize fermion mass matrix means here

$$-\frac{\phi_0}{\Lambda_r}\ \mathbf{\bar{d}_L^{phys}}\left[(U_{Q_d}^\dagger \mathbf{c_Q} U_{Q_d})\ \mathbf{m_{diag}^d} + \mathbf{m_{diag}^d}\ (W_d^\dagger \mathbf{c_D} W_d)\right]\quad \mathbf{d_R^{phys}}$$

In the physical basis we obtain the estimate:

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

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

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

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

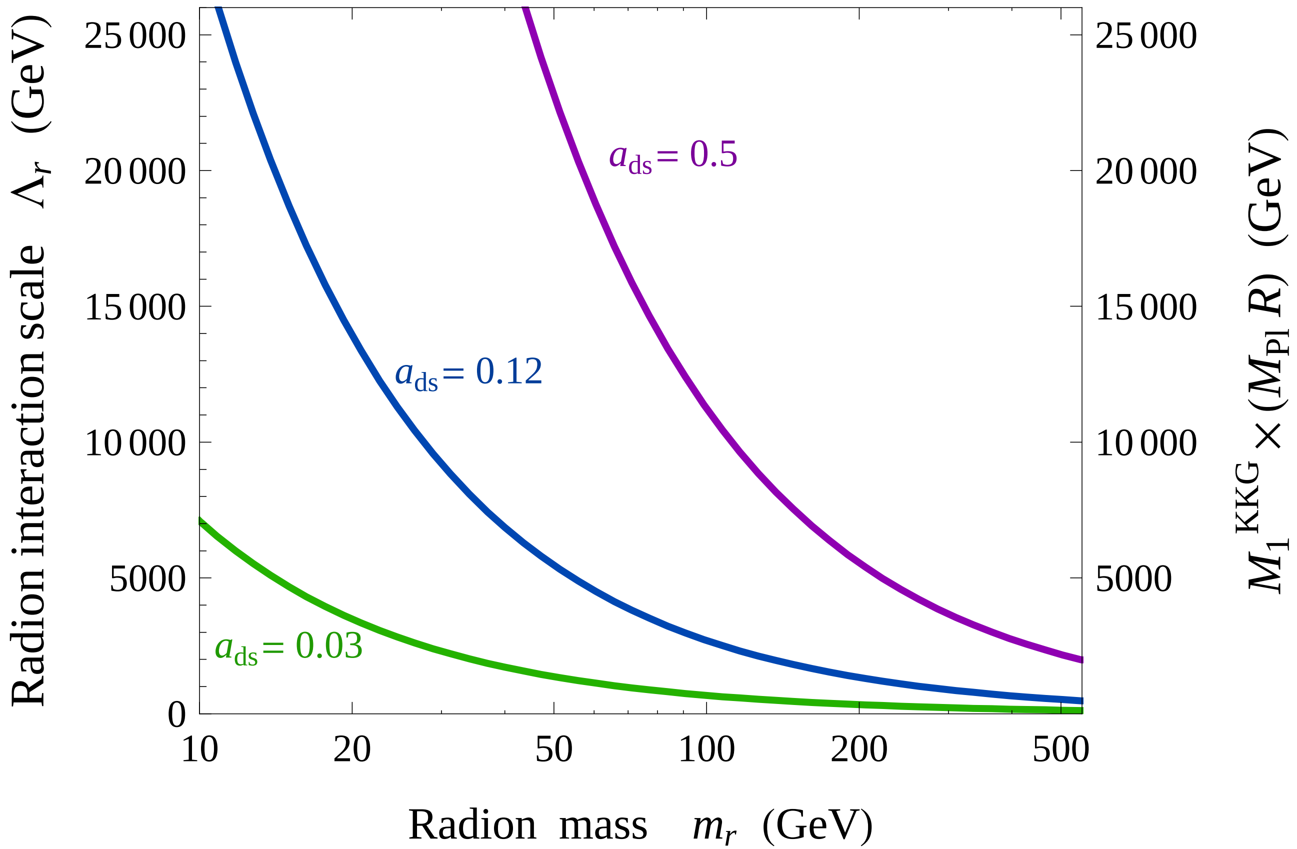


Figure 1: Bounds in $m_\phi - \Lambda_r$ plane from ϵ_K. [A. Azatov, **M. T.**, L. Zhu]

Bounds on lighter radion even stronger [Ponton, Davoudiasl]

Tree level Higgs FCNC's

Effective Theory Approach [Buchmuller,Wyler(86)], [delAguila,Perez-Victoria,Santiago(00)] [Agashe,Contino(09)]

Consider in 4D effective action, Dim 6 operators (down sector):

$$\lambda_{ij}\frac{H^2}{\Lambda^2}\ H\overline{Q}_{L_i}D_{R_j}$$

$\Rightarrow$ Corrections to mass matrix

$$v_4\left(y_{ij}+\lambda_{ij}\frac{v_4^2}{\Lambda^2}\right)$$

$\Rightarrow$ Correction to Higgs Yukawa couplings

$$\left(y_{ij}+3\lambda_{ij}\frac{v_4^2}{\Lambda^2}\right)\frac{h}{\sqrt{2}}\overline{Q}_{L_i}D_{R_j}$$

Tree level Higgs FCNC's

Effective Theory Approach [Buchmuller,Wyler(86)], [delAguila,Perez-Victoria,Santiago(00)] [Agashe,Contino(09)]

Consider in 4D effective action, Dim 6 operators (down sector):

$$\lambda_{ij}\frac{H^2}{\Lambda^2}\ H\overline{Q}_{L_i}D_{R_j} \qquad k^D_{ij}\frac{H^2}{\Lambda^2}\ \overline{D}_{R_i}\partial\!\!\!/ D_{R_j} \qquad k^Q_{ij}\frac{H^2}{\Lambda^2}\ \overline{Q}_{L_i}\partial\!\!\!/ Q_{L_j}$$

$\Rightarrow$ Corrections to mass matrix (also from canonical normalization)

$$v_4\left(y_{ij}+\lambda_{ij}\frac{v_4^2}{\Lambda^2}\right)\overline{Q}_{L_i}D_{R_j} \quad \left(\delta_{ij}/2+k^D_{ij}\frac{v_4^2}{\Lambda^2}\right)\overline{D}_{R_i}\partial\!\!\!/ D_{R_j} \quad \left(\delta_{ij}/2+k^Q_{ij}\frac{v_4^2}{\Lambda^2}\right)\overline{Q}_{L_i}\partial\!\!\!/ Q_{L_j}$$

$\Rightarrow$ Correction to Higgs Yukawa couplings

$$\left(y_{ij}+3\lambda_{ij}\frac{v_4^2}{\Lambda^2}\right)\frac{h}{\sqrt{2}}\overline{Q}_{L_i}D_{R_j} \quad \left(2k^D_{ij}\frac{v}{\Lambda^2}\right)\frac{h}{\sqrt{2}}\overline{D}_{R_i}\partial\!\!\!/ D_{R_j} \quad \left(2k^Q_{ij}\frac{v_4}{\Lambda^2}\right)\frac{h}{\sqrt{2}}\overline{Q}_{L_i}\partial\!\!\!/ Q_{L_j}$$

Higgs Couplings

Q and U 5d fermions $\longrightarrow$ $Q = Q_L + Q_R$ and $U = U_L + U_R$

- Bulk Higgs

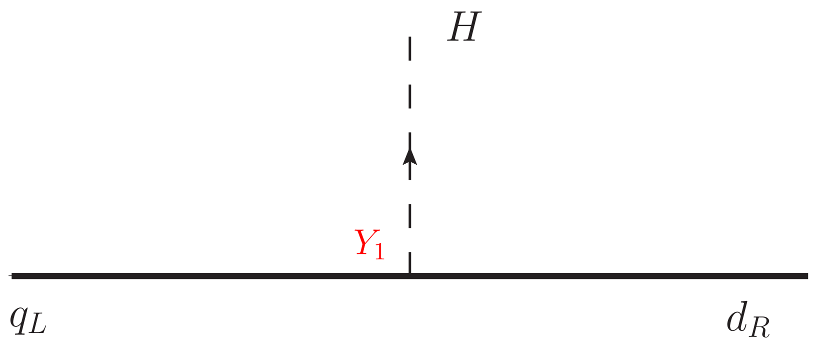
$$\int d^5x \ \mathbf{Y} \ H\bar{Q}U \quad \Rightarrow \ Y_1 \ HQ_LU_R + Y_2 \ HQ_RU_L \qquad \textit{with} \qquad Y_1 = Y_2$$

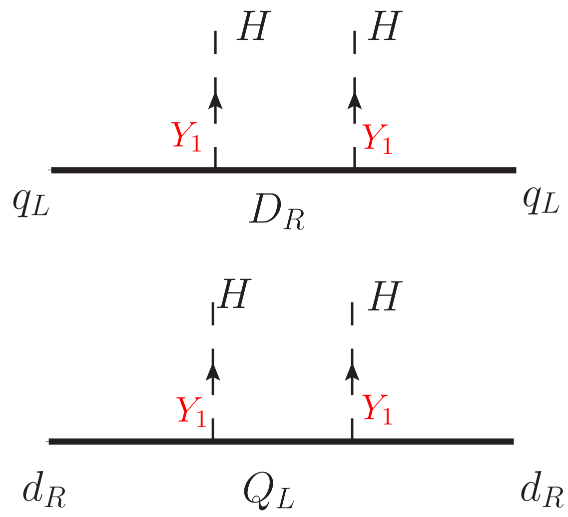
- Brane Higgs

$$\int dx^4 \ Y_1 \ HQ_LU_R + Y_2 \ HQ_RU_L \qquad \textit{with} \qquad Y_1 \neq Y_2$$

Higgs FCNC's in RS

[Neubert et.al.(08); Buras et.al.(09)]





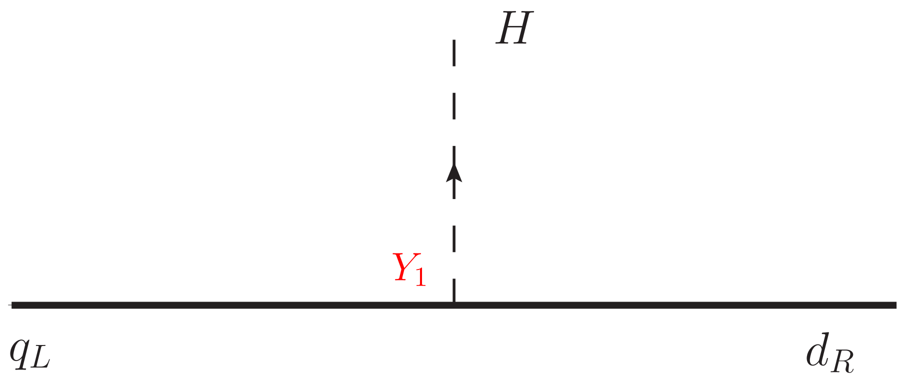
$$m^d_{SM} \approx v\, f_Q Y_1 f_d \left(1 - f_Q^2 \frac{Y_1^2 v^2}{M_{KK}^2} - f_d^2 \frac{Y_1^2 v^2}{M_{KK}^2}\right)$$

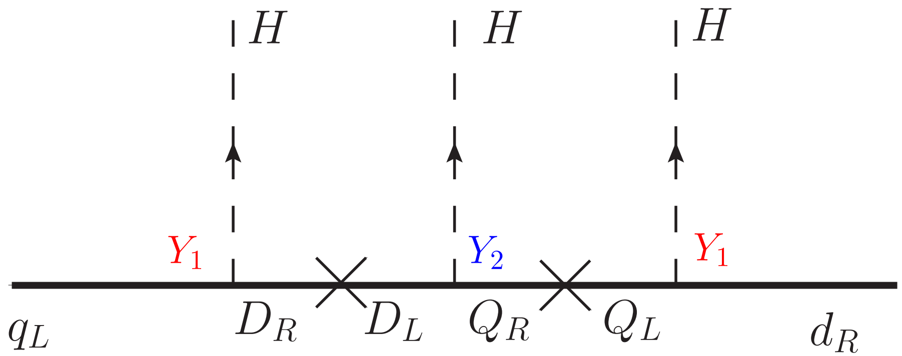
$$Y^d_{SM} \approx f_Q Y_1 f_d \left(1 - 2 f_Q^2 \frac{Y_1^2 v^2}{M_{KK}^2} - 2 f_d^2 \frac{Y_1^2 v^2}{M_{KK}^2}\right)$$

$$m^d_{SM} - Y^d_{SM} v \approx m^d_{SM} \frac{Y_1^2 v^2}{M_{KK}^2} \left(f_Q^2 + f_d^2\right)$$

Higgs FCNC's in RS

[Agashe, Contino(09); Azatov,M.T.,Zhu(09)]



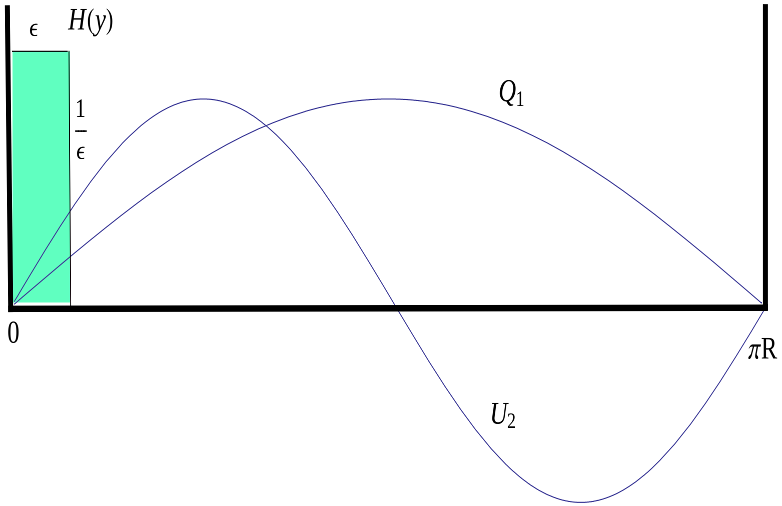


$$m^d_{SM} \approx v \; f_Q Y_1 f_d \left(1 - \frac{Y_1 Y_2 v^2}{M^2_{KK}}\right)$$

$$Y^d_{SM} \approx f_Q Y_1 f_d \left(1 - 3\,\frac{Y_1 Y_2 v^2}{M^2_{KK}}\right)$$

$$m^d_{SM} - Y^d_{SM} v \approx m^d_{SM}\; 2\frac{Y_1 Y_2 v^2}{M^2_{KK}}$$

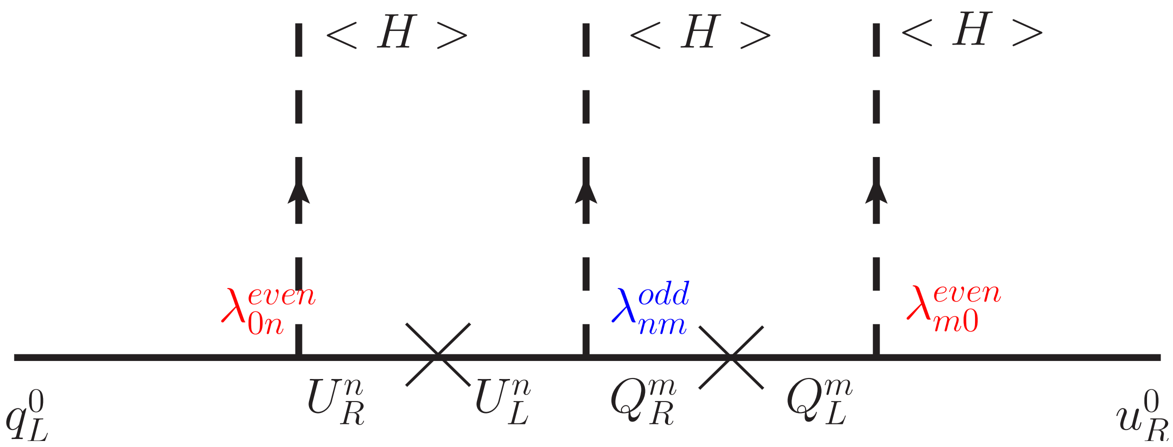
ODD-ODD-Higgs Couplings: Y_2



$$Q_R^n(y) \sim \sin\left(\frac{n}{R}\,y\right) \sim \sin\left(M_n y\right) \sim M_n y \quad for \quad M_n < 1/\epsilon$$

$$U_L^m(y) \sim \sin\left(\frac{m}{R}\,y\right) \sim \sin\left(M_m y\right) \sim M_m y \quad for \quad M_m < 1/\epsilon$$

$$\lambda_{mn}^{odd} = Y_2 \int_0^{\pi R} H(y) Q_R^n(y) U_L^m(y) \sim Y_2\, M_n M_m \frac{1}{\epsilon} \int_0^{\epsilon} y^2 \sim Y_2\, M_n M_m \frac{\epsilon^2}{3}$$



$$\lambda^{even}_{0n} \sim Y_1$$

$$\lambda^{odd}_{mn} \sim Y_2 \; M_n M_m \frac{\epsilon^2}{3}$$

$$\text{SINGLE Contribution} \sim v^3 \, \lambda^{even}_{0n} \lambda^{odd}_{nm} \lambda^{even}_{m0} \, \frac{1}{M_n M_m} \sim \epsilon^2 \;\; \rightarrow \mathbf{0} \quad _{for\ (\epsilon \rightarrow 0)}$$

$$\text{TOTAL Contribution} \sim v^3 \sum_{n,m}^{R/\epsilon} \lambda^{even}_{0n} \lambda^{odd}_{nm} \lambda^{even}_{m0} \, \frac{1}{M_n M_m}$$

$$\sim v^3 \, {Y_1}^2 Y_2 \, \frac{\epsilon^2}{3} \sum_{n,m}^{R/\epsilon} 1$$

$$\sim v^3 \, {Y_1}^2 Y_2 \, R^2 \quad \rightarrow \textbf{CONSTANT} \quad _{for\ (\epsilon \rightarrow 0)}$$

Tree-level Higgs FCNC's!

Define : $$\mathcal{L}_{HFV} = a^d_{ij}\sqrt{\frac{m^d_i m^d_j}{v_4^2}}\, H \bar{d}^i_L d^j_R \ + h.c.$$

Solve perturbatively in $(Y\ v_4/M_{KK})$:

$$a^d_{ij} \sim \delta_{ij} - \bar{Y}^2 \frac{v_4^2}{M_{KK}^2} \begin{pmatrix} 1 & \lambda\sqrt{\frac{m_s}{m_d}} & \lambda^3\sqrt{\frac{m_b}{m_d}} \\ \frac{1}{\lambda}\sqrt{\frac{m_d}{m_s}} & 1 & \lambda^2\sqrt{\frac{m_b}{m_s}} \\ \frac{1}{\lambda^3}\sqrt{\frac{m_d}{m_b}} & \frac{1}{\lambda^2}\sqrt{\frac{m_s}{m_b}} & 1 \end{pmatrix}$$

$$a^u_{ij} \sim \delta_{ij} - \bar{Y}^2 \frac{v_4^2}{M_{KK}^2} \begin{pmatrix} 1 & \lambda\sqrt{\frac{m_c}{m_u}} & \lambda^3\sqrt{\frac{m_t}{m_u}} \\ \frac{1}{\lambda}\sqrt{\frac{m_u}{m_c}} & 1 & \lambda^2\sqrt{\frac{m_t}{m_c}} \\ \frac{1}{\lambda^3}\sqrt{\frac{m_u}{m_t}} & \frac{1}{\lambda^2}\sqrt{\frac{m_c}{m_t}} & 1 \end{pmatrix}$$

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

$$C_4 = a_{ds} a_{sd} m_d m_s \frac{1}{m_h^2 v_4^2} \quad \Rightarrow K - \bar{K} \text{ mixing and } \epsilon_K \text{ put tight bounds}$$

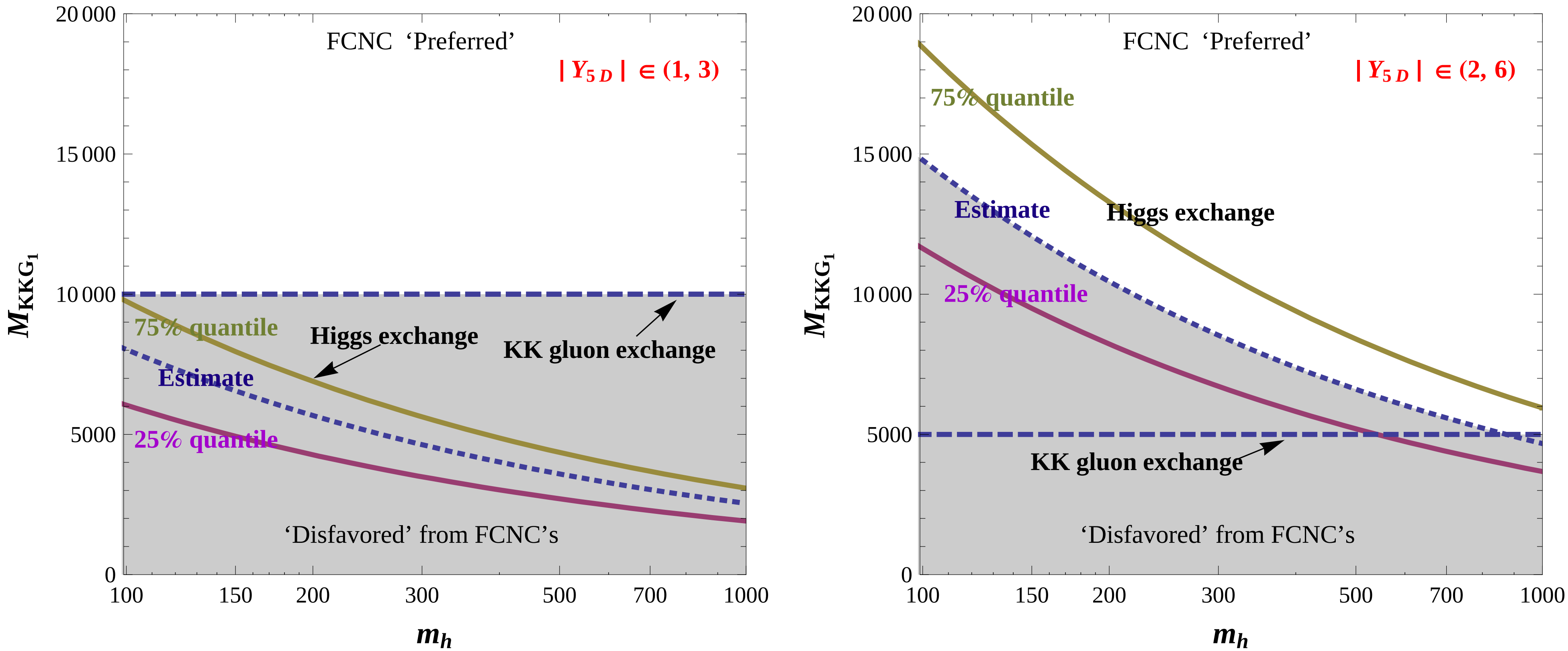


Figure 2: "Bounds" from ϵ_K in(m_h-M_{KK})plane from Higgs exchange

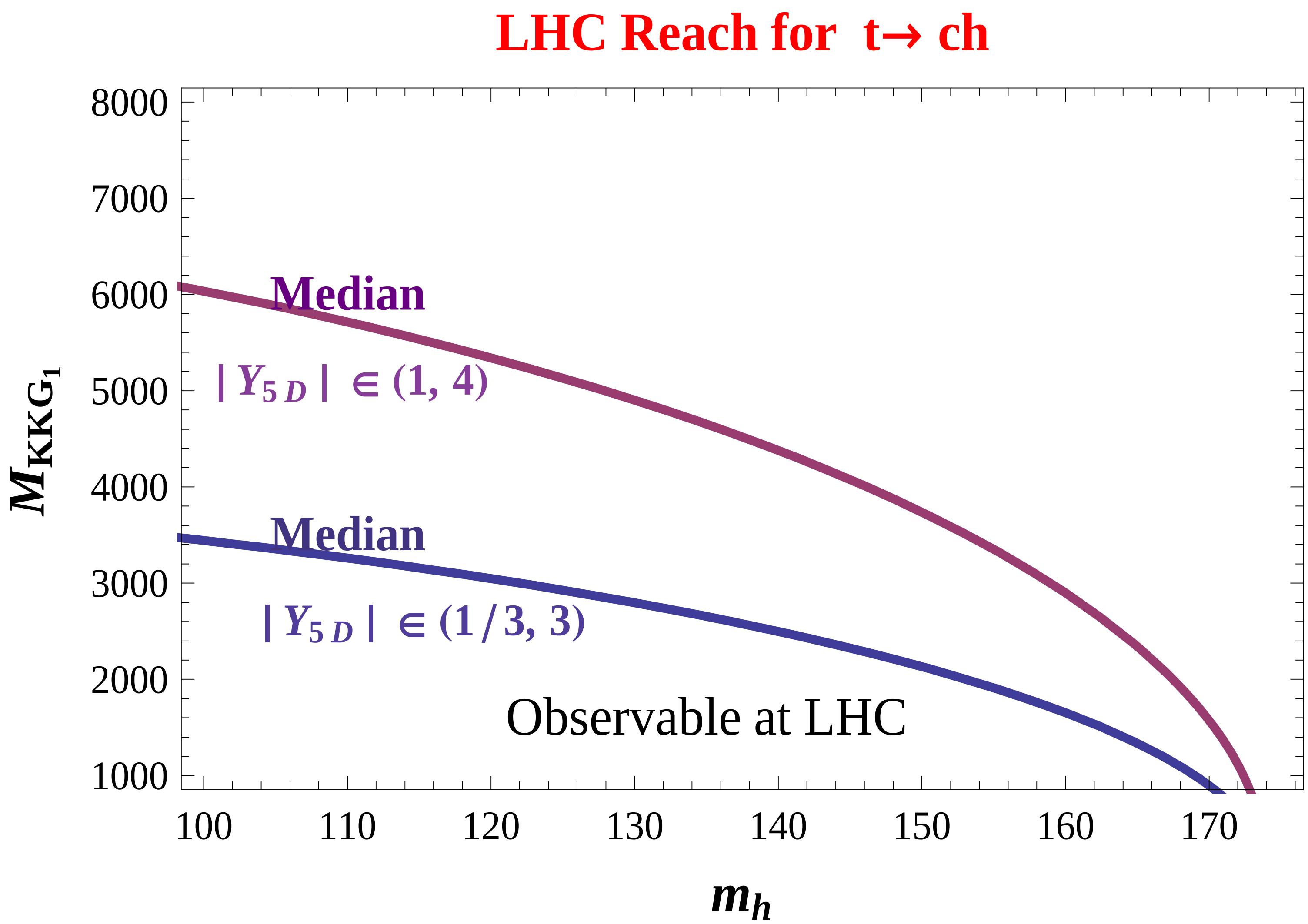


Figure 3: LHC observability $t \to ch$ in the plane (m_h, M_{KKG_1}). (using [Aguilar−Saavedra,Branco(00)] study)

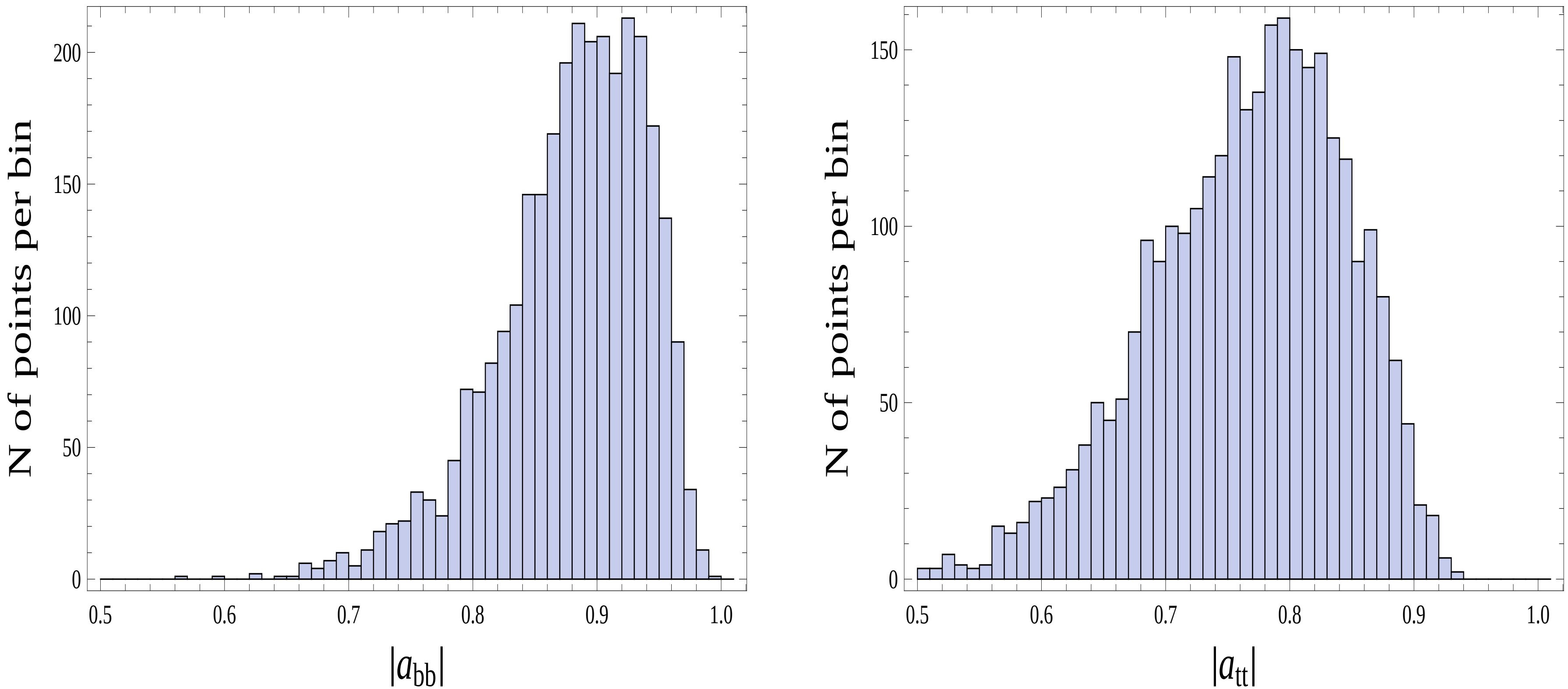


Figure 4: Distribution of a_{tt} and a_{bb}, in our numerical scan, with a fixed KK scale of $R'^{-1} = 1500$ GeV (KK gluon mass $M_{KKG} = 2.45R'^{-1}$) and for 5D Yukawas $|Y_{5D}^{ij}| \in [0.3, 3]$.

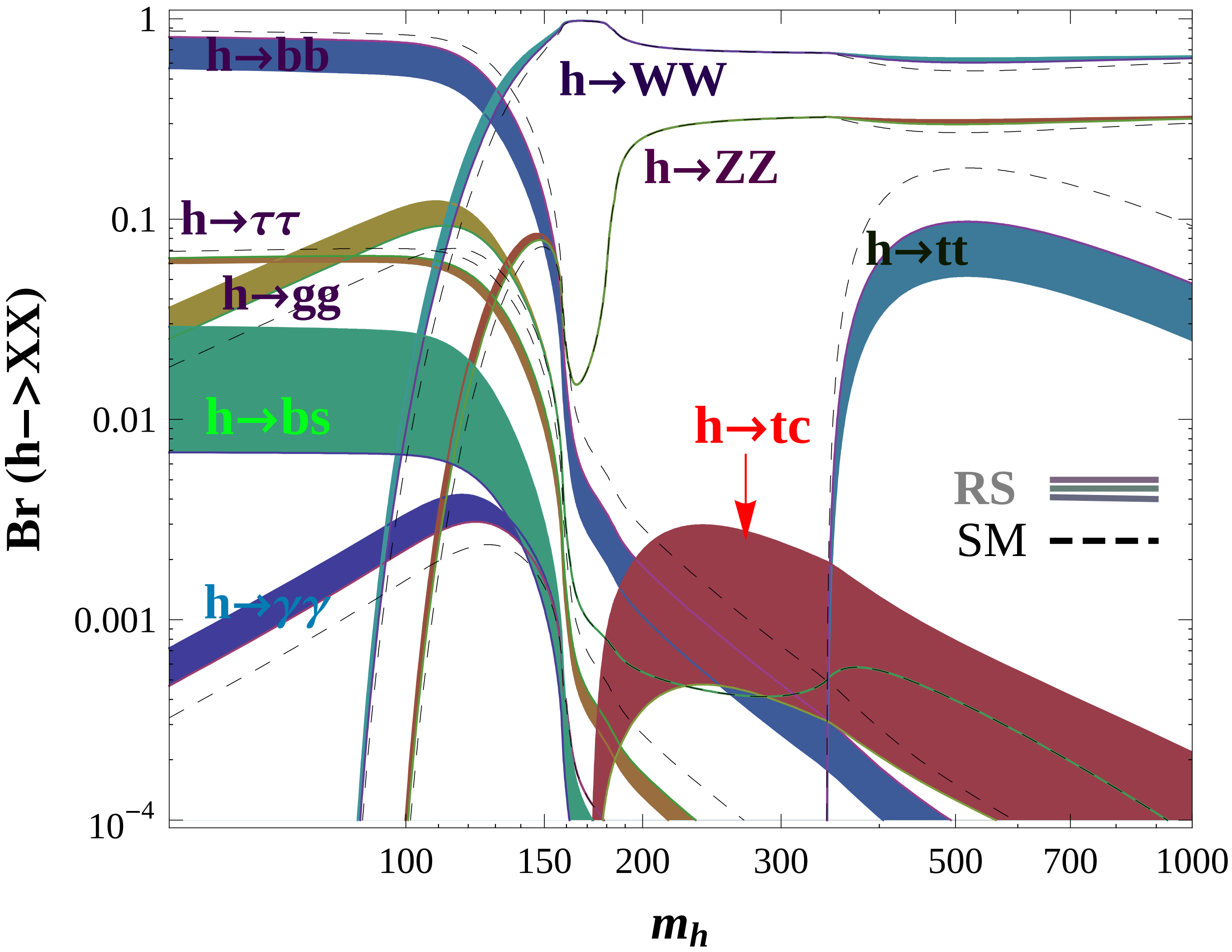


Figure 5: Higgs Branchings, for $\bar{Y} \sim 3$ and $1/R' = 1500$ GeV. ($KKG_1 \sim 3.5\text{TeV}$)

Higgs Production - work in progress

Consider a truncated quark KK-tower. 4D effective yukawa couplings:

$$y_{SM}\ q_L^0 u_R^0 H + y_{Qu}\ Q_L^1 u_R^0 H + y_{qU}\ q_L^0 U_R^1 H + Y_1\ Q_L^1 U_R^1 H + Y_2\ Q_R^1 U_L^1 H$$
$$M_Q\ Q_L^1 Q_R^1 + M_U\ U_L^1 U_R^1$$

Mass matrix

$$M_{up} = \begin{pmatrix} v\ y_{SM} & 0 & v\ y_{qU} \\ v\ y_{Qu} & M_Q & v\ Y_1 \\ 0 & v\ Y_2 & M_U \end{pmatrix}$$

Contribution to H-glu-glu coupling:

$$\sim\ -\frac{\alpha}{4\pi}\frac{4}{3}\frac{1}{v}\left(2Y_1Y_2\frac{v^2}{M_QM_U} + \frac{1}{2}y_{Qu}^2\frac{v^2}{M_Q^2} + \frac{1}{2}y_{qU}^2\frac{v^2}{M_U^2}\right)$$

$\sim\ 5-15\%$ extra contribution to the coupling from EACH light quark tower (u,d,s,c,b)...

Outlook

Maybe LHC discovers just one (or two) scalar(s) and that's IT.

Is it the SM Higgs? (or a 2 Higgs doublet model?)
or is it the radion of RS? (or radion plus a Higgs?)

- Probing couplings to fermions important (and hard).
- Higgs production may be significantly enhanced (work in progress)
- Probing the size of the Flavor structure also important.
- Flavor at LHC? ($t \to ch$, $(h, \phi) \to$ t c, $(h, \phi) \to \mu\tau$..)
- Linear Collider? Muon Collider?
- Higgs-radion mixing..

Backup – Calculation

Down quark Action with a Bulk Higgs, in RS:

$$S = \int d^4x dz \sqrt{g} \left[\frac{i}{2} \left(\bar{Q}\Gamma^A \mathcal{D}_A Q - D_A \bar{Q}\Gamma^A Q \right) + \frac{i}{2} \left(\bar{U}\Gamma^A \mathcal{D}_A U - \mathcal{D}_A \bar{U}\Gamma^A U \right) \right.$$
$$\left. + \frac{c_Q}{R} \bar{Q}Q + \frac{c_U}{R} \bar{U}U \; + \; \left(Y \; \bar{Q}\mathcal{H}U + h.c. \right) \right]$$

Decompose $Q = \begin{pmatrix} \mathcal{Q}_L \\ \mathcal{Q}_R \end{pmatrix}$ and $D = \begin{pmatrix} \mathcal{D}_L \\ \mathcal{D}_R \end{pmatrix}$ and perform a mixed KK expansion:

$$\begin{aligned} \mathcal{Q}_L(x,z) &= q_L(z)\, Q_L(x) + ... \\ \mathcal{Q}_R(x,z) &= q_R(z)\, D_R(x) + ... \\ \mathcal{D}_L(x,z) &= d_L(z)\, Q_L(x) + ... \\ \mathcal{D}_R(x,z) &= d_R(z)\, D_R(x) + ... \end{aligned}$$

$\Rightarrow$ Mixed profile equations

$$-m_d\, q_L - q_R' + \frac{c_q+2}{z} q_R + \left(\frac{R}{z}\right) v(z) Y_d\, d_R = 0$$

$$-m_d^*\, q_R + q_L' + \frac{c_q-2}{z} q_L + \left(\frac{R}{z}\right) v(z) Y_d\, d_L = 0$$

$$-m_d\, d_L - d_R' + \frac{c_d+2}{z} d_R + \left(\frac{R}{z}\right) v(z) Y_d^*\, q_R = 0$$

$$-m_d^*\, d_R + d_L' + \frac{c_d-2}{z} d_L + \left(\frac{R}{z}\right) v(z) Y_d^*\, q_L = 0$$

Massaging them we arrive at:

$$m_d = R^4 \int_R^{R'} dz \left(\frac{m_d}{z^4} (|d_L|^2 + |q_R|^2) + \frac{R v(z)}{z^5} \left(Y_d\, d_R q_L^* - Y_d^*\, q_R d_L^* \right) \right)$$

4D Higgs Yukawa is : $\quad y_4^d = R^5 \int_R^{R'} dz \frac{h(z)}{z^5} (Y_d\, d_R q_L^* + Y_d^*\, q_R d_L^*)$

Misalignement between 4D fermion mass matrix and Yukawas!

$$\Delta^d = R^4 \int_R^{R'} dz \left(\frac{m_d}{z^4} (|d_L|^2 + |q_R|^2) - 2Y_d^* \frac{Rv(z)}{z^5} q_R d_L^* \right).$$