Higgs-Radion mixing in RS with Bulk fields

(Radion Phenomenology from the Tevatron to the LHC)

by

Manuel Toharia

(University of Maryland)

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Outline

- Introduction
- The radion in RS1
- radion with matter in bulk
- Higgs-radion mixing
- 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 → 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

- Radion couplings are higgs-like (except to gluons and photons)
- Radion might be the lightest new particle in warped scenarios
- When SM matter in the bulk, KK modes are constrained to be at ~ 3 TeV. The radion could be the only accessible mode from these models.
- Radion can in principle mix with the Higgs

The Radion and its interactions

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

$$ds^2 = e^{-2\sigma}\eta_{\mu\nu}\, dx^\mu dx^\nu + dy^2$$

with $\sigma(y) = ky$ and such that a hierarchy is created between the two boundaries at $y = 0$ and $y = \pi r_0$ is created.

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[$Golberger, Wise('99)$])

INTERACTIONS

Matter-gravity interactions come from the matter action

$$S_{mat} = \int dx^5 \sqrt{-g}\, \mathcal{L}_{mat}$$

We expand this action in powers of the radion perturbation

$$S_{mat}(r^0) = \int dx^5\, \sqrt{-g^{(0)}} \mathcal{L}_{mat}$$

$$S_{int}(r) = -\frac{1}{2} \int dx^5 \sqrt{-g^{(0)}} e^{2\sigma} \left(-T^{\mu}_{\mu} + 2T_{55}\right) r(x)$$ [Rizzo(02),Csaki,Hubisz,Lee(07)]

But the radion $r(x)$ is NOT canonically normalized (canonical kinetic term).

The canonically normalized radion is $\phi_r(x) \frac{2}{\Lambda_r} = e^{2k\pi r_0} r(x)$

where $\Lambda_r = \sqrt{6} M_{Pl} e^{-k\pi r_0}$

RS1 - Matter on the brane

Single radion interaction becomes

$$S_{int}(r) = \frac{1}{\Lambda_r}\int dx^4 T^\mu_\mu \, \phi_0(x) \qquad \Rightarrow \text{Higgs} - \text{like couplings!}$$

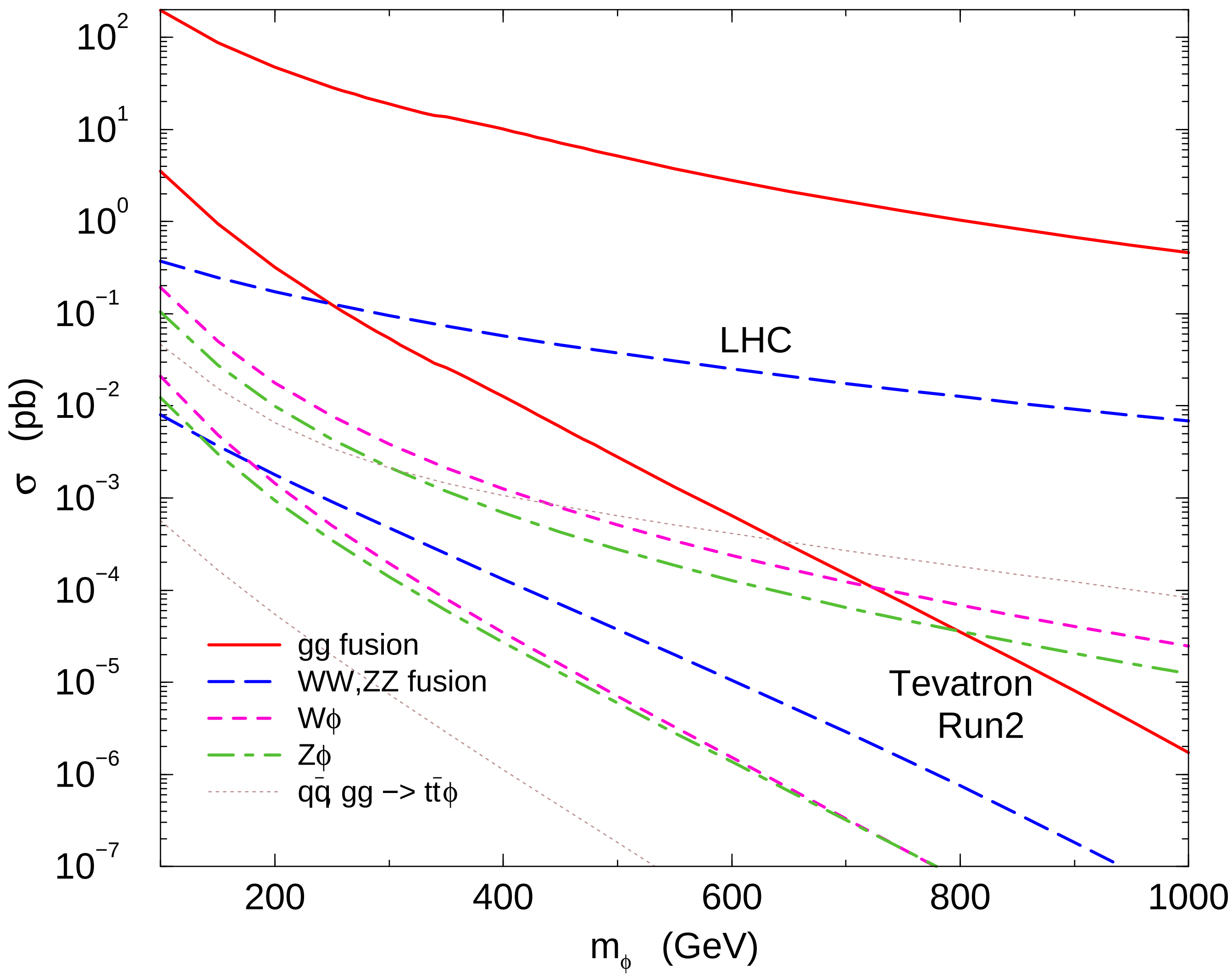
gluons $$-\frac{\alpha_s}{8\pi}\left[\sum_i F_{1/2}(\tau_i)/2 - b_3\right] \frac{\phi_0}{\Lambda_r} G_{\mu\nu}G^{\mu\nu}$$

photons $$-\frac{\alpha}{8\pi}\left[\sum_i e_i^2 N_c^i F_i(\tau_i) - (b_2 + b_Y)\right] \frac{\phi_0}{\Lambda_r} F_{\mu\nu}F^{\mu\nu}$$

massive bosons $$\frac{\phi_0}{\Lambda_r} M_V^2 V^\alpha V_\alpha$$

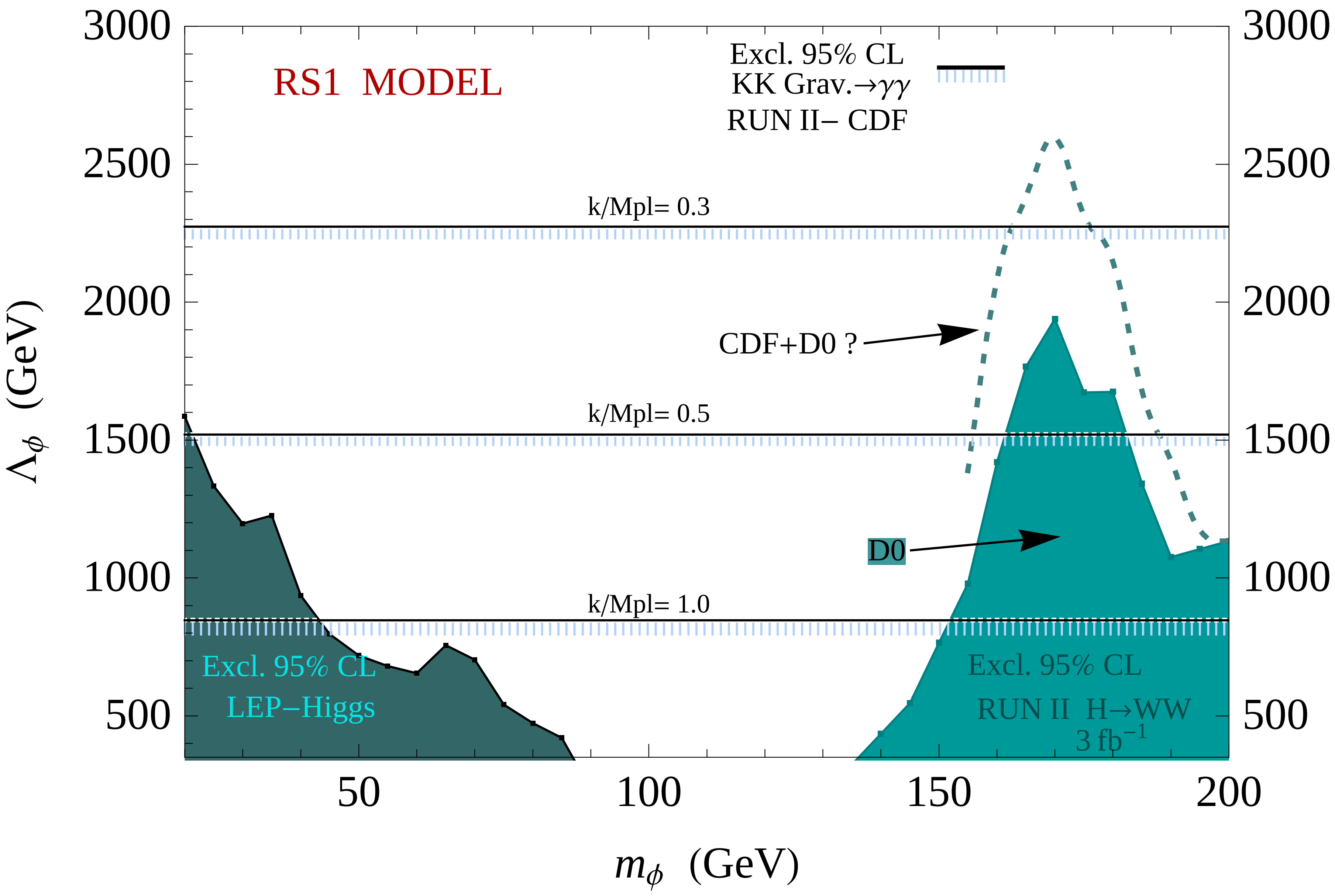
fermions $$\frac{\phi_0}{\Lambda_r} m_f \bar{f} f$$

Radion Production



(from K.Cheung ('00), here $\Lambda_\phi = 1$ TeV)

Experimental Bounds in $(m_\phi - \Lambda_\phi)$ (with Nobu Okada)



The Radion and Matter in the bulk [Csaki,Hubisz,Lee(07)]

With gauge fields and fermions in the bulk (but Higgs on the TeV brane) we need the new interactions with the radion.

$$S_{int}(r) = -\frac{1}{2}\int dx^5 \sqrt{-g^{(0)}} e^{2\sigma} \left(-T^{\mu}_{\ \mu} + 2T_{55}\right) r(x)$$

- For Massless gauge fields:
  - The T_{55} term $\Rightarrow$ tree level coupling r-glu-glu and r-γ-γ.
  - Brane localized kinetic terms for gauge fields.
  - Trace anomaly effect
  - Loop contributions (tops and W's)

$$\left[\frac{1 - 4\pi\alpha(\tau^0_{UV} + \tau^0_{IR})}{4k\pi r_0} + \frac{\alpha}{8\pi}\left(b - \sum_i \kappa_i F_i(\tau_i)\right)\right] \frac{\phi}{\Lambda_r} F_{\mu\nu}F^{\mu\nu}$$

- Radion interaction with Massive Gauge bosons maintains its main contribution from the boson mass
- Interaction with fermions, although model dependent remains proportional to the mass of the fermion with an $\mathcal{O}(1)$ coefficient
- Interaction with the higgs is computed as in RS1 since Higgs localized

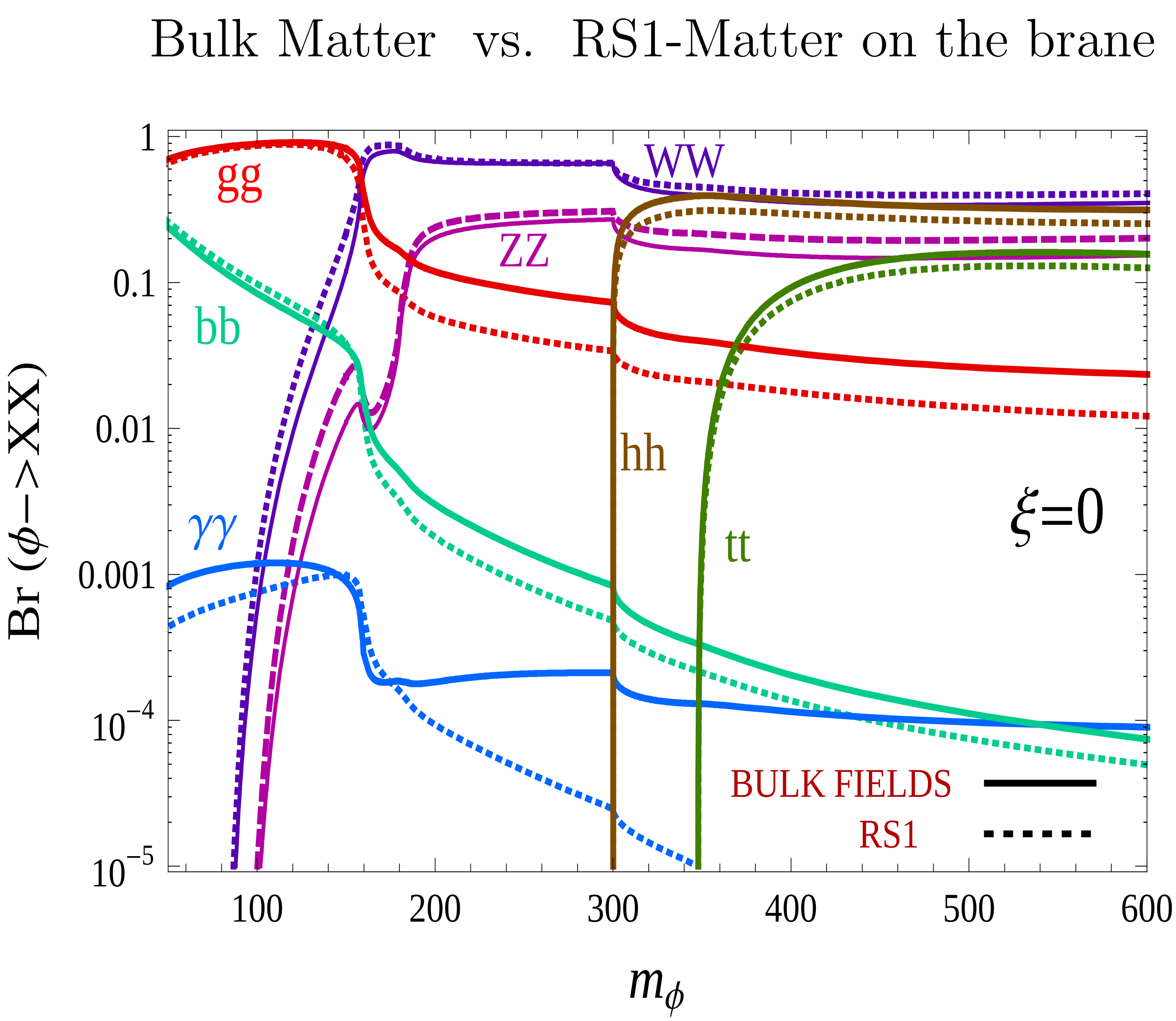
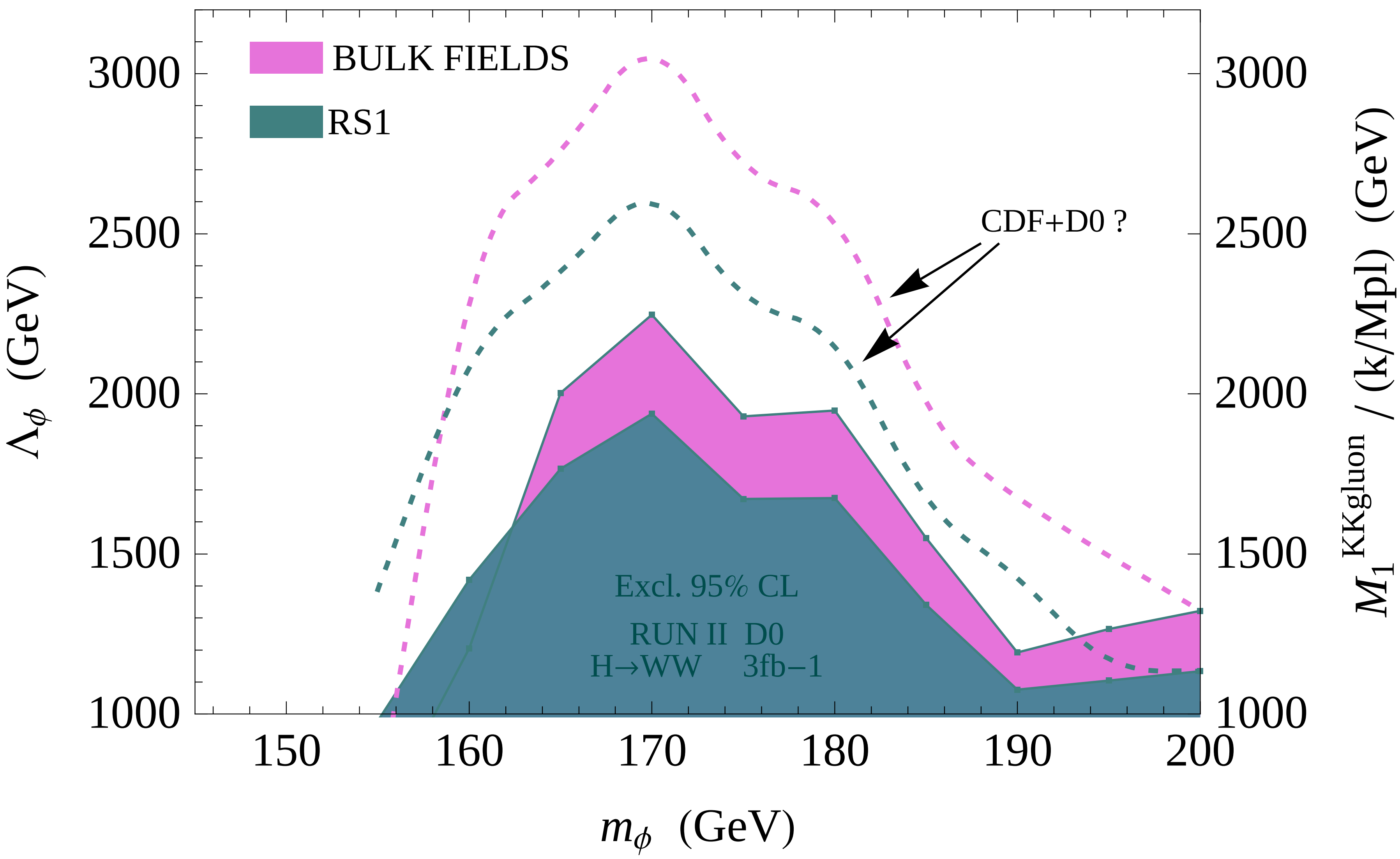


Figure 1: Branchings of the radion vs. its mass m_ϕ

Tevatron Bounds in $(m_\phi - \Lambda_\phi)$ (with Nobu Okada)



Higgs-radion mixing

[Giudice,Rattazzi,Wells(00), Csaki,Graesser,Kribs(00), Han,Kribs,McElrath(01),

Rizzo,Hewett(02), Dominici,Gunion,Grzadkowski,MT(02)], Gunion,MT,Wells(03)]...

We now consider the brane operator:

$$S_\xi = \xi \int d^4x \sqrt{g_{ind}} R(g_{ind}) \; H_0^\dagger H_0 \, .$$

$$\mathcal{L}_{scalar} = -\frac{1}{2}\left\{1 + 6\xi\left(\frac{v_0}{\Lambda_r}\right)^2\right\}\phi_0 \Box \phi_0 - \frac{1}{2}\phi_0 m_{\phi_0}^2 \phi_0$$

$$-\frac{1}{2}h_0(\Box + m_{h_0}^2)h_0 - \frac{6\xi v}{\Lambda_r} \; h_0 \Box \phi_0$$

Radion mass added "by hand".

NORMALIZED HIGGS AND RADION PHYSICAL FIELDS

$$h_0 = \left(\cos\theta - \frac{6\xi\gamma}{Z}\sin\theta\right) h + \left(\sin\theta + \frac{6\xi\gamma}{Z}\cos\theta\right)\phi \equiv d\,h + c\,\phi$$

$$\phi_0 = \left(-\cos\theta\,\frac{1}{Z}\right)\phi + \left(\sin\theta\,\frac{1}{Z}\right) h \equiv a\,\phi + b\,h$$

with $\gamma = \frac{v}{\Lambda}$ and Z and θ depend on m_ϕ, m_h, Λ and ξ.

$\Rightarrow$ 4 parameters in Higgs-radion sector: m_ϕ , m_h , Λ_ϕ and ξ

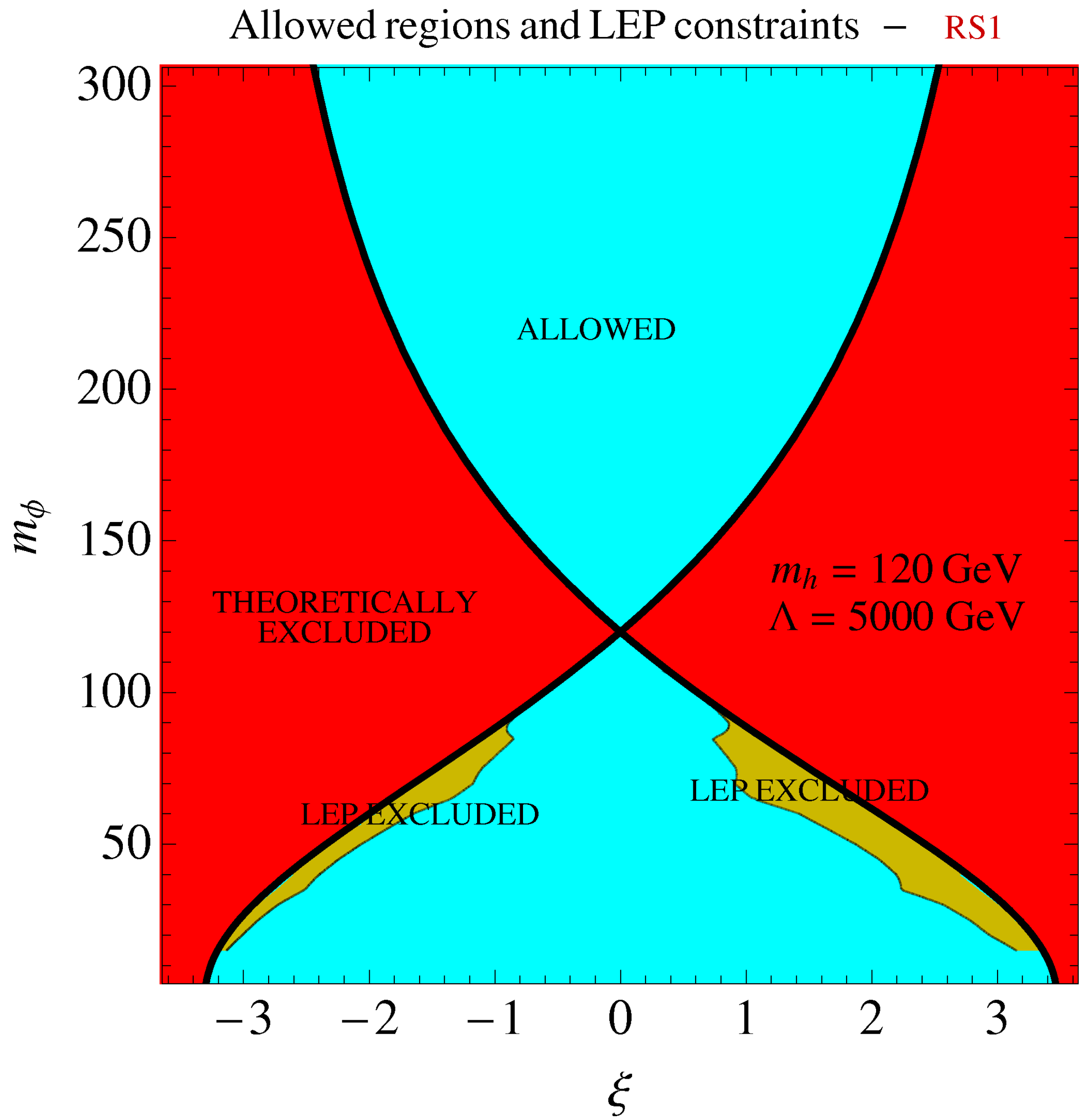


Figure 2: Allowed m_ϕ and ξ for $m_h = 120\text{GeV}$ and $\Lambda = 5\text{TeV}$

(from Dominici,Gunion,Grzadkowski,M.T. ('02))

VV and ff COUPLINGS

$$g_{ZZh} = \frac{g\,M_z}{c_W}(d + \gamma b) \qquad g_{ZZ\phi} = \frac{g\,M_z}{c_W}(c + \gamma a)$$

$$g_{f\bar{f}h} = -\frac{g\,m_f}{2\,M_w}(d + \gamma b) \qquad g_{f\bar{f}\phi} = -\frac{g\,m_f}{2\,M_w}(c + \gamma a)$$

Very interesting property of the ξ-mixing: the different couplings of the physical radion to matter photons, gluons, fermions and massive bosons can vanish at different points in parameter space.

$\Rightarrow$ ϕ can be photon-phobic, gluon-phobic or massive-phobic

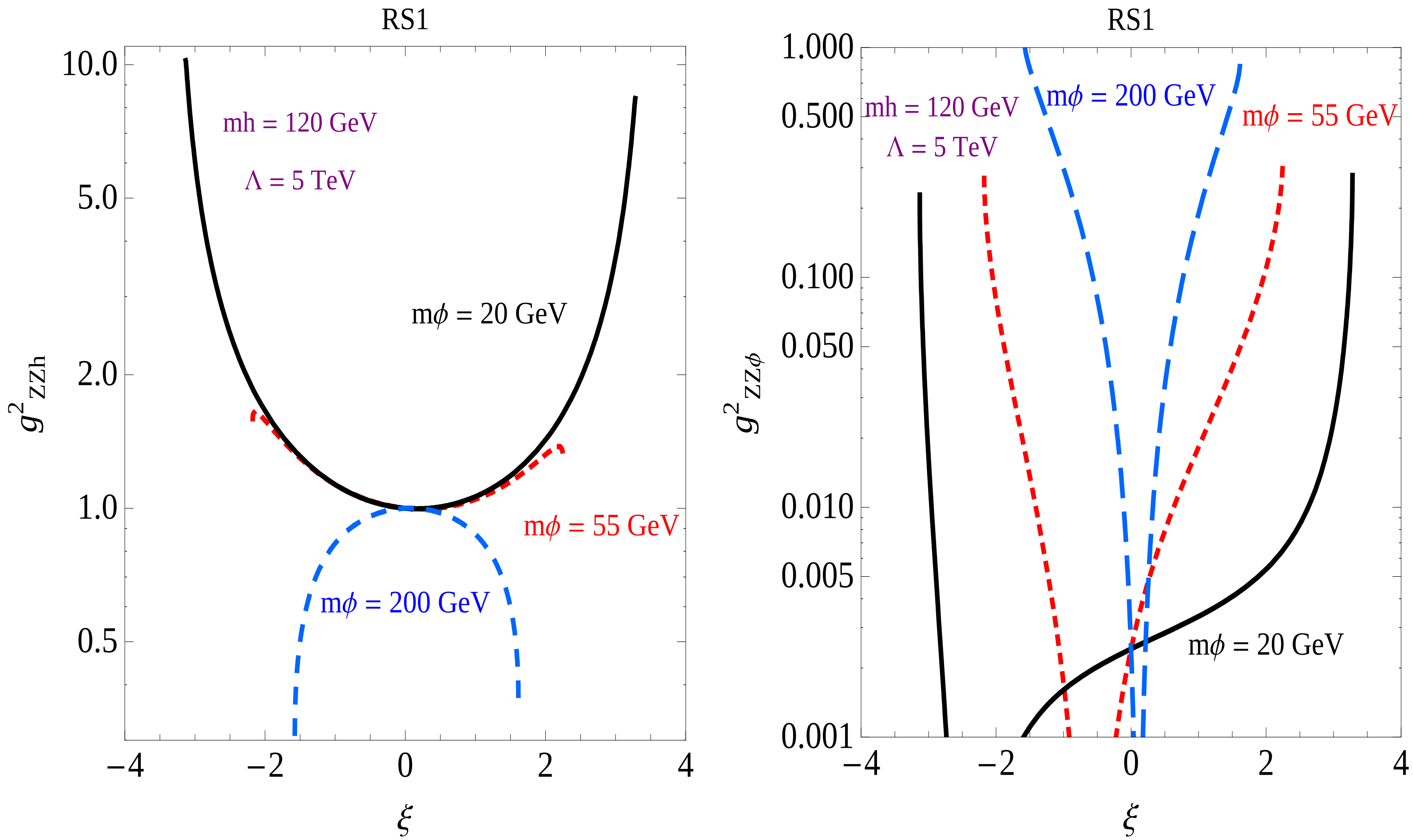


Figure 3:

(from Dominici,Gunion,Grzadkowski,M.T. ('02))

Higgs-radion mixing & Matter in the bulk

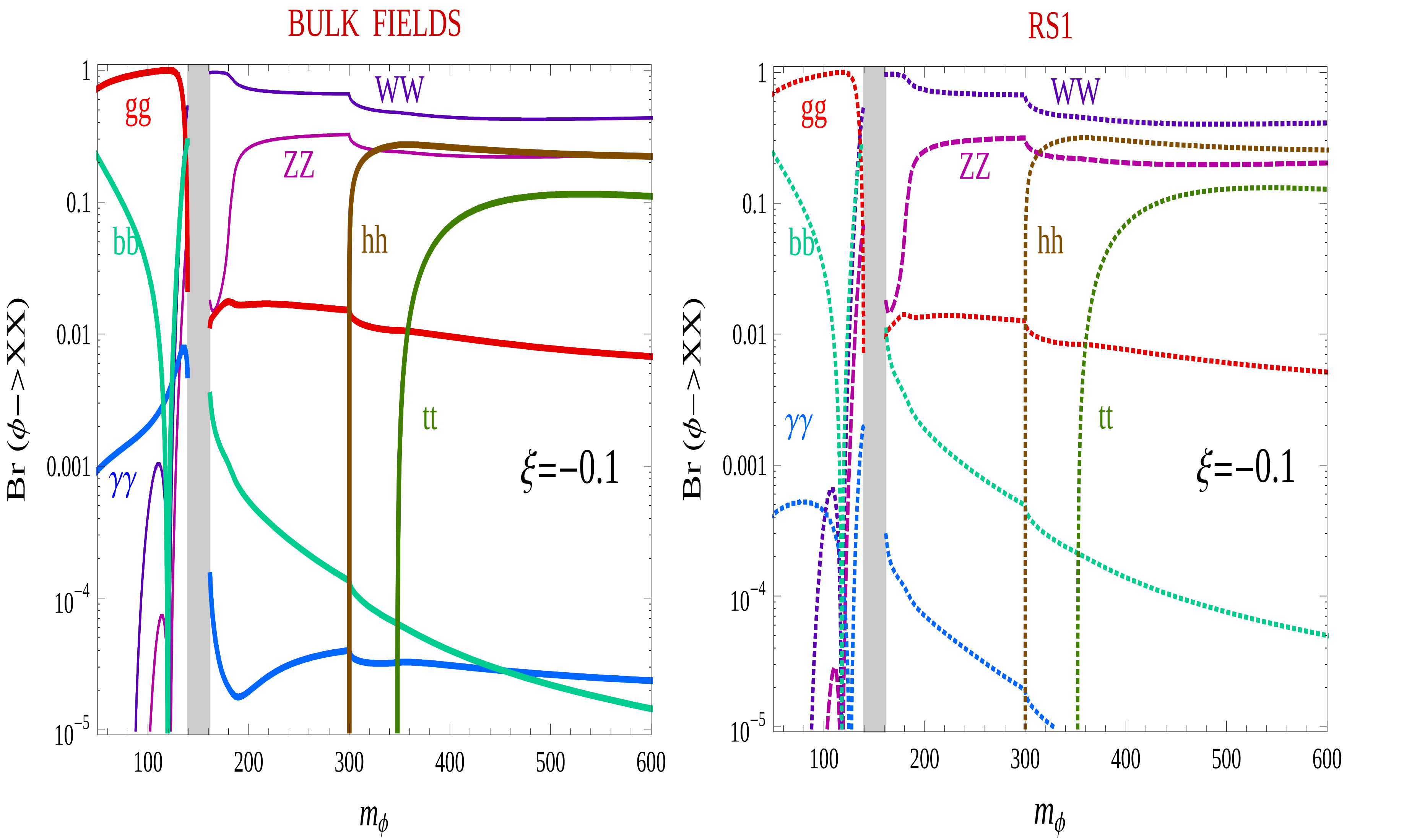


Figure 4: Branchings of the radion vs. its mass m_ϕ. Here we fix $m_h = 150$ GeV and $\Lambda = 2000$ GeV.

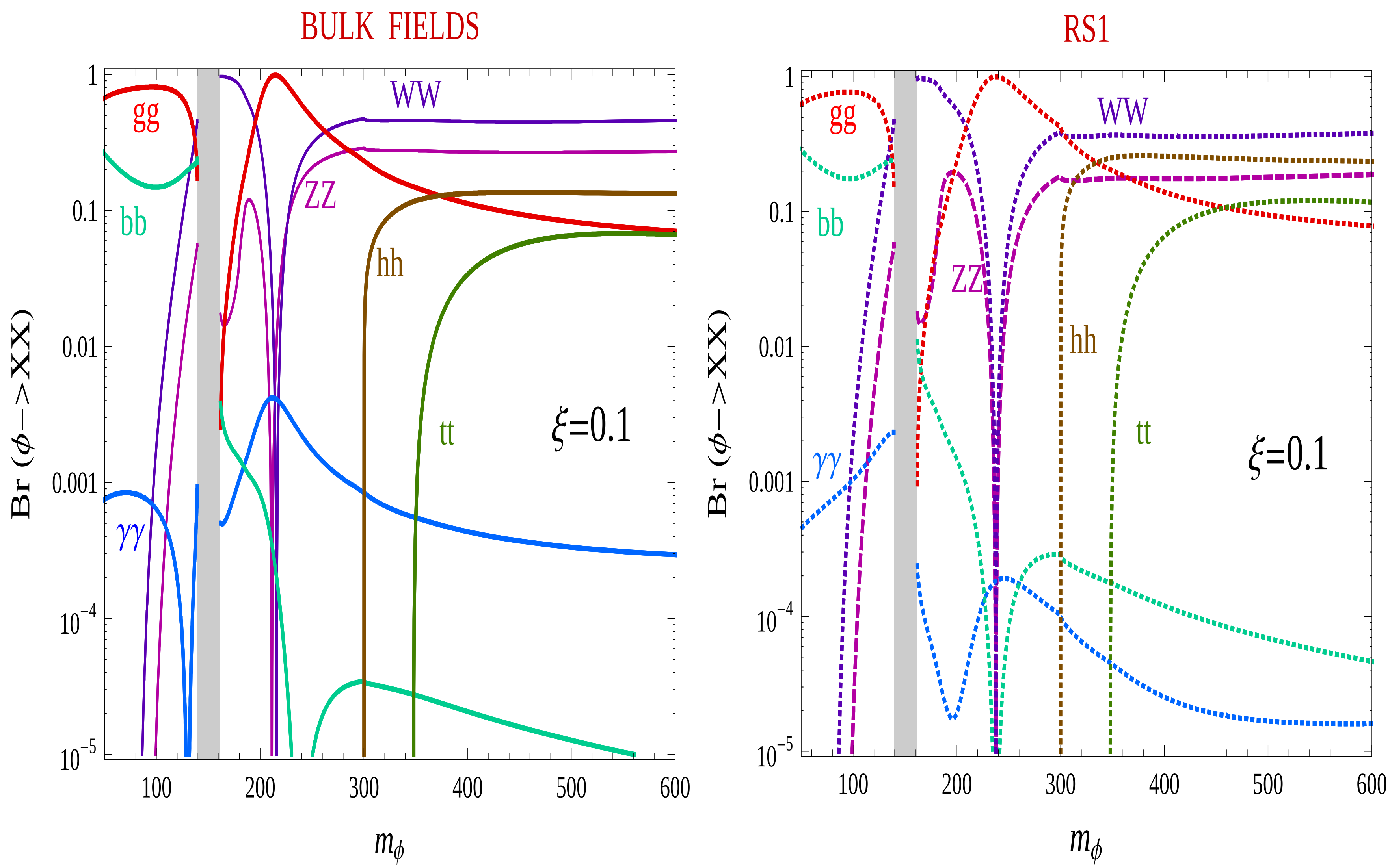


Figure 5: Branchings of the radion vs. radion mass m_ϕ. Here we fix $m_h = 150$ GeV and $\Lambda = 2000$ GeV.

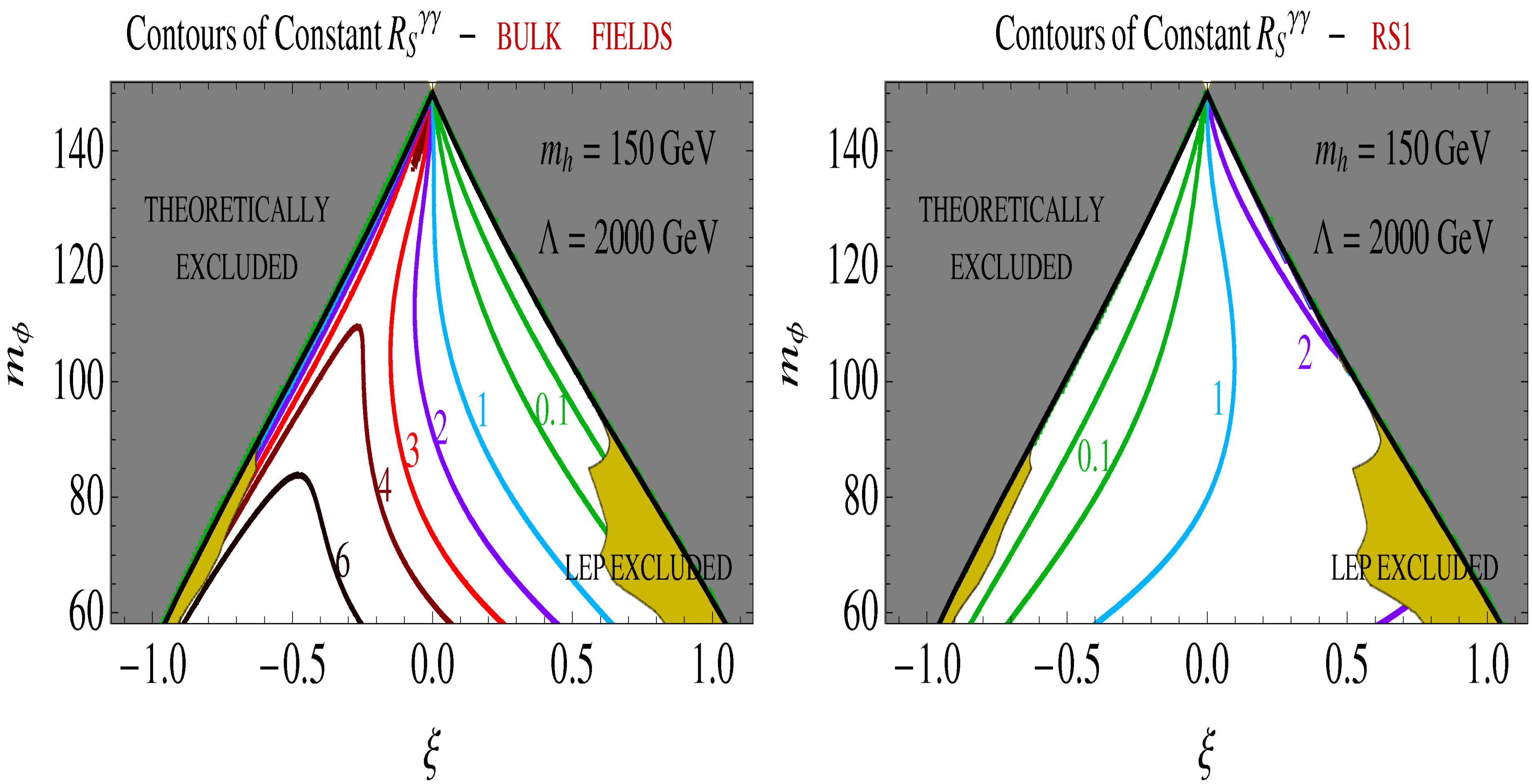


Figure 6: Contours of the Ratio $R_S^{\gamma\gamma}$ between the discovery significance (in $\gamma\gamma$ channel) of a radion and that of a SM Higgs of same mass.

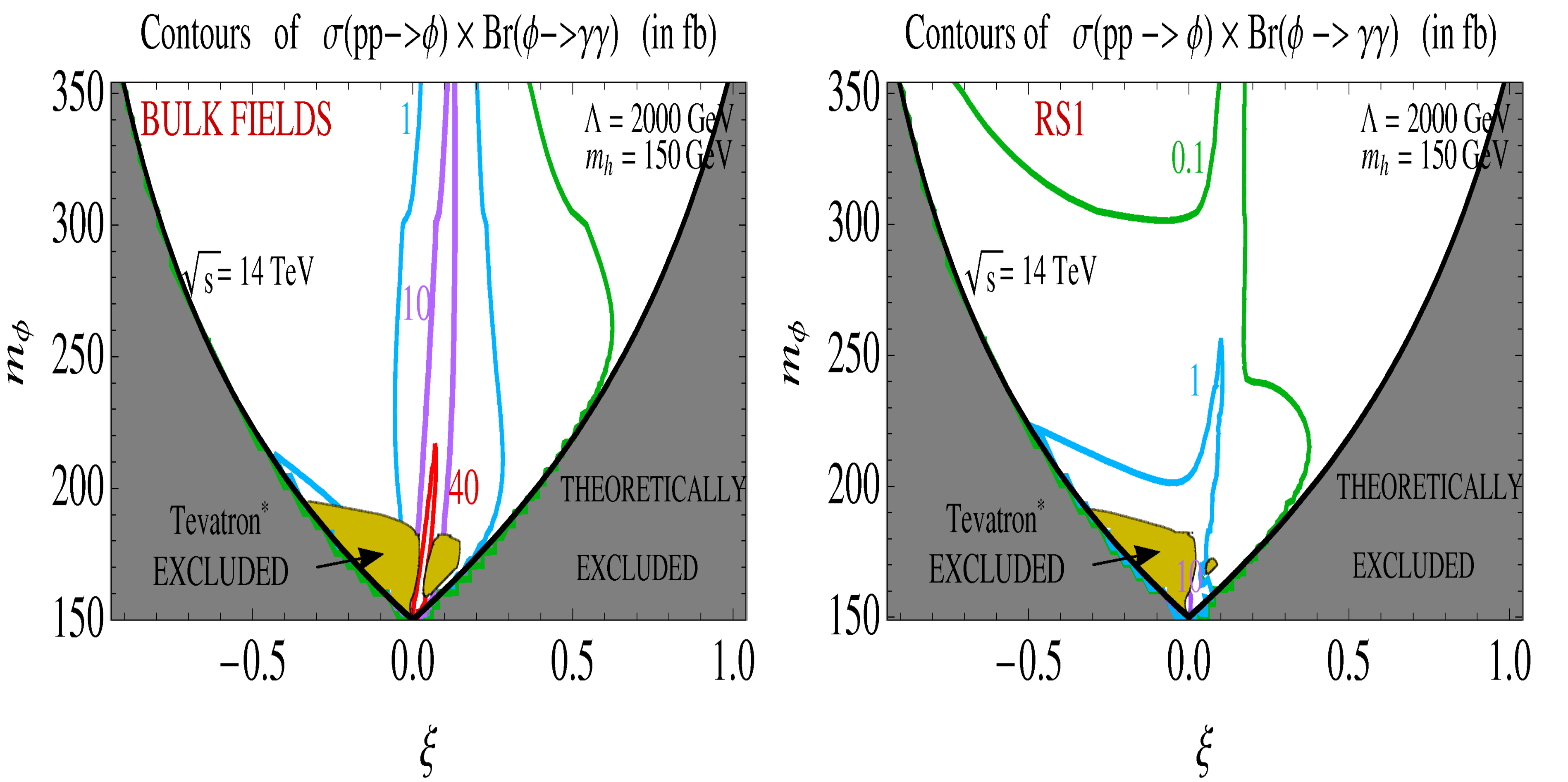


Figure 7: Contours of the cross section for $pp \to \phi \to \gamma\gamma$ at LHC for a heavier radion (using CTEQ5L pdf's and no QCD corrections..).

Conclusions - work in progress

- Radion phenomenology is generically very similar to the Higgs
- Higgs-radion mixing adds interesting properties to both the radion (phobic couplings) and the Higgs (suppressed/enhanced couplings)
- $\gamma\gamma$ signal generically enhanced in Radion-higgs mixing with Bulk matter $\rightarrow$ maybe help differentiate between RS1 and Bulk-Fields scenario?

- radion couplings to bulk fermions depend on c-masses..
- radion mediated FCNC's?
- Bulk Higgs-radion mixing?