Radion Production in Association with a Z Boson at the LHC and the ILC in a Custodial Randall-Sundrum Model

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Overview

(Custodial) Randall-Sundrum Models

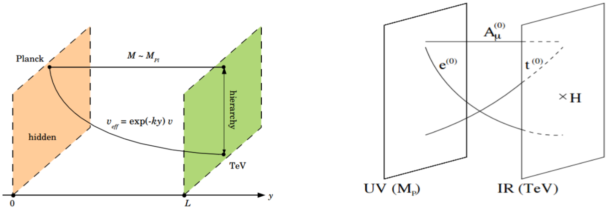


Figure: Randall-Sundrum setup with a brane Higgs.

- Setup → 5D anti-de Sitter space: $\mathrm{d}s^2 = \mathrm{e}^{-2ky}\eta_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu + \mathrm{d}y^2, \quad y \in [0, L]$.
- Solves two hierarchy problems: gauge ($m_W \ll M_{\mathrm{Pl}}$) + flavour ($m_e \ll m_t$);
- Predicts new states: Kaluza-Klein partners (excited states in an "infinite potential well"). Mass of the first KK gluon/photon: $m_{KK} \simeq 2.45\, k\mathrm{e}^{-kL} = \mathcal{O}$ (few TeV);
- EWPT constraints: $m_{KK} \gtrsim 10$ TeV → implement custodial symmetry in the bulk ($\mathrm{SU}(3)_c \otimes \mathrm{SU}(2)_R \otimes \mathrm{SU}(2)_L \otimes \mathrm{U}(1)_X$) → $m_{KK} \gtrsim 3$ TeV (hep-ph/0308036).

Scalar Fluctuations of the Metric: The Radion

- Metric perturbed by scalar fluctuation F (arXiv:0705.3844 [hep-ph]):

$$\mathrm{d}s^2 = \mathrm{e}^{-2[ky+F(x,y)]}\eta_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu + [1+2F(x,y)]^2\mathrm{d}y^2; \tag{1}$$

- Radion wavefunction:

$$F(x,y) = \frac{\phi_0(x)}{\Lambda_\phi}\mathrm{e}^{2k(y-L)}, \quad \Lambda_\phi \simeq M_{\mathrm{Pl}}\,\mathrm{e}^{-kL} = \mathcal{O}(\mathrm{TeV}); \tag{2}$$

- Couplings to other particles: $S_{\mathrm{rad}} = -\frac{1}{2}\int \mathrm{d}^5x\sqrt{g}\,T^{MN}\delta g_{MN},\ T^{MN}\delta g_{MN} \sim F(x,y)\,T^M_{M,\mathrm{eff}}$;
- Dominant couplings to massive SM particles are similar to the Higgs:

$$c_{\phi_0 ff} \sim \frac{m_f}{\Lambda_\phi}, \quad c_{\phi_0 VV} \sim \frac{m_V^2}{\Lambda_\phi}; \tag{3}$$

- Expected to be the lightest particle predicted in extra dimensional models (hep-th/0008151).

Overview

Higgs-Radion Mixing

- Term inducing the mixing (hep-ph/0002178, hep-ph/0206192, arXiv:1512.05771 [hep-ph]):

$$S_{\rm mix} = \xi \int \mathrm{d}^4 x \sqrt{g_{\rm IR}}\, R_{4D}(g_{\rm IR}) H^\dagger H. \tag{4}$$

- Higgs-Gravity coupling $\rightarrow$ Higgs-radion kinetic mixing:

$$\mathcal{L} = -\begin{pmatrix}\phi_0 & h_0\end{pmatrix} \underbrace{\begin{pmatrix}1+6\xi\ell^2 & -3\xi\ell \\ -3\xi\ell & 1\end{pmatrix}}_{\det K \equiv Z^2} \begin{pmatrix}\Box\phi_0 \\ \Box h_0\end{pmatrix} - \frac{1}{2} m_{\phi_0}^2 \phi_0^2 - \frac{1}{2} m_{h_0}^2 h_0^2, \quad \ell \equiv \frac{v}{\Lambda_\phi}. \tag{5}$$

- "Rotating" to mass basis:

$$\begin{pmatrix}\phi_0 \\ h_0\end{pmatrix} = \begin{pmatrix}a & -b \\ c & d\end{pmatrix} \begin{pmatrix}\phi \\ h\end{pmatrix}, \tag{6}$$

$$a = c_\theta/Z,\ b = s_\theta/Z,\ c = s_\theta + 6\xi\ell\, c_\theta/Z,\ d = c_\theta - 6\xi\ell\, s_\theta/Z. \tag{7}$$

- Parameters: $\xi, m_\phi, \Lambda_\phi, m_{KK}$.

Theoretical Constraints

- Positive kinetic terms (no ghosts) $\rightarrow Z^2 > 0$;
- Real values for $m^2_{\phi_0, h_0}$.

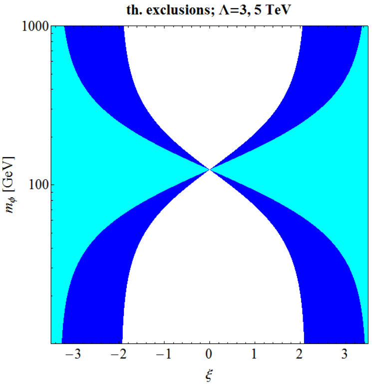


Figure: Theoretical constraints on the Higgs-radion parameter space for Λ_ϕ equal to (blue) 3 and (cyan) 5 TeV.

Couplings to Massive Gauge Bosons

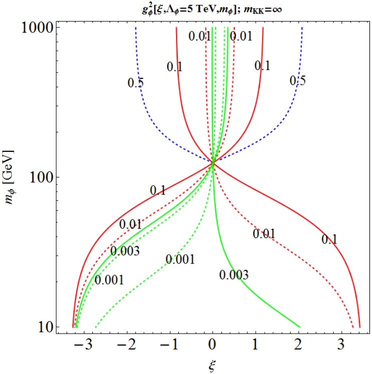


Figure: $g_\phi^2(\xi, m_\phi, \Lambda)$.

- Dominant coupling of ϕ to ZZ:

$$\frac{g_{\phi ZZ}}{g_{h_{\rm SM} ZZ}} \equiv g_\phi = c - \ell a = s_\theta + \frac{(6\xi - 1)\ell}{Z}\, c_\theta. \tag{8}$$

Radion Branching Ratios

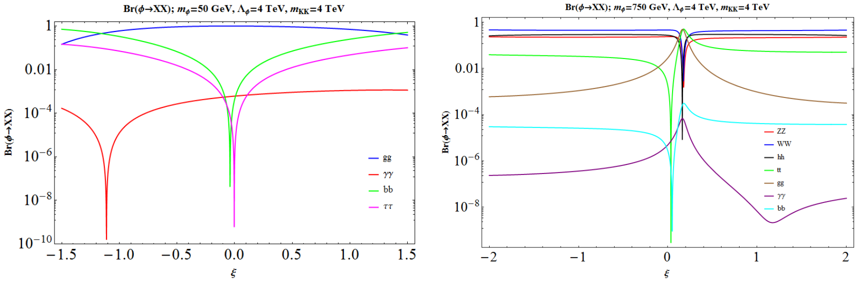


Figure: Radion branching fractions.

Overview

Frank et al., arXiv:1606.07689 [hep-ph]

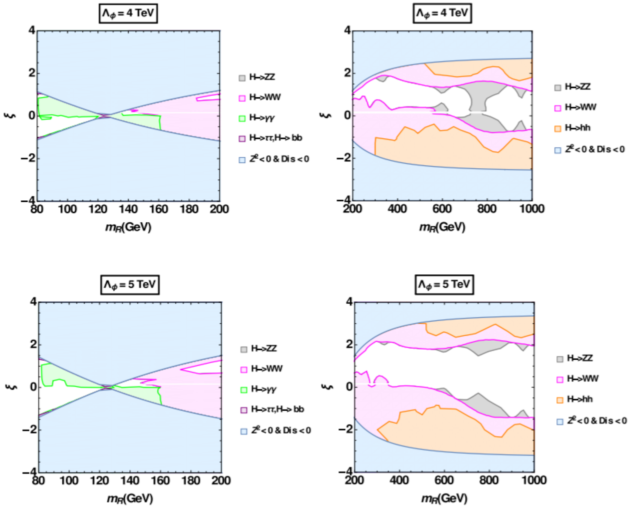


Figure: Current LHC exclusion limits (1606.07689 [hep-ph]).

Radion + Z at the LHC (preliminary)

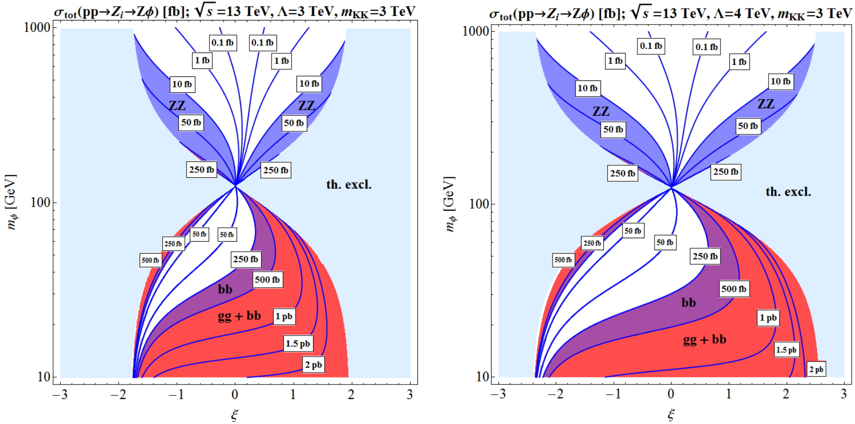


Figure: $Z\phi$ production cross section at the LHC.

Radion + Z at the ILC: $\sqrt{s} = 250$ GeV (preliminary)

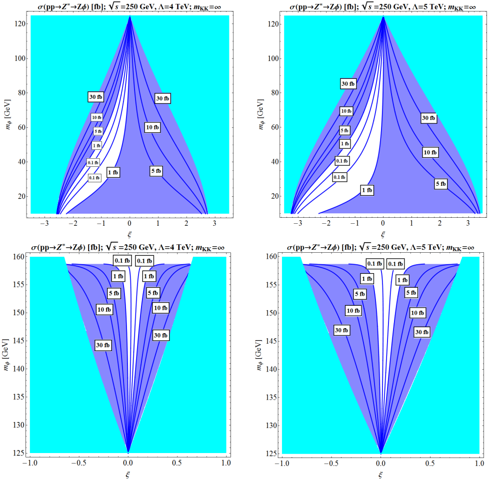


Figure: $Z\phi$ production cross section at the ILC. Search strategy: Z recoil mass technique. Luminosity assumed: 2000/fb (arXiv:1506.07830 [hep-ex]).

Radion + Z at the ILC $\sqrt{s} = 0.5, 1$ TeV (preliminary)

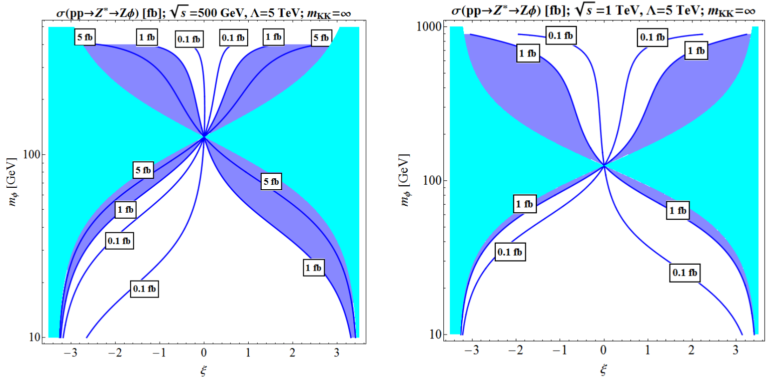


Figure: $Z\phi$ production cross section at the ILC. Search strategy: Z recoil mass technique. Luminosity assumed: 4000/fb @ 500 GeV, 8000/fb @ 1 TeV (arXiv:1506.07830 [hep-ex]).

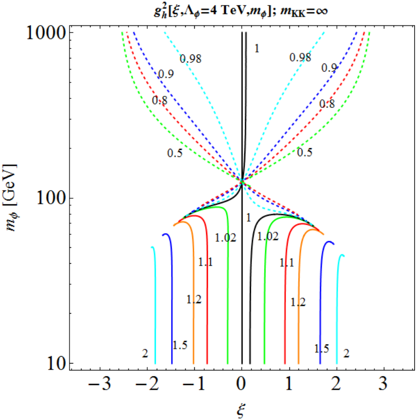
Overview

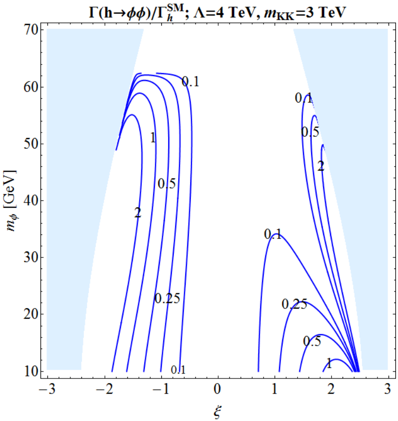
Conclusions

- Warped extra-dimensional models $\rightarrow$ alleviation the gauge and flavour hierarchy problems.
- Radion needed in order to stabilize the extra dimension $\rightarrow$ likely the lightest particle predicted by warped extra-dimensional theories $\rightarrow$ promising avenue to test such theories.
- Studied $Z + \phi$ production at the LHC and the ILC.
- Not very promising for LHC, where gg fusion is more suitable (but somewhat model dependent).
- Much better sensitivity at the ILC (especially for smaller radion masses), if one uses Z recoil mass techniques.

Thank you for your attention !

Backup


$g_h^2[\xi,\Lambda_\phi=4$ TeV$,m_\phi]$; $m_{KK}=\infty$
m_ϕ [GeV]
ξ
1000
100
10
−3
−2
−1
0
1
2
3
1
0.98
0.9
0.8
0.5
1.02
1.1
1.2
1.5
2


$\Gamma(h\to\phi\phi)/\Gamma_h^{SM}$; Λ=4 TeV, m_{KK}=3 TeV
m_ϕ [GeV]
ξ
70
60
50
40
30
20
10
−3
−2
−1
0
1
2
3
0.1
1
0.5
2
0.25
0.1
0.5
2
0.1
0.25
0.5
1