Higgs-radion interpretation of the 750 GeV di-photon excess

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MPIK, Heidelberg,   May 23, 2016

Outline

- Randall-Sundrum model: a brief review

- Higgs-radion phenomenology

- The 750 GeV di-photon excess and ways of accommodating the result BSM

- The Higgs-radion interpretation

- Summary

★ A. Ahmed, B.M. Dillon, BG, J.F. Gunion and Y. Jiang, "Higgs-radion interpretation of 750 GeV di-photon excess at the LHC", arXiv:1512.05771 and "Higgs-radion phenomenology at the LHC-13 TeV".

★ BG, J.F. Gunion and M. Toharia, "Higgs-Radion interpretation of the LHC data?", *Phys.Lett.* *B712 (2012) 70-80*, arXiv:1202.5017

★ D. Dominici, BG, J.F. Gunion and M. Toharia, "The Scalar sector of the Randall-Sundrum model", *Nucl.Phys.* *B671 (2003) 243-292*, hep-ph/0206192

★ D. Dominici, BG, J.F. Gunion and M. Toharia, "Higgs Boson interactions within the Randall-Sundrum model", *Acta Phys.Polon.* *B33 (2002) 2507-2522*, hep-ph/0206197

Why extra-dimensions

- (Gauge) Hierarchy problem:
  Why gravity is much weaker than the other fundamental forces? or why $m_{EW} \ll M_{Pl}$?

- *(Fermion) Mass hierarchy problem:*
  Why $m_\nu \lesssim 10^{-9}$ GeV $\ll m_t \sim 10^3$ GeV?

- *Dark matter and so on $\cdots$.*

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...BUT THIS IDEA OF EXTRA DIMENSIONS MIGHT EXPLAIN IT!

Large extra-dimensions

- Flat extra-dimensions (e.g. ADD, UED).   hep-ph/9803315; 9804398; 9807344
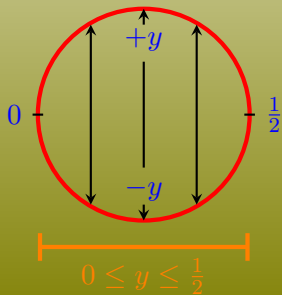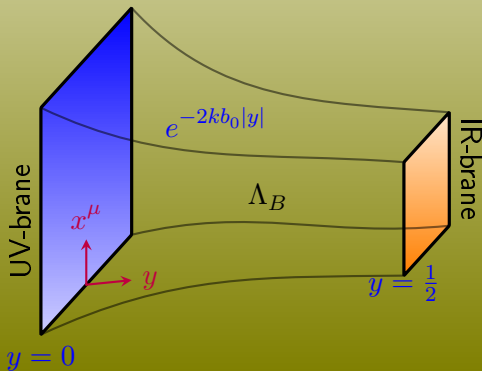- Warped extra-dimensions (e.g. RS).   hep-ph/9905221; hep-th/9906064

Randall-Sundrum model with two branes (RS1)

A 5D model with two D3-branes on $S_1/\mathbb{Z}_2$ orbifold along the extra-dimension to solve hierarchy problem. `hep-ph/9905221`

- A UV-brane is located at $y = 0$ orbifold fixed point and an IR-brane is located at $y = \frac{1}{2}$ orbifold fixed point.
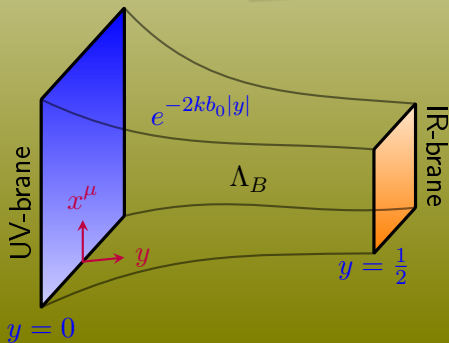
RS1 background solution

5D gravity action for RS1

$$S_{RS1} = \int d^4x dy \sqrt{-g} \left\{ -M_*^3 R + \Lambda_B - \lambda_{UV}\delta(y) - \lambda_{IR}\delta(y - \frac{1}{2}) \right\}$$

- Solution preserving 4D Poincaré symmetry:

$$ds^2 = e^{-2kb_0|y|}\eta_{\mu\nu}dx^\mu dx^\nu + b_0^2 dy^2$$

UV-brane

$e^{-2kb_0|y|}$

x^μ

y

Λ_B

IR-brane

$y = \frac{1}{2}$

$y = 0$

- Negative 5D cosmological const.

$$\Lambda_B = -12k^2 M_*^3$$

- Fine tuning to have 4D cosmological constant zero.

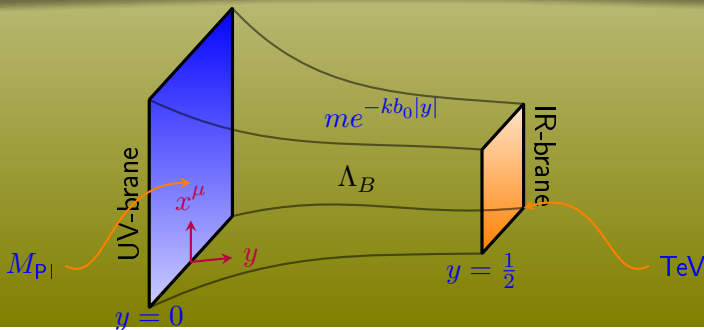$$\lambda_{UV} = -\lambda_{IR} = 12kM_*^3$$

RS solution to the hierarchy problem

- All mass scales in RS model are of the order of 5D fundamental scale M_*

$$m \sim M_* \simeq M_{Pl} \simeq 10^{19} \text{ GeV}$$

- The physical (observed) mass scales on the IR-brane (our brane) are rescaled due to the non-trivial warp factor e^{-kL}

$$m_{obs} \simeq m e^{-kb_0/2} \simeq m_{EW} \sim \mathcal{O}(10^2) \text{ GeV}, \quad \text{for} \quad kb_0/2 \approx \mathcal{O}(37)$$

Warped models

- There are many scenarios of warped extra dimensions depending on the localization of the fields:
  - ▸ <u>IR SM</u>: whole SM localized on the IR brane.
  - ▸ <u>Mixed SM</u>: gauge bosons+light fermions in the bulk, whereas, Higgs+heavy quarks on the IR brane.
  - ▸ <u>Bulk SM</u>: the full SM in the bulk.

- We consider the "Mixed SM" scenario, where Higgs, $t_{L,R}$ and b_L are localized on the IR brane while the remaining fields propagate in the bulk.

A_μ

gauge boson

b

$t,$

IR-brane

UV-brane

light fermions

Higgs

y

$y = 0$ $y = \frac{1}{2}$
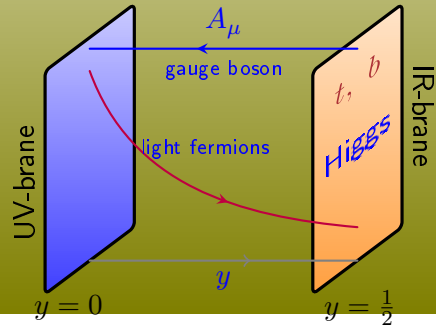
- Zero-modes of bulk fermions and gauge bosons correspond to the SM fields.

- Overlap integrals of fermionic wave-functions with the Higgs field determine the fermion masses.

- Hence, geometric localization solves the fermion mass hierarchy problem.

The RS dynamics

$$ds^2 = e^{-2kb_0|y|}\eta_{\mu\nu}dx^\mu dx^\nu + b_0{}^2 dy^2$$

- Expansion around the background solution:

$$\eta_{\mu\nu} \to \eta_{\mu\nu} + M_*^{-3/2}h_{\mu\nu}(x,y) \qquad b_0 \to b_0 + b(x)$$

- 4-D gravity and a scalar (the radion):

$$S_4 = \int d^4x \sqrt{|g_4|}\Big[-\frac{M_*^3(1-\Omega_b^2)}{k}R_4 + \frac{6M_*^3}{k}\partial_\mu\Omega_b\,\partial^\mu\Omega_b + \cdots \Big]$$

where $\Omega_b(x) \equiv e^{-k[b_0+b(x)]/2}$.

- The standard gravity is reproduced by requiring

$$\frac{M_{Pl}}{2} = \frac{M_*^3(1-\Omega_0^2)}{k} \ \text{ for } \ \Omega_0 \equiv e^{-kb_0/2}$$

- The canonically normalized massless radion: $\phi_0(x) \equiv \sqrt{\frac{12M_*^3}{k}}\Omega_b(x)$

Stabilization of the extra dimension
- the Goldberger-Wise mechanism -

$$ds^2 = e^{-2kb_0|y|}\eta_{\mu\nu}dx^\mu dx^\nu + b_0{}^2 dy^2$$

- In order to fix dynamically b_0 a bulk scalar field could be invoked

$$S_{GW} = \int d^4x dy \sqrt{-g}\left[-M_*^3 R + \left(\frac{1}{2}\partial_\mu\varphi\partial^\mu\varphi - V(\varphi)\right)\right.$$

$$\left. -V_{UV}(\varphi)\delta(y) - V_{IR}(\varphi)\delta\left(y - \frac{1}{2}\right)\right]$$

- Ansatz:

$$\varphi(x,y) = \varphi_0(y) \ \text{ and } \ ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2$$

- Solution

$$\varphi_0(y) \propto e^{-uy} \ \text{ and } \ A(y) = kb_0|y| + \cdots$$

Distance between branes is stabilized. Back-reaction not very relevant.

Radion – brane SM interactions

- SM localized at the IR brane

- The ϕ_0-SM couplings:

$$-\frac{\phi_0}{\Lambda_\phi}\, T_\mu{}^\mu = -\frac{\phi_0}{\Lambda_\phi} \times \left\{ -\partial_\mu h_0 \partial^\mu h_0 + 2m_W^2 W_\mu^+ W^{-\,\mu} + m_Z^2 Z_\mu Z^\mu + \cdots \right\}$$

where $\Lambda_\phi \equiv \sqrt{6}\, e^{-kb_0/2} M_{Pl}$

- Trace anomaly:

$$-\frac{\phi_0}{\Lambda_\phi} \times \underbrace{\left[b_3 \frac{\alpha_s}{8\pi} \mathrm{Tr}[G_{\mu\nu} G^{\mu\nu}] + (b_2 + b_Y) \frac{\alpha_{\mathrm{QED}}}{8\pi} F_{\mu\nu} F^{\mu\nu} \right]}_{\text{Trace anomaly terms}}$$

where $b_3 = 7$, $b_2 = 19/6$ and $b_Y = -41/6$.

Radion – bulk SM interactions

- Higgs and heavy fermions localized at the IR brane

- vector bosons in the bulk

$$S = \int d^4x\, dy \sqrt{-g} \left[-\frac{1}{4} g^{MN} g^{KL} F_{MK} F_{NL} - \frac{1}{2} g^{MN} g^{KL} W_{MK}^\dagger W_{NL} \right.$$

$$\left. + g^{\mu\nu} \frac{\delta(y - \frac{1}{2})}{\sqrt{g_{55}}} (g_5 v)^2 W_\mu^\dagger W_\nu + \cdots \right]$$

- integration over dy adopting the 0-mode solution for $W(x,y)$

$$W_\mu(x,y) \sim f(y) W_\mu(x)$$

- corrections to e.g. $(\phi_0/\Lambda_\phi)\, 2m_W^2 W_\mu^+ W^{-\,\mu}$ are generated:

$$\propto \frac{\phi_0}{\Lambda_\phi} F_{\mu\nu} F^{\mu\nu}, \quad \propto \frac{\phi_0}{\Lambda_\phi} W_{\mu\nu}^\dagger W^{\mu\nu}, \quad \propto \frac{\phi_0}{\Lambda_\phi} W_\mu^+ W^{-\,\mu}$$

Higgs-radion mixing

- The 4D effective action for the stabilized RS model is

$$S_{\text{IR}} = \int d^4x \sqrt{|g_4|} \Big[\xi R(g_4) \hat{H}^\dagger \hat{H} + g_4^{\mu\nu} D_\mu \hat{H}^\dagger D_\nu \hat{H} - V(\hat{H}) \Big]$$

$$+ \int d^4x \Big[\frac{1}{2} \partial_\mu \phi_0 \partial^\mu \phi_0 - \frac{1}{2} m_{\phi_0}^2 \phi_0^2 \Big]$$

$$g_{\mu\nu}^{IR} \equiv e^{-kb_0} \Omega^2(\phi_0) \eta_{\mu\nu}, \qquad \Omega(\phi_0) \equiv e^{-\phi_0/\Lambda_\phi}, \qquad \Lambda_\phi \equiv \sqrt{6} M_{\text{Pl}} e^{-kb_0/2}$$

- After rescaling $\hat{H} \to e^{kb_0/2} H_0$ the Higgs field is properly normalized

$$\mathcal{L}_{\text{eff}} = \frac{1}{2}(\partial_\mu \phi_0)^2 - \frac{1}{2} m_{\phi_0}^2 \phi_0^2 - 6\xi \Omega \Box \Omega H_0^\dagger H_0 + |D_\mu H_0|^2 - V(H_0)$$

- In the unitary gauge the Higgs-radion Lagrangian at the quadratic level

$$\mathcal{L}_{\text{eff}}^{(2)} = -\frac{1}{2}(1 + 6\xi\ell^2)\phi_0 \Box \phi_0 - \frac{1}{2} m_{\phi_0}^2 \phi_0^2 + 6\xi\ell h_0 \Box \phi_0 - \frac{1}{2} h_0 \Box h_0 - \frac{1}{2} m_{h_0}^2 h_0^2$$

where h_0 is the neutral real component of the Higgs doublet H_0 and $\ell \equiv v_0/\Lambda_\phi$.
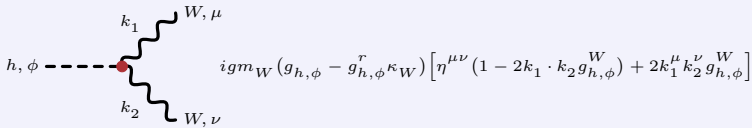
Higgs-radion mixing

- Mass eigenstate basis for the Higgs-radion system

$$\begin{pmatrix} \phi_0 \\ h_0 \end{pmatrix} = \begin{pmatrix} -a & -b \\ c & d \end{pmatrix} \begin{pmatrix} \phi \\ h \end{pmatrix}$$
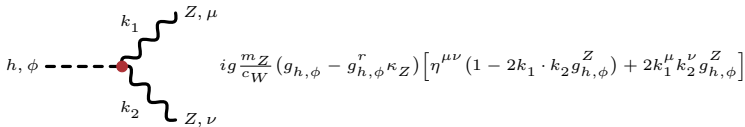
$a = -\cos\theta/Z$, $b = \sin\theta/Z$, $c = \sin\theta + t\cos\theta$ and $d = \cos\theta - t\sin\theta$

$t \equiv 6\xi\ell/Z$, $Z^2 \equiv 1 + 6\xi\ell^2(1-6\xi)$ and $\tan 2\theta \sim 12\xi\ell \left(\frac{m_h}{m_\phi}\right)^2 \left[1 - 3\xi(1-6\xi)\ell^2\right.$
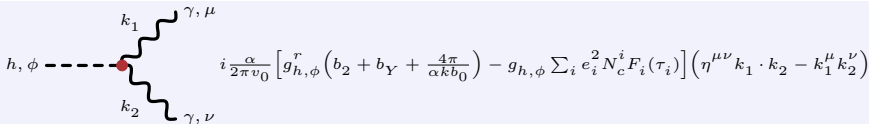
- The mixing angle θ is small for $\ell < 1/6$ ($\Lambda_\phi > 1.5$ TeV) and $m_h^2 \ll m_\phi^2$, then the scalar h couplings are very much like the SM.

- We identify h as the SM-like Higgs boson at 125 GeV.

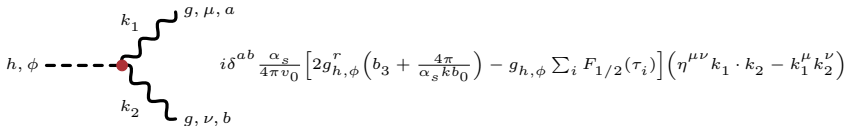- Can the radion ϕ be the 750 GeV resonance?

$h, \phi \quad\cdots\cdots\quad \begin{matrix} k_1 & W, \mu \\ & \\ k_2 & W, \nu \end{matrix}$

$$ig\, m_W \left(g_{h,\phi} - g^{r}_{h,\phi}\kappa_W\right)\left[\eta^{\mu\nu}\left(1 - 2k_1\cdot k_2\, g^{W}_{h,\phi}\right) + 2k_1^{\mu} k_2^{\nu}\, g^{W}_{h,\phi}\right]$$

$h, \phi \quad\cdots\cdots\quad \begin{matrix} k_1 & Z, \mu \\ & \\ k_2 & Z, \nu \end{matrix}$

$$ig\,\frac{m_Z}{c_W}\left(g_{h,\phi} - g^{r}_{h,\phi}\kappa_Z\right)\left[\eta^{\mu\nu}\left(1 - 2k_1\cdot k_2\, g^{Z}_{h,\phi}\right) + 2k_1^{\mu} k_2^{\nu}\, g^{Z}_{h,\phi}\right]$$

$h, \phi \quad\cdots\cdots\quad \begin{matrix} k_1 & \gamma, \mu \\ & \\ k_2 & \gamma, \nu \end{matrix}$

$$i\,\frac{\alpha}{2\pi v_0}\left[g^{r}_{h,\phi}\left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0}\right) - g_{h,\phi}\sum_i e_i^2 N_c^i F_i(\tau_i)\right]\left(\eta^{\mu\nu} k_1\cdot k_2 - k_1^{\mu} k_2^{\nu}\right)$$

$h, \phi \quad\cdots\cdots\quad \begin{matrix} k_1 & g, \mu, a \\ & \\ k_2 & g, \nu, b \end{matrix}$

$$i\delta^{ab}\,\frac{\alpha_s}{4\pi v_0}\left[2g^{r}_{h,\phi}\left(b_3 + \frac{4\pi}{\alpha_s k b_0}\right) - g_{h,\phi}\sum_i F_{1/2}(\tau_i)\right]\left(\eta^{\mu\nu} k_1\cdot k_2 - k_1^{\mu} k_2^{\nu}\right)$$

$h, \phi \quad\cdots\cdots\quad \begin{matrix} f \\ \\ \bar{f} \end{matrix}$

$$-i\,\frac{g}{2}\,\frac{m_f}{m_W}\,g_{h,\phi}$$

with $\quad g_h \equiv (d + \ell b), \quad g_\phi \equiv (c + \ell a), \quad g^{r}_h \equiv \ell b, \quad g^{r}_\phi \equiv \ell a,$

$$\kappa_V \equiv \frac{3m_V^2 k b_0}{2\Lambda_\phi^2 (k/M_{\text{Pl}})^2}, \quad g^{V}_{h,\phi} \equiv \frac{g^{r}_{h,\phi}}{g_{h,\phi} - \kappa_V g^{r}_{h,\phi}}\,\frac{1}{2m_V^2 k b_0}$$
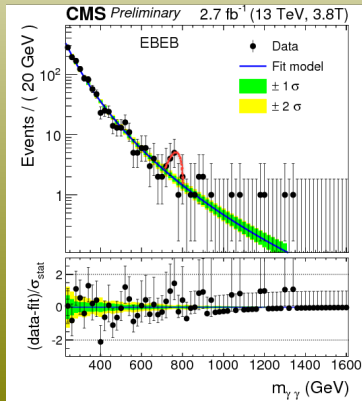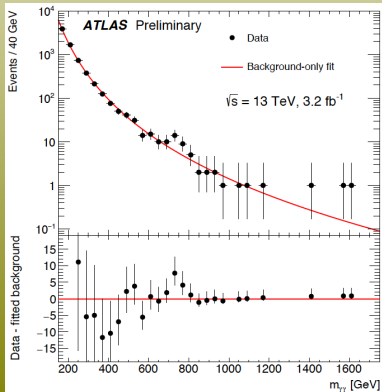
$$b_2 + b_Y = -11/3, \qquad b_3 = 7$$
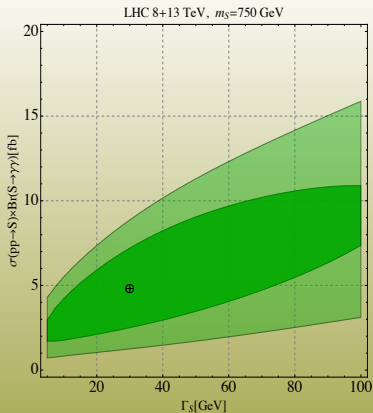
What is the $\gamma\gamma$ resonance at 750 GeV?

- ATLAS and CMS collaborations have observed di-photon excess at the invariant mass of ~ 750 GeV at energy $\sqrt{s} = 13$ TeV.

$\sigma(pp \to \gamma\gamma)$	ATLAS 3.9 σ	CMS 3.4 σ
8 TeV	(0.4 ± 0.6) fb	(0.5 ± 0.6) fb
13 TeV	(10 ± 3) fb	(6 ± 2.6) fb

LHC 8+13 TeV, m_S=750 GeV

from A. Falkowski, O. Slone and T. Volansky, JHEP 1602, 152 (2016), arXiv:1512.05777

$$\mathcal{L} \supset c_{sgg} \frac{g_s^2}{4v} S G_{\mu\nu}^a G^{a\,\mu\nu} + c_{s\gamma\gamma} \frac{e^2}{4v} S F_{\mu\nu} F^{\mu\nu}$$
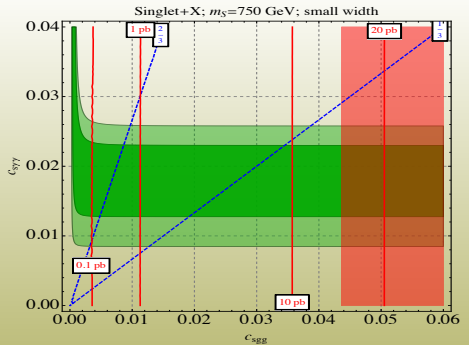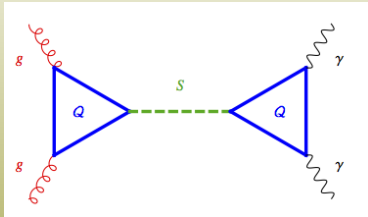
Singlet+X; m_S=750 GeV; small width

Figure from http://resonaances.blogspot.com/ and A. Falkowski, O. Slone and T. Volansky, JHEP 1602, 152 (2016), arXiv:1512.05777

$$\mathcal{L}_{\text{eff}} \supset c_{sgg} \frac{g_s^2}{4v} S G_{\mu\nu}^a G^{a\,\mu\nu} + c_{s\gamma\gamma} \frac{e^2}{4v} S F_{\mu\nu} F^{\mu\nu}$$

for $\mathcal{L} \supset -y_X S \bar{X} X$ and $X \sim (3, Q_X)$ for $Q_X = 1/3(2/3)$ one needs e.g. for $y_X = 10.8(2.7)$ to get $c_{s\gamma\gamma} = 0.02$.

Strong couplings are needed!

Bounds and compatibility
8 TeV vs 13 TeV

$\sigma(pp \rightarrow XX)_{750}$ upper bounds

XX	8 TeV	13 TeV
jj	$\lesssim 2.5$ pb	< 12.5 pb
$\bar{t}t$	< 300 fb	< 1500 fb
hh	< 39 fb	< 120 fb
$Z\gamma$	< 11 fb	< 28 fb
WW	< 38 fb	< 190 fb
ZZ	< 17 fb	< 85 fb
$\ell^+\ell^-$	$\lesssim 0.65$ fb	$\lesssim 2.25$ fb

- The gain factor $r \equiv \sigma_{13}/\sigma_8 \simeq 5$ for gg initiated processes.

- Hard to explain $\sigma(pp \rightarrow \gamma\gamma) \sim (3-10)$ fb in most of the BSM scenarios due to stringent 8 TeV constraints for the WW, ZZ, hh and $t\bar{t}$ channels.

- However, $300+$ papers appeared so far 'explaining' the signal by adding 'extra spices' to the elegant BSM models.

Higgs-radion Phenomenology: Model details

- SM gauge fields in the bulk, Higgs doublet localized at the IR-brane.

- EWPOs, in particular T parameter receive large corrections due to gauge KK-modes, therefore we employ custodial symmetry in the bulk.

Contours of Λ_ϕ (TeV)
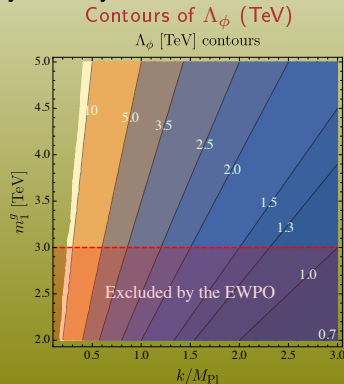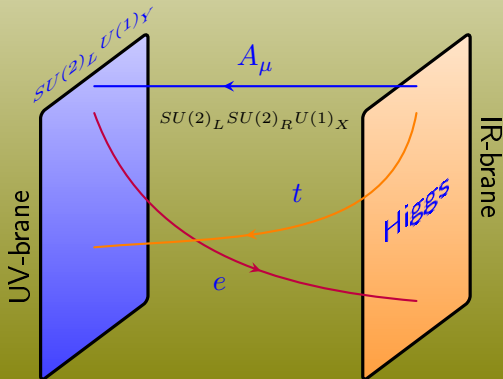
- EWPOs bound on 1st KK-gluon $m_1^g \gtrsim 3$ TeV, $m_1^g = \frac{x_1^g}{\sqrt{6}} \frac{k}{M_{Pl}} \Lambda_\phi$

Radion (dilaton) − SM interactions

■ For the SM fields localized at the IR-brane, the radion (like dilaton) couples with the trace of the energy-momentum tensor, i.e.

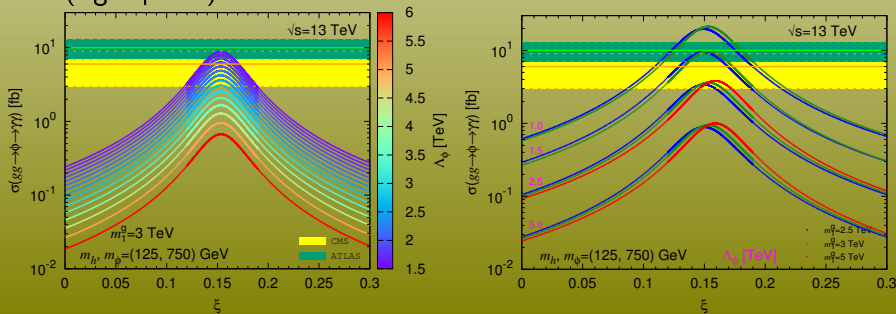$$\mathcal{L}_{\text{int}}^{\phi_0\text{-SM}} = -\frac{\phi_0}{\Lambda_\phi} T^\mu_\mu$$

■ With the Higgs-gravity mixing, the trace of the energy-momentum tensor could be rewritten (EoM) as

$$T^\mu_\mu = -(1-6\xi)\left[\partial_\mu h_0 \partial^\mu h_0 + m_V^2 V_{a\,\mu} V^{a\,\mu}\left(1+\frac{h_0}{v_0}\right)^2 - m_i\bar\psi_i\psi_i\left(1+\frac{h_0}{v_0}\right) - \lambda(v_0+h_0)^4\right]$$

$$-(1-3\xi)m_{h_0}^2(v_0+h_0)^2 + \underbrace{b_3\frac{\alpha_s}{8\pi}\text{Tr}[G_{\mu\nu}G^{\mu\nu}] + (b_2+b_Y)\frac{\alpha_{\text{QED}}}{8\pi}F_{\mu\nu}F^{\mu\nu}}_{\text{Trace anomaly terms}}$$
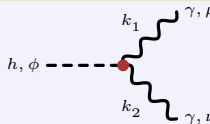
■ In the conformal limit $\xi = 1/6$, the radion couples to VV by the anomalous terms which break the scale (conformal) symmetry at the quantum level.
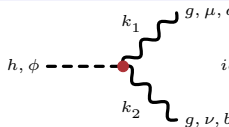
Phenomenology of the 750 GeV radion

- The Higgs-radion scenario gives a cross section of $(5-15)$ fb in the di-photon final state at 750 GeV for 1.5 TeV $\lesssim \Lambda_\phi \lesssim 3$ TeV near the conformal limit $\xi \approx 1/6$.

- The cross-section $\sigma(gg \to \phi \to \gamma\gamma)$ as a function of ξ for $m_h = 125$ GeV, $m_\phi = 750$ GeV and $m_1^g = 3$ TeV (left panel).

- The cross-section $\sigma(gg \to \phi \to \gamma\gamma)$ for different values of m_1^g and Λ_ϕ (right panel).

gg and γγ enhancement - deconstruction

h, ϕ ---- $\begin{matrix} k_1 & \gamma, \mu \\ & \\ k_2 & \gamma, \nu \end{matrix}$ $\quad i\frac{\alpha}{2\pi v_0}\left[g_{h,\phi}^r\left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0}\right) - g_{h,\phi}\sum_i e_i^2 N_c^i F_i(\tau_i)\right]\left(\eta^{\mu\nu}k_1 \cdot k_2 - k_1^\mu k_2^\nu\right)$

h, ϕ ---- $\begin{matrix} k_1 & g, \mu, a \\ & \\ k_2 & g, \nu, b \end{matrix}$ $\quad i\delta^{ab}\frac{\alpha_s}{4\pi v_0}\left[2g_{h,\phi}^r\left(b_3 + \frac{4\pi}{\alpha_s k b_0}\right) - g_{h,\phi}\sum_i F_{1/2}(\tau_i)\right]\left(\eta^{\mu\nu}k_1 \cdot k_2 - k_1^\mu k_2^\nu\right)$

with $\quad g_h \equiv (d + \ell b), \quad g_\phi \equiv (c + \ell a), \quad g_h^r \equiv \ell b, \quad g_\phi^r \equiv \ell a, \quad b_2 + b_Y = -11/3, \quad b_3 = 7$

ϕgg: $\propto \left[2g_\phi^r\left(b_3 + \frac{4\pi}{\alpha_s k b_0}\right) - g_\phi \sum_i F_{1/2}(\tau_i)\right]\left(\eta^{\mu\nu}k_1 \cdot k_2 - k_1^\mu k_2^\nu\right)$

$\phi\gamma\gamma$: $\propto \left[g_\phi^r\left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0}\right) - g_\phi \sum_i e_i^2 N_c^i F_i(\tau_i)\right]\left(\eta^{\mu\nu}k_1 \cdot k_2 - k_1^\mu k_2^\nu\right)$

gg and $\gamma\gamma$ enhancement - deconstruction

For small θ ($\theta \lesssim (1/6)^3$) and $\xi = 1/6$: $g_\phi^r \sim \ell$ and $g_\phi \sim 0$
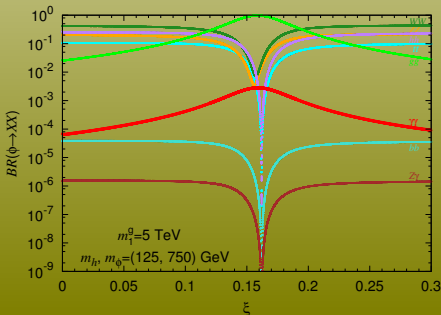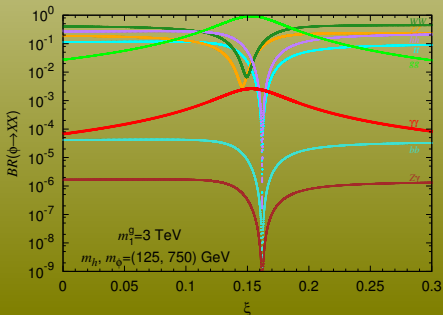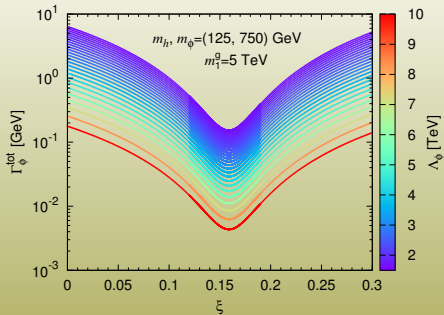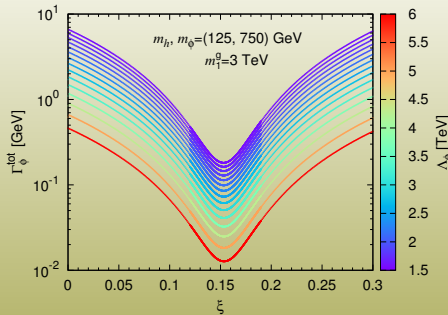
- ϕgg:

$$\propto \left[2g_\phi^r \left(b_3 + \frac{4\pi}{\alpha_s k b_0} \right) - g_\phi \sum_i F_{1/2}(\tau_i) \right] \simeq \left(b_3 + \frac{4\pi}{\alpha_s k b_0} \right) \simeq \left(7 + 1.8 \right)$$

- $\phi\gamma\gamma$:

$$\propto \left[g_\phi^r \left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0} \right) - g_\phi \sum_i e_i^2 N_c^i F_i(\tau_i) \right]$$

$$\simeq \left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0} \right) \simeq \left(-11/3 + 22 \right)$$

gravitational $\phi\gamma\gamma$ intercations $\Rightarrow$ no dim4 strong coupling is needed!

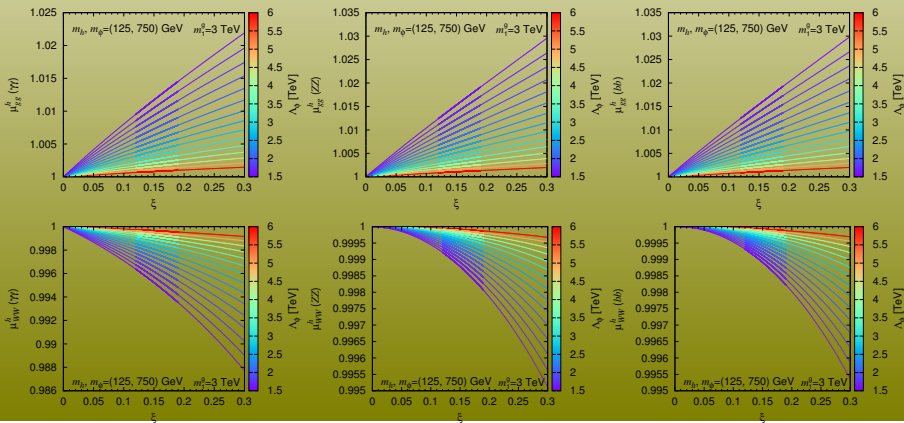# Phenomenology of the 750 GeV radion

Phenomenology of the 125 GeV Higgs

- The Higgs-radion scenario must fit the Higgs data for the 125 GeV state.

- Below we show $\mu_Y^h(X)$, where $X = \gamma\gamma$, ZZ, $b\bar{b}$ and $Y = gg$, WW as functions of ξ for $m_h = 125$ GeV, $m_\phi = 750$ GeV and $m_1^g = 3$ TeV:

$$\mu_Y^h(X) \equiv \frac{\sigma(Y \to h \to X)}{\sigma_{SM}(Y \to h \to X)}$$

Radion@750 GeV: Benchmarcks

BMP	m_1^g[GeV]	ξ	Λ_ϕ[TeV]	k/M_{Pl}	$\mu_{gg}^h(\gamma\gamma)$	$\mu_{gg}^h(ZZ)$	$\mu_{WW}^h(ZZ)$
1	3	0.153	1.5	2	1.013	1.017	0.999
2	5	0.159	1.67	3	1.011	1.015	0.999
3	5	0.159	2.0	2.5	1.008	1.01	0.999
4	5	0.159	2.5	2	1.005	1.006	1.000
5	5	0.159	2.78	1.8	1.004	1.005	1.000
6	3	0.148	1.87	1.6	1.008	1.011	0.999
7	5	0.167	1.67	3.0	1.012	1.015	0.999

BMP	Γ_ϕ^{tot}[GeV]	$\sigma_{gg}^\phi(\gamma\gamma)$	$\sigma_{gg}^\phi(jj)$	$\sigma_{gg}^\phi(ZZ)$	$\sigma_{gg}^\phi(WW)$	$\sigma_{gg}^\phi(\bar{t}t)$	$\sigma_{gg}^\phi(hh)$
1	0.201	9.70	3.54	51.2	38.2	32.5	75.2
2	0.153	8.37	3.05	12.8	17.6	3.38	7.78
3	0.106	5.89	2.12	8.86	12.3	2.35	5.42
4	0.068	3.83	1.36	5.65	7.88	1.50	3.48
5	0.055	3.12	1.01	4.71	6.55	1.14	2.65
6	0.135	6.01	2.18	6.5	14.0	51.5	120
7	0.168	7.64	2.77	77.1	122	6.52	15.2
upper bounds @ 13 TeV		12.5	85	190	1500	120

$\sigma_{gg}^\phi(VV, tt, hh)$ [fb] and $\sigma_{gg}^\phi(jj)$ [pb]. $\sigma_{gg}^\phi(Z\gamma) \lesssim 10^{-3}$ fb for all BMPs

Summary

- The Higgs-radion scenario predicts two relatively light scalar state h and ϕ.

- We interpret the state h as the SM-like Higgs at 125 GeV with small mixing angle and $\xi \approx 1/6$.

- We have shown that (Higgs-)radion ϕ can be 750 GeV state with the cross section of (5-15) fb in the di-photon final state, while at the same time satisfying all the current experimental bounds.

Backup slides