

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

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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. B* **712** (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. B* **671** (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. B* **33** (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 $m_\nu \lesssim 10^{-9} \text{ GeV} \ll m_t \sim 10^3 \text{ GeV}$?
- *Dark matter and so on $\dots$.*

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- *Dark matter and so on ...*



Large extra-dimensions

- Flat extra-dimensions (e.g. ADD, UED).
- Warped extra-dimensions (e.g. RS).

[hep-ph/9803315](#); [9804398](#); [9807344](#)

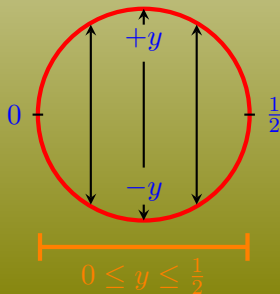
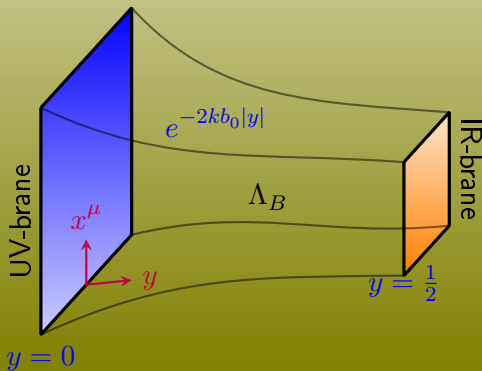
[hep-ph/9905221](#); [hep-th/9906064](#)

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.



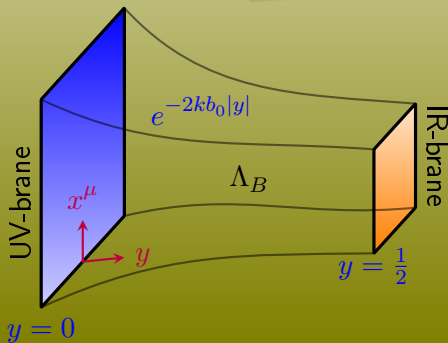
RS1 background solution

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:

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



- Negative 5D cosmological const.

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

- Fine tuning to have 4D cosmological constant zero.

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

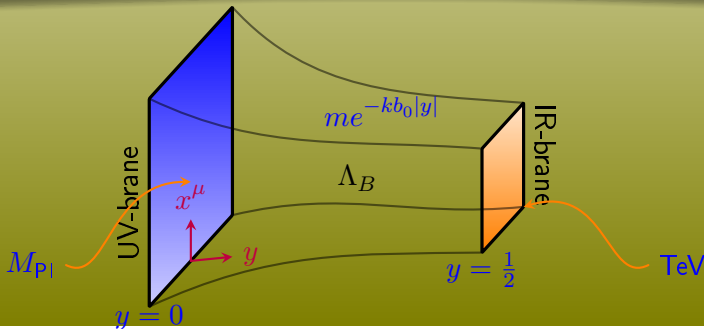
RS solution to the hierarchy problem

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

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

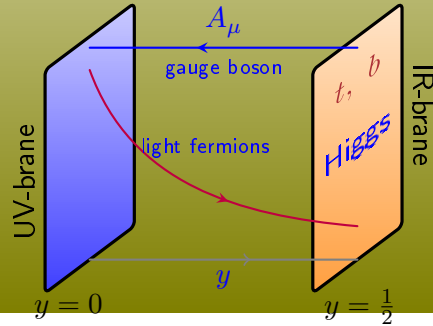
- The physical (observed) mass scales on the IR-brane (our brane) are rescaled due to the non-trivial warp factor e^{-kL}

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



Warped models

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



- Zero-modes of bulk fermions and gauge bosons correspond to the SM fields.
- Overlap integrals of fermionic wavefunctions 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:

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

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

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

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

- The standard gravity is reproduced by requiring

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

- 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

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

- Ansatz:

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

- Solution

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

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:

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

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

- Trace anomaly:

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

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

$$S = \int d^4x dy \sqrt{-g} \left[-\frac{1}{4} g^{MN} g^{KL} F_{MK} F_{NL} - \frac{1}{2} g^{MN} g^{KL} W_{MK}^\dagger W_{NL} \right. \\ \left. + g^{\mu\nu} \frac{\delta(y - \frac{1}{2})}{\sqrt{g_{55}}} (g_5 v)^2 W_\mu^\dagger W_\nu + \dots \right]$$

- 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

$$S_{\text{IR}} = \int d^4x \sqrt{|g_4|} \left[\xi R(g_4) \hat{H}^\dagger \hat{H} + g_4^{\mu\nu} D_\mu \hat{H}^\dagger D_\nu \hat{H} - V(\hat{H}) \right] \\ + \int d^4x \left[\frac{1}{2} \partial_\mu \phi_0 \partial^\mu \phi_0 - \frac{1}{2} m_{\phi_0}^2 \phi_0^2 \right]$$

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

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

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

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

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

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

Higgs-radion mixing

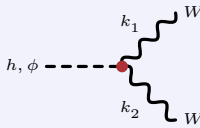
- Mass eigenstate basis for the Higgs-radion system

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

$$a = -\cos \theta/Z, \quad b = \sin \theta/Z, \quad c = \sin \theta + t \cos \theta \quad \text{and} \quad d = \cos \theta - t \sin \theta$$

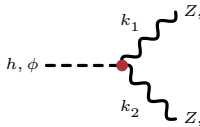
$$t \equiv 6\xi\ell/Z, \quad Z^2 \equiv 1+6\xi\ell^2(1-6\xi) \quad \text{and} \quad \tan 2\theta \sim 12\xi\ell \left(\frac{m_h}{m_\phi}\right)^2 \left[1 - 3\xi(1-6\xi)\ell^2\right]$$

- 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?



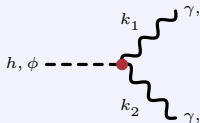
A Feynman diagram showing a dashed line labeled h, ϕ entering a red vertex. From this vertex, two wavy lines emerge: one labeled k_1 and W, μ , and the other labeled k_2 and W, ν .

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



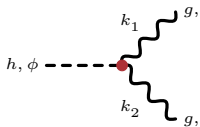
A Feynman diagram showing a dashed line labeled h, ϕ entering a red vertex. From this vertex, two wavy lines emerge: one labeled k_1 and Z, μ , and the other labeled k_2 and Z, ν .

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



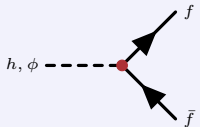
A Feynman diagram showing a dashed line labeled h, ϕ entering a red vertex. From this vertex, two wavy lines emerge: one labeled k_1 and γ, μ , and the other labeled k_2 and γ, ν .

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



A Feynman diagram showing a dashed line labeled h, ϕ entering a red vertex. From this vertex, two wavy lines emerge: one labeled k_1 and g, μ, a , and the other labeled k_2 and g, ν, b .

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



A Feynman diagram showing a dashed line labeled h, ϕ entering a red vertex. From this vertex, two solid lines emerge: one labeled f and the other labeled $\bar{f}$.

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

with $g_h \equiv (d + \ell b)$, $g_\phi \equiv (c + \ell a)$, $g_h^r \equiv \ell b$, $g_\phi^r \equiv \ell a$,

$$\kappa_V \equiv \frac{3m_V^2 k b_0}{2\Lambda_\phi^2 (k/M_{\mathbf{Pl}})^2}, \quad g_{h,\phi}^V \equiv \frac{g_{h,\phi}^r}{g_{h,\phi} - \kappa_V g_{h,\phi}^r} \frac{1}{2m_V k b_0}$$

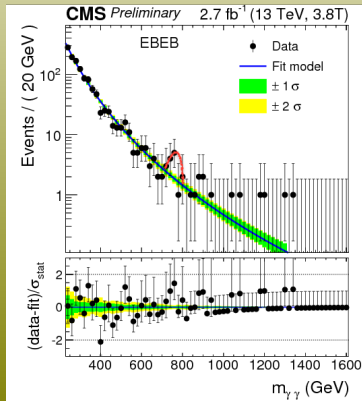
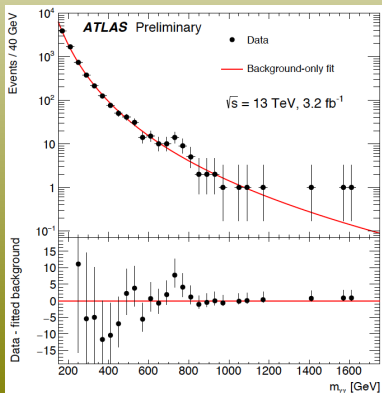
$$b_2 + b_Y = -11/3,$$

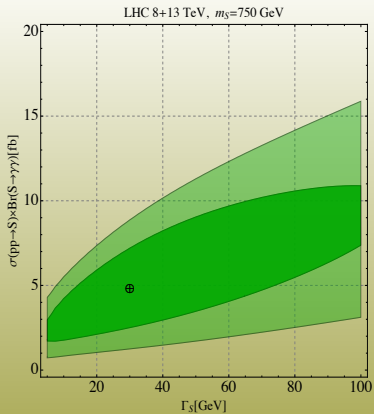
$$b_3 = 7$$

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.

$\sigma(pp \rightarrow \gamma\gamma)$	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





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

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

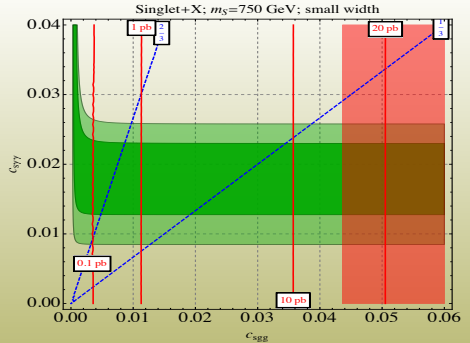
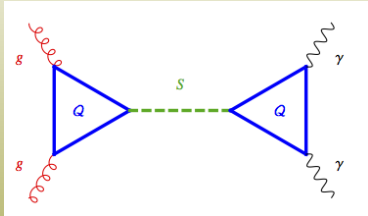


Figure from <http://resonaances.blogspot.com/> and A. Falkowski, O. Slone and T. Volansky, JHEP 1602, 152 (2016), arXiv:1512.05777

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

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

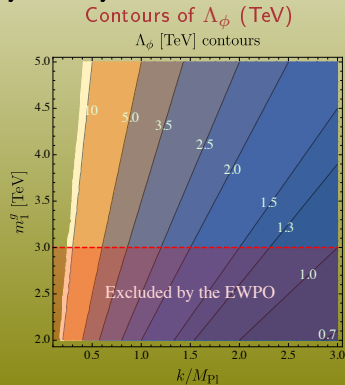
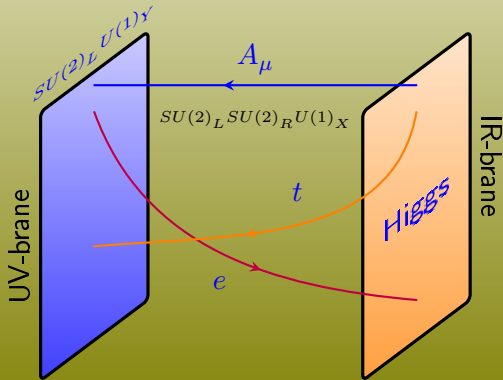
XX	8 TeV	13 TeV
jj	$\lesssim 2.5$ pb	< 12.5 pb
$t\bar{t}$	< 300 fb	< 1500 fb
hh	< 39 fb	< 120 fb
$Z\gamma$	< 11 fb	< 28 fb
WW	< 38 fb	< 190 fb
ZZ	< 17 fb	< 85 fb
$\ell^+\ell^-$	$\lesssim 0.65$ fb	$\lesssim 2.25$ fb

- 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.



- 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.

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

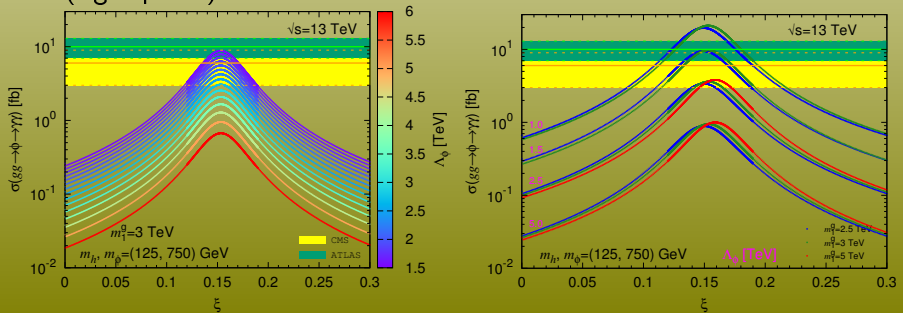
- With the Higgs-gravity mixing, the trace of the energy-momentum tensor could be rewritten (EoM) as

$$T^\mu_\mu = - (1 - 6\xi) \left[\partial_\mu h_0 \partial^\mu h_0 + m_V^2 V_a{}_\mu V^a{}^\mu \left(1 + \frac{h_0}{v_0} \right)^2 - m_i \bar{\psi}_i \psi_i \left(1 + \frac{h_0}{v_0} \right) - \lambda (v_0 + h_0)^4 \right] \\ - (1 - 3\xi) m_{h_0}^2 (v_0 + h_0)^2 + \underbrace{b_3 \frac{\alpha_s}{8\pi} \text{Tr}[G_{\mu\nu} G^{\mu\nu}] + (b_2 + b_Y) \frac{\alpha_{\text{QED}}}{8\pi} F_{\mu\nu} F^{\mu\nu}}_{\text{Trace anomaly terms}}$$

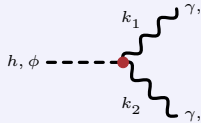
- In the conformal limit $\xi = 1/6$, the radion couples to VV by the anomalous terms which break the scale (conformal) symmetry at the quantum level.

Phenomenology of the 750 GeV radion

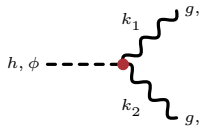
- The Higgs-radion scenario gives a cross section of $(5 - 15)$ fb in the di-photon final state at 750 GeV for $1.5 \text{ TeV} \lesssim \Lambda_\phi \lesssim 3 \text{ TeV}$ near the conformal limit $\xi \approx 1/6$.
- The cross-section $\sigma(gg \rightarrow \phi \rightarrow \gamma\gamma)$ as a function of ξ for $m_h = 125 \text{ GeV}$, $m_\phi = 750 \text{ GeV}$ and $m_1^g = 3 \text{ TeV}$ (left panel).
- The cross-section $\sigma(gg \rightarrow \phi \rightarrow \gamma\gamma)$ for different values of m_1^g and Λ_ϕ (right panel).



gg and $\gamma\gamma$ enhancement - deconstruction



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



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

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

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

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

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 :

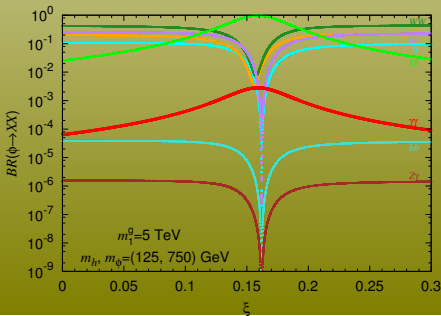
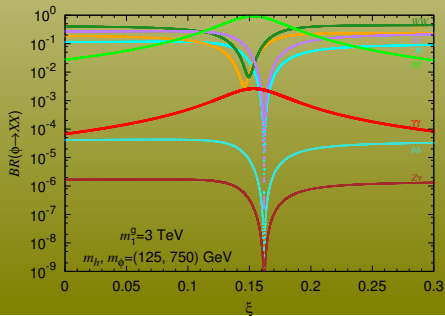
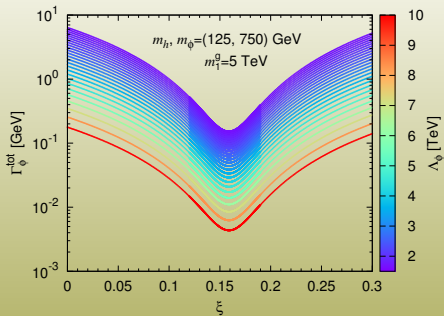
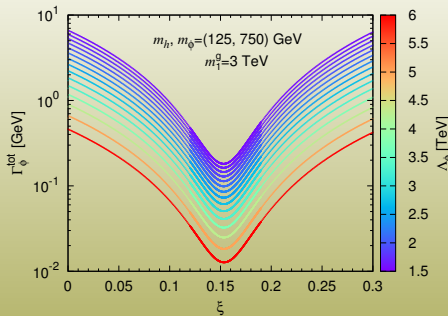
$$\propto \left[2g_\phi^r \left(b_3 + \frac{4\pi}{\alpha_s k b_0} \right) - g_\phi \sum_i F_{1/2}(\tau_i) \right] \simeq \left(b_3 + \frac{4\pi}{\alpha_s k b_0} \right) \simeq (7 + 1.8)$$

■ $\phi\gamma\gamma$:

$$\begin{aligned} &\propto \left[g_\phi^r \left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0} \right) - g_\phi \sum_i e_i^2 N_c^i F_i(\tau_i) \right] \\ &\simeq \left(b_2 + b_Y + \frac{4\pi}{\alpha k b_0} \right) \simeq (-11/3 + 22) \end{aligned}$$

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

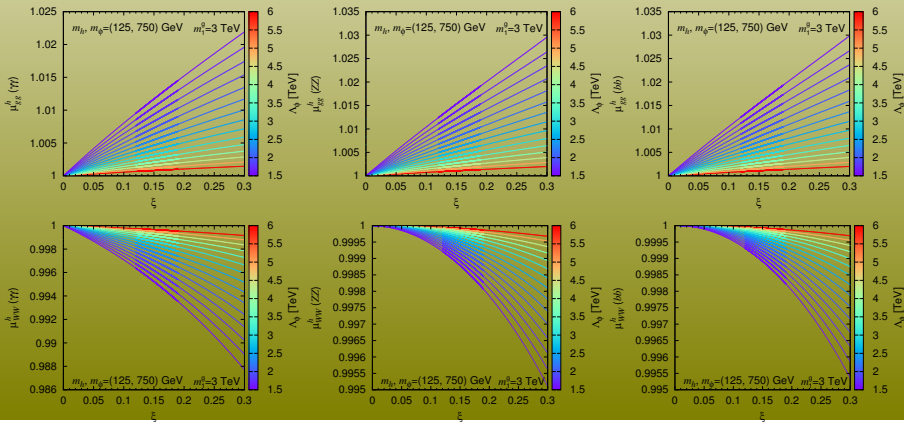
Phenomenology of the 750 GeV radion



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:

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



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]	$\sigma_{gg}^\phi(\gamma\gamma)$	$\sigma_{gg}^\phi(jj)$	$\sigma_{gg}^\phi(ZZ)$	$\sigma_{gg}^\phi(WW)$	$\sigma_{gg}^\phi(t\bar{t})$	$\sigma_{gg}^\phi(hh)$
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

$\sigma_{gg}^\phi(VV, t\bar{t}, hh)$ [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