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

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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. 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

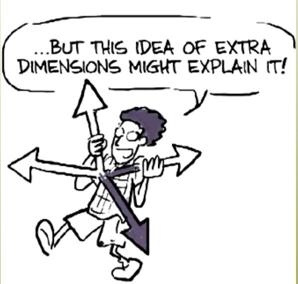
Why extra-dimensions

- (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* $\cdots$.

Why extra-dimensions



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

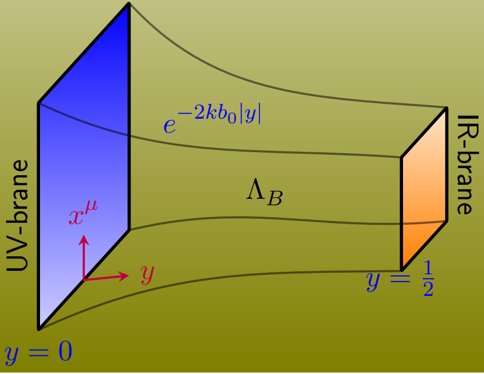
Large extra-dimensions

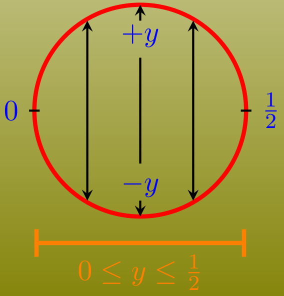
- Flat extra-dimensions (e.g. ADD, UED). hep-ph/9803315; 9804398; 9807344
- Warped extra-dimensions (e.g. RS). hep-ph/9905221; hep-th/9906064

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.





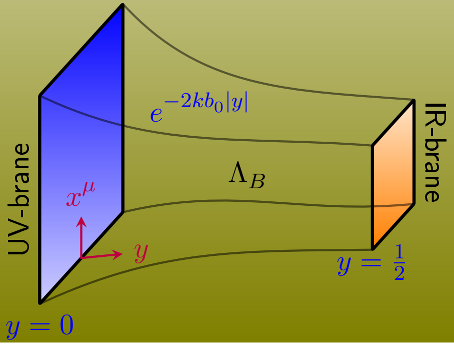
RS1 background solution

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:

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



- Negative 5D cosmological const.

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

- Fine tuning to have 4D cosmological constant zero.

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

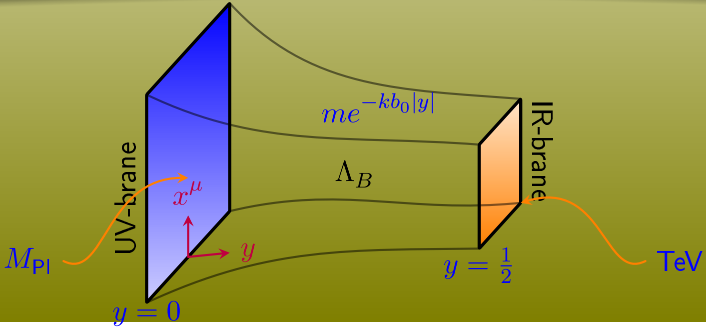
RS solution to the hierarchy problem

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

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

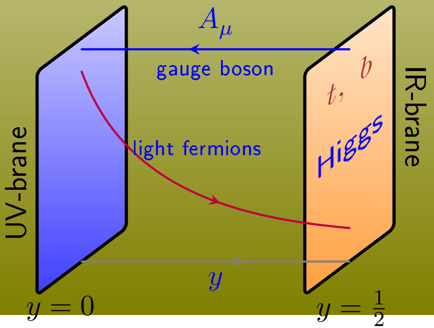
- The physical (observed) mass scales on the IR-brane (our brane) are rescaled due to the non-trivial warp factor e^{-kL}

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



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 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):

$$S_{\text{IR}} = \int d^4x \sqrt{|g_{IR}|}\left[-\frac{M_*^3(1-\Omega_b^2)}{k} R_{IR} + \frac{6M_*^3}{k}\partial_\mu\Omega_b\,\partial^\mu\Omega_b + \cdots \right]$$

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

- The standard gravity is reproduced by requiring

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

- 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

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

- 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:

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

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

- Trace anomaly:

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

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

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

- 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:

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

Higgs-radion mixing

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

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

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

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

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

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

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

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

Higgs-radion mixing

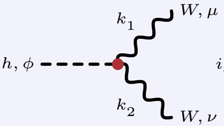
- Mass eigenstate basis for the Higgs-radion system

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

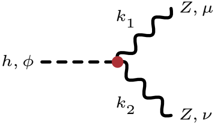
$$\boxed{a = -\cos\theta/Z,\ b = \sin\theta/Z,\ c = \sin\theta + t\cos\theta \text{ and } d = \cos\theta - t\sin\theta}$$

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

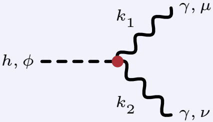
- The mixing angle θ is small for $\ell < 1/6$ ($\Lambda_\phi > 1.5$ TeV) and $m_h^2 \ll m_\phi^2$, then the scalar h couplings are very much like the SM.
- We identify h as the SM-like Higgs boson at 125 GeV.
- Can the radion ϕ be the 750 GeV resonance?



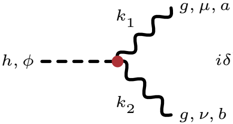
$$i g m_W \left(g_{h,\phi} - g^r_{h,\phi}\kappa_W\right)\left[\eta^{\mu\nu}\left(1 - 2k_1\cdot k_2 g^W_{h,\phi}\right) + 2k_1^\mu k_2^\nu g^W_{h,\phi}\right]$$



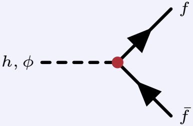
$$i g \frac{m_Z}{c_W}\left(g_{h,\phi} - g^r_{h,\phi}\kappa_Z\right)\left[\eta^{\mu\nu}\left(1 - 2k_1\cdot k_2 g^Z_{h,\phi}\right) + 2k_1^\mu k_2^\nu g^Z_{h,\phi}\right]$$



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



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



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

with $\quad g_h \equiv (d + \ell b), \quad g_\phi \equiv (c + \ell a), \quad g^r_h \equiv \ell b, \quad g^r_\phi \equiv \ell a,$

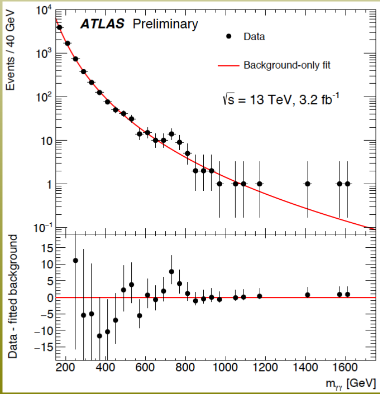
$$\kappa_V \equiv \frac{3 m_V^2 k b_0}{2\Lambda_\phi^2 (k/M_{\mathbf{Pl}})^2}, \quad g^V_{h,\phi} \equiv \frac{g^r_{h,\phi}}{g_{h,\phi} - \kappa_V g^r_{h,\phi}}\frac{1}{2m_V^2 k b_0}$$

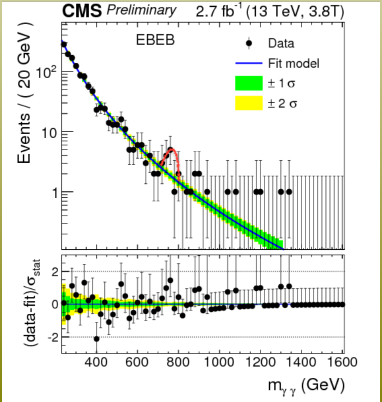
$$b_2 + b_Y = -11/3, \qquad b_3 = 7$$

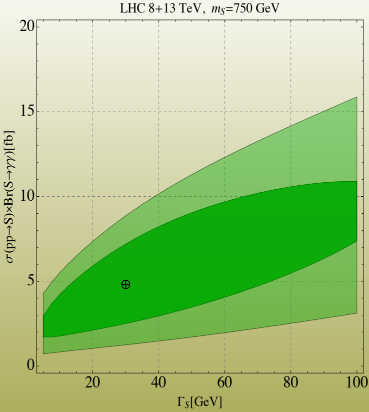
What is the $\gamma\gamma$ resonance at 750 GeV?

- 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 $3.9\ \sigma$	CMS $3.4\ \sigma$
8 TeV	(0.4 ± 0.6) fb	(0.5 ± 0.6) fb
13 TeV	(10 ± 3) fb	(6 ± 2.6) fb

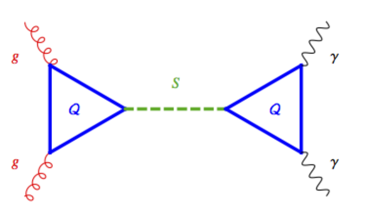






from A. Falkowski, O. Slone and T. Volansky, JHEP 1602, 152 (2016), arXiv:1512.05777

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



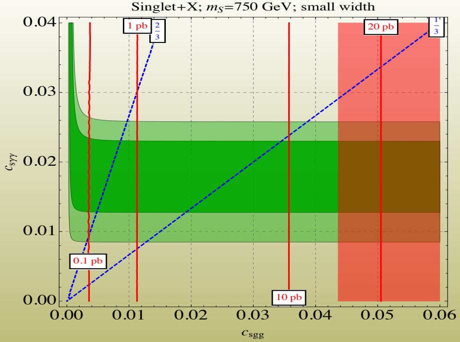


Figure from http://resonaances.blogspot.com/ and A. Falkowski, O. Slone and T. Volansky, JHEP 1602, 152 (2016), arXiv:1512.05777

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

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

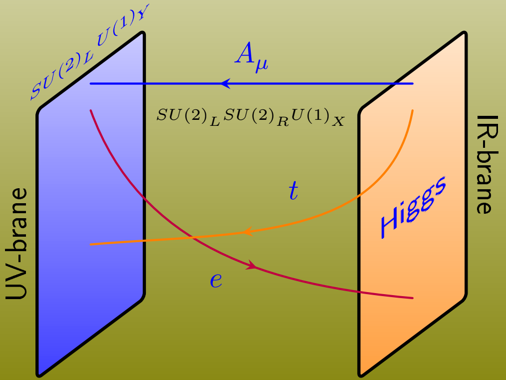
$\sigma(pp \to XX)_{750}$ upper bounds

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

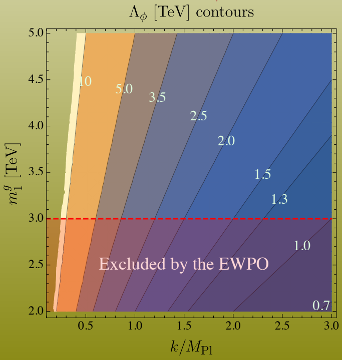
- The gain factor $r \equiv \sigma_{13}/\sigma_8 \simeq 5$ for gg initiated processes.
- Hard to explain $\sigma(pp \to \gamma\gamma) \sim (3-10)$ fb in most of the BSM scenarios due to stringent 8 TeV constraints for the WW, ZZ, hh and $t\bar{t}$ channels.
- However, $300+$ papers appeared so far 'explaining' the signal by adding 'extra spices' to the elegant BSM models.

Higgs-radion Phenomenology: Model details

- SM fields in the bulk, whereas 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, $m_1^g = \frac{x_1^g}{\sqrt{6}} \frac{k}{M_{\rm Pl}} \Lambda_\phi$

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.

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

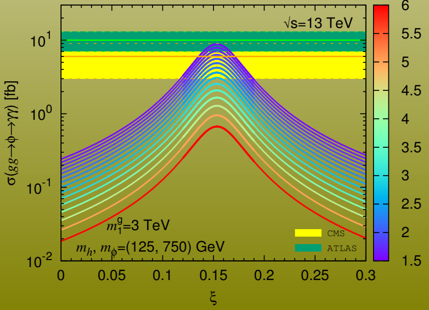
- With the Higgs-gravity mixing, the trace of the energy-momentum tensor could be rewritten (EoM) as

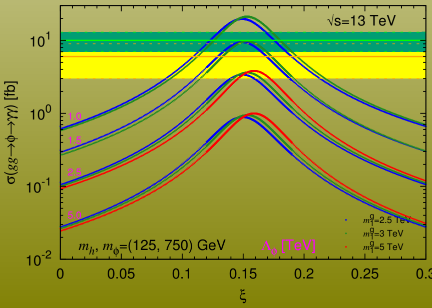
$$T^\mu_\mu = -(1-6\xi)\left[\partial_\mu h_0 \partial^\mu h_0 + m_V^2 V_{a\,\mu} V^{a\,\mu}\left(1+\frac{h_0}{v_0}\right)^2 - m_i \bar\psi_i \psi_i \left(1+\frac{h_0}{v_0}\right) - \lambda (v_0+h_0)^4\right]$$
$$-(1-3\xi) m_{h_0}^2 (v_0+h_0)^2 + \underbrace{b_3 \frac{\alpha_s}{8\pi} \mathrm{Tr}[G_{\mu\nu}G^{\mu\nu}]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

- 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.

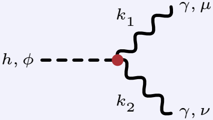
Phenomenology of the 750 GeV radion

- 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).

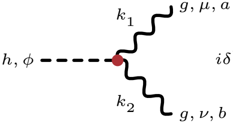




gg and $\gamma\gamma$ enhancement - deconstruction



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



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

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

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

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

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:

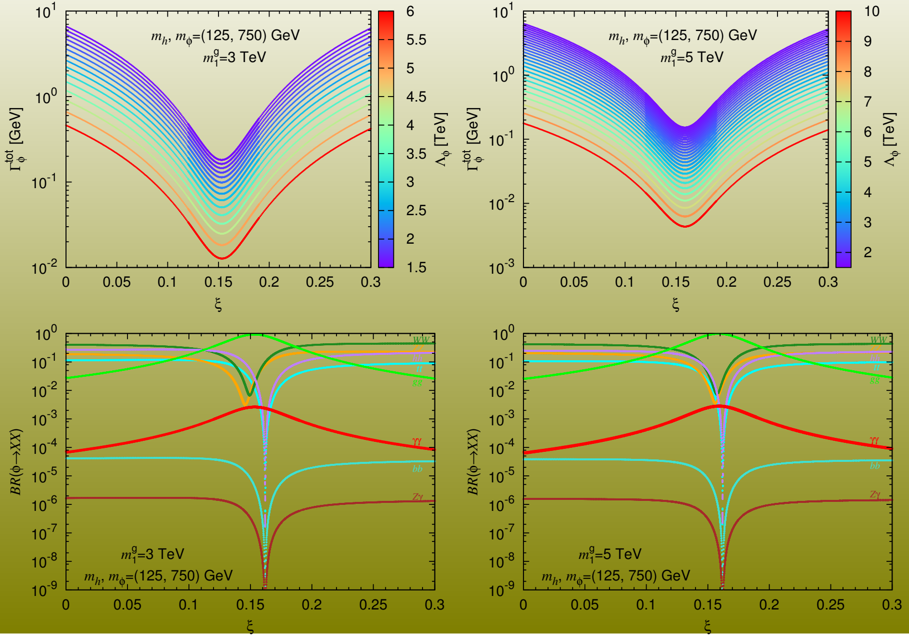
$$\propto \left[2g_\phi^r\left(b_3 + \frac{4\pi}{\alpha_s k b_0}\right) - g_\phi \sum_i F_{1/2}(\tau_i)\right] \simeq \left(b_3 + \frac{4\pi}{\alpha_s k b_0}\right) \simeq \left(7 + 1.8\right)$$

- $\phi\gamma\gamma$:

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

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

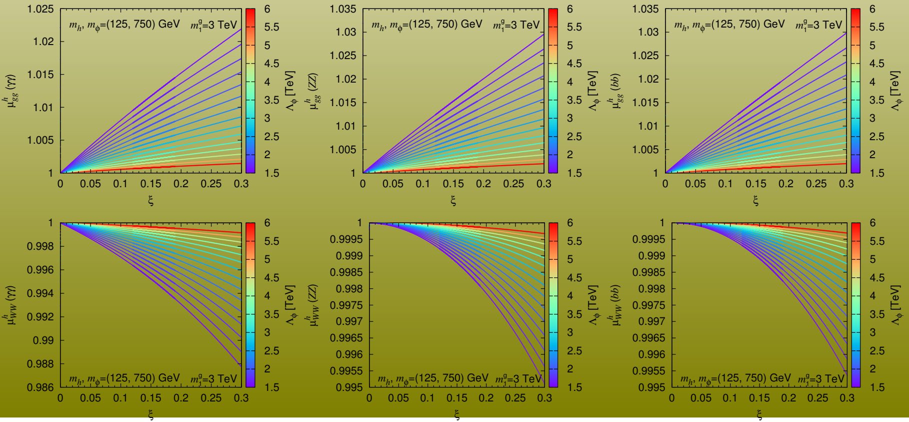
Phenomenology of the 750 GeV radion



Phenomenology of the 750 GeV radion

- The Higgs-radion scenario must fit the Higgs data for the 125 GeV state.
- Below we show $\mu^h_Y(X)$, 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:

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



Radion@750 GeV: Benchmarcks

BMP	m_1^g[GeV]	ξ	Λ_ϕ[TeV]	$k/M_{\rm Pl}$	$\mu_{gg}^h(\gamma\gamma)$	$\mu_{gg}^h(ZZ)$	$\mu_{WW}^h(ZZ)$
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	$\Gamma_\phi^{\rm tot}$[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].

$\boxed{\sigma_{gg}^\phi(Z\gamma) \lesssim 10^{-3} \text{ fb for all BMPs}}$

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.