Neutral Pion-like Resonances at Photon Colliders

7th ACFA 2004 Kingman Cheung, Hsin-Wu Tseng (hep-ph/0410231)

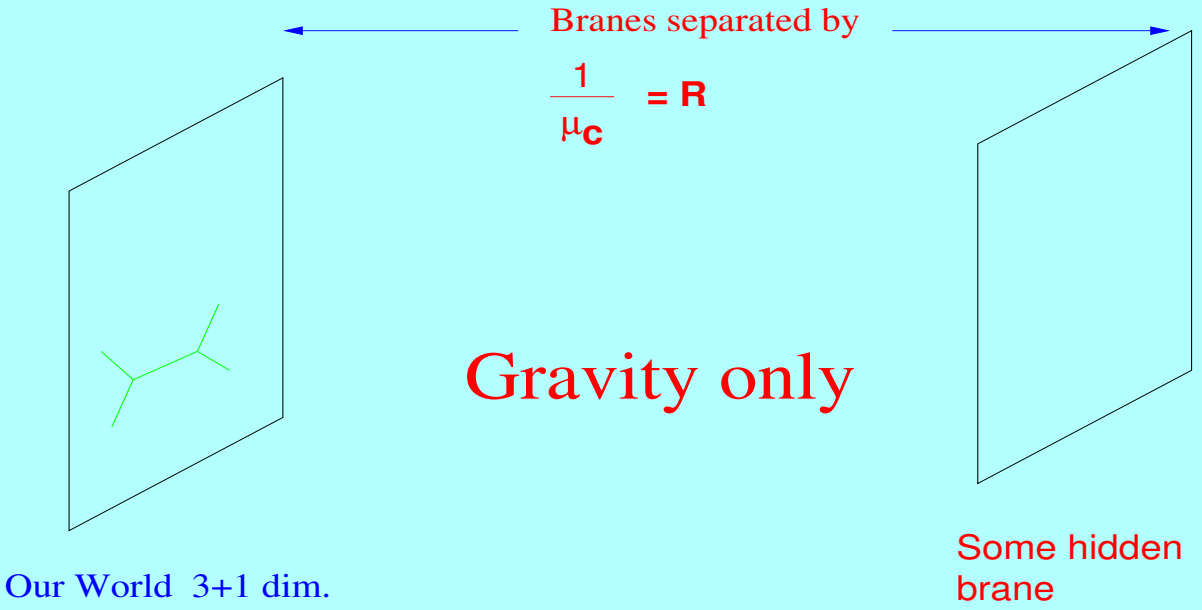
Outline

- What so unique about $\gamma\gamma$ collisions in probing new physics
- Highlights from large extra dimensions and Randall-Sundrum scenarios
- Techni-Pions of TC model

What so unique of $\gamma\gamma$ Collisions

- The SM $\gamma\gamma \to \gamma\gamma$ amplitude only goes through box diagrams, so highly suppressed.
- Any new physics that involves tree-level exchanges would be easily seen over the SM background.
- In particular, those with anomaly-type couplings to $\gamma\gamma$.
- Examples are low-scale gravity, the radion of RS model, techni-pions, ...

Low-scale gravity (ADD model)

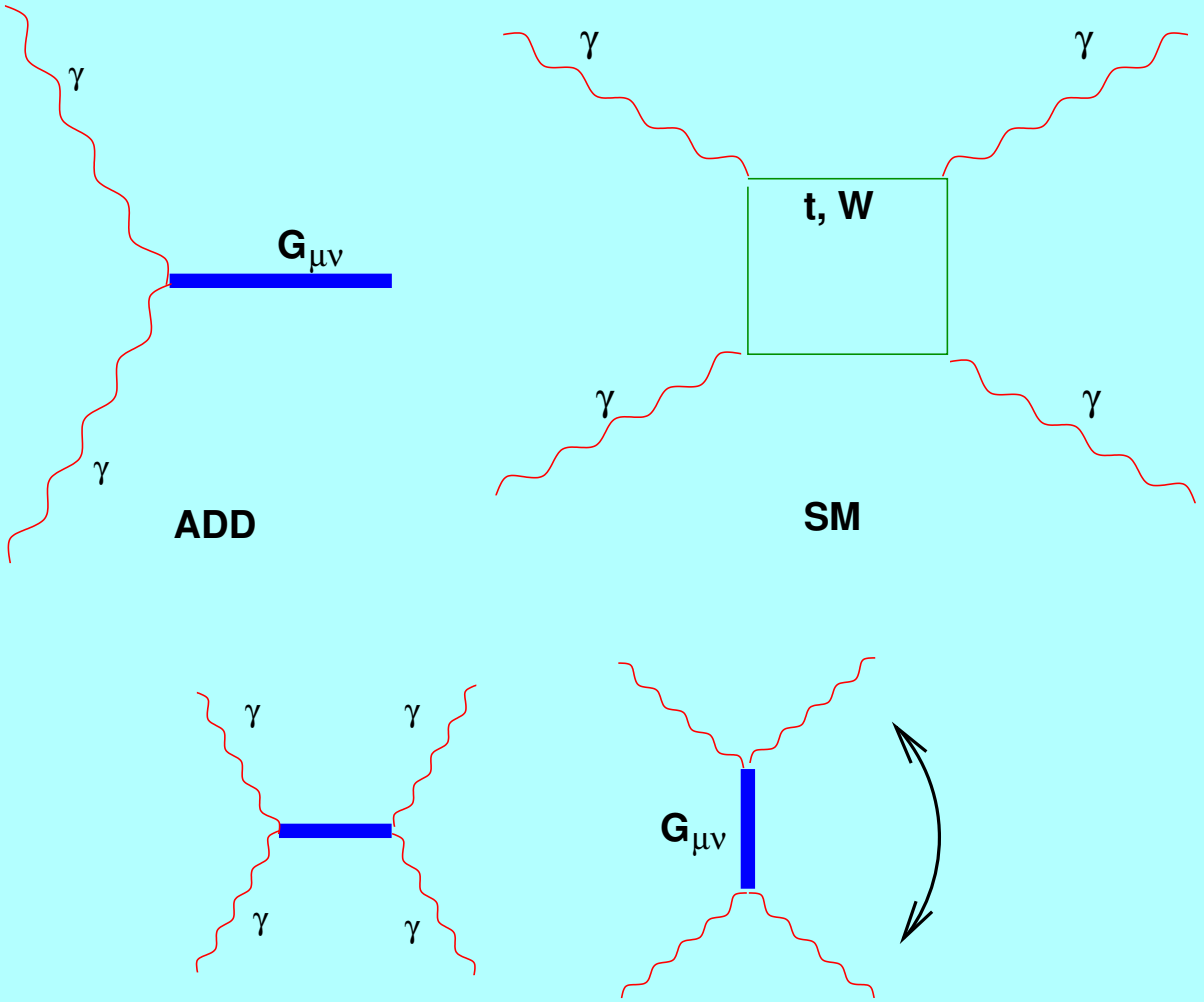


The size of the extra dimensions can be as large as $R \lesssim 1$ mm.

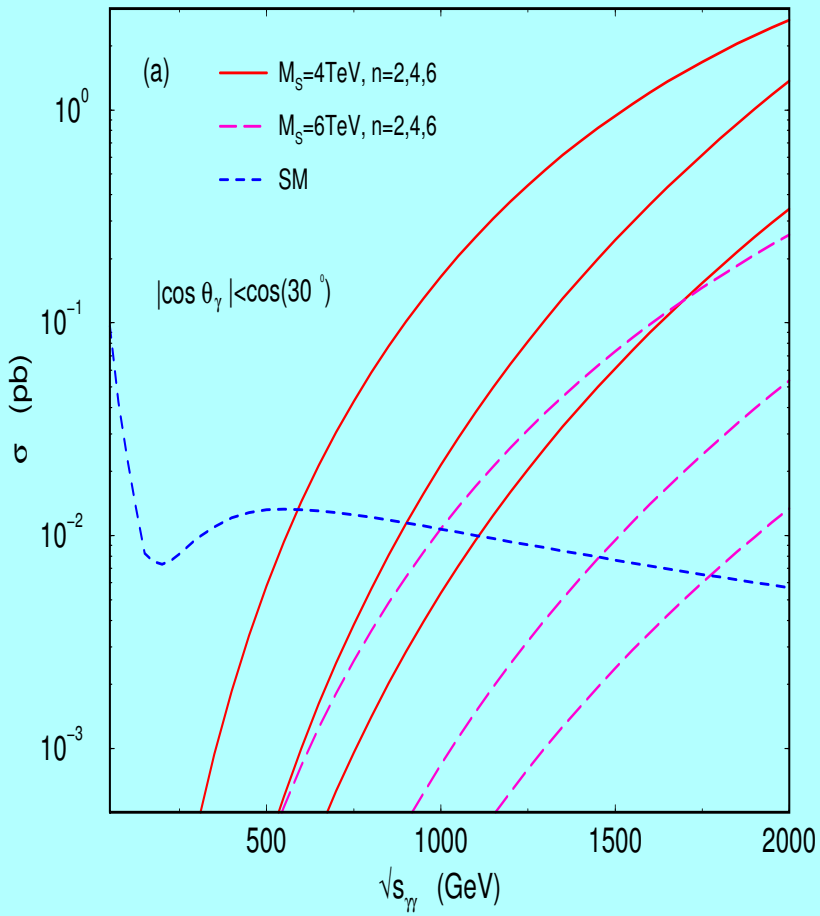
$$\mu_c \equiv R^{-1} \gtrsim 10^{-4} \text{ eV} \ll M_{\text{EW}}$$

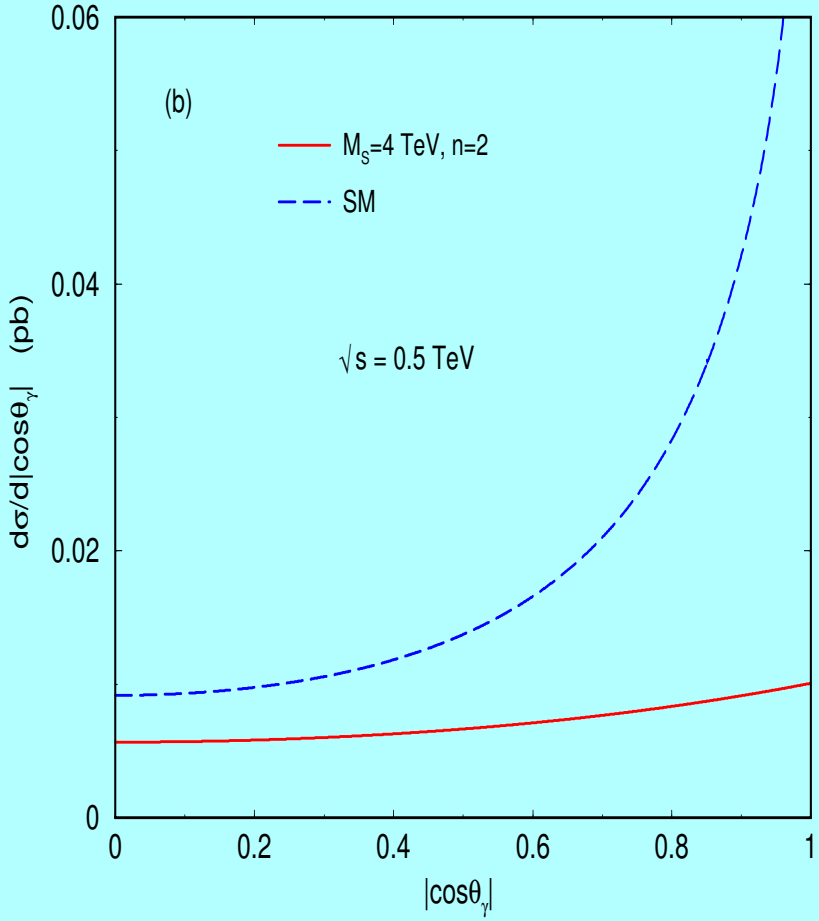
$$M_{\text{Pl}}^2 \sim M_D^{n+2} \, R^n \qquad \text{(Gauss)}$$

Light-by-light Scattering

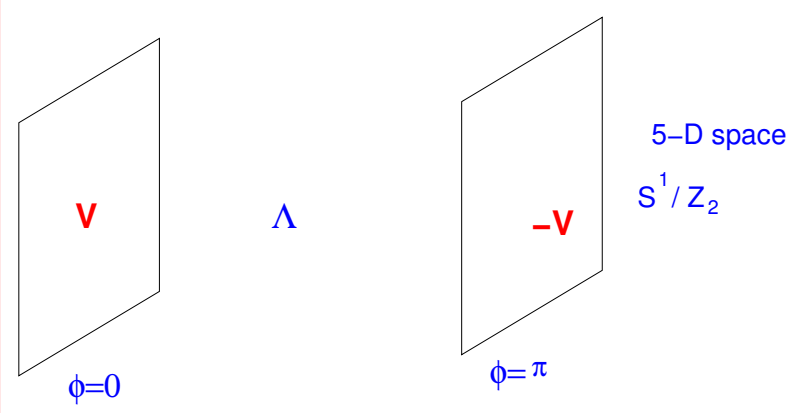


$\gamma\gamma \to \gamma\gamma$





Randall Sundrum Model: Radion



The RS model has a 4D massless scalar, radion, about the background metric

$$ds^2 = e^{-2k\phi T(x)} g_{\mu\nu}(x)\, dx^\mu dx^\nu - T^2(x) d\phi^2$$

$T(x)$ is the modulus field describing the distance between the two branes.

A stabilization mechanism (GW) using a bulk scalar field to generate a potential.

The radion acquires a $O(0.1 - 1TeV)$ mass with a coupling strength 1/TeV.

Interactions of the Radion:

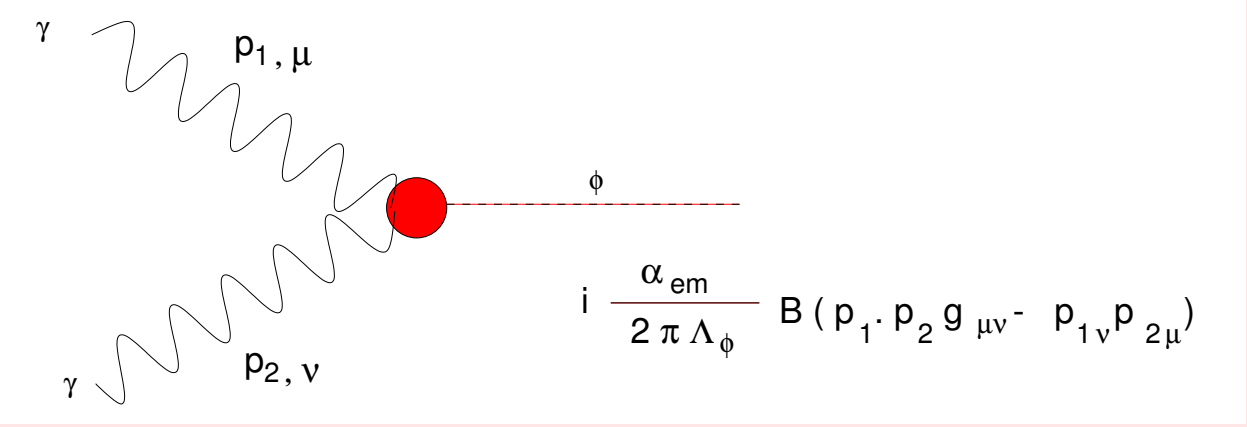
$$\mathcal{L}_{\rm int} = \frac{\phi}{\Lambda_\phi}\, T^\mu_\mu({\rm SM}) \ ,$$

RS Radion

The radion coupling to a pair of gluons (photons) has a contribution from the trace anomaly.

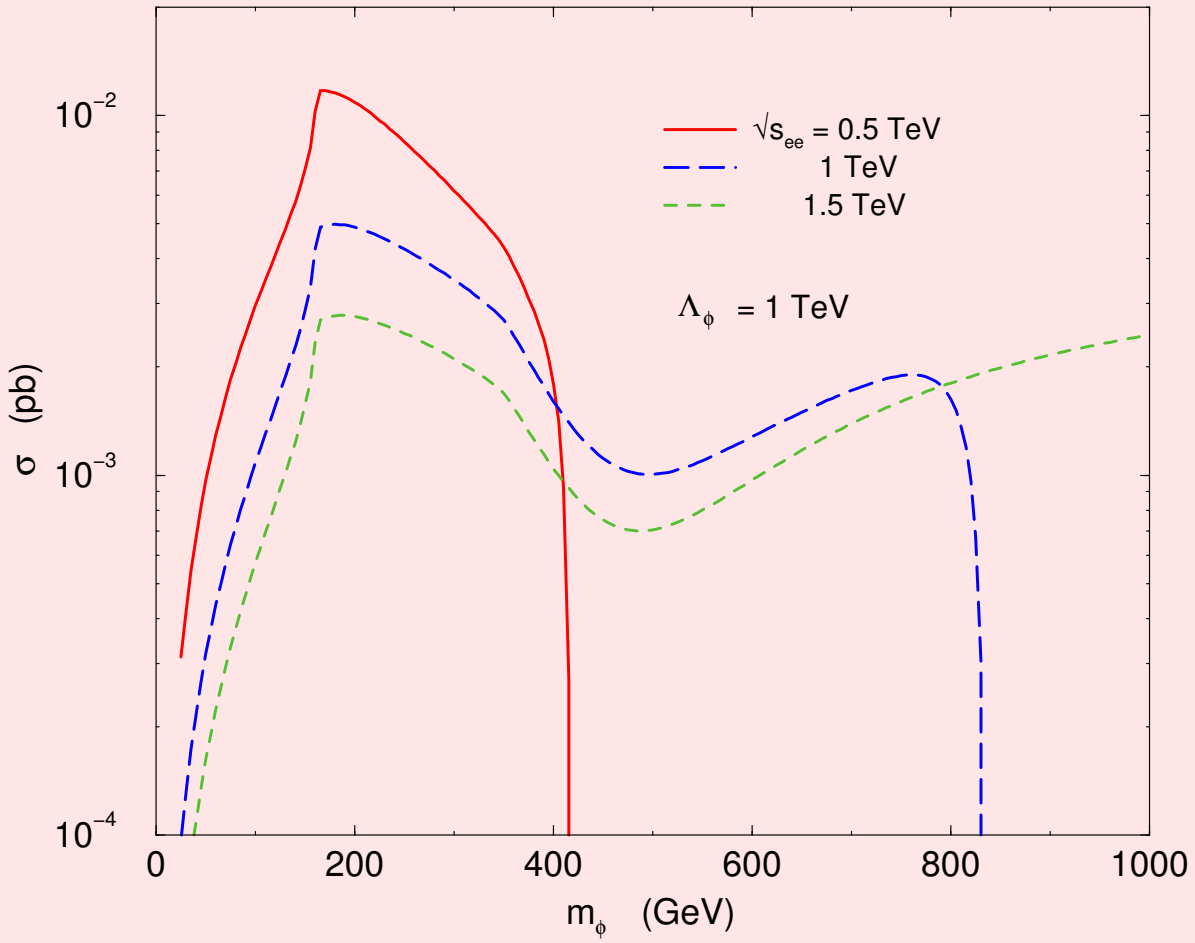
$$T^{\mu}_{\mu}(\mathrm{SM})^{\mathrm{anom}} = \sum_a \frac{\beta_a(g_a)}{2g_a} F^a_{\mu\nu} F^{a\mu\nu} \ .$$

where $\beta_{\mathrm{QCD}}/2g_s = -(\alpha_s/8\pi)b_{\mathrm{QCD}}$ and $b_{\mathrm{QCD}} = 11 - 2n_f/3$



where
$B = b_2 + b_Y - (2 + 3y_W + 3y_W(2 - y_W)f(y_W)) + \frac{8}{3}y_t(1 + (1 - y_t)f(y_t)), y_i = 4m_i^2/2p_1 \cdot p_2.$

Randall Sundrum Radion



Higgs-Radion Mixing

Gauge and Poincare invariance do not forbid the mixing between the gravity scalar and the Higgs boson:

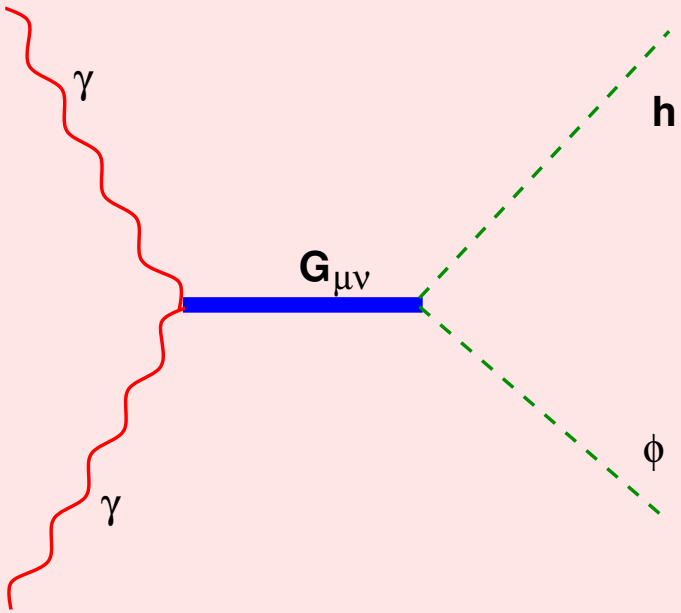
$$S_\xi = \xi \int d^4x \sqrt{g_{\rm vis}} R(g_{\rm vis}) \hat{H}^\dagger \hat{H} \,,$$

where $R(g_{\rm vis})$ is the Ricci scalar on the visible brane.

$\star$ A nonzero ξ will induce some triple couplings

$$h\text{-}\phi\text{-}\phi, \quad h^{(n)}_{\mu\nu}\text{-}h\text{-}\phi, \quad \phi\text{-}\phi\text{-}\phi, \quad h^{(n)}_{\mu\nu}\text{-}\phi\text{-}\phi$$

$$\gamma\gamma \to G^{(n)}_{\mu\nu} \to h\phi$$



The corresponding analogs at e^+e^- and hadronic machines:

$$e^+e^- \to G^{(n)}_{\mu\nu} \to h\phi, \qquad pp \to G^{(n)}_{\mu\nu} \to h\phi$$

have been performed (Cheung, Kim, Song PRD03, PRD04)

Neutral Techni-Pions

Because of the anomaly type coupling (like π^0-γ-γ), we can use $\gamma\gamma$ collision to probe neutral-pion-like resonances.

Technicolor Straw Man model (TCSM, Lane 99):

- techni-isospin is a good symmetry
- the lightest techni-mesons are constructed solely from the lightest techni-fermion doublet (T_U, T_D). They form isotriplet, isosinglet:

pseudoscalar: $\pi_T^{0,\pm}$, $\pi_T^{\prime 0}$, vector: $\rho_T^{0,\pm}$, ω_T^0

Consider two models of technicolor

Rescaled QCD model:

- A simple rescaling by the v/f_{π^0}. π_T^0 couples to $\gamma\gamma,\ \gamma Z,\ ZZ$ only.

Low-scale technicolor model:

- It is a multi-scale technicolor models. Quark and lepton masses are generated by broken extended technicolor gauge interactions in the walking technicolor model.
- There are two types of techni-fermions. One set condense at high scale set by $v = 246$ GeV. One set condense at low scale set by $f_{\pi_T} = v/\sqrt{N_D}$.
- Techni-pions will couple to normal quarks and leptons through Yukawa-type couplings.

$$\pi_T^0 \to b\bar{b},\ t\bar{t}$$

- π_T^0 couples to $\gamma\gamma,\ \gamma Z,\ ZZ,\ gg,\ b\bar{b}$.

The Anomaly Vertex

The anomaly coupling to π_T^0 - G_1 - G_2:

$$\mathcal{M} = N_{TC}\mathcal{A}_{G_1G_2}\frac{g_1 g_2}{2\pi^2 f_{\pi_T}}\epsilon_\nu\epsilon_\lambda\epsilon^{\nu\lambda\alpha\beta}P_{1\alpha}P_{2\beta}\ ,$$

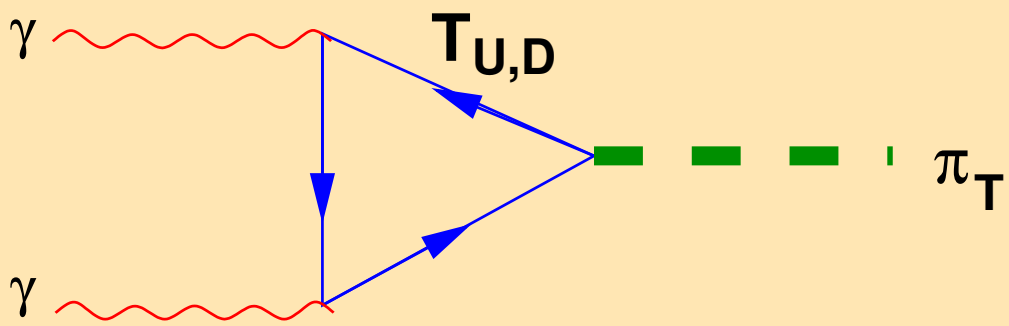
with

$$\mathcal{A}_{G_1G_2} = Tr[T^a(\{T_1,T_2\}_L + \{T_1,T_2\}_R)]$$

T_i's are the generators with the gauge boson G_i, and T^a is the axial current associated with the techni-pion

$$j^{\mu 5a} = \bar{\psi}\gamma^\mu\gamma^5 T^a\psi$$

$\gamma\gamma \to \pi_T$



$$\mathcal{A}_{\gamma\gamma} = Tr(T^a Q^2) \qquad \text{with} \qquad Q = \begin{pmatrix} Q_u & 0 \\ 0 & Q_d \end{pmatrix} ,$$

	Q_u	Q_d
rescaled	$2/3$	$-1/3$
low-scale	$4/3$	$1/3$

π_T^0 Production

$$\hat{\sigma}(\gamma\gamma \to \pi_T^0) = \frac{\pi m_{\pi_T}}{64}\left(N_{TC}\mathcal{A}_{\gamma\gamma}\frac{e^2}{\pi^2 f_{\pi_T}}\right)^2 \delta^{(0)}(\sqrt{\hat{s}} - m_{\pi_T})$$

Fold with photon luminosity function:

$$\sigma(\gamma\gamma \to \pi_T^0) = \frac{m_{\pi_T}^2}{2^5 s\pi^3}\left(\frac{N_{TC}\mathcal{A}_{\gamma\gamma}e^2}{f_{\pi_T}}\right)^2 \int_{x_{min}}^{x_{max}} \frac{1}{x} F_{\gamma/e}(x) F_{\gamma/e}\left(\frac{m_{\pi_T}^2}{sx}\right) dx$$

where

$$F_{\gamma/e}(x_i) = \frac{1}{D(\xi)}\left[1 - x_i + \frac{1}{1-x_i} - \frac{4x_i}{\xi(1-x_i)} + \frac{4x_i^2}{\xi^2(1-x_i)^2}\right]$$

π_T^0 Decay

Rescaled model:

$$\Gamma_{total} = \frac{1}{2^4 \pi m_{\pi_T}} \left[\frac{c^2 m_{\pi_T}^4}{2^2} + \frac{c_1^2 (m_{\pi_T}^2 - m_Z^2)^3}{(m_{\pi_T}^2 + m_Z^2)} + c_2^2 (m_{\pi_T}^2 - 4 m_Z^2)^2 \right]$$

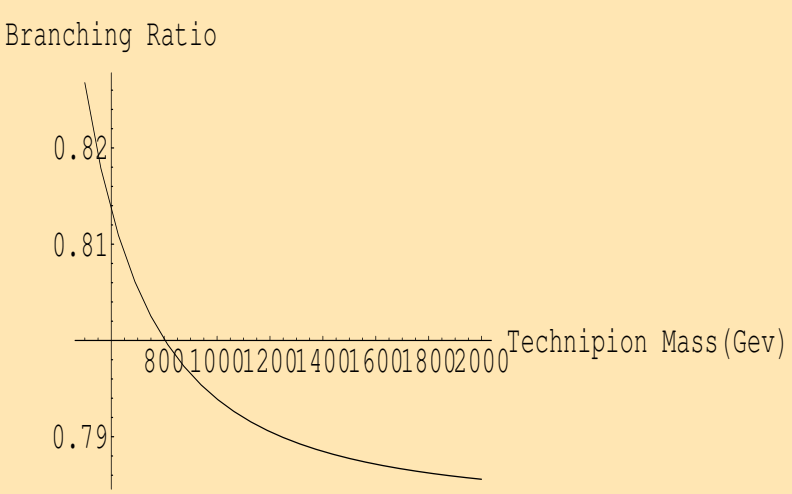
$$B(\pi_T^0 \to \gamma\gamma) = \frac{\Gamma_{\gamma\gamma}}{\Gamma_{total}}$$

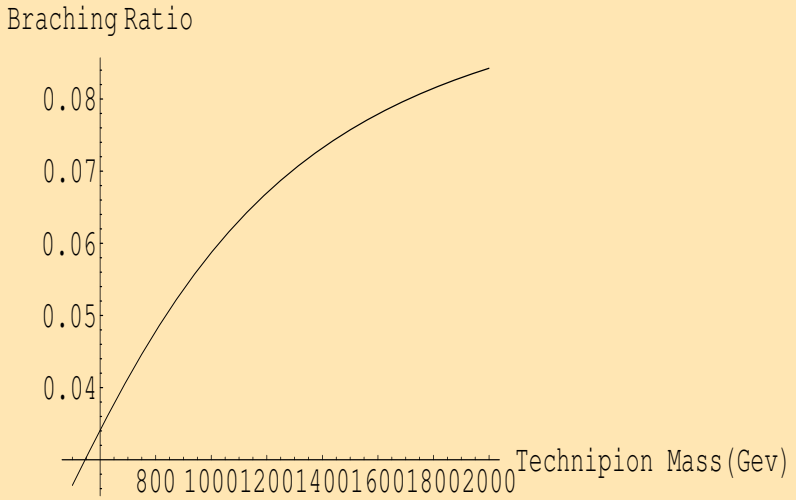
Low-scale model:

Additional contribution to the total width

$$\Gamma(\pi_T^0 \to b\bar{b})\Big|_{\text{low-scale}} = \frac{1}{16\pi f_{\pi_T}^2} N_b P_b C_{1b}^2 (m_b + m_b)^2$$

π_T^0 Decay: $B(\pi_T^0 \to \gamma\gamma)$

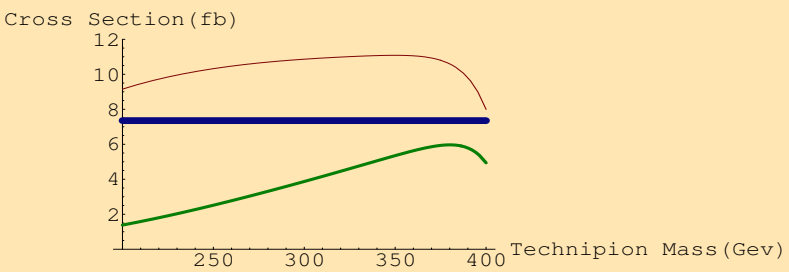




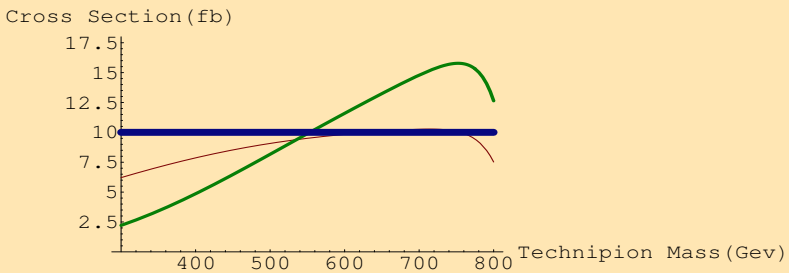
Rescaled model

low-scale model

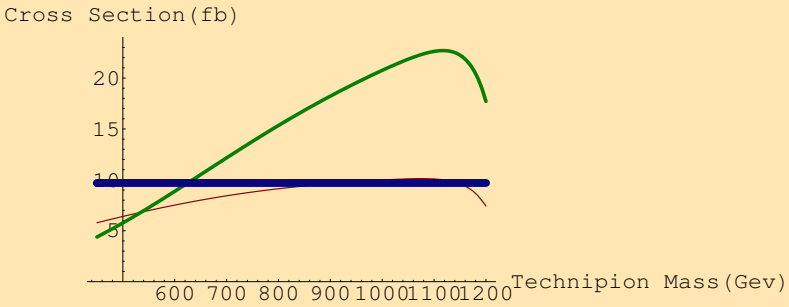
$\gamma\gamma \to \pi_T^0 \to \gamma\gamma$ production



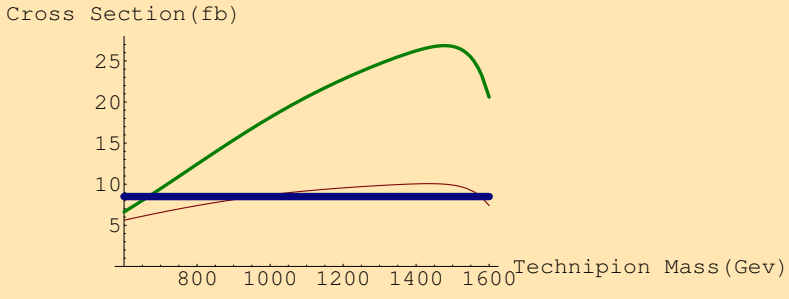
$\sqrt{s_{ee}} = 0.5$ TeV



$\sqrt{s_{ee}} = 1$ TeV



$\sqrt{s_{ee}} = 1.5$ TeV



$\sqrt{s_{ee}} = 2$ TeV

Summary

- Light-by-light scattering and $\gamma\gamma \to ZZ$ proceed via box diagrams in the SM.
- $\gamma\gamma \to \gamma\gamma$ is sensitive to the new physics that involves either tree-level couplings or anomaly-type couplings.
- Low scale gravity, RS radion are interesting examples.
- Neutral techni-pions of many technicolor models have anomalous couplings with photons. Photon colliders are unique in probing these kind of resonances.