Precocious Diphoton Signals of the Little Radion at Hadron Colliders

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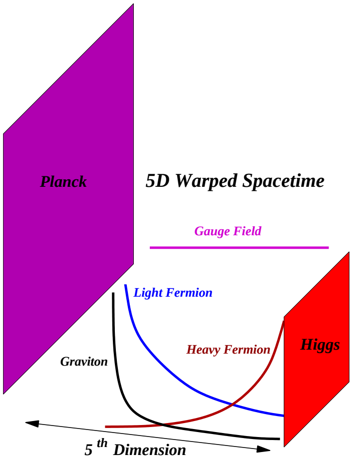
Introduction
Randall-Sundrum

- SM hierarchy problem: $\frac{M_{\text{Planck}}}{M_{\text{EW}}} \sim 10^{16}$.
- A possible explanation: warped 5th dimension

  [Randall, Sundrum 1999]
- A slice of 5D anti-de Sitter space:
  $ds^2 = e^{-ky}\eta_{\mu\nu}dx^{\mu}dx^{\nu} - dy^2$
- UV brane at $y = 0$, IR brane at $y = L$.
- k is the curvature scale.
- New particles
  - Kaluza-Klein excitations of 5D fields
  - A scalar, the radion (ϕ) [Goldberger, Wise 2000]

Introduction
Randall-Sundrum



With SM fields in the bulk, RS can address the flavor puzzle.

Introduction
Little Randall-Sundrum

- Suppose we think of RS as a model of flavor
- and don't require it to solve the hierarchy problem.
- We can move the UV scale from M_{Planck} to some lower scale.
- This relaxes some constraints and enhances KK signals.

  [Davoudiasl, Perez, Soni 2008; Davoudiasl, Gopalakrishna, Soni 2009; Rehermann, Tweedie 2010]
- What happens to the radion in this scenario?

Model parameters
(just a few)

- k: curvature scale
- L: size of the fifth dimension
- $\Lambda_\phi = \sqrt{6} k e^{-kL} \sim$ TeV
- $m_\phi \sim 100\,\text{GeV}$

In original RS, $kL \approx 35$.
In LRS, we can have a viable model of flavor with $kL \gtrsim 7$.

[Bauer, Casagrande, Gründer, Haisch, Neubert 2009]

Let's take $kL = 7$.

Coupling of radion to gauge bosons
(massless ones)

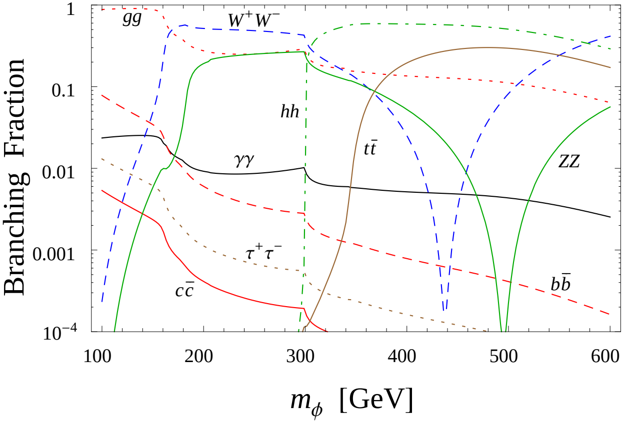
$$\mathcal{L}_A = -\frac{1}{4\Lambda_\phi kL}\left[1 + \frac{\alpha_G}{2\pi} b_G kL\right] \phi F_{\mu\nu} F^{\mu\nu}$$

where b_G is the β-function coefficient of gauge group G.

- This coupling is significantly enhanced in LRS ($kL = 7$) relative to original RS ($kL \approx 35$).
- Very promising for $gg \to \phi \to \gamma\gamma$

Radion branching fractions

LRS, $kL = 7$, $\Lambda_\phi = 3$ TeV



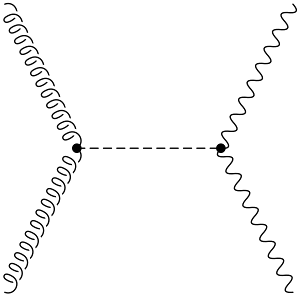
- BR($\phi \to \gamma\gamma$) $\sim$ 1% for a wide range of radion masses.
- Compare to BR($\phi \to \gamma\gamma$) $\lesssim 10^{-3}$ in original RS.

Coupling of radion to Z bosons
(Ws are similar)

$$\mathcal{L}_Z = -\frac{\phi}{\Lambda_\phi}\left[m_Z^2\left(1 - \frac{kL}{12}\frac{m_Z^2}{\Lambda_\phi^2}\right) Z_\mu Z^\mu + \frac{1}{4kL} Z_{\mu\nu} Z^{\mu\nu}\right]$$

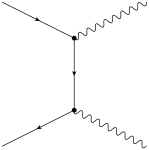
- The plunge in $\Gamma(\phi \to ZZ)$ is due to an accidental cancellation between these two terms, when $m_\phi \approx m_Z \sqrt{4kL + 2}$.

Searching for the radion
Signal

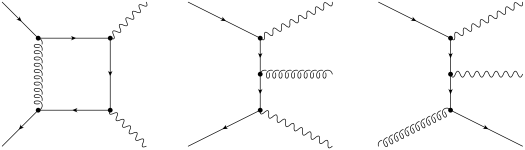


Searching for the radion
SM background

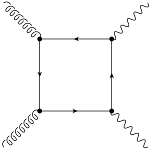
LO:



NLO:



(NNLO):



(Neglect interference with signal.)
[Dicus, Willenbrock 1988; Dixon, Siu 2003]

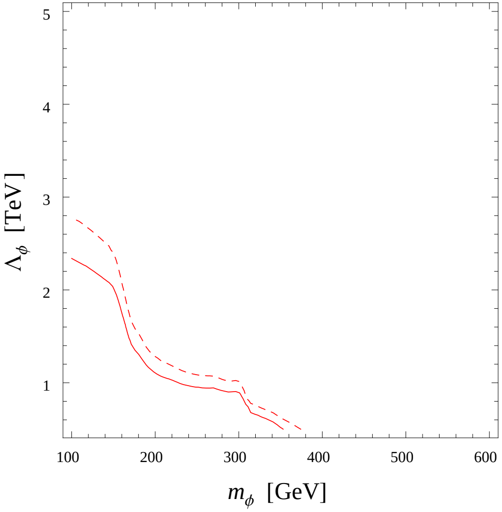
All of these are included in `DIPHOX`. [Binoth, Guillet, Pilon, Werlen 2000]

Cuts
at the Tevatron

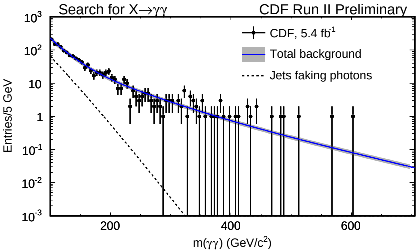
- transverse momentum: $p_{T\gamma} > 25\,\text{GeV}$
- pseudorapidity: $|\eta| < 1.1$
- $\Delta R_{\gamma\gamma} \equiv \sqrt{(\Delta\varphi)^2 + (\Delta\eta)^2} > 0.4$
- hadronic $E_T < 10\,\text{GeV}$ within $\Delta R = 0.4$ of each photon
- invariant mass: $|m_{\gamma\gamma} - m_\phi| < 10\,\text{GeV}$
- 70% photon id efficiency

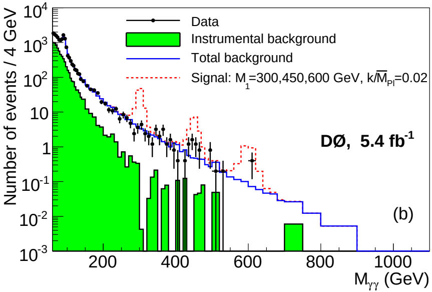
2σ reach at the Tevatron

$5\,\text{fb}^{-1}$ (solid), $10\,\text{fb}^{-1}$ (dashed)



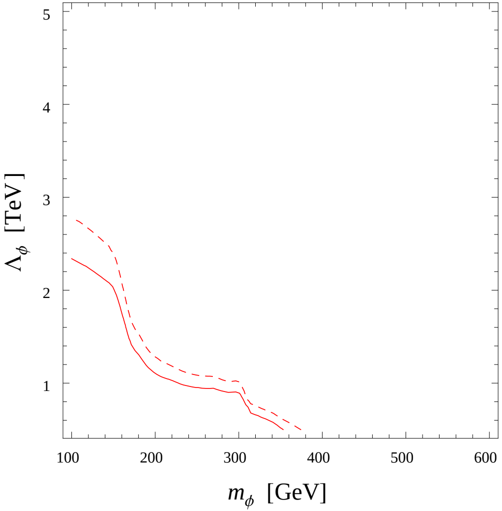
Tevatron diphoton results





2σ reach at the Tevatron

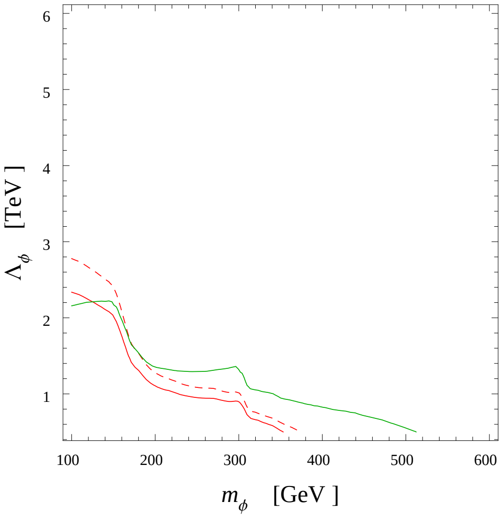
5 fb^{-1} (solid), 10 fb^{-1} (dashed)



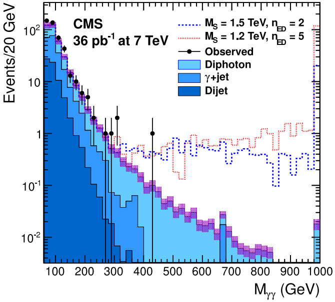
Cuts
at the LHC

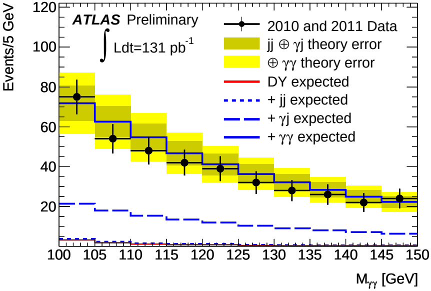
- transverse momentum: $p_{T\gamma} > 30\,\text{GeV}$
- pseudorapidity: $|\eta| < 2.4$
- $\Delta R_{\gamma\gamma} \equiv \sqrt{(\Delta\varphi)^2 + (\Delta\eta)^2} > 0.4$
- hadronic $E_T < 10\,\text{GeV}$ within $\Delta R = 0.4$ of each photon
- invariant mass: $|m_{\gamma\gamma} - m_\phi| < 10\,\text{GeV}$
- 80% photon id efficiency

2σ reach at the LHC, 7 TeV, 36 pb^{-1}

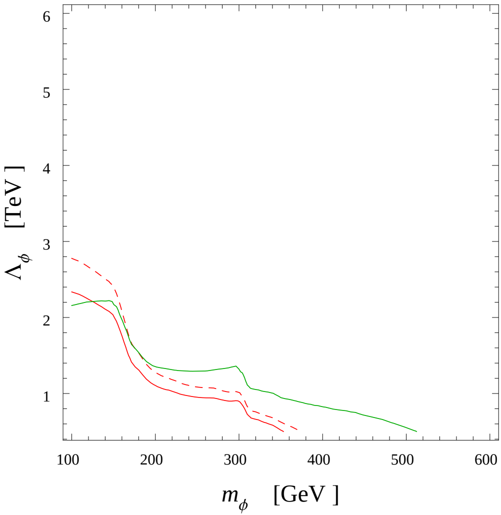


LHC diphoton results



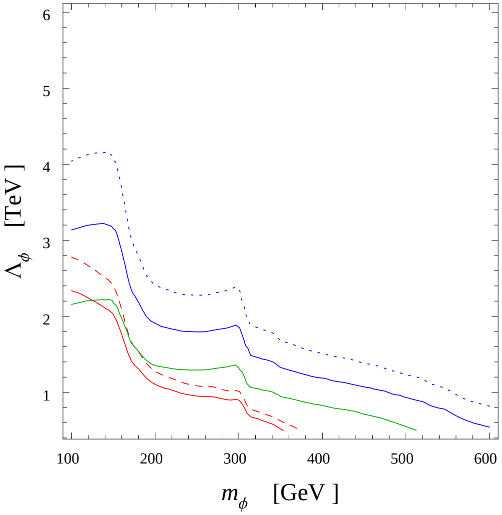


2σ reach at the LHC, 7 TeV, 36 pb^{-1}

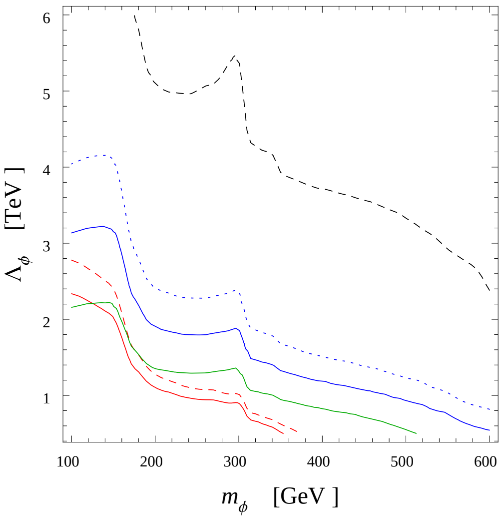


Reach at the LHC, 7 TeV, 1 fb^{-1}

5σ (solid), 3σ (dotted)



5σ reach at the LHC, 14 TeV, 1 fb^{-1}



Summary

- LRS models provide an interesting geometric description of flavor.
- Enhanced couplings of the radion to gauge bosons lead to a much larger diphoton signal.
- Hints of this signal may show up at the Tevatron.
- The LRS radion can be detected at the LHC early run for a wide range of parameters.

And a final comment. . .

- It may be possible to observe other decay modes (e.g. WW), which would help to extract various combinations of model parameters and reveal the underlying physics.