Clean Signals of Little Randall-Sundrum Models at the LHC

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Based on:

- H. D., G. Perez, and A. Soni

Phys.Lett.B665:67-71,2008, arXiv:0802.0203 [hep-ph]

- H. D., S. Gopalakrishna, and A. Soni

Phys.Lett.B686:239-243,2010, arXiv:0908.1131 [hep-ph]

- H. D., T. McElmurry, and A. Soni

Work in progress.

Joint HET/BNL-ATLAS Meeting, June 16, 2010

Introduction:

- SM effective theory below scale Λ.
- Precision EW: $\Lambda \gtrsim 10$ TeV; Flavor: $\Lambda \gtrsim 1000$ TeV.
- SM poses unresolved questions:
  - The hierarchy problem: Why is $m_H \ll \Lambda$?

$$\langle H \rangle \sim m_H \sim 10^2 \text{ GeV}; \; \delta m_H^2 \sim \Lambda^2.$$

  - Flavor puzzle: pattern of fermion masses and mixing.
- Beyond SM physics proposals: SUSY, strong dynamics,. . . .

Warped Hierarchy/Flavor Models

- **Randall-Sundrum Model:** Randall, Sundrum, 1999

A slice of AdS_5.

Flat Planck (UV), TeV (IR) branes.

- **Metric:** $ds^2 = e^{-2ky}\eta_{\mu\nu}\, dx^\mu dx^\nu - dy^2$.

$k \lesssim M_5$ and $y \in [0, \pi r_c]$.

- **Redshift:** $e^{-kr_c\pi}\langle H_5\rangle \sim m_W$; $\langle H_5\rangle \sim k$.

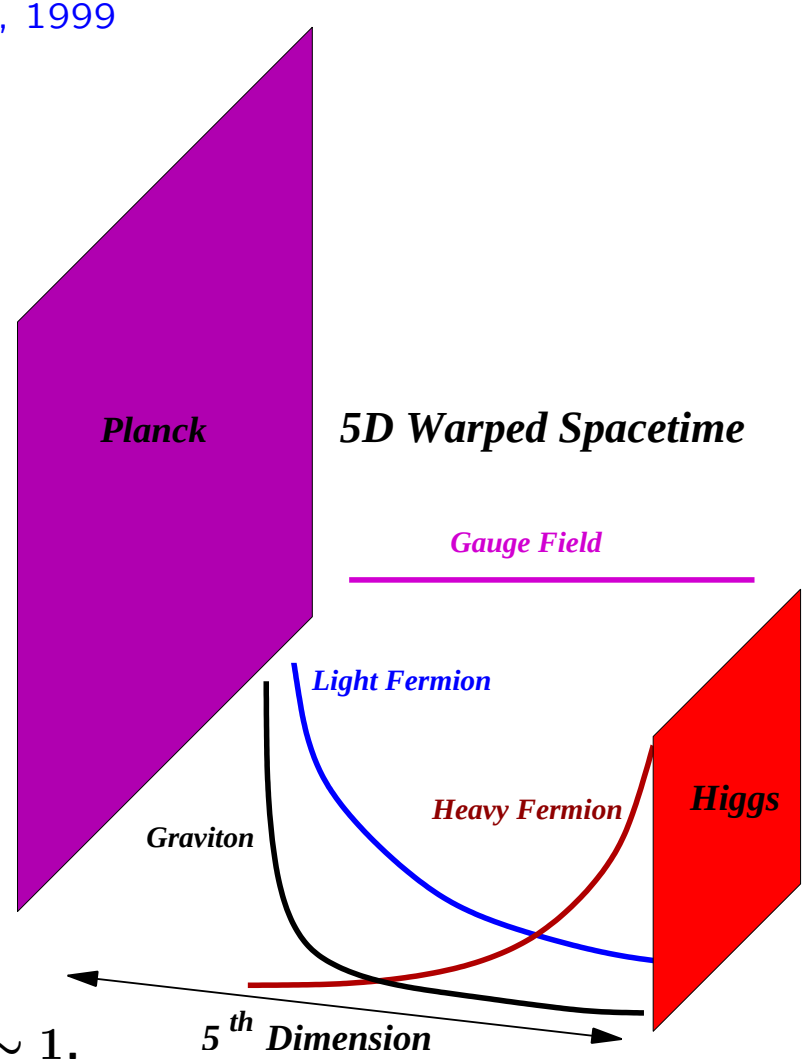
$k \gg 1$ TeV with $kr_c\pi \gtrsim 10$ (Hierarchy).

- **TeV-scale Kaluza-Klein (KK) modes**

Collider signals.

- **Stabilization: radion scalar** ϕ.

$m_\phi \lesssim m_{KK}$ Goldberger, Wise, 1999



- **Localized fermions via 5D masses,** $m/k \sim 1$.
- UV(IR)-localization: Light (heavy) fermion. Grossman, Neubert, 1999
- Large effective cutoff scales for UV-localized flavors. Gherghetta, Pomarol, 2000

Little Randall-Sundrum (LRS) Models

H.D., Perez, Soni, 2008

- RS as a model of <u>flavor</u>: $M_5 \ll \bar{M}_P$ viable option.
- $M_5 \gg$ TeV needed to suppress unwanted (FCNC,. . .) operators.
- Volume-truncated RS models: $1 \ll kr_c\pi \ll 35$.

- LRS: some unwanted (*e.g.*, $T_{\text{tree}} \propto kr_c\pi$) contributions suppressed.
- Explain $\langle H \rangle / M_5 \ll 1$ hierarchy $\Rightarrow$ warped TeV-scale KK modes.

- LRS: significant improvement in *clean* collider signals.

- Flavor constraints on LRS from ϵ_K: $k\pi r_c \gtrsim 7$ ($M_5 \gtrsim 10^4$ TeV).

Bauer, Casagrande, Grunder, Haisch, Neubert, 2008

Little Z' Couplings

- LRS truncation factor: $y \equiv (kr_c|_{RS})/(kr_c|_{LRS}) \quad (y > 1)$

- Gauge KK mode couplings:

$$g_{KK}|_{UV} \sim g_4/\sqrt{kr_c\pi} \quad (q, e, \ldots) \quad ; \quad g_{KK}|_{IR} \sim g_4\sqrt{kr_c\pi} \quad (H, t, \ldots)$$

Example: $\sigma(q\bar{q} \to Z' \to \ell^+\ell^-) \propto \overbrace{\Gamma(Z' \to q\bar{q})}^{\sim y}\,\overbrace{\mathrm{BR}(Z' \to \ell^+\ell^-)}^{\sim y^2}$

$\boxed{\mathcal{S} \sim y^3}$ and $\boxed{\mathcal{S}/\mathcal{B} \sim y^4}$! Background: $\mathcal{B} \sim 1/y$ (over width)

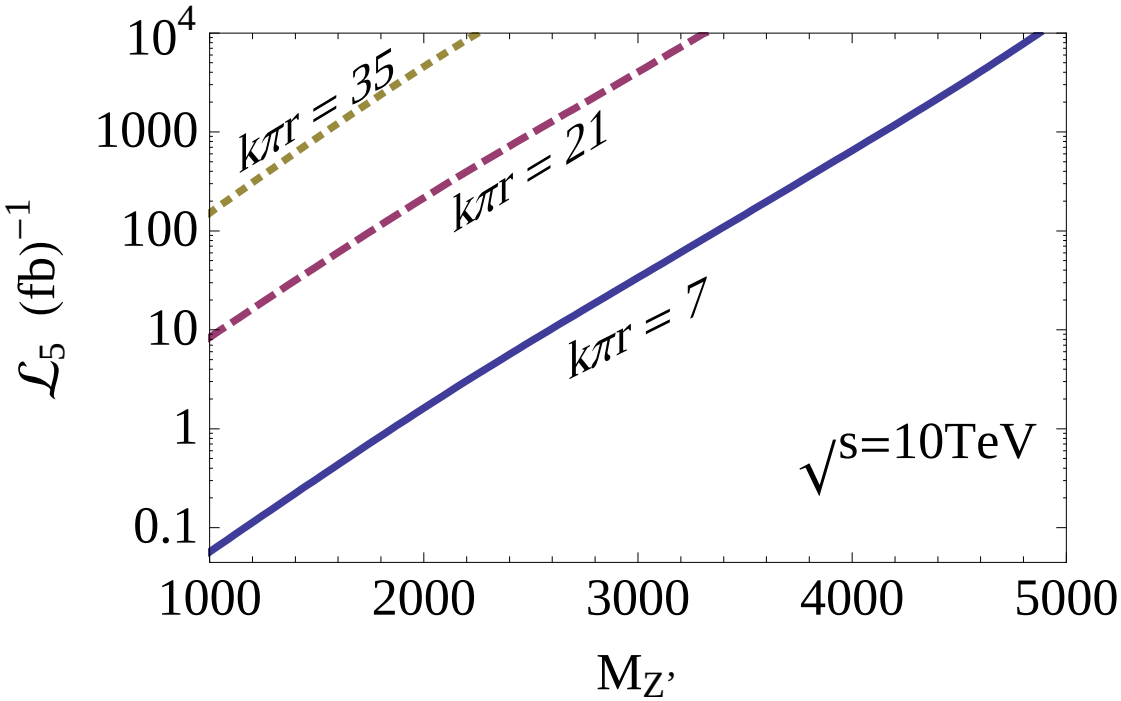
- Experimental sensitivity to the UV-brane scale.

$y \approx 1 \Rightarrow M_5 \sim \bar{M}_P \;\; ; \;\; y \gg 1 \Rightarrow M_5 \ll \bar{M}_P.$

- Brane kinetic terms ignored for simple phenomenology.

Dilepton Channel LHC Reach for the Little Z'

H.D., Gopalakrishna, Soni, Phys.Lett.B686:239-243,2010



- Cuts: $|\eta_\ell| < 3.0$, $p_{T_\ell} > 100$ GeV, $M_{\ell^+\ell^-}$ within $M_{Z'} \pm 100$ GeV.
- Background: irreducible SM only, due to low leptonic jet-fake rate (10^{-3}).
- $\mathcal{L}_5$: $\int L\,dt$ for 5σ signal (≥ 3 events) in $pp \to \ell^+\ell^-$ ($\ell = e$ *or* μ).
- For $kr_c\pi \approx 7$:

$$M_{Z'} \approx 2 \text{ TeV at } \sqrt{s} = 10 \text{ TeV with 1 fb}^{-1}.$$

Little KK gluons

H.D., Gopalakrishna, Soni, 2009

- Expect same enhanced *production* (coupling to $q\bar{q}$) for $g^{(1)}$.

- Light quark decay modes overwhelmed by large QCD background.

$\Rightarrow$ Discovery signal: $g^{(1)} \to t\bar{t}$.

- 5σ discovery estimates for $g^{(1)}$: $pp \to t\bar{t} \to bW(jj)\,\bar{b}W(\ell\nu)$

- Hadronic t reconstruction efficiency 5%.
Agashe, Belyaev, Krupovnickas, Perez, Virzi, 2006

- Efficiency includes b-tagging and kinematic acceptance.

- Simple analysis, ignore large boost of tops.

- 3-TeV KK gluon ($\sqrt{s} = 14$ TeV): (2,8,21) fb^{-1} for $kr_c\pi = (7, 21, 35)$.

- Good agreement with ABKPV results for $kr_c\pi = 35$.

$\star$ Rough estimate for a 2-TeV Little KK gluon: 5σ with ~ 0.3 fb^{-1} at $\sqrt{s} = 10$ TeV.

A Light Little Radion

H.D., McElmurry, Soni, work in progress

- Typically, $m_\phi \ll m_{KK}$, assume $m_\phi \lesssim 140$ GeV.

- $gg \to \phi \to \gamma\gamma$ important. (*)

- ϕgg, $\phi\gamma\gamma$ couplings depend on $1/(kr_c\pi)$:

Csáki, Hubisz, Lee, 2007

Enhanced in LRS ($kr_c\pi \ll 35$) for fixed gravity scale Λ_ϕ.

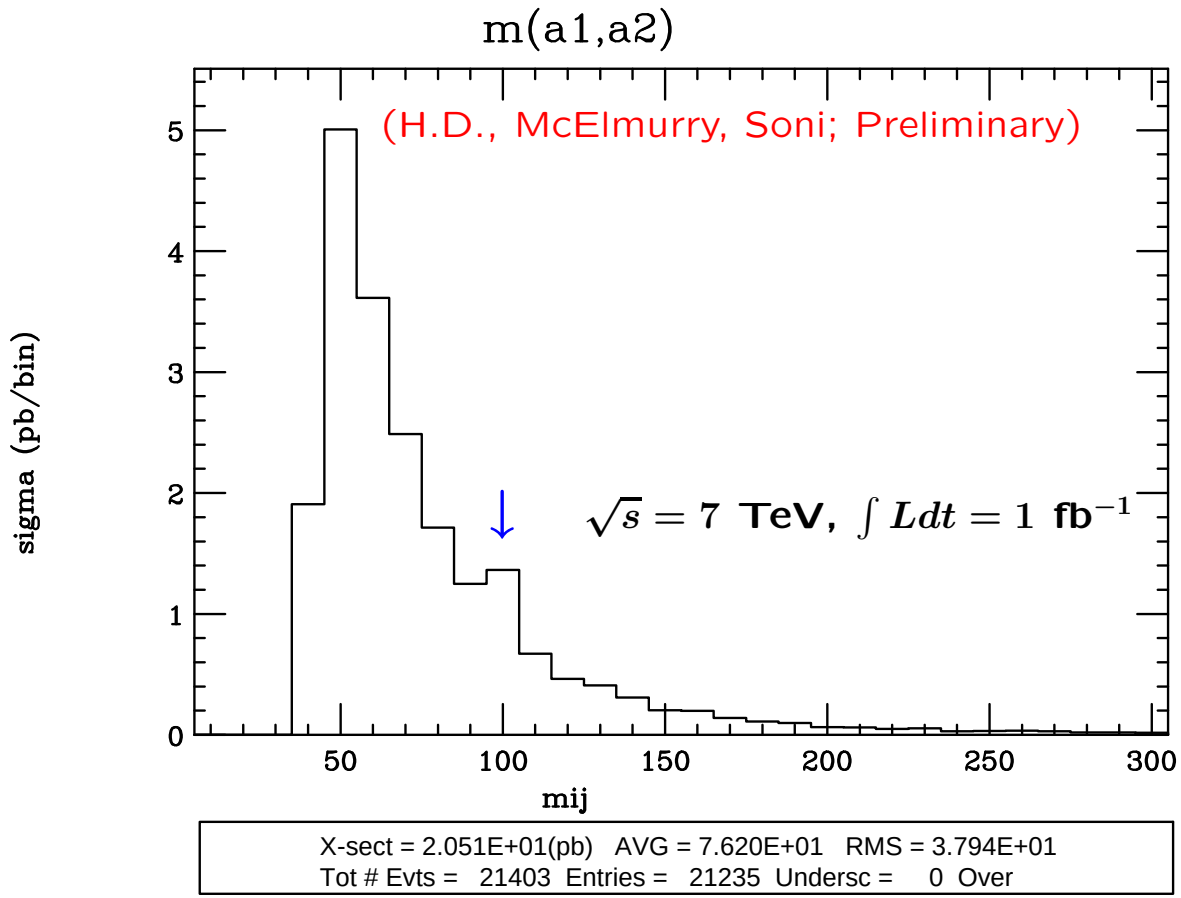
$\Rightarrow$ Little radion may be interesting for the $\sqrt{s} = 7$ TeV LHC run.

- $q\bar{q} \to W^*/Z^* \to W/Z\,\phi$: (**)

(*) $\oplus$ (**) $\Rightarrow$ extract Λ_ϕ and $kr_c\pi$ (brane kinetic terms ignored).

Infer bulk volume (CFT: "Conformal Depth").

$pp \to \phi \to \gamma\gamma$



- $m_\phi = 100$ GeV, $\Lambda_\phi = 3$ TeV, $kr_c\pi = 7$ ($M_5 \sim 10^4$ TeV).
- Br$(\phi \to gg, b\bar{b}, \gamma\gamma) = 89.6\%, 8.0\%, 2.4\%$.
- Cuts: $p_T(\gamma) > 20$ GeV, $|\eta| < 2.5 \Rightarrow S \approx 460$ fb, $B \approx 2.1 \times 10^3$ fb (LO).
- 90 GeV $< M_{\gamma\gamma} <$ 110 GeV $\Rightarrow S/B \approx 0.2$, $S/\sqrt{B} \approx 10$.

Concluding Remarks

- RS background an interesting framework for flavor.
- Volume-truncated LRS as a model of flavor:
  - The fundamental scale $M_5 \gg$ TeV can be much lower than $\bar{M}_P$.
  - Some constraints can be alleviated by volume truncation.
  - LRS still addresses Higgs-M_5 hierarchies $\rightarrow$ TeV-scale KK modes.
- Some clean LRS signals quite sensitive to the hierarchy (UV scale).
  - Simple models: $kr_c\pi$ (M_5) may be inferred from weak scale data.
  - 4D CFT dual: UV conformal depth.