PROSPECTS FOR XD@LHC
EXTRA DIMENSIONS

Flip Tanedo

Cornell CMS mini-Workshop, January 19, 2012
Focus: Randall-Sundrum (many local experts)

I Motivation one slide

II Definition: Theorist RS vs. Experimentalist RS

III Signatures: spin-2, spin-1, spin-0

IV Breadth: comments on RS variants

Omissions: rigorous equations, model-building, electroweak precision observables, flavor, current collider constraints, references (see notes)
Motivation: AdS/CFT, why XD isn’t so far-fetched

Theorist
I have a new $\mathcal{L}_{\text{BSM}}$!

A tower of resonances coming from Kaluza-Klein excitations of fields living in an extra dimension. These include same-spin partners of the Standard Model fields identified with the zero-mode excitations. This solves the hierarchy problem by introducing a non-factorizable metric...

Experimentalist
Neat! What’s the signal?

Oh, we already found that. It’s QCD.
Evolution of Randall-Sundrum

Modern models have different phenomenology!
Not in this talk: ADD, UED, and RS+(⋯)
Evolution of Randall-Sundrum

Original RS1 Model: Hierarchy problem
Evolution of Randall-Sundrum

RS1 with bulk gauge bosons: unification, ...
Evolution of Randall-Sundrum

RSI with bulk fermions: $S$ parameter, ...
Evolution of Randall-Sundrum

RS1 with bulk fermions: FCNC, anarchic flavor
Evolution of Randall-Sundrum

Realistic (custodial) RS1: $T$-parameter

$$\text{SU}(3) \times \text{SU}(2)_L \times \text{SU}(2)_R \times \text{U}(1)_X$$

Light fermions

$$\text{SU}(2)_R \times \text{U}(1)_X \rightarrow \text{U}(1)_Y$$

Gauge Boson

$$\text{SU}(2)_L \times \text{SU}(2)_R \rightarrow \text{SU}(2)_V$$

Higgs

$Q_L, t_R$
Evolution of Randall-Sundrum
Other developments

Even with ‘realistic models,’ there is a little Hierarchy between the IR scale (TeV) and the electroweak breaking scale (100 GeV).

- Embed within a little Higgs model
- Little RS, for small Hierarchies
- Higgsless model, EWSB by boundary conditions

Other signals include additional reggeon states from a realization of Randall-Sundrum within string theory.
Spin-2: Kaluza-Klein gravitons

Original RS1: only gravitons in the bulk. Signature: $G^{(1)} \rightarrow \gamma\gamma, \ell\ell$
Spin-2: Kaluza-Klein gravitons

But $G \to \gamma\gamma, \ell\ell$ is no good in realistic models with bulk fields!

- $G^{(1)} \to \gamma\gamma$ vanishes by orthogonality of 5D profiles
- $G^{(1)} \to \ell\ell$ exponentially small $m_\ell/M_{\text{KK}}$ suppression
Spin-2: Kaluza-Klein gravitons

- Production: Gluon fusion (subdominant: $W$ fusion)
- Decay: IR localized, decays to $t_R$ and $H$ (narrow width)

From hep-ph/0701150

**Signal:** boosted top resonance Expect: $\sim 2$ TeV with 100/ fb
Some BG from KK gluons, can use angular distribution.

**Signal:** $G^{(1)} \rightarrow 2Z_L \rightarrow 4\ell$ Expect: $\sim 2$ TeV with 300/ fb
Spin-2: Kaluza-Klein gravitons
Spin-1: KK gluons, resonances

Likely first signal of RS: $q\bar{q} \rightarrow g^{(1)} \rightarrow t_R \bar{t}_R$

- No $ggg^{(1)}$ coupling by orthogonality of profile
- Profile peaked on IR, couples dominantly to $t_R$
- Need boosted top tagging (substructure, $b/\ell$ sep., invt. mass)

From hep-ph/0701166; Expect $\sim 5 \, \text{TeV}$ with 100/fb
Spin-1: KK gluons, spin determination

From: hep-ph/0701166; BG is forward peaked. High $p_T$ cut helps.
Can play similar games with spin-2, spin-0.
Spin-1: KK gluons, spin correlation

Large boost, $t_R \approx$ helicity state. Measure $A_{FB}$ of $\ell^+$. From: hep-ph/0612015. Just like $A_{FB}$ from $Z$ in SM.
Spin-1: KK electroweak gauge bosons

- Much lower production rates and more model dependent
- Coupling to $H$: allow vector fusion production of KK modes
- $Z^{(1)}$ contribution to $A_{FB}$, opposite sign as $Z$ in SM
- In custodial models: $Z'$ and $W'$ gauge bosons
  See Peter’s talk for $W'$

Spin-1/2: KK fermions

- Lower production and typically heavier than spin-1 excitations
- Custodial fermions can have exotic charges, same-sign dilepton
Spin-0: the radion/dilaton

**Radion**: fluctuation in the size of the 5th dimension, couples to the breaking of scale invariance.

- **Classically**: couples to trace of energy-momentum tensor. These couplings *looks just like those of the Higgs*.
- **Quantum’ly**: couples to gauge bosons via trace anomaly, $\propto \beta$

Additional tree-level coupling if gauge bosons in the bulk

![Graph showing branching fractions as a function of mass](image.png)
Remarks on RS variants

Higgsless models

Take Higgs vev \( \rightarrow \infty \), decouple Higgs; repel gauge profiles

Unitarity of \( WW \) scattering from exchange of KK gauge bosons. \( W' \) and \( Z' \) resonances with weak couplings to SM fermions
Remarks on RS variants

Little Higgs

Strong dynamics at $\sim 10$ TeV with collective symmetry breaking. Higgs as a pseudo-Goldstone boson.

Electroweak precision constraints: $T$-parity
Search for $T$-odd quarks. Can retrofit SUSY jet+MET search.
Conclusions

- Modern RS: richer phenomenology, many variants
- Priority: boosted top tagging
- Lots of local hep-ph interest and expertise

Notes and references
Slides and TeX’d notes for this talk with references are available on my web page under ‘Talks.’
• Evolution illustration from Smithsonian.com (19 Nov 2010)
• Low energy resonance graph from A. Golutvin, La Thuile 2011
• Beamer theme Flip, available online
  http://www.lepp.cornell.edu/~pt267/docs.html
• All other images by Flip using TikZ, Photoshop, and Illustrator