The Randall-Sundrum model and high pT tops

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Outline

• Description of the RS model
• Importance of top quarks
• Model variations
• Probes of model properties
• Outlook

See also: Agashe, Belyaev, Krupovnickas, Perez, Virzi hep-ph/0612015
The Randall-Sundrum model

- Five dimensions
- Extra dimension is “warped”
- Warping scales masses, solving the hierarchy problem
- Parameters are natural

L. Randall, R. Sundrum hep-ph/9905221

$M \to e^{-\pi kr_c}$

Standard Model fields

- SM fields in bulk to suppress dangerous operators
- Gauge fields must be in bulk
- Provides explanation of flavor hierarchy
- Structure constrained by SM precision observables
- $Z \rightarrow b\bar{b}$ dominant constraint

$\psi_{\text{light}}$, $Q^3_L$, $t_R$
Kaluza-Klein states

- KK states are IR localized
- Universal couplings to light fermions
- Large coupling to top

\[
g f \bar{f} g^{(1)} \sim 0.2 g_s \\
g Q^3 \bar{Q}^3 g^{(1)} \sim g_s \\
g t_R \bar{t}_R g^{(1)} \sim 4 g_s
\]
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All gauge KK states decay predominantly to top pairs!
Top pairs from KK gluons

- Nice signal above SM top production
- PDF and stat. errors shown, assuming 100 fb$^{-1}$
- Width/Mass $\sim$17%

Cross-section at LHC reasonable, limited by small coupling to light fermions, and lack of glue-glue coupling
Other model variants

![Graph showing differential cross-section for pp → g^1g^1 and pp → btt signals and SM backgrounds with respect to the tt invariant mass, in the standard RS model.](image)

IR brane terms

\[ 2\delta(y - \pi r_c)r_{IR}F_{\mu\nu}F^{\mu\nu} \]

Davoudiasl, Hewett, Rizzo hep-ph/0212279
Carena, Ponton, Tait, Wagner, hep-ph/0212307
Other model variants

Custodial symmetry for $Z \rightarrow b\bar{b}$

- Produces new light fermions
- KK gluon can decay into $N$ new states

Agashe, Contino, Da Rold, Pomarol, hep-ph/0605341
Bottom quark coupling

- Measure $b$ associated production
- Probe of $b$ localization
Tevatron constraints

Used narrow-width approximation, so constraint is qualitative, but probably improves with proper treatment.

~ 950 GeV


Top collimation

Threshold production

High mass production
Top collimation

- Tops can be highly boosted
- Can they be resolved into separate objects for top ID and reconstruction?
Top collimation (cont.) 2 TeV resonance

Fraction of events vs. $\sqrt{s}$ (GeV)

$\sqrt{s}$ GeV

Separation: $\Delta R > 0.4$

One top completely collimated

6 isolated decay products

Fraction of events vs. $p_T$ (GeV)
Top collimation (cont.)

- One top completely collimated
- 6 isolated decay products

\[ \sqrt{s} \text{ GeV} \]

Fraction of events

- 4 TeV resonance

July 26, 2007
Compare to dijets?

• Possibly significant at lower masses
  • Very challenging!

• Would like a way to identify tops, even if collimated

• In some models may be the discovery mode
Finding collimated $t\bar{t}$

First demonstration
Agashe, Belyaev, Krupovnickas, Perez, Virzi hep-ph/0612015
found leptons inside jets

See also: U. Baur, L. Orr 0707.2006

Used isolated leptons
jet mass cut
note long tail for $k_T$ algorithm

\[ \text{The invariant mass of a jet with a given } p_T \text{ strongly depends on the jet algorithm used} \]
\[ \text{Long tail with } k_T \text{ algorithm} \]
\[ \text{very difficult to have a jet with the cone algorithm which has} \]
\[ m(j) > 0.3 \times p_T(j) \]

Ulrich Baur Pheno07 May 2007
Finding collimated $tt\bar{t}$

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More work ongoing!
Top helicity

- Tops from KK decays are right-polarized
- Other models where they are left-polarized
  - e.g. Carena et al. hep-ph/0607106
  - Agashe, Contino, Da Rold, Pomarol, hep-ph/0605341
Sign of the couplings

\[ g \quad +g \quad +g \quad g(1) \quad -1/5g \quad +4g \]

light

+0.2g_s

-0.2g_s

KK state

Arbitrary Units

\( m_{tt} \) (GeV)

Plot showing the mass distribution of pp → tt in models with positive and negative coupling to light fermions, along with the SM prediction.
Sign of the couplings

\[ A_i = -\frac{\int dm (\frac{d\sigma}{dm} - \frac{d\sigma}{dm \text{ SM}}) * \epsilon (m - M g^{(1)})}{\int dm |\frac{d\sigma}{dm} - \frac{d\sigma}{dm \text{ SM}}|} \]

<table>
<thead>
<tr>
<th>(g^{(1)}) Mass</th>
<th>plus</th>
<th>minus</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 TeV</td>
<td>0.57</td>
<td>-0.44</td>
</tr>
<tr>
<td>3 TeV</td>
<td>0.54</td>
<td>-0.28</td>
</tr>
<tr>
<td>4 TeV</td>
<td>0.52</td>
<td>-0.16</td>
</tr>
</tbody>
</table>

(parton level without efficiencies, just an illustration)
Possibilities at the ILC

- No s-channel gluon production. Gives direct access to EW KK states
  - Disentangle KK gluons from EW bosons
- Unlikely to have on-shell production, but not necessarily problematic
  - See, e.g. TESLA TDR
- Better top helicity measurement?
Outlook

• Another reminder that large resonances can occur in models that solve the hierarchy problem

• Example of a model where almost all new physics appears in hadronic channels

• Possible to extract interesting, qualitative features that probe the model structure.
  • Couplings to top and bottom
  • Light fermion coupling sign