PROSPECTS FOR

XD@LHC

EXTRA DIMENSIONS

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Outline

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

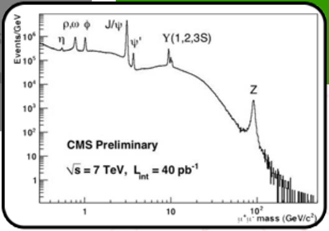
I have a new $\mathcal{L}_{\mathrm{BSM}}$!

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 fiel... identified with the z... ations. This solves h... n by introducing a n... metric...

Experimentalist

Neat! What's the signal?

Oh, we already found that. It's QCD.



Evolution of Randall-Sundrum

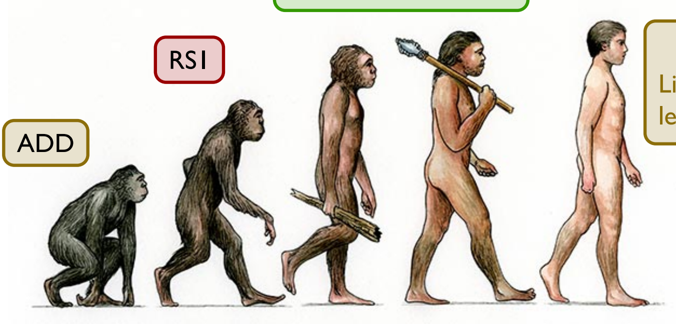
ADD

RS1

RS1 with bulk fields
Gauge fermions

Realistic RS1
Custodial protection

RS1+
Little Higgs, Higgs-less, gaugephobic

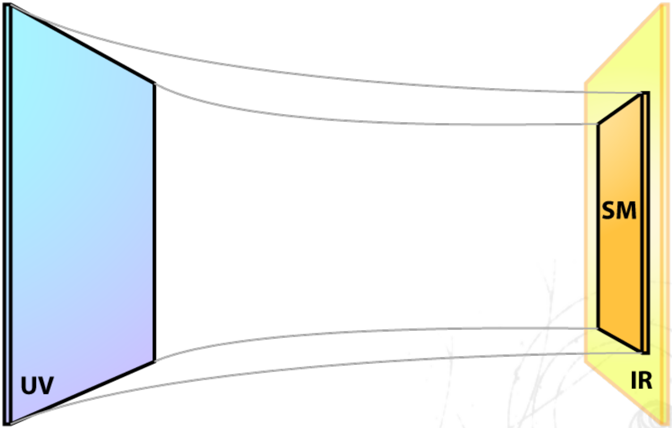


Modern models have different phenomenology!

Not in this talk: ADD, UED, and RS+$(\cdots)$

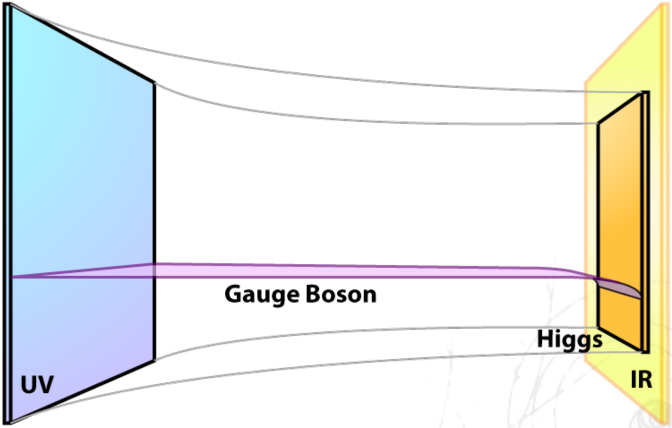
Evolution of Randall-Sundrum

Original RS1 Model: Hierarchy problem



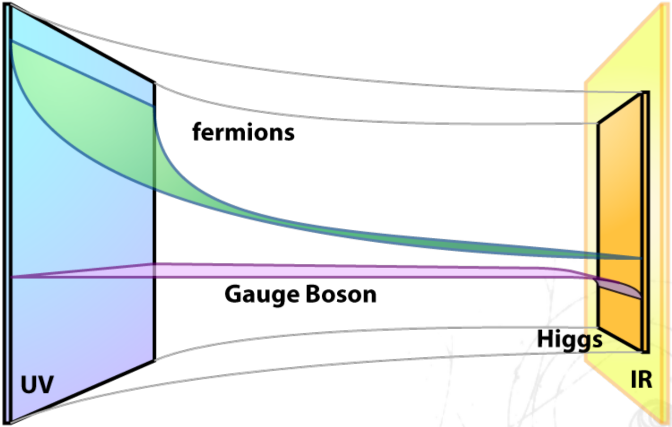
Evolution of Randall-Sundrum

RS1 with bulk gauge bosons: unification, ...



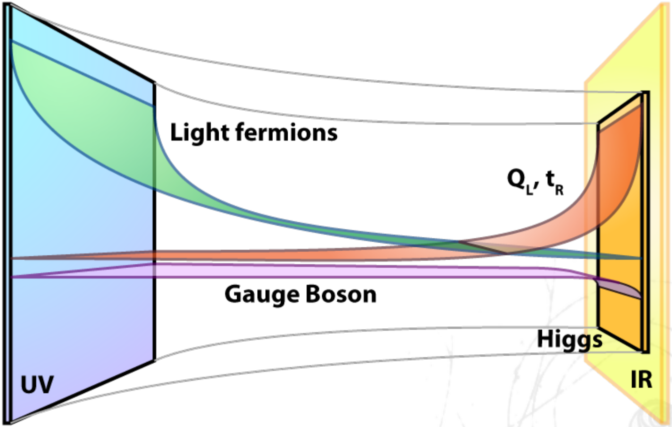
Evolution of Randall-Sundrum

RS1 with bulk fermions: S parameter, ...



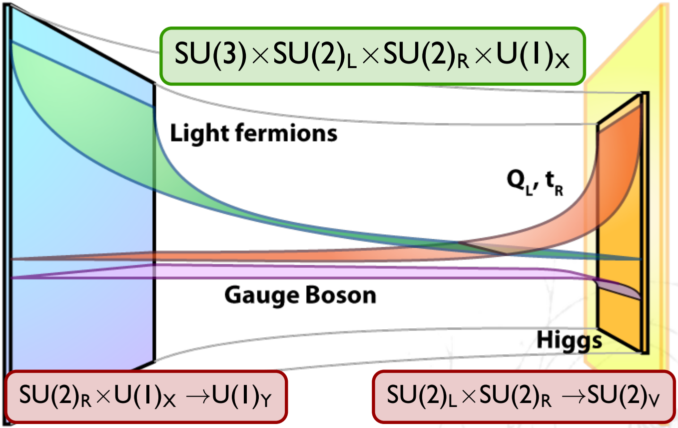
Evolution of Randall-Sundrum

RS1 with bulk fermions: FCNC, anarchic flavor



Evolution of Randall-Sundrum

Realistic (custodial) RS1: T-parameter



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: $G^{(1)} \to \gamma\gamma, \ell\ell$

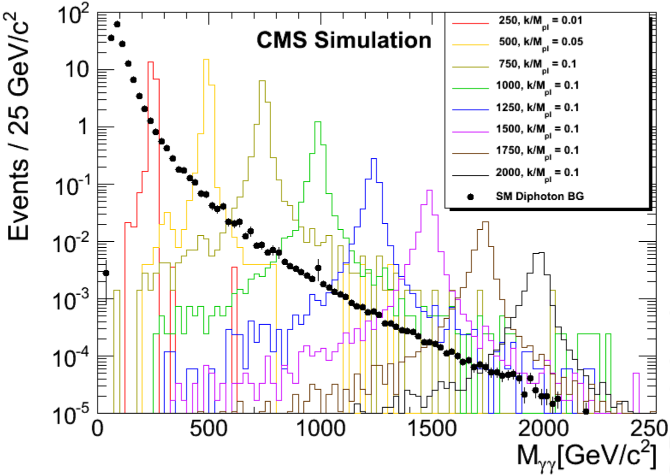
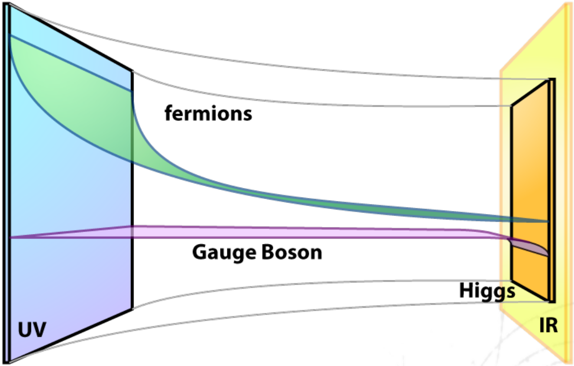


Image from CMS: EXO-10-019

Spin-2: Kaluza-Klein gravitons

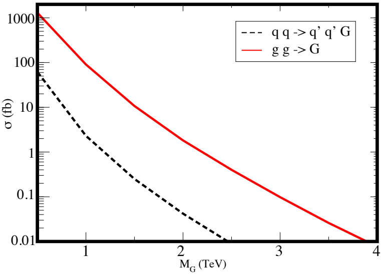
But $G \to \gamma\gamma, \ell\ell$ is no good in realistic models with bulk fields!

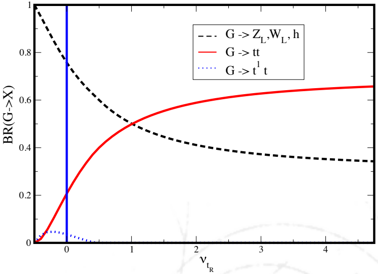


- $G^{(1)} \to \gamma\gamma$ vanishes by orthogonality of 5D profiles
- $G^{(1)} \to \ell\ell$ exponentially small m_ℓ / M_{KK} suppression

Spin-2: Kaluza-Klein gravitons

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

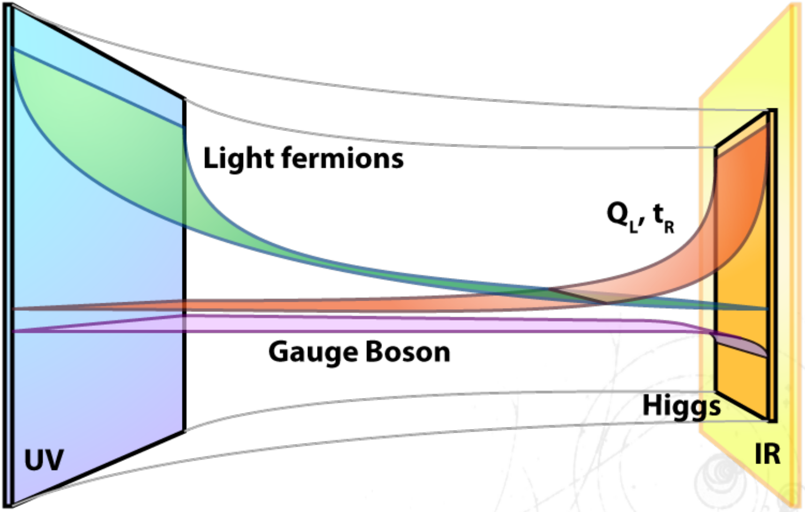




From hep-ph/0701150

Signal: boosted top resonance Expect: $\sim$ 2 TeV with 100/fb
Some BG from KK gluons, can use angular distribution.
Signal: $G^{(1)} \to 2Z_L \to 4\ell$ Expect: $\sim$ 2 TeV with 300/fb

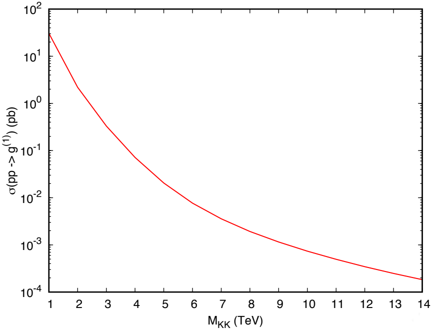
Spin-2: Kaluza-Klein gravitons

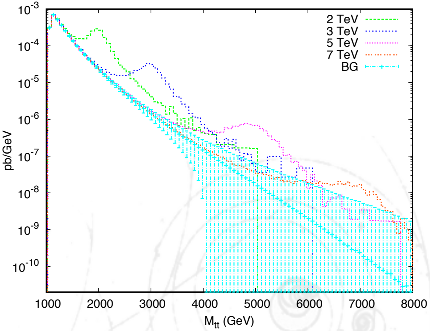


Spin-1: KK gluons, resonances

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

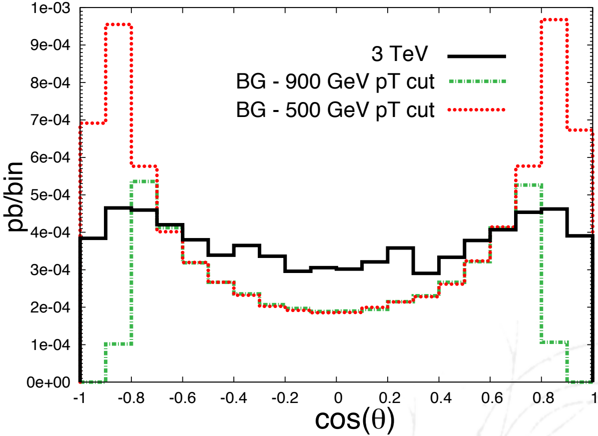
- No $ggg^{(1)}$ coupling by orthogonality of profile
- Profile peaked on IR, couples dominantly to t_R
- Need **boosted top tagging** (substructure, b/ℓ sep., invt. mass)





From hep-ph/0701166; Expect $\sim 5\,TeV$ with 100/fb

Spin-1: KK gluons, spin determination

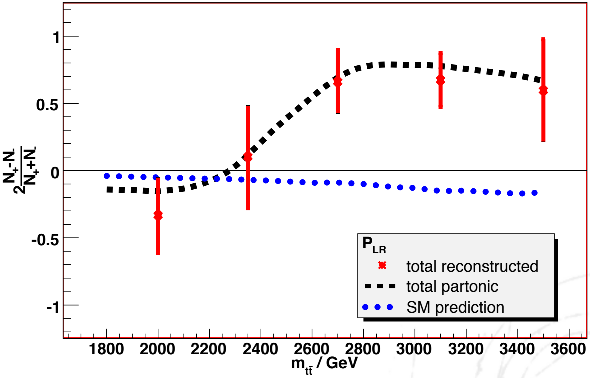


From: hep-ph/0701166; BG is forward peaked. High p_T cut helps.

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 ℓ^+.



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

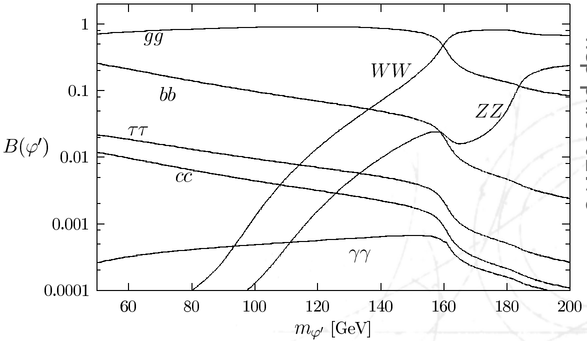
- Lower production and typically heavier than spin-1 excitations
- Custodial fermions can have exotic charges, same-sign dilepton

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

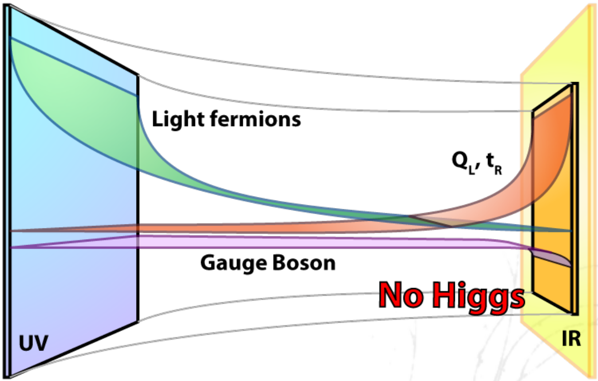


hep-ph/0002178

Remarks on RS variants

Higgsless models

Take Higgs vev $\to \infty$, decouple Higgs; repel gauge profiles



Unitarity of WW scattering from exchange of KK gauge bosons.

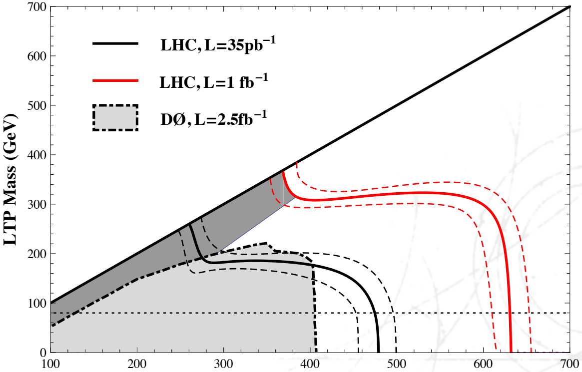
W' and Z' resonances with weak couplings to SM fermions

Remarks on RS variants

Little Higgs

Strong dynamics at ~ 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.



1103.3014

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.'

Image Credits and Colophon

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