phenomenology of beyond the SM searches

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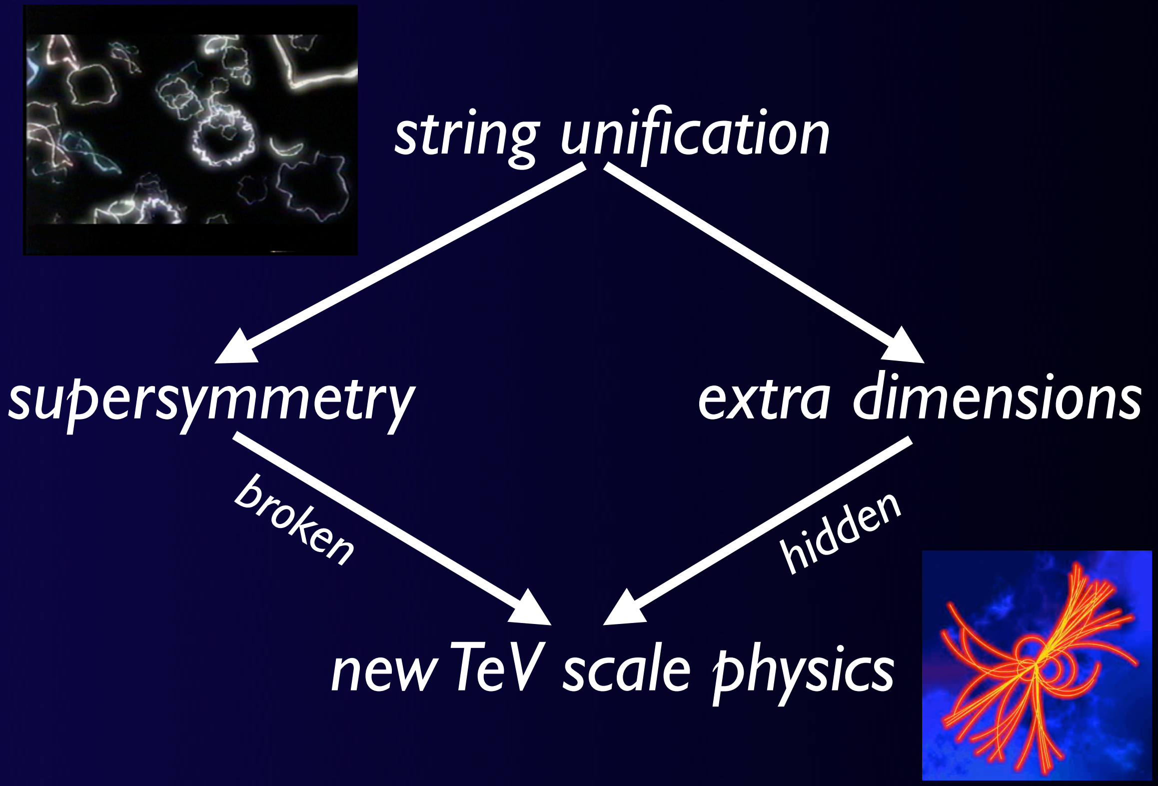
the big picture (we think)



string unification

supersymmetry

extra dimensions

broken

hidden

new TeV scale physics

+ *neutrinos, cosmology, rare processes, astrophysics, etc*

the two big ideas

- since we already had a whole day of SUSY, I will concentrate on extra dimensions
- but SUSY and extra dimensions are not mutually exclusive
- strings require both
- ED probably needs SUSY to be stable
- SUSY probably needs ED to be pretty

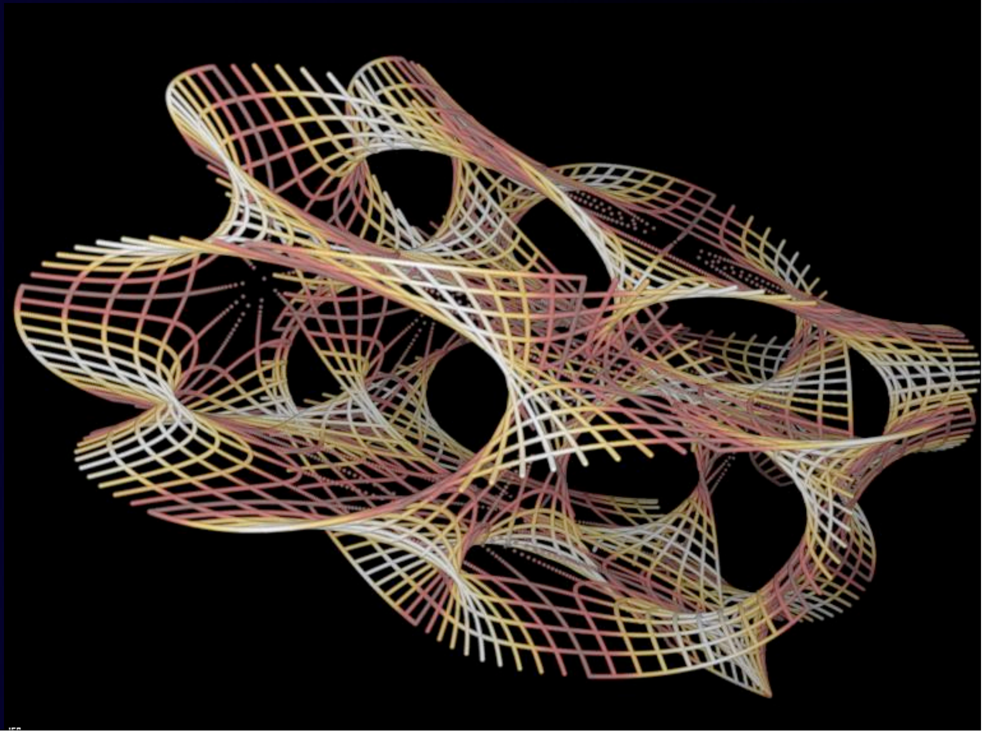
shortening the laundry list

why only SUSY and ED?
what about:

- technicolor? ⟶ ED (e.g. Higgsless) or SUSY (e.g. fat Higgs)
- leptoquarks? ⟶ SUSY and/or ED (examples later)
- excited fermions? → deconstructed ED

why extra dimensions?

- the Standard Model
- string theory
- general relativity



what is the energy scale of ED’s?

- we don’t know
- but as with SUSY we expect ED’s to appear at scales associated with other kinds of physics
- there are three or four plausible candidate scales:

what is the energy scale of ED's?

- the GUT/Planck/see-saw scale, i.e. the superheavy region around $10^{15} - 10^{18}$ GeV
- the TeV scale, i.e. 100 GeV - 10 TeV
- the dark energy/neutrino mass scale, i.e. $\frac{\mathrm{TeV}^2}{M_{\mathrm{planck}}}$

the GUT scale seems the most likely!
but some of the ED's could show up sooner

the trouble with extra dimensions models:

(1) there are too many of them

the trouble with extra dimensions models:

(1) there are too many of them

(2) none of them are any good

partial bestiary of ED models

- ADD: 2-6 large circular ED's, SM on a brane, gravity in bulk
- RS-1: one small warped ED with brane at each end, SM on TeV brane
- RS-1 variations: as above but redistribute SM and other particles between TeV brane, Planck brane, and bulk, or add second warped ED
- RS-2 and LR: one infinite warped ED, light KK gravitons
- DGP: one or more infinite (or large) flat (or slightly warped) ED's
- UED: one or more TeV^{-1} sized ED's, SM in the bulk, branes are for symmetry-breaking
- generic braneworlds: SM on various branes, 6-7 small ED's, complicated (but stable?) symmetry-breaking geometries
- deconstructed ED's: new degrees of freedom approximately resemble an ED in some energy regime

none of them are any good

- most are scenarios rather than models
- scenario = set of physical assumptions which, with more work, could turn into a respectable class of models
- many have deep theoretical problems or “gaps”
- many have generic phenomenological problems
- no benchmarks!

what is the physics that hides extra dimensions?

possible explanations:

- the extra dimensions are compact and small (circle, torus, line interval, sphere, Calabi-Yau, etc)
- Some/all SM particles are trapped on a brane and only probe the dimensions of that brane, not the full extra dimensional “bulk” space
- the extra dimensions are fundamentally different (fermionic=SUSY, discretized, deconstructed...)
- some combination of the above

three classes of LHC-friendly models

- UED
- ADD
- RS

UED = Universal Extra Dimensions

Appelquist, Cheng, Dobrescu

- basically the same as Kaluza and Klein
- all particles probe all dimensions (i.e. live in the bulk)
- extra dimensions are “orbifolds” of circles with common radius R
- so we should see Kaluza-Klein modes with mass ~1/R, could be as low as ~300 GeV

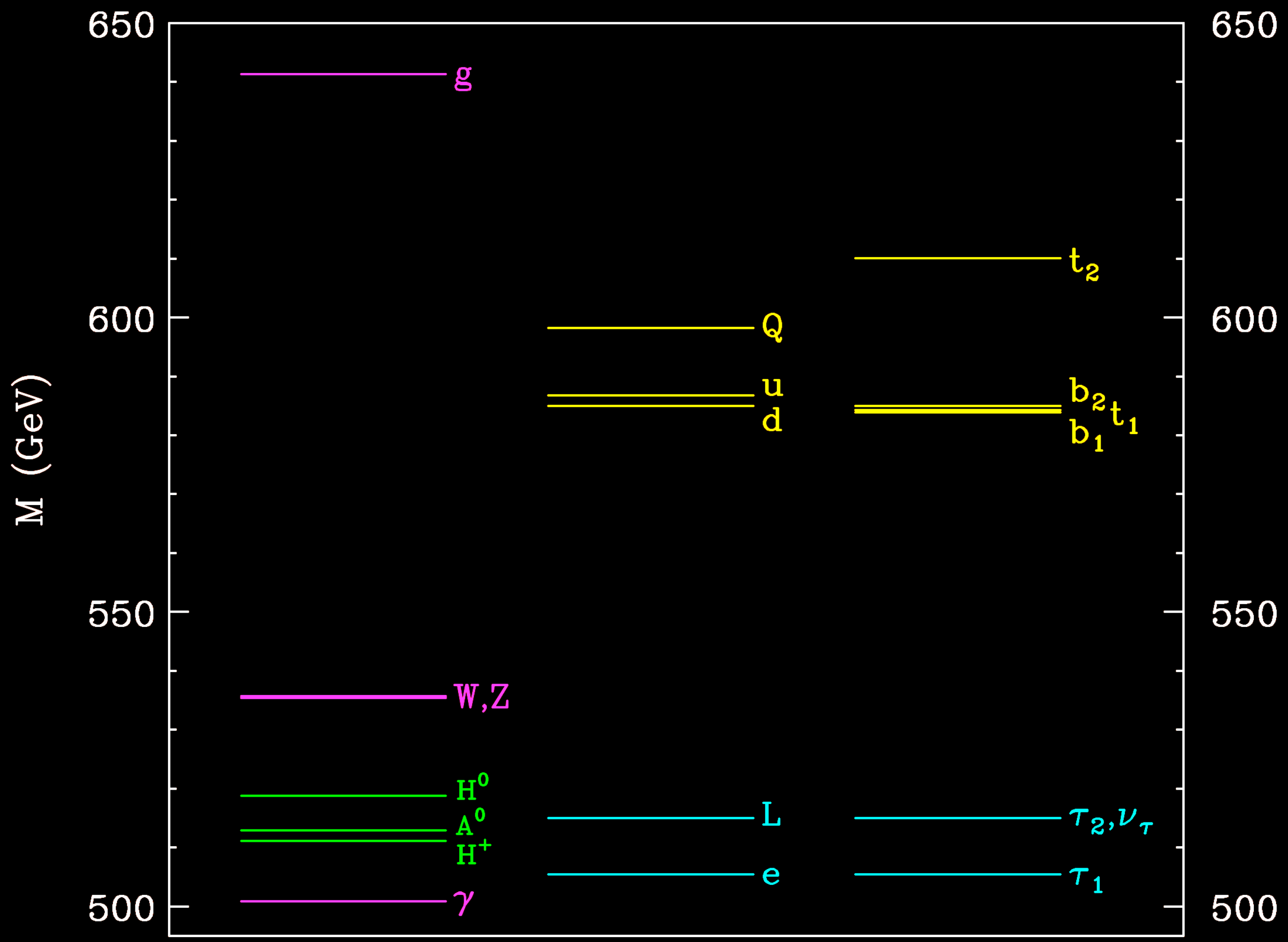
UED = Universal Extra Dimensions

- the “orbifold” means we truncate the circles to line intervals, and keep only even or odd KK modes for each kind of particle
- e.g. for a 5dim gauge boson $\mathbf{A_M = (A_\mu, A_5)}$, keep only the even KK modes of $\mathbf{A_\mu}$, and only the odd KK modes of $\mathbf{A_5}$ (since it appears in a covariant derviative with $\mathbf{d/dx^5}$).
- thus the orbifolding avoids having massless scalars in the adjoint of the SM gauge group!
- orbifolding also allows chiral fermion zero modes

UED = Universal Extra Dimensions

- the orbifolding breaks translational symmetry around the circles, so KK momentum is no longer conserved
- but a discrete remnant of KK momentum conservation, called KK parity, is conserved
- this is like R parity in SUSY
- it means that KK modes in UED have to be pair-produced
- and the lightest massive KK mode (the LKP) is stable (a dark matter candidate too)

lowest KK modes of UED look like SUSY!



Cheng, Matchev, Schmaltz, hep-ph/0205314

- so UED explains dark matter, and LKP will be produced at the LHC
- if you don’t measure spins and if you only see the first KK modes, UED at the LHC will look like SUSY
- don’t want to announce the discovery of SUSY and then have to take it back!
- simplest way to distinguish is by observing the second massive KK modes, if they are kinematically accessible
- needs more study

how to distinguish a large UED from SUSY:

heavy flavor physics!

- no tree level effects
- loop effects give minimal flavor violation
- effects are large for $1/R \simeq 300 GeV$, becoming unobservable for $1/R >\sim 1 TeV$

Buras et al, hep-ph/0307202 etc

UED can affect many observables

Enhanced vs SM :

$$B \rightarrow X_s \mu^+ \mu^-$$

$$\Delta M_s$$

$$B_s \rightarrow \mu^+ \mu^-$$

$$K_L \rightarrow \pi^0 \nu \bar{\nu}$$

$$K^+ \rightarrow \pi^+ \nu \bar{\nu}$$

Suppressed vs SM :

$$B \rightarrow X_s \gamma$$

$$\frac{\epsilon'}{\epsilon}$$

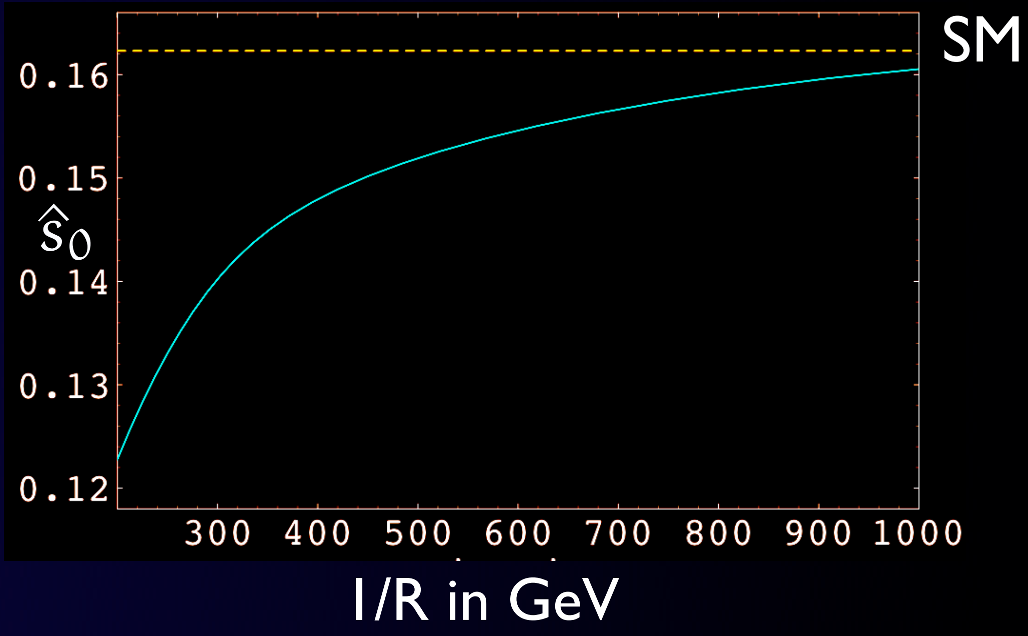
$$\hat{s}_0$$

Buras et al, hep-ph/0307202 etc

forward/backward asymmetry in SM $B \to X_s \mu^+ \mu^-$ vanishes at some

$$\hat{s}_0 = \frac{(p_{\mu^+} + p_{\mu^-})^2}{m_b^2}$$

note NLO → NNLO correction shifts $\hat{s}_0$ from 0.142 to 0.162!



Buras et al, hep-ph/0307202 etc

ADD braneworld models

Arkani-Hamed, Dimopoulos, Dvali

assume that only gravity sees n large extra compact dimensions with common circumference R:

$$\mathbf{M^2_{\mathrm{Planck}} = M_*^{2+n}\, R^n}$$

in ADD models M_* is supposed to be of order a TeV. Then the largeness of R generates the observed hierarchy between the Planck scale and the electroweak scale

these are large extra dimensions

$n = 1 \quad \Rightarrow \quad R \sim 10^{9}\,\mathrm{Km}$ **Solar system**

$n = 2 \quad \Rightarrow \quad R \sim 1\mathrm{mm}$ **Pinhead**

$n = 3 \quad \Rightarrow \quad R \sim 1\mathrm{nm}$ **Gold atom**

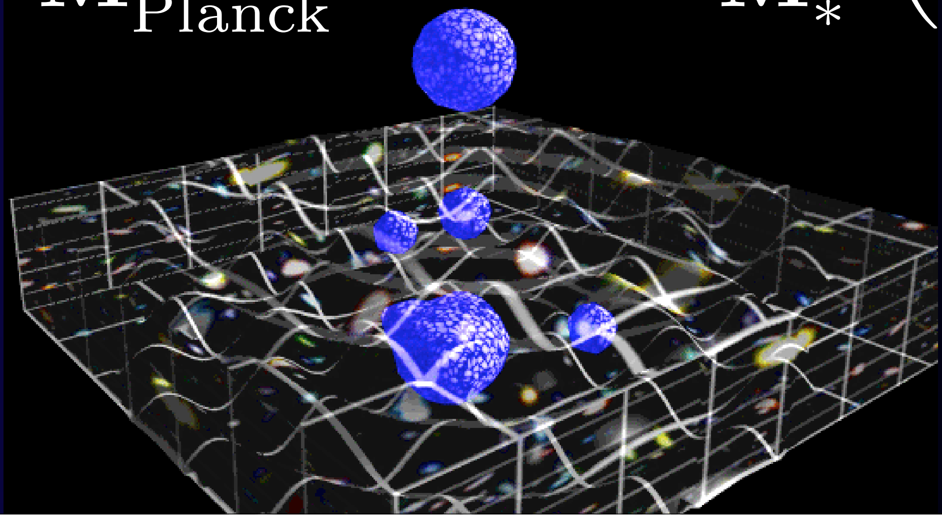
$n = 6{,}7 \quad \Rightarrow \quad R \sim 10\ \mathrm{fm}$

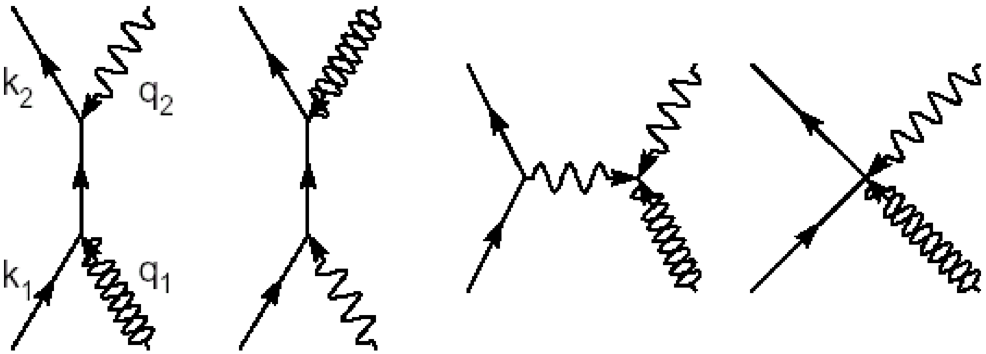
we can test these models in a variety of experiments

quantum gravity at colliders

if ADD is correct collider expts should see effects of both real and virtual massive KK gravitons

$$\sigma_{\mathbf{KK}} \sim \frac{\mathbf{1}}{\mathbf{M}^{\mathbf{2}}_{\mathrm{Planck}}}(\mathbf{ER})^{\mathbf{n}} \sim \frac{\mathbf{1}}{\mathbf{M}^{\mathbf{2}}_{*}}\left(\frac{\mathbf{E}}{\mathbf{M}_{*}}\right)^{\mathbf{n}}$$





KK graviton production (monojets)

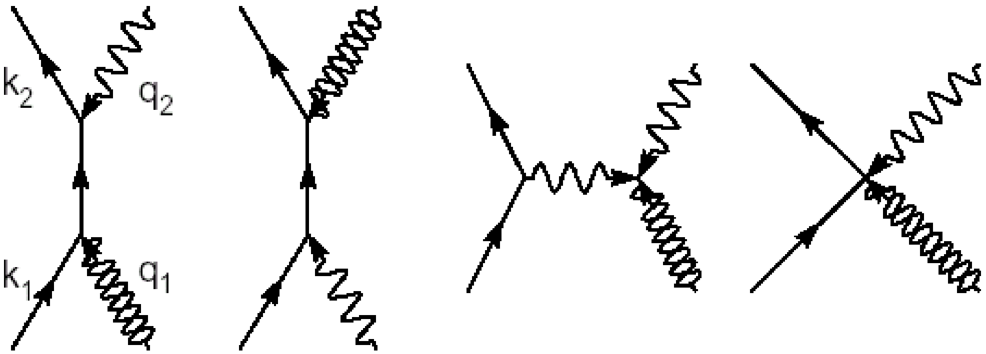
(HLZ): Han, JL, and Zhang, hep-ph/9811350
(GRW): Giudice, Rattazzi, Wells, hep-ph/9811291

$$\sigma(\mathbf{1}+\mathbf{2}\rightarrow \mathbf{KK}+4) = \int \mathbf{dx_1 dx_2 d\hat{t}\, f_1(x_1) f_2(x_2)} \int_{\mathbf{0}}^{\sqrt{\hat{\mathbf{s}}}} \mathbf{dm}\, \rho(\mathbf{m}) \frac{\mathbf{d}\sigma_{\mathbf{m}}}{\mathbf{d\hat{t}}}(\hat{\mathbf{s}},\hat{\mathbf{t}})$$

the dependence on "n", the number of extra dimensions, is all in the KK density of states:

$$\rho(\mathbf{m}) = \frac{\mathbf{M}^{\mathbf{2}}_{\mathbf{Planck}}}{\mathbf{M}^{\mathbf{3}}_{\mathbf{s}}}\left(\frac{\mathbf{m}}{\mathbf{M_s}}\right)^{\mathbf{n-1}}$$

$$\mathbf{M}_{\mathbf{s}}^{\mathbf{n+2}} = \frac{(\mathbf{2}\pi)^{\mathbf{n}}}{\mathbf{S}_{\mathbf{n-1}}}\mathbf{M}_*^{\mathbf{n+2}} = \mathbf{2}^{\mathbf{n-1}}\pi^{\mathbf{n/2}}\boldsymbol{\Gamma}\left(\frac{\mathbf{n}}{\mathbf{2}}\right)\mathbf{M}_*^{\mathbf{n+2}}$$



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$$\sigma(\mathbf{q\bar{q} \to KK + g})$$

$$= \frac{2\pi\alpha_s}{9M^2_{\rm Planck}} \int \mathbf{dx_1 dx_2 dm d\hat{t}\, f_1(x_1) f_2(x_2)}\, \rho_n(\mathbf{m})\, \frac{1}{\hat{s}} \mathbf{F_1}\left(\frac{\hat{t}}{\hat{s}}, \frac{\mathbf{m^2}}{\hat{s}}\right)$$

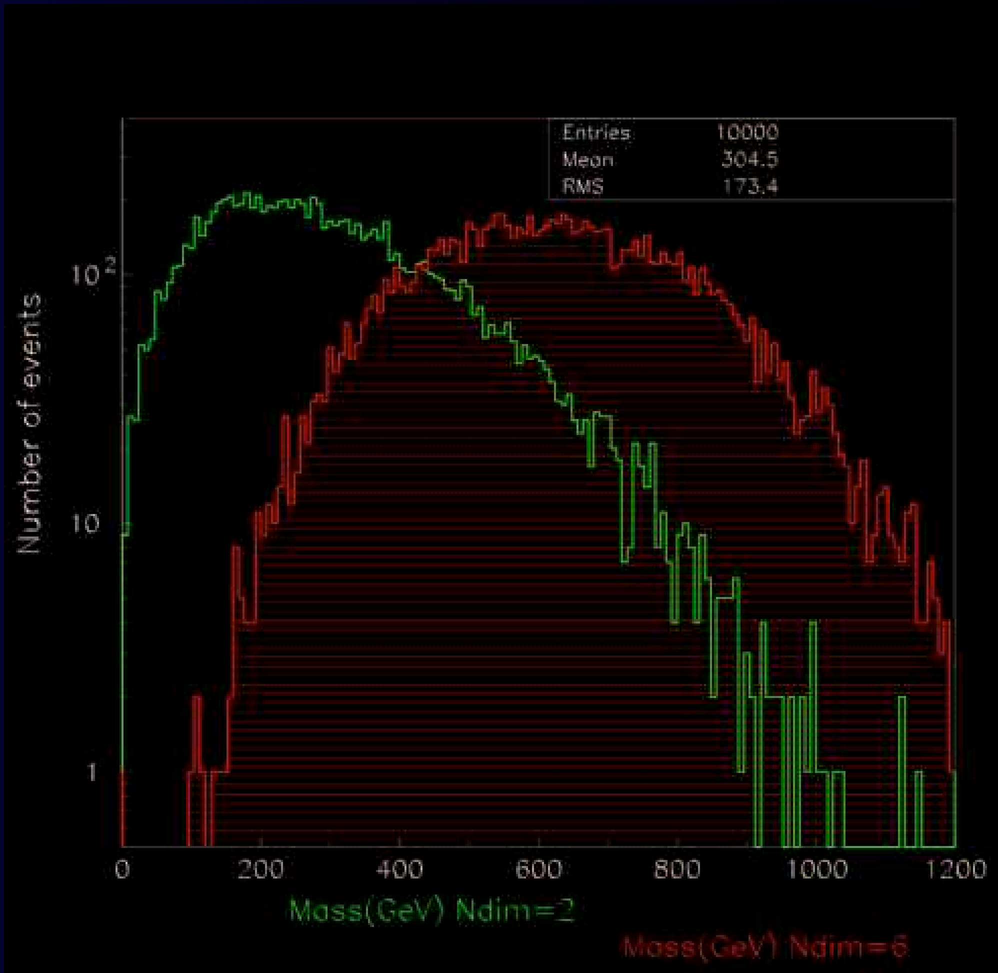
$$F_1(x,y) = \frac{1}{x(y-1-x)}\Big[-4x(1+x)(1+2x+2x^2)+ y(1+6x+18x^2+16x^3) - 6y^2x(1+2x) + y^3(1+4x)\Big],$$

this is the KK graviton spectrum, as it would be produced at the Tevatron for $\mathrm{M_s} \sim 1$ TeV

the n=6 KK gravitons are about 3 times heavier than for n=2

this is because the cross section formula, integrated over $\mathrm{x_1}$, $\mathrm{x_2}$, and $\hat{\mathrm{t}}$, gives

$$\sigma \sim \int_0^{\sqrt{\mathrm{s}}} \mathrm{dm} \left(1 - \frac{\mathrm{m}}{\sqrt{\mathrm{s}}}\right)^{2\mathrm{p}} \left(\frac{\mathrm{m}}{\sqrt{\mathrm{s}}}\right)^{\mathrm{n}}$$



JL, Matchev, and Spiropulu

with $\mathrm{p} \sim 6$ from the pdfs ⟶ peaks at $\frac{\mathrm{m}}{\sqrt{\mathrm{s}}} \sim \frac{\mathrm{n}}{2\mathrm{p}}$

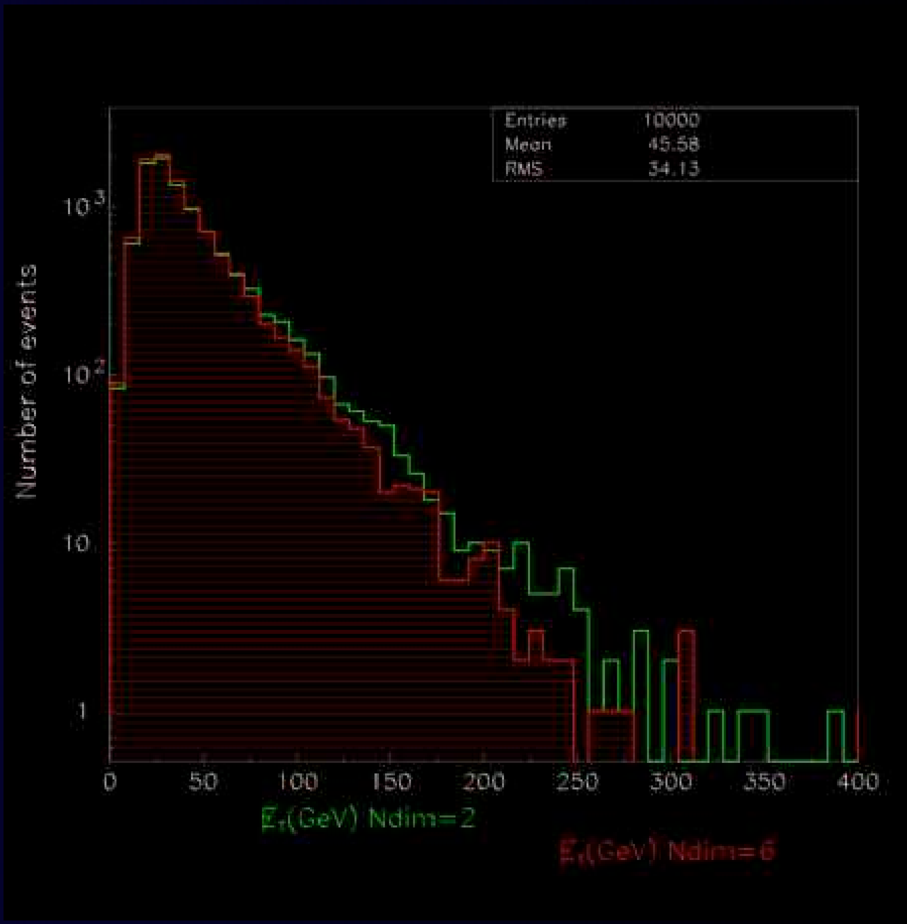
But, the pT distribution of the recoiling jet is almost completely independent of the number of extra dims!

this is because

$$\mathrm{m^n = (\sqrt{\hat{s}})^n \left(\frac{m}{\sqrt{\hat{s}}}\right)^n = (\sqrt{\hat{s}})^n y^{n/2}}$$

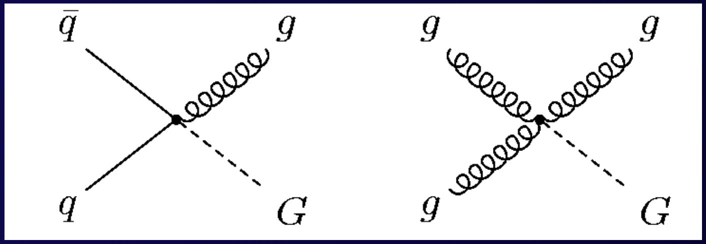
for a given fixed $\mathrm{\hat{s}}$, this wants $\mathrm{y} \sim 1$, i.e. production near threshold.

This effect suppresses pT for fixed $\mathrm{\hat{s} \simeq m}$, by $1/\mathrm{n}$

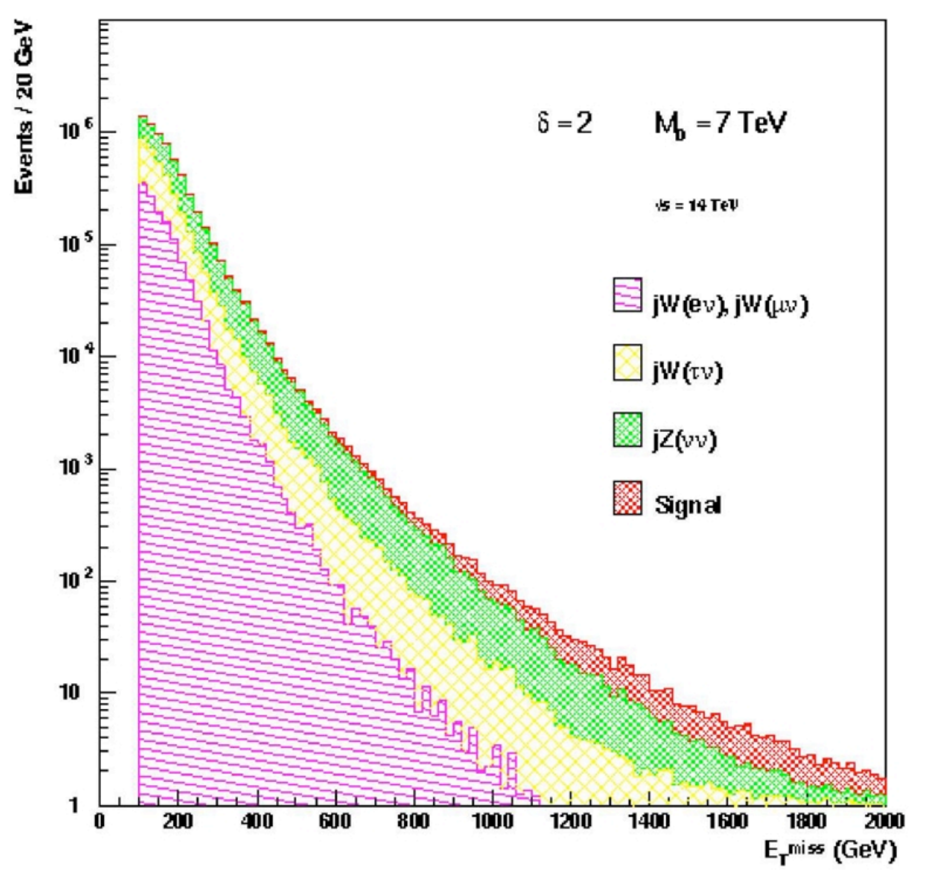


so to count the number of dims you probably have to vary s.

signals in ADD scenarios are smooth excesses over SM backgrounds, e.g.



on-shell production of single KK gravitons produces a smooth MET distribution after convolving closely spaced KK spectrum with pdfs



Hinchliffe and Vacavant, hep-ex/0005033

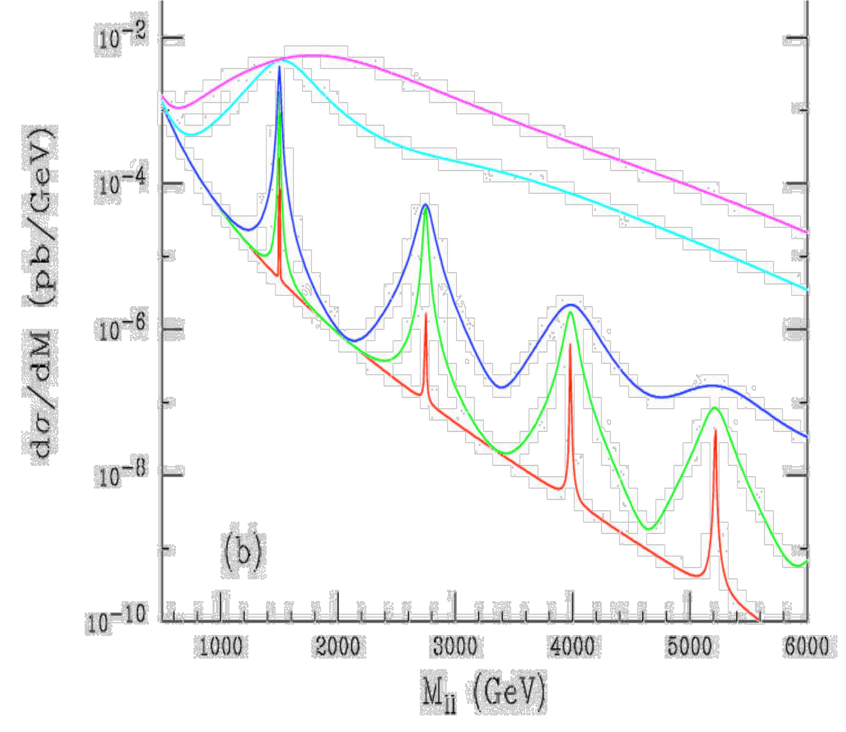
RS = Randall Sundrum

Randall and Sundrum (!)

- only one extra dimension, and at least one brane
- but the extra dimension has negative curvature ("warped", "AdS") caused by the brane
- there are many versions of RS, but when phenomenologists say RS they always mean RS-1
- RS-1 means the fifth dim is a line interval; at one end is the "Planck brane", at the other end is the "TeV" brane
- all/some SM particles live on the TeV brane

RS = Randall Sundrum

- the KK gravitons have masses ~ TeV, and their couplings to SM particles are only TeV suppressed, not Planck suppressed
- so at the LHC you can see them as difermion resonances



Davoudiasl, Hewett, Rizzo

what defines an ED scenario?

- number of ED’s at each scale
- what is the compactification?

  - what is the geometry?
  - are there background fields, e.g. gauge fluxes, in the EDs?
  - what symmetries are broken/unbroken?
  - is there curvature/warping in the bulk?
  - are there visible radions or other moduli fields?

what defines an ED scenario?

- what is gravity doing?
- who is on the branes and who is in the bulk?
  - who has KK modes?
  - who gets volume-suppressed couplings?
- what about stability? consistency? UV completion?

a behaviorist approach to ED’s

- for phenomenology we just care what the models do, not where they came from
- classify ED models by what “problems” they solve
- don’t worry (much) whether they can be fleshed out into globally respectable theories

what problems do ED's solve?

- explain (or assist) EWSB
- explain dark matter
- lower the effective Planck or string scale
- break SUSY
- explain (some) flavor properties of SM
- improve grand unification
- explain neutrinos*
- explain dark energy*

*=not this talk

higgsless models

- suppose the gauge bosons of the SM live in a 5-dim orbifold (e.g. ED = a line interval) or a 6-dim orbifold (e.g. ED = a square)
- boundary conditions at the "ends" of the ED's can break the gauge symmetry
- for TeV^{-1} size ED's, can produce EWSB without a higgs

e.g. Csaki, Grojean, Murayama, Pilo, Terning (2003)
Nomura, Burdman+Nomura (2003)
Barbieri, Pomarol, Rattazzi (2003)
Gabriel, Nandi, Seidl (2004)

higgsless models

- there is a theorem that longitudinal WW scattering violates unitarity at ~ 1 TeV unless there is a higgs

see talk by M. Chanowitz

- in ED, the long. mode of the first massive KK W can play this role instead
- then the long. mode of the second KK W unitarizes the scattering of the first KK W, etc

higgsless models

- this weakly coupled loophole only works for the first few KK gauge boson modes, because ED gauge theory becomes strongly interacting
- but it may be possible to have a weakly coupled higgsless theory up to 6-7 TeV!

e.g. Davoudiasl, Hewett, Lillie, Rizzo (2004)

- see talk by C. Csaki, this session
- predicts KK modes of EW gauge bosons with masses starting at Tevatron bounds

little higgs

- “little higgs” refers to weakly coupled non-SUSY models of TeV scale EWSB
- arose from deconstructing 5-dim gauge theories
-

Arkani-Hamed, Cohen, Georgi (2001)

- little higgs model builders will claim their 4-dim models have nothing to do with ED’s!
- but deconstructing ED’s still seems the best motivation...

deconstruction deconstructed

- consider a 5-dim SU(N) gauge theory
- deconstruct the circular extra dimension to a finite periodic lattice with m sites and lattice spacing $1/\mathbf{f}$
-
-

$$\mathcal{L} = \frac{1}{2\mathbf{g}^2}\sum_{\mathbf{i}=1}^{\mathbf{m}} \mathbf{tr}\mathbf{F}_{\mathbf{i}}^2 + \mathbf{f}^2 \sum_{\mathbf{i}=1}^{\mathbf{m}} \mathbf{tr}\left[(\mathbf{D}_\mu \mathbf{U}_{\mathbf{i}})^\dagger \mathbf{D}^\mu \mathbf{U}_{\mathbf{i}}\right]$$

- looks like m copies of a 4-dim SU(N) gauge theory, plus scalar “link” fields $\mathbf{U}_{\mathbf{i}}$
- the scalars are massless Goldstones which get eaten by the gauge bosons, turning most of the gauge bosons into massive “KK” modes
- deconstruction: special 4d theories with “copies” can mimic ED’s

little higgs

- in this example one scalar mode, $\mathbf{U_1 U_2 \ldots U_m}$ doesn't get eaten, and remains as a naturally light pseudo-Goldstone boson, i.e. a "little higgs"
- the little higgs avoids quadratic divergences because it is secretly a nonlocal object in the quasi-ED
- the price is we introduce:

  - new heavy gauge boson "copies"
  - perhaps extra higgses, e.g. higgs triplets, singlets
  - these particles have masses of order f

little higgs

- since we butchered the ED, don't expect little higgs models to explain a hierarchy 100 GeV - 10^{16} GeV
- but maybe a hierarchy between 100 GeV and 10 TeV!
- actually with fermions even this doesn't work unless we add heavy vectorlike "copies" of the right-handed top quark
- these extra weak singlet, charge 2/3 quarks are as in the "top see-saw" models

Dobrescu and Hill (1997)

generic TeV scale predictions of little higgs

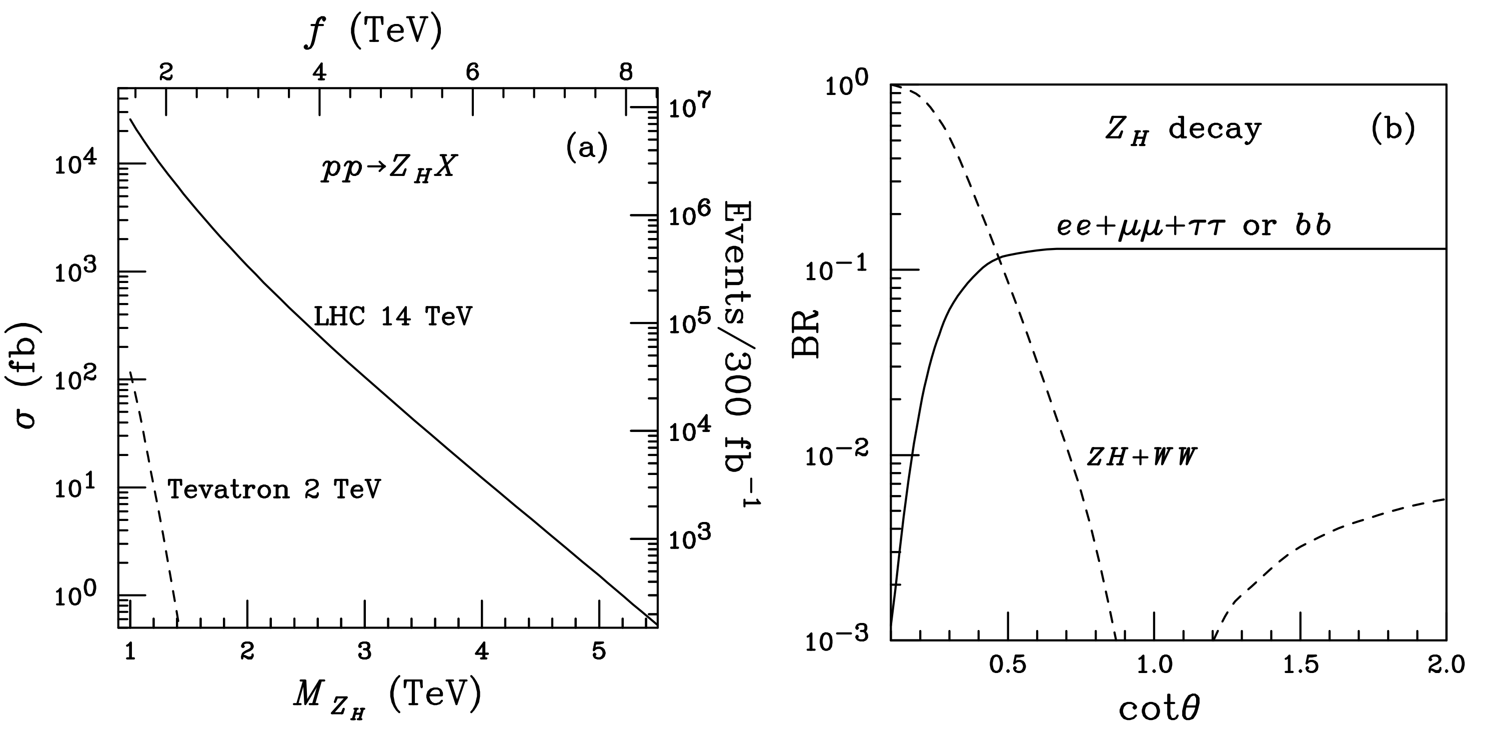
- new heavy gauge bosons $\mathrm{W}', \ \mathrm{B}', \ \mathrm{Z}'$ with couplings closely related to SM counterparts
- heavy exotic higgs triplets, singlets
- heavy vectorlike pairs of weak singlet, charge 2/3 quarks

e.g. Csaki et al (2002,2003)
Burdman, Perelstein, Pierce (2002)
Han, Logan, McElrath, Wang (2003)
Perelstein, Peskin, Pierce (2003)

generic TeV scale predictions of little higgs

- generic models make tree level modifications of precision EW observables, $\longrightarrow$ overall scale $\mathrm{f} > \sim 1 - 4$ TeV
- can invoke "T-parity" (like R-parity in SUSY), making all the exotics T-odd, to suppress tree level effects and allow a lighter overall scale ~ 500 GeV Cheng and Low (2004)
- the second case has completely different phenomenology, since the exotics have to be pair-produced

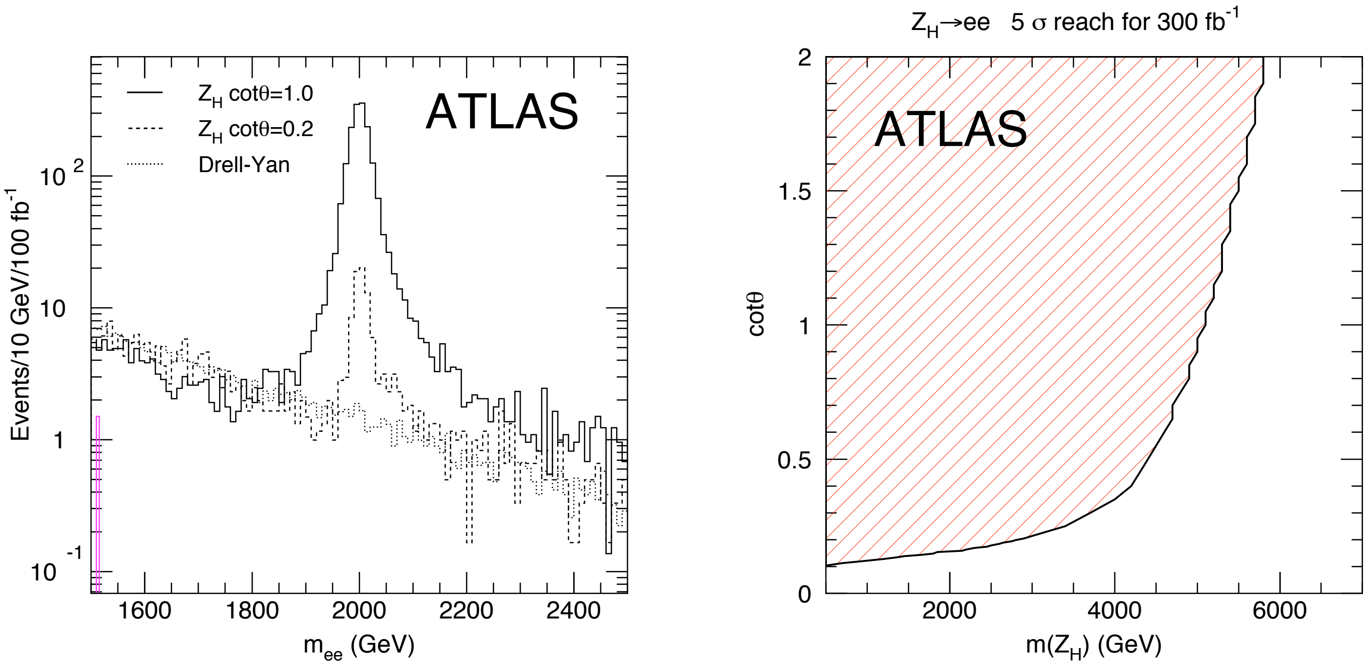
LHC: little higgs *without* T parity



Han, Logan, McElrath, Wang (2003)

produce > TeV mass Z' via Drell-Yan;
decays mostly to W^+W^- and ZH, but also $\ell^+\ell^-$

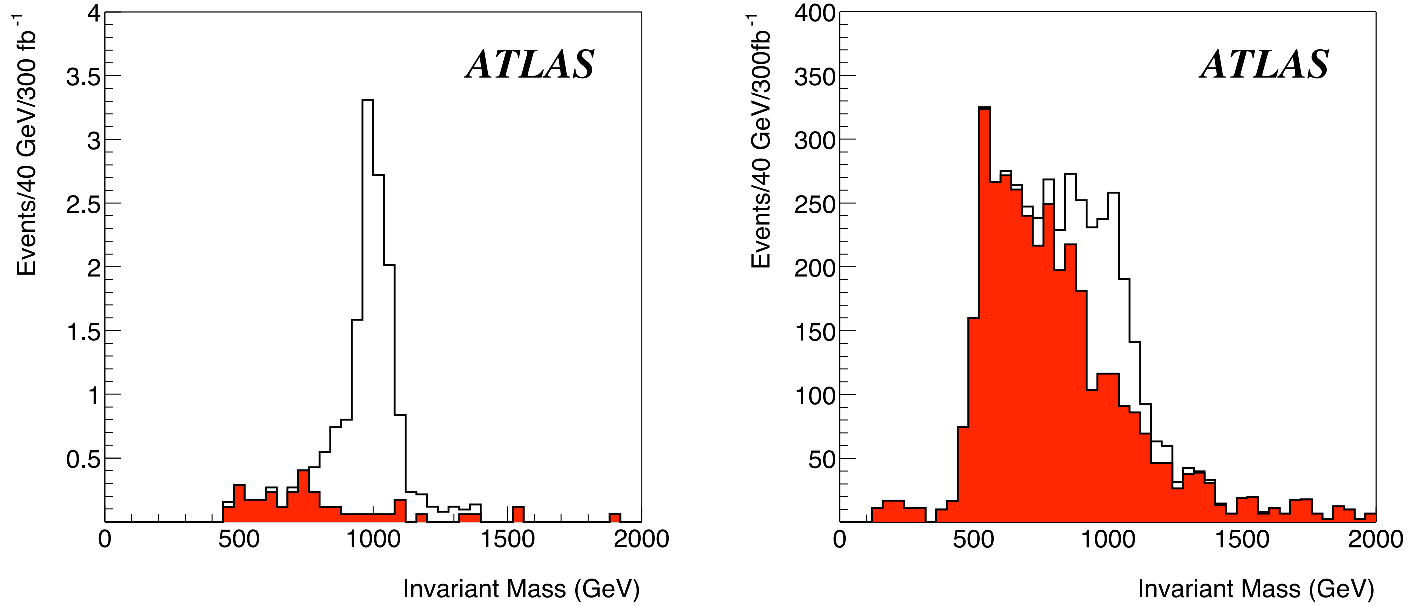
LHC: little higgs *without* T parity



Azuelos et al hep-ph/0402037

of course observing this Z' is just the first step!

LHC: little higgs *without* T parity



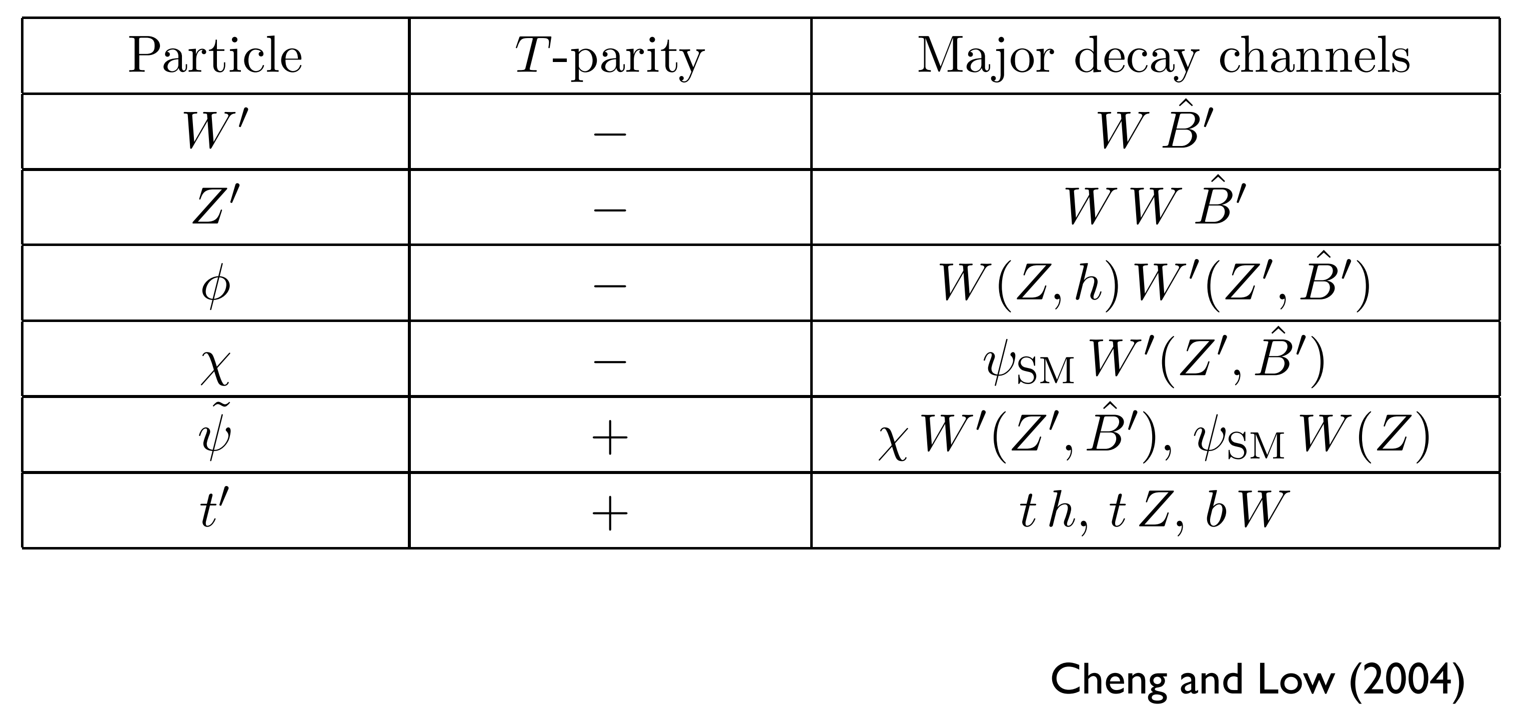
Azuelos et al hep-ph/0402037

single T production followed by decay $\mathrm{T} \rightarrow \mathrm{tZ},\ \mathrm{bW}$
discovery reach for at least $\mathrm{M_T}$ ~ 1 TeV

LHC: little higgs *with* T parity

- like R-parity conserving SUSY, the lightest T-odd exotic is stable
- this is likely to be the B', a good CDM candidate!
- T-odd exotics are pair-produced, then have cascade decays with missing energy

LHC: little higgs *with* T parity



Particle	T-parity	Major decay channels
W'	$-$	$W\,\hat{B}'$
Z'	$-$	$W\,W\,\hat{B}'$
ϕ	$-$	$W(Z,h)\,W'(Z',\hat{B}')$
χ	$-$	$\psi_{\rm SM}\,W'(Z',\hat{B}')$
$\tilde{\psi}$	$+$	$\chi\,W'(Z',\hat{B}'),\ \psi_{\rm SM}\,W(Z)$
t'	$+$	$t\,h,\ t\,Z,\ b\,W$

Cheng and Low (2004)

your homework: simulate this for the LHC

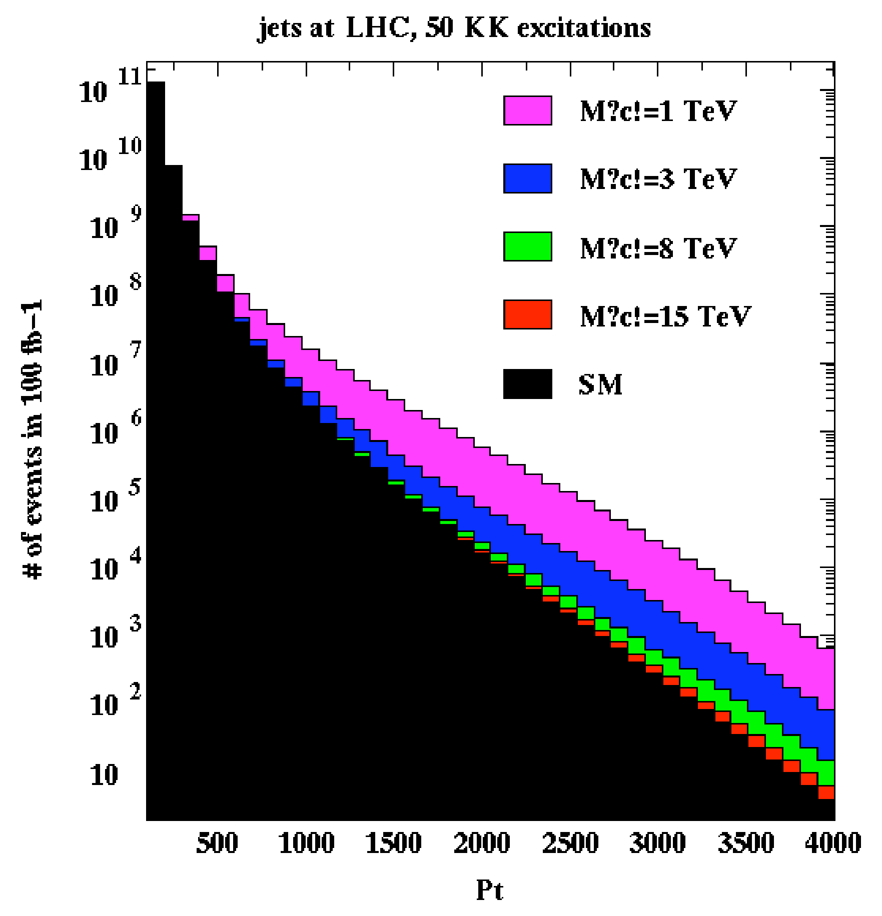
asymmetrical ADD models

- brane models with flat TeV^{-1} size EDs
- SM gauge bosons assumed to live in bulk
- KK gluon exchange enhances dijet cross section at high pT

JL and Nandi, PLB485, 224 (2000)
Dicus, McMullen, Nandi, hep-ph/0012259

impact on LHC dijet cross section

smooth excess
at high pT

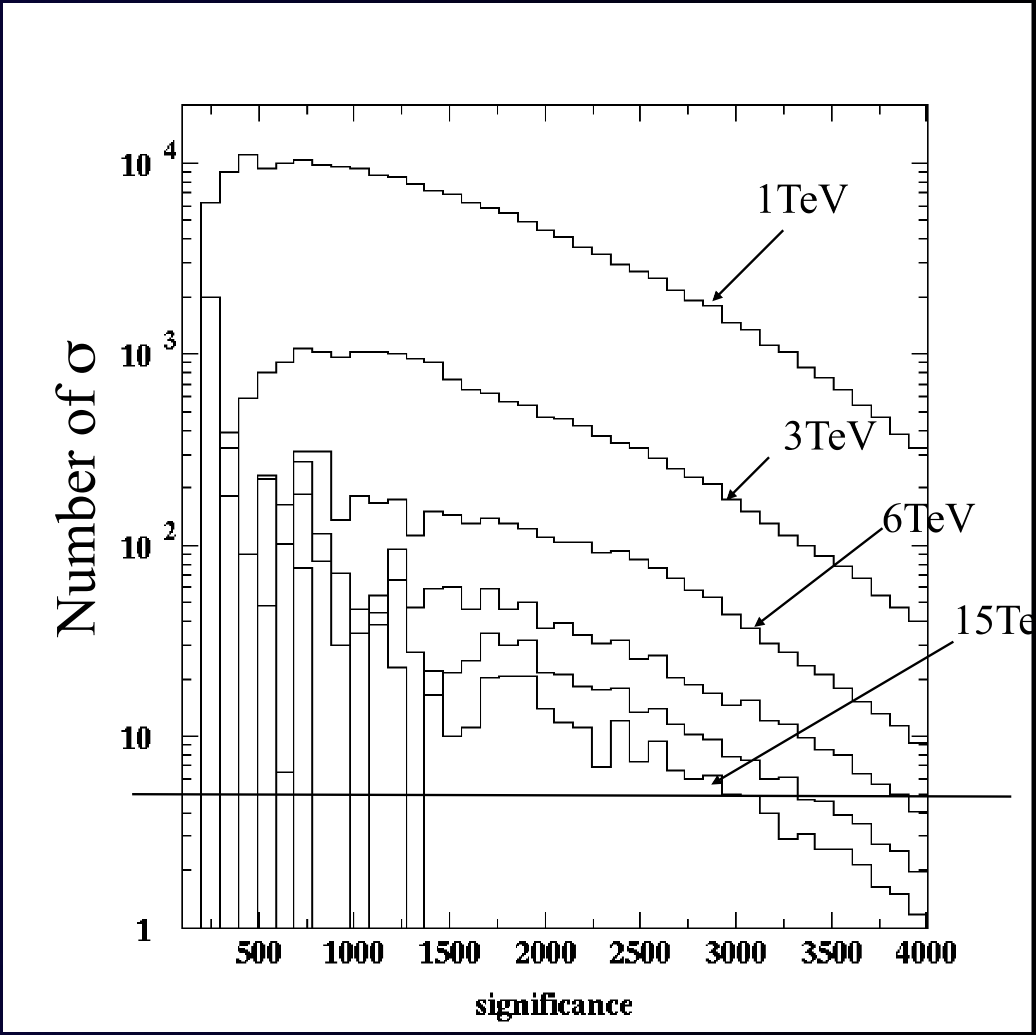


Balazs, Escalier, Ferrag, Polesello, Atlas talk 12/03

impact on LHC dijet cross section

sensitivity up to 15 TeV!

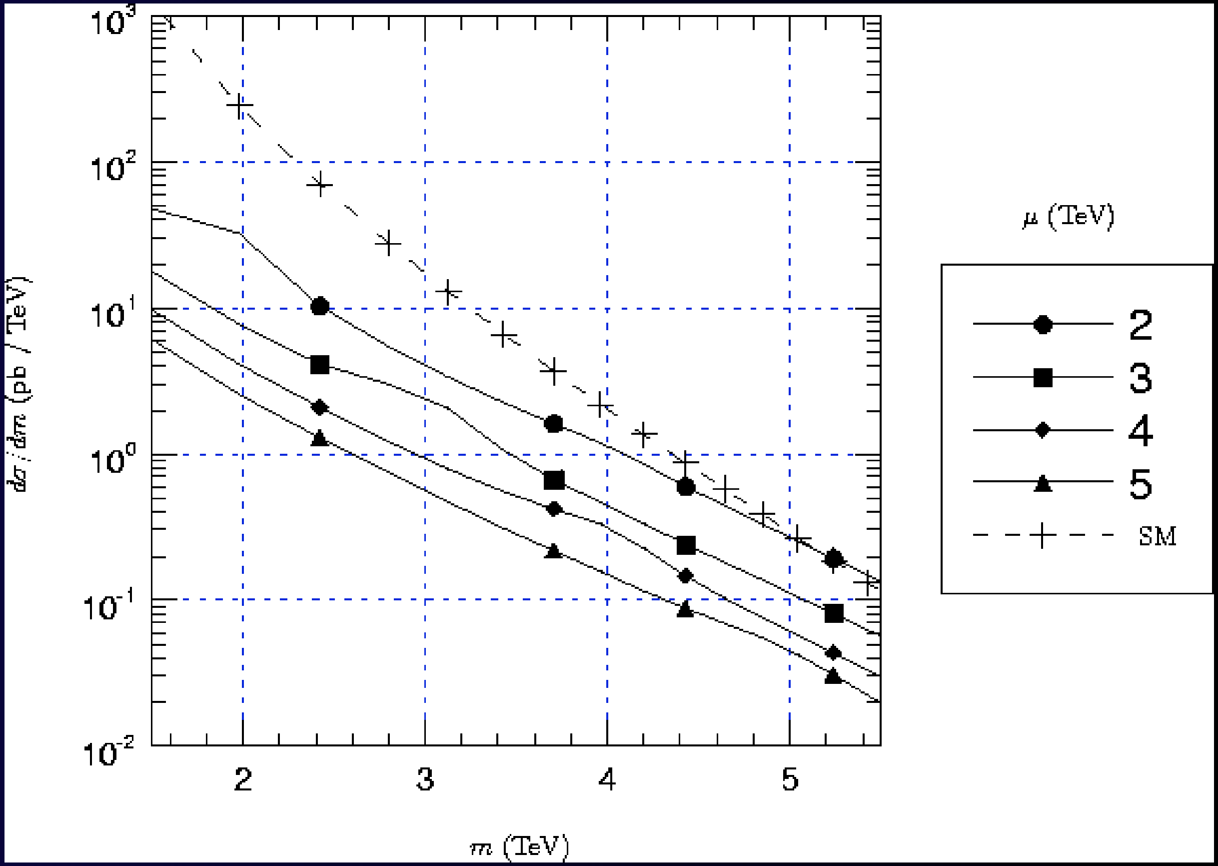
but how do you know this is ED?



Balazs, Escalier, Ferrag, Polesello, Atlas talk 12/03

why not look for peaks in the dijet invariant mass?

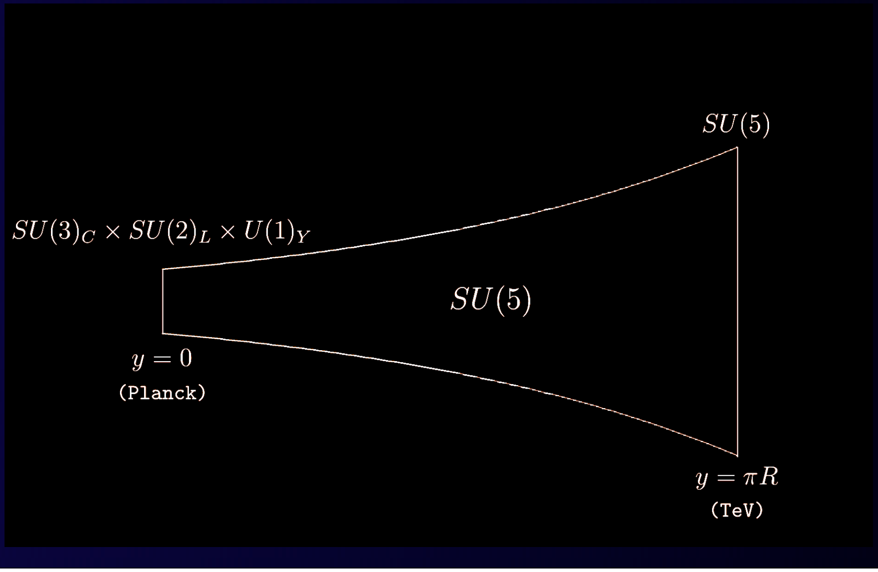
too small
too broad



Dicus, McMullen, Nandi, hep-ph/0012259

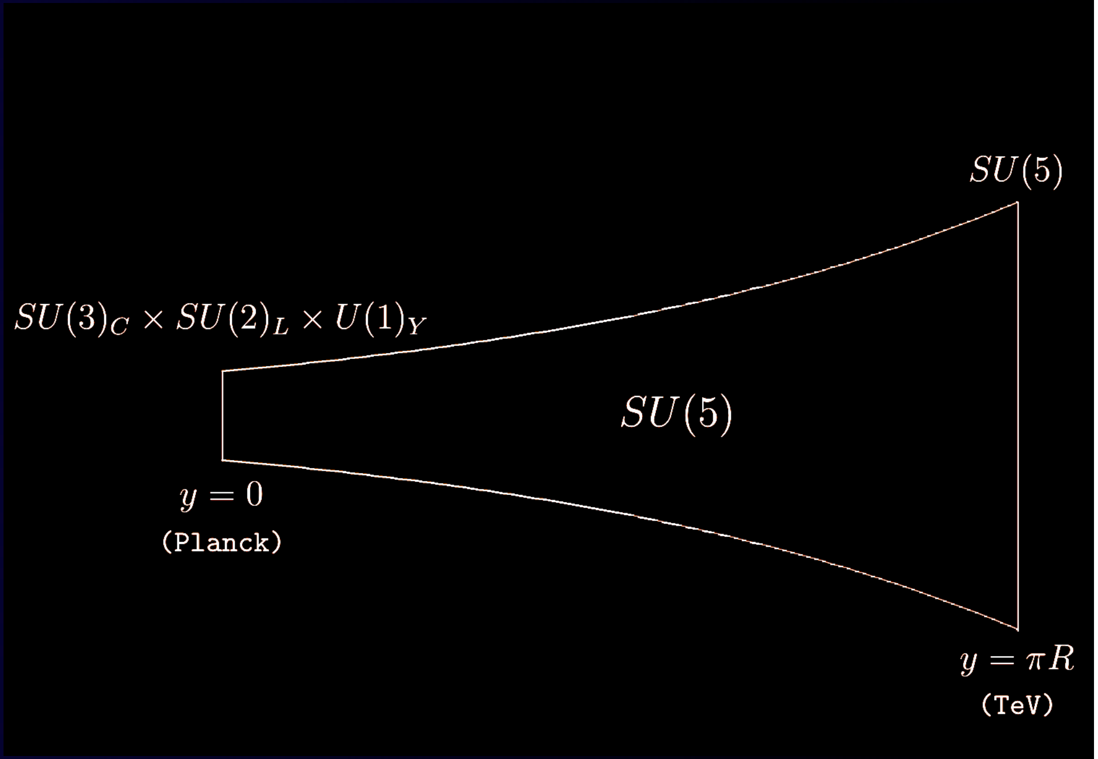
warped SUSY GUTs

- boundary conditions on branes (or background fields in the bulk) can break symmetries (EW, SUSY, GUT, etc)
- take any SUSY or GUT model, and "improve" it with an extra dimension
- for GUTs, a single small warped ED can do a lot:



warped SUSY GUTs

- gauge bosons and Higgs in the bulk
- SM fermions on the Planck brane
- SU(5) broken by boundary conditions on the Planck brane



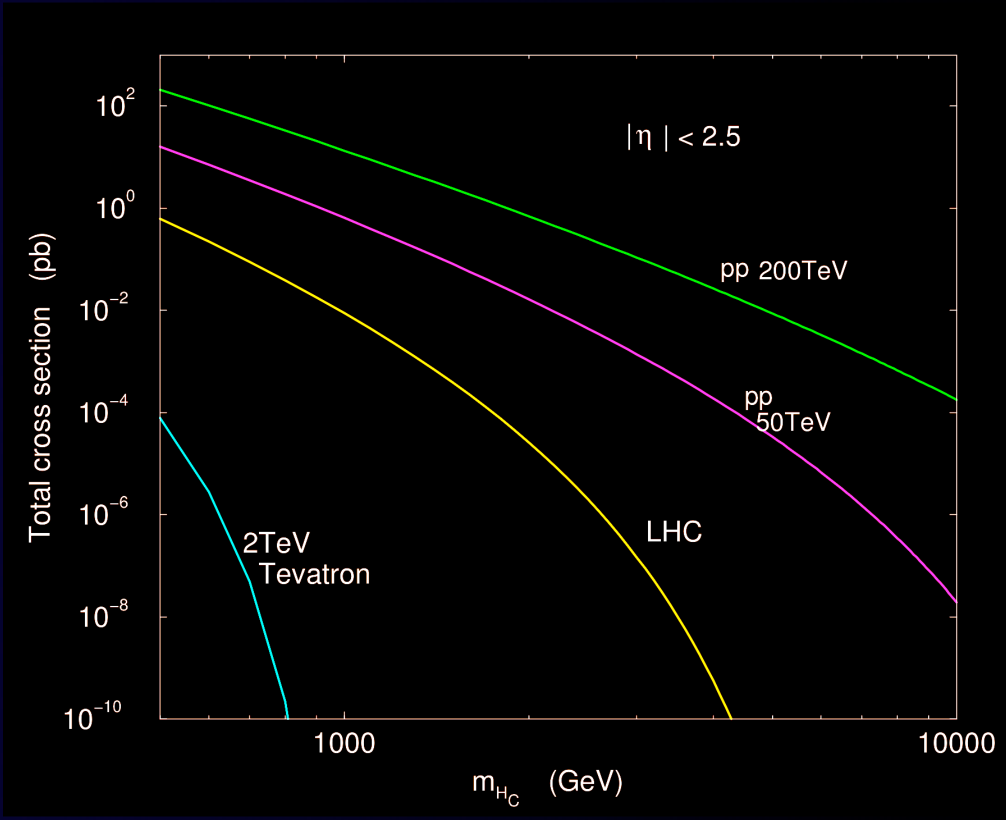
Goldberger, Nomura, Smith, hep-ph/0209158

warped SUSY GUTs

- in the bulk are the usual Higgs color triplet as well as the X and Y bosons of SU(5), which induce proton decay.
- chose b.c. so they vanish at the Planck brane; this kills the zero modes, but still have KK modes with TeV masses
- but proton decay is OK (maybe) because of wave-function suppression!
- look for the Higgs color triplet at the LHC...

warped SUSY GUTs

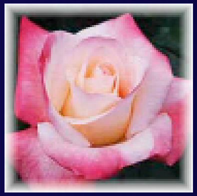
- the lighter of the colored Higgs and colored Higgsino is stable, hadronizes
- look for heavy stable charged particles, “heavy muons”



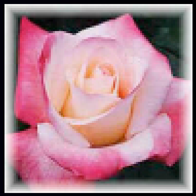
Cheung and Cho, hep-ph/0306068

whatever happened to leptoquarks?

- there continue to be diligent searches for leptoquarks at colliders
- but the theorists lost interest after 1997
- ~3 theory papers on leptoquarks in the last five years, versus e.g. ~3 *thousand* theory papers on extra dimensions
- why forgotten?



a leptoquark by any other name would smell as sweet



- leptoquark = any boson which decays into a lepton and a quark through a renormalizable chiral coupling that respects SM gauge symmetries
- so the squarks of SUSY are leptoquarks, if we allow one of the standard R-parity violating couplings:
- $\lambda' \ell \mathbf{q} \tilde{\mathbf{d}}$ $\qquad$ $\lambda' \ell \tilde{\mathbf{q}} \mathbf{d}$
-
- these are theoretically natural TeV scale leptoquarks

leptoquarks in GUTs

- the original motivation for leptoquarks was grand unified theories
- in GUTs the SM leptons and quarks are members of the same GUT multiplets, e.g. 5bar and 10 of SU(5) or the 16 of SO(10)
- thus some of the heavy GUT bosons in other multiplets -e.g. the X,Y gauge bosons of SU(5)- are leptoquarks
- but their typical masses will be GUT scale, not TeV scale

leptoquarks in extra dimensions

- the 5d warped SU(5) model can naturally have TeV mass leptoquarks:
- e.g. add bulk scalars in the 5 and 5bar of SU(5)
- chose boundary conditions so that they vanish at the TeV brane, but not at the Planck brane
- so they have no zero modes, only TeV mass KK modes
- and their couplings to SM fermions are not suppressed
- to avoid proton decay, only allow coupling to 3rd gen.

black holes and string balls

- if the effective Planck scale is at ~ TeV, then the string scale should be at ~ TeV
- look for string excitations (heavy higher spin particles) at the LHC

JL hep-th/9603133
Cullen, Perelstein, Peskin, hep-ph/0001166

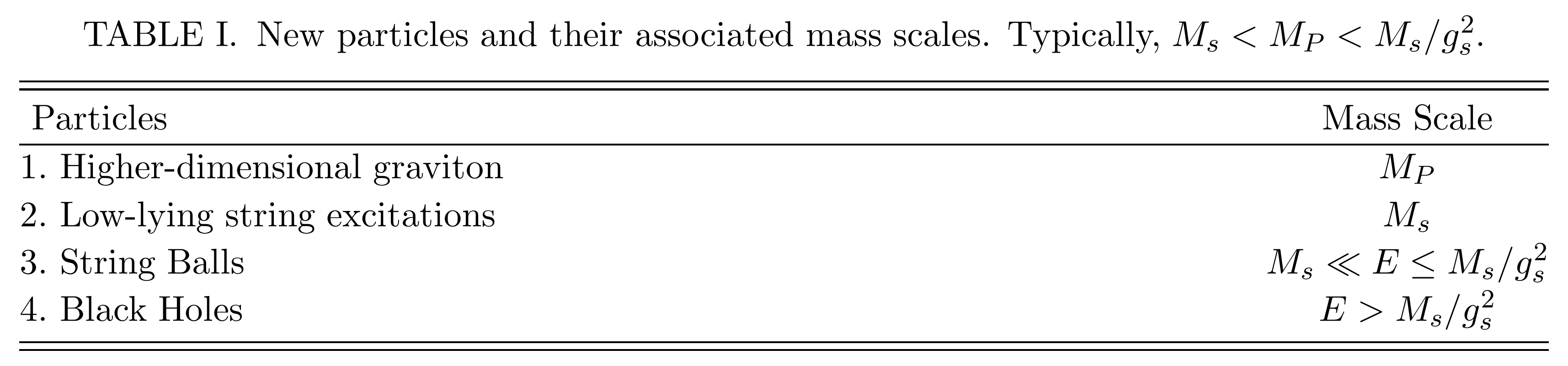


TABLE I. New particles and their associated mass scales. Typically, $M_s < M_P < M_s/g_s^2$.

Particles	Mass Scale
1. Higher-dimensional graviton	M_P
2. Low-lying string excitations	M_s
3. String Balls	$M_s \ll E \leq M_s/g_s^2$
4. Black Holes	$E > M_s/g_s^2$

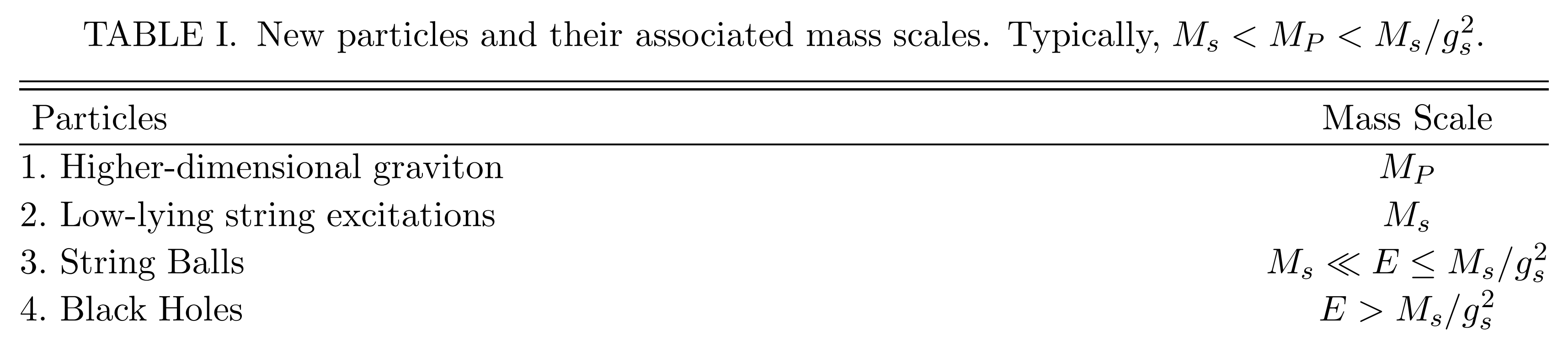
black holes and string balls

- because strings are extended objects, the number of string excitations grows extremely rapidly with energy
- at multi-TeV, typical hard pp scattering will produce a single highly excited string: a “string ball”

Dimopoulos and Emparan, hep-ph/0108060

black holes and string balls

- at even higher energies, string balls collapse into black holes, i.e. pp scattering produces black holes.
- the LHC will not have enough energy to do this
- but if the LHC discovers KK gravitons, the required energy upgrade will be funded!



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ALICE in wonderland

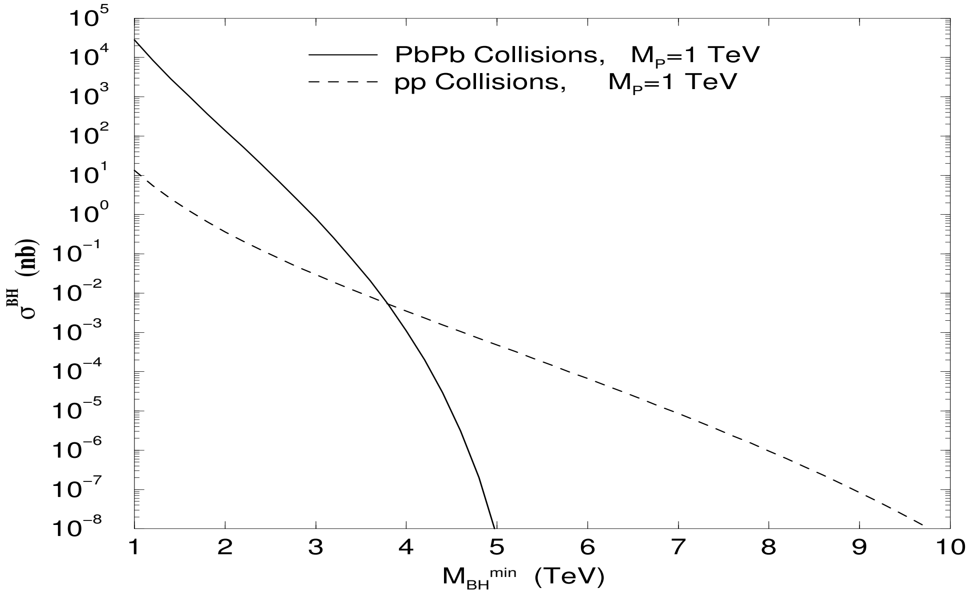

FIG. 3b: The total cross section for black hole production in a PP collision at $\sqrt{s}^{NN} = 14$ TeV at LHC and in a PbPb collision at $\sqrt{s}^{NN} = 5.5$ TeV at LHC

Chamblin and Nayak, hep-ph/0206060

who’s on the bench?

- SUSY has official benchmark models ratified by intergalactic treaties
- ED has no benchmark models at all
- some of the most popular ED models, e.g. n=2 ADD, are not suitable benchmarks as they are already experimentally excluded
- this needs to change before 2007

event generators for ED

- until recently, the only event generators for ED models were custom hacks:
- ADD in Pythia (Matchev + JL bootleg) used for CDF and D0 monjet analyses
- ADD in Isajet (Hinchliffe + Vacavant) used for ATLAS monojet studies, now in official Isajet release
- RS-I in Herwig, also used for Atlas studies
- nothing in CompHEP
- very recently, AMEGIC has implemented complete ADD Feynman rules (Gleisberg, Krauss, Matchev)

experimental issues = opportunities

- how do you know it is ED and not something else?
- how to get experimental handles on all the features of ED scenarios
- direct versus indirect versus really indirect
- event generation and benchmark models
- collider vs flavor vs astro signals/constraints