SIGNALS FROM UNIVERSAL EXTRA DIMESIONS AT TEVATRON & LHC

S. NANDI

OKLAHOMA STATE UNIVERSITY
&
OKLAHOMA CENTER FOR HIGH ENERGY PHYSICS (OCHEP)

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COLLABORATORS: C. Macesanu, C.D. McMullen, M. Rujoiu

OUTLINE

1. INTRODUCTION
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   - : MOTIVATION, THEORY BENEFITS AND EXPERIMENTAL IMPLICATIONS
2. UNIVERSAL EXTRA DIMENSIONS
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   - : MODEL DESCRIPTIONS
3. COLLIDER SIGNALS
   - : CURRENT BOUND FROM TEVATRON
   - : REACH FOR RUN 2 & LHC
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1. INTRODUCTION

EXTRA DIMENSIONS

IDEA : KALUZA (1921), KLEIN (1926)

: POPULAR , PAST 5 YRS.
(Arkani-Hamed, Dimopoulos & Dvali)

THEORY BENEFITS :

: TRUE UNIFICATION (gogoladze, mimura + SN)

⇒ UNIFICATION OF "ALL PARTICLES.
GAUGE , HIGGS , MATTER

⇒ UNIFICATION OF GAUGE & YUKAWA

$$g_3 = g_2 = g_1 = g_t = g_b = g_\tau$$

⇒ WORKS VERY WELL

: AN ALTERNATIVE TO HIGGS MECHANISM (Kawamura, Altarelli & Ferglio) Hall & Nomura, ..)

THEORY BENIFITS (CONTD.)

: NO GAUGE HIERARCHY PROBLEM (Arkani-Hamed, Dimopoulos + Dvali)

: A MECHANISM FOR SUSY BREAKING (Scherk & Schwarz; Hosotani)

: UNDERSTANDING OF WHY $m_\nu \ll m_q, m_\ell$

: POSSIBILITY OF MULTITEV SCALE GUT (Dienes, Dudas & Gherghetta)

: CANDIDATE FOR COLD DARK MATTER (Cheng, Matchev & Schmaltz; Tait & Servant; Cheng, Feng & Matchev)

: EXPLORING QUANTUM GRAVITY

EXPERIMENTAL IMPLICATIONS:

: EXISTENCE OF A TOWER OF NEW PARTICLES (KK EXCITATIONS)

: POWER LAW RUNNING OF GAUGE COUPLINGS

: DEVIATIONS FROM NEWTONS LAW OF GRAVITY

: BLACKHOLES AT COLLIDERS

: ASTROPHYSICAL IMPLIÇATIONS

: TRANSPLANKIAN PHYSICS

THIS TALK : HIGH ENERGY COLLIDER IMPLICATIONS

EXTRA DIMENSIONS

- FLAT (Arkani-Hamed, Dimopoulos & Dvali)
- WARPED (Randall & Sundram)

NUMBER : ? STRING THEORY ⇒ 6

SIZE :

: INVERSE PLANCK SCALE

⇒ : INVERSE TEV SCALE *

: SUBMM SCALE

* MOST INTERESITING FOR HIGH ENERGY COLLIDERS

DO SM PARTICLES PROPAGATE IN EXTRA DIMENSIONS ?

NO
(ADD SCENARIO)

YES,
BUT
ONLY
GAUGE
BOSONS
(Antoniadis)

YES,
ALL SM
PARTICLES
(UNIVERSAL
EXTRA DIM)
(Appelquist,
Cheng & Dobrescu)

MOST INTERESITING
FOR HE COLLIDERS

2. UNIVERSAL EXTRA DIMENSION

Model Description

- **Particle Content**

all SM particles propagating in one extra dimension of radius $R \sim 1\ \text{TeV}^{-1}$

↓ flat

Expansion in KK modes:

for gauge fields (similarly for the Higgs field)

$$A^{\mu}(x,y) = \frac{1}{\sqrt{\pi R}}\left[\underbrace{A_0^{\mu}(x)}_{\text{SM}} + \sqrt{2}\sum_{n=1}^{\infty} \underbrace{A_n^{\mu}(x)}_{\text{KK excitations}} \cos(\frac{ny}{R})\right]$$

for fermionic fields

need for chiral fermions ⇒ impose an orbifold structure on the fifth dimension: S_1/Z_2, with two sets of fields:

SU(2) doublet: left-hand fields even and right-hand fields odd under the Z_2 parity → $y \in [0, \pi R]$

$$Q(x,y) = \frac{1}{\sqrt{\pi R}}\left\{Q_L + \sqrt{2}\sum_{n=1}^{\infty}\left[Q_L^n \cos\left(\frac{ny}{R}\right) + Q_R^n \sin\left(\frac{ny}{R}\right)\right]\right\}$$

SU(2) singlet: left-hand fields odd and right-hand fields even under the Z_2 parity

$$q(x,y) = \frac{1}{\sqrt{\pi R}}\left\{q_R + \sqrt{2}\sum_{n=1}^{\infty}\left[q_R^n \cos\left(\frac{ny}{R}\right) + q_L^n \sin\left(\frac{ny}{R}\right)\right]\right\}$$

the SM field : $q = Q_L + q_R$

KK excitations:

$$q_n^{\bullet} = Q_L^n + Q_R^n \qquad q_n^{\circ} = q_L^n + q_R^n$$

• Interactions

the effective 4D Lagrangian:

$$\mathcal{L}_4(x) = \int_0^{\pi R} dy \; \mathcal{L}(x, y)$$

Mass of the n-th KK excitation:

$$m_n = \sqrt{\left(\frac{n}{R}\right)^2 + m_{SM}^2}$$

for light quarks and leptons: $m_n \simeq n/R$ → same level degeneracy

KK excitations interaction:

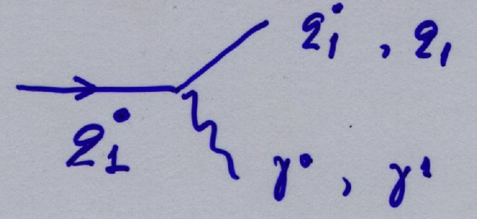
$$\mathcal{L}_4(\psi_n A_k \psi_m) \sim \bar{\psi}_n \gamma_\mu \psi_n A_k^\mu \; \times \; \left[\int_0^{\pi R} \cos(\frac{ny}{R}) \cos(\frac{my}{R}) \cos(\frac{ky}{R}) \; dy\right]$$

⇒ KK number conservation rules :

$$|m \pm n \pm k| = 0$$

⇒ pair production

⇒ no decay for first level KK excitations



but mass degeneracy

COLLIDER PRODUCTIONS

Pair-Production rates at hadron colliders

Processes:

Double KK gluon production		KK quark-gluon production	
$gg \to g_n^\star g_n^\star$	$q\bar{q} \to g_n^\star g_n^\star$	$qg \to q_n^\bullet g_n^\star$	$qg \to q_n^\circ g_n^\star$
	Double KK quark production		
$q\bar{q} \to q_n^\bullet \bar{q}_n^\bullet$	$q\bar{q} \to q_n^\circ \bar{q}_n^\circ$	$gg \to q_n^\bullet \bar{q}_n^\bullet$	$gg \to q_n^\circ \bar{q}_n^\circ$
$q\bar{q} \to {q'}_n^\bullet {\bar{q}'}_n^\bullet$	$q\bar{q} \to {q'}_n^\circ {\bar{q}'}_n^\circ$	$qq \to q_n^\bullet q_n^\bullet$	$qq \to q_n^\circ q_n^\circ$
$q\bar{q}' \to q_n^\bullet {\bar{q}'}_n^\bullet$	$q\bar{q}' \to q_n^\circ {\bar{q}'}_n^\circ$	$qq' \to q_n^\bullet {q'}_n^\bullet$	$qq' \to q_n^\circ {q'}_n^\circ$
$q\bar{q} \to q_n^\bullet \bar{q}_n^\circ$	$q\bar{q} \to q_n^\circ \bar{q}_n^\bullet$	$qq' \to q_n^\bullet {q'}_n^\circ$	$qq' \to q_n^\circ {q'}_n^\bullet$
$q\bar{q}' \to q_n^\bullet {\bar{q}'}_n^\circ$	$q\bar{q}' \to q_n^\circ {\bar{q}'}_n^\bullet$	$qq \to q_n^\bullet q_n^\circ$	

Figure 2: Subprocesses leading to double KK production at hadronic colliders. Not shown are subprocesses that are simply related by the exchange of a particle and antiparticle.

Collider reach (100 events):

Tevatron Run I : $1/R = 350$ GeV

Run II : 480 (with 2fb^{-1}) to 540 GeV (with 15fb^{-1})

LHC : 3 TeV, with 100 fb^{-1} of luminosity.

PAIR PRODUCTIONS AT TEVATRON (9)

(Macesanu, McMullen & Nandi, PRD)

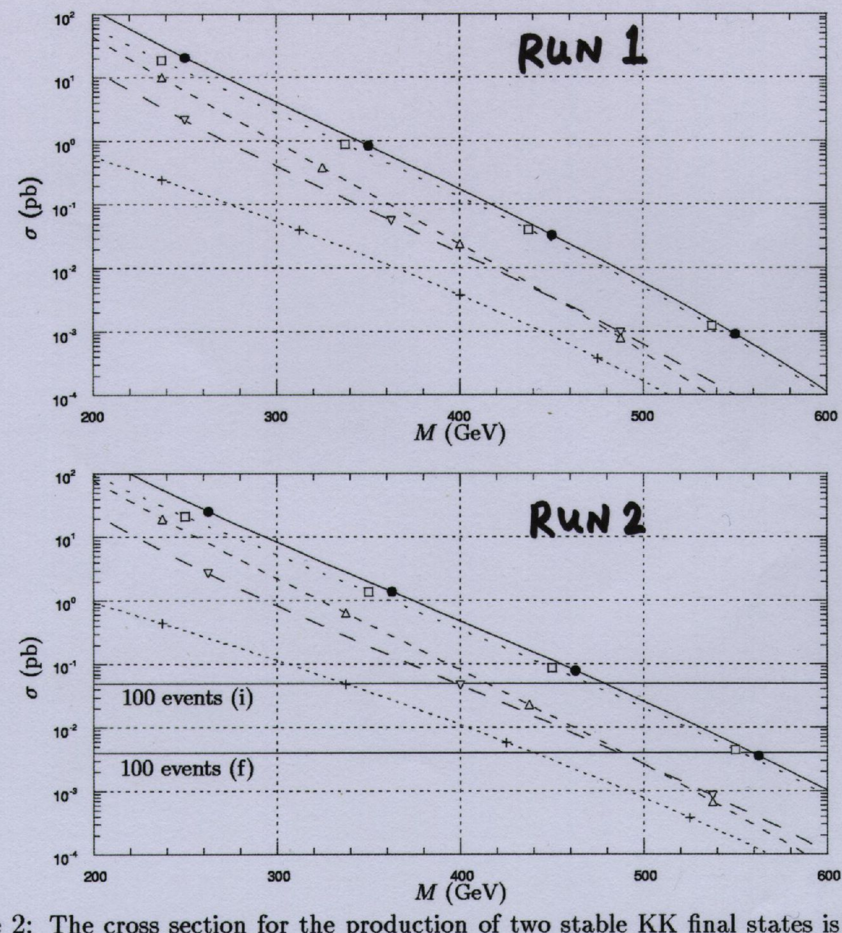


Figure 2: The cross section for the production of two stable KK final states is shown as a function of the KK mass for Tevatron Run I (top) and II (bottom). The solid curve corresponds to the total contribution, while the dashed lines represent the partial contributions of KK quark pair (□), KK quark-gluon (△), and KK gluon pair (▽) production. Also shown is top production (+), which features a different collider signature (namely, the top will subsequently decay into additional states). Solid horizontal lines mark 100 events at the initial and final projected luminosities for Run II.

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PAIR PRODUCTIONS AT LHC

(Macesanu, McMullen & Nandi, PRD)

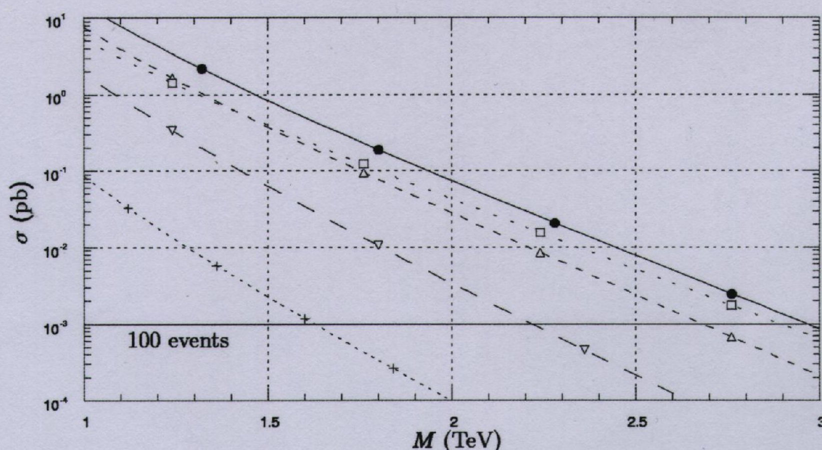


Figure 3: The same as Fig. 2, but for the LHC. The solid horizontal line represents 100 annual events at the projected luminosity.

are illustrated in Fig. 3. A dedicated study is required to find the exact reach of the LHC in this case, but, by requiring at least 100 events to be produced, we can estimate that the LHC will discover the first stable KK excitations if their mass is smaller than about 3 TeV.

Thus, stable KK quarks and gluons of the UED scenario will either be discovered at the Tevatron Run II or the LHC, or the lower bound on their masses will be raised to around 450 GeV or 3 TeV, respectively. However, cosmological constraints require new physics to explain the existence of stable KK excitations in this mass range. This cosmological restriction can be lifted via a new physics mechanism that causes the lowest-lying KK excitations to have a lifetime that is short compared to the cosmological scale. We now focus on this possibility.

5. Decay Mechanisms

The lowest-lying KK excitations of the light fermions and the massless gauge bosons can decay into SM fields via new physics mechanisms that produce a violation in KK number conservation. Various decay schemes have been considered in the literature [13], [12], [14]. However, provided that the KK excitations decay within the detector, the effect of a specific decay mechanism on the final state distributions presented here can be expected to be small.

For purposes of illustration, we shall analyze in some detail the decay properties of KK excitations in the fat brane scenario proposed in Ref. [13]. In this scenario, the "small" universal extra dimension is assumed to be the thickness of the D_4 brane in which the SM particles propagate. In turn, this brane is embedded in a 4 +

SIGNALS

: DEPENDS ON DECAY SCENARIO

KK CONSERVING DECAYS:

$$g^* \to \bar{q} q^*, \quad q^* \to q Z^*, \quad Z^* \to \ell \ell^*, \quad \ell^* \to \ell \gamma^*$$

$$\Rightarrow \bar{q} q \ell \ell \gamma^*$$ ← LKP

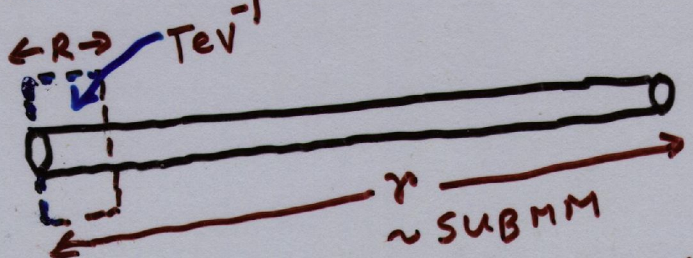
or

$$\bar{q} q \ell \ell' \gamma^*$$

SIGNAL $\Rightarrow \gamma^* \gamma^*$ + SOFT QUARKS & LEPTONS

(γ^* ↑ $\not{E}_T$)

KK VIOLATING DECAYS: (FAT BRANE)



: NO COLD DARK MATTER

$$g^* \to g\, G_n, \quad q^* \to q\, G_n, \quad \gamma^* \to \gamma\, G_n$$

SIGNAL $\Rightarrow$ HIGH P_T DIJETS + $\not{E}_T$

OR

HIGH P_T DIPHOTONS + $\not{E}_T$

UED: One loop theory

(Cheng, Matchev and Schmaltz: hep-ph/0204342)

• on $M4 \times S_1$ space, we get mass corrections due to virtual particles propagating in bulk:

$$\delta\left(m_{g_n}^2\right) = -\frac{3}{2}\frac{g_s^2}{16\pi^4}\zeta(3)\left(\frac{1}{R}\right)^2 \ , \ \delta(m_{f_n}) = 0$$

these bulk corrections are finite, and the same for each KK level.

• on an orbifold ($M4 \times S_1/Z_2$), the breaking of translational invariance at the orbifold boundaries generates localized corrections to the lagrangian (Georgi, Grant and Hailu). But,

these terms are divergent

Upon renormalization, the finite part remains undetermined ⇒ need an *ansatz* to specify them.

Assuming (1) that they vanish as some cutoff scale Λ and

(2) universality, we have:

boundary corrections to the massess of KK excitations:

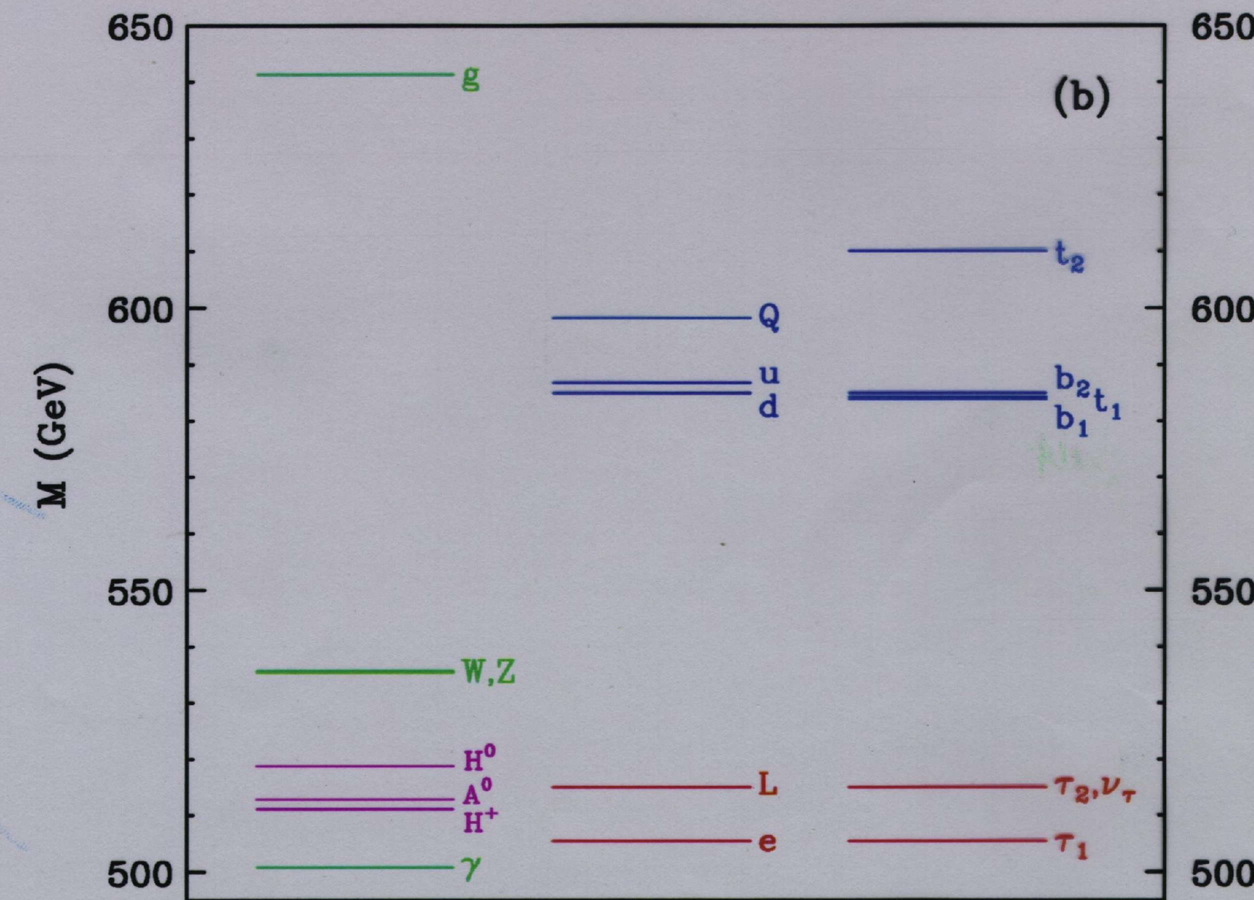
$$\delta_b(m_{g_n}^2) = m_n^2 \frac{23}{2}\frac{g_s^2}{16\pi^2}\ln\frac{\Lambda^2}{m_n^2}$$

$$\delta_b(m_{f_n}) = m_n \frac{g_s^2}{16\pi^2}\ln\frac{\Lambda^2}{m_n^2}$$

Note that they are of opposite sign and much larger than the bulk terms. Also these corrections increase with n.

Masses of first level KK excitations at one loop

(from Cheng, Matchev and Schmaltz: hep-ph/0204342)



Here $1/R = 500$ GeV, $\Lambda = 10$ TeV

Order of magnitude for one loop corrections:

- gluon excitation $\simeq 30\%$
- quark excitations $\simeq 20\%$
- lepton excitations $\simeq 5\%$

3. COLLIDER SIGNALS

KK excitations decays and collider signals

production : pair production of first level KK excitations

decay :

if $\left\{ \begin{array}{l} \text{KK number conservation} \\ \text{degenerate spectrum (at tree level)} \\ \text{no other physics} \end{array} \right\} \Rightarrow$

the first level KK excitations are stable

search for long lived charged massive particles in collider experiments.

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if mass degeneracy at first level is lifted (loop corrections)
$\Rightarrow$ we will have cascade decays to the lightest KK particle (LKP) for example

$$q_1^\bullet \to q\, Z_1^* \to q\, l\, l_1^\bullet \to q\, l\, l\, \gamma^*$$

- the SM particles radiated in this decay are observable.
- γ^* (the LKP) is stable, and does not interact in the detector (it may have cosmological implications, though).

Analysis of the collider signals in this scenario have been performed by Cheng, Matchev and Schmaltz (hep-ph/0205314).

Conclusion: since the ammount of energy available to SM particles is small (being of the order of magnitude of the mass splitting between the q^* or g^* and the LKP), the signal is rather difficult to detect. (SUSY with almost degenerate spectrum)

In the $4l + \not{E}_T$ mode, the Tevatron Run II reach is about 300 GeV, while the LHC reach is about 1.5 TeV.

TEVATRON REACH FOR KK-CONSERVIN DECAYS

(Cheng, Matchev & Smaltz)

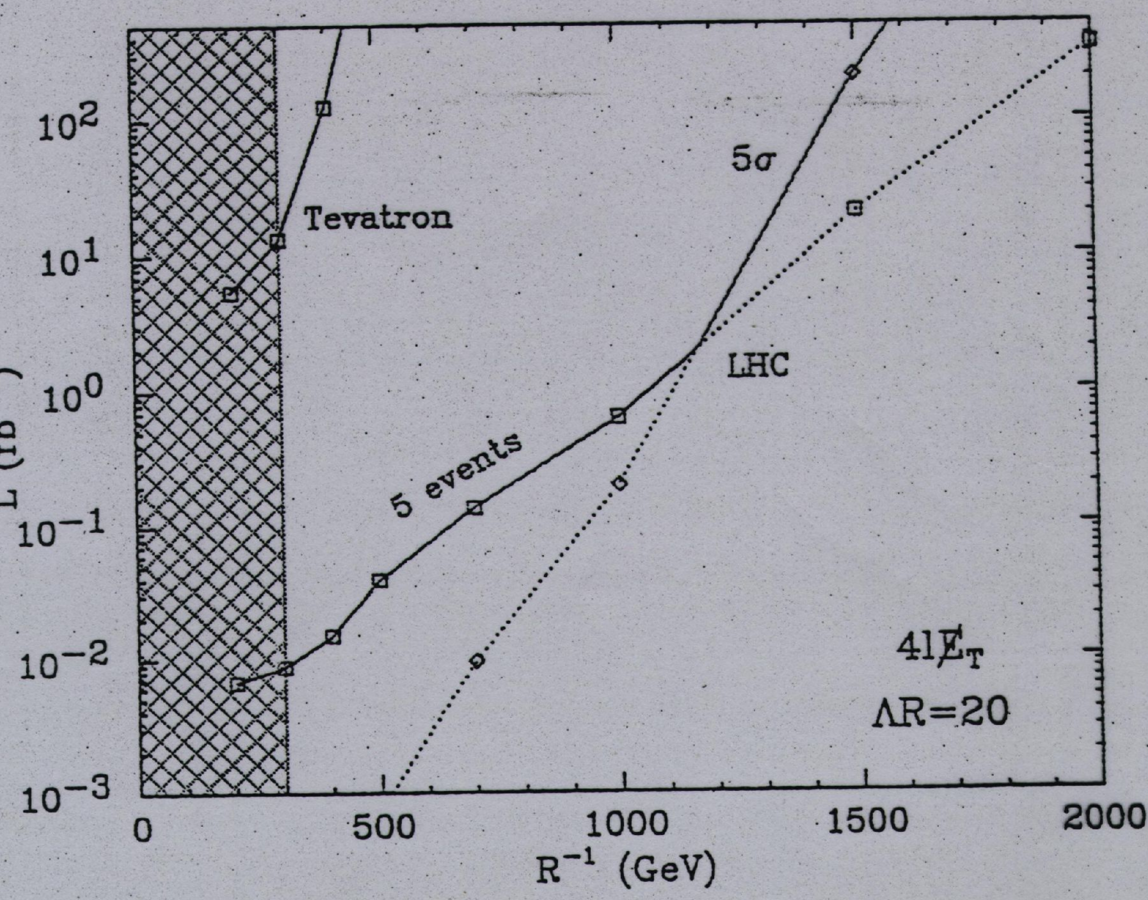


FIG. 4: *Discovery reach for MUEDs at the Tevatron (blue) and the LHC (red) in the 4ℓ $\not{E}_T$ channel. We require a 5σ excess or the observation of 5 signal events, and show the required total integrated luminosity per experiment (in* fb^{-1}*) as a function of R^{-1}, for $\Lambda R = 20$. (In either case we do not combine the two experiments).*

Gravity-mediated decays (FAT BRANE SCENARIO)

look for new physics, which can break KK number conservation

Gravity:

in N symmetric extra dimensions, the ADD relation:

$$M_P^2 = M_D^{N+2} r^N$$

if we take M_D of order 10 TeV, then

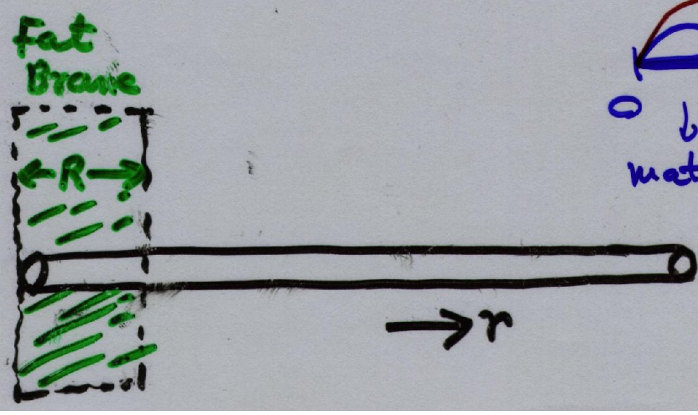
$r \sim \mathrm{eV}^{-1}$ (for $N = 2$) up to keV^{-1} (for $N = 6$)

Consider the fat brane scenario:

- gravity propagates in $4 + N$ dimensions, with radius r
- matter can propagate along the $4D$ brane, and a limited length of order R (the thickness of the brane) along the y direction

(for models with SM fields localized on a fat brane see, for example, Georgi, Grant and Hailu, hep-ph/0007350)

we shall consider a simplified (toy) model, in which the SM fields are confined on the brane by a 'infinite well' potential (as in Rujula, Donini, Gavela, Rigolin, hep-ph/0001335)



Gravity-matter interactions

For matter in $4D$, we have:

$$\mathcal{L}_{G\psi} = \hat{h}^{\mu\nu} T_{\mu\nu} \to \sum_n \left(\tilde{h}^{\mu\nu,n} T_{\mu\nu} + \omega \tilde{\phi}^n T^\mu_\mu \right)$$

(For Feynman rules, see Han, Lykken and Zhang, hep-ph/9811350, also Giudice, Rattazi and Wells, hep-ph/9811291)

With matter in $5D$, we will have:

$$\mathcal{L}_{G\psi} = \int_0^{\pi R} \hat{h}^{MN} T_{MN} \to \sum_{l,m,n} \mathcal{F}_{lmn} \Big(\tilde{h}^{\mu\nu,n} T^{l,m}_{\mu\nu} + \omega \tilde{\phi}^n T^{\mu,l,m}_\mu + \ldots \Big)$$

The form factor $\mathcal{F}_{lmn}$ describe the superposition of the graviton wave function with the fermion wave functions along the y direction:

$$\mathcal{F}_{lmn} = \frac{\sqrt{2}}{\pi R} \int_0^{\pi R} dy \exp(i \frac{2\pi n y}{r}) \cos(\frac{ly}{R}) \cos(\frac{my}{R})$$

For the decay of the first level KK excitations:

$$|\mathcal{F}_{01n}|^2 = \frac{4}{\pi^2} \frac{x_n^2}{(1 - x_n^2)^2} [1 + \cos(\pi x_n)]$$

with

$$0 < x_n = \frac{2\pi n R}{r} < 1$$

$q_1 \to q_0 G_n$

$g^* \to g G_n$

$q^* \to q G_n$

(18)

Macesanu, McMullen + Nandi

UED, DECAY OF q^*, g^*

$g^* \to g\, G_n$, $q^* \to q\, G_n$

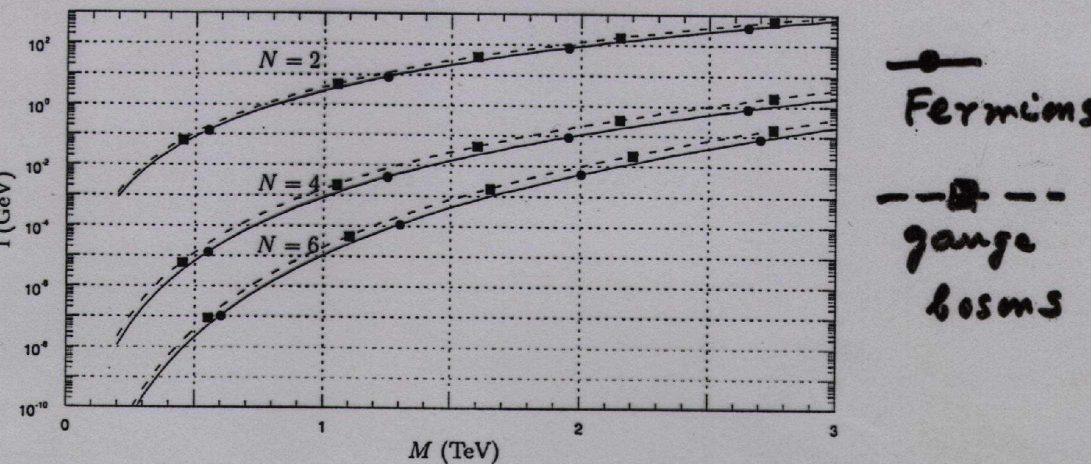


Figure 4: The decays of the $q_1^\bullet$ or q_1° (solid) and g_1^* (dashed) into SM fields via graviton emission (spin 2 and scalar combined) are shown as a function of the compactification scale $\mu = M = 1/R$ for $M_D = 5$ TeV. The pairs of curves correspond to 2, 4, and 6 extra dimensions from top to bottom, respectively.

in this scenario, when gravity propagates in two extra-dimensions ($N = 2$), the decays of KK quark or gluon excitations will be mediated mostly by very light gravitons, while for $N \geq 3$ the heavy graviton (mass of order μ) contribution will dominate (see the top of Fig. 5). As a consequence, for $N = 2$ the missing energy distribution will have a peak at half the KK excitation mass, while with increasing N the distribution will shift toward larger values. Note also that all of these decays will occur within the detectors in the range of parameter space that we will explore and is depicted here.

The collider signature for the production and decay of gluon or light quark (except the top) KK excitations in this model is SM dijet production with missing energy carried off by the gravitons. This production rate is related to the cross sections for the stable case and the differential branching fractions of the decaying KK states via:

$$d\sigma_{tot} = \sum_{A,B} d\sigma_{prod}(p\bar{p} \to A\ B)\ \frac{d\Gamma_A}{\Gamma_A}\ \frac{d\Gamma_B}{\Gamma_B}. \qquad (35)$$

The sum is over the KK intermediate states, denoted by A and B. The spin correlations are not taken into account. The top case will be discussed separately.

We consider the following two distributions of experimental interest in Fig. 6: the two-jets + missing energy cross-section as a function of the minimum transverse momentum, p_T^{min}, of the jets (top), and the cross-section as a function of the missing transverse momentum, $|\vec{p}_T|$ (bottom). The dependence of these distributions on the number of extra dimensions in which gravity propagates (or on the decay mechanism) is encoded in the mass distributions of the gravitons which mediate this decay. For example, if the quark (or gluon) KK excitations decay mostly to light gravitons, the

DIJET + $\not{E}_T$ SIGNAL

Collider signals for gravity mediated decays

If the first level KK excitations are stable due to mass degeneracy (or, if the widths of the decays due to mass splitting are much smaller that the width of the decay due to gravity interactions)

$$\Gamma_{ew}, \Gamma_s \ll \Gamma_G$$

then, at a hadron collider:

$$pp \to q^* \, q^* \to q_1 G_n \; q_2 G_m$$

the signal will be **two jets + missing energy ($\not{E}_T$)**

Properties of the jets

- Energy : E_1, E_2 of order $M_{KK}/2$ ($M_{KK} \simeq 1/R$) - large
- transverse momentum - p_{1T}, p_{2T} also large, since the KK excitation will be produced almost at rest.
- Missing transverse energy: $\not{E}_T = |p_{1T} - p_{2T}|$ - large

Actually, these quantities depend on the mass distributions of the gravitons which mediate the decay - which is related to the number of extra dimensions of the space.

- for $N = 2$ mostly light gravitons contribute to decay: $m_G \sim \mathrm{eV}$. Then the jet energies have maximum value $M_{KK}/2$.

- for $N = 6$ heavy gravitons are predominant: $m_G \sim M_{KK}$; $\Rightarrow$ lower values for jet energies and transverse momenta.

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DIJET SIGNALS AT RUN 2

(Macesanu, McMullen & Nandi, PRD)

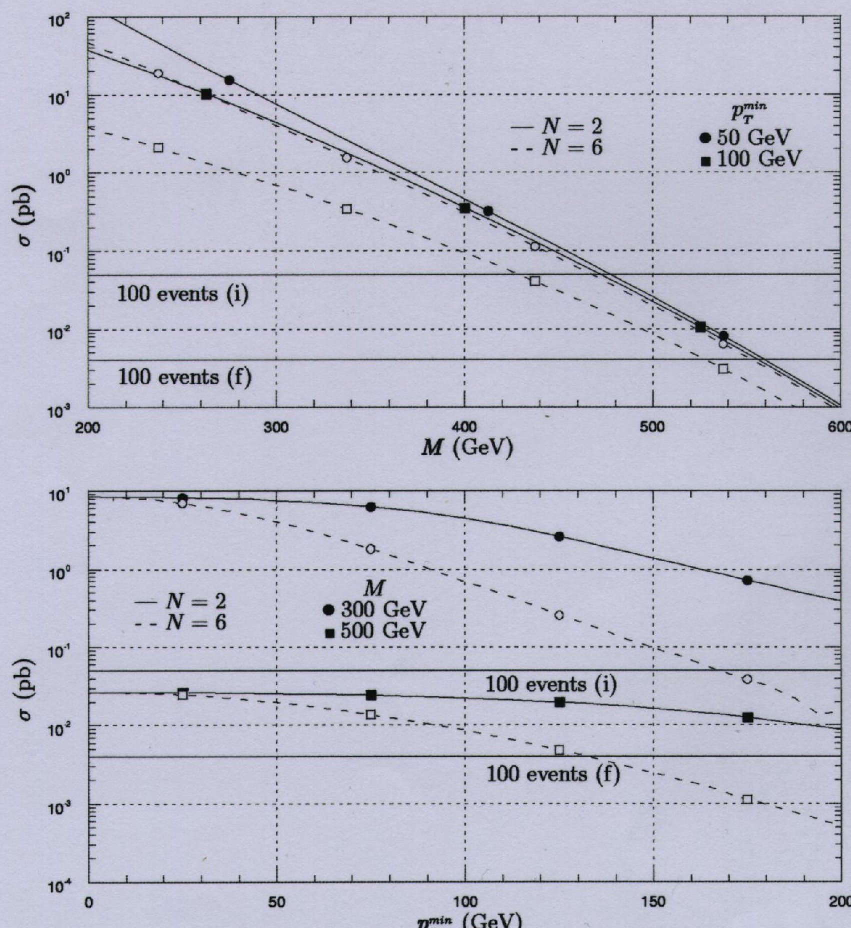


Figure 7: The total cross section for the dijet production plus missing energy from decaying KK final states at the Tevatron Run II energy is illustrated as a function of μ for fixed p_T^{min} (top) and as a function of the minimum transverse momentum p_T^{min} for fixed values of the compactification scale μ (bottom). Solid horizontal lines mark 100 events at the initial and final projected luminosities. In this and the following figures, we implement cuts on the p_T, rapidity, and separation of the jets.

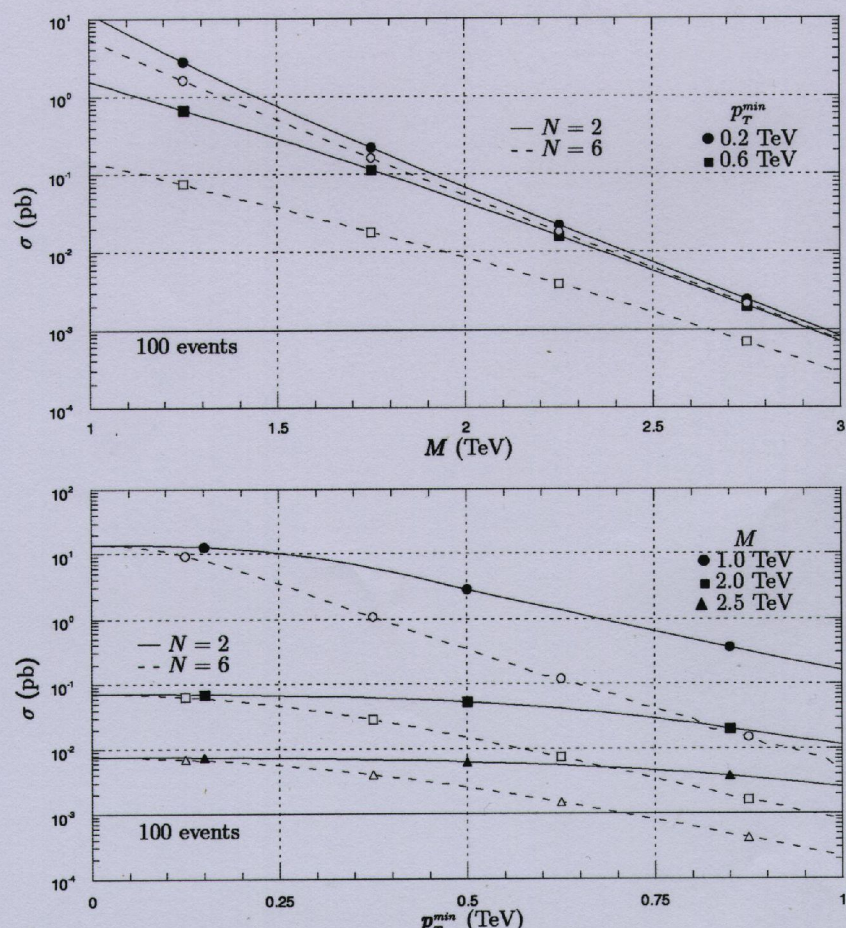
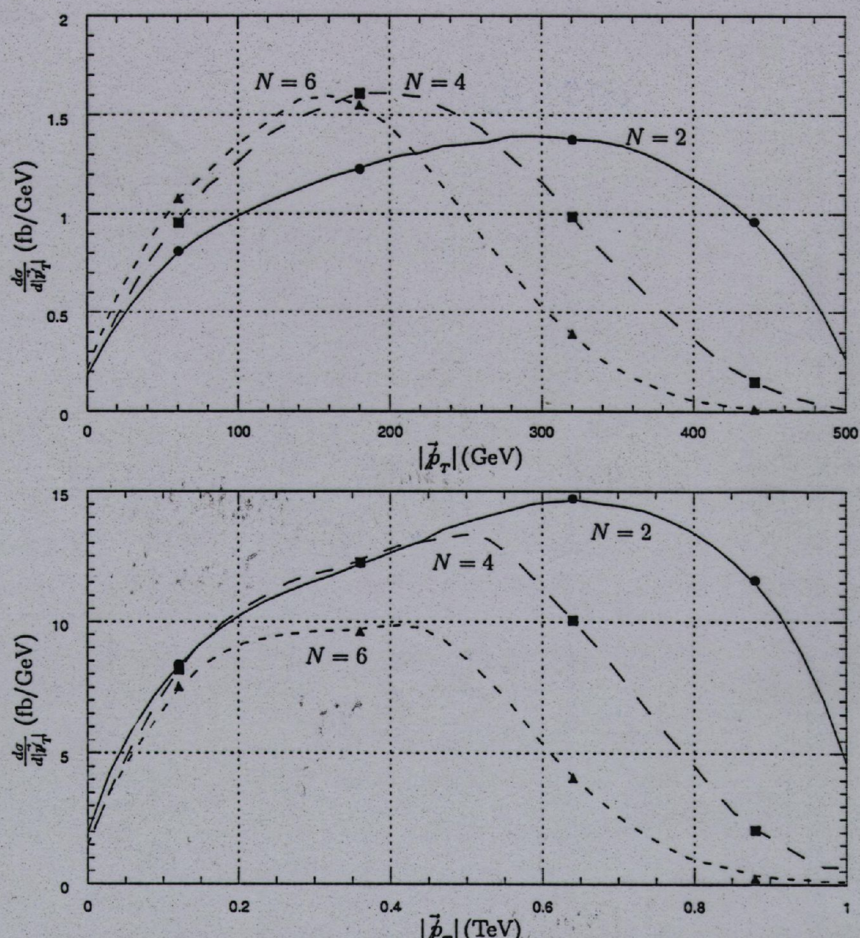


Figure 8: The same as Fig. 7, but for the LHC. The solid horizontal line marks 100 annual events at the projected luminosity.

(21)

MISSING E_T DISTRIBUTION

(Macesanu, McMullen & Nandi, PRD)



TETATRON

LHC

Figure 9: The missing transverse momentum distribution is illustrated for Run II of the Tevatron (top) and the LHC (bottom). The three curves represent 2, 4, and 6 extra dimensions. By $|\vec{p}_T|$ we denote the vectorial sum of the transverse momentum of the two emitted gravitons (which is equal and opposite to that of the quarks). The compactification scale and minimum transverse momentum are 400 GeV and 50 GeV for the Tevatron and 1 TeV and 200 GeV for the LHC, respectively.

Collider reach

Backgrounds for the two jets + $\not\!\!E_T$ signal:

- WZ, ZZ, $q\bar{q}Z$ and $t\bar{t}$ production
- $2 \to 2$ QCD processes with mismeasurement of jet energies

Use cuts on transverse momentum and $\not\!\!E_T$:

p_T^{cut} (GeV)	Background (evts.)	Signal (evts.) $M = 1$ TeV $N=2$	$M = 1$ TeV $N=6$	$M = 2$ TeV $N=2$	$M = 2$ TeV $N=6$	$M = 3$ TeV $N=2$	$M = 3$ TeV $N=6$
100	3×10^6	1×10^6	9×10^5	7×10^3	6×10^3	84	80
200	2×10^5	9×10^5	2×10^5	6×10^3	4×10^3	80	65
300	9×10^3	4×10^5	4×10^4	5×10^3	3×10^3	73	50
400	1×10^3	1×10^5	2×10^3	4×10^3	1×10^3	65	34
500	2×10^2	5×10^4	2×10^2	3×10^3	4×10^2	58	20
600	4×10	6×10^2	3×10	2×10^3	1×10^2	50	10

Table 1: SM background and UED signals with $p_T > p_T^{cut}$, $\not\!\!E_T > 2p_T^{cut}$ (for 10^5pb^{-1} at LHC).

Collider reach:

Tevatron Run II : $M_{KK} = 550$ GeV

LHC : about 3 TeV

(depending on the number of extra dimensions)

DIPHOTON + $\not{E}_T$ SIGNAL

Gravity in the nondegenerate mass spectrum case

When there is splitting between the masses of the first level KK excitations:

• Assume:

$$\Gamma_{ew}, \Gamma_s \gg \Gamma_G$$

Then, we'll have the cascade decays as before:

$$q_1^{\bullet} \rightarrow q\, Z_1^{*} \rightarrow q\, l\, l_1^{\bullet} \rightarrow q\, l\, l\, \gamma^{*}$$

but in this case the LKP γ^* is stable no more:

$$\gamma^* \rightarrow \gamma\, G_n$$

Fig.

The signal will be two photons + $\not{E}_T$!

•The mixed case:

$$\Gamma_{ew}, \Gamma_s \simeq \Gamma_G$$

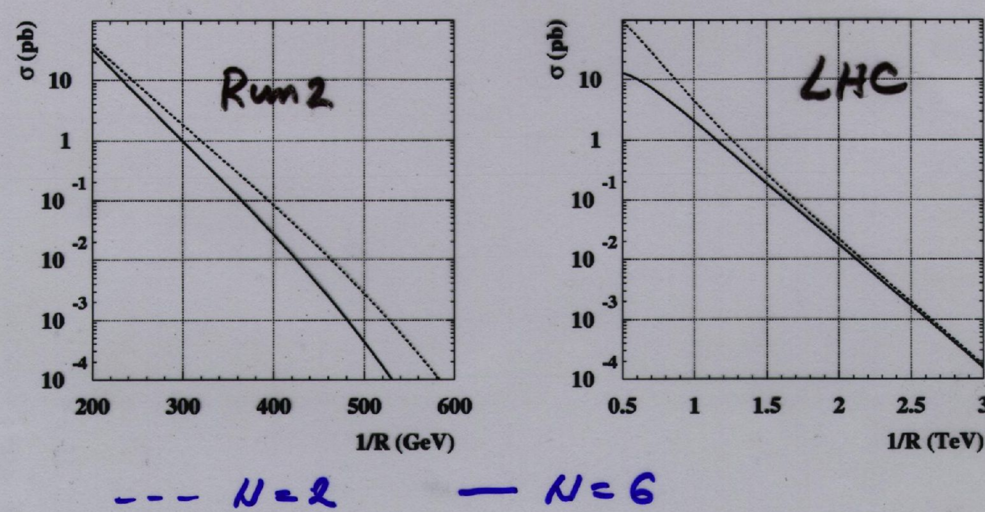
Then, gravity mediated decay can take place at any step of the decay chain above.

The signal will then appear in multiple channels containing hard jets, leptons and photons with large $\not{E}_T$.

the branching ratio for each of this channels is dependent on the parameters of the model through the relative decay widths.

Collider reach for $2\gamma + \not\!\!E_T$

Cross sections:



Backgrounds:

multijet, direct photon, $W + \gamma$, W + jets, $Z \to ee$ and $Z \to \tau\tau \to ee$ with misidentified photons and/or mismeasured $\not\!\!E_T$

Collider reach

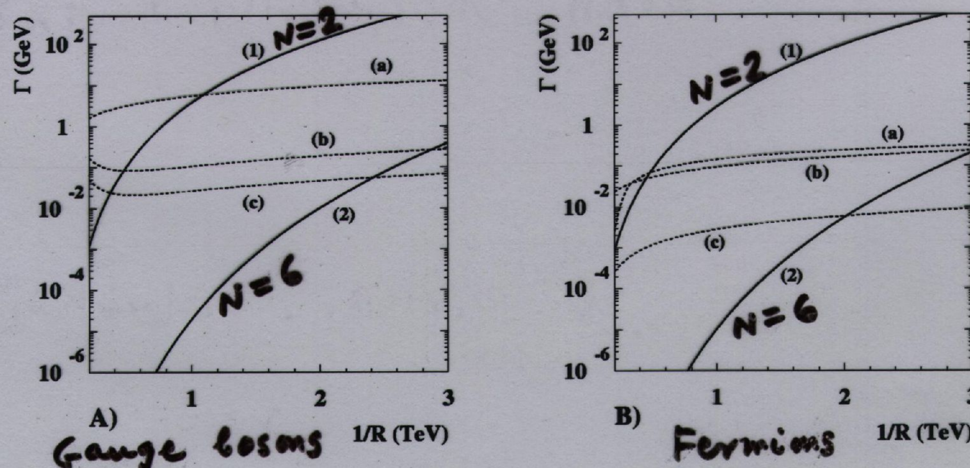
Tevatron Run I: est. bkgr: 2.3 ± 0.9 evts, found 2 events
(with $p_T^{\gamma 1} > 20$ GeV, $p_T^{\gamma 2} > 12$ GeV, and $\not\!\!E_T > 25$ GeV)
⇒ lower limit on the UED scale : $1/R > 380$ GeV (at 95%CL)

Tevatron Run II: est. bkgr: 0.6 ± 0.12 fb
(with $p_T^{\gamma 1}, p_T^{\gamma 2} > 20$ GeV, and $\not\!\!E_T > 25$ GeV)
⇒ 5σ discovery up to 490 GeV (IIA) or 520 GeV (IIB)
exclusion at 95%CL up to 510 GeV (IIA) or 540 GeV (IIB)

LHC: est. bkgr: 0.05 fb
(with $p_T^{\gamma 1}, p_T^{\gamma 2} > 200$ GeV, and $\not\!\!E_T > 200$ GeV)
⇒ reach to about 3 TeV.

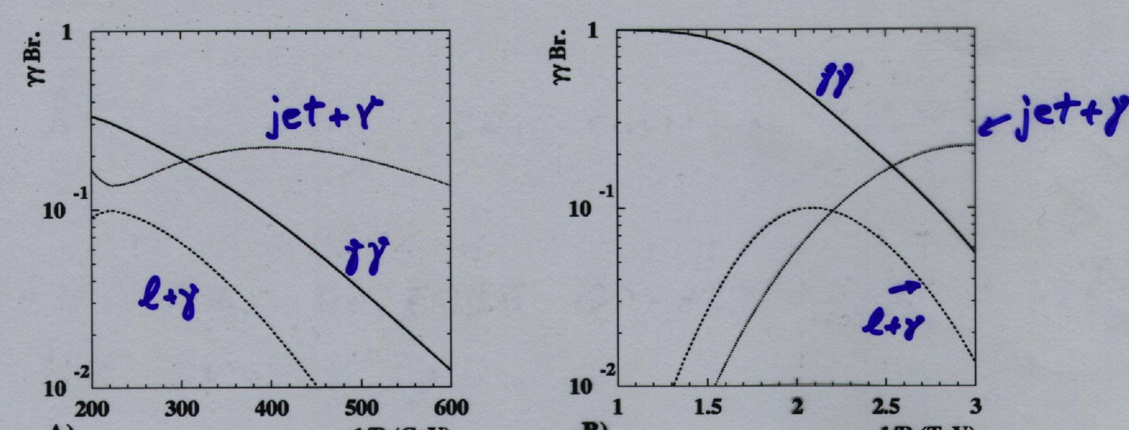
Mixed case

Decay widths: → dependent on the parameters : M_D, Λ,...



Decay widths for the first level KK excitations of gauge bosons (left) and fermions (right). The solid lines correspond to gravity mediated decays, with $N = 2$ (1) and $N = 6$ (2). The dashed lines correspond to decays allowed by mass splittings: $g^* \to q\bar{q}^\bullet, q\bar{q}^\circ$ + h.c. (a), $W^* \to l\bar{\nu}^\bullet, \nu\bar{l}^\bullet$ + h.c. (b), $Z^* \to l\bar{l}^\bullet$ + h.c. (c) (left), and $q^\bullet \to q'W^*, qZ^*$ (a), $q^\circ \to q\gamma^*$ (b), $l^\bullet \to l\gamma^*$ (c) (right).

Branching ratios:



Tevatron Run II, N=2 — LHC, N=6

if N=6, γγ predominates — if N=2, 2 jets predominates

4. CONCLUSIONS

: EXTRA DIMENSIONS HAVE

⇒ GOOD THEORY MOTIVATION

⇒ OBSERVABLE EXPERIMENTAL IMPLICATIONS

: CLASSIC SIGNATURE

⇒ OBSERVATION OF KK STATES

: UNIVERSAL EXTRA DIMENSIONS

⇒ HAS THE LOWEST LIMIT ~ 350 GeV

: DOMINANT SIGNALS AT HIGHENERGY HADRON COLLIDERS

⇒ DIJETS + $\not{E}_T$

⇒ DIPHOTONS + $\not{E}_T$

: REACH FOR TEVATRON RUN2 ~ 500 GeV

LHC ~ 3 TeV

: LHC MAY OBSERVE COUPLE OF LOW LYING KK STATES ⇒ CLASSIC SIGNATURE OF EXTRA DIMENSIONS

⇒ EXTRA DIMENSIONS EXCITING AT TEVATRON AND LHC