Two Universal Extra Dimensions

Gustavo Burdman

University of Sao Paulo

with Bogdan Dobrescu and Eduardo Pontón,
JHEP **0602**, *033 (2006) (hep-ph/0506334)*

and hep-ph/0601186.

SUSY06, Irvine, CA June 12-17 2006

Universal Extra Dimensions

(Appelquist, Cheng, Dobrescu '01)

- If some SM fields propagate in the bulk $\Rightarrow$ $\boxed{1/R \gtrsim 1 \text{ TeV}}$.
- But if we assume *all* fields can propagate in the extra dimensions. What is the allowed R ?
- p_5 conservation in the bulk $\Rightarrow$ KK number conservation.
- Orbifolding breaks KK number $\longrightarrow$ KK parity (LKP is stable)

UED Phenomenology

- Electroweak precision constraints:

$$1/R \gtrsim 300 \text{ GeV for 5D}$$
$$1/R \gtrsim (400 - 600) \text{ GeV for 6D}$$

- Current direct searches give similar bounds.
- But, almost degenerate KK levels $\Rightarrow$ little energy release. (Cheng, Matchev, Schmaltz '02).
- Phenomenology of 1 UED with level 2 KK modes (Datta, Kong, Matchev)

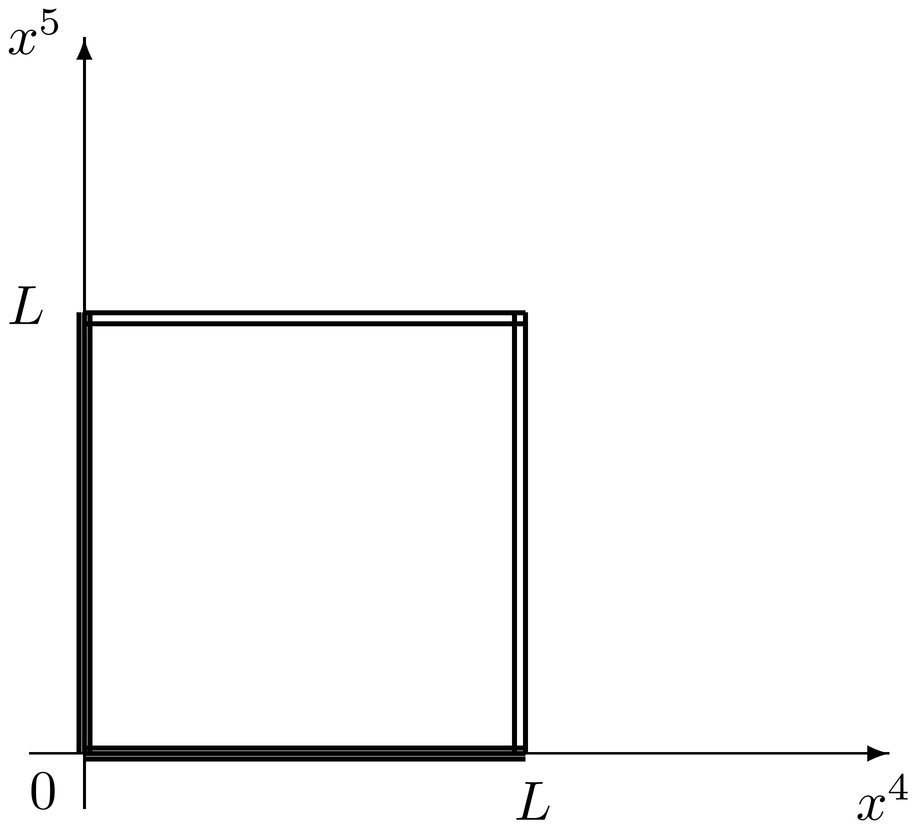
Two Universal Extra Dimensions

Motivation:

- Possible to avoid proton decay (Appelquist, Dobrescu, Ponton)
- To cancel anomalies $\Rightarrow$ 3 generations (Dobrescu, Poppitz).
- Explore different phenomenology

2 UED: Orbifolding

The Chiral Square



$\Rightarrow$ chiral fermions in the 4D effective theory.

TED: KK Modes

- KK Expansion:

$$\Phi = \frac{1}{\pi R} \sum_{j,k} \frac{\Phi^{(j,k)}(x)}{(1+\delta_{j,0})} \left(\cos \frac{jx^4 + kx^5}{R} + \cos \frac{kx^4 - jx^5}{R} \right)$$

- Masses:

$$M_{j,k} = \frac{1}{R} \sqrt{j^2 + k^2} = 0, 1/R, \sqrt{2}/R, 2/R, \cdots$$

- Presence of the non-eaten GB. For each gauge boson in 6D, a scalar in the spectrum: G_H, W_H, B_H.
- 6D Gauge bosons:
  - Tower of spin-1
  - Tower of spin-0 (eaten)
  - Tower of spin-0 (in the spectrum)

Localized Operators

Fixed points in the conical singularities:

- At $(0,0)$, $(\pi R, \pi R)$ and $(0, \pi R)$
- Bulk interactions invariant under reflections w.r.t. center of square $\Rightarrow Z_2^{KK}$, KK parity: Operators at $(0,0)$ same as ops. at $(\pi R, \pi R)$

$$\int_0^{\pi R} dx^4 \int_0^{\pi R} dx^5 \, \{\mathcal{L}_{\text{bulk}} + \delta(x_4)\delta(\pi R - x_5)\mathcal{L}_2 + [\delta(x_4)\delta(x_5) + \delta(\pi R - x_4)\delta(\pi R - x_5)]\, \mathcal{L}_1\}$$

- But, physics above cut-off can also induce localized operators. Assume this respects Z_2^{kk}

$\Rightarrow$ KK parity is preserved $\Rightarrow$ LKPs

Localized Operators

- Operators: Fermion and gauge kinetic terms. E.g.

$$\frac{C_{pU}}{\Lambda^2} i\overline{U}_{-_R}\Gamma^\mu D_\mu U_{-_R} + \left(\frac{C'_{pU}}{\Lambda^2} i\overline{U}_{-_R}\Gamma^l D_l U_{-_L} + \text{H.c.}\right) ,$$

$$-\frac{1}{4}\,\frac{C_{pG}}{\Lambda^2} G^{\mu\nu}G_{\mu\nu} - \frac{1}{2}\,\frac{C'_{pG}}{\Lambda^2}\,(G_{45})^2$$

- Will induce:
  - Mass splitting in the KK spectrum
  - KK-number violating couplings

Localized Operators

From:

- UV physics above the cut-off. NDA estimate

$$\simeq \Lambda^2 \frac{N_c\, g_6^2}{\ell_6} \simeq 1 \Rightarrow \Lambda\, R \simeq \left(\frac{32}{N_c\, \alpha_s}\right)^{1/2} \simeq 10$$

Also

$$C's \sim \frac{\ell_6}{\ell_4} \sim 8\pi$$

$\Rightarrow$ Effective 4D coupling is

$$\sim \frac{g_s^2\, N_c}{16\pi^2}$$

Localized Operators

- Also contributions from below Λ.
  E.g. at one-loop, for one of the fermion couplings

$$\frac{C_{1f}}{(\pi\Lambda R)^2} = \left[-4\sum_A g_A^2 C_2(f) + \frac{5}{8}\sum_i \lambda_i^2\right]\frac{1}{16\pi^2}\ln\frac{\Lambda^2}{\mu^2}$$

  For one of the gauge couplings

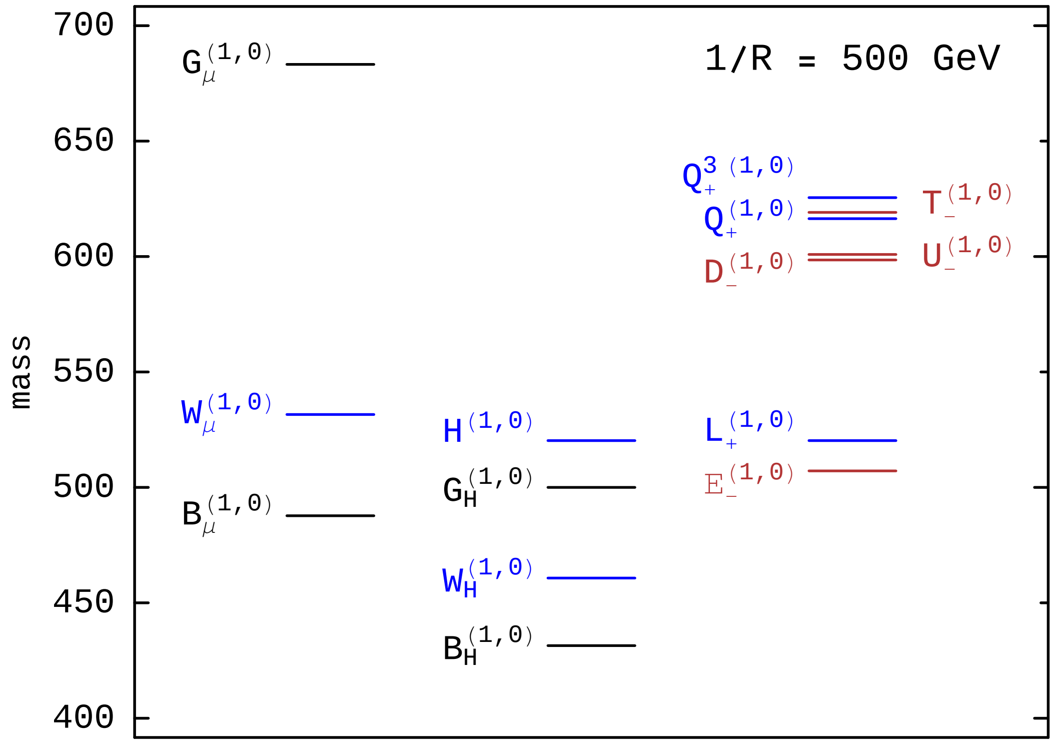
$$\frac{C_{1A}}{(\pi\Lambda R)^2} = \left[-\frac{14}{3}C_2(A) + \frac{2}{3}\sum_f T(f) + \frac{5}{12}\sum_s T(s)\right] \times \frac{g_A^2}{16\pi^2}\ln\frac{\Lambda^2}{\mu^2}\,,$$

(1)

Log enhanced w.r.t. the bare contributions.

Kaluza-Klein Spectrum Level 1

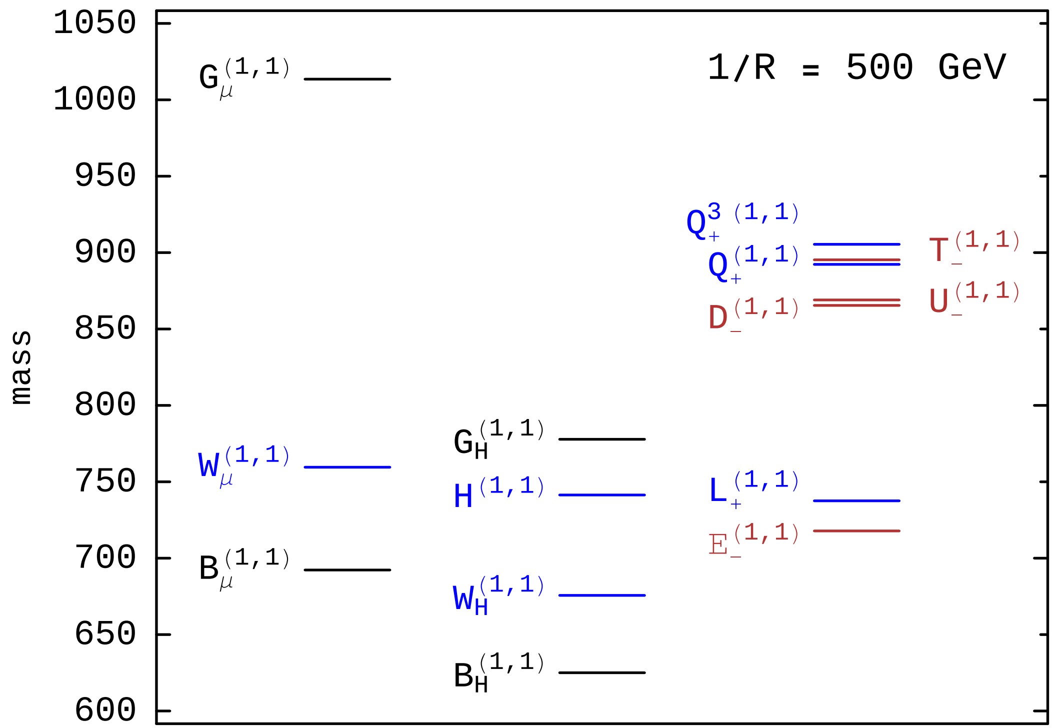
The $(1,0)$ level spectrum:



B_H is the LKP $\Rightarrow$ spin-0 Dark Matter

Kaluza-Klein Spectrum Level 2

The $(1,1)$ level spectrum:



KK-number Violating Interactions

Bulk loops $\rightarrow$ localized KK-number violation:

- KK gluon with zero-mode quarks

$$g_s C^{qG}_{j,k} \left(\overline{q}\gamma^\mu T^a q\right) G^{(j,k)a}_\mu \ ,$$

- The spinless adjoint G_H couples through the operator

$$\frac{g_s \tilde{C}^{qG}_{j,k}}{M_{j,k}} \left(\overline{q}\gamma^\mu T^a q\right) \, D_\mu G^{(j,k)a}_H \ ,$$

G_H, W_H and B_H coupling proportional to m_f.

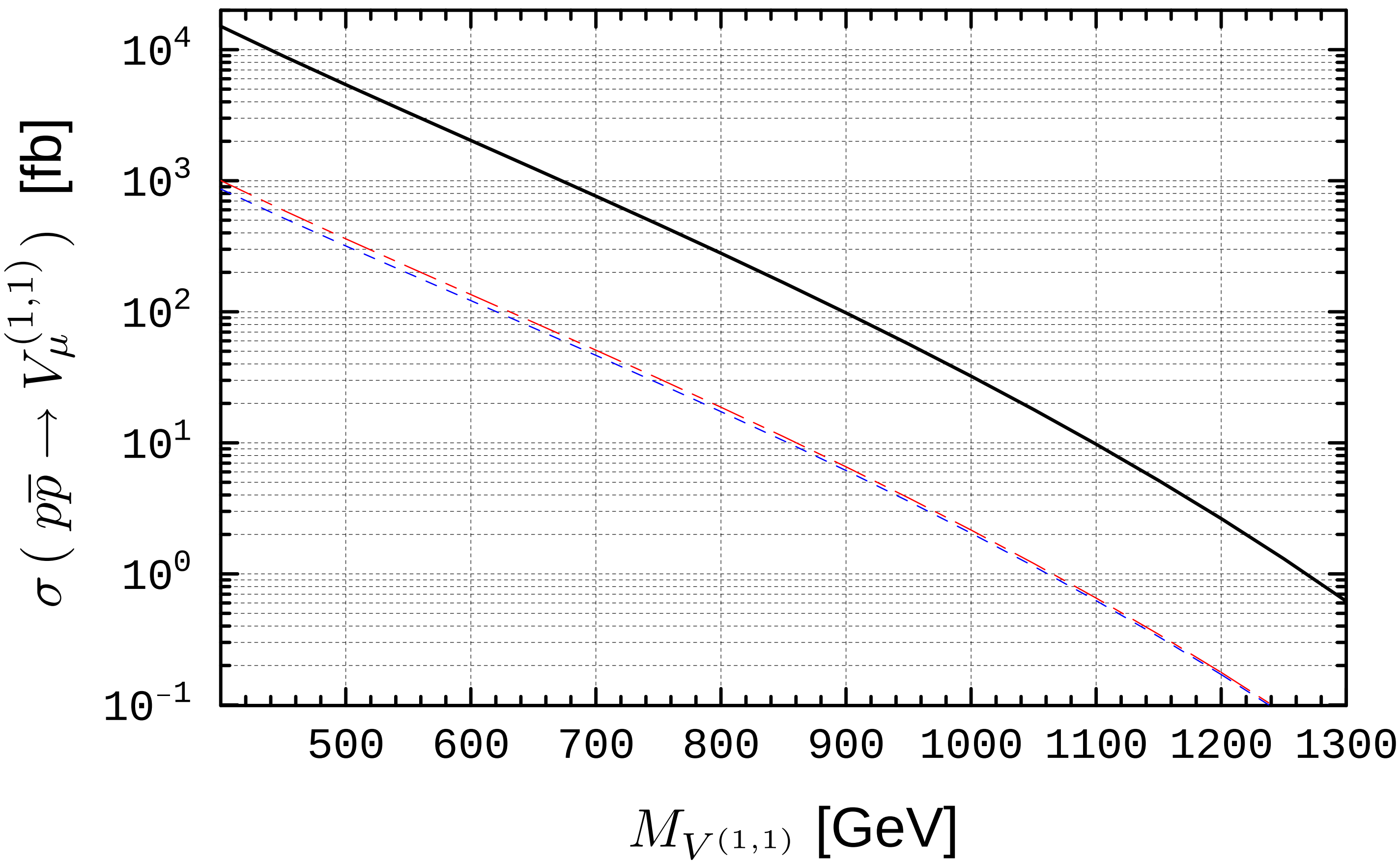
$$\boxed{\Rightarrow Br(X_H \rightarrow t\bar{t}) \simeq 100\%}$$

TED Phenomenology

- 1st KK level $(1,0)$ must be pair produced
- 2nd KK level $(1,1)$ can be in s-channel:
  - $q\bar{q} \longrightarrow G_\mu^{(1,1)}$
  - $q\bar{q} \longrightarrow W_\mu^{3(1,1)}$
  - $q\bar{q} \longrightarrow B_\mu^{(1,1)}$

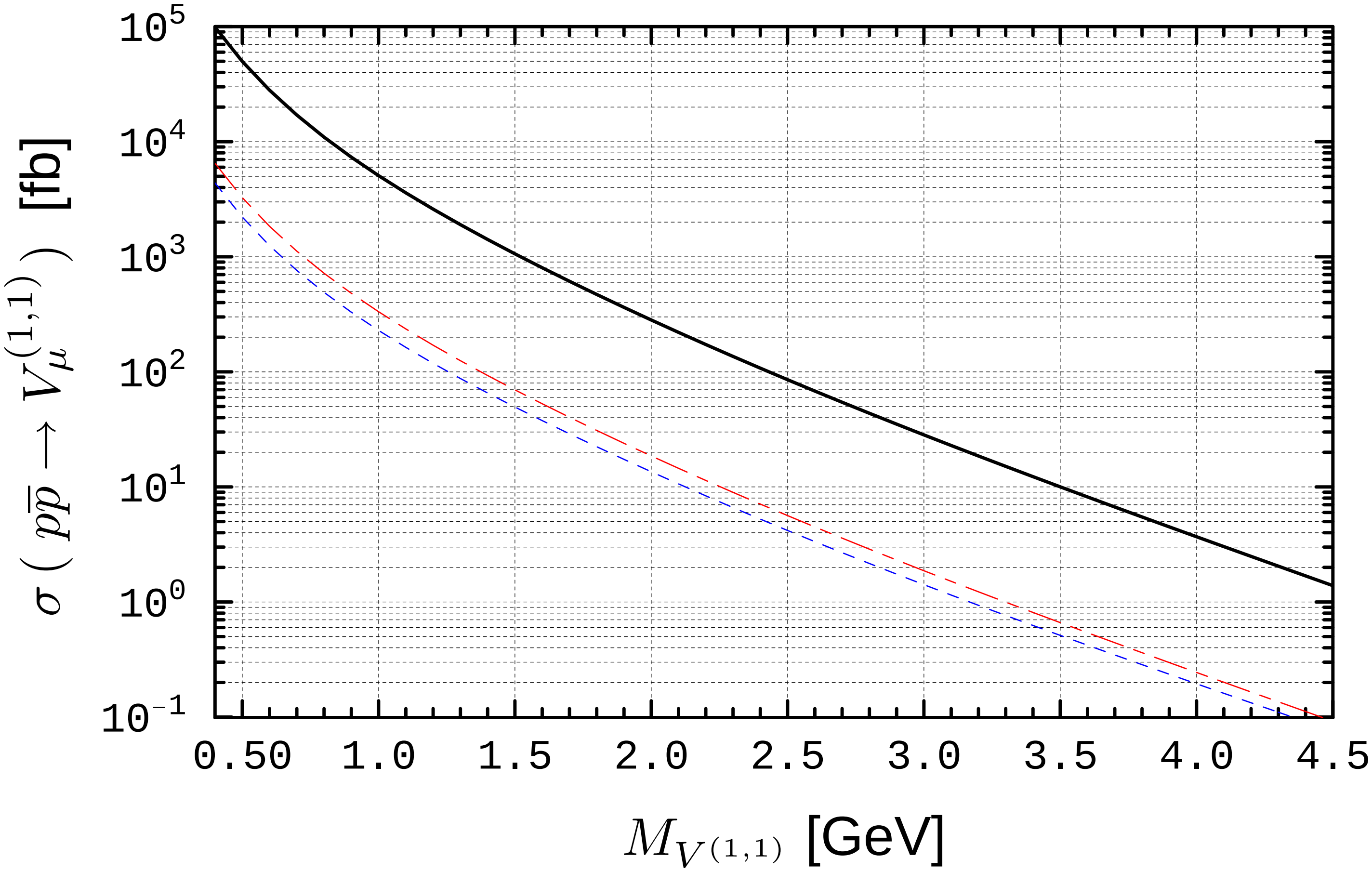
TED Phenomenology

S-Channel $(1,1)$ gauge boson production at the Tevatron



TED Phenomenology

S-Channel $(1,1)$ gauge boson production at the LHC



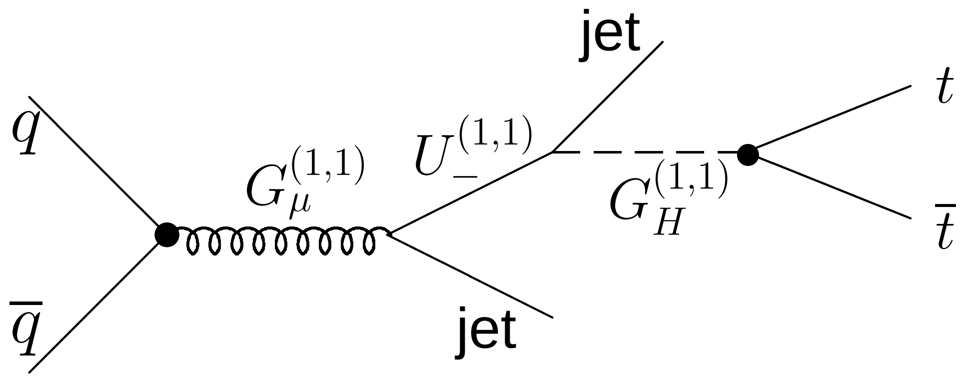
TED Phenomenology

- But, decays of $W_\mu^{3(1,1)}$ and $B_\mu^{(1,1)}$ dominated by $q\bar{q}$ final states (originated by QCD-dominated loops).

$\Rightarrow$ EW KK modes are *Leptophobic*

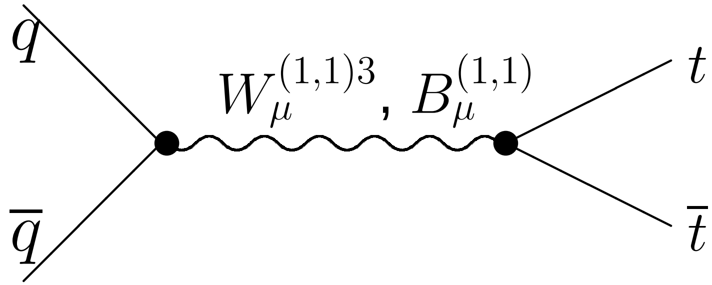
TED Phenomenology

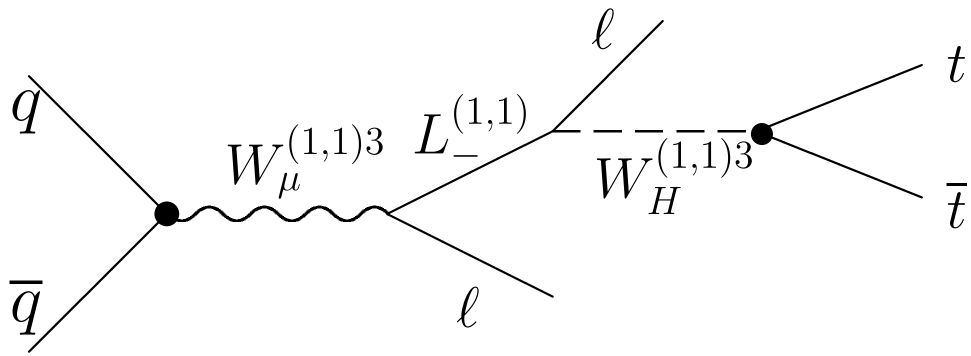
S-channel production of the $G_\mu^{(1,1)}$.



TED Phenomenology

Production and Decay of $W_\mu^{(1,1)}$ and $B_\mu^{(1,1)}$





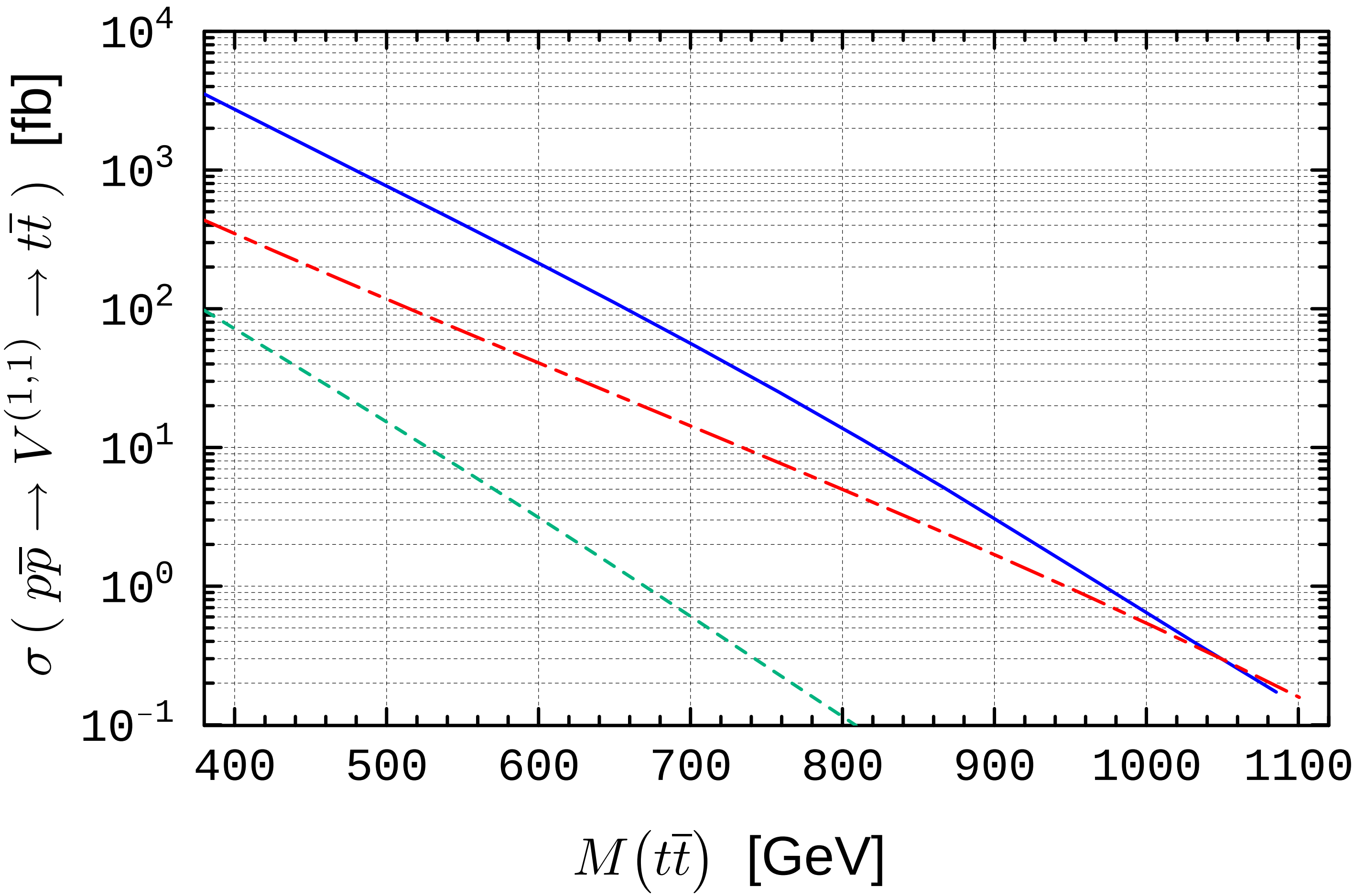
$t\bar{t}$ Resonances

- 5 Resonances in the $t\bar{t}$ spectrum ($G_\mu^{(1,1)} \to t\bar{t}$ small)
- But only 3 will be resolved:
  - $G_H^{(1,1)}$ + $W_\mu^{3(1,1)}$: $\sim 1.10\, M_{1,1}$
  - $B_\mu^{(1,1)}$ + $W_H^{3(1,1)}$: $\sim 0.97\, M_{1,1}$
  - $B_H^{(1,1)}$: $\sim 0.86\, M_{1,1}$

  and $M_{1,1} = \sqrt{2}/R$.

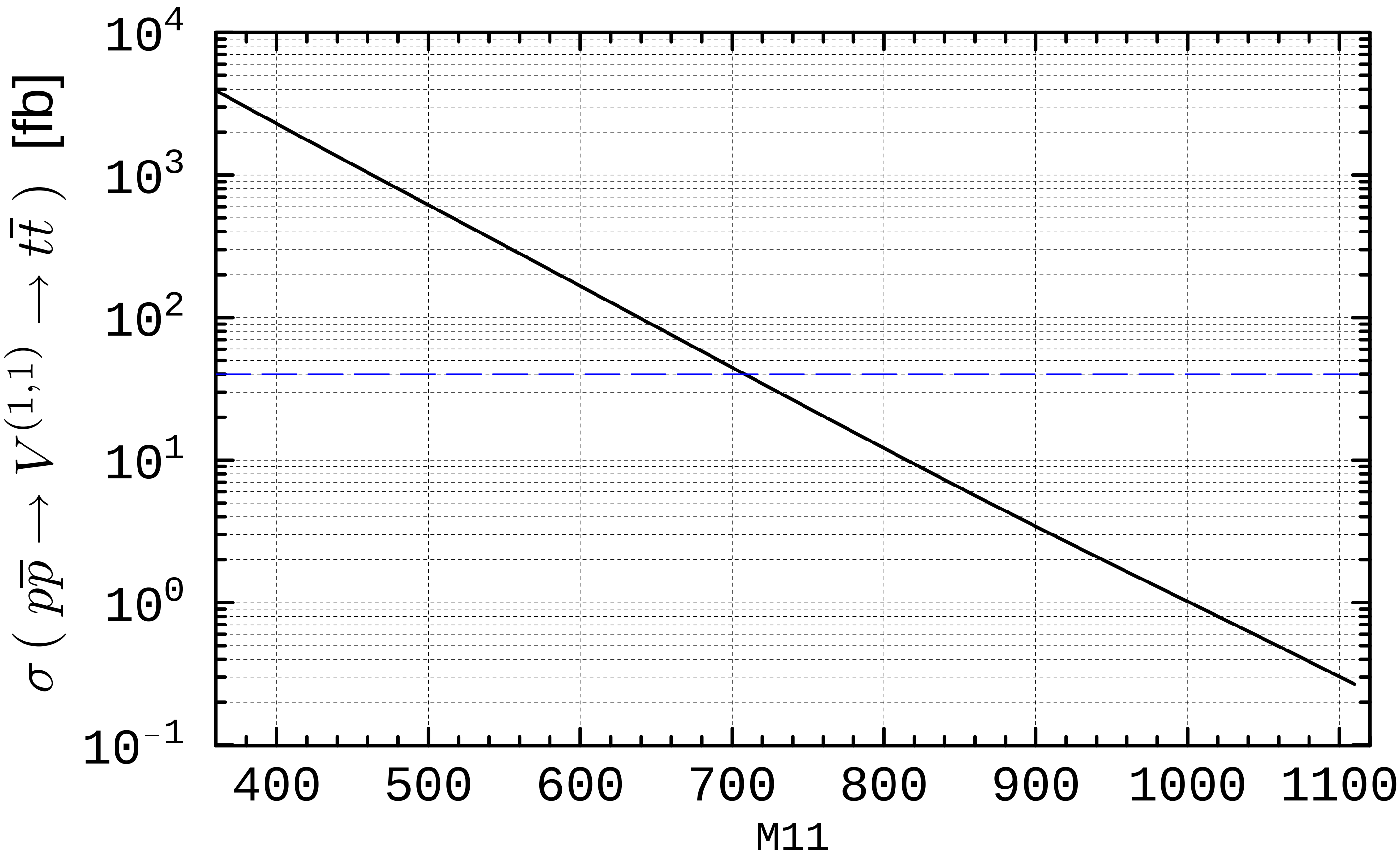
$t\bar{t}$ Resonances - Tevatron

Production of $t\bar{t}$ resonances at the Tevatron

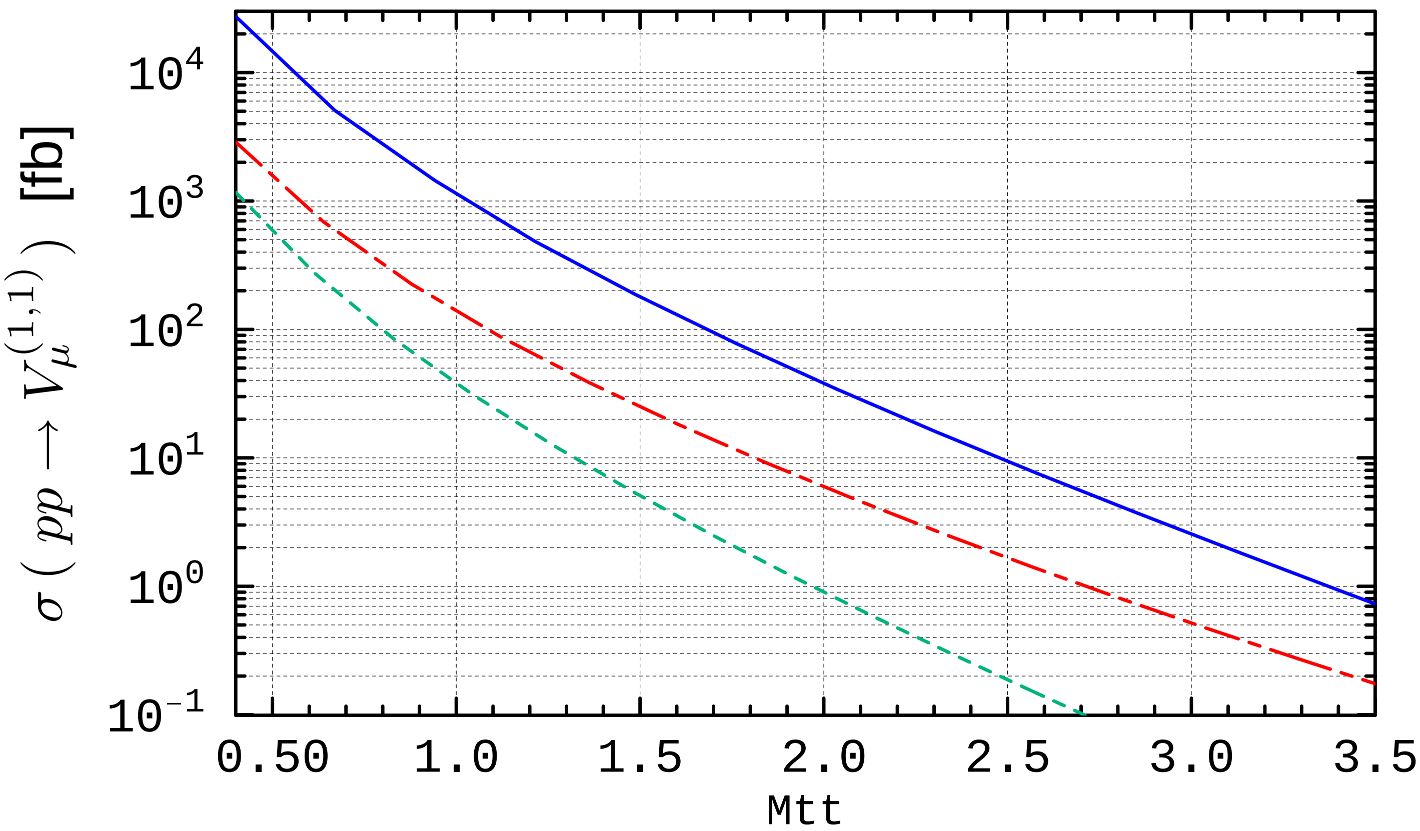


$t\bar{t}$ Resonances - Tevatron

Sum of $t\bar{t}$ pairs from all resonances at the Tevatron



$t\bar{t}$ Resonances - LHC



Conclusions

- Two Universal Extra Dimensions is a well-motivated/distinct scenario
- Crucial differences with 1 UED:
  - Spinless adjoints X_H, with $Br(X_H \to \bar{t}t) \simeq 100\%$
  - B_H is the LKP
  - $M_{1,1} = \sqrt{2}/R$: $\Rightarrow$ 2-level$\rightarrow$ 1st level pair is strictly forbidden.
  - $t\bar{t}$ rich signals at the Tevatron and LHC
- Very different phenomenology
- Generic: We can see leptophobic, weakly coupled resonances at hadron colliders
- SM in UEDs not natural. But basic features of analysis will remain