Phenomenology of Two Universal Extra Dimensions

K.C. Kong

Fermilab

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JCAP 0710:012,2007	with B. Dobrescu, D. Hooper, R. Mahbubani
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Outline

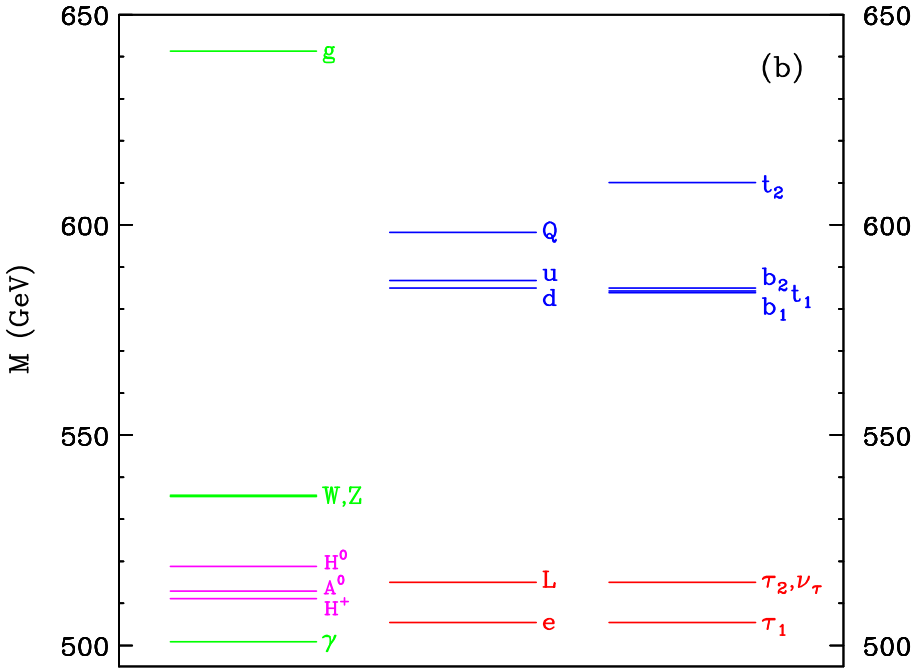
- Introduction to UED
  - 5D (S_1/Z_2)
  - 6D (Chiral square)
- Collider Implication
  - Decays of (1,0) modes
  - (1,0) modes (Tevatron/LHC)
  - (1,1) modes (Tevatron/LHC)
- Dark Matter in 6D UED
- Opportunity for ILC
- Summary

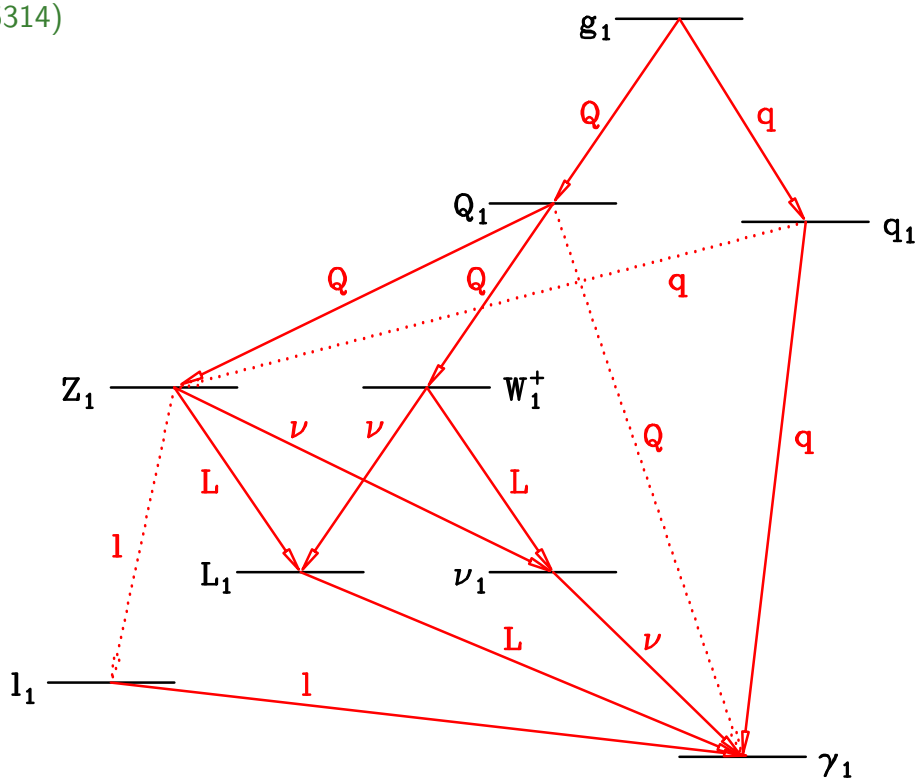
5D UED Phenomenology

- EW precision constraints: $R^{-1} \geq 300$ GeV (Appelquist, Cheng, Dobrescu,hep-ph/0012100)
- Current Tevatron limit: $R^{-1} > 280$ GeV in $3\ell + \not{E}_T$ channel at 95% C.L. (CDF)
- Region preferred by WMAP: $R^{-1} \sim 500 - 600$ GeV

  (Kong, Matchev, hep-ph/0509119, Burnell, Kribs, hep-ph/0509118, Servant, Tait, hep-ph/0206071)
- LHC reach: $R^{-1} \sim 1.5$ TeV in $4\ell + \not{E}_T$ channel

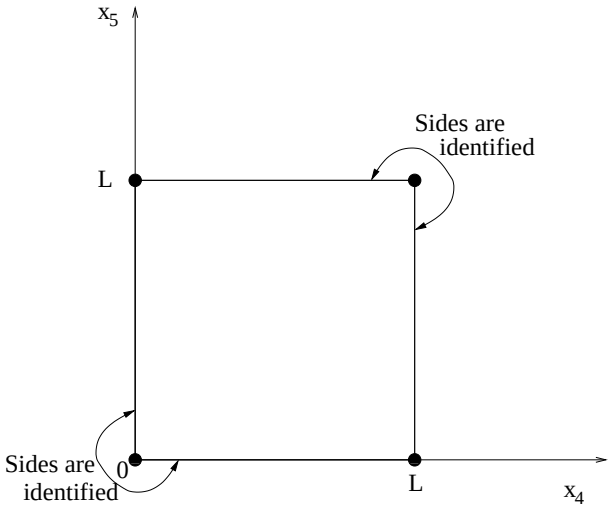
  (Cheng, Matchev, Schmaltz, hep-ph/0204342, hep-ph/0205314)

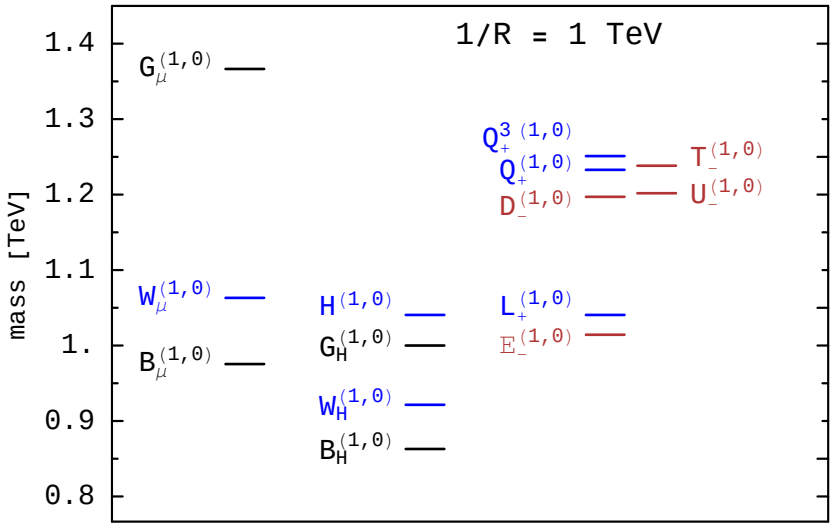




Two Universal Extra Dimensions on Chiral Square

- Motivation:
  - Possible to avoid proton decay (Appelquist, Dobrescu, Ponton hep-ph/0107056)
  - To cancel anomalies $\longrightarrow$ 3 generations (Dobrescu, Poppitz hep-ph/0102010)
- Chiral Square $\longrightarrow$ (n,m) KK-mode (Dobrescu, Ponton, hep-th/0401032)
  (Burdman, Dobrescu, Ponton, hep-ph/0506334) (Ponton, Wang, hep-ph/0512304)
- Different dark matter candidate: $B_H^{(1,0)}$ (Burdman, Dobrescu, Ponton, hep-ph/0601186)
  - $A_M^a = (A_\mu^a, A_5^a, A_6^a)$
  - $A_H^a \sim A_5^a - iA_6^a$ survives: a physical degree of freedom
  - $A_G^a \sim A_5^a + iA_6^a$ eaten: NGB
- $B_H^{(1,0)}$ self-annihilation: All fermion final states are suppressed by their mass

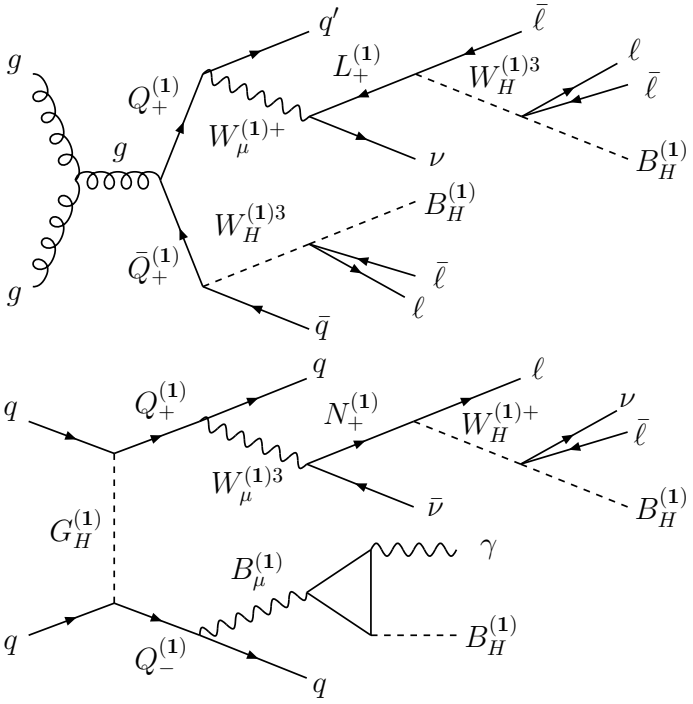


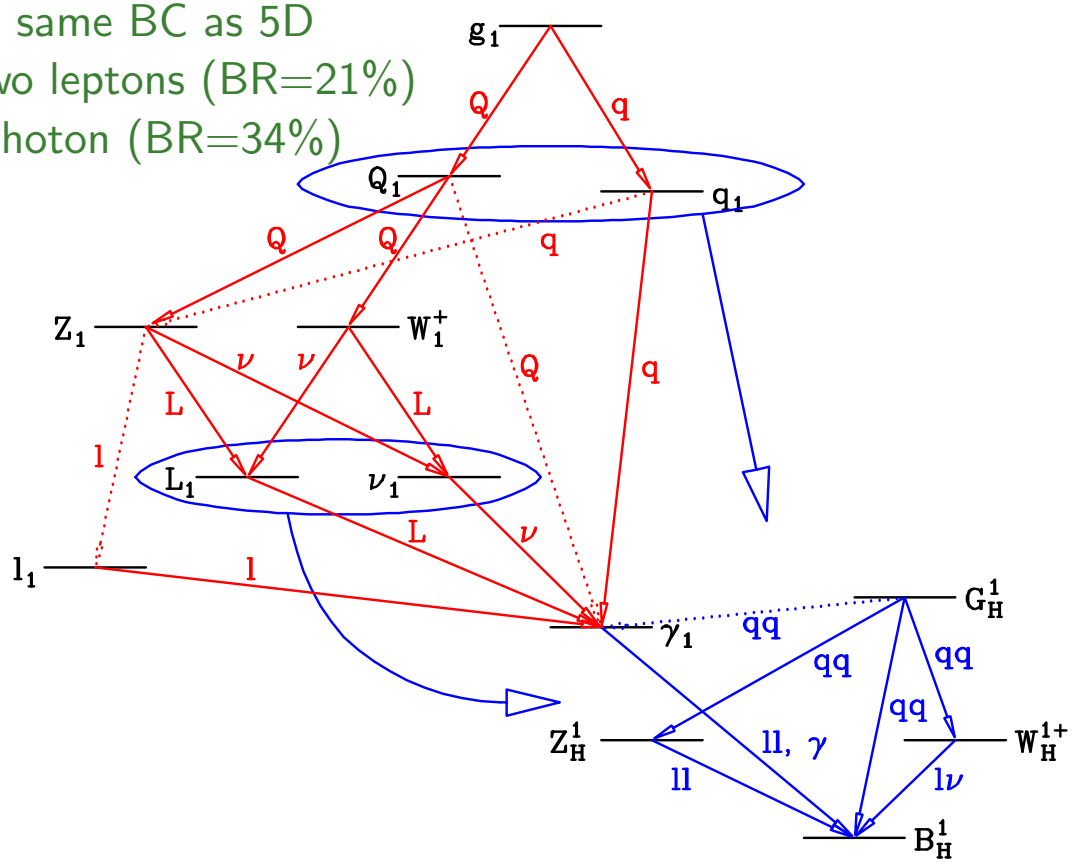


Longer cascade decays

(Dobrescu, Kong, Mahbubani, hep-ph/0703231)

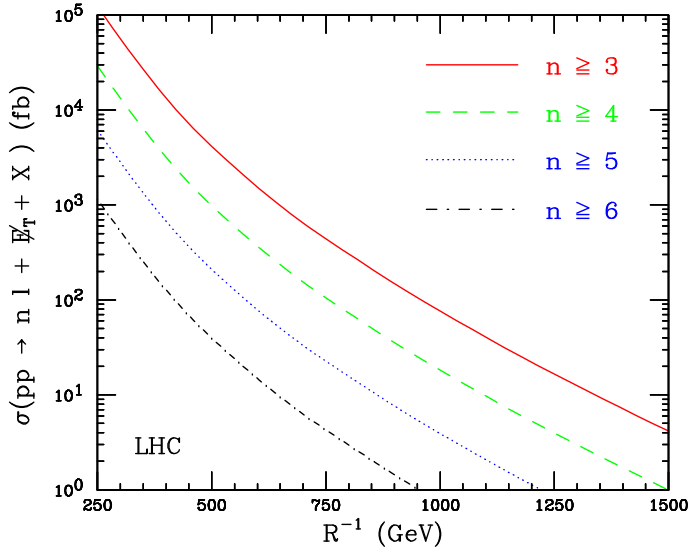
- Explore different phenomenology: (1,0) mode with $M_{(1,0)} \sim \frac{1}{R}$
  - Spinless Adjoints: uneaten NGB, G_H, W_H and B_H
  - B_H: the lightest assuming the same BC as 5D
  - Tree-level 3-body decays $\longrightarrow$ two leptons (BR=21%)
  - One-loop 2-body decay $\longrightarrow$ a photon (BR=34%)
  - GMSB?

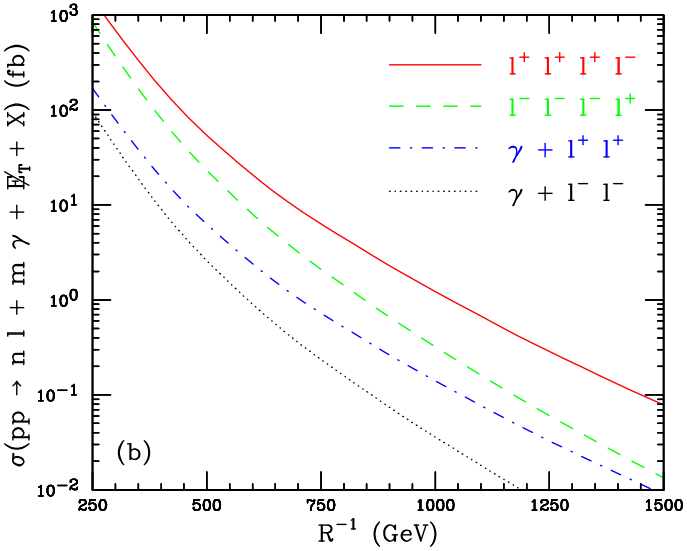


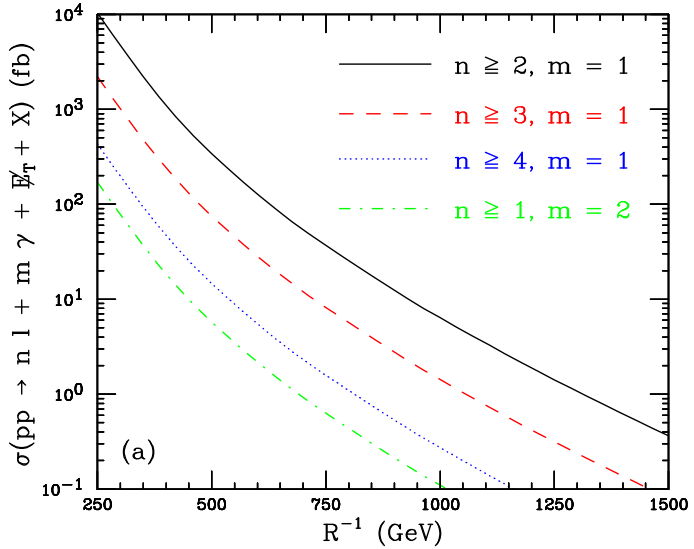


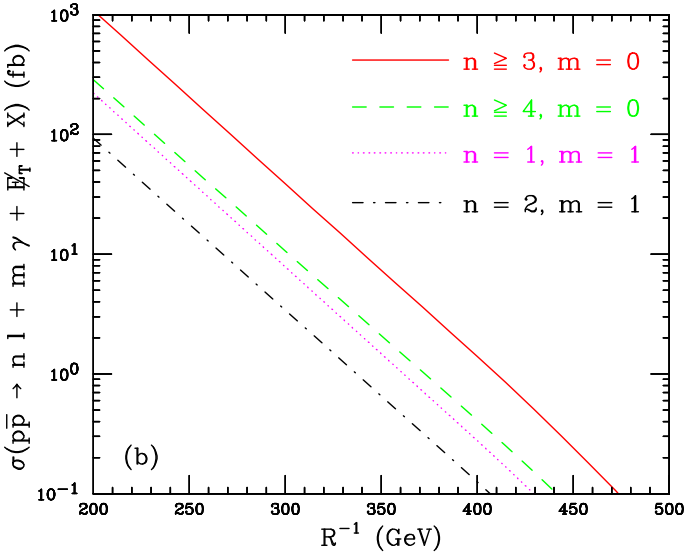
Leptons/Photons in Two Universal Extra Dimensions

(Dobrescu, Kong, Mahbubani, hep-ph/0703231)





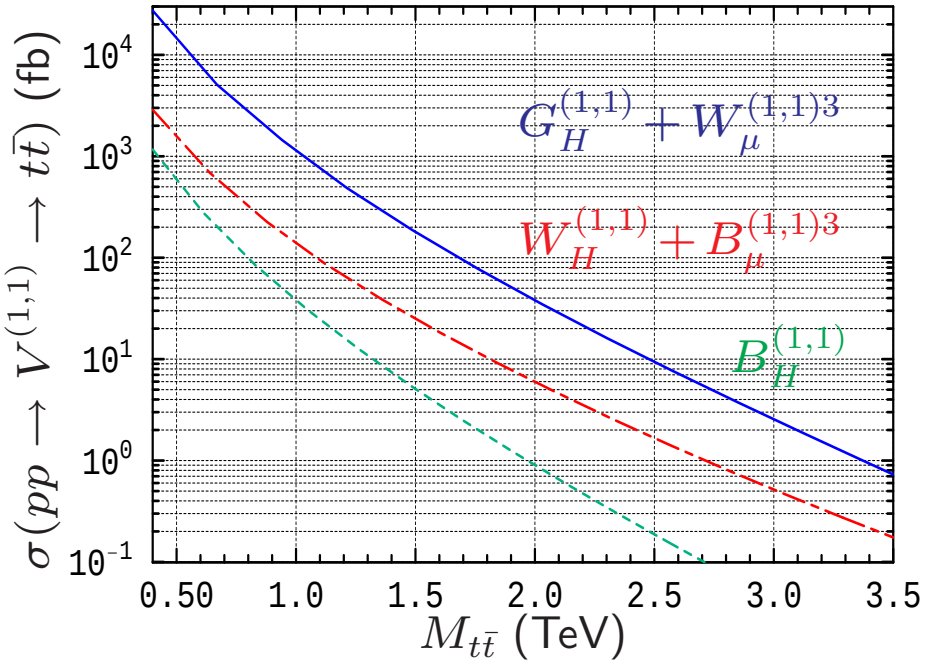




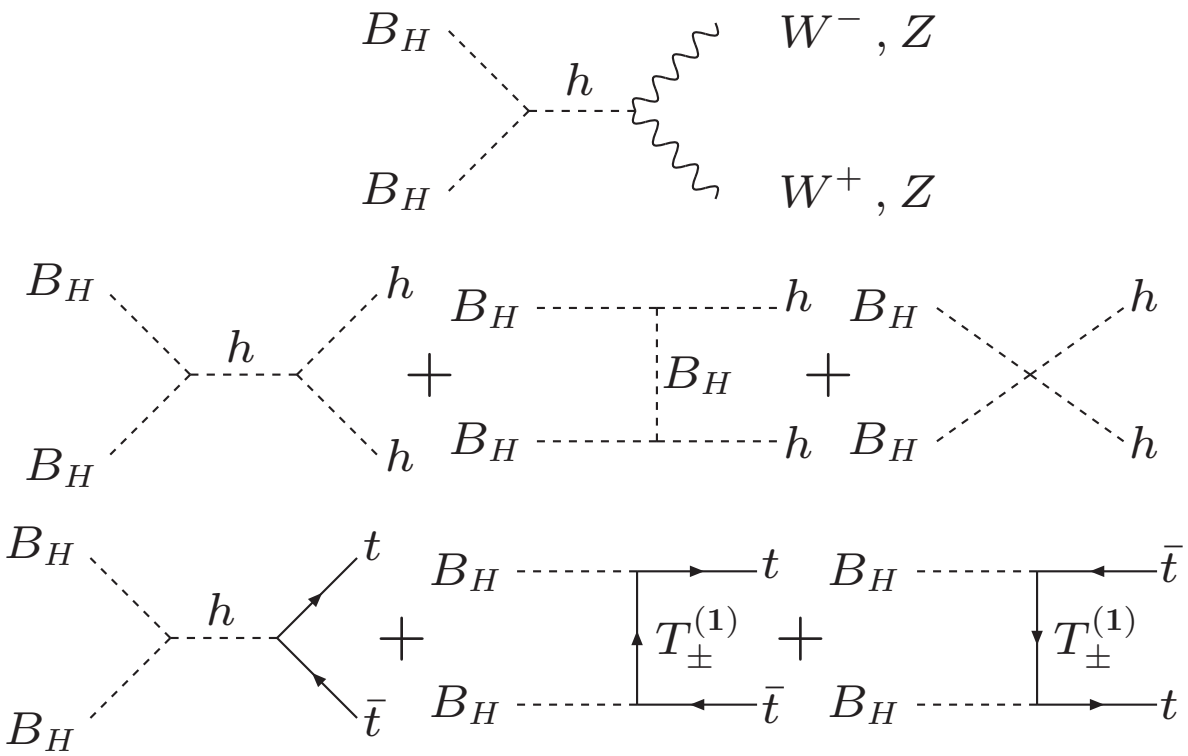
Resonances in Two Universal Extra Dimensions

(Burdman, Dobrescu, Ponton, hep-ph/0601186)

- (1,1) mode: $M_{(1,1)} \sim \frac{\sqrt{2}}{R}$
  - (1,1) mode is lighter than (2,0) mode
  - Three (neutral) gauge bosons: $G_\mu^{(1,1)}$, $W_\mu^{(1,1)}$, $B_\mu^{(1,1)}$
    - Loop-induced couplings $\longrightarrow$ lepto-phobic
    - $Br(W_\mu^{(1,1)},\ B_\mu^{(1,1)} \longrightarrow \ell^+\ell^-\ ) \sim 1\%$
  - Three (neutral) spinless adjoints: $G_H^{(1,1)}$, $W_H^{(1,1)}$, $B_H^{(1,1)}$
    - Derivative coupling, $\bar{q}\gamma^\mu q \partial_\mu X_H^{(1,1)} \longrightarrow Br(X_H^{(1,1)} \longrightarrow t\bar{t}\ ) = 1$
- 5 resonances in $t\bar{t}$: ($Br(G_\mu^{(1,1)} \longrightarrow t\bar{t}\ )$ is small)
  - But only 3 may be resolved:
    - $G_H^{(1,1)} + W_\mu^{(1,1)3} \sim 1.1\frac{\sqrt{2}}{R}$
    - $B_\mu^{(1,1)} + W_H^{(1,1)3} \sim 0.97\frac{\sqrt{2}}{R}$
    - $B_H^{(1,1)} \sim 0.86\frac{\sqrt{2}}{R}$
  - Top reconstruction?
  - Jet-energy resolution?
  - B-tagging?
  - A single bump with $\frac{\Gamma}{M} \sim 0.1$?

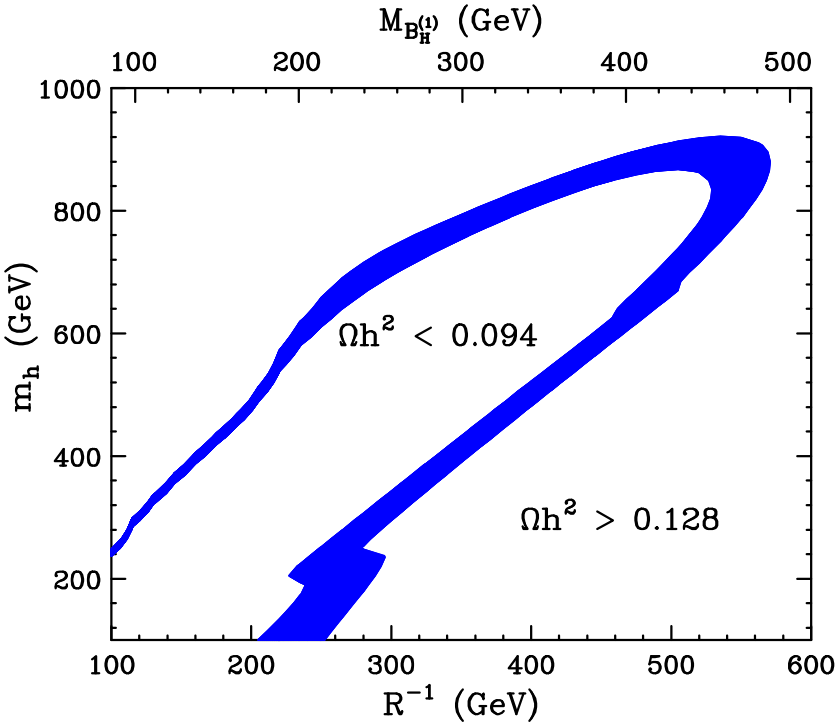


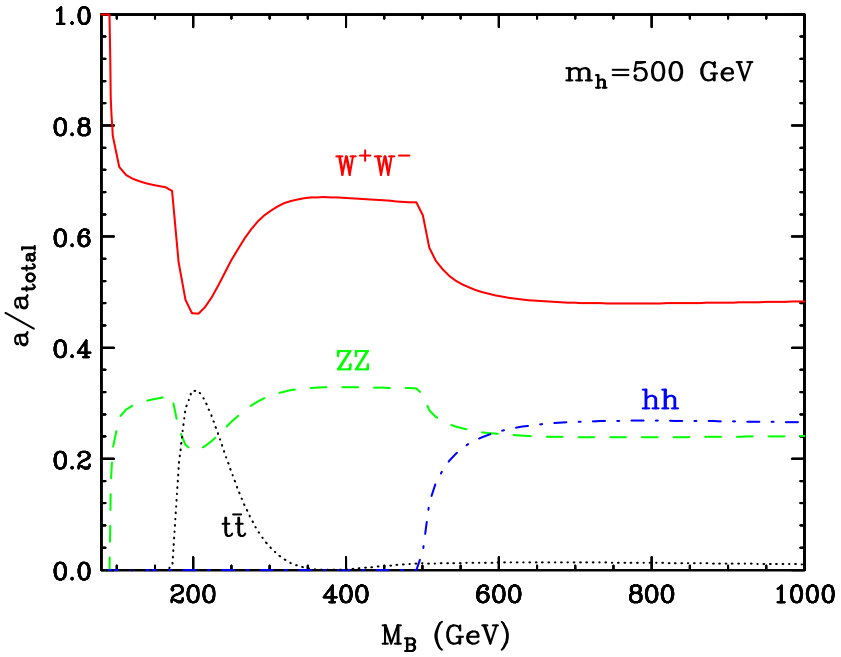
Relic Density of 6D Candidate



Relic Density of 6D Candidate

(Dobrescu, Hooper, Kong, Mahbubani, arXiv:0706.3409)

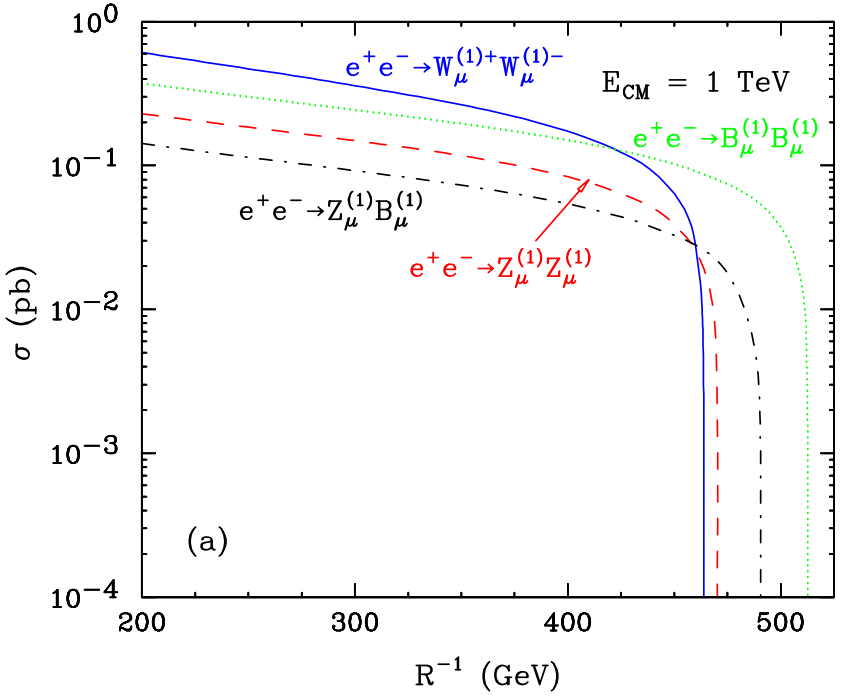




- $R^{-1} < 600$ GeV
- Light higgs requires light KK particles
  $\longrightarrow$ large production cross-sections at the LHC/Tevatron

Opportunity for ILC

- Relatively light KK state (small R^{-1} is preferred compared to 5D model)
- The second KK modes (1,1) modes are lighter than ones in 5D by a factor of $\sqrt{2}$
- Signatures with photons and many leptons
- Branching fractions of (1,0) models :
  (Dobrescu, Hooper, Kong, Mahbubani, arXiv:0706.3409)
- Production cross sections for variaous processes at ILC with $\sqrt{s} = 1$ TeV :
  (Freitas, Kong, arXiv:0711.4124)



Branching Fractions of KK-Leptons and $W_\mu^{(1)}$

Final-state	$W_\mu^{(1)3} \to \ldots \to B_H^{(1)}$	
e, μ, γ	Branching fractions	%
X	$\frac{2}{3}(b_{l1} + b_{l2} + b_{l3}b_{Be})$	30.4
$(e^+ + e^-)X$	$\frac{4}{9}b_{l2}$	10.5
$(e^+\mu^- + e^-\mu^+)X$	$\frac{4}{9}b_{l2}$	10.5
$e^+e^-\,X$	$\frac{b_{l1}}{6} + \frac{4}{9}b_{l2} + \frac{5}{6}b_{l3}b_{Be}$	15.5
$e^+e^-e^+e^-$	$\frac{1}{36}(b_{l2} + 6b_{l3}b_{Be})$	1.0
$e^+e^-\mu^+\mu^-$	$\frac{1}{18}(b_{l2} + 6b_{l3}b_{Be})$	2.0
$\gamma\,X$	$\frac{2}{3}b_{l3}b_{B\gamma}$	2.1
$\gamma\,e^+e^-\,X$	$\frac{1}{6}b_{l3}b_{B\gamma}$	0.5

Final-state	$W_\mu^{(1)+} \to \ldots \to B_H^{(1)}$	
e, μ, γ	Branching fractions	%
X	$\frac{1}{3}(b_{l1} + 2b_{l2} + b_{l3}b_{Be})$	23.1
$e^+\,X$	$\frac{1}{3}(b_{l1} + 2b_{l2} + b_{l3}b_{Be})$	23.1
$e^+e^-\,X$	$\frac{1}{6}(b_{l2} + 2b_{l3}b_{Be})$	4.6
$e^+e^-e^+X$	$\frac{1}{6}(b_{l2} + 2b_{l3}b_{Be})$	4.6
$e^+e^-\mu^+X$	$\frac{1}{6}(b_{l2} + 2b_{l3}b_{Be})$	4.6
$\gamma\,X$	$\frac{1}{3}b_{l3}b_{B\gamma}$	1.1
$\gamma\,e^+\,X$	$\frac{1}{3}b_{l3}b_{B\gamma}$	1.1

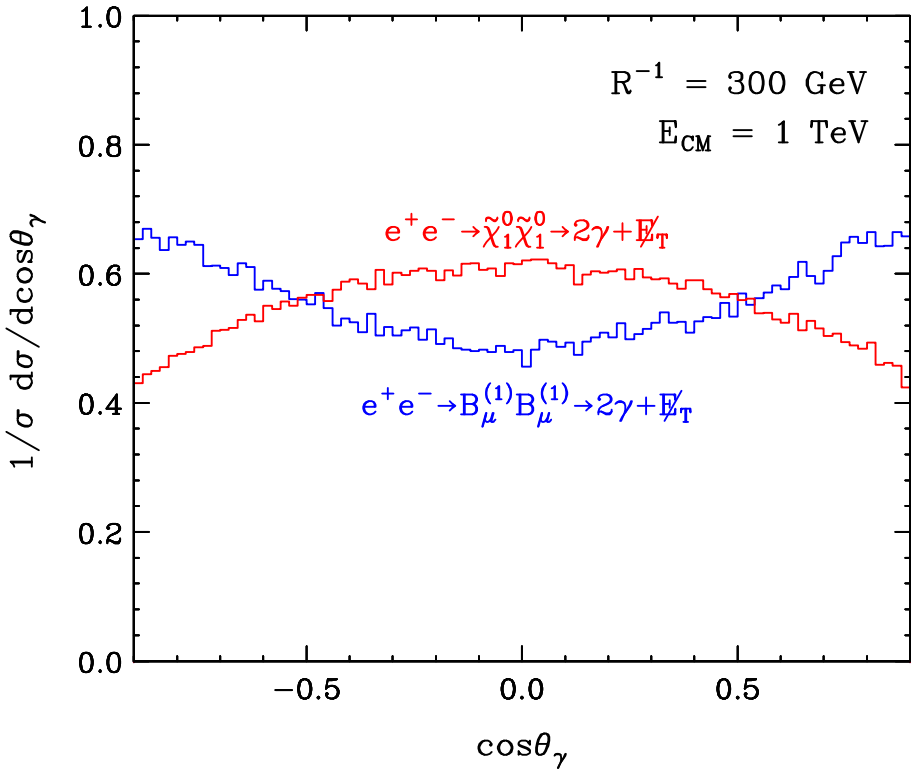
$$\mathrm{Br}\left[(N_+^{(1)}, E_+^{(1)}) \to B_H^{(1)}(\nu_L, e_L)\right] \equiv b_{l1} \approx 20.1\%$$

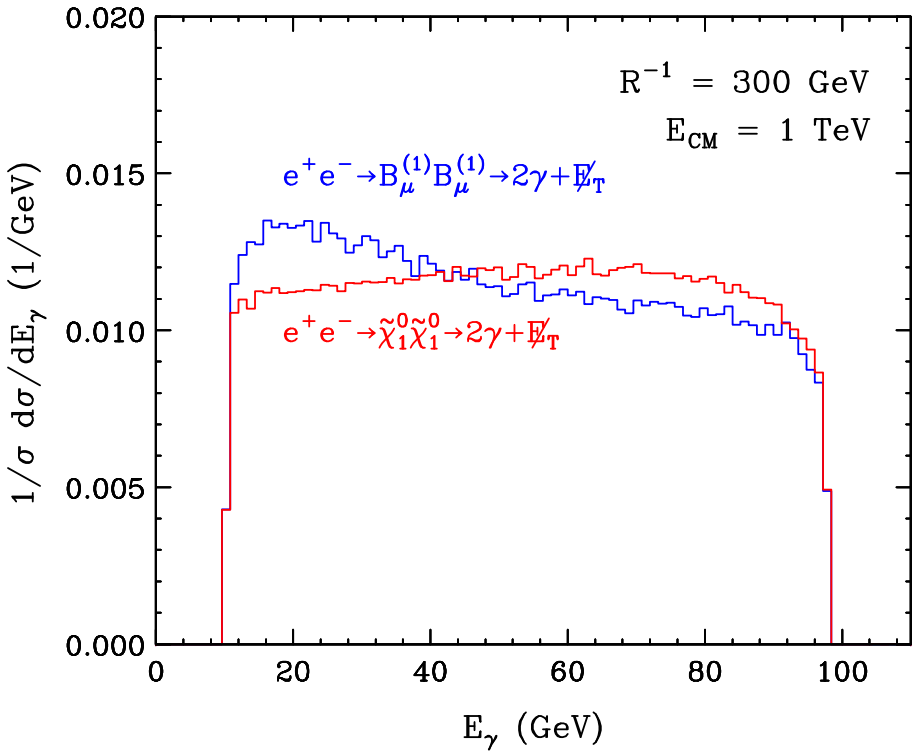
$$\frac{1}{2}\,\mathrm{Br}\left[(N_+^{(1)}, E_+^{(1)}) \to W_H^{(1)+}(e_L, \nu_L)\right] = \mathrm{Br}\left[(N_+^{(1)}, E_+^{(1)}) \to W_H^{(1)3}(\nu_L, e_L)\right] \equiv b_{l2} \approx 23.5$$

$$\mathrm{Br}\left[(N_+^{(1)}, E_+^{(1)}) \to B_\mu^{(1)}(\nu_L, e_L)\right] \equiv b_{l3} \approx 9.3\%$$

$2\gamma + \not{E}_T$ at ILC

(Freitas, Kong, arXiv:0711.4124)

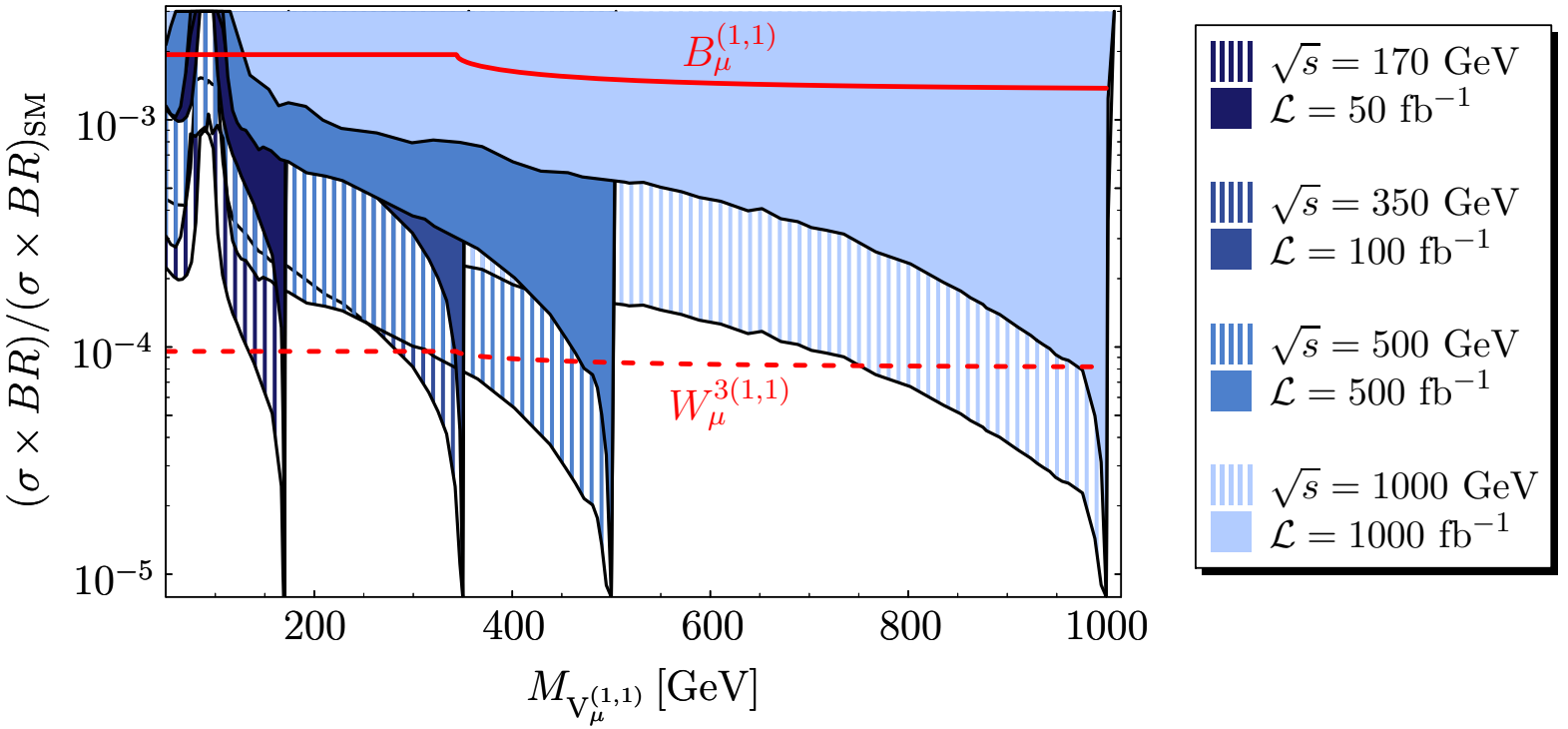




- $-\frac{R}{4}C_B\epsilon^{\mu\nu\rho\sigma}F_{\mu\nu}B^{(1)}_{\rho\sigma}B^{(1)}_H$
- $-\frac{R}{4}C_B F_{\mu\nu}B^{(1)}_{\mu\nu}B^{(1)}_H$?

(1,1) Resonances at ILC

(Freitas, Kong, arXiv:0711.4124)



- $BR(B_\mu^{(1,1)} \to jj) \approx BR(W_\mu^{(1,1)3} \to jj) \approx 70\%$
- Projected sensitivity of ILC of $B_\mu^{(1,1)}$ and $W_\mu^{(1,1)3}$ for different run scenarios.
  - Hatched region: 95% confidence level exclusion reach
  - Solid region: 5σ discovery reach

Summary

- 5D and 6D UED have different phenomenology
- Longer cascade decays in 6D UED through 3 body or 1-loop decays
- Signatures with multi-leptons and leptons + photons
- Mutiple $t\bar{t}$ resonances
- Spin-0 KK dark matter $\rightarrow$ correlated to Higgs mass
- Better opportunity for ILC
  - Probing two Universal Extra Dimension model with leptons and photons at the LHC and ILC, Ghosh, arXiv:0809.1827
  - Probing two Universal Extra Dimensions at International Linear Collider, Ghosh, Datta, arXiv:0802:2162
  - Two universal extra dimensions and spinless photons at the ILC, Ayres, Kong, arXiv:0711.4124