Excited Scalars of the UED model

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Based on:

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- Different models: Number of EDs, compactification manifold, and which particles can go into the bulk .
- In Universal Extra Dimension (UED) type models,all standard model particles are placed in the bulk , no need for branes.
- Best candidate to mimic SUSY, and the second best (after SUSY) to give cold dark matter

Minimal UED model

Minimal UED : We consider a five-dimensional model (x^μ, y)

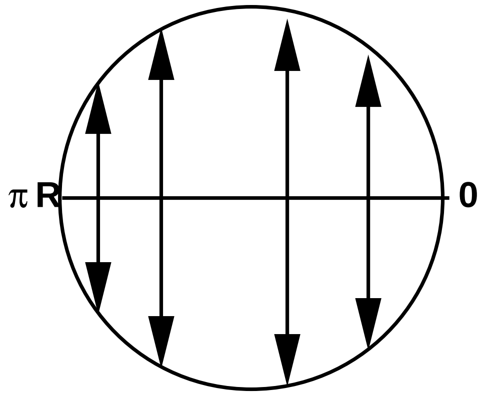
(Appelquist, Cheng and Dobrescu, PRD 64, 035002, 2001)

The fifth dimension, y, is compactified: $y \equiv y + 2\pi R \quad (S^1)$,
where $R \equiv$ Compactification Radius

Orbifolding: Necessary to get chiral fermions of the SM

$y \equiv -y \quad$ ($\mathcal{Z}_2$ symmetry)

$y = 0, \pi R$ are *fixed points* under $\mathcal{Z}_2$



Dimensional reduction

- In 4d for each low mass(zero mode) SM particle we get an associated KK tower:equispaced (∽1/R)

  Mass of n-th level state is

$$m_n^2 = m_0^2 + \frac{n^2}{R^2}$$

n is the KK number

  Since m_0« $\frac{1}{R}$ so $m_n \simeq \frac{n}{R}$
- Mass degenerate spectrum
- Conservation of KK number:conservation of p_5

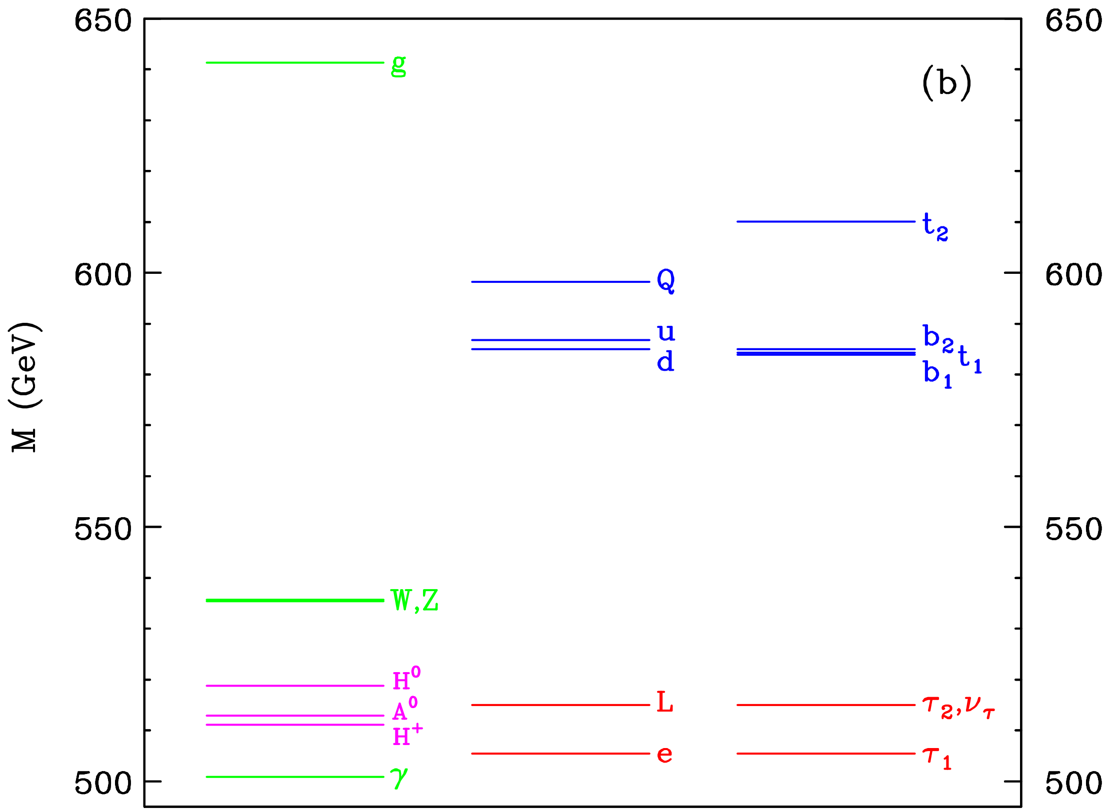
Radiative Corrections

- Tree level relation gets modified when radiative corrections are taken into account.
- Two types:

  a.Bulk Corrections : (breaking of Lorentz invariance)

  b.Orbifold Corrections :(breaking of translational invariance in 5th dim.)
- Boundary corrections break KK number down to KK Parity $(-1)^n$, which is conserved.
- $n = 1$ particles must be pair produced(Conservation of KK Parity) They must decay to γ_1 (LKP:D.M Candidate)

UED Spectrum



Radiative correction is included. $R^{-1} = 500$ GeV,$\Lambda R = 20$.

Taken from Cheng, Matchev, Schmaltz, PRD 66, 036005, 2002

Scalar sector of UED

The n-th level Higgs field is parametrized as

$$H_n = \begin{pmatrix} \chi_n^+ \\ \frac{h_n - i\chi_n^0}{\sqrt{2}} \end{pmatrix}$$

where χ_n^+ , h_n and χ_n^0 are excitations of charged scalar ,CP even neutral and CP odd neutral scalars.

There are three more scalars ,which are 5th components of excitations of gauge bosons Z_n^5 ,$W_n^{5\pm}$.

Scalar sector of UED(cont.)

The Goldstone combinations are given by

$$G_n^0 = \frac{1}{m_{Z_n}} \left[m_Z \chi_n^0 - \frac{n}{R} Z_n^5 \right],$$

$$G_n^\pm = \frac{1}{m_{W_n}} \left[m_W \chi_n^\pm - \frac{n}{R} W_n^{5\pm} \right].$$

The orthogonal combinations are the physical fields given by $H_n^\pm$, A_n^0

if 1/R $\gg M_{(W,Z)}$,the $n \neq 0$ Goldstones are the 5th component of gauge bosons. (We will work in this limit only.)

Radiative correction on scalars

The tree level masses of the excited scalars are given by

$$m^2_{h_n, A^0_n, H^\pm_n} = m_n^2 + m^2_{h,Z,W^\pm}$$

The radiative correction is given by

$$\delta m_H^2 = m_n^2 \left[\frac{3}{2} g^2 + \frac{3}{4} g'^2 - \lambda\right] \frac{1}{16\pi^2} \ln \frac{\Lambda^2}{\mu^2} + \overline{m_h^2}$$

where $\overline{m_h^2}$ is the boundary mass term for the excited scalars, (not a priori calculable)

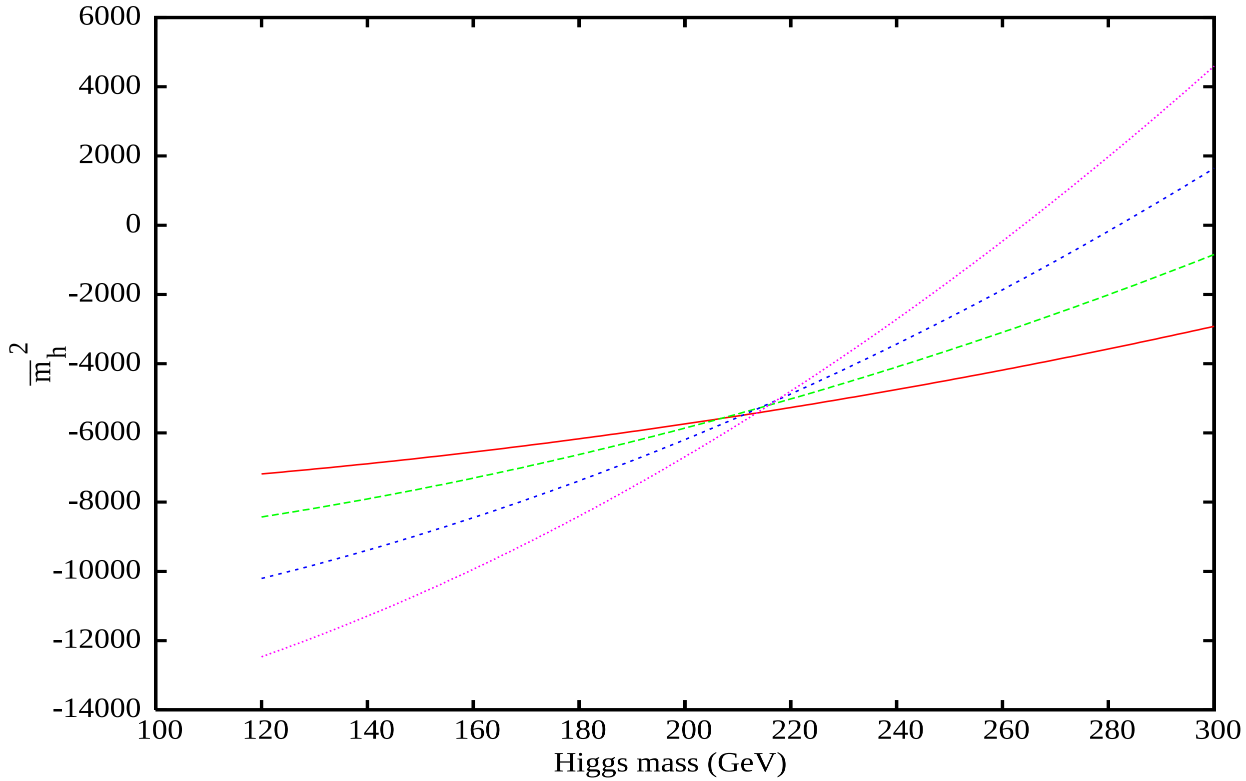
A few points to be noted :

- Radiative correction to the excited scalar masses is universal.
- $H^\pm$ will be the lowest-lying one.
- The hierarchy $m_{h_n} > m_{A_n^0} > m_{H_n^\pm}$ is fixed.
- For larger SM Higgs mass $H_1^\pm$ and A_1^0 masses go down if we keep $\overline{m_h^2}$ fixed. h_1 will become more massive.
- The excited scalar sector becomes more massive as $\overline{m_h^2}$ goes up, this affects the decay kinematics.

Theoretical bound on $\overline{m_h^2}$

- $\overline{m_h^2}$ can also be negative
- For sufficiently negative values of $\overline{m_h^2}$, the H^+ mass can go down below that of γ_1
- This sets the lower bound on $\overline{m_h^2}$ as a function of $1/R$ and Λ.
- $\overline{m_h^2}$ can have large positive values.
- the excited Higgs masses may go above the corresponding electroweak gauge boson masses
- This will open up a new set of decay channels like $H^0 \to W_1^+ \ell \bar{\nu}_\ell$

Theoretical bound on $\overline{m_h^2}$



The lower bound on $\overline{m_h^2}$ as a function of the SM Higgs boson mass and $1/R$. ΛR is fixed at 20. From top to bottom (at the right-hand edge) are the curves for $1/R =$ 600, 500, 400, and 300 GeV respectively.

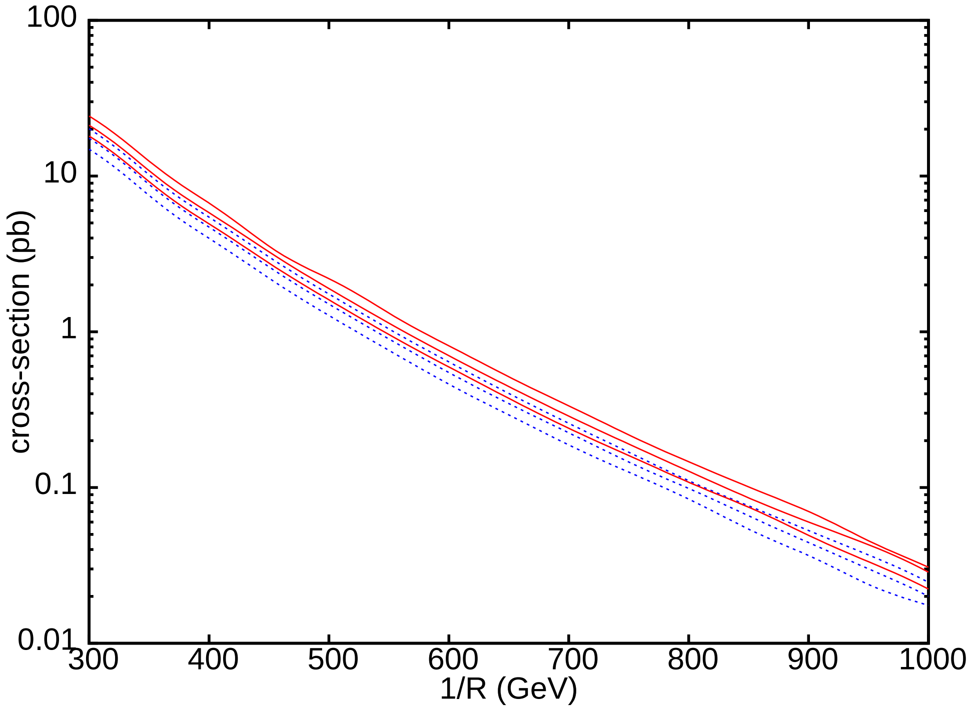
UED model in CalcHEP

- We want to study the excited scalars at LHC
- We add minimal UED model in calcHEP
- Masses with radiative correction is also included
- CalcHEP v2.4.5 is used for calculation of the cross sections and decay width calculation
- Parton level events are generated

Charged Higgs at LHC

- Dominant mechanism through the real production of $n = 1$ top pair $pp \to t^{(1)}\bar{t}^{(1)}$ and its subsequent decay to charged Higgs
- The n=1 top production results from $q\bar{q}$ annihilation and gg fusion
- The NLO corrections should be significant(yet to be computed)
- Evaluate the cross-section at three different regularization scale : $\mu = 0.5R^{-1}$,R^{-1}, and $2R^{-1}$

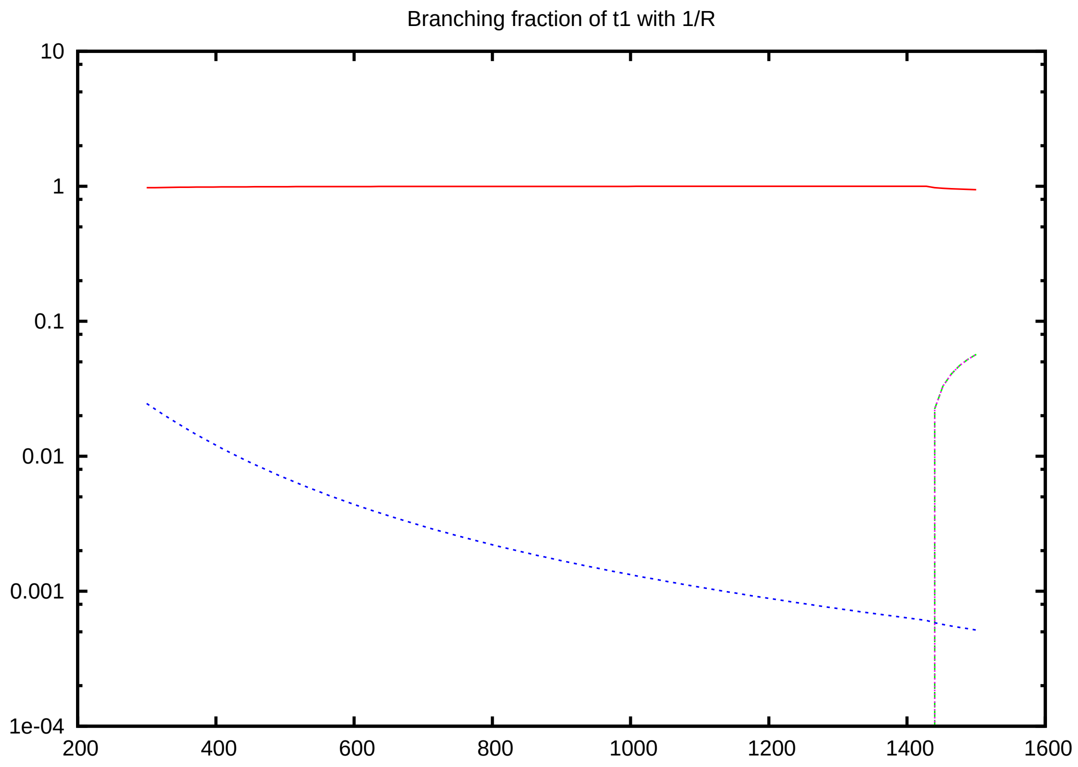
$t_1(t_2)$ production and decay at LHC



$pp \rightarrow t^{(1)}\bar{t}^{(1)}$ and $pp \rightarrow t^{(2}\bar{t}^{(2)}$(dotted) for different regularization scale μ

n=1 top decay

$t^{(1)} \rightarrow H_1^+ \, b_0$ is the dominant decay process(Branching $\simeq$ 1)
(Other singlet quarks can only decay to $\gamma 1$)



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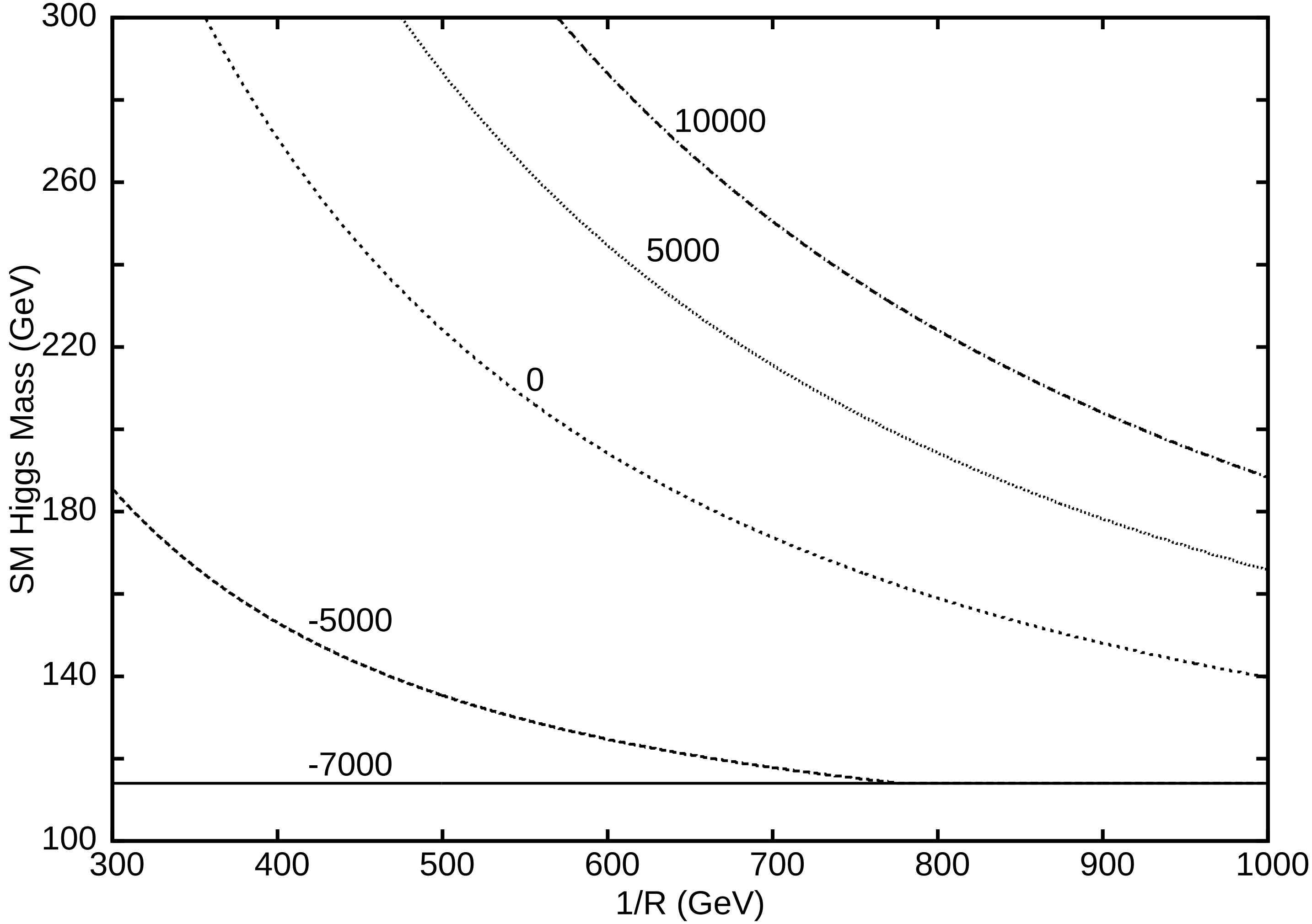
- WHY?

Decay of n=1 charged scalar

Charged higgs decay

- H_1^+ decays into $\tau_1^+(singlet)\nu_{\tau 0}$ and $\tau_0^+\nu_{\tau 1}$(small Branching).
- final state is the soft $\tau 0$ and missing energy.
- $H_1^+ \rightarrow W_1^+ + \gamma$ opens only at very high $\overline{m_h^2}$ ($\sim 10^4$ GeV^2)
- For high R^{-1} and SM higgs mass two body Chanels close.
- 3 body Channels:H_1^+->$f\bar{f}'$ + LKP (through a virtual n=0 W^+)

Parameter space for $H^{\pm}$ decay



The parameter space for Charged higgs decay

Event table

Signal: One or two soft τs ,2 hard b jets and a large amount of missing energy.

R^{-1} (GeV)	Signal events	BG1a events	BG1b events	BG1c events	BG2a events	BG2b events	BG2c events	Total Background
500	42	77	170	188	92	265	136	928
600	67	68	93	161	26	351	90	789
800	60	24	23	46	12	178	19	302
1000	54	6	6	12	4	56	5	89

p_T of τ between 20 to 30 GeV, Missing p_T between 150 to 300 GeV

417 background events coming from SM top pair production

1a:$W_1 \to \tau_1$ pair;   1b:$W_1 \to \tau_0$ pair;   1c:$W_1^+ W_1^- \to \tau_1^\pm \tau_0^\pm$

2a: b_1 pair production ,$b_1 \to b_0 Z_1 \to \tau_1 \tau_0, \bar{b_1} \to \bar{b_0} + LKP$

2b: b_1 pair to Z_1 pair ,$Z_1 \to \tau_0 \tau_1$,$Z_1 \to \nu_0 \nu_1$

2c: Z_1 pair to 4 τs, 2 or 3 are missed

Possible improvements

- τ polarization technique may be helpful.

  The distribution of the final-state mesons depend upon whether the τ came from H_1^+ or from W_1^+ .

- If we trigger on b jets then this signals can be improved .

- Detailed simulation is needed.

Production of h_1, A_1^0 at the LHC

Three major processes for their production:

(i) Bjorken process $V_0^* \longrightarrow V_1 h_1(A_1^0)$

suppressed: The Bjorken process suffers from excessive off-shellness of V_0

(ii) electroweak vector-boson fusion

suppressed: one must produce two $n = 1$ states in tandem

(iii) associated production $pp \longrightarrow b_1\bar{b}_1$, $b_1 \longrightarrow b_0 h_1(A_1^0)$

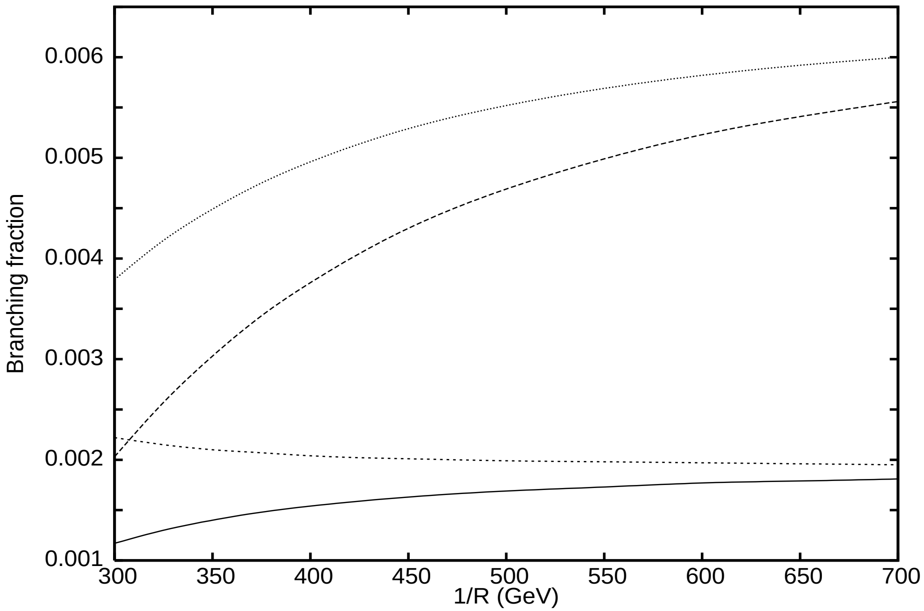
Third process is dominant but cross section is low

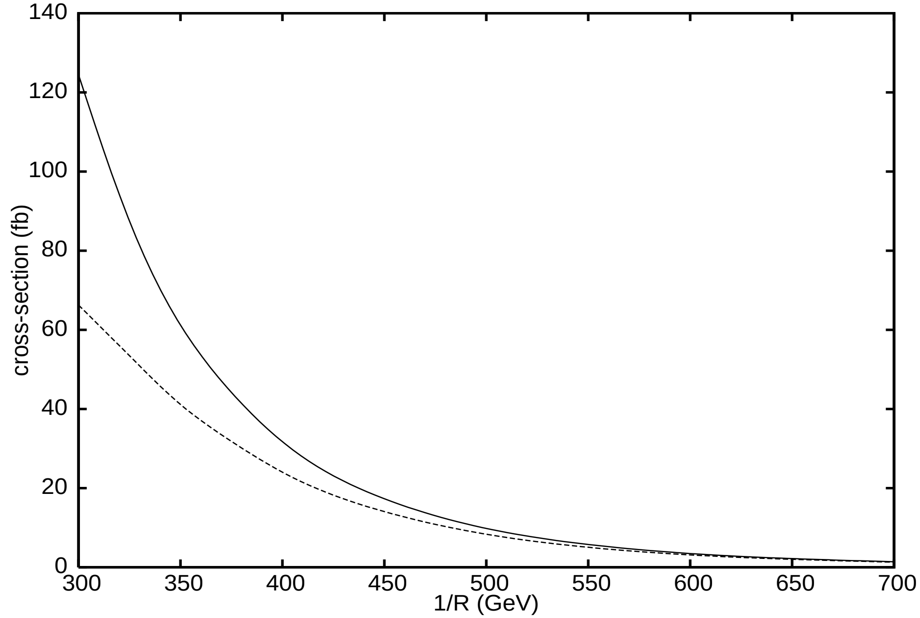
Our signal: one $b^{(1)}$ decays to a neutral Higgs and the other decays to $b_0\gamma_1$

We get two hard b jets plus one τ plus large missing energy

Background is identical to the $H^{\pm}$ signal.

X section and branching for h_1, A_1^0





Neutral Higgs decay

h_1 and A_1^0 -> $n = 1$ and one $n = 0$ τ lepton

3 body Channels:h_1 and A_1^0->γ + LKP

The cross section is at least two order smaller than charged Higgs case (No hope for detection)

Summary

- Minimal UED model contains three scalars: $H_n^{\pm}$, h_n^0, A_n^0
- Masses depend on Λ, R^{-1}, m_h and $\overline{m_h^2}$
- These Higgses can decay only leptonically (only to τ)
- Spectrum dictates that the τs must be soft
- This poses a serious challenge in their detection
- The detector limitation for identifying the τ removes the majority of the signal
- One may significantly reduce the background by using τ polarization

  We also stress that this work is more of a qualitative nature, and a detailed quantitative study should be taken up.

Thank you !

Extra Slides

Backgrounds

There are two types of backgrounds

- Standard model background:
  top pair production and decays to b and W and W to τ ν_τ
- missing p_T(<150 GeV) with soft tau cut reduces large this background

  UED backgrounds:
  i).BG1a: $pp \longrightarrow t^{(2)}\bar{t}^{2}$, $t^{(2)} \longrightarrow b_0 W_1$.
  first $W_1 \longrightarrow \tau_0 \nu_{\tau_1}$ and second $W_1 \longrightarrow \tau_0 \nu_{\tau_1}$
  ii).BG1b: $pp \longrightarrow t^{(2)}\bar{t}^{2}$, $t^{(2)} \longrightarrow b_0 W_1$.
  first $W_1 \longrightarrow \tau_1 \nu_{\tau_0}$ and second $W_1 \longrightarrow \tau_1 \nu_{\tau_0}$

Backgrounds

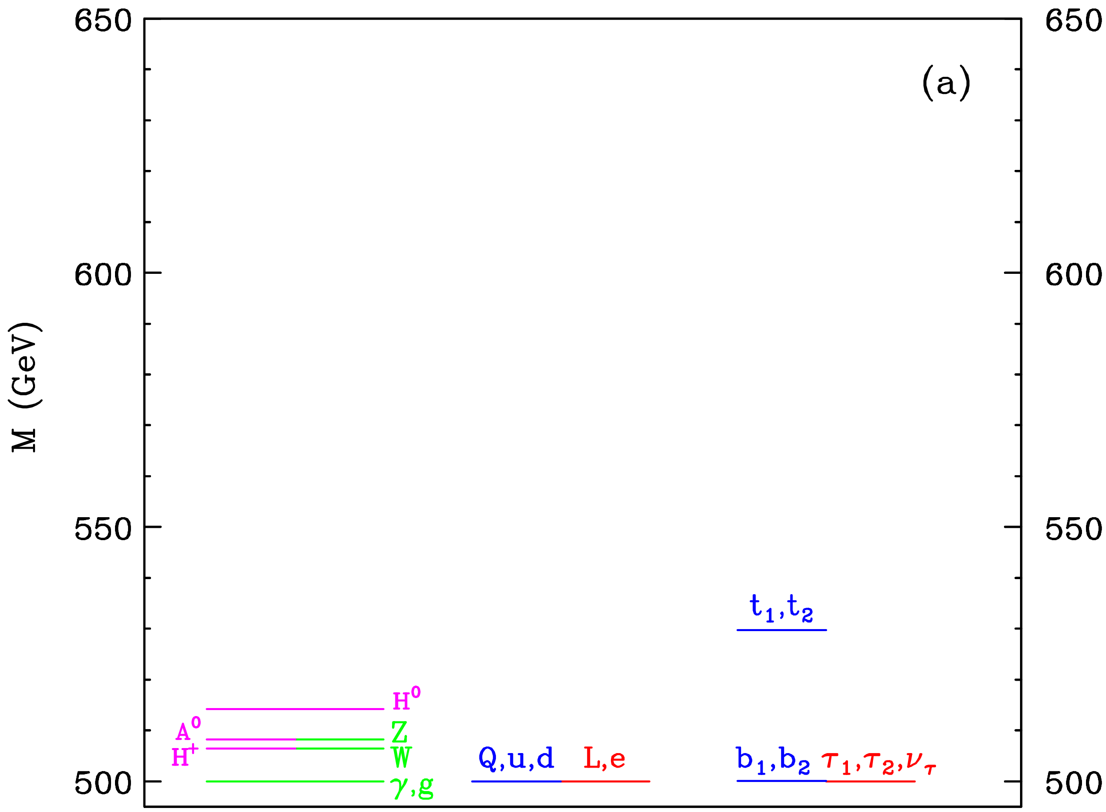
iii).BG1c: $pp \to t^{(2)}\bar{t}^{2}$, $t^{(2)} \to b_0 W_1$.
first $W_1 \to \tau_1 \nu_{\tau_0}$ and second $W_1 \to \tau_0 \nu_{\tau_1}$

iv).$pp \to b^{(2)} b^{(\bar{2})}$
one $b^{(2)}$ decays to Z_1 which in turn decays to $\tau_0 \tau_1$, and the other $b^{(2)}$ decays to B_1

v).(BG2b), both $b^{(2)}$ go to $b_0 Z_1$, and while one Z_1 decays to $\tau_0 \tau_1$, the other decays to $\nu_0 \nu_1$

vi).BG3c, is the one where both $b^{(2)}$ go to $b_0 Z_1$, ultimately giving rise to a $2b + 4\tau + \not{p}_T$ background, but 2 or 3 τs are missed as their p_T fall below the 20 GeV cut, and none of them are harder than 30 GeV.

UED Spectrum



Radiative correction is not included. $R^{-1} = 500$ GeV. Taken from Cheng, Matchev, Schmaltz, PRD 66, 036005, 2002