

Models with Long-Lived Particles :

Short

A Survey

- What are the types of models which predict long-lived particles decaying macroscopically, ie, $d \sim 10^{-3} - 10^0$ m ??
- How likely is it the model's parameters allow such lifetimes ?? What are their signatures ??

→ Quick + dirty intro to models

→ Numerics

Summary + Conclusions

TGR1330
12/03

Gauge Mediation : A Story of 3 Sectors

- A 'secluded' SUSY breaking sector which

Communicates ~~SUSY~~ at $\begin{cases} \text{tree} & k \sim g^2 \lesssim 1 \\ \text{1-loop} & k \sim \alpha \sim 10^{-2} \\ \text{2-loops} & k \sim \alpha^2 \sim 10^{-4} \end{cases}$

[The Scale is $\sqrt{F/k}$]

to the

- Messenger sector : (i) a SM Singlet field S

$$\langle S \rangle = M + \theta^2 F \quad \{ M, \sqrt{F} \text{ are fund. scales} \}$$

- (ii) messenger fields $\{$ anomaly free combos of SM fields $\}$ $5 + \bar{5} / 10 + \bar{10}$ in $SU(5)$ language

e.g., q, q^c, l, l^c $W = \lambda_1 S q q^c + \lambda_2 S l l^c$

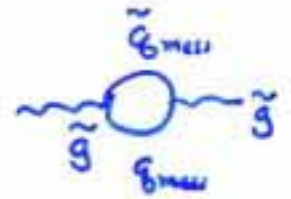
$$m_{\text{fermion}}^{\text{mess}} \approx \lambda M$$

$$m_{\text{boson}}^2 \approx \begin{pmatrix} \lambda^2 M^2 & \lambda F \\ \lambda F & \lambda^2 M^2 \end{pmatrix}, \Rightarrow \frac{\sqrt{F}}{M} \leq 1 \text{ for } \underline{m^c > 0}$$

\sqrt{F}, M range from $\lesssim 1 \text{ TeV}$ up to M_{GUT} ,
in principle...

→ Lastly ..

- Messengers communicate with ordinary 'sector' superfields ... via loops



→ gauginos

$$M_i = \left\{ \begin{matrix} 1 \\ 1 \\ 5/3 \end{matrix} \right\} N g(x) \frac{\alpha_i}{4\pi} \Lambda$$

$O(1)$ loop functions

F/M

→ Scalars

$$m^2 = 2N^2 N f(x) \sum_i c_i \left(\frac{\alpha_i}{4\pi} \right)^2$$

of $S+\bar{S}$ messengers (≤ 4 GUT)

$$x = \lambda \frac{M^2}{F} \quad (\text{boson/messenger fermion mass ratio})$$

$O(1)$ constants from grp theory

RGE ($M \rightarrow$ electroweak scale)

\therefore masses calculable in terms of a few parameters

Measuring masses tells us Λ ; we'd like to get \sqrt{F} , $M + K \dots$, (K $\sim O(1)$ favored by tuning arguments) ? ?

So what?

• LSP is gravitino! $m_{3/2} = \frac{F/k}{\sqrt{3} \bar{M}_{pl}} = 2.37 \left(\frac{\sqrt{F/k}}{100 \text{ TeV}} \right)^2 \underline{\underline{eV}}$

... for $\sqrt{F/k} \gtrsim 3000 \text{ TeV}$, \tilde{G} dominates + over closes universe

• N LSP is typically χ_1 or $\tilde{\tau}_R$ + decays to

$$\tilde{G} : \begin{cases} \chi_1^0 \rightarrow \tilde{G} \gamma / Z \\ \tilde{\tau} \rightarrow \tau \tilde{G} \end{cases}$$

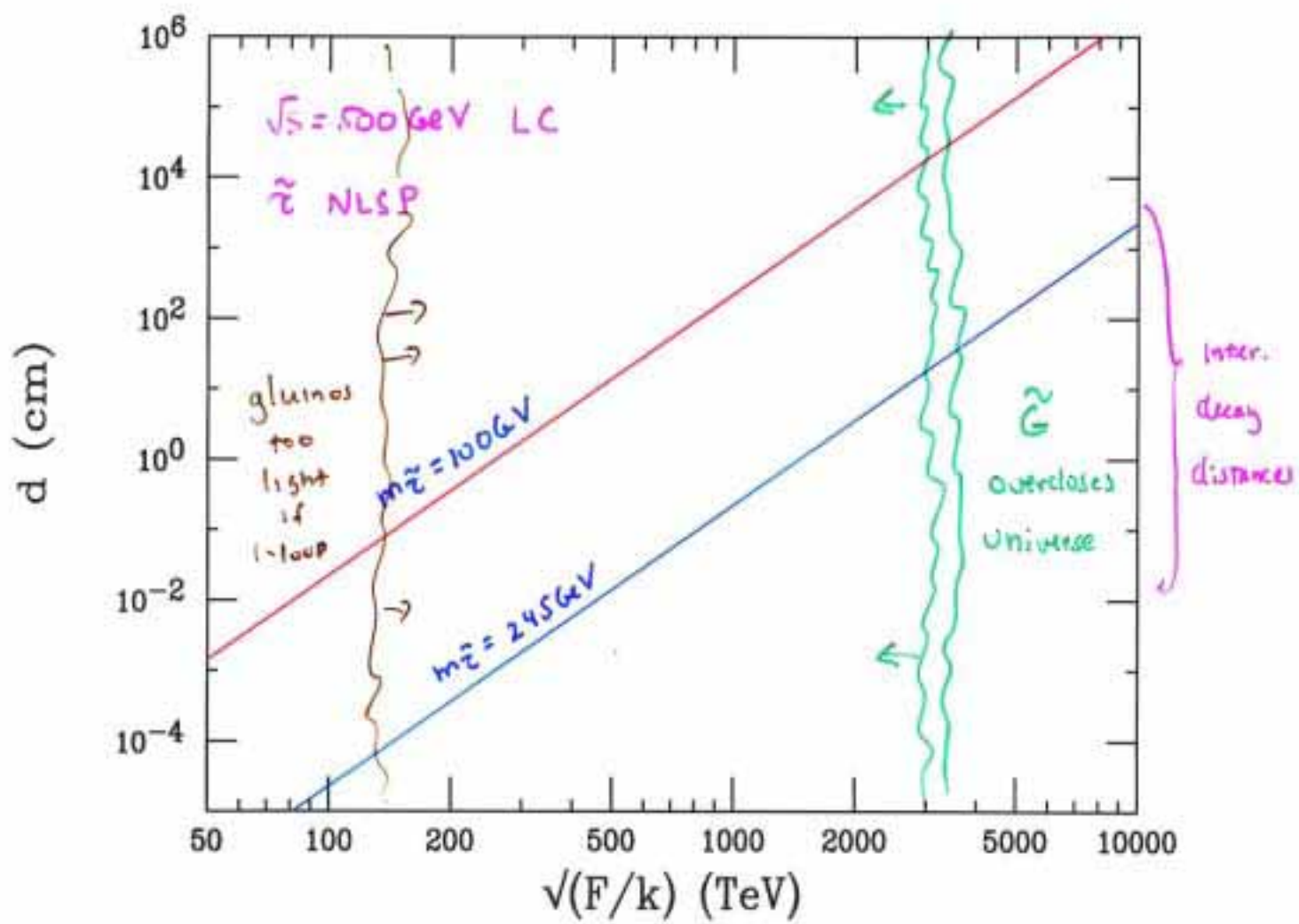
Clebschs $\sim O(1)$

$$\Gamma \begin{pmatrix} \chi_1^0 \\ \tilde{\tau} \end{pmatrix} = \left(\frac{k}{F} \right)^2 \frac{m_{\chi, \tau}^5}{16\pi} (K_{\gamma, Z})$$

about for $\tilde{\tau}$'s

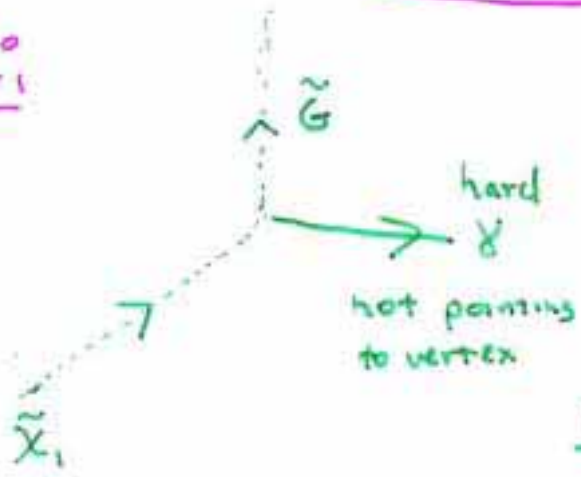
$$d [\text{cm}] = \left(\frac{1}{K_{\gamma, Z}} \right) \left(\frac{100 \text{ GeV}}{m} \right)^5 \left(\frac{\sqrt{F/k}}{100 \text{ TeV}} \right)^4 \left[\frac{5}{4m^2} - 1 \right]^{1/2} \cdot (4.92 \cdot 10^{-5} \text{ cm})$$

$$\Rightarrow \left\{ \begin{array}{l} \text{Note: } \sqrt{F} \approx M, N=4, k=1; d_s \approx 0.11, m_{\tilde{g}} > 200 \text{ GeV} \\ \rightarrow \sqrt{F} \gtrsim \text{few TeV} \quad \text{more naturally} \\ \gtrsim 50 \text{ TeV or more} \end{array} \right.$$

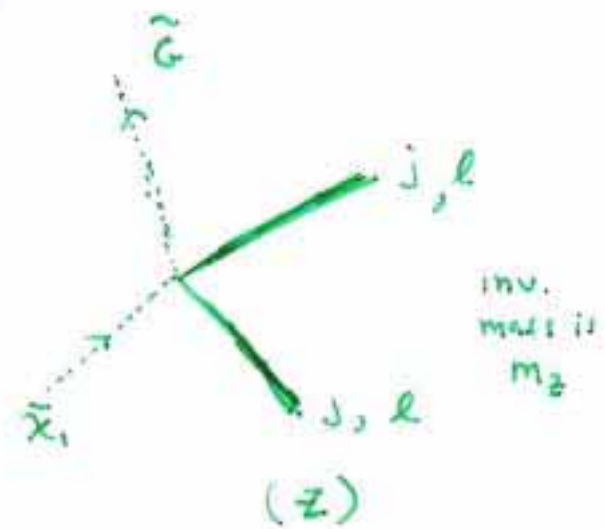


Signatures

χ_1^0

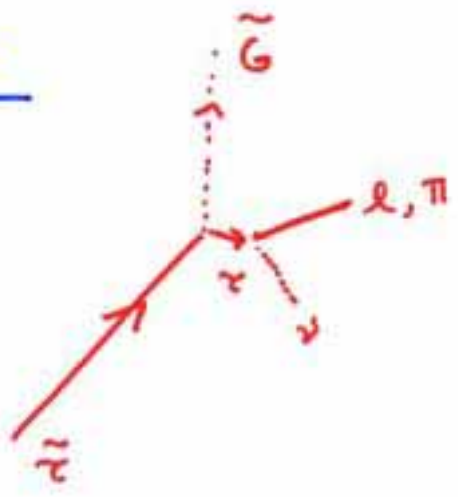


or



again, traces not pointing to vertex

$\tilde{\tau}$



$$\text{MIP} \rightarrow \tau \text{ can} \rightarrow l, \pi + \cancel{E} + \cancel{E}$$

as above

Refs

- Chen + Gunion - hep-ph/9802252
- Mercadante, Miukoshi + Yamamoto, hep-ph/0010067
- Giudice + Rattazzi, hep-ph/9801271

Close-Mass Fermions

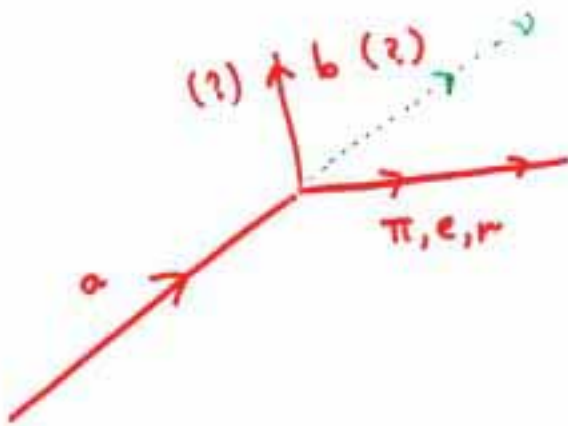
$$\begin{pmatrix} a \\ b \end{pmatrix}_{L,R}$$

$$a \rightarrow b W^*, \quad W^* \rightarrow \{ \pi, e\nu, \mu\nu \}$$

Degenerate[†], vector like fermions split by R.C.

$\lesssim 1 \text{ GeV}$, e.g.,

$$\Delta m \approx \frac{\alpha}{4\pi} m \approx 120 \text{ MeV} \quad (m/200 \text{ GeV})$$



Signal depends somewhat on what b does -

probably decaying via mixing w/ sm fields

+ would be short-lived

Recall: $\begin{pmatrix} a \\ b \end{pmatrix}$ may be quarks or leptons...!!

\Rightarrow And $Q(a) = 0$ is possible \Rightarrow multiple signatures!

† Vector-like fermions are naturally degenerate avoiding STU bounds on oblique parameters

$$\Gamma(a \rightarrow b \pi) = \frac{G_F^2 f_\pi^2}{2\pi} \frac{(E_\pi^2 - m_a^2)^{1/2}}{m_a} \left\{ 2m_a E_\pi (m_a E_\pi - m_\pi^2) - m_\pi^2 (m_a^2 - m_a E_\pi) \right\}$$

$$E_\pi = \frac{m_a^2 + m_\pi^2 - m_b^2}{2m_a}$$

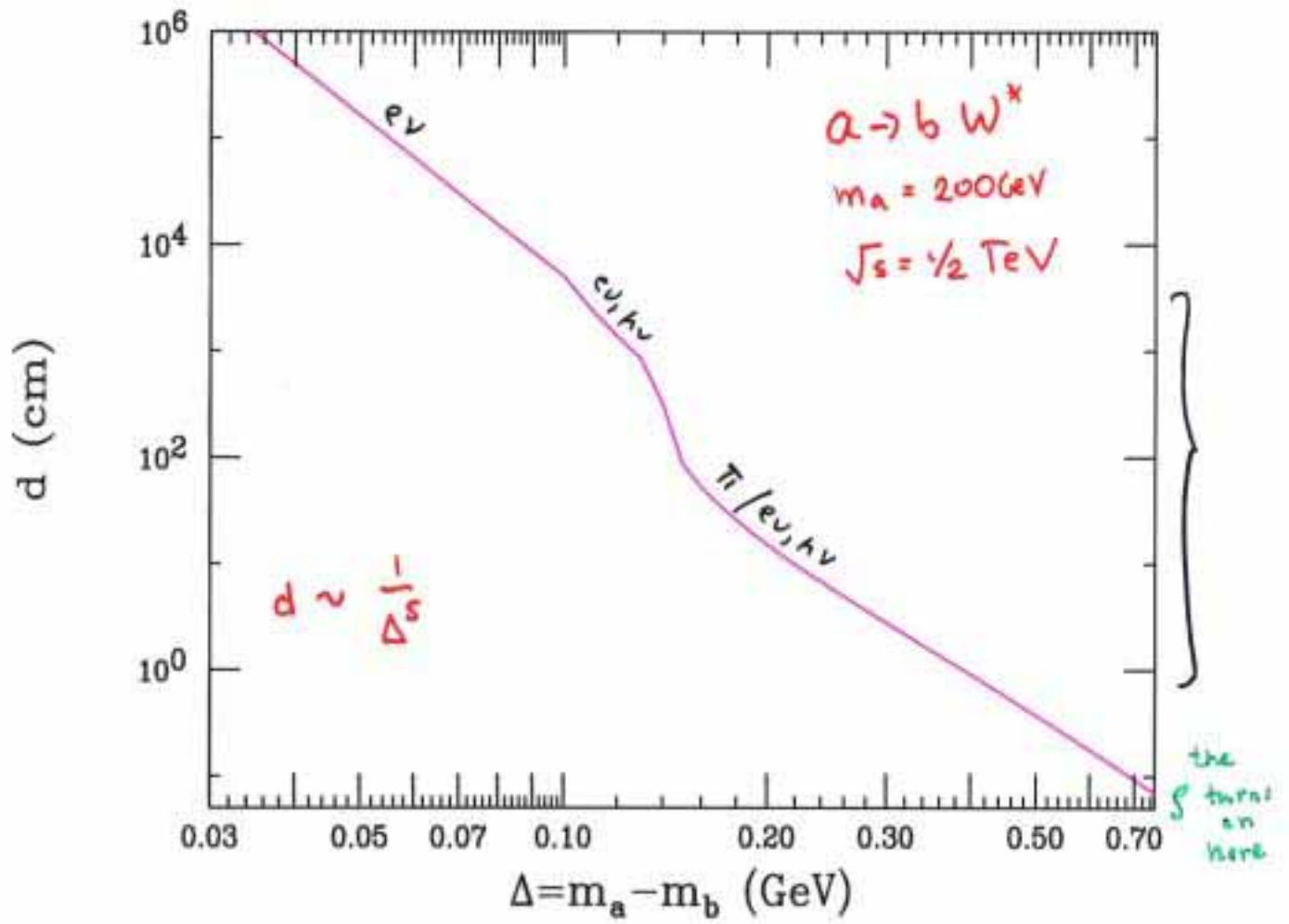
$$\Gamma(a \rightarrow b e \nu) = \frac{G_F^2 m_a^5}{192\pi^3} \left\{ (1-z^2)(1-2z+z^2) - 12z^2 \ln z \right\}$$

$$z \equiv m_b^2/m_a^2$$

$$(m_a - m_b \gg m_e)$$

→ enormous PS suppression
leads to long lifetime!

$$\Gamma(a) \approx (m_a - m_b)^5 !$$

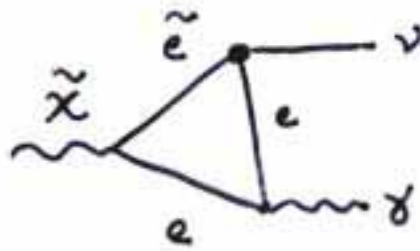


Natural mass splittings range
 \rightarrow detector decays

decay of LSP †

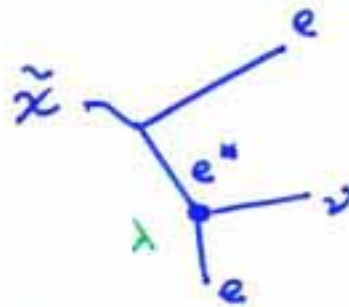
$$W = \lambda L L E^c + \lambda' L Q D^c + \lambda'' U D^c D^c$$

loop
decay

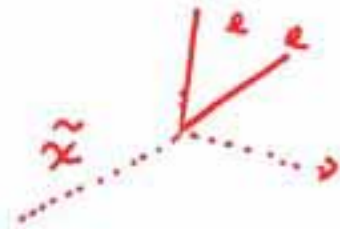


$B \approx 5-10\%$
(for $\lambda, \lambda' \neq 0$)

tree level
decay
dominant!



$$\Gamma \sim (\lambda g^2 / m_x^4)^5 m_x^5$$



$$\frac{\Gamma}{\Gamma_r} \approx \left(\frac{\lambda g}{g^2/8} \right)^2 \left(\frac{m_W^2}{m_x^2} \right)^2 \left(\frac{m_x}{m_p} \right)^5 \approx (10^4)^5$$

$$= \left(\lambda/g \right)^2 \left(\frac{2\sqrt{2} m_W}{m_x} \right)^4 \cdot 10^{20} \cdot (m_x/100 \text{ GeV})^5$$

$$\approx 10^{20} (\lambda/g)^2 (m_x/100 \text{ GeV})^5$$

interesting if $(\lambda/g) \sim 10^{-7} - 10^{-8}$

natural ??
size ??

Possible, not likely!

† Balyas + Gondolo hep-ph/9709445

Universal Extra Dimensions

- All SM fields in extra dimension of size $R^{-1} \approx 300 \text{ GeV}$ [RC bound / $b \rightarrow s \gamma$ etc]
- At tree level the masses of the first KK excitations are

$$m_n^2 = m_0^2 + n^2/R^2 \quad (n \geq 1)$$

e.g., $\left\{ \begin{array}{l} m_{1e}^2 = m_e^2 + 1/R^2 \\ m_{1\gamma}^2 = 1/R^2 \end{array} \right\}$ almost degenerate!

- 1 loop radiative corrections split these KK levels ...
- Important in calculating $\Gamma(e_1 \rightarrow e_0 + \gamma_1)$
 - at tree level there is almost NO PS!
 - γ_1 is DM candidate + stable (LKP)
 - will e_1 decay in the 'bulk' of the detector?

†

$$\delta_B = -\frac{3g}{2} \frac{g'^2}{16\pi^4} J(3)/R^2 - \frac{1}{6} m_n^2 \frac{g'^2}{16\pi^2} \ln \Lambda^2 R^2$$

$$\delta_W = -\frac{5}{2} \frac{g^2}{16\pi^4} J(3)/R^2 + \frac{15}{2} m_n^2 \frac{g^2}{16\pi^2} \ln \Lambda^2 R^2$$

$$\delta_L = m_n \left(\frac{27}{16} \frac{g^2}{16\pi^2} + \frac{9}{16} \frac{g'^2}{16\pi^2} \right) \ln \Lambda^2 R^2$$

$$\delta_e = m_n \frac{g}{4} \frac{g'^2}{16\pi^2} \ln \Lambda^2 R^2$$

note
cutoff
dependence

$$\begin{pmatrix} n/R^2 + \delta_B + m_n^2 \frac{g'^2}{g^2} & m_n \frac{g'}{g} \\ m_n \frac{g'}{g} & n/R^2 + \delta_W + m_n^2 \end{pmatrix}$$

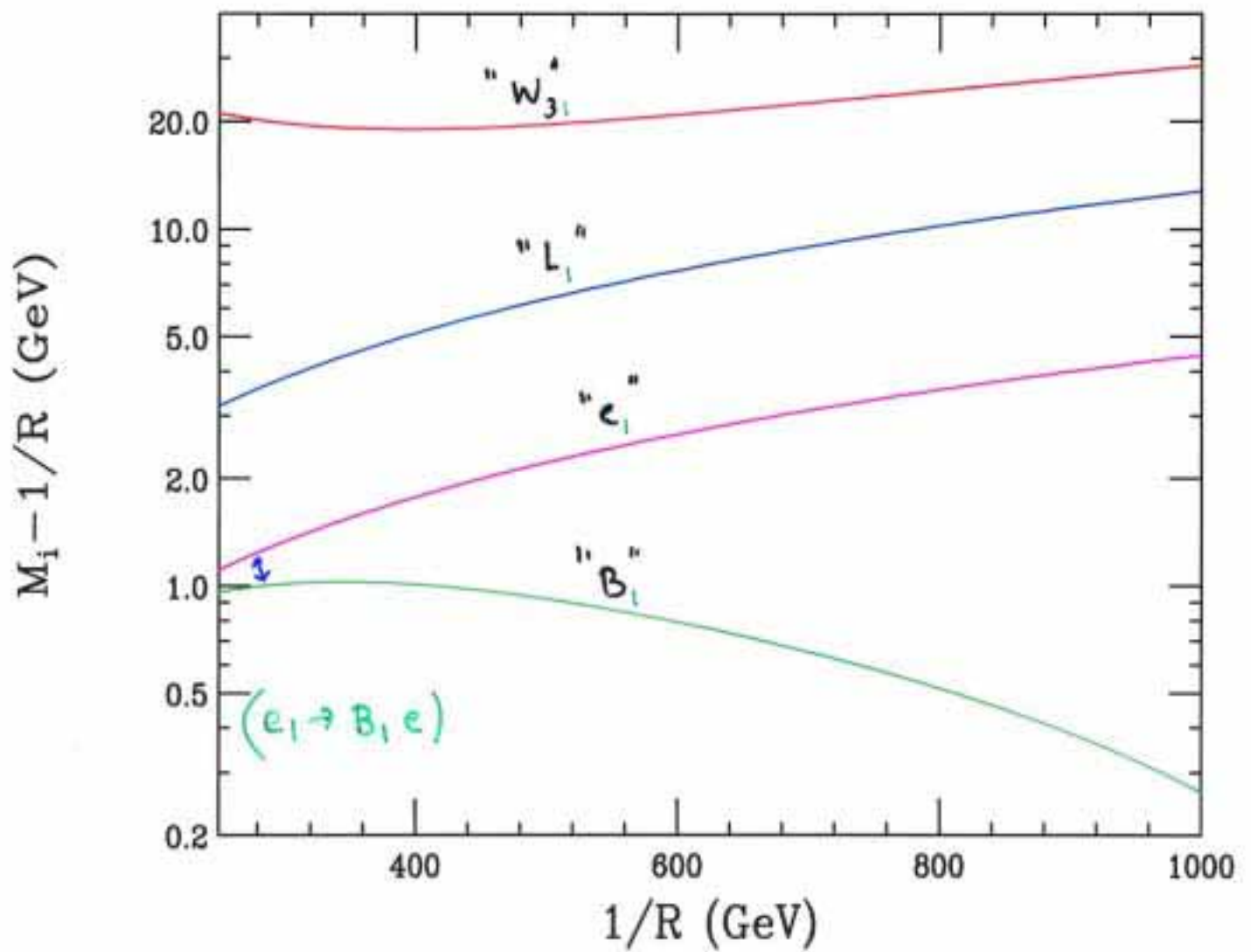
$$\begin{pmatrix} n/R + \delta_L & m_e \\ m_e & -(n/R + \delta_e) \end{pmatrix}$$

Then
diagonalise
mass
matrices
(level by level)

• These loop contributions are quite significant!

† Cheng, Matchev + Schmaltz PRD66 036005 '02

Radiative Mass Splittings UED



INVERSE compactification radius

$$\Gamma(e_1 \rightarrow e_0 B_1) \approx \frac{\alpha}{4} m_1 \cdot \epsilon, \quad \epsilon \equiv 1 - \delta$$

$$\delta \equiv m_{B_1}^2 / m_{e_1}^2 \approx 1$$

$$\approx 750 \text{ keV} \left(\frac{m_1}{250 \text{ GeV}} \right) !! \text{ Narrow but...}$$

This is a very short lifetime for us....

* In this case the RC are BIG ENOUGH to induce splittings leading to short lifetimes!

No finite track length decays in this model...

too bad.

Just because near degeneracy exist we do not

necessarily get a long lifetime...

Summary

- There are a wide variety of models that can lead to long-lived particles that can decay inside the detector $d = 10^{-3} - 10^0$ m ...
- The signatures are also widely varying
 - jets, leptons, π 's ... appearing from nowhere
 - track-kinks, γ 's ... etc etc
- This is not an exhaustive survey and many other possibilities exist...
- Impact on detectors ??