Title: Modified Randall-Sundrum Models

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Abstract: The warped geometry present in Randall-Sundrum (RS) models provides an elegant means by which to generate stable scale hierarchies. Given the famous hierarchy problem of the Standard Model, and the relatively small number of known mechanisms which may solve it, the RS model has deservedly received a lot of attention. However the construction of a completely realistic RS model remains difficult and requires a number of modifications beyond the minimal framework. In this talk I will give an overview of the RS model, the difficulties encountered in realistic implementations and the types of modifications necessary to address them.

Modified Randall – Sundrum Models

Kristian McDonald

TRIUMF

Theory Group

Outline

- RS Model
- Little RS Model
- RS in D > 5
  - Multiple Warping
  - RS6

RS Model

$$ds^2 = a^2(y)\,dx^2 - dy^2$$
$$= A^2(z)\left[dx^2 - dz^2\right]$$
$$y \in [0, L]$$

$$\Lambda = \mathrm{diag}(\Lambda, \Lambda, \Lambda, \Lambda, \Lambda_5)$$

Einstein Eqn's

$\mu\nu$ $$3\left[\frac{a''}{a} + \frac{a'^2}{a^2}\right] = -\frac{1}{24M^3}\Lambda$$

55 $$6\,\frac{a'^2}{a^2} = -\frac{1}{24M^3}\Lambda_5$$

Solution

$$\Lambda = \Lambda_5$$

$$a(y) = \exp(-ky)$$

$$V_0 = -V_L = \sqrt{-24M^3\Lambda}$$

Weak / Planck Hierarchy

$$S_{y=L} \supset \int d^5x \sqrt{-g_L}\left((DH)^2 - \lambda(H^2 - v_0^2)^2\right) \times \delta(y-L)$$

$$S_{eff} \supset \int d^4x \sqrt{-g}\left((DH)^2 - \lambda(H^2 - v^2)^2\right)$$

$$v^2 = e^{-2kL} v_0^2$$

$$kL \sim 35 \implies \frac{M_{PL}}{1\,\text{TeV}} \sim e^{-kL}$$

SM . . . . .

- TeV brane
- KK gravitons

$$\frac{1}{M^2}\bar{\psi}_i \psi_j \bar{\psi}_k \psi_l \longrightarrow \frac{1}{(e^{-kL}M)^2}\bar{\psi}_i \psi_j \bar{\psi}_k \psi_l$$

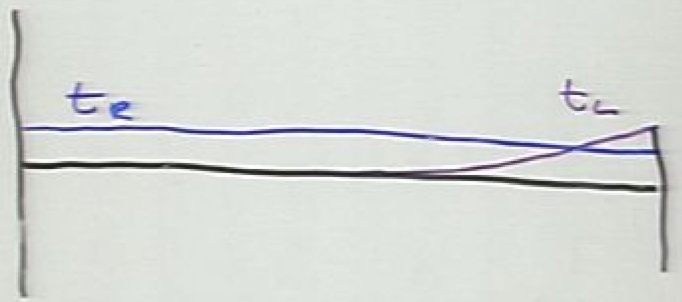
- FCNC, ν-mass, p-decay . . .

- Bulk fermion & gauge fields

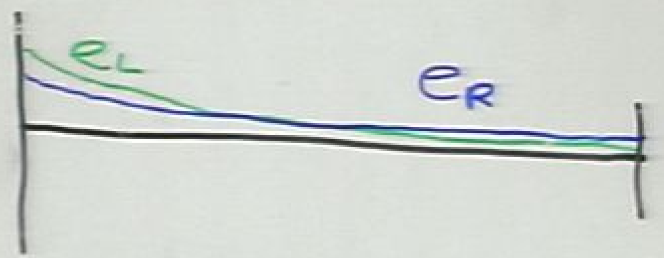
Flavour

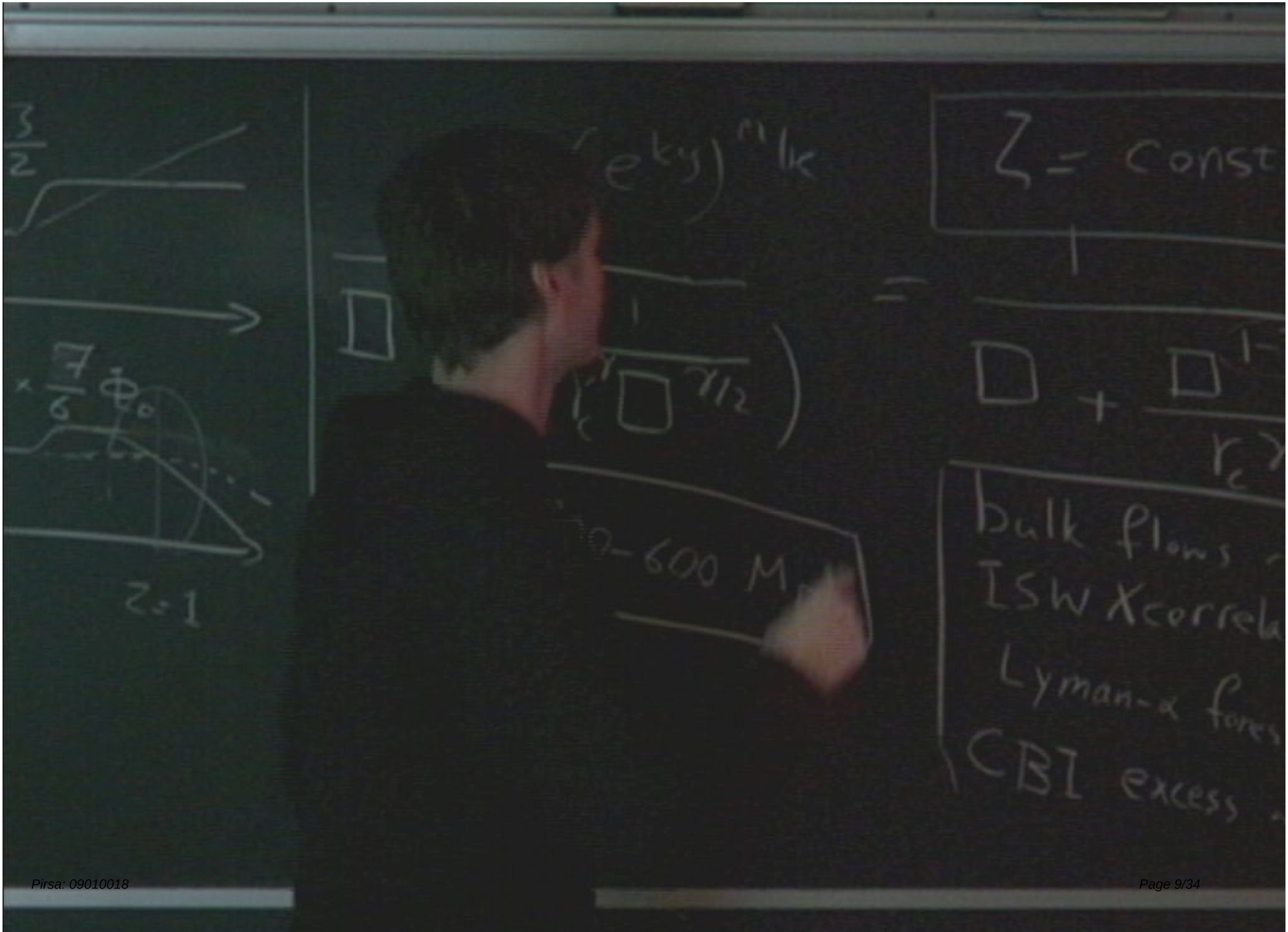
$$(\bar{\Psi}\not{\partial}\Psi - m\bar{\Psi}\Psi)$$

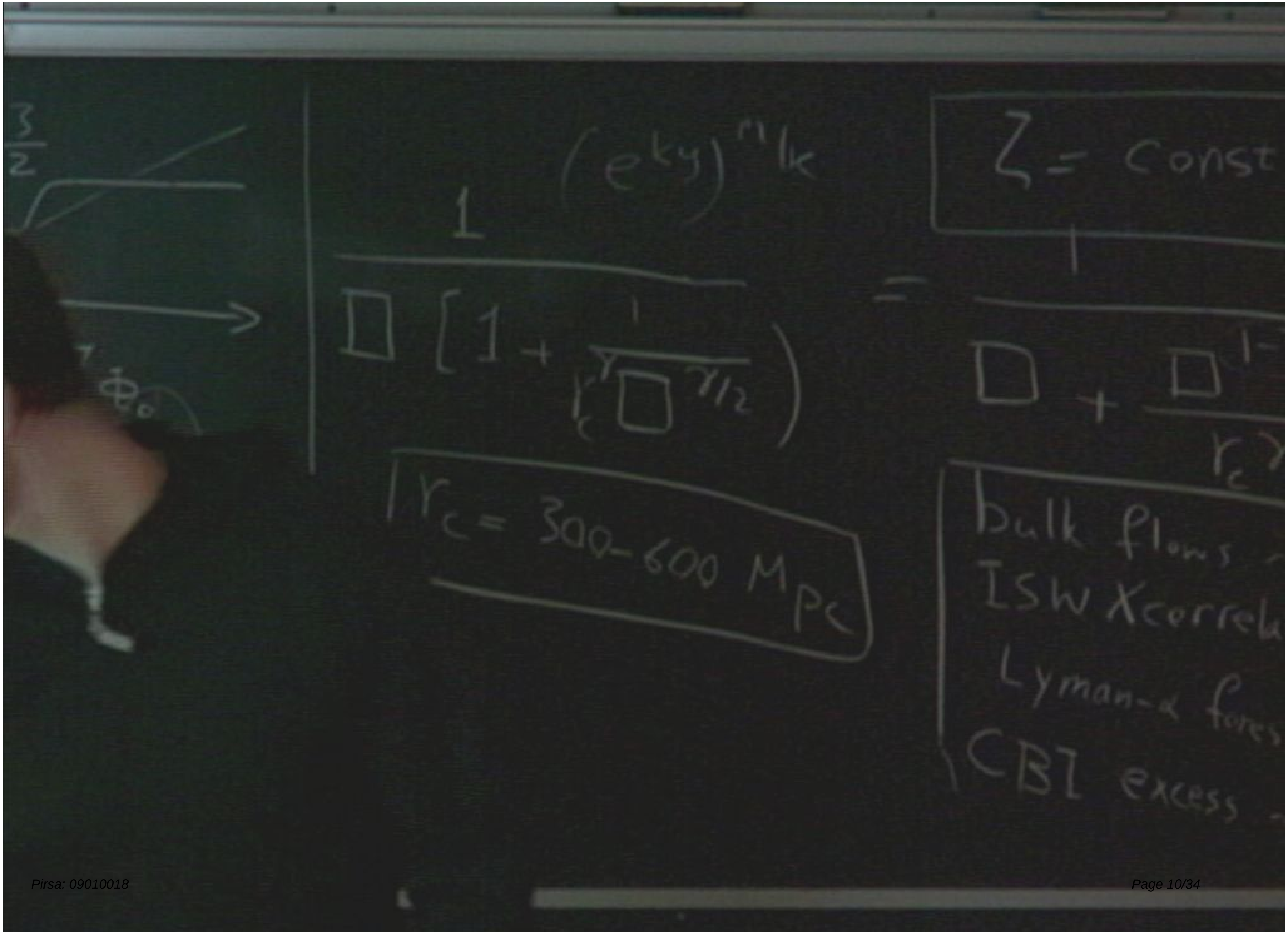
Top



electron



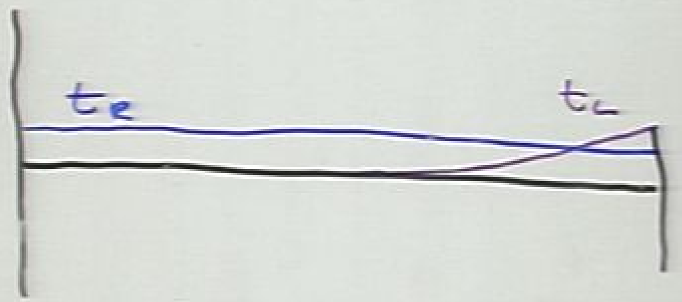

ζ = const
bulk flows
ISW Xcorrel
Lyman-α fores
CBI excess
600 M
z=1


ζ = const
r_c = 300-600 Mpc
bulk flows
ISW Xcorrel
Lyman-α fores
CBI excess

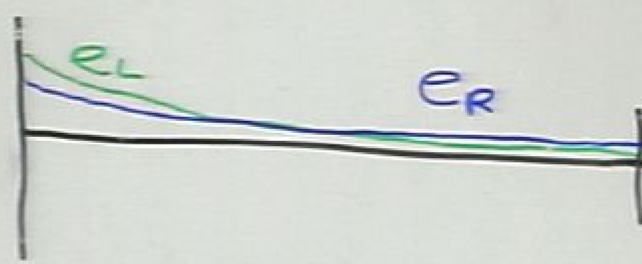
Flavour

$$(\bar{\psi} \not{\partial} \psi - m \bar{\psi} \psi)$$

Top



electron

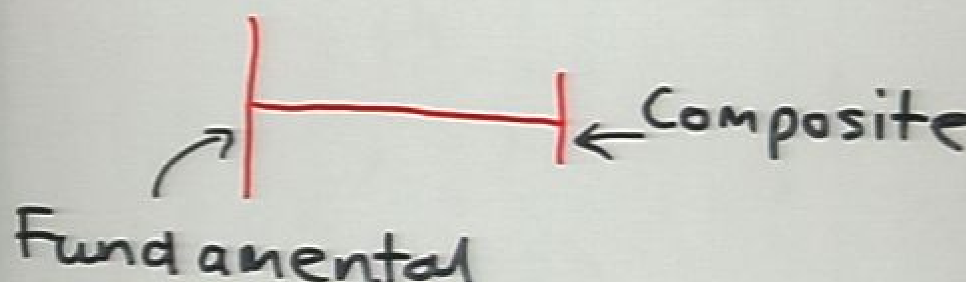


AdS/CFT

- Extra Dimensions ???

- RS $\longleftrightarrow$ Strongly Coupled Large N SU(N) theory + 4D gravity

- Breaks E/W $\longrightarrow$ no $\sim \Lambda^2$



- Symmetries.

Hierarchy Problems

- $\frac{M_{PL}}{1\,TeV}$???

Little hierarchy

- $\frac{\Lambda}{1\,TeV} \simeq 10$

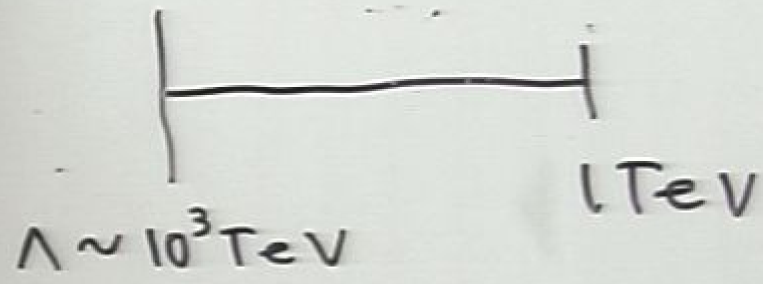
EW data

Flavour hierarchy

- $\frac{\Lambda}{1\,TeV} \simeq 10^2 - 10^3$

Flavour data.

LRS model



$$\frac{\Lambda}{1\ \text{TeV}} \sim 10^3 \rightarrow kL \sim 6$$

- $N_{LRS} > N_{RS}$
- Solve RS problems??
- exp. input??

Davoudiasl, Perez, Soni,
arxiv: 0802:0203

Oblique Constraints

(S, T) KK mixing

$$S_{Tree} = 2\pi \left(\frac{v}{M_{IR}}\right)^2 \left[1 - \frac{1}{kL}\right] + \ldots$$

$$T_{Tree} = \frac{\pi}{2 c_\theta^2} \left(\frac{v}{M_{IR}}\right)^2 \left[kL - \frac{1}{kL}\right] + \ldots$$

data : $(S, T) \simeq 0.1 - 0.3$

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data : $(S, T) \simeq 0.1 - 0.3$

RS

$kL \sim 35$

$M_{KK} \simeq 5$ TeV

$(S, T) \simeq (0.7, 1.1)$

LRS

$kL \sim 6$

$M_{KK} \simeq 5$ TeV

$(S, T) \simeq (0.1, 0.2)$

Also loop & Cutoff effects

$\Rightarrow M_{KK} \sim O(10)$ TeV

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Non-oblique : $Zb\bar{b}$

$t_L \rightarrow y=L$
$b_L \rightarrow y=L$

KK states near L.

- $Z - Z_{KK}$ mixing

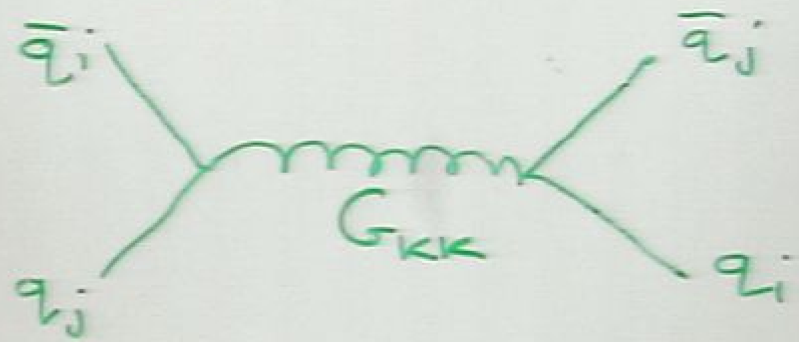
$$\propto \left(\frac{kL}{M_{KK}^2}\right) M_Z^2$$

- $b_L - b_R$ KK mixing

LRS $\quad m_{KK} \gtrsim 3$ TeV

RS $\quad$ " $\gtrsim 5$ TeV

$\Delta F = 2$



$\delta(\epsilon_K) \Rightarrow$

RS $\quad m_{KK} \gtrsim 8\,\text{TeV}$

LRS $\quad \gtrsim 3\,\text{TeV}$

but $\quad m_{KK} \gtrsim 20\,\text{TeV}$ RS & LRS

Summary

LRS improves: T_{Tree}, $Z b\bar{b}$

- Still need G_{LR} : T_{loop}
- FCNC $M_{KK} \gtrsim 20\,TeV$
- More structure
- p-decay needs more too!!

RS with Extra Dimensions.

- RS Problems
- Experimental Interest
- UV Complete LRS
- AdS / CFT
  $AdS_5 \times S^5$

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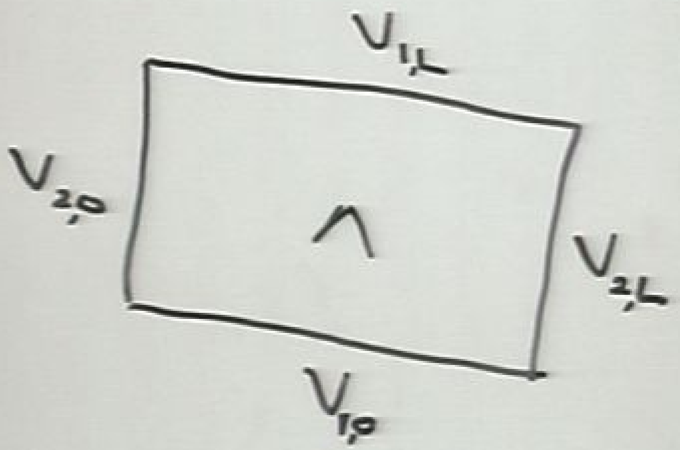
Doubly Warped Space

KM, PRD, (08)

$$ds^2 = A^2(z_1)\left(dx^2 - dz_1^2 - dz_2^2\right)$$

$$ds^2 = a^2(y_1)\, b^2(y_2)\; dx^2 - dy_1^2 - dy_2^2$$



$$\Lambda = \mathrm{diag}(\Lambda, \Lambda, \Lambda, \Lambda, \Lambda_5, \Lambda_6)$$

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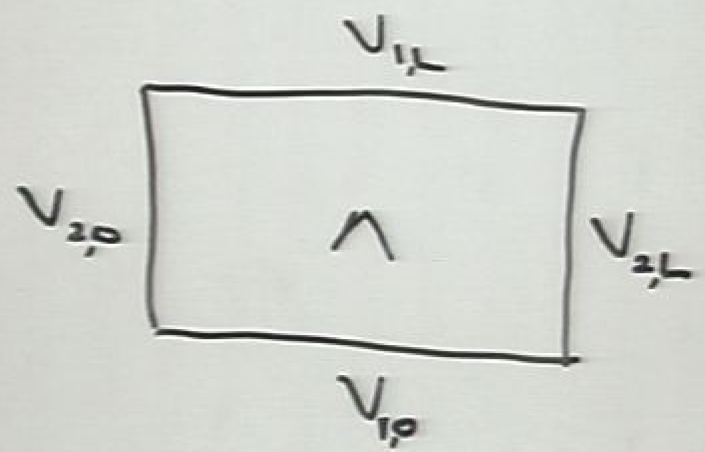


$$\Lambda = \mathrm{diag}(\Lambda, \Lambda, \Lambda, \Lambda, \Lambda_5, \Lambda_6)$$

Sol$\underline{n}$:

$$a(y_1) = e^{-k_1 y_1}$$

$$b(y_2) = e^{-k_2 y_2}$$

$$\Lambda = \frac{8}{3}(\Lambda_5 + \Lambda_6)$$

$$V_{1,0} = -V_{1,L} = \frac{1}{4k_1}\left(\Lambda_5 - \frac{5}{3}\Lambda_6\right)$$

$$V_{2,0} = -V_{2,L} = \frac{1}{4k_2}\left(\Lambda_6 - \frac{5}{3}\Lambda_5\right)$$

LRS

$$S_{LRS} = \int d^6x \sqrt{-G}\, \mathcal{L}_{LRS}\, \delta(y_2 - L_2)$$

$$= \int d^6x \sqrt{-G} \left[(DH)^2 - \lambda (H^2 - v_0^2)^2 \right] \times$$

$$\delta(y_1 - L_1)\, \delta(y_2 - L_2) + \ldots$$

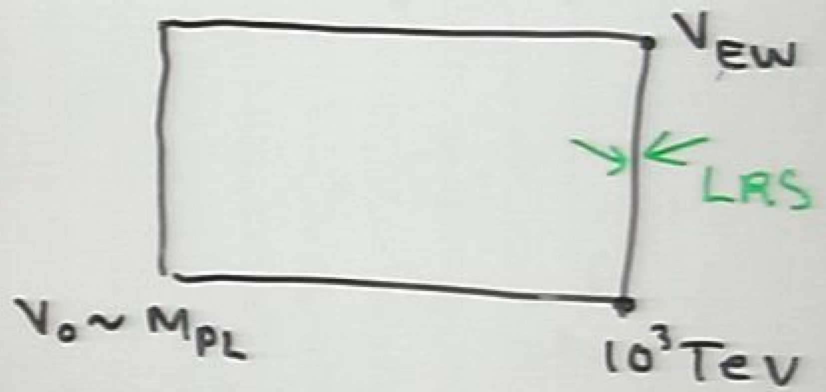
$$= \int d^4x \sqrt{-g} \left[(DH)^2 - \lambda (H^2 - v^2)^2 \right]$$

$$+ \ldots$$

$$v = e^{-k_1 L_1} e^{-k_2 L_2} v_0$$

LRS

$$\frac{k_1 L_1}{k_2 L_2} \simeq 4.3$$

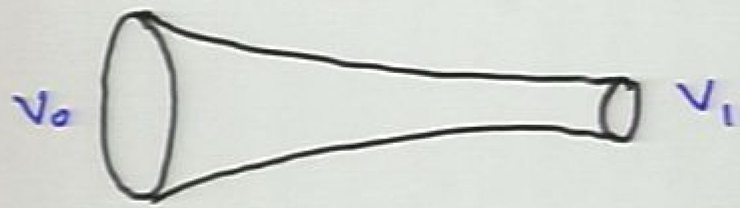


$$\frac{V_0}{10^3\,\text{TeV}} \sim e^{-k_1 L_1}$$

$$\frac{V_0}{1\,\text{TeV}} \sim e^{-k_1 L_1} e^{-k_2 L_2}$$

RS6

$AdS_5 \times S^1$



$$ds^2 = a^2(y_1)\,dx^2 - dy_1^2 - dy_2^2$$

- p-decay, flavour??
- Dark Matter??

Davoudiasl, Hewett, Rizzo;
JHEP 2003

Bulk Gauge Fields

RS: $f \sim A\,J_1(y) + B\,Y_1(y)$

$$M_n \sim n\pi k e^{-kL}$$

$n = 0, 1, 2 \ldots$

RS6:

$$f_a \sim A_a\,J_{\nu_a}(y) + B_a\,Y_{\nu_a}(y)$$

$$\nu_a = \sqrt{1 + m_a^2/k^2}$$

$$M_{n,a} \sim n\pi k e^{-kL}$$

$n = 1, 2, \ldots \quad a \neq 0$

- lots more states.

Rizzo, Davoudiasl; JHEP, 08

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Rizzo, Davoudiasl; JHEP, 08

Bulk Fermions

<u>5D</u> $\psi = \begin{pmatrix} \psi_L \\ \psi_R \end{pmatrix}$

Orbifold BCs:

$$\psi \rightarrow P\gamma^5 \psi = P \begin{pmatrix} -\psi_L \\ +\psi_R \end{pmatrix}$$

- $P = \pm 1$
- one always odd
  $\rightarrow$ no zero mode
- Chiral zero mode

RS6 Fermions

$$\Psi = \begin{pmatrix} \Psi_{+L} \\ \Psi_{+R} \\ \Psi_{-R} \\ \Psi_{-L} \end{pmatrix} \qquad \Psi_+ = \begin{pmatrix} \Psi_{+L} \\ \Psi_{+R} \\ 0 \\ 0 \end{pmatrix}$$

BC's: $\Psi_+ \to \Gamma^5 \Psi_+ = \begin{pmatrix} 0 \\ 0 \\ \Psi_{+R} \\ -\Psi_{+L} \end{pmatrix}$

- mixed parity
- no chiral zero mode

Conclusion

- RS model constraints
  - G_{LR}
  - Flavour
  - p-decay
- Modified RS
  - LRS
  - Multiple warping
  - RSG
- LHC .....