

LECTURE 4.

WARPED E.D.

LITTLE & COMPOSITE HIGGS

LARGE ED:

only one scale $M_* \sim \text{TeV}$

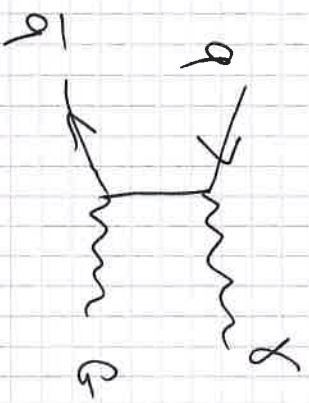
$$r = \frac{1}{M_*} \left(\frac{M_p}{M_*} \right)^{\frac{2}{n}}$$

gravity weak: large extra dimensions will allow to spread flux & dilute strength of gravitational

hierarchy problem translated to question of why $r \rightarrow \frac{1}{M_*} ?$

exp || consequences :

very light but weakly coupled KK graviton states



effective interaction strength

$$\frac{\lambda}{M_*} \rightarrow \text{bound on } M_*$$

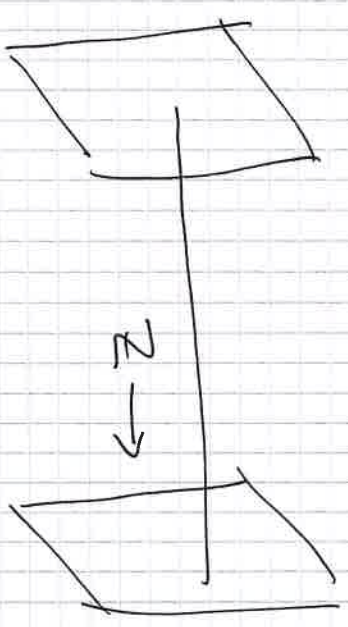
WARPED EXTRA DIMENSIONS

ADDITIONAL INGREDIENT : CURVATURE ALONG EXTRA DIM'S.

4D metric observing should be flat, but along X-D there could be curvature!

particular metric AdS₅

$$ds^2 = \left(\frac{R}{z}\right)^2 (dx^2 - dz^2)$$



$$H^2 = \frac{R}{z} H$$

S_{Higgs}

$$= \int d^4x$$

$$[(\partial_\mu H)^2]^2$$

$$- \lambda [|H|^2 - (v \frac{R}{z})]^2]^2$$

$$V_{eff} = V \left(\frac{R}{z} \right)$$

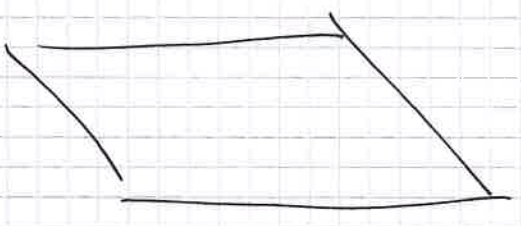
Start with $v \sim M_{pl}$

$$z \gg R$$

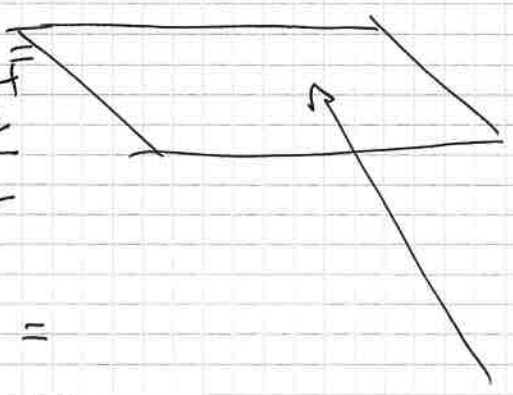
$$\frac{R}{z} \sim 10^{-16}$$

original R-S model

"RS1"

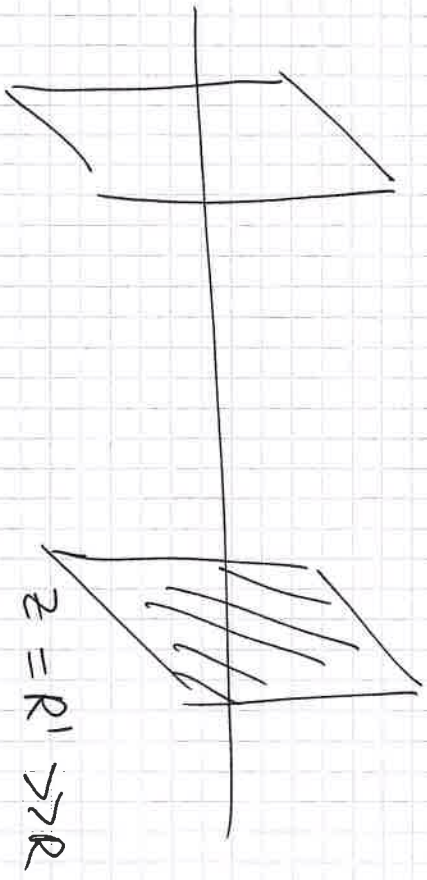


Planck brane
UV brane



"IR brane"
"UV brane"

What is the natural mass of Higgs if we
 live at $z \rightarrow R$



$$S_{\text{Higgs}} = \int d^4x \sqrt{g_{\text{ind}}} \left[\partial_\mu H \partial_\nu H g^{\mu\nu} - \lambda \left(|H|^2 - \frac{v^2}{2} \right)^2 \right]$$

$$\left[\left(\frac{R}{z} \right)^2 (dx^2 - dz^2) \right]$$

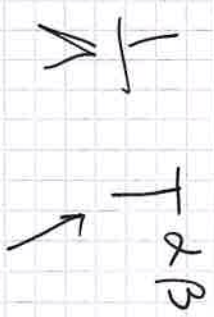
$$g_{\text{ind}} = \left(\frac{R}{z} \right)^2 \begin{pmatrix} +1 & & & \\ & -1 & & \\ & & -1 & \\ & & & -1 \end{pmatrix}$$

$$S_{\text{Higgs}} = \int d^4x \left(\frac{R}{z} \right)^4 \left[\partial_\mu H^* \partial^\mu H \left(\frac{z}{R} \right)^2 - \lambda \left(|H|^2 - \frac{v^2}{2} \right)^2 \right]$$

Rescale Higgs to get canonical normalization

Exp'l consequences:

$m_{KK} \sim \text{TeV}$



$$\sum_{\alpha\beta} \rho_{\alpha\beta}^{(n)}$$

n^{th} KK mode

SM energy-mom. tensor

$$N = M_{\text{pl}} \frac{R}{R_1} \sim \text{TeV}$$

KK modes of graviton!

resonance search for spin 2
resonances in direct
diphoton / dilepton ...

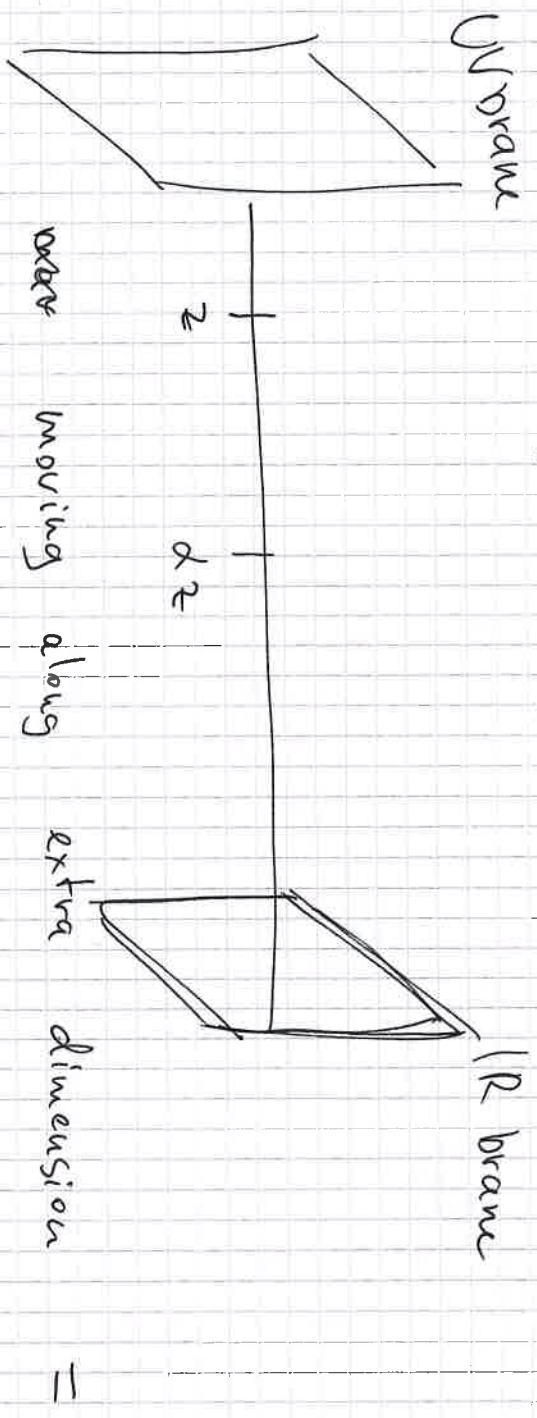
do

Holographic interpretation

$$ds^2 = \left(\frac{R}{z}\right)^2 (dx^2 - dz^2)$$

$z \rightarrow dz$
 $x \rightarrow dx$

} invariance of metric!



if this is an invariance (w/o branes true) \rightarrow

secretly this 5D theory corresponds to a scale invariant 4D theory!

UV brane } will break conformal symmetry!
IR brane }

UV brane: theory cut off...

IR brane: Spontaneous breaking of conformal symmetry...
generating mass scale in the theory \rightarrow TeV scale.

generates mass gap whole tower of resonances
(like in QCD)

In this holographic RS1: entire SM is COMPOSITE!

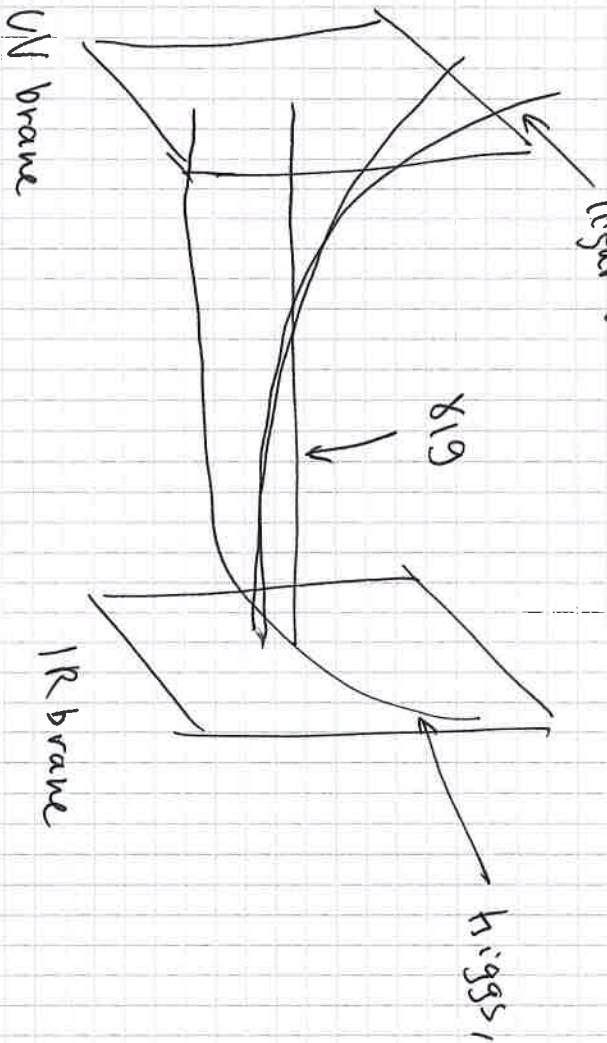
Good part: Higgs composite (secret way of solving hierarchy!)

Bad part: everything composite.

Realistic RS models

SM fields are mainly elementary

Higgs (maybe top) are composite!



light fermion

exponentially peaked

UV

Higgs1 top

IR

δ, g mainly elementary

KK graviton is no

longer a good search channel.

Instead: KK gluon,

KK g, W, Z !

KK gluon peaked

on IR (but also

has a tail on the

UV)



LITTLE HIGGS & COMPOSITE HIGGS

STRONG DYNAMICS PRODUCES A COMPOSITE HIGGS

$$\Lambda \sim 10 \text{ TeV} \quad (5 \text{ TeV})$$

Still expect corrections to

$$\frac{1}{16\pi^2} \Lambda^2$$

Still too big!

$$\Delta m_h^2 \sim (1 \text{ TeV})^2$$

$$\text{vs. } m_h^2 \sim (125 \text{ GeV})^2$$

little hierarchy problem!

$$\boxed{\frac{\Delta m_h^2}{m_h^2} \sim 100}$$

Little Higgs:

new set of particles

"little partners":

cancel 1-loop quadratic divergences