LECTURE 4.

WARPED E.D.
LITTLE & COMPOSITE HIGGS

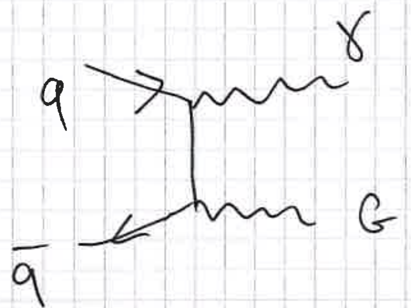
LARGE ED: only one scale $M_* \sim 1\,\text{TeV}$

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

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

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

exp'l consequences : very light but weakly coupled KK graviton states



effective interaction strength

$\frac{1}{M_*}$ $\rightarrow$ bound on M_*

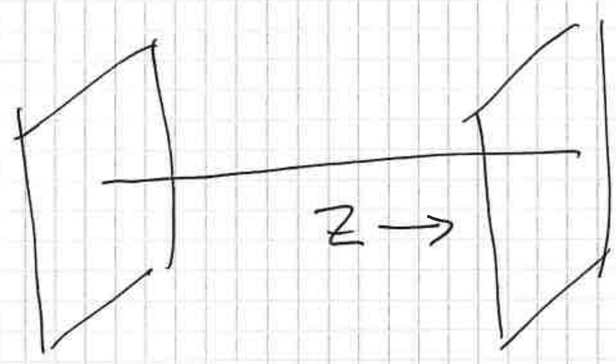
WARPED EXTRA DIMENSIONS

ADDITIONAL INGREDIENT : CURVATURE ALONG EXTRA DIM'S.

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

particular metric AdS_5

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



$$\tilde{H} = \frac{R}{z} H$$

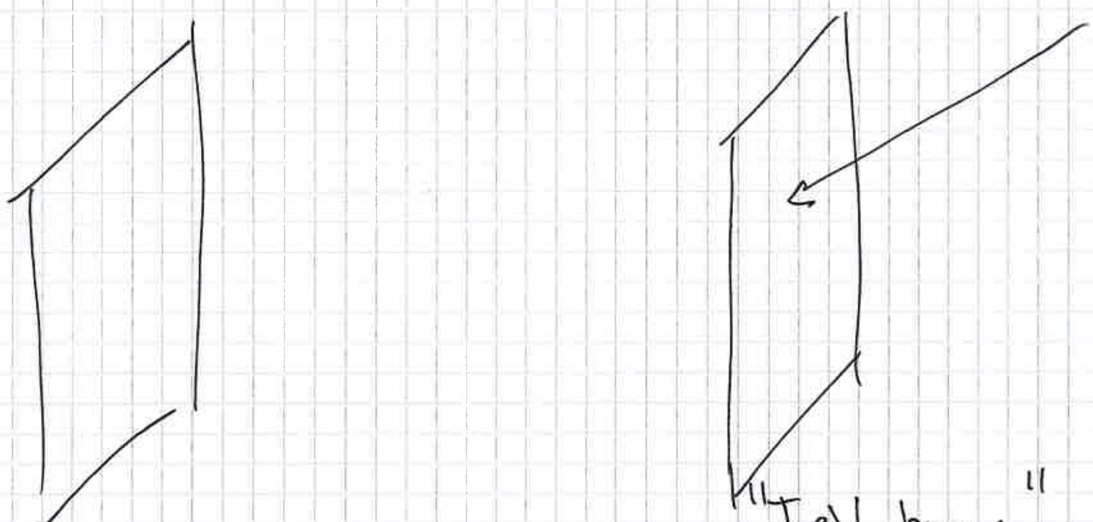
$$S_{Higgs} = \int d^4x \left[(\partial_\mu \tilde{H})^2 - \lambda \left[|\tilde{H}|^2 - \left(v \frac{R}{z}\right)^2 \right]^2 \right]$$

$$v_{eff} = v \left(\frac{R}{z}\right) \qquad z \gg R$$

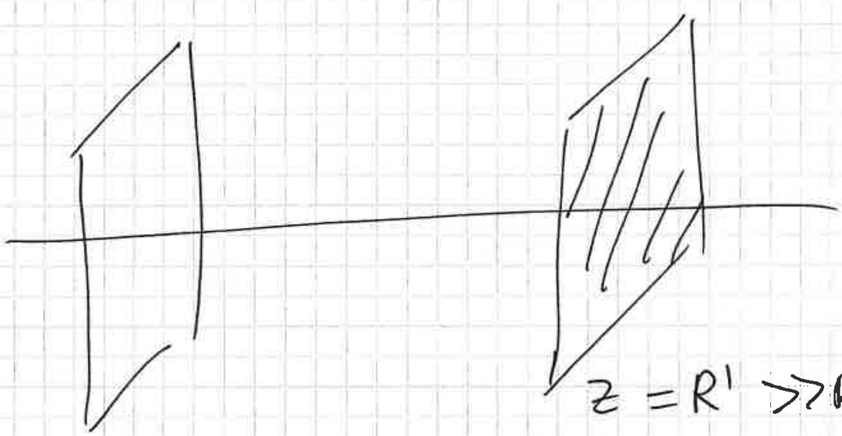
Start with $v \sim M_{pl}$ $\qquad \frac{R}{z} \sim 10^{-16}$

original R-S model

"RS1"



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



$z = R' \gg R$

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

$$\boxed{\left(\frac{R}{z}\right)^2 \left(dx^2 - dz^2\right)} \qquad g^{ind} = \left(\frac{R}{z}\right)^2 \begin{pmatrix} +1 & & & \\ & -1 & & \\ & & -1 & \\ & & & -1 \end{pmatrix}$$

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

rescale Higgs to get canonical normalization

Exp'l consequences: KK modes of graviton!

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

$$\frac{1}{\Lambda} T^{\alpha\beta} \sum h_{\alpha\beta}^{(n)}$$

n^{th} KK mode

SM energy-mom. tensor

$$\Lambda = M_{Pl} \frac{R}{R'} \sim \text{TeV}$$

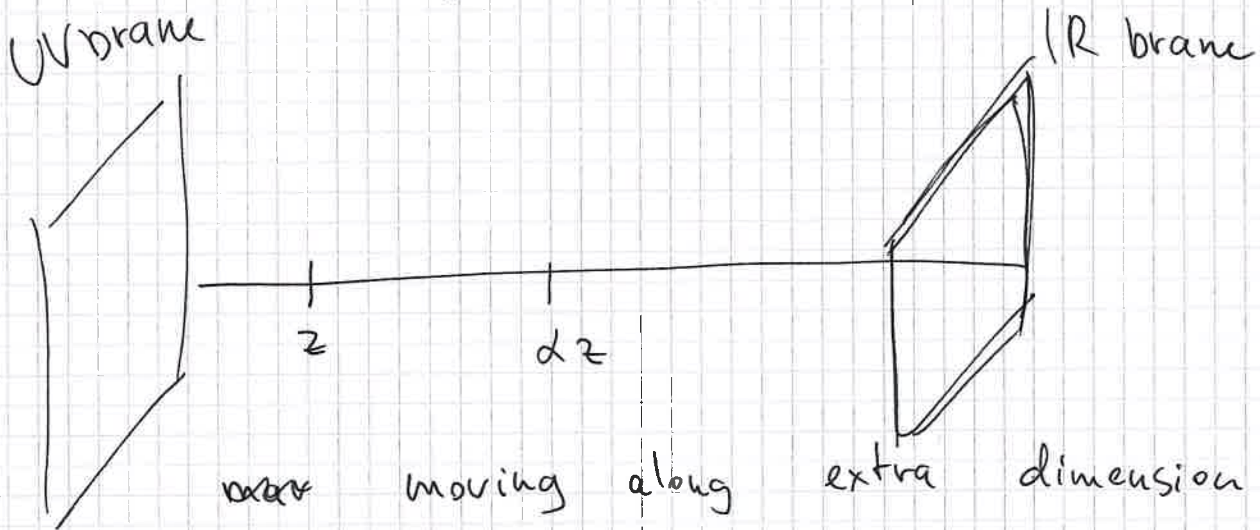
resonance search for spin 2 resonances in dijet diphoton, dilepton ...

bo

Holographic interpretation

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

$$\left.\begin{array}{l} z \to \alpha z \\ x \to \alpha x \end{array}\right\} \text{ invariance of metric!}$$



~~xxx~~ moving along extra dimension = doing a 4D scale transformation.

if this is an invariance (w/o branes true) → secretly this 5D theory corresponds to a scale invariant 4D theory!

$\left.\begin{array}{l}\text{UV brane}\\ \text{IR brane}\end{array}\right\}$ will break conformal symmetry!

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 <u>COMPOSITE!</u>

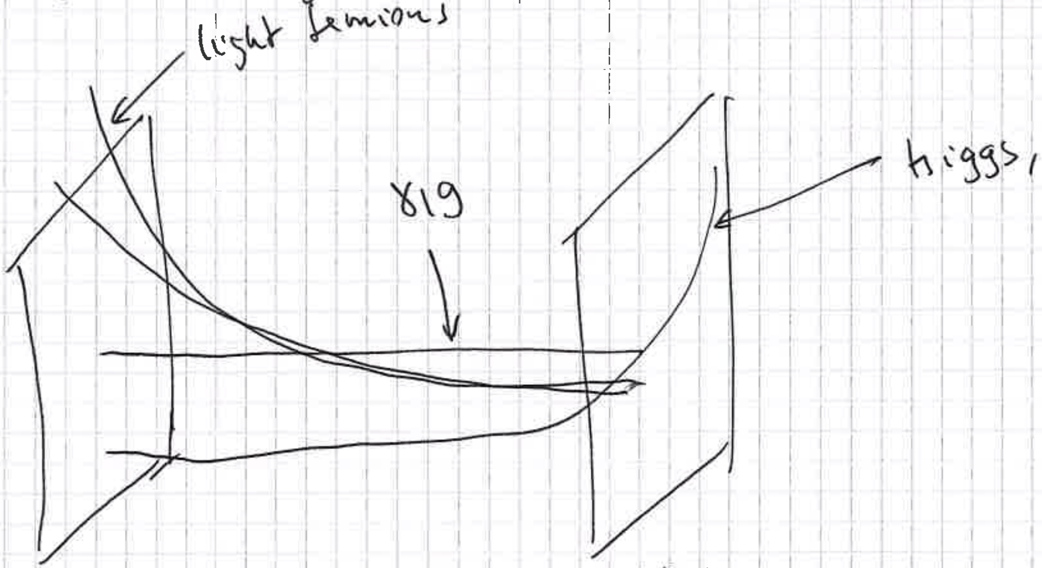
Good part: Higgs composite (secret way of solving hierarchy)!

Bad part: everything composite.

Realistic RS models

SM fields are mainly elementary

Higgs (maybe top) are composite!



light fermion exponentially peaked UV

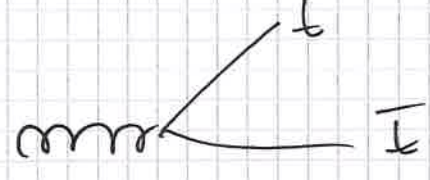
higgs, top — " — IR

γ, g mainly elementary

KK graviton is no longer a good search ~~ms~~ channel.

Instead: KK gluon, KK 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

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

still expect corrections to $\frac{1}{16\pi^2}\Lambda^2$

<u>still too big!</u> $\Delta m_h^2 \sim (1\,\text{TeV})^2$

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

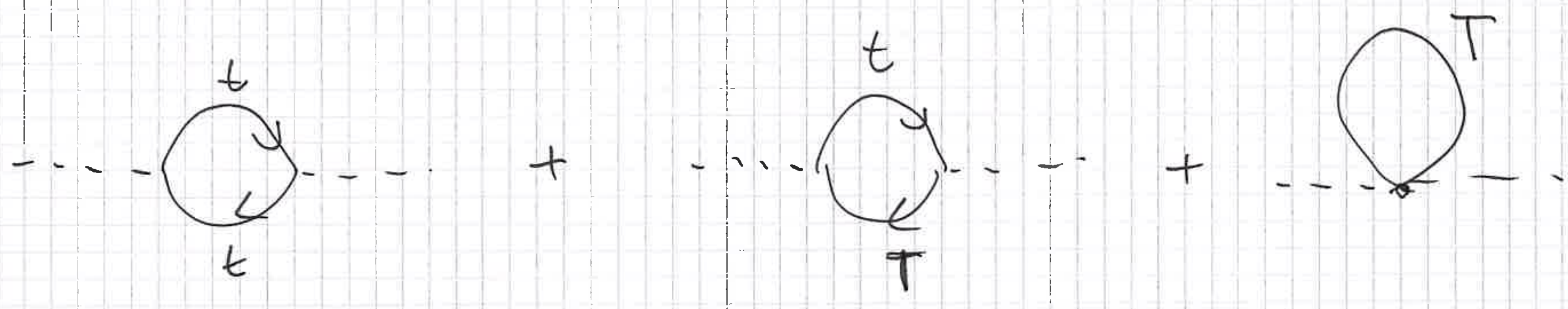
$\boxed{\frac{\Delta m_h^2}{m_h^2} \sim 100}$ little hierarchy problem!

<u>Little higgs:</u> new set of particles

"little partners" : cancel 1-loop quadratic divergences little higgs: little partners cancel

1-loop quadratic divergence

New scale: $f \sim 1\,\text{TeV}$ $\leftarrow$ scale of little partners!



Has to be an ~~of~~ additional symmetry that enforces cancellation.

<u>A global symmetry</u> $SU(3) \longrightarrow SU(2)$

$f \sim \text{TeV}$

higgs is a Goldstone of this symmetry!

"<u>collective breaking</u>"

Experimental search: little top partners!

$$T \to bW \longleftarrow \text{CMS search} \qquad m_T \gtrsim 460\,\text{GeV}$$
$$\quad\;\; tZ$$
$$\quad\;\; th$$

COMPOSITE Higgs vs. little higgs

- still Goldstone
- but no little partners!
- compositeness scale high
- deviation in higgs couplings!

$$\sim \left(1 - \frac{v^2}{f^2}\right)$$