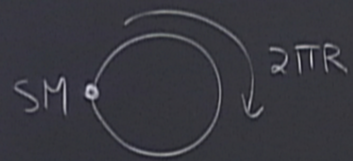
Title: Beyond Standard Model-13

Date: Mar 05, 2015 09:00 AM

URL: http://pirsa.org/15030004

Abstract:

LED




$$M_{Pl}^2 = M_*^{n+2} V_n$$

$$h_{MN}(x, w) = \sum_{\vec{n}} h^{(n)}_{MN}(x) \left(\frac{1}{\sqrt{2\pi R}}\right)^n e^{i\vec{n}\cdot\vec{w}/R}$$

| | | | |
|---|---|---|---|
| ○ : | $h^{(0)}_{\mu\nu}$ , | $V^{(0)}_{\mu,a}$ , | $S^{(0)}_{ab}$ |
| | $2$ | $n \cdot 2$ | $n(n+1)/2$ |
| $\vec{n} \neq \vec{0}$ | $h^{(\vec{n})}_{\mu\nu}$ | $V^{(\vec{n})}_{\mu,a}$ | $S^{(\vec{n})}_{ab}$ |
| | $5$ | $3(n-1)$ | $n(n+1)/2 - n$ |

$$m_n = \frac{1}{R} \|\vec{n}\| \quad " \sqrt{n_1^2 + n_2^2 + \dots + n_N^2}$$

$$= \sum_{\vec{n}} h^{(n)}_{MN}(x) \left(\frac{1}{\sqrt{2\pi R}}\right)^n e^{i\vec{n}\cdot\vec{w}/R}$$

$$h^{(0)}_{\mu\nu}, \quad V^{(0)}_{\mu,a}, \quad S^{(0)}_{ab}$$

$$2 \qquad n\cdot 2 \qquad n(n+1)/2 \quad = \frac{1}{2}(n^2+5n+4) = \frac{d(d-3)}{2}$$

$$\neq \vec{0} \quad h^{(\vec{n})}_{\mu\nu} \qquad V^{(\vec{n})}_{\mu,a} \qquad S^{(\vec{n})}_{ab}$$

$$5 \qquad 3(n-1) \qquad n(n+1)/2 - n \quad = \frac{1}{2}(n^2+5n+4) = \frac{d(d-3)}{2}$$

$$= \frac{1}{R}\|\vec{n}\|$$

$$\| \sqrt{n_1^2 + n_2^2 + \cdots + n_N^2}$$

$(0)$
$ab$

$(n+1)/2 \;=\; \frac{1}{2}(n^2+5n+4) = \frac{d(d-3)}{2}$

$(\vec{n})$
$ab$

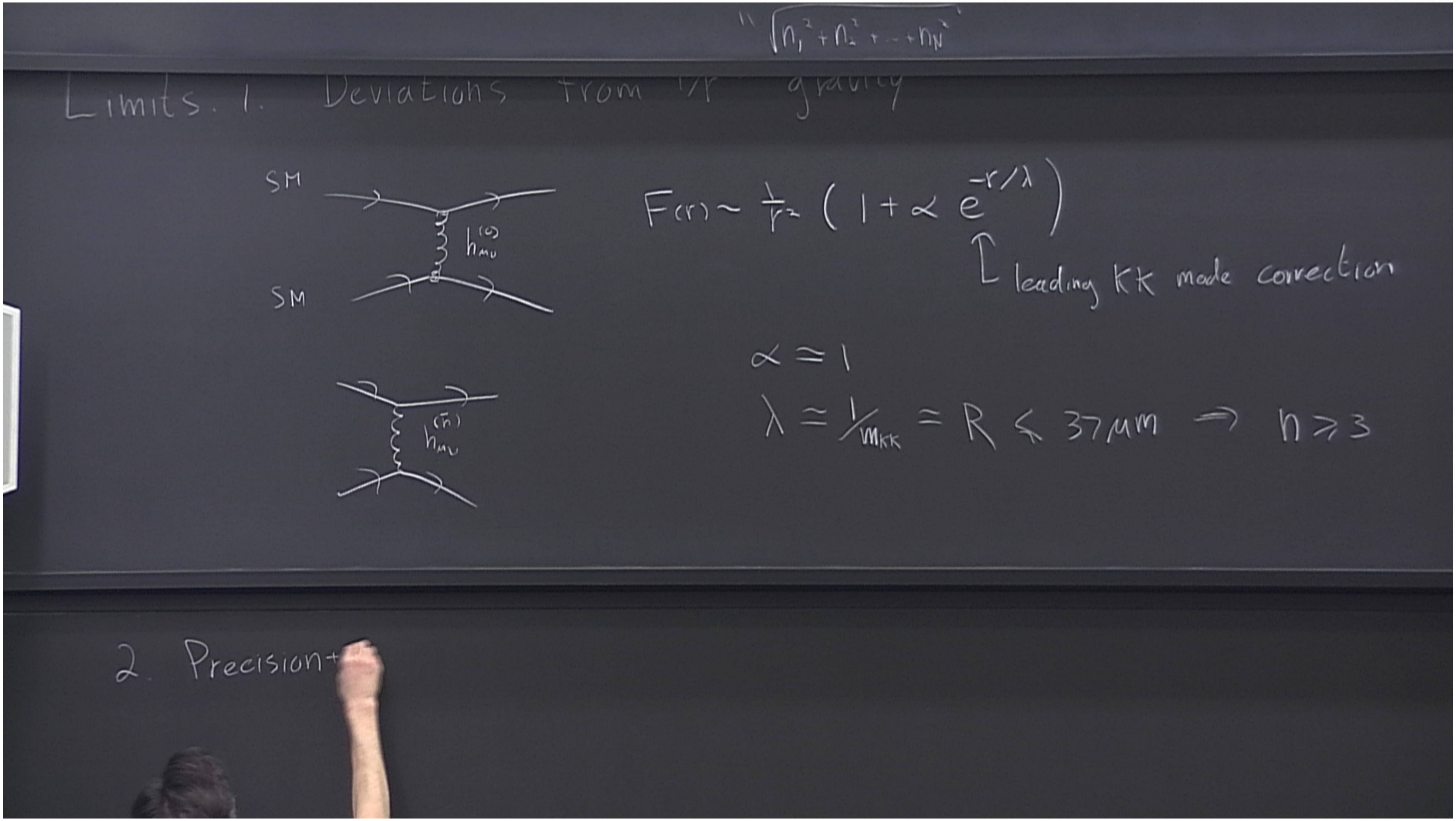
$(n+1)/2 - n \;=\; \frac{1}{2}(n^2+5n+4) = \frac{d(d-3)}{2}$

$h^{(0)}_{\mu\nu},\ h^{(\vec{n})}_{\mu\nu}$ couple to $T_{SM}^{\mu\nu}\,\frac{1}{M_{Pl}}$

$H^{(\vec{n})} = \sum_a S^{(\vec{n})}_{aa}$ = "dilaton"

couples to $T^{\mu}_{SM\,\mu}\,\frac{1}{M_{Pl}}$

Other stuff doesn't couple to SM


$\sqrt{n_1^2 + n_2^2 + \dots + n_N^2}$
Limits. 1. Deviations from 1/r gravity
SM
SM
$h_{\mu\nu}^{(0)}$
$h_{\mu\nu}^{(\vec{n})}$
$F(r) \sim \frac{1}{r^2}\left(1 + \alpha\, e^{-r/\lambda}\right)$
leading KK mode correction
$\alpha \simeq 1$
$\lambda \simeq 1/m_{KK} = R \lesssim 37\,\mu m \Rightarrow n \gtrsim 3$
2. Precision

2. Precision + Collider Measurements

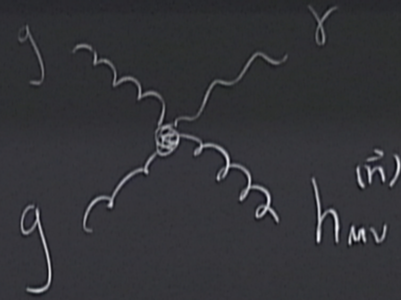
Expect new higher-dim ops suppressed by $\frac{1}{M_*}$ powers.

$\frac{1}{M_*^2} QQQL \to p$ decay for $M_* \lesssim 10^{16}$ GeV

$\frac{1}{M_*^2} \bar{f}\gamma^\mu f \, \bar{f}'\gamma_\mu f' \to$ deviations in $e^+e^- \to \mu^+\mu^-$, precision electroweak

$M_* \gtrsim$ TeV

sion electroweak




= monophoton

$$\sum_{\vec n} \frac{1}{M_{Pl}} h_{\mu\nu}^{(\vec n)} T_{SM}^{\mu\nu}$$

$$\sigma\left(gg \to \gamma + h_{\mu\nu}^{(\vec n)}\right) \sim \frac{1}{M_{Pl}^2}$$

$$\equiv \sigma(\vec n)$$

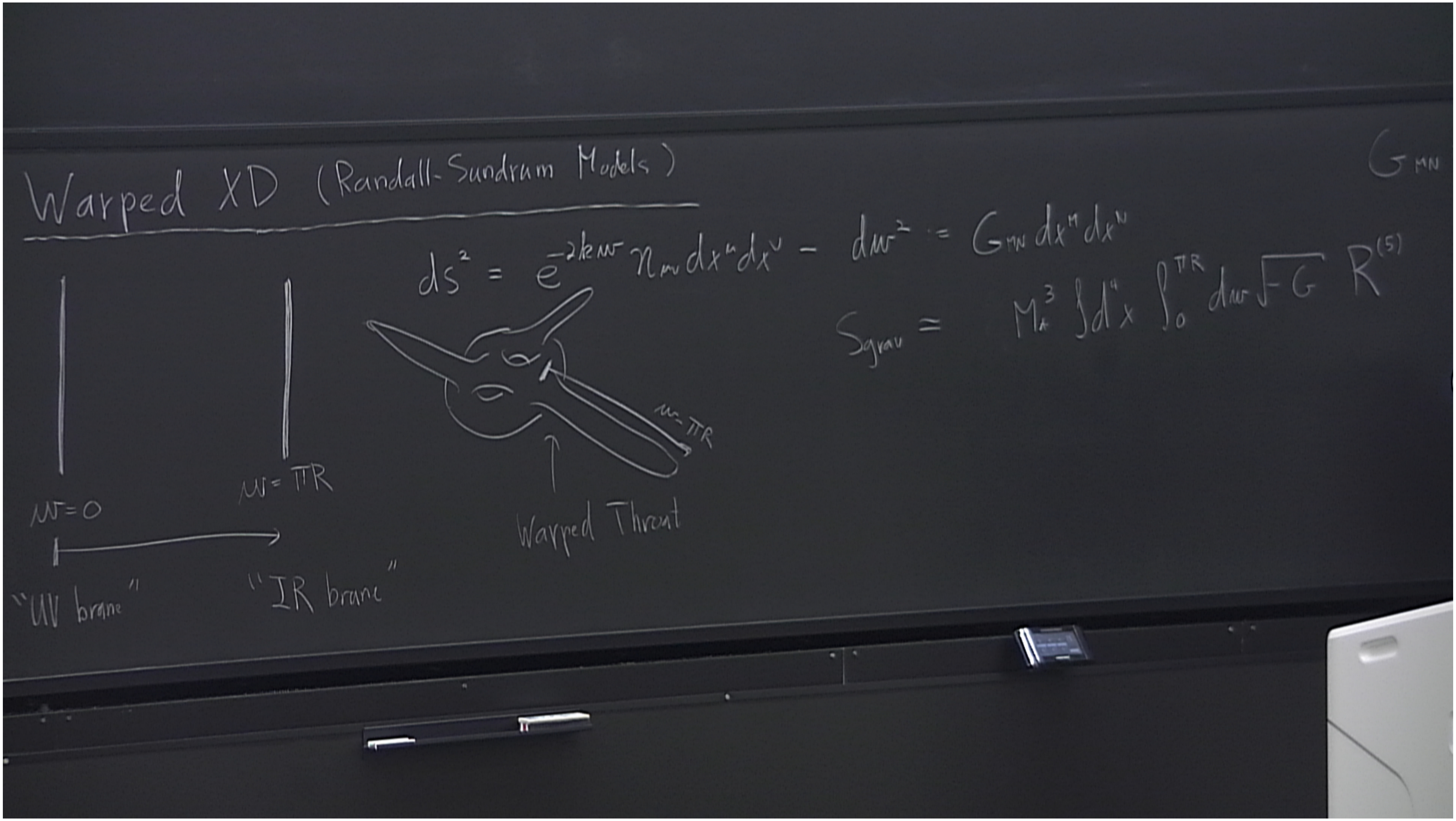
$$\sigma_{tot} = \sum_{\vec n} \sigma(\vec n)$$

$$\sum_{\vec n} \to \int dN \sim m^{n-1}\, dm\, R^{n-1}$$

$$\to R^n \frac{1}{M_{Pl}^2} \int_0^{E_{max}} dm\, m^{n-1}$$

$$\sim \frac{1}{M_*^{n+2}} E_{max}^n$$

$$M_* \gtrsim \begin{cases} 1.4\,\text{TeV}, & n=2 \\ 1.5\,\text{TeV}, & n=3 \\ \vdots \end{cases}$$


Warped XD (Randall-Sundrum Models)
$G_{MN}$
$ds^2 = e^{-2kw}\eta_{\mu\nu}dx^\mu dx^\nu - dw^2 = G_{MN}dx^M dx^N$
$S_{grav} = M_*^3 \int d^4x \int_0^{\pi R} dw \sqrt{-G}\, R^{(5)}$
$w=0$
$w=\pi R$
"UV brane"
"IR brane"
$w=\pi R$
Warped Throat

$$G_{MN} = \left( \begin{array}{c|c} g_{\mu\nu} & 0 \\ \hline 0 & -1 \end{array} \right)$$

$$\ldots^2 = G_{MN}\, dx^M dx^N$$

$$\simeq M_*^3 \int d^4x \int_0^{\pi R} dw \sqrt{-G}\, R^{(5)}$$

$$\simeq \underbrace{\frac{1}{2}\frac{M_*^3}{k}\left(1 - e^{-2\pi k R}\right)}_{\frac{M_{Pl}^2}{2}} \cdot \underbrace{\int d^4x \sqrt{-\bar{g}}\, \bar{R}}_{\text{usual 4d gravity}}$$

$$g_{\mu\nu} = \underbrace{e^{-2kw}\left(\eta_{\mu\nu} + h_{\mu\nu}/M_*^{3/2}\right)}_{\bar{g}_{\mu\nu}(x)}$$

$$\sqrt{-G}\, R^{(5)} = \sqrt{-\bar{g}}\, \underbrace{\bar{R}}_{\text{built from } \bar{g}_{\mu\nu}} \cdot e^{-2kw}$$

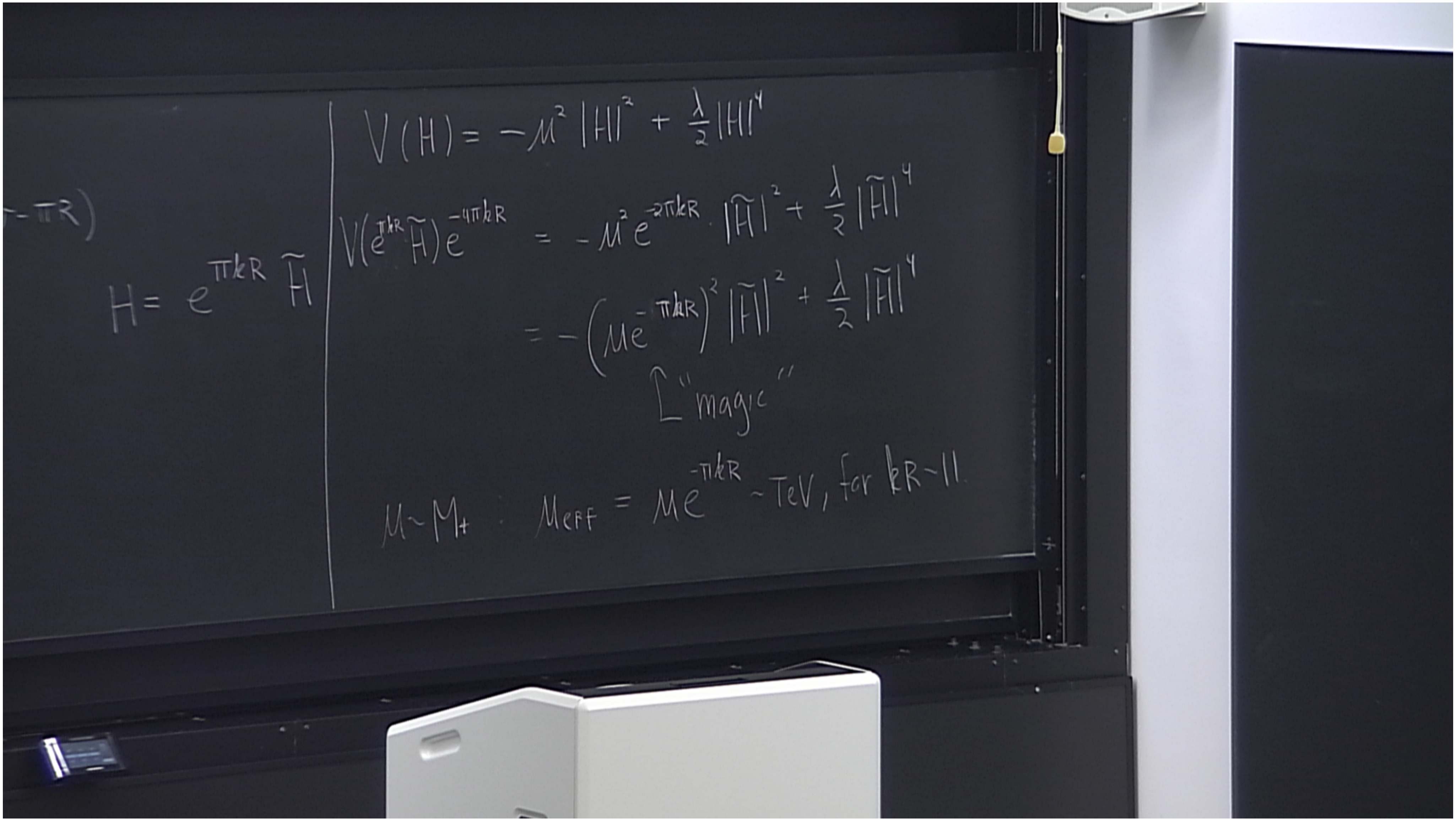
Suppose we confine the Higgs to the IR brane.

$$S_{Higgs} = \int d^4x \int dw \sqrt{-G} \left[ G^{\mu\nu} \partial_\mu H^\dagger \partial_\nu H - V(|H|) \right] \delta(w - \pi R)$$

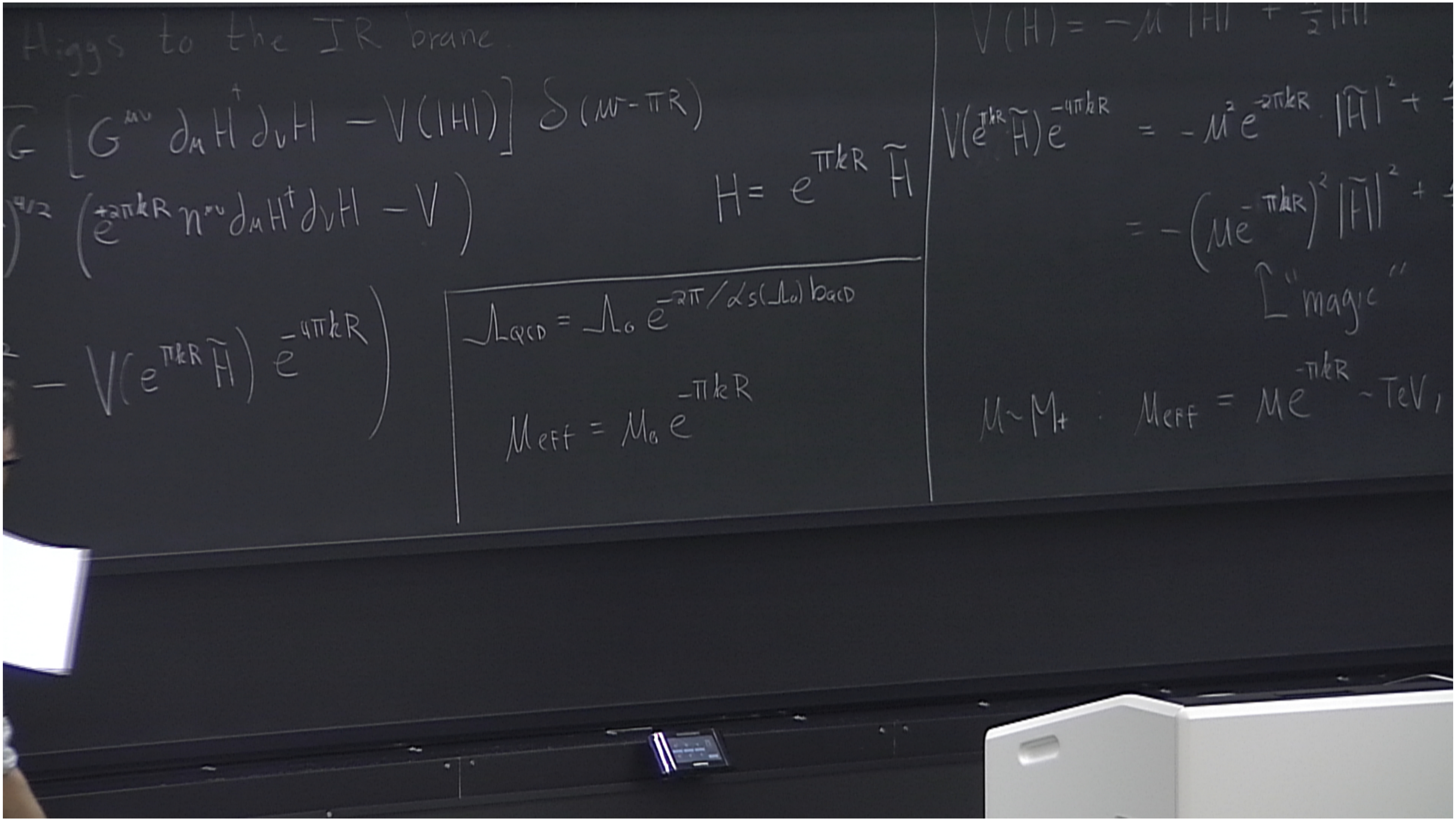
$$= \int d^4x \left(e^{-2k\pi R}\right)^{4/2} \left( e^{+2\pi k R} \eta^{\mu\nu} \partial_\mu H^\dagger \partial_\nu H - V \right)$$

$$H = e^{\pi k R} \tilde{H}$$

$$= \int d^4x \left( |\partial H|^2 - V(e^{\pi k R} \tilde{H})\, e^{-4\pi k R} \right)$$



$-\pi R)$
$H = e^{\pi k R}\tilde{H}$
$V(H) = -\mu^2 |H|^2 + \frac{\lambda}{2}|H|^4$
$V(e^{\pi k R}\tilde{H})e^{-4\pi k R} = -\mu^2 e^{-2\pi k R}|\tilde{H}|^2 + \frac{\lambda}{2}|\tilde{H}|^4$
$= -(\mu e^{-\pi k R})^2 |\tilde{H}|^2 + \frac{\lambda}{2}|\tilde{H}|^4$
"magic"
$\mu \sim M_* : \mu_{eff} = \mu e^{-\pi k R} \sim \mathrm{TeV}$, for $kR \sim 11$


Higgs to the IR brane
$\sqrt{G}\,[G^{\mu\nu}\partial_\mu H^\dagger \partial_\nu H - V(|H|)]\,\delta(w-\pi R)$
$)^{4/2}\,(e^{+2\pi kR}\eta^{\mu\nu}\partial_\mu H^\dagger\partial_\nu H - V)$
$H = e^{\pi kR}\tilde{H}$
$- V(e^{\pi kR}\tilde{H})\,e^{-4\pi kR})$
$\Lambda_{QCD} = \Lambda_0\, e^{-2\pi/\alpha_s(\Lambda_0) b_{QCD}}$
$\mu_{eff} = \mu_0\, e^{-\pi kR}$
$V(H) = -\mu^2|H|^2 + \frac{\lambda}{2}|H|^4$
$V(e^{\pi kR}\tilde{H})e^{-4\pi kR} = -\mu^2 e^{-2\pi kR}|\tilde{H}|^2 +$
$= -(\mu e^{-\pi kR})^2|\tilde{H}|^2 +$
"magic"
$\mu \sim M_*$ : $\mu_{eff} = \mu e^{-\pi kR} \sim \mathrm{TeV}$,

RS1 = all of SM on IR brane

More general RS has gauge + fermions in bulk.

$$e^{-kw} = \frac{1}{kz} \Leftrightarrow \begin{cases} w = k^{-1}\ln(kz) \\ dw = \frac{1}{kz} \end{cases} \Rightarrow ds^2 = \left(\frac{L_0}{z}\right)^2\left(\eta_{\mu\nu}dx^\mu dx^\nu - dz^2\right)$$

$$z \in [L_0, L_1], \quad L_0 = k^{-1}, \quad L_1 = k^{-1}e^{\pi kR}$$

RS1 = all of SM on IR brane

More general RS has gauge + fermions in bulk.

$$e^{-kw} = \frac{1}{kz} \iff \begin{cases} w = k^{-1}\ln(kz) \\ dw = \frac{1}{kz} \end{cases} \Rightarrow ds^2 = \left(\frac{L_0}{z}\right)^2 \underbrace{\left(\eta_{\mu\nu}\, dx^\mu dx^\nu - dz^2\right)}_{\text{flat}}$$

$$z \in [L_0, L_1], \quad L_0 = k^{-1}, \quad L_1 = k^{-1} e^{\pi k R}$$

$$\begin{cases} G_{MN} = \left(\frac{L_0}{z}\right)^2 \eta_{MN} \\ G^{MN} = \left(\frac{z}{L_0}\right)^2 \eta^{MN} \end{cases}$$