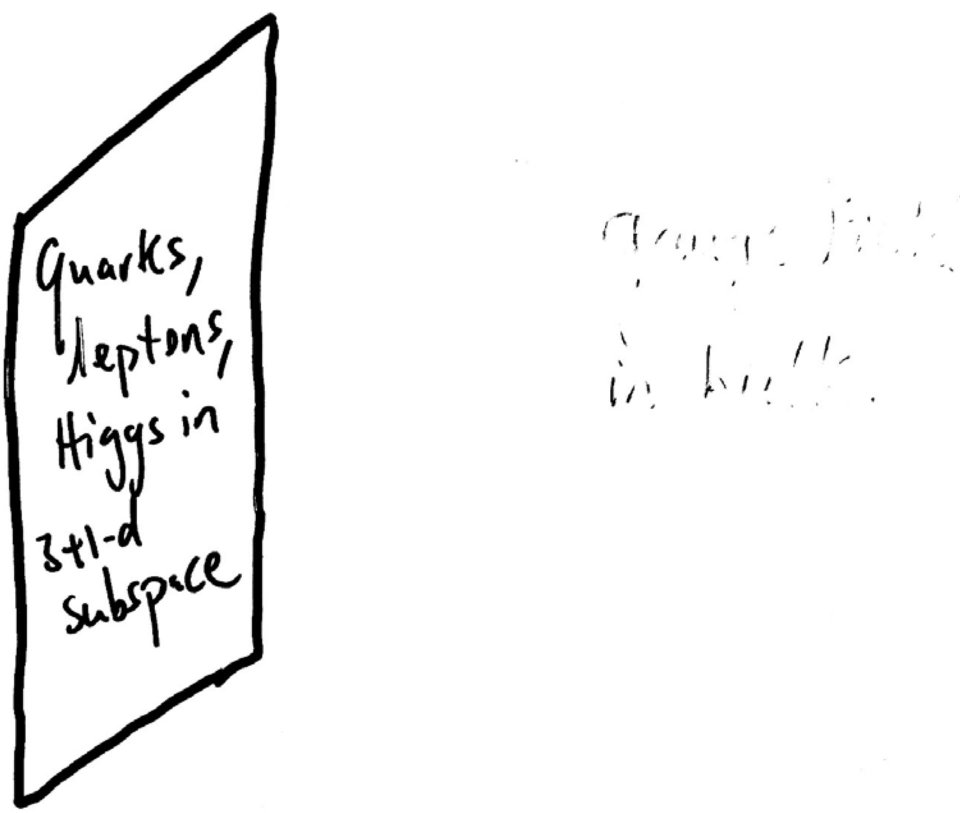
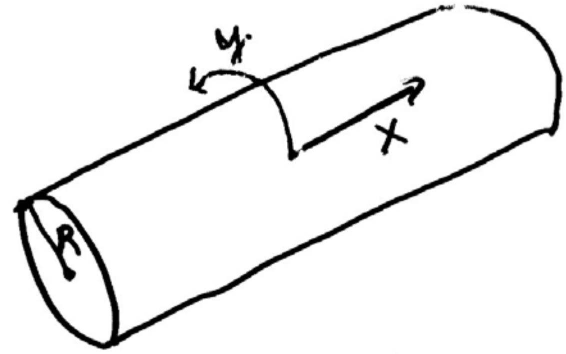
J. Wells

One of the simplest extensions of SM is to put gauge fields in bulk.



<u>Why?</u> D-brane models like it, and holds promise of geometrically introducing Weak scale.



Orbifold compactification S^1/Z_2

The fifth dimension, y, is made periodic on a circle S^1 with radius R, and $y = -y$ (from Z_2) are equivalent points. The 4-d fields live on the S^1/Z_2 orbifold fixed points at $y = 0, \pi R$.

Fields in 5-d gauge fields are compactified to 4-d by

$$V_\mu(x,y) = \sum_{n=0}^{\infty} V_\mu^{(n)}(x) \cos ny/R.$$

Derivatives w.r.t. the 5th dimension yield KK mass tower of $m^2 = n^2/R^2$ as usual.

$$\mathcal{L}_5 = -\frac{1}{4g_5^1} F_{MN}^2 + |D_M H|^2 \delta(y) + i\bar{\psi} D_\mu \psi \delta(y)$$

After compactifying

0 mode mixing with KK modes

$$\mathcal{L}_4 = \sum_{n=0}^{\infty} \left[-\frac{1}{4} F_{\mu\nu}^{(n)2} + \frac{1}{2}\frac{n^2}{R^2} V_\mu^{(n)} V^{\mu(n)} + g^2 |H|^2 \left(V_\mu^{(0)} + \sqrt{2} \sum_{n=1}^{\infty} V_\mu^{(n)} \right)^2 \right] + i\bar{\psi}\sigma^\mu \left[\partial_\mu + igV_\mu^{(0)} + ig\sqrt{2} \sum_{n=1}^{\infty} V_\mu^{(n)} \right] \psi + \ldots$$

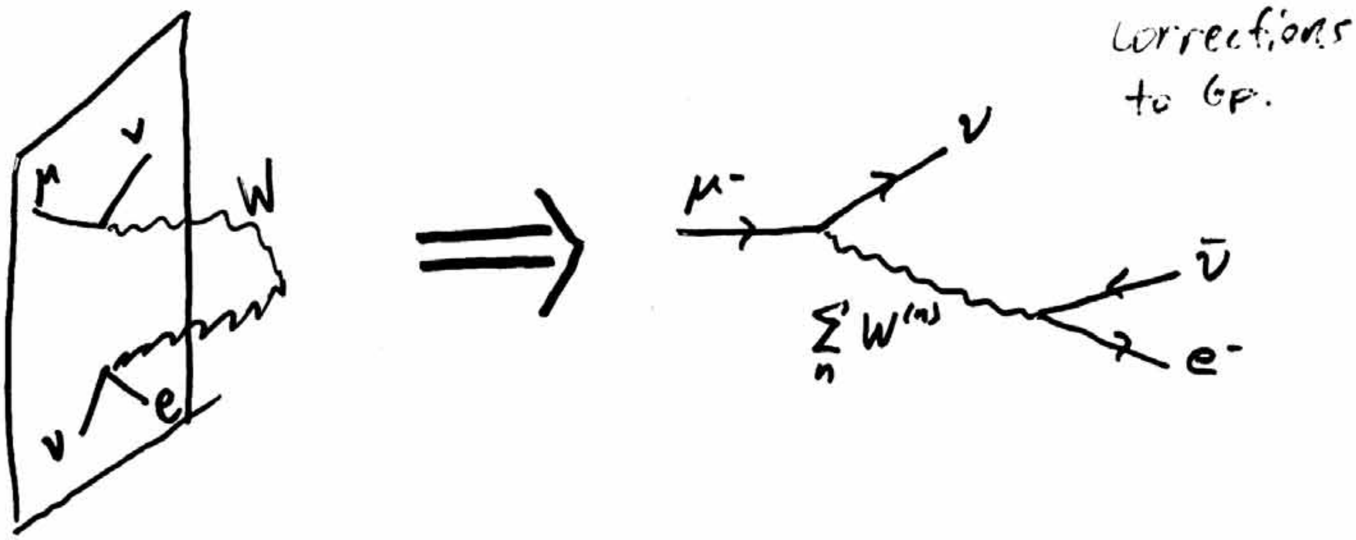
The vector boson KK states then have masses

$$m_V^{(n)2} = m_V^2 + \frac{n^2}{R^2}$$

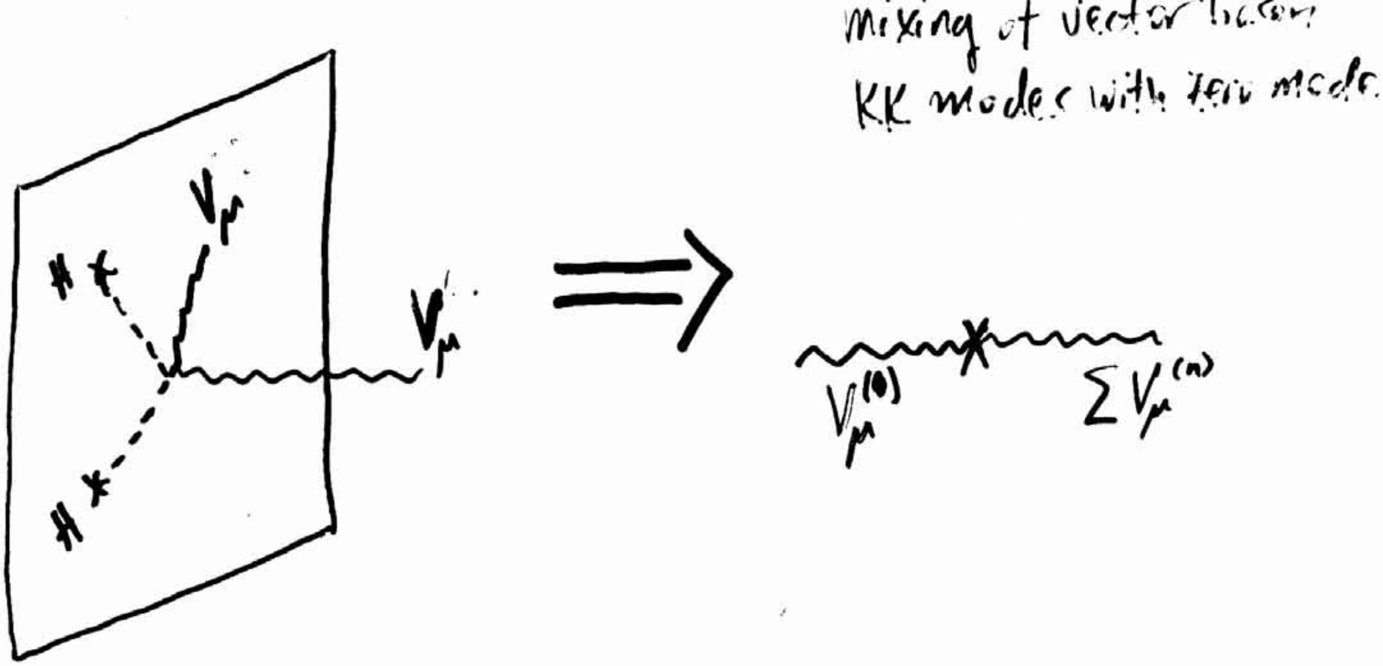
and their couplings to fermions are $\sqrt{2}$ larger than the zero mode coupling.

Impact of KK states on precision electroweak observables

KK excitations have several important effects:



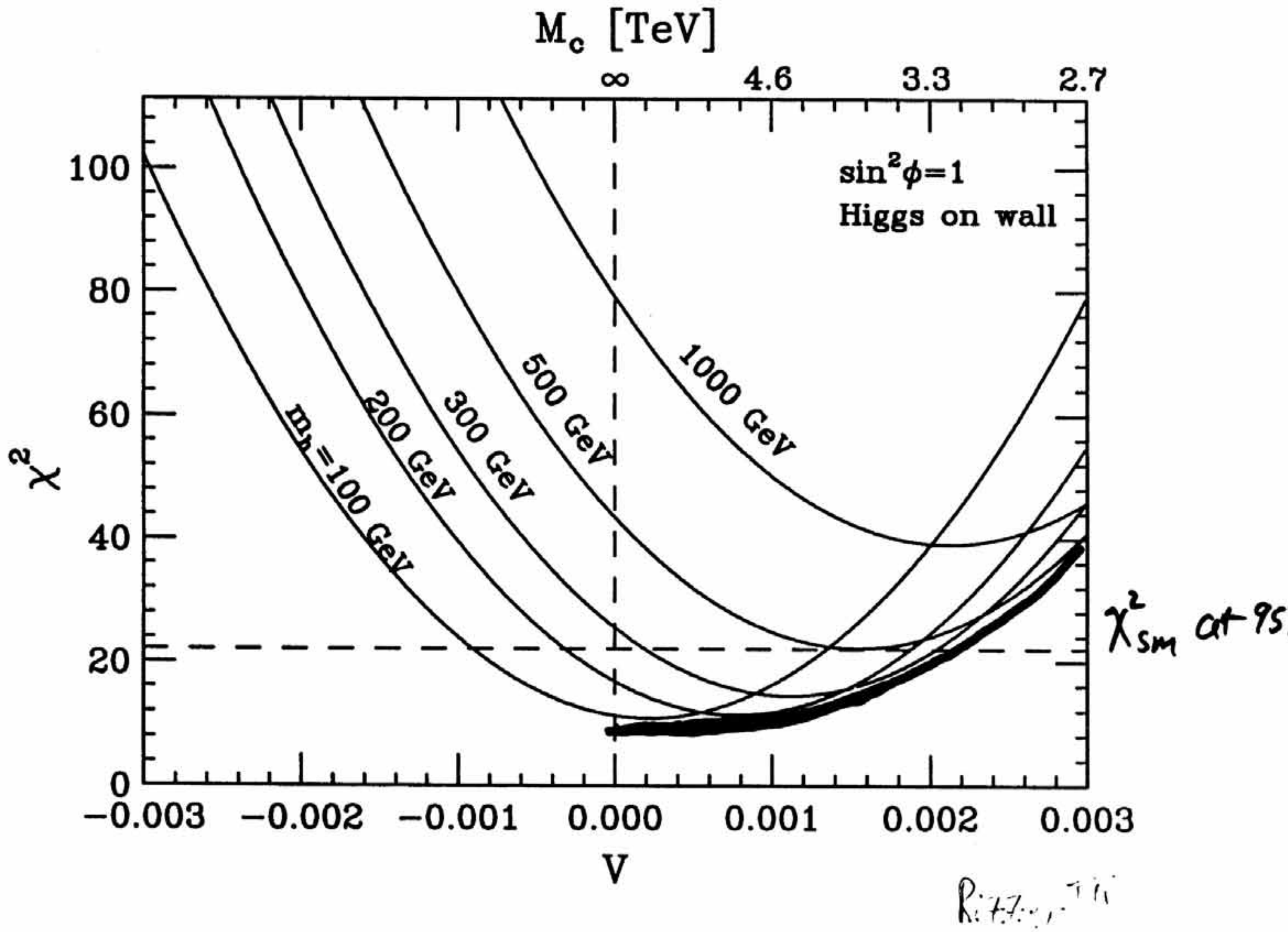
and with Higgs stuck to wall we get important mixing effects of KK excitations with the zero modes:



An effective Lagrangian summary of the effects (after E.O.M.) is

$$\mathcal{L} = \mathcal{L}_{SM} - \sum_n \frac{1}{2M^2_{KK(n)}} \left[(D_\rho W^a_{\mu\nu})^2 + (\partial_\rho B_{\mu\nu})^2 \right].$$

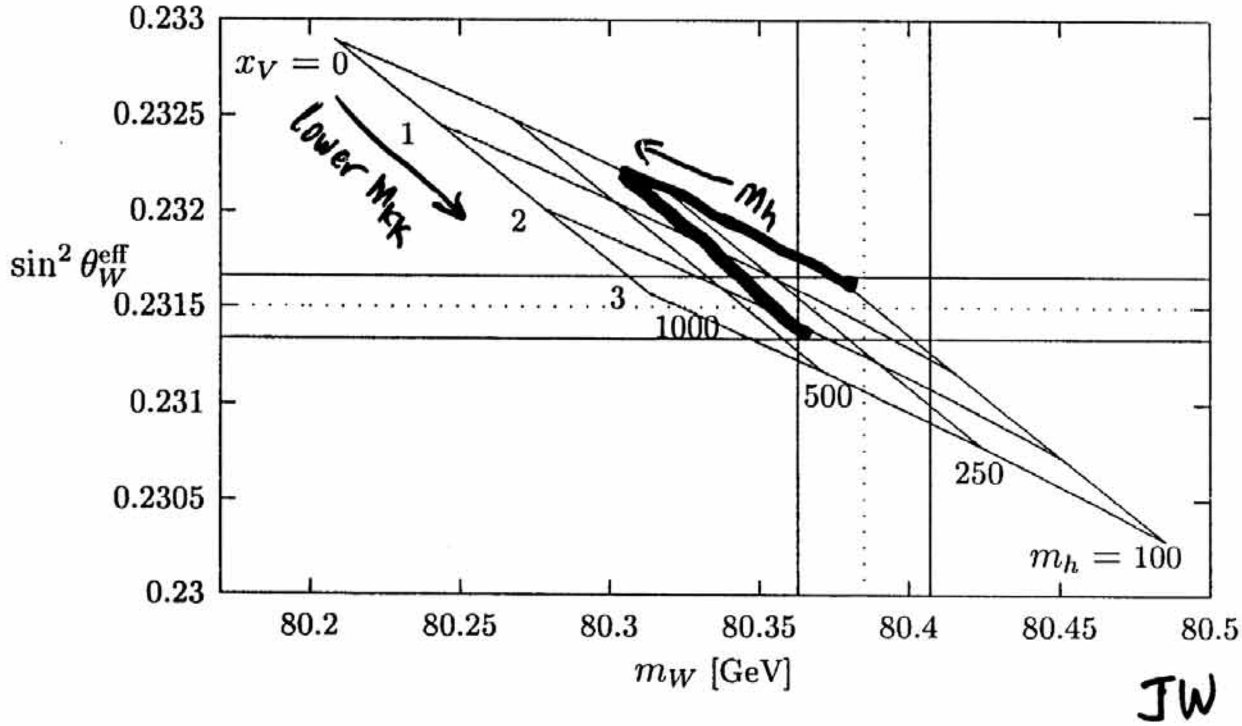
Global χ^2 analysis



The Higgs boson can be as high as 500 GeV with χ^2 lower than the SM χ^2_{SM} at $m_h = 220\,\text{GeV}$ (1999 EW data).

Current 5DSM fits still allow Higgs boson masses above 300 GeV.

Conspiracies among observables



$$x_V \equiv 1000\frac{\pi^2}{3}\frac{m_W^2}{M_{KK}^2} = 2530\frac{m_Z^2}{M_{KK}^2},$$

where M_{KK} is the mass of lightest KK excitation of the gauge fields.

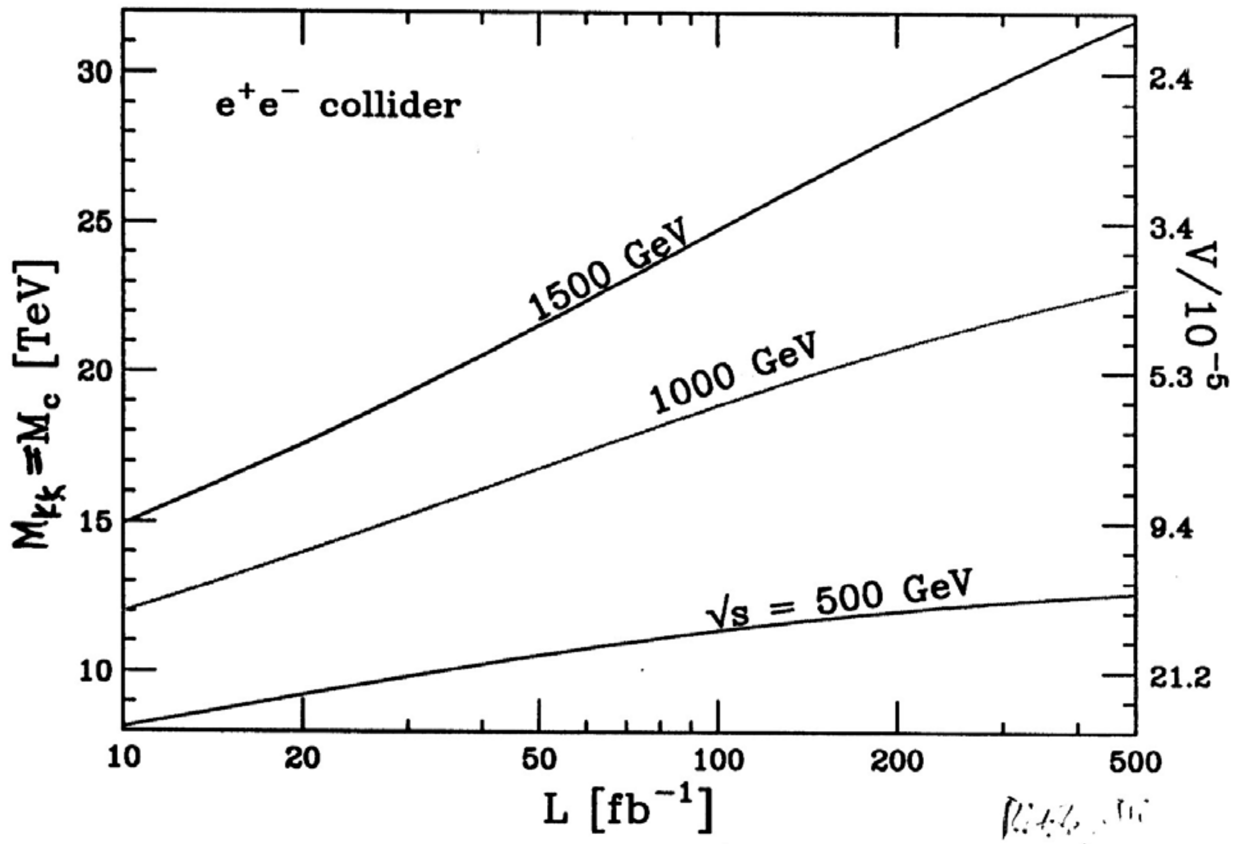
KK gauge field effects

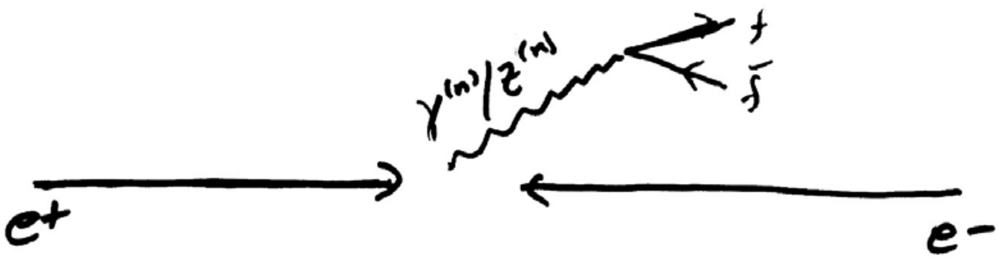
$$\begin{aligned}\sin^2\theta_W^{\rm eff} &\simeq 0.23035 + 0.0005\,\log(m_h/100\,\text{GeV}) - 1.09\frac{m_Z^2}{M_{KK}^2},\\ m_W(\text{GeV}) &\simeq 80.397 - 0.06\,\log(m_h/100\,\text{GeV}) + 87.0\frac{m_Z^2}{M_{KK}^2}.\end{aligned}$$

There is a partial cancellation conspiracy between the Higgs logs and the KK excitations.

$M_{KK} \simeq$ 3-4 TeV

Finding heavy KK states at a linear collider





Plot made for the 5-dimensional standard model. The extraordinary reach (greater than usual Z' models) is due to larger couplings ($\sqrt{2}g$) and more states ($Z^{(n)}/\gamma^{(n)}$).

Interesting lesson: More complicated conspiracies allow more leads for future prosecution ($W_\mu^{(n)}$ at hadron colliders also).

(Antoniadis, ...)

Numerous authors have considered having different gauge groups feel extra dimensions differently. (Mück, Pilaftsis, Rückl)

For example, (many permutations...)

- Hypercharge in bulk with $R = R_1$ $\quad g_1 = g/\sqrt{R_1}$

  SU(2) in bulk' with $R = R_2$ $\quad g_2 = g/\sqrt{R_2}$

"Explanation" of gauge coupling hierarchies.

The precision EW lagrangian becomes

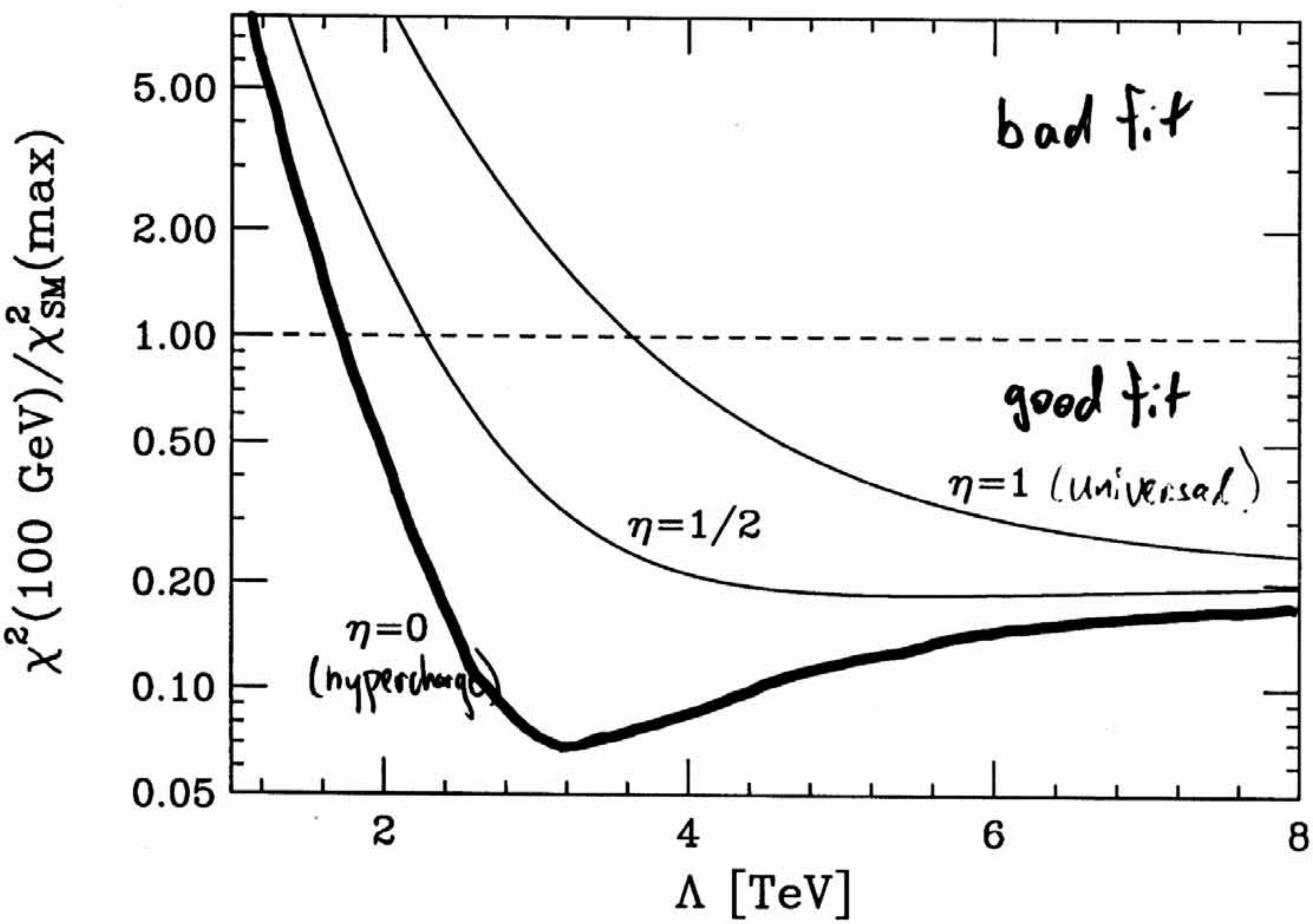
$$\mathcal{L} = \mathcal{L}_{SM} - \frac{R_1^{-2}}{2}\left(\partial_\rho B_{\mu\nu}\right)^2 - \frac{R_2^{-2}}{2}\left(D_\rho W^a_{\mu\nu}\right)^2 + \ldots$$

Useful variable is $\eta = R_2^2/R_1^2$

$\eta = 0$ hypercharge only relevant (Y in bulk)

$\eta = 1$ universal extra dimensions (every field in bulk of same size)

Precision EW



$M_H = 100$ GeV

$$\frac{1}{\Lambda^2} = \sum_{\vec{n}} \frac{e^{-a^2 \vec{n}\cdot\vec{n}}}{M_{\vec{n}}^2} = \frac{f_\delta(a)}{M_{KK}^2}$$

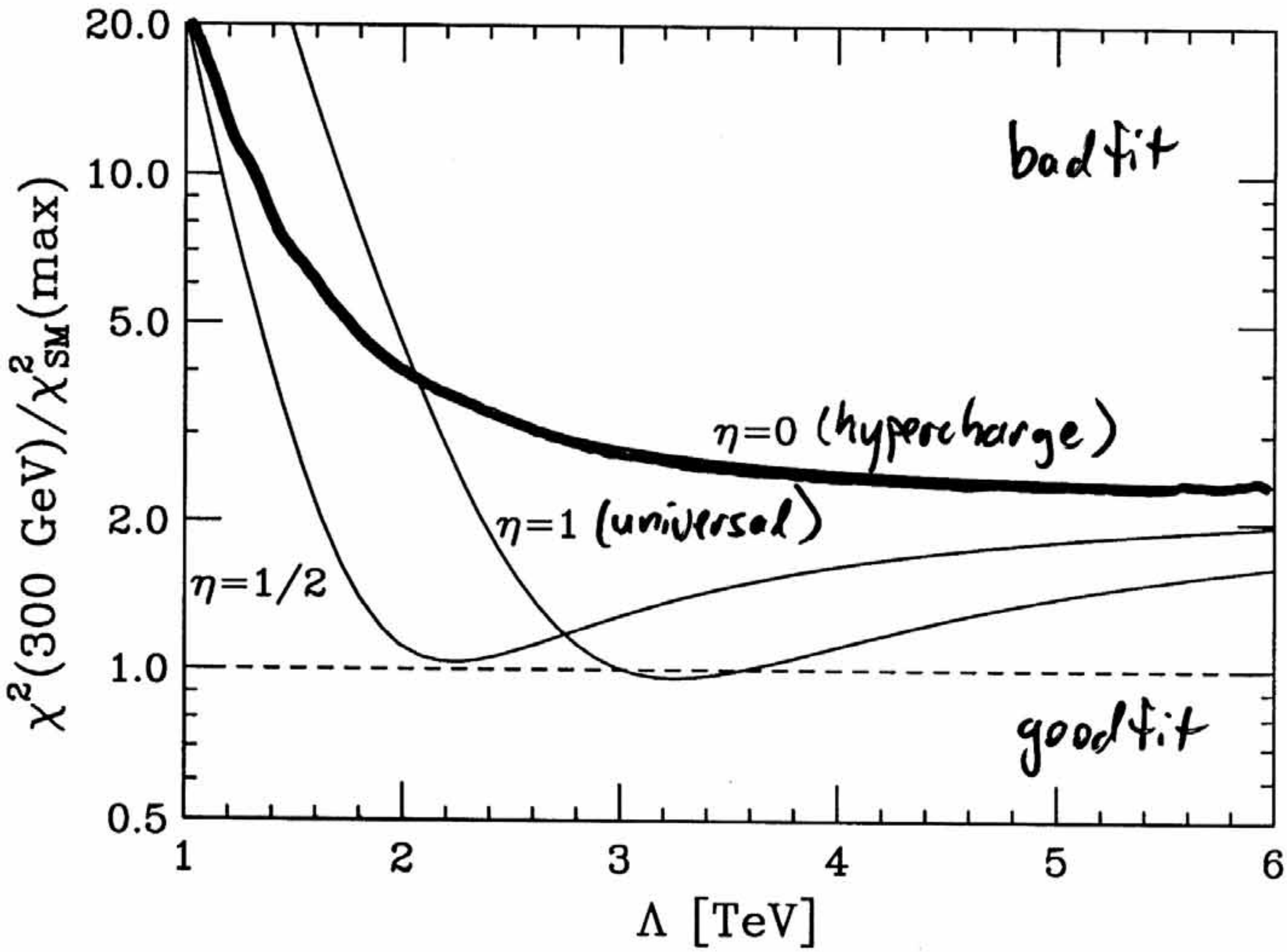
$$f_1(0) = \frac{\pi^2}{6} = 1.64 \quad \left(M_{KK} = \frac{\pi}{\sqrt{6}} \Lambda \right)$$

$\Delta \sin^2\theta_W \propto (1-4.3\eta)$ •

$\Delta m_W \propto (1+\eta)$

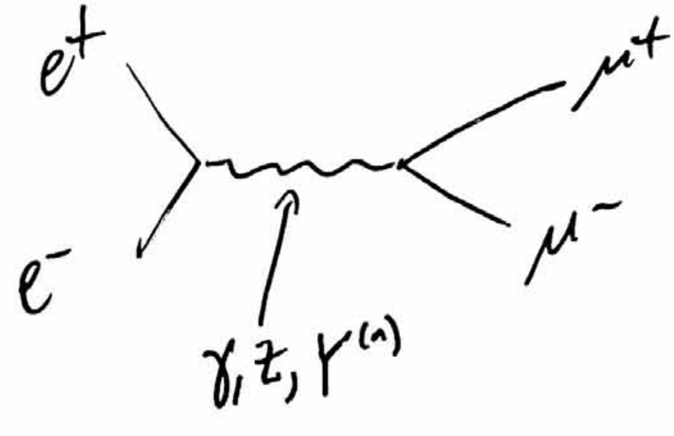
Precision EW

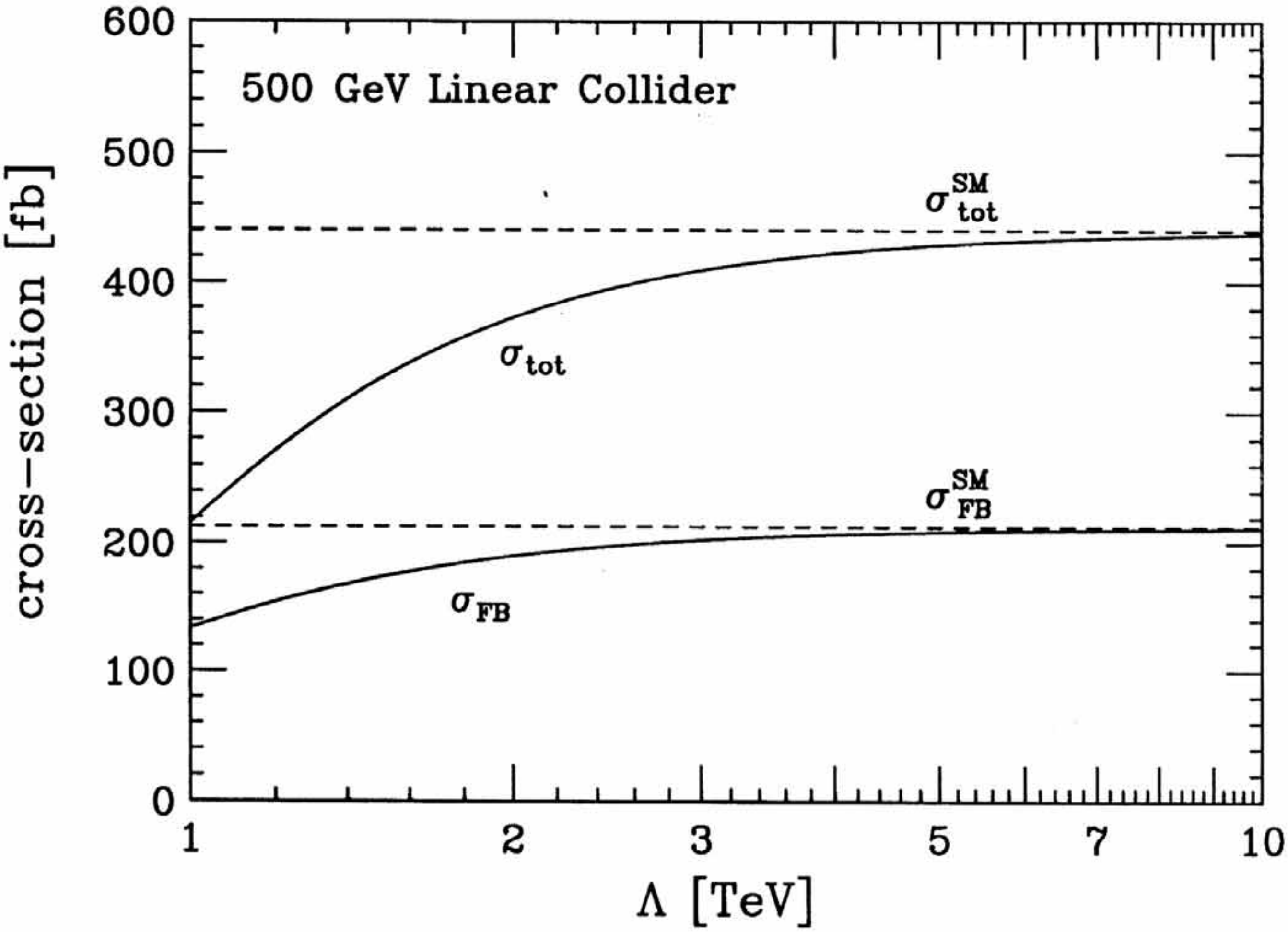
$\Delta\Gamma_\ell \propto (1+1.8\eta)$



$M_H = 300$ GeV (100 GeV over allowed value in SM)

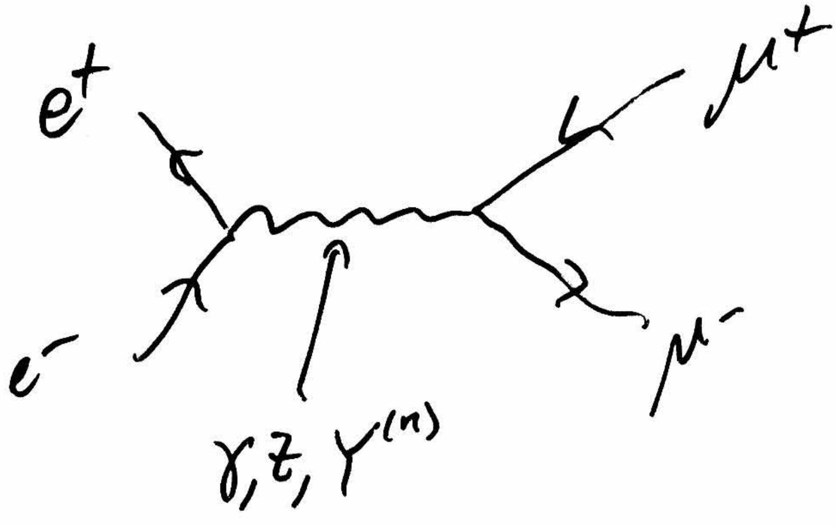
$$\frac{1}{\Lambda^2} = \sum_{\vec{n}} \frac{e^{-a\vec{n}\cdot\vec{n}}}{M_{KK}^2} = \frac{\pi^2}{6}\frac{1}{M_{KK}^2} \quad (1 \text{ extra dim.})$$

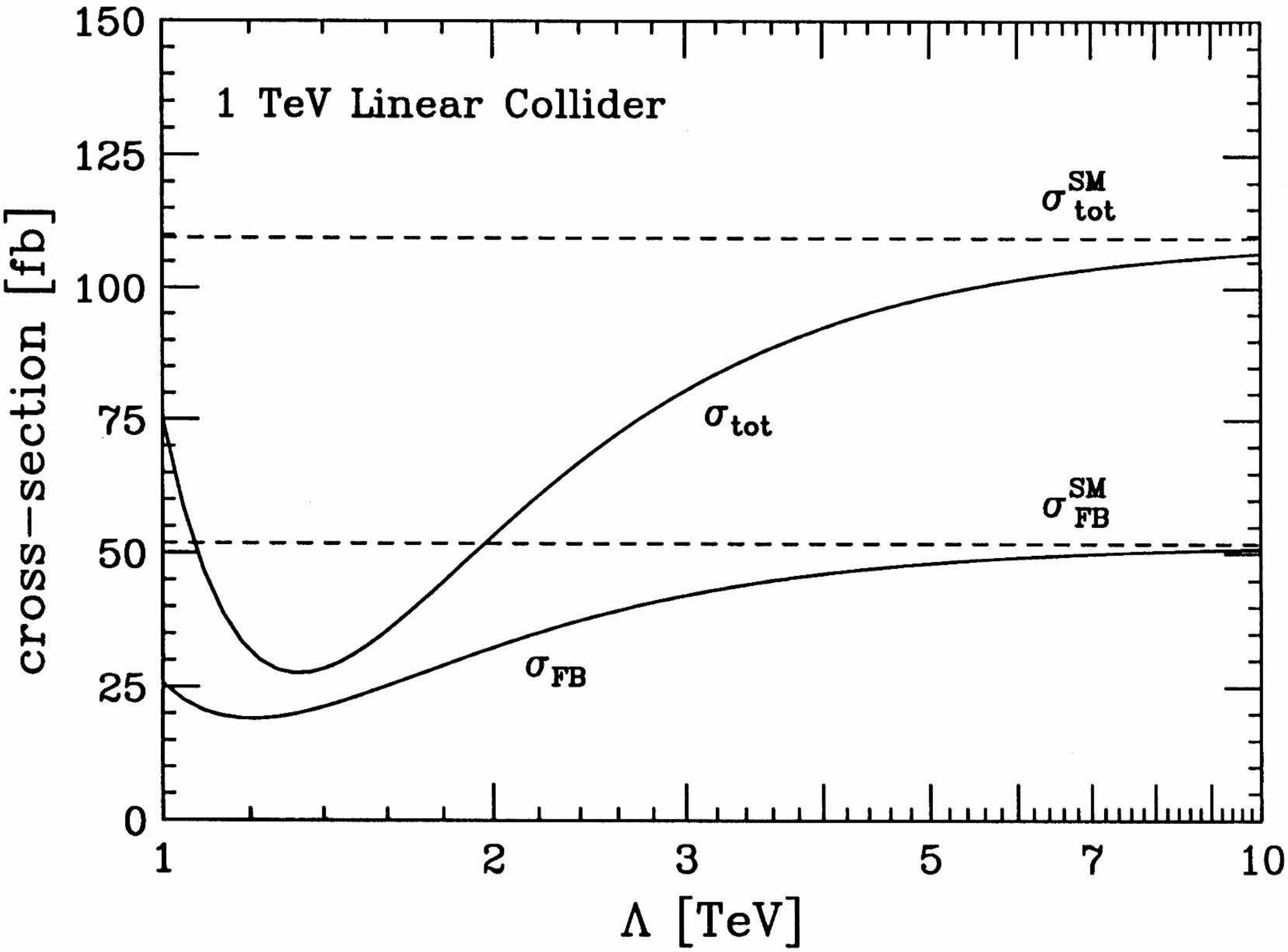




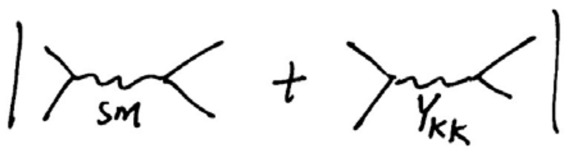
$$\sigma_{FB} = \int_0^1 d\cos\theta \, \frac{d\sigma}{d\cos\theta} - \int_{-1}^0 d\cos\theta \, \frac{d\sigma}{d\cos\theta}$$

$\Lambda \lesssim 5$ TeV probed





$\Lambda \gtrsim 10$ TeV probed

$\sigma \Rightarrow \Big|$  $\Big|^2$

$$\delta\sigma_{tot} = \delta\sigma_{tot}\left(Y_{f_L}/\Lambda, Y_{f_R}/\Lambda\right)$$

$$\delta\sigma_{FB} = \delta\sigma_{FB}\left(Y_{f_L}/\Lambda, Y_{f_R}/\Lambda\right)$$

With these two observables can determine if

$$r = \frac{Y_{f_L}}{Y_{f_R}} = \frac{+1}{2}$$

$$\frac{\delta\sigma_{FB}}{\delta\sigma_{tot}} \simeq f\left(Y_{f_L}/Y_{f_R}\right)$$

measuring $\delta\sigma_{FB}/\delta\sigma_{tot}$ to 5% $\Rightarrow$ Y_{f_L}/Y_{f_R} to ~10%.

* Linear collider very good at testing these ideas.

* More work to do to begin incorporating more realistic brane scenarios (type I string scenarios, etc.)