Precision electroweak and perturbative unitarity constraints on Warped Higgsless Models

Ben Lillie

H. Davoudiasl, J. Hewett, BL, T. Rizzo	hep-ph/0312193
H. Davoudiasl, J. Hewett, BL, T. Rizzo	hep-ph/0403300
J. Hewett, BL, T. Rizzo	hep-ph/0407059

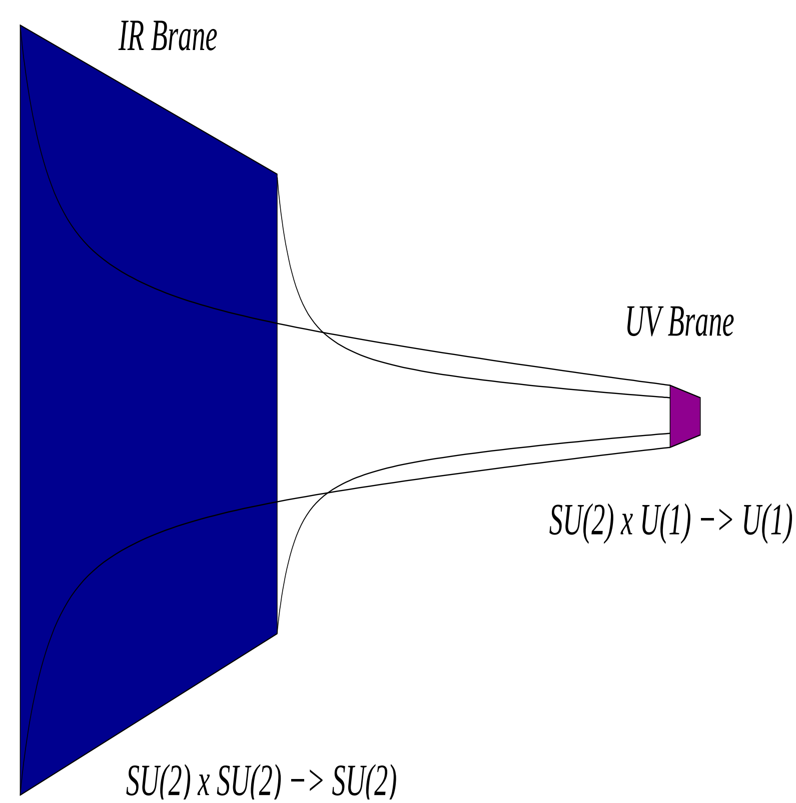
Outline

- Warped Higgsless Models
- Precision electroweak constraints
- Perturbative unitarity
- Collider Phenomenology
- Conclusion

What does the Higgs do in the Standard Model?

- Breaks electroweak symmetry $\Rightarrow m_{W,Z} \neq 0$
- Ensures unitarity of scattering amplitudes, *e.g.* $W_L W_L \rightarrow W_L W_L$
- Has custodial $SU(2)$ symmetry $\Rightarrow \rho \approx 1$.

Can we do this without a Higgs?



YES!

Boundary conditions in an extra dimension.

Csaki, Grojean, Murayama, Pilo, and Terning hep-ph/0305237

- Wavefunctions distorted

  $\Rightarrow$ masses for gauge bosons

- KK states unitarize* gauge boson scattering

- Left-right symmetric model $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

  in warped space ($\Rightarrow SU(2)_{\mathrm{custodial}}$)

Agashe, Delgado, May, Sundrum hep-ph/0308036
Csaki, Grojean, Pilo, Terning hep-ph/0308038

Parameter space

The size of the extra dimension, r_c.

Three gauge couplings g_{5L}, g_{5R}, g_{5B}.

A gauge group unbroken on a brane can have a localized kinetic term $\frac{\delta_i}{2kg_{5i}}$

IR brane: $SU(2)_L \times SU(2)_R \to SU(2)_D$.

$\Rightarrow SU(2)_D, U(1)_{B-L}$

UV brane: $SU(2)_R \times U(1)_{B-L} \to U(1)_Y$.

$\Rightarrow SU(2)_L, U(1)_Y$

$\Rightarrow$ 4 brane kinetic terms $\delta_{D,B,L,Y}$.

Use m_W, m_Z, G_F to fix three parameters. Leaves 5 free parameters:

$$\kappa \equiv g_{5R}/g_{5L}$$
$$\delta_{D,B,L,Y}.$$

Electroweak Constraints

- Require *rough* agreement with tree-level SM relations. In our scheme:

$$1 - \sin^2\theta_{\rm os} \equiv \frac{m_W^2}{m_Z^2}.$$

We can also define:

$$\sin^2\theta_{eg} \equiv \frac{e^2}{g^2_{f\bar{f}W_1}},$$

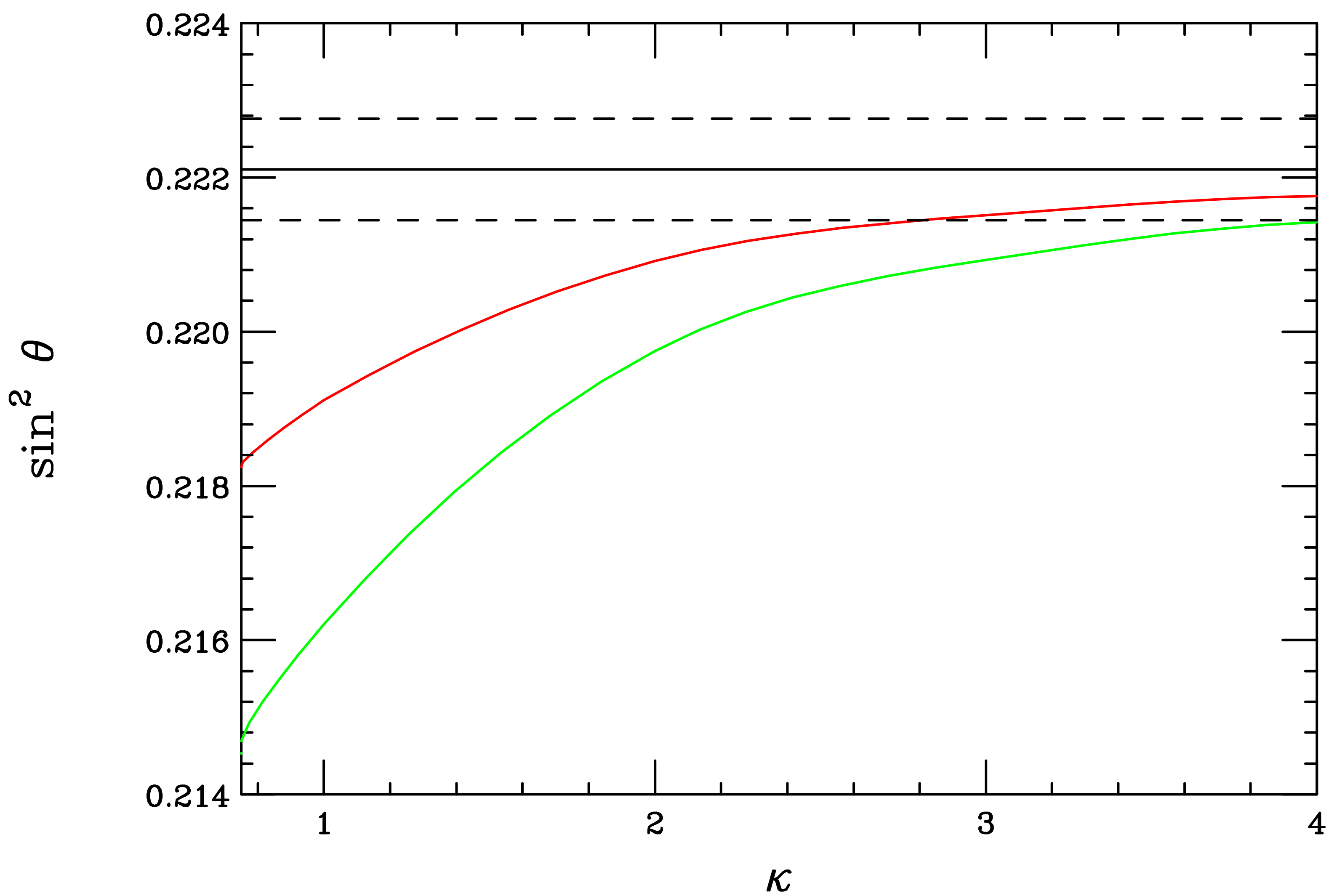
From the coupling of the neutral KKs to fermions, as measured on the Z-pole:

$$\sqrt{\rho^Z_{\rm eff}}\,\frac{g_{f\bar{f}W_1}}{c_W^{\rm os}}\left(T_{3\rm L} - \sin^2\theta_{\rm eff} Q\right)$$

- In the SM at *tree-level*, all these must be equal.

- Note

$$\rho^Z_{\rm eff} = \Gamma_\nu/\Gamma_{\nu{\rm SM}} = g^2_{Z_1 f\bar{f}}/g^2_{W_1 f\bar{f}}.$$


$\sin^2\theta$
0.224
0.222
0.220
0.218
0.216
0.214
1
2
3
4
κ

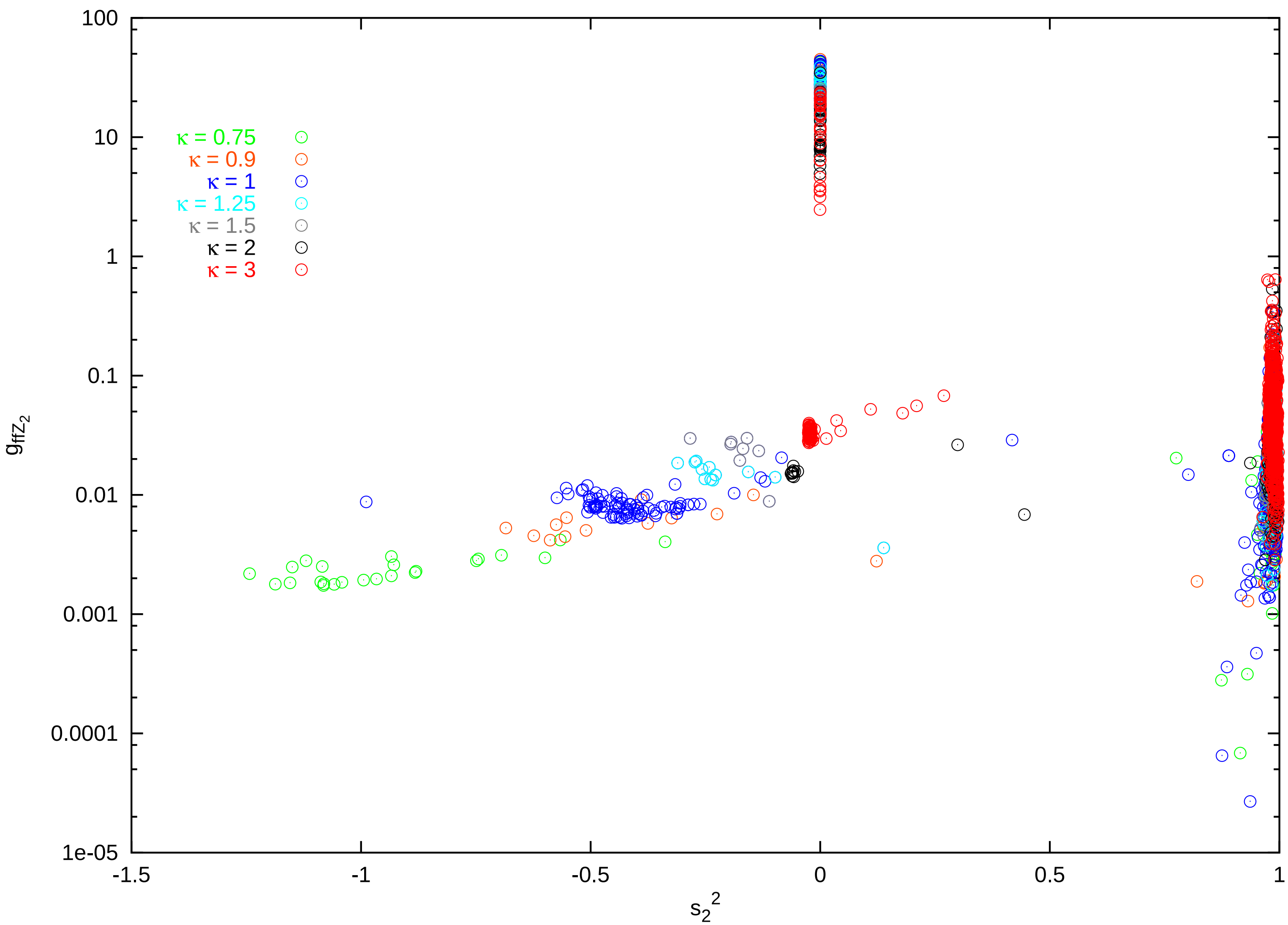
Monte Carlo

Pick parameter set $\{\kappa, \delta_i\}$, then demand

- No ghosts.
- Consistency with precision electroweak tree-level relations
  $|\delta\rho| < 0.005|, \quad \frac{|\sin^2\theta_i - \sin^2\theta_{\rm OS}|}{\sin^2\theta_{\rm OS}} < 0.005.$
- KK states not excluded by Tevatron or LEP II.
- KK states light enough and coupled correctly to help with perturbative unitarity

We tried $\sim$ 4.5 million points. About $12,000$ passed all electroweak and collider constraints. Zero passed perturbative unitarity constraints.

Points passing precision electroweak cuts



Perturbative Unitarity

We look at the S-wave partial amplitude, a_0.

$$a_0 = \frac{1}{32\pi}\int_{-1}^{1} d\cos\theta\, A(W_L^+ W_L^- \rightarrow W_L^+ W_L^-)$$

Apply the partial wave unitarity test

$$|\mathrm{Re}(a_0)| \leq \frac{1}{2}$$

All numerical calculations done independently on at least two platforms. Required agreement to 12 digits.

Expand at high $\sqrt{s}$

$$A \approx A_4 \frac{s^2}{m_W^4} + A_2 \frac{s}{m_W^2} + A_0 + \mathcal{O}(1/s)$$

Two sum rules guarantee cancellation

$$A_4 \sim g_{1111}^2 - \sum_{k=\gamma,1}^{\infty} g_{11k}^2 = 0$$

$$A_2 \sim 4m_W^2 g_{1111}^2 - 3\sum_{k=1}^{\infty} m_k^2 g_{11k}^2 = 0$$

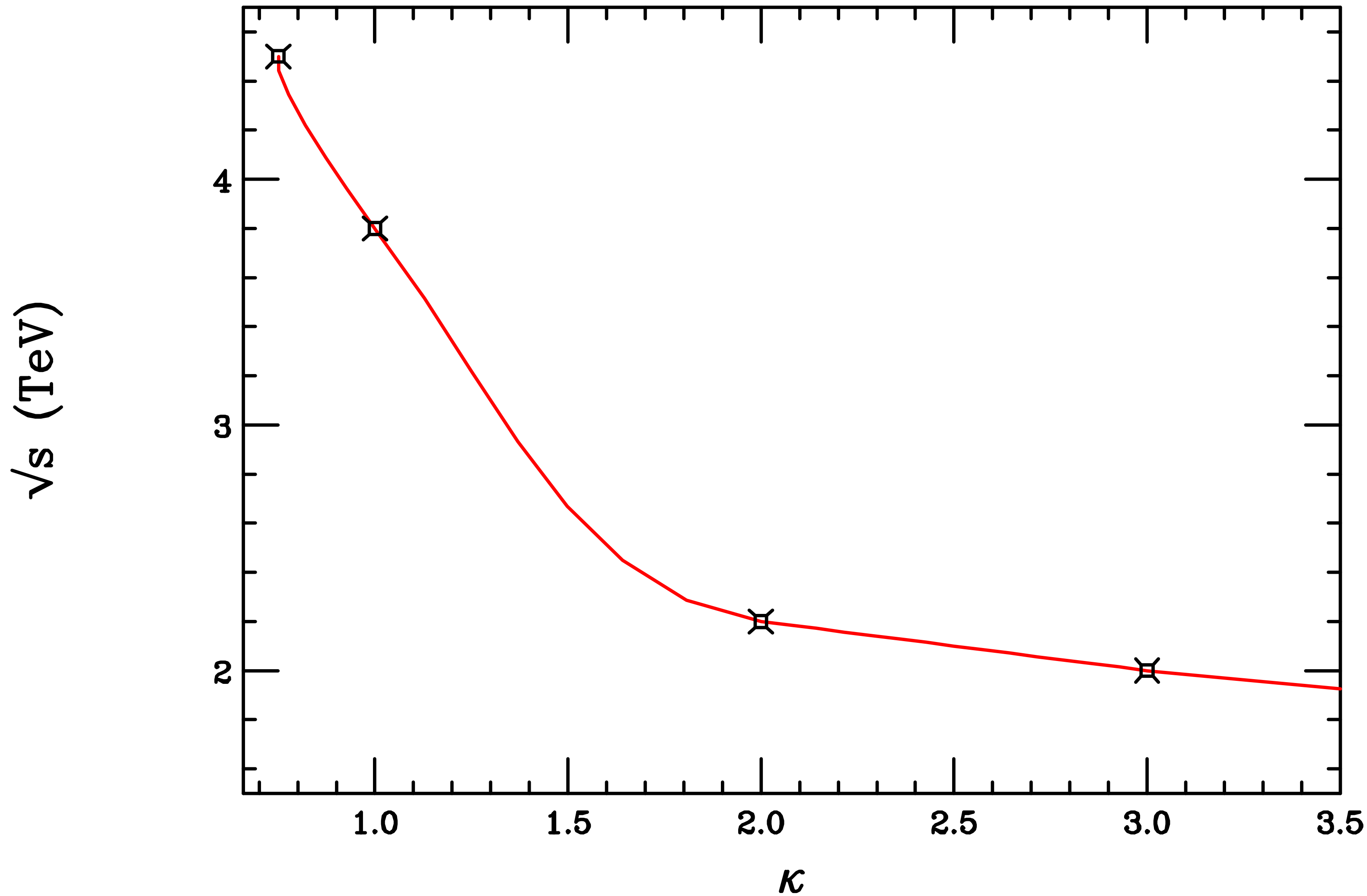
The first is zero by completeness of wavefunctions. The second is true for pure Neumann or Dirichlet boundary conditions.

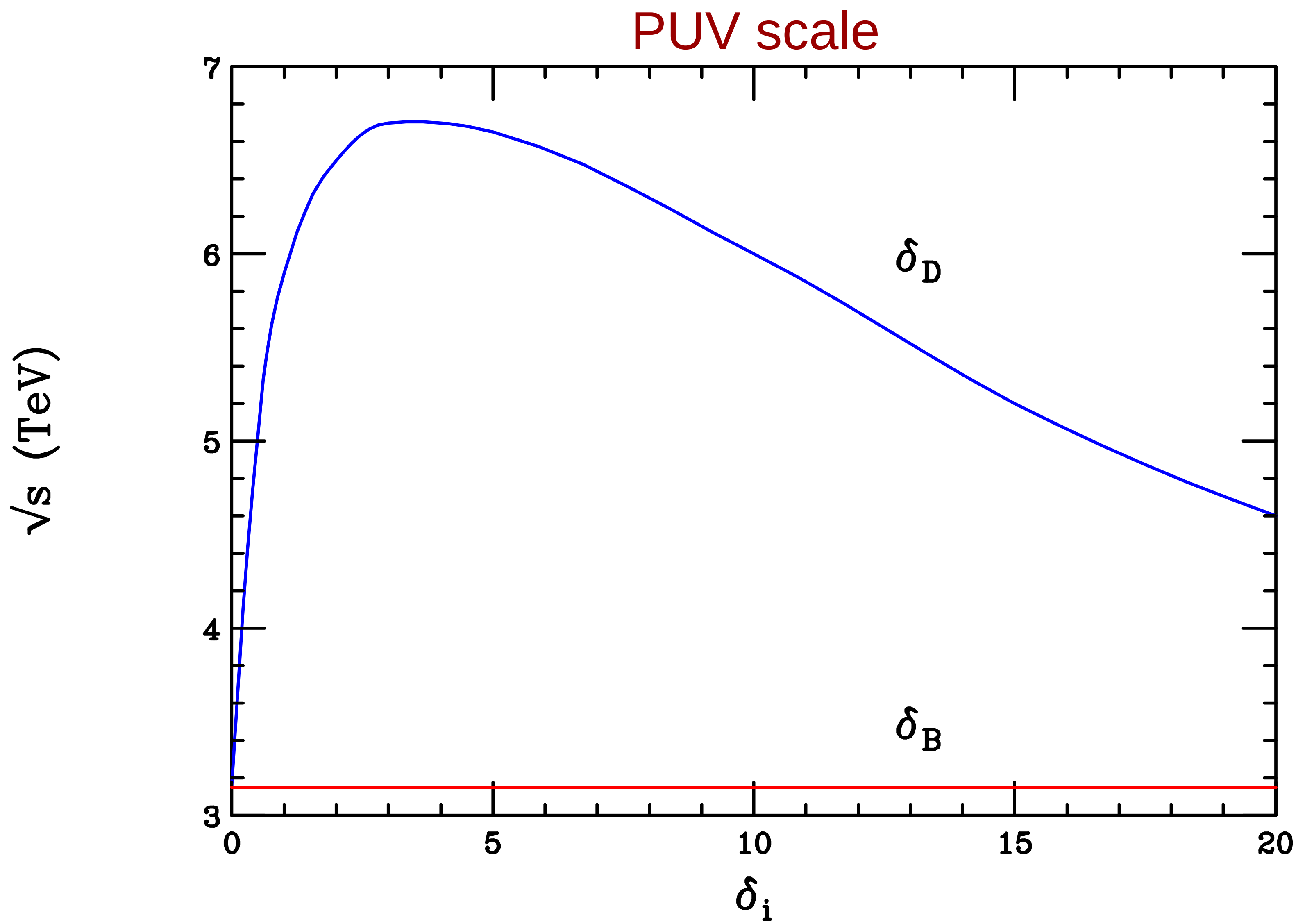
Note: these are Necessary, but not Sufficient conditions for perturbative unitarity.

hep-ph/0305237 Csaki, Grojean, Murayama, Pilo, and Terning

hep-ph/0302263 Chivukula, Dicus, He, and Nandi

PUV scale




PUV scale
√s (TeV)
δ_i
δ_D
δ_B
0
5
10
15
20
3
4
5
6
7

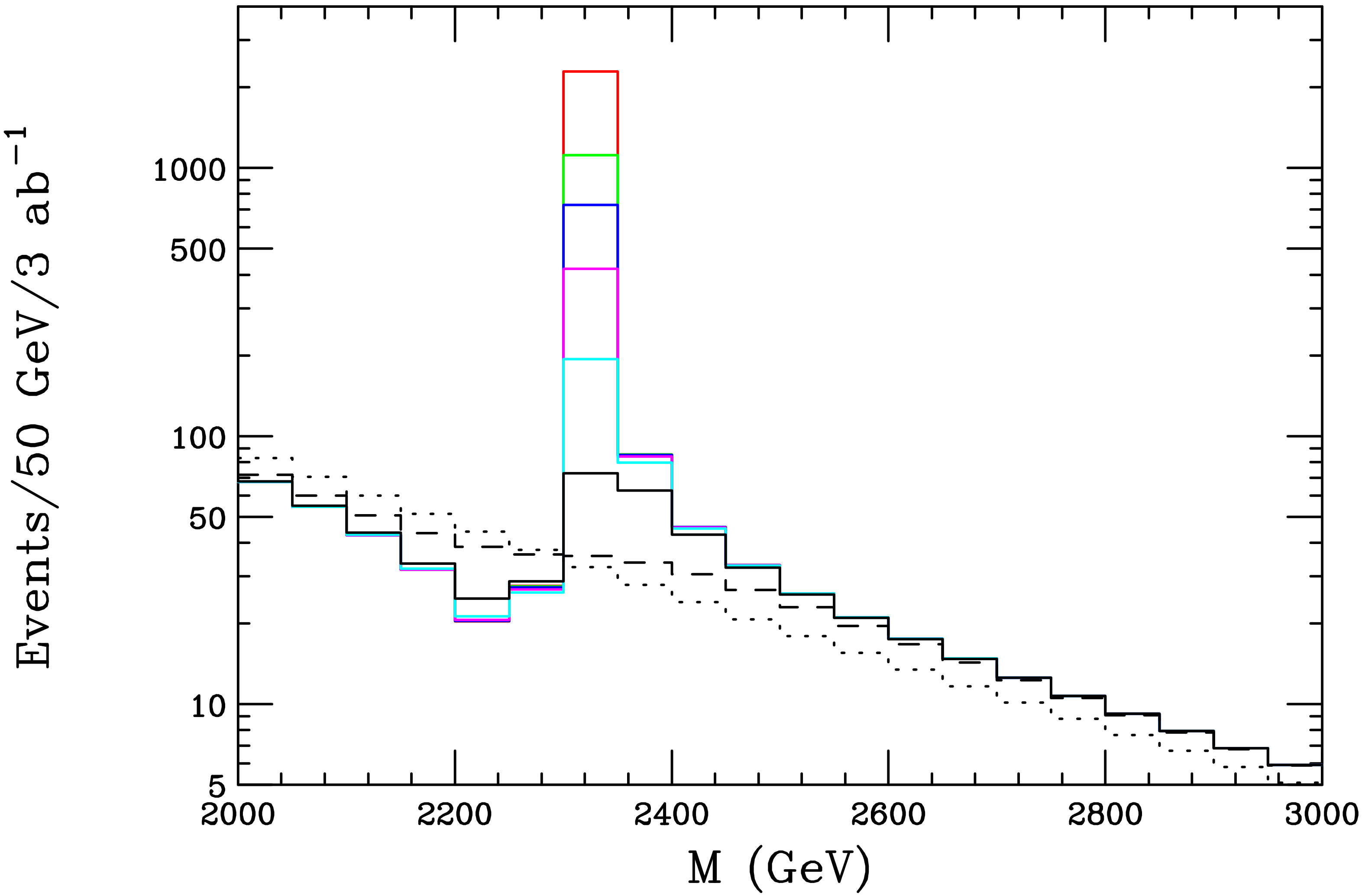
Collider Signatures

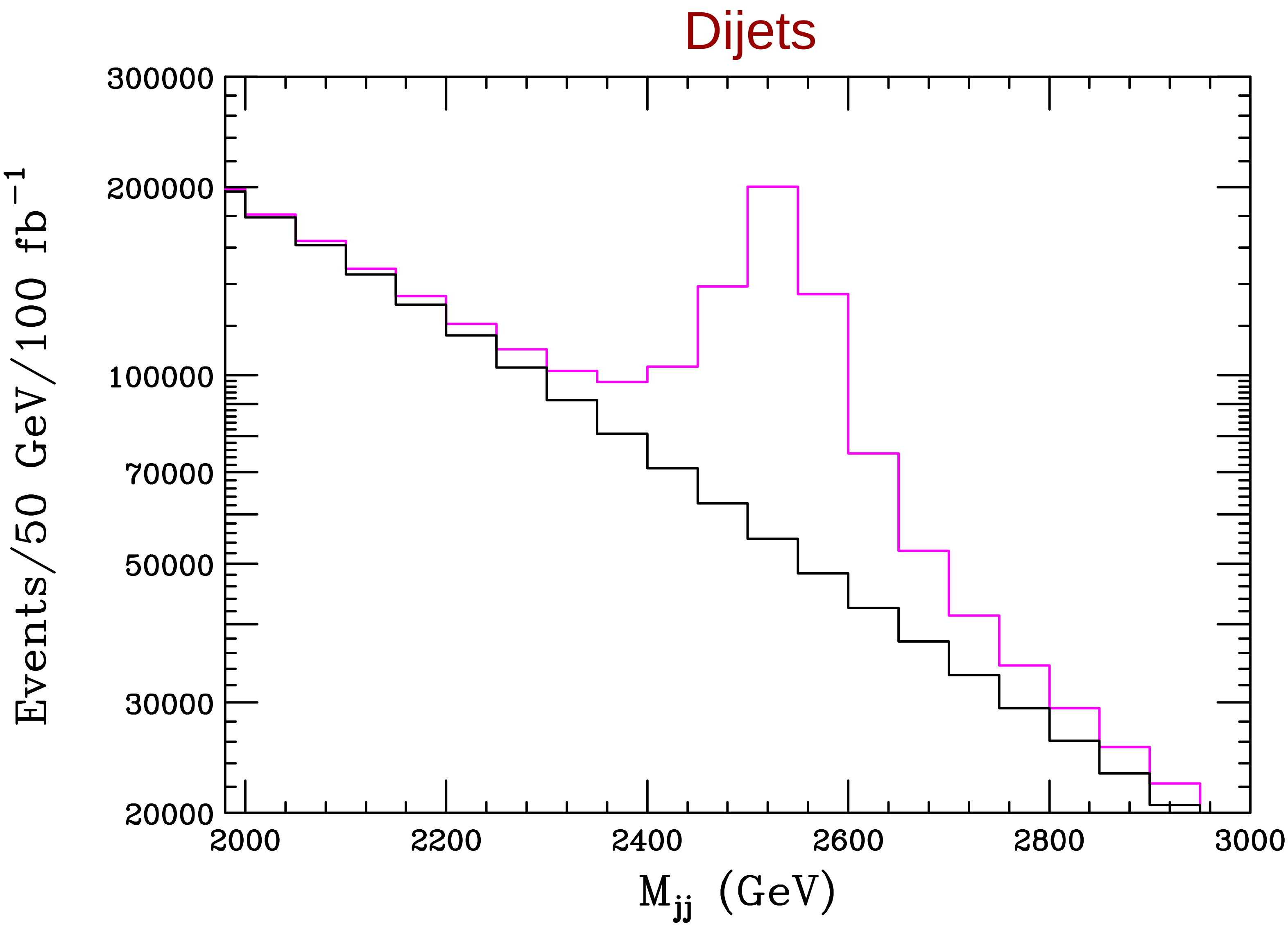
Suppose we find a resolution to the unitarity problem (Possible)

What does this model look like at colliders?

- No Higgs
- First one or two electroweak gauge boson KK modes visible at the LHC
- First two or three gluon KK modes highly visible at LHC
- Graviton KK resonances not visible
- Strong $W_L W_L$ scattering? (Depends on resolution of unitarity problem).

Drell-Yan production




Dijets
Events/50 GeV/100 fb^{-1}
300000
200000
100000
70000
50000
30000
20000
2000
2200
2400
2600
2800
3000
M_{jj} (GeV)

Conclusions

- The Warped Higgsless Model is a new approach to electroweak symmetry breaking
- Regions of parameter space are consistent with all precision electroweak and collider constraints
- Need a resolution to the perturbative unitarity problem
- Signals are easily visible at the LHC
- Very likely to be a state light enough to be produced at the LC