LHC Without a Higgs

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hep-ph/0310355

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hep-ph/0401160

hep-ph/0409126

Outline

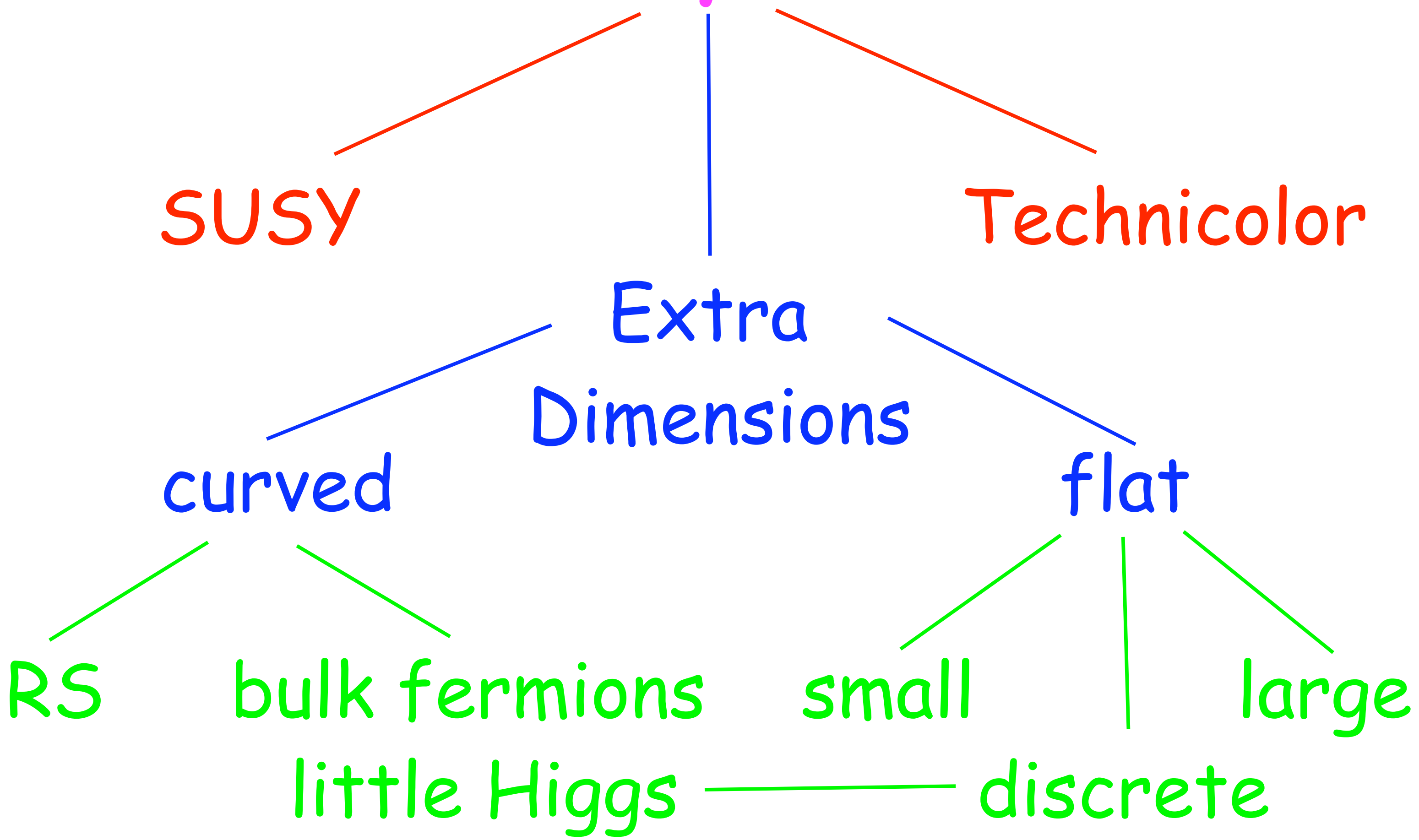
- Motivation
- Gauge Theory on an Interval
- Unitarity of WW Scattering
- LHC without a Higgs
- Conclusions

Hierarchy Problem

SUSY

Technicolor

Hierarchy Problem



Can we break Electroweak Symmetry with Boundary Conditions?

- is WW scattering unitary?
- why does $M_W^2 = \cos\theta_W M_Z^2$?
- precision electroweak measurements??

Gauge Theory on an Interval

Slice of AdS_5

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

$$R \leq z \leq R'$$

Mixed Boundary Conditions

$$\partial_z A_\mu(x,z) = -\frac{g_5^2 v^2}{2} A_\mu(x,z)$$

Dirichlet and Neumann are special cases

KK Modes

$$A^a_\mu(x,z) = \sum_n \psi^a_n(z) a_\mu(x) e^{ip_n x}, \text{ where } p_n^2 = M_n^2$$

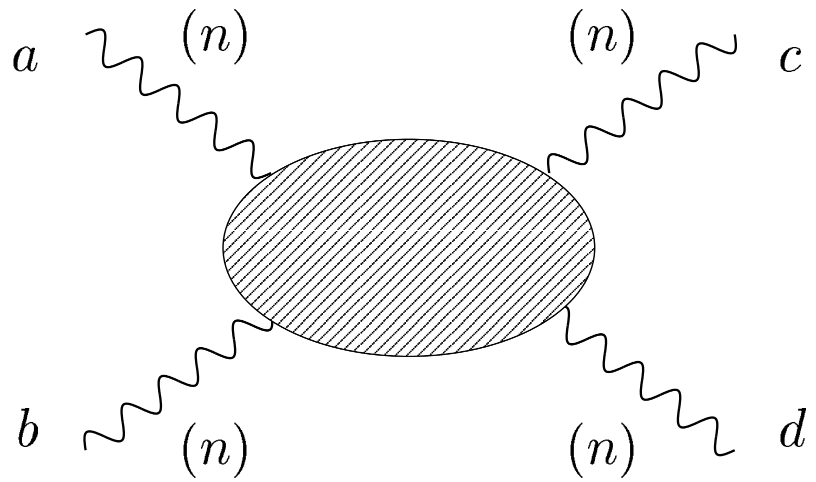
$$\left(\partial_z^2 - \frac{1}{z}\partial_z + M_n^2\right)\psi^a_n(z) = 0, \quad \psi^{a\,\prime}_n = V^a \psi^a_n$$

$$g_{cubic} \quad \longrightarrow \quad g_{mnk} = g_5 \langle \psi_m \psi_n \psi_k \rangle$$

$$g^2_{quartic} \quad \longrightarrow \quad g^2_{mnkl} = g_5^2 \langle \psi_m \psi_n \psi_k \psi_l \rangle$$

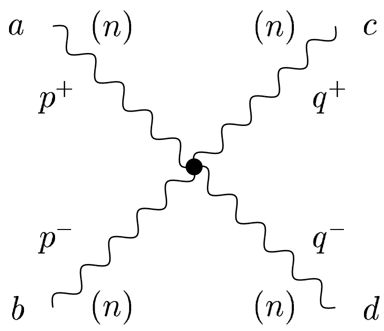
Scattering Amplitude

incoming: $p_\mu = (E, 0, 0, \pm\sqrt{E^2 - M_n^2})$
outgoing: $k_\mu = (E, \pm\sqrt{E^2 - M_n^2}\sin\theta, 0, \pm\sqrt{E^2 - M_n^2}\cos\theta)$
longitudinal polarization: $\epsilon_\mu = (\frac{|\vec{p}|}{M}, \frac{E}{M}\frac{\vec{p}}{|\vec{p}|})$

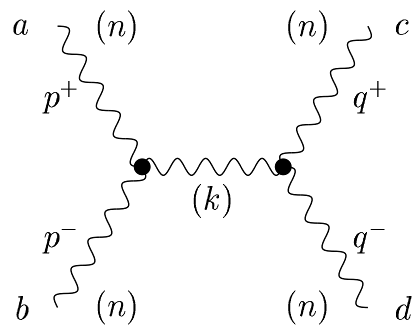


$$\mathcal{A} = A^{(4)}\frac{E^4}{M_n^4} + A^{(2)}\frac{E^2}{M_n^2} + A^{(0)} + \ldots$$

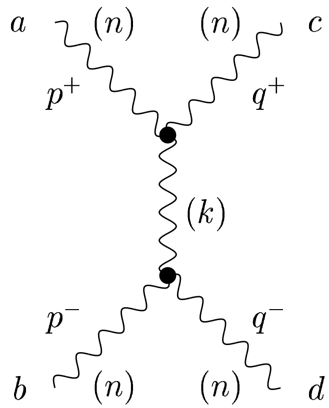
WW Scattering via KK bosons



contact interaction



s channel exchange



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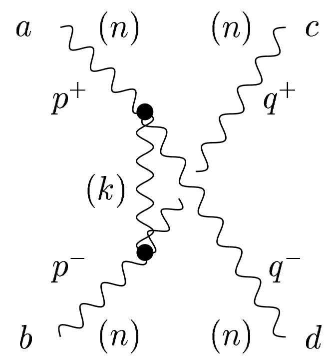


u channel exchange

Cancellation

E^4 term: $g^2_{nnnn} - \sum_k g^2_{nnk}$

$$\langle \psi_n^4(z) \rangle_z = \sum_k \langle \psi_n^2(y) \psi_n^2(z) \psi_k(y) \psi_k(z) \rangle_{y,z}$$

completeness of hermitian operator:

$$\sum_k \psi_k(y)\psi_k(z) = \delta(y-z)$$

E^2 term: $4g^2_{nnnn} M_n^2 - 3 \sum_k g^2_{nnk} M_k^2$

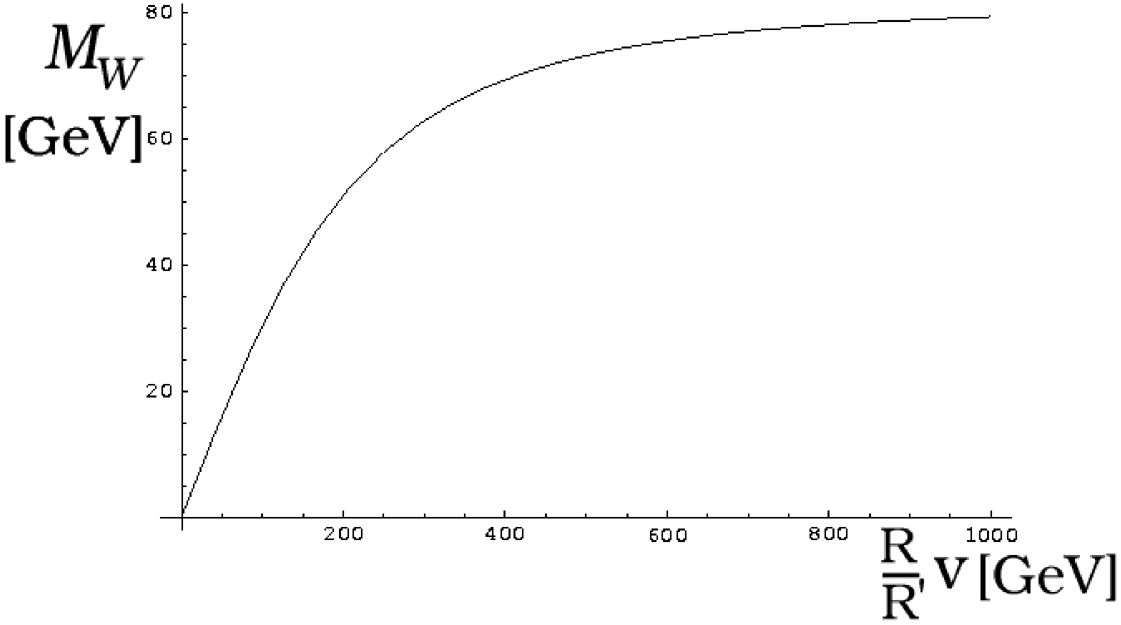
$$\begin{aligned} \sum_k M_k^2 \, \langle \psi_n^2 \psi_k \rangle^2 \quad = \quad & \tfrac{4}{3} M_n^2 \langle \psi_n^4 \rangle - \tfrac{2}{3} [\psi_n^3 \psi_n'] \\ & + 2 \sum_k [\psi_n \psi_n' \psi_k] \langle \psi_n^2 \psi_k \rangle \\ & - \sum_k [\psi_n^2 \psi_k'] \langle \psi_n^2 \psi_k \rangle \end{aligned}$$

for Dirichlet or Neumann BC's the E^2 terms cancel

Finite VEV

$$\partial_z \psi(z) = -\frac{g_5^2 v^2}{2} \psi(z)$$

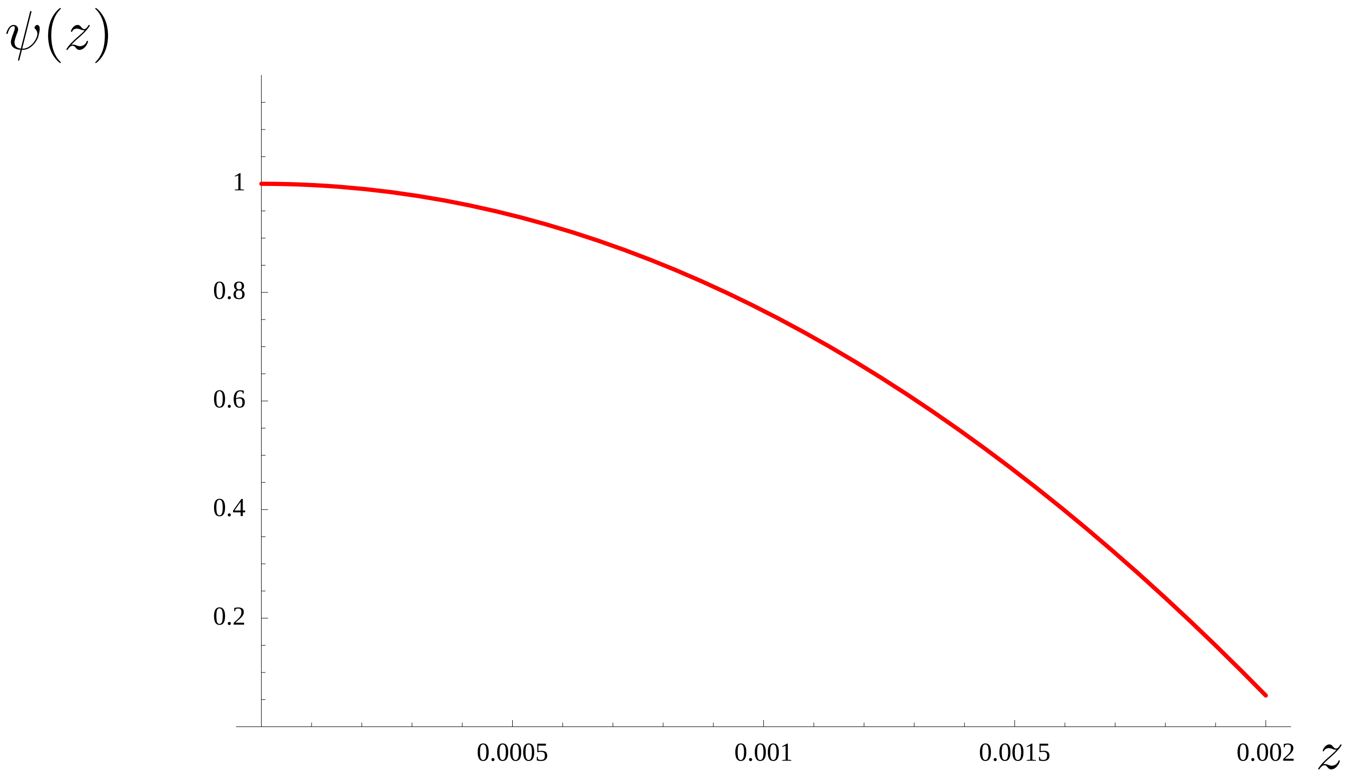
for small v: $M_W^2 = \frac{g^2 v^2}{4} \frac{R^2}{R'^2}$



for $R' = 2 \cdot 10^{-3}$ GeV^{-1}, $R = 10^{-19}$ GeV^{-1}

Decoupling the Higgs

for $v = 1$ TeV



Higgs decouples from scattering as $v \to \infty$

Towards a Realistic Model

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

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

BC's:

$$\begin{array}{rl} \text{Planck}: & A_\mu^{R\,1,2} = 0, \quad \tilde{g}_5 B_\mu - g_5 A_\mu^{R\,3} = 0 \\ \text{TeV}: & A_\mu^{L\,a} - A_\mu^{R\,a} = 0 \end{array}$$

$$\psi_k^{(A)}(z) = z\left(a_k^{(A)} J_1(q_k z) + b_k^{(A)} Y_1(q_k z)\right)$$

$$M_W^2 = \frac{1}{R'^2 \log\left(\frac{R'}{R}\right)}$$

$$M_Z^2 = \frac{g_5^2 + 2\tilde{g}_5^2}{g_5^2 + \tilde{g}_5^2} \frac{1}{R'^2 \log\left(\frac{R'}{R}\right)}$$

SM Gauge Couplings

$$
\begin{aligned}
g^2 &= \frac{\langle g_5 \psi_1^{(L\pm)} \psi_{\text{fermion}} \psi_{\text{fermion}} \rangle^2}{\langle \psi_1^{(L\pm)} \rangle^2 + \langle \psi_1^{(R\pm)} \rangle^2} = \frac{g_5^2}{R \log(R'/R)} \\
e^2 &= \frac{g_5^2 \tilde{g}_5^2}{(g_5^2 + 2\tilde{g}_5^2) R \log(R'/R)} \\
g'^2 &= \frac{g_5^2 \tilde{g}_5^2}{(g_5^2 + \tilde{g}_5^2) R \log(R'/R)}, \\
\sin\theta_W &= \frac{\tilde{g}_5}{\sqrt{g_5^2 + 2\tilde{g}_5^2}} = \frac{g'}{\sqrt{g^2 + g'^2}}
\end{aligned}
$$

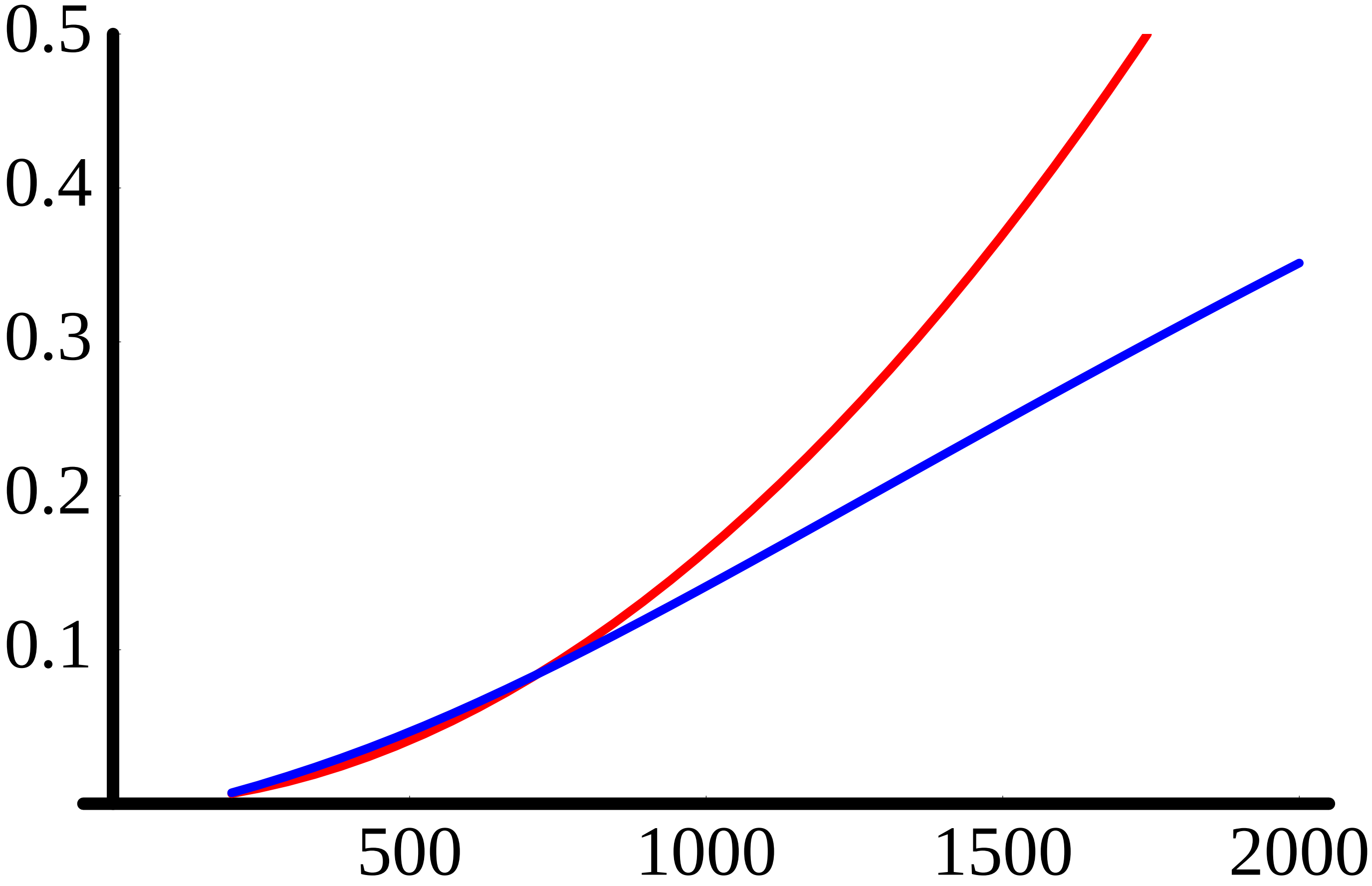
Custodial Symmetry

$$
\cos^2\theta_W = \frac{g_5^2 + \tilde{g}_5^2}{g_5^2 + 2\tilde{g}_5^2},
$$

$$
M_W^2 = \frac{1}{R'^2 \log\left(\frac{R'}{R}\right)}, \quad M_Z^2 = \frac{g_5^2 + 2\tilde{g}_5^2}{g_5^2 + \tilde{g}_5^2} \frac{1}{R'^2 \log\left(\frac{R'}{R}\right)}
$$

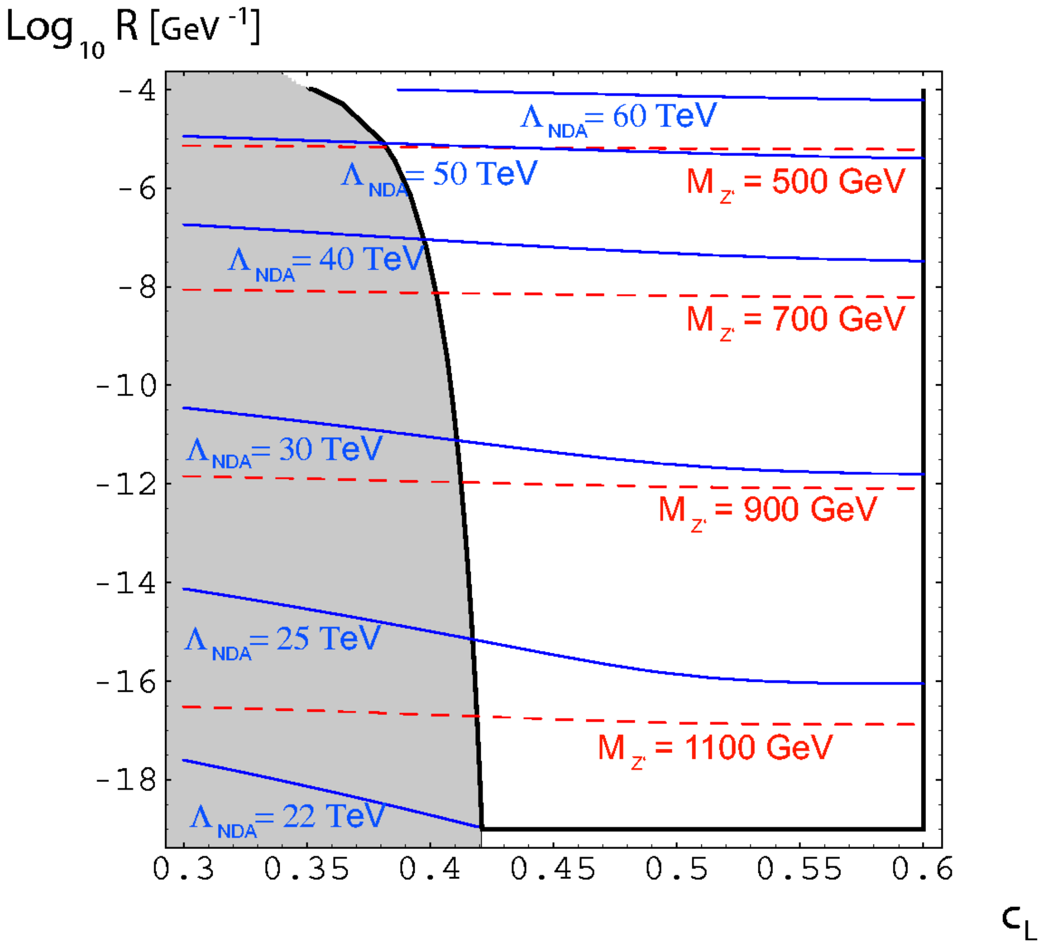
Hence $\rho = \frac{M_W^2}{M_Z^2 \cos^2\theta_W} = 1$

Scattering Amplitude

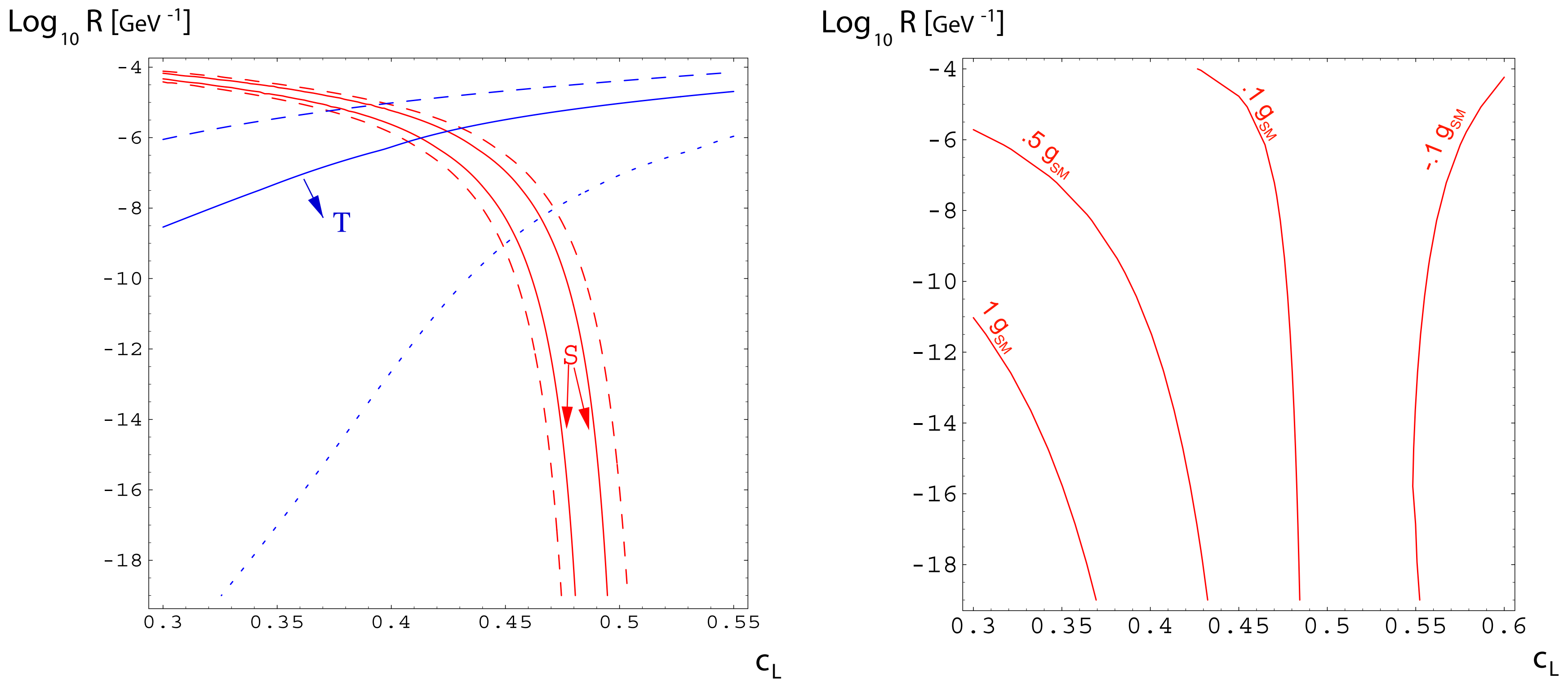


Perturbative Unitarity

$$\Lambda_{\mathrm{NDA}} \sim \frac{24\pi^3}{g_5^2}\frac{R}{R'} \sim \frac{12\pi^4 M_W^2}{g^2 M_{W'}} = \mathcal{O}\left(\frac{12\pi^4 R'}{\log(R'/R)}\right)$$



Light Resonances, Small S

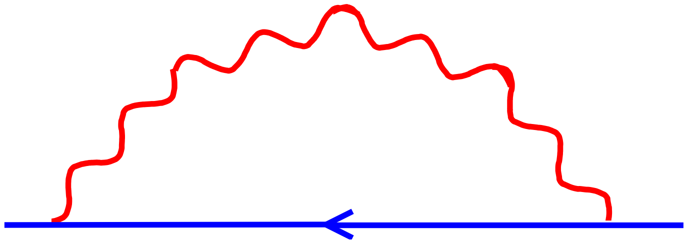


Remaining Problem

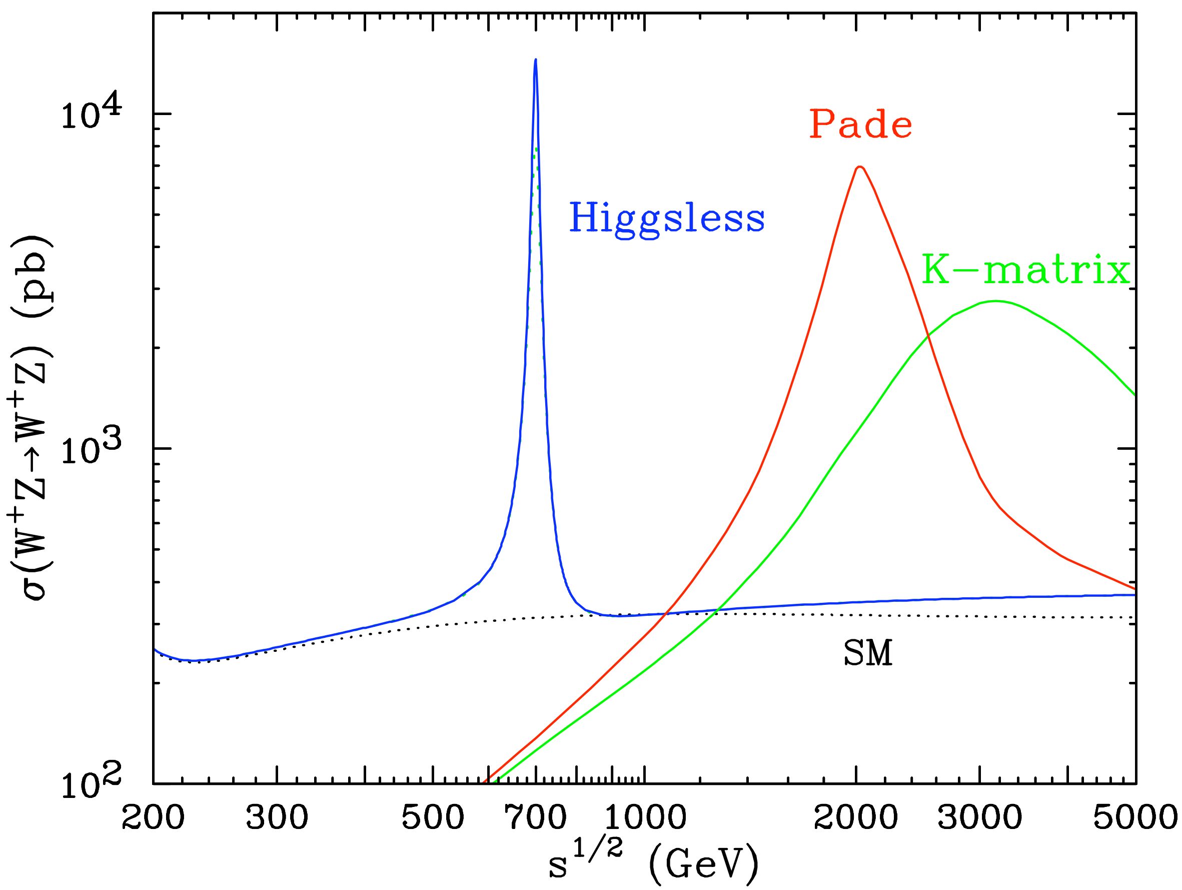
heavy top without messing up $Zb\bar{b}$

1) Higgs profile in bulk, finite VEV

2) Radiative top mass generation

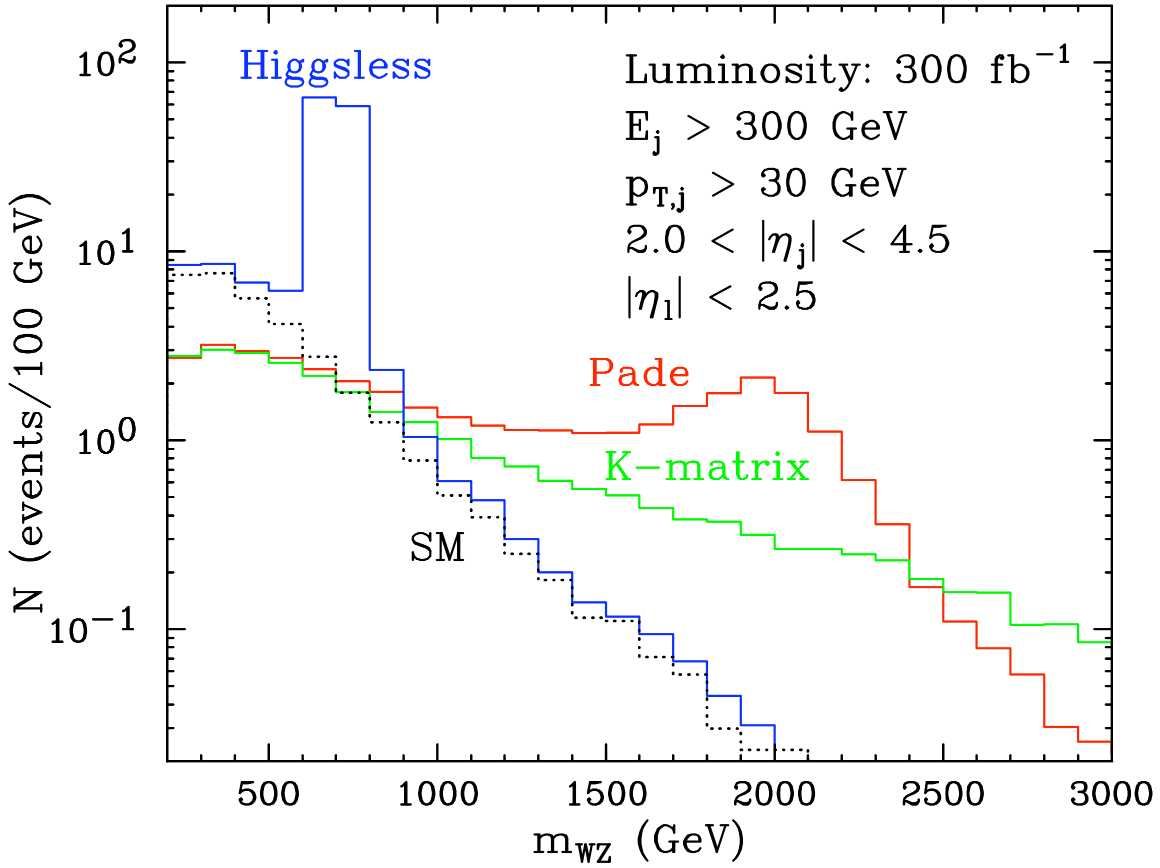


WZ Cross-Section



Birkedal, Matchev, Perelstein, hep-ph/0308038

LHC Signal



Birkedal, Matchev, Perelstein, hep-ph/0308038

Conclusions

- BC's can be used to break electroweak symmetry
- WW scattering can be unitarized without a Higgs
- models with custodial symmetry exist
- oblique corrections can be small