Extra Dimensional Models for TeV-scale Physics

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Outline

- Motivation
- Realistic RS models
- Flavor Models from warped models
- Higgsless models
- Composite Higgs
- AdS/QCD?

1. Motivation: the little hierarchy

- Expect new TeV scale physics solves the hierarchy problem
- However, have not seen any trace of new TeV scale physics at LEP or Tevatron (“LEP paradox”)
- Generic new TeV scale physics tightly constrained:

Dimensions six operators	$m_h = 115\ GeV$		$m_h = 300\ GeV$		$m_h = 800\ GeV$	
	$c_i = -1$	$c_i = +1$	$c_i = -1$	$c_i = +1$	$c_i = -1$	$c_i = +1$
$(H^\dagger \tau^a H) W^a_{\mu\nu} B_{\mu\nu}$	9.7	10	7.5			
$\lvert H^\dagger D_\mu H \rvert^2$	4.6	5.6	3.4		2.8	
$\frac{1}{2}(\bar{L}\gamma_\mu \tau^a L)^2$	7.9	6.1				
$i(H^\dagger D_\mu \tau^a H)(\bar{L}\gamma_\mu \tau^a L$	8.4	8.8	7.5			
$i(H^\dagger D_\mu \tau^a H)(\bar{Q}\gamma_\mu \tau^a Q)$	6.6	6.8				
$i(H^\dagger D_\mu H)(\bar{L}\gamma_\mu L)$	7.3	9.2				
$i(H^\dagger D_\mu H)(\bar{Q}\gamma_\mu Q)$	5.8	3.4				
$i(H^\dagger D_\mu H)(\bar{E}\gamma_\mu E)$	8.2	7.7				
$i(H^\dagger D_\mu H)(\bar{U}\gamma_\mu U)$	2.4	3.3				
$i(H^\dagger D_\mu H)(\bar{D}\gamma_\mu D)$	2.1	2.5				

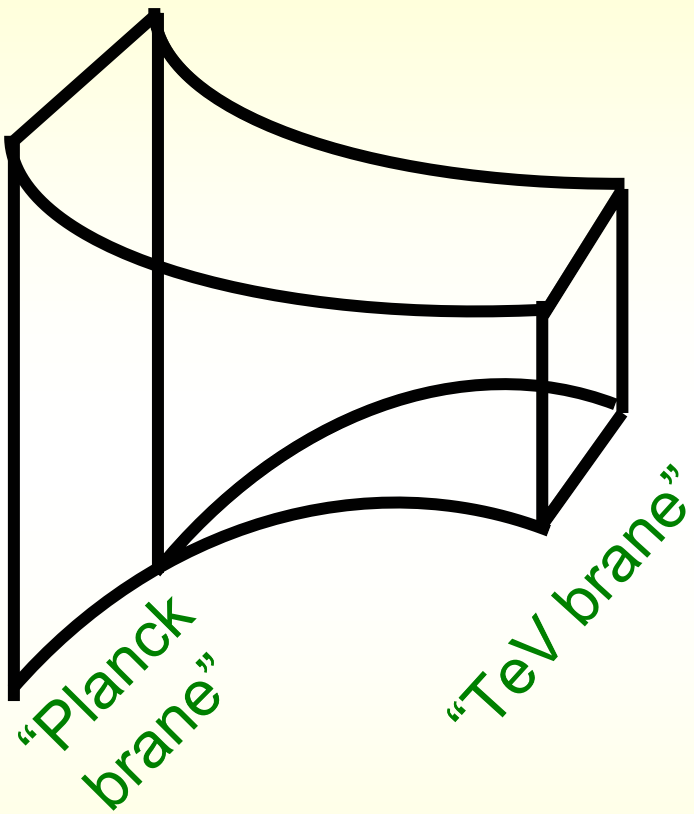
(Barbieri & Strumia ’99)

- Generic new physics is allowed only at 5-10 TeV

- **Little hierarchy**: why have we not seen indirect effects already (if it comes in at 1 TeV)?

- Flavor constraints could of course be much stronger, up to 10^5 TeV constraints possible…

2. Realistic warped models

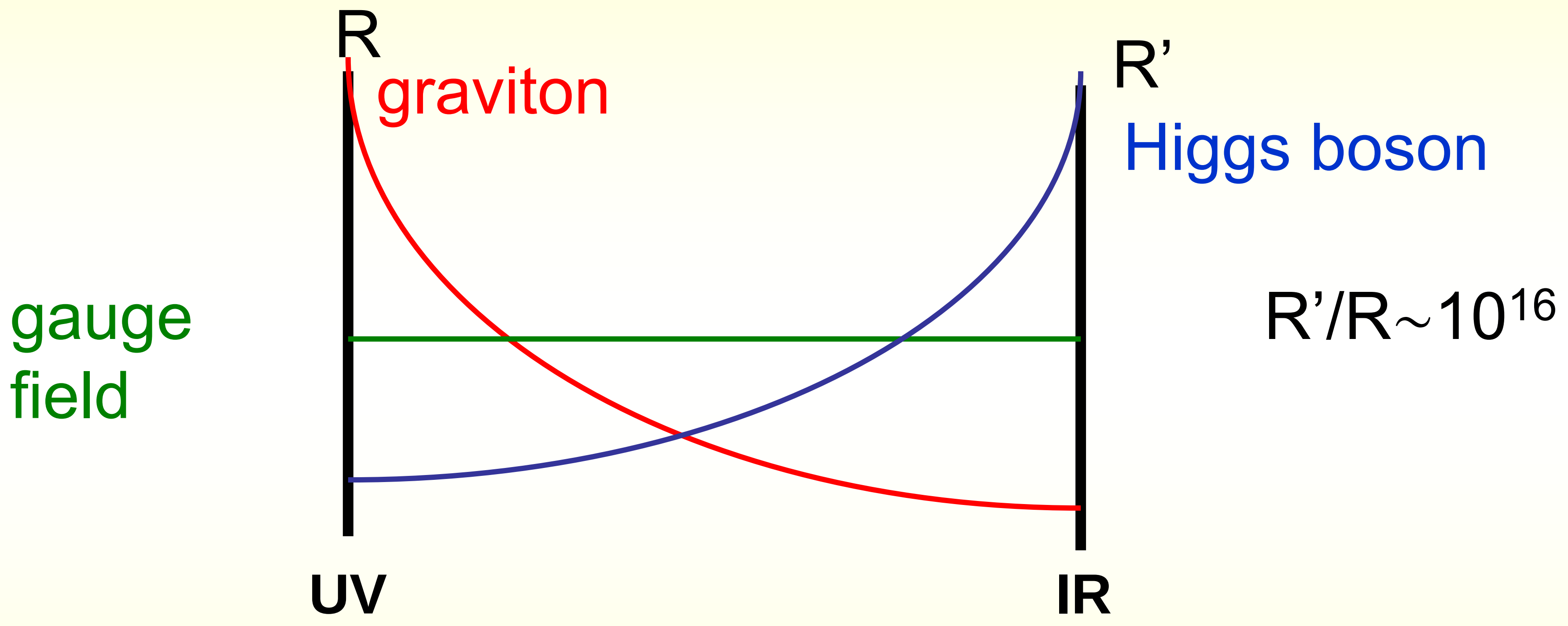


(Randall,Sundrum; Maldacena;…)

- Metric exponentially falling

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

- Mass scales very different at endpoints
- Graviton peaked at Planck
- Gauge field flat
- Higgs peaked at TeV

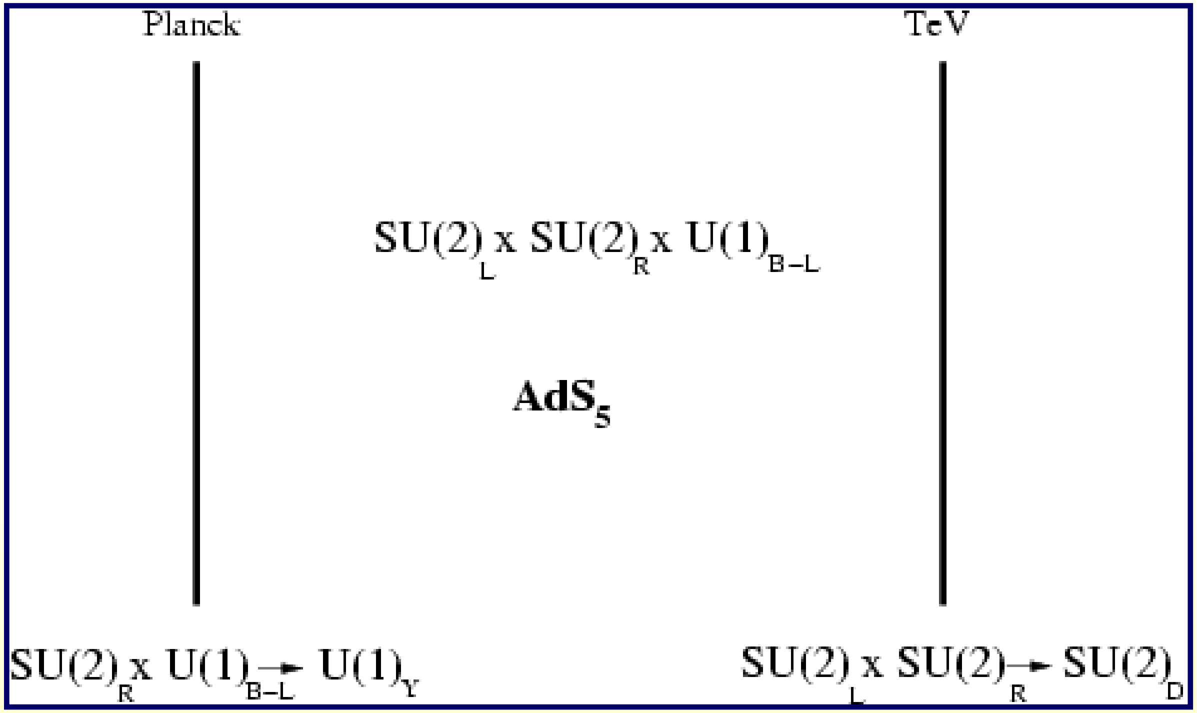


Solves the hierarchy problem.

But: electroweak precision? If all fields on IR brane expect large EWP contributions, large FCNC's

Realistic RS models

- Need to put fermions away from IR brane for FCNC
- To protect T-parameter need to include $SU(2)_R$ custodial symmetry

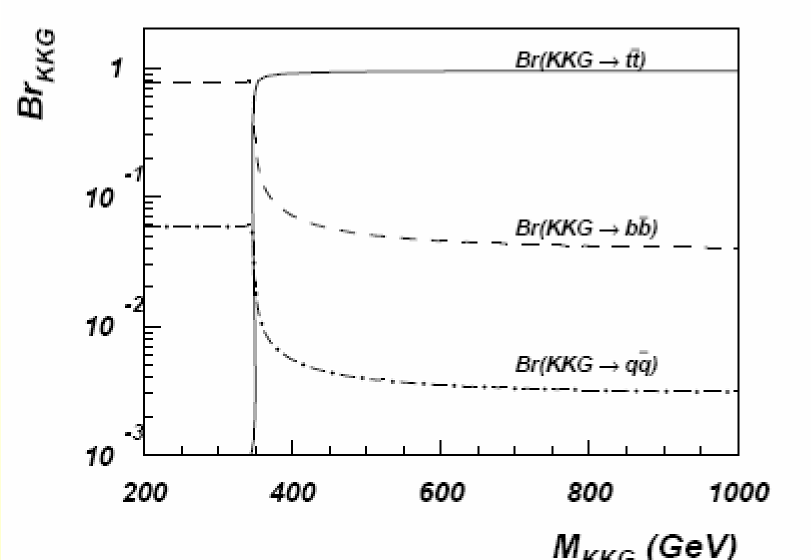


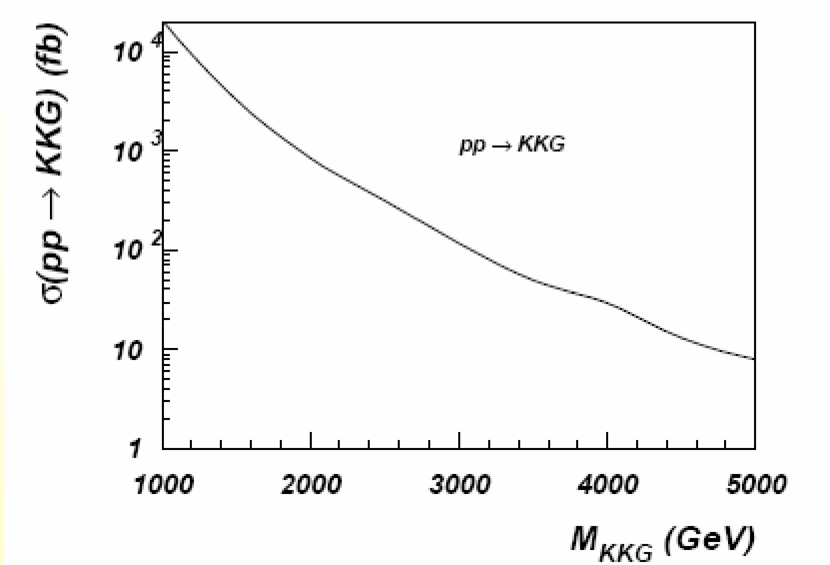
(Agashe, Delgado, May, Sundrum)

- $S \sim 12\pi\, v^2/m_{KK}^2$ Bound m_{KK}>3 TeV
- T parameter at tree level suppressed

(Carena,Delgado, Ponton,Tait, Wagner)

- Signals:
- Light top partners
- 3 TeV KK gluon, but mostly coupled to t_R





(From Agashe, Belyaev, Krupvnickas, Perez, Virzi; see also Davoudiasl, Randall, Wang)

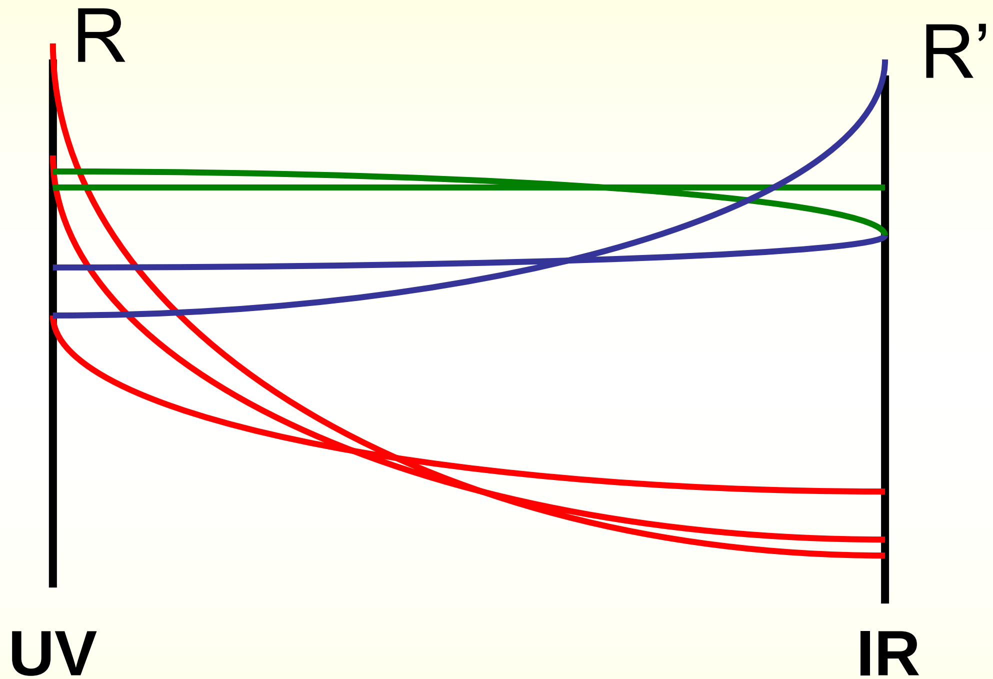
- Little hierarchy: NOT solved here either
- Cutoff scale: $$\Lambda \sim \frac{16\pi^2}{g^2 R' \log \frac{R'}{R}} \sim 10 - 100 \text{ TeV}$$
- Natural Higgs mass $m_H \sim \Lambda/(4\pi) > 1$ TeV
- Can give theory of flavor – next topic
- To also solve little hierarchy:

  Higgsless (gauge-phobic)

  Pseudo-Goldstone Higgs

3. Flavor from warped extra dim's (Hierarchies w/o symmetries)

Wavefunction overlap generates hierarchies



R'/R$\sim 10^{16}$

—— Light fermions
—— Top quark
—— Gauge bosons (γ, W,Z,g)

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

(Arkani-Hamed, Schmaltz; Grossman, Neubert; Gherghetta, Pomarol)

- For c>1/2: fermions localized exponentially on Planck brane
- For c<1/2 fermions localized on TeV brane

- Light fermions: on UV brane, $\mathcal{O}(1)$ differences in c result in hierarchies

- Top right should be on IR brane to ensure heavy top mass

•Fermion wave function on TeV brane:

$$f(c) = \frac{\sqrt{1-2c}}{\left[1-(\frac{R'}{R})^{2c-1}\right]^{\frac{1}{2}}}$$

~ √(1-2c) for c<1/2

~√(2c-1) (R/R')$^{c-1/2}$

•Structure of Yukawa matrix on TeV brane:

$$m_u^{SM} = \frac{v}{\sqrt{2}} f_q \tilde{Y}_u f_{-u},$$

$$m_d^{SM} = \frac{v}{\sqrt{2}} f_q \tilde{Y}_d f_{-d}$$

Anarchic flavor model:

- **Assume all 5D Yukawa couplings $\mathcal{O}$(1) in natural units**

- **The flavor hierarchies in the masses and mixing angles all arise from the c's**

• Hierarchical eigenvalues

$$(m_{u,d})_{ii} \sim \frac{v}{\sqrt{2}} Y_* f_{q_i} f_{-u_i,d_i}$$

• AND hierarchical mixing angles (Huber)

$$|U_{L\ ij}| \sim \frac{f_{q_i}}{f_{q_j}}, \quad |U_{R\ ij}| \sim \frac{f_{-u,d_i}}{f_{-u,d_j}}, \quad i \leq j$$

• Have 9 unknown c's: can exactly fit 6 masses and 3 mixing angles. Predicts hierarchical masses and mixings, but no specific relation, except that $V_{13}/V_{23} \sim V_{12}$ perfect!

- To fit V_{CKM} of the form

$$V_{CKM} \sim \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & \lambda^3 \\ \lambda & 1-\frac{\lambda^2}{2} & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

- We need for mixing angles

$$f_{q_2}/f_{q_3} \sim \lambda^2, \qquad f_{q_1}/f_{q_3} \sim \lambda^3$$

- Remaining c's fixed by mass eigenvalues

$$f_{-d_3} \sim \frac{m_b}{m_t}, \quad f_{-u_2} \sim \frac{m_c}{m_t}\frac{1}{\lambda^2}, \quad f_{-d_2} \sim \frac{m_s}{m_t}\frac{1}{\lambda^2}, \quad f_{-u_1} \sim \frac{m_u}{m_t}\frac{1}{\lambda^3}, \quad f_{-d_1} \sim \frac{m_d}{m_t}\frac{1}{\lambda^3}$$

- Good theory of flavor, but we want more: also (or mostly) want to explain hierarchy problem, scale TeV

A numerical example

Flavor	$c_Q,\ f_Q$	$c_u,\ f_u$	$c_d,\ f_d$
I	$0.64, 0.002$	$0.68,\ \ 7\,10^{-4}$	$0.65, 2\,10^{-3}$
II	$0.59, 0.01$	$0.53, 0.06$	$0.60, 0.008$
III	$0.46,\ \ 0.2$	- $0.06, 0.8$	$0.58, 0.02$

The constraints on RS flavor from FCNC's

(Falkowski, Weiler, C.C.)

- Coupling to heavy gauge bosons in gauge basis diagonal but flavor dependent. Eg. KK gluon:

$$g_x \approx g_{s*} \left(-\frac{1}{\log R'/R} + f_x^2 \gamma(c_x) \right)$$

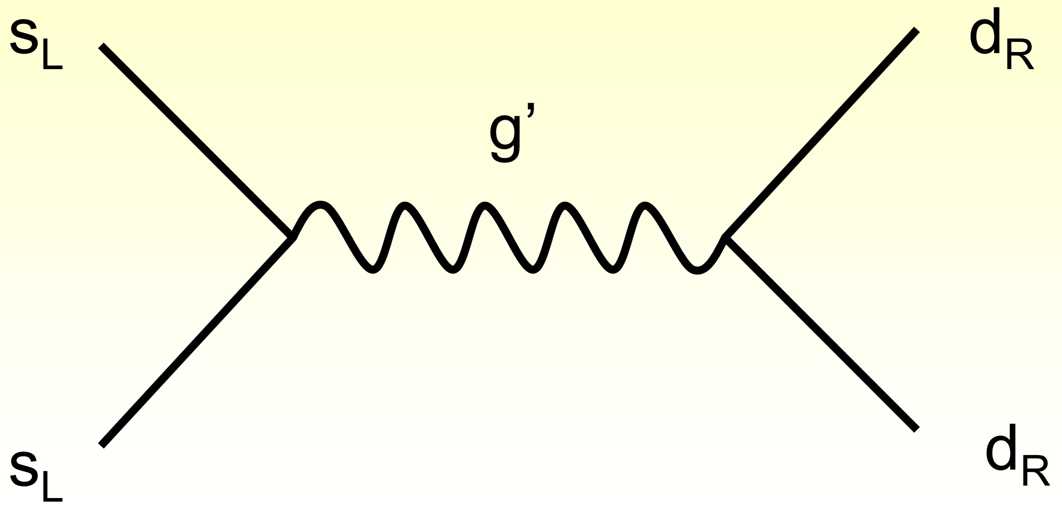
- Structure of coupling after flavor rotations

$$g^{ij}_{L,u} \bar{u}^i_L \gamma_\mu G^{\mu(1)} u^j_L + g^{ij}_{L,d} \bar{d}^i_L \gamma_\mu G^{\mu(1)} d^j_L + (L \to R)$$

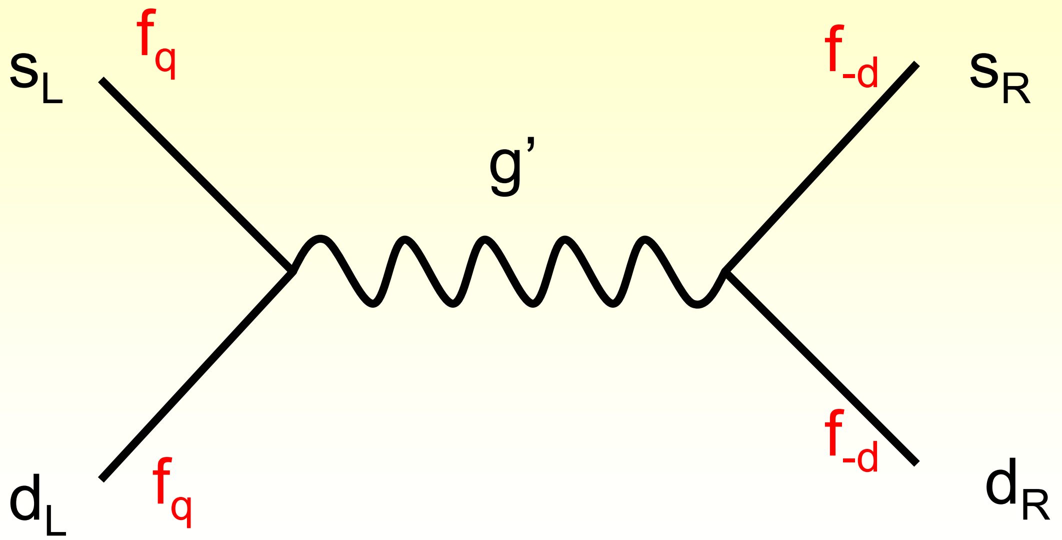
Where

$$(g_{L,q})_{ij} \sim g_{s*} f_{q_i} f_{q_j} \quad (g_{R,u})_{ij} \sim g_{s*} f_{-u_i} f_{-u_j} \quad (g_{R,d})_{ij} \sim g_{s*} f_{-d_i} f_{-d_j}$$

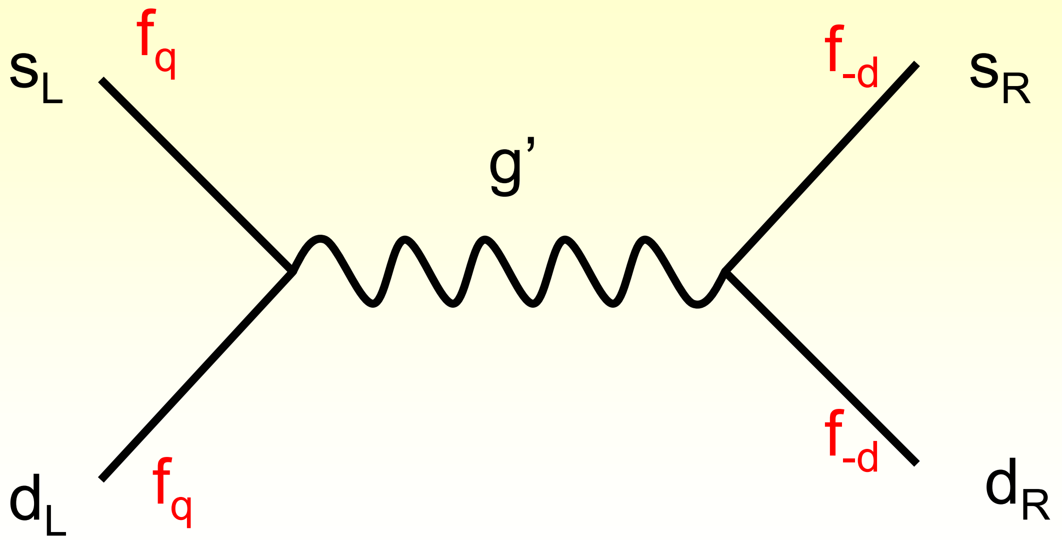
- RS GIM! FCNC's suppressed by f's as well! But is enough?



s_L
d_R
g'
s_L
d_R



after rotation at every leg gets
f(c) factor suppressing operator



RS GIM: after rotation at every leg gets f(c) factor suppressing operator

(Gherghetta, Pomarol; Agashe, Perez, Soni)

- RS-GIM makes it possible for scale to be quite low, M_{KK}~few 10 TeV
- Generic expressions for FCNC 4-Fermi op's:

$$\frac{g_{s*}^2}{M_G^2} f_{q_1} f_{q_2} f_{-d_1} f_{-d_2} \sim \frac{1}{M_G^2} \frac{g_{s*}^2}{Y_*^2} \frac{2 m_d m_s}{v^2}$$

- Since $m_d = Y_* v f_Q f_{-d}/\sqrt{2}$
- RS-GIM greatly reduces FCNC's
- But: is it enough to make it a viable model of flavor AND of the hierarchy problem at the SAME time?

•Effective 4-fermi operators generated:

$$\mathcal{H} = \frac{1}{M_G^2}\left[\frac{1}{6}g_L^{ij}g_L^{kl}(\bar{q}_L^{i\alpha}\gamma_\mu q_{L\alpha}^j)\ (\bar{q}_L^{k\beta}\gamma^\mu q_{L\beta}^l) - g_R^{ij}g_L^{kl}\left((\bar{q}_R^{i\alpha}q_{L\alpha}^k)\ (\bar{q}_L^{l\beta}q_{R\beta}^j) - \frac{1}{3}(\bar{q}_R^{i\alpha}q_{L\beta}^l)\ (\bar{q}_L^{k\beta}q_{R\alpha}^j)\right)\right]$$
$$= C^1(M_G)(\bar{q}_L^{i\alpha}\gamma_\mu q_{L\alpha}^j)\ (\bar{q}_L^{k\beta}\gamma^\mu q_{L\beta}^l) + C^4(M_G)(\bar{q}_R^{i\alpha}q_{L\alpha}^k)\ (\bar{q}_L^{l\beta}q_{R\beta}^j) + C^5(M_G)(\bar{q}_R^{i\alpha}q_{L\beta}^l)\ (\bar{q}_L^{k\beta}q_{R\alpha}^j)$$

•In particular we get estimate for $C^4{}_K$:

$$C_{4K}^{RS} \sim \frac{g_{s*}^2}{M_G^2} f_{q_1} f_{q_2} f_{-d_1} f_{-d_2} \sim \frac{1}{M_G^2}\frac{g_{s*}^2}{Y_*^2}\frac{2m_d m_s}{v^2}$$

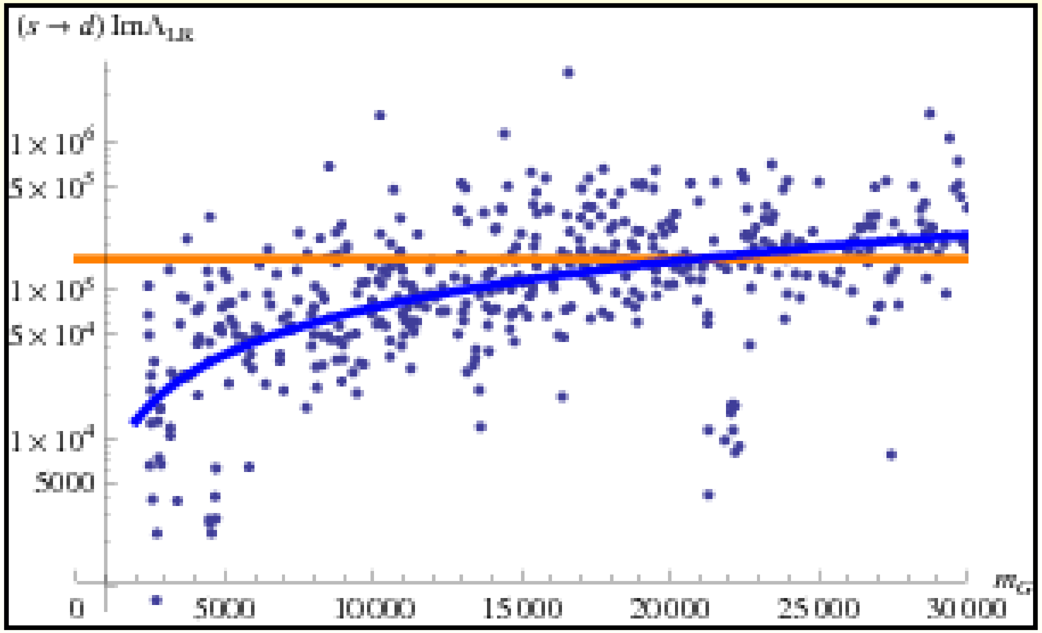
•This will have both real AND O(1) imaginary parts, Many new physical phases will appear

Bounds vs. RS GIM suppression scales

Parameter	Limit on Λ_F (TeV)	Suppression in RS (TeV)
$\mathrm{Re}C_K^1$	$1.0 \cdot 10^3$	$\sim r/(\sqrt{6}\,\lvert V_{td}V_{ts}\rvert f_{q3}^2) = 23 \cdot 10^3$
$\mathrm{Re}C_K^4$	$12 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{2\,m_d m_s}) = 22 \cdot 10^3$
$\mathrm{Re}C_K^5$	$10 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{6\,m_d m_s}) = 38 \cdot 10^3$
$\mathrm{Im}C_K^1$	$15 \cdot 10^3$	$\sim r/(\sqrt{6}\,\lvert V_{td}V_{ts}\rvert f_{q3}^2) = 23 \cdot 10^3$
$\mathrm{Im}C_K^4$	$160 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{2\,m_d m_s}) = 22 \cdot 10^3$
$\mathrm{Im}C_K^5$	$140 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{6\,m_d m_s}) = 38 \cdot 10^3$
$\lvert C_D^1\rvert$	$1.2 \cdot 10^3$	$\sim r/(\sqrt{6}\,\lvert V_{ub}V_{cb}\rvert f_{q3}^2) = 25 \cdot 10^3$
$\lvert C_D^4\rvert$	$3.5 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{2\,m_u m_c}) = 12 \cdot 10^3$
$\lvert C_D^5\rvert$	$1.4 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{6\,m_u m_c}) = 21 \cdot 10^3$
$\lvert C_{B_d}^1\rvert$	$0.21 \cdot 10^3$	$\sim r/(\sqrt{6}\,\lvert V_{tb}V_{td}\rvert f_{q3}^2) = 1.2 \cdot 10^3$
$\lvert C_{B_d}^4\rvert$	$1.7 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{2\,m_b m_d}) = 3.1 \cdot 10^3$
$\lvert C_{B_d}^5\rvert$	$1.3 \cdot 10^3$	$\sim r(vY_*)/(\sqrt{6\,m_b m_d}) = 5.4 \cdot 10^3$
$\lvert C_{B_s}^1\rvert$	30	$\sim r/(\sqrt{6}\,\lvert V_{tb}V_{ts}\rvert f_{q3}^2) = 270$
$\lvert C_{B_s}^4\rvert$	230	$\sim r(vY_*)/(\sqrt{2\,m_b m_s}) = 780$
$\lvert C_{B_s}^5\rvert$	150	$\sim r(vY_*)/(\sqrt{6\,m_b m_s}) = 1400$

$r = M_g/g_{s*}$

Scan over parameter space for Im C_4^K



Generically need m_G>21 TeV to satisfy constraint in ϵ_K

BUT: some points do satisfy constraint, any rationale to live at those points? ("Coincidence problem")

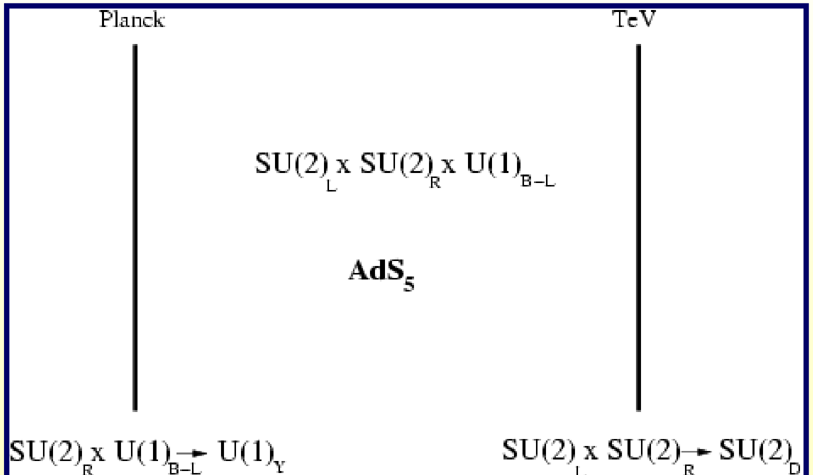
4. Higgsless models

(C.C., Grojean, Murayama, Pilo, Terning)

- Realistic RS: little hierarchy problem

- Simply let Higgs VEV to be big on IR brane

- Higgs VEV will repel gauge boson wave functions, Higgs will simply decouple from theory



Same as for RS, except Higgs VEV →∞ on IR brane

•In practice, just implies BC's for gauge fields

$$\text{at } z = R: \quad \begin{cases} \partial_z (g_{5R} B_\mu + \tilde{g}_5 A_\mu^{R3}) = 0 \ \partial_z A_\mu^{La} = 0, \ A_\mu^{R1,2} = 0, \\ \tilde{g}_5 B_\mu - g_{5R} A_\mu^{R3} = 0, \end{cases}$$

$$\text{at } z = R': \quad \{ \ \partial_z (g_{5R} A_\mu^{L\,a} + g_{5L} A_\mu^{R\,a}) = 0, \ \partial_z B_\mu = 0, \ g_{5L} A_\mu^{L\,a} - g_{5R} A_\mu^{R\,a} = 0.$$

•Typical mass spectrum:

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

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

•Get correct M_W/M_Z due to matching of g, g' to g_5, $\tilde{g}_5$

$$\sin\theta_W = \frac{\tilde{g}_5}{\sqrt{g_5^2 + 2\tilde{g}_5^2}} = \frac{g'}{\sqrt{g^2 + g'^2}}$$

- Lightest additional KK modes not too light:

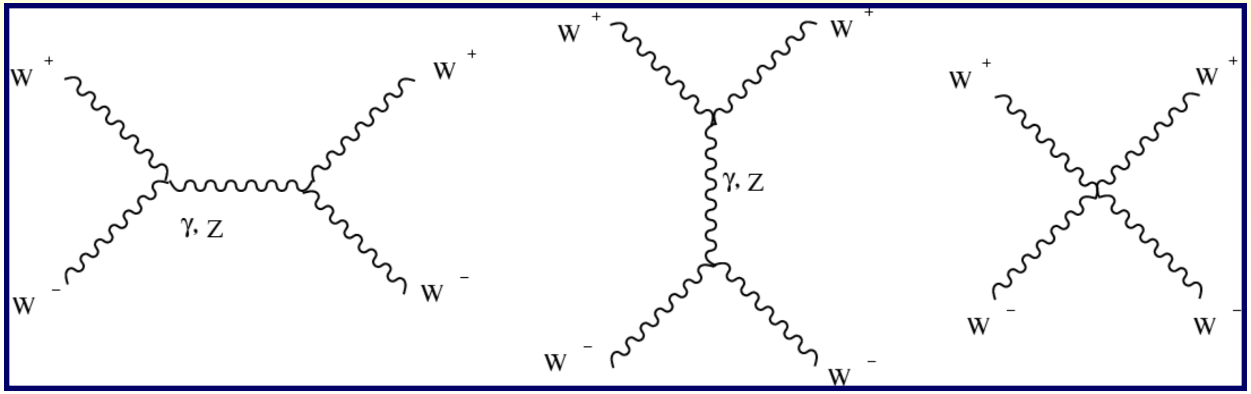
$$m_{W_n} = \frac{\pi}{2}\left(n + \frac{1}{2}\right)\frac{1}{R'}, \quad n = 1, 2, \ldots$$

- So mass ratio is log enhanced:

$$\frac{m_W}{m_{W'}} \sim \frac{4}{3\pi}\frac{1}{\sqrt{\log\left(\frac{R'}{R}\right)}}$$

But: usual argument for guaranteed discovery of Higgs

Massive gauge bosons without scalar violate unitarity:



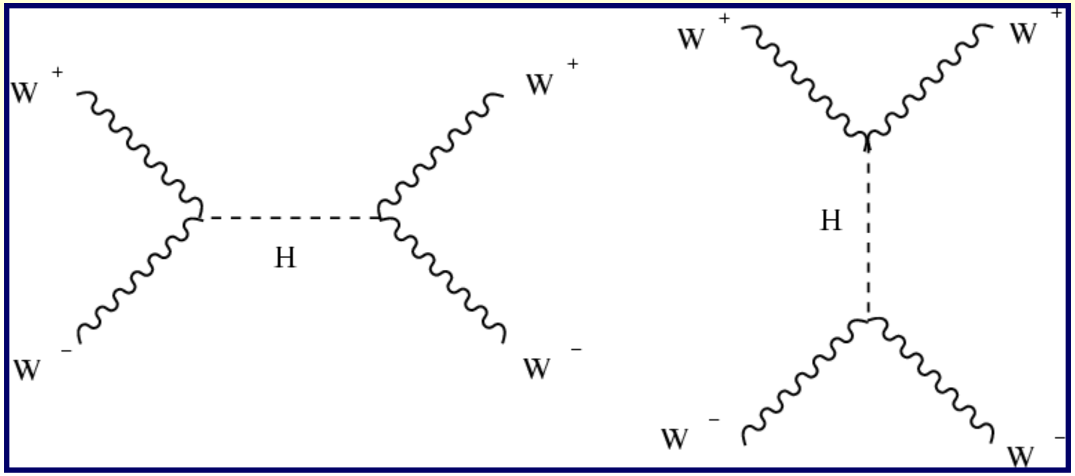
$$\mathcal{A} = A^{(4)} \frac{E^4}{M_W^4} + A^{(2)} \frac{E^2}{M_W^2} + \ldots$$

At energy scale $\Lambda = 4\pi M_W / g \sim 1.6 \text{ TeV}$

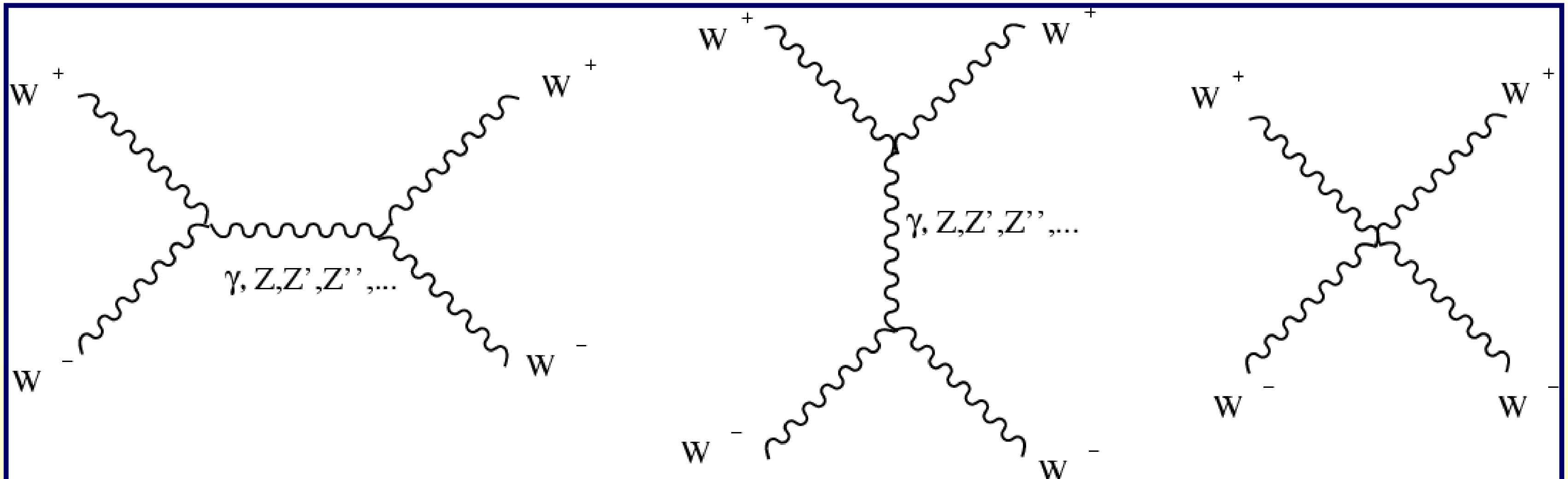
scattering amplitudes **violate unitarity**

Higgs exchange must become important **significantly below** this scale

In SM **Higgs exchange** will cancel growing terms in amplitude



In extra dimensional models, **exchange of KK modes** can play similar role as Higgs:



•**Predicts sum rules** among masses and couplings:

$$g_{WWWW} = g^2_{WW\gamma} + g^2_{WWZ} + \sum_i g^2_{WWZ^i}$$

$$\frac{4}{3} g_{WWWW} M^2_W = g^2_{WWZ} M^2_Z + \sum_i g^2_{WWZ^i} M^2_{Z^i}$$

For WW $\longrightarrow$ WW scattering (similar for WZ $\longrightarrow$ WZ)

•Predicts at least W', Z' below 1 TeV, with small but non-negligible coupling to light gauge bosons

$$g_{WZW^1} \leq 0.04$$

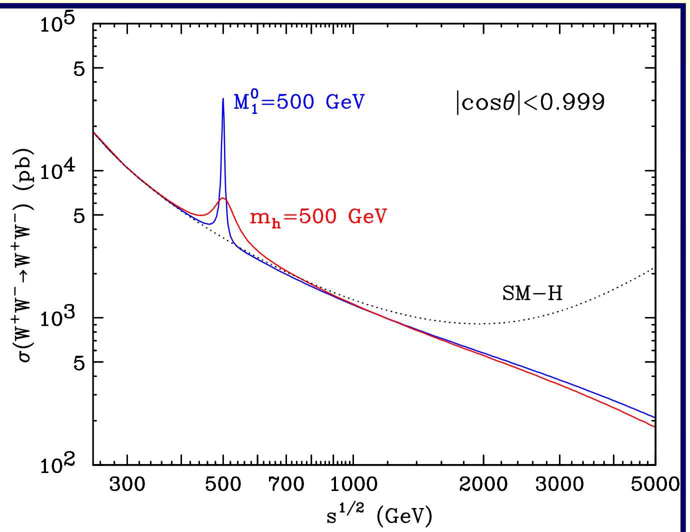
- Higgsless: (weakly coupled) dual to technicolor theories
- Solves little hierarchy, but generically large S-parameter

$$S \sim \frac{N}{\pi} \sim \frac{12\pi}{g^2}\frac{M_W^2}{m_\rho^2}$$

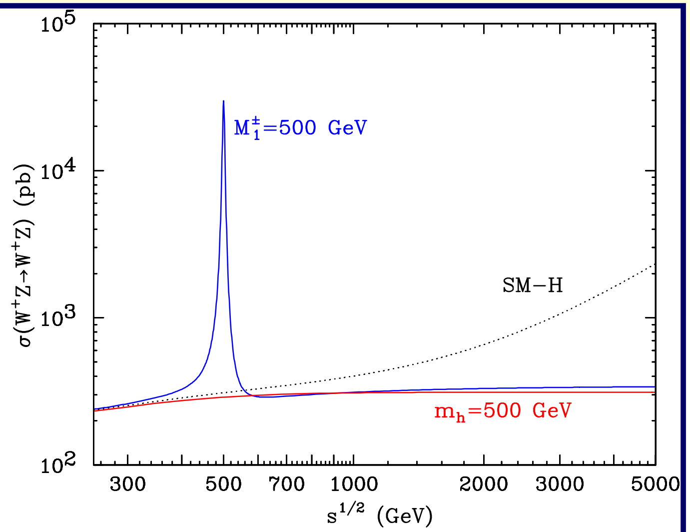
- S generically $\mathcal{O}(1)$ contrary to observations
- Can reduce via tuning shape of fermion wave function

LHC predictions

(Birkedal, Matchev, Perelstein)



WW → WW

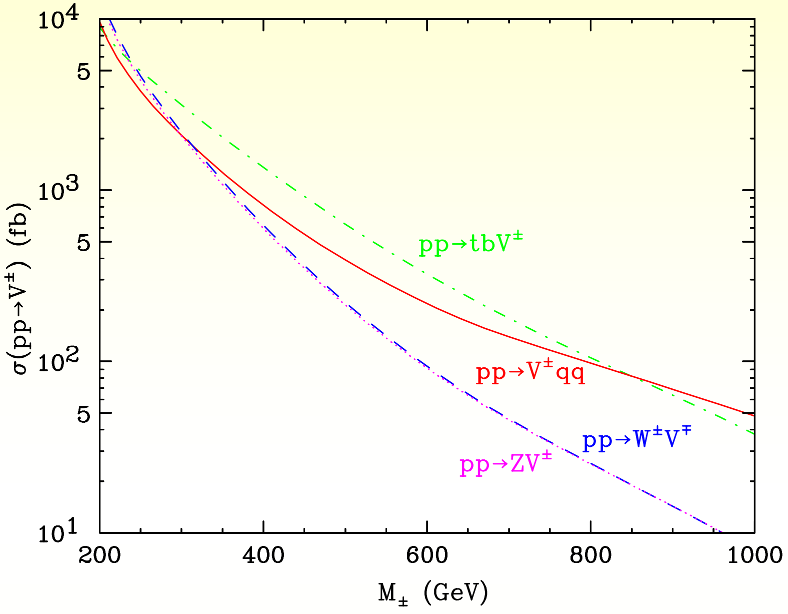


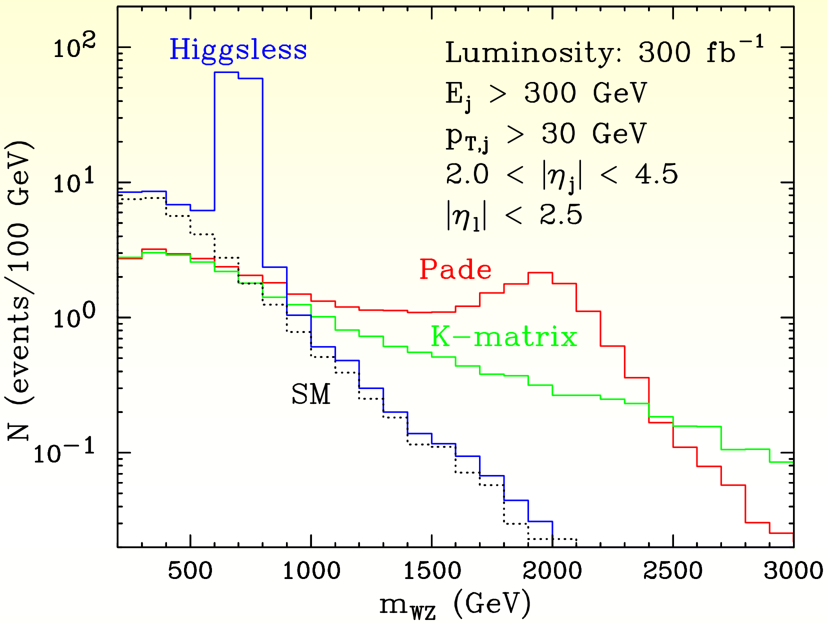
WZ → WZ

- WW scattering not that different from SM
- WZ scattering is **very different** (new peak!)

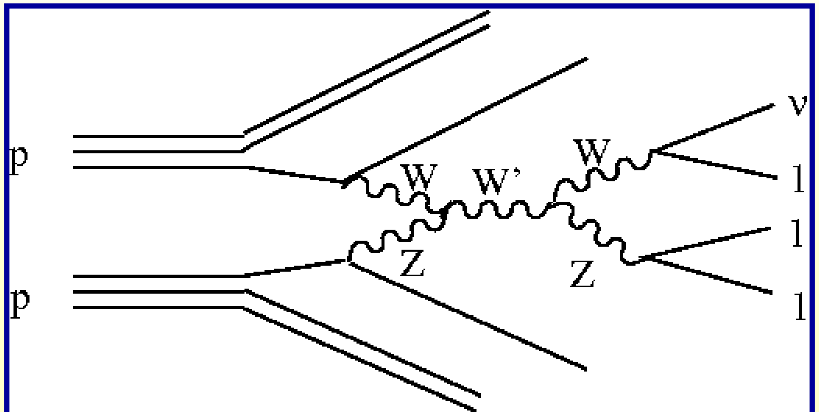
W’ production at the LHC

(Birkedal, Matchev, Perelstein)





•Assumption W’ff, Z’ff coupling completely negligible



A serious recent study of same process including NLO QCD corrections

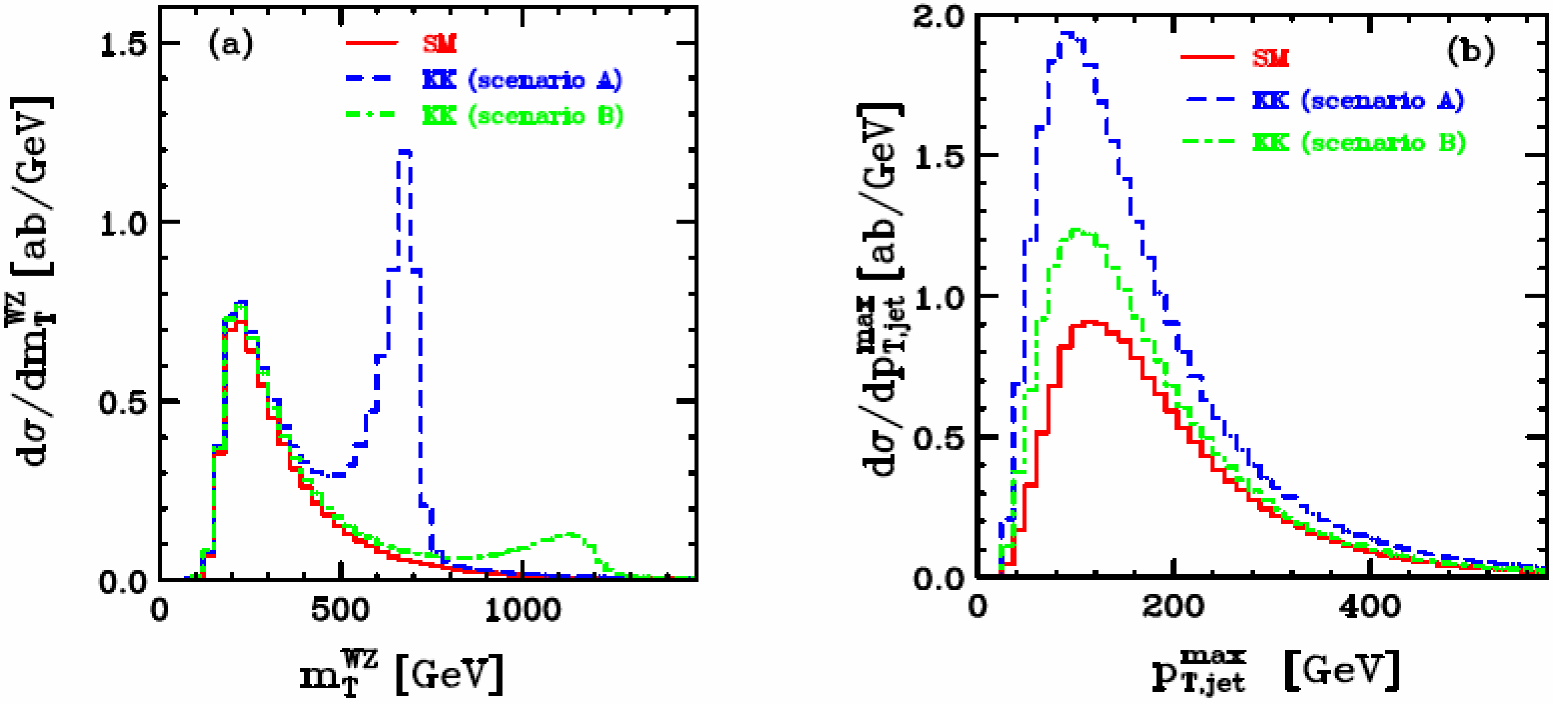


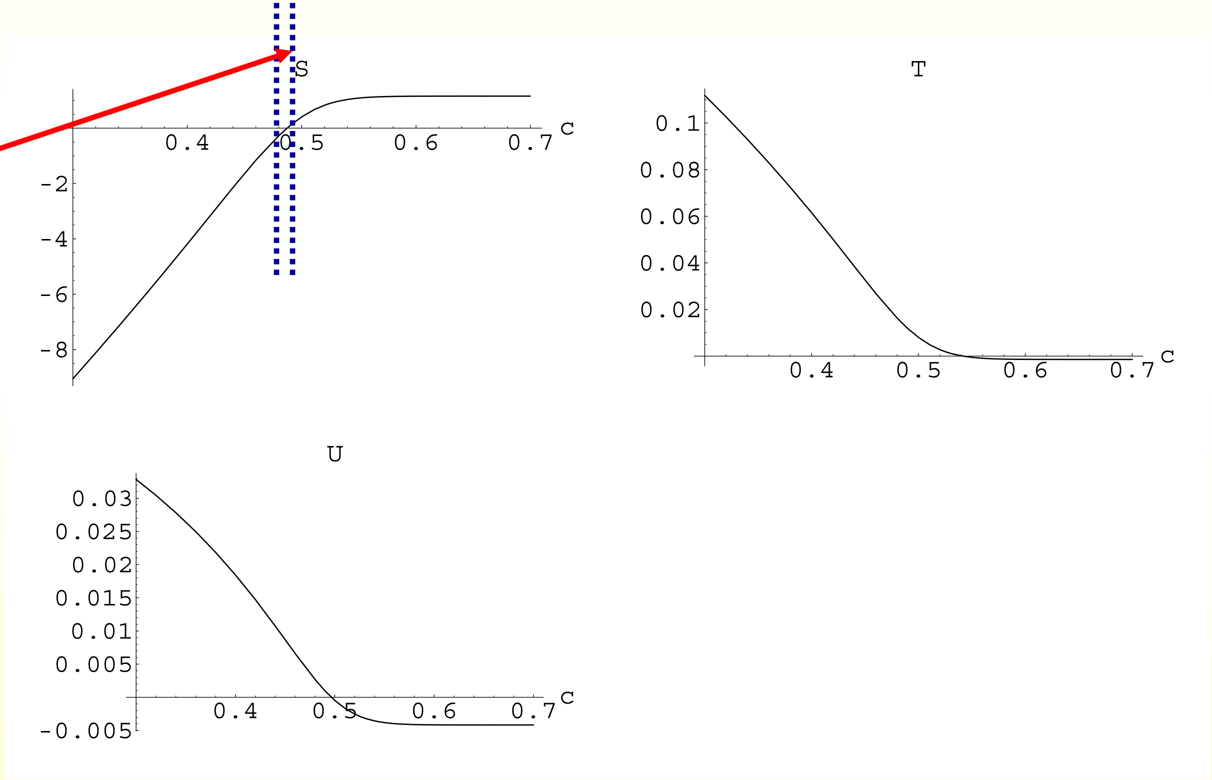
Figure 9: *Transverse cluster mass distribution (a) and transverse momentum distribution of the hardest tagging jet (b) for* $pp \to W^+ Zjj$. *Shown are predictions for the SM (red, solid), and for the two Higgsless scenarios A (blue, dashed) and B (green, dot-dashed).*

(Englert, Jäger, Zeppenfeld)

Electroweak precision tests

- If fermions elementary, S parameter too large
- If fermions close to flat, S can be reduced

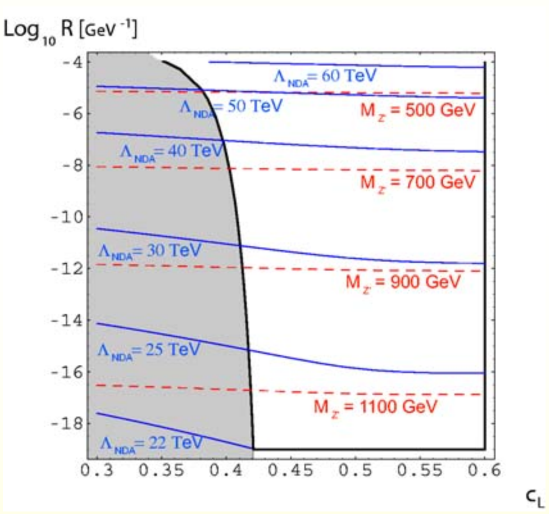
Need to be here % level tuning of c

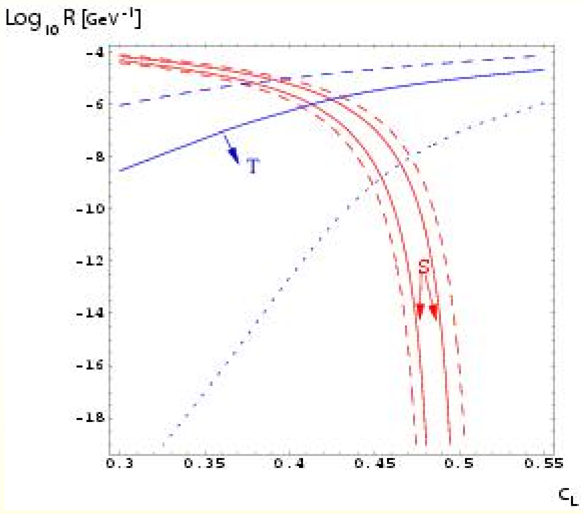


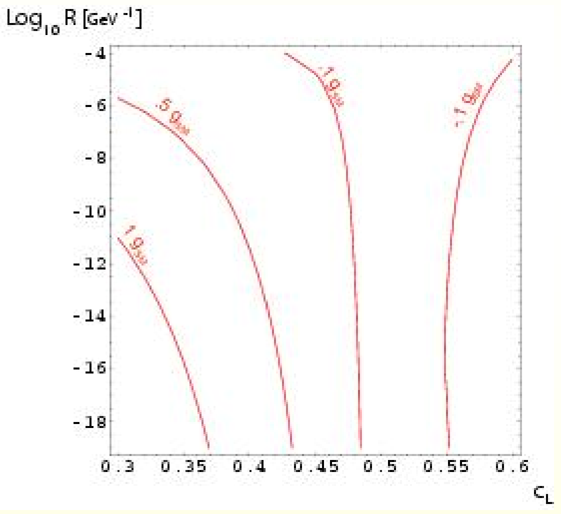
(Cacciapaglia, C.C.,Grojean, Terning)

Can find region where:

- S is sufficiently small
- KK modes sufficiently heavy
- Couplings to KK modes small



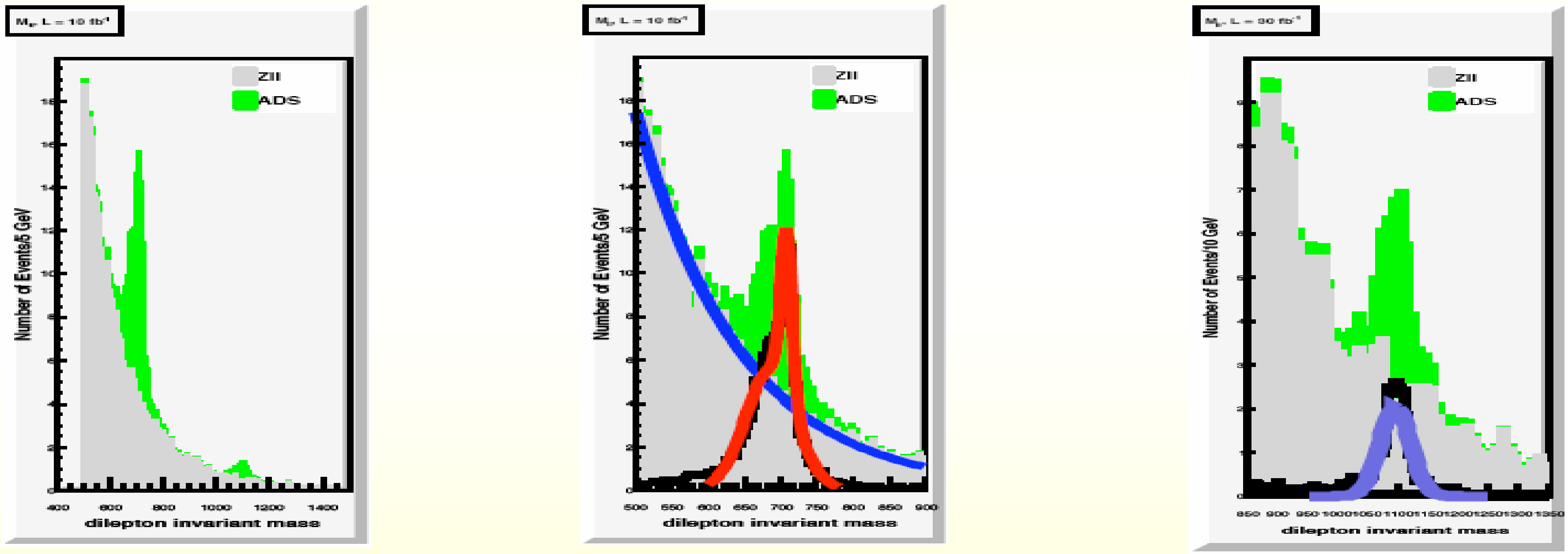




(Cacciapaglia, C.C.,Grojean, Terning)

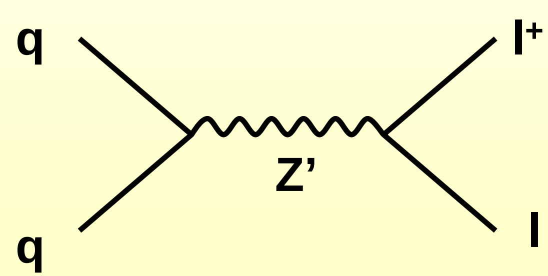
- Coupling to fermions not that small, DY will still be leading channel at LHC

Example $Z' \to l^+ l^-$ DY at LHC for a sample point



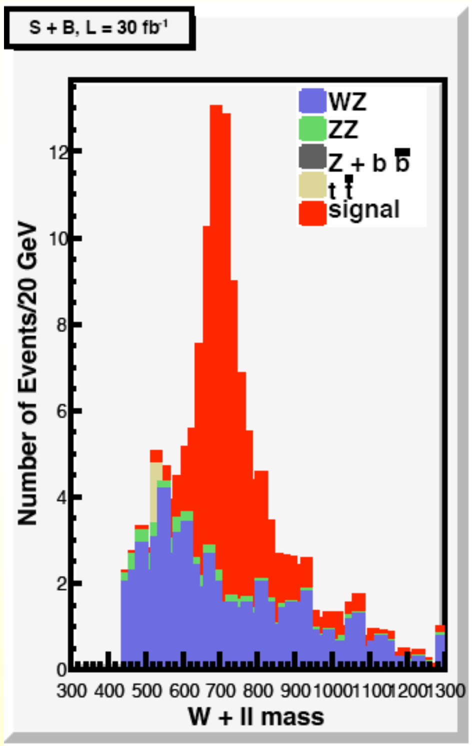
(To appear by Martin and Sanz)

Process	σ	ϵ	# events
$Z_i \to \ell^+\ell^-$	0.045 pb	0.34	152
$Z \to \ell^+\ell^-$	1.58 pb	0.032	521



•Coupling to fermions not that small, DY will still be leading channel at LHC

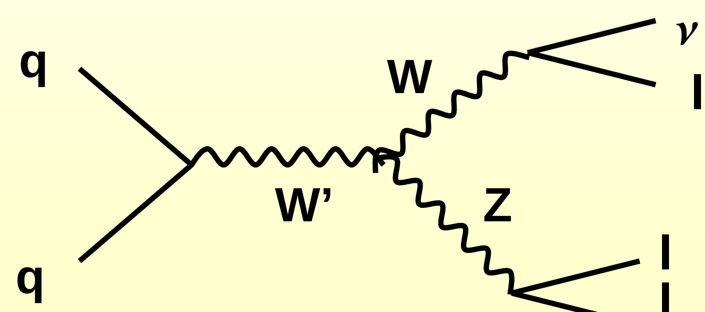
Example W' DY at LHC for a sample point



Process	σ	ϵ	# events
$W_{1,2} \to WZ \to 3\ell\nu$	0.0065 pb	0.397	77
$WZ \to 3\ell + \nu$	0.965 pb	2.43×10^{-3}	70
$ZZ \to 4\ell(\text{miss-}\ell)$	0.116 pb	1.6×10^{-3}	6
$Z\bar{b} \to \ell^+\ell^-\bar{b}b$	11.4 pb	0	0
$\bar{t}t \to b\bar{b}\ell\ell'\nu\nu'$	22.8 pb	2.0×10^{-6}	2

Figure 11: Signal and background cross-sections, efficiencies, and number of events in $\mathcal{L} = 30\ \text{fb}^{-1}$

(To appear by Martin and Sanz)



The Gaugephobic Higgs

(Cacciapaglia, C.C., Marandella, Terning)

- Higgsless: crank up Higgs VEV to max, completely decouple Higgs
- Intermediate possibility: turn up Higgs VEV somewhat
- Coupling to gauge fields reduced, Higgs could be light

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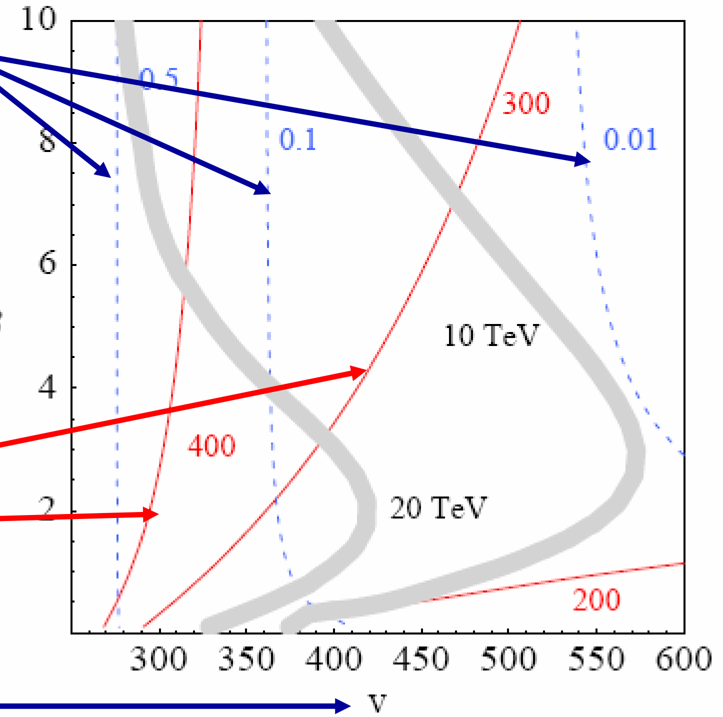
Higgs contribution to WW scat. vs SM

How strongly Higgs is peaked

R'-1

Effective VEV v



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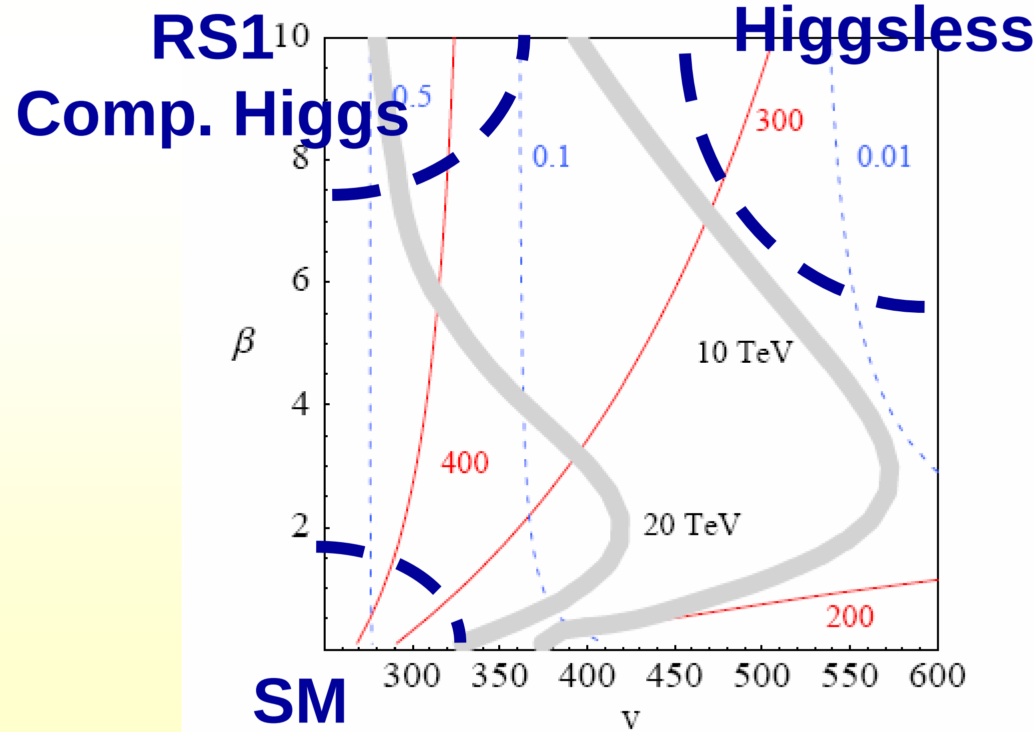
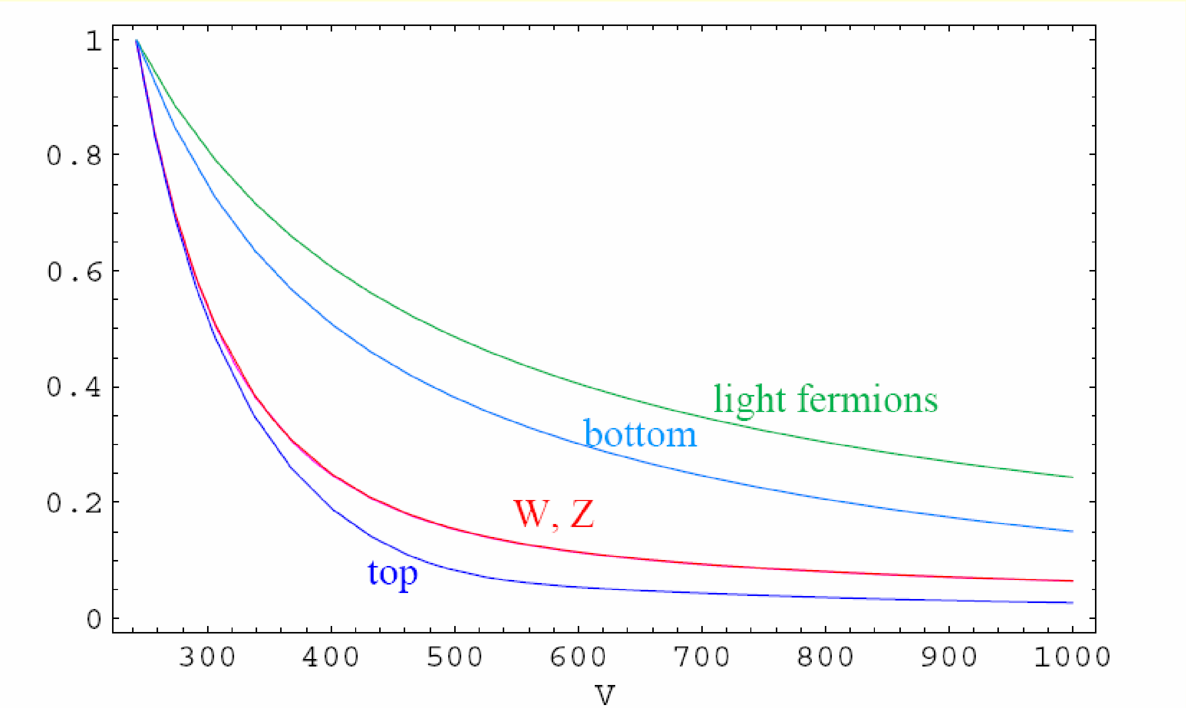
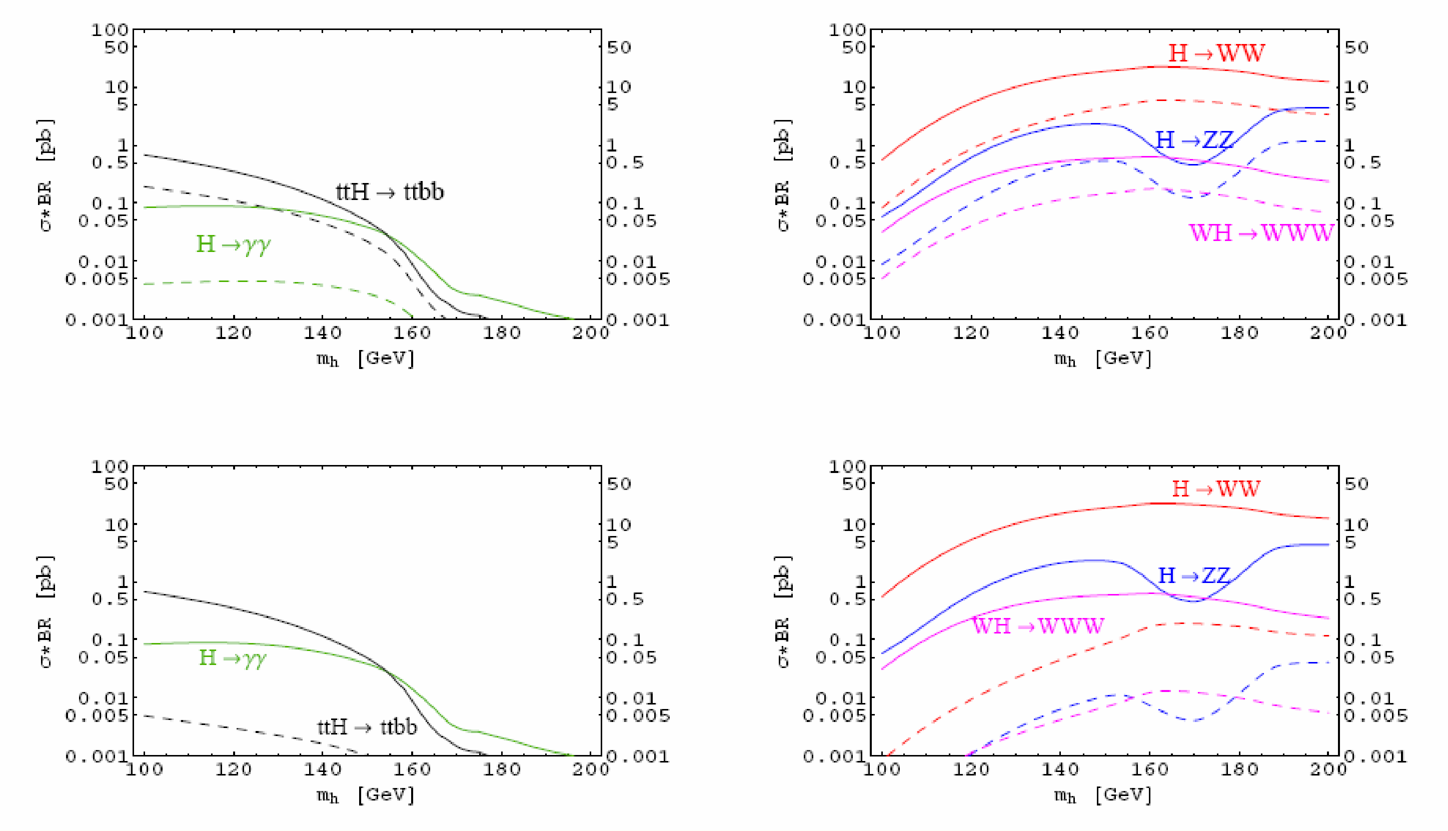


Suppression of the Higgs coupling:



Higgs phenomenology



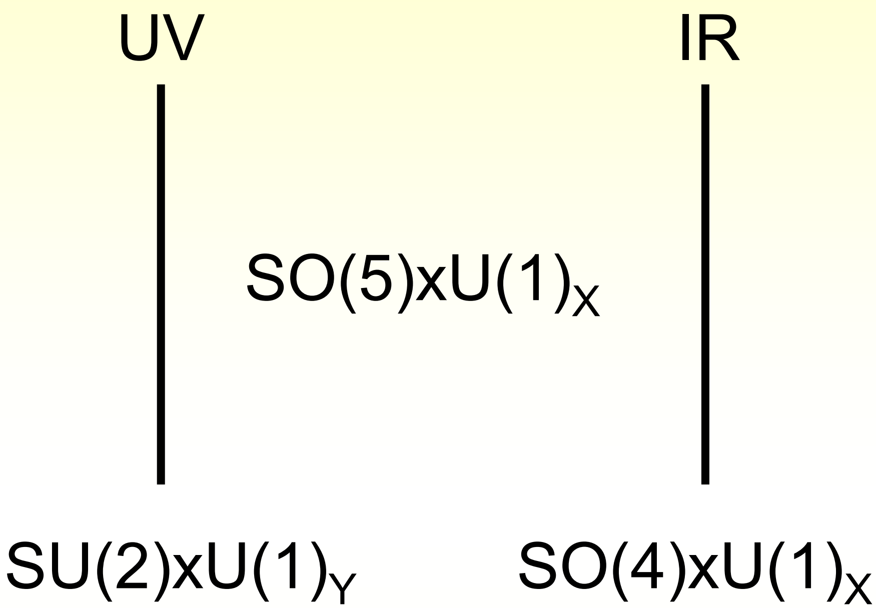
Sample spectra

a) $V = 300$ GeV, $\beta = 2$		b) $V = 500$ GeV, $\beta = 2$	
$1/R'$	372.5 GeV	$1/R'$	244 GeV
W'	918 GeV	W'	602 GeV
Z'_1	912 GeV	Z'_1	598 GeV
Z'_2	945 GeV	Z'_2	617 GeV
G'	945 GeV	G'	617 GeV

5. Composite pGB Higgs models

- In technicolor (or Higgsless): the S too large: not enough separation between m_W and m_ρ
- Other possibility: still strong dynamics, but scales separated more $m_\rho \gg m_W$
- If strong dynamics produces a composite Higgs
- But then Higgs mass expected at the strong scale
- To lower Higgs mass: make it a Goldstone boson
- Higgs mass due to 1-loop electroweak corrections

The minimal example



(Contino, Nomura, Pomarol;
Agashe, Contino, Pomarol;
Carena, Ponton, Santiago, Wagner,…)

- A 5D model (doesn't have to be)
- Sym. breaking pattern:
- SO(5)xU(1)$_X$ global→ SO(4)xU(1)$_X$ global
- SM subgroup gauged

Higgs potential:

$$V(h) = 0 \cdot |h|^2 + 0 \cdot |h|^4 + \frac{g^2}{16\pi^2} f^4 \cos^n(|h|/f)$$

Tree-level vanishes
Due to PGB nature

Generic PGB pot.

•The main difficulty: in Higgs potential everything radiative, again no natural separation between v, f

Mass:

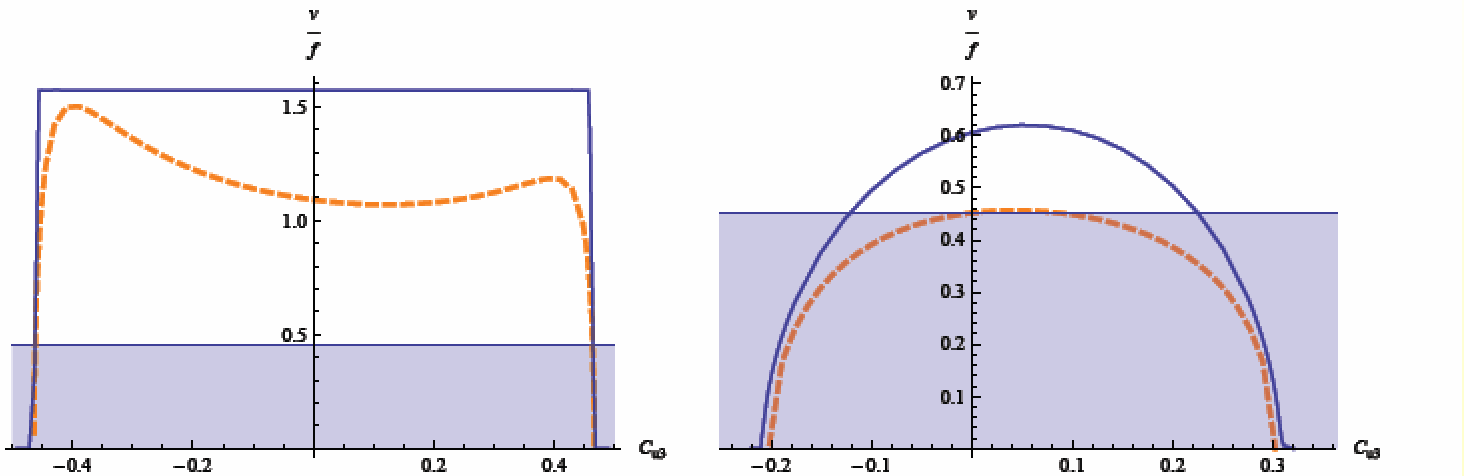
$$m_h^2 \propto \frac{g^2}{16\pi^2} f^2$$

Quartic:

$$\lambda \propto \frac{g^2}{16\pi^2}$$

•Generically would expect v~f. Need some tuning to avoid

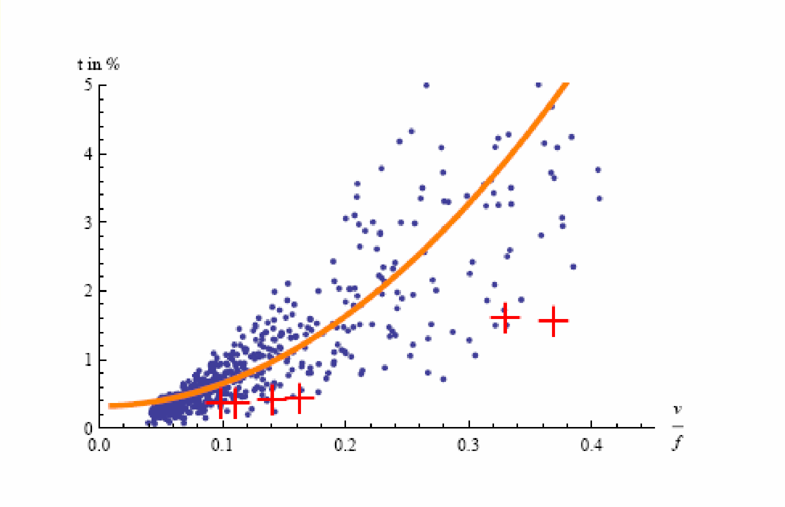
(Carena, Ponton, Santiago, Wagner; C.C., Falkowski, Weiler)



•Fine tuning quantified:

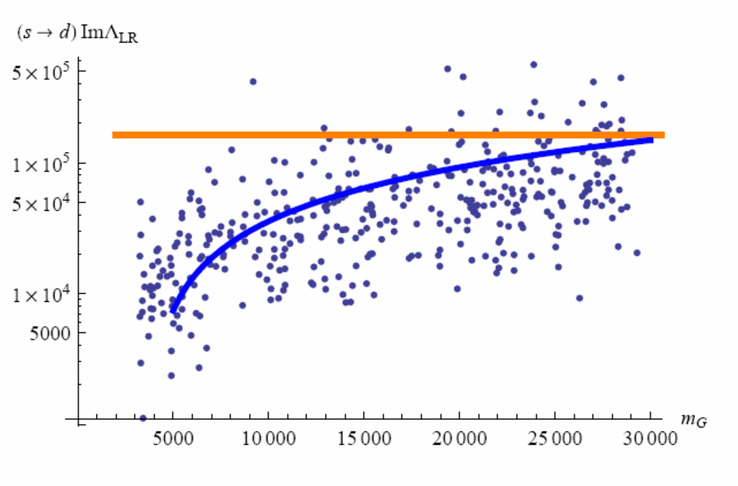
$$t \sim \frac{1}{4}\frac{v^2}{f^2}$$

•For v/f~0.1 about 0.5% tuning



•Also flavor slightly worse off than ordinary RS

•Flavor bound ~30 TeV

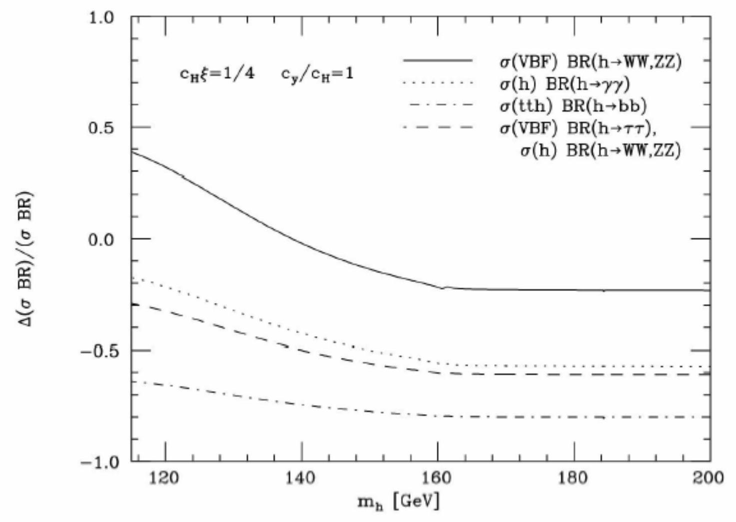


Experimental consequences of pGB MCH

•Try to find states from extra sector: similar to RS searches (m_ρ >3 TeV, KK gluon,…)

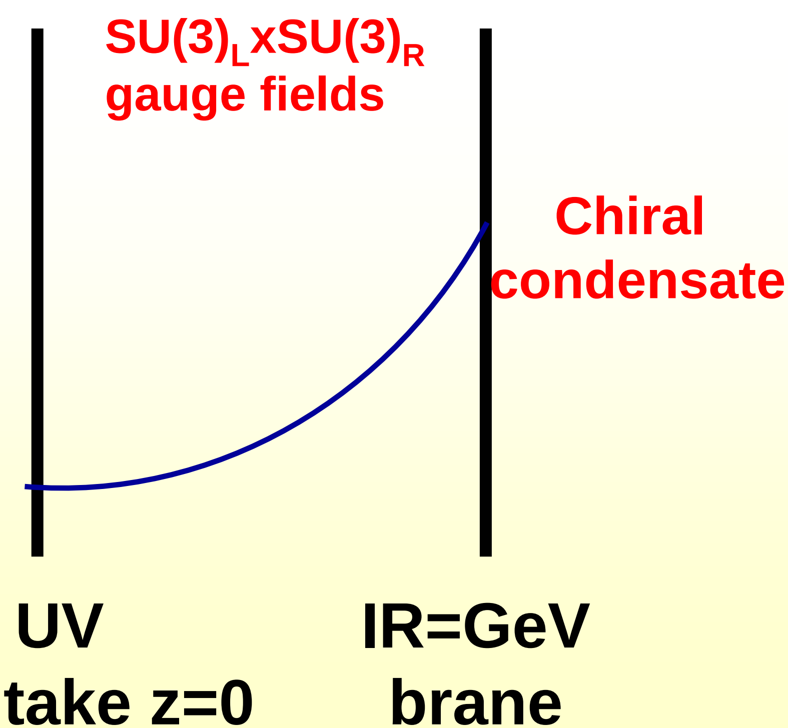
•Higgs properties modified due to compositeness ("Higgs form factors")

(Giudice, Grojean, Pomarol, Rattazzi)



7.AdS/QCD?

- Original motivation of AdS: describe duals of strongly interacting theories (eg. N=4 SUSY)
- Old question: can it be used for QCD itself?
- AdS/QCD proposal

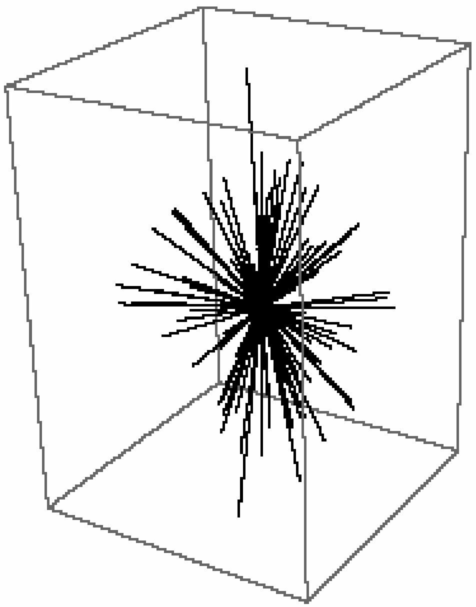


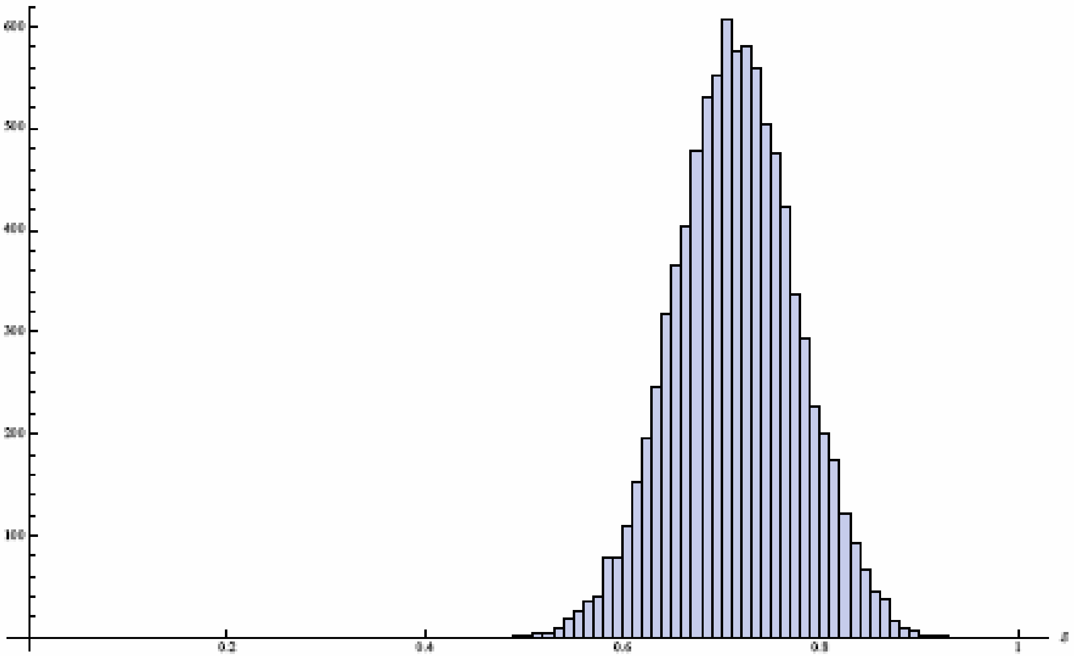
Observable	Measured (Central Value - MeV)	Model (MeV)
m_π	139.6	141
m_ρ	775.8	832
m_{a_1}	1230	1220
f_π	92.4	84.0
$F_\rho^{1/2}$	345	353
$F_{a_1}^{1/2}$	433	440
$g_{\rho\pi\pi}$	6.03	5.29

(Erlich, Katz, Son, Stephanov; da Rold Pomarol)

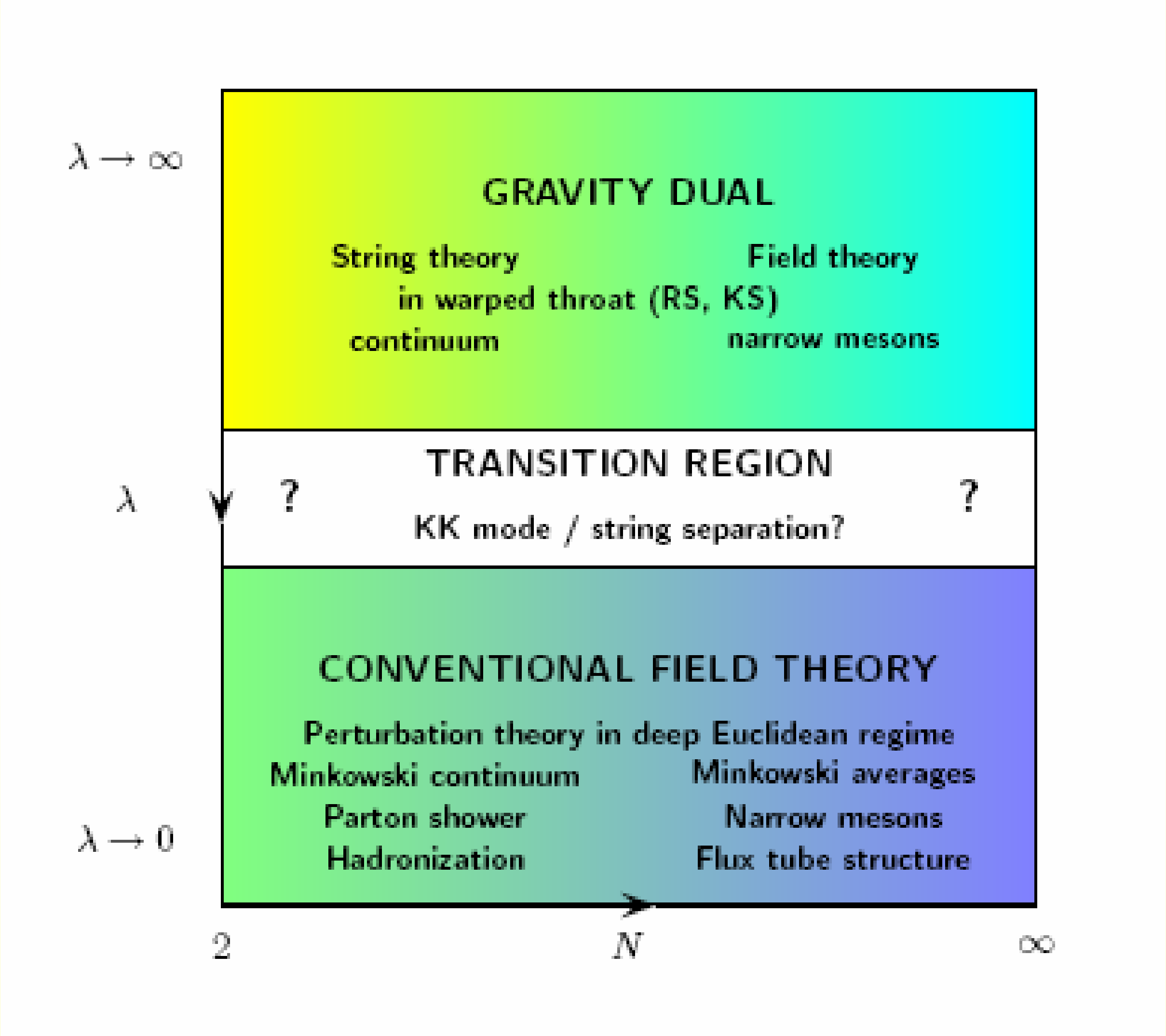
Observable	Measured (Central Value - MeV)	Model (MeV)
m_{K^*}	892	897
m_ϕ	1020	994
m_{K_1}	1272	1290
m_K	498	411
f_K	113	117
m_{f_2}	1275	1236
m_{ω_3}	1667	1656
m_{f_4}	2025	2058
m_η	548	520
m'_η	958	867

- However, dynamics does not seem to be properly captured. Eg. $m_n^2 \propto n^2$ rather than Regge
- Polchinsky, Strassler: at large ‘t Hooft coupling all partons at small x
- Strassler; Hoffman, Maldacena: likely no jets produced
- We verified the absence of jets in simplest AdS/QCD models (C.C., Reece, Terning)





• The right phase diagram for QCD in (N,λ) would be:



Summary

TeV scale, little hierarchy and EWPO

RS: original RS large EWP, flavor issues

Realtistic RS: custodial symmetry, bulk fields
little hierarchy remains

Higgsless: solves little hierarchy, but large S
need to tune S away

Gaugephobic: interpolates between Higgsless
and ordinary RS

Summary

TeV scale, little hierarchy and EWPO

Composite pGB Higgs: some tuning left in higgs potential, might be hard to see

Don’t have a complete model where everything just fits together

Reality: Some combination of these ideas? Completely different?