Emergent EWSB

Tony Gherghetta
University of Melbourne

CERN Theory Institute, August 24, 2009

with Yanou Cui and James Wells (arXiv:0907.0906)

What is the origin of mass?

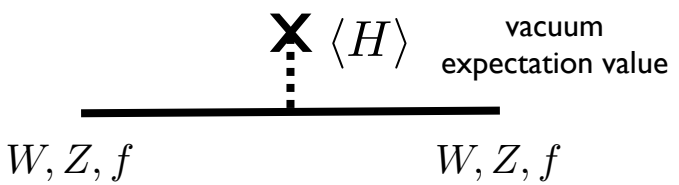
1. Higgs mechanism

[Guralnik, Hagen, Kibble `64; Englert, Brout `64; Higgs `64]

- Elementary fermion and W, Z boson masses

W, Z-boson: $m_{W,Z} \propto g\langle H \rangle$

Fermion: $m_f \propto \lambda\langle H \rangle$



2. Strong dynamics

- QCD Hadron mass spectrum

proton: $m_P \propto \Lambda_{QCD}$

vector-mesons: e.g. SU(2) isospin-triplet $\rho^{0,\pm}$ $m_\rho \propto \Lambda_{QCD}$

In fact, hidden local gauge symmetry! [Bando, Kugo, Uehara, Yamawaki, Yanagida 1985]

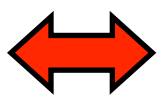
Question:

Can one generate mass in the Standard Model with strong dynamics?

YES, but not easy...

Use AdS/CFT correspondence! [Maldacena, 97; Gubser, Klebanov, Polyakov, 98; Witten 98]

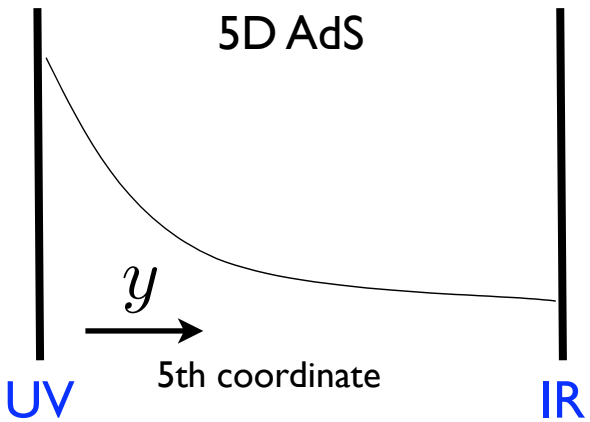
Effective 4D chiral Lagrangian of composite W, Z, fermions

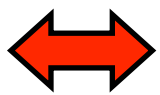


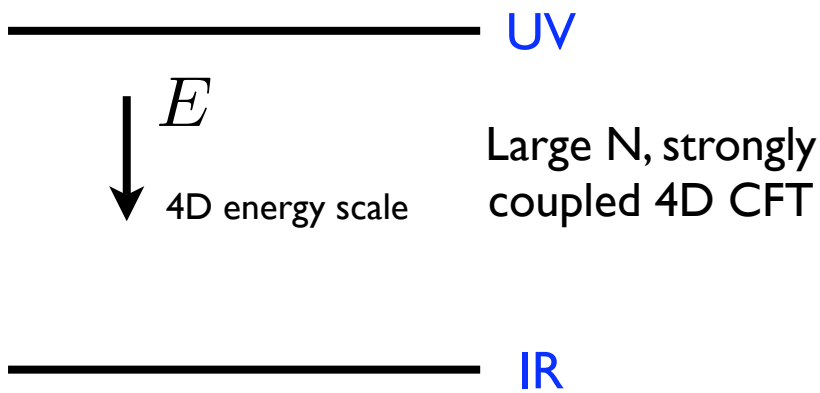
5D Lagrangian in warped dimension!
[Randall, Sundrum 99]

AdS/CFT dictionary

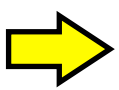
[Arkani-Hamed, Randall, Porrati 00; Rattazzi, Zaffaroni 00; Perez-Victoria 01]

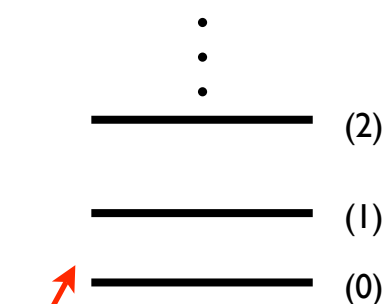






IR brane breaks conformal symmetry



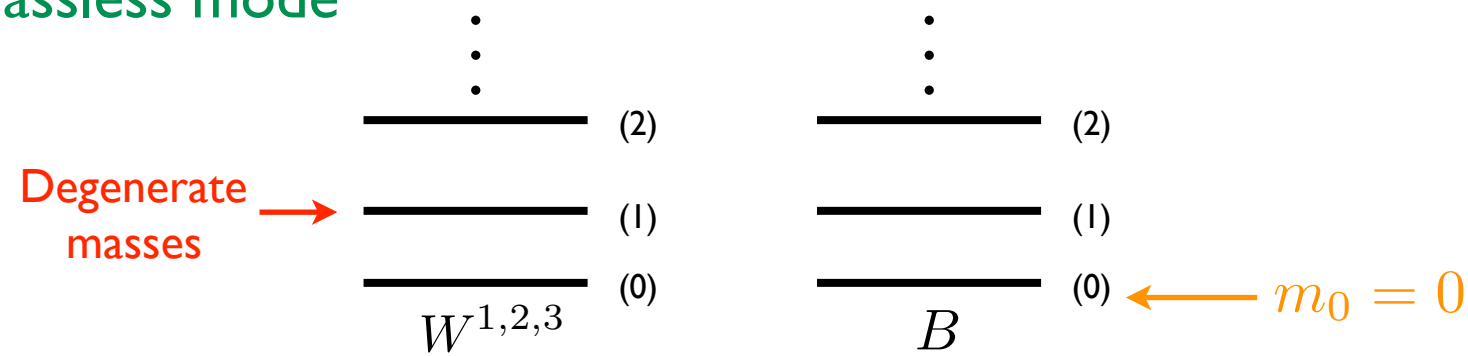


Generates mass!

KK modes OR composite states of dual theory!

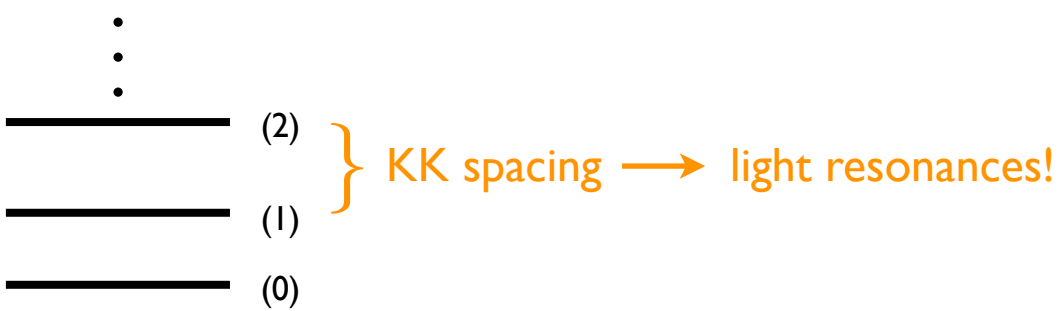
But,

- Massless mode



Break EW symmetry at Planck scale!

- Heavy KK modes

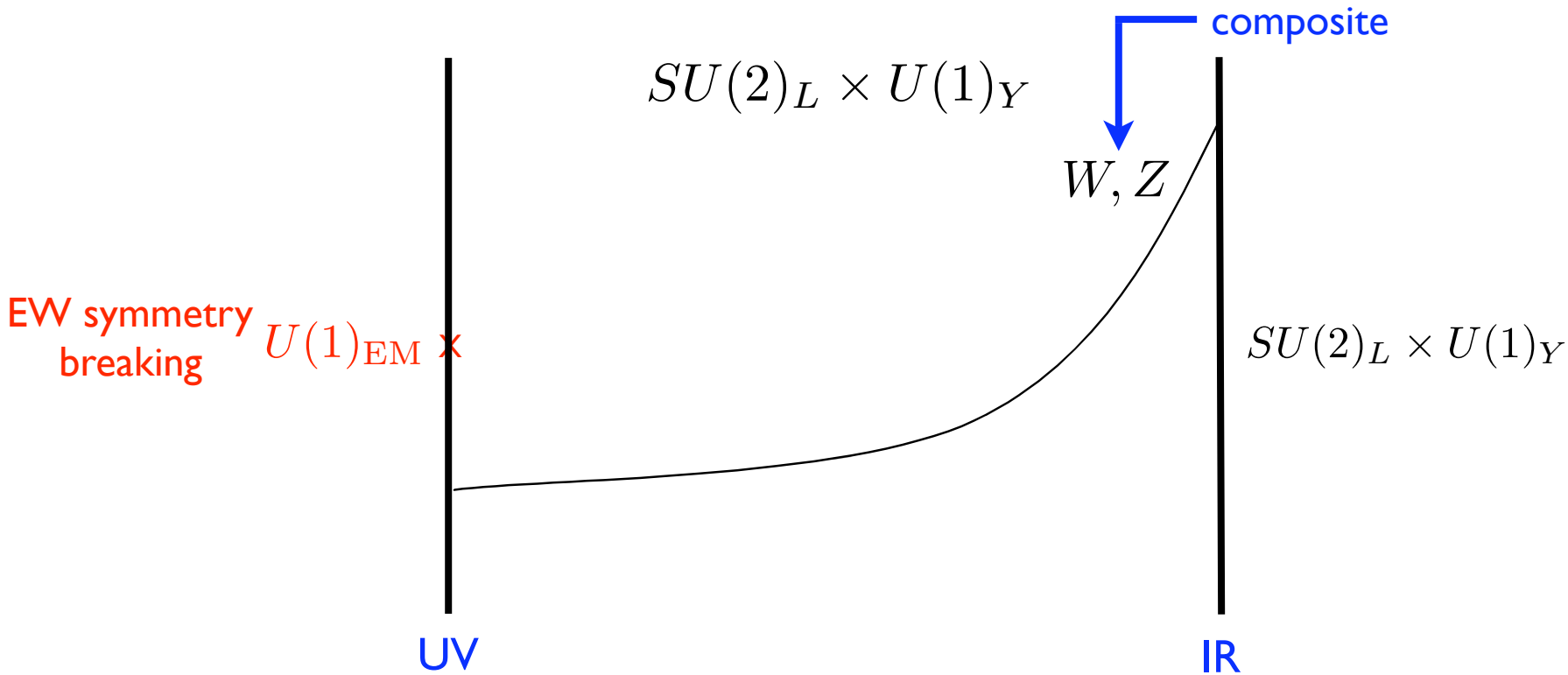


Separate lightest KK mode from rest of tower with brane kinetic terms!

[Carena, Ponton, Tait, Wagner 2002; Davoudiasl, Hewett, Rizzo 2002]

5D Model

[Cui, TG, Wells, arXiv:0907.0906]



5D action:

$$S = \int d^4x\, dz \sqrt{-g} \left[-\frac{1}{4}(F^{La}_{MN})^2 - \frac{1}{4}(F^{Y}_{MN})^2 - \frac{1}{2}(kz)\delta(z - z_{UV}) \frac{\zeta_Q}{g^2_{Y5} + g^2_{L5}} (g_{Y5} F^{L3}_{\mu\nu} + g_{L5} F^{Y}_{\mu\nu})^2 \right.$$
$$\left. -\frac{1}{2}(kz)\delta(z - z_{IR}) \left(\zeta_L (F^{La}_{\mu\nu})^2 + \zeta_Y (F^{Y}_{\mu\nu})^2 \right) \right]$$

$\zeta_Q, \zeta_L, \zeta_Y$ = boundary kinetic term coefficients

Mass spectrum:

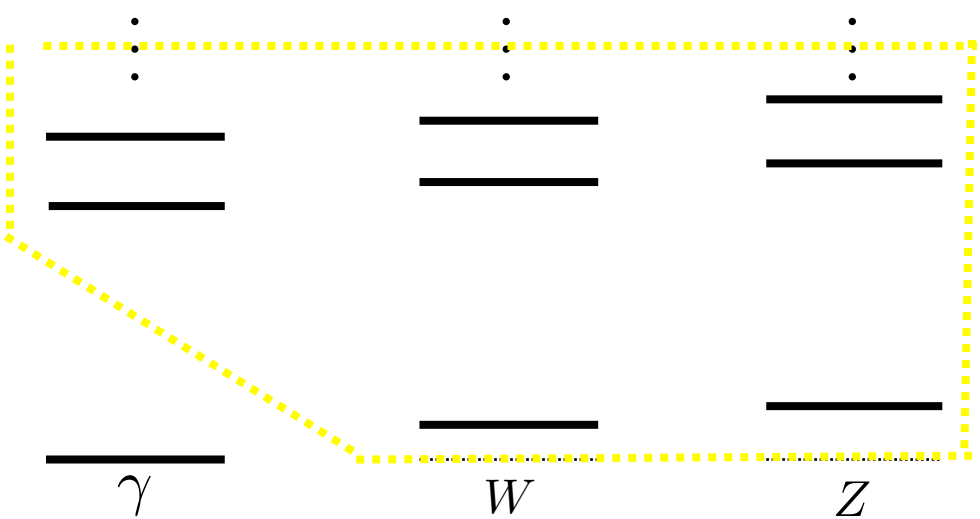
$$m_\gamma = 0$$

$$m_W \simeq \sqrt{\frac{2}{\zeta_L k}}\, m_{IR}$$

$$m_Z \simeq \sqrt{\frac{2}{\zeta_L k} + \frac{2}{\zeta_Q k (1 + g_{L5}^2/g_{Y5}^2)}}\, m_{IR}$$

For: $m_{IR} = \mathrm{TeV}$ $\zeta_Q k \simeq 500, \zeta_L k \simeq 310, \zeta_Y k \simeq 0.1$

$$\Rightarrow \quad m_W \simeq 80.4\,\mathrm{GeV}, \quad m_Z \simeq 91.2\,\mathrm{GeV} \quad (m_{KK} \gtrsim 2\,\mathrm{TeV})$$



EWSB emerges at IR scale

⇒ "Emergent" EWSB

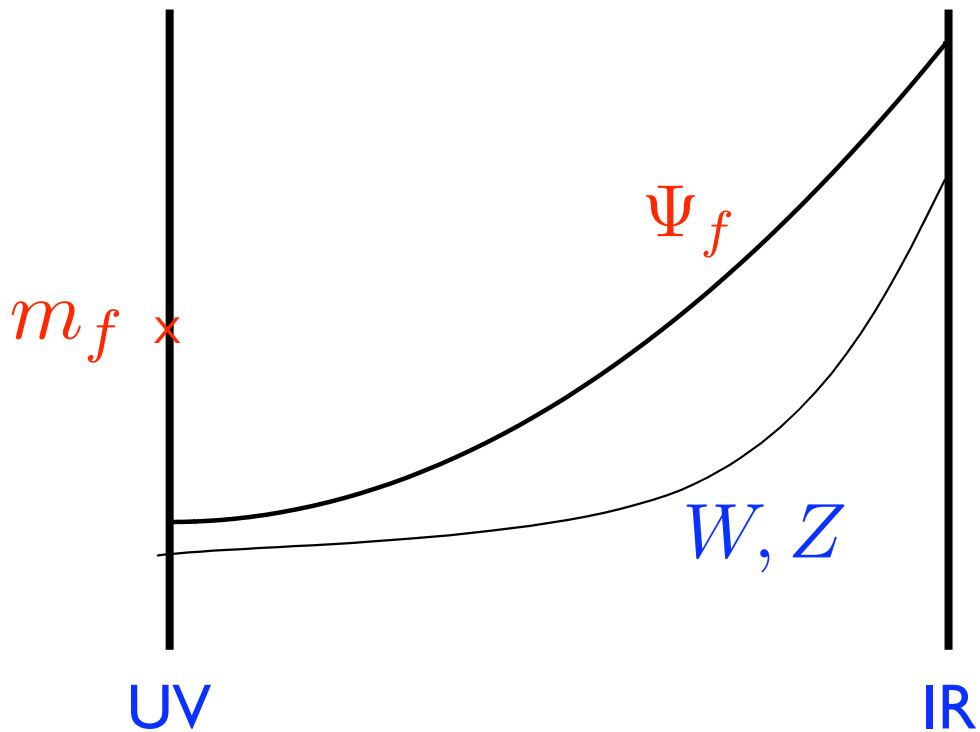
∴ Composite W, Z but elementary photon!

Fermion masses [In progress]

Assume universal bulk fermion profile

- Add UV boundary fermion masses

Fermion mass hierarchy via Froggatt-Nielsen mechanism →



⇒ Gauge coupling nonuniversality at the per-mille level

Electroweak constraints

Assume fermions on IR brane

Matching at IR brane requires: $g_5^2 k \simeq \dfrac{425}{1+\delta}$ $\delta \propto$ brane thickness

- T parameter — Custodial symmetry in limit $\zeta_Y \to 0, \zeta_Q \to \infty$

  i.e. same boundary condition for $A^{L1,2,3}$

- S parameter $S \propto \dfrac{16\pi}{g^2+g'^2}(m_Z z_{IR})^2$

$\zeta_L k \simeq 1000, \zeta_Q k \simeq 1700, \zeta_Y k \simeq 0.2$
$m_{IR} \simeq 1.8\,\mathrm{TeV}$ ⇒ $S \simeq 0.1, \quad T \simeq 0.05$

But depends on fermion details....

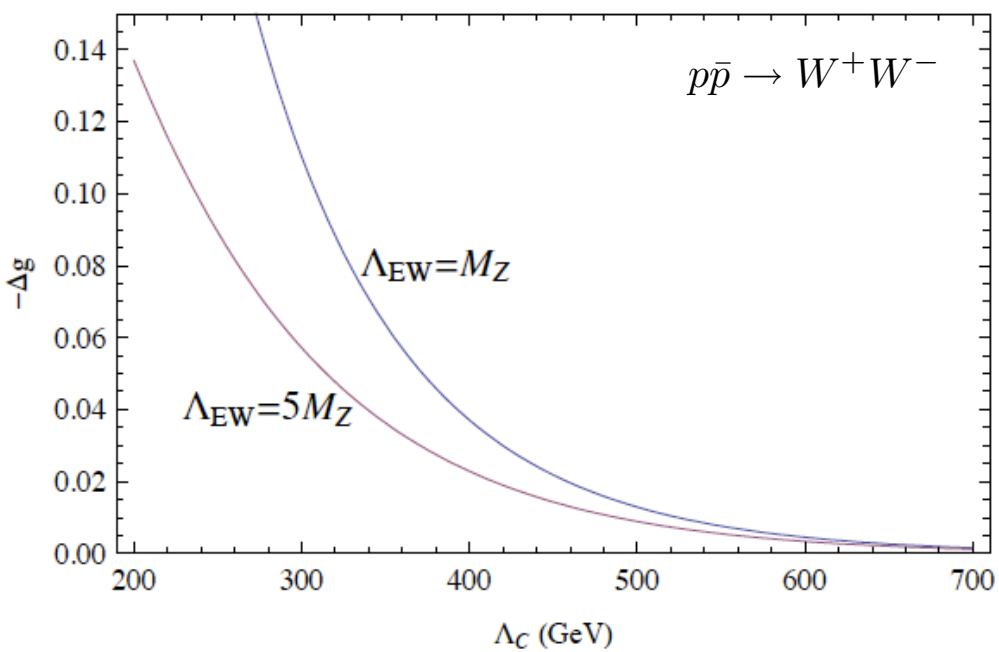
WW scattering

Composite W,Z boson ⇒ Momentum dependent form factor

e.g. $$F_{WWZ}(q^2) = \frac{1}{N_Z(q^2)N_W^2}\left\{\left[\int_{z_{UV}}^{z_{IR}} \frac{dz}{kz} f^{L3}(q^2,z)(f_W(z))^2\right] + \zeta_L f^{L3}(q^2,z_{IR})(f_W(z_{IR}))^2\right\}$$

Approximate form factor:

$$F(q^2) = \begin{cases} 1, & \text{for } q^2 < \Lambda_C^2 \\ (1+\Lambda_C^2/\Lambda_{EW}^2)/(1+q^2/\Lambda_{EW}^2), & \text{for } q^2 > \Lambda_C^2 \end{cases}$$



⇒ Possible deviation in W, Z-boson vertices at LHC

Conclusion

- Generate W, Z boson mass from strong dynamics, not Higgs mechanism
- Electroweak symmetry breaking "emerges" at IR scale
- Consistent with electroweak precision tests (S, T parameters)
- Composite W, Z bosons lead to deviations in vertices at LHC