Approaches to the Hierarchy: Old and New

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OTHER INTERESTS

- AdS$_4$/CFT$_3$

Recently we showed that gauge bosons naturally acquire mass in AdS$_4$ similarly to the photon 1+1 massless electrodynamics. For example the SM would be massive in AdS$_4$. Consequences for AdS/CMT?

R. Rattazzi and M. Redi,
"Gauge Boson Mass Generation in AdS4,"
arXiv:0908.4150 [hep-th]

- AdS/QCD

The basic features of strongly coupled large N gauge theories can be generically described by theories with one extra-dimension independently from its warping. Can this be used to parameterize arbitrary strongly coupled systems?

D. Becciolini, M. Redi and A. Wulzer,
"AdS/QCD: The Relevance of the Geometry,"
arXiv:0906.4562 [hep-ph].

TeV Quantum Gravity

The hierarchy problem is the inexplicable ratio,

$$\frac{M_P^2}{TeV^2} = 10^{32}$$

This is the tuning in the SM if it is valid up to M_p. It is an exciting possibility that the explanation of the hierarchy might have to do with gravity itself.

In extra dimensions,

$$M_P^2 = M_{4+n}^{2+n} V_n$$

The hierarchy can be accounted if the fundamental scale of gravity is TeV.

M_P is a derived scale and the weakness of gravity is due to the large volume of the extra-dimensions.

In this scenario quantum gravity could be probed at the LHC. Strong gravitational dynamics and production of micro Black-holes are expected.

The class of theories which explain the hierarchy by lowering the fundamental scale of gravity is however much larger.

G. Dvali and M. Redi,
Phys. Rev. D **77**, 045027 (2008)
Phys. Rev. D **80**, 055001 (2009)

In ANY theory with N particle species there is gravitational cutoff M_*

$$M_P^2 > N M_*^2$$

This can be shown for example from black-holes,

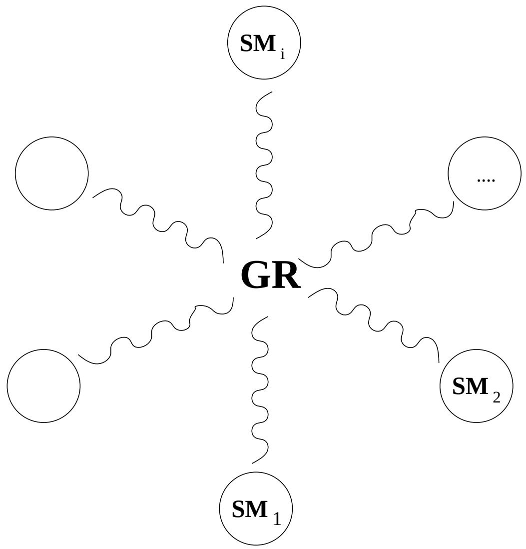
$$\tau_{BH} \approx \frac{1}{N} r_g^3 M_p^2$$

A hierarchy is automatically generated by large number of fields.
The electro-weak hierarchy would require 10^{32} states.
Large extra-dimensions are indeed in this class:

$$M_p^2 = M_*^2 (M_* R)^n = M_*^2 N$$

The nature of the species is irrelevant.

Identical copies of the SM would work equally well.



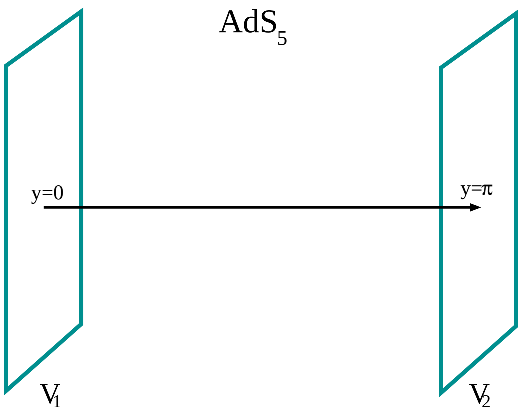
This corresponds to the maximal departure from a geometrical picture.

Quite different phenomenology from Large Extra-dimensions:

- Other copies are maximally hidden
- Mixing with the hidden sectors
- New gravitational dynamics at TeV

COMPOSITE HIGGS

An old idea is that the Higgs is light because it is a composite object emerging from some strongly interacting dynamics. This possibility has acquired new momentum through realizations within the Randall-Sundrum scenario.



By the AdS-CFT correspondence these models are related to 4D strongly coupled CFTs. The hierarchy is obtained by dimensional transmutation. The Higgs is part of the composite sector while the SM is mostly elementary (except the top). Important implications for:

- Collider Physics: New Resonances, strong dynamics
- Flavor Physics

An appealing scenario is the one where the Higgs is a (pseudo)-Goldstone boson analogous to the pions in QCD.

Any breaking $G \to H$ can be engineered in 5D as a gauge theory G broken to H by boundary conditions.

$$\Pi = \int_{z_1}^{z_2} A_z \, dz$$

The "Minimal Composite Higgs Model" is based on the symmetry breaking,

$$SO(5) \to SU(2)_L \otimes SU(2)_R$$

If the Higgs is a Goldstone boson there is a priory no reason to expect just one Higgs doublet. Other interesting possibilities exist,

- Extra Singlets

$$\frac{SO(N)}{SO(N-1)}$$

- Extra doublets

$$\frac{SU(4)}{SU(2)_L \otimes SU(2)_R}, \qquad \frac{Sp(6)}{SU(2)_L \otimes Sp(4)}$$

- Extra triplets

$$\frac{SU(5)}{SO(5)}, \qquad \frac{SU(4) \otimes SU(4)}{SU(4)}$$

Roughly the phenomenology depends on two parameters,

$$\xi = \frac{v}{f} \qquad\qquad m_\rho = \frac{4\pi f}{\sqrt{N}}$$

Precision electro-weak measurements and flavor strongly constrain these models. For $\xi << 1$ the non-renormalizable interactions are small and the phenomenology approaches the one of multiple-Higgs models.

The model building becomes increasingly harder as $\xi \to 1$. Interesting new features such as dark matter candidates and exotic signatures are possible.