Partial Compositeness and its implications for the LHC

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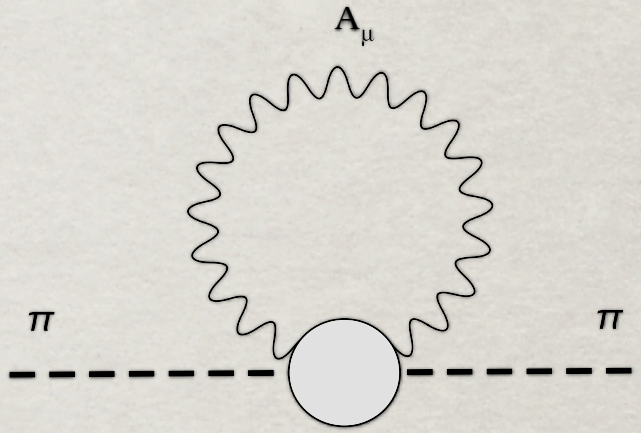
Motivation:

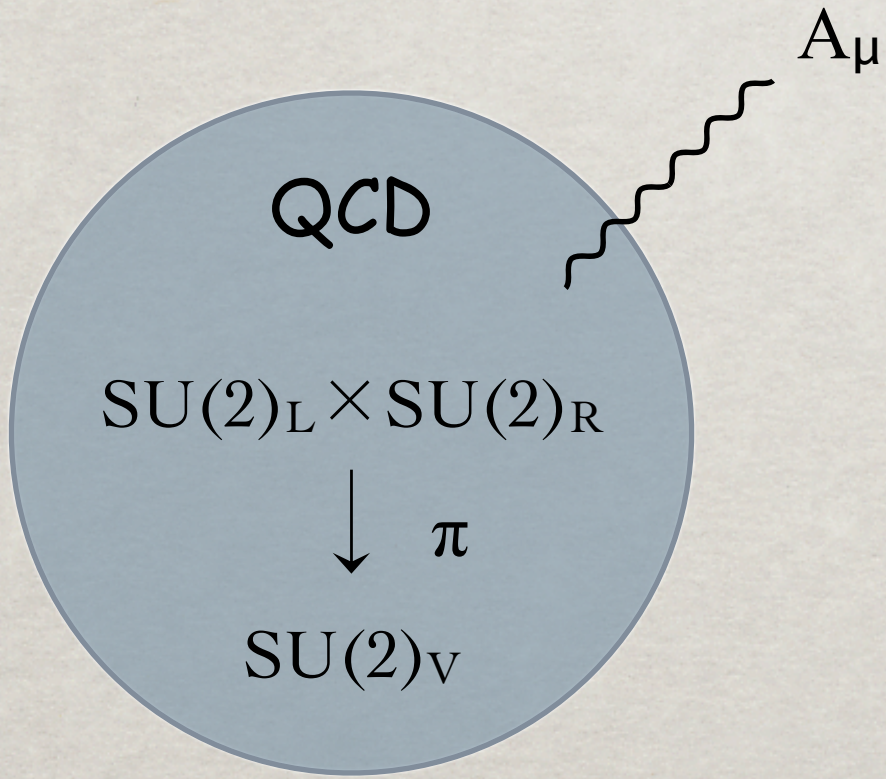
- Solving the Hierarchy Problem by having the Higgs as a composite at ~ TeV

Partial Compositeness
and
its implications for the LHC

A SCENARIO WE KNOW:

The electromagnetic correction to the pion mass





$$\Delta m_\pi^2 \approx 3\,\frac{\alpha_{em}}{4\pi}\,m_\rho^2$$

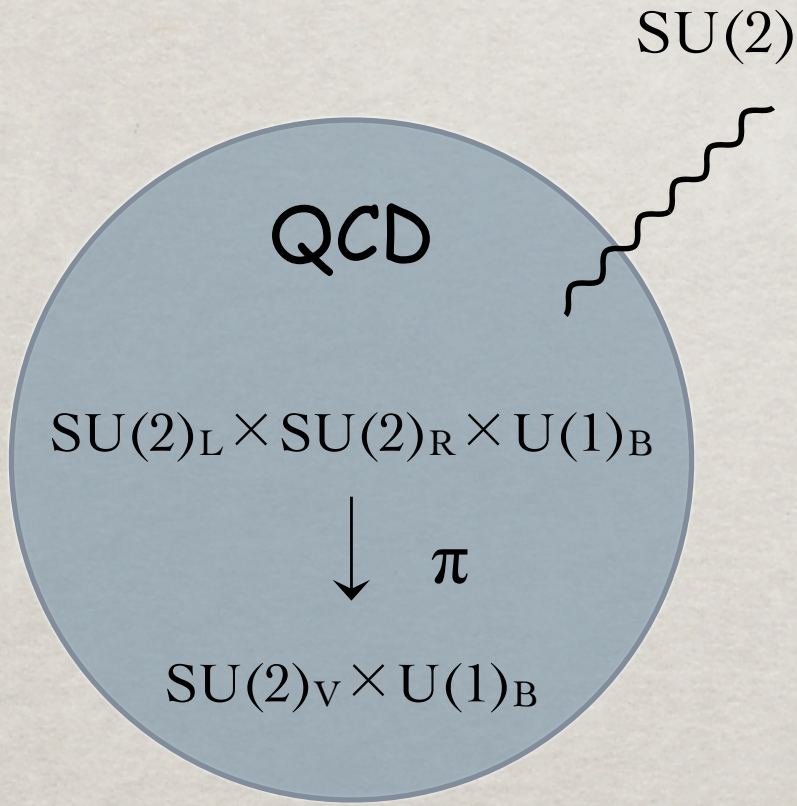
$$m_{\pi^+} - m_{\pi^0} \simeq 5.0\,\mathrm{MeV}$$

[Das, Guralnik, Mathur, Low, Yang 1967]

$$(\mathrm{exp.} \simeq 4.6\,\mathrm{MeV})$$

Turning on the full electroweak group:

The pions are eaten and the EWS is broken



✓ $U(1)_Q$ unbroken: massless photon

☹ <u>Problems</u>:

1) $f_\pi = 93$ MeV $\Rightarrow$
$M_W = g f_\pi / 2 = 30$ MeV !

2) we actually observe the pions !

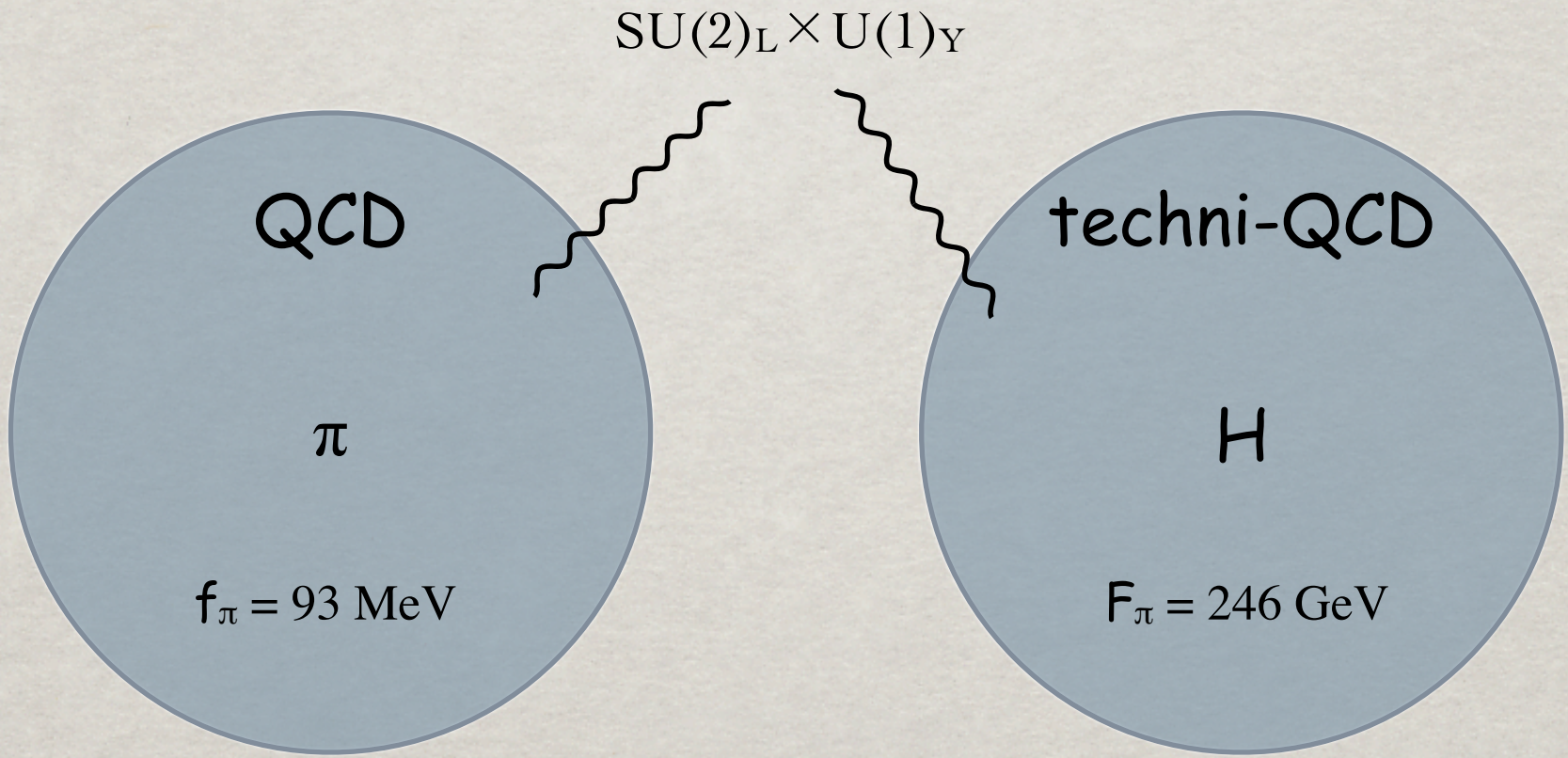
Idea: what if there is a techni-QCD ?

Technicolor
[Weinberg, Susskind]

✓ $F_\pi \gg f_\pi$ ⇨

1) W_{long}, Z_{long} mostly from H : $M_W \simeq g F_\pi/2 = 80$ GeV

2) still a physical pion in the spectrum, mostly π



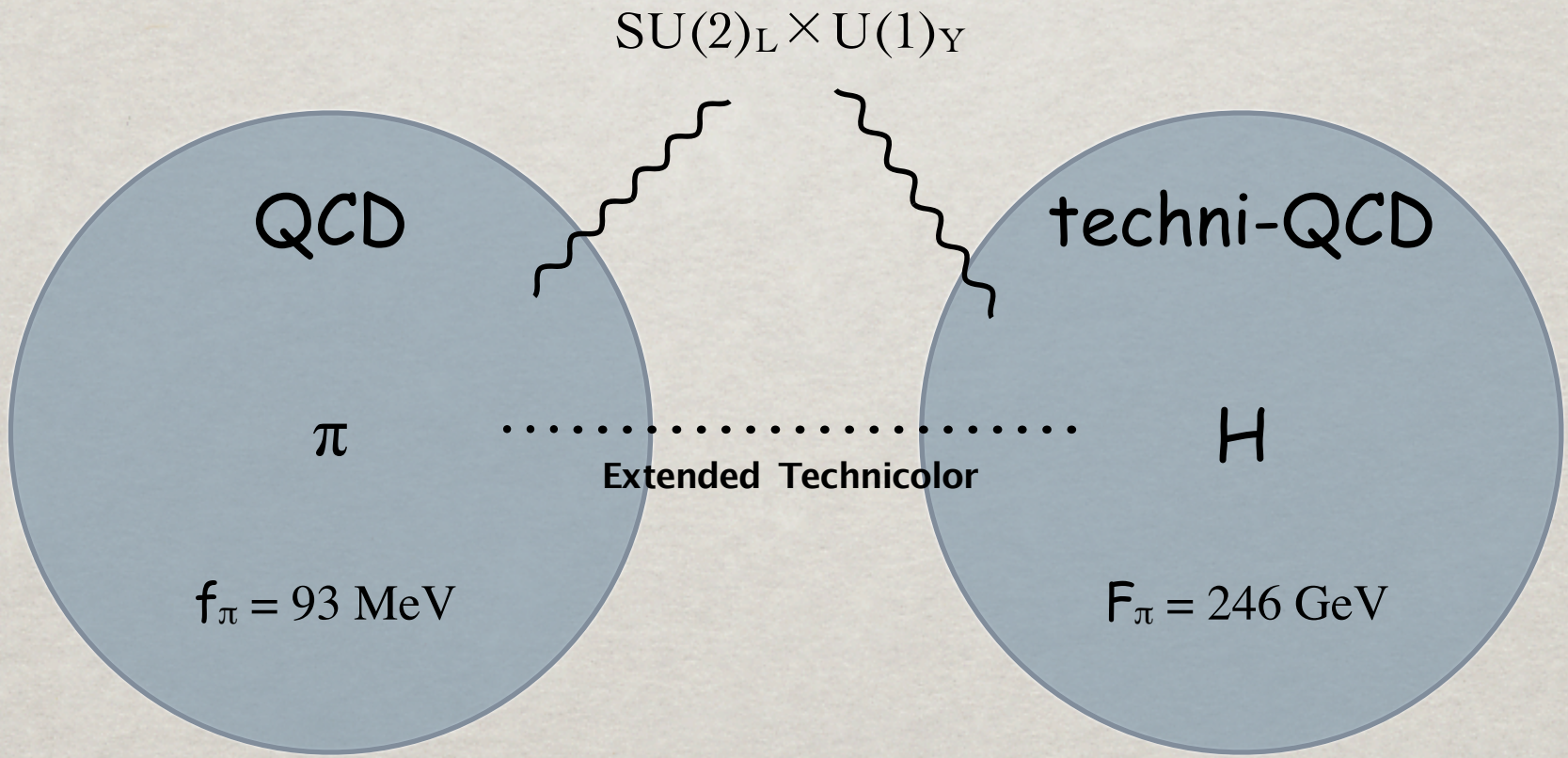
1) if H comes from $SU(2)_L \times SU(2)_R \to SU(2)_V$ ⇨ tension with the EW precision test

no physical Higgs leftover

☹

2) usual ETC mechanism to generate the quark masses leads to generally large FCNC :

$$\frac{(\bar{\Psi}\Psi)(\bar{\Psi}_{TC}\Psi_{TC})}{\Lambda^2_{ETC}} \to \frac{(\bar{\Psi}\Psi)^2}{\Lambda^2_{ETC}}$$



Solution to 1)

[Georgi, Kaplan `80]

- Enlarge the flavor symmetry of the new strong sector to: $G \xrightarrow{H} G'$ such that

1) H is a doublet of $SU(2)_L$

2) $G_{SM} \subset G'$ $\rightarrow$ extra alignment parameter $0<\epsilon<1$ suppresses all EWPT:

ex: $S = S_{TC} \cdot \epsilon^2$

Example: $SO(5) \rightarrow SO(4) \sim SU(2)_L \times SU(2)_R$

gives 4 real Goldstones: one $SU(2)_L$ doublet H

Solution to 2)

[Kaplan 1991]

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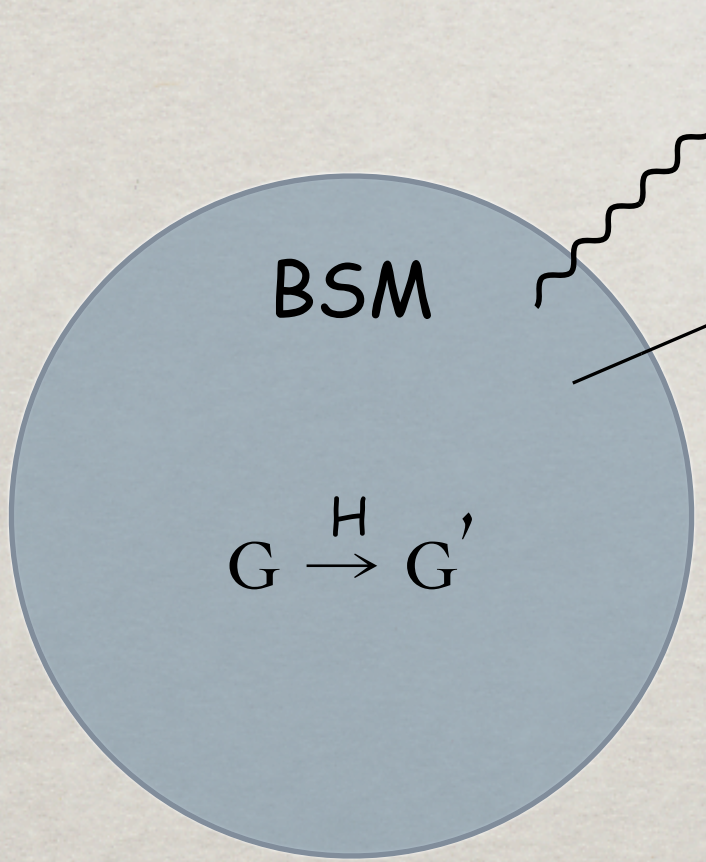
New ingredient:

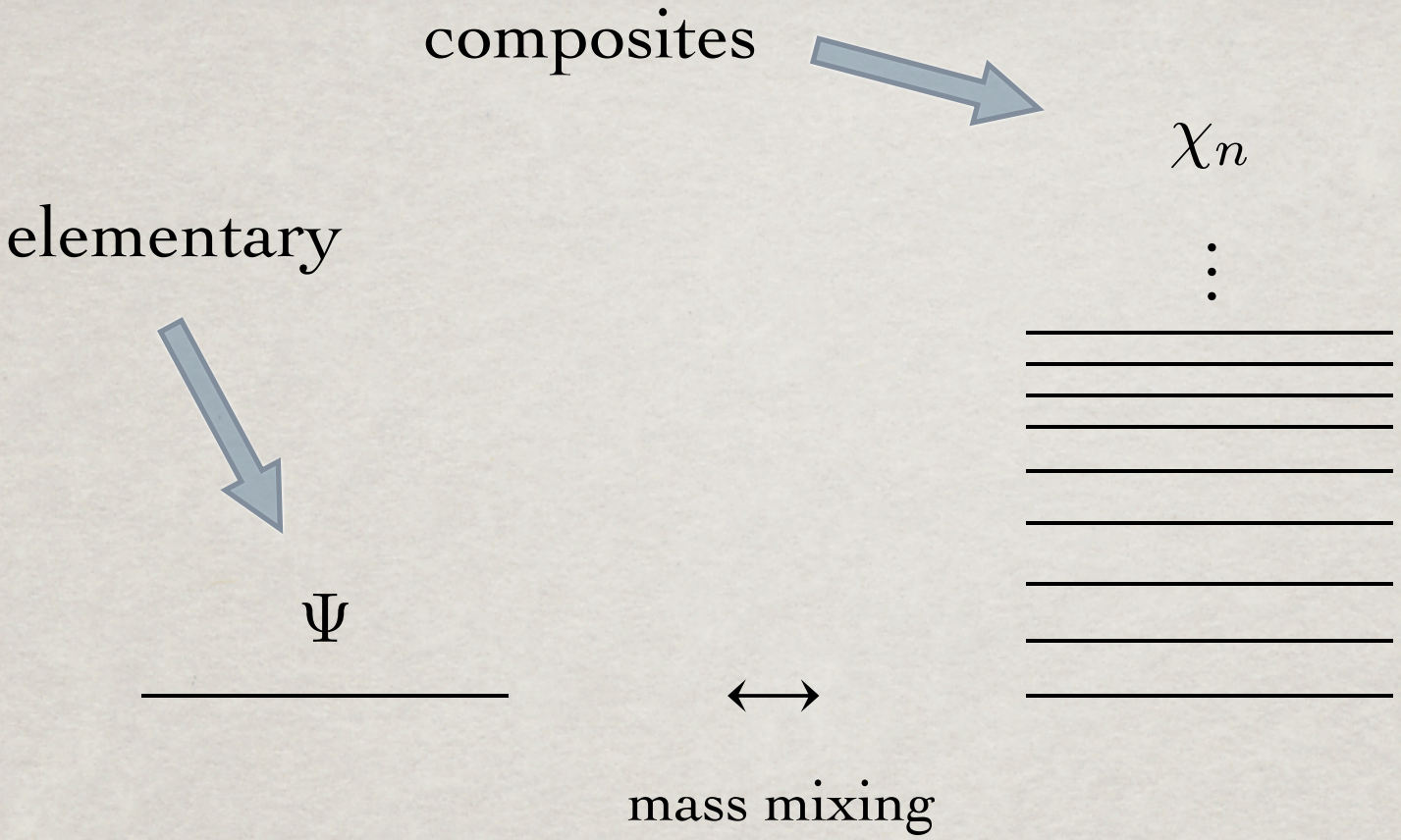
Linear couplings



$$\mathcal{L}_{int} = A_\mu J^\mu + \bar{\Psi} O + h.c.$$

$$O \sim \left(\bar{\Psi}_{TC}\Psi_{TC}\Psi_{TC}\right) \sim \chi$$

$$J^\mu \sim \rho^\mu$$



$$\mathcal{L}_{mix} = \sum_n \Delta_n \, \bar{\Psi} \chi_n + h.c.$$

connection to Extra Dimensions:

if BSM = conformal field theory (CFT) at E ≫ TeV :

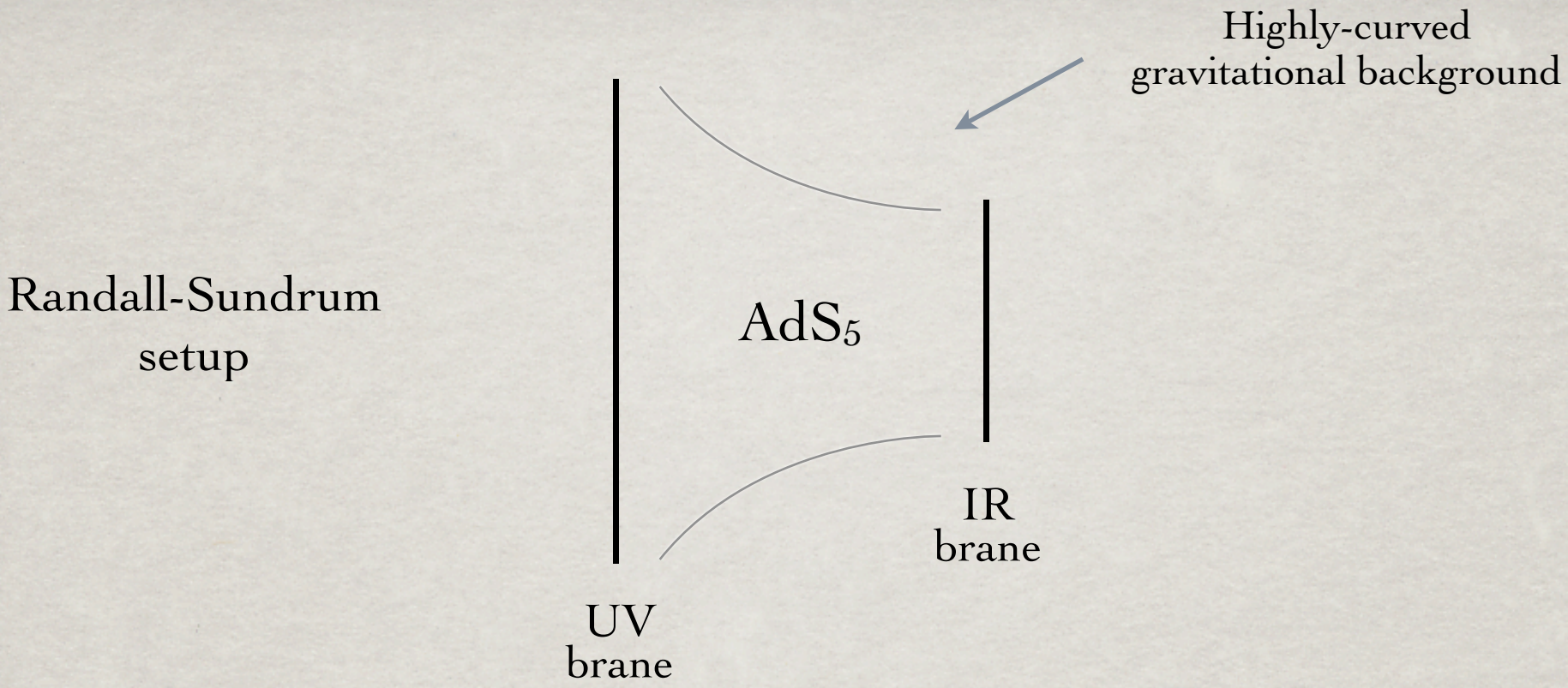
4D picture

DUAL to

(**AdS/CFT correspondence**)

5D (warped) theory

where χ_n = Kaluza-Klein modes

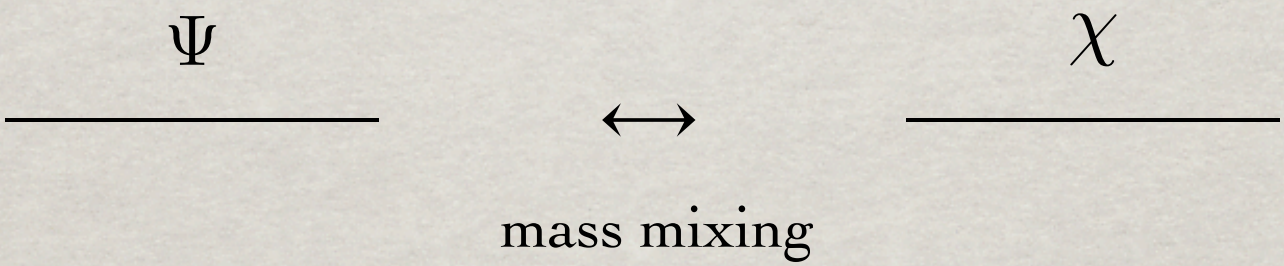


- 5D model gives an explicit realization of the 4D composite Higgs theory

- 5D field theory is perturbative (= calculable)!

Warped/composite Phenomenology Simplified

☞ Keep only the first resonance of each tower



$$\mathcal{L}_{mix} = \Delta\, \bar{\Psi}\chi + h.c.$$

RULES

- Elementary sector: {SM - Higgs}

  inter-elementary coupling: $g_{el} \sim 1$

- Composite sector: {ρ, χ + Higgs}

  [~ excited massive copy of the SM]

  inter-composite coupling: $g_* \gg 1$

- Mixing: only mass mixings allowed

- Higgs: H couples only to ρ and χ

... enough to derive a lot of physics

$$|\mathrm{SM}\rangle = \cos\varphi\,|\Psi\rangle + \sin\varphi\,|\chi\rangle$$

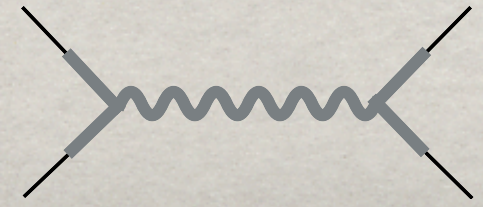
φ parametrizes the degree of partial compositeness

- the larger φ the more "composite" will be a SM particle
- the Higgs is a full composite (= solution to the Hierarchy Problem)
- heavier SM particles = more composites
  light SM particles = almost elementary

$$y = g_* \sin\varphi_L \sin\varphi_R$$

- Precision Tests: sort of GIM mechanism

$$(\bar{\Psi}\Psi)^2 \left(\frac{\sin^4\varphi}{M_*^2}\right)$$



small enough for light fermions

Partial Compositeness and its implications for the LHC

$$|\mathrm{SM}\rangle = \cos\varphi\,|\Psi\rangle + \sin\varphi\,|\chi\rangle$$

$$|\mathrm{heavy}\rangle = -\sin\varphi\,|\Psi\rangle + \cos\varphi\,|\chi\rangle$$

amplitude for single production:

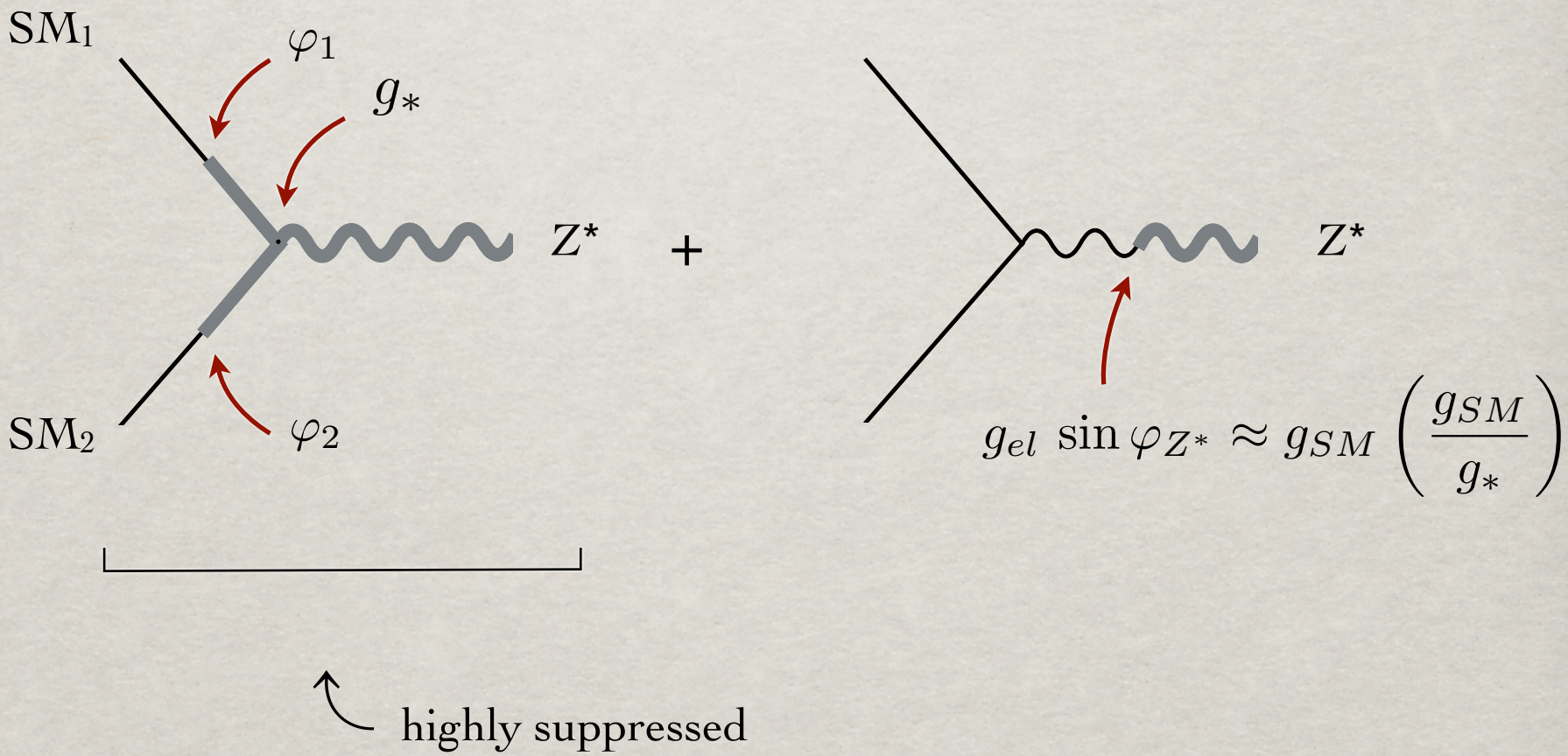
$$\mathcal{A}\left[\mathrm{SM}_1 + \mathrm{SM}_2 \to \mathrm{heavy}\right] \propto g_* \varphi_1 \varphi_2 \cos\varphi_{\mathrm{heavy}} - g_{el} \sin\varphi_{\mathrm{heavy}}$$

g_* more than compensated by $\varphi_1 \varphi_2$ suppression

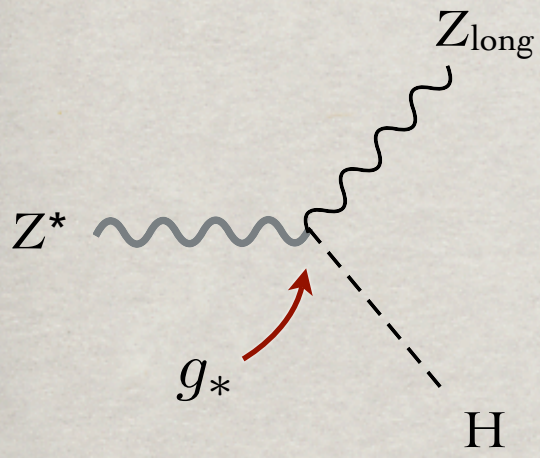
despite g_* large seems promising:

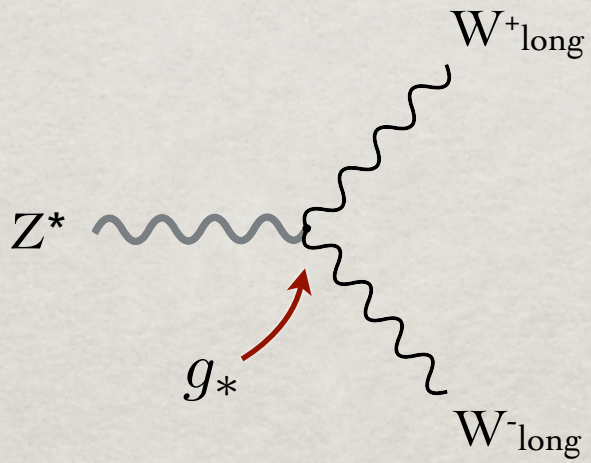
might be cheaper to proceed via the elementary component of the heavy state

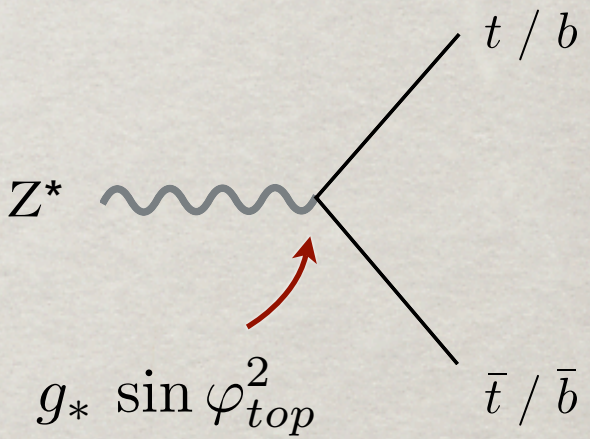
Example: Z^* production & decay



Once produced the heavy resonances will decay mostly to the SM particles with the largest mixing angle: H, W_{long}, Z_{long}, top, bottom

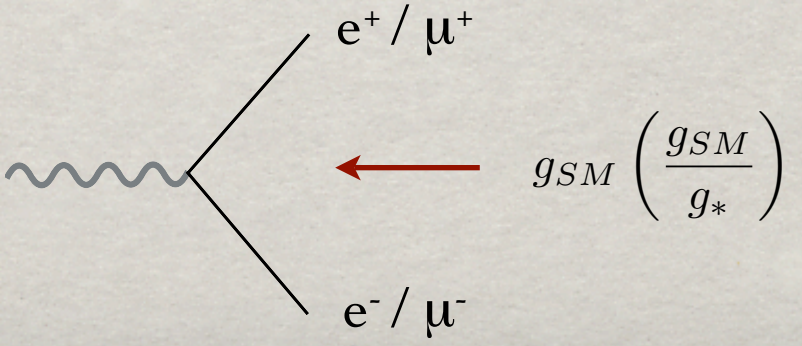




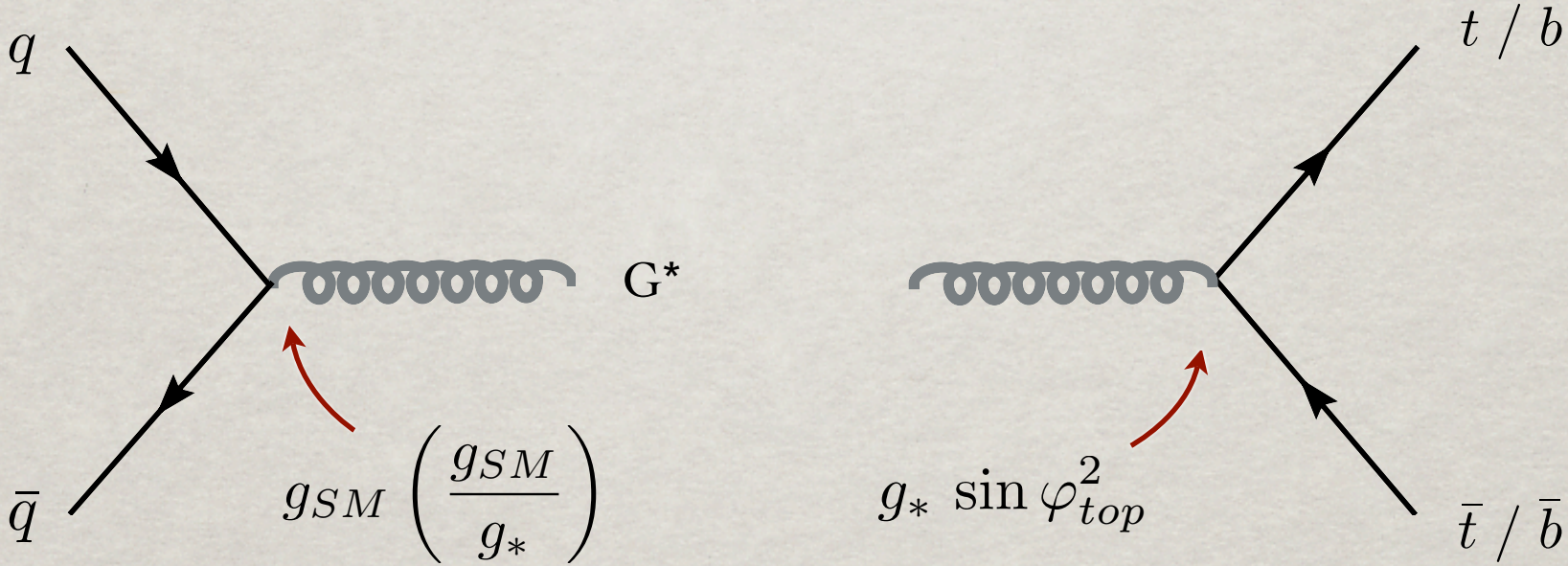


decays to e^+e^-, $\mu^+\mu^-$

SUPPRESSED

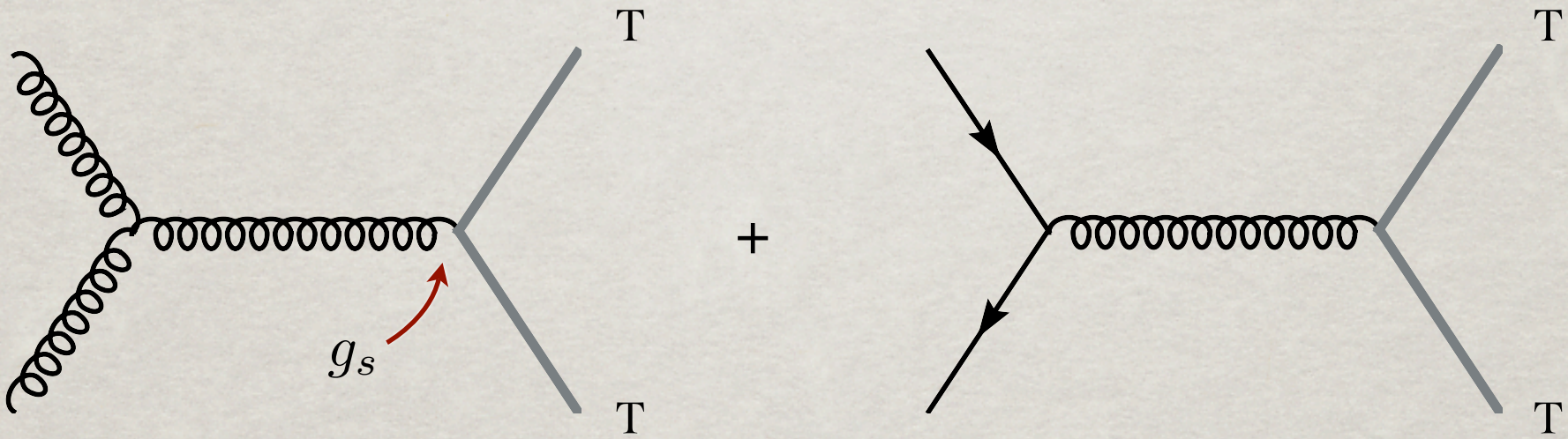


G* PRODUCTION & DECAY

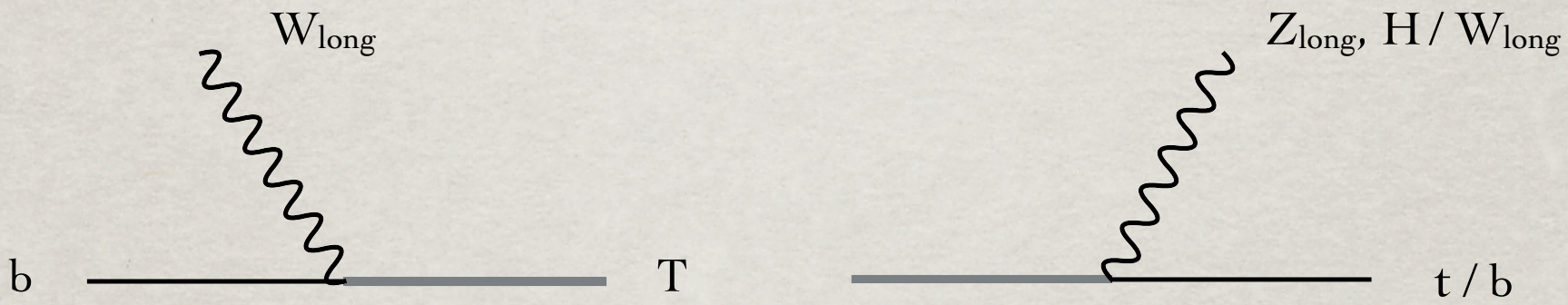


The efficiency for identifying top and bottom quarks will be a key determinant of our ability to find New Physics

T pair production



T SINGLE PRODUCTION & DECAY



top and bottom quarks important also
in the production mechanism

Conclusions

- A non-supersymmetric solution to the Hierarchy Problem is theoretically motivated

  ☞ new insight on strongly interacting theories from extra dimensions makes it even more attractive

- Partial Compositeness might be the way in which New Physics hides from precision and flavor tests

- prediction: well defined pattern of new signals at the LHC

  ☞ final states populated by tops and bottoms