UV Descriptions of Composite Higgs Models Without Elementary Scalars

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In collaboration with

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JHEP 02 (2014) 002

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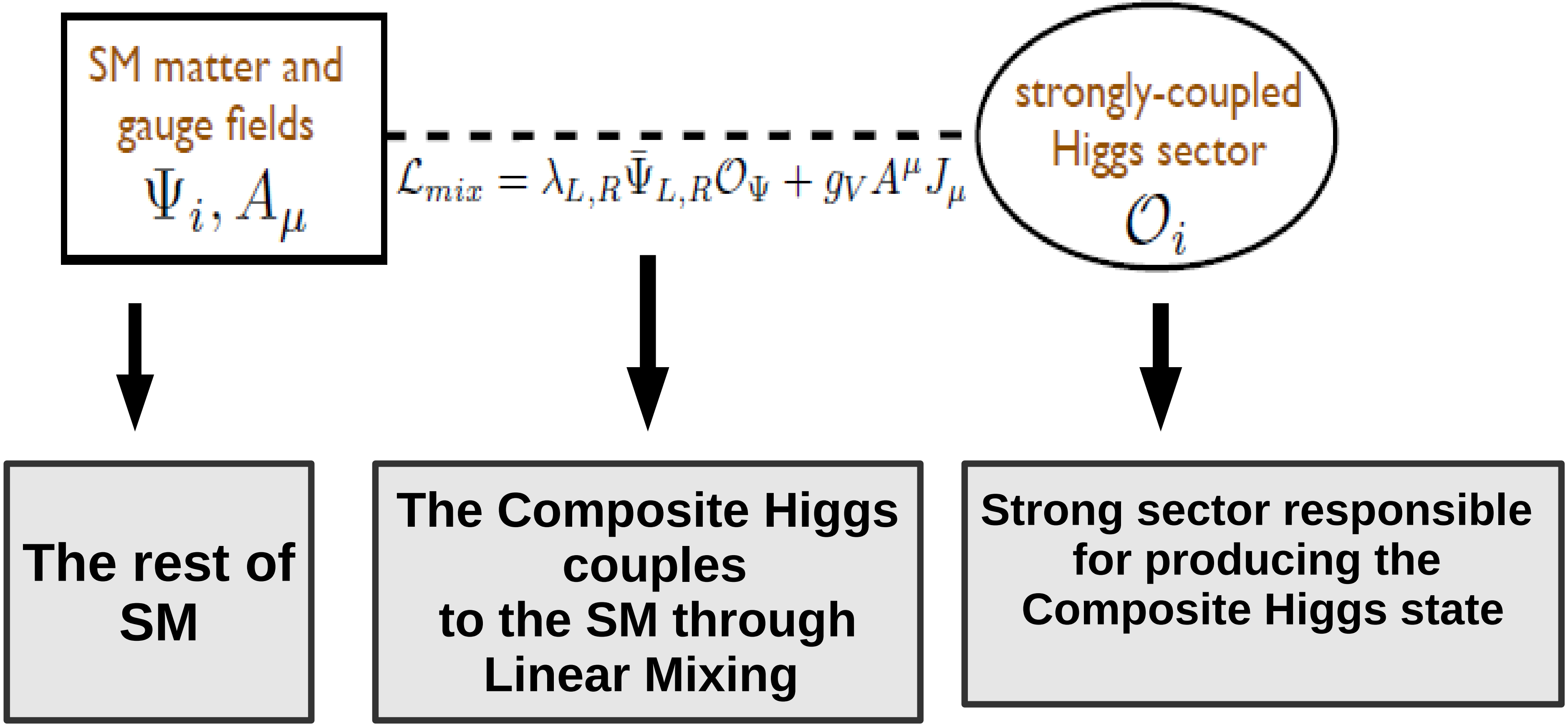
Composite Higgs Models

- Solution to the Gauge Hierarchy Problem: lack of symmetry for Higgs field for protectection against UV destabilization

- Two popular solutions: Supersymmetry (Chiral symmetry) or Shift symmetry

- Composite Higgs models with Higgs identified as pNGBs, are realization of the models with shift symmetry

The Composite Higgs Program



SM matter and gauge fields Ψ_i, A_μ

$$\mathcal{L}_{mix} = \lambda_{L,R}\bar{\Psi}_{L,R}\mathcal{O}_{\Psi} + g_V A^\mu J_\mu$$

strongly-coupled Higgs sector $\mathcal{O}_i$

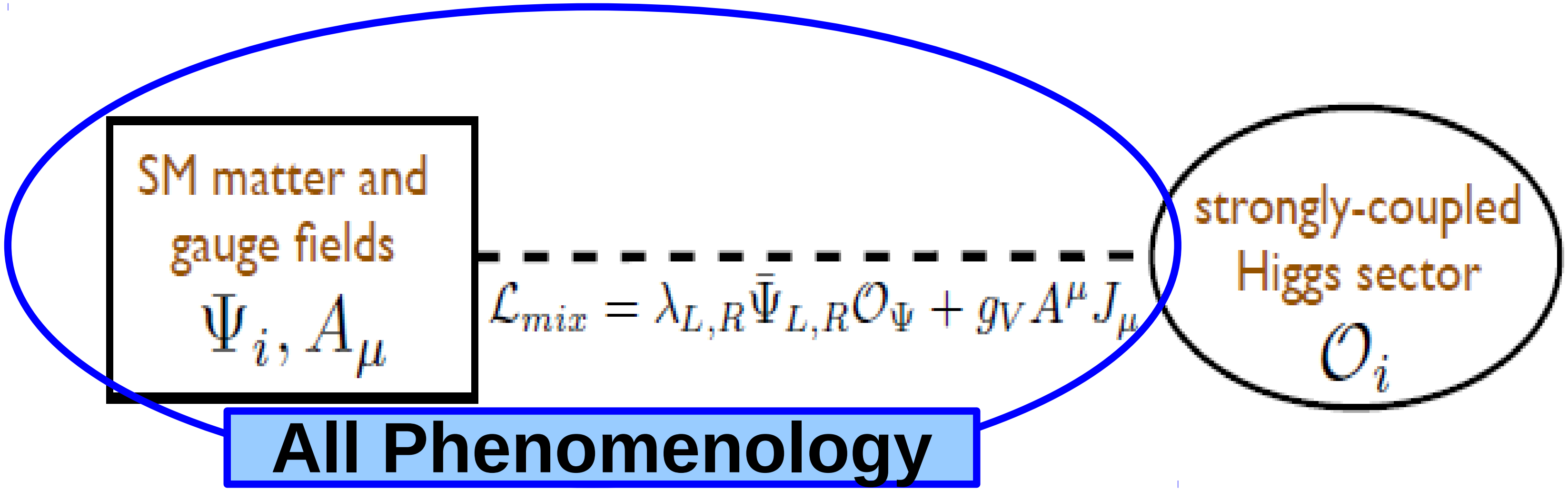
The rest of SM

The Composite Higgs couples to the SM through Linear Mixing

Strong sector responsible for producing the Composite Higgs state

Talk by Tony Gherghetta SCGT14 Mini-Workshop, Japan, 2014

The Composite Higgs Phenomenology



SM matter and gauge fields

Ψ_i, A_μ

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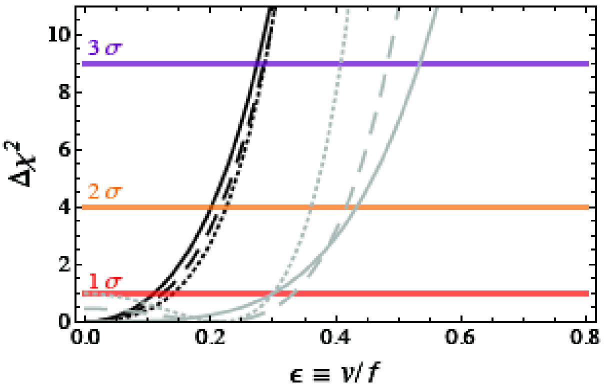
strongly-coupled Higgs sector

$\mathcal{O}_i$

All Phenomenology

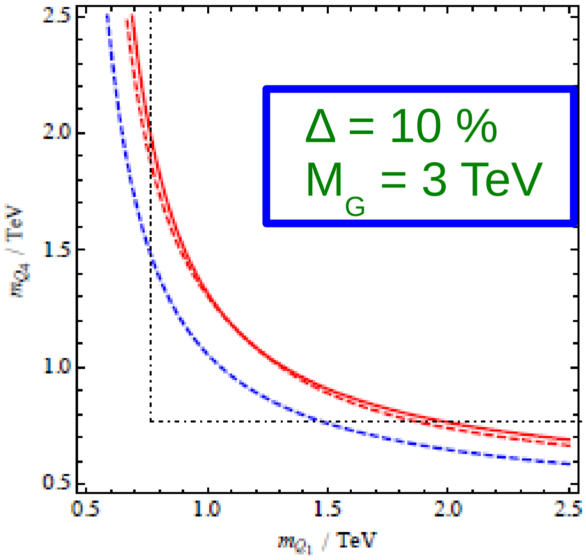
Higgs Couplings

coupling	SM	MCHM
c_V	1	$\sqrt{1-\xi}$
c_ψ	1	$\frac{1-(1+n_\psi)\xi}{\sqrt{1-\xi}}$



Falkowski, Riva, Urbano,
arXiv: 1303.1812

Higgs Mass

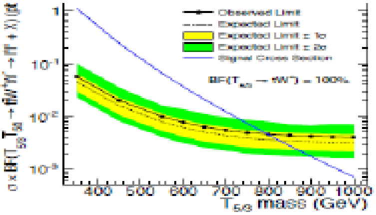


Barnard, Gherghetta,
Medina, TSR,
JHEP10(2013)055.

Collider Studies

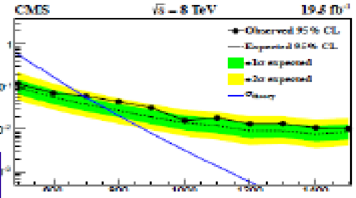
$Q:\ \frac{5}{3}$

$m_{T_{5/3}} > 800$

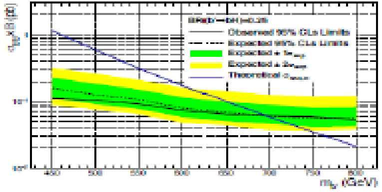


$Q:\ \frac{2}{3}$

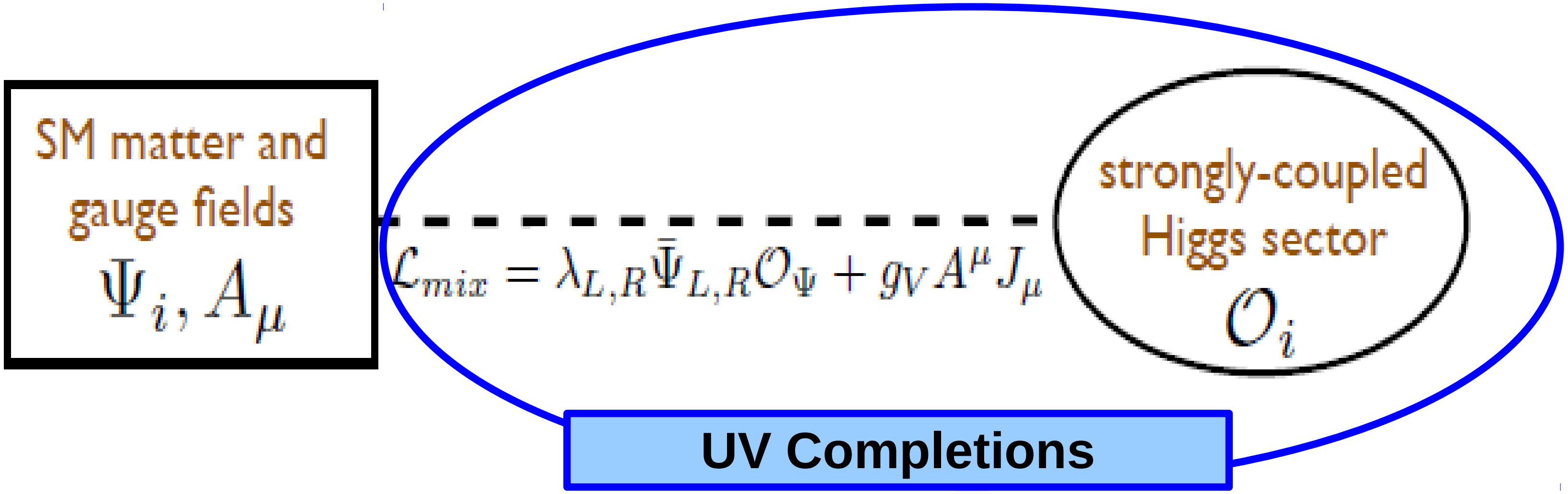
$m_{T_{2/3}}, m_B > 700$



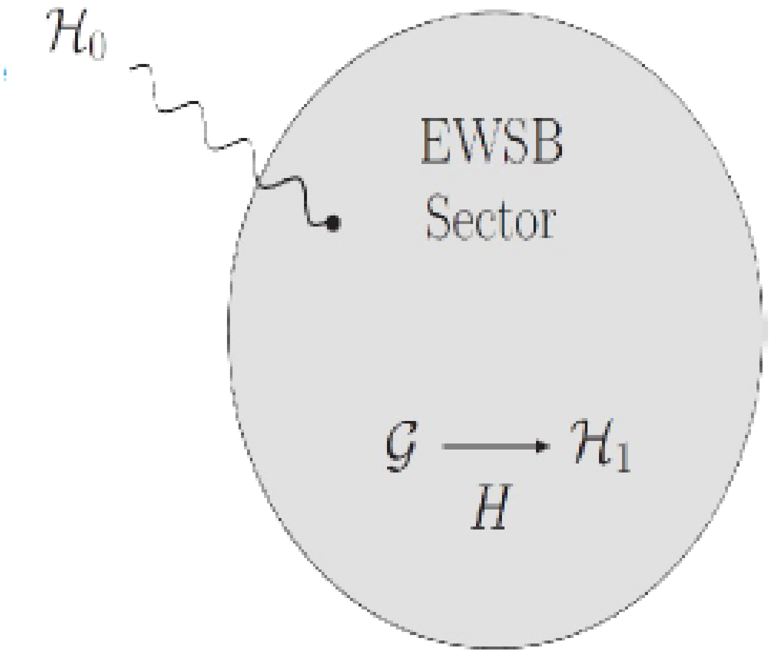
$Q:\ -\frac{1}{3}$



The Strong Sector



- Drive the spontaneous symmetry breaking G/H
- Generate the pNGBs
- Responsible for generating the resonances for the mixing Lagrangian



UV Completion: $\mathcal{L}_{\text{strong}}$

(1) Consider that the strong sector has conformal invariance and is holographic view of a 5d dual theory with warped geometry.

Gherghetta, arXiv:1008.2570 [hep-ph]

(2) The strong sector has a perturbative UV free Seiberg dual which is supersymmetric.

Caracciolo, Parolini, Serone, JHEP 1302 (2013) 066

(3) Is an UV completion with fermions and gauge bosons of the strong sector possible?

Consider a set of fermions charged under some gauge group G_c, having a global exchange/flavor symmetry G. Certain gauge invariant fermion condensates can develop vev to break the global group G to H.

The question is whether G can be broken to a subgroup H in such a way that a mass term for the fermions charged under the unbroken symmetry is forbidden? Use NJL framework to study this.

Barnard, Gherghetta, TSR, JHEP 02 (2014) 002

UV Description with Chiral Fermions: Example

SO(6)/SO(5) Model aka SU(4)/Sp(4)

Note: chiral fermions are complex thus exchange symmetry has to be SU (not SO (?))

Consider a gauge theory with the following particle content:

This theory is asymptotically free and confining at the IR

$$b = \frac{2}{3}(11N_c + 7)$$

Gauged

Global

	$Sp(2N_c)$	$SU(4)$
ψ	$\square$	$\mathbf{4}$
M	$\mathbf{1}$	$\mathbf{6}$

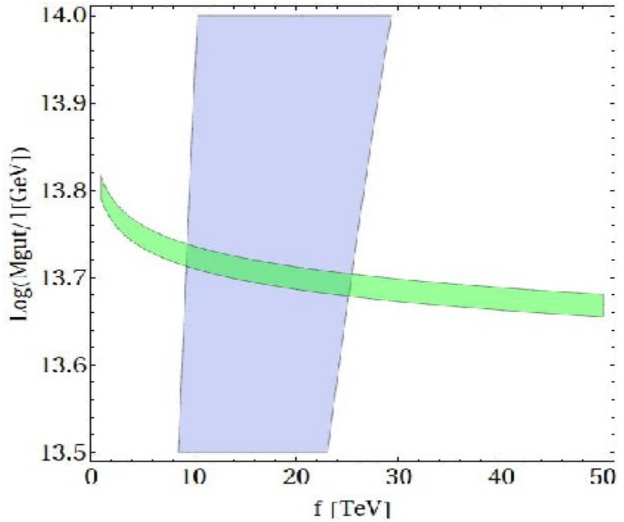
Global symmetry breaking:

$$M \equiv \langle \psi\psi \rangle$$

$$\langle M \rangle \implies SU(4) \to Sp(4)$$

Radial components of the matrix M give the pNGBs to be identified with the Higgs

Gauge coupling unification:



Unification better than MSSM (M$_{SUSY}$ =1 TeV))in the overlap region

Large Anomalous Dimension

- Large 3rd generation Yukawa coupling implies that the dimension of the Higgs condensate cannot be very different from 1.
- This implies that the condensate should be tightly bound resulting in large anomalous dimension
- Can be achieved by introducing four fermion interactions among the states

① **A gauged NJL model:**

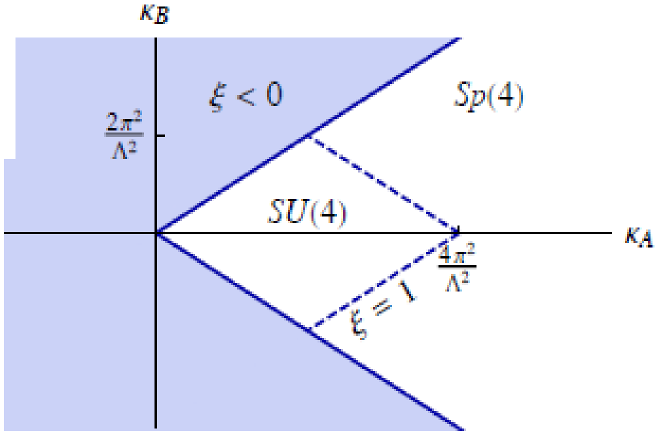
$$\mathcal{L}_{int} = \frac{\kappa_A}{2N_c}(\psi^a\psi^b)(\bar{\psi}_a\bar{\psi}_b) + \frac{\kappa_B}{8N_c}\epsilon_{abcd}(\psi^a\psi^b)(\psi^c\psi^d) + \text{h.c.}$$

② **Auxiliary field:**

$$M^{ab} = -\frac{\kappa_A+\kappa_B}{2N_c}(\psi^a\psi^b) = \begin{pmatrix} 0 & m_1 & 0 & 0 \\ -m_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_2 \\ 0 & 0 & -m_2 & 0 \end{pmatrix}$$

③ **Minimum of C-W potential:**

$$m_1 = m_2 = \frac{\bar{m}}{2} \Longleftrightarrow \frac{\bar{m}^2}{\Lambda^2}\ln\frac{\Lambda^2}{\bar{m}^2} \approx 1 - \frac{1}{\xi}$$



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Assume that Λ is a running scale:

Remember the function of the couplings:

$$\xi = \Lambda^2(\kappa_A+\kappa_B)/(4\pi^2)$$

A

$\xi = 1$ is a fixed point !

$$\frac{\bar{m}^2}{\Lambda^2}\ln\frac{\Lambda^2}{\bar{m}^2} \approx 1-\frac{1}{\xi}$$

$$\Longrightarrow \beta(\xi) = \Lambda\partial_\Lambda\xi \approx 2\xi(1-\xi)$$

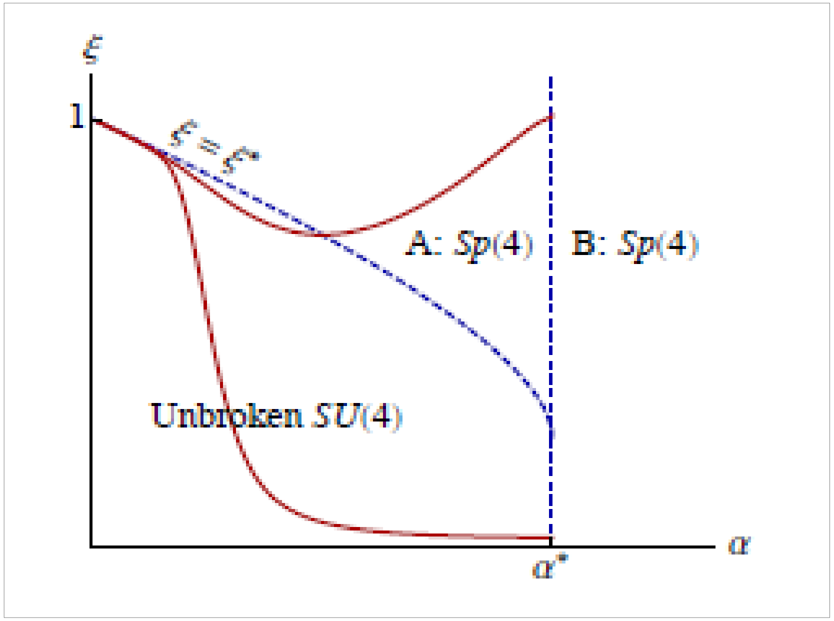
B

Large Anomalous Dimension

$$\bar{m} = -\frac{4\pi^2\xi}{N_c\Lambda^2}\langle\psi\psi\rangle$$

$$\bar{m}(\Lambda) = \mu_0\Lambda^2\bar{m}(\mu_0) \equiv Z_m\bar{m}(\mu_0) \Longrightarrow \gamma_m \equiv -\frac{\Lambda}{Z_m}Z_m\Lambda \sim 2$$

Thus the auxiliary field is a fermion bilinear having the right quantum number and vev to be a Higgs and also has the right anomalous dimension

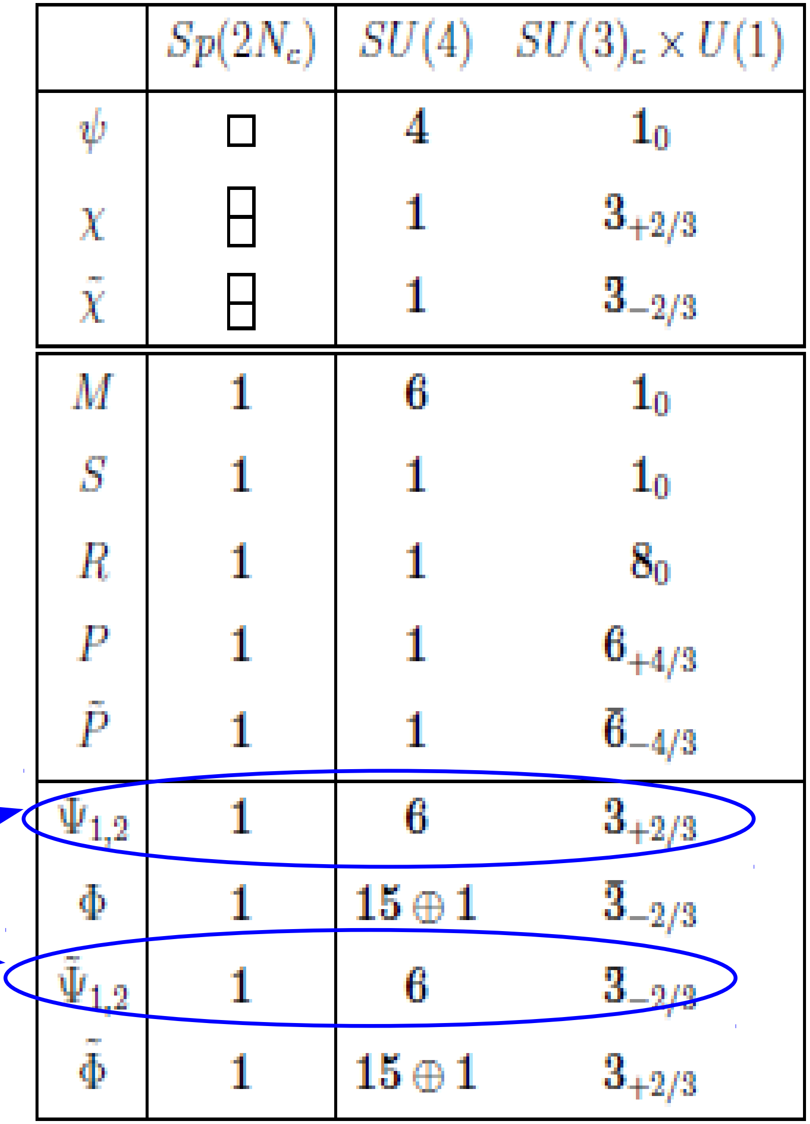


Requires solution of Schwinger-Dyson equation: Should be considered as a plausibility argument rather than a rigorous proof!

Including the Top Partners

- The Yukawa couplings are generated by mixing between the SM fermions and their partners in the strong sector
- The strong sector should generate these resonances
- In our scenario the baryons of the preons can be considered to be these resonances.
- Minimal model including the top partner:

One can argue that with the right choice of parameters the correct meson gets a vev



	$Sp(2N_c)$	$SU(4)$	$SU(3)_c \times U(1)$
ψ	$\square$	$\mathbf{4}$	$\mathbf{1}_0$
χ	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$	$\mathbf{1}$	$\mathbf{3}_{+2/3}$
$\bar{\chi}$	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$	$\mathbf{1}$	$\bar{\mathbf{3}}_{-2/3}$
M	$\mathbf{1}$	$\mathbf{6}$	$\mathbf{1}_0$
S	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}_0$
R	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{8}_0$
P	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{6}_{+4/3}$
$\bar{P}$	$\mathbf{1}$	$\mathbf{1}$	$\bar{\mathbf{6}}_{-4/3}$
$\Psi_{1,2}$	$\mathbf{1}$	$\mathbf{6}$	$\mathbf{3}_{+2/3}$
Φ	$\mathbf{1}$	$\mathbf{15} \oplus \mathbf{1}$	$\bar{\mathbf{3}}_{-2/3}$
$\bar{\Psi}_{1,2}$	$\mathbf{1}$	$\mathbf{6}$	$\bar{\mathbf{3}}_{-2/3}$
$\bar{\Phi}$	$\mathbf{1}$	$\mathbf{15} \oplus \mathbf{1}$	$\mathbf{3}_{+2/3}$

PREONS

MESONS

BARYONS

Conclusions

- The composite Higgs models provide a consistent theoretical framework to solve the gauge hierarchy problem
- These can have simple 4d UV completions in terms of chiral fermions
- Plausibility of such UV completions was demonstrated using the example of SU(4)/Sp(4) coset
- The key features of these models are large anomalous dimensions that can be induced by strong 4 fermion couplings
- Can be extended to other cosets

Thank You!

Back up Slides

Rg evolution of parameters

Relation obtained by solving S-D equation in Ladder approximation:

$$\frac{2}{1-\omega^2}\left(\frac{\bar{m}}{\Lambda}\right)^{2\omega} = \frac{1}{\xi^*} - \frac{1}{\xi}$$

where

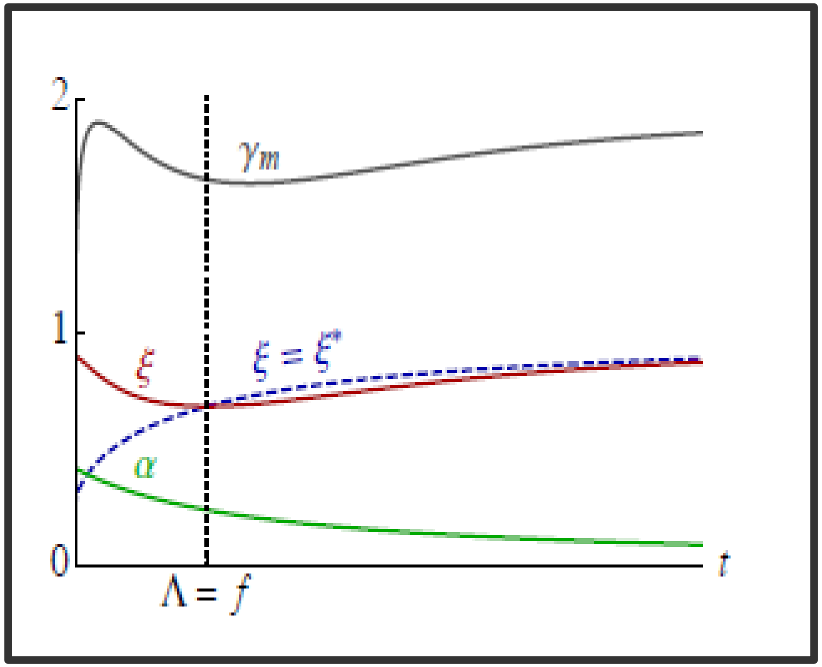
$$\xi^* = \frac{1}{4}(1+\omega)^2 \qquad \omega = \sqrt{1-\frac{\alpha}{\alpha^*}} \qquad \alpha^* = \frac{\pi}{3C_2(\square)} = \frac{2\pi}{3(2N_c+1)}.$$

Evolution of the 4-fermion couplings and the anomalous dimension:

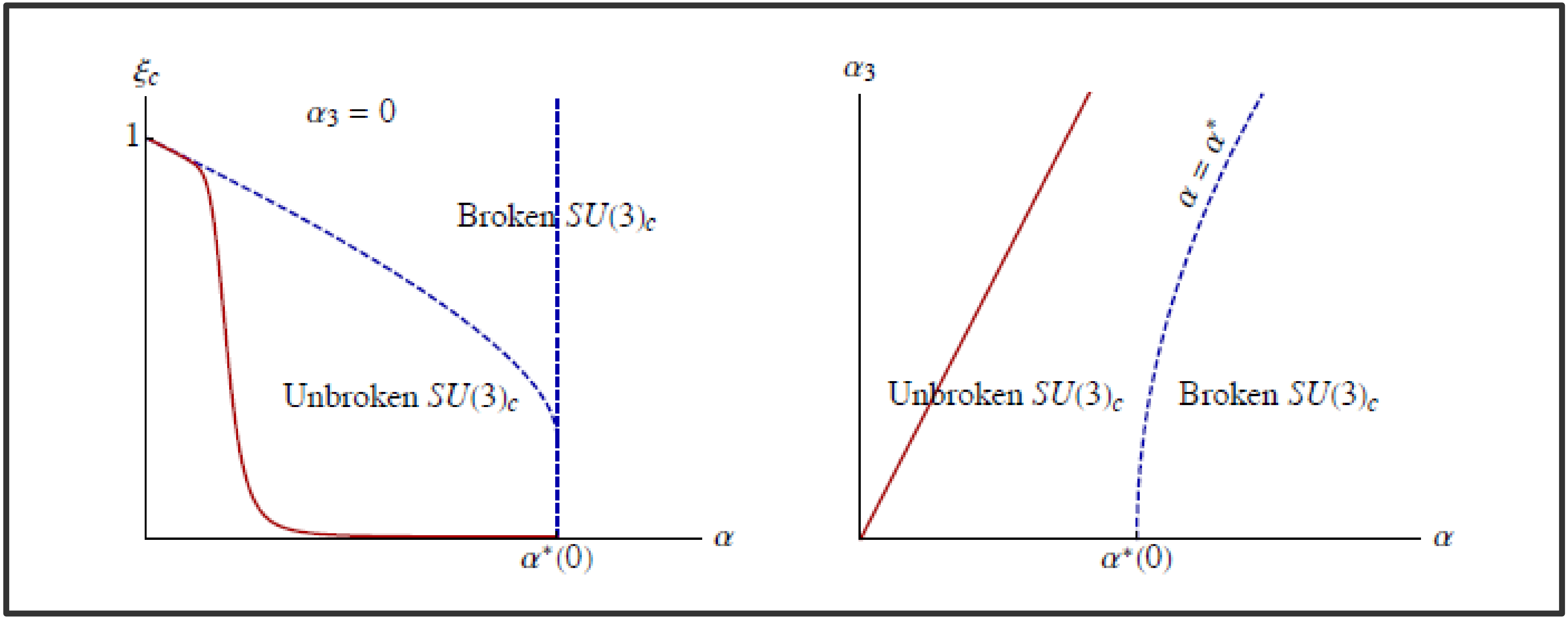
$$\beta(\xi) = 2\omega\xi\left(1-\frac{\xi}{\xi^*}\right) \qquad \gamma_m(\xi) = 1-\omega\left(1-\frac{2\xi}{\xi^*}\right).$$

Evolution of the gauge coupling:

$$\alpha(\Lambda) = \frac{2\pi}{b\ln(\Lambda/\Lambda_\alpha)}$$



The phase diagrams for the colored mesons



Turning on the SM color interactions prevents these states from developing a vev