APPLYING ADS/QCD METHODS TO COMPOSITE HIGGS MODELS

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MOTIVATION

Composite Higgs naturally explains

- ➤ the light Higgs mass
- ➤ The large top mass

But

- ➤ Strongly coupled theory, perturbative calculations not viable in low energy regime

Therefore

- Use AdS/CFT correspondence dual to a weakly coupled theory.

Composite Higgs: A Tiny Review

COMPOSITE HIGGS: A REVIEW

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SM without Higgs and Yukawa

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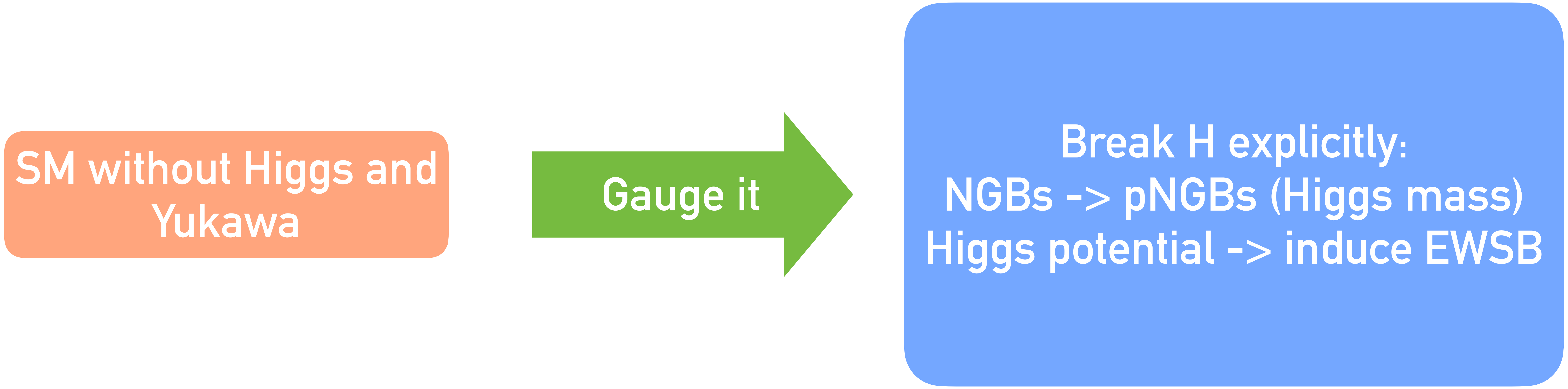
SM without Higgs and Yukawa

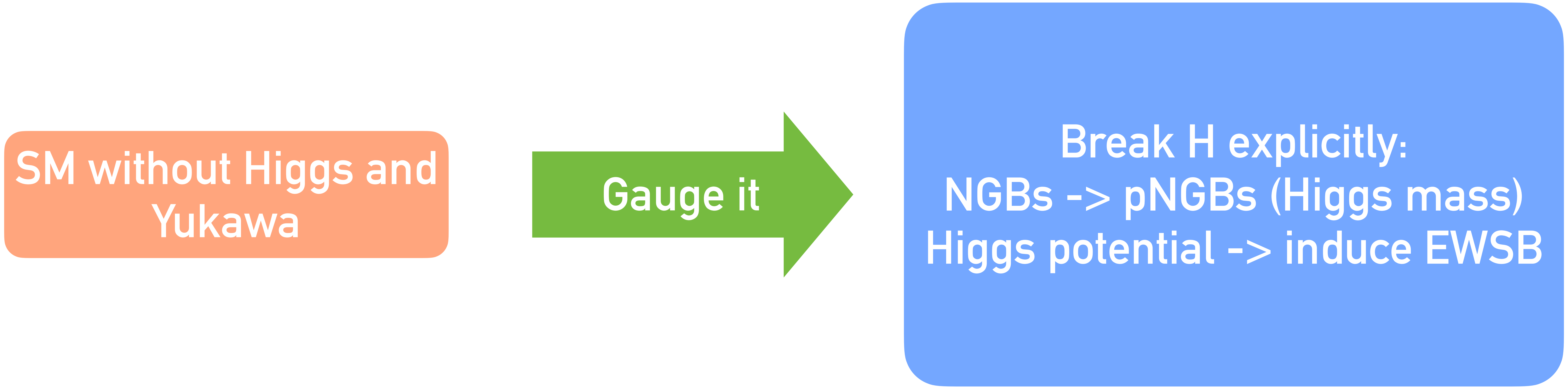
Composite Sector With NGBs

COMPOSITE HIGGS: A REVIEW

COMPOSITE HIGGS: A REVIEW



COMPOSITE HIGGS: A REVIEW



- Similar to χPT, $G \to SU(N_f)_L \times SU(N_f)_R$, $H \to SU(N_f)_V$

How does the dual theory look like?

THE MODEL, ABELIAN

- [J.Erdmenger, N.Evans, W.Porod, K.S.Rigatos, hep-th/2010.10279]
- Takes the form of “chiral perturbation theory”, but 5D AdS
- Abelian in the sense only one D7-brane is present
- →all (hyper)quark masses are degenerated

PROMOTE TO NON-ABELIAN

Promoting to $\mathrm{U}(N_f)$ non-degenerated theory

$\rightarrow$fields, metric, coordinates $N_f \times N_f$ matrices

But matrices' positions matter

$\rightarrow$ use $\mathrm{STr}(X_a X_b \ldots X_n) = \frac{1}{n!}\sum$ (all permutations of X_i), but only on $D_a X$, F_{ab}, $[X_a, X_b]$

ends up equiv. to Tr at $O(F^2)$.

LAGRANGIAN

$$\mathscr{L} = \rho^3 Tr\left\{ \frac{1}{r^2} D^a X^\dagger D_a X + \frac{1}{\rho^2}\left[\Delta m^2 X^\dagger X + L\frac{\partial \Delta m^2}{\partial L}\left(\frac{1}{\sqrt{2N}}\sigma id_N + \sum_k \frac{\xi_k(x)}{\sqrt{2N}} T_k \right)^2 \right] + \frac{1}{g_5^2}\left(F_L^2 + F_R^2\right) \right\}$$

- $X = \left(L + \sigma + \xi_i T^i\right) e^{i(\phi + \pi_i T^i)}$, T^i: Pauli matrices. $A_{L,R} = \frac{1}{2}(V \pm A)$
- σ is the scalar singlet, ξ_i is the scalar triplet, $a = 0,...,4 = \mu, \rho$

$L = \frac{1}{\sqrt{2N_f}} \begin{pmatrix} L_u & 0 \\ 0 & L_d \end{pmatrix}$ is the vacuum configuration

$r = \begin{pmatrix} r_u & 0 \\ 0 & r_d \end{pmatrix}$ is the radial coordinate, Δm^2 and $\frac{\partial \Delta m^2}{\partial L}$ are also diagonal matrices defined in the same sense as r.

Δm^2

- $\Delta m^2 = \Delta m^2(\rho)$ acts as the scalar mass,
- Vacuum UV solution: $L(\rho) = m\rho^{-\gamma} + \langle \bar{q}q \rangle \, \rho^{\gamma-2}$, $\Delta m^2 = \gamma(\gamma - 2) \sim -2\gamma$,
- γ: anomalous dimension of the quark bilinear.
- Breitenlohner-Freedman bound: $\Delta m^2 = -1 \to \gamma = \dfrac{1}{2}$,
- below this: chiral symmetry breaking.
- $\rho \dfrac{d\alpha}{d\rho} = -b_0\alpha^2 - b_1\alpha^3, \quad \gamma = \dfrac{3C_2(R)}{2\pi}\alpha$, the b_0, b_1 are omitted here

OVERLAPPING BRANES

- When $L_u = L_d$ the two branes overlap, 4 copies of the abelian theory.
- But if add $\mathcal{O}(X^4)$ contributions to the scalar potential: $\kappa[Tr(X^\dagger X)]^2$, κ small, $\rightarrow$ Scalar singelt & triplet are different
- Singlet eom - $3\kappa L_0(\rho)^2\sigma(\rho)\rho$, triplet eom - $\kappa L_0(\rho)^2\xi_3(\rho)\rho$
- Can get the scalar masses splitting in the correct range.

SEPARATED BRANES, 2 FLAVOURS

- $L_u \neq L_d$
- The off diagonal ones have coupled eoms, mixing $\sim (L_d - L_u)$, can be ignored
- E.g. Vector:

$$\partial_\rho\left(\rho^3 \partial_\rho V_1^\mu(x^\mu,\rho)\right) + \rho^3\left(\frac{1}{r_u^4}+\frac{1}{r_d^4}\right)\left[M_{V_1}^2 - \frac{g_5^2}{4}(L_u(\rho)-L_d(\rho))^2\right]V_1^\mu(x^\mu,\rho) = 0$$

- Impose boundary conditions:

$$f(IR) = 1, \partial_\rho f(IR) = 0, f(UV) = 0$$

- Shoot from IR and solve for the masses s.t. the field f vanished in the UV →get triplet masses

SEPARATED BRANES, 2 FLAVOURS

The diagonal ones are decoupled in states that are not mass eigenstates in SU(2)

Impose plane-wave ansatz for the singlet and triplet (vector as an example)

$$V_{0,3}(x,\rho) = V_{0,3}(\rho)e^{ikx}, \qquad \partial_\mu \partial^\mu V_{0,3}(x,\rho) = M^2_{V_{0,3}} V_{0,3}(x,\rho)$$

Eoms are now

$$V_0 : 2\partial_\rho \left(\rho^3 \partial_\rho V_0(x^\mu,\rho)\right) + \rho^3 \left(\frac{1}{r_u^4} + \frac{1}{r_d^4}\right) M^2_{V_0} V_0(x^\mu,\rho) + \rho^3 \left(\frac{1}{r_u^4} - \frac{1}{r_d^4}\right) M^2_{V_3} V_3(x^\mu,\rho) = 0$$

$$V_3 : 2\partial_\rho \left(\rho^3 \partial_\rho V_3(x^\mu,\rho)\right) + \rho^3 \left(\frac{1}{r_u^4} + \frac{1}{r_d^4}\right) M^2_{V_3} V_3(x^\mu,\rho) + \rho^3 \left(\frac{1}{r_u^4} - \frac{1}{r_d^4}\right) M^2_{V_0} V_0(x^\mu,\rho) = 0.$$

SEPARATED BRANES, 2 FLAVOURS

Impose boundary conditions

diagonal : $\partial_\rho \left(V_0(x^\mu, \rho) + V_3(x^\mu, \rho) \right) |_{\rho_u} = 0,\ \partial_\rho \left(V_0(x^\mu, \rho) - V_3(x^\mu, \rho) \right) |_{\rho_d} = 0$

$$\left[V_0(x^\mu, \rho) + V_3(x^\mu, \rho) \right]_{\rho_u} = \alpha,\ \left[V_0(x^\mu, \rho) - V_3(x^\mu, \rho) \right]_{\rho_d} = \beta$$

Shoot from IR (ρ_u, ρ_d), and feed the triplet mass (from off-diagonal) to M_{V_3}

$$M_{V_3} = M_{V_1}$$

demand the masses found should satisfy

$$\frac{M_{V_0}}{M_{V_3}} =: \frac{M_\omega}{M_\rho}$$

Solve a boundary condition pair (α, β): intrinsic, apply to scalar, axial-vector and π

SEPARATED BRANES, 2 FLAVOURS

Observables	$I^G(J^{PC})$	QCD(MeV)[2]	non-Abelian AdS/SU(3) (MeV)	Deviation
$M_{\omega(782)}$	$0^-(1^{--})$	782.66 ± 0.13	783*	fitted
$M_{\rho(770)}$	$1^+(1^{--})$	775.26 ± 0.23	775*	fitted
$M_{f_0(980)}$	$0^+(0^{++})$	990 ± 20	998	1%
$M_{a_0(980)}$	$1^-(0^{++})$	980 ± 20	999	2%
$M_{f_1(1285)}$	$0^-(1^{+-})$	1281.9 ± 0.5	1234	4%
$M_{a_1(1260)}$	$1^+(1^{+-})$	1230 ± 40	1197	3 %
M_{π^0}	$1^-(0^{-+})$	134.9768 ± 0.0005	146	8 %
$M_{\pi^\pm}$	$1^-(0^-)$	139.57039 ± 0.00018	145	4 %

$m_u = 2.3$ MeV and $m_d = 4.6$ MeV

SEPARATED BRANES, 3 FLAVOUR

The flavour group is U(3)

Lagrangian, set-up same as 2-flavour case

Simply extended to 3-flavour: $m_u = m_d < m_s$

Eoms grouped in 3 classes:

$$(u,1,2,3)\text{: } u\bar{u}, u\bar{d}, d\bar{d}; \qquad (4,5,6,7)\text{: } u\bar{s},\, d\bar{s}; \quad s\text{: } s\bar{s}$$

$$f_u := \frac{\sqrt{2}}{\sqrt{3}} f_0 + \frac{1}{\sqrt{3}} f_8, \quad f_s := \frac{\sqrt{2}}{\sqrt{3}} f_0 - \frac{2}{\sqrt{3}} f_8\,.$$

SEPARATED BRANES, 3 FLAVOUR

Vectors & scalars: well defined meson states, ideally mixed, phy. states: SU(2) singlet and $s\bar{s}$;

Axial-vectors: not so well defined, but might follow the same structure

Pseudo-scalars: slightly mixed, phy. states: SU(3) singlet and 8th component of the octet: η' and η.

Can't use the diagonal procedure to get η and η' masses.

SEPARATED BRANES, 3 FLAVOUR

Observables	$I^G(J^{PC})$	QCD (MeV)	$N_f = 3$ Numerics (MeV)	Deviation
$\rho(770)$	$1^+(1^{--})$	775.26 ± 0.23	775*	fitted
$K^*(892)$	$\frac{1}{2}(1^-)$	891.67 ± 0.26	966	8%
$\phi(1020)$	$0^-(1^{--})$	1019.461 ± 0.016	1121	9%
$a_1(1260)$	$1^-(1^{++})$	1230 ± 40	1104	11%
$K_1(1400)$	$\frac{1}{2}(1^+)$	1403 ± 7	1433	2%
$f_1(1420)$	$0^+(1^{++})$	1426.3 ± 0.9	1849	26%
$a_0(980)$	$1^-(0^{++})$	980 ± 20	929	5%
$K_0^*(700)$	$\frac{1}{2}(0^+)$	845 ± 17	987	16%
$f_0(1370)$	$0^+(0^{++})$	1370	1032	28%
$\pi^{0,\pm}$	$0, 1^-(0^{-+})$	139.57039 ± 0.00017	133	5%
$K^{0,\pm}$	$\frac{1}{2}(0^-)$	497.611 ± 0.013	498	0%

$m_u = m_d = 2.5\,MeV,\ m_s = 95.5\,MeV$

CONCLUSIONS & OUTLOOK

Conclusions:

- A non-abelian AdS/YM that can explain QCD meson spectrum well.

Outlook:

- Apply the same method to the $SU(4) \to sp(4)$ case, link it to the composite Higgs models;
- Include fermion states, to complete the full theory.

THANKS FOR YOUR ATTENTION !