Phd04: New physics from a natural electroweak symmetry breaking
status report nov 2014

presented by J-L Kneur for the collaboration

Nicolas Bizot; supervisors: M. Frigerio, M. Knecht, J-L Kneur

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Participants, Physics perimeter, Keywords

PhD student: Nicolas Bizot
(NB many thanks for preparing large part of this presentation!)
supervisors: Michele Frigerio, Marc Knecht, Jean-Loic Kneur

Context: Beyond Standard Model theories "for a more natural EWSB":

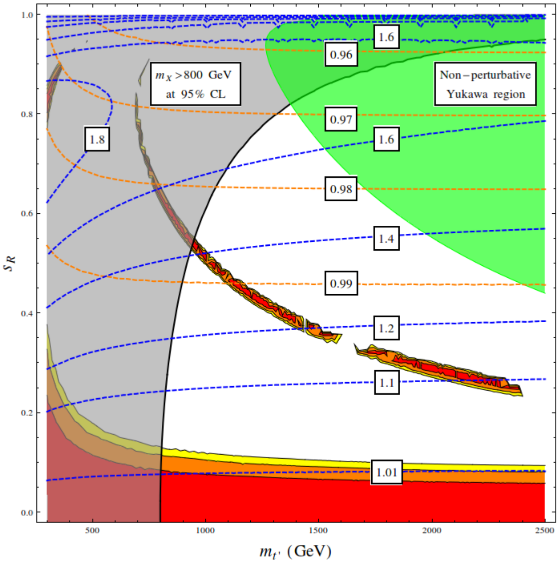
- Extensions of the Standard Model that modify the Higgs properties;
- Electroweak symmetry breaking from a strongly-coupled sector;
- Composite Higgs models: UV completions and predictions for the Large Hadron Collider;
- ...

Two main projects/work in progress (at the moment):

- Minimal fermionic extensions of the Standard Model (*SM*):
  (N. Bizot, M. Frigerio)
  - Aim: classification of viable extensions of the SM modifying Higgs couplings: no massless charged particles, no gauge anomalies etc
  - Methods: Constraints on parameter space: direct searches at LHC, electroweak precision parameters,...
  - Extensions from 1 to 4 additional fermions: already known cases (seesaw type I and III, Vector-like quarks and leptons,...) + new cases not studied before.

  $\Rightarrow$ Milestones: phenomenological aspects, LHC physics and constraints.
- UV completions of composite Higgs models
  (N. Bizot, M. Frigerio, M. Knecht, J-L Kneur)
  - Aim: Calculation of the mass spectrum: spin 0, 1 and 1/2 resonances.
  - Study of different possible UV completions; comparing their predictions.

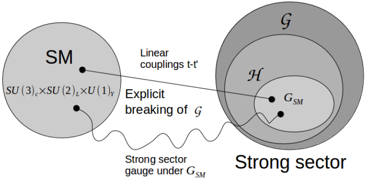
  $\Rightarrow$ Methods: theoretical non-perturbative techniques (Milestones: NJL-model inspired and $1/N$-expansion).


1.0
0.8
0.6
0.4
0.2
0.0
s_R
500
1000
1500
2000
2500
$m_{t'}$ (GeV)
m_X >800 GeV
at 95% CL
Non–perturbative
Yukawa region
1.6
0.96
0.97
1.6
1.8
0.98
1.4
0.99
1.2
1.1
1.01

A composite light Higgs boson

- New strongly-interacting sector invariant under a global symmetry $\mathcal{G}$.
- Spontaneous breaking of global symmetry $\mathcal{G}$ (by condensate) to subgroup $\mathcal{H}$.$\rightarrow$ composite Goldstone bosons live in the coset $\mathcal{G}/\mathcal{H}$.

- 4 (at least) Goldstone bosons associated with the Higgs doublet with right quantum numbers under SM gauge group G_{SM}.
  $\rightarrow$ Strong sector gauged such that
  G_{SM}(global 'custodial') $\sim SU(2) \times SU(2) \subset \mathcal{H}$;
  $+$ asymptotically free (IR confining); top partners; ...



$\Rightarrow$ Composite Higgs models provide a solution to Hierarchy problem: Goldstone theorem ensures a naturally light Higgs.

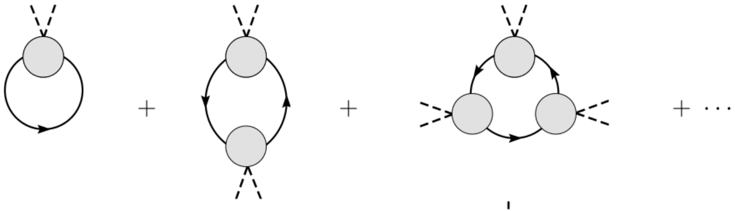
Composites resonances and explicit breaking

- Condensation also imply composite resonances of different spin: scalar, vector, but also fermionic.
- Link between SM elementary and composite sectors through:
  - the gauging of the strong sector under the SM group.
  - the proto-Yukawa couplings.

  $\Rightarrow$ Mixing between SM elementary particles and composite resonances.

- Mixing between the two sectors explicitly breaks the global symmetry $\Rightarrow$ Higgs emerges naturally light as a *pseudo*-Goldstone boson with its mass (more generally the Higgs potential) generated radiatively by SM gauge boson and fermions loops.

Radiatively generated (Coleman-Weinberg) Higgs potential:



Most important contribution to the Higgs potential comes from top loops (without those no possible EWSB):

$$V(h) \simeq \alpha \cos\frac{h}{f} - \beta \sin^2\frac{h}{f} \quad \text{SO(5)/SO(4) model: MCHM}$$

α and β are (integrals of) the form factors in the effective theory
$\rightarrow$ possible to calculate them within a UV completion.

Why UV completion?

General approaches of composite Higgs models are often effective ones, based on the global symmetry breaking pattern (on the coset structure).

An UV completion is based on some fundamental fermions, with underlying new gauge symmetry.
NB: No new fundamental scalars, not to reintroduce the hierarchy problem at higher scale.

Advantages of UV completion:

- to eventually prove the symmetry breaking (non-zero vev) (not just assume it).
- to know precisely what resonances appear in the spectrum (in terms of fundamental fermions).
- to calculate explicitly forms factors of the effective theory in terms of parameters of the fundamental theory.

Method: NJL-like model and $1/N$-expansion

Actually Full UV-completion vey model-dependent + requires full non-perturbative calculation (strong dynamics!) (Lattice?)

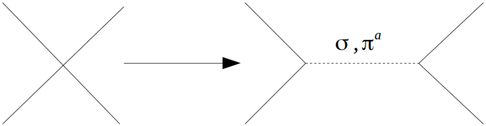
$\Rightarrow$ We choose intermediate approach: NJL 4-fermion interactions (allow non-pertubative estimates by $1/N$-expansions:)
cf Nambu and Jona-Lasinio (NJL) model as low-energy model for QCD:

$$\mathcal{L}_{NJL}^{QCD} = \overline{\Psi} i \not\partial \Psi + \frac{G_S}{2}\left[(\overline{\Psi}\Psi)^2 + (\overline{\Psi} i \gamma_5 \tau^a \Psi)^2\right]$$

$$\Psi = \begin{pmatrix} u \\ d \\ \vdots \end{pmatrix} \rightarrow N_f \text{ flavors .}$$

- Gluons not present: frozen degrees of freedom (Their dynamic assumed to be included in the four-fermions interactions).
- Chiral symmetry $SU(N_f)_L \times SU(N_f)_R$ spontaneously broken to $SU(N_f)_V$; + explicit breaking by $m = diag(m_u, m_d, m_s, ...)$.

Scalar resonances σ and π^a associated to fermionic bilinears $(\overline{\Psi}\Psi)$ and $(\overline{\Psi} i \gamma_5 \tau^a \Psi)$ respectively.
Introduce auxiliary fields $\Rightarrow$ interactions with 4 fermions replaced by 2 fermions + auxiliary fields:



Well-known Calculation trick: easier bookkeeping of large N dominant graphs (those with maximal closed fermion loops);
but scalars will also become 'dynamical': easiest way to identify the physical resonances.
$\Rightarrow$ same procedure for other fermionic bilinears.

H-composite model: $SU(4)/Sp(4) \cong SO(6)/SO(5)$ theory

- Introduce fundamental **(Weyl)** fermions ψ:
  $\psi^a \sim 4$ of the global symmetry SU(4)
  $\psi_i \sim (2N_c)$ of the gauge symmetry $Sp(2N_c)$.

- Two scalar 4-fermions operators allowed [Gherghetta et al '13]:

$$L^S_{int} = \frac{\kappa_A}{2N_c}(\psi^a\psi^b)(\bar\psi^a\bar\psi^b) + [\frac{\kappa_B}{8N_c}\varepsilon_{abcd}(\psi^a\psi^b)(\psi^c\psi^d) + h.c.]$$

  $\kappa_{A,B} \sim 1/\Lambda^2$ (UV cutoff); at wich full UV-theory needed;
  κ_B term present due to SU(4) symmetry with 4-fermions interaction.
  If $\kappa_B = 0$ additional $U(1)$ symmetry.

- Note color contraction: $(\psi^a\psi^b) = (\psi^a_i\Omega_{ij}\psi^b_j) \equiv -(\psi^b\psi^a) \sim 6_A$ under SU(4) since $Sp(2N_c)$ antisymmetric.
  $\Rightarrow$ Underlying gauge group restricts possible resonances (10_S is zero).

$4 \times 4 = (10_S + 6_A)_{SU(4)} = (10 + 5 + 1)_{Sp(4)}$

Auxiliary scalar fields

- Introducing auxiliary field: $M^{ab} = -\frac{\kappa_A+\kappa_B}{2N_c}(\psi^a\psi^b) \sim 6_A$

$$L^S_{int} \to L^{scal} = -\frac{1}{2}[\bar{M}_{ab}(\psi^a\psi^b) + \frac{N_c}{\kappa_A+\kappa_B} M^{ab}\bar{M}_{ab} + h.c.]$$

$$\bar{M}^{ab} = \frac{2}{\kappa_A+\kappa_B}[\kappa_A M^*_{ab} + \frac{1}{2}\kappa_B \varepsilon_{abcd} M^{cd}]$$

$\Rightarrow$ Splits the 4-fermions interaction.

$$M = \begin{pmatrix} 0 & m_1 & 0 & 0 \\ -m_1 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_2 \\ 0 & 0 & -m_2 & 0 \end{pmatrix}$$

$\rightarrow$ only 6 complex degrees of freedom instead of 16 ($= 10_s + 6_A$).
$\rightarrow$ Right form to break SU(4) into Sp(4) if $\langle \bar{m}_1 \rangle = \langle \bar{m}_2 \rangle \neq 0$.

- Tree-level potential:

$$V^{tree}(\bar{m}_1, \bar{m}_2) = \frac{N_c}{\kappa_A^2 - \kappa_B^2}[\kappa_A(|\bar{m}_1|^2 + |\bar{m}_2|^2) - \kappa_B(\bar{m}_1\bar{m}_2 + \bar{m}_1^*\bar{m}_2^*)]$$

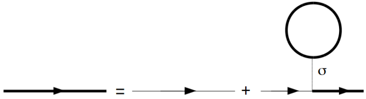
Effective potential and Mass-Gap equation

- One-loop Colemann-Weinberg potential:

$$V^{1-loop}(\bar{m}_1,\bar{m}_2) = -\frac{N_c}{8\pi^2}\sum_{i=1}^{2}[\Lambda^2|\bar{m}_i|^2 + |\bar{m}_i|^4 \log\frac{|\bar{m}_i|^2}{\Lambda^2+|\bar{m}_i|^2} + \Lambda^4 \log\frac{\Lambda^2+|\bar{m}_i|^2}{\Lambda^2}]$$

$\Rightarrow$ Well-minimized for $\bar{m}_1 = \bar{m}_2 = \langle\bar{m}\rangle$.

- Equivalently, Mass Gap equation: (self-consistent equation $\equiv$ all loop corrections resummed at first order in 1/N expansion):

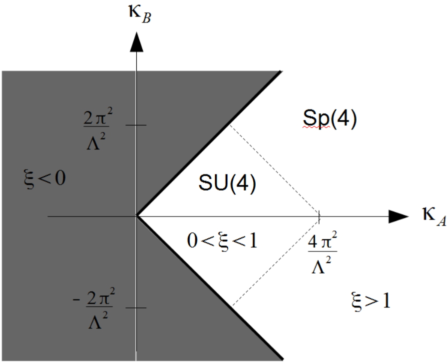


gives the dynamical fermion mass (condensate):

$$1 - \frac{\langle\bar{m}\rangle^2}{\Lambda^2}\log\frac{\Lambda^2+\langle\bar{m}\rangle^2}{\langle\bar{m}\rangle^2} = \frac{4\pi^2}{\Lambda^2}\left(\frac{\kappa_A}{\kappa_A^2-\kappa_B^2} - |\frac{\kappa_B}{\kappa_A^2-\kappa_B^2}|\right) \equiv \frac{1}{\xi}$$

$\xi = 1$ defines a critical coupling (separates broken/unbroken phase)

Phase diagram: broken and unbroken phases



- $\langle \bar{m} \rangle \neq 0$ if $\xi > 1$ (ie four-fermions interaction strong) $\rightarrow$ broken phase.
- $\langle \bar{m} \rangle = 0$ if $0 < \xi < 1$ $\rightarrow$ unbroken phase.
- $\xi_{crit} = 1$ Critical coupling separating the two phases (like QCD-NJL).

Parametrization of scalar resonances

The vacuum of the theory is known: $\Sigma_0 = \begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$

Expanding $\bar{M}$(at first order) around the vev Σ_0:

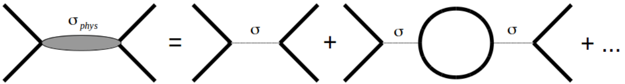
$$\bar{M} = \langle \bar{m} \rangle \Sigma_0 + \frac{s}{2\sqrt{2}} \Sigma_0 + \Pi^{\hat{a}} T^{\hat{a}} \Sigma_0$$

$s = \sigma + ia \rightarrow$ scalar and pseudo-scalar singlets. $\Rightarrow 6_{SU(4)} \sim (1+5)_{Sp(4)}$
$\Pi^{\hat{a}} = S^{\hat{a}} + iG^{\hat{a}} \rightarrow$ scalar and pseudo-scalar quintuplets

$$L^{scal} = -\frac{1}{2} \psi^a [\langle \bar{m} \rangle (\Sigma_0)_{ab} + \frac{s}{2\sqrt{2}} (\Sigma_0)_{ab} + \Pi^{\hat{a}} (T^{\hat{a}} \Sigma_0)_{ab}] \psi^b + h.c.$$
$$-\frac{1}{2} \frac{N_c}{2} [P_- (\sigma^2 + G_{\hat{a}}^2) + P_+ (a^2 + S_{\hat{a}}^2)]$$

$$P_\pm = \frac{\kappa_A}{\kappa_A^2 - \kappa_B^2} \pm \left| \frac{\kappa_B}{\kappa_A^2 - \kappa_B^2} \right| \rightarrow P_+ = P_- \quad if\, \kappa_B = 0$$

Bethe-Salpeter equation interpreted as the propagator of the physical meson:



Resummation of those fermionic loops (geometric series) allow to identify the pole (ie the mass of the meson):

$$iD_\sigma(p) \equiv \frac{ig^2_{\sigma\bar{\Psi}\Psi}}{p^2 - m^2_\sigma} = \frac{-2iG_S}{1 - iG_S\,\Pi_\sigma(p^2)}$$

In the chiral limit: $m^2_\sigma = 4M^2 \to$ mass gap $\equiv \sigma$ (vev).

Similarly for pseudo-scalars: $m^2_\pi = 0$ pole found $\to \pi_a$ Goldstones associated to broken symmetry.

Scalar spectrum (specific $SU(4)/Sp(4)$ model)

Using the Bethe-Salpeter equations for each channels:

- Scalar masses(singlet, quintuplet):

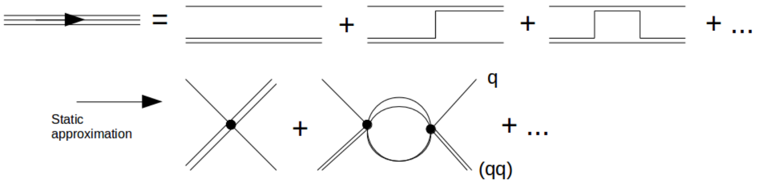
$$m_\sigma^2 = 4\langle\bar{m}\rangle^2, \quad m_S^2 = 2\frac{A_0(\langle\bar{m}\rangle^2)}{B_0(m_S^2, \langle\bar{m}\rangle^2)}(1 - \frac{P_+}{P_-}) + 4\langle\bar{m}\rangle^2$$

- Pseudo-scalar masses:

$$m_a^2 = 2\frac{A_0(\langle\bar{m}\rangle^2)}{B_0(m_a^2, \langle\bar{m}\rangle^2)}(1 - \frac{P_+}{P_-}), \quad m_G^2 = 0$$

- All very similar to NJL-QCD (difference comes only from $\kappa_B \neq 0$).
- Well-known relations: $m_S^2 = m_a^2 + m_\sigma^2$ (neglecting the B_O variation) and $m_\sigma^2 = m_G^2 + 4\langle\bar{m}\rangle^2$ (NJL-like)
- If $\kappa_B = 0$ the pseudo-scalar singlet is also massless $\to$ 1 additional Goldstone corresponding to the breaking of the additional U(1) symmetry.

- NB for mesons channels, 4-fermions interactions have (**Dirac**) form $(\bar{\Psi}\Lambda_\alpha\Psi)^2$ [e.g. define $\bar{U}_1^D \equiv (\psi_2, \bar{\psi}_1)$; $\bar{U}_2^D \equiv (\psi_4, \bar{\psi}_3)$, use $U^c_{1,2}$ etc] using Fierz transformations can be rewritten as $(\bar{\Psi}\Gamma_\alpha\Psi^c)^2$.
  $\Rightarrow$ Diquark channel: 'baryon' $\equiv$ bound state of quark + diquark.
- Bethe-Salpeter Eq. works for diquarks like for mesons $\rightarrow$ diquark masses.
- Identification of the baryon pole (mass)$\rightarrow$ Fadeev equation:



Static approximation (heavy quark exchange: $\frac{1}{\not{p}-M} \rightarrow \frac{1}{M}$):
Fadeev Eq. reduces to Bethe-Salpeter Eq. $\rightarrow$ Calculation of 'baryon' resonance masses made possible!

Spin 1 resonances Lagrangian

- Other color contractions are allowed by symmetries ($\kappa_{C,D}$ reals):

$$L^V_{int} = (\psi^a_i \psi^b_j)(\bar{\psi}_{ak}\bar{\psi}_{bl})[\frac{\kappa_C}{2N_c}\Omega_{ik}\Omega_{jl} + \frac{\kappa_D}{2N_c}\Omega_{il}\Omega_{jk}]$$

- After Fierz transformations lead to current-current operators:

$$L^V_{int} = \frac{1}{2}[\frac{\kappa_C}{2N_c}(\psi^a\sigma^\mu\bar{\psi}_a)(\psi^b\sigma_\mu\bar{\psi}_b) + \frac{\kappa_D}{2N_c}(\psi^a\sigma^\mu\bar{\psi}_b)(\psi^b\sigma_\mu\bar{\psi}_a)]$$

- Introducing auxiliary field: $a_1^\mu = -\frac{\kappa_C}{4N_c}(\psi^a\sigma^\mu\bar{\psi}_a) \sim 1_{SU(4)}$

  $(V^\mu)^a_b = -\frac{\kappa_D}{4N_c}(\psi^a\sigma^\mu\bar{\psi}_b) \sim 15_{SU(4)}$

  $V_\mu = \rho^a_\mu T^a + A^{\hat{a}}_\mu T^{\hat{a}} \rightarrow$ Split in term of broken and unbroken generators

  $\Rightarrow$ vectorial resonances: ρ^a_μ and axial resonances: $a_1^\mu, A^{\hat{a}}_\mu$.

NB: $4 \times \bar{4} = (15+1)_{SU(4)} = (10+5+1)_{Sp(4)}$

Calculating spin 1 spectrum in $1/N$-expansion

$$L^V_{int} \to L^{vect} = -2a_1^\mu(\psi^a\sigma_\mu\bar{\psi}_a) - 2\psi^a[\rho_c^\mu(T^c)^T_{ab} + A_c^\mu(T^{\hat{c}})^T_{ab}]\sigma_\mu\bar{\psi}_b - \frac{4N_c}{\kappa_C}a_1^\mu a_{1\mu} - \frac{2N_c}{\kappa_D}\sum_c[\rho_c^\mu\rho_\mu^c + A_c^\mu A_\mu^c] \quad (1)$$

- Vectorial masses:
  $m_\rho^2 = \frac{3}{2i\kappa_D B_0(m_\rho^2,\langle\bar{m}\rangle^2)} + \frac{2A_0(\langle\bar{m}\rangle^2}{B_0(m_\rho^2,\langle\bar{m}\rangle^2)} - 2\langle\bar{m}\rangle^2$
- Axial masses:
  $m_{a1}^2 = \frac{3}{8i\kappa_C B_0(m_{a_1}^2,\langle\bar{m}\rangle^2)} + \frac{2A_0(\langle\bar{m}\rangle^2}{B_0(m_{a_1}^2,\langle\bar{m}\rangle^2)} + 4\langle\bar{m}\rangle^2$

  $m_A^2 = \frac{3}{2i\kappa_D B_0(m_{a1,A}^2,\langle\bar{m}\rangle^2)} + \frac{2A_0(\langle\bar{m}\rangle^2}{B_0(m_A^2,\langle\bar{m}\rangle^2)} + 4\langle\bar{m}\rangle^2$

- Masses very similar to QCD-NJL.
- Well-known relations between axial and vector resonances:
  $m_A^2 = m_\rho^2 + 6\langle\bar{m}\rangle^2$ (Neglecting the B_0 variation).

Introduction of (further) spin 1/2 resonances

- Top partners: **Required** for Higgs-top coupling and explicit breaking of the global symmetry.
  $\Rightarrow$ pair of vector-like colored (QCD)fundamental fermions χ and $\tilde{\chi}$.

- Traceless antisymmetric representation of $Sp(2N_c)$:
  $\Omega_{ij}\chi^f_{ij} = \Omega_{ij}\tilde{\chi}_{ijf} = 0$
- t-t' coupling (partial compositeness): $\chi^f \sim 3_{+2/3}$ and $\tilde{\chi}_f \sim \bar{3}_{-2/3}$ under $SU(3)_c \times U(1)_Y$.
- 6 top partners candidates: [Gherghetta and al '13]
  $$\Psi_1^{abf} = (\psi^a \chi^f \psi^b) \quad \Psi_{2ab}^f = (\bar{\psi}_a \chi^f \bar{\psi}_b) \quad \Phi_{af}^b = (\bar{\psi}_a \bar{\chi}_f \psi_b)$$
  $$\tilde{\Psi}_1^{abf} = (\psi^a \tilde{\chi}^f \psi^b) \quad \tilde{\Psi}_{2ab}^f = (\bar{\psi}_a \tilde{\chi}^f \bar{\psi}_b) \quad \tilde{\Phi}_{af}^b = (\bar{\psi}_a \bar{\tilde{\chi}}_f \psi_b)$$

  $\Rightarrow$ χ and ψ transform in a different way: more complicated baryons than in the standard (QCD) NJL.

  NB: $(\psi^a \chi^f \psi^b) = \psi^a_i \Omega_{ij} \chi^f_{jk} \Omega_{kl} \psi^b_l$

Colored scalar resonances

χ, $\tilde{\chi} \rightarrow$ New composite colored scalar resonances [Gherghetta et al '13]

$$L_{int}^{color} = (m_\chi \chi^f \tilde{\chi}_f + h.c.) + \frac{\kappa_S}{2N_c}(\chi^f \tilde{\chi}_f)(\bar{\chi}_g \bar{\tilde{\chi}}^f) + \frac{\kappa_R}{2N_c}(\chi^f \tilde{\chi}_g)_{Tr=0}(\bar{\chi}_f \bar{\tilde{\chi}}^g)_{Tr=0}$$
$$+\frac{\kappa_P}{2N_c}(\chi^f \chi^g)(\bar{\chi}_f \bar{\chi}_g) + \frac{\tilde{\kappa}_P}{2N_c}(\tilde{\chi}_f \tilde{\chi}_g)(\bar{\tilde{\chi}}^f \bar{\tilde{\chi}}^g)R$$

Introducing auxiliary fields($L_{int}^{color} \rightarrow L^{color}$):

$$L^{color} = -[S^*(\chi^f \tilde{\chi}_f) + R_f^{g*}(\chi^f \tilde{\chi}_g)_{Tr=0} + P_{fg}^*(\chi^f \chi^g) + \tilde{P}^{fg*}(\tilde{\chi}_f \tilde{\chi}_g) + h.c.]$$
$$-\frac{2N_c}{\kappa_S}|S + m_\chi^*|^2 - \frac{2N_c}{\kappa_R} R_f^{g*} R_g^f - \frac{2N_c}{\kappa_P} P_{fg}^* P^{fg} - \frac{2N_c}{\tilde{\kappa}_P} \tilde{P}^{fg*} \tilde{P}_{fg}$$

$\Rightarrow$ A lot of new resonances: **Calculation of their spectrum**

$\Rightarrow$ possibly new vectorial resonances

Diquark lagrangian and top partners

- Interaction between ψ and χ, $\tilde{\chi}$:

$$L_{int}^{\psi\chi} = \kappa_{\psi\chi}(\psi\sigma^{\mu}\bar{\psi})(\chi\sigma^{\mu}\bar{\chi}) + \tilde{\kappa}_{\psi\chi}(\psi\sigma^{\mu}\bar{\psi})(\tilde{\chi}\sigma^{\mu}\bar{\tilde{\chi}}) \qquad (2)$$

- $L_{int}^{\psi\chi} + L_{int}^{S} \rightarrow$ Contain "diquarks" channels. Find the attractive channels in order to **calculate the "diquarks" masses** with Bethe-Salpeter equation.

- Calculation of the top partners masses possible using again *static approximation* of 3-body Fadeev Eq. $\Rightarrow$ more complicated than in QCD-NJL (two fundamental fermions ψ and χ, whereas only one in QCD).

Explicit symmetry breaking and phenomenology

- Adding explicit breaking terms:
  - Linear couplings $t - t'$ (SM multiplets are not SU(4) multiplets):
  - Gauging SM group within the global SU(4) symmetry.

  $\Rightarrow$ Recalculate all mass spectrum (Generate the Higgs potential)
  But expect moderate corrections of $\mathcal{O}(m_h)$ relative to (chiral symmetric) previous resonance mass results $\mathcal{O}(\Lambda)$.

- Phenomenology:
  - Link between couplings constants (model parameters) and (LHC) observables: Higgs mass, form factors...
    $\Rightarrow$ Need to calculate "pion" decay constant,...
  - Theoretical assumptions about couplings? try to reduce the number of free parameters: all couplings are related to the underlying strong dynamics
    $\Rightarrow$ Can we link the differents couplings constant?
    Like QCD-NJL: large $N_c \rightarrow G_S = 2G_V$ for example.

What is done, what is foreseen for 2015

- 1) Calculation of all scalar resonances masses for bound states of ψ: done, well crosschecked
- 2) Calculation of vector (axial) resonances masses for bound states of ψ: done, partial crosscheck
- 3) Calculation of fermionic (baryon) resonances masses for bound states of ψ: done, partial crosscheck
  $\rightarrow$ publication expected soon (end 2014 or early 2015) for chiral limit mass spectrum results 1)-3)
- Calculation of scalar (vectorial?) masses for bound states of χ and $\tilde{\chi}$: work in progress.
- Introduction of fermionic resonances, calculation of "diquarks" masses and of top partners masses: work in progress.
- Introduction of explicit breaking terms (adding couplings between composite and elementary SM fermions; calculating Higgs potential)scheduled soon
- Phenomenology: link model parameters to experimental constraints ("pion" decay constant, form factors,...); Generalisation of previous calculations to other UV completions or cosets: scheduled soon

Meetings, participation to conferences,.. (how we (well) spend our money)

OCEVU funding: 1 PhD, + 1.5 kE 2013, 2.5 kE 2014 (approximately same next years)

- Series of lectures by M. Knecht in Montpellier "Spontaneous breaking of continuous global symmetries and effective lagrangians", December 2013.
- Scientific discussions among the 4 team members organized 3-4 times in Marseille and in Montpellier, also in the context of general OCEVU meeting or other conferences.
- N. Bizot attended Schools: Lectures on the theory of fundamental interactions (GGI, Florence, 7-24 january 2014); IN2P3 School of Statistics (Autrans, 26-30 may 2014); + doctoral courses in Montpellier.
- J.-L. Kneur attended the workshop 'Higgs effective field theories' in Madrid, 28-30 September 2014
- Two workers on composite models (G. Ferretti and B. Bellazzini) external to OCEVU invited for seminars and discussions
- Buying a number of specialized textbooks