A road to a beyond-the-Standard-Model model without Higgs

G. C. Rossi

Università di Roma *Tor Vergata*, Roma - Italy
INFN - Sezione di Roma *Tor Vergata*, Roma - Italy
Centro Fermi, Roma - Italy

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Bibliography

- The talk is based on the papers
  R. Frezzotti and G. C. Rossi
  - Phys. Rev. D **92** (2015) no.5, 054505
  - LFC19: Frascati Physics Series Vol. 70 (2019)

  S. Capitani, P. Dimopoulos, R. Frezzotti, M. Garofalo, B. Kostrzewa, F. Pittler, G. C. Rossi and C. Urbach
  - PRL **123** (2019) 061802
- Preliminary simulation results can be found in
  S. Capitani, plus the same Authors as above
  - EPJ Web Conf. **175** (2018) 08008 & 08009
- Theoretical considerations can be found in
  G. C. Rossi
  - EPJ Web Conf. **258** (2022), 06003
- See also
  R. Frezzotti, M. Garofalo and G. C. Rossi
  - Phys. Rev. D **93** (2016) no.10, 105030

Outline of the talk (take home message)

1. I'll jump [Introduction & Motivation: SM and its limitations] and discuss
2. milestones of an unfinished road towards a bSMm with no Higgs
   - the simplest model yielding NP "naturally" light quark masses
     $$m_q^{NP} \sim c_q(\alpha_s)\Lambda_{\rm RGI}\,, \quad c_q(\alpha_s) = O(\alpha_s^2)$$
   - extension to weak interactions (skip hypercharge and leptons), leading to
     $$M_W^{NP} \sim g_w c_w(\alpha)\Lambda_{\rm RGI}\,, \quad c_w(\alpha) = O(\alpha)\,,$$
3. A few phenomenological implications
   - top and W mass formulae require $\Lambda_{\rm RGI} \gg \Lambda_{\rm QCD}$
   - need for super-strongly interacting (Tera) particles
     $\to$ to have a full theory with $\Lambda_{\rm RGI} \equiv \Lambda_T = O(\#\text{TeV})$
4. A few conceptual achievements
   - "Mass tuning" problem bypassed - no Higgs to care about!
   - Coupling ranking $\alpha_y \ll \alpha_s \ll \alpha_T \to$ fermion mass ranking $m_\ell \ll m_q \ll m_{Q_T}$
   - A bonus: SM + Tera-sector $\to$ gauge coupling unification (no SUSY!)
5. Conjecture: 125 GeV boson a WW/ZZ state bound by Tera-exchanges
6. LEEL$_{d=4}$ ($E \ll \Lambda_T$) after integrating out Tera-dof's very similar to $\mathcal{L}_{\rm SM}$
7. Conclusions

The simplest model endowed with NP mass generation

A recap of previous results

A (toy) model with NP mass generation

Consider a model – where an SU(2) fermion doublet, subjected to non-abelian gauge interactions (of the QCD type), is coupled to a complex scalar doublet via $d=4$ Yukawa and "irrelevant" $d=6$ Wilson-like chiral breaking terms – described by the Lagrangian

$$\mathcal{L}_{\rm toy}(q,A,\Phi)=\mathcal{L}_{kin}(q,A,\Phi)+\mathcal{V}(\Phi)+\mathcal{L}_{Yuk}(q,\Phi)+\mathcal{L}_{Wil}(q,A,\Phi)$$

- $\mathcal{L}_{kin}(q,A,\Phi)=\frac{1}{4}(F^A\cdot F^A)+\bar q_L \not{\mathcal{D}}^A q_L+\bar q_R \not{\mathcal{D}}^A q_R+\frac{1}{2}{\rm Tr}\left[\partial_\mu\Phi^\dagger\partial_\mu\Phi\right]$
- $\mathcal{V}(\Phi)=\frac{\mu_0^2}{2}{\rm Tr}\left[\Phi^\dagger\Phi\right]+\frac{\lambda_0}{4}\left({\rm Tr}\left[\Phi^\dagger\Phi\right]\right)^2$
- $\mathcal{L}_{Yuk}(q,\Phi)=\eta\left(\bar q_L\Phi q_R+\bar q_R\Phi^\dagger q_L\right)$
- $\mathcal{L}_{Wil}(q,A,\Phi)=\frac{b^2}{2}\rho\left(\bar q_L\overleftarrow{\mathcal{D}}^A{}_\mu\Phi\mathcal{D}^A_\mu q_R+\bar q_R\overleftarrow{\mathcal{D}}^A_\mu\Phi^\dagger\mathcal{D}^A_\mu q_L\right)$

- $\mathcal{L}_{\rm toy}$ key features (at variance with the SM)
  - presence of the "irrelevant" chiral breaking $d=6$ Wilson-like term
  - Φ, despite appearances, not the Higgs, but UV completion of $\mathcal{L}_{\rm toy}$
- $\mathcal{L}_{\rm toy}$ notations
  - $b^{-1}\sim\Lambda_{UV}=$UV cutoff, $\eta=$ Yukawa coupling, ρ to keep track of $\mathcal{L}_{Wil}$

Theoretical background

1. $\mathcal{L}_{\rm toy}$ is formally power-counting renormalizable (like Wilson LQCD despite the presence of $d = 5$ Wilson term)
2. and exactly invariant under the (global) transformations

$$\chi_L \times \chi_R = [\tilde{\chi}_L \times (\Phi \to \Omega_L \Phi)] \times [\tilde{\chi}_R \times (\Phi \to \Phi \Omega_R^\dagger)]$$

$$\tilde{\chi}_{L/R} : \begin{cases} q_{L/R} \to \Omega_{L/R} q_{L/R} \\ \bar{q}_{L/R} \to \bar{q}_{L/R} \Omega_{L/R}^\dagger \end{cases} \qquad \Omega_{L/R} \in \mathrm{SU}(2)$$

   - $\chi_L \times \chi_R$ exact, can be realized
     - *á la* Wigner
     - *á la* Nambu–Goldstone
   - $\tilde{\chi}_L \times \tilde{\chi}_R$ (chiral transformations) broken for generic η and ρ
3. Standard fermion masses are forbidden because the operator $\bar{q}_L q_R + \bar{q}_R q_L$ is not invariant under the exact $\chi_L \times \chi_R$ symmetry
4. No quantum linear mass divergencies allowed (unlike Wilson LQCD)

The road to NP mass generation - I

- Yukawa and Wilson-like terms break $\tilde{\chi}_L \times \tilde{\chi}_R$ and mix
- As we showed, chiral $\tilde{\chi}_L \times \tilde{\chi}_R$ symmetry can be restored at $\eta = \eta_{cr}$ (like what happens in Wilson LQCD at m_{cr}). Here it implies
  1. in Wigner phase $\langle|\Phi|^2\rangle = 0 \rightarrow$ effective $\bar{q}_R \Phi q_L + \text{hc}$ vertex absent

[box is the O(b^2) Wilson-like vertex]

  2. in NG phase $\langle|\Phi|^2\rangle = v^2 \rightarrow$ Higgs mechanism is made ineffective

- Observation
  - b^2 factor introduced by the Wilson-like vertex compensated by the quadratic loop divergency b^{-2}, yielding finite (1-loop) diagrams
- Q: after Higgs-like mass cancellation, is any fermion mass term left?

  A: YES, a non-perturbative one is generated in the NG phase!

The road to NP mass generation - II

A “heuristic” argument for NP mass generation in critical model NG phase

1. As in QCD (recovered) chiral $\tilde{\chi}_L \times \tilde{\chi}_R$ symmetry is spontaneously broken
2. At $O(b^2)$ in the Symanzik expansion also NP operators occur
   - they are found to be

$$O_{6,FF} \propto b^2 \Lambda_s \alpha_s |\Phi| \Big[F^A \cdot F^A \Big] \qquad O_{6,\bar{q}q} \propto b^2 \Lambda_s \alpha_s |\Phi| \Big[\bar{q} \not{\mathcal{D}}^A q \Big]$$

   - $O_{6,FF}$ & $O_{6,\bar{q}q}$ expression fixed by symmetries $(\chi_L \times \chi_R)$ & dimension

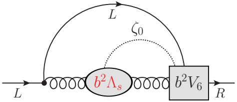
3. The effect of these operators is standardly described by taking into account all diagrams derived from the extended Symanzik Lagrangian

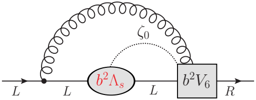
$$\mathcal{L}_{\rm toy} \to \mathcal{L}_{\rm toy} + \Delta \mathcal{L}_{NP}^{Sym} + \dots$$
$$\Delta \mathcal{L}_{NP}^{Sym} = b^2 \Lambda_s \alpha_s |\Phi| \Big[c_{FF} F^A \cdot F^A + c_{\bar{q}q} \bar{q} \not{\mathcal{D}}^A q \Big] + O(b^4)$$

   - $\Delta \mathcal{L}_{NP}^{Sym}$ matters in the limit $b \to 0$, as formally $O(b^2)$ effects can be promoted to finite contributions by UV power divergencies in loops

A diagrammatic understanding of NP masses - III

- New NP self-energy diagrams emerge from $\mathcal{L}_{\rm toy} + \Delta\mathcal{L}_{NP}^{Sym}$





  - masses are 1PI diagrams at vanishingly small external momenta
  - blobs = NP vertices from the Symanzik term,
    $\Delta\mathcal{L}_{NP}^{Sym} = b^2\Lambda_s\alpha_s|\Phi|\Big[c_{FF}F^A\cdot F^A + c_{\bar{q}q}\bar{q}\,\tilde{\not{D}}^A q\Big]$
  - box = Wilson-like vertex from the fundamental $\mathcal{L}_{\rm toy}$

$$\underline{\underline{m_q^{NP}}} \propto \underline{\underline{\alpha_s^2}}\ \mathrm{Tr}\int^{1/b}\frac{d^4k}{k^2}\frac{\gamma_\mu k_\mu}{k^2}\int^{1/b}\frac{d^4\ell}{\ell^2+m_{\zeta_0}^2}\frac{\gamma_\nu(k+\ell)_\nu}{(k+\ell)^2}\cdot$$

$$\cdot b^2\gamma_\rho(k+\ell)_\rho\, b^2\underline{\underline{\Lambda_s}}\gamma_\lambda(2k+\ell)_\lambda \sim \underline{\underline{\alpha_s^2\Lambda_s}}$$

- Self-energy diagrams are finite
  - b^4 S$\tilde{\chi}$SB IR effects compensate 2-loop UV quartic divergency
  - Thus masses are a kind of NP anomalies that appear as obstructions to a full recovery of the $\tilde{\chi}_L\times\tilde{\chi}_R$ chiral symmetry

Quantum Effective Lagrangian (QEL) in NG phase

1. We saw that
   - in the NG phase at η_{cr} the "Higgs" fermion mass get cancelled, but (lattice simulations confirm that) the fermion acquires a NP mass

$$m_q^{NP} = c_q(g_s^2)\Lambda_s\,, \quad c_q(g_s^2) = \mathrm{O}(\alpha_s^2)$$

2. QEL, describing physics of the critical model in NG phase, Γ^{NG}, is determined by including all terms compatible with
   - symmetries: $\chi_L \times \chi_R$ (exact) and $\tilde{\chi}_L \times \tilde{\chi}_R$ (recovered)
   - dimensional arguments
   - $m_q^{NP} \neq 0$

3. For $\Gamma^{NG}_{d=4}$ one then finds $\Big[\Phi = (v+\zeta_0)U\,, U = \exp[i\vec{\tau}\vec{\zeta}/v]\Big]$

$$\Gamma^{NG}_{d=4} = \Gamma^0_{d=4} + \underline{c_q(g_s^2)\Lambda_s[\bar{q}_L U q_R + \bar{q}_R U^\dagger q_L]} + \frac{c^2\Lambda_s^2}{2}\mathrm{Tr}\,[\partial_\mu U^\dagger \partial_\mu U]$$

$$\Gamma^0_{d=4} = \frac{1}{4}(F^A \cdot F^A) + \bar{q}_L \mathcal{D}\!\!\!/^A q_L + \bar{q}_R \mathcal{D}\!\!\!/^A q_R + \frac{1}{2}\mathrm{Tr}\,[\partial_\mu \Phi^\dagger \partial_\mu \Phi] + \mathcal{V}(\Phi) = \Gamma^{Wig}_{d=4}\Big|_{\hat{\mu}_\Phi^2 < 0}$$

4. From $U = 1\!\!1 + i\vec{\tau}\vec{\zeta}/v + \dots$ we get a fermion mass plus NGBs interactions
5. The mass emerges from a more complicated structure than usual

A step forward

Introducing weak interactions Why Tera-interactions?

Why Tera-interactions?

Obviously we want weak interactions. But why Tera-interactions?

- In the previous mass formulae $\Lambda_s = \Lambda_{\rm RGI}$ is the RGI scale of the theory
- Let us focus on the top quark. Can we make the NP formula

$$m_q^{NP} = c_q(g_s^2)\Lambda_{\rm RGI}\,, \qquad c_q(g_s^2) = \mathrm{O}(\alpha_s^2)$$

compatible with the phenomenological value of the top mass?

- As an order of magnitude, we clearly need to have for $\Lambda_{\rm RGI}$

$$\Lambda_{\rm QCD} \ll \Lambda_{\rm RGI} = \mathrm{O}(\text{a few TeV's})$$

so as to get a top mass in the 10^2 GeV range $\to$

- Super-strongly interacting particles must exist, yielding a full theory with

$$\Lambda_{\rm RGI} \equiv \Lambda_T = \mathrm{O}(\text{a few TeV's})$$

- We refer to them as Tera-particles Glashow (to avoid confusion with Techni-particles)

- Revealing Tera-hadrons $\to$ an unmistakable sign of New Physics

Towards a BSMm: including weak- & Tera-interactions

- It is trivial to extend $\mathcal{L}_{\rm toy}$ to include weak and Tera-interactions
  - Tera-particles $\to$ we duplicate what we did for quarks
  - Weak bosons $\to$ we gauge the exact χ_L symmetry

$$\mathcal{L}(q, Q; \Phi; A, G, W) = \mathcal{L}_{kin}(q, Q; \Phi; A, G, W) + \\ + \mathcal{V}(\Phi) + \mathcal{L}_{Yuk}(q, Q; \Phi) + \mathcal{L}_{Wil}(q, Q; \Phi; A, G, W)$$

- $\mathcal{L}_{kin}(q, Q; \Phi; A, W) = \frac{1}{4}\Big(F^A \cdot F^A + F^G \cdot F^G + F^W \cdot F^W\Big) + \\ + \Big[\bar{q}_L \not{\mathcal{D}}^{AW} q_L + \bar{q}_R \not{\mathcal{D}}^{A} q_R\Big] + \Big[\bar{Q}_L \not{\mathcal{D}}^{AGW} Q_L + \bar{Q}_R \not{\mathcal{D}}^{AG} Q_R\Big] + \frac{k_b}{2} \underline{\mathrm{Tr}\left[(\mathcal{D}^W_\mu \Phi)^\dagger \mathcal{D}^W_\mu \Phi\right]}$
- $\mathcal{V}(\Phi) = \frac{\mu_0^2}{2} k_b \mathrm{Tr}\left[\Phi^\dagger \Phi\right] + \frac{\lambda_0}{4}\left(k_b \mathrm{Tr}\left[\Phi^\dagger \Phi\right]\right)^2$
- $\underline{\mathcal{L}_{Yuk}(q, Q; \Phi)} = \eta_q \left(\bar{q}_L \Phi\, q_R + \bar{q}_R \Phi^\dagger q_L\right) + \eta_Q \left(\bar{Q}_L \Phi\, Q_R + \bar{Q}_R \Phi^\dagger Q_L\right)$
- $\underline{\mathcal{L}_{Wil}(q, Q; \Phi; A, G, W)} = \frac{b^2}{2} \rho_q \left(\bar{q}_L \overleftarrow{\mathcal{D}}^{AW}_\mu \Phi \mathcal{D}^A_\mu q_R + \bar{q}_R \overleftarrow{\mathcal{D}}^{A}_\mu \Phi^\dagger \mathcal{D}^{AW}_\mu q_L\right) + \\ + \frac{b^2}{2} \rho_Q \left(\bar{Q}_L \overleftarrow{\mathcal{D}}^{AGW}_\mu \Phi \mathcal{D}^{AG}_\mu Q_R + \bar{Q}_R \overleftarrow{\mathcal{D}}^{AG}_\mu \Phi^\dagger \mathcal{D}^{AGW}_\mu Q_L\right)$

Symmetries and criticality

- χ_L : $\tilde{\chi}_L \times (\Phi \to \Omega_L \Phi)$ exact

$$\tilde{\chi}_L : \begin{cases} q_L \to \Omega_L q_L \\ \bar{q}_L \to \bar{q}_L \Omega_L^\dagger \\ W_\mu \to \Omega_L W_\mu \Omega_L^\dagger \\ Q_L \to \Omega_L Q_L \\ \bar{Q}_L \to \bar{Q}_L \Omega_L^\dagger \end{cases} \qquad \Omega_L \in SU_L(2)$$

- χ_R : $\tilde{\chi}_R \times (\Phi \to \Phi \Omega_R^\dagger)$ exact

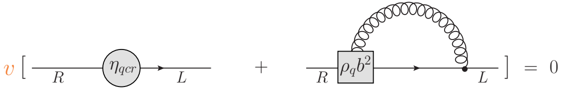
$$\tilde{\chi}_R : \begin{cases} q_R \to \Omega_R q_R \\ \bar{q}_R \to \bar{q}_R \Omega_R^\dagger \\ \\ Q_R \to \Omega_R Q_R \\ \bar{Q}_R \to \bar{Q}_R \Omega_R^\dagger \end{cases} \qquad \Omega_R \in SU_R(2)$$

- $\tilde{\chi}_L \times \tilde{\chi}_R$ breaking terms are $\mathcal{L}_{Yuk}$, $\mathcal{L}_{Wil}$ & scalar kinetic term
- We need to tune η_q, η_Q & k_b to enforce invariance under $\tilde{\chi}_L \times \tilde{\chi}_R$

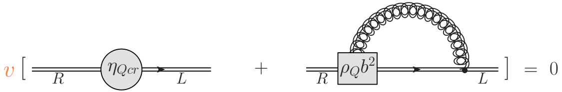
Critical tuning in the NG phase $\langle|\Phi|^2\rangle = v^2$ (at 1-loop)

Again, in NG phase criticality implies Higgs-like masses cancellation

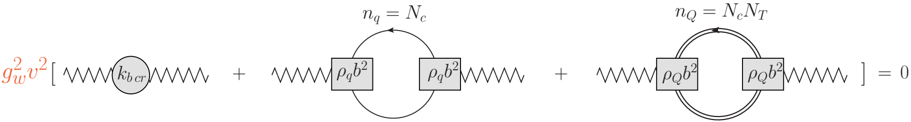
- The cancellation mechanism of the "Higgs-like" quark mass term



- The cancellation mechanism of the "Higgs-like" Tera-quark mass term



- The cancellation mechanism of the "Higgs-like" W mass term

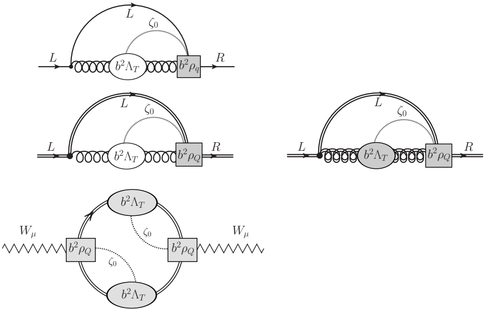


NP elementary particle masses: fermions & W-bosons

O(b^2) NP Symanzik operators (white & gray ovals) come to rescue masses

- $O^T_{6,\bar{Q}Q} = b^2\alpha_T\rho_Q\Lambda_T|\Phi|\Big[\bar{Q}_L\not{\mathcal{D}}^{AGW}Q_L + \bar{Q}_R\not{\mathcal{D}}^{AG}Q_R\Big]$
- $O^s_{6,\bar{Q}Q} = b^2\alpha_s\rho_Q\Lambda_T|\Phi|\Big[\bar{Q}_L\not{\mathcal{D}}^{AGW}Q_L + \bar{Q}_R\not{\mathcal{D}}^{AG}Q_R\Big]$
- $O_{6,GG} = b^2\alpha_T\rho_Q\Lambda_T|\Phi|F^G\cdot F^G$ • $O_{6,AA} = b^2\alpha_s\rho_Q\Lambda_T|\Phi|F^A\cdot F^A$

combine with Wilson-like vertices (boxes) leading to 1PI self-energy graphs



quark

Tera-quark

W

give finite results, owing to UV-IR compensation, yielding O(Λ_T) masses

The critical QEL in the NG phase

Following the same line of arguments as in the case of the previous toy-model, one gets for the $d=4$ piece of the critical QEL in the NG phase

$$\Gamma^{NG}_{4\,cr}(q,Q;\Phi;A,G,W) = \frac{1}{4}\Big(F^A\cdot F^A + F^G\cdot F^G + F^W\cdot F^W\Big) +$$
$$+\Big[\bar q_L \not{\mathcal{D}}^{WA} q_L + \bar q_R \not{\mathcal{D}}^{A} q_R\Big] + C_q\Lambda_T\Big(\bar q_L U q_R + \bar q_R U^\dagger q_L\Big) +$$
$$+\Big[\bar Q_L \not{\mathcal{D}}^{WAG} Q_L + \bar Q_R \not{\mathcal{D}}^{AG} Q_R\Big] + C_Q\Lambda_T\Big(\bar Q_L U Q_R + \bar Q_R U^\dagger Q_L\Big) +$$
$$+\frac{1}{2}c_w^2\Lambda_T^2 \mathrm{Tr}\left[(\mathcal{D}^W_\mu U)^\dagger \mathcal{D}^W_\mu U\right]$$

$$U = \frac{\Phi}{\sqrt{\Phi^\dagger\Phi}} = \exp\Big(i\frac{\vec\tau\cdot\vec\zeta}{c_w\Lambda_T}\Big) = 1\!\!1 + i\frac{\vec\tau\cdot\vec\zeta}{c_w\Lambda_T} + \dots$$

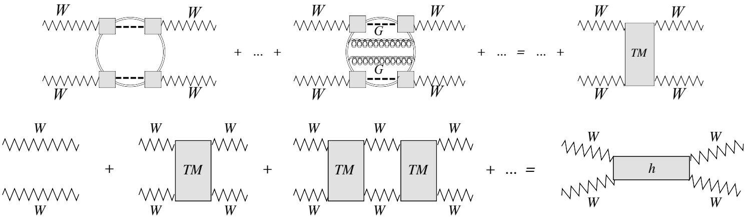
incorporating non-vanishing q, Q & W masses with parametric expression

$$m_q^{NP} = C_q\,\Lambda_T\,, \qquad C_q = \mathrm{O}(\alpha_s^2)$$
$$m_Q^{NP} = C_Q\,\Lambda_T\,, \qquad C_Q = \mathrm{O}(\alpha_T^2,\dots)$$
$$M_W^{NP} = C_w\,\Lambda_T\,, \qquad C_w = g_w c_w\,,\;\; c_w = k_w\mathrm{O}(\alpha_T,\dots)$$

The 125 GeV resonance
&
comparison with the SM

125 GeV resonance & comparison with the SM

- No need for a Higgs $\rightarrow$ how do we interpret the 125 GeV resonance?
  - At $p^2/\Lambda_T^2 \ll 1$ Tera-dof's can be integrated out
  - Tera-forces bind a $|W^+W^- + ZZ\rangle = |h\rangle$ state Bethe–Salpeter



  - $|h\rangle$ resonance with $m_h \sim 125 \ll \Lambda_T$ is left behind
- We must include this "light" $\chi_L \times \chi_R$ singlet in the LEEL of the model
  - If we do so, perhaps not surprisingly, one finds that, up to small corrections, $\mathrm{LEEL}_{d=4}$ resembles very much the SM with $v_H \sim \Lambda_T$
  - possibly with the exception of tri- and four-linear h couplings

$d=4$ LEEL of the critical NG model vs. $\mathcal{L}^{SM}$

- LEEL$_{d=4}$ of the critical NG model for $p^2/\Lambda_T^2 \ll 1$, including h reads [we ignore weak isospin, leptons & $U_Y(1)$]

$$\mathcal{L}^{NG}_{4\,cr}(q; A, W; U, h) = \frac{1}{4}F^A\cdot F^A + \frac{1}{4}F^W\cdot F^W + \Big[\bar q_L \not{\mathcal{D}}^{AW} q_L + \bar q^u_R \not{\mathcal{D}}^A q^u_R + \bar q^d_R \not{\mathcal{D}}^A q^d_R\Big] +$$
$$+\frac{1}{2}\partial_\mu h \partial_\mu h + \frac{1}{2}(k_v^2 + 2k_v k_1 h + k_2 h^2)\mathrm{Tr}\left[(\mathcal{D}^W_\mu U)^\dagger \mathcal{D}^W_\mu U\right] + \widetilde{\mathcal{V}}(h) +$$
$$+(y_q h + k_q k_v)\left(\bar q_L U q_R + \bar q_R U^\dagger q_L\right)$$

- $\mathcal{L}^{NG}_{4\,cr}$ is neither renormalizable nor unitary (unlike our fundamental Lagrangian) for generic k_v, k_1, k_2, y_q, k_q. Unitarity and renormalizability require to set in $\mathcal{L}^{NG}_{4\,cr}$

$$k_q/y_q = 1\,, \qquad k_1 = k_2 = 1$$

So exactly the combination $\Phi \equiv (k_v + h)U$ appears (except in $\widetilde{\mathcal{V}}(h)$) and we get

$$\mathcal{L}^{NG}_{4\,cr}(q; A, W; \Phi) \to \frac{1}{4}F^A\cdot F^A + \frac{1}{4}F^W\cdot F^W + \Big[\bar q_L \not{\mathcal{D}}^{AW} q_L + \bar q^u_R \not{\mathcal{D}}^A q^u_R + \bar q^d_R \not{\mathcal{D}}^A q^d_R\Big] +$$
$$+\frac{1}{2}\mathrm{Tr}\left[(\mathcal{D}^W_\mu \Phi)^\dagger \mathcal{D}^W_\mu \Phi\right] + \widetilde{\mathcal{V}}(h) + y_q\left(\bar q_L \Phi q_R + \bar q_R \Phi^\dagger q_L\right) \sim \mathcal{L}^{\rm SM}$$
$$m_q = y_q k_v = C_q \Lambda_T\,, \quad M_W = g_w k_v = g_w c_w \Lambda_T$$

- An expression amazingly similar to the SM Lagrangian!

Conclusions

Conclusions

- We have identified a NP mechanism for elementary particle mass generation successfully confirmed by lattice simulations
- yielding $m_f^{NP} \propto \alpha_f^2 \Lambda_{\rm RGI}$ & $M_W \propto g_w \alpha \Lambda_{\rm RGI}$ (to the lowest loop order)
  - $m_{top}, M_W \sim 10^2$ GeV call for a Tera-strong interaction
  - necessary to have the full theory with $\Lambda_{\rm RGI} \equiv \Lambda_T =$ O(a few TeV's)
- The approach provides an understanding of the
  - EW scale magnitude (as a fraction of Λ_T)
  - fermion mass ranking ($\alpha_y \ll \alpha_s \ll \alpha_T \rightarrow m_\ell \ll m_q \ll m_{Q_T}$)
  - mass tuning problem (as there is no (fundamental) Higgs)
- NP masses are “naturally" light ['t Hooft] owing to
  - symmetry enhancement ($\sim$ recovery of $\tilde{\chi}$) in the massless theory
- We get gauge coupling unification in SM+Tera-sector (no SUSY)
- Phenomenology largely to be still worked out
- To move towards a realistic model
  - need to introduce families
  - need to split quarks & leptons within $SU(2)_L$ doublets
  - need to give mass to neutrinos that are (naturally) massless

  - None of these is a trivial task

Thanks for your attention

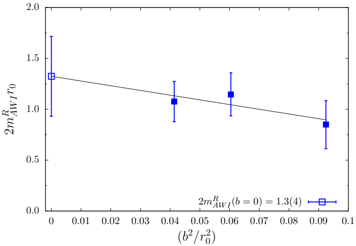
Back-up Slides

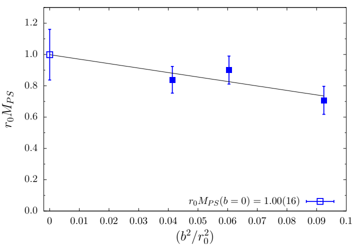
NP mass in NG phase: a lattice confirmation

- At $\eta = \eta_{cr}$, where invariance under $\tilde{\chi}_L \times \tilde{\chi}_R$ is recovered and the quark Higgs mass is killed, we compute in the NG phase the "PCAC mass"

$$m_q^{NP} = m_{PCAC}(\eta_{cr}) = \frac{\sum_{\vec{x}} \partial_\mu \langle \tilde{A}^i_\mu(\vec{x}, x_0) P^i(0) \rangle}{\sum_{\vec{x}} \langle P^i(\vec{x}, x_0) P^i(0) \rangle} \Big|^{NG}_{\eta_{cr}}, \qquad P^i = \bar{q}\gamma_5 \frac{\tau^i}{2} q$$

- Surprisingly we find that neither m_{PCAC} nor M_{PS} vanish
  $\rightarrow$ a NP fermion mass is getting dynamically generated
  $\rightarrow$ together with a non-vanishing PS-meson mass





- $2m^R_{AWI} r_0 \equiv 2 r_0 m_{PCAC} Z_{\tilde{A}} Z_P^{-1}$ (left) and $r_0 M_{PS}$ (right) vs. $(b/r_0)^2$
- straight lines are linear extrapolations to the $b \rightarrow 0$ limit