EWPT and strong EWSB

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AO, Slava Rychkov, arXiv:1111.3534v1 [hep-ph]

Outline

1. Short introduction to EWPT
2. EWSB before H-day
3. $\hat{S}$ parameter in a higgsless TC model: how to reconciliate TC with EWPT?
4. Adding a 125 GeV composite Higgs in the spectrum: the difficulties

EWPT in a few words

- EWPT: precise measurement of M_W, $\Gamma(Z- > l^+ l^-)$, A^l_{FB}
  $\Rightarrow$ measure of the departure from the tree level relations.
- parametrization of the loop effects: ϵ_1, ϵ_2, ϵ_3:
  $M_W^2 = M_Z^2 c_w^2 + \delta M_W^2(\epsilon_1, \epsilon_2, \epsilon_3)$
- oblique versus non oblique:
  - $\epsilon_1 = e_1 - e_5 - \frac{\delta G}{G} - 4\delta g_A$
  - $\epsilon_2 = e_2 - s^2 e_4 - c^2 e_5 - \frac{\delta G}{G} - \delta g_V - 3\delta g_A$
  - $\epsilon_3 = e_3 + c^2 e_4 - c^2 e_5 + \frac{c^2 - s^2}{2s^2}\delta g_V - \frac{1+2s^2}{2s^2}\delta g_A$
- for heavy models, the study is in general simplified:
  - $\epsilon_1 \sim \epsilon_1^{SM} + \underbrace{(e_1 - e_1^{SM})}_{\equiv \hat{T}}$ $\quad e_1 = \frac{A_{W_3 W_3}(0) - A_{W^+ W^-}(0)}{M_W^2}$
  - $\epsilon_2 \sim \epsilon_2^{SM} + \underbrace{(e_2 - e_2^{SM})}_{\equiv \hat{U}}$ $\quad e_2 = F_{W^+ W^-}(M_W^2) - F_{W_3 W_3}(M_Z^2)$
  - $\epsilon_3 \sim \epsilon_3^{SM} + \underbrace{(e_3 - e_3^{SM})}_{\equiv \hat{S}}$ $\quad e_3 = \frac{c_W}{s_W} F_{W_3 B}(M_Z^2)$

Theory point of view before Higgs discovery

- Gauge group $\supset SU(2)_L \times U(1)_Y \to U(1)_Q$
- Global Symmetry: $\supset SU(2)_L \times SU(2)_R \to SU(2)_V$
  - protect the ratio $\rho = \frac{m_W^2}{m_Z^2 \cos\theta_W}$ (no large $\hat{T}$, and $\hat{U}$ negligible)
  - explicitly broken by g' and $\lambda_u \neq \lambda_d$

Under those assumptions, one can build the Electroweak Chiral Lagrangian (EFT with cutoff $\Lambda \sim 3\,TeV$):

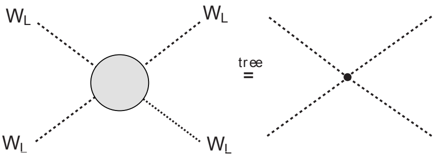
Effective Lagrangian

$$\mathcal{L}_{eff} = \frac{v^2}{4} Tr\left(D_\mu U \left(D^\mu U\right)^\dagger\right) + \mathcal{L}_{gauge/fermions} + \mathcal{L}_{Yukawa}\left(U, \psi_i\right)$$

where $U = e^{2i\frac{\pi^a T^a}{v}}$ and $D_\mu U = \partial_\mu U - ig' T^3 B_\mu U + igUT^a W_\mu^a$

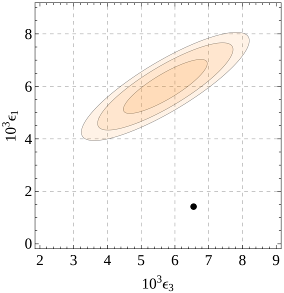
Why new physics was needed?

- Unitarity in WW longitudinal scattering:



The partial wave amplitude grows linearly with s, and violates its unitarity bound at $\sqrt{s} \sim 1\,TeV$

- Electroweak Precision Tests:



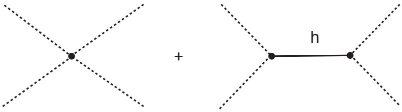
- $\epsilon_1 \sim -\frac{3g'^2}{32\pi^2} \log \frac{\Lambda}{m_Z} + cst$
- $\epsilon_3 \sim \frac{g^2}{96\pi^2} \log \frac{\Lambda}{m_Z} + cst'$

$\Rightarrow$ Bad fit to EWPT...

$\Rightarrow$ new physics needed around or below the TeV scale

Two solutions to unitarize WW scattering before higgs discovery

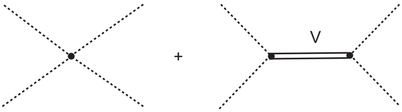
a scalar



(SM,SUSY,CH...)

$\Rightarrow$ Unitarity can be restored up to arbitrarily high scales depending on the model.

a spin-1 Vector Resonance



(TC,5D Higgsless...)

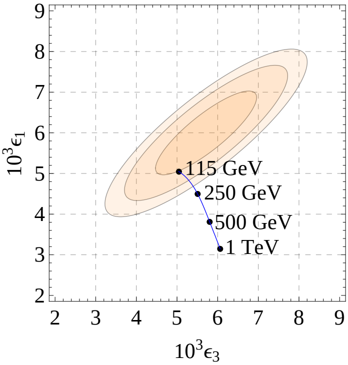
$\Rightarrow$ Unitarity can be restored up to 6-10 TeV.

M_V and G_V constrained.

But unitarity restoration can be due to an interplay between the two scenarios: Technicolor scenarios including a composite higgs, 5D gauge models...

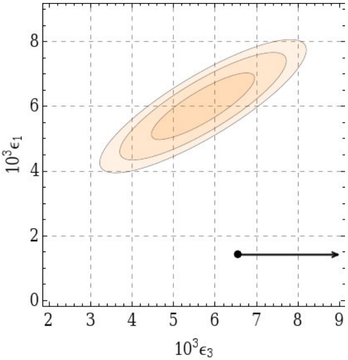
EWPT in those two scenarios

SM Higgs



Good fit to EWPT with $m_h \sim 125\ GeV$

most of the Technicolor/5D higgsless models



$\hat{S}$ is usually too big to have a good fit to EWPT

$\hat{S}$ parameter computation

Assumptions:

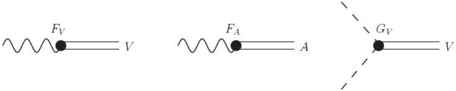
- Parity
- Vector Meson Dominance (VMD): Only one vector and one axial spin-1 resonances in the EFT (like the ρ and a_1 resonances in QCD, which saturate the low energy observables)
- no higgs (minimal global symmetry breaking pattern $SU(2) \times SU(2) \to SU(2)$)
- mass gap: $M_Z^2 << M_V^2,\ M_A^2 \Rightarrow \hat{S}$ and $\hat{T}$ only

Peskin-Takeuschi formula for $\hat{S}$

$$\hat{S} = \frac{g^2}{4} \int_0^\infty \frac{ds}{s} \left[(\rho_V(s) - \rho_A(s)) - (\rho_V^{SM}(s) - \rho_A^{SM}(s))\right]$$

Why $\hat{S} = e_3 - e_3^{SM}$ is big in Technicolor?

- $\hat{S}$ from the Peskin-Takeuchi formula (from the EFT):
  $\hat{S} = \frac{g^2}{4}\left(\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2}\right) + \frac{g^2}{96\pi^2}\left(\log\frac{M_V}{m_h^{ref}} + O(1)\right)$
  couplings:



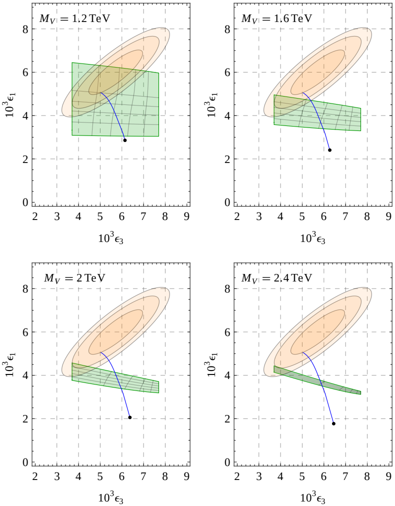
- Constraints on the parameter space:
  - 2 Weinberg sum rules: $F_V^2 - F_A^2 = v^2$ and $F_V^2 M_V^2 - F_A^2 M_A^2 = 0$
  - Unitarity in $W_L W_L$ scattering $\Rightarrow M_V < 2.6\ TeV$ and $G_V \sim \frac{v}{\sqrt{3}}$
  - Good UV behavior of $\pi\pi$ form factor $\Rightarrow F_V G_V = v^2$

$\Rightarrow \frac{g^2}{4}\left(\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2}\right)$ positive and too big to agree with EWPT.

A way out: Conformal Technicolor

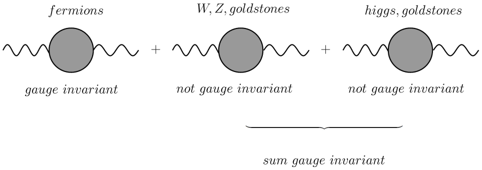
- Conformal TC in a few words: TC model reaching a **strongly coupled** fixed point in the IR (above the EW scale)
- Consequence: 2nd Weinberg sum rule not satisfied $\Rightarrow$ more freedom on the space of parameters, allowing for a cancelation between the axial and the vector part in the dangerous contribution : $(\Delta\hat{S} = \frac{g^2}{4}\left(\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2}\right))$
- negative contributions even possible (the positivity of $\hat{S}$ is not rigorously proven, specially in the case of conformal dynamics in the UV)

EWPT fit


$M_V = 1.2\,\mathrm{TeV}$
$M_V = 1.6\,\mathrm{TeV}$
$M_V = 2\,\mathrm{TeV}$
$M_V = 2.4\,\mathrm{TeV}$
$10^3\epsilon_1$
$10^3\epsilon_3$
0
2
4
6
8
2
3
4
5
6
7
8
9

Adding a 125 GeV composite higgs: difficulties with gauge invariance

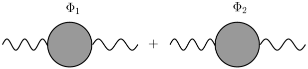
- in composite higgs models : $g_{h...}^{SM} \rightarrow a \times g_{h...}^{SM}$ with $a < 1$
- gauge invariance for the SM e_1 parameter:



- In CH models, the third class of diagramms is affected by the new couplings while the second is not, leading to an imperfect cancelation of the gauge dependance.

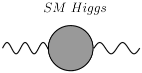
Toy model to see what could restore gauge invariance: 2HDM

- 2HDM in two words: 2 higgs doublet Φ_1, Φ_2 $\Rightarrow$ 2 neutral CP even scalars: h_0 and H_0, 2 charged scalars $\phi^{\pm}$, 1 neutral CP odd scalar A_0 and 3 goldstones.
- R_ξ gauge dependance for e_1 in the 2HDM model:



$$= (g^2_{h_0VV} + g^2_{H_0VV}) f^{SM}(\xi) + \ldots$$

- R_ξ gauge dependance for e_1 in the SM:



$$= g^2_{hVV} f^{SM}(\xi) + \ldots$$

- Sum rule: $g^2_{h_0VV} + g^2_{H_0VV} = g^2_{hVV}$

$\Rightarrow$ Same ξ dependance in both cases and the sum with the pure EW gauge boson/goldstones contribution is gauge invariant

What can we expect in TC models with a composite Higgs?

- gauge dependance of the composite higgs contribution to the ϵ's parameters should be cancelled by the gauge dependance of the spin-1 resonances contributon
- difference between the 2HDM and the composite higgs scenario: in 2HDM a sum rule for the couplings is predicted while in the strongly coupled scenario there is not such a relation. Imposing gauge invariance could lead to impose a sum rule between the different couplings a, F_V, G_V, F_A...
- difficulty:$m_h = 125\ GeV$ too light to perform an analysis in terms of $\hat{T}$ and $\hat{S}$ $\Rightarrow$ full ϵ's computation needed...

Conclusions

- CTC models provide a way to reduce $\hat{S}$
- $\hat{T} \sim 0$ and $\hat{S} \sim 0$ possible in the higgsless case $\Rightarrow$ encouraging for the CH case.
- The quantitative analysis with a composite higgs is complicated by its lightness and gauge invariance issues.
- Gauge invariance might give a constraint on a priori unknow parameters of the strong sector.
- The precise measurements of the higgs couplings and direct search for spin-1's are crucial to investigate those kind of strongly coupled scenarios.

Thank You!