(Minimal) Walking Technicolor

Constraints and Unitarity

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TECHNICOLOR:

1. Take a strongly interacting gauge theory with a chiral symmetry.
2. Let the gauge coupling be strong enough to trigger spontaneous chiral symmetry breaking.
3. Let the electroweak gauge group be a subgroup of the chiral symmetry group. (Weinberg 79, Susskind 79)

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Example: QCD !

How do the SM fermions interact with the technifermion condensate to acquire mass ?

Extended Technicolor:

A new gauge theory, at a higher scale, with SM fermions and technifermions in the same multiplet.

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PROBLEM:

Tension between SM fermion masses and flavor changing neutral currents.

Walking dynamics enhances the technifermion bilinears, not the SM fermion bilinears.

Walking Technicolor:

Enhanced SM fermion masses and suppressed FCNC. (Holdom 81)

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WALKING TECHNICOLOR:

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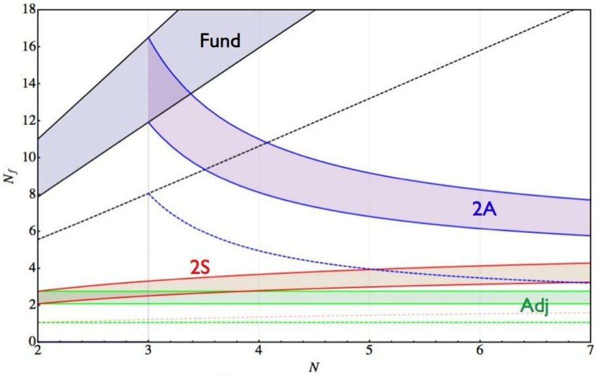
QUESTION:

Which gauge theories do display walking behavior ?

Conformal Windows in Ladder Approximation



(Sannino and Dietrich 06)

S Parameter in Walking Technicolor

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- $S_{\mathrm{pert}} = \frac{8}{6\pi} \simeq 0.42$ in the fundamental representation.
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(Minimal) Walking Technicolor:

Walking Technicolor with small N_f in a higher dimensional representation. (Sannino and Tuominen 05)

Minimal Walking Technicolor:

$N_c = 2$, $N_f = 2$ in the adjoint or two-index symmetric.

Next to Minimal Walking Technicolor:

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MWT on the lattice: tests in progress. (Catteral and Sannino 07; Del Debbio, Frandsen, Panagopoulos, and Sannino 08)

Alternatives: Partially gauged Technicolor, and Split Technicolor. (Dietrich and Sannino 05)

Underlying Gauge Theory

New Physics:

$$\mathcal{L}_{\rm newphysics} = -\frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu} + i\bar{Q}_{\rm L}\gamma_\mu D^\mu Q_{\rm L} + i\bar{Q}_{\rm R}\gamma_\mu D^\mu Q_{\rm R}$$

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- Plus possible lepton doublets or matter in the adjoint.
- Plus ETC interactions.

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- Model the spin-1 spectrum with a vector and an axial resonances and a close-to-continuum spectrum in the near conformal region.
- Use some trustable approximation to compute the contribution of the near conformal region to the vacuum polarization amplitudes. (Appelquist and Sannino 98)

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S parameter, or "zeroth WSR": important contributions from the near conformal region.

$$S = 4\pi F_\pi^2 \left[\frac{1}{M_{\mathrm{V}}^2} + \frac{1}{M_{\mathrm{A}}^2} - a \frac{8\pi^2 F_\pi^2}{d(\mathrm{R}) M_{\mathrm{V}}^2 M_{\mathrm{A}}^2} \right]$$

S Parameter in (M)WT

- Notice: $S_{\rm pert} \simeq 0.16$ both in QCD and MWT.
- $S_{\rm QCD} \simeq 2S_{\rm pert}$.
- Therefore, in the worst case scenario we can expect a QCD-like (running) behavior in MWT: $S_{\rm MWT} \simeq 0.3$.

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- $S_{\rm QCD} \simeq 2 S_{\rm pert}$.
- Therefore, in the worst case scenario we can expect a QCD-like (running) behavior in MWT: $S_{\rm MWT} \simeq 0.3$.

However in walking theories there is a negative contribution.

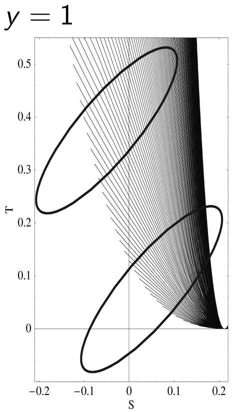
S in Walking Technicolor

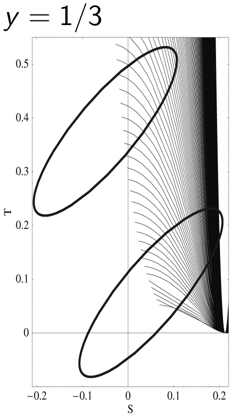
$$S = 4\pi F_\pi^2 \left[\frac{1}{M_{\rm V}^2} + \frac{1}{M_{\rm A}^2} - a \frac{8\pi^2 F_\pi^2}{d({\rm R}) M_{\rm V}^2 M_{\rm A}^2} \right], \; a \in \mathcal{O}(1)$$

Therefore in Walking Technicolor S is expected to be smaller than in running theories. (Appelquist and Sannino 95; Kurachi, Shrock, and Yamawaki 07)

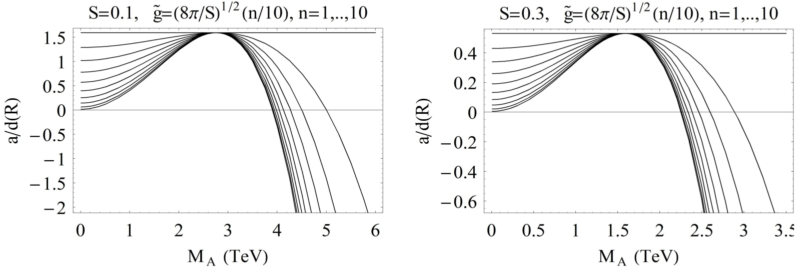
- The full S is the sum of the Technicolor contribution and the contribution from the new leptons $S = S_{\rm TC} + S_{\rm leptons}$.
- A positive value of T is favored by electroweak precision data.
- The new leptons can easily give a negative contribution to S and a positive contribution to T.

S Parameter in (M)WT

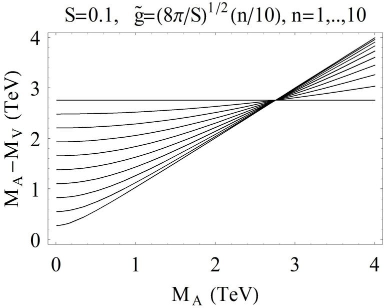


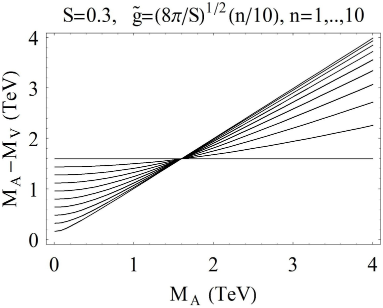


1. Impose WSR-1.
2. Impose WSR-0 and small S.
3. For different values of the vector coupling, check on the behavior of a, which is expected to be positive $\mathcal{O}(1)$ in a walking theory.

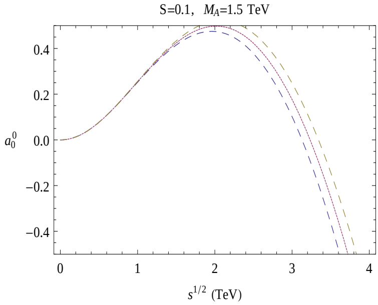


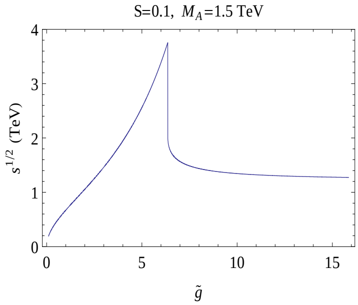
- In a walking regime the vector can be heavier than the axial.
- In (M)WT, if the spin-1 resonances are within the LHC range, then $M_V > M_A$.



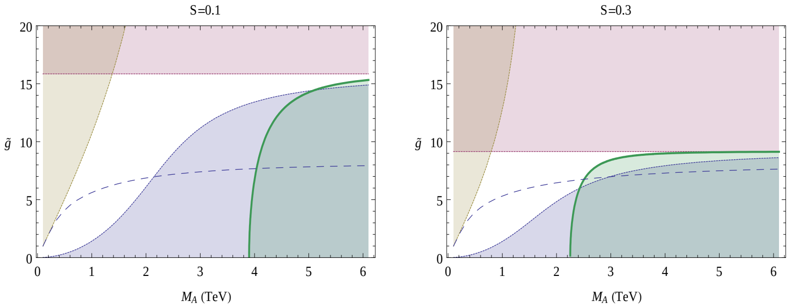


- If the Higgs boson is heavy, the technirho meson delays unitarity violation to higher energy scales.
- The unitarization drops after a threshold value of the $\tilde{g}$ coupling is reached.



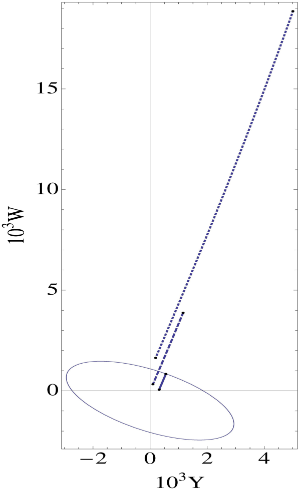


- The technirho mass needs not be within the LHC range, because of the strong coupling.
- Upper and lower bounds on $\tilde{g}$ from the requirements $\Gamma_{\mathrm{V}\to\pi\pi}/M_{\mathrm{V}} < 0.5$, $\Gamma_{\mathrm{V}\to\mathrm{AA}}/M_{\mathrm{V}} < 0.5$. Upper (consistency) bound from $\tilde{g} < \sqrt{8\pi/S}$.

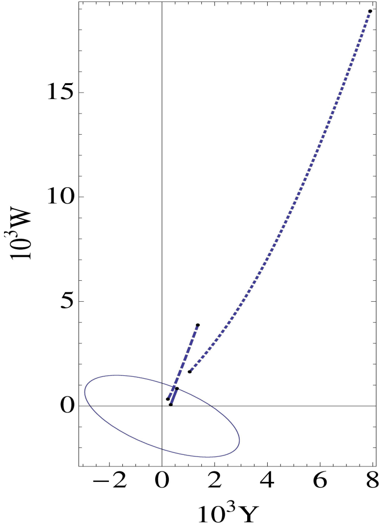


Constraints from Electroweak Parameters

- (M)WT are universal theories, in the sense of Barbieri *et. al.*. (Barbieri, Pomarol, Rattazzi, and Strumia 04)
- $\hat{T} = \hat{U} = V = 0$, because of custodial symmetry.
- $\hat{S}$ or S are used as input, since these are small in (M)WT.
- W and Y impose constraints on the Lagrangian parameters.



$y = 0$; solid=$\tilde{g} = 8$, dashed=$\tilde{g} = 4$, dotted=$\tilde{g} = 2$; closer to the ellipse $M_{\rm A} = 600$ GeV, farther from the ellipse $M_{\rm A} = 150$ GeV.



$y = 1$; solid=$\tilde{g} = 8$, dashed=$\tilde{g} = 4$, dotted=$\tilde{g} = 2$; closer to the ellipse $M_{\rm A} = 600$ GeV, farther from the ellipse $M_{\rm A} = 150$ GeV.

Conclusions

- (Minimal) Walking Technicolor is an ordinary 4D gauge theory.
- It satisfies the electroweak constraints.
- It does not give rise to FCNC.
- It can be extended to include more models, like split technicolor or partially gauged technicolor.
- It can be written as an effective field theory with vector and axial resonances and a Higgs (NMWT), plus other resonances in models with a large chiral symmetry group (MWT).

Conclusions

- New leptons can always be added in the spectrum (needed in MWT), as well as matter in the adjoint.
- Dark matter candidates were discussed in previous works. (Gudnason, Kouvaris, and Sannino 06; Kainulainen, Tuominen, and Virkajarvi 06)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