Template for Walking technicolor

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Outline

- Introduction to (minimal walking) technicolor
- Template with $SU(2)_L \times SU(2)_R$ chiral symmetry
- Constraints of parameter space

...phenomenology in the next talk by

Mads Toudal Frandsen

Introduction: Technicolor

Dynamical electroweak symmetry breaking

- The Higgs sector of the standard model produced by a strongly interacting gauge theory
- The scale of the new theory $\leftrightarrow G_F$: a few hundred GeV
- Chiral symmetry breaking of the strong dynamics triggers electroweak symmetry breaking

Introduction: Technicolor

Original idea: scaled up QCD (which does not work)

- Electroweak $SU(2)_L \times U(1)_Y$ gauge symmetry embedded into (global) chiral symmetry $SU(2)_L \times SU(2)_R$
- Breaking $SU(2)_L \times SU(2)_R \to SU(2)_V$ triggers $SU(2)_L \times U(1)_Y \to U(1)_Q$

Introduction: Towards (Minimal) walking technicolor

Why should it be exactly like QCD?

Different gauge groups and numbers of fermions N_f

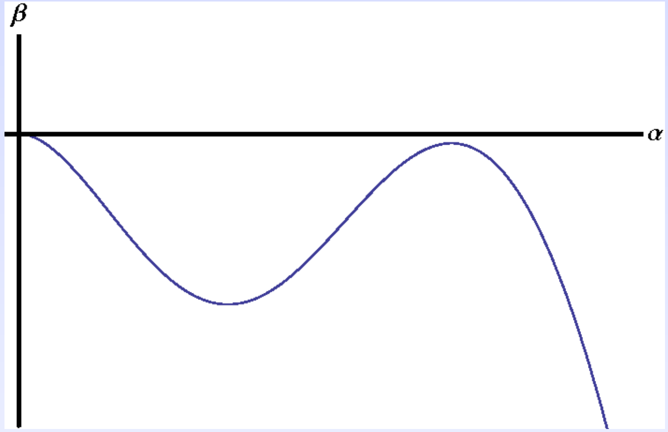
$$U(1)_Y \times SU(2)_L \times SU(3)_C \times SU(N_{TC})_{TC}$$

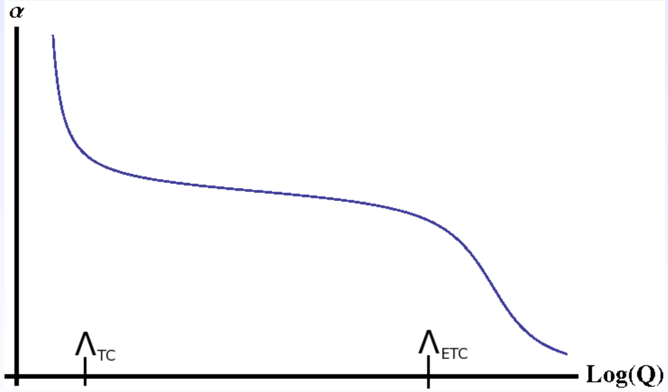
Theory can be near to conformal: α is "walking" instead of running?

[Holdom 81]

Fermions in higher dimensional representations (adjoint, two index symmetric)

[Sannino, Tuominen 2005]





Introduction: Problems?

- Composite Higgs $\Longrightarrow$ no hierarchy problem
- Walking dynamics $\Longrightarrow$ flavor changing neutral currents suppressed wrt. fermion masses
- Fermions in higher dimensional representations $\Longrightarrow$ N_f can be low within walking dynamics $\Longrightarrow$ passes eletroweak precision tests, small S parameter (!)

Our Strategy

- Build an effective field theory of the lightest composite fields of the strongly interacting theory
- Explicit Lagrangian with chiral symmetry breaking pattern encoded (compare to chiral perturbation theory in QCD)
- Two main candidates
  - Minimal walking $SU(2)_{TC}$ and $N_f = 2$ in the adjoint representation: $SU(4) \to SO(4)$
  - “Next-to-minimal” walking $SU(3)_{TC}$ and $N_f = 2$ in the two-index-symmetric representation: $SU(2)_L \times SU(2)_R \to SU(2)_V$

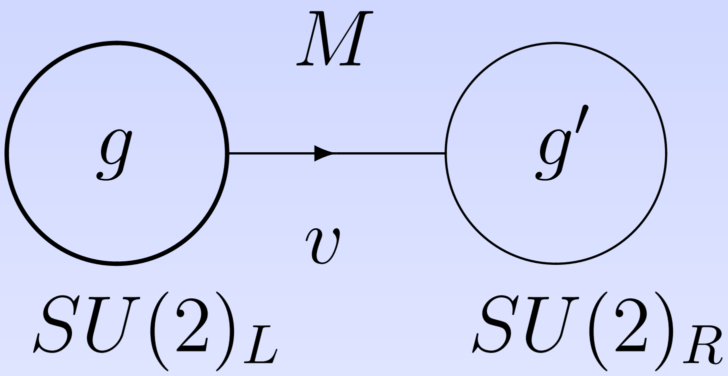
Template with $SU(2)_L \times SU(2)_R$ chiral symmetry

- Particle content: Standard model + (composite) Higgs H, rho and axial vectors V/A or $R_{1,2}$, and (eaten) pions
- Possible underlying theory: $N_f = 2, N_C = 3 +$ fermions in two-index-symmetric representation
- Includes the (degenerate) BESS (Breaking Electroweak Symmetry Strongly) models

[Casalbuoni et al. 1995]

Template: Structure

Electroweak symmetry embedded in $SU(2)_L \times SU(2)_R$ in the standard way



$M = \frac{1}{\sqrt{2}}(\sigma + i\Pi^a T^a)$, 2×2 linear sigma field, contains Higgs and the pions (which will be eaten by B and W)

$M \longrightarrow u_L M u_R^\dagger$

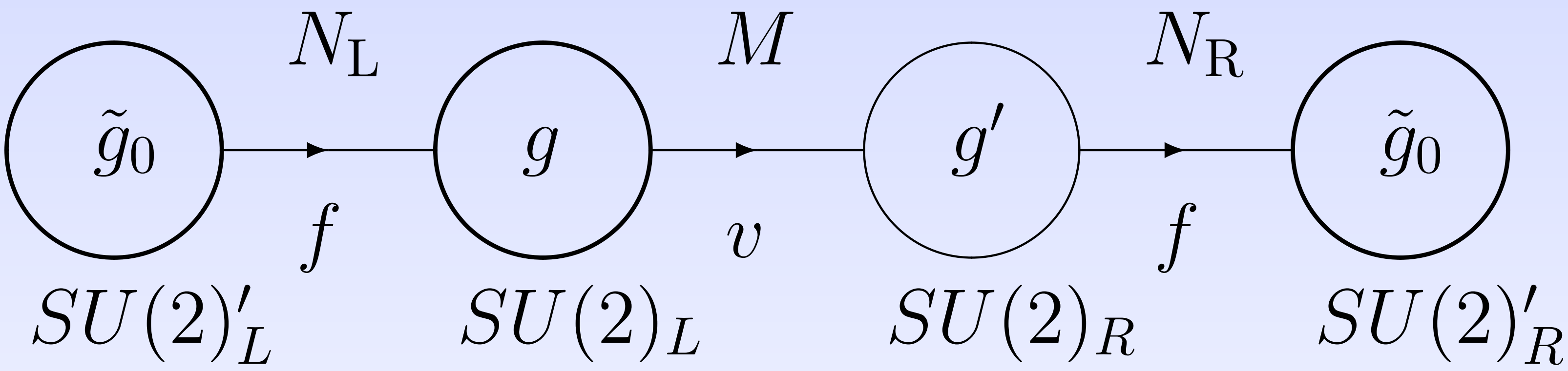
Condensate $M \sim v\,\mathbf{1}$ or $\sigma = v + H$

Coupling to rho and axial vector mesons . . .

Template: Structure

- Rho and axial vector mesons introduced as gauge fields of a hidden local gauge symmetry (a copy of $SU(2)_L \times SU(2)_R$)

$\Rightarrow$ four-site moose



$N_L \to u'_L N_L u_L^\dagger \,; \quad N_R \to u_R N_R u_R'^\dagger$ nonlinear sigma

Condensing $N_{L/R} \sim f$ breaks symmetry back to $SU(2)_L \times SU(2)_R$

Template: Lagrangian

$\longrightarrow$ write down a general (parity & gauge invariant) effective field theory...

$$M = \frac{1}{\sqrt{2}}\left(\sigma + i\Pi^a T^a\right) \leftrightarrow v\,; \quad N_{L/R} = \exp\left(2i\Pi^a_{L/R}T^a/f\right) \leftrightarrow f$$

$$D_\mu M = \partial_\mu M - i\,g\,\widetilde{W}^a_\mu\,T^a M + i\,g'\,M\,B_\mu\,T^3$$

$$D_\mu N_{\rm L} = \partial_\mu N_{\rm L} - i\,\tilde{g}_0\,A^a_{{\rm L}\mu}\,T^a\,N_{\rm L} + i\,g\,N_{\rm L}\,\widetilde{W}^a_\mu\,T^a$$

$$\mathcal{L} = \mathcal{L}_{\rm kin} + \mathcal{L}_{\rm Higgs} + \mathcal{L}_{\rm MN} + \mathcal{L}_\gamma + \mathcal{L}_{\rm ferm}$$

$$\begin{aligned}
\mathcal{L}_{\rm kin} &= -\frac{1}{4}{\rm Tr}\left[\widetilde{W}_{\mu\nu}\widetilde{W}^{\mu\nu}\right] - \frac{1}{4}{\rm Tr}[B_{\mu\nu}B^{\mu\nu}] - \frac{1}{4}{\rm Tr}[F_{L\mu\nu}F^{\mu\nu}_L] - \frac{1}{4}{\rm Tr}[F_{R\mu\nu}F^{\mu\nu}_R] \\
\mathcal{L}_{\rm Higgs} &= \frac{1}{2}{\rm Tr}\left[D_\mu M (D^\mu M)^\dagger\right] + \frac{v^2\lambda}{2}{\rm Tr}\left[MM^\dagger\right] + \cdots \\
\mathcal{L}_{\rm MN} &= r_2\,{\rm Tr}\left[(D_\mu N_{\rm L})^\dagger N_{\rm L} M D^\mu N_{\rm R} N^\dagger_{\rm R} M^\dagger\right] + \cdots \\
\mathcal{L}_\gamma &= -\frac{2\gamma}{v^2}{\rm Tr}\left[N^\dagger_L F_{L\mu\nu} N_L M N_R F^{\mu\nu}_R N^\dagger_R M^\dagger\right]
\end{aligned}$$

Parameter space

As usual, e, G_F, M_Z fix g, g', v ; Higgs mass M_H free

Also eight new parameters $\tilde{g}_0, f, \gamma, k, r_2, r_3, s, \kappa \longrightarrow$ seven after imposing first Weinberg sum rule

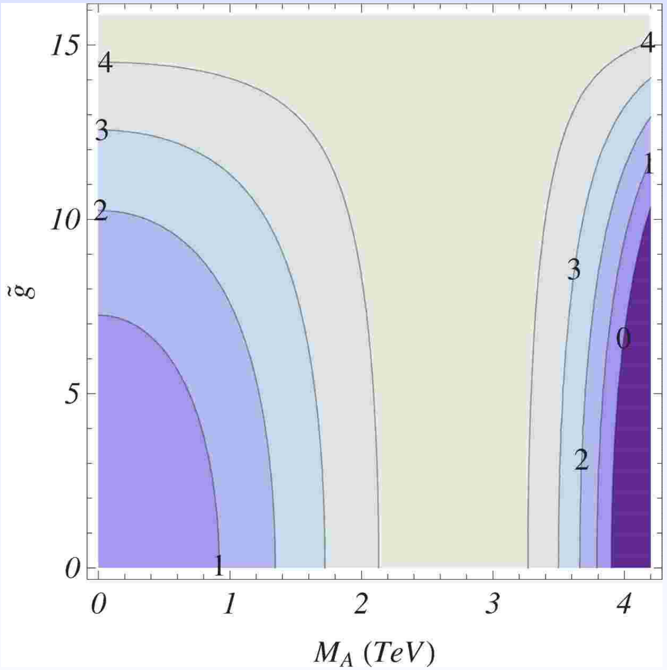
- We choose as input
  - The Axial mass M_A
  - The (rescaled) strong coupling $\tilde{g}$
  - The electroweak S parameter
  - The L/R mixing parameter γ
  - The vector-Higgs couplings k, s
  - Fermionic anomalous coupling κ

Constraints: Weinberg sum rules

By analyzing the energy dependence of the $\langle VV \rangle - \langle AA \rangle$ vacuum polarization amplitude

- 1st WSR: $F_V^2 - F_A^2 = F_\pi^2 \Rightarrow r_2 = 1 - r_3$
- 2nd WSR modified to walking dynamics:
  $F_V^2 M_V^2 - F_A^2 M_A^2 = a \frac{8\pi^2}{d(R)} F_\pi^4$ where $a = \mathcal{O}(1)$ and positive
- "0th WSR": $S = 4\pi \left[\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2} \right]$

a for $S = 0.1$



S and a constrained:

- S is input
- $a \longrightarrow$ two favored regions

Further constraints

- Widths: The use of Weinberg sum rules and naturality of the theory $\Rightarrow$ rho and the axial to be narrow
- Electroweak precision measurements
  - S as input, T and U zero $\Rightarrow$ no further constraints
  - Barbieri et al. Y and W parameters
  - ZWW vertex

Constraint plots

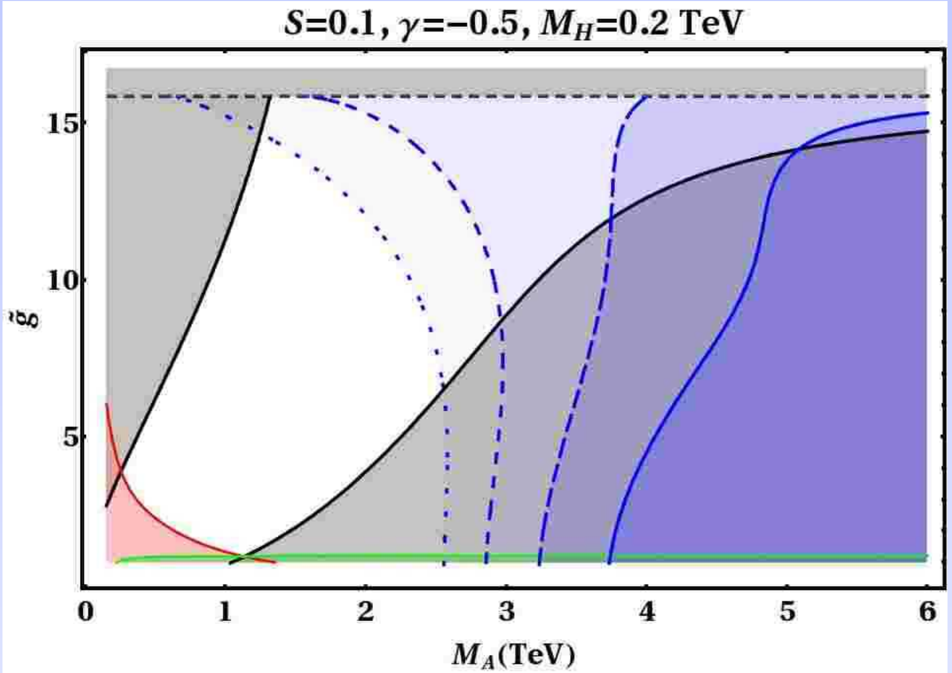
Black: vector width

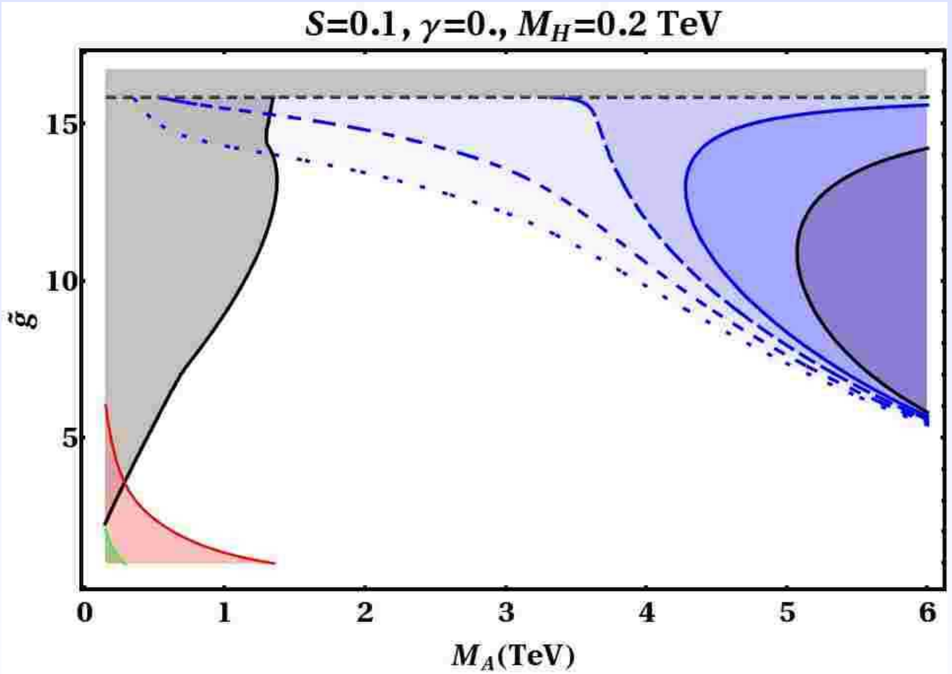
Blue: axial width

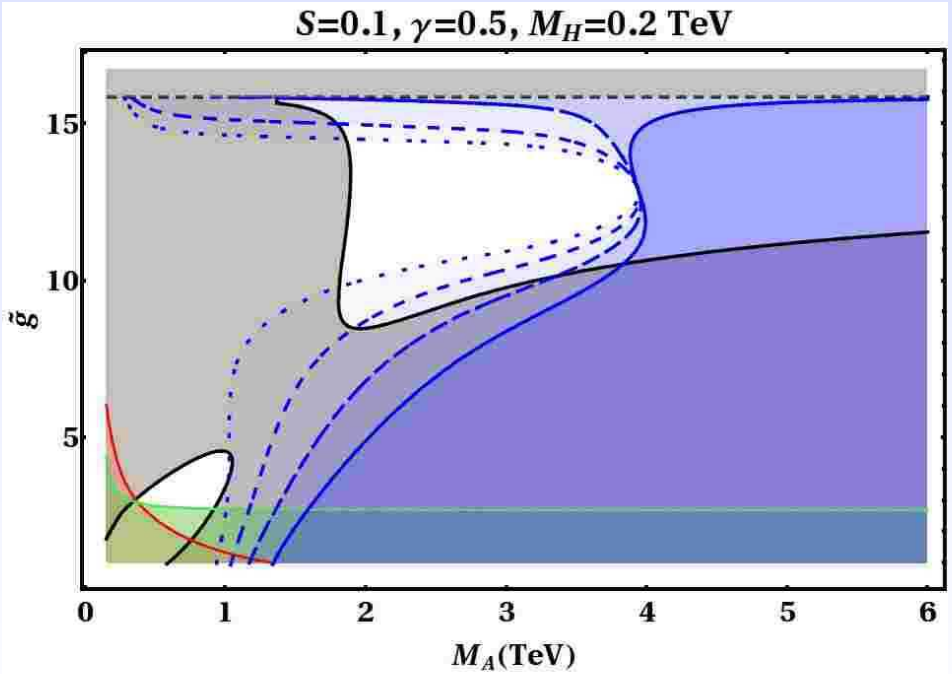
Red: Y and W precision

Green: ZWW precision

$S = 0.1$







Constraint plots

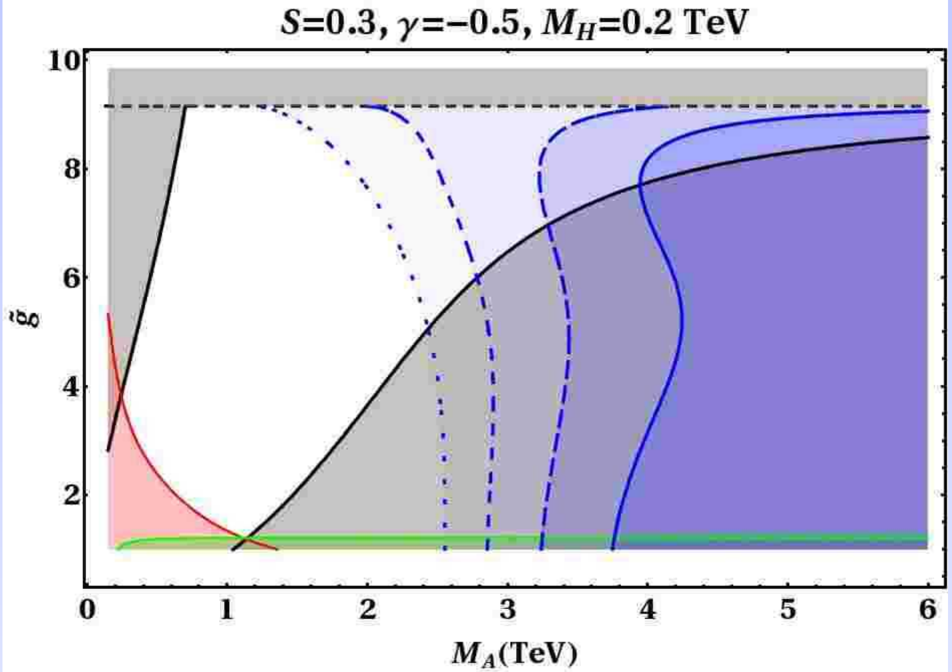
Black: vector width

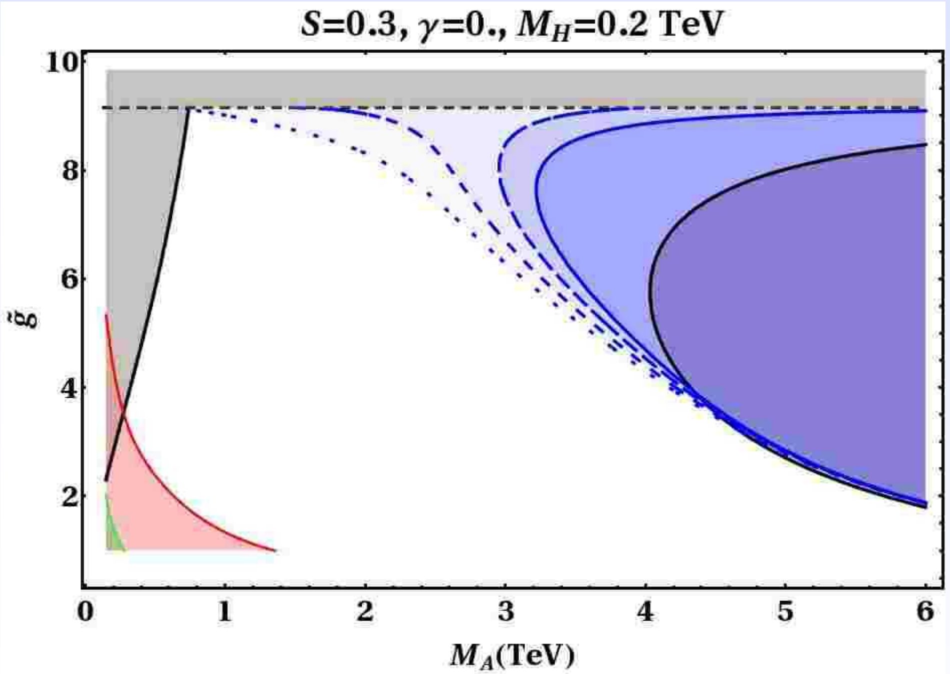
Blue: axial width

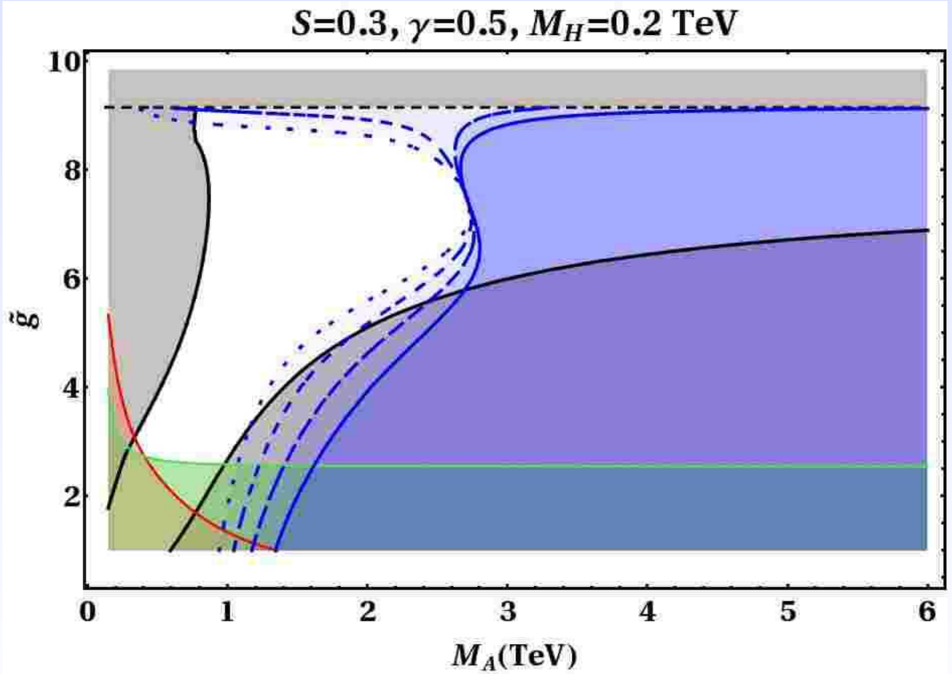
Red: Y and W precision

Green: ZWW precision

$S = 0.3$







Anomalous fermion coupling κ

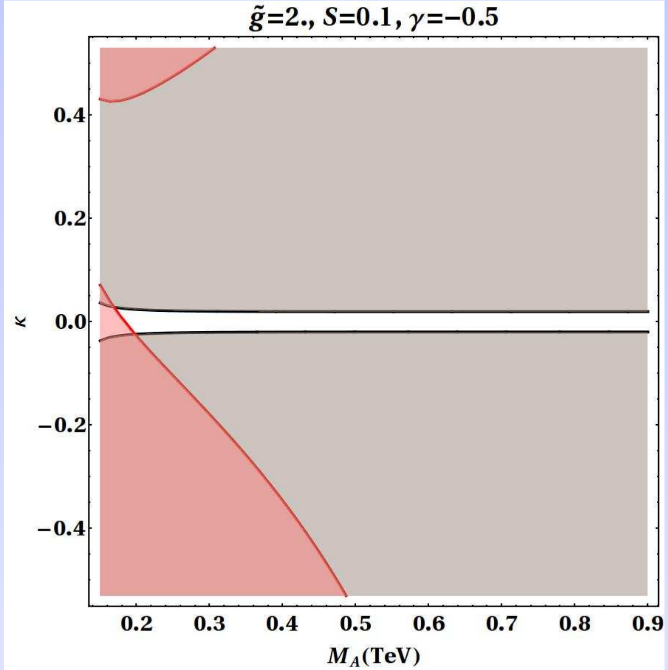
$$\mathcal{L}_{\text{ferm}} = \kappa\, \bar{q}_L\, N_{\text{L}}^{\dagger} i \not{D} N_{\text{L}}\, q_L + \kappa\, \bar{q}_R\, i \not{D} N_{\text{R}} N_{\text{R}}^{\dagger}\, q_R + \cdots$$

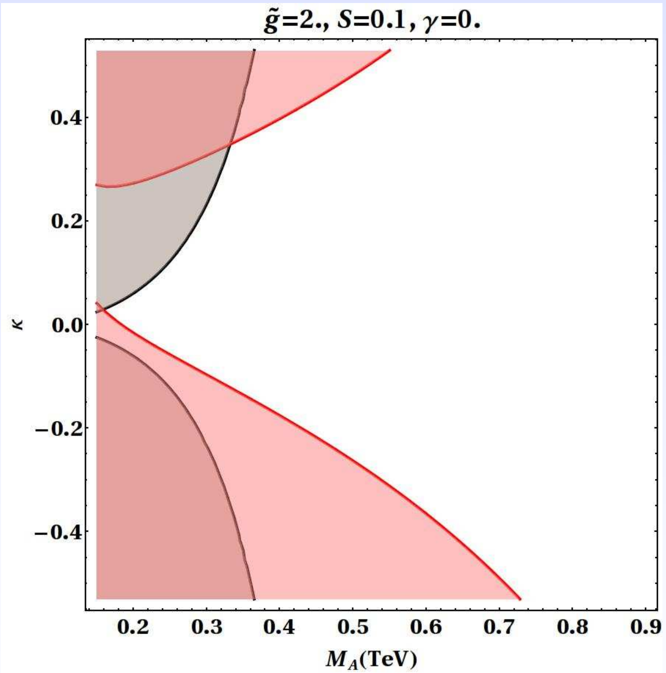
- Direct coupling to techni vector mesons
- No flavor mixing $\Rightarrow$ No FCNC
- Constrained by measurements of tbW vertex and direct vector boson production

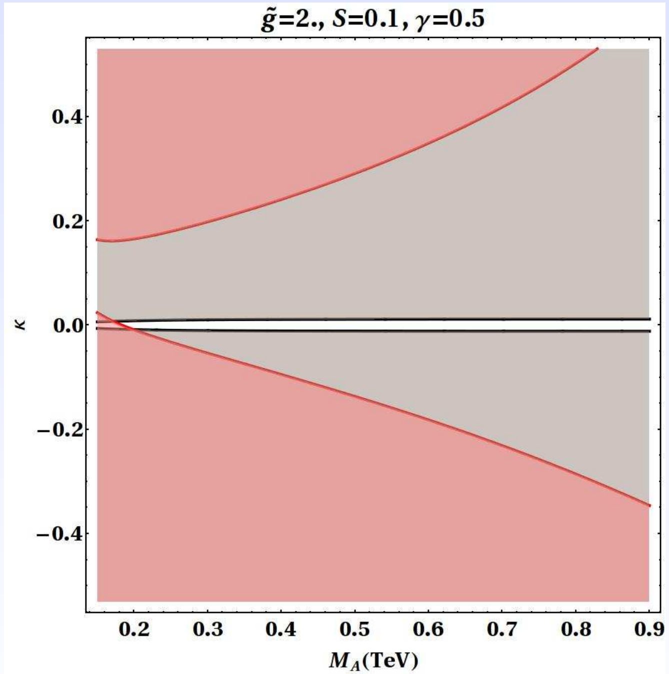
Constraints on κ

Black: Right handed tbW vertex from $B \to X_s\gamma$ branching

Red: Tevatron bound on direct axial production







Summary

- Walking technicolor passes all experimental contraints
- We study a $SU(2)_L \times SU(2)_R$ version of walking technicolor using effective field theory
- The model is consistent within a wide region of parameter space