Heavy leptons, precision tests and technicolor

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Outline

- Introduction: What is (walking) technicolor?
- Heavy leptons in the technicolor
- LHC phenomenology
- Conclusions

Technicolor (Weinberg, Susskind, 79')

Program:

A new as. free gauge group G_{TC} with N_F techniquark flavors

Gauge an $SU(2)_L \times U(1)_Y$ subgroup of the chiral symmetry

Identify with electroweak gauge invariance

The chiral condensate breaks the electroweak symmetry to $U(1)_{EM}$

V V scattering is unitarized by the low-lying resonances

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Good: No fundamental scalars – no hierarchy problem

Bad: 1.Estimates of precision electroweak observables disagree with experiment, large FCNC processes ! Cure by: Walking TC

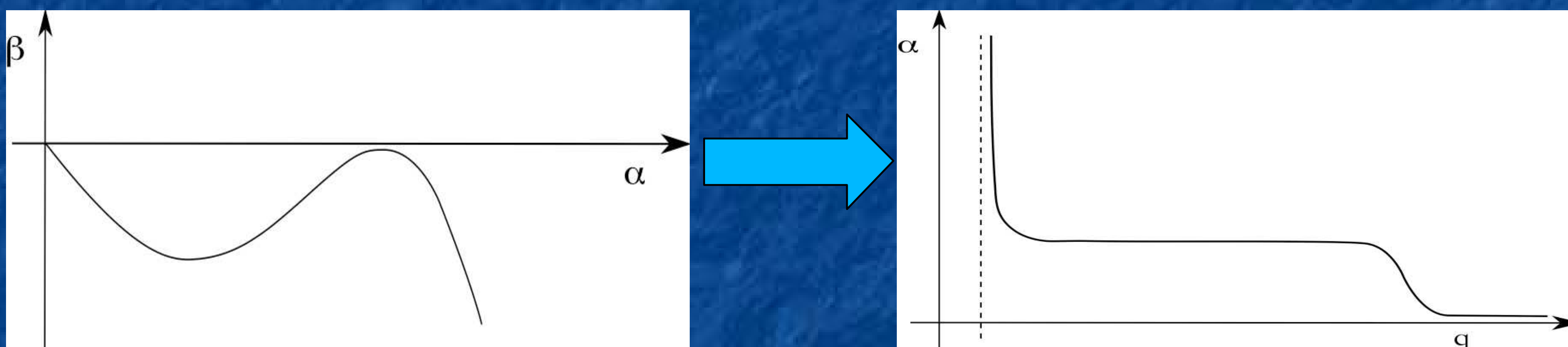
2. No fermion masses ! Cure by: Extended Technicolor

Example: Minimal walking TC

- TC Gauge group: SU(2)
- Two techniquarks in the two-index symmetric (= adjoint) representation of the gauge group (left-handed fields are arranged in three doublets of $SU(2)_L$)

• Near conformal (=walking) → FCNC's suppressed

⟶ Beta function ≈ 0, coupling constant runs slowly, "walks"



- Chiral symmerty group: SU(4) (broken to SO(4) by quark condensate)
- Witten anomaly (odd number of LH doublets) is cured by introducing new lepton family

New lepton family: heavy neutrino mass term

- Dirac mass term for charged lepton
- For neutrino we consider three cases:

1. Pure Dirac mass term
2. Pure Majorana mass term
3. Mixed Dirac-Majorana mass term:

Two Weyl spinors: $\nu_L \,, \nu_R{}^C$

$$-2L_{mass} = \begin{pmatrix} \overline{\nu}_L{}^C & \overline{\nu}_R \end{pmatrix} \begin{pmatrix} M_L & m_D \\ m_D & M_R \end{pmatrix} \begin{pmatrix} \nu_L \\ \nu_R{}^C \end{pmatrix} + h.c.$$

In general, after diagonalization, we have two Majorana particles (mass eigenstates):

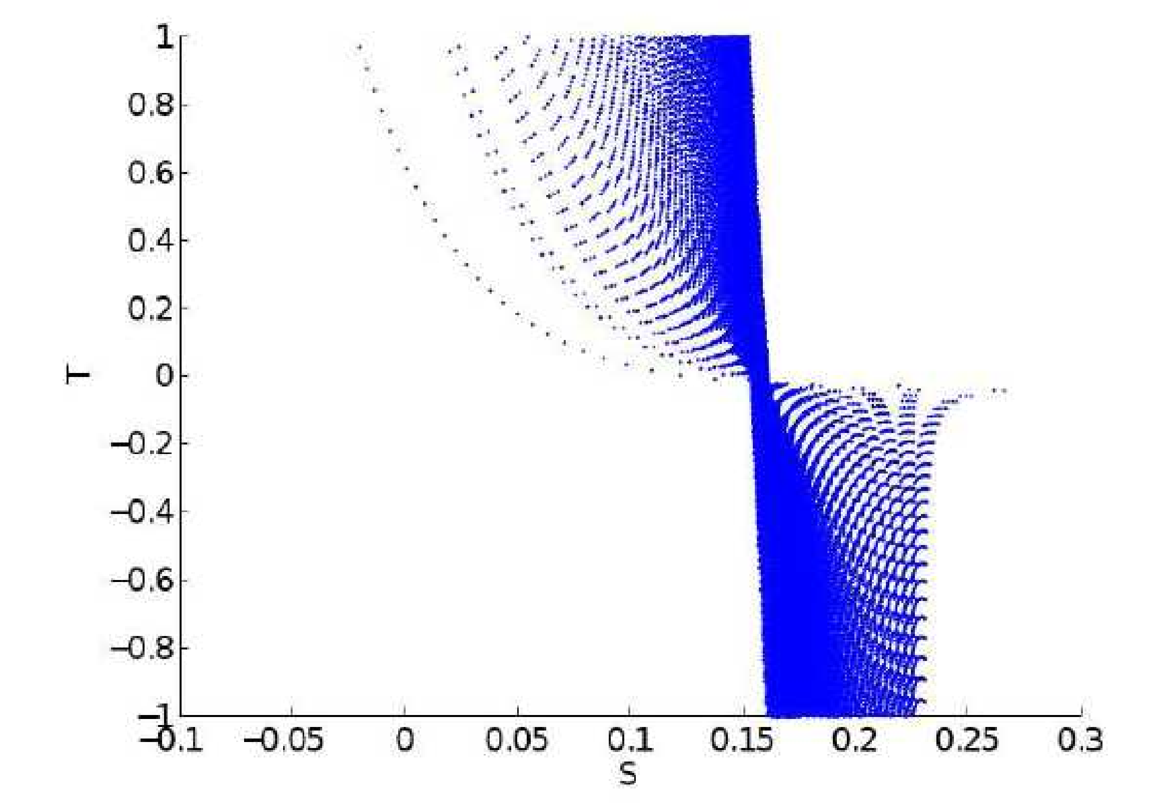
$$\lambda_{1,2} = \frac{1}{2}\left[(M_L + M_R) \pm \sqrt{(M_L - M_R)^2 + 4m_D^2}\right]$$

The mixing angle θ is given by $\tan(2\theta) = 2m_D/(M_R - M_L)$.

We have only 4th generation leptons and no QCD quarks (replaced by techniquarks)

LHC Phenomenology I

EWPT: guiding limits $|S| \leq 0.3$ and $0 < T < 1.$



Masses of the heavy leptons:

Mz/2 – 10 Mz

The mixing angle:

$\sin\theta = 0.3.$

Always possible to find a region in parameter space reproducing given S and T.

LHC Phenomenology II

<u>Production and decay of new heavy leptons</u> : Precision Tests favor the range for the 4th generation leptons near the EW scale.

Consider the production of 4th generation neutrinos because:

1. They are expected to be lighter than charged leptons
2. Their decay modes may provide more interesting observables

(in case they are not absolutely stable)

We focus on the $\ell^\pm\ell^\pm$ and $\ell^\pm\ell^\pm\ell^\mp$ final states arising from

$Z^* \to \chi\chi$ and $W^* \to \ell^\pm\chi$ production channels.

Decay channel to Higgs is assumed to be kinematically forbidden for our neutrinos

LHC Phenomenology II

Production and decay of new heavy leptons :

Table 1: Signal cross-sections σ(in fb) with the corresponding leading SM background for three scenarios described in the text. Pre-selection and selection criteria are also described in the text.

$\mu^\pm\mu^\pm$ X (M_{χ_1}=100 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	S/$\sqrt{B}$
$\mu^\pm\chi_1 : \mu^\pm\mu^\pm$ + 2 jets	1.11	0.6	6	7.25
$\chi_1\chi_1 : \mu^\pm\mu^\pm$ + 4 jets	2.5	1.32	13.2	
SM background	10.25	0.7	7	
$\mu^\pm\mu^\pm$ X (M_{χ_1}=90 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	S/$\sqrt{B}$
$\mu^\pm\chi_1 : \mu^\pm\mu^\pm$ + 2 jets	0.21	0.113	1.1	1.89
$\chi_1\chi_1 : \mu^\pm\mu^\pm$ + 4 jets	0.73	0.39	3.9	
SM background	10.25	0.7	7	
$\mu^\pm\mu^\pm$ X (M_{χ_1}=135 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	S/$\sqrt{B}$
$\mu^\pm\chi_1 : \mu^\pm\mu^\pm$ + 2 jets	2.1	1.1	11	6.95
$\chi_1\chi_1 : \mu^\pm\mu^\pm$ + 4 jets	1.4	0.74	7.4	
SM background	10.25	0.7	7	
$\ell^\pm\ell^\pm\ell^\mp$ X (M_{χ_1}=100 GeV)	Pre-selected σ(fb)	Selected σ(fb)	Events/10 fb^{-1}	S/$\sqrt{B}$
$\mu^\pm\chi_1 : \ell^\pm\ell^\pm\ell^\mp + \not{E}$	1.95	1.52	15.2	12.15
$\chi_1\chi_1 : \ell^\pm\ell^\pm\ell^\mp$+ 2 jets+$\not{E}$	4.10	3.20	32	
SM background	76.7	1.51	15.1	

LHC Phenomenology III

<u>(Composite) Higgs decay:</u>

Charged lepton is like top. Heavy neutrino (set to have 50 GeV mass) is light but couple only weakly to the EW currents and hence evade LEP bounds.

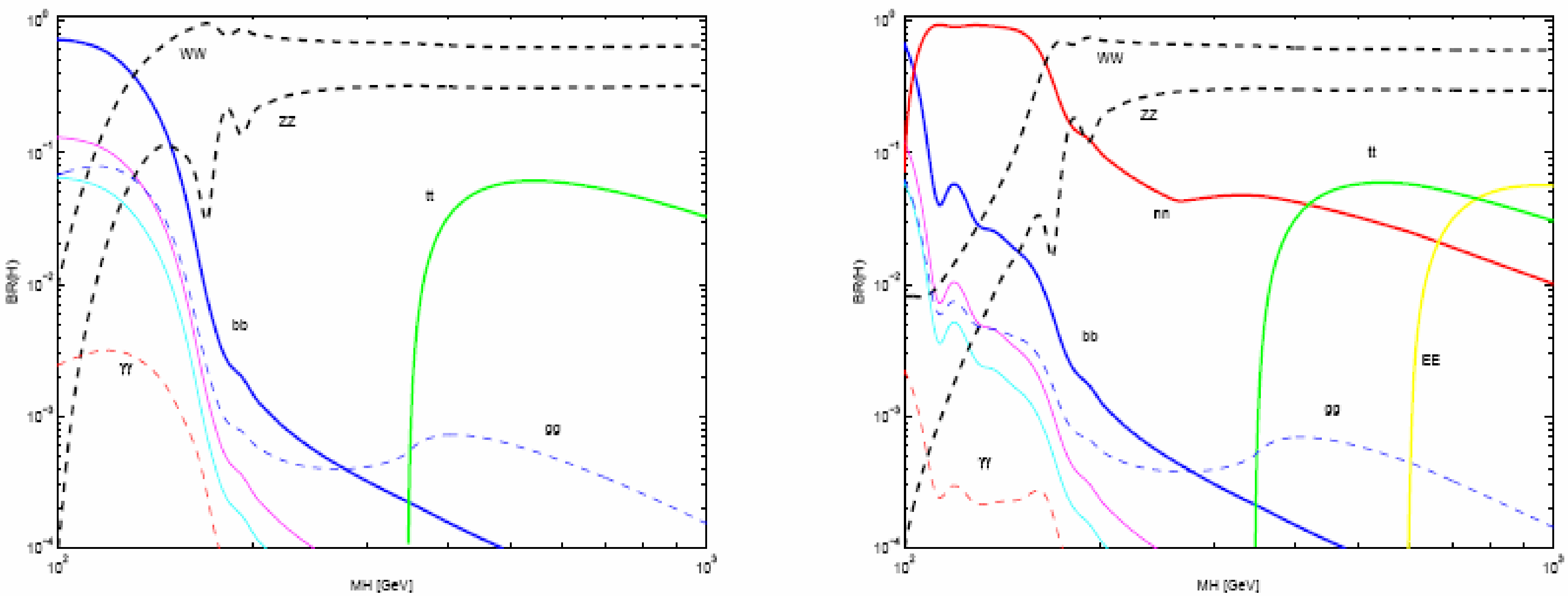


Figure 7: The branching ratios for the decay of the Higgs boson in Standard Model (left panel) and in MWTC (right panel)

Higgs production in the gluon fusion is unaffected compared to sequential 4th family

Conclusions

- Lepton sector of the minimal walking TC model passing the Precision Tests was considered.
- In the most optimistic cases early discoveries at the LHC might be expected.
- For ~100 GeV (composite) Higgs, decay to heavy neutrinos is the dominant channel with no enhancement of the Higgs production in the gluon fusion process.

Thank you!

Fermion mass in TC: ETC and FCNC

No Yukawa interactions in TC, they are four-Fermi interactions interpreted to come from higher energy theory. Extended TC (ETC) theories inevitably lead to the following relic low energy four-Fermi interactions…

$$\alpha_{ab}\frac{\bar{Q}T^aQ\bar{Q}T^bQ}{\Lambda_{ETC}^2} + \beta_{ab}\frac{\bar{Q}_LT^aQ_R\bar{\psi}_RT^b\psi_L}{\Lambda_{ETC}^2} + \gamma_{ab}\frac{\bar{\psi}_LT^a\psi_R\bar{\psi}_RT^b\psi_L}{\Lambda_{ETC}^2} + \cdots$$

PNG Masses

SM-Fermion Masses

FCNC Operators

Λ_{ETC} should be sufficiently larger than $\Lambda_{TC} \approx 250GeV$

to reduce FCNC.

Now, let's see some explicit TC theories, starting with familiar QCD-like one…

Walking

The value of the condensate should be evaluated at the ETC scale:

$$\langle \bar{Q}Q \rangle_{ETC} = \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d(\ln \mu) \gamma(\alpha(\mu)) \right) \langle \bar{Q}Q \rangle_{TC}$$

QCD:

$$\langle \bar{Q}Q \rangle_{ETC} \sim \ln \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma} \langle \bar{Q}Q \rangle_{TC}$$

$$\Rightarrow$$

$$m_q \approx \frac{g^2_{ETC}}{M^2_{ETC}} \Lambda^3_{TC} \,, \qquad \langle \bar{Q}Q \rangle_{TC} \sim \Lambda^3_{TC}$$

Walking:

$$\langle \bar{Q}Q \rangle_{ETC} \sim \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma(\alpha^*)} \langle \bar{Q}Q \rangle_{TC}$$