Dark Matter from Technicolor?

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The old idea of Technicolor

$$SU(N)_{TC} \times SU(3)_C \times SU_L(2) \times U_Y(1)$$

The Electroweak symmetry breaks dynamically via Technicolor Strong Interactions at ~ 250 GeV by the formation of the condensate

$$\left\langle Q^{c,f} \widetilde{Q}_{c,f'} \right\rangle \neq 0 \quad \Rightarrow \quad \text{breaks EW symmetry}$$

Motivation ⟶ Dynamical Symmetry breaking

1. QCD
2. Superconductivity

No fundamental boson has been found yet (apart gauge bosons)

Extended Technicolor

$$\bar{\alpha}_{ab}\frac{\bar{Q}\gamma_\mu \bar{T}^a Q \bar{Q}\gamma^\mu \bar{T}^b Q}{\Lambda^2_{ETC}} + \bar{\beta}_{ab}\frac{\bar{Q}\gamma_\mu \bar{T}^a \psi \bar{\psi}\gamma^\mu \bar{T}^b Q}{\Lambda^2_{ETC}} + \bar{\gamma}_{ab}\frac{\bar{\psi}\gamma_\mu \bar{T}^a \psi \bar{\psi}\gamma^\mu \bar{T}^b \psi}{\Lambda^2_{ETC}}$$

After Fierz transformation…

$$\alpha_{ab}\frac{\bar{Q}T^a Q \bar{Q}T^b Q}{\Lambda^2_{ETC}} + \beta_{ab}\frac{\bar{Q}_L T^a Q_R \bar{\psi}_R T^b \psi_L}{\Lambda^2_{ETC}} + \gamma_{ab}\frac{\bar{\psi}_L T^a \psi_R \bar{\psi}_R T^b \psi_L}{\Lambda^2_{ETC}} + \cdots$$

Contribution to the masses of the Goldstone bosons

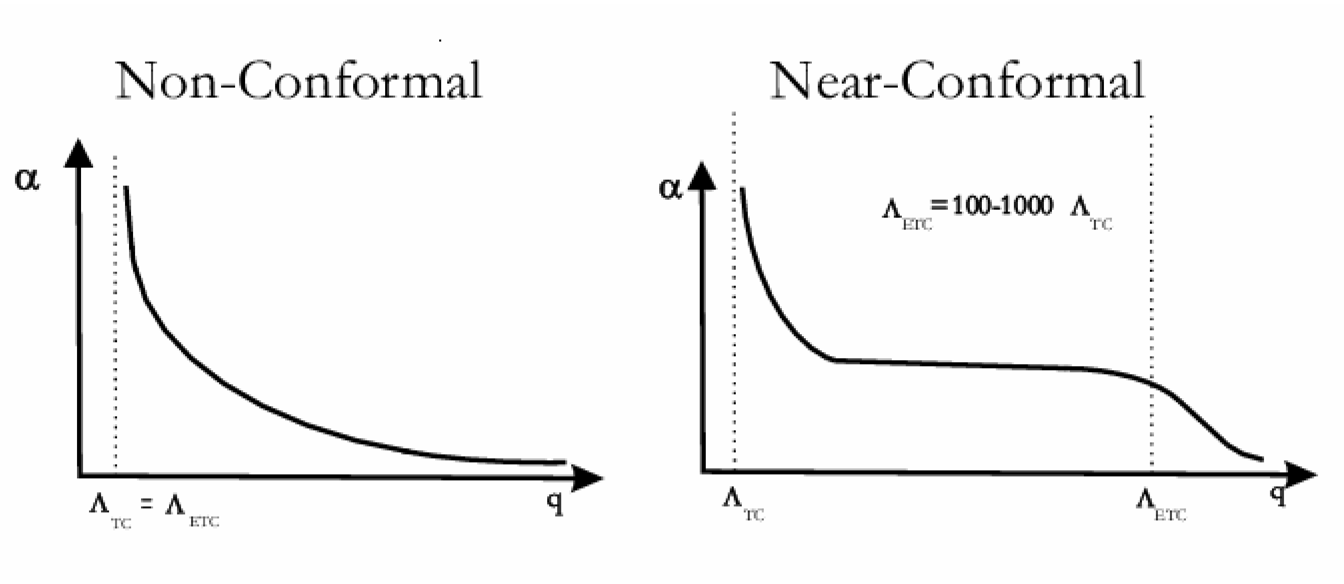
Contribution to the masses of the SM fermions

Contribution to the flavor changing neutral currents

The Problems of the Old Technicolor Theories

We need large α_{ab} β_{ab} and small γ_{ab}

Only way out is walking coupling!



Why Walking?

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

$$\exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} d\ln(\mu)\ \gamma_m(\alpha(\mu)) \right)$$

QCD-like → $\sim \quad (\ln(\Lambda_{ETC}/\Lambda_{TC}))^{\gamma_m}$

Near Conformal → $\sim \quad (\Lambda_{ETC}/\Lambda_{TC})^{\gamma_m(\alpha^\star)}$

$$m_{q,\ell} \sim \beta \frac{N_{TC}\Lambda_{TC}^3}{\Lambda_{ETC}^2} \longrightarrow m_{q,\ell} \sim \Lambda_{TC}^2/\Lambda_{ETC}$$

…but in order to be close at
the conformal window
for the fundamental representation

$$N_f^c \sim 4\,N$$

The Oblique S parameter is too large!!!

$$S = \frac{N_f\, N}{12\pi} - \bullet$$

$$\begin{aligned} S &= -16\pi \frac{\Pi_{3Y}(m_Z^2) - \Pi_{3Y}(0)}{m_Z^2}\,, \\ T &= 4\pi \frac{\Pi_{11}(0) - \Pi_{33}(0)}{s_W^2 c_W^2 m_Z^2}\,, \\ U &= 16\pi \frac{[\Pi_{11}(m_Z^2) - \Pi_{11}(0)] - [\Pi_{33}(m_Z^2) - \Pi_{33}(0)]}{m_Z^2} \end{aligned}$$

However…if techniquarks transform under higher representations
The situation is different!

F. Sannino and K. Tuominen, hep-ph/0405209 PRD (RC)
D.K.Hong, S.D. Hsu, F. Sannino, PLB597 (2004) 90 [hep-ph/0406200]
D. Dietrich, F. Sannino and K. Tuominen, hep-ph/0505059 PRD
D. Dietrich, F. Sannino and K. Tuominen, hep-ph/0510217
S. B. Gudnason, C. Kouvaris and F. Sannino, hep-ph/0603014

For two technicolors in  two flavors are enough to be close to conformal

S-parameter:

$$\mathbf{S} = \left(\frac{1}{6\pi} - \delta\right) \cdot \frac{N(N+1)}{2} \cdot \frac{N_f}{2} ,$$

Symmetry SU(4) → SO(4)

subgroup $SU(2)_L \times SU(2)_R \rightarrow SU(2)_{L=R}$

- Not Excluded by the EPM
- No big FCNC

$$Q = \begin{pmatrix} U_L \\ D_L \\ -i\sigma^2 U_R^* \\ -i\sigma^2 D_R^* \end{pmatrix}$$

transforms under the fundamental of SU(4)

Spontaneous Symmetry Breaking

$$\langle Q_i^\alpha Q_j^\beta \epsilon_{\alpha\beta} E^{ij} \rangle = -2 \langle \overline{U}_R U_L + \overline{D}_R D_L \rangle \qquad E = \begin{pmatrix} 0 & \mathbb{1} \\ \mathbb{1} & 0 \end{pmatrix}$$

9 Goldstone Bosons

$$\overline{D}_R U_L \ , \qquad \overline{U}_R D_L \ , \qquad \frac{1}{\sqrt{2}} (\overline{U}_R U_L - \overline{D}_R D_L)$$

Eaten by W’s and Z

$$U_L U_L \ , \qquad D_L D_L \ , \qquad U_L D_L$$

carrying technibaryon number

One extra lepton family to cancel gauge anomalies $\nu' \ \zeta$

$$U_L U_L \ , \quad D_L D_L \ , \quad U_L D_L$$

Electric charges

y+1, y-1, y

For y = 1 $D_L D_L$ is electrically neutral!

If $D_L D_L$ is also the lightest technibaryon

It carries technibaryon number
It can be stable !!!

Two ways to violate technibaryon number
• Extended Technicolor Interactions
• Sphaleron Processes

Calculation of Dark Matter Density

Ingredients

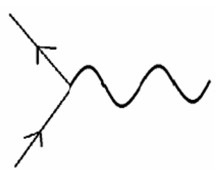
- Technibaryon-antitechnibaryon asymmetry
- Weak equilibration
- Baryon Number violating processes
- Electric Neutrality

Harvey, Turner (1990)

Extra Conditions for technicolor

TB-L and TB-L' is conserved

UD (DD)



W+

UU (UD)

TB violating processes

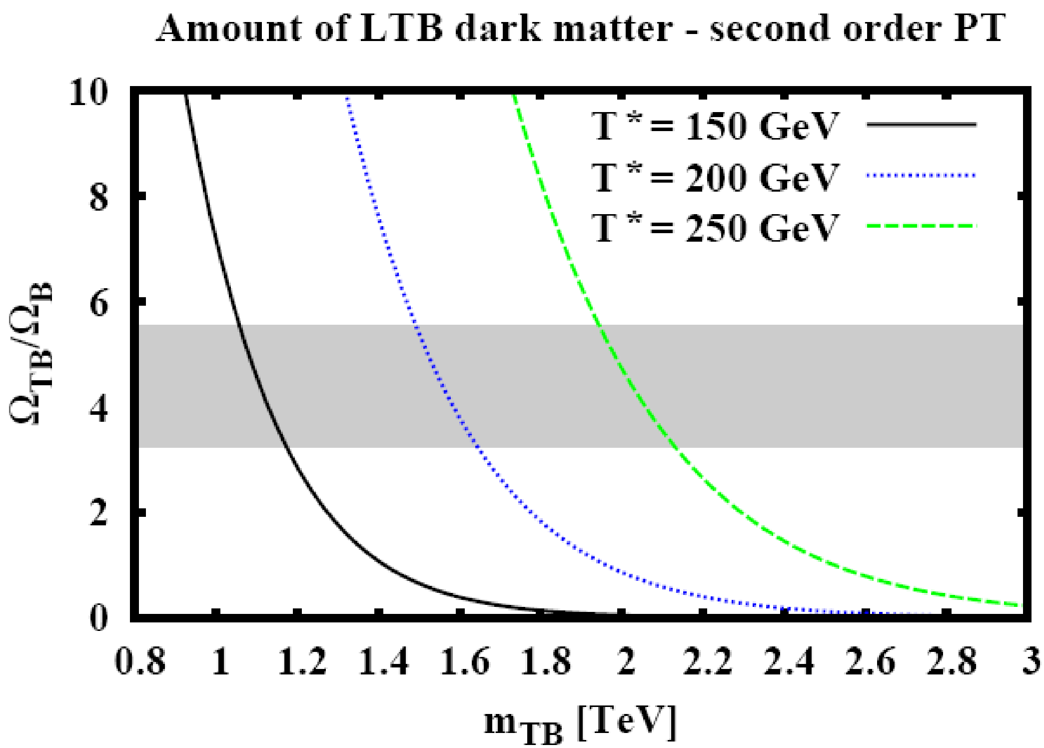
$$DD\nu_L \longrightarrow \phi$$

$$UU\zeta_L \longrightarrow \phi$$

$$\frac{\Omega_{TB}}{\Omega_B} = \frac{TB}{B}\frac{m_{TB}}{m_p}$$

2^{nd} Order Phase Transition

Net electric charge and the chemical potential for the Higgs are zero

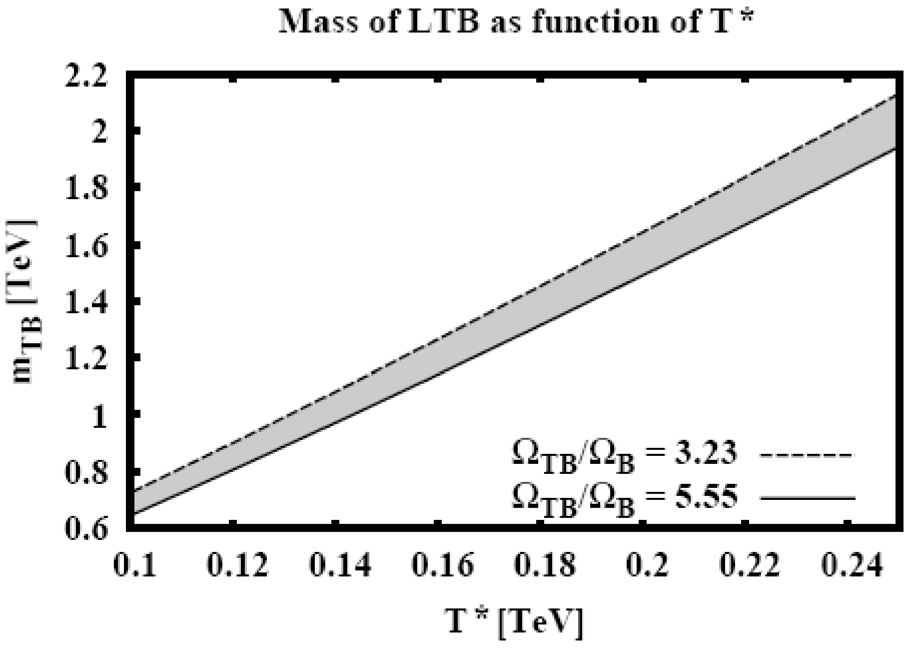


$$\frac{TB}{B} = \left(\frac{1}{10 + 2\sigma_t} + \frac{2}{9} \right) \sigma_{DD}$$

Freeze out temperature below the phase transition

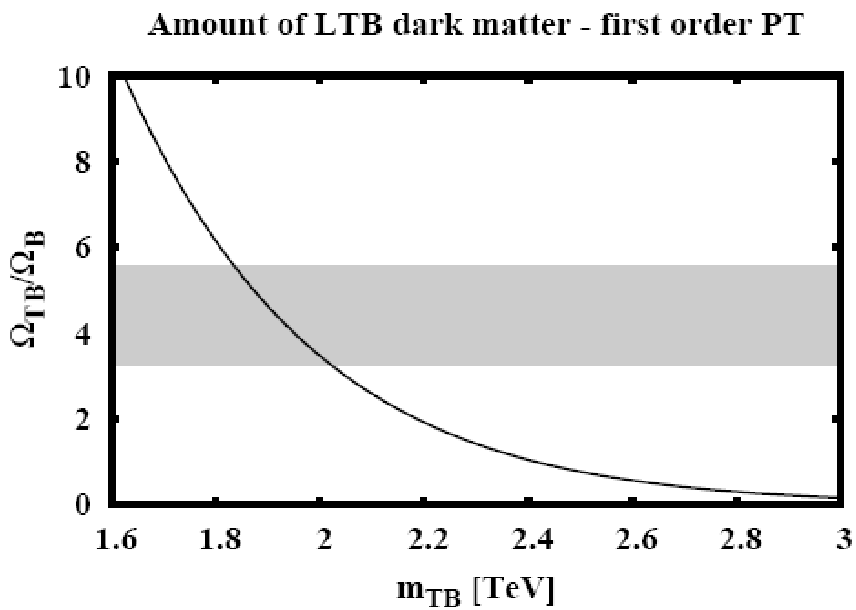
$$\sigma = \begin{cases} 6f\left(\frac{m_i}{T^*}\right) \\ 6g\left(\frac{m_i}{T^*}\right) \end{cases} \longrightarrow \begin{array}{ll} \frac{1}{4\pi^2}\int_0^\infty dx\, x^2 \cosh^{-2}\left(\frac{1}{2}\sqrt{x^2+z^2}\right) & \text{for fermions} \\ \frac{1}{4\pi^2}\int_0^\infty dx\, x^2 \sinh^{-2}\left(\frac{1}{2}\sqrt{x^2+z^2}\right) & \text{for bosons} \end{array}$$

The lowest mass of the technibaryon for being component of dark matter



1st Order Phase Transition

Net electric charge and the isospin charge are zero



Freeze out temperature above the phase transition

$$\frac{TB}{B} \simeq \frac{11\sigma_{DD}}{44 + 2\sigma_{DD}}$$

Detection in CDMS II

$$\text{counts} = \frac{dR}{dT}\Delta T \times \tau$$

$$\frac{dR}{dT} = \frac{R_0}{E_0 r} e^{-T/E_0 r}$$

$$R_0 = \frac{2}{\pi^{1/2}} \frac{N_0}{A} \frac{\rho_{dm}}{m} \sigma_0 v_0$$

$$\sigma_0 = \frac{G_F^2}{2\pi} \mu^2 Y^2 \bar{N}^2 F^2$$

$$\bar{N} = N - (1 - 4sin^2\theta_w)Z$$

The cross section is 4 times the spin independent cross section of heavy neutrino

With dark matter density 0.4GeV/cm^3,
we should have seen it in CDMS

If the technibaryon is a component of dark matter ~10 - 20% or less
is not ruled out for a mass larger than 2.5 - 3 TeV.

Conclusions

- The new technicolor theories are not ruled out by the electroweak measurements
- They have distinct signatures in LHC
- The technibaryon number protects the lightest technibaryon (if it is neutral) from decaying
- It can be seen in CDMS II when the exposure days X kilograms increase
- Currently if the technibaryon consists a component of the dark matter density, it is not ruled out for masses larger than 3 TeV.