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 \( \sim 250 \text{ GeV} \) by the formation of the condensate

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

Motivation \rightarrow Dynamical Symmetry breaking

1. QCD
2. Superconductivity

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

\[ \tilde{\alpha}_{ab} \frac{\bar{Q} \gamma_\mu \bar{T}^a \bar{Q} \gamma^\mu \bar{T}^b Q}{\Lambda_{ETC}^2} + \tilde{\beta}_{ab} \frac{\bar{Q} \gamma_\mu \bar{T}^a \bar{\psi} \bar{\gamma}^\mu \bar{T}^b \psi}{\Lambda_{ETC}^2} + \tilde{\gamma}_{ab} \frac{\bar{\psi} \gamma_\mu \bar{T}^a \bar{\psi} \bar{\gamma}^\mu \bar{T}^b \psi}{\Lambda_{ETC}^2} \]

After Fierz transformation…

\[ \alpha_{ab} \frac{\bar{Q} T^a \bar{Q} \bar{T}^b Q}{\Lambda_{ETC}^2} + \beta_{ab} \frac{\bar{Q}_L T^a Q_R \bar{\psi}_R T^b \psi_L}{\Lambda_{ETC}^2} + \gamma_{ab} \frac{\bar{\psi}_L T^a \psi_R \bar{\psi}_R T^b \psi_L}{\Lambda_{ETC}^2} + \ldots \]

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 $\alpha_{ab}$, $\beta_{ab}$, and small $\gamma_{ab}$.

Only way out is walking coupling!
Why Walking?

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

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

\[ \sim (\ln(\Lambda_{ETC}/\Lambda_{TC}))^{\gamma_m} \]

\[ \sim (\Lambda_{ETC}/\Lambda_{TC})^{\gamma_m(\alpha^*)} \]

\[ m_{q,\ell} \sim \beta \frac{N_{TC} \Lambda_{TC}^3}{\Lambda_{ETC}^2} \]

\[ m_{q,\ell} \sim \Lambda_{TC}^2/\Lambda_{ETC} \]
...but in order to be close at the conformal window for the fundamental representation

The Oblique S parameter is too large!!!

\[ S = \frac{N_f N}{12\pi} - \bullet \]

\[ N_f^c \sim 4N \]

\[ S = -16\pi \frac{\Pi_{3Y}(m_Z^2) - \Pi_{3Y}(0)}{m_Z^2}, \]

\[ T = 4\pi \frac{\Pi_{11}(0) - \Pi_{33}(0)}{s_W^2 c_W^2 m_Z^2}, \]

\[ U = 16\pi \frac{[\Pi_{11}(m_Z^2) - \Pi_{11}(0)] - [\Pi_{33}(m_Z^2) - \Pi_{33}(0)]}{m_Z^2} \]
However...if techniquarks transform under higher representations
The situation is different!

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

Symmetry
\[ SU(4) \quad \rightarrow \quad SO(4) \]

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

• Not Excluded by the EPM
• No big FCNC
transforms under the fundamental of SU(4)

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

Spontaneous Symmetry Breaking

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

9 Goldstone Bosons

\[
\overline{D}_R U_L , \quad \overline{U}_R D_L , \quad \frac{1}{\sqrt{2}}(\overline{U}_R U_L - \overline{D}_R D_L)
\]

Eaten by W’s and Z

\[
U_L U_L , \quad D_L D_L , \quad U_L D_L
\]

carrying technibaryon number

One extra lepton family to cancel gauge anomalies \( \nu' \ \zeta \)
Electric charges

\[ U_L U_L, \quad D_L D_L, \quad U_L D_L \]

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

\[
\frac{\Omega_{TB}}{\Omega_B} = \frac{TB}{B} \frac{m_{TB}}{m_p}
\]
2\textsuperscript{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.

\[ \sigma = \begin{cases} 
6 f \left( \frac{m_i}{T^*} \right) & \text{for fermions} \\
6 g \left( \frac{m_i}{T^*} \right) & \text{for bosons} 
\end{cases} \]

\[
= \frac{1}{4\pi^2} \int_0^{\infty} dx \ x^2 \cosh^{-2} \left( \frac{1}{2} \sqrt{x^2 + z^2} \right)
\]

\[
= \frac{1}{4\pi^2} \int_0^{\infty} dx \ x^2 \sinh^{-2} \left( \frac{1}{2} \sqrt{x^2 + z^2} \right)
\]
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

\[
\frac{T_B}{B} \approx \frac{11\sigma_{DD}}{44 + 2\sigma_{DD}}
\]
Detection in CDMS II

\[
\text{counts} = \frac{dR}{dT} \Delta T \times \tau \\
\frac{dR}{dT} = \frac{R_0}{E_0} e^{-T/E_0r} \\
R_0 = \frac{2}{\pi^{1/2}} \frac{N_0 \rho_{dm}}{A m} \sigma_0 v_0
\]

\[
\sigma_0 = \frac{G_F^2}{2\pi} \mu^2 Y^2 \bar{N}^2 F^2 \\
\bar{N} = N - (1 - 4\sin^2\theta_w)Z
\]

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 \(\sim10\text{-}20\%\) 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.