Techni-Dilaton as a dark matter

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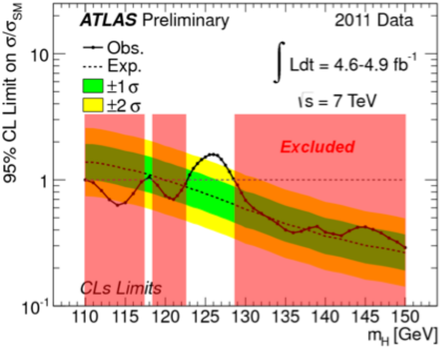
Based on arXiv:1101.5326 and arXiv:1201.4988
with K. Y. Choi and S. Matsuzaki

Introduction

- Higgs holds a key to BSM, since it is sensitive to short distance phyics.
- Current mass bound (at Moriond12) is

$$122.5 \text{ GeV} \lesssim m_H \lesssim 127.5 \text{ GeV}$$



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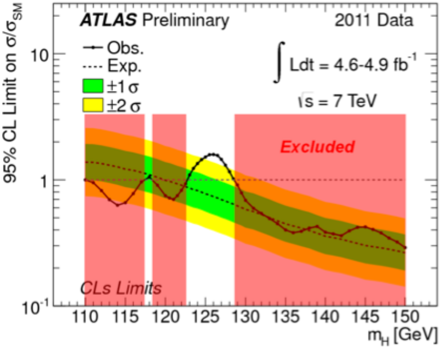

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- Technicolor theory (TC) introduces a new strong dynamics at TeV scale to break EW symmetry dynamically. (Weinberg '76, Susskind '79)
- In TC Higgs is a composite particle below TeV.
- In WTC there is a very light scalar, called techni-dilaton, due to scale invariance. (Bando, Matumoto, Yamawaki '86)
- In this talk I assume there is a very light TD and show that it can be a dark matter candidate.

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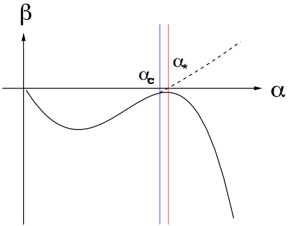
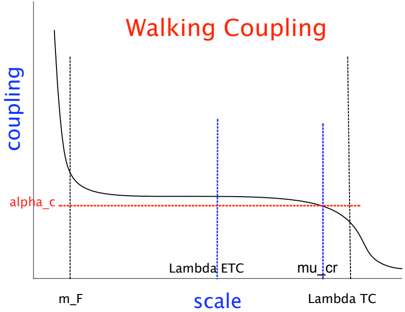
Introduction

- Modern TC is called "Walking Technicolor" (Holdom '81, Yamawaki et al '86, Appelquist et al '86)





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- As a candidate for physics BSM, it will be nice if TC explains dark matter as well.
- Indeed, I will show that WTC can have a very light dilaton, techni-dilaton as a Nambu-Goldstone boson, associated with spontaneously broken (approximate) scale symmetry, which can be a good candidate for DM. (Cf. Techni-baryons)

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Review of WTC

- Introduce new strong dynamics in addition to SM

$$SU(3)_c \times SU(2)_L \times U(1)_Y \times G_{\mathrm{TC}}$$

- Introduce new particles, techniquarks, which transform as

$$Q_L^{\mathrm{TC}} \sim (*, 2, y_L, r),\ U_R^{\mathrm{TC}} \sim (*, 1, y_R, r),\ D_R^{\mathrm{TC}} \sim (*, 1, y_R', r)$$

- such that theory is anomaly-free, (asymptotically free) and has a (quasi) IR fixed point.
- Lattice simulation shows the conformal window exists when $8 < N_F < 12$ for $N_{TC} = 3$ for $SU(3)$ (AFN '09)

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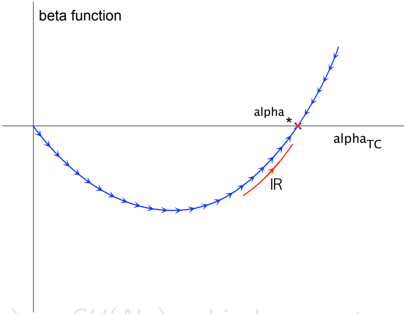

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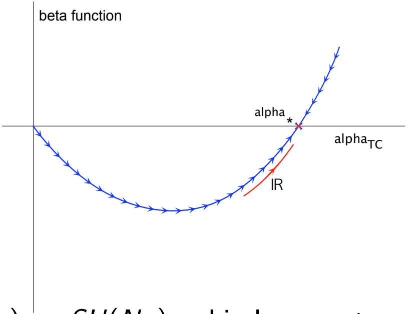

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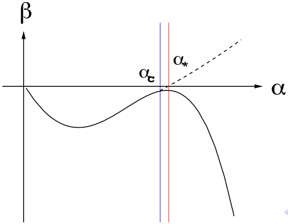
- We assume that chiral symmetry is spontaneously broken by TC interactions: the critical coupling for χSB, $\alpha_c < \alpha_*$.

$$\alpha_c \approx \frac{\pi}{3C_2(r)}$$

- We assume that $\alpha_c \approx \alpha_*$ to have walking behavior.
- Once techni-fermions get dynamical mass, they decouple for $E < m_F$ and coupling runs quickly and confines technicolor.



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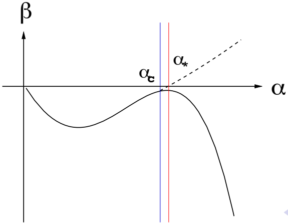

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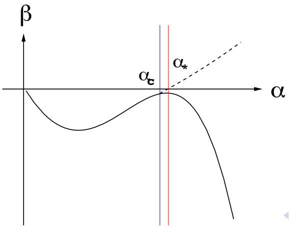

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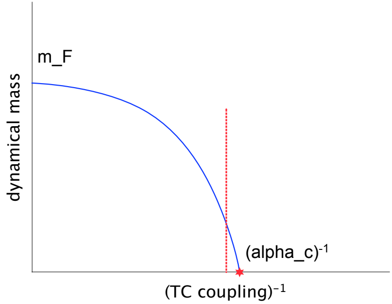
- Large mass hierarchy, Miransky (or BKT) scaling near the phase transition



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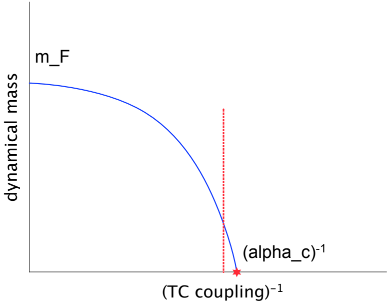

$$\gamma_{\bar{Q}Q} = 1 + \sqrt{\frac{\alpha}{\alpha_c} - 1} \approx 1$$

$$m_F = \Lambda_{\rm UV}\, e^{-\frac{\pi}{\sqrt{\frac{\alpha}{\alpha_c}-1}}}$$

Very light techni-dilaton

- Physics of Miransky scaling: In the walking region we have approximate scale invariance and ladder approximation is good. The BS equation for the bound state then becomes

$$\left[P^2 + \partial^2 + \frac{\alpha/\alpha_c}{r^2}\right]\chi_P(x) = 0.$$

- Since the potential is singular, we need to regularize it:

$$V(r) = \begin{cases} -\frac{\alpha/\alpha_c}{r^2} & \text{if } r \geq a, \\ -\frac{\alpha/\alpha_c}{a^2} & \text{if } r \leq a. \end{cases}$$

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- For bound states to be the cutoff-independent, we require the coupling to depend on the cutoff. (DKH+Rajeev '90)

$$\alpha(a) = \alpha_c + \alpha_c \frac{\pi^2}{[\ln{(a\mu)}]^2} \,.$$

- The non-perturbative beta function is then

$$\beta^{\rm np}(\alpha) = a\frac{\partial}{\partial a}\alpha(a) = -\frac{1}{\pi}\left(\alpha - \alpha_c\right)^{3/2}$$

- The gap equation has a nontrivial solution with this beta function for $\alpha \geq \alpha_c$. (Bardeen et al '86):

$$m_F \simeq \Lambda(\alpha)\exp\left[\int_{\alpha_0}^{\alpha}\frac{d\alpha}{\beta^{\rm np}(\alpha)}\right] = \Lambda_{UV}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} \,.$$

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- Non-perturbative renormalization and new scale:
- In the walking region $\gamma_{\bar{Q}Q} \simeq 1$ new marginal operator emerges and therefore generates a new scale, $m_F \ll \Lambda_{UV}$ (DKH+Rajeev '90):

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- Techni-dilaton arises as pseudo Nambu-Goldstone boson, associated with spontaneously broken (approximate) scale symmetry.

$$\langle 0 | D^\mu | \sigma \rangle = i F_{TD} p^\mu e^{-ip\cdot x} \tag{1}$$

- By PCDC

$$\langle \partial_\mu D^\mu \rangle = F_{TD} m_{TD}^2 \langle \sigma \rangle = F_{TD}^2 m_{TD}^2 \, . \tag{2}$$

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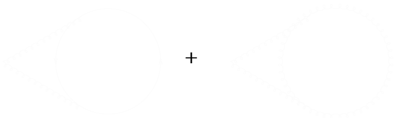

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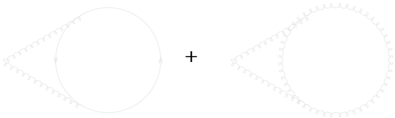

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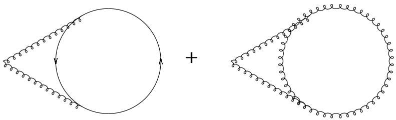

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- We therefore find

$$F_{TD}^2 m_{TD}^2 \approx \frac{16 N_{TC} N_F}{\pi^4} m_F^4 \,.$$

- SD analysis by Hashimoto and Yamawaki and holographic analysis by Haba et al show that as $\alpha \to \alpha_c$

$$\frac{m_F}{F_{TD}} \to 0 \,.$$

- Since $\left(\frac{m_{TD}}{m_F}\right)^2 \sim \left(\frac{m_F}{F_{TD}}\right)^2$, TD is very light and decoupled:

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- Composite Higgs and Light TD ($v = 247\ \mathrm{GeV}/\sqrt{N_F}$):

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- Higgs mass is finite near the conformal phase transition (cf. D. Kutasov)

$$\frac{m_H}{m_V} \approx 0.2 \quad (m_V \sim m_F)$$

- Higgs mass is a fraction of techni fermion mass but much larger than TD mass:

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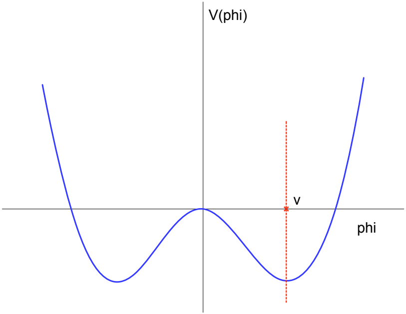

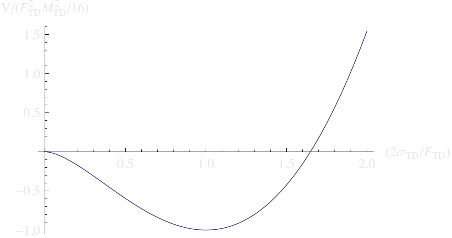

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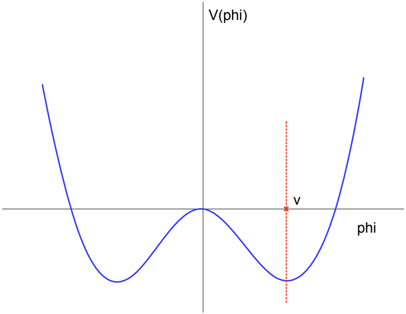
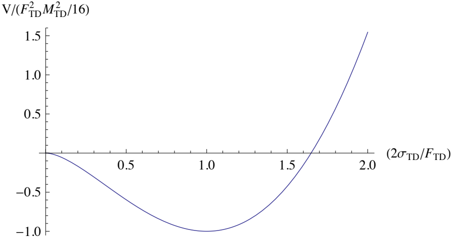
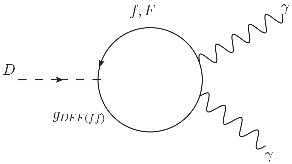




Dark matter TD

- Decay of very light TD



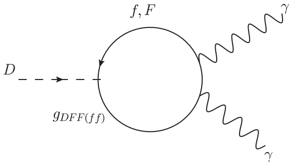
$$\Gamma(\sigma \to \gamma\gamma) \simeq \frac{\alpha_{em}^2}{36\pi^3} \frac{m_{TD}^3}{F_{TD}^2} |\mathcal{C}|^2$$

$$\tau_{\rm TD} \simeq 10^{17}\,{\rm sec}\,(N_{\rm TC} N_{\rm F}) \left(\frac{16}{\mathcal{C}}\right)^2 \left(\frac{10\,{\rm keV}}{m_{\rm TD}}\right)^5 \left(\frac{m_F}{10^3\,{\rm GeV}}\right)^4$$

- To be a dark matter candidate, TD has to be long-lived and $m_{TD} < 10$ keV.

Dark matter TD

- Decay of very light TD



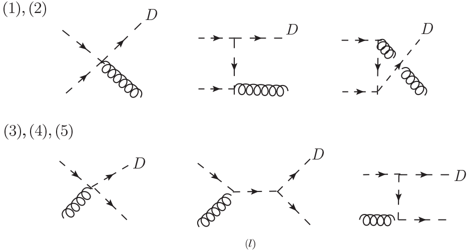
$$\Gamma(\sigma \to \gamma\gamma) \simeq \frac{\alpha_{em}^2}{36\pi^3}\frac{m_{TD}^3}{F_{TD}^2}|\mathcal{C}|^2$$

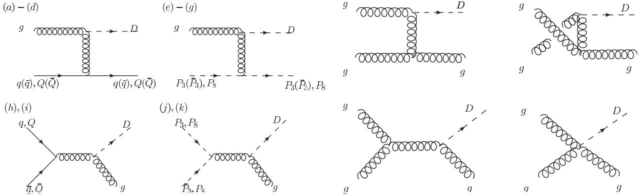
$$\tau_{\rm TD} \simeq 10^{17}\,{\rm sec}\,(N_{\rm TC}N_{\rm F})\left(\frac{16}{\mathcal{C}}\right)^2\left(\frac{10\,{\rm keV}}{m_{\rm TD}}\right)^5\left(\frac{m_F}{10^3\,{\rm GeV}}\right)^4$$

- To be a dark matter candidate, TD has to be long-lived and $m_{TD} < 10$ keV.

Dark matter TD

- Thermal production of TD





Dark matter TD

- The Boltzmann equation for the TD number density $n_{\rm TD}$

$$\frac{dn_{\rm TD}}{dt} + 3Hn_{\rm TD} = \sum_{i,j} \langle \sigma(i+j \to D + \cdots)v \rangle n_i n_j$$

where H is the Hubble parameter $H(T) = (\frac{\pi^2}{30} g_* T^4 / 3M_P^2)^{1/2}$.

$$\Omega_{\rm TD}^{\rm tp} h^2 \simeq \left(\frac{\mu_{\rm cr}}{10^8 {\rm GeV}}\right)\left(\frac{M_{\rm TD}}{\rm keV}\right)\left(\frac{200}{g_*(\mu_{\rm cr})}\right)^{3/2}\left(\frac{10^{11}{\rm GeV}}{F_{\rm TD}}\right)^2 \times \begin{cases} 4.4 \times 10^{-1} & {\rm for} \quad N_{\rm TC} = 2 \\ 2.6 \times 10^{-2} & {\rm for} \quad N_{\rm TC} = 3 \end{cases},$$

Dark matter TD

Contour plot of $\Omega^{tp}_{TD} h^2$ for $\mu_{cr} = 10^{-3} F_{TD}$.

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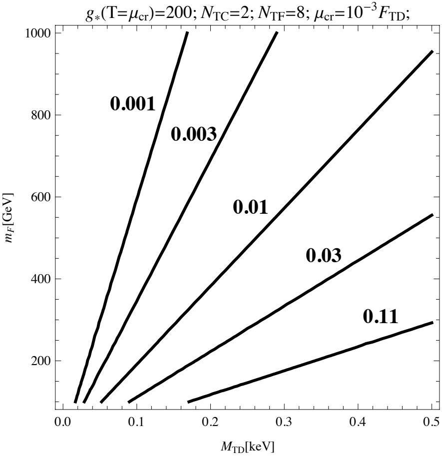
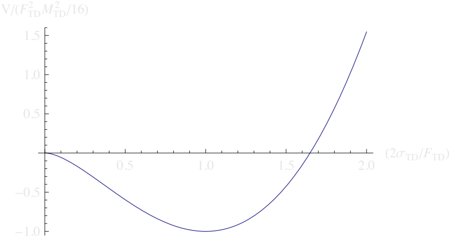


Dark matter TD

- Non-thermal production of TD due to mis-alignment. TD potential is determined by scale anomaly (Schechter '80):

$$\frac{V(\sigma_D)}{F_{\rm TD}^2 m_{\rm TD}^2} \simeq \left(\frac{\sigma_D}{2F_{\rm TD}}\right)^2 \left[\log\left(\frac{2\sigma_D}{F_{\rm TD}}\right)^2 - 1\right]$$



$$\Omega_{\rm TD}^{\rm ntp} h^2 \simeq 11 \times \left(\frac{\theta_{\rm os}}{0.1}\right)^2 \left(\frac{200}{g_*(T_{\rm os})}\right) \left(\frac{m_F}{10^3 {\rm GeV}}\right)^4 \left(\frac{10^5 {\rm GeV}}{T_{\rm os}}\right)^3$$

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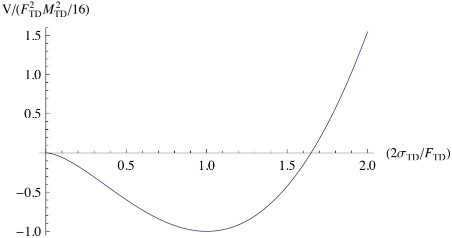

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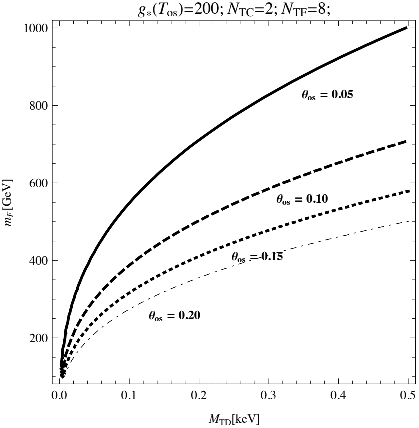

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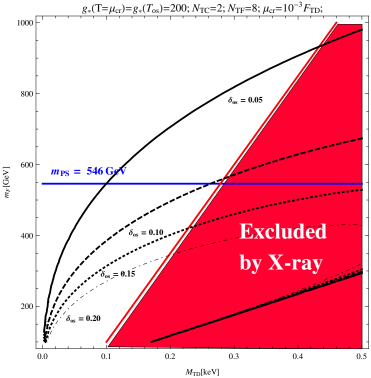

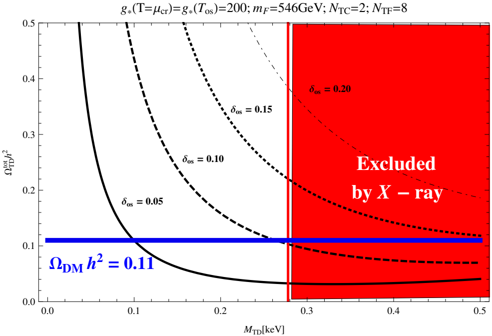

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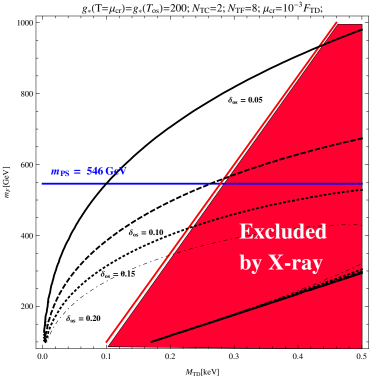

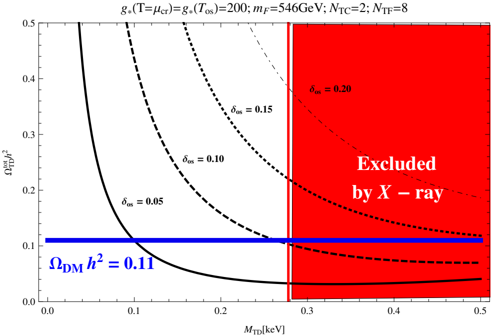

Conclusion

- WTC predicts very light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- If the critical coupling for chiral symmetry breaking is very close to the (quasi) Banks-Zaks IR fixed point of WTC, large hierarchy is dynamically generated:

$$m_F \approx \Lambda_{UV}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}}\,.$$

- By PCDC we have $m_{TD} \ll m_F \ll F_{TD}$.
- TD can be a good candidate for dark matter.
- Cosmological and astrophysical constraints require

$$0.01\ \mathrm{eV} \lesssim m_{TD} \lesssim 500\ \mathrm{eV}$$

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