Light Dilaton and Holographic Walking Technicolor

Deog-Ki Hong

Pusan National University, Busan, S. Korea

Sep. 13, 2012

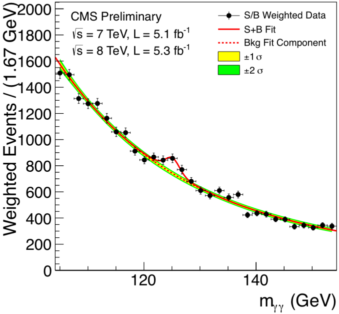
The 2nd KIAS Phenomenology Workshop

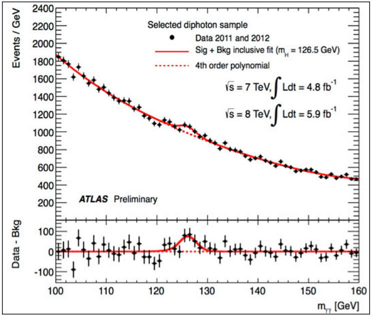
Based on

(1) DKH+Yee, PRD '06
(2) arXiv:1101.5326,1201.4988 (with Choi +Matsuzaki)
(3) Work under progress

Introduction and Review

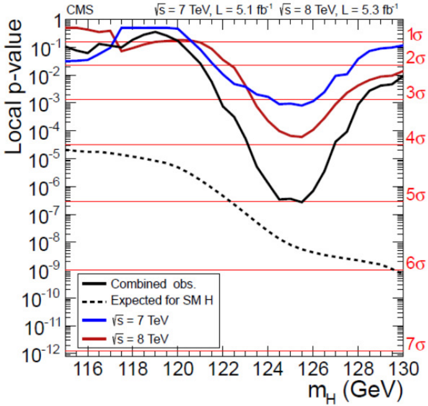
- A new (scalar) boson of 125 GeV has been discovered at LHC:





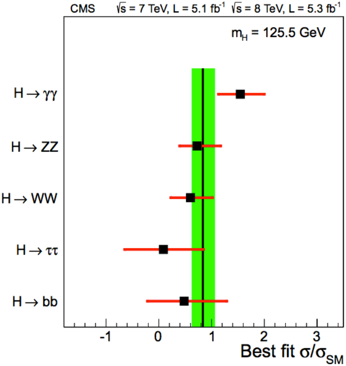
Introduction and Review

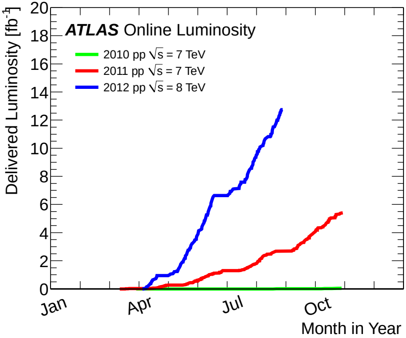
- Combined results p-value for the new (scalar) boson:



Introduction and Review

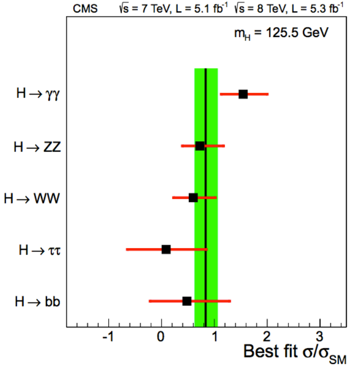
- Currently it is much like the SM Higgs.
- However, there are some anomalies, though we need more data:
- Excess in $H \to \gamma\gamma$ and suppression in $H \to b\,\bar{b}\,,\tau^+\tau^-$.

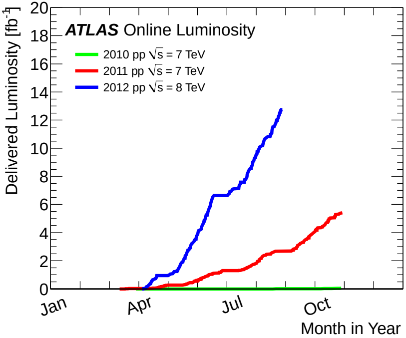




Introduction and Review

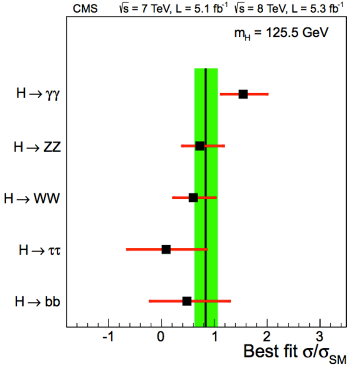
- Currently it is much like the SM Higgs.
- However, there are some anomalies, though we need more data:
- Excess in $H \to \gamma\gamma$ and suppression in $H \to b\,\bar{b}\,, \tau^+\tau^-$.

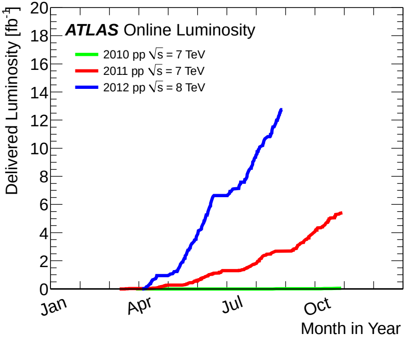




Introduction and Review

- Currently it is much like the SM Higgs.
- However, there are some anomalies, though we need more data:
- Excess in $H \to \gamma\gamma$ and suppression in $H \to b\,\bar{b}\,, \tau^+\tau^-$.





Introduction and Review

- The anomalies are naturally explained in walking technicolor (WTC).
- In WTC all new particles are heavy ($\sim 1\ \mathrm{TeV}$) except techni-dilaton (TD), Goldstone boson associated with spontaneous breaking of scale symmetry:

$$m_{TD} \sim \frac{m_{TQ}^2}{F_{TD}} \ll m_{TQ}, \quad \text{if } F_{TD} \gg v_{\rm ew} \text{ (or } m_{TQ}\text{)}.$$

- If $m_{\rm TD}$ turns out to be 125 GeV, then $v_{\rm ew}/F_{\rm TD} \ll 1$ and the dilaton coupling to fermions are suppressed, while coupling to two photons are enhanced.

Introduction and Review

- The anomalies are naturally explained in walking technicolor (WTC).
- In WTC all new particles are heavy ($\sim 1\ \mathrm{TeV}$) except techni-dilaton (TD), Goldstone boson associated with spontaneous breaking of scale symmetry:

$$m_{TD} \sim \frac{m_{TQ}^2}{F_{TD}} \ll m_{TQ}, \quad \text{if } F_{TD} \gg v_{\rm ew} \ (\text{or } m_{TQ}\,).$$

- If $m_{\rm TD}$ turns out to be 125 GeV, then $v_{\rm ew}/F_{\rm TD} \ll 1$ and the dilaton coupling to fermions are suppressed, while coupling to two photons are enhanced.

Introduction and Review

- The anomalies are naturally explained in walking technicolor (WTC).
- In WTC all new particles are heavy ($\sim 1\ \mathrm{TeV}$) except techni-dilaton (TD), Goldstone boson associated with spontaneous breaking of scale symmetry:

$$m_{TD} \sim \frac{m_{TQ}^2}{F_{TD}} \ll m_{TQ}, \quad \text{if } F_{TD} \gg v_{\rm ew} \ (\text{or } m_{TQ}).$$

- If $m_{\rm TD}$ turns out to be 125 GeV, then $v_{\rm ew}/F_{\rm TD} \ll 1$ and the dilaton coupling to fermions are suppressed, while coupling to two photons are enhanced.

Introduction and Review

- Dilaton coupling to fermions ($m_f = y_f v_{\rm ew}$), suppressed by $v_{\rm ew}/F_{\rm TD}$:

$$\mathcal{L}_{Dff} = e^{D/F_{TD}} m_f \bar{f} f = \frac{m_f}{F_{TD}} D\bar{f} f + \cdots$$

- Dilaton coupling to two photons and gluons, enhanced:

$$\mathcal{L}_{D\gamma\gamma, Dgg} = \frac{\beta(e)}{2e^3}\frac{D}{F_{TD}} F_{\mu\nu}^2 + \frac{\beta(g_s)}{2g_s^3}\frac{D}{F_{TD}} G_{\mu\nu}^{a\ 2}$$

Introduction and Review

- Dilaton coupling to fermions ($m_f = y_f v_{\rm ew}$), suppressed by $v_{\rm ew}/F_{\rm TD}$:

$$\mathcal{L}_{Dff} = e^{D/F_{TD}} m_f \bar{f} f = \frac{m_f}{F_{TD}} D \bar{f} f + \cdots$$

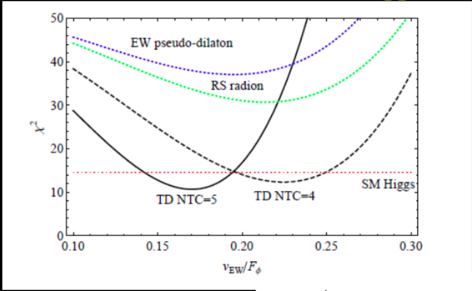
- Dilaton coupling to two photons and gluons, enhanced:

$$\mathcal{L}_{D\gamma\gamma,Dgg} = \frac{\beta(e)}{2e^3} \frac{D}{F_{TD}} F_{\mu\nu}^2 + \frac{\beta(g_s)}{2g_s^3} \frac{D}{F_{TD}} {G_{\mu\nu}^a}^2$$

Introduction and Review

- χ-squared fit, excluding Tevatron data, by Matsuzaki and Yamawaki, arXiv:1206.6703:

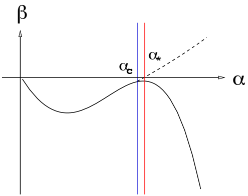
* chi^2 fit based on the current data on Higgs search categories

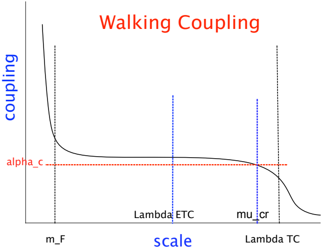


N_{TC}	$(v_{EW}/F_\phi)_{best}$	χ^2_{min}/d.o.f
4	0.22	$12/13 \simeq 0.9$
5	0.17	$10/13 \simeq 0.7$

Introduction and Review

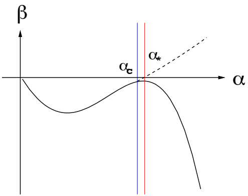
- Modern TC is called “Walking Technicolor (WTC)” (Holdom ’81, Yamawaki et al ’86, Appelquist et al ’86)
- WTC is a strongly coupled gauge theory with two intrinsic scales, at which walking starts and ends:

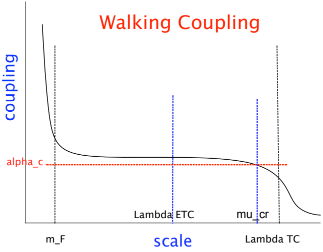




Introduction and Review

- Modern TC is called "Walking Technicolor (WTC)" (Holdom '81, Yamawaki et al '86, Appelquist et al '86)
- WTC is a strongly coupled gauge theory with two intrinsic scales, at which walking starts and ends:



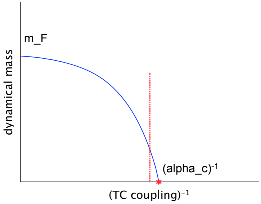


Introduction and Review

- Due to strong and walking dynamics the fermion bilinear has a large, constant anomalous dimension, $\gamma_m \simeq 1$:

$$\left\langle \bar{Q}Q \right\rangle\Big|_{\Lambda} = e^{-\int_{\Lambda}^{\mu_{\rm cr}} \frac{d\mu}{\mu}\gamma_m(\mu)} \left\langle \bar{Q}Q \right\rangle\Big|_{\mu_{\rm cr}} = \frac{\Lambda}{\mu_{\rm cr}} \left\langle \bar{Q}Q \right\rangle\Big|_{\mu_{\rm cr}}$$

- The chiral phase transition of WTC is known as a quantum conformal phase transition. (Miransky, Yamawaki '96)

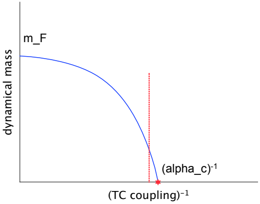


Introduction and Review

- Due to strong and walking dynamics the fermion bilinear has a large, constant anomalous dimension, $\gamma_m \simeq 1$:

$$\langle \bar{Q}Q \rangle\Big|_{\Lambda} = e^{-\int_{\Lambda}^{\mu_{\rm cr}} \frac{d\mu}{\mu}\gamma_m(\mu)} \langle \bar{Q}Q \rangle\Big|_{\mu_{\rm cr}} = \frac{\Lambda}{\mu_{\rm cr}} \langle \bar{Q}Q \rangle\Big|_{\mu_{\rm cr}}$$

- The chiral phase transition of WTC is known as a quantum conformal phase transition. (Miransky, Yamawaki '96)



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

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

Introduction and Review

- In the walking region $\gamma_m \simeq 1$ new marginal operator emerges and therefore generates a new scale, $m_F \ll \Lambda_{\rm TC}$ (DKH+Rajeev '90):

$$\frac{g^2}{\Lambda_{TC}^2}\left(\bar{Q}Q\right)^2 .$$

- Conformality lost. (Kaplan-Lee-Son-Stephanov, '09)

Introduction and Review

- In the walking region $\gamma_m \simeq 1$ new marginal operator emerges and therefore generates a new scale, $m_F \ll \Lambda_{\rm TC}$ (DKH+Rajeev '90):

$$\frac{g^2}{\Lambda_{TC}^2}\left(\bar{Q}Q\right)^2 .$$

- Conformality lost. (Kaplan-Lee-Son-Stephanov, '09)

Light Dilaton and PCDC

- WTC has approximate scale invariance, $\beta(\alpha_{\rm TC}) \approx 0$, for $m_F < \mu < \Lambda_{\rm TC}$.
- Therefore there exists a dilatation current, $D^\mu = x_\nu \theta^{\mu\nu}$, approximately conserved:

$$\langle \partial_\mu D^\mu \rangle = \langle \theta^\mu_\mu \rangle = \frac{\pi\beta(\alpha_{\rm TC})}{\alpha_{\rm TC}^2} \left\langle \left(F^a_{\mu\nu}\right)^2 \right\rangle + m \left\langle \bar{Q} Q \right\rangle + \langle {\rm SM} \rangle \approx 0.$$

Light Dilaton and PCDC

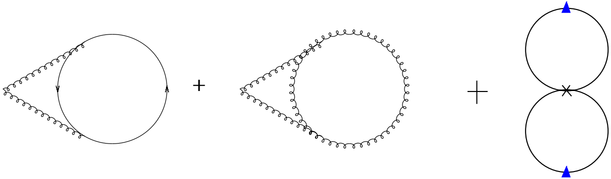
- WTC has approximate scale invariance, $\beta(\alpha_{\rm TC}) \approx 0$, for $m_F < \mu < \Lambda_{\rm TC}$.
- Therefore there exists a dilatation current, $D^\mu = x_\nu \theta^{\mu\nu}$, approximately conserved:

$$\langle \partial_\mu D^\mu \rangle = \langle \theta^\mu_\mu \rangle = \frac{\pi \beta(\alpha_{\rm TC})}{\alpha_{\rm TC}^2} \left\langle \left(F^a_{\mu\nu} \right)^2 \right\rangle + m \left\langle \bar{Q} Q \right\rangle + \langle {\rm SM} \rangle \approx 0.$$

Light Dilaton and PCDC

- The order parameter for CSB, $\langle \bar{Q}Q \rangle$ or m_F, is also an order parameter for the scale symmetry.
- Scale symmetry is spontaneously broken, when $\langle \bar{Q}Q \rangle \neq 0$:

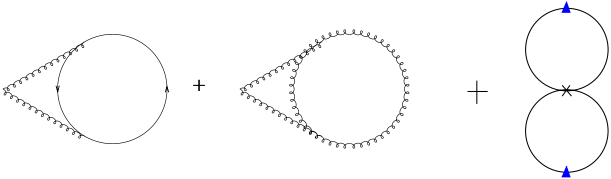
$$\langle \theta^\mu_\mu \rangle = \frac{\pi\beta(\alpha_{\rm TC})}{\alpha_{\rm TC}^2} \left\langle \left(F^a_{\mu\nu}\right)^2 \right\rangle + \frac{g^2}{\Lambda_{\rm TC}^2} \left\langle \left(\bar{Q}Q\right)^2 \right\rangle \sim m_F^4 .$$



Light Dilaton and PCDC

- The order parameter for CSB, $\langle \bar{Q}Q \rangle$ or m_F, is also an order parameter for the scale symmetry.
- Scale symmetry is spontaneously broken, when $\langle \bar{Q}Q \rangle \neq 0$:

$$\langle \theta^\mu_\mu \rangle = \frac{\pi \beta(\alpha_{\rm TC})}{\alpha_{\rm TC}^2} \left\langle \left(F^a_{\mu\nu} \right)^2 \right\rangle + \frac{g^2}{\Lambda_{\rm TC}^2} \left\langle \left(\bar{Q}Q \right)^2 \right\rangle \sim m_F^4 .$$



Light Dilaton and PCDC

- By Goldstone theorem light dilaton arises as pseudo Nambu-Goldstone boson:

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

- By PCDC, if dilaton pole dominates,

$$\partial_{\mu} D^{\mu} = F_{TD} m_{TD}^2 \sigma\,, \quad \langle \partial_{\mu} D^{\mu}\rangle \simeq F_{TD}^2 m_{TD}^2 \simeq m_F^4\,.$$

- Dilaton is light if WTC is close to the conformality, provided that $F_{\rm TD} \sim \mu_{\rm cr} \lesssim \Lambda_{\rm TC}$, which is much bigger than $m_F \sim 1\ {\rm TeV}$:

$$m_{\rm TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F (\approx 1\ {\rm TeV}) \ll F_{TD}$$

Light Dilaton and PCDC

- By Goldstone theorem light dilaton arises as pseudo Nambu-Goldstone boson:

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

- By PCDC, if dilaton pole dominates,

$$\partial_\mu D^\mu = F_{TD} m_{TD}^2 \sigma \,, \quad \langle \partial_\mu D^\mu \rangle \simeq F_{TD}^2 m_{TD}^2 \simeq m_F^4 \,.$$

- Dilaton is light if WTC is close to the conformality, provided that $F_{\rm TD} \sim \mu_{\rm cr} \lesssim \Lambda_{\rm TC}$, which is much bigger than $m_F \sim 1 \ {\rm TeV}$:

$$m_{\rm TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F (\approx 1 \ {\rm TeV}) \ll F_{TD}$$

Light Dilaton and PCDC

- By Goldstone theorem light dilaton arises as pseudo Nambu-Goldstone boson:

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

- By PCDC, if dilaton pole dominates,

$$\partial_{\mu} D^{\mu} = F_{TD} m_{TD}^2 \, \sigma \,, \quad \langle \partial_{\mu} D^{\mu} \rangle \simeq F_{TD}^2 m_{TD}^2 \simeq m_F^4 \,.$$

- Dilaton is light if WTC is close to the conformality, provided that $F_{\rm TD} \sim \mu_{\rm cr} \lesssim \Lambda_{\rm TC}$, which is much bigger than $m_F \sim 1~{\rm TeV}$:

$$m_{\rm TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F (\approx 1~{\rm TeV}) \ll F_{TD}$$

Light Dilaton and PCDC

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

$$\lim_{y \to x} Q_{TC}(x)\bar{Q}_{TC}(y) = (\mu\,|x-y|)^{\gamma_{\bar{Q}Q}}\, Q_{TC}\bar{Q}_{TC}(x)$$

$$Q_{TC}\bar{Q}_{TC}(x) \sim e^{i\pi_{TC}/F_{TC}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix} .$$

- Higgs mass is finite near the conformality (Kutasov-Lin-Parnachev '11)

$$\frac{m_H}{m_V} \approx 0.2$$

- But, dilaton mass can be very small near the conformal window. (Choi+DKH+Matsuzaki '11)

Light Dilaton and PCDC

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

$$\lim_{y \to x} Q_{TC}(x)\bar{Q}_{TC}(y) = (\mu\,|x-y|)^{\gamma_{\bar{Q}Q}}\, Q_{TC}\bar{Q}_{TC}(x)$$

$$Q_{TC}\bar{Q}_{TC}(x) \sim e^{i\pi_{TC}/F_{TC}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix} .$$

- Higgs mass is finite near the conformality (Kutasov-Lin-Parnachev '11)

$$\frac{m_H}{m_V} \approx 0.2$$

- But, dilaton mass can be very small near the conformal window. (Choi+DKH+Matsuzaki '11)

Light Dilaton and PCDC

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

$$\lim_{y \to x} Q_{TC}(x)\bar{Q}_{TC}(y) = (\mu\,|x-y|)^{\gamma_{\bar{Q}Q}}\, Q_{TC}\bar{Q}_{TC}(x)$$

$$Q_{TC}\bar{Q}_{TC}(x) \sim e^{i\pi_{TC}/F_{TC}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix} .$$

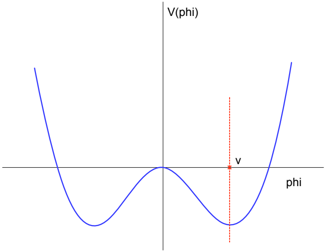
- Higgs mass is finite near the conformality (Kutasov-Lin-Parnachev '11)

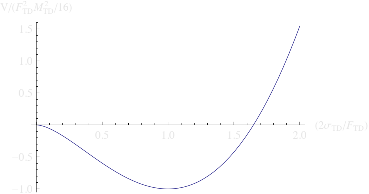
$$\frac{m_H}{m_V} \approx 0.2$$

- But, dilaton mass can be very small near the conformal window. (Choi+DKH+Matsuzaki '11)

Light Dilaton and PCDC

- Higgs potential versus dilaton potential (Schechter '80)



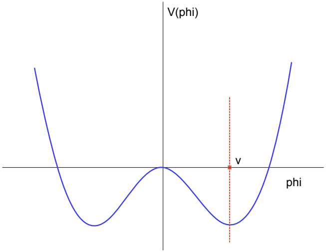


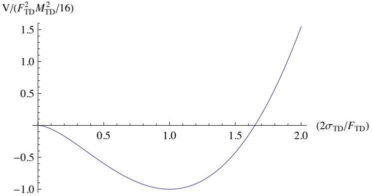
- They do, however, mix with mixing angle, m_H/F_{TD}:

$$\mathcal{L}_H = \frac{1}{2}\left|D_\mu H\right|^2 - \frac{1}{2}m_H^2\, e^{2\sigma/F_{\mathrm{TD}}} H^\dagger H + \cdots$$

Light Dilaton and PCDC

- Higgs potential versus dilaton potential (Schechter '80)





- They do, however, mix with mixing angle, $m_H/F_{\rm TD}$:

$$\mathcal{L}_H = \frac{1}{2}\,|D_\mu H|^2 - \frac{1}{2} m_H^2\, e^{2\sigma/F_{\rm TD}}\, H^\dagger H + \cdots$$

Composite Higgs

- In WTC composite Higgs can be light:
  - In a holographic model (D3-D7) by Kutasov-Lin-Parnachev, $m_H \approx 0.2 m_V$. ($m_H = 125\ \mathrm{GeV?}$)
  - In the CPT, m_H can be parametrically small. (See for instance Sannino-Tuominen '05, DKH+Hsu+Sannino '04)
- For $F_{TD} \gg m_F$ or extreme walking, $m_D \ll m_F$ and TD can be a dark matter. (Choi+DKH+Matsuzaki '11). Then the 125 GeV boson has to be the composite Higgs. (C_γ and C_g can be calculated using holography.)
- For $v_{EW}/F_{TD} \approx 0.2$ we may have two light scalar bosons: Gluon fusion and two-photon channel is enhanced but vector boson fusion is just like SM higgs.

Composite Higgs

- In WTC composite Higgs can be light:
  - In a holographic model (D3-D7) by Kutasov-Lin-Parnachev, $m_H \approx 0.2 m_V$. ($m_H = 125\ \mathrm{GeV}$?)
  - In the CPT, m_H can be parametrically small. (See for instance Sannino-Tuominen '05, DKH+Hsu+Sannino '04)
- For $F_{TD} \gg m_F$ or extreme walking, $m_D \ll m_F$ and TD can be a dark matter. (Choi+DKH+Matsuzaki '11). Then the 125 GeV boson has to be the composite Higgs. (C_γ and C_g can be calculated using holography.)
- For $v_{EW}/F_{TD} \approx 0.2$ we may have two light scalar bosons: Gluon fusion and two-photon channel is enhanced but vector boson fusion is just like SM higgs.

Composite Higgs

- In WTC composite Higgs can be light:
  - In a holographic model (D3-D7) by Kutasov-Lin-Parnachev, $m_H \approx 0.2 m_V$. ($m_H = 125$ GeV?)
  - In the CPT, m_H can be parametrically small. (See for instance Sannino-Tuominen '05, DKH+Hsu+Sannino '04)
- For $F_{TD} \gg m_F$ or extreme walking, $m_D \ll m_F$ and TD can be a dark matter. (Choi+DKH+Matsuzaki '11). Then the 125 GeV boson has to be the composite Higgs. (C_γ and C_g can be calculated using holography.)
- For $v_{EW}/F_{TD} \approx 0.2$ we may have two light scalar bosons: Gluon fusion and two-photon channel is enhanced but vector boson fusion is just like SM higgs.

Holographic dual

- Almost all quantities of WTC are difficult to calculate, a typical problem for strong dynamics.
- We try to calculate some of them by gauge/gravity duality ($F_{\rm TD}$, $m_{\rm TD}$, $\cdots$): work under progress!
- Holographic dual: Dilaton-deformed $AdS_5 \times M$ with probe branes (cf. Tuominen et al; Wijewardhana et al) or deformed Maldacena-Nunez background.

$$S = \frac{1}{2\kappa^2}\int \mathrm{d}^5x\sqrt{g}\left(R + \frac{1}{2}g^{ab}\partial_a\phi\partial_b\phi - V(\phi)\right) + S_{\rm probe}\,.$$

Holographic dual

- Almost all quantities of WTC are difficult to calculate, a typical problem for strong dynamics.
- We try to calculate some of them by gauge/gravity duality ($F_{\rm TD}$, $m_{\rm TD}$, $\cdots$): work under progress!
- Holographic dual: Dilaton-deformed $AdS_5 \times M$ with probe branes (cf. Tuominen et al; Wijewardhana et al) or deformed Maldacena-Nunez background.

$$S = \frac{1}{2\kappa^2}\int \mathrm{d}^5x\sqrt{g}\left(R + \frac{1}{2}g^{ab}\partial_a\phi\partial_b\phi - V(\phi)\right) + S_{\rm probe}\,.$$

Holographic dual

- Almost all quantities of WTC are difficult to calculate, a typical problem for strong dynamics.
- We try to calculate some of them by gauge/gravity duality ($F_{\rm TD}$, $m_{\rm TD}$, $\cdots$): work under progress!
- Holographic dual: Dilaton-deformed $AdS_5 \times M$ with probe branes (cf. Tuominen et al; Wijewardhana et al) or deformed Maldacena-Nunez background.

$$S = \frac{1}{2\kappa^2}\int \mathrm{d}^5x\sqrt{g}\left(R + \frac{1}{2}g^{ab}\partial_a\phi\partial_b\phi - V(\phi)\right) + S_{\rm probe}\,.$$

Holographic dual

- For $m_F < \mu < \Lambda_{\rm TC}$ the coupling is almost constant. Thus $\phi \approx {\rm const.}$ for $\epsilon = \Lambda_{\rm TC}^{-1} < z < z_m = m_F^{-1}$.
- AdS/TC might be a good approximation for flavor physics! (DKH+Yee, 06):

$$S_{\rm probe} \approx \int d^5x\sqrt{g}\,{\rm Tr}\left[\left|DX\right|^2 - m_5^2\left|X\right|^2 - \frac{1}{2g_5^2}\left(F_L^2+F_R^2\right)\right]$$

  where $m_5^2 = \Delta\left(\Delta-4\right) = -4$ and $D_\mu X = \partial_\mu X - iA_{L\mu}X + iX\,A_{R\mu}$.
- The bi-fundamental bulk scalar X is dual of $\bar{Q}Q$, corresponding to composite Higgs.

Holographic dual

- For $m_F < \mu < \Lambda_{\rm TC}$ the coupling is almost constant. Thus $\phi \approx {\rm const.}$ for $\epsilon = \Lambda_{\rm TC}^{-1} < z < z_m = m_F^{-1}$.
- AdS/TC might be a good approximation for flavor physics! (DKH+Yee, 06):

$$S_{\rm probe} \approx \int d^5x \sqrt{g}\, {\rm Tr}\left[\left|DX\right|^2 - m_5^2 \left|X\right|^2 - \frac{1}{2g_5^2}\left(F_L^2 + F_R^2\right)\right]$$

where $m_5^2 = \Delta\left(\Delta - 4\right) = -4$ and
$D_\mu X = \partial_\mu X - iA_{L\mu} X + iX A_{R\mu}$.

- The bi-fundamental bulk scalar X is dual of $\bar{Q}Q$, corresponding to composite Higgs.

Holographic dual

- For $m_F < \mu < \Lambda_{\rm TC}$ the coupling is almost constant. Thus $\phi \approx {\rm const.}$ for $\epsilon = \Lambda_{\rm TC}^{-1} < z < z_m = m_F^{-1}$.
- AdS/TC might be a good approximation for flavor physics! (DKH+Yee, 06):

$$S_{\rm probe} \approx \int d^5x \sqrt{g}\, {\rm Tr}\left[|DX|^2 - m_5^2 |X|^2 - \frac{1}{2g_5^2}\left(F_L^2 + F_R^2\right)\right]$$

where $m_5^2 = \Delta(\Delta - 4) = -4$ and $D_\mu X = \partial_\mu X - i A_{L\mu} X + i X A_{R\mu}$.

- The bi-fundamental bulk scalar X is dual of $\bar{Q}Q$, corresponding to composite Higgs.

Holographic dual

- The oblique corrections due to new physics

$$\int_x e^{-iq\cdot x}\left\langle J_X^\mu(x) J_Y^\nu(0)\right\rangle = i g_T^{\mu\nu}\Pi_{XY}(q^2) + q^\mu q^\nu \Pi_L$$
$$\Pi_{XY}(q^2) = \Pi_{XY}^{\rm sm} + \Pi_{XY}^{\rm new}$$

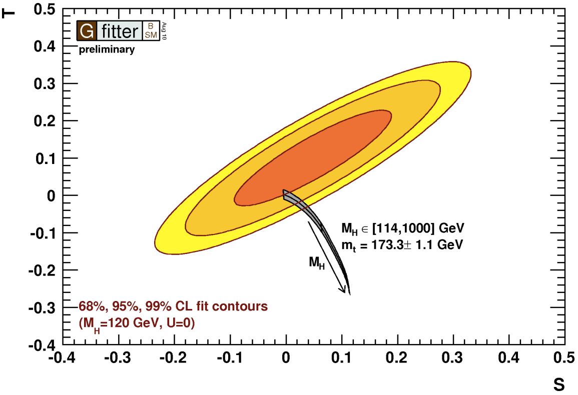
- Peskin-Takeuchi parameters:

$$x = x_{\rm sm}(m_t, m_H) + a_x S + b_x T + c_x U$$

$$S = 16\pi\left[\Pi_{33}'^{\rm new}(0) - \Pi_{3Q}'^{\rm new}(0)\right]$$
$$T = \frac{4\pi}{s^2c^2M_Z^2}\left[\Pi_{11}^{\rm new}(0) - \Pi_{33}^{\rm new}(0)\right]$$
$$U = 16\pi\left[\Pi_{11}'^{\rm new}(0) - \Pi_{33}'^{\rm new}(0)\right]$$

Holographic dual

- EXPERIMENTALLY: $S = 0.02 \pm 0.11$ @ LEP10.



Holographic dual

- Peskin-Takeuchi S parameter

$$S = -4\pi \frac{\mathrm{d}}{\mathrm{d}q^2}\left[\Pi_V(q^2) - \Pi_A(q^2)\right]_{q^2=0},$$

- In holographic dual the two-point functions can be written as

$$\Pi(-q^2) = -\sum_\rho \frac{F_\rho^2}{(q^2 - m_\rho^2)m_\rho^2}$$

The S-parameter is given also as

$$S = 4\pi \sum_n \left(\frac{f_{n,V}^2}{m_{n,V}^2} - \frac{f_{n,A}^2}{m_{n,A}^2}\right).$$

- Each terms are not necessary small, but there is large cancelation for WTC.

Holographic dual

- Peskin-Takeuchi S parameter

$$S = -4\pi \frac{\mathrm{d}}{\mathrm{d}q^2} \left[\Pi_V(q^2) - \Pi_A(q^2)\right]_{q^2=0},$$

- In holographic dual the two-point functions can be written as

$$\Pi(-q^2) = -\sum_\rho \frac{F_\rho^2}{(q^2 - m_\rho^2) m_\rho^2}$$

The S-parameter is given also as

$$S = 4\pi \sum_n \left(\frac{f_{n,V}^2}{m_{n,V}^2} - \frac{f_{n,A}^2}{m_{n,A}^2} \right).$$

- Each terms are not necessary small, but there is large cancelation for WTC.

Holographic dual

- Peskin-Takeuchi S parameter

$$S = -4\pi \frac{\mathrm{d}}{\mathrm{d}q^2} \left[\Pi_V(q^2) - \Pi_A(q^2)\right]_{q^2=0},$$

- In holographic dual the two-point functions can be written as

$$\Pi(-q^2) = -\sum_\rho \frac{F_\rho^2}{(q^2 - m_\rho^2)m_\rho^2}$$

The S-parameter is given also as

$$S = 4\pi \sum_n \left(\frac{f_{n,V}^2}{m_{n,V}^2} - \frac{f_{n,A}^2}{m_{n,A}^2} \right).$$

- Each terms are not necessary small, but there is large cancelation for WTC.

Holographic dual

- By the AdS/CFT dictionary the bulk action becomes the generating functional for the current correlation functions, when evaluated on-shell.

$$W[V,A] = -\frac{1}{2g_5^2}\int_x \left(\frac{1}{z}V_\mu^a\partial_z V^{\mu a} + \frac{1}{z}A_\mu^a\partial_z A^{\mu a}\right)\Bigg|_{z=\epsilon} .$$

- The gauge fields satisfy the bulk equations of motion in unitary gauge,

$$\begin{aligned} \left[\left(\partial^2 - z\partial_z\frac{1}{z}\partial_z\right)\eta_{\mu\nu} - \partial_\mu\partial_\nu\right]V^\nu &= 0 \\ \left[\left(\partial^2 - z\partial_z\frac{1}{z}\partial_z + \frac{g_5^2X_0^2}{z^2}\right)\eta_{\mu\nu} - \partial_\mu\partial_\nu\right]A^\nu &= 0 . \end{aligned}$$

Holographic dual

- Introduce the 4D Fourier transform with $V(q,\epsilon) = A(q,\epsilon) = 1$ and $\partial_z V(q,z_m) = \partial_z A(q,z_m) = 0$ (in a gauge $A_z = 0 = V_z$):

$$
\begin{aligned}
V^\mu(q,z) &= \left(\eta^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right) V^0_\nu(q) V(q,z) \\
A^\mu(q,z) &= \left(\eta^{\mu\nu} - \frac{q^\mu q^\nu}{q^2}\right) A^0_\nu(q) A(q,z) + \frac{q^\mu}{q^2} A(0,z)\,,
\end{aligned}
$$

where $V(q,z)$ and $A(q,z)$ satisfy

$$
\begin{aligned}
\left[z\partial_z\left(\frac{1}{z}\partial_z\right) + q^2\right] V(q,z) &= 0 \\
\left[z\partial_z\left(\frac{1}{z}\partial_z\right) + q^2 - \frac{g_5^2 X_0^2}{z^2}\right] A(q,z) &= 0\,.
\end{aligned}
$$

Holographic dual

- By differentiating the generating functional one finds

$$\Pi_V(-q^2) = \frac{1}{g_5^2} \left. \frac{\partial_z V(q,z)}{z} \right|_{z=\epsilon}, \Pi_A(-q^2) = \frac{1}{g_5^2} \left. \frac{\partial_z A(q,z)}{z} \right|_{z=\epsilon} .$$

- The solution for $V(q,z)$ with the boundary conditions, $V(q,\epsilon) = 1$ and $\partial_z V(q, z_m) = 0$.

$$V(q,z) = a_1\,|q|\,z\,Y_1(|q|\,z) + a_2\,|q|\,z\,J_1(|q|\,z)\,,$$

$$\Pi_V(-q^2) = \frac{|q|}{g_5^2 \epsilon} \frac{J_0(|q|z_m)Y_0(|q|\epsilon) - Y_0(|q|z_m)J_0(|q|\epsilon)}{J_0(|q|z_m)Y_1(|q|\epsilon) - Y_0(|q|z_m)J_1(|q|\epsilon)}\,,$$

- Matching for $-q^2 \to \infty$, we find

$$\Pi_V(-q^2) = \frac{q^2}{g_5^2} \ln\left(\frac{z_m}{\epsilon}\right) = \frac{d_R}{24\pi^2} q^2 \ln\left(-q^2\right) .$$

Holographic dual

- Since the scaling dimension of X is $\Delta = 2$ for walking TC,

$$X_0(z) = \frac{M}{2}\, z^2 + \frac{\langle \bar{q}\, q \rangle}{4}\, z^2 \ln(z/\epsilon)\,.$$

- To solve Eq. for $A(q,z)$, we introduce $T(q,z) \equiv \partial_z \ln A(q,z) = T^{(0)}(z) + q^2\, T^{(1)}(z) + \cdots$
- $T^{(0)}$ satisfies with $T^{(0)}(z_m) = 0$ and $\frac{1}{g_5^2} \frac{T^{(0)}(z)}{z}\Big|_{\epsilon} = -F_T^2$

$$z\partial_z \left(\frac{1}{z} T^{(0)} \right) + \left(T^{(0)} \right)^2 \;=\; \frac{g_5^2 X_0^2}{z^2}\,,$$

Holographic dual

- Since the scaling dimension of X is $\Delta = 2$ for walking TC,

$$X_0(z) = \frac{M}{2}\, z^2 + \frac{\langle \bar{q}\, q\rangle}{4}\, z^2 \ln(z/\epsilon)\,.$$

- To solve Eq. for $A(q,z)$, we introduce $T(q,z) \equiv \partial_z \ln\, A(q,z) = T^{(0)}(z) + q^2\, T^{(1)}(z) + \cdots$
- $T^{(0)}$ satisfies with $T^{(0)}(z_m) = 0$ and $\frac{1}{g_5^2}\frac{T^{(0)}(z)}{z}\Big|_{\epsilon} = -F_T^2$

$$z\partial_z\left(\frac{1}{z}T^{(0)}\right) + \left(T^{(0)}\right)^2 = \frac{g_5^2 X_0^2}{z^2}\,,$$

Holographic dual

- Since the scaling dimension of X is $\Delta = 2$ for walking TC,

$$X_0(z) = \frac{M}{2}\, z^2 + \frac{\langle \bar{q}\, q \rangle}{4}\, z^2 \ln(z/\epsilon)\,.$$

- To solve Eq. for $A(q,z)$, we introduce
  $T(q,z) \equiv \partial_z \ln\, A(q,z) = T^{(0)}(z) + q^2\, T^{(1)}(z) + \cdots$
- $T^{(0)}$ satisfies with $T^{(0)}(z_m) = 0$ and $\frac{1}{g_5^2} \frac{T^{(0)}(z)}{z}\Big|_{\epsilon} = -F_T^2$

$$z\partial_z \left(\frac{1}{z} T^{(0)} \right) + \left(T^{(0)} \right)^2 \;\; = \;\; \frac{g_5^2 X_0^2}{z^2}\,,$$

Holographic dual

- The equation for $T^{(1)}(z)$ is given as

$$z\partial_z\left(\frac{1}{z}T^{(1)}\right)+2T^{(0)}(z)T^{(1)}(z)=-1\,. \tag{1}$$

- Solving it, we find

$$T^{(1)}(z)=-z\int_{z_m}^{z}\frac{\mathrm{d}z'}{z'}\exp\left[2\int_{z}^{z'}\mathrm{d}\omega\,T^{(0)}(\omega)\right]\,. \tag{2}$$

$$\frac{\mathrm{d}}{\mathrm{d}q^2}\Pi_A(-q^2)\bigg|_{q^2=0}=\frac{1}{g_5^2 z}\,\frac{\mathrm{d}}{\mathrm{d}q^2}\partial_z\ln A(q,z)\bigg|_{q^2=0,z=\epsilon}=\frac{1}{g_5^2}\frac{1}{z}T^{(1)}(z)\bigg|_{\epsilon=0}$$

Holographic dual

- The equation for $T^{(1)}(z)$ is given as

$$z\partial_z\left(\frac{1}{z}T^{(1)}\right)+2T^{(0)}(z)T^{(1)}(z)=-1\,. \tag{1}$$

- Solving it, we find

$$T^{(1)}(z)=-z\int_{z_m}^{z}\frac{\mathrm{d}z'}{z'}\exp\left[2\int_{z}^{z'}\mathrm{d}\omega\,T^{(0)}(\omega)\right]\,. \tag{2}$$

$$\frac{\mathrm{d}}{\mathrm{d}q^2}\Pi_A(-q^2)\Big|_{q^2=0}=\frac{1}{g_5^2 z}\frac{\mathrm{d}}{\mathrm{d}q^2}\partial_z\ln A(q,z)\Big|_{q^2=0,z=\epsilon}=\frac{1}{g_5^2}\frac{1}{z}T^{(1)}(z)\Big|_{\epsilon=0}$$

Holographic dual

- The equation for $T^{(1)}(z)$ is given as

$$z\partial_z\left(\frac{1}{z}T^{(1)}\right)+2T^{(0)}(z)\,T^{(1)}(z)=-1\,. \qquad (1)$$

- Solving it, we find

$$T^{(1)}(z)=-z\int_{z_m}^{z}\frac{\mathrm{d}z'}{z'}\exp\left[2\int_{z}^{z'}\mathrm{d}\omega\,T^{(0)}(\omega)\right]\,. \qquad (2)$$

$$\left.\frac{\mathrm{d}}{\mathrm{d}q^2}\Pi_A(-q^2)\right|_{q^2=0}=\frac{1}{g_5^2 z}\left.\frac{\mathrm{d}}{\mathrm{d}q^2}\partial_z\ln A(q,z)\right|_{q^2=0,z=\epsilon}=\left.\frac{1}{g_5^2}\frac{1}{z}T^{(1)}(z)\right|_{\epsilon=0}$$

- The S parameter is then given as

$$S = \frac{4\pi}{g_5^2} \int_{\epsilon}^{z_m} \frac{\mathrm{d}z'}{z'} \left[1 - e^{2 \int_{\epsilon}^{z'} \mathrm{d}\omega \, T^{(0)}(\omega)} \right] .$$

- Numerical solutions:

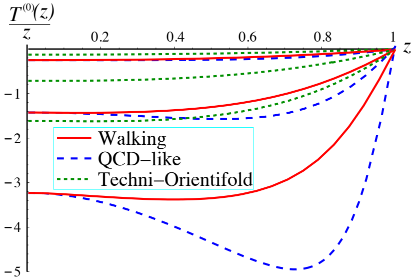


Figure: The profiles for $N_{TC} = 3$ with various $T^{(0)}(\epsilon)/\epsilon = -g_5^2 F_T^2$.

- The S parameter is then given as

$$S = \frac{4\pi}{g_5^2} \int_\epsilon^{z_m} \frac{\mathrm{d}z'}{z'} \left[1 - e^{2 \int_\epsilon^{z'} \mathrm{d}\omega\, T^{(0)}(\omega)} \right] .$$

- Numerical solutions:

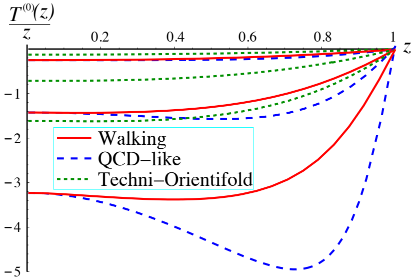


Figure: The profiles for $N_{TC} = 3$ with various $T^{(0)}(\epsilon)/\epsilon = -g_5^2 F_T^2$.

Holographic dual

- In AdS/TC the S-parameter depends on two parameters:
  1. The range of walking, z_m/ϵ. (Very mild dependence)
  2. The value of F_T in terms of z_m or $F_T\, z_m$. (Strong dependence!)
- Parameters of holographic models:
  1. $z_m \simeq 1/\Sigma(0)$, $g_5^2 = 24\pi^2/d(R)$ $(F_T = 246\sqrt{2/N_{TF}}\ \mathrm{GeV})$
  2. $F_T\, z_m = 1/4\pi,\ 0.86/g_5\,(\mathrm{ladder}),\ \frac{m_\rho}{4\pi}(=0.19),\ 0.29\,(\mathrm{QCD})$.
- To get small S, we need small $F_T z_m$ or small F_T/m_{TQ}. This is possible if the slope at z_m is small:

$$\frac{1}{z_m}\,\partial_z T^{(0)}\Big|_{z_m} = g_5^2\,\frac{X_0^2(z_m)}{z_m^3} \ll z_m^{-1}\,.$$

- Then all the new particles will decouple except techni-dilaton, giving $S \to 0$.

Holographic dual

- In AdS/TC the S-parameter depends on two parameters:
  1. The range of walking, z_m/ϵ. (Very mild dependence)
  2. The value of F_T in terms of z_m or $F_T\, z_m$. (Strong dependence!)
- Parameters of holographic models:
  1. $z_m \simeq 1/\Sigma(0)$, $g_5^2 = 24\pi^2/d(R)$ ($F_T = 246\sqrt{2/N_{TF}}$ GeV)
  2. $F_T\, z_m = 1/4\pi$, $0.86/g_5\,(\mathrm{ladder})$, $\frac{m_\rho}{4\pi}(=0.19)$, $0.29\,(\mathrm{QCD})$.
- To get small S, we need small $F_T z_m$ or small F_T/m_{TQ}. This is possible if the slope at z_m is small:

$$\frac{1}{z_m}\,\partial_z T^{(0)}\Big|_{z_m} = g_5^2\frac{X_0^2(z_m)}{z_m^3} \ll z_m^{-1}\,.$$

- Then all the new particles will decouple except techni-dilaton, giving $S \to 0$.

Holographic dual

- In AdS/TC the S-parameter depends on two parameters:
  1. The range of walking, z_m/ϵ. (Very mild dependence)
  2. The value of F_T in terms of z_m or $F_T\, z_m$. (Strong dependence!)
- Parameters of holographic models:
  1. $z_m \simeq 1/\Sigma(0)$, $g_5^2 = 24\pi^2/d(R)$ ($F_T = 246\sqrt{2/N_{TF}}\ \mathrm{GeV}$)
  2. $F_T\, z_m = 1/4\pi$, $0.86/g_5\,(\mathrm{ladder})$, $\frac{m_\rho}{4\pi}(= 0.19)$, $0.29\,(\mathrm{QCD})$.
- To get small S, we need small $F_T z_m$ or small F_T/m_{TQ}. This is possible if the slope at z_m is small:

$$\frac{1}{z_m}\,\partial_z T^{(0)}\Big|_{z_m} = g_5^2\,\frac{X_0^2(z_m)}{z_m^3} \ll z_m^{-1}\,.$$

- Then all the new particles will decouple except techni-dilaton, giving $S \to 0$.

Holographic dual

- In AdS/TC the S-parameter depends on two parameters:
  1. The range of walking, z_m/ϵ. (Very mild dependence)
  2. The value of F_T in terms of z_m or $F_T\, z_m$. (Strong dependence!)
- Parameters of holographic models:
  1. $z_m \simeq 1/\Sigma(0)$, $g_5^2 = 24\pi^2/d(R)$ ($F_T = 246\sqrt{2/N_{TF}}\ \mathrm{GeV}$)
  2. $F_T\, z_m = 1/4\pi$, $0.86/g_5\,(\mathrm{ladder})$, $\frac{m_\rho}{4\pi}(=0.19)$, $0.29\,(\mathrm{QCD})$.
- To get small S, we need small $F_T z_m$ or small F_T/m_{TQ}. This is possible if the slope at z_m is small:

$$\frac{1}{z_m}\,\partial_z T^{(0)}\Big|_{z_m} = g_5^2\frac{X_0^2(z_m)}{z_m^3} \ll z_m^{-1}\,.$$

- Then all the new particles will decouple except techni-dilaton, giving $S \to 0$.

Holographic dual

- Numerical values for various TC models:

$F_T z_m$	$N=2$	$N=3$	$N=4$
$1/4\pi$	0.034	0.034	0.035
0.19	0.15	0.17	0.18
0.29	0.24	0.30	0.34

(a) QCD-like Technicolor

$F_T z_m$	$N=2, S$	$2, F$	$3, S$	$3, F$	$4, S$	$4, F$
$1/4\pi$	0.031	0.031	0.031	0.031	0.031	0.031
$0.86 g_5^{-1}$	0.086	0.057	0.17	0.086	0.29	0.12
0.19	0.15	0.14	0.17	0.15	0.17	0.16
0.29	0.28	0.22	0.34	0.26	0.37	0.31

(b) Techni-orientifold and walking technicolor

Holographic dual

General Aspects of holographic S parameter

- The S parameter is positive.
- The S parameter is reduced at least about 10-20% by walking. The reduction is due to bringing down the axial vectors closer to proper vectors by walking.
- A slight change in $F_T\, z_m$ results in a substantial change in S.

Holographic dual

General Aspects of holographic S parameter

- The S parameter is positive.
- The S parameter is reduced at least about 10-20% by walking. The reduction is due to bringing down the axial vectors closer to proper vectors by walking.
- A slight change in $F_T\, z_m$ results in a substantial change in S.

Holographic dual

General Aspects of holographic S parameter

- The S parameter is positive.
- The S parameter is reduced at least about 10-20% by walking. The reduction is due to bringing down the axial vectors closer to proper vectors by walking.
- A slight change in $F_T\, z_m$ results in a substantial change in S.

Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$m_F \approx \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} \;:\; m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

- Holographic dual of WTC is a system of probe branes in a dilaton-deformed asymptotic AdS_5 .: Work under progress.
- The bulk dilaton is almost constant for $m_F < \mu < \Lambda_{\rm TC}$.
- AdS/TC is a good approximation for flavor physics of WTC.
- The S parameter of WTC is consistent with experiments.
- Phenomenology of light composite Higgs and light TD is interesting: will be testable soon!

Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$m_F \approx \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} \;:\; m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

- Holographic dual of WTC is a system of probe branes in a dilaton-deformed asymptotic AdS_5 .: Work under progress.
- The bulk dilaton is almost constant for $m_F < \mu < \Lambda_{\rm TC}$.
- AdS/TC is a good approximation for flavor physics of WTC.
- The S parameter of WTC is consistent with experiments.
- Phenomenology of light composite Higgs and light TD is interesting: will be testable soon!

Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$m_F \approx \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} \,:\, m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

- Holographic dual of WTC is a system of probe branes in a dilaton-deformed asymptotic AdS_5 .: Work under progress.
- The bulk dilaton is almost constant for $m_F < \mu < \Lambda_{\rm TC}$.
- AdS/TC is a good approximation for flavor physics of WTC.
- The S parameter of WTC is consistent with experiments.
- Phenomenology of light composite Higgs and light TD is interesting: will be testable soon!

Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$m_F \approx \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} \; : m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

- Holographic dual of WTC is a system of probe branes in a dilaton-deformed asymptotic AdS_5 .: Work under progress.
- The bulk dilaton is almost constant for $m_F < \mu < \Lambda_{\rm TC}$.
- AdS/TC is a good approximation for flavor physics of WTC.
- The S parameter of WTC is consistent with experiments.
- Phenomenology of light composite Higgs and light TD is interesting: will be testable soon!

Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$m_F \approx \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} : m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

- Holographic dual of WTC is a system of probe branes in a dilaton-deformed asymptotic AdS_5 .: Work under progress.
- The bulk dilaton is almost constant for $m_F < \mu < \Lambda_{\rm TC}$.
- AdS/TC is a good approximation for flavor physics of WTC.
- The S parameter of WTC is consistent with experiments.
- Phenomenology of light composite Higgs and light TD is interesting: will be testable soon!

Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$m_F \approx \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} \;:\; m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

- Holographic dual of WTC is a system of probe branes in a dilaton-deformed asymptotic AdS_5 .: Work under progress.
- The bulk dilaton is almost constant for $m_F < \mu < \Lambda_{\rm TC}$.
- AdS/TC is a good approximation for flavor physics of WTC.
- The S parameter of WTC is consistent with experiments.
- Phenomenology of light composite Higgs and light TD is interesting: will be testable soon!

Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry.
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$m_F \approx \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\alpha/\alpha_c - 1}}} \;:\; m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

- Holographic dual of WTC is a system of probe branes in a dilaton-deformed asymptotic AdS_5 .: Work under progress.
- The bulk dilaton is almost constant for $m_F < \mu < \Lambda_{\rm TC}$.
- AdS/TC is a good approximation for flavor physics of WTC.
- The S parameter of WTC is consistent with experiments.
- Phenomenology of light composite Higgs and light TD is interesting: will be testable soon!