Composite Higgs and Techni-dilaton at LHC

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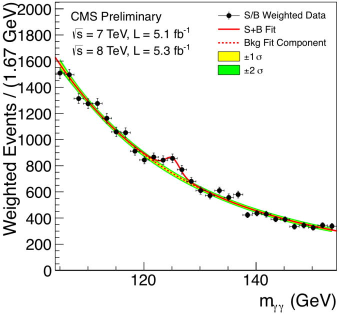
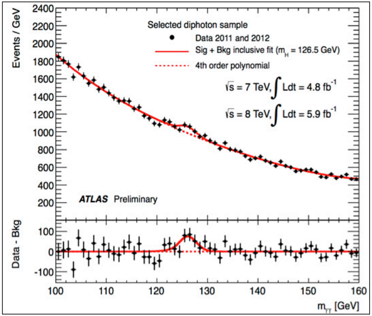
SCGT12, KMI, Nagoya

Introduction and Review

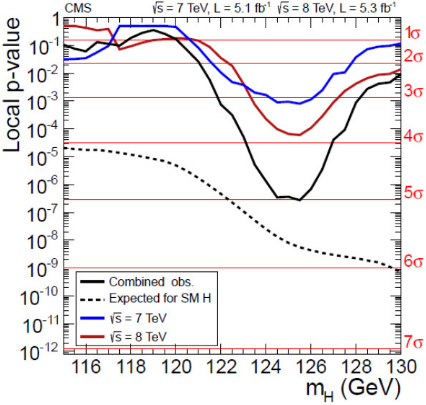
- A new (scalar) boson of 125 GeV has been discovered at LHC:





Introduction and Review

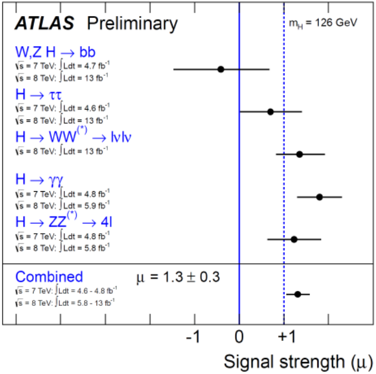
- Combined results p-value for the new (scalar) boson:



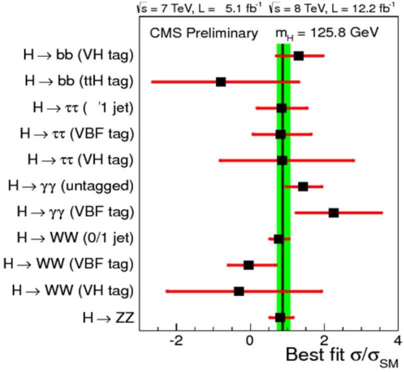
Introduction and Review

- It is much like the SM Higgs as of mid Nov. '12.

Best–fit Higgs mass m_H :
126.0 ± 0.4 (stat) ± 0.4 (syst) GeV



- M=125.8 ±0.4 (stat) ± 0.4 (syst) GeV



- σ/σ_{SM}=0.88±0.21

Introduction and Review

- There are some mild anomalies, which might be naturally explained in WTC.
- In WTC all particles are heavy ($\sim 1\ \mathrm{TeV}$), unless protected by symmetry. Techni-dilaton (TD), a Goldstone boson associated with spontaneous breaking of scale symmetry, is therefore naturally light.
- If the order parameter for the scale symmetry is much bigger than the size of explicit breaking, $F_{\mathrm{TD}} \gg m_F$, TD can be very light:

$$m_{TD} \sim \frac{m_{TQ}^2}{F_{TD}} \ll m_{TQ}, \quad \text{if } F_{TD} \gg m_{TQ} \, (\sim 1\ \mathrm{TeV})$$

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Introduction and Review

- If $m_{\rm TD} = 125\,{\rm GeV}$, $F_{\rm TD} \gg v_{\rm ew}$ and its coupling to fermions ($m_f = y_f v_{\rm ew}$), suppressed by $v_{\rm ew}/F_{\rm TD}$:

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

- Dilaton coupling to two photons and gluons can be enhanced:

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

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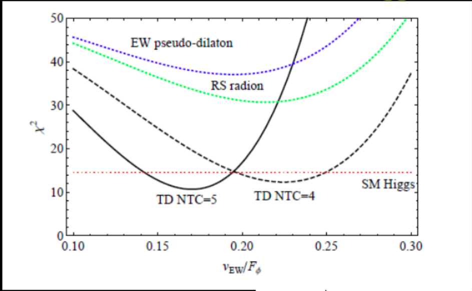
Introduction and Review

- 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

- VBF is too small for TD (Low+Lyken+Shaughnessy):

$$\mu(\mathbf{VBF} \to \gamma\gamma) = \frac{\mathbf{c_V^2 c_\gamma^2}}{\mathbf{R_{tot}}} = \mathbf{0.01}$$

$$\mathbf{P_{g/V}} = \frac{\mu(\mathbf{gg} \to \gamma\gamma)}{\mu(\mathbf{VBF} \to \gamma\gamma)} = \mathbf{140}$$

- If one includes Tevatron data, TD is ruled out at 99.8%(Low+Lyken+Shaughnessy):

$$\mu(\mathbf{VH} \to \mathbf{Vb\bar{b}}) = \frac{\mathbf{c_V^2 c_f^2}}{\mathbf{R_{tot}}} = \mathbf{0.005}$$

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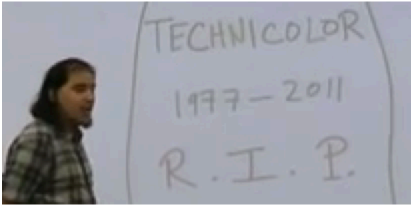

- Not really! WTC has a composite Higgs, which might be light.
- The 125 GeV boson might be a mixed state of two. Then, it could explain both $\mathrm{H} \to \gamma\gamma$ and VBF, and the Tevatron data, $\mathrm{VH} \to \mathrm{V}\bar{b}\,b$ (work under progress with Jeong and Jung).

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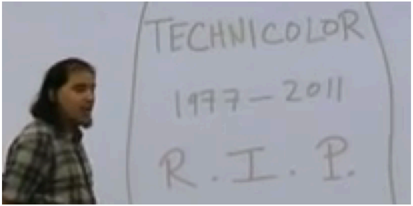

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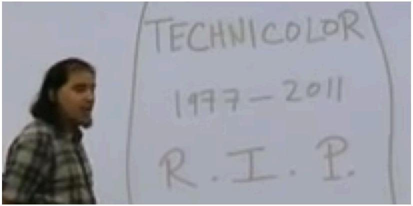

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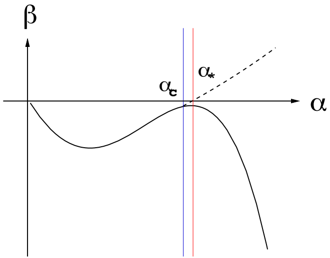
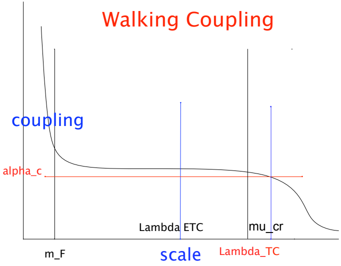
Introduction and Review

- Walking Technicolor (WTC) (Holdom '81, Yamawaki et al '86, Appelquist et al '86)



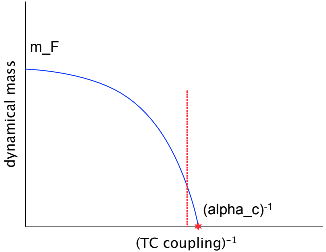


Introduction and Review

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

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

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



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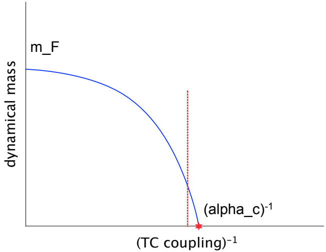

$$m_F = \Lambda_{\rm TC}\, e^{-\frac{\pi}{\sqrt{\frac{\alpha}{\alpha_c}-1}}}$$

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

Light Dilaton and PCDC

- WTC has approximate scale invariance, broken spontaneously, for $m_F < \mu < \Lambda_{\mathrm{TC}}$.
- There exists a dilatation current, $D^\mu = x_\nu \theta^{\mu\nu}$, approximately conserved but anomalous:

$$\langle \partial_\mu D^\mu \rangle = \langle \theta^\mu_\mu \rangle \neq 0.$$

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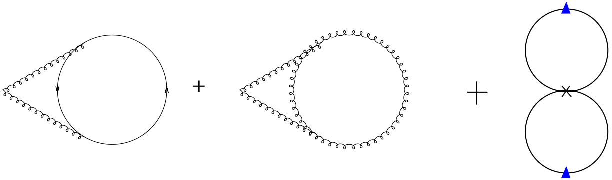
- The scale anomaly in WTC is found to be proportional to m_F^4 (m_F being the dynamical Techni fermion mass.)
- By an explicit calculation in the ladder approximation (Miransky+Yamawaki '96) and by the holographic calculation (D.Elander+DKH+M.Piai, to appear)

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



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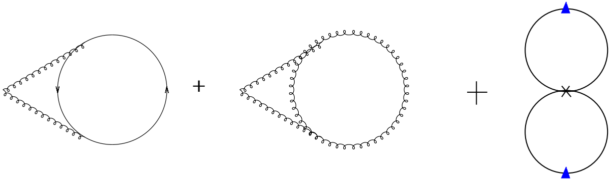

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- By Goldstone theorem light dilaton arises as pseudo Nambu-Goldstone boson:

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

- By PCDC, if dilaton pole dominates,

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

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

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

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Light Dilaton and PCDC

- Confusions on $F_{\rm TD}$.
- Can it be really much bigger than m_F?
- Suppose chiral symmetry of WTC is not spontaneously but explicitly broken by small mass:

$$m_0\bar{Q}Q \to m_0 e^{D/F}\bar{Q}Q\,.$$

If we integrate out the massive fermions, we get an effective potential

$$V(D) = 4\kappa\, m_0^4 \left(\frac{D}{F}\right)^4 \left[\ln\left(\frac{D}{F}\right) - \frac{1}{4}\right],$$

which gives mass to dilation

$$m_D^2 = \kappa\,\frac{m_0^4}{F^2} \to 0, \quad \text{if } m_0 \to 0\,.$$

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Light Dilaton and PCDC

- In the holographic dual one certainly can calculate F_{TD}. (Work under progress with Elander and Piai.)
- Holographic dual: Dilaton-deformed $AdS_5 \times M$ with probe branes (cf. Tuominen et al; Wijewardhana et al) or deformed Maldacena-Nunez background.

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

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Composite Higgs

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

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

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

Composite Higgs

- Composite Higgs can be light in WTC.
- In the CPT, m_H can be parametrically small. (See for instance Sannino-Tuominen '05, DKH+Hsu+Sannino '04)
- Holographic calculation shows Higgs mass is finite and small near the conformality (Kutasov-Lin-Parnachev '11)

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

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Composite Higgs

- Composite Higgs turns out to be light in Kutasov-Lin-Parnachev model (SCGT12mini).

$$\mathcal{S} = -\int d^{d+1}x V(T)\sqrt{-G} = -\int d^{d+1}x\sqrt{-g}V(T)\sqrt{1 + g^{MN}\partial_M T\partial_N T},$$

$$G_{MN} = g_{MN} + \partial_M T\partial_N T$$

σ - mesons: $m^2/\bar{\mu}^2 \approx 0.44, 9.65, 26.63, 51.35, 84, \cdots$

vector mesons: $m^2/\bar{\mu}^2 \approx 3.08, 15.12, 34.87, 62.32, 97.46, \cdots$

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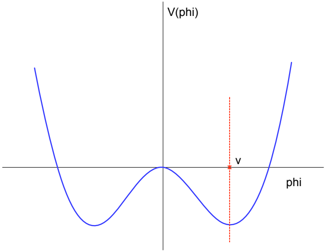
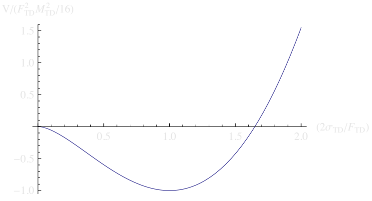
- Higgs potential versus dilaton potential (Schechter '80)





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

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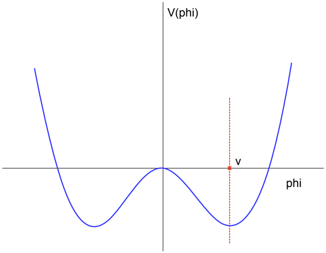

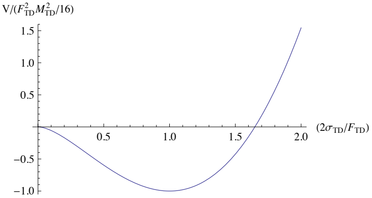

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Composite Higgs

- For $v_{EW}/F_{TD} \approx 0.2$ we may have two light scalar bosons.

125 GeV boson is a mixed state of TD and composite Higgs. Gluon fusion and two-photon channel is enhanced but vector boson fusion is just like SM higgs.

Composite Higgs

- Physics with two light composite scalars?
- Stay tuned!

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Conclusion

- WTC predicts light technidilaton (TD) due to spontaneously broken (approximate) scale symmetry, whose order parameter is given as

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

- $F_{\rm TD}$ is a UV scale, $F_{\rm TD} \sim \Lambda_{\rm TC}$??
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

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

- $F_{\rm TD}$ is a UV scale, $F_{\rm TD} \sim \Lambda_{\rm TC}$??
- Near conformality, $\alpha(\Lambda_{\rm TC}) \approx \alpha_c$,

$$F_{\rm TD} \sim \Lambda_{\rm TC} \gg m_F\,.$$

- Then by PCDC

$$m_{TD} \simeq \frac{m_F^2}{F_{\rm TD}} \ll m_F \ll F_{TD}$$

Conclusion

- WTC has a light composite Higgs near the conformality (Kutasov et al):

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

- The $125\,\mathrm{GeV}$ scalar might be a mixed state of techni-dilaton and composite Higgs.
- Then, both the enhancement in two-photon decay and the Tevatron data on $\bar{b}\,b$ can be explained. (work under progress with Jeong and Jung.)

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