Holographic Techni-Dilaton

Deog-Ki Hong

Pusan National University, Busan, Korea

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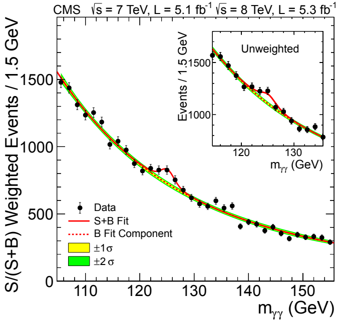
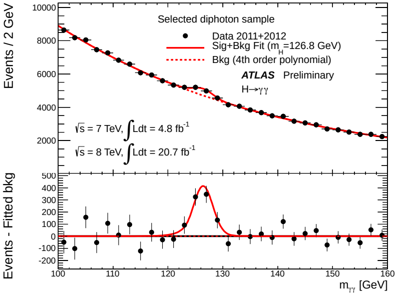
The Higgs Centre for Theoretical Physics, Edinburgh, UK

- With K. Y. Choi and S. Matsuzaki arXiv 1101.5326, arXiv:1201.4988.
- and to appear soon.

Introduction and Review

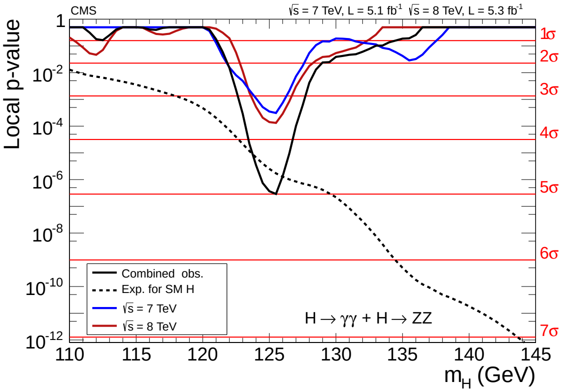
- A Higgs boson of 125 GeV has been discovered at LHC:





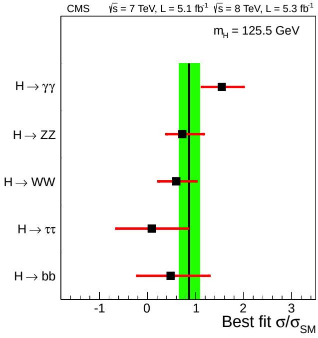
Introduction and Review

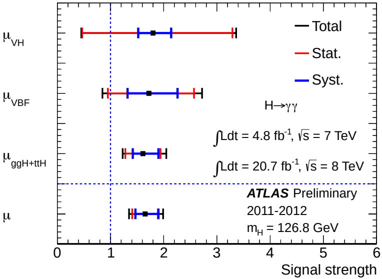
- Combined results p-value for the new boson (CMS):



Introduction and Review

- As of March '13, it is much like the SM Higgs:





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- The data is consistent with SM, with deviation less than 2σ and the statistical error will be reduced significantly at the LHC14.
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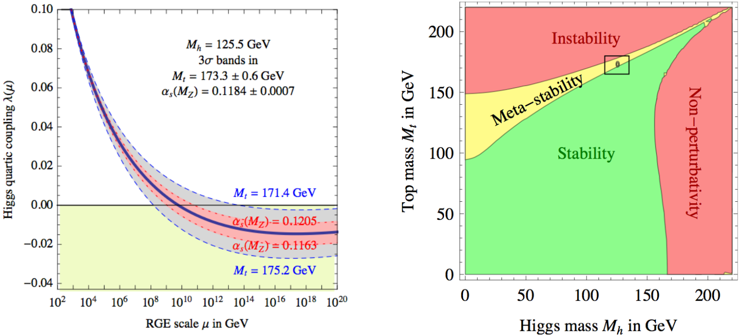
- And the SM vacuum is meta-stable (A. Strumia, Moriond EW2013):



Introduction and Review

- At LHC8 we have not seen any significant deviation from SM or any new BSM particles.
- The scale of new physics beyond SM might be much higher than we've anticipated. ($\Lambda_{\rm NP} > 2 \sim 3\,{\rm TeV?}$)
- The newly discovered boson could a composite Higgs of strong dynamics such as walking technicolor (WTC). (cf. DKH+Hsu+Sannino '04)

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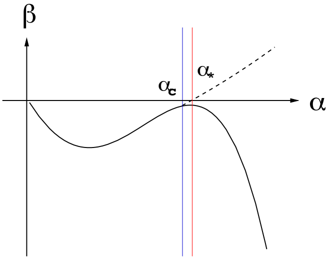
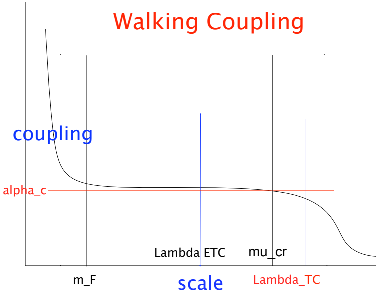
Introduction and Review

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



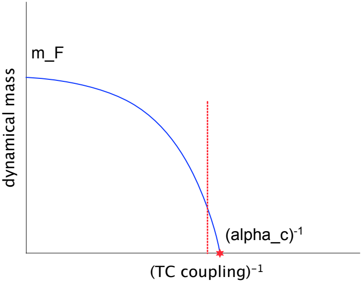


Introduction and Review

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

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

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



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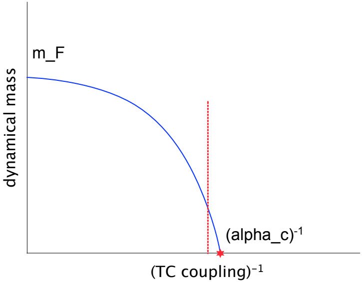

$$\gamma_{\bar{Q}Q} = 1 + \sqrt{\frac{\alpha}{\alpha_c} - 1} \approx 1$$

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

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)

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Composite Higgs

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

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

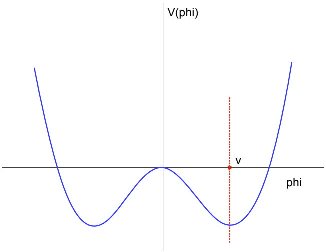
$$G_{MN} = g_{MN} + \partial_M T \partial_N T$$

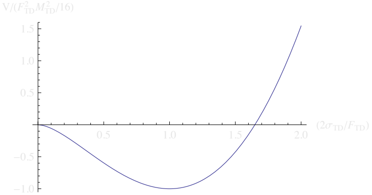
σ - mesons: $m^2/\bar{\mu}^2 \approx 0.44, 9.65, 26.63, 51.35, 84, \cdots$

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

Composite Higgs

- Higgs potential versus dilaton potential (Schechter '80)





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

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

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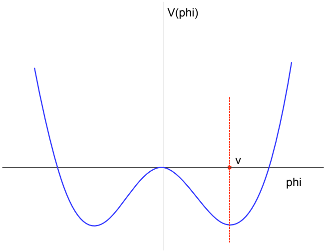

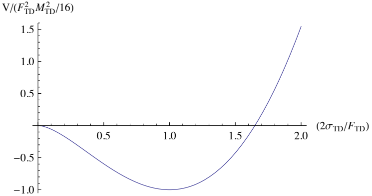

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Light Dilaton and PCDC

- Near conformality, $\alpha(m_F) \approx \alpha(\mu_{\rm cr}) = \alpha_C$, there is a wide separation of two scales, $m_F \ll \mu_{\rm cr}$.
- WTC has approximate scale invariance, broken spontaneously, for $m_F < \mu < \mu_{\rm cr}$.
- 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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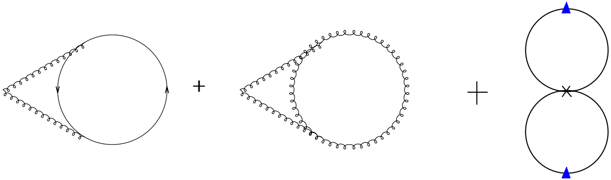
- The scale anomaly in WTC is found to be proportional to m_F^4 (m_F being the dynamical Techni fermion mass.)
- By an explicit calculation in the ladder approximation (Miransky+Yamawaki '96)

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



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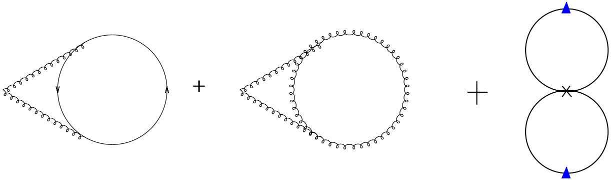

Light Dilaton and PCDC

- 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,

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

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

- Confusions on F_{TD}.
- Can it be much bigger than m_F?
- Gauge/gravity duality is very useful for (conformal) strong dynamics such as WTC.
- Holographic dual: Dilaton-deformed $AdS_5 \times M$ with probe branes (cf. Tuominen et al; Wijewardhana et al) or deformed Maldacena-Nunez background.

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Holographic Techni-Dilaton

- We consider a bottom-up model for holographic techni-dilaton:

$$S = \frac{1}{2\kappa^2} \int \mathrm{d}^5 x \sqrt{g} \, (R + 12) + \int \mathrm{d}^5 x \sqrt{g} \, \mathcal{L}_{\mathrm{m}} \, ,$$

where

$$\mathcal{L}_{\mathrm{m}} = D_M X^\dagger D_N X \, g^{MN} - m_X^2 \, |X|^2 - \frac{1}{4 g_5^2} \left(F_L^2 + F_R^2 \right) \, .$$

Holographic Techni-Dilaton

- We take an Ansatz for the metric due to the back-reaction of matter as

$$\mathrm{d}s^2 = e^{2\phi}\left(-\mathrm{d}z^2 + \mathrm{d}x_\mu \mathrm{d}x_\nu \eta^{\mu\nu}\right) .$$

- For WTC $m_X^2 = -4$ and the vacuum solution is

$$X_0 = \sigma\, z^2 , \quad \sigma = \langle \bar{Q} Q \rangle .$$

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- By Solving the Einstein equations for χ we find near $z = 0$

$$\chi = \frac{3}{5}\,\kappa^2\,\sigma^2\,z^4 + \frac{A}{z} + B \qquad (\kappa^2 = 8\pi G_5)$$

- By the B.C. $A = 0 = B$ and by AdS/CFT

$$\langle \theta^\mu_\mu \rangle = \frac{3}{5}\kappa^2\sigma^2\,.$$

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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? Namely $F_{\rm TD} \sim \mu_{\rm cr}$?
- Near conformality, $\alpha(m_F) \approx \alpha_c$,

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- The $125\,\mathrm{GeV}$ scalar might be a mixed state of techni-dilaton and composite Higgs.
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