Holographic Techni-dilaton and LHC searches

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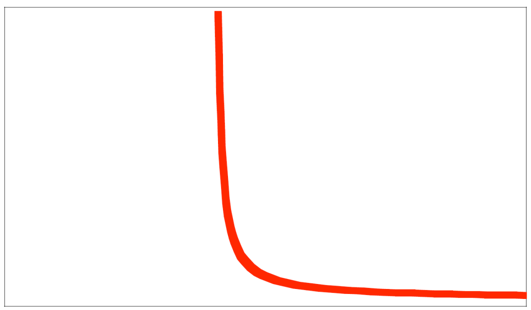
D. Elander, MP arXiv: 1112.2915
R. Lawrance, MP arXiv: 1207.0427
D. Elander, MP arXiv: 1208.0546
C. Nunez, I. Papadimitriou, MP arXiv0812.3655
D. Elander, C. Nunez, MP arXiv: 0908.2808
S.P. Kumar, D. Mateos, A. Paredes, MP, arXiv: 1012.4678
D. Elander, MP arXiv: 1010.1964
D. Elander, J. Galliard, C.Nunez, MP, arXiv:1104.3963

Outline

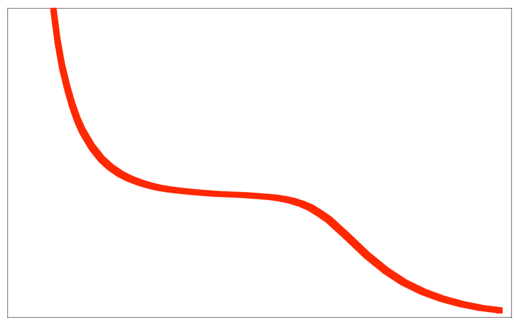
- Motivations.
- Holographic techni-dilaton: mass from bottom-up and top-down
- Phenomenology: decay constant F and S parameter (bottom-up only!).
- LHC searches (phenomenological analysis).
- Conclusions

Motivations

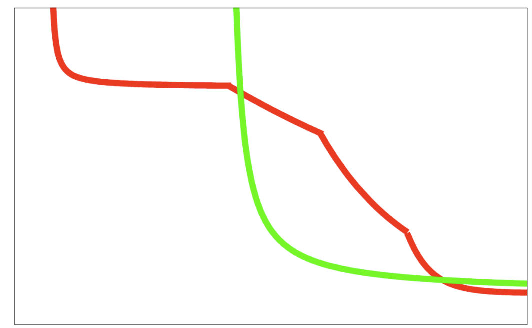
- Strongly-coupled models of EWSB require highly non-trivial dynamics.



QCD-like TC



Walking TC



Tumbling ETC + Walking TC

- Reconcile strong coupling with precision physics, FCNC, fermion masses...
- Walking TC: is there a light dilaton? If so, how can we distinguish it from the Higgs particle? What is the LHC telling us so far?
- Idea: use holography (top-down or bottom-up?).

Dilaton Mass

- Very difficult QFT open question. No general consensus. But very plausible light techni-dilaton in walking TC: approximate scale invariance and condensates (spontaneous breaking).
- Open question: which effect dominates, between explicit and spontaneous breaking of scale invariance?

M. Bando *et al.* Phys. Lett. B 178, 308 (1986); Phys. Rev. Lett. 56, 1335 (1986); B. Holdom and J. Terning, Phys. Lett. B 187, 357 (1987); Phys. Lett. B 200, 338 (1988); D. D. Dietrich, F. Sannino and K. Tuominen, Phys. Rev. D 72, 055001 (2005) [arXiv:hep-ph/0505059]. T. Appelquist and Y. Bai, arXiv:1006.4375 [hep-ph]; K. Haba, S. Matsuzaki, K. Yamawaki, Phys. Rev. D82, 055007 (2010). [arXiv:1006.2526 [hepph]]; L. Vecchi, [arXiv:1007.4573 [hep-ph]]; M. Hashimoto, K. Yamawaki, Phys. Rev. D83, 015008 (2011). [arXiv:1009.5482[hep-ph]].

- Gauge/gravity dualities: is it POSSIBLE that the techni-dilaton be light? What classes of models would this identify?
- Advantage: precise prescription for the calculations exists! Instead of a strongly-coupled field theory, write the model as a weakly-coupled gravity theory in extra-dimensions.
- Difficulty: severe model-dependence, very hard technical work at model-building level (top-down) needed to find right backgrounds (as known also from EFT+NDA approach).

Top-down approach (consistent truncation)

- Start from 10D superstring theory (Type IIB for example), consider supergravity limit.
- Write a general ansatz: internal 5D compact manifold with given symmetries, non-compact 5D.
- Perform KK reduction to 5D (obtain infinite number of 5D states, discrete spectrum).
- Choose subgroup of symmetries, and perform consistent truncation (keep only few 5D states).

- Write sigma-model with n scalars coupled to 5D gravity.
- Solve bulk equations for scalars and gravity, and identify physical meaning of integration constants.
- Fix background of interest (=choose and fix integration constants).

- Add boundaries in UV and IR, as regulators, and infer appropriate boundary conditions.
- Fluctuate 5D scalars and gravity.
- Rewrite fluctuations in gauge-invariant form and focus on physical degrees of freedom.
- Solve for scalar fluctuations and mass spectrum.
- Remove regulators (if possible), and obtain physical quantities of dual field theory (phenomenology).

- Lift to 10-dimensions.
- Study extended objects, probe strings (confinement), probe D-branes (chiral symmetry breaking)...

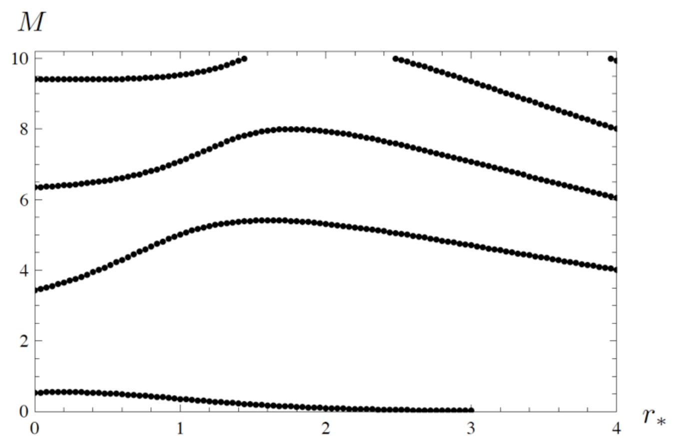
Bottom-up approach

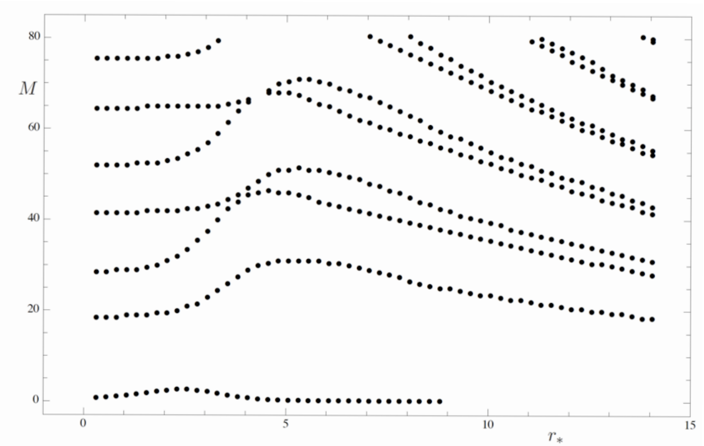
- Write sigma-model with n scalars coupled to 5D gravity.
- Solve bulk equations for scalars and gravity, and identify physical meaning of integration constants.
- Fix background of interest.

- Add boundaries in UV and IR, as regulators, and infer appropriate boundary conditions.
- Fluctuate 5D scalars and gravity.
- Rewrite fluctuations in gauge-invariant form and focus on physical degrees of freedom.
- Solve for scalar fluctuations and mass spectrum.
- Remove regulators (possible in UV, NOT in IR) and study phenomenology.

Dilaton Mass: bottom-up approach

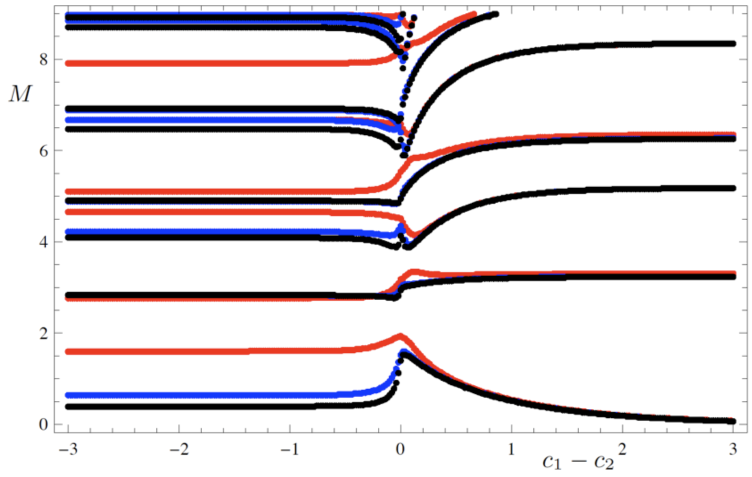
- Randall-Sundrum: exactly massless dilaton.
- GW mechanism: quadratic potential, light dilaton for D>2 or D~4. But UV-dependence.
- Flow between fixed-points: cubic superpotential, UV-independent results, similarities with string-theory models (PW).





Dilaton Mass: bottom-up approach

- GPPZ model: from string-theory, but singular, 10-d lift not useful.
- Space ends in IR, UV regular (no UV-cutoff needed).
- Light dilaton provided D=3 (VEV!) deformation dominant.



- Phenomenology easy to study.

Walking Dynamics from top-down approach

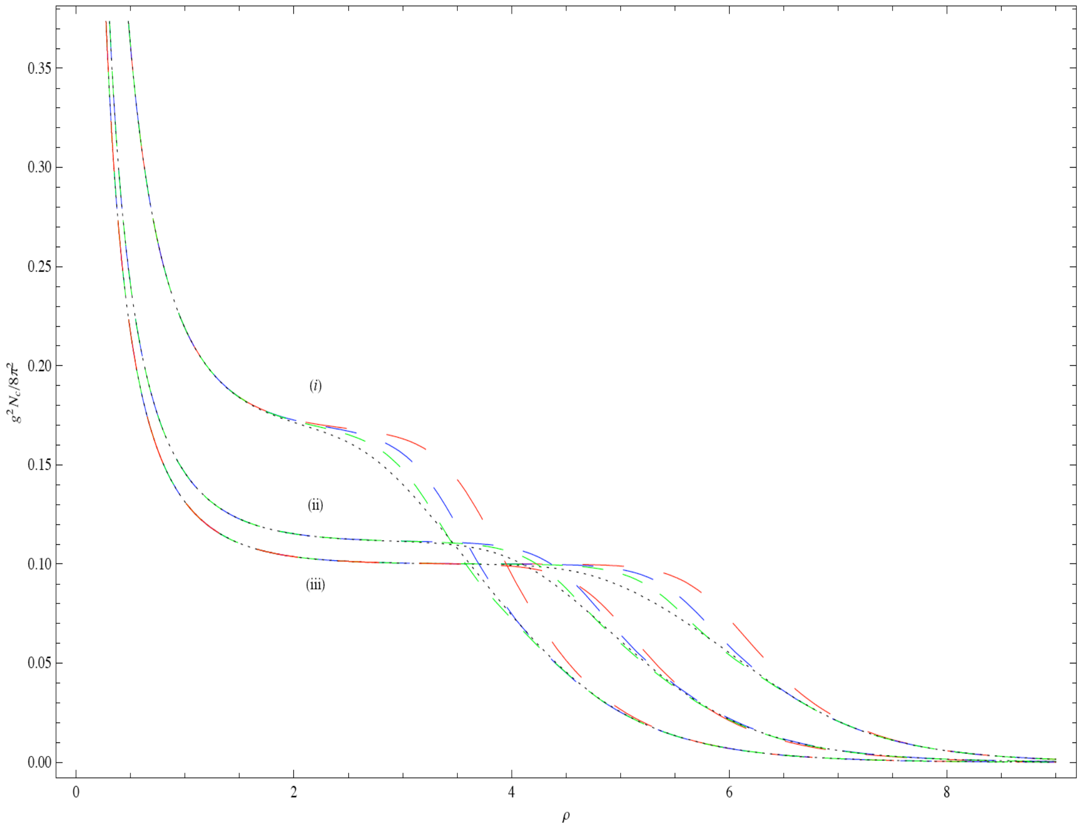
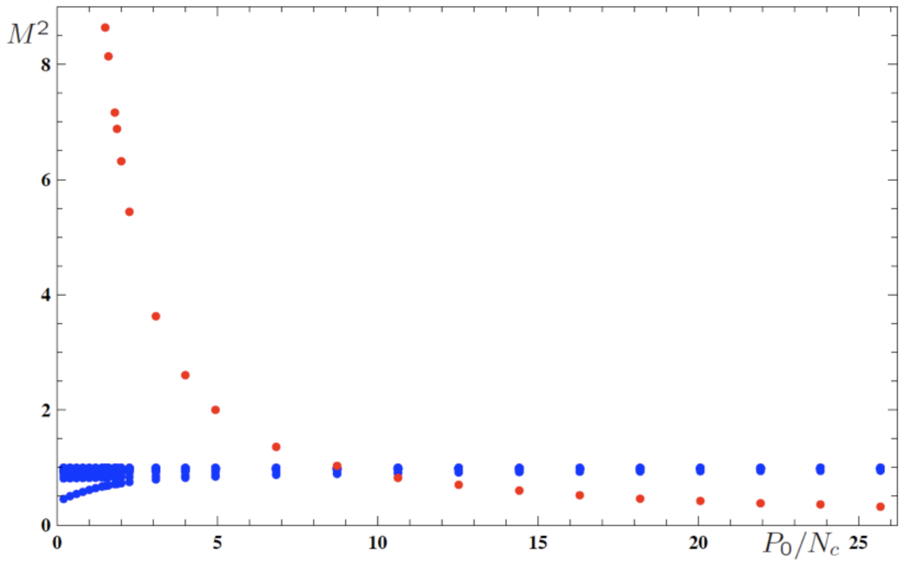


FIG. 3: The 't Hooft coupling $g^2N_c/(8\pi^2)$ as a function of ρ for various values of the parameters c, α. All three curves are for $N_c = 10$, while $c = 60$, $\alpha = 0.01$ for (i), $c = 90$, $\alpha = 0.002$ for (ii) and $c = 100$, $\alpha = 0.0005$ for (iii). The red (long dashes) curves are the $\mathcal{O}(c)$ approximation in the expansion (20), the blue (medium dashes) lines are the $\mathcal{O}(1/c)$ approximation, the green (short dashes) lines are the $\mathcal{O}(1/c^3)$ approximation, and the black (dotted) lines are the numerical solutions.

Dilaton Mass
top-down approach



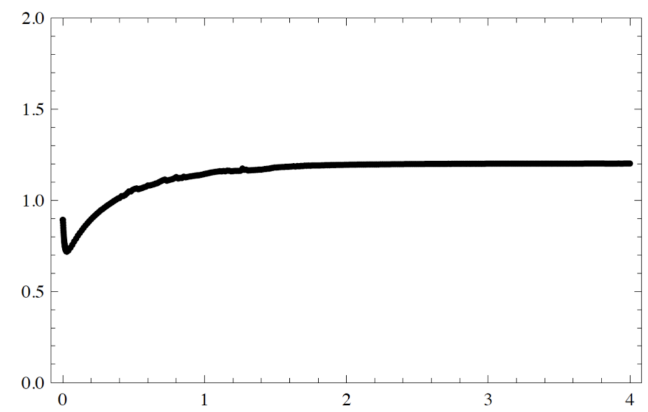
- A light dilaton emerges when the walking region is long.
- Confinement dynamical feature (Wilson loop can be computed).
- Proof of concept: there exist strongly-coupled models with light dilaton, in spite of EFT+NDA estimates.
- Phenomenology: calculation of S parameter exist, but little more.

L. Anguelova,P. Suranyi, R.Wijewardhana, arXiv:1105.4185

Phenomenology: bottom-up approach

- Bottom-up approach: easy. Top-down: very little done (yet!).
- S-parameter computed in many ways and for many variants.
- Generic result consistent with EFT expectations: mass of techni-rho meson must be large, M>2.5-3 TeV.
- Decay constant of dilaton F computed in many ways and for many variants.
- Generic results (and GPPZ example)

$$\frac{M_\rho}{\Lambda_0} \simeq 2.5 - 3\,,$$
$$\frac{F}{\Lambda_0} \simeq 1.2\,,$$



- Reinstating units implies large F>1.1 TeV.

LHC Discovery

- On July 4th, 2012, LHC collaborations discovered new particle with mass 125-126 GeV.
- Several decay channels studied.
- Many phenomenological analysis carried out:

I. Low, J. Lykken, G. Shaughnessy 1207.1093
P.P. Giardino, K, Kannike, M. Raidal, A. Strumia 1207.1347
J. Ellis, T. You 1207.1693
J. R. Espinosa, C. Grojean, M. Muhlleitner, M. Trott 1207.1717
D. Carmi, A. Falkowski, E. Kuflik, T. Volansky, J. Zupan 1207.1718
S. Matzusaki, K. Yamawaki 1207.5911
M. Montull, F. Riva 1207.1716
D. Bertolini M. McCullough 1207.4209
T. Corbett, O.J.P. Eboli, J. Gonzalez-Fraile, M.C. Gomzalez-Garcia 1207.1344
D. Elander, MP arXiv: 1208.0546
...

- Broad agreement with SM Higgs particle.
- At present, large error bars.

Our Analysis

- Generic dilaton model, simplified leading-order analysis.
- Three parameters: decay constant, coupling to photons and to gluons.

MSM Higgs h	Dilaton d
$2\frac{h}{v_W}M_W^2 W_\mu W^\mu$	$2a\frac{d}{v_W}M_W^2 W_\mu W^\mu$
$\frac{h}{v_W}M_Z^2 Z_\mu Z^\mu$	$a\frac{d}{v_W}M_Z^2 Z_\mu Z^\mu$
$-\frac{h}{v_W}M_\psi \bar{\psi}\psi$	$-a\frac{d}{v_W}M_\psi \bar{\psi}\psi$
$\frac{1}{4}\beta_e \frac{h}{v_W}F_{\mu\nu}F^{\mu\nu}$	$\frac{1}{4}c_\gamma a\beta_e \frac{d}{v_W}F_{\mu\nu}F^{\mu\nu}$
$\frac{1}{2}\beta_s \frac{h}{v_W}\mathrm{Tr}\, G_{\mu\nu}G^{\mu\nu}$	$\frac{1}{2}c_g a\beta_s \frac{d}{v_W}\mathrm{Tr}\, G_{\mu\nu}G^{\mu\nu}$

- Notice: only leading-order, and fermion treatment simplified.

Our Analysis

- Many fits by several collaborations exists, broad agreement.
- We focus on most important measurements for dilaton.
- LHC and TeVatron signal significance, units of the SM.
- 3 parameter fit:

$$
\begin{aligned}
\sigma(pp \to d)_{7,8} &= a^2\, c_g^2\, \sigma(pp \to h)^{SM}_{7,8} \,, \\
\sigma(pp \to qqd)_{7,8} &= a^2\, \sigma(pp \to qqh)^{SM}_{7,8} \,, \\
\sigma(pp \to Vd)_{7,8} &= a^2\, \sigma(pp \to Vh)^{SM}_{7,8} \,, \\
\sigma(pp \to ttd)_{7,8} &= a^2\, \sigma(pp \to tth)^{SM}_{7,8} \,.
\end{aligned}
$$

$$
\rho \equiv \frac{1}{0.913 + 0.0022\, c_\gamma^2 + 0.085\, c_g^2}
$$

$$
\begin{aligned}
BR(d \to b\bar{b}) &= \rho\, BR(h \to b\bar{b})_{SM} \,, \\
BR(d \to c\bar{c}) &= \rho\, BR(h \to c\bar{c})_{SM} \,, \\
BR(d \to \tau^+\tau^-) &= \rho\, BR(h \to \tau^+\tau^-)_{SM} \,, \\
BR(d \to ZZ^*) &= \rho\, BR(h \to ZZ^*)_{SM} \,, \\
BR(d \to WW^*) &= \rho\, BR(h \to WW^*)_{SM} \,, \\
BR(d \to \gamma\gamma) &= c_\gamma^2\, \rho\, BR(h \to \gamma\gamma)_{SM} \,, \\
BR(d \to gg) &= c_g^2\, \rho\, BR(h \to gg)_{SM} \,.
\end{aligned}
$$

Results (as of July 2012)

- 3-parameter fit, marginalized over coupling to gluons.
- SM, generic dilaton and holographic techni-dilaton all competitive.
- Holographic techni-dilaton would have suppressed VBF, Vh and tth.
- Holographic techni-dilaton would have enhanced 2photon signal.

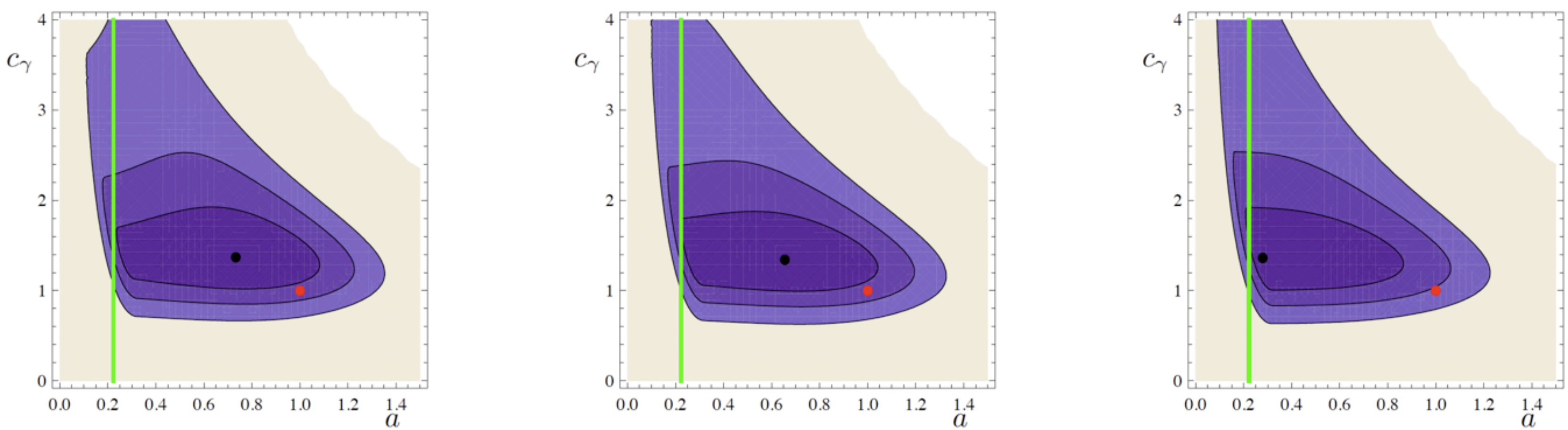
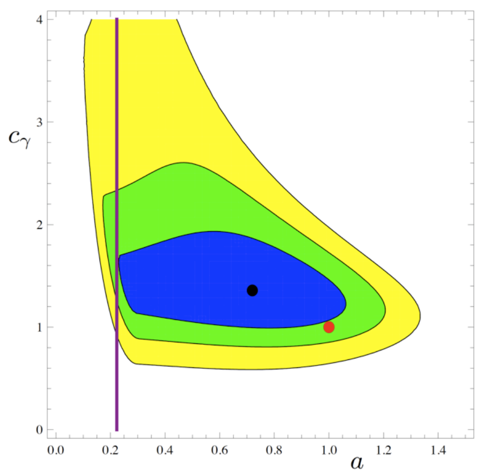
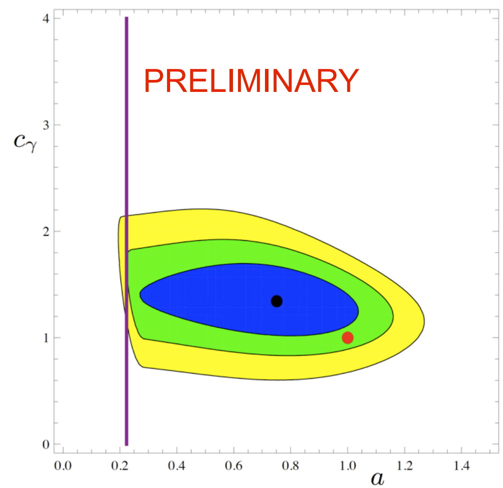


FIG. 6: Numerical result of χ^2 analysis of CMS+ATLAS+TeVatron data. Shown is the best fit point (black dot), the SM prediction (red dot), and the 1σ, 2σ and 3σ contours obtained by minimizing in respect to c_g. The left panel uses all the data, in the central we omitted the $h \to \gamma\gamma$ dijet tagged events at 7 TeV from CMS, and in the right panel we omitted both this and the bb data from TeVatron. The lines correspond to $a \simeq 0.22$

HCP update.

- 2tau channel analyzed (gFF, VBF and Vh). Consistent both with dilaton and SM Higgs (ggF), but VBF and Vh disfavor large decay constant.
- 2b from Vh updated: CMS in agreement with TeVatron. NOT ATLAS.
- WW, ZZ updates: consistent with SM, marginally disfavor dilaton.
- 2gamma: no update, favors dilaton, disfavors SM.





- Conclusion: more data on VBF, Vh and tth needed!

Conclusions

- (Holographic techni-)dilaton competitive with SM Higgs in interpreting LHC and TeVatron data.
- Photon-photon events favor dilaton models.
- VBF, Vh and tth disfavor techni-dilaton (large F), but no coherent picture from the data (yet), more precise measurements needed.

- There exist top-down models with light dilaton (proof of existence), but phenomenology has not been studied in details (yet).
- Bottom-up models have been studied in details: decay constant large. What about top-down? (in progress...)

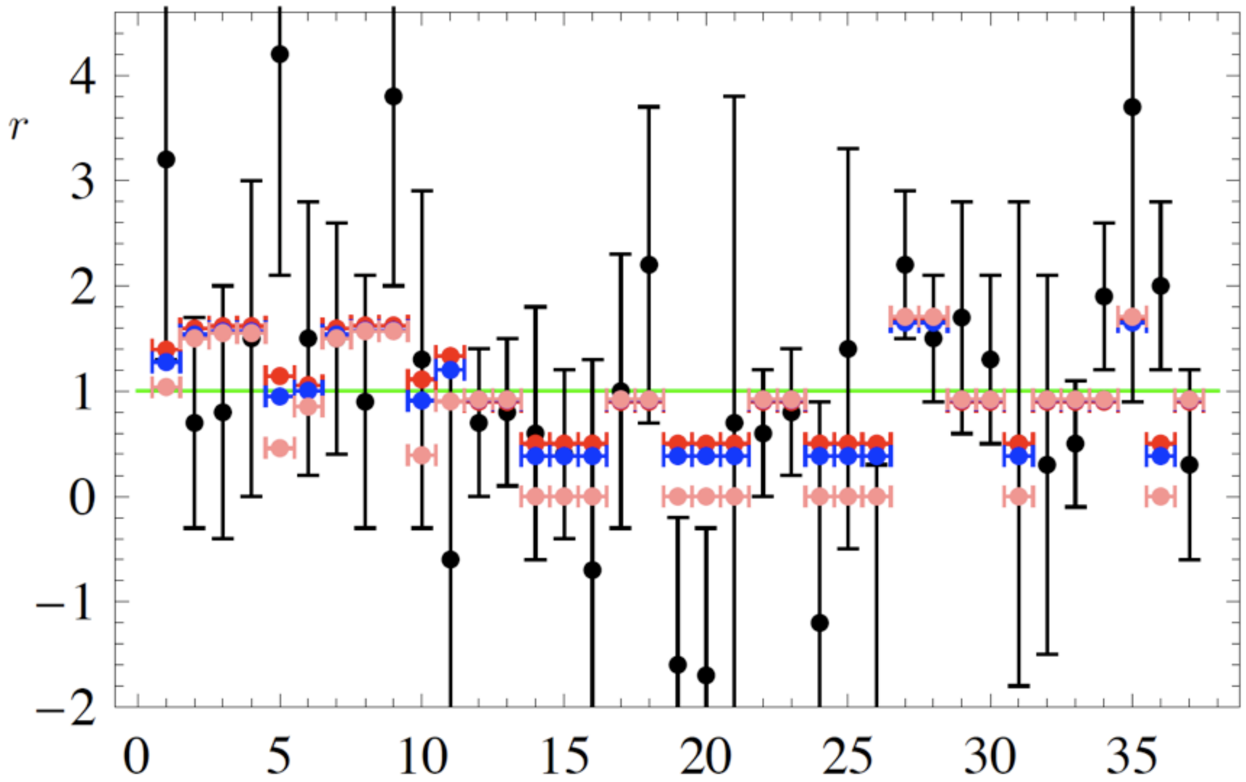
- More experimental data and more theoretical work on top-down approach needed.

Backup slides

Data (as of July 2012)

	Process	Comments	(ggF, VBF, Vh, tth)%
CMS			
1	$h \to \gamma\gamma$	7 TeV Untagged 0	$(61, 17, 19, 3)$
2	$h \to \gamma\gamma$	7 TeV Untagged 1	$(88, 6, 6, 1)$
3	$h \to \gamma\gamma$	7 TeV Untagged 2	$(91, 4, 4, 0)$
4	$h \to \gamma\gamma$	7 TeV Untagged 3	$(91, 4, 4, 0)$
5	$h \to \gamma\gamma$	7 TeV Dijet Tag	$(27, 73, 1, 0)$
6	$h \to \gamma\gamma$	8 TeV Untagged 0	$(68, 12, 16, 4)$
7	$h \to \gamma\gamma$	8 TeV Untagged 1	$(88, 6, 6, 1)$
8	$h \to \gamma\gamma$	8 TeV Untagged 2	$(92, 4, 3, 0)$
9	$h \to \gamma\gamma$	8 TeV Untagged 3	$(92, 4, 4, 0)$
10	$h \to \gamma\gamma$	8 TeV Dijet Tight	$(23, 77, 0, 0)$
11	$h \to \gamma\gamma$	8 TeV Dijet Loose 0	$(53, 45, 2, 0)$
12	$h \to ZZ \to 4\ell$	7 TeV	
13	$h \to ZZ \to 4\ell$	8 TeV	
14	$h \to bb$	7 TeV Vh Tag	
15	$h \to bb$	8 TeV Vh Tag	
16	$h \to bb$	8 TeV tth Tag	
17	$h \to \tau\tau$	7 TeV 0/1 jet	
18	$h \to \tau\tau$	8 TeV 0/1 jet	
19	$h \to \tau\tau$	7 TeV VBF Tag	
20	$h \to \tau\tau$	8 TeV VBF Tag	
21	$h \to \tau\tau$	7 TeV Vh Tag	
22	$h \to WW$	7 TeV 0/1 jet	
23	$h \to WW$	8 TeV 0/1 jet	
24	$h \to WW$	7 TeV VBF Tag	
25	$h \to WW$	8 TeV VBF Tag	
26	$h \to WW$	7 TeV Vh Tag	
ATLAS			
27	$h \to \gamma\gamma$	7 TeV	
28	$h \to \gamma\gamma$	8 TeV	
29	$h \to ZZ \to 4\ell$	7 TeV	
30	$h \to ZZ \to 4\ell$	8 TeV	
31	$h \to bb$	7 TeV	
32	$h \to \tau\tau$	7 TeV	
33	$h \to WW$	7 TeV	
34	$h \to WW$	8 TeV	
TeVatron			
35	$h \to \gamma\gamma$		
36	$h \to bb$		
37	$h \to WW$		

Data and Results (July 2012)



Data (black), SM (green), global best fit (red), best fit excluding point 5 (blue), best fit excluding points 5 and 36 (pink).

5D sigma-models (consistent truncation)

- Systematic way of constructing sugra backgrounds uses consistent truncation to 5D sigma-model (n scalars) coupled to gravity.

$$\begin{aligned}\mathcal{S} \;\equiv\; & \int \mathrm{d}^4x\mathrm{d}r \left\{ \sqrt{-g}\Theta \left[\frac{1}{4}R + \mathcal{L}_5(\Phi^a, \partial_M \Phi^a, g) \right] \right. \\ & + \sqrt{-\tilde{g}}\delta(r-r_1)\left[c_K K + \mathcal{L}_1(\Phi^a, \partial_\mu \Phi^a, \tilde{g})\right] \\ & \left. - \sqrt{-\tilde{g}}\delta(r-r_2)\left[c_K K + \mathcal{L}_2(\Phi^a, \partial_\mu \Phi^a, \tilde{g})\right] \right\}\end{aligned}$$

$$\mathrm{d}s^2_{1,4} \equiv e^{2A}\eta_{\mu\nu}\mathrm{d}x^\mu \mathrm{d}x^\nu + \mathrm{d}r^2$$

$$\begin{aligned}\mathcal{L}_5 &\equiv -\frac{1}{2}G_{ab}g^{MN}\partial_M\Phi^a\partial_N\Phi^b - V(\Phi^a) \\ \mathcal{L}_1 &\equiv -\lambda_{(1)}(\Phi^a)\,, \\ \mathcal{L}_2 &\equiv -\lambda_{(2)}(\Phi^a)\,.\end{aligned}$$

- Bulk equations and boundary terms determine 5D background, lift to 10D known.

$$\bar{\Phi}''^a + 4A'\bar{\Phi}'^a + \mathcal{G}^a{}_{bc}\bar{\Phi}'^b\bar{\Phi}'^c - V^a = 0$$

$$\begin{aligned}6A'^2 + 3A'' &= -G_{ab}\bar{\Phi}'^a\bar{\Phi}'^b - 2V, \\ 6A'^2 &= G_{ab}\bar{\Phi}'^a\bar{\Phi}'^b - 2V.\end{aligned}$$

- First-order equations may exist:

$$V = \frac{1}{2}G^{ab}W_aW_b - \frac{4}{3}W^2$$

$$\begin{aligned}A' &= -\frac{2}{3}W\,, \\ \bar{\Phi}'^{\,a} &= G^{ab}W_b = W^a\end{aligned}$$

5D sigma-models (consistent truncation)

- Given a background, one can study the spectrum of scalar fluctuations (systematic algorithmic procedure exists!), using gauge-invariant variables:

$$
\begin{aligned}
\mathfrak{a}^a &= \varphi^a - \frac{\bar{\Phi}'^a}{6A'}h, \\
\mathfrak{b} &= \nu - \frac{\partial_r(h/A')}{6}, \\
\mathfrak{c} &= e^{-2A}\partial_\mu \nu^\mu - \frac{e^{-2A}\Box h}{6A'} - \frac{1}{2}\partial_r H, \\
\mathfrak{d}^\mu &= e^{-2A}\Pi^\mu{}_\nu \nu^\nu - \partial_r \epsilon^\mu, \\
\mathfrak{e}^\mu{}_\nu &= h^{TT\mu}{}_\nu.
\end{aligned}
$$

Berg, Haack, Mueck hep-th/0507285

- Bulk equations and boundary terms known in general:

$$
\left[\mathcal{D}_r^2 + 4A'\mathcal{D}_r + e^{-2A}\Box\right]\mathfrak{a}^a - \left[V^a{}_{|c} - \mathcal{R}^a{}_{bcd}\bar{\Phi}'^b\bar{\Phi}'^d + \frac{4(\bar{\Phi}'^a V_c + V^a\bar{\Phi}'_c)}{3A'} + \frac{16V\bar{\Phi}'^a\bar{\Phi}'_c}{9A'^2}\right]\mathfrak{a}^c = 0,
$$

$$
\left[\delta^a{}_b + e^{2A}\Box^{-1}\left(V^a - 4A'\Phi'^a - \lambda^a{}_{|c}\bar{\Phi}'^c\right)\frac{2\bar{\Phi}'_b}{3A'}\right]\mathcal{D}_r\mathfrak{a}^b\Big|_{r_i} =
$$
$$
\left[\lambda^a{}_{|b} + \frac{2\bar{\Phi}'^a\bar{\Phi}'_b}{3A'} + e^{2A}\Box^{-1}\frac{2}{3A'}\left(V^a - 4A'\bar{\Phi}'^a - \lambda^a{}_{|c}\bar{\Phi}'^c\right)\left(\frac{4V\bar{\Phi}'_b}{3A'} + V_b\right)\right]\mathfrak{a}^b\Big|_{r_i}
$$

D. Elander, MP, arXiv:1010.1964

- Procedure: take your (confining) background, introduce UV and IR cutoffs (regulators), solve bulk equations and apply boundary conditions, repeat by progressively removing the two cutoffs. If IR and UV are healthy, the cutoff effects will decouple.

5D sigma-models (consistent truncation)

- Under sensible assumptions, and in the presence of a superpotential, the system can be simplified:

$$\begin{aligned} N^d_{\ b} &\equiv W^d_{\ |b} - \frac{W^d W_b}{W}\,, \\ \lambda_{(1)}{}^a_{\ |c} &\equiv W^a_{\ |c}\Big|_{r_1} + \left(m_1^2\right)^a_{\ c} \\ \lambda_{(2)}{}^a_{\ |c} &\equiv W^a_{\ |c}\Big|_{r_2} - \left(m_2^2\right)^a_{\ c} \end{aligned}$$

- Taking conservative approach (infinite boundary mass terms) accidentally light states avoided:

$$\left[e^{-4A}\left(\delta^a_b \mathcal{D}_r + N^a_{\ b}\right) e^{4A}\left(\delta^b_c \mathcal{D}_r - N^b_{\ c}\right) + \delta^a_c e^{-2A}\Box\right]\mathfrak{a}^c = 0$$

$$\left[e^{2A}\Box^{-1}\frac{W^c W_d}{W}\right]\left(\delta^d_{\ b}\mathcal{D}_r - N^d_{\ b}\right)\mathfrak{a}^b\Big|_{r_i} = \delta^c_{\ b}\mathfrak{a}^b\Big|_{r_i}$$

- Systematic study of scalar fluctuations for a given background requires only numerical (hard) work.

- Caveat: this procedure does not include holographic renormalization (yet!).

Dilaton Mass

- Example 1: Randall-Sundrum 1.
- AdS space, two boundaries (IR and UV).
- Dilaton is present in the spectrum (good).
- It is exactly massless (bad for phenomenology).
- Confinement by hand (hard-wall)

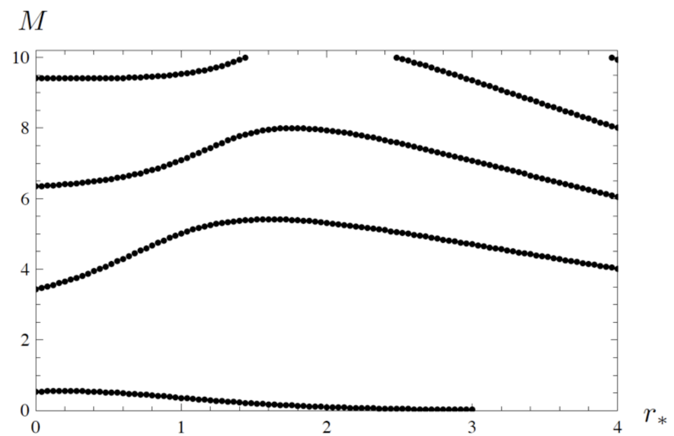
- Example 2: Goldberger-Wise.
- Add one bulk scalar to the RS1 set-up, with quadratic (super-)potential.
- Dilaton acquires finite mass, parametrically small provided the scalar is dual to a VEV ($\Delta>2$), or to a quasi-marginal deformation ($\Delta\cong 0$).
- Mass is UV-cutoff dependent (bad).
- Confinement by hand (hard-wall)

Dilaton Mass

- Example 3: cubic superpotential.
- Kink solution for the bulk scalar, models the flow between fixed points:

$$\bar{\Phi} = \frac{\Phi_I}{1 + e^{\Delta(r - r_*)}}.$$

- Similar models exist in the stringy context (see Pilch-Warner).
- Light dilaton present, finite mass independent of UV cutoff (good).



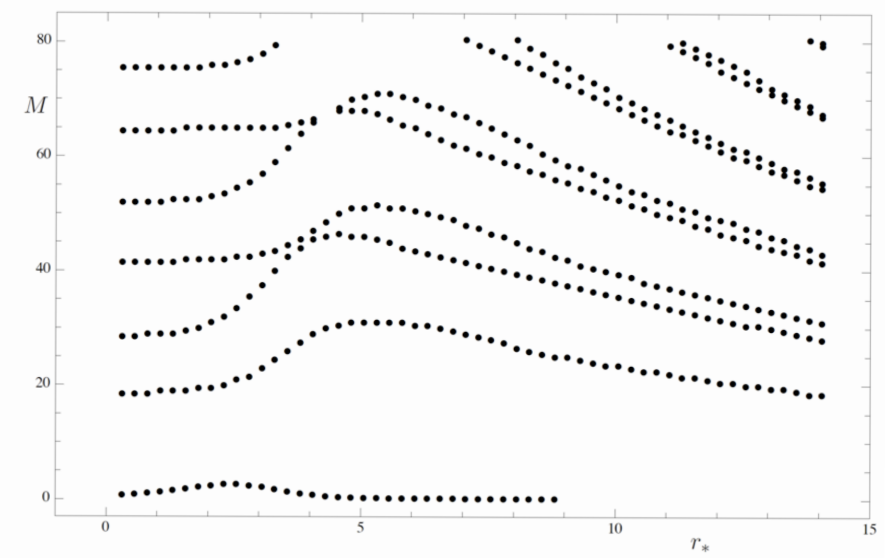
- Dependence on crude IR cutoff modeling still there (bad).

Dilaton Mass

- Pilch-Warner 2-scalar system, more complicated dynamics (dual to flow to Leigh-Strassler fixed point):

$$W = \frac{e^{-2\alpha}}{4}\left[\cosh(2\chi)\left(e^{6\alpha}-2\right)-\left(3e^{6\alpha}+2\right)\right]$$

- Solution still a kink. Spectrum contains light scalar:



Dilaton Mass

- Example 4: GPPZ (and its truncations or generalizations).
- No IR cut-off, end-of-space emerges dynamically from non-trivial superpotential:

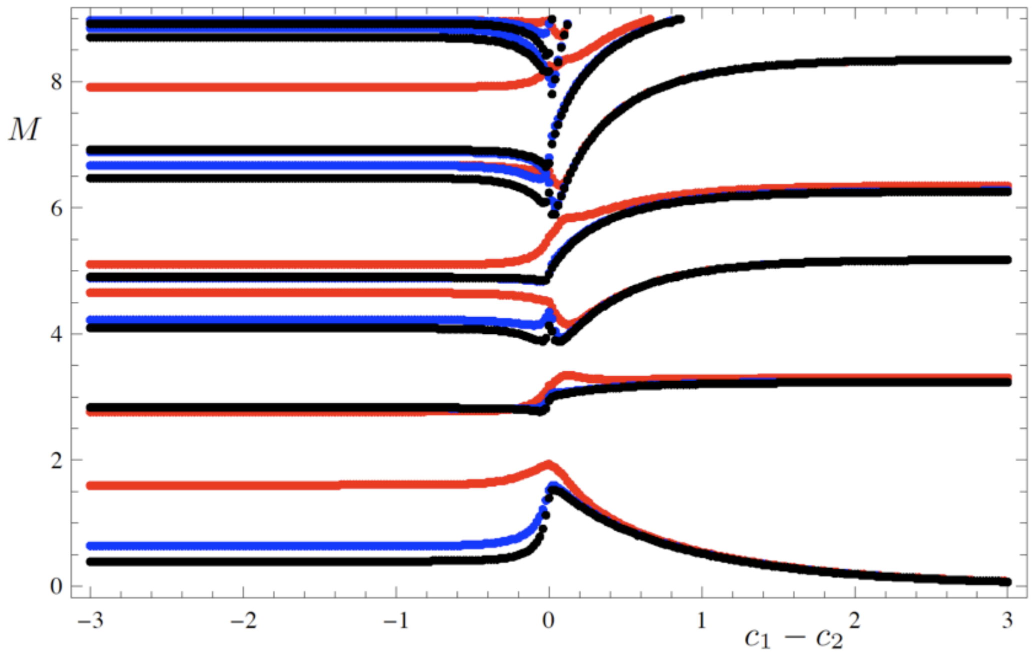
$$W = -\frac{3}{4}\left(\cosh 2\sigma + \cosh\frac{2m}{\sqrt{3}}\right)$$

- Singular behavior of the five-dimensional theory in the IR, while UV is asymptotically AdS:

$$\begin{aligned}
\sigma &= \ \text{arctanh}\ \left(e^{-3r+3c_1}\right) \simeq e^{3c_1}\xi^3\,,\\
m &= \sqrt{3}\,\text{arctanh}\ \left(e^{-r+c_2}\right) \simeq \sqrt{3}e^{c_2}\xi\,,\\
e^{2A} &= e^{-2r}\left(-1+e^{6(r-c_1)}\right)^{1/3}\left(-1+e^{2(r-c_2)}\right)e^{2c_1+2c_2} \simeq e^{2r}\,,
\end{aligned}$$

- Dilaton present, and mass is finite and UV-independent, PROVIDED the singularity is controlled by the Δ=3 VEV.

Dilaton Mass



- A light dilaton is present in the right part of the plot (Δ=3 dominates),
- Spurious state is NOT a dilaton in the left half (Δ=1 dominates),
- 10D lift known, this is a full stringy model. Unfortunately, badly singular: no Wilson loop (confining potential) can be computed.

Dilaton Mass

- Example 5: walking backgrounds from conifold and deformations.
- Very rich type-IIB class of models, many solutions.
- 5D consistent truncation(s) known but complicated (PT):

$$
\begin{aligned}
V \;=\; & -\frac{1}{2}e^{2p-2x}\left(e^{\tilde{g}}+(1+a^2)e^{-g}\right)+\frac{1}{8}e^{-4p-4x}\left(e^{2\tilde{g}}+(a^2-1)^2e^{-2\tilde{g}}+2a^2\right)\\
& +\frac{1}{4}a^2e^{-2\tilde{g}+8p}+\frac{1}{8}N^2e^{\Phi-2x+8p}\left[e^{2\tilde{g}}+e^{-2\tilde{g}}(a^2-2ab+1)^2+2(a-b)^2\right]\\
& +\frac{1}{4}e^{-\Phi-2x+8p}h_2^2+\frac{1}{8}e^{8p-4x}\left(M+2N(h_1+bh_2)\right)^2 .
\end{aligned}
$$

- Walking behavior seen in classes of solutions.
- Walking region NOT AdS: hyperscaling violation.
- UV asymptotic NOT AdS: computing couplings challenging.
- Light dilaton is present in the spectrum.
- Well behaved 10D sugra: Wilson loop can be computed, yields linear confining potential from quark-antiquark test particles.

Walking backgrounds from the conifold

- Three large classes of models identified, with very similar IR but very different UV.
- a) dimension-8 operator dominates UV,
- b) Maldacena-Nunez-like in the UV,
- c) Klebanov-Strassler-like in the UV.
- Gauge coupling from wrapping D5 on internal 2-cycle in classes a) and b):

$$\lambda_6 = g_s \alpha' N_c$$

$$g_4^2 = \frac{g_6^2}{Vol\Sigma_2}$$

$$\Sigma_2 = [\theta = \tilde{\theta},\ \ \varphi = 2\pi - \tilde{\varphi},\ \ \psi = \pi],$$

$$\frac{8\pi^2}{g^2} = 2[e^{2h} + \frac{e^{2g}}{4}(a-1)^2] = Pe^{-\tau}$$

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Nunez Paredes Ramallo hep-th/0311201
...

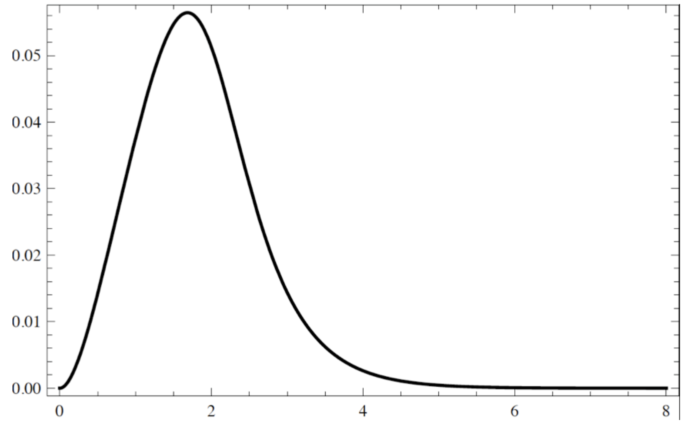
- With these definitions, the Maldacena-Nunez background reproduces NSVZ beta function.
- In the presence of dimension-6 VEV, something very different happens.

Precision Physics

- Example: kink solution, but the bulk scalar is the composite Higgs field:

$$H = \frac{1}{\sqrt{2}}\Phi e^{i\theta} \qquad \Phi = \frac{\Phi_I}{1+e^{\Delta(r-r_*)}}$$

- EWSB induced by integrating over holographic direction the profile:

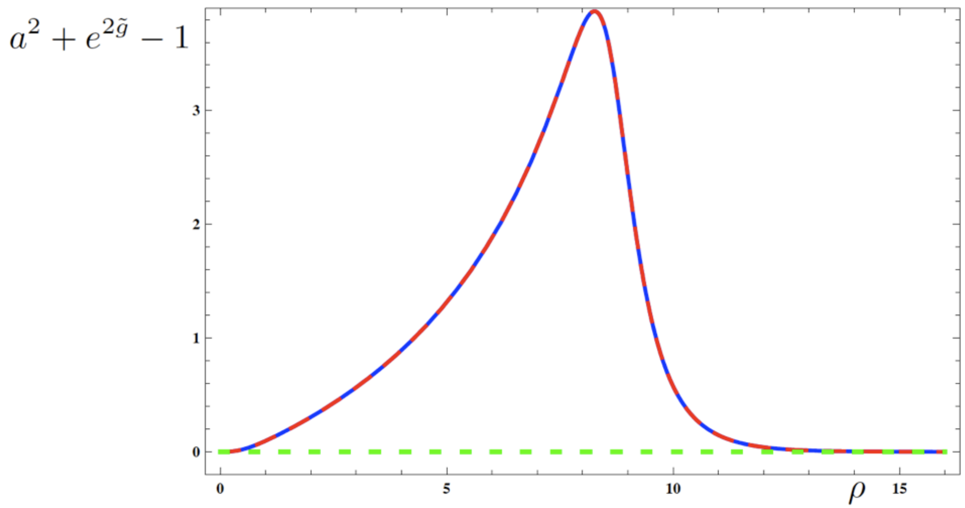


- Breaking effects localized away from IR boundary, S parametrically suppressed

$$\hat{S} \simeq \cos^2\theta_W M_Z^2 \left(\frac{1}{2} + r_* + r_*^2\right) e^{-2r_*}$$

Precision Physics

- Example of similar phenomenon in well-understood example: baryonic branch of Klebanov-Strassler.
- Profile of baryonic VEV (Δ=2) in one subclass of models:



- This is NOT a TC model. However this VEV induces Higgsing of part of the dual quiver gauge symmetry! (Proof of concept). But from here to an actual model, it is a long way to go...