Walking Dynamics from Gauge/Gravity dualities.

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C. Nunez, I.Papadimitriou, MP,	arXiv:0812.3655
O. C. Gurdogan,	arXiv:0906.0307
C. Nunez, MP, A. Rago,	arXiv:0909.0748
D. Elander, C. Nunez, MP,	arXiv:0908.2808
D. Elander,	arXiv: 0912.1600
MP,	arXiv:1004.0176
D. Elander, MP,	arXiv:1010.1964
S.P. Kumar, D. Mateos, A. Paredes, MP,	arXiv:1012.4678
D. Elander, J. Gaillard, C. Nunez, MP,	arXiv:1104.3963

Outline

- Electro-Weak Symmetry Breaking and Walking.
- Light Dilatons.

- Program: Walking and Gauge/Gravity dualities.

- Light Scalars from 5D sigma-models.
- ‘Walking’ backgrounds and the sphere.
- ‘Walking’ backgrounds and the conifold.

- Summary and Outlook.

Standard MODEL of Electro-weak and Strong Interactions

- Quantum Field Theory.
- Gauge Theory.
- Spontaneous Symmetry Breaking.

Specific Definition:

- Gauge Group: SU(3)xSU(2)xU(1).
- Quantum Numbers of Quarks and Leptons.
- Spontaneous Symmetry Breaking:

  i) Symmetry Breaking to SU(3)xU(1),

  ii) Mechanism (Fields an Interactions).

Standard MODEL of Electro-weak and Strong Interactions

- SM provides accurate description of fundamental interactions.
- Most fundamental particles are massive.
- Masses arise from EWSB.
- Known fields do not induce EWSB.
- Known interactions do not induce EWSB

SAFE BETS

- New particles MUST exist
- New interaction MUST exist.

Standard MODEL of Electro-weak and Strong Interactions

- What kind of particles?
- What kind of new interaction? Weakly or strongly coupled?
- How do you tell the difference?

Examples:

- Weak coupling: elementary scalar field, quartic coupling, light scalar particle (Higgs)
- Strong coupling: QCD-like new interaction (technicolor), no light scalar.

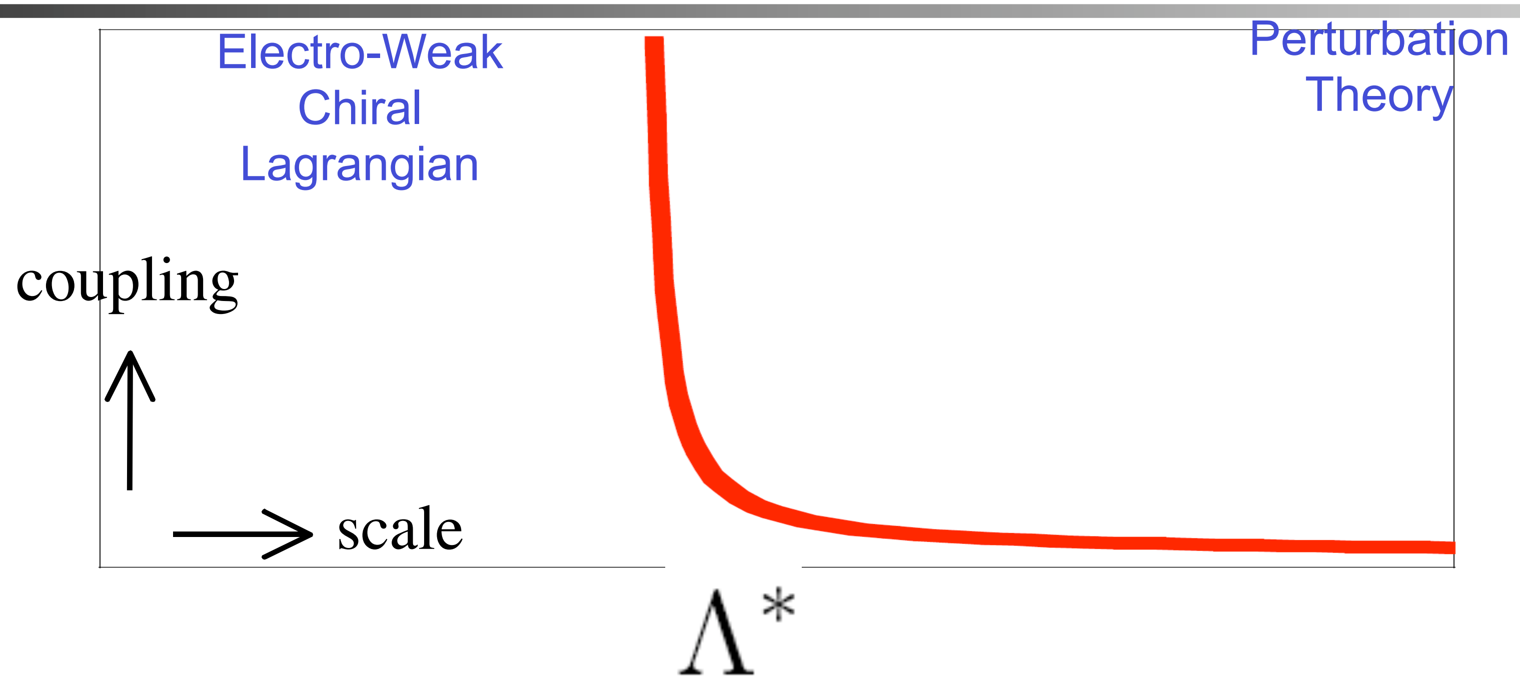
TECHNICOLOR

- Instead of (Higgs) weakly coupled sector responsible for EWSB, along the lines of the scalar theory in the example, introduce a new strongly-coupled sector responsible for EWSB, along the lines of QCD.
- Question 1: calculating at strong coupling?
- Question 2: models with QCD-like dynamics already ruled out (by precision measurements). But most importantly: why?

- Answer 2: dynamics MUST be very different from QCD. Walking TC important candidate.

- Question 3: is there or not a light scalar? (in QCD, we know there is not, but what about walking TC?)

QCD-like Technicolor.



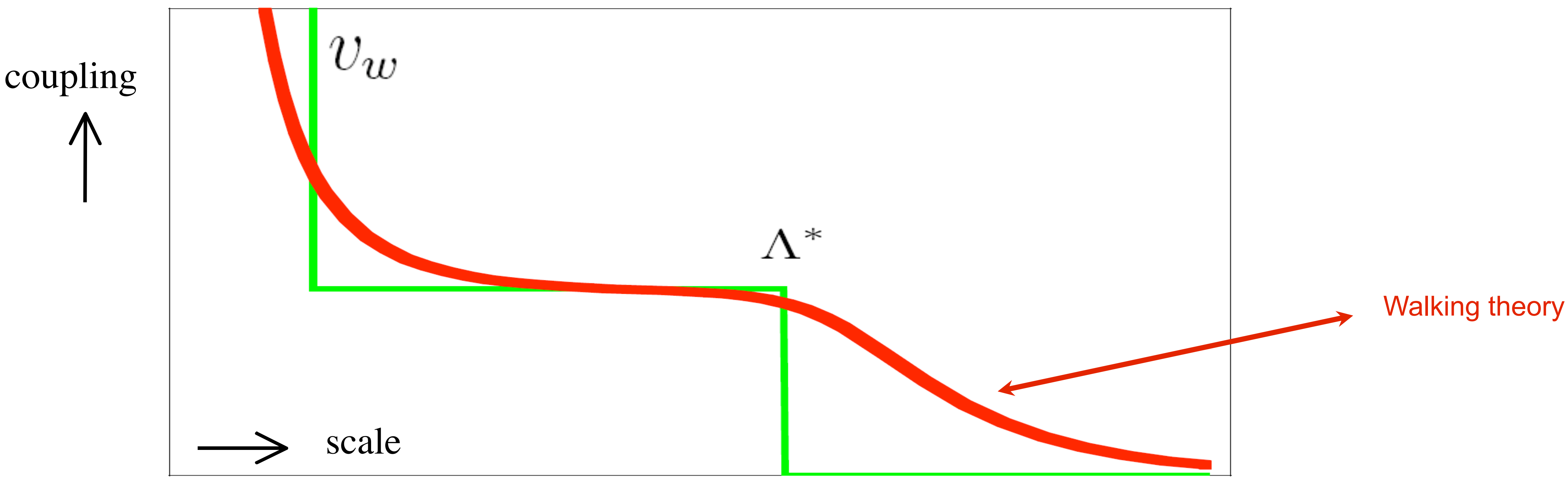
Traditional Technicolor, QCD-like. ONE dynamical scale:

NO big hierarchy problem (CFT at weak coupling), but

- Computational problem: strong coupling.
- Phenomenological problem(s): one only scale and no small parameters, and hence, even if you do not know how to compute precisely, expect problems with precision physics, FCNC, fermion masses, light pseudo-scalars ...

WALKING TC

Holdom 1985, Yamawaki et al. 1986, Appelquist et al. 1986



- Strong dynamics, very different from QCD: approximate scale invariance, large anomalous dimensions, long intermediate energy range...
- Multi-scale dynamics: NDA expectations changed, large hierarchies introduce small parameters.
- Phenomenology can be accommodated!

- Computing?
- Is there a light scalar (dilaton)? In field theory, not known!

W. A. Bardeen *et al.* Phys. Rev. Lett. 56, 1230 (1986); 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]].

Higgs particle as a Dilaton

MINIMAL STANDARD MODEL

- Gauge bosons kinetic terms

$$\mathcal{L}_1 = -\frac{1}{2}\mathrm{Tr}F_{\mu\nu}F^{\mu\nu} + \cdots ,$$

- Fermions kinetic terms

$$\mathcal{L}_{1/2} = \bar{\psi}\, i\not{D}\, \psi + \cdots ,$$

- Scalar kinetic term

$$\mathcal{L}_0 = (D_\mu H)^\dagger D^\mu H$$

- Yukawa couplings

$$\mathcal{L}_y = -y\, \bar{\psi}_L\, H\, \psi_R + \cdots ,$$

- Scalar potential

$$\mathcal{L} = -\mathcal{V} = -\mu^2 H^\dagger H - \lambda\left(H^\dagger H\right)^2 .$$

Minimization

- Vacuum Expectation Value (VEV)

$$\langle H^\dagger H\rangle = -\frac{\mu^2}{2\lambda} \equiv \frac{v^2}{2} ,$$

- Physical Higgs mass

$$H = \frac{v+h}{\sqrt{2}} \rightarrow m_h^2 = -2\mu^2 = 2\lambda v^2 .$$

Classical scaling dimensions

- Action

$$\mathcal{S} = \int \mathrm{d}^4x\, \mathcal{L} \rightarrow [\mathcal{L}] = [x]^{-4}$$

- Bosons

$$[A_\mu] = [x]^{-1} \rightarrow [F_{\mu\nu}] = [\partial_\mu A_\nu] = [x]^{-2} ,$$
$$[H] = [x]^{-1} \rightarrow [D_\mu H] = [\partial_\mu H] = [x]^{-2} ,$$

- Fermions

$$[\psi] = [x]^{-3/2} \rightarrow [D_\mu \psi] = [\partial_\mu \psi] = [x]^{-5/2} ,$$

Conformal Symmetry Breaking

- **Explicit**: the μ^2 term is the **ONLY** term in the Lagrangian that breaks dilatation symmetry at the classical level.
- **Spontaneous**: the VEV v^2 breaks the symmetry in the vacuum.
- **Higgs as a Dilaton**: taking the limit $\lambda \rightarrow 0$ ($\mu^2 \rightarrow 0$) while keeping v^2 fixed, implies $m_h^2 \rightarrow 0$. The Higgs is the dilaton, the pseudo-Goldstone boson associated with global scaling invariance.

Higgs Couplings

- At classical level the SM Higgs is a (pseudo-)dilaton.
- Coupling to stress-energy tensor yields coupling via the masses:

$$\begin{aligned}\mathcal{L} \;=\; & 2\frac{h}{v}\, m_W^2\, W^{\mu\,+} W_\mu^- \\ & +\frac{h}{v}\, m_Z^2\, Z^\mu Z_\mu \\ & -\frac{h}{v}\, m_\psi\, \bar{\psi}\psi\, \cdots\end{aligned}$$

- Huge predictive power: the phenomenology is completely determined by symmetry principles. Only one parameter (the explicit symmetry breaking parameter, i.e. the Higgs mass).
- Deviations come from quantum effects (coupling to gluons and photons...) and/or from higher-order operators (new physics at TeV scale...).
- General question: in your favorite extension of the Standard Model, is there a dilaton? If so, it will look very similar to a light Higgs!
- Specific question: is there a light dilaton in walking TC? After all, the theory at scales just above the EWSB is approximately scale invariant!

Using gauge/gravity dualities: Program

MP, arXiv:1004.0176

- Build string backgrounds dual to non-conformal D=4 theory,
- Walking TC: multi-scale dynamics, quasi-conformal, confinement, non-trivial condensates...
- Analyze field theory: scales, symmetries, operators...
- Is there a light scalar? Is it a dilaton? does it resemble the Higgs particle?

- Realistic model: couple to SM fermions and gauge bosons.
- Test the models against precision data.
- Make predictions for LHC.

Where do we stand?

- Given a background (within sugra!), algorithmic procedure exists for checking whether a light scalar is present in the spectrum.
  D. Elander, MP, arXiv:1010.1964

- Sphere: backgrounds dual to N=4 offer nice field theory environment, in which walking behavior is a natural expectation. Clean environment to test tools. However, it is hard to describe confinement...
  S.P. Kumar, D. Mateos, A. Paredes, MP, arXiv:1012.4678

- Conifold: backgrounds related to the conifold have nicer and richer structure, confinement can be described within sugra (!), many condensates present (dimension-2, dimension-3, dimension-6) yield multi-scale dynamics, irrespectively of UV-details.
  C. Nunez, I.Papadimitriou, MP, arXiv:0812.3655
  O. C. Gurdogan, arXiv:0906.0307
  C. Nunez, MP, A. Rago, arXiv:0909.0748
  D. Elander, C. Nunez, MP, arXiv:0908.2808
  D. Elander, arXiv: 0912.1600
  D. Elander, J. Gaillard, C. Nunez, MP, arXiv:1104.3963

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.

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

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

$$6A'^2 = G_{ab}\bar{\Phi}'^a\bar{\Phi}'^b - 2V.$$

- First-order equations may exist (easier and supersymmetric):

$$\begin{aligned}V &= \frac{1}{2}G^{ab}W_aW_b - \frac{4}{3}W^2 \\ A' &= -\frac{2}{3}W\,, \\ \bar{\Phi}'^{\,a} &= G^{ab}W_b = W^a\end{aligned}$$

5D sigma-models (consistent truncation)

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

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

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!).

Walking backgrounds from the sphere

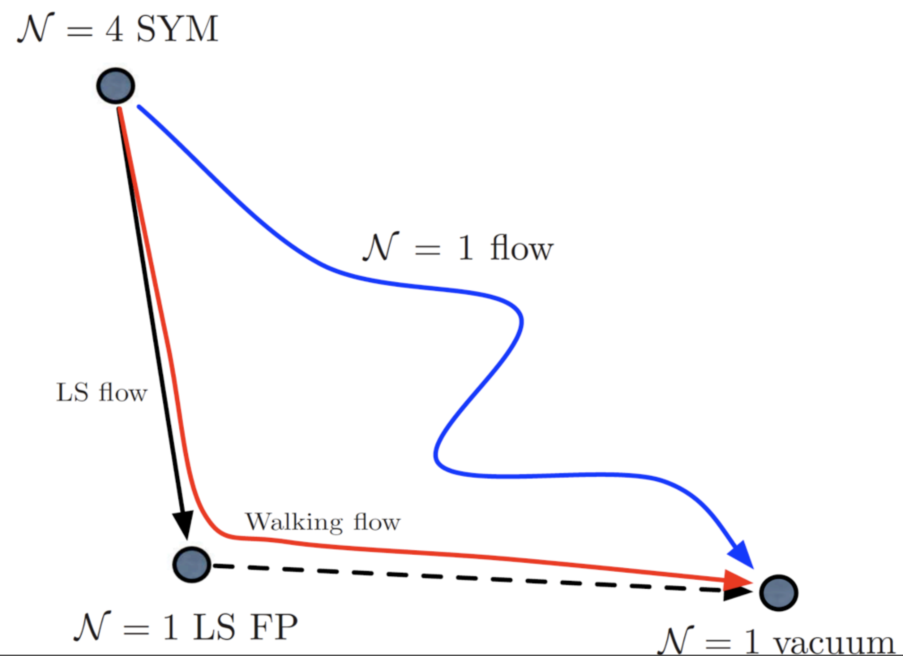
- Field Theory: N=4 SYM, deformed by mass M for one of the chiral superfields admits N=1 IR fixed-point (Leigh-Strassler).
- Gravity Dual: type IIB, consistent truncation to 5D sigma-model (two scalars), the whole flow between the two fixed points is known (numerically) from:

$$-\frac{1}{2}G_{ab}g^{MN}\partial_M\phi^a\partial_N\phi^b = -\frac{1}{2}(\partial\chi)^2 - 3(\partial\alpha)^2$$

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

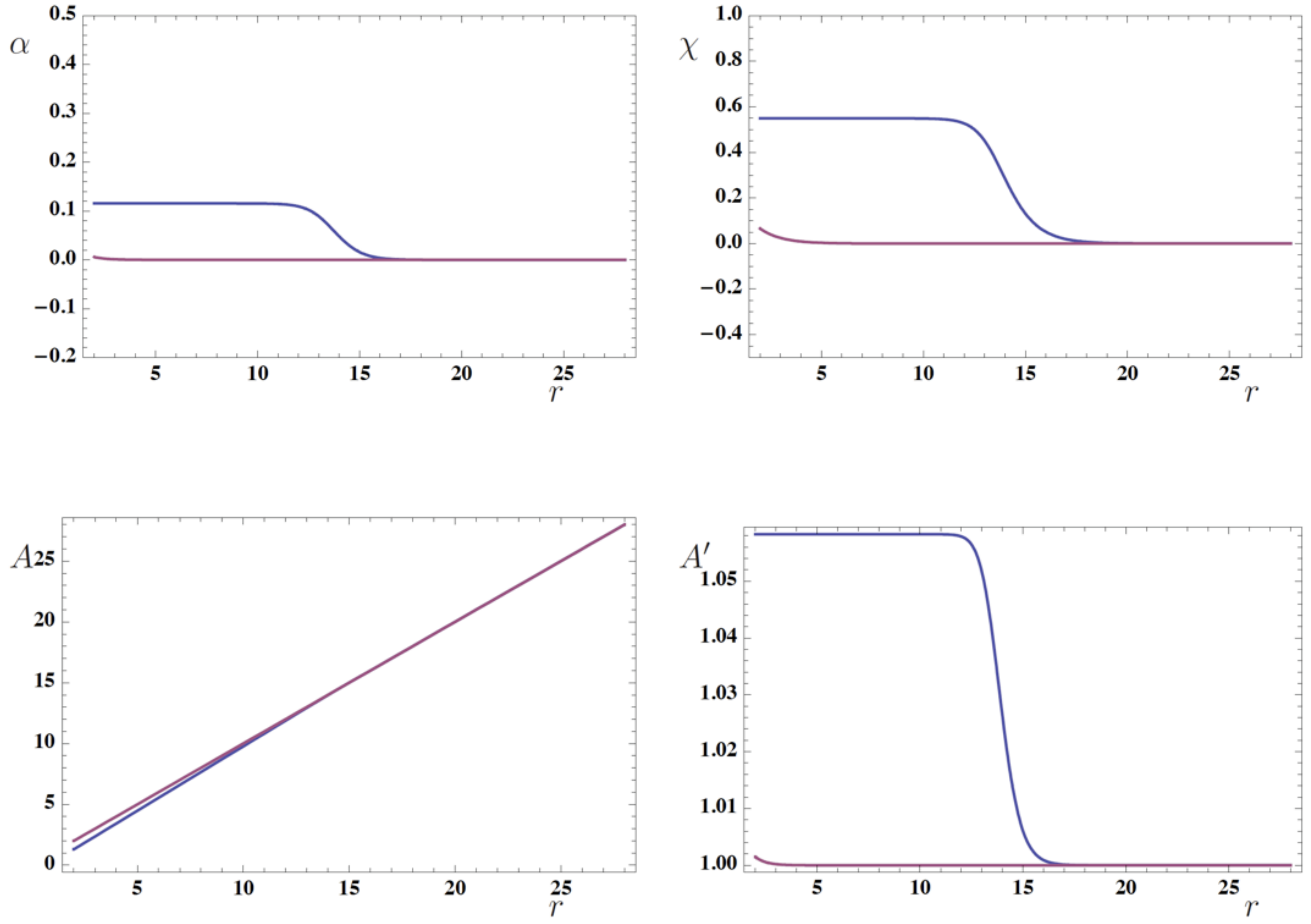
R.G. Leigh, M. J. Strassler, hep-th/9503121
J. Polchinski, M.J. Strssler, hep-th/0003136
K. Pilch, N. Warner, hep-th/0006066
S.P. Kumar, D. Mateos, A. Paredes, MP, arXiv:1012.4678

- Walking theory: add mass m for the other two chiral fields: at very low energy this should confine in the same way as N=1 SYM (Polchinski-Strassler). If hierarchy m<<M, then walking region expected.



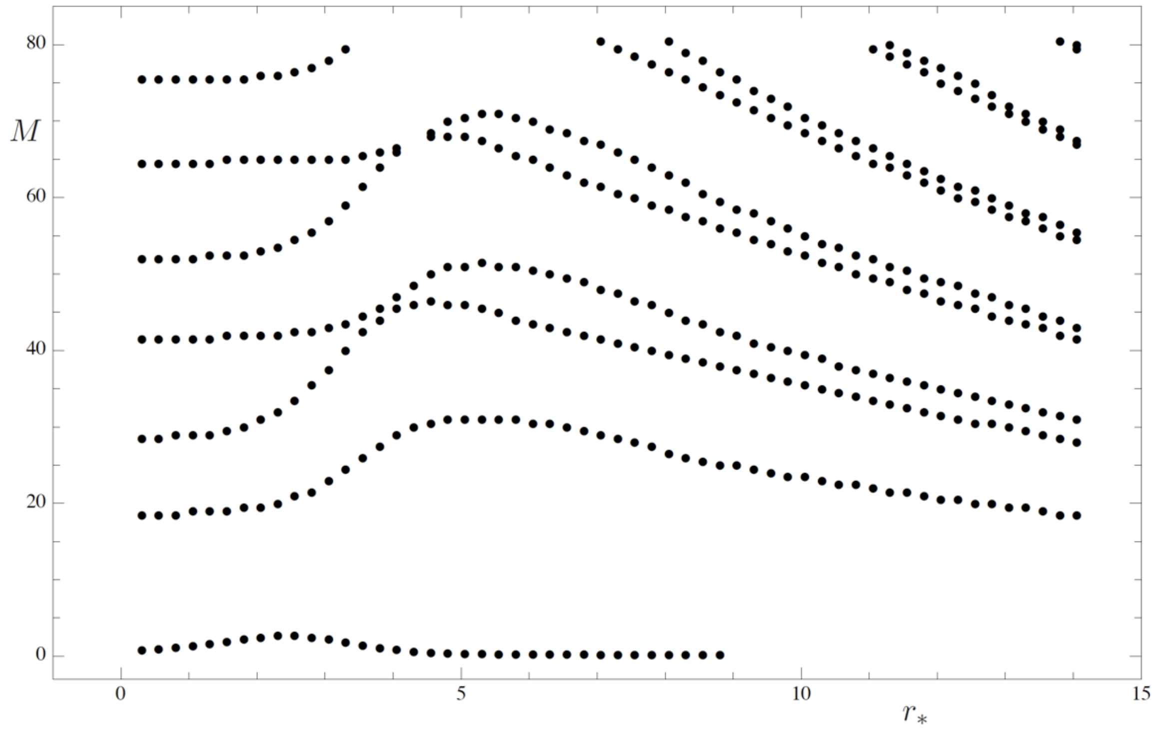
Walking backgrounds from the sphere

- Pilch-Warner flow, background functions of the radial coordinate, IR and UV AdS with different curvature.



Walking backgrounds from the sphere

- Confinement: sigma-model must be extended, maybe string IR completion needed (not known).
- Spectrum of scalars: model with hard-wall IR cut-off (crude), and compute by keeping IR cut-off fixed, but varying scale at which theory approaches IR fixed point.



- Result: two series of resonances, scale determined by IR cut-off, plus ONE LIGHT scalar, with mass suppressed by the 'walking' scale.
- Conclusion: the whole procedure works. Now, needs to be applied to a confining theory!

Walking backgrounds from the conifold

- Next order of complexity in IIB: replace internal space with base of the conifold (N=1 at most), and add fluxes (curved geometry).
- Truncation exists and understood: PT (8 scalars), CF/BGGHO (16 scalars + 9 vectors, N=4 D=5).
- Several (regular) confining models exist: Maldacena-Nunez, Klebanov-Strassler, Butti et al. (!!!!!!!!)
- Focus on Papadopoulos-Tseytlin:

J. M. Maldacena, C. Nunez hep-th/0008001

I. Klebanov, M.J. Strassler, hep-th/0007191

A. Butti et. al. hep-th/0412187

G. Papadopoulos, A. A. Tseytlin hep-th/0012034

...many more!

$$
\begin{aligned}
G_{ab}\partial_M\Phi^a\partial_N\Phi^b \;=\; & \frac{1}{2}\partial_M\tilde{g}\partial_N\tilde{g} + \partial_M x\partial_N x + 6\partial_M p\partial_N p + \frac{1}{4}\partial_M\Phi\partial_N\Phi + \frac{1}{2}e^{-2\tilde{g}}\partial_M a\partial_N a \\
& + \frac{1}{2}N^2 e^{\Phi-2x}\partial_M b\partial_N b + \frac{e^{-\Phi-2x}}{e^{2\tilde{g}}+2a^2+e^{-2\tilde{g}}(1-a^2)^2}\Big[(1+2e^{-2\tilde{g}}a^2)\partial_M h_1\partial_N h_1 \\
& + \frac{1}{2}(e^{2\tilde{g}}+2a^2+e^{-2\tilde{g}}(1+a^2)^2)\partial_M h_2\partial_N h_2 + 2a(e^{-2\tilde{g}}(a^2+1)+1)\partial_M h_1\partial_N h_2\Big]
\end{aligned}
$$

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

- Significantly richer and more complicated vacuum structure.
- A number of backgrounds have been found which show interesting features.
- IR determined by 3 different condensates, of dimension-2 (resolution, baryonic branch), dimension-3 (deformation, gaugino condensate) and dimension-6 (regularization, ?).

Walking backgrounds from the conifold

- The full 10-dimensional background is known, once a solution of the 5D system is:

$$
\begin{aligned}
ds^2 &= e^{2p-x} ds_5^2 + (e^{x+\tilde{g}} + a^2 e^{x-\tilde{g}})(e_1^2 + e_2^2) + e^{x-\tilde{g}} \left(e_3^2 + e_4^2 - 2a(e_1 e_3 + e_2 e_4) \right) + e^{-6p-x} e_5^2, \\
ds_5^2 &= dr^2 + e^{2A} dx_{1,3}^2, \\
F_3 &= N \left[e_5 \wedge (e_4 \wedge e_3 + e_2 \wedge e_1 - b(e_4 \wedge e_1 - e_3 \wedge e_2)) + dr \wedge (\partial_r b (e_4 \wedge e_2 + e_3 \wedge e_1)) \right], \\
H_3 &= -h_2 e_5 \wedge (e_4 \wedge e_2 + e_3 \wedge e_1) + dr \wedge \Big[\partial_r h_1 (e_4 \wedge e_3 + e_2 \wedge e_1) - \\
&\quad \partial_r h_2 (e_4 \wedge e_1 - e_3 \wedge e_2) + \partial_r \chi (-e_4 \wedge e_3 + e_2 \wedge e_1) \Big], \\
F_5 &= \tilde{F}_5 + \star \tilde{F}_5, \quad \tilde{F}_5 = -\mathcal{K} e_1 \wedge e_2 \wedge e_3 \wedge e_4 \wedge e_5.
\end{aligned}
$$

- The internal space depends on five angles via

$$
\begin{aligned}
e_1 &= -\sin\theta \mathrm{d}\phi \,, \\
e_2 &= \mathrm{d}\theta \,, \\
e_3 &= \cos\psi \sin\tilde{\theta} \mathrm{d}\tilde{\phi} \, - \, \sin\psi \mathrm{d}\tilde{\theta} \,, \\
e_4 &= \sin\psi \sin\tilde{\theta} \mathrm{d}\tilde{\phi} \, + \, \cos\psi \mathrm{d}\tilde{\theta} \,, \\
e_5 &= \mathrm{d}\psi + \cos\tilde{\theta} \mathrm{d}\tilde{\phi} + \cos\theta \mathrm{d}\phi \,.
\end{aligned}
$$

- I will focus on models where the dimension-6 condensate appears.
- I will show three ‘observable’ quantities, computed starting from the backgrounds, as a function of the scale at which the dimension-6 VEV becomes important: gauge coupling, Wilson loop and scalar spectrum.

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:

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

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

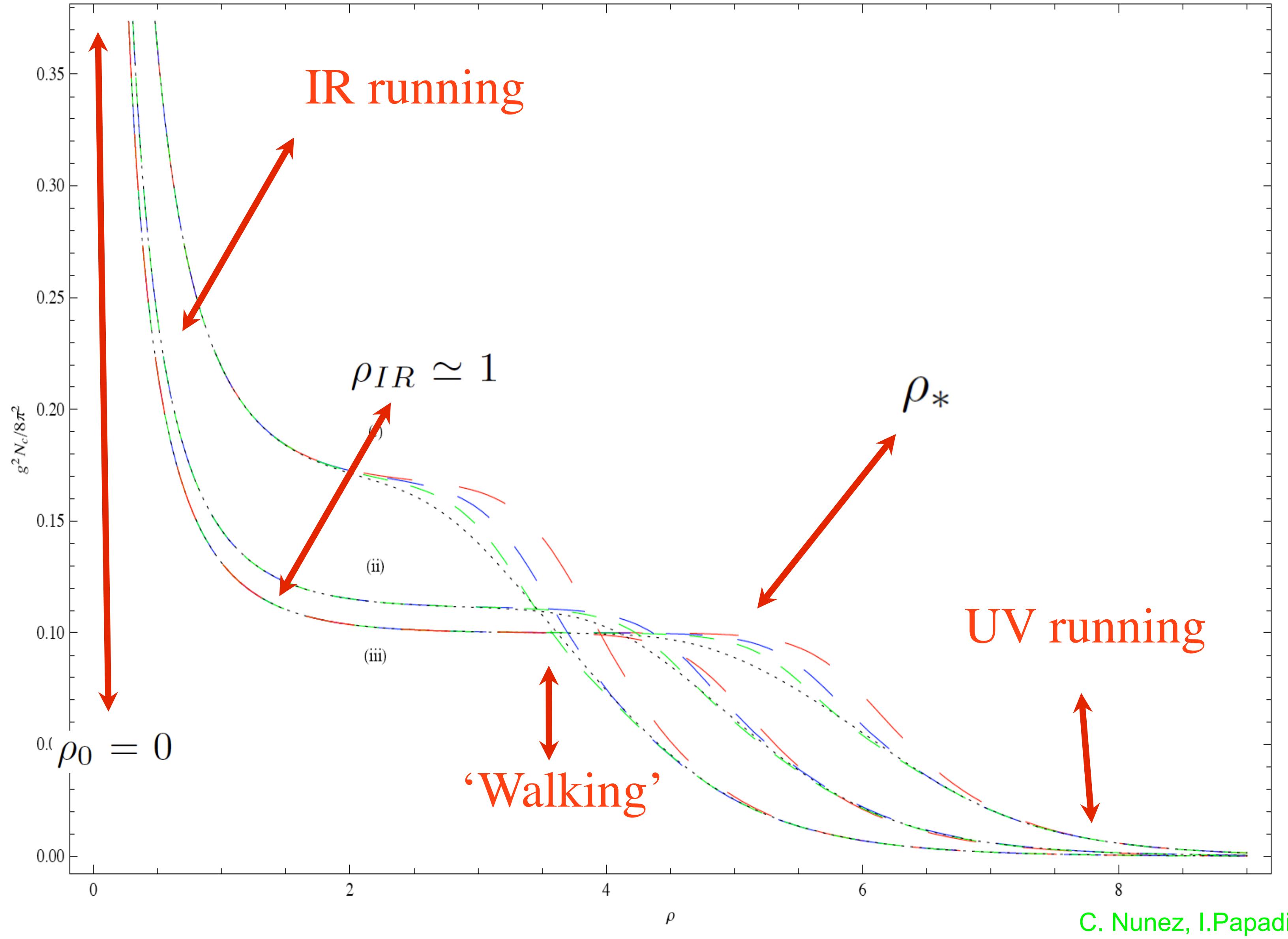
$$\Sigma_2 = [\theta = \tilde{\theta}, \ \ \varphi = 2\pi - \tilde{\varphi}, \ \ \psi = \pi],$$

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

Di Vecchia Lerda Merlatti hep-th/0205204
Bertolini Merlatti hep-th/0211142
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.

The gauge coupling (class a)

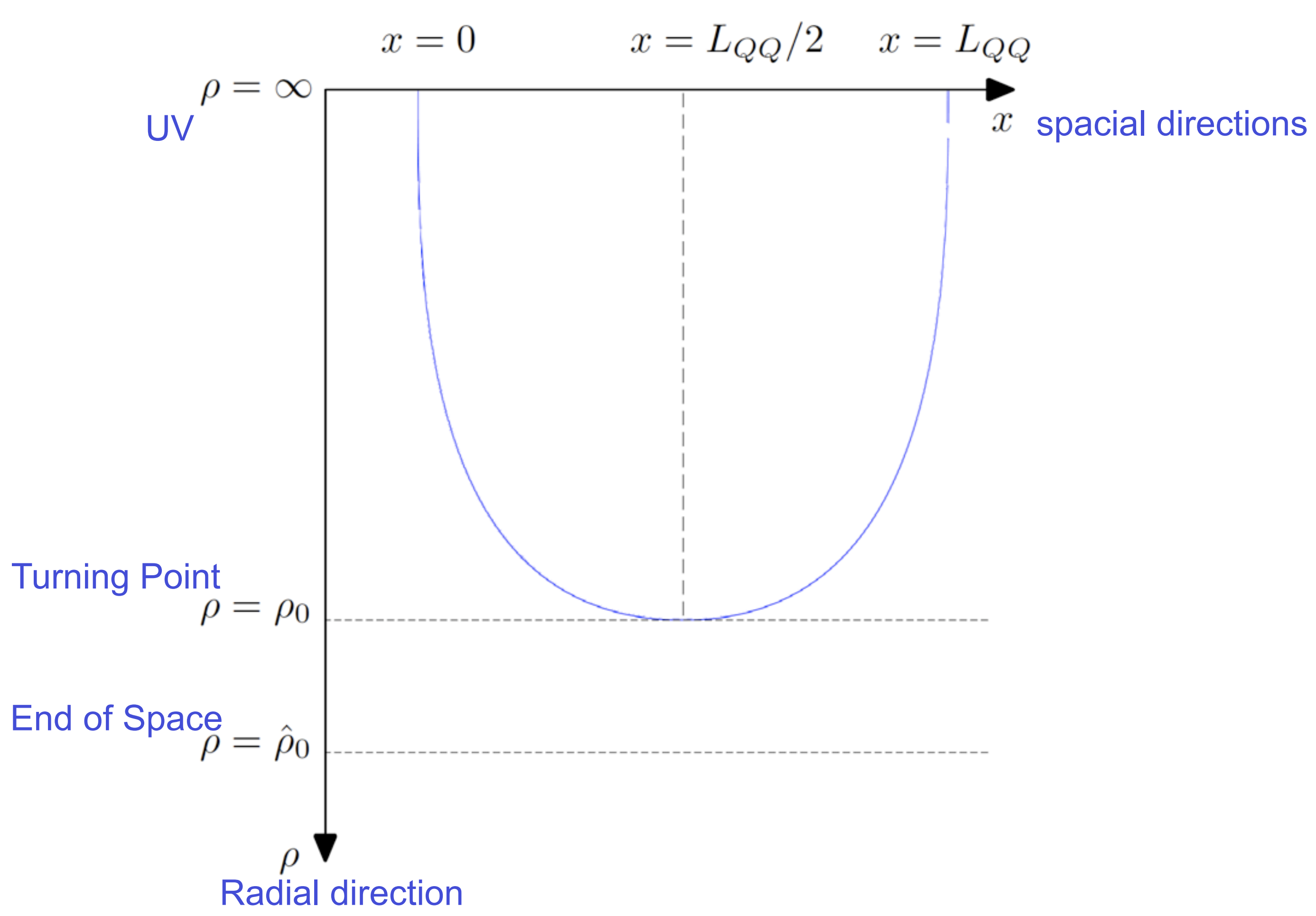


C. Nunez, I.Papadimitriou, MP, arXiv:0812.3655

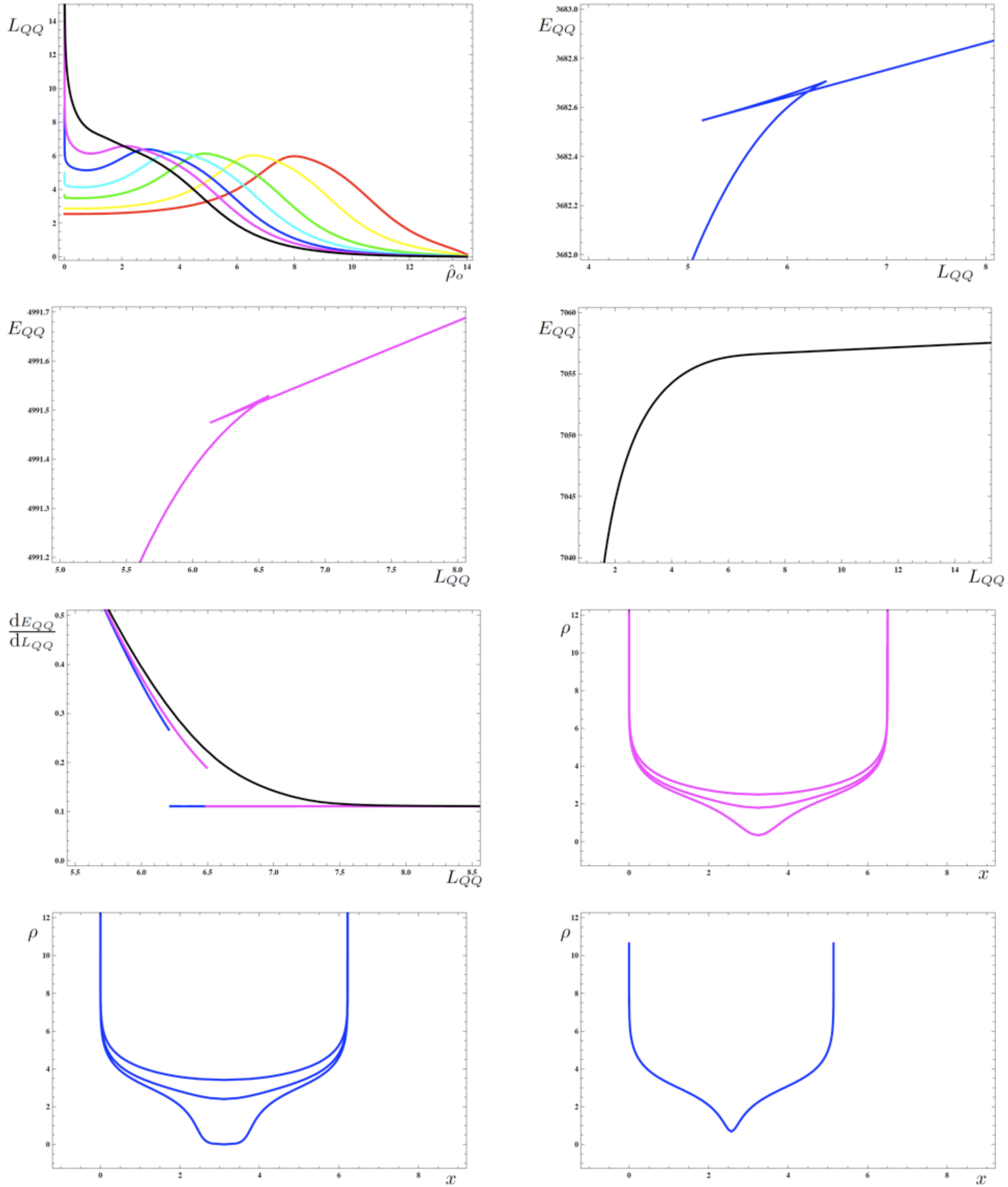
FIG. 3: The 't Hooft coupling $g^2N_c/(8\pi^2)$ as a function of ρ for various values of the parameters c, α. All three curves are for $N_c = 10$, while $c = 60$, $\alpha = 0.01$ for (i), $c = 90$, $\alpha = 0.002$ for (ii) and $c = 100$, $\alpha = 0.0005$ for (iii). The red (long dashes) curves are 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.

Wilson loops (class b and c)

- Confinement can be studied by probing backgrounds with string, hanging from D3 at infinity.
- Wilson-loop VEV calculable, potential for heavy quark-antiquark system extracted.



D. Elander, J. Gaillard, C. Nunez, MP, arXiv:1104.3963

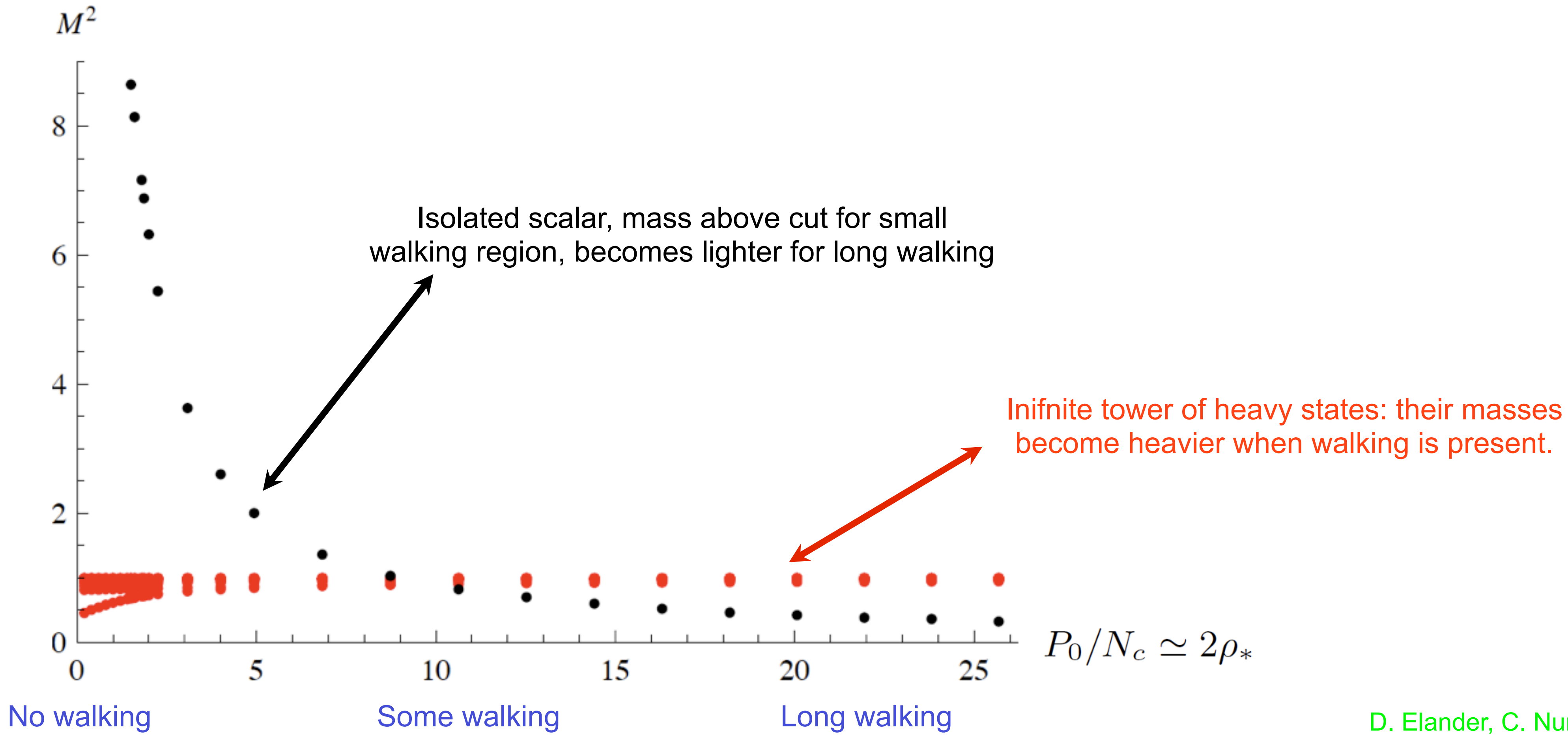


Wilson loops summary

- Wilson loop calculation can be done, no problems.
- At large distance, potential is linear: confinement.
- At short distance potential is inverse power-law (approximately).
- At intermediate distance, a region appears where three different classical configurations coexist: first-order phase transition is taking place!
- The transition disappears in the absence of the dimension-6 VEV (which also controls existence of walking region).
- The transition is strongly first-order.
- This behavior exists for backgrounds that in the UV are very different (KS-like vs. MN-like).
- THIS IS A MULTI-SCALE SYSTEM.
- What is the order parameter? (work in progress...)

Scalar Spectrum (class b)

- Scalar spectrum can be studied, but heavy (numerical) problem.
- We computed the scalar spectrum for one class of such models, and with simplified boundary conditions.
- Work in progress: spectrum of other classes, theory algorithm to be simplified, holographic renormalization to be developed and applied, simpler models to be tested.



D. Elander, C. Nunez, MP, arXiv:0908.2808

Summary and Outlook

- Gauge/gravity dualities useful tools, allow to study strongly coupled models of DEWSB.
- Models exist that 'resemble' walking TC: non-trivial RG flow, multi-scale dynamics, confinement...
- New feature emerging from dimension-6 VEV: strong first-order phase transition.
- Parametrically light scalar present in the spectrum (in simplest cases: work in progress!).

- D7 probe system exhibits chiral symmetry breaking (analogous to Sakai-Sugimoto), but with chiral condensate parametrically small (suppression of S parameter). L. Anguelova,P. Suranyi, R.Wijewardhana, arXiv:1105.4185

- More models need to be found (sugra confining model from sphere would be useful... others?).
- Certain dynamical features not clear: conformal invariance (walking) never visible in the metric.
- Field theory duals not completely understood (where is the dimension-6 VEV coming from?)
- Calculation of the scalar spectrum done only for simplest models, and in simplified framework (better studies are in progress).
- Complete implementation, coupling to Standard Model still to be done (D7 probe study exists only for one very special case).