Holographic Tools for Beyond the Standard Model Physics

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STAG RESEARCH CENTRE

There are a wide range of BSM models that assume strong coupling…

both across a wide range of scales… and including strongly coupled broken gauge interactions…

Eg Technicolour, including walking and ideal
- Extended Technicolour
- Top condensation
- Composite higgs models
- Tumbling
- Dark Matter sectors
- Inflatons….

Motivated by a distrust of fundamental scalars… but an array of interesting gauge theories have been proposed independent of that…

Many of these ideas are beyond the lattice since they are spread over many decades of RG scale or involve chiral fermions… a role for holography?

Holography for Generic Symmetry Breaking Gauge Theories

Start top down at large Nc

Move to bottom up

QCD – the symmetry breaking arch-type

One of the most remarkable aspects of the Standard Model is that the ground state symmetries are less than those of the bare Lagrangian…

- Higgs potential is adhoc and not yet understood
- QCD provides a DYNAMICAL symmetry breaking mechanism

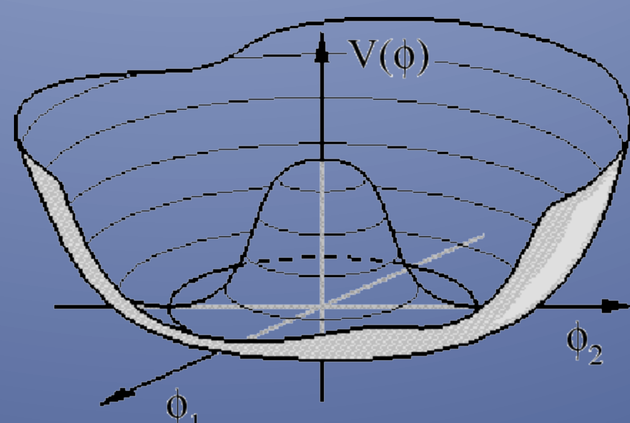
$$SU(2)_L \times SU(2)_R \to SU(2)_V$$

$$m\bar{\psi}\psi = m(\bar{\psi}_L\psi_R + h.c.)$$

$$\bar{u}\gamma^\mu u = \bar{u}_L\gamma^\mu u_L + \bar{u}_R\gamma^\mu u_R$$

Evidence: lack of parity doubling, proton mass, Goldstone pions

$$\langle \bar{u}_L u_R + \bar{d}_L d_R + h.c. \rangle \neq 0$$



$$U_L \to \bar{U}_L U_R \to U_R$$

Holographic Quarks

The simplest holographic model of quarks is D3/ probe D7

Adds quarks with conformal N=4 gauge interactions

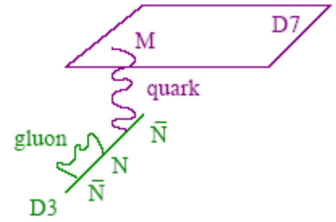
These do not trigger chiral symmetry breaking on their own

Quark mass = T L(ρ)

Mateos, Myers, Kruczenski... hep-th/0304032

Adding Quarks

Bertolini, DiVecchia...; Polchinski, Grana; Karch, Katz...



Quarks can be introduced via D7 branes in AdS

The brane set up is

	0	1	2	3	4	5	6	7	8	9
D3	—	—	—	—	●	●	●	●	●	●
D7	—	—	—	—	—	—	—	—	●	●

$\underbrace{4\ 5\ 6\ 7}_{\text{fills radial dirn of AdS, } S^3 \text{ embedded in } S^5}$ $\underbrace{8\ 9}_{U(1)_A}$

We will treat D7 as a probe - quenching in the gauge theory.

Minimize D7 world volume with DBI action

$$S_{D7} = -T_7 \int d\xi^8 \sqrt{P[G_{ab}]}, \qquad P[G_{ab}] = G_{MN} \frac{dx^M}{d\xi^a} \frac{dx^N}{d\xi^b}$$

$$P[G]+F = \begin{pmatrix} -\frac{r^2}{R^2} & & & & & & & \\ & \frac{r^2}{R^2} & B^z & & & & & \\ & -B^z & \frac{r^2}{R^2} & & & & & \\ & & & \frac{r^2}{R^2} & & & & \\ & & & & \frac{R^2}{r^2}\left(1+(\partial_\rho L)^2\right) & & & \\ & & & & & \frac{R^2}{r^2}\rho^2 & & \\ & & & & & & \frac{R^2}{r^2}\rho^2.. & \\ & & & & & & & \frac{R^2}{r^2}.. \end{pmatrix}$$

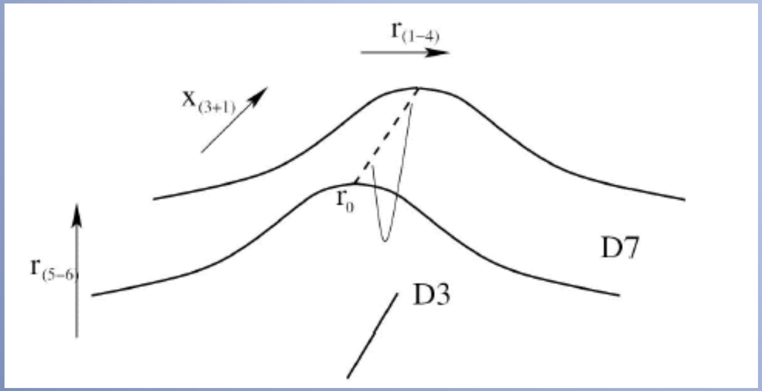
$$ds^2 = r^2 dx_{3+1}^2 + \frac{1}{r^2}\left[d\rho^2 + \rho^2 d\Omega_3^2 + dL^2 + L^2 d\phi^2\right]$$

$$\mathcal{L} = \rho^3 \sqrt{1 + (\partial_\rho L)^2} \sqrt{1 + \frac{B^z R^4}{r^4}}$$

Johnson, Filev... **hep-th/0701001**

D3/ Probe D7 Model

Alvares, NE, Kim,
1204.2474



λ

$$S_{D7} = -T \int d^4x d\rho\, \rho^3 e^{\phi} \sqrt{1 + (\partial_\rho L)^2}$$

$$S = \int \mathrm{d}\rho \lambda(r) \rho^3 \sqrt{1 + L'^2}$$

We expand for small L

$$S = \int \mathrm{d}\rho \left(\frac{1}{2}\lambda(r)\Big|_{L=0} \rho^3 L'^2 + \rho^3 \frac{d\lambda}{dL^2}\Big|_{L=0} L^2 \right)$$

we can now make a coordinate transformation

$$\lambda(\rho)\rho^3 \frac{d}{d\rho} = \tilde{\rho}^3 \frac{d}{d\tilde{\rho}}\,, \qquad \tilde{\rho} = \sqrt{\frac{1}{2} \frac{1}{\int_\rho^\infty \frac{d\rho}{\lambda \rho^3}}}$$

$$L = \tilde{\rho}\phi$$

$$S = \int \mathrm{d}\tilde{\rho} \frac{1}{2} \left(\tilde{\rho}^5 \phi'^2 - 3\tilde{\rho}^3 \phi^2 \right) + \int \mathrm{d}\tilde{\rho} \frac{1}{2} \lambda \frac{\rho^5}{\tilde{\rho}} \frac{d\lambda}{d\rho} \phi^2$$

This is the action of a scalar in AdS with a mass squared of -3 + ρ dependent correction from the gradient of λ

LESSONS

We model the qq condensate by a scalar in “AdS”…

The background gauge dynamics enters through a running mass/anomalous dimension

$$m^2 = \Delta(\Delta - 4)$$

Note that the background could include running due to glue, Nf quark effects on top of which we add this probe, bulk stringy corrections(?)…

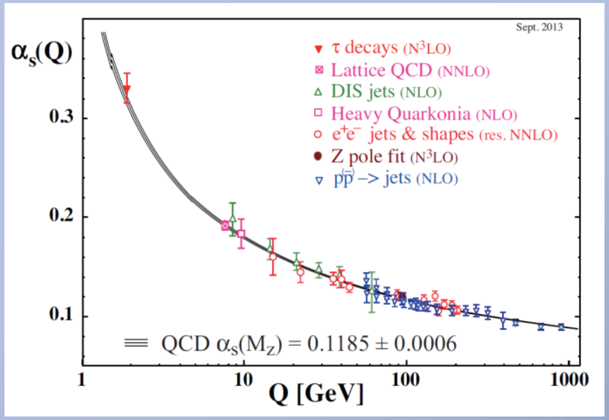
Symmetry breaking occurs when the Breitenlohmer-Freedman Bound is violated . (Matti Jarvinen, Elias Kiritsis 1112.1261)

$$m^2 = -3 \to m^2 < -4 \qquad\qquad \gamma = 0 \to \gamma > 1$$

QCD/TC Dynamics

$$SU(2)_L \times SU(2)_R \to SU(2)_V$$

$$\langle \bar{u}_L u_R + \bar{d}_L d_R + h.c. \rangle \neq 0$$



The gauge coupling runs

$$\mu \frac{d\alpha}{d\mu} = -b_0 \alpha^2, \qquad b_0 = \frac{1}{6\pi}(11N_c - 2N_F),$$

$$\gamma = \frac{3C_2}{2\pi}\alpha = \frac{3(N_c^2 - 1)}{4N_c\pi}\alpha\,.$$

$$\Delta\mathcal{L} = m\,\bar{\psi}\psi$$

m has dimension 1 + γ condensate dimension 3 - γ

The RG scale where γ = 1 is special and gap equations suggest the point of condensation…

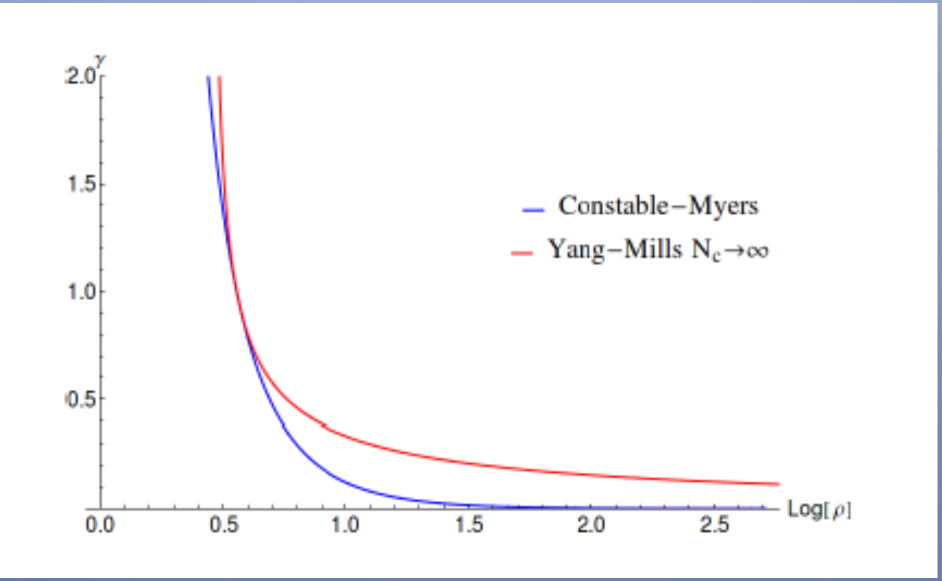
In technicolour one repeats this at f π = 246 GeV… the breaking to the vector symmetry breaks $SU(2)_L$… the pions are eaten by the W and Z… the remaining hadronic spectrum is there to find above 1 TeV…

The Original Back-reacted Hardwall

$$ds^2 = H^{-1/2}\left(1+\frac{2b^4}{r^4}\right)^{\delta/4} dx_4^2 + H^{1/2}\left(1+\frac{2b^4}{r^4}\right)^{(2-\delta)/4} \frac{r^2}{\left(1+\frac{b^4}{r^4}\right)^{1/2}}\left[\frac{r^6}{(r^4+b^4)^2}dr^2 + d\Omega_5^2\right]$$

$$H = \left(1+\frac{2b^4}{r^4}\right)^{\delta} - 1 \qquad\qquad e^{2\phi} = e^{2\phi_0}\left(1+\frac{2b^4}{r^4}\right)^{\Delta}$$

Dilaton Flow Geometry: Constable, Myers... D7s: Babington, EEGK



Top-down probe-brane models of QCD are just AdS/QCD with the background providing a running γ…

Dynamic AdS/QCD

Timo Alho, NE, KimmoTuominen
1307.4896

$$S = \int d^4x\, d\rho\, \mathrm{Tr}\, \rho^3 \left[\frac{1}{\rho^2 + |X|^2} |DX|^2 + \frac{\Delta m^2}{\rho^2} |X|^2 \right.$$

$$X = L(\rho)\, e^{2i\pi^a T^a}.$$

$$ds^2 = \frac{d\rho^2}{(\rho^2 + |X|^2)} + (\rho^2 + |X|^2) dx^2,$$

|X| = L is now the dynamical field whose solution will determine the condensate as a function of m - the phase is the pion.

We use the top-down IR boundary condition on mass-shell: X'(r=X) = 0

X enters into the AdS metric to cut off the radial scale at the value of m or the condensate – no hard wall

The gauge DYNAMICS is input through a guess for Δm

$$\Delta m^2 = -2\gamma = -\frac{3(N_c^2 - 1)}{2N_c\pi}\alpha$$

The only free parameters are Nc, Nf, m, Λ

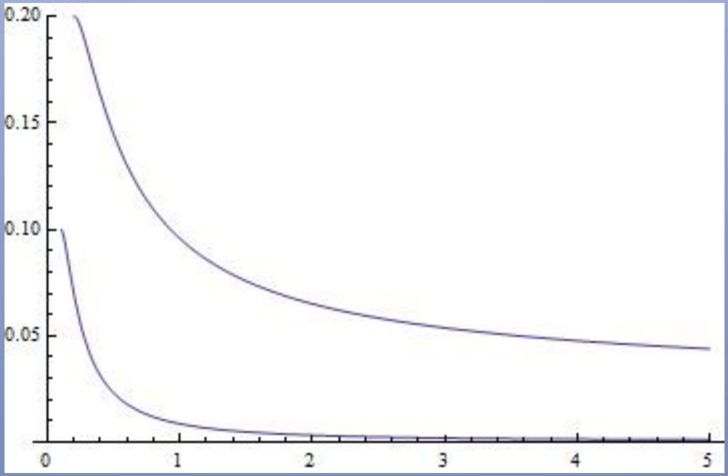
Formation of the Chiral Condensate

We solve for the vacuum configuration of L

$$\partial_\rho[\rho^3\partial_\rho L] - \rho\Delta m^2 L = 0\,.$$

Shoot out with

L'(ρ=L) = 0



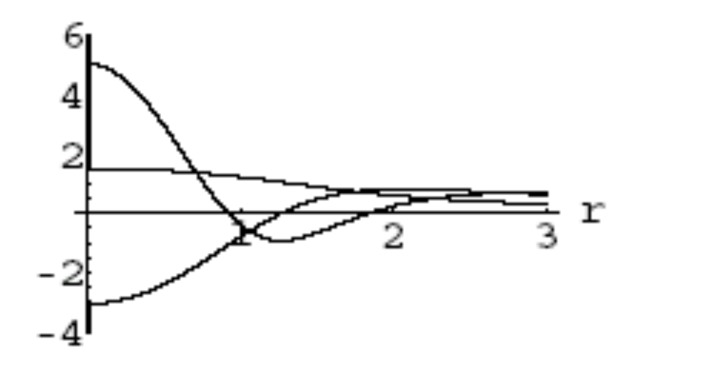
Read off m and qq in the UV…

Meson Fluctuations

$$S = \int d^4x \, d\rho \, \mathrm{Tr}\, \rho^3 \left[\frac{1}{\rho^2 + |X|^2} |DX|^2 + \frac{\Delta m^2}{\rho^2} |X|^2 + \frac{1}{2\kappa^2} (F_V^2 + F_A^2) \right]$$

$$L = L_0 + \delta(\rho) e^{ikx} \qquad k^2 = -M^2$$

$$\partial_\rho(\rho^3 \delta') - \Delta m^2 \rho \delta - \rho L_0 \delta \left. \frac{\partial \Delta m^2}{\partial L} \right|_{L_0} + M^2 R^4 \frac{\rho^3}{(L_0^2 + \rho^2)^2} \delta = 0 \,.$$



The normalizable solutions pick out particular mass states… the σ and its radial excited states…

The gauge fields let us also study the operators and states

$$\bar{q}\gamma^\mu q \to \rho \text{ meson}$$

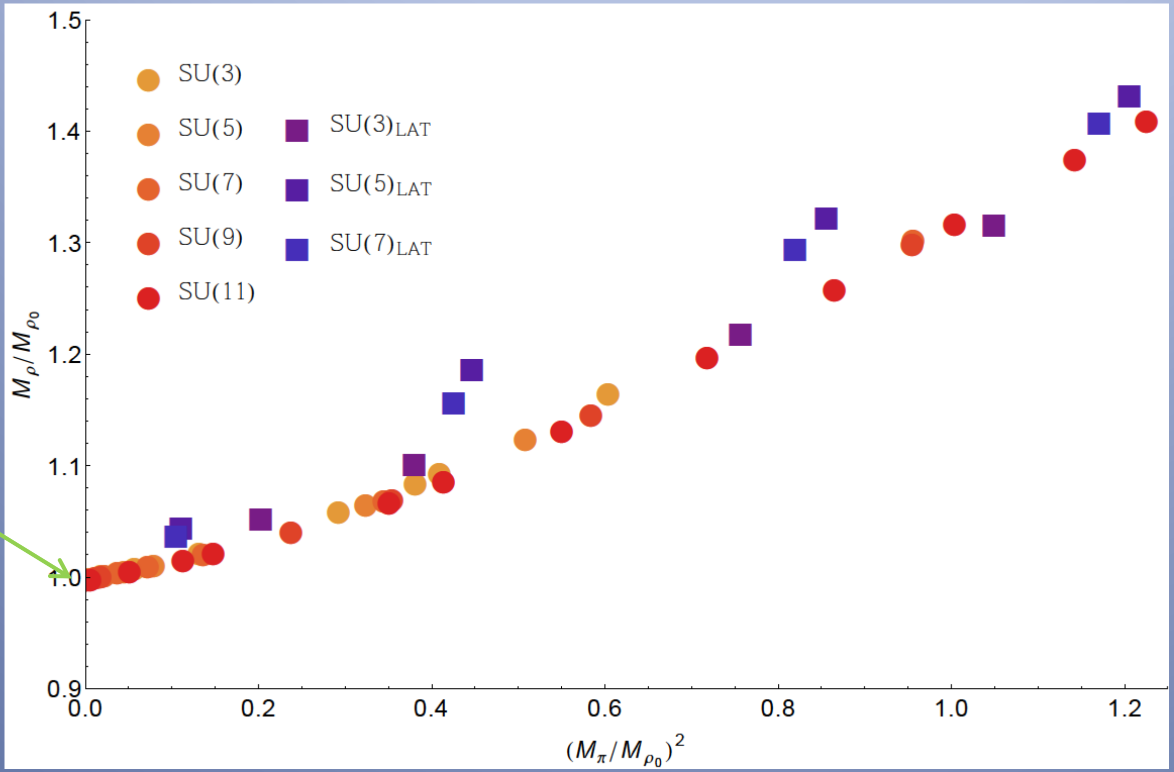
$$\bar{q}\gamma^\mu \gamma^5 q \to \text{a meson}$$

SU(Nc) gauge + 3 quarks

NE, Erdmenger & Mark Scott
arXiv:1412.3165 [hep-ph]

M_rho = 1 defines Λ

Real QCD lies here



Nf=2 κ = 8.5
Clemens 1702.08693

	Model	QCD
m_ρ	775 MeV	775 MeV
m_{a_1}	1467 MeV	1230 MeV
m_σ	981 MeV	500 MeV & 980 MeV
F_ρ	311 MeV	345 MeV
F_{a_1}	390 MeV	433 MeV
f_π	77 MeV	92 MeV

There is very little Nc dependence – basically quenched…
Hence comparison to quenched lattice data (Bali et al… arXiv1304.4437)
All of these models lie within 15% on any point....

Excited States…

There is the usual hard wall - soft wall problem

$$M_n^2 \sim n,\ n^2$$

a soft wall here looks like (1508.06540)…

And the quarks are sensitive to physics below their mass scale….

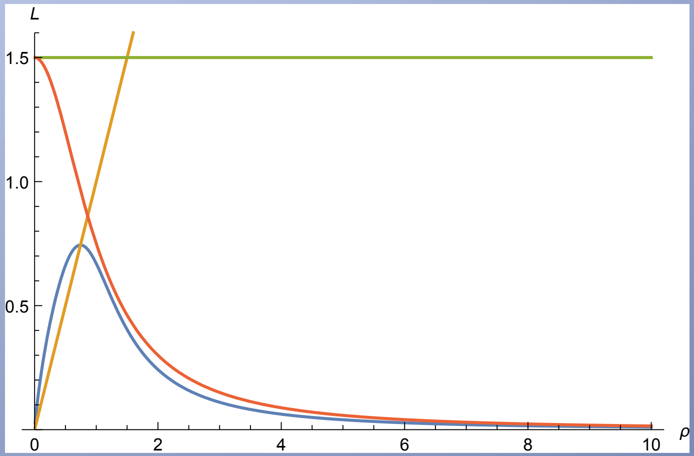


Figure 4: The function $L(\rho)$ which reproduces the softwall behaviour of [13] with a constant dilaton. Also shown are examples of the profiles for the $\mathcal{N}=2$ theory (L =constant) and for the dynamically generated mass example ($L = 1/(1+\rho^2)$). The line $L=\rho$ is also plotted to show where the on-mass shell condition is satisfied.

I think these states should be strings… we can get away with supergravity for the n=0 but softwalls are not the answer…

OTHER RUNNINGS
SU(Nc) gauge theory with Nf fundamental quarks

Nf=11/2 Nc

No AF

CFT/CW

Nf = 4 Nc

χ SB

$$\beta(g) = -\frac{g^3}{(4\pi)^2}\left\{\frac{11}{3}N_c - \frac{2}{3}N_f\right\} - \frac{g^5}{(4\pi)^4}\left\{\frac{34}{3}N_c^2 - \frac{N_f}{N_c}\left[\frac{13}{3}N_c^2 - 1\right]\right\} + \cdots$$

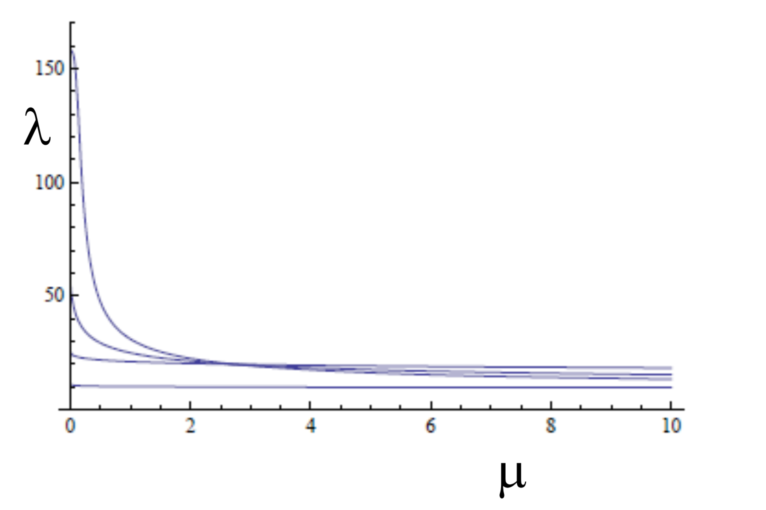
Using the 't Hooft coupling, and setting $\frac{N_f}{N_c} \to x$ we obtain

$$\lambda \equiv g^2 N_c \quad , \quad \dot{\lambda} = -b_0\lambda^2 + b_1\lambda^3 + \mathcal{O}(\lambda^4)$$

with

$$b_0 = \frac{2}{3}\frac{(11-2x)}{(4\pi)^2} \quad , \quad \frac{b_1}{b_0^2} = -\frac{3}{2}\frac{(34-13x)}{(11-2x)^2}$$

$$\gamma_m^{(1)} = \mu\frac{d\ln m_q}{d\mu} = \frac{3\lambda}{(4\pi)^2} \cdot \frac{3(N_c^2-1)}{4N_c\pi}\alpha$$



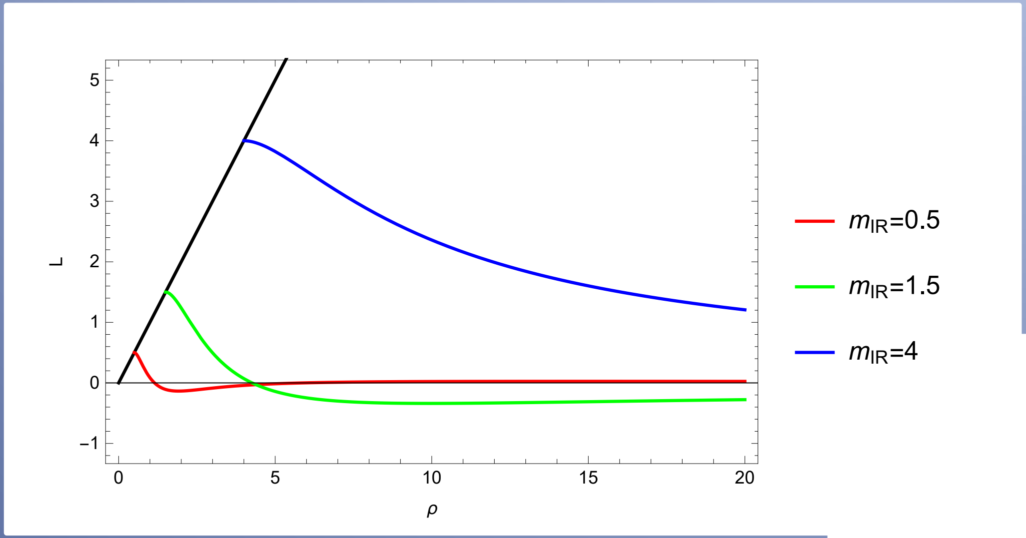
If critical γ = 1…. Nf/Nc ~ 4

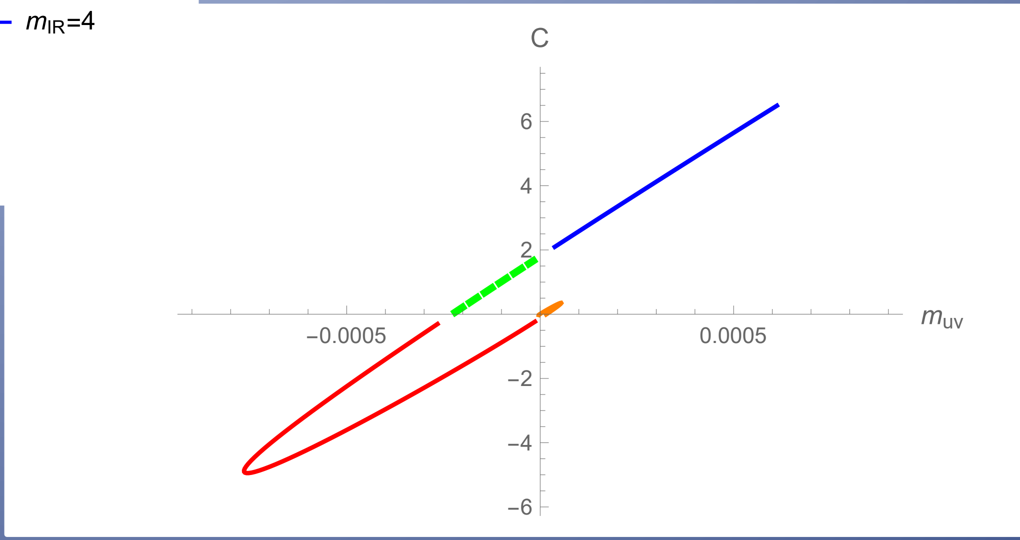
Yamawaki,Appelquist, Terning, Sannino,…

The Phase Transition is BKT

At some point varying Nf (which is continuous at large Nc) means the IR fixed point value of Δm is -1 exactly…. Such transitions are BKT in nature (Son, Kaplan... arXiv:0905.4752)

$$\langle \bar{q}q \rangle \sim e^{-1/(N_f - N_f^c)}$$





There are Efimov states…

(Matti Jarvinen, Elias Kiritsis 1112.1261)

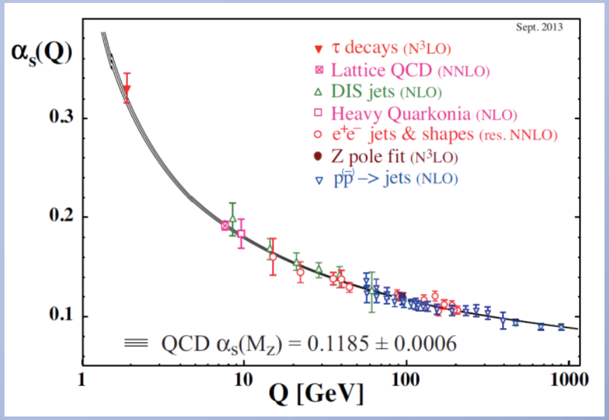
Anyway we don't quite believe the details of these runnings...

So lets cook a working model of technicolour...

The S problem...

The m_h problem...

QCD/TC Dynamics



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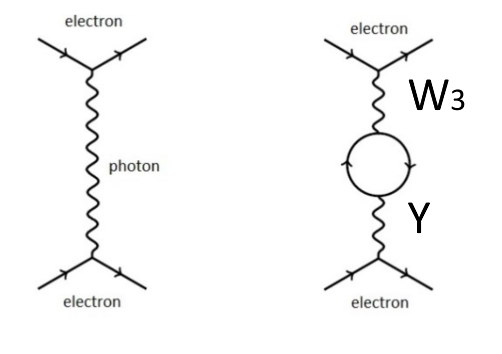
Technicolour Exclusions

S broken gauge theories have non-decoupling effects. (Peskin, Takeuchi 90)

$$\left.\frac{d\Pi_{3Y}}{dq^2}\right|_{q^2=0}$$

Counts the number of electroweak doublets

S < 0.3



Low energy computation:

$$S = 4\pi\left[\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2}\right]$$

$S_{QCD} = 0.3$

It has been suggested that as one approaches the critical Nf at the edge of the conformal window V-A symmetry is restored and S-> 0

$$S = \int d^4x\, d\rho\, \mathrm{Tr}\, \rho^3 \left[\frac{1}{\rho^2+|X|^2}|DX|^2 + \frac{\Delta m^2}{\rho^2}|X|^2 + \frac{1}{2\kappa^2}(F_V^2+F_A^2)\right]$$

V-A symmetry is restored holographically by κ -> 0 (no Nf prediction)

Technicolour Exclusions

Higgs

We've found m_h = 125 GeV

What is the QCD-like bound state?

F0 at 550 MeV is probably a molecule. F0 980 MeV is higgs like?

That would be m_h > 2 TeV

It has been suggested that as one approaches the critical Nf at the edge of the conformal window the conformal symmetry tends to flatten the effective sigma potential and make m_h light .....

Our holographic model does precisely this

$$\partial_\rho[\rho^3\partial_\rho L] - \rho\Delta m^2 L = 0$$

$$\partial_\rho(\rho^3\delta') - \Delta m^2\rho\delta - \rho L_0\delta \left.\frac{\partial\Delta m^2}{\partial L}\right|_{L_0} + M^2R^4\frac{\rho^3}{(L_0^2+\rho^2)^2}\delta = 0\,.$$

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$$\partial_\rho(\rho^3 \delta') - \Delta m^2 \rho \delta - \cancel{\rho L_0 \delta \left.\frac{\partial \Delta m^2}{\partial L}\right|_{L_0}}$$

= 0

$$+ M^2 R^4 \frac{\rho^3}{(L_0^2 + \rho^2)^2} \delta = 0 \, .$$

Giving TC a last chance…

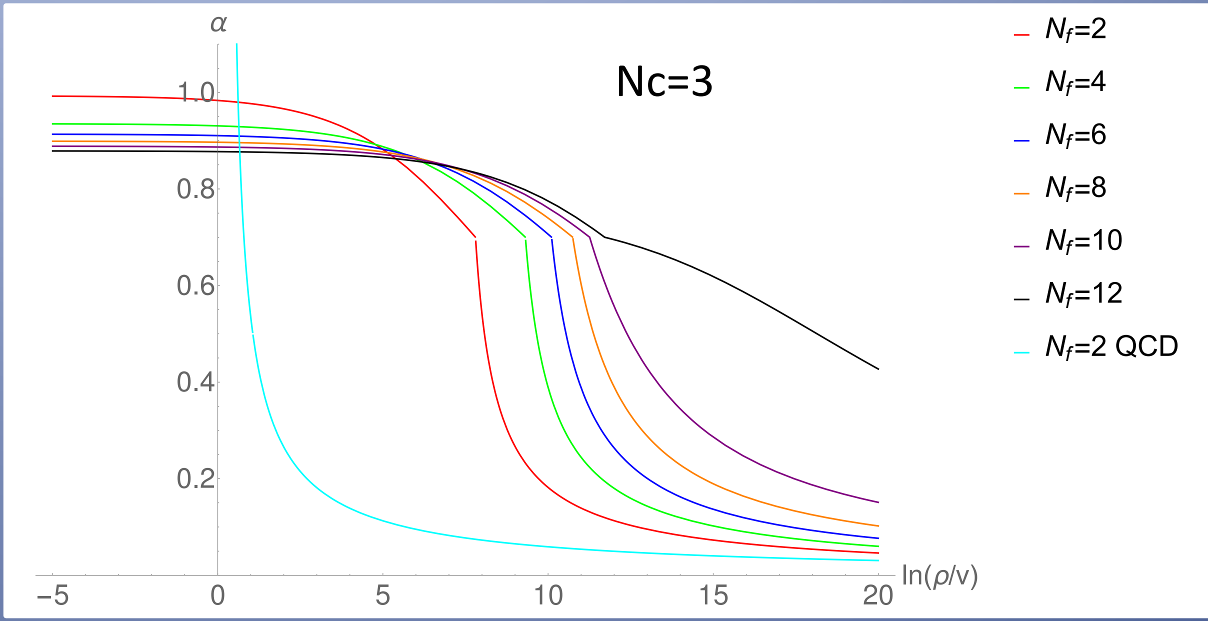
Most likely there is no choice of Nc Nf that will realize the physical S (the best hope is to have Nf=2 as EW doublet and the rest as singlets) and m_h…

But let's imagine we get lucky… because we don't know the IR running of the gauge coupling we don't know which Nc Nf combination to pick…

So lets holographically describe all Nc Nf pairs:

tune κ to give S=0.1…

Change the IR running (Nf_{IR}) to give $m_h = f_p/2$

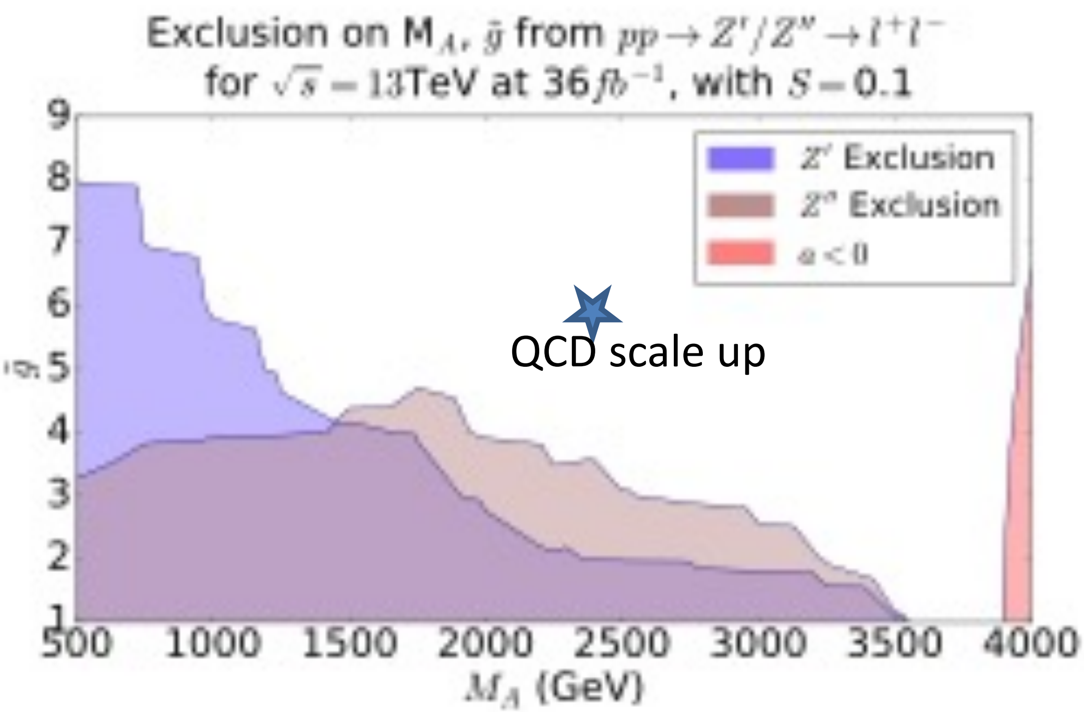


Most likely the spectrum is in every case wrong! BUT if there is one theory that works we hope to have captured it… can we rule it out?

For each Nc, Nf we fix the scale and Nf$_{IR}$ with f_π, m_σ

The model then predicts M_ρ, F_ρ, M_A, F_A as a function of the 5d gauge coupling, κ. We tune κ to give S=0.1. The remaining three predictions we will express as

$$M_A,\ \tilde{g} = \frac{\sqrt{2}M_V}{F_V},\ \omega = \frac{1}{2}\left(\frac{F_\pi^2 + F_A^2}{F_V^2} - 1\right).$$



The same parameter space as Belyaev et al 's pheno model!
arXiv:1805.10867

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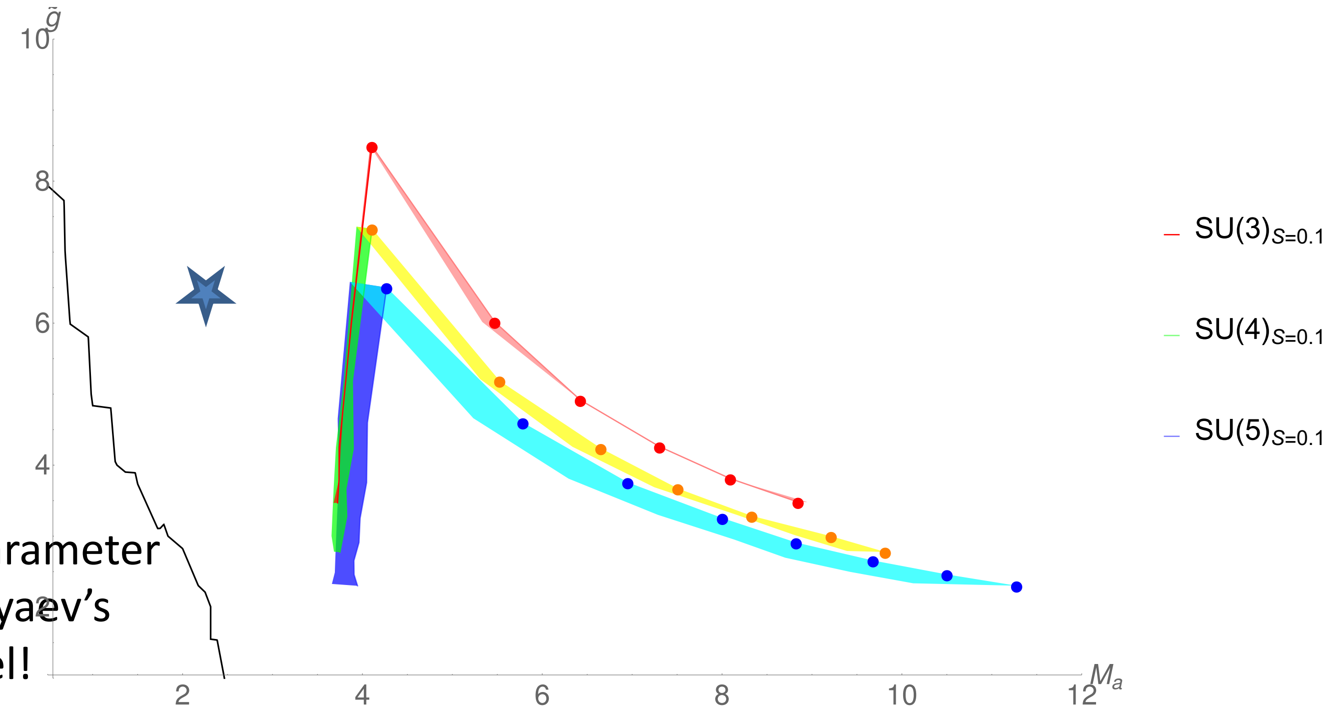
The vector meson masses are enhanced relative to QCD because the strong coupling communicates with higher scales



The same parameter space as Belyaev's pheno model!

Walking

Traditionally walking was used to enhance the condensate at UV scales Holdom '81

$$\Delta m^2 = \gamma(\gamma - 2)$$

$$L_{IR} = \frac{\hat{m}}{\rho^\gamma} + \frac{\hat{c}}{\rho^{2-\gamma}}$$

$$L_{UV} = m_{UV} + \frac{c_{UV}}{\rho^2}$$

$$\hat{m} \sim m_{IR}^{1+\gamma}, \ \hat{c} \sim m_{IR}^{3-\gamma}$$

$$m_{UV} \sim \frac{m_{IR}^{1+\gamma}}{\Lambda_1^\gamma}, \ c_{UV} \sim m_{IR}^{3-\gamma}\Lambda_1^\gamma$$

mIR

$\Lambda 1$

$$y\psi_L t_R h \ \rightarrow \ \frac{g^2}{M^2}\bar{\psi}_L t_R \bar{U}_R \Psi_L$$

Makes the flavour scale M bigger...

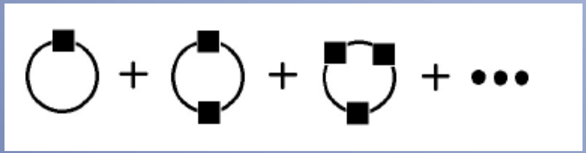
Nambu Jona-Lasinio Model

The toy model that encapsulates Nambu's Nobel concepts (before quarks).

$$\mathcal{L} = \bar{\psi}_L \partial\!\!\!/ \psi_L + \bar{\psi}_R \partial\!\!\!/ \psi_R + \frac{g^2}{\Lambda_{UV}^2} \bar{\psi}_L \psi_R \bar{\psi}_R \psi_L$$

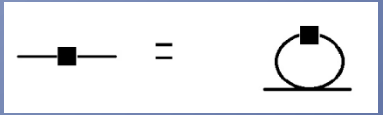
NB L & R symmetries respected

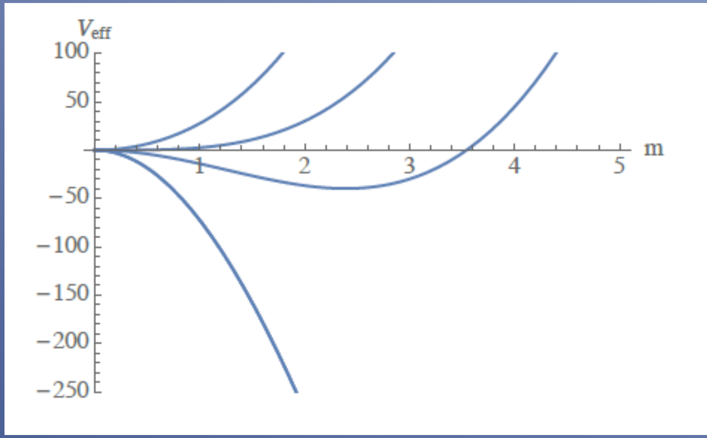
Calculate effective potential

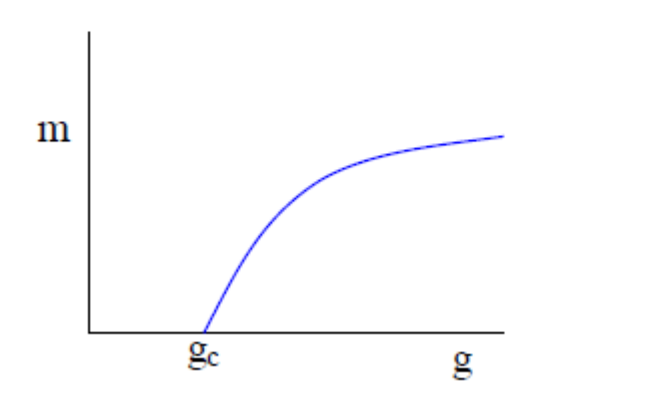


$$\Delta V_{\text{eff}} = -\int_0^{\Lambda_{UV}} \frac{d^4k}{(2\pi)^4} \mathrm{Tr} \log(k^2 + m^2)$$

$$\frac{g^2}{\Lambda_{UV}^2} \bar{\psi}_L \psi_R \bar{\psi}_R \psi_L \to \frac{g^2}{\Lambda_{UV}^2} \langle \bar{\psi}_L \psi_R \rangle \bar{\psi}_R \psi_L \to \frac{m^2 \Lambda_{UV}^2}{g^2}$$







Witten's Multi-Trace Operator Prescription

hep-th/0112258

$$\frac{g^2}{\Lambda_{UV}^2}\bar{\psi}_L\psi_R\bar{\psi}_R\psi_L \rightarrow \frac{g^2}{\Lambda_{UV}^2}\langle\bar{\psi}_L\psi_R\rangle\bar{\psi}_R\psi_L \rightarrow \frac{m^2\Lambda_{UV}^2}{g^2}$$

so add

$$S = \int d\rho\mathcal{L} + \left.\frac{L^2\rho^2}{g^2}\right|_{\Lambda_{UV}}$$

On variation…

$$0 = EL\ eqn\ + \frac{\partial\mathcal{L}}{\partial L'}\delta L|_{UV,IR} + \frac{2L\Lambda_{UV}^2}{g^2}\delta L|_{UV}$$

$$L = m + \frac{c}{\rho^2}$$

$$\frac{\partial\mathcal{L}}{\partial L'} = \rho^3\partial_\rho L = -2c$$

Now we let the mass vary in the UV and need…

$$m = \frac{g^2}{\Lambda_{UV}^2}c$$

The Euler Lagrange equation solutions are left unchanged but we pick those that satisfy the UV and IR boundary conditions..

See NE, Kim for explict discussion of holographic NJL model arXiv:1601.02824

The Holographic Gauged NJL Model

Will Clemens, NE, arXiv:1702.08693 [hep-th]

$$\mathcal{L} = \frac{1}{4g^2} F^{\mu\nu} F_{\mu\nu} + i\bar{q} \not{D} q + \frac{g^2}{\Lambda^2} (\bar{q}_L q_R \bar{q}_R q_L + h.c.)$$

Quarks with asymptotically free non-abelian gauge interactions and Four fermion NJL operator….

Underlies many BSM models eg extended technicolour

We model by Dynamic AdS/QCD + Witten’s NJL prescription

QCD + NJL term

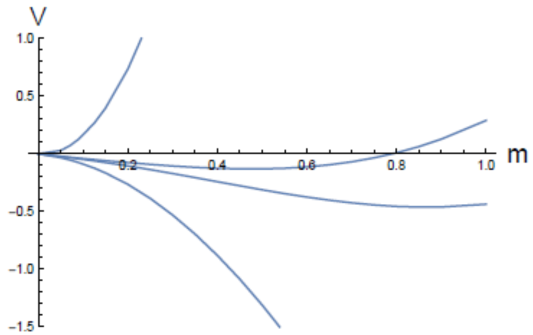


FIG. 2: Plots of the potential against the UV quark mass: the lower curve is that of the underlying gauge theory without an NJL term and is unbounded. Moving up we have added the term $\Lambda^2 m^2/g^2$ with $g = 2.5, 2.3, 1$ from bottom to top. The addition of an NJL term generates a minimum of the potential that tracks to $m = 0$ at $g = 0$. All dimensionful objects are expressed in terms of Λ_{BF}.

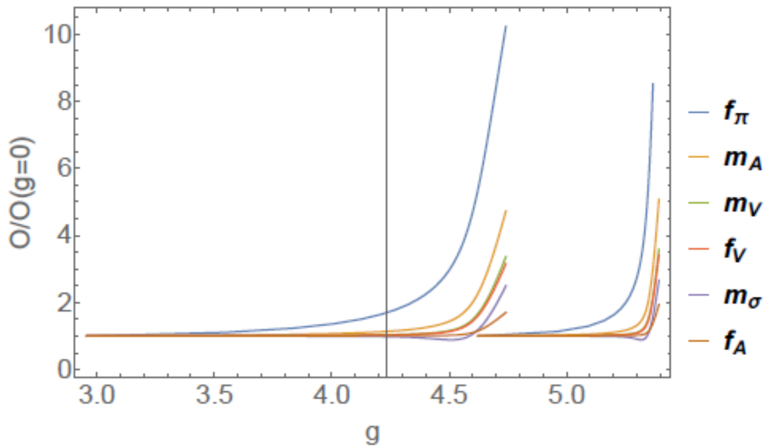


FIG. 5: Plots showing the full set of observables against NJL coupling g for $\Lambda = 20$ and $50\Lambda_{BF}$.

The gauge theory breaks chiral symmetry on its own and the NJL term just enhances the condensation…

One Doublet TC + ETC for the top mass

Will Clemens, NE, Marc Scott, arXiv:1703.08330 [hep-ph]

SU(3) QCD + 6 flavours

SU(3) TC + (2 + Nf) flavours

ETC

$$\begin{pmatrix} U^r \\ U^g \\ U^b \\ U^R \\ U^B \\ U^G \end{pmatrix} \rightarrow \begin{pmatrix} t^r \\ t^g \\ t^b \\ \hline U^R \\ U^B \\ U^G \end{pmatrix}$$

QCD

TC

ETC NJL terms representing broken generators from SU(6) unification

$$\frac{g^2}{2\Lambda_{ETC}^2}\bar{\Psi}_L^\alpha U_R^\alpha \bar{t}_R^i \psi_L^i$$

$$\frac{g^2}{12\Lambda^2}\bar{\Psi}_L^\alpha U_R^\alpha \bar{U}_R^\beta \Psi_L^\beta + \frac{g^2}{12\Lambda^2}\bar{\psi}_L^i t_R^i \bar{t}_R^j \psi_L^j$$

$$m_U = \frac{g^2}{12\Lambda^2}c_U + \frac{g^2}{2\Lambda^2}c_t$$

$m_D=0$, c_D. controlled by Λ_{TC}

$$m_t = \frac{g^2}{12\Lambda^2}c_t + \frac{g^2}{2\Lambda^2}c_U$$

Search 3 parameter space for match to v, mt. and g

One Doublet TC + ETC for the top mass

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ETC NJL terms representing broken generators from SU(6) unification

$$\frac{g^2}{2\Lambda_{ETC}^2}\bar{\Psi}_L^{\alpha} U_R^{\alpha} \bar{t}_R^{i} \psi_L^{i}$$

$$\frac{g^2}{12\Lambda^2}\bar{\Psi}_L^{\alpha} U_R^{\alpha} \bar{U}_R^{\beta} \Psi_L^{\beta} + \frac{g^2}{12\Lambda^2}\bar{\psi}_L^{i} t_R^{i} \bar{t}_R^{j} \psi_L^{j}$$

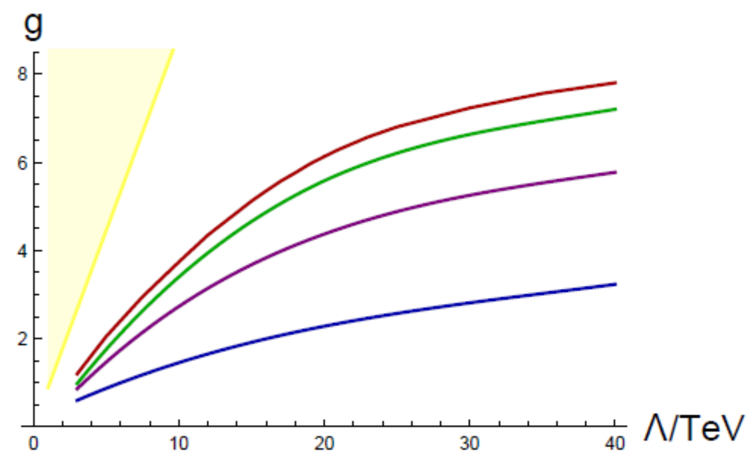

FIG. 7: g vs UV cut off Λ for consistent solutions with the physical top mass on the TC dominated branch for $N_c = 3$, $N_f = 2, 4, 8, 11$ from the top down. The shaded region is excluded by the two loop $\delta\rho$ contribution.

Remarkably shows the effects of walking and strong ETC….

Ideal Walking (Sannino)

Now we live in the conformal window and trigger mIR with an NJL term only at ΛUV...

$$\Delta m^2 = \gamma(\gamma - 2)$$

$$L_{IR} = \frac{\hat{m}}{\rho^\gamma} + \frac{\hat{c}}{\rho^{2-\gamma}}$$

$$\hat{m} \sim m_{IR}^{1+\gamma}, \ \hat{c} \sim m_{IR}^{3-\gamma}$$

$$L_{UV} = m_{UV} + \frac{c_{UV}}{\rho^2}$$

$$m_{UV} \sim \frac{m_{IR}^{1+\gamma}}{\Lambda_1^\gamma}, \ c_{UV} \sim m_{IR}^{3-\gamma}\Lambda_1^\gamma$$

mIR Λ1 ΛUV

We get the enhancement of the condensate and a naturally light higgs (frequently too light if mIR is in a very conformal regime)

Bitaghsir, Clemens, Evans arXiv:1807.04548

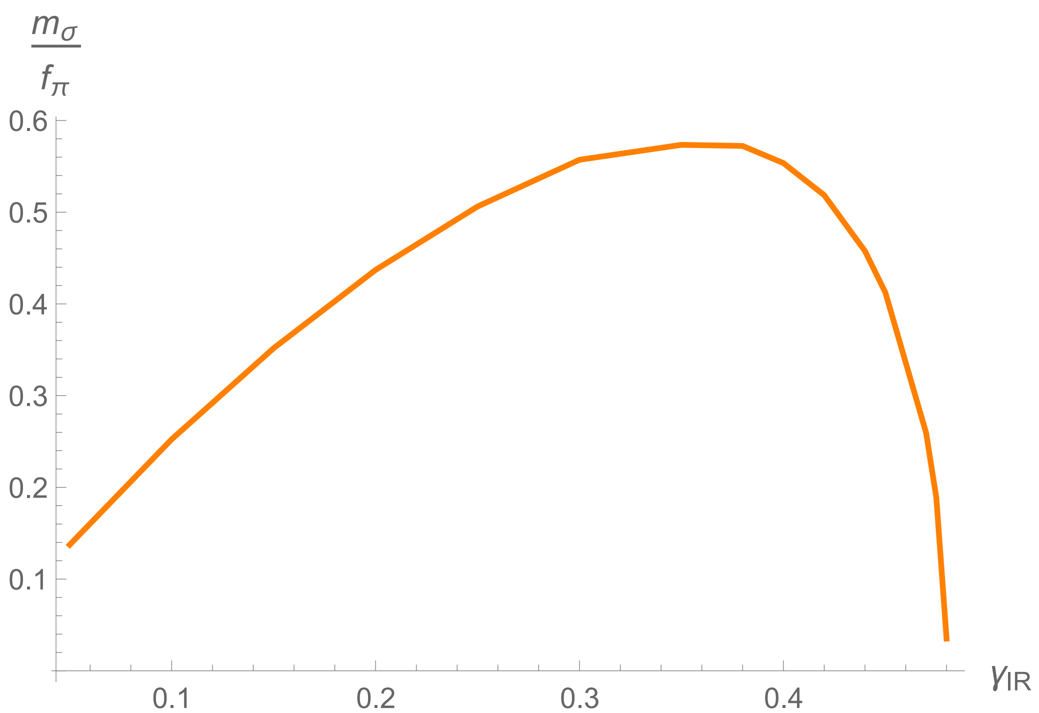

FIG. 10: This is a plot in the $N_f = 12$ theory where the IR fixed point is $\gamma_{IR} = 0.48$. Here we have a separation of 7.5 between the m_{IR} and Λ. We vary m_{IR} to scales with different values of γ_{IR} and compute the σ mass in units of f_π.

Conclusions

Holography has taught us how to compute the meson spectrum of theories with different running γ. In some cases these models are as good a technique as we have...

Witten's NJL prescription can include strong four fermion operators

We have the tools to study...

Eg Technicolour, including walking and ideal
Extended Technicolour
Top condensation
Composite higgs models
Tumbling
Dark Matter sectors
Inflatons....