Holographic model for exotic gauge dynamics

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Based on 1807.04548

Fallahi Miniaturist

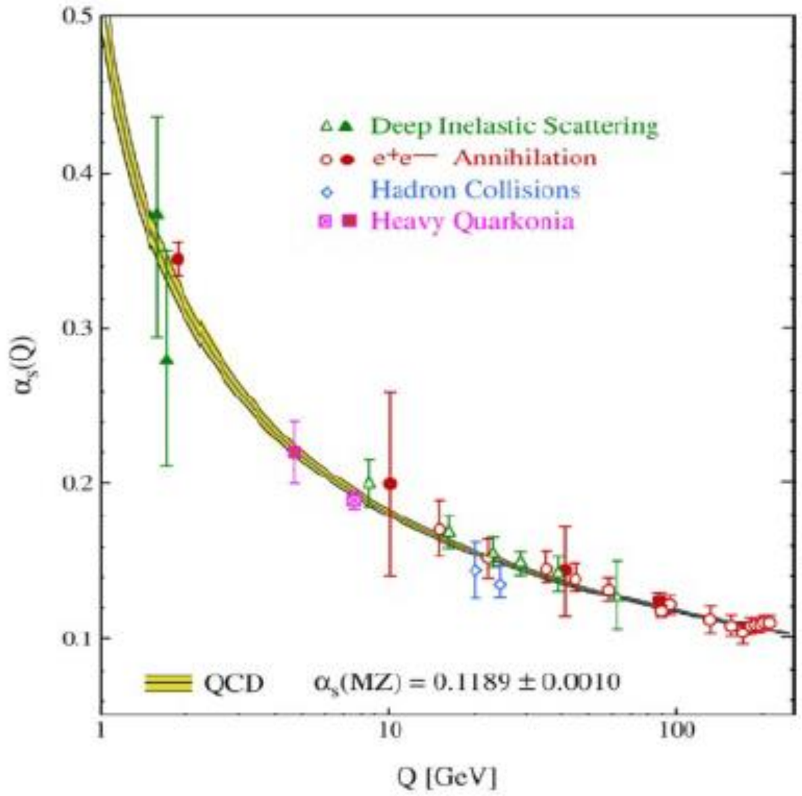
Collaborations

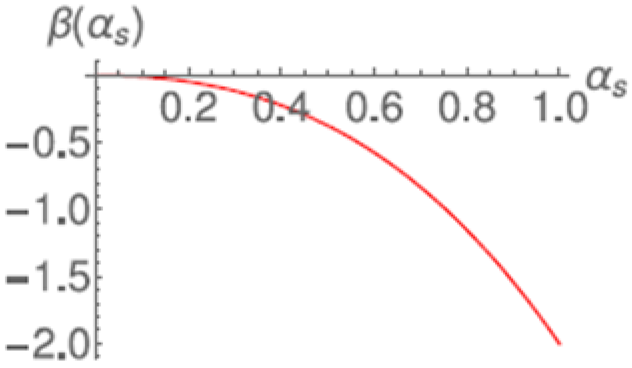
- Nick Evans(University of Southampton)
- Giacomo Cacciapagila(University of Lyon)
- Will Clemens(University of Southampton)
- Jesus. C. Rojas(University of Southamton)
- Moslem Ahmadvand(IPM)
- Mansoureh Gholamzadeh(Shahrood University of Technology

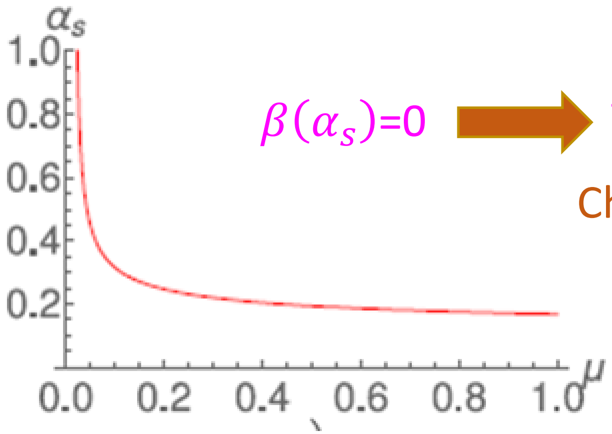
QCD

$N_f = 6 \quad N_c = 3$

The standard model of particle physics







$\beta(\alpha_s)=0$ → The running has ceased and are therefore called fixed-points

Chiral symmetry breaking

Confinement

UV fixed point

Non- interacting theory

Asymptotic freedom

SU(N_c) gauge theory with N_f fundamental flavors

Dennis D. Dietrich and Francesco Sannino hep-ph 0611341

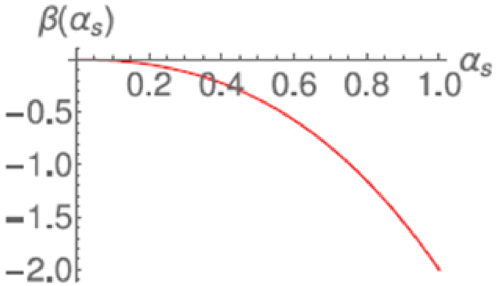
Two loop beta function N_c=3

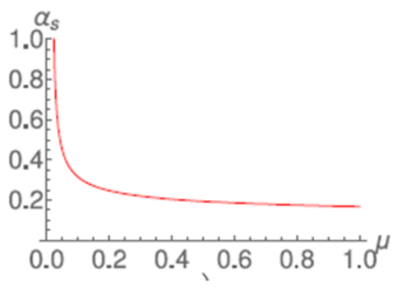
$$\beta(\alpha_s) = -\frac{1}{6\,\pi}\underbrace{(33 - 2\,N_f)}_{\beta_0}{\alpha_s}^2 - \frac{1}{24\,\pi^2}\underbrace{(306 - 38\,N_f)}_{\beta_1}{\alpha_s}^3 + \cdots$$

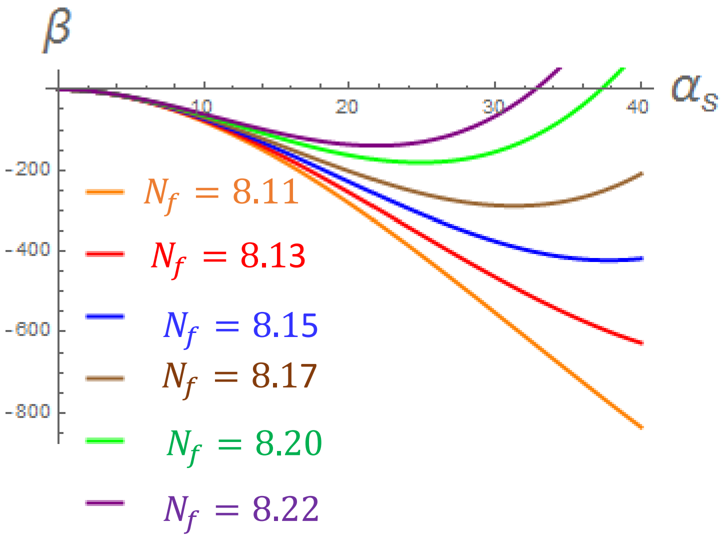
$\beta_1 > 0$ $\beta_0 > 0$ | $\frac{306}{38} \cong 8.05$ | $\beta_1 < 0$ $\beta_0 > 0$ | $\frac{33}{2} = 16.5$ | $\beta_1 < 0$ $\beta_0 < 0$ | N_f

QCD like theory

EXOTIC DYNAMICS

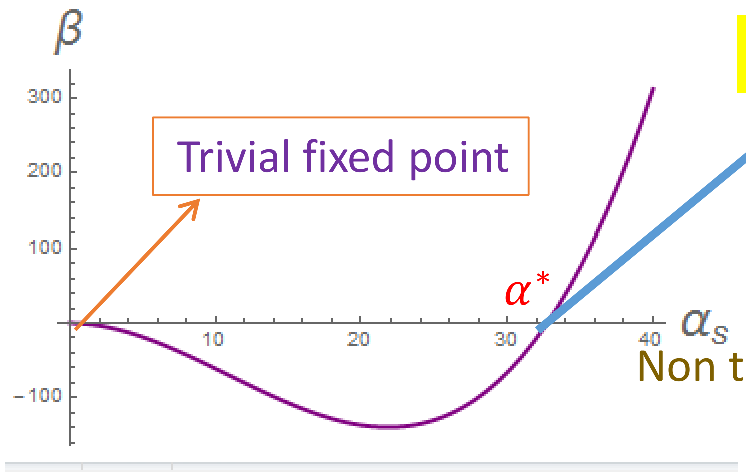






No asymptotic freedom

Walking regime



Non trivial IR fixed point

$\beta_0 \rightarrow 0^+$

Non trivial fixed point goes to zero

The regime of Banks-Zaks fixed point

Conformal Window

The running in the conformal window effectively does not change

Comparing with chiral symmetry breaking coupling

α_s^χ

Notice our discussions are based on the two loop beta functions

Large N_c and SU(N_c) gauge theory with N_f fundamental flavors

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

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

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

Anomalous dimension

Under a rescaling of the coordinates $x^\mu \to \lambda x^\mu$ The operator O(x) has classical dimension $O(x) \to \lambda^{-\Delta} O(\lambda x)$

From the renormalization process, the quantum dimension of O(x) is $\Delta - \gamma_O$

Anomalous dimension

We model chiral symmetry breaking phase of $q\bar{q}$ as a scalar field in AdS space time

$2.6N_c < N_f < 4N_c$ $\gamma = \gamma_* > 1$ Generating the chiral symmetry breaking by the gauge theory

We will set all the dynamical scales in terms of this scale

Chiral Symmetry breaking => violation of Breitenlohmer-Freedmann bound for a scalar field in AdS_5

Raul Alvares, N. Evans, Keun-Young arXiv:1204.2474 ; Matti Jarvinen, Elias Kiritsis arXiv:1112.1261

$N_f \sim 4N_c$ $\gamma_* = 1$ Walking regime, BKT phase transition T. Alho, N. Evans, and K. Tuominen

$4N_c \leq N_f < \frac{11}{2} N_c$ $\gamma_* \to 0$ Conformal window

a strongly coupled NJL interaction is used to trigger chiral symmetry breaking

Dynamic AdS/QCD

J. Erlich, E. Katz, D. T. Son, M. A. Stephanov (2005)
T. Alho, N. Evans, and K. Tuominen, J. Erdmenger (2013)

Based on the D3/probe D7 model

Scalar field dual to quark condensation $X = L = q\bar{q}$

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

$$ds^2 = r^2 dx_{3+1}^2 + \frac{1}{r^2}d\rho^2, \qquad r^2 = \rho^2 + |X|^2.$$

Vector field dual to $q\gamma^\mu\bar{q}$

Axial vector field dual to $q\gamma^\mu\gamma^5\bar{q}$

Mass term which depends on the renormalization group scale. We fix it using one loop running of the gauge coupling of SU(N_c) theory with N_f quarks in the fundamental representation as

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

Free parameters: N_c, N_f, IR value, Cut off

Meson spectrum

N. Evans, Erdmenger & Mark Scott arXiv:1412.3165

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

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

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

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

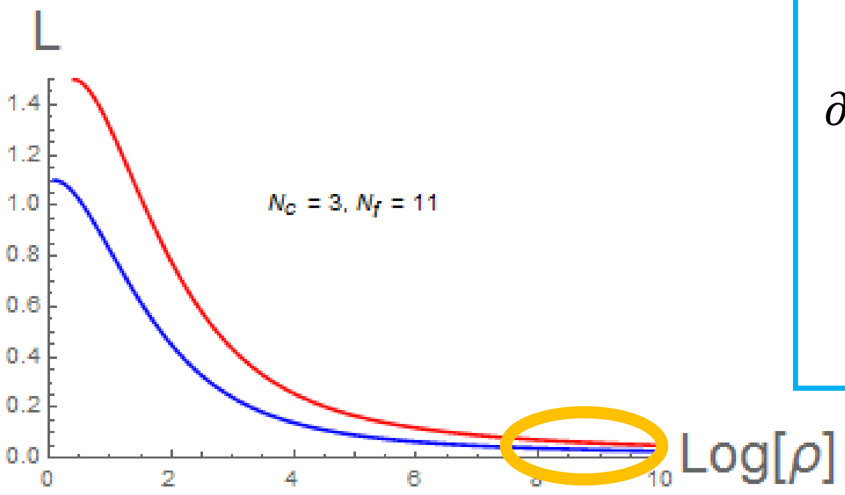
The normalizable solutions pick out particular mass states… the σ and its radial excited states…

Comparison to quenched lattice data (Bali et al… arXiv1304.4437) shows reliable results.

$2.6N_c < N_f < 4N_c$

Vacuum of the Dynamic AdS/QCD

Vacuum of the theory means setting all fields to zero, except: $X = L$ which is a scalar field dual to quark condensation $q\bar{q}$



$$\partial_\rho\left(\rho^3 \partial_\rho L\right) - \rho \Delta m^2 L = 0$$

Running of dimension of $q\bar{q}$

IR boundary conditions:

$$L'(\rho = m_{IR}) = 0$$

$$L(\rho = m_{IR}) = m_{IR}$$

Shoot out with initial condition from IR to UV in the AdS boundary

Quark mass

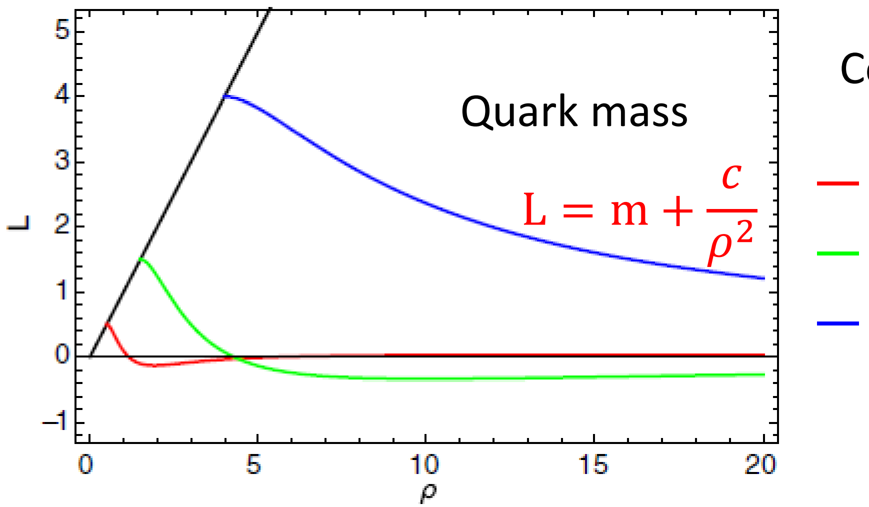
Condensation

In the UV:

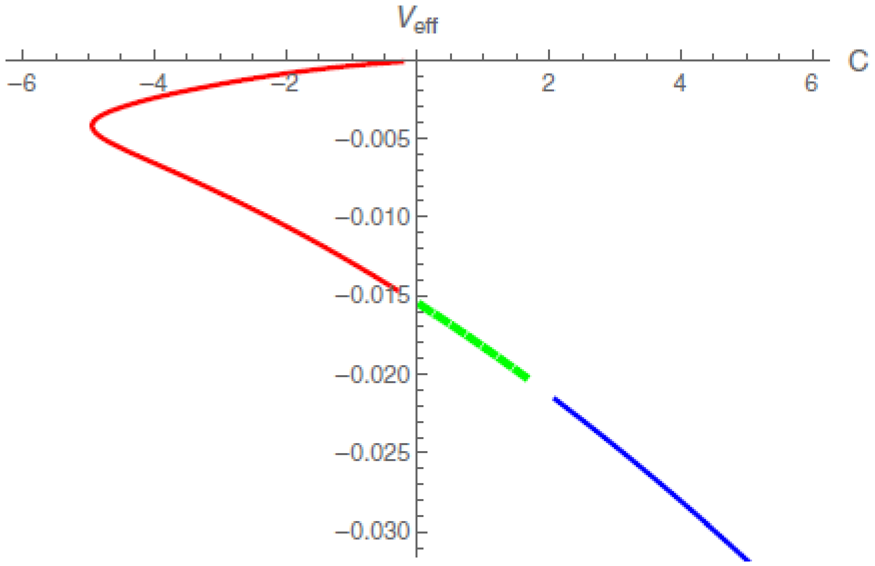
$$\mathrm{L} = \mathrm{m} + \frac{c}{\rho^2}$$

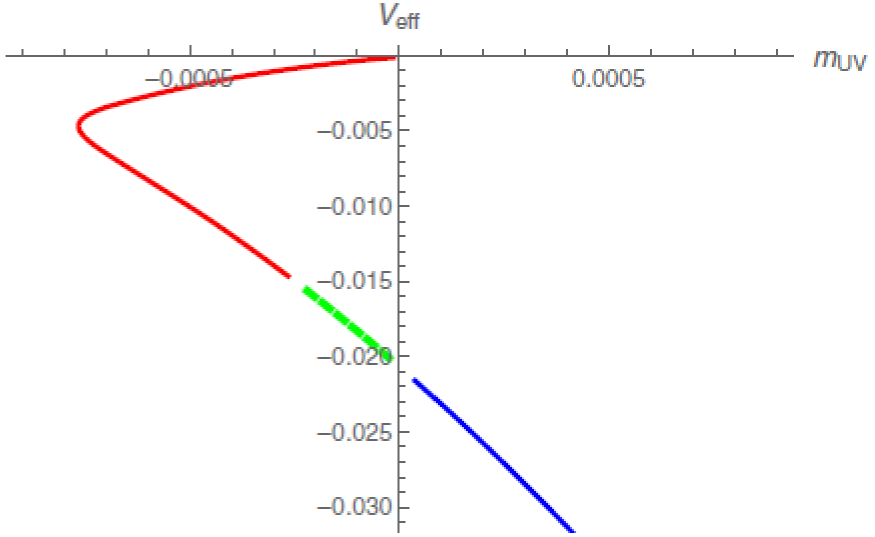
$2.6N_c < N_f < 4N_c$

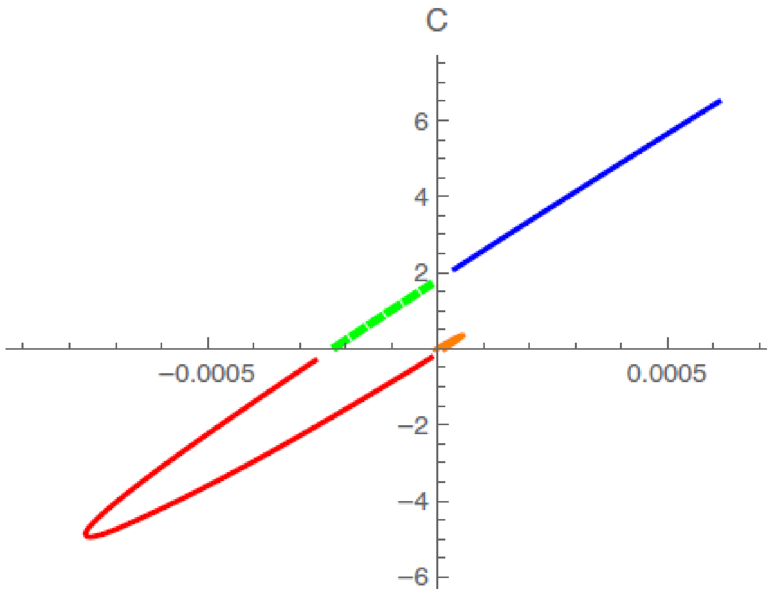
Spiral in m-c curve



$N_f = 9$



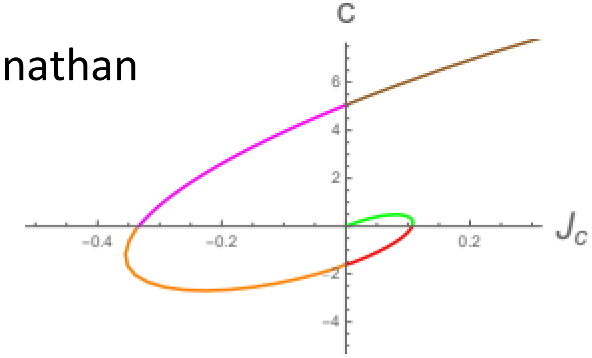


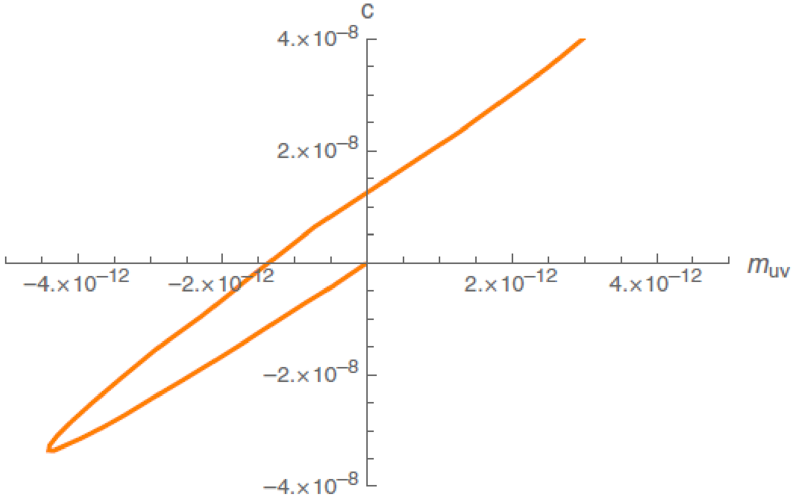


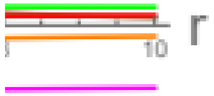
$2.6N_c < N_f < 4N_c$

A Universal Picture from Holographic Chiral Symmetry Breaking?

- D3/D7 with B field V.G. Filev, C.V. Johnson, R.C. Rashkov, and K.S. Viswanathan
- Condensed matter N. Iqbal, H. Liu, and M. Mezei
- Holographic superconductors K. B. F, J. Cruz Rojas, and N. Evans
- Considering backreaction E. Kiritsis M. .





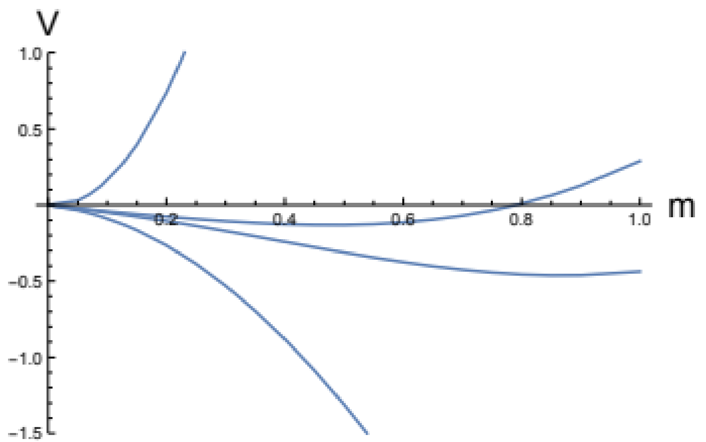


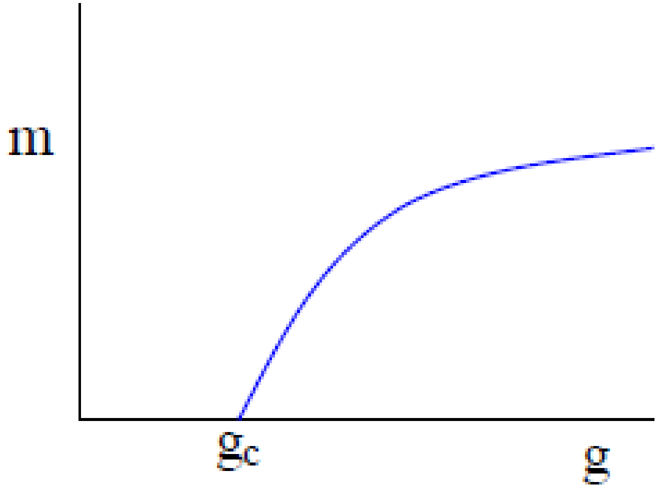
Efimov states?

Metastable vacua of QCD, superconductors…???

Nambu Jona-Lasinio (NJL) model

A free fermion with a four fermion interaction $\frac{g^2}{\Lambda^2}\bar{q}_L q_R \bar{q}_R q_L$





Holographic NJL model: We add the extra potential term as a boundary term at UV cut off(Witten's Prescription)

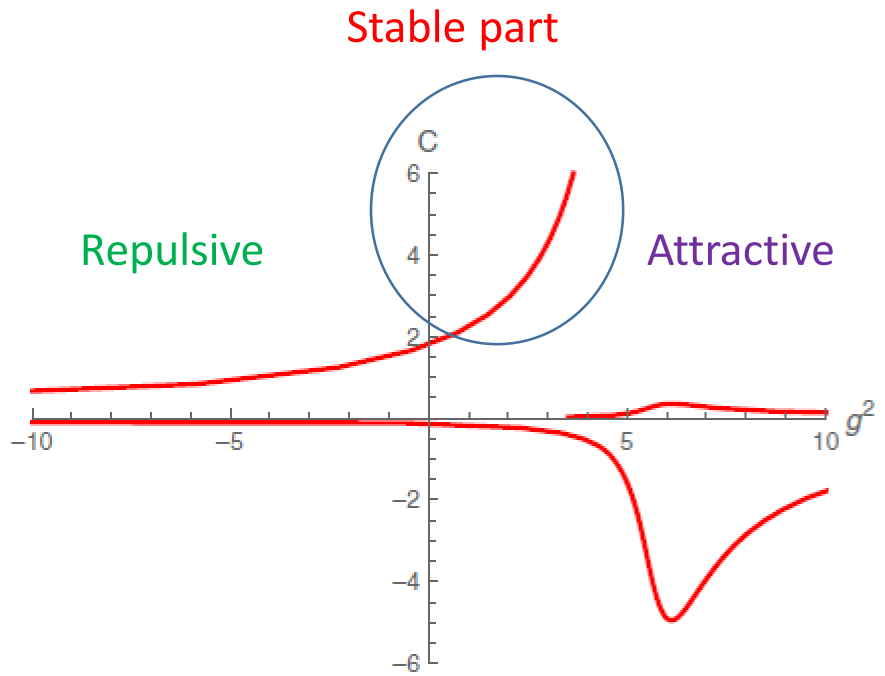
$$\delta S = 0 = -\int d\rho \left(\partial_\rho \frac{\partial \mathcal{L}}{\partial L'} - \frac{\partial \mathcal{L}}{\partial L} \right) \delta L + \frac{\partial \mathcal{L}}{\partial L'} \delta L \Big|_{\mathrm{UV,IR}}$$

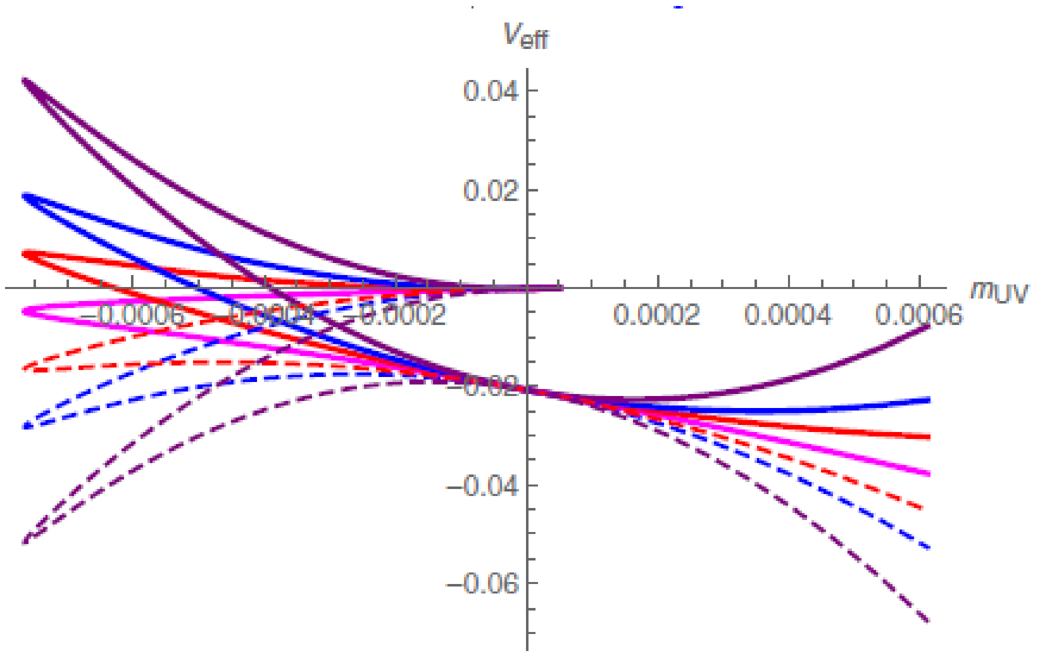
$$\boxed{m \simeq \frac{g^2}{\Lambda^2} c}$$

Equivalently, We apply this condition on the solutions

$2.6N_c < N_f < 4N_c$

KBF, W. Clemens, N. Evans 1807.04548





$$4N_c \leq N_f < \frac{11}{2} N_c$$

In this case, the pure gauge theory lives in the conformal window with an IR interacting fixed point but no chiral symmetry breaking.

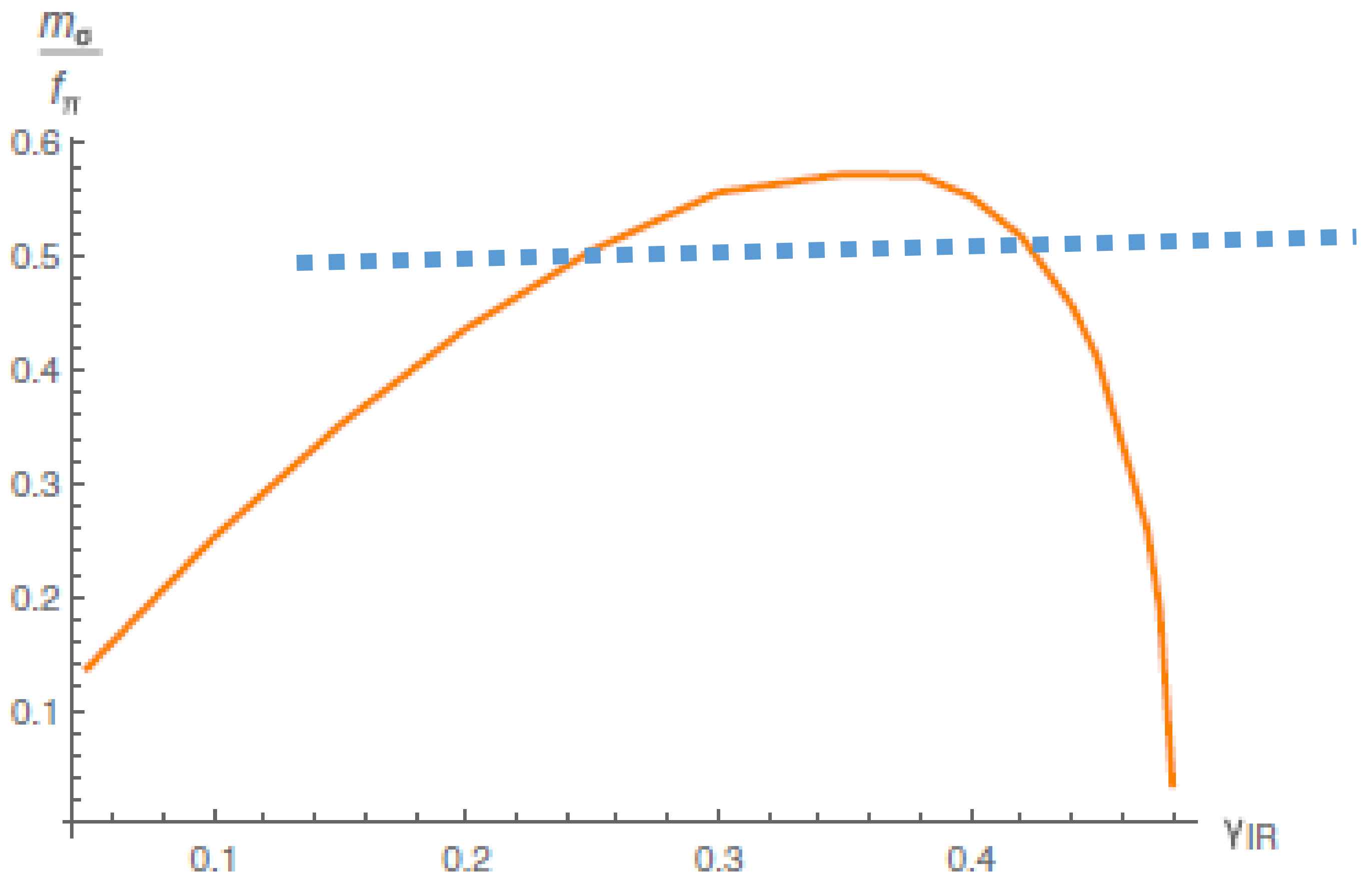
Trigger chiral symmetry breaking by an NJL interaction term.

Walking + NJL= *Ideal Walking*

One might again wonder whether a light σ particle could emerge in this ideal walking setting to provide a different possibility for electroweak physics and its light Higgs .

Discovering a Light-Higgs Particle?!

What we need is: $m_\sigma \simeq f_\pi/2$



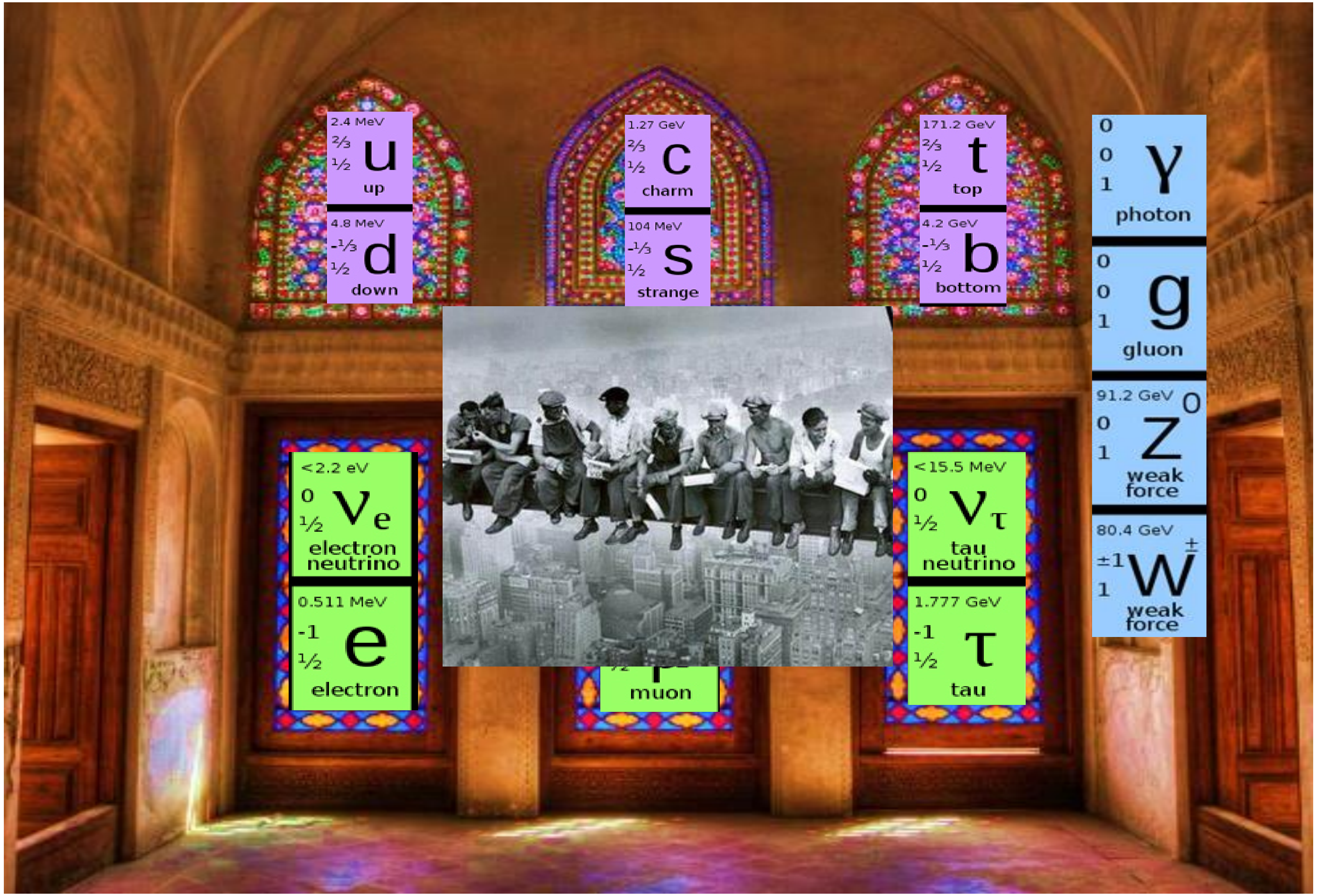
This is a plot in the $N_f = 12$ theory where the IR fixed point is $\gamma_{\rm IR} = 0.48$. Here, we have a separation of 7.5 between the $m_{\rm IR}$ and Λ. We vary $m_{\rm IR}$ to scales with different values of $\gamma_{\rm IR}$ and compute the σ mass in units of f_π.

Nick Evans, Giacomo Cacciapagila, Moslem Ahmadvand, Mansoureh Gholamzadeh

- Application to Beyond Standard Model (BSM):

  - Technicolor and Extended models
  - Walking gauge theories
  - Composite models
  - Top condensation

Thanks for your attention



Back up slides

Beta function and running of coupling

Lagrangian for an SU(Nc) gauge theory with Nf massless quarks

$$\mathcal{L} = -\frac{1}{2}\mathrm{tr}\left(F^{\mu\nu}F_{\mu\nu}\right) + i\bar{q}\not{D}q$$

$$F_{\mu\nu} = \frac{1}{g_s}[D_\mu, D_\nu], \qquad D_\mu = \partial_\mu + ig_s\lambda^a A_\mu^a$$

a dimensionless coupling in four dimensions

The generators of the SU(Nc) gauge group

$$\beta(g_s) = \mu\frac{\partial g_s}{\partial\mu}$$

Two loop beta function

$$\alpha_s \equiv \frac{g_s^2}{4\pi}$$

$$\beta(\alpha_s) = \quad -\beta_0\alpha_s^2 - \beta_1\alpha_s^3 + \mathcal{O}(\alpha_s^4)$$

$$\beta_0 = \frac{1}{2\pi}\left(\frac{11}{3}C_2(G) - \frac{4}{3}N_f C_2(R)\frac{\dim(R)}{\dim(G)}\right)$$

adjoint representation as G and its respective quadratic Casimir

$$\beta_1 = \frac{1}{8\pi^2}\left(\frac{34}{3}[C_2(G)]^2 - \left[\frac{20}{3}C_2(G)C_2(R) + 4[C_2(R)]^2\right]N_f\frac{\dim(R)}{\dim(G)}\right)$$

Dennis D. Dietrich and Francesco Sannino. Conformal window of SU(N) gauge theories with fermions in higher dimensional representations, PRD, hep-ph/0611341.

Walking regime