Technicolor at Criticality

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Motivations

The SM with a fundamental Higgs remarkably explains the EW physics:
the EW precision parameters are compatible with "zero" $(S, T \approx 0)$.

This suggests that **the Higgs sector of the SM is weakly coupled**.
If so, what about naturalness, then?

More fundamental descriptions:

- Supersymmetry is technically natural, but...
  its perturbative formulation (though predictive) does not solve the hierarchy problem
- Technicolor (potentially) solves the hierarchy problem but...
  does it have an IR weakly coupled Higgs?

Dynamical EW Symmetry Breaking[1]

– Start with a chirally invariant strong dynamics (Technicolor = TC) and "weakly" gauge an $SU(2) \times U(1)$ subgroup of the flavor group.
– Spontaneous Chiral Symmetry Breaking, i.e. $\langle \bar{\psi}\psi \rangle \sim \Lambda_\chi^3$, implies EWSB.
– Choose appropriate boundary conditions so that the dynamical scale is set to $\Lambda_\chi = O(1)$ TeV.

YOU GET:

- a natural explanation, and stabilization, of the hierarchy $\Lambda_\chi \ll \Lambda_{UV}$
- $W^\pm, Z^0$ masses at the right scale (and $\rho = 1$)

BUT:

- what about Fermion Masses ?!
- what about Precision Tests ?!

[1] S. Weinberg '76, Susskind '79

Fermion Mass Generation (1)

We would need to couple the SM fermions q to the Higgs operator $\bar{\psi}\psi$.
This is generally accomplished with an Extended TC framework[2],
and leads to $(f, y, G = O(1))$

$$f\frac{(\bar{\psi}\psi)(\bar{\psi}\psi)}{\Lambda^2_{ETC}} \qquad y\frac{(\bar{q}q)(\bar{\psi}\psi)}{\Lambda^2_{ETC}} \qquad G\frac{(\bar{q}q)(\bar{q}q)}{\Lambda^2_{ETC}}$$

- $f \neq 0$: masses for the (pseudo) NGBs;
- $y \neq 0$: SM Fermion Masses;
- $G \neq 0$: FCNC !

[2] Dimopoulos and Susskind '79, Eichten and Lane '80

Fermion Mass Generation (2)

The typical SM fermion mass $m_f(\mu \sim \Lambda_{ETC})$ **strongly depends on the scaling dimension** $\Delta(\bar{\psi}\psi)$ **of the Higgs**:

$$m_f = y\Lambda_\chi \left(\frac{\Lambda_\chi}{\Lambda_{ETC}}\right)^{\Delta-1} \qquad \Lambda_{ETC} > 10^3\,\text{TeV} \;\; \text{(FCNC)}$$

- with $\Delta(\bar{\psi}\psi) \sim 3$ (QCD-like) we have $m_f \sim 1$ MeV
  we cannot explain the 2nd and 3rd generations;
- with $\Delta(\bar{\psi}\psi) \sim 2$ we could explain the 2nd generation[3]
  (still, the top is too heavy...)
- with $\Delta(\bar{\psi}\psi) \sim 1$ we could explain also the 3rd generation
  (hierarchy hidden in y...)

[3] Holdom '81

EW Precision Tests

The S parameter tends to be too large in models of Dynamical EW Symmetry Breaking.

- with $\Delta(\bar{\psi}\psi) \sim 3$ the Higgs $\bar{\psi}\psi$ is a loose bound state of N_{dof} techni-quarks and we expect

$$S \sim \frac{N_{dof}}{6\pi}$$

- with $\Delta(\bar{\psi}\psi) < 3$ in the UV, the perturbative estimates are not reliable (2nd WSR is not satisfied, AdS/CFT) and the S parameter decreases[4]

$$S \sim ???$$

[4] Sundrum and Hsu '93, Appelquist et al. '99, ...

Asymptotic Non-Freedom ?!

The bottom line of the above discussion is that models with

- $\Delta(\bar{\psi}\psi) < 3$ in the UV: **asymptotic NON-freedom**
- $\Delta(\bar{\psi}\psi) \sim 1$ in the IR: **"weakly coupled" Higgs**

are phenomenologically very compelling (m_f,S,...)

Nice. But:

(i) **Are there explicit examples?** (main criticism to Holdom's)

(ii) **What about Naturalness?** (main motivation for Technicolor)

In order to answer (i) and (ii), a deeper understanding of the IR structure of non-abelian gauge theories is required.

This aim motivates the present talk.

I will assume that

- the TC physics is analytic in N_f (number of massless flavors)
- Chiral Symmetry Breaking (χSB) is responsible for confinement and the Schwinger-Dyson (SD) equation approach is a sensible tool

and conjecture that

- non-abelian gauge theories posses an asymptotically non-free phase where χSB is induced by an order parameter with scaling dimension

$$(\text{IR}) \quad 1 \lesssim \Delta \leq 2 \quad (\text{UV})$$

- and that such a theory (TC at criticality) admits a description in terms of a NJL-like model

Outline

1. Basic idea behind TC at Criticality
2. Phases of non-abelian gauge theories
   - The Banks-Zaks (BZ) fixed point and the Conformal Window
   - Confinement without χSB or Asymptotic Non-Freedom?
3. Asymptotic Non-Freedom?!
   - Lattice?
   - Schwinger-Dyson equation and Quenched QED
   - An effective (dual) approach
4. TC at Criticality
   - The Composite Higgs
   - Flavor Physics
5. Conclusions

The Basic Ideas

The Nambu Jona-Lasinio (NJL) model

$$\bar{\psi} i\partial\psi + \frac{f}{2}(\bar{\psi}\psi)^2$$

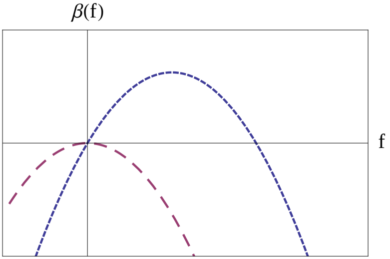
nicely describes dynamical chiral symmetry breaking.
However, it suffers from 2 big problems:

- it is non-renormalizable (a scalar d.o.f. is hidden in the description...)
- it is unnatural: if defined at a scale Λ, then χSB occurs at $\Lambda_\chi \sim \Lambda$ unless fine-tuning is allowed

NJL in $d = 2$ dimensions

The problems of the NJL model can be solved by defining the theory in a generic space-time dimension d:

- renormalizability (Taylor expansion in $1/N$) for $d < 4$[5]
- naturalness in $d = 2$ (Gross-Neveu model): $\Lambda_\chi = \Lambda e^{-1/f(\Lambda)}$



[5] [Parisi '75, Gross '75]

Lessons from the NJL in $d = 2$ dimensions

- The theory is natural (namely, the IR scale depends only very mildly on the UV cutoff) because it is defined (at the UV cutoff!) in terms of marginally relevant operators:

  the mass term of the Higgs field $\bar{\psi}\psi$ is marginally relevant

- It might be phenomenologically interesting (in a $d = 2$ dimensional world...) because the order parameter $\bar{\psi}\psi$ behaves as a "weakly coupled" scalar in the IR:

  the scale dimension of the order parameter is $\Delta(\bar{\psi}\psi) = O\left(\frac{1}{4\pi}\right)$ at $\mu \sim \Lambda_\chi$ (recall that $\Delta = 0$ for a free scalar and $1/4\pi$ is the loop factor in $d = 2$)

Can we construct a similar model in $d = 4$ dimensions?

Interestingly, it turns out that
the large class of theories defined as

$$CFT + f\mathcal{O}^2$$

(where CFT is a large N conformal field theory, and $\mathcal{O} \in CFT$ with arbitrary scaling dimension Δ)
has an universal behavior at leading order in a planar analysis[6].

Examples include:

- the NJL model with $\mathcal{O} = \bar{\psi}\psi$ and massless LσM with $\mathcal{O} = \phi^2$ (where the CFT is trivial)
- quenched QED with $\mathcal{O} = \bar{\psi}\psi$ and orb. proj. of $\mathcal{N} = 4$ with $\mathcal{O} = \phi^2$ (where the CFT is nontrivial)

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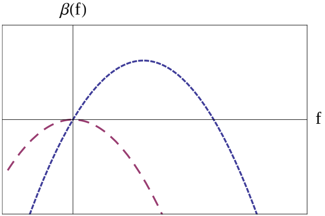
[6] [LV '10]

Universal properties

These models have the same phase structure:

$$\mu \frac{df}{d\mu} = -f^2 + (2\Delta - d)f$$
$$\Delta(\mathcal{O}) = \Delta - f$$



Focusing on $d = 4$:

- for $\Delta = 2$ we have $\beta_f = -f^2$ and the theory is natural ($\Lambda_\chi \ll \Lambda$)
- $\Delta(\mathcal{O}) < 2$ at scales $\mu > \Lambda_\chi$

Idea:

If we are able to find a CFT such that $\Delta(\bar{\psi}\psi) = 2$, and place on top of it the 4-fermion deformation $f(\bar{\psi}\psi)^2$, then we would have

(i) a natural model for dynamical symmetry breaking: $\Lambda_\chi = \Lambda e^{-1/f}$

(ii) a "weakly coupled" Higgs field in the IR: $\Delta(\bar{\psi}\psi) < 2$ for $\mu > \Lambda_\chi$

NOW: **Is there any candidate CFT?**

The Conformal Window

Technicolor at Criticality (TCC) is based on the well established existence of the Conformal Window (CW) in non-abelian gauge theories:

CW: a region in flavor space in which the UV-free dynamics flows towards an interacting IRFP. In the CW the IR dimension satisfies

$$2 \leq \Delta(\bar{\psi}\psi) < 3 \tag{1}$$

In particular, there exists $N_f = N_f^c$ such that $\Delta(\bar{\psi}\psi) = 2$

TC at Criticality

TC at Criticality is defined via

$$\langle e^{i\int f(\bar\psi\psi)^2}\rangle_{CFT} \qquad \text{with} \qquad \Delta(\bar\psi\psi)=2$$

with $\langle\ldots\rangle_{CFT}$ the Green's functions of the $SU(N)$ gauge theory at $\lambda=\lambda_{IR}$ and $N_f=N_f^c$:

- in the broken phase ($f>0$) we have

$$\Lambda_\chi=\Lambda e^{-1/f(\Lambda)}$$

- and the scaling dimension of the quark bilinear (for $f\neq 0$) satisfies

$$1\lesssim\Delta(\bar\psi\psi)\leq 2$$

What is the physical meaning of this construction?

Phases of non-abelian gauge theories

Consider a non-supersymmetric $SU(N)$ gauge theory with a number N_f of massless fermions and 't Hooft coupling λ.

1-loop analysis and the QCD example tell us that:

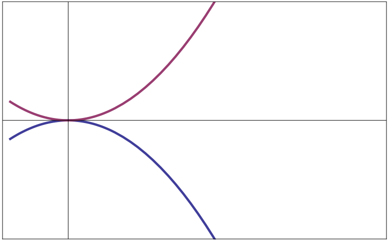
(i) if N_f is "large" asymptotic freedom is lost ($\lambda \to 0$ in the IR)

(ii) if N_f is "small" the theory manifests χSB and confines

The Banks-Zaks fixed point and the conformal window

More precisely:

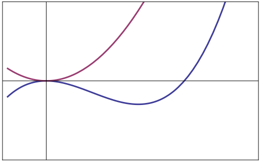
- for $N_f > N_f^{af}$ asymptotic freedom is lost: positive beta function β_λ. ($\lambda = 0$ is an IR fixed point)
- for $N_f < N_f^{af}$ asymptotic freedom sets in: negative beta function. ($\lambda = 0$ is an UV fixed point)



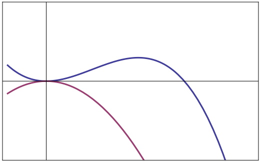
Q: **Is the physics smooth at $N_f = N_f^{af}$?**

Banks and Zaks [7] assumed the physics is smooth (analytic) in N_f.
Continuity of β_λ requires a zero: fixed point. There are 2 possibilities:

- IR fixed point approaching $\lambda_* = 0$ with $N_f \to N_f^{af} - 0$:



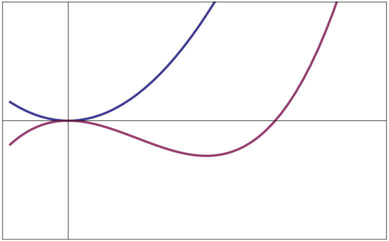
- UV fixed point approaching $\lambda_* = 0$ with $N_f \to N_f^{af} + 0$:



Since in both cases we expect $\lambda_* \to 0$ we can use perturbation theory to verify our guess.

[7] Banks and Zaks '81

It turns out that Nature has chosen the first possibility: $\lambda_* = \lambda_{IR}$

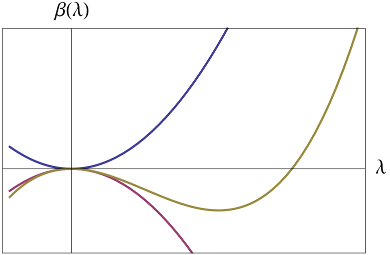


Continuity of β_λ requires the BZ fixed point

Conformality lost

The existence of the BZ IR fixed point has been established. Still, we expect confinement to occur for "small" N_f. Hence:

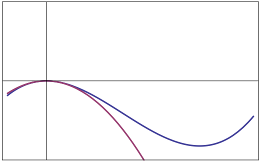
- for $N_f > N_f^{af}$ the theory is IR-free
- for $N_f^c < N_f < N_f^{af}$ the theory is IR-conformal: **conformal window**.
- for $N_f < N_f^c$ we expect confinement and χSB: negative beta function.



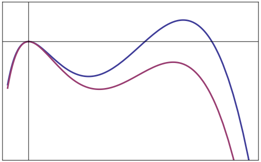
Q: **Is the physics smooth at $N_f = N_f^c$?**

Assume the physics is smooth (analytic) in N_f.
There are 2 possibilities [8] :

- the Banks-Zaks IR fixed point approaches $\lambda_{IR} = \infty$ for $N_f \to N_f^c + 0$:



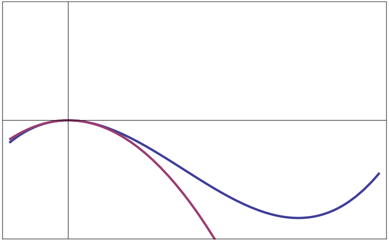
- there exists a nontrivial UV fixed point $\lambda_{UV} \neq 0$ approaching λ_{IR} as $N_f \to N_f^c + 0$:



In both cases λ can be "large": perturbation theory may not be reliable.

[8] D.B. Kaplan et al. '09

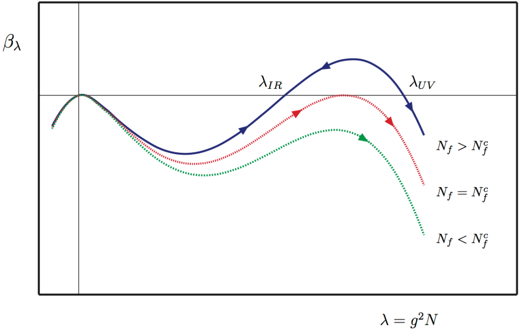
The first possibility



there are reasons to believe it is realized in SUSY QCD:

- existence of a weakly coupled ($\lambda_{mag} \sim 1/\lambda_{IR} \to 0$) "magnetic" dual theory.
- at $N_f = N_f^c$ the dual theory is weakly coupled: **confinement without χSB!**

The second possibility



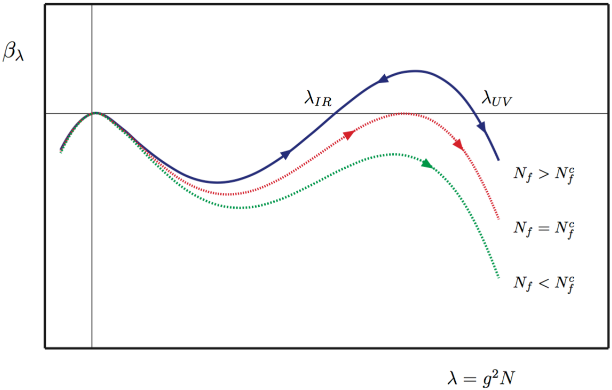
- there exists an asymptotically non-free branch $\lambda \geq \lambda_{UV}$ with χSB
- for $N_f \leq N_f^c$ χSB becomes visible to the UV-free phase: χ**SB drives the theory away from conformality!**

We cannot prove analytically either the first nor the second guess (lattice!). Yet, in both cases we expect remarkable implications:

- if the first possibility is realized we might hope that a magnetic QCD dual actually exists (this would solve the strongly coupled theory!)
- if the second possibility is realized we would have at our disposal an *asymptotically non-free* phase with new, and potentially interesting, phenomenological properties (realization of Holdom's idea [9])

[9] Holdom '81

I will propose a number of arguments in favor of the second possibility



and **conjecture TC at Criticality to be a dual description of the strong branch** $\lambda > \lambda_{IR}$ **for** $N_f \sim N_f^c$

Main features of this physics:

1. there exists an asymptotically non-free branch $\lambda \geq \lambda_{UV}$ with χSB.
2. for $N_f = N_f^c$ the two nontrivial fixed points merge.
   The order parameter for χSB has the form characterizing a Conformal Phase Transition [10]$(c > 0)$:

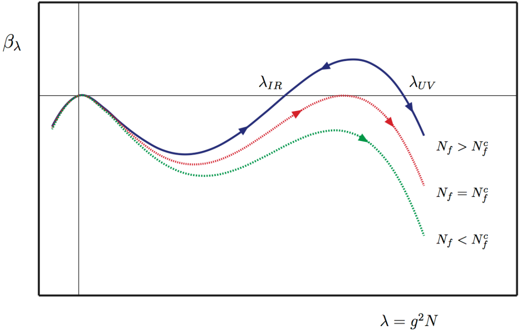
$$\Lambda_\chi = \theta(N_f^c - N_f)\Lambda\, e^{-c/|\Delta(N_f)-\Delta_c|}$$

   with $\Delta_c = \Delta(N_f^c)$ the dimension of the quark bilinear $\bar{\psi}\psi$ at the IR fixed point ($\Delta_c = 2$ in [11])
3. for $N_f < N_f^c$ χSB becomes visible to the UV-free phase if $\lambda > \lambda_c$

[10] Miransky and Yamawaki '97

[11] Cohen and Georgi '89

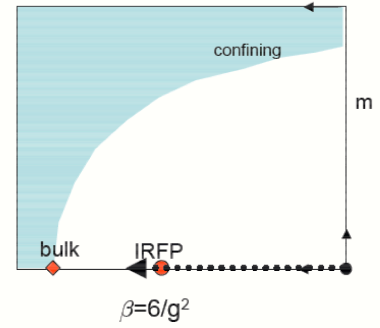
Q: **Can we confirm this picture?**



- LATTICE (?!)
- ANALYTICAL TOOLS

Lattice

Lattice simulations seem to suggest that χSB and confinement are tightly connected (no indication of confinement without χSB). In this sense, the second possibility seems more appropriate... Now:



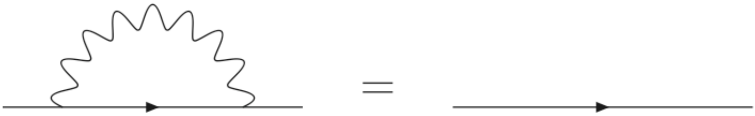
- does the confining phase extends all the way to the chiral limit?
- is the bulk transition 2nd order?

SD approach

If the conjectured picture is right χSB is expected to play a crucial role (as opposed to the SUSY case...)

A study of the Schwinger-Dyson equations in this case would provide useful information, but requires approximations in order to be handled.

For example, in the "rainbow approximation":



A solution of the equation gives the dynamical fermion mass $\Sigma(p)$: χSB occurs if $\Sigma(0) \neq 0$ in the chiral limit.

Quenched QED (1)

Consider massless QED

$$\mathcal{L}_{CFT} = -\frac{1}{4\lambda}F^2 + \bar{\psi} iD\psi$$

In the quenched limit (fermion loops are suppressed as in large N QCD) the rainbow approximation is justified.
An analysis of the SD equation reveals that

$$\Sigma(0) \simeq \Lambda e^{-\pi/\sqrt{\frac{\lambda}{\lambda_c}-1}} \qquad \lambda_c = \text{number}.$$

(i) χSB requires $\lambda > \lambda_c$

(ii) $\beta_\lambda \propto -\left(\frac{\lambda}{\lambda_c} - 1\right)^{3/2} \neq 0$ (Miransky scaling [12]) with λ_c an UVFP.

(iii) Conformal Phase Transition (CPT) at $\lambda = \lambda_c$, where $\Delta(\bar{\psi}\psi) = 2$

[12] Miransky '85

Quenched QED (2)

Note that:

- $\beta_\lambda \neq 0$ is not consistent with the quenched approximation (not true in the non-abelian case...)
- for $\lambda = \lambda_c$ the 4-fermion deformation $(\bar{\psi}\psi)^2$ is marginal

We are thus led to consider[13]

$$-\frac{1}{4\lambda}F^2 + \bar{\psi}iD\psi + f(\bar{\psi}\psi)^2$$

This theory belongs to the general class introduced earlier:

(i) $\lambda = const$ in the leading quenched approximation

(ii) $\beta_f = -f^2 + (2\Delta - 4)f$ and χSB for $f > f_{UV}$.

(iii) CPT at $\lambda = \lambda_c$, where $\Delta(\bar{\psi}\psi) = 2$ and $\Lambda_\chi = \Lambda e^{-1/f} \propto \Sigma(0)$.

[13] [W.A.Bardeen et al. '86]

Extrapolating these results to the non-abelian case, χSB requires:

- either a strong coupling $\lambda > \lambda_c$ and $f = 0$

OR

- $\lambda = const$ and a $f(\bar{\psi}\psi)^2$ deformation

Are these theories
2 equivalent descriptions of the same dynamics ?!

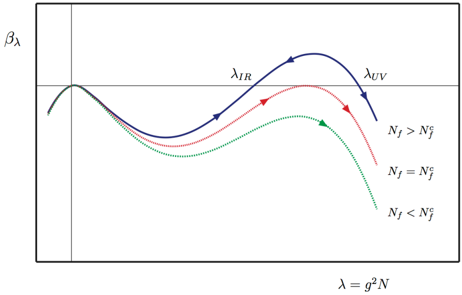
If this is true the dynamical mass (and phase structure) must be the same:

$$\text{IF:} \qquad \Lambda e^{-\pi/\sqrt{\frac{\lambda}{\lambda_c}-1}} \equiv \Lambda e^{-1/f} \quad \Leftrightarrow \quad f \propto \sqrt{\frac{\lambda}{\lambda_c}-1} \quad ???$$

$$\text{THEN:} \qquad \beta_f = -f^2 \quad \Leftrightarrow \quad \beta_\lambda \propto -\left(\frac{\lambda}{\lambda_c}-1\right)^{3/2} \quad !!!$$

Where do the "equivalence" come from?

Assume we would like to model the strong branch defined at $\lambda = \lambda_{UV}$:



How can this be done? There are two equivalent ways:

1. Study the Yang Mills action at strong coupling (this is $\lambda =$ *large* and $f = 0$...)
2. Use an effective approach! Sit at λ_{IR} and add CFT deformations (this is $\lambda =$ *const* and $f \neq 0$...)

Conformal Perturbation Theory:

introduce on the top of the CFT all operators compatible with the symmetries. The theory is now defined by the path integral

$$\langle e^{i\int \mathcal{L}_{pert}}\rangle_{CFT} = \int \mathcal{D}[\mathrm{CFT}]\, e^{i\int \mathcal{L}_{pert}}$$

In order for this theory to describe the strong, asymptotically non-free branch:

- The CFT must be defined in terms of the Green's functions of the $SU(N)$ gauge theory with $\lambda = \lambda_{IR}$.
- $\mathcal{L}_{pert} = \sum_n f_n \mathcal{O}_n$ must include the CFT deformations responsible for the flow $\lambda_{UV} \to \lambda_{IR}$ ($\mathcal{L}_{pert}$ is relevant at λ_{UV}).
  Because $\mathcal{L}_{pert}$ is "dynamical" we expect $f_n = f_n(\lambda)$

What is $\mathcal{L}_{pert}$??? The SD approach strongly suggests that

$$\mathcal{L}_{pert} = f(\bar{\psi}\psi)^2 + \ldots \quad \text{with} \qquad f = f(\lambda)$$

At leading order in the planar expansion we can consistently assume the 4-fermion operator is the ONLY deformation and consider the path integral [14]

$$\langle e^{i\int f(\bar{\psi}\psi)^2} \rangle_{CFT}$$

CONJECTURE: **This generalized formulation of the Nambu-Jona Lasinio model represents an effective (dual) description of the asymptotically non-free phase of non-abelian gauge theories**

[14] LV '10

Q: Is there any indications in favor of the conjecture?

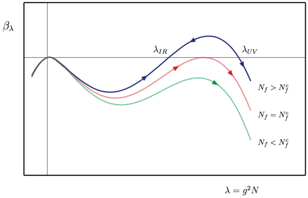
Yes. From a large N (colors) analysis of

$$\langle e^{i\int f(\bar{\psi}\psi)^2}\rangle_{CFT}$$

we find

- 2 fixed points $f = f_{IR,UV}$ only if $2 \leq \Delta < 3$ (namely if the CW of the gauge theory is there)
- f_{IR} is mapped into λ_{IR} via $f_{IR} = f(\lambda_{IR})$. The same for f_{UV} (λ_{UV} is predicted ONLY if the CW exists!)
- The fixed points $f_{IR,UV}$ merge when $\Delta = 2$: Conformal Phase Transition and $\Lambda_\chi = \Lambda e^{-1/f}$ (agreement with the SD equation approach)

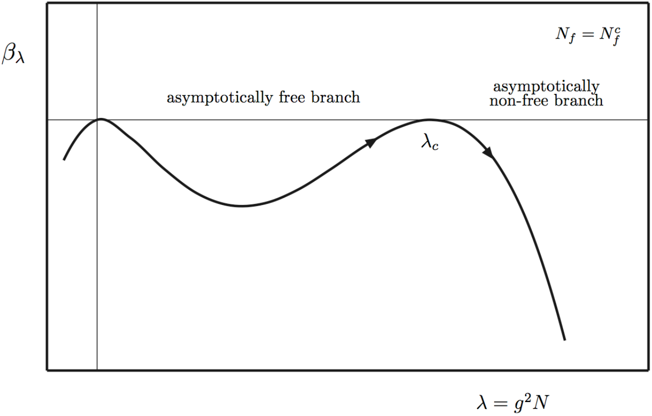
The emerging physical picture is the following:



- the UV free phase is described by the Yang-Mills action
- the UV non-free phase ($\lambda > \lambda_{IR}$) is dual to CFT$+f(\bar{\psi}\psi)^2$, where $\lambda = \lambda_{IR}$ is mapped into $f_{IR} = 0$, while $\lambda = \lambda_{UV}$ into $f = f_{UV}$.
- When $N_f = N_f^c$ the fixed points merge $\lambda_{IR} = \lambda_{UV} \equiv \lambda_c$ ($f_{IR} = f_{UV}$)
  - the dual model consistently predicts a CPT at $\Delta = 2$.
  - λ_c must be identified as the Miransky UV fixed point.

TC at Criticality: the physical meaning

Technicolor at Criticality is expected to describe the non-abelian dynamics defined at $\lambda > \lambda_{IR} = \lambda_{UV} = \lambda_c$



The Composite Higgs

A "weakly coupled" Higgs $\bar{\psi}\psi$ is anticipated by analogy with the Gross-Neveu model (the natural version of the NJL).

The Higgs physics can be understood by identifying H with a dilaton, i.e. the pseudo NGB of dilatation invariance

(in analogy with the η' of QCD, in our framework the Higgs/dilaton mixing is maximal...)

- if $\Delta = 1 + \epsilon$ is the IR dimension of the Higgs ($\epsilon \lesssim O(0.1)$ from NJL), then ϵ is the explicit CFT breaking ($\Lambda_\chi = 0$ for $\epsilon = 0$)
- by symmetry arguments $m^2_{Higgs} \sim \epsilon \Lambda^2_\chi$.
  More generally, $g_{\bar{\psi}\psi} = g_{SM\ Higgs}(1 + O(\epsilon))$ for any coupling

The phenomenology is analogous to that of CH models[15]:
The Higgs in TCC is a pseudo-NGB of an Approximate Dilatation Invariance of the Strong Dynamics

[15] D.B. Kaplan and Georgi '84

The Flavor Sector

The renormalization effects from the scale Λ_{ETC} (at which the Yukawa operator is generated) down to Λ_χ (at which the chiral condensate is formed) gives

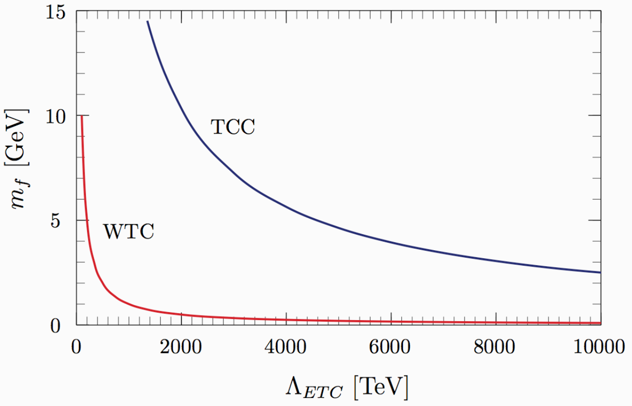
$$
\begin{aligned}
m_f &= y\frac{\Lambda_\chi^3}{\Lambda_{ETC}^2}\exp\left(\int_{\Lambda_\chi}^{\Lambda_{ETC}}\gamma\ \mathrm{d}\log\mu\right)\\
&= y\frac{\Lambda_\chi^2}{\Lambda_{ETC}}\left[e\log\left(\frac{\Lambda_{ETC}}{\Lambda_\chi}\right)\right].
\end{aligned}
$$

There are two competing contributions:

- $\Lambda_\chi/\Lambda_{ETC}$ suppression typical of $\Delta(\bar\psi\psi)\sim 2$ (WTC)
- Log enhancement coming from $f(\mu)$ ($1\sim\Delta(\bar\psi\psi)<2$ in TCC)

The Flavor Sector: $i = 1, 2$

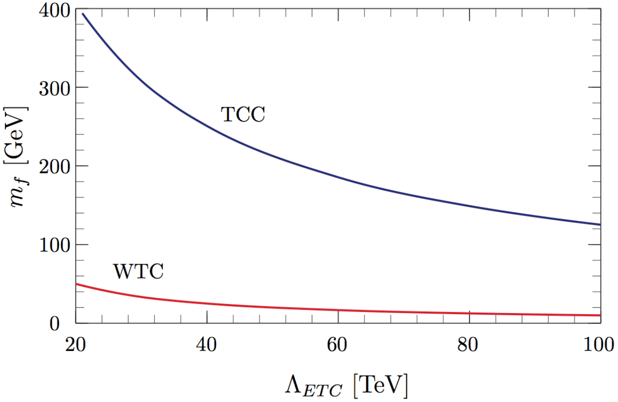
The fermion mass in TCC lies in between a WTC dynamics with $\Delta(\bar{\psi}\psi) \sim 2$ and a fundamental Higgs with $\Delta(\bar{\psi}\psi) \sim 1$



$\Lambda_{ETC}^{i=1,2} > O(10^4)$ **TeV for 1st and 2nd generations**

The Flavor Sector: $i = 3$

The fermion mass in TCC lies in between a WTC dynamics with $\Delta(\bar{\psi}\psi) \sim 2$ and a fundamental Higgs with $\Delta(\bar{\psi}\psi) \sim 1$



$\Lambda_{ETC}^{i=3} = O(10^2)$ **TeV for the top**

Summery

- the well established phases of QCD with many massless flavors N_f:
  1) $N_f > N_f^{af}$: the theory is in an IR-free phase
  2) $N_f^c < N_f < N_f^{af}$: the theory is IR conformal
  3) $N_f < N_f^c$: the theory develops a chiral condensate and confines
- the Conformal Window exists because the beta function β_λ is continuous at $N_f = N_f^{af}$
- continuity of the beta function β_λ at $N_f = N_f^c$ admits two scenarios:
  a) the theory manifests confinement without χSB (and possibly a magnetic dual)
  b) the theory has an asymptotically non-free phase

Lattice simulations are needed!!!

Conclusions (1)

(1) **I presented a number of argument in support of the existence of an asymptotically non-free phase for ordinary (non SUSY) non-abelian theories.** In particular I (re)interpreted the analysis of Miransky as an indication in favor of this physics:

- the Miransky scaling would be the running close to the non-trivial UV fixed point
- the (unphysical) statement "χSB occurs at $\lambda > \lambda_c$" would be replaced by the (physical) statement "χSB occurs in the phase $\lambda > \lambda_{UV}$"

(2) **I speculated on the existence of a dual description of the strong branch.** The physics agrees with that extracted from the SD equation approach:

- χSB becomes visible to the UV-free phase when $\Delta(\bar{\psi}\psi) = 2$ (agreement with Georgi and Cohen)
- at that critical point the theory undergoes a Conformal Phase Transition (the asymptotically non-free theory is natural!)

Conclusions (2)

(3) **I proposed a class of asymptotically non-free theories**
(these exist irrespective of the validity of the above conjectures on non-abelian gauge theories!)
strong coupling throughout the RG flow: dual AdS/CFT description?!

(4) **Technicolor at Criticality** represents one such example:

- TCC solves the hierarchy problem ($\Delta(\bar{\psi}\psi) = 2$ in the UV)
- TCC predicts the existence of a "weakly coupled" Higgs in the IR (i.e. a dilaton $\Delta(\bar{\psi}\psi) \simeq 1$ in the IR)
  strong impact on Flavor Physics and (potentially) on EW physics

Thank You

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