CreutzFest 2014

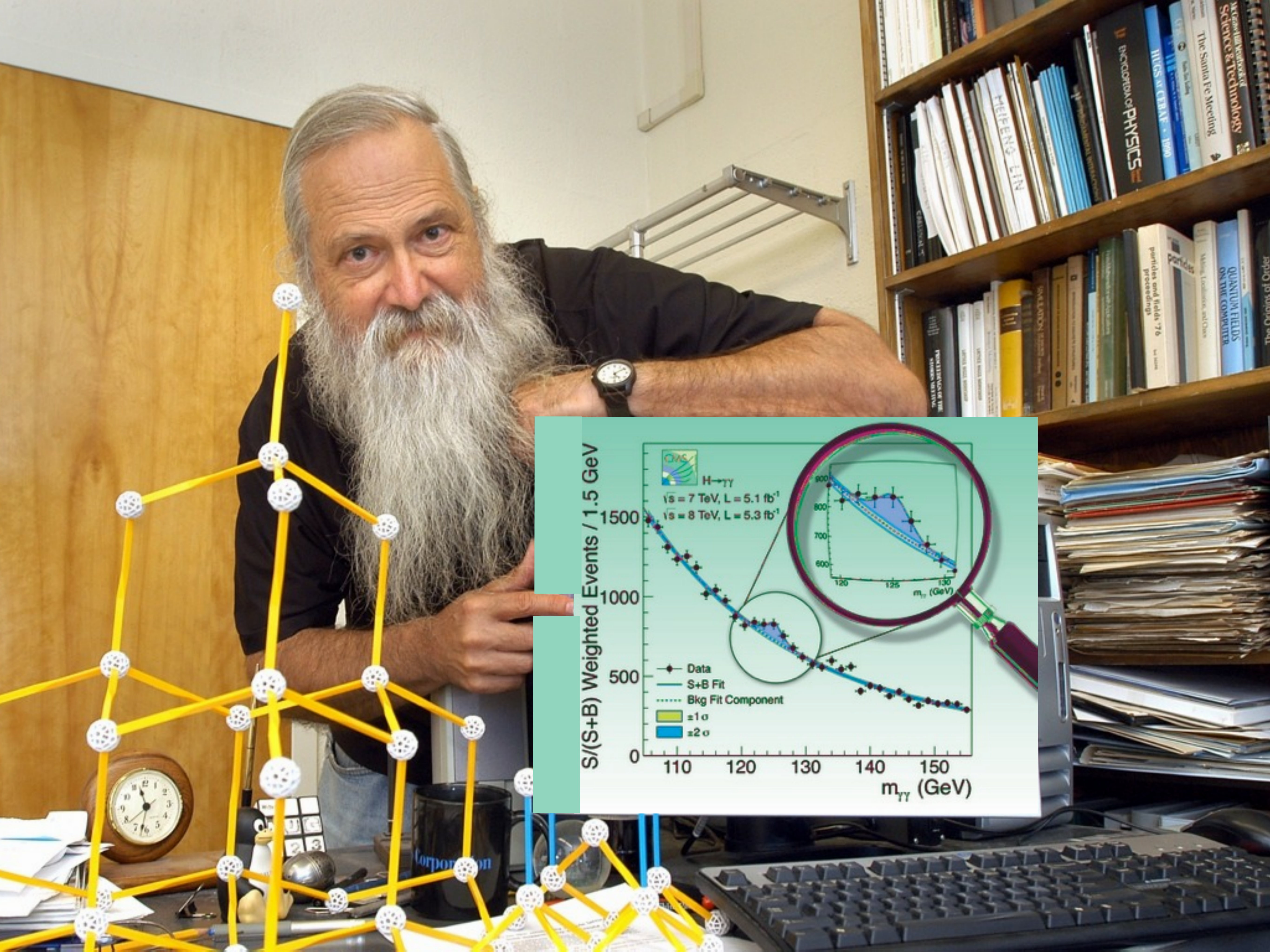
From Mike to the Higgs impostor and the dilaton

Julius Kuti

University of California, San Diego

Creutz Fest 2014

BNL, September 4-5, 2014



H→γγ
√s = 7 TeV, L = 5.1 fb⁻¹
√s = 8 TeV, L = 5.3 fb⁻¹
S/(S+B) Weighted Events / 1.5 GeV
1500
1000
500
0
110
120
130
140
150
m γγ (GeV)
Data
S+B Fit
Bkg Fit Component
±1σ
±2σ
900
800
700
600
120
125
130
m γγ (GeV)
ENCYCLOPEDIA of PHYSICS
The Santa Fe Meeting
Science & Technology
particles and fields '76 proceedings
QUANTUM FIELDS ON THE COMPUTER

Outline

Mike's impact on my early lattice work

two seminal papers in 1979: Creutz and Wilson
1979-80: first lattice work after off-lattice frustration
the story of the first QCD simulation in Hungary

What is the composite Higgs?

searching the needle in the haystack?
or, searching for the haystack?

The sextet model and the toolset

low mass scalar emerging
resonance spectrum ~ 2 TeV range
running coupling
spectral density and chiral condensate

Early universe

EW phase transition
dark matter

Summary and Outlook

Physics Letters B
Volume 95, Issue 1, 8 September 1980, Pages 75–79

The quark-nucleon phase diagram and quantum chromodynamics

J. Kuti, B. Lukács, J. Polónyi, K. Szlachányi

Abstract

The temperature dependence of a conjectured first-order phase transition between nuclear matter and quark-gluon matter is calculated for temperatures below T = 200 MeV. On the nuclear side a rather successful meson-nucleon mean field theory is applied while quark-gluon matter at large densities and finite temperatures is described perturbatively by quantum chromodynamics. Outside the finite volume of hot and dense quark-gluon matter the physical vacuum is characterized, by the newly determined bag parameter Λ_B = 235 MeV. We observe a dramatic drop in the density of nuclear matter at the phase transition point as the temperature increases, if the scale parameter Λ of QCD is chosen as Λ = 100 MeV. For larger values of Λ the effect is less pronounced. Further work is required to settle this problem.

1979 : frustrations to describe the QCD phase transition

Two seminal papers appear in preprint form in 1979: Mike is on both

After reading Mike's string tension result I knew what to do

How on earth can I do a lattice simulation in Hungary in 1979?

the iPhone today would beat the R40 russian "supercomputer" Hungary had
(with 1 MB disk storage for research institute where I worked at that time)
broke down every few hours, served several hundred researchers

Early 1980: Hungarian National Academy buys and IBM 3030 computer (like a VAX 780)

U.S. Congress sets condition: no atomic or nuclear research on the machine and particle physics is nuclear

Dubna-CERN deep-inelastic muon experiment with strong group from Hungary
They cannot use the badly needed computer either - experiment is East-West poster child
Van Hove (DG of CERN) comes to Hungary to convince Academy and IBM office to ask for US congressional exception for the experiment

remaining condition: IBM rep will check computer output every night

There we go “doing the muon experiment” and outputting in the lattice Monte Carlo some phony lines: “now we are calculating muon scattering at 5 degrees …”

trouble: IBM reps notices that this angle was already calculated (oh my, the real experimental group had real scattering at real angles printed the previous night)

We find the phase transition before I board the plane for Madison, Wisconsin (ICHEP 1980)

Roman Jackiw gives me 10 minutes to talk in the session and Mike lists the result in the crowded room of his talk as part of the first QCD applications emerging

Thank you Mike for showing the way and fueling the excitement!

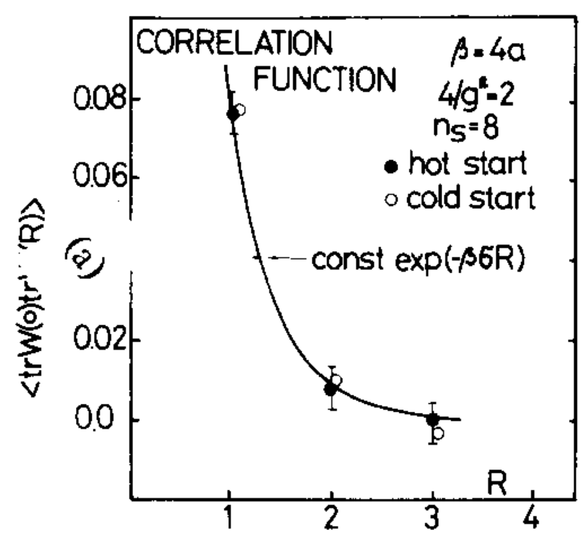
MONTE CARLO STUDY OF SU(2) GAUGE THEORY AT FINITE TEMPERATURE

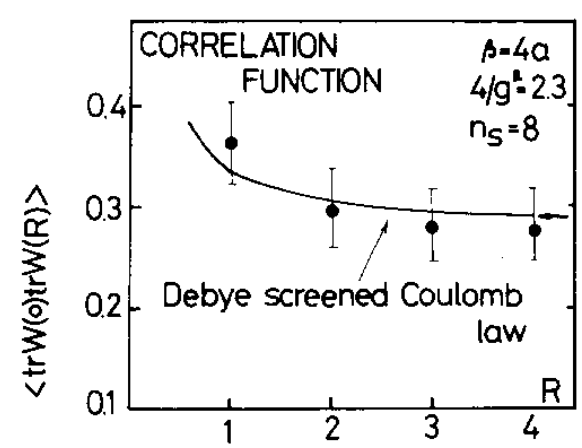
J. KUTI, J. POLÓNYI and K. SZLACHÁNYI
Central Research Institute for Physics, H-1525 Budapest, Hungary

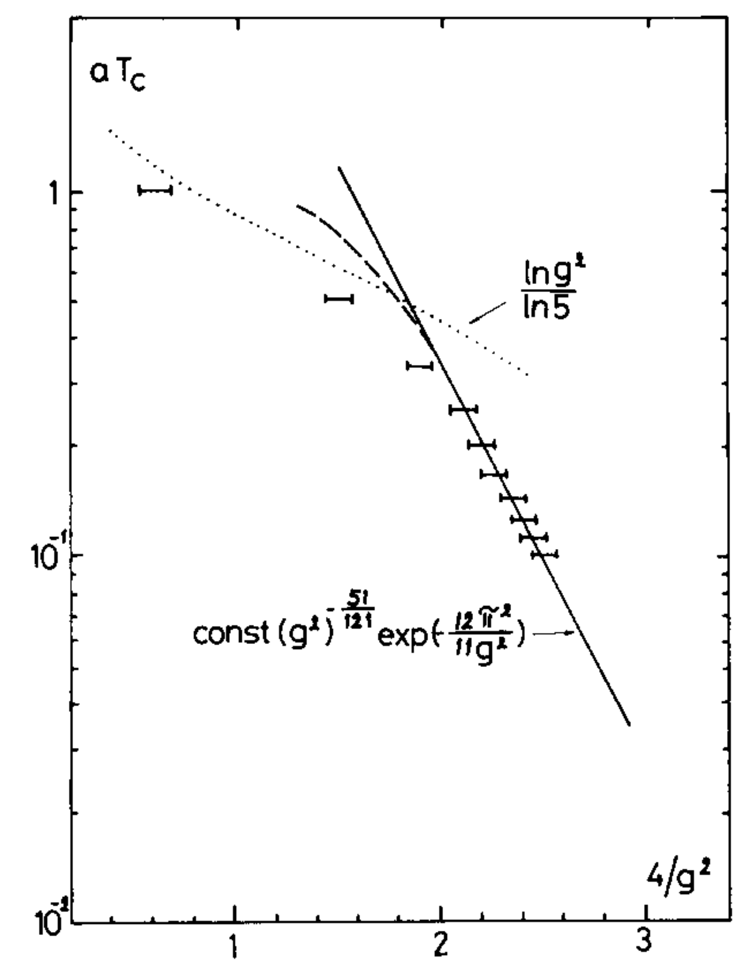
Received 9 September 1980

We find numerical evidence for the phase transition between the confinement phase and free Coulomb phase of SU(2) Yang–Mills theory with lattice cut-off. The search for the critical temperature is based on a Monte Carlo study of the string tension between a heavy $Q\bar{Q}$-pair in a heat bath. The arbitrary normalization 0.2 GeV^2 is used for the string tension at zero temperature when a smooth extrapolation of the lattice theory to the continuum limit is carried out. Our numerical estimate for the critical temperature is $\boxed{T_c \approx 160 \pm 30 \text{ MeV}}$ in the absence of quark degrees of freedom. It is suggested that the phase transition is of second-order.

important scale setting
Hasenfratz[2]





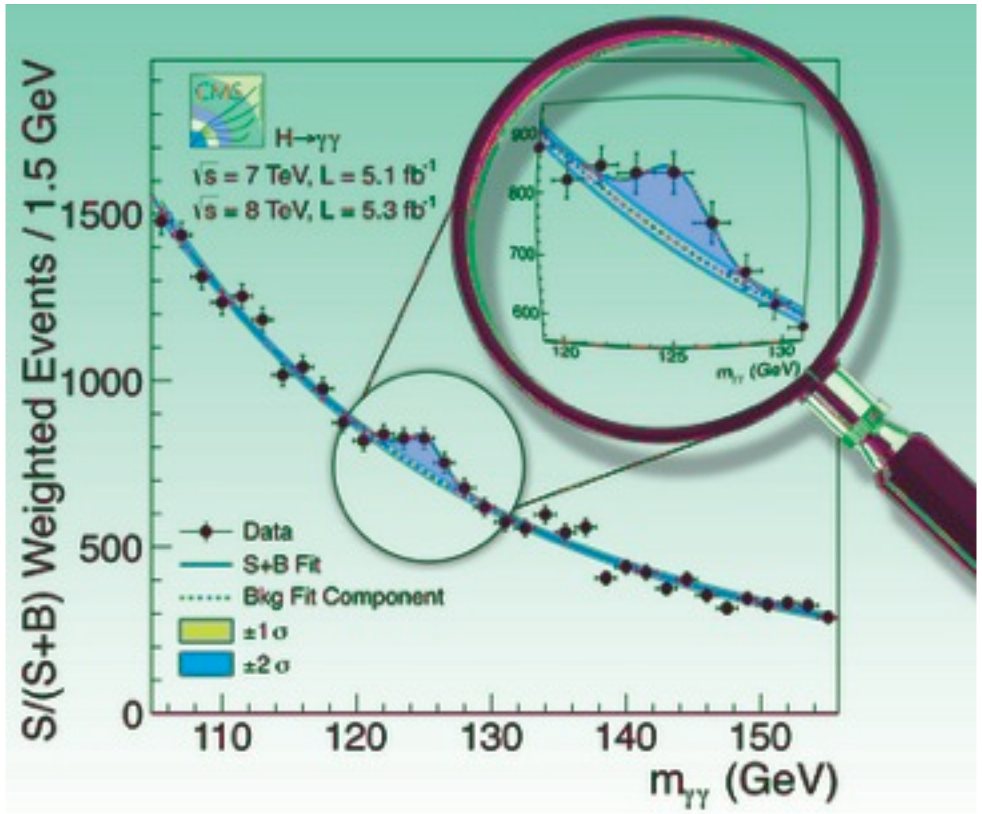


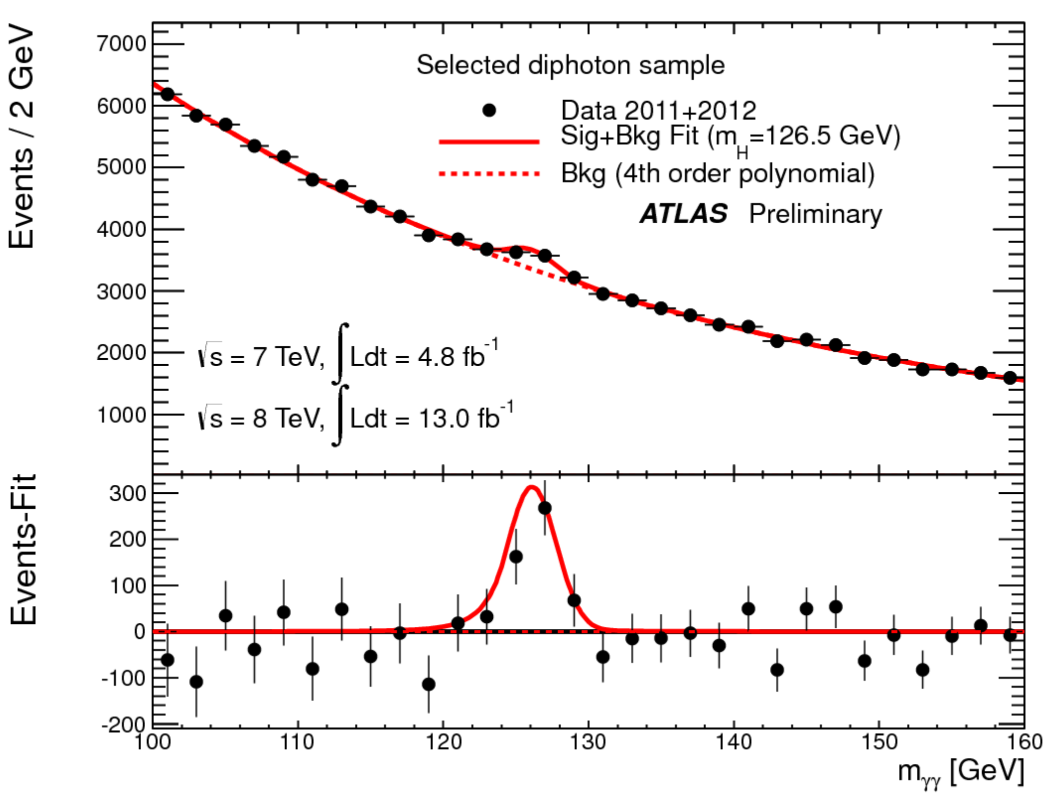
onto the Higgs

Lattice Higgs Collaboration (L$_{at}$HC)

Zoltan Fodor, Kieran Holland, Santanu Mondal, Daniel Nogradi, Chik Him Wong

Rational for lattice BSM?





voices: a light Higgs-like scalar was found, consistent with SM within errors, and composite states have not been seen below 1 TeV. Strongly coupled BSM gauge theories are Higgs-less with resonances below 1 TeV

facts: Compositeness has not been shown to be incompatible with the light Higgs scalar; earlier search for compositeness was based on naively scaled up QCD and unacceptable old technicolor guessing games. Resonances, out of first LHC run reach, are in the 2-3 TeV range in the theory I will discuss

lattice BSM plans: LHC14 run will search for new physics from compositeness and SUSY, and the lattice BSM community is preparing quantitative lattice based predictions to be ruled in or ruled out.

What is the composite Higgs mechanism?

the Higgs doublet field

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} \pi_2 + i\,\pi_1 \\ \sigma - i\,\pi_3 \end{pmatrix} \qquad\qquad \frac{1}{\sqrt{2}}(\sigma + i\,\vec{\tau}\cdot\vec{\pi}) \equiv M$$

$$D_\mu M = \partial_\mu M - i\,g\,W_\mu M + i\,g' M\,B_\mu\,, \qquad \text{with} \qquad W_\mu = W_\mu^a \frac{\tau^a}{2}\,, \quad B_\mu = B_\mu \frac{\tau^3}{2}$$

The Higgs Lagrangian is

spontaneous symmetry breaking

Higgs mechanism

$$\mathcal{L} \;=\; \frac{1}{2}\mathrm{Tr}\left[D_\mu M^\dagger D^\mu M\right] - \frac{m_M^2}{2}\mathrm{Tr}\left[M^\dagger M\right] - \frac{\lambda}{4}\,\mathrm{Tr}\left[M^\dagger M\right]^2$$

strongly coupled gauge theory

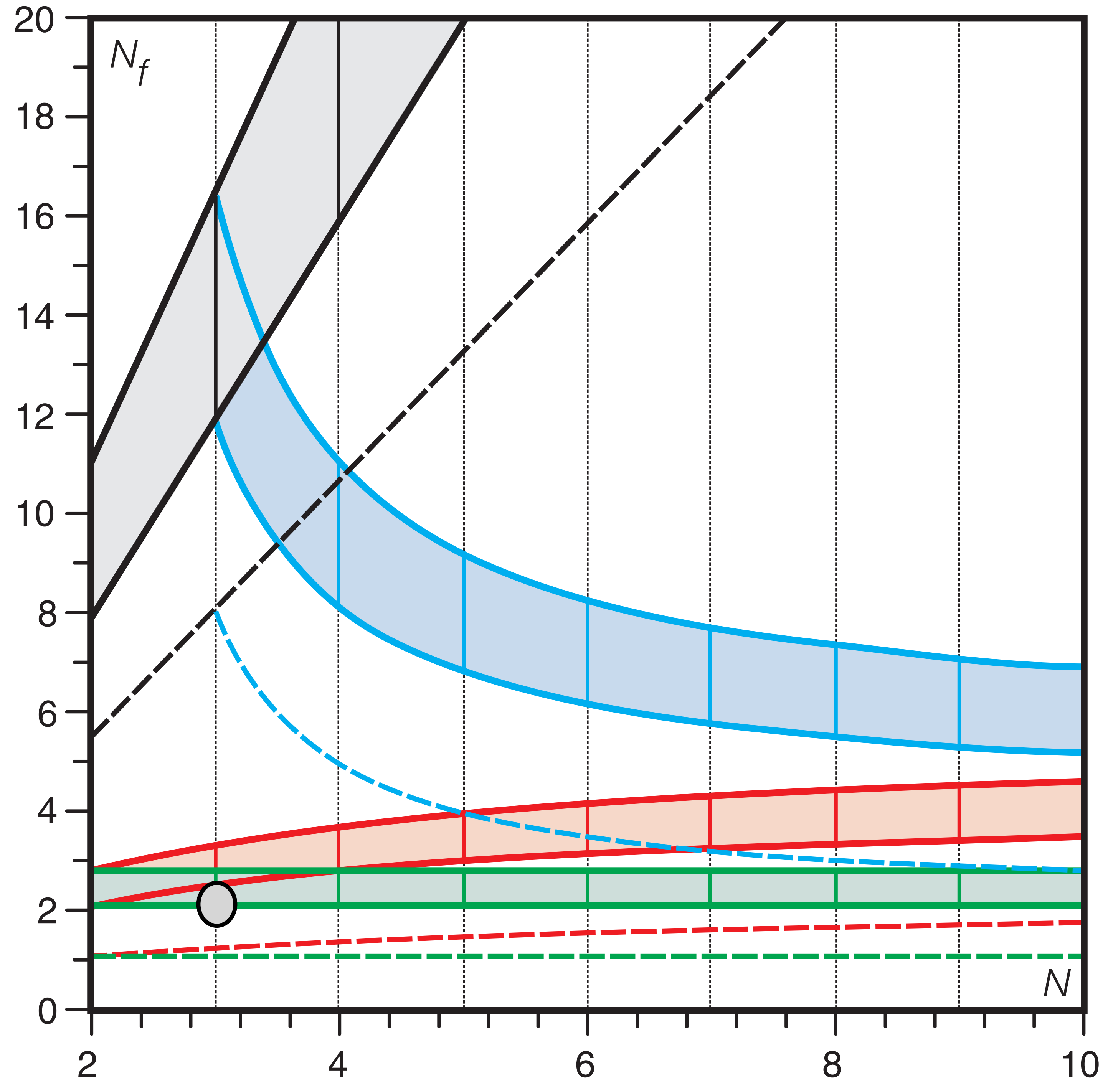
fermions (Q) in gauge group reps

$$\mathcal{L}_{Higgs} \rightarrow -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{Q}\gamma_\mu D^\mu Q + \ldots$$

needle in the haystack?

or, just one of the haystacks?

near-conformal light Higgs (dilaton-like?) sextet rep



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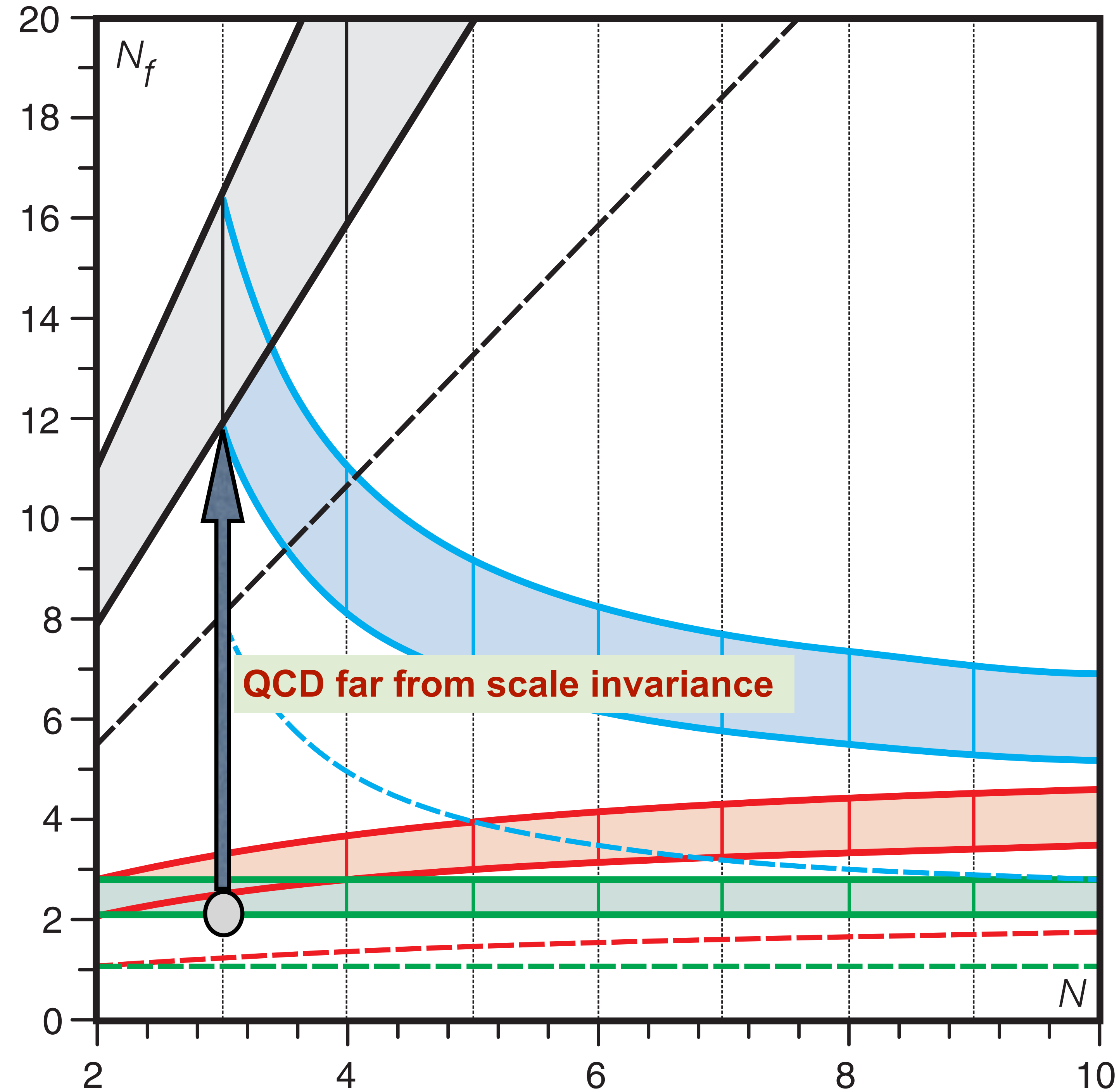

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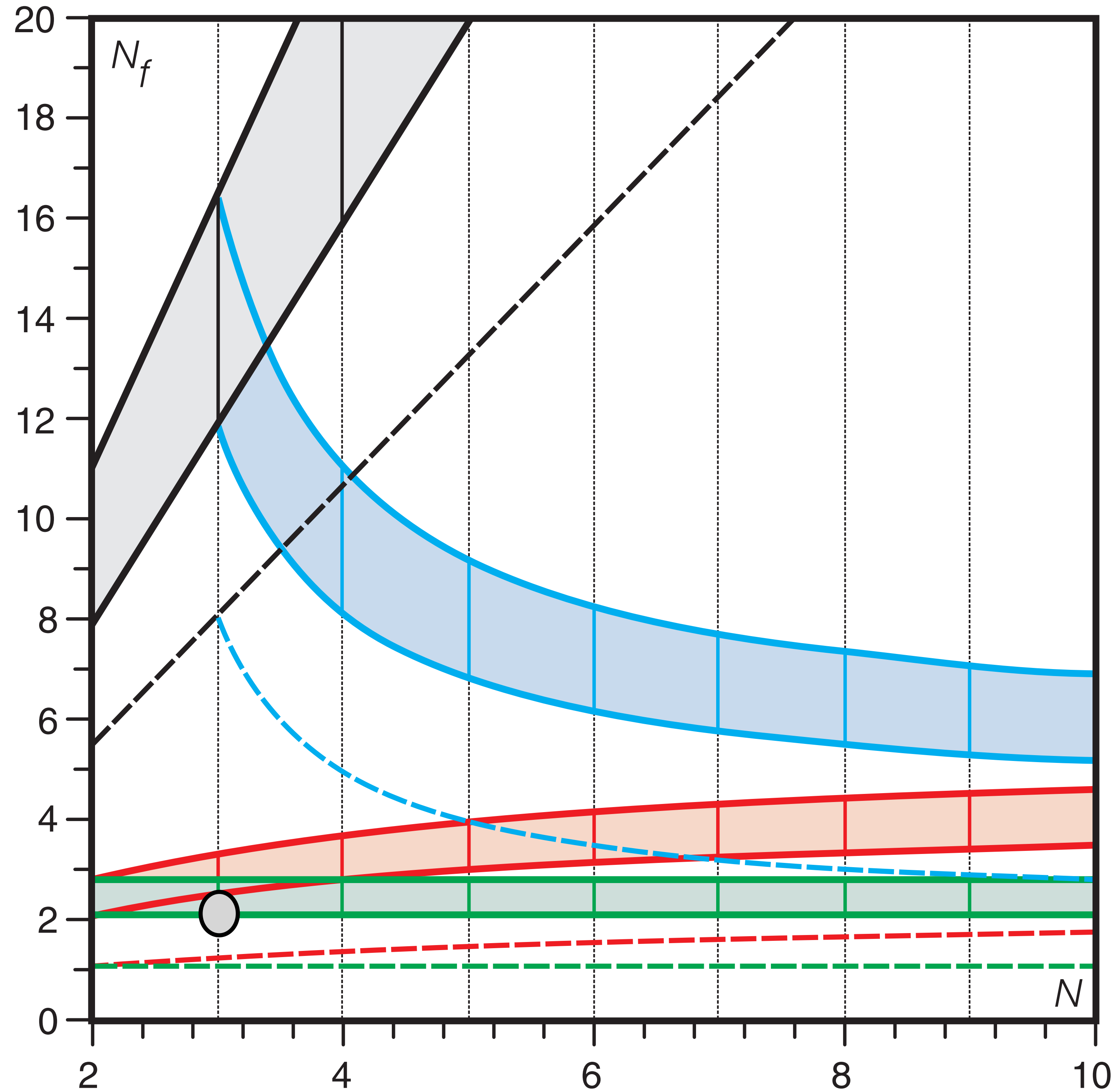


near-conformal light Higgs (dilaton-like?) sextet rep

to illustrate: sextet SU(3) color rep

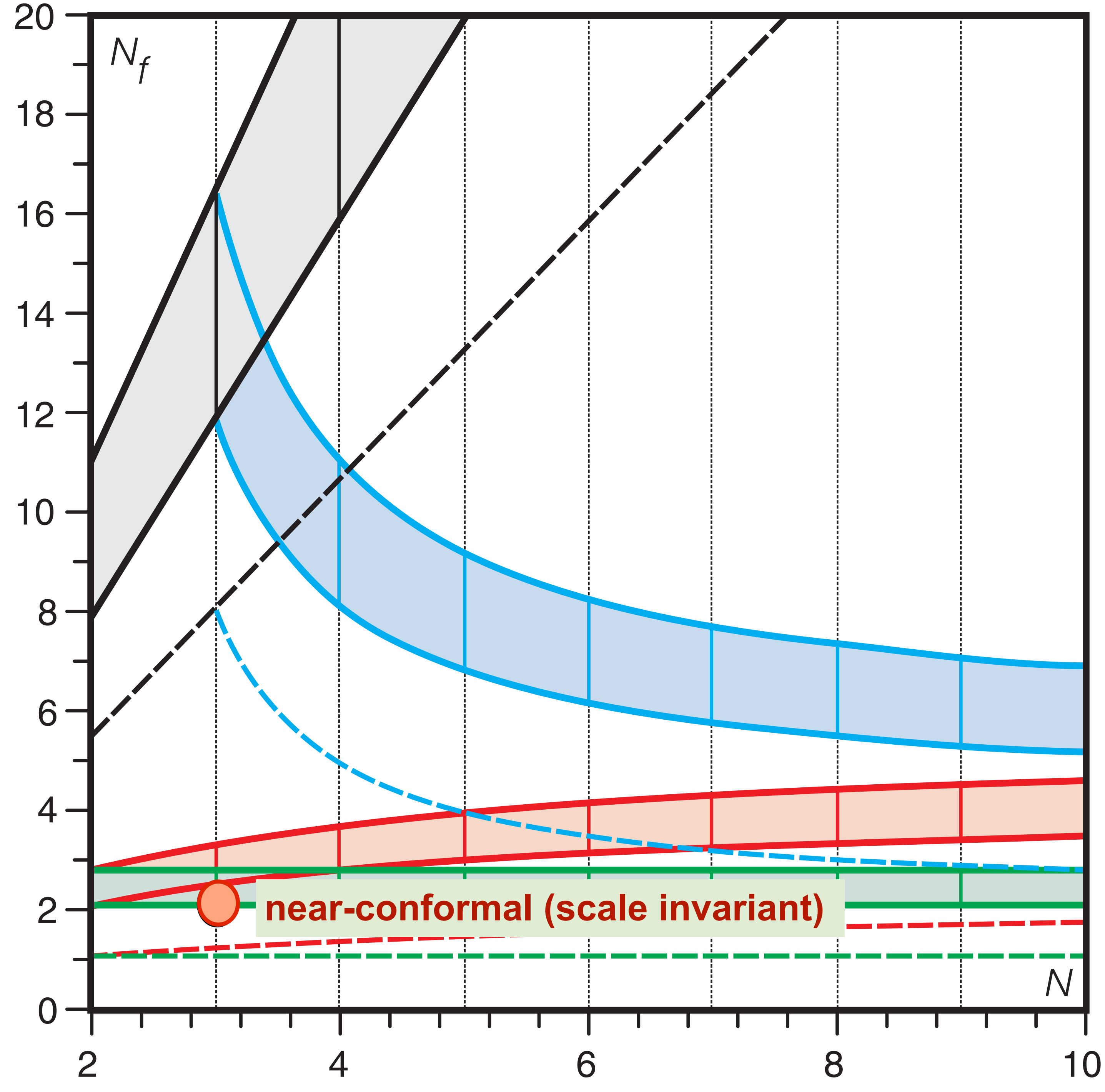
one massless fermion doublet $\begin{bmatrix} u \\ d \end{bmatrix}$

χSB on Λ~TeV scale

three Goldstone pions
become longitudinal
components of weak bosons

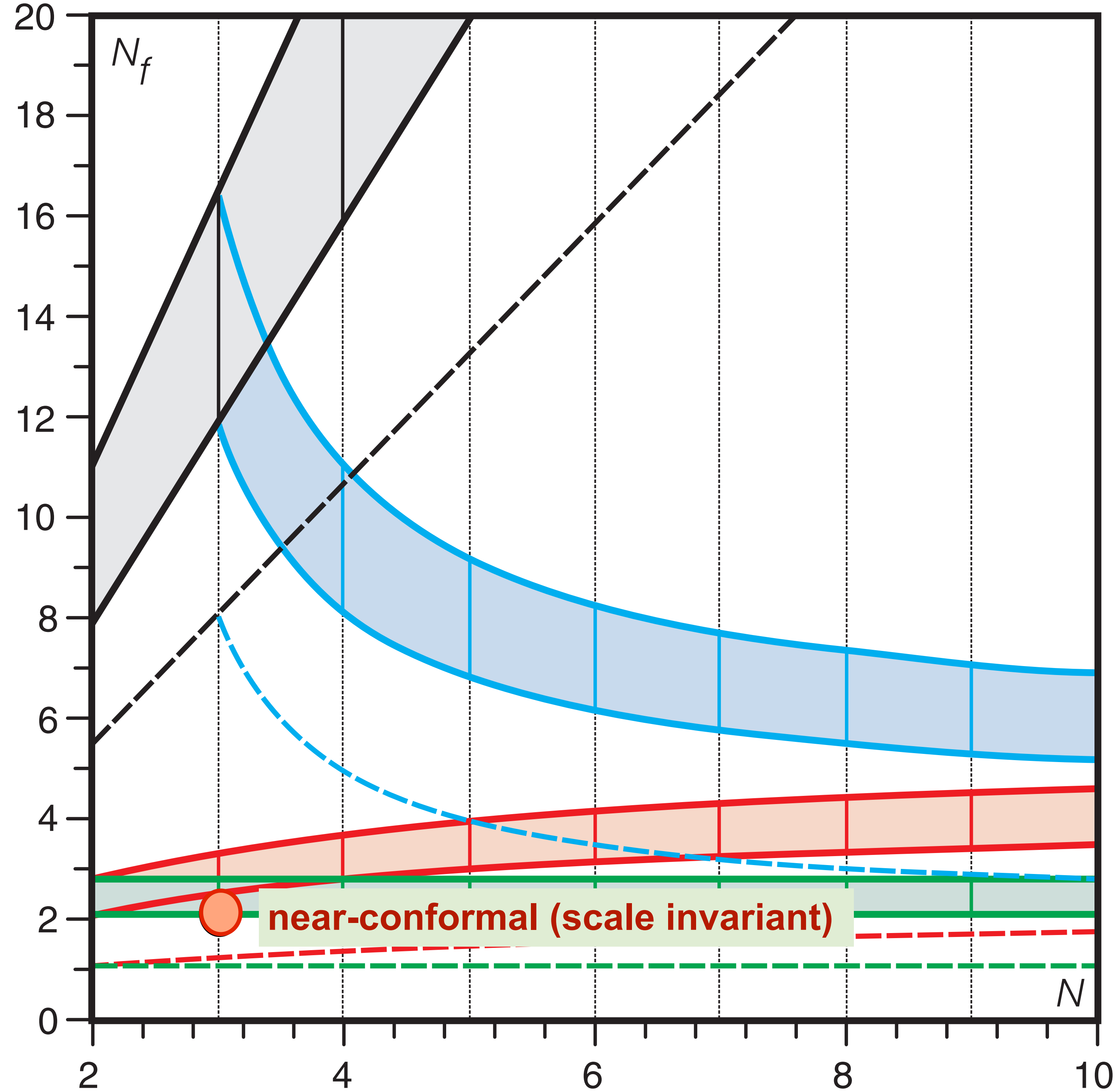
composite Higgs mechanism
scale of Higgs condensate
~ F=250 GeV

conflicts with EW constraints?



near-conformal light Higgs (dilaton-like?) sextet rep

to apply QCD intuition to
near-conformal compositeness
is just plain wrong



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Technicolor was scaled up QCD
too early to worry about
new naming rights

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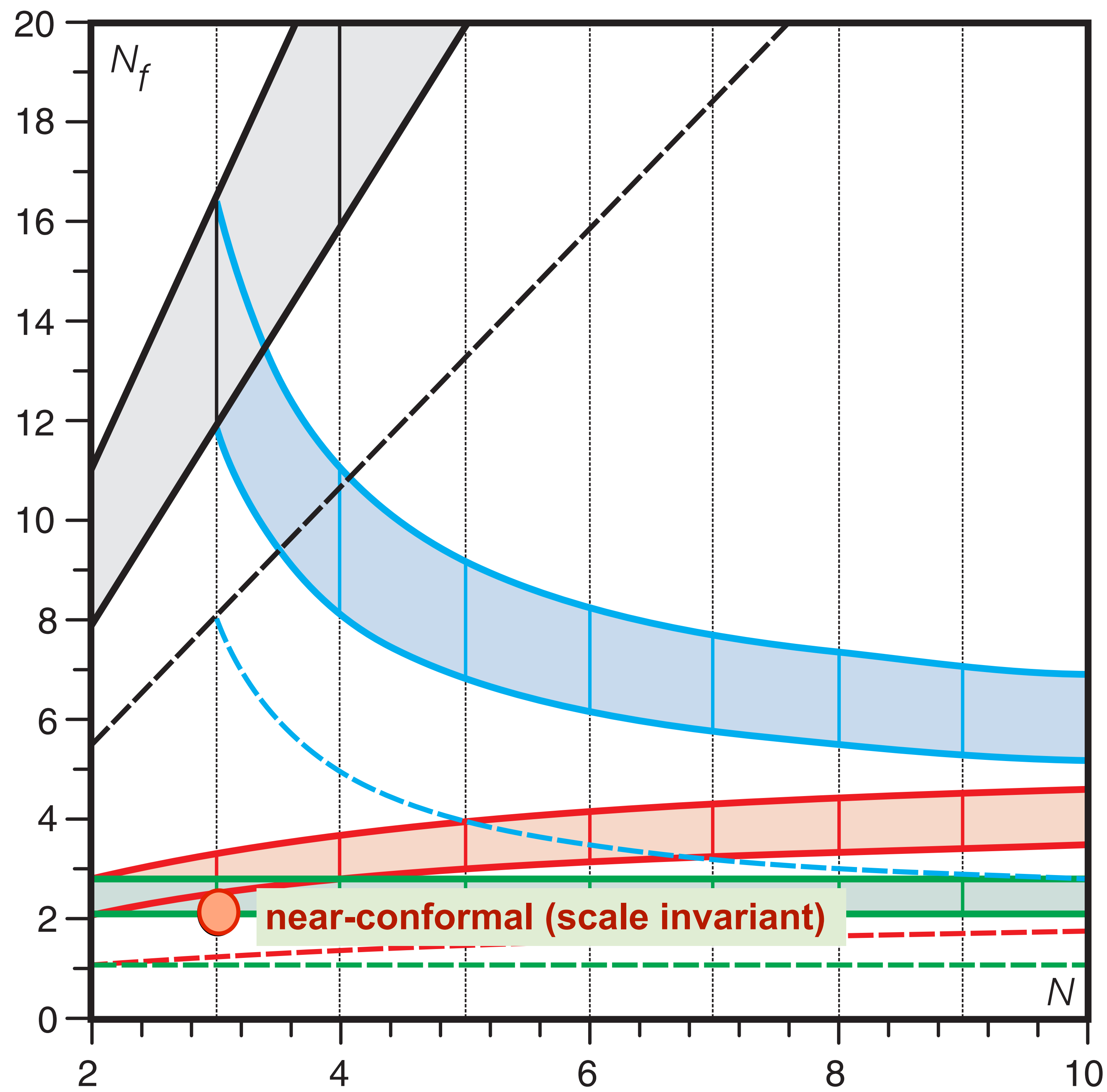
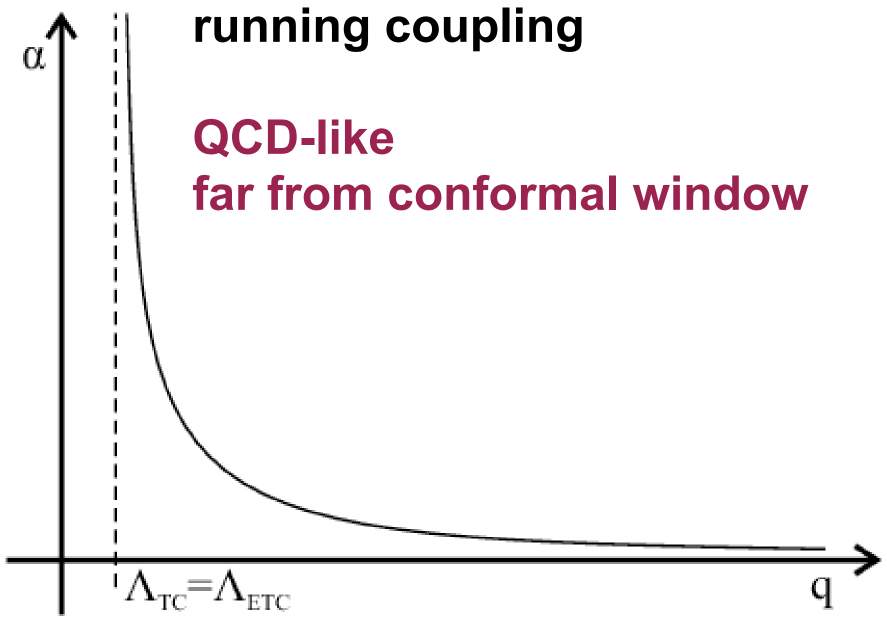
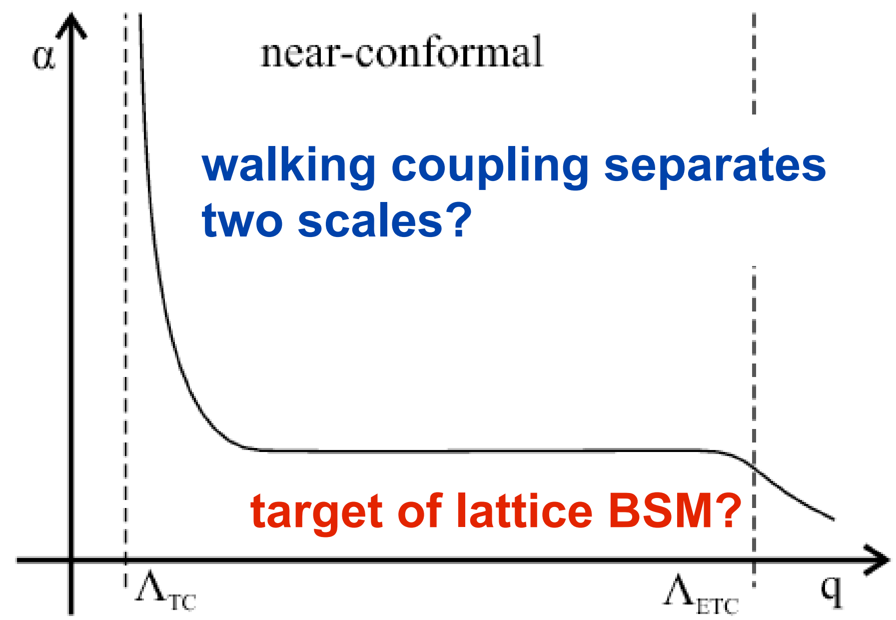


light Higgs near conformality (dilaton-like?) sextet





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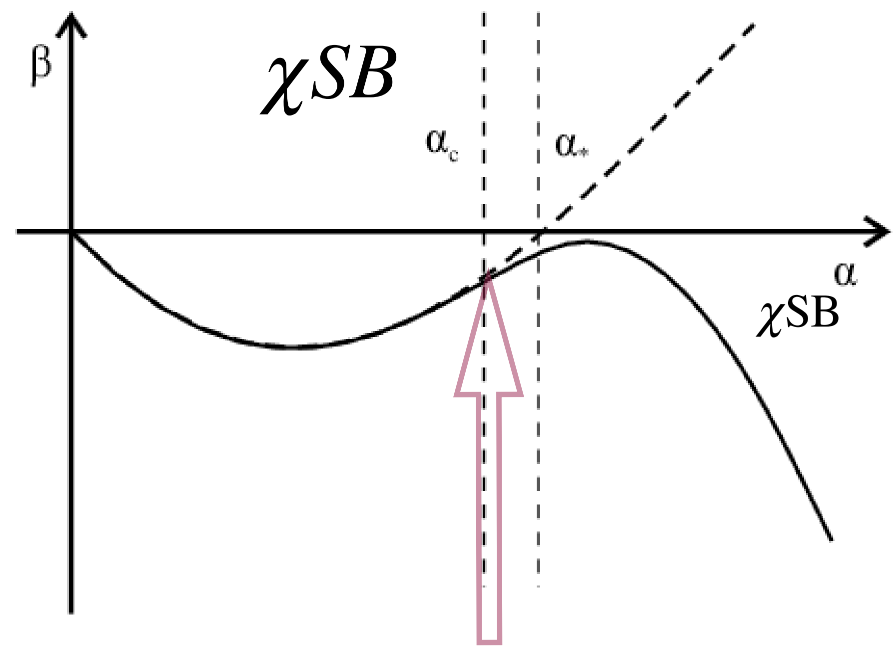


when chiral symmetry breaking
turns conformal FP into walking

χSB on Λ~TeV scale

walking gauge coupling?

fermion mass generation (effective EW int)

composite Higgs mechanism ?

broken scale invariance (dilaton) ?
or light non-SM composite Higgs
particle?

Early work using sextet rep:

Marciano (QCD paradigm, 1980)

Kogut,Shigemitsu,Sinclair
(quenched, 1984)

recent work:

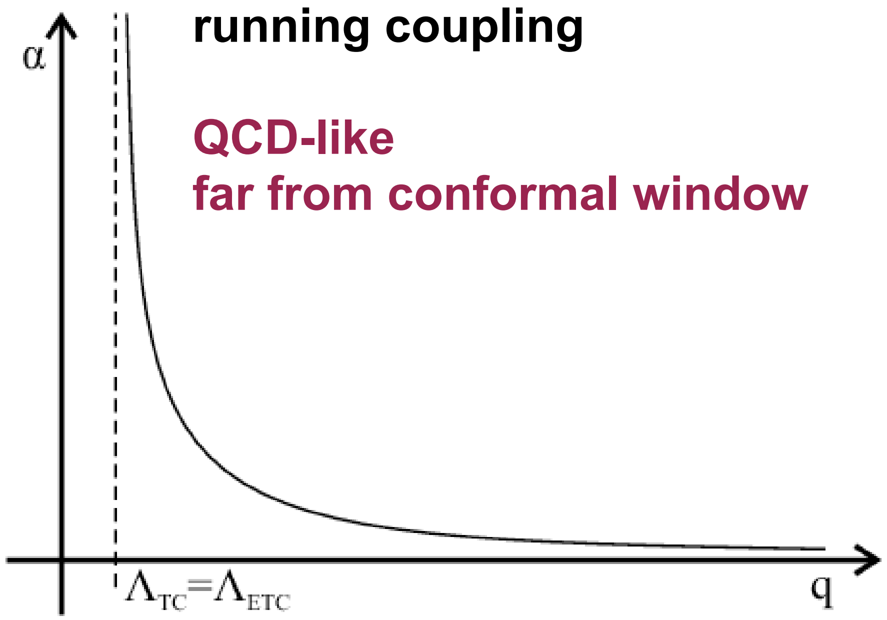
Sannino and collaborators

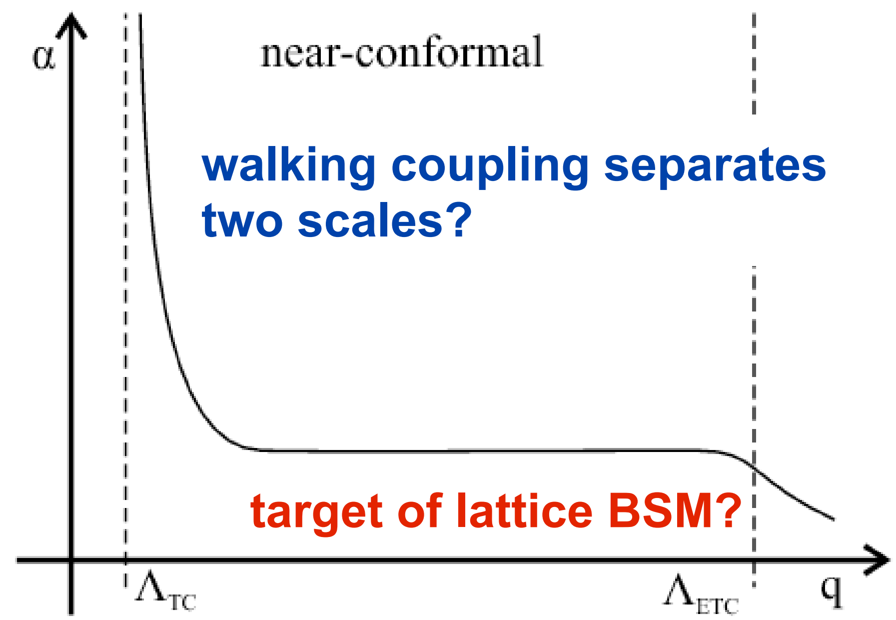
DeGrand,Shamir,Svetitsky
IRFP or walking gauge coupling

Lattice Higgs Collaboration

Kogut,Sinclair
finite temperature

light Higgs near conformality (dilaton-like?) sextet





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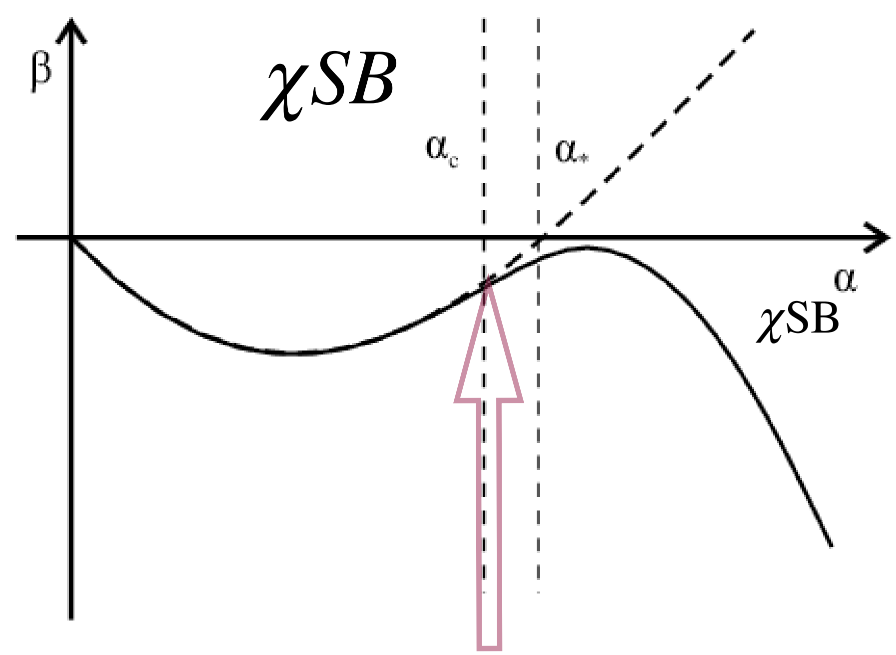


when chiral symmetry breaking
turns conformal FP into walking

two expectations:

(1) χSB and confinement

(2) light scalar close to CW (with walking) ?

light Higgs near conformality (dilaton-like?) sextet

$$m_\sigma^2 \simeq -\frac{4}{f_\sigma^2}\langle 0|\left[\Theta_\mu^\mu(0)\right]_{NP}|0\rangle$$

Partially Conserved Dilatation Current (PCDC)

Will gradient flow based technology make the argument less slippery?

$$\partial_\mu \mathcal{D}^\mu = \Theta_\mu^\mu = \frac{\beta(\alpha)}{4\alpha}G_{\mu\nu}^a G^{a\mu\nu}$$

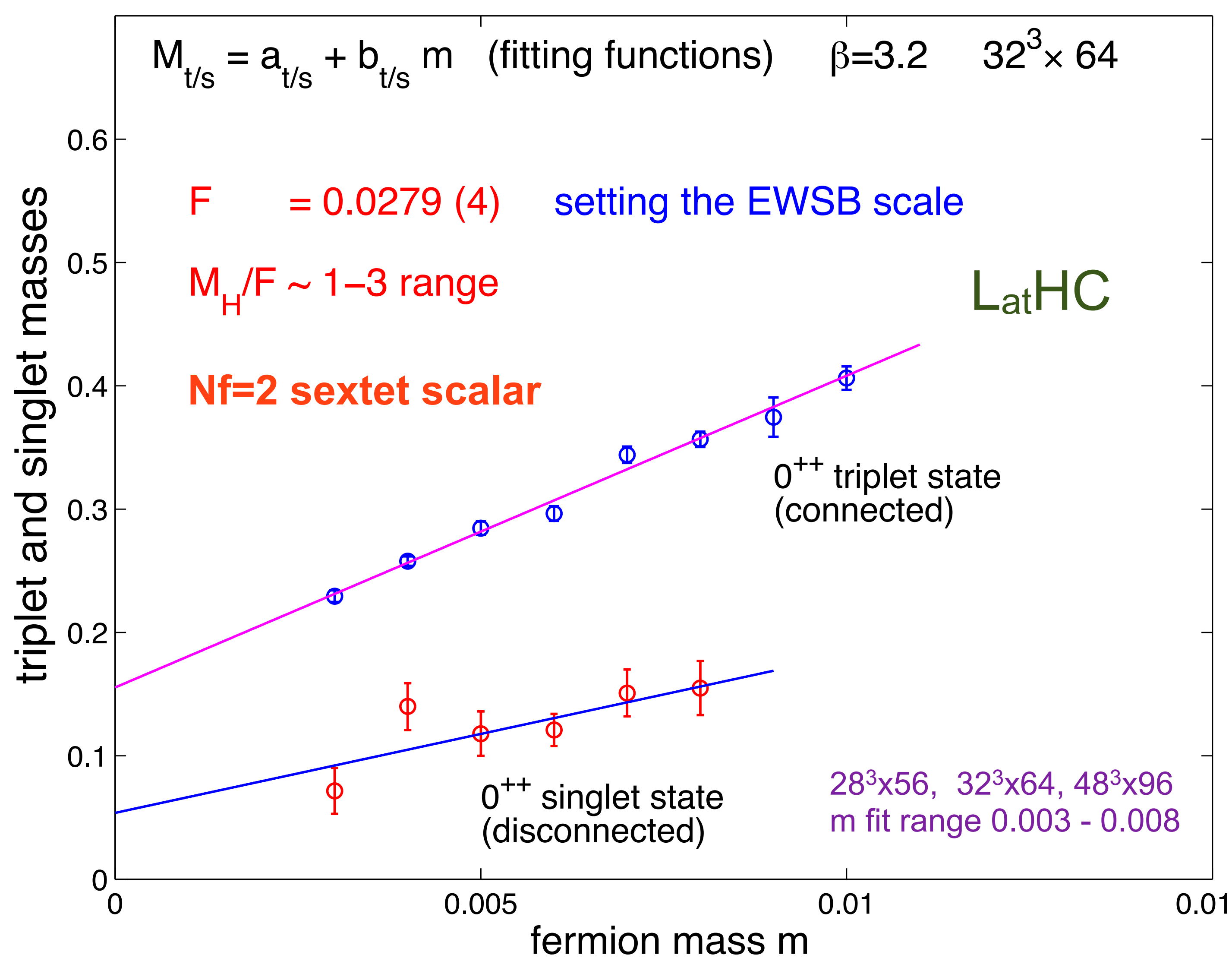
Dilatation current

$$\langle 0|\Theta^{\mu\nu}(x)|\sigma(p)\rangle = \frac{f_\sigma}{3}(p^\mu p^\nu - g^{\mu\nu}p^2)e^{-ipx}$$

$$\langle 0|\partial_\mu \mathcal{D}^\mu(x)|\sigma(p)\rangle = f_\sigma m_\sigma^2 e^{-ipx}$$

$$\left[\Theta_\mu^\mu\right]_{NP} = \frac{\beta(\alpha)}{4\alpha}\left[G_{\mu\nu}^a G^{a\mu\nu}\right]_{NP} \qquad \frac{m_\sigma}{f_\sigma} \to ?$$

Triplet and singlet masses from 0^{++} correlators



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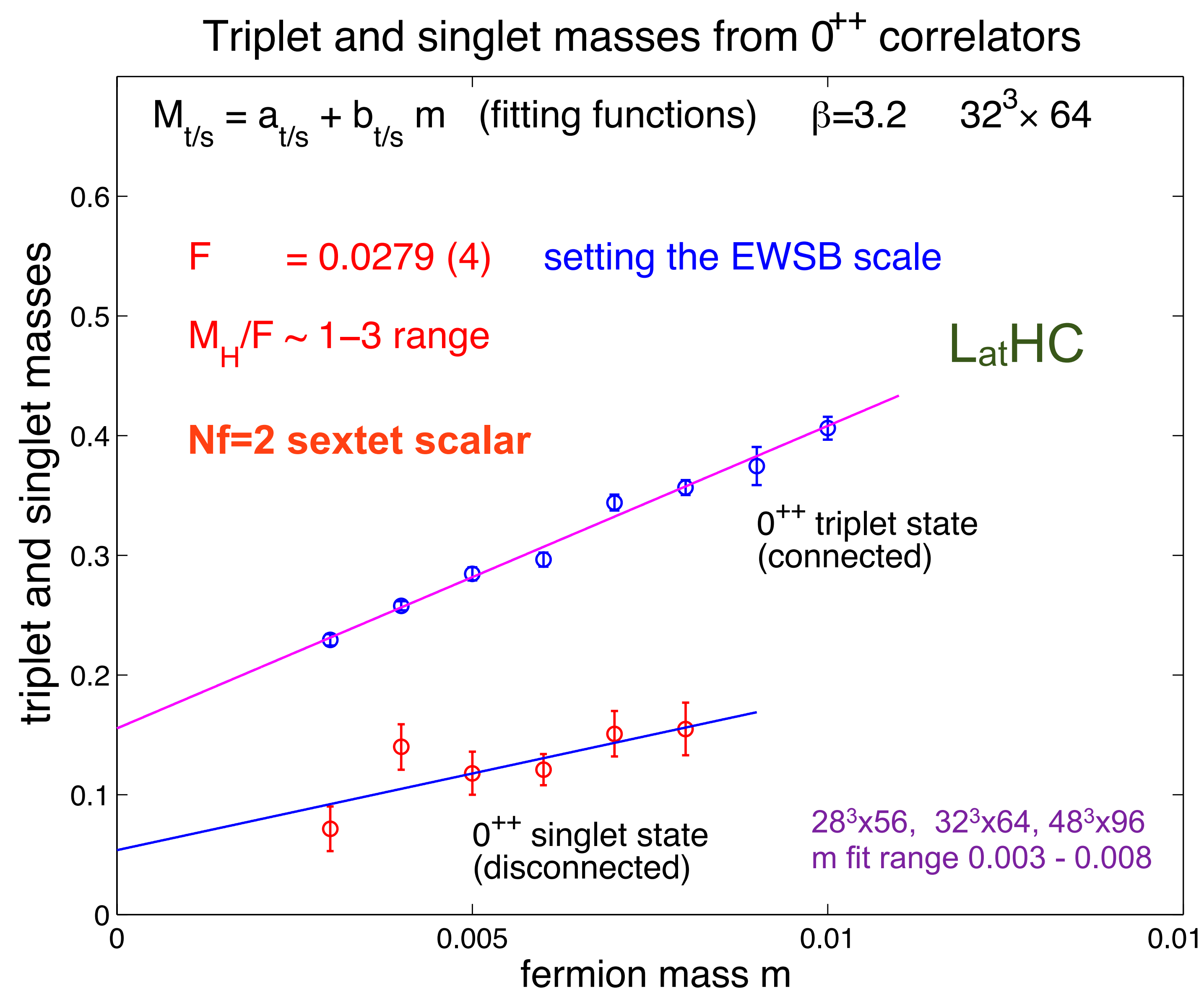
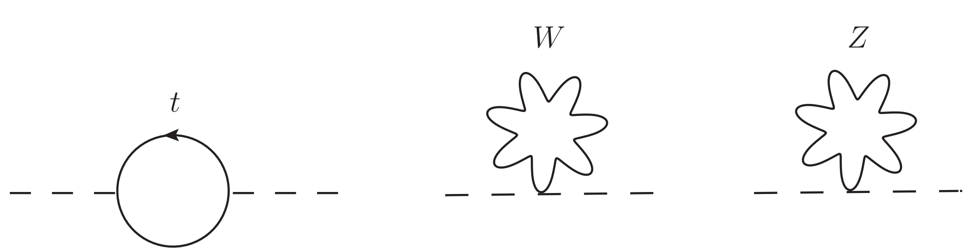


but how light is light ?

few hundred GeV Higgs impostor?

Foadi, Fransden, Sannino

open for spirited theory discussions



$$\delta M_H^2 \sim -12\kappa^2 r_t^2 m_t^2 \sim \quad -\kappa^2 r_t^2 (600\,\mathrm{GeV})^2$$

light Higgs near conformality (dilaton-like?) sextet

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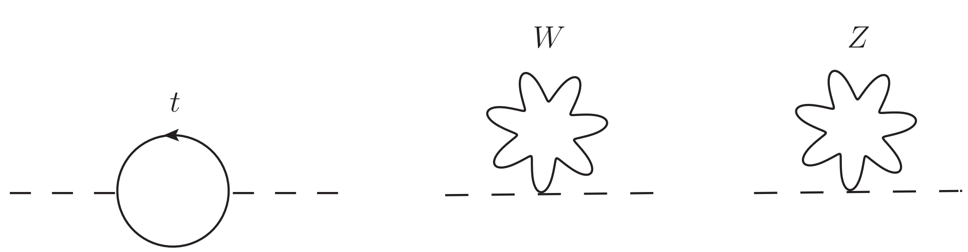
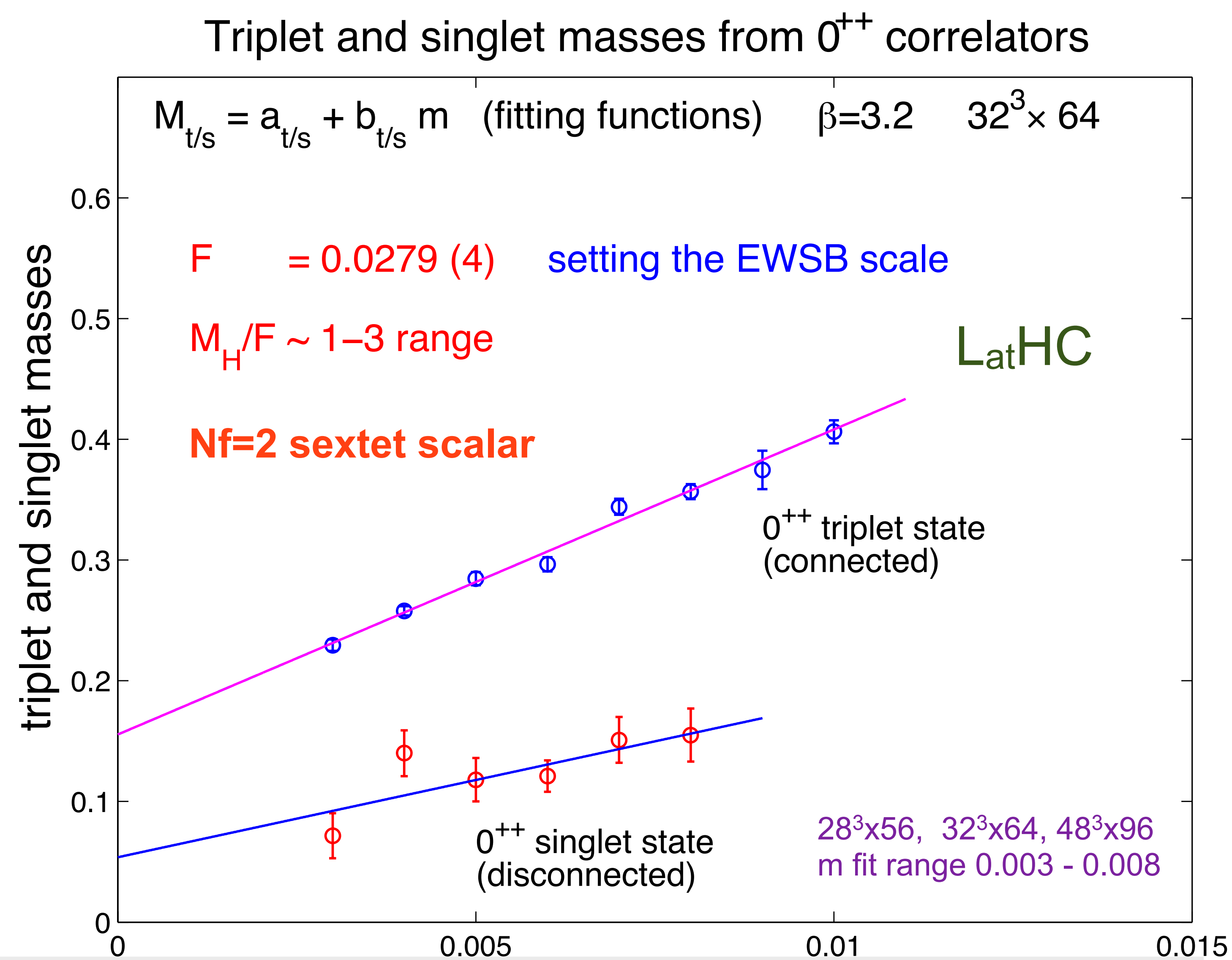




dilaton-like scalar states in SCGT, or "just a light Higgs" ?

Our new code (sextet Janos) is highly optimized for BG/Q **impressive Borsanyi/Wong effort**
In Mira production now to answer questions in second generation run set:

We started second generation run set
(ALCC Award on Mira)

Our new code (sextet Janos) is highly optimized for BG/Q **impressive Borsanyi/Wong effort**
In Mira production now to answer questions in second generation run set:

1. Test of chiral perturbation theory below the scale of low mass scalar?

how to test if light scalar is dilaton-like close to CW?
both require new low energy effective action

is there an f_σ/f_π crisis?

2. Needs precise scale setting and resonance spectrum

S and T parameters of Electroweak precision tests
large volumes **$F \cdot L \sim 1$, or larger!**

slow topology

We started second generation run set (ALCC Award on Mira)

3. Running (walking?) coupling

volume-dependent running coupling
scale-dependent $L=\infty$ coupling in chiral limit

4. Consistent chiral condensate?

GMOR relation is important consistency check
new method for spectral density and mode number
anomalous dimension of chiral condensate

the spectrum

TeV

N ~ 3.2 TeV

A_1 ~ 2.7 TeV

Rho ~ 1.9 TeV

A_0 ~ 1.7 TeV

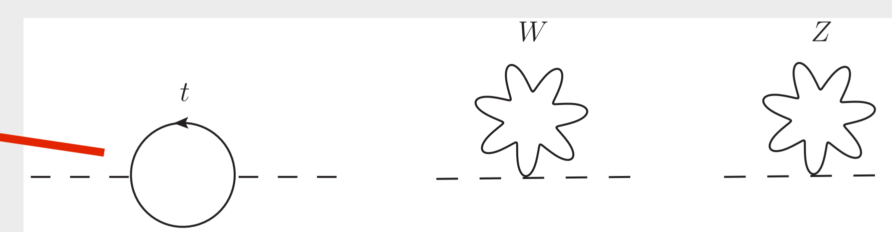
near-conformal resonance spectrum
separated from light scalar

within LHC14 reach

scalar impostor few hundred GeV?

EW self-energy shift

observed Higgs-like?



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light composite Higgs and EW constraints

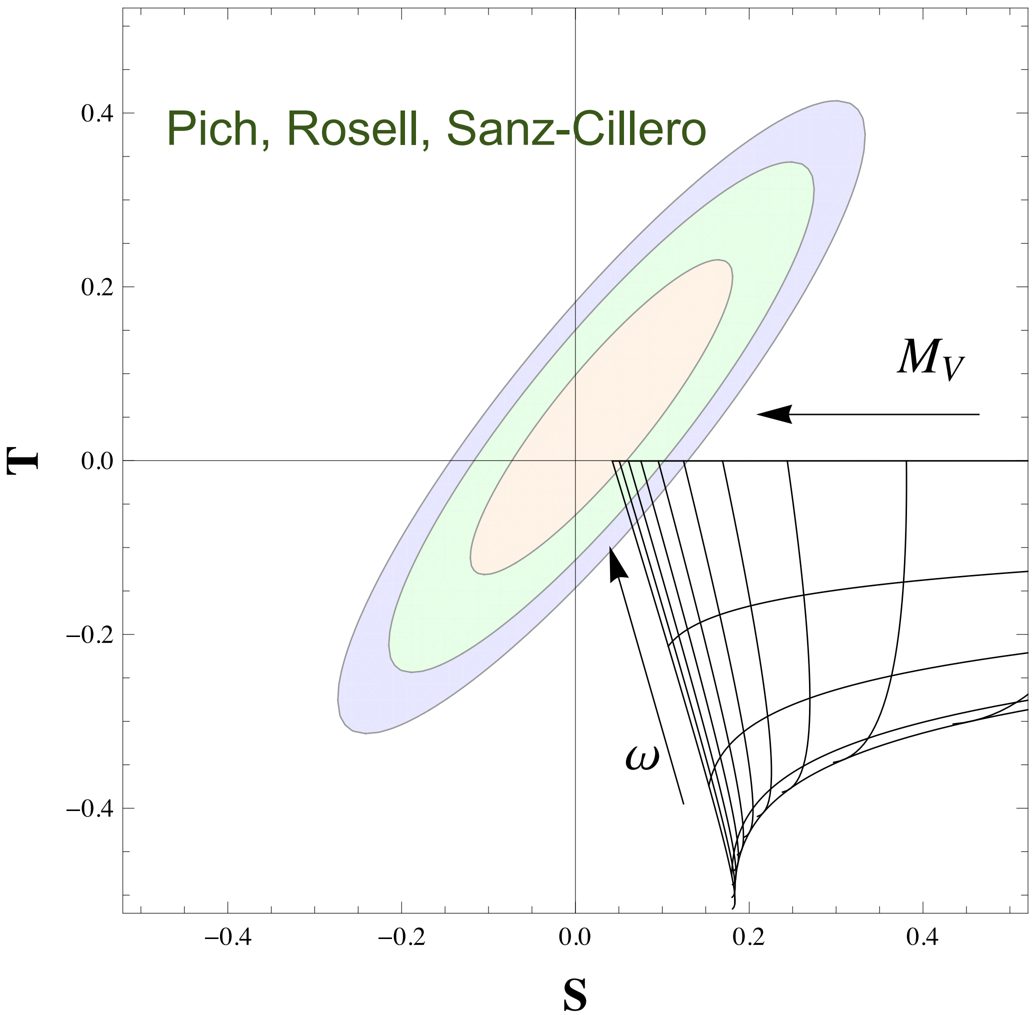


FIG. 2. NLO determinations of S and T, imposing the two WSRs. The approximately vertical curves correspond to constant values of M_V, from 1.5 to 6.0 TeV at intervals of 0.5 TeV. The approximately horizontal curves have constant values of ω: 0.00, 0.25, 0.50, 0.75, 1.00. The arrows indicate the directions of growing M_V and ω. The ellipses give the experimentally allowed regions at 68% (orange), 95% (green) and 99% (blue) CL.

$$S = \frac{16\pi}{g^2 \tan\theta_W} \int_0^\infty \frac{\mathrm{dt}}{t} \left[\rho_S(t) - \rho_S(t)^{\mathrm{SM}} \right]$$

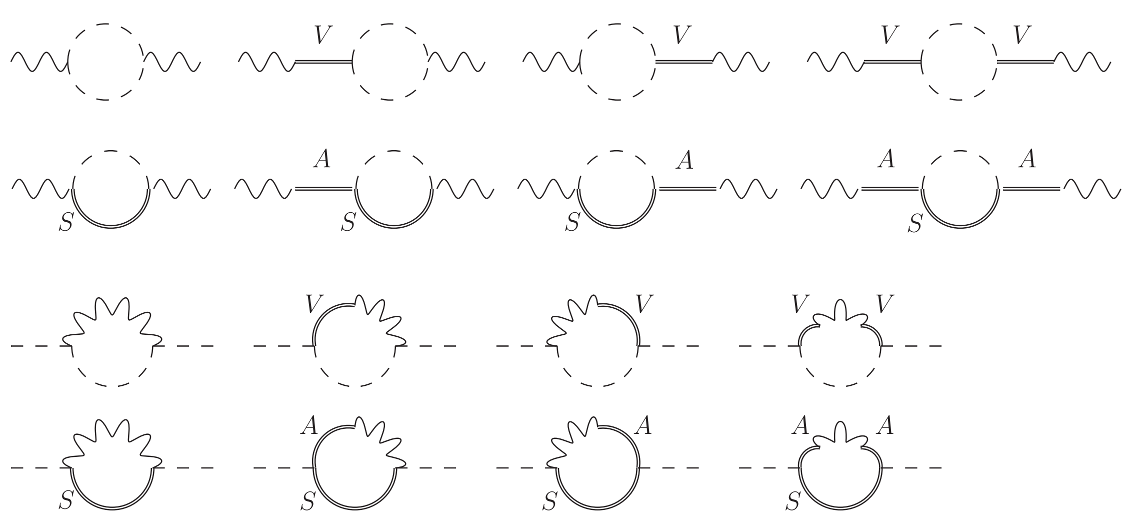
$$S_{\mathrm{LO}} = 4\pi \left(\frac{F_V^2}{M_V^2} - \frac{F_A^2}{M_A^2} \right)$$

$$T = \frac{4\pi}{g'^2 \cos^2\theta_W} \int_0^\infty \frac{\mathrm{dt}}{t^2} \left[\rho_T(t) - \rho_T(t)^{\mathrm{SM}} \right]$$

From two Weinberg sum rules and from NLO loop expansion:

M_V, M_A ~ 2 TeV or higher is compatible with S,T constraints (it is tight and arguably ambiguous)

more work needed



NLO S-param

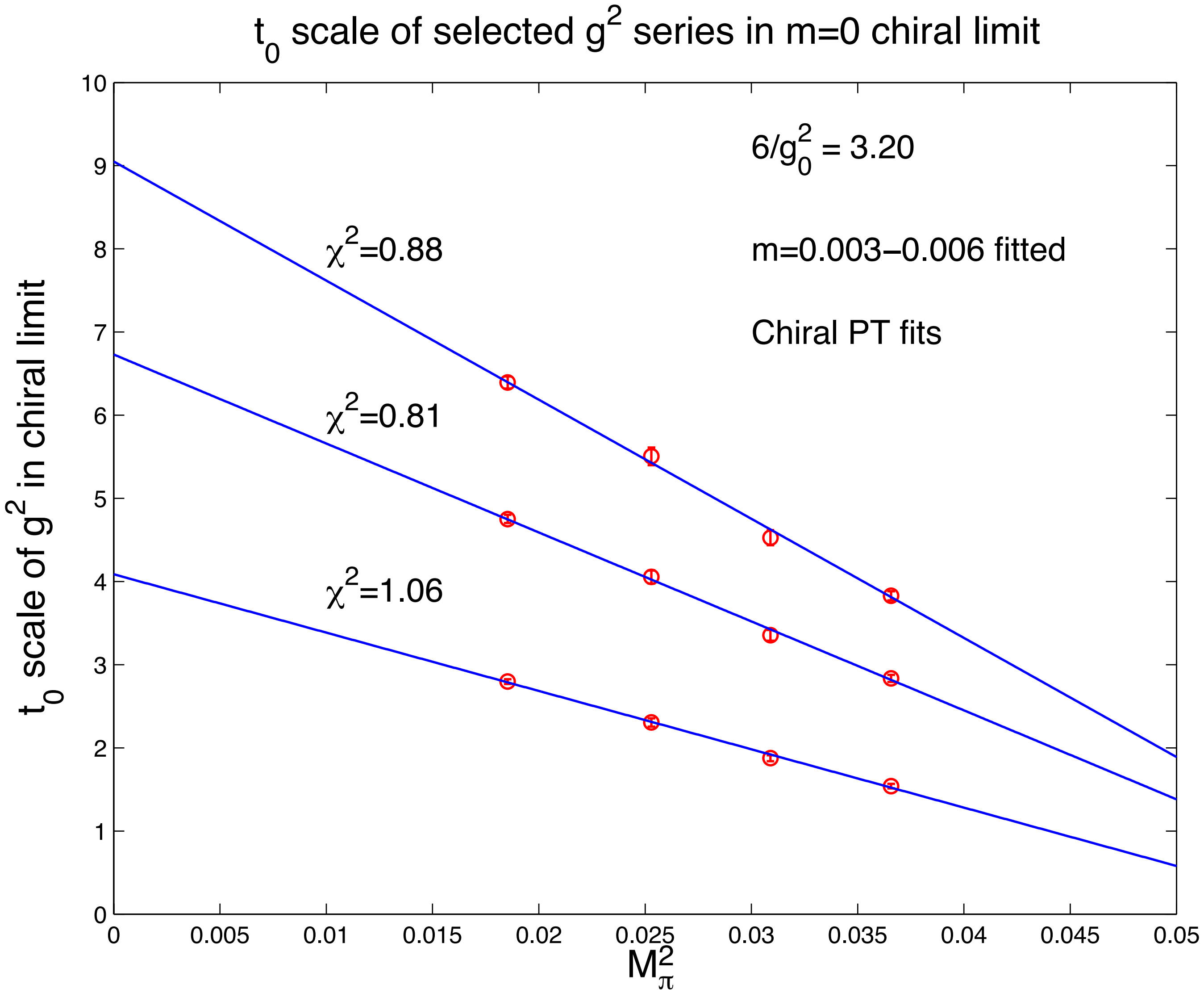
$$S = 0.03 \pm 0.10$$

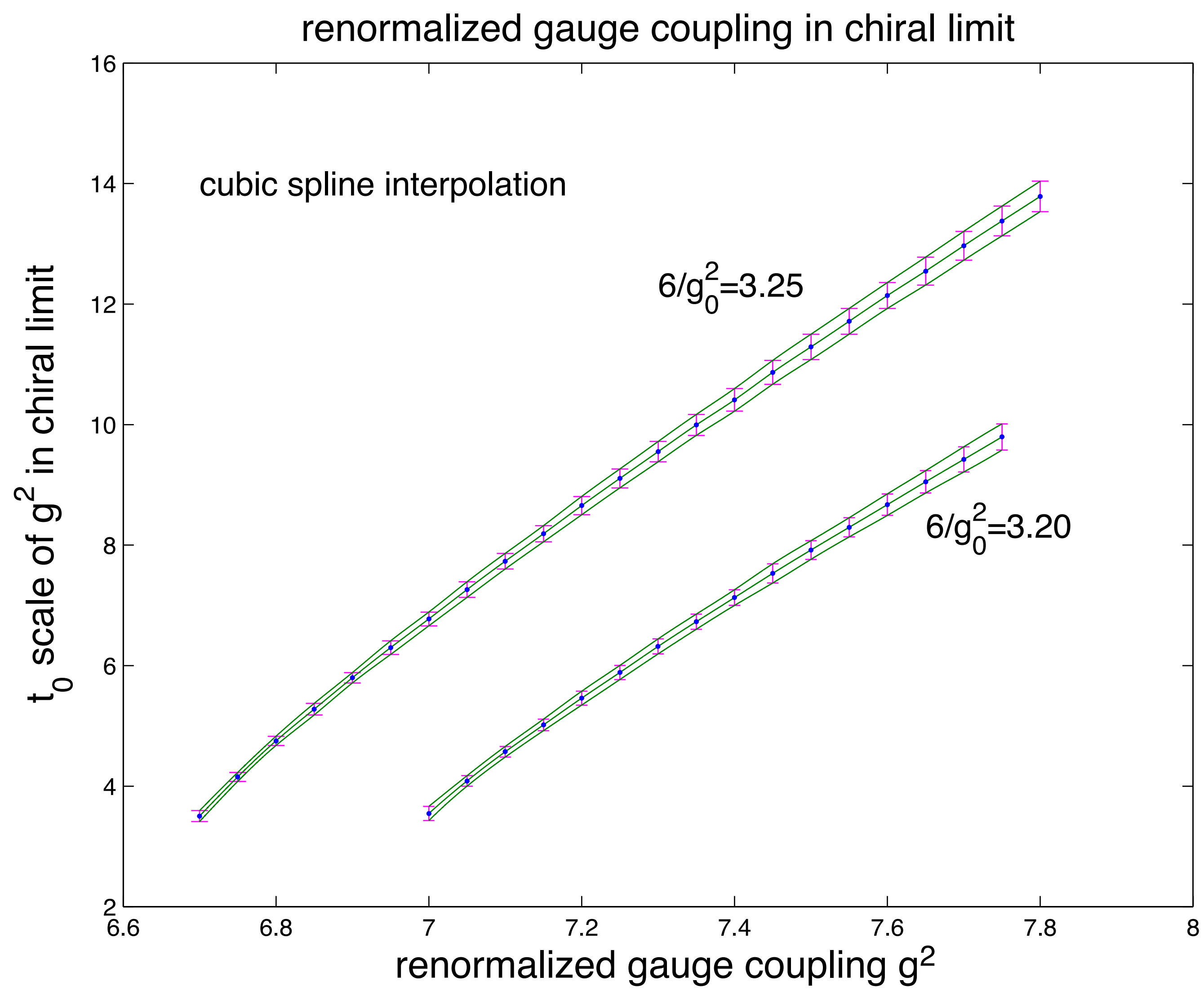
global fits

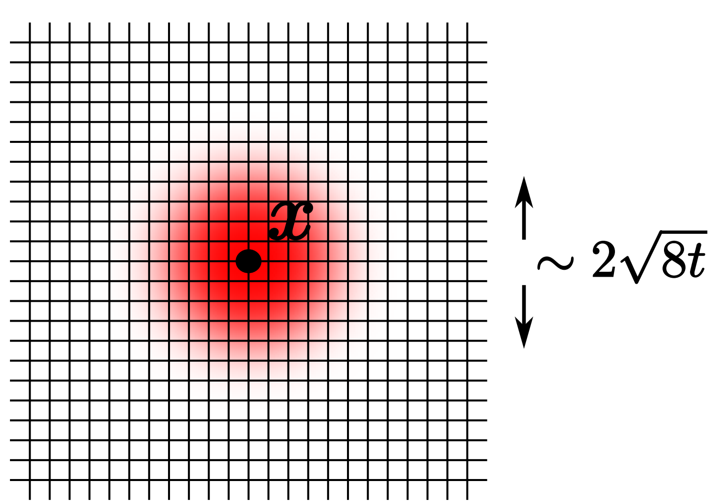
NLO T-param

$$T = 0.05 \pm 0.12$$

gradient flow and gauge dependent renormalized coupling in chiral limit







$$\langle t^2 E(t)\rangle = g_0^2 t^2 \int_{-\frac{\pi}{a}}^{\frac{\pi}{a}} \frac{d^4p}{(2\pi)^4} \mathrm{Tr}\left(e^{-t\left(\mathcal{S}^f+\mathcal{G}\right)}(\mathcal{S}^g+\mathcal{G})^{-1}e^{-t\left(\mathcal{S}^f+\mathcal{G}\right)}\mathcal{S}^e\right)$$

We presented to scale dependent running
coupling methods at Lattice 2014
both are gradient flow based

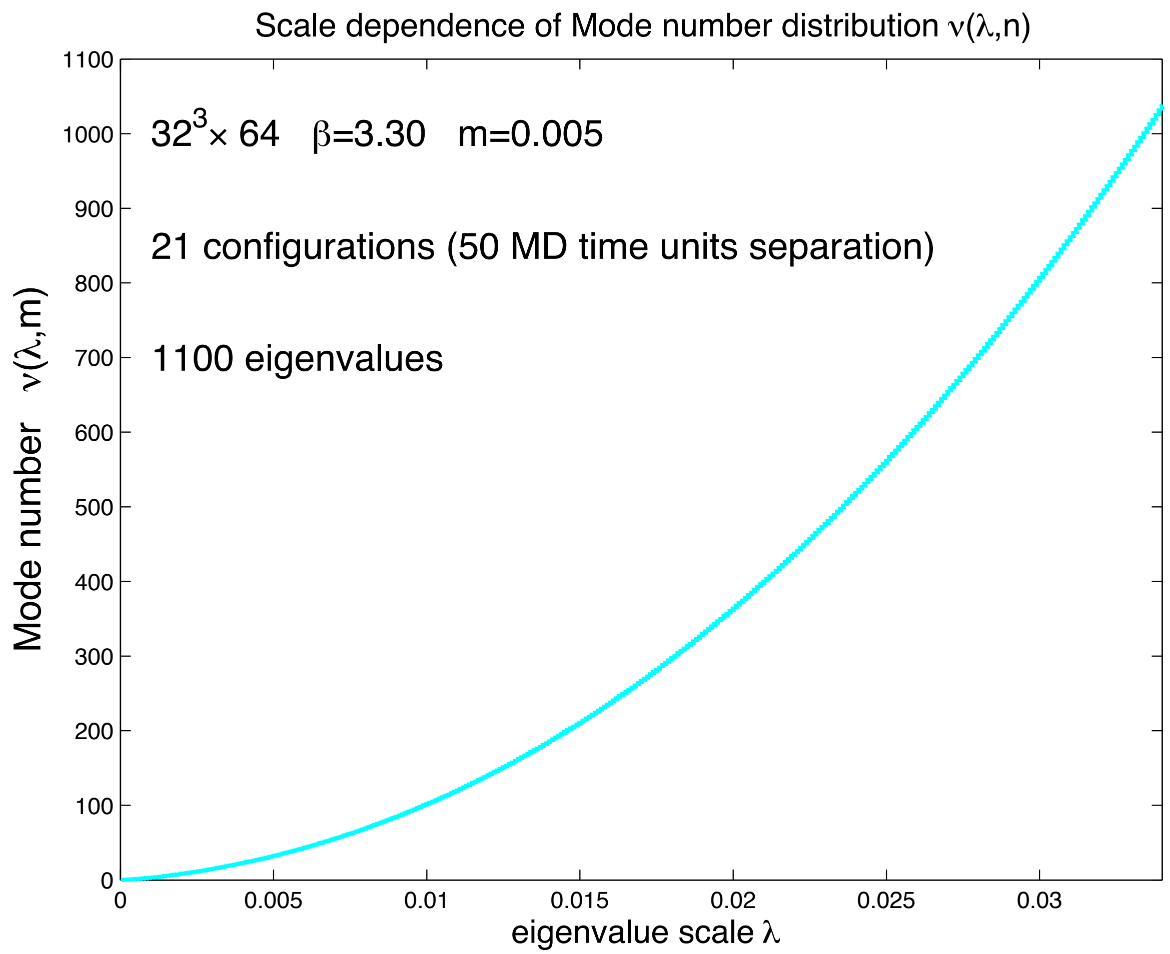
The chiral condensate in the sextet model

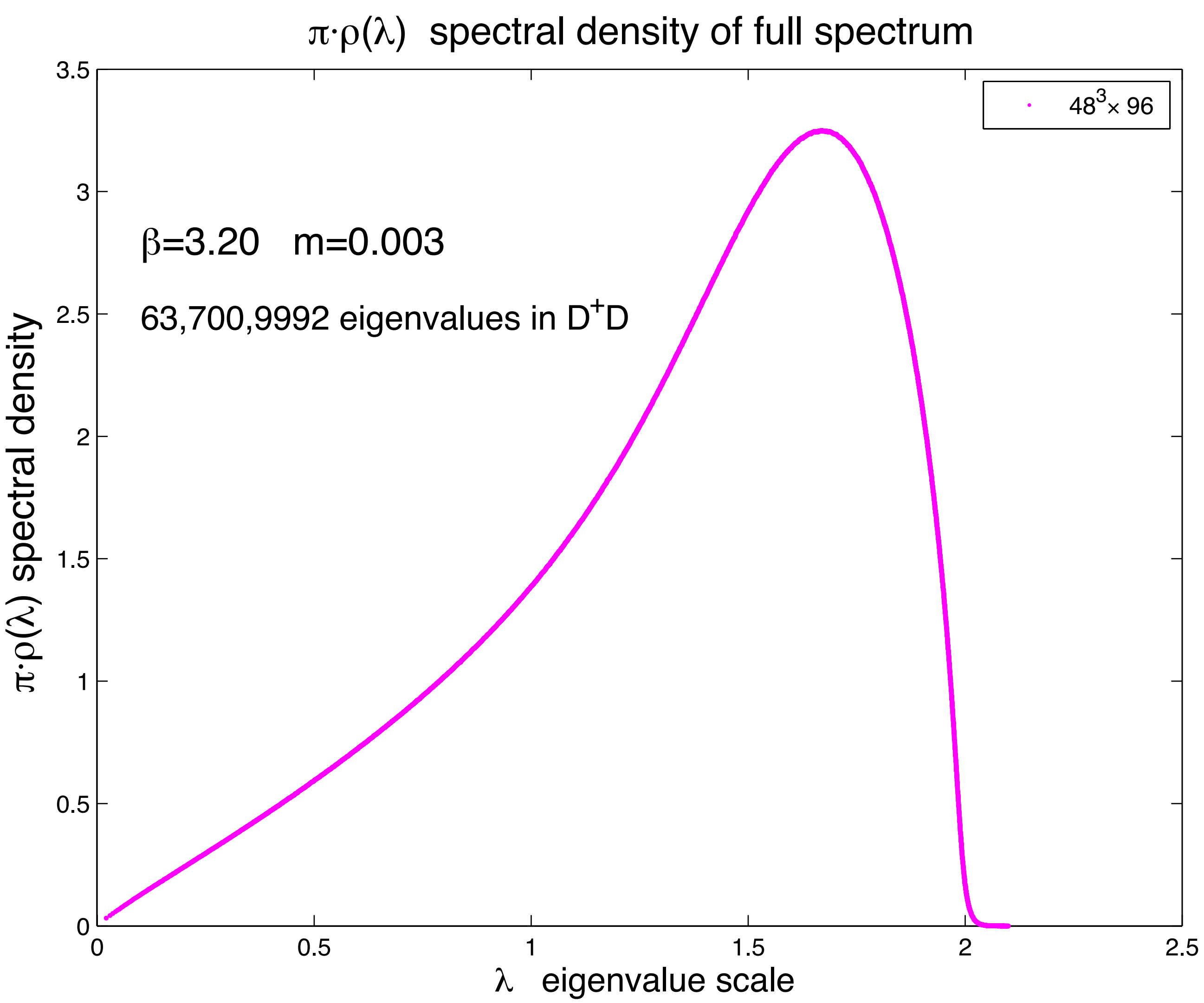
new stochastic method sextet Nf=2

direct determination of full spectral density and mode number distribution on gauge configurations

passed all tests so far
scale-dependent determination of the anomalous dimension of the chiral condensate

deployed now in our RMT and crossover regime studies of the condensate (Damgaard,Fukaya, Aoki et al.)





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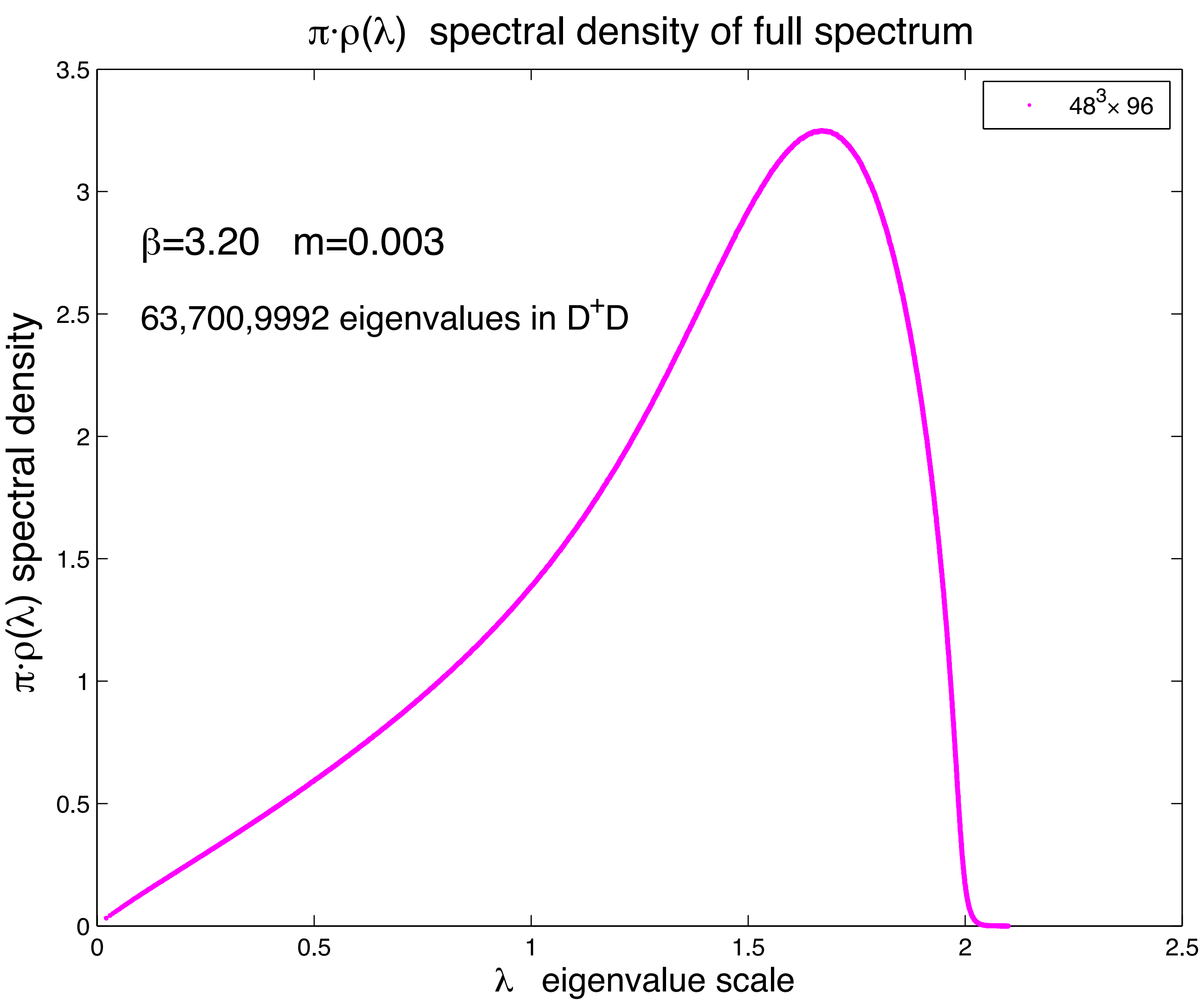
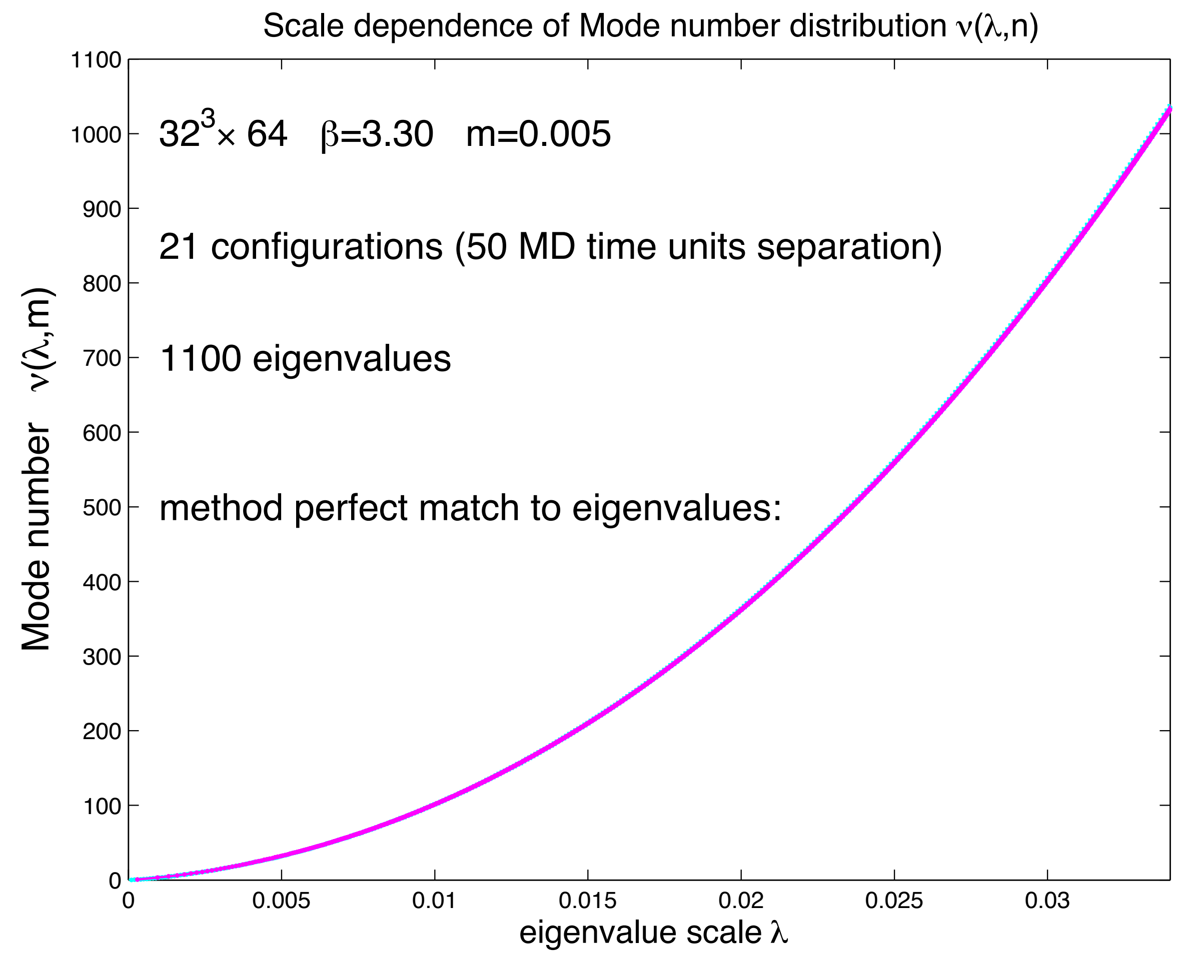
direct determination of full spectral density and mode number distribution on gauge configurations

passed all tests so far
scale-dependent determination of the anomalous dimension of the chiral condensate

deployed now in our RMT and crossover regime studies of the condensate (Damgaard,Fukaya, Aoki et al.)





Early universe and the sextet model?

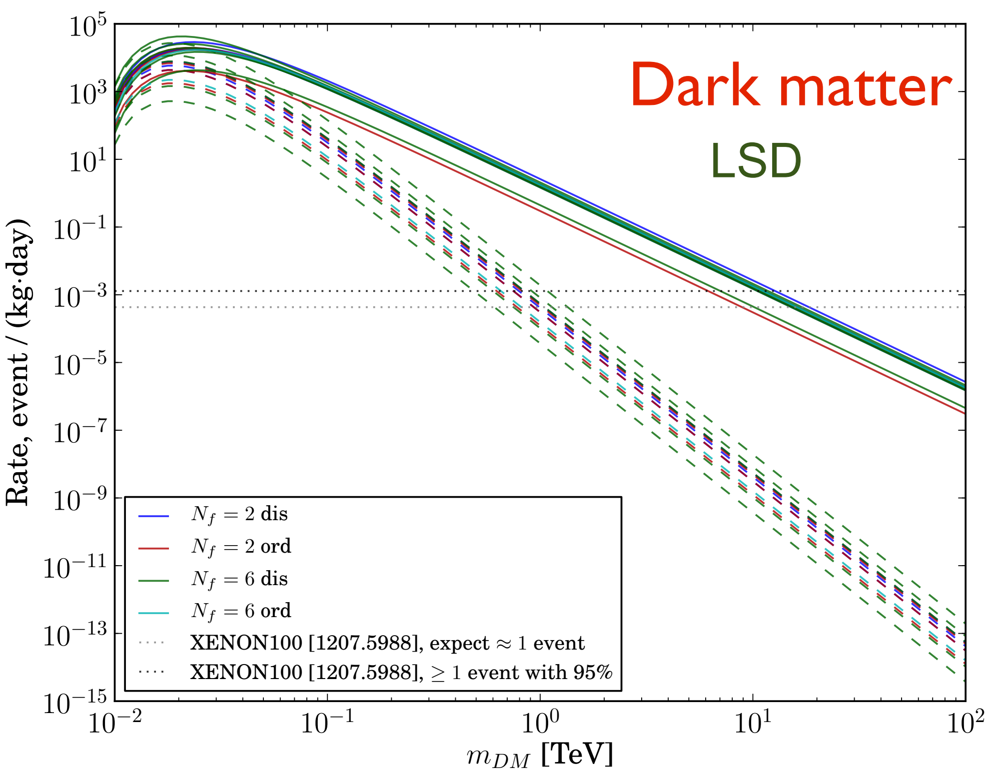
Kogut-Sinclair work consistent with finite temperature χSB phase transition
Relevance in early cosmology? (order of the phase transition?)

The Total Energy of the Universe:
Vacuum Energy (Dark Energy) ~ 67 %
Dark Matter ~ 29 %
Visible Baryonic Matter ~ 4 %

Dark matter

self-interacting?
O(barn) cross section would be challenging

T. Appelquist, R. C. Brower, M. I. Buchoff, M. Cheng, S. D. Cohen, G. T. Fleming, J. Kiskis, M. F. Lin, E. T. Neil, J. C. Osborn, C. Rebbi, D. Schaich, C. Schroeder, S. Syritsyn, G. Voronov, P. Vranas, and J. Wasem (Lattice Strong Dynamics (LSD) Collaboration)



- lattice BSM phenomenology of dark matter
  pioneering LSD work
- Nf=2 Qu=2/3 Qd = -1/3
  udd neutral dark matter candidate
- dark matter candidate sextet Nf=2
  electroweak active in the application
- there is room for third heavy fermion
  flavor as electroweak singlet
- rather subtle sextet baryon ~ 3 TeV
  construction (symmetric in color)

Summary and Outlook

Simplest composite scalar is light near conformality

light scalar (dilaton-like?) emerging — close to conformal window?

running (walking) coupling in progress — gradient flow deployed

chiral condensate — new method is promising

spectroscopy — emerging resonance spectrum ~ 2-3 TeV

dark matter — implications are intriguing
strong self-interactions?

Tuning with third flavor ?

We have a candidate for the minimal Higgs impostor

Can we make it fail?

Congratulations and best wishes Mike!

We will need your wise councel in the future!