KMI 2013

The Higgs Particle and the Lattice

Julius Kuti

University of California, San Diego

KMI International Symposium 2013
Nagoya, December 11-13, 2013

Outline

Lattice BSM after the Higgs discovery

Light Higgs near conformality

- light scalar (dilaton-like?) close to conformal window
- EW precision and S-parameter
- scale setting and spectroscopy

Running coupling

- running (walking?) coupling from gradient flow

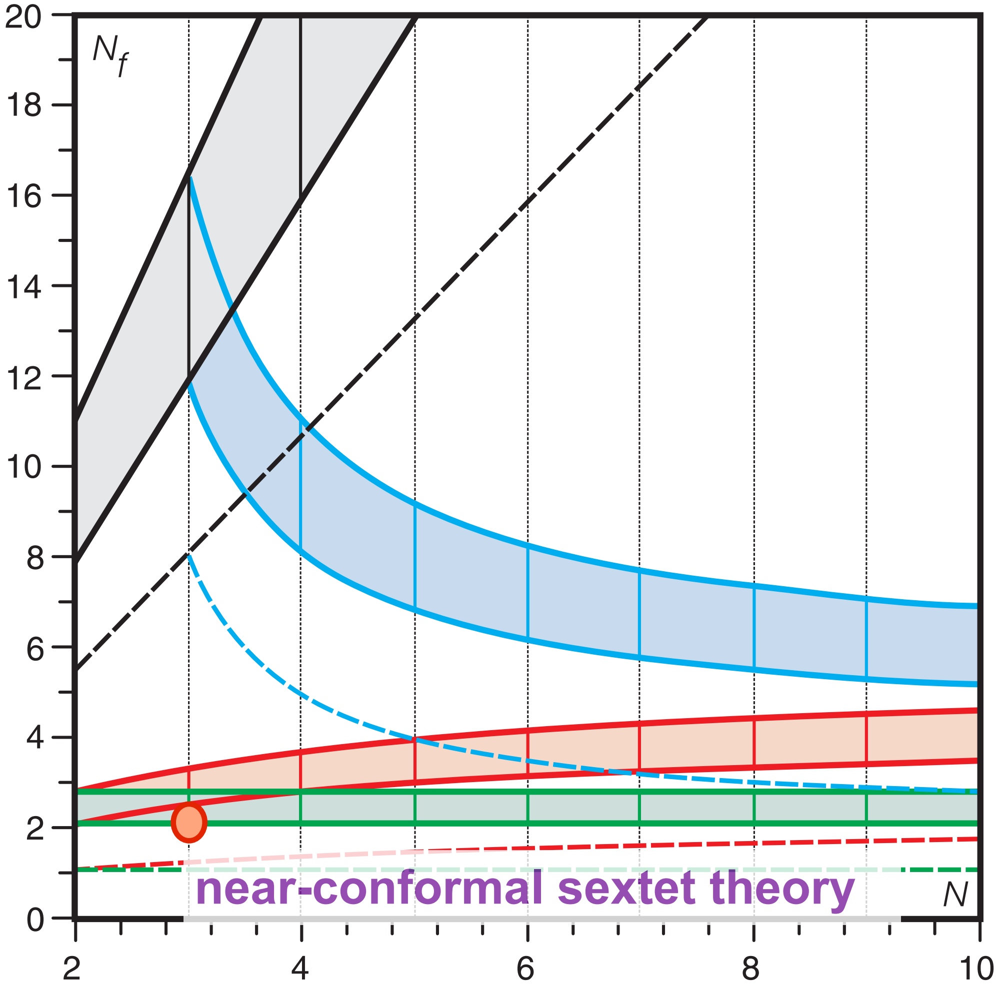
Chiral condensate

- new stochastic method for spectral density
- large anomalous dimension

Early universe

- EW phase transition
- dark matter

Summary and Outlook



Large Hadron Collider - CERN

primary mission:

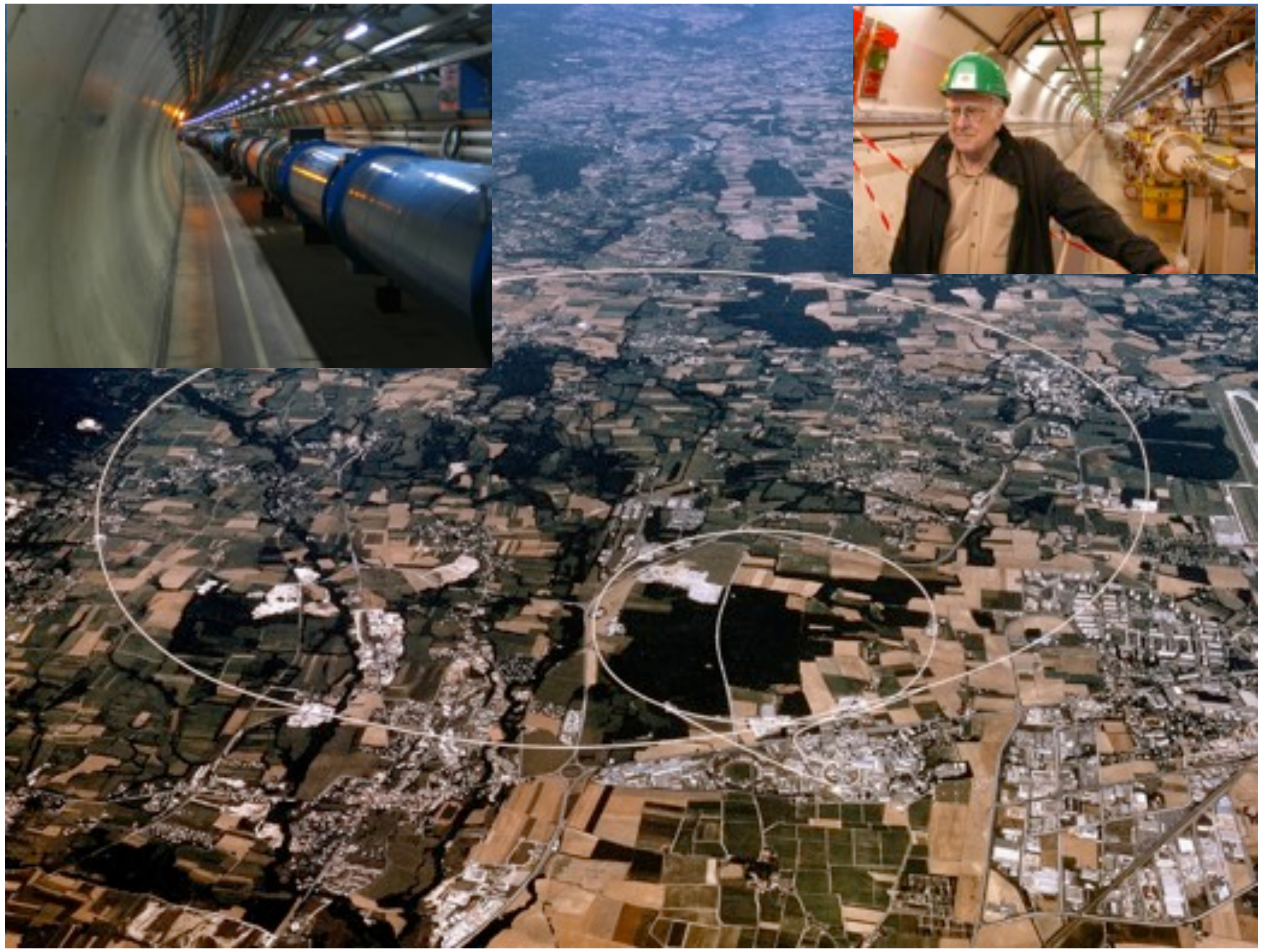
- Search for Higgs particle

- Origin of Electroweak symmetry breaking

- **A Higgs-like particle is found**
  Is it the Standard Model Higgs? or
- Near-conformal strong dynamics?
- Composite PNGB-like Higgs?
- SUSY?
- 5 Dim?

…

Primary focus of BSM lattice effort and this talk



LATTICE GAUGE THEORIES AT THE ENERGY FRONTIER

Thomas Appelquist, Richard Brower, Simon Catterall, George Fleming,
Joel Giedt, Anna Hasenfratz, Julius Kuti, Ethan Neil, and David Schaich

(USQCD Collaboration)

(Dated: March 10, 2013)

USQCD BSM White Paper - community based effort
input into US Snowmass 2013 planning:

USQCD and the composite Higgs at the Energy Frontier

The recent discovery of the Higgs-like particle at 126 GeV is the beginning of the experimental search for a deeper dynamical explanation of electroweak symmetry breaking beyond the Standard Model (BSM). The USQCD collaboration has developed an important BSM research direction with the primary focus on the composite Higgs mechanism as outlined in our recent USQCD BSM white paper [1] and in this short report. Deploying advanced lattice field theory technology, we are investigating new strong gauge dynamics to explore consistency with a composite Higgs particle at 126 GeV which will require new non-perturbative insight into this fundamental problem. The organizing principle of our program is to explore the dynamical implications of approximate scale invariance and chiral symmetries with dynamical symmetry breaking patterns that may lead to the composite Higgs mechanism with protection of the light scalar mass, well separated from predicted new resonances, which maybe on the 1-2 TeV scale. Based on an underlying strongly-coupled theory, lattice calculations provide the masses and decay constants of these new particles, enabling concrete predictions for future experimental results at colliders and in dark matter searches.

On the other hand, if the higher resonances are too heavy to be directly probed at the LHC, indirect evidence for Higgs compositeness may appear for example as altered rates for electroweak gauge boson scattering, changes to the Higgs coupling constants, or the presence of additional light Higgs-like resonances. Here lattice calculations are used to derive the low energy constants in an Effective Field Theory description to predict departures of a composite Higgs dynamics from the standard model predictions. Of course as new experimental evidence from the LHC is forthcoming, BSM lattice simulations will be focused on an increasingly narrower class of candidate theories, consistent with experimental constraints, increasing its power as a theoretical tool in the search for BSM physics. Two major components of our BSM lattice program are carefully planned and coordinated, as summarized below.

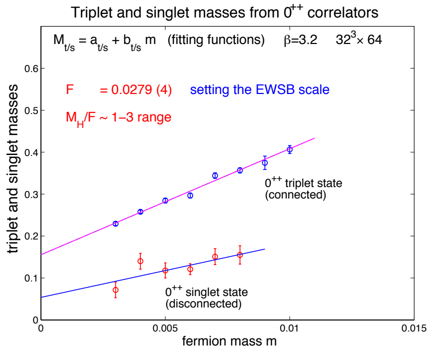


FIG. 1. This plot is unpublished and for illustration only. Some of the flavor singlet scalar data points are expected to remain in flux before final analysis and publication [3]. The ongoing work indicates the emergence of a light flavor singlet scalar state (red) with 0^{++} quantum numbers in the sextet rep of a fermion doublet with the minimal realization of the composite Higgs mechanism. Annihilation diagrams driven by strong gauge dynamics downshift the mass of the flavor singlet state close to the EWSB scale. Turning on a third massive EW singlet in the model might bring the β-function even closer to zero with minimal tuning. The fermion mass dependence of the isotriplet meson (blue) is also shown, not effected by disconnected annihilation diagram. In the chiral limit it is a heavy resonance above 1 TeV. The model predicts several resonances in the 1-2 TeV range.

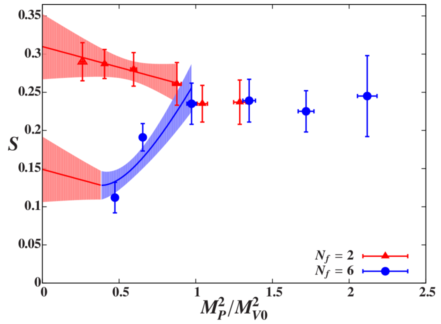


FIG. 2. From [11], lattice simulation results for the S-parameter per electroweak doublet, comparing SU(3) gauge theories with $N_f = 2$ (red triangles) and $N_f = 6$ (blue circles) degenerate strongly-coupled fermions in the fundamental representation. The horizontal axis is proportional to the pseudoscalar Goldstone boson mass squared, or equivalently the input fermion mass m. The $N_f = 2$ value of S is in conflict with electroweak precision measurements, but the reduction at $N_f = 6$ indicates that the value of S in many-fermion theories can be acceptably small, in contrast to more naïve scaling estimates [13].

USQCD lattice BSM project sites

(a few years ago map was empty)

It is a world-wide effort !

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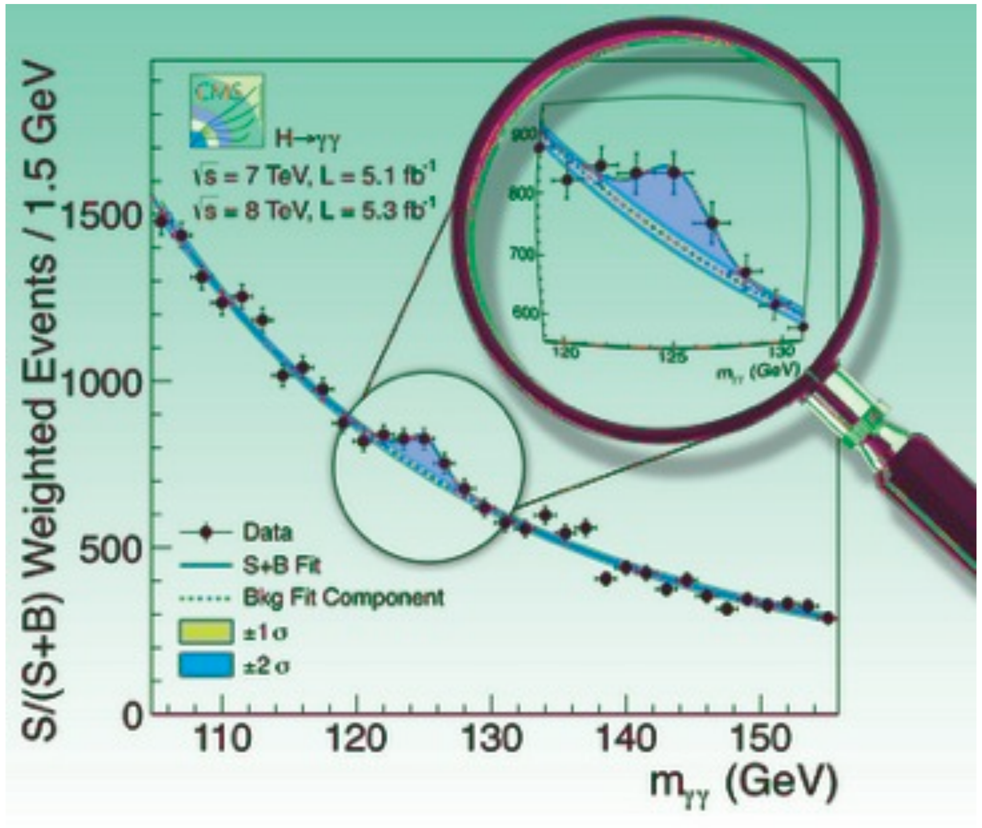
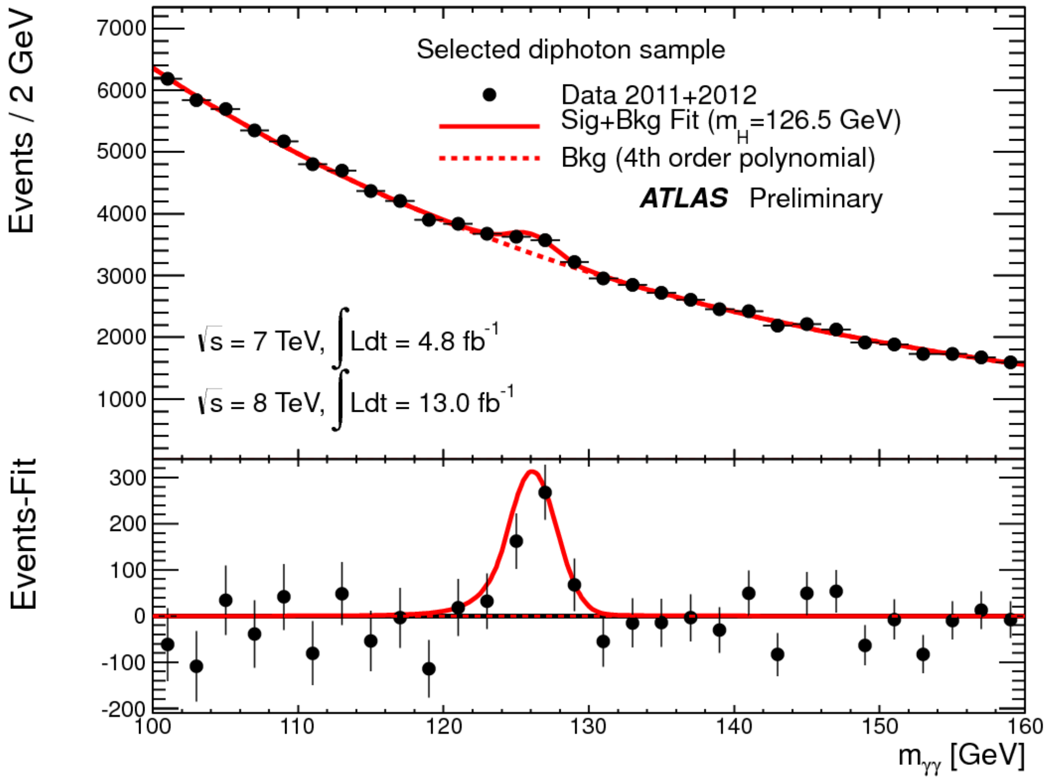
Leading effort on spectrum of 0^{++} vacuum (Higgs) channel:
latKMI and LHC group

Lattice Higgs Collaboration:
with **Zoltan Fodor, Kieran Holland, Santanu Mondal, Daniel Nogradi,** (Chris Schroeder)**, Chik Him Wong**

Congratulations latKMI for the excellent lattice BSM work !

Rational for BSM:





- After the Higgs is found why bother with BSM? Nothing else was seen and perhaps no new physics below the Planck scale?
- But Standard Model Higgs potential is parametrization rather than dynamical explanation ?

  $\lambda\phi^4$ not a fundamental gauge force - consequences?
- Built in cutoff from triviality with quadratic divergences leading to fine tuning and the hierarchy problem; vacuum instability
- Standard Model is low energy effective theory with built in cut-off ?
- Can new physics from compositeness hide within the LHC run2 reach ?
- Isn't compositeness dead anyway and we should not expect it in LHC run2 ?

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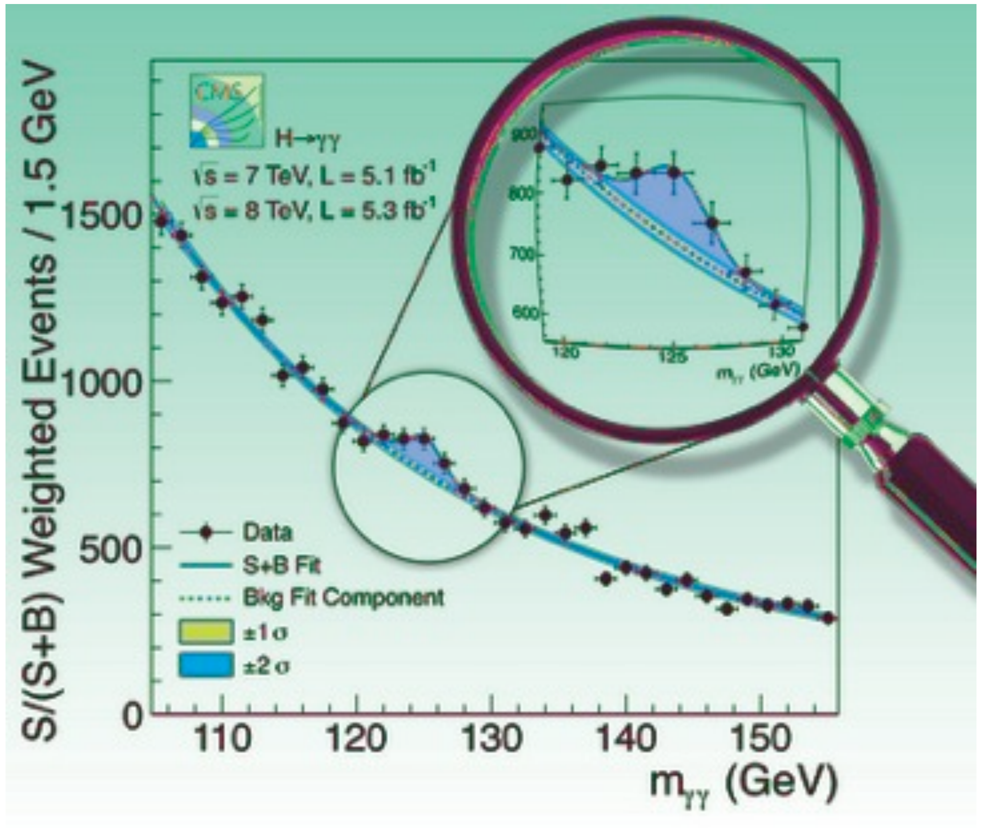
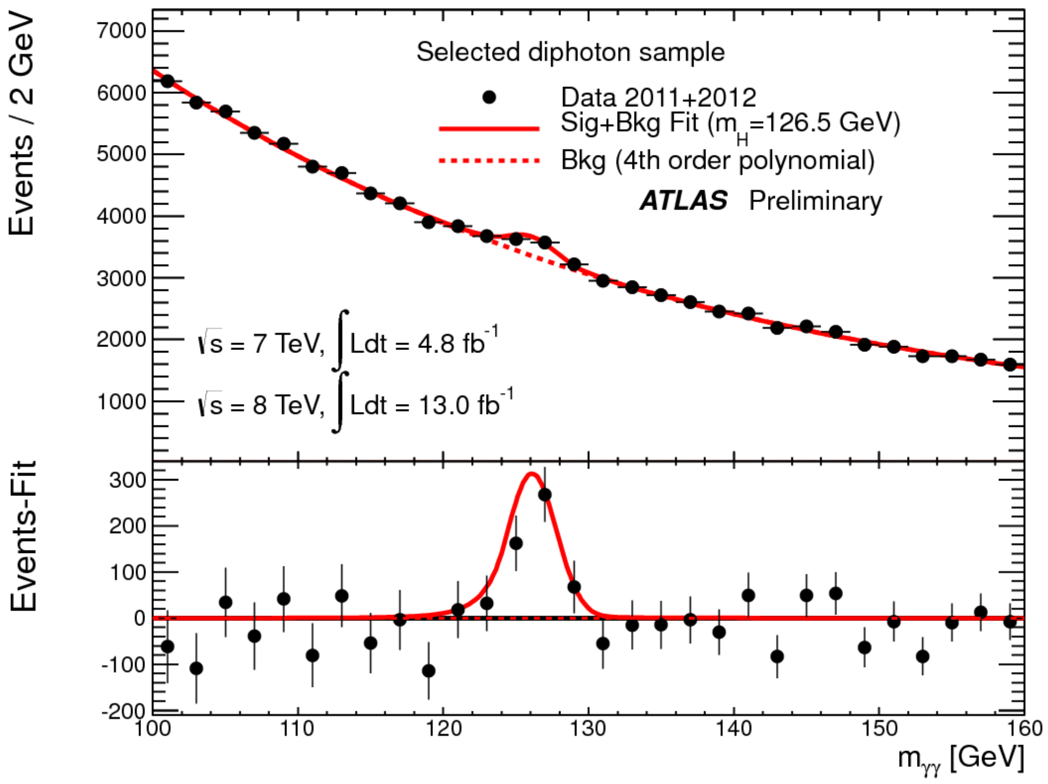




voices: a light Higgs-like scalar was found, consistent with SM within errors, and composite states have not been seen below 1 TeV. Strongly coupled BSM gauge theories are Higgs-less with resonances below 1 TeV

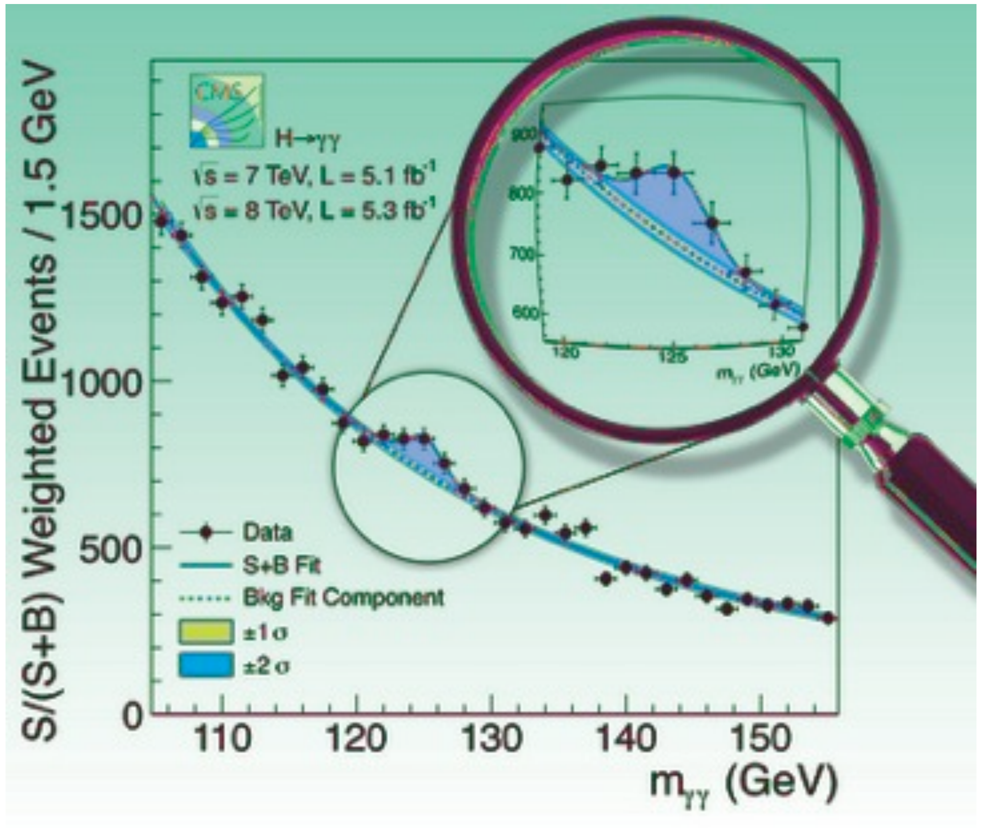
facts: Compositeness and a light Higgs scalar are not incompatible; search for composite states was not based on solid predictions but on naively scaled up QCD and unacceptable old technicolor guessing games. Resonances, out of LHC run1 reach, are in the 2-3 TeV range in the theory I will discuss

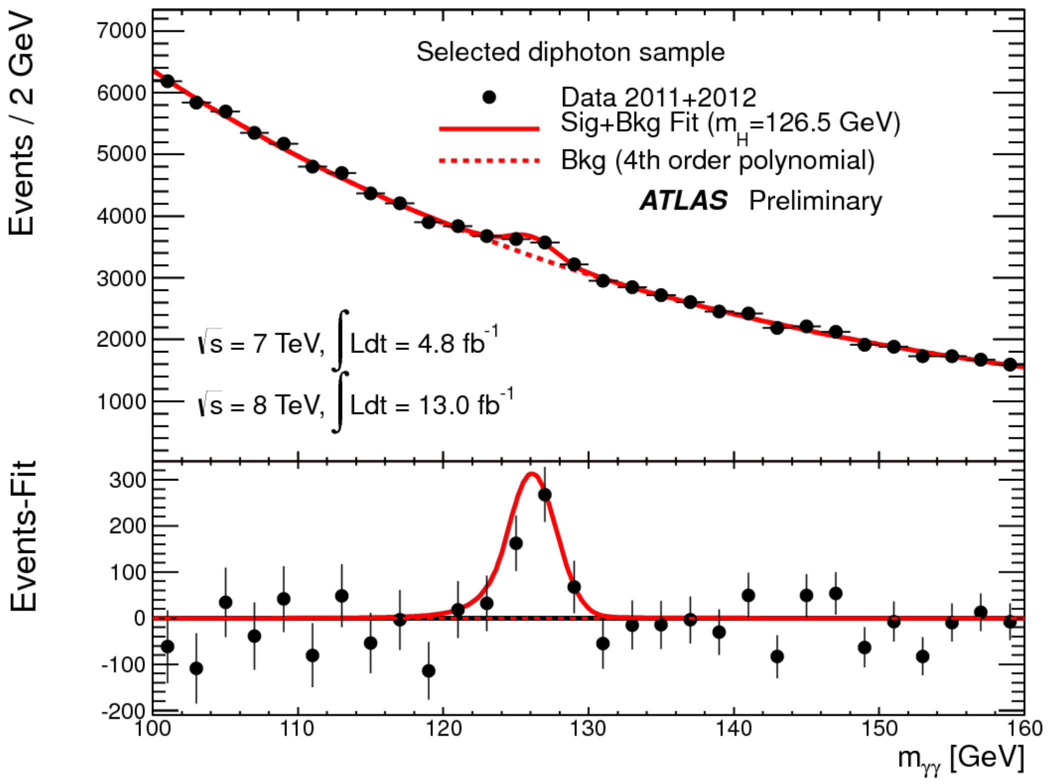
lattice BSM plans: LHC run2 will search for new physics from compositeness and SUSY, and the lattice BSM community is preparing quantitative lattice based predictions to be ruled in or ruled out.

We better get this right !

Rational for BSM:

three USQCD BSM directions based on gauge force:





- strongly coupled near-conformal gauge theories
  - light scalar is expected from approximate scale invariance (dilaton, or just light scalar?)
  - QCD is NOT approximately scale invariant making old technicolor guessing games irrelevant
- light pseudo-Goldstone boson (like little Higgs)
  - starts from a scalar massless Goldstone boson
  - expects to make quantitative predictions about composite spectrum above 1 TeV

SUSY

- for better understanding of dynamical symmetry breaking and to explore susy theory scenarios

- **We are making testable quantitative predictions for LHC run2 (e.g. sextet)**

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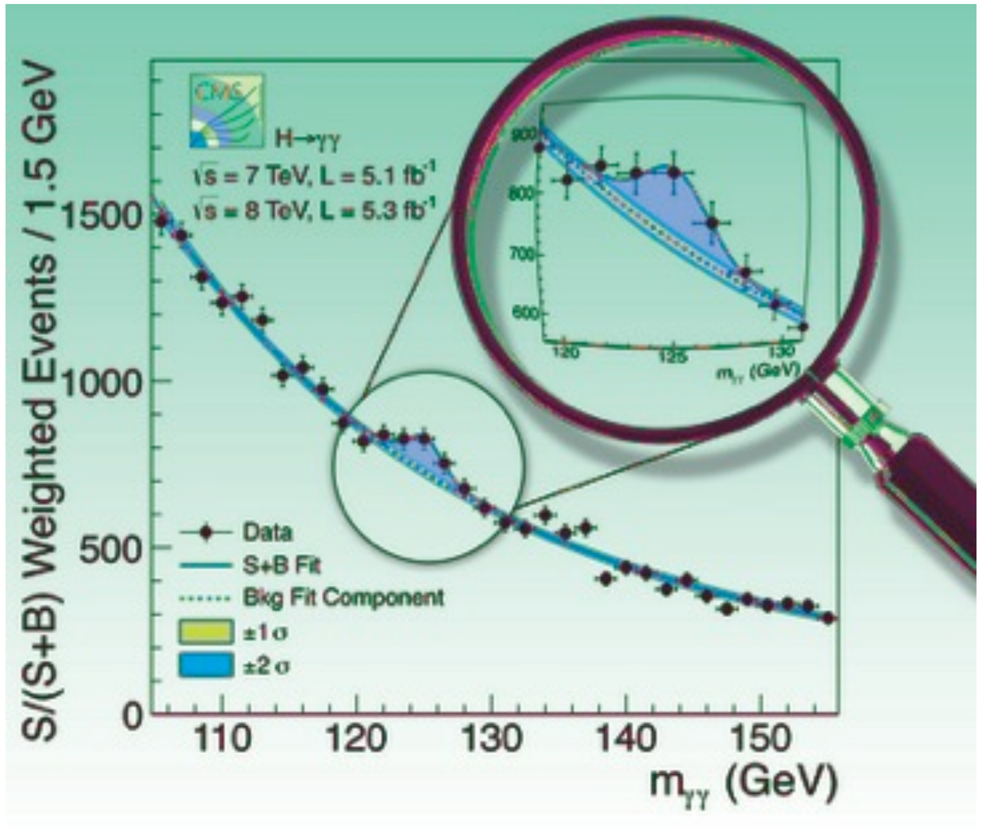

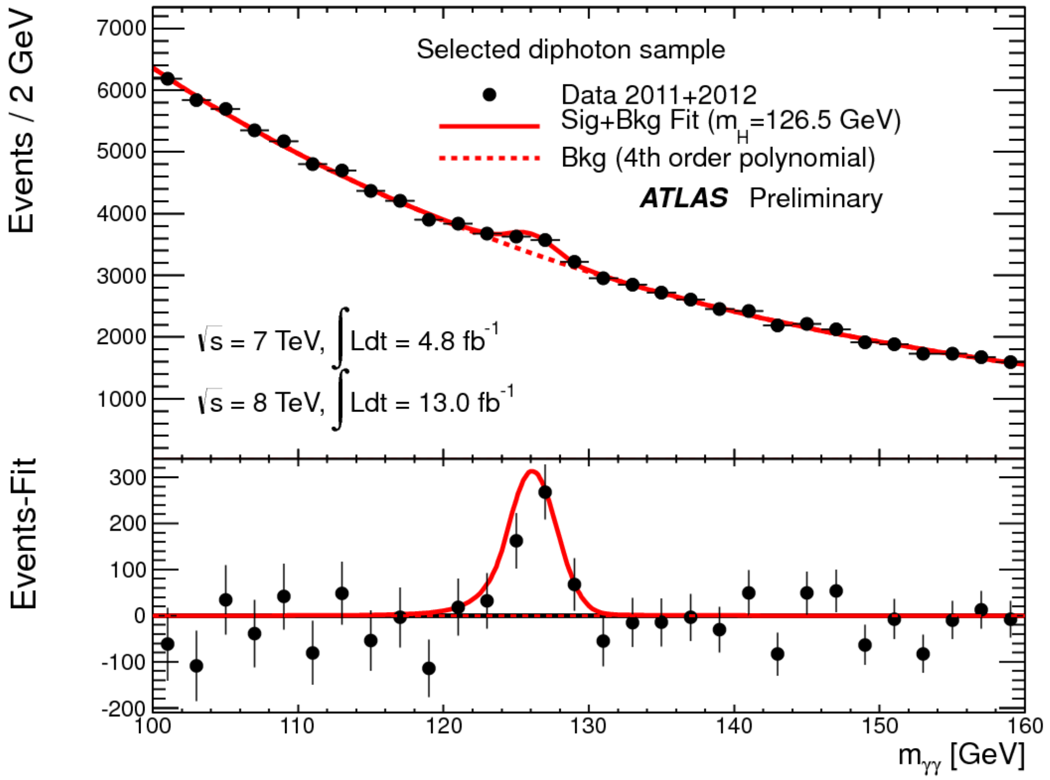

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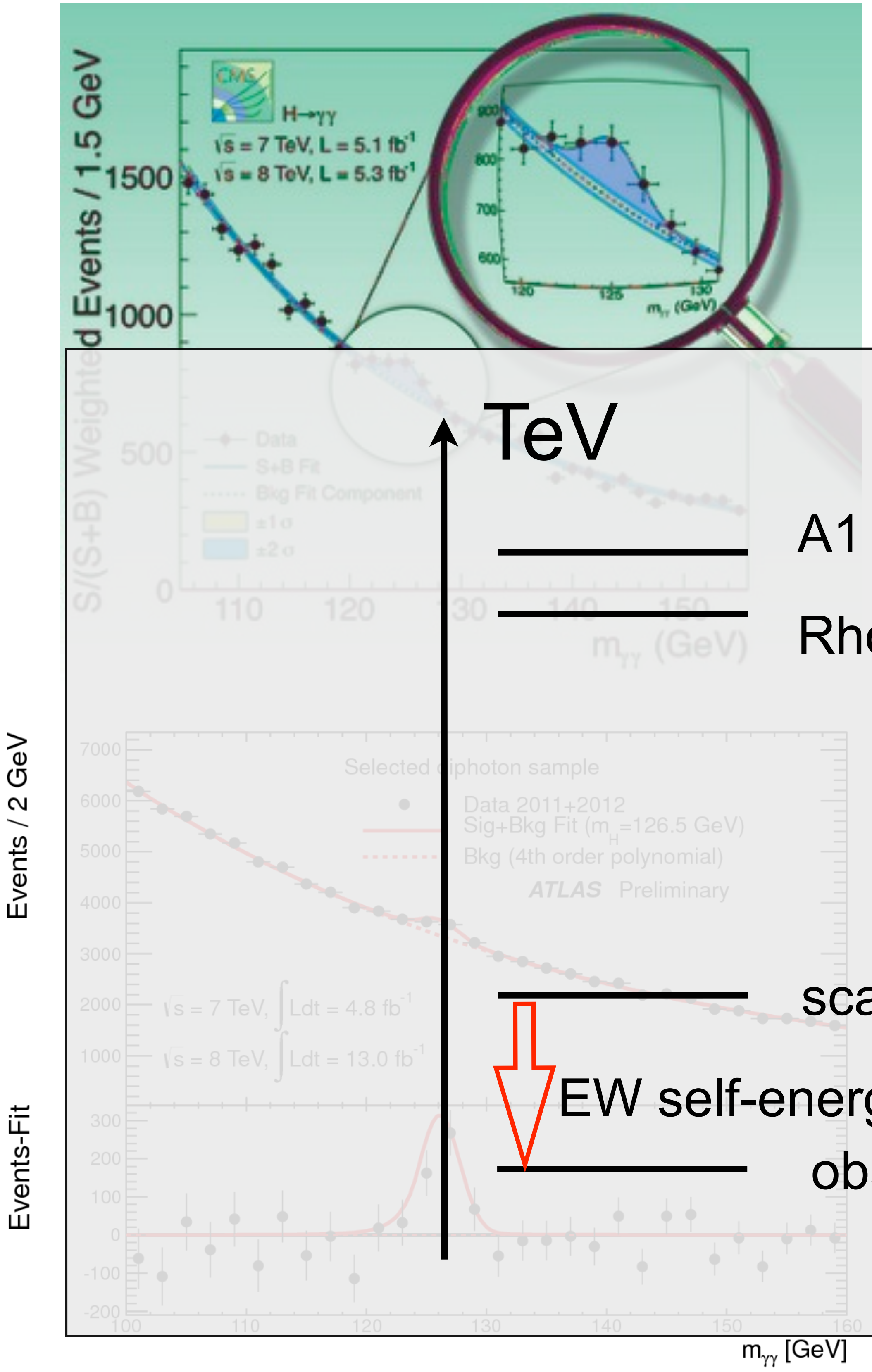
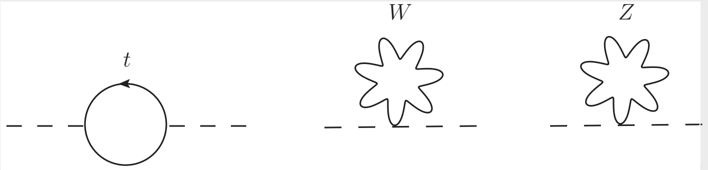
compositeness

from approximate scale invariance





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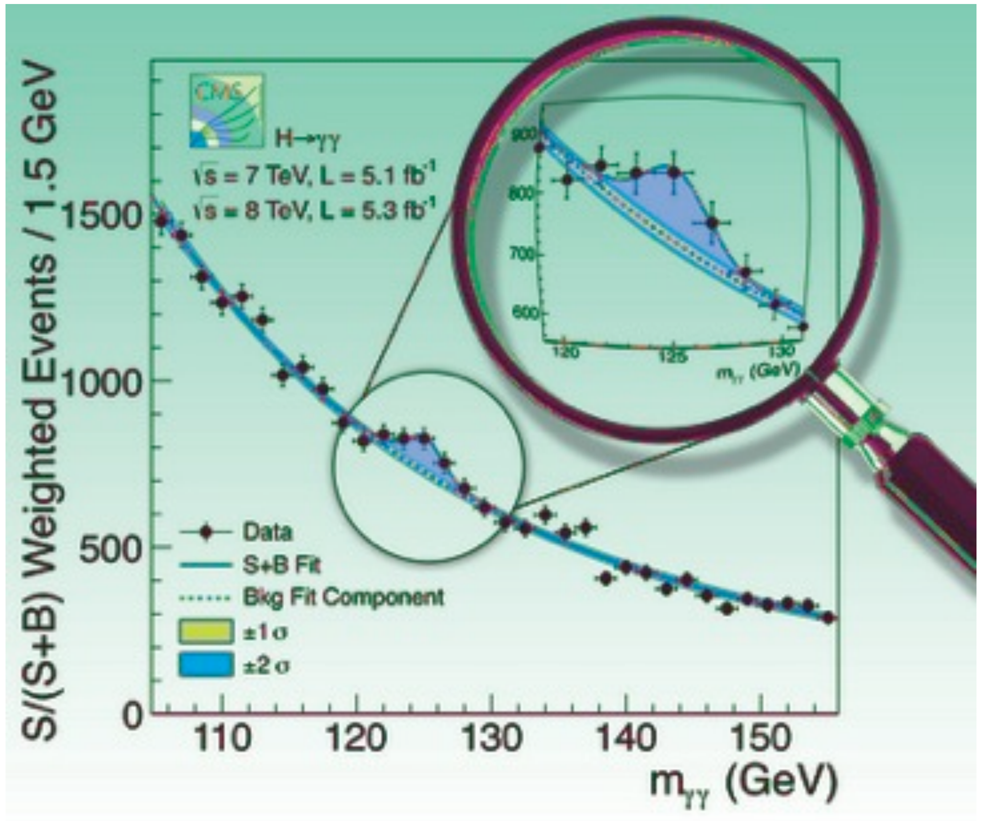

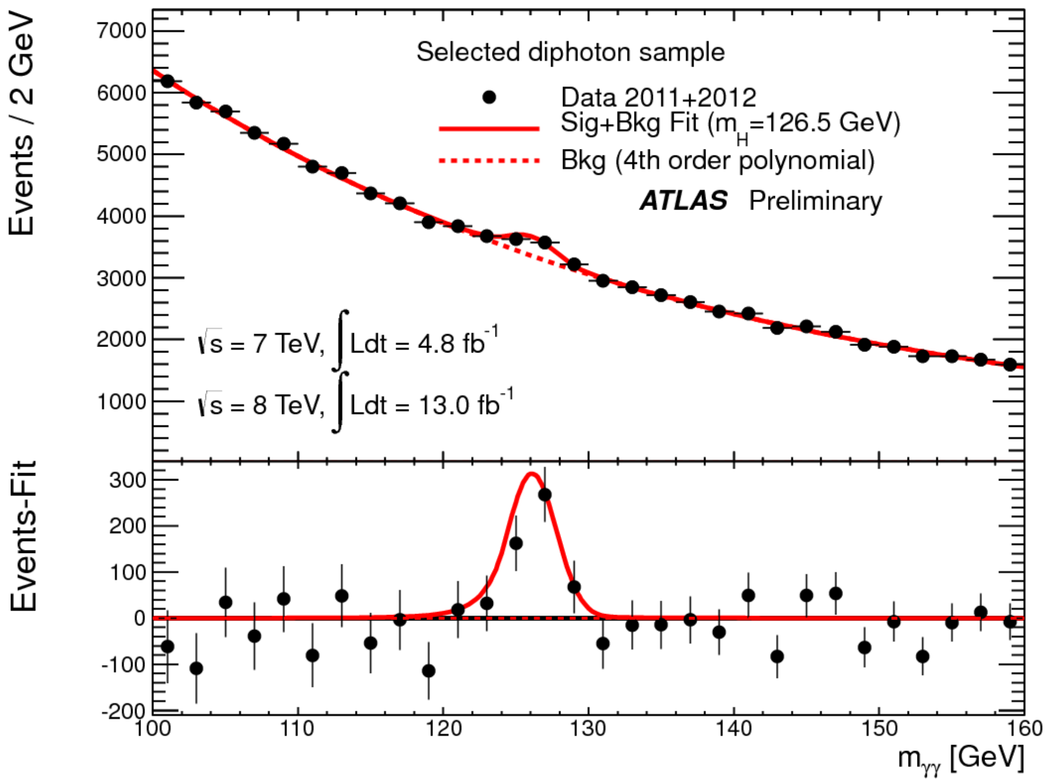

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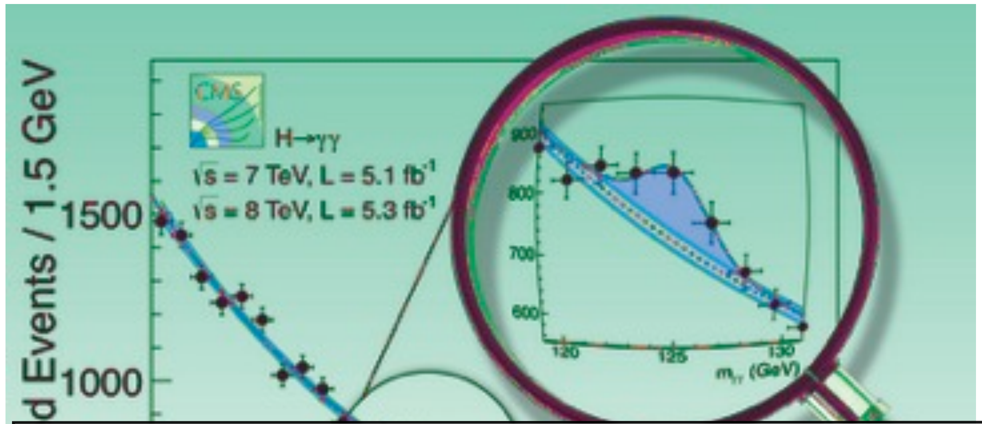

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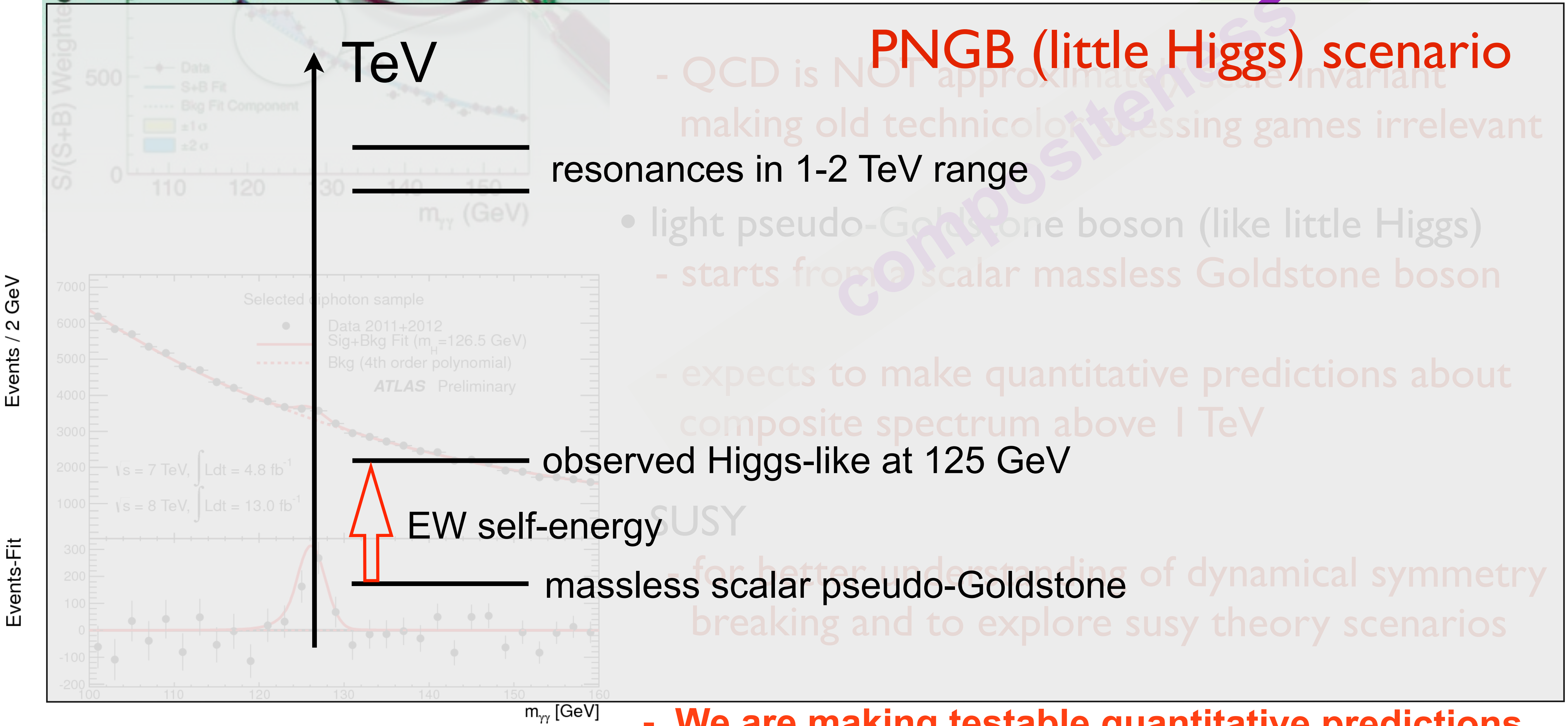
PNGB (little Higgs) scenario



- **We are making testable quantitative predictions for LHC run2 (e.g. sextet)**

What is the composite Higgs mechanism?

the Higgs doublet field

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

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

The Higgs Lagrangian is

spontaneous symmetry breaking

Higgs mechanism

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

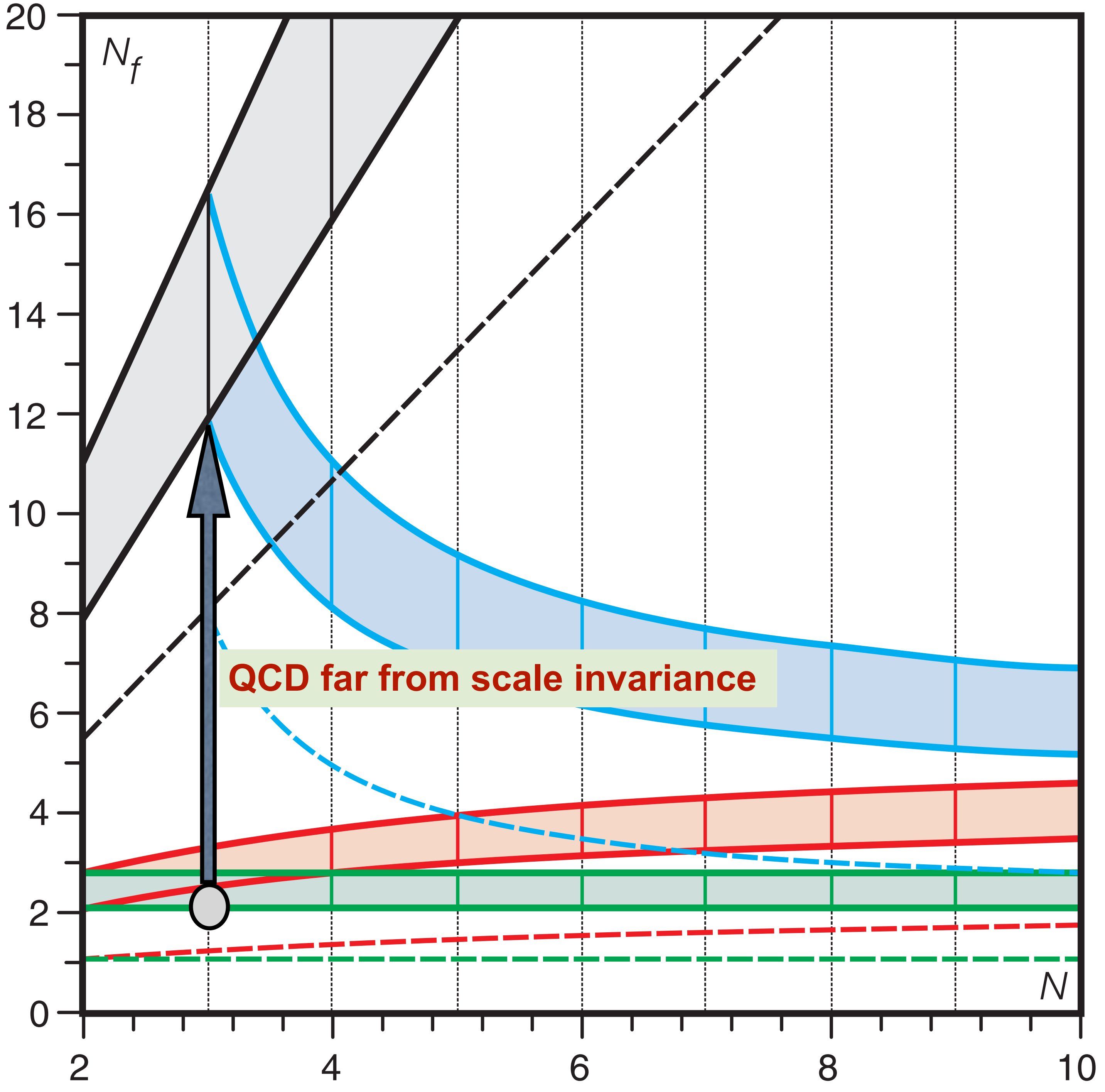
$$\mathcal{L}_{Higgs} \to -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{Q}\gamma_\mu D^\mu Q + \dots$$

strongly coupled gauge theory

fermions (Q) in gauge group reps

needle in the haystack?

light Higgs near conformality (dilaton-like?) sextet



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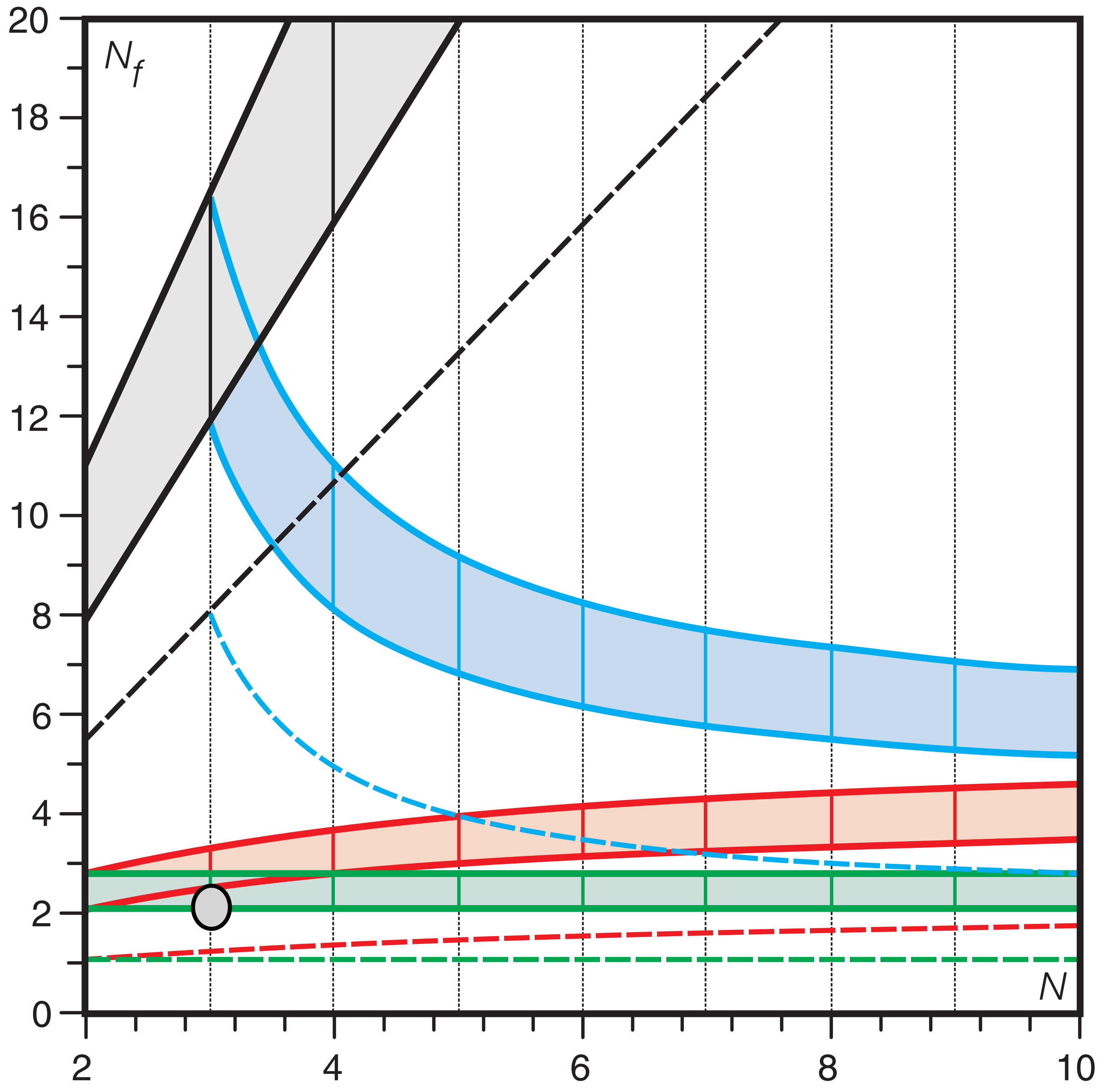


light Higgs near conformality (dilaton-like?) sextet

to illustrate: sextet SU(3) color rep

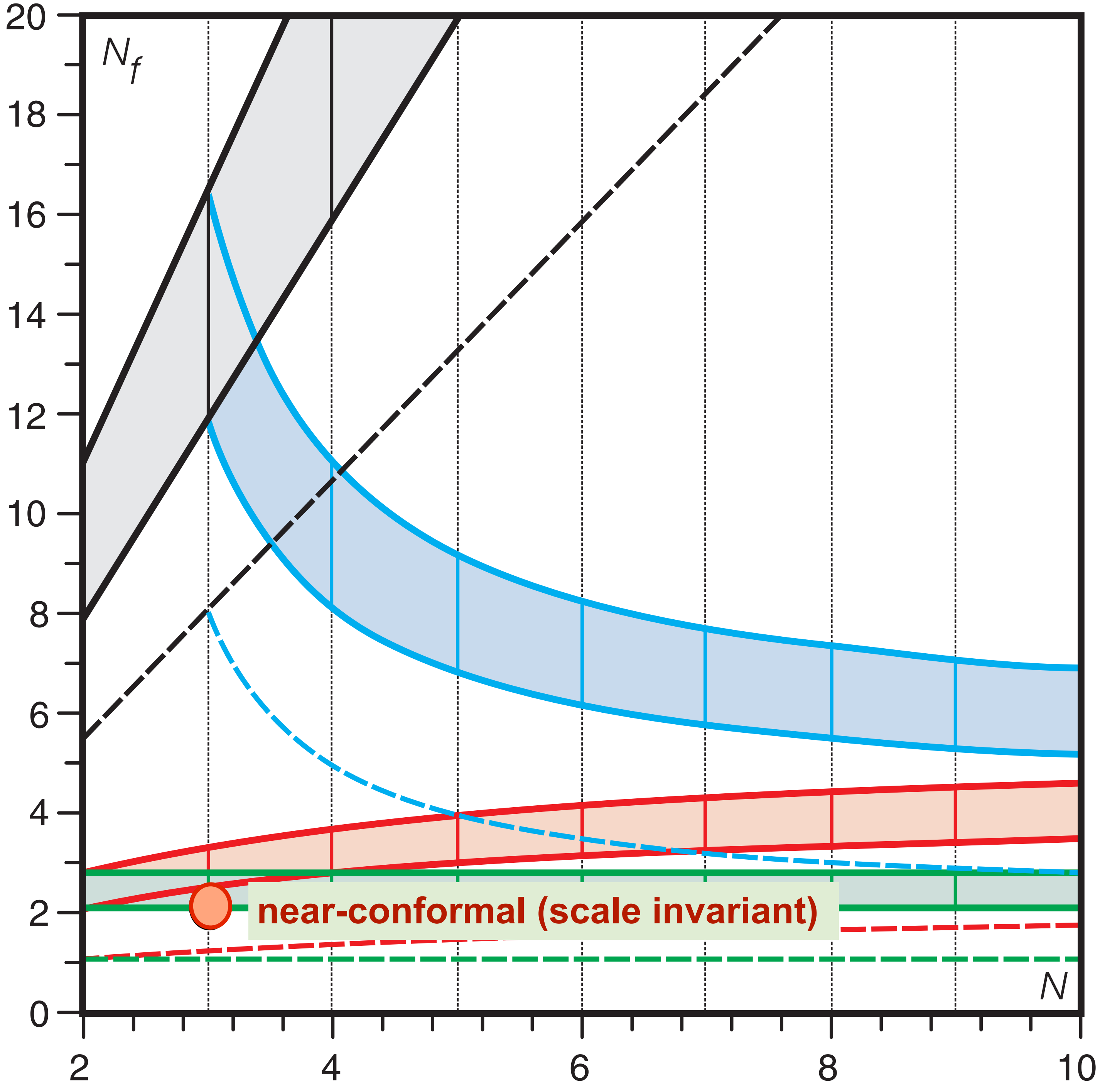
one massless fermion doublet $\begin{bmatrix} u \\ d \end{bmatrix}$

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?



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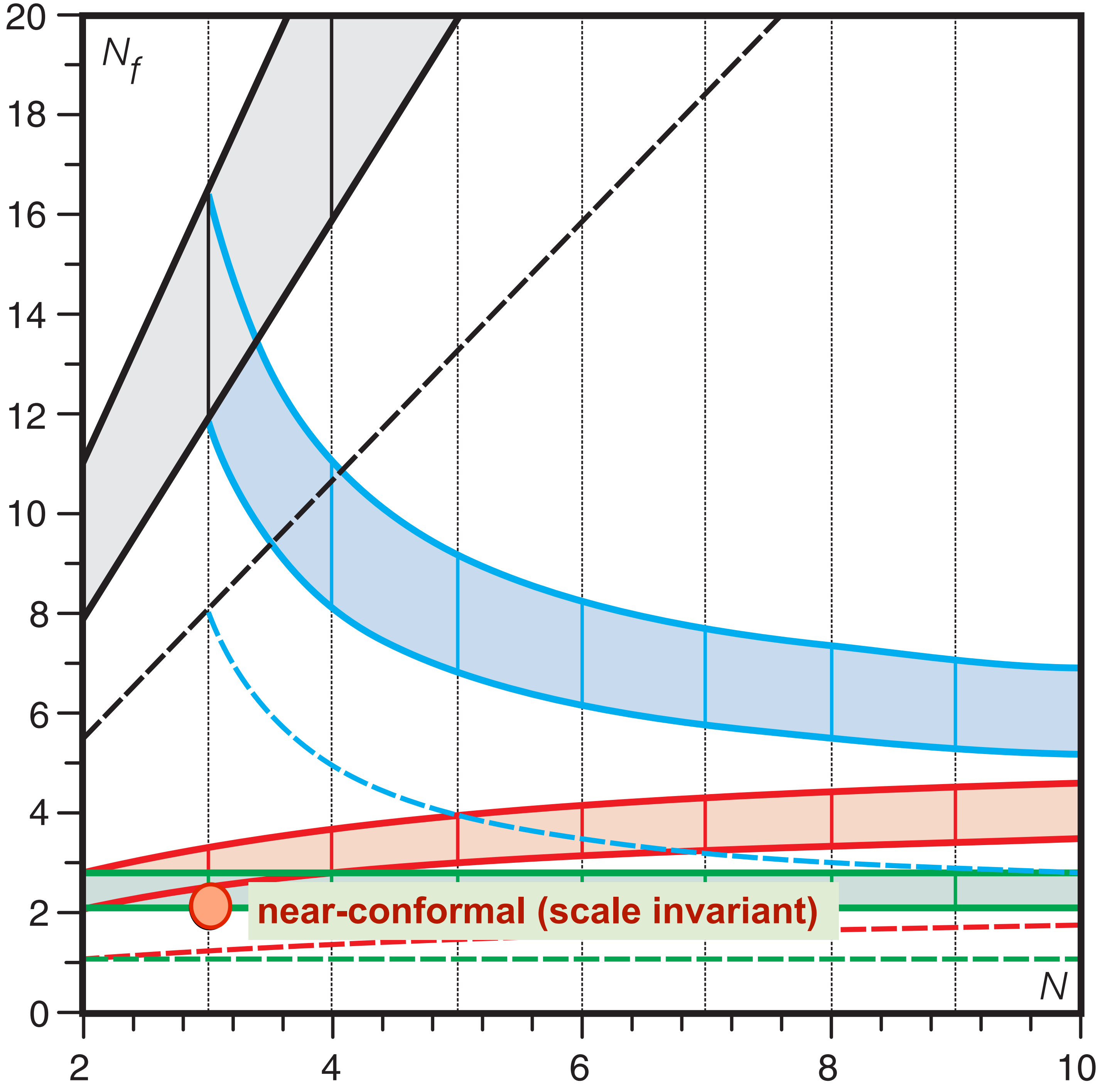
auction for naming rights?



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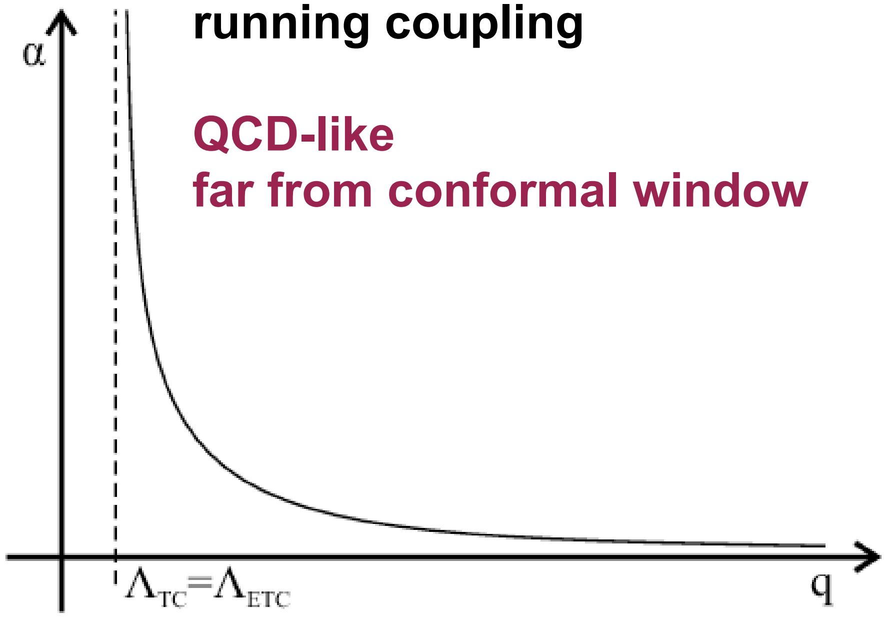

running coupling

QCD-like
far from conformal window

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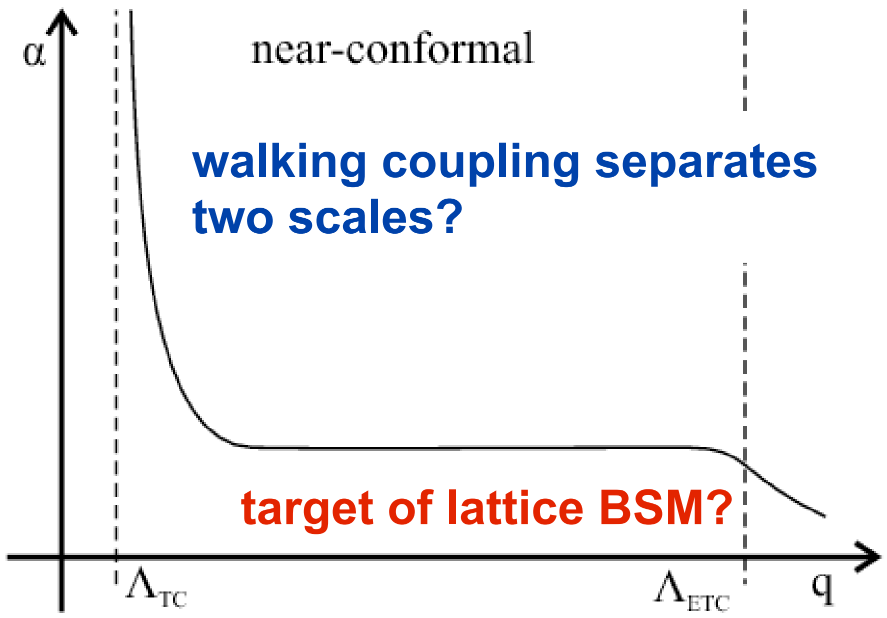
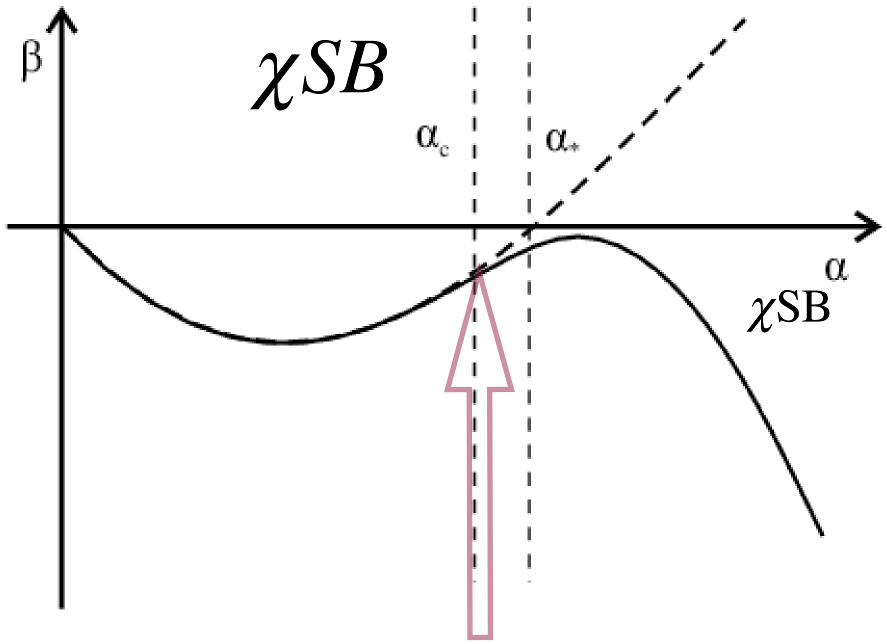


walking coupling separates two scales?

target of lattice BSM?



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:

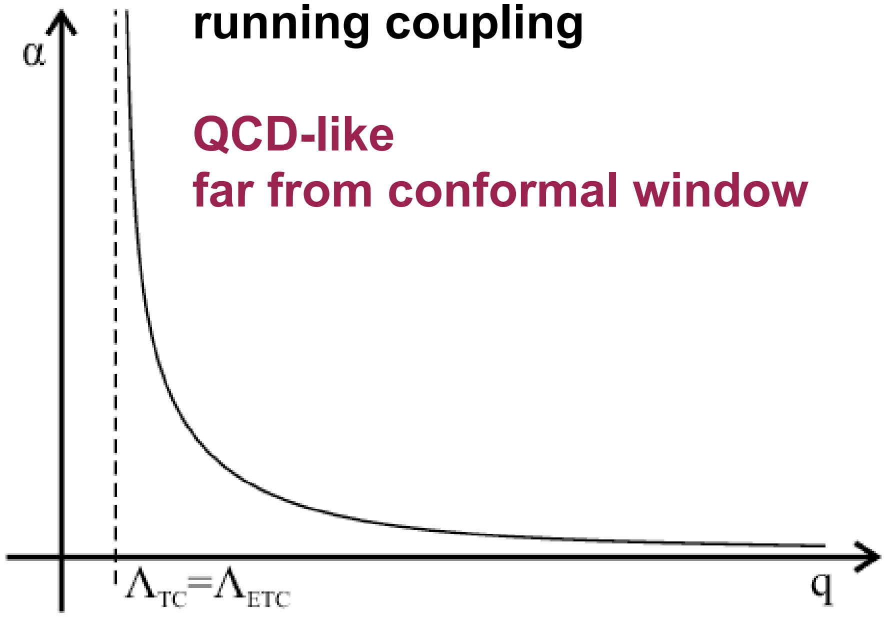
Sannino and collaborators

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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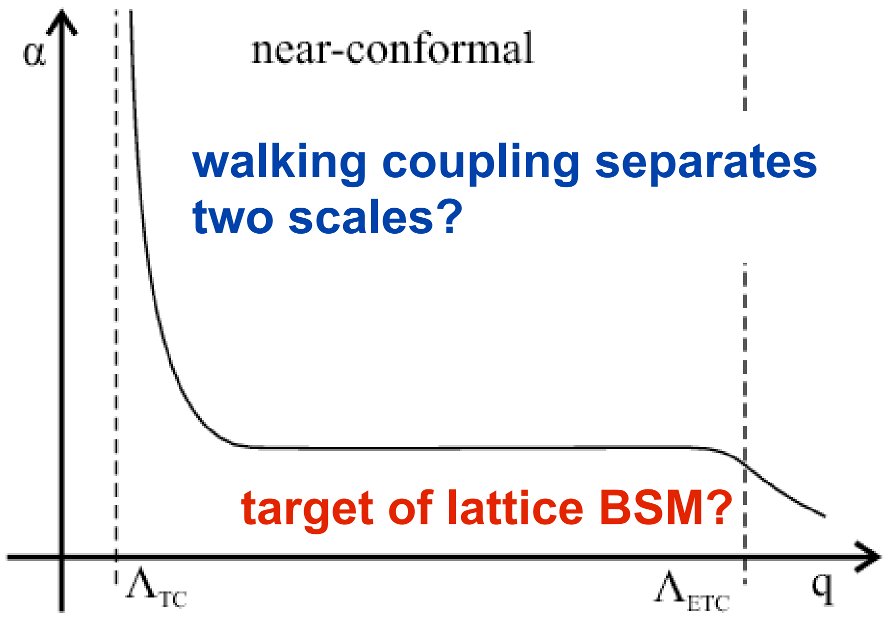

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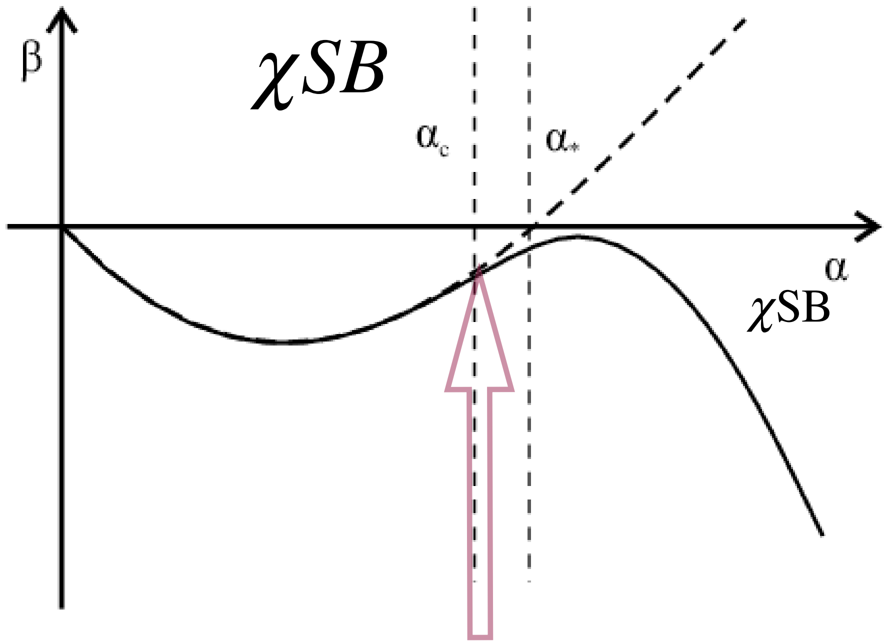

when chiral symmetry breaking
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two expectations:

(1) χSB and confinement

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

light Higgs near conformality (dilaton-like?) sextet

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

$$\partial_\mu \mathcal{D}^\mu = \Theta^\mu_\mu = \frac{\beta(\alpha)}{4\alpha} G^a_{\mu\nu} G^{a\mu\nu}$$

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

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

Partially Conserved Dilatation Current (PCDC)

Will gradient flow based technology make the argument less slippery?

Dilatation current

Bardeen, Ellis, Yamawaki, Appelquist, ...

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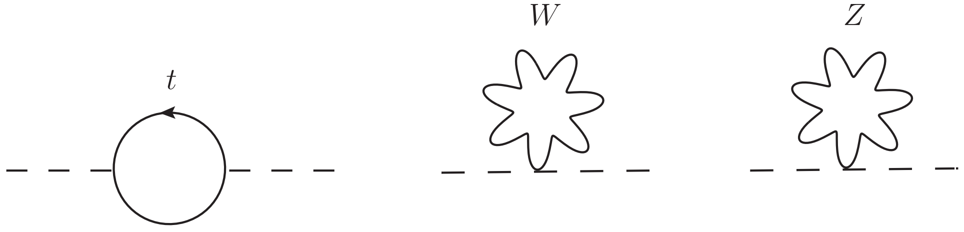
but how light is light ?

few hundred GeV Higgs impostor?

Foadi, Fransden, Sannino

open for spirited theory discussions



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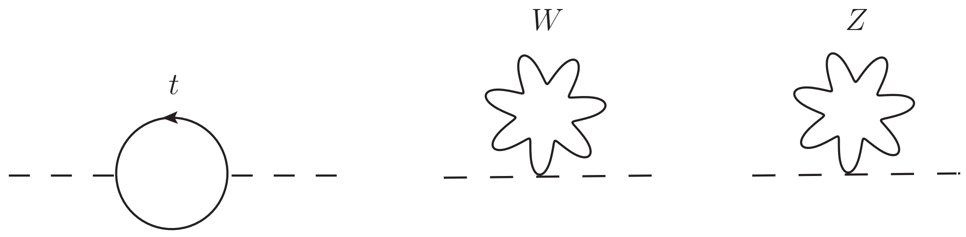

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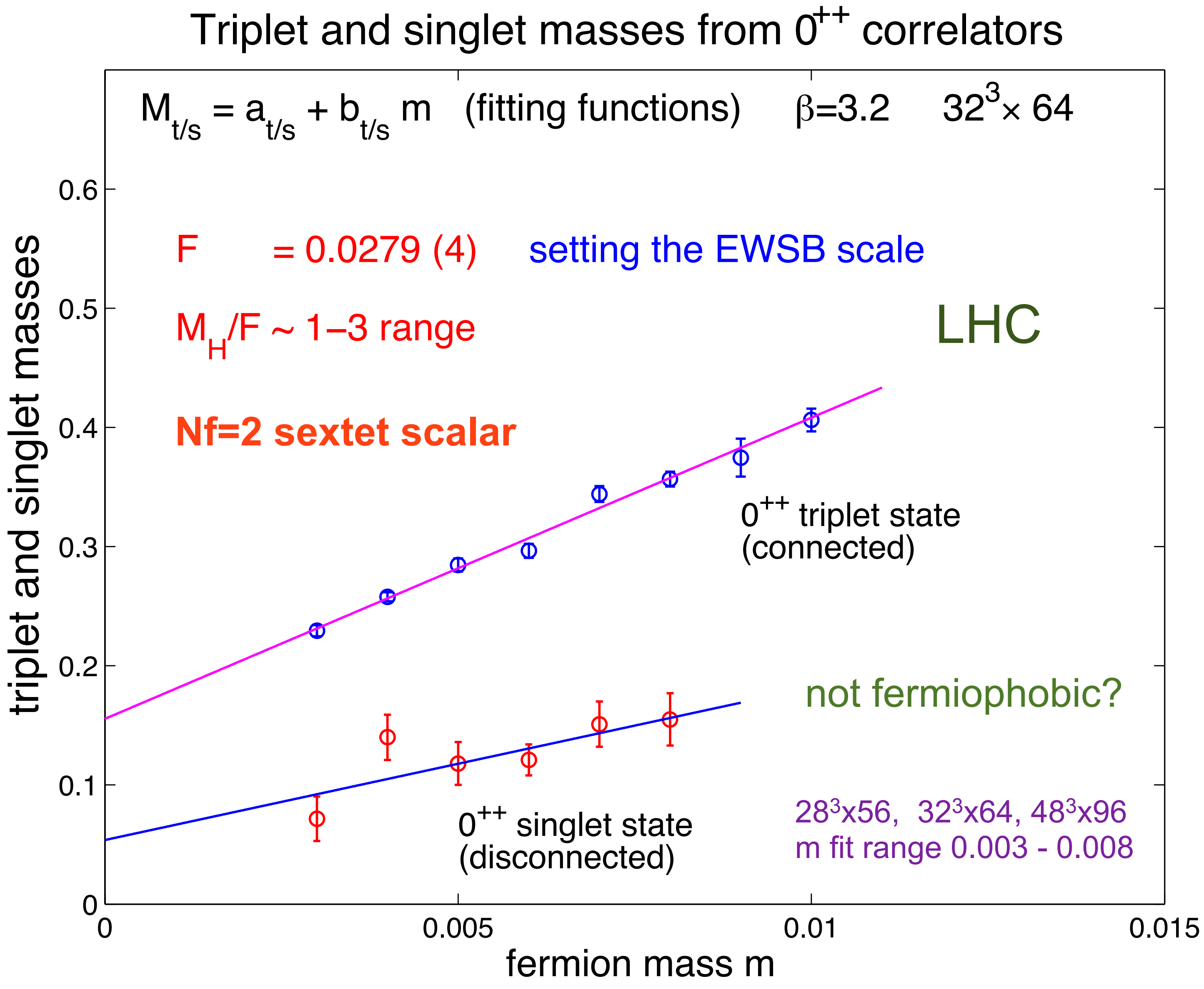
Triplet and singlet masses from 0^{++} correlators

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Partially Conserved Dilatation Current (PCDC)

Will gradient flow based technology make the argument less slippery?

$$\partial_\mu \mathcal{D}^\mu = \Theta^\mu_\mu = \frac{\beta(\alpha)}{4\alpha} G^a_{\mu\nu}G^{a\mu\nu}$$

Dilatation current

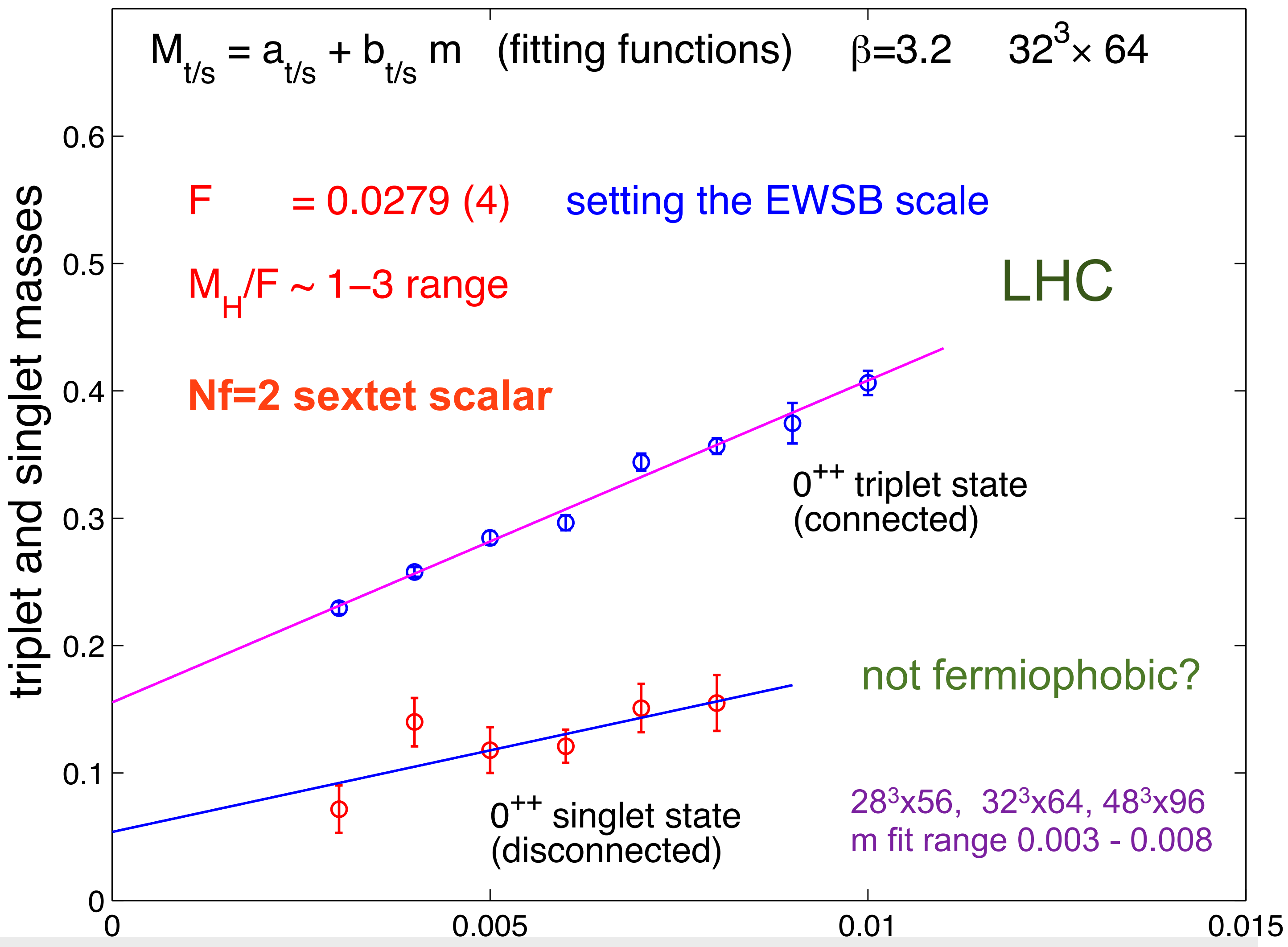
Bardeen, Ellis, Yamawaki, Appelquist, ...

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

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

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

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



$M_{t/s} = a_{t/s} + b_{t/s}\, m$ (fitting functions) β=3.2 $32^3 \times 64$

F = 0.0279 (4) setting the EWSB scale

M_H/F ~ 1–3 range

Nf=2 sextet scalar

LHC

0^{++} triplet state (connected)

not fermiophobic?

0^{++} singlet state (disconnected)

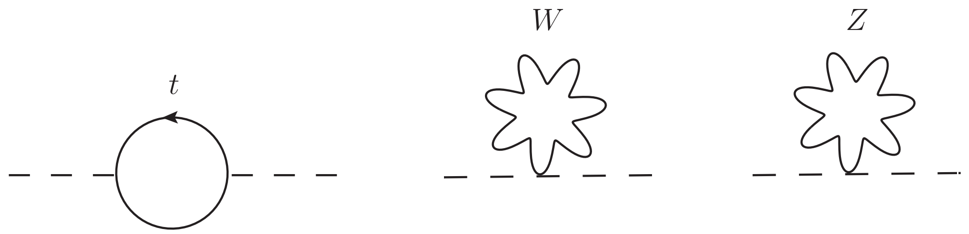
28^3x56, 32^3x64, 48^3x96
m fit range 0.003 - 0.008

but how light is light ?

few hundred GeV Higgs impostor?

Foadi, Fransden, Sannino

open for spirited theory discussions



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

light composite Higgs and EW constraints

Decay Mode	ATLAS	CMS	Tevatron
$H \to bb$	$0.2^{+0.7}_{-0.6}$	1.15 ± 0.62	$1.59^{+0.69}_{-0.72}$
$H \to \tau\tau$	$0.7^{+0.7}_{-0.6}$	1.10 ± 0.41	$1.68^{+2.28}_{-1.68}$
$H \to \gamma\gamma$	$1.55^{+0.33}_{-0.28}$	0.77 ± 0.27	$5.97^{+3.39}_{-3.12}$
$H \to WW^*$	$0.99^{+0.31}_{-0.28}$	0.68 ± 0.20	$0.94^{+0.85}_{-0.83}$
$H \to ZZ^*$	$1.43^{+0.40}_{-0.35}$	0.92 ± 0.28	
Combined	1.23 ± 0.18	0.80 ± 0.14	$1.44^{+0.59}_{-0.56}$

$$\mu \equiv \sigma \cdot \mathrm{Br}/(\sigma_{\mathrm{SM}} \cdot \mathrm{Br}_{\mathrm{SM}})$$

$$\mu = 0.96 \pm 0.11$$

From Higgs potential and Top coupling:

M_H > 130 GeV absolute stable vacuum below M_{Pl}

observed Higgs -> Metastable vacuum

$$\begin{aligned}\mathcal{L} &= \frac{v^2}{4}\langle u_\mu u^\mu \rangle \left(1 + \frac{2\omega}{v} S_1\right) + \frac{F_A}{2\sqrt{2}}\langle A_{\mu\nu} f_-^{\mu\nu} \rangle \\ &+ \frac{F_V}{2\sqrt{2}}\langle V_{\mu\nu} f_+^{\mu\nu} \rangle + \frac{iG_V}{2\sqrt{2}}\langle V_{\mu\nu}[u^\mu, u^\nu] \rangle \\ &+ \sqrt{2}\lambda_1^{SA} \partial_\mu S_1 \langle A^{\mu\nu} u_\nu \rangle ,\end{aligned}$$

effective theory of strongly coupled composite Higgs scenario

$$\omega \sim 1$$

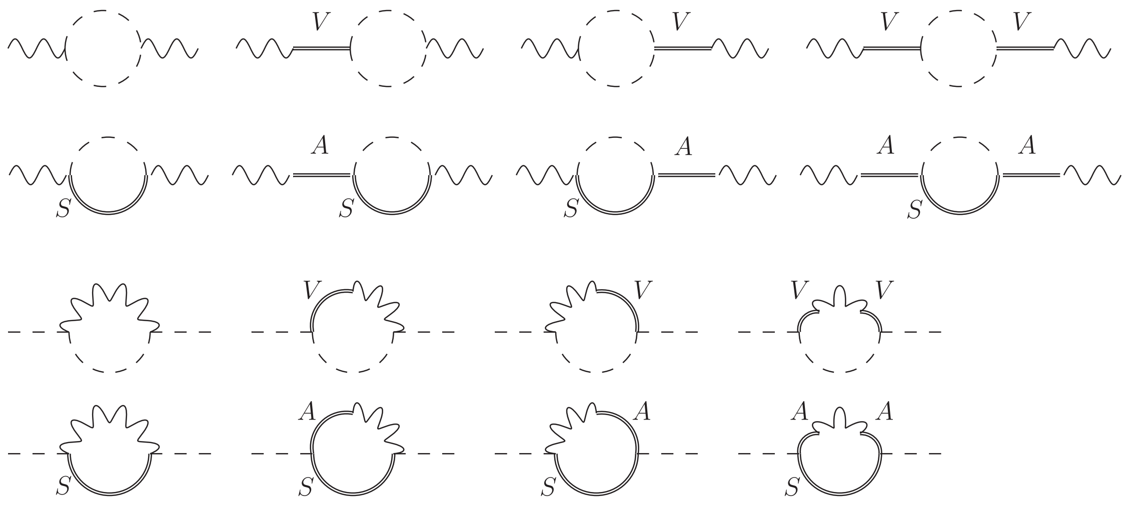
u: Goldstone

S: scalar (Higgs)

f: gauge field

A: axial resonances

V: vector resonance



NLO S-param

$$S = 0.03 \pm 0.10$$

global fits

NLO T-param

$$T = 0.05 \pm 0.12$$

light composite Higgs and EW constraints

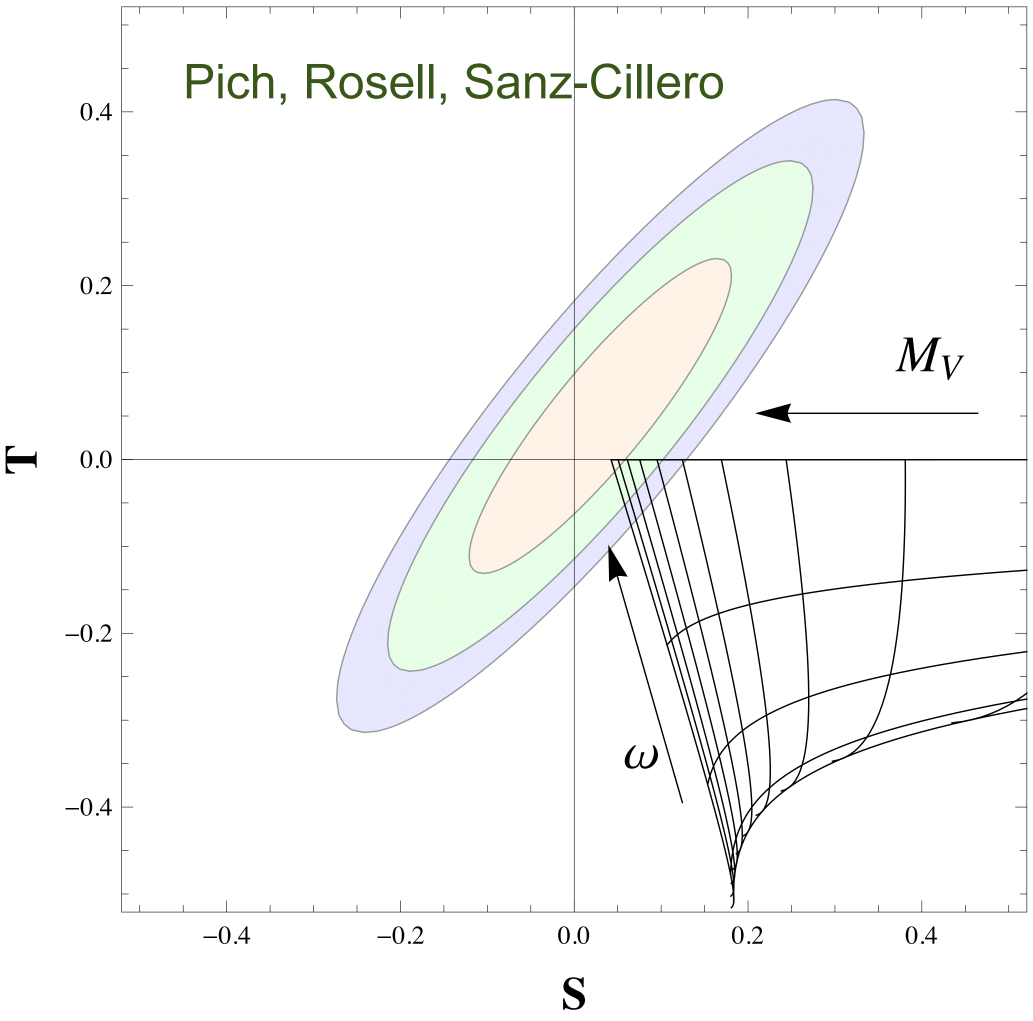


FIG. 2. NLO determinations of S and T, imposing the two WSRs. The approximately vertical curves correspond to constant values of M_V, from 1.5 to 6.0 TeV at intervals of 0.5 TeV. The approximately horizontal curves have constant values of ω: 0.00, 0.25, 0.50, 0.75, 1.00. The arrows indicate the directions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

$$S \;=\; \frac{\pi}{g \qquad \theta_W} \int^{\infty} \frac{\quad}{t} \;\; \rho_S \;\; t \;\; - \rho_S \;\; t$$

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

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

From two Weinberg sum rules and from NLO loop expansion:

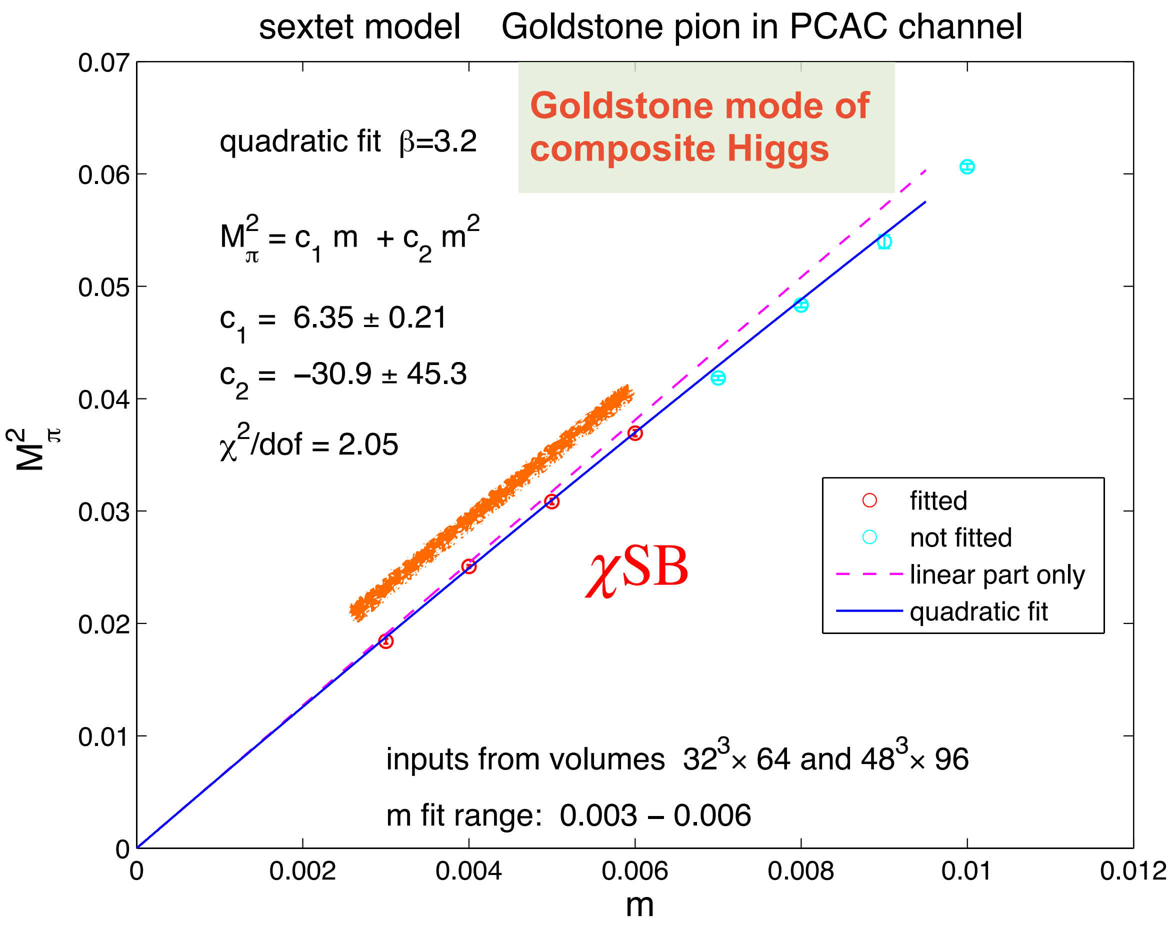
M_V, M_A ~ 2 TeV or higher is compatible with S,T constraints (it is tight and arguably ambiguous)

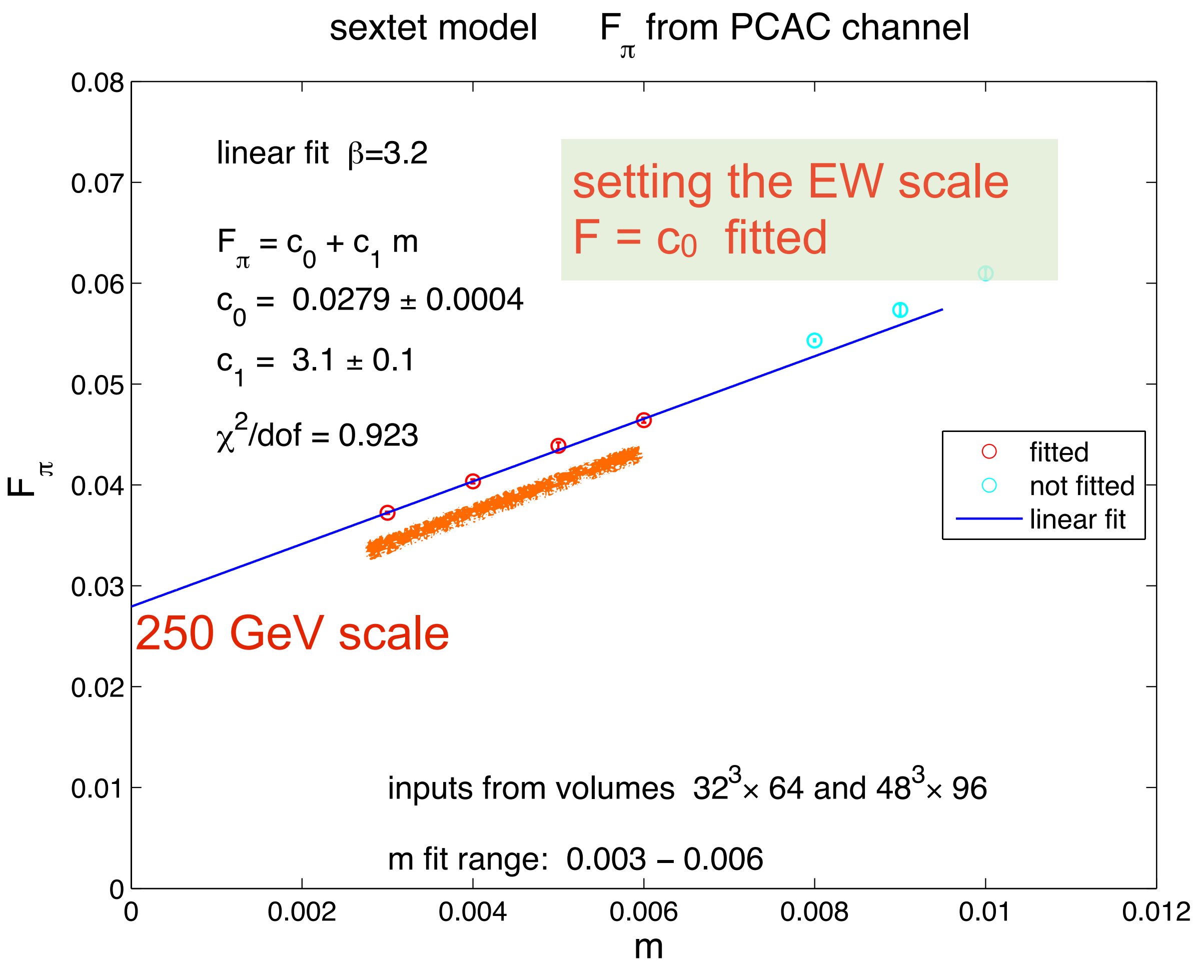
more work needed

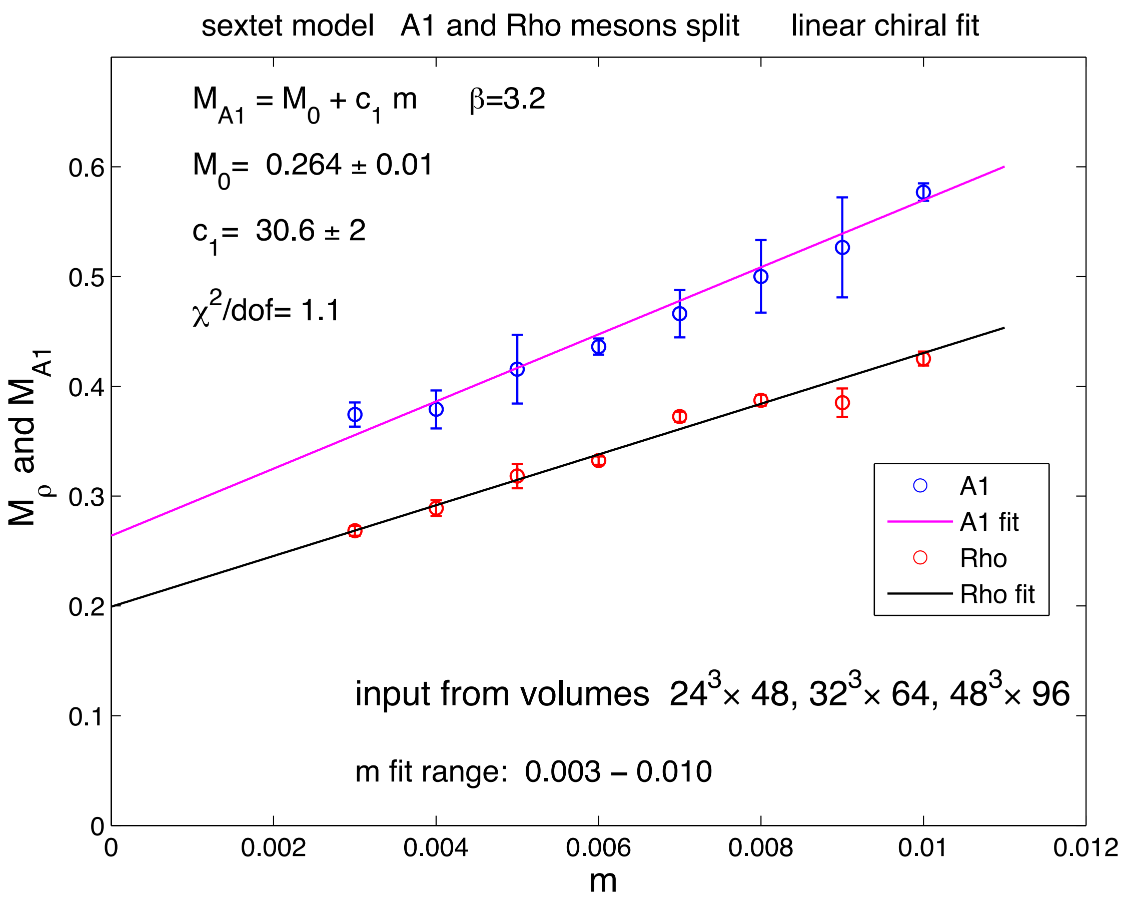
related body of work by Sannino and collaborators

Spectroscopy and scale setting

sextet N_f=2







A1/F ~ 9.5

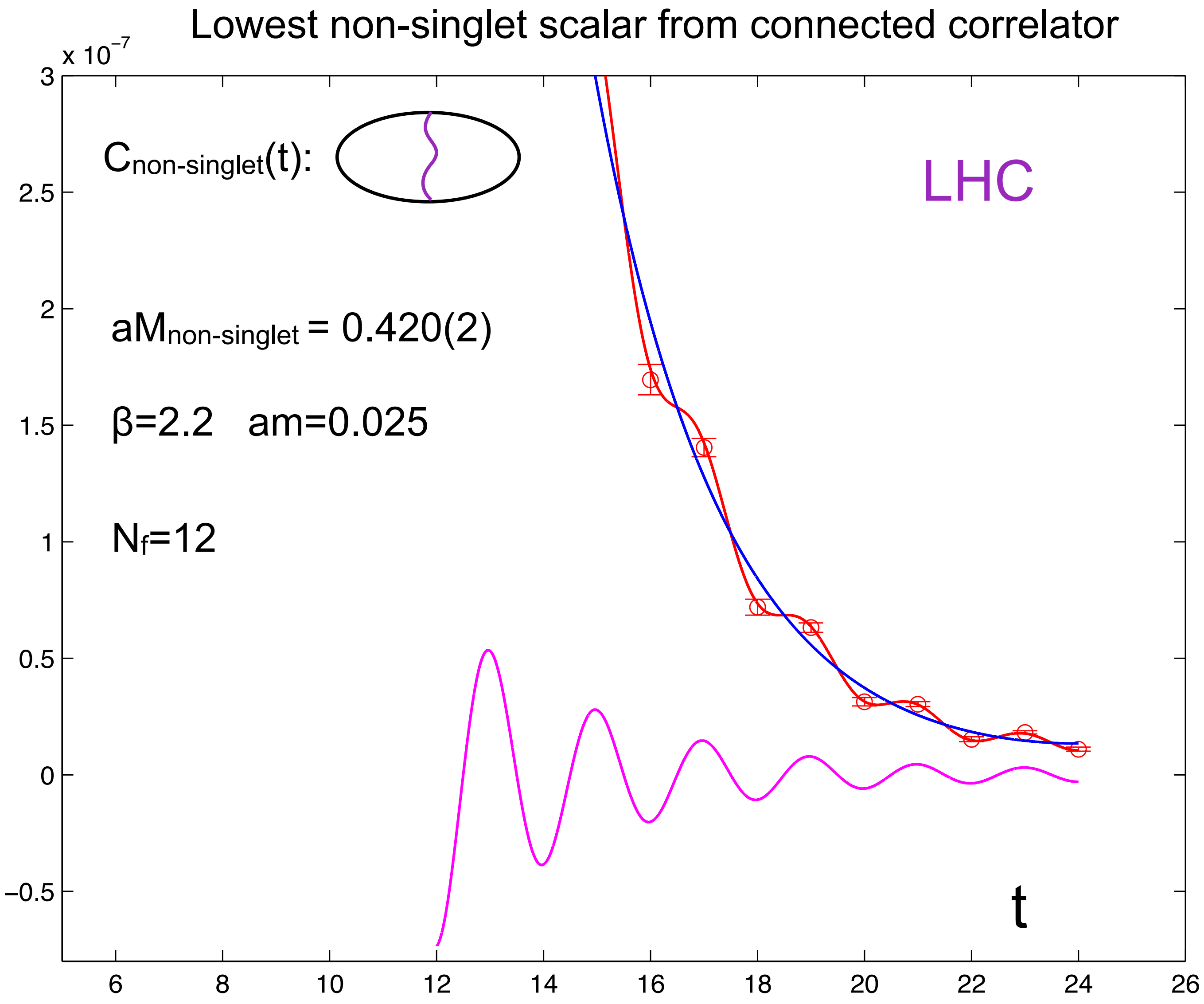
M_{A1}~ 2.37 TeV

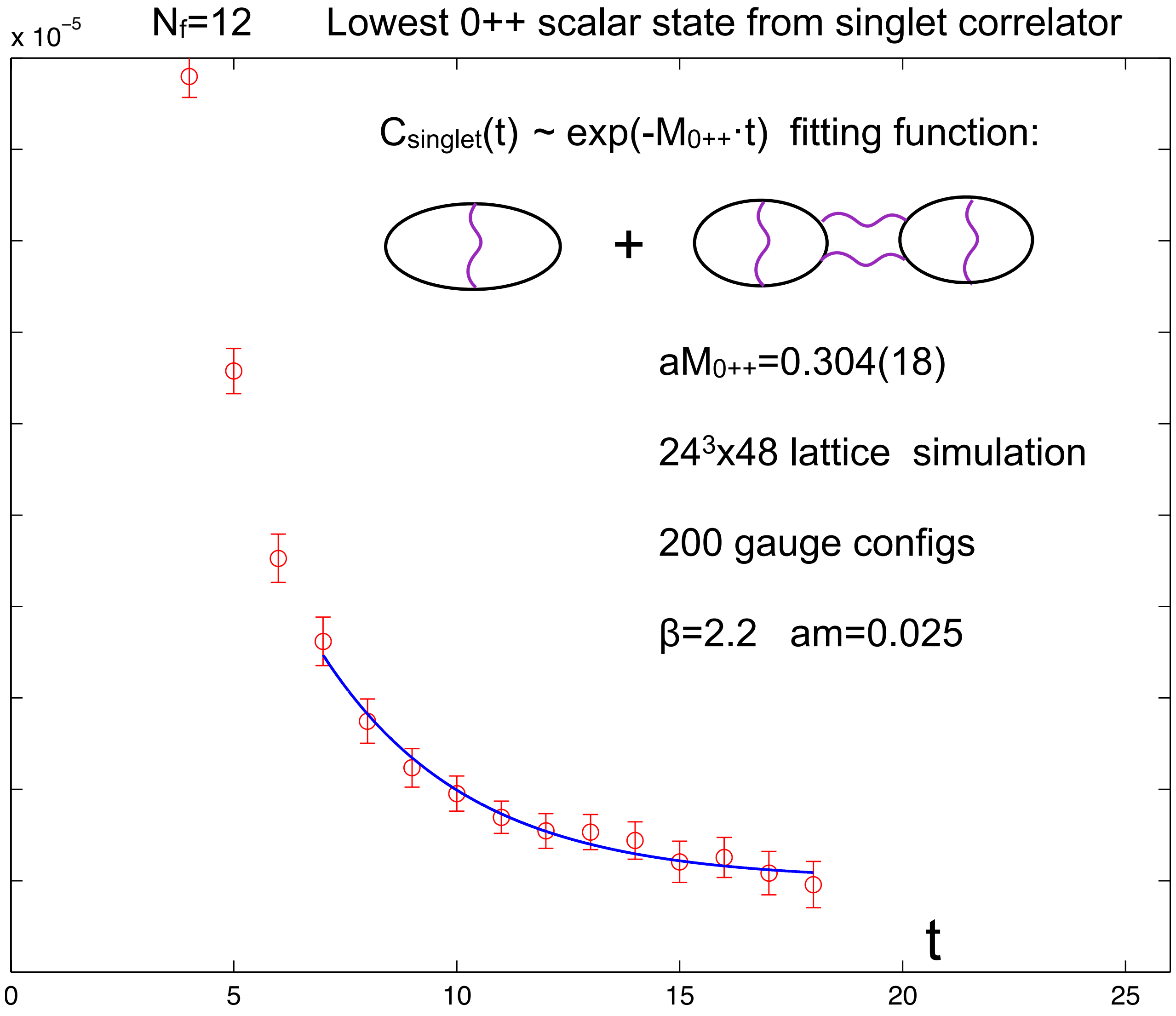
LHC14?

- Nf=2 SU(3) sextet M_{a0}, M_ρ, and M_{A1}
- three lowest states above light scalar “Higgs state”

Spectroscopy and scale setting (scalar) N_f=12

test of technology:


Lowest non-singlet scalar from connected correlator


N_f=12 Lowest 0++ scalar state from singlet correlator

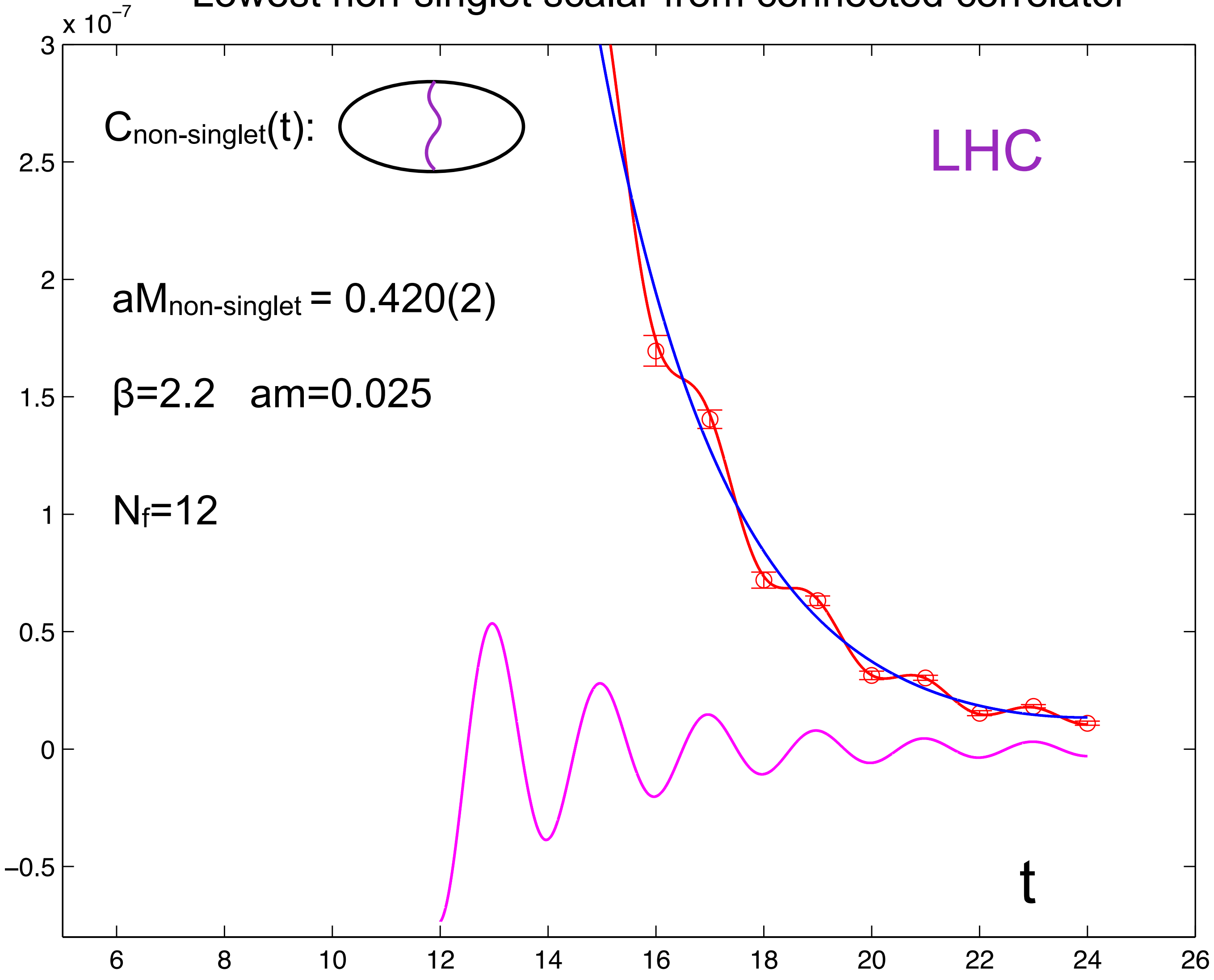
$$C(t) = \sum_n \left[A_n e^{-m_n(\Gamma_S\otimes\Gamma_T)t} + (-1)^t B_n e^{-m_n(\gamma_4\gamma_5\Gamma_S\otimes\gamma_4\gamma_5\Gamma_T)t}\right]$$

staggered correlator

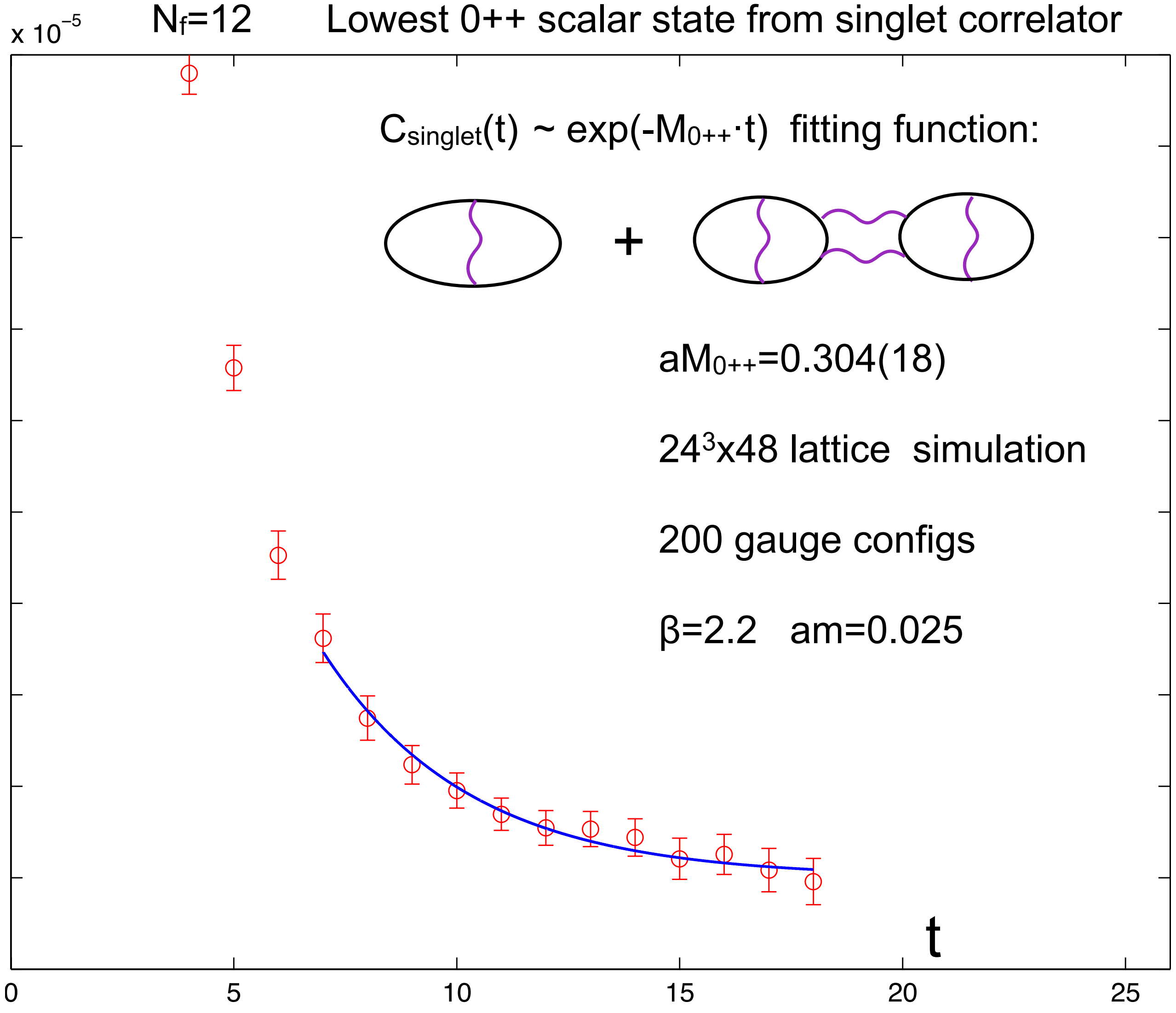
Spectroscopy and scale setting (scalar) N_f=12

test of technology:

Lowest non-singlet scalar from connected correlator



N_f=12 Lowest 0++ scalar state from singlet correlator

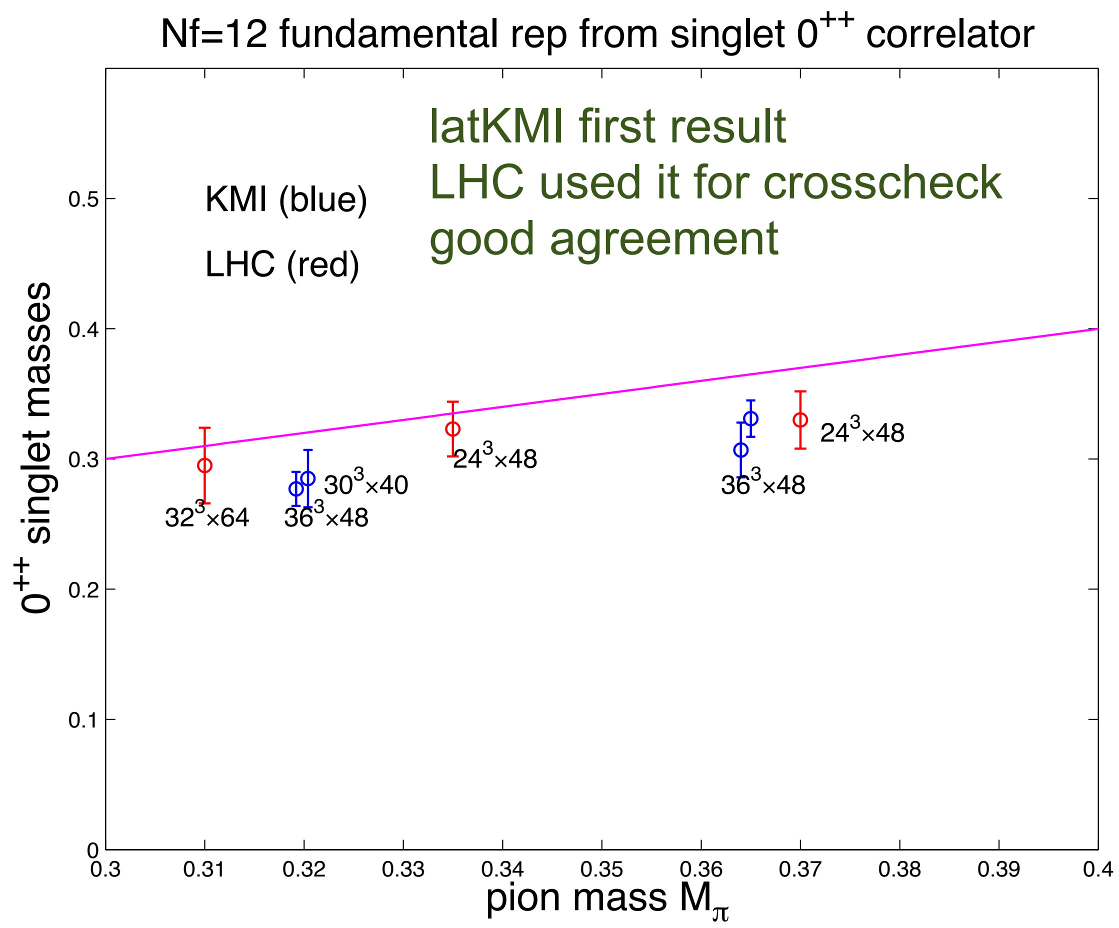


$$C(t) = \sum_n \left[A_n e^{-m_n(\Gamma_S\otimes\Gamma_T)t} + (-1)^t B_n e^{-m_n(\gamma_4\gamma_5\Gamma_S\otimes\gamma_4\gamma_5\Gamma_T)t}\right]$$

staggered correlator

similar analysis in sextet model with N_f=2

Spectroscopy and scale setting (scalar) N_f=12

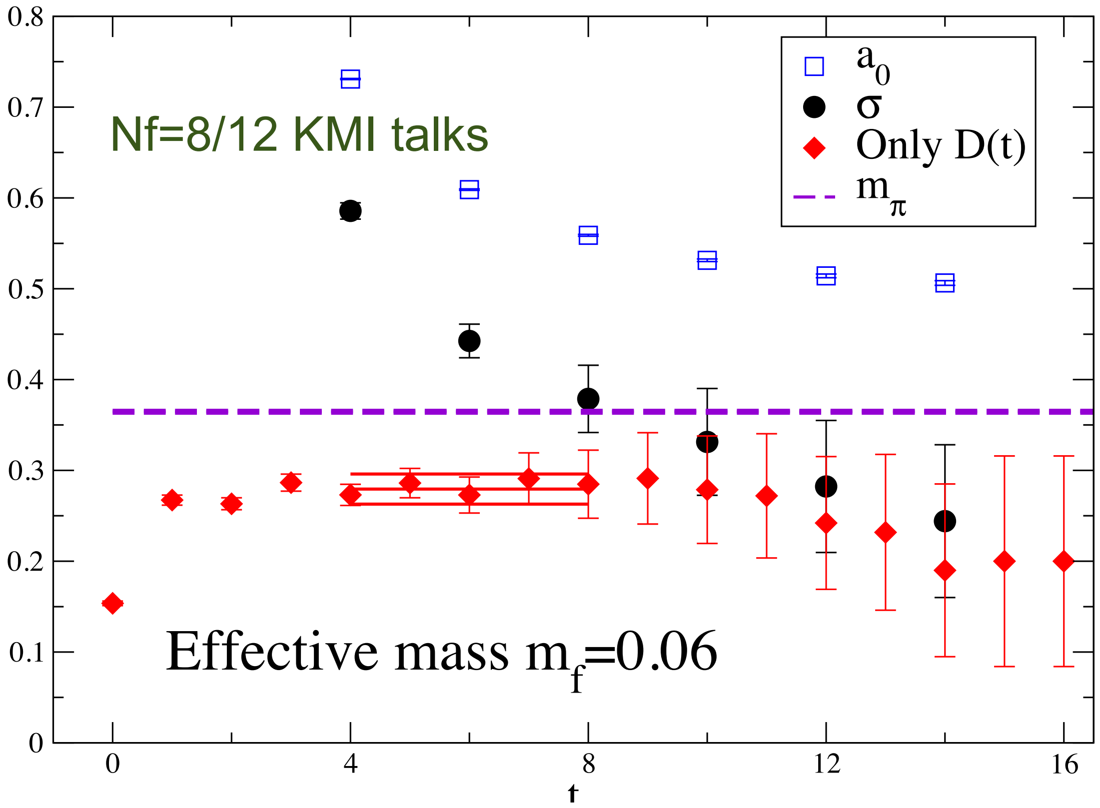


latKMI first result
LHC used it for crosscheck
good agreement

LHC group was holding back on Nf=8 (USBSM incite)

It has always been a low-hanging fruit

New development: LHC is doing Nf=8 now
second generation rerun of earlier published work



Nf=8/12 KMI talks

Non-singlet scalar
a_0: $-C_+(t)$

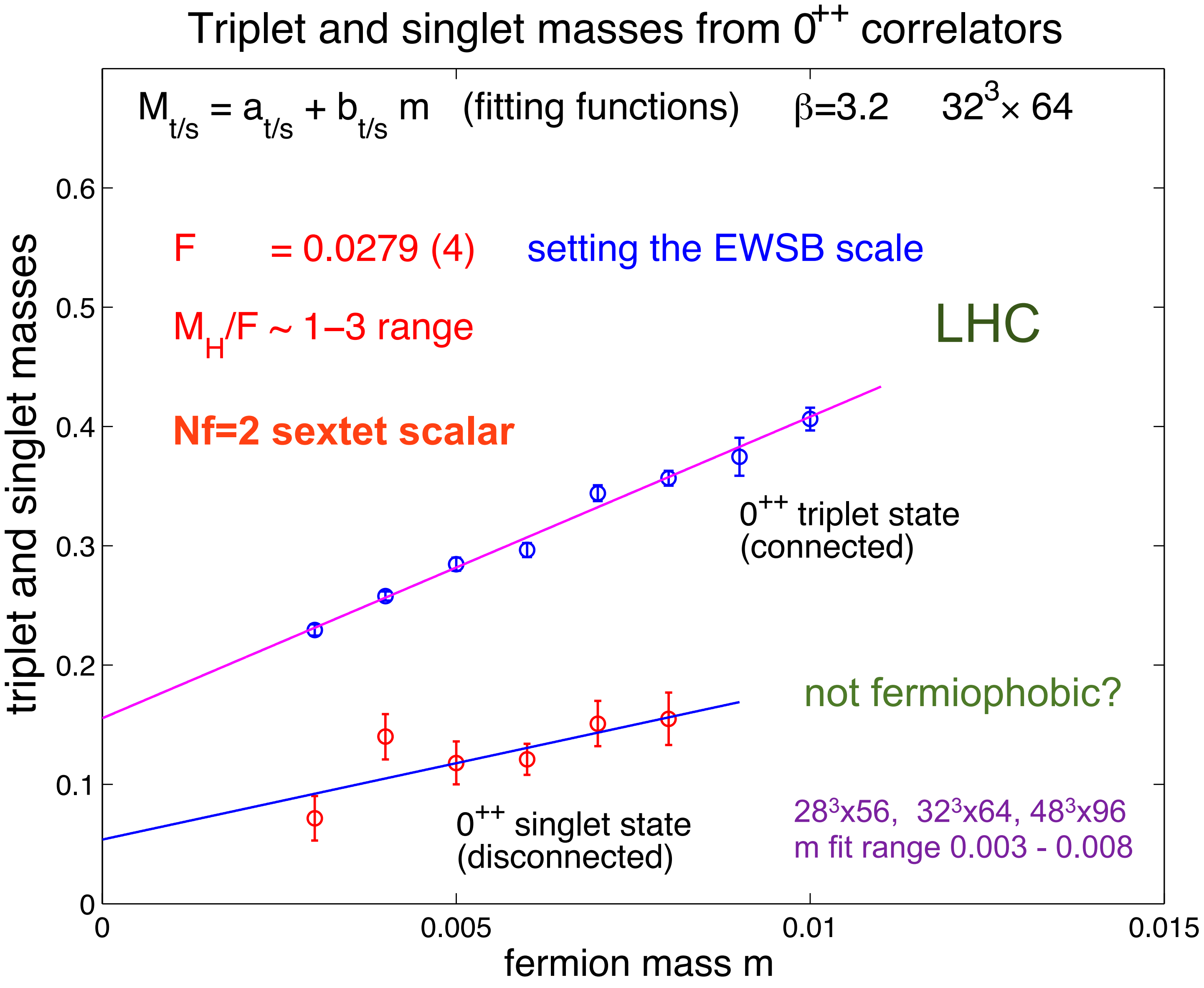
Singlet scalar
σ: $3D_+(t) - C_+(t)$
σ: $D(t)$ i.e. $m_\sigma < m_{a_0}$
Consistent m_σ
with smaller error
also Jin and Mawhinney
$m_\sigma < m_\pi$ at $m_f = 0.06$

Spectroscopy (scalar)

sextet $N_f=2$

Spectroscopy (scalar)

sextet N_f=2



Spectroscopy for LHC run2

sextet $N_f=2$

TeV

A_1 ~ 2.4 TeV

Rho ~ 1.7 TeV

A_0 ~ 1.5 TeV

scalar impostor few hundred GeV?

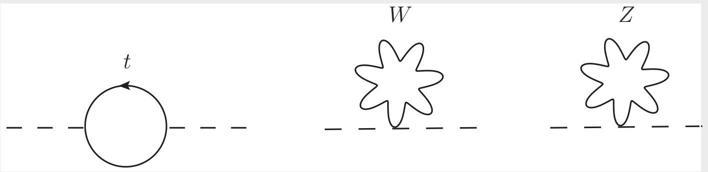
EW self-energy

observed Higgs-like?

not ruled out from LHC run1

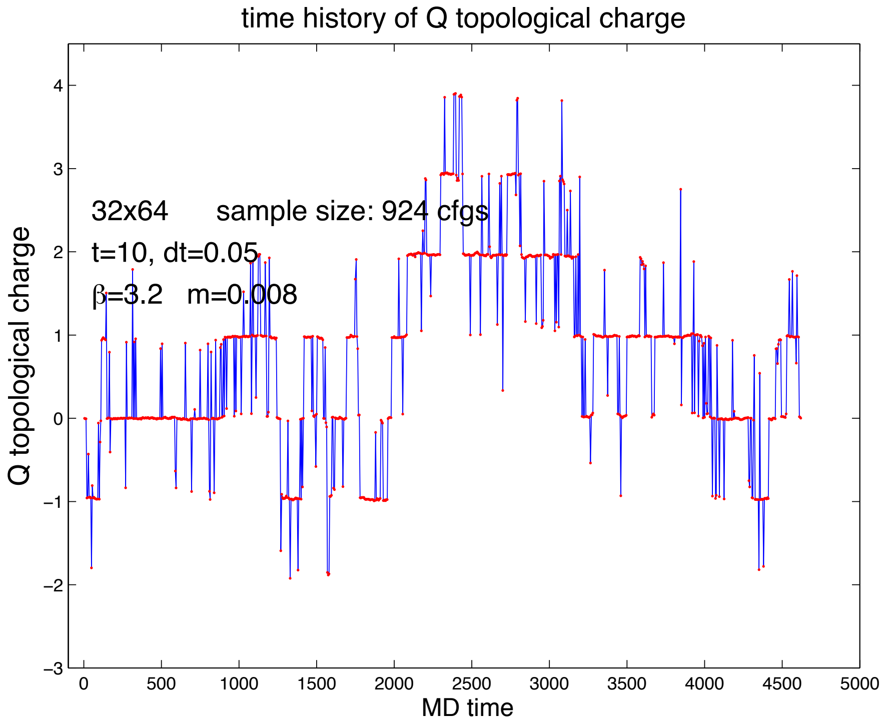
within reach of LHC run2

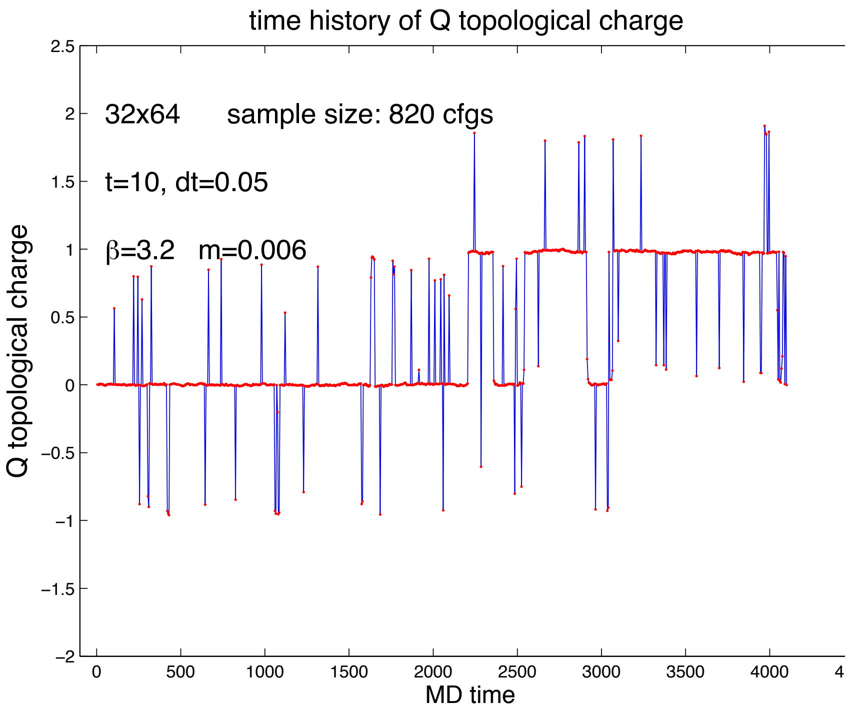
LHC is working on second generation precision now

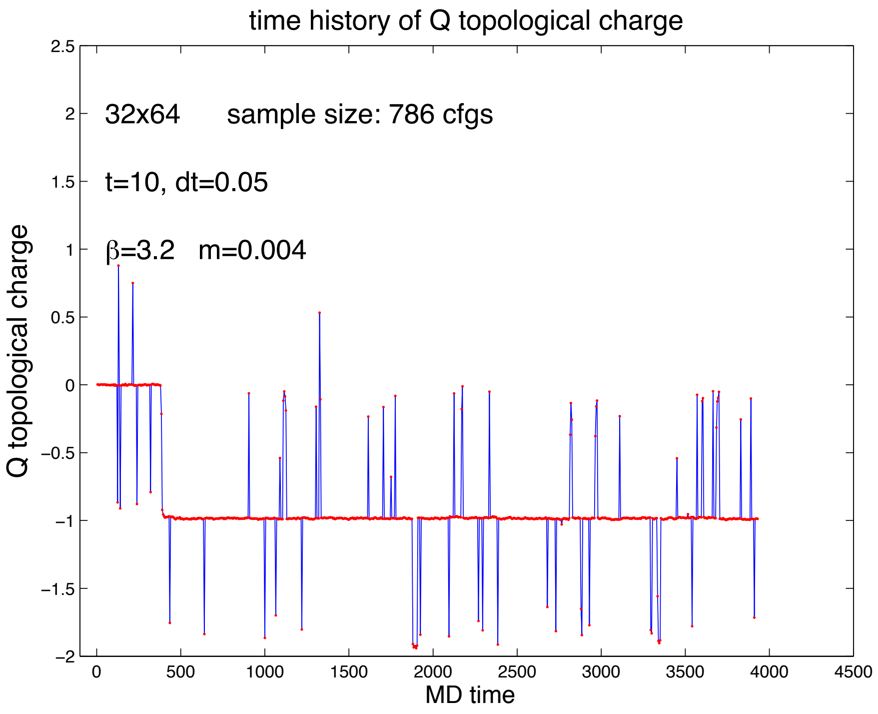


$$\delta M_H^2 \sim -12\kappa^2 r_t^2 m_t^2 \sim -\kappa^2 r_t^2 (600\,\mathrm{GeV})^2$$

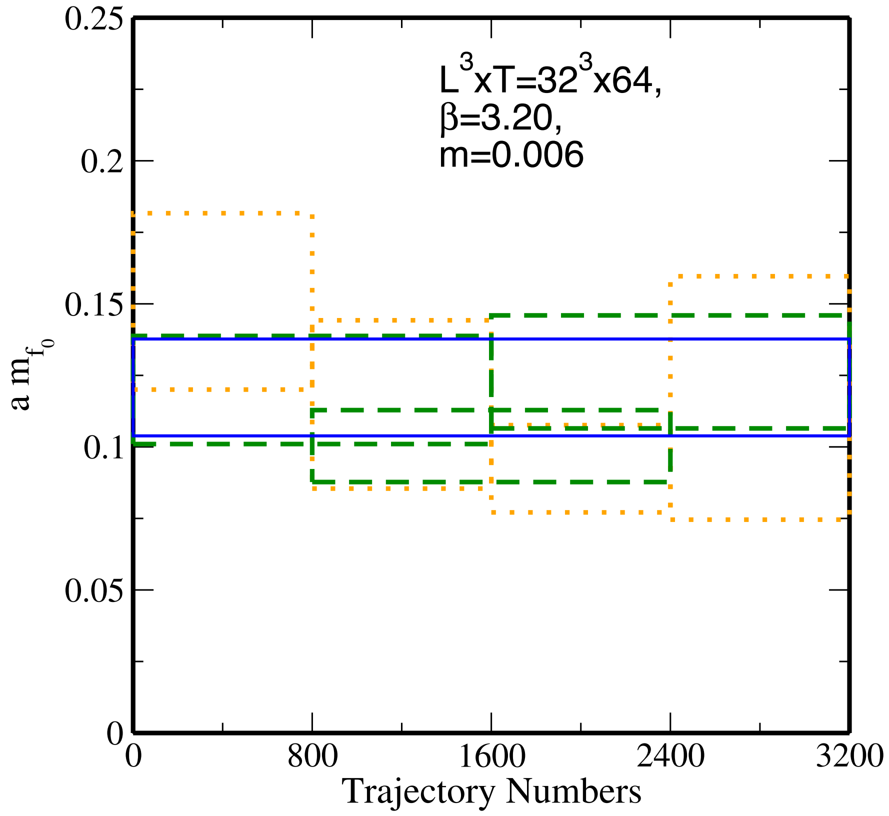
slowly changing topology complicates the analysis:







- it is challenging to deal with it
- effect on scalar spectrum is hardly detectable
- slow topology can be synthesized by stochastic algorithms but its practical utilization is unclear
- slowly changing topology perhaps can be accelerated in open segments of very long lattices in time direction



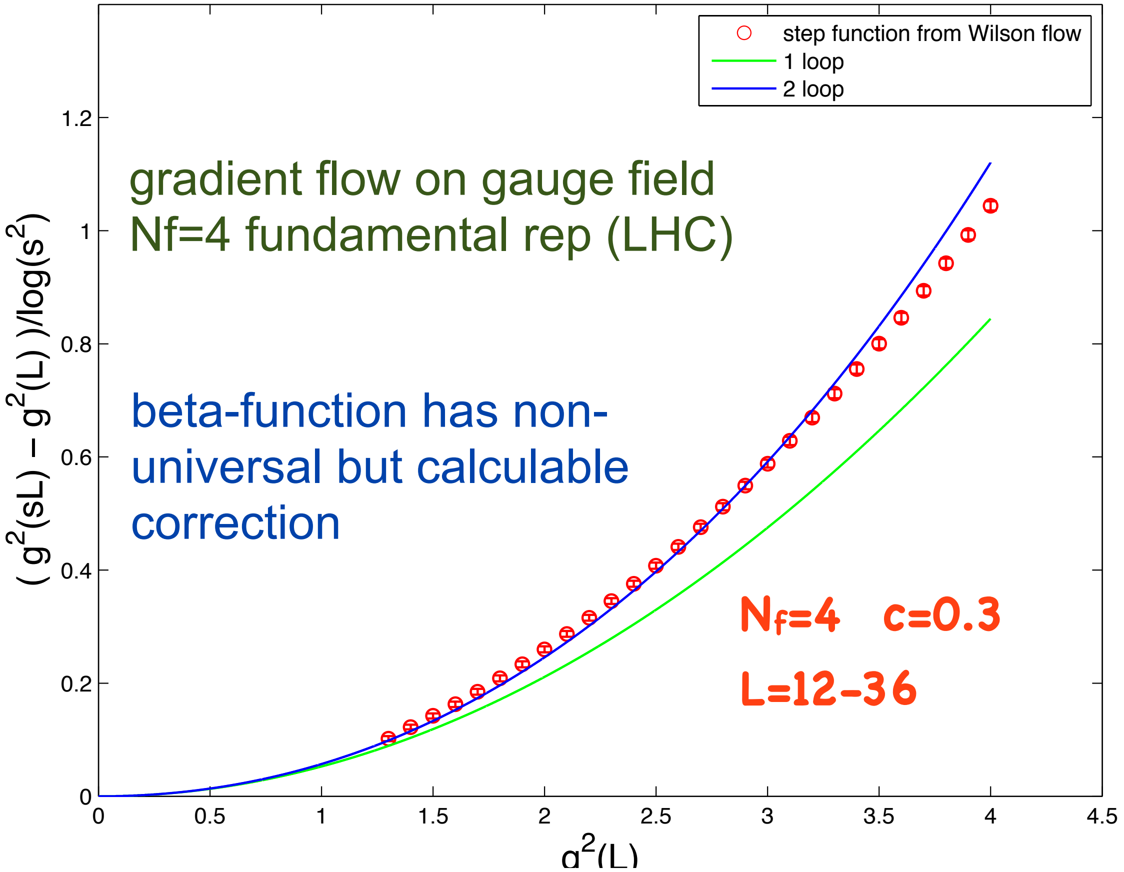
running coupling and beta-function from gradient flow

Running coupling definition from gauge field gradient flow

$$\langle E(t)\rangle = \frac{3}{4\pi t^2}\alpha(q)\{1+k_1\alpha(q)+O(\alpha^2)\}, \quad q=\frac{1}{\sqrt{8t}}, \quad k_1 = 1.0978 + 0.0075\times N_f$$

while holding $c=(8t)^{1/2}/L$ fixed: $\quad \alpha_c(L) = \frac{4\pi}{3}\frac{\langle t^2E(t)\rangle}{1+\delta(c)}$

$$\delta(c) = \vartheta_3^4(e^{-1/c^2}) - 1 - \frac{c^4\pi^2}{3}$$



gradient flow on gauge field
Nf=4 fundamental rep (LHC)

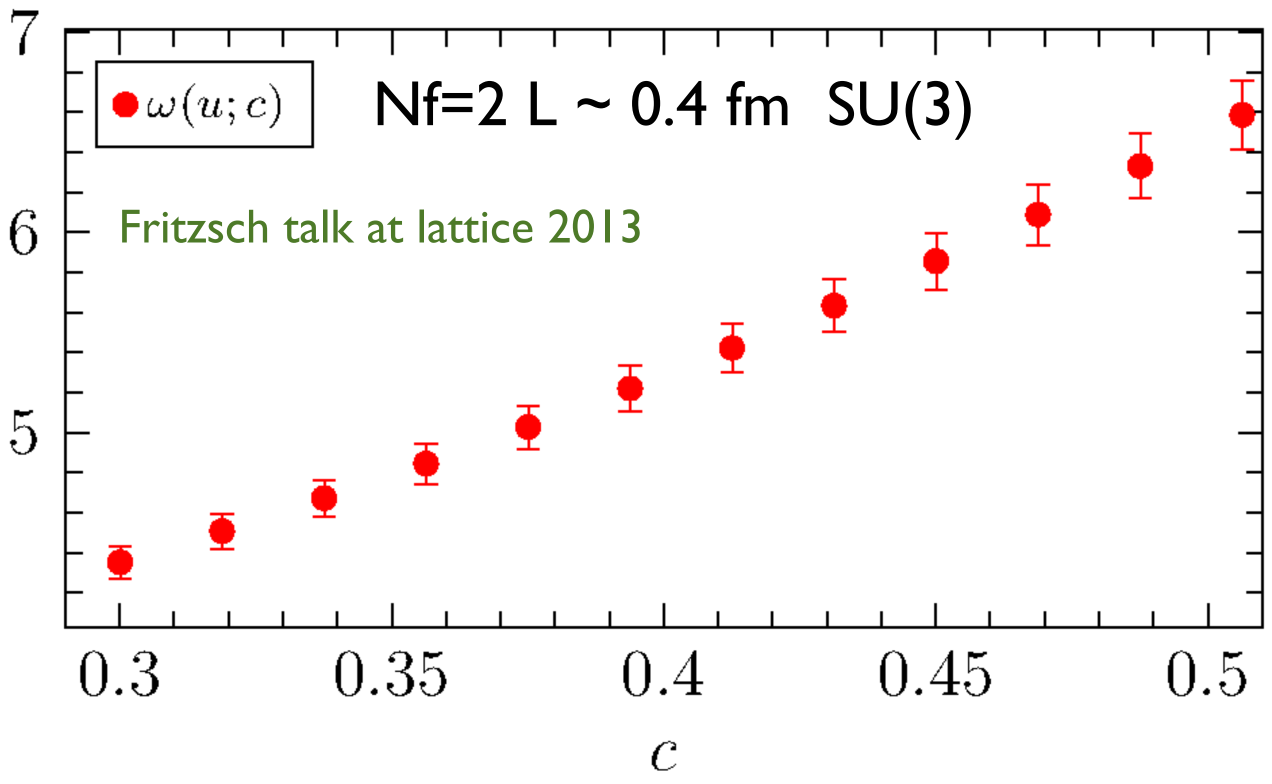
beta-function has non-universal but calculable correction

N_f=4 c=0.3

L=12-36

massless fermions; antiperiodic all directions
s=1.5 step N_f=4 staggered fermions; 4-stout; L=12-36
we have results for Nf=8,12 and Nf=2 sextet

gradient flow coupling with SF boundary conditions



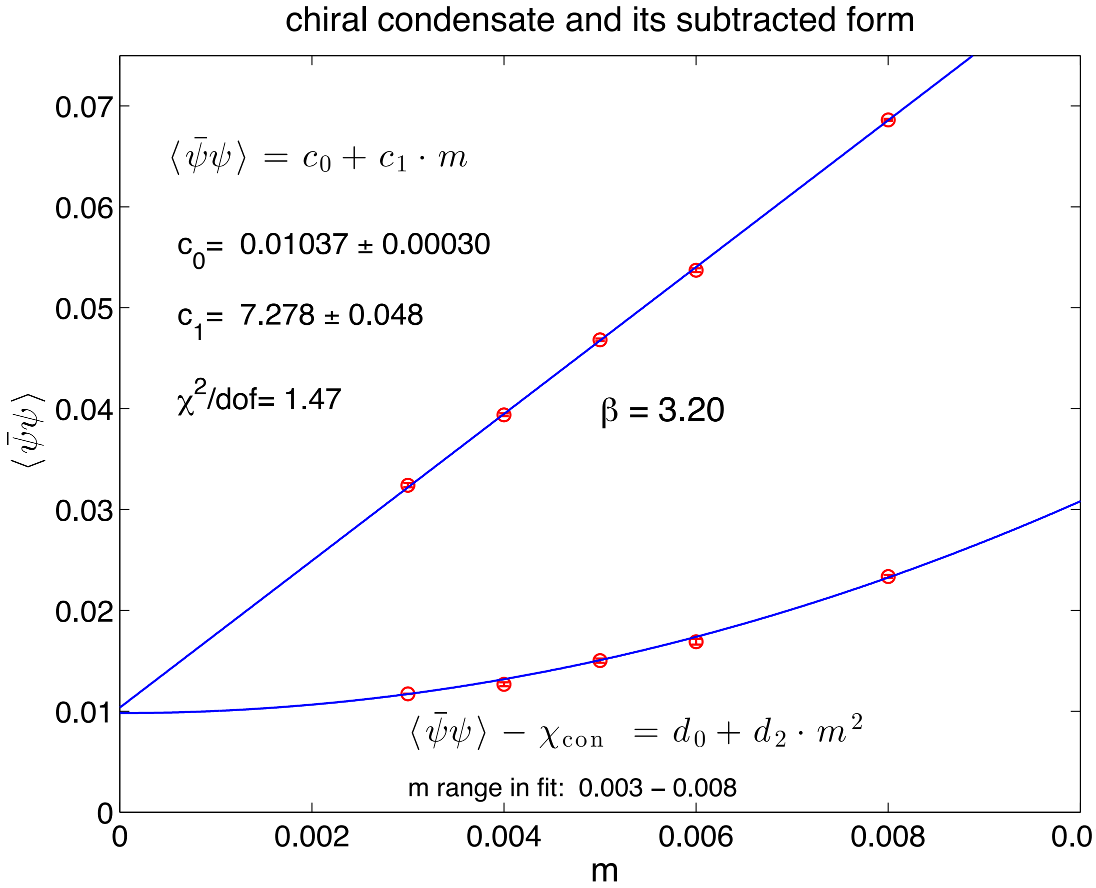
Fritzsch talk at lattice 2013

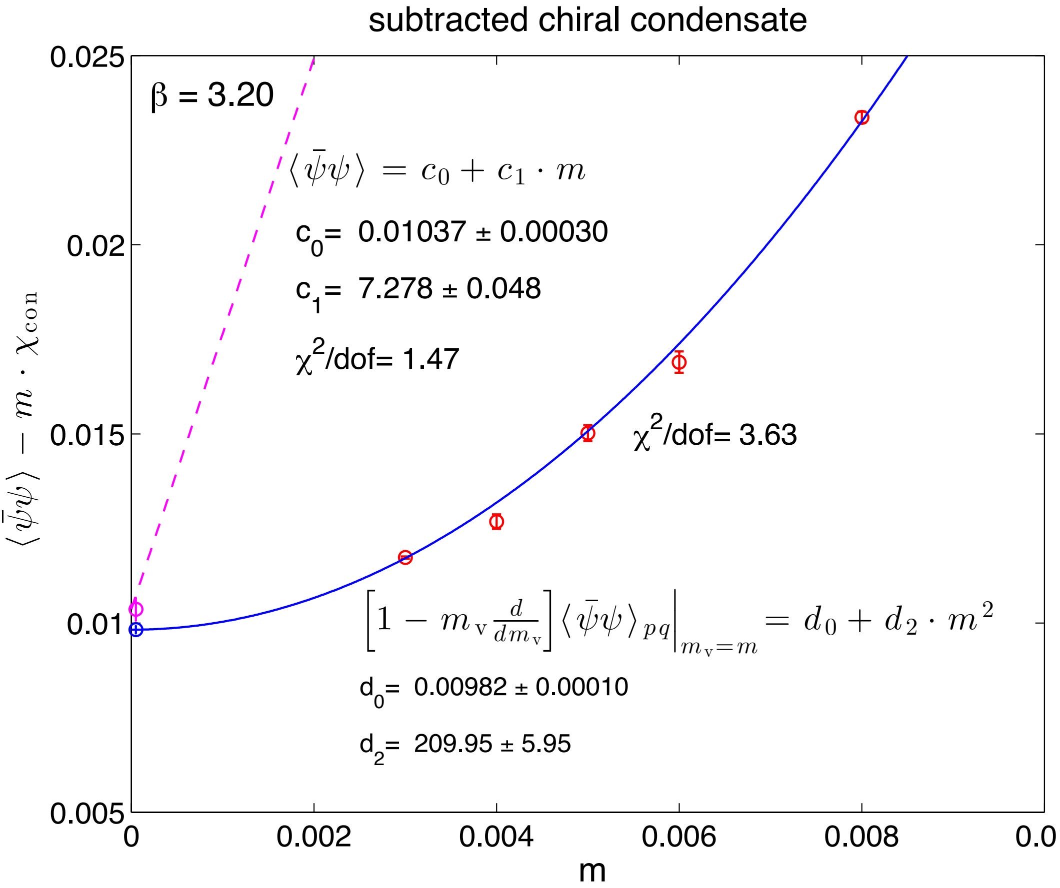
beta-function has conventional loop expansion

The chiral (Higgs) condensate

- New stochastic method
- Direct determination of full spectral density and mode number distribution on gauge configurations
- To remove UV divergences at finite fermion mass
- To investigate internal (in)consistencies with GMOR relation
- To determine anomalous dimension of the chiral condensate

The chiral condensate in the sextet theory


chiral condensate and its subtracted form


subtracted chiral condensate

control on UV divergences: mode number density of chiral condensate

$$\rho(\lambda, m) = \frac{1}{V}\sum_{k=1}^{\infty}\langle\delta(\lambda-\lambda_k)\rangle \qquad \lim_{\lambda\to 0}\lim_{m\to 0}\lim_{V\to\infty}\rho(\lambda,m) = \frac{\Sigma}{\pi}$$

spectral density

$$\nu(M,m) = V\int_{-\Lambda}^{\Lambda} {\rm d}\lambda\,\rho(\lambda,m), \qquad \Lambda = \sqrt{M^2 - m^2}$$

mode number density

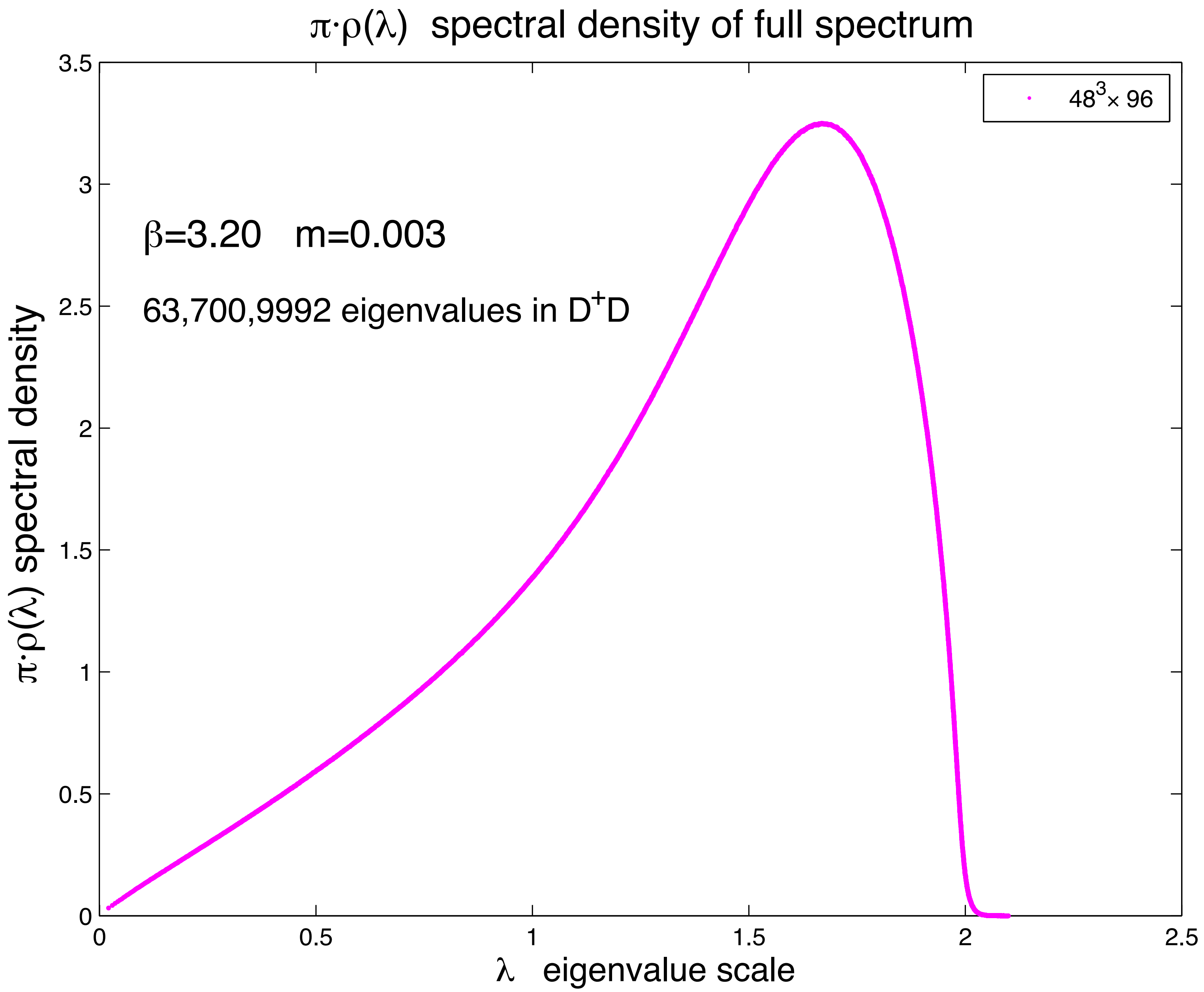
$$\nu_{\rm R}(M_{\rm R}, m_{\rm R}) = \nu(M, m_{\rm q})$$

renormalized and RG invariant (Giusti and Luscher)

The chiral condensate in the sextet theory

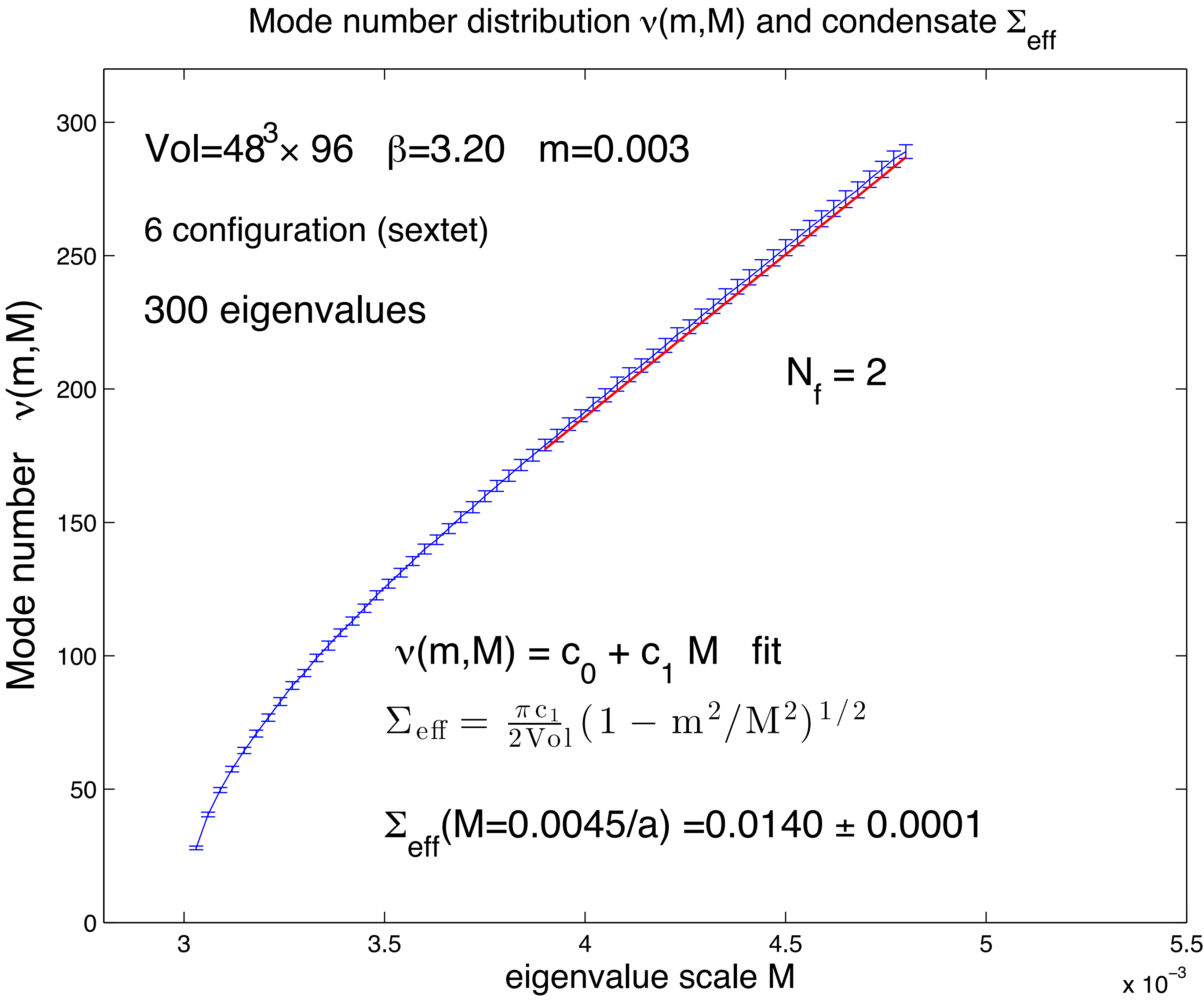
new stochastic method sextet Nf=2

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



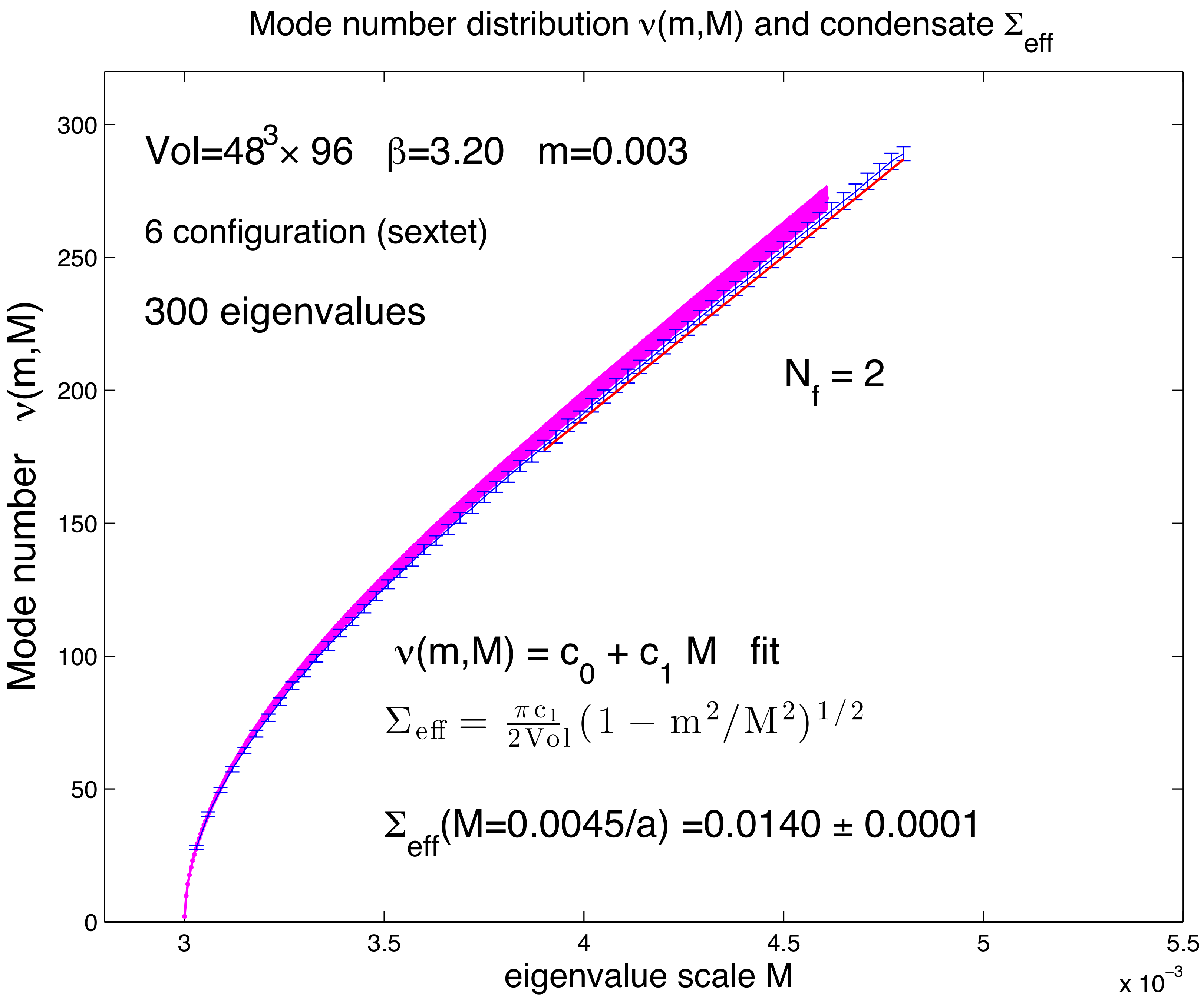
- Passed all tests so far
- example is from 48^3x96 lattices
- allows the scale-dependent determination of the anomalous dimension of the chiral condensate

The chiral condensate in the sextet theory



- new stochastic method sextet Nf=2
- comparison with direct calculation of mode number distribution from eigenvalue spectrum
- stringent test
- details in forthcoming publication

The chiral condensate in the sextet theory



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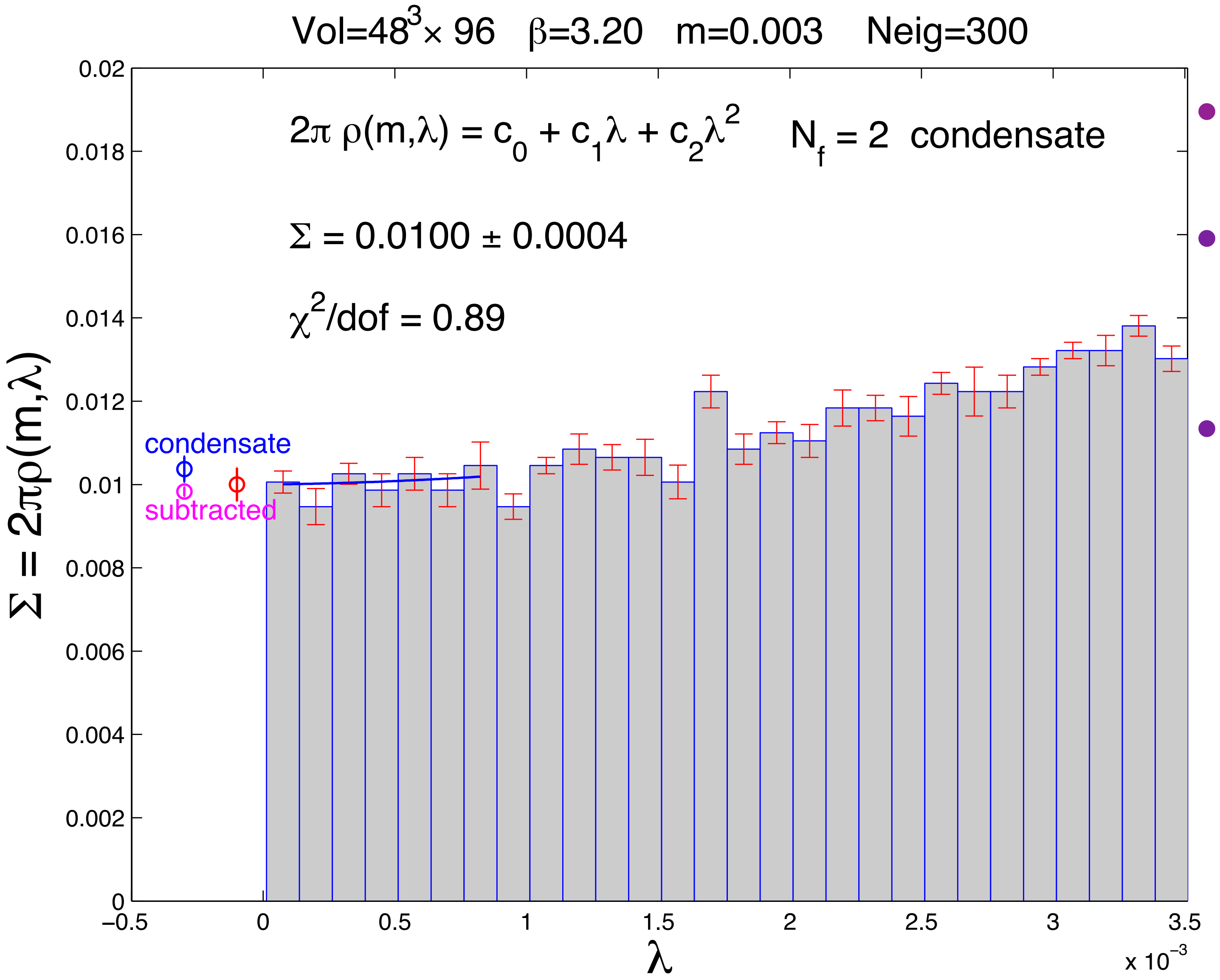
The chiral condensate in the sextet theory

new stochastic method sextet Nf=2

comparison with direct determination of spectral density from eigenvalue spectrum



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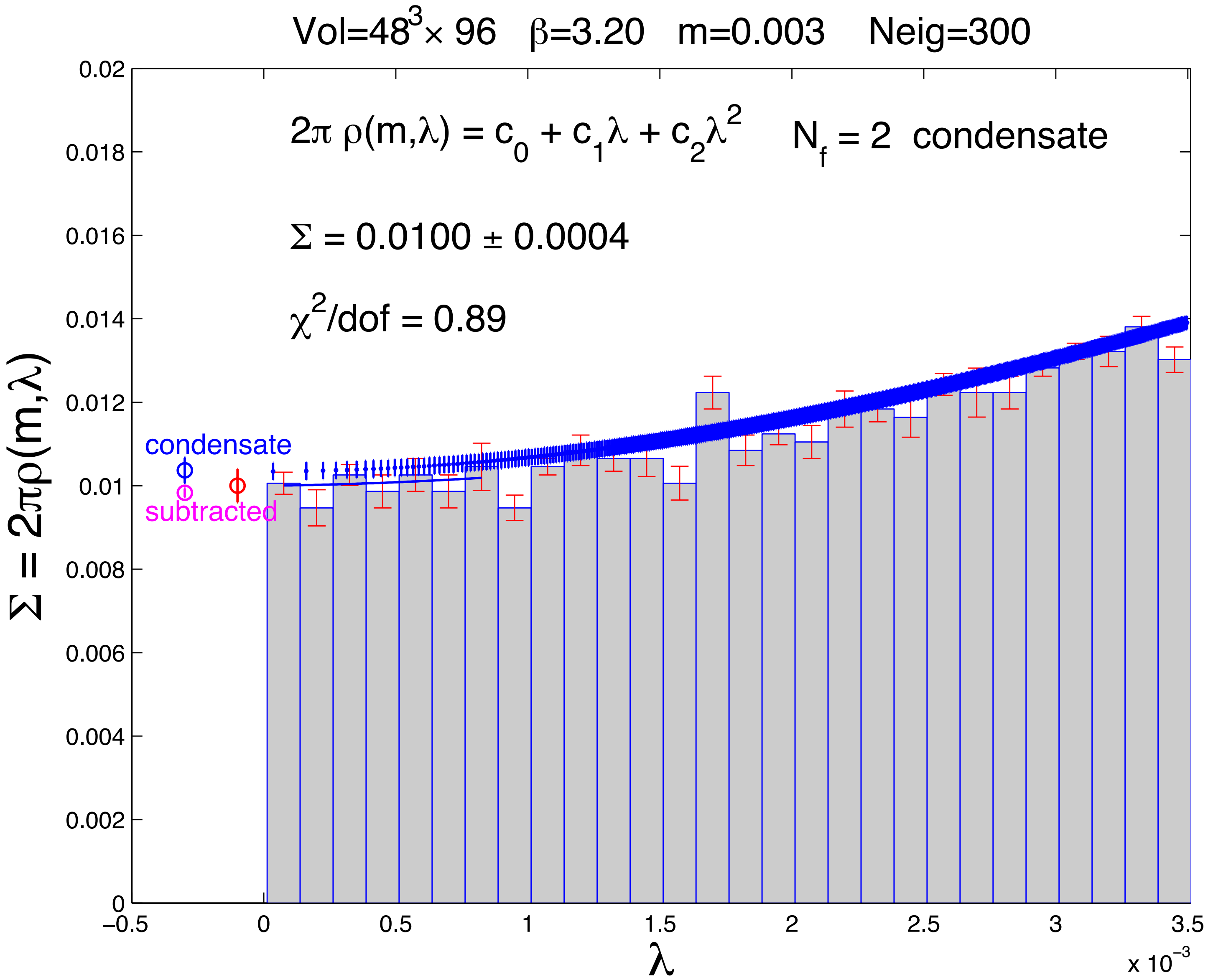
The chiral condensate in the sextet theory

new stochastic method sextet Nf=2

comparison with direct determination of spectral density from eigenvalue spectrum

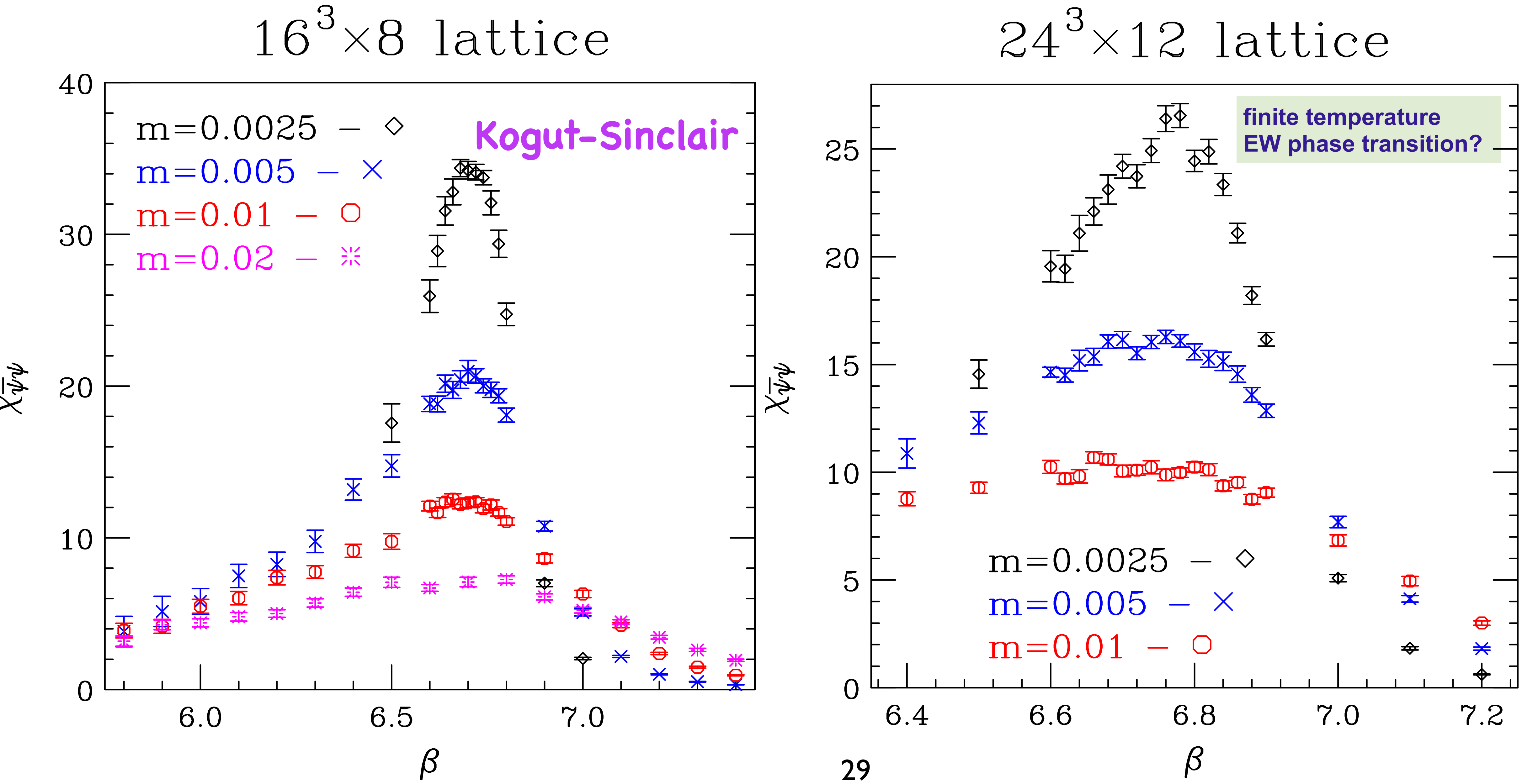


- new stochastic method sextet Nf=2
- comparison with direct determination of spectral density from eigenvalue spectrum
- stringent test

Early universe

Kogut-Sinclair work consistent with χSB phase transition

Relevance in early cosmology (order of the phase transition?)



$16^3\times 8$ lattice

$24^3\times 12$ lattice

finite temperature EW phase transition?

Early universe

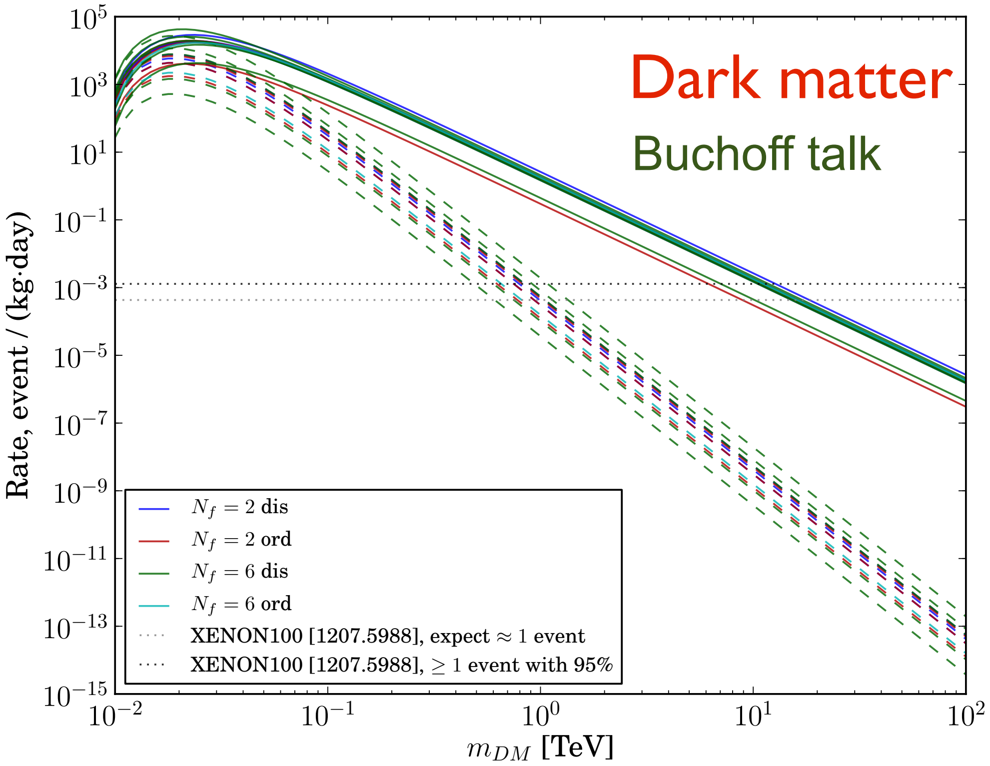
The Total Energy of the Universe:

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)



Dark matter

Buchoff talk

- 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
  construction (symmetric in color)

Summary and Outlook

Simplest composite Higgs is light near conformality

light scalar (dilaton-like) emerging	close to conformal window
running (walking) coupling in progress	really challenging to do
chiral condensate	new method
spectroscopy	emerging resonance spectrum ~ 2 TeV
dark matter	implications are intriguing strong self-interactions?

We have the simplest Higgs impostor candidate (but it can fail)

more work and resources needed to investigate viability