Lattice meets Experiment: BSM

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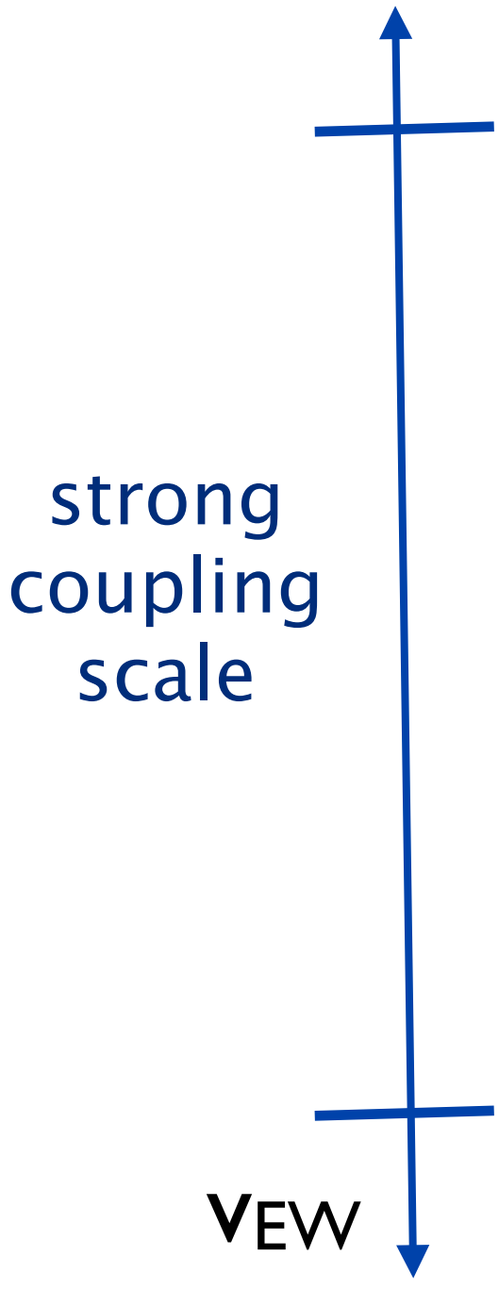
USQCD all hands meeting, Fermilab
May 4th, 2012

synopsis of the interplay between lattice and BSM phenomenology/experiment

Lattice Meets Experiment 2011: Beyond the Standard Model

USQCD US Lattice Quantum Chromodynamics

the natural setting for lattice in BSM is
new TeV-scale strong dynamics



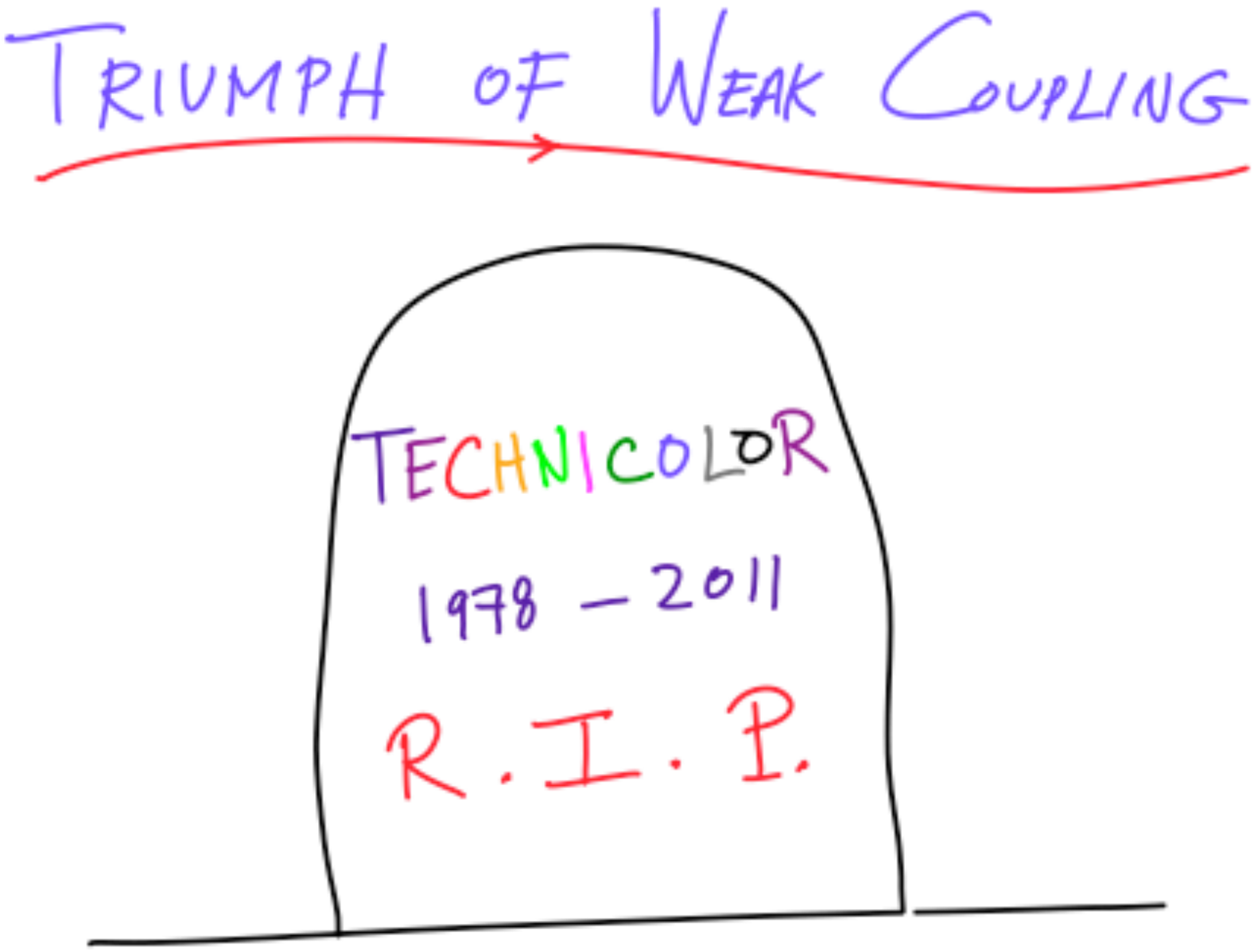
strong dynamics at $f > v_{EW}$,
generates Goldstones, including Higgs $(1,2)_{1/2}$
Higgs potential generated radiatively -> EWSB

Composite Higgs

strong dynamics breaks SU(2)xU(1)
EWS realized non-linearly

Technicolor

wait... Technicolor?!?!



Nima Arkani-Hamed, Madrid 12/16/11

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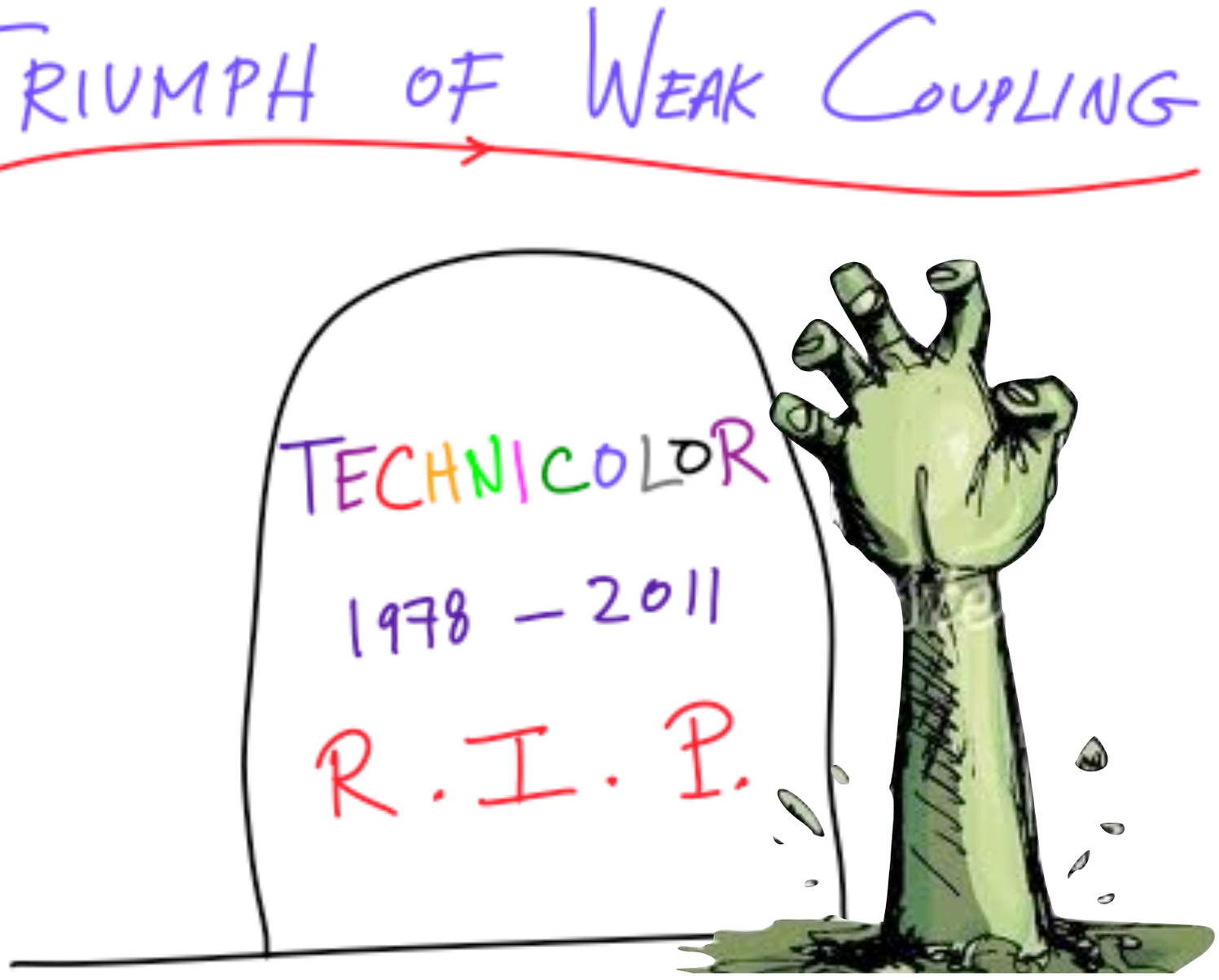

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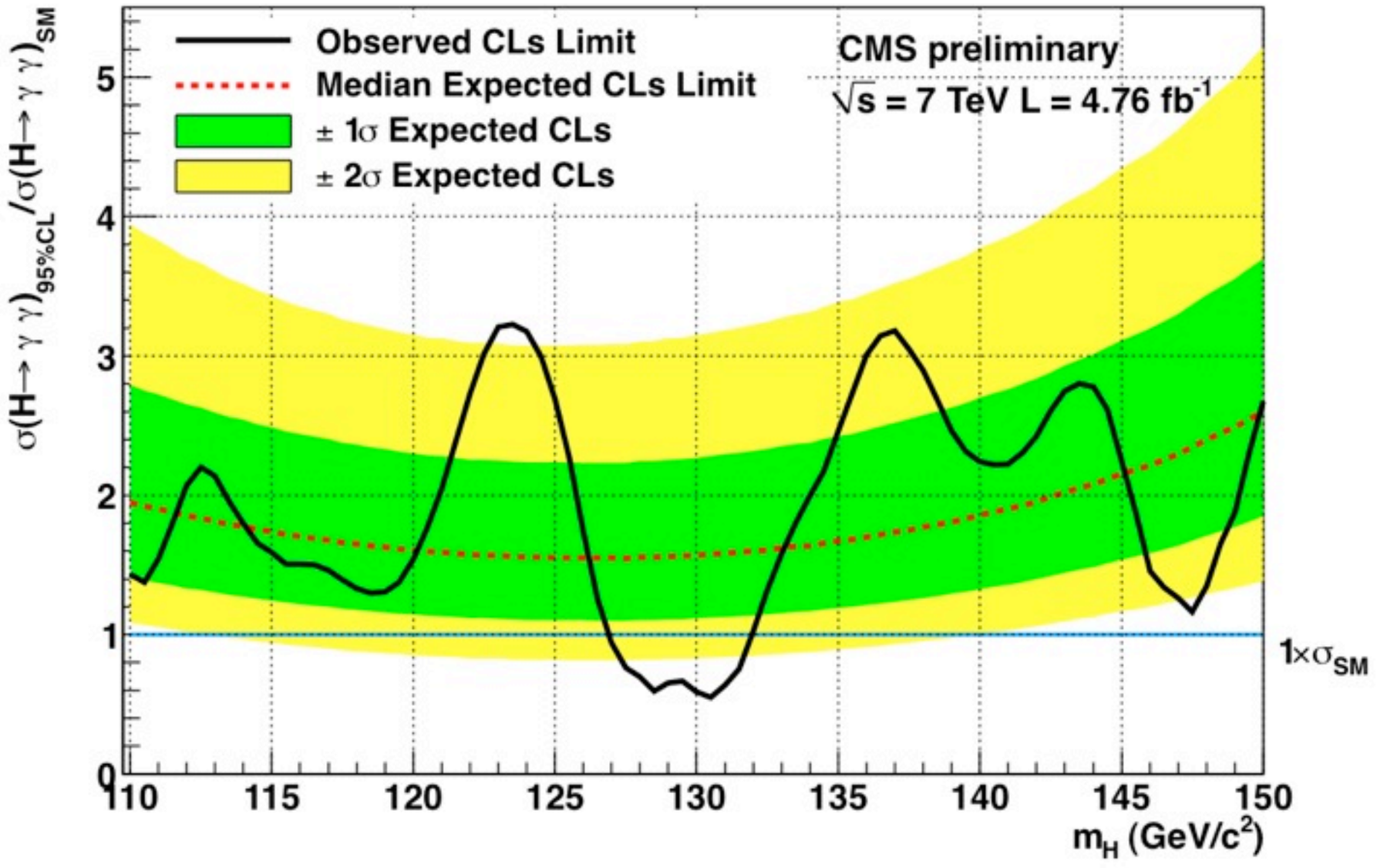
why so skeptical? as a wise experimentalist told me...



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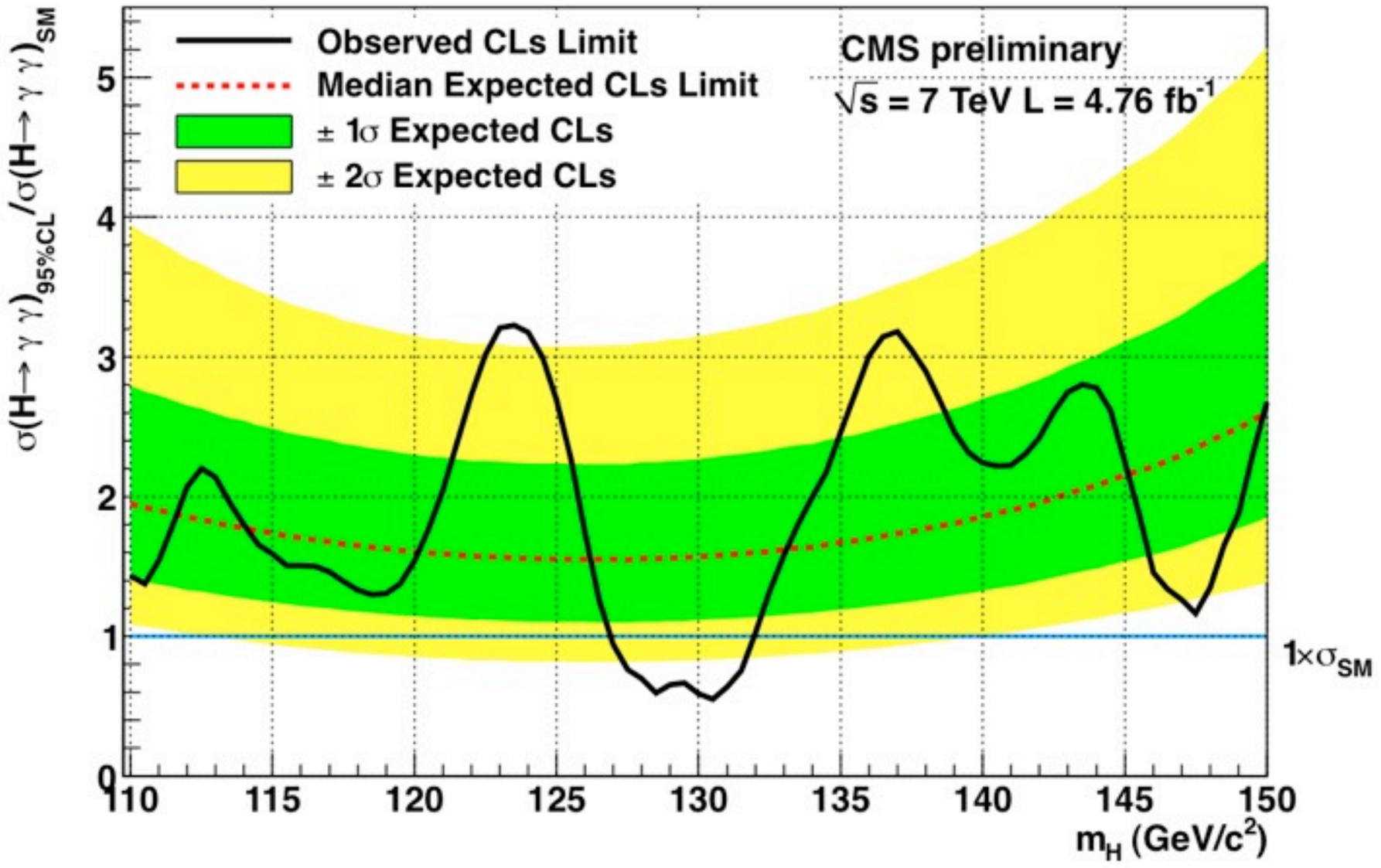
be wary of peaks if you also see them with the graph upside-down



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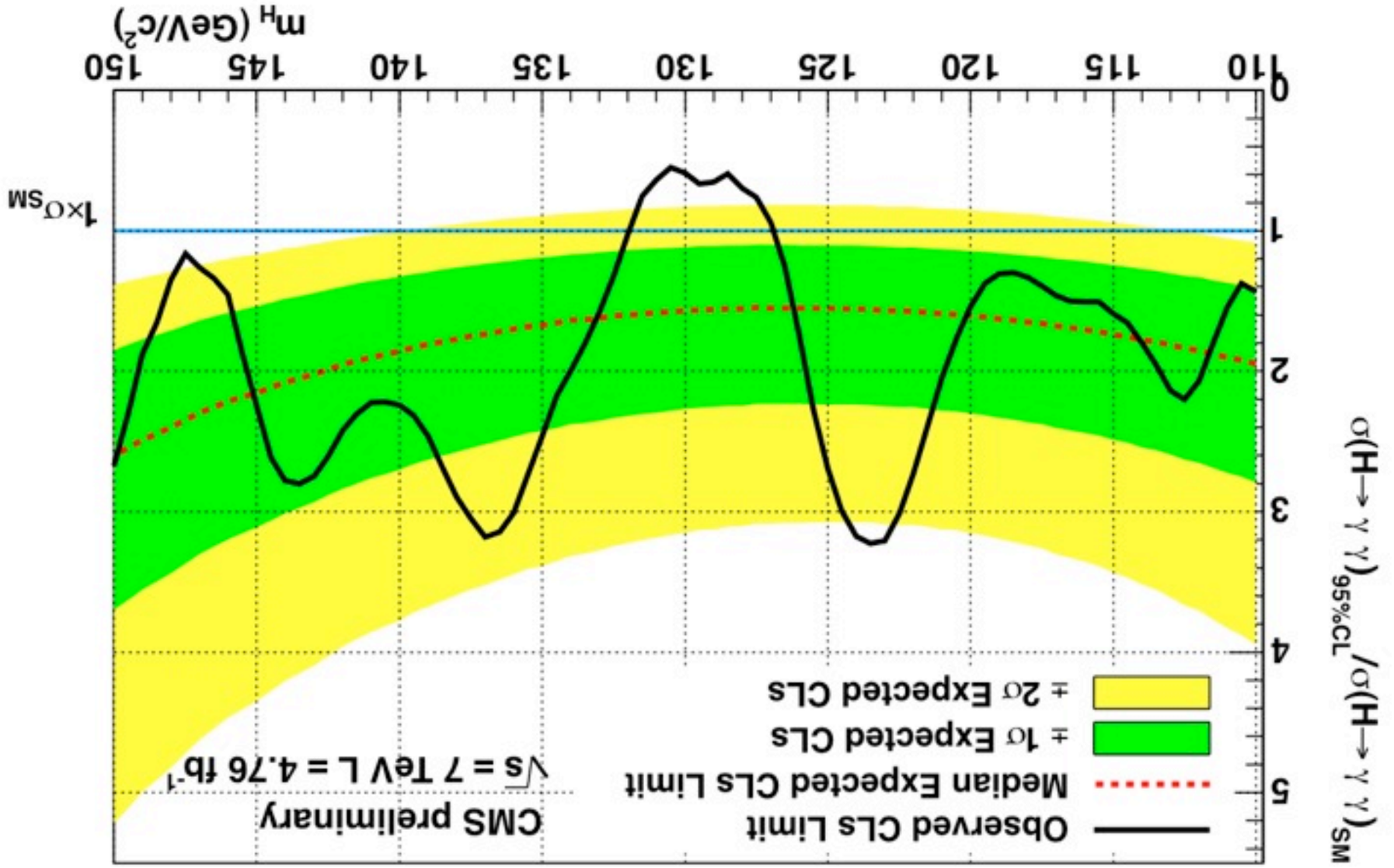
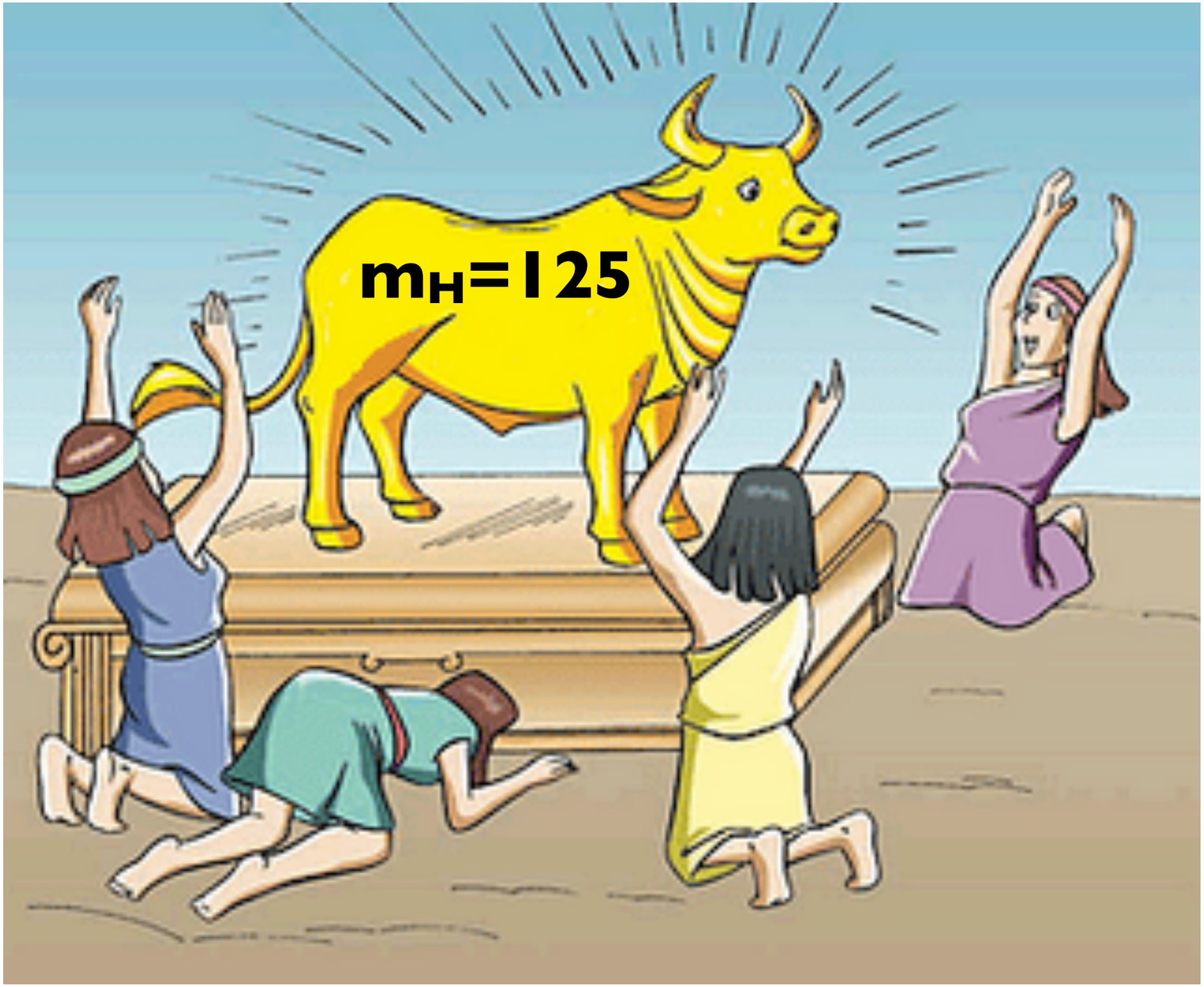


... so lets not get carried away



on a more serious note

Higgs boson is not discovered yet

if it is: **composite** or fundamental?

if it isn't: **what is there?**

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lattice input vital

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lattice input vital

umm.. where are all those superpartners?

generic problem with new strong dynamics,

how do you get the physics you want from new dynamics without side effects?

want: W/Z masses, fermion masses, CKM

don't want:

flavor

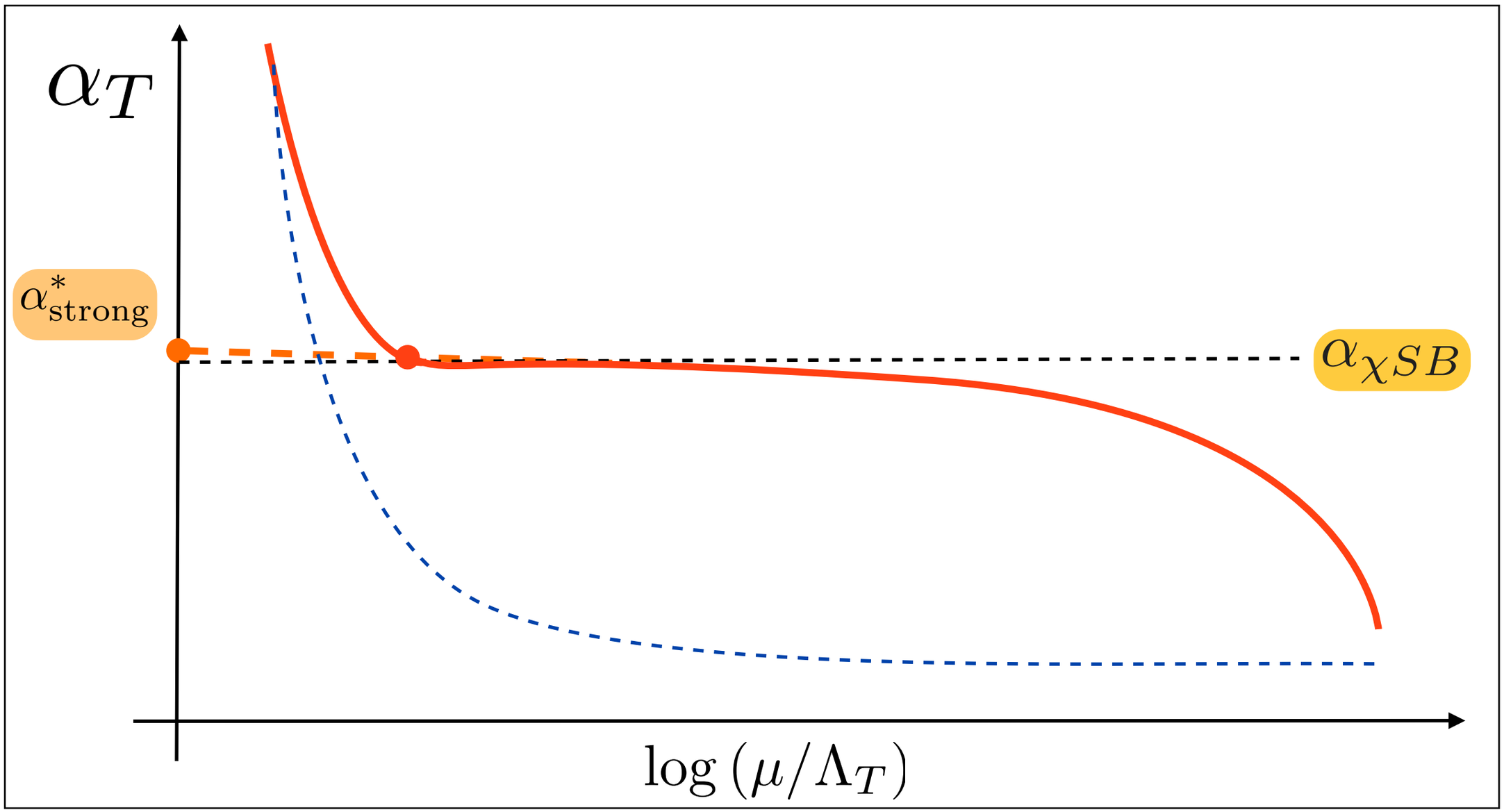
precision electroweak

EDMs

proton decay

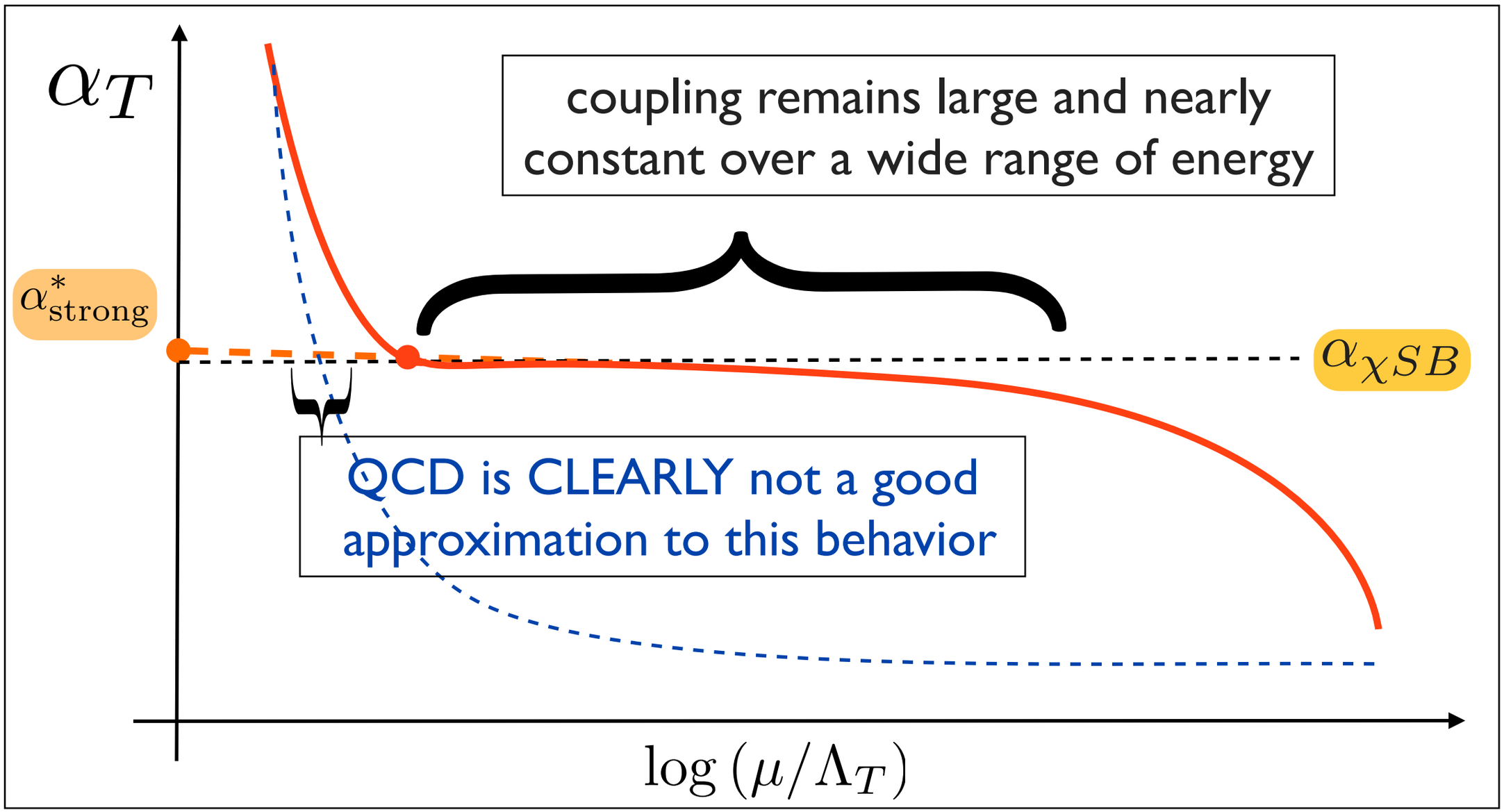
$$\frac{(\bar{f}f)(\bar{f}f)}{\Lambda^2}$$

(near) conformal gauge theory -> separates scales



BSM lattice has focused on studying this scenario

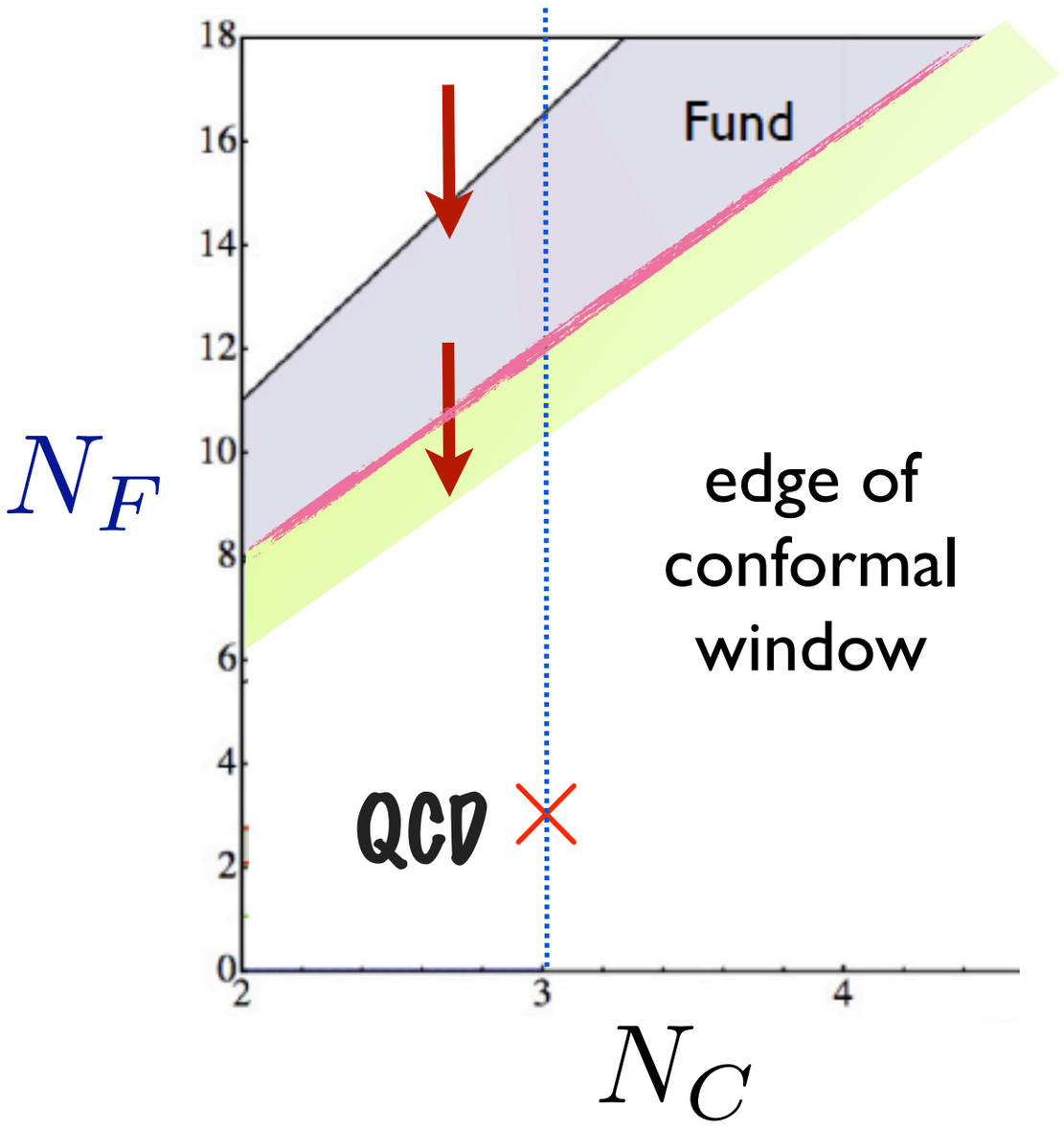
(near) conformal gauge theory -> separates scales



(Lane, Appelquist & Sannino)

BSM lattice has focused on studying this scenario

conformal theory

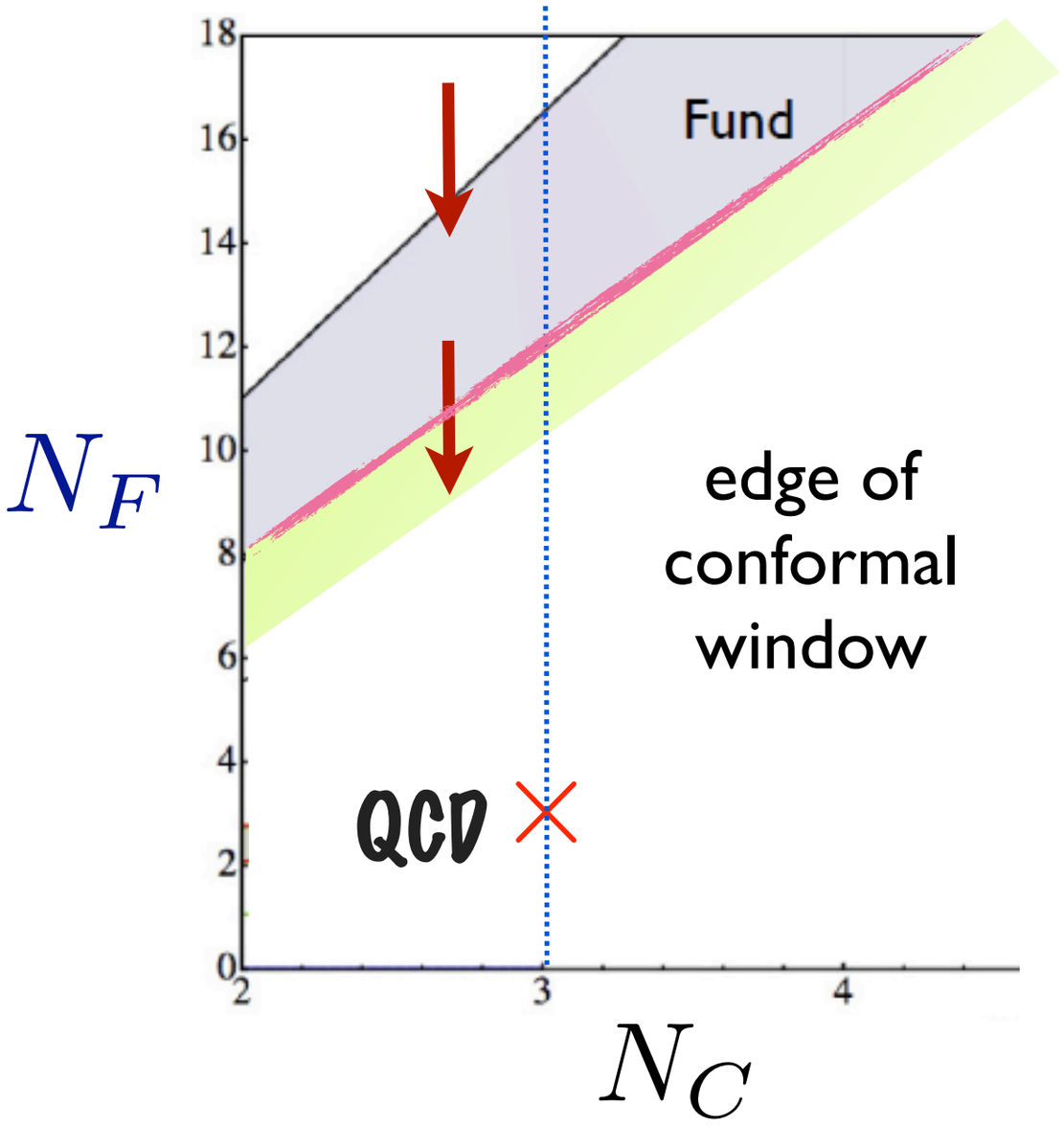


edge of conformal window

phase diagram has been the subject of numerous studies

figuring out which techniques work best

conformal theory



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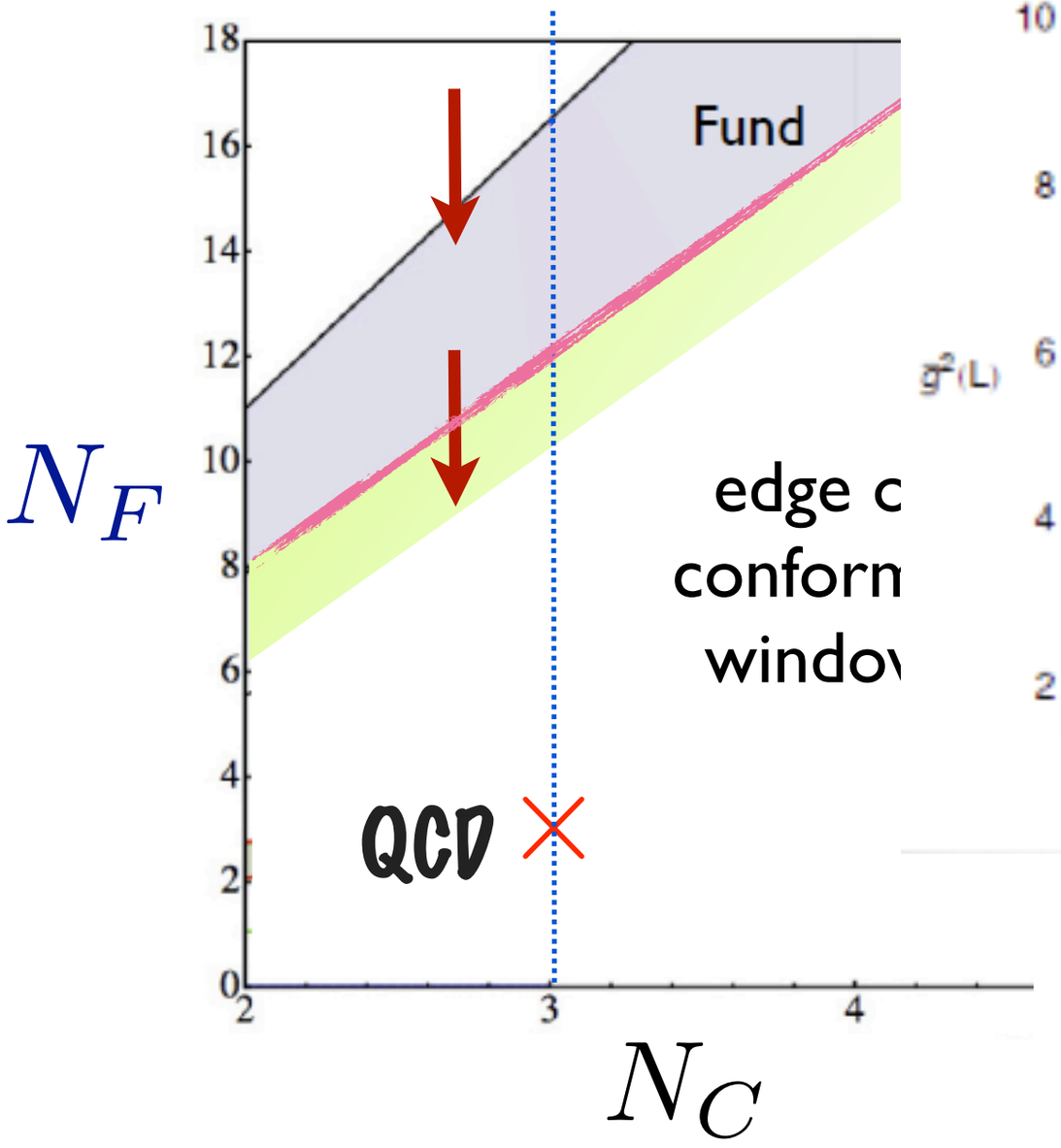

edge c
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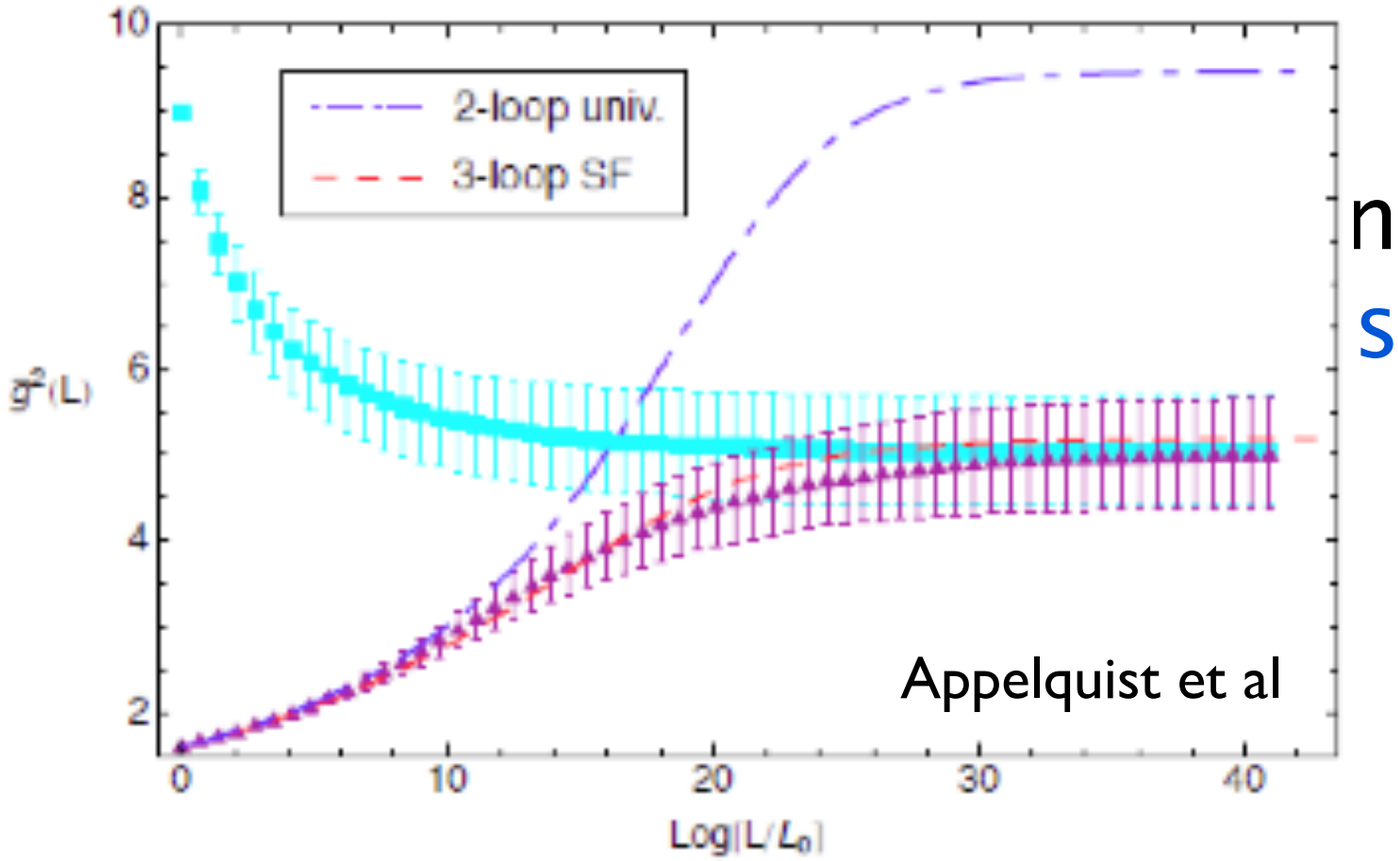

n
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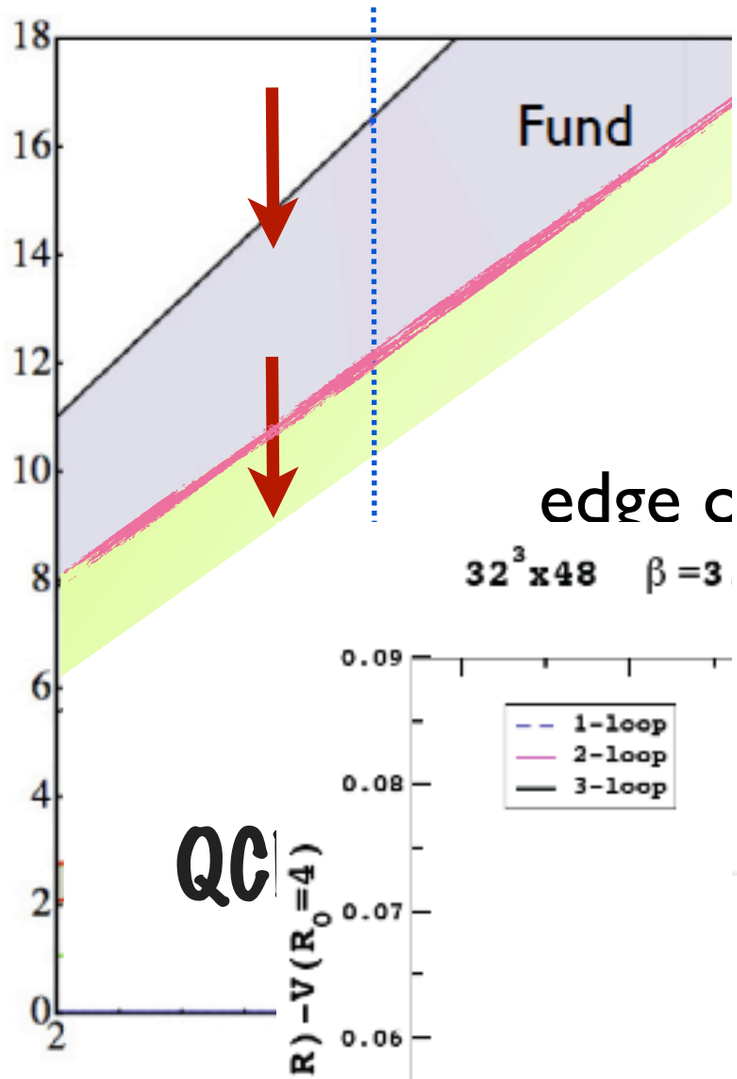
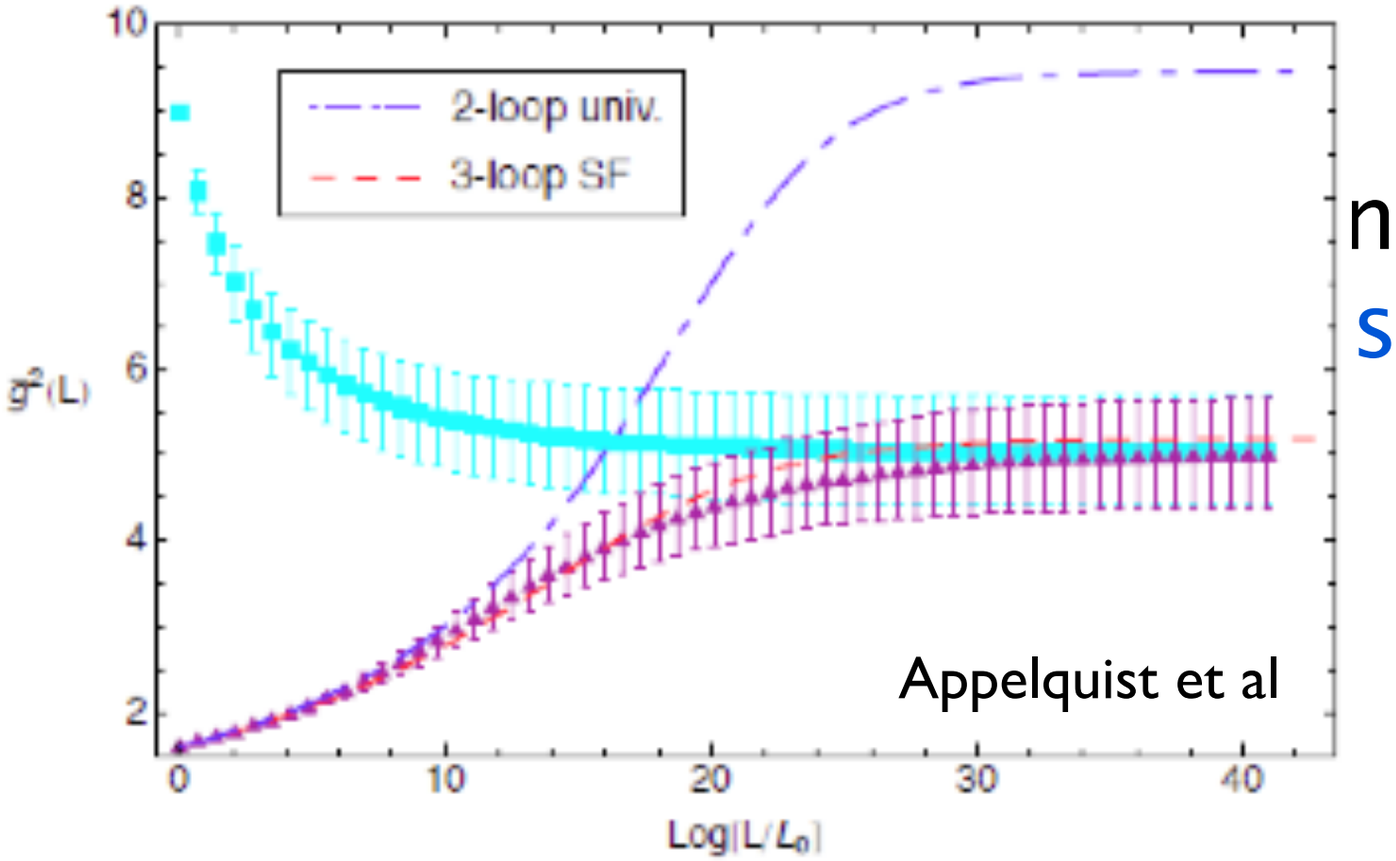
N_F





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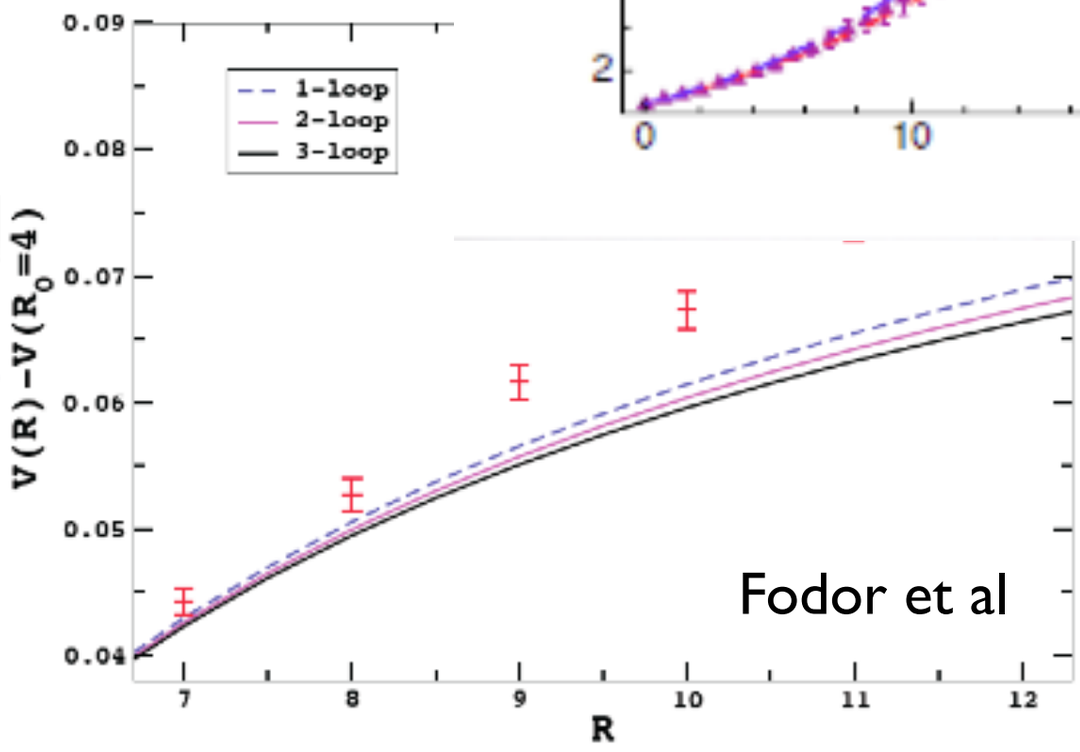

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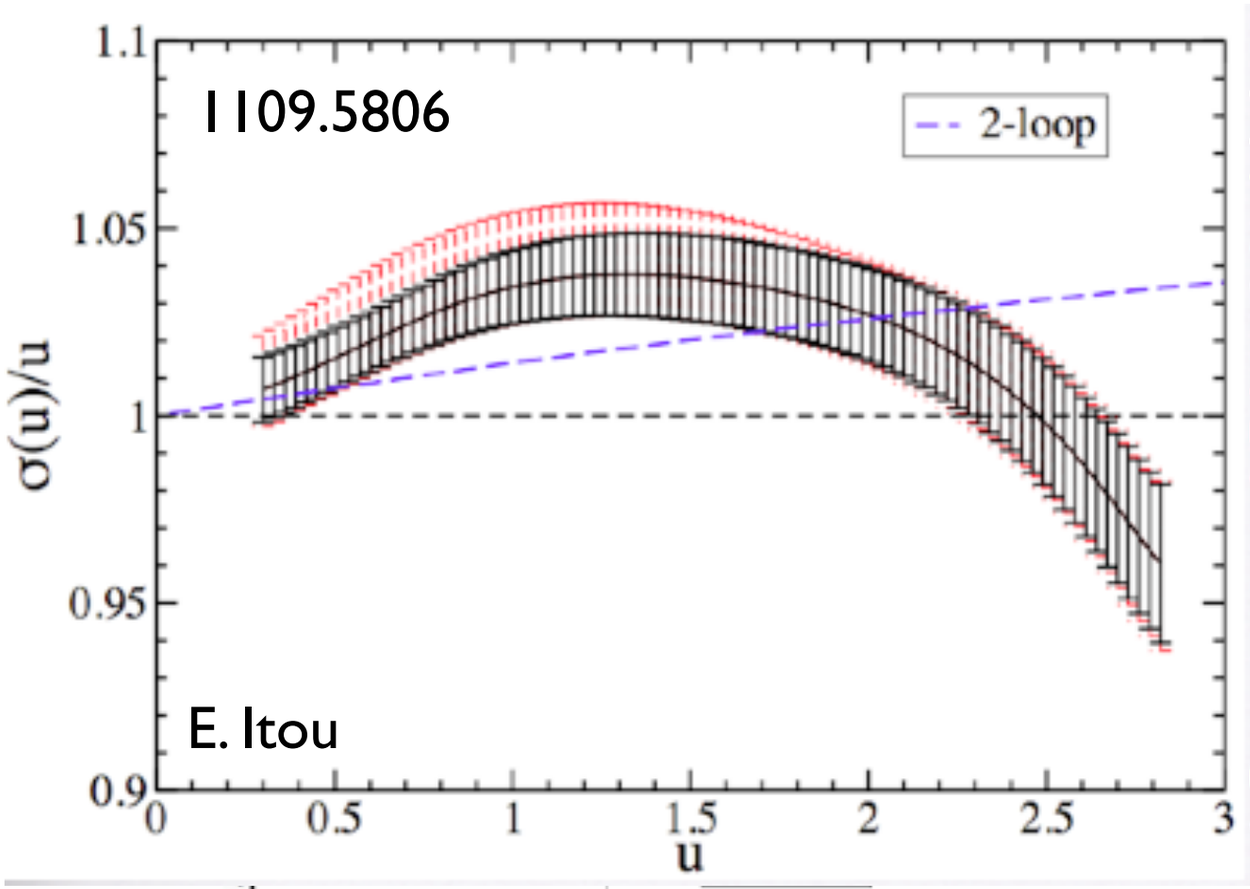

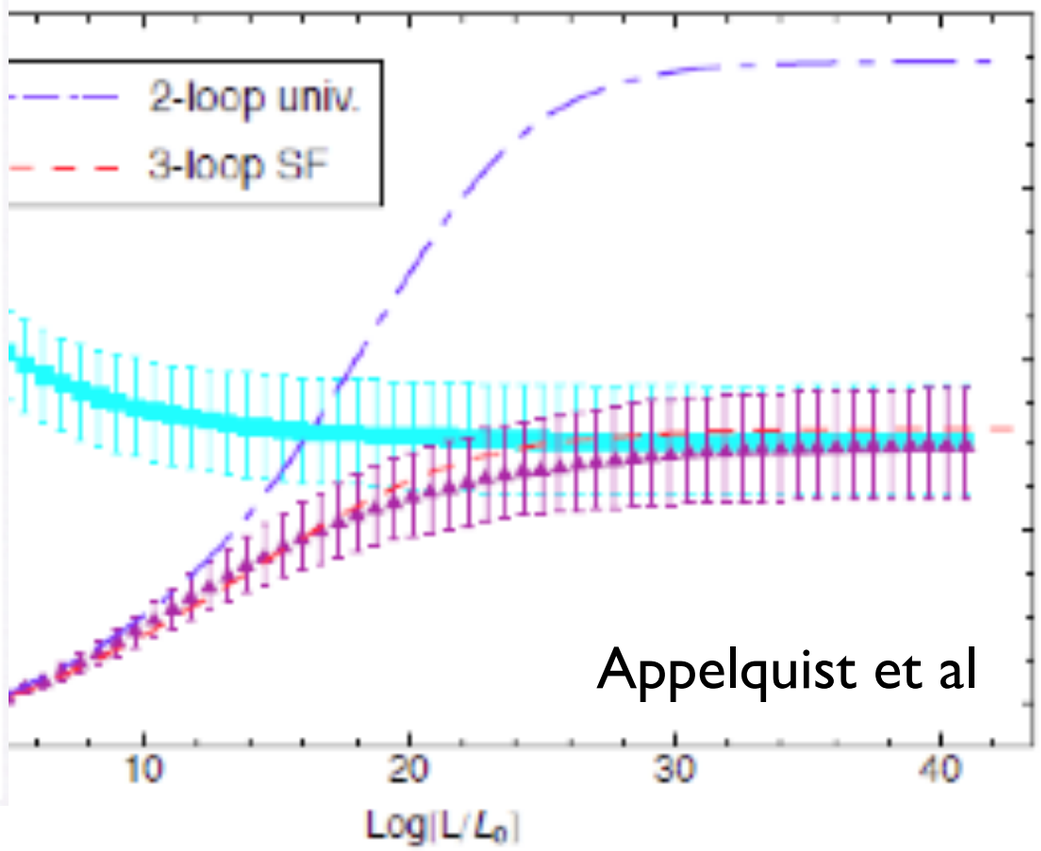

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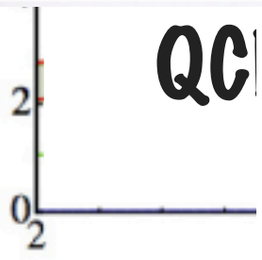

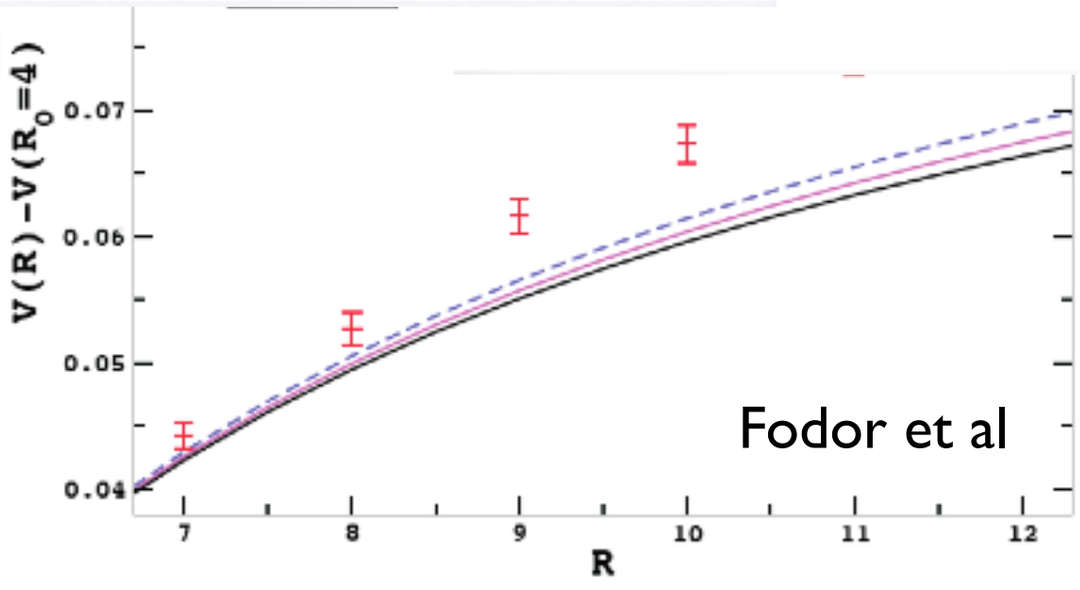

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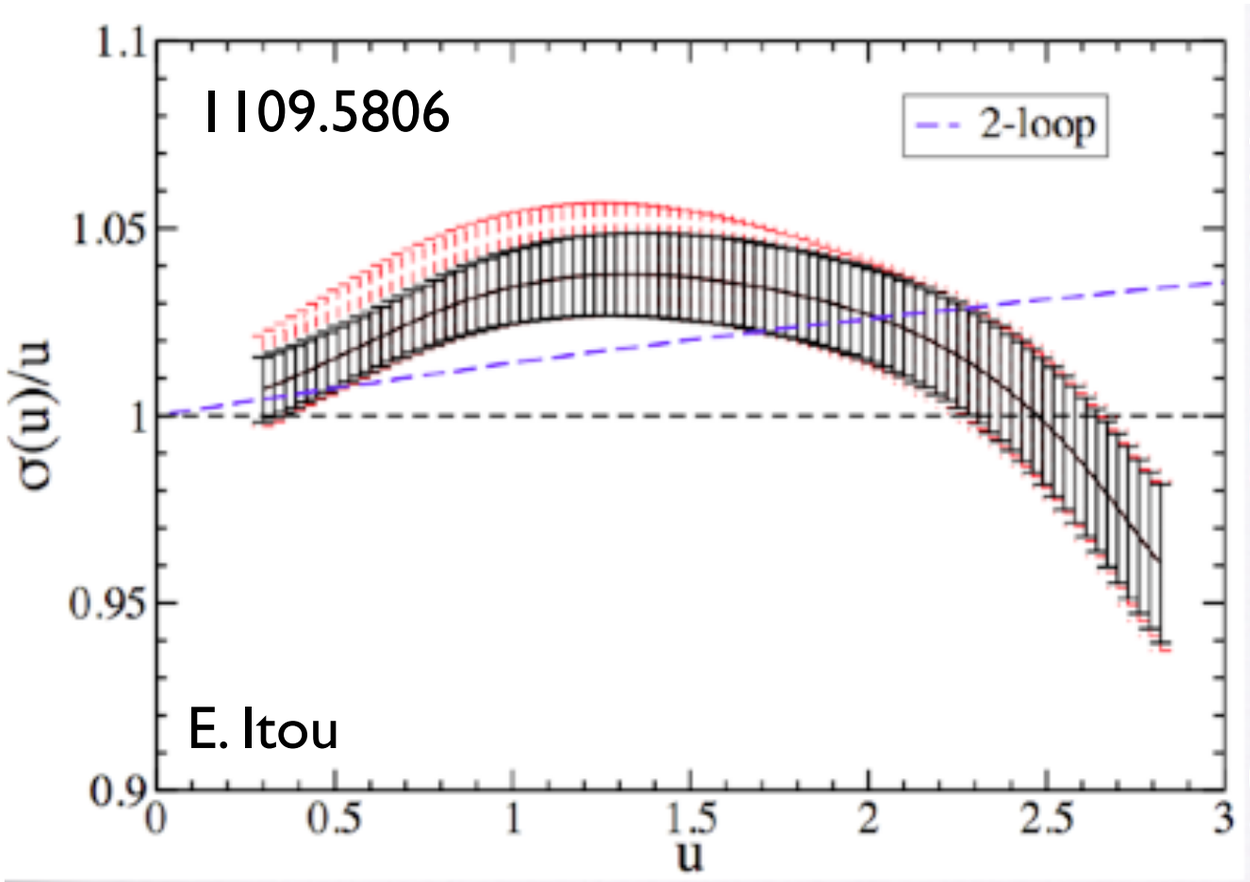

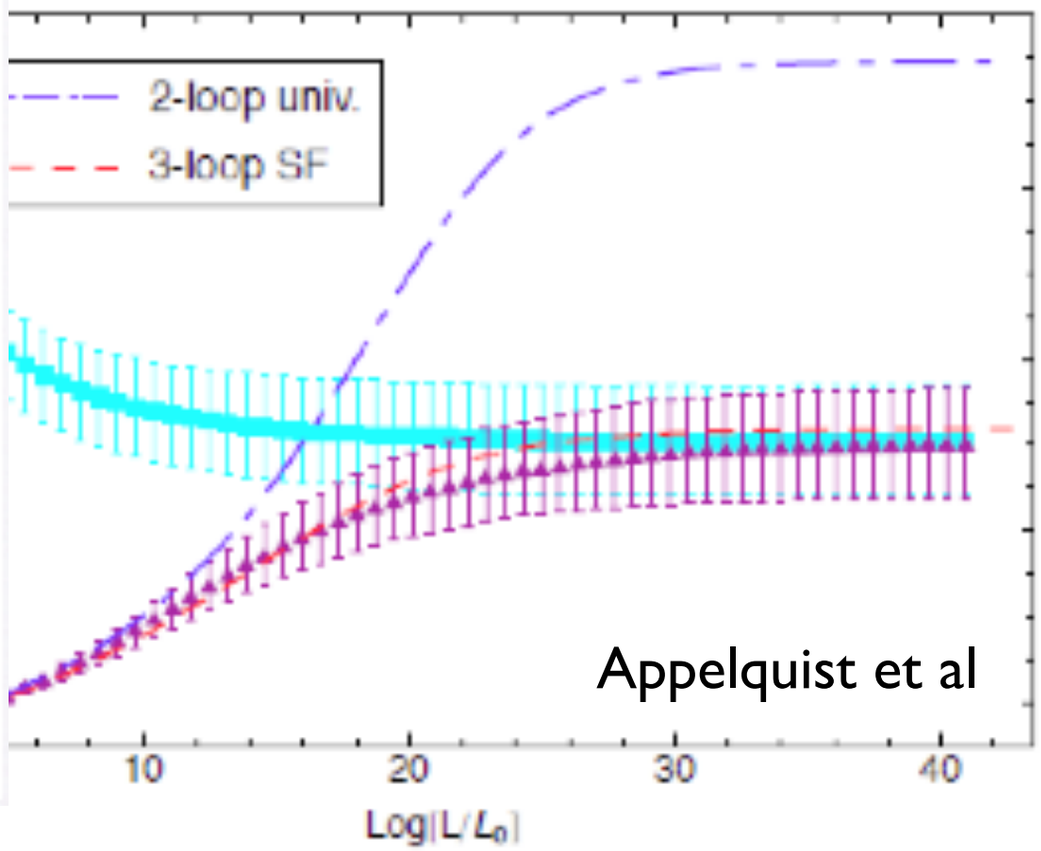

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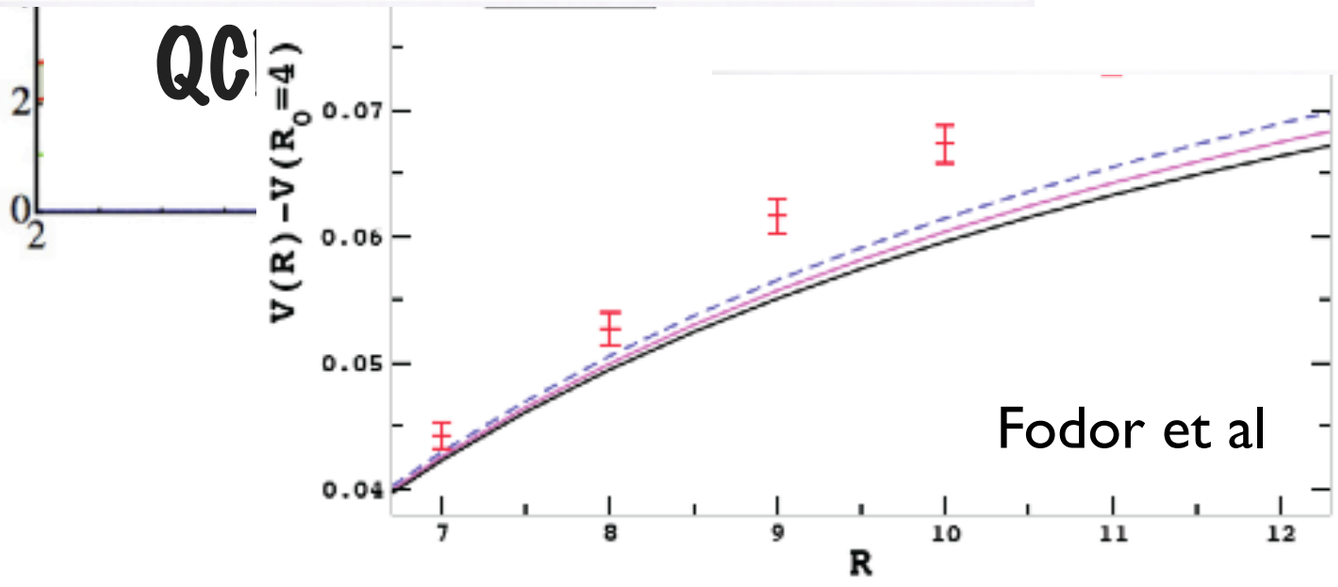

out which
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once better understood, can study properties of near-conformal theories

properties of $N_F >> 3$ theories

ex.) anomalous dimension of $<\bar{\psi}\,\psi>$

generates fermion mass, want low Λ

$$\frac{(\bar{f}f)(\bar{T}T)}{\Lambda^2}$$

generates FCNC, want high Λ

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what is γ_m in near conformal theories?

properties of $N_F >> 3$ theories

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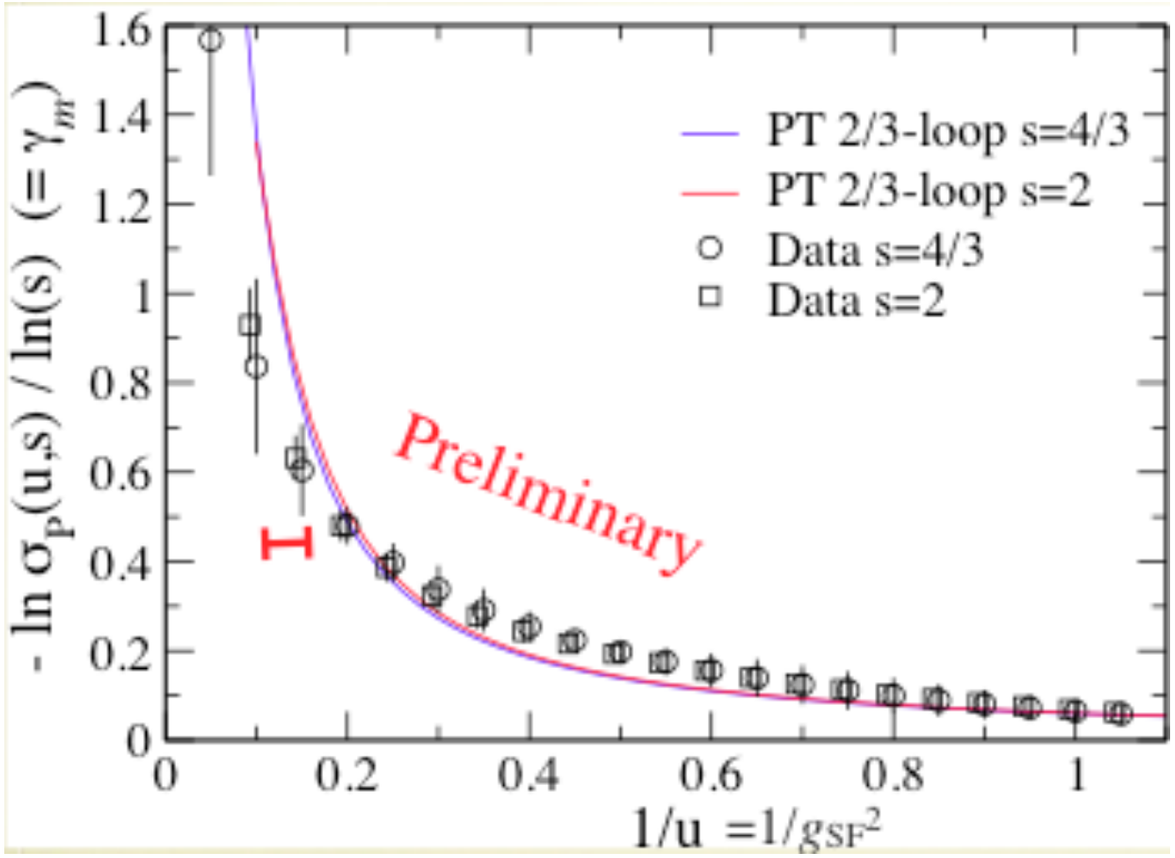


$N_F = 10$, indications of $\gamma_m \sim O(1)$

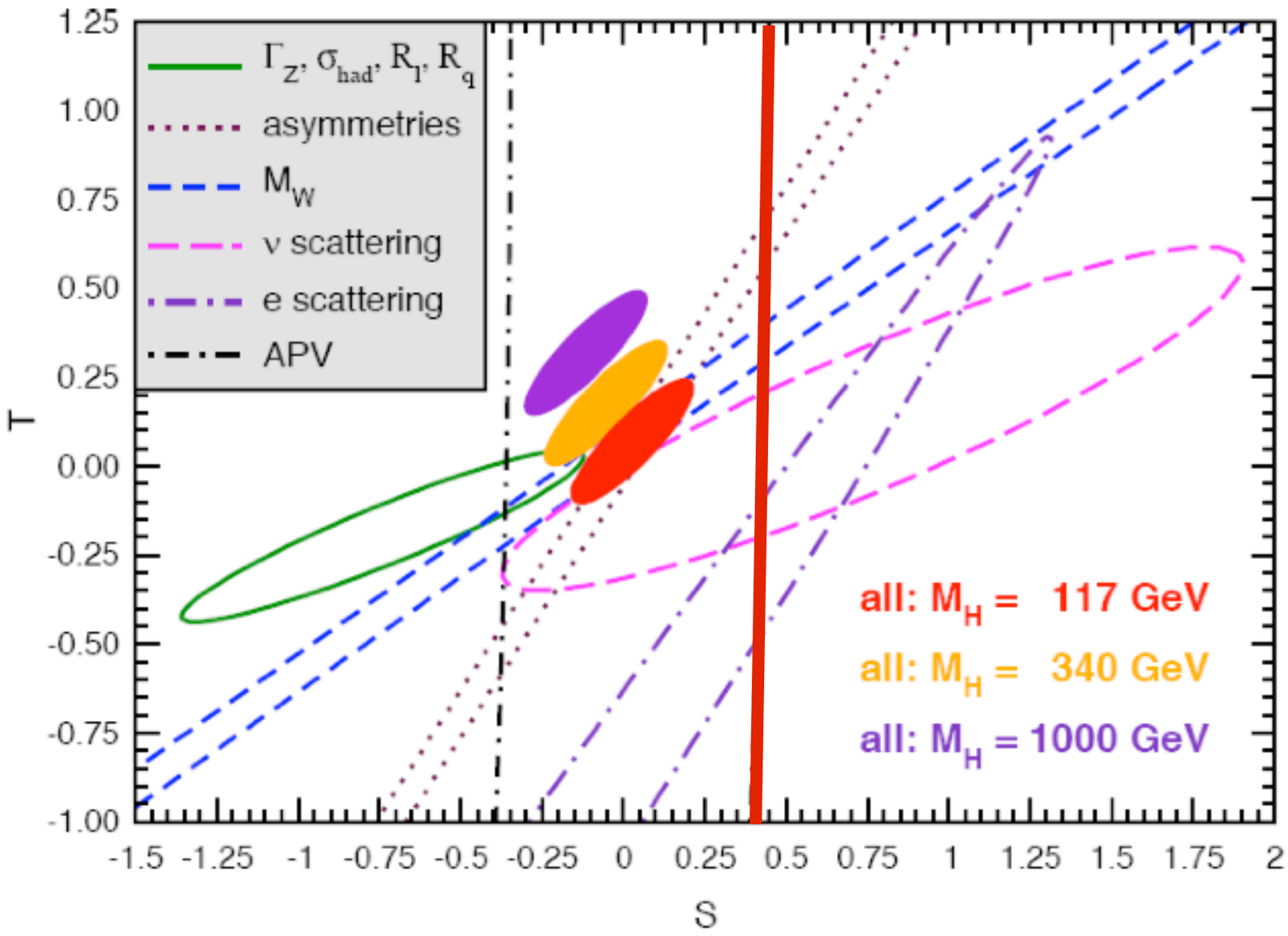
(N. Yamada)

can have Λ that satisfy flavor constraints, while generating realistic fermion masses

properties of $N_F >> 3$ theories

precision electroweak parameters:

if TeV-scale dynamics is QCD-like, expect S~0.3

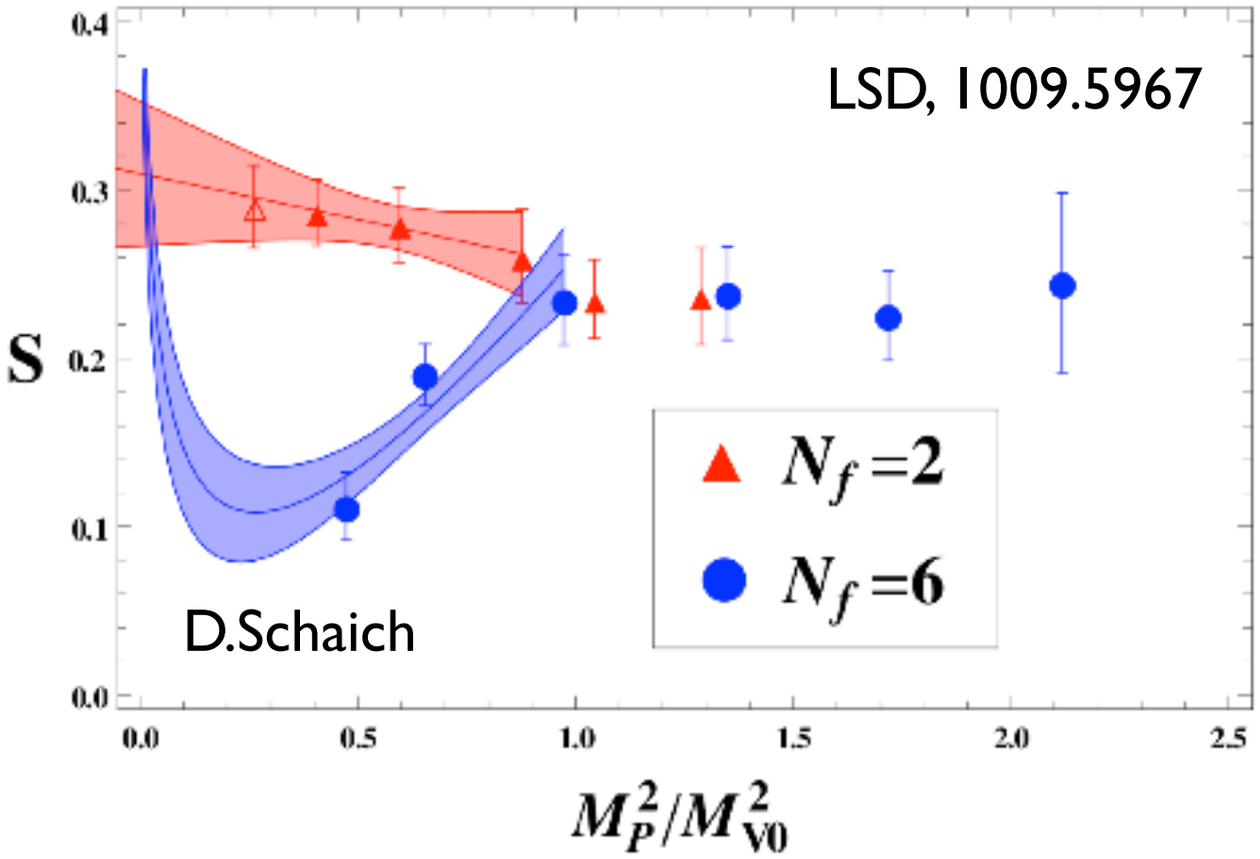


what about in a near-conformal theory?

$$S = 4\pi N_D \lim_{Q^2 \to 0} \frac{d}{dQ^2} \Pi_{V-A}(Q^2) - \Delta S_{SM}$$

properties of $N_F >> 3$ theories

indications that S (per EW doublet) can be small



points the way for model-building:

- 1 chiral EW doublet (all you need)
- N_F-1 vector-like doublets or singlets

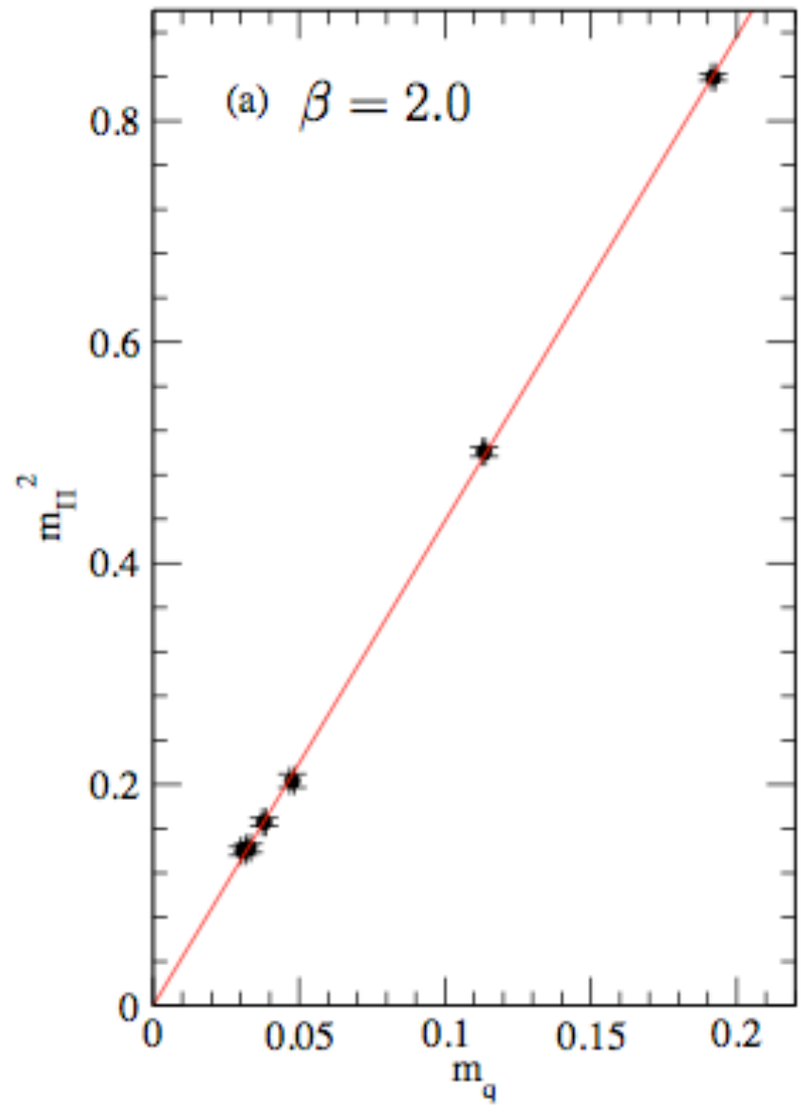
and phenomenology:

small S tied to ~restoration of parity doubling in spectra

Other directions

other patterns of chiral symmetry breakdown

we're most familiar with **SU(N)xSU(N)->SU(N)**,
but what about **SU(N) -> SO(N) or Sp(N)**



commonly used in
composite Higgs
models

study of
SU(4)/Sp(4)
breaking
(R. Lewis 1109.3513)

Other directions

role of four-fermion operators

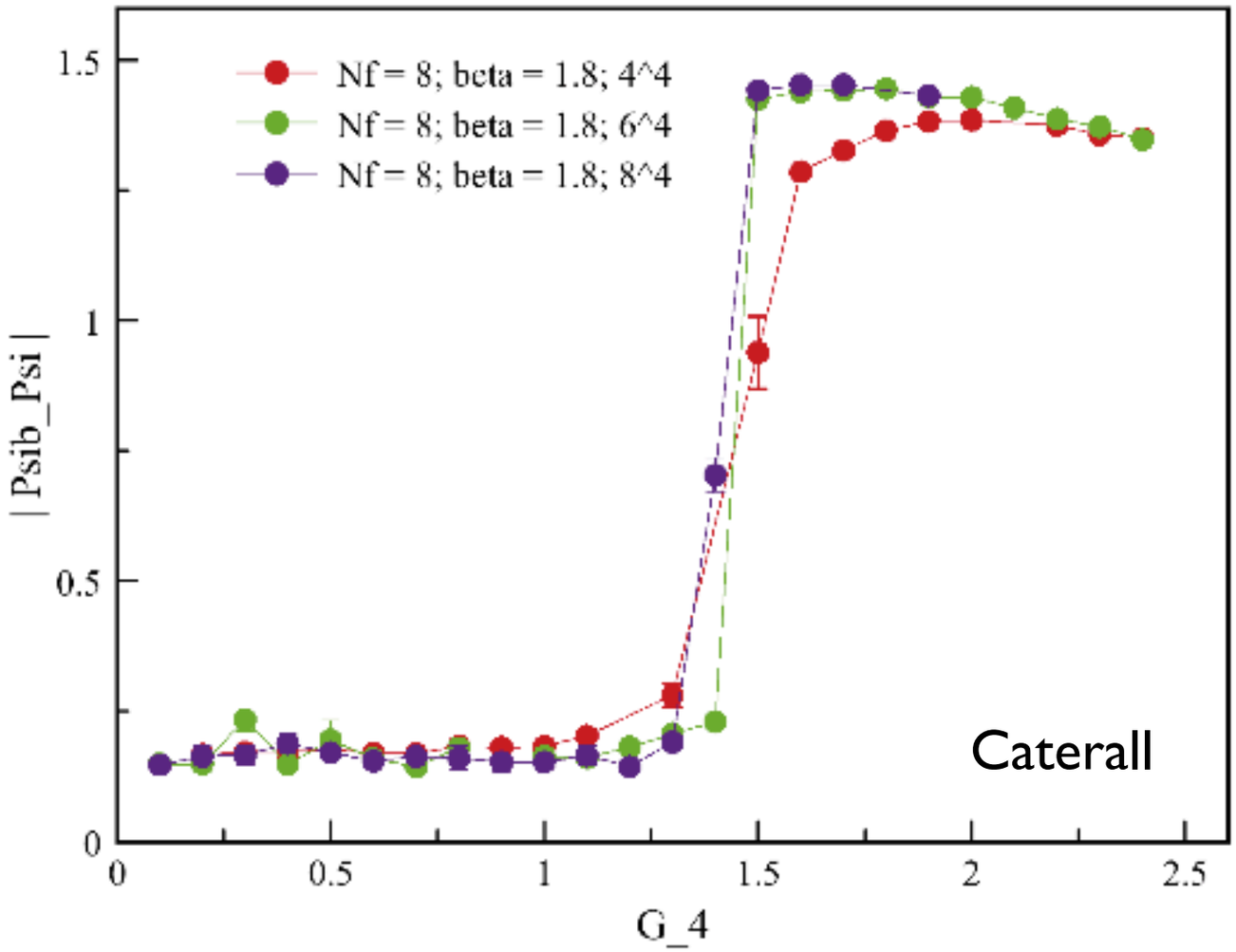
$$S = \int d^4x\, \bar{\psi}(i\partial\!\!\!/ - A\!\!\!/)\psi + \underbrace{\frac{G^2}{2}[(\bar{\psi}\psi)^2 + (\bar{\psi} i\gamma_5 \tau^a \psi)^2]} - \frac{1}{2g^2} Tr[F_{\mu\nu}F^{\mu\nu}]$$

expected/necessary in all models of BSM strong dynamics

‘gauged NJL’ model

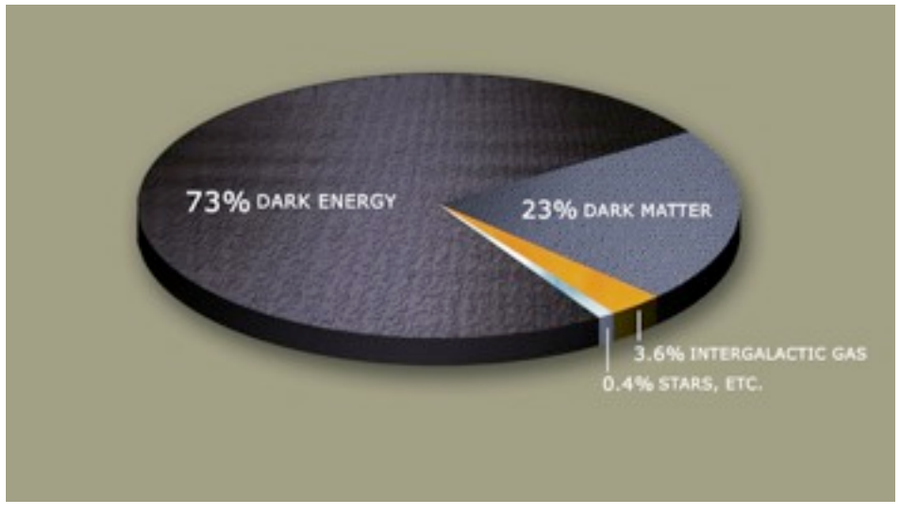
chiral symmetry breaking at large **G**

interesting to extend to more flavors, complexity



Other directions

technicolor & Dark Matter:



- lightest technibaryon can be stable by analog of $U(1)_B$

- an initial matter/anti-matter asymmetry gets shared among baryons, leptons, technibaryons via sphalerons

(Chivukula, Barr, Fahri, Nussinov)

- can get observed $\Omega_{DM}/\ \Omega_B$ easily for ~ TeV scale DM

  must be electrically neutral, EW singlets to avoid direct detection

  Then leading operators are charge radius and polarizability:

ex.) $$\frac{B^* B\, v_\mu\, \partial_\nu F^{\mu\nu}}{\Lambda_{TC}^2}\ ,\ \frac{B^* B\, F_{\mu\nu} F^{\mu\nu}}{\Lambda_{TC}^3}$$

lattice input?

BSM<->lattice wish list (~few years)

- continue search for best techniques for study of near-CFT (ex.) N_F, N_C phase diagram)

- 0^{++} state? a dilaton associated with approximate scale invariance?
- baryon spectroscopy in non-QCD scenarios
- more complex gauged NJL scenarios

- S-parameter
- WW-scattering, additional coefficients in EW-chiral Lagrangian

Conclusions

- lattice is an invaluable tool to studying viable models of TeV-scale strong dynamics

- focus so far on conformal/near conformal theories

difficult problem, still learning which techniques/tools work best

- insight into properties/spectra in these theories

input to model building and collider physics

LOTS TO DO!