Conformality and the Higgs

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Partly based on work with: A. Deuzeman, M.P. Lombardo, K. Miura, T. Nunes da Silva (lattice) A. Barranco, J. Russo (AdS/CFT)

Outline

Lattice:

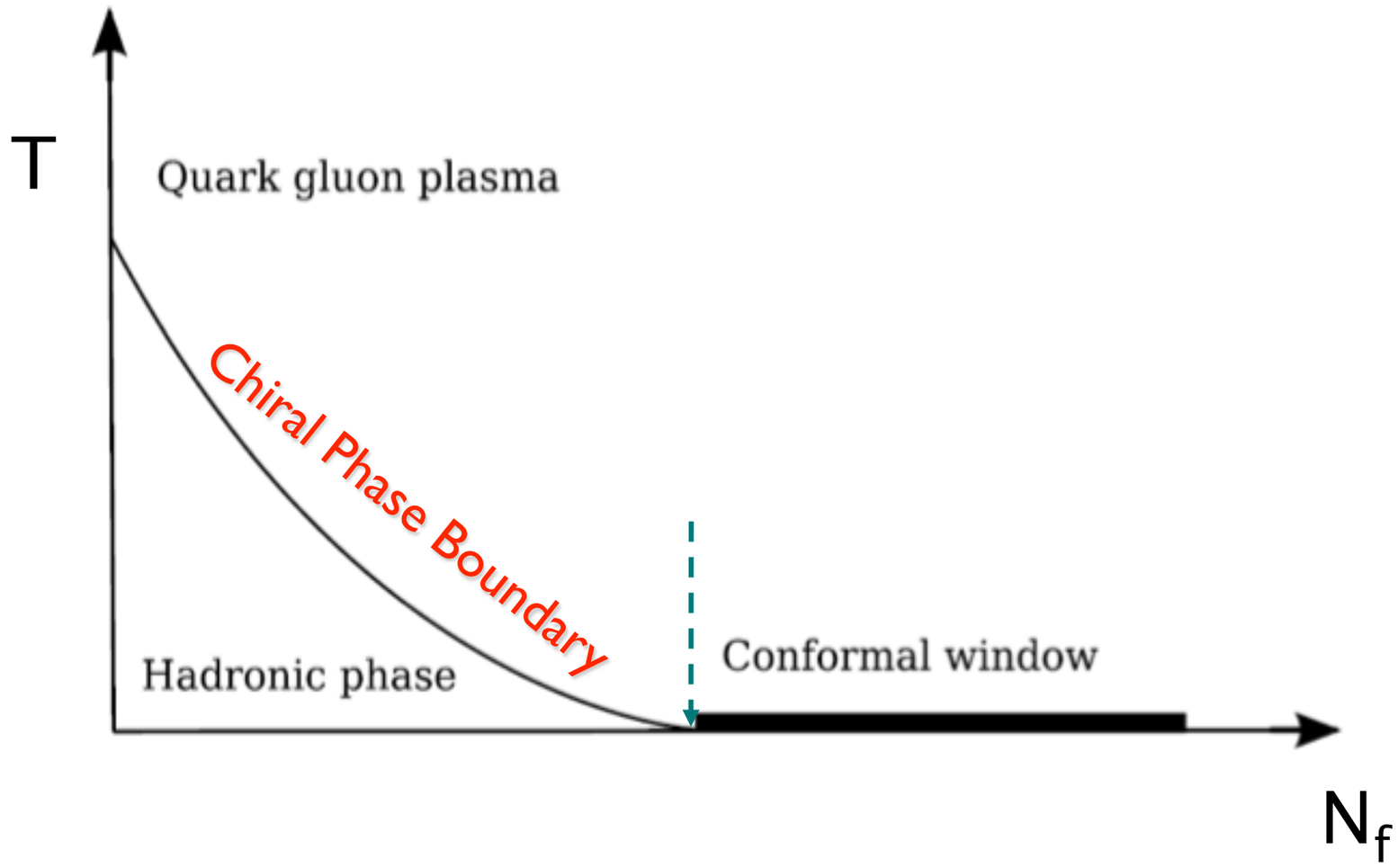
- Inside and below the Conformal Window: the example of QCD with fundamental fermions
- The effects of improvement: QCD and graphene

BSM thoughts:

- Possible roles of conformal symmetry between the EW scale and the Planck scale

The Phase Diagram

QCD: fundamental fermions



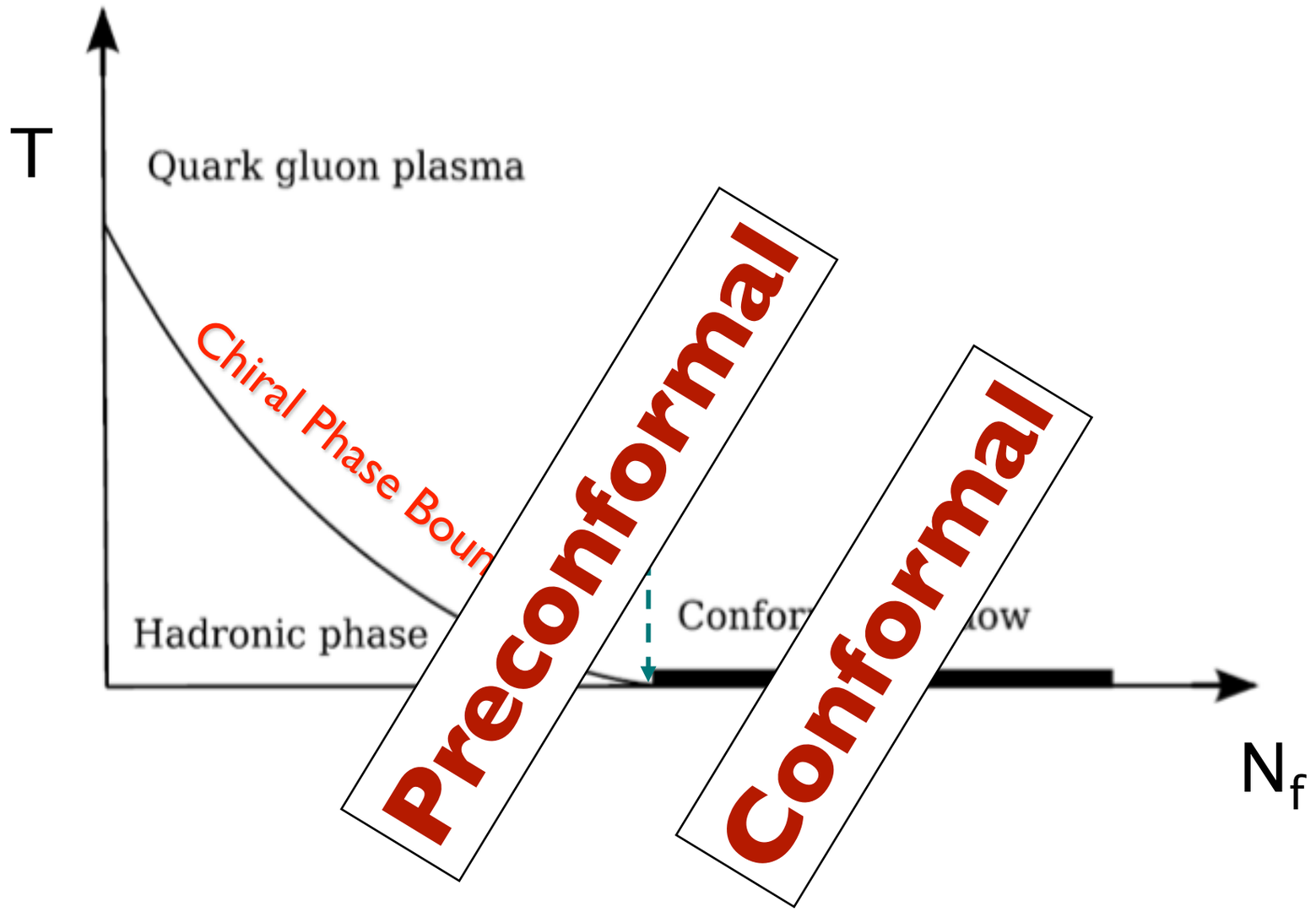
Physics of:

✓quark gluon plasma (QGP): high T - low Nf

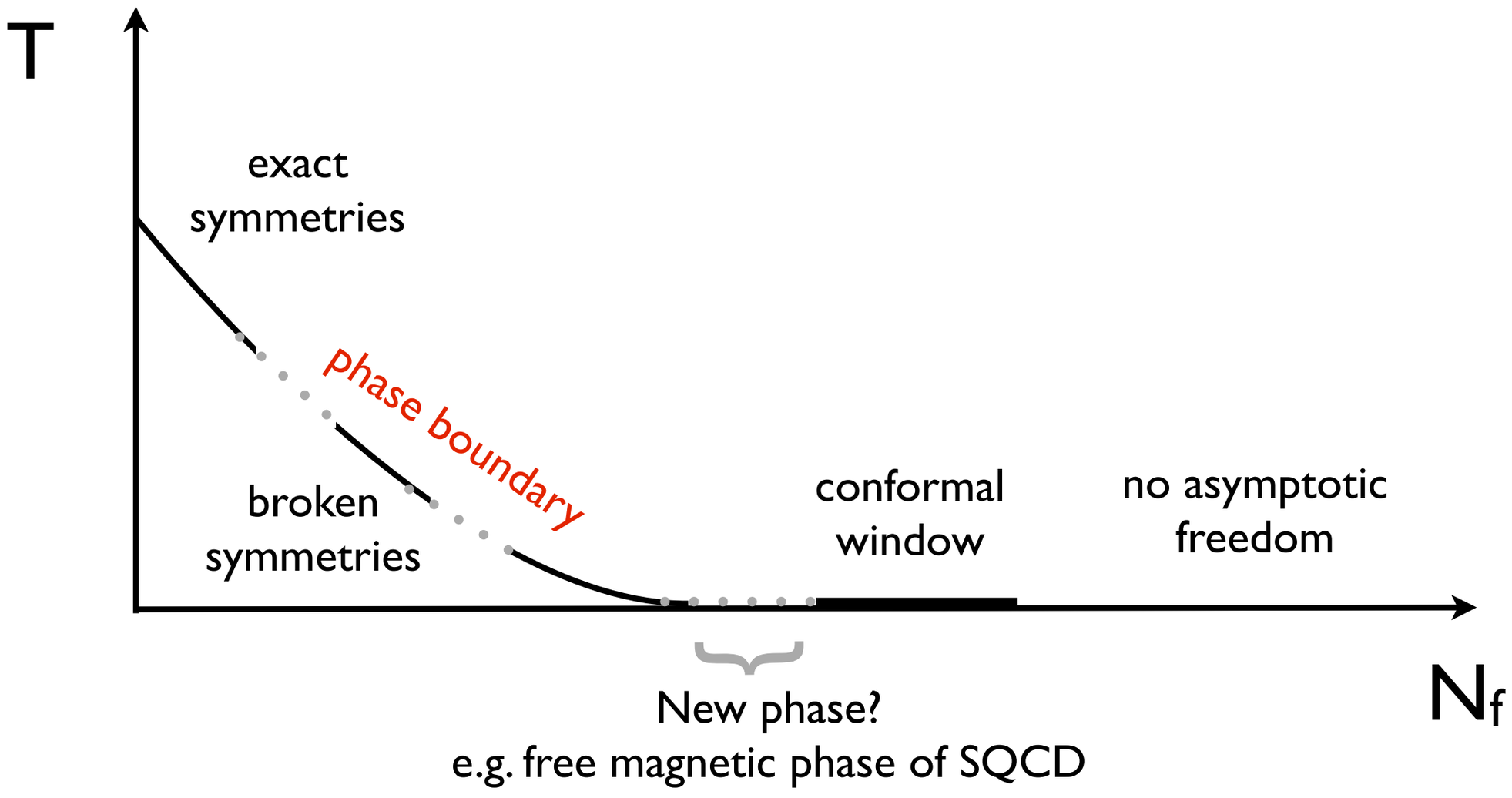
✓preconformal regime (T=0, low T - high Nf)

✓conformal regime (T=0)

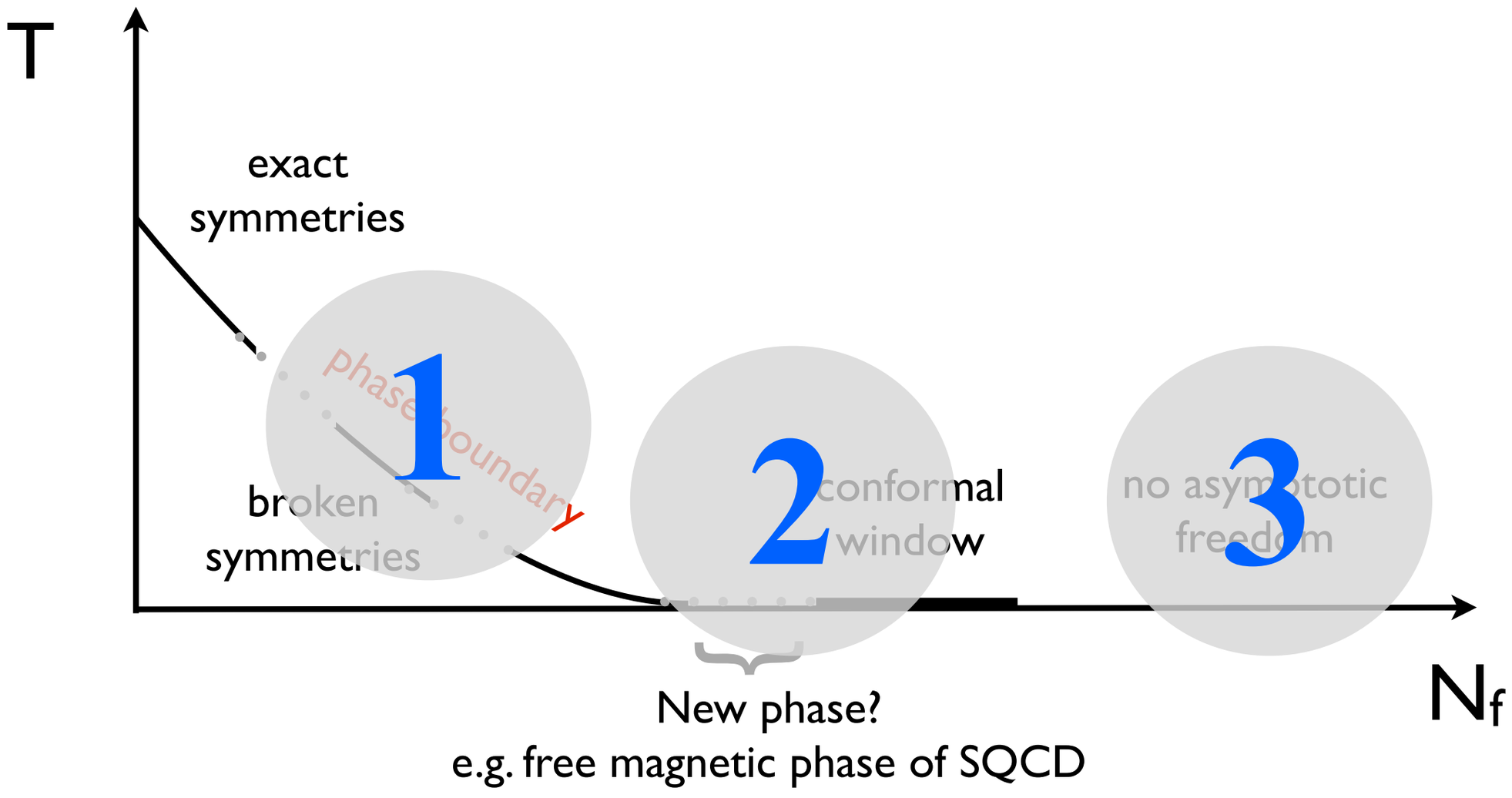
QCD: fundamental fermions



Features beyond QCD and open questions



Features beyond QCD and open questions



1

What symmetries determine the phase boundary?
What is the relative role of confinement and chiral symmetry?

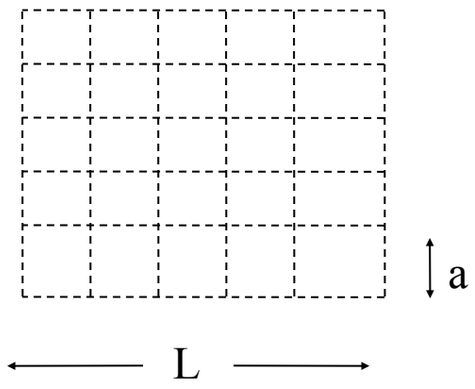
2

Is there a preconformal dynamics?
What are its signatures?
What is the mechanism (phase transition) that opens the conformal window?
Are there UVFP at strong coupling in addition to IRFP ?

3

Are there UVFP at strong coupling?

Put the system on a (Euclidean spacetime) lattice



volume = $L^3 \times T$

Do the physics of phase transitions

QCD $\Rightarrow$ chiral symmetry

order parameter = chiral condensate

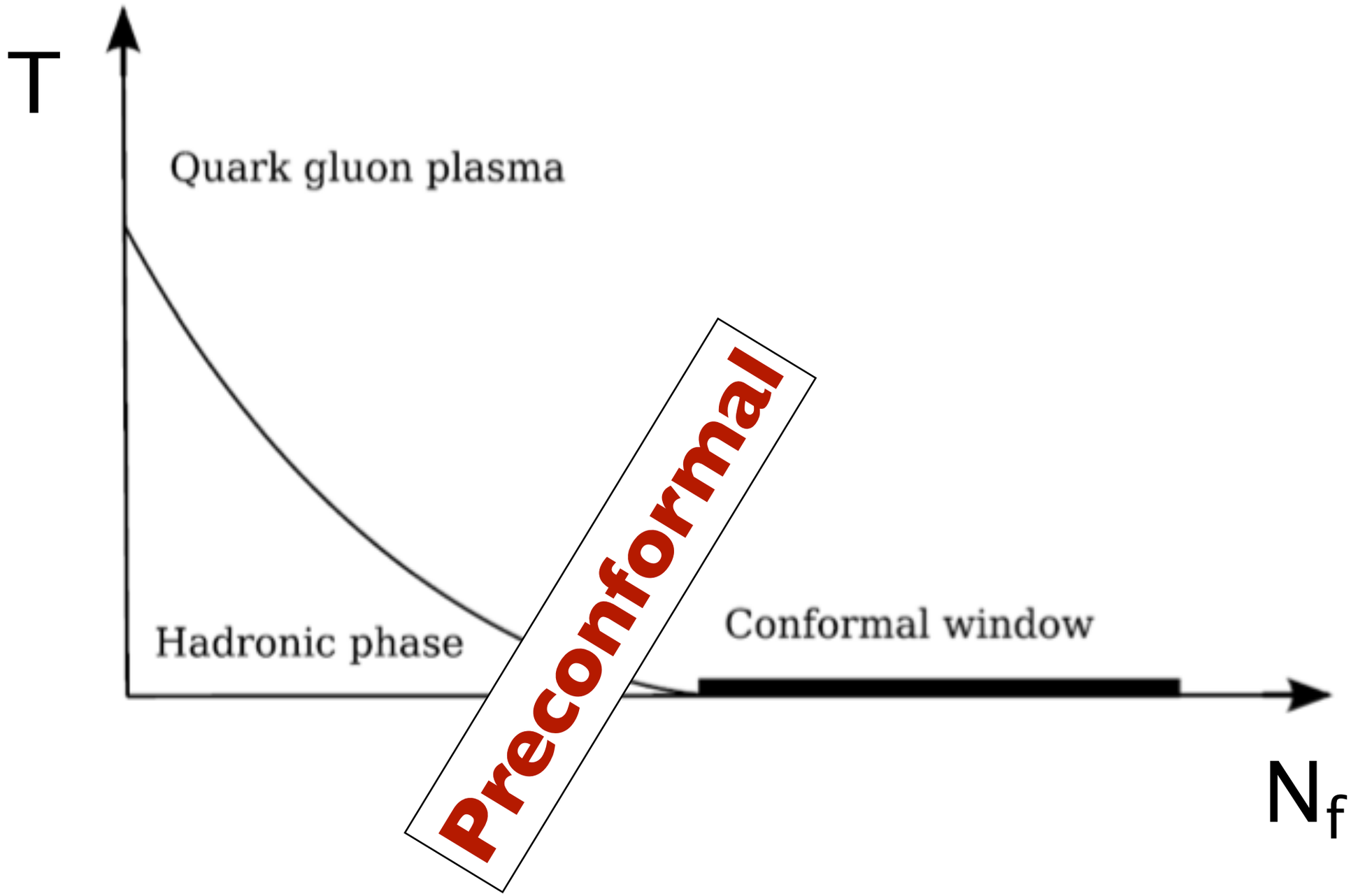
2008 Nf=8 “is” in the QCD phase (massive case)

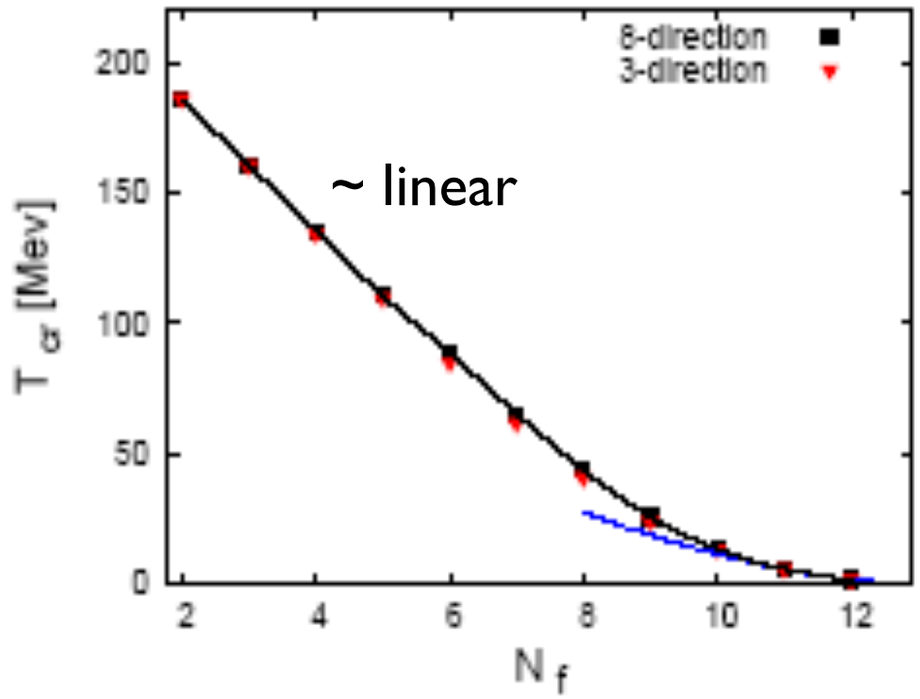
2009 Nf=12 “is” in the conformal window
(there is a conformal window)

Deuzeman, Lombardo EP 2008 2009

Many studies in recent years for different fermion representations and for varying Nf and Nc

Just below the conformal window


T
Quark gluon plasma
Hadronic phase
Conformal window
N_f
Preconformal



Braun, Gies '06
Braun, Fischer, Gies '10

$$k_{\rm SB} \;\propto\; k_0\,\theta(N_f^{\rm cr}-N_f)\,|N_f^{\rm cr}-N_f|^{-1/\Theta}\,\exp\left(-\frac{\pi}{2\epsilon\sqrt{\alpha|N_f^{\rm cr}-N_f|}}\right)$$

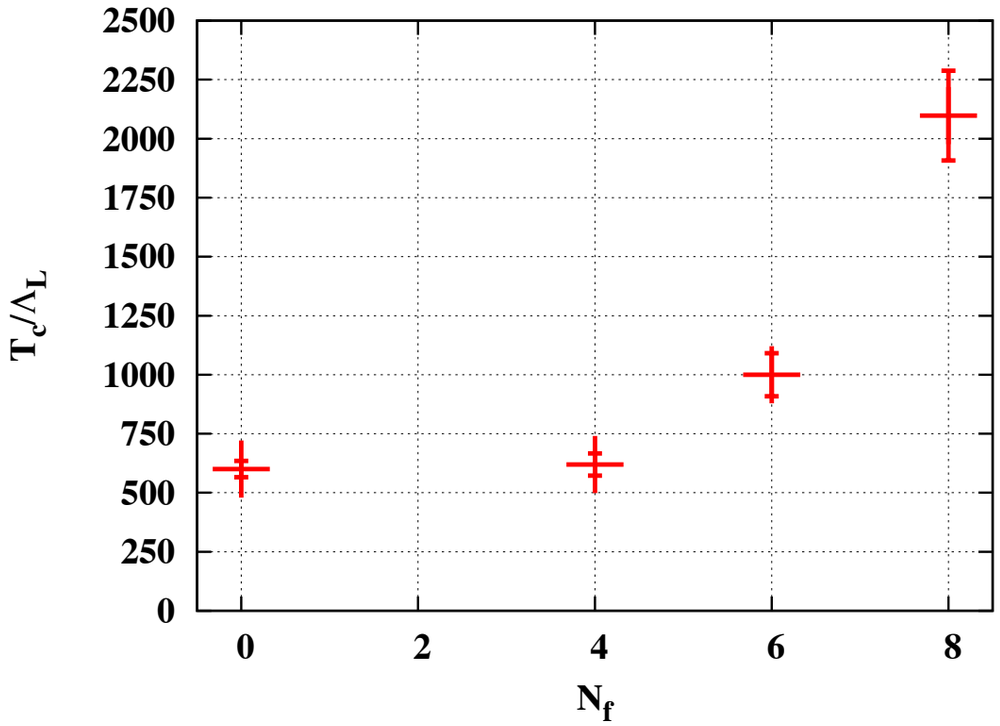
power-law
(due to running coupling)

exponential-law
(Miransky-BKT scaling)

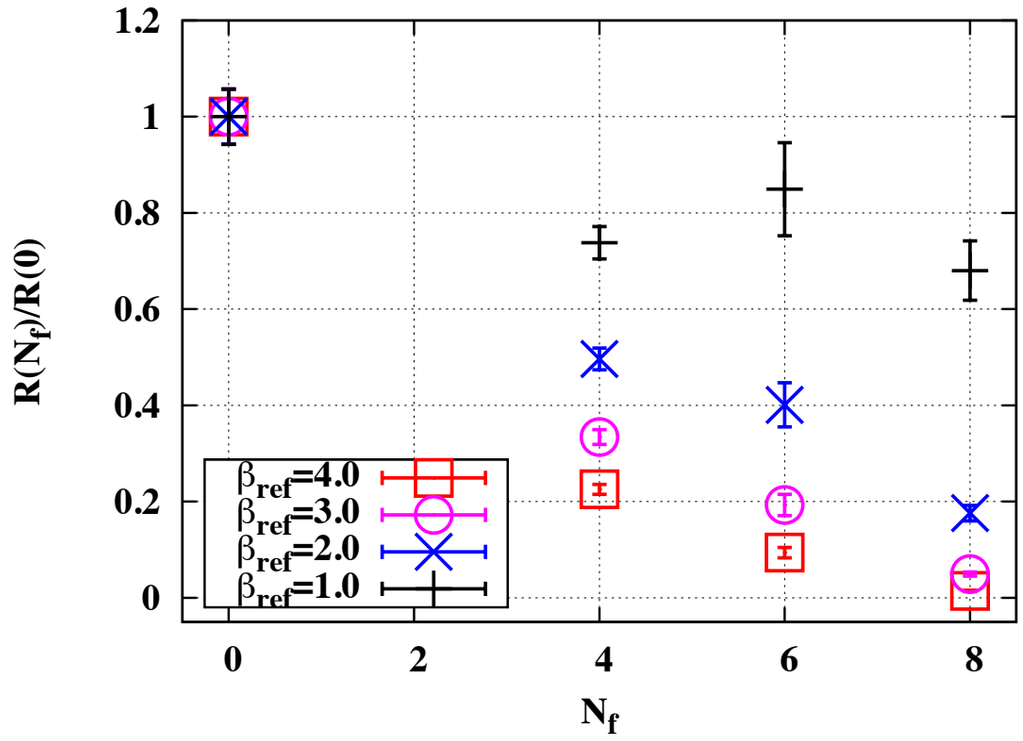
$\bar\psi\psi$, Tc

$$\beta(g^2) \;=\; -\Theta(g^2-g_\star^2)+\ldots \qquad \Theta<0$$

From a IR scale to a UV scale



[Miura, Lombardo, EP '11]



$$\frac{T_c}{\Lambda_L} \cdot a(\beta_c)\Lambda_L = \frac{1}{N_t} \qquad \begin{array}{l}\text{UV} \rightarrow \\ \text{IR} \rightarrow\end{array} \quad \frac{\Lambda_{\text{ref}}}{\Lambda_{\text{L}}} = \exp\left[\frac{\beta_{\text{L}}^{\text{ref}}}{4N_c b_0}\right]$$

Very rough extrapolation

$$N_f^c = 11(2) \text{ for } \beta_{\text{L}}^{\text{ref}} = 2 \qquad 1.1 < 1/|\theta| < 2.5$$

$$N_f^c = 9(1) \text{ for } \beta_{\text{L}}^{\text{ref}} = 4.0$$

Physics questions

Universal scaling law for the critical Temperature precursor of a conformal phase transition (BKT phase transition) ⇒ preconformal IR dynamics

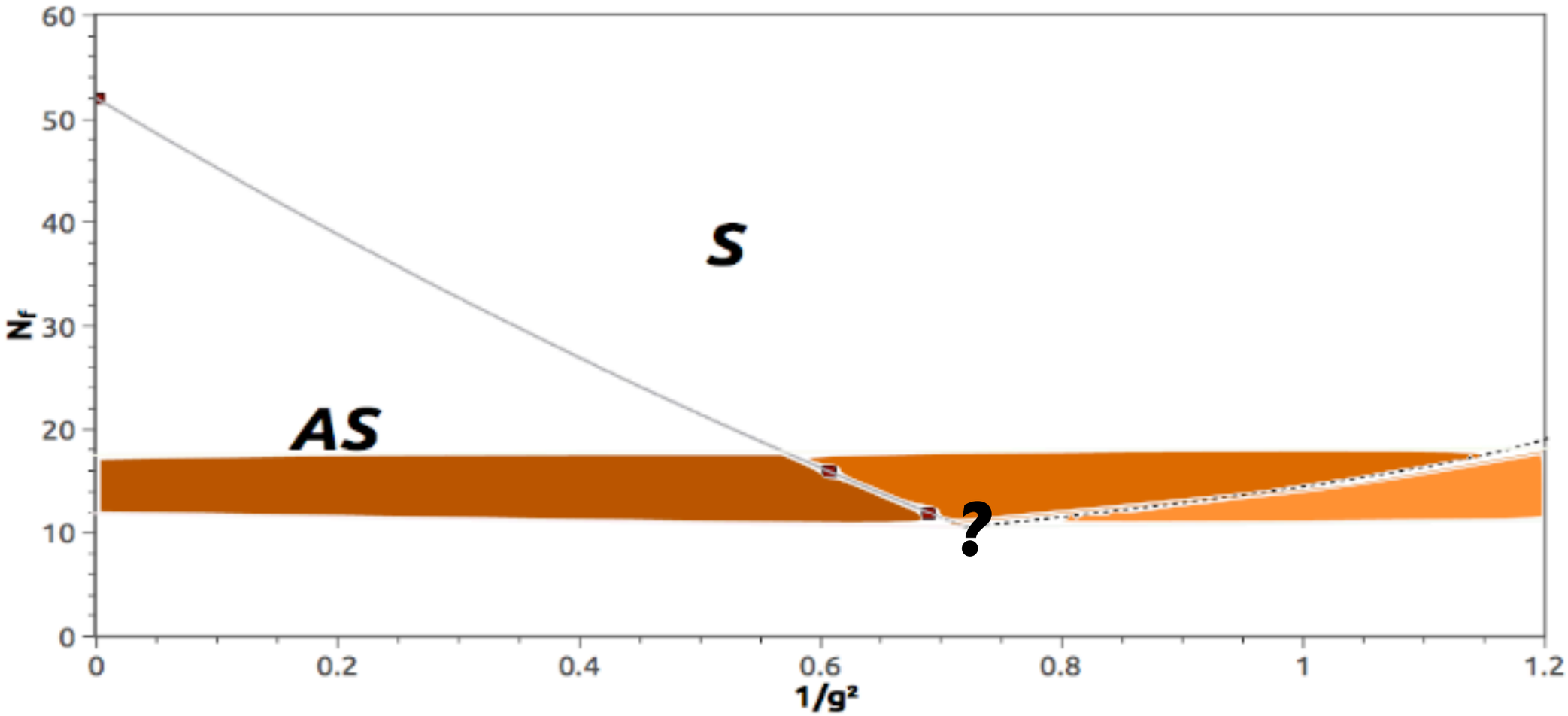
How large is the anomalous dimension γ at the would-be IR fixed point?

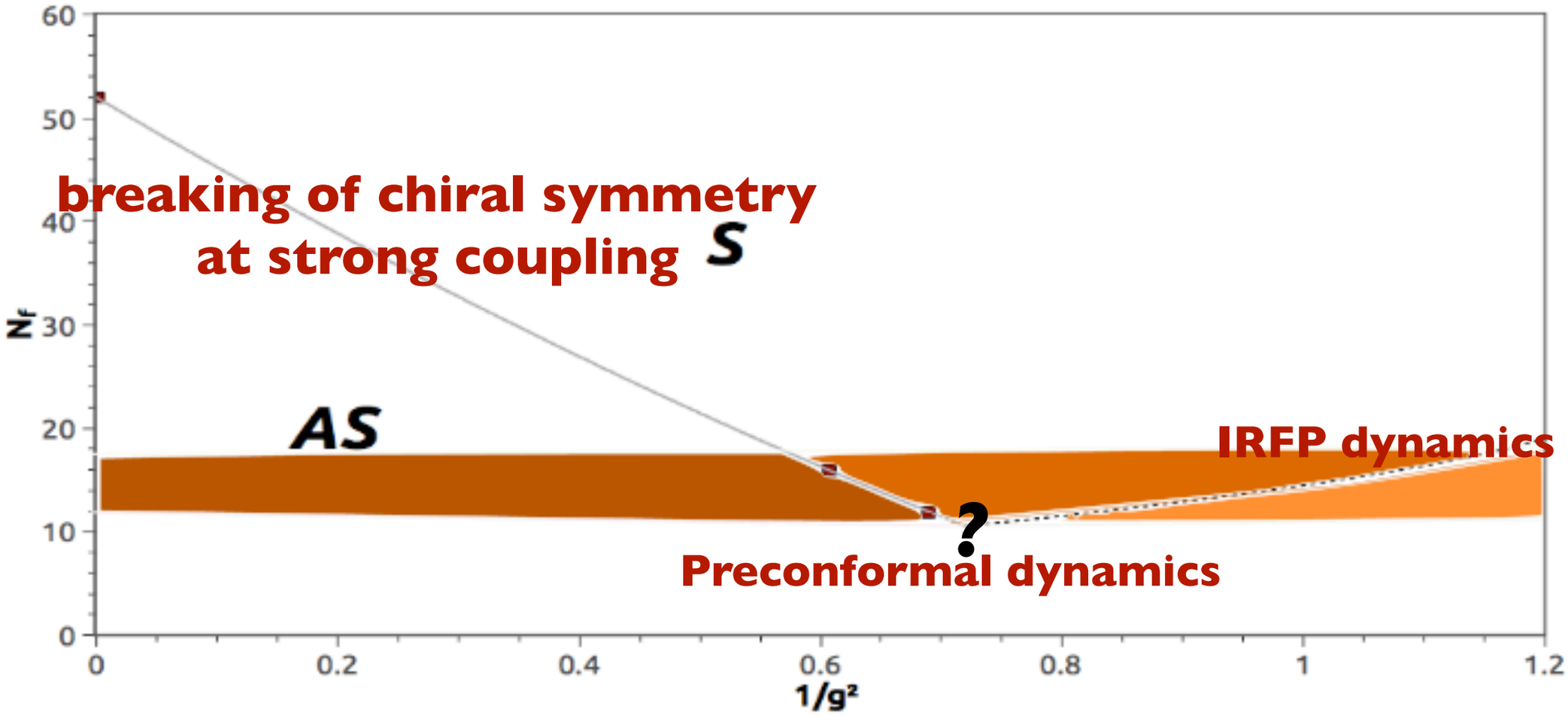
What is the ratio of the Higgs and rho masses?

Or, is a different mechanism in place?

Inside the Conformal Window

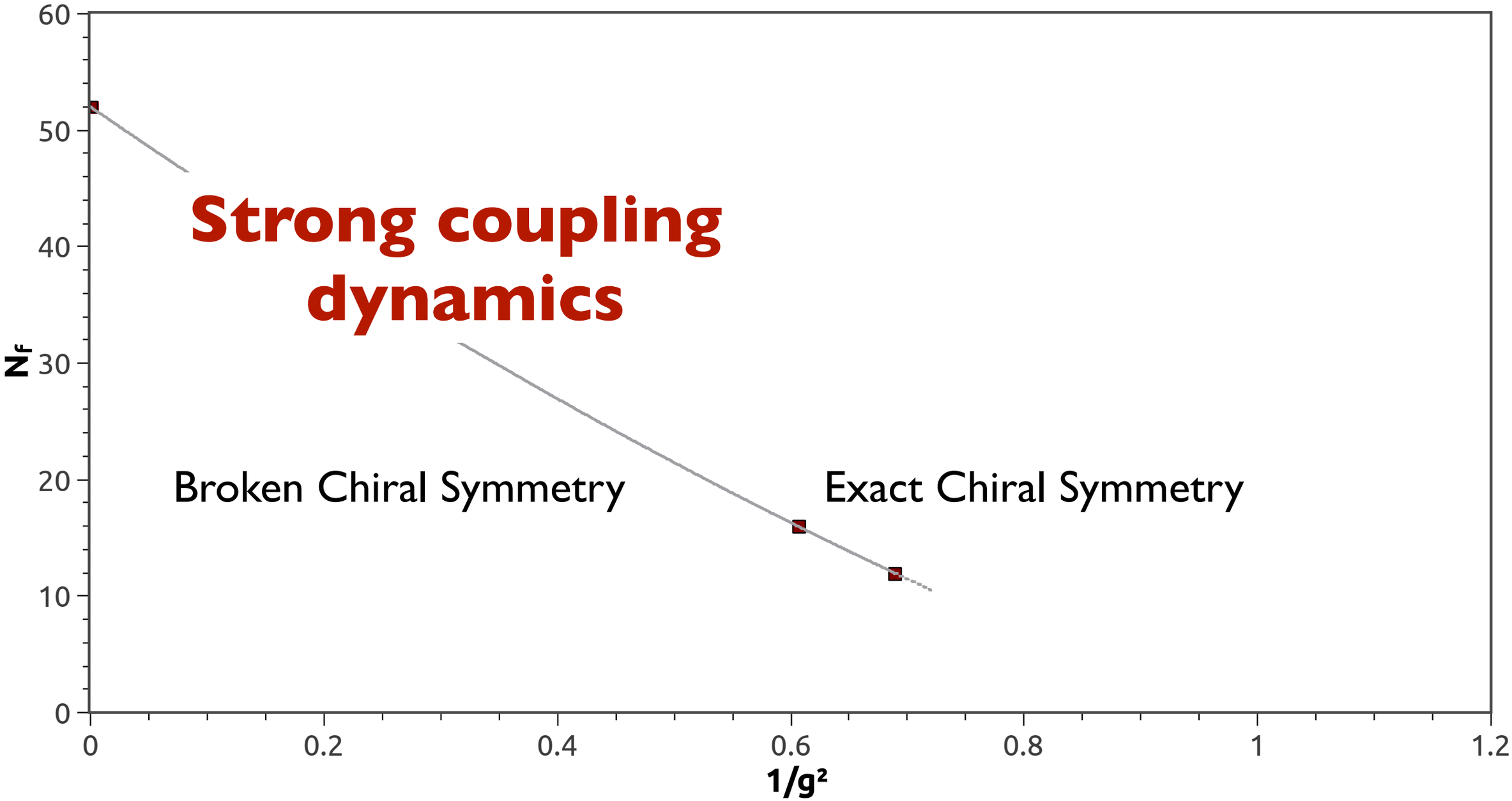
On the lattice



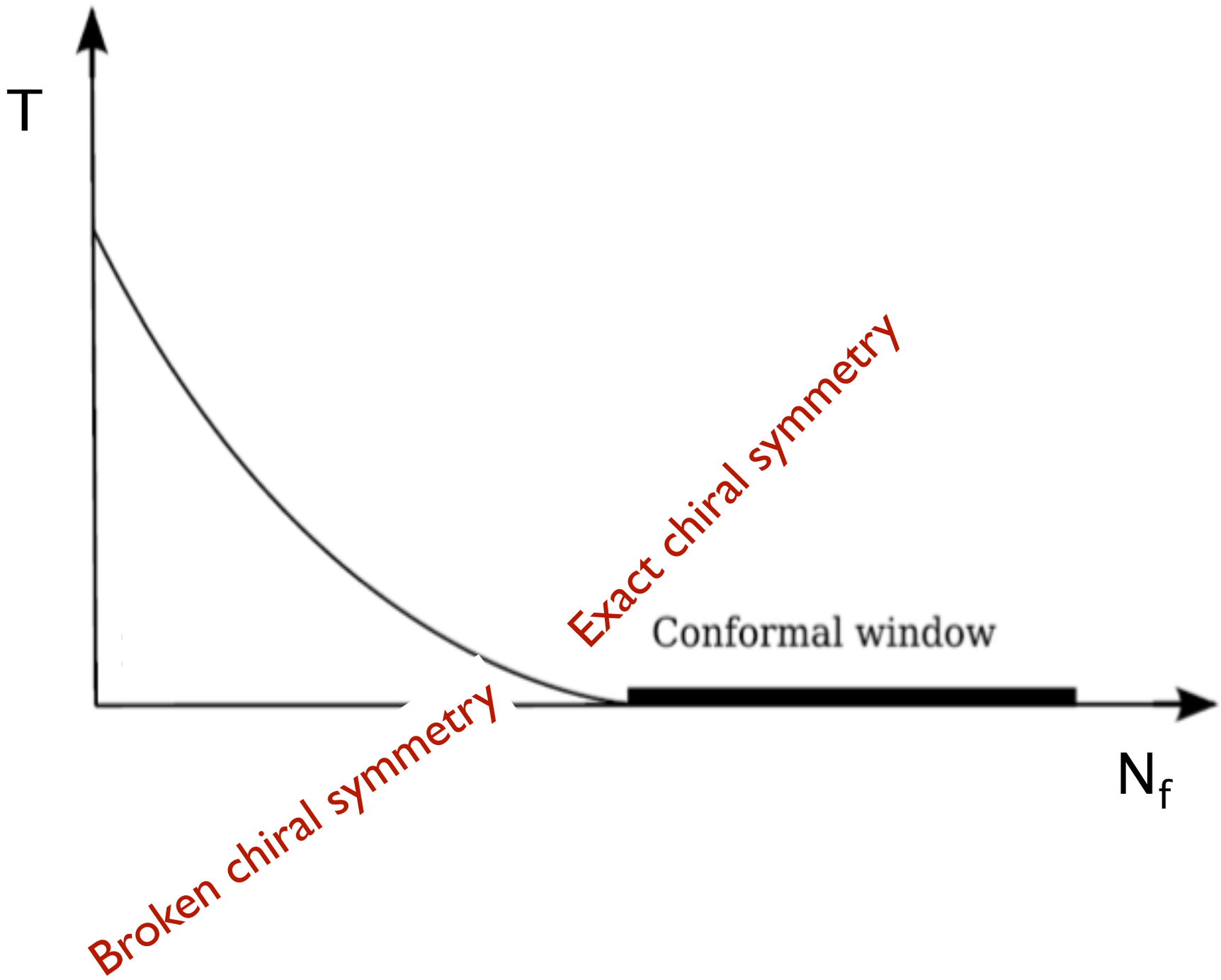

breaking of chiral symmetry
at strong coupling
S
AS
IRFP dynamics
?
Preconformal dynamics
N_f
$1/g^2$
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2

Strong coupling dynamics
Improvement & Funny phases

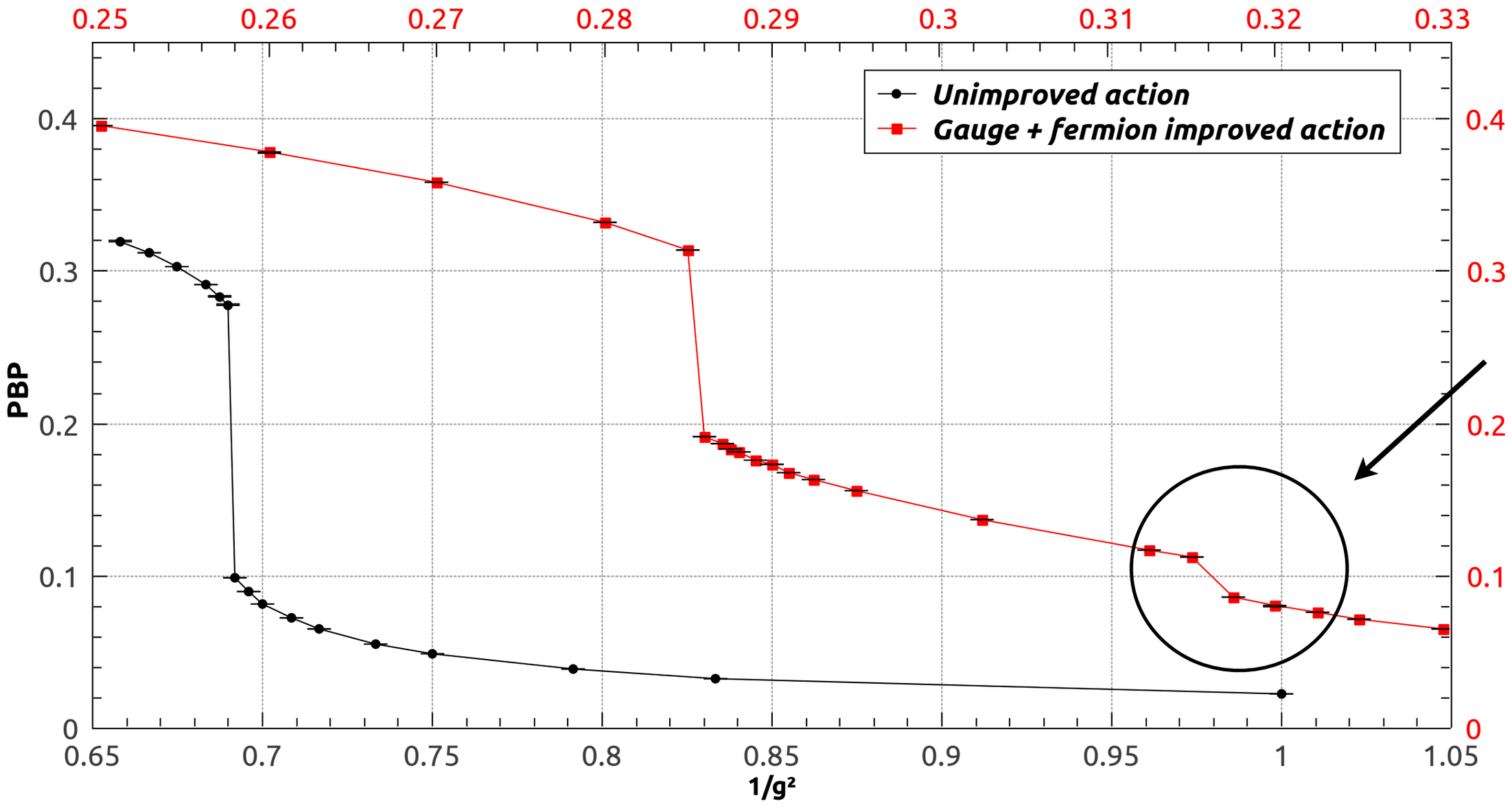
[Deuzeman,Lombardo,Nunes EP '12]



Also


T
Exact chiral symmetry
Conformal window
Broken chiral symmetry
N_f

The bulk transition(s)



Symanzik improvement @ strong coupling

Gauge action:

$$S_G = \beta_0 \,\mathrm{Re}(1-\underbrace{U(1\times 1)}) + \beta_1 \,\mathrm{Re}(1-\underbrace{U(2\times 1)}) \qquad \beta_0 = \frac{5}{3}\beta,\ \ \beta_1 = -\frac{1}{12}\beta \qquad \beta = \frac{6}{g^2}$$

nearest neighbor next-to-nearest neighbor

Fermion action:

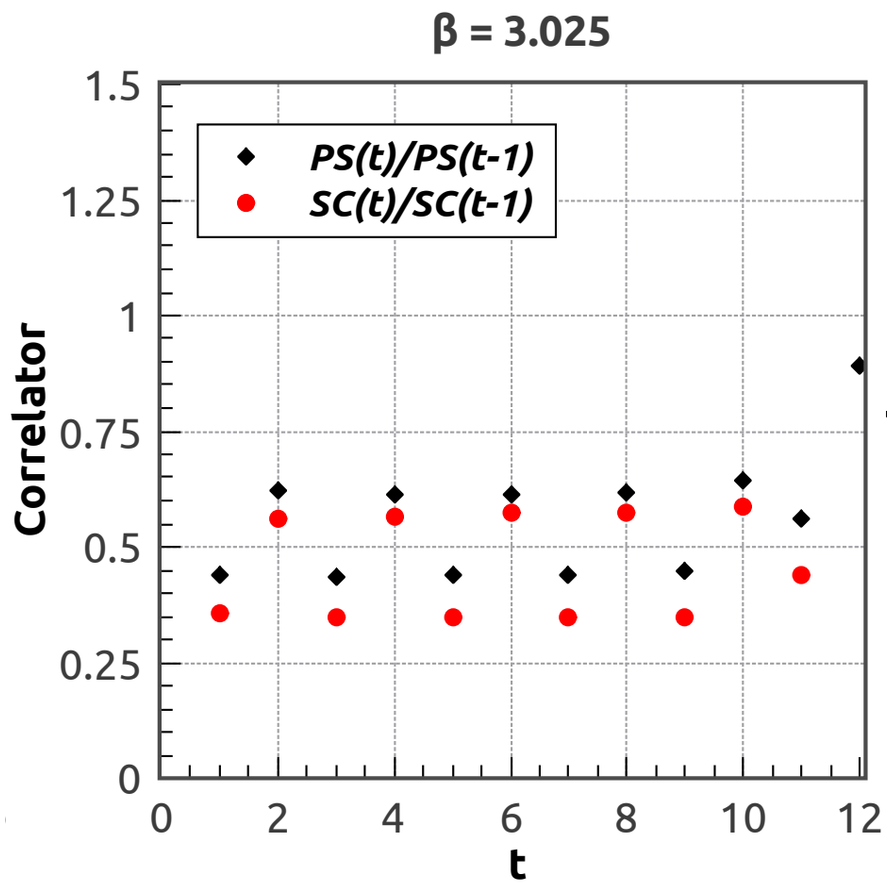
$$\begin{aligned} S_F \quad &= a^4 \sum_{x;\mu} \eta_\mu(x)\bar{\chi}(x)\frac{1}{2a}\Big\{c_1\left[U_\mu(x)\chi(x+\mu) - U^\dagger(x-\mu)\chi(x-\mu)\right] \\ &+c_2\left[U_\mu(x)U_\mu(x+\mu)U_\mu(x+2\mu)\chi(x+3\mu)\right. \\ &\left.-U^\dagger_\mu(x-\mu)U^\dagger_\mu(x-2\mu)U^\dagger_\mu(x-3\mu)\chi(x-3\mu)\right]\Big\} \\ &+a^4 m\sum_x \bar{\chi}(x)\chi(x) \end{aligned}$$

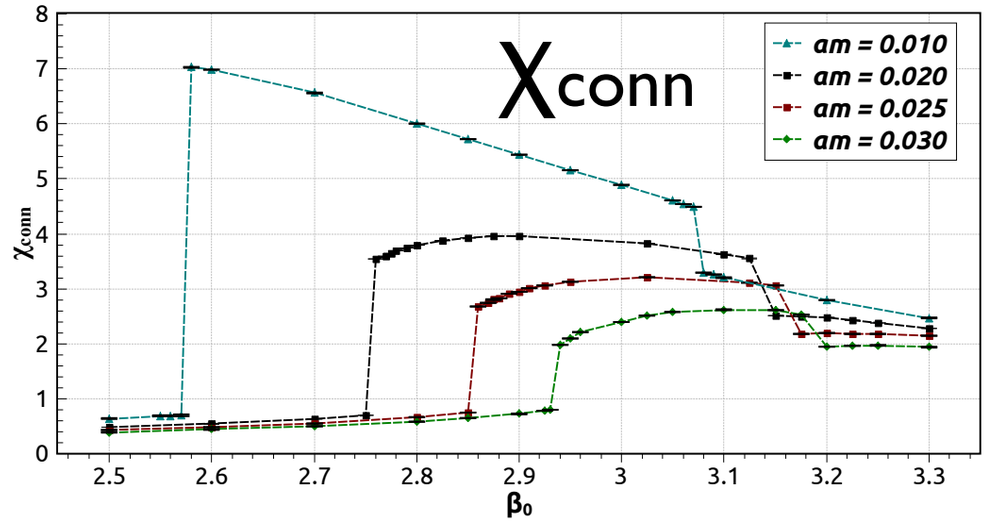
} Naik term 3rd-nn

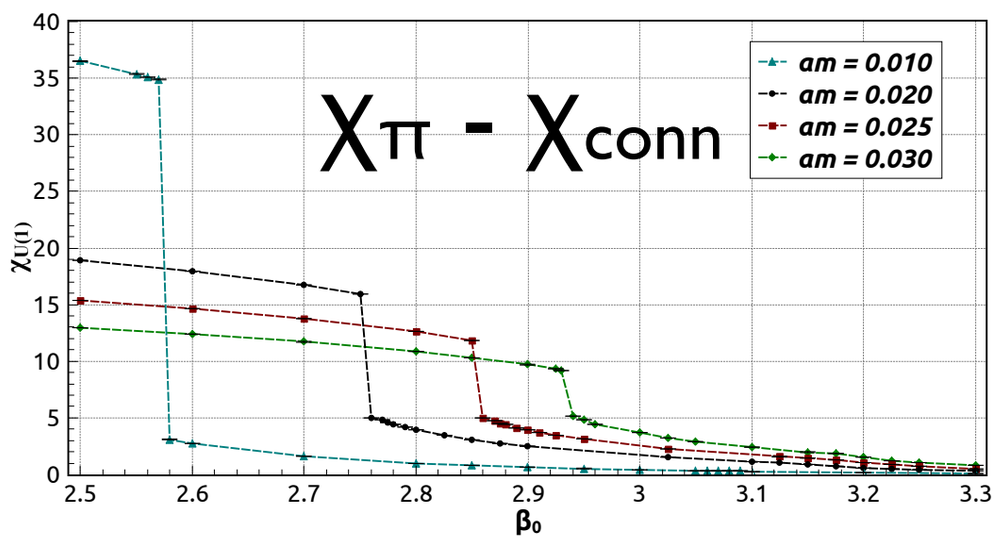
Propagators Susceptibilities

$$C_\pi(t) \qquad \chi_\pi = \frac{\langle\bar{\psi}\psi\rangle}{m} = \int C_\pi(t)$$

oscillation+asymmetry ⇒ discontinuity







The improvement of actions far from the continuum

Hermiticity of the **improved Transfer matrix** is lost (complex energy eigenvalues) When and how does it manifest?

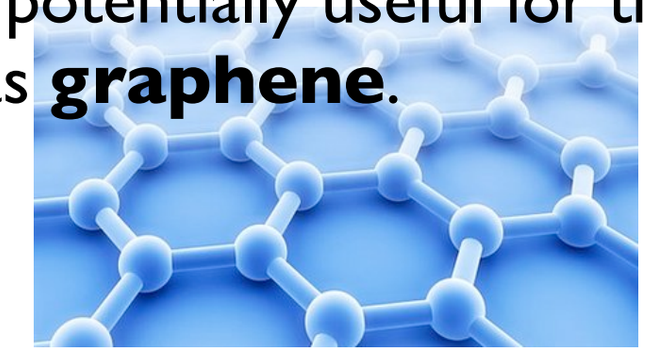
Luscher, Weisz '84

A solvable model: (1d) Ising chain with n-n-n interactions (ANNNI models)

⇒ **New Lattice Phases**

Arisue, Fujiwara '84

The same theoretical analysis is potentially useful for the lattice formulation of strongly coupled systems such as **graphene**.

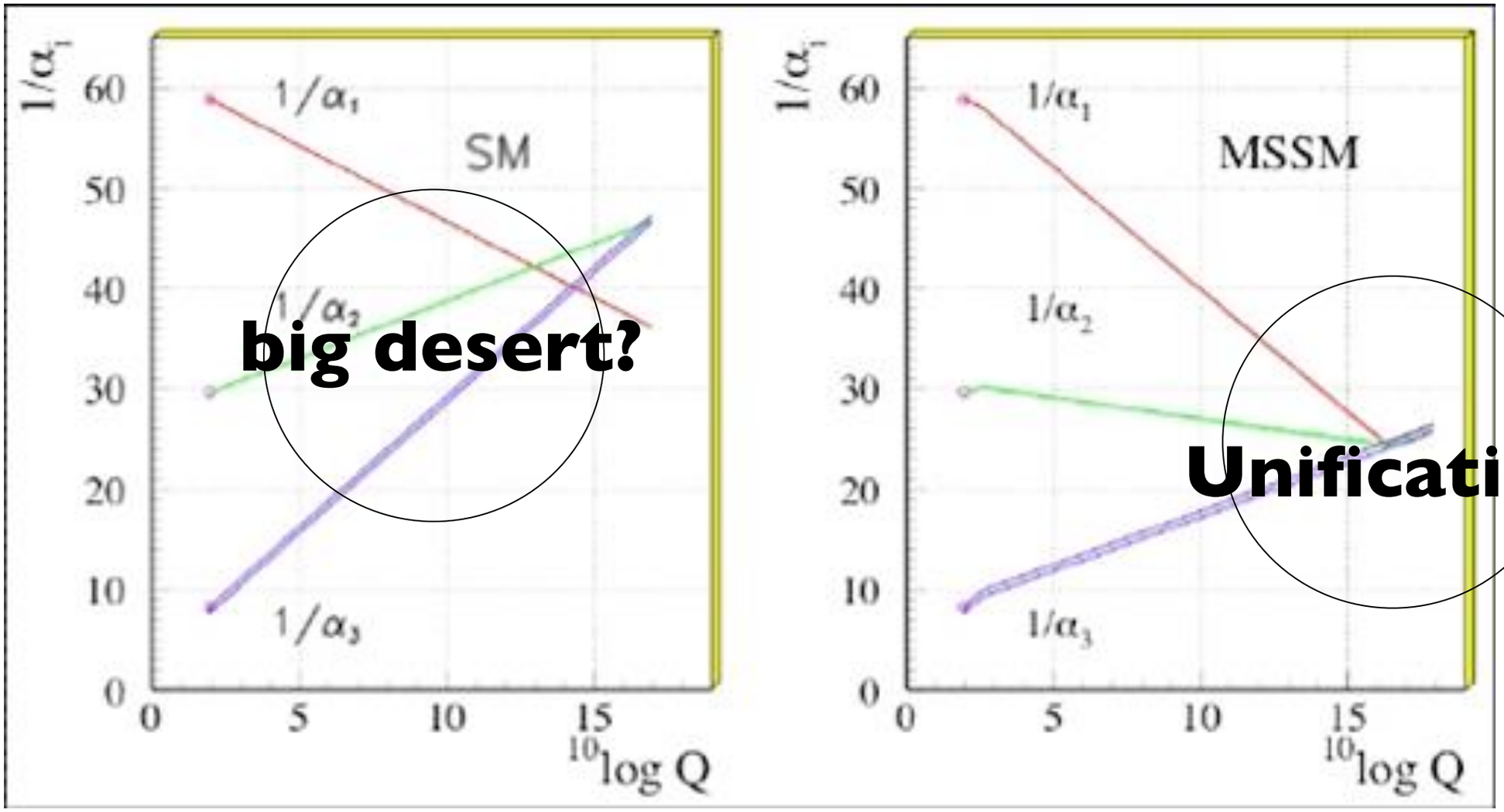


Thoughts about conformality and the Higgs boson

Can we enhance the symmetry of the SM without enlarging the particle content?

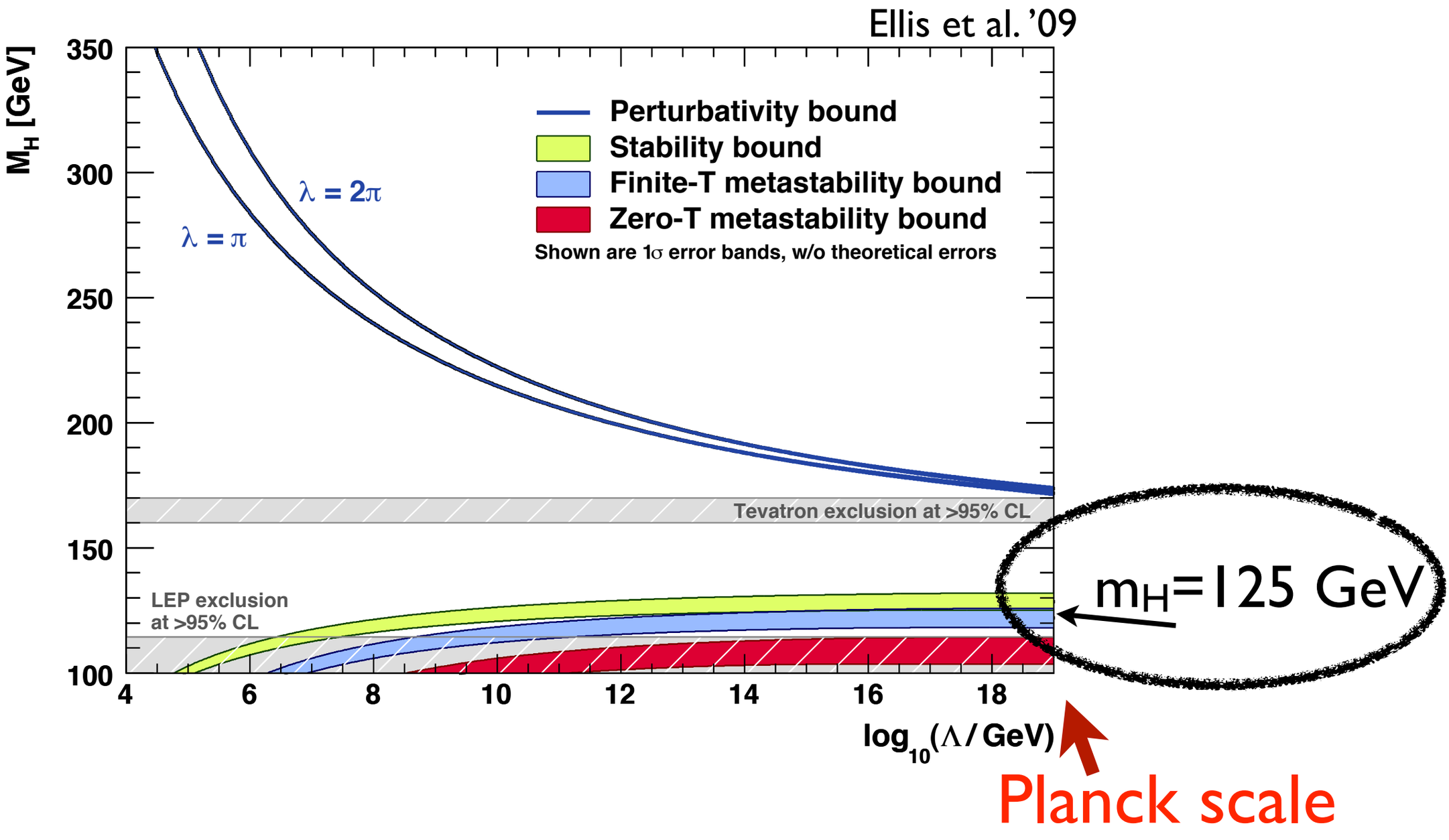
Apply this to conformal symmetry/scale invariance

Extreme scenarios

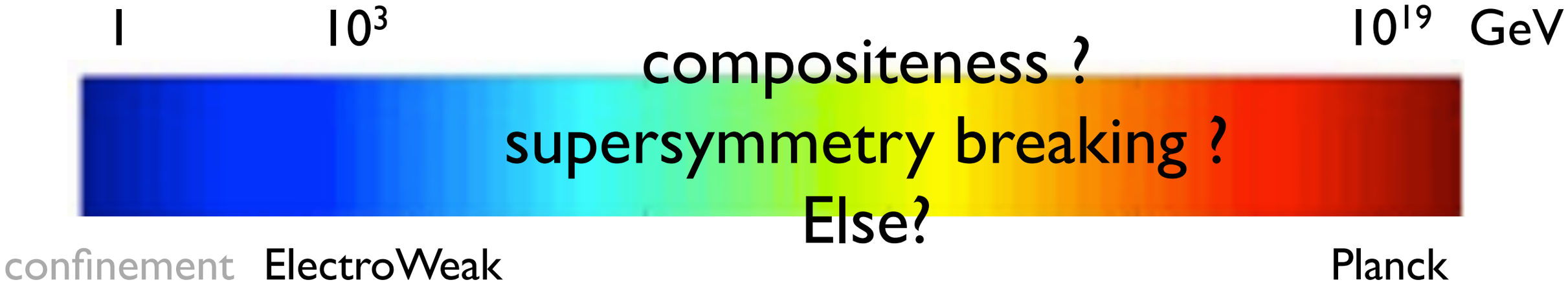


⇒ triviality and radiative corrections Cortese Petronzio EP '92

⇒ vacuum stability Isidori Ridolfi Strumia '01



The SM may be a valid EFT up to the Planck scale



We may need to (partly) give up naturalness

We may still be missing one key ingredient in the interplay of gravity and the other forces at high energies.

Light Higgs and conformal symmetry

Light Composite Higgs ± Warped ED

SM + strongly coupled new sector

Higgs = PNGB of new sector

EW scale < Compositeness scale << Planck scale

New particles = vector resonances,
fermions, heavier scalars

Light Higgs ⇐ small explicit symmetry breaking

Dilaton as Higgs impostor

SM + strongly coupled new conformal sector

Dilaton = PNGB of new conformal sector

EW scale < SSB Conformal scale << Planck scale

New particles = vector resonances,
fermions, heavier scalars

Light dilaton ⇐ small explicit conformal
symmetry breaking

$$v < f \ (<< M_{Planck}\ ?)$$

(Fundamental) Higgs + Dilaton

SM (+Majorana neutrinos) + nothing

SSB conformal symmetry ~ Planck scale

Dilaton =NGB conformal symmetry gives mass to Higgs

Renormalized theory scale invariant to all orders in PT

Addresses in one step gravity + DM + inflation + DE

[works by Shaposhnikov et al.]

Drawbacks?

If LHC does not see new states up to a few TeV

Does not address the physics up to the Planck scale

Requires "compensating" contributions at higher energies to maintain small explicit breaking effects

Enhancement of H →γγ, suppression of H →bb,cc

Alleviates the hierarchy problem

Higgs or dilaton

Higgs and dilaton

Addresses partially the hierarchy problem

Unitarity?

Scale invariance maintained via a "compensating" prescription (new states unavoidable?)

Scale invariance maintained non-perturbatively?

Discussion