

Strongly Coupled Theories BSM

Confinement XI

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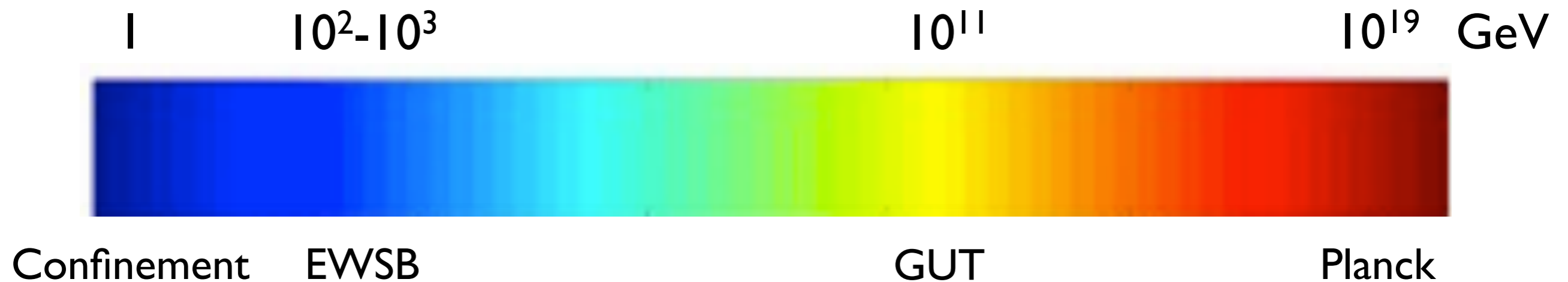
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Outline

- ▶ New Physics guided by scales
- ▶ Strongly coupled BSM theories
- ▶ The role of conformal symmetry
- ▶ To GUT and Planck scales
- ▶ LHC Phase II

Disparate Scales



Is the LHC announcing a desert from EWSB to Planck ?

Disparate Scales



Confinement

EWSB

GUT

Planck

←
Light new particles
not seen by the LHC

It cannot be a desert

Dark energy (the cosmological constant problem)

Dark matter

Baryon Asymmetry

Neutrinos: Majorana and Dirac

Muon $g-2$?

Electric Dipole Moments (EDMs) ?

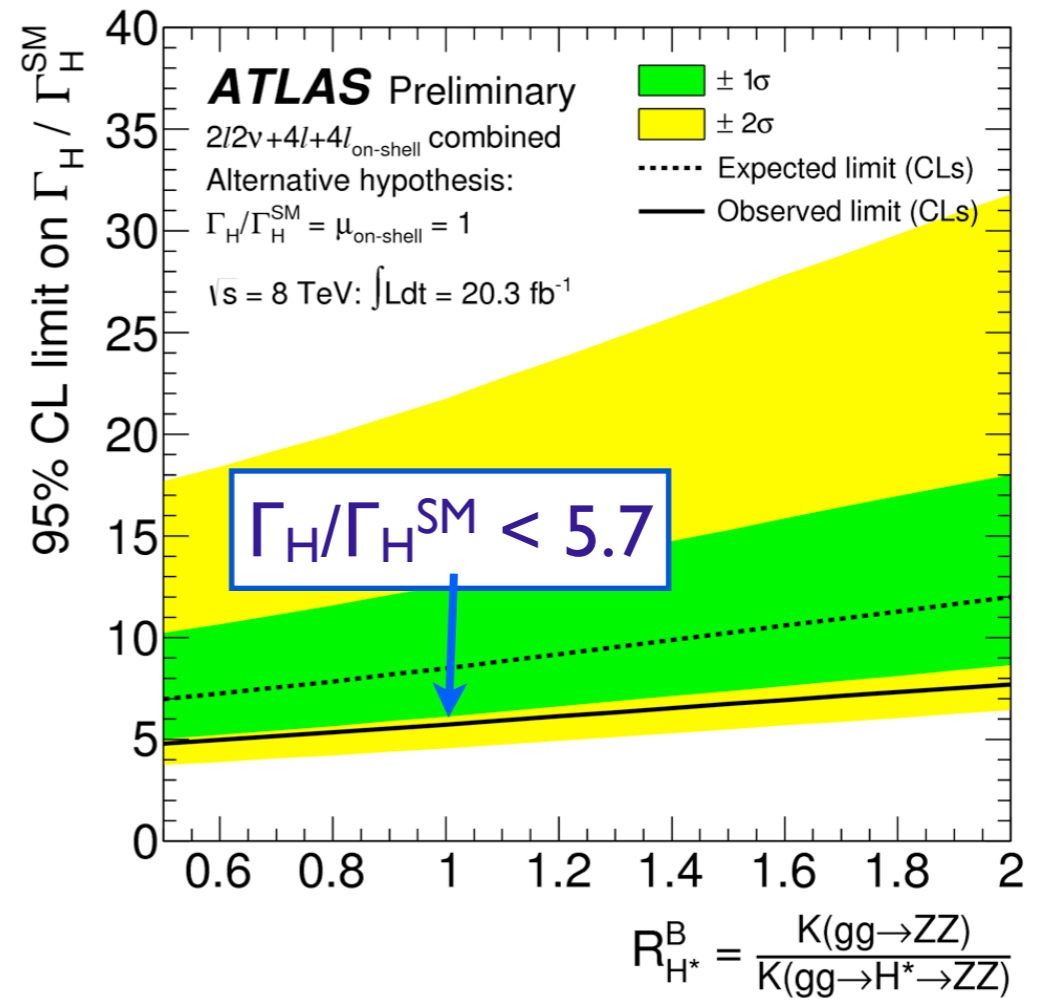
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Cosmology
& Astronomy

Particle Physics

ATLAS

Limit on Higgs full width



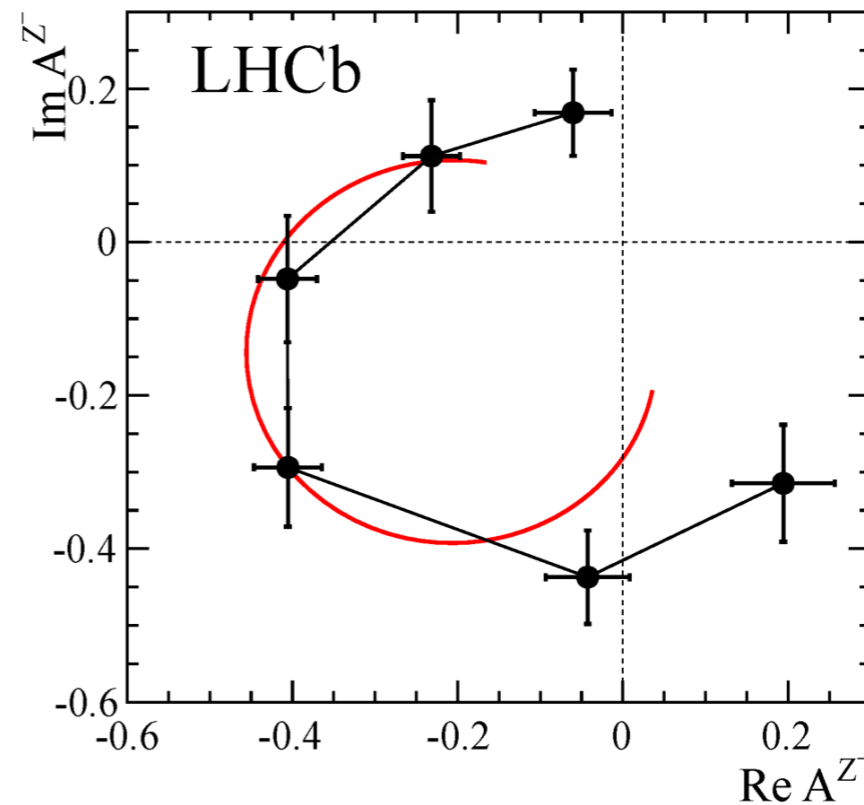
LHCb

the tetraquark $Z(4430)^-$

$c\bar{c}d\bar{u}$

$J^P = 1^+$

13.9σ

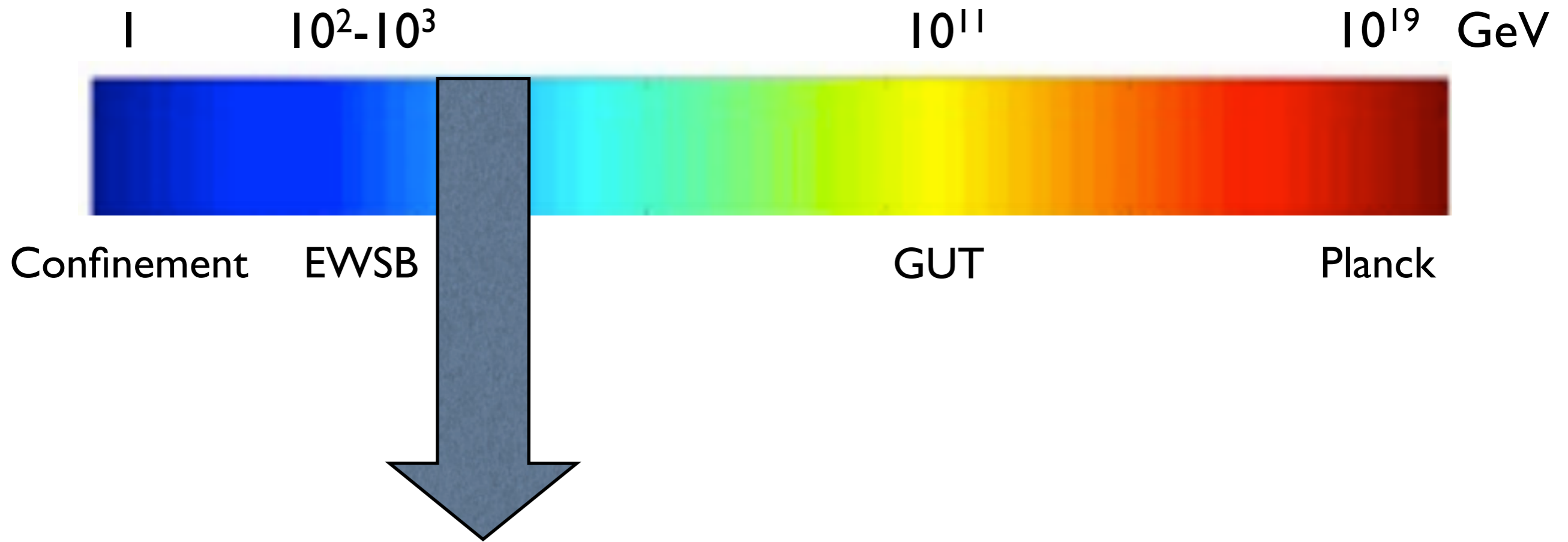


Strongly coupled BSM extensions are still on the plate

- ✓ Light Higgs boson $m_H \sim 125$ GeV possible
- ✓ S, T parameters
- ✓ FCNC suppressed

Signatures
at LHC Phase II

- ▶ couplings \neq SM prediction
- ▶ Higgs self coupling
- ▶ new resonances $>$ LHC Phase I bounds

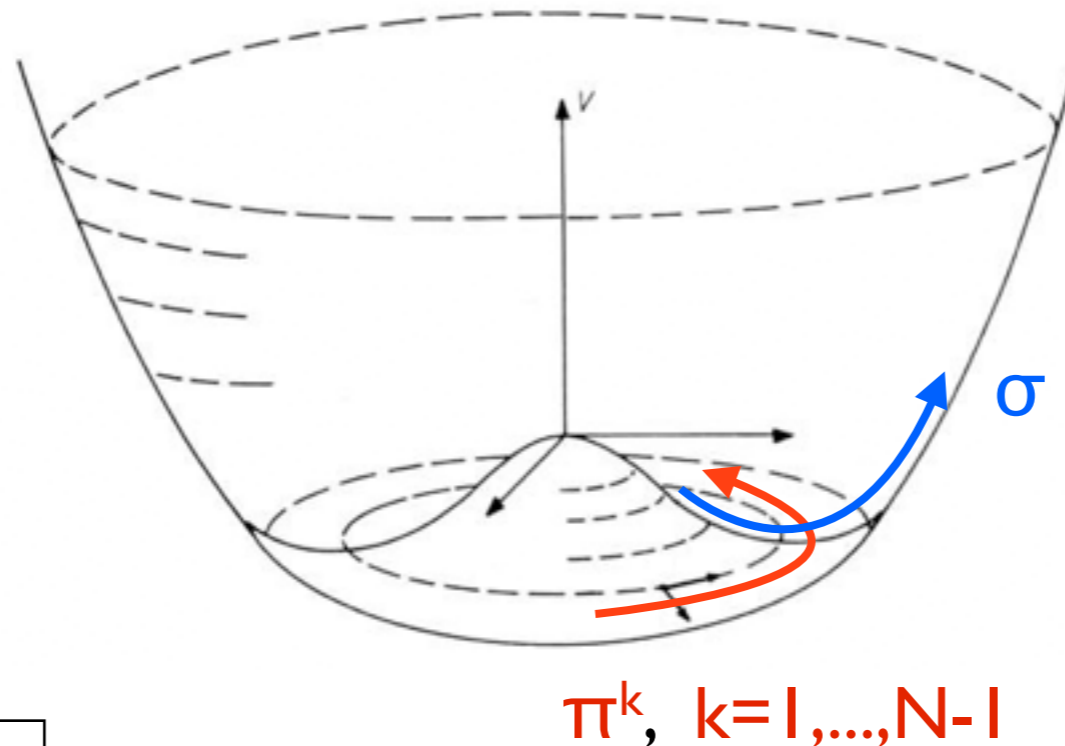


Strongly coupled BSM sector
to dynamically explain the EWSB mechanism

The birth of a composite Higgs boson

Spontaneous symmetry breaking of a global symmetry $G \rightarrow H$ $H \supset G_{SM}$

e.g. $O(N) \rightarrow O(N-1)$



σ heavy
 π^k Goldstone bosons

PGB Composite Higgs
 $\pi^k = \text{Higgs boson(s)}$

$m_H=0$
 $\langle H \rangle=0$



EWSB via Coleman-Weinberg potential

Composite Higgs
 $\pi^k = \text{Technipions}$
Scalar resonance = Higgs boson

Higgsless Technicolor
(QCD replica)
 $\pi^k = \text{Technipions}$
No scalar (very heavy)

Two scales: f_π and v

Two examples

Minimal Composite Higgs SO(5)/SO(4)

Agashe Contino Pomarol 05

$$v = \epsilon f_\pi \quad f_\pi \sim \frac{\sqrt{N}}{4\pi} m_\rho \quad m_H^2 \sim \frac{2N_c}{N} y_t^2 v^2$$

$$S, T, Zbb \Rightarrow \epsilon \lesssim 0.4$$

$$m_H \lesssim 140 \text{ GeV}$$

Minimal Walking TC

Sannino Tuominen 04

Foadi Frandsen Sannino 12

$$M_H^2 = (M_H^{\text{TC}})^2 + \frac{3(4\pi\kappa F_\Pi)^2}{16\pi^2 v^2} \left[-4r_t^2 m_t^2 - 2s_\pi \left(m_W^2 + \frac{m_Z^2}{2} \right) \right] + \dots$$

EW corrections

$$F_\Pi = v \Rightarrow (M_H^{\text{TC}})^2 \simeq M_H^2 + 12 \kappa^2 r_t^2 m_t^2$$

$$kr_t \sim TC \times ETC \sim 1 \Rightarrow M_H^{\text{TC}} \sim 700 \text{ GeV}$$

A Model independent analysis

Pich Rosell Sanz-Cillero 12

Pich Rosell Sanz-Cillero 13

$$SU(2)_L \times SU(2)_R \rightarrow SU(2)_{L+R}$$

WSR I and II:

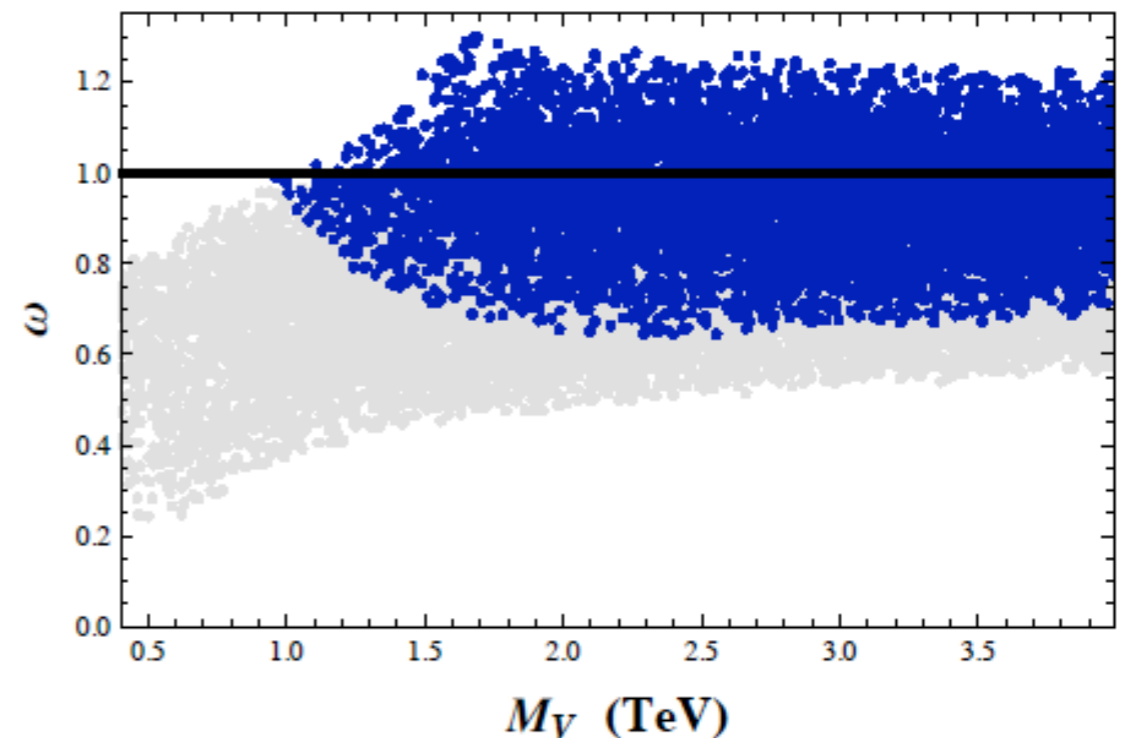
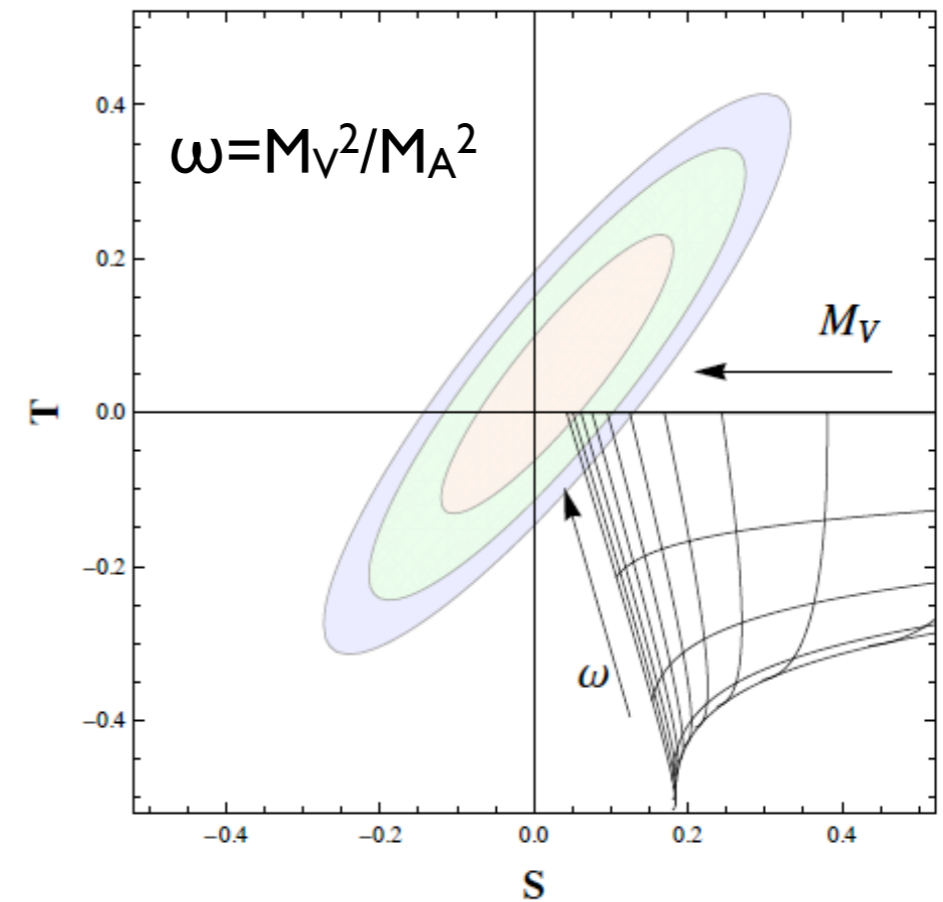
→ $\omega \in [0.94, 1]$ 95% CL : HWW close to SM

→ A, V very heavy $M_A \approx M_V > 4\text{TeV}$ 95% CL

WSR I:

allowed 68% CL region for $0 < M_V/M_A < 1$

$\omega=1$: coupling HWW = SM



Implications:

MCHM
SO(5)/SO(4)

$\omega = \cos\theta \leq 1$ (SO(4) vacuum angle) \Rightarrow viable scenario

Higgs=dilaton ?

$\omega = v/f_\phi$ $\omega \sim 1$ \Rightarrow unlikely scenario

The role of Conformal Symmetry

What is the fixed point structure of fundamental forces?

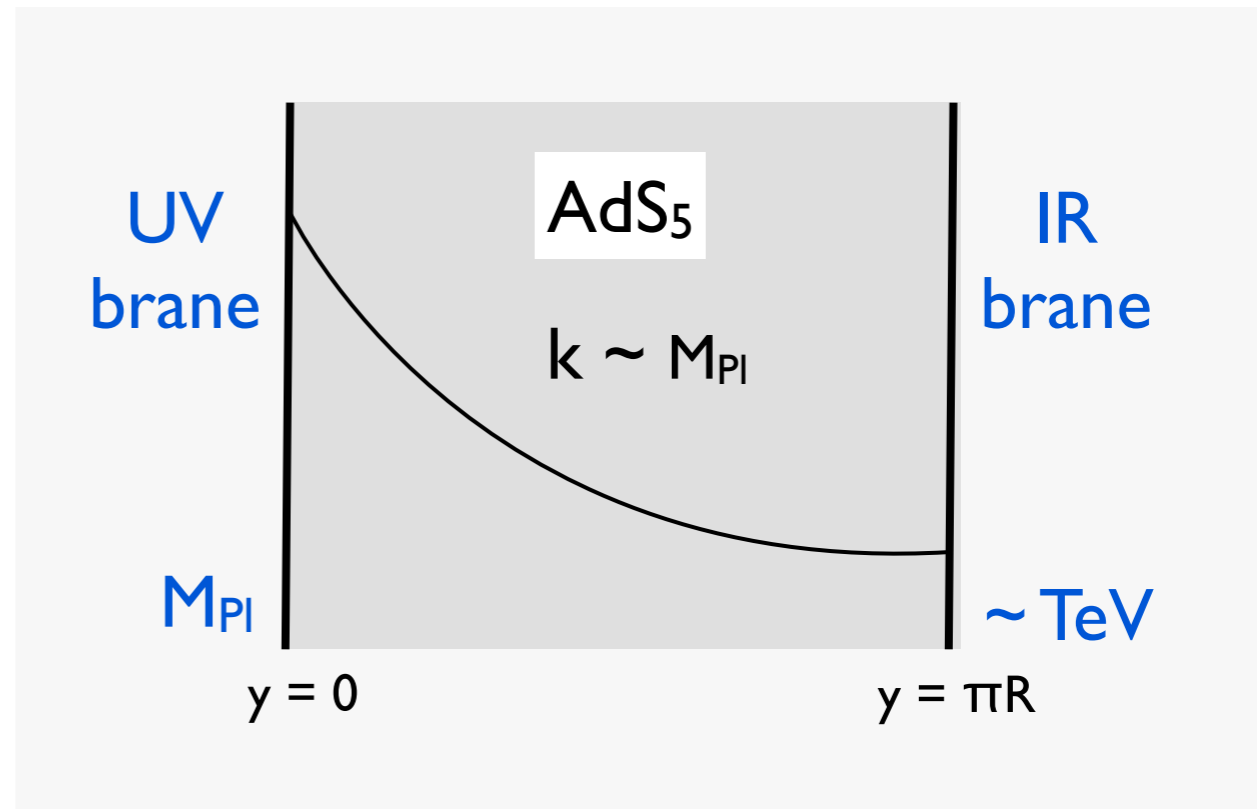
Conformal symmetry appealing because:

SM is conformal for $\mu_H=0$

BSM extensions are often rescued by quasiconformality
e.g. calculability via AdS/CFT, walking phenomenon

CMB data tell that the Universe is not, but almost is scale invariant

AdS/CFT in place (large N)



Bulk profiles $\sim k e^{-ky}$

Flavour physics

Flavour anarchy disfavoured unless custodial symmetry augmented

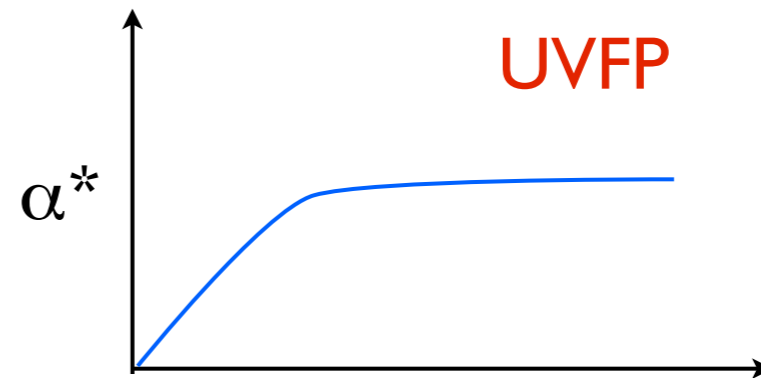
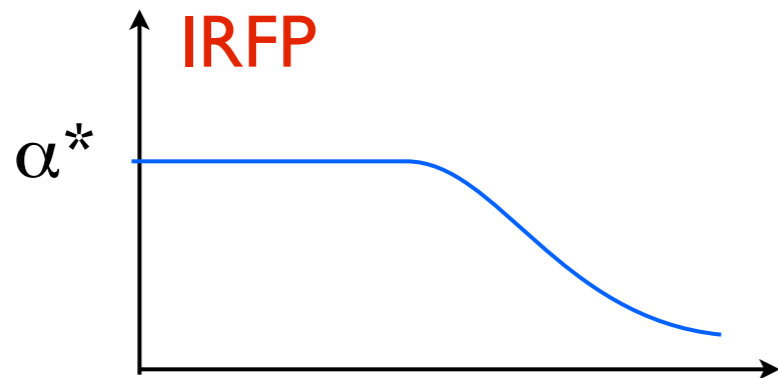
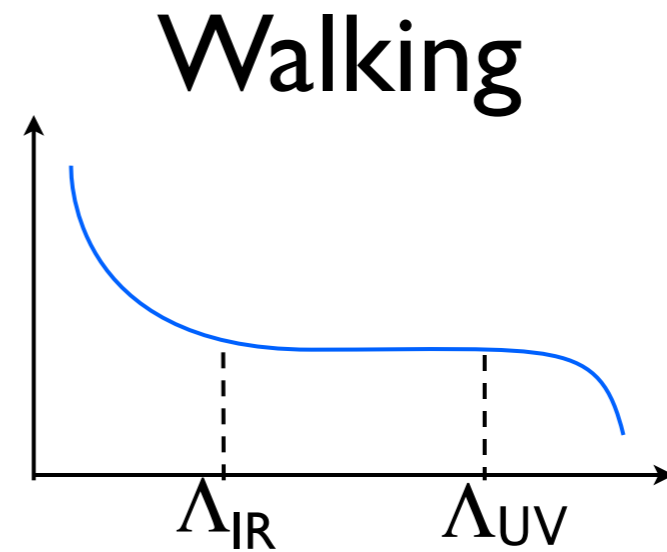
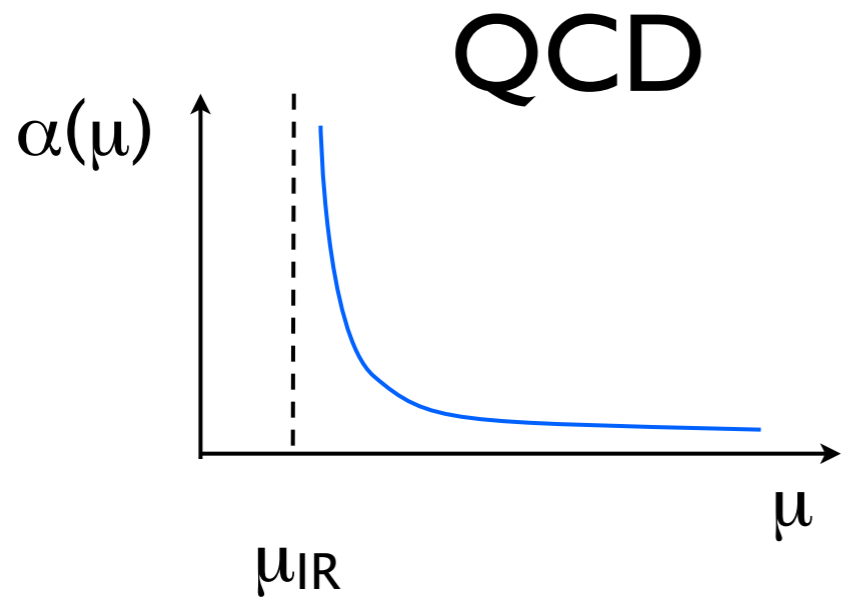
e.g. P_{LR} Agashe et al 06

Flavour hierarchy protects EDMs FCNC Z_{bb}

e.g. RS-A4 Kadosh EP II

Running coupling scenarios

Given a gauge group and a matter content look for the zeros of the β -functions



α^* RG-scheme dependent

Interacting IR or UV conformal field theories

Anomalous dimensions

Physics at the fixed point

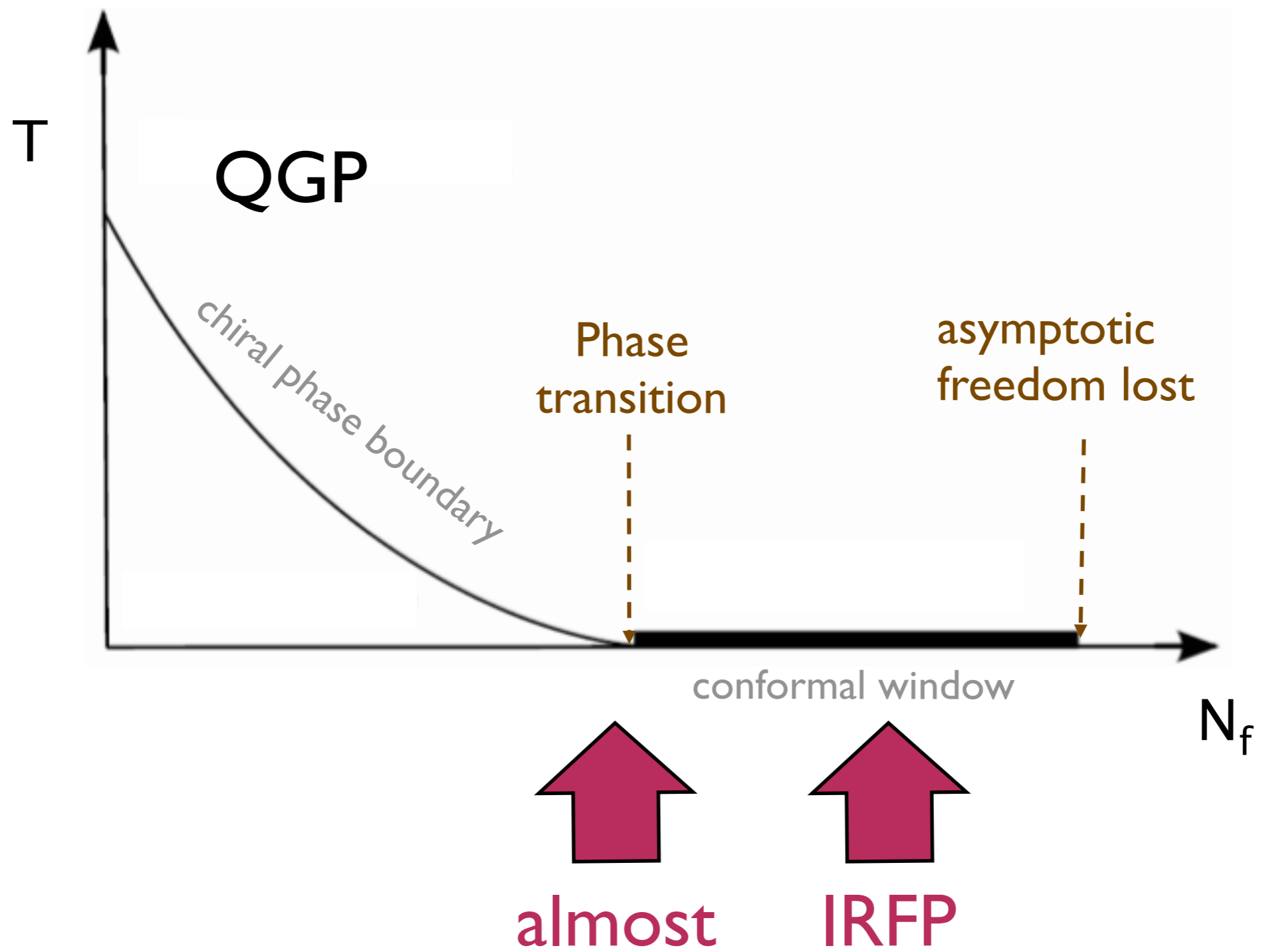
Walking and chiral condensate

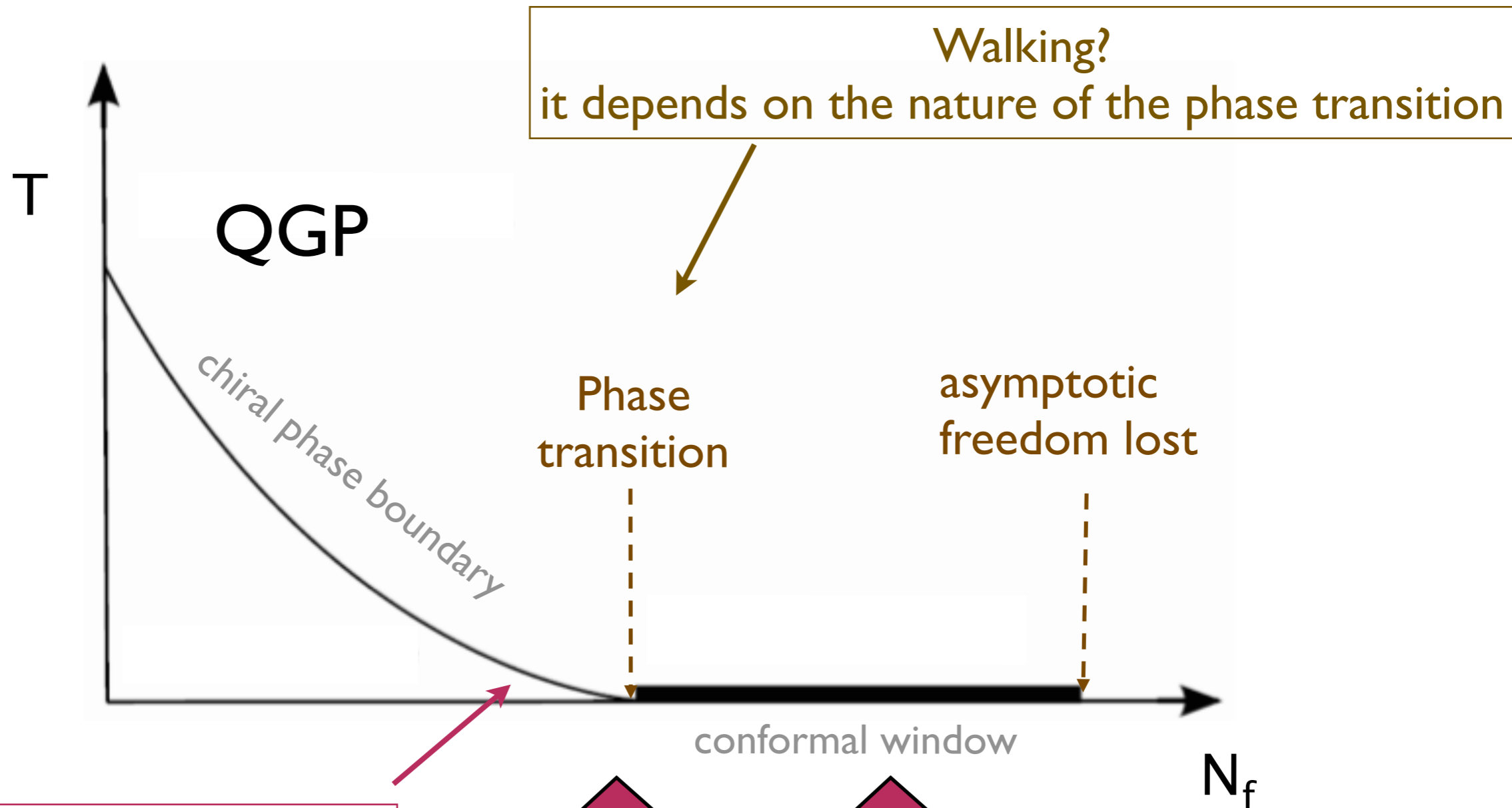
Large and slowly running anomalous dimensions

$$\langle \bar{\psi}\psi \rangle_{\Lambda'} = \langle \bar{\psi}\psi \rangle_{\Lambda} e^{\int_{\Lambda}^{\Lambda'} \frac{d\mu}{\mu} \gamma(\mu)} \simeq \langle \bar{\psi}\psi \rangle_{\Lambda} \left(\frac{\Lambda'}{\Lambda} \right)^{\gamma}$$

produce a large hierarchy of condensates : Technicolor rescued

The conformal window





What is the mass of the scalar state?
(Lattice studies)

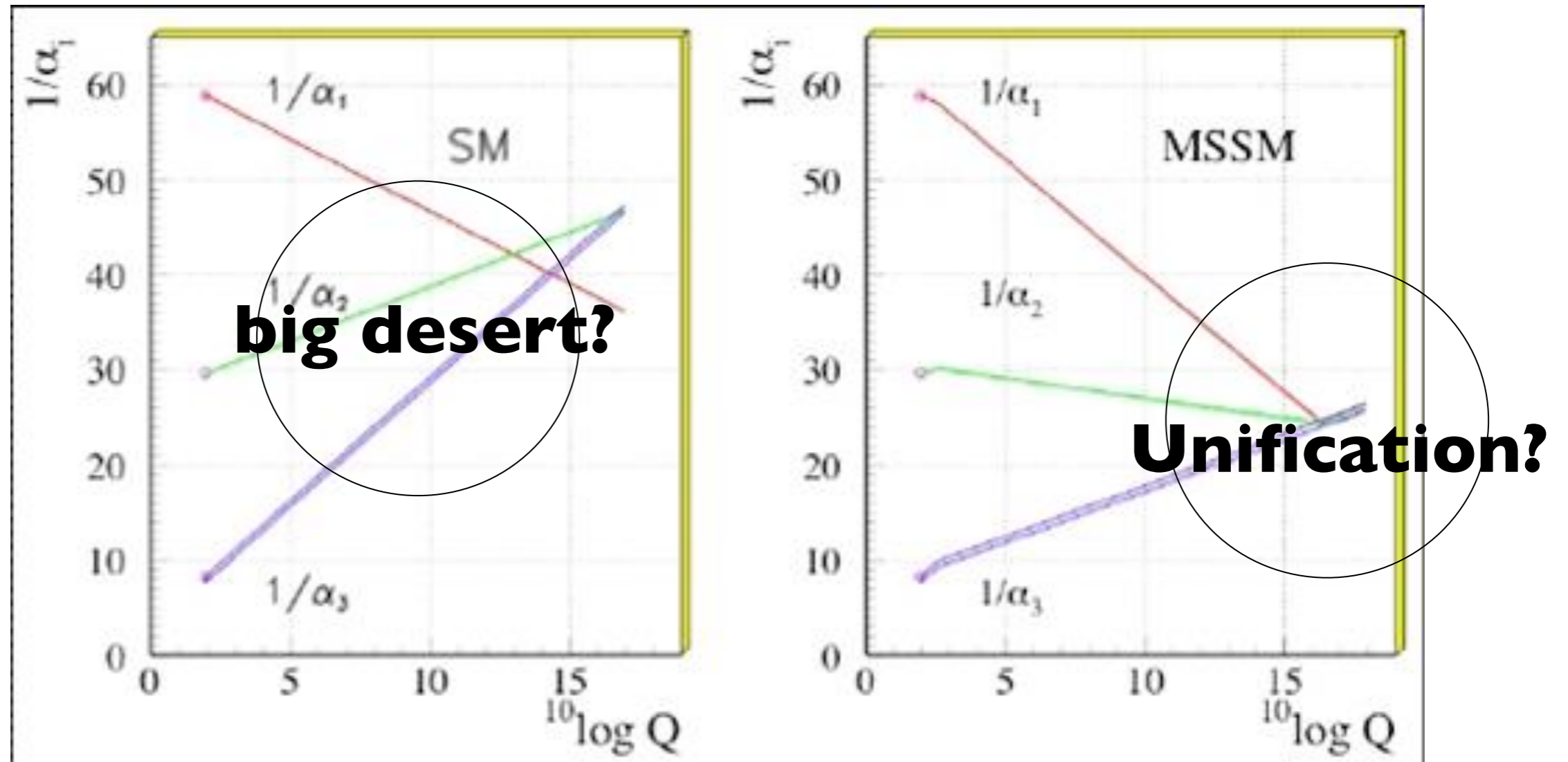
↑ almost IRFP

e.g. on conformal window
Deuzeman, Lombardo EP 09
Lombardo, Miura, Nunes, EPI4

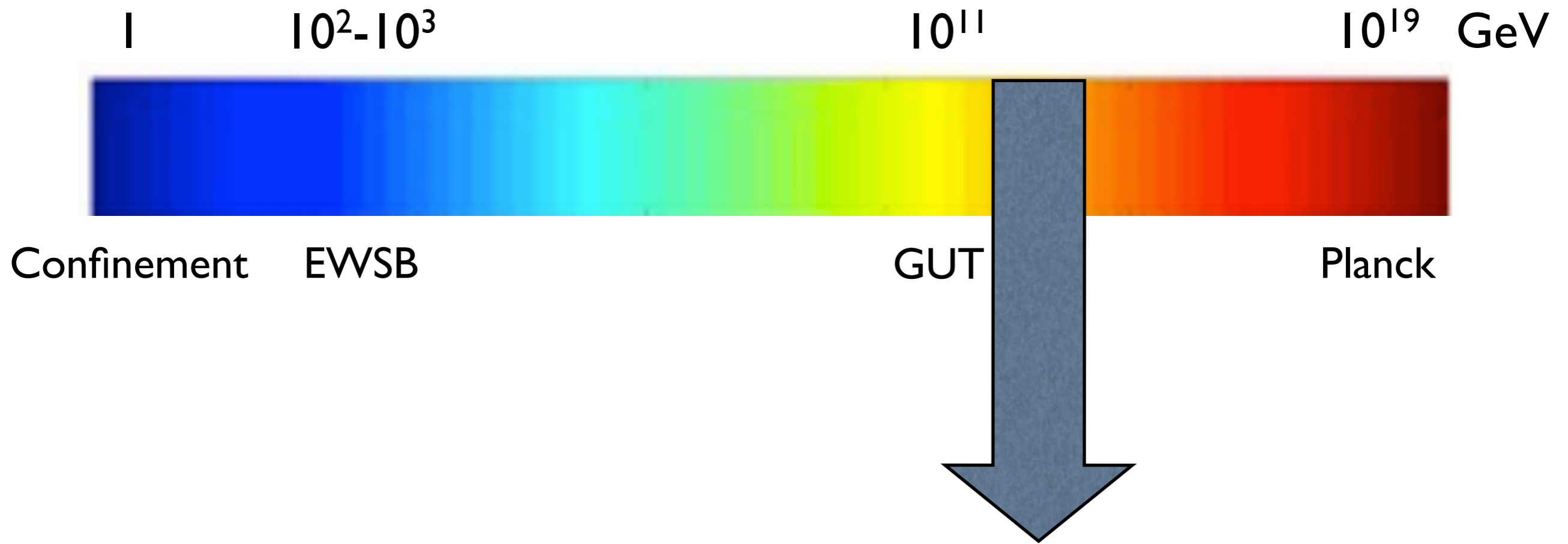
To the GUT scale

The ultraviolet fate of the Standard Model

What happens to the unification of forces?



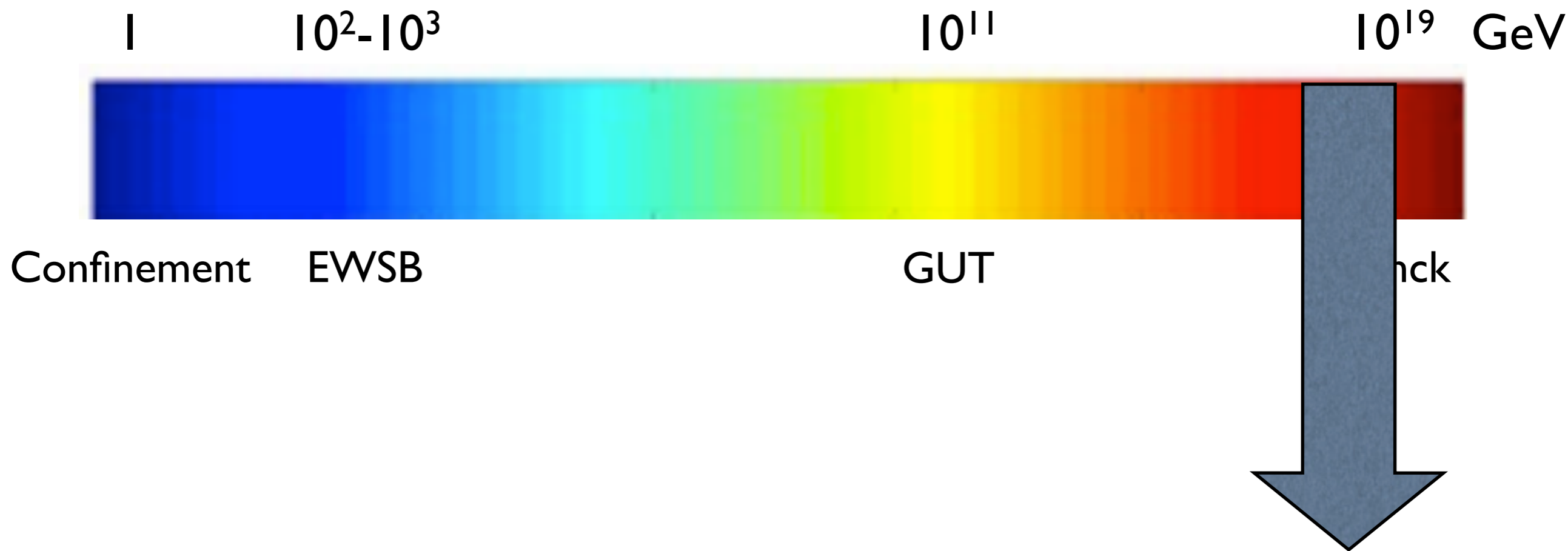
Need to determine how new physics — if there — changes the running to the Planck scale



Unification of couplings

Inflation (nonperturbative aspects arise for $\Delta\phi/\phi \gtrsim M_{\text{Pl}}$)

Stability EW vacuum



UV completion

Conformal symmetry spontaneously broken?

Still two avenues at LHC Phase II

Add new scales
⇔ new particles

(but heavier than thought)

e.g.
compositeness
supersymmetry broken at high scale

No new scale
⇔ minimal particle content

lighter than thought?

e.g.
Conformal symmetry at Planck
Need to break it spontaneously

The ultimate T-shirt, Leon Lederman



needs a formula