SUSY SPLITS

BUT THEN RETURNS

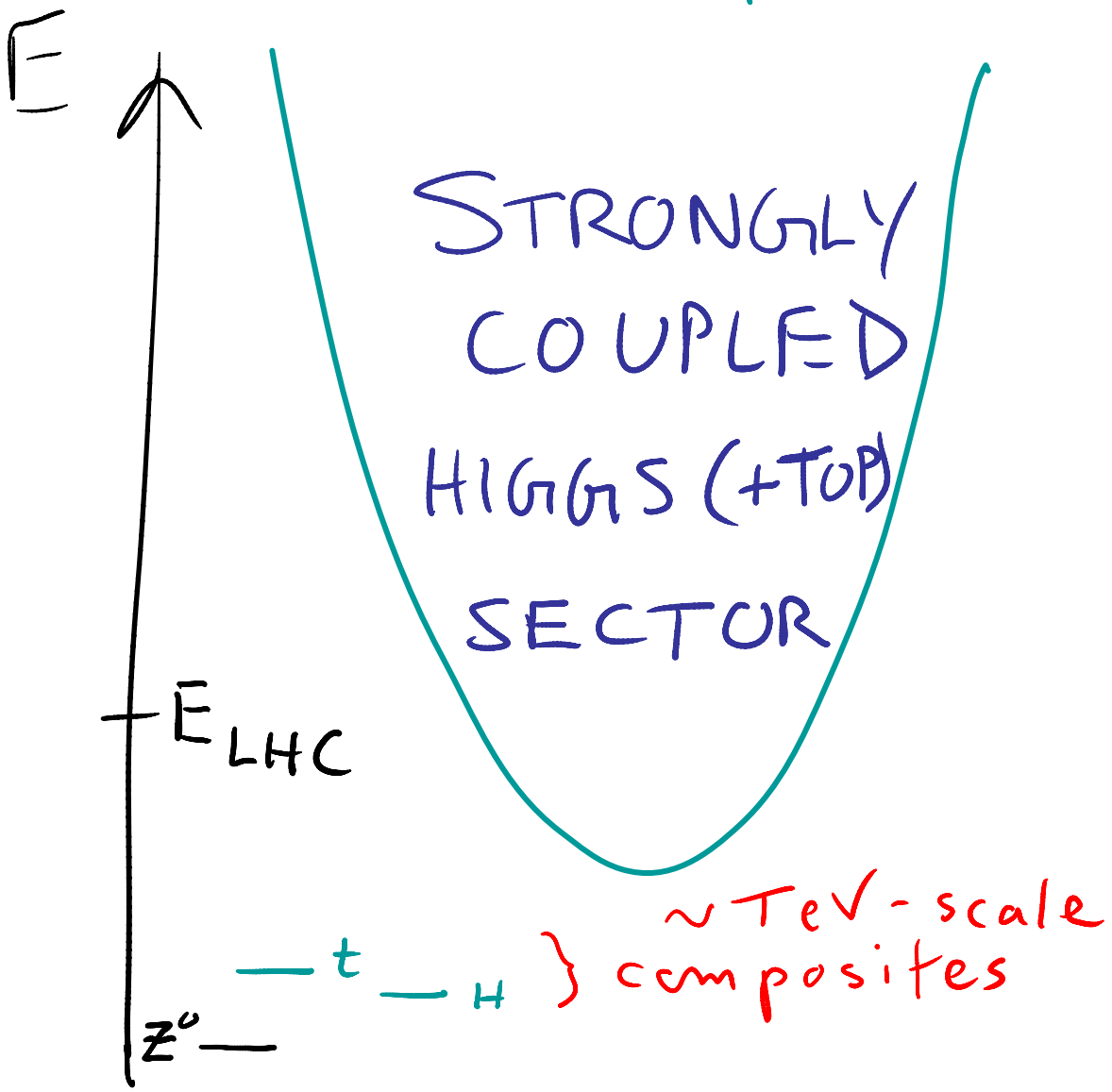
Raman Sundrum

Johns Hopkins University

(early work with Tom Kramer)

arXiv 0909.5430

HIERARCHY WITHOUT SUSY



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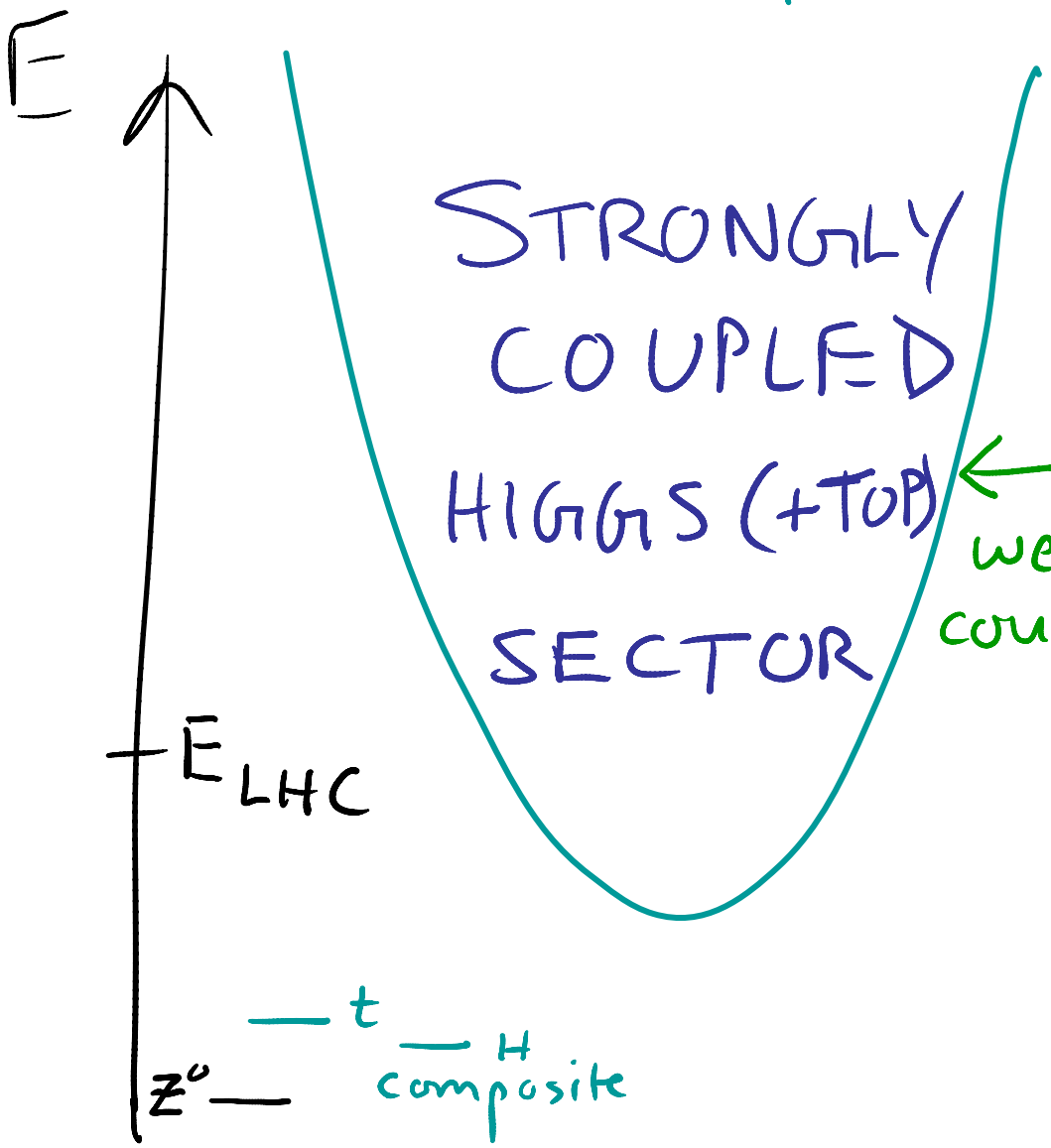


weakly coupled

gluons, W, Z, γ

+

light Fermions

METHODOLOGY

$$\mathcal{L} = -\frac{1}{4} F^2_{\mu\nu\,SM} + \mathcal{L}_{strong} + A^{\mu}_{SM} J^{strong}_{\mu} + \dots$$

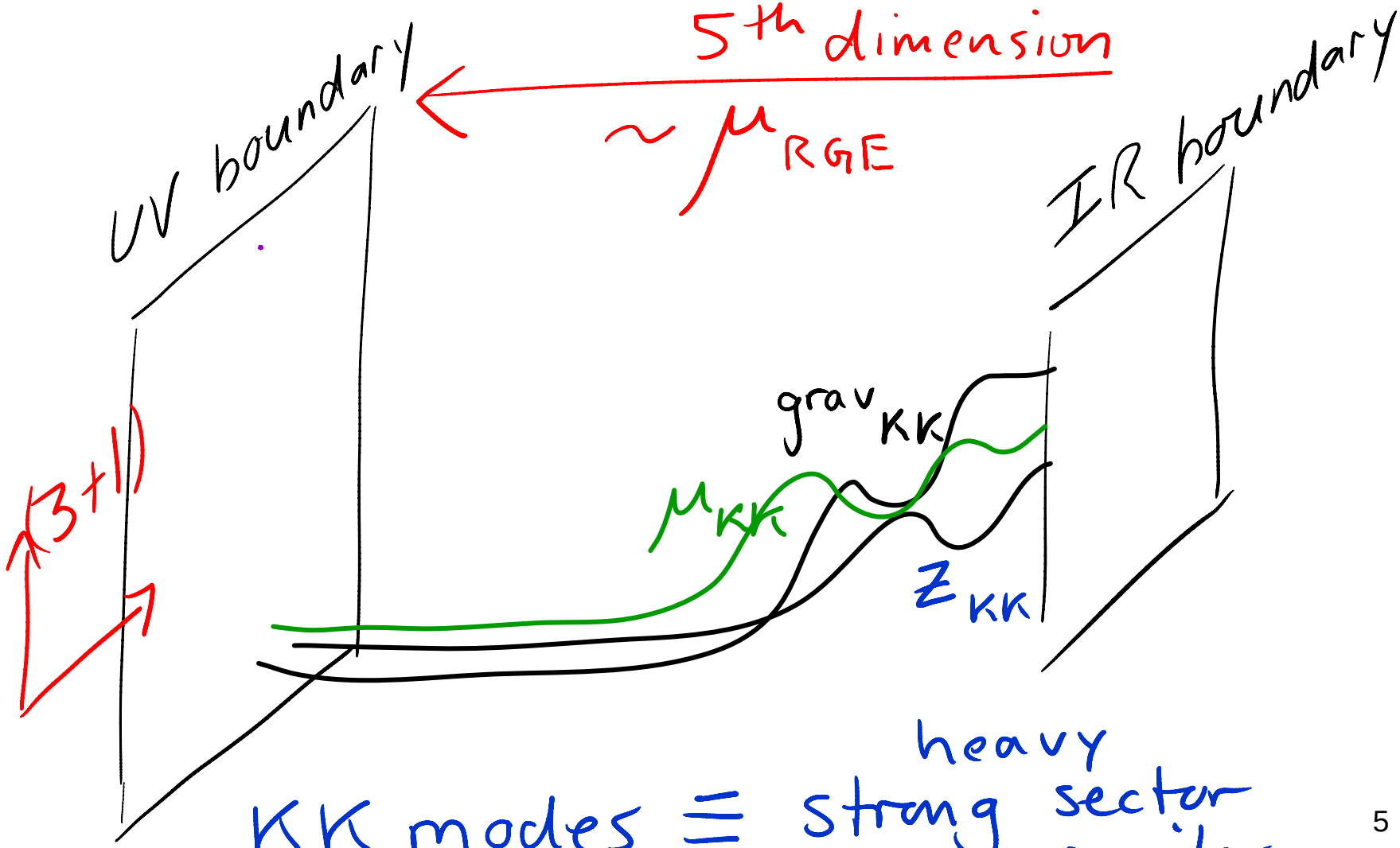
Scaling dimension of $J^{strong}_{\mu} = 3$ by current conservation

ASSUME scaling dimension $\mathcal{O}^{strong}_{(x)\,other} \gg 1$

$\Rightarrow$ $1/\dim.(\mathcal{O}^{strong}_{other})$ - EXPANSION!

⇒ WARPED COMPACTIFICATION

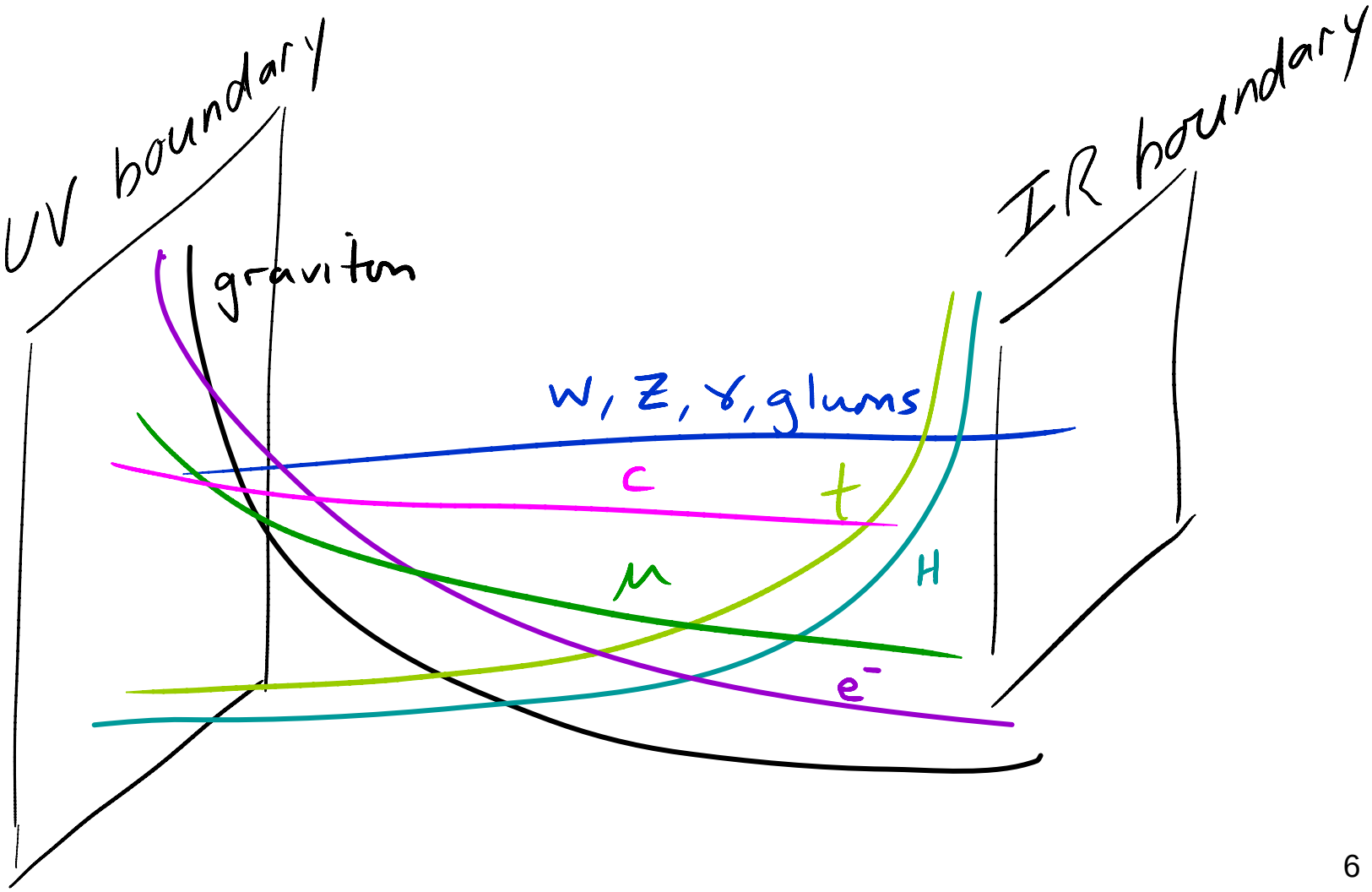
Ads/CFT



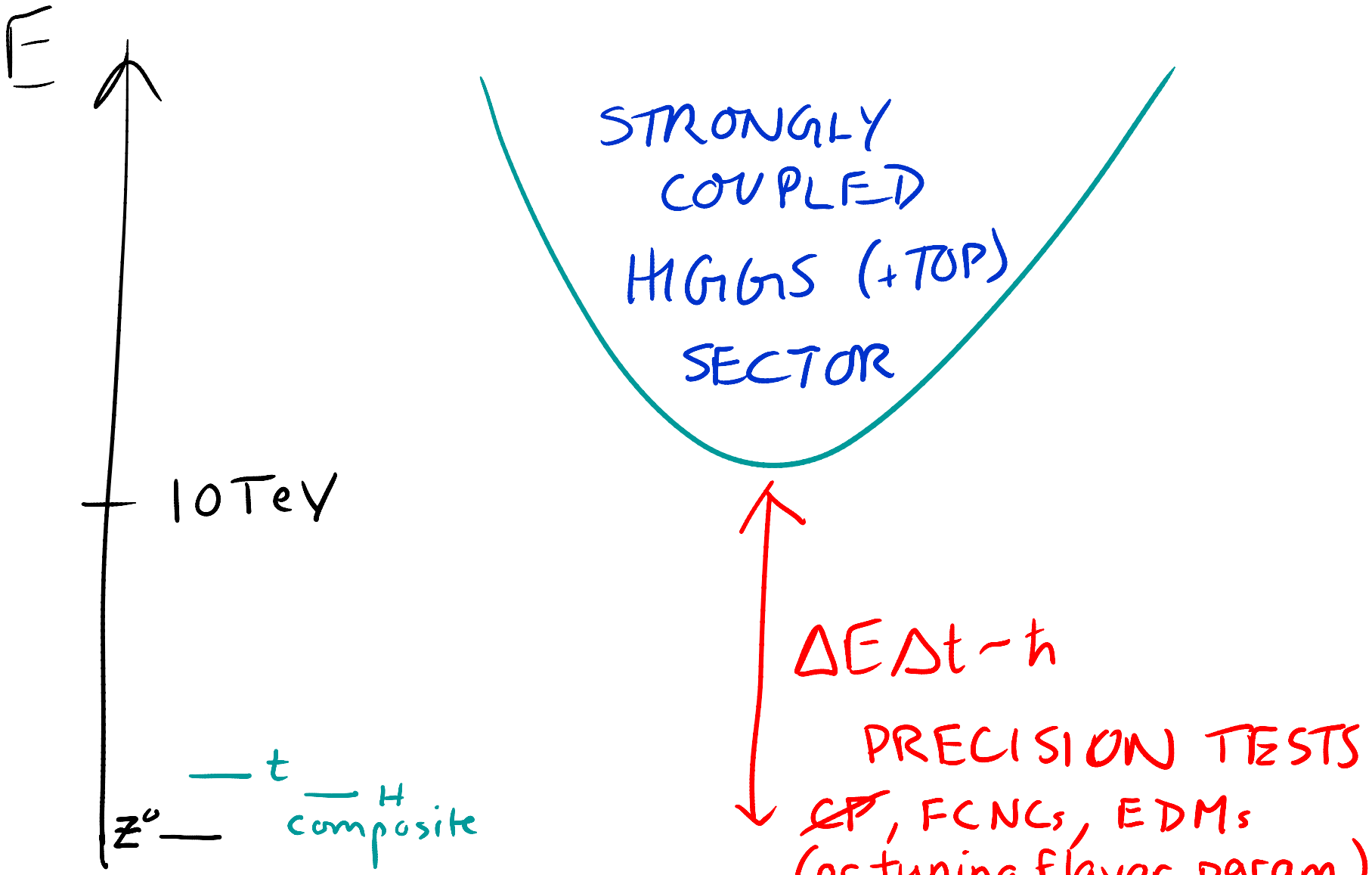
KK modes ≡ heavy strong sector composites

WARPED COMPACTIFICATION

EW + FLAVOR HIERARCHIES + $\approx$ GIM FROM WAVEFUNCTION OVERLAPS



LITTLE HIERARCHY PROBLEM



Agashe, Perez, Soni '05 ; Csaki, Falkowski, Weiler '08; Blum, Grossman, Nir, Perez '09

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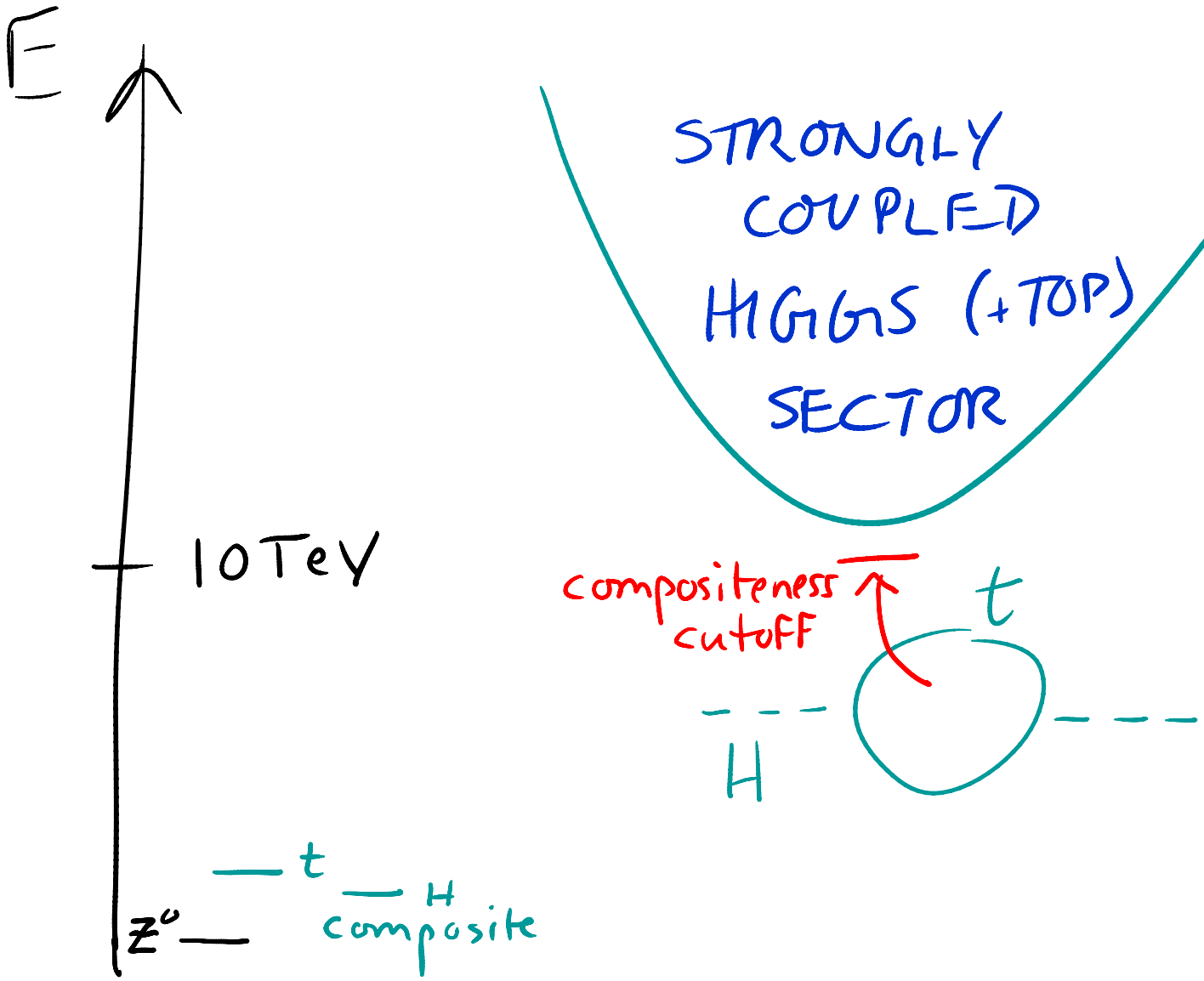
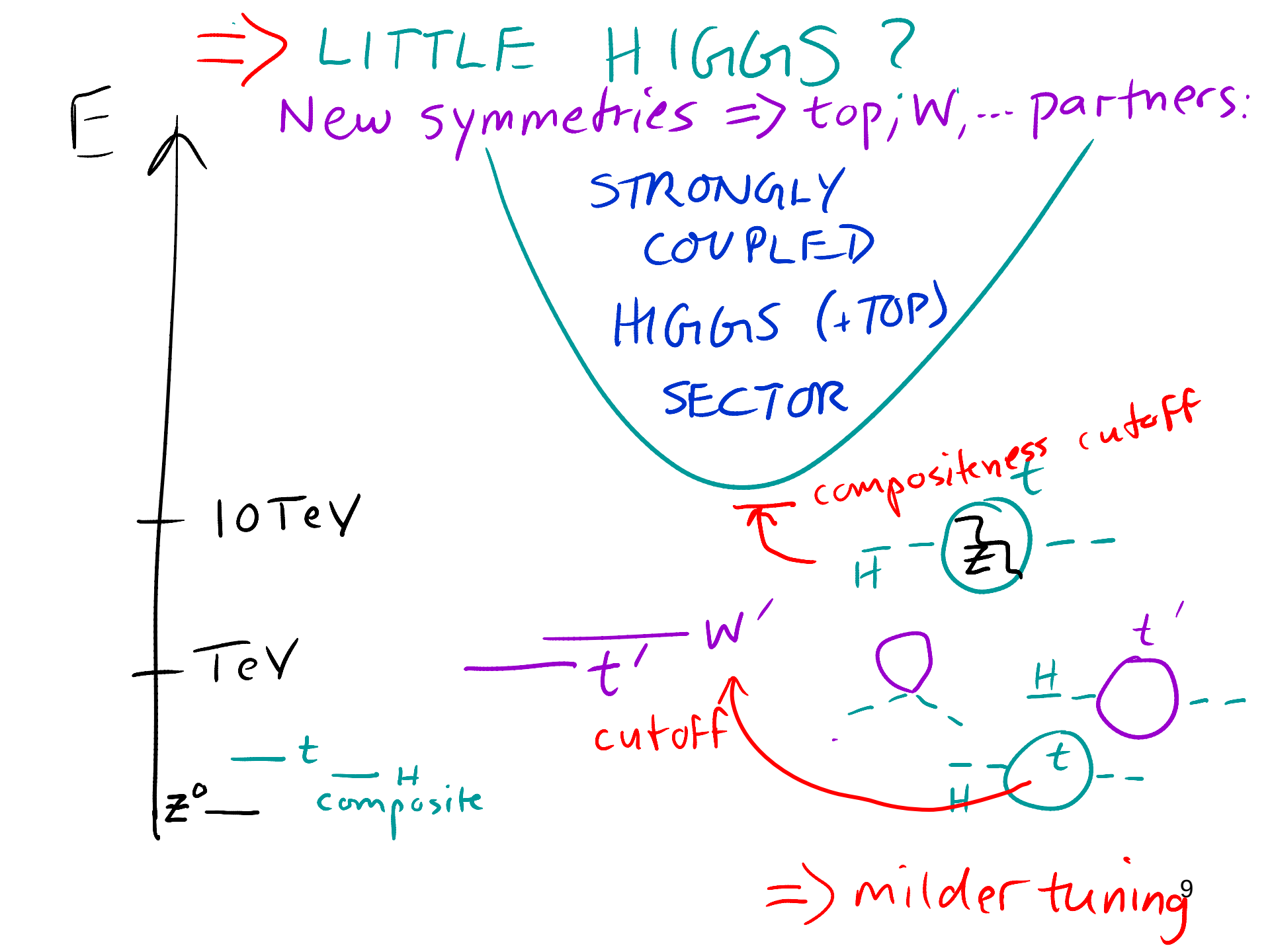
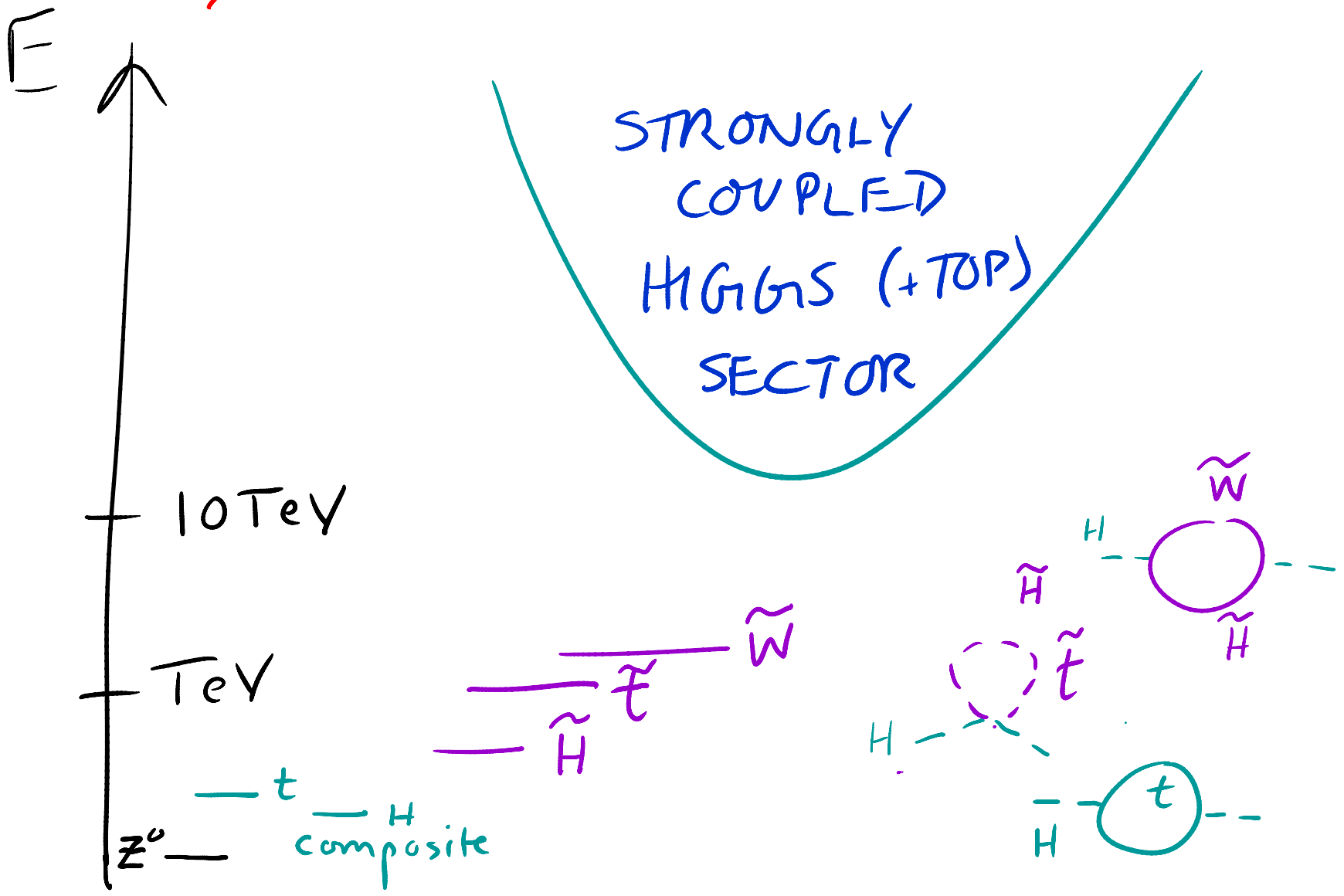


$\Rightarrow$ EW %-LEVEL TUNING


⇒ LITTLE HIGGS ?
New symmetries ⇒ top, W, ... partners:
E
STRONGLY COUPLED HIGGS (+TOP) SECTOR
10TeV
TeV
z^0
t
H
composite
compositeness cutoff
t
H
Z
W'
t'
cutoff
t'
H
t
H
t
⇒ milder tuning

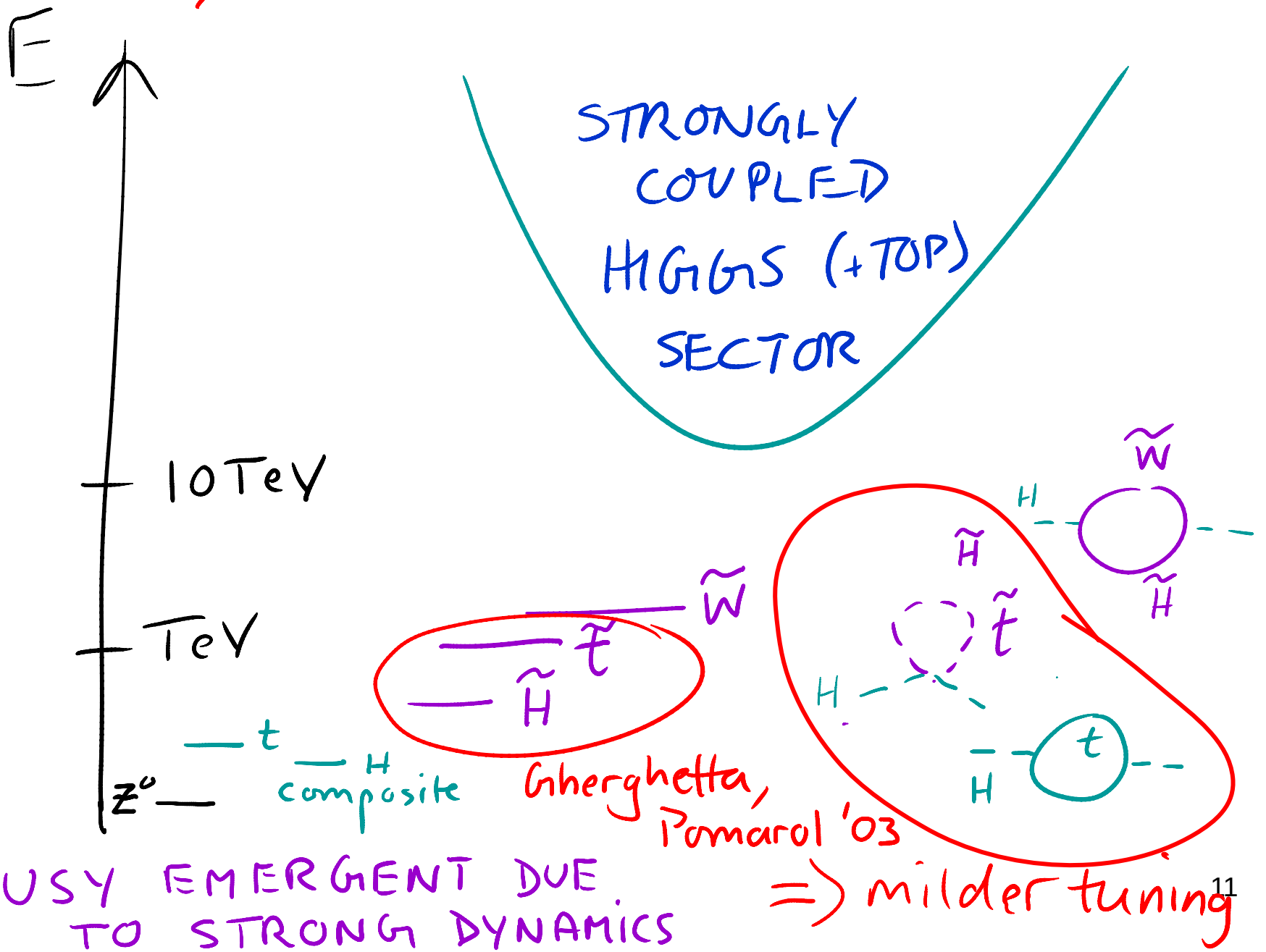
⇒ MINIMAL SUPERPARTNERS ?



SUSY EMERGENT DUE TO STRONG DYNAMICS

⇒ milder tuning

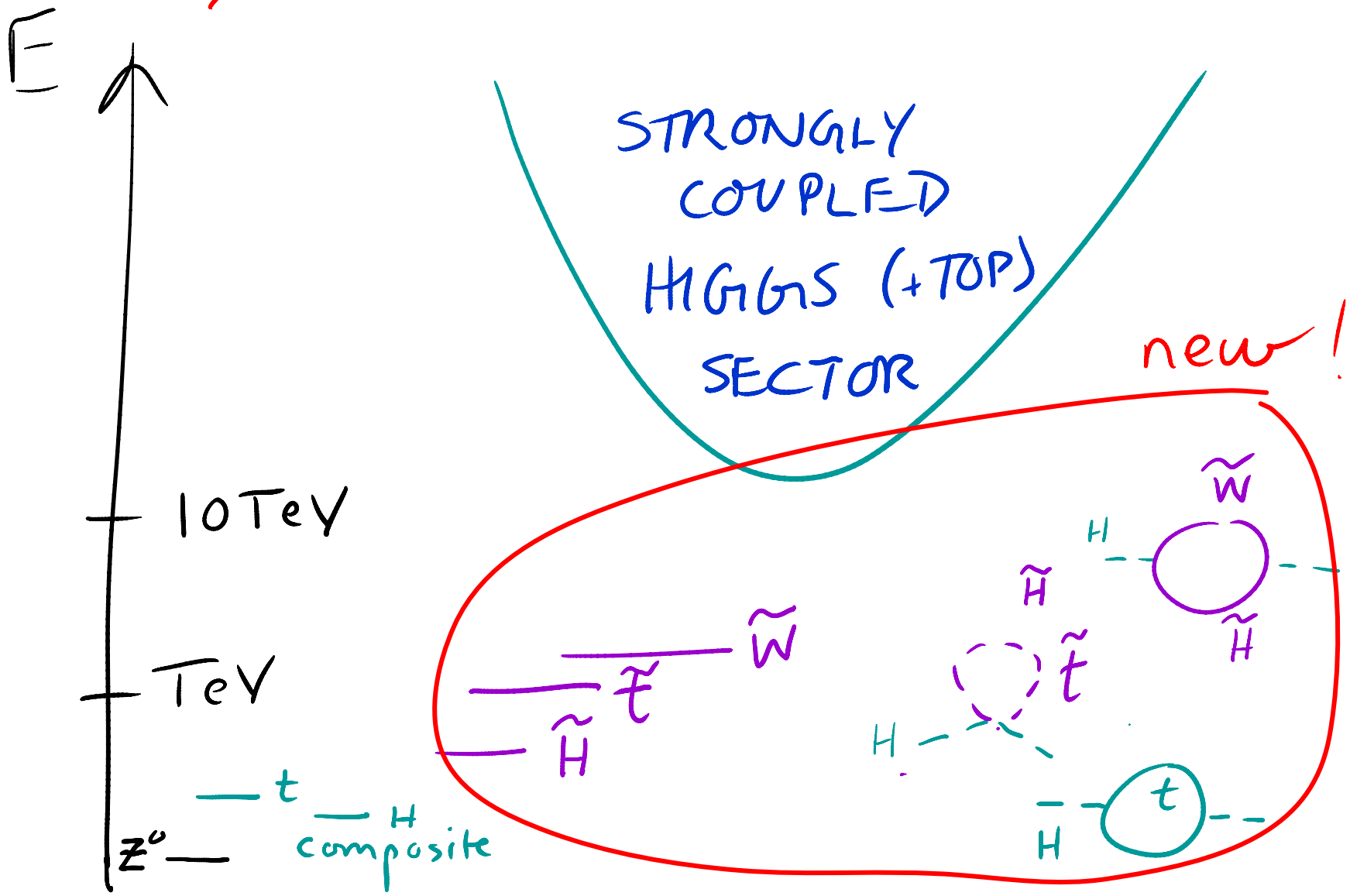
⇒ MINIMAL SUPERPARTNERS ?



SUSY EMERGENT DUE TO STRONG DYNAMICS

⇒ milder tuning

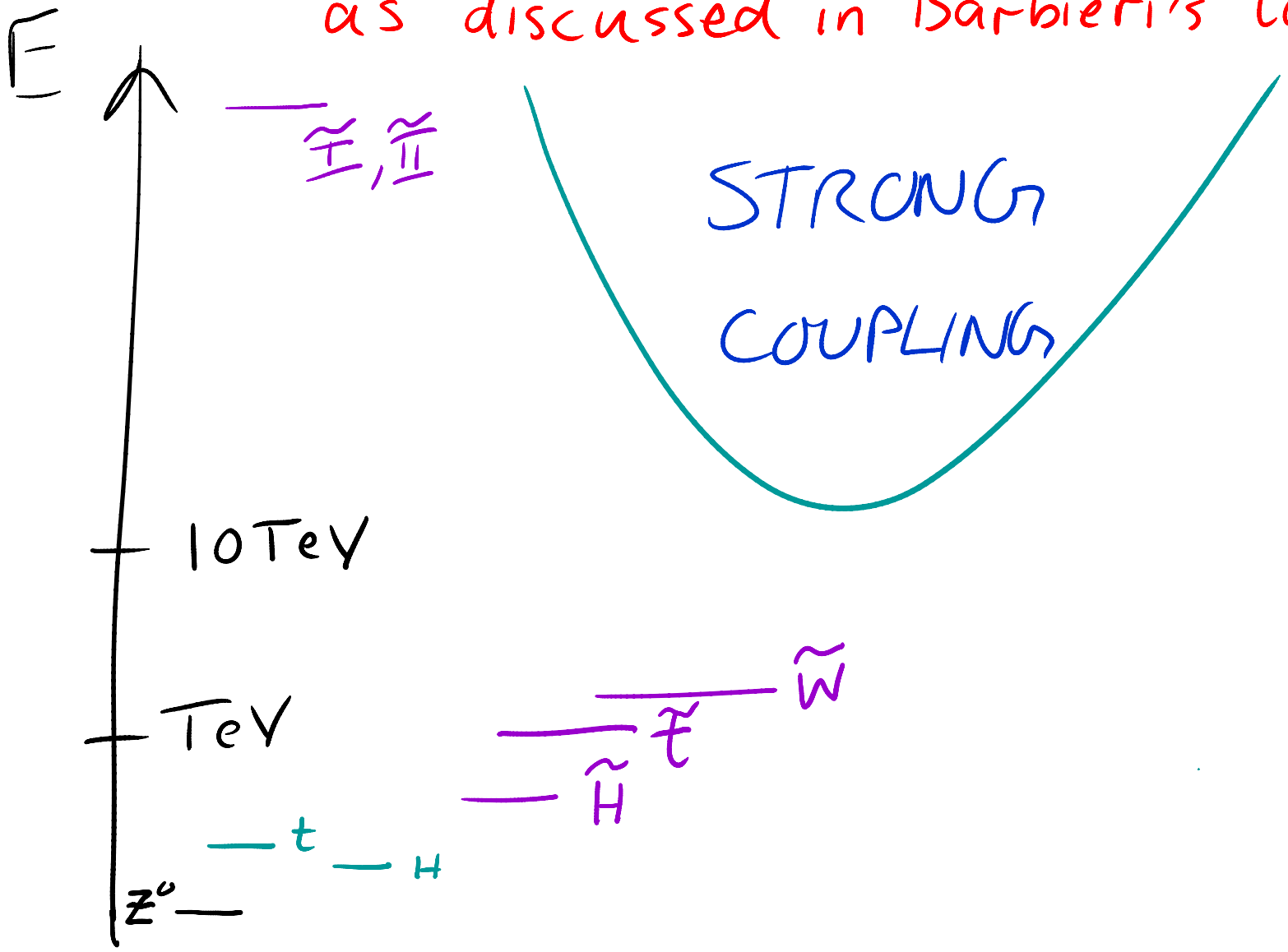
⇒ MINIMAL SUPERPARTNERS ?



SUSY EMERGENT DUE TO STRONG DYNAMICS

⇒ milder tuning

ALSO, ≈ more minimal SUSY
as discussed in Barbieri's talk



EMERGENT SUSY

$$\mathcal{L}(M_{h_i}) = -\frac{1}{4} F^{a\,2}_{\mu\nu} + \bar{\lambda} i D.\sigma \lambda$$

Weyl adjoint

D.B. Kaplan '84

$$+ \frac{\bar{\lambda}\bar{\lambda}\lambda\lambda}{M^2}$$

no mass $\lambda\lambda$ by chiral symmetry

IR irrelevant ~~SUSY~~ => accidental "emergent" SUSY @ low-E.

SUSY SPLITS, BUT THEN RETURNS

SUSY > M, broken @ M, returns ≪ M.

$$\mathcal{L}(M_{hi}) = -\frac{1}{4} F^{a\,2}_{\mu\nu} + \bar{\lambda} i D.\sigma \lambda$$

Weyl adjoint

$$+ \frac{\bar{\lambda}\bar{\lambda}\lambda\lambda}{M^2}$$

no mass $\lambda\lambda$ by chiral symmetry

IR irrelevant ~~SUSY~~ ⇒ accidental

re-"emergent" SUSY @ low-E.

SUSY MATTER CANNOT "EMERGE" ....

$$\mathcal{L}(M_{hi}) = \int d^4\theta\, |\Phi_i|^2 + \int d^2\theta\, W(\Phi) + M^2 \Sigma_i |\varphi_i|^2$$

↑ can't forbid by any non-SUSY symmetry

... WITHOUT STRONG COUPLING

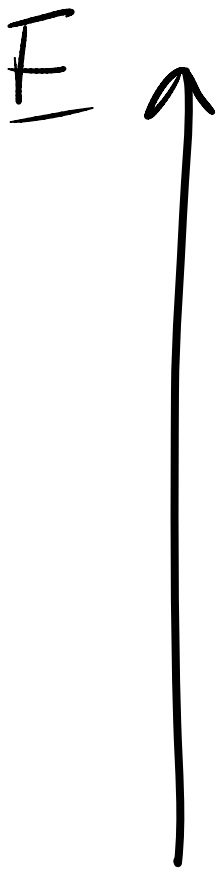
scaling dimension $\Sigma_i |\varphi_i|^2 > 4$?

Luty, Rattazzi '99

Warped modeling + other physics: Goh, Luty, Ng '03

"ISING MODEL"

Strassler '03



$N=4$ SYM + $\mathcal{O}_{\not{SUSY}}$

$N=4$ SYM ?

adjoint squarks $\phi_{I=1,\cdots,6}$:

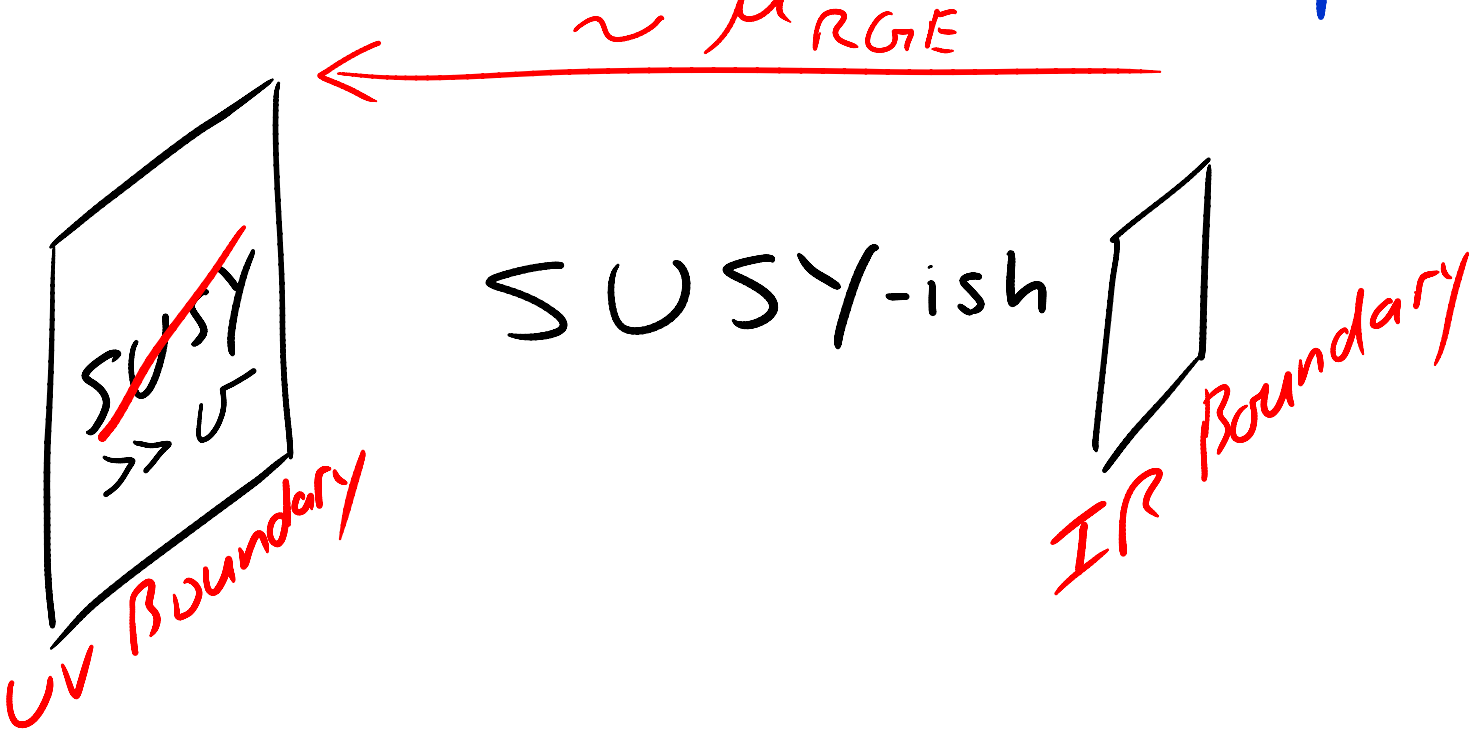
$$\text{dimension}^{\text{scale}}\left(\text{tr}\sum_I |\phi_I|^2\right) \gg 4 \; !$$

AdS/CFT

"ISING MODEL" + Quantum Gravity

Kachru, Simic, Trivedi '09

String theory in KKLT warped compactification



FIGHTING A STRONG CURRENT

Strong Higgs sector $\ni$ flavor symmetry

conserved currents

$\supseteq SU(3) \times SU(2) \times U(1)$

& has emergent SUSY

$\Rightarrow (J_\mu, \Psi_J, D)$ composite operator super-multiplet

scale dimension $3, 5/2, 2$

$\mathcal{L}(M_{hi}) \ni M^2 D_{U(1)_Y}$ destroys hierarchy!!

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scale dimension $3, 5/2, 2$

$\mathcal{L}(M_{hi}) \ni M^2 D_{U(1)_Y}$ destroys hierarchy!!

$\Rightarrow$ EXTEND SM Gauge sym. Eg. $\dfrac{SU(3) \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}}{\mathbb{Z}_2}$ left-right

Strong + (A_μ, λ) RGE

$$\mathcal{L} = \mathcal{L}_{strong} + \int d^2\theta \, W_\alpha^2$$

supersymmetric

$$+ g A_\mu J^\mu + \tilde{g} \lambda \Psi_J + g_D^2 D^2 + \text{irrelevant}$$

only "hard" ~~SUSY~~.

(Exact SUSY $\equiv$ $g = \tilde{g} = g_D$)

RGE in Warped limit ("$1/N$-limit") of (AdS/CFT dual of) Strong Dynamics

$$\frac{d\tilde{g}^2}{d\ln\mu} = b_{strong}\tilde{g}^4$$

$$\frac{dg^2}{d\ln\mu} = b_{strong}g^4$$

$$\frac{dg_D^2}{d\ln\mu} = b_{strong}g_D^4$$

$$\frac{\tilde{g}^2-g^2}{g^2} = \frac{\Delta\tilde{g}^2}{g^2} \approx \frac{g^2}{g_0^2}\cdot\frac{\Delta\tilde{g}_0^2}{g_0^2}$$

$\ll 1$ by IR Freedom

$$\frac{\Delta g_D^2}{g^2} \approx \frac{g^2}{g_0^2}\cdot\frac{\Delta g_{D0}^2}{g_0^2}$$

SUSY returns!

IMPORTANT SUBLEADING CORRECTIONS

$$\frac{d\tilde{g}^2}{d\ln\mu} = b_{strong}\,\tilde{g}^4$$

scaling dimension(D^2) = 2 × scaling dimension(D) + $\gamma_{anomalous}$

$$\frac{dg^2}{d\ln\mu} = b_{strong}\,g^4$$

$$\frac{dg_D^2}{d\ln\mu} = b_{strong}\,g_D^4 - \gamma\,\Delta g_D^2,$$

$$\gamma = \frac{n}{12\pi^2 b_{strong}}$$

for SU(n) SYM

in warped modeling

Strong + (A_μ, λ) RGE

+ light fermions

$$\mathcal{L}(M_{hi}) = \underbrace{\mathcal{L}_{strong} + \int d^2\theta\, W_\alpha^2}_{\text{supersymmetric}}$$

$$+ g A_\mu J^\mu + \tilde{g} \lambda \Psi_J + g_D^2 D^2$$

$$+ \bar{\psi} i \not{D} \psi_{light} + |D_\mu \varphi|^2 - M^2 |\varphi|^2 + \cdots$$

Strong + (A_μ, λ) RGE

+ light fermions

$$\mathcal{L}(M_{hi}) = \underbrace{\mathcal{L}_{strong} + \int d^2\theta\, W_\alpha^2}_{\text{supersymmetric}} + g A_\mu J^\mu + \tilde{g}\lambda\Psi_J + g_D^2 D^2$$

$$+ \underbrace{\bar{\psi} i\not{D} \psi_{light}}_{\text{non-SUSY particle content.}} + |D_\mu \varphi|^2 - M^2|\varphi|^2 + \cdots$$

Integrate out

IMPORTANT SUBLEADING CORRECTIONS

$$\frac{d\tilde{g}^2}{d\ln\mu} = b_{strong}\,\tilde{g}^4$$

$$\frac{dg^2}{d\ln\mu} = (b_{strong} + b_{elementary})\,g^4$$

$$\frac{dg_D^2}{d\ln\mu} = b_{strong}\,g_D^4 - \gamma\,\Delta g_D^2$$

$$g_0^2 = \tilde{g}_0^2 = g_{D_0}^2 \Rightarrow \frac{\Delta\tilde{g}^2}{g^2} = b_{elt.}\,g^2 \ln(m_\phi/\mu)$$

$$\frac{\Delta g_D^2}{g^2} = \frac{b_{elt.}}{\gamma}\,g^2\left[\left(\frac{m_\phi}{\mu}\right)^\gamma - 1\right]$$

$<$ Compositeness Scale ~ 10 TeV

H, t → super-mult.

$$\mathcal{L}_{eff} = \mathcal{L}_{SYM} + \int d^4\theta \, \Phi^\dagger e^{gV} \Phi + \int d^2\theta \, W_{eff}(\Phi)$$

$$+ \Delta\tilde{g}\, \varphi^\dagger \lambda \psi_\Phi - \Delta g_D^2 \sum_\varphi \underbrace{(\varphi^\dagger T^a \varphi)}_{D^a_{eff}}{}^2$$

$$+ \bar{\psi} i \not{D} \psi_{elementary}$$

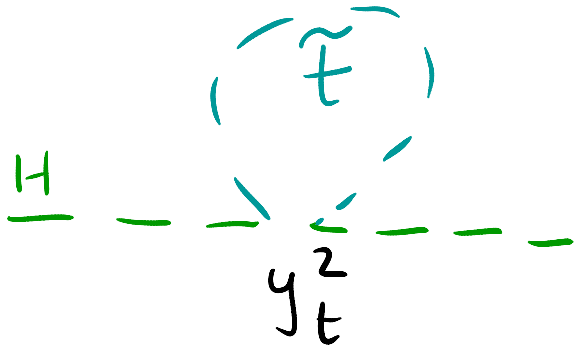
+ v. small Yukawa couplings for $\psi_{elt.}$

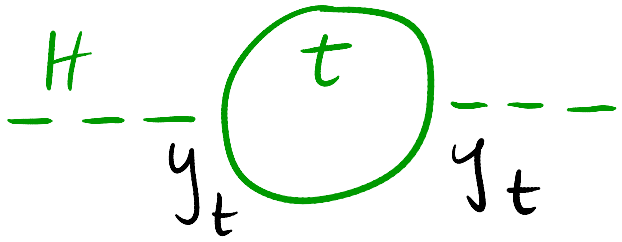
$$\Rightarrow \Delta m_\varphi^2 \sim \frac{\Delta g^2}{16\pi^2} \Lambda_{comp}^2$$

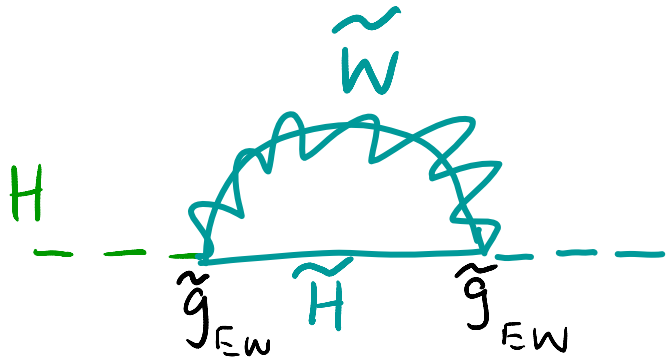
$$\sim \frac{g^4}{16\pi^2} \frac{b_{elt.}}{\gamma} \left[\left(\frac{m_\varphi}{\Lambda_{comp}} \right)^\gamma - 1 \right] \Lambda_{comp}^2$$

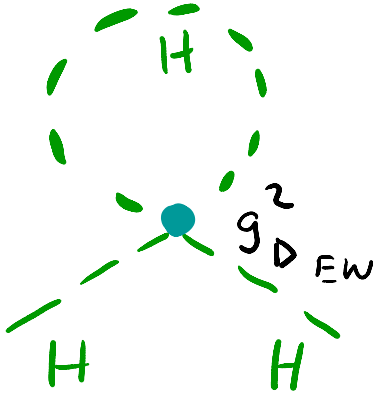
LITTLE SUSY

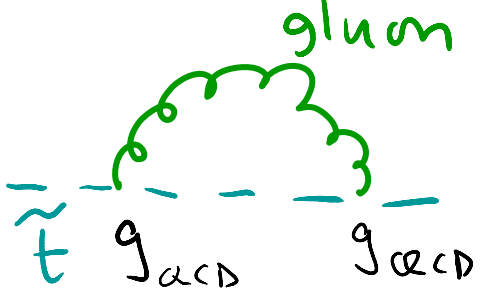
to solve Little Hierarchy Problem $\lesssim$ 10 TeV

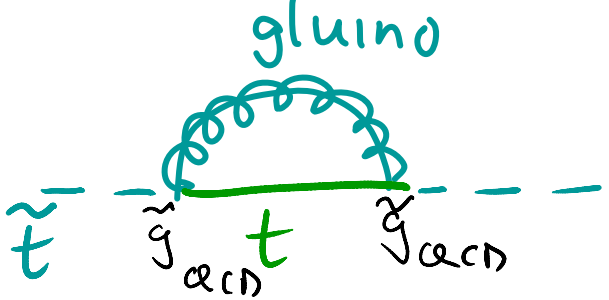


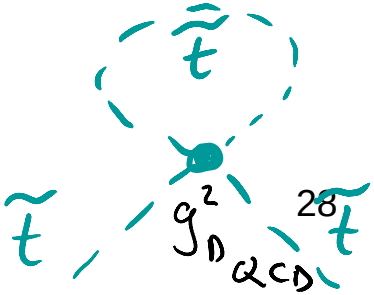












SAMPLE NUMBERS (Conservative)

For simplicity H + III generation super-composite

$$A_\mu = \frac{SU(3) \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}}{\mathbb{Z}_2} > \Lambda_{comp} \equiv 10\,\text{TeV}$$

I, II elementary generations

$$m_{\text{I,II scalars}} \sim 10^4\,\text{TeV} \equiv M_{hi}$$

$$b^{SU(2)}_{strong} = 1/5\,, \quad b^{SU(3)}_{strong} = \frac{1}{10} \quad \text{by choice}$$

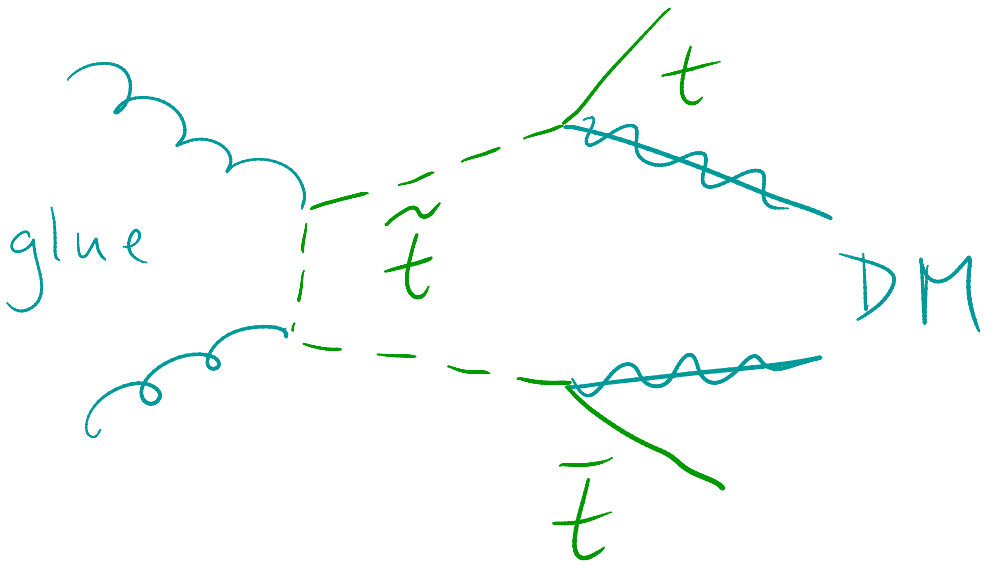
$$b^{SU(2)}_{elt} = b^{SU(3)}_{elt} = 1/3\pi^2$$

$$\Rightarrow \quad g_2(m_{scalar}) \approx 1\,, \quad g_3(m_{scalar}) \approx 3$$

$$\gamma_{SU(2)} \approx \frac{1}{12}\,, \quad \gamma_{SU(3)} \approx 1/4$$

$$\Delta m^2_{stop} \sim (700\,\text{GeV})^2\,, \quad \Delta m^2_H \sim (130\,\text{GeV})^2$$

SIGNALS



$t\bar{t} + \not{E}$

$m_{Z'} \sim$ few TeV

$m_{KK} \sim 10$ TeV > LHC ?

$g \neq \tilde{g}$?

FUTURE

More fully corrected RGE

Detailed Warped model see talk by Redi!

In particular $m_{gaugino}$, μ, EWSB

Gauge Unification

Extra light degrees of freedom,
pseudo-Goldstino

SUGRA corrections; how split can it be?

Robust phenomenology