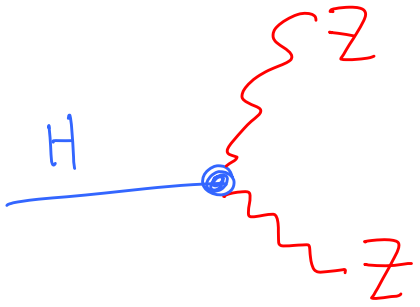
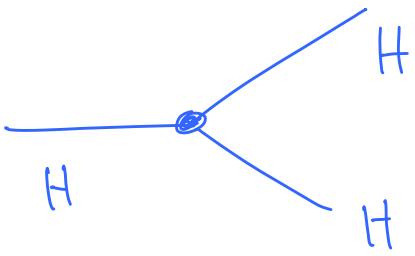
Further Motivations for the CEPC [+ SPPC]

Guaranteed Physics of CEPC/SppC



CEPC: does it look more pointlike than pion?



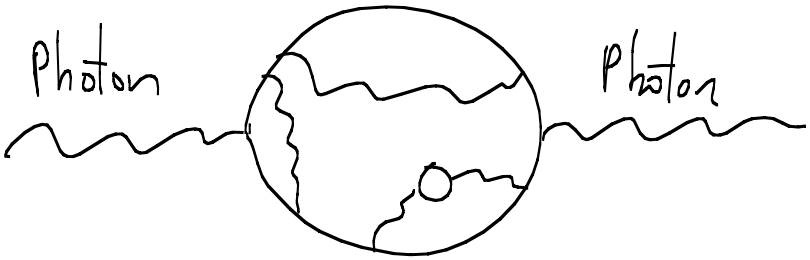
SppC: does it look pointlike to itself?

In immediate future – lots of work for theorists to finish CD R, even completing the story of (existing, outstanding!) theoretical motivations. [One ex: more precisely correlating 1st order EWK transitions w/ grav wave signals @ LISA-type future detectors]

Burning Question of Summer 2016

WHAT THE HELL IS GOING ON AT THE LHC?

Essence of Hierarchy Problem



Massless: $2 \neq 3$!

UltraMassive, $1 = 1$!

Crucial Novelty of Spin 0

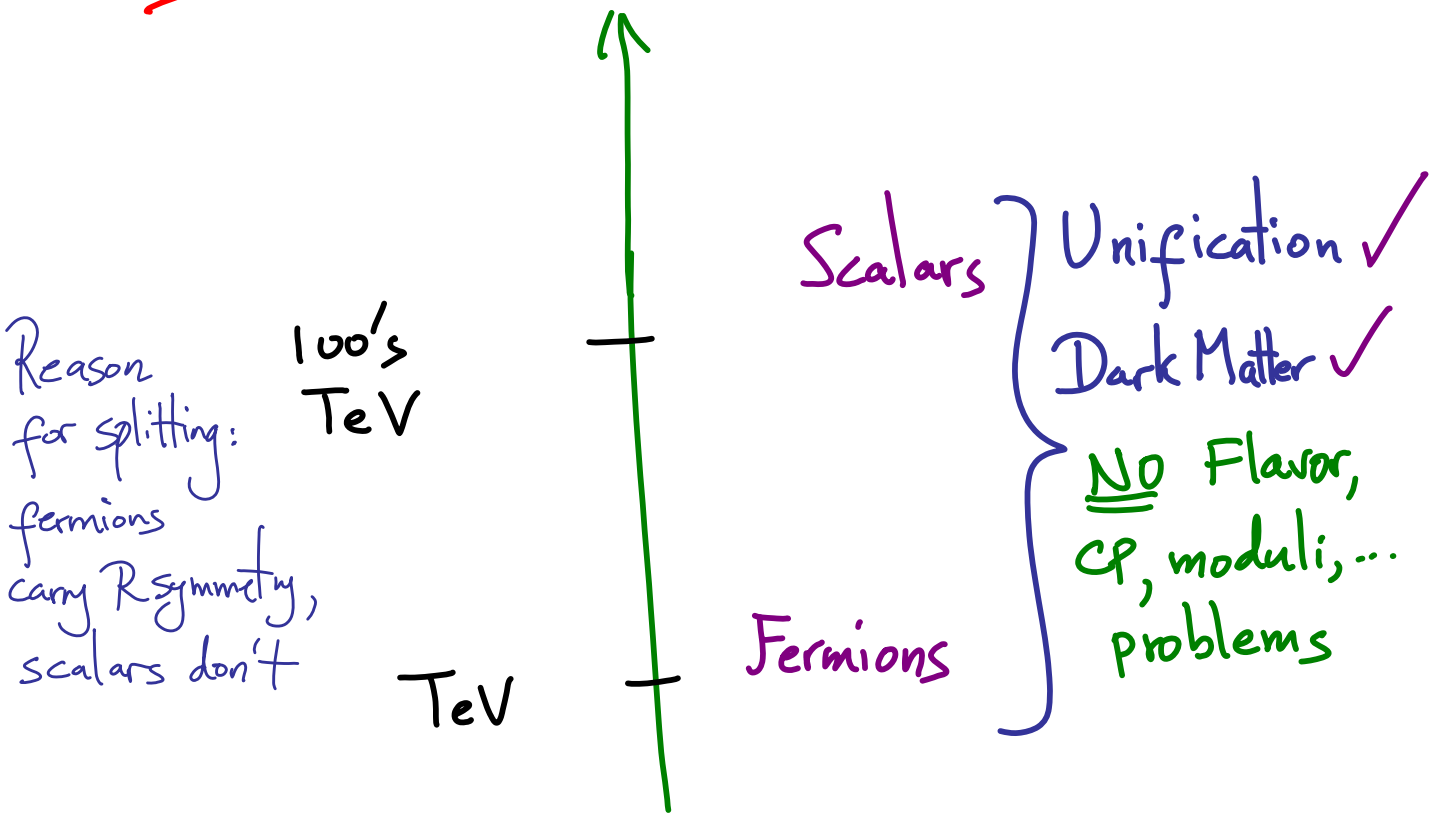
In every theory we have ever found where we can compute even sign of m_h^2, we see the real teeth of hierarchy problem

My Own Best Bet

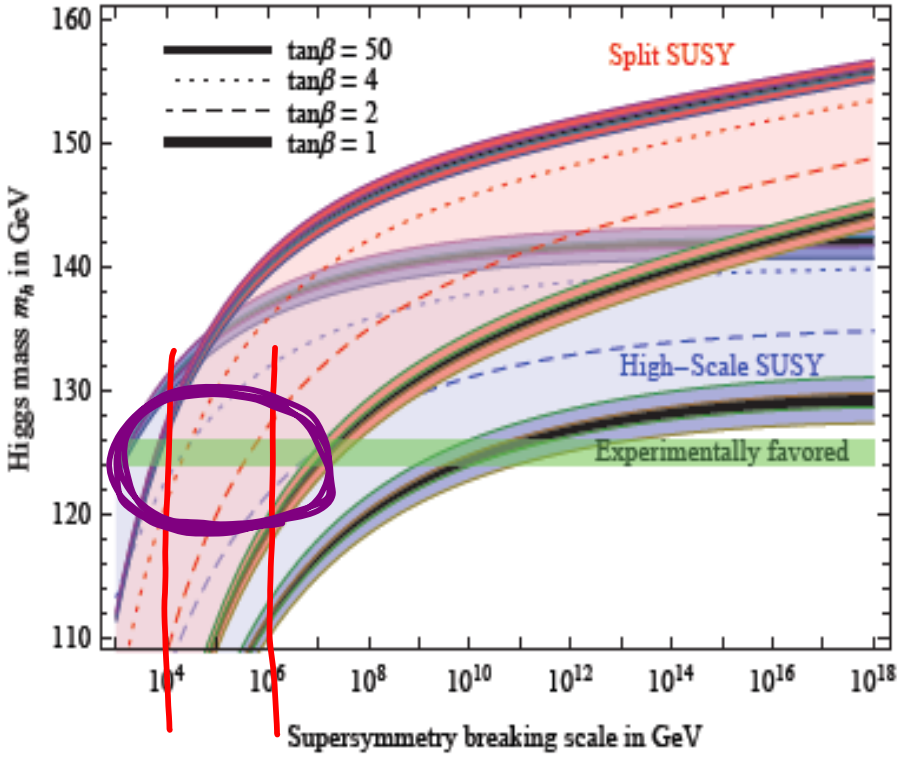
(Since ~ 2004/2005)

Minimal Split SUSY

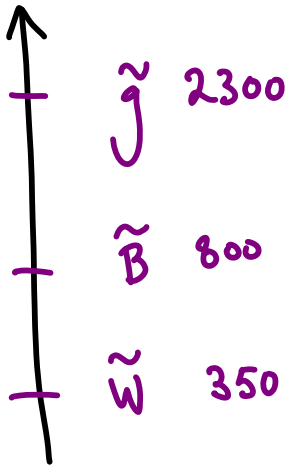
Minimal Split SUSY

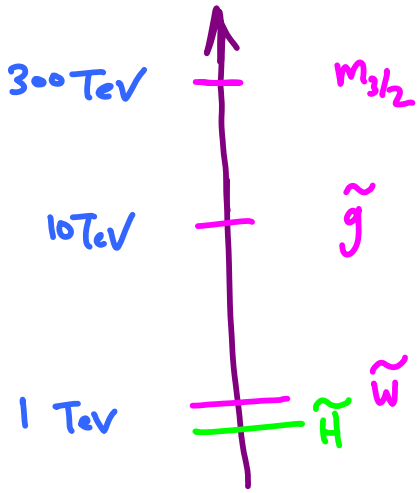


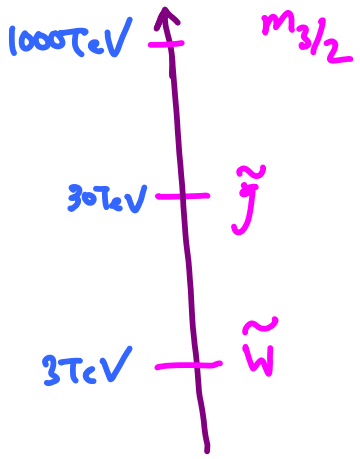
Predicted range for the Higgs mass



120 GeV $\lesssim m_{Higgs} \lesssim$ 135 GeV







LHC Accessible

LHC Inaccessible

SppC Accessible

[SppC can decisively exclude this model via DM reach]

Nature is teaching us deep, surprising, (disquieting to some!) lessons via the L·H·C

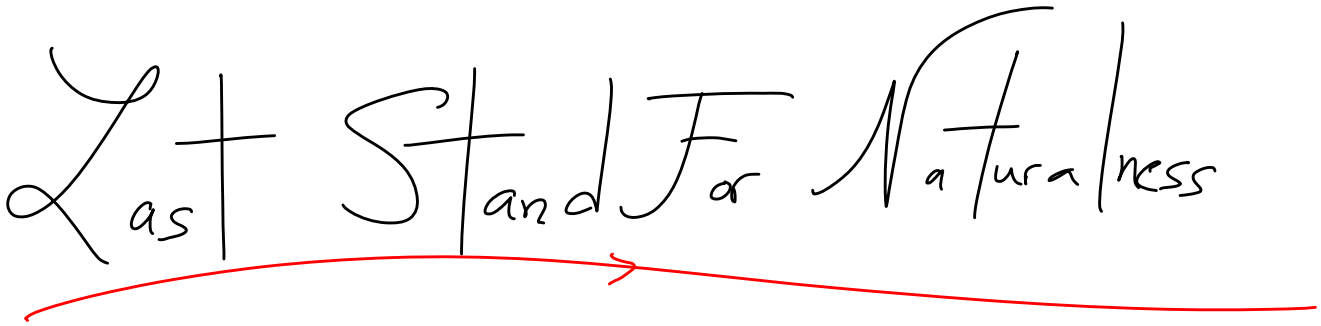
Very important to revisit + rethink the foundations of our conventional thinking

Outline

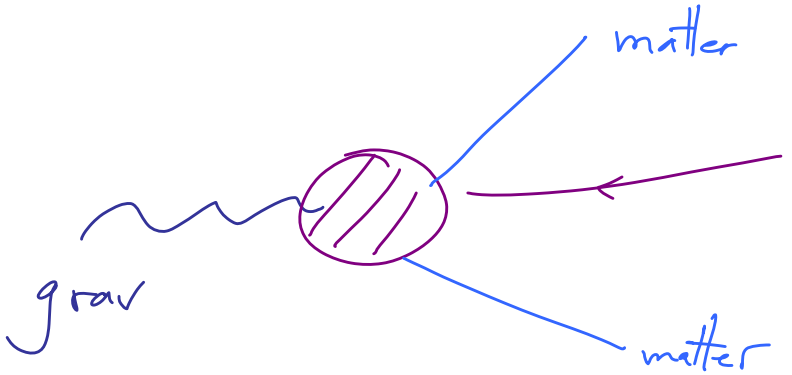
* Perfect Naturalness' last-stand:
  NO signals @ LHC, but big deviations
  in $h \to gg$ + $h \to \gamma\gamma$ visible @ CEPC,
  dramatic shut-off of $\bar{t}th$ production @ SppC

* New cosmological approach to hierarchy problem
  $\Longrightarrow$ new signals @ CEPC/SppC

* Possible direct probes of the "landscape" @ CEPC


Last Stand For Naturalness

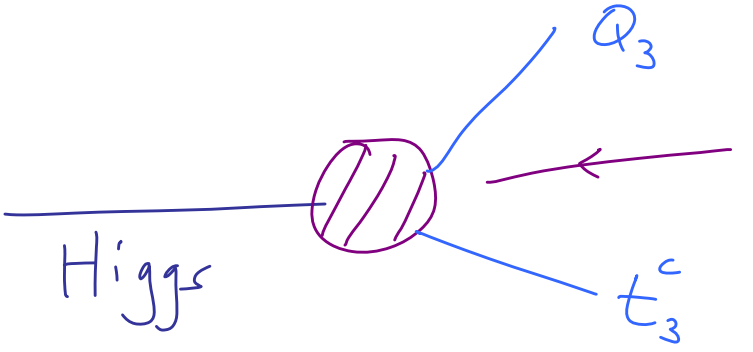
Raman's "Fat Gravity" for CC



shuts off when off-shell by more than $\sim 10^{-3}\,eV$ $\sim .\ mm^{-1}$

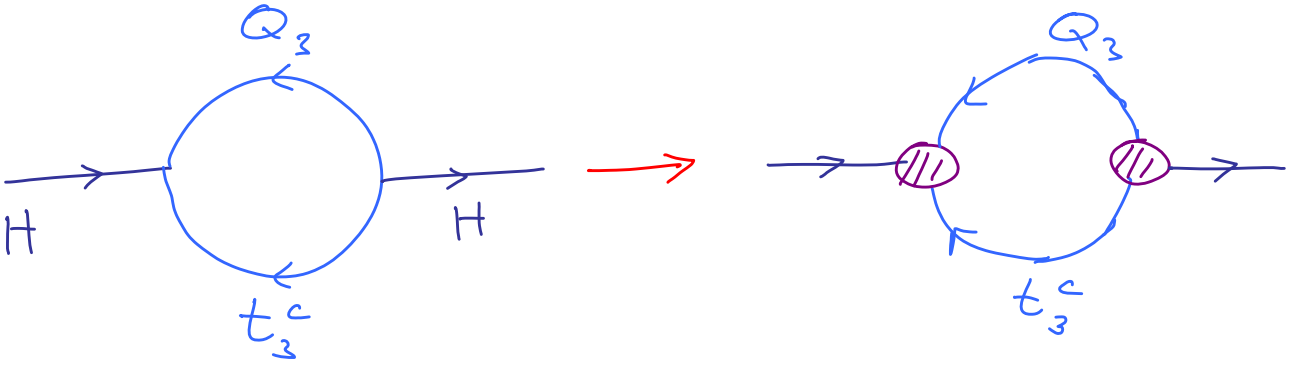
* Equivalence Principle a challenge!
* Currently being probed

"Fat Higgs" for Hierarchy



shuts off when off-shell by ~ 400 GeV

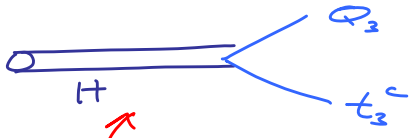
* No analog of equivalence principle challenge.
* Not even close to probing @ LHC!



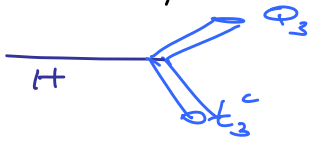
$$\frac{3}{8\pi^2}\int d^4p\ \frac{\lambda_t^2}{p^2} \longrightarrow \frac{3}{8\pi^2}\int d^4p\ \frac{\lambda_t^2}{p^2}\left(F(p^2/\Lambda^2)\right)^2$$

$$\Longrightarrow \Lambda \lesssim 400\ \text{GeV}$$

* Note: NOT standard compositeness of higgs (or both).



or of tops



Already probing with Zh coupling @ CEPC

highly constrained by eg $Z \to b\bar{b}$

* A more minimal (+ more radical!) idea. Higgs, tops are pointlike to themselves, but mutually nonlocal @ short scales [cf electric + magnetic charges]

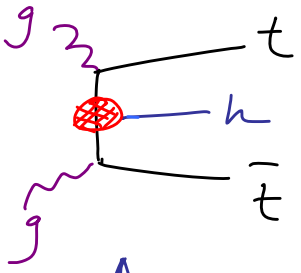
As yet no know theoretical implementation of this idea.

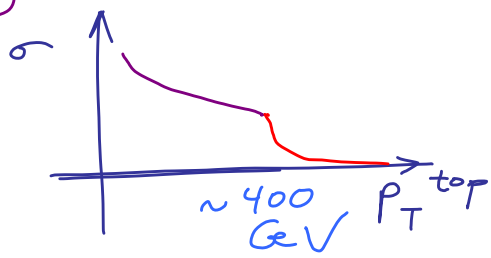
Is it possible to soften coupling while identifiable particle states are pushed to parametrically higher scales?

Challenge — consistency w/ causality!

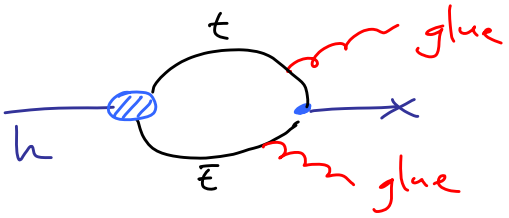
Experimentally: probe $t\bar{t}h$ vertex off-shell!

Direct: SppC





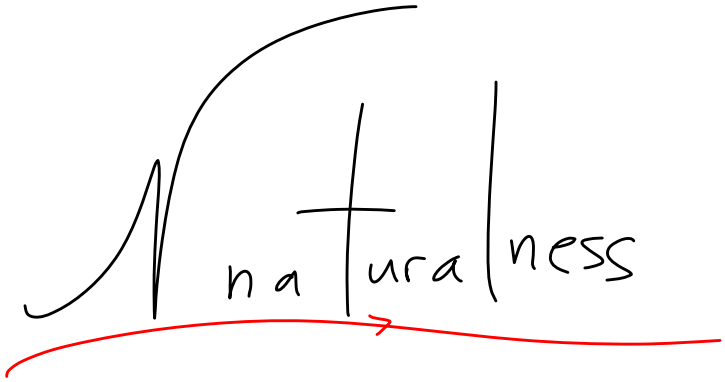
Indirect: CEPC



$K_g \sim \left(\frac{m_t^2}{\Lambda^2}\right) \sim 10\%$ Easy @CEPC

$K_\gamma \sim$ few % Possible @ CEPC

CRITICAL, model-independent probe of perfect naturalness, impossible@ LHC!


naturalness

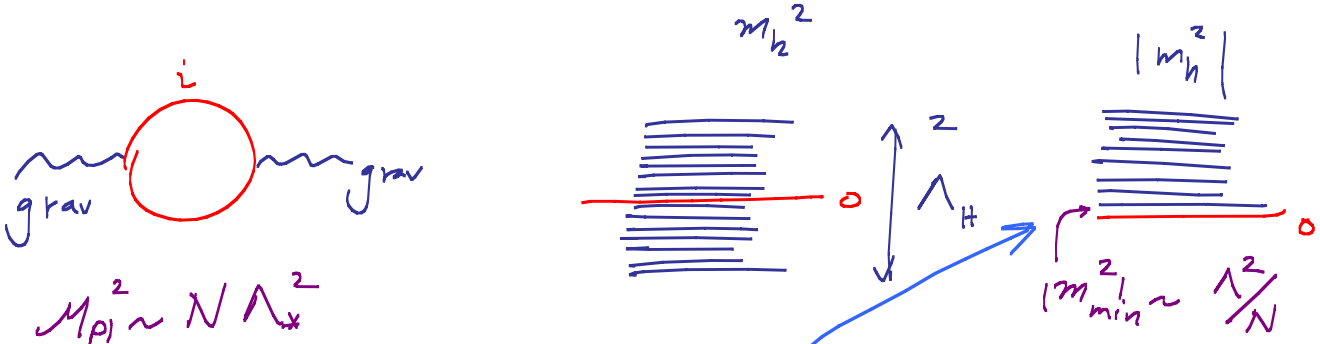
* Naturalness: New solution of hierarchy problem with no new particles @ LHC.

* But possible striking expt'l signals from next gen. CMB+LargeScale Structure expts on ~ decade timescale.

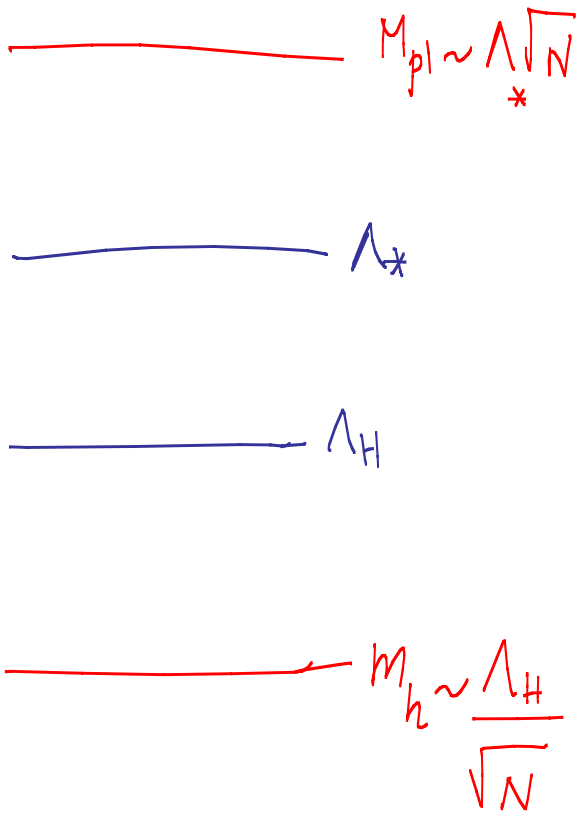
* In best SUSY version, SUSY beneath $\sim m_W \times \frac{M_{Pl}}{M_{GUT}} \sim 10\,TeV$ accessible to SppC

* In non-SUSY version → new vector-like leptons needed giving sizeable K_γ @ CEPC [+acc. to SppC]

$\sqrt{\ }$ copies of (MS) SM



Cosmology Dominantly Reheats Bottom of Spectrum



Natural Limits

* $N \sim \frac{M_{pl}^2}{M_{GUT}^2} \sim 10^2 - 10^4$

{ $\Lambda_* \sim M_{GUT}$?. SUSY beneath

$\sim m_W \times \frac{M_{pl}}{M_G} \sim 10$ TeV! Within Reach of SppC

* $N \sim \frac{M_{pl}}{m_h} \sim 10^{16}$

Complete-N-soln of hier. prob.

Needs new vector-like doublets with QCD couplings to higgs for pheno consistency - gives $K_Y \sim \mathcal{O}(10\%)$

"Reheaton"

Boson ϕ | Fermion S

Lowest dim operator coupling:

$a\,\phi\, h_i^\dagger h_i$ | $\lambda S \ell_i h_i$

Crucially, involve h_i!

Flipside of hierarchy problem!

Cosmological Signals

* ΔN_{eff} ~ few % → $O(1)$ [will get to 2%!]

* Possible smoking gun: tower of more massive ν_i! Probe with: damping of structure on a (tower of) smaller scales, also grav. lensing.

[Next Large Scale Structure expt, sensitive to $\sum_i m_{\nu_i}$ @ expected value!]

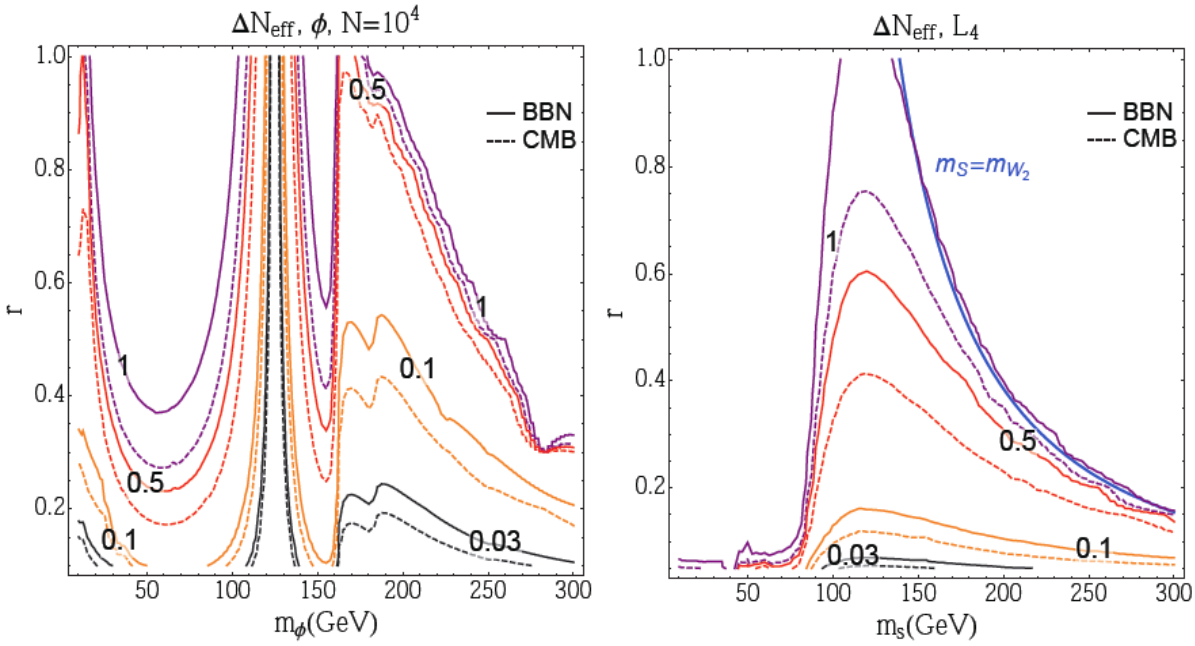
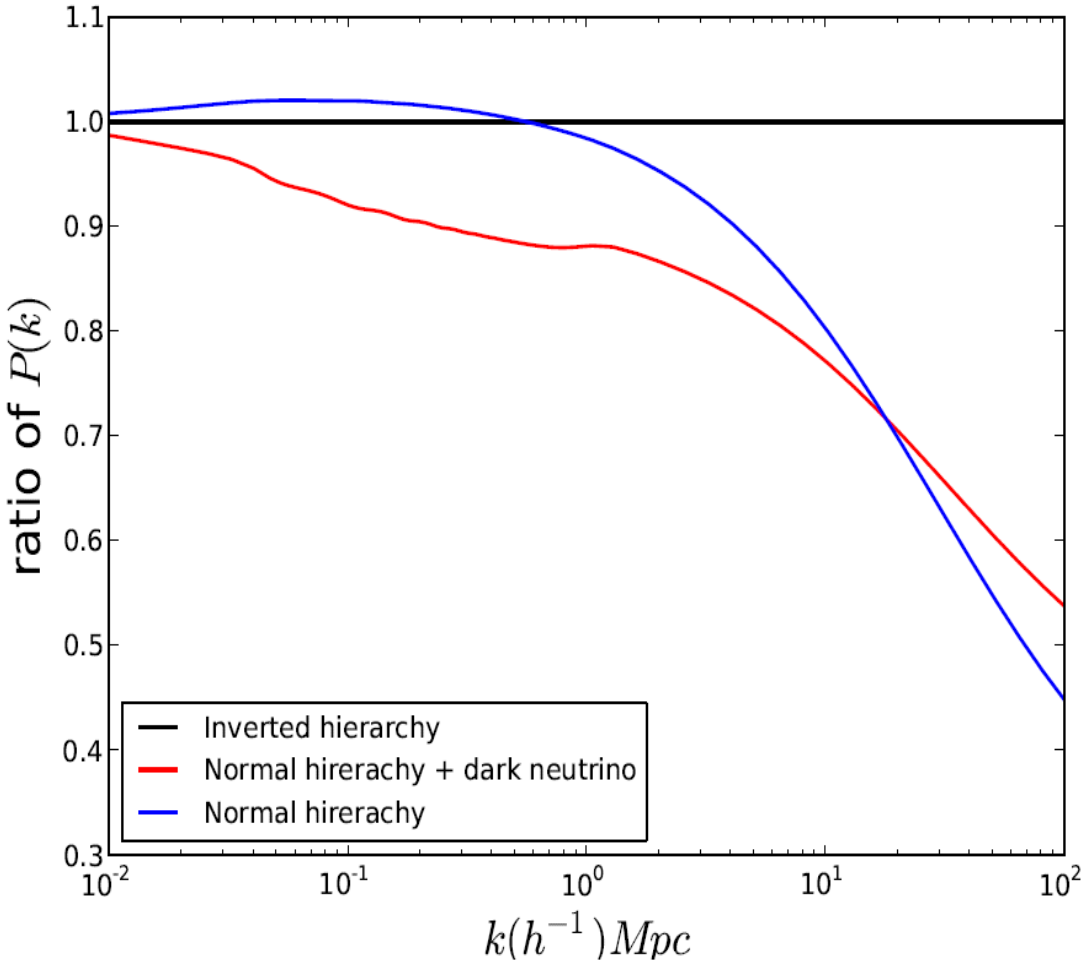
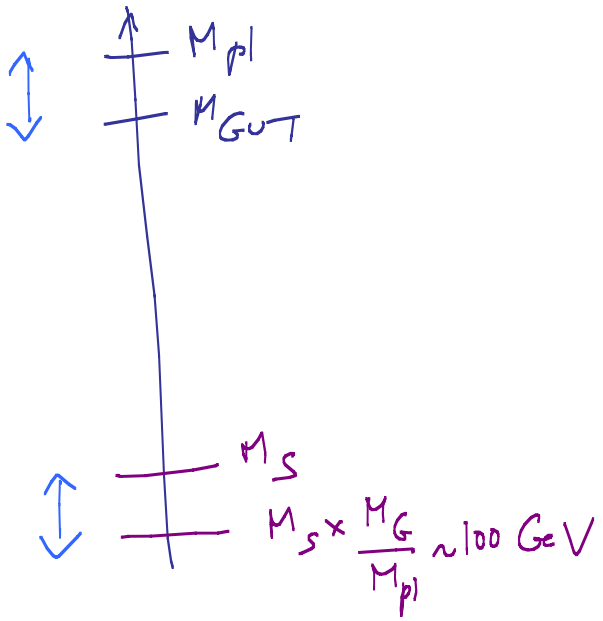


FIG. 5: $\Delta N_{\rm eff}$ contours as a function of reheaton mass and the r parameter defined in Eq. (1). $\Delta N_{\rm eff} \simeq 0.03$ corresponds to the sensitivity of CMB stage 4 experiments. The current upper bound at the CMB epoch is around 0.6. The left panel is for the ϕ model, with $a =$ MeV. The right panel is for the L_4 model, with $\lambda \times \mu_E = 10^{-3}$ GeV, $M_L = 400$ GeV, $M_{E,N} = 500$ GeV, $Y_E = Y_N = 0.2$, and $Y_E^c = -Y_N^c = 0.5$. As discussed in the text the plot is valid for a large range of N, namely $30 \lesssim N \lesssim 10^{13}$.

Note: $\Delta N_{eff} \sim 0.5$ allowed (even welcome...)

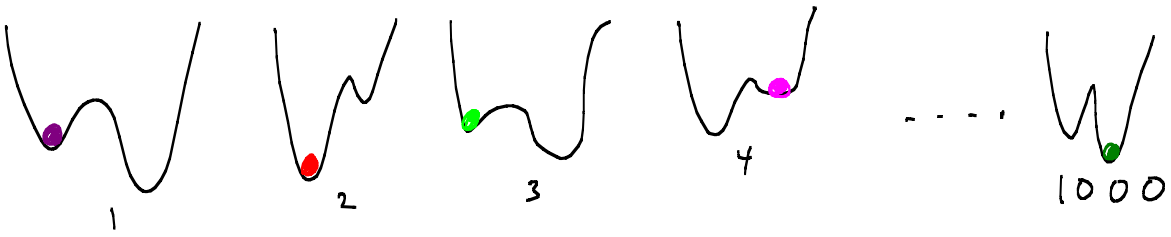

1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
ratio of $P(k)$
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
$k(h^{-1})Mpc$
Inverted hierarchy
Normal hirerachy + dark neutrino
Normal hirerachy

SUSY Beneath ~ 10 TeV



* Unification ✓
* DM ✓
* Higgs @ 125 GeV ✓
* Flavor, CP safer but still constraints/signals!
* Not split SUSY! [Can't have 10^2–10^3 TeV scalars]

Low-scale Landscapes



$\Rightarrow 2^{1000}$ different values of energy

Energy $\sim \left(\frac{1}{2}\right)^{1000}$ — just statistically!

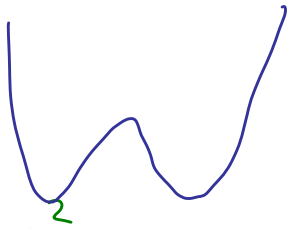
Landscape: $\sim 10^2 - 10^3$ SM singlet scalars!

* They could all be @ GUT/string scale....

* But some part might be pegged to higgs mass for good reasons. Singlets S_i dominant coupling is to higgs unfamiliar: $S_i H^\dagger H, S_i S_j H^\dagger H$.

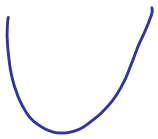
* Central "landscape" novelty: $\sim 10^2 - 10^3$ S's!

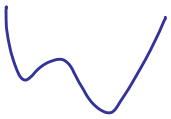
Motivation for light landscape: Correlating Hierarchy + CC



$\lambda_i\left(S_i^2 - \mu_i^2\right)^2 + a_i S_i h_u h_d$

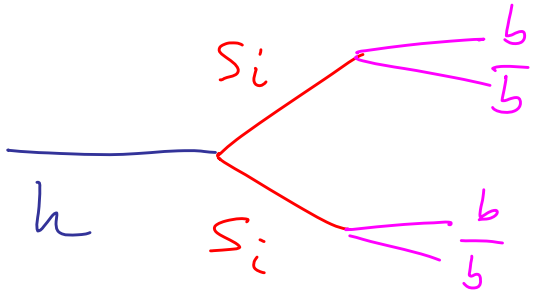
$m^2_{h_u,d} > 0$ NO scanning for CC

$|m^2_{h_u,d}| \gg \mu^2$  NO scanning for CC

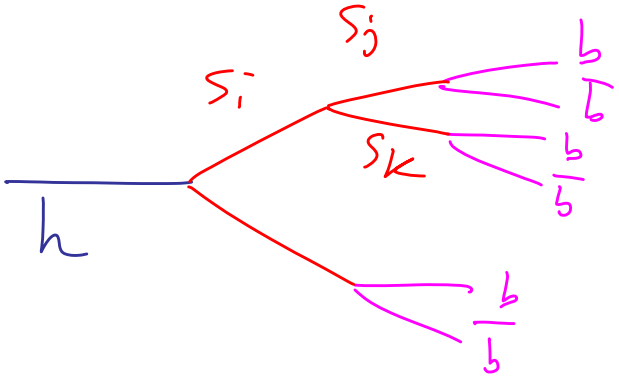
$m^2_{h_u,d} \sim \mu^2$  CAN scan for CC

MUST tune m_h^2 in order to be able to tune the Cosmological Constant!

Dramatic Signals for CEPC

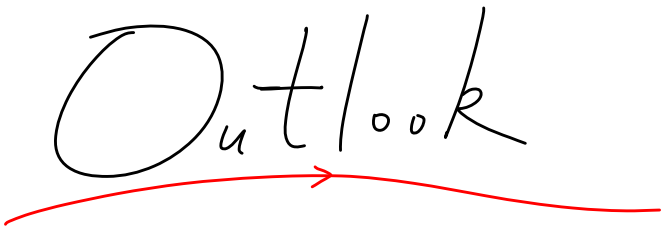


hundreds of $b\bar{b}$ resonances!



6 b events show $s_i s_j s_k$ interactions

$\Rightarrow$ $\Rightarrow$ direct exp. proof of exponentially many vacua!


Outlook

The longer we go with no new particles at the LHC, the more theoretically shocking it is — and the more crucial the CEPC program for Higgs physics becomes!

I am certain that as we further grapple with the profound challenge Nature has given us theorists, qualitatively new ideas we find will only further reinforce this conclusion!