

Fundamental Physics & the Energy Frontier

- What would we learn?
- Is exploring the unknown a sufficient motivation?
- How important are the perspectives and lessons we have learned in attempting to address fundamental questions in motivating such a step?
- Imagining the SM will in the end be confirmed, will the acquired knowledge be worthy? and why?

Problems

vs

Mysteries

- Dark Matter
- Baryogenesis
- Strong CP
- Fermion mass spectrum & mixing

Plausible EFT solutions exist

- EW hierarchy
- Cosmological Constant
- Very Early Universe
- Black Hole information paradox

Challenge or outside EFT paradigm

One Perspective

the Energy Frontier through the lens of
the Hierarchy Paradox

Can you propose other perspectives?

Simplicity vs Naturalness: The Hierarchy Paradox

SM is EFT valid below
physical cut-off Λ_{UV}

$$\mathcal{L}_{SM} = \mathcal{L}^{d \leq 4} + \frac{1}{\Lambda_{UV}} \mathcal{L}^{d=5} + \frac{1}{\Lambda_{UV}^2} \mathcal{L}^{d=6} + \dots$$

Observations
speak for
Simplicity

$\Lambda_{UV} \gg m_{weak}$

$\mathcal{L}_{SM} \rightarrow \mathcal{L}^{d \leq 4}$ B, L, “GIM suppression”, custodial symm, ...

$m_\nu \ll m_{weak}$ beautifully explained

Theory
expects
Naturalness

$\delta m_h^2 \sim \frac{y_t^2}{4\pi^2} \Lambda_{UV}^2 + \dots$

$\rightarrow \Lambda_{UV} \lesssim 500 \text{ GeV}$

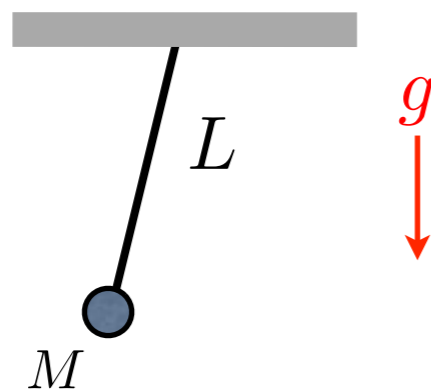
Clash between Simplicity and Naturalness

Made concrete by *basically* all available Natural models (SUSY, Comp Higgs,...)

$$m_h^2 = c \frac{y_t^2}{4\pi^2} \Lambda_{UV}^2 + \dots$$

high
spin
symm
dilatation
symm

As good as dimensional analysis in mechanics



$$\omega = c \sqrt{\frac{g}{L}}$$

The two Chief Systems

Simplicity

I. The SM is valid up to $\Lambda_{UV} \gg TeV$

- B, L and Flavor: beautifully in accord with observation
- Higgs mass & C.C. hierarchy point beyond naturalness
 - multiverse
 - cosmological relaxation, Nnaturalness, ...
 - failure of EFT ideology (UV/IR connection)

II. Naturalizing New Physics appears at $\Lambda_{UV} \sim 1 TeV$

- Constraints on B, L, Flavor & CP met by clever model building

Naturalness

Λ_{NP}

10^{12} TeV

High Scale SM:
super simple & super un-natural

perfect Flavor and CP

10^4 TeV

Middle Options?
just simpler and not yet
super un-natural

better Flavor and
perfect EW

10^2 TeV

TeV

TeV Scale New Physics:
not simple & almost natural

See also talk by R. Sundrum HEFT 2016

Hierarchy
Paradox



unavoidable and ***global*** perspective
on energy frontier exploration

In any model with calculable m_h :

$$m_h^2 = \sum_i \Delta m_i^2$$

fine tuning

$$\epsilon \equiv \frac{m_h^2|_{exp}}{\Delta m_h^2|_{max}}$$

offers a measure of where Nature stands in the negotiation
between Simplicity and Naturalness and **one key** to the
experimental strategy

Fine Tuning Theorems

- Higgs couplings

HL-LHC, ILC, Fccee, μ -collider

$$\longrightarrow \frac{\delta g_h}{g_h} \sim \epsilon$$

- direct searches

HL-LHC, Fcchh, μ -collider

$$\longrightarrow \left(\frac{m_h}{m_{NP}} \right)^2 \div \left(\frac{500 \text{ GeV}}{m_{NP}} \right)^2 \sim \epsilon$$

- EWPT

HL-LHC, ILC, Fccee, μ -collider

$$\longrightarrow \frac{\delta O_{EW}}{O_{EW}} \sim 10^{-2} \div 10^{-3} \times \epsilon$$

- Flavor

HL-LHC, Belle, NA62

\longrightarrow model dependent but worth more and better attention

The foreseeable and unforeseeable future machines
will allow to explore down to

$$\epsilon \lesssim 10^{-3}$$

Higgs couplings

$$\epsilon \lesssim 10^{-3} \div 10^{-4}$$

direct searches

Imagining the SM will in the end be confirmed,
do you consider the acquired knowledge worthy?
and why?