

High Energy Physics: What's happening and where are we heading ?

Theorist's perspective

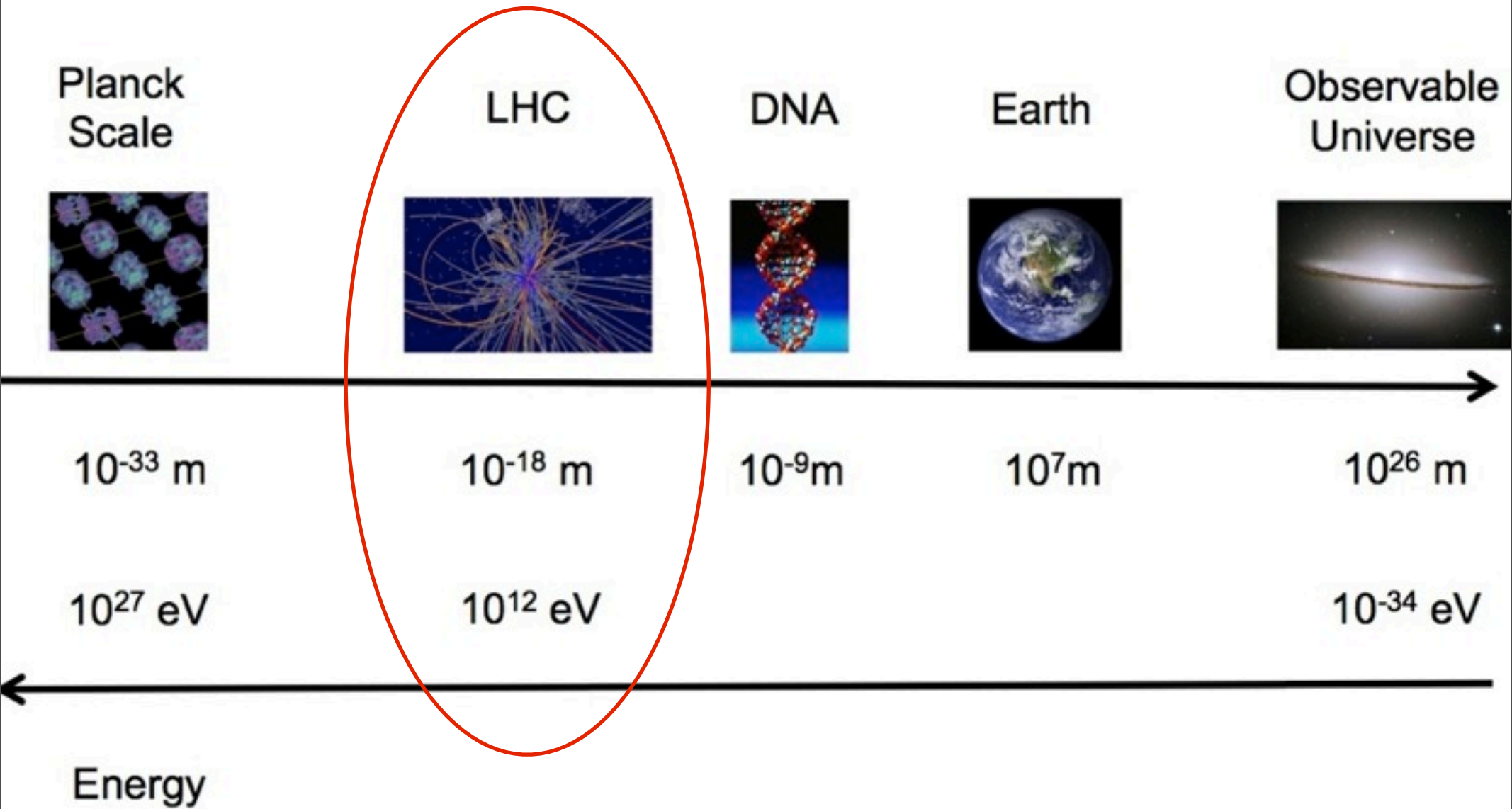
M. Shifman/ May 7, 2014, U of M Colloq



M. Shifman

Monday, May 5, 14

Scales of Physics

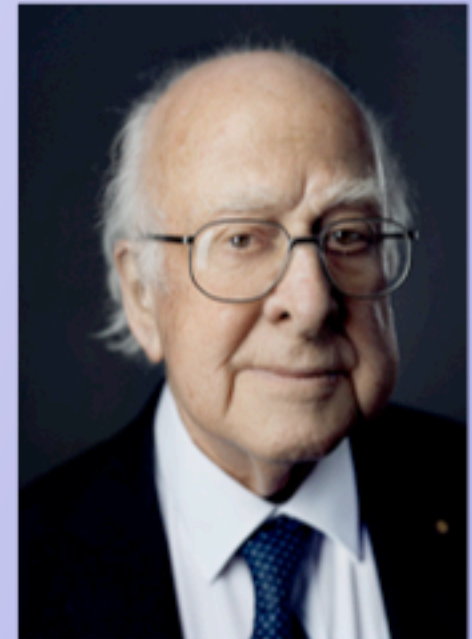


MAP OF HEP THEORY



Great event separating the past and the future: discovery of the Higgs particle

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"



☞ The discovery of Higgs at LHC sets a line between past and future: SM is complete!

- * So far SM with 1 Higgs (and with ν 's updated) fits everything; it works (disturbingly) well;
- * One can be certain the SM description of nature is true (at least approximately);
- * More data are to come from LHC in 2015 at twice the previous energy and higher luminosity;
- * Hopefully bring more information about short distances.

What will LHC find? Nobody knows...

Options:

- 1) Nothing else besides Higgs, SM confirmed to better accuracy;
- 2) Beyond SM e.g. additional particles not present in SM, irrelevant for the hierarchy problem;
- 3) Relevant for the hierarchy problem i.g SUSY;
- 4) Something completely unexpected!

BSM Options (technical):

- 1) Second Higgs (or other unknown scalars);
- 2) Additional (vectorlike) generations;
- 3) Z' or W' ;
- 4) Something completely unexpected.

BSM Options (conceptual):




- 1) Weakly coupled SUSY – very lucky if yes, unlucky if no;
- 2) Strong coupling dynamics;
- 3) ???

Theorist's (bird's eye) view

1) The measured Higgs mass 125 GeV is uncomfortably high for SUSY and low for strong coupling.

Beware of caveats

Why do we need to go BSM?





-  SM is extremely successful.
The most successful theory ever;
-  Logically consistent, withstands many-many tests...
Not a single discrepancy between SM and experiment found;
-  Unprecedented accuracy e.g. in $g-2$.

Exciting things in science start when we encounter problems. They give clues for future progress. Do we have problems?

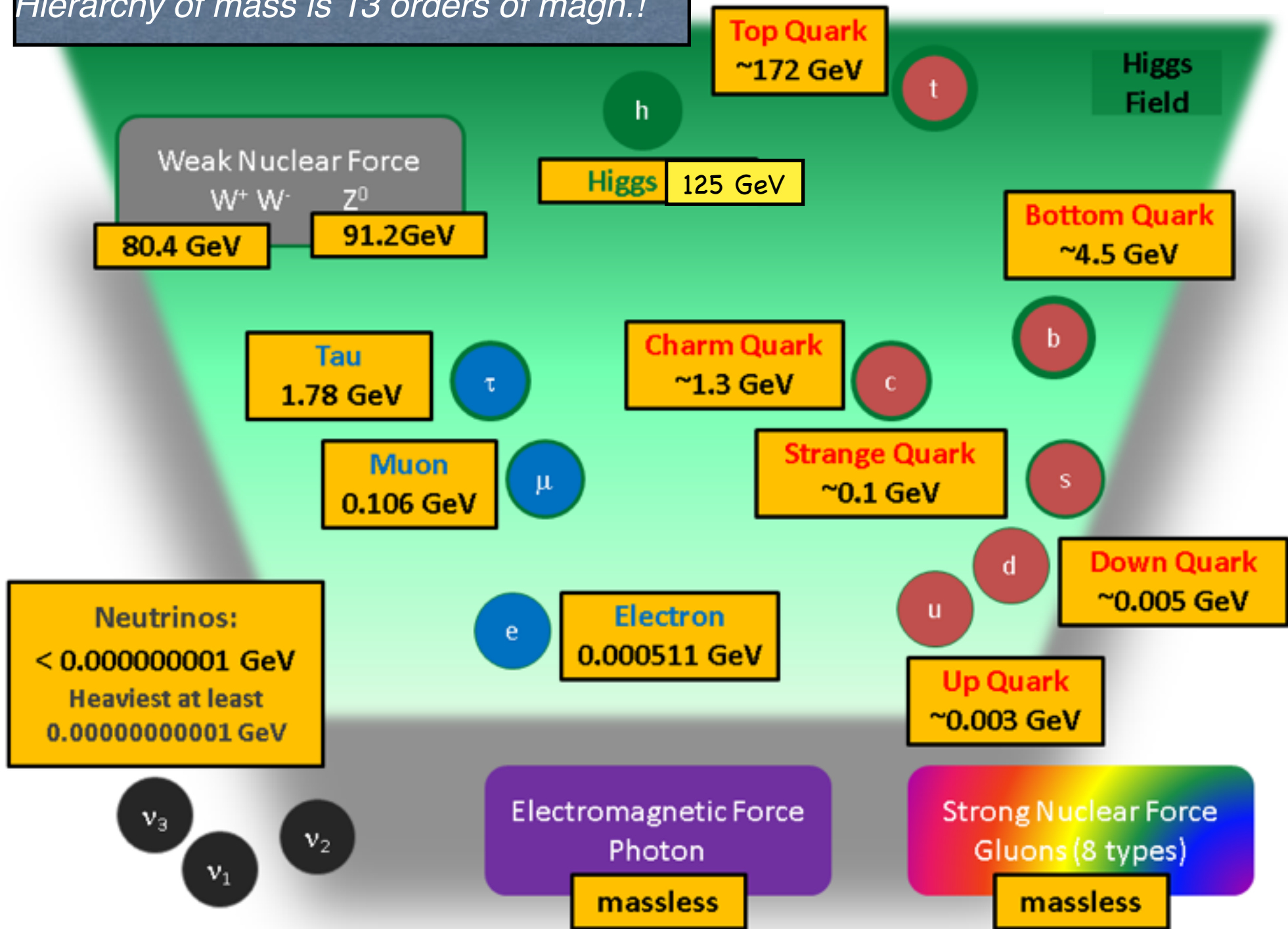
- ✎ Where the spectrum/mixing angles/CP comes from?;
- ✎ Where the gauge group $SU(3) \times SU(2) \times U(1)$ comes from?;
- ✎ Why three generations (38 years ago μe problem)?
- ✎ What determines electroweak scale?

Mendeleev's Periodic Table 🧑🏫 😊 Answer to Mendeleev' challenge → Quantum Mechanics

Hierarchies

-  Fermions masses;
-  Quark (but NOT neutrino) CKM;
-  Why θ angle is $< 10^{-11}$ \rightarrow perhaps, axions;
-  Why all scales are so small in the units of M_p ; is M_p the (only) fundamental scale?

Hierarchy of mass is 13 orders of magn.!



Axions???

If we include gravity, the hierarchy becomes even worse

$$m_{\text{P}} = \sqrt{\frac{\hbar c}{G}} \approx 1.22 \times 10^{19} \text{ GeV}/c^2 = 2 \times 10^{-5} \text{ g}$$

Hierarchy is 30 orders of magnitude

(And this is not all ☹ ☹ ☹)

Naturalness



(Standard Model is highly unnatural ☹ ☹ ☹)

What is natural? $\leftrightarrow \langle H \rangle \sim M_P$; all masses $\sim M_P$; no hierarchy!

But ... one cannot live in this world !

★ All these problems are known for decades;

★ Enormous progress achieved (exp & theor) →

★ Still no clue as to the solution of **these**
problems.

★ The best hopes are associated with LHC!

PROGRESS ⇒

Experiment:

All SM parameters measured;

All quarks & mixing angles

Higgs mass

Neutrino mixing angles and masses

Cosmology (precision)/ Dark energy /Inflation gaining ground

Theory:

Inflation;

Deep understanding of QFT, phases, strong coupling;

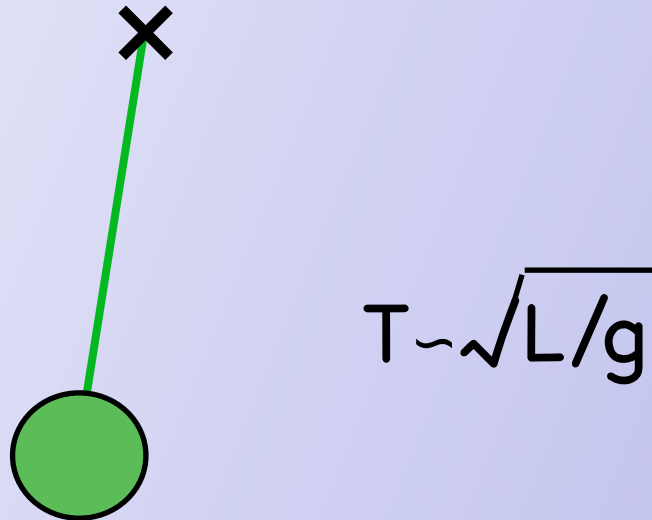
String theory \rightarrow QFT;

Physics \leftrightarrow Mathematics

None known 38 years ago.

THE problem: Hierarchy problem /naturalness / dimensional analysis

Dimensional analysis usually works in physics. When dimensional analysis fails (if we get a very small number for no good reason) usually there is something deep which we do not understand!



Example of Solution in QCD (i.e. SU(3) part)

Asymptotic freedom implies

$$\Lambda \sim M_p \exp(-c \times 2\pi / \alpha), \quad \alpha \sim 1/42, \quad c \sim 1/5$$

DOES NOT WORK FOR SPIN ZERO PARTICLES,

unless $M_p \sim \text{few TeV} \rightarrow \text{LED} \rightarrow \text{KK towers/}$

not yet seen!

Intuitive Hierarchy Problem

Weinberg: small changes of parameters at short distances should cause small changes in low-energies physics →
no cancellation/fine tuning/ scalar masses

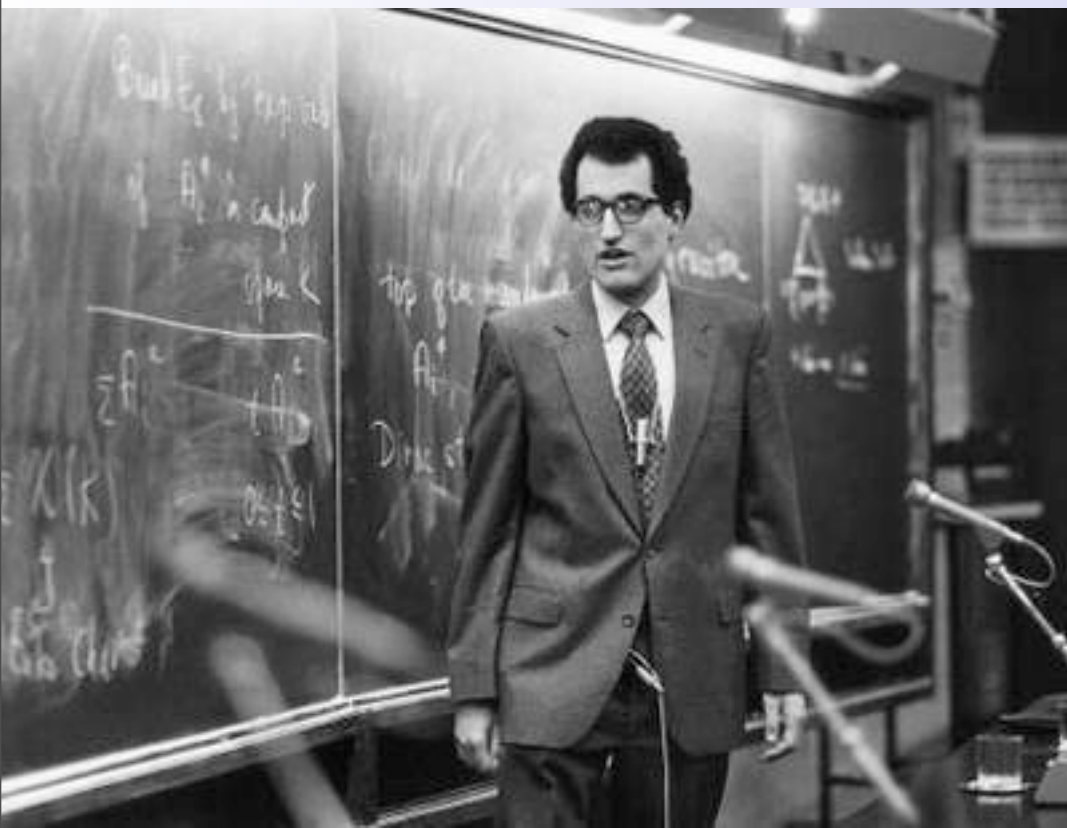
't Hooft: numbers should not be close zero for no good reason, i.e. unless zero is a special point (singular). E.g. fermion masses.

The intuitive problem solution can be postponed.
One day we will understand physics at high energy and it will explain all.

Technical Hierarchy

If we have achieve hierarchy in some approximation, higher order corrections should not destroy it.

This is NOT easy!



Edward Witten, 1982

- ★ *Supersymmetry guarantees technical solution*
- ★ *Exact SUSY would nullify CC!*
- ★ *In SUSY there are natural candidates for dark matter*
- ★ EW scale \rightarrow both intuitive & technical problem (SUSY)
LHC may or may not solve it (SUSY)

- ☺ *Split supersymmetry, spread supersymmetry, A-terms, you name it, “unnatural” SUSY*
- ☺ Cosmological Constant biggest failure -> 38 years ago it was believed to be zero -> 124 orders of magnitude -> mind-boggling

Maybe naturalness is a wrong paradigm?

Options about Naturalness

a) Naturalness is correct. (Almost) natural susy or some other solution at LHC-2015;

b) Physics at 1 TeV is unnatural -> Higgs and nothing else, split susy or other particles not addressing naturalness.

IF UNNATURAL:

Current ideas to be reexamined fully!

Perhaps, ☹ coming soon to a theater near you ☹

Options for UNnatural

Landscape (anthropic) Multiverse laws are different in different places -> "physics" -> environmental; (historic example: Kepler and orbits of planets; planet orbits are environmental - depend on accidental initial conditions).

Should we try to accept that hierarchy is environmental?

Some say "everything is environmental"

Uncomfortable possibility

Four centuries of “matryoshka-doll” layer structure:
molecules→atoms→nuclei→nucleons→quarks...

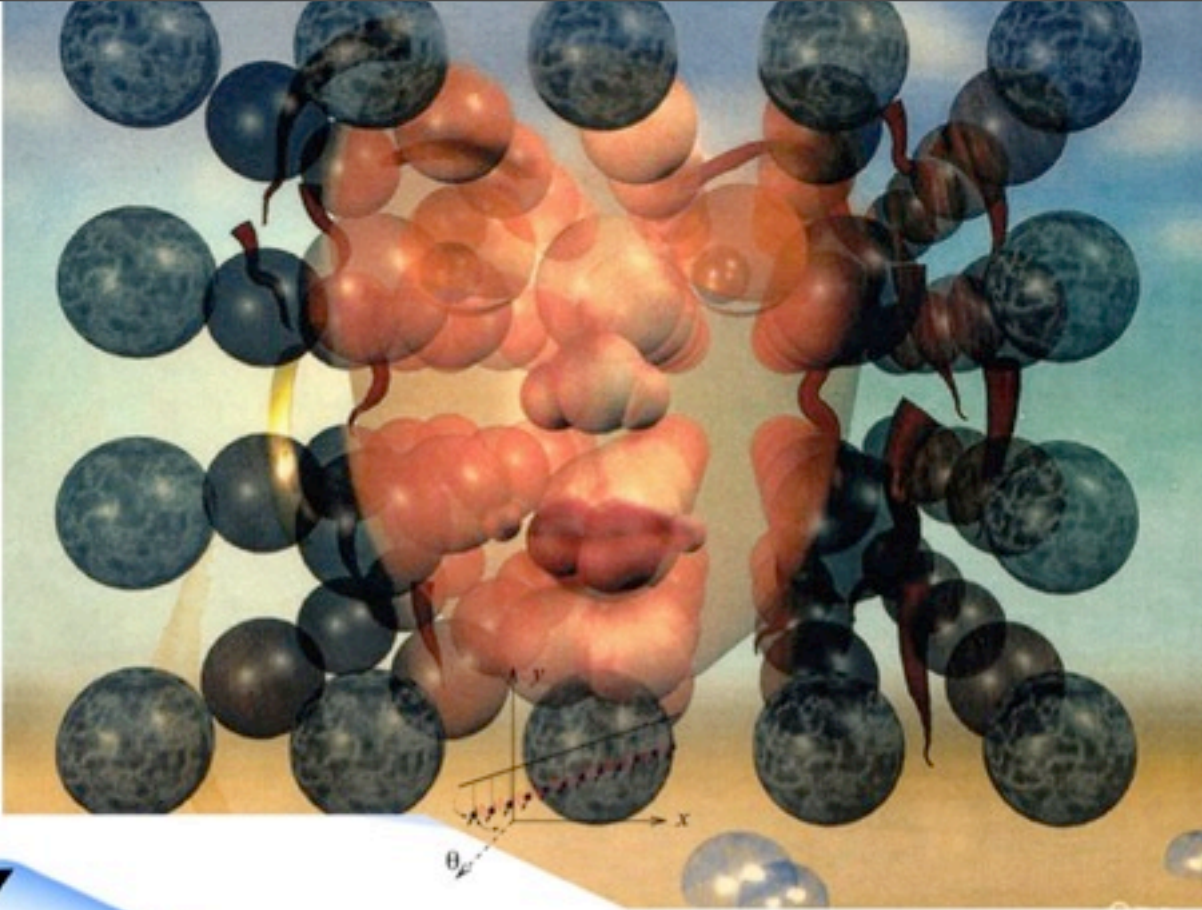
Reductionism

If Multiverse/anthropic deep questions to be
abandoned...

 The end of reductionism?

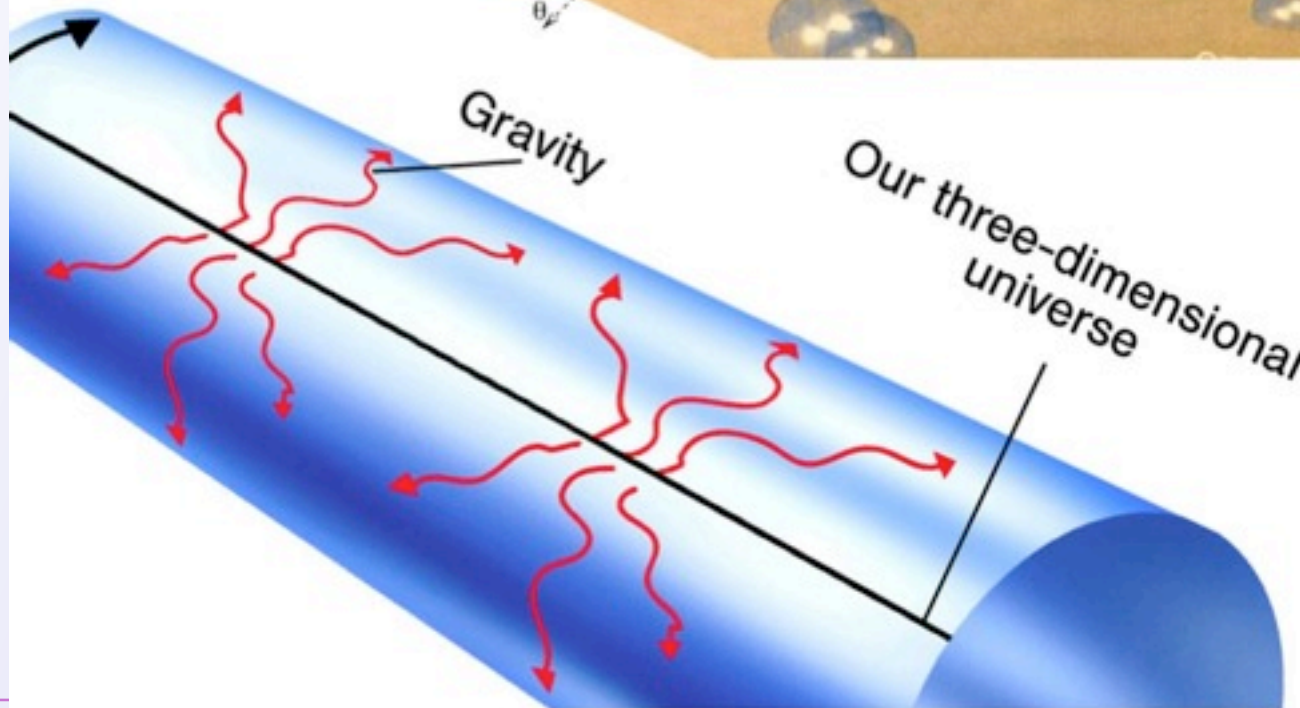
I hope that New physics which invigorates
Naturalness will come at rescue!!!!

Win-win for young people



✳ *LED*

✳ *Multiverse*



✳ ✳ ✳ ???????

DOE Office of Science Funding: % of Total Appropriation

