Can the LHC rule out natural SUSY?

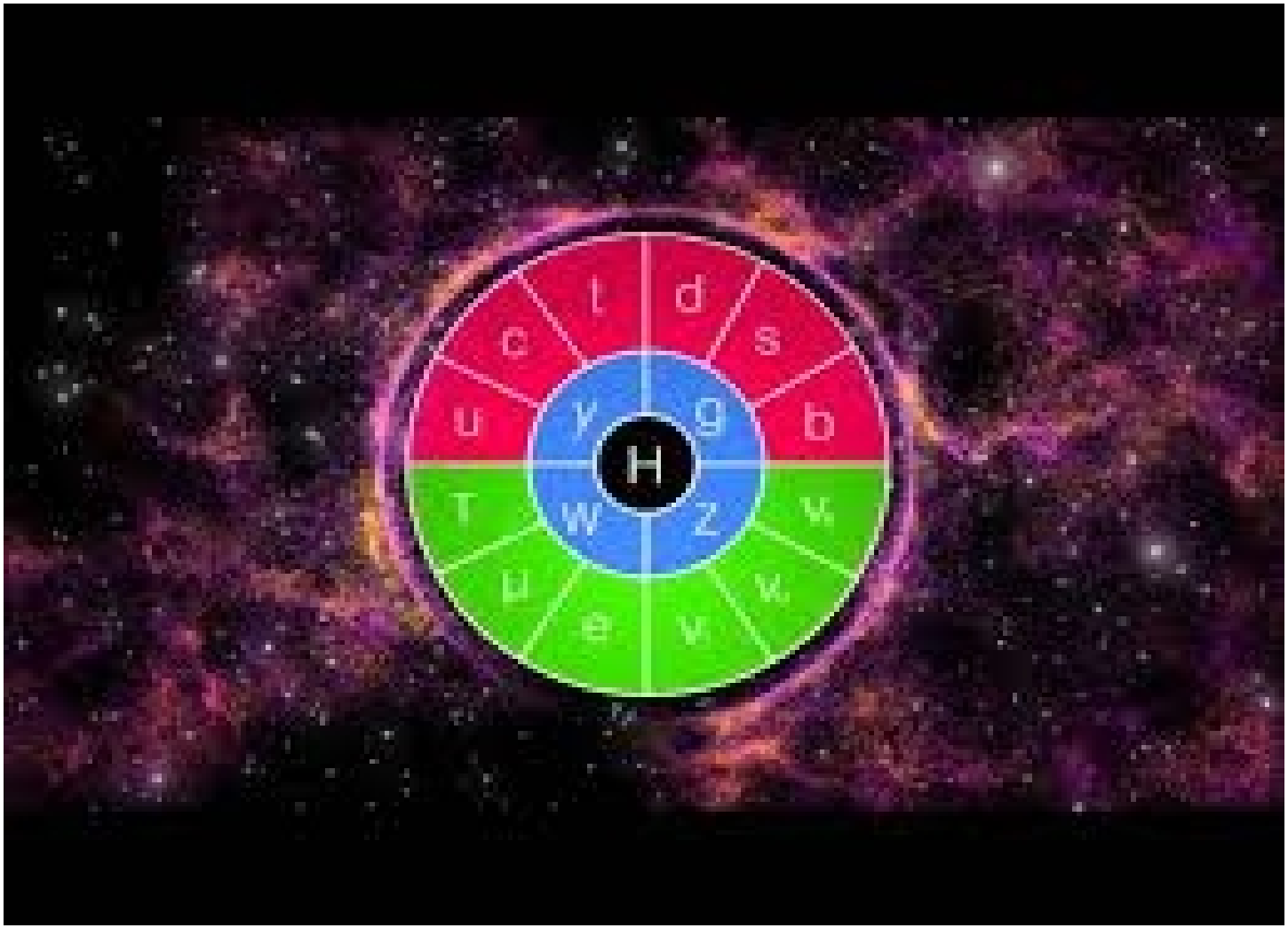
Ann Nelson

August 4, 2014

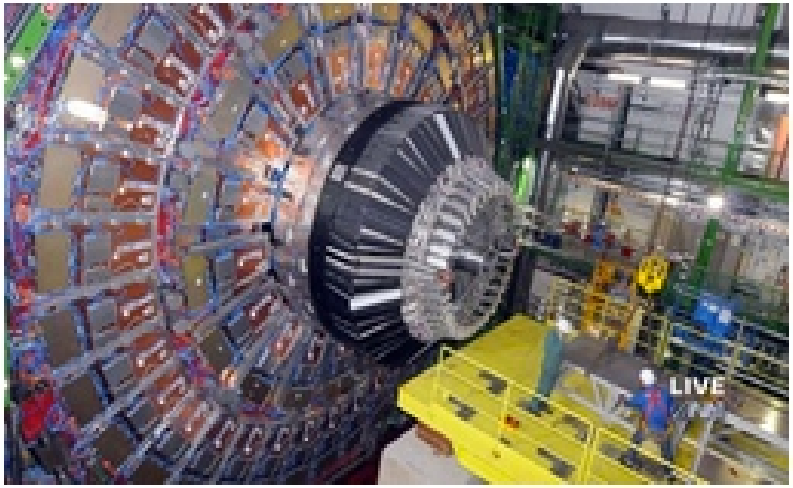
Open Day

North American Atlas meeting

The Newly Complete Standard Model



What to look for now?

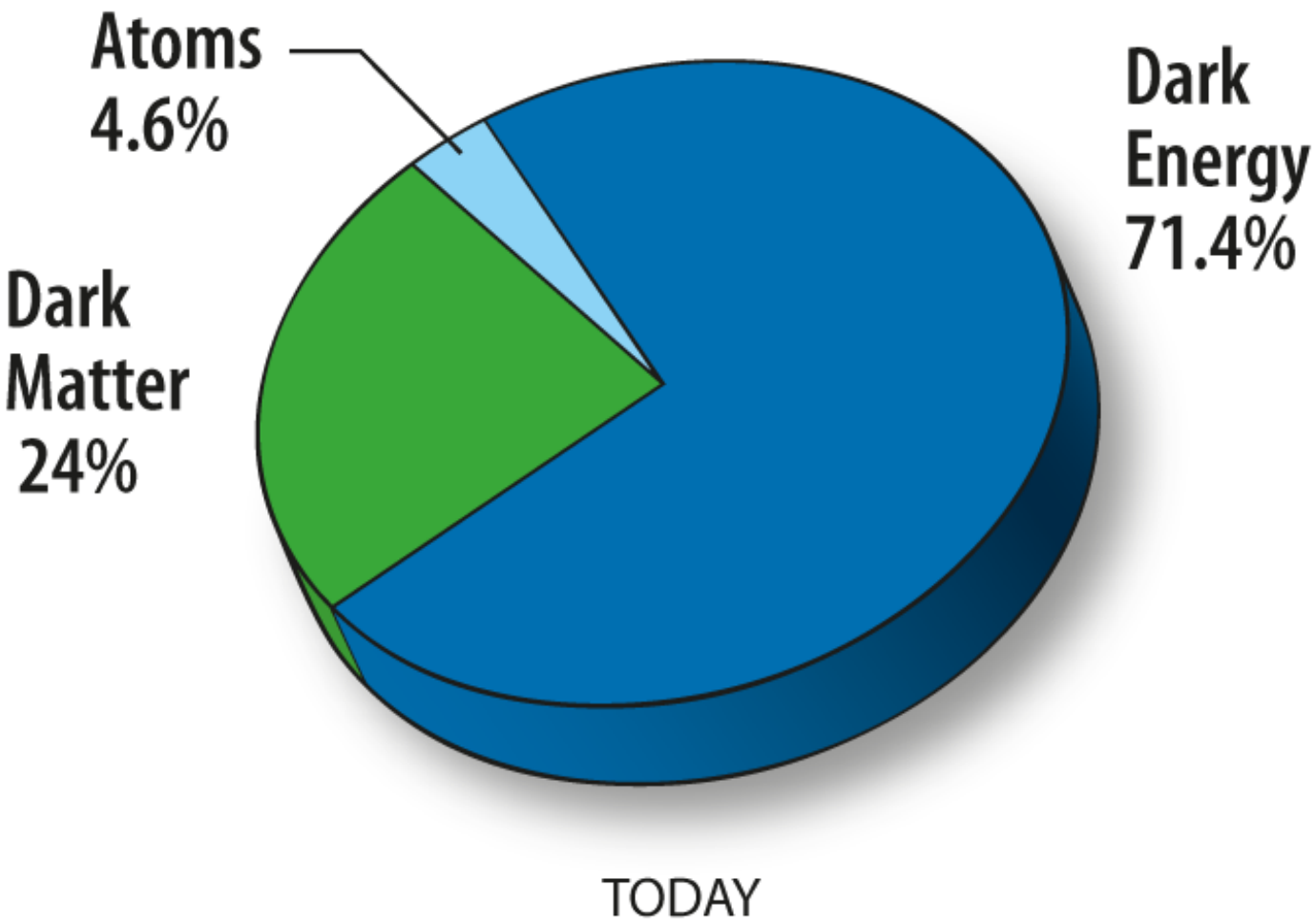


Bored Scientists Now Just Sticking Random Things Into Large Hadron Collider

Video: Tech Trends 07.08.14

One year after confirming the existence of the Higgs Boson, or "God Particle," scientists at CERN say they are struggling to find other uses for ...

The Standard Model is already dead



Motivated Things to look for

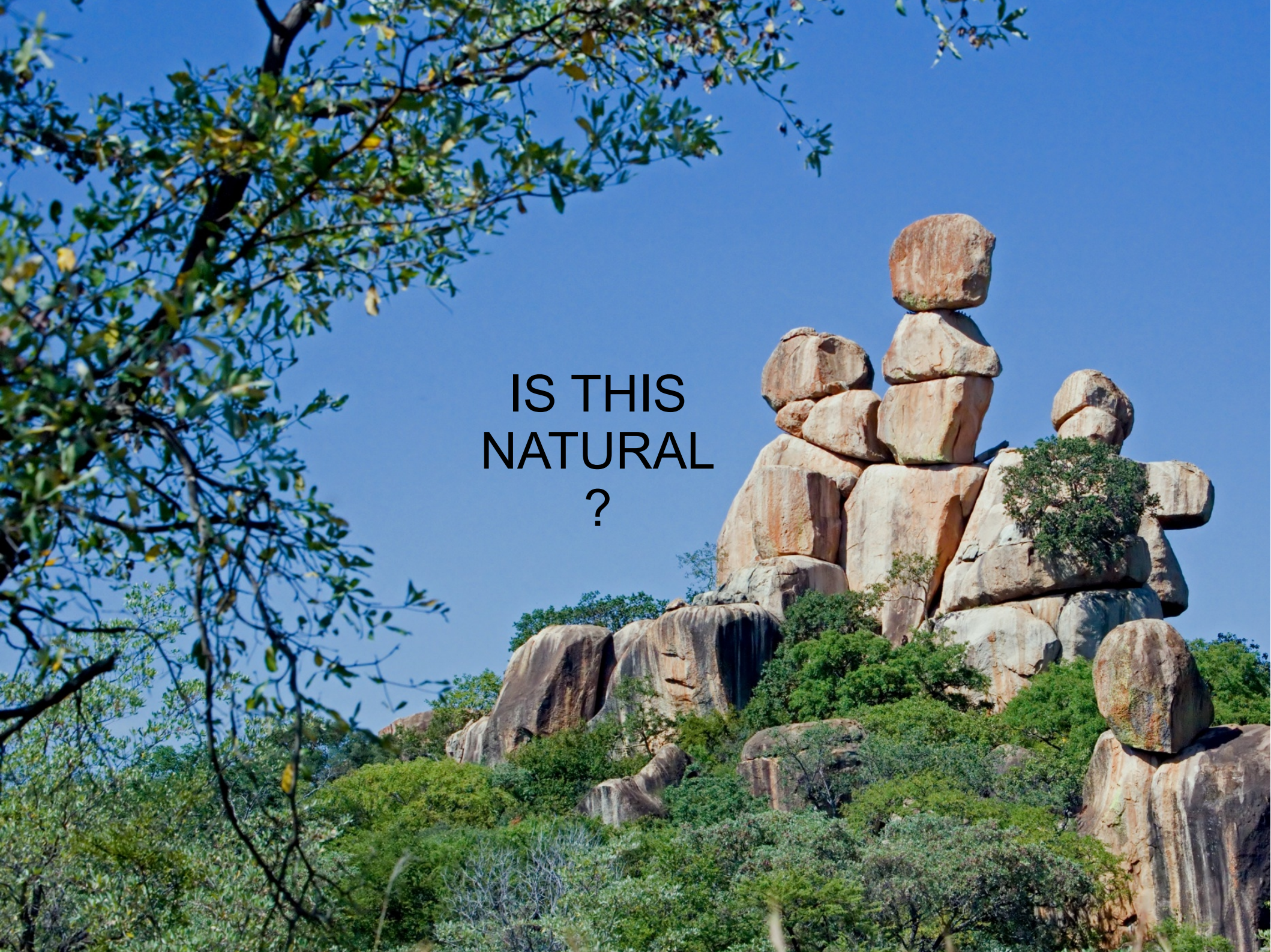
- Top partners (required for “naturalness”)
- Dark Matter
- Extended Higgs sector for Baryogenesis
- New CPV for Baryogenesis

“What is naturalness”

In food advertising, “natural” means ...basically nothing. Implication is “found in nature”. But this is not the definition theorists use in physics.

Natural

Un
Natural


IS THIS
NATURAL
?

“Naturalness”

- (Higgs mass)/(scale of new physics) is starting to look like a small parameter
- 'tHooft: A parameter is naturally small iff setting it to zero increases the symmetry of the theory. Then the radiative corrections to the parameter are also small. If unnatural, a finely tuned cancellation of the corrections is required.
- Why is this important?

Unnatural theory

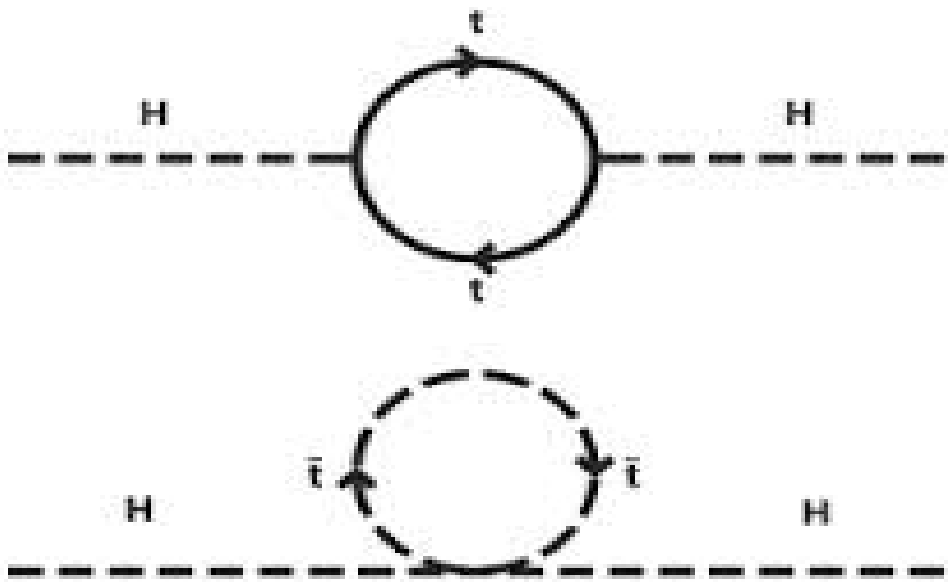
- “the multiverse” (theory of **many** different universes with different values of the “fundamental” constants) gives “anthropic” justification of fine-tuning, “prediction” of string theory.
- Stark contrast with Einstein's principle “Nature is constituted so that it is possible to lay down such strong determined laws that within these laws only rationally completely determined constants appear, not constants that could be changed without completely destroying the theory”

Somewhere in the multiverse...

Supersymmetry, naturalness and Einstein's principle

- In SUSY theories, renormalization less UV sensitive, (at most log sensitive), more things are calculable, e.g. some parameters in Higgs potential (in terms of other parameters)
- Negative correction to Higgs mass^2 parameter proportional to top squark mass^2
- If top squark too heavy, need fine tuned cancellation from μ (Higgsino mass parameter) and other SUSY breaking terms

Corrections to the Higgs potential



Quadratically
UV sensitive

Sum is only log UV sensitive, correction to Higgs mass^2
Proportional to top squark mass^2

Recently, a lot of discussion like this

'In peril is the notion of “naturalness,” Albert Einstein’s dream that the laws of nature are sublimely beautiful, inevitable and self-contained. Without it, physicists face the harsh prospect that those laws are just an arbitrary, messy outcome of random fluctuations in the fabric of space and time.'

QUANTA MAGAZINE illuminating science

THEORETICAL PHYSICS

Is Nature Unnatural?

Decades of confounding experiments have physicists considering a startling possibility: The universe might not make sense.

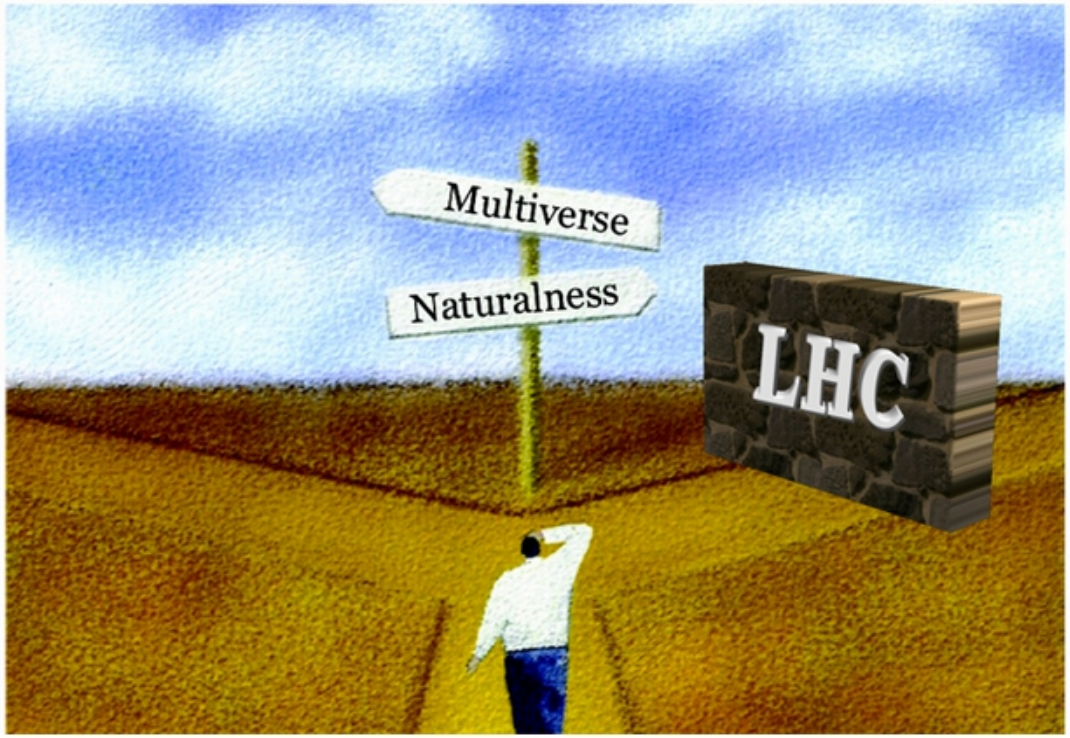


Illustration by Giovanni Villadoro

Is the universe natural or do we live in an atypical bubble in a multiverse? Recent results at the Large Hadron Collider have forced many physicists to confront the latter possibility.

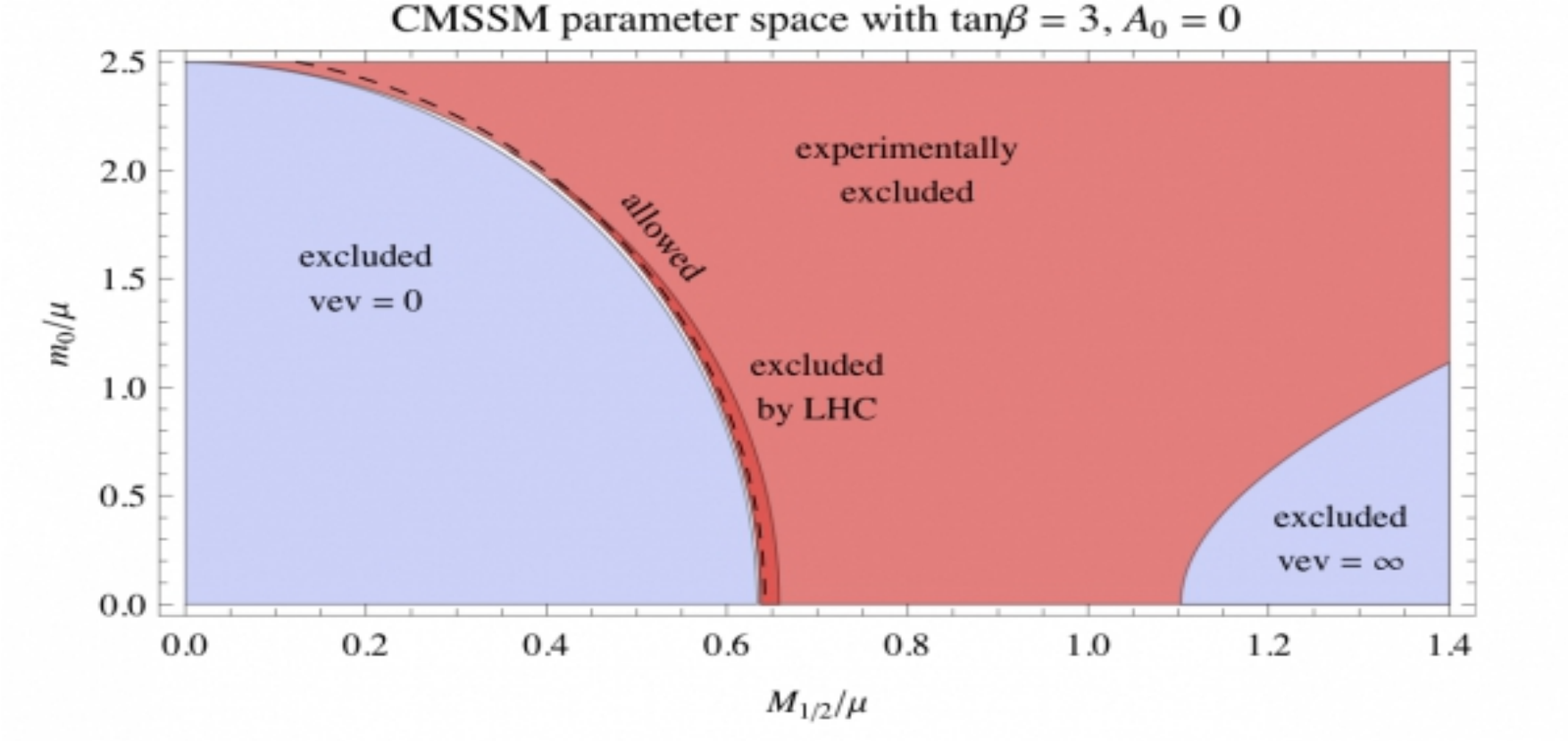
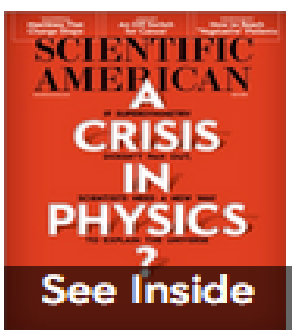


Image credit: Alessandro Strumia, via http://resonaances.blogspot.com/.



Supersymmetry and the Crisis in Physics

For decades physicists have been working on a beautiful theory that has promised to lead to a deeper understanding of the quantum world. Now they stand at a crossroads: prove it right in the next year or confront an epochal paradigm shift

By Joseph Lykken and Maria Spiropulu

Does unnatural=multiverse?

- Ignore power law sensitivity to UV? (many people have proposed this, since way back).
- Ignoring power law divergences now called "modified naturalness"
- No new particles much heavier than weak scale=no (modified) naturalness problem

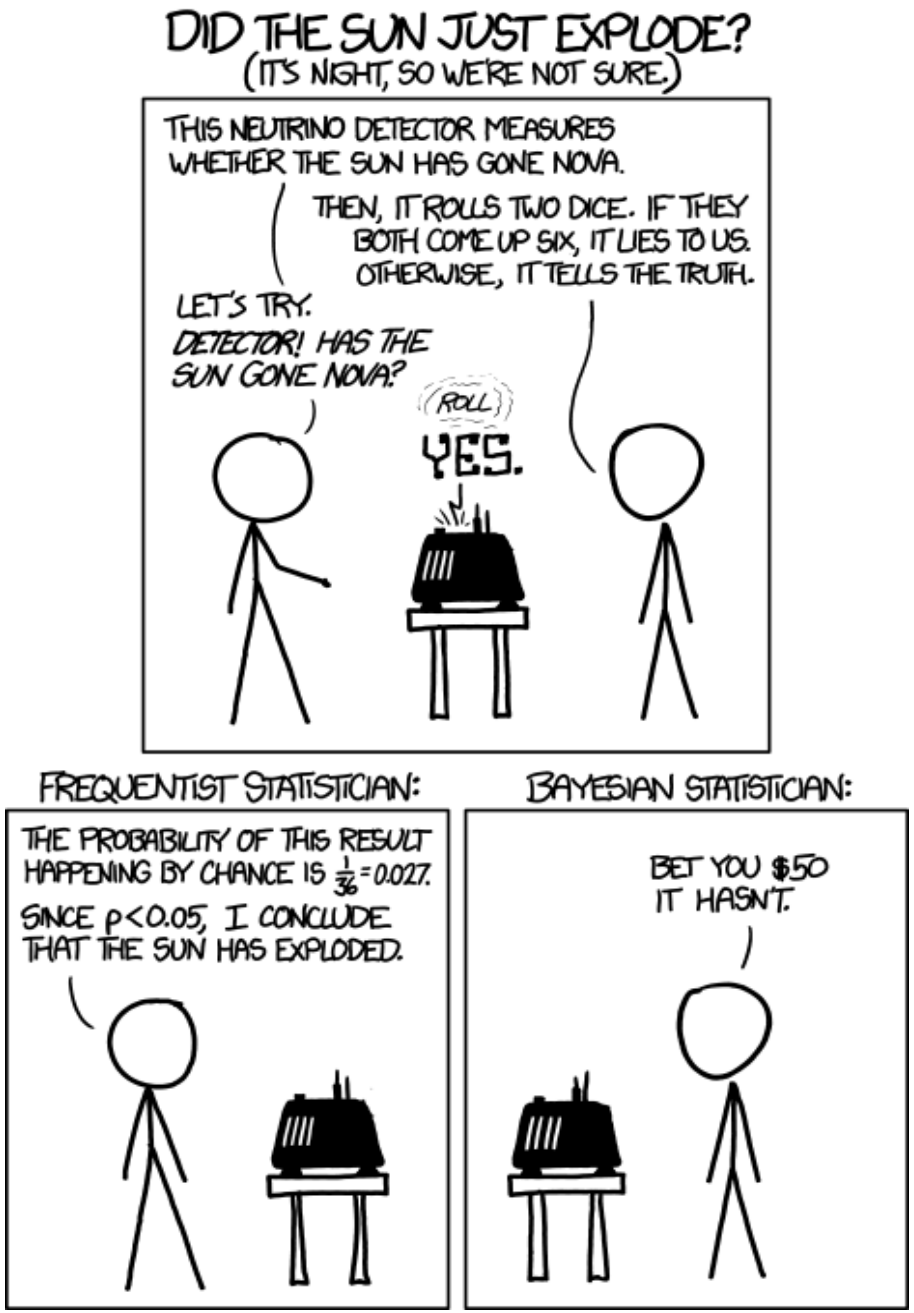
- Modified naturalness:
  Either subTeV scale susy or no susy?

To find evidence against naturalness

- Evidence against classic naturalness- conceptually simple. Push bounds on top partners to several TeV
- Evidence against any kind of naturalness,

  find new particles with mass above many TeV coupled to Higgs (argument for 100 TeV collider) and show they give huge correction to Higgs mass^2

How much finetuning to throw out naturalness?



In a predictive theory where all inputs are of order 1

- Accidentally small numbers happen! e.g. (1/3+1/2-2Ln(3/2))~.02
- “Focus point” SUSY a reasonable example of a predictive theory with near cancellations not resulting from symmetry.
- Just because a theory only works for particular relations between the parameters doesn't mean its wrong
- Giudice: “We have no idea how this 'Theory space' looks like, and the procedure of independently varying parameters may be too simple minded”

Do we currently know SUSY has to be finely tuned at all?

- (No UV assumptions), no fine-tuning: top squark lighter than ~700 GeV
- 1% fine-tuning: top squark lighter than ~7 TeV
- Currently, if other squarks and gluino are much much heavier than top squark, top squark mass bounds do not require SUSY to be finely tuned
- A spectrum with very heavy gluino (in the MSSM) is, however unnatural

Toward full LHC coverage of natural supersymmetry

Jared A. Evans, Yevgeny Kats, David Shih, Matthew J. Strassler

Download PDF (3,292 KB)

Abstract

We argue that combining just a handful of searches for new physics at Run I of the LHC is sufficient to exclude most supersymmetric extensions of the Standard Model in which the gluino is kinematically accessible and the spectrum is natural. Such models typically give rise to significant $\not{E}_T$ $_T$, top quarks and/or high object multiplicity, and we show that having even one of these signatures generally results in stringent limits. We also identify, among models that lack these signatures, the few gaps in coverage remaining, and propose search strategies to close these gaps. Our results are general and independent of the details of the spectrum, assumptions about minimality, *R*-parity, etc. Our analysis strategy should remain applicable when the LHC moves to higher energy. Central to our argument are ATLAS and CMS searches for many jets and low $\not{E}_T$ $_T$, a proposed lepton + many jets search, an ATLAS search for 6-7 high-p $_T$ jets, and a reexamination of the control and signal regions of the CMS black hole search.

- ArXiv ePrint: 1310.5758

LHC searches to find gluino (independent of how gluino decays)

- Many jets
- Leptons+ jets
- Many high pt jets
- stuff + MET
- Top quarks
- high multiplicity

EKSS no-lose theorem

- In (N)MSSM: Correction to top squark mass^2 proportional to (Majorana) gluino mass^2 (times log(UV scale))
- no-finetuning=TeV gluinos
- μ term gives large mass^2 to Higgs and Higgsino
- no-finetuning=light Higgsinos
- EKSS theorem: higgsinos+gluino+searches= LHC discovery

Before we debate when to give up naturalness or SUSY

Some viable versions of SUSY still arguably natural

PHYSICAL REVIEW D
particles, fields, gravitation, and cosmology

SUSY models under siege: LHC constraints and electroweak fine-tuning

Phys. Rev. D **89**, 115019 – Published 23 June 2014

Howard Baer, Vernon Barger, Dan Mickelson, and Maren Padeffke-Kirkland

"We find mSUGRA, mGMSB, mAMSB and MMAMSB models all to be highly fine-tuned."

- Amount of fine-tuning depends on model assumptions-e.g. relations among parameters
- Least fine tuned SUSY model of the 15 they examined (NUHM2) has ~10% fine tuning, others typically more than part in a thousand. Fine tuning measured by

The electroweak measure Δ_{EW} requires that there be no large/unnatural cancellations in deriving the value of m_Z from the weak scale scalar potential:

$$\frac{m_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d^d) - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{(\tan^2\beta - 1)} - \mu^2 \simeq -m_{H_u}^2 - \mu^2 \qquad (1)$$

where $m_{H_u}^2$ and $m_{H_d}^2$ are the *weak scale* soft SUSY breaking Higgs masses, μ is the *supersymmetric* higgsino mass term and Σ_u^u and Σ_d^d contain an assortment of loop corrections to the

“NUHM2”

D. Matalliotakis and H. P. Nilles, Nucl. Phys. B **435** (1995) 115; P. Nath and R. L. Arnowitt, Phys. Rev. D **56** (1997) 2820; J. Ellis, K. Olive and Y. Santoso, *Phys. Lett.* **B 539** (2002) 107; J. Ellis, T. Falk, K. Olive and Y. Santoso, *Nucl. Phys.* **B 652** (2003) 259; H. Baer, A. Mustafayev, S. Profumo, A. Belyaev and X. Tata, *J. High Energy Phys.* **0507** (2005) 065.

- SU(5) GUT relations imposed at high scale of soft parameters but otherwise parameters independent
- Different mass^2 parameters for up and down Higgs
- “radiatively driven naturalness”
- low μ (Higgsino mass parameter), light Higgsinos
- Gluino lighter than 4 TeV
- Mixed top squarks in 1-5 TeV
- First 2 squark generations much heavier
- Additional Higgses several TeV and mostly decay to gauge/Higgs, Higgsinos

Focus point SUSY Feng, Matchev, Moroi

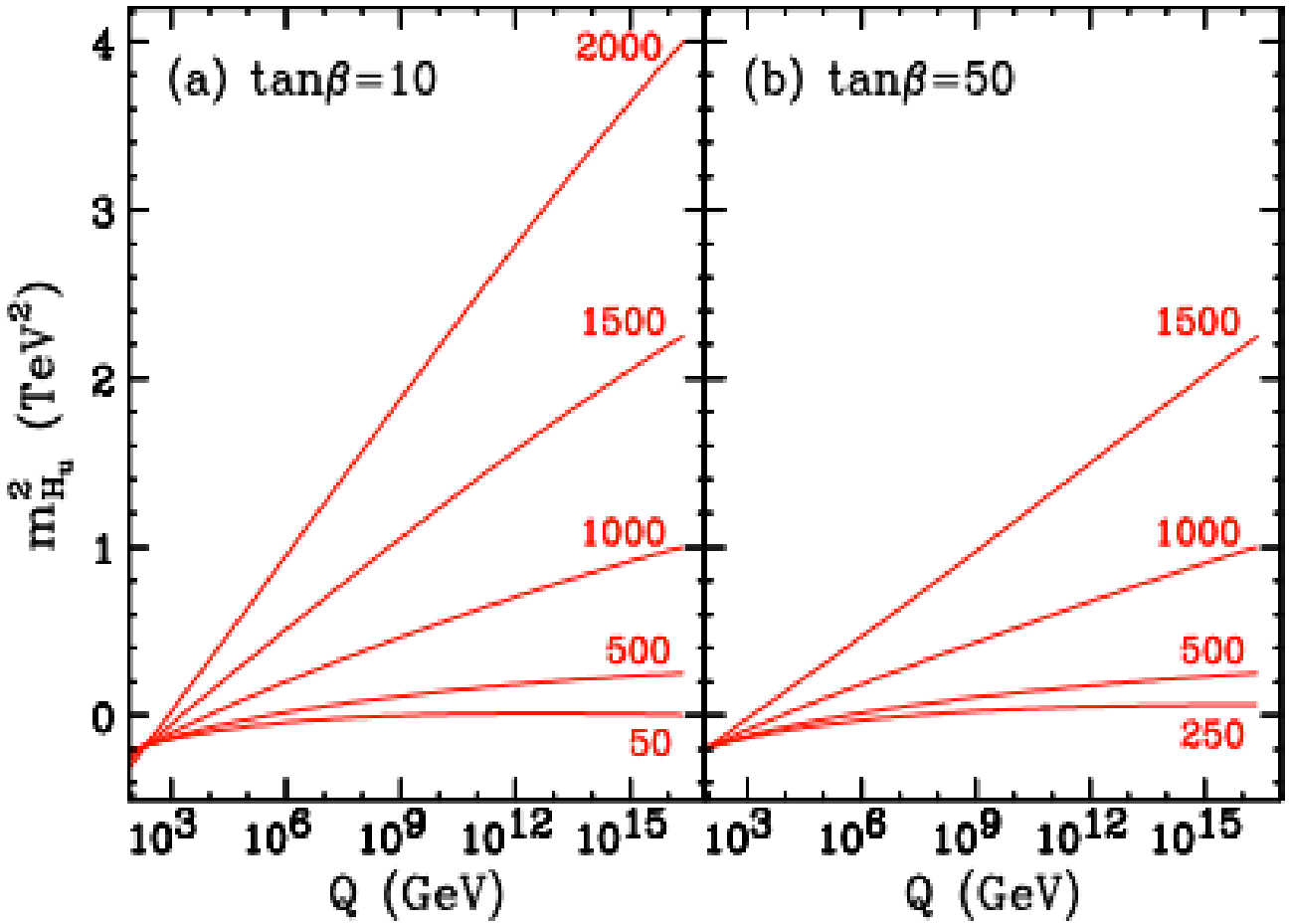


FIG. 10: The RG evolution of $m^2_{H_u}$ in the focus point region of mSUGRA for $\tan\beta = 10$ (left) and 50 (right), several values of m_0 (as shown in GeV), $M_{1/2} = 300$ GeV, and $A_0 = 0$. For both values of $\tan\beta$, $m^2_{H_u}$ exhibits an RG focus point near the weak scale, implying that the weak scale is insensitive to variations in the GUT-scale supersymmetry-breaking parameters [133].

From Feng arXiv:1302.6587

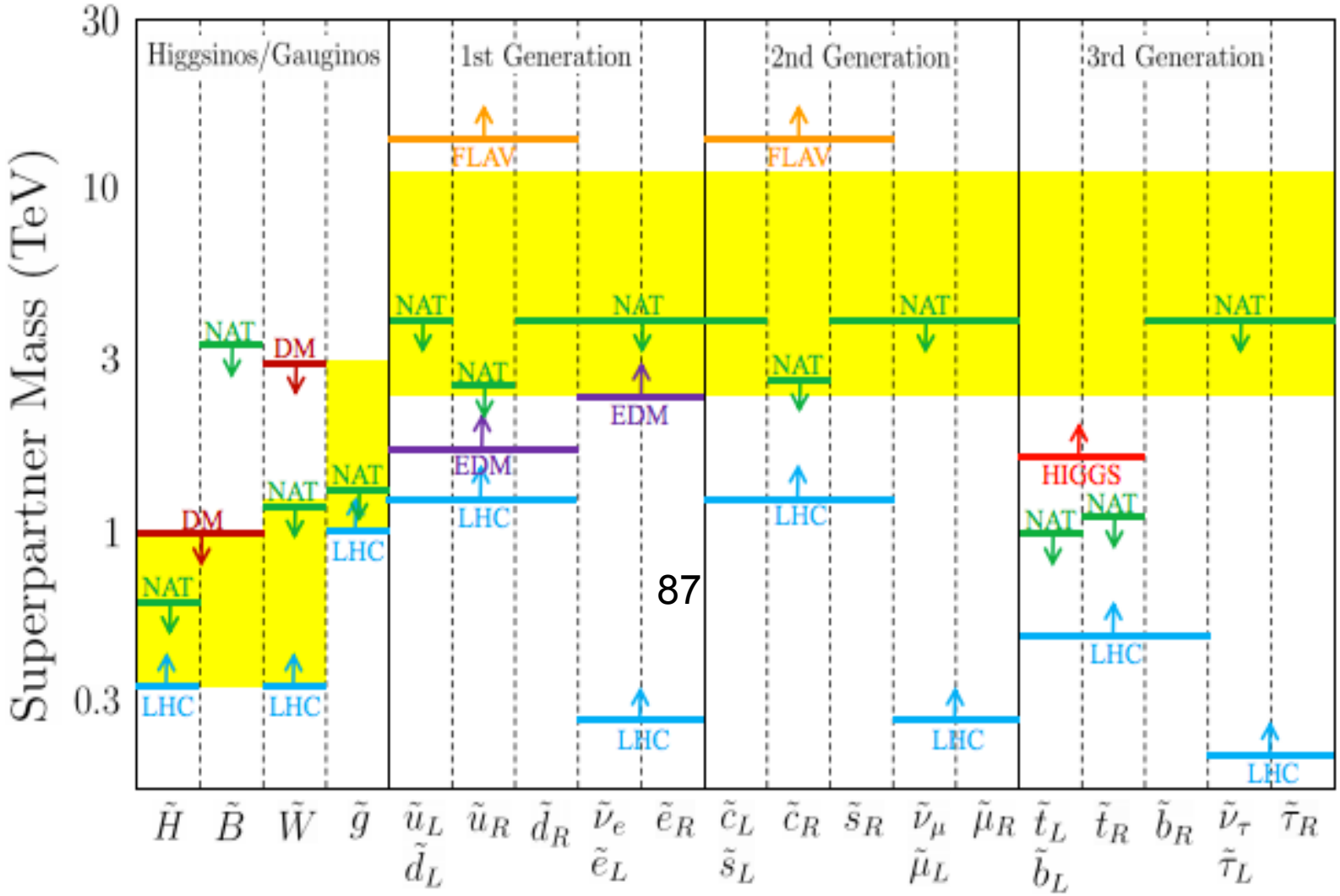


FIG. 9: Example superpartner mass ranges for focus point supersymmetry (shaded) with constraints as given in Fig. 7. Heavy and degenerate first and second generation sfermions satisfy flavor and EDM constraints and heavy third generation sfermions raise the Higgs mass, while naturalness is preserved despite heavy stops by correlations between GUT-scale parameters.

More Minimal SUSY

(Drees, Pomarol, Thomassini, Dimopoulos, Giudice, Cohen, Kaplan, Nelson....)

- Aka “Natural SUSY”
- Flavor/CP physics motivates a SUSY spectrum with very heavy $1^{st}/2^{nd}$ generation squarks
- Naturalness motivates lighter top/bottom squarks, gauginos,higgsinos
- “inverted hierarchy” spectrum motivated by some flavor/susy breaking models

From Feng arXiv:1302.6587

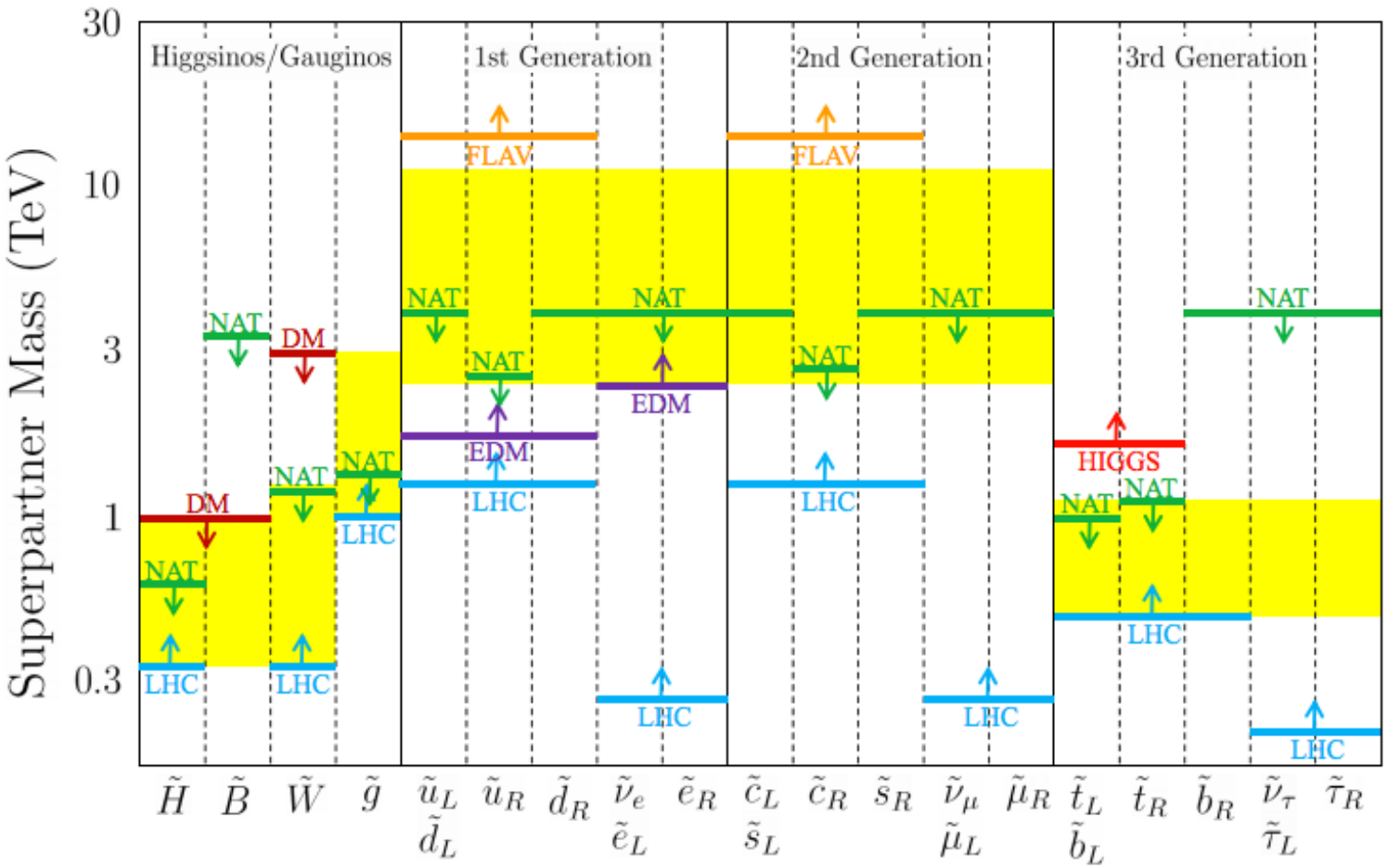


FIG. 8: Example superpartner mass ranges for effective supersymmetry (shaded) with constraints as given in Fig. 7. Heavy and degenerate first and second generation sfermions satisfy flavor and EDM constraints, and light third generation sfermions satisfy naturalness. The Higgs mass constraint requires either near-maximal stop mixing, or physics beyond the MSSM.

Very heavy natural gluinos?

- In MSSM with Majorana gluino masses, heavy gluinos mean heavy squarks (radiative corrections)
- *(Fox,A.N., Weiner)* Dirac masses for gauginos can be a loop factor larger than scalar masses (require extension of field contact of MSSM to allow Dirac partners)
- Allows “supersoft” supersymmetry breaking—no log sensitivity to UV
- Gluino could be out of LHC reach in natural supersymmetric theory

Advantages of Heavy Dirac gauginos

- Relaxation of SUSY FCNC, EDM, proton decay constraints

  squark degeneracy constraint relaxed
- Heavy Dirac 4 TeV gluino+700 GeV top squark + no fine tuning
- Additional terms in Higgs potential can make Higgs mass 125 GeV, heavy/mixed top squark not required

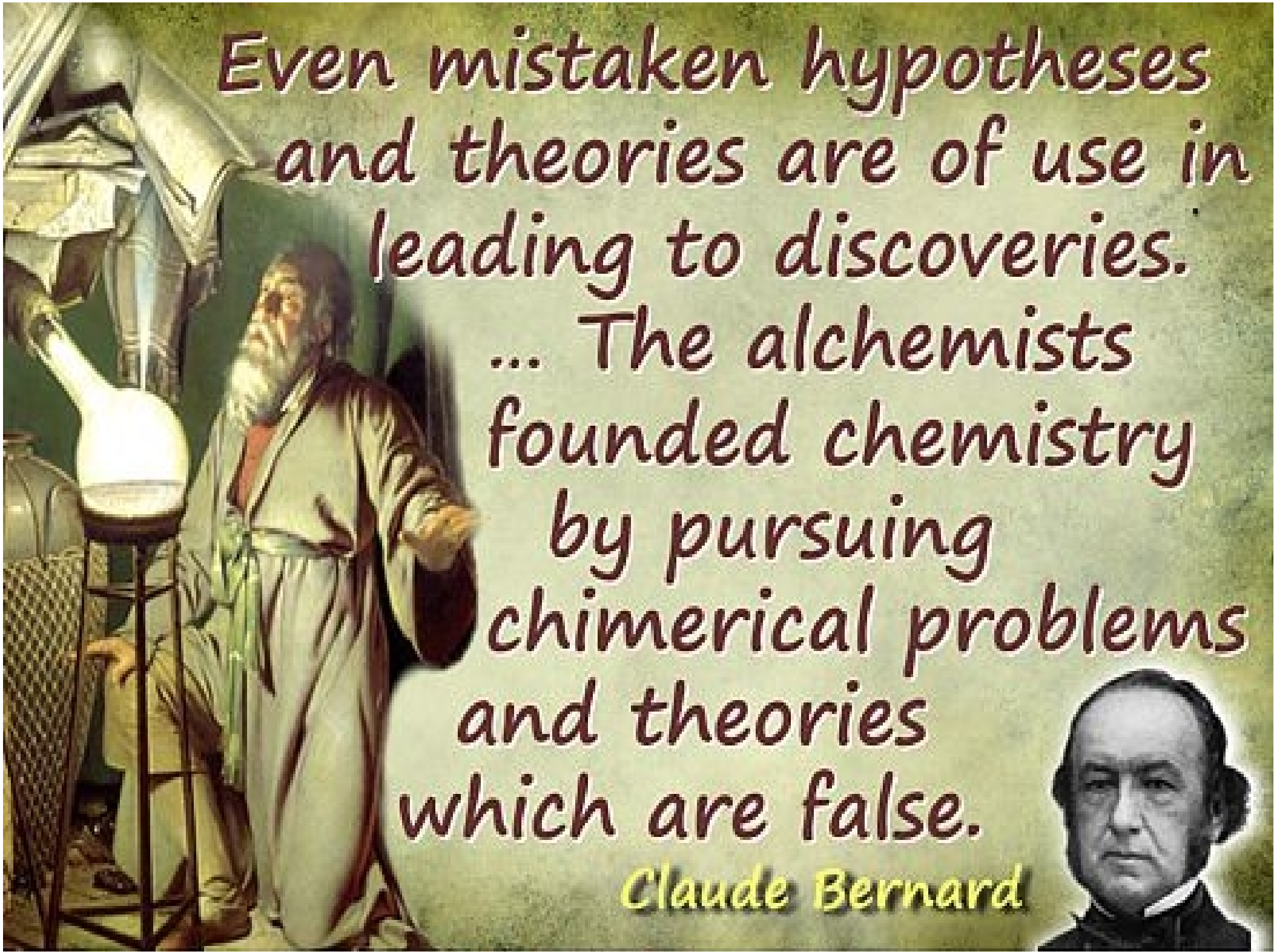
Another Einstein Principle

“If you are out to describe the truth, leave elegance to the tailor”

A. Einstein, on being reproached that his formula of gravitation was longer and more cumbersome than Newton's.

Minimal Naturalness in SUSY

- Top squarks+ Higgsinos lighter than TeV seem to be necessary
- Can we establish a “No-lose” LHC theorem? (independent of additional particle content, decay modes)


Even mistaken hypotheses and theories are of use in leading to discoveries.
... The alchemists founded chemistry by pursuing chimerical problems and theories which are false.
Claude Bernard