Beyond the Standard Model

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Lecture 2

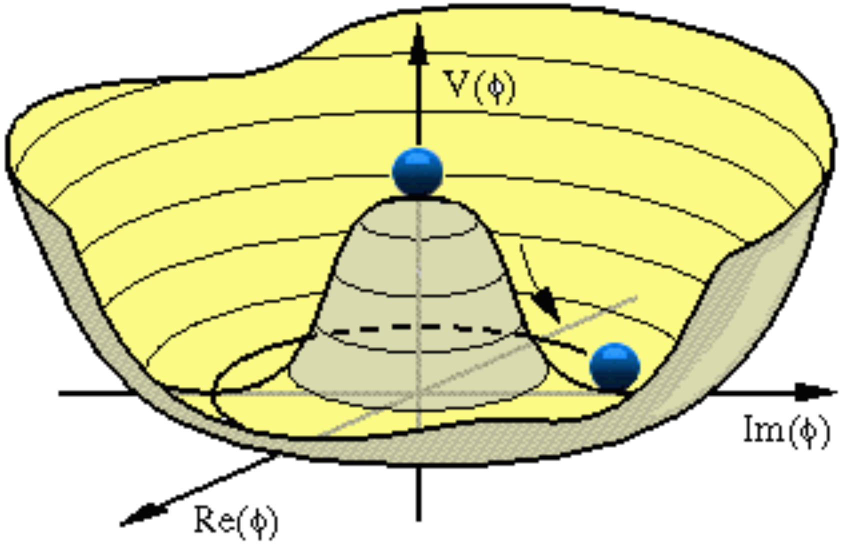
CERN Summer Student Programme 2012

What do we learn from m_H = 125-126 GeV?

Do we live on the verge of a cosmic catastophe?

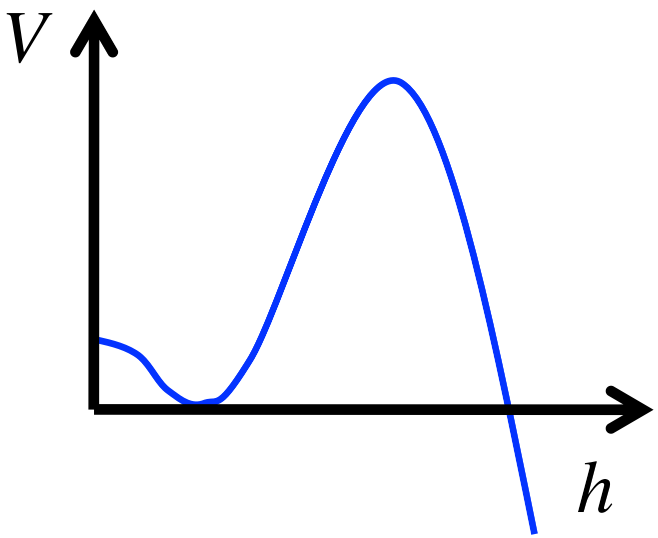
When the universe was 10^{-10} second old, it underwent a phase transition.

Is a new phase transition going to happen?



$$V = \frac{\lambda}{4}\left(|h|^2 - v^2\right)^2$$

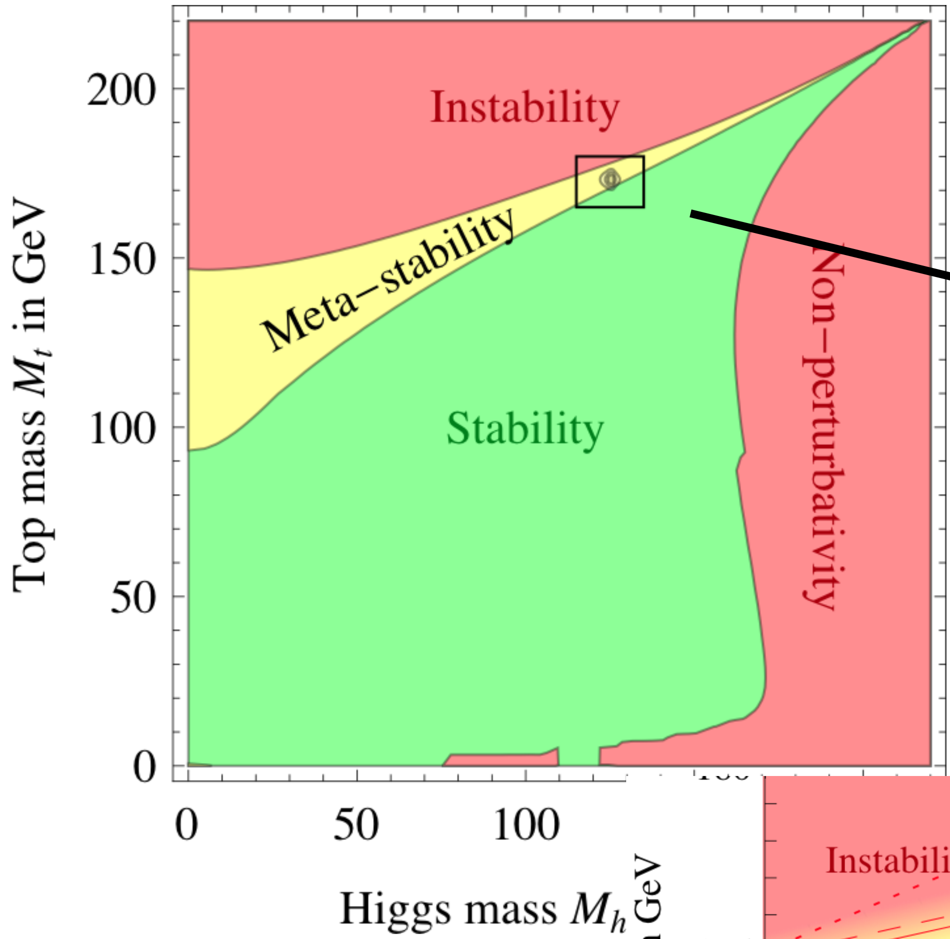
Extrapolate the SM up to very high energies

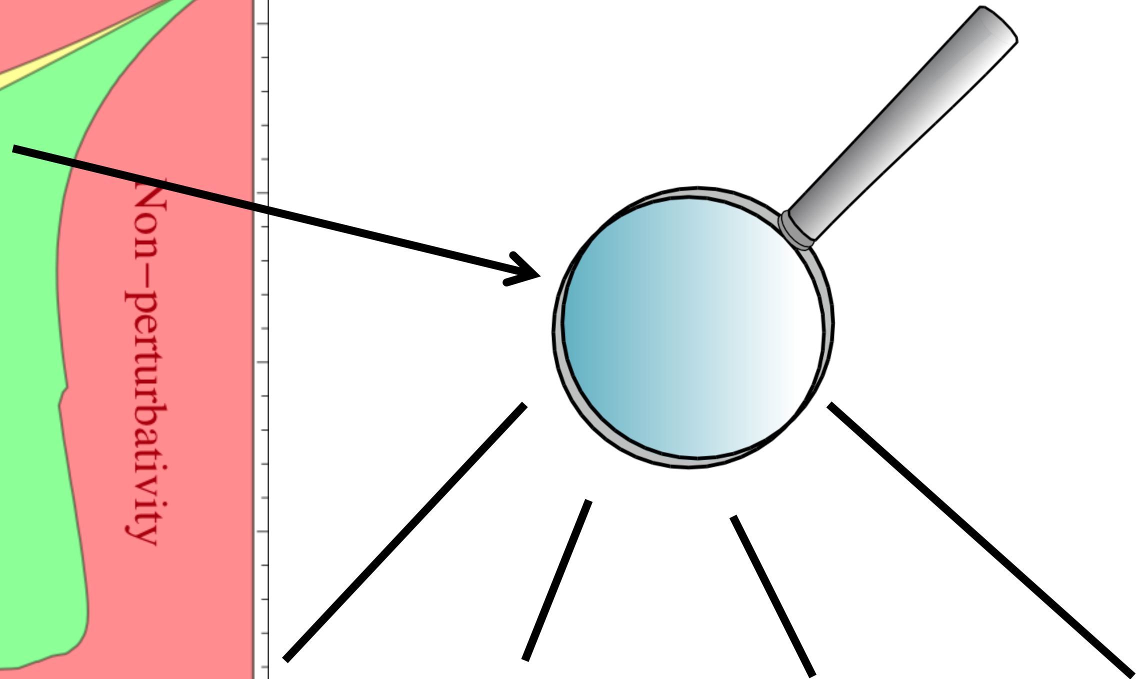


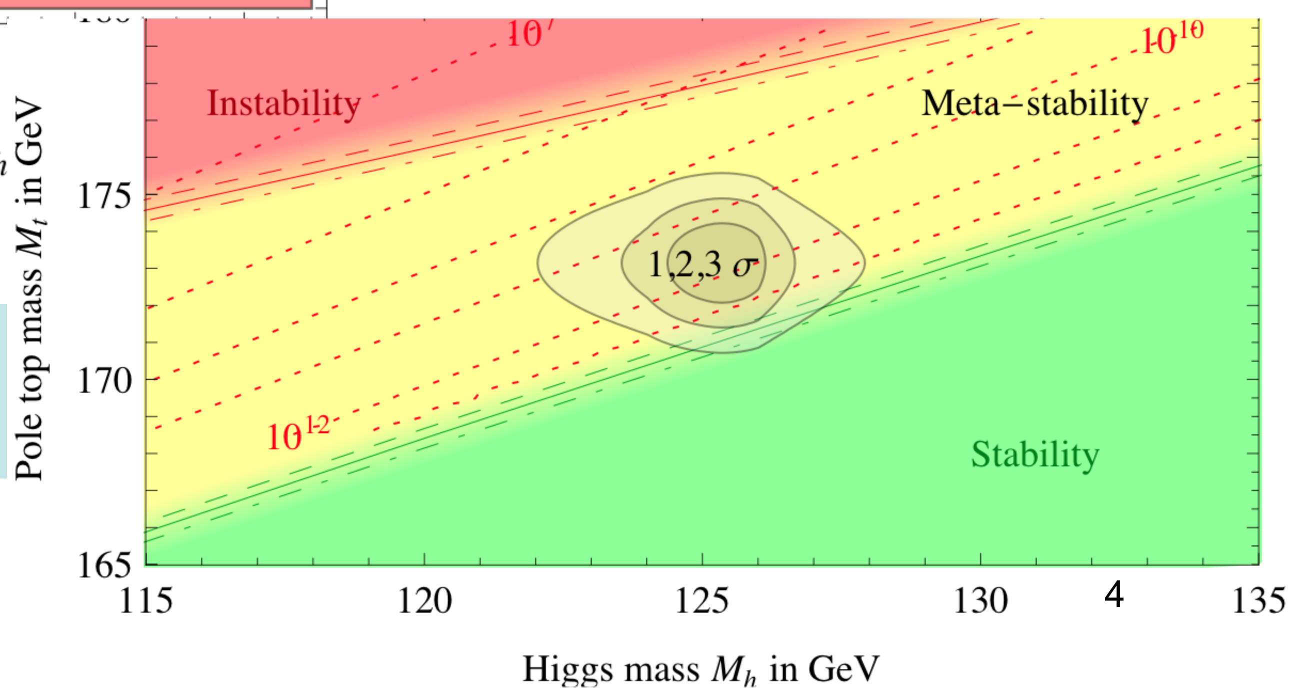
↑Higgs mass

↓Top quark mass

- Quantum tunneling
- Thermal tunneling

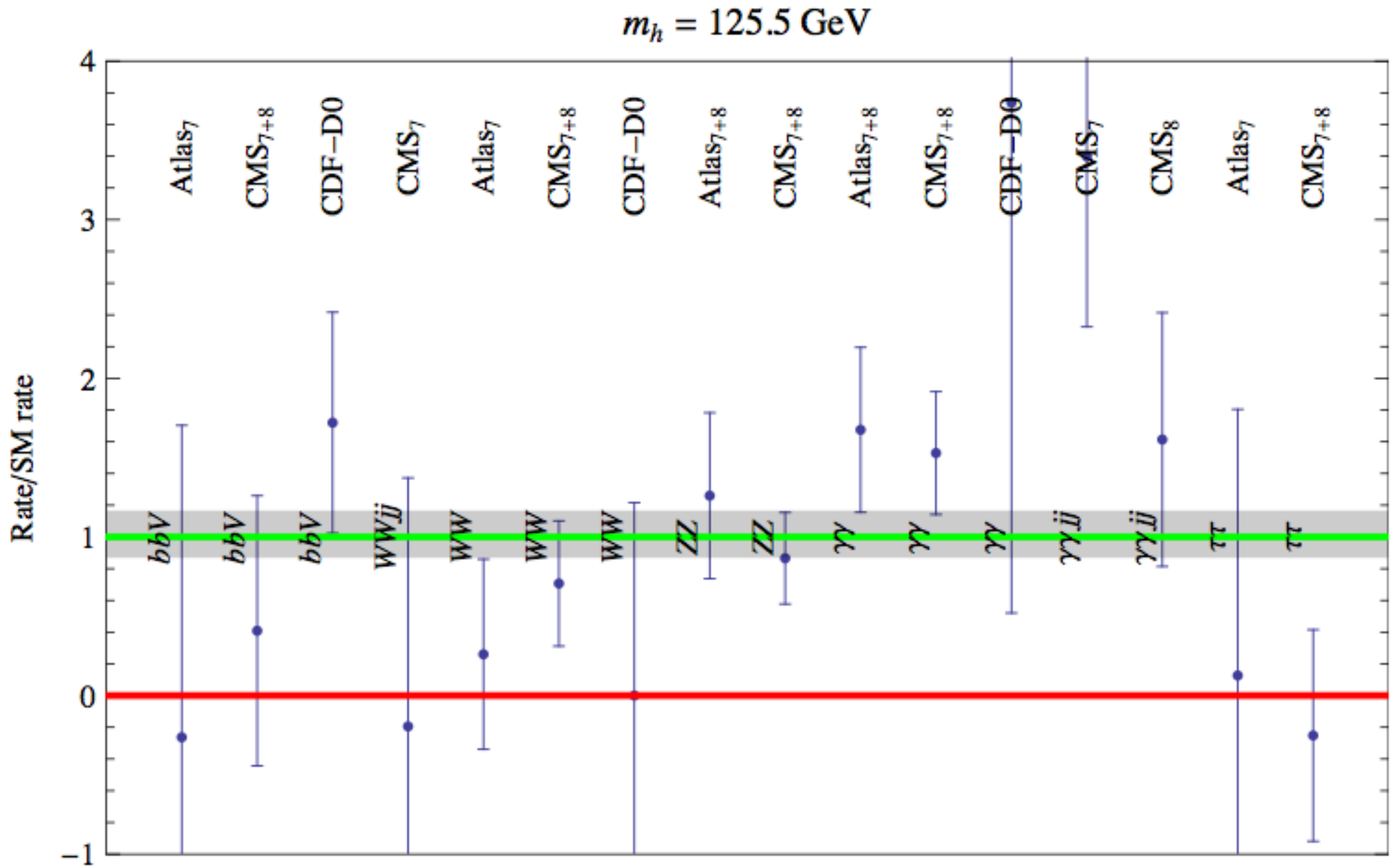




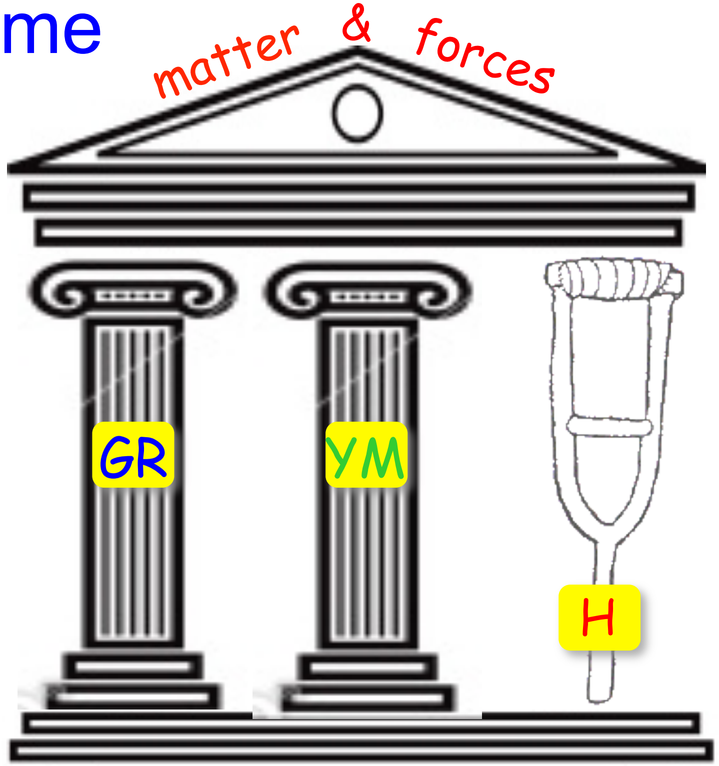


We seem to live near a critical condition

What do we learn from measuring the Higgs couplings?



Discovering the Higgs is not *just* finding a new particle: it is unveiling a fundamental element of nature's scheme



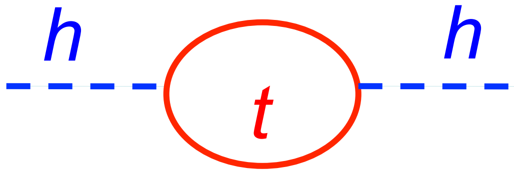
• GR & YM are elegant structures dictated by symmetry, have few free parameters, and fare marvelously with exp. data

• The Higgs sector looks like a provisional structure

➔ the LHC may find surprises

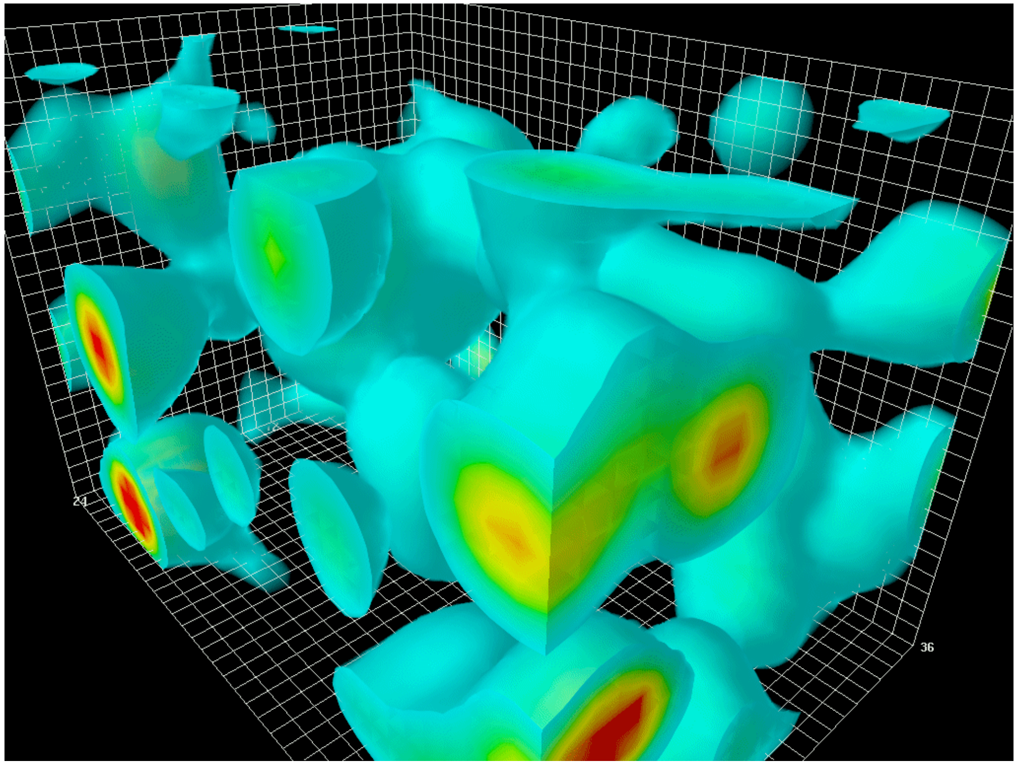
Courtesy of C. Grojean & A. Weiler

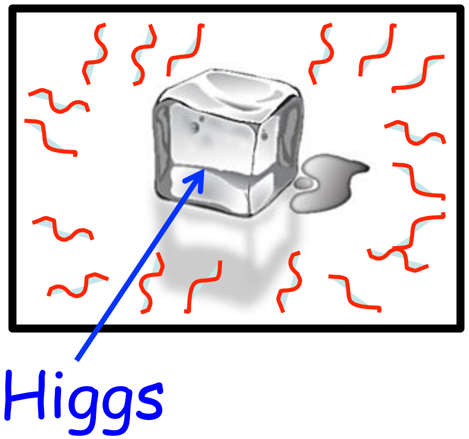
Sensitivity to quantum fluctuations



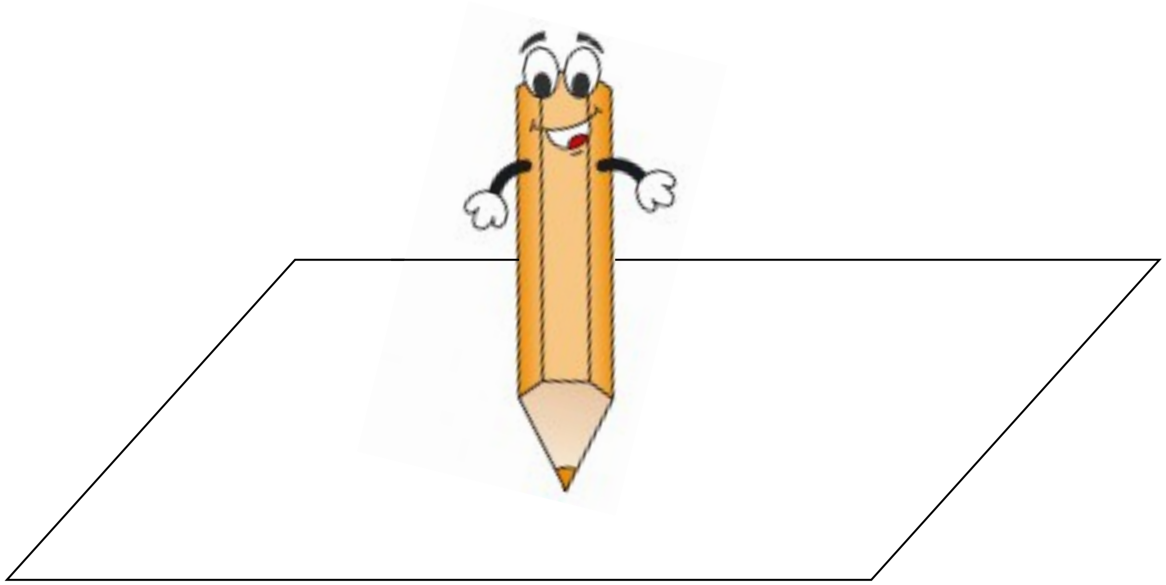
$$M_Z \propto \frac{\Lambda}{4\pi}$$

No separation of scales:
why $M_Z << M_{Pl}$ ($G_N << G_F$)?



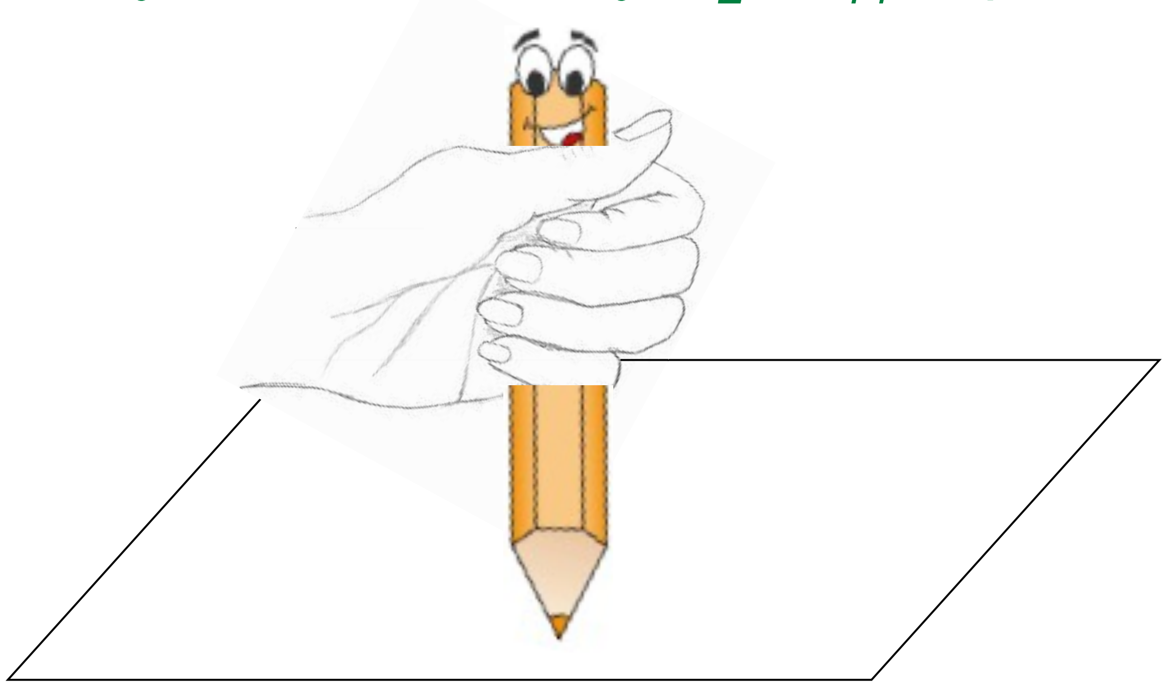


Having $M_Z << M_{Pl}$ requires tuning up to 34th digit !

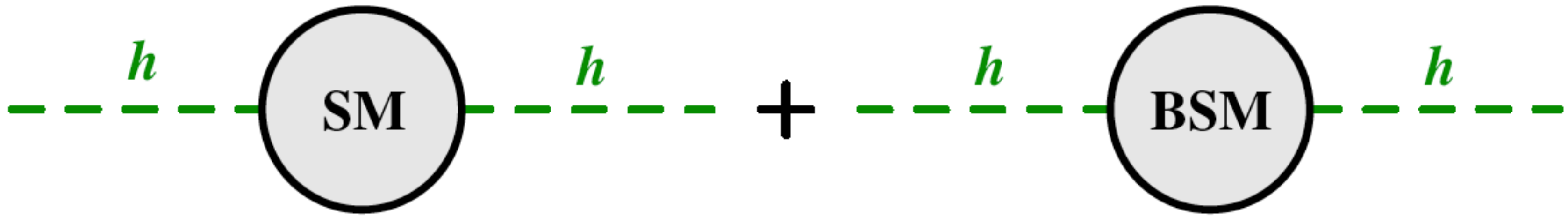


Poising a pencil as long as the solar system
on a tip 0.1 mm wide!

The “stability” of the hierarchy M_Z / M_{Pl} requires an explanation



Higgs is “screened” at energies larger than TeV ⇒
new forces and new particles within LHC energy range

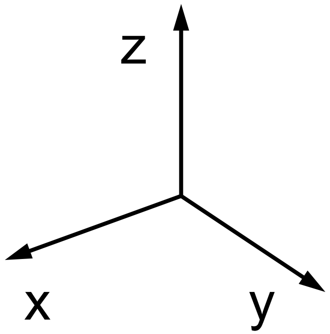


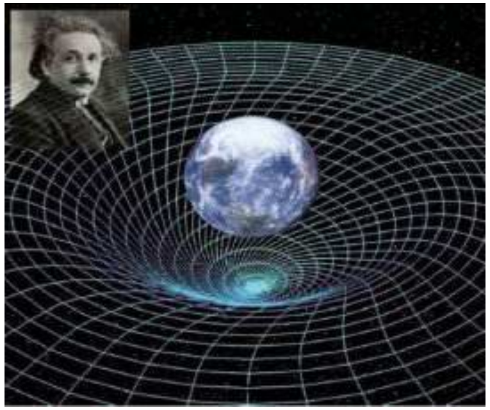
What is the new phenomenon? Enter pure speculation…

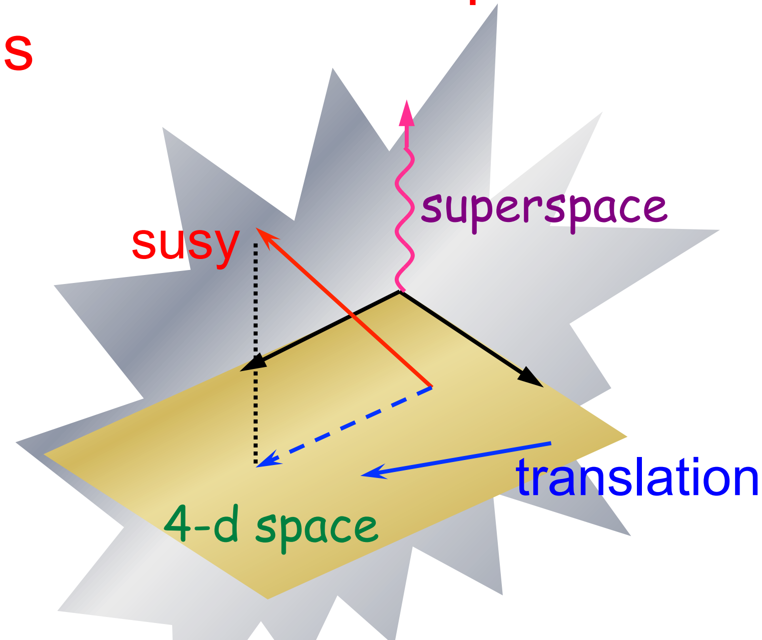
These speculations created remarkable conceptual discoveries

Some of the new ideas about naturalness and EW breaking revolutionize our concepts of space-time, matter and forces

Supersymmetry emerges from the search for new space-time symmetries

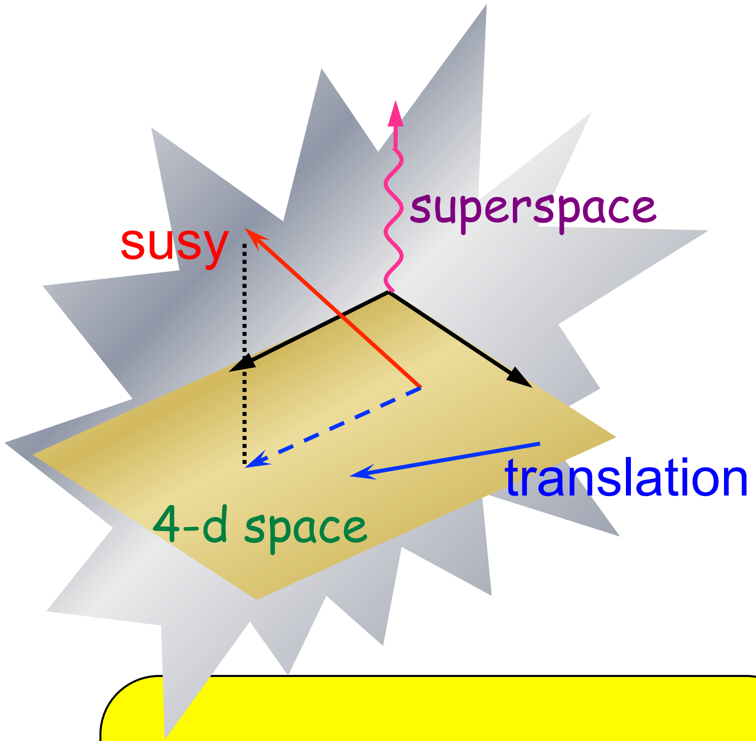






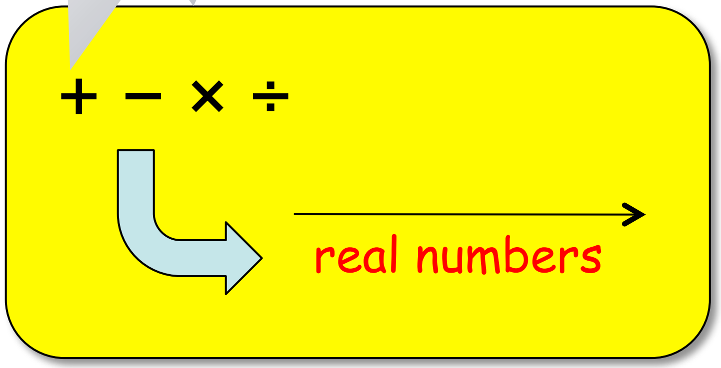
3-d space	4-d space-time	superspace
translations/rotations	Poincaré	supersymmetry
$P = (x,y,z)$	$P = (t,x,y,z)$	$P = (t,x,y,z,\theta,\bar{\theta})$

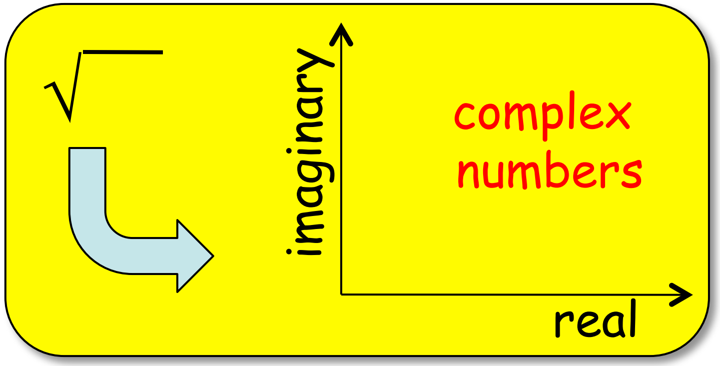
The new coordinates have a quantum character and cannot be described by ordinary numbers

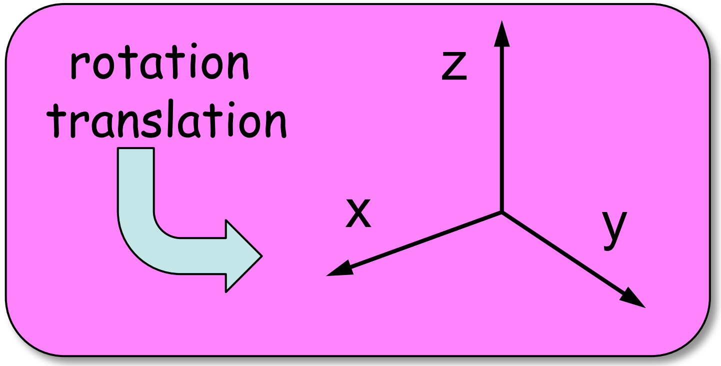


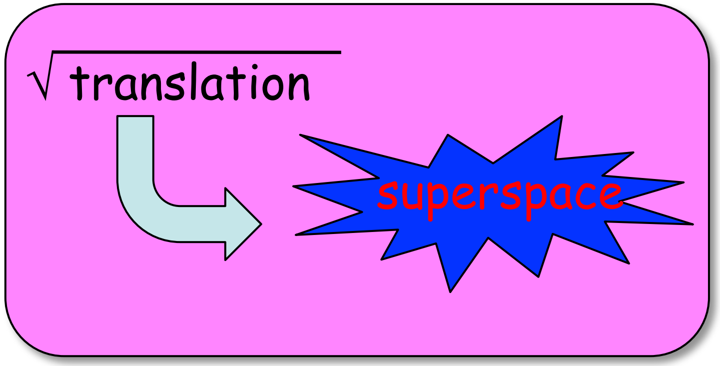
$$\theta \times \eta = -\eta \times \theta \quad \Rightarrow \quad \theta^2 = 0$$

SUSY × SUSY = Translation









This new space has unfamiliar geometric properties
(but it is mathematically consistent)

What is the physical meaning of superspace?

Fields: $\psi(x)$ ➔ particles

Taylor expansion of superfields:

$$\varphi(x,\theta) = \sum_n \varphi_n(x)\,\theta^n = \varphi_0(x) + \varphi_1(x)\,\theta$$

What happens to particles propagating in superspace? Superparticle!

Supersymmetry
particle spin S
particle spin S+1/2

Special relativity & quantum mechanics
particle charge Q
antiparticle charge -Q