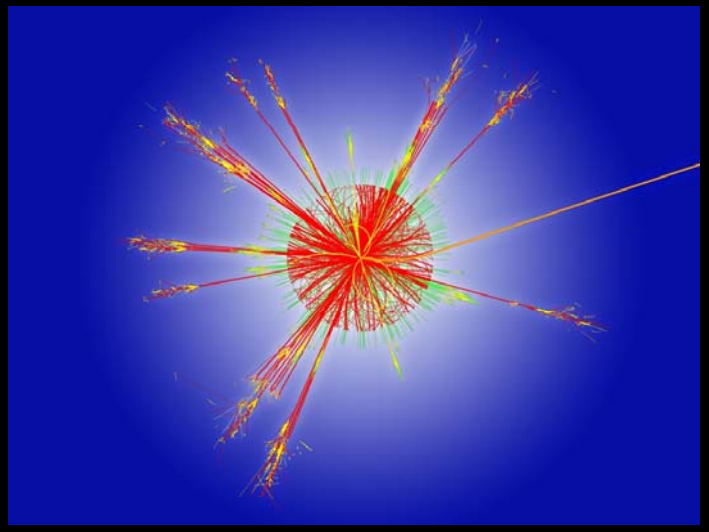


3

How can we solve the mysteries of the Unive

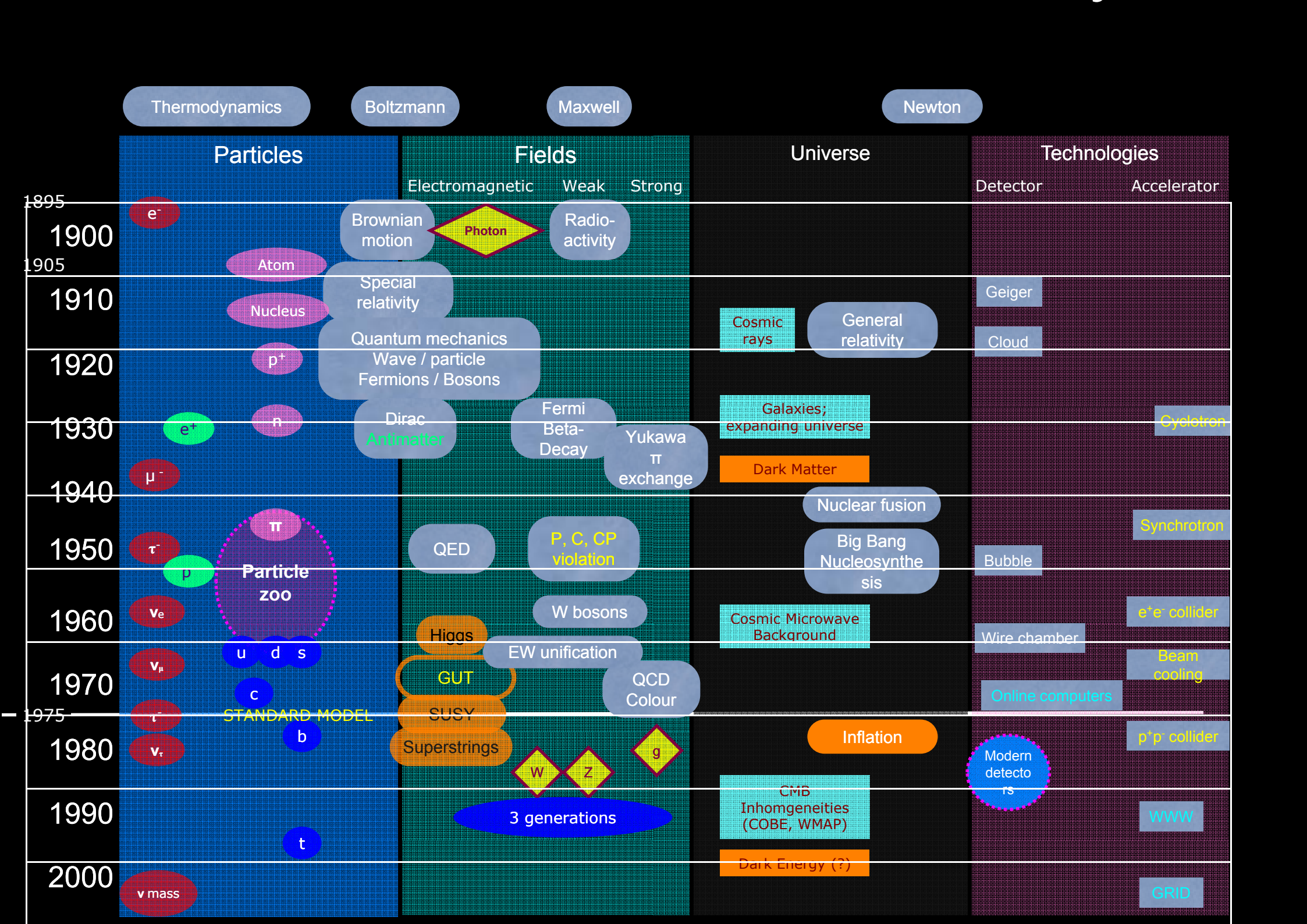
Remind

ll that remains to do in physics is to fill in the sixth decimal
ace

(Albert Michelson,

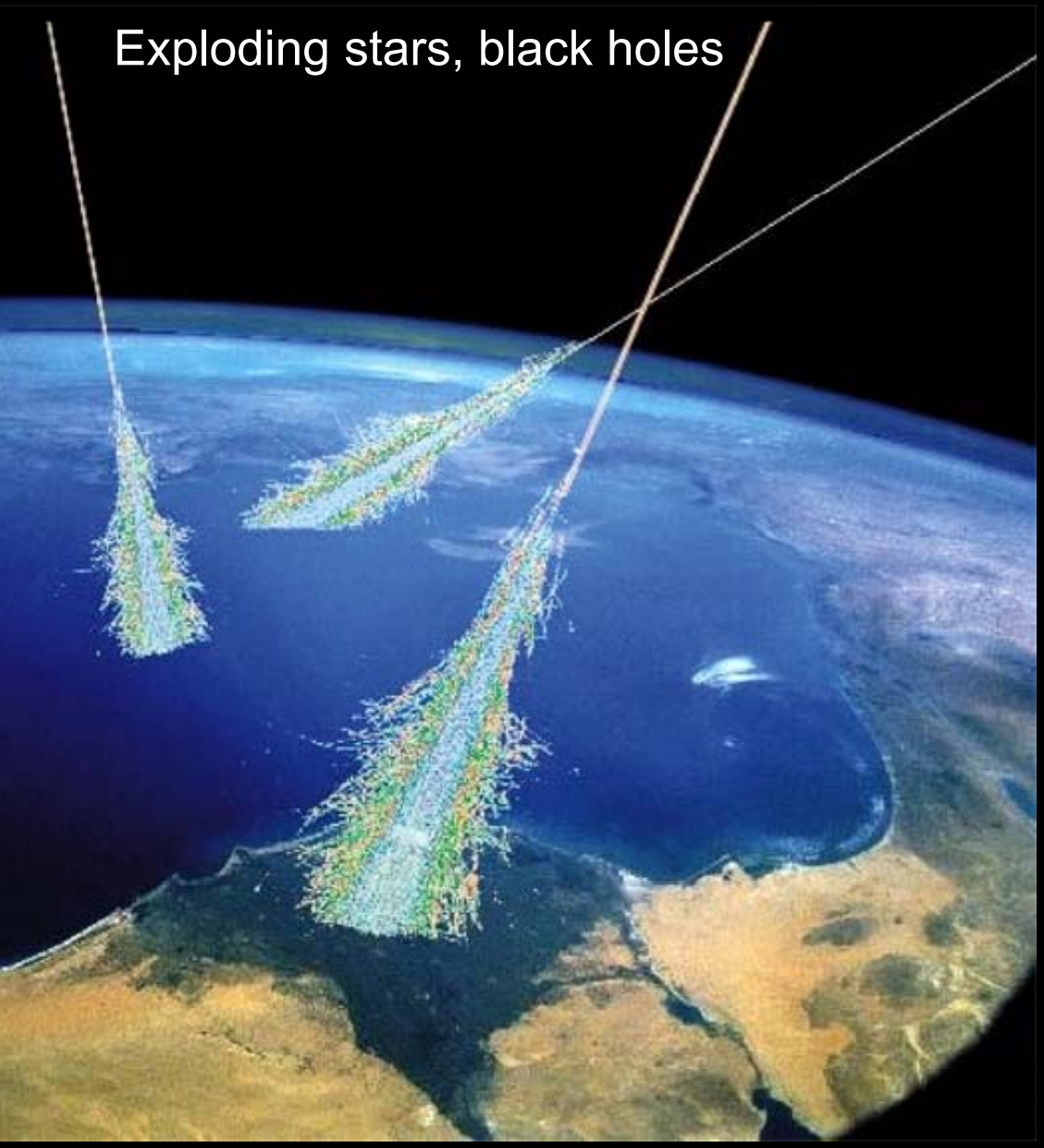
here is nothing new to be discovered in physics now.
ll that remains is more and more precise measurement.

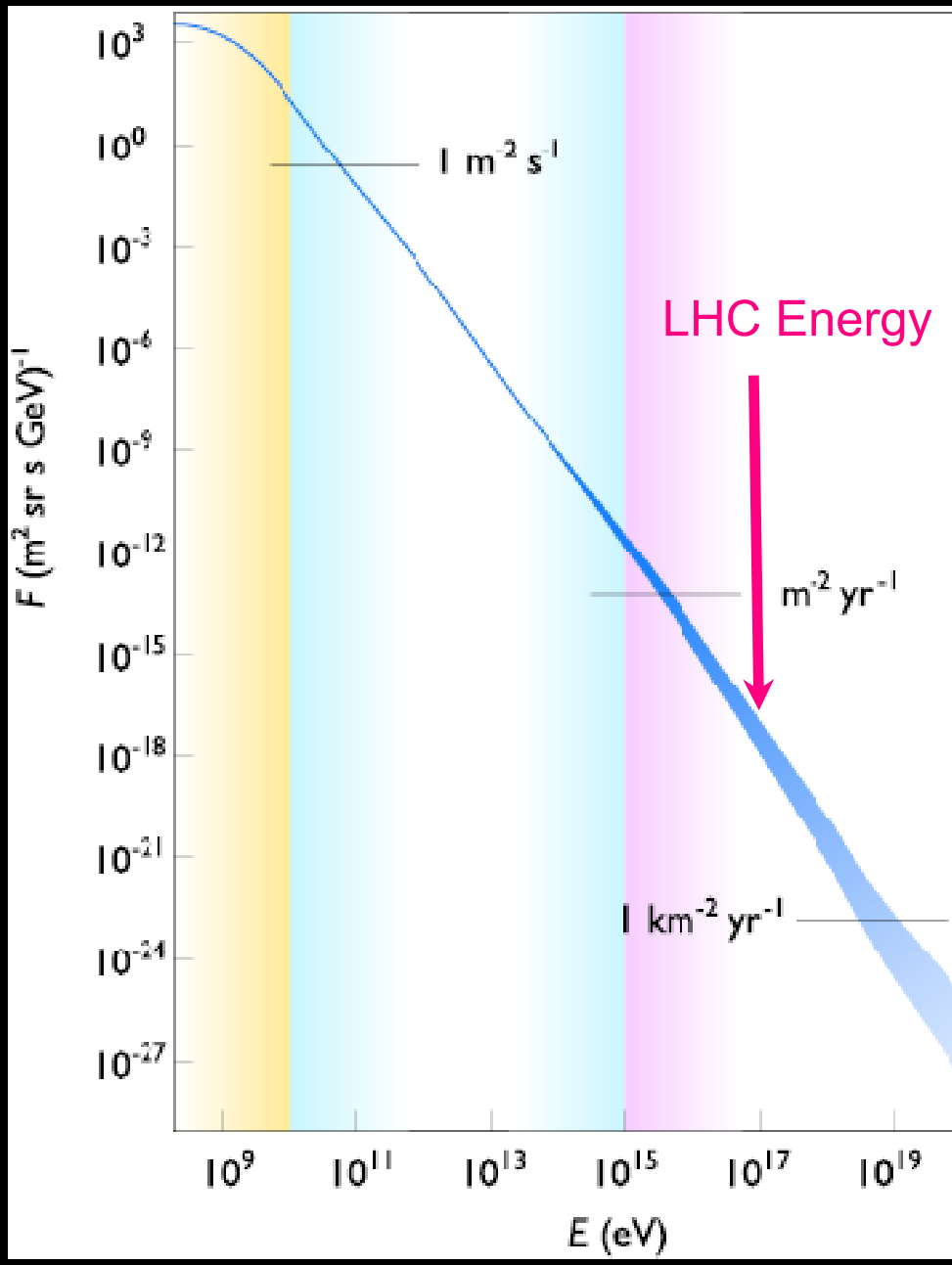
(Lord Kelvin, 1


Thermodynamics
Boltzmann
Maxwell
Newton
Particles
Fields
Universe
Technologies
Electromagnetic
Weak
Strong
Detector
Accelerator
1895
1900
1905
1910
1920
1930
1940
1950
1960
1970
1975
1980
1990
2000
e-
Brownian motion
Photon
Radio-activity
Atom
Special relativity
Nucleus
Quantum mechanics
Wave / particle
Fermions / Bosons
Geiger
Cloud
Cosmic rays
General relativity
p+
n
e+
Dirac
Antimatter
Fermi
Beta-
Decay
Yukawa
π
exchange
Galaxies;
expanding universe
Cyclotron
Dark Matter
μ-
Nuclear fusion
π
τ-
ρ
Particle zoo
QED
P, C, CP violation
Big Bang
Nucleosynthesis
Synchrotron
Bubble
νe
W bosons
Cosmic Microwave Background
e+e- collider
Higgs
Wire chamber
u
d
s
νμ
EW unification
Beam cooling
GUT
QCD
Colour
c
Online computers
τ-
STANDARD MODEL
SUSY
b
Inflation
p+p- collider
Superstrings
Modern detectors
ντ
W
Z
g
CMB
Inhomgeneities
(COBE, WMAP)
3 generations
WWW
t
Dark Energy (?)
ν mass
GRID

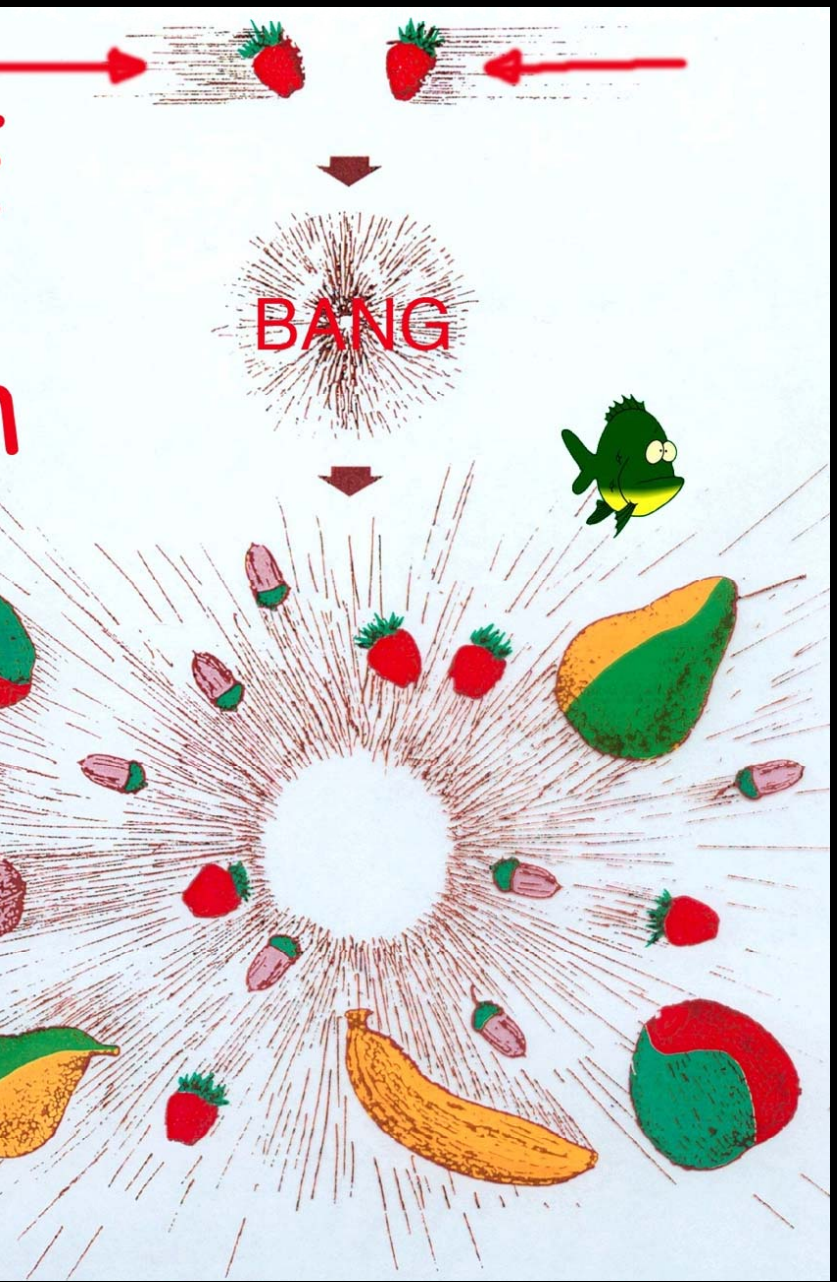
Cosmic Radiation

ic rays (1913) - first discoveries* in particle physics Measured energy spectrum

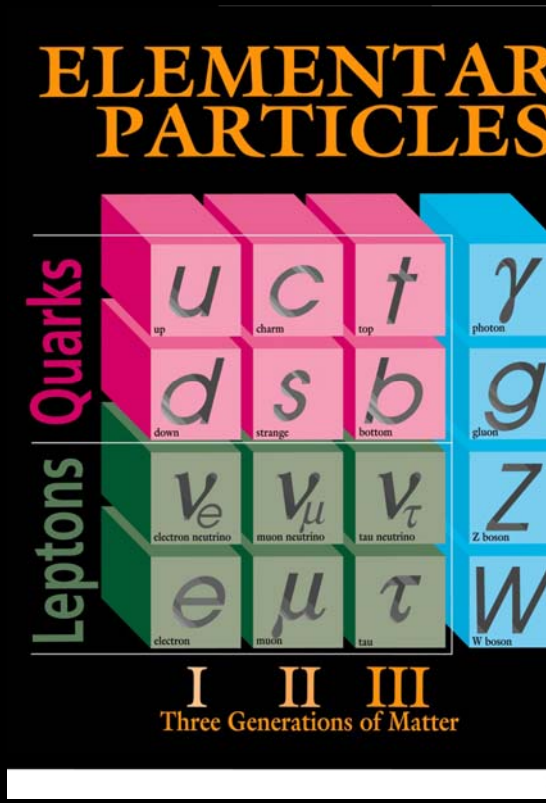




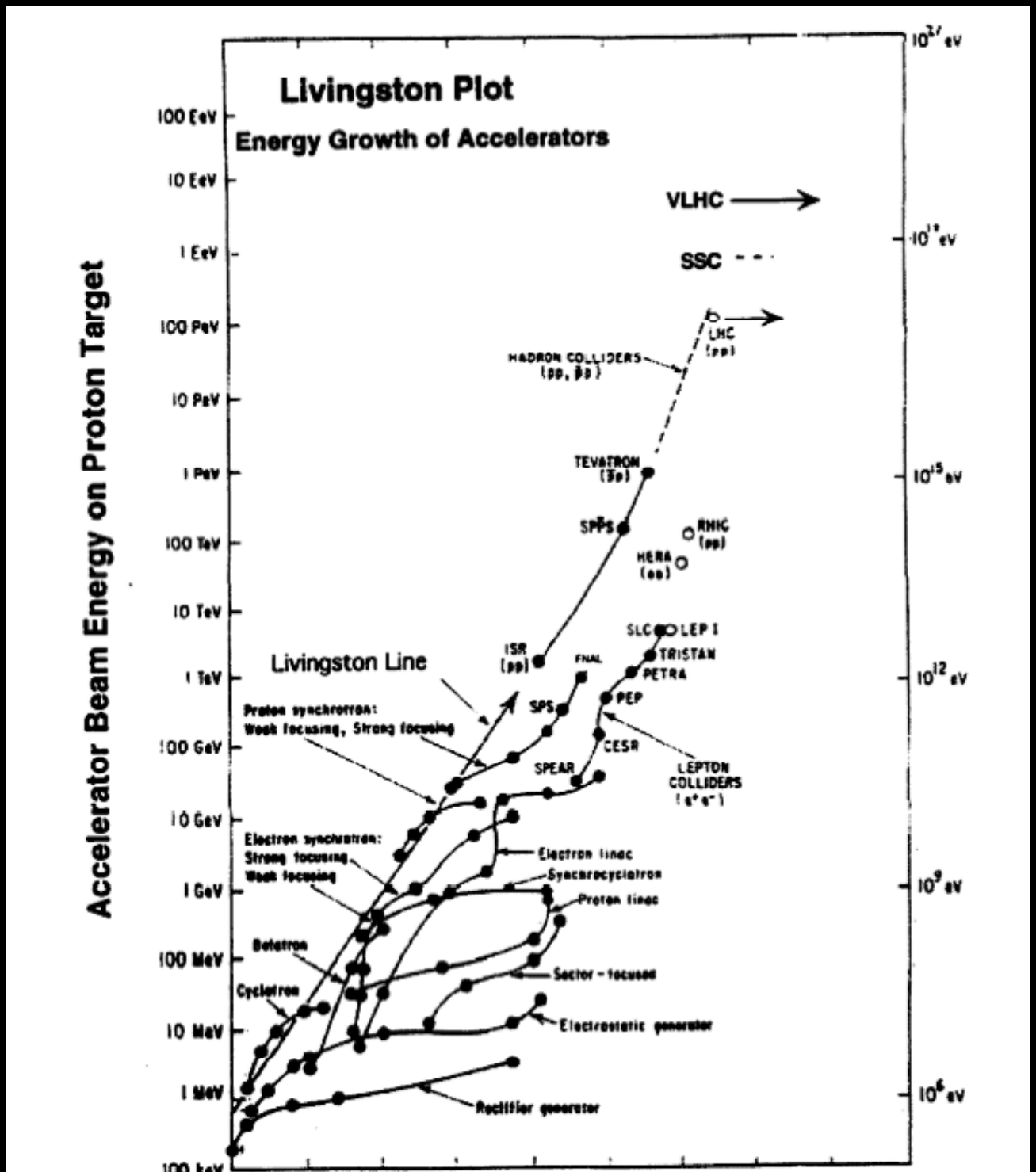
Energy into Mass



produce all
these particles ...
and more

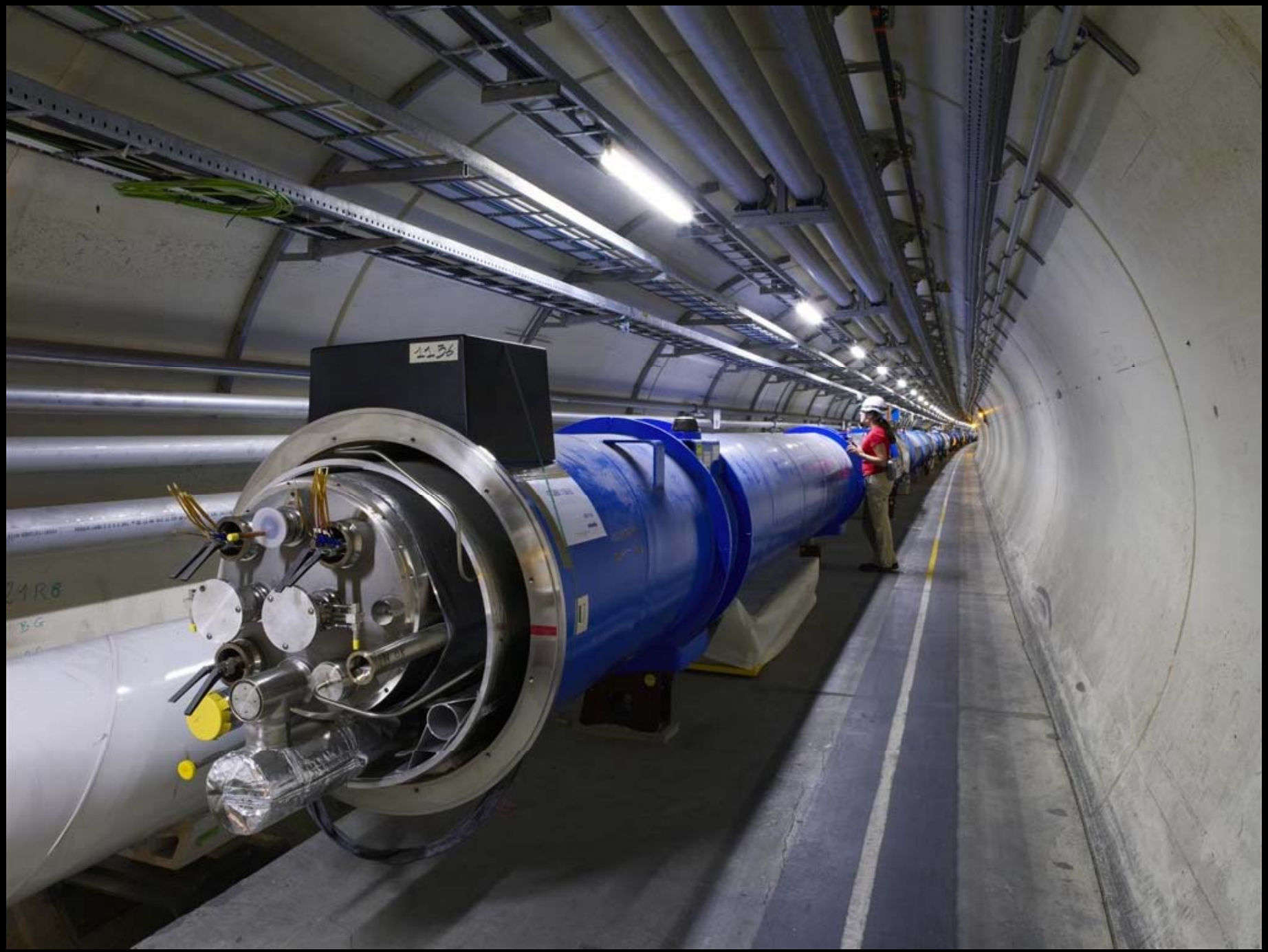


The Growth of Accelerators



Large Hadron Collider

27 km long, underground



LHC Milestones

1976	First idea
1984	R+D starts
1987	Proto-Collaborations
1989	First public presentation by D
1994	Approval of LHC project
1996-1998	Approval of experiments (ATLAS, CMS, ALICE, LHCb
2008	Construction complete

LHC Technology

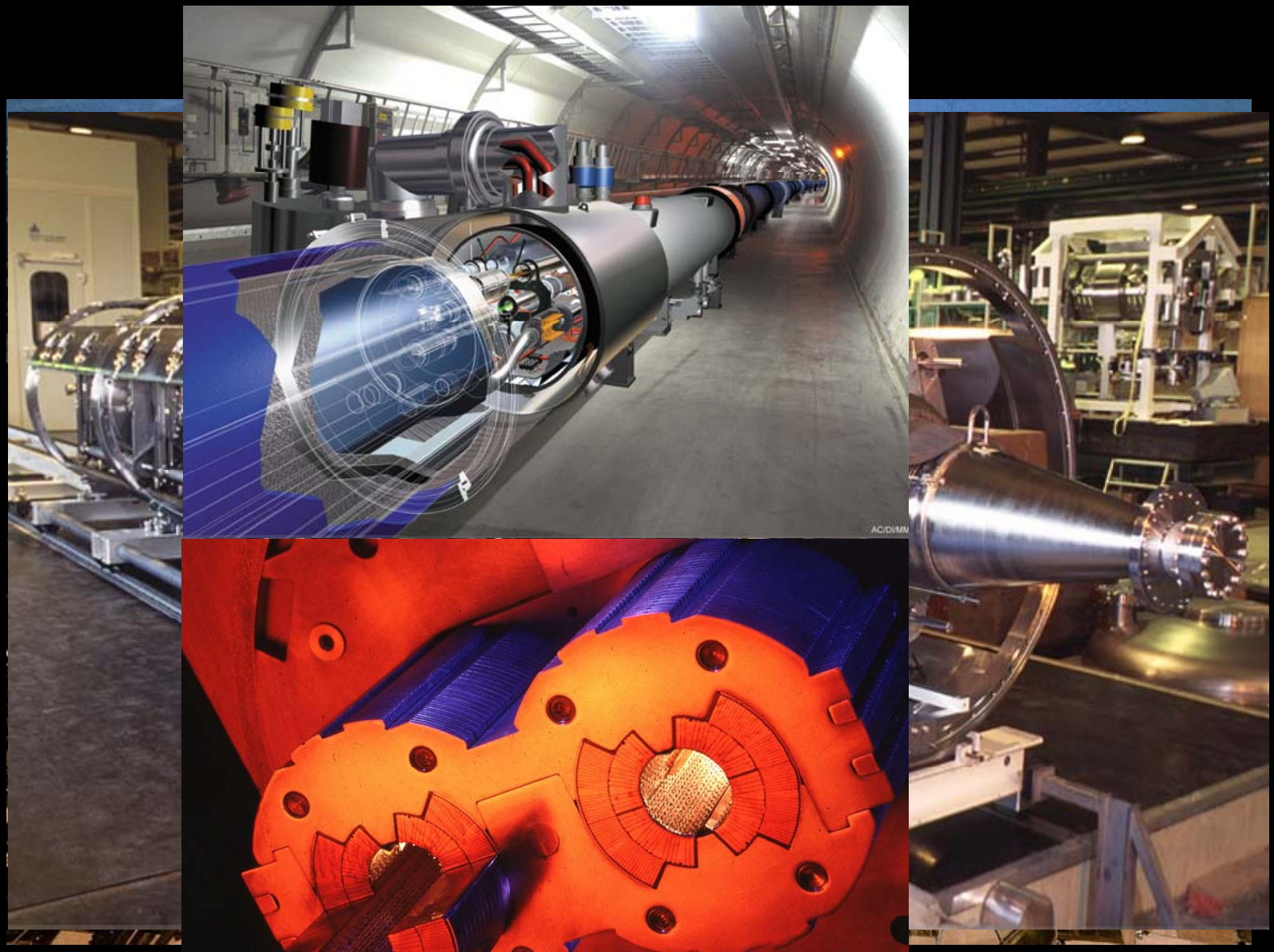
Circumference
26 659 m

Magnets
9300

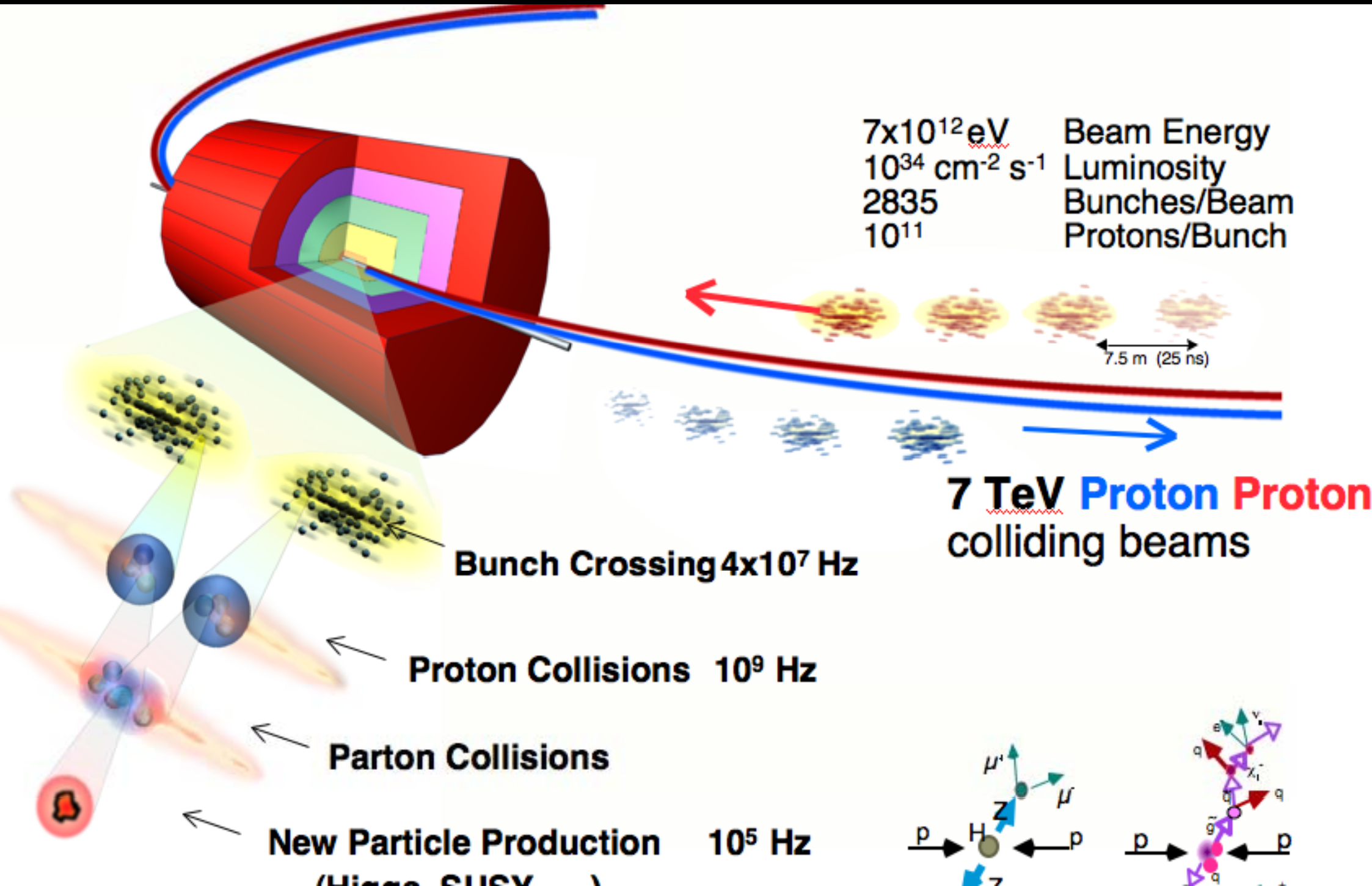
Dipoles
1232

Magn. field (max.)
8.33 T

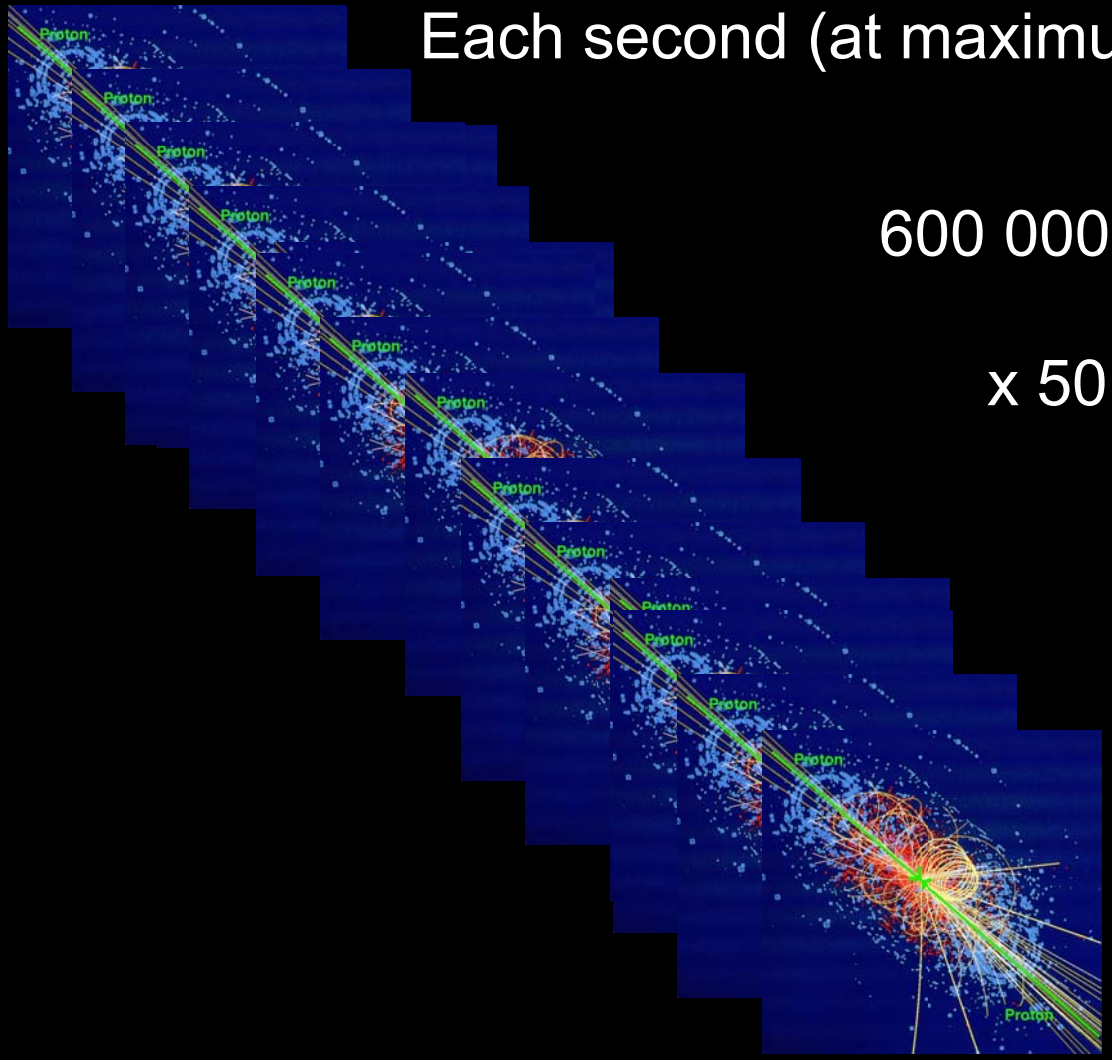
RF Cavities
2 x 8



LHC Collisions



The Data



Each second (at maximum luminosity):

600 000 000 events -

x 50 000 000 sensors

Data filter

1 : 10 000 000

Data storage

15 000 TB per year

3 questions for the 21st century

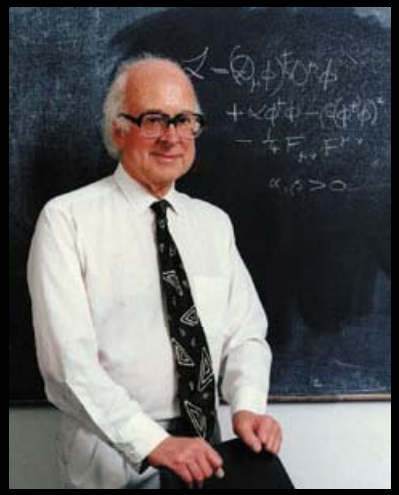
1 - How do particles acquire mass ?

2 - Does ‘Supersymmetry’ exist ?

3 - How many dimensions has space ?

mass ?

The Standard Model makes no (mathematical) sense without the Higgs field
either they are massless, or if they are given masses, the mathematics of the theory collaps



Peter Higgs

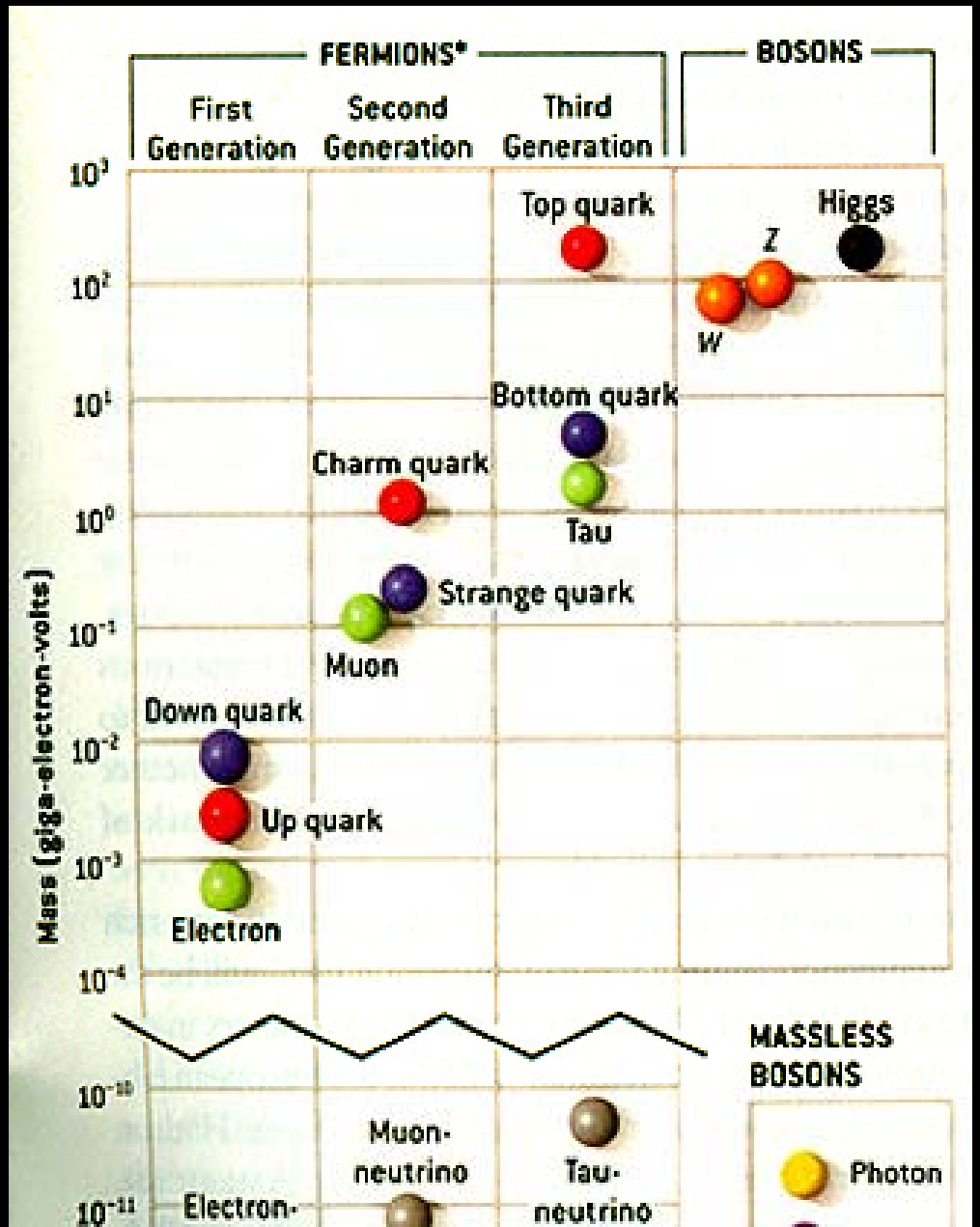
1 TeV →

100 GeV →

1 GeV →

1 MeV →

0.01 eV →



Higgs Field

fills all of space since the ‘spontaneous symmetry breaking’ at Big Ban

new type of interaction

‘cosmic DNA’: gives particles their specific properties (e.g. mass)

Higgs Mechanism

Metaphore

A cocktail party ...

.. a famous guest wants to cross the room...

.. but everybody wants an autograph - the guest is difficult to accelerate...

The Higgs field ...

... a new particle is created ...

... the Higgs field gives the parti its 'inertia' ...

The Higgs Particle

A rumour originates ...

The Higgs field is excited and receives energy....

.. many guest clump together to discuss the rumour...

... which produces a "real" field particle ...

Higgs animation

The ‘Higgs’ field gives mass (inertia) to particles
“friction with the vacuum “

ortant note:

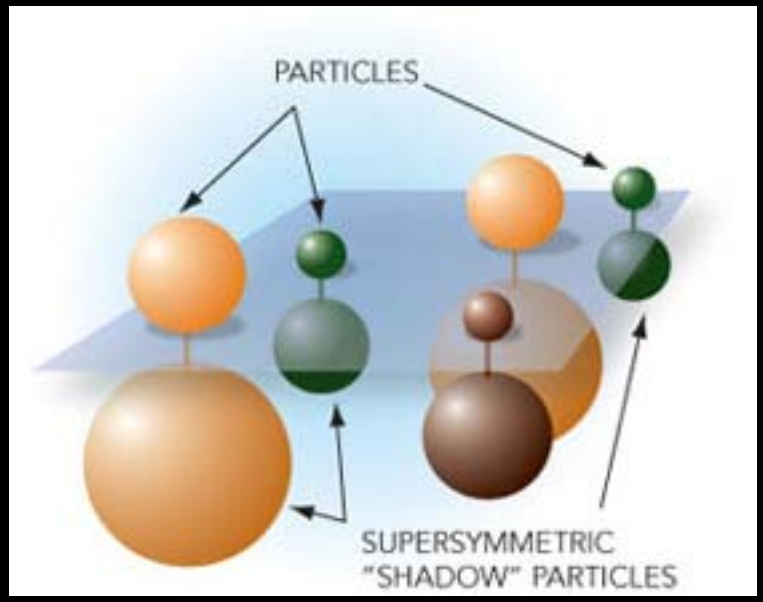
e could also be other
) fields or particles
have the same effect
e Higgs field

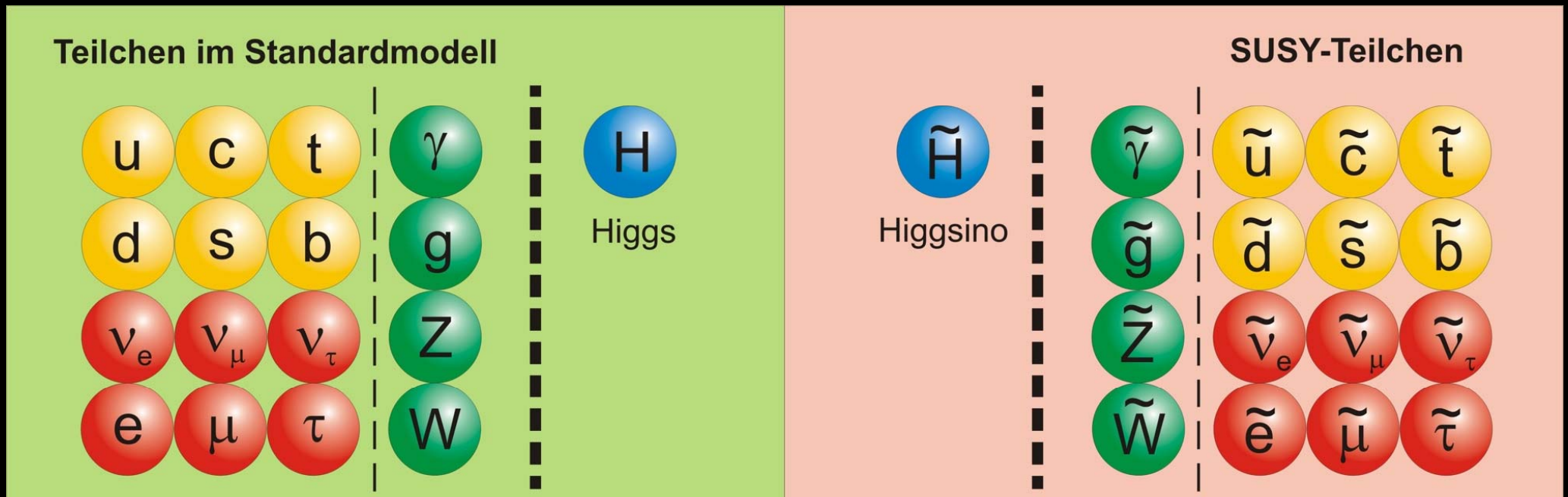
How electrons and quarks acquire a mass

?

Is there a deeper SUPERSYMMETRY between matter and fields?

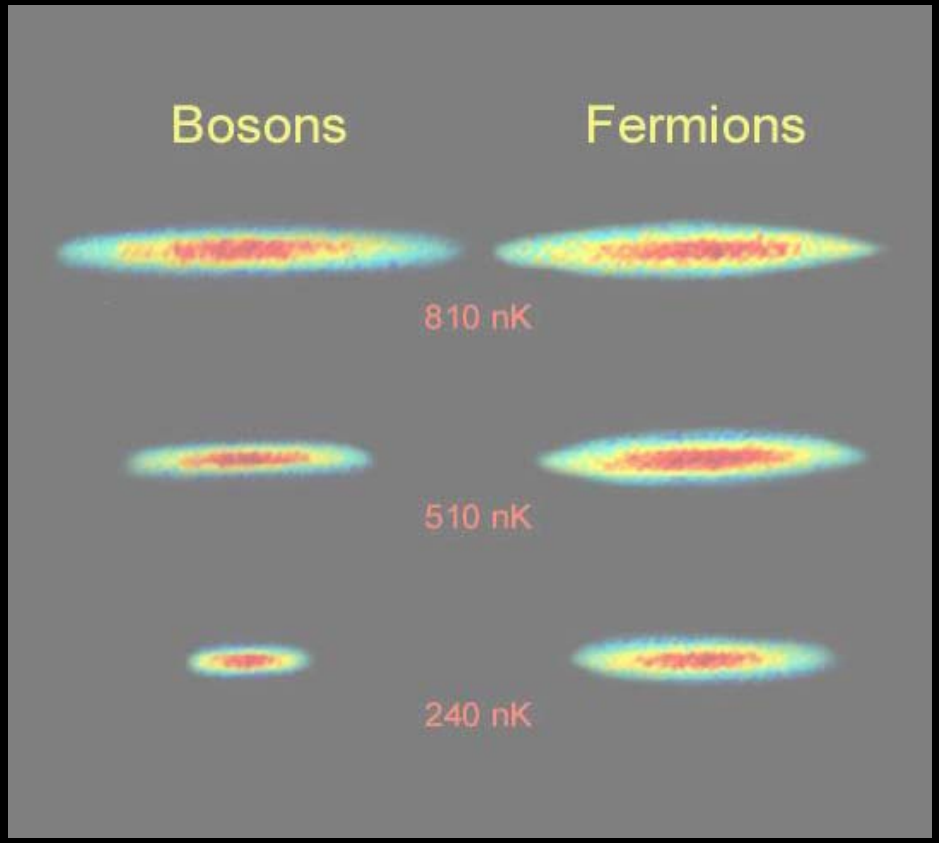
all matter particles have a field partner
all field particles have a matter partner





Bosons and Fermions

social



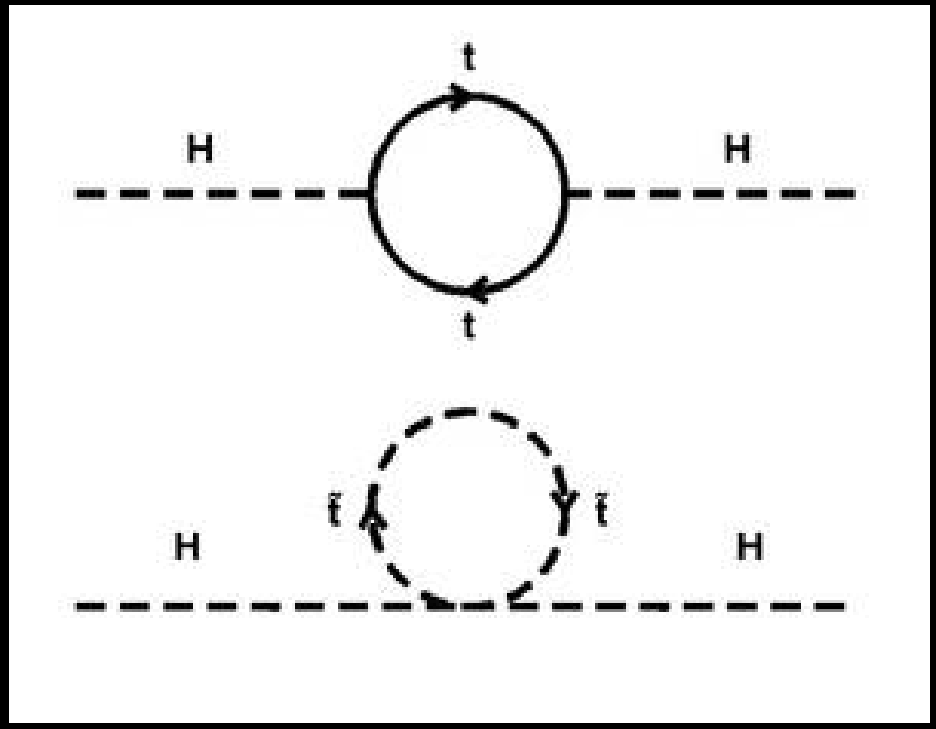
anti-social

Integer spin	Spin 1/2
selectron (S=0)	electron
squark (S=0)	quark
photon (S=1)	photino

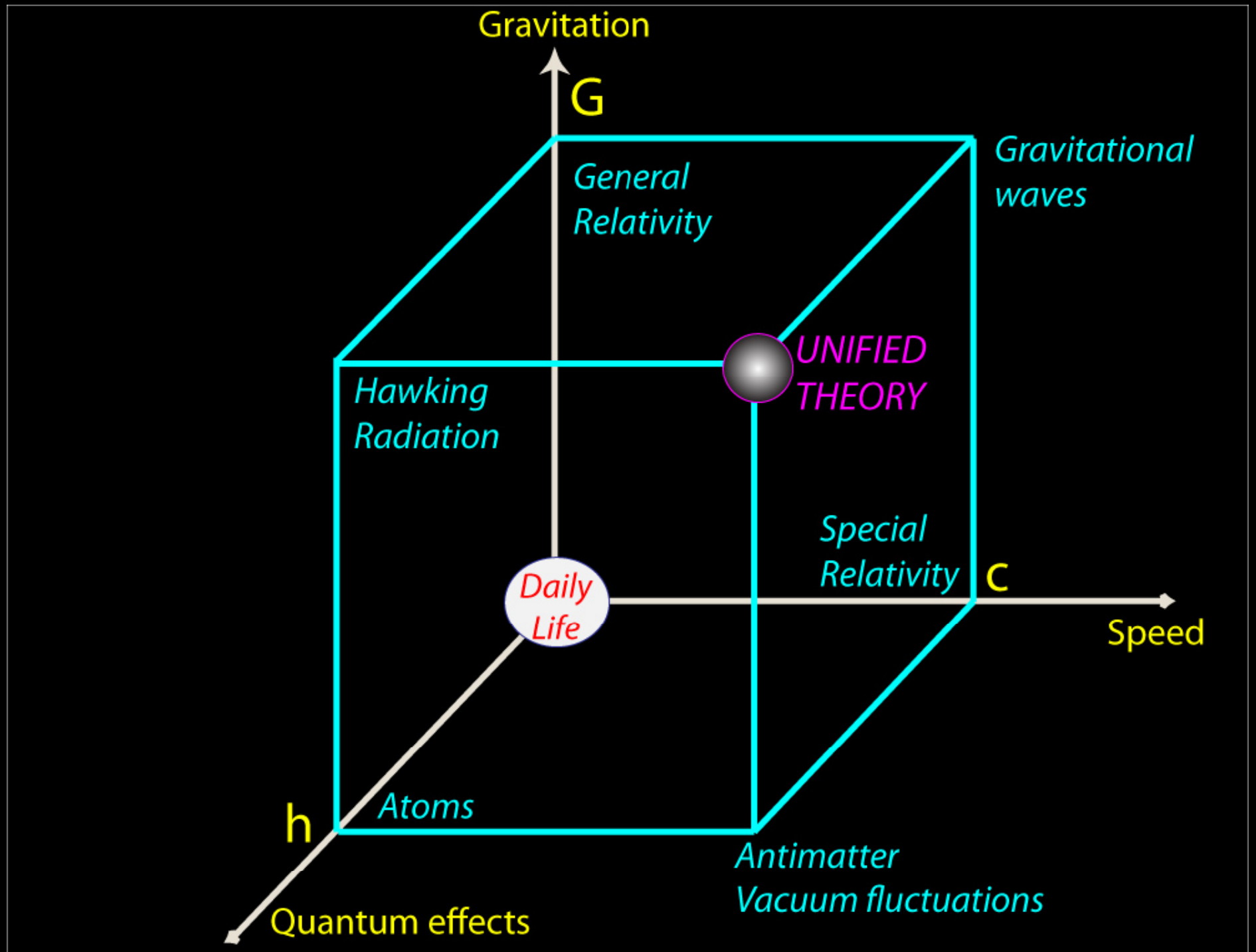
Why Supersymmetry ?

1) A fundamental symmetry of space and time

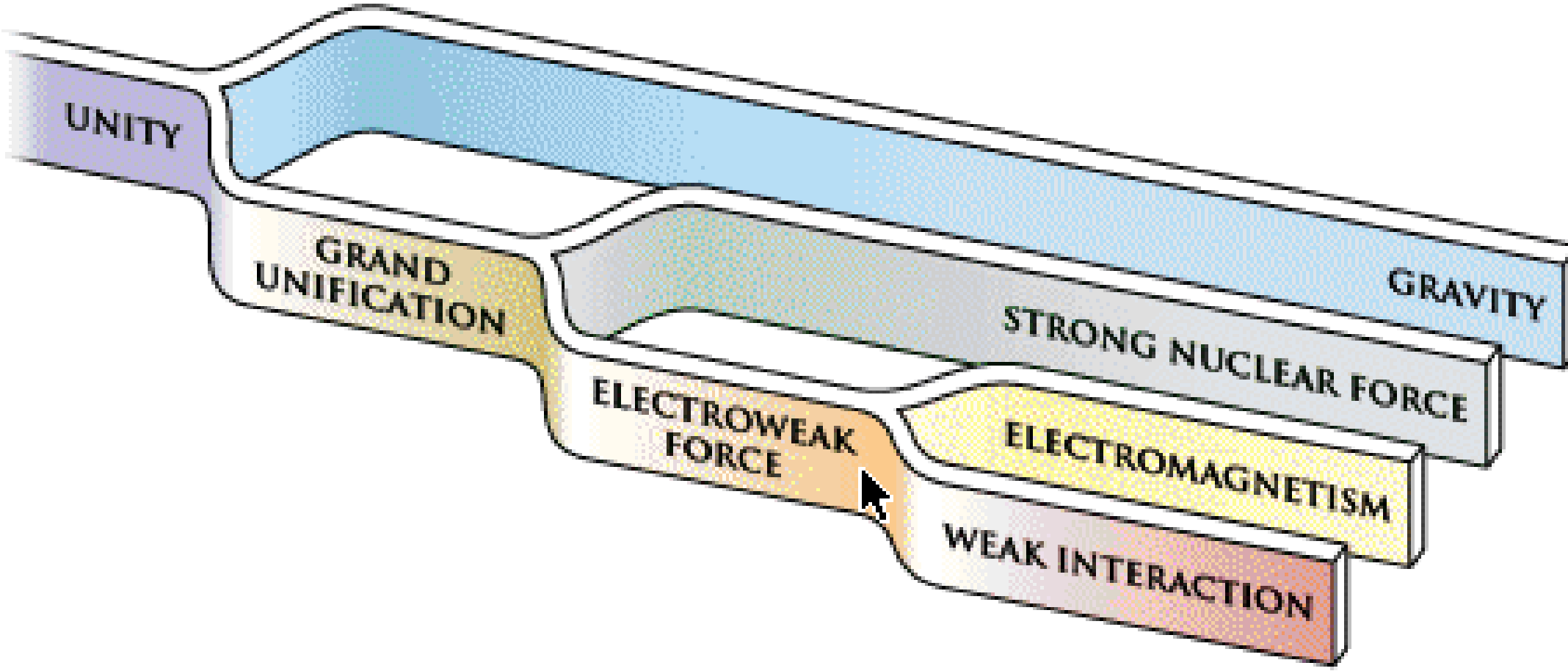
2) "Protection" of SM particle masses (< 10^3 GeV)
from vacuum fluctuations up to Planck Scale* (10^{19} GeV)



constants


Gravitation
G
General
Relativity
Gravitational
waves
UNIFIED
THEORY
Hawking
Radiation
Special
Relativity
C
Daily
Life
Speed
h
Atoms
Antimatter
Vacuum fluctuations
Quantum effects

Unification of forces



Natural Planck Units

Why is gravitation so weak?

$$F_G = \left(\frac{m_{proton}}{m_{Planck}}\right)^2 \cdot \frac{1}{r^2} \approx 10^{-38} \cdot \frac{1}{r^2}$$

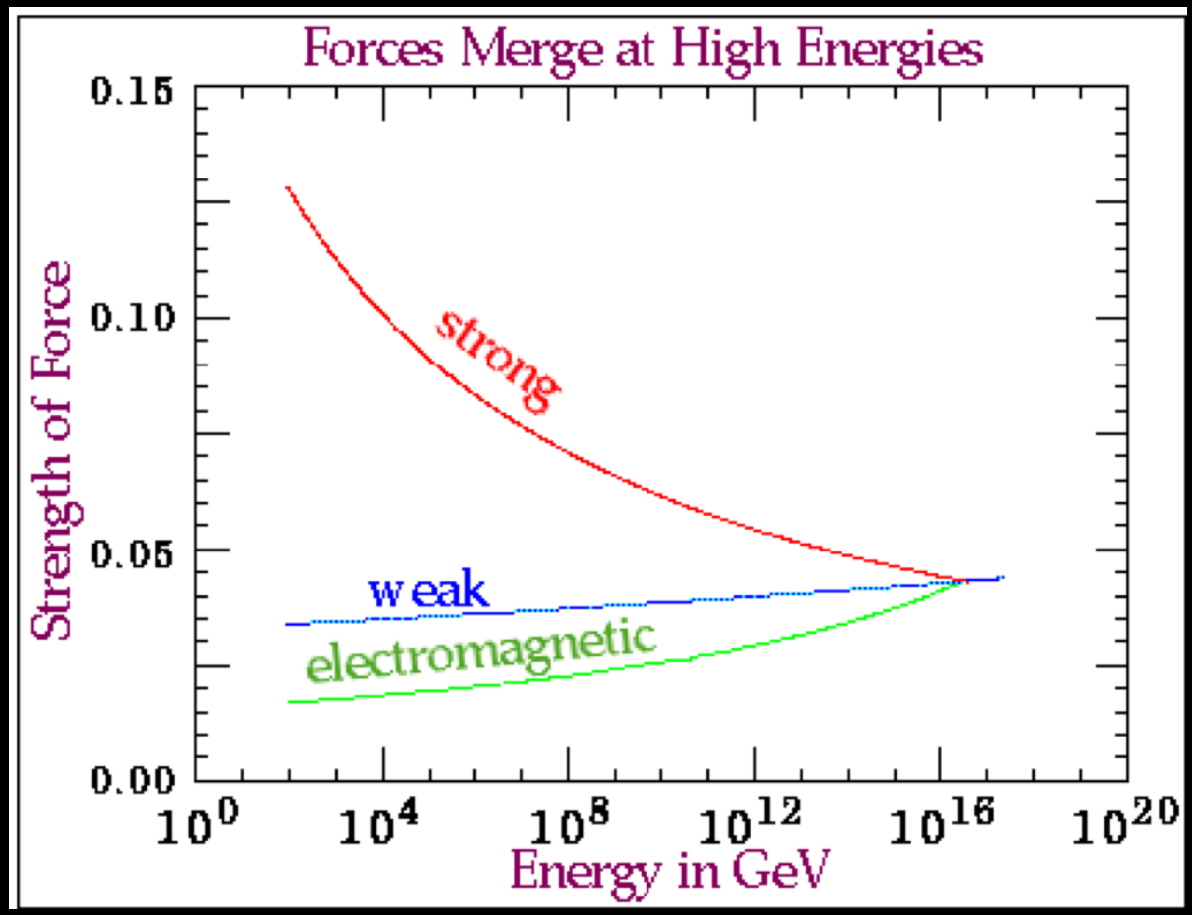
Planck length $l_{\mathrm{P}} = \sqrt{\frac{\hbar G}{c^3}}$ = 1.6 · 10^{-35} m

Planck mass $m_{\mathrm{P}} = \sqrt{\frac{\hbar c}{G}}$ = 2.1 · 10^{-8} kg = 1.2 · 10^{19} GeV

Planck time $t_{\mathrm{P}} = \frac{l_{\mathrm{P}}}{c} = \frac{\hbar}{m_{\mathrm{P}} c^2} = \sqrt{\frac{\hbar G}{c^5}}$ = 5.4 · 10^{-44} s

More reasons for SUSY

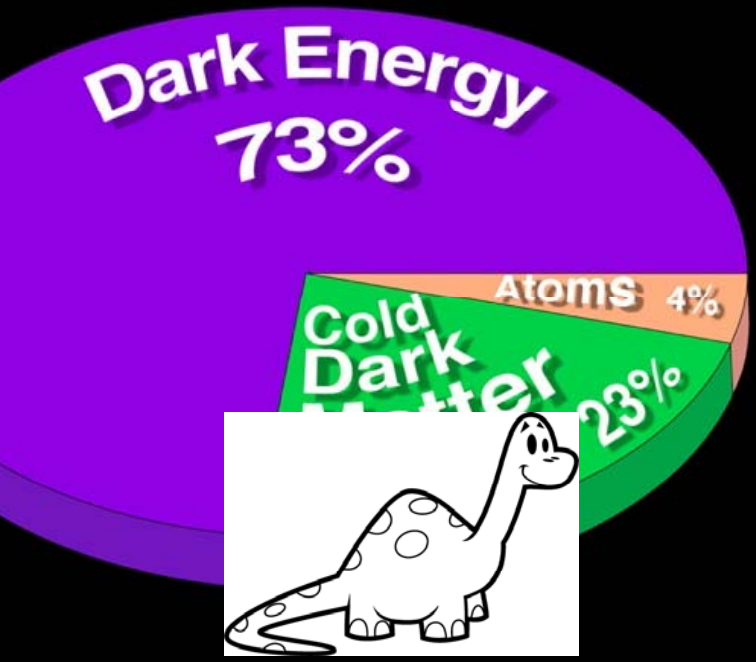
3) Suggests unification of three forces at a single unification point (~10^{17} G

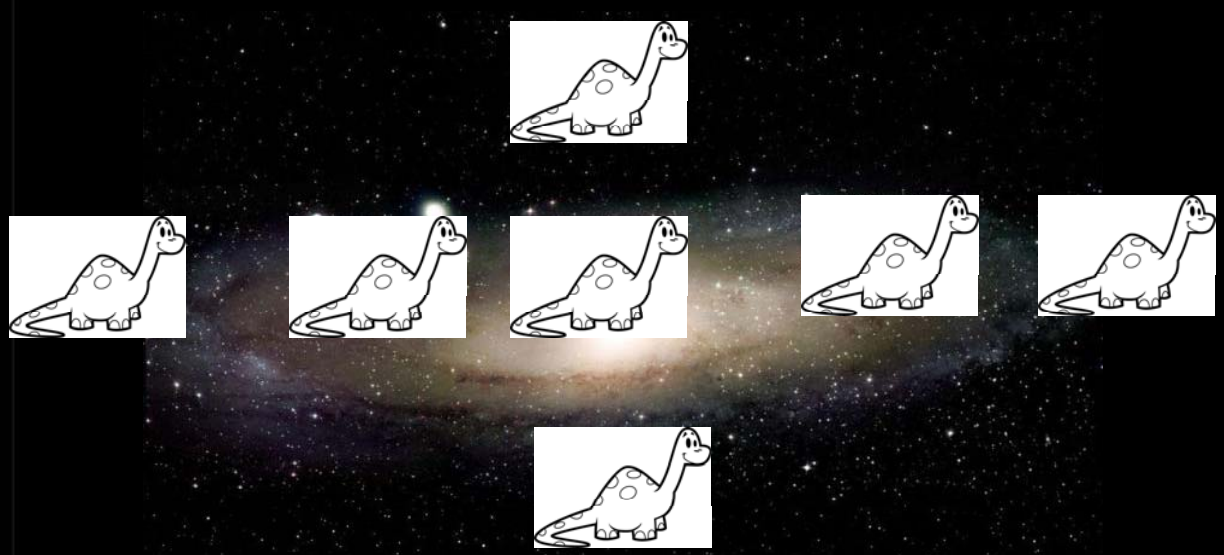


4) Possible explanation of cosmological matter-antimatter asymmetry

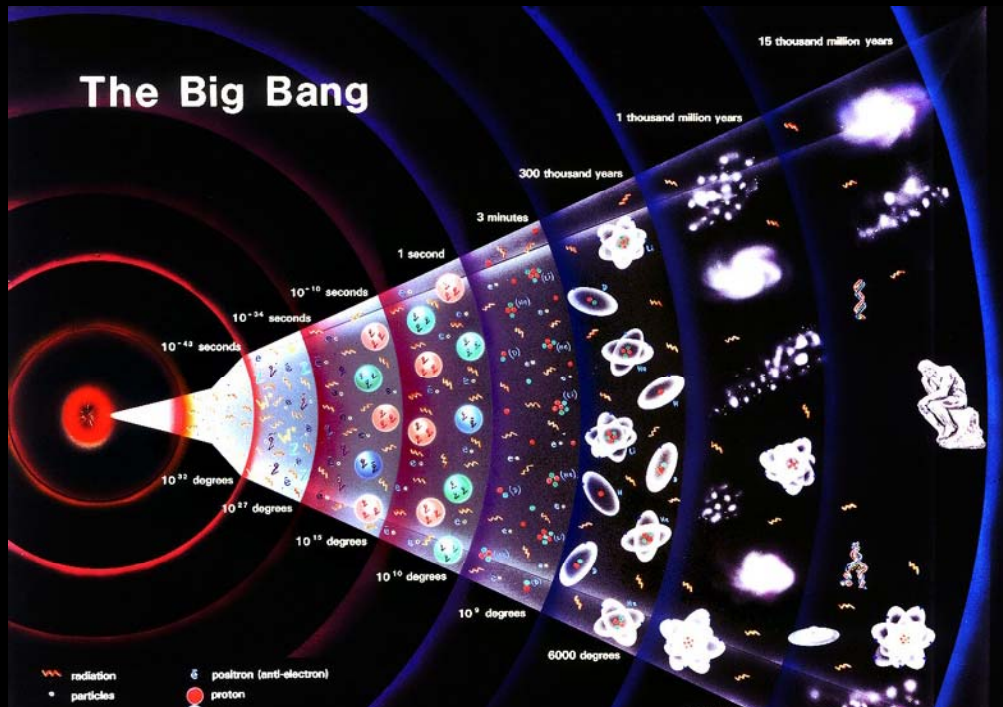
5) **Dark matter**?

Matter?

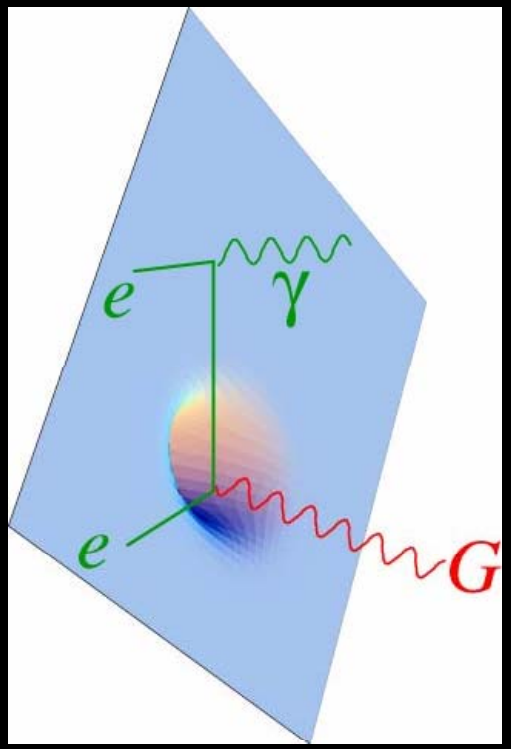




SUSY = Dark matter particles
left over from Big Bang?



?



Is gravity so weak because 'gravitons' escape into the small extra-dimensions? (Arkani-Hamed et al., Randall-Sundrum)

Does gravity act in more than 3 spatial dimensions?

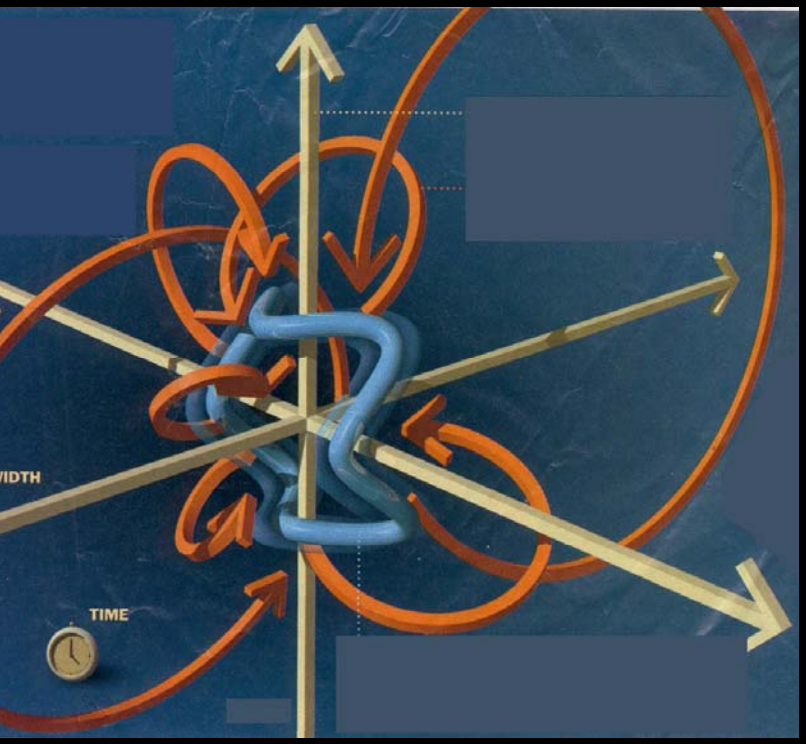
Validity of Newton's Law tested to ~ 10 μm

LHC collisions may produce 'mini' Black Holes

Characteristics:

Mass ~ 10^{-21} g
Lifetime ~ 10^{-26} s
Decay ~ symmetric, many hundred low-E particles

?



String theory (only) works in 9+1-dimensional space

Particles + fields are oscillating ‘strings’ (size ~10^{-35}

Different vibration patterns = different particles

Spectrum of lowest vibrations includes ‘graviton’

Many problems:

How did the six additional dimensions curl up into Planck length?

No prediction on the scale of the supersymmetry breaking

More (profound) questions

We know what matter is made of.

We know the principle steps in the evolution of the Universe.

Where is the antimatter gone? (Matter-Antimatter asymmetry)

Where is the link between quarks and leptons ($Q_e + Q_p = 0$)

Why three families?

What caused inflation?

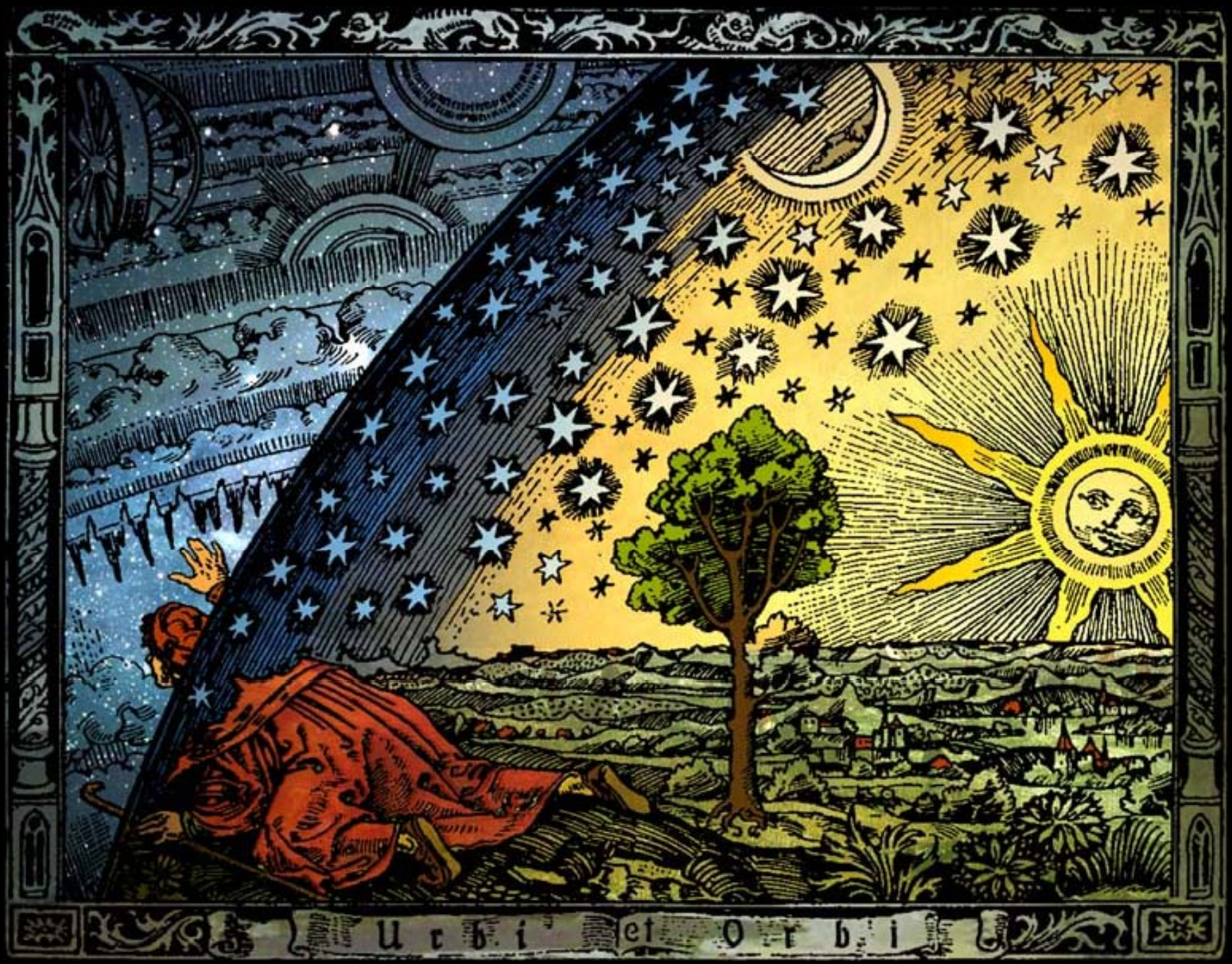
What is dark energy - why is the cosmological constant so small?

What is the origin of the fundamental constants?

What is a particle?

What is VACUUM?

The new era of physics



Flammarion

End of part 2

Questions ?