Intro to Particle Physics

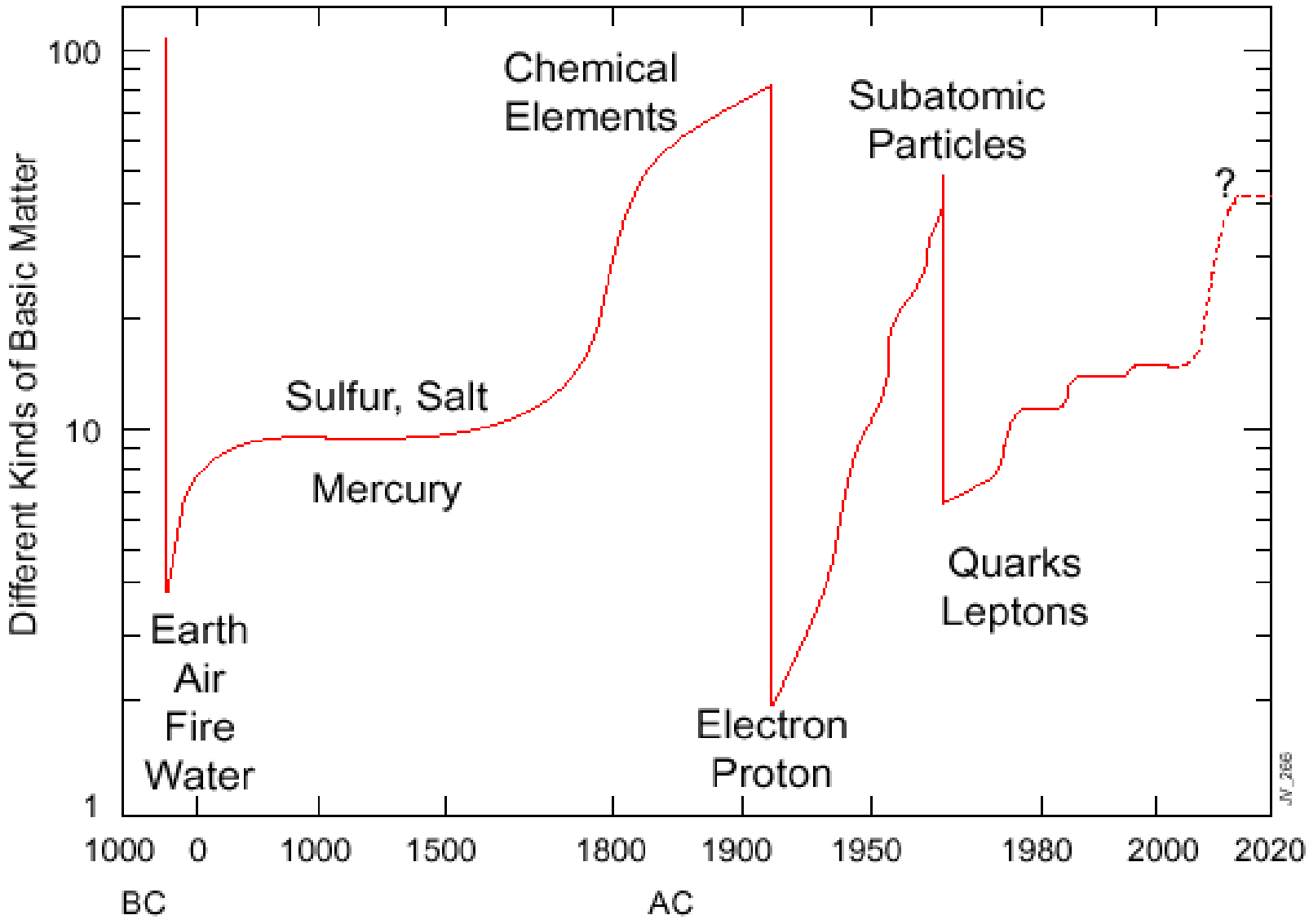
Particle Physics

-What are the Elementary Constituents of Matter?

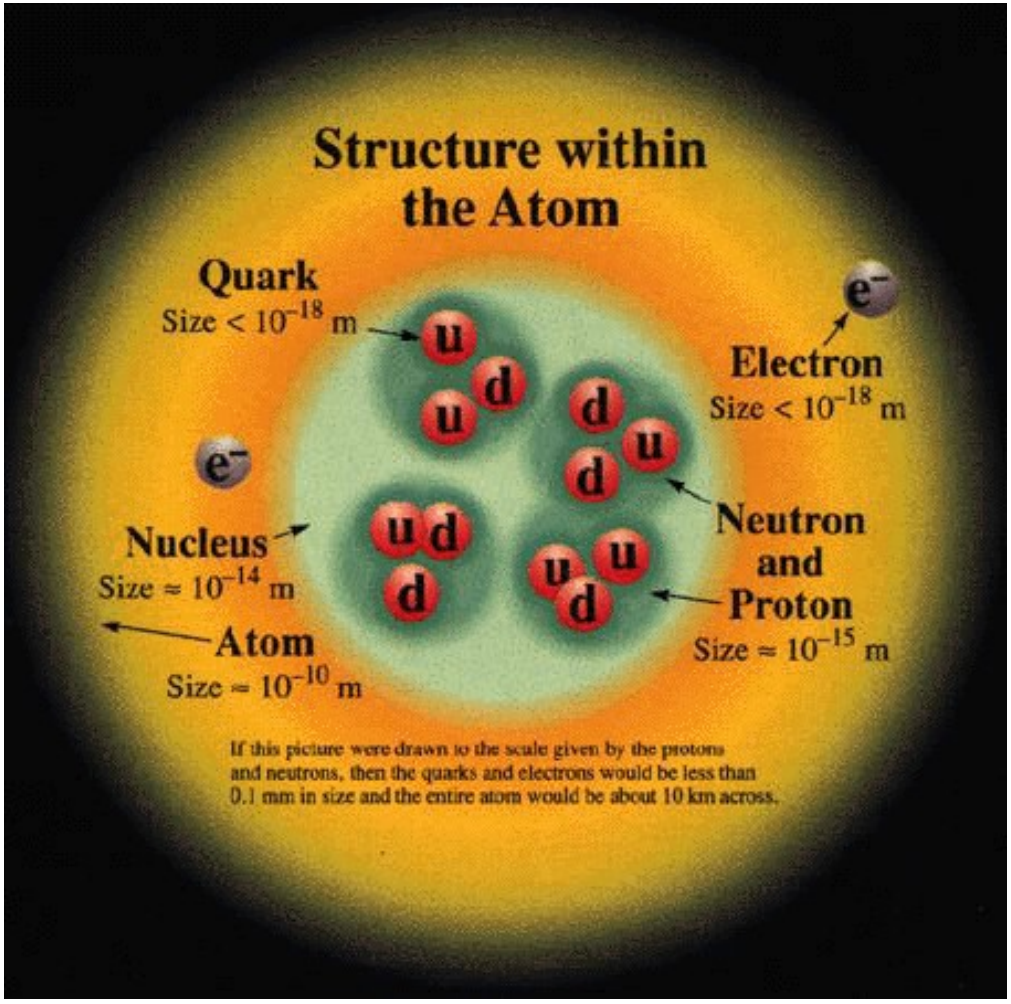
-What are the forces that control their behaviour at the most basic level?

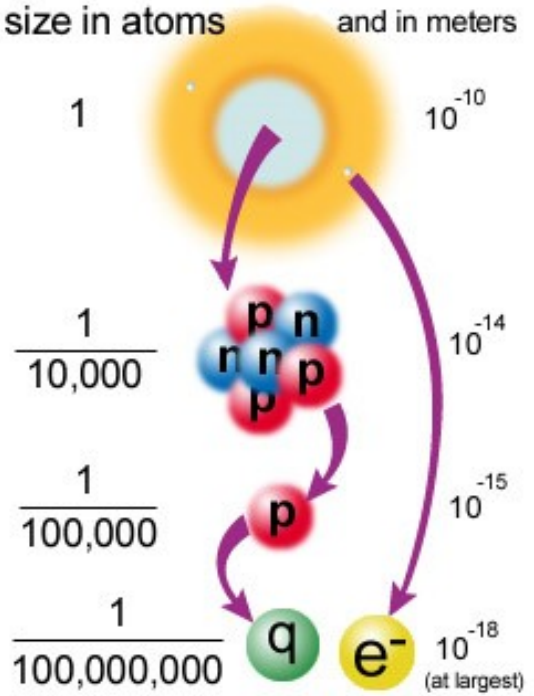
In the ancient times ...

Elementary Constituents of Matter through the ages

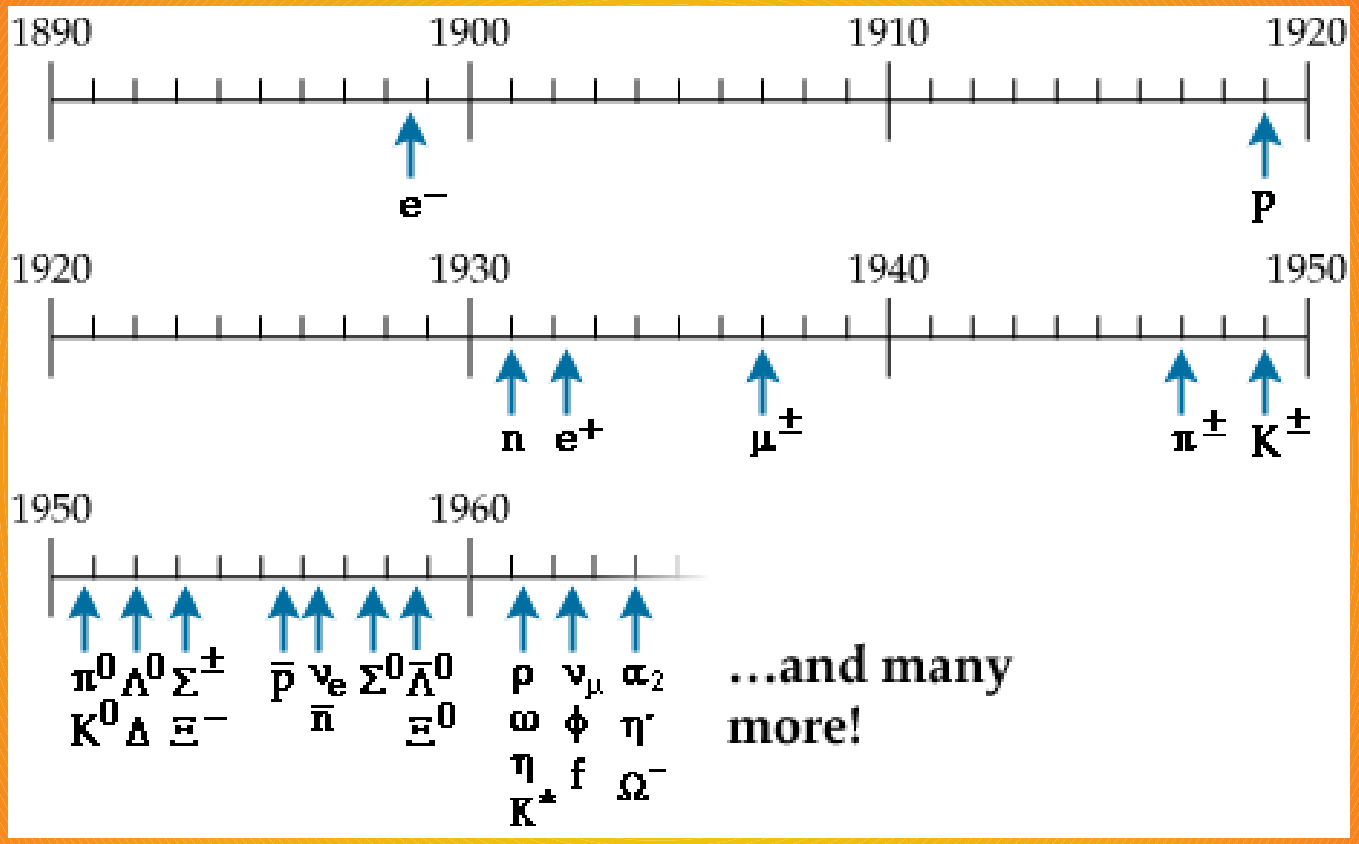


Atoms ...

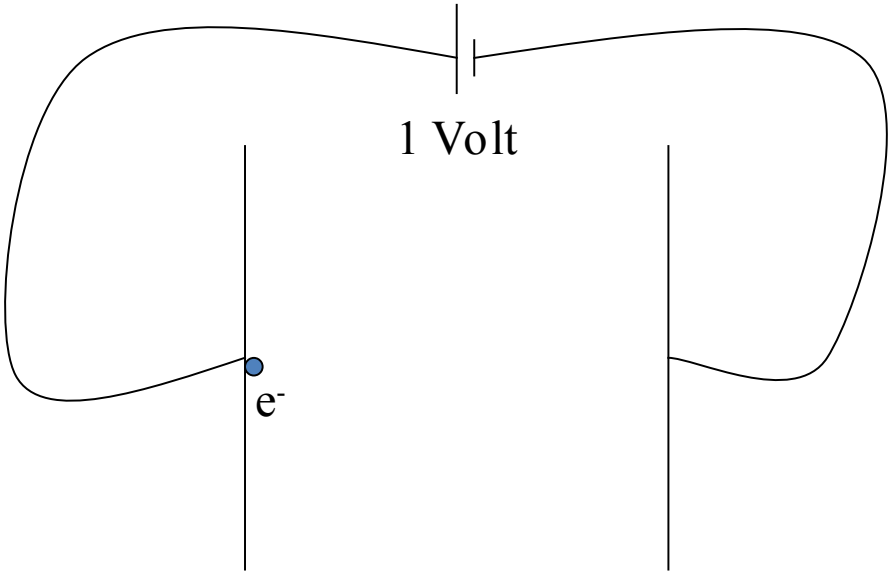

Structure within the Atom
Quark
Size < 10^{-18} m
Electron
Size < 10^{-18} m
Nucleus
Size ≈ 10^{-14} m
Neutron and Proton
Size ≈ 10^{-15} m
Atom
Size ≈ 10^{-10} m
If this picture were drawn to the scale given by the protons and neutrons, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.


size in atoms
and in meters
1
10^{-10}
$\frac{1}{10,000}$
10^{-14}
$\frac{1}{100,000}$
10^{-15}
$\frac{1}{100,000,000}$
10^{-18}
(at largest)

Particle discoveries



Units



1 eV = kinetic energy gained by an electron when it accelerates through an electrostatic potential of 1 volt

$$1 \text{ eV} = 1.6\times10^{-19} \text{ J}$$

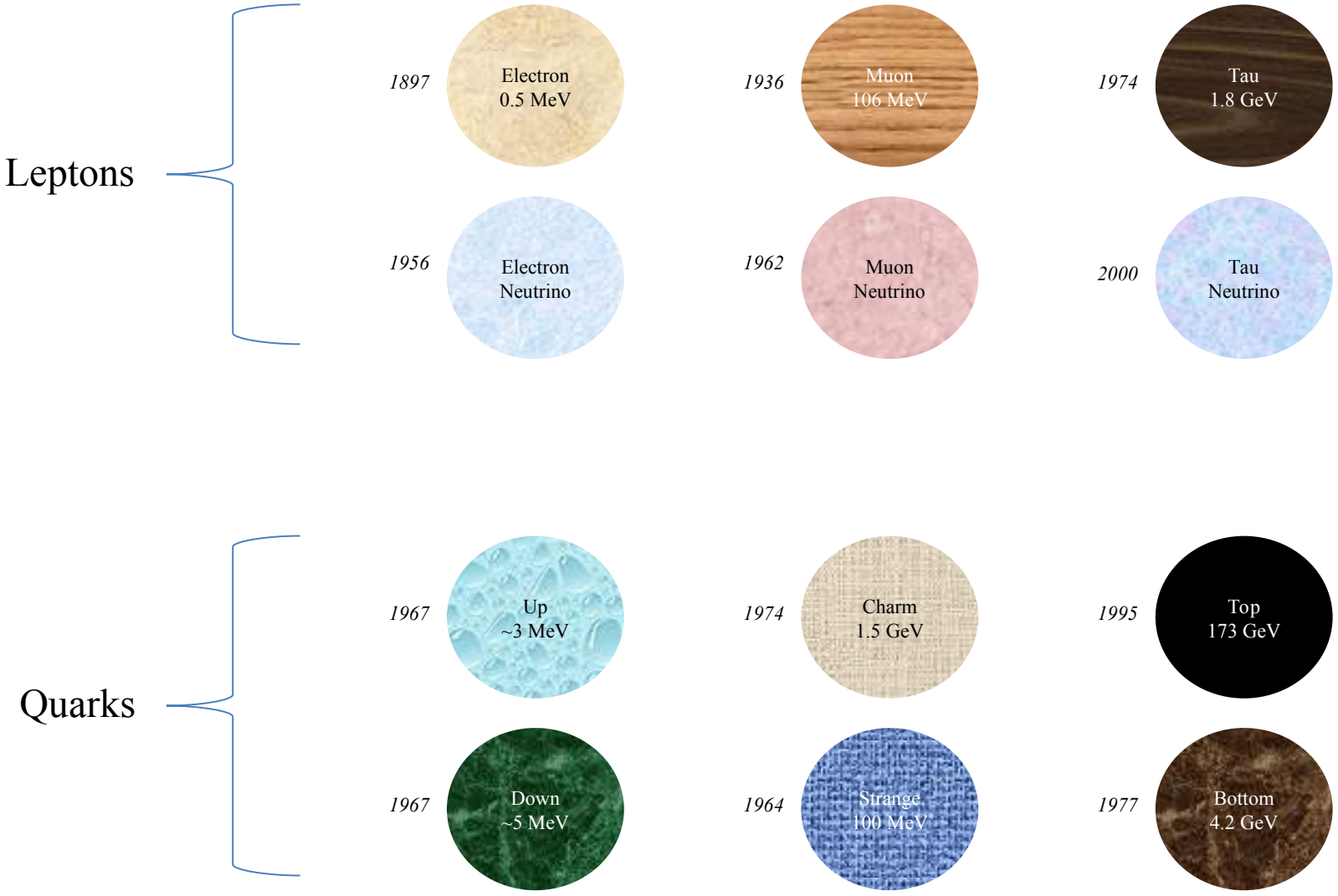
Einstein's mass-energy equivalence allows us to quote mass in terms of energy.

The mass of subatomic particles are quoted in eV, MeV (million electron volts), GeV (billion electron volts) and TeV (thousand billion electron volts).

$$\text{mass of a proton} = 1.67\times10^{-27} \text{ kg} = 938 \text{ MeV/c}^2 \approx 1 \text{ GeV}$$

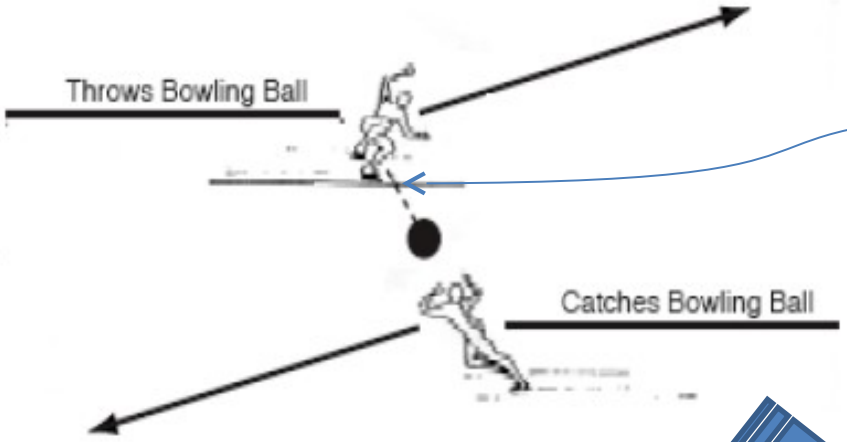
The constituents of matter

Why 3 generations ?



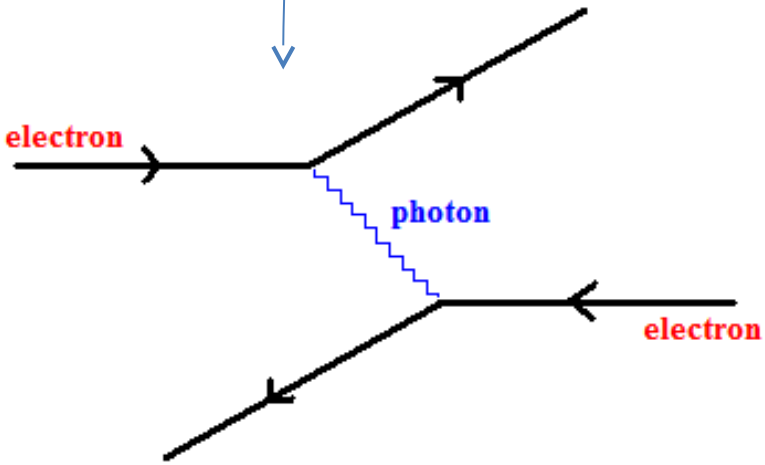
Force carriers

All forces can be thought of as interactions between elementary particles.



All forces are mediated by a force-carrying particle.

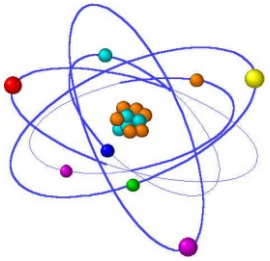
Richard Feynman



A Feynman Diagram for two electrons repelling each other

Electromagnetic interaction

Electricity



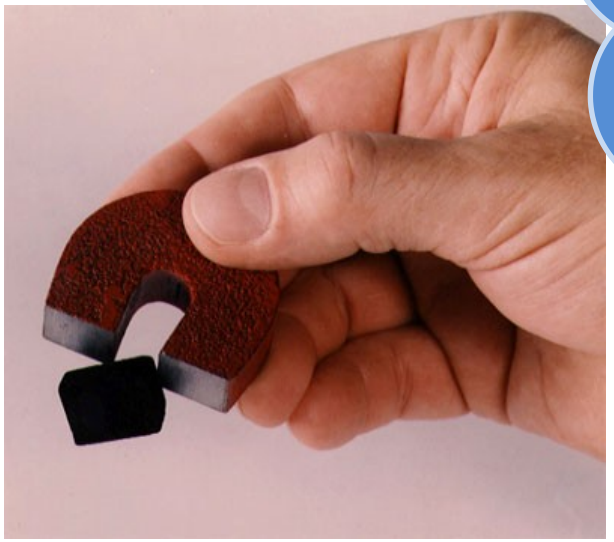
Chemistry

Light

The Electromagnetic Force

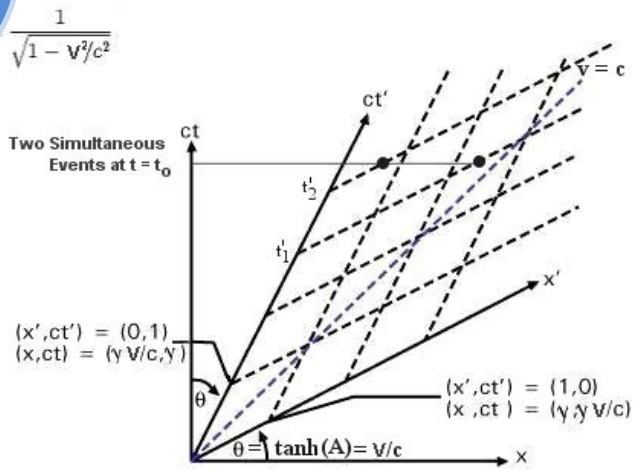
- Felt by all charged particles
- Carried by particles called *photons* in the quantum theory

Photon
0 mass

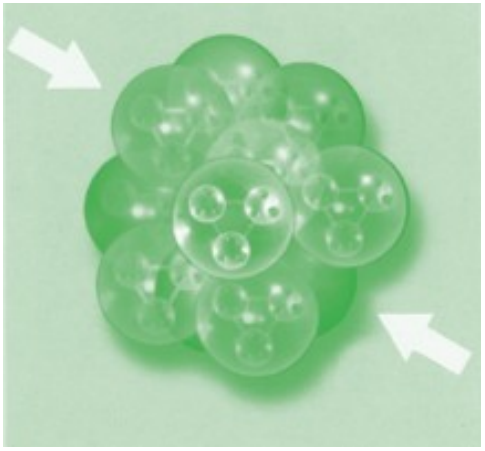


Magnetism

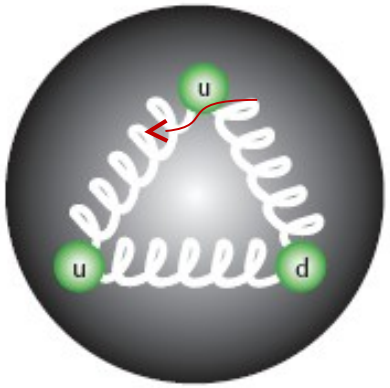
4 dimensional space-time



Strong nuclear force



Binds protons and neutrons together to form atomic nuclei



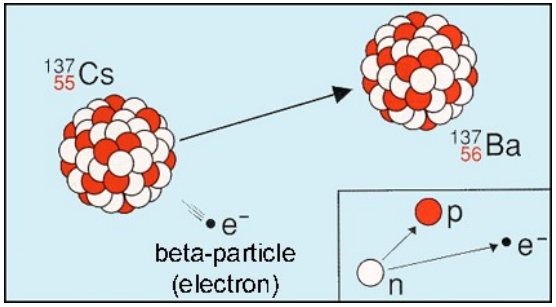
gluon
0 mass

Binds quarks together to form protons and neutrons

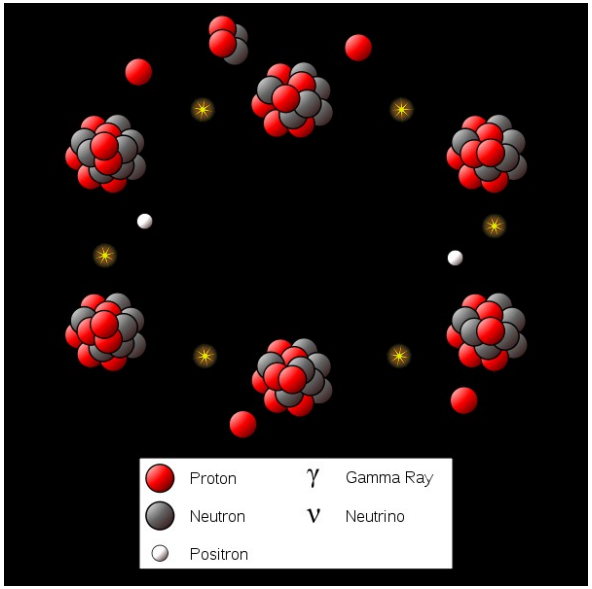
The Strong Nuclear Force

- Holds nuclei and nucleons together.
- Quarks and gluons feel this force
- Mediated by particles called *gluons*
- Very short in range

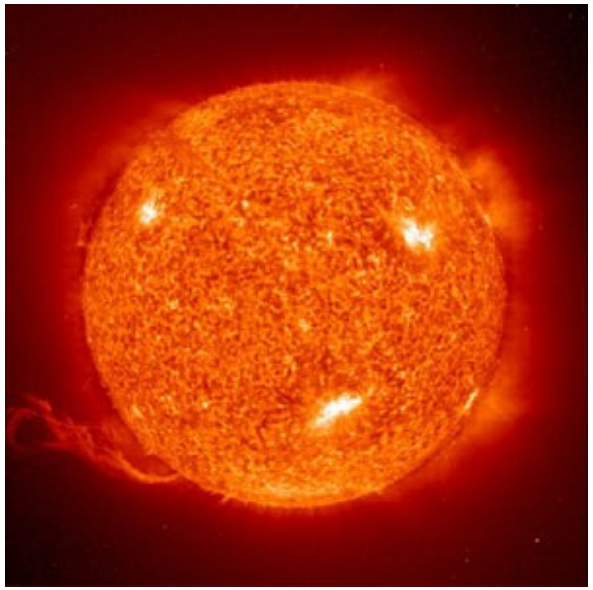
Weak nuclear force



Officiates nuclear (beta) decays



Give us nuclear cycles…



… that powers our sun and other stars.

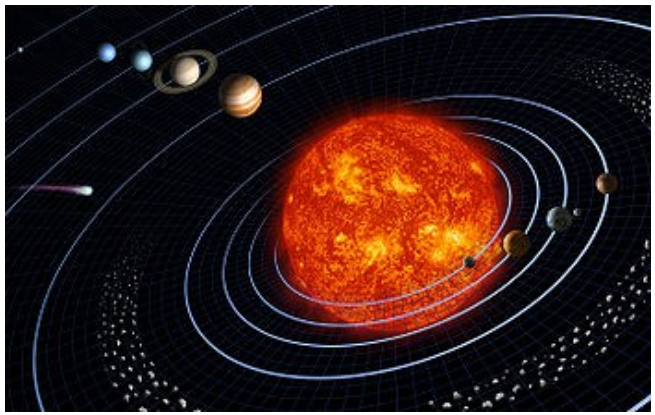
The Weak Nuclear Force

- All matter particles feel this force
- Mediated by particles called *W and Z bosons*
- Short ranged

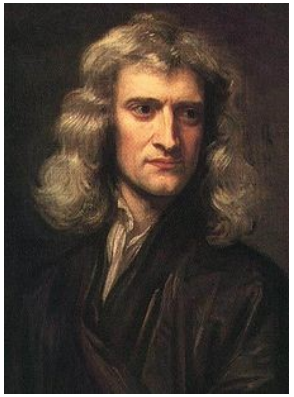
W 80 GeV

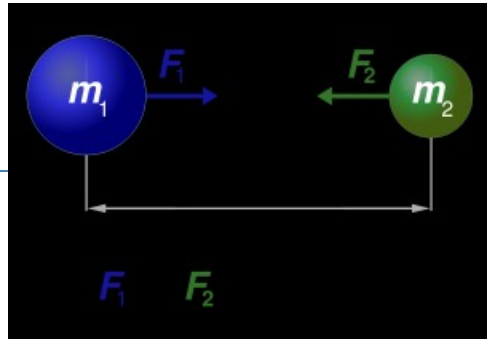
Z 91 GeV

Gravity

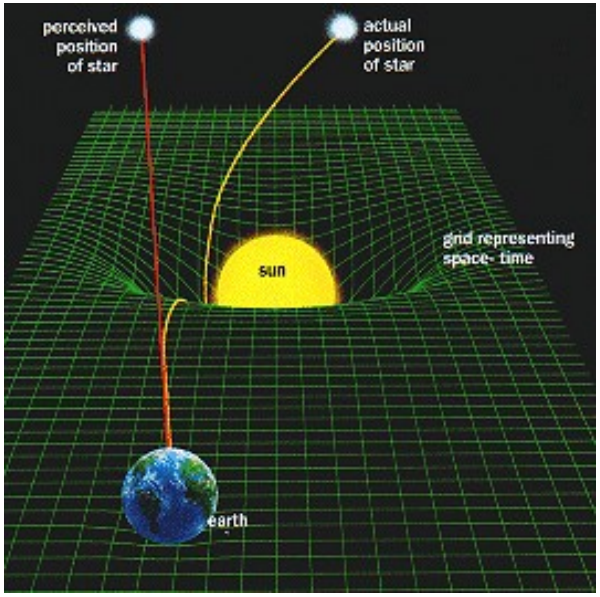


Celestial Gravitation





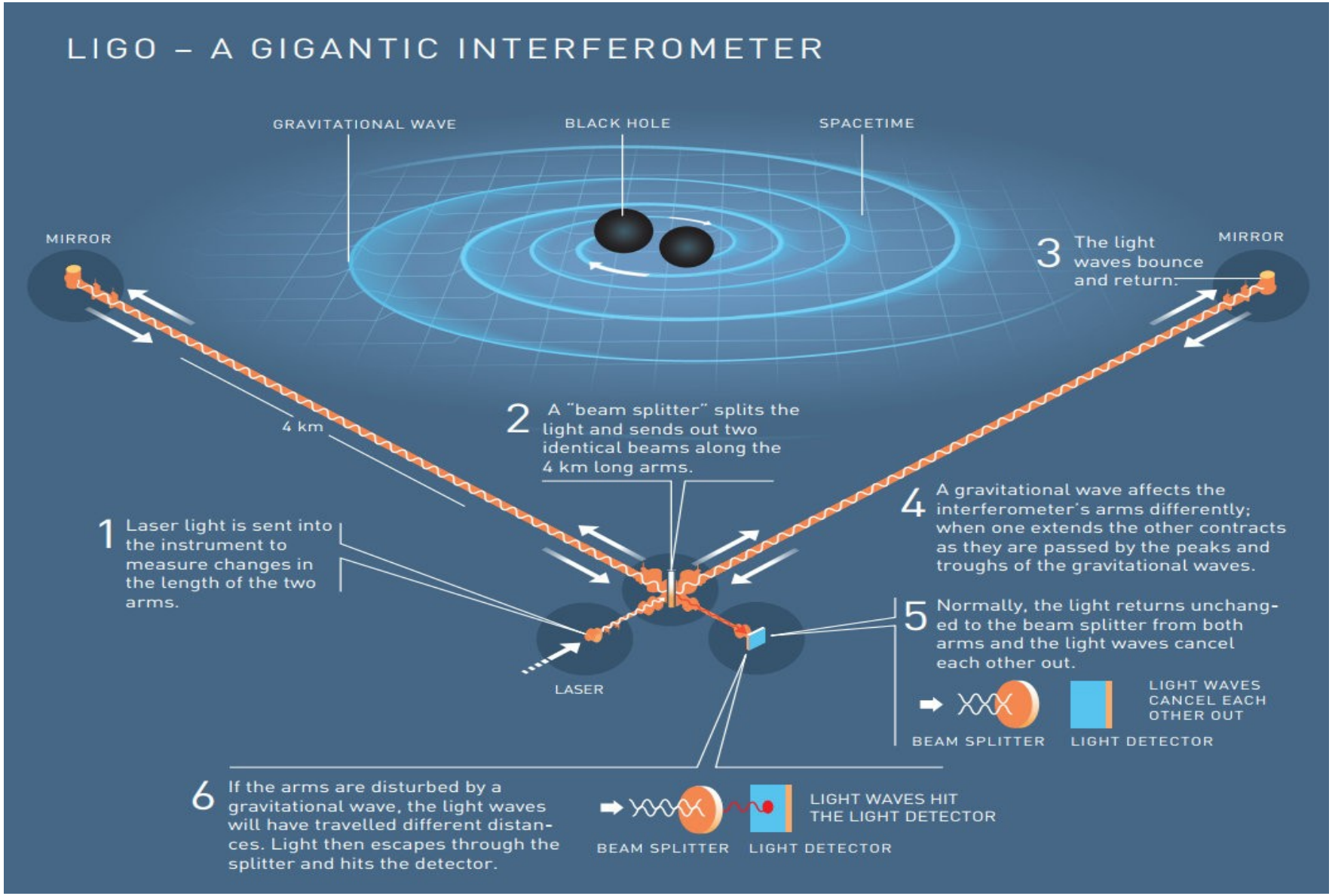
Newton's Law of
Universal Gravitation



Einstein's
General Theory of Relativity

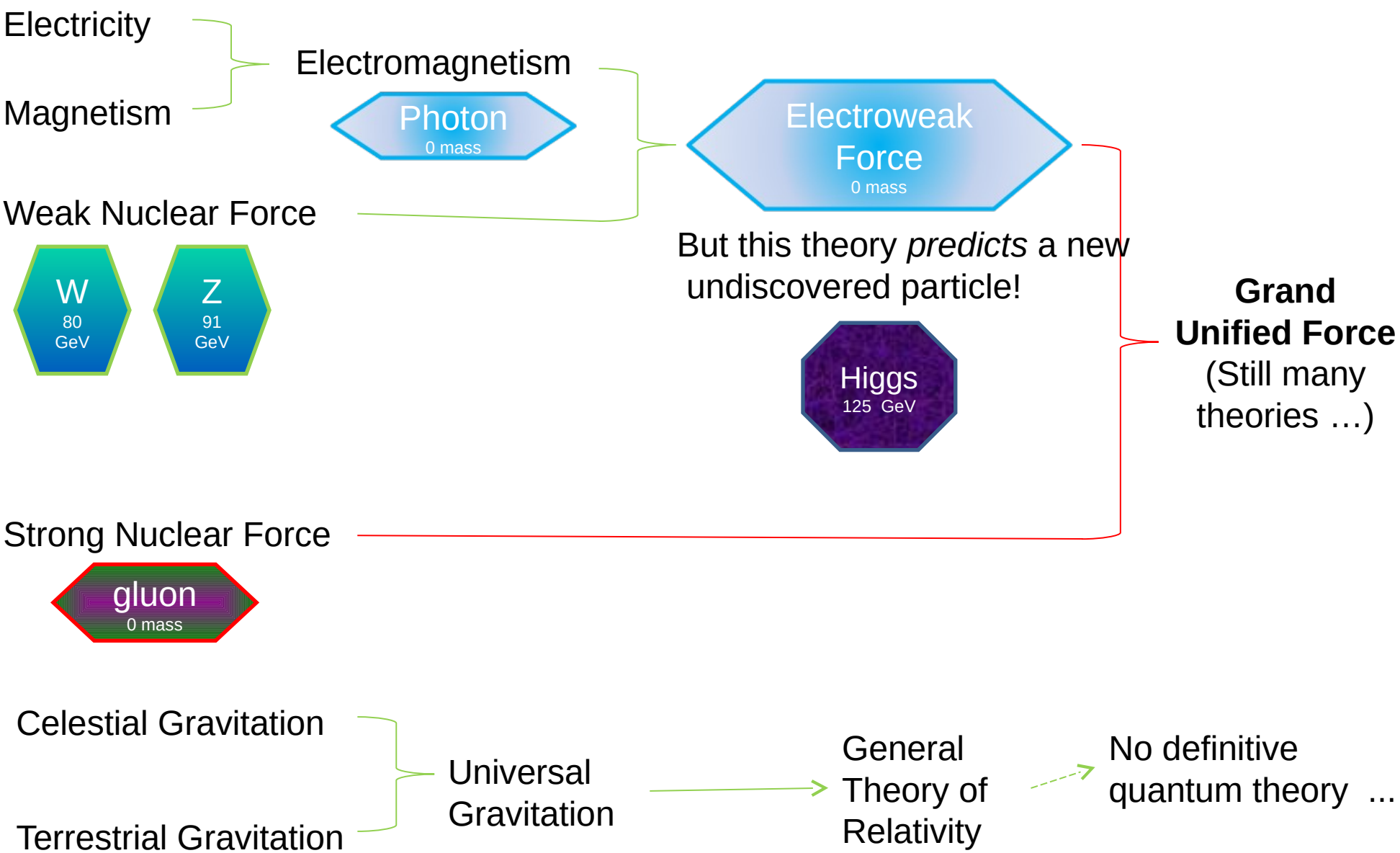
Terrestrial Gravitation

Gravitational waves

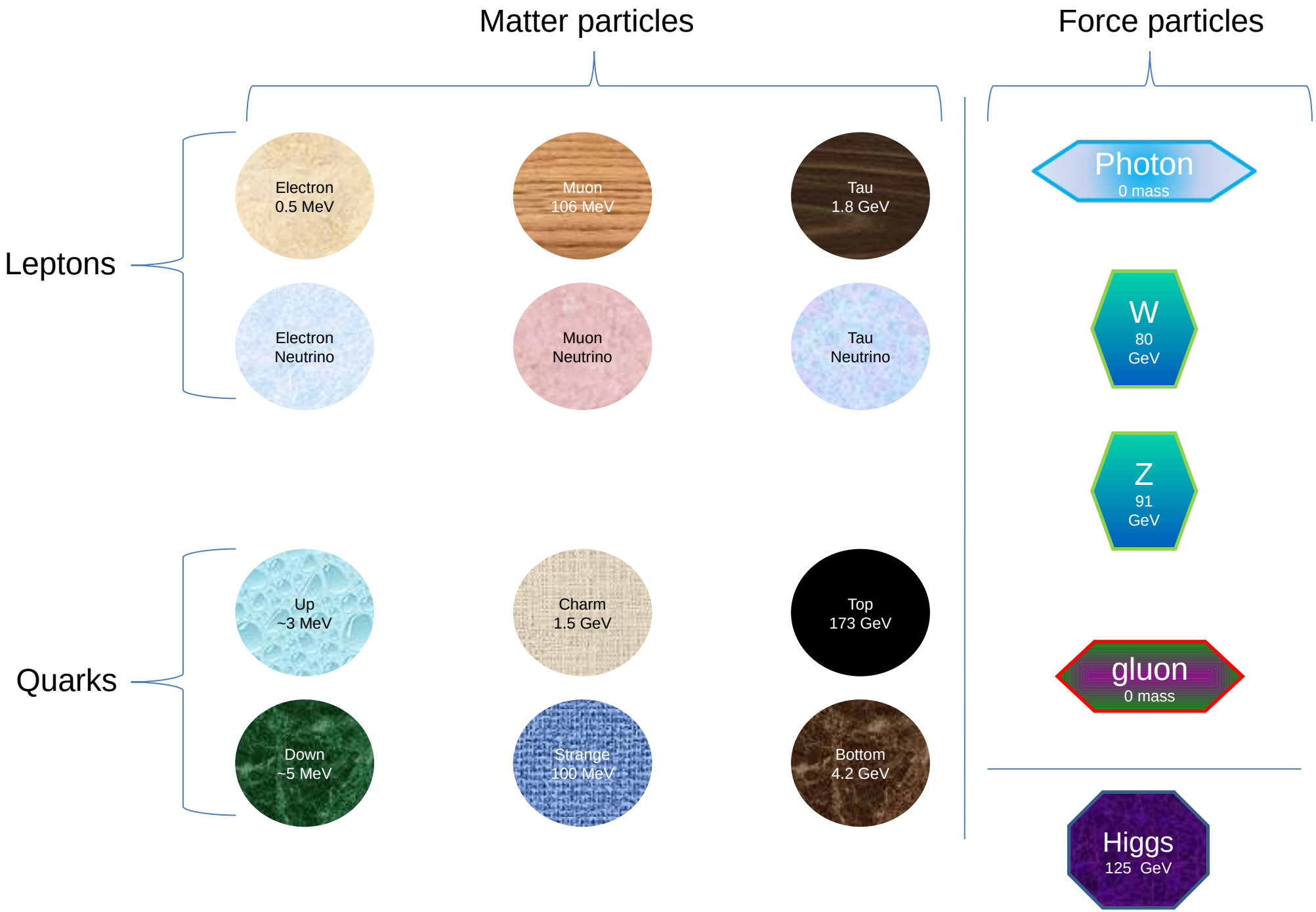


The first direct observation of gravitational waves was made on 14 September 2015

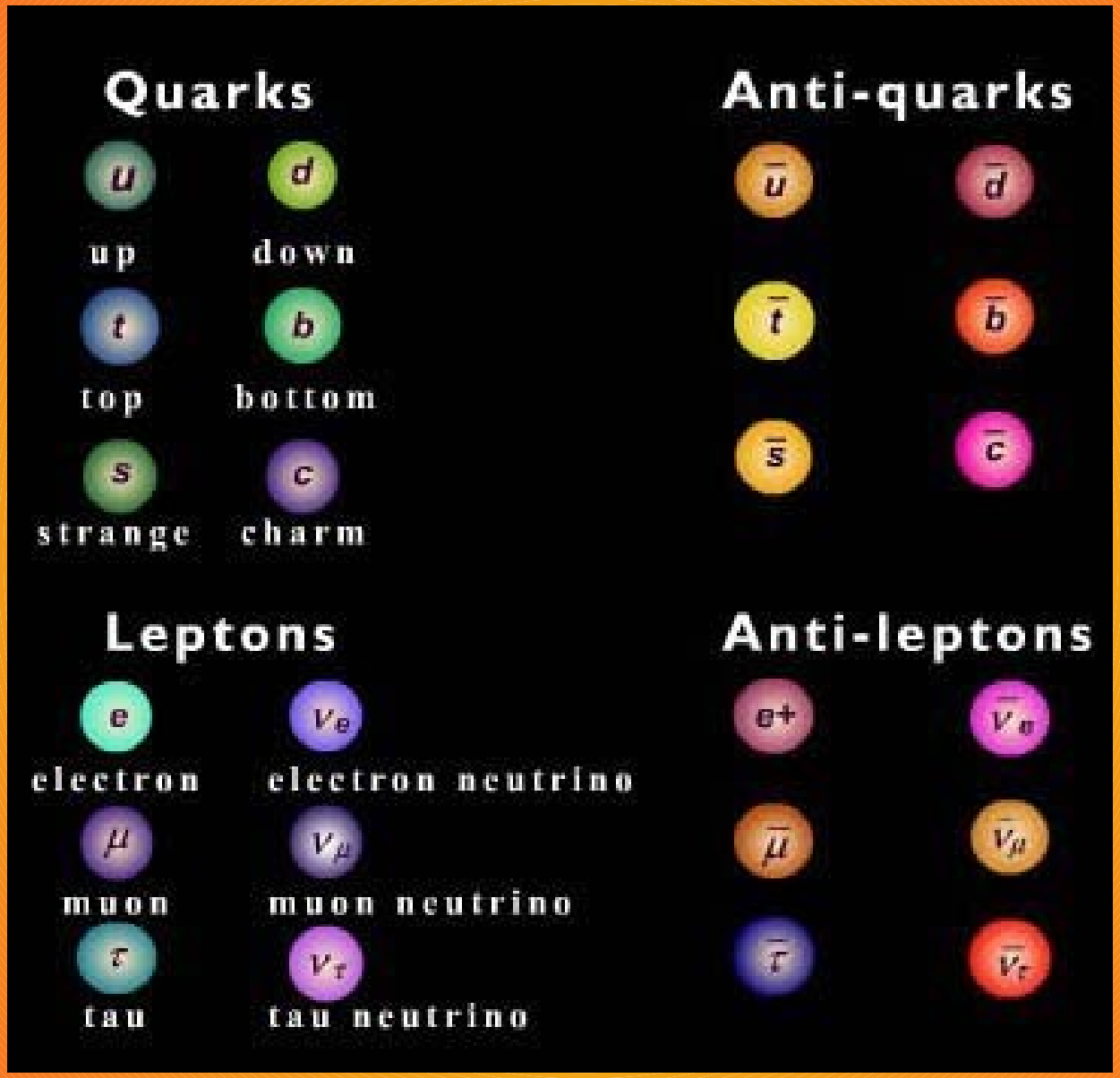
Unification of forces



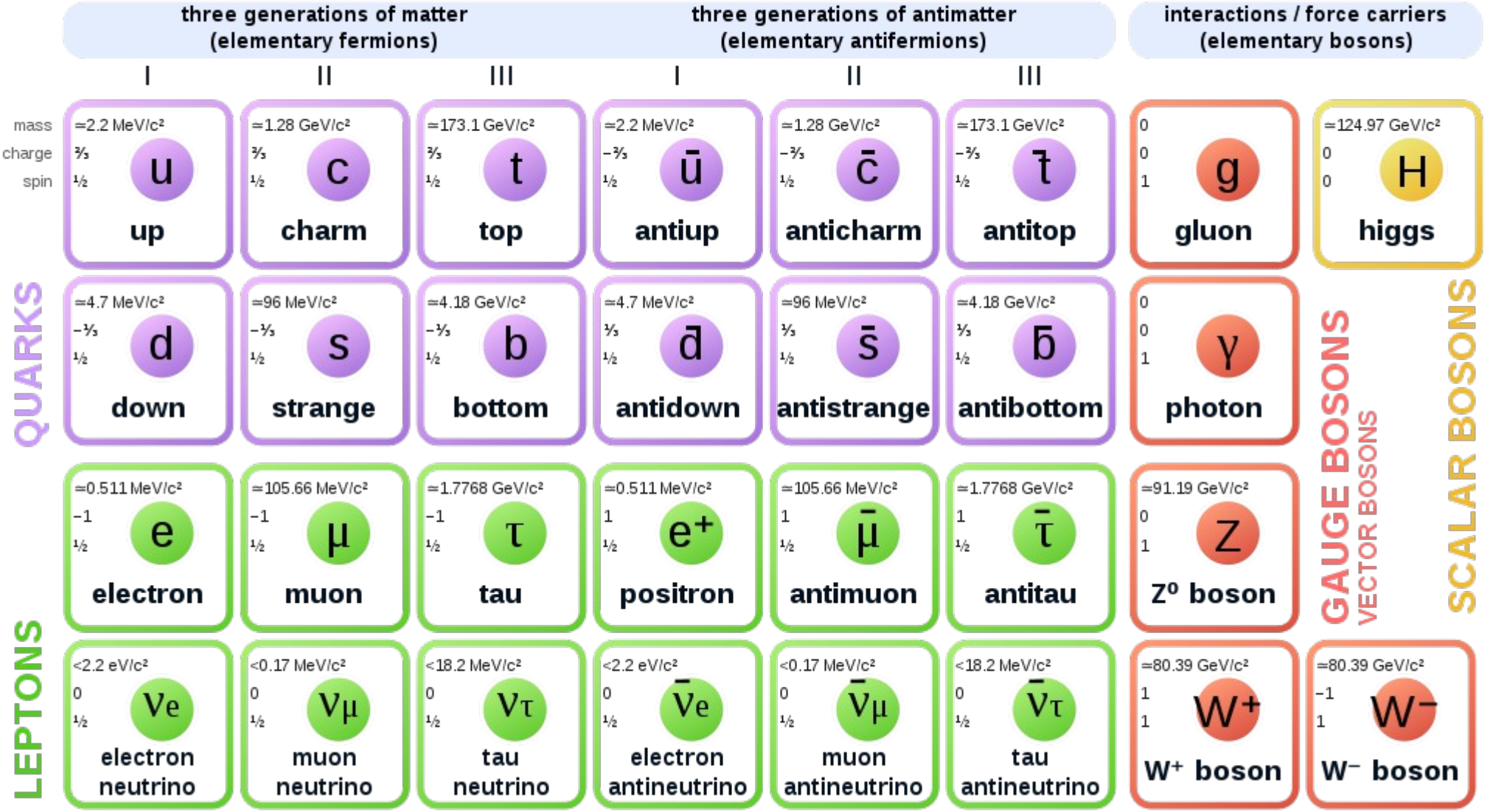
Elementary particles in the Standard Model



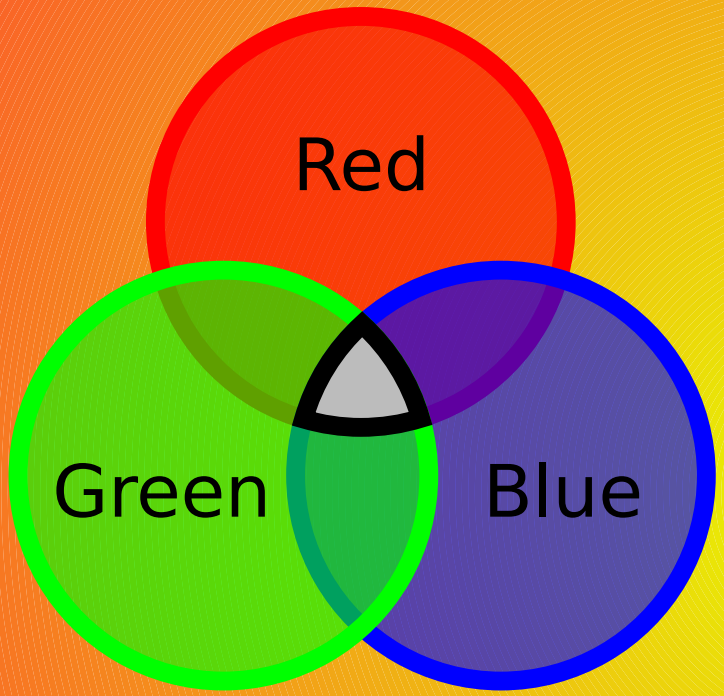
Antiparticles ...

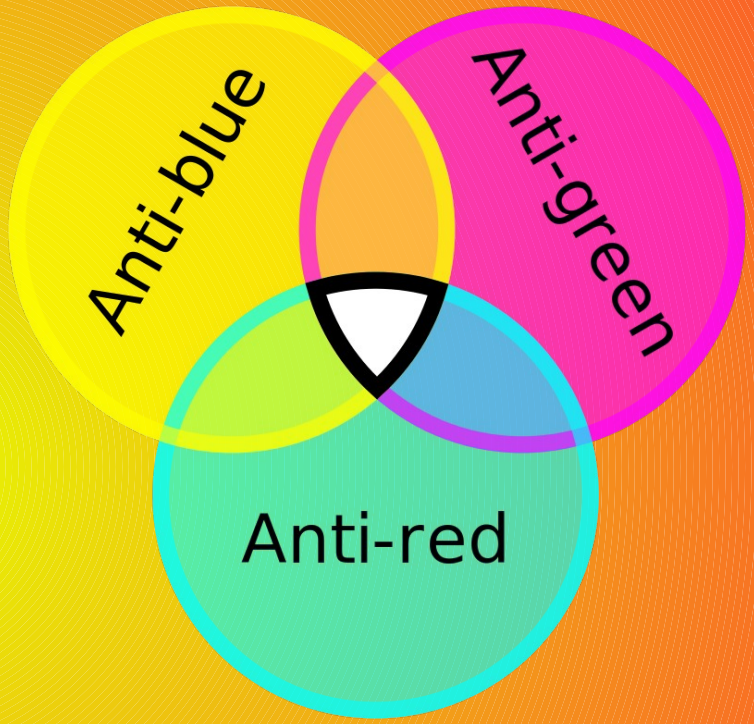


Standard Model of Elementary Particles

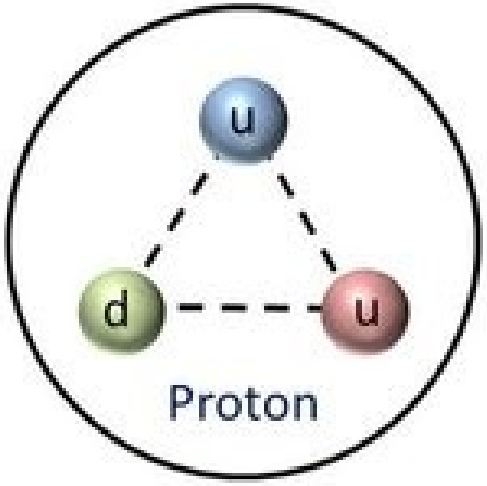


Color

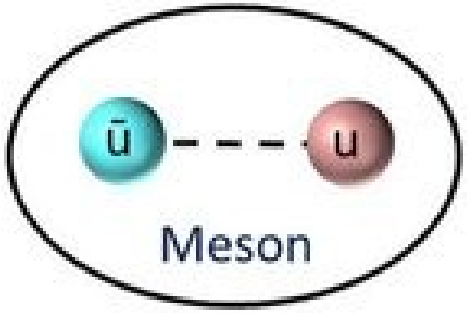




Hadrons (baryons and mesons)



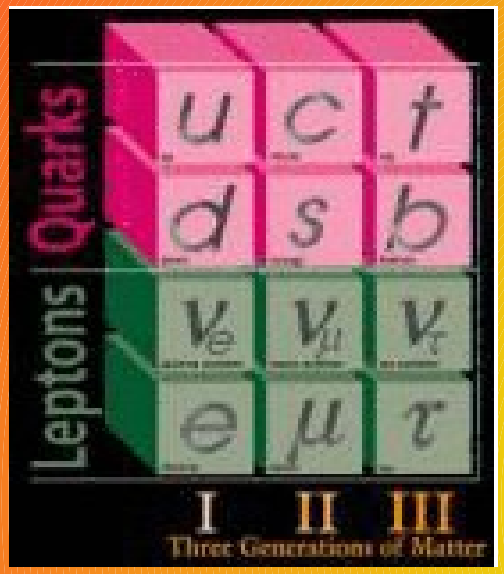
Blue + Green + Red = White



Anti-Red (Cyan) + Red = White

Elementary particles

The elementary particles today:



3 x 6 = 18 quarks
+ 6 leptons
= 24 fermions (constituents of matter)
+ 24 antiparticles
48 elementary particles

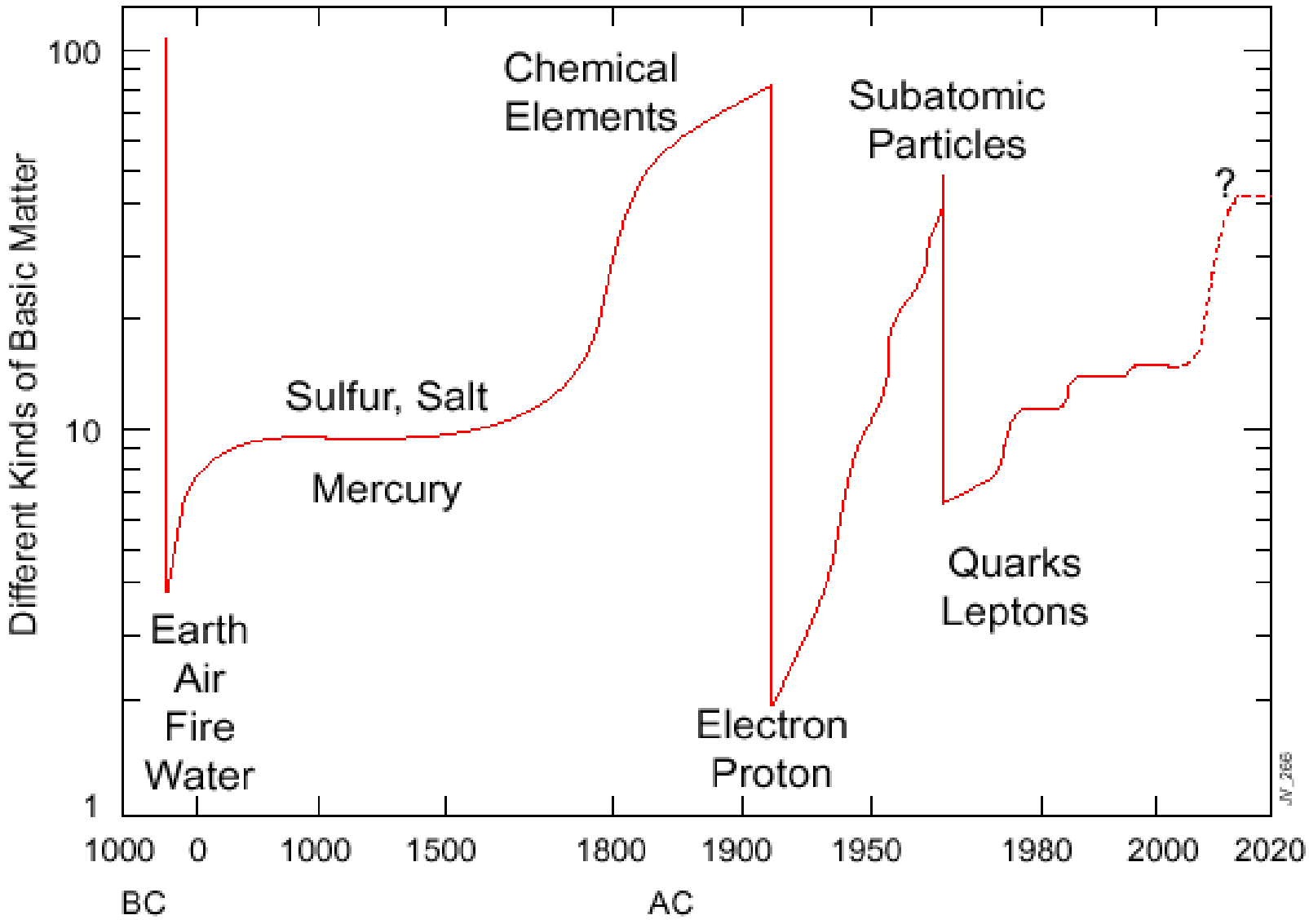
consistent with point-like dimensions within the resolving power of present instrumentation

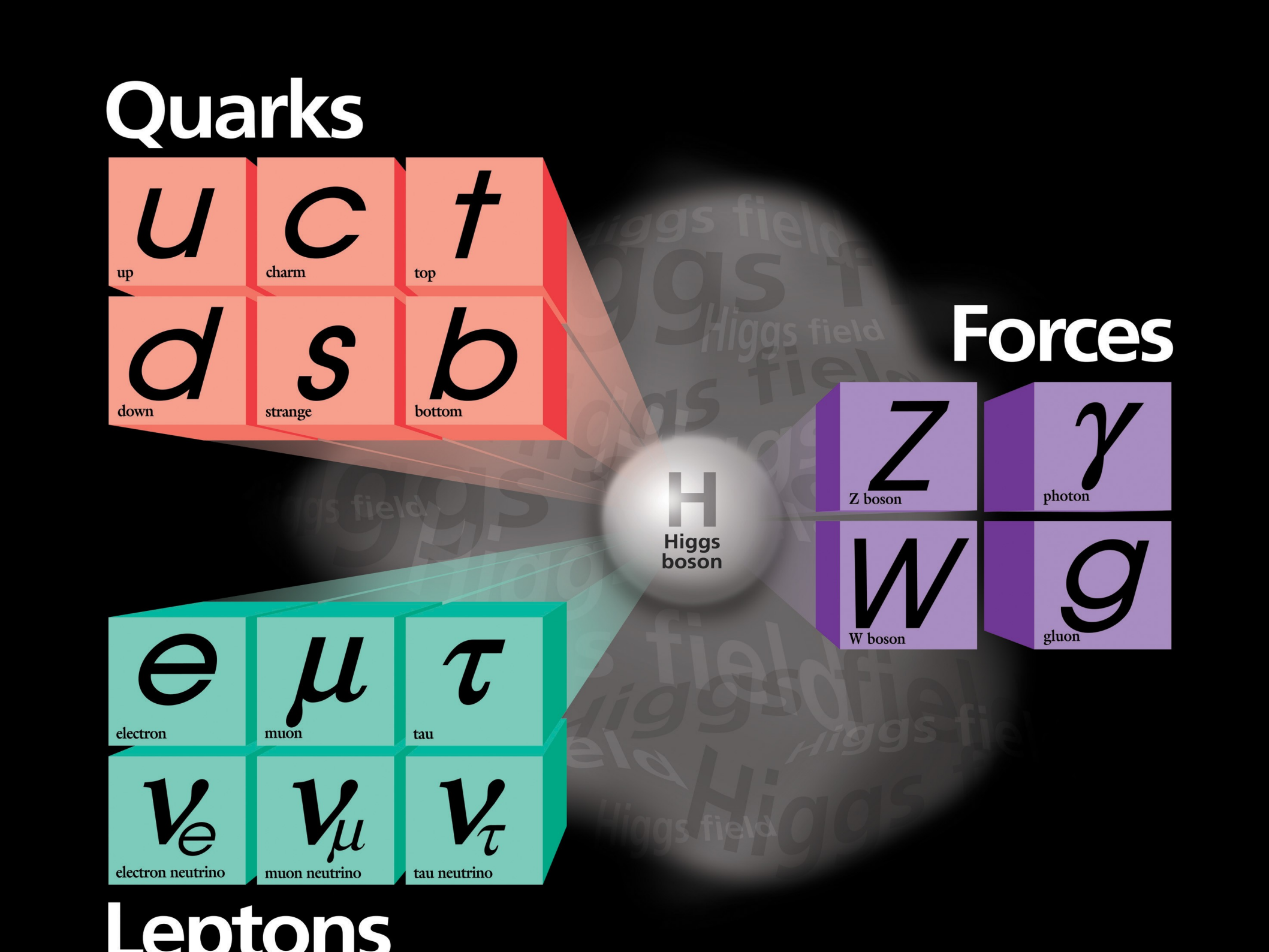
(~ 10^{-16} cm)

12 force carriers (γ, $W^{\pm}$, Z, 8 gluons)

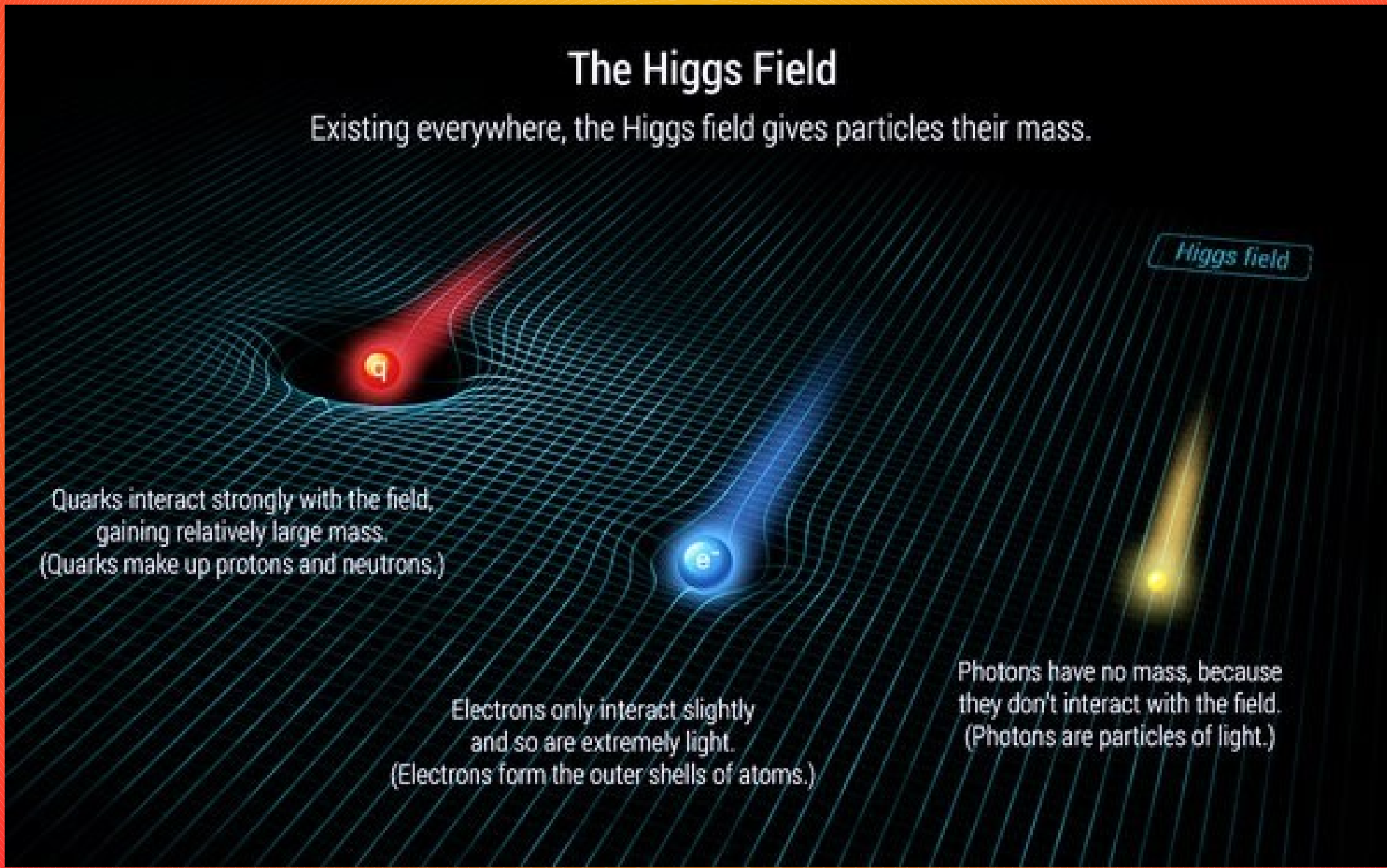
+ the Higgs spin 0 particle (discovered 2012) responsible for generating the masses of all particles

Elementary Constituents of Matter through the ages

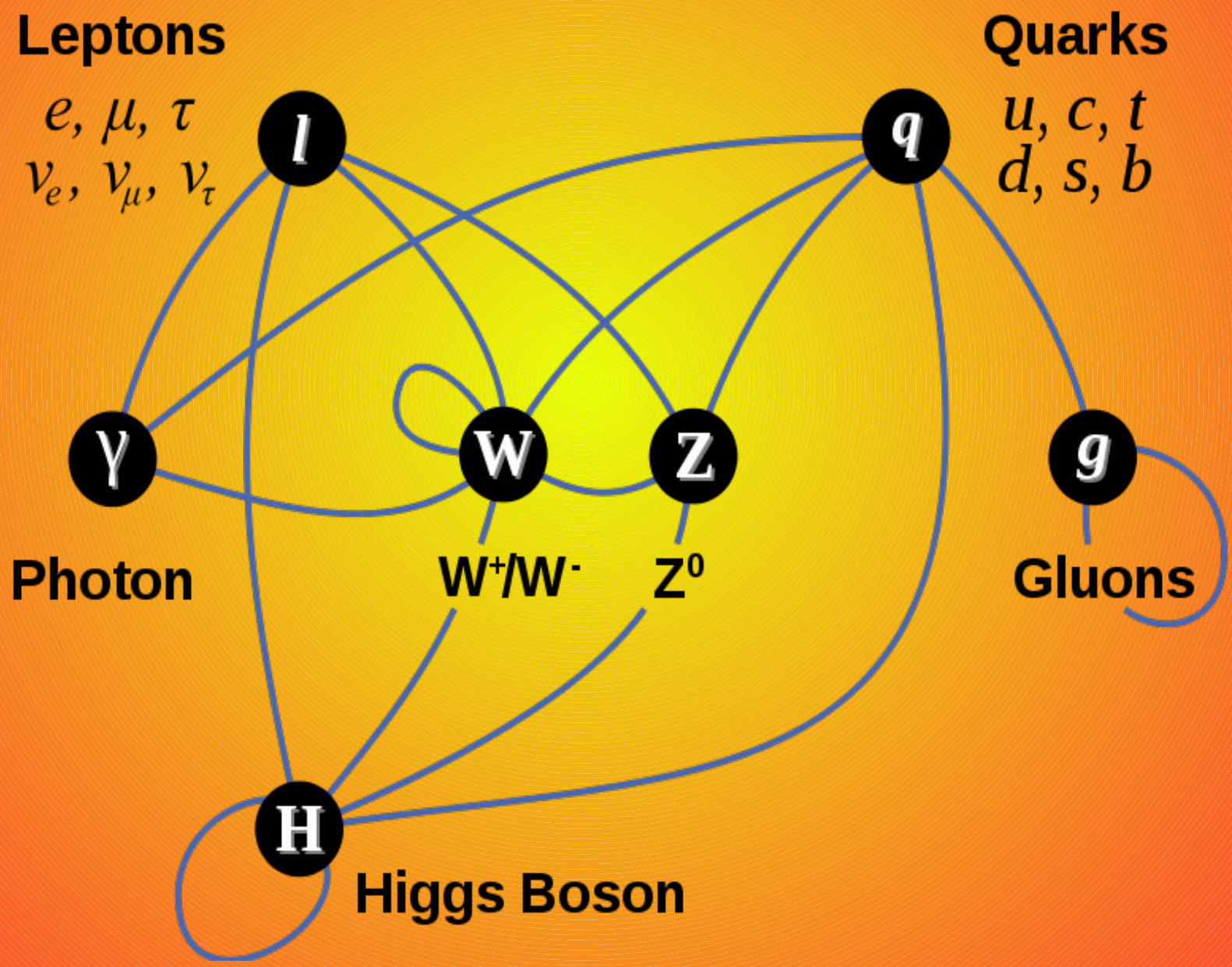


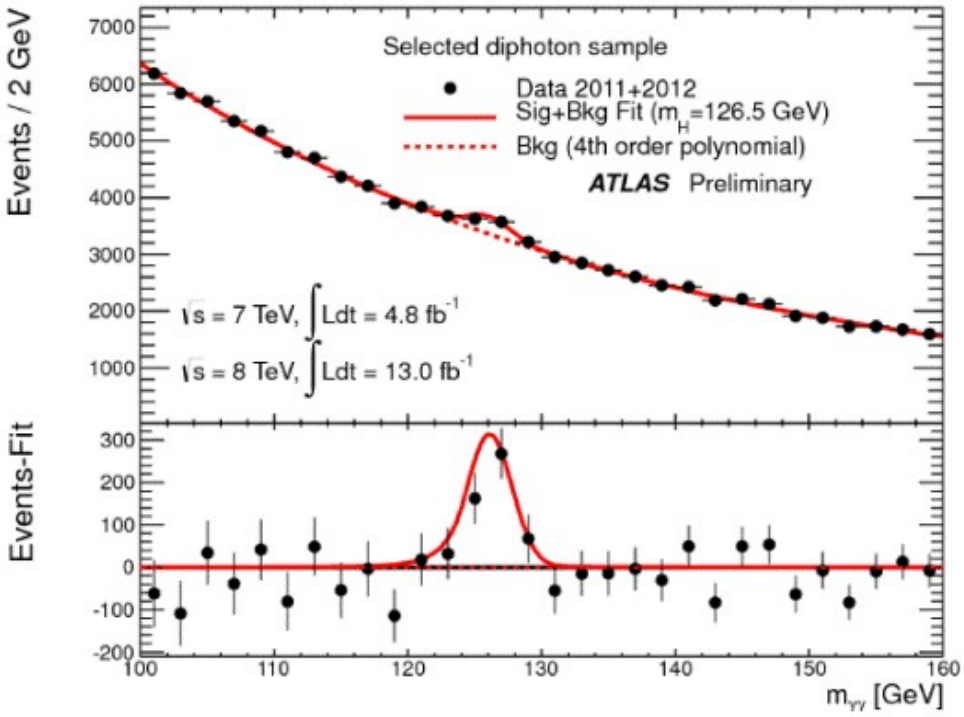

Quarks
u
up
c
charm
t
top
d
down
s
strange
b
bottom
Forces
Z
Z boson
γ
photon
W
W boson
g
gluon
H
Higgs boson
e
electron
μ
muon
τ
tau
νe
electron neutrino
νμ
muon neutrino
ντ
tau neutrino
Leptons

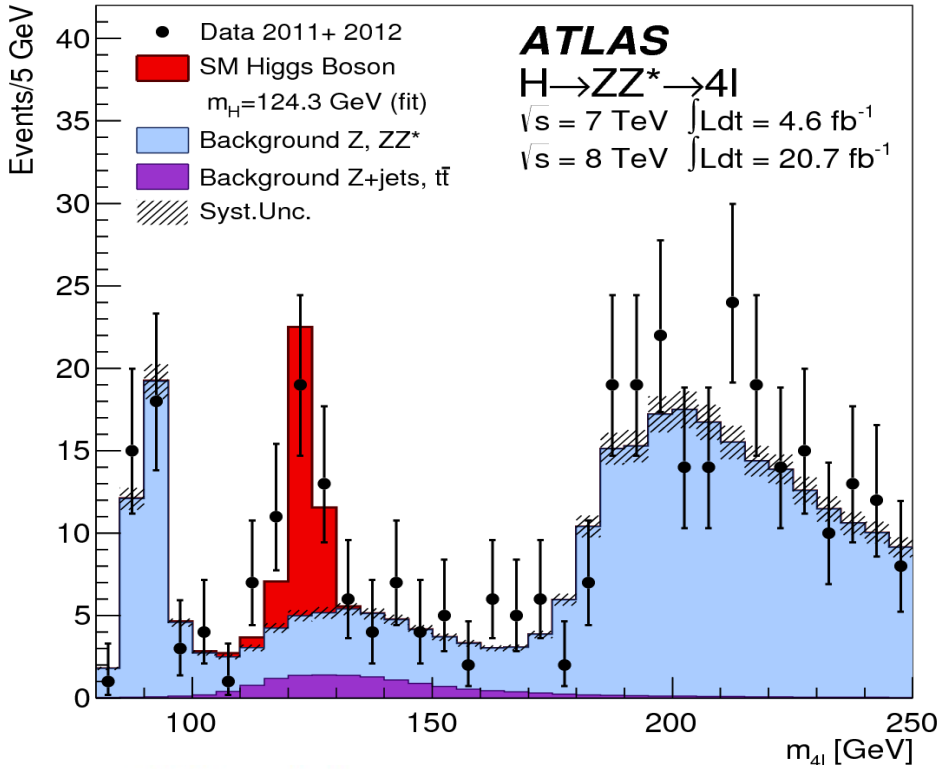
The Higgs Boson

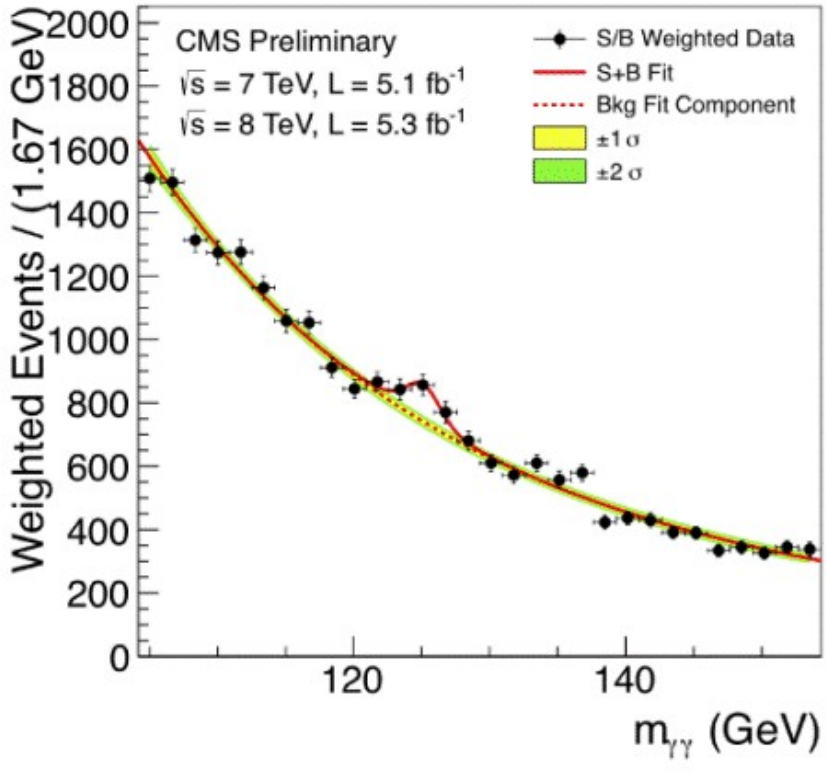


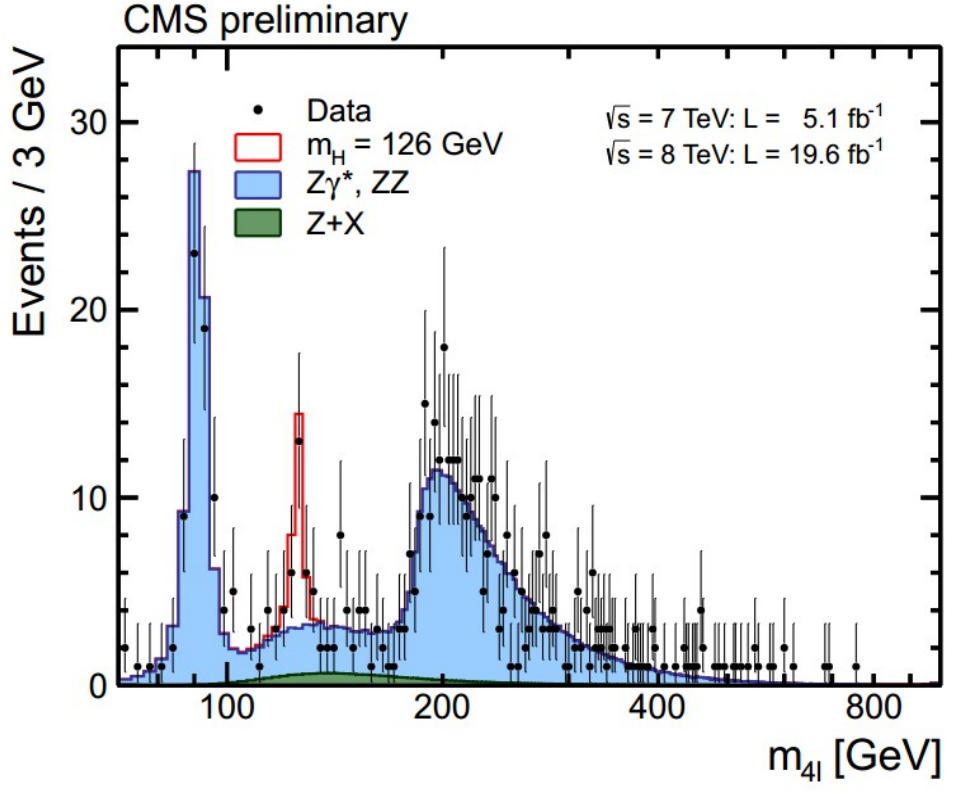
Particles and interactions



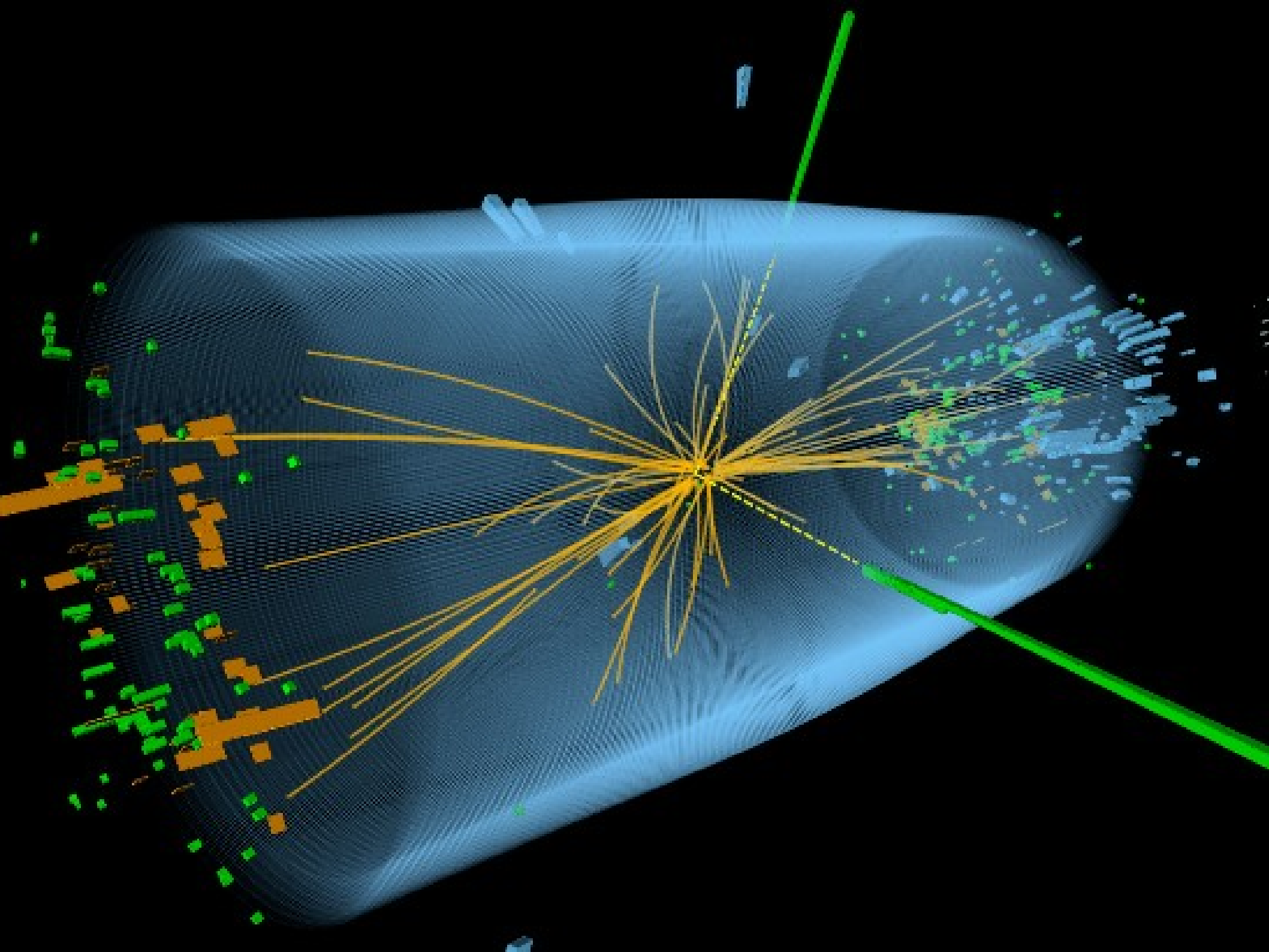

Selected diphoton sample
Data 2011+2012
Sig+Bkg Fit (m_H=126.5 GeV)
Bkg (4th order polynomial)
ATLAS Preliminary
√s = 7 TeV, ∫Ldt = 4.8 fb-1
√s = 8 TeV, ∫Ldt = 13.0 fb-1
Events / 2 GeV
Events-Fit
m_γγ [GeV]

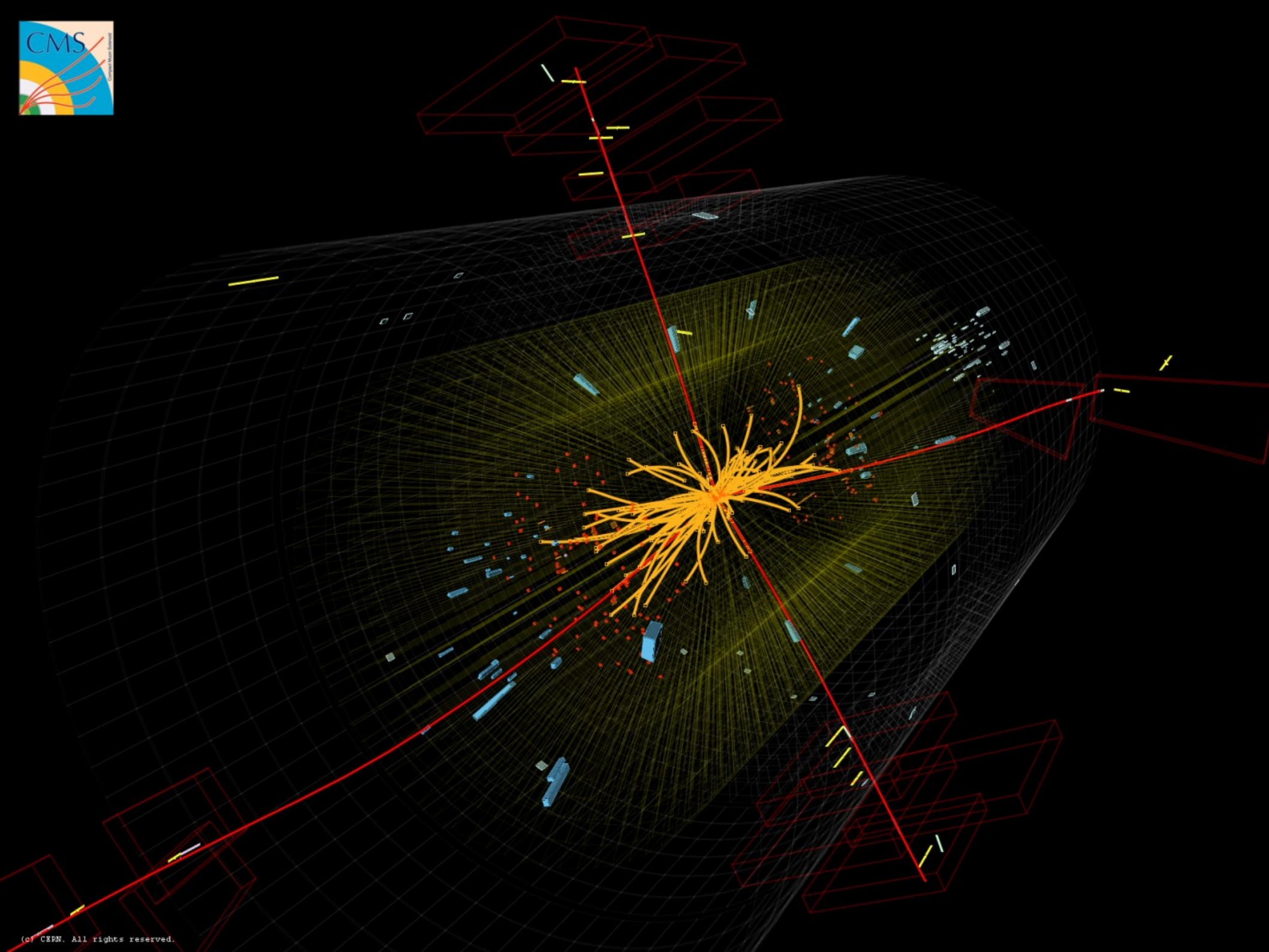

Data 2011+ 2012
SM Higgs Boson
m_H=124.3 GeV (fit)
Background Z, ZZ*
Background Z+jets, tt̄
Syst.Unc.
ATLAS
H→ZZ*→4l
√s = 7 TeV ∫Ldt = 4.6 fb-1
√s = 8 TeV ∫Ldt = 20.7 fb-1
Events/5 GeV
m_4l [GeV]

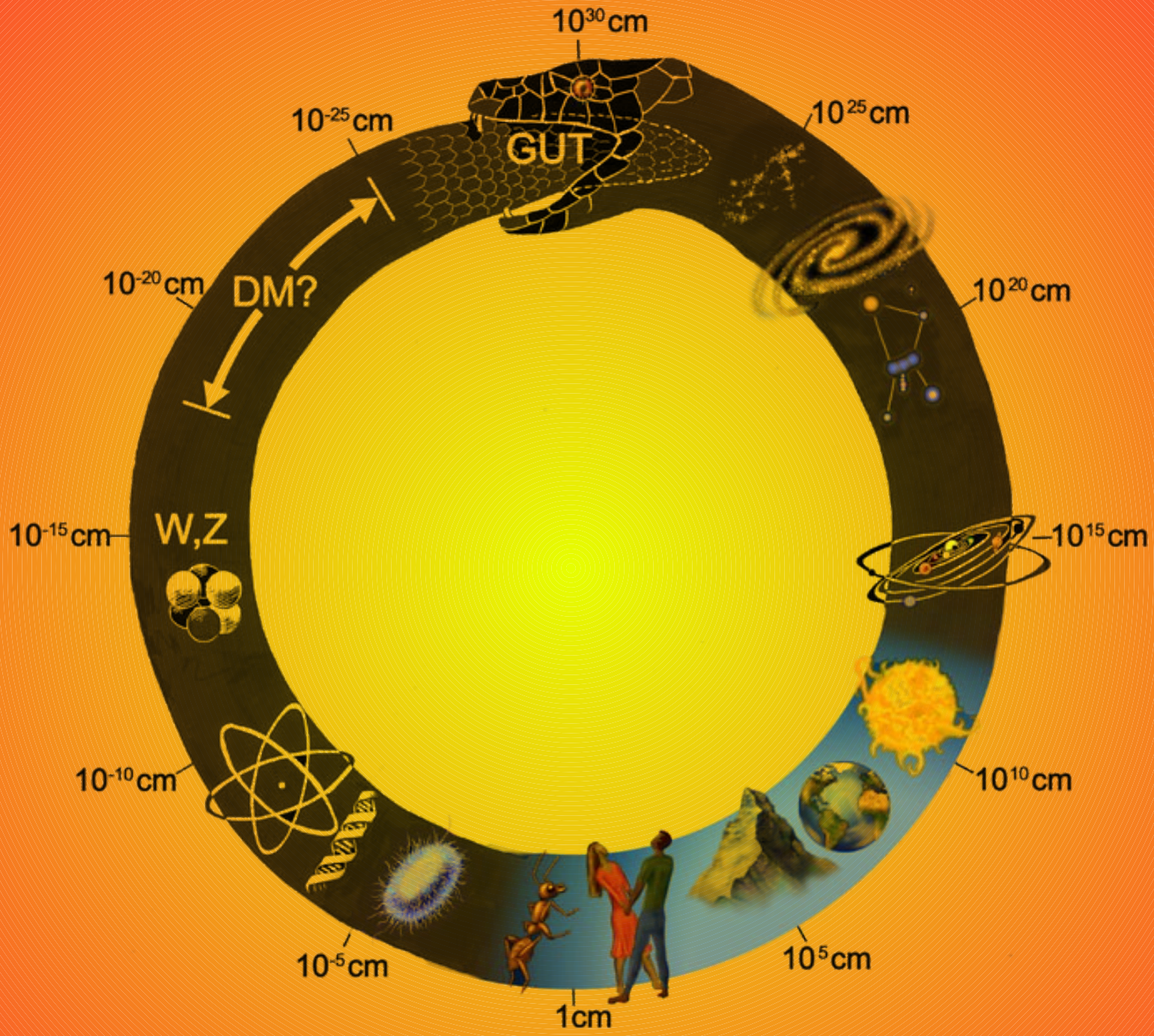

CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
m_γγ (GeV)


CMS preliminary
Data
m_H = 126 GeV
Zγ*, ZZ
Z+X
√s = 7 TeV: L = 5.1 fb-1
√s = 8 TeV: L = 19.6 fb-1
Events / 3 GeV
m_4l [GeV]

4 July 2012

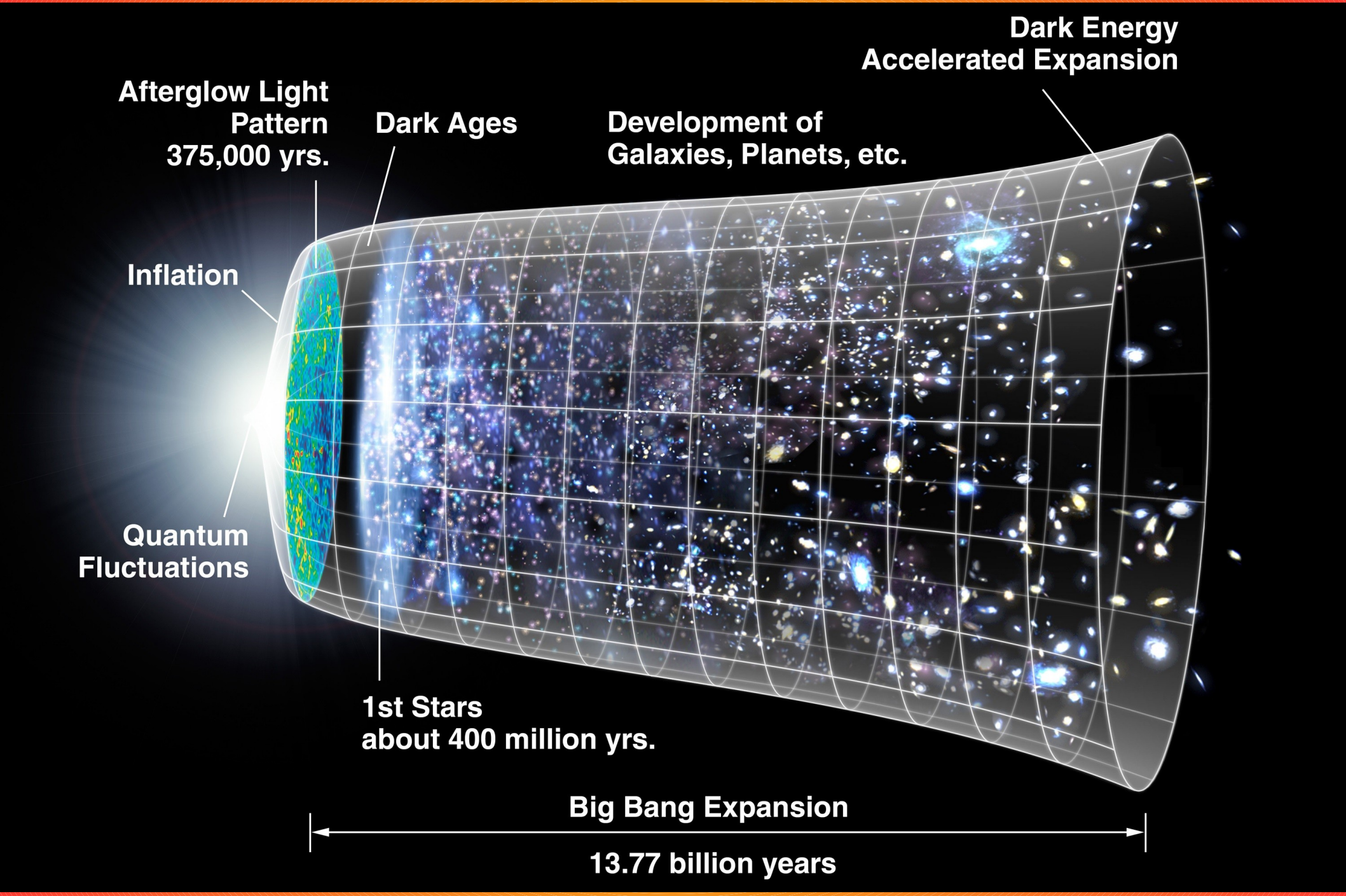






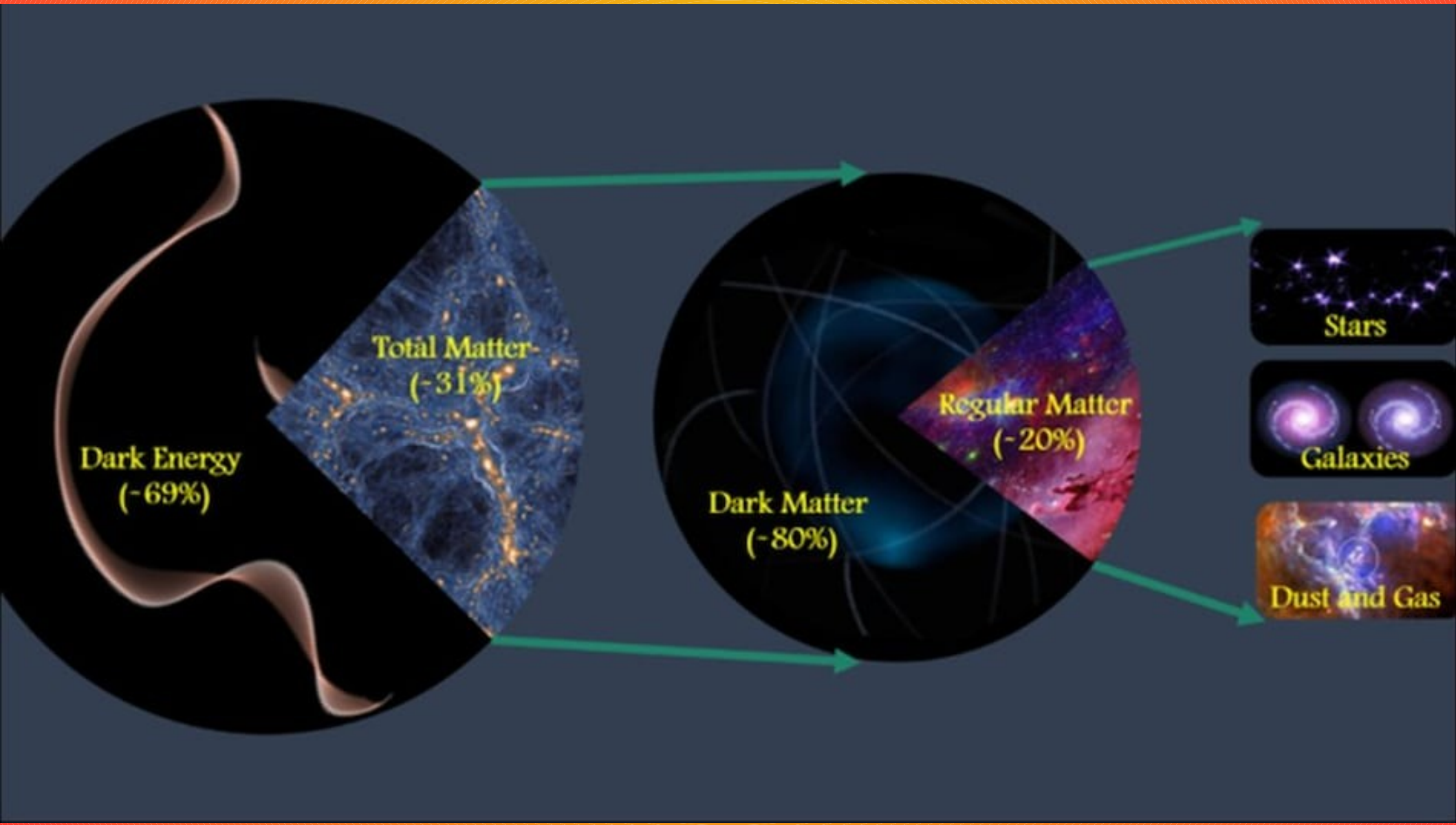
The Cosmic Uroboros

Cosmology



More in the backup slides

Regular Matter. Dark Matter. Dark Energy.



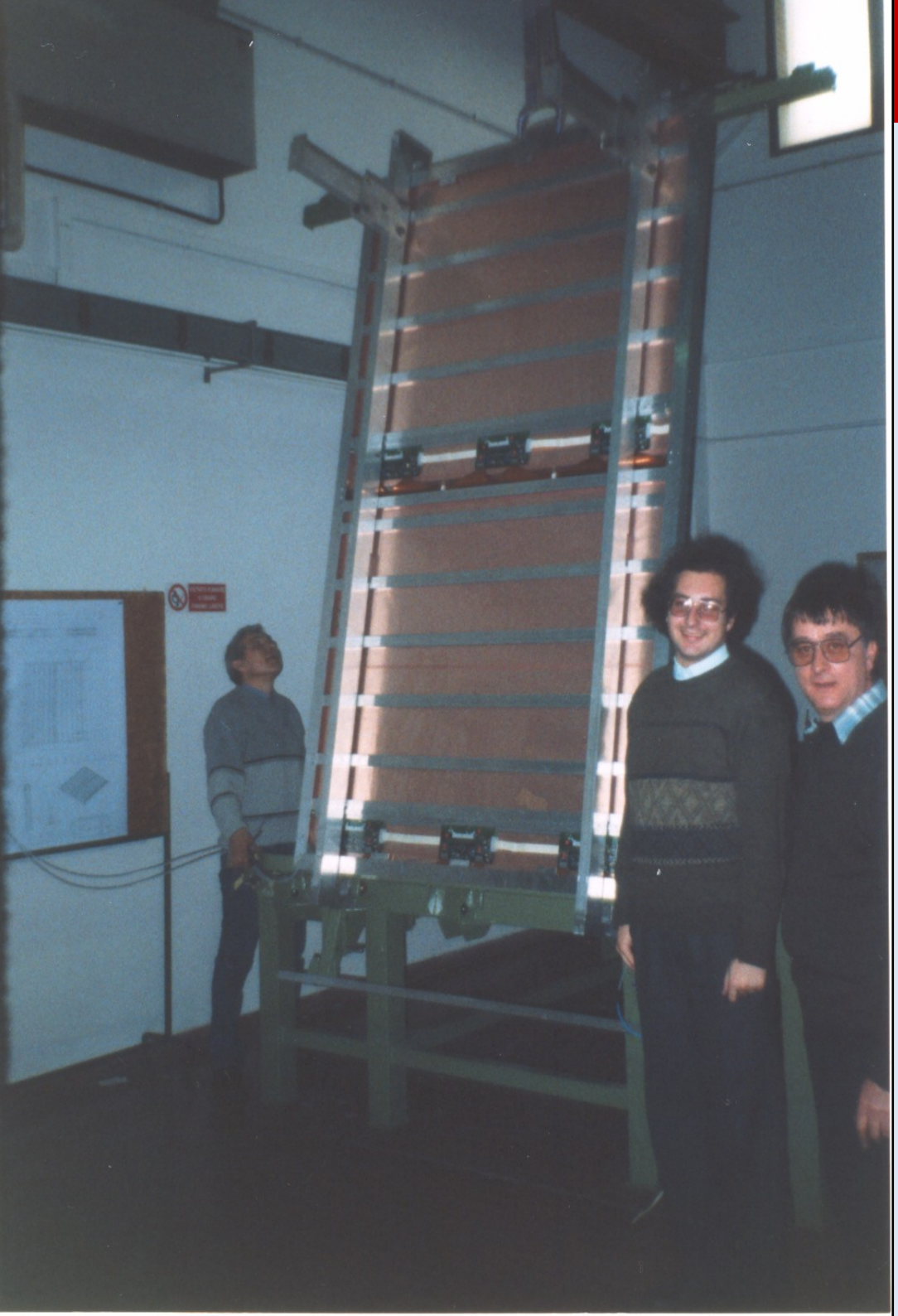
CERN – European Centre for Nuclear Research

CERN – European Centre for Nuclear Research

The detectors together have 140 million data channels observing at 40 million times a second.

CMS & Bulgaria

CMS & Bulgaria



The first CMS RPC
14 February 2002

CMS Physics Analysis Groups

BPH: B Physics and Quarkonia

SMP: Standard Model Physics

TOP: Top Physics

HIG: Higgs Physics

SUS: Searches for new physics in final states with Unbalanced pT and Standard objects

EXO: Searches for Exotica

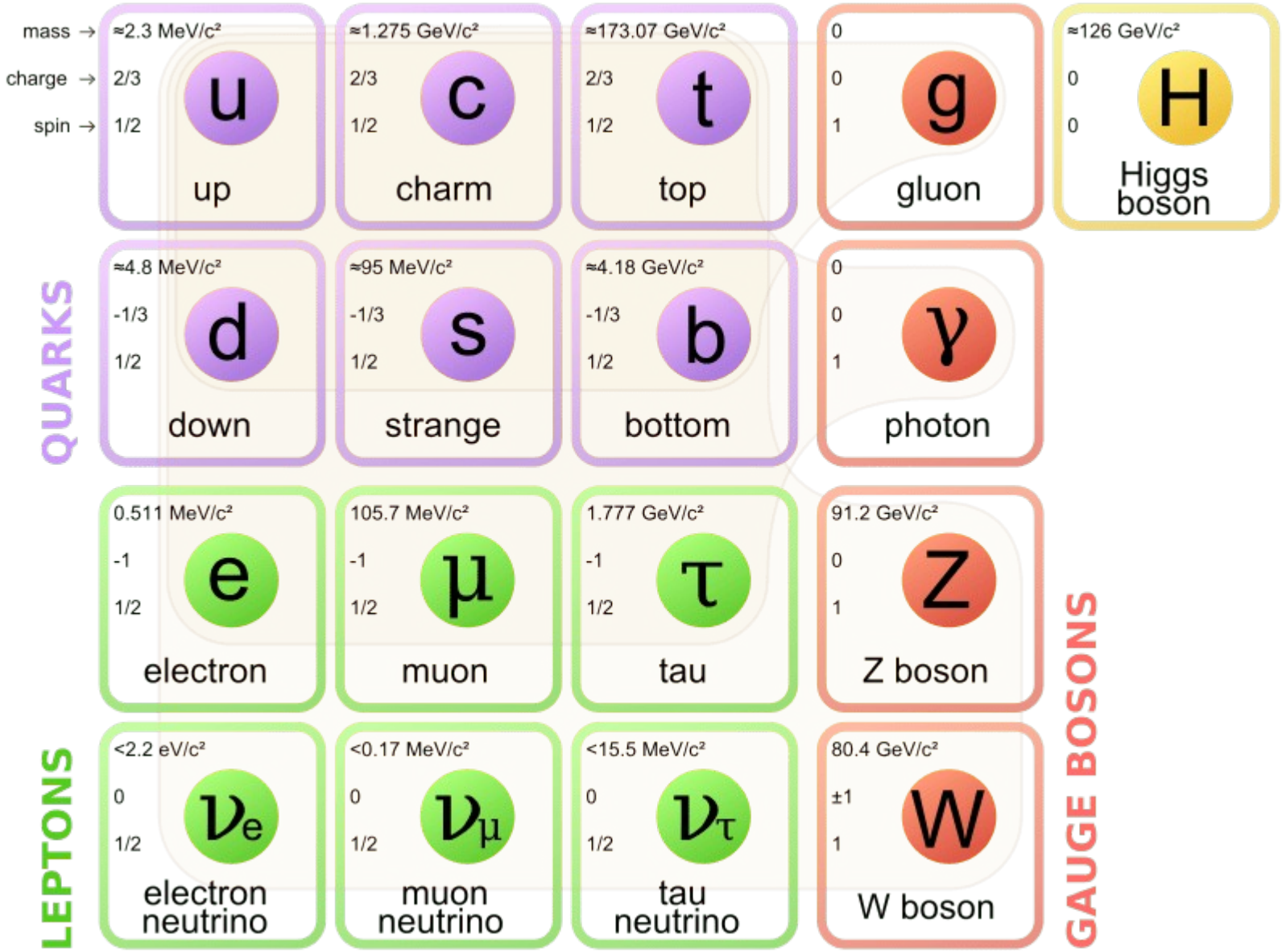
B2G: Searches for Beyond SM particles decaying to top quarks and Higgs and Gauge bosons

HIN: Heavy-Ion Physics

Thank you for your attention !

Backup slides

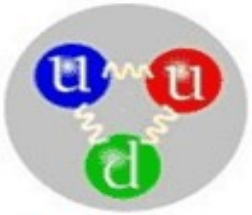
Елементарни частици - параметри



Адрони (бариони и мезони)

Hadrons

Baryons are composed of three quarks



Baryons

Mesons are composed of one quark and one antiquark

Mesons

Nucleons

Particle	Mass (MeV/c^2)	τ (sec)
p	938.2	$>10^{11}$
n	939.5	10^{3}

Pions

Particle	Mass (MeV/c^2)	τ (sec)
π^-, π^+	139	2.5×10^{-8}
π^0	135	1.8×10^{-16}

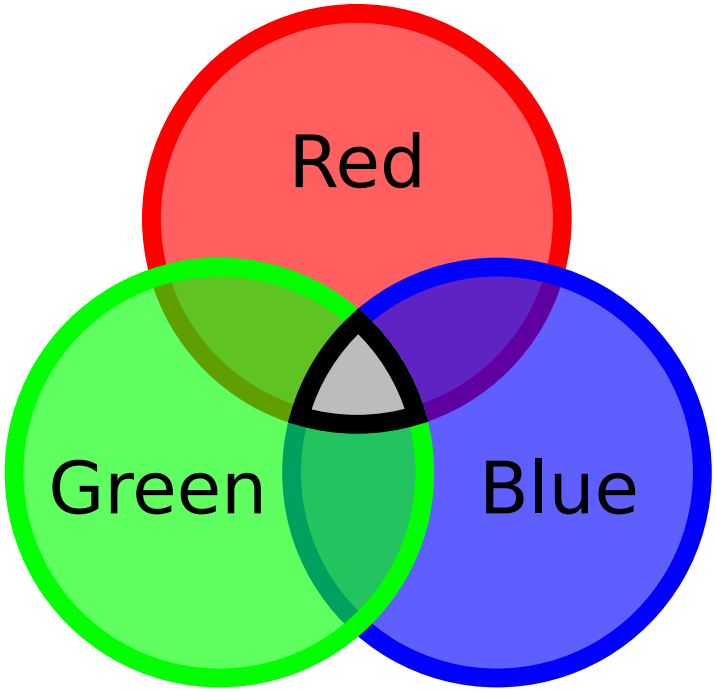
Hyperons

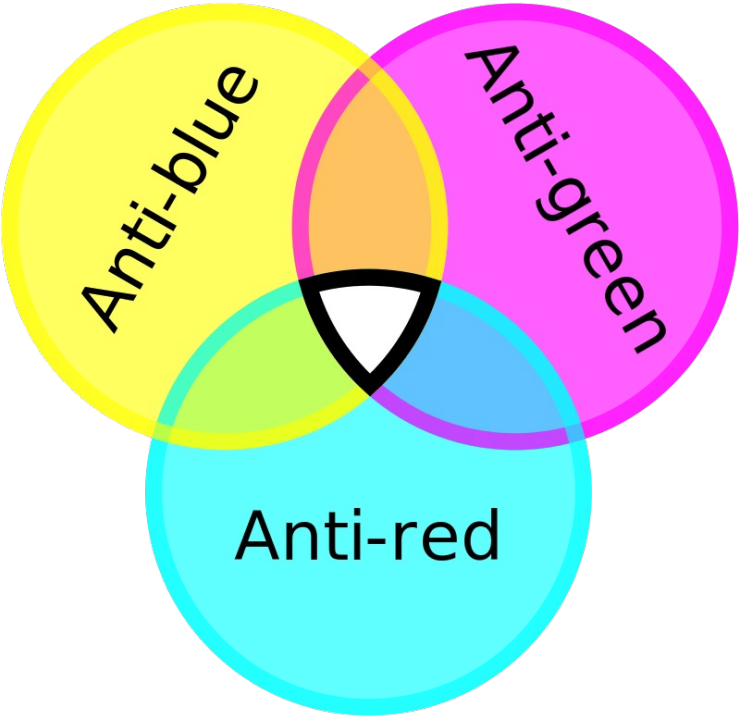
Particle	Mass (MeV/c^2)	τ (sec)
Λ	1115	2.6×10^{-10}
Σ^+	1189	0.8×10^{-10}
Σ^0	1192	10^{-14}
Σ^-	1197	1.6×10^{-10}
Ξ^0	1314	3×10^{-10}
Ξ^-	1321	1.8×10^{-10}
Ω^-	1675	1.3×10^{-10}

Kaons

Particle	Mass (MeV/c^2)	τ (sec)
K^-, K^+	494	1.2×10^{-8}
K^0	498	
η	550	10^{-18}

Цвят. „Цветен заряд“





CERN – European Centre for Nuclear Research

lies the world's **fastest** and most **brutal** racetrack…

Protons race around a 27 km circuit at **99.999999%** the speed of light,

crashing head on into each other **40,000,000** times a second.

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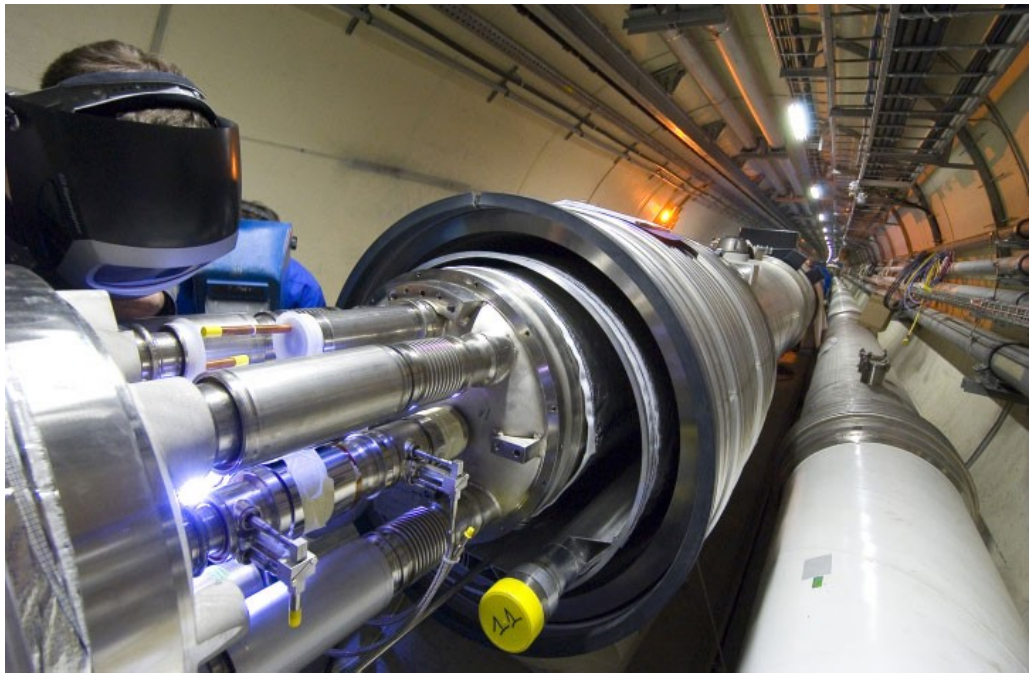
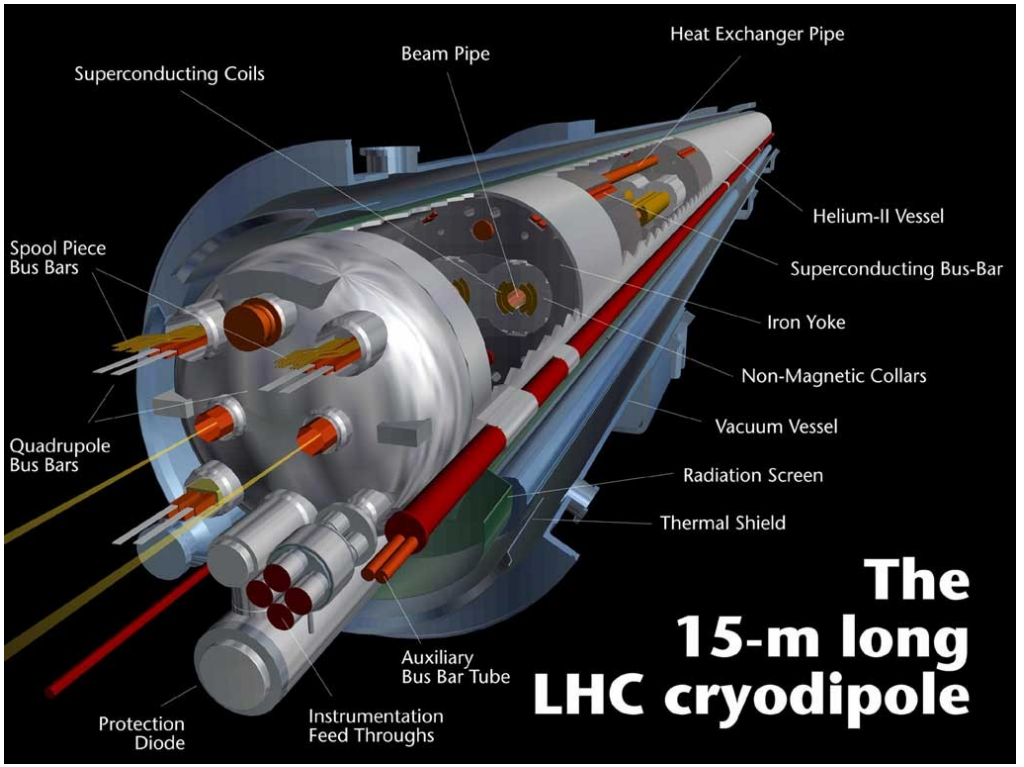
in the **emptiest** space in our solar system…





The beam pipe is evacuated to the same vacuum as interplanetary space
The pressure is about 1/10th that of the surface of the moon.

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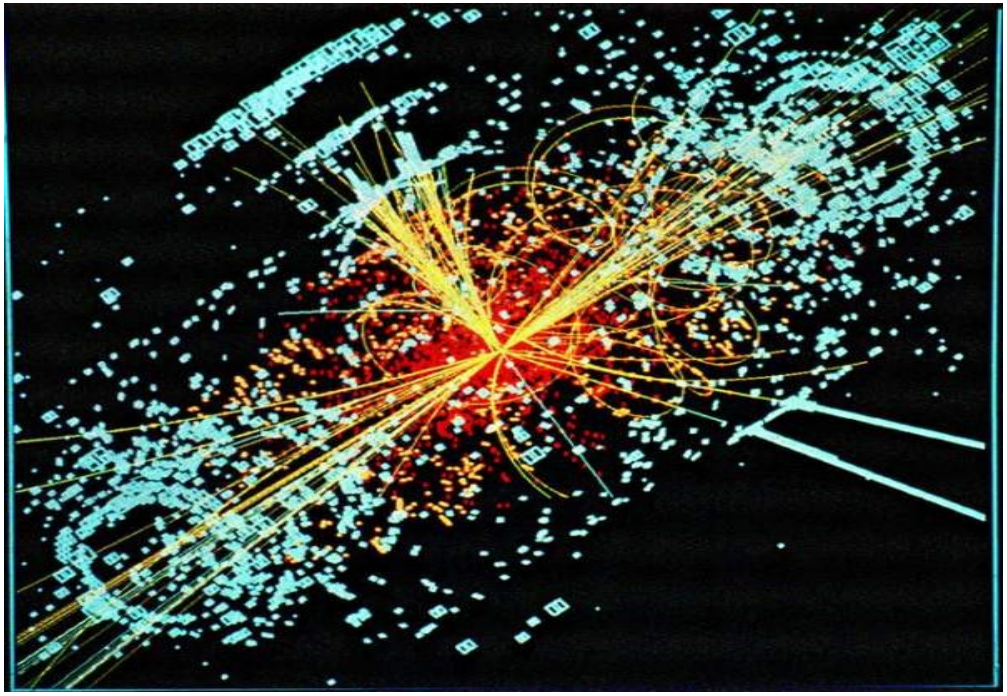
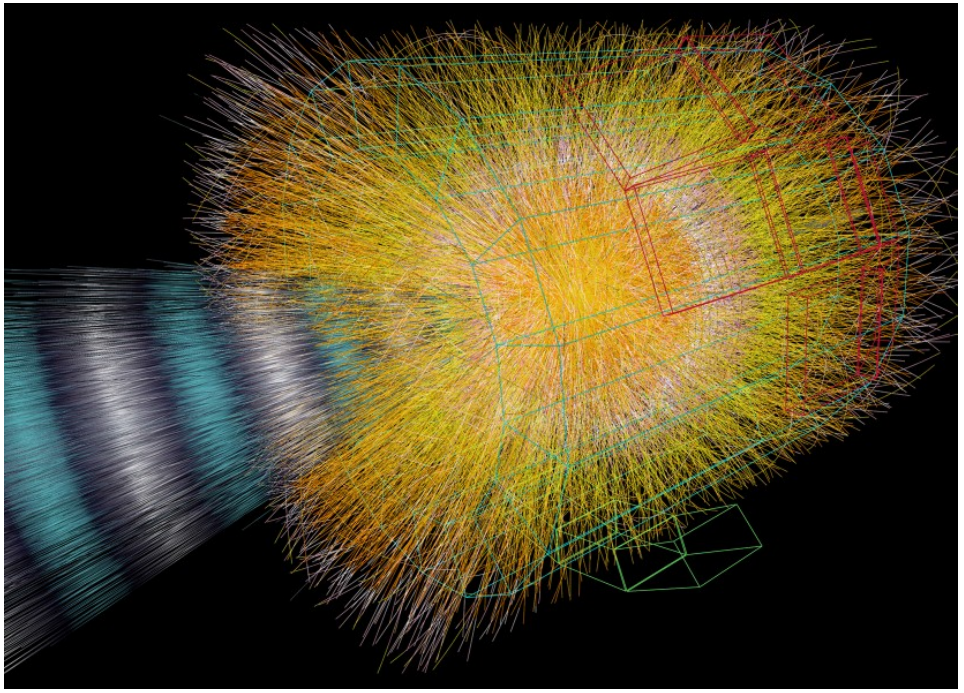
in one of the **coldest** regions in the universe…

Superconducting and superfluid liquid helium is maintained at -271.3 C or 1.9 K.

That is a little colder than interstellar space.

will occur some of the **hottest** reactions in our galaxy…





Violent collisions corresponding to temperatures a billion times higher than the core of the sun will be produced.

That is roughly 160,000,000,000,000,000 C

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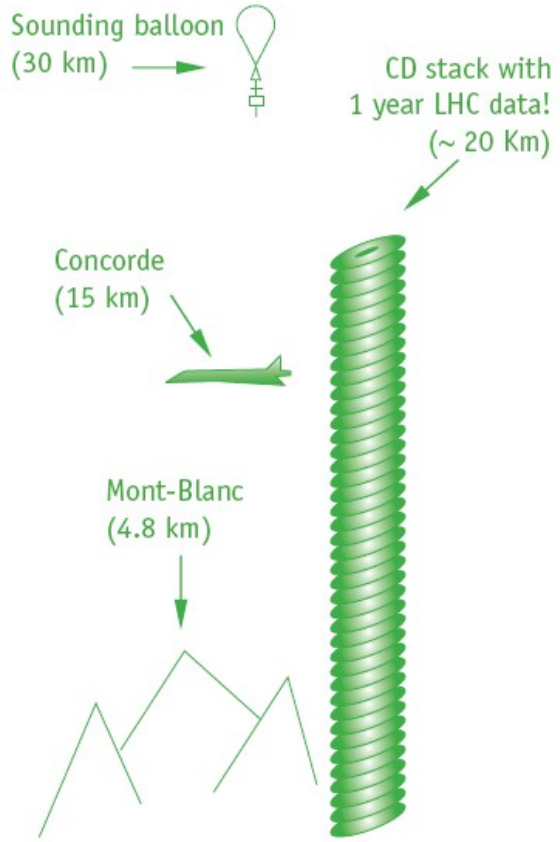
and analyzed by the most powerful computing system in the world.



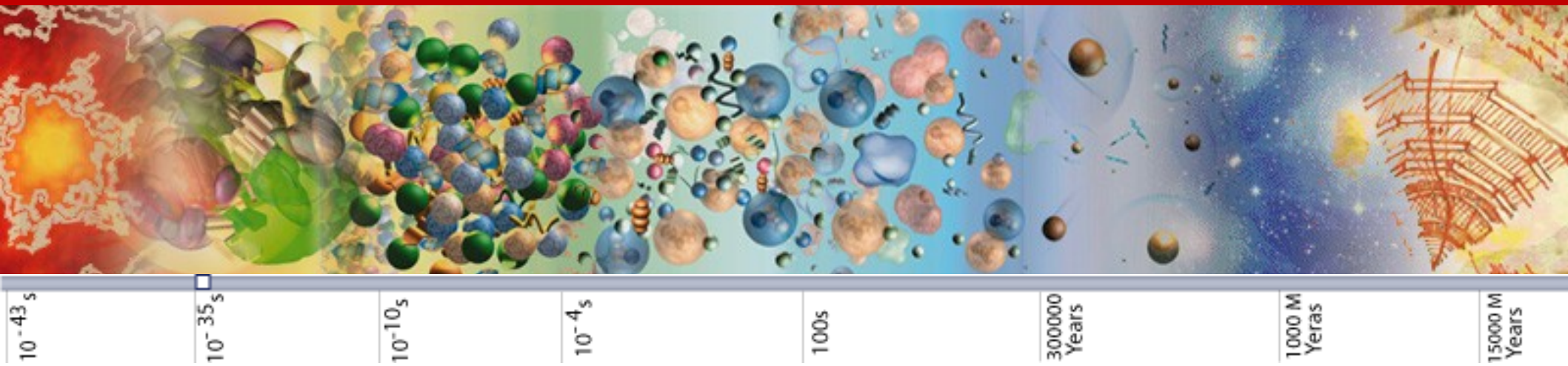
The detectors will spew out analyzed data at **700 MB/sec.**

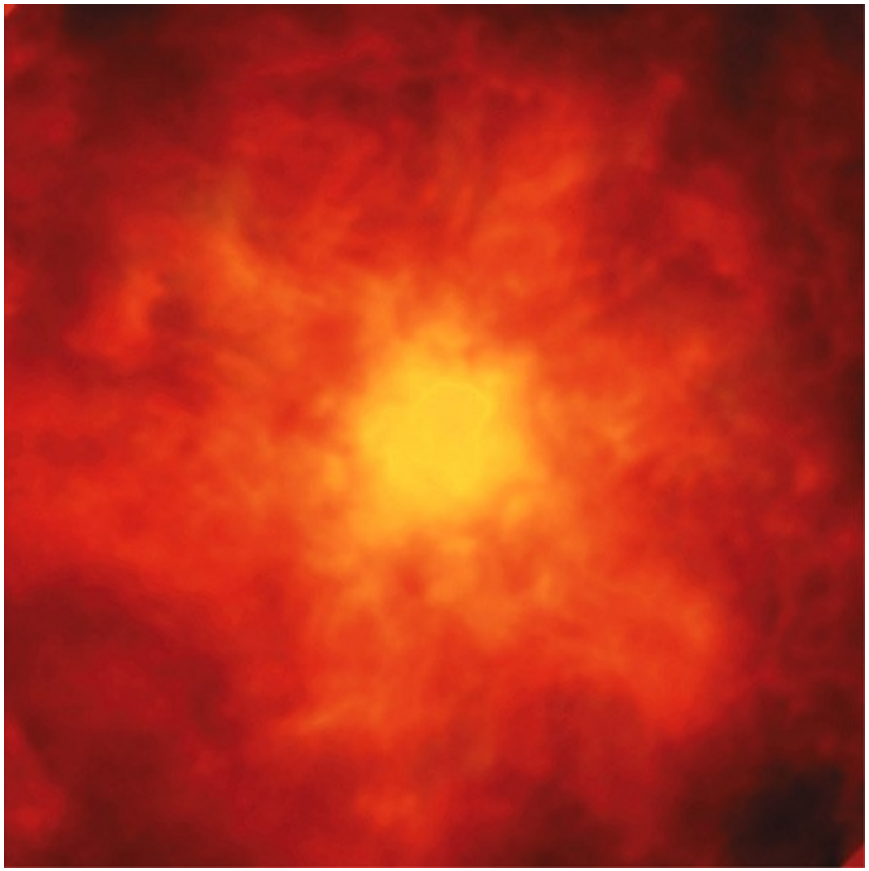
That is ~30,000 Encyclopedia Britannicas *every second*!

That is 15,000,000 GB (15 PB) per year

20 km stack of average CDs per year.

Големият взрив



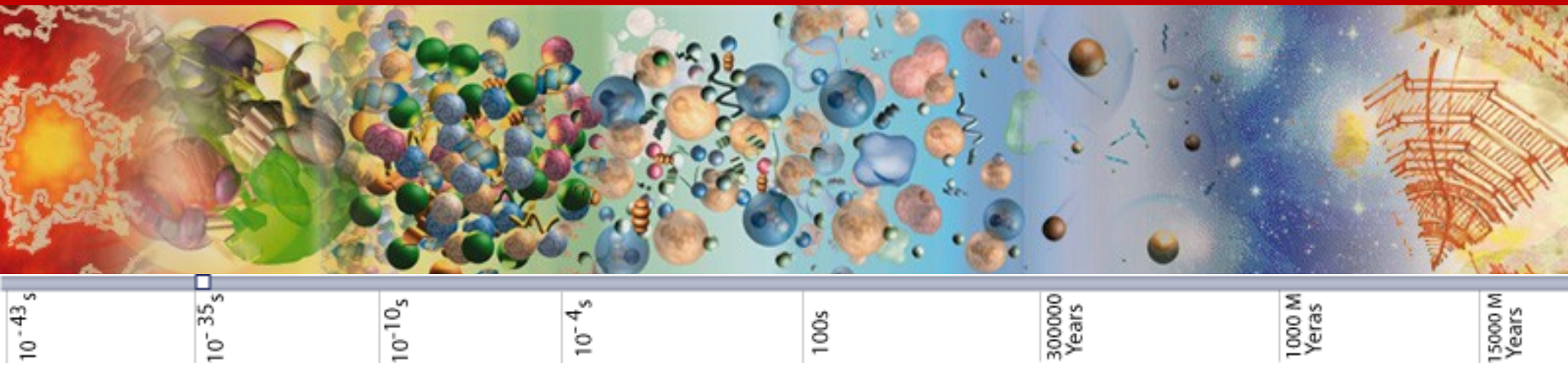


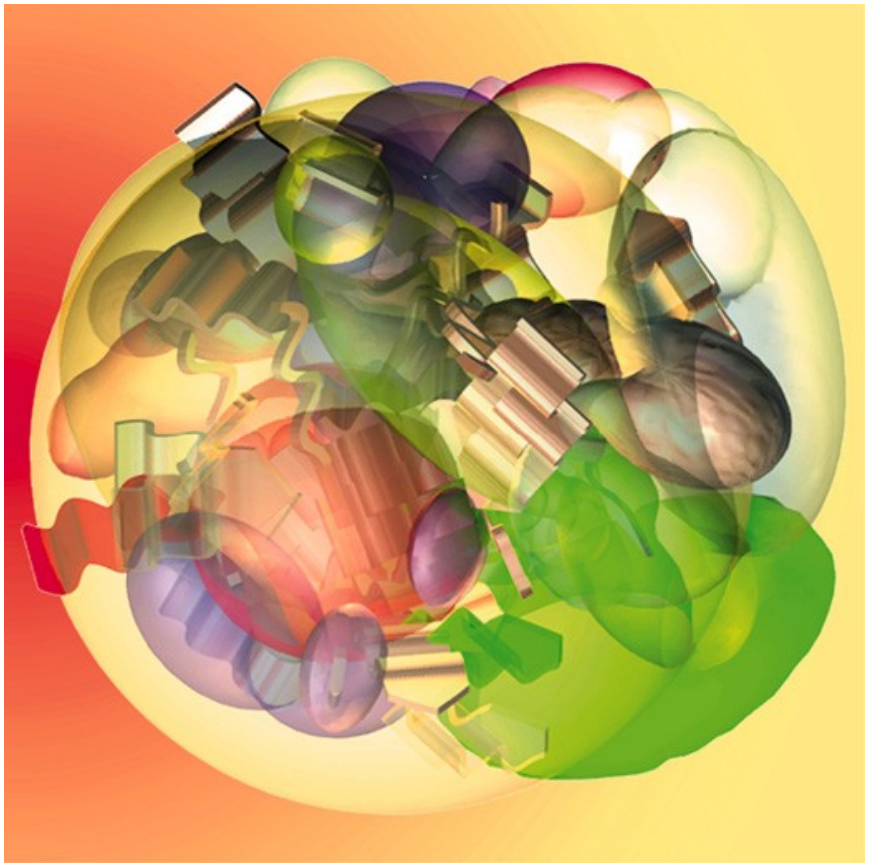
The Era of Quantum Gravity (10^{-43} sec, 10^{32} K)

- All particles, quarks, leptons, force carriers and other undiscovered particles existed in thermal equilibrium.

- Gravity “froze out” in a phase transition to be a force distinct from the strong nuclear, weak nuclear and electromagnetic forces by the end of this era.

In the Beginning... the Grand Unified Force degenerated





The Era of Inflation (10^{-35} sec, 10^{27} K)

• The universe *inflates* by a factor of 10^{50} in ~ 100 seconds. It reaches a total size of 10^{23} m.

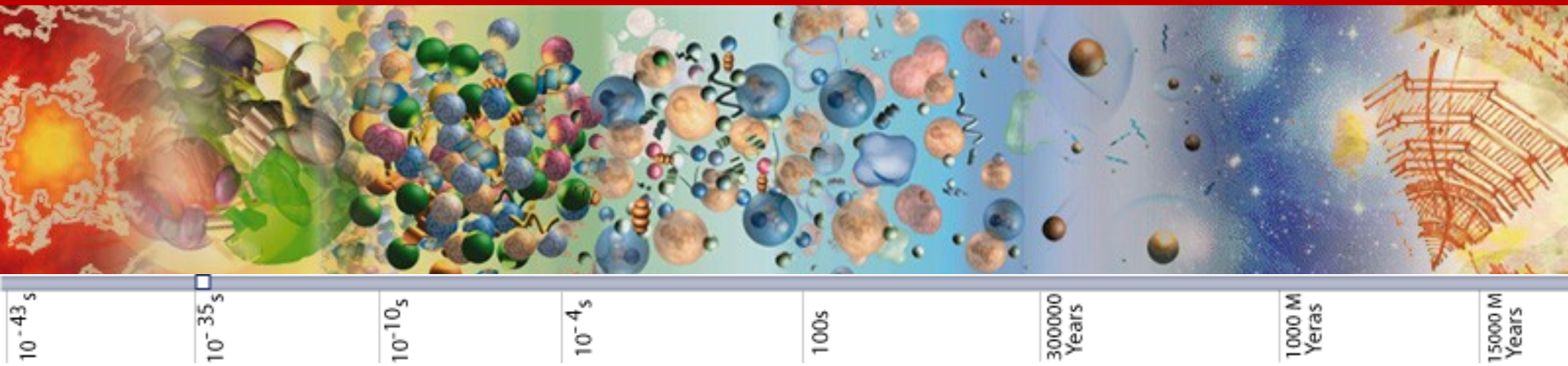
Degeneration of the Grand Unified Force (10^{-32} sec)

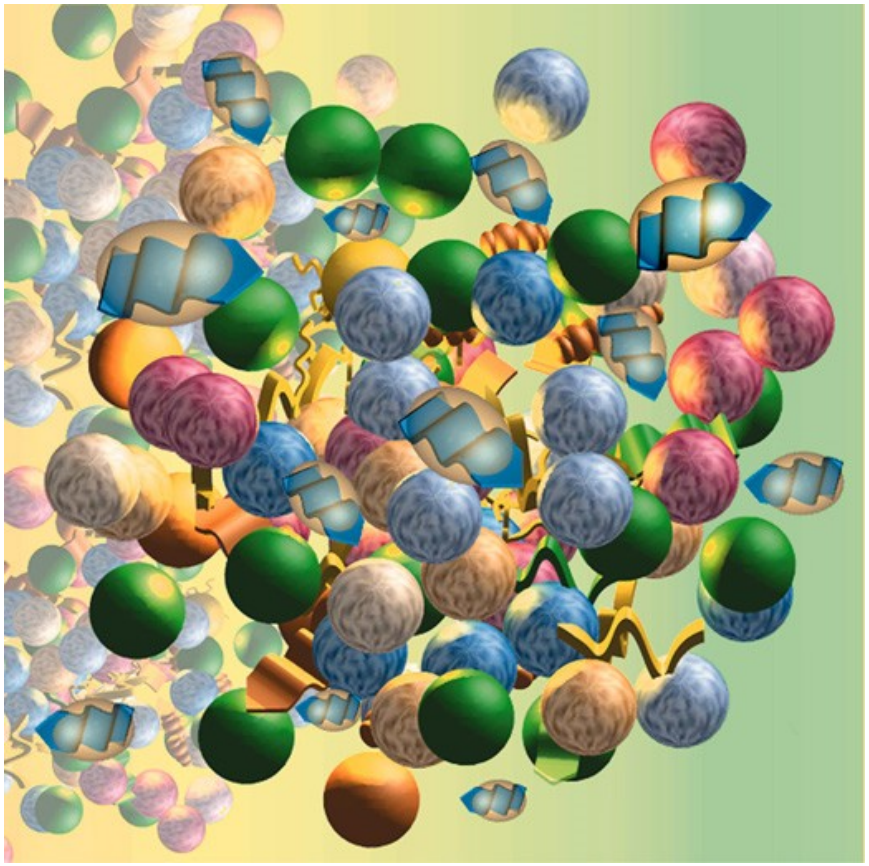
•The strong nuclear force "freezes out" as distinct from the electroweak force.

•A billion to one excess of matter over antimatter develops

(The LHC can reproduce this era!)

In the Beginning... the Electroweak Force degenerated





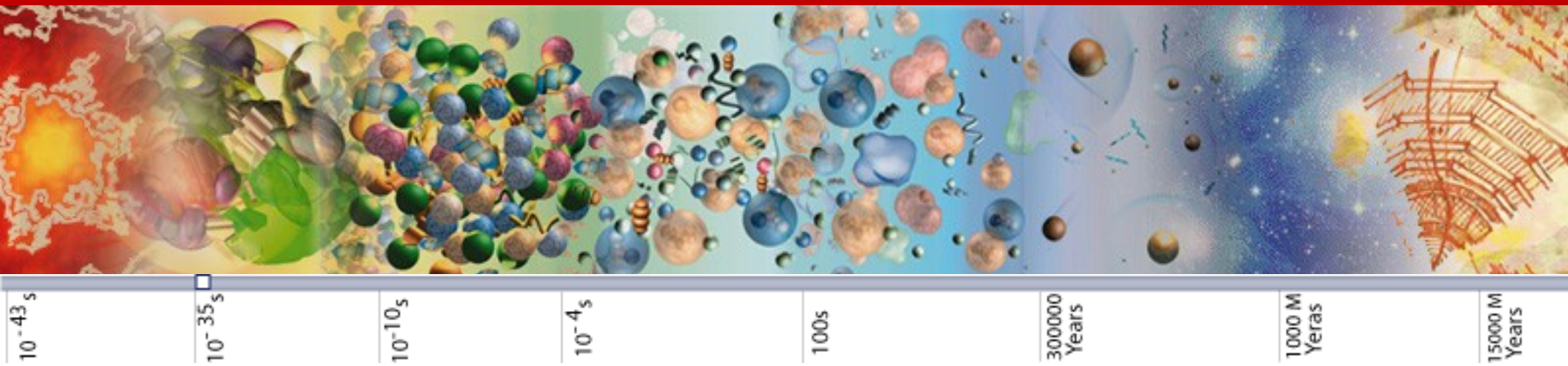
Electroweak Degeneration Era (10^{-10} sec, 10^{15} K)

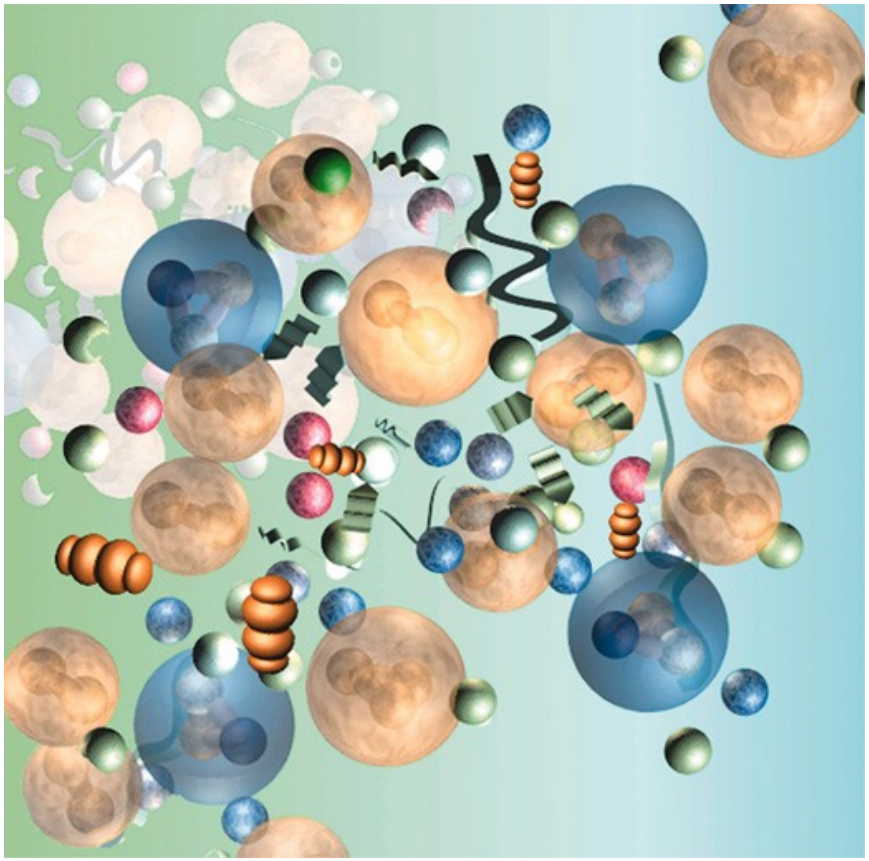
• The weak nuclear force separates from the electromagnetic force. The W & Z bosons put on weight while the photon remains massless.

•Quarks annihilates with anti-quarks, leaving a tiny excess of quarks.

(These conditions have been reproduced and studied in previous experiments like the LEP)

Protons and Neutrons formed





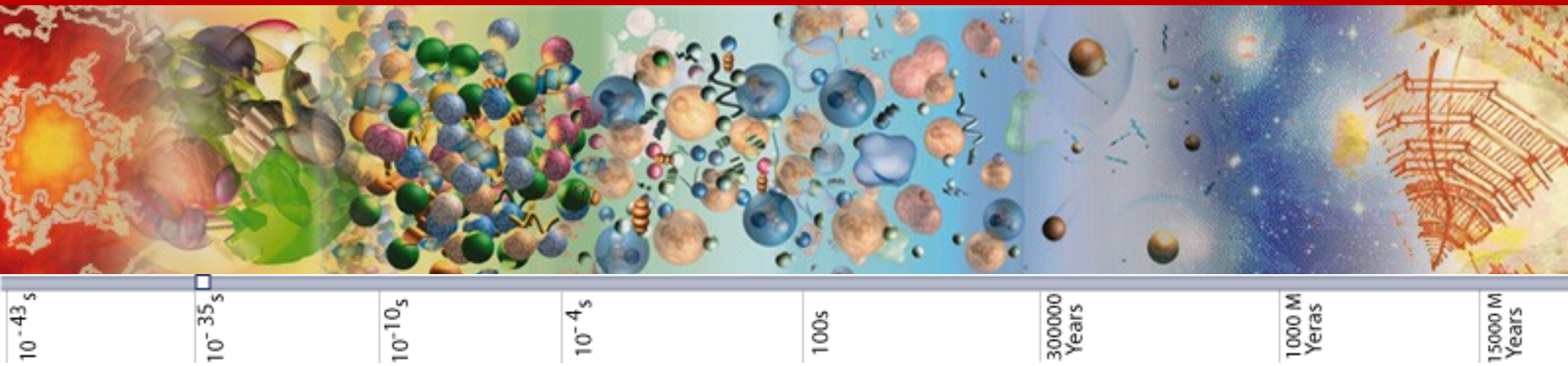
Protons and Neutrons form (10^{-4} sec, 10^{13} K)

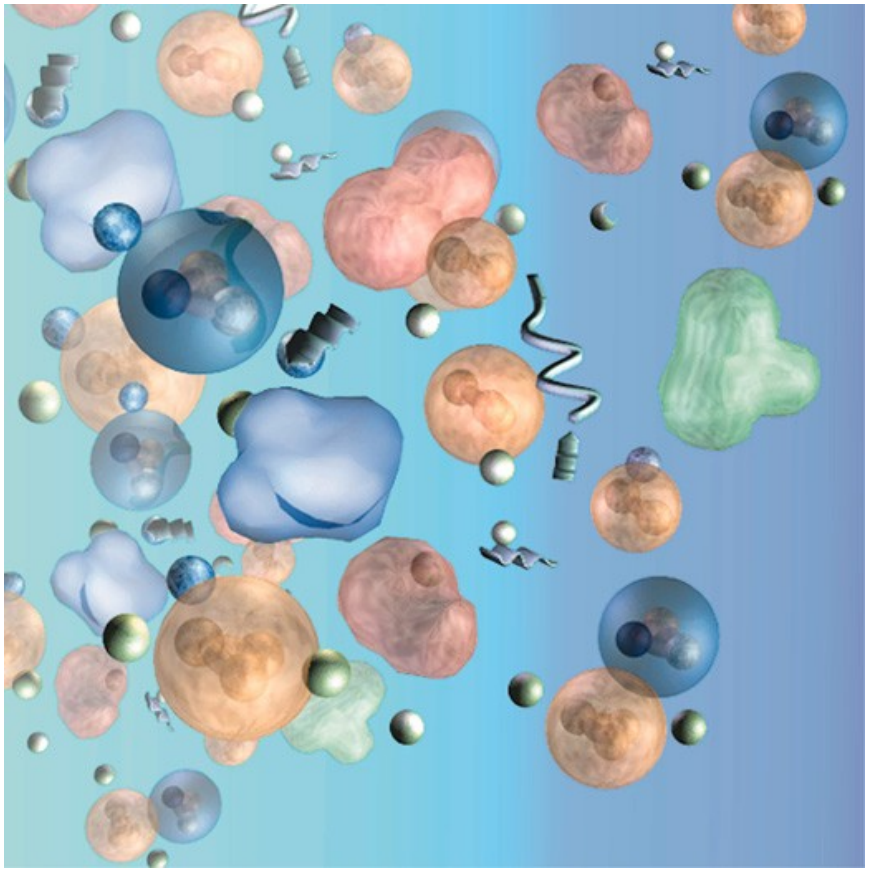
• Quarks remaining from the annihilation bind with each other under the influence of the strong nuclear force to form protons and neutrons

Neutrinos decouple (10^{-4} sec, 10^{10} K)

•Neutrinos shy away from further interactions
•Electrons and positrons annihilate till a slight excess is left
•Neutron:Proton ratio shifts from 50:50 to 25:75

Atomic Nuclei formed

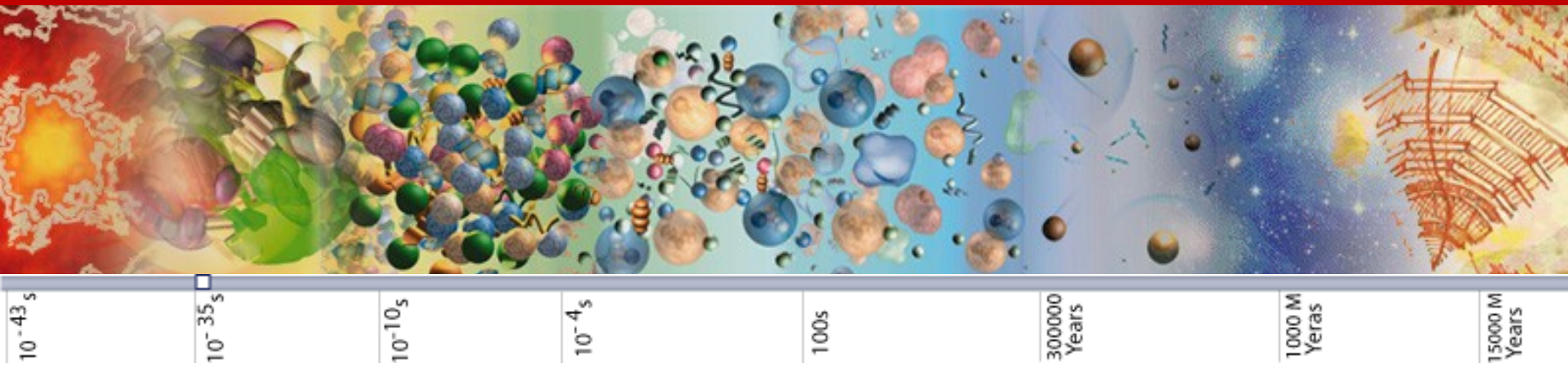


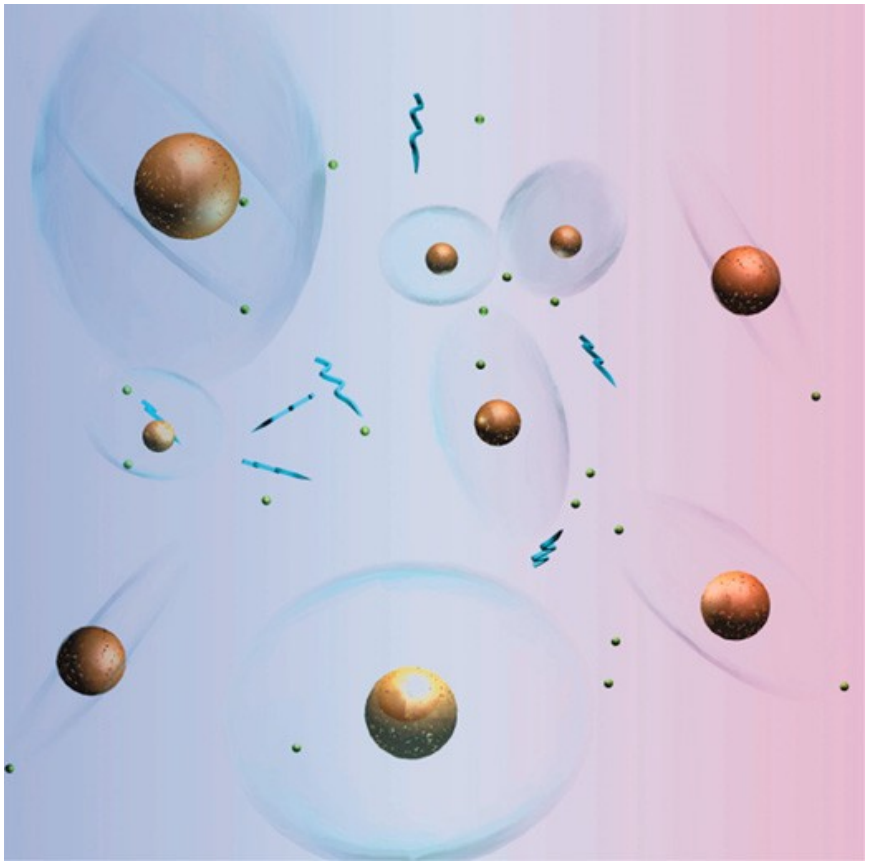


Helium Age (100 sec, 10^9 K)

- Helium nuclei can form now. Conditions similar to stars or hydrogen bombs.
- Atoms cannot form as yet.

Atoms formed and Light could travel freely



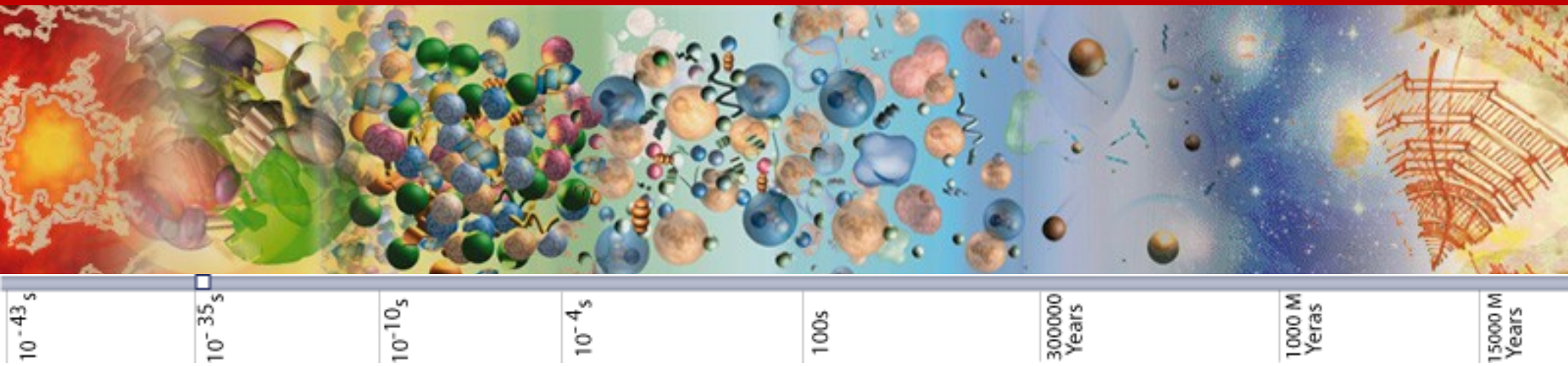


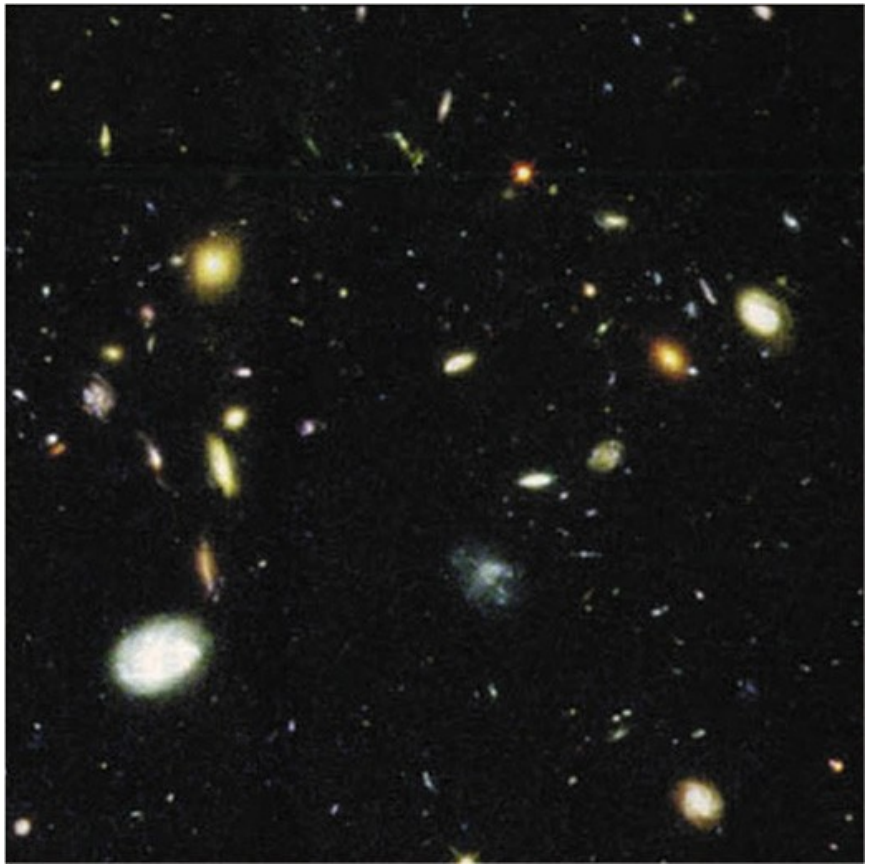
Atoms form (300,000 years, 6000 K)

- Light particles (photons) are not strong enough to break up atoms anymore. So, stable atoms of hydrogen and helium can form.

- The universe becomes transparent to radiation and finally there is light!

Stars and Galaxies formed



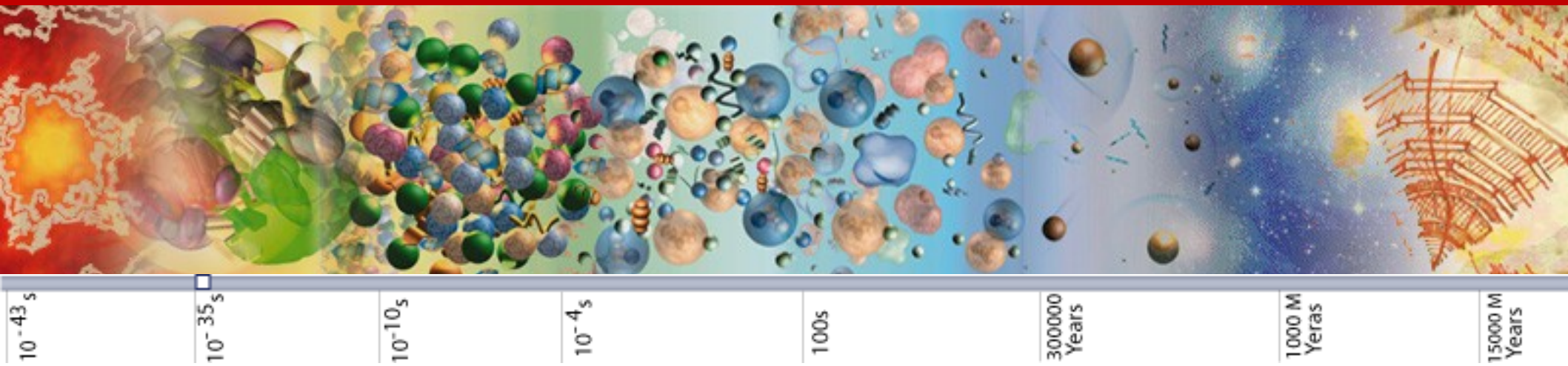


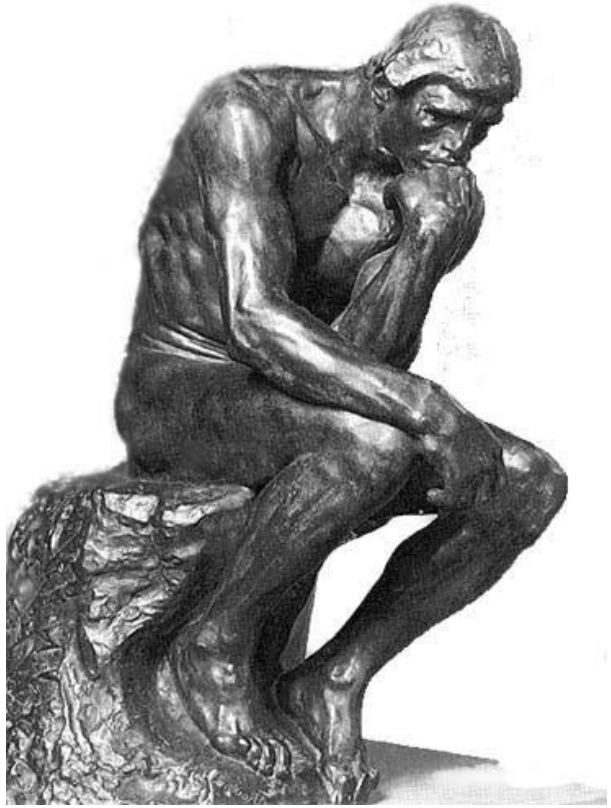
Stars and Galaxies form (1 billion years, 18 K)

- Stars begin to glow, turning lighter elements into heavier ones (of which planets and ourselves are going to be made of)

- Galaxies of stars begin to form

Life has arisen to soak in the Mystery





Today (13.7 billion years, 3 K)

- The dust of stars spewed out in supernovae explosions accumulate into planets

- Carbon atoms concatenate into complex molecules while the relentless energy from stars animate their ever-more-sophisticated dance of self-replication.

- And out of the stardust living creatures emerge to observe the universe and ponder its mystery