

# LHC: The Big Bang Machine

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# We are searching for the genetic code of the universe

- What is the universe, how did it begin, what's it made of and how will it evolve in the future?
- What are the fundamental building blocks and forces of the universe?
  - Cosmology and Particle Physics are the areas of science that address these questions now.
  - These questions are very old...



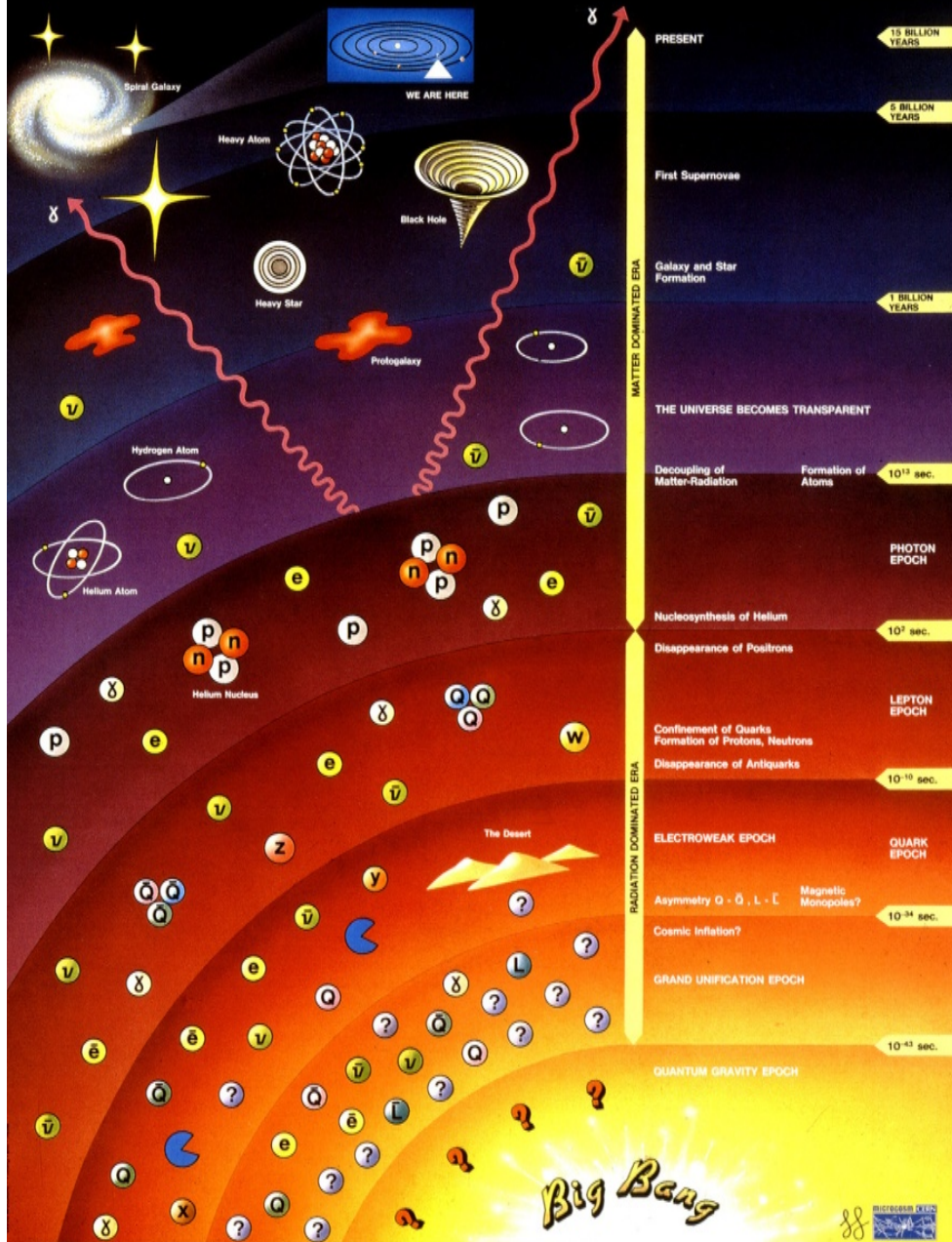
# The questioning mind

- In the history of science many scientists had trouble initially to understand the breakthroughs which occurred during their time.
- But great minds faced the facts and interpreted them correctly.

Example :

- Experiments showed that light traveled on nothing. This was unexpected turn of events.
- Einstein: there is no absolute reference frame for motion in the universe → the speed of light must be the same in all reference frames: *Relativity*

# History of the Universe

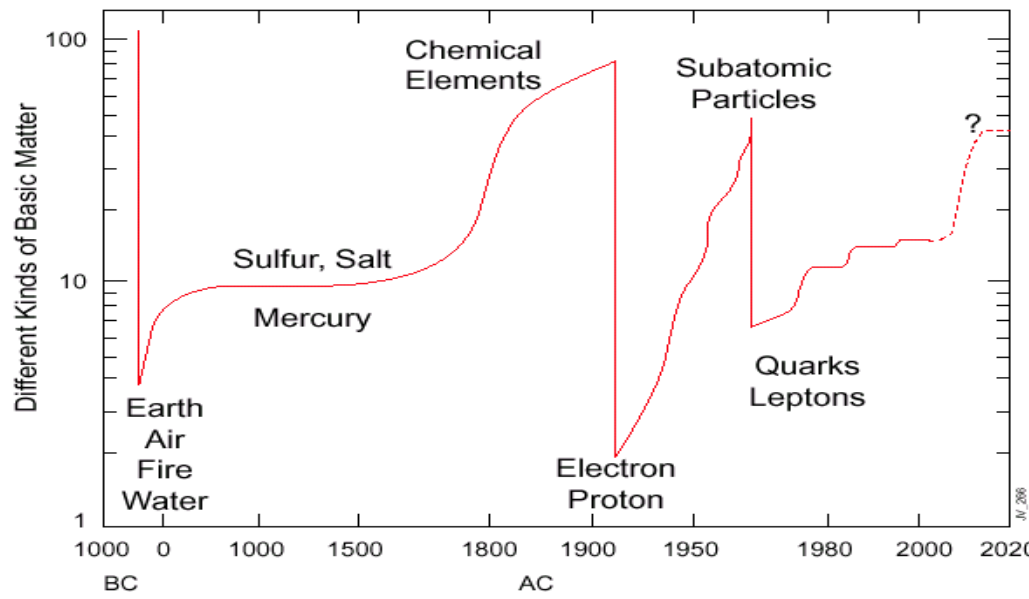


**How old is the universe?  
13.7 billion years!**

**What did the Big Bang  
produce during its first  
few minutes?  
All elementary particles**

**What is elementary?**

Curiosity about the constituents of nature is as old as human civilization (philosophers in India, Greece,..)



Los Alamos National Laboratory's Chemistry Division Presents a

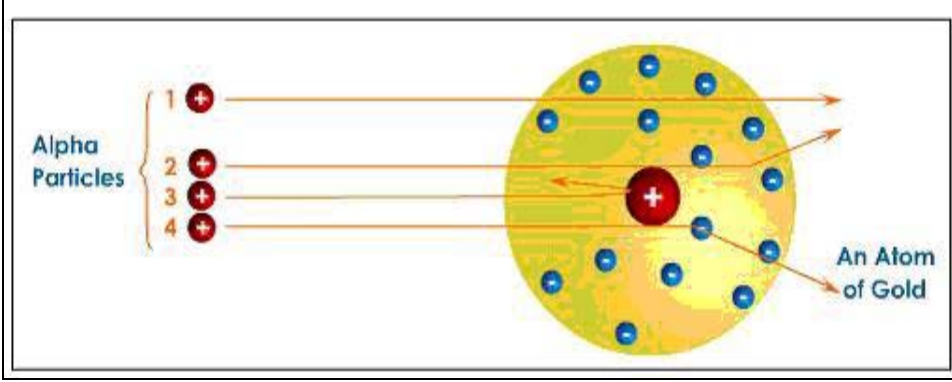
### Periodic Table of the Elements

Group\*\*

Period

1	2											13	14	15	16	17	18		
IA	IIA											IIIA	IVA	VA	VIA	VIIA	VIIIA		
1	2											3A	4A	5A	6A	7A	8A		
1	H 1.008	2	He 4.001																
2	3	4											5	6	7	8	9	10	
2	Li 6.941	Be 9.012											B 10.81	C 12.01	N 14.01	O 16.00	F 19.00	Ne 20.18	
3	11	12	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
3	Na 22.99	Mg 24.31	III B 3B	IV B 4B	V B 5B	VI B 6B	VII B 7B	VIII			IB 1B	II B 2B	Al 26.98	Si 28.09	P 30.97	S 32.07	Cl 35.45	Ar 39.95	
4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
4	K 39.10	Ca 40.08	Sc 44.96	Ti 47.88	V 50.94	Cr 52.00	Mn 54.94	Fe 55.85	Co 58.47	Ni 58.69	Cu 63.55	Zn 65.39	Ga 69.72	Ge 72.59	As 74.92	Se 78.96	Br 79.90	Kr 83.80	
5	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	
5	Rb 85.47	Sr 87.62	Y 88.91	Zr 91.22	Nb 92.91	Mo 95.94	Tc (98)	Ru 101.1	Rh 102.9	Pd 106.4	Ag 107.9	Cd 112.4	In 114.8	Sn 118.7	Sb 121.8	Te 127.6	I 126.9	Xe 131.3	
6	55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	
6	Cs 132.9	Ba 137.3	La* 138.9	Hf 178.5	Ta 180.9	W 183.9	Re 186.2	Os 190.2	Ir 190.2	Pt 195.1	Au 197.0	Hg 200.5	Tl 204.4	Pb 207.2	Bi 209.0	Po (210)	At (210)	Rn (222)	
7	87	88	89	104	105	106	107	108	109	110	111	112	114	116	118				
7	Fr (223)	Ra (226)	Ac~ (227)	Rf (257)	Db (260)	Sg (263)	Bh (262)	Hs (265)	Mt (266)	--- 0	--- 0	--- 0	--- 0	--- 0	--- 0				
Lanthanide Series*			58	59	60	61	62	63	64	65	66	67	68	69	70	71			
Lanthanide Series*			Ce 140.1	Pr 140.9	Nd 144.2	Pm (147)	Sm 150.4	Eu 152.0	Gd 157.3	Tb 158.9	Dy 162.5	Ho 164.9	Er 167.3	Tm 168.9	Yb 173.0	Lu 175.0			
Actinide Series~			90	91	92	93	94	95	96	97	98	99	100	101	102	103			
Actinide Series~			Th 232.0	Pa (231)	U (238)	Np (237)	Pu (242)	Am (243)	Cm (247)	Bk (248)	Cf (251)	Es (252)	Fm (257)	Md (258)	No (259)	Lr (262)			

Mandeleev: 19<sup>th</sup> century



Early 20<sup>th</sup> century: Bohr, Rutherford  
2 basic elements: electron, nucleus

10 thousand km



We belong to Milkyway galaxy



A galaxy: 100 million million ( $10^8$ ) larger than the earth!

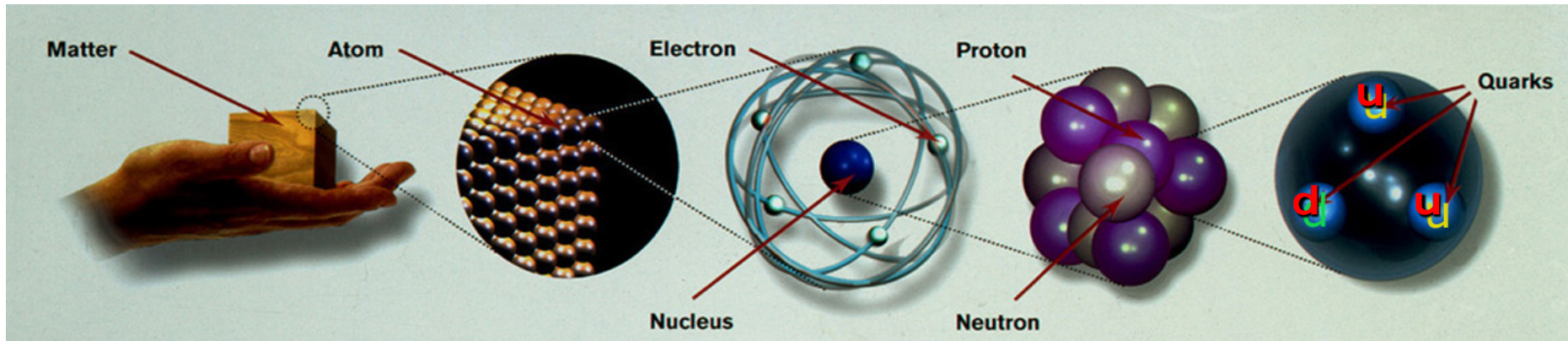
Contains a million million of stars!



Our universe contains hundred thousand million ( $10^{11}$ ) galaxies  
→  $10^{22}$  stars : all made up of same elements of matter!



# What are the smallest building blocks of matter?



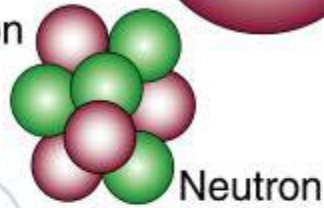
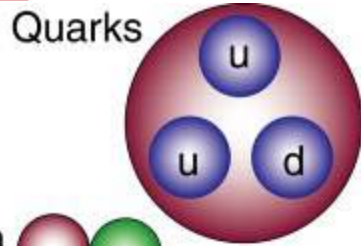
In the Universe there are about  $10^{80}$  quarks formed in the earliest moments of life of the Universe.



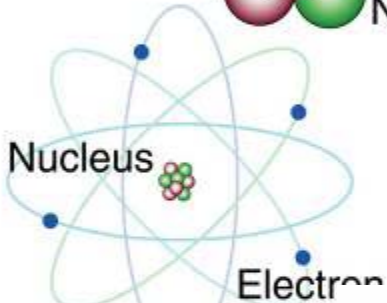
Are there more inside?

# Modern idea of Nature's ingredients

Matter



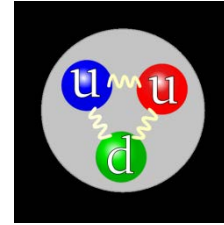
To remove a proton from a nucleus need 10 Million ( $10^6$  eV)



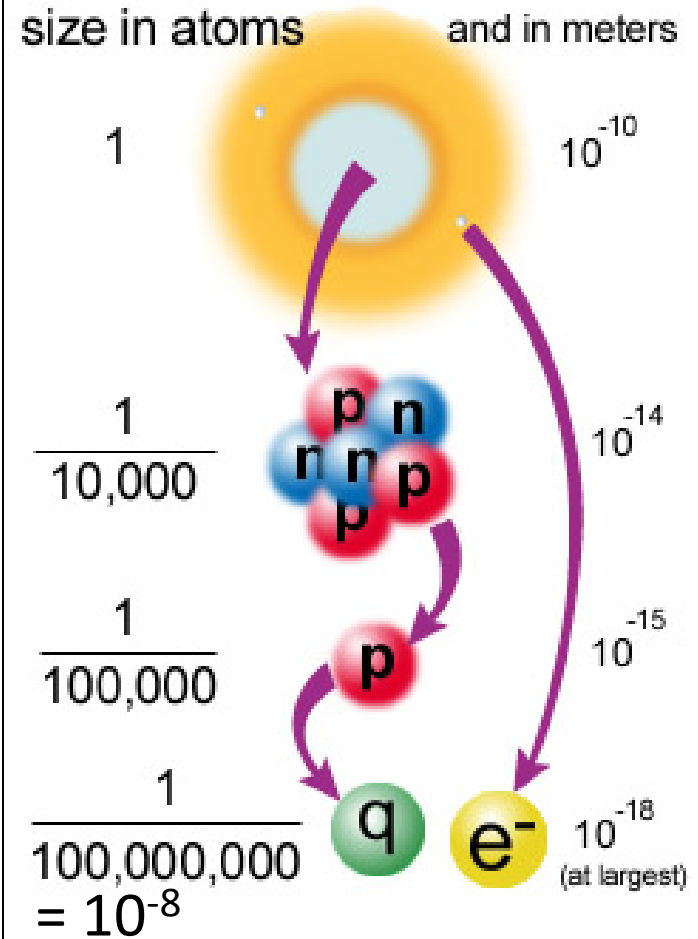
1.5Volts

An electron will gain an energy of 1.5 electron Volt (eV)

To remove an electron from an atom need 10 eV



Protons and neutrons are up made of quarks and are held together by gluons.



92 Elements

⇒ Atoms

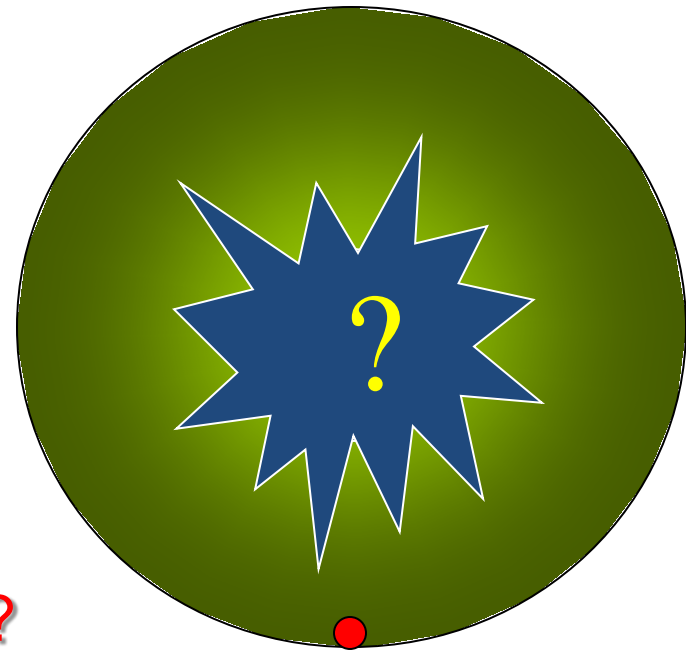
⇒ Nuclei (and Electrons)

⇒ protons & neutrons

⇒ quarks

⇒ ?

What lies within...?



**Tool**



The probe wavelength/energy should be smaller than the distance scale to be probed.

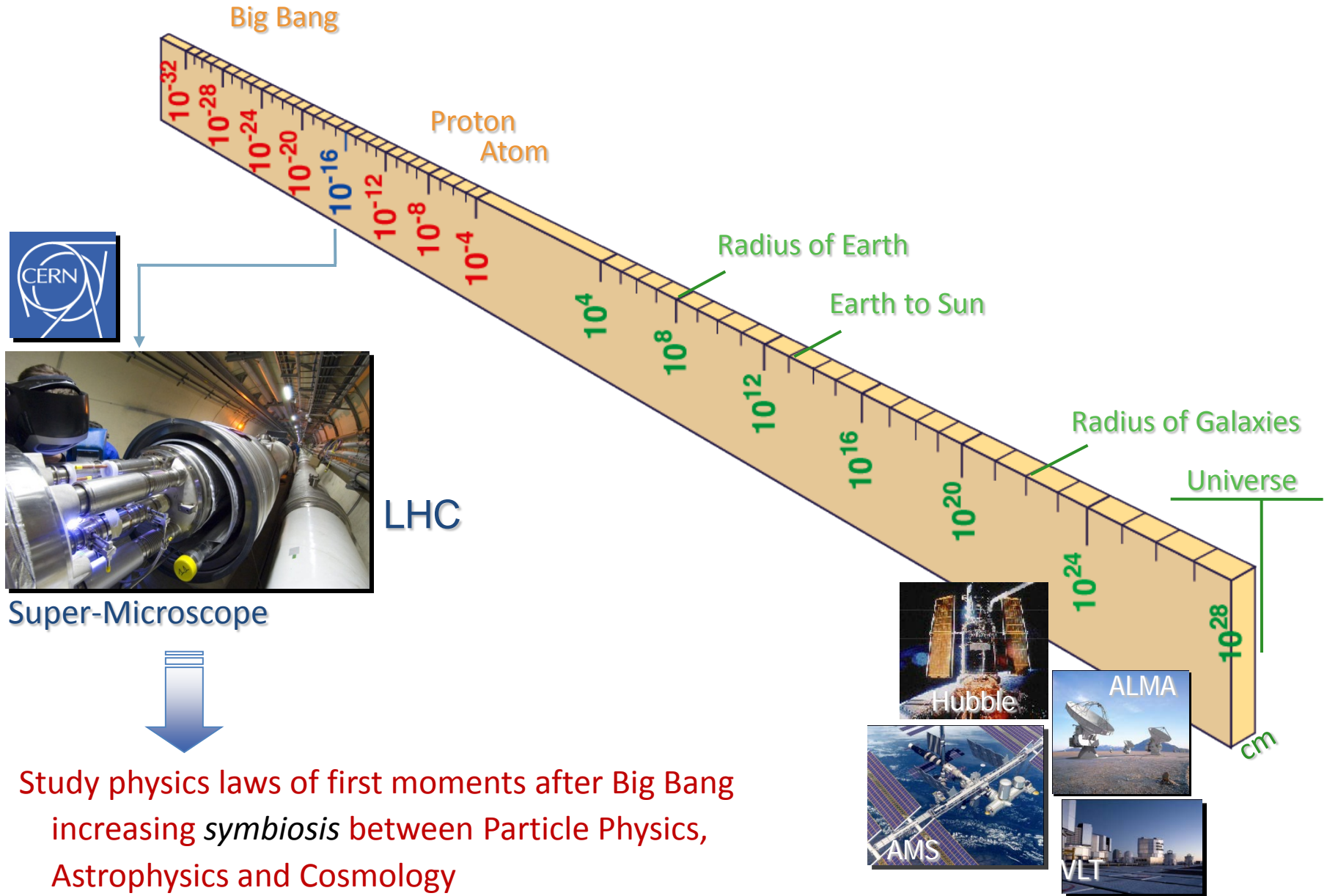
For 1 millimeter we need 1/10000 eV  
1 nanometer ( $10^{-9}$ ) → 1/100 eV

(1 TeV =  $10^{12}$  electronVolt  
=  $1.6 * 10^{-7}$  Joule)

100 Watt bulb for 1 hour  
→ 1 Mega ( $10^6$ ) Joule

$10^{-20}$  m  $\approx 10^{+13}$  eV  
= 10 TeV

# Dimensions in Physics



## Energy/mass scales

- Our unit for energy is the electron-volt eV
  - Motion of air atom, room temp  
0.04 eV
  - Chemical reactions/atom, visible photons of light:  
1 to a few eV
  - Nuclear reactions, per atom  
Millions of eV (MeV) (M -> Mega)
  - Rest energy  $mc^2$  of proton  
~1 Billion eV (1 GeV) (G ->Giga)
  - Each proton in each LHC beam  
4 Trillion eV (4 TeV) (T->Terra)

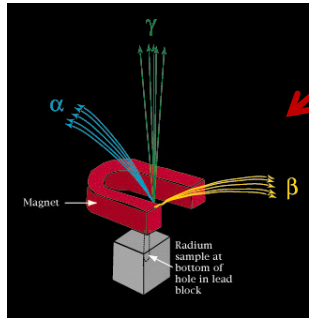
# Fundamental Forces



**Electro-magnetic**

atoms  
molecules  
optics  
electronics  
telecom.

**inverse square law**



**Weak**

beta decay  
  
solar fusion

**short range**

**Strong**

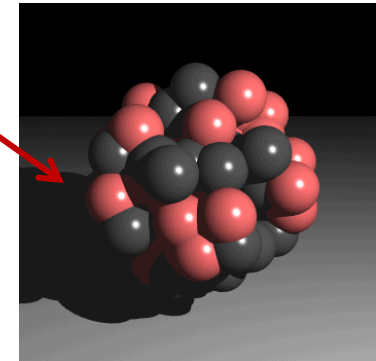
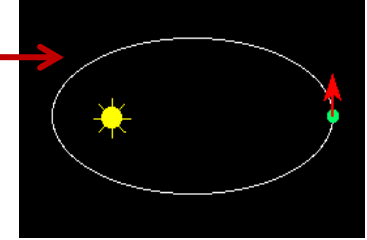
nuclei  
  
particles

**short range**

**Gravity**

falling objects  
planet orbits  
stars  
galaxies

**inverse square law**



Relative strength of gravitation, weak, electromagnetic, strong:  
 $\sim 10^{-40} : 10^{-5} : 10^{-2} : 1$

**BUT MATTER IN THE UNIVERSE IS NEUTRAL**, because positive and negative charges cancel each other precisely.

**THEREFORE:**  
**Gravitation is the dominant force in the Universe**

# Crowning achievement of 20<sup>th</sup> century science

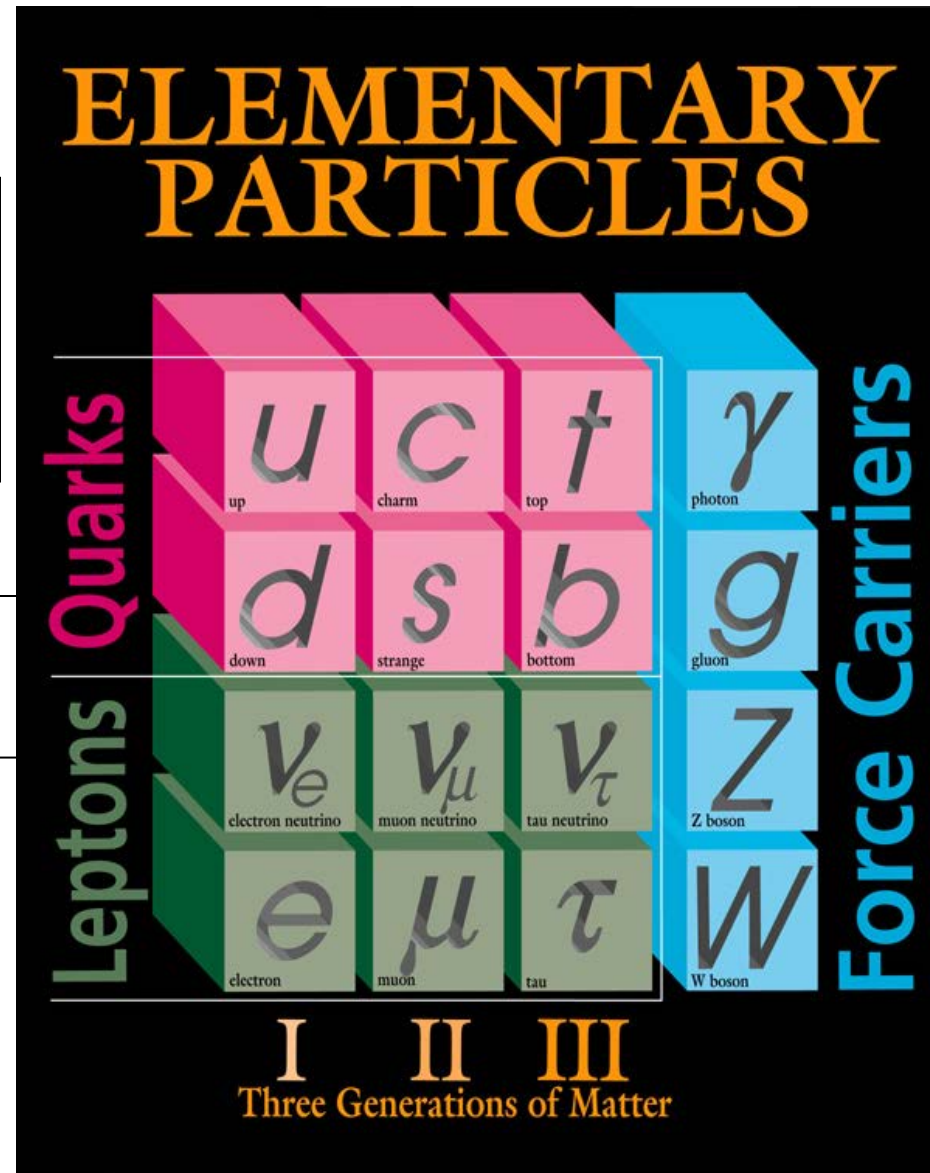
Matter particles interact with forces  
Via their carriers.

The messengers of the forces:

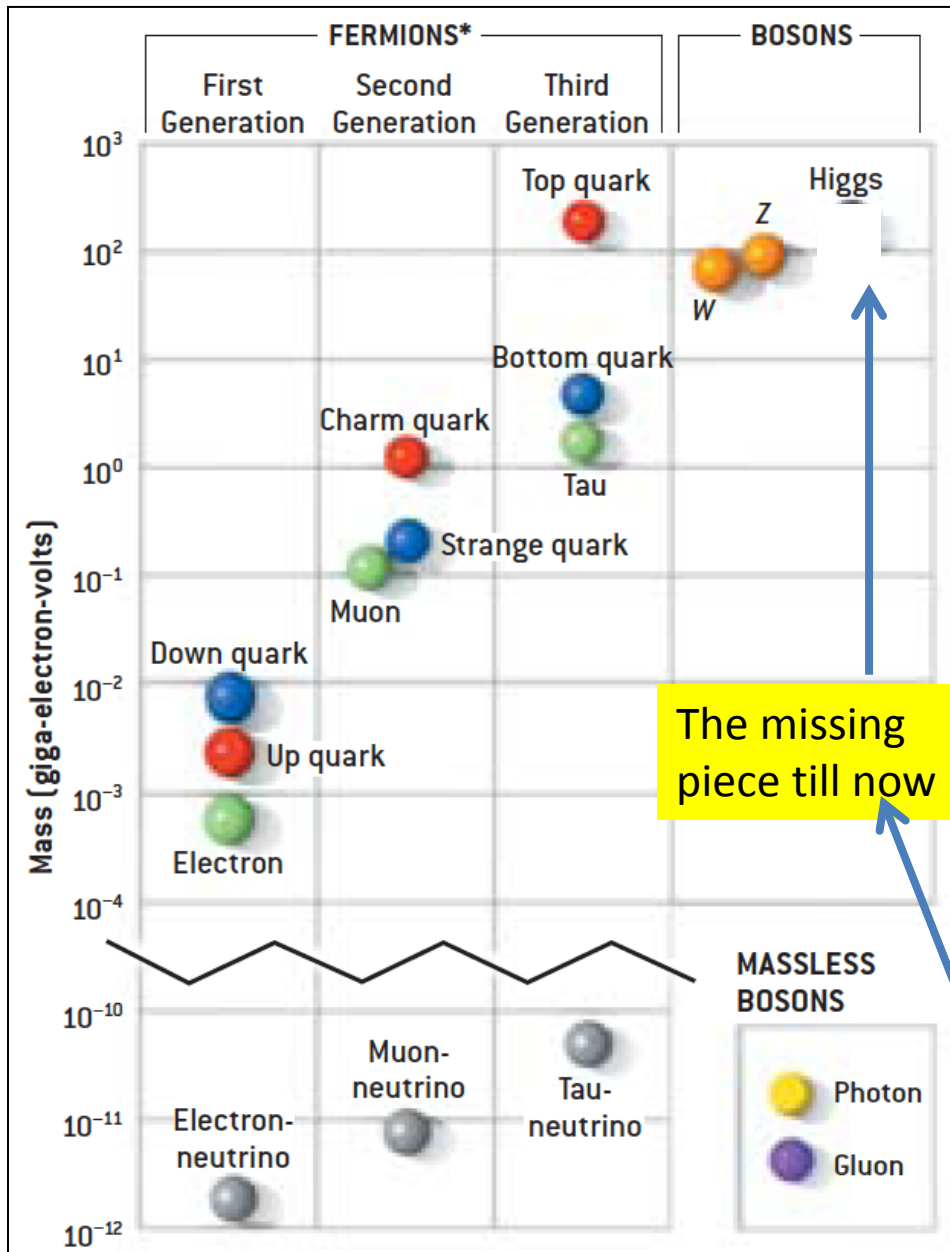
- 1)  $\gamma$  for electromagnetic interaction
- 2)  $W^\pm, Z$  for weak ..
- 3) 8 gluons for strong ..

31 Nobel prizes to get the simple and elegant picture of the Nature.

Experiments measure the masses of all the elementary particles.



# But there is a massive problem



Newton:  $F = ma$

Einstein:  $E = mc^2$

- Electron is 350,000 times lighter than the heaviest quark
- Photon is massless.
- Neutrinos are very light.
- In the theory we could not deal with massive particles!
- Several scientists, worked the way out : there has to be another new particle: **Higgs boson!**



# **We discovered the Higgs boson in the LHC!**

LHC is a facility to study the conditions which existed few moments after the Big Bang: less than one billionth of a second after the Big Bang → ***Time Machine!***

This also helps us to understand how that Universe has evolved into today's.

What characterizes that situation? **Very high energy!**

It is a machine which accelerates protons and collides them to achieve very high energy.

Hence the name Large Hadron Collider (LHC).

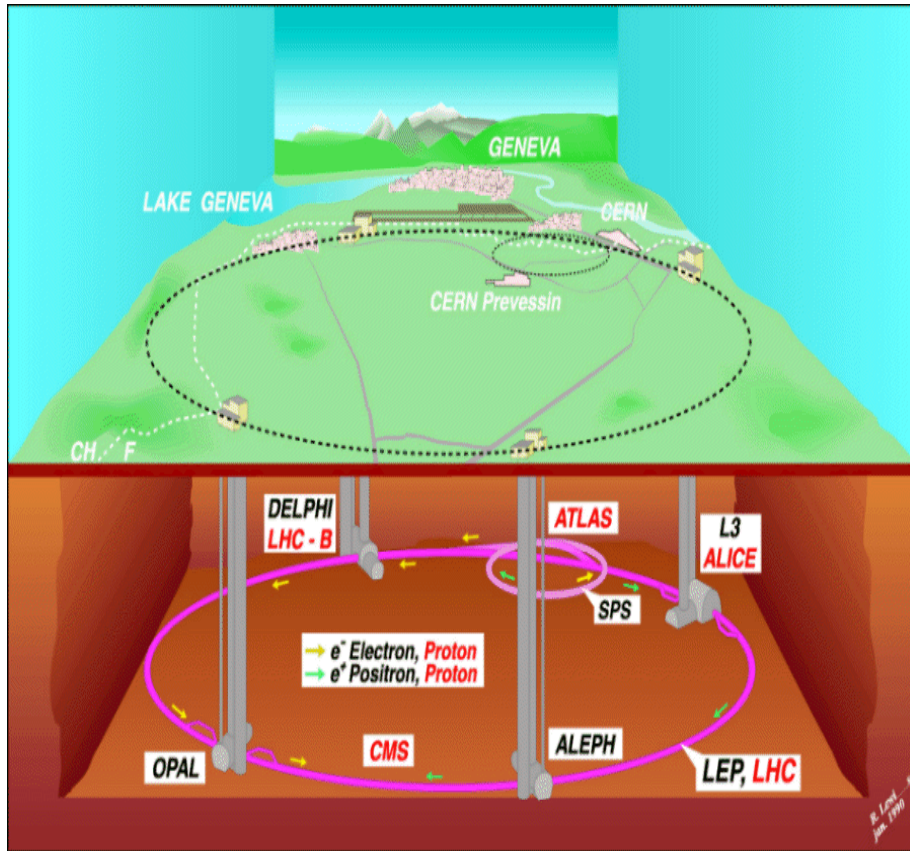
It allows us to recreate fundamental particles and their behaviour rarely seen since  $10^{-12}$  sec. after the Big Bang.

# Where is LHC?



**27 km circumference  
~ 100 m underground.**

**Near Geneva.**

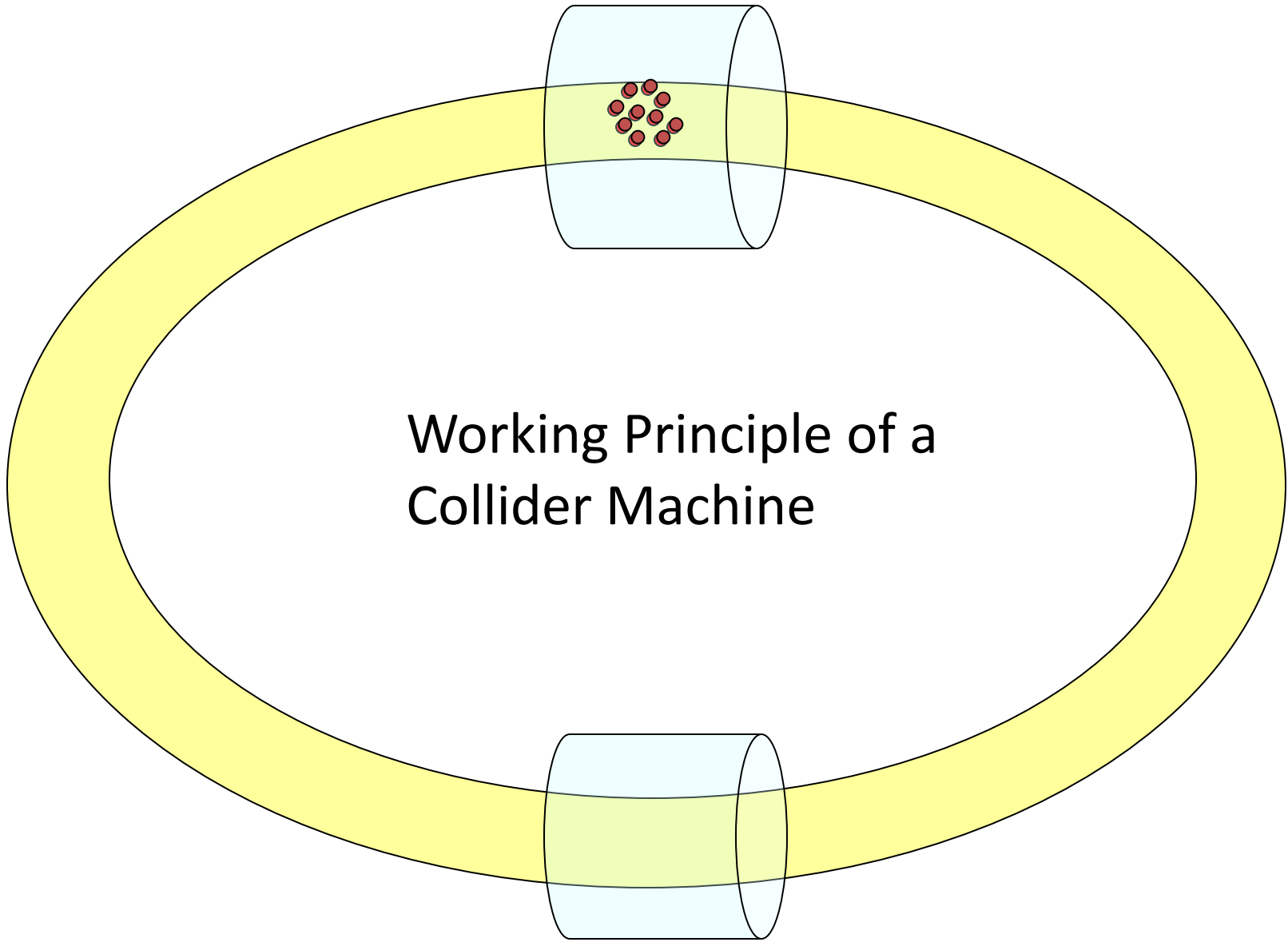


The 'Large Hadron Collider' accelerates  $\sim 10^{13}$  protons ( $\sim 0.5$  ng, small grain of dust) to 99.999999999 % of the speed of light.

What does the energy of the proton beams correspond to?

- A herd of 1000 elephants at 30 m/s
- About 3 microgram of matter





Working Principle of a  
Collider Machine



**What would happen to this theoretical physicist if he circulated in the LHC machine with 99.9999999% of the speed of light?**

**His hair would contract to 0.05 mm length**

**We would observe his life span to be ~ 500,000 yrs**

**He would have the same energy as 500 tons of matter**

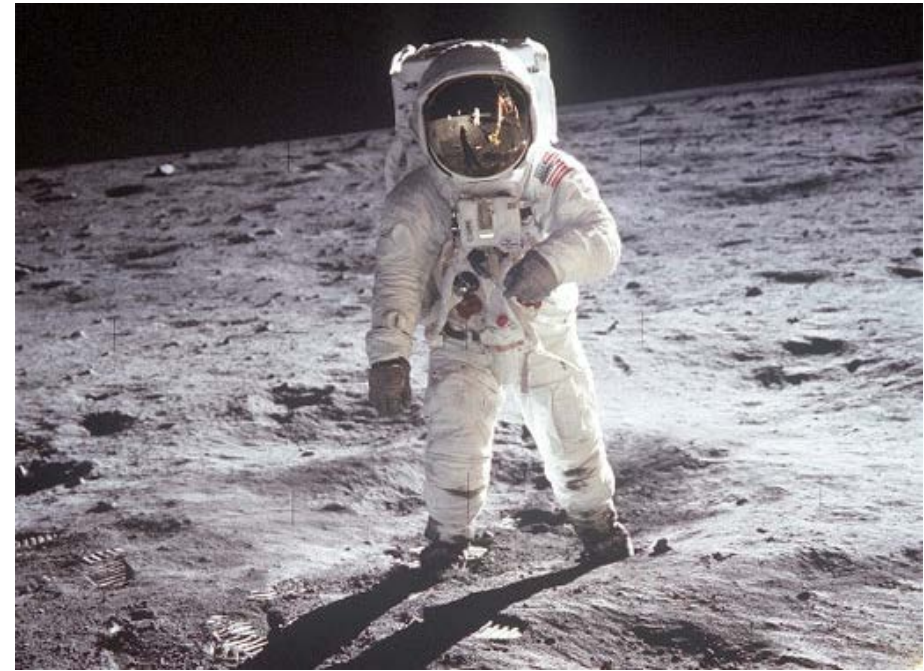
# Like Swiss chocolate

- LHC magnets have a huge store of energy
  - Enough to melt 12 tons of Copper!
  - The kinetic energy of an A380 at 700 km per hour



- 90 kg of TNT
- 15 kg of chocolate
- How much energy is stored in the LHC beams?

Inside LHC: It is emptier than space



- Air pressure (inside two 27 km-long vacuum pipes)
  - lower than on the moon!
- Magnets cooled by 100 tons of liquid helium
  - Colder than outer space.

# LHC: The Giant Marvel of Technology

- 50-175 m under the surface
- 27 km at 1.9 K (superfluid He)
- Vacuum  $\sim 10^{-13}$  Atm.
- Superconducting coils: 12000 tonnes/7600
- Temperature generated at LHC due to proton-proton collision  $\sim 10^{16}$  °C, compare with sun: 5506 °C, a matchstick: 250 °C

LHC machine to be maintained at -271 °C vs. Home freezer: -8 °C  
Boomerang nebula: -272 °C, antarctica: -89.2 °C,

Largest ever human endeavour, requires huge resources to be put in.  
To be passed on to younger generations of today and tomorrow: YOU!



# Journey of > 20 years

- October 1990: Scientists first started thinking about LHC .
- First collisions of protons in 2009.



**CMS Collaboration: ~ 4000 people  
(100 from India)**

Fraction of people who made CMS possible



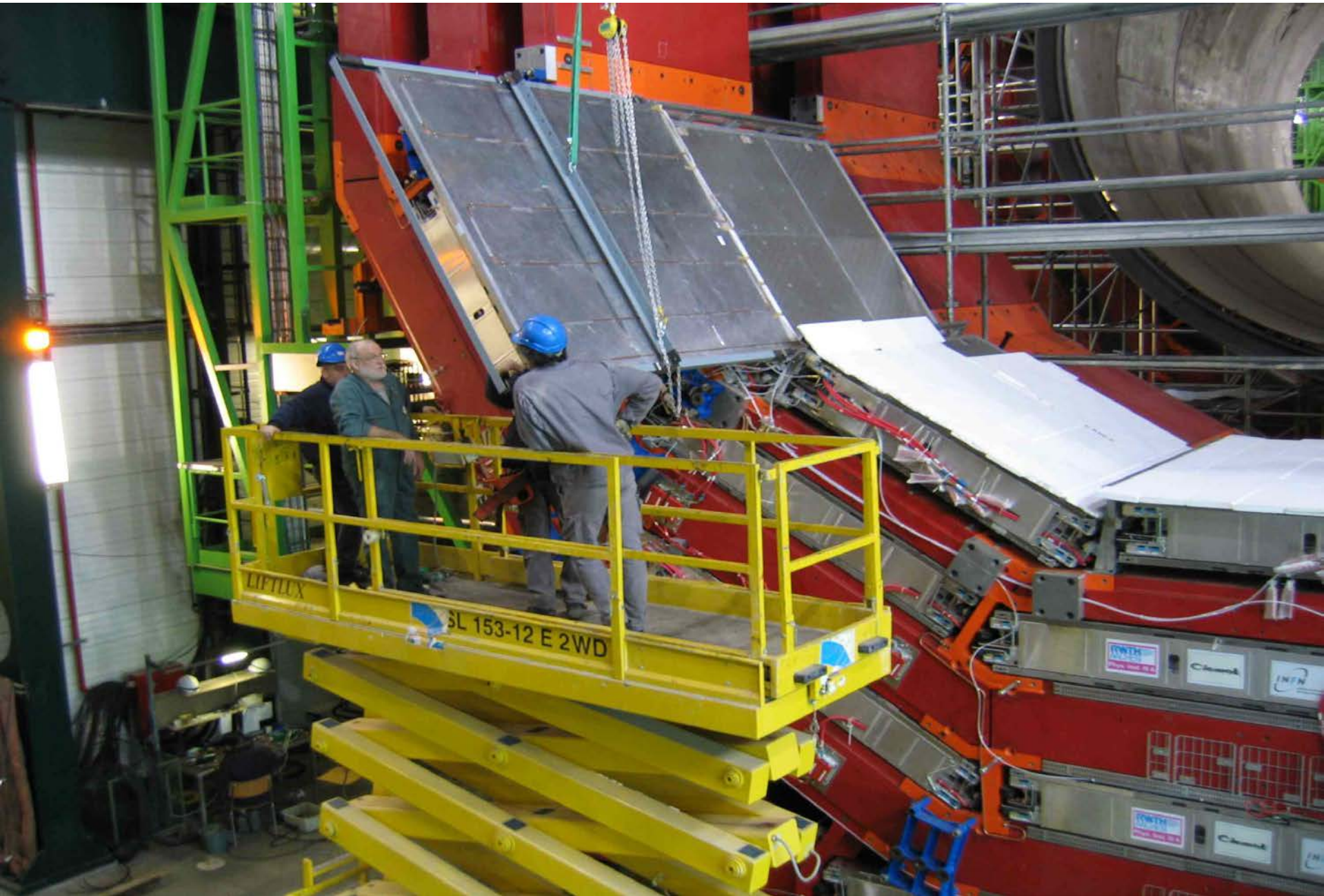
CMS surface  
Hall: 2008



Roman coins  
of 4<sup>th</sup> century  
AD at CMS site

**20 more years to operate**

# Installation of detector components built in India (2006)



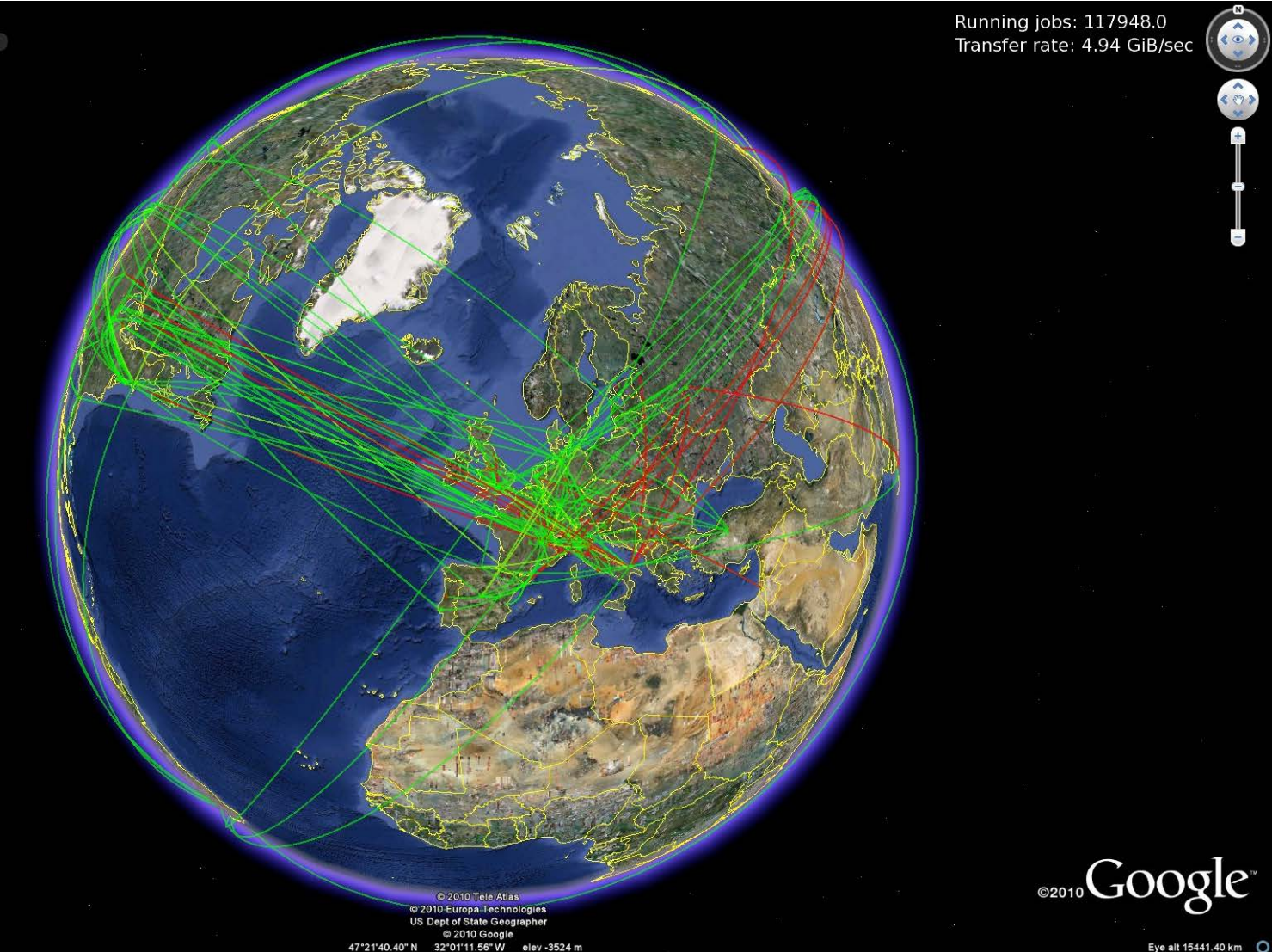
# Components of CMS Detector

- **Silicon Tracker ~250 sq. m- 25m-long swimming pool**
- **80,000 crystals: 98% metal by mass, but completely transparent.**
- **The brass used in one part of the detector came from recuperated artillery shells from Russian warships**
- **CMS Magnet, the largest solenoid on earth, strength 100,000 times stronger.**
- **Amount of iron used as the magnet return yoke ~ Eiffel Tower**
- **Data volume per second ~ 10,000 Encyclopedia Britannica..**
- **20 years to build 20 more years to run.**

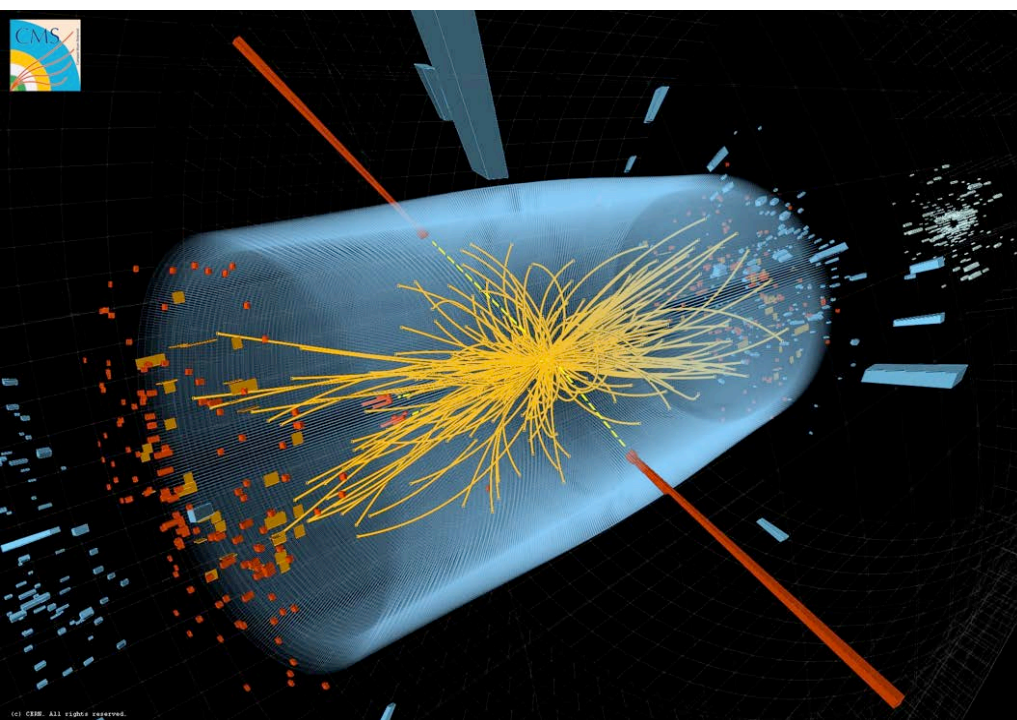
# Quite a camera!

- Experiments are like detectives.
- When the protons collide inside the accelerator, many things happen which we can guess by looking at hints afterwards.
- Different possibilities give different hints, some even similar.
- So we wait for a long time to ensure that our analysis of the hints are correct.
  
- These hints are recorded in mammoth “detectors”, like CMS, ATLAS etc.
- Each of them have about 80 Million pixels, taking upto 40 Million pictures every sec.
  
- We are interested only in the good and interesting pictures, so throw most of them
  
- Still we have lot of pictures to look at details  
➔ lot of data which can fill up 4 DVDs / sec.

Data is distributed across the globe, including 2 centres in India, Using high speed network connections.







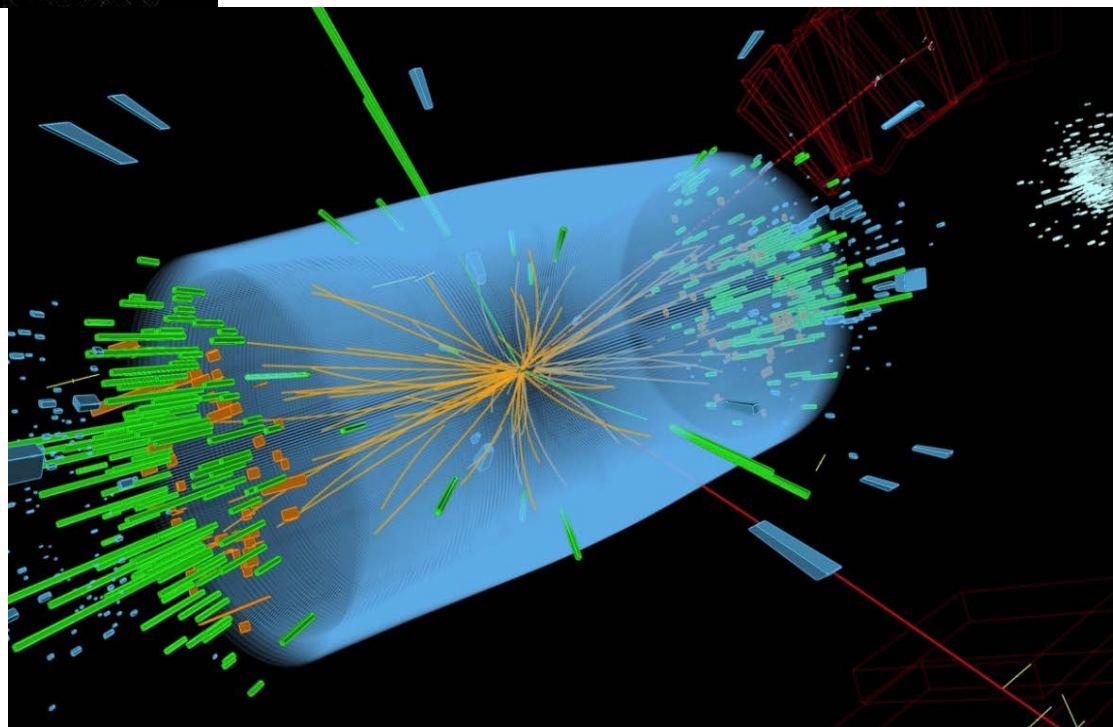
In the experiments many information are compiled to “reconstruct an event”

The inference of the analyses of the information is thoroughly scrutinized at every stage → Has to be convincing to the Whole world .

**by many people**

**→ lot of efforts for many years**

**→ Anticipation of the success provides the sustenance**



# The discovery of the Higgs boson brought unprecedented attention

> **1 billion**

people saw TV footage

**1,034**

TV stations

**5,016**

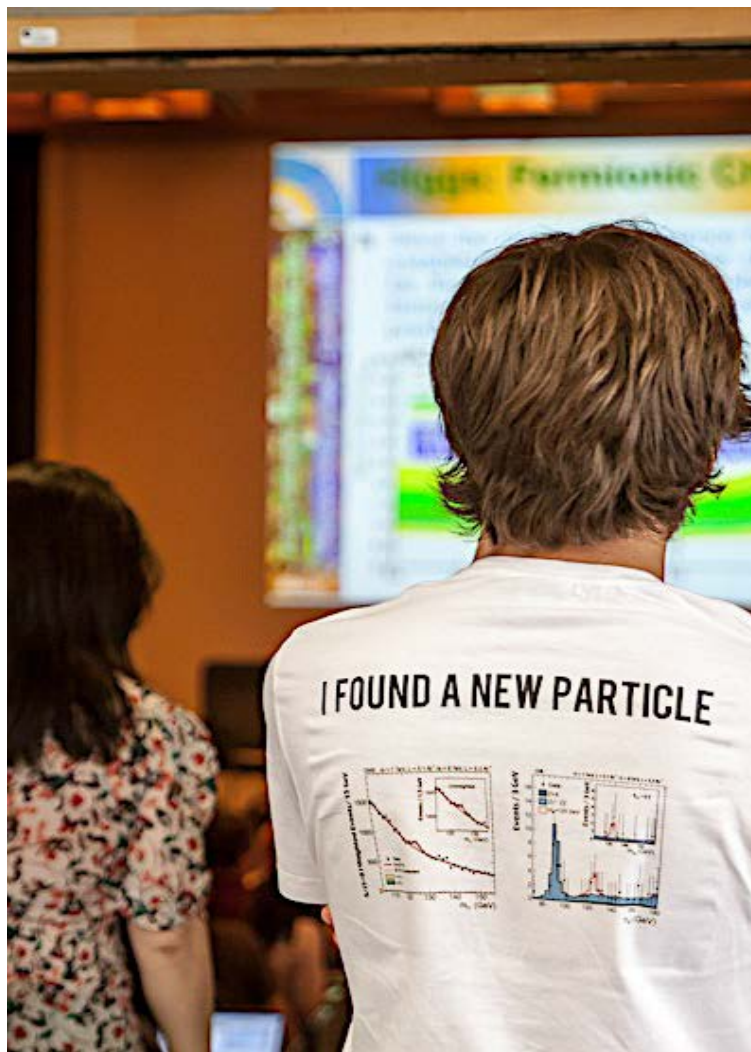
Broadcasts

**17,000**

news articles in

**108**

Countries





# LHC will also answer many more questions

## Black hole

- **How is a black hole formed?**  
In the collapse of a massive star.
- **What happens to the scientist when he falls into a Black hole?**  
He becomes flat as a dosa!  
Gravity rips him apart!  
Actually he never arrives there!

## Dark Matter

- **Does it exist?**

Yes, by looking through big Telescopes we learnt about it.

- **What is it?**

**We do not know as yet!**



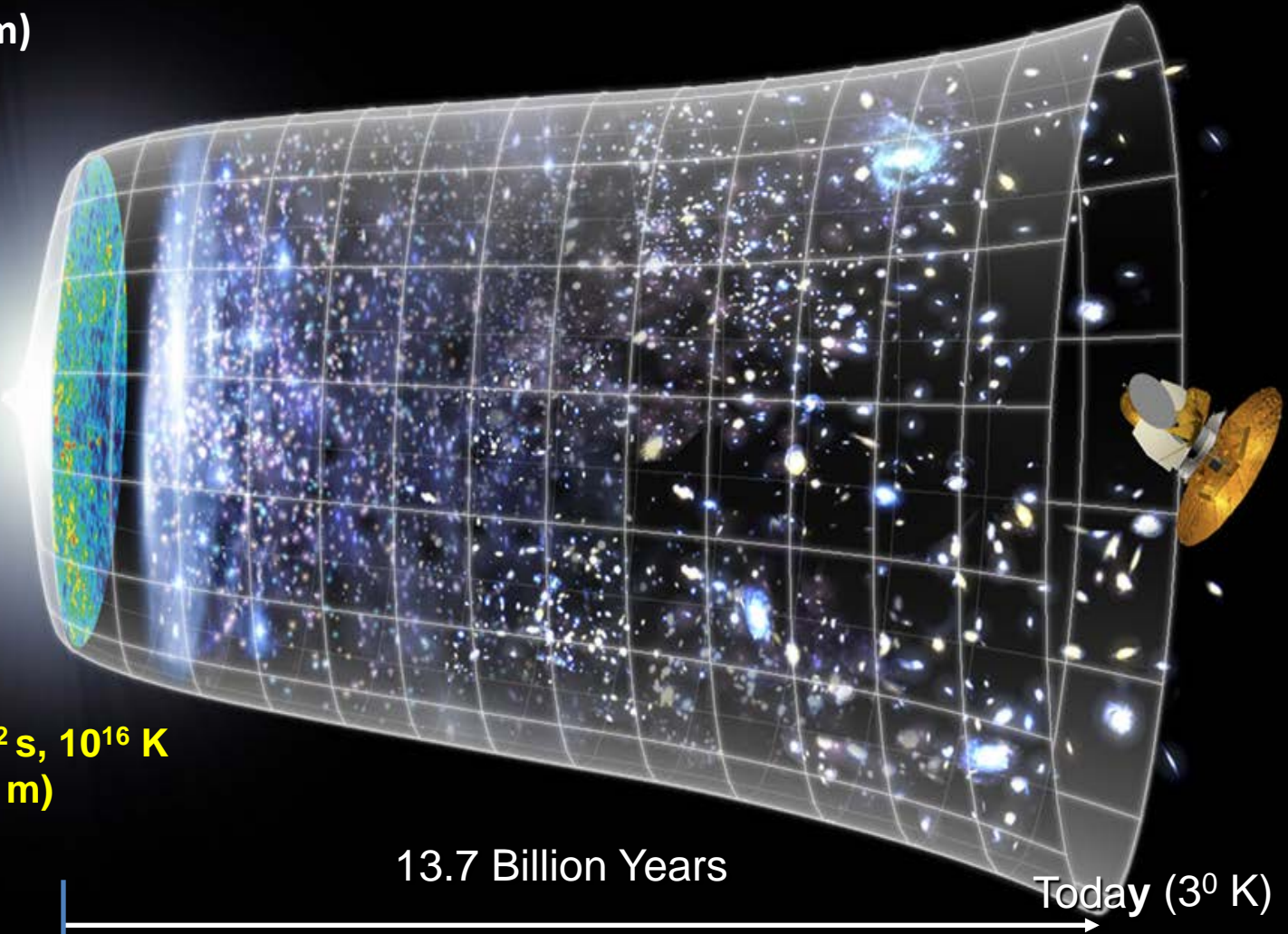
# Cartoon of our Universe

$$\text{Energy} = kT$$

$$\text{Length scale} = hc/E$$

1. Quantum gravity era:  $t \approx 10^{-43} \text{ s}$ ,  $10^{32} \text{ K}$   
( $10^{19} \text{ GeV}$ ,  $10^{-34} \text{ m}$ )

Big Bang



2. LHC  $\rightarrow 10^{-12} \text{ s}$ ,  $10^{16} \text{ K}$   
( $10^4 \text{ GeV}$ ,  $10^{-20} \text{ m}$ )

13.7 Billion Years

Today ( $3^0 \text{ K}$ )

$10^{28} \text{ cm}$

3. Protons and neutrons formed:  
 $t \approx 10^{-4} \text{ s}$ ,  $10^{13} \text{ K}$  ( $1 \text{ GeV}$ ,  $10^{-16} \text{ m}$ )

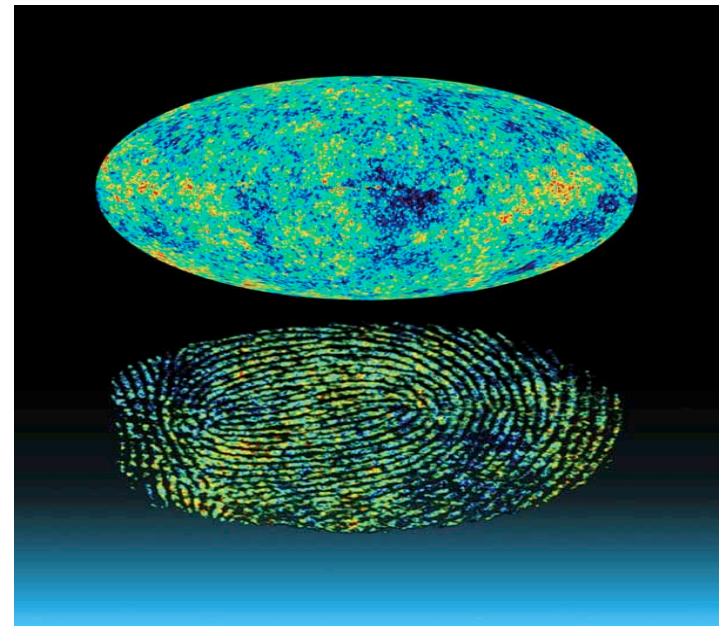
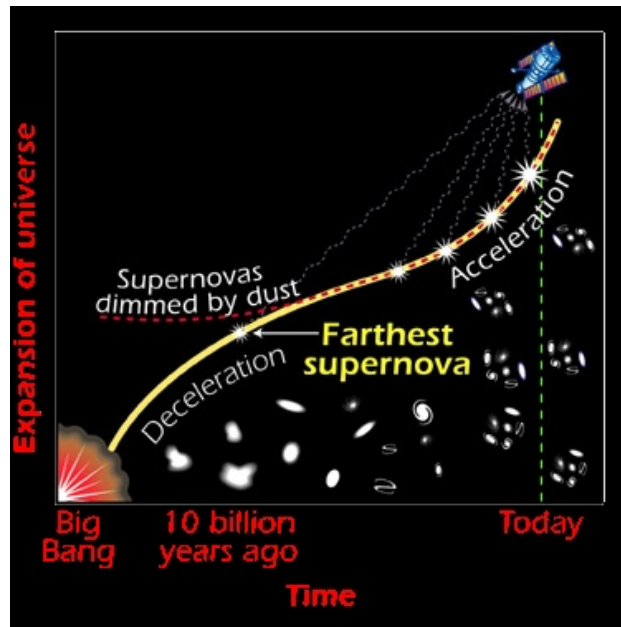
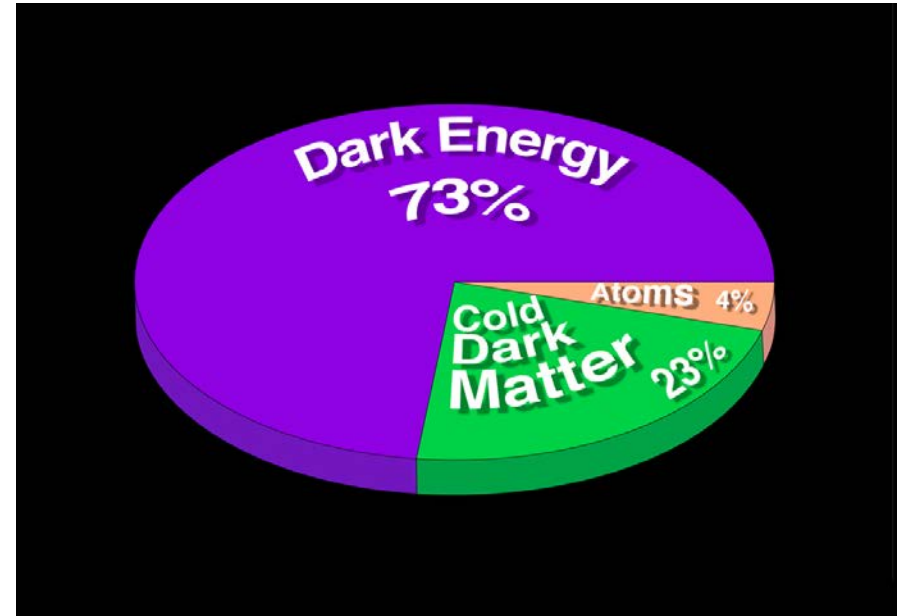
4. Nuclei are formed  $t = 3 \text{ minutes}$ ,  
 $10^9 \text{ K}$  ( $0.1 \text{ MeV}$ ,  $10^{-12} \text{ m}$ )

- **What is the Universe made of?**

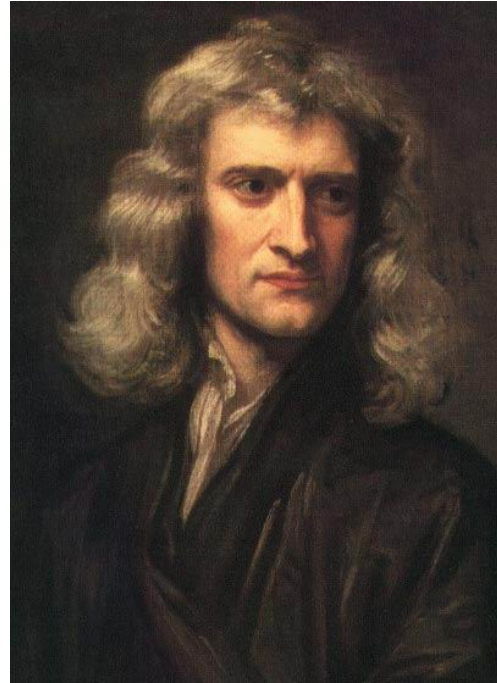
Mostly by a mysterious type of energy

- **How do we know about “dark energy” ?**

1. By observing distant exploding stars
2. By observing cosmic background radiation.



**Last word**



**“What we know is a droplet, what we  
don’ t know is an Ocean”**

***Sir Isaac Newton (1643-1727)***

***Thank you!***