# Archaeology of the Universe:
## Making the Invisible Visible and the Impossible Possible

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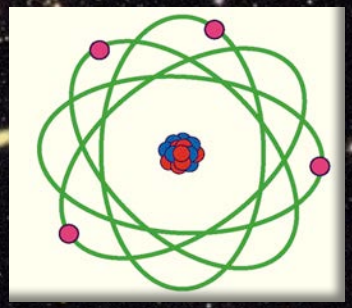
# The visible Universe


~$10^{11}$ galaxies

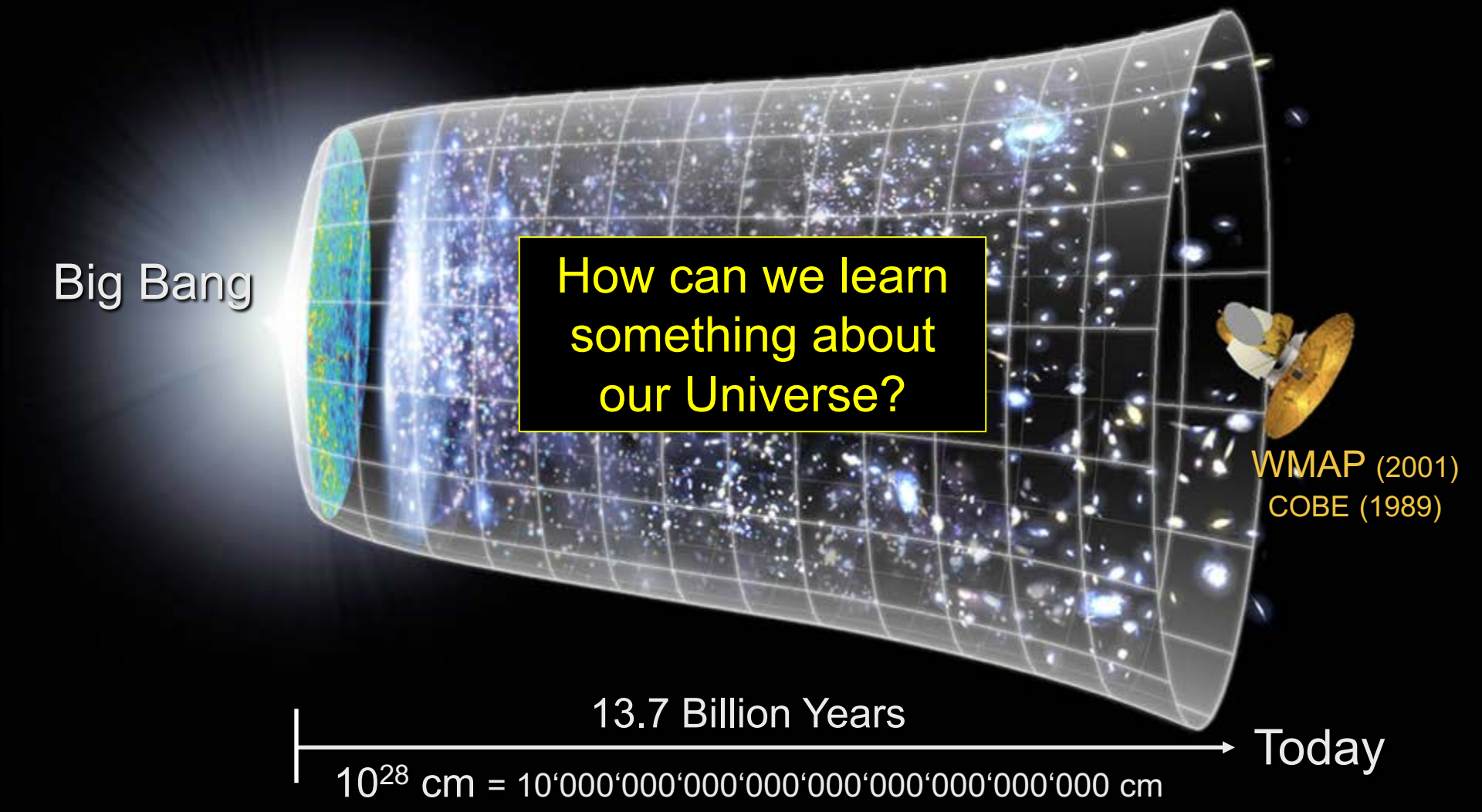
~$10^{21}$ stars



~$10^{78}$ atoms

~$10^{88}$ photons

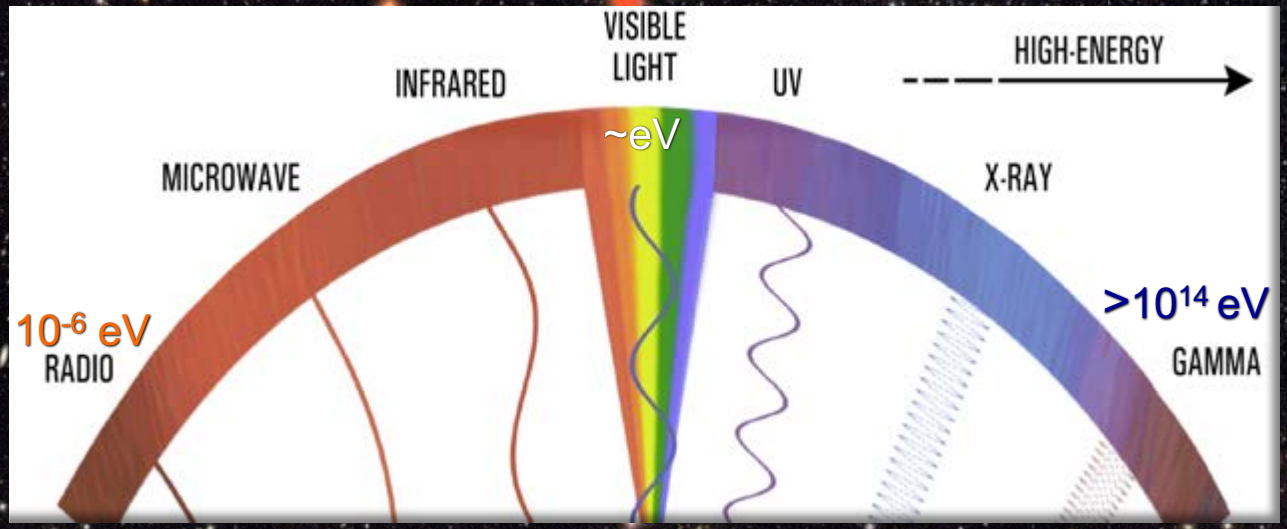
# Our Universe ..... How did it evolve after the BB?




The prevailing model is one of an expanding Universe, evolving from very small to very big, from very hot to very cold, from simple to complex

# Spectrum of electromagnetic radiation

from radio waves to very high energy gamma rays




Total spectrum: >70 octaves

Visible Light (~ eV):
$4 \times 10^{14}$ – $8 \times 10^{14}$ HZ


Music:
1 octave corresponds to frequency doubling

W. Hofmann

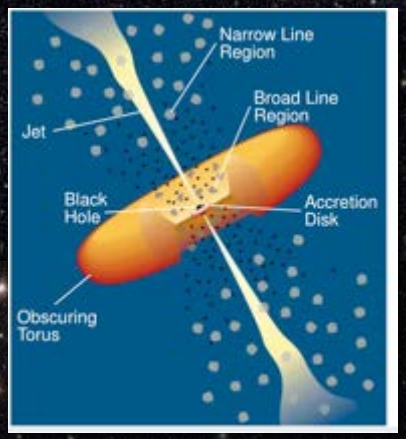
grand piano: 7.5 octaves

..... Nature plays on a grand piano with a more than 12 m long keyboard.....

# Very High-energy gamma rays from Active Galactic Nuclei (AGNs)

Accretion of matter by black hole

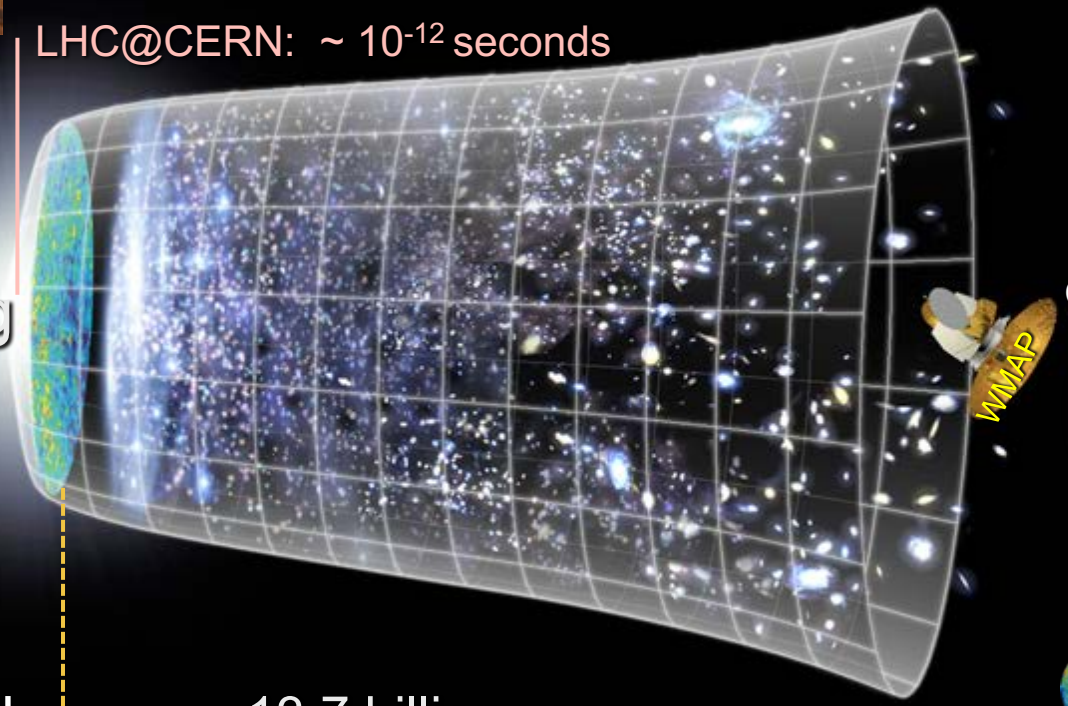
<u>Assumption:</u>
Super-massive black hole ($10^6$-$10^{10}$) $m_{sun}$ in the central region of the AGN




Central region of a galaxy, where high-energy processes take place
very different to those in our sun

LHC@CERN: ~ $10^{-12}$ seconds

Big Bang




13.7 billion years

today

$10^{28}$ cm

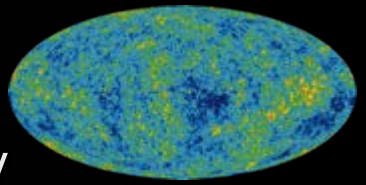
Experiments in Astrophysics & Cosmology

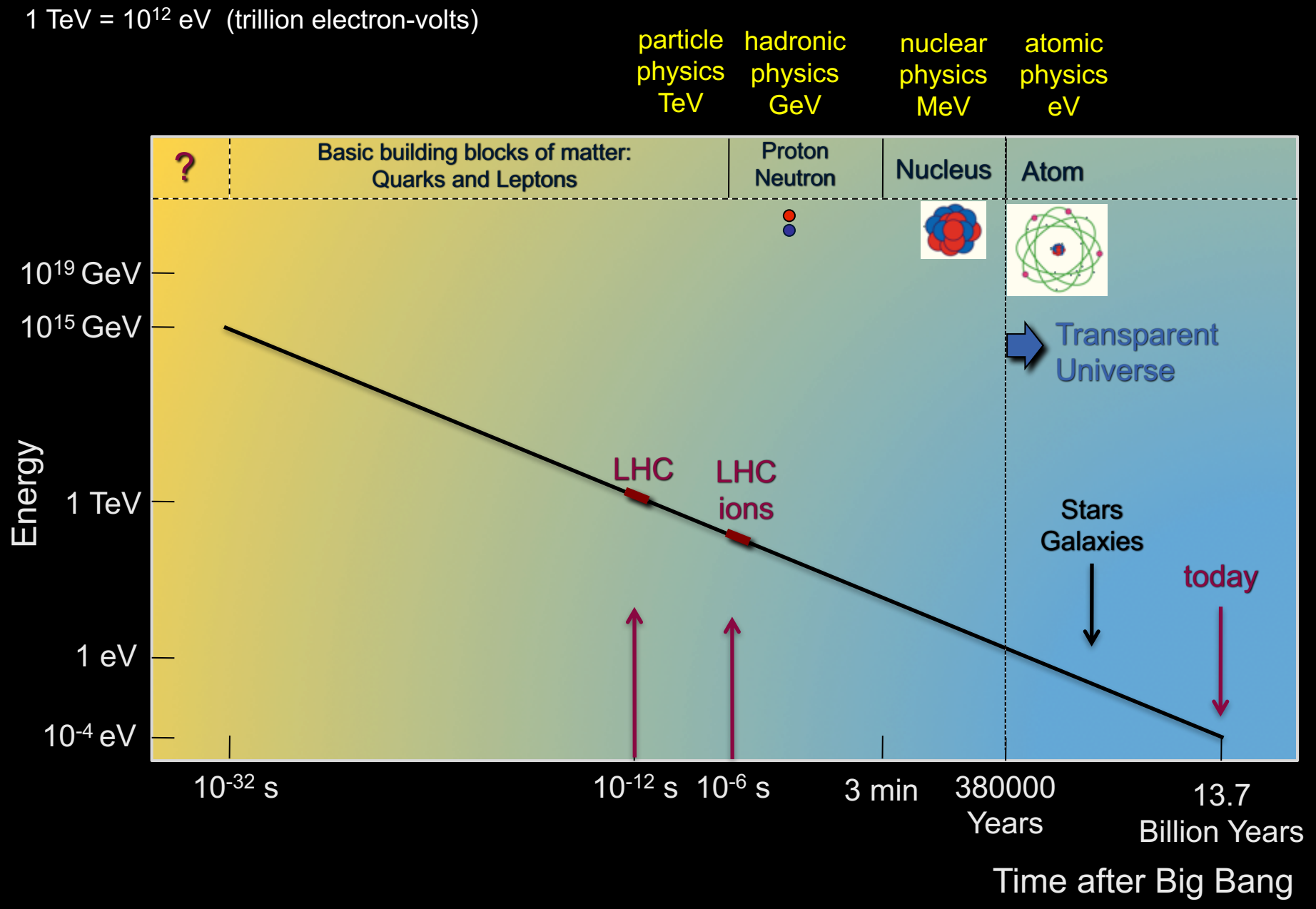
~380‘000 years

Hubble
M74; 32.5MLj

Hubble
Crab Nubular; 6.5kLJ

WMAP: CMB




1 TeV = 10^12 eV (trillion electron-volts)
particle physics TeV
hadronic physics GeV
nuclear physics MeV
atomic physics eV
?
Basic building blocks of matter: Quarks and Leptons
Proton
Neutron
Nucleus
Atom
Transparent Universe
LHC
LHC ions
Stars Galaxies
today
Energy
10^19 GeV
10^15 GeV
1 TeV
1 eV
10^-4 eV
10^-32 s
10^-12 s
10^-6 s
3 min
380000 Years
13.7 Billion Years
Time after Big Bang

# Dimensions in Physics

Big Bang

Proton

Atom

$10^{-32}$ $10^{-28}$ $10^{-24}$ $10^{-20}$ $10^{-16}$ $10^{-12}$ $10^{-8}$

Radius of Earth

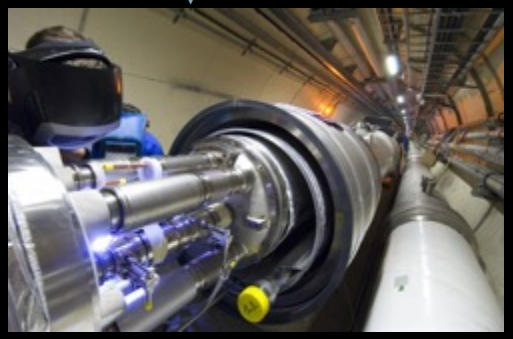
Earth to Sun

$10^{8}$ $10^{12}$ $10^{16}$ $10^{20}$ $10^{24}$

Radius of Galaxies

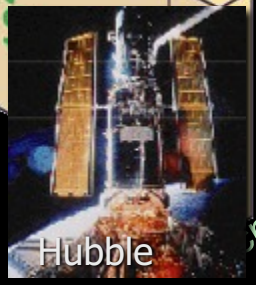
Universe

CERN



Super-Microscope

LHC



Hubble



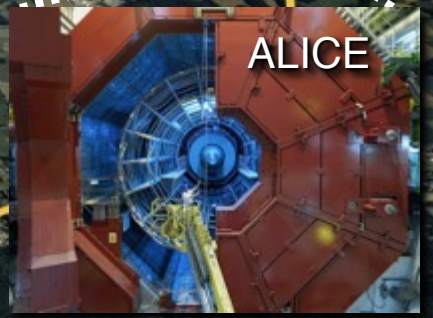
Study physics laws of first moments after Big Bang

→ increasing symbiosis between Particle Physics, Astrophysics and Cosmology

# A New Era in Fundamental Science




Since March 2010 exploration of a new energy frontier
in p-p and Pb-Pb collisions


| | |
|---|---|
| ATLAS | **A** Toroidal **L**HC **A**pparatu**S** |
| CMS | **C**ompact **M**uon **S**olenoid |
| LHCb | **L**arge **H**adron **C**ollider **b**eauty |
| ALICE | **A** **L**arge **I**on **C**ollider **E**xperiment |

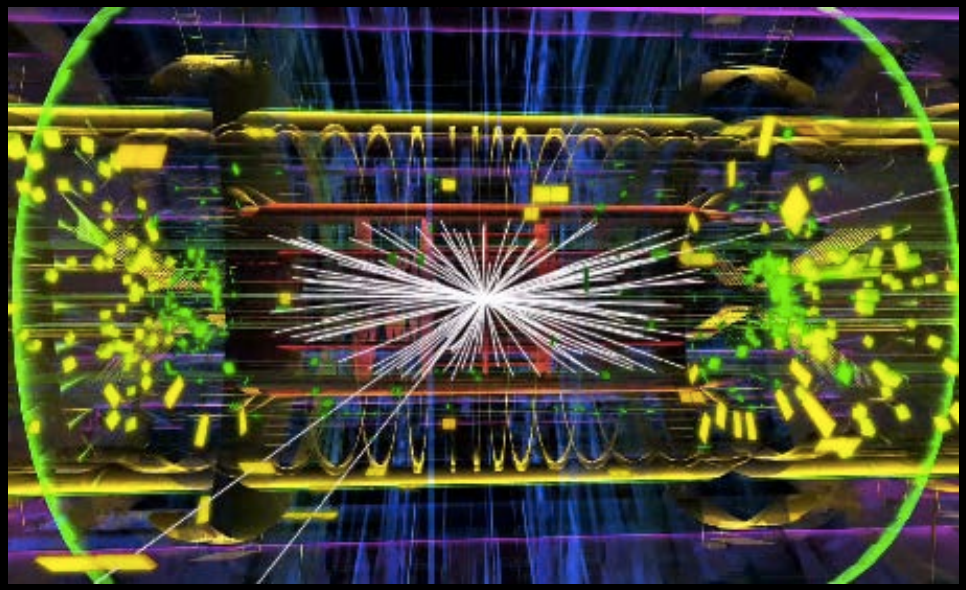
# 4 July 2012: CERN press conference

"CERN experiments observe particle consistent with long-sought Higgs boson"


$E = mc^2$

what did we look for?
what did we observe?

Making the invisible visible



The challenge was:
find the ~200 Higgs events in 4 Billion events recorded.

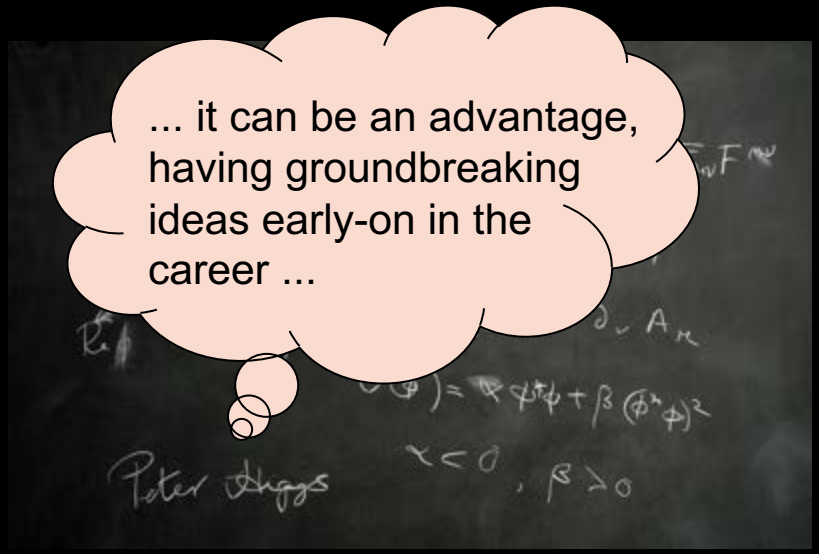
one Higgs → 4e produced in $10^{13}$ pp collisions

# 2013 Nobel Prize in Physics

## to François Englert & Peter Higgs

*"For the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*


CERN, July 2012



# 4 July 2012: CERN press conference

"CERN experiments observe particle consistent with long-sought Higgs boson"

Why was this discovery important?

Newton: weight proportional to mass

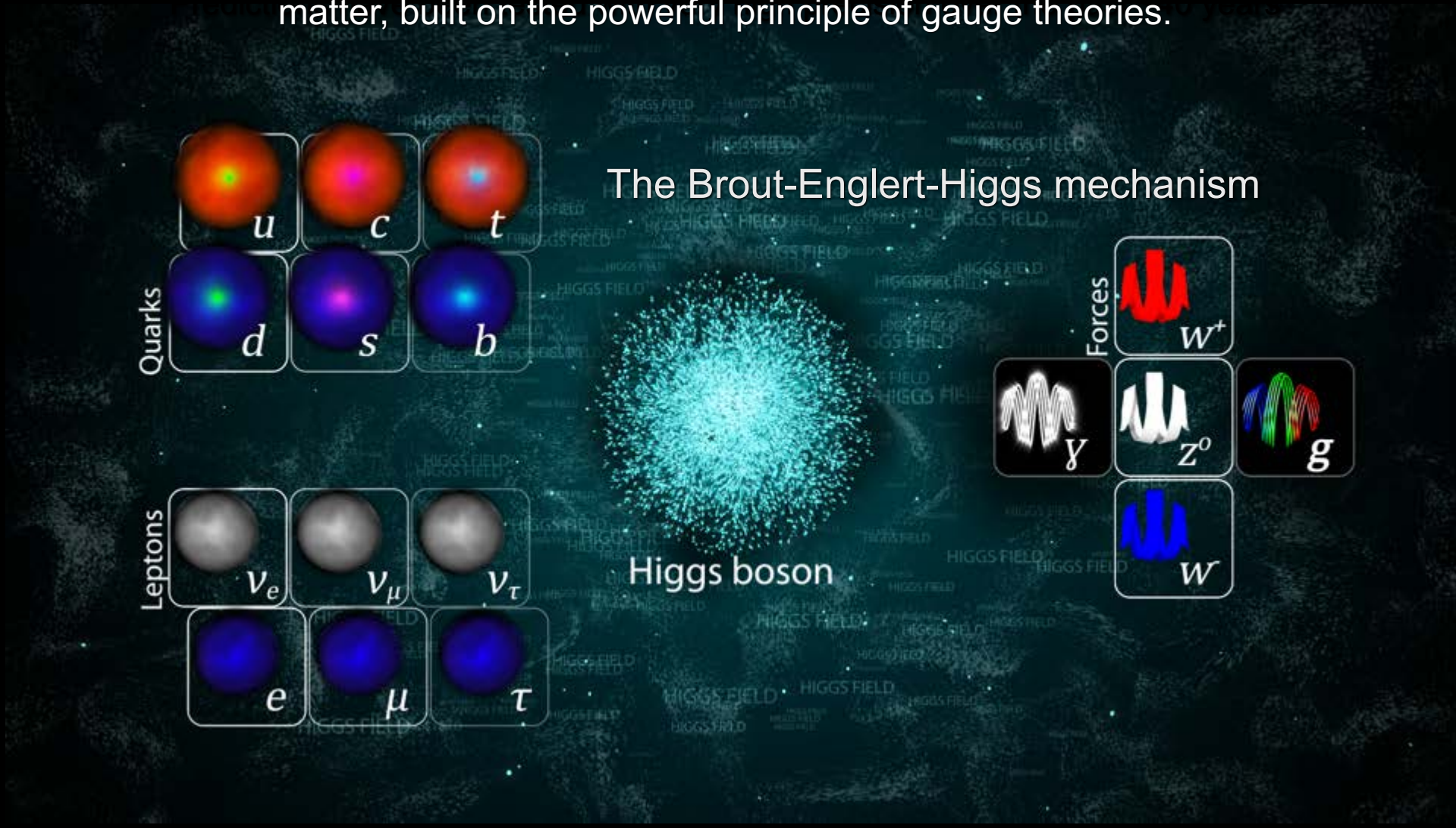
Einstein: Energy related to mass

No explanation of origin of mass

Where does mass come from?
Is it related to the Higgs Boson?

# The Standard Model of Particle Physics

very successfully describes the interactions between the fundamental building blocks of matter, built on the powerful principle of gauge theories.

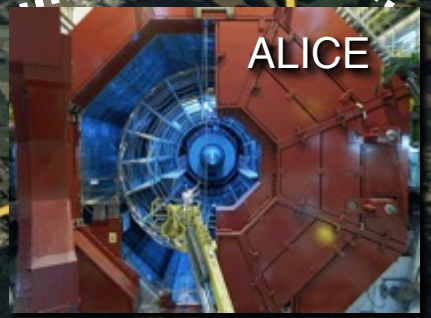


# The challenges on the way to the Higgs discovery ...




One of the most ambitious project in science on the global scale

Experim. challenges:
very high-tech, comple
detectors, very adv
computing infr
very larg
co

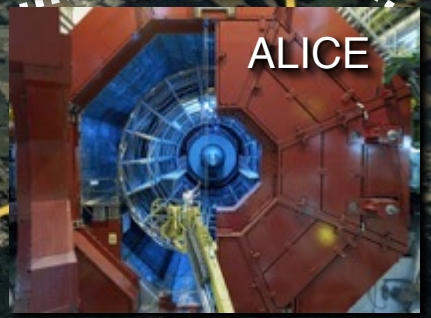




LHC challenge:
~1200 SC magnets of 8.3T
operated at 1.9K (-271°C)

# LHC and experiments are masterpieces of technology!




- 1984: official start of LHC project
- experimental programme started in beginning of 1990's
- many years of R&D
- construction of experiments lasted for ~ 8 years

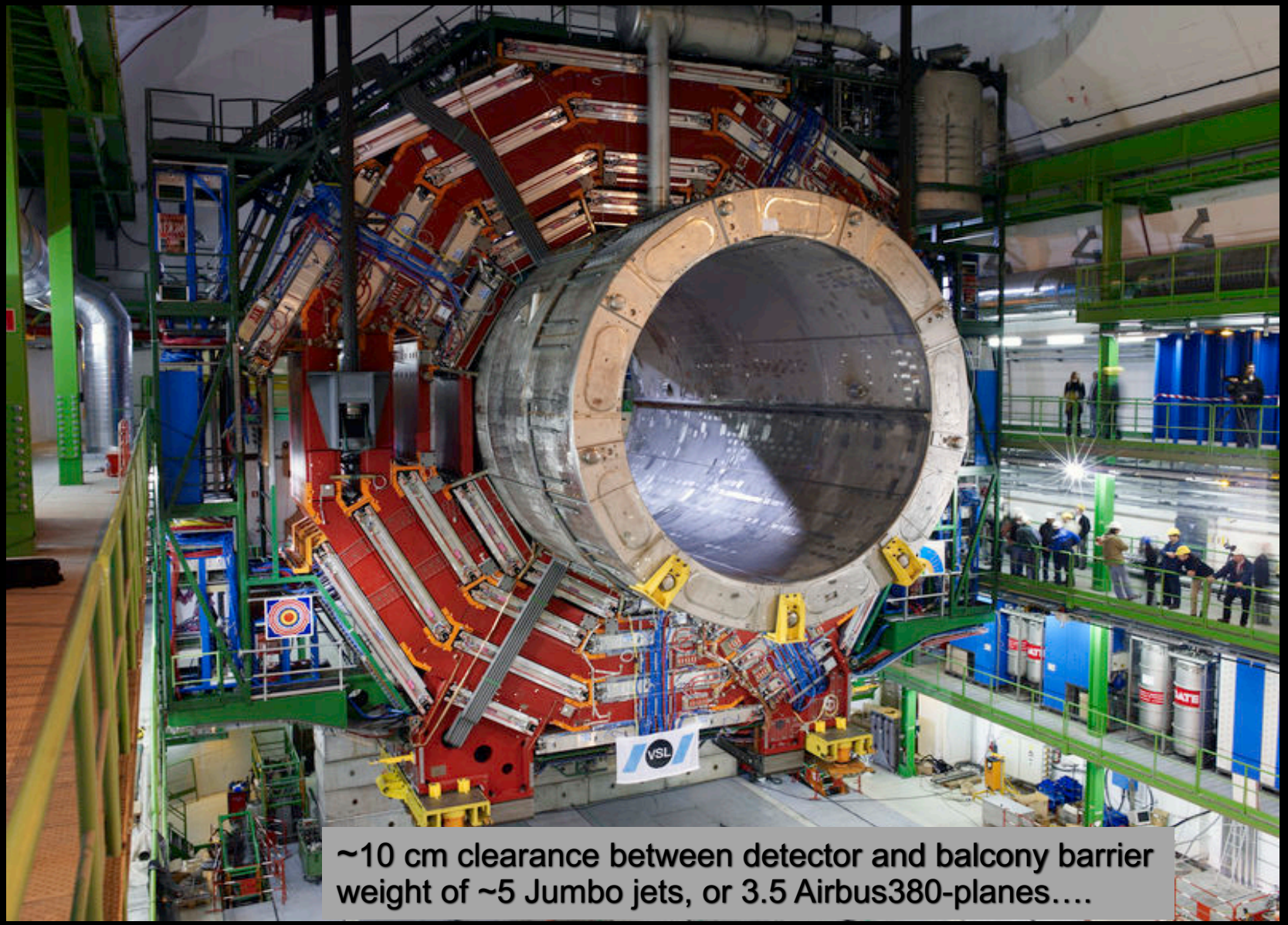




Innovative technologies developed together with industry

CMS surface building at Point 5 of LHC

Nov 2006:
lowering of first heavy element

# Lowering of central and heaviest element (~ 2000 t) on 28/02/2007



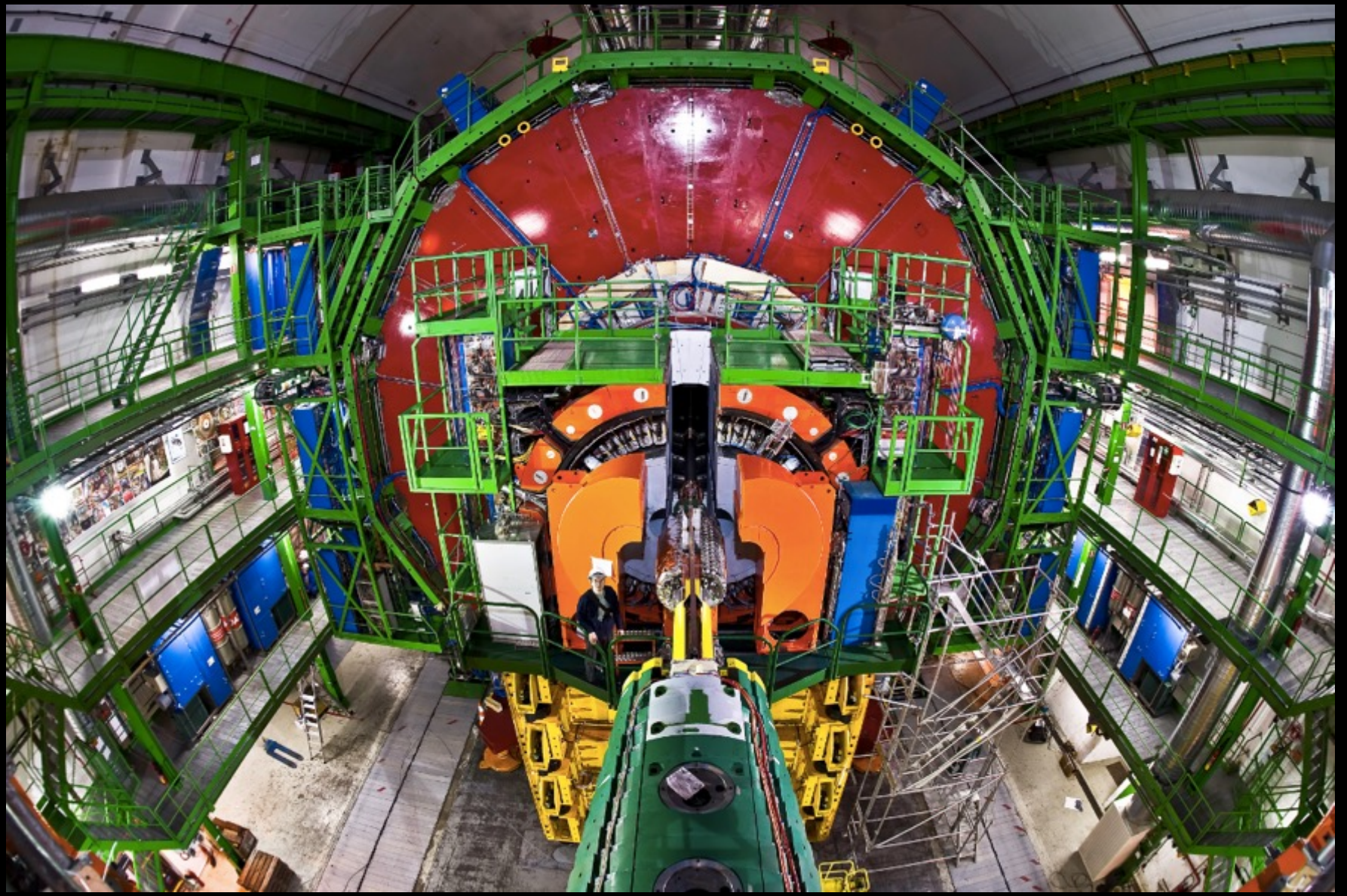

~10 cm clearance between detector and balcony barrier
weight of ~5 Jumbo jets, or 3.5 Airbus380-planes….

Lowering of the last heavy element on
22 January  2008

July 2008:
Pixel detector
installation

Closing CMS to be ready for collisions

# Ready to take data .....




CMS = Compact Muon Solenoid
Gigantic digital camera
Making the impossible possible
CMS
ETH Institute for Particle Physics
PAUL SCHERRER INSTITUT
PSI
Universität Zürich
CMS Detector
Weight: 12'500 t
Diameter: 15 m
Length: 21.6 m
Magnetic field: 4 T
~ 100M individual detecting elements

# LHC and experiments are masterpieces of technology!




LHCb

ATLAS

CERN Meyrin

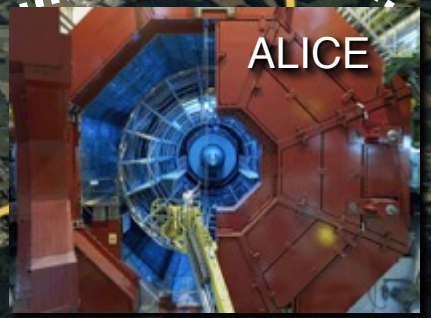
CERN Prévessin

7 km

CMS

ALICE

Success of the Higgs discovery is the success of a truly global scientific project

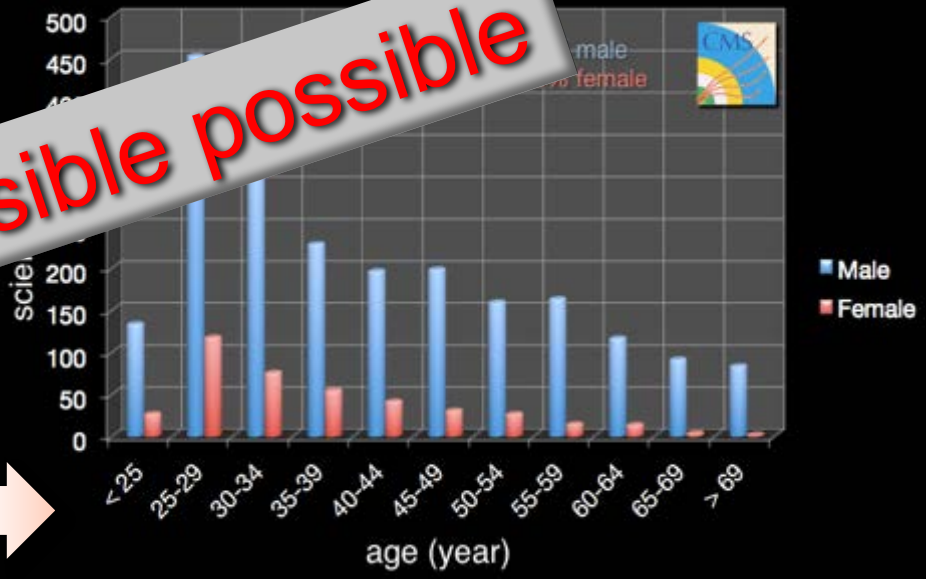

Innovative technologies developed together with industry

CERN

# CMS: a truly global scientific project

~3000 scientists, ~200 institutes, ~40 countries

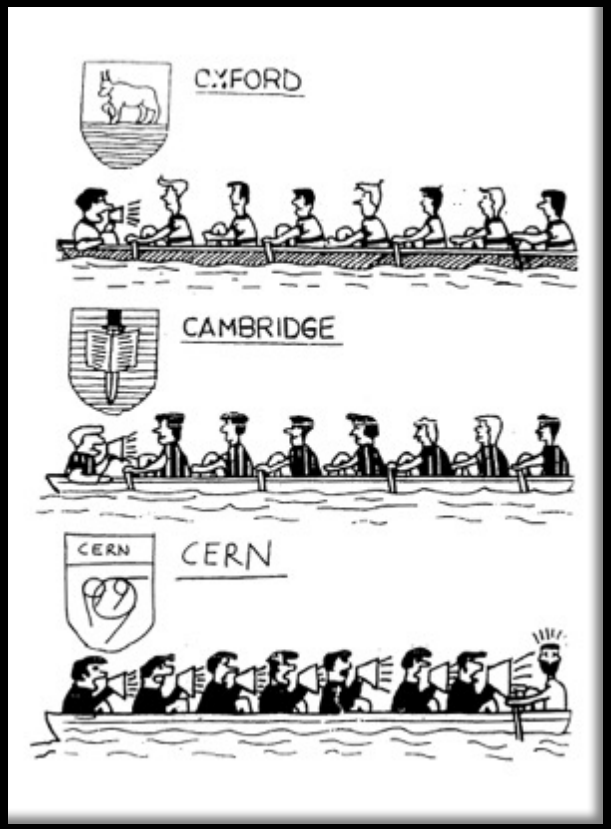
Making the impossible possible




Impact of large international collaborations:

- a place where people learn how to work together
- cooperation and competition are the path to success
- open access and sharing results allows everyone to participate and contribute to new developments

# .....you learn how to collaborate and to manage .....




# Our next challenges

## LHC timeline

- 2015 – 2018: 13 TeV (~150fb$^{-1}$)
- 2021 – 2023: 14 TeV (2x$L_{nominal}$): 300fb$^{-1}$
- HL-LHC: 2026 – 2035: 14 TeV: 3000fb$^{-1}$

- or HE-LHC (~ 2x $E_{cm}$) by 2035?
- or FCC (100TeV/100km) / ILC (CLIC) by ??

So far, we have successfully managed our different challenges ....

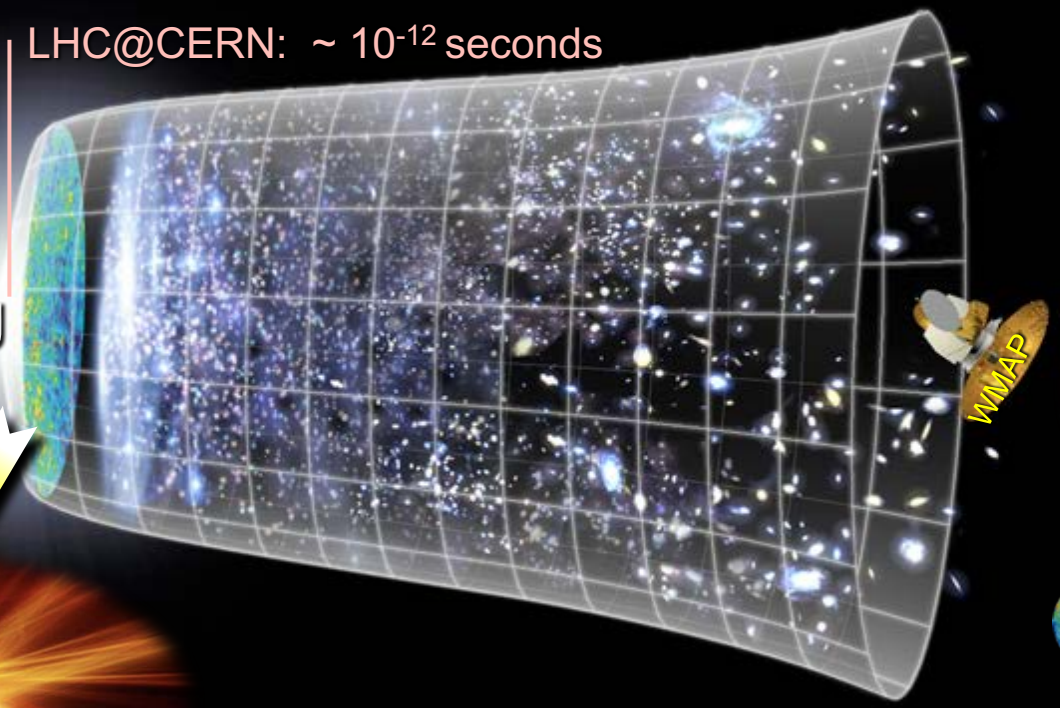
Need more data!

So far ~ 1% of data collected from what we expect by the end of HL-LHC operation (in 2035)

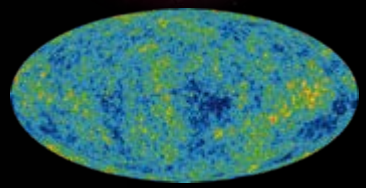
Very intense R&D and upgrade programme is necessary to reach the goals!

# The next scientific challenge

LHC@CERN: ~ $10^{-12}$ seconds




Big Bang



What is the reason why antimatter and matter did not completely destroy each other during the evolution of the Universe?

Supersymmetry? → tested at the LHC

# The visible Universe

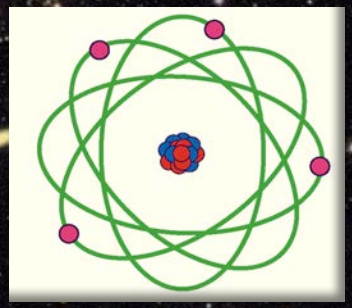
What makes up the mysterious "Dark Matter" in our Universe?

$10^{11}$ galaxies

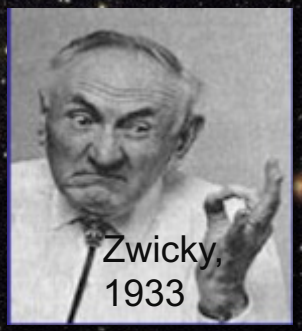
~$10^{21}$ stars

However:
this makes only ~16% of the Matter in our Universe!
~84% is "Dark Matter"

Is there a new form of matter?
→ Supersymmetry?



~$10^{78}$ atoms

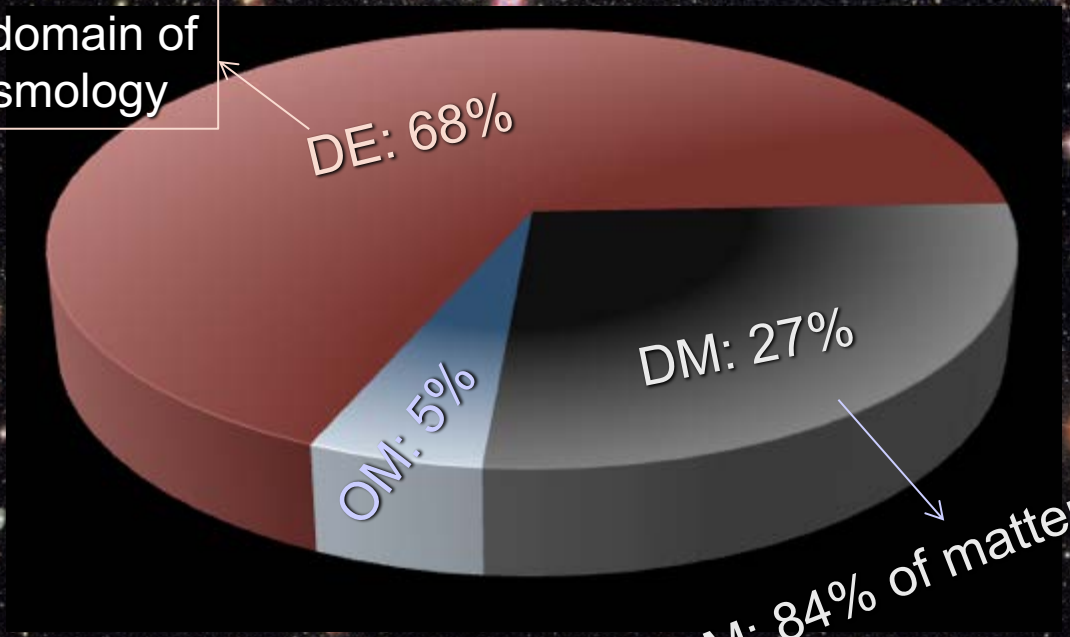



~$10^{88}$ photons

The “Dark Side” of our Universe: 95% of the total mass-energy content!!

DE is associated with a repulsive force, which tends to accelerate the expansion of the Universe. This accelerated expansion has been measured, leading to the prediction of DE.

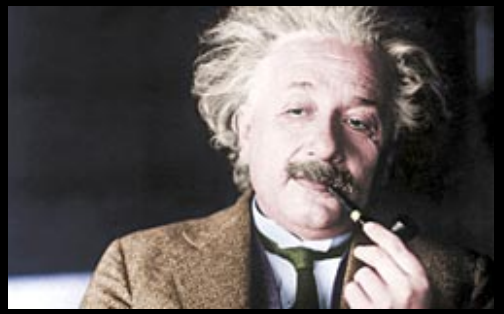
DE is a priori a domain of astrophysics/cosmology

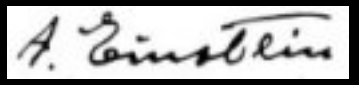



DE ... Dark Energy
DM ... Dark Matter
OM... Ordinary Matter

*“The most incomprehensible thing about the universe is that it is comprehensible”*

*“Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world.”*

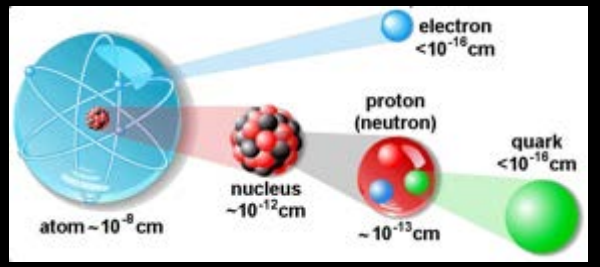




# Imagination .....

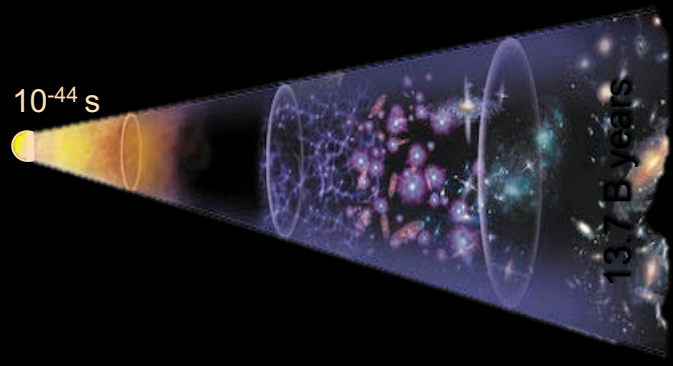
There are more atoms in your fingertip than stars in the whole Universe

Atoms are almost empty space – without that empty space you would compress into a tiny volume (cube with length ~0.02 mm)




The components of our body are truly ancient:

Protons we are made of were formed about 3 minutes after the Big Bang i.e. we all are about "13.7 billion years old"




Thank you very much !!!