



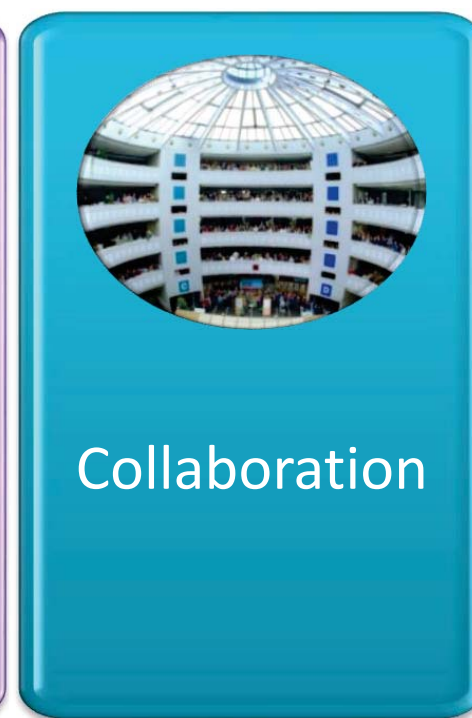
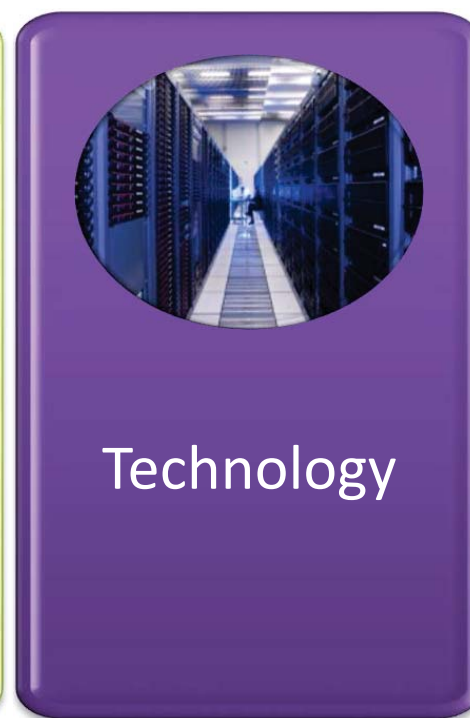
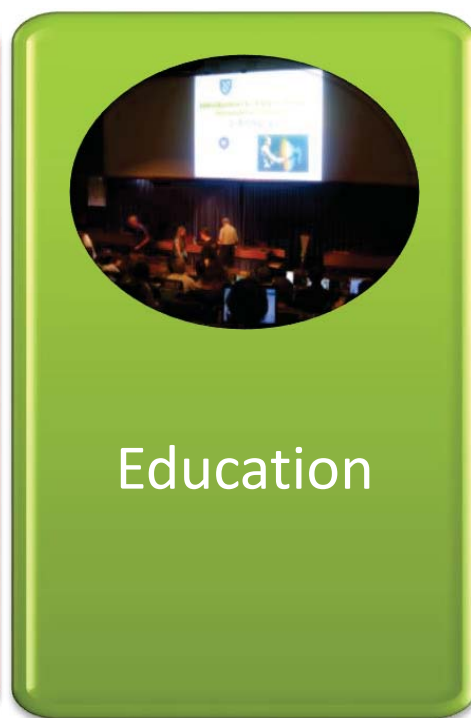
# CERN. Opportunities at the cutting edge of technology

Edda Gschwendtner, CERN

*All images copyright CERN*

# Our mission

- *To provide a unique range of particle accelerator facilities that enable research at the forefront of human knowledge*
  - *To perform world-class research in fundamental physics*
- *To unite people from all over the world to push the frontiers of science and technology, for the benefit of all.*
  - *Train scientists and engineers of tomorrow.*



# What is CERN?



## Sur le terrain du futur institut nucléaire

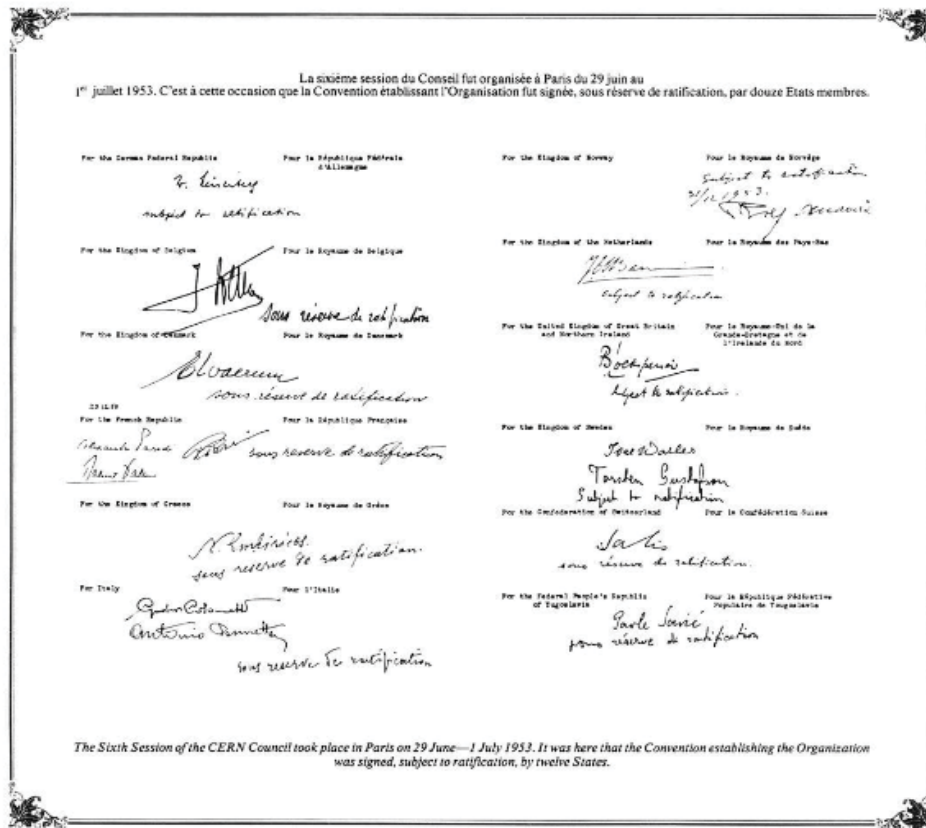


Sous la conduite de M. A. Picot, les membres du Conseil européen pour la recherche nucléaire se sont rendus hier à Meyrin pour reconnaître le terrain où s'élèvera le Centre nucléaire (voir en Dernière heure)

(Photo Freddy Bertrand, Genève)

**La Suisse** du 30 octobre 1953

# CERN Birth Certificate, 29.9.1954



- Germany
- Belgium
- Denmark
- France
- Greece
- Italy
- Norway
- Netherlands
- Great Britain
- Sweden
- Suisse
- Yugoslavia

# CERN Convention

## ARTICLE II: Purposes

The Organization shall provide for collaboration among European States in nuclear research of a **pure scientific and fundamental character** [...]

The Organization shall have **no concern with work for military requirements** and the **results of its experimental and theoretical work shall be published** or otherwise made generally available.

# The Organization

# CERN

A Worldwide  
collaboration  
Funded by 23 Member  
States



# Over 17'000 people

Engineers, technicians, support staff and physicists

**> 12 000  
users**

**> 800  
Fellows (post-docs)**

**> 2500  
Staff  
Members**

**> 700  
Students  
&  
trainees**

**> 1000  
Associates**



# Why....?

What are the smallest building blocks of matter?

What is the origin of the universe?

Why do we need huge accelerators...

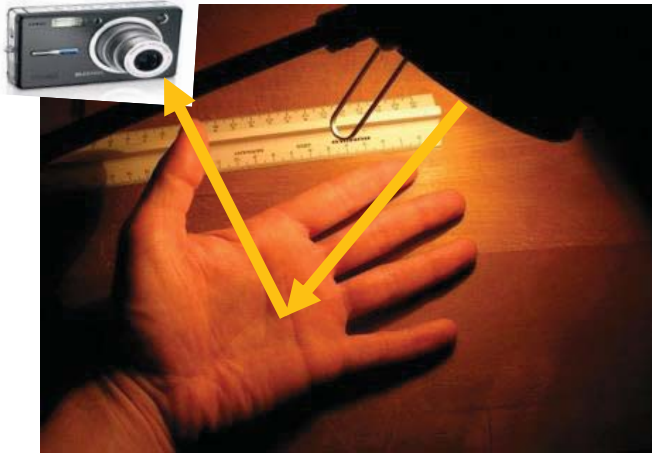


... to study the smallest building blocks of matter?

# Why Do We Need Huge Accelerators?

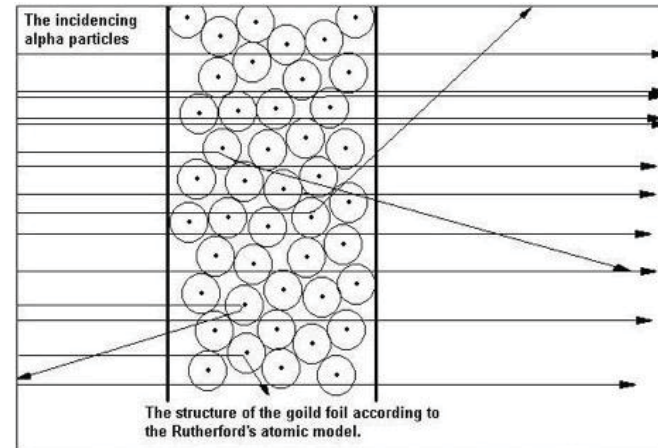
- To study the smallest building blocks of matter

Pattern of the scattered light  
→ structure of the hand.



Visible light  $\sim 1$  micrometer =  
 $0.001\text{mm}$   $\sim$  size of a bacterium

Pattern of scattered high energy particles  
→ structure of the atom.



Atoms ( $10^{-10}$  m) consist of an extremely small  
Nucleus ( $10^{-15}$  m), electrons are moving around.

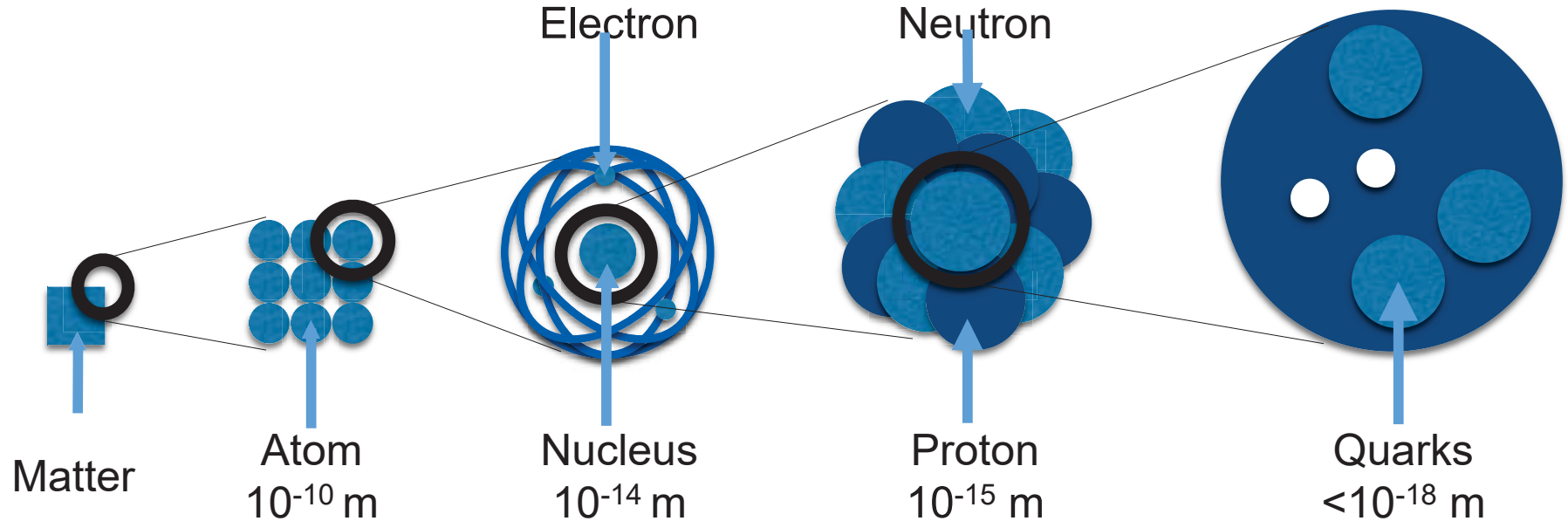
Higher particle energy → smaller wavelength → smaller structures

**Accelerators are Super-Microscopes !**

# Why Do We Need Huge Accelerators?

- To study the smallest building blocks of matter

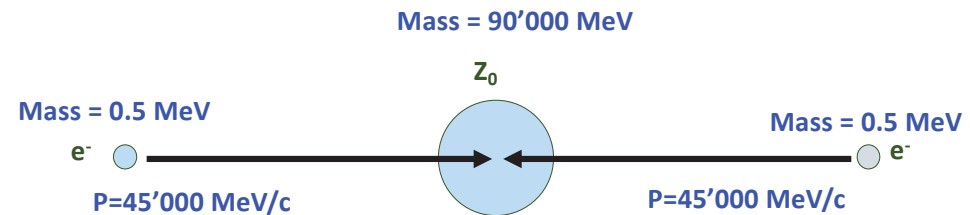
Optical Microscope:  $10^{-6}$  m  
Radioactive Source:  $10^{-14}$  m  
LHC:  $<10^{-21}$  m



# Why Do We Need Huge Accelerators?

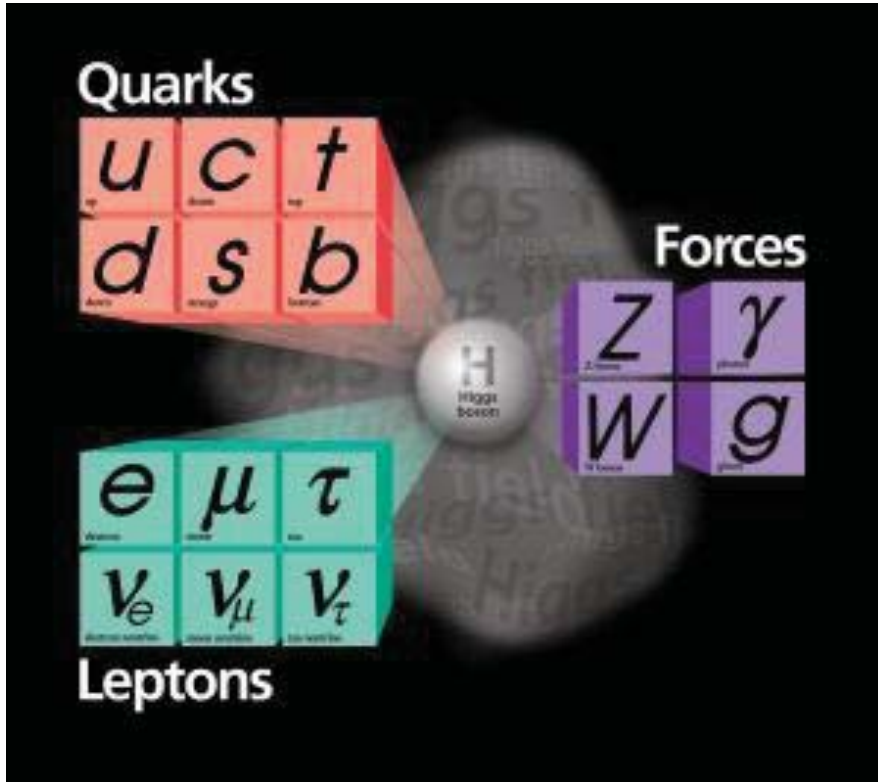
- To produce massive particles (e.g. W, Z, top, Higgs) that are either unknown or predicted by theories.
  - The study of the smallest building blocks of matter with high energy particle colliders and the production of new massive particles is connected.

$$E = mc^2$$



→ Accelerators are a powerful tool for particle discoveries and precision measurements!

# Standard Model



We have a model that describes the physics extremely well, but for it to work we need the Higgs particle.

$$\begin{aligned}
 \mathcal{L}_{SM} = & \underbrace{\frac{1}{4} \mathbf{W}_{\mu\nu} \cdot \mathbf{W}^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - \frac{1}{4} G_{\mu\nu}^a G^{\mu\nu a}}_{\text{kinetic energies and self-interactions of the gauge bosons}} \\
 & + \underbrace{\bar{L} \gamma^\mu (i \partial_\mu - \frac{1}{2} g \boldsymbol{\tau} \cdot \mathbf{W}_\mu - \frac{1}{2} g' Y B_\mu) L + \bar{R} \gamma^\mu (i \partial_\mu - \frac{1}{2} g' Y B_\mu) R}_{\text{kinetic energies and electroweak interactions of fermions}} \\
 & + \underbrace{\frac{1}{2} \left| (i \partial_\mu - \frac{1}{2} g \boldsymbol{\tau} \cdot \mathbf{W}_\mu - \frac{1}{2} g' Y B_\mu) \phi \right|^2 - V(\phi)}_{W^\pm, Z, \gamma \text{ and Higgs masses and couplings}} \\
 & + \underbrace{g'' (\bar{q} \gamma^\mu T_a q) G_\mu^a}_{\text{interactions between quarks and gluons}} + \underbrace{(G_1 \bar{L} \phi R + G_2 \bar{L} \phi_c R + h.c.)}_{\text{fermion masses and couplings to Higgs}}
 \end{aligned}$$

Higgs particle is heavy, so need high energy particle accelerator. Discovered with Large Hadron Collider, LHC at CERN.

# Discovery in 2012, Nobel Prize 2013

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC<sup>☆</sup>

ATLAS Collaboration\*

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

## ARTICLE INFO

Article history:  
Received 31 July 2012  
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Available online 14 August 2012  
Editor: W.-D. Schlatter

## ABSTRACT

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately  $4.9 \text{ fb}^{-1}$  collected at  $\sqrt{s} = 7 \text{ TeV}$  in 2011 and  $5.8 \text{ fb}^{-1}$  at  $\sqrt{s} = 8 \text{ TeV}$  in 2012. Individual searches in the channels  $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$ ,  $H \rightarrow \gamma\gamma$  and  $H \rightarrow WW^{(0)} \rightarrow e\nu\mu e$  in the 8 TeV data are combined with previously published results of searches for  $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$ ,  $WW^{(0)}$ ,  $bb$  and  $\tau^+\tau^-$  in the 7 TeV data and results from improved analyses of the  $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$  and  $H \rightarrow \gamma\gamma$  channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of  $125.0 \pm 0.4 \text{ (stat)} \pm 0.4 \text{ (sys)} \text{ GeV}$  is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of  $1.7 \times 10^{-9}$ , is compatible with the production and decay of the Standard Model Higgs boson.

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Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC<sup>☆</sup>

CMS Collaboration\*

CERN, Switzerland

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

## ARTICLE INFO

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## ABSTRACT

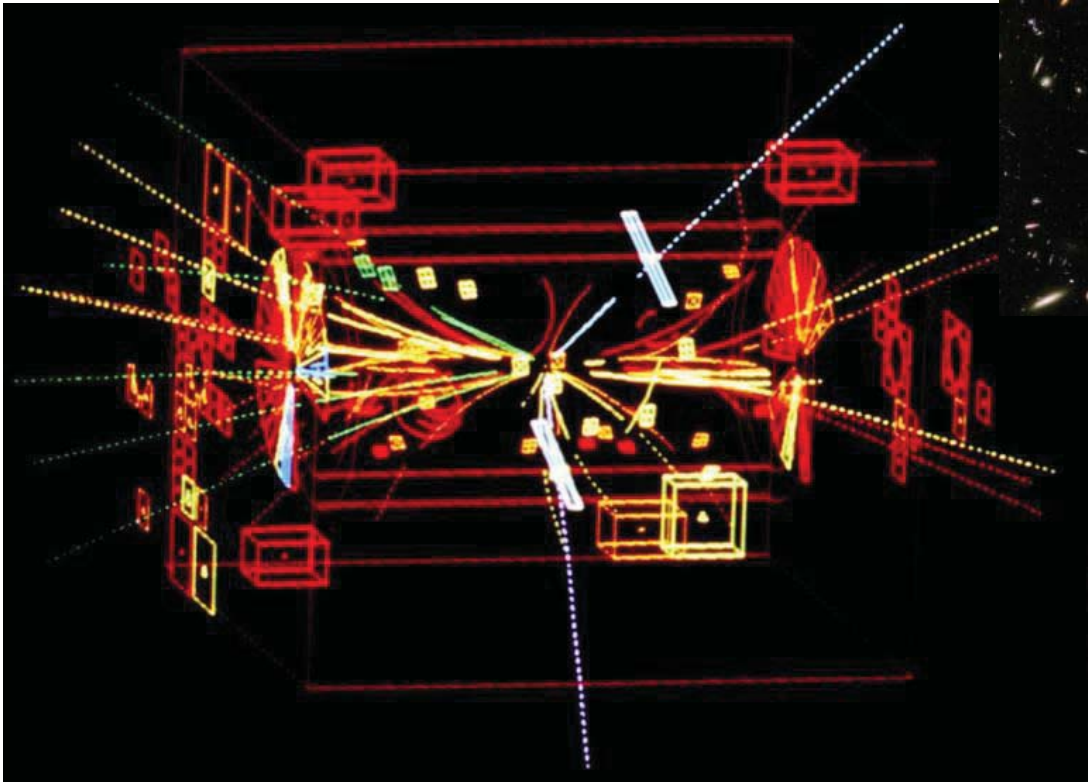
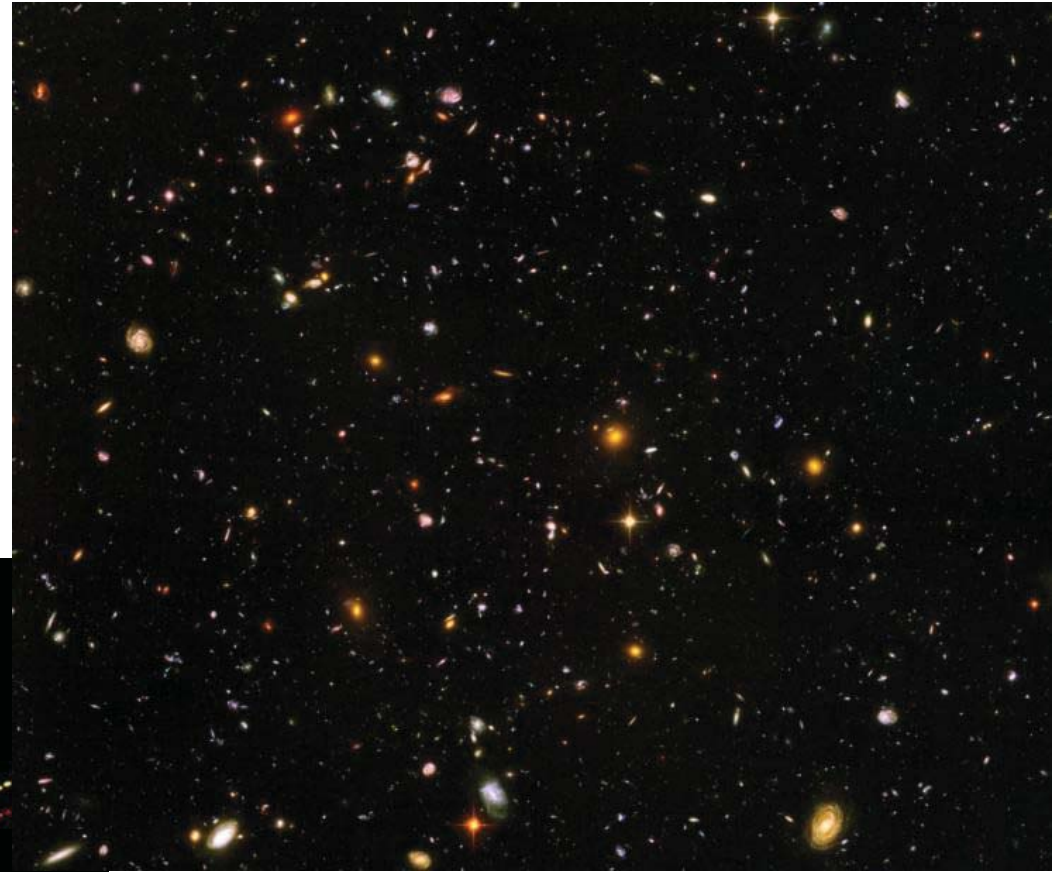
Results are presented from searches for the standard model Higgs boson in proton-proton collisions at  $\sqrt{s} = 7$  and 8 TeV in the Compact Muon Solenoid experiment at the LHC, using data samples corresponding to integrated luminosities of up to  $5.1 \text{ fb}^{-1}$  at 7 TeV and  $5.3 \text{ fb}^{-1}$  at 8 TeV. The search is performed in five decay modes:  $\gamma\gamma$ ,  $ZZ$ ,  $WW^{(0)}$ ,  $\tau^+\tau^-$ , and  $bb$ . An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution,  $\gamma\gamma$  and  $ZZ$ ; a fit to these signals gives a mass of  $125.3 \pm 0.4 \text{ (stat.)} \pm 0.5 \text{ (syst.)} \text{ GeV}$ . The decay to two photons indicates that the new particle is a boson with spin different from one.

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**The Nobel Prize in Physics 2013** was awarded jointly to François Englert and Peter W. 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**"

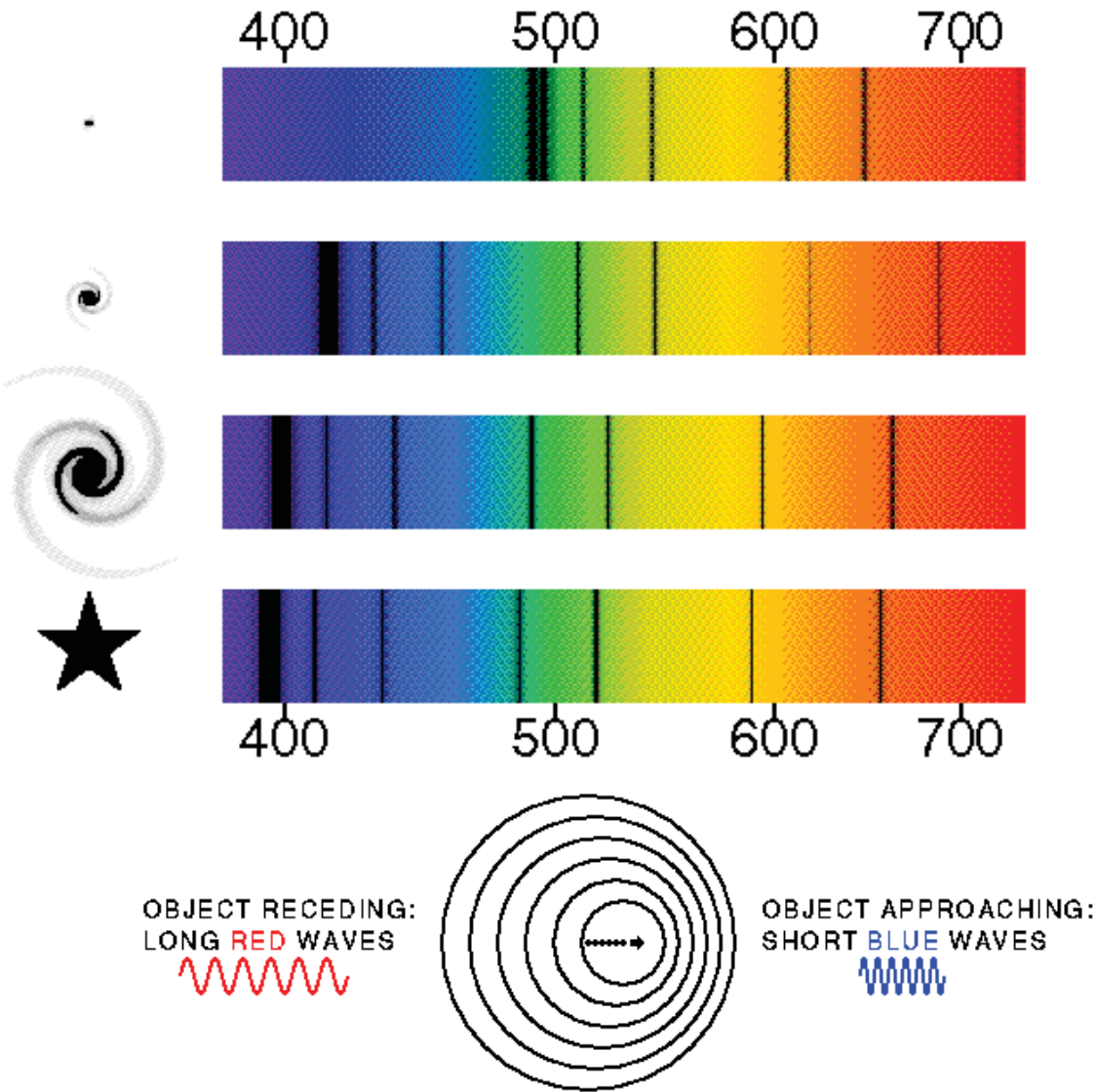
**How is cosmology  
connected...**



**... with particle  
physics?**



# Particle Physics and Cosmology



In 1929 Edwin Hubble discovered that galaxies are moving away at great speed.

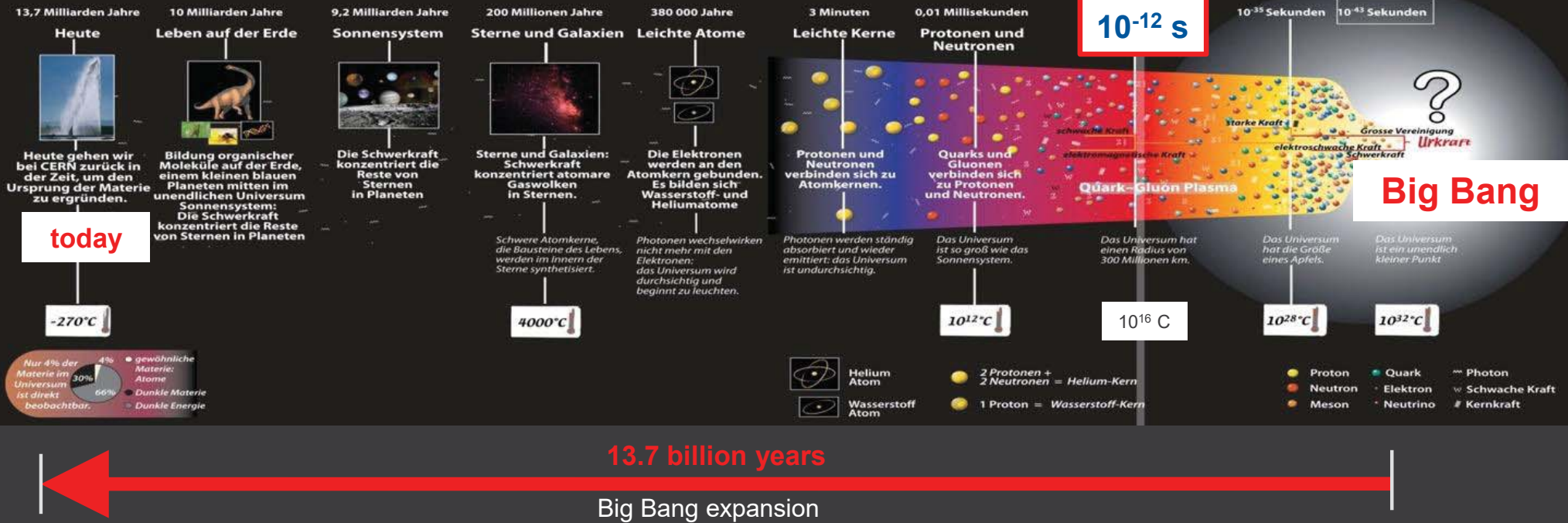
**This means that the galaxies were much closer long ago and the universe had much 'higher temperature' (today it's 2.7K)**

Together with Einstein's General Theory of Relativity, it can be calculated that the universe is approx. 15 billion years from a gigantic explosion – the Big Bang.

# What is the Origin of the Universe?

Particle physics dominates the events in the first seconds of the universe

## Die Evolution des Universums



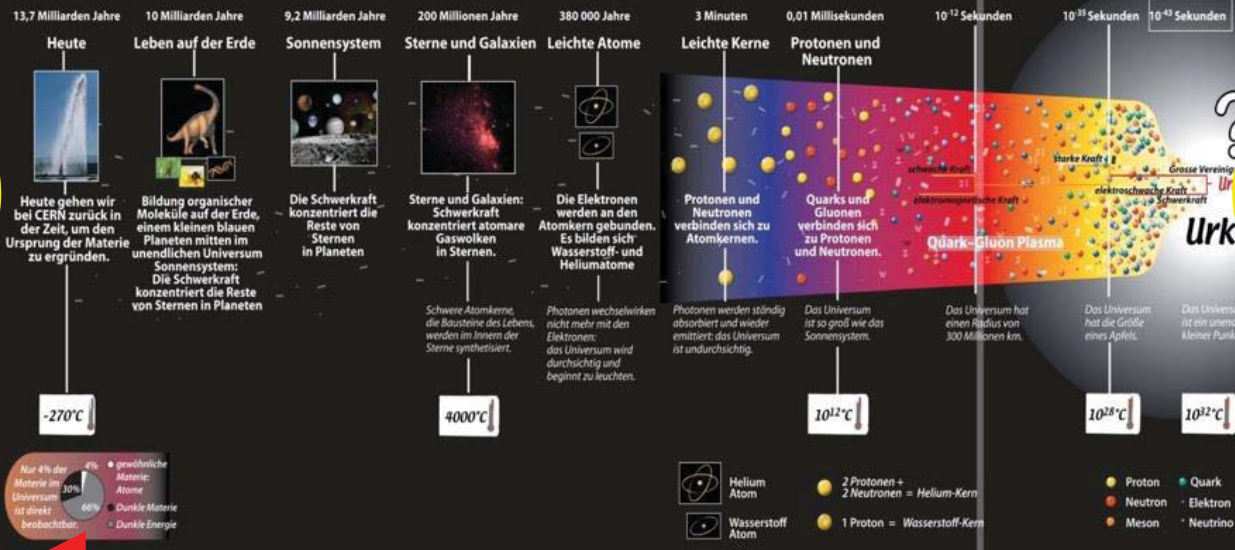
The collision energies of the particles in the LHC experiments correspond to the state of matter about one million x millionth of a second after the Big Bang.

# More Questions...

Today

Only matter survives

## Die Evolution des Universums

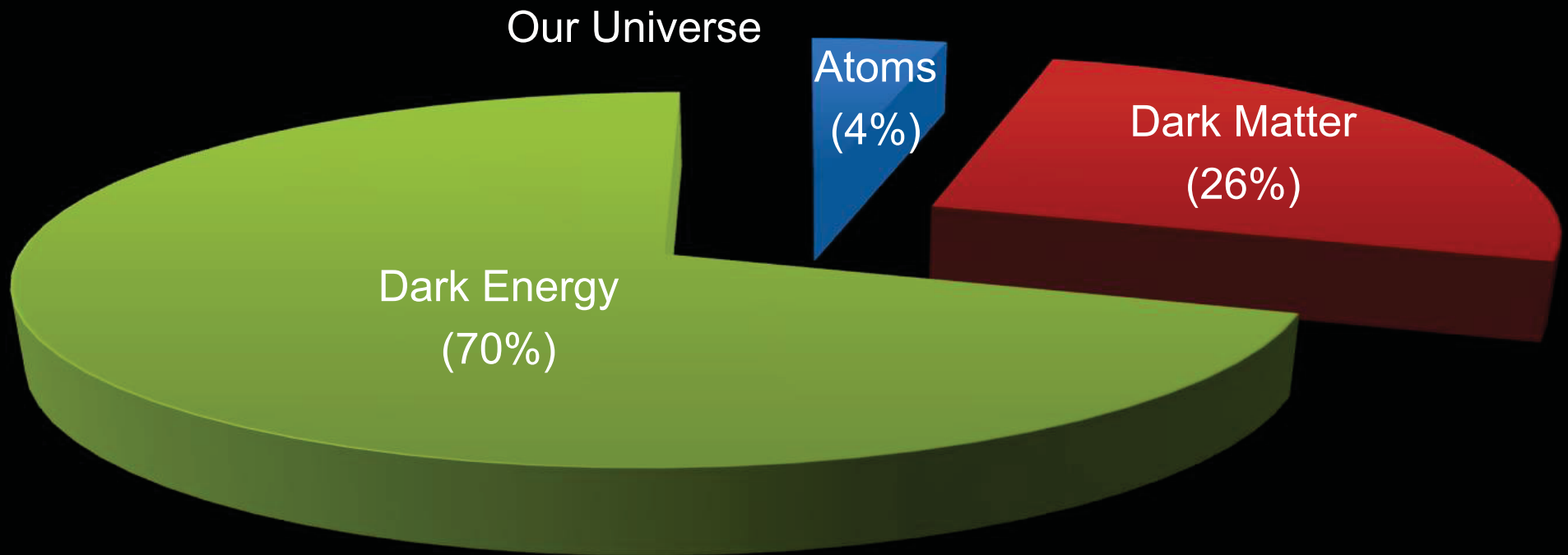


BIG BANG

The same amount of matter and antimatter was created

Why?

# More Questions ....

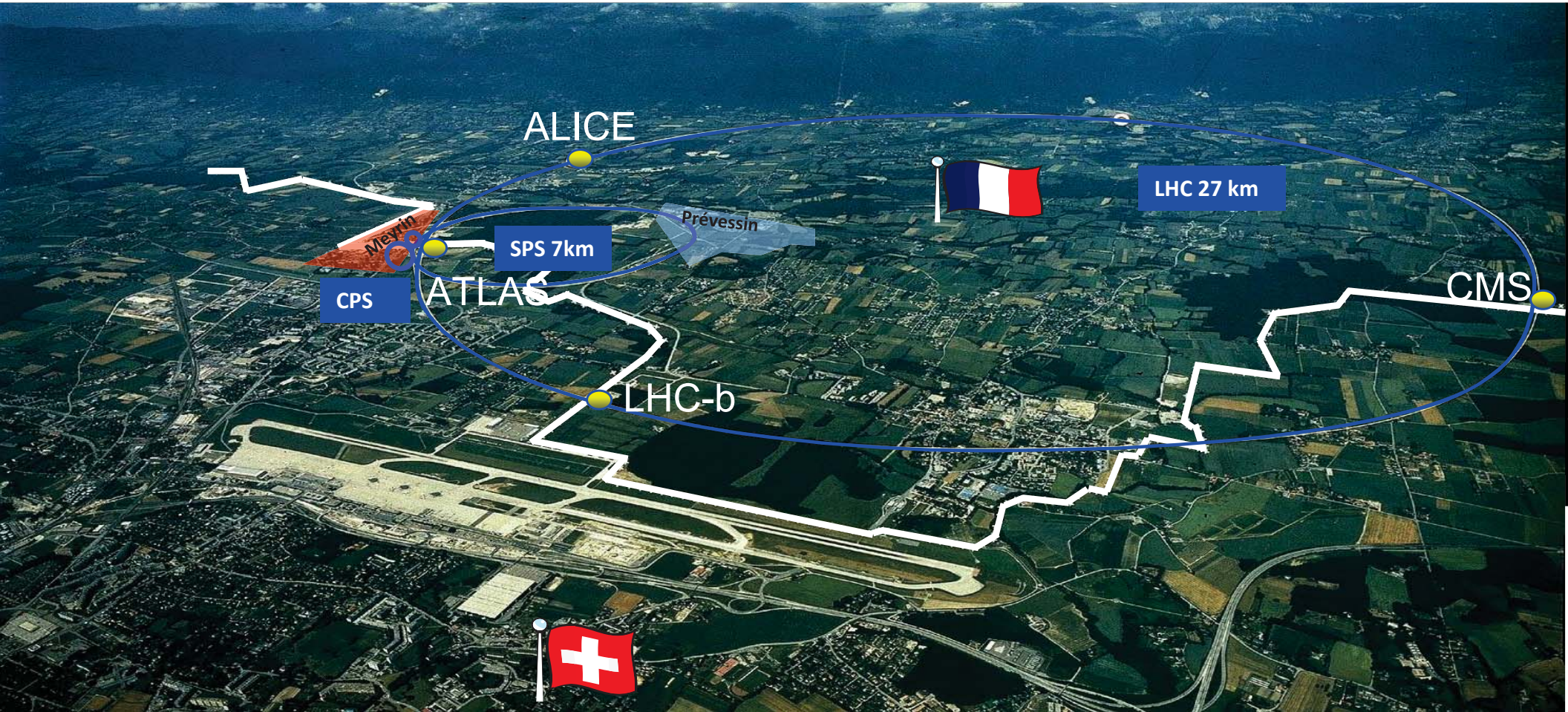


What is this other 96%?

# How...?



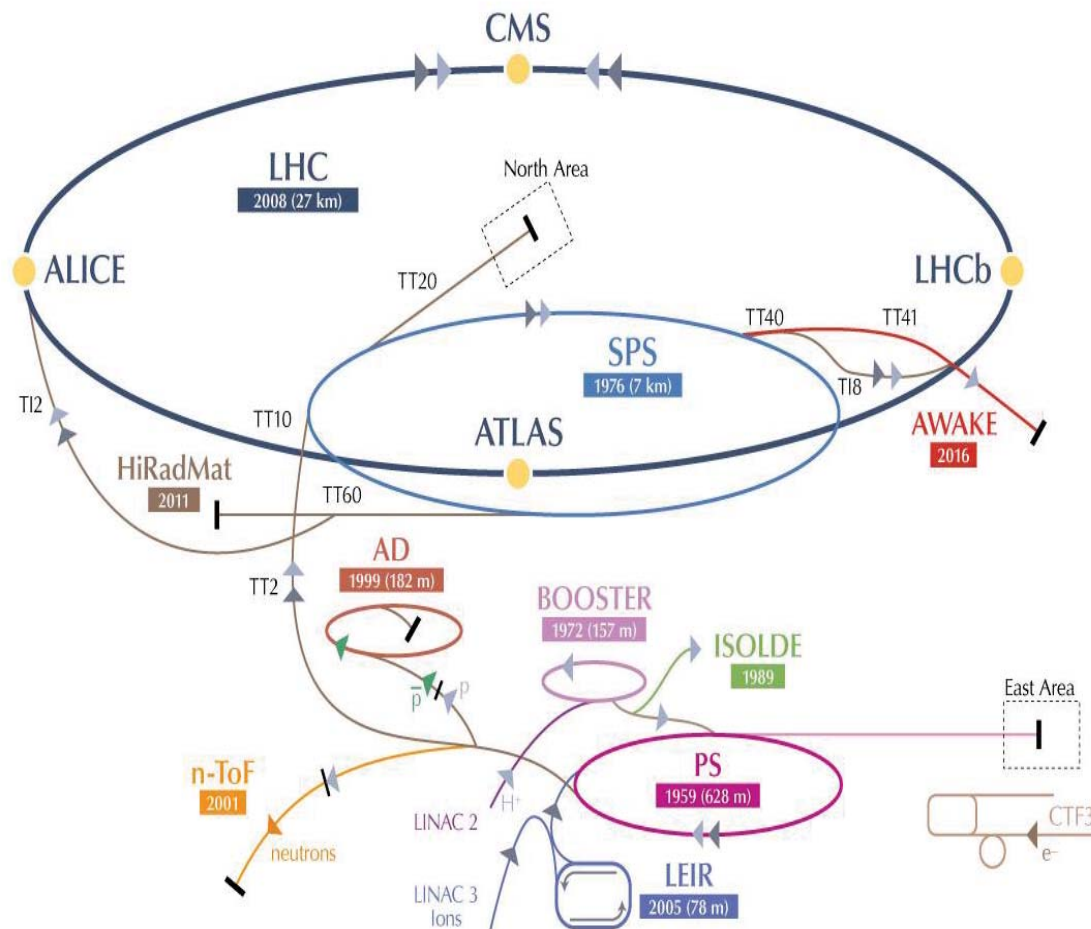
# CERN's Accelerators



# LHC /CERN Accelerator chain

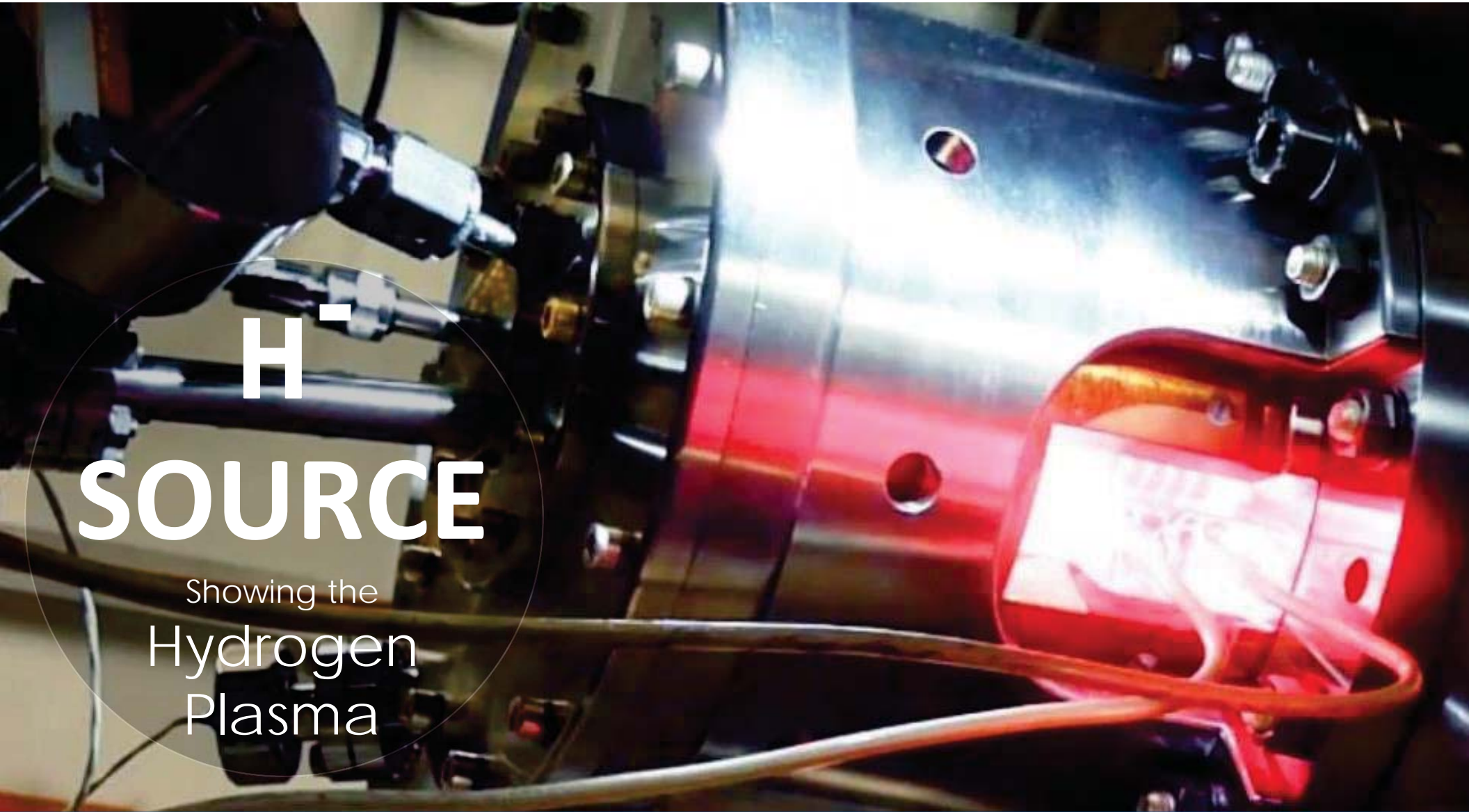
Like the **gears of a car**, a chain of accelerators is used to boost the energy of the beam in stages.

The proton journey from the source until injection into the LHC lasts ~ 7-24 seconds



	Max. P (GeV/c)	Length / Circ. (m)
LINAC4	0.160	30
Booster	2	157
PS	26	628
SPS	450	6'911
LHC	6'800	26'657

# Where it all Begins



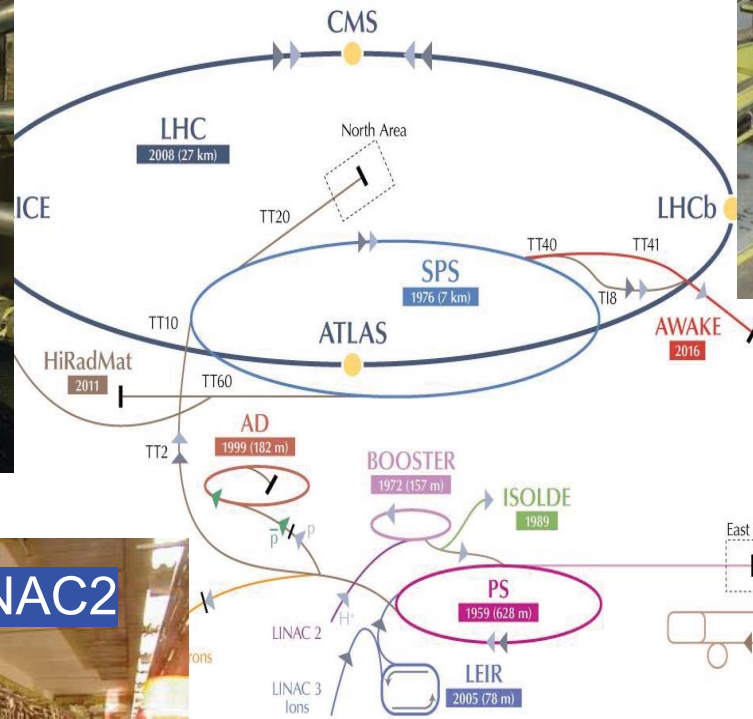
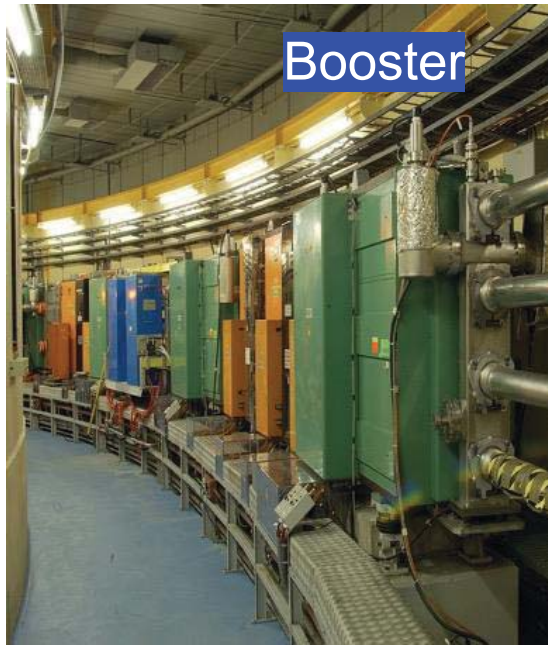
H<sup>-</sup>

SOURCE

Showing the  
Hydrogen  
Plasma



# CERN Accelerator Chain

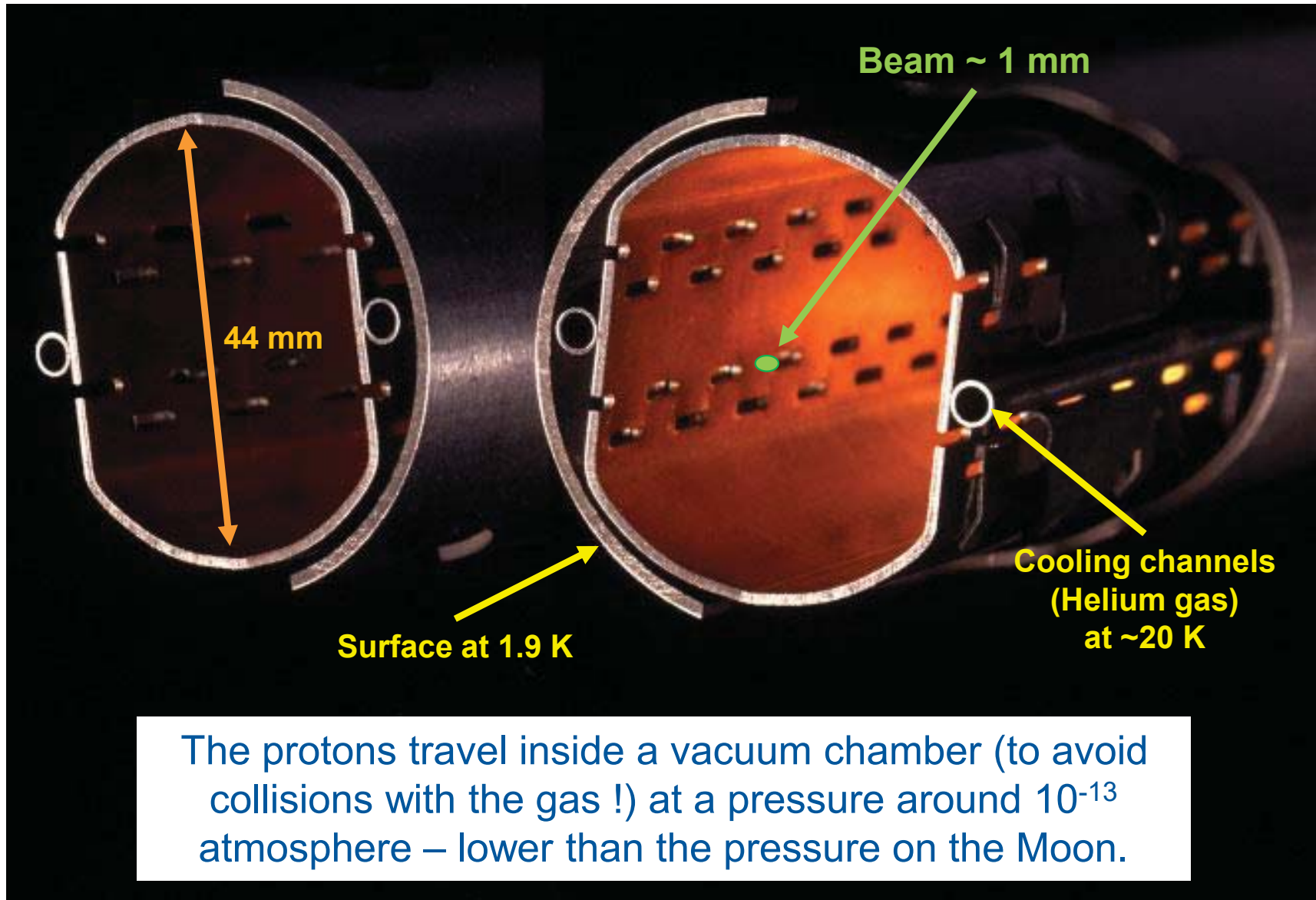


# LHC

- 1232 main dipoles of 15 m each that deviate the beams around the 27 km circumference
- 858 main quadrupoles that keep the beam focused
- 6000 corrector magnets to preserve the beam quality

- Main magnets use superconducting cables
- Operating in superfluid helium at 1.9K

# A Cold and Dark Place



# LHC Beams

The LHC operates with 2 beams of particles that travel in opposite directions.

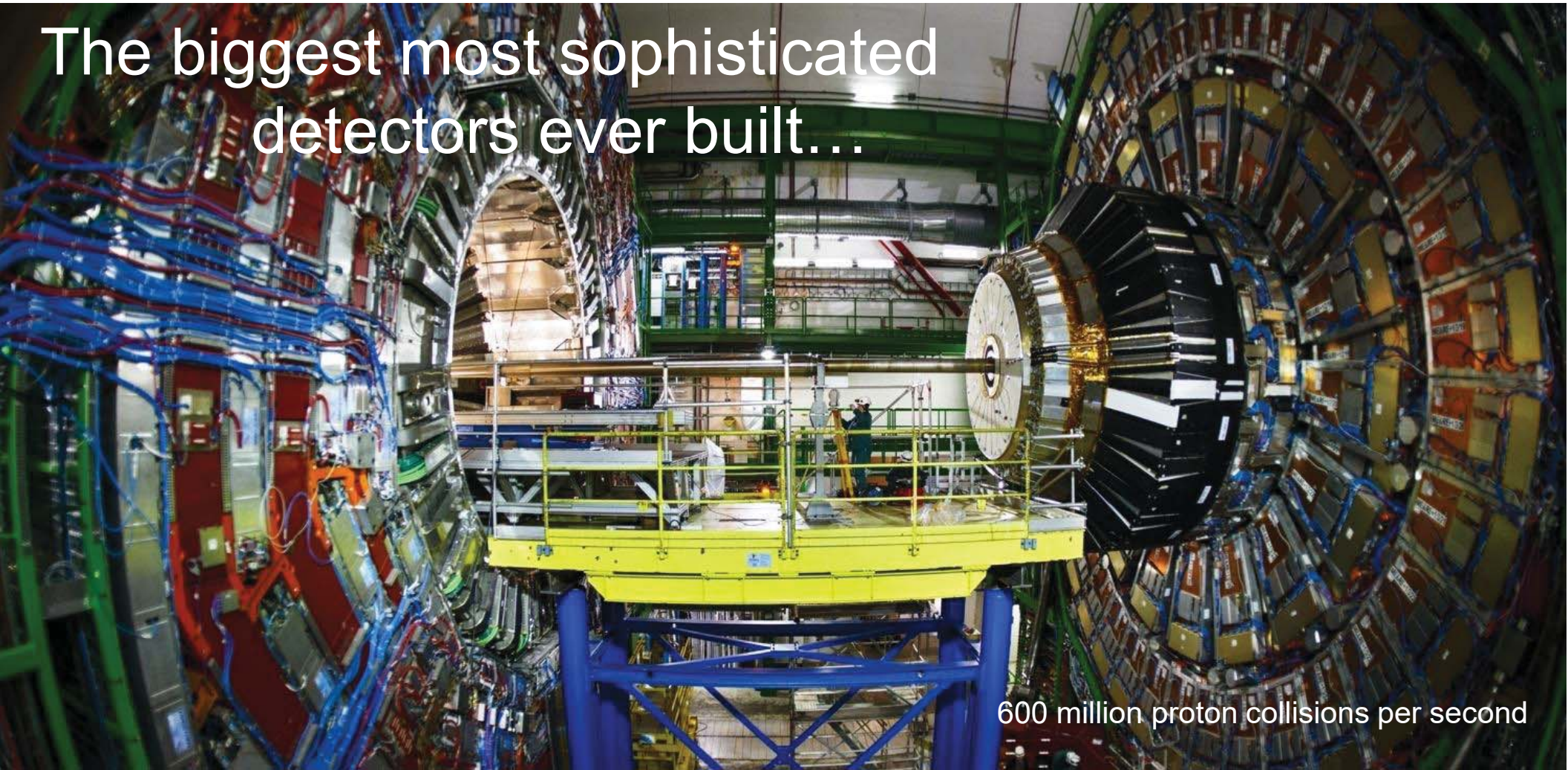
The protons are grouped in small packets called '*bunches*'. We operate typically with around **2000** bunches separated by **7.5 m**.

Each bunch:

- is ~ 30 cm long,
- contains up to around 140 billion protons,
- has its width squeezed to the size of a thin human hair (12 micrometers) at the points where it collides with other bunches inside the experiments.



The biggest most sophisticated  
detectors ever built...



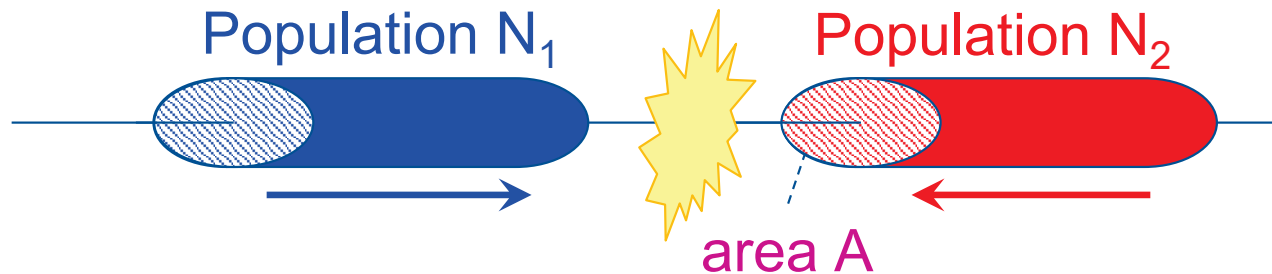
600 million proton collisions per second

# Luminosity

A key parameter for the LHC experiments is the rate of events  $dN/dt$ . For a physics process with cross-section  $\sigma$  it is proportional to the collider Luminosity  $L$ :

$$dN / dt = L \sigma$$

unit of  $L$  :  
 $1/(\text{surface} \times \text{time})$



$$\text{Collision rate} \propto \sigma \times \underbrace{\frac{N_1 \times N_2}{A}}_{\text{Luminosity}} \times \text{encounters/second}$$

**To maximize  $L$  we are trying to squeeze as many particles as possible into the smallest possible volume !**

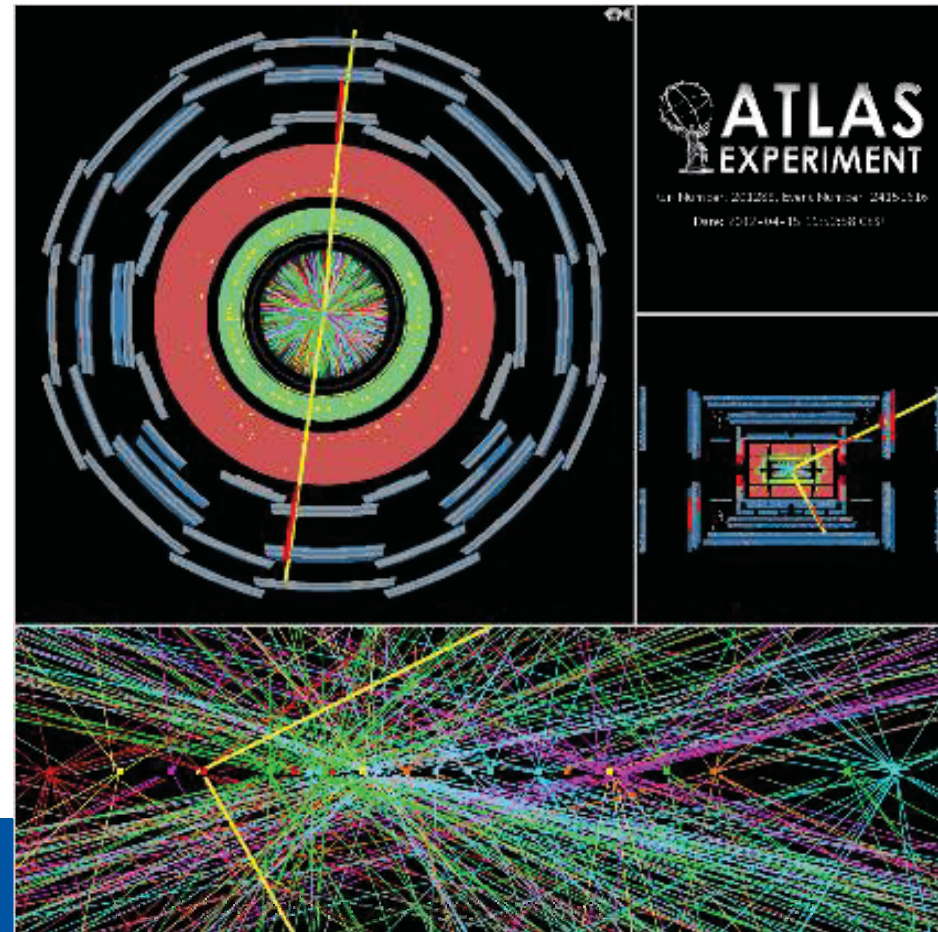
# Luminosity and Collision Rates

At its current performance the LHC produces **1.2 billion** ( $1.2 \times 10^9$ ) proton-proton (pp) collisions **per second** in the ATLAS and CMS experiments.

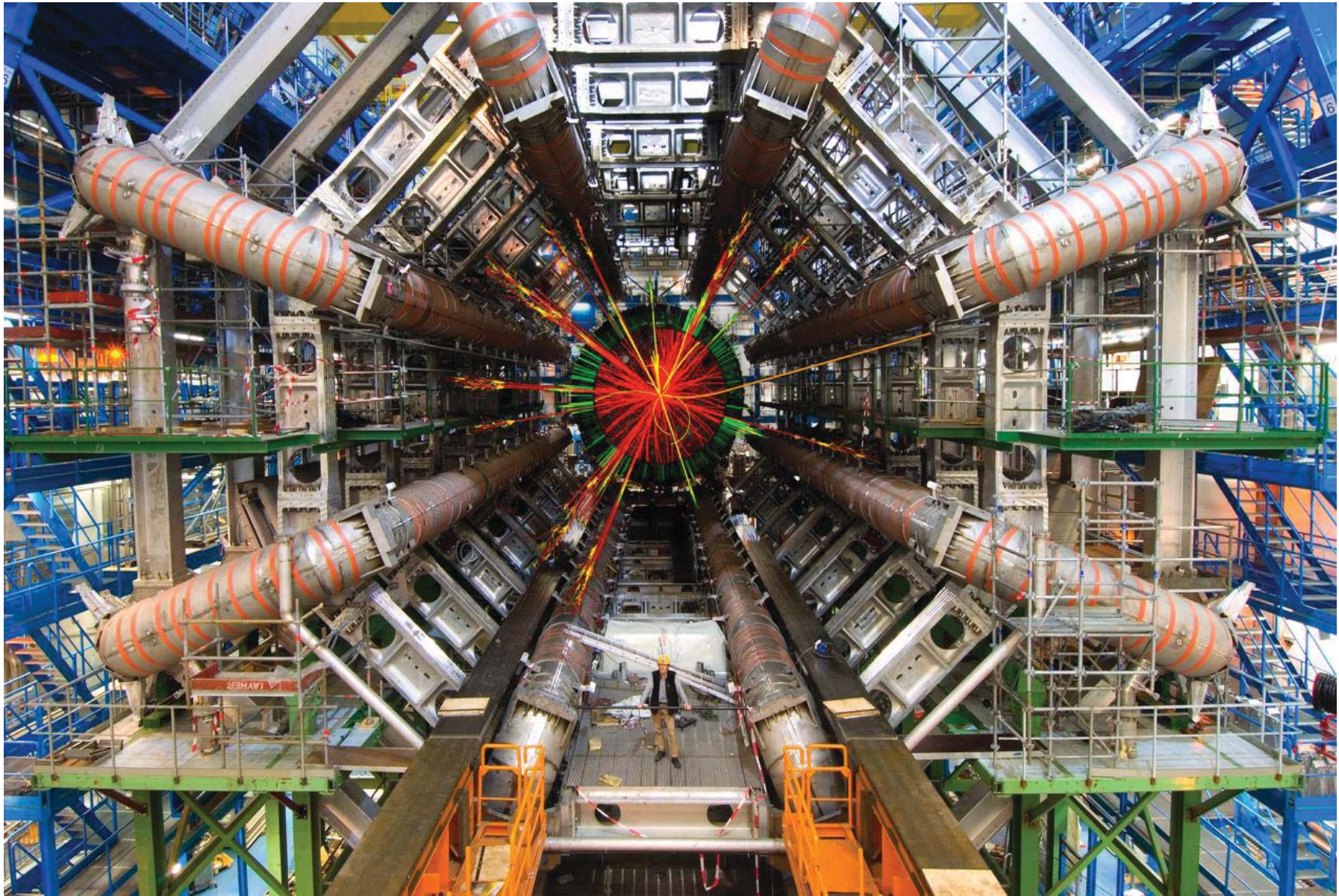
The bunches of protons cross each other **~ 21 million times per second**.

Every time 2 bunches cross there are **~50-60 individual pp collisions** happening at the same time.

The experiments have to filter in real time this huge data stream for interesting physics. They can only store **~1000 out of the 21 million collisions**.



# LHC ATLAS Detector





From the LHC experiments: 1 petabyte of data every day – the equivalent of ~210'000 DVDs  
GRID computing to share with computer centres around the world

The  
**Birthplace**  
of the  
**WORLD WIDE  
WEB**

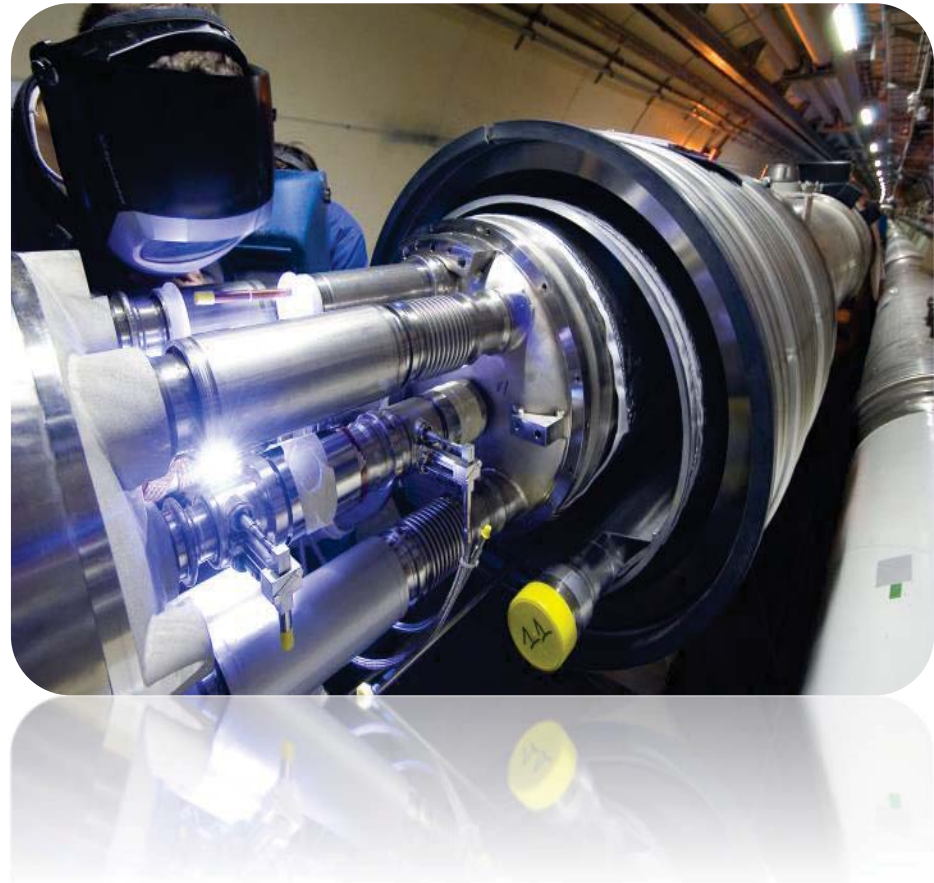
The most global  
computer system in the world...

# Basic Research as an Engine of Applied Research: Spin-Off

- Training location and academic institution
- Application of accelerator technology in medicine (CHUV – FLASH)
- Application of detector technology in medicine (Medipix, crystals)
- Development of high-end technology for industry
- Development of techniques for data communication
- (WWW invented at CERN !)

# The Technology

- Computing/IT
- Vacuum & cryogenics
- Electronics
- Electricity
- Magnets
- Mechanics
- Material Science
- Radiofrequency
- Control Systems
- Etc.

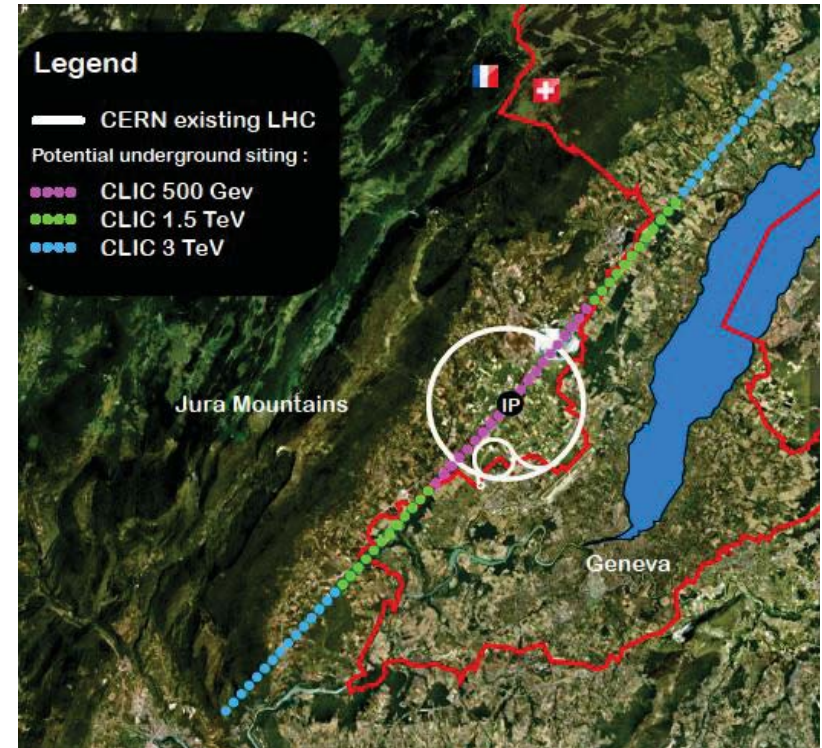
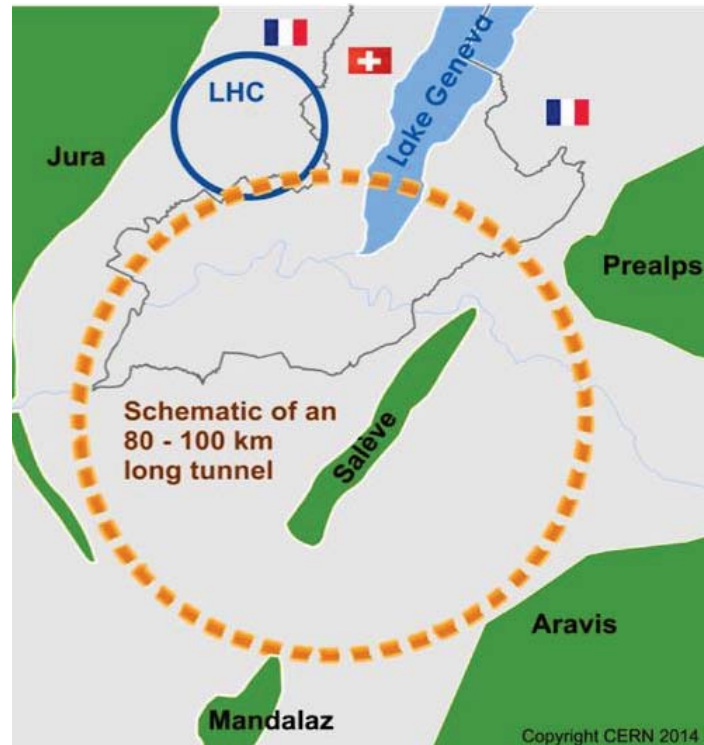


# Discover New Physics

Accelerate particles to even higher energies:  
**Bigger accelerators**

Future Circular Collider: FCC

Linear Collider: CLIC, ILC



# Discover New Physics

Accelerate particles to even higher energies:  
New Technologies

## Plasma Wakefield Acceleration

→ Obtain ~1000 factor stronger acceleration with same size of machine.



VOLUME 45, NUMBER 4      PHYSICAL REVIEW LETTERS      23 JULY 1979

**Laser Electron Accelerator**      1979

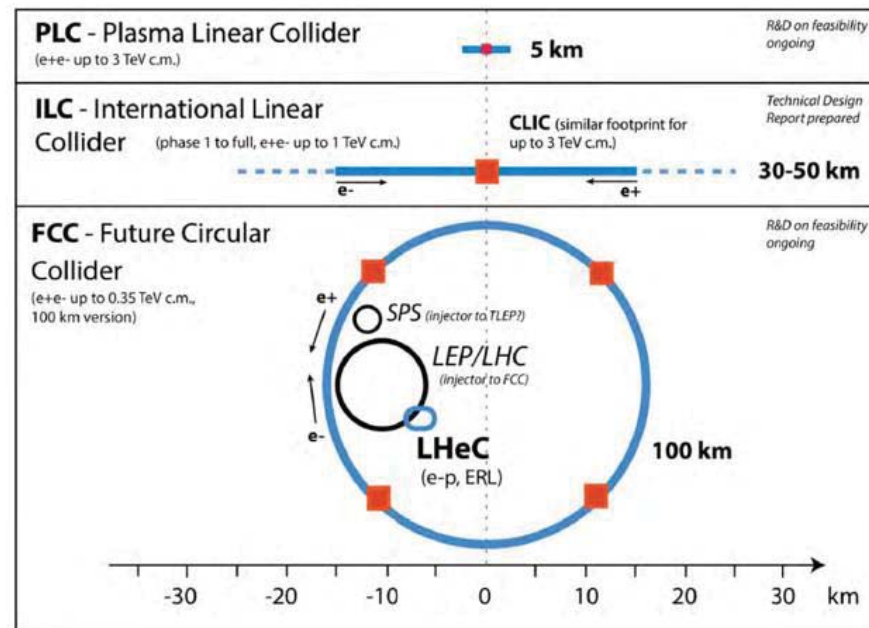
T. Tajima and J. M. Dawson  
Department of Physics, University of California, Los Angeles, California 90024  
(Received 9 March 1979)

An intense electromagnetic pulse can create a weak plasma oscillation through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density  $10^{10}$  W/cm<sup>2</sup> shone on plasmas of densities  $10^{18}$  cm<sup>-3</sup> can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

Collective plasma accelerators have recently received considerable theoretical and experimental investigation. Earlier Fermi<sup>1</sup> and McMillan<sup>2</sup> considered cosmic-ray particle acceleration by moving magnetic fields<sup>3</sup> or electromagnetic waves.<sup>4</sup> In terms of the realizable laboratory technology for collective accelerators, present-day electron beams<sup>5</sup> yield electric fields of  $\sim 10^7$  V/cm and power densities of  $10^{11}$  W/cm<sup>2</sup>.

the wavelength of the plasma waves in the wake:  
$$L_p = \lambda_p / 2 = c / \omega_p. \quad (2)$$

An alternative way of exciting the plasmon is to inject two laser beams with slightly different frequencies (with frequency difference  $\Delta\omega \sim \omega_p$ ) so that the beat distance of the packet becomes  $2\pi c / \Delta\omega$ . The mechanism for generating the wakes can be simply seen by the following approximate



... but before handing over to Patric...

# Working at CERN: How?



<https://careers.cern>

Check out: <https://careers.cern/student-and-graduate-recruitment-processes>  
And <https://careers.cern/tips-applying>

# Working at CERN: what do I get?

- Being at the forefront of technology and physics
- Collaborating with multicultural and multidisciplinary teams, without political or religious barriers
- Following experts in their technical domain
- Being part of a dynamic environment with training opportunities
- Making valuable and long-lasting contacts from all over Europe
- Learning languages: CERN is a bi-lingual organization (English and French)
- An attractive remuneration package
- A unique experience!



# Follow us! "CERNJobs"

