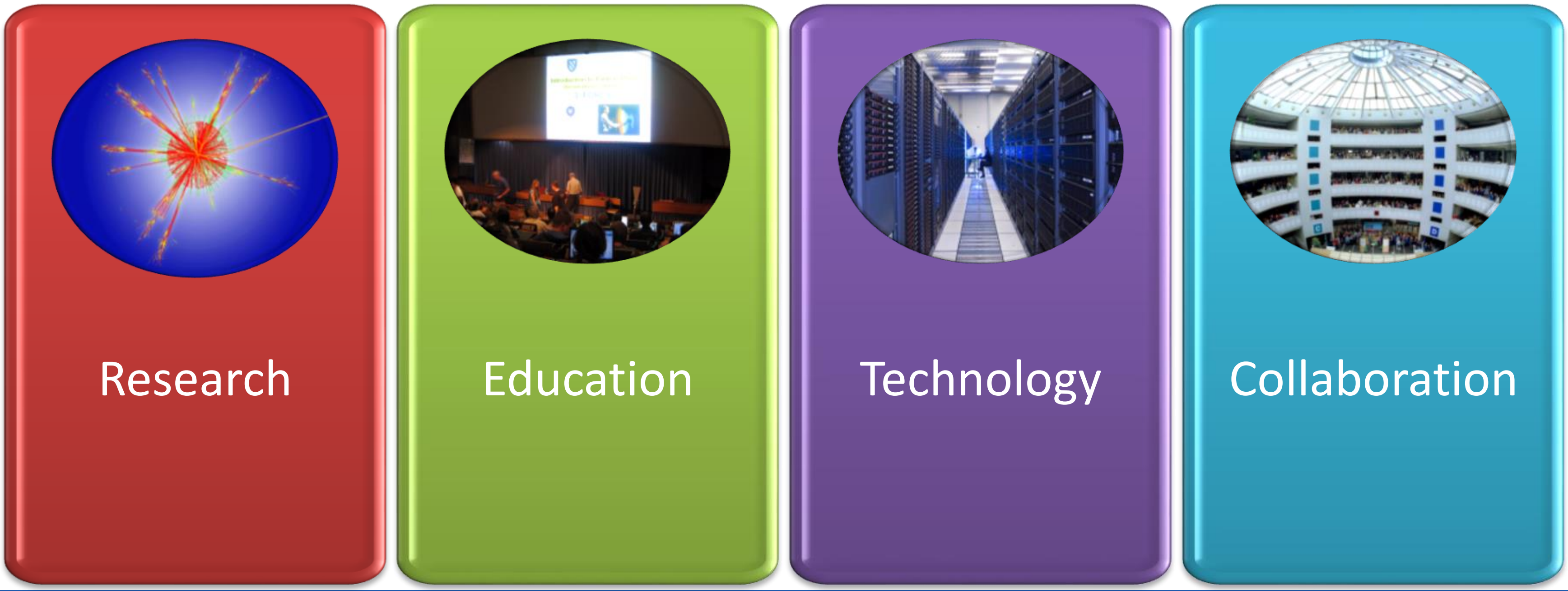
CERN. Opportunities at the cutting edge of technology

Edda Gschwendtner, 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?

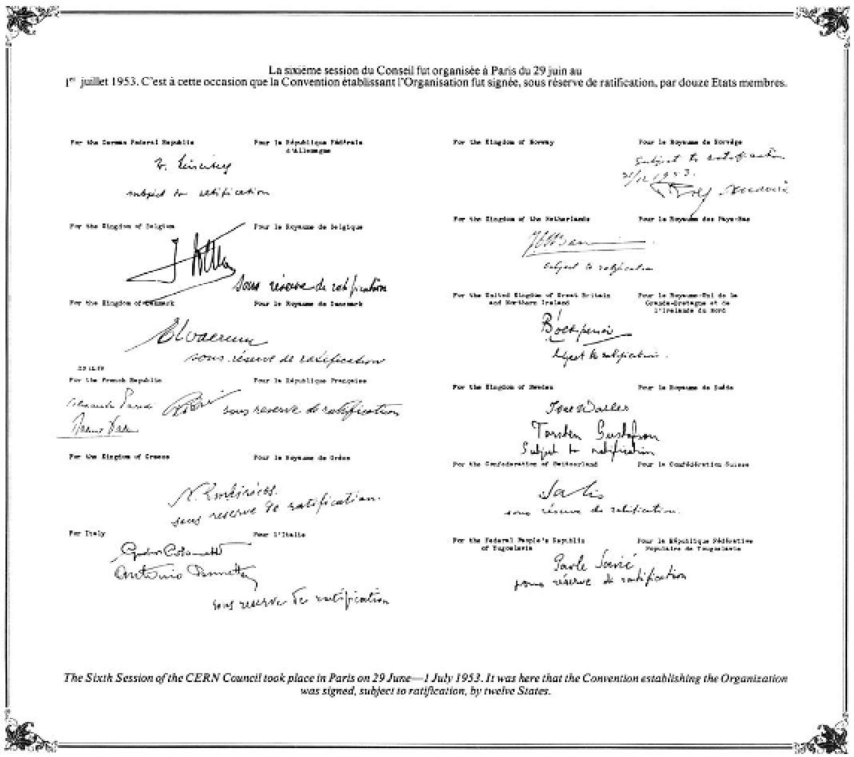
Sur le terrain du futur institut nucléaire

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



La sixième session du Conseil fut organisée à Paris du 29 juin au 1er juillet 1953. C'est à cette occasion que la Convention établissant l'Organisation fut signée, sous réserve de ratification, par douze Etats membres.

For the German Federal Republic — Pour la République Fédérale d'Allemagne

For the Kingdom of Belgium — Pour le Royaume de Belgique

For the Kingdom of Denmark — Pour le Royaume de Danemark

For the French Republic — Pour la République Française

For the Kingdom of Greece — Pour le Royaume de Grèce

For Italy — Pour l'Italie

For the Kingdom of Norway — Pour le Royaume de Norvège

For the Kingdom of the Netherlands — Pour le Royaume des Pays-Bas

For the United Kingdom of Great Britain and Northern Ireland — Pour le Royaume-Uni de la Grande-Bretagne et de l'Irlande du Nord

For the Kingdom of Sweden — Pour le Royaume de Suède

For the Confederation of Switzerland — Pour la Confédération Suisse

For the Federal People's Republic of Yugoslavia — Pour la République Fédérative Populaire de Yougoslavie

The Sixth Session of the CERN Council took place in Paris on 29 June—1 July 1953. It was here that the Convention establishing the Organization was signed, subject to ratification, by twelve States.

- 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?

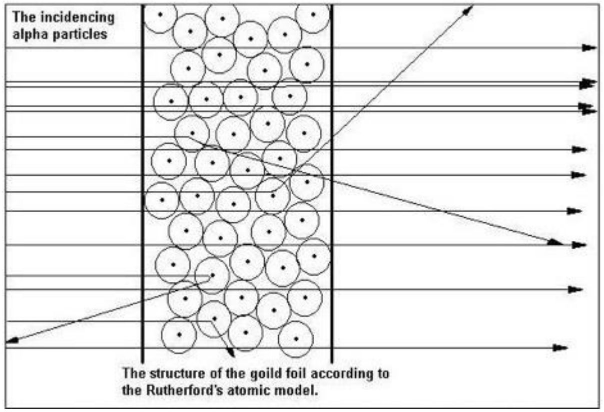
Why Do We Need Huge Accelerators?

- To study the smallest building blocks of matter

Pattern of the scattered light
→ structure of the hand.

Visible light ~ 1 micrometer = 0.001mm ~ 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.

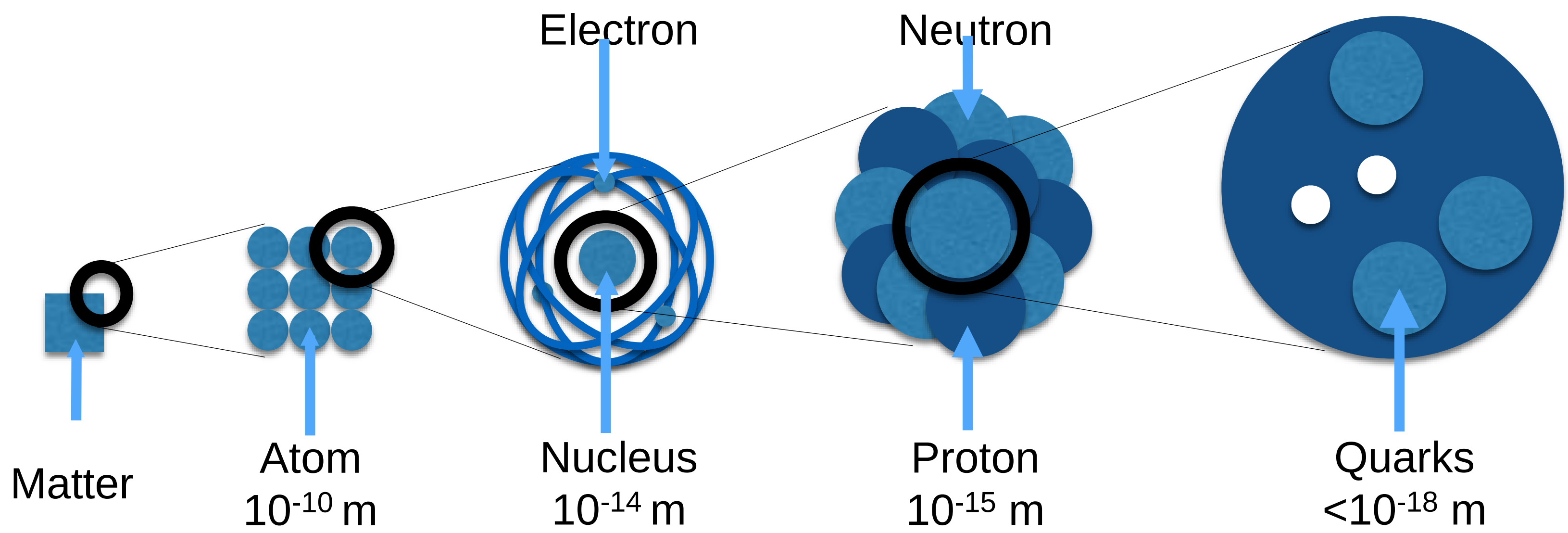
Higher particle energy → smaller wavelength → smaller structures

Accelerators are Super-Microscopes !

Why Do We Need Huge Accelerators?

- To study the smallest building blocks of matter

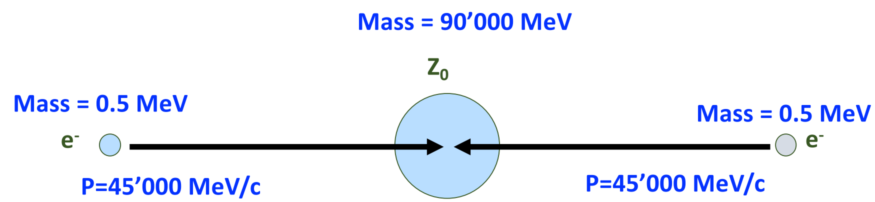
Optical Microscope: 10^{-6} m
Radioactive Source: 10^{-14} m
LHC: $<10^{-21}$ m



Why Do We Need Huge Accelerators?

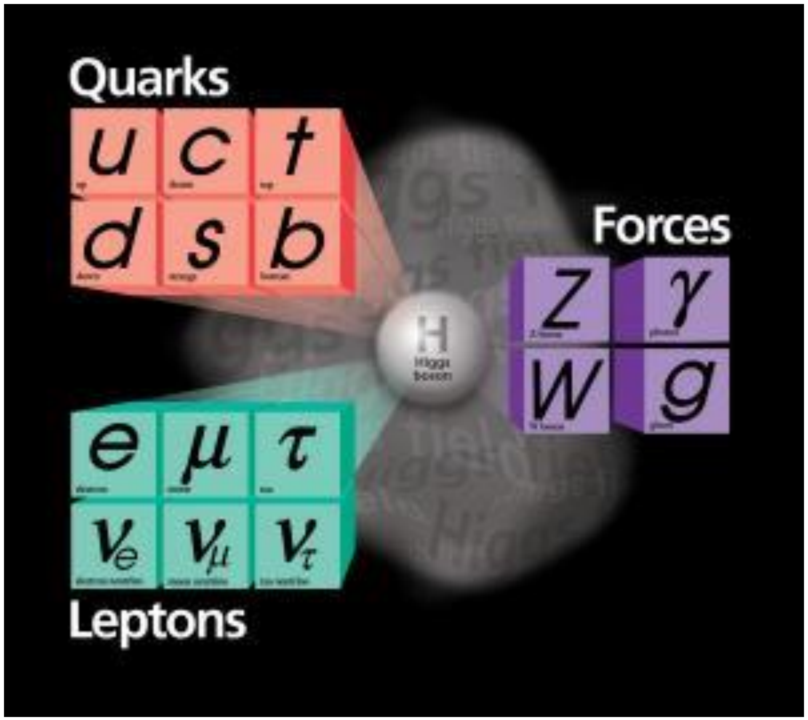
- To produce massive particles (e.g. W, Z, top, Higgs) that are either unknown or predicted by theories.
  - The study of the smallest building blocks of matter with high energy particle colliders and the production of new massive particles is connected.

$$E = mc^2$$



➔ 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.

$$\mathcal{L}_{SM} = \underbrace{\frac{1}{4}\mathbf{W}_{\mu\nu}\cdot\mathbf{W}^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - \frac{1}{4}G^a_{\mu\nu}G^{\mu\nu}_a}_{\text{kinetic energies and self-interactions of the gauge bosons}}$$

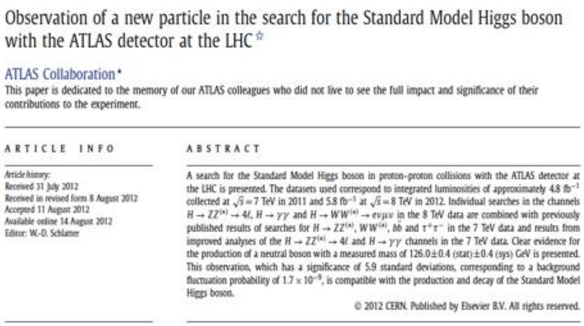
$$+ \underbrace{\bar{L}\gamma^\mu\left(i\partial_\mu - \frac{1}{2}g\tau\cdot\mathbf{W}_\mu - \frac{1}{2}g'YB_\mu\right)L + \bar{R}\gamma^\mu\left(i\partial_\mu - \frac{1}{2}g'YB_\mu\right)R}_{\text{kinetic energies and electroweak interactions of fermions}}$$

$$+ \underbrace{\frac{1}{2}\left|\left(i\partial_\mu - \frac{1}{2}g\tau\cdot\mathbf{W}_\mu - \frac{1}{2}g'YB_\mu\right)\phi\right|^2 - V(\phi)}_{W^\pm, Z, \gamma \text{ and Higgs masses and couplings}}$$

$$+ \underbrace{g''(\bar{q}\gamma^\mu T_a q)G^a_\mu}_{\text{interactions between quarks and gluons}} + \underbrace{(G_1\bar{L}\phi R + G_2\bar{L}\phi_c R + h.c.)}_{\text{fermion masses and couplings to Higgs}}$$

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 ☆

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

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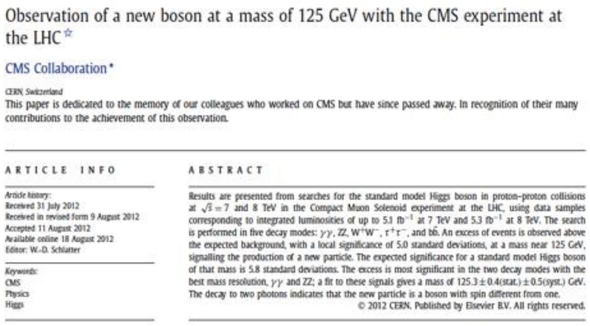
ABSTRACT

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 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.



Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

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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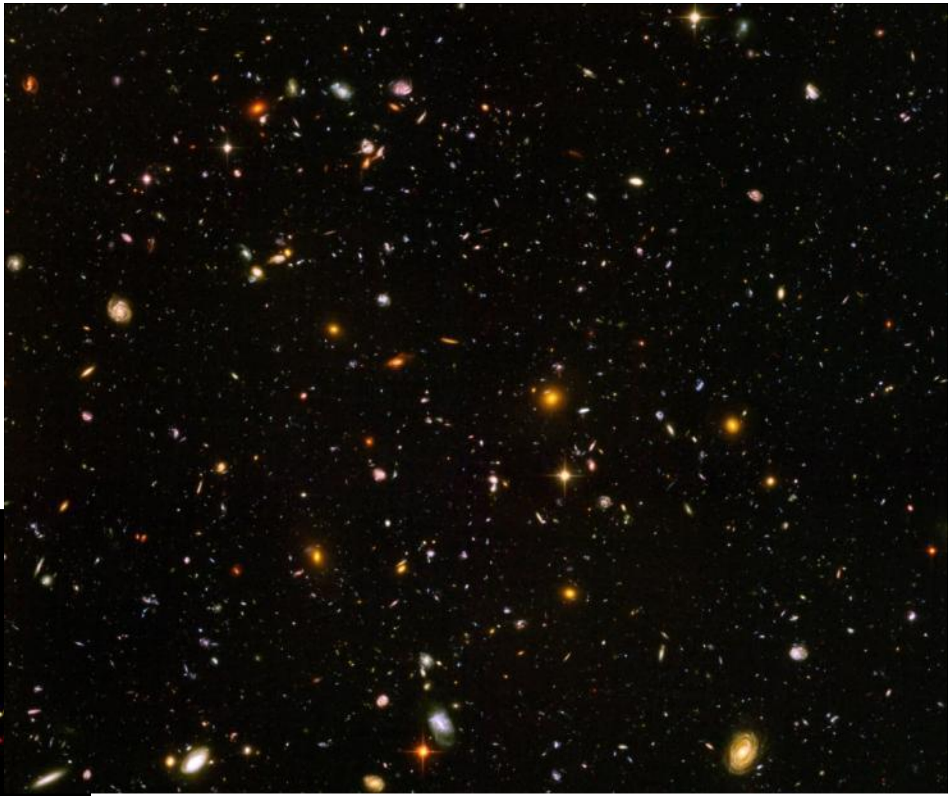
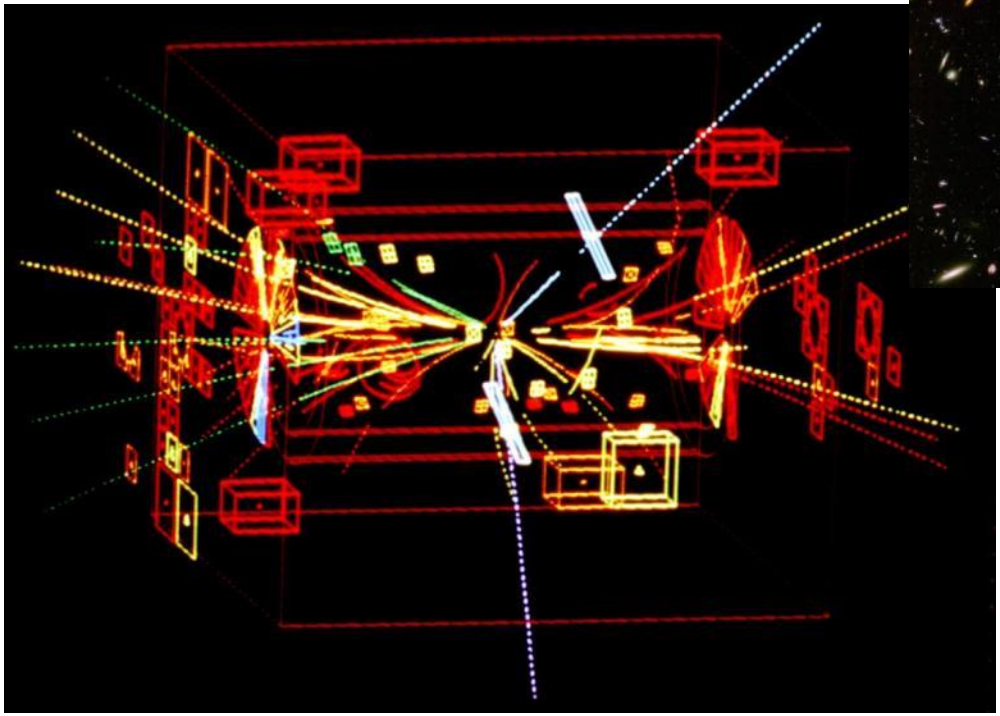
ABSTRACT

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 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, and $b\bar{b}$. 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 $125.3 \pm 0.4(\text{stat.}) \pm 0.5(\text{syst.})$ GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

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**"

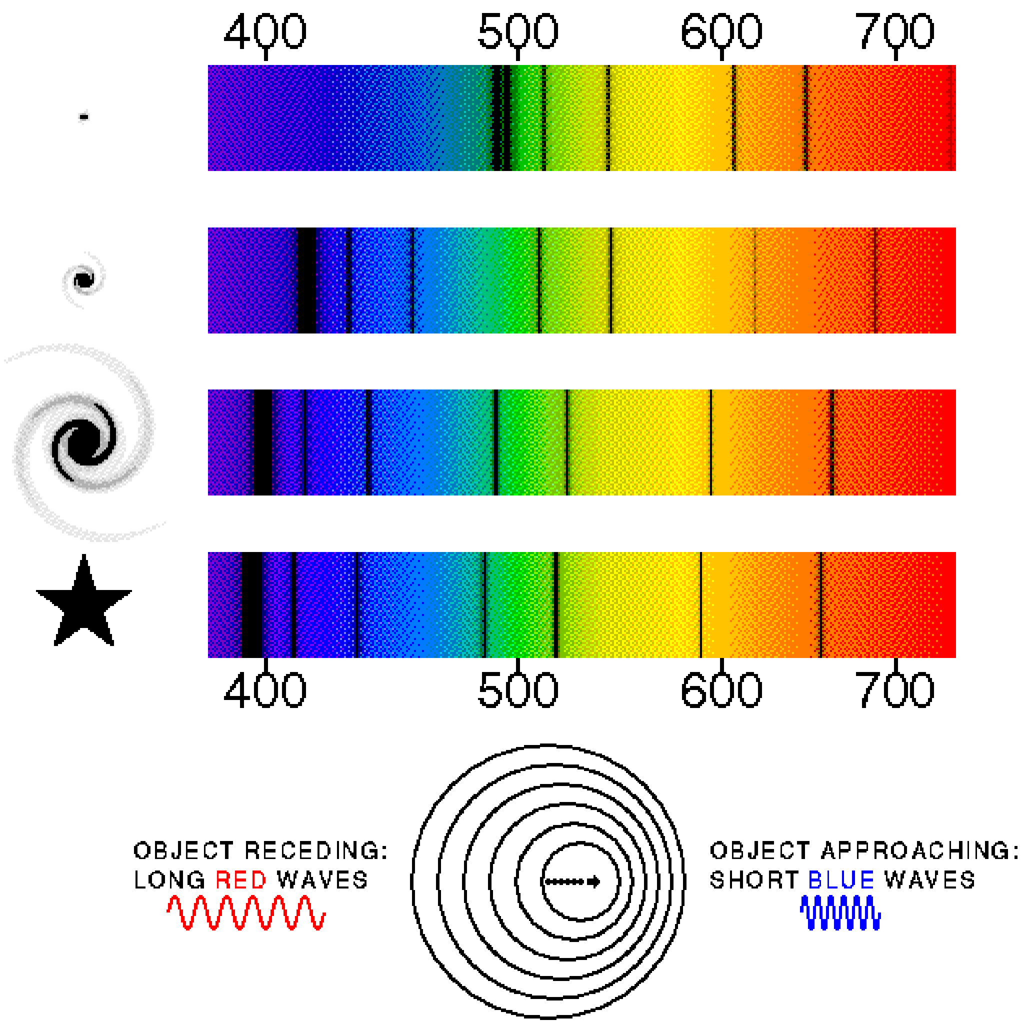
How is cosmology connected…





… with particle physics?

Particle Physics and Cosmology



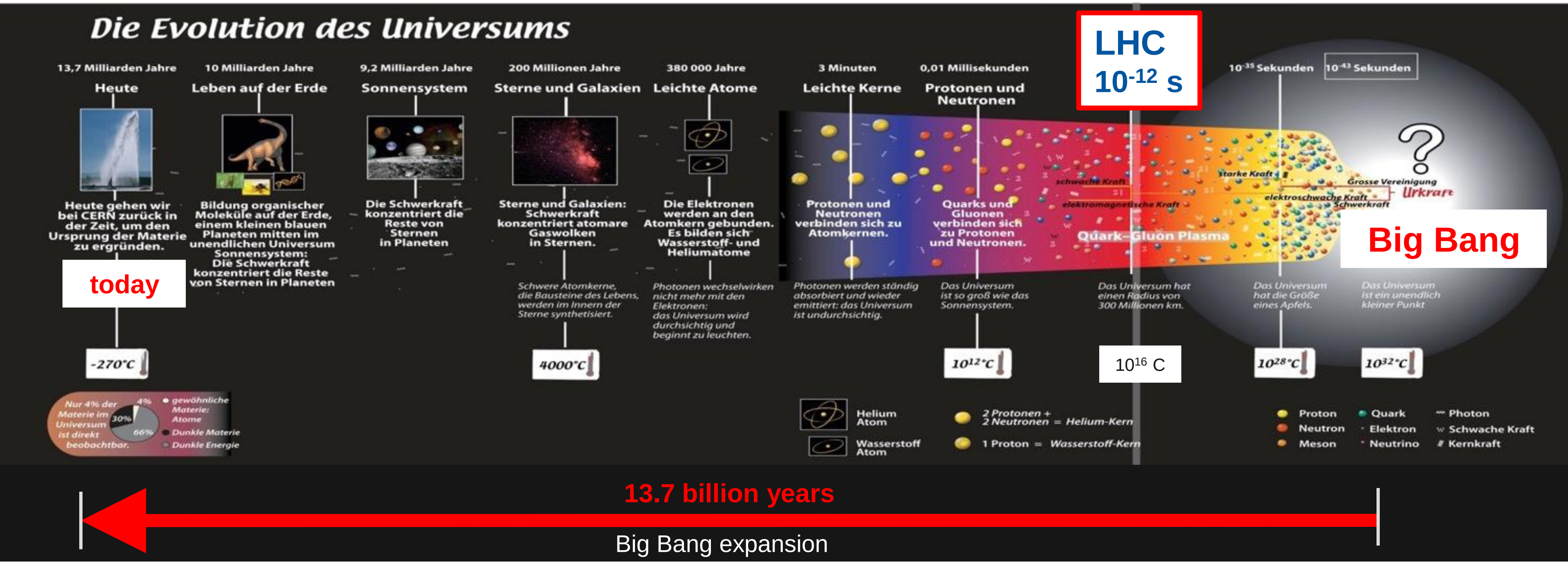
In 1929 Edwin Hubble discovered that galaxies are moving away at great speed.

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.

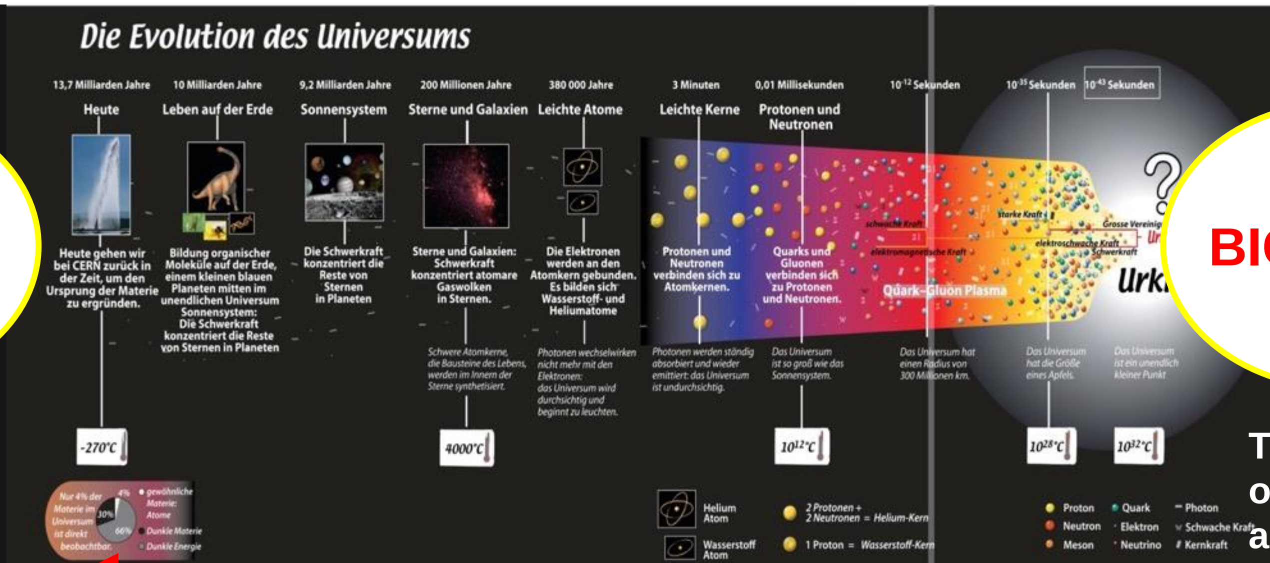
What is the Origin of the Universe?

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



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

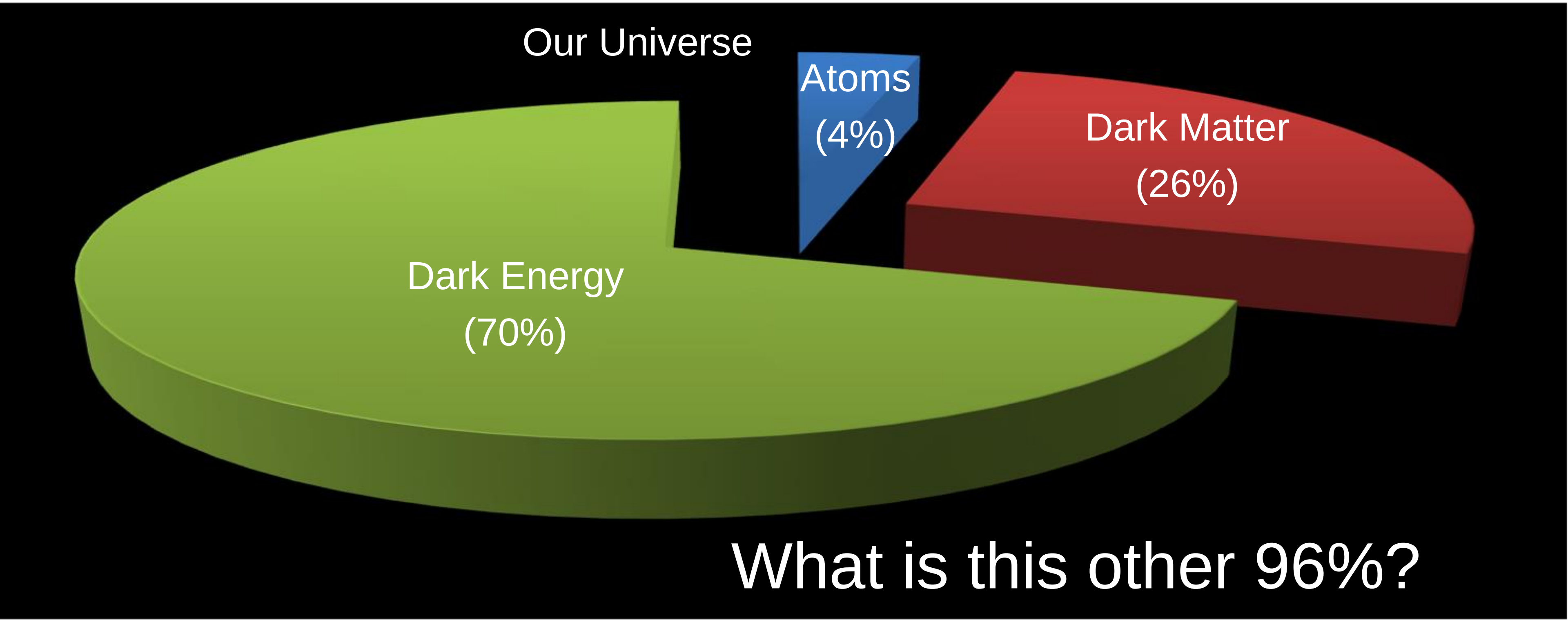
BIG BANG

Only matter survives

The same amount of matter and antimatter was created

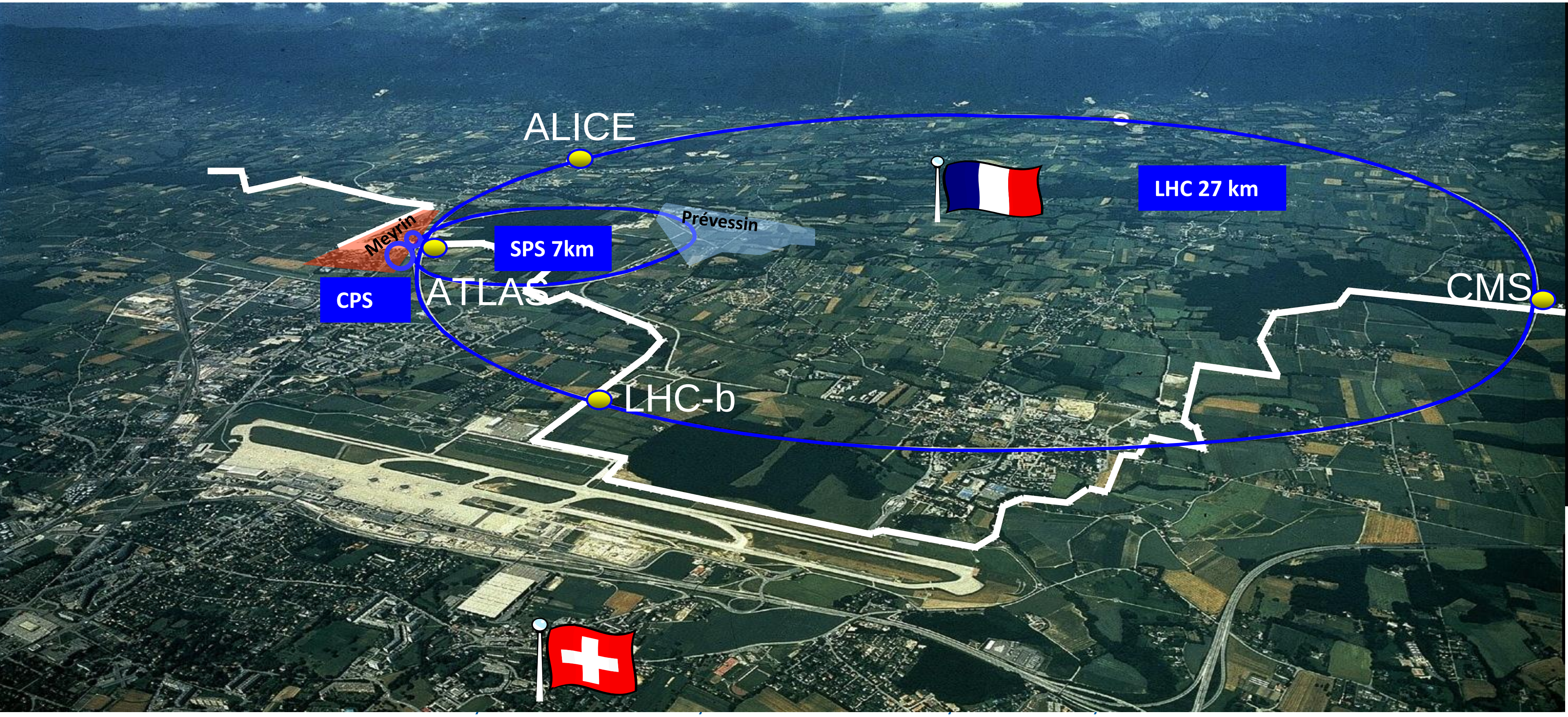
Why?

More Questions ....



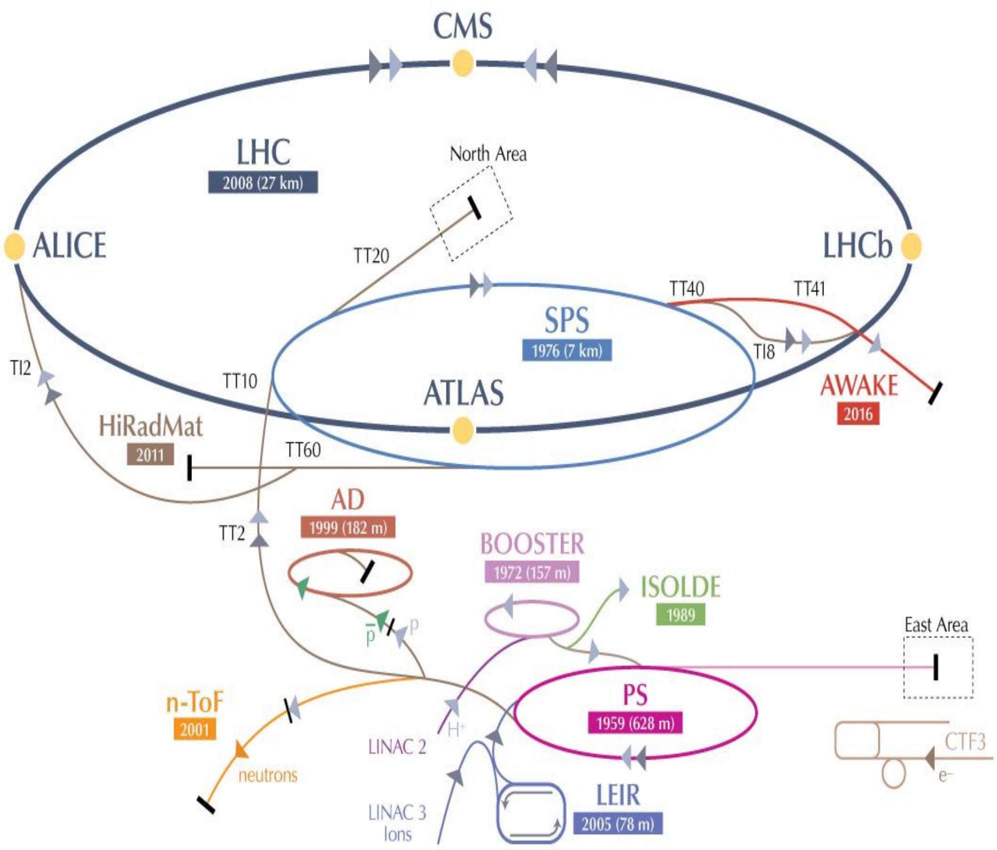
How…?

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

CERN

Where it all Begins

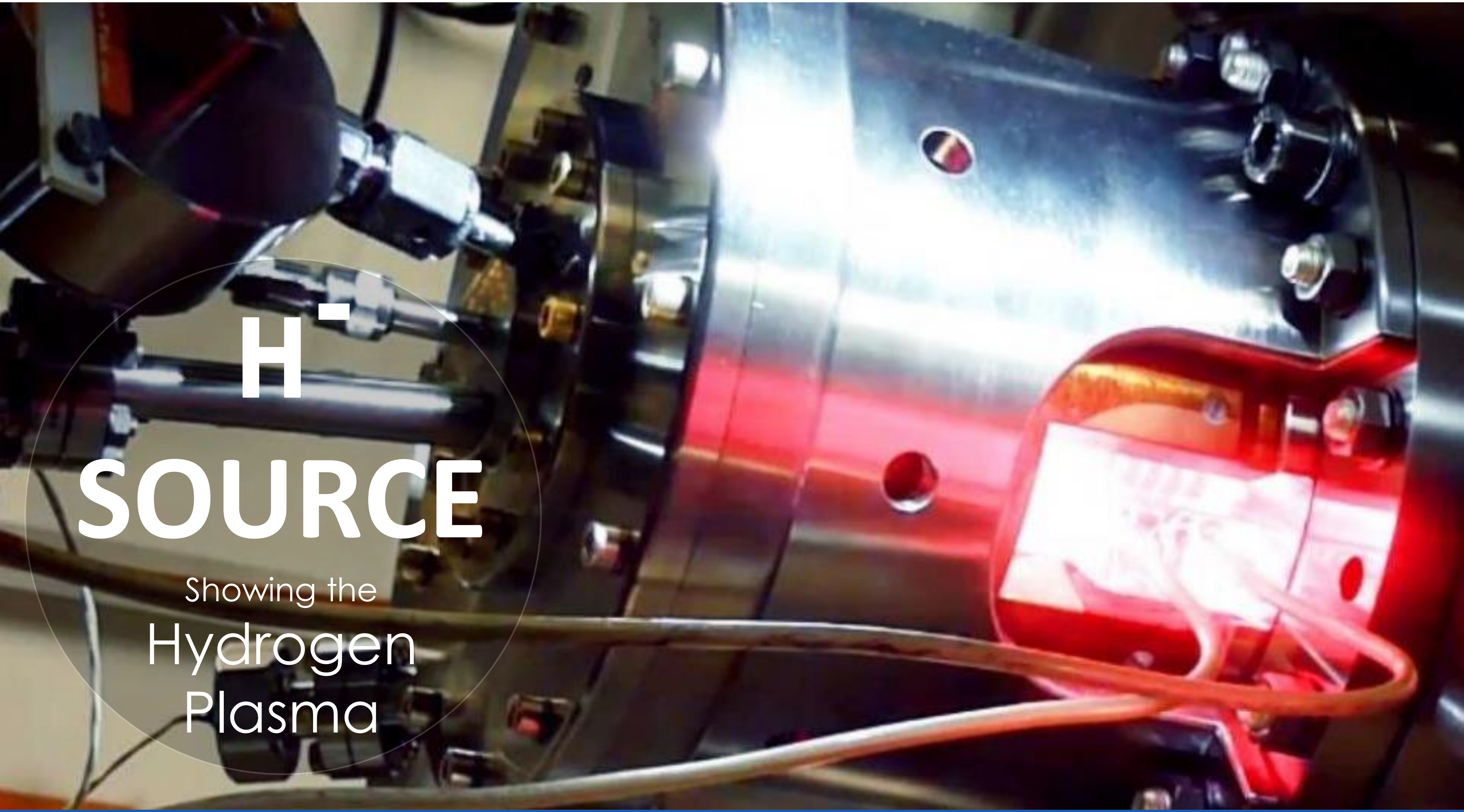
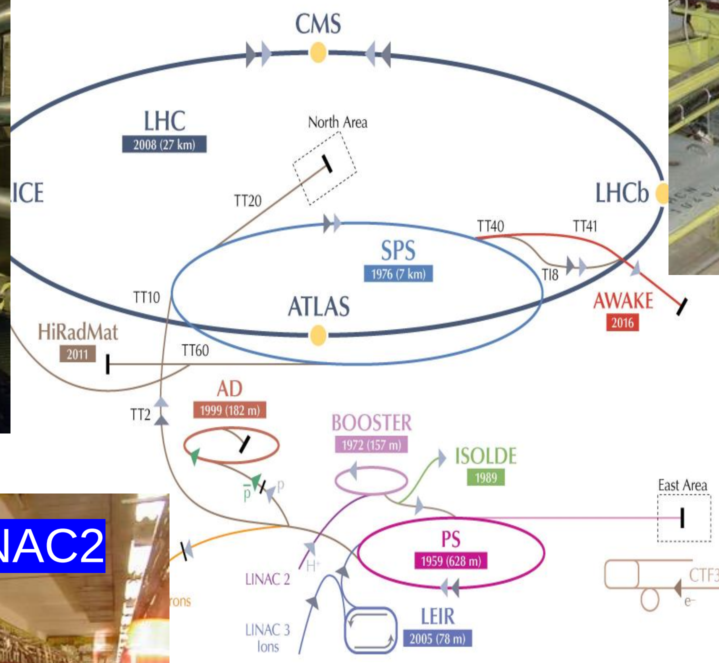
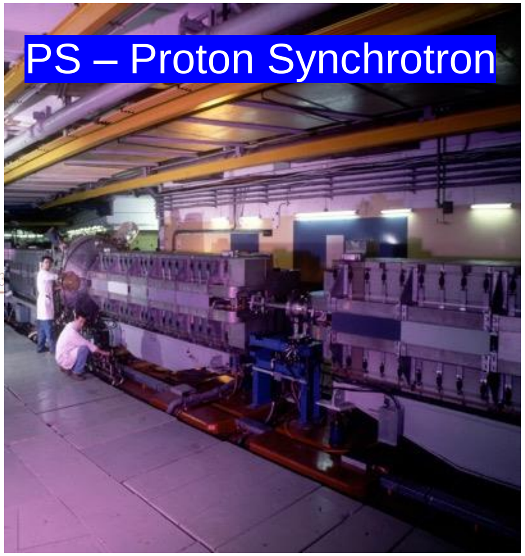


Image credit: CERN

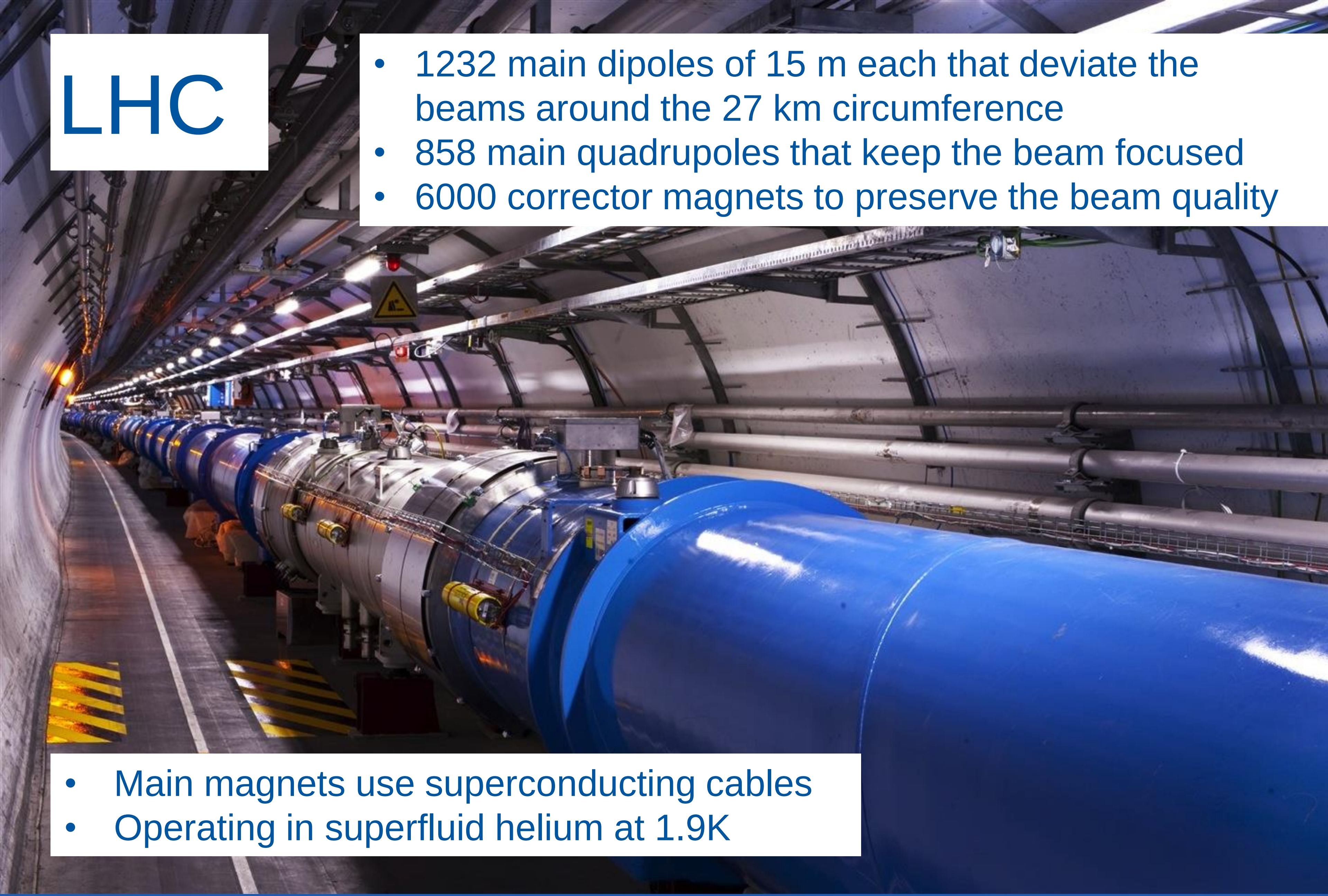
CERN Accelerator Chain





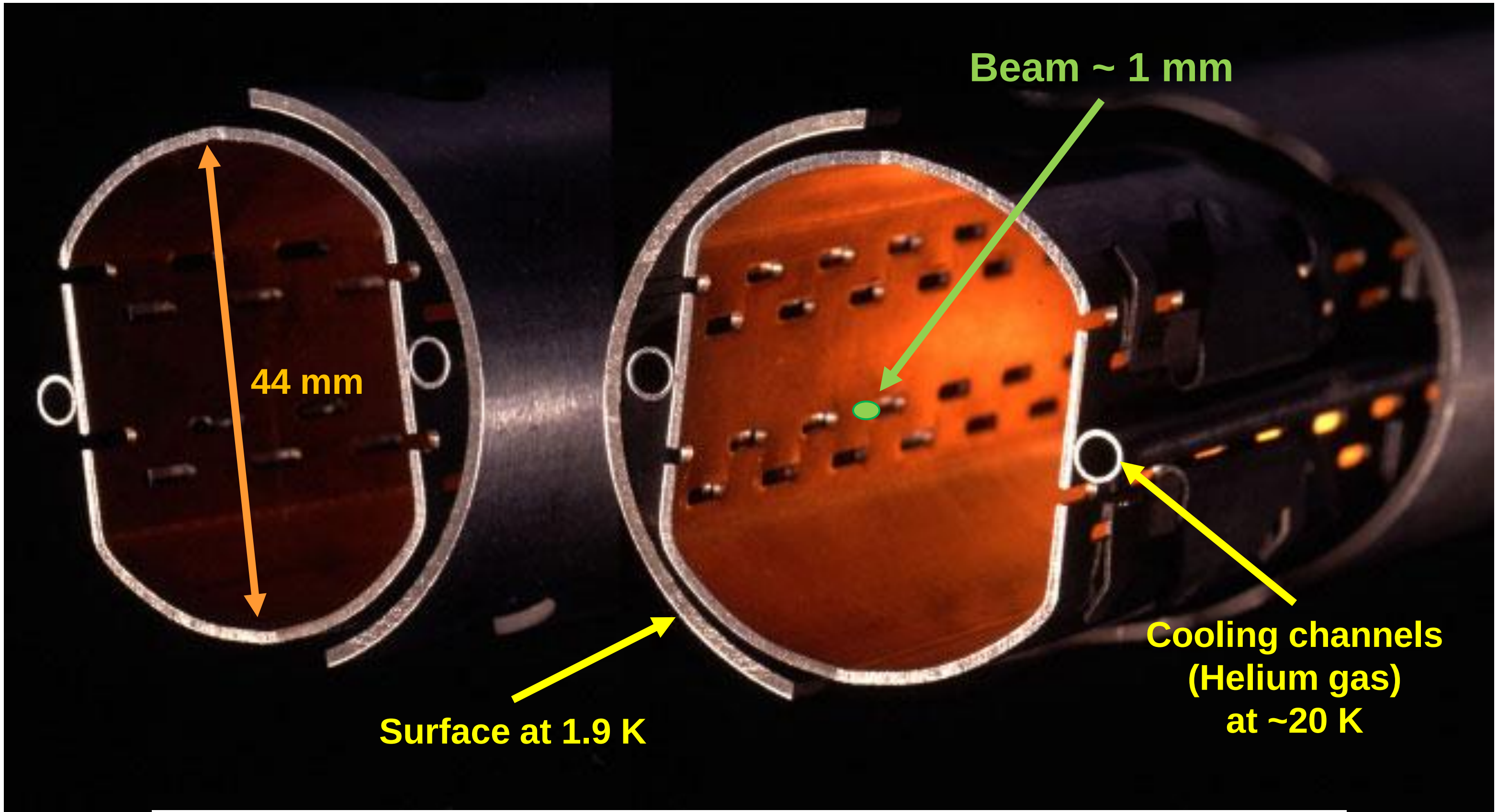
LHC

- 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



The protons travel inside a vacuum chamber (to avoid collisions with the gas !) at a pressure around 10^{-13} atmosphere – lower than the pressure on the Moon.

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…

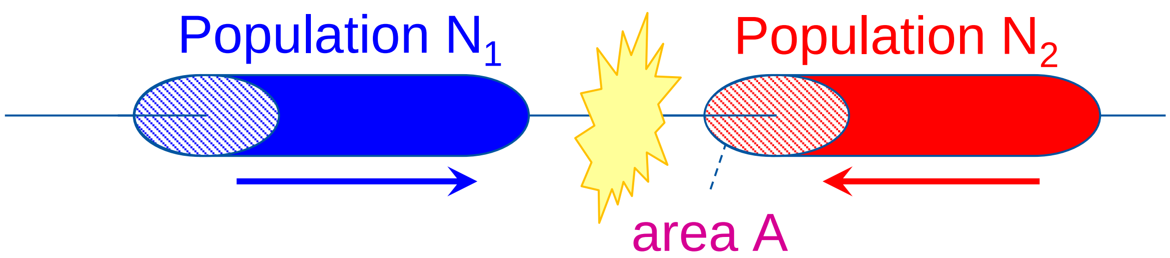
600 million proton collisions per second

Luminosity

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

$$dN / dt = L\sigma$$

unit of L :
1/(surface × time)



$$\text{Collision rate} \propto \sigma \times \underbrace{\frac{N1 \times N2}{A} \times \text{encounters/second}}_{\textit{Luminosity}}$$

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

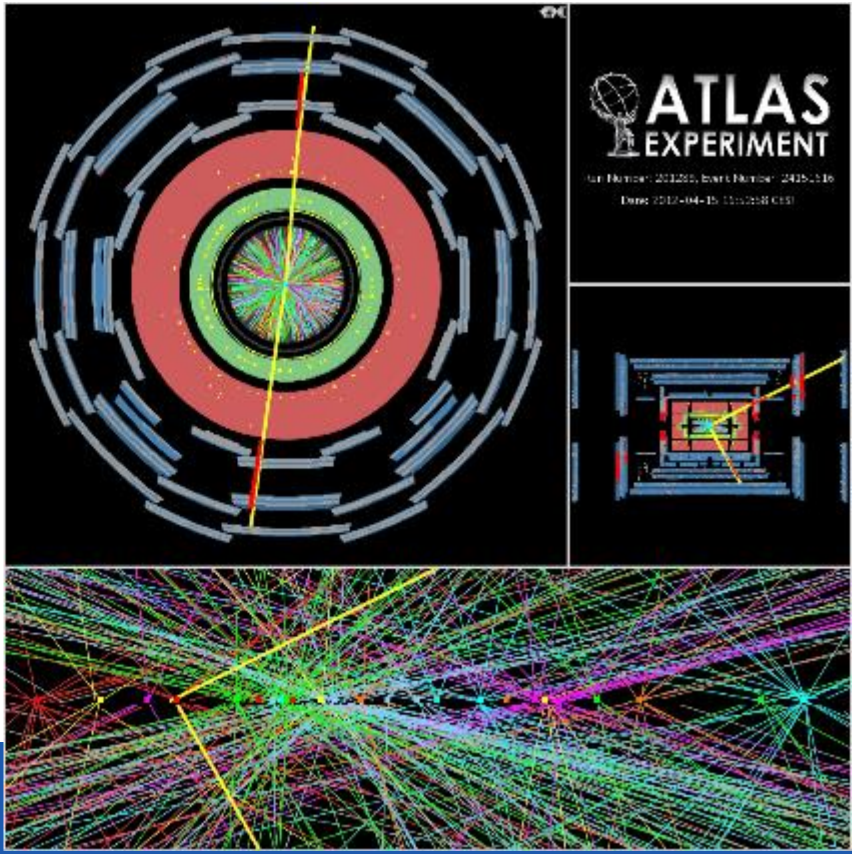
Luminosity and Collision Rates

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

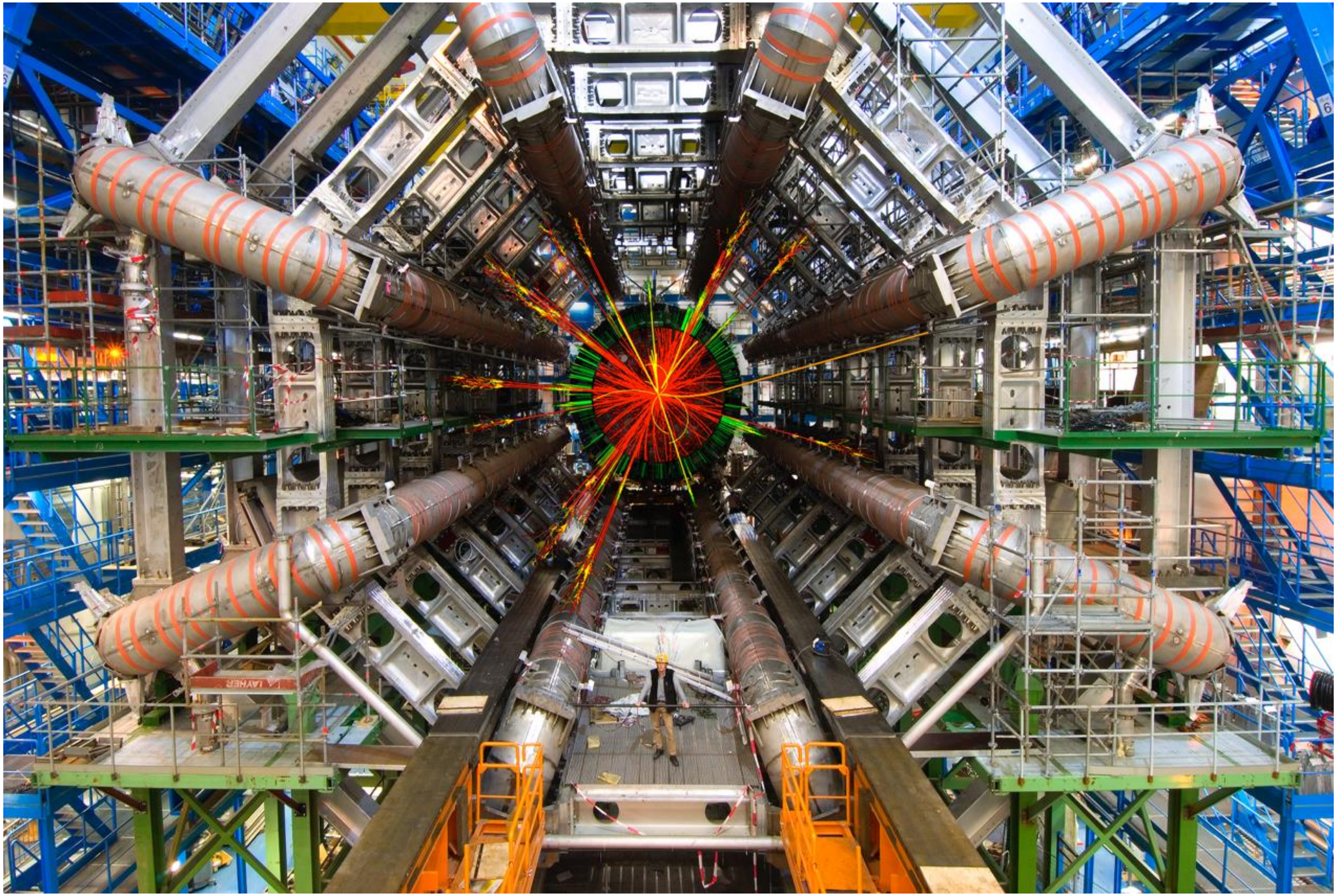
The bunches of protons cross each other **~ 21 million times per second**.

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

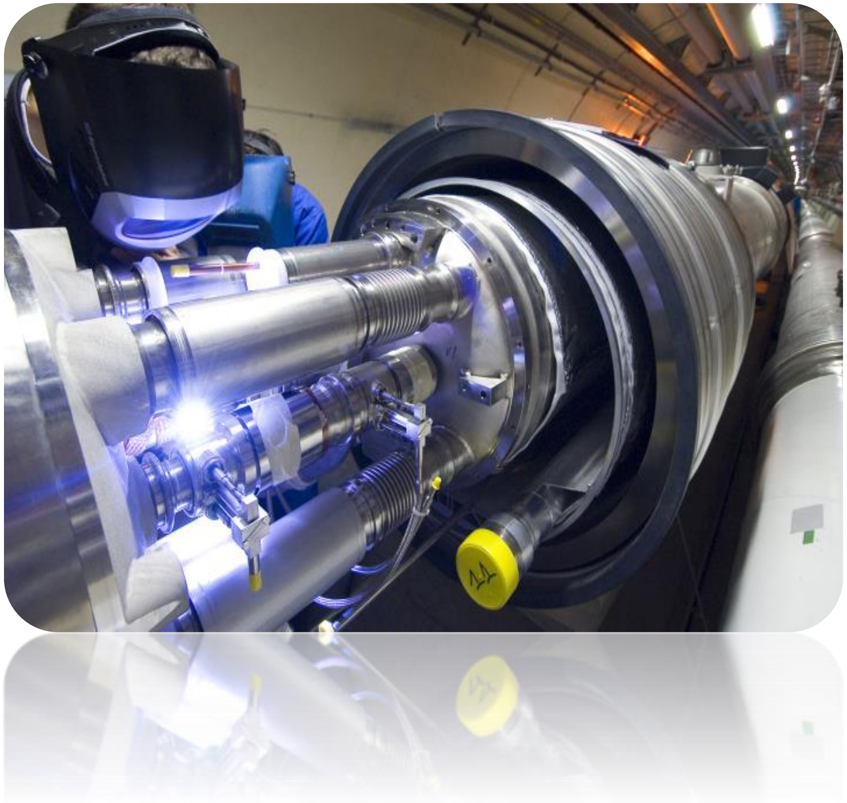
The most global computer system in the world…

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

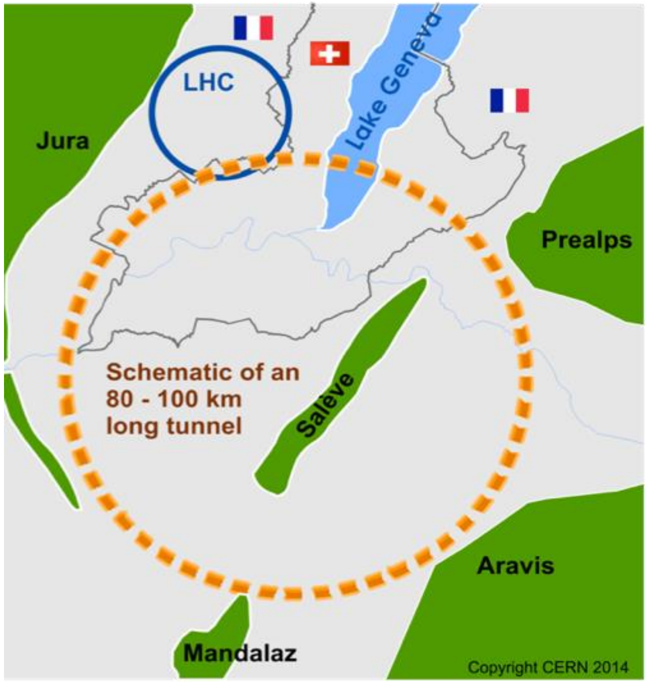
- Computing/IT
- Vacuum & cryogenics
- Electronics
- Electricity
- Magnets
- Mechanics
- Material Science
- Radiofrequency
- Control Systems
- Etc.

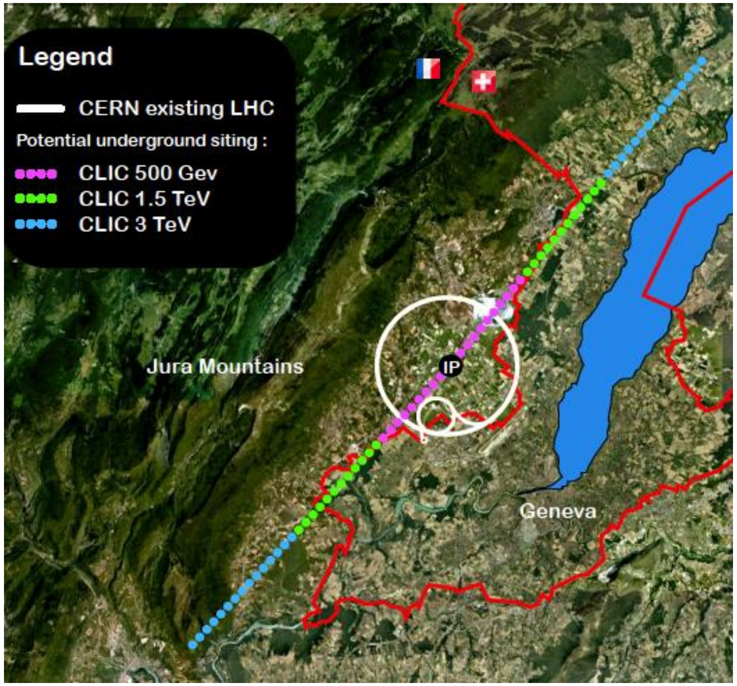


Discover New Physics

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

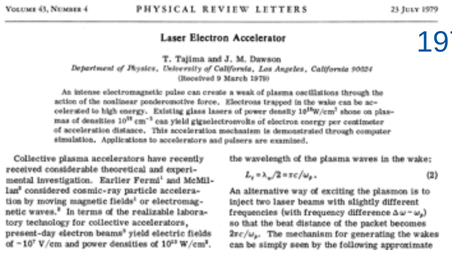
- Future Circular Collider: FCC
- Linear Collider: CLIC, ILC





Discover New Physics

1979



VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

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Department of Physics, University of California, Los Angeles, California 90024

(Received 9 March 1979)

An intense electromagnetic pulse can create a weak of plasma oscillations 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^{18}W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} 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[1] and McMillan[2] considered cosmic-ray particle acceleration by moving magnetic fields[1] or electromagnetic waves.[2] In terms of the realizable laboratory technology for collective accelerators, present-day electron beams[3] yield electric fields of ~10^7 V/cm and power densities of 10^{13} W/cm^3.

the wavelength of the plasma waves in the wake:

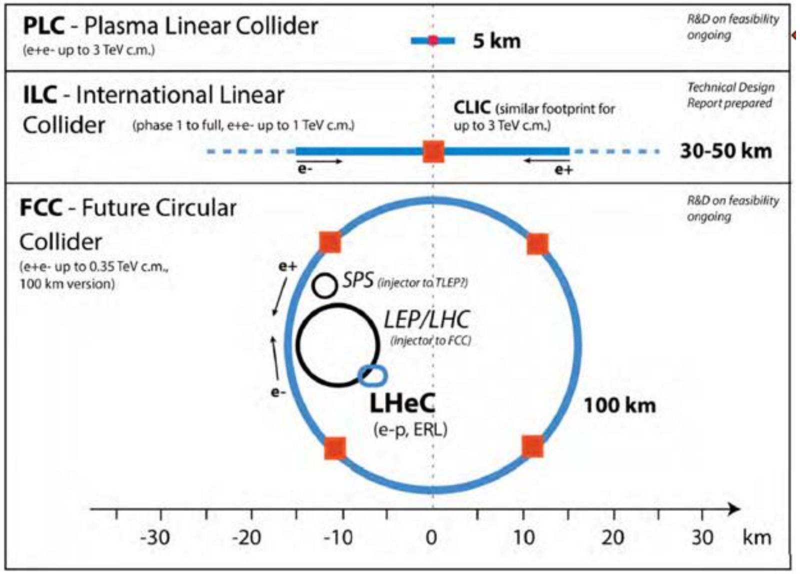
$$L_t = \lambda_w/2 = \pi c/\omega_p. \quad (2)$$

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 $2\pi c/\omega_p$. The mechanism for generating the wakes can be simply seen by the following approximate

Accelerate particles to even higher energies:
New Technologies

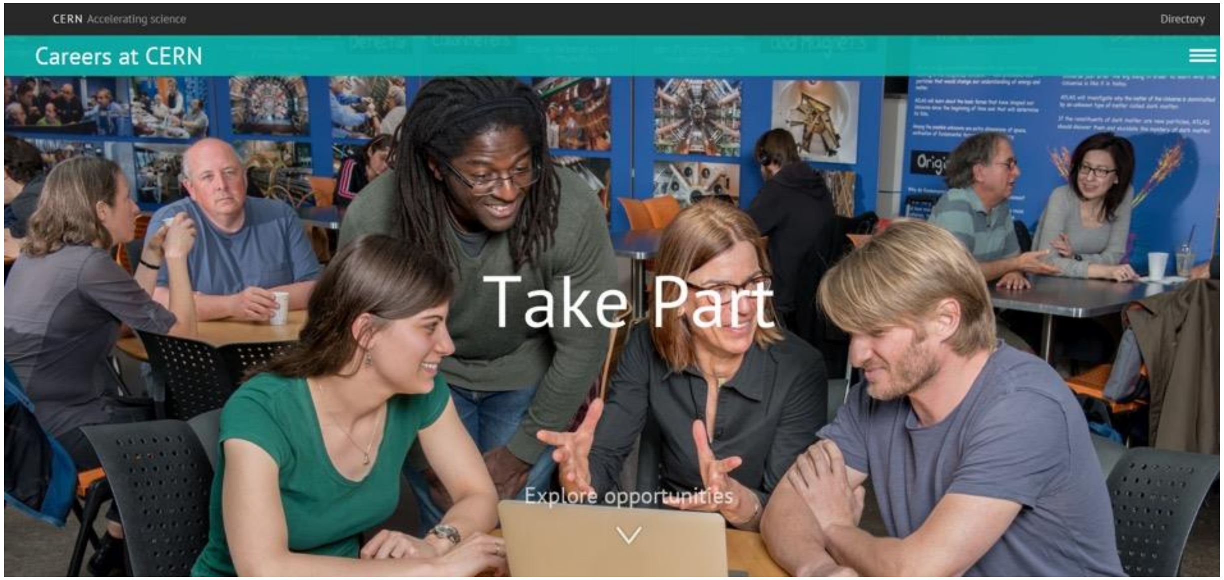
Plasma Wakefield Acceleration

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



… 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”