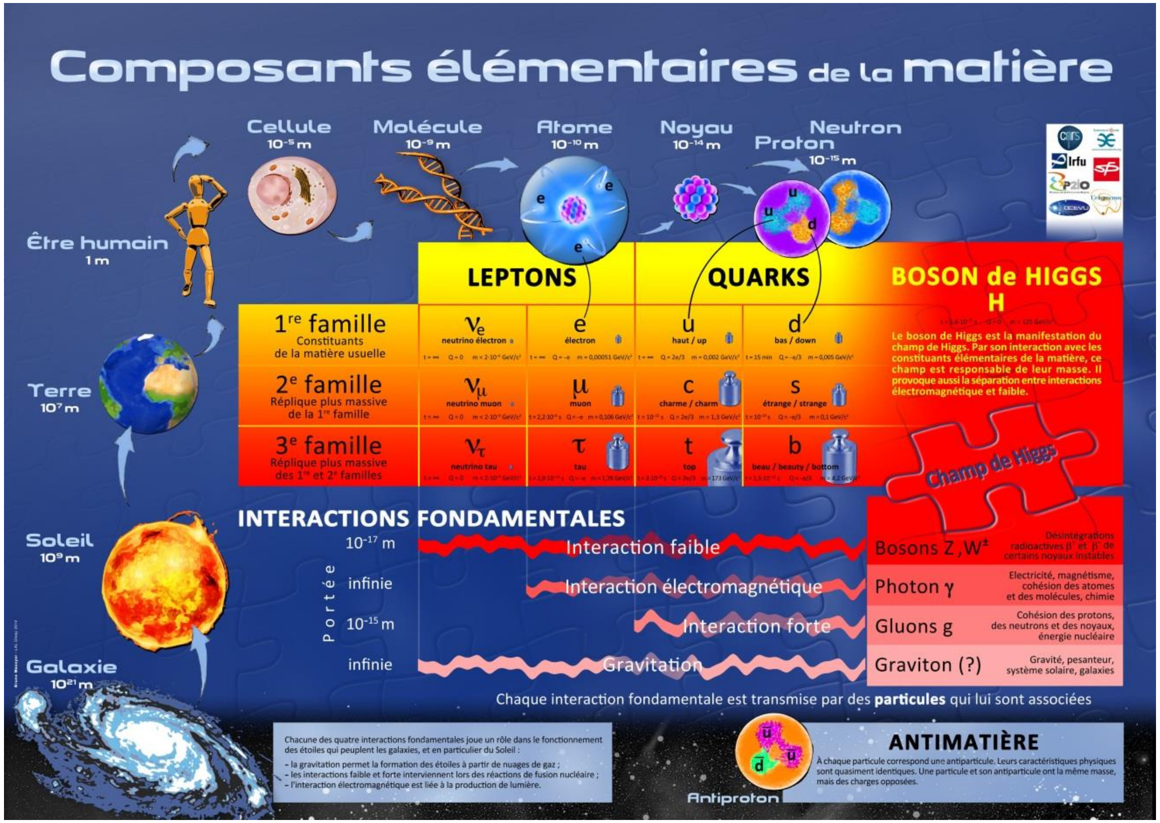
Un changement d'échelle : quelques exemples



Le boson de Higgs est la manifestation du champ de Higgs. Par son interaction avec les constituants élémentaires de la matière, ce champ est responsable de leur masse. Il provoque aussi la séparation entre interactions électromagnétique et faible.

Bosons Z, W±	Désintégrations radioactives β⁺ et β⁻ de certains noyaux instables
Photon γ	Electricité, magnétisme, cohésion des atomes et des molécules, chimie
Gluons g	Cohésion des protons, des neutrons et des noyaux, énergie nucléaire
Graviton (?)	Gravité, pesanteur, système solaire, galaxies

Chaque interaction fondamentale est transmise par des **particules** qui lui sont associées

Chacune des quatre interactions fondamentales joue un rôle dans le fonctionnement des étoiles qui peuplent les galaxies, et en particulier du Soleil :
- la gravitation permet la formation des étoiles à partir de nuages de gaz ;
- les interactions faible et forte interviennent lors des réactions de fusion nucléaire ;
- l'interaction électromagnétique est liée à la production de lumière.

ANTIMATIÈRE

À chaque particule correspond une antiparticule. Leurs caractéristiques physiques sont quasiment identiques. Une particule et son antiparticule ont la même masse, mais des charges opposées.

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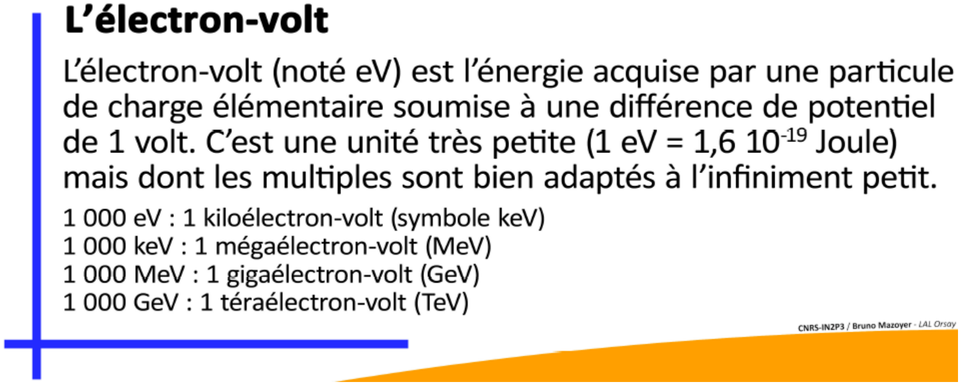
Nicolas Arnaud (nicolas.arnaud@ijclab.in2p3.fr)
Laboratoire de Physique des 2 Infinis Irène Joliot-Curie
(Université Paris-Saclay & CNRS/IN2P3)

Échelle d’énergies

L’électron-volt et ses multiples



L’électron-volt

L’électron-volt (noté eV) est l’énergie acquise par une particule de charge élémentaire soumise à une différence de potentiel de 1 volt. C’est une unité très petite (1 eV = 1,6 10^{-19} Joule) mais dont les multiples sont bien adaptés à l’infiniment petit.

1 000 eV : 1 kiloélectron-volt (symbole keV)
1 000 keV : 1 mégaélectron-volt (MeV)
1 000 MeV : 1 gigaélectron-volt (GeV)
1 000 GeV : 1 téraélectron-volt (TeV)

CNRS-IN2P3 / Bruno Mazoyer - LAL Orsay

Energie thermique d’une molécule	0.04 eV
Lumière visible	1.5-3.5 eV
Energie de dissociation NaCl en ions	4.2 eV
Energie d’ionisation d’un atome d’hydrogène	13.6 eV
Energie d’un électron frappant un écran cathodique	20 keV
Rayons X pour la médecine	0.2 MeV
Rayonnements nucléaires (α, β, γ)	1-10 MeV
Energie de masse d’un proton	1 GeV
Énergie de collision au LHC	7-14 TeV
Rayons cosmiques	1 MeV à 1000 TeV

Unités naturelles: Cte de Planck $\hbar =$ vitesse de la lumière $c = 1$:

$$\Longrightarrow 1\ \mathrm{eV} = 1/(0.2\ \mu m) = 10^{-36} kg = 1/(0.7\ fs)$$

Accélérateurs de particules

Progrès des accélérateurs

- Diagramme de Livingston

Premier accélérateur ●

Cyclotrons ● ●

Accélérateurs électrostatiques Cockroft-Walton ●

Accélérateurs électrostatiques Van de Graaff ●

Bétatrons ●

Synchrocyclotrons ●

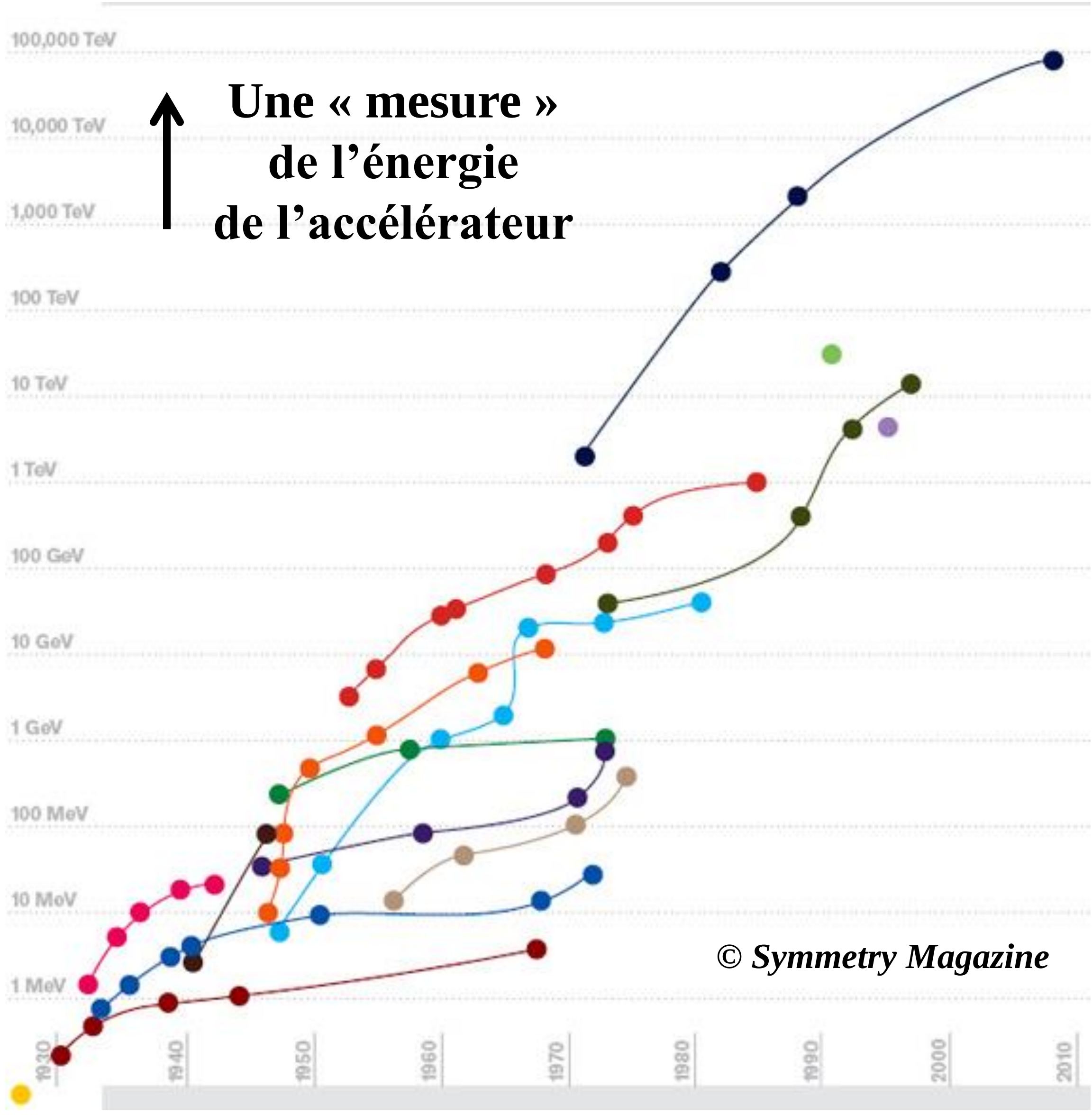
Accélérateurs linéaires ● ●

Synchrotrons à électons ●

Synchrotrons à protons ●

Collisionneurs à anneau de stockage ● ● ●

Collisionneurs linéaires ●



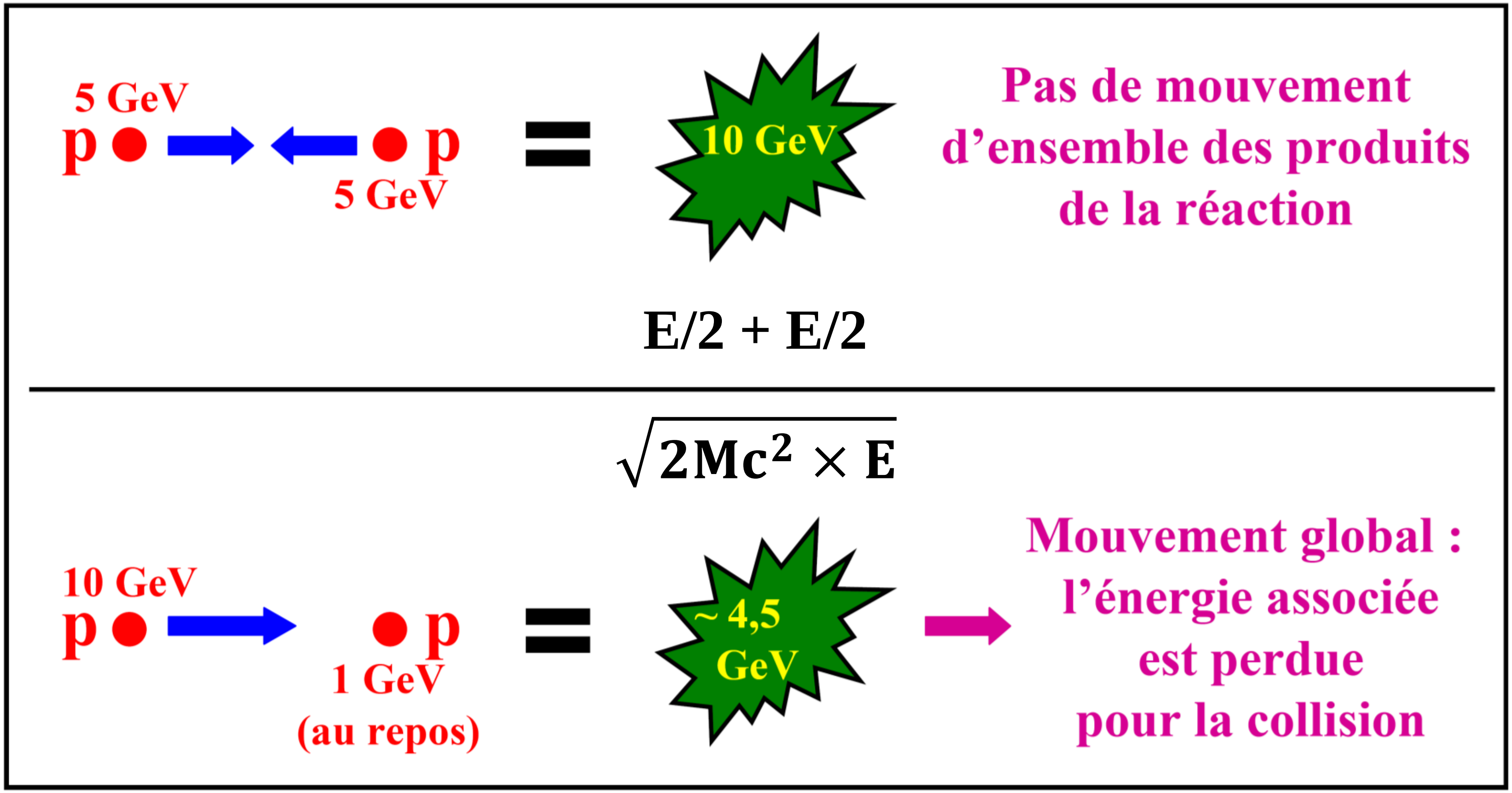
Une « mesure » de l'énergie de l'accélérateur

© Symmetry Magazine

Année

Progrès des accélérateurs

- The energy of colliders is plotted in terms of the laboratory energy of particles colliding with a proton at rest to reach the same center of mass energy.
  → Using these units, the energy of collisions at the Large Hadron Collider is nearly 100,000 TeV.



Pas de mouvement d'ensemble des produits de la réaction

$$E/2 + E/2$$

$$\sqrt{2Mc^2 \times E}$$

Mouvement global : l'énergie associée est perdue pour la collision

Progrès des accélérateurs

First accelerator ●

Most accelerators in operation today, including thousands of machines used for treating the surfaces of materials, apply the same principle of resonance acceleration that Norwegian engineer Rolf Wideröe explored when he built the world's first accelerator in Aachen, Germany in 1928. His linear accelerator, or linac, powered by an alternating voltage, propelled potassium ions through an 88-cm-long glass tube, achieving an energy gain equivalent to twice the peak voltage he used. This proof of principle opened the door to a vast new field of research and many types of accelerators.

Cyclotrons ● ●

More than 350 cyclotrons around the world produce radioactive isotopes for medical applications, such as PET scans. Inspired by Wideröe's success, Ernest Lawrence and his student M. Stanley Livingston built the first of these circular accelerators, about four inches in diameter, and operated it in 1931 in Berkeley. **(A)** The cyclotron's magnetic field forces particles to travel in spirals. On each turn, the particles cross an electric field, which accelerates them to higher energy.

Cockcroft-Walton electrostatic accelerators ●

In 1932, John Cockcroft and Ernest Walton became the first scientists to split the atomic nucleus with artifically accelerated particles when they aimed a proton beam from a new type of accelerator at the nuclei of lithium atoms. Physicists still use Cockcroft-Walton accelerators to deliver strong, steady streams of low-energy protons. The machines can turn alternating currents into electrostatic fields corresponding to more than one million volts.

Van de Graaff electrostatic accelerators ●

Scientists used this type of accelerator for several decades in physics and biomedical research. Commercial companies now build modern versions of this machine. Invented at Princeton University in the 1930s, the accelerator generates a high voltage by charging a large sphere through a moving belt. In the early 1950s, the Massachusetts Institute of Technology donated its Van de Graaff machine to the Museum of Science in Boston, where visitors can still see it in action.

Betatrons ●

In 1940, Donald Kerst at the University of Illinois modified the design of the cyclotron to accelerate particles to higher energy. The betatron's large magnet provides a variable field and keeps particles on a circular orbit inside a beam pipe, a major step forward in accelerator technology. In 1957, Dr. O. Arthur Stiennon opened in Wisconsin the first private medical center to treat cancer patients with a betatron. Because of cost and size limitations, demand for betatrons started to fall in the 1970s.

Synchrocyclotrons ●

For many years physicists struggled to build accelerators that work for both low- and high-speed particles. The problem is that slow particles gain energy and speed when traveling through an electric field while particles traveling close to the speed of light gain energy while barely speeding up at all, a phenomenon explained by the theory of special relativity. This creates a timing problem in accelerators with electric fields that alternate at constant frequency. The synchrocyclotron, invented in the 1940s but no longer built today, solved the problem by introducing an electric field with variable frequency, paving the way for even better accelerators.

Linear accelerators ● ●

Physicists built the first modern linear accelerators after World War II, using microwave technology developed for radar. Today, thousands of hospitals use linacs for radiotherapy in cancer treatment. **(B)** Linacs use radio-frequency waves to create electric fields inside cylindrical cavities. Luis Alvarez built the first standing-wave linac to accelerate protons at the University of California, Berkeley, in 1946. William Hansen and his team at Stanford University constructed the first traveling-wave linac to accelerate electrons in 1947. High-energy accelerators often rely on a standing-wave linac to give heavy particles an initial boost before injecting them into the circular machines that accelerate them to high energy.

Electron synchrotrons ●

The operation of the first electron synchrotron in the United States, at General Electric in 1946, led to the discovery of synchrotron radiation, the light emitted by charged, high-energy particles traveling in a circle. Today, more than 50 synchrotrons, known as lightsources, **(C)** produce intense beams of light for research in material science, chemistry, molecular biology, and other fields. By injecting particles into a synchrotron at close to the speed of light, scientists can operate its alternating electric field at an almost constant frequency. An adjustable magnetic field guarantees that the particles stay on a fixed circular path, so beams can circulate for long periods of time.

Proton synchrotrons ●

Because protons are about 2000 times heavier than electrons, they must be accelerated to higher energies, and hence over longer distances, to attain relativistic speeds. The discovery in the 1950s of strong beam focusing, which controls the size of a particle beam through a series of magnets, allowed the construction of large, circular proton accelerators for nuclear and high-energy research, starting at Brookhaven National Laboratory and the European laboratory CERN. Hospitals have begun to use proton synchrotrons for cancer treatment.

Storage ring colliders ● ● ●

Particle colliders have led to the discoveries of many subatomic building blocks and the forces that govern their behavior. Storage ring colliders are based on synchrotron technology. They accelerate two beams of particles in opposite directions and circulate them for hours. Every time the beams cross, a few particles collide. In the 1960s, scientists built the first electron-positron collider at Frascati, Italy, followed by machines in the United States and Russia. Today, colliders at KEK, Fermilab, Brookhaven—and, soon, CERN **(D)**—smash electrons, positrons, protons, antiprotons, and ions into each other. Scientists now are developing the technology for a proposed muon collider.

Linear colliders ●

The Stanford Linear Accelerator Center started operating the world's first linear particle collider in 1989. Today, a worldwide collaboration of scientists is advancing plans for the proposed International Linear Collider, which would use superconducting radio-frequency (RF) cavities to accelerate electrons and positrons to much higher energy than achieved at SLAC. A collaboration based at CERN is developing a new linac concept, the Compact Linear Collider.

Text: Kurt Riesselmann
Image: Adapted from the 2001 Snowmass Accelerator R&D Report

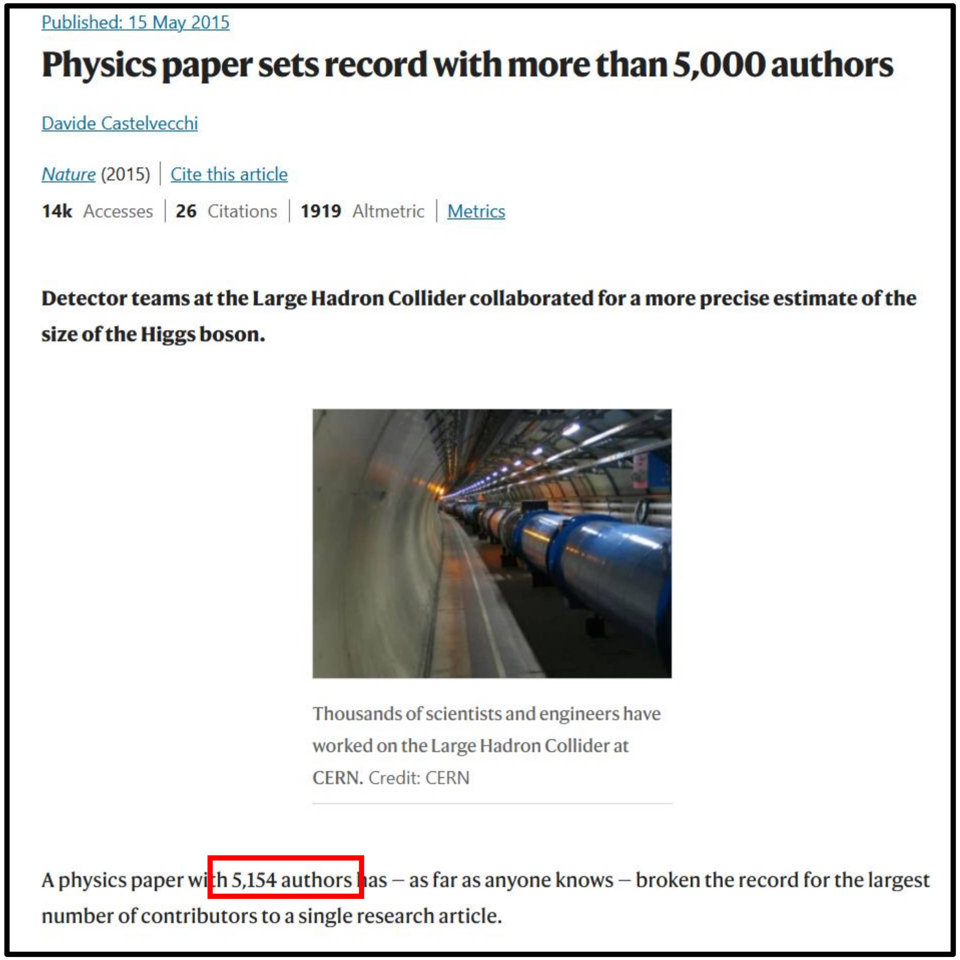
Signataires des articles scientifiques

Nombre de signataires / découverte

- Jusqu'à la seconde guerre mondiale : quelques auteurs au plus
  - 1 souvent
- 1955, antiproton : 4
- 1956, neutrino électron : 2
- 1968, quarks : 11
- 1974, J/Psi (quark c) : 35 (SLAC) + 14 (Brookhaven)
- 1977, quark b : 16-17
- 1983, W et Z : ~120 (UA1) + ~60 (UA2)
- 1995, quark top : ~410 (D∅) + ~450 (CDF)
- 2012, boson BEH : ~3160 (ATLAS) + ~3060 (CMS)

- Mon comptage
- Ingénieurs, techniciens, administratifs non inclus

Des listes d’auteurs toujours plus grandes



Published: 15 May 2015

Physics paper sets record with more than 5,000 authors

Davide Castelvecchi

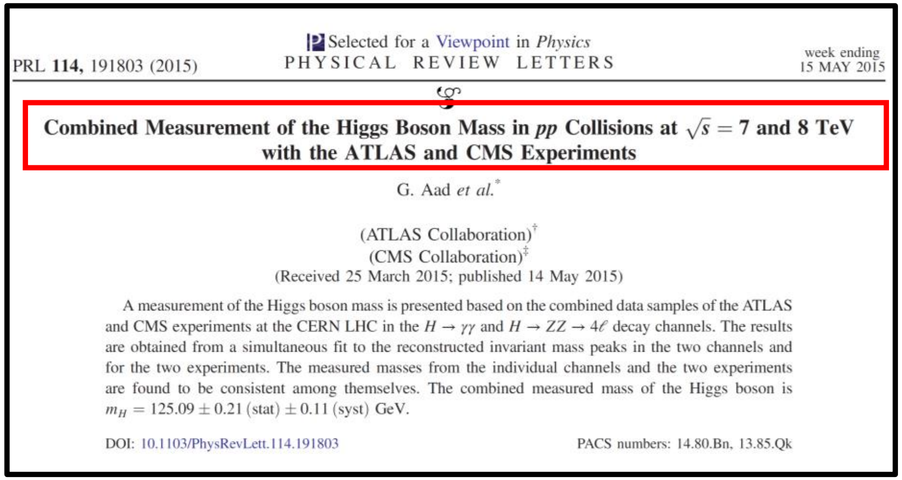
Nature (2015) | Cite this article

14k Accesses | **26** Citations | **1919** Altmetric | Metrics

Detector teams at the Large Hadron Collider collaborated for a more precise estimate of the size of the Higgs boson.

Thousands of scientists and engineers have worked on the Large Hadron Collider at CERN. Credit: CERN

A physics paper with 5,154 authors has — as far as anyone knows — broken the record for the largest number of contributors to a single research article.



Selected for a Viewpoint in *Physics*

PRL **114,** 191803 (2015) PHYSICAL REVIEW LETTERS week ending 15 MAY 2015

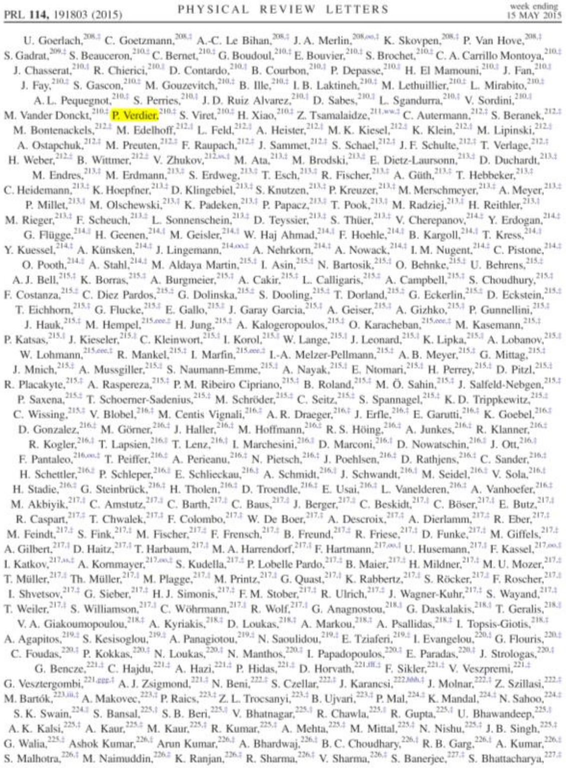
Combined Measurement of the Higgs Boson Mass in pp Collisions at $\sqrt{s} = 7$ and 8 TeV with the ATLAS and CMS Experiments

G. Aad *et al.*[*]

(ATLAS Collaboration)[†]
(CMS Collaboration)[‡]
(Received 25 March 2015; published 14 May 2015)

A measurement of the Higgs boson mass is presented based on the combined data samples of the ATLAS and CMS experiments at the CERN LHC in the $H \to \gamma\gamma$ and $H \to ZZ \to 4\ell$ decay channels. The results are obtained from a simultaneous fit to the reconstructed invariant mass peaks in the two channels and for the two experiments. The measured masses from the individual channels and the two experiments are found to be consistent among themselves. The combined measured mass of the Higgs boson is $m_H = 125.09 \pm 0.21\,(\text{stat}) \pm 0.11\,(\text{syst})$ GeV.

DOI: 10.1103/PhysRevLett.114.191803 PACS numbers: 14.80.Bn, 13.85.Qk



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