# CERN: 7 decades of global collaboration, scientific achievements and technology innovation

XIII International Conference on New Frontiers in Physics
ICNFP, 2 September 2024, Kolymbari, Crete, Grece

**Luciano Musa**
CERN

YEARS / ANS CERN

# Peaceful scientific collaboration: a vision takes shape

**1945:** Europe is in ruins after World War II

**1946**: French proposal to the United Nations

**1949**: European Cultural Conference, Lausanne

# Common vision of politicians and scientists

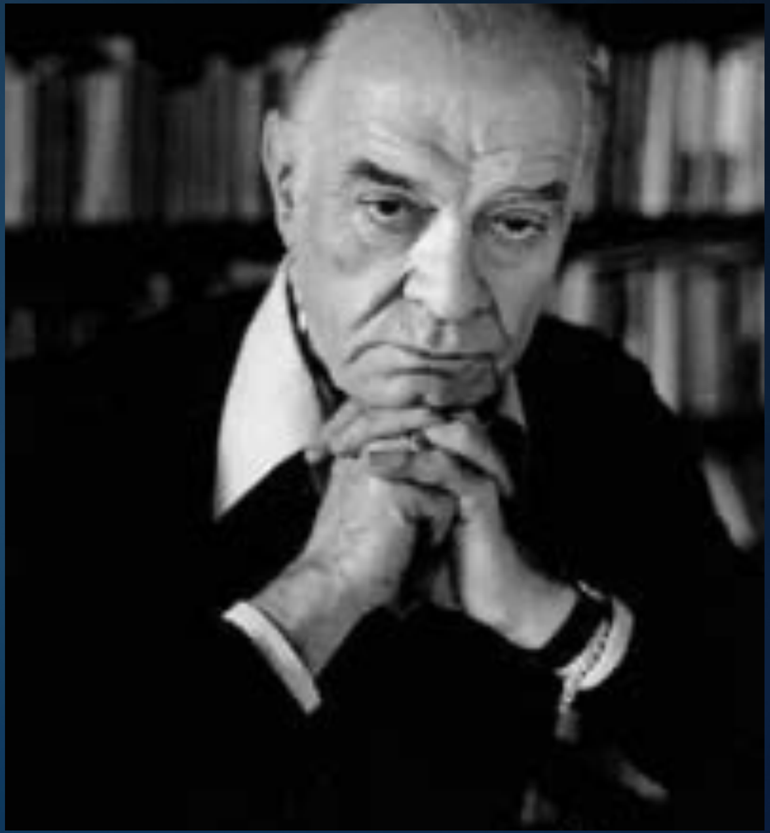
Renew peaceful collaboration following the destruction of war

Focus on fundamental scientific research at a scale beyond the capacity of any single nation

Restore scientific excellence and reverse and prevent brain drain

# 1940s: first proposals

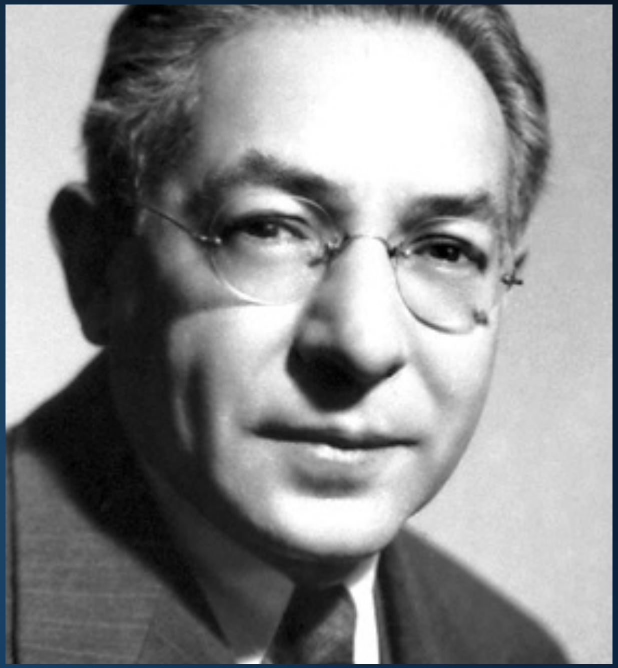
Louis de Broglie proposed: *"the creation of a laboratory or institution where it would be possible to do scientific work, but somehow beyond the framework of the different participating states [Endowed with more resources than national facilities, such a laboratory could] undertake tasks, which, by virtue of their size and cost, were beyond the scope of individual countries".*



# 1950: UNESCO Conference

US Nobel laureate Isidor Rabi tables a resolution authorising UNESCO to:

*"assist and encourage the formation of regional research laboratories in order to increase international scientific collaboration…"*



# 1951: UNESCO Resolution

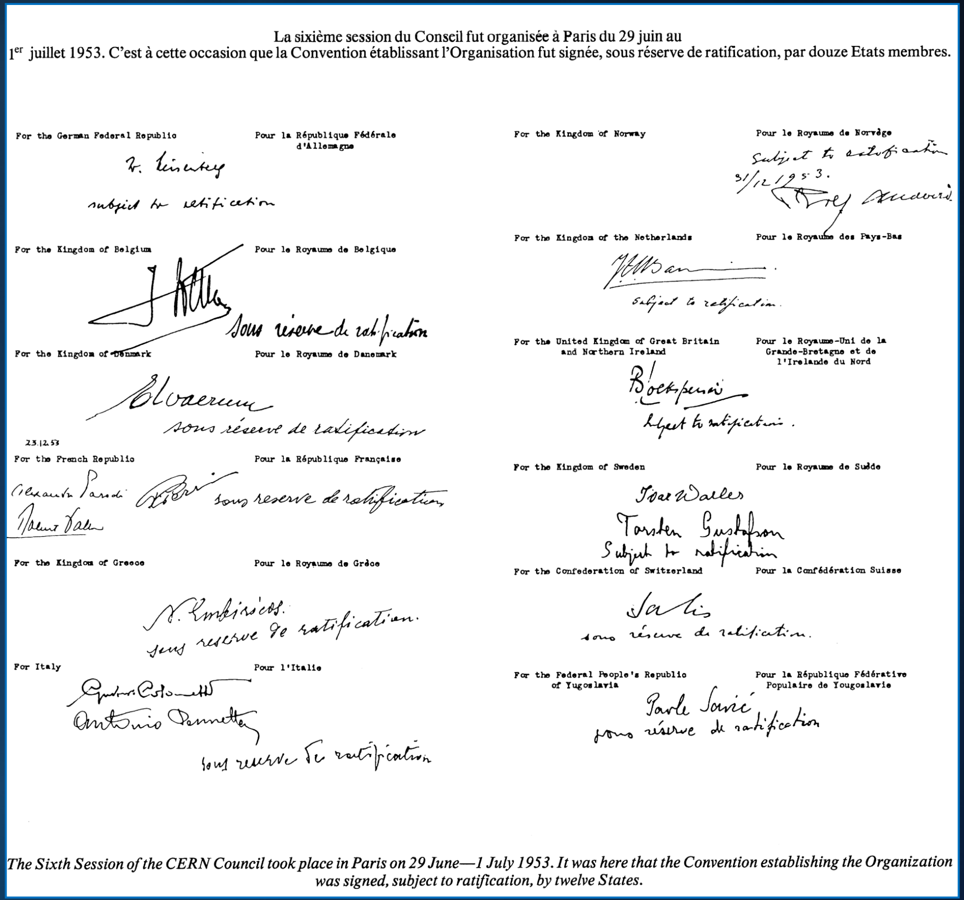
- At a meeting of UNESCO in Paris in December 1951, the first resolution concerning the establishment of a European Council for Nuclear Research was adopted.
- Two months later, 11 countries signed an agreement establishing the provisional Council – **the acronym CERN was born**.

# 1954: CERN is born

- The CERN Convention, established in July 1953, was ratified by 12 founding Member States: Belgium, Denmark, France, the Federal Republic of Germany, **Greece**, Italy, the Netherlands, Norway, Sweden, Switzerland, the UK, and Yugoslavia.

- On 29 September 1954, the European Organization for Nuclear Research officially came into being.

- CERN was dissolved but the acronym remains.



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

23.12.53

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'Irelande 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.*

# 1957: first accelerator

## The **Synchrocyclotron**

# From founders' vision to today's global collaboration

## **24** Member States

Austria – Belgium – Bulgaria – Czech Republic
Denmark – Estonia – Finland – France – Germany
Greece – Hungary – Israel – Italy – Netherlands – Norway
Poland – Portugal – Romania – Serbia – Slovakia Spain
Sweden – Switzerland – United Kingdom

## **2** Associate Member States in the pre-stage to membership

Cyprus – Slovenia

## **8** Associate Member States

Brazil – Croatia – India – Latvia – Lithuania – Pakistan
Türkiye – Ukraine

## **6** Observers

Japan – Russia (suspended) – USA
European Union – JINR (suspended) – UNESCO

**Geographical & cultural diversity**
**Users of 110 nationalities**
**22.5 % women**

As of 31 December 2023
Employees:
**2666** staff, **1002** graduates
Associates:
**12 370** users, **1513** others

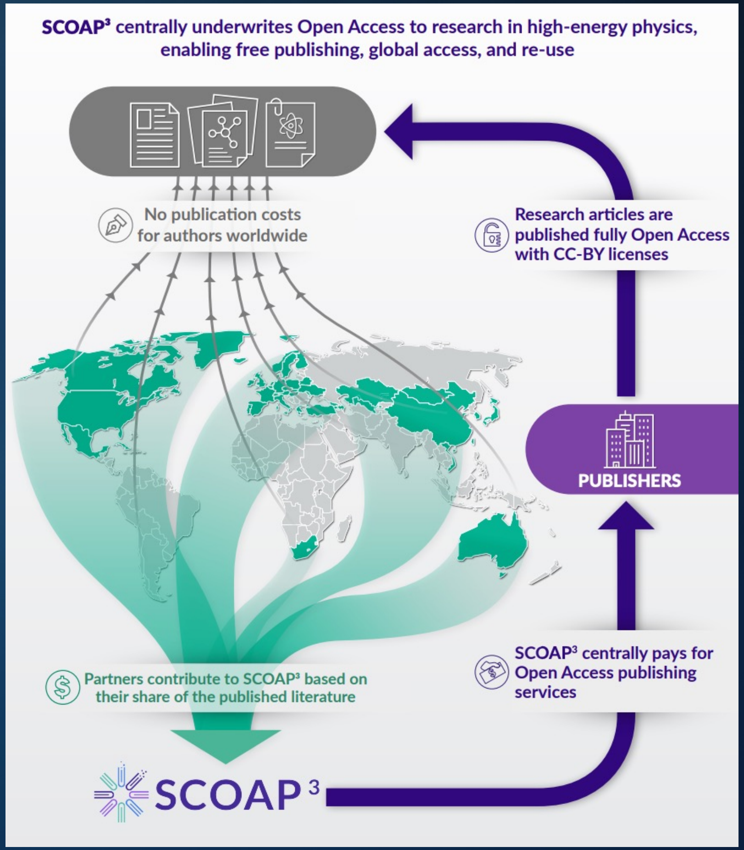
## Around 50 Cooperation Agreements with non-Member States and Territories

Albania – Algeria – Argentina – Armenia – Australia – Azerbaijan – Bangladesh – Belarus – Bolivia
Bosnia and Herzegovina – Canada – Chile – Colombia – Costa Rica – Ecuador – Egypt – Georgia – Honduras
Iceland – Iran – Jordan – Kazakhstan – Lebanon – Malta – Mexico – Mongolia – Montenegro – Morocco – Nepal
New Zealand – North Macedonia – Palestine – Paraguay – People's Republic of China – Peru – Philippines – Qatar
Republic of Korea – Saudi Arabia – Sri Lanka – South Africa – Thailand – Tunisia – United Arab Emirates – Vietnam

# Core value underlying the collaboration: Open Science

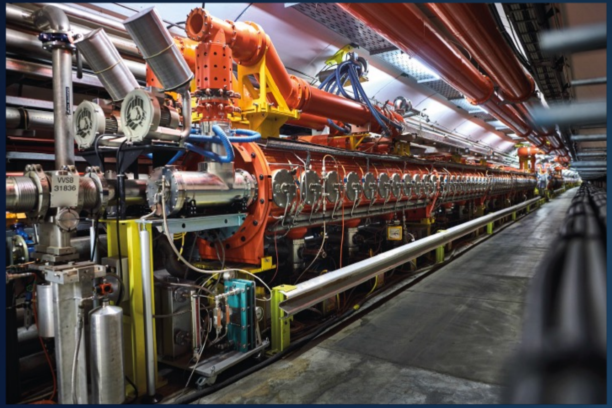
CERN Convention Art. II.1.: *The Organization shall have no concern with work for military requirements, and **the results of its experimental and theoretical work shall be published or otherwise made generally available***

- **Open Access Policy (2014)**
  - >90% of research produced at CERN published OA (CC-BY licenses)
  - Sponsoring Consortium for Open Access Publishing in Particle Physics - SCOAP$^3$ (44 countries)
  - Inspired major global OA initiatives: PlanS, OA2020, etc.
- **LHC Open Data Policy (2020)**
  - LHC experiments release experimental data and associated analysis tools for diverse scientific and educational uses
- **CERN Open Science Policy (2022)**
  - Policy broadened to explicitly include open software, hardware, research integrity and assessment, education, training and outreach, citizen science



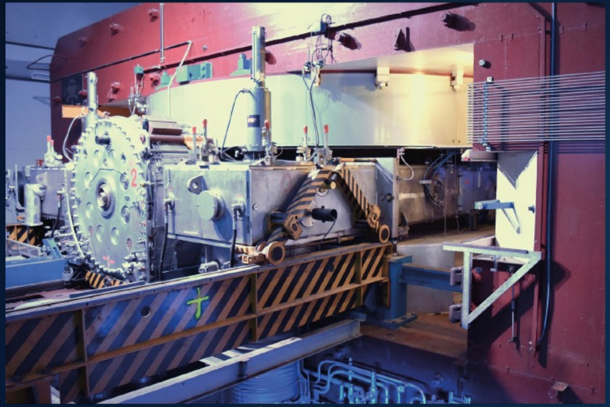
PS – 28 GeV

SPS – 630 GeV



LHC – 13 600 GeV

SC 0.6 GeV



ISR - 31.5 GeV

LEP - 209 GeV

1957 | 1959 | 1971 | 1976 | 1989 | 2009

# 1958: CERN’s first discovery

**1957**: the **Synchrocyclotron is** CERN’s first accelerator to begin operation (600 MeV proton beam)

**Discovery of “rare pion decays” 1958-1962**

$$R = \frac{\Gamma(\pi \rightarrow e\nu_e)}{\Gamma(\pi \rightarrow \mu\nu_\mu)} = (1.22 \ \pm 0.30) \times 10^{-4}$$

*G. Fidecaro et al.*

Crucial verification of a universal “weak” force with a Vector - Axial coupling

A turning point for the emerging electroweak theory

# 1973: the discovery of neutral currents

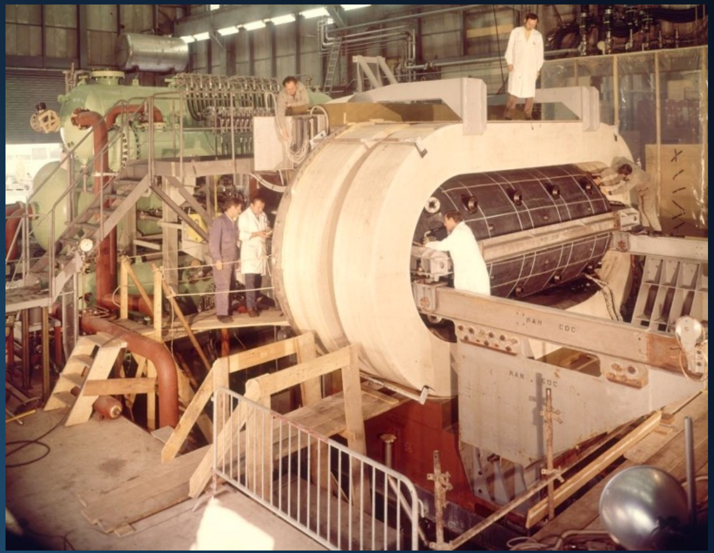
**1959:** the **Proton Synchrotron** (PS) begins operation
proton beam of 24 GeV (briefly the highest-energy accelerator)

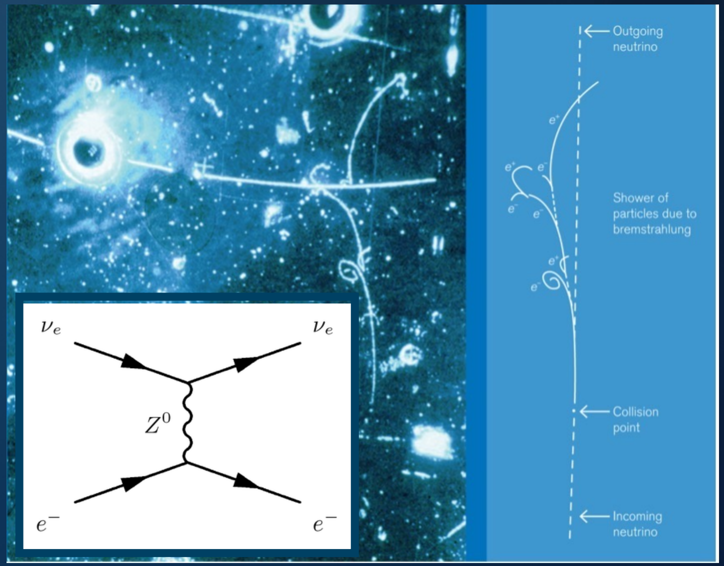
With the PS CERN entered the “high-energy neutrino beam era”

**Gargamelle** (4.8 m x 2 m, 1000 tonnes, 12 m$^3$ heavy-liquid freon)

crucial evidence for the existence of quarks, essential contributions to the confirmation of their fractional charge
….

**discovery of neutral currents**
⇨ establishes the electroweak theory





# Discovery of neutral currents

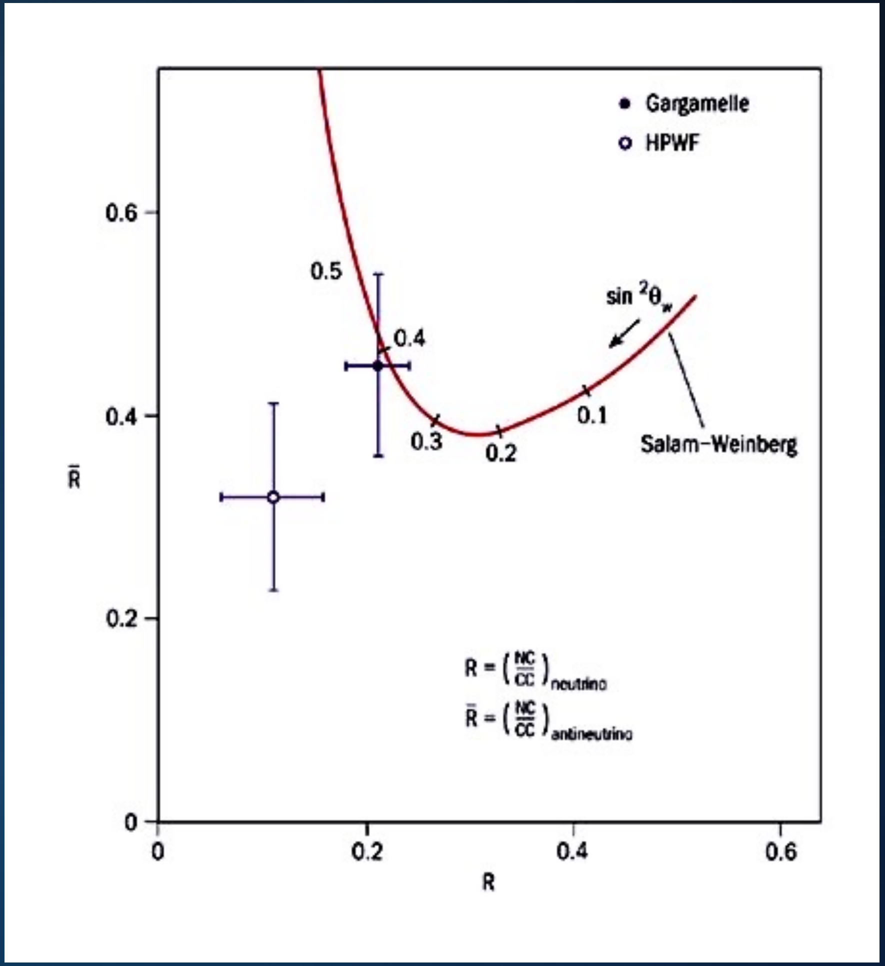
Combined rate measurement of neutral and charged current events using neutrino and anti-neutrino beams:

⇨ first direct evidence for the existence of the W and Z bosons as well as of their mass

$$M_W = \sqrt{\frac{\pi\alpha}{\sqrt{2}G}\frac{1}{\sin\theta_W}} = \frac{37\ GeV}{\sin\theta_W} \approx 70\ GeV$$

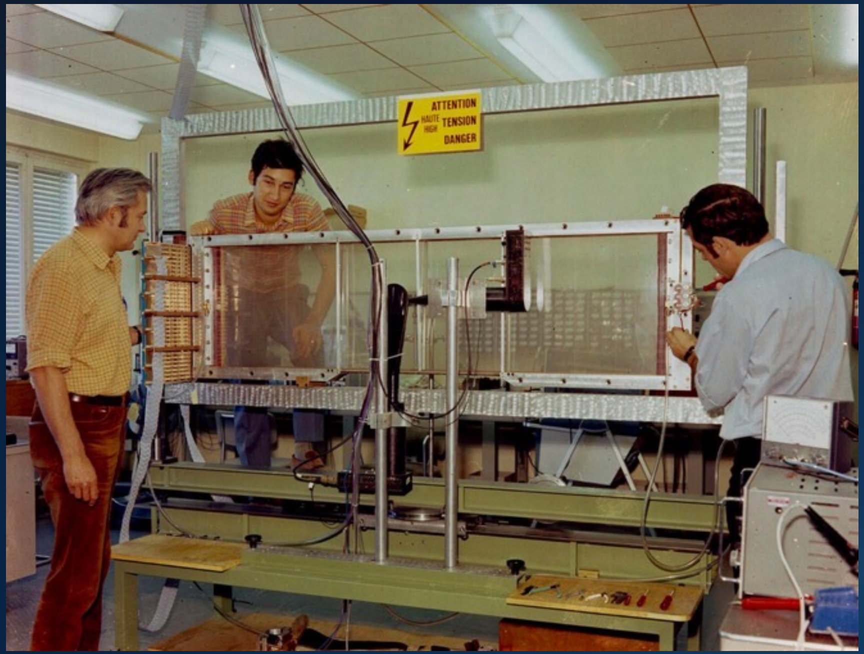
well before the direct observation of W and Z

⇨ guided the CERN future accelerator path

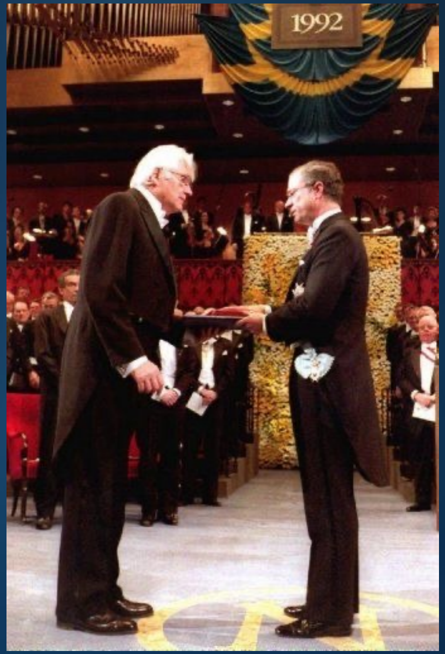


# Georges Charpak: Revolutionizing particle detection

from "visual detectors" to "electronic detectors"




1971-1972 – Large-size Multiwire Proportional Chamber




1992 Nobel award ceremony

# Multiwire Proportional Chambers: a transformative innovation

Medical imaging and healthcare

Security and inspection

Material science and archaeology

Environmental monitoring

Industrial applications

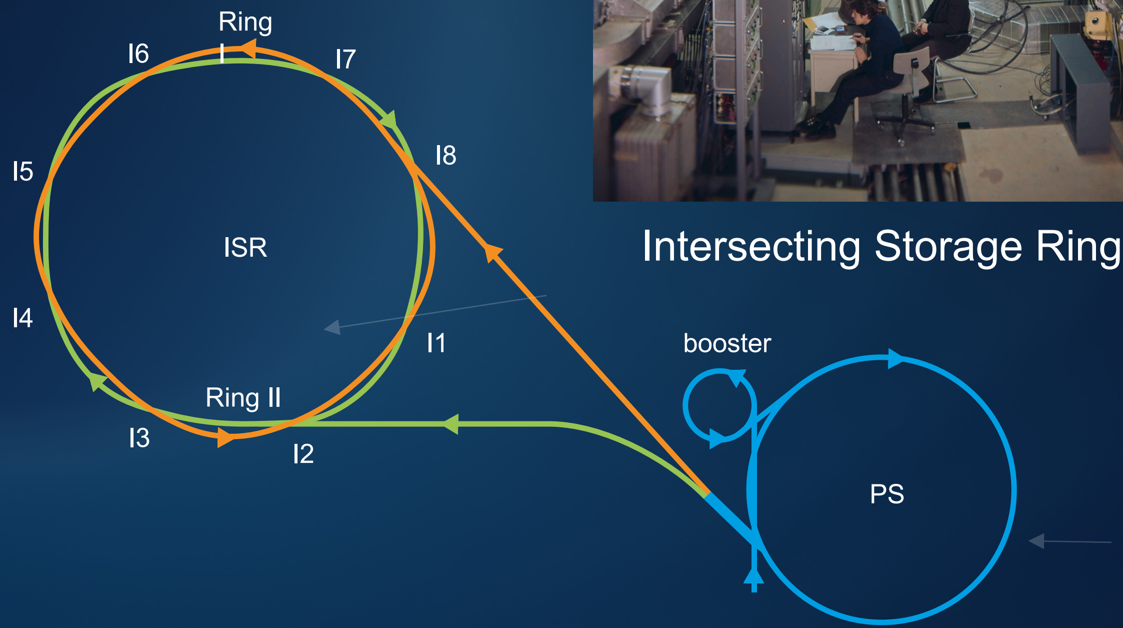
# Intersecting Storage Rings

- The **Intersecting Storage Rings** was the **World's first hadron collider** (protons, center of mass energy of up to 62 GeV)

- The rings crossing angle and the detectors were designed to privilege forward going debris of collisions

- Crucial contributions to QCD, the emerging theory of the strong nuclear force and the structure of hadrons, complementing the findings from the deep inelastic scattering experiments at SLAC

Intersecting Storage Ring

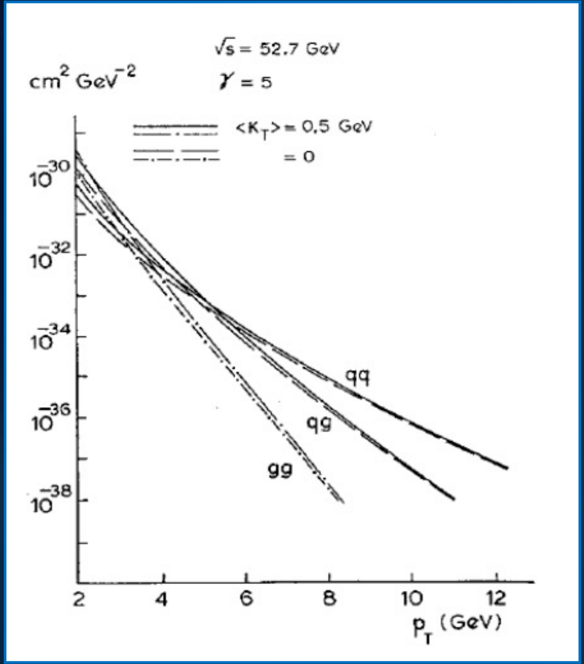


# Intersecting Storage Ring

- 1972-1973: ISR announces the observation of totally unexpected production of hadrons at large transverse momentum.

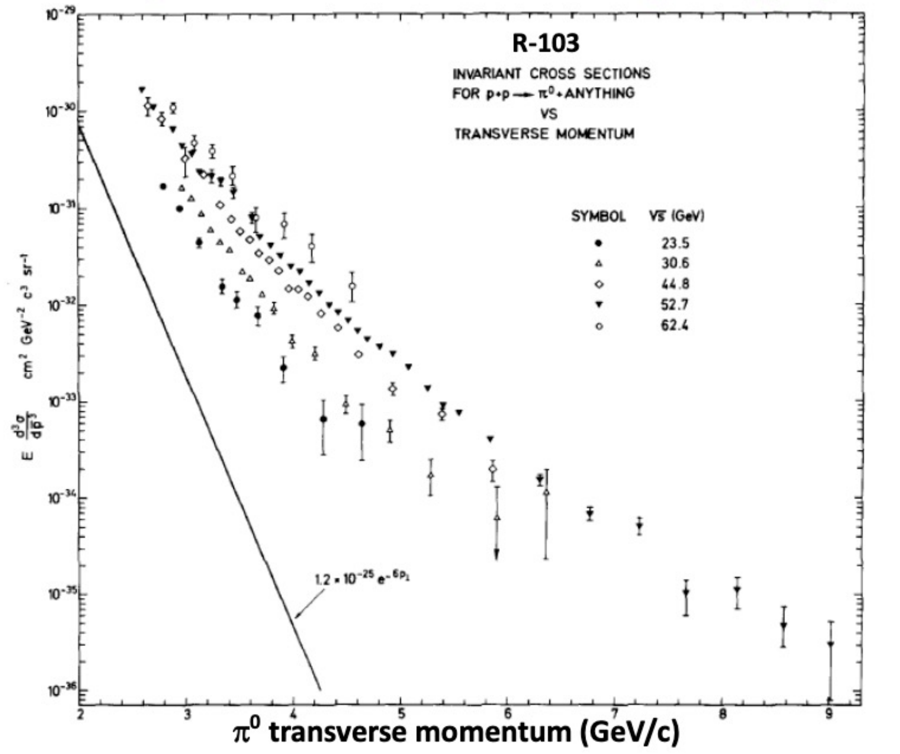
- A shocking surprise, but consistent with the emerging view (QCD) of protons made of quarks and gluons.

- New QCD predictions treating proton collisions as collisions between quarks (qq), gluons (gg) or mixed (qg)



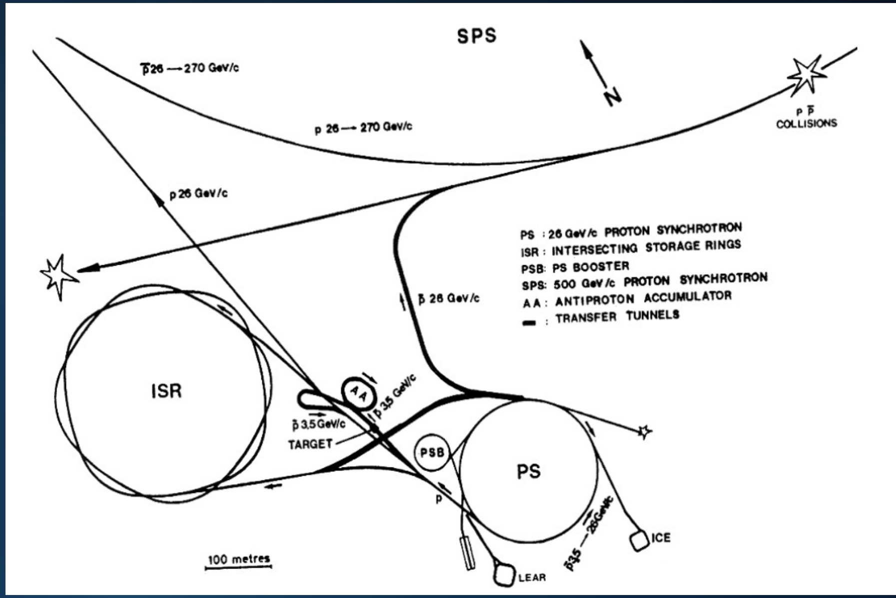

CERN– Columbia – Rockefeller coll., Phys. Lett. B46 (1973) 471

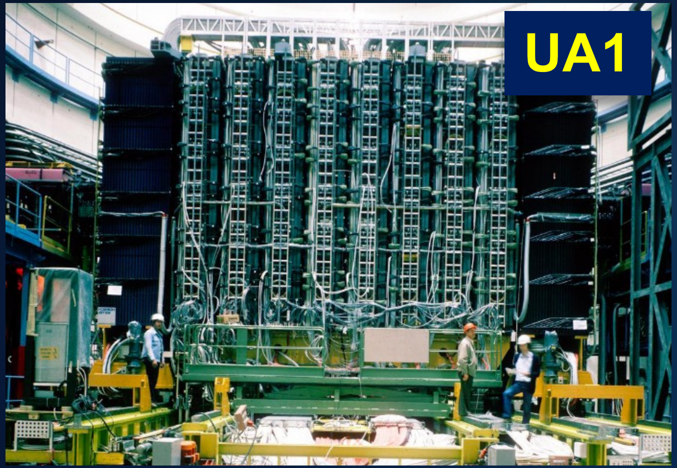
Results presented at the 1972 Int. Conf. on High Energy Physics

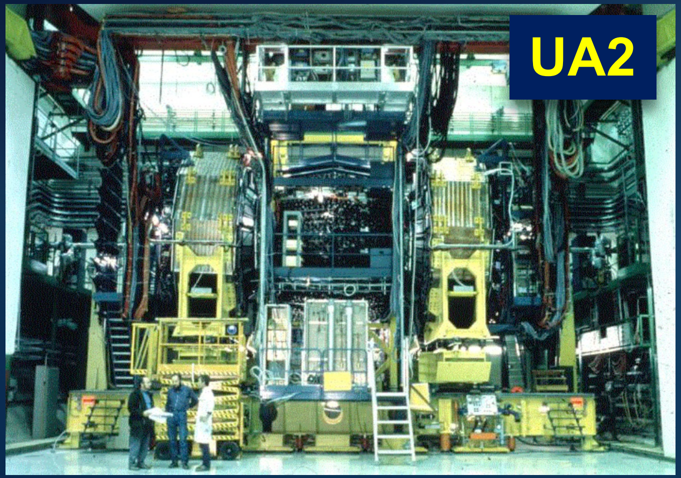


# 1983: discovery of the W and Z

- Gargamelle and the discovery of neutral currents guided the search: look in the region 60-90 GeV
- In 1976 Rubbia proposes to modify the SpS into a collider of protons and antiprotons
- First collisions at sqrt(s)=540 GeV were obtained in 1981



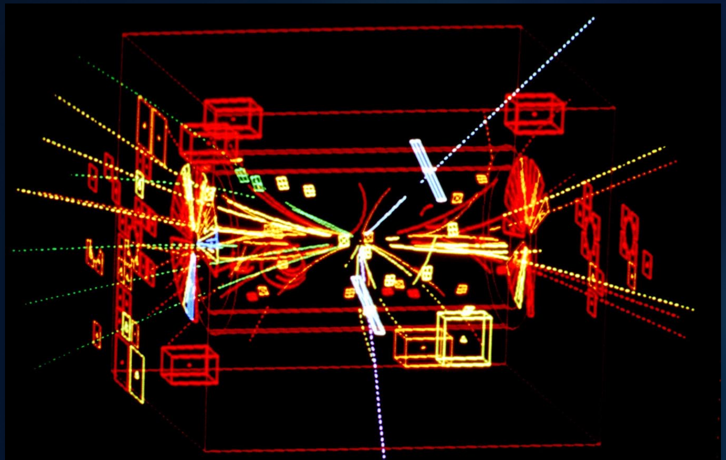




Two multipurpose detectors UA1 and UA2 were built to detect the elusive W and Z in their decays to leptons.

# 1983: discovery of the W and Z

- UA1 and UA2 presented the first results (in two separate seminars) at CERN on 20 and 21 **January 1983**
- 6 candidates for both experiments with high energy electrons and high missing energy (i.e. neutrinos).
- **The quest for the W boson was over!**



$Z^0$ decay event recorded by UA1 in 1983

In **July 1983**, **clear evidence of the Z boson** was also presented.

Carlo Rubbia and Simon van der Meer were awarded the 1984 Nobel prize

# Nailing down the Standard Model

In the mid-1970s the Standard Model was an attractive theory, but many aspects were still unknown:

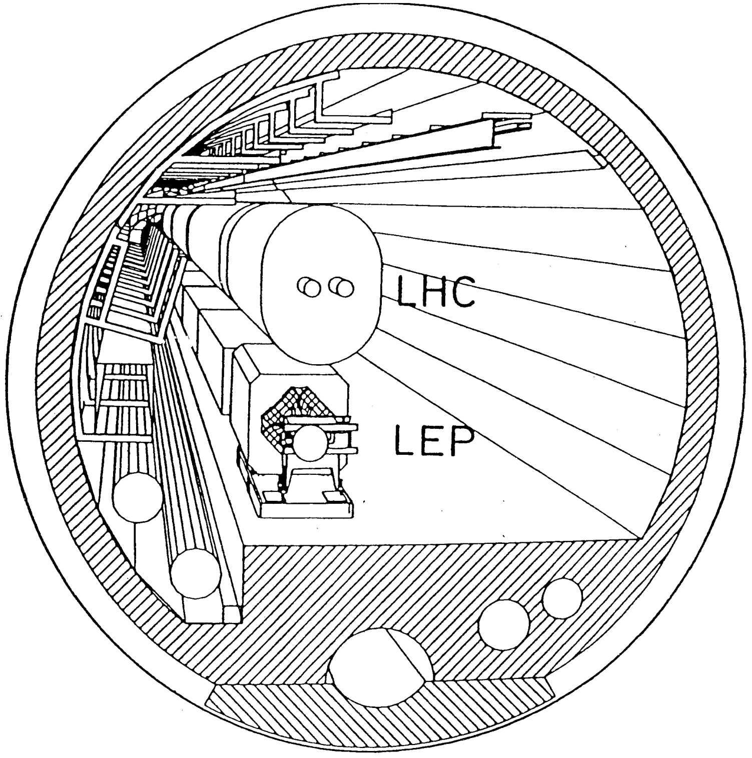
- QCD was increasingly confirmed, but the number of families (both for leptons and for quarks) was unclear. CP violation provided some clue for the quark sector, but not much for leptons.
- The vector bosons, which mediate the electroweak force, were believed to be around the corner, in the 60 - 100 GeV range.

In 1976, CERN established a study group for a Large Electron–Positron Collider (LEP) to produce and study the W and Z bosons.

LEP was approved in 1982, around the time as the discovery of the W and Z bosons.

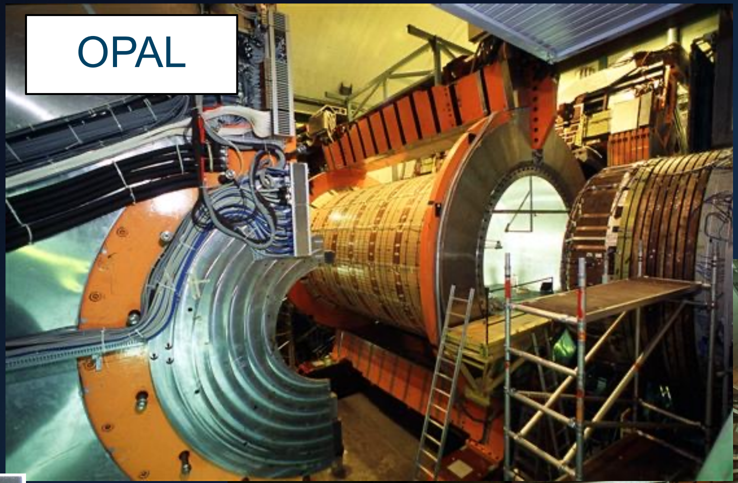
## ECFA – CERN Workshop
## Lausanne, 5 Sep 1984

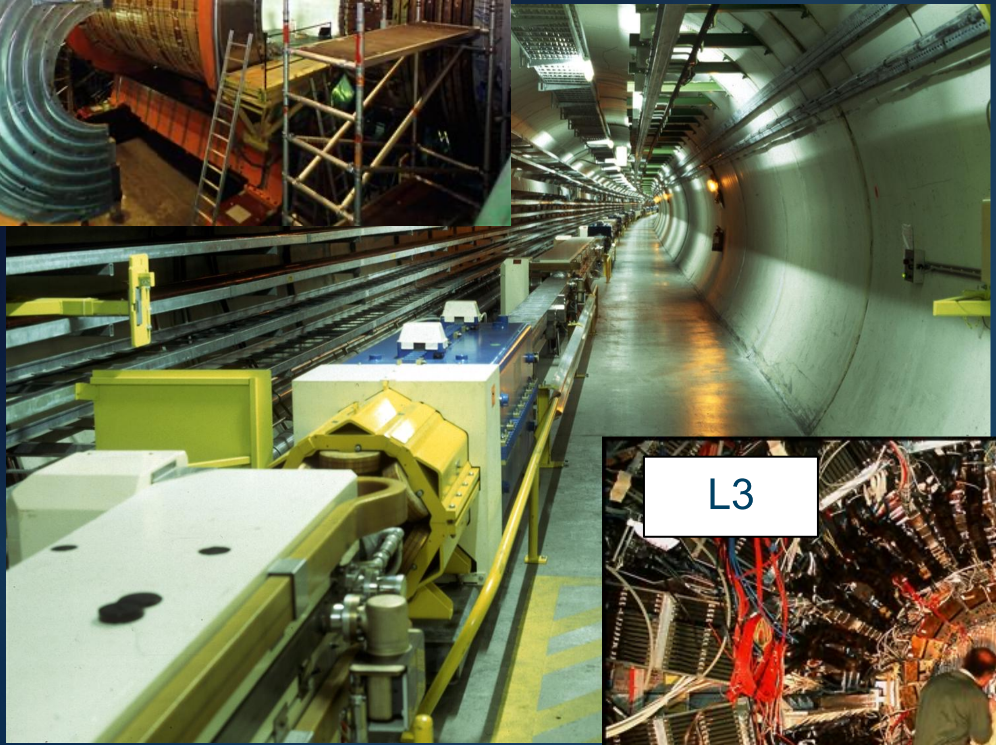
Thes possibility of hosting the LHC was one of the motivations for a 27km tunnel.

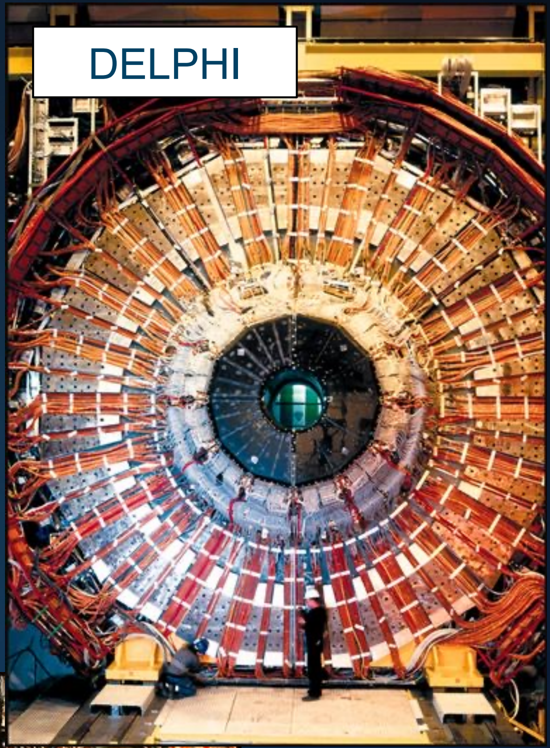


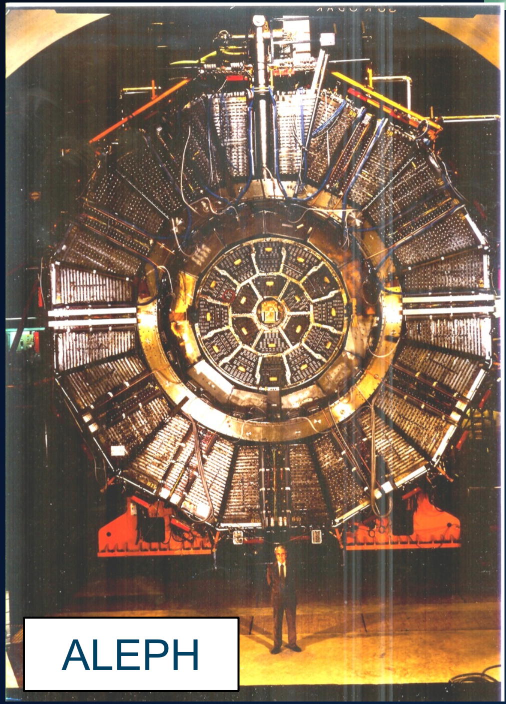

LARGE HADRON COLLIDER
IN THE LEP TUNNEL

# LEP era



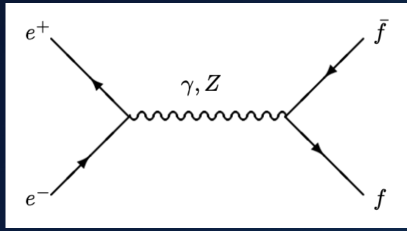





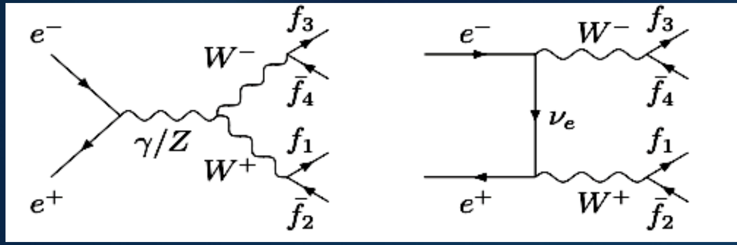




# LEP era

- First beams in LEP: 15 July 1989
- LEP 1: center of mass  energy around the mass of the Z boson (91 GeV) for 7 years. LEP was a Z-factory with millions of produced Z bosons.




- LEP 2: starting in 1996, energy reached and surpassed the threshold for production of 2 W boson (160 GeV). Max energy reached 209 GeV.




# The World Wide Web

March 1989: Tim Berners Lee submits the first proposal for the World Wide Web

merge data networks and hypertext in an easy-to-use global information system

By the end of 1990, the first Web server and browser is up and running

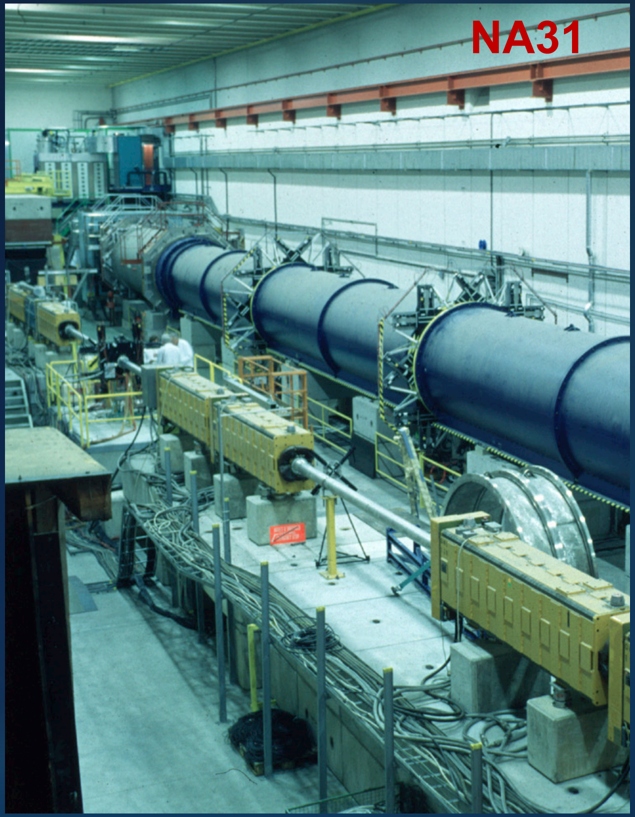
In 1993, CERN makes the source code of the World Wide Web available on a royalty-free basis

By the end of 1994, the Web already has **10,000 servers** and **10 million users**


Tim Berners Lee displaying some of the first web pages in 1994

# Discovery of direct CP Violation

- CERN uses the powerful SPS beam to produce conspicuous yields of Kaons
- Two generations of experiments, NA31 and NA48, were setup between 1982 and 1993 to study direct CP violation through kaon decays
- NA31: first evidence of direct CP violation (a 3 standard deviation effect) in 1988.
- NA48 (final publication in 2002): observation well above 5 standard deviation.

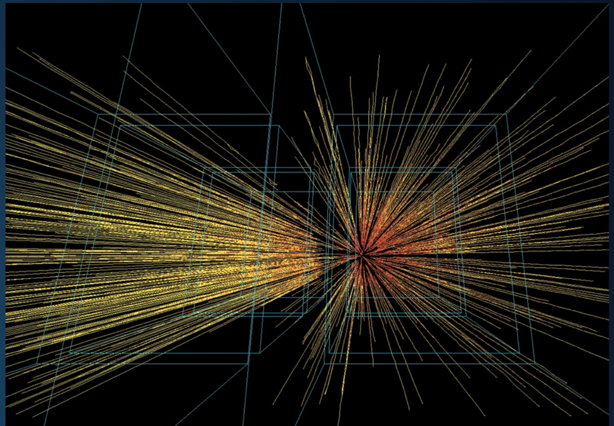


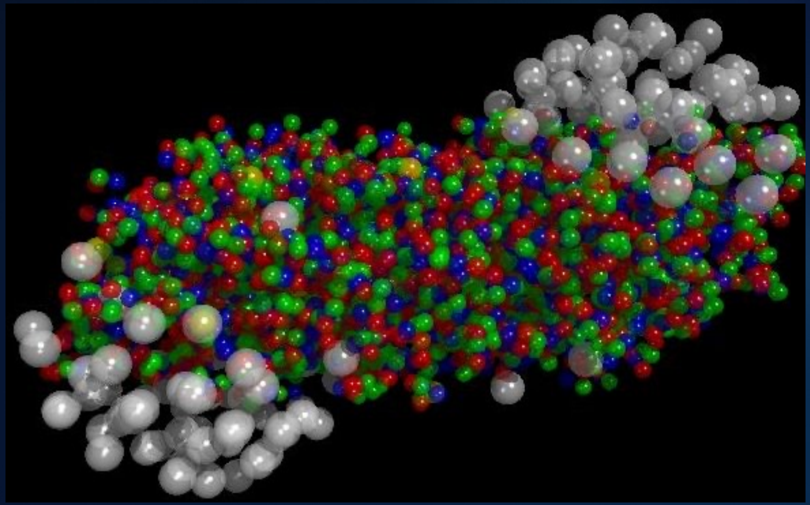


$\varepsilon \sim 2.2 \times 10^{-3}$ indirect    $\varepsilon'/\varepsilon \sim 1.7 \times 10^{-3}$ direct

# CERN, February 2000: first evidence of a new state of matter, the quark-gluon plasma

- Combined data from the 7 experiments on CERN's HI programme
- Proves an important prediction of the QCD theory. An important step forward in the understanding of the early evolution of the Universe.


Event recorded by NA49 at SPS



**Luciano Maiani** (CERN DG): "… We now have evidence of a new state of matter where quarks and gluons are not confined. … There is still an entirely new territory to be explored concerning the physical properties of quark-gluon matter. The challenge now passes to RHIC at BNL and later to the LHC."

# The Large Hadron Collider era


ATLAS

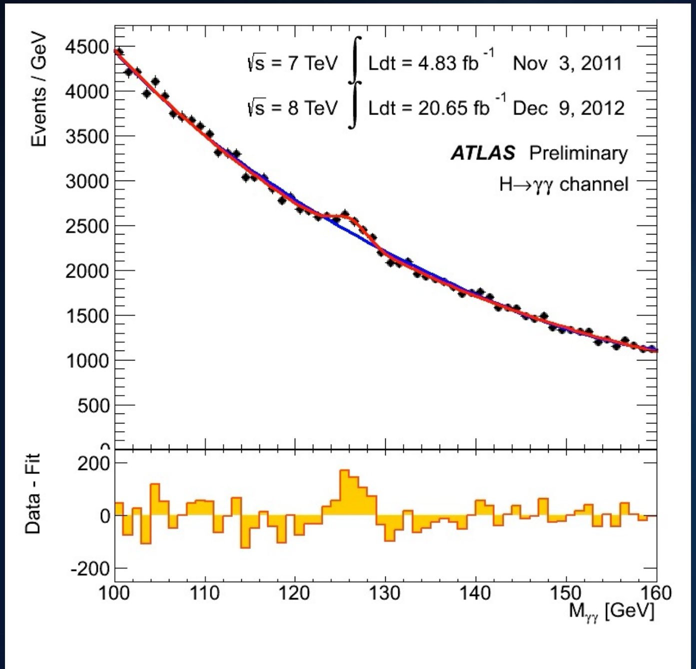
CMS

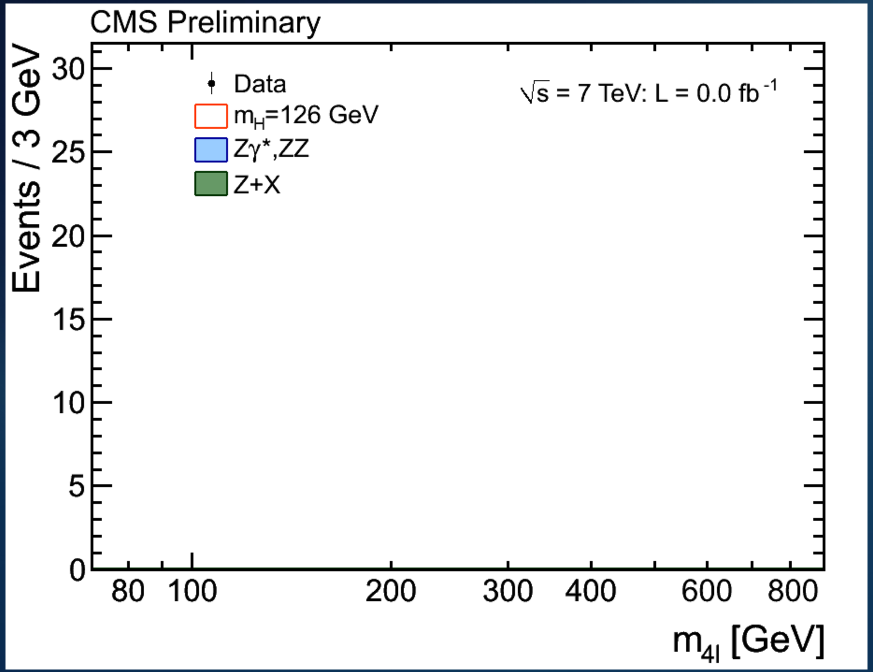
ALICE

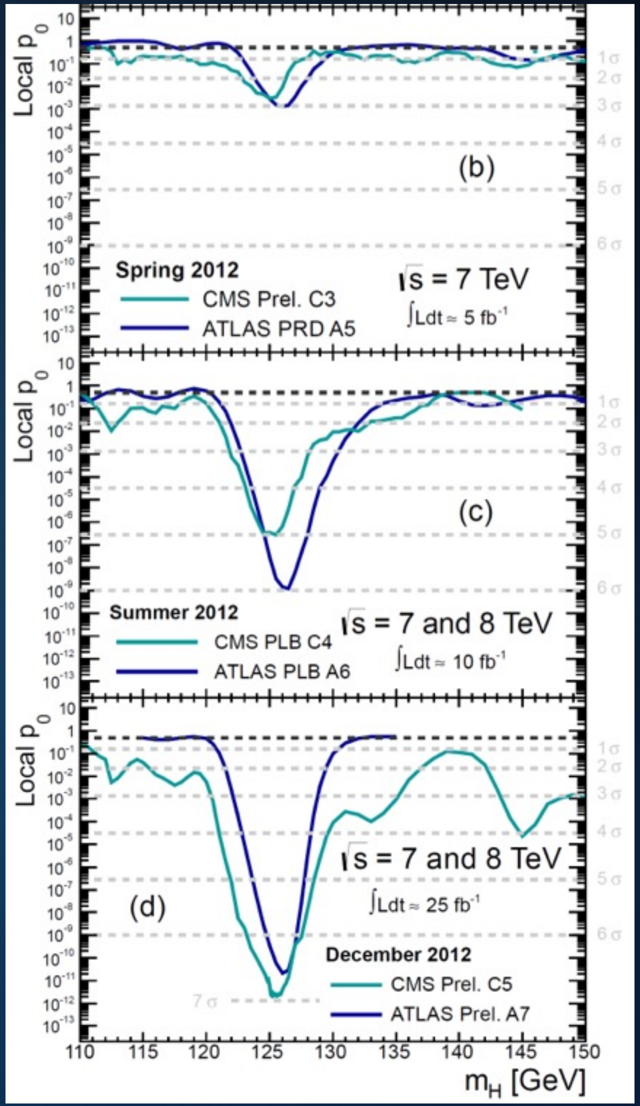
LHCb

# Higgs discovery

- End of 2011: tantalizing hint, the trail begins
- Summer 2012: discovery! 5σ from both experiments
- End of 2012: confirmation! Measurement era begins



# Higgs discovery … and the SM triumph

July 4$^{th}$ 2012 announcement

F. Gianotti (ATLAS) and J. Incandela (CMS)

F. Englert and P. Higgs

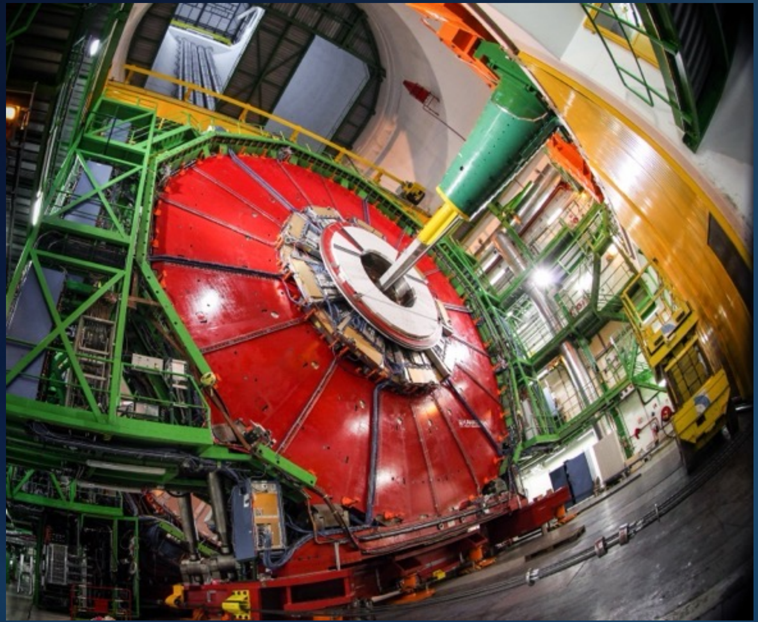
2013 Nobel Prize

# LHC beyond the Higgs discovery

- Measure all properties of the Higgs boson up to the ultimate precision
- The LHC as a precision measurement machine challenging LEP on its own territory
- Searches for physics beyond the Standard Model
- Discovery of new hadronic states composed by 4 quarks
- Observation of very rare processes
- Characterization of the quark-gluon plasma properties

# CERN develops technologies in three key areas

ACCELERATORS



DETECTORS

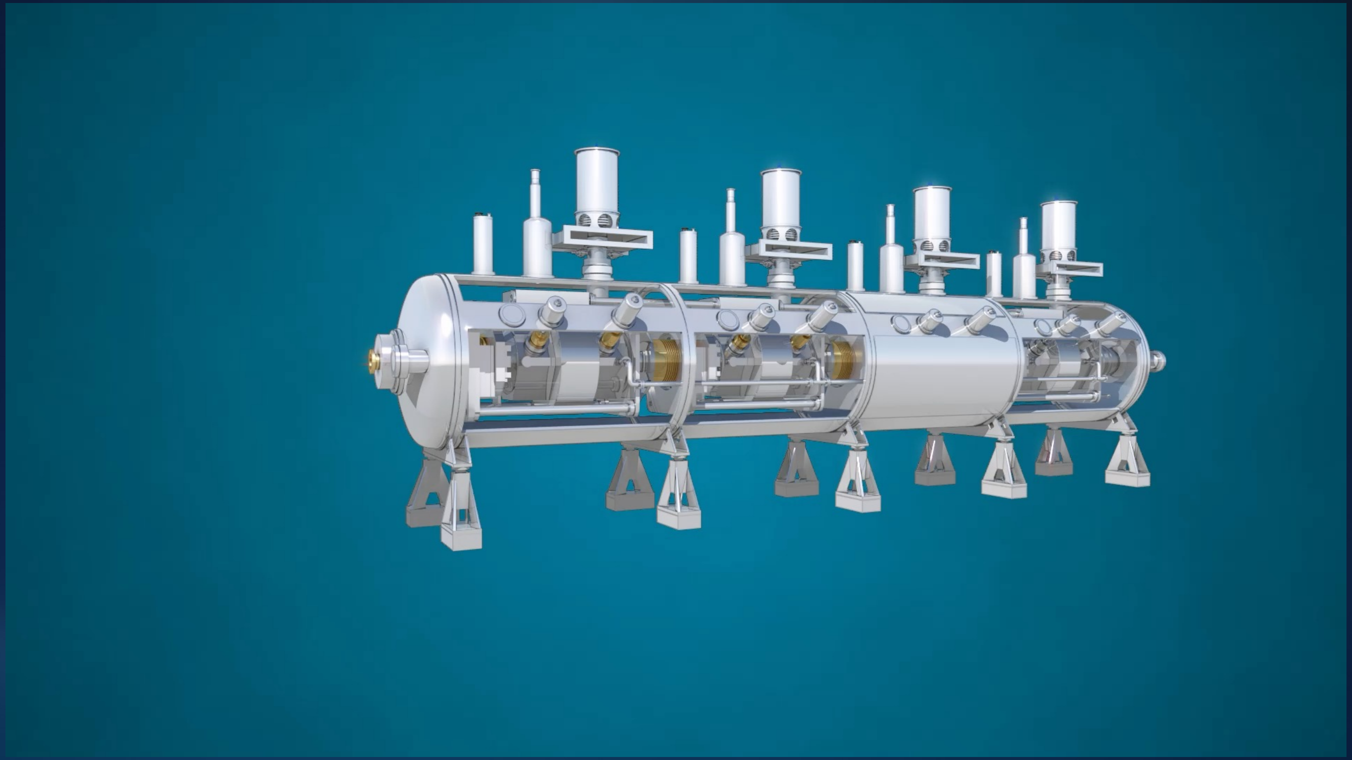
COMPUTING

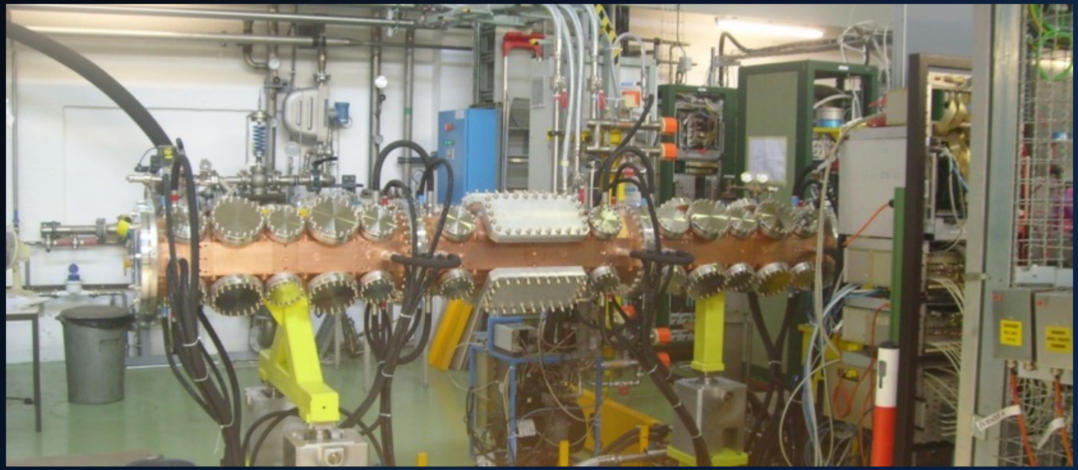
# CERN will continue to play a crucial role in the journey of exploration


Fundamental research is a cornerstone of our future, driving the continuous cycle of discovery and application that propels human progress

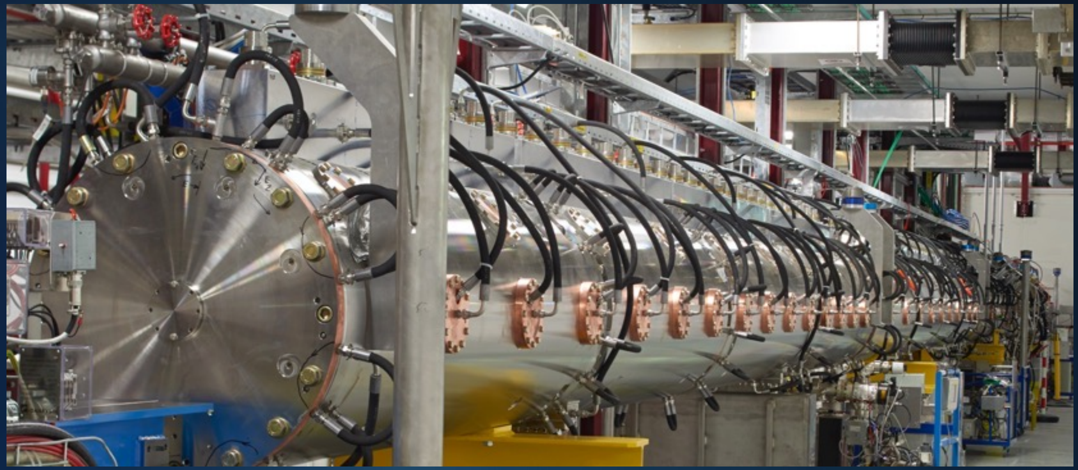
CERN | 70 YEARS / ANS CERN

# Accelerator key technologies

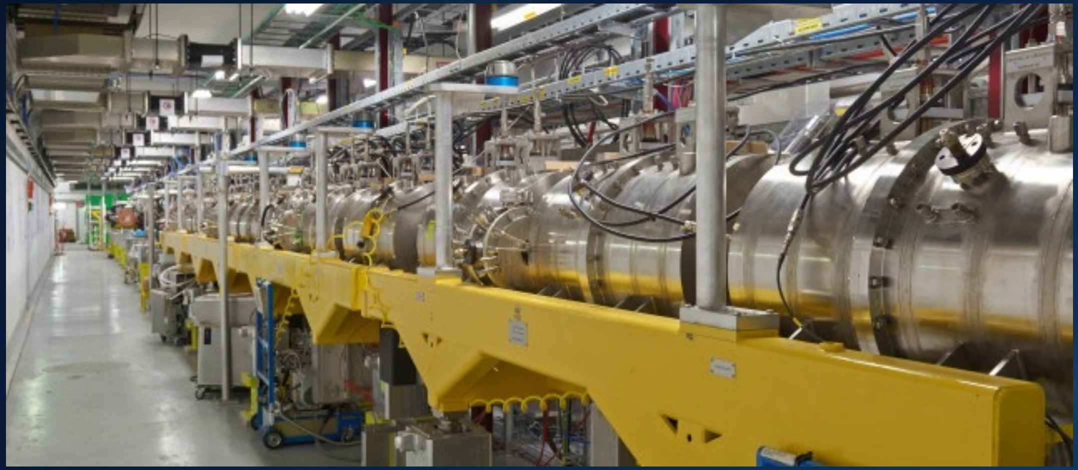




Radio Frequency Quadrupole



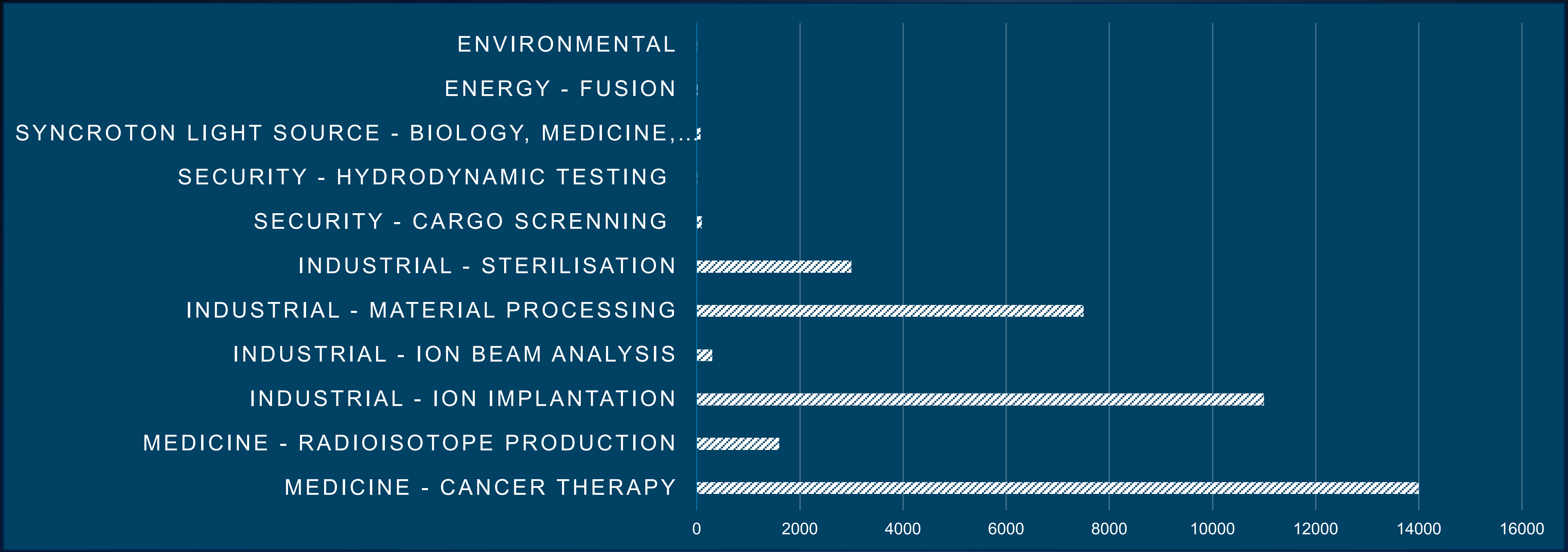
Drift Tube Linac

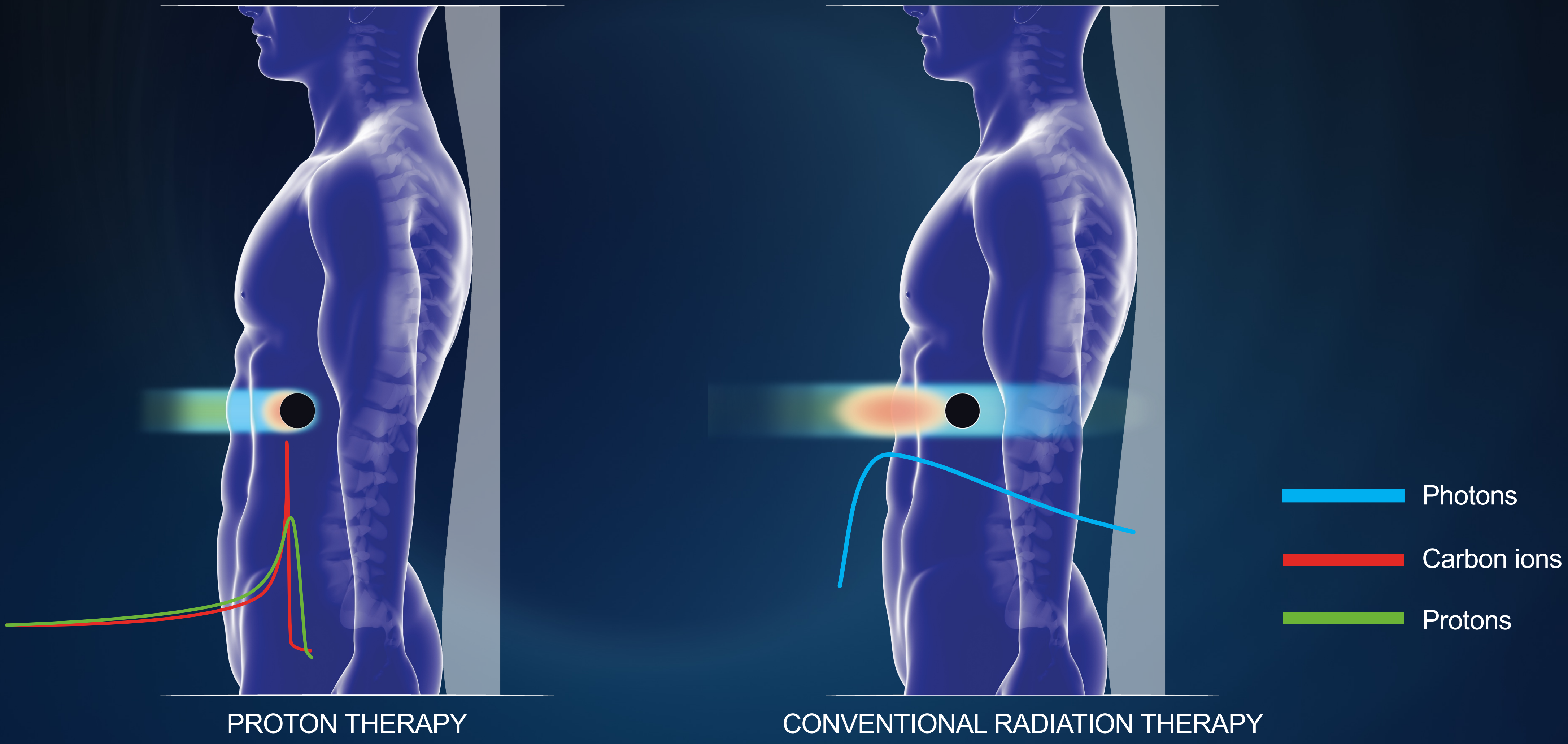


Cell-coupled DTL

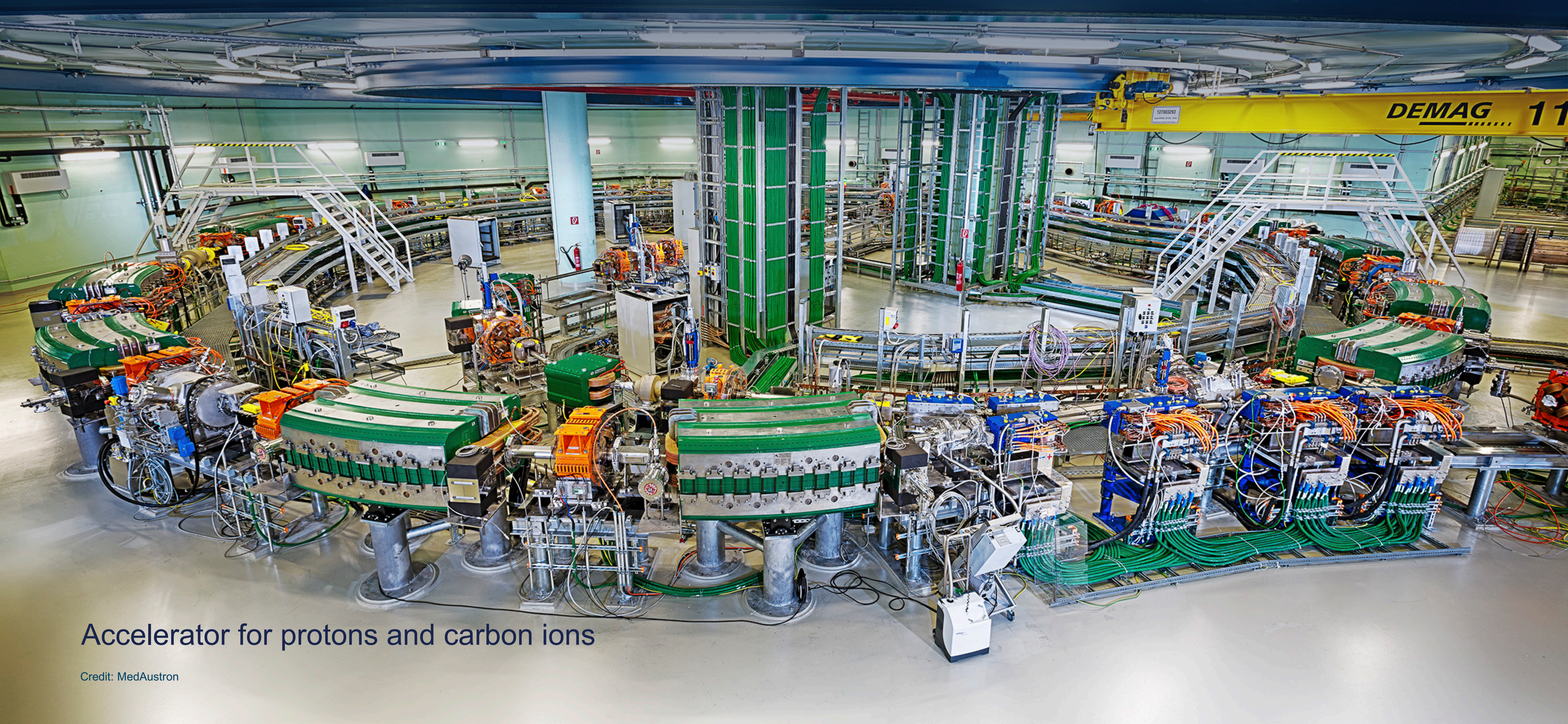
PI-mode Structure

# Application of low-energy accelerators






Credit: Shutterstock




## Accelerator for protons and carbon ions

Credit: MedAustron


# Carbon ion therapy treatment room

Credit: CNAO

# Superconductivity in the LHC

~ 10000 superconducting magnets

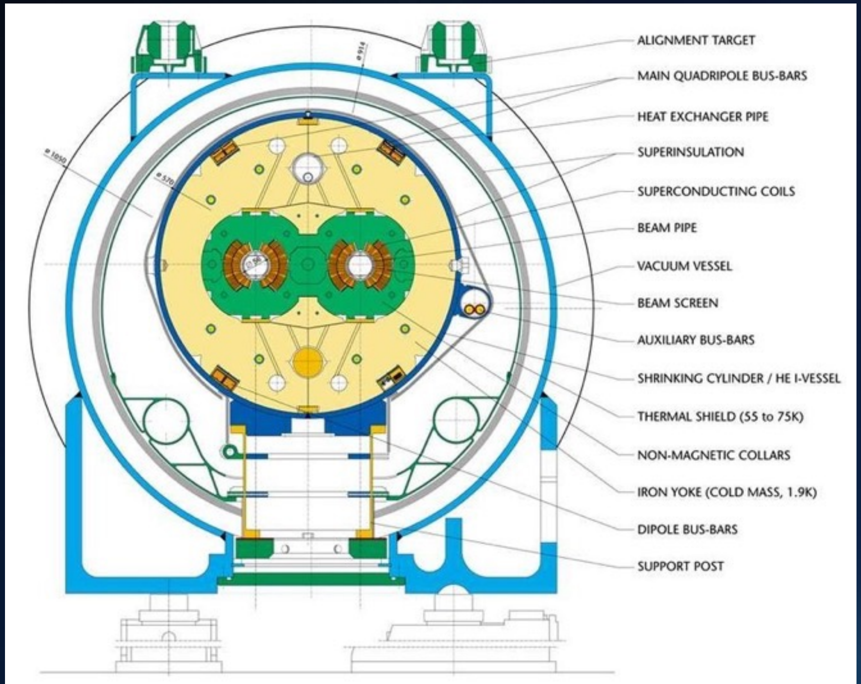
~ 1.5 Million Ampere

30 tons of superfluid helium

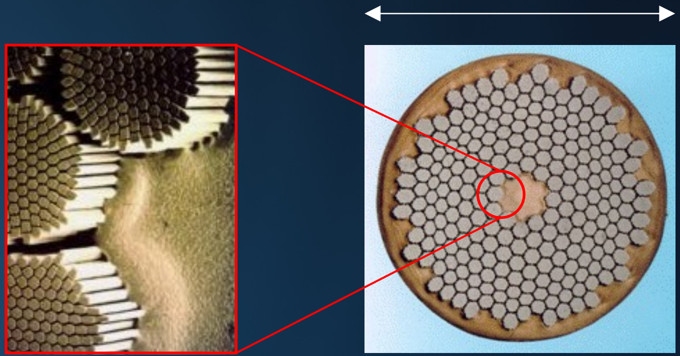
superfluid helium at 1.9 K (- 271.3 $^{0}$C)

1200 tons/7600 km of Nb-Ti cables

# The Large Hadron Collider Magnets

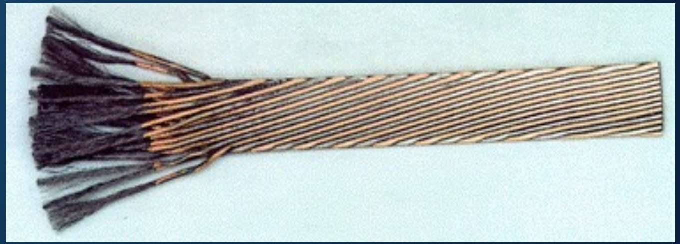



**LHC Nb-Ti wire**
**1mm**



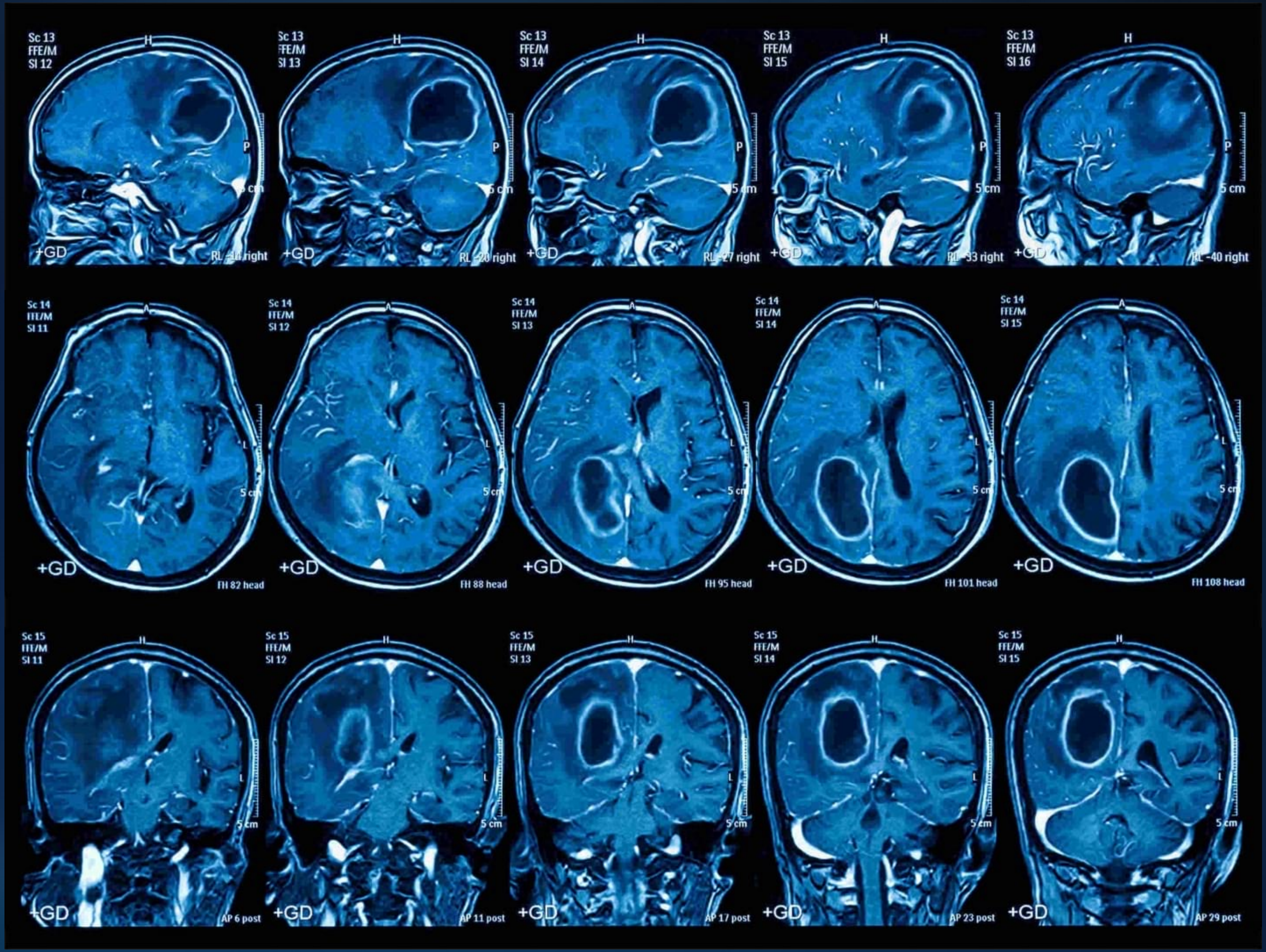
Ic(5T, 4.2 K) ~ 1000 A

**LHC Nb-Ti Cable**



**Ic(10T, 1.9 K) ~ 13000 A**

# MRI Magnets



Superconducting magnets in MRI:
Non-invasive 3D anatomical imaging

MRI industry consumes ~4000 tons of Nb-Ti annually

Over 50,000 MRI scanners worldwide

# Transmission of Electric Power


**High-Temperature Superconductors:**

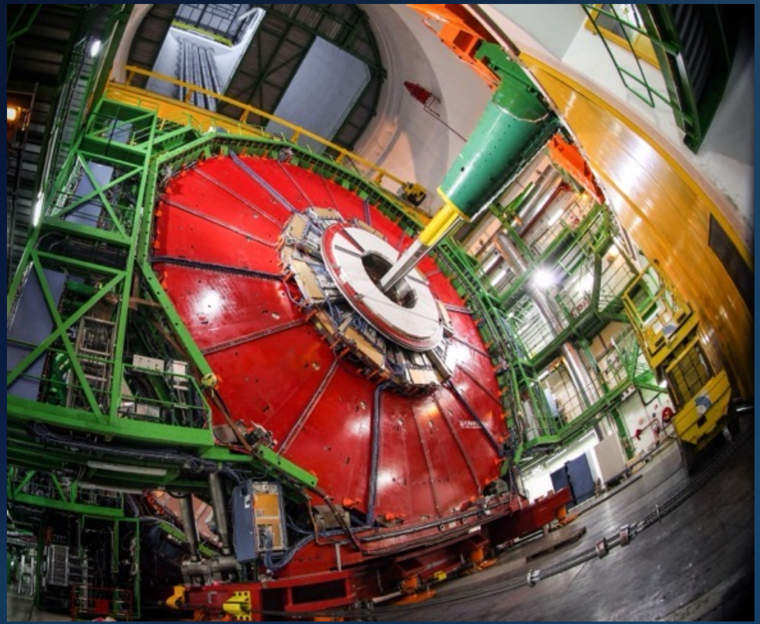
Used for High Luminosity upgrade of the LHC

Tc above liquid nitrogen temperature
**(77 K or -195.15 °C)**

Handles 120 kA in DC mode at up to 50 K
**(-223.1 °C)**

# We develop technologies in three key areas

ACCELERATORS



**DETECTORS**

COMPUTING

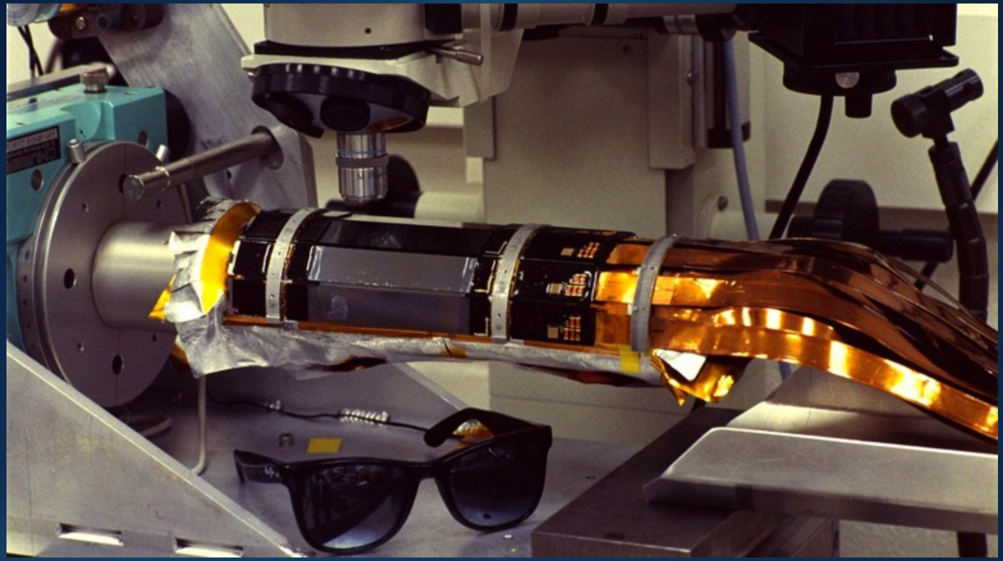
# The silicon revolution and discoveries

1980 - search for particles with charm and beauty quarks (decay length ~ 100 μm)

Silicon technology for microelectronics

**Kemmer 1979,** KETEK
from electronics to detector fabrication

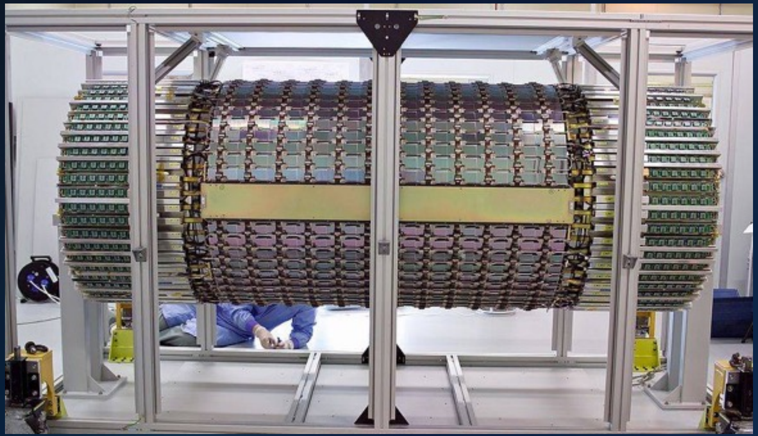
NA11- NA32: measurements of Lifetimes of particles containing c-quarks
MARK II: measurement of charm, tau, and b-lifetime

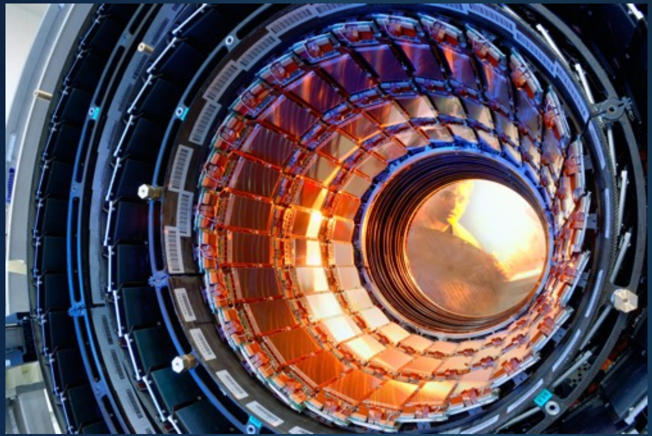


# Silicon trackers at the heart of all LHC experiments

## Giant, ultra-fast and very complex 3D camera

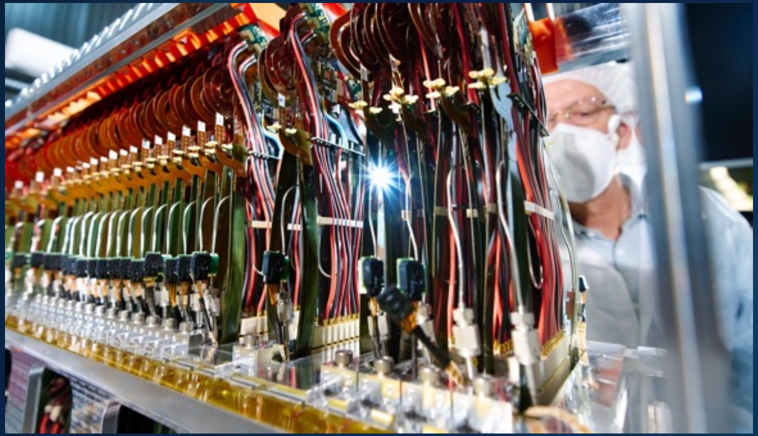
ATLAS

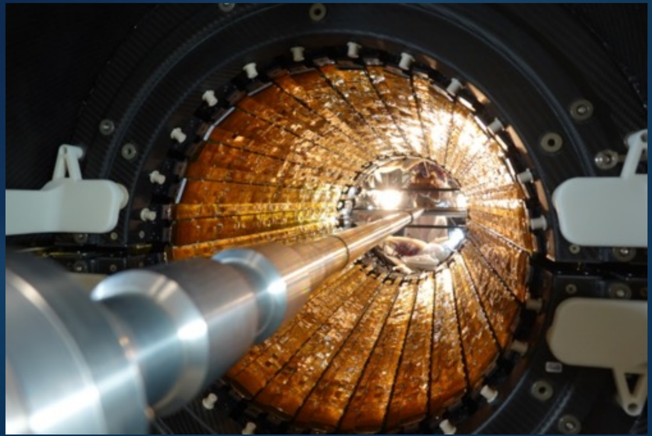




CMS

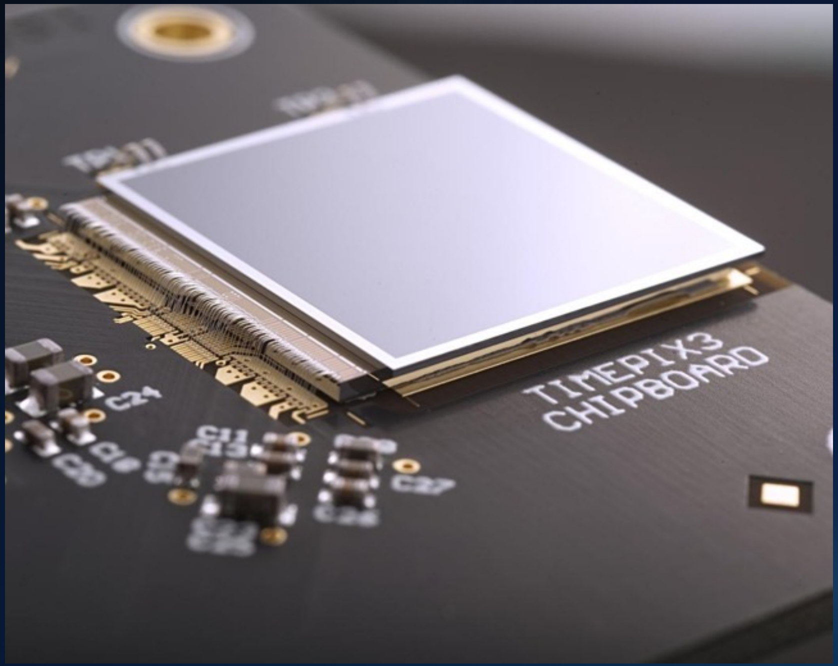
LHCb





ALICE

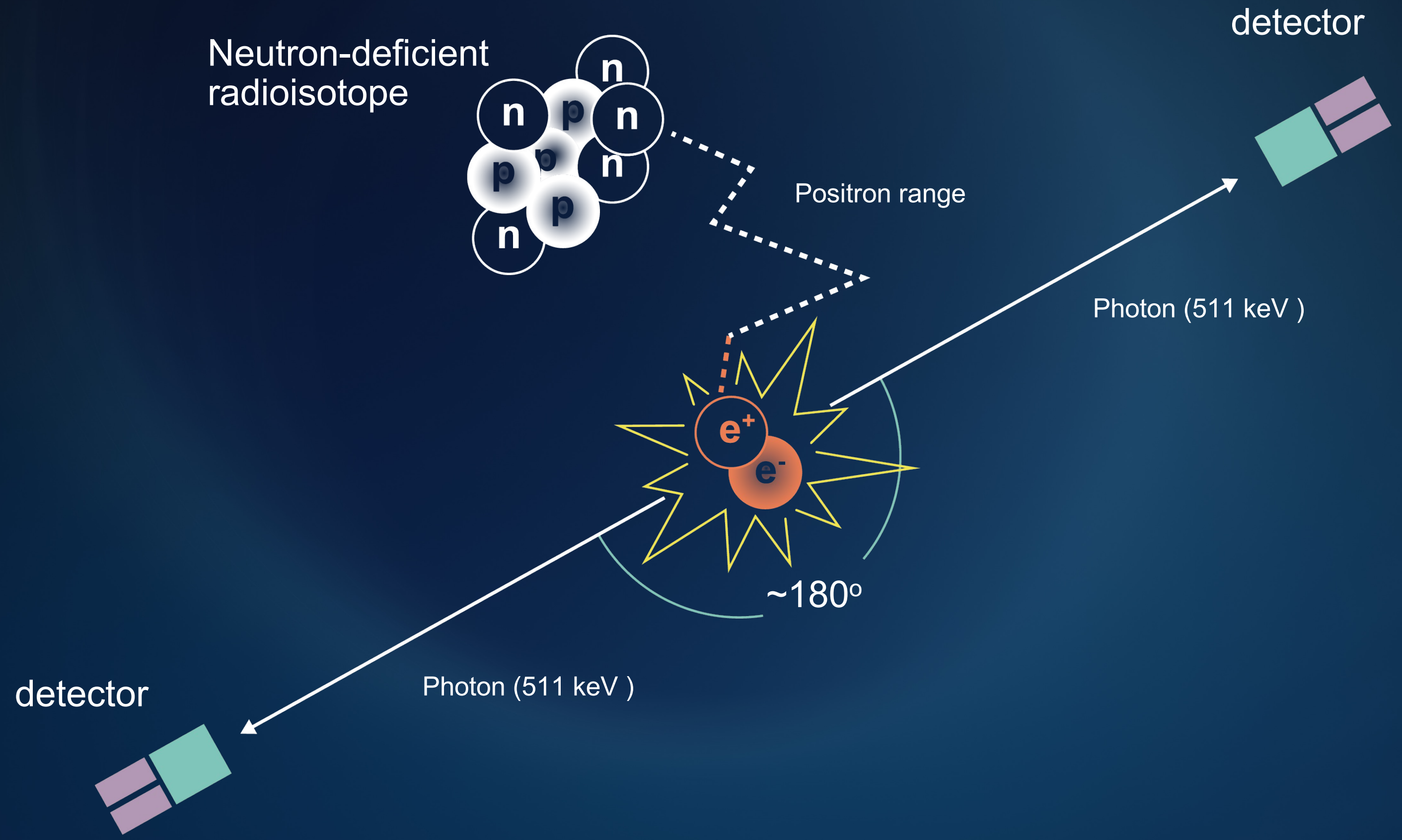
# From particle physics to technology and back




Space | Biology | Research | Mining | Non-destructive testing

# Positron Emission Tomography

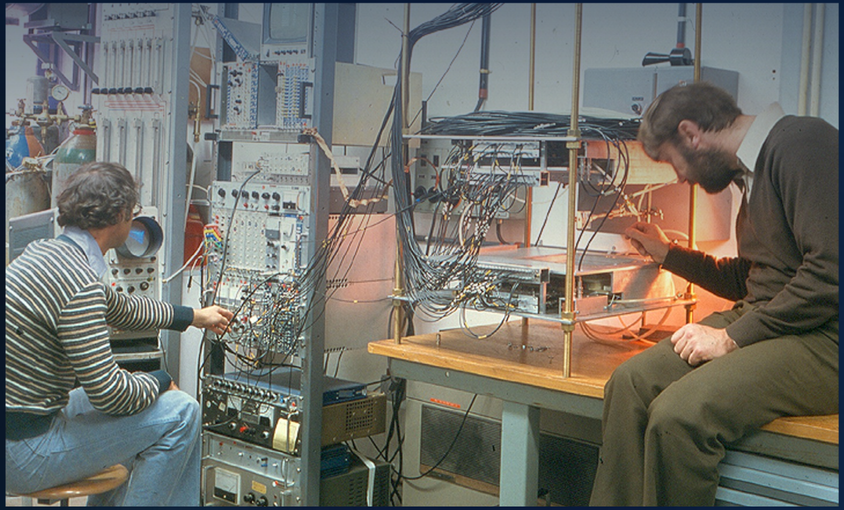
$p \rightarrow n + e^{+} + \nu_e$

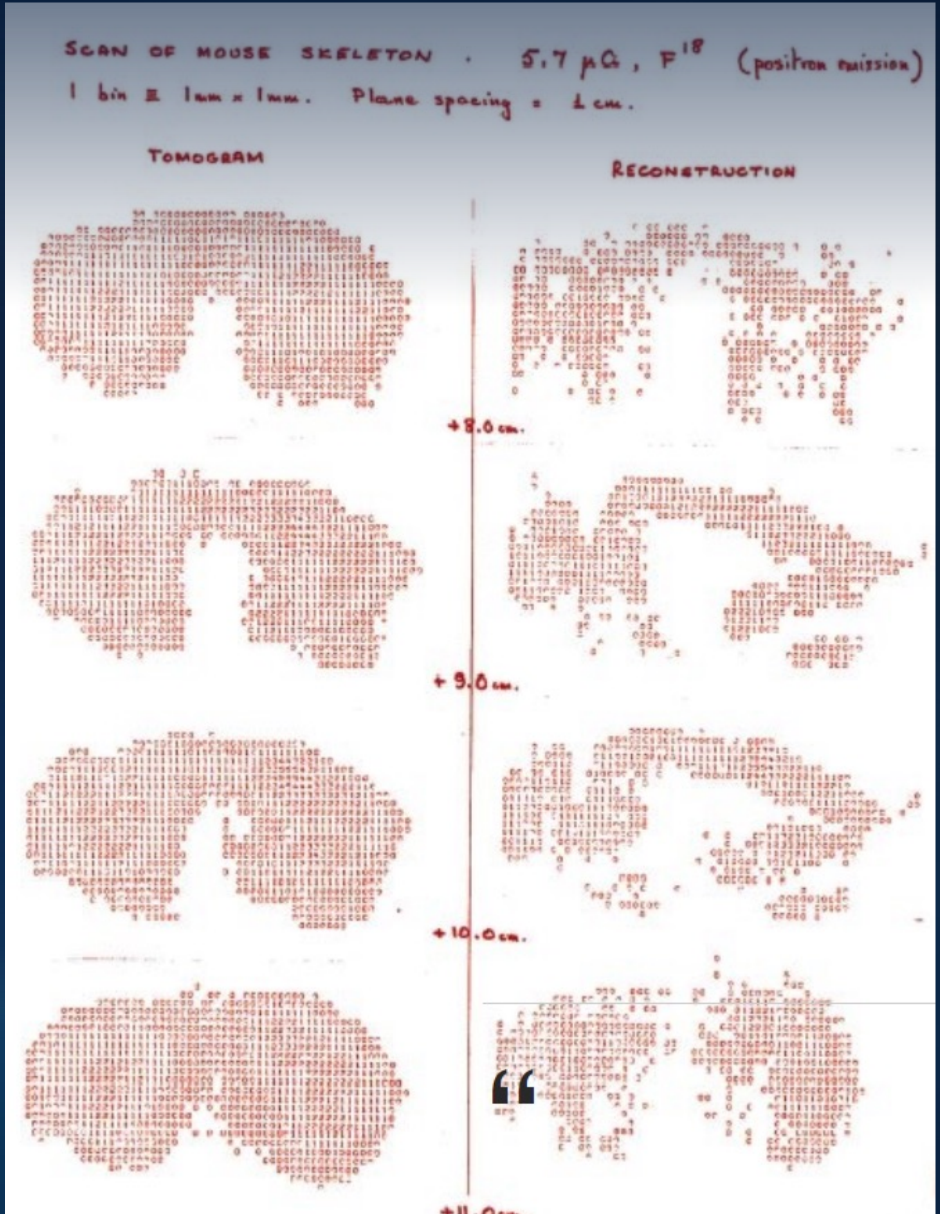



Credit: CERN


Credit: Jeroen Huijben

## 1977

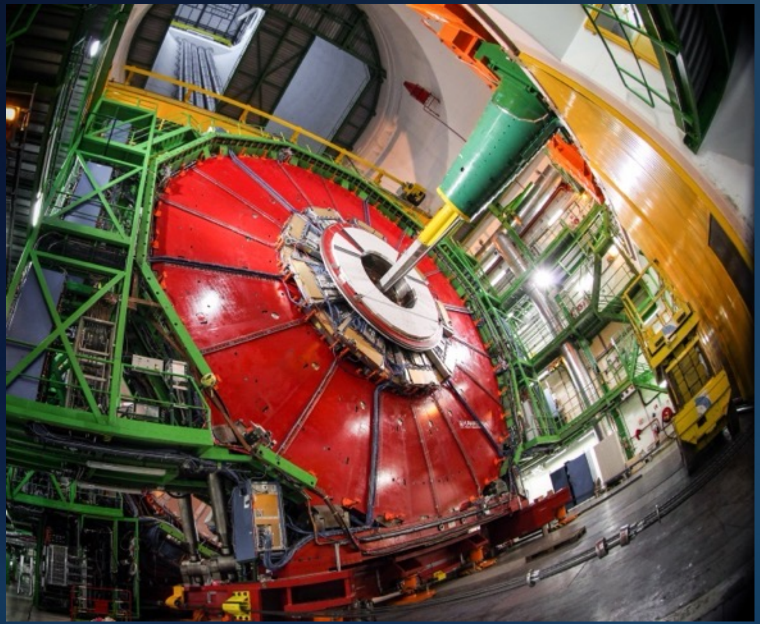





Credit: CERN

# We develop technologies in three key areas

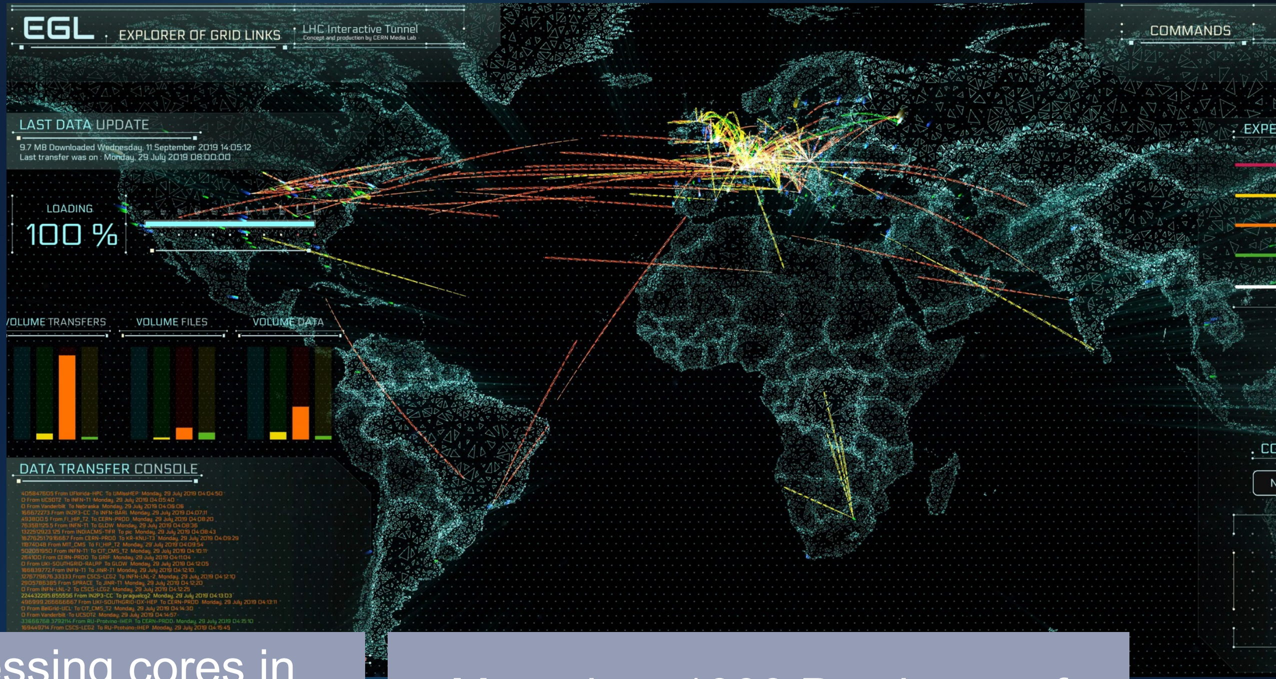
ACCELERATORS



DETECTORS

**COMPUTING**

# The Worldwide LHC Computing Grid (WLCG)




Used to store, distribute, process and analyse data.

1 million processing cores in about 160 data centres and 42 countries.

More than 1000 Petabytes of CERN data stored world-wide.