



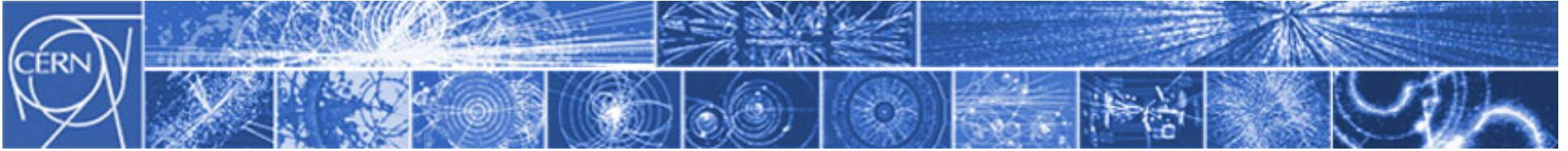
# CERN

European Organization for Nuclear Research  
Organisation Européenne pour la Recherche Nucléaire

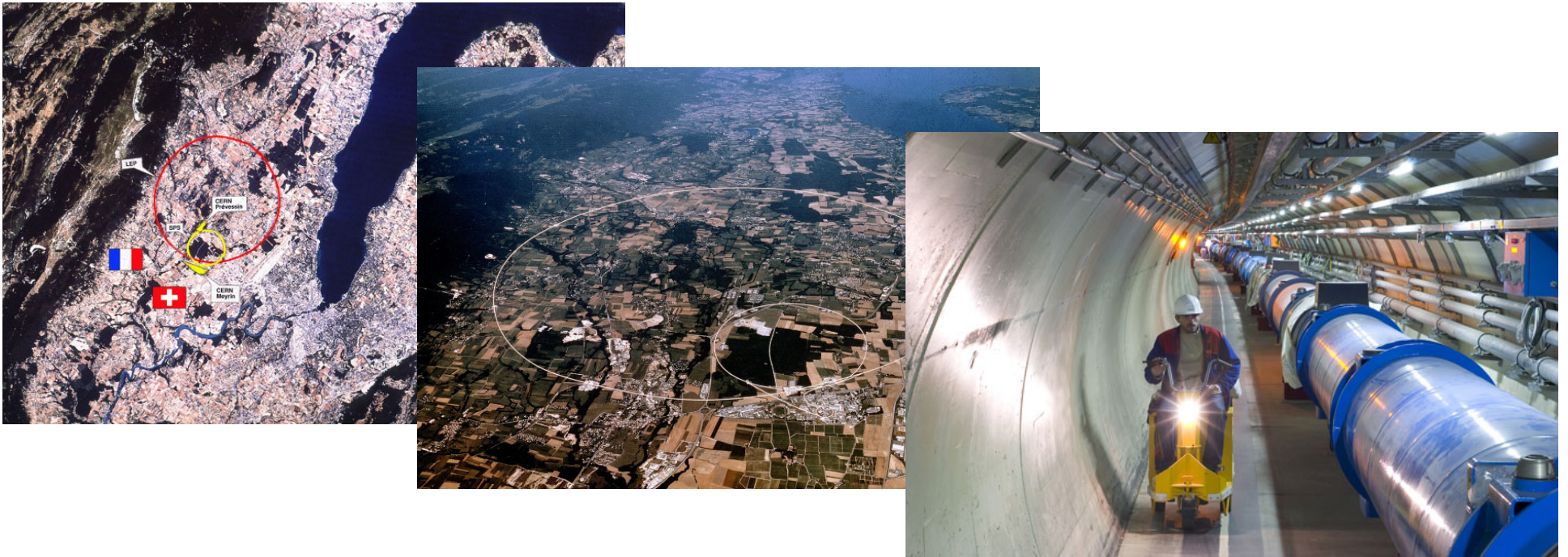
## The Large Hadron Collider *the world's most complex machine*



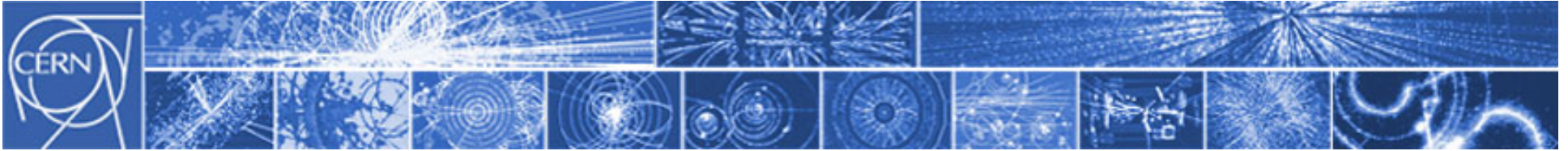
Dr James Gillies, Head of communication, CERN



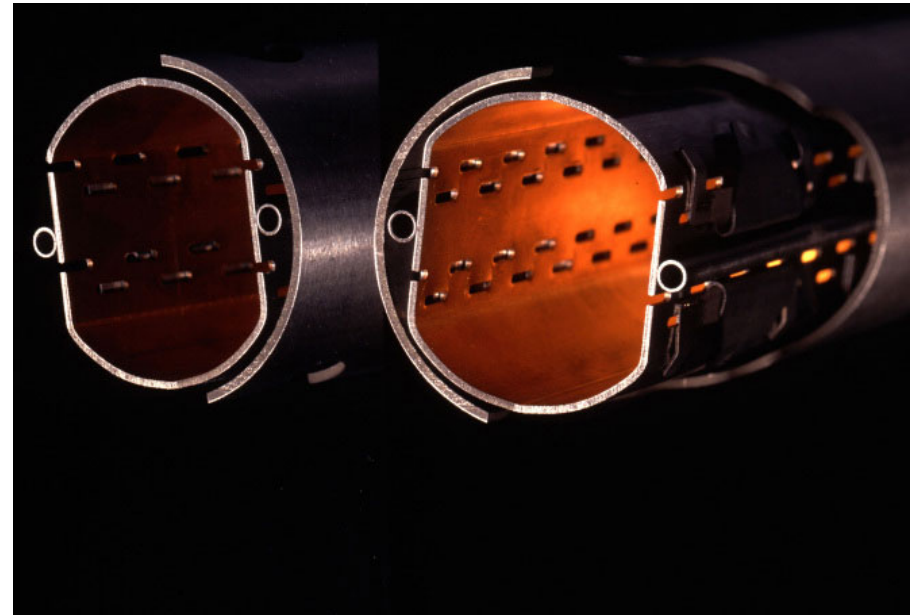
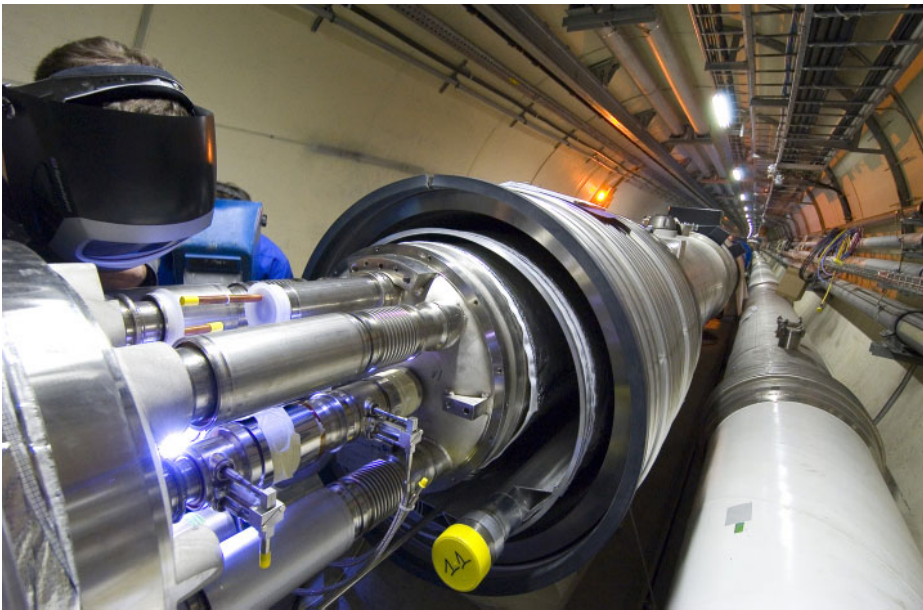
## The fastest racetrack on the planet...



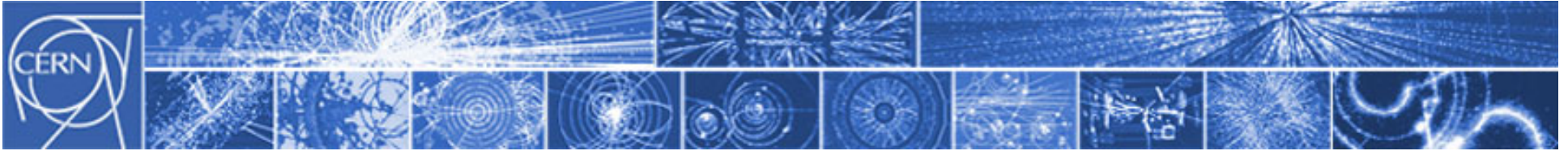
Trillions of protons will race around the 27km ring in opposite directions over 11,000 times a second, travelling at 99.9999991 per cent the speed of light.



One of the emptiest places in the solar system...



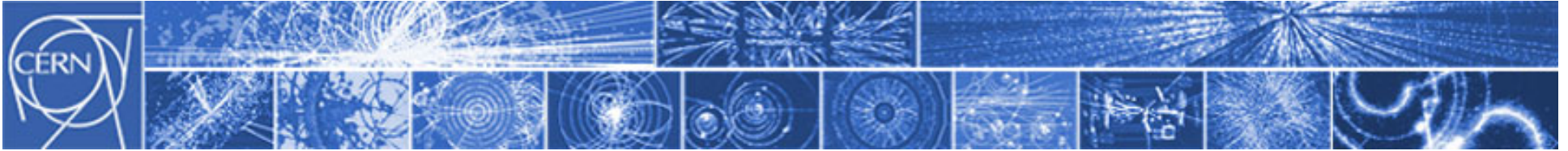
To accelerate protons to almost the speed of light requires a vacuum as empty as interplanetary space. There is 10 times more pressure on the moon than there is in the LHC.



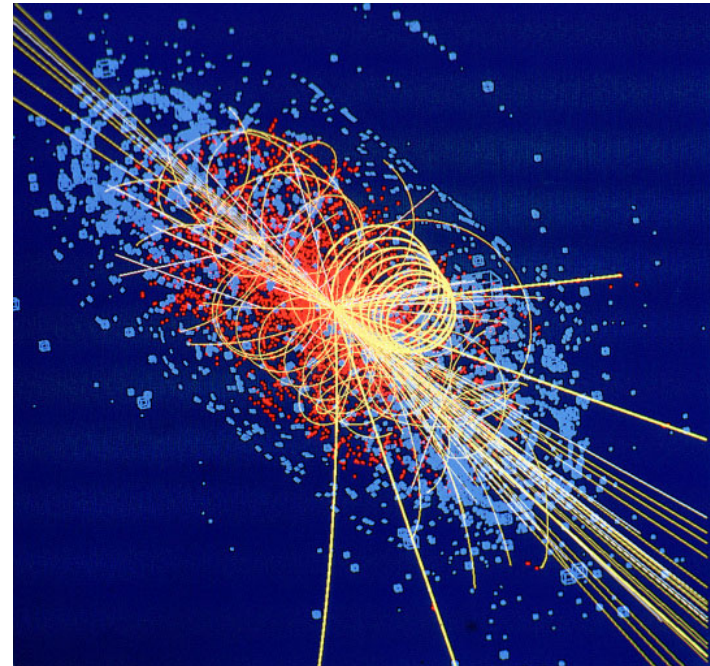
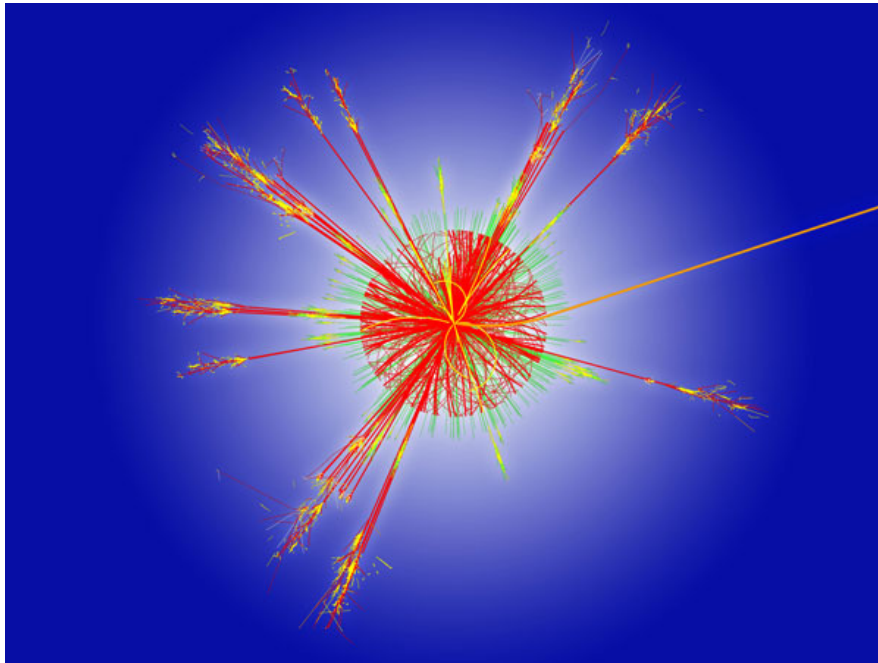
One of the coldest places in the universe...



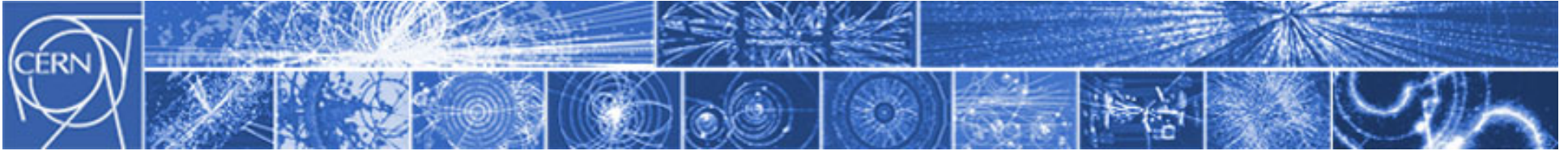
With an operating temperature of about  $-271$  degrees Celsius, just  $1.9$  degrees above absolute zero, the LHC is colder than outer space.



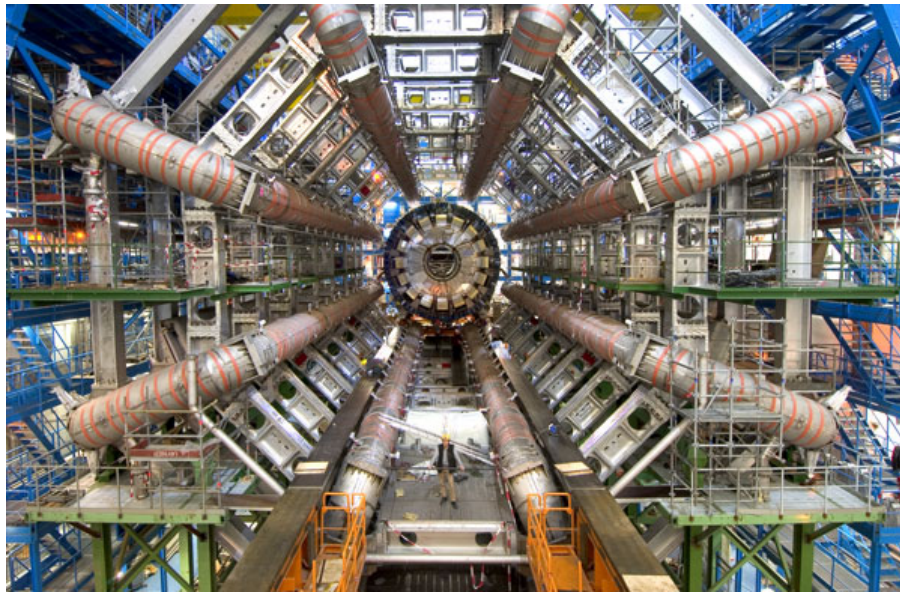
## The hottest spots in the galaxy...



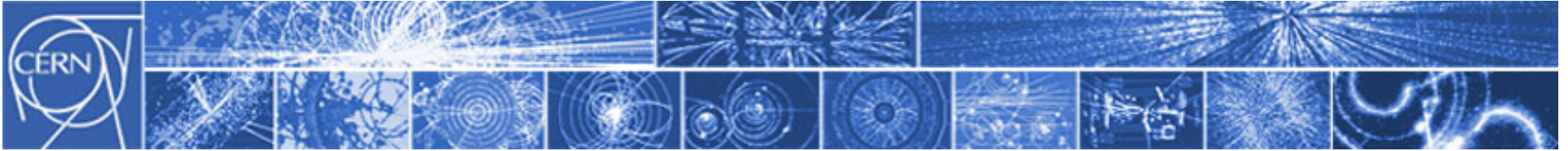
When two beams of protons collide, they will generate temperatures 1000 million times hotter than the heart of the sun, but in a minuscule space.



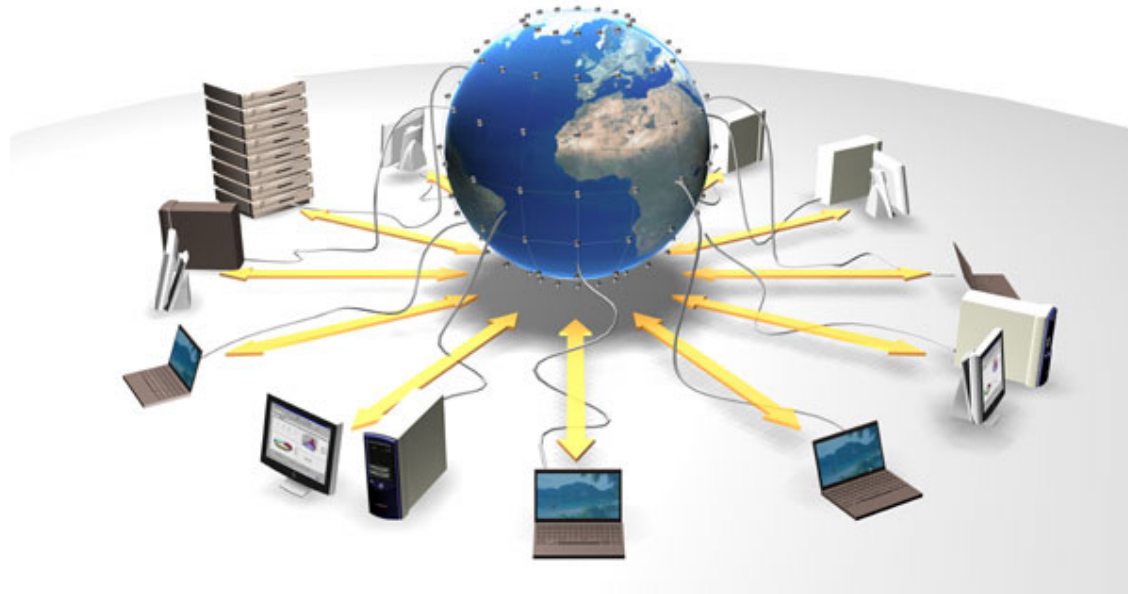
The biggest most sophisticated detectors ever built...



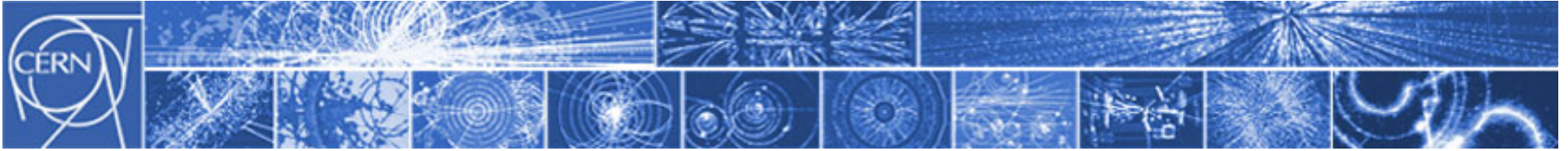
To sample and record the debris from up to 600 million proton collisions per second, scientists are building gargantuan devices that measure particles with micron precision.



The most extensive computer system in the world...

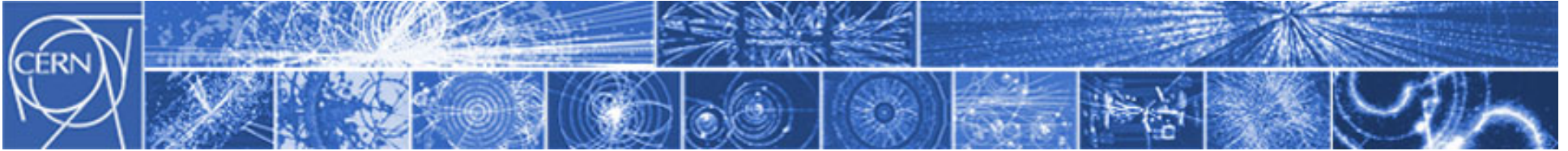


To analyse the data, tens of thousands of computers around the world are being harnessed in the Grid. The laboratory that gave the world the web, is now taking distributed computing a big step further.



## The accelerator





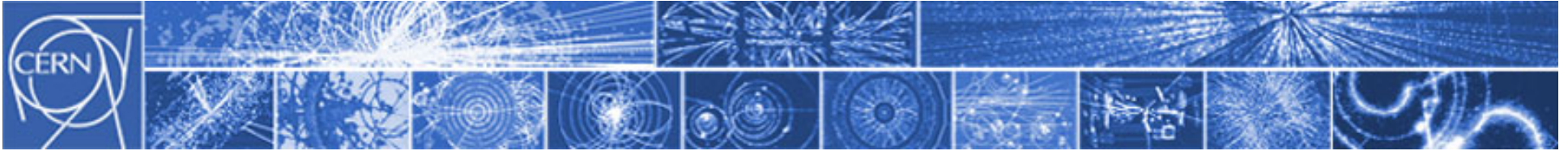
## Early accelerators...



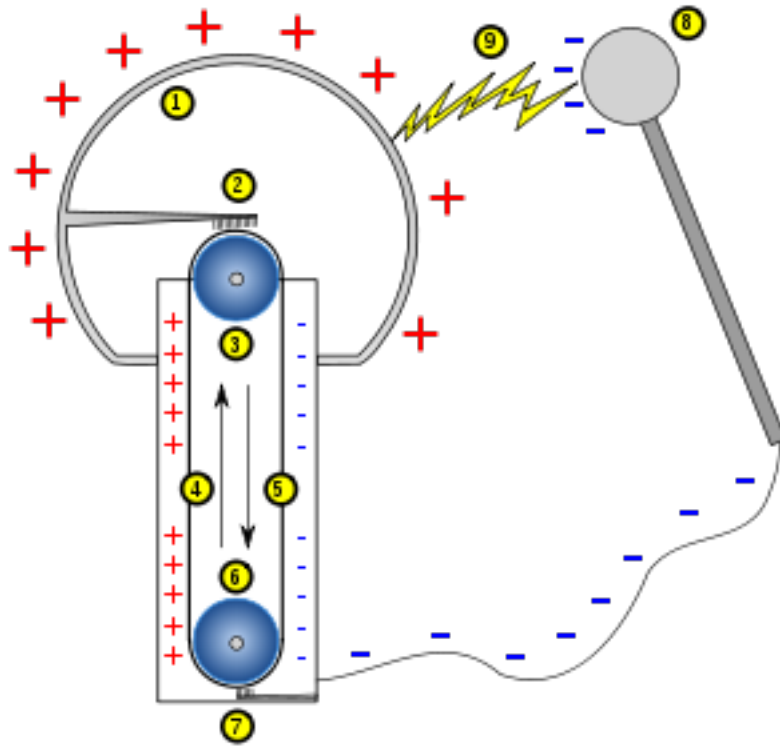
J. J. Thomson  
Cathode ray tube  
Discovered electrons in  
1897



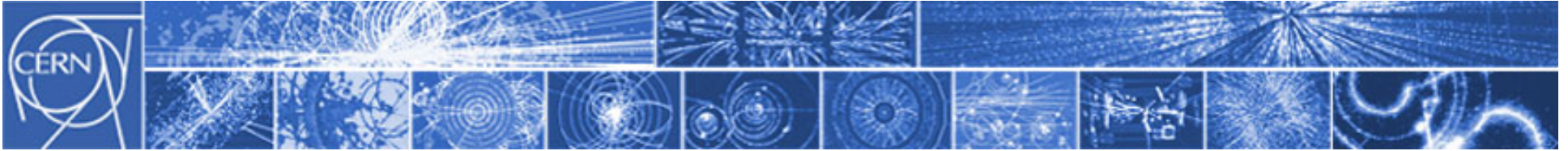
Van de Graaf generator  
Invented in 1929



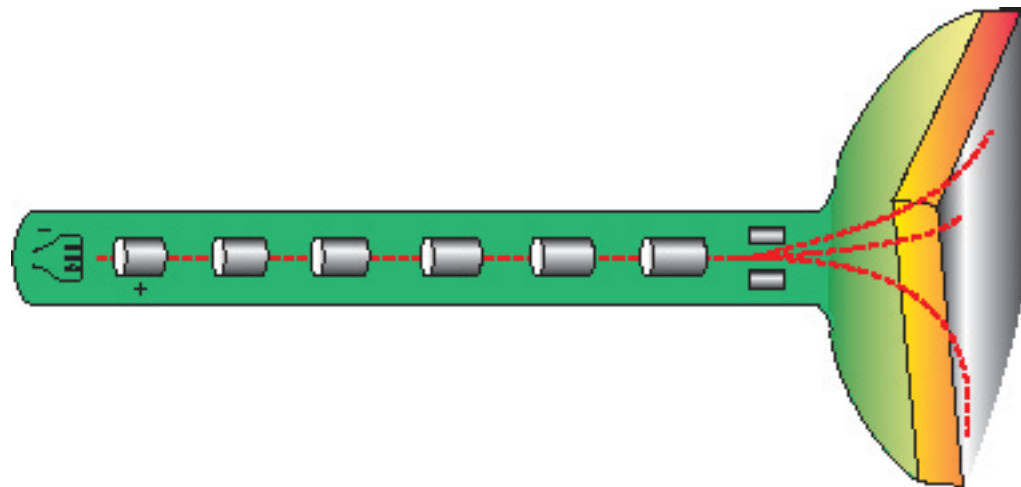
## Early accelerators...

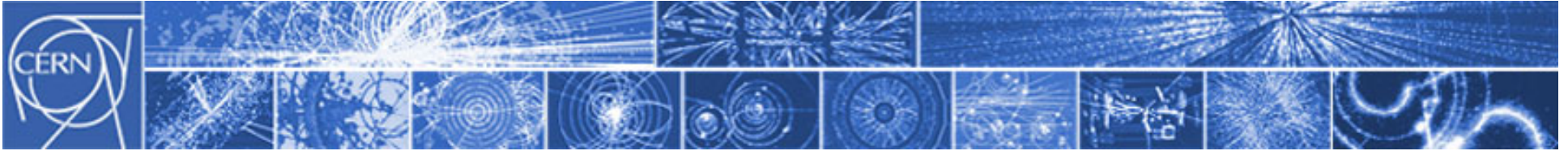


Cockcroft Walton  
Nuclear transmutation  
Nobel Prize 1951

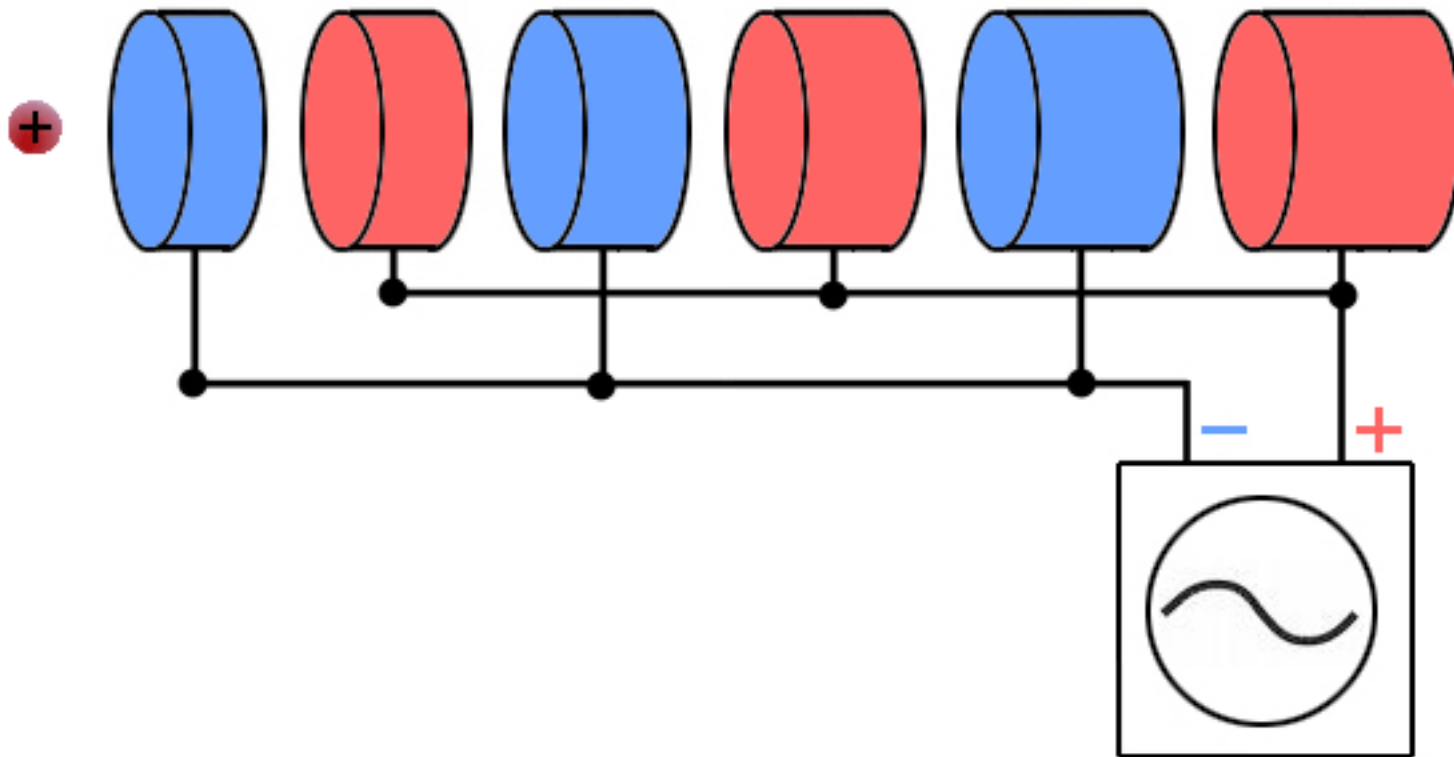


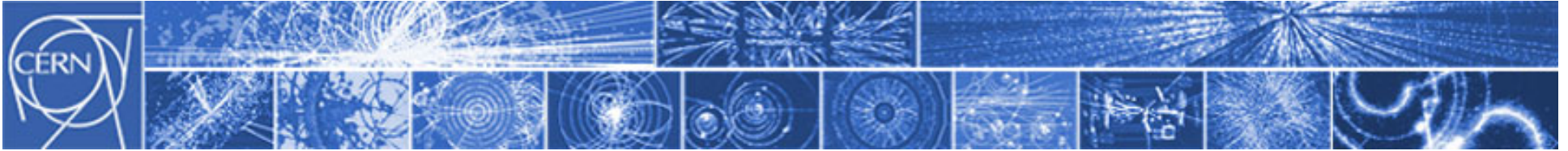
The accelerator (that used to be) in your living room



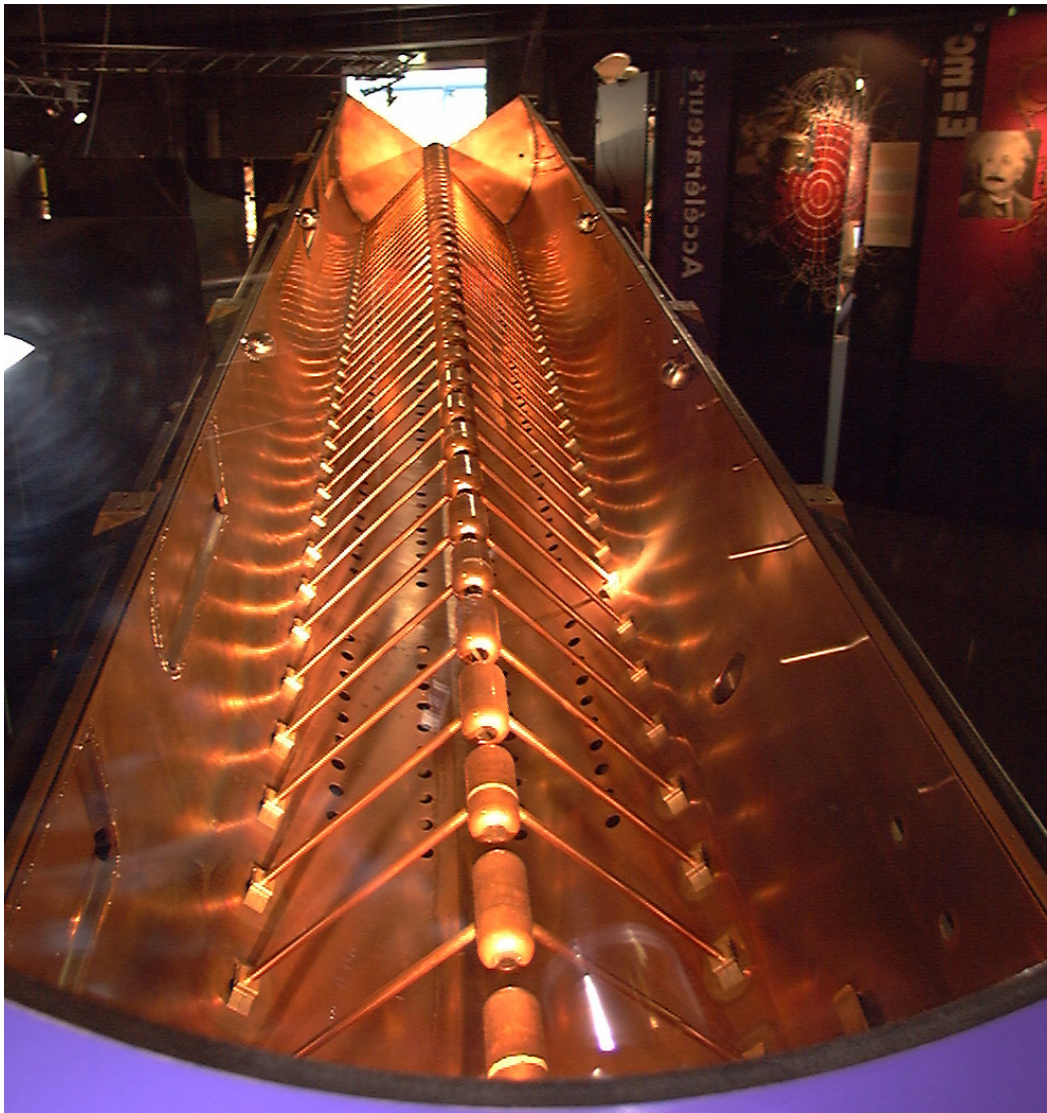


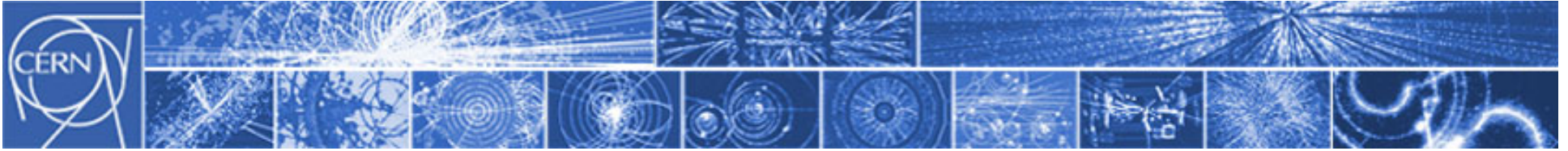
# Linacs...





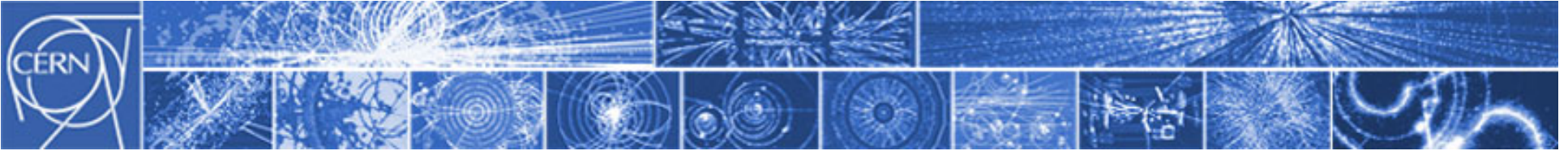
# Linacs...





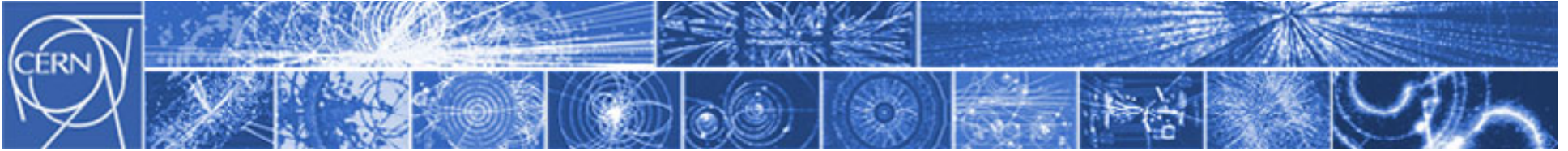
## The motion of particles in a magnetic field



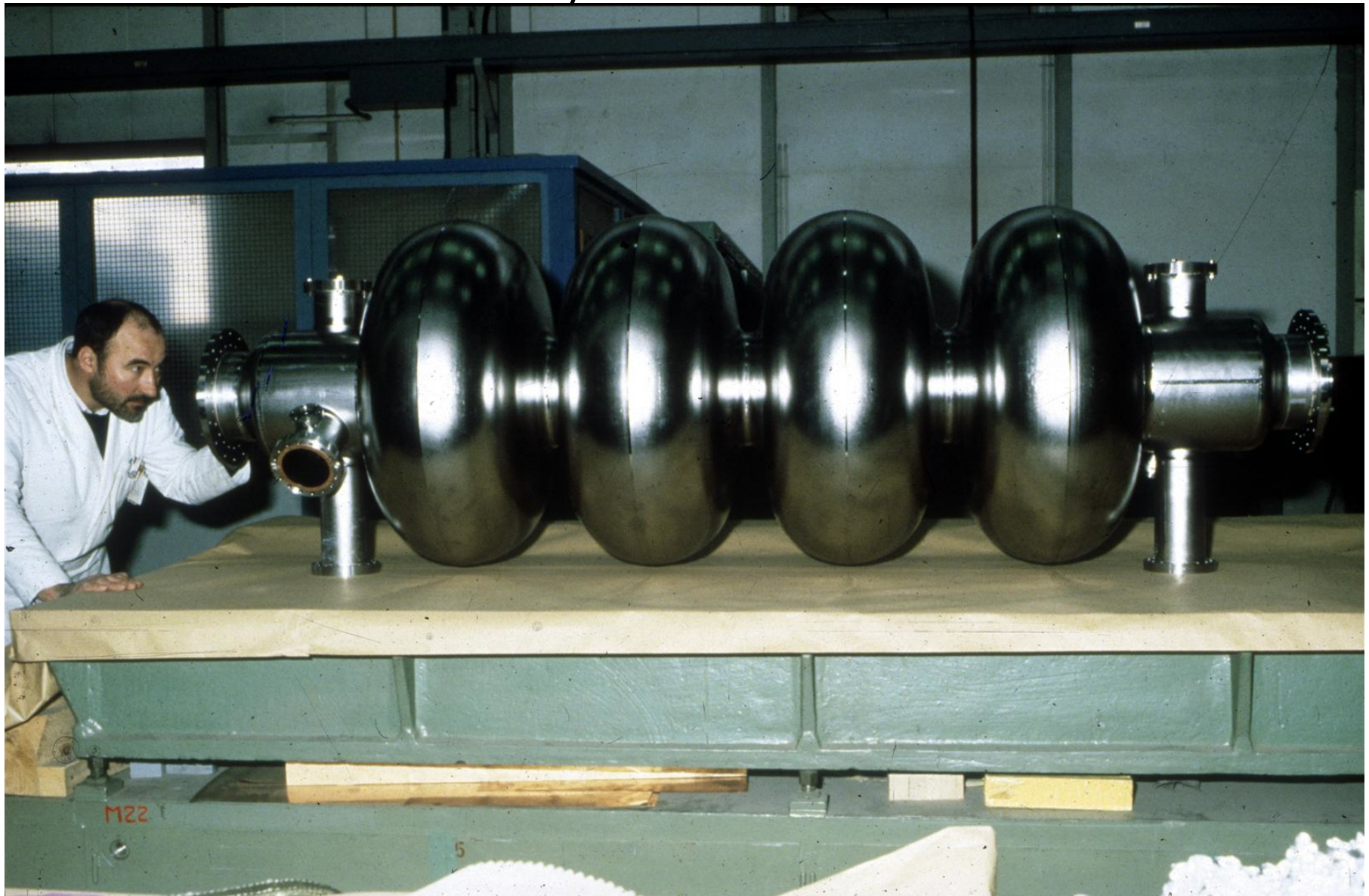


## Basic principles: electric and magnetic fields

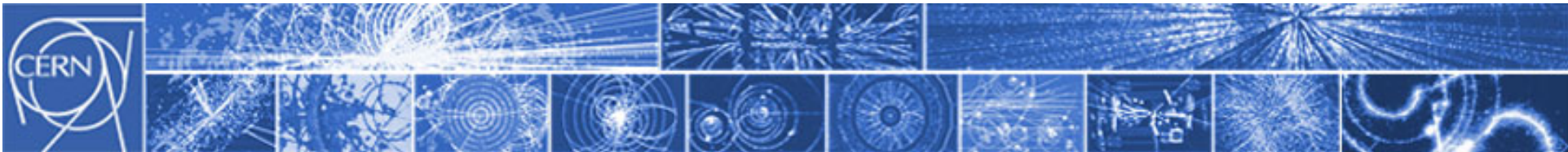




# synchrotrons







## Leptons or hadrons?

SR01C-DI-SRM-01 and SR01C-DI-DCAM-03

Camera Image

3.88 mm

Camera Status

Enable Enabled

- Energy loss goes as  $1/\text{mass}^4$
- Protons are 2000 times more massive than electrons
- So they lose  $1.6 \times 10^{13}$  times less energy

Camera Controls

Gain: 1023

Exposure: 1081

1

Frames/s: 1.8

Digital Zoom and Pan

1/2 1/1 Width: 512

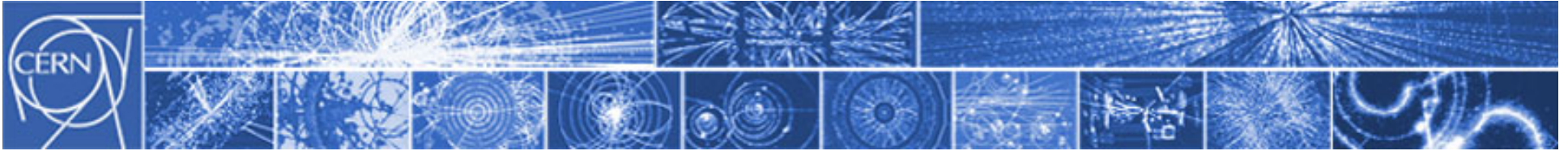
Horizontal centre: 512

Vertical centre: 390

Camera Config Position Info Grey Scale Show Grid EXIT

-3.64 mm

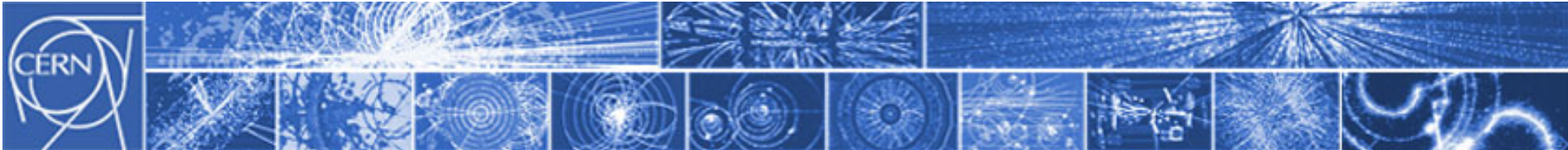
5.02 mm 0.00 mm -5.02 mm



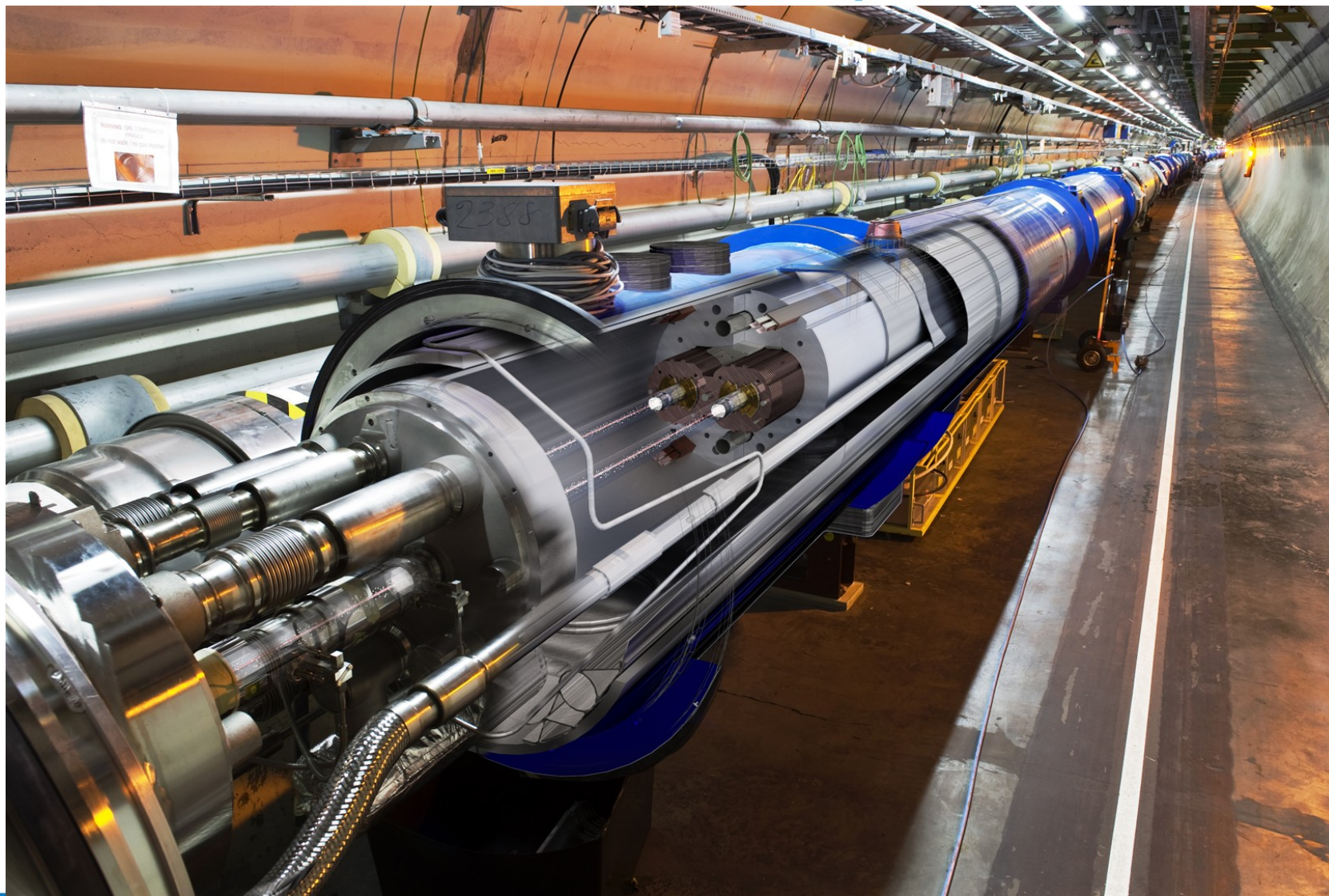
## Leptons or hadrons?

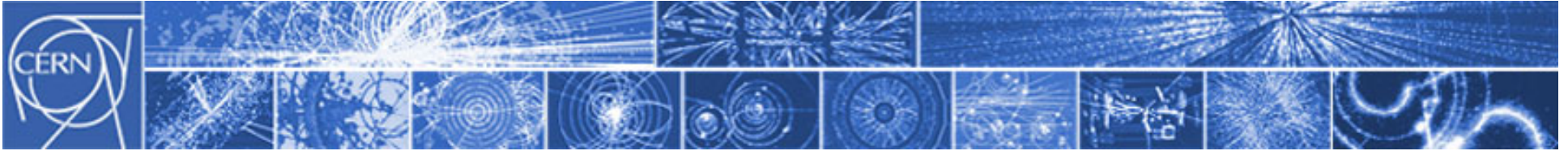


- Hadron machines are discovery machines
- Lepton machines are precision machines



## CERN's accelerator complex

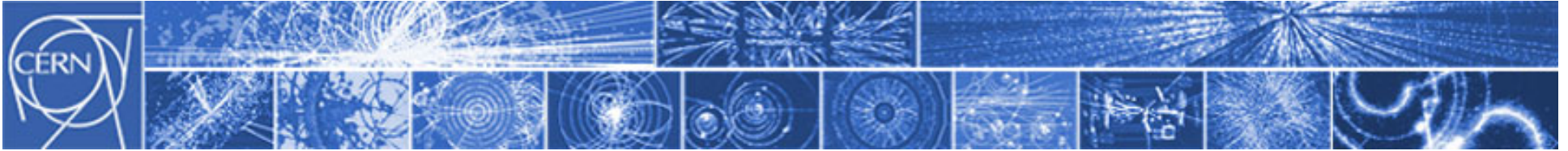




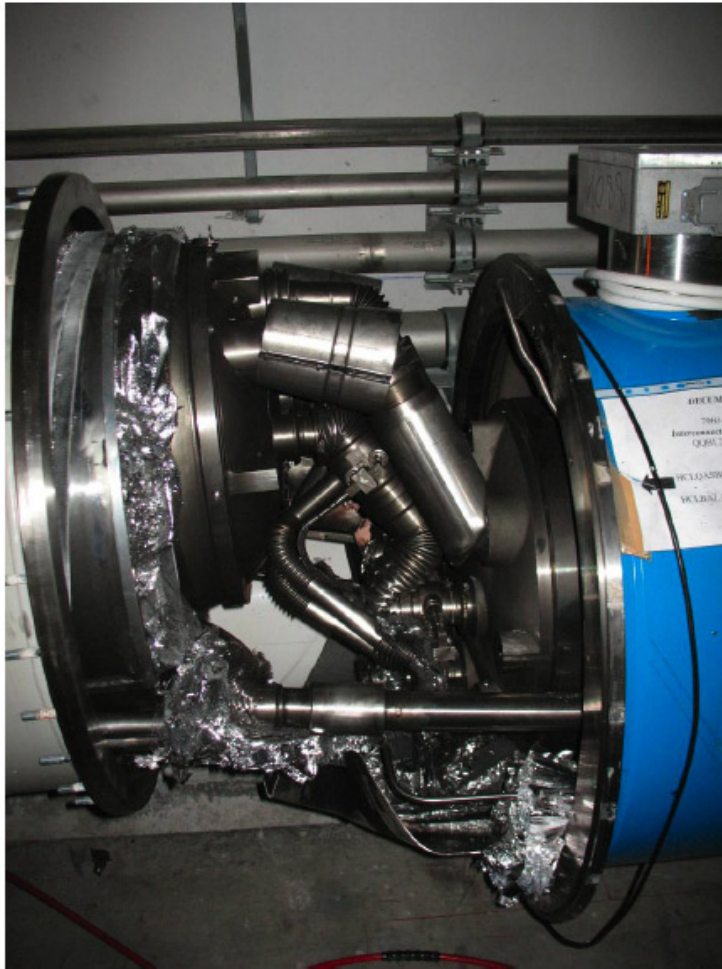
## The LHC facts and figures

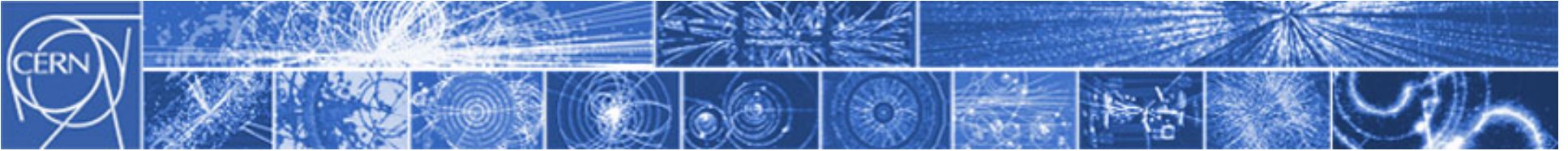
Quantity	number
Circumference	26 659 m
Dipole operating temperature	1.9 K (-271.3°C)
Number of magnets	9593
Number of main dipoles	1232
Number of main quadrupoles	392
Number of RF cavities	8 per beam
Nominal energy, protons	7 TeV
Nominal energy, ions	2.76 TeV/u (*)
Peak magnetic dipole field	8.33 T
Min. distance between bunches	~7 m
Design luminosity	$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
No. of bunches per proton beam	2808
No. of protons per bunch (at start)	$1.1 \times 10^{11}$
Number of turns per second	11 245
Number of collisions per second	600 million

(\*) Energy per nucleon

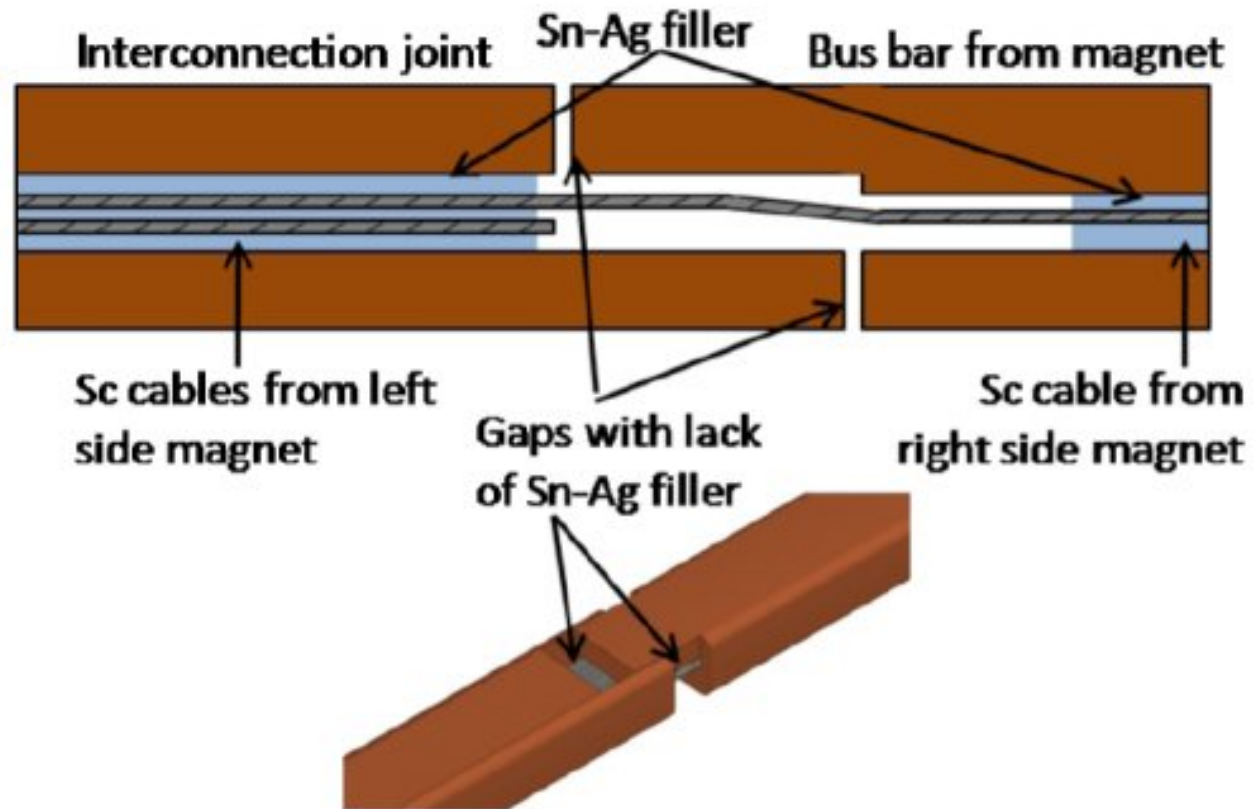


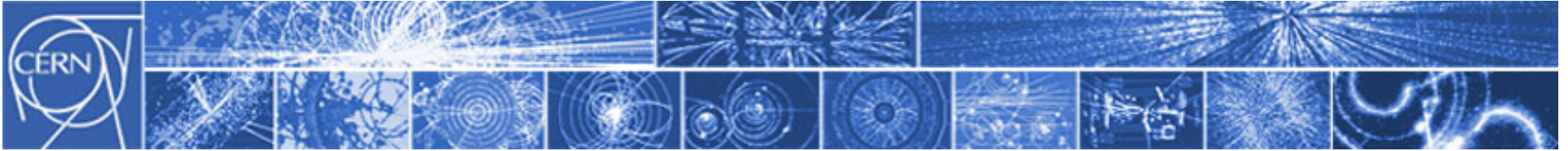
## What went wrong in 2008?



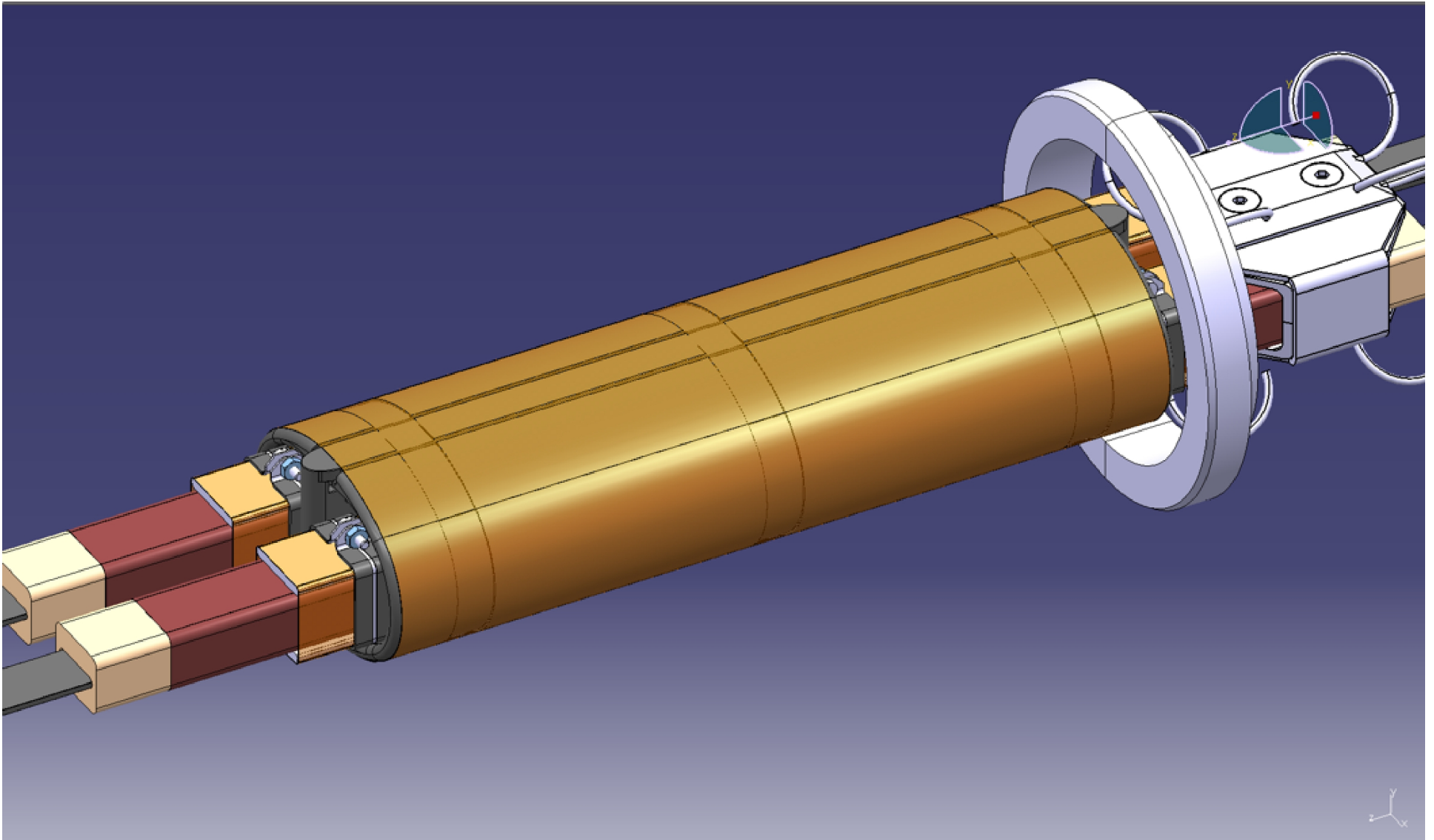


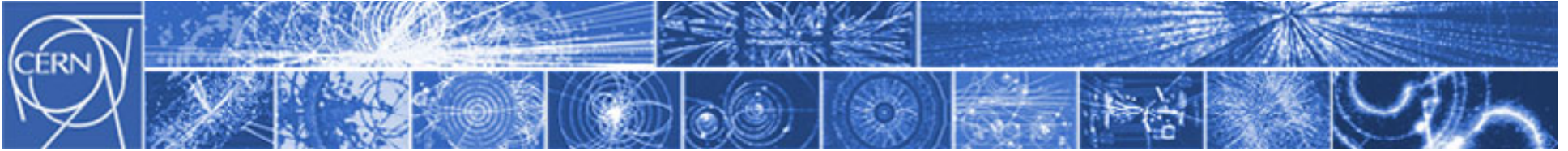
## What went wrong in 2008?





And what are we doing about it?

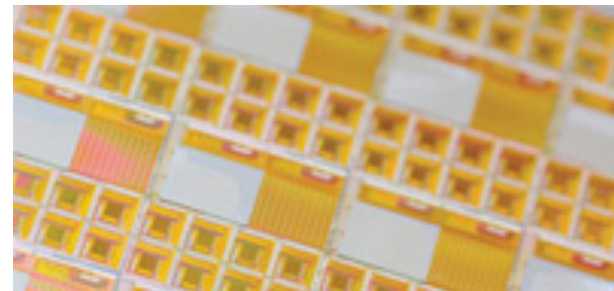
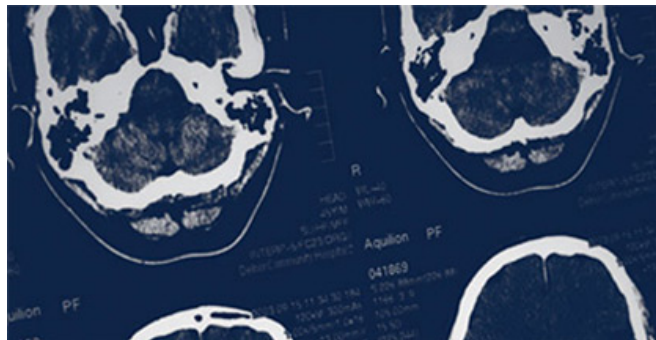




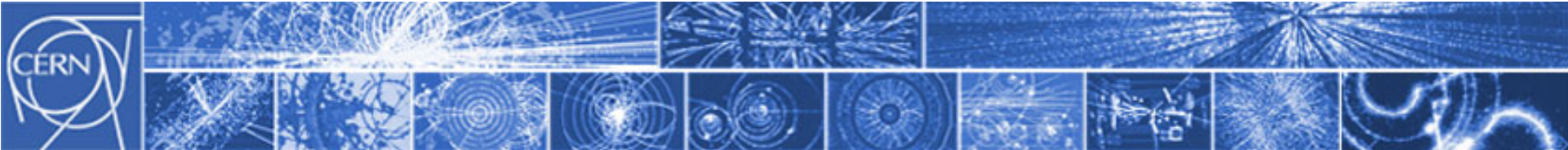
## Applications of accelerators



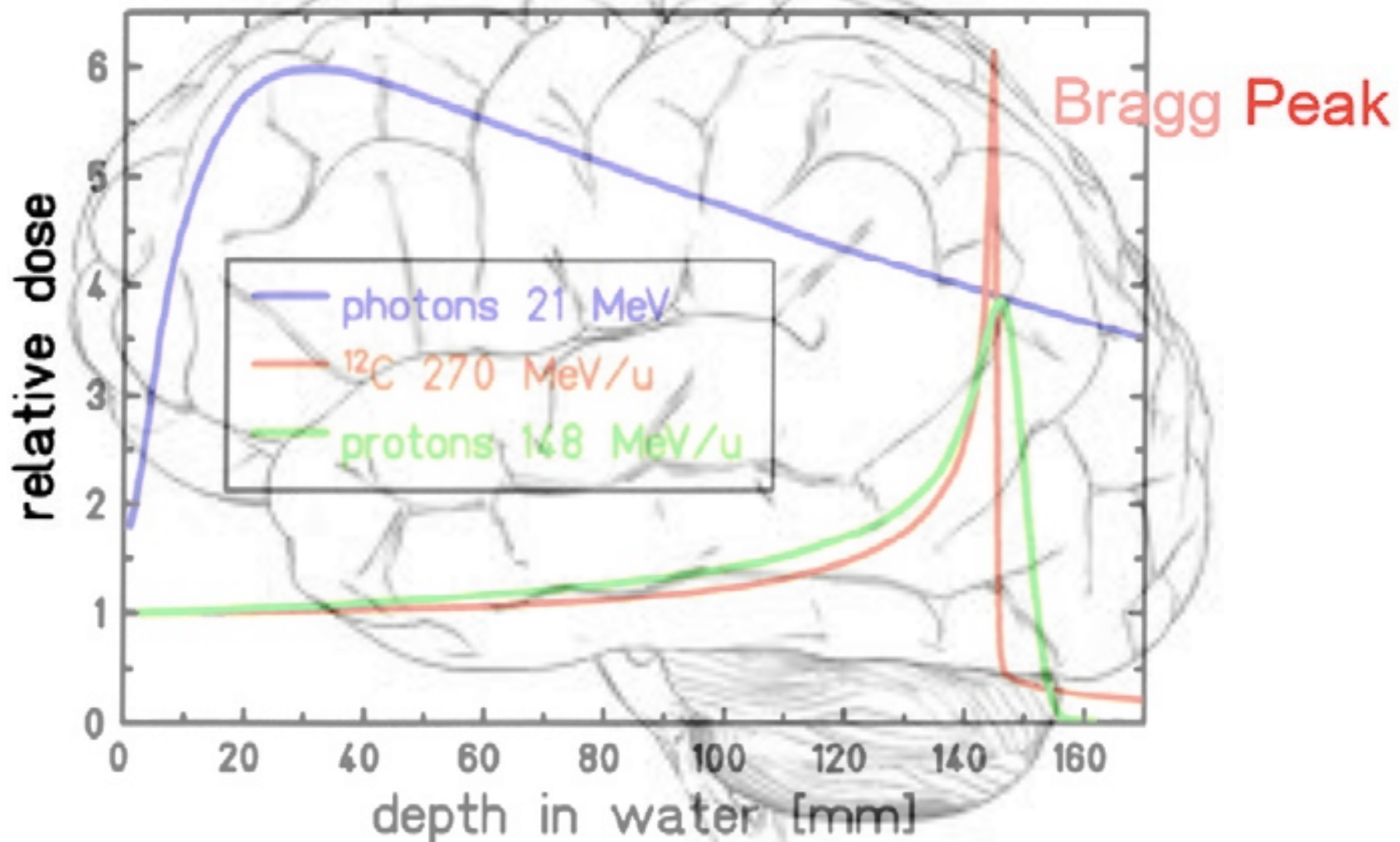
Materials  
Shrink wrap  
Medical imaging  
Ion implantation  
Energy  
Cancer therapy...

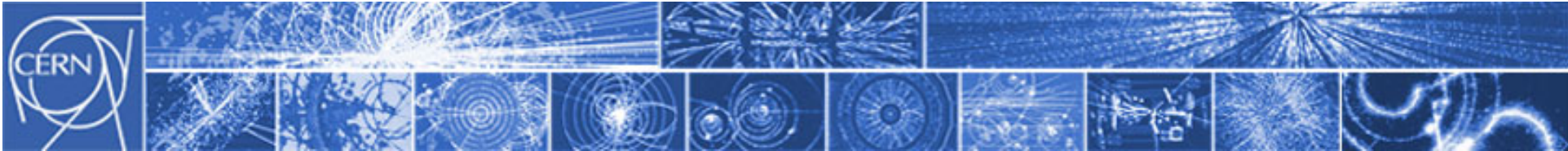




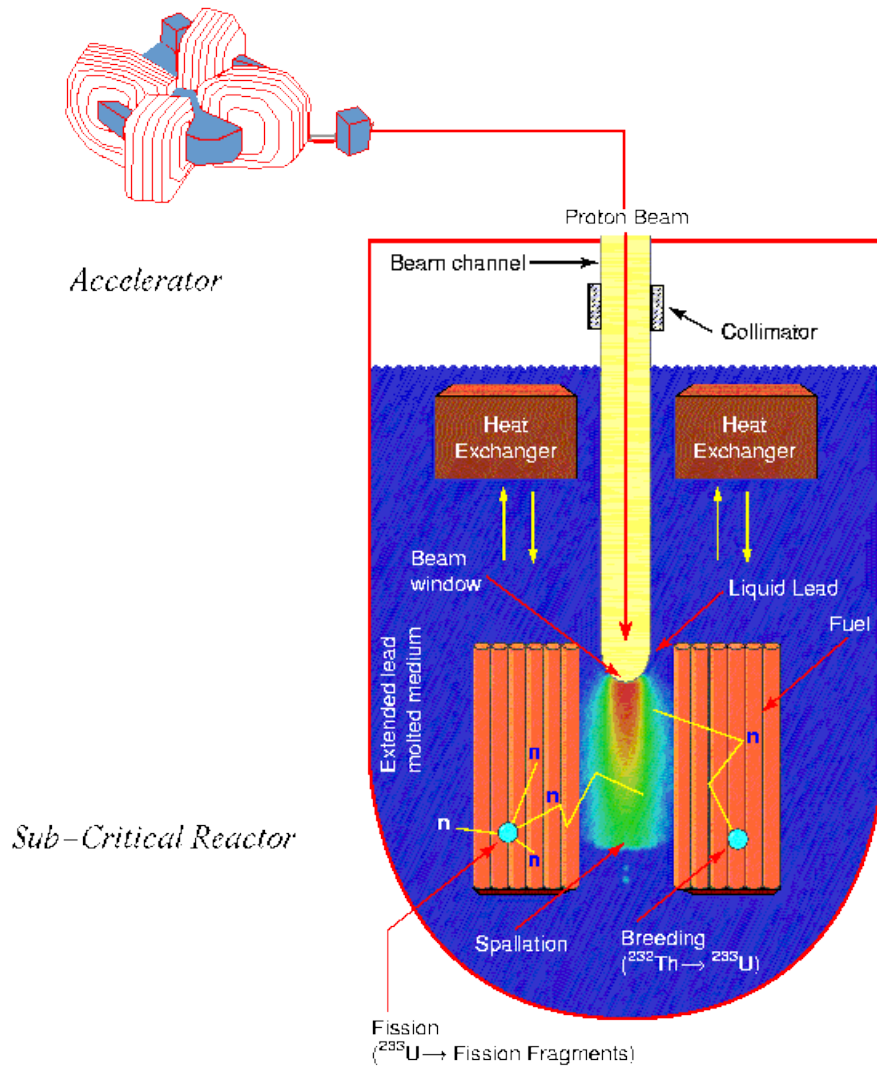


## Hadron therapy



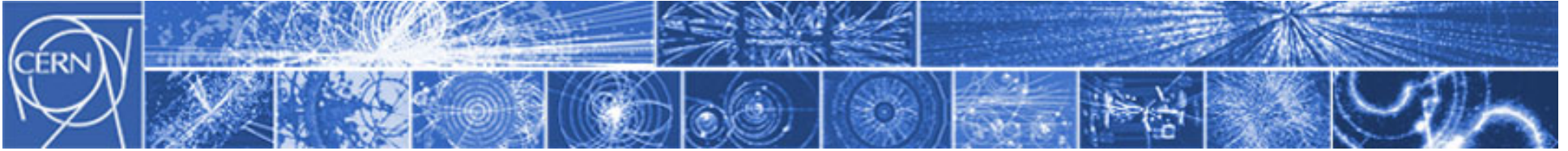


# Accelerator Driven Systems

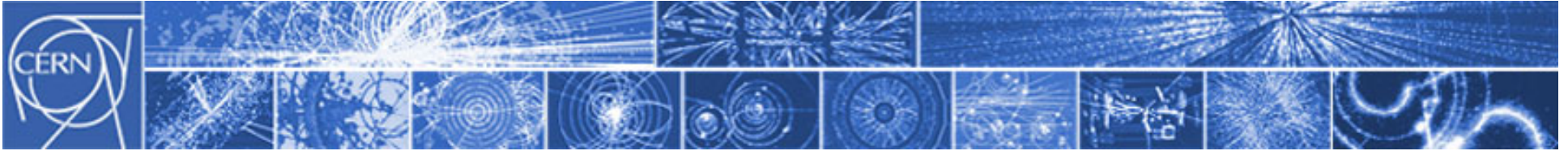


C. Rubbia E.A.

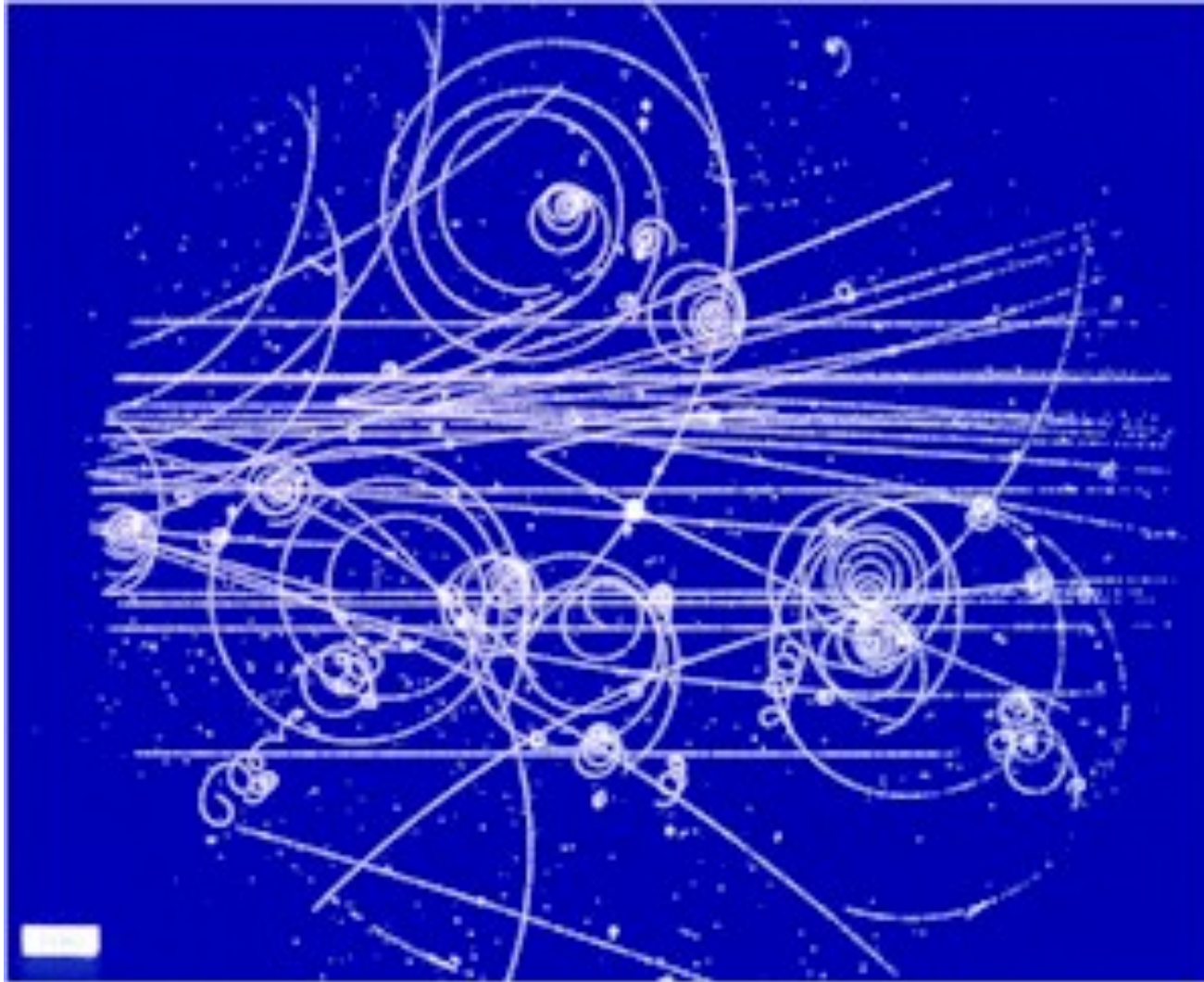


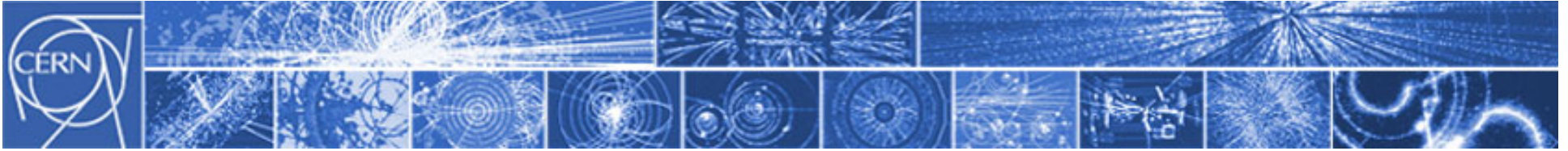


## The detectors



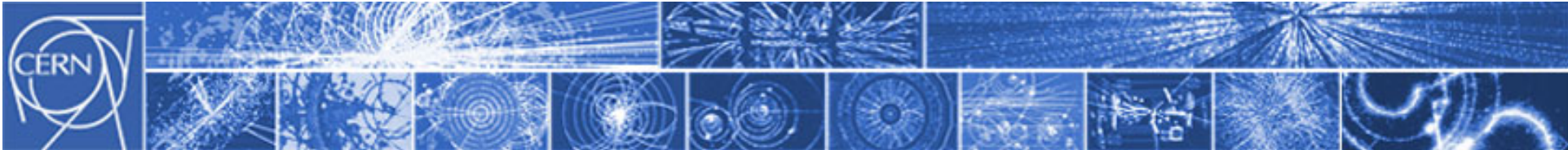
## The basics - ionisation





## The basics - scintillation

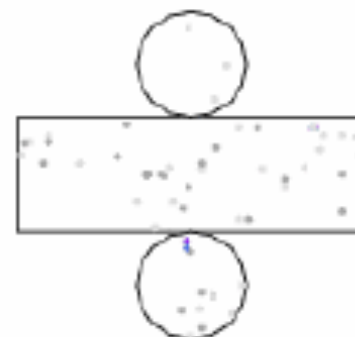
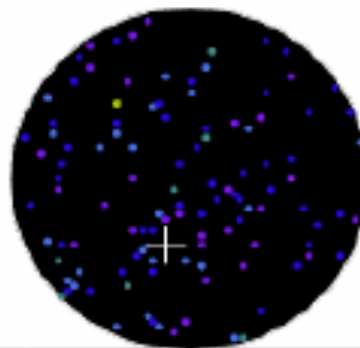




# The basics – Cerenkov light

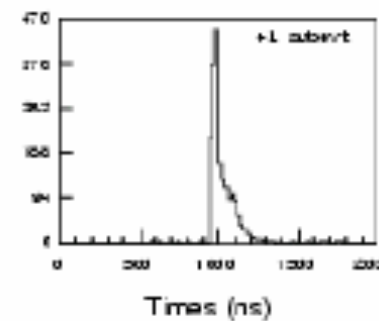
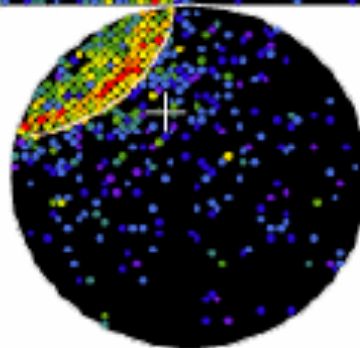
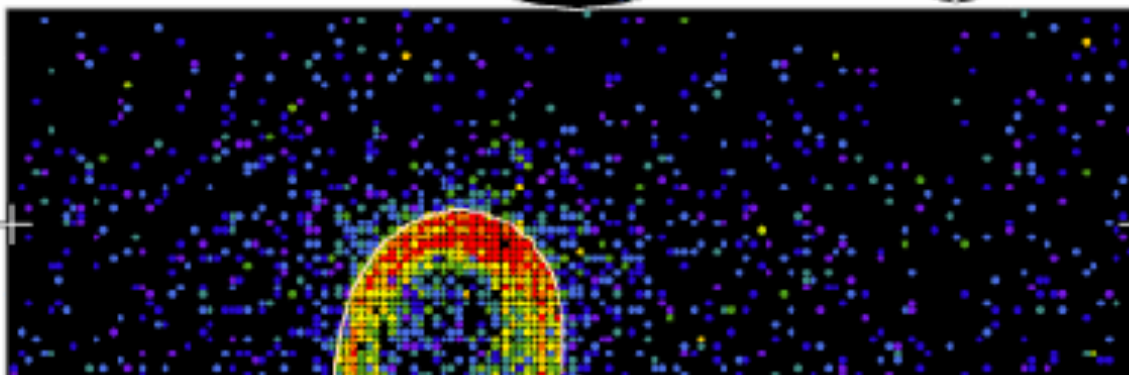
## Super-Kamiokande

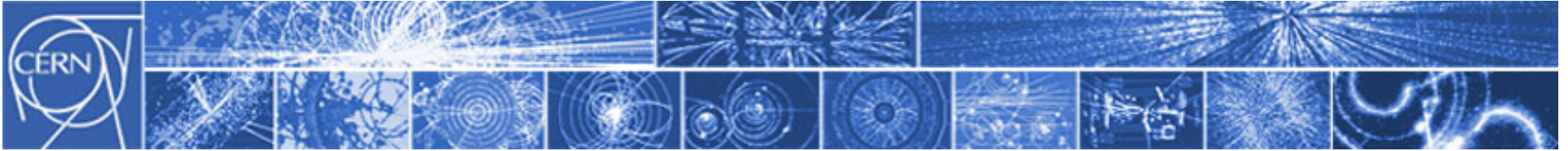
Run 10034 Sub 334 Ev 04818841  
 01-04-2010 08:10:07  
 Inner: 1976 hits, 10755 pE  
 Outer: 1 hits, 3 pE (sum-time)  
 Trigger ID: 0x07  
 Quality: 001.1 var  
 IC no-like, p = 1291.0 MeV/c



### charge (pe)

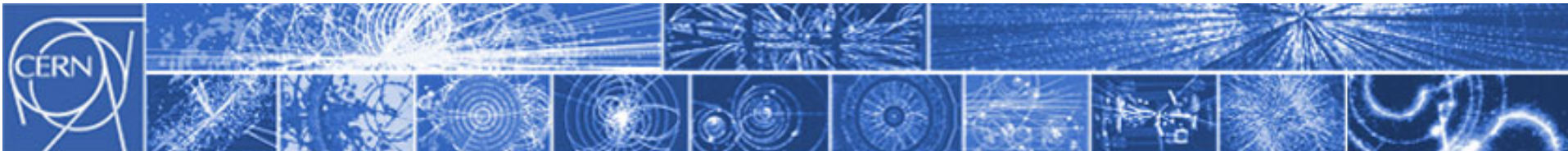
- \* >26.7
- \* 23.3-26.7
- \* 20.2-23.3
- \* 17.3-20.2
- \* 14.7-17.3
- \* 12.0-14.7
- \* 10.0-12.0
- \* 8.0-10.0
- \* 6.2-8.0
- \* 4.7-6.2
- \* 3.3-4.7
- \* 2.2-3.3
- \* 1.3-2.2
- \* 0.7-1.3
- \* 0.2-0.7
- \* < 0.2



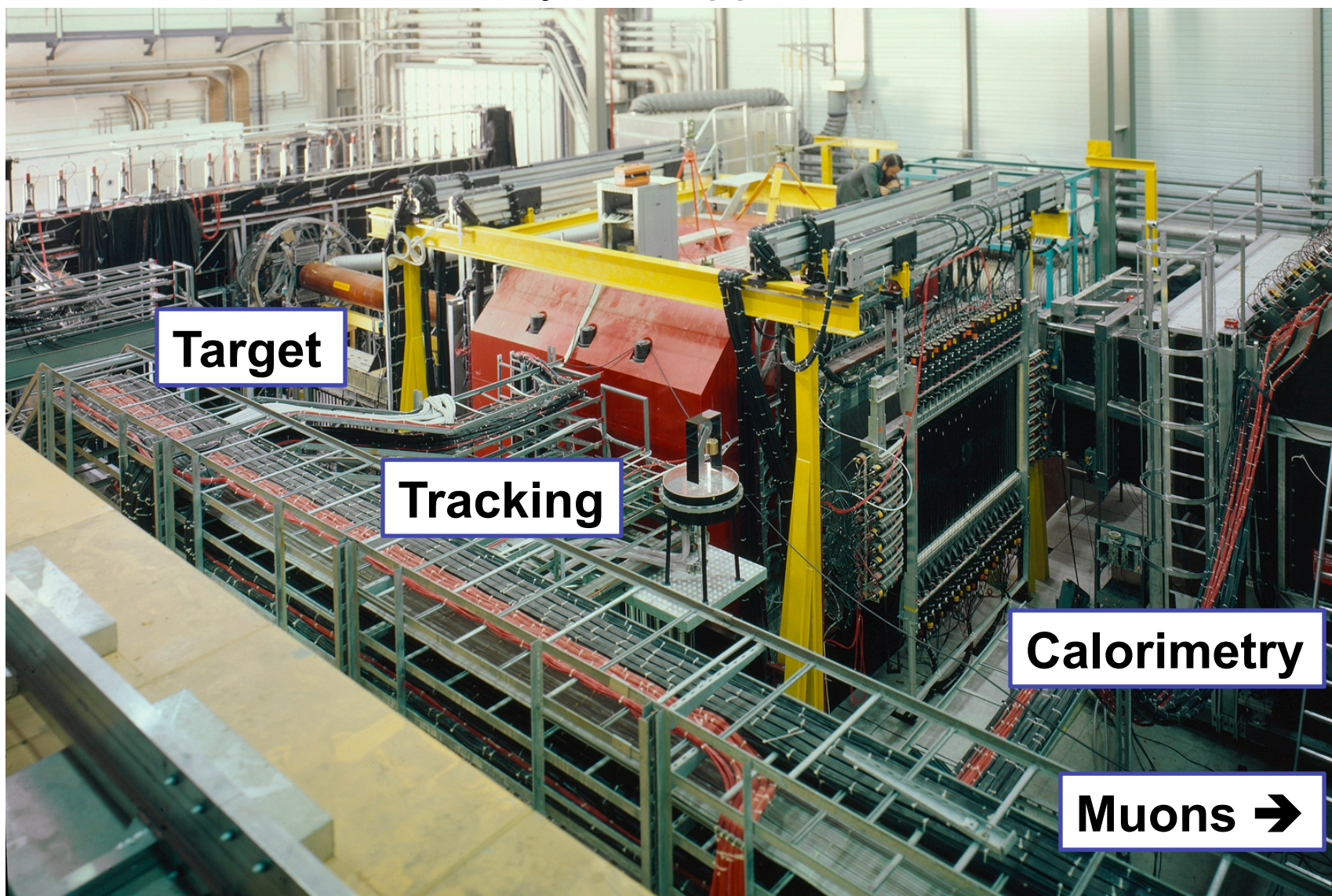


## Georges Charpak 1924-2010





## A layered approach



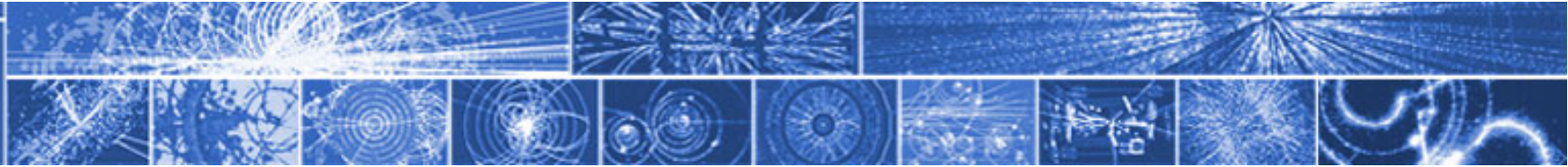
**Target**

**Tracking**

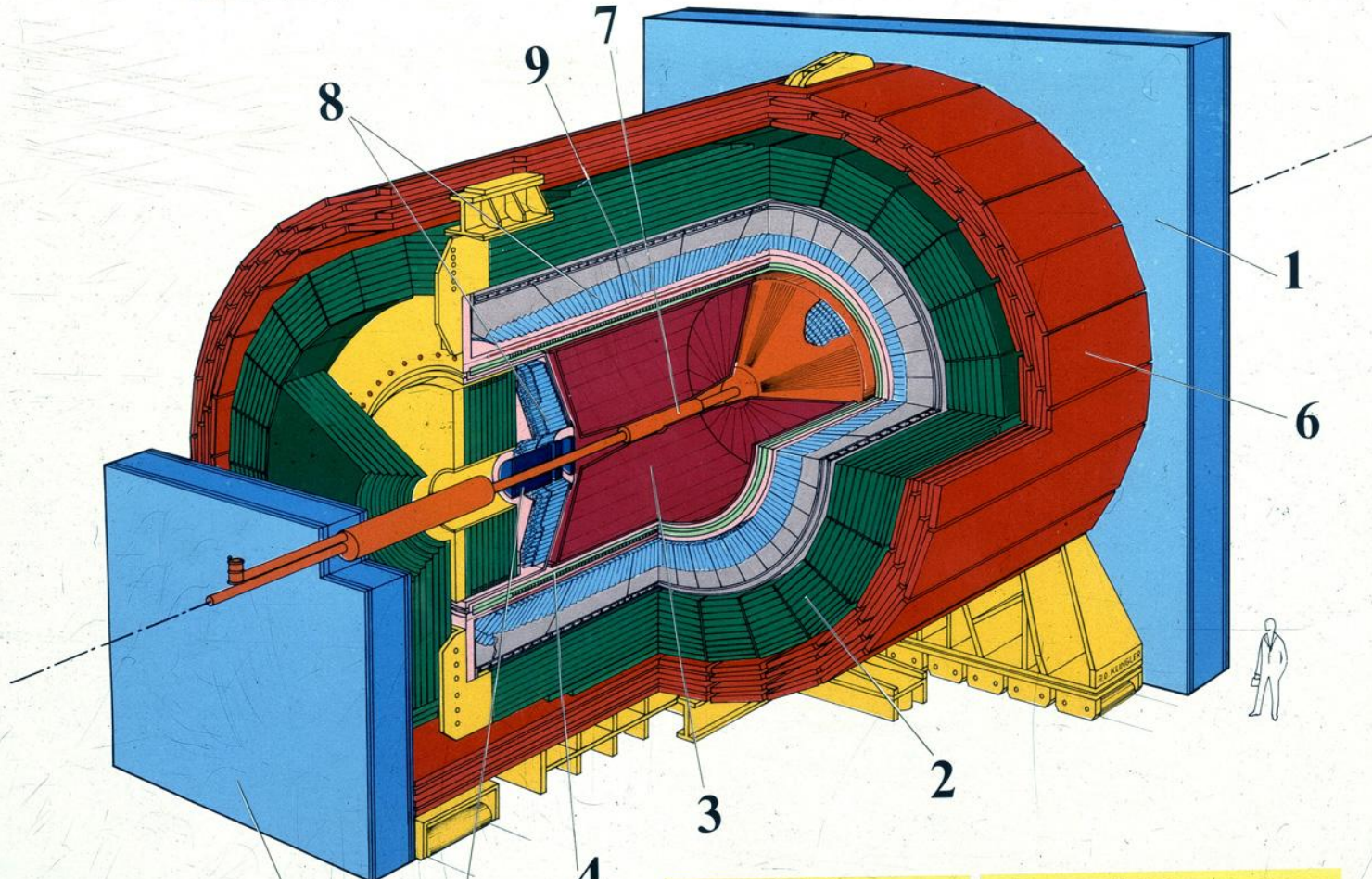
**Calorimetry**

**Muons →**

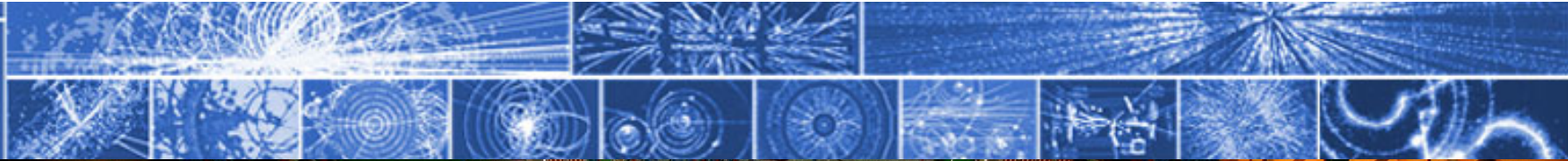




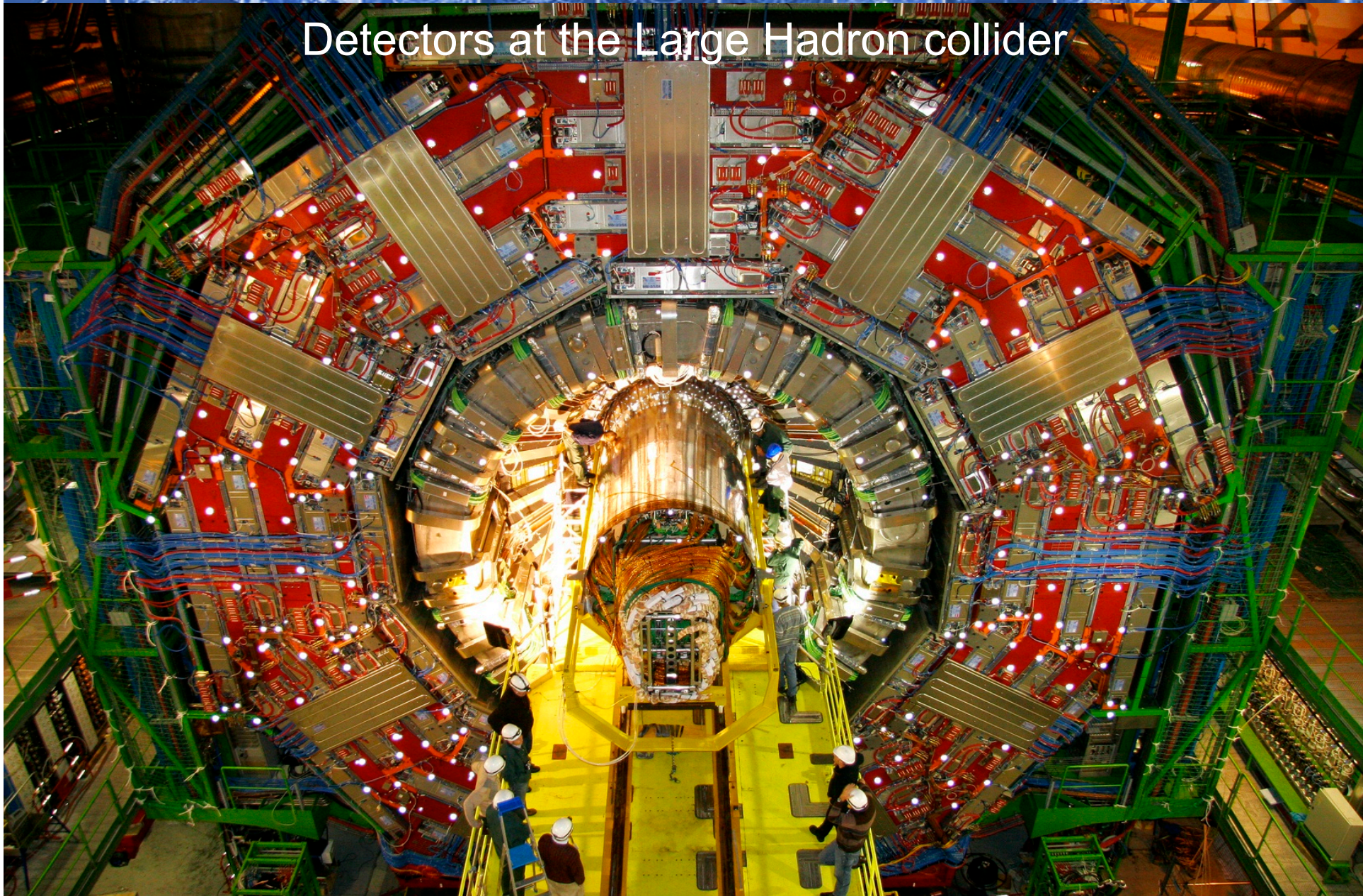
# OPAL

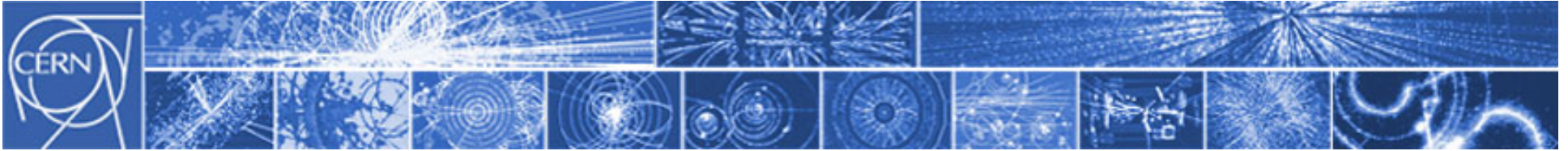


- |                       |   |
|-----------------------|---|
| 1. MUON-END CAP       | 6. MUON BARREL                            |
| 2. HADRON CALORIMETER | 7. VERTEX DETECTOR                        |
| 3. JET CHAMBER        | 8. LEAD GLASS                             |
| 4. MAGNET COIL        | 9. PRESAMPLER AND TIME-OF-FLIGHT DETECTOR |
| 5. FORWARD DETECTOR   |   |



# Detectors at the Large Hadron collider

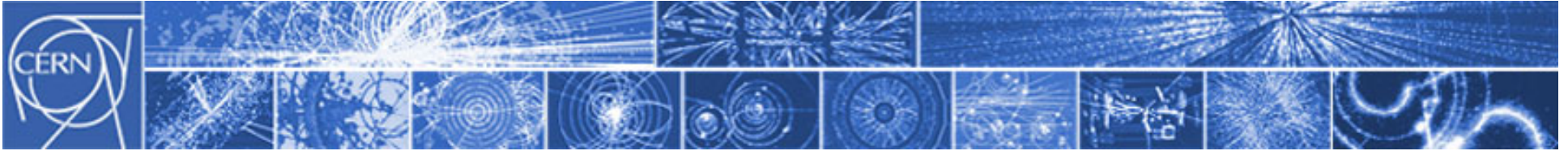




## The anatomy of the Compact Muon Solenoid

### **Largest silicon-sensor system ever made**

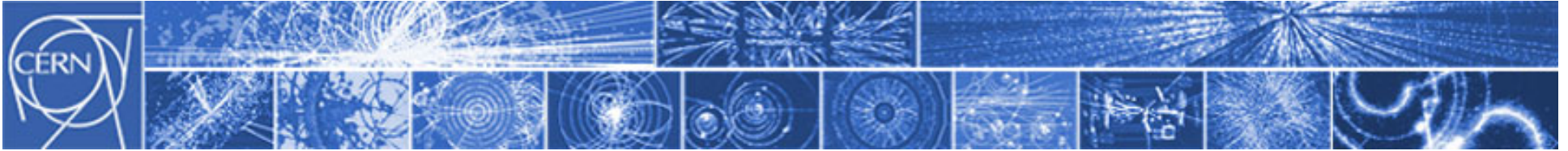
- More than 220m<sup>2</sup> of sensors
- More than 60 million electronics channels (pixels and microstrips)
- 6m long, ~2.2m diameter, operates at -15°C



## The anatomy of the Compact Muon Solenoid

### Hermetic calorimeter

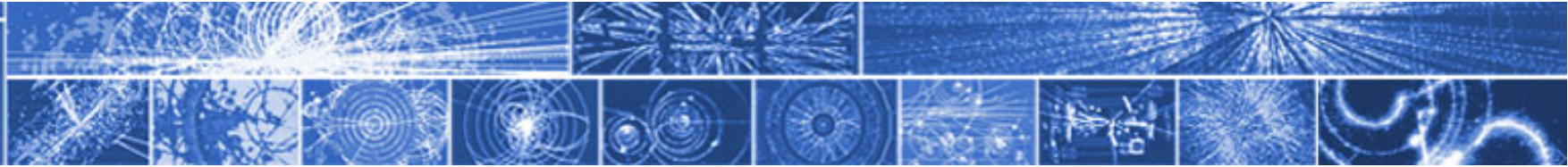
- Lead tungstate ( $\text{PbWO}_4$ ) crystals create electromagnetic showers and produce scintillation light
- Barrel: ~64000 crystals constructed in 36 “supermodules” (1700 crystals each); light detected by avalanche photodiodes
- Endcaps: ~16000 crystals constructed as “supercrystals” – 5x5 arrays; light detected by vacuum phototriode



## The anatomy of the Compact Muon Solenoid

### Three parts to the puzzle

- Barrel HCAL made of 36 brass wedges, each of which is ~35 tonnes
- Endcap HCAL made from brass recuperated from Russian military
- Forward HCAL (known as HF) made from steel embedded with quartz fibres

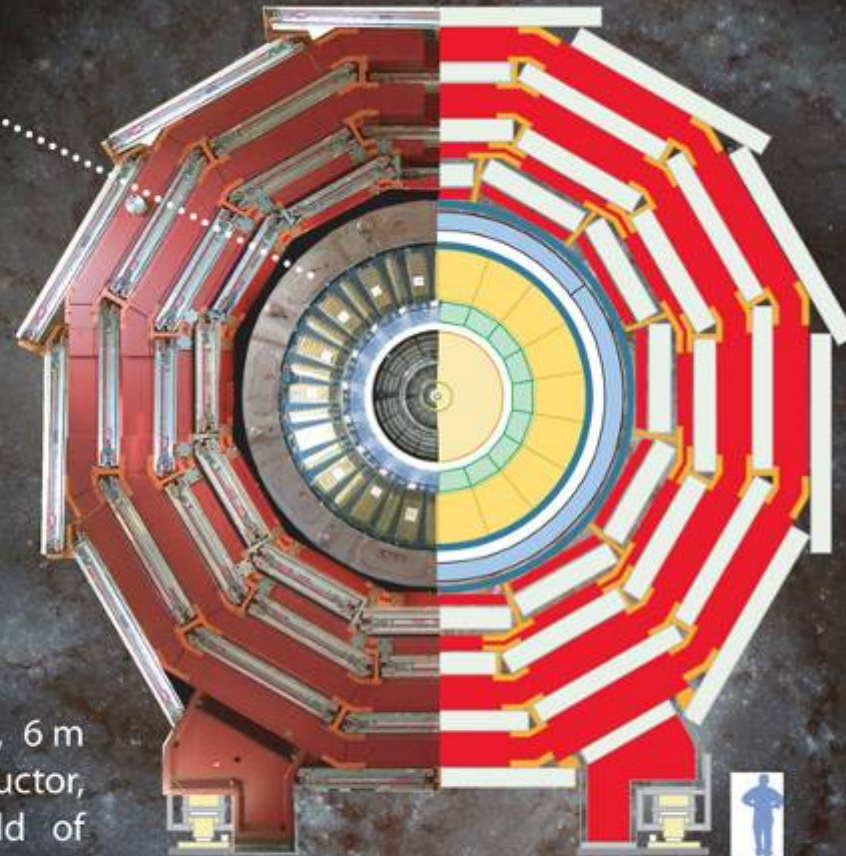


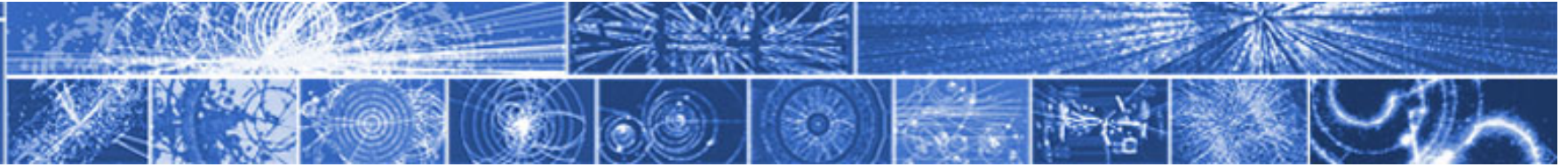
## The anatomy of the Compact Muon Solenoid



### Superconducting Solenoid

Passing 20 000 amperes through a 13 m long, 6 m diameter coil of niobium-titanium superconductor, cooled to  $-270^{\circ}\text{C}$ , produces a magnetic field of 4 teslas (about 100 000 times stronger than that of the Earth). This field bends the trajectories of charged particles, allowing their separation and momenta measurements.



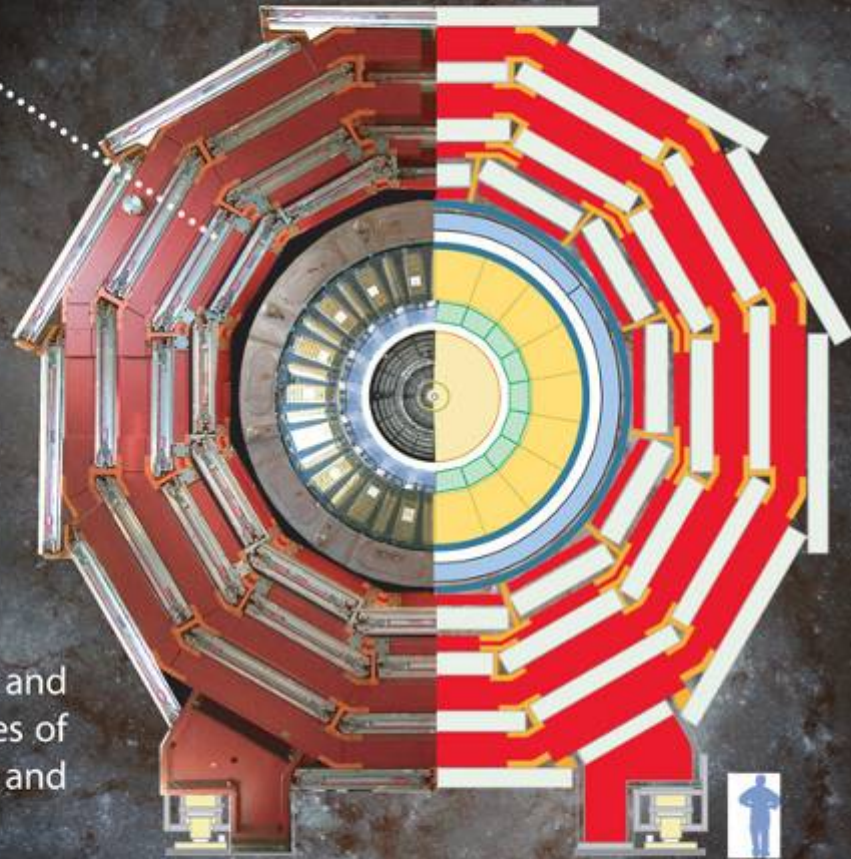


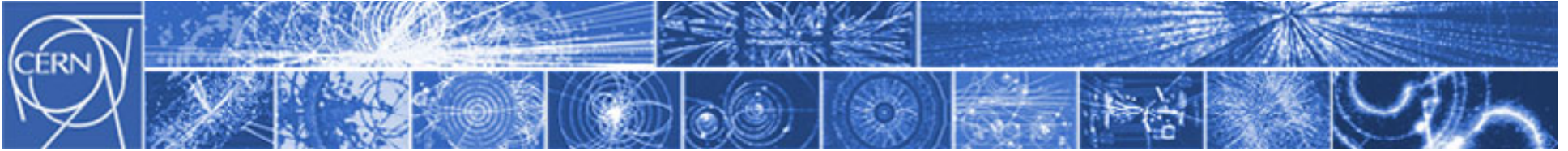
## The anatomy of the Compact Muon Solenoid



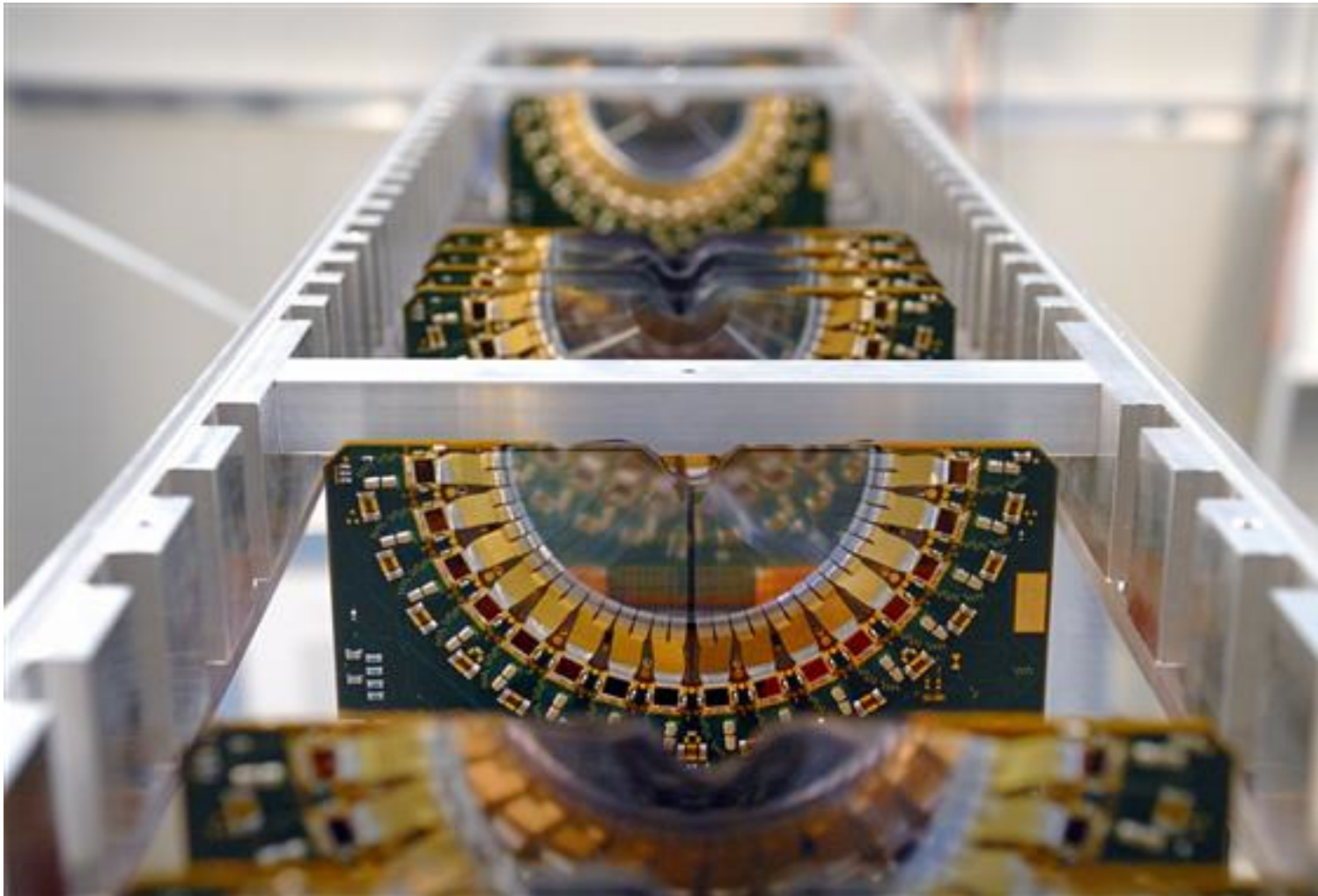
### **Muon Detectors**

To identify muons (essentially heavy electrons) and measure their momenta, CMS uses three types of detector: drift tubes, cathode strip chambers and resistive plate chambers.



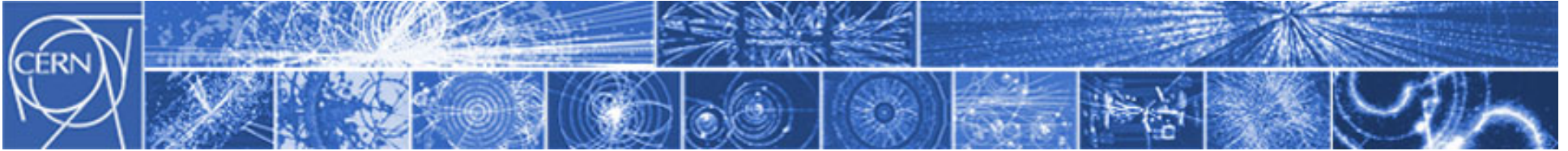


## LHC examples: VELO

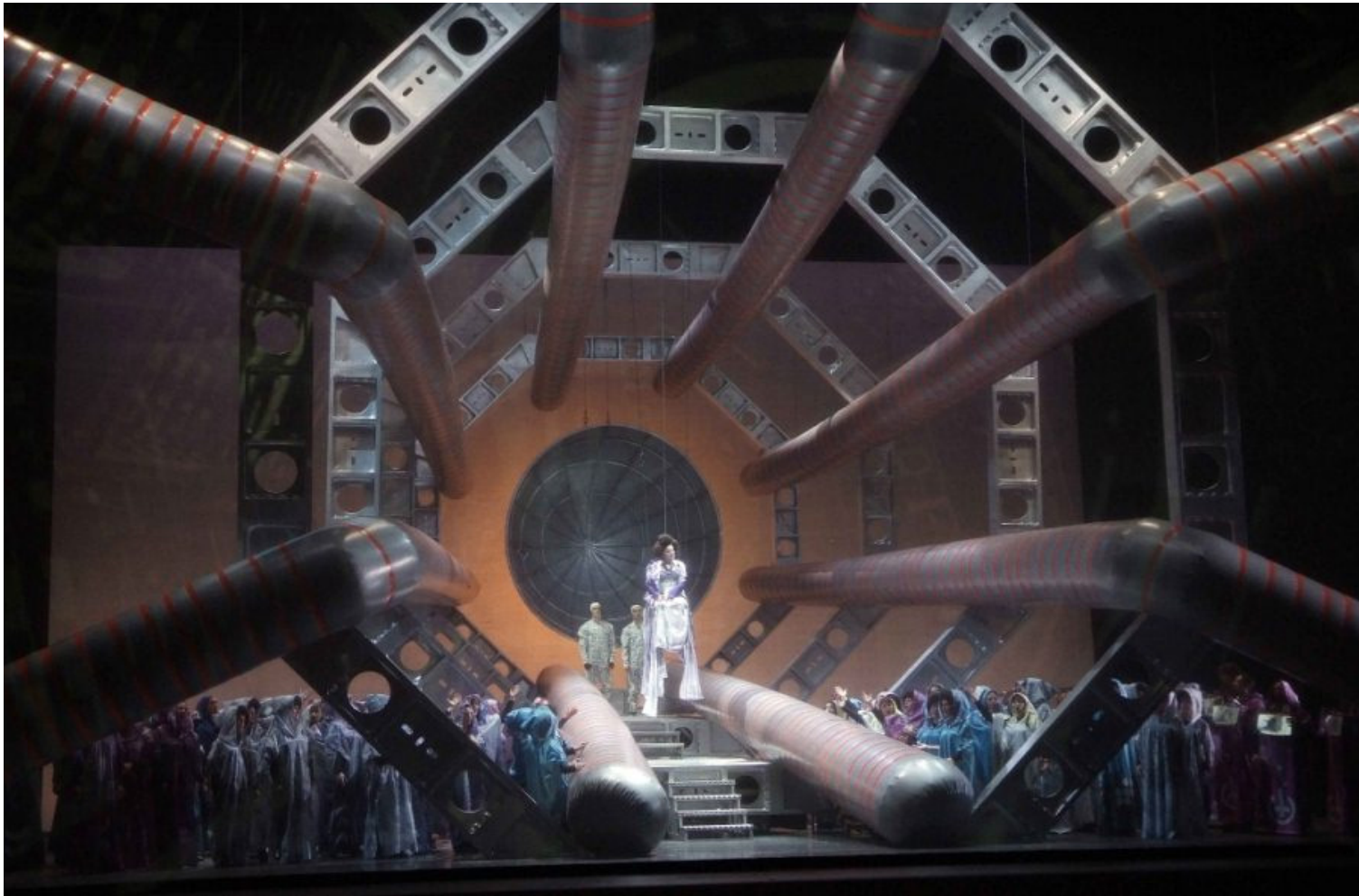


Approaches 5mm of the beam. Measures to 10microns

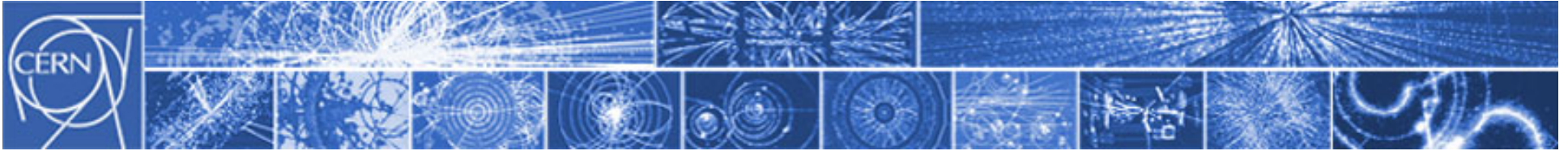




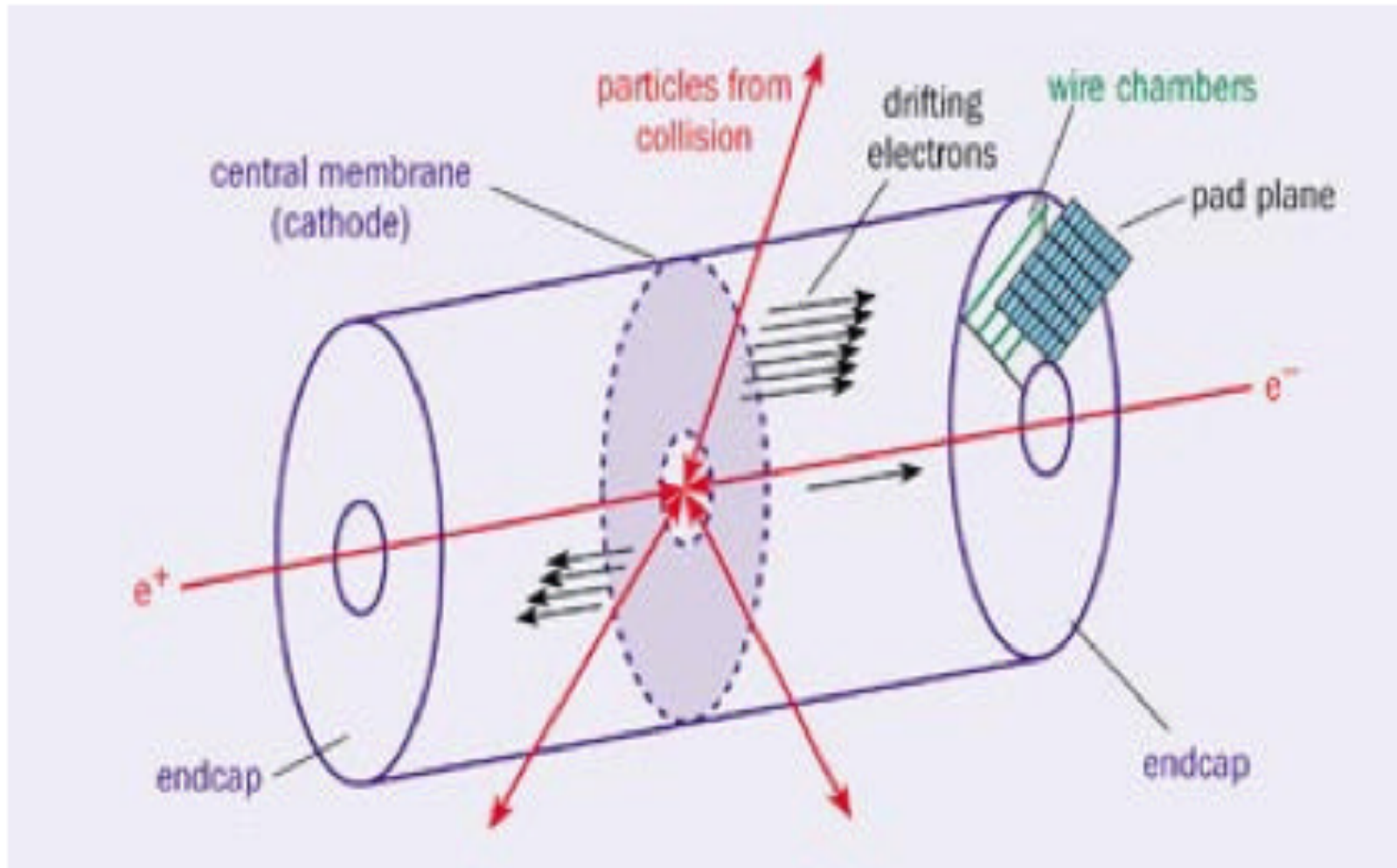
## LHC examples: ATLAS muons



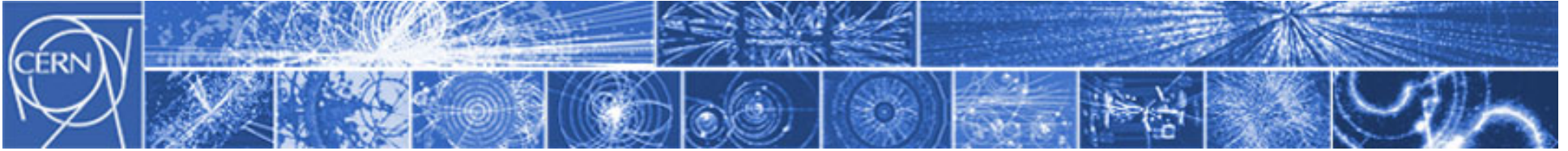
The world's largest toroid magnet. Air cored so can be bigger



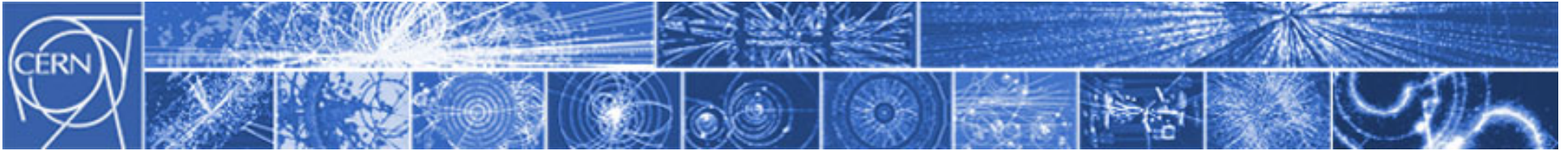
## LHC examples: ALICE TPC



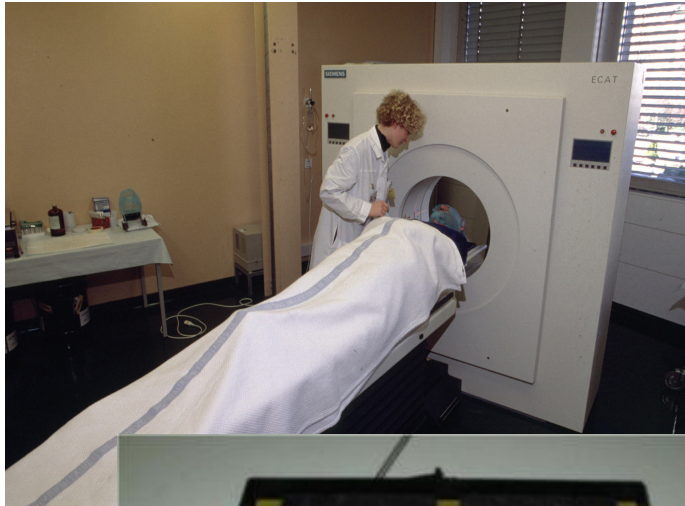
**Figure 1.** The TPC principle as proposed by David Nygren in 1974



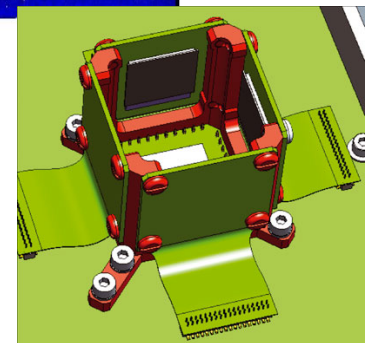
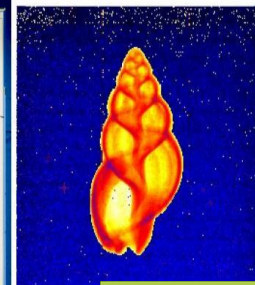
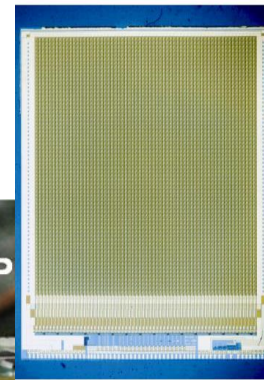
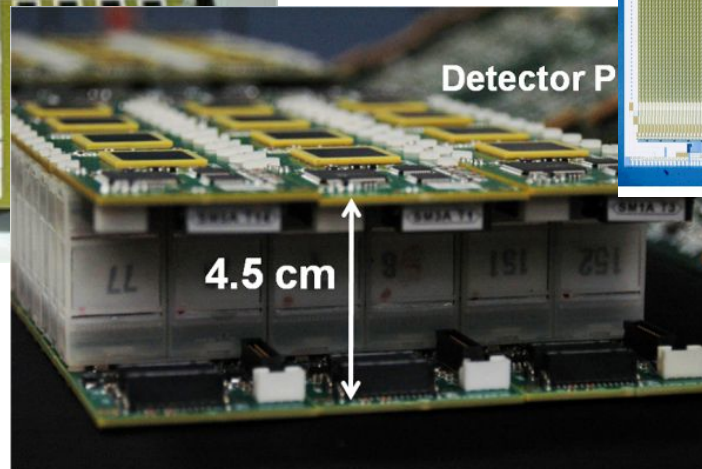
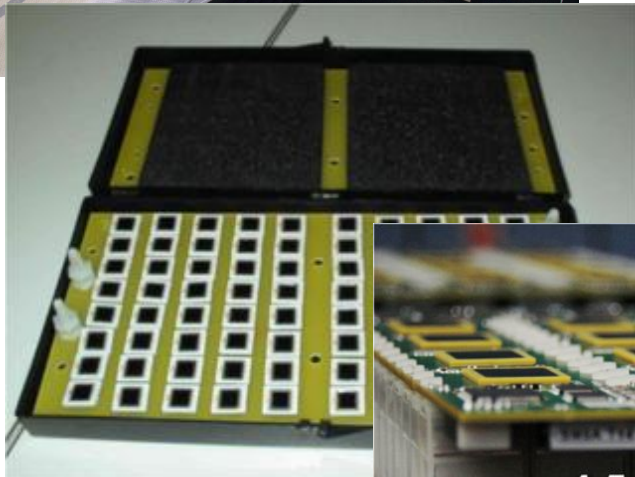
## Applications of detectors

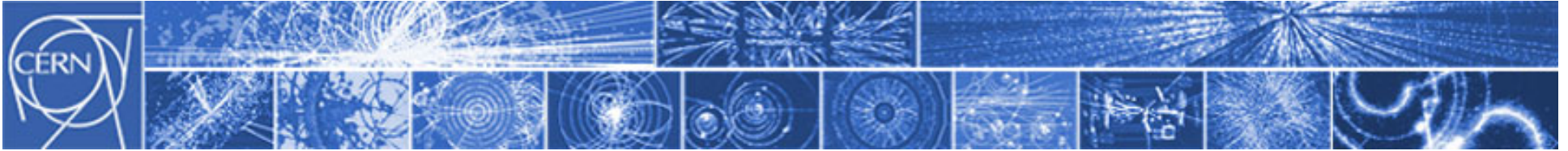


# Applications of detectors

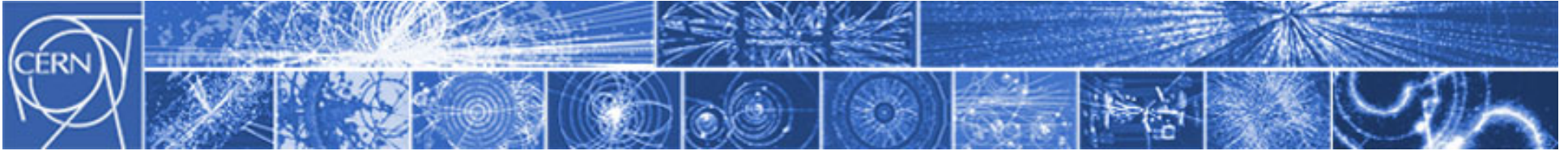


Medical imaging: PET, PET/MRI, Medipix  
Electronics: APD  
Education: LUCID



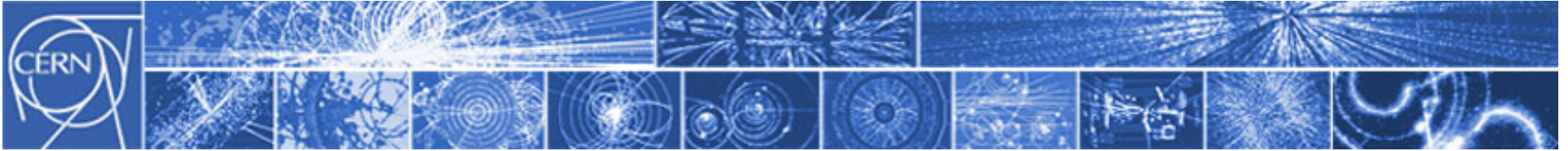


## The computing



## 1950s: CERN's human computer

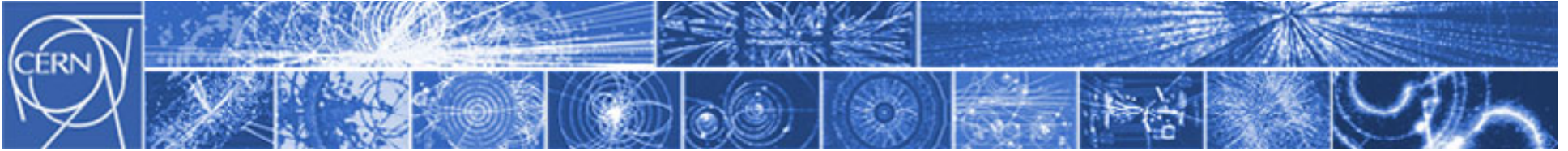




## 1958: Ferranti Mercury



17 hours...

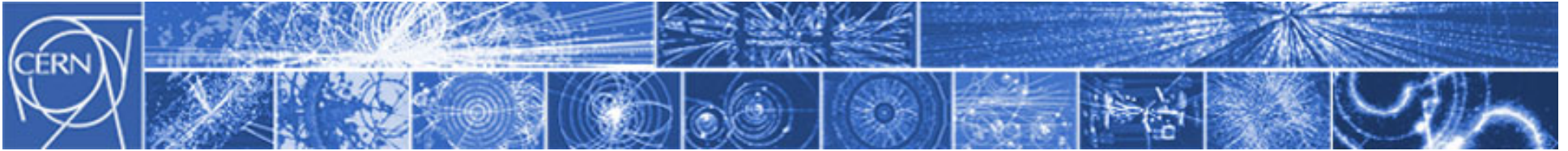


1960s-1990s: Norsk data, PDP, Vax, IBM mainframe, CRAY...

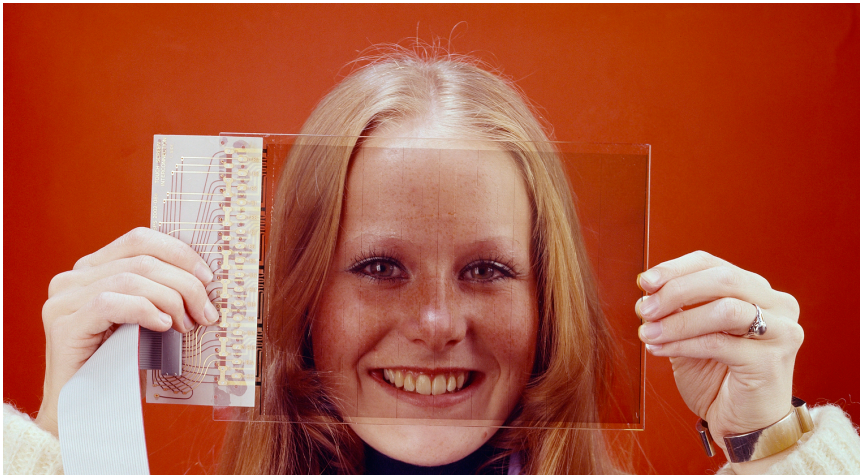


1 second...

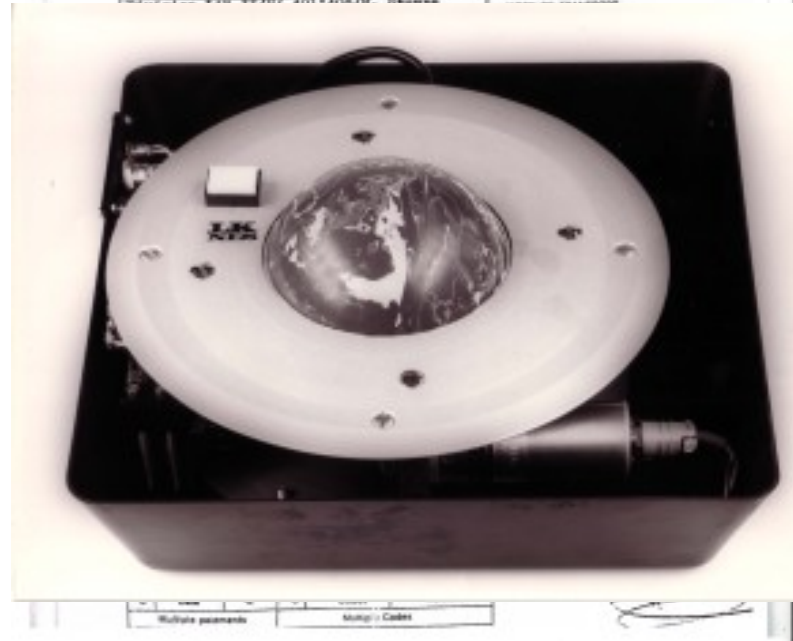


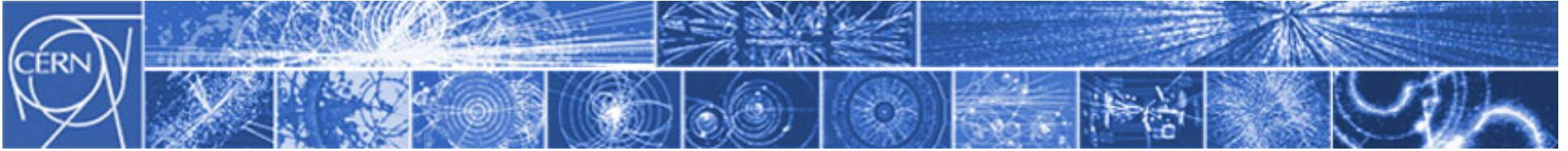


# SPS Accelerator control systems

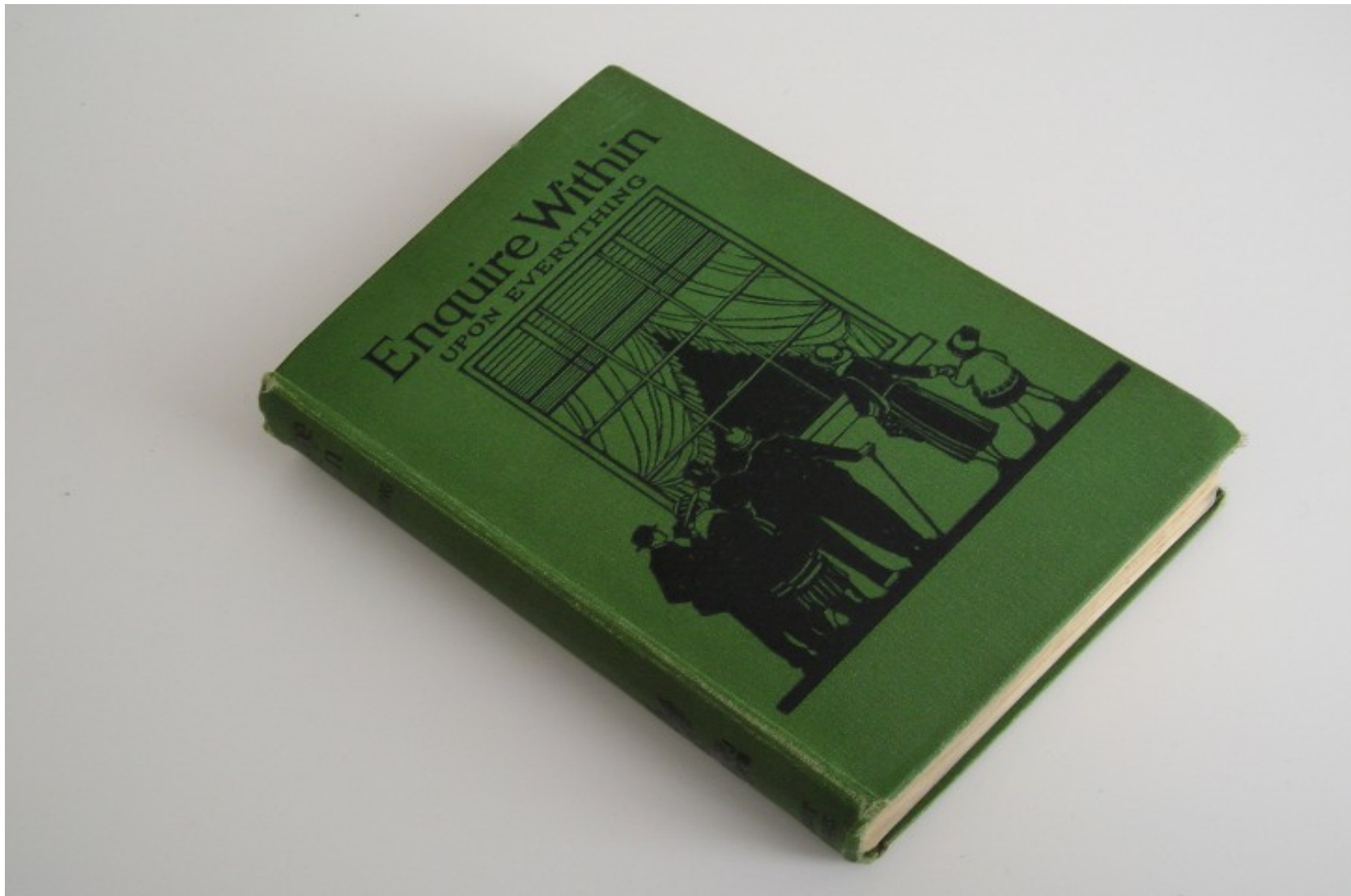


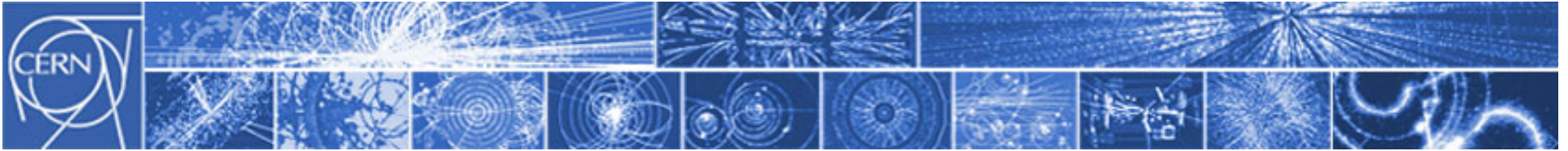
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						Façon. N°	R 1620																				
						Date de	20.10.72																				
M. Zenicbo FIS/rj No: 4628						RAYBOSTON-MANHATTAN ENG. Bowling Ball Div. 92, Townsend St. PISCATAE, New Jersey 07055 USA																					
M. Storage No: 3180																											
OFFRE DU N°:																											
Control No.						\$ Pays d'origine																					
Facture à l'attention						POB.																					
Réception basée de FIS						10.11.72																					





## PS control system computerised 1980



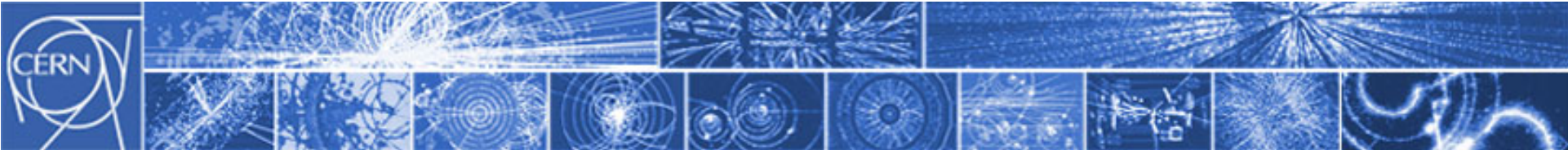


## Early networking at CERN



Top priority status at  
computer centre:  
Bicycle online

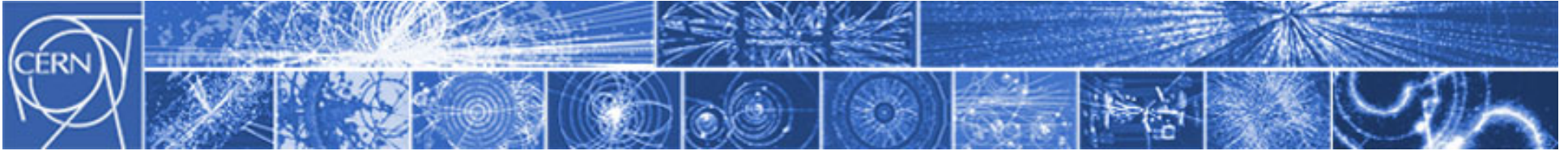




# ~~CERN~~ INTERNET

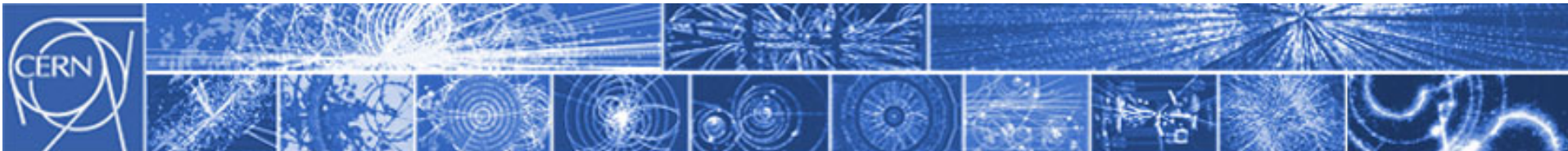






## The World Wide Web





# The most valuable document ever?

930480

**ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE**  
**CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH**

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**STATEMENT CONCERNING CERN W3 SOFTWARE RELEASE INTO PUBLIC DOMAIN**

**TO WHOM IT MAY CONCERN**

**Introduction**

The World Wide Web, hereafter referred to as W3, is a global computer networked information system.

The W3 project provides a collaborative information system independent of hardware and software platform, and physical location. The project spans technical design notes, documentation, news, discussion, educational material, personal notes, publicity, bulletin boards, live status information and numerical data as a uniform continuum, seamlessly intergated with similar information in other disciplines.

The information is presented to the user as a web of interlinked documents .

Acces to information through W3 is:

- via a hypertext model;
- network based, world wide;
- information format independent;
- highly platform/operating system independent;
- scalable from local notes to distributed data bases.

Webs can be independent, subsets or supersets of each other. They can be local, regional or worldwide. The documents available on a web may reside on any computer supported by that web.

2.

**Declaration**

The following CERN software is hereby put into the public domain:

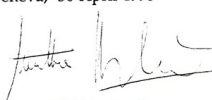
- W 3 basic ("line-mode") client
- W 3 basic server
- W 3 library of common code.


CERN's intention in this is to further compatibility, common practices, and standards in networking and computer supported collaboration. This does not constitute a precedent to be applied to any other CERN copyright software.

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Geneva, 30 April 1993

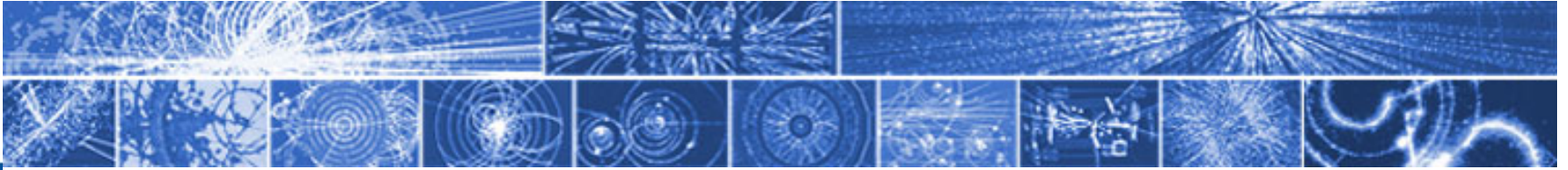
  
W. Hoogland  
Director of Research

  
H. Weber  
Director of Administration

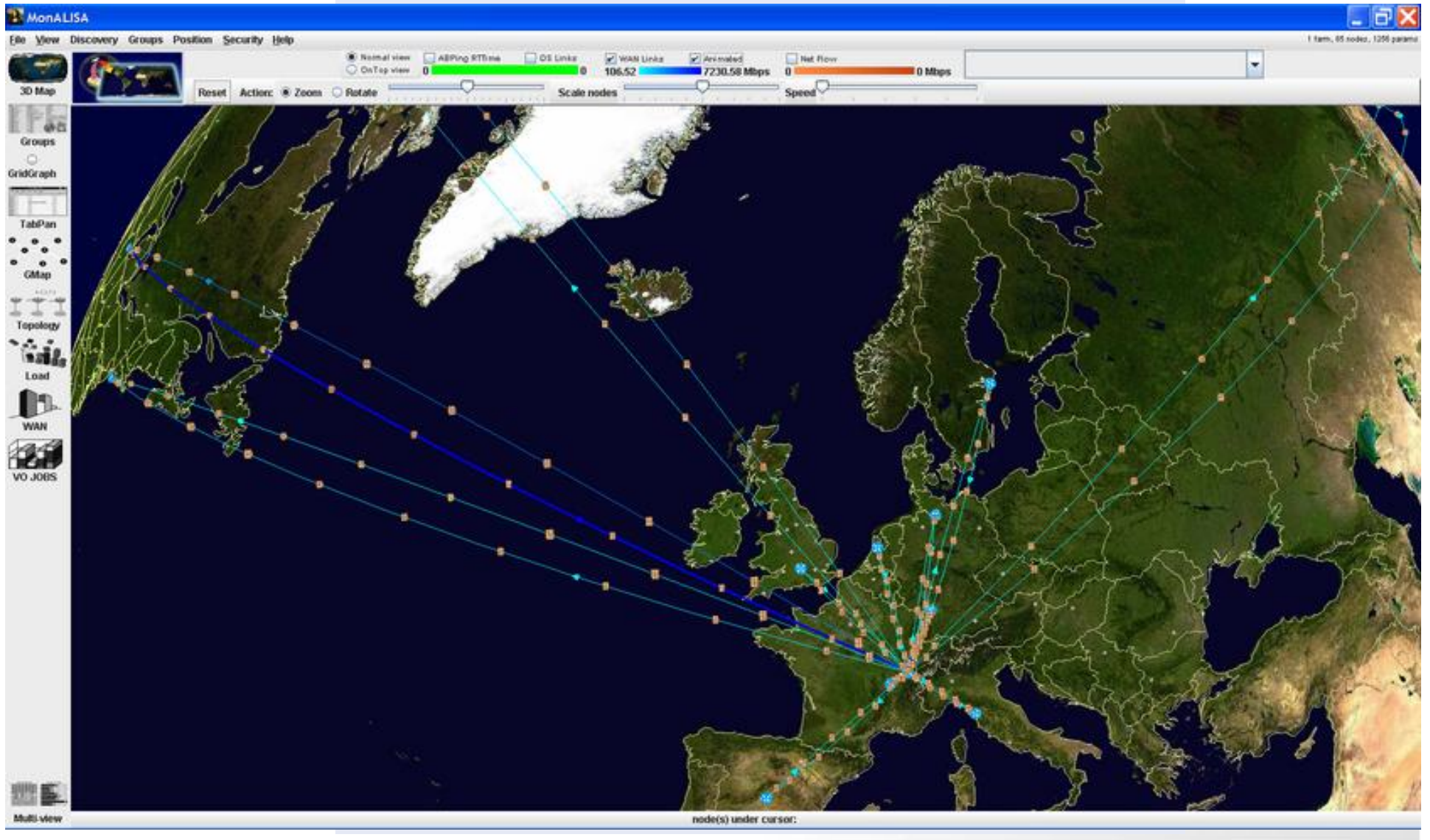
copie certifiée conforme

fait à Genève le 03-05-93

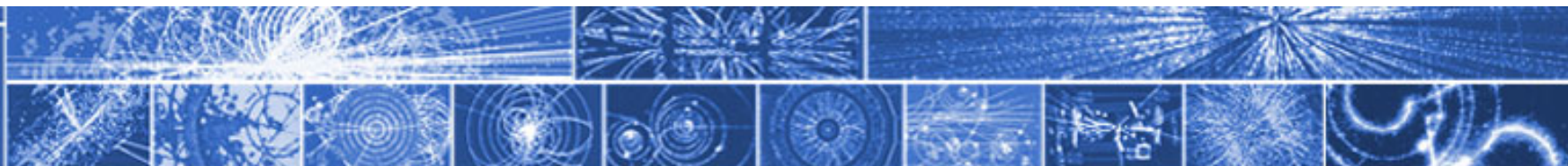




# The Grid







## Summary....

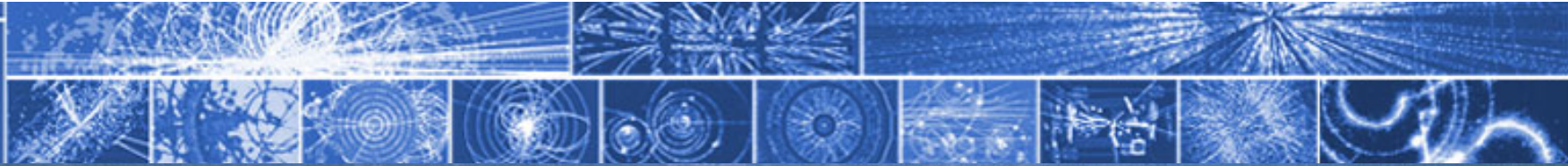
Particle physics requires three tools...

Accelerators

Detectors

Computing

All push the limits of technology and bring tangible benefit to society in the form of new knowledge and innovation



Next time....

# Angels, Demons and Black Holes Demystifying the LHC

