

# Welcome

## Joint Universities Accelerator School Course 1 "The science of particle accelerators" 12 January 2018

SUISSE  
FRANCE

CMS

LHCb

CERN Prévessin

ATLAS

CERN Meyrin

ALICE

LHC 27 km

to



***Accelerating Science and Innovation***

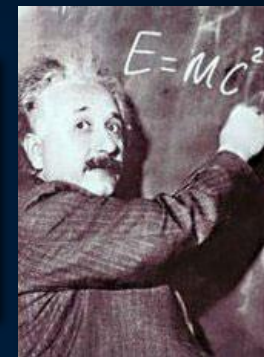
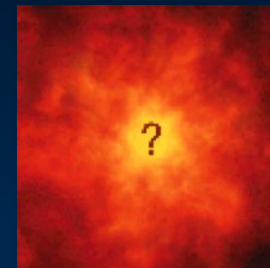




# The mission of CERN

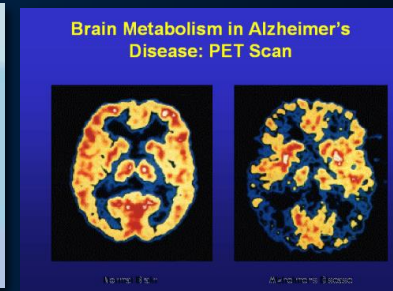
## ❑ Push back the frontiers of knowledge

e.g. the secrets of the Big Bang ...what was the matter like within the first moments of the Universe's existence?

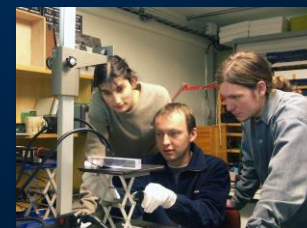


## ❑ Develop new technologies for accelerators and detectors

Information technology - the Web and the GRID  
Medicine - diagnosis and therapy



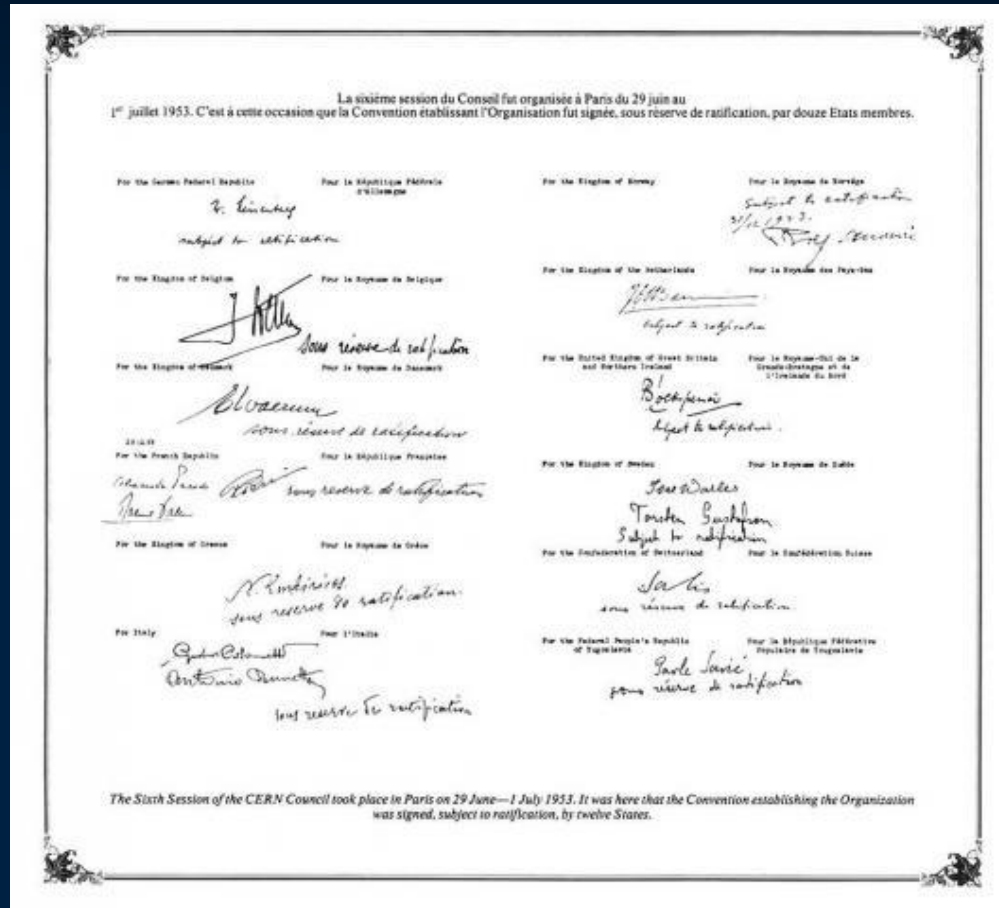
## ❑ Train scientists and engineers of tomorrow



## ❑ Unite people from different countries and cultures



# 1954: the Convention, 12 founding Member States



«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»

# CERN today: 22 Member States... and growing

~ 2300 staff  
~ 1800 other paid personnel  
~ 13000 scientific users  
Budget (2017) ~1100 MCHF

**Member States:** Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom

**Associate Member States:** India, Lithuania, Pakistan, Turkey, Ukraine

**States in accession to Membership:** Cyprus, Serbia, Slovenia

**Applications for Membership or Associate Membership:**

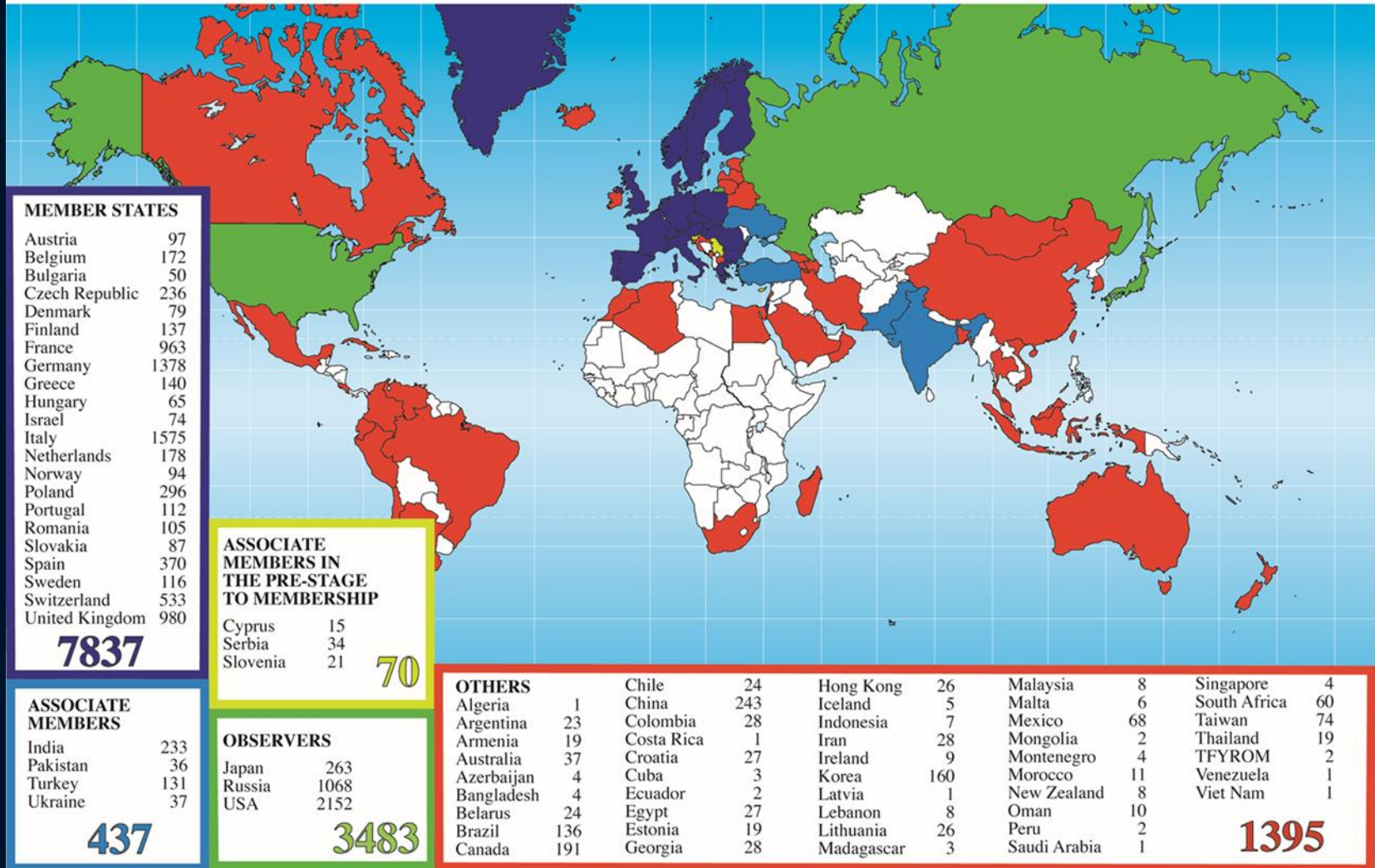
Brazil, Croatia, Russia

**Observers to Council:** Japan, Russia, United States of America; European Union, JINR and UNESCO

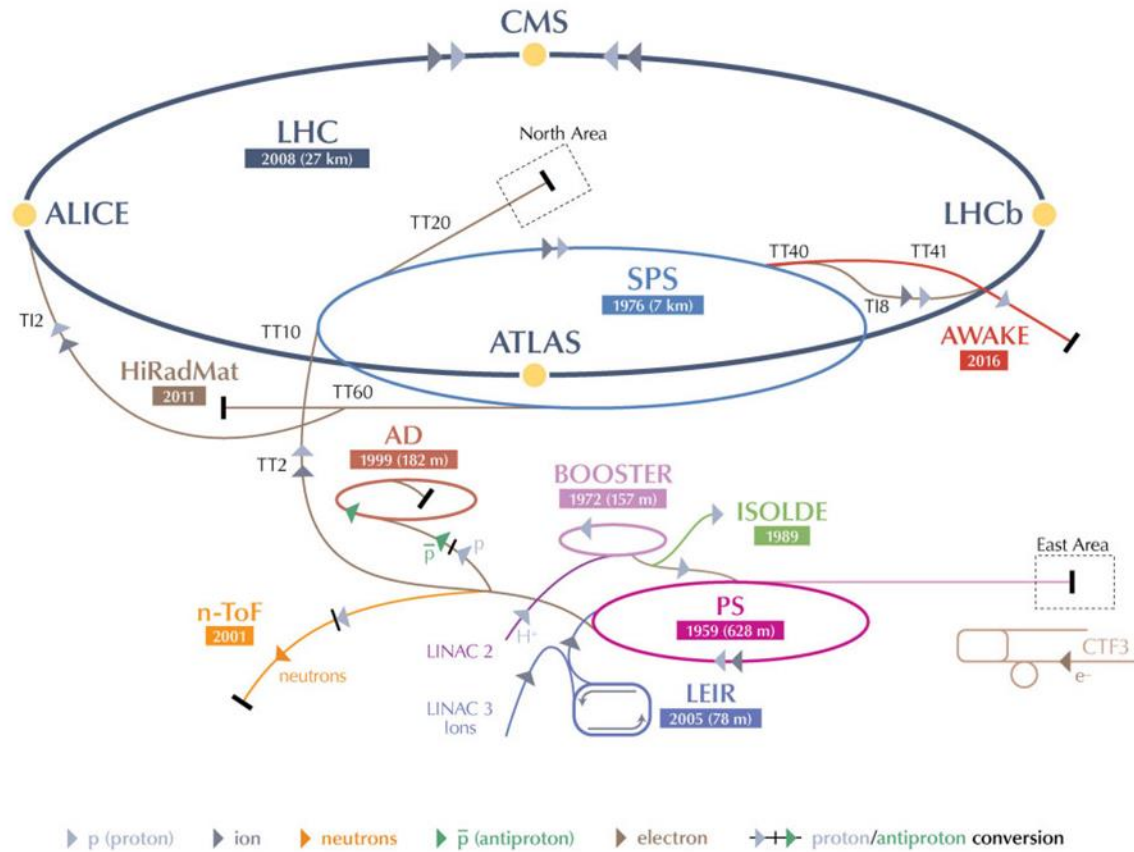


# A global laboratory

## Distribution of All CERN Users by Location of Institute on 5 July 2017



# A unique network of interconnected accelerators



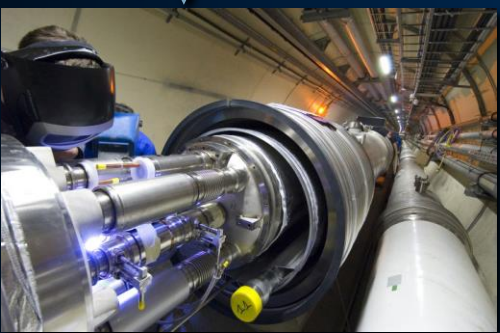
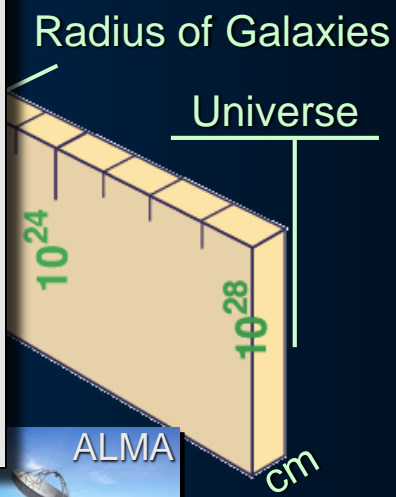
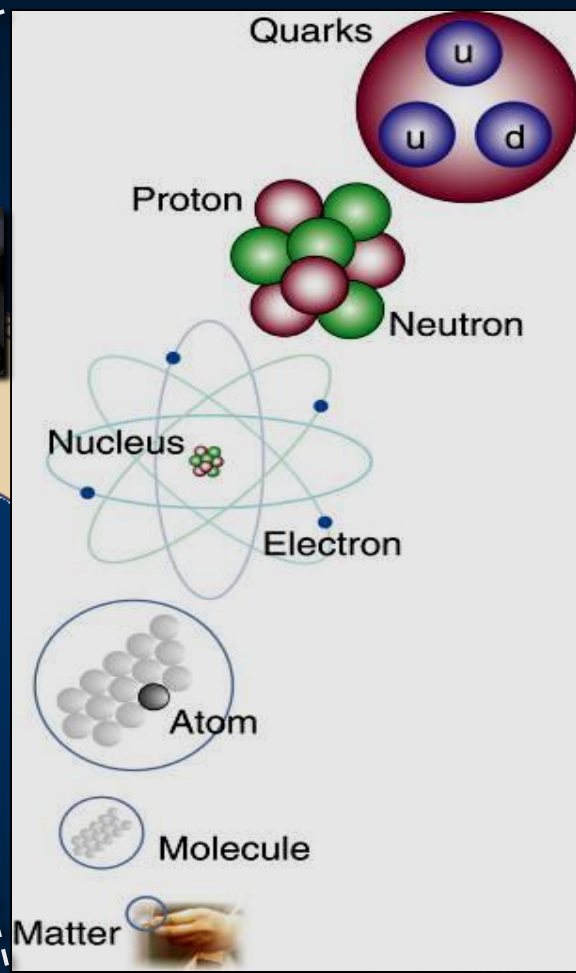
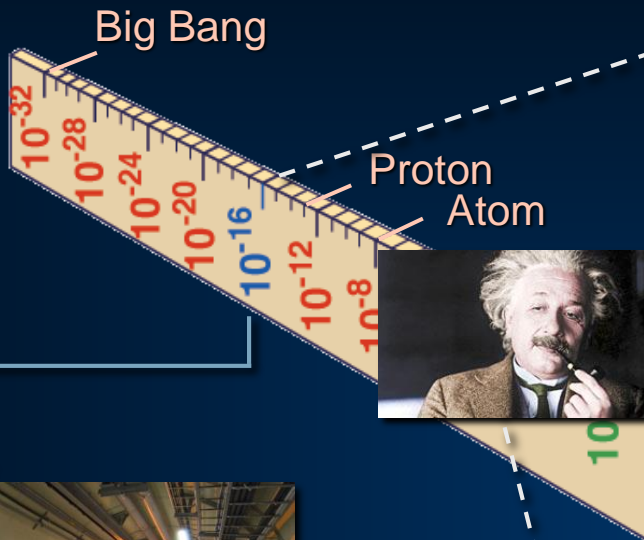
LHC Large Hadron Collider    SPS Super Proton Synchrotron    PS Proton Synchrotron

AD Antiproton Decelerator    CTF3 Clic Test Facility    AWAKE Advanced WAKEfield Experiment    ISOLDE Isotope Separator OnLine DEvice

LEIR Low Energy Ion Ring    LINAC LINear ACcelerator    n-ToF Neutrons Time Of Flight    HiRadMat High-Radiation to Materials

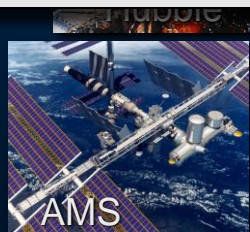
© CERN 2013





LHC

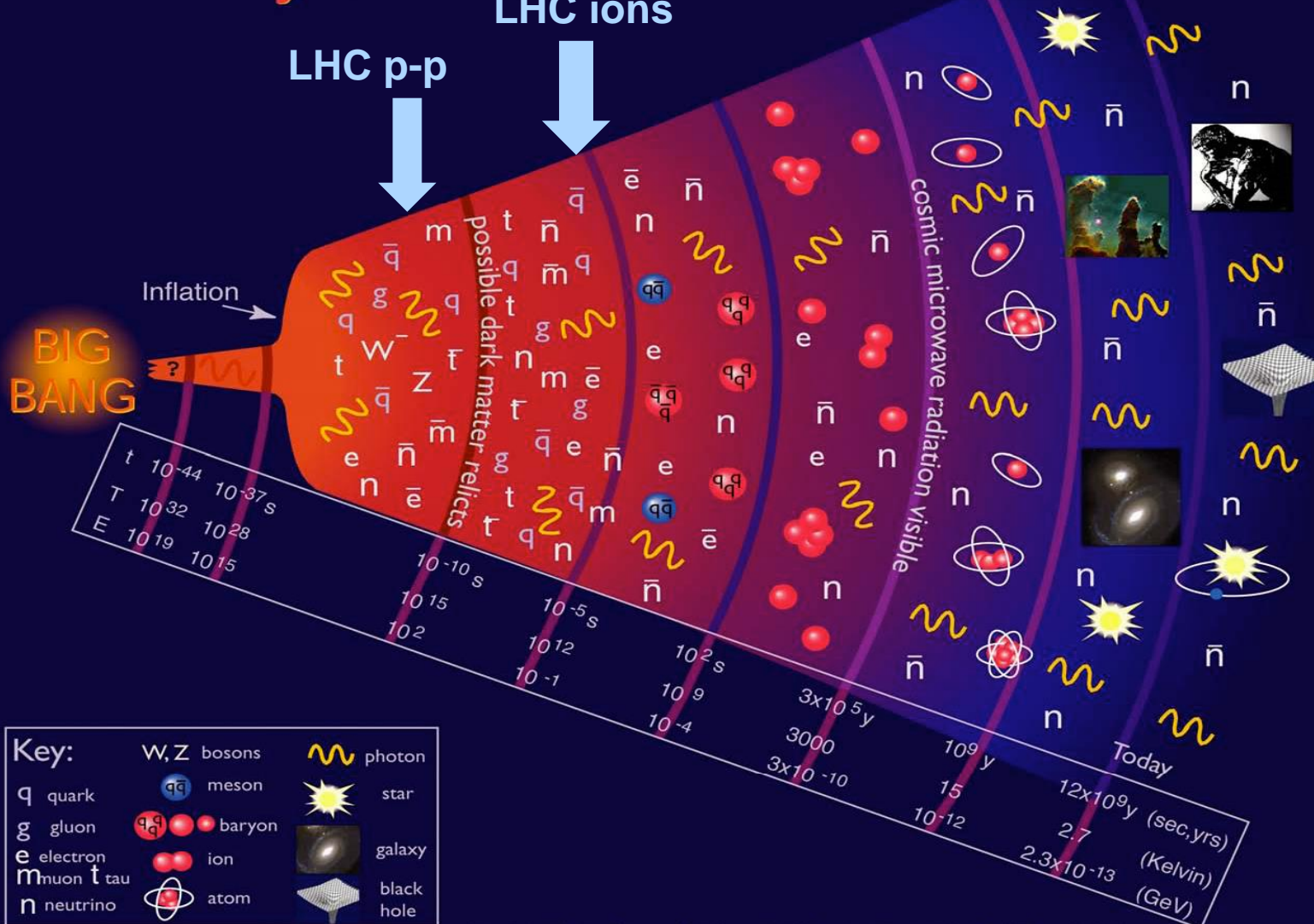
Super-Microscope





# Time back-travel towards the Big Bang

## History of the Universe





# LHC, the largest scientific instrument in the world





# Development of circular accelerators



Lawrence's first cyclotron  
(1930)

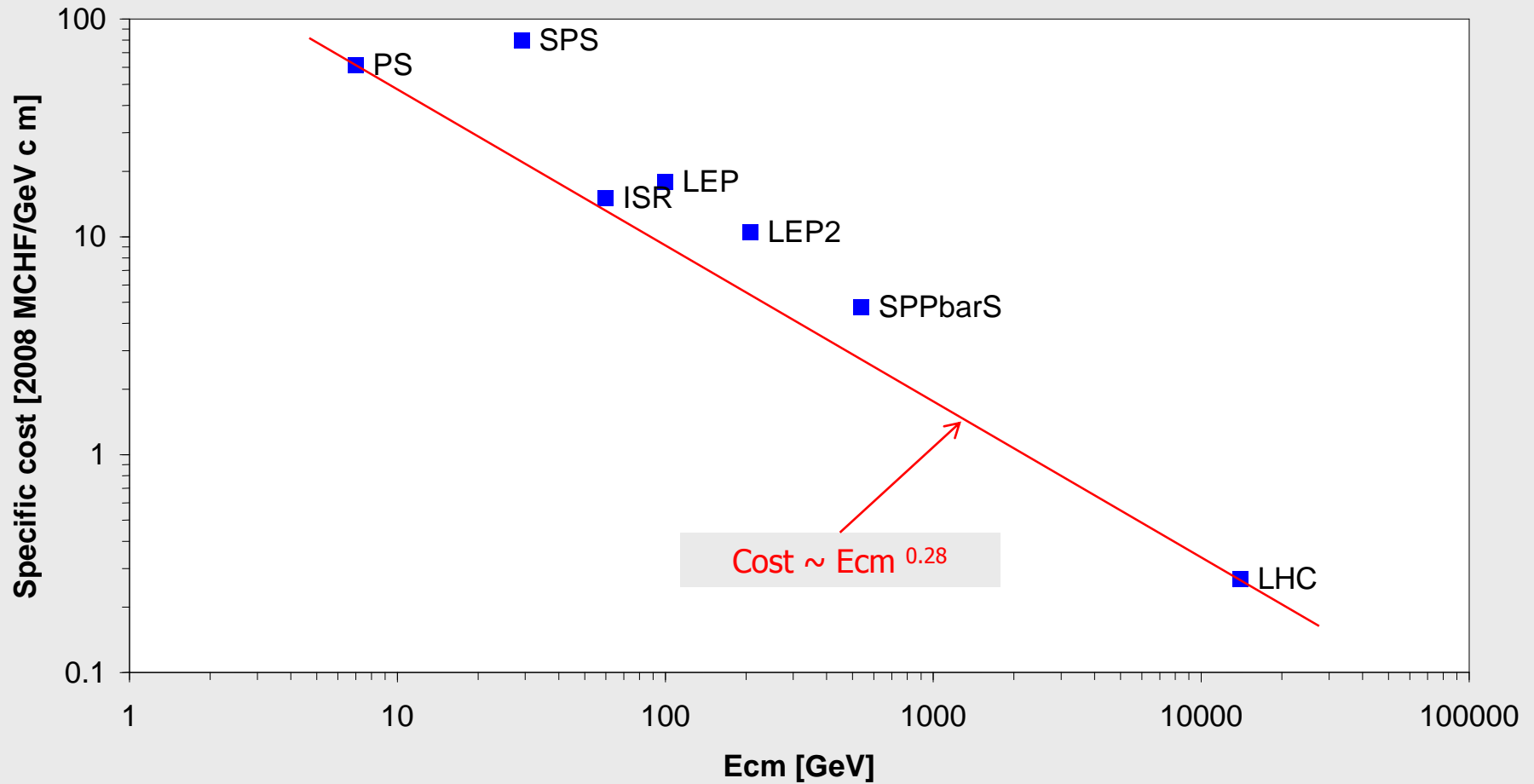


80 years  
 $10^5$  increase in size  
 $10^8$  increase in beam energy

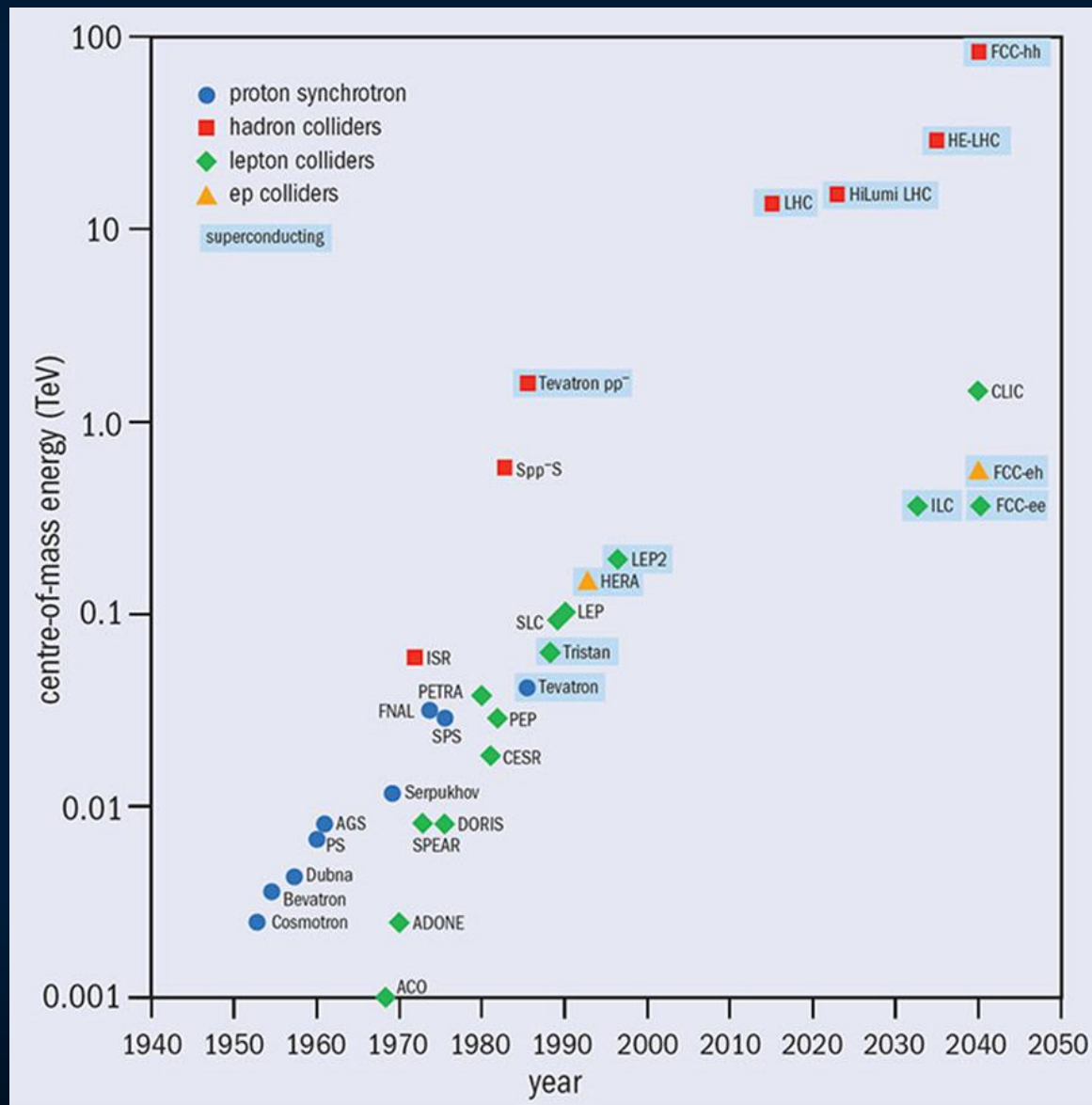
Large Hadron Collider  
(2009)



# Specific cost vs center-of-mass energy of CERN accelerators

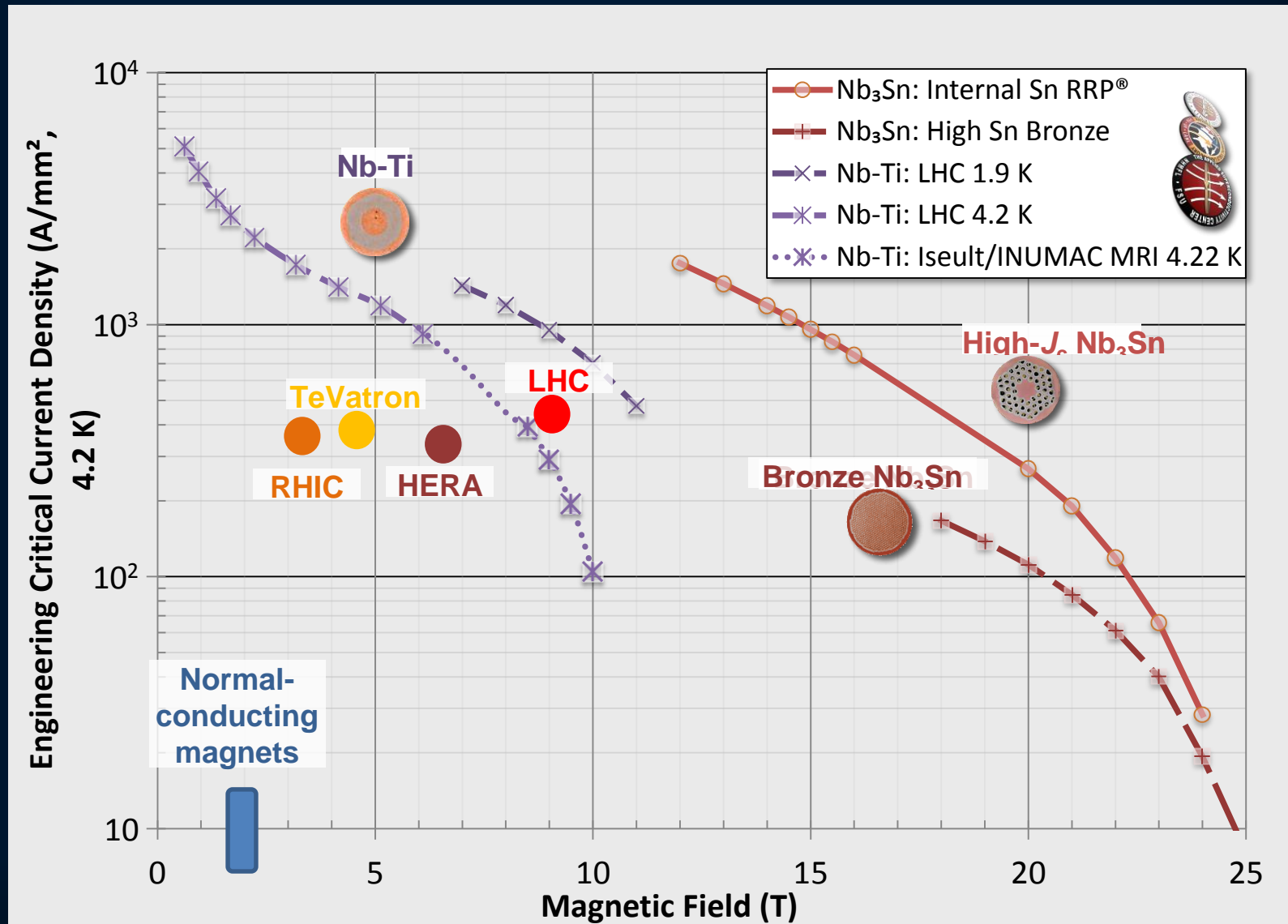


# Superconductivity, key technology of high-energy accelerators

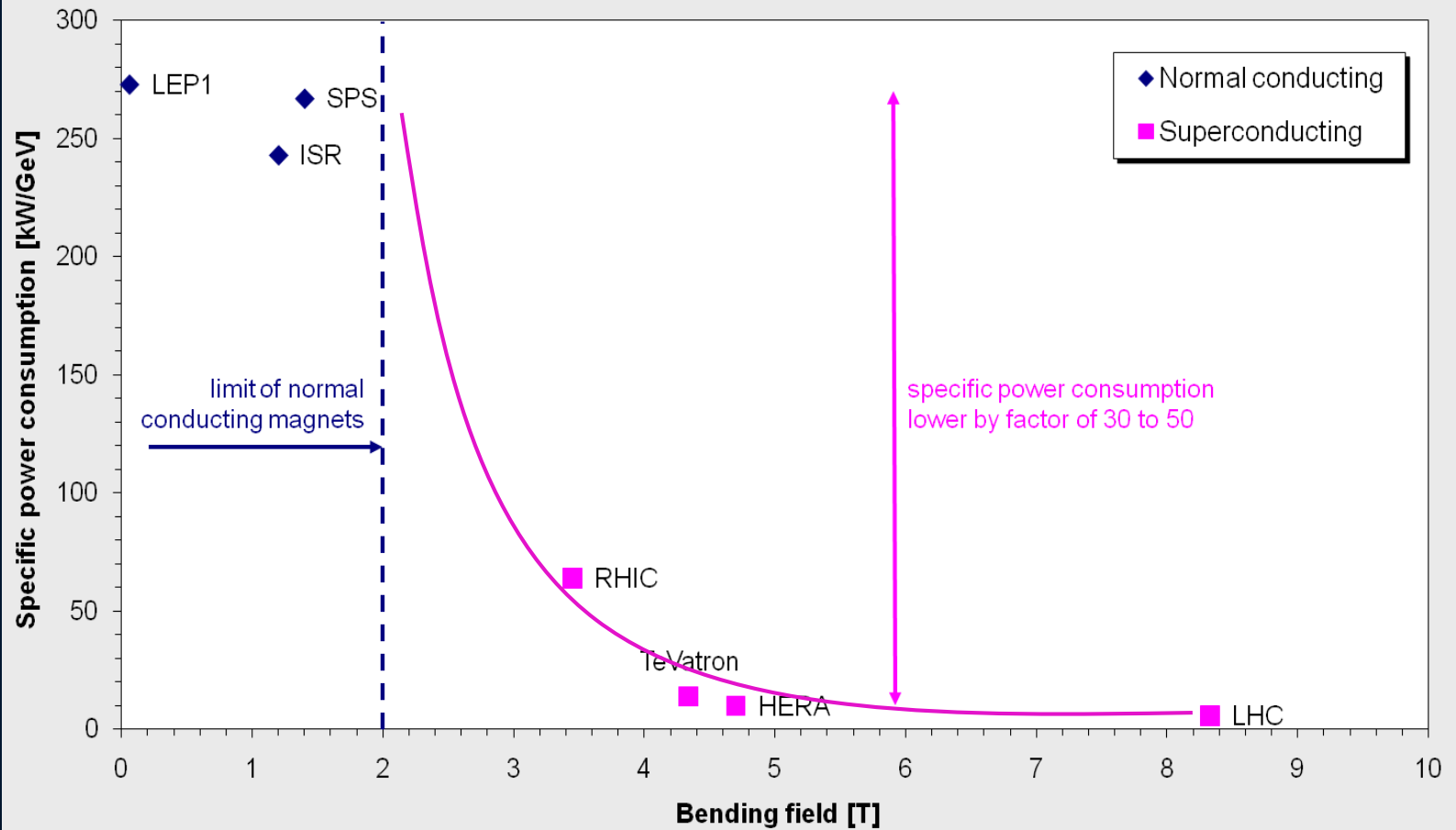




# Superconductivity to produce high magnetic fields



# Superconductivity for energy efficiency

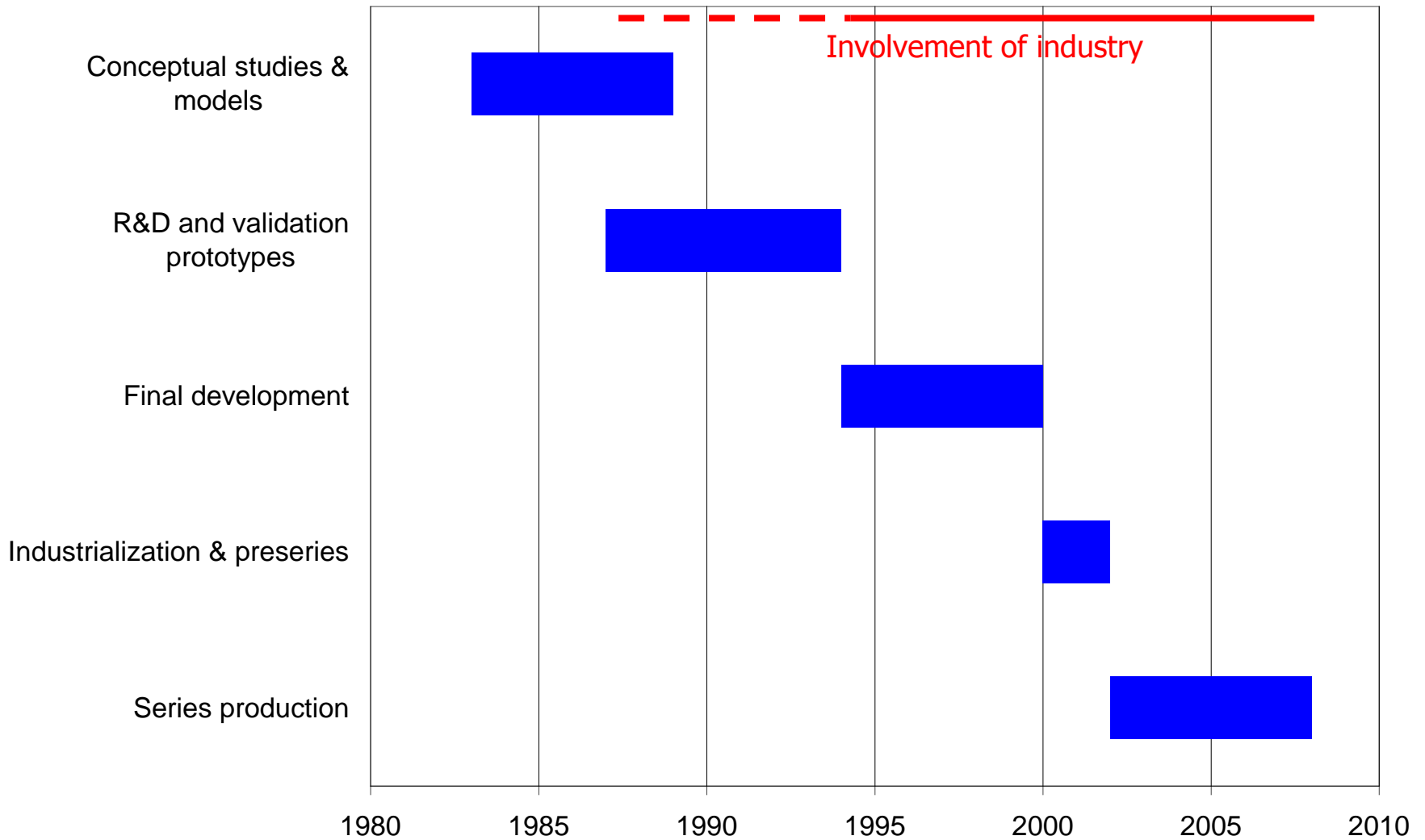




# LHC major industrial production contracts

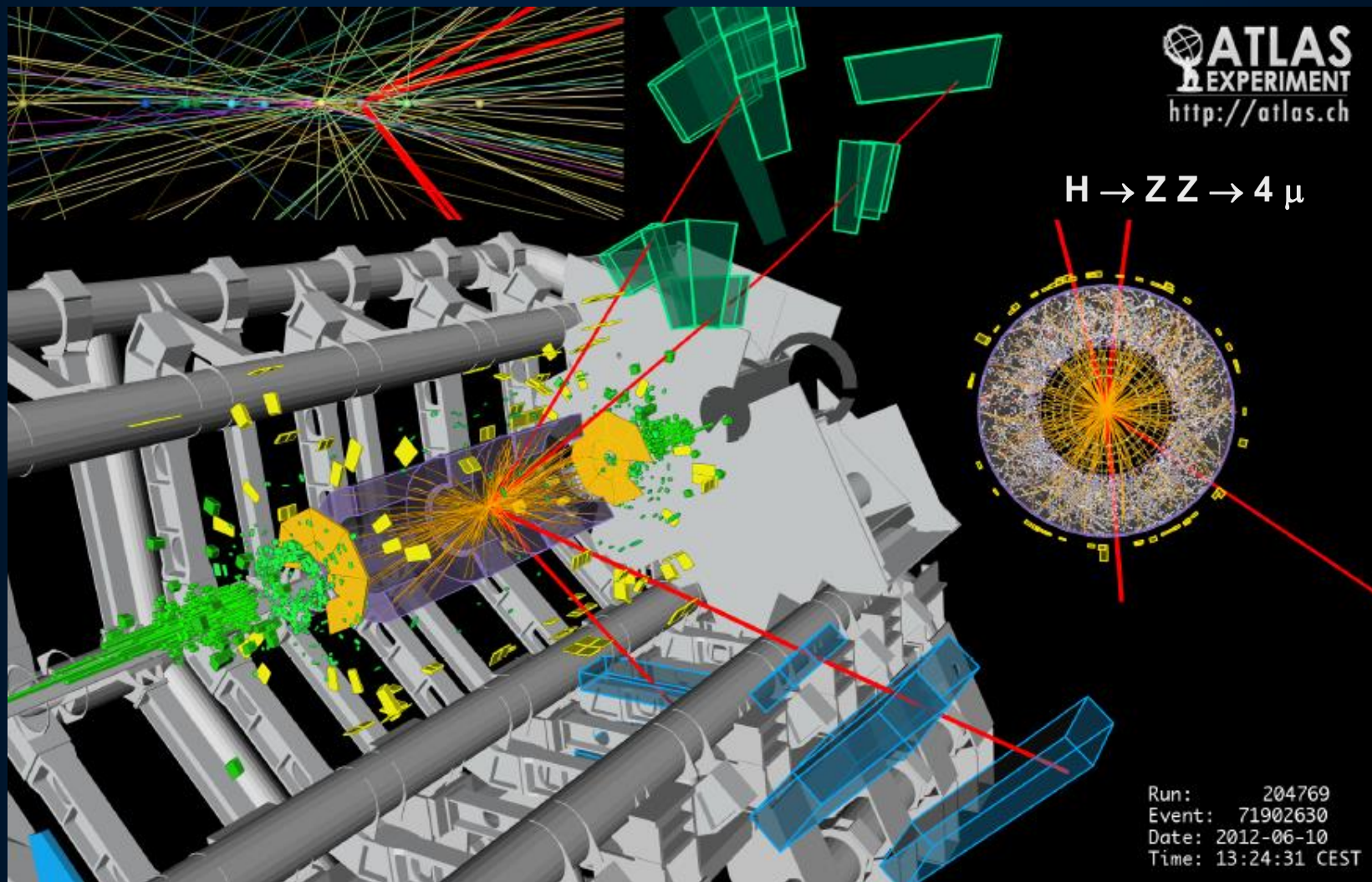


# Time span of LHC project





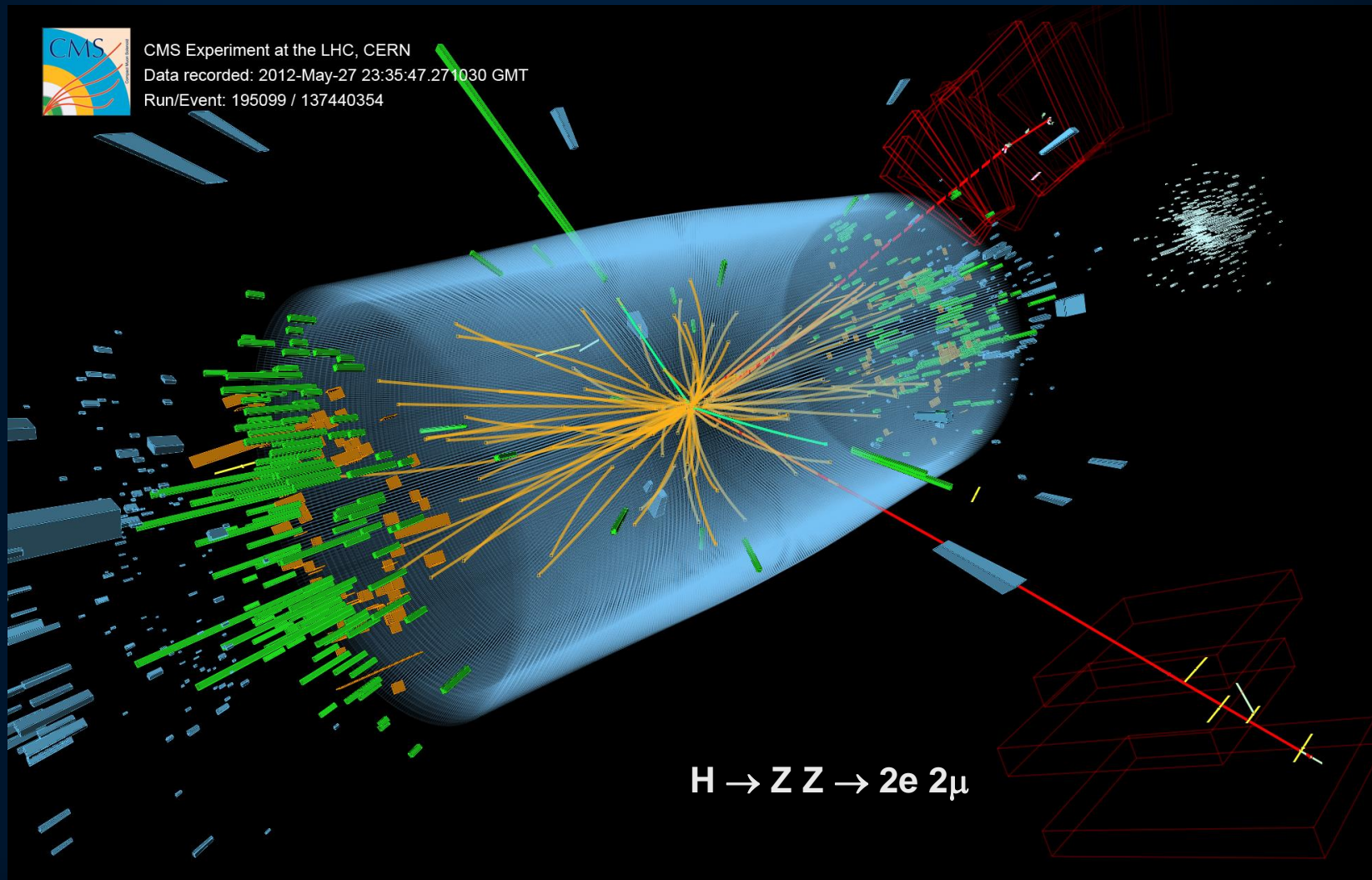
# Disintegration of Higgs boson produced in proton collisions at the LHC



# Disintegration of Higgs boson produced in proton collisions at the LHC



CMS Experiment at the LHC, CERN  
Data recorded: 2012-May-27 23:35:47.271030 GMT  
Run/Event: 195099 / 137440354



$H \rightarrow Z Z \rightarrow 2e 2\mu$



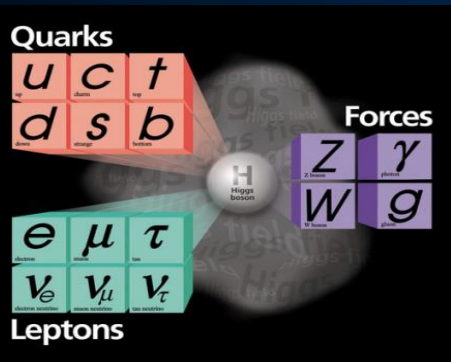
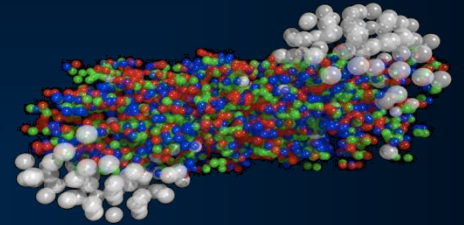
# Discovery 2012, Nobel Prize in Physics 2013



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"*.

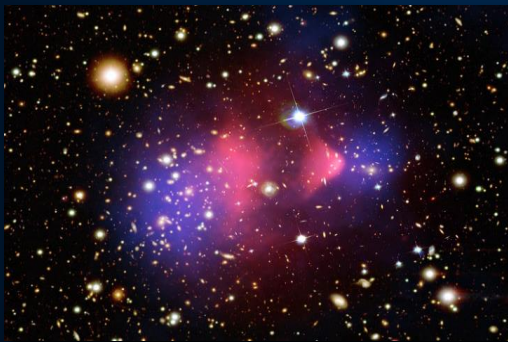
# Experimental research at the LHC will allow us to answer some of the big questions ...

Will we understand the **primordial state of matter** after the Big Bang before protons and neutrons formed?



Have we found “THE” **Higgs particle** that is responsible for **giving mass** to all elementary particles?

Will we find the reason why **antimatter and matter** did not completely annihilate each other?



Will we find the **particle(s)** that make up the **mysterious ‘dark matter’** in our Universe?



# The High-Luminosity LHC project

## Paths to high luminosity

Increase bunch population

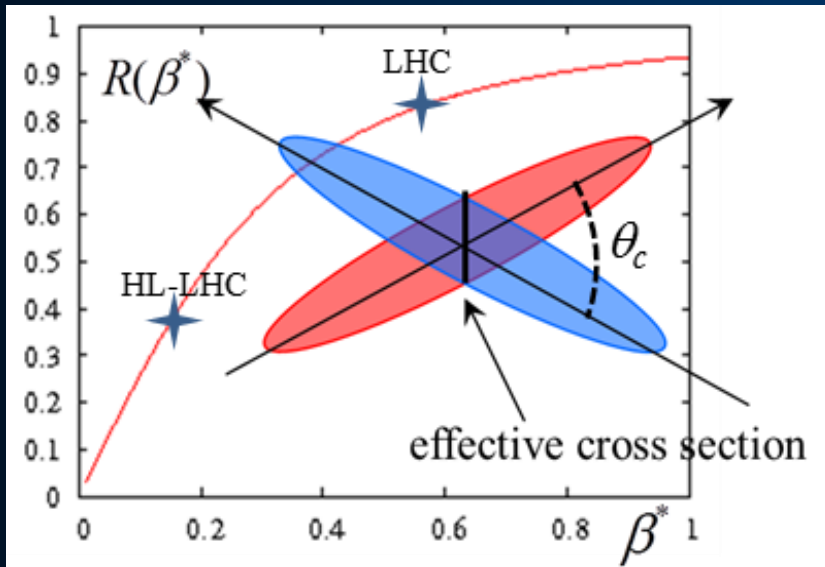
Increase R = reduce crossing angle?

$$L = \gamma \frac{n_b N^2 f_{rev}}{4\pi \beta^* \epsilon_n} R;$$

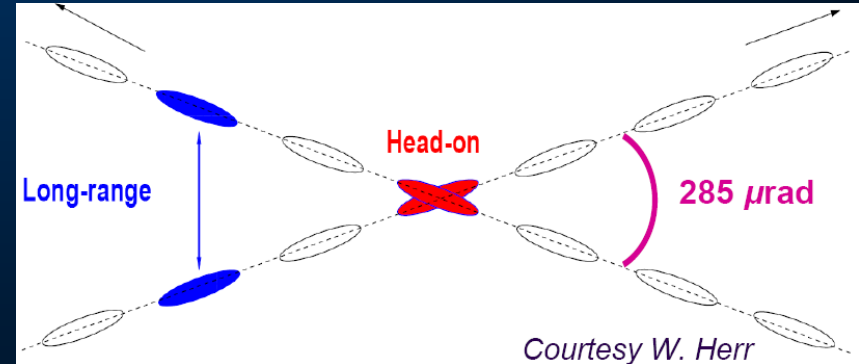
$$R = 1 / \sqrt{1 + \frac{\theta_c \sigma_z}{2\sigma}}$$

Reduce beta at collision

Reduce emittance



Beam-beam effect precludes too low crossing angle



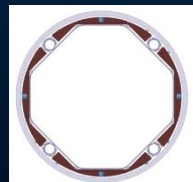
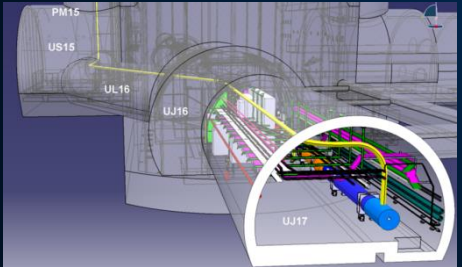
# The HL-LHC project from accelerator physics to technology

Reduce emittance      Increase bunch population      Reduce beta at collision      Reduce crossing angle

Increase intensity & brightness of injectors:  
the LIU project

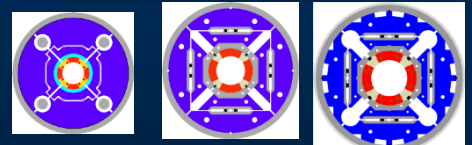


More powerful cryogenics  
Improved collimation  
Improved machine protection  
Stronger R to E → relocation



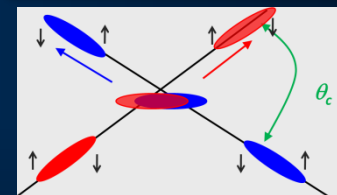
Limit beam-beam effect

New low-beta quadrupoles



Limit beam-beam effect

"Crab" cavities



Accelerator physics

Accelerator technology



# The HL-LHC collaboration





# Particle Physics and Innovation

*Il n'y pas d'un côté la recherche fondamentale et de l'autre la recherche appliquée. Il y a la recherche et les applications de celle-ci, unies l'une à l'autre comme le fruit de l'arbre est uni à la branche qui l'a porté*

**Louis Pasteur**

## □ CERN Technologies and Innovation



Accelerating particle beams



Detecting particles



Large-scale computing (Grid)



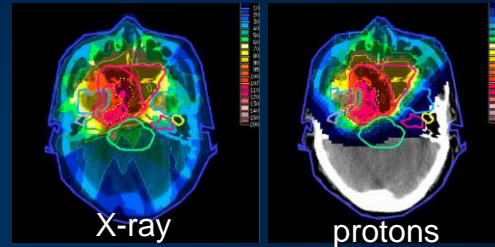
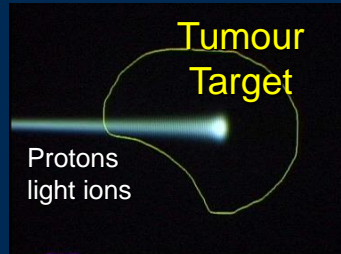
# Medical Application as an Example of Particle Physics Spin-off

Combining Physics, ICT, Biology and Medicine to fight cancer



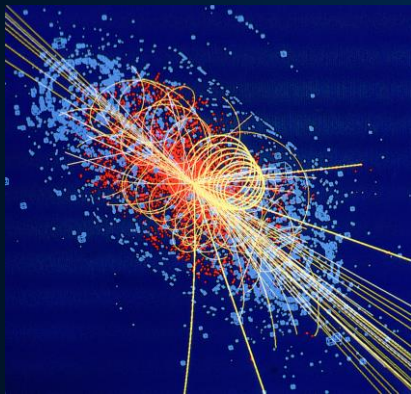
## Hadron Therapy

Accelerating particle beams  
~30'000 accelerators worldwide  
~17'000 used for medicine



Leadership in Ion Beam Therapy now in Europe and Japan

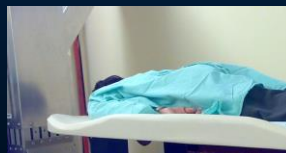
>100'000 patients treated worldwide (45 facilities)  
>50'000 patients treated in Europe (14 facilities)



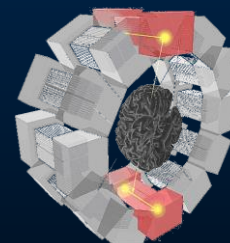
Detecting particles

## Imaging

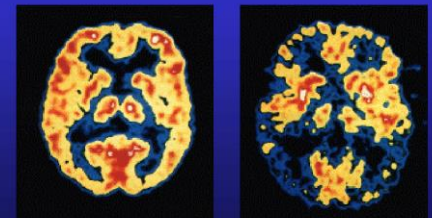
Clinical trial in Portugal, France and Italy for new breast imaging system (ClearPEM)



## PET Scanner



Brain Metabolism in Alzheimer's Disease: PET Scan

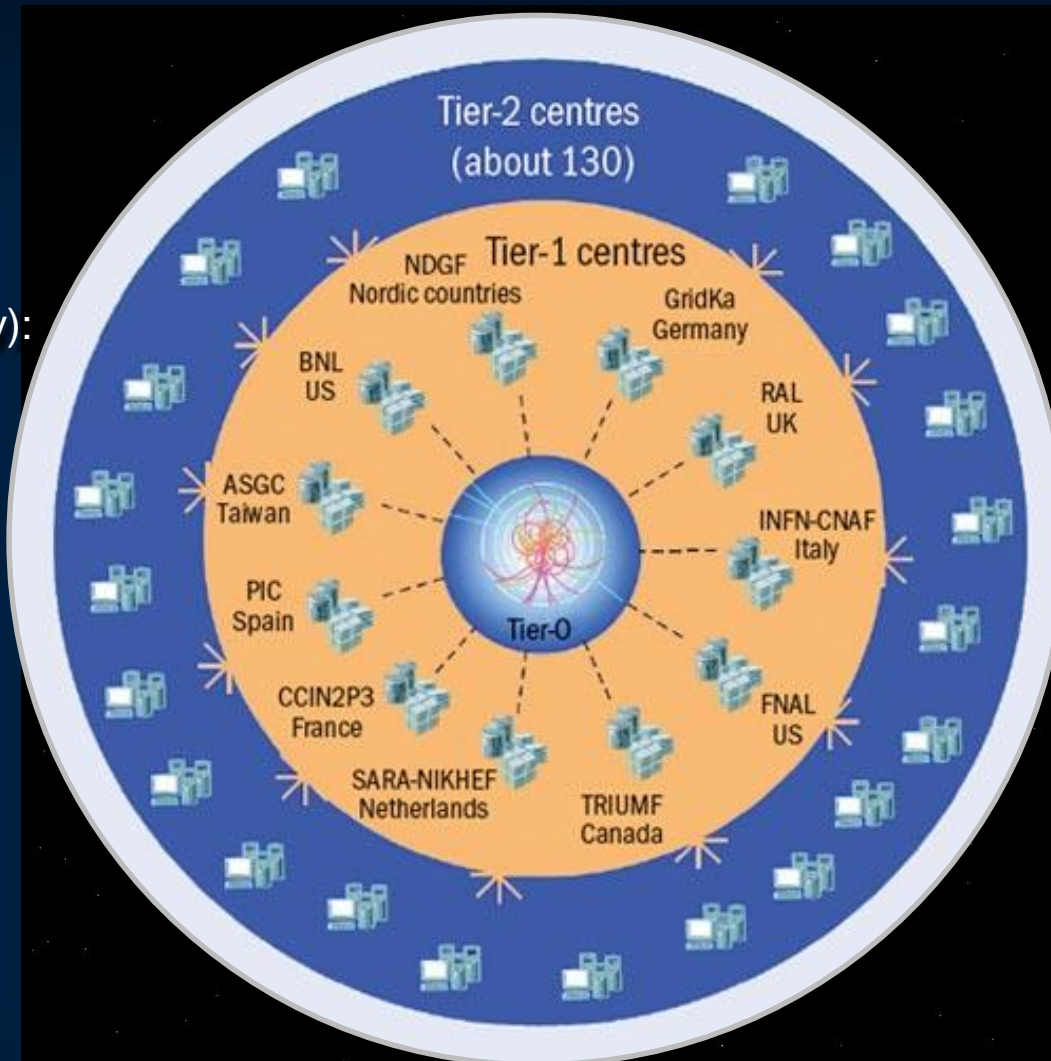


# The Worldwide LHC Computing Grid

Tier-0  
(CERN and Hungary):  
data recording,  
reconstruction and  
distribution

Tier-1: permanent  
storage, re-  
processing,  
analysis

Tier-2: simulation,  
end-user analysis



nearly 160 sites,  
35 countries

~250'000 cores

173 PB of storage

> 2 million jobs/day

10 Gb links

## WLCG:

An International collaboration to distribute and analyse LHC data

Integrates computer centres worldwide that provide computing and storage resource into a single infrastructure accessible by all LHC physicists



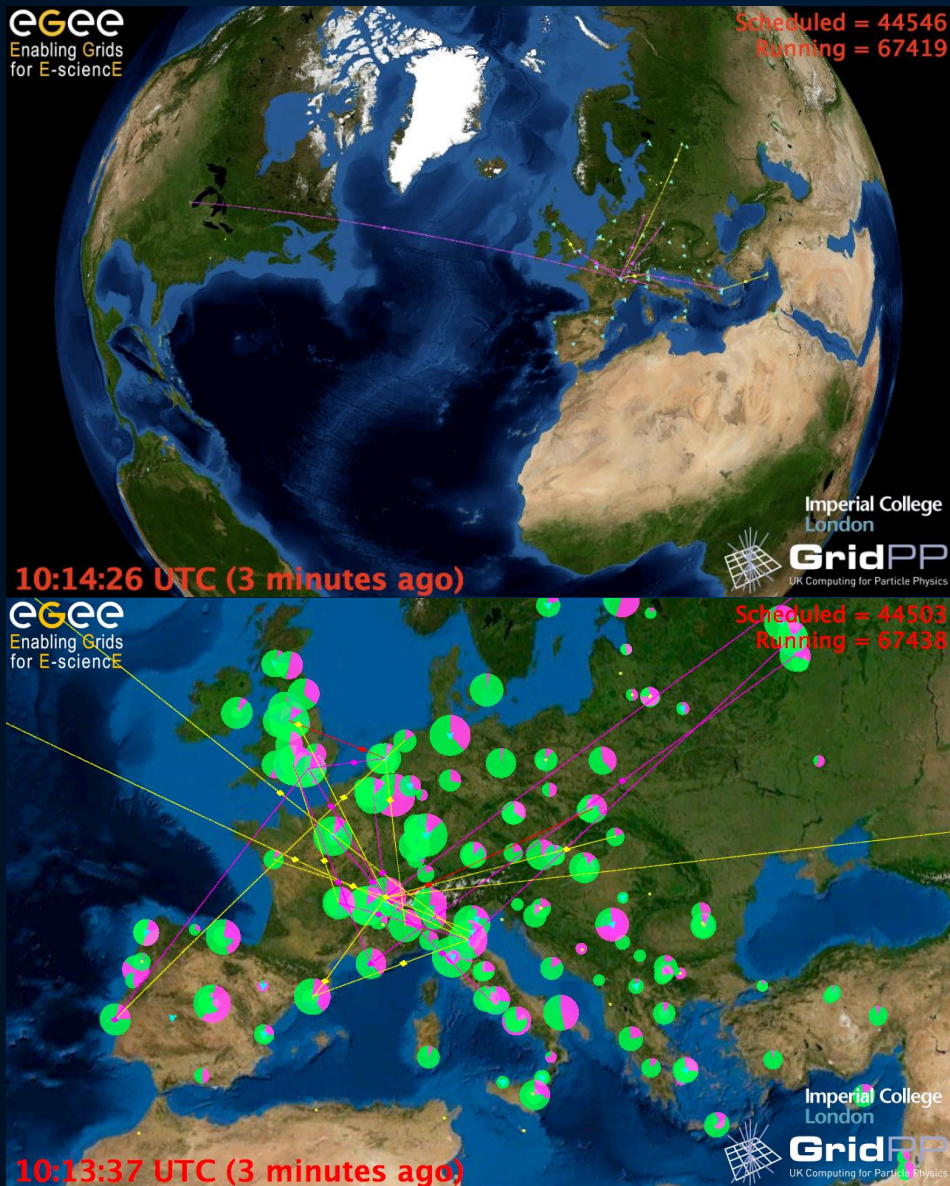
# Tier 0 of LHC Computing Grid

## 50'000 PC «farm» at CERN





# Computing grids beyond particle physics



- Astrophysics
- Plasma physics
- Geosciences
- Climatology
- Meteorology
- Pollution tracking & analysis
- Bioinformatics
- Pharmacology *in silico*
- Epidémiology
- Finance
- ...

# CERN Education Activities

## Scientists at CERN

Academic Training Programme



## Young Researchers

CERN School of High Energy Physics  
CERN School of Computing  
CERN Accelerator School



## Physics Students

Summer Students  
Programme



## CERN Teacher Schools

International and National  
Programmes







SUISSE  
FRANCE

LHCb

ATLAS

CERN Meyrin

CERN Prévessin

SPS 7 km

CMS

ALICE

Questions?

LHC 27 km