Welcome

"The science of particle accelerators" Course
Joint Universities Accelerator School
13 January 2017

to CERN *Accelerating Science and Innovation*

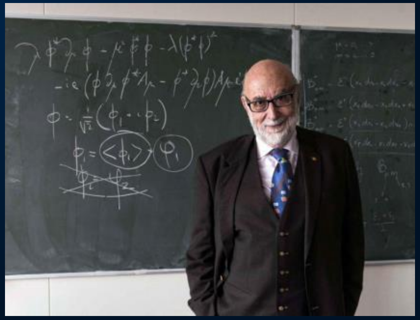
The origins of CERN

Council meeting, Copenhagen 1952

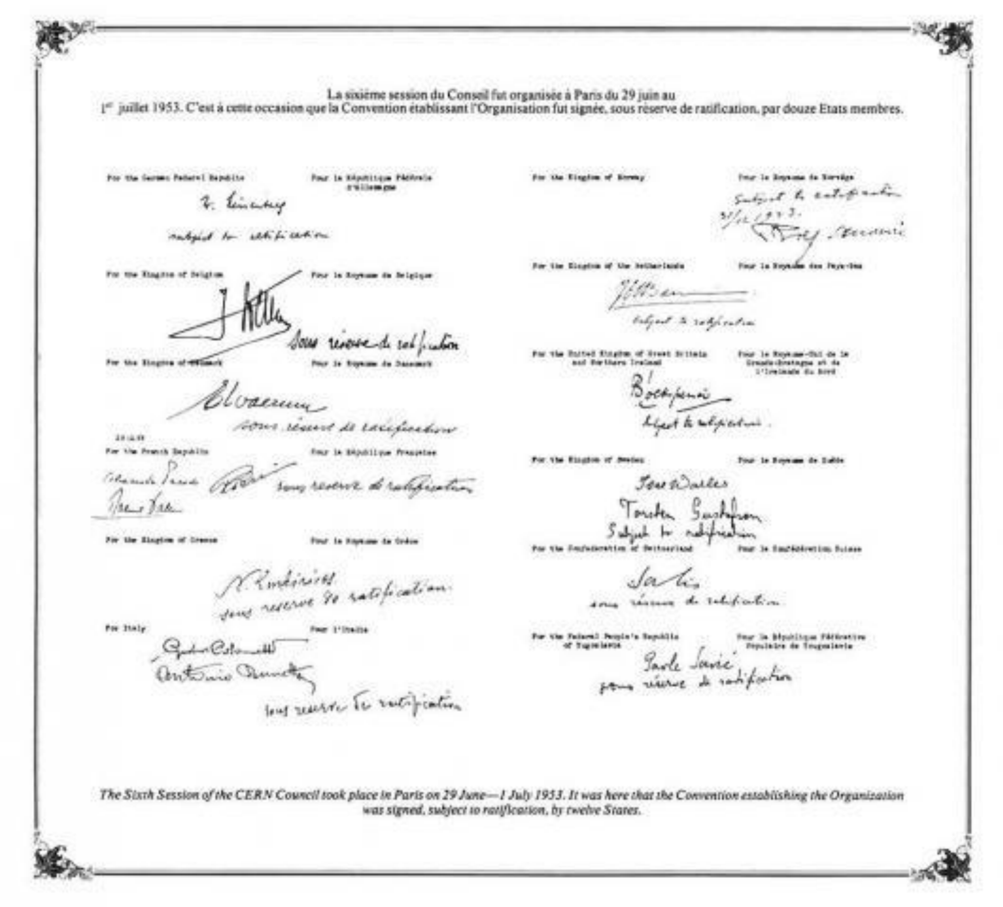
Conseil
Européen pour la
Recherche
Nucléaire

Nucléaire?

Only fundamental research in physics



1954: the Convention, 12 founding Member States



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.

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.

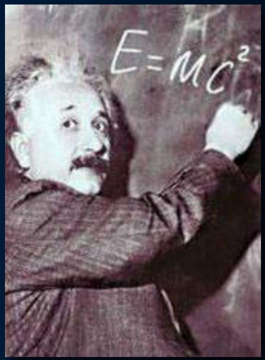
«The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available»

Innovation
Education
CERN
uniting people
Research

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?

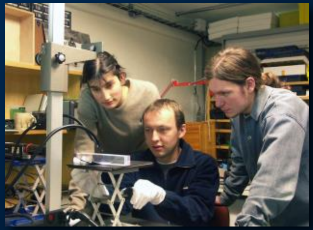


- **Develop** new technologies for accelerators and detectors

  Information technology - the Web and the GRID

  Medicine - diagnosis and therapy

- **Train** scientists and engineers of tomorrow



- **Unite** people from different countries and cultures

CERN

CERN today: 22 Member States… and growing

~ 2300 staff
~ 1400 other paid personnel
~ 12000 scientific users

Budget (2016) ~1000 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

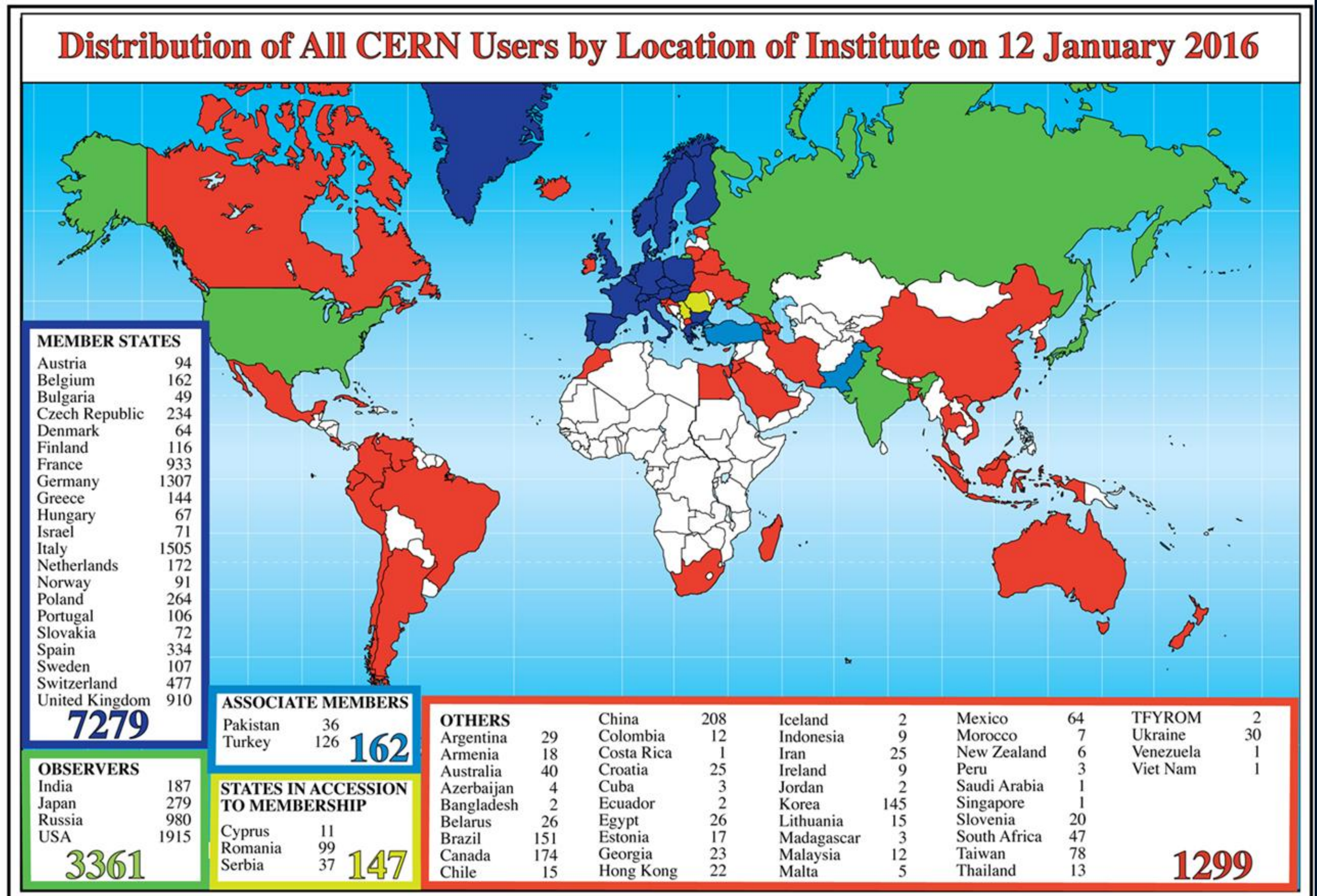
Associate Member States: Pakistan, Turkey

States in accession to Membership: Serbia

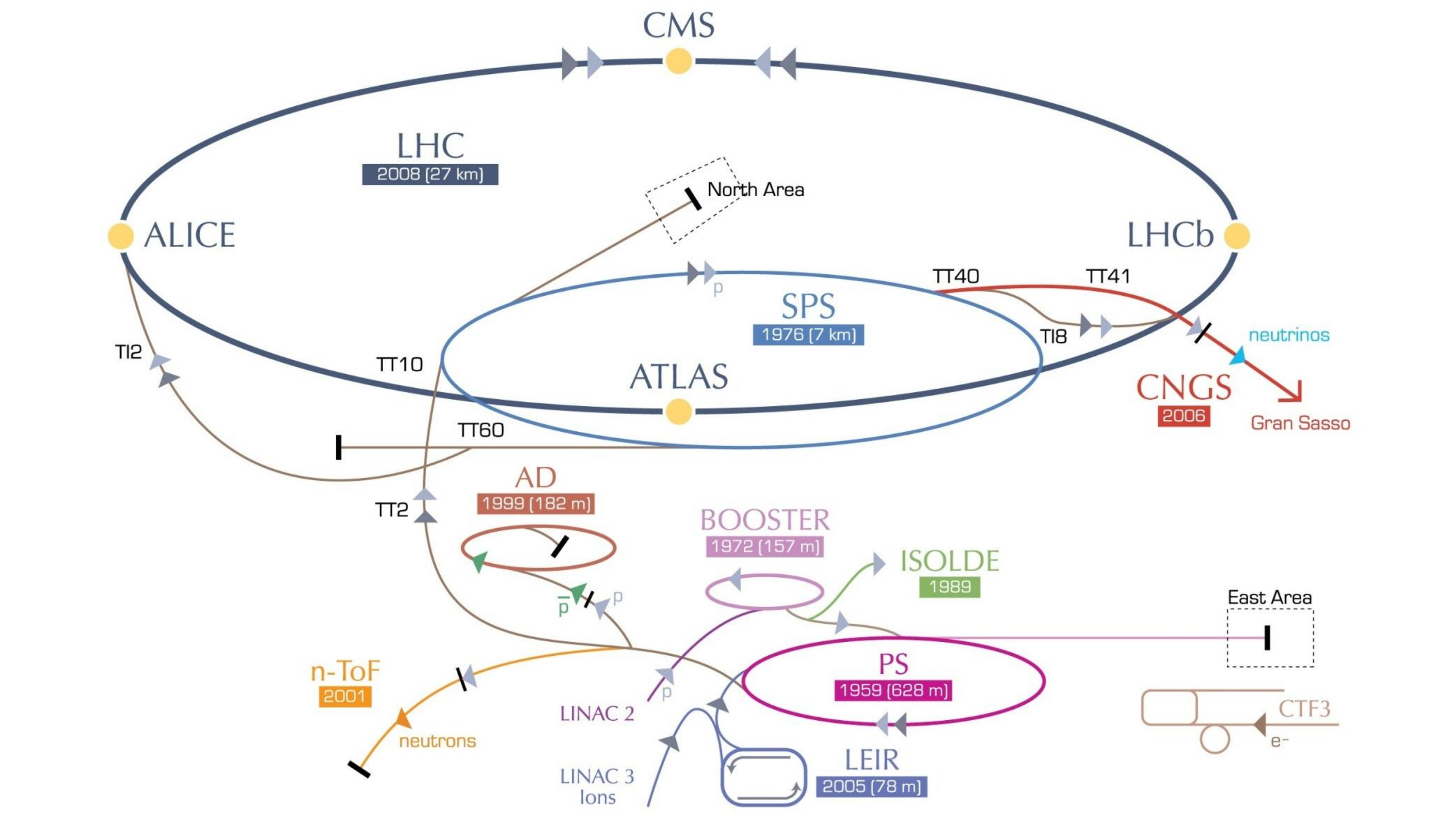
Applications for Membership or Associate Membership: Azerbaijan, Brazil, Croatia, Cyprus, India, Russia, Slovenia, Ukraine

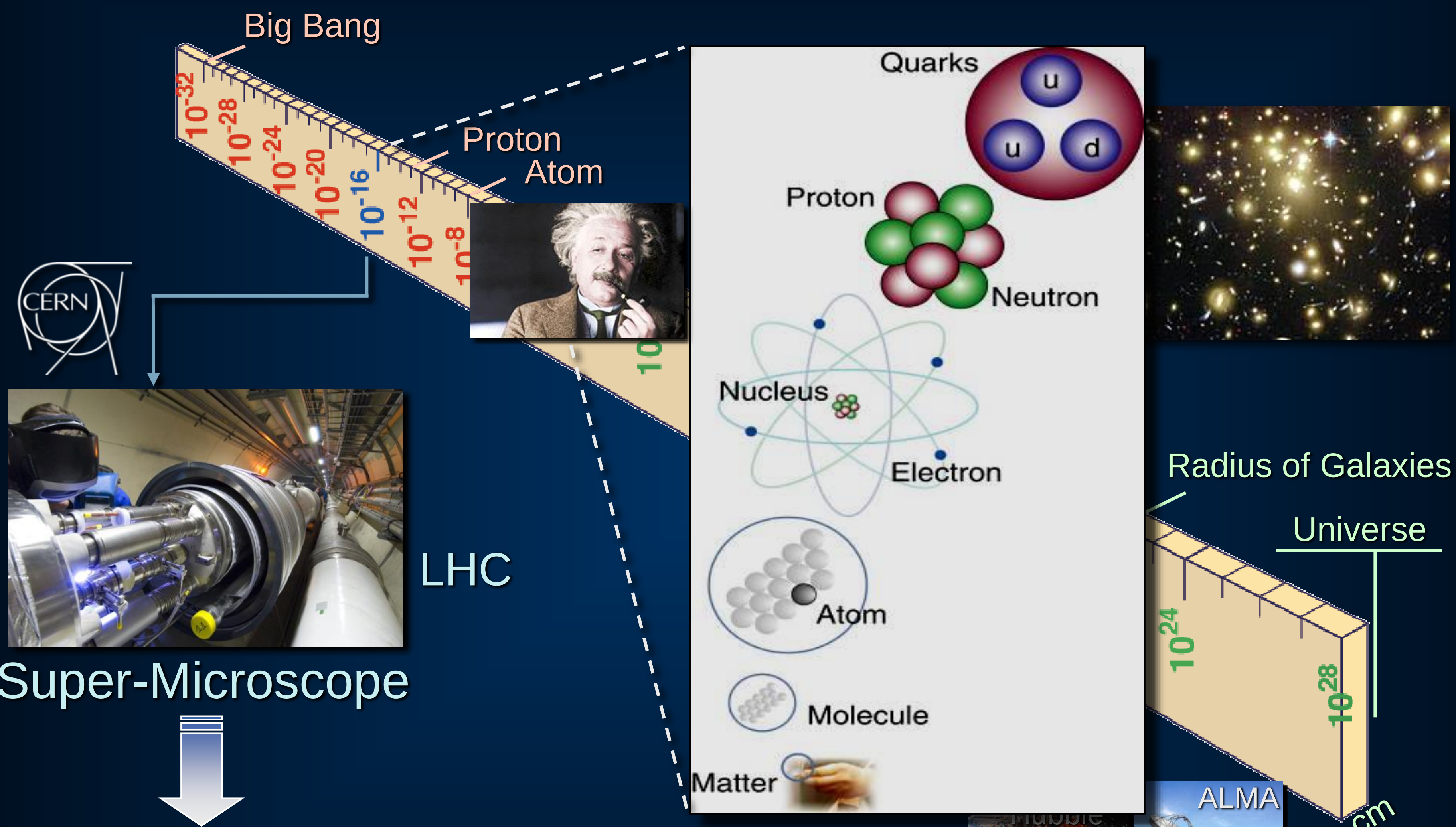
Observers to Council: India, Japan, Russia, United States of America; European Union, JINR and UNESCO

A global laboratory



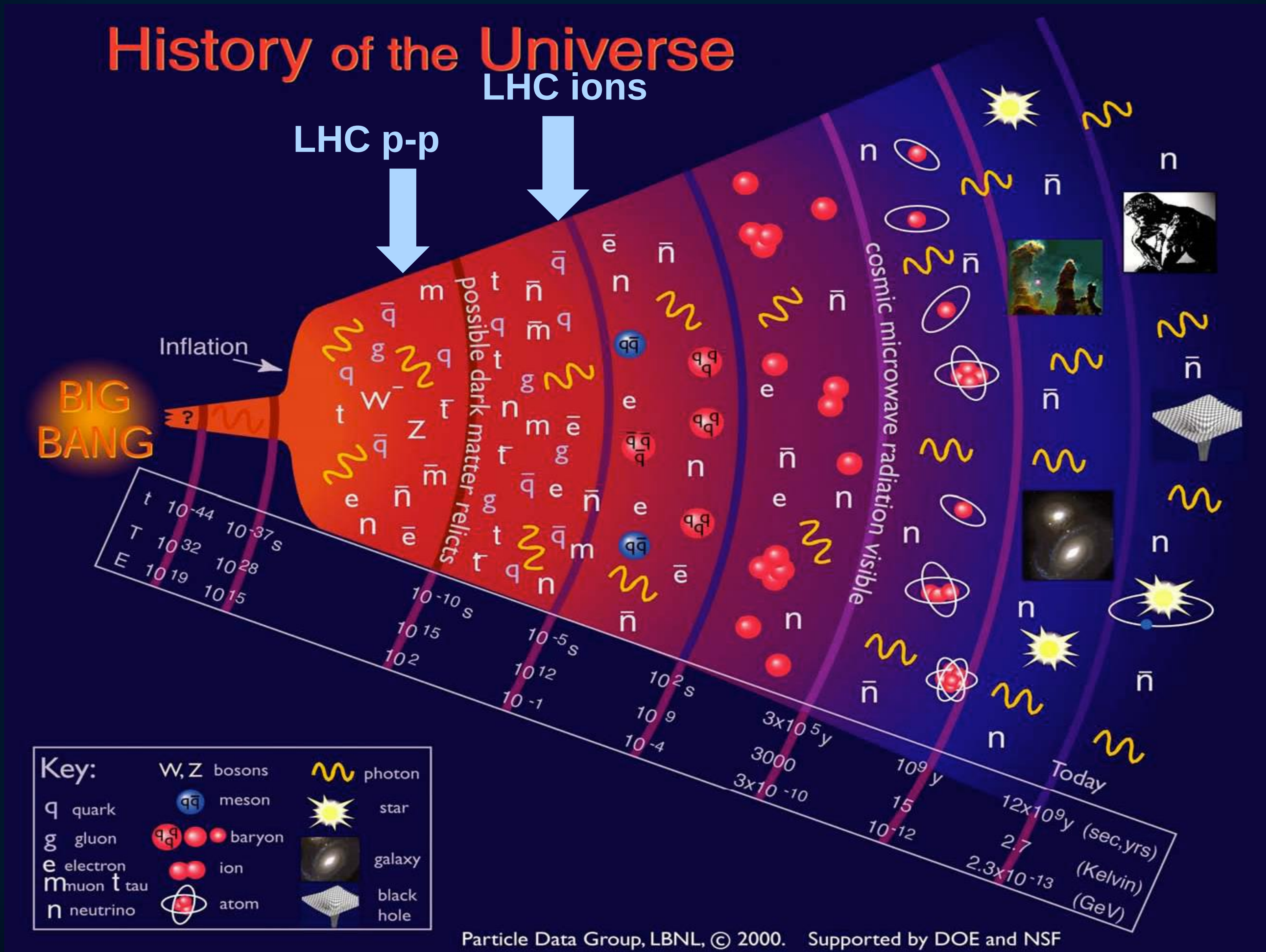
A unique network of interconnected accelerators





Study physics laws of first moments after Big Bang
increasing Symbiosis between Particle Physics,
Astrophysics and Cosmology

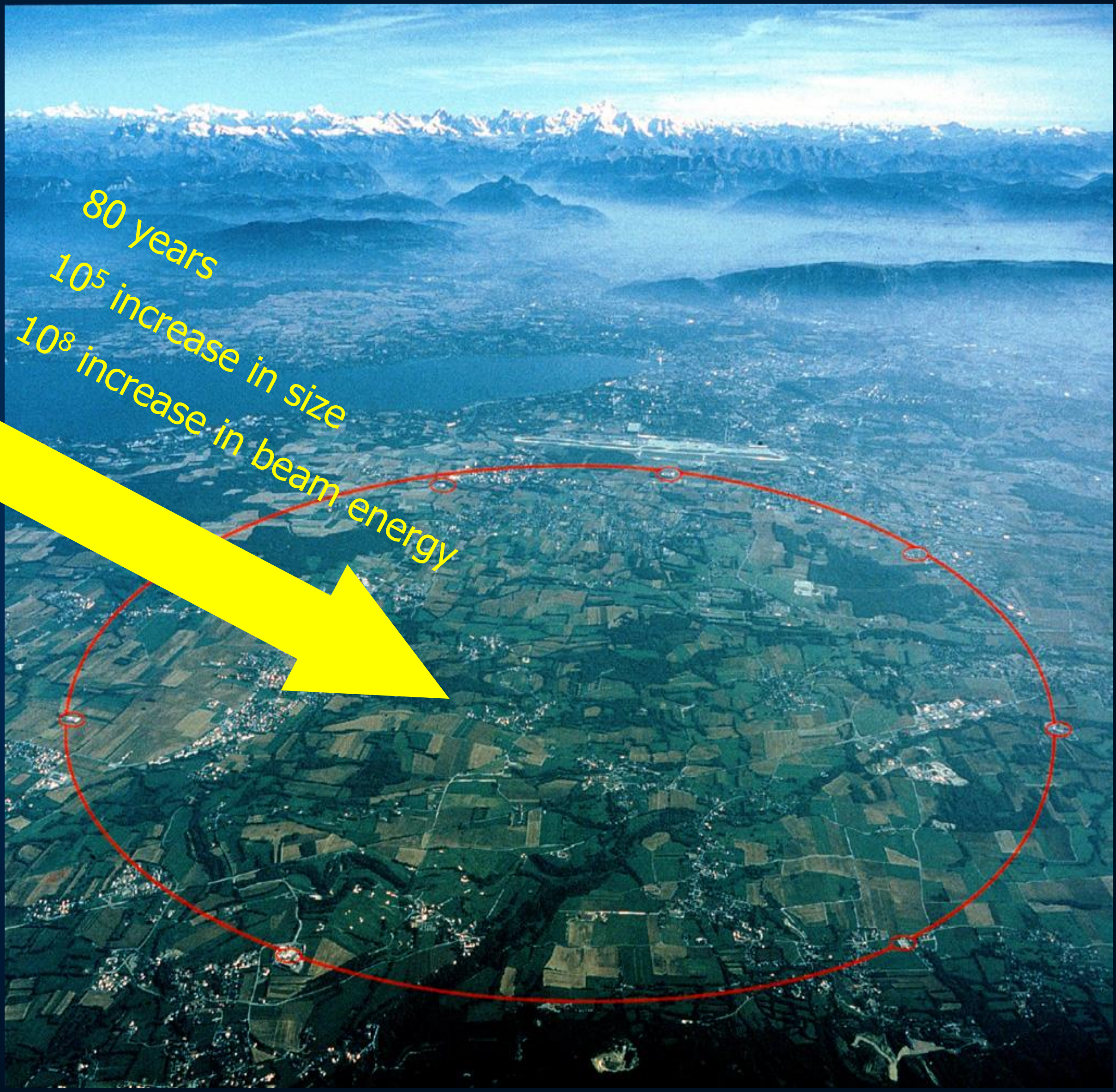
Time back-travel towards the Big Bang



LHC, the largest scientific instrument in the world

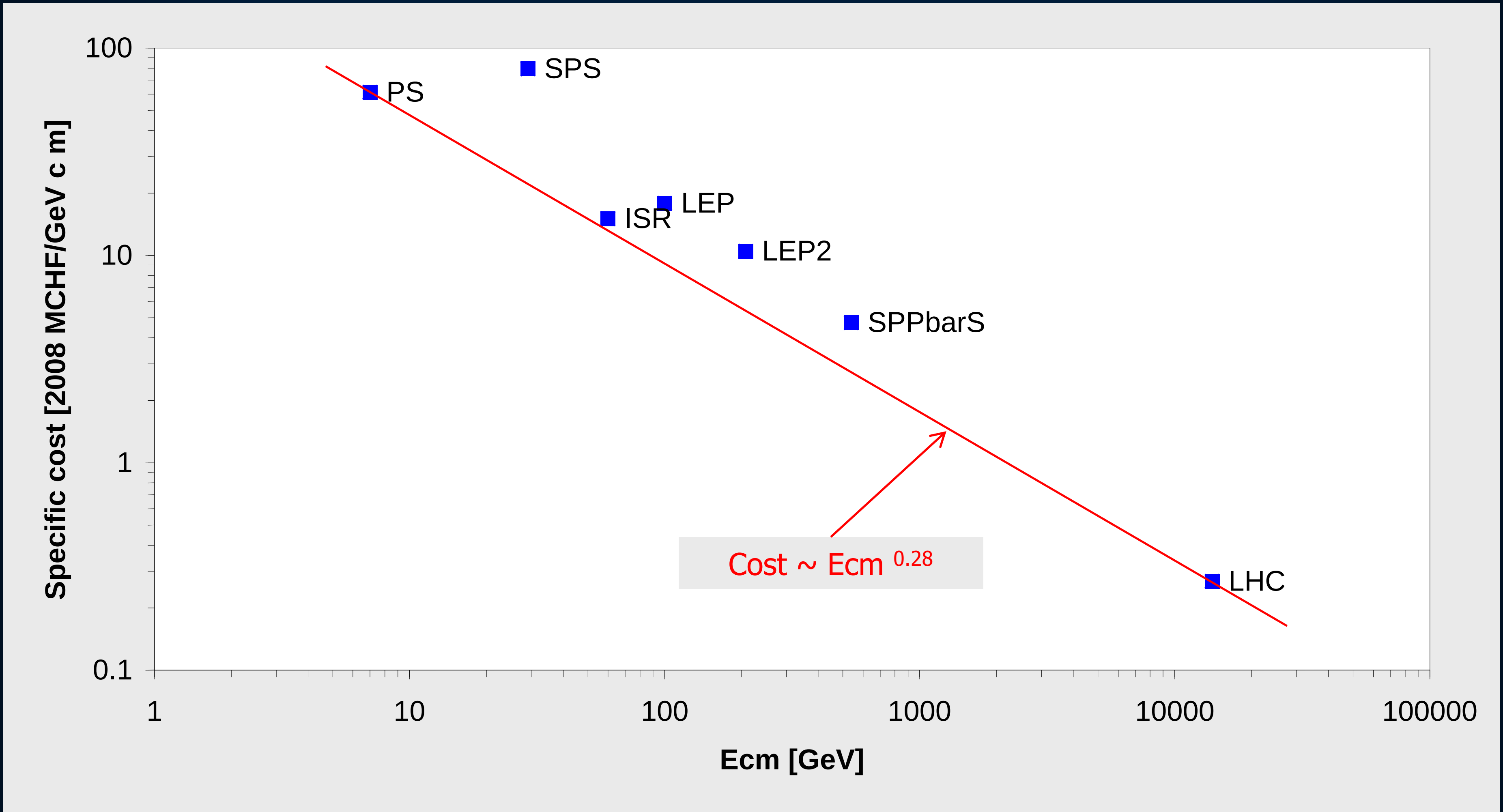
Development of circular accelerators

Lawrence's first cyclotron
(1930)

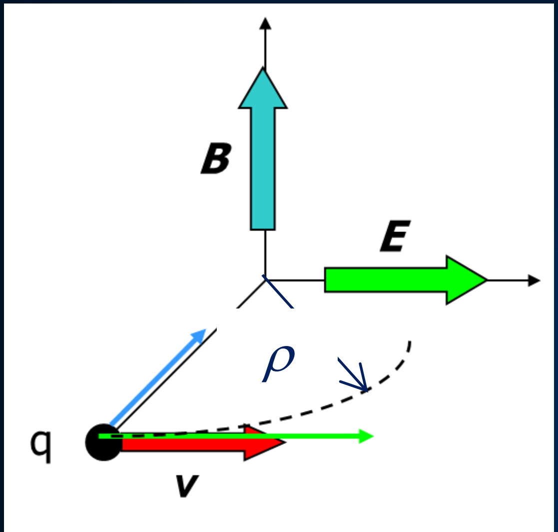


Large Hadron Collider
(2009)

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

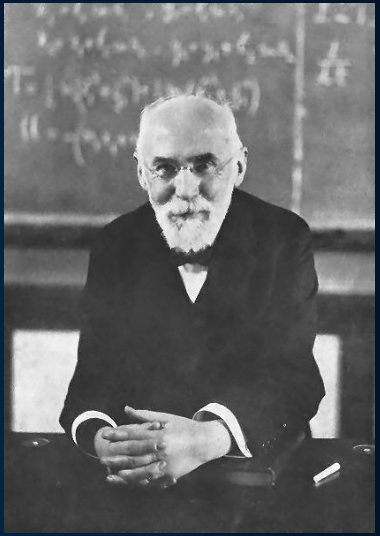


Circular accelerator basics



Lorentz force

$$\frac{d\vec{p}}{dt} = e(\vec{E} + \vec{v} \times \vec{B})$$



H.A. Lorentz

- In plane normal to $\vec{B}$

$$evB = \frac{mv^2}{\rho} = \frac{\gamma m_0 v^2}{\rho}$$

- Hence

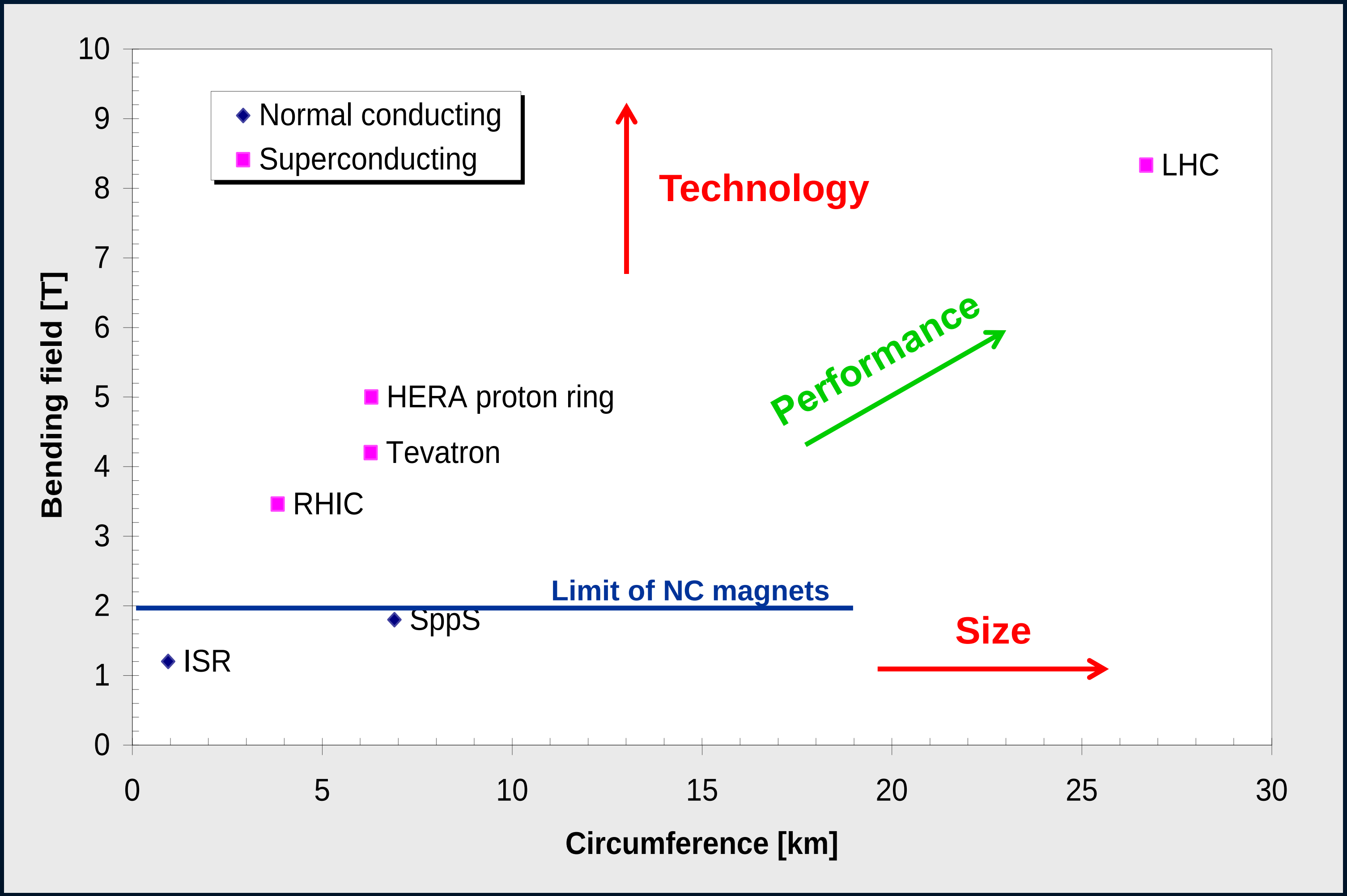
$$\frac{p}{e} = B\rho \qquad B\rho[\mathrm{T.m}] \approx \frac{p[\mathrm{GeV/c}]}{0.3}$$

magnetic rigidity

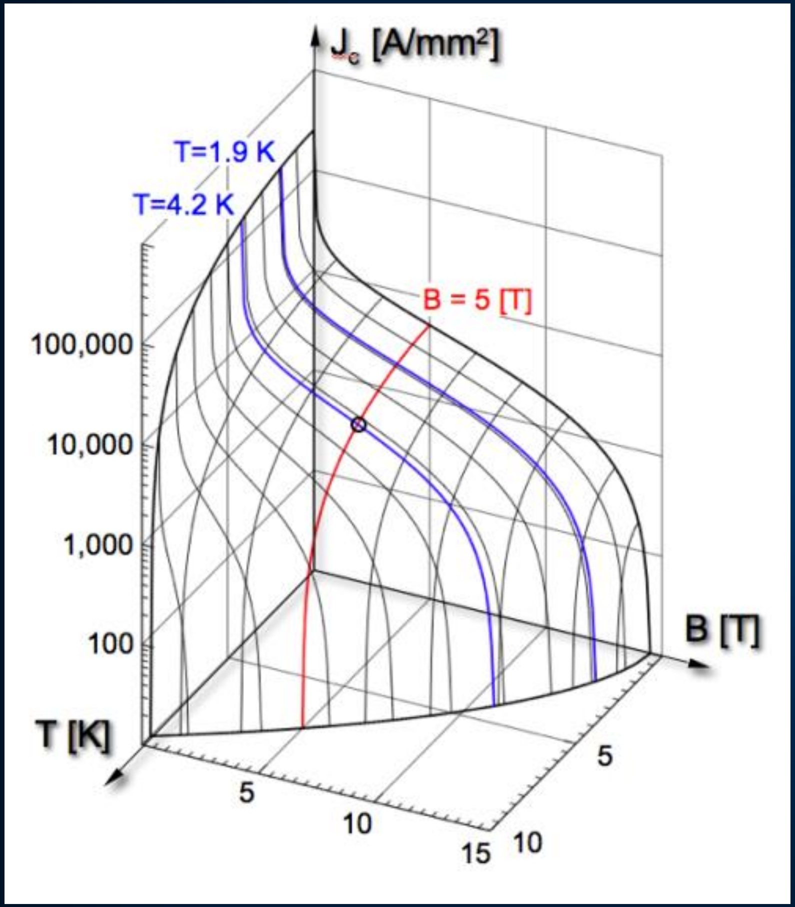
- Example: the LHC
  - Nominal bending field 8.3 T
  - Bending radius 2804 m
  - Nominal momentum ≈ 0.3 x 8.3 x 2804 ≈ 7000 GeV/c

Evolution of high-energy hadron colliders

Technological progress helps containing increase in size and cost

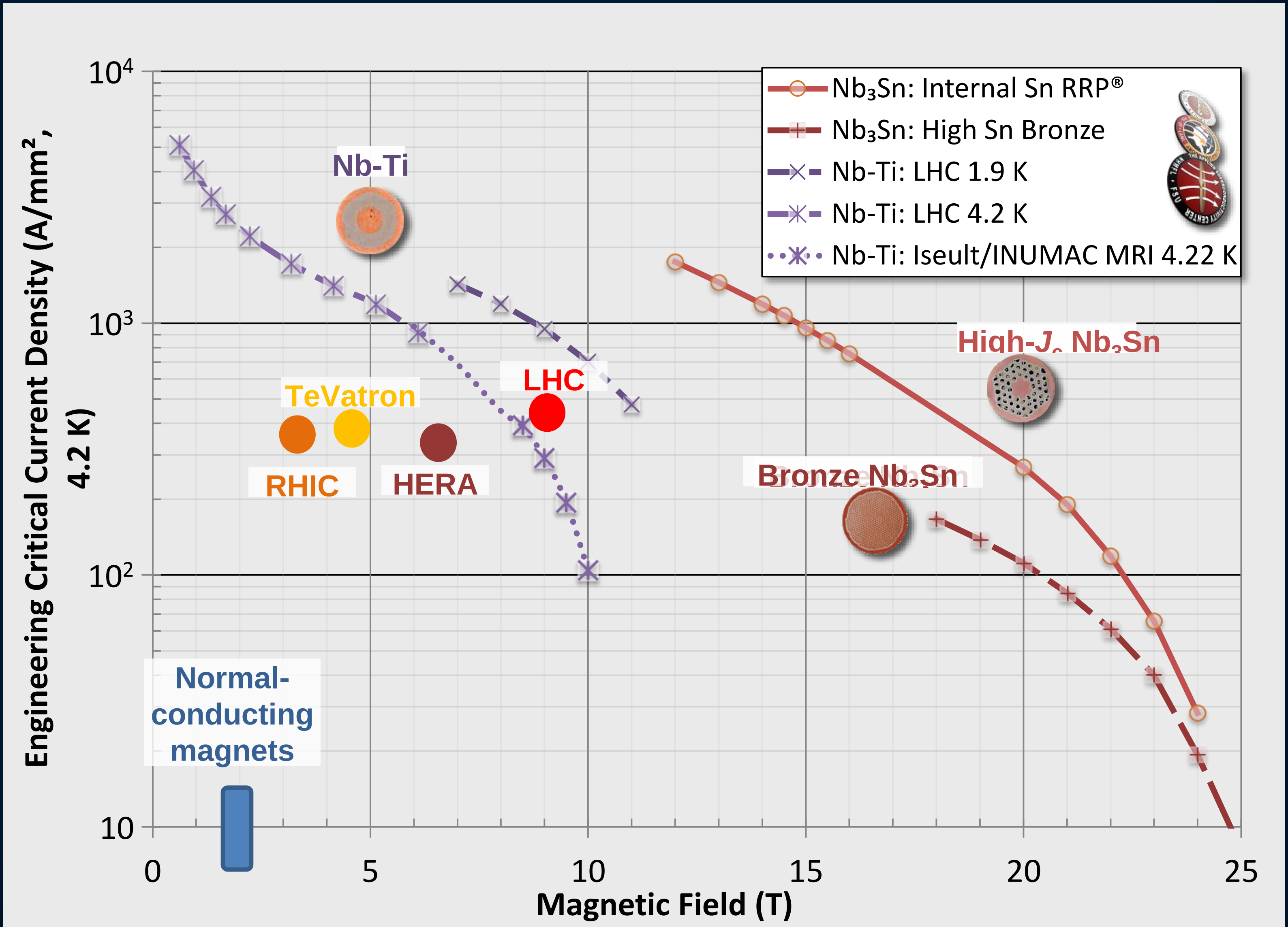


Basics of superconductivity

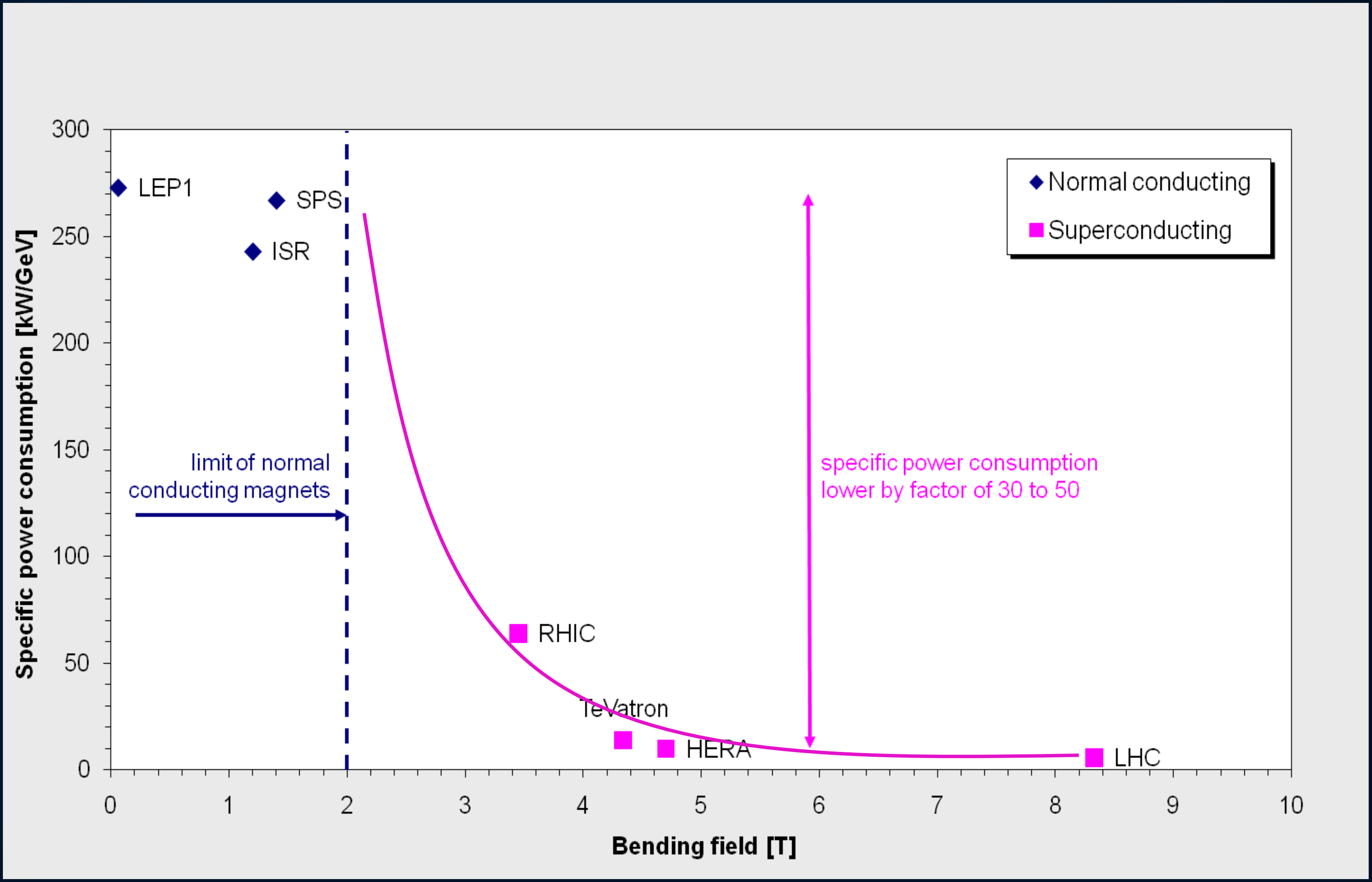


- The superconducting state only occurs in a limited domain of (low) temperature, magnetic field and current density, limited by the «critical surface» of the material
- The working point must remain below the «critical surface» of the superconductor
- Operating at lower temperature increases the working range in the magnet design plane (J_c,B)
- In practice, operate at temperature well below T_c
- Most of superconducting magnets in use today use Nb-Ti with T_c = 9.2 K

Superconductivity to produce high magnetic fields

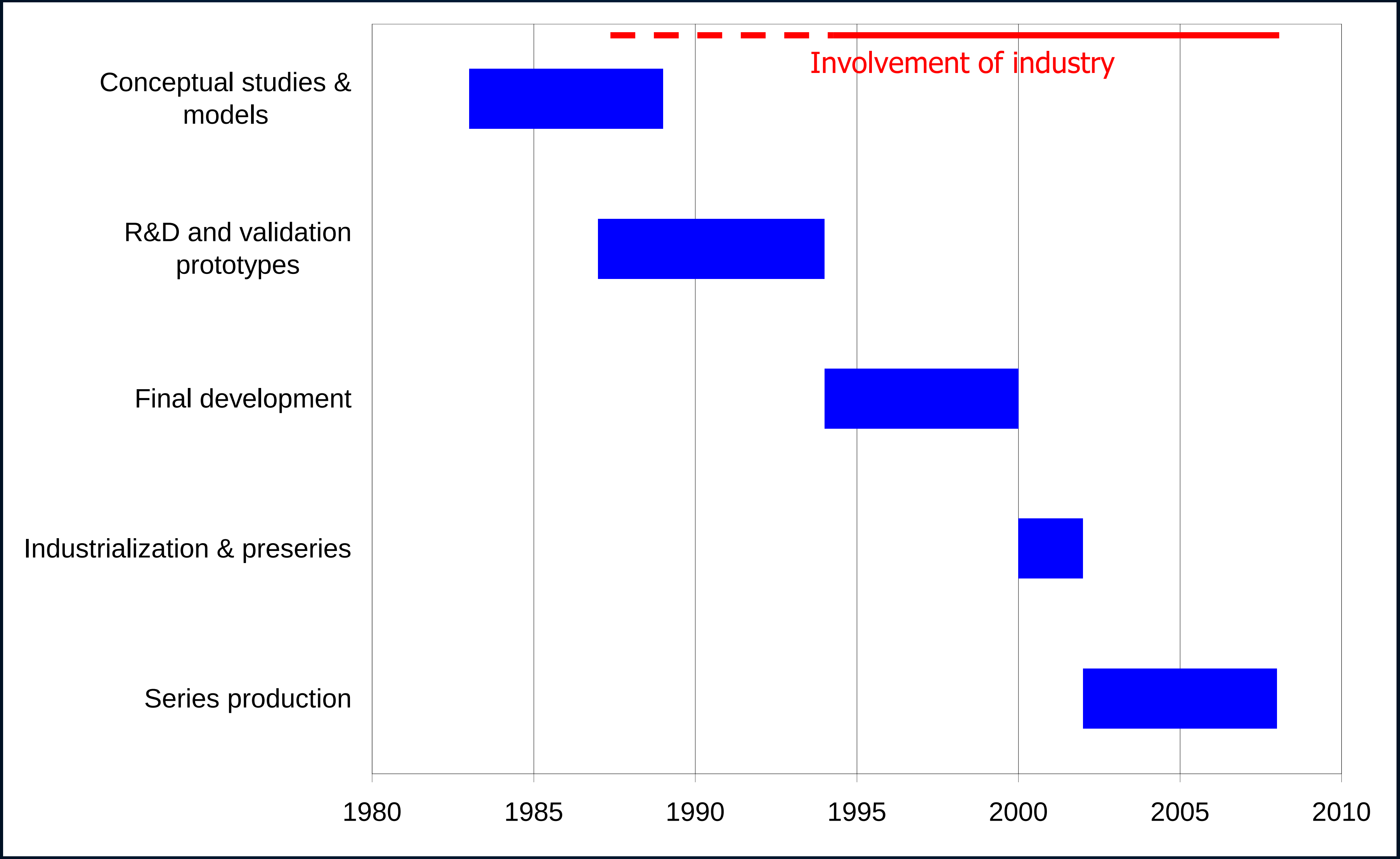


Superconductivity for energy efficiency

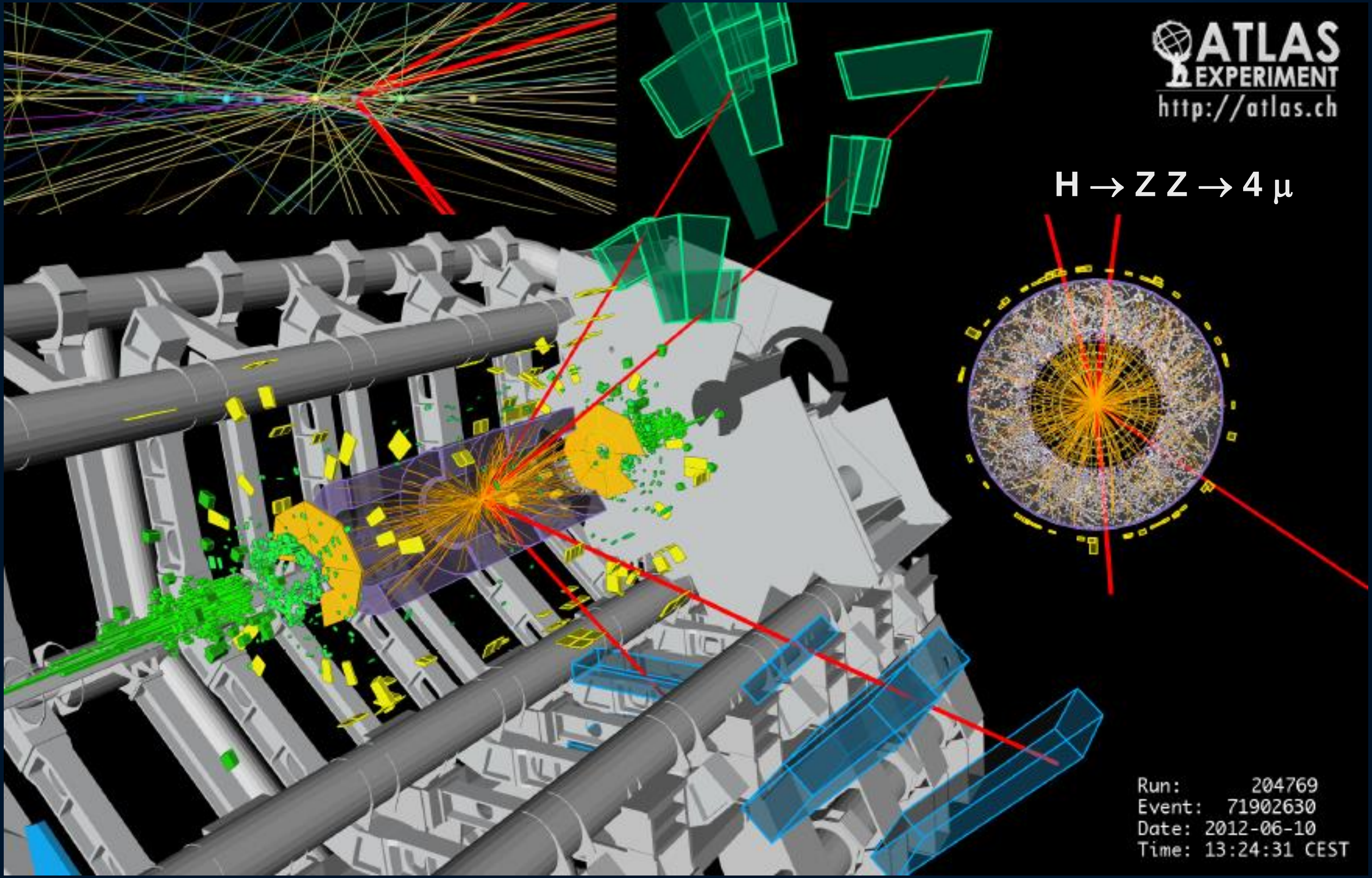


LHC major industrial production contracts

Time span of LHC project



Disintegration of Higgs boson produced in proton collisions at the LHC



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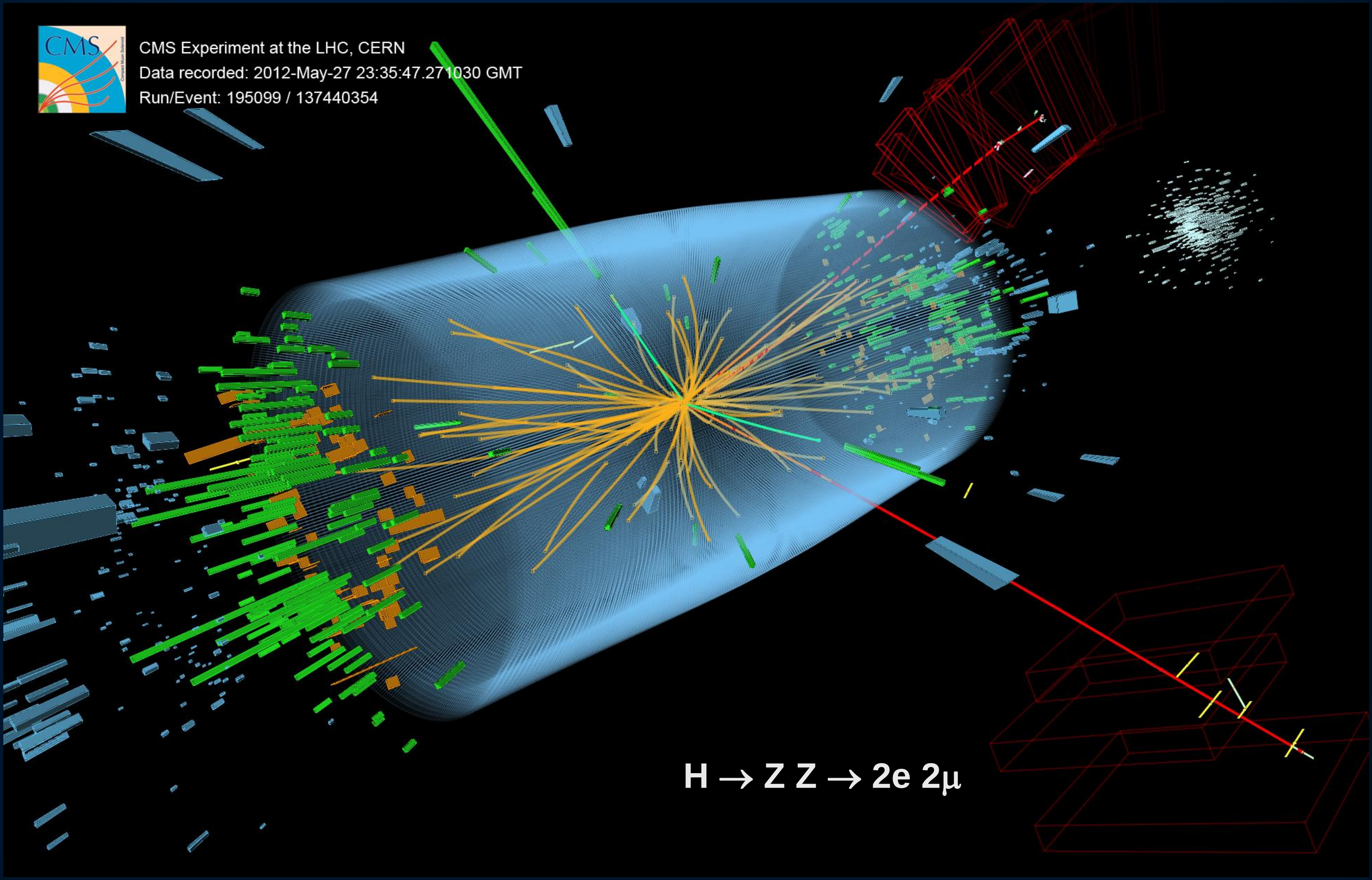
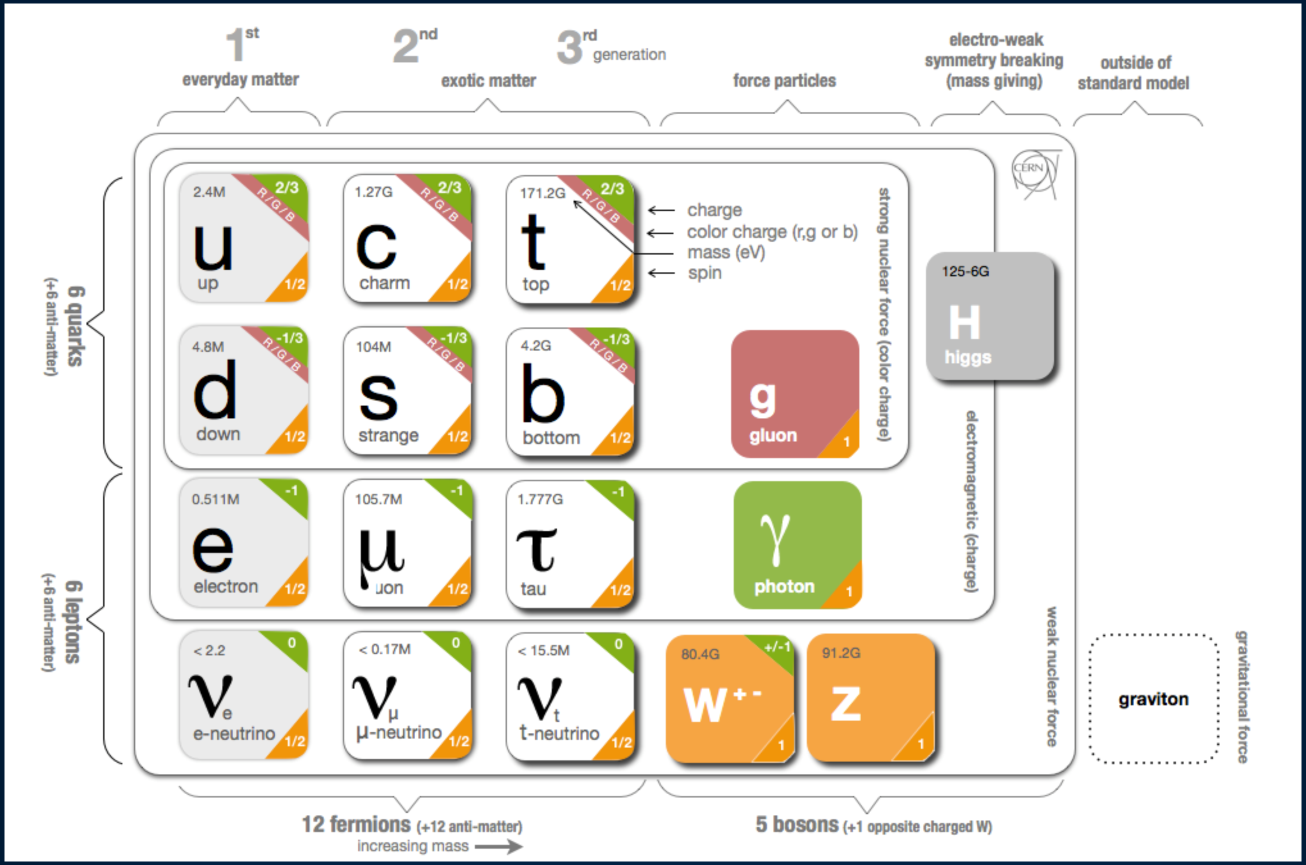


Discovery 2012, Nobel Prize in Physics 2013

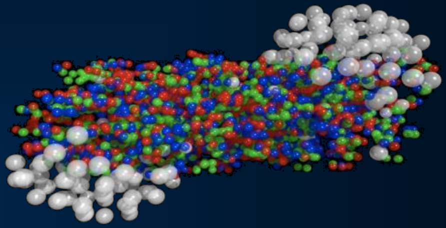
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".*

The Higgs boson completes the Standard Model …but does not answer all questions!

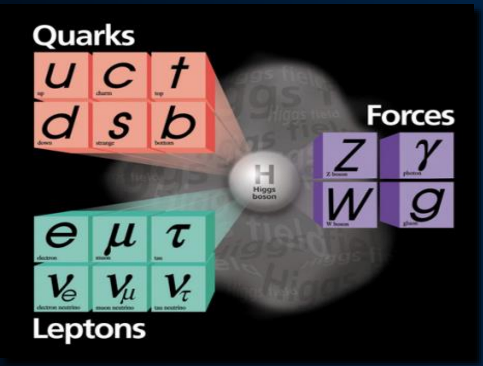


- Does this description of nature remain valid at energies >> 1 TeV?
- How should it be modified to account for unexplained phenomena (matter-antimatter asymmetry, «dark» matter in the universe, cosmological inflation, quantum gravity)?

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?



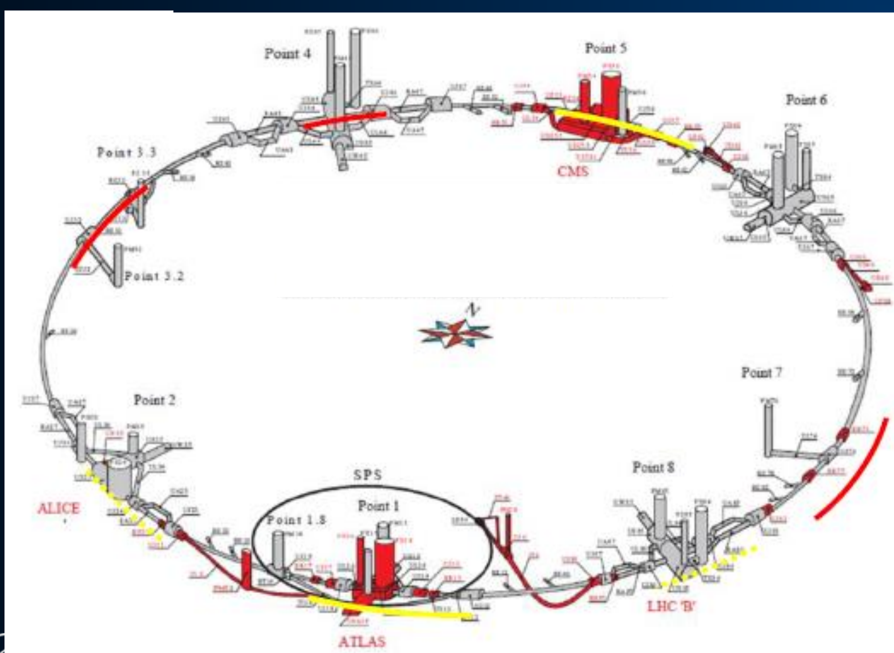
Have we found “THE” Higgs particle that is responsible for giving mass to all elementary particles?

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

- Determine a **hardware configuration** and a set of **beam parameters** that will allow the LHC to reach the following targets:
  - enable a total integrated luminosity of 3000 fb^{-1}
  - enable an integrated luminosity of 250-300 fb^{-1} per year
  - design for $\mu \sim 140$ (~ 200) (peak luminosity of 5 (7) 10^{34} cm^{-2} s^{-1})
  - design equipment for ‘ultimate’ performance of 7.5 10^{34} cm^{-2} s^{-1} and 4000 fb^{-1}



Major intervention on 1.2 km of LHC ring

- New IR-quads using Nb_3Sn superconductor
- New 11 T Nb_3Sn (short) dipoles
- Collimation upgrade
- Cryogenics upgrade
- Crab Cavities
- Cold powering
- Machine protection

Paths to high luminosity

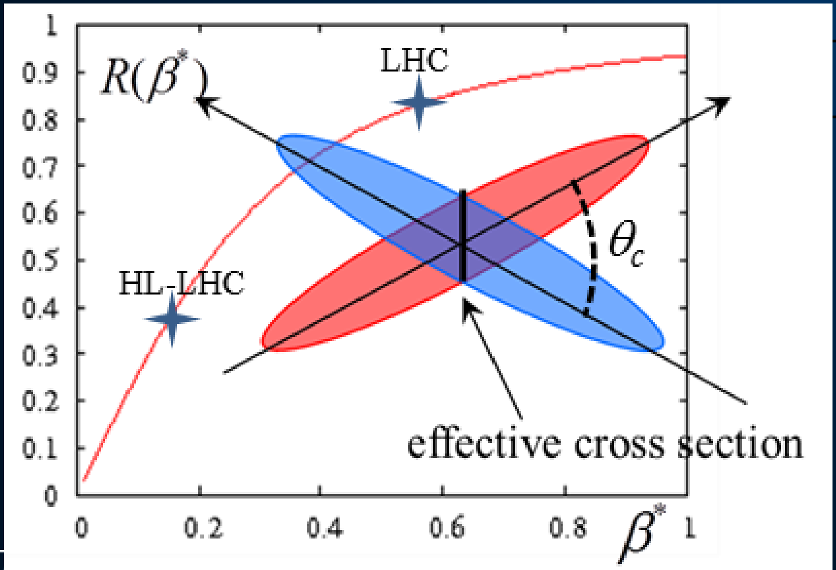
Increase bunch population

Increase R = reduce crossing angle?

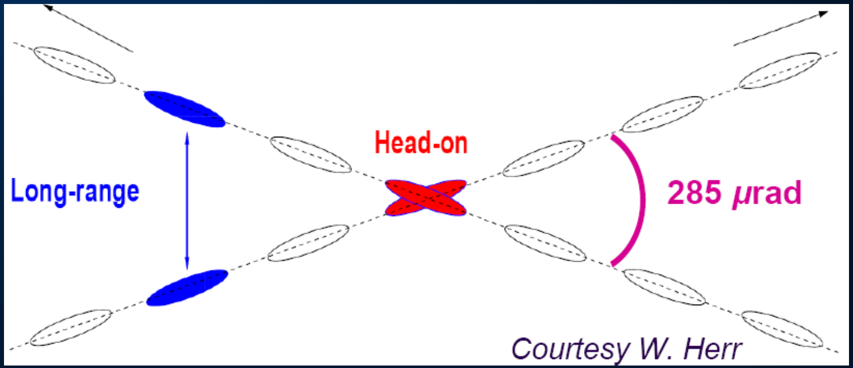
$$L = \gamma \frac{n_b N^2 f_{rev}}{4\pi\, \beta^*\, \varepsilon_n} R; \qquad R = 1 \Big/ \sqrt{1 + \frac{\theta_c\, \sigma_z}{2\sigma}}$$

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

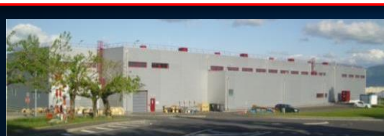
Reduce beta at collision

Reduce crossing angle

Accelerator physics

Increase intensity & brightness of injectors: the LIU project

Limit beam-beam effect

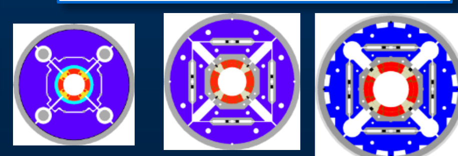


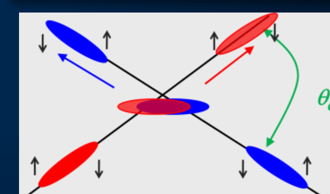
More powerful cryogenics
Improved collimation
Improved machine protection
Stronger R to E → relocation

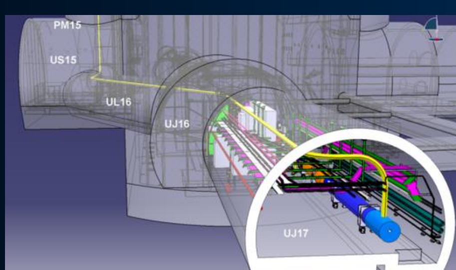
New low-beta quadrupoles

"Crab" cavities

Accelerator technology







The HL-LHC collaboration

CERN

Particle Physics and Innovation

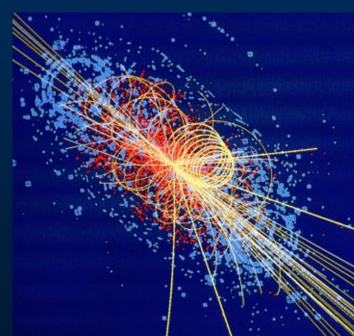
Innovation Education CERN uniting people Research

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



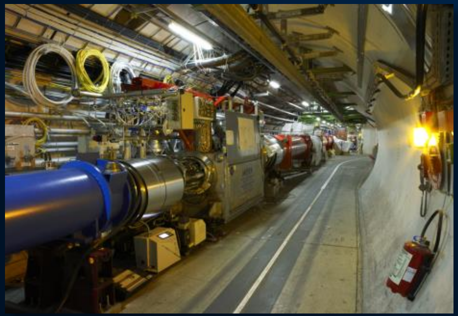
Detecting particles

Large-scale computing (Grid)

CERN

Medical Application as an Example of Particle Physics Spin-off

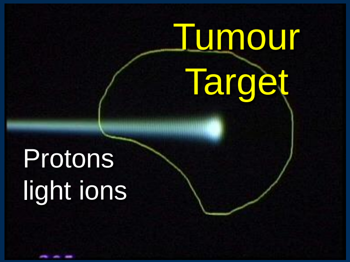
Combining Physics, ICT, Biology and Medicine to fight cancer

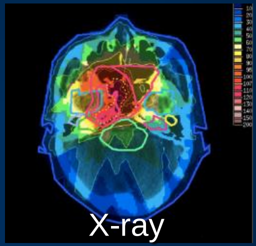


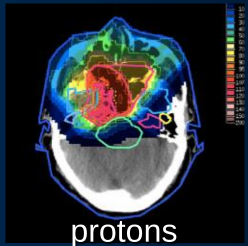
Accelerating particle beams

~30’000 accelerators worldwide
~17’000 used for medicine

Hadron Therapy

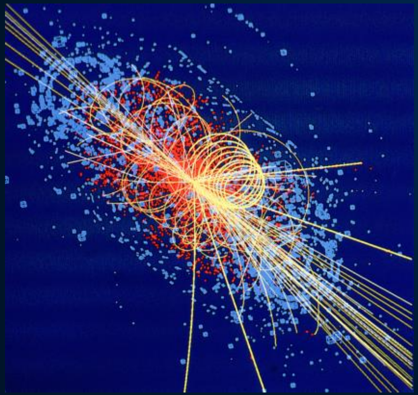






Leadership in Ion Beam Therapy now in Europe and Japan

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

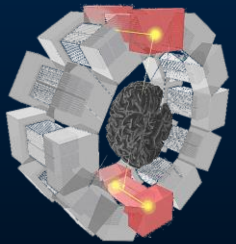


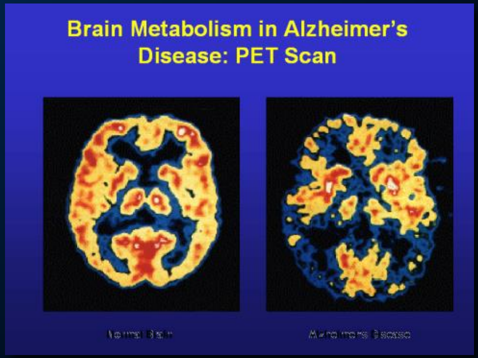
Detecting particles

Imaging

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

PET Scanner



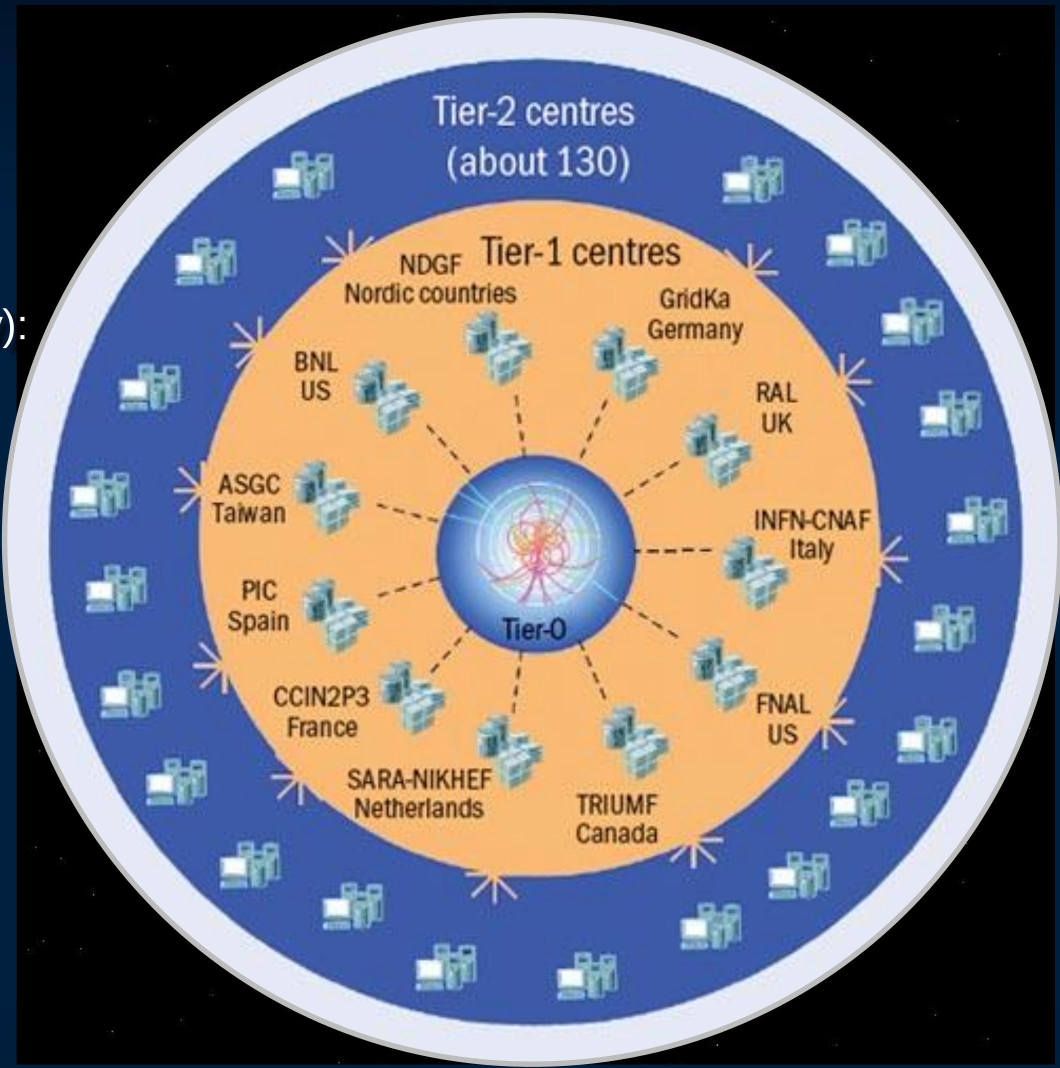


The Worldwide LHC Computing Grid

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

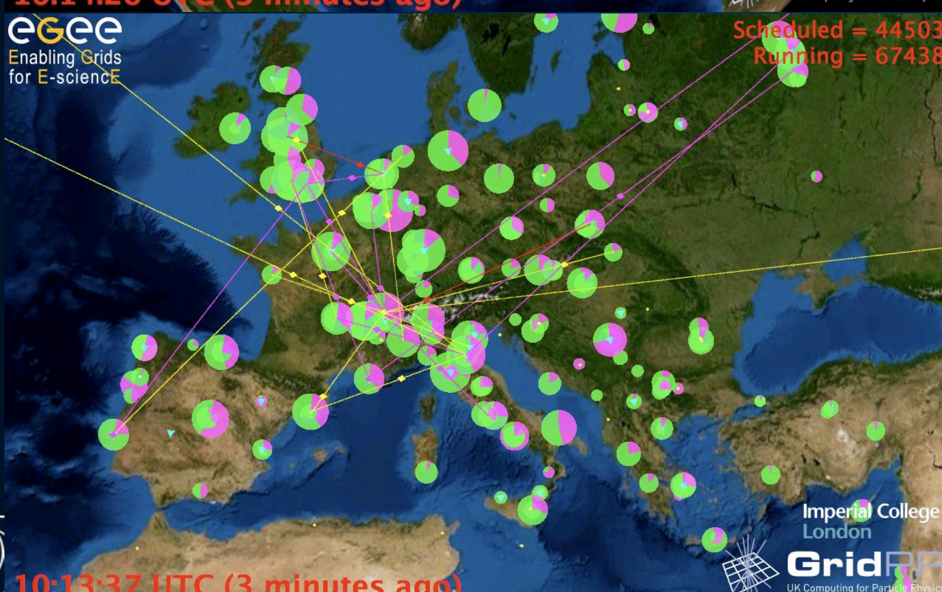
10 Gb links

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

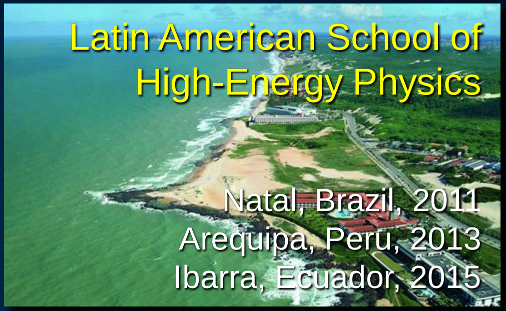
Computing grids beyond particle physics



- 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

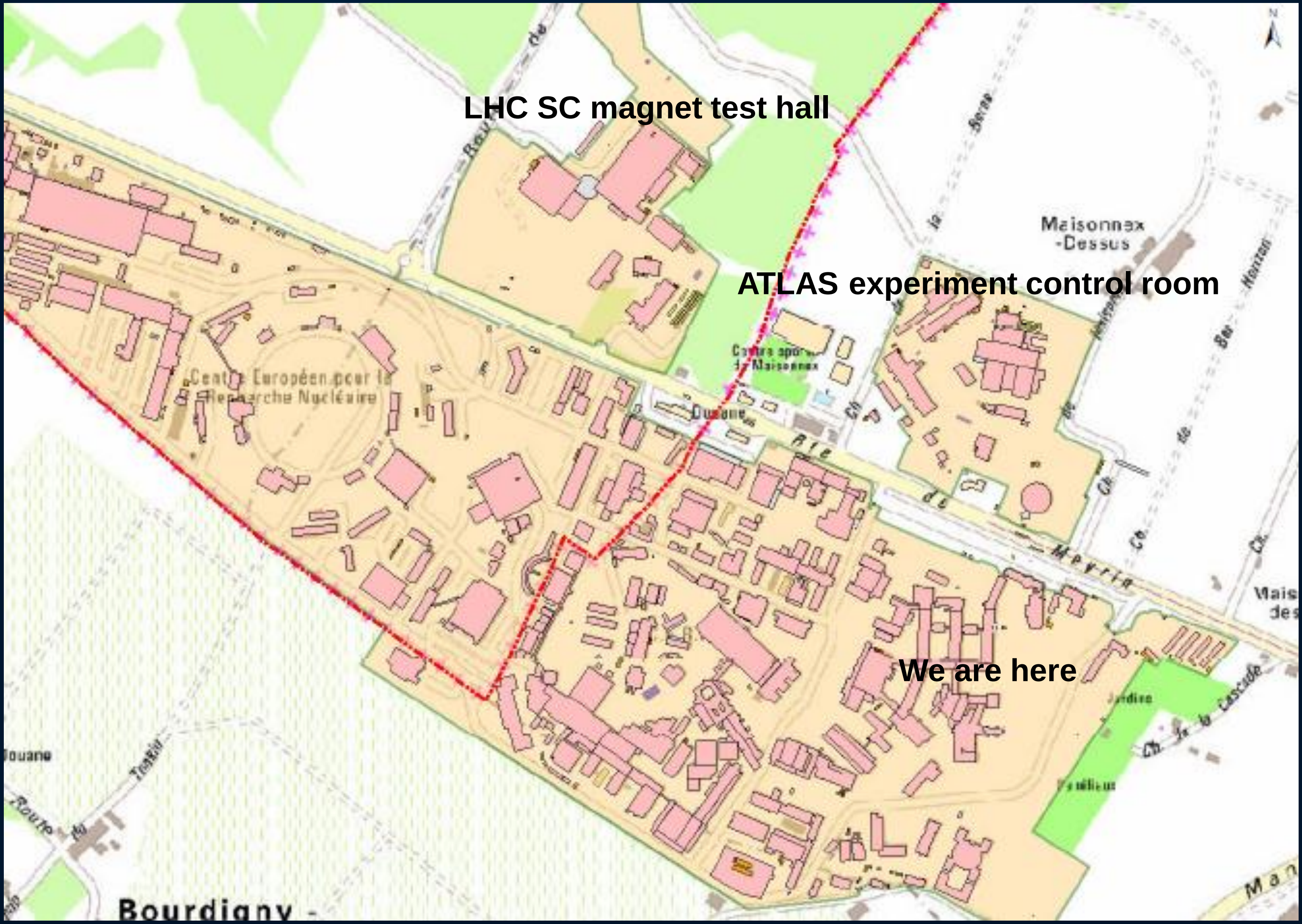
CERN Teacher Schools
International and National
Programmes

What we will see today
Focus on the LHC accelerator

- LHC magnet test hall
  - Superconducting wires and cables
  - Main superconducting magnets
  - HTS current feedthroughs
  - Magnet measurements
  - Cryostat assemblies

- ATLAS experiment control room
  - Collider experiment analysis

What we will see today
Focus on the LHC accelerator



LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SUISSE
FRANCE
SPS 7 km
ALICE
CMS
Questions?
LHC 27 km
CERN
Accelerating Science and Innovation