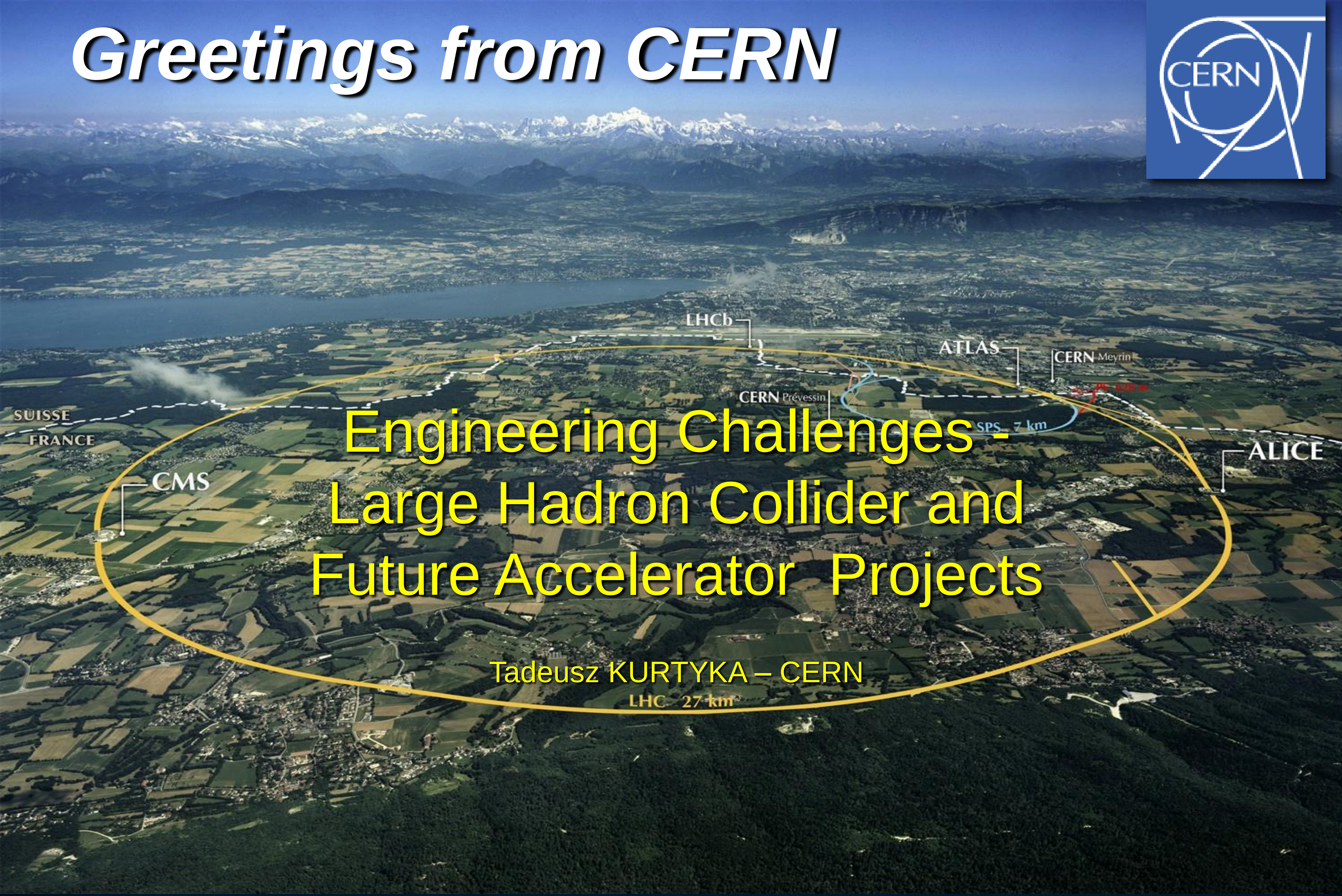
Second International Workshop on recent LHC results and related topics
Tirana, 26-27 September 2016

Tadeusz KURTYKA – CERN

Greetings from CERN



Engineering Challenges - Large Hadron Collider and Future Accelerator Projects

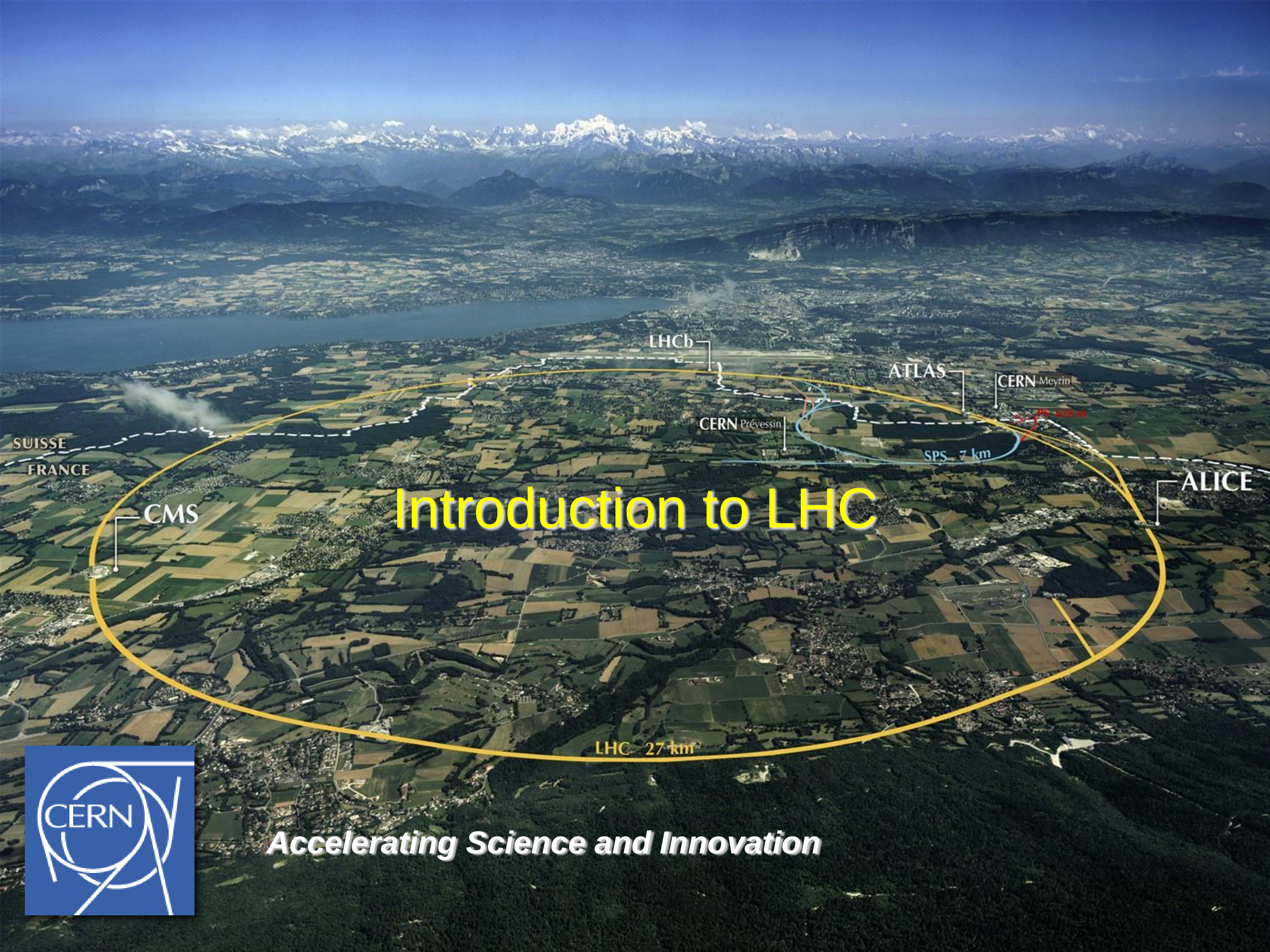
Tadeusz KURTYKA – CERN

Outline of the presentation

LHC Machine;
Why the LHC has been so challenging to construct;
CERN Accelerator Complex;
LHC and what further?
Directions of the R&D work;

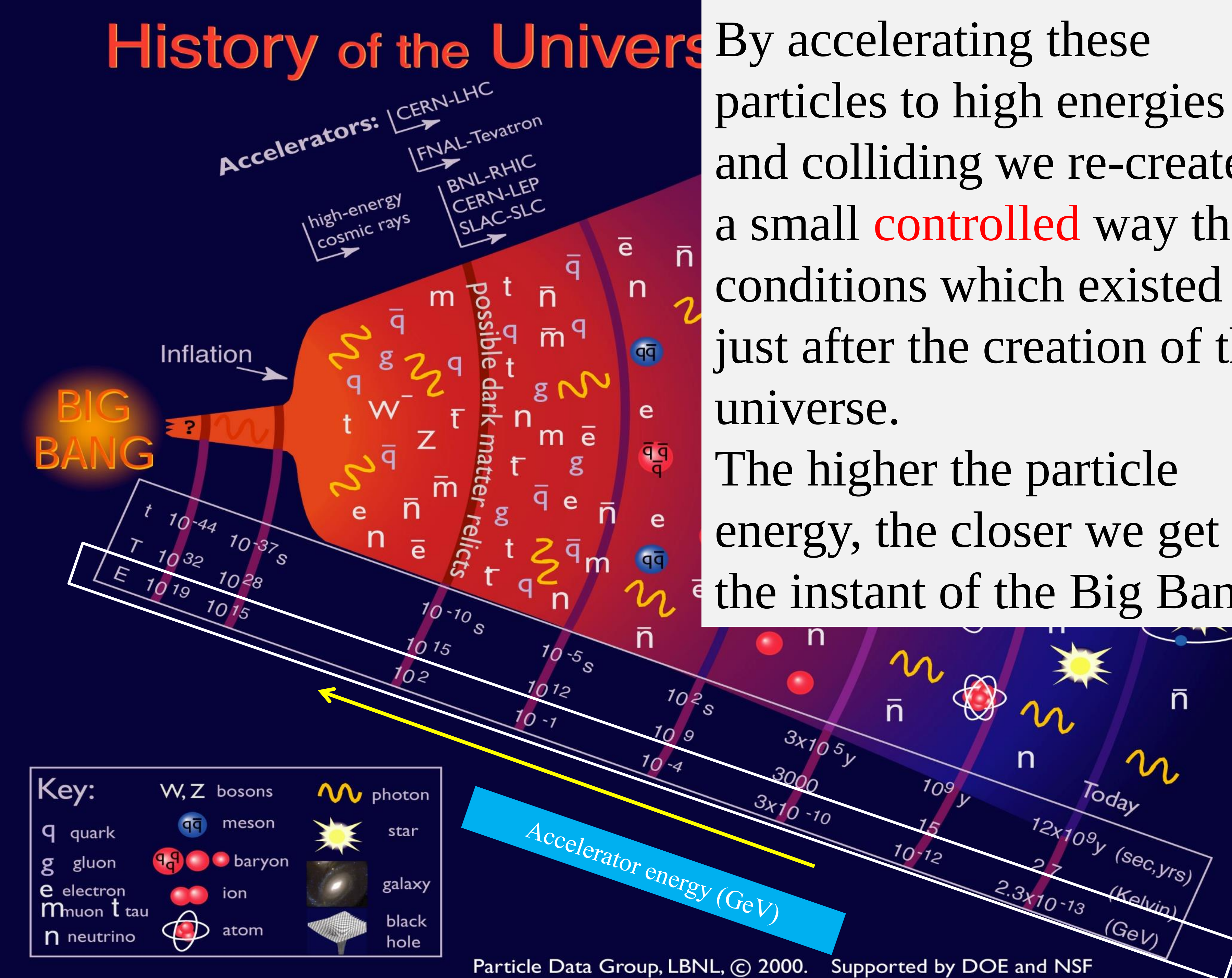
Important aspects:
International Collaboration
Interdisciplinary Research

Introduction to LHC



CERN

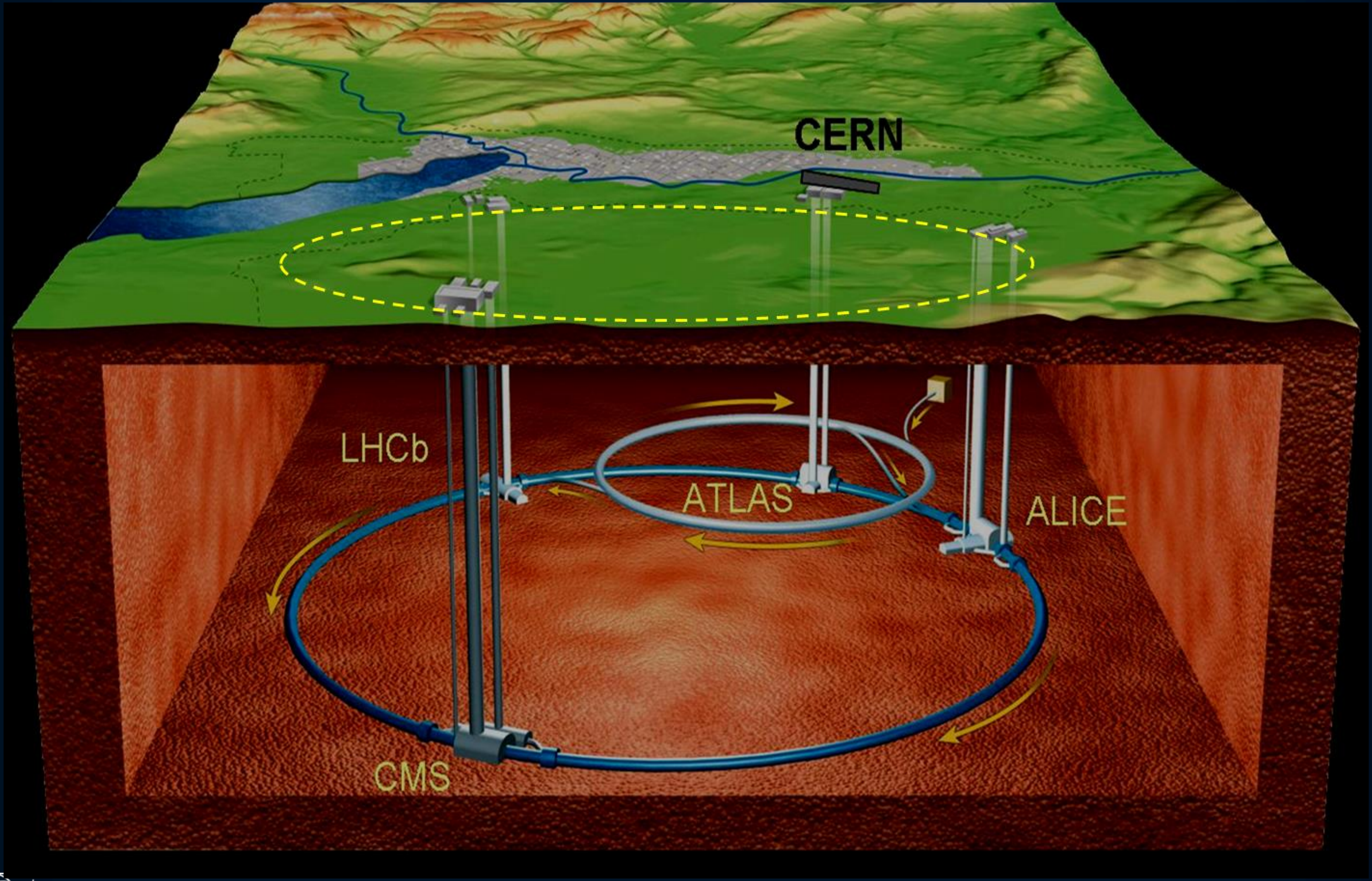
Accelerating Science and Innovation



By accelerating these particles to high energies and colliding we re-create in a small controlled way the conditions which existed just after the creation of the universe.

The higher the particle energy, the closer we get to the instant of the Big Bang

LHC – Large Hadron Collider



LHC - Large Hadron Collider

7 TeV + 7 TeV

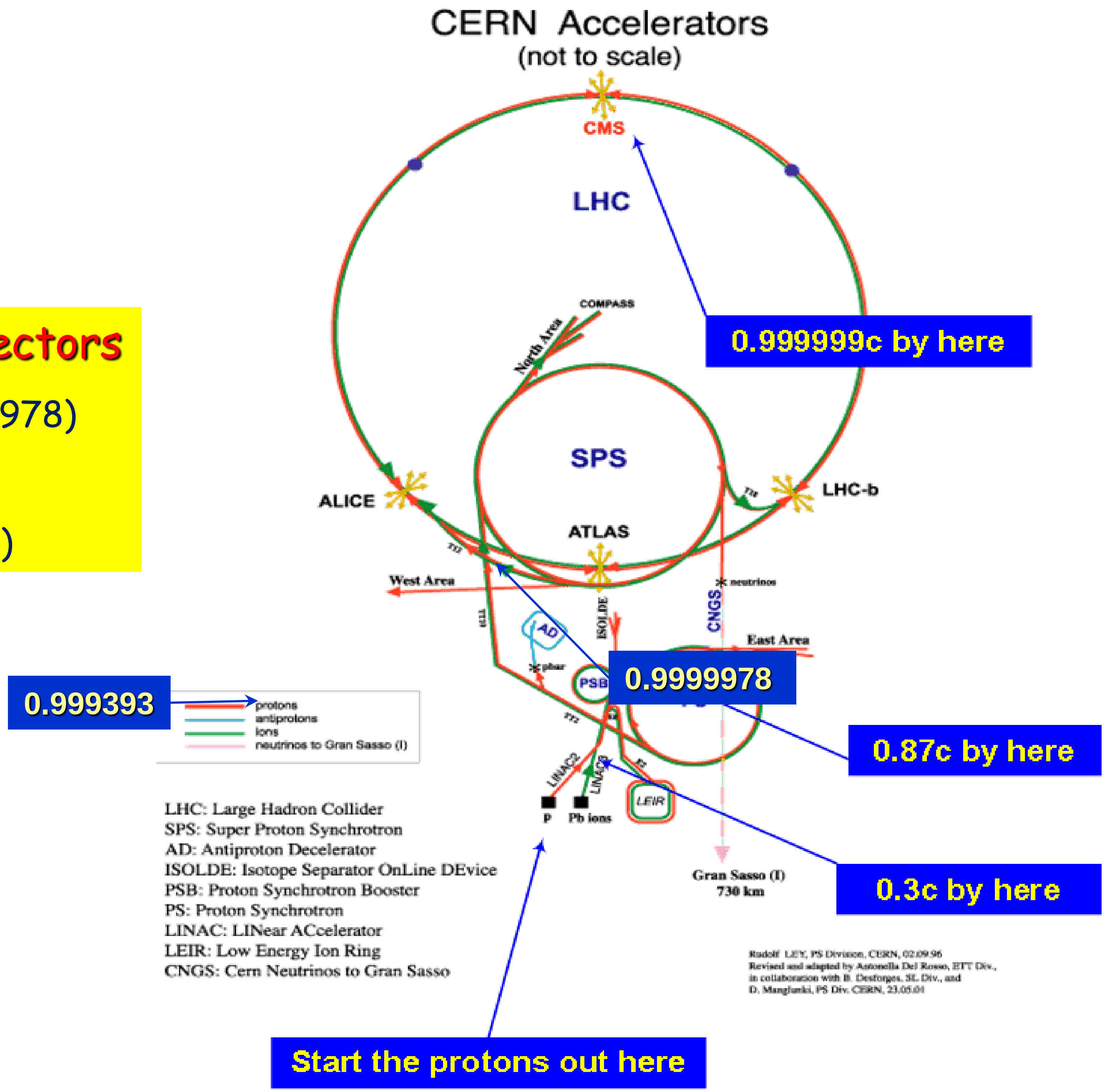
Luminosity = $10^{34} cm^{-2} sec^{-1}$

Primary targets:
- Origin of mass
- Nature of Dark Matter
- Primordial Plasma
- Matter vs Antimatter

The LHC results will determine the future course of High Energy Physics

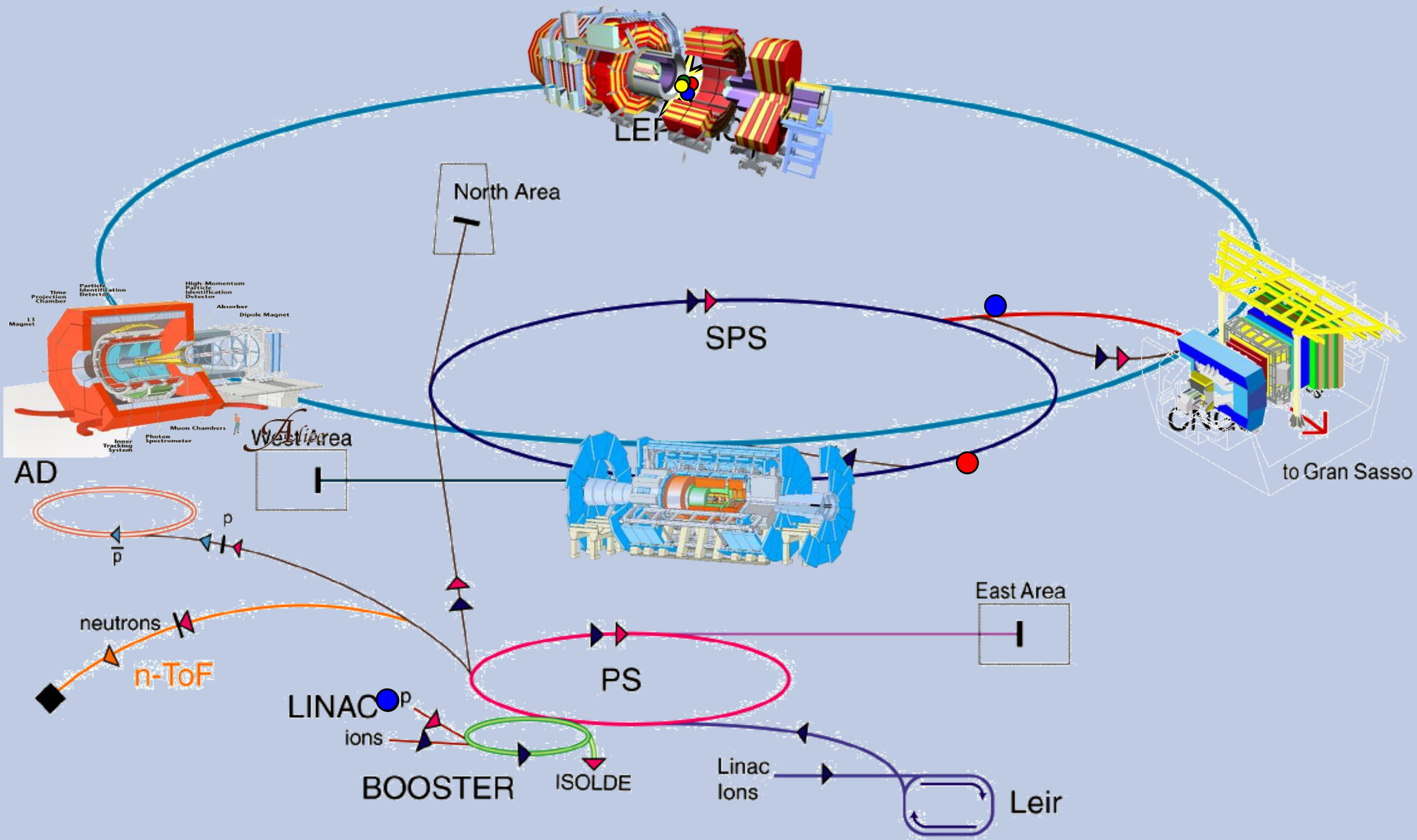
Present LHC Injectors

- -Linac2 (p, 50 MeV, 1978)
- -PSB (1.4 GeV, 1972)
- -PS (28 GeV, 1959)
- -SPS (450 GeV, 1976)



The large Hadron Collider

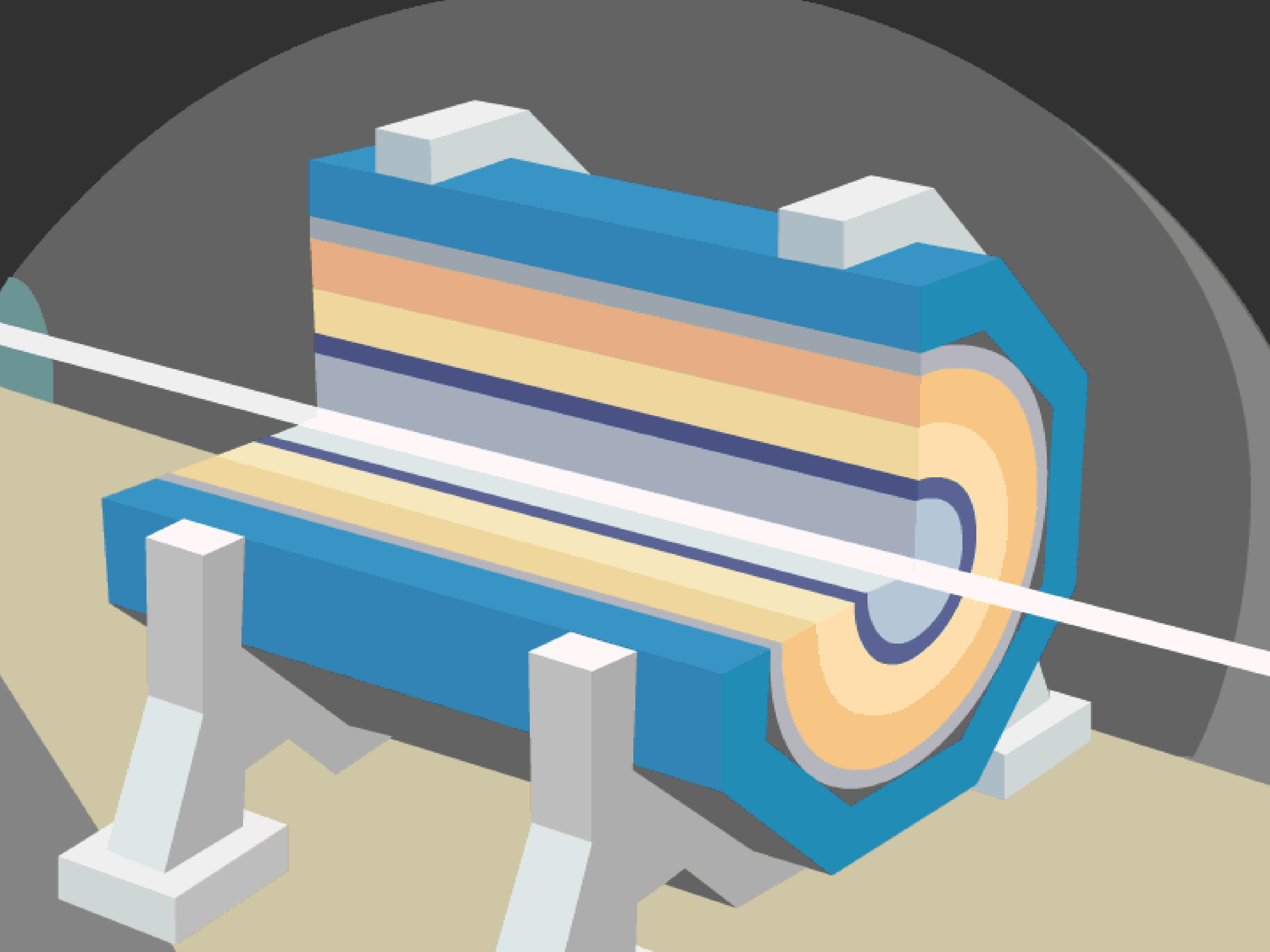
Collision of proton beams… …observed in giant detectors



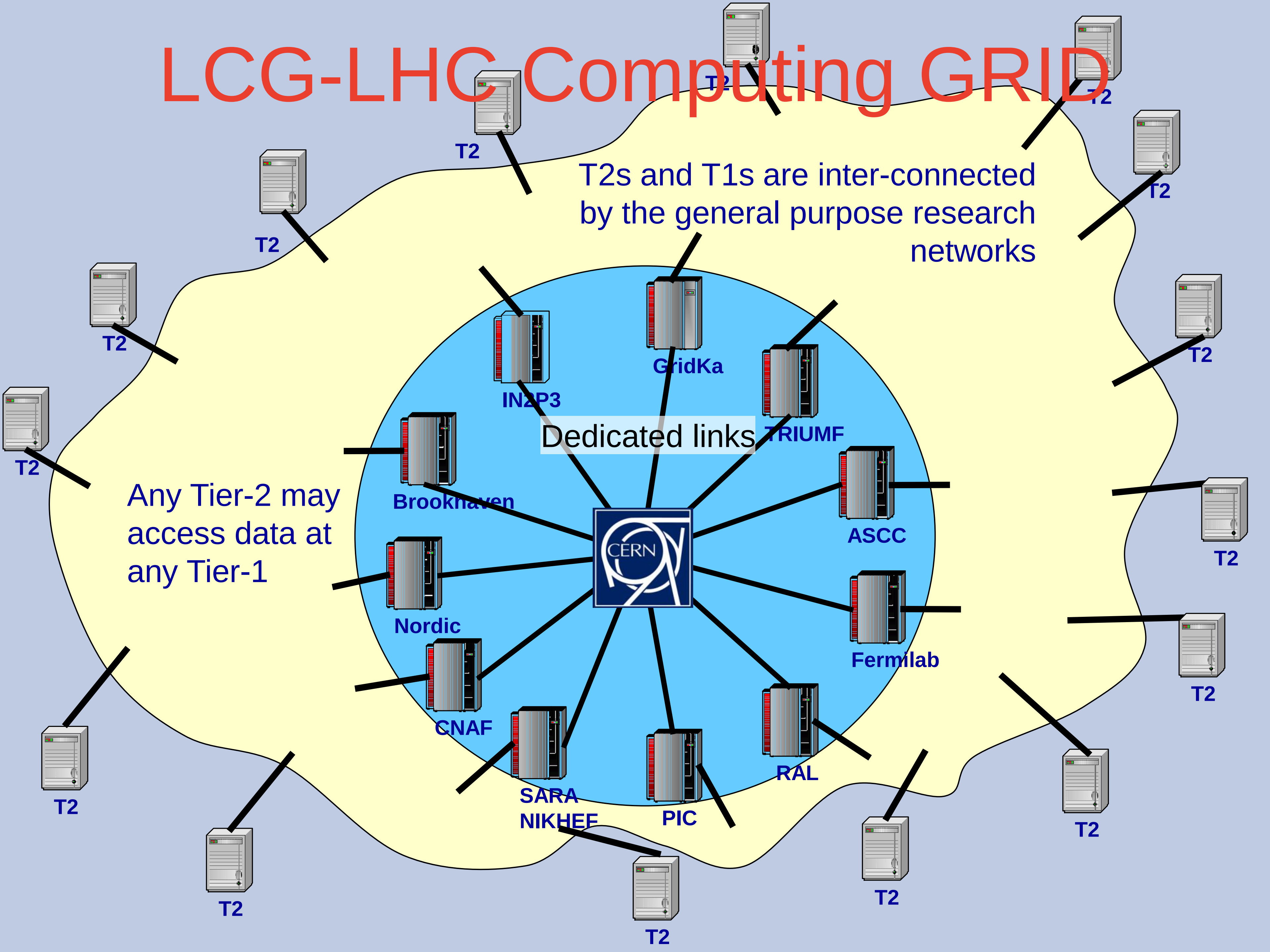
p (proton)
ion
neutron
p̄ (antiproton)
proton/antiproton conversion
neutrino

AD Antiproton Decelerator
PS Proton Synchrotron
SPS Super Proton Synchrotron

LHC Large Hadron Collider
n-ToF Neutron Time of Flight
CNGS Cern Neutrinos Gran Sasso



LCG-LHC Computing GRID



Three main challenges of the LHC Project

LHC Accelerator: Construct a 2x7 TeV proton collider using existing tunnel of 27 km circumference (tunnel diameter 3.8 m). Solution: Innovative design of superconducting magnets bending the beam to the tunnel radius, and cooled with superfluid helium.

LHC Detectors: Construct detectors with unprecedented granularity, dimensions and rapidity of registration. Solution: Innovative detector types, new materials, giant superconducting magnets, fast electronics for events registration….**See other lectures**

Data analysis: Develop a new computing system to handle an analyze enormous amount of data. . Solution: LCG – LHC Computing GRID – distributed computing concept.

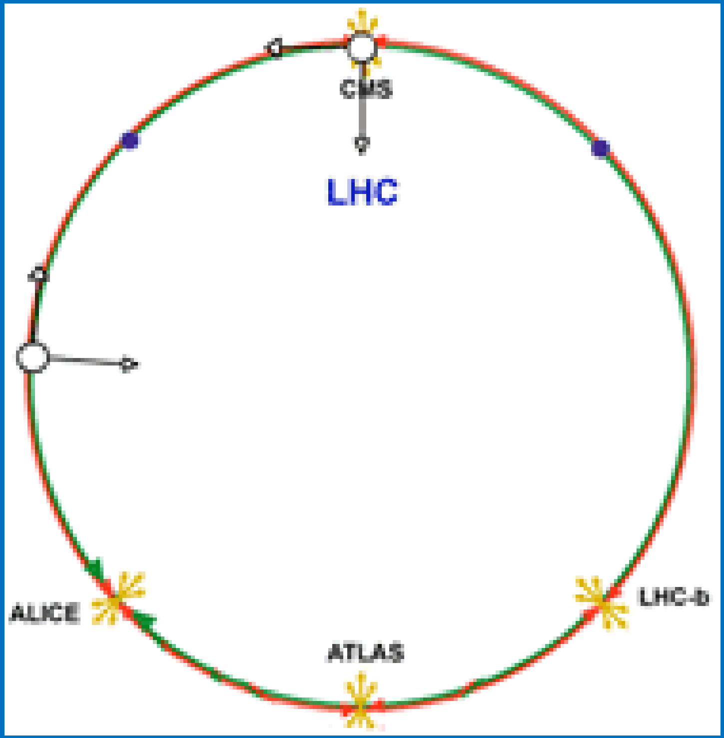
ALL THE THREE REQUIRED GLOBAL COLLABORATION !

LHC Magnets or how to keep particles on a circular path? What magnetic field is needed ?

Lorenz force=centripetal force

$$F = qvB = \frac{mv^2}{\rho}$$

$$B\rho = \frac{p}{q}$$



Bρ – magnetic rigidity, p-momentum

LHC Dipole Magnets

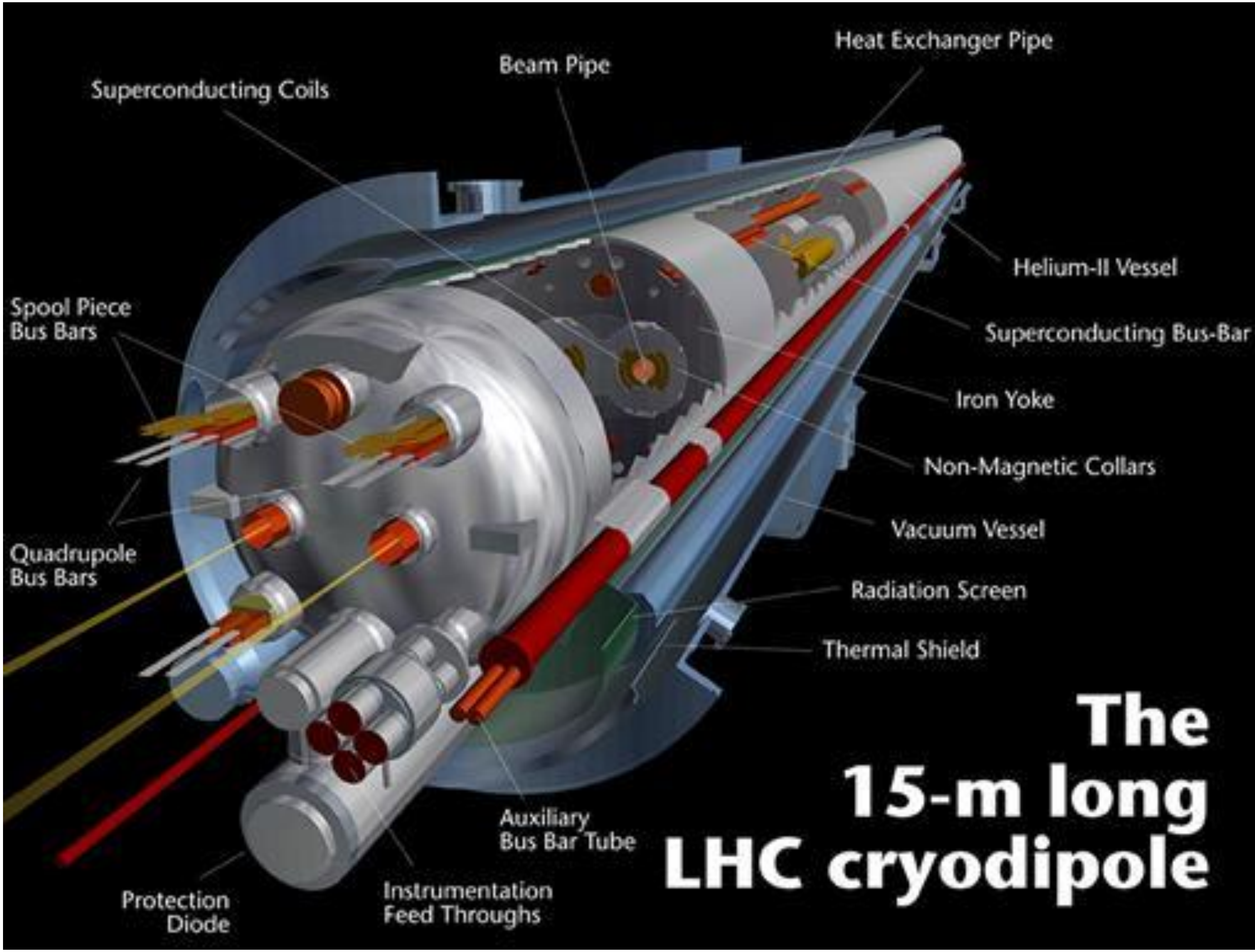
Dipole magnets are bending the trajectory of particles (keep them on circular trajectory)

For the proton beam energy E= 7 TeV

the dipole magnets of LHC must have

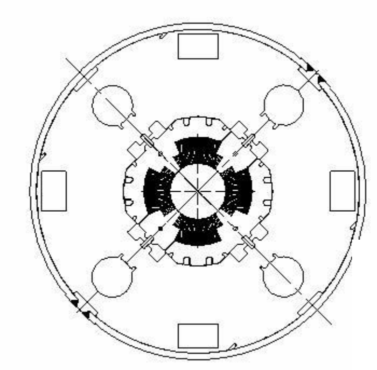
B = 8.3 T

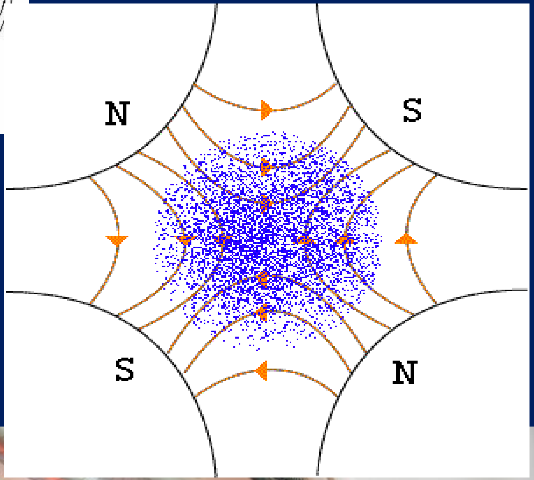
Solution: Superconducting magnets (NbTi superconductor) cooled by superfluid helium at T=1.9 K,

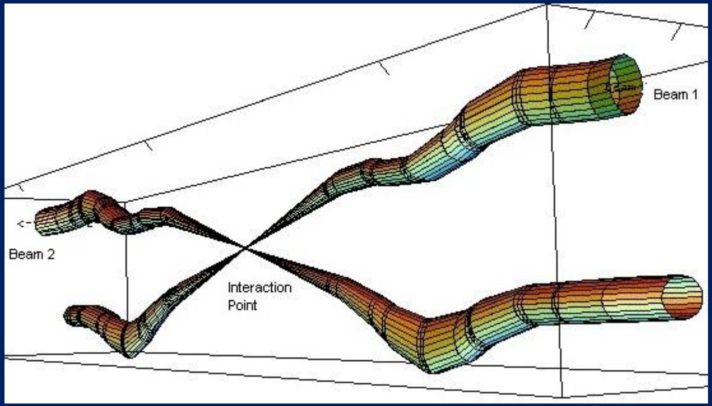

Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Vacuum Vessel
Quadrupole
Bus Bars
Radiation Screen
Thermal Shield
The
15-m long
LHC cryodipole
Auxiliary
Bus Bar Tube
Protection
Diode
Instrumentation
Feed Throughs

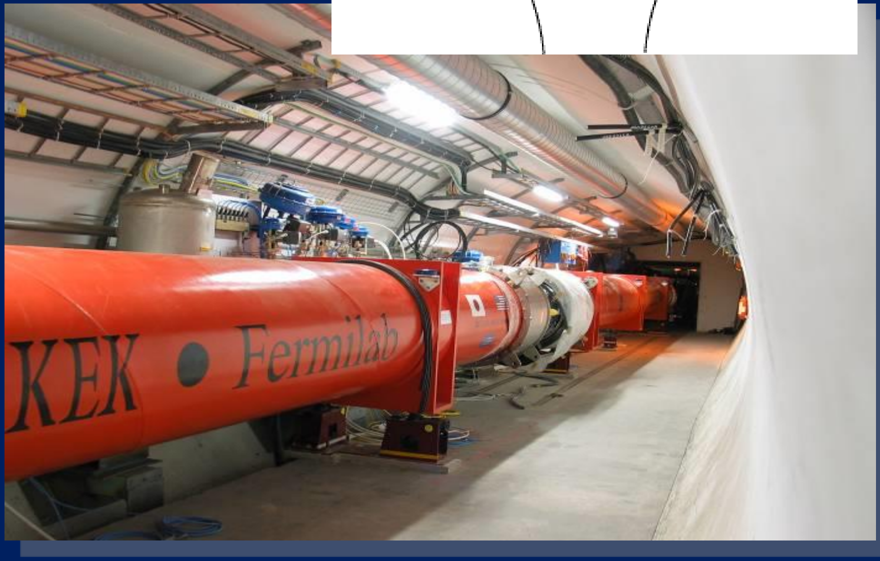
Beam focusing - LHC quadrupoles

- Superconducting
- Length about 3.5 m
- Many types
- Special type in the interaction points
- Other correctors: sextupoles, octupoles, decatupoles





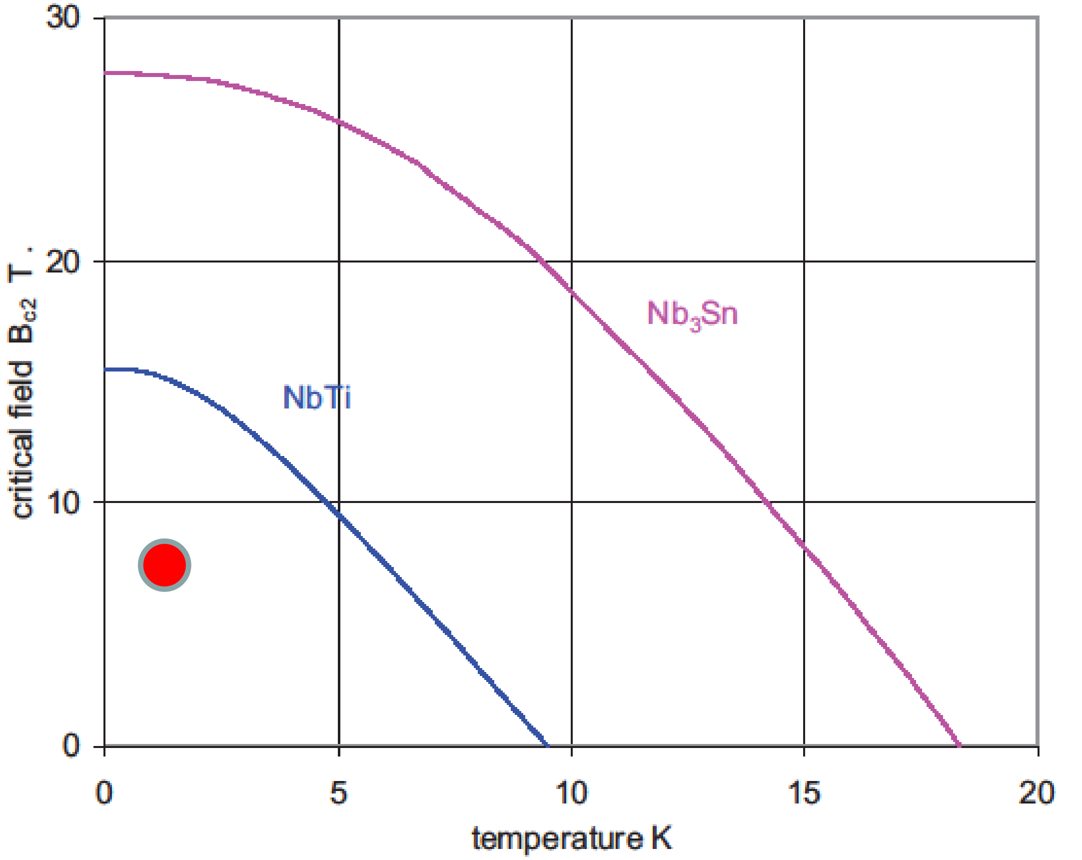




Production of LHC SC magnets (D,F,I, J, USA)

1232 superconducting dipoles of 14.3m length operated at 1.9 ºK giving a field of B = 8.3T , 500 quadrupoles with 215T/m, + SC corrector magnets

Critical field & temperature of metallic superconductors

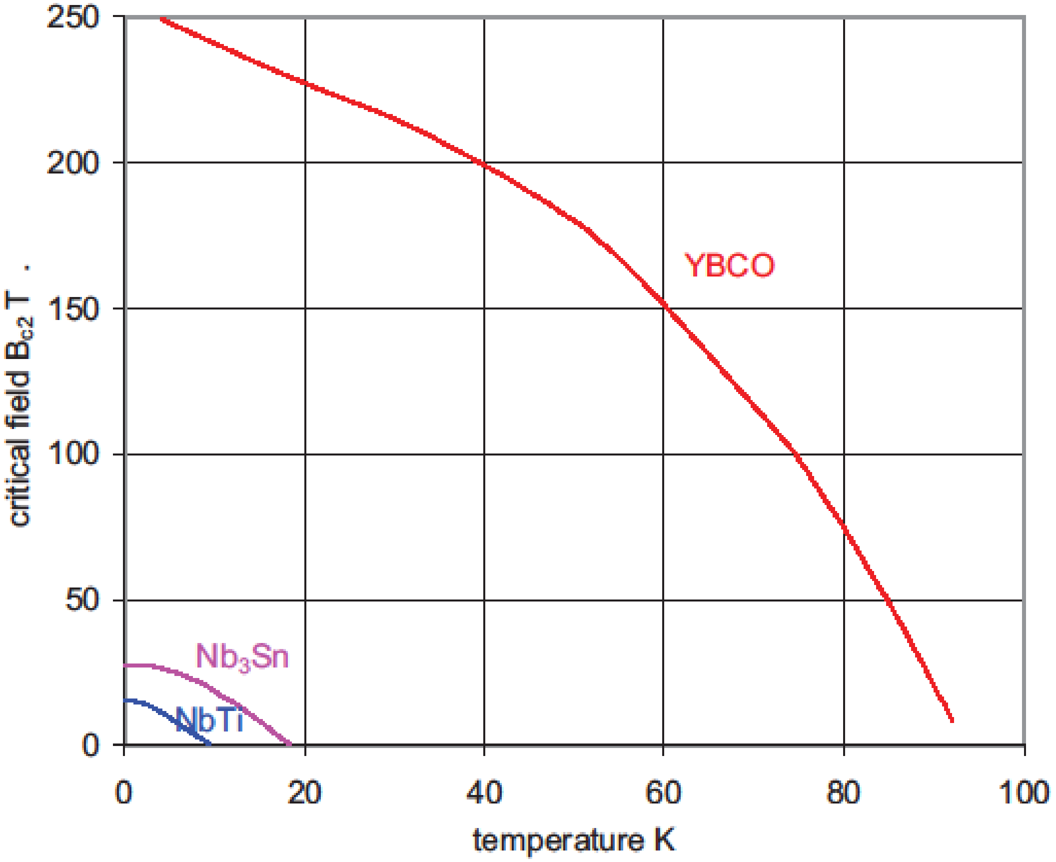


To date, all superconducting accelerators have used NbTi.

Of the intermetallics, only Nb_3Sn has found significant use in magnets

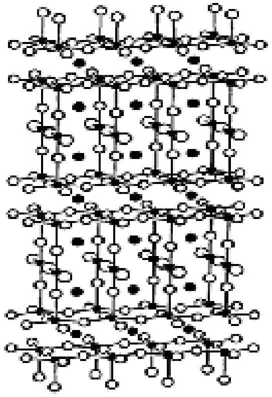
High temperature superconductors

1987 Bednortz and Muller



High critical temperature also brings high critical field

Yttrium Barium Copper Oxide $YBa_2Cu_3O_7$



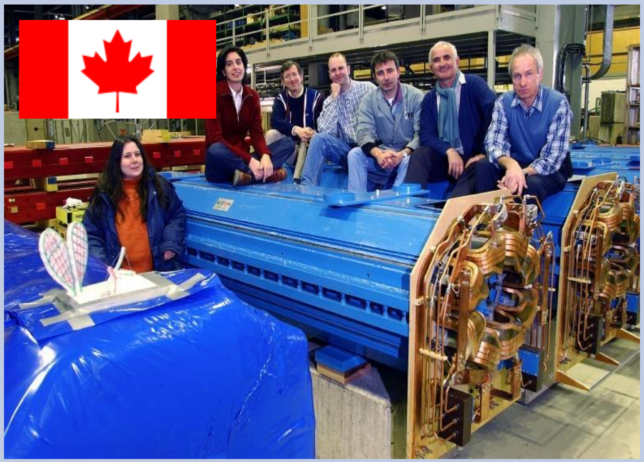
Participation of Non-Member States in CERN scientific programmes

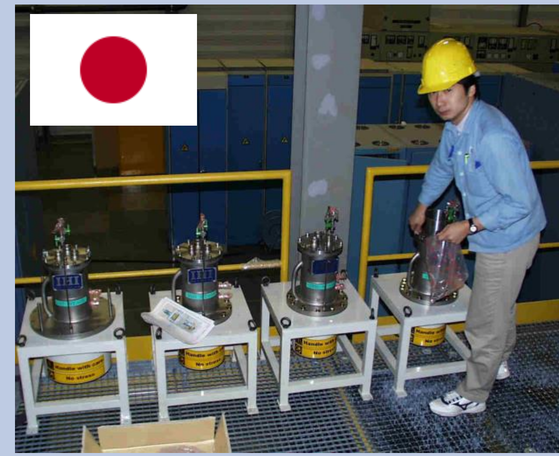
- CERN is financed by 21 Member States, with annual contributions proportional to the Net National Income (or GDP), but has scientific and educational links with nearly 100 countries!

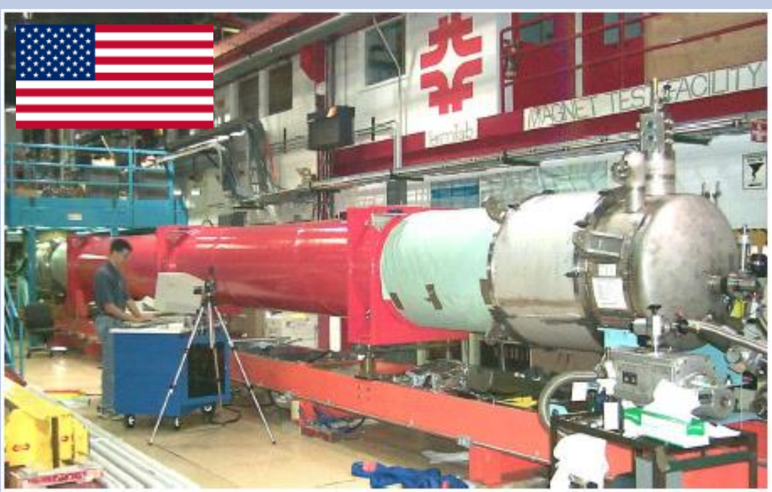
- Non-Member States participate in financing selected Projects

- Over 40 Non-Member States participated in the LHC construction, providing around 1/6 th of its cost and over 3000 of physicists and engineers (over 1/3 of the total);

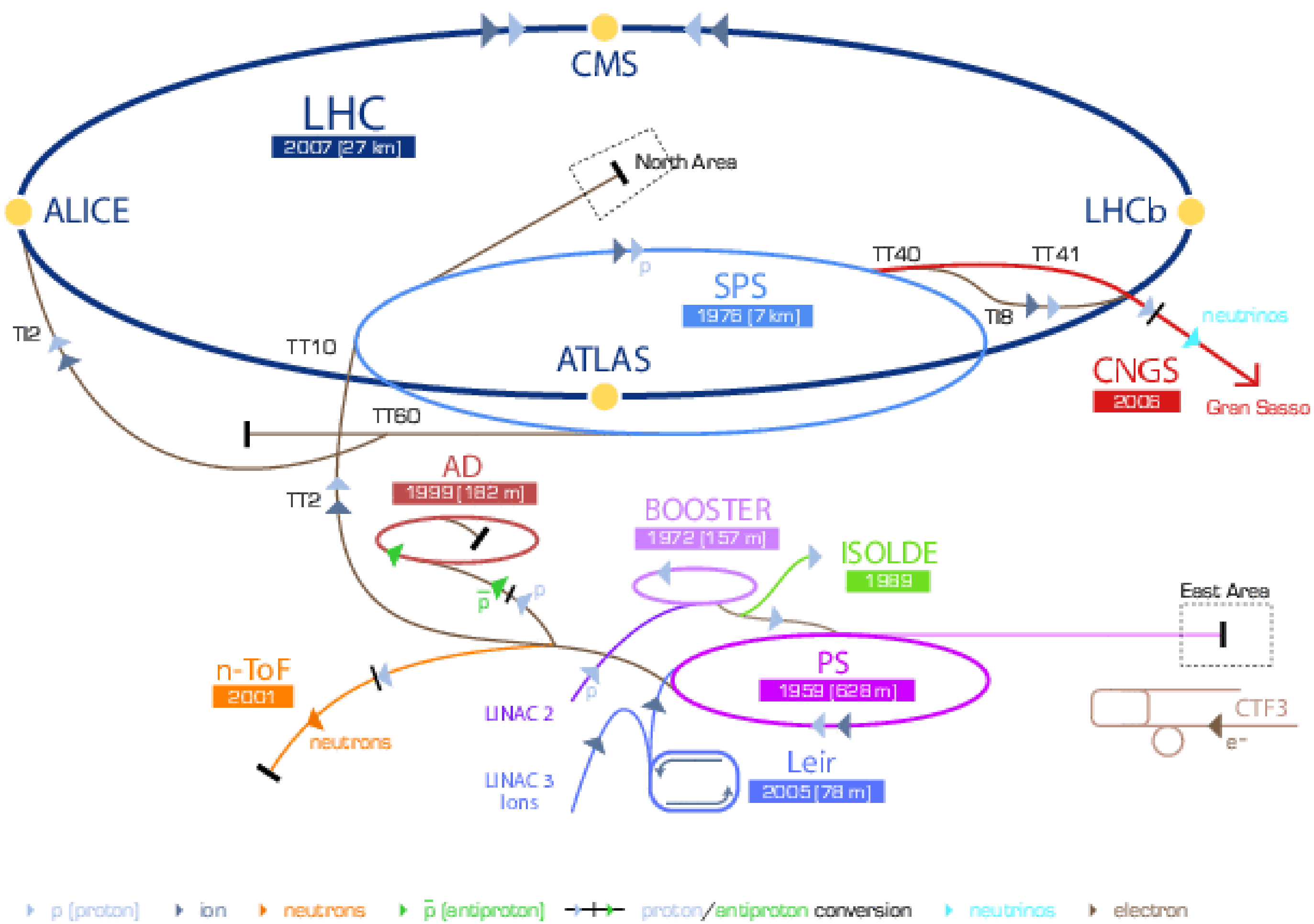
LHC Machine - Vital Contribution of Non-Member States: Canada, India, Japan, Russia, US



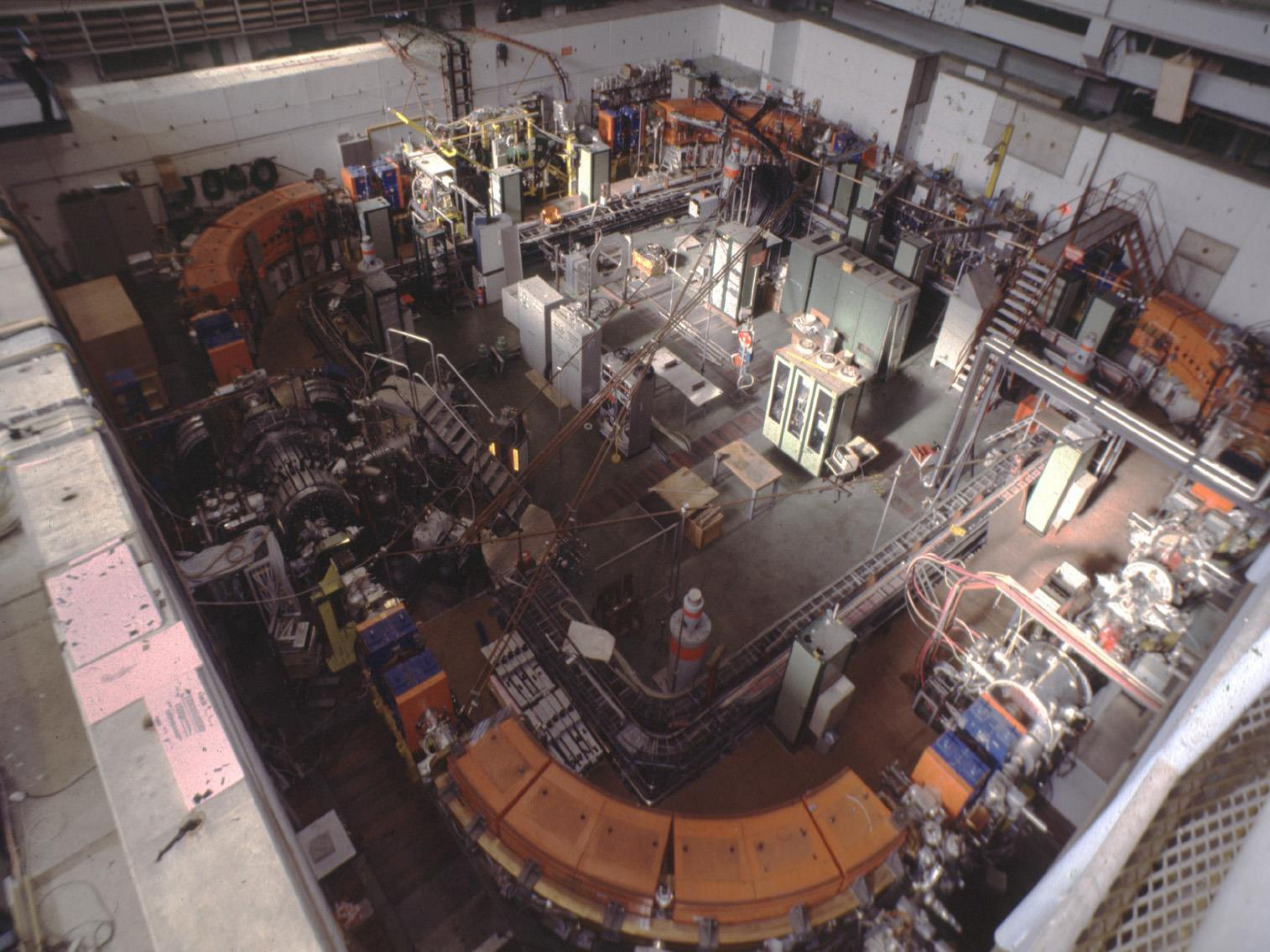


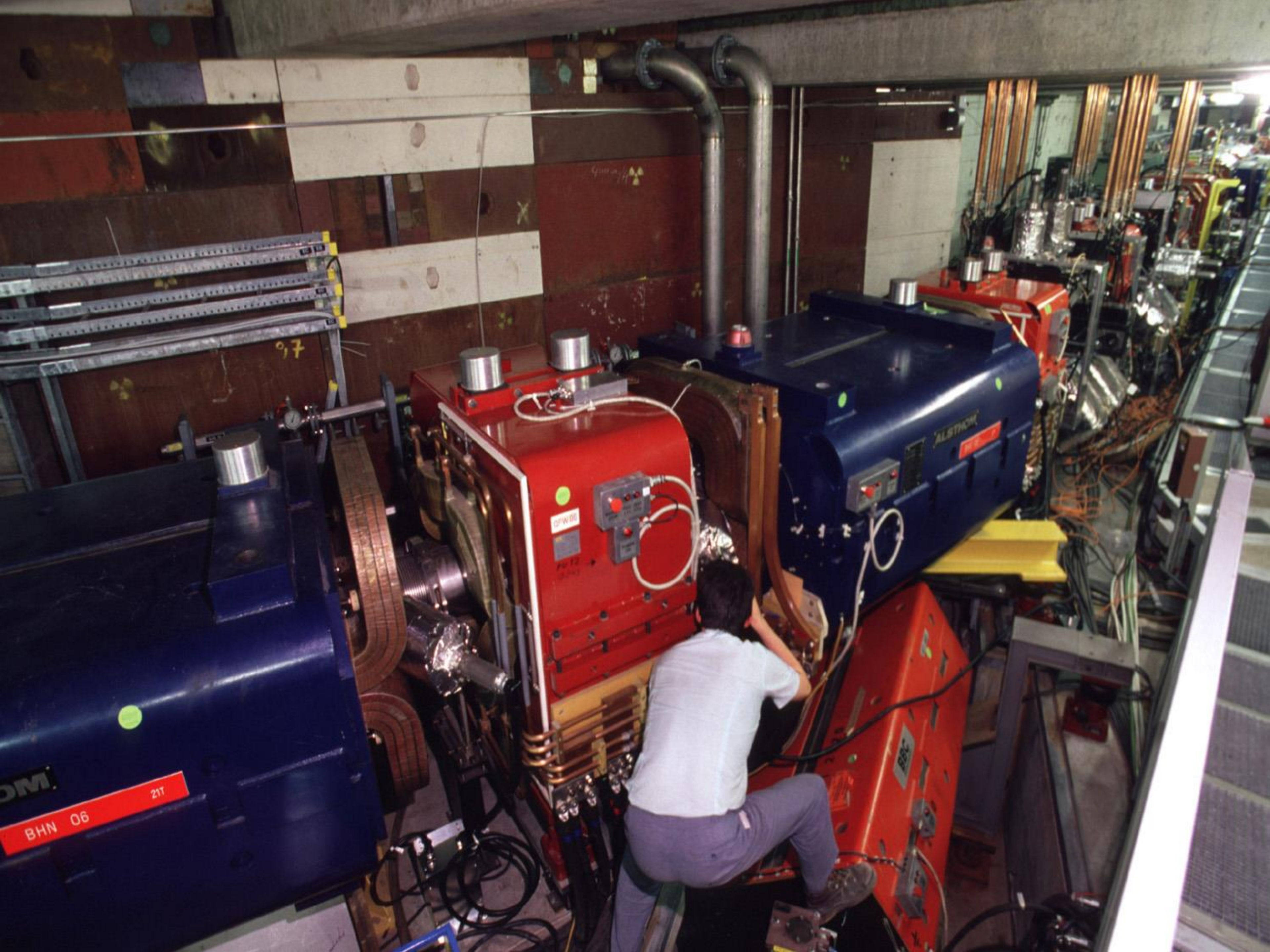


CERN – world biggest accelerator complex

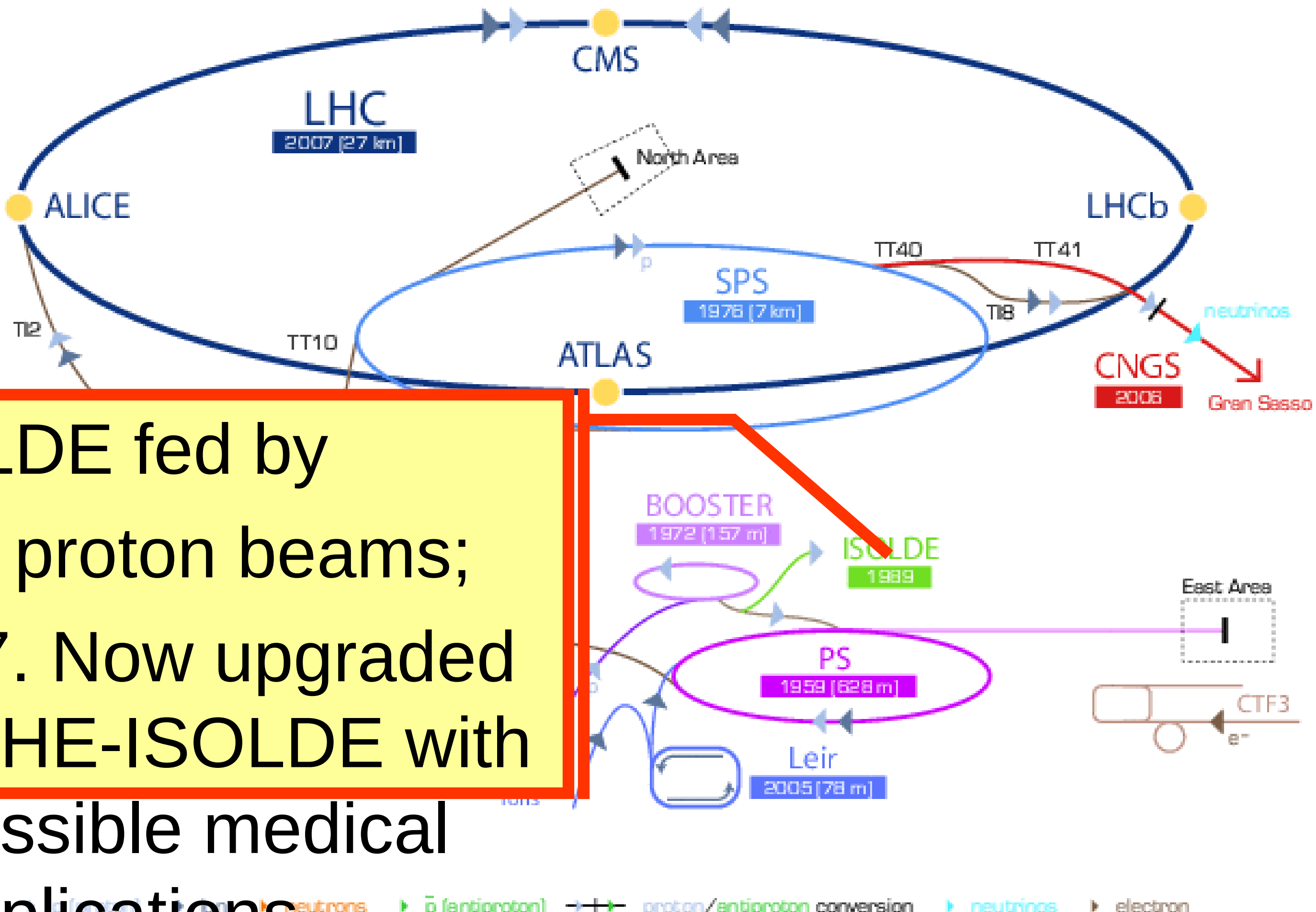


A. Siemko




ALSTHOM
BHN 06
21T

CERN accelerator complex,
working not only for LHC

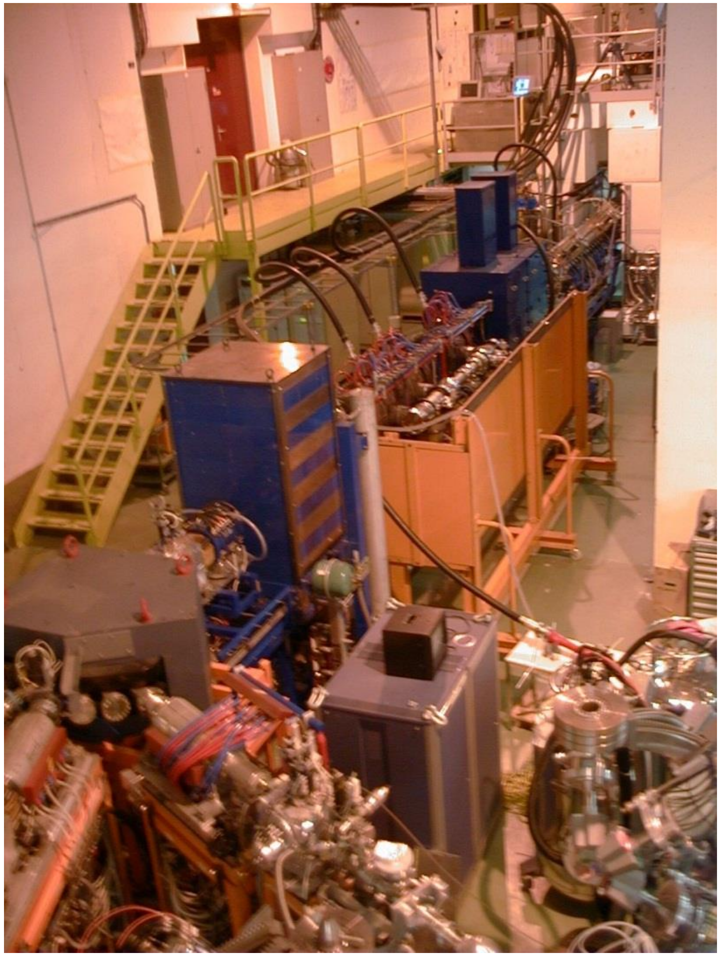


ISOLDE fed by PSB proton beams; 1967. Now upgraded to HE-ISOLDE with possible medical applications

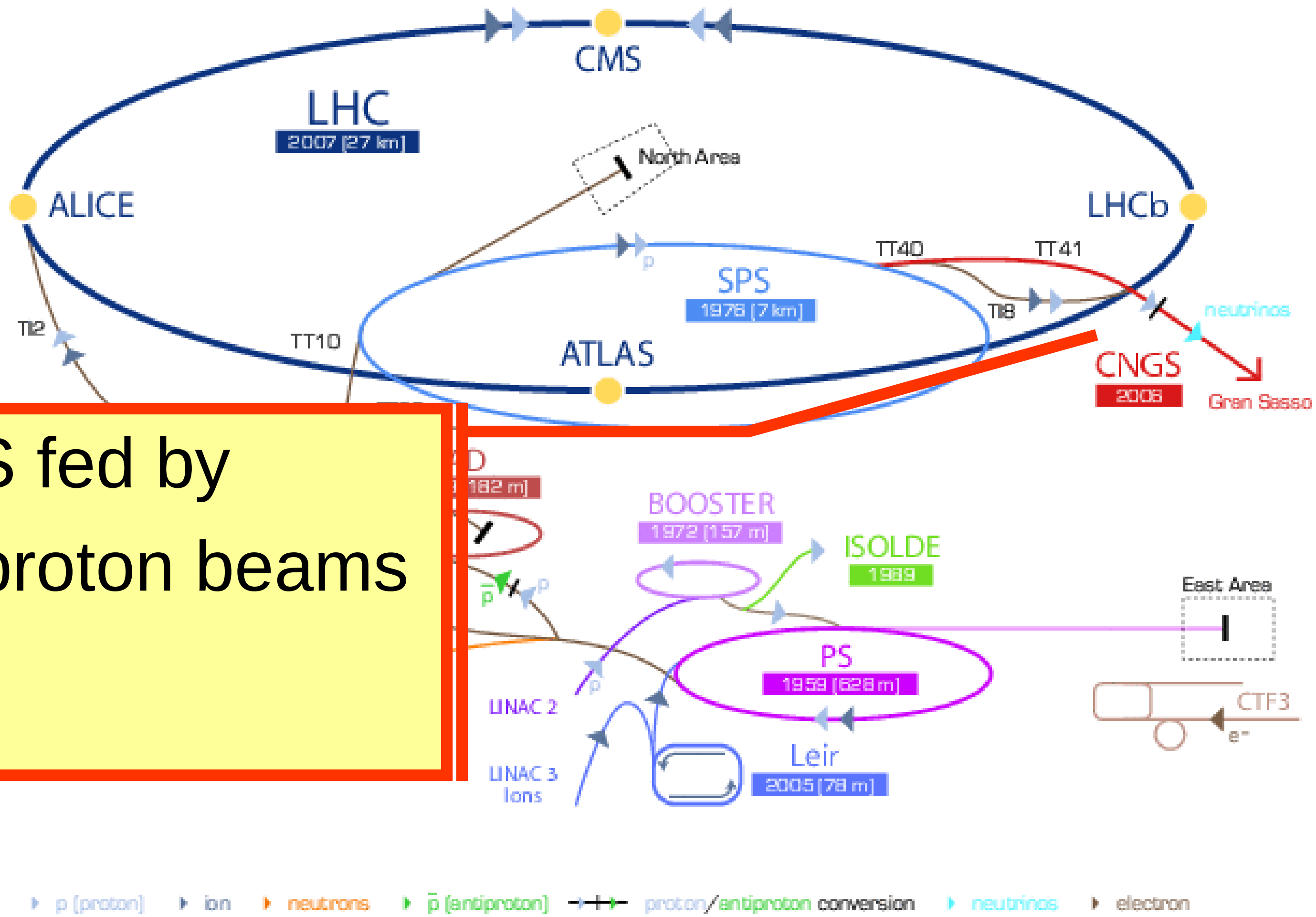
ISOLDE - Isotope Separator On Line, and Radioactive beam EXperiment (REX)

An alchemical factory for nuclear physics

Low-energy beams of radioactive isotopes - atomic nuclei. The facility, located at the Proton-Synchrotron Booster (PSB), is like a small alchemical factory, changing one element to another. It produces a total of more than 1000 different isotopes for a wide range of research.



CERN accelerator complex, working not only for LHC !

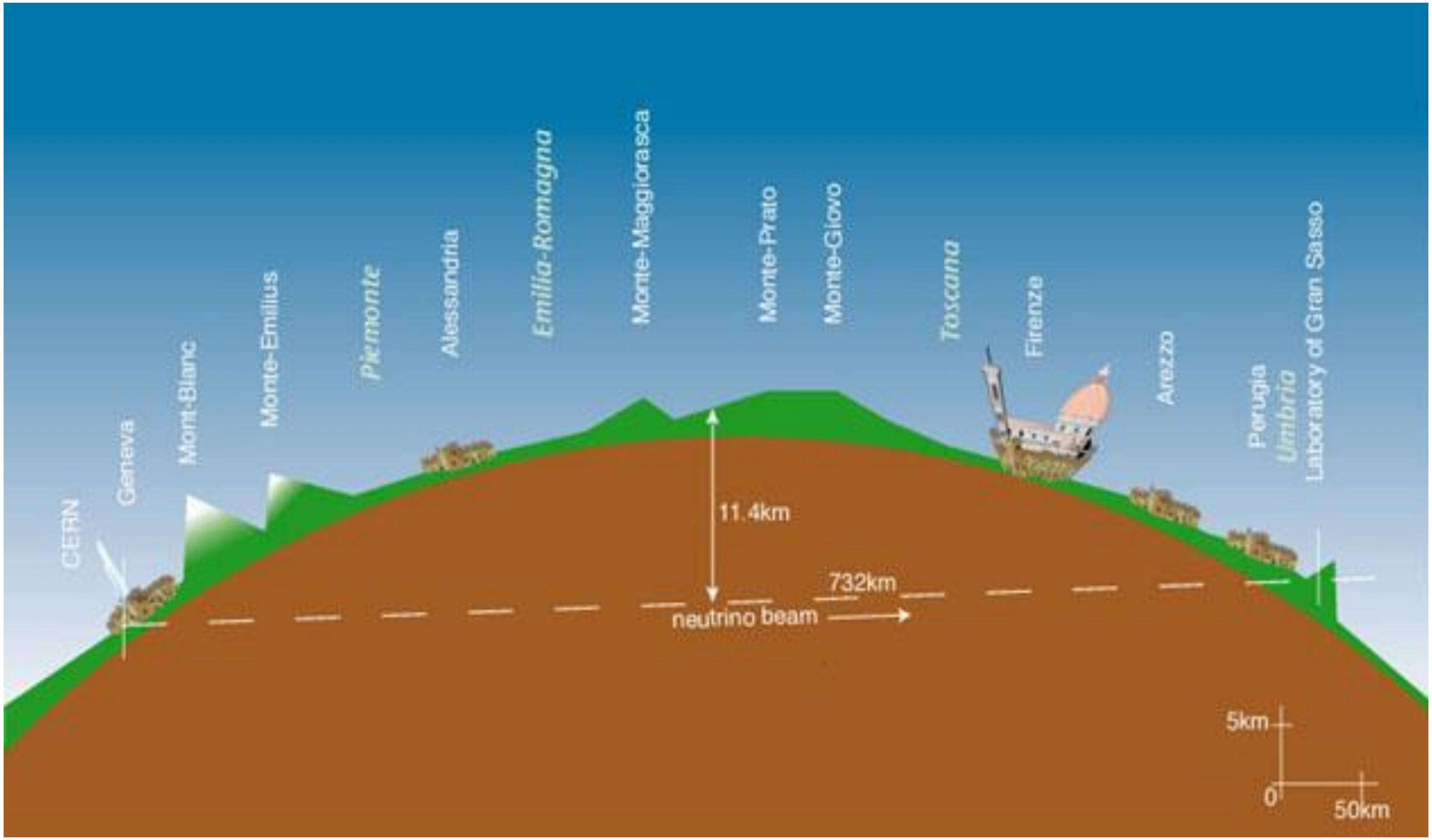


CNGS fed by

SPS proton beams

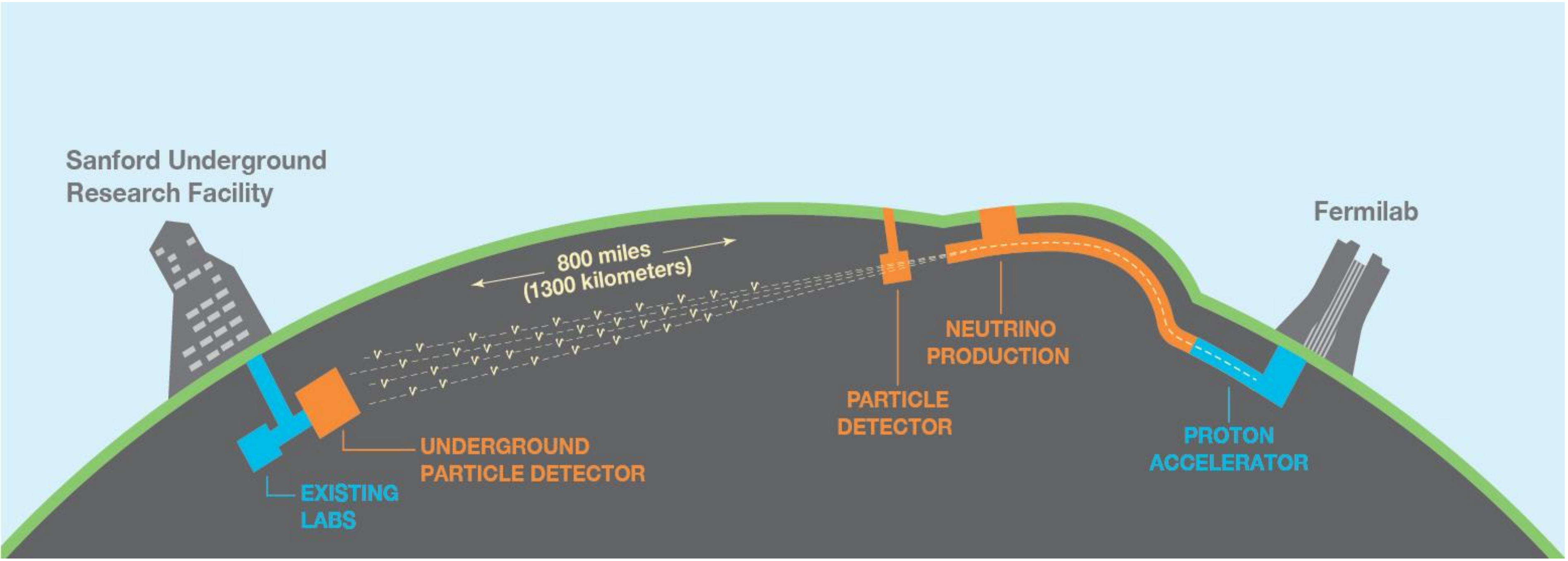
CNGS – CERN Neutrino to Gran Sasso experiment - investigation of the nature of neutrinos

CERN sends muon neutrinos to the Gran Sasso National Laboratory (LNGS), 732 km away in Italy. There, two experiments, OPERA and ICARUS, wait to find out if any of the muon neutrinos have transformed into tau neutrinos. To create the neutrino beam, a proton beam from the Super Proton Synchrotron (SPS) is used.



DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

An international mega-science project



Higgs boson… and what further?

LHC – further milestones:

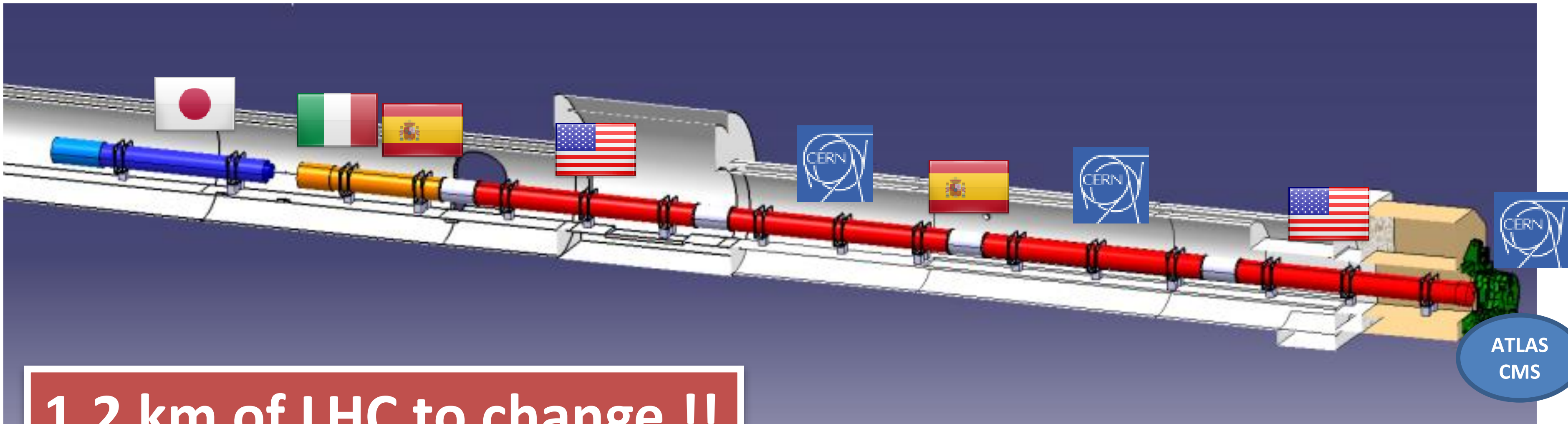
Long Shutdown 2013-14

- to achieve the nominal energy 2 x 7 TeV

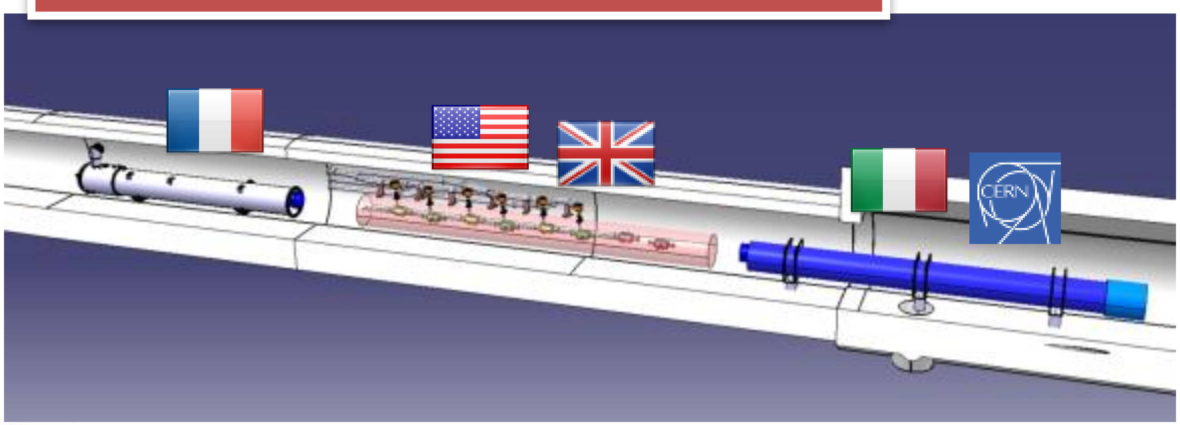
Upgrade of LHC: 2018, 2022..

- to increase the luminosity > HL-LHC
- to replace weak elements of the injection chain (e.g. new Linac4….)

Contributions and Collaboration for High Luminosity LHC (HL-LHC) design and prototypes



1.2 km of LHC to change !!



Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

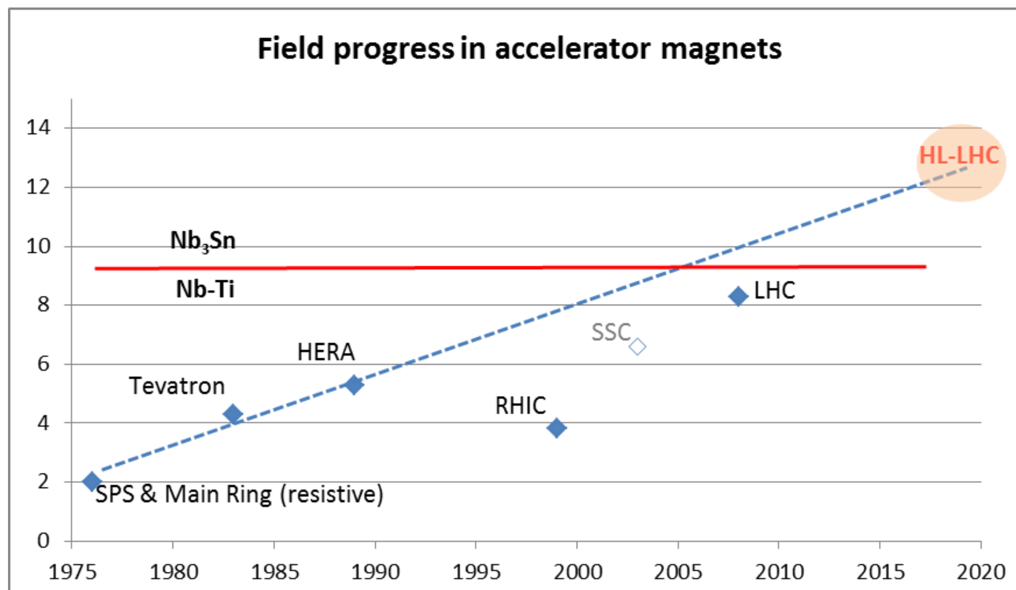
CC : R&D, Design and in-kind **USA**

CC : R&D and Design **UK**

Courtesy L. Rossi HL-LHC

Magnets : IT quads

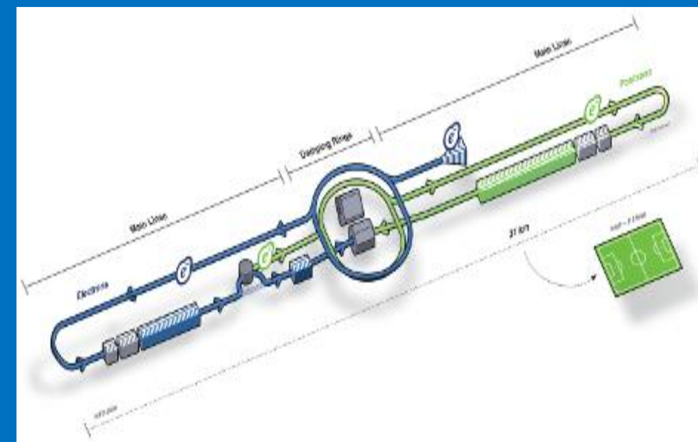
- LHC dipoles features 8.3 T in 56 mm (designed for 9.3 peak field)
- LHC IT Quads features 205 T/m in 70 mm with 8 T peak field
- **HL-LHC ; use of Nb3Sn**
  - 11 T dipole (designed for 12.3 T peak field, 60 mm)
  - New IT Quads features 140 T/m in 150 mm, B > 12 T operational field, designed for 13.5 T).
  - Energy is more than a factor 4 beyond LHC Quads, and even larger than LHC dip.

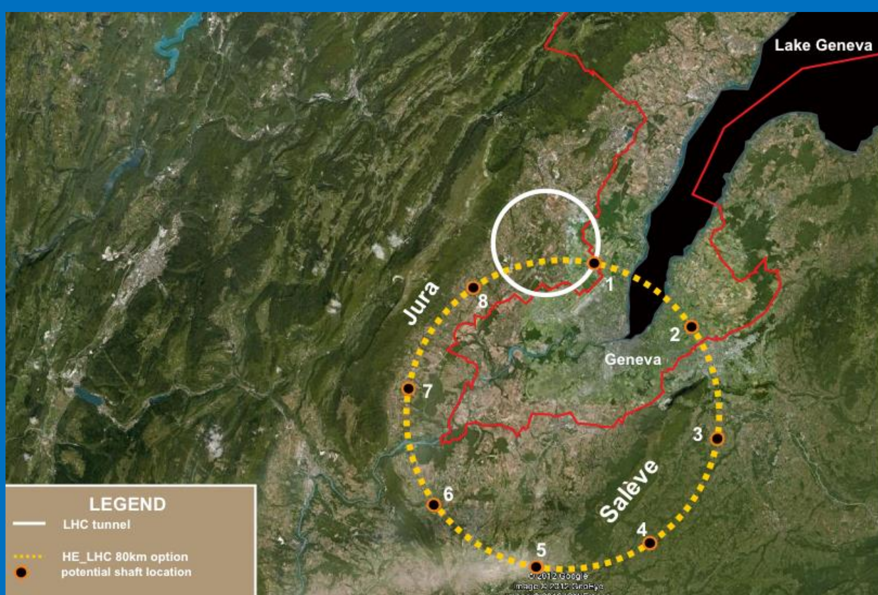


High Luminosity LHC

LHC… and what further as a global physics PROJECT?

- **Higgs "factory" :**
  - Linear or Circular e+/e- ?
  - Or, perhaps, Muon Collider?





80-km tunnel for VHE-LHC – "best" option

LHC… and what further?

R&D on **future linear colliders**

Competition of two concepts of linear electron-positron colliders:

Length determined by efficiency (gradient) of RF cavities.

ILC – International Linear Collider, 0.5 TeV, based on Superconducting RF cavities (gradient 31.5 MV/m)

CLIC – Compact Linear Collider, developed by CLIC Collaboration (CERN), 0.5 -3 TeV , based on warm RF cavities at 12 GHz with very high el. gradient ~ 100 MV/m .

Competition but also cooperation CLIC + ILC > LC

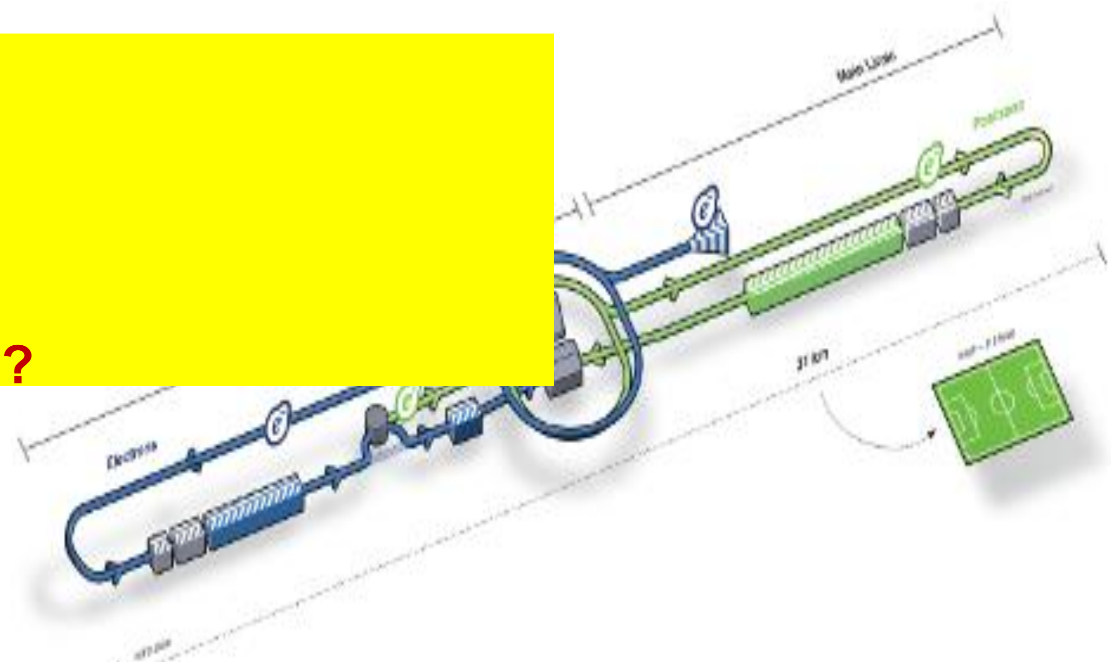
ILC-International Linear Collider

If ILC, so where?

Japan?

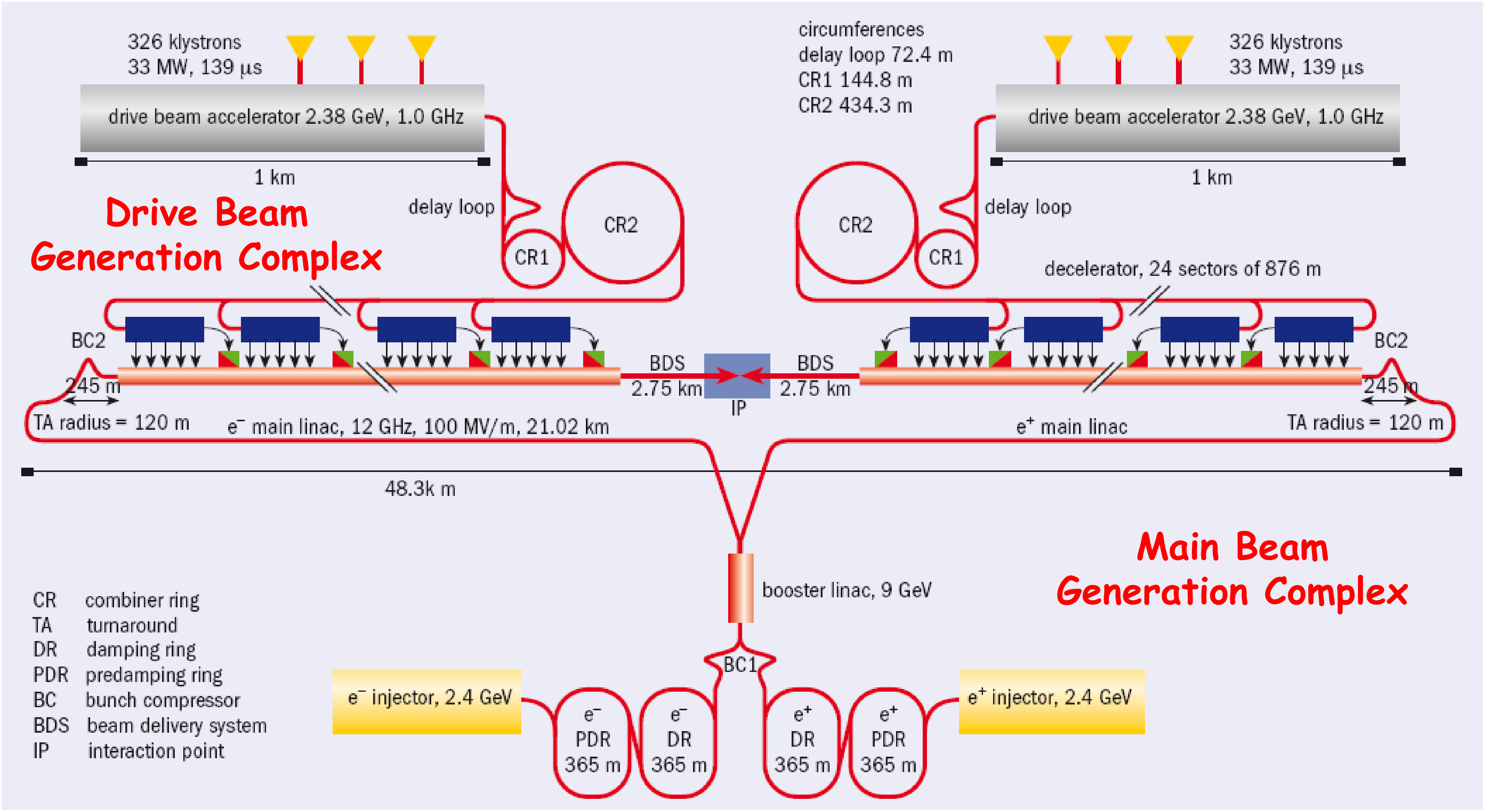
Dubna?

Or…?



- **Collisions:** Between electrons <>positrons, in bunches of 5 nm
- **Energy: Up to 0.5 TeV with an option to upgrade to 1 TeV**
- **Acceleration Technology:** 16,000 superconducting accelerating cavities made of pure niobium
- **Length: Approximately 31 kilometres**
- **Accelerating Gradient:** 31.5 megavolts per metre

CLIC - Layout @ 3 TeV (not to scale)



Courtesy of JP Delahaye

World-wide CLIC / CTF3 collaboration

http://clic-meeting.web.cern.ch/clic-meeting/CTF3_Coordination_Mtg/Table_MoU.htm

43 institutes from 22 countries

Ankara University (Turkey)
BINP (Russia)
CERN
CIEMAT (Spain)
Cockcroft Institute (UK)
Gazi Universities (Turkey)
IRFU/Saclay (France)

Helsinki Institute of Physics (Finland)
IAP (Russia)
IAP NASU (Ukraine)
Instituto de Fisica Corpuscular (Spain)
INFN / LNF (Italy)
J.Adams Institute, (UK)

JINR (Russia)
JLAB (USA)
KEK (Japan)
LAL/Orsay (France)
LAPP/ESIA (France)
NCP (Pakistan)
North-West. Univ. Illinois (USA)

University of Oslo (Norway)
PSI (Switzerland),
Polytech. University of Catalonia (Spain)
RRCAT-Indore (India)
Royal Holloway, Univ. London, (UK)
SLAC (USA)
Uppsala University (Sweden)

Concepts of Future Circular Colliders- FCC collaboration at CERN

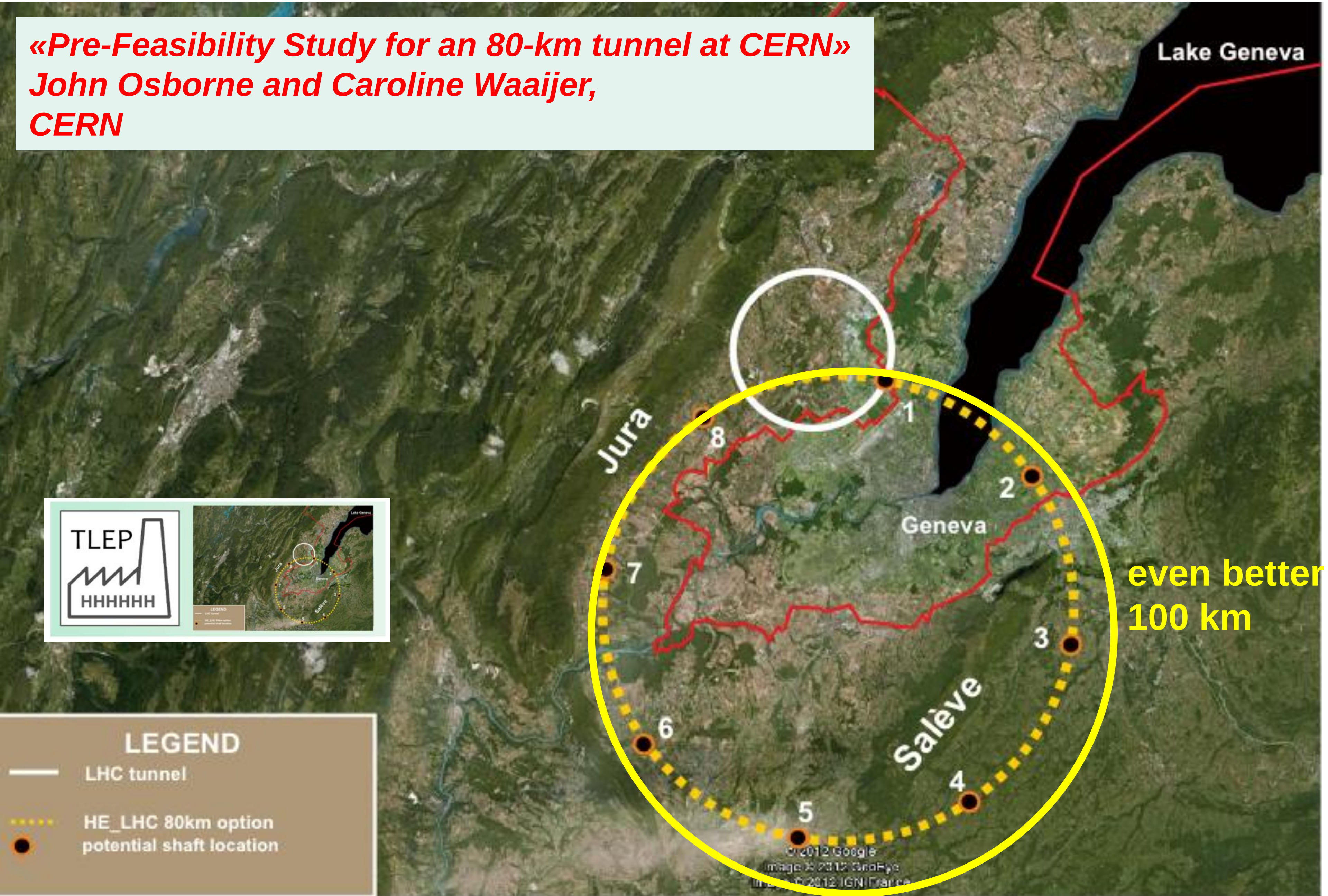
- **e^+e^- Higgs factories**

  TLEP at CERN, but also projects in USA, Japan, China…

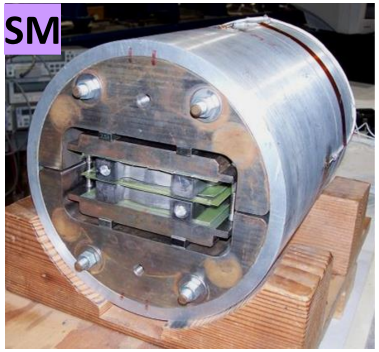
- **HE-LHC: in LHC tunnel (2035?). E=33 TeV; magnets B=20T**
- **VHE-LHC: in new 80-100 km tunnel (2040?). E=84-104 TeV; magnets B=20 T.**

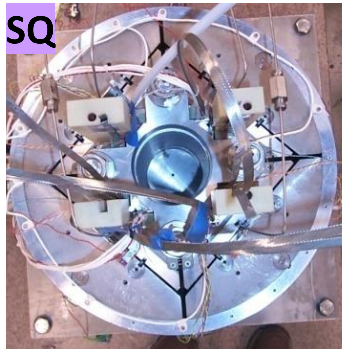
80-km tunnel for TLEP/VHE-LHC

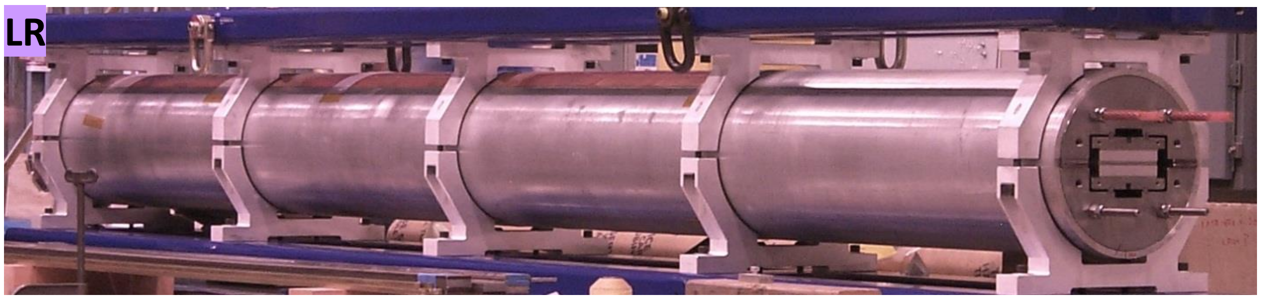
«Pre-Feasibility Study for an 80-km tunnel at CERN»
John Osborne and Caroline Waaijer,
CERN

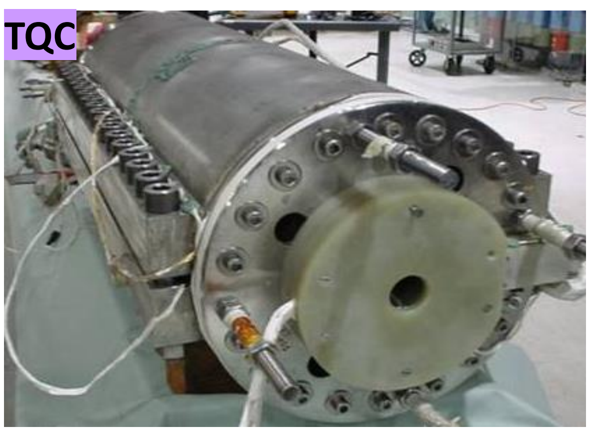


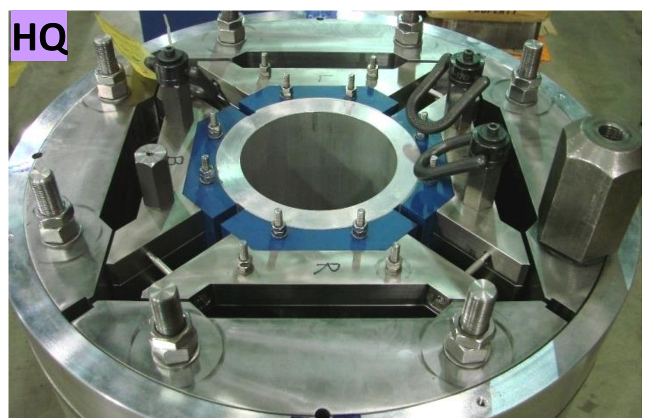
LARP (US LHC program) Magnets











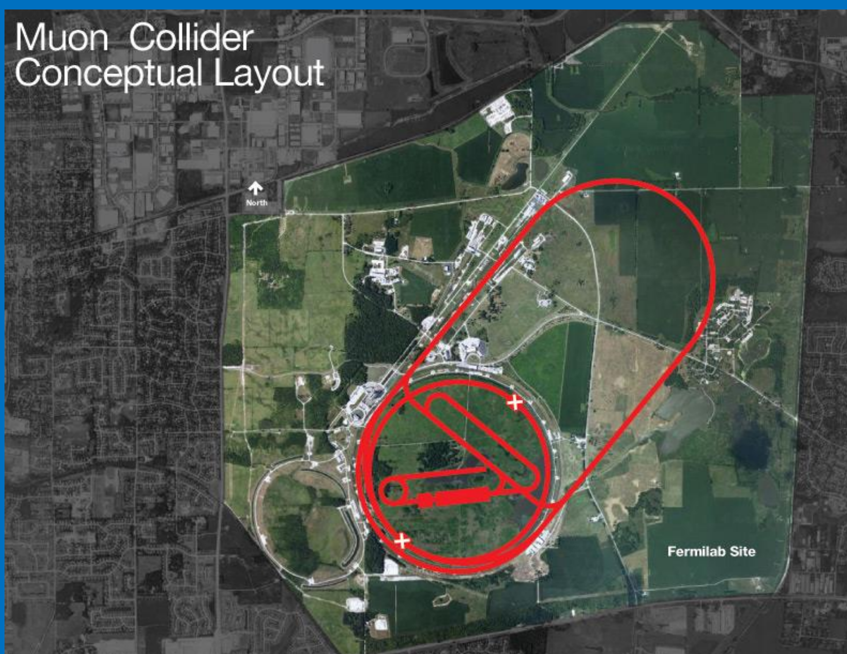
But why these accelerators

are so big ??

!!...

Future Muon Collider??

MAP-Muon Accelerator Program (2010)
http://map.fnal.gov



New boson sparks call for 'Higgs factory'

Former CERN boss Carlo Rubbia wants a muon collider

Jul 5, 2012

...The technology is there to construct a Higgs factory. You don't need €10bn; it could be done relatively cheaply.....

See also:

A millimole of muons for a Higgs Factory? Carlo Rubbia , Venice_March2013

Old dream- “desk” collider

The Economist Oct 19th 2013 - Small really is beautiful

Particle accelerators

Fundamental physics seems to have an insatiable appetite for bigger, more expensive machines. There may, though, be a way to shrink them radically......> Dielectric Laser Acceleration

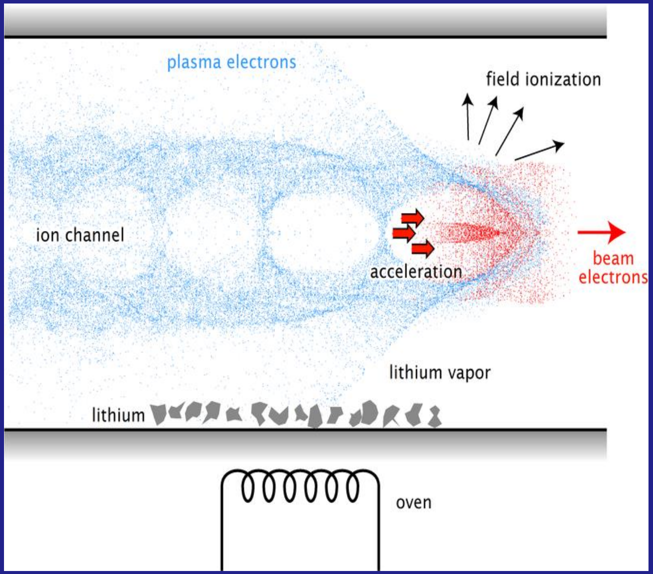
New (old) ideas: plasma wakefield acceleration
VERY HIGH Electric **Field Gradients**

- Plasma wakefield provoked by a driving beam (laser, electron, proton) creates a zone of separation of electrons from ions > a very high field gradient is formed.

Gradients:

Resonant cavity: ~30 MV/m

Plasma wakefield: ~100 GV/m



Proton-driven plasma wakefield acceleration could accelerate electrons to the terascale.
The **AWAKE** project is set to verify this novel technique using proton beams at CERN.

Acceleration record:
42 GeV on 85 cm
(Nature 445)!

for comparison:
SLAC: 50 GeV – 3 km!

CERN Initiatives for Medical Applications

1. Medical Accelerator Design
   - coordinate an international collaboration to design a new compact, cost-effective accelerator facility, which would use the most advanced technologies
2. Biomedical Facility
   - creation of a facility at CERN that provides particle beams of different types and energies to external users interested in radiobiology and detector development
3. Detectors for beam control and medical imaging
4. Dosimetry for control of radiation
5. Radio-Isotopes
   - Set up a European user facility to supply innovative radioisotopes (produced at ISOLDE-CERN, ILL, PSI, Arronax,...) for R&D in life sciences (preclinical and clinical studies)

- Large Scale Computing for medical applications

Accelerator projects – multidisciplinary tasks requiring collaboration of Physicists with top specialists from various branches of Engineering and Industry:

- Electrical
- Vacuum and UH Vacuum
- Mechanical
- Cryogenics
- Electronics and Controls
- Materials / Surface techniques
- Instrumentation
- Computing
- Civil Engineering, Survey specialists, Environmental expertise…


See you at CERN !
Thank you
Faleminderit