La grand collisionneur LHC du CERN : Les nouvelles technologies pour la découverte de l’infiniment petit

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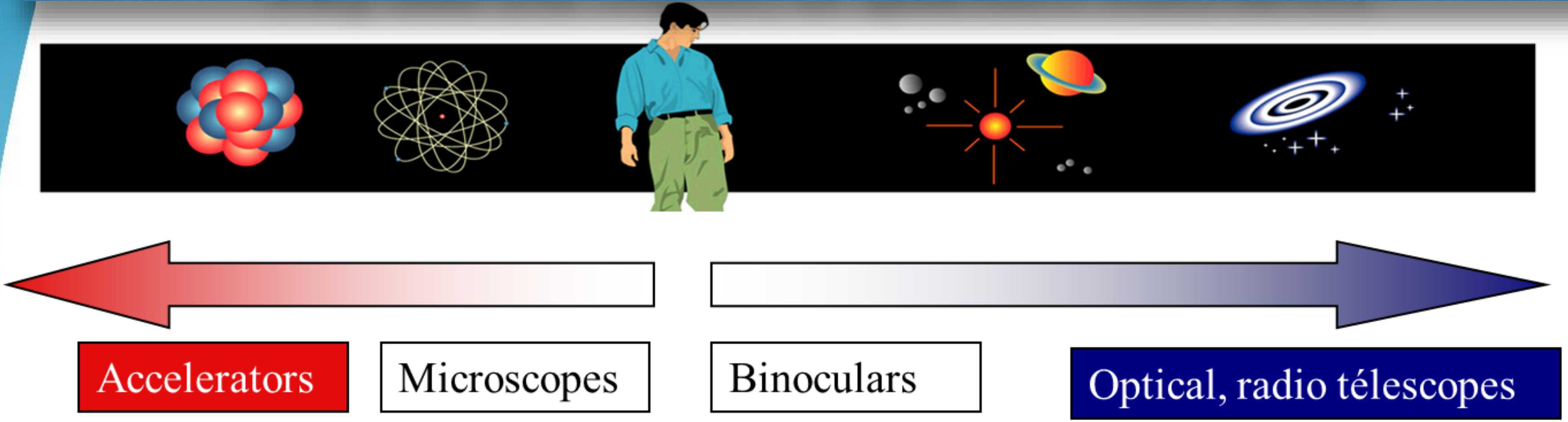
Lucio Rossi – CERN

HL-LHC Project Leader (2010-1Juillet2020)

Assemblée Générale Ordinaire IESF – celebration Ampère 2020 - Paris , 17/09/2020

Particle accelerators like generator of very fine light they use the «light», of quantum mechanics

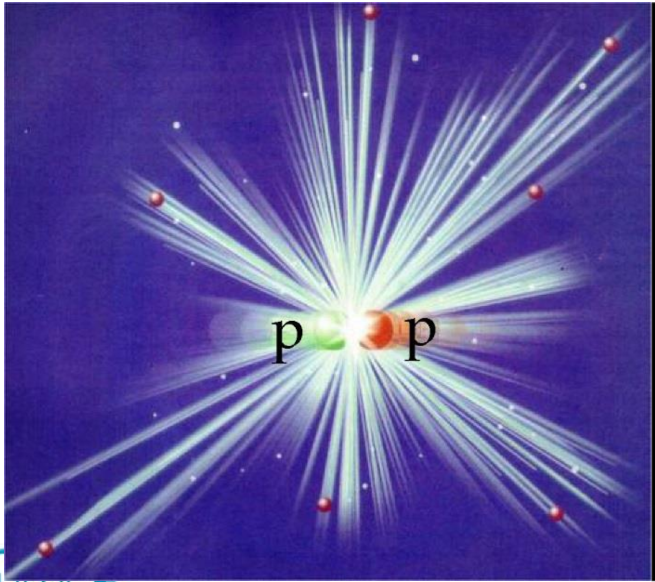


Particle physics looks at matter in its smallest dimensions and accelerators are very fine microscopes or, better, ***atto-scopes!***

$\lambda = h/p$; @LHC: $T = 1$ TeV $\Rightarrow \lambda \simeq 10^{-18}$ m

Accelerators also a wonderful «time machines»

- Trip back toward the Big Bang: $t_{\mu s} \cong 1/E^2_{Gev}$
- t ≅ 1 ps for single particle creation
- t ≅ 1 μs for collective phenomena QGS (Quark-Gluon Soup)



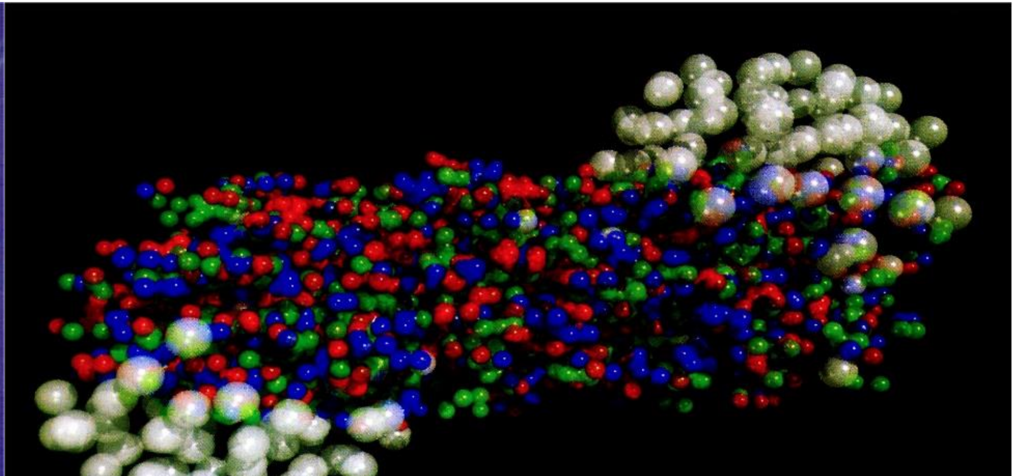
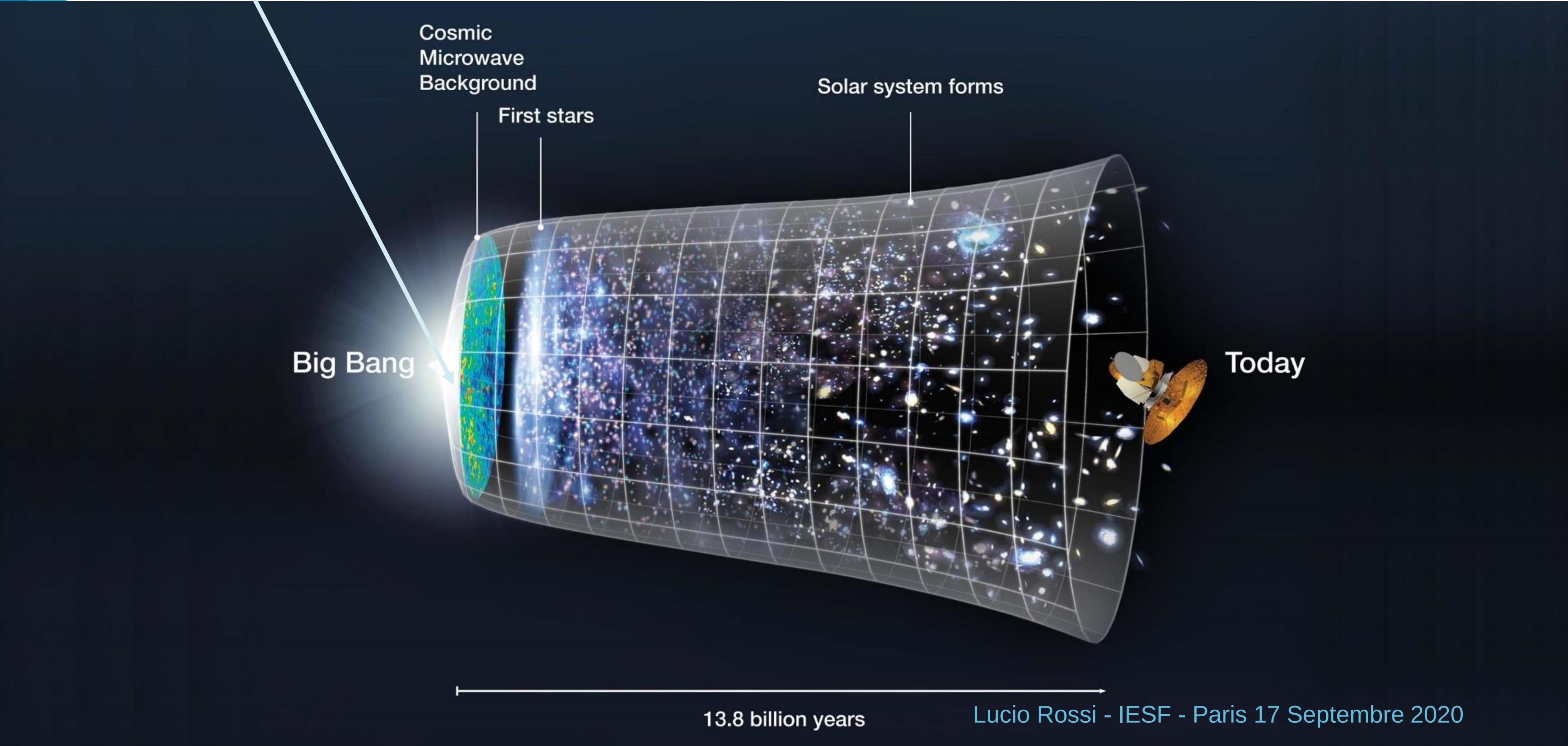
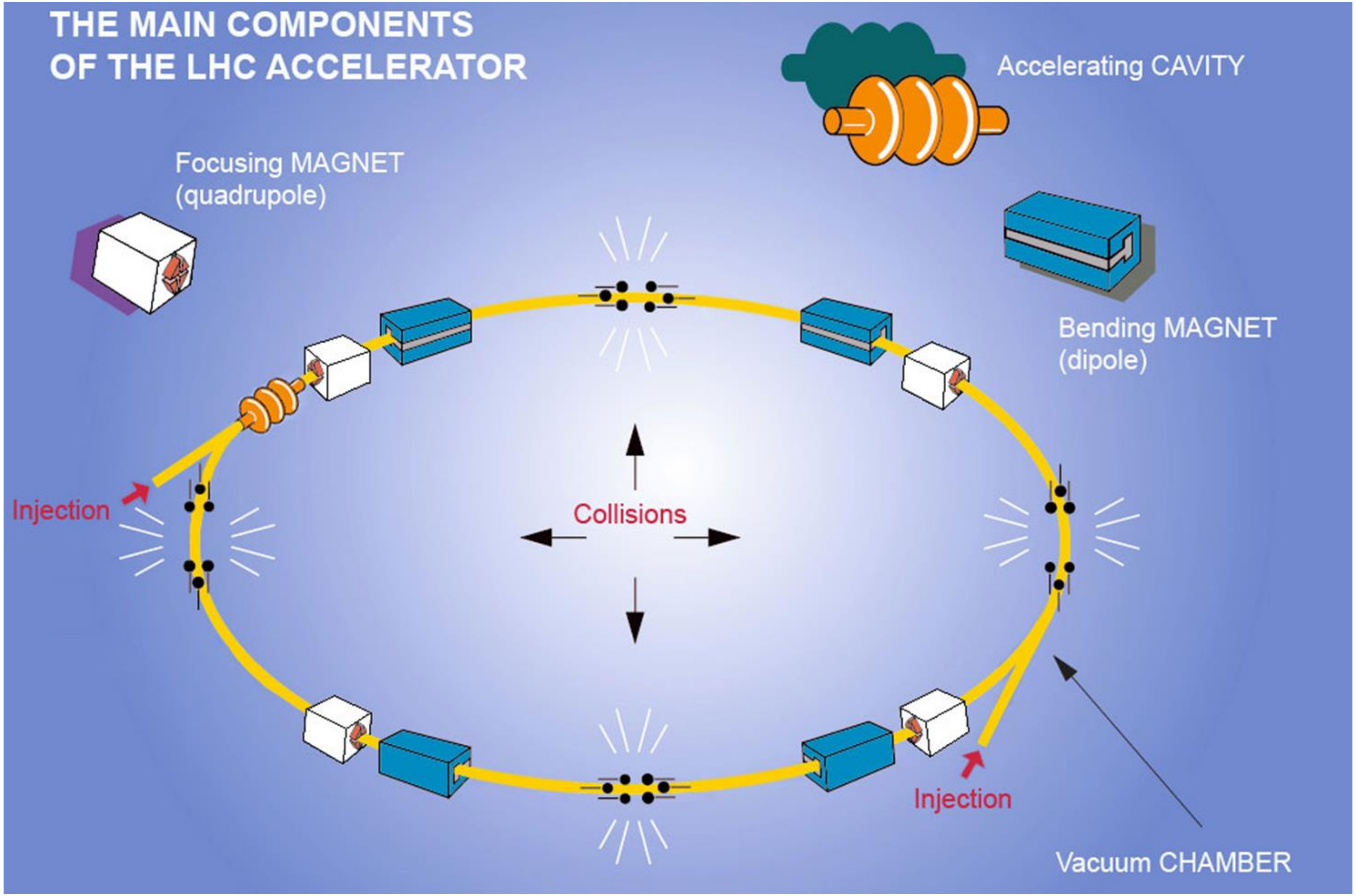


Fig 1 Snapshot of two colliding lead ions just after impact (simulation)

The Universe (and all particles within) is 13.8 billion years old

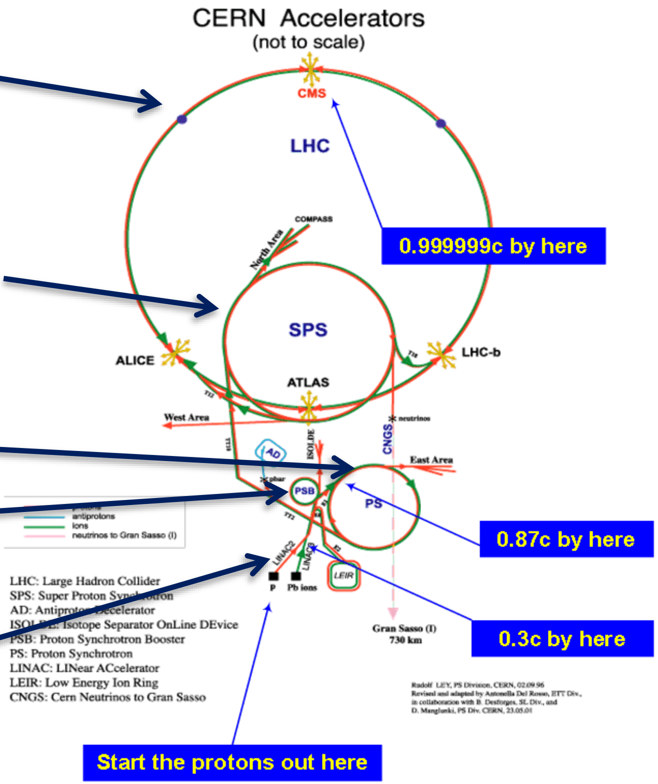
Particle physics reproduces the conditions of the Universe just after the Big Bang




THE MAIN COMPONENTS
OF THE LHC ACCELERATOR
Accelerating CAVITY
Focusing MAGNET
(quadrupole)
Bending MAGNET
(dipole)
Injection
Collisions
Injection
Vacuum CHAMBER

CERN proton accelerator chain: the force or tradition!

- LHC : 2x(0.45 – 7) TeV
- SPS : 26 – 450 GeV
- PS : 1.4 - 26 GeV
- PSB : 0.05 -1.4 GeV
- Linac: 0-50 MeV

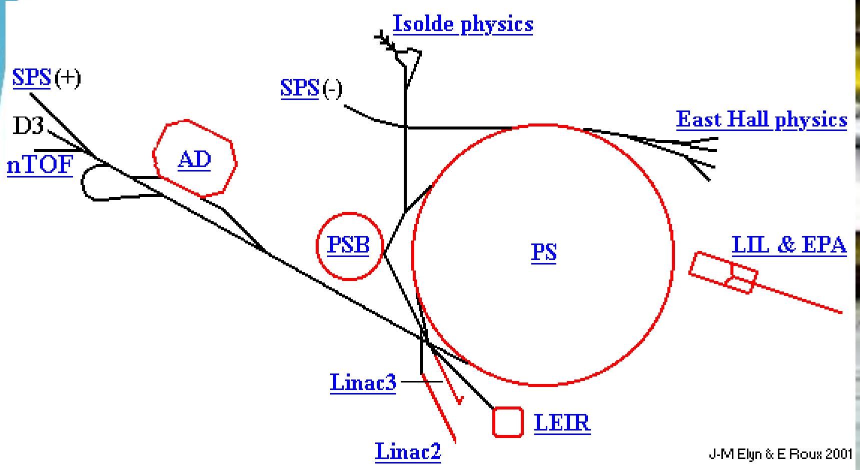


PSB (Booster): 1.4 GeV

Magnetic structure of PSB
Length : 150 m

Actually are four rings. Each beam is injected in the PS

The PS complex: injector for LHC and more…



SPS: 450 GeV proton beam
(in the 1980’s worked as p-pbar)

SPS tunnel (almost 7 km)

SPS complex with experimental

CERN: founded in 1954: 12 European States

"Science for Peace"

Today: 22 Member States

~ 2500 staff
~ 1800 other paid personnel
~ 13000 scientific users

Budget (2017) ~ 1100 MCHF

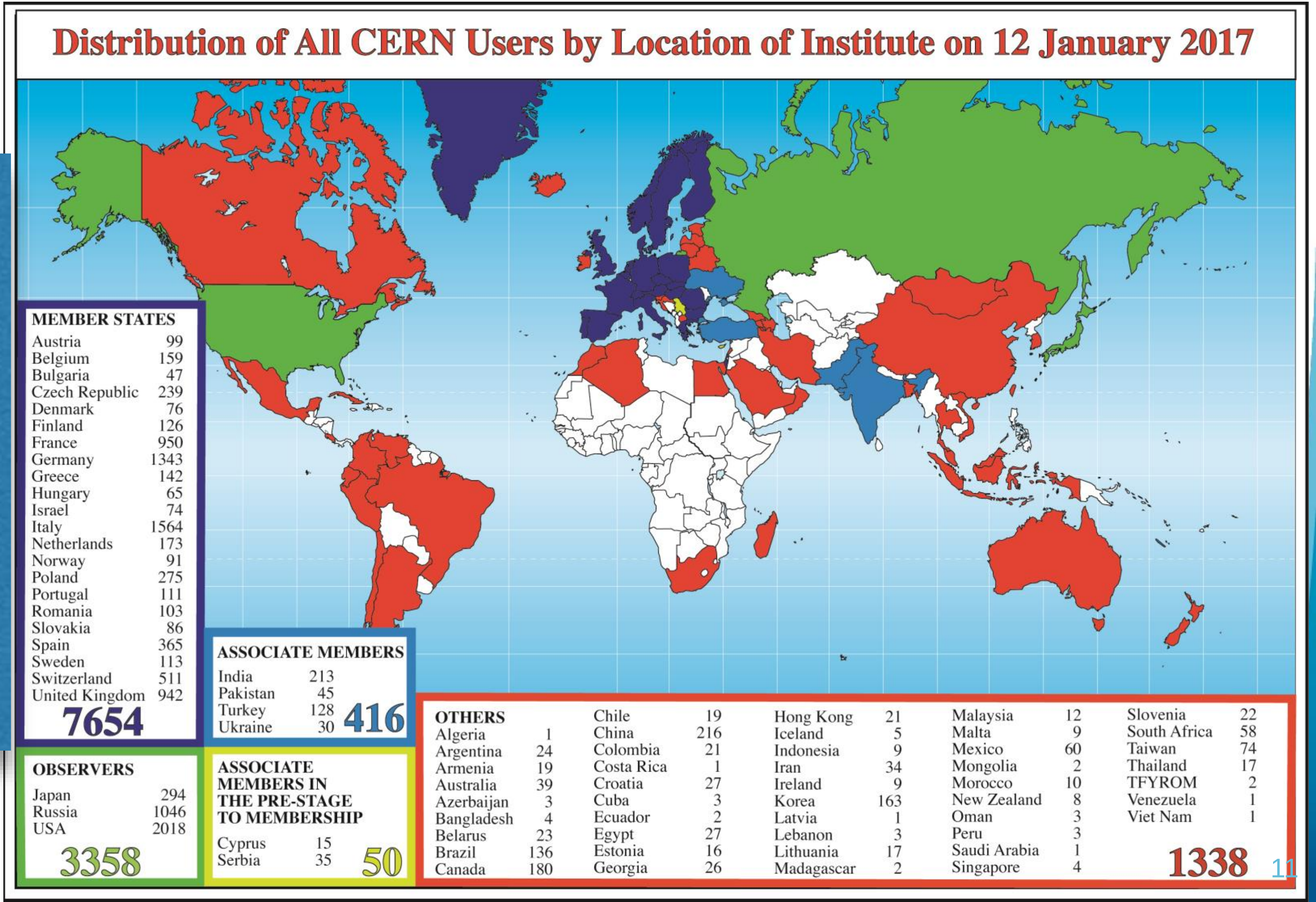
Member States: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom

Associate Member States: India, Pakistan, Turkey, Ukraine

Associate Members in the Pre-Stage to Membership: Cyprus, Serbia

Applications for Membership or Associate Membership: Brazil, Croatia, Lithuania, Russia, Slovenia

Science is getting more and more global
Note: CERN is «largest US laboratory» …



CERN & LHC

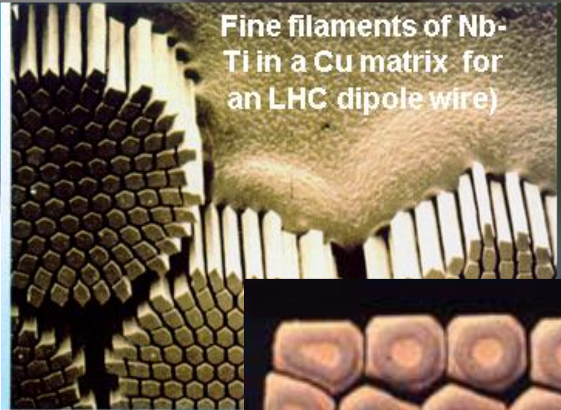
Superconducting LHC

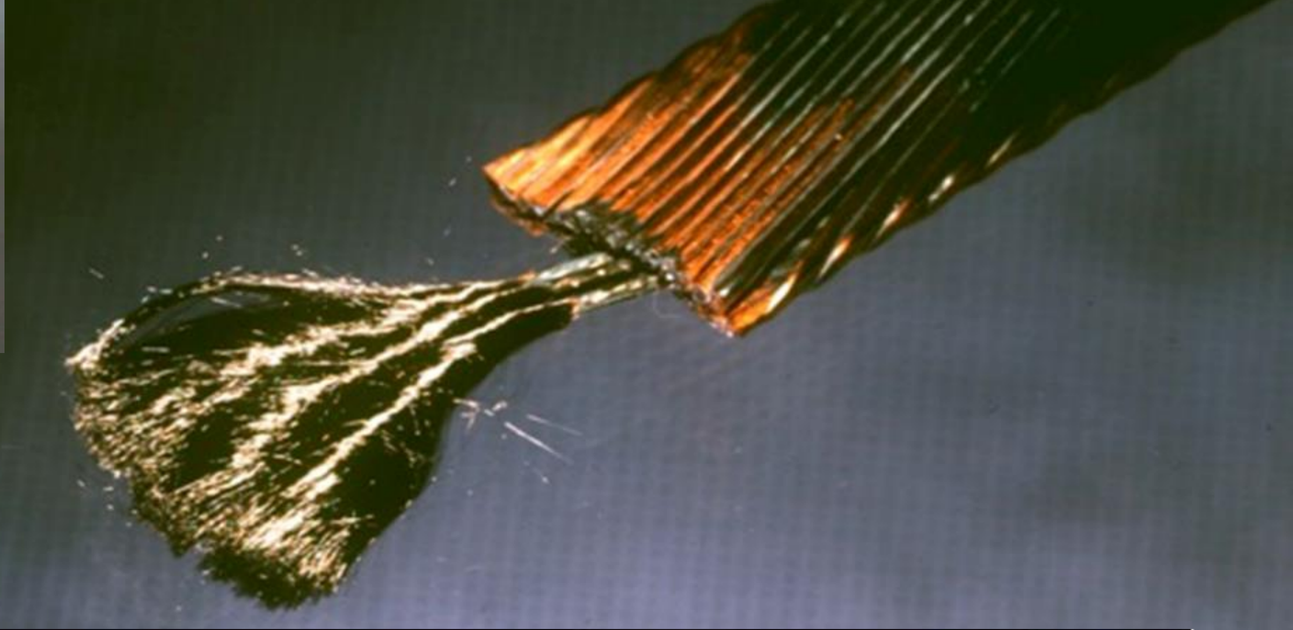
- Tunnel : 27 km
- Field : 8.3 T
- Cryoplant power at the plug: 40 MW: **always on**
- ~ 70 MW for LHC.
- 150 MW for the accelerator complex
- 180 for the whole CERN complex

Normalconducting LHC

- Tunnel 120 km
- Field : 1.8 T
- Dissipated power at collision: ~ 2,200 MW
- Average power (0.4 coefficient): 900 MW only for accelerator

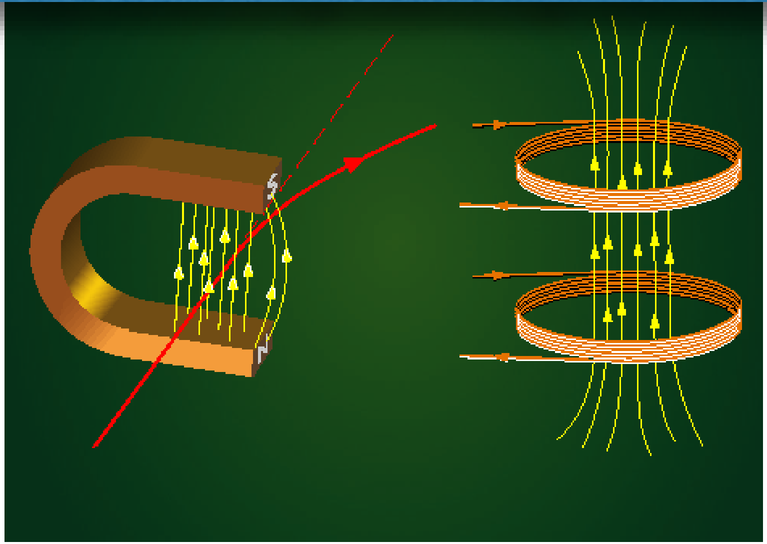
Very complex architecture
Thousands of fine Nb-Ti filaments well separated along km of wires

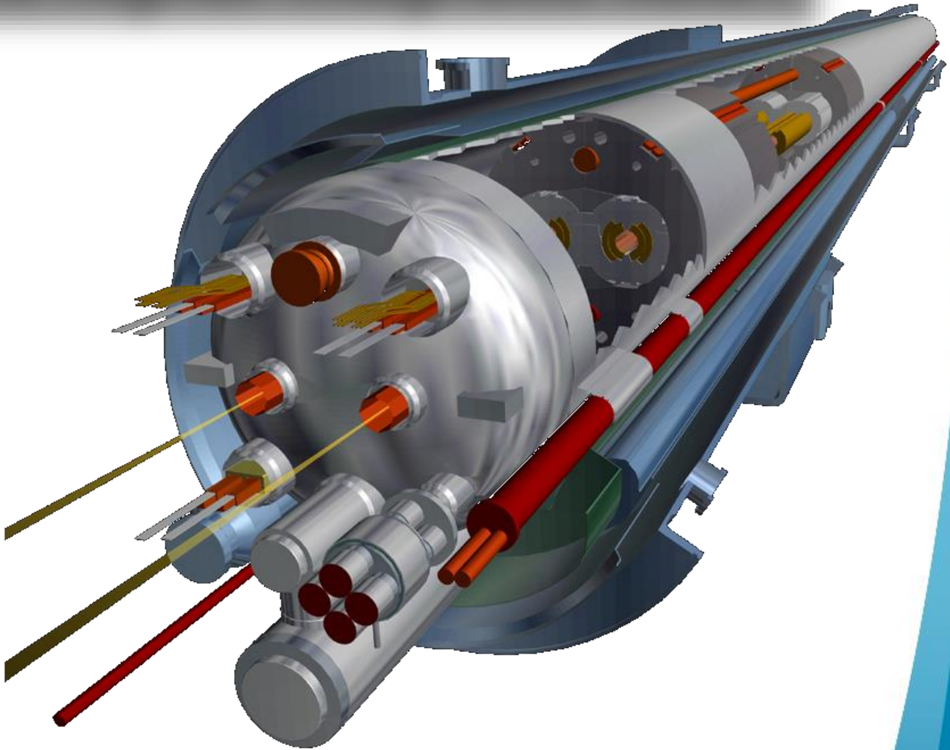




Cable of 15 kA!)

Why looking for higher and higher magnetic field?

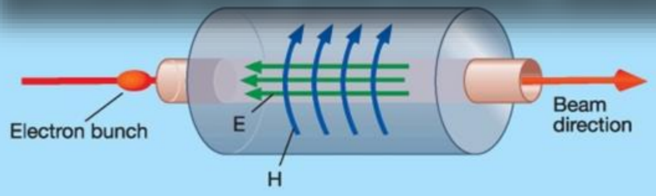


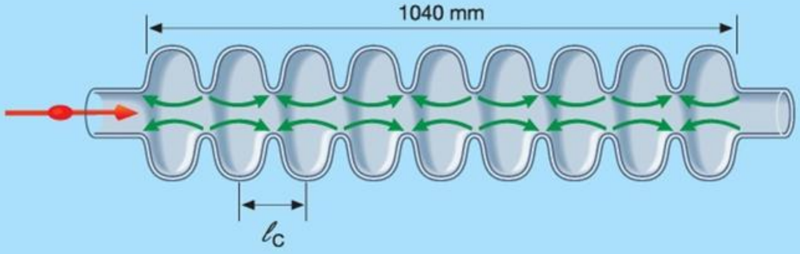


- Circular Accelerators

$$E_{beam} = 0.3\ \boldsymbol{B}\ r \quad [GeV]\ [T]\ [m]$$

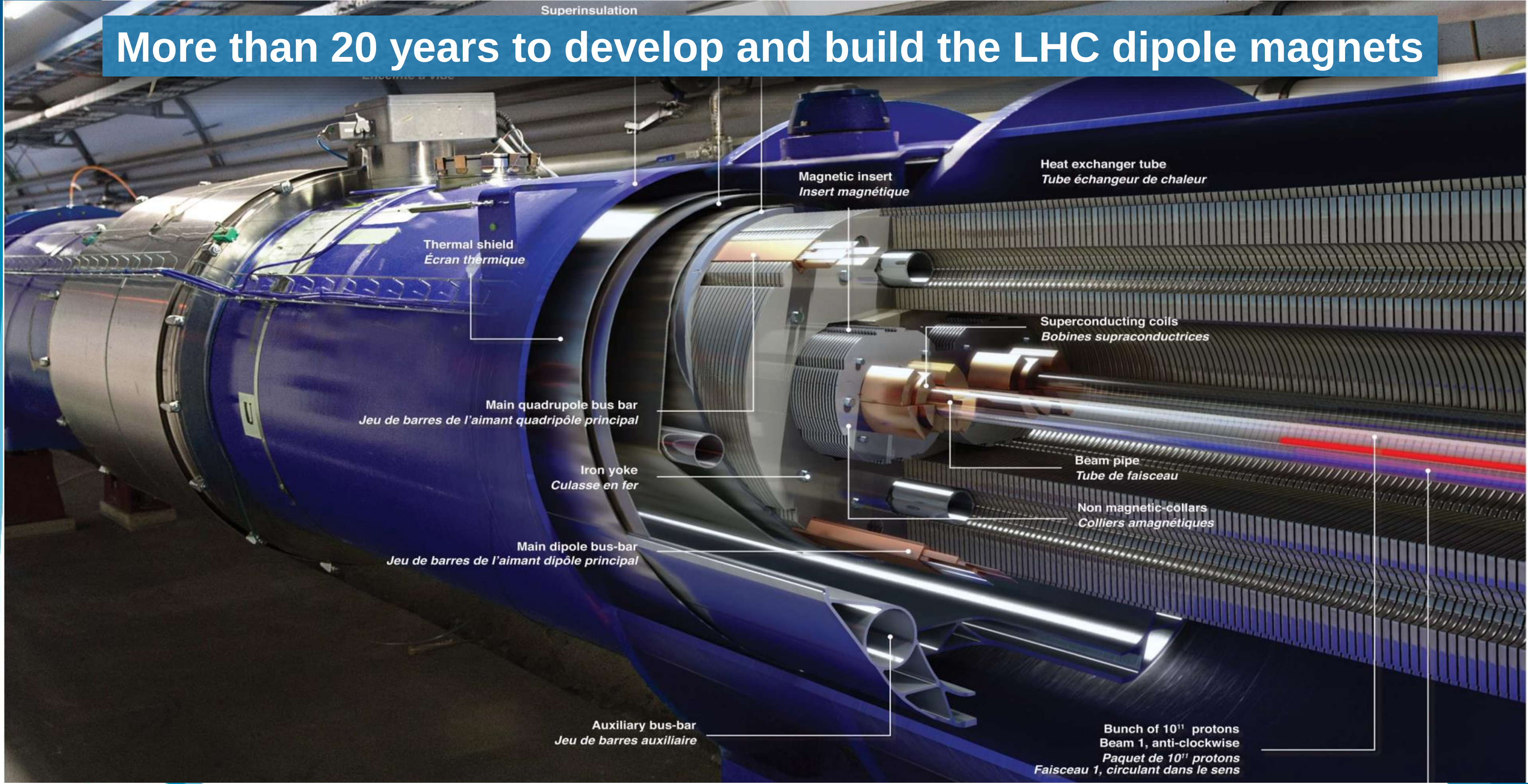
Superconductors (usually pure Niobum) are used to accelerate particles: electric fields in RF cavities (30-50 MV/m)



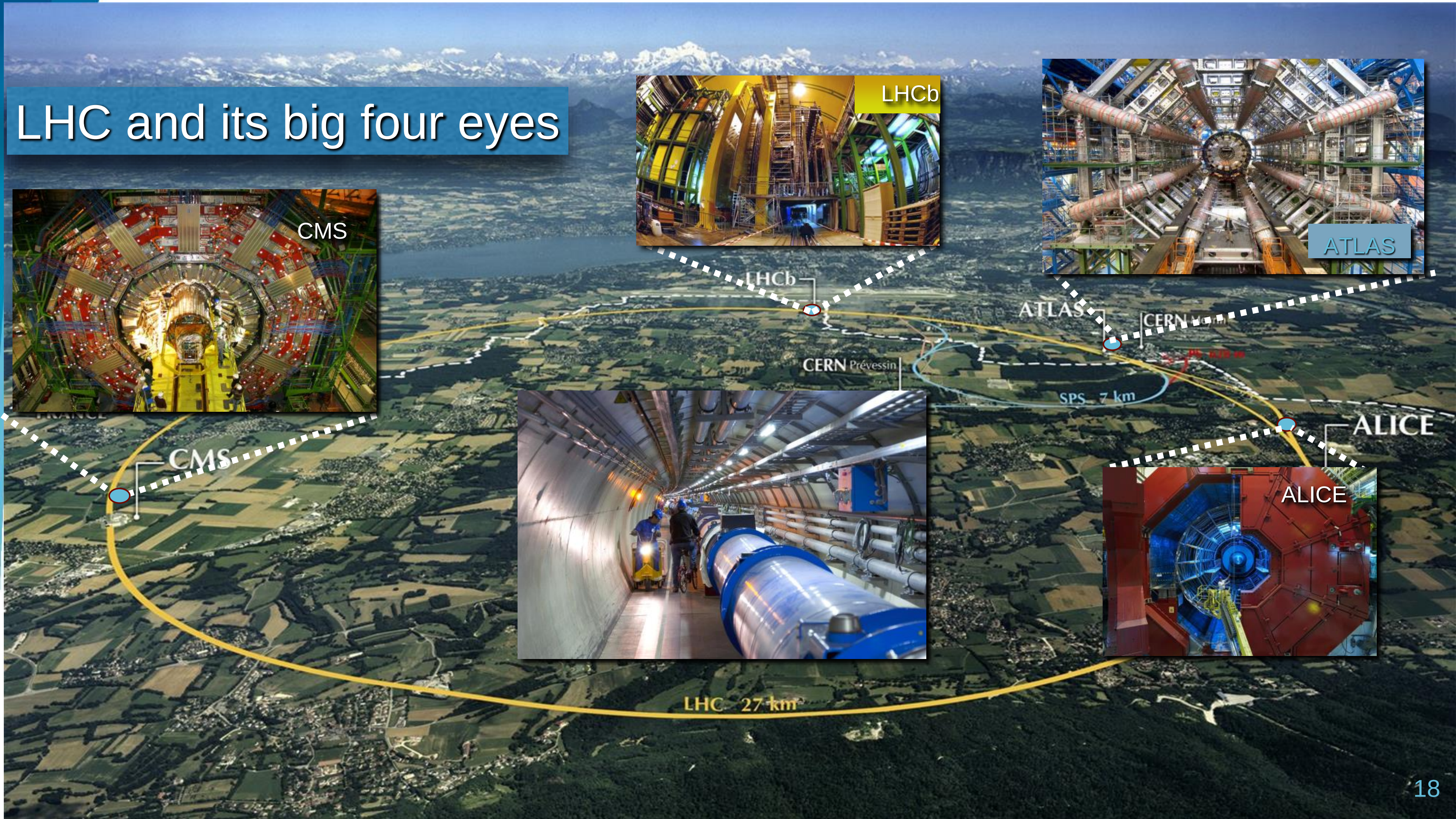


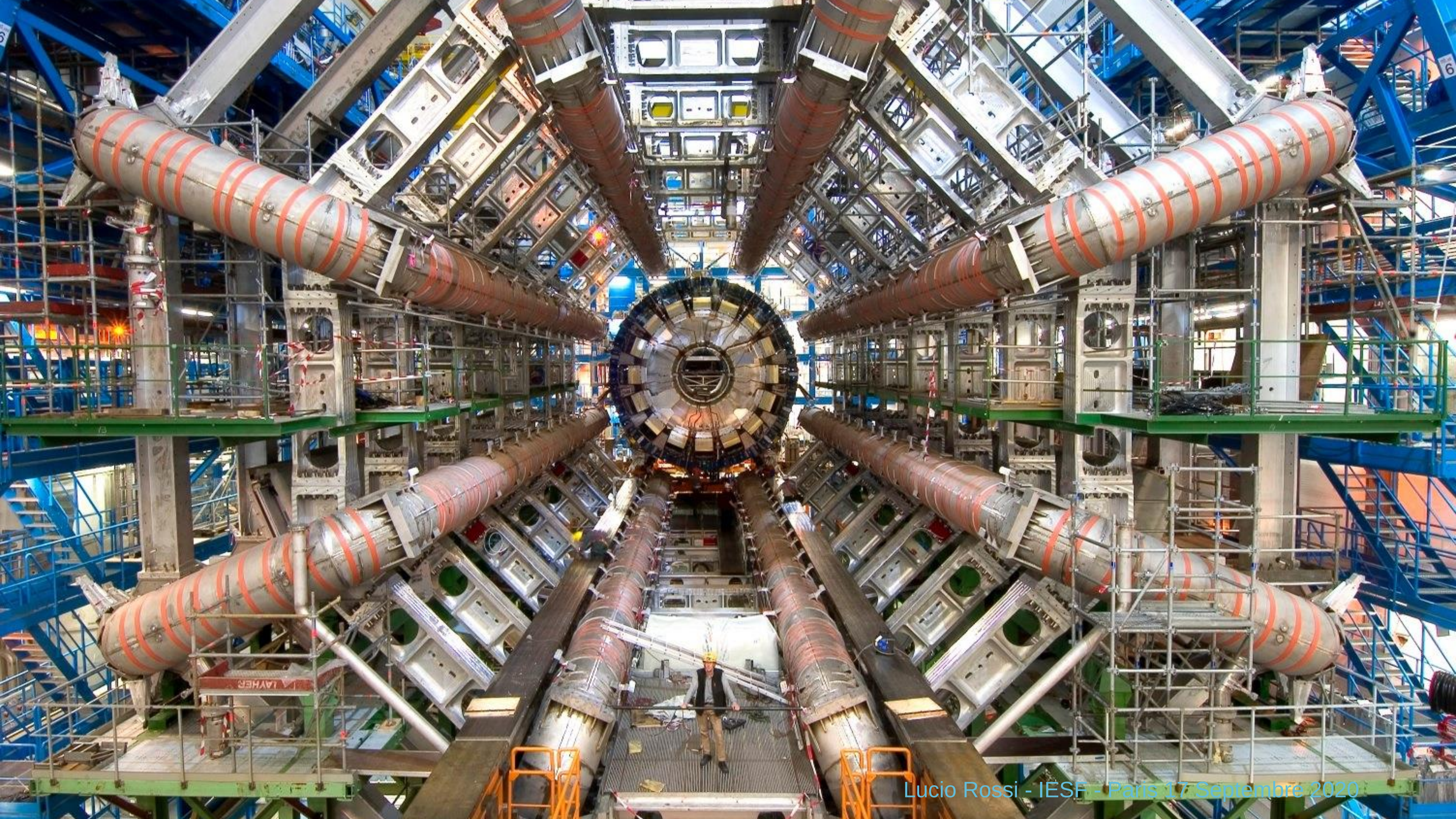
HL-LHC PROJECT

More than 20 years to develop and build the LHC dipole magnets



LHC and its big four eyes




LAYHER

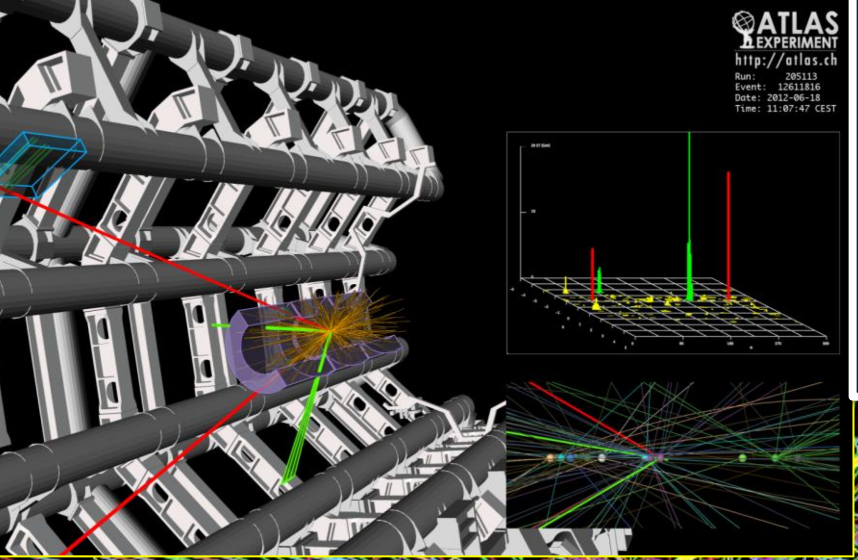
Beams collides 40 MHz

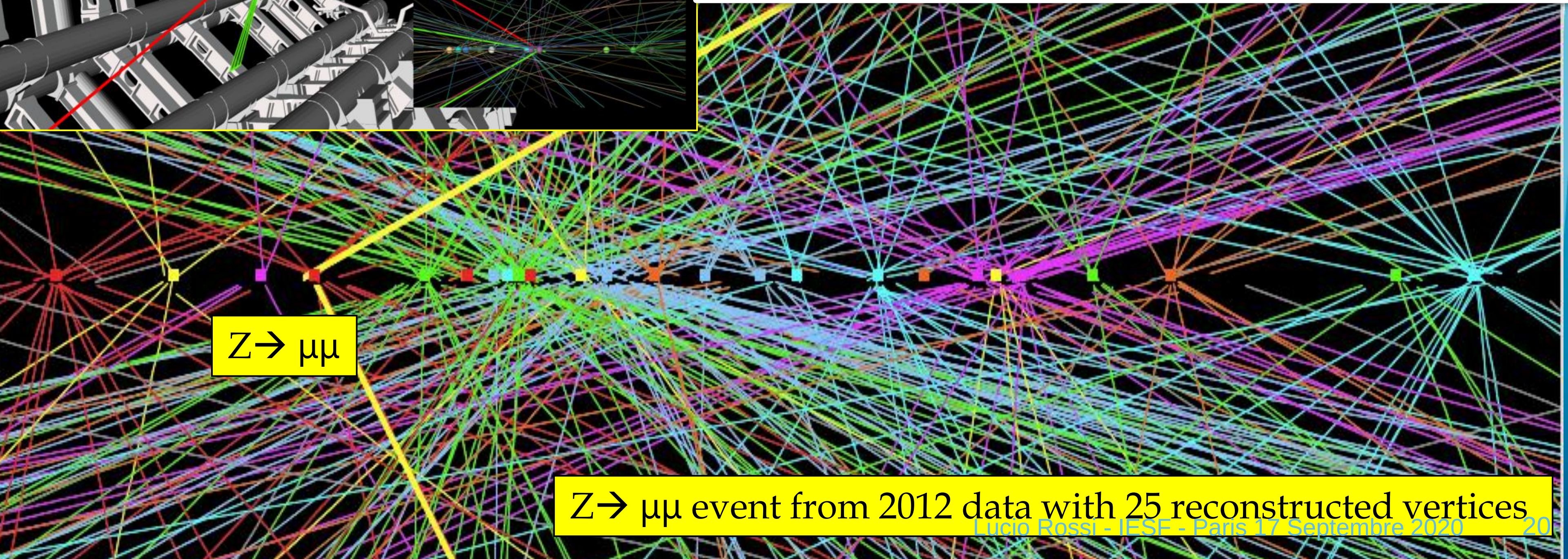
25-50 Pile up

⇒1-2 Billions collisions/s!

Only 1/10 Bil we “can see” a Higgs boson!

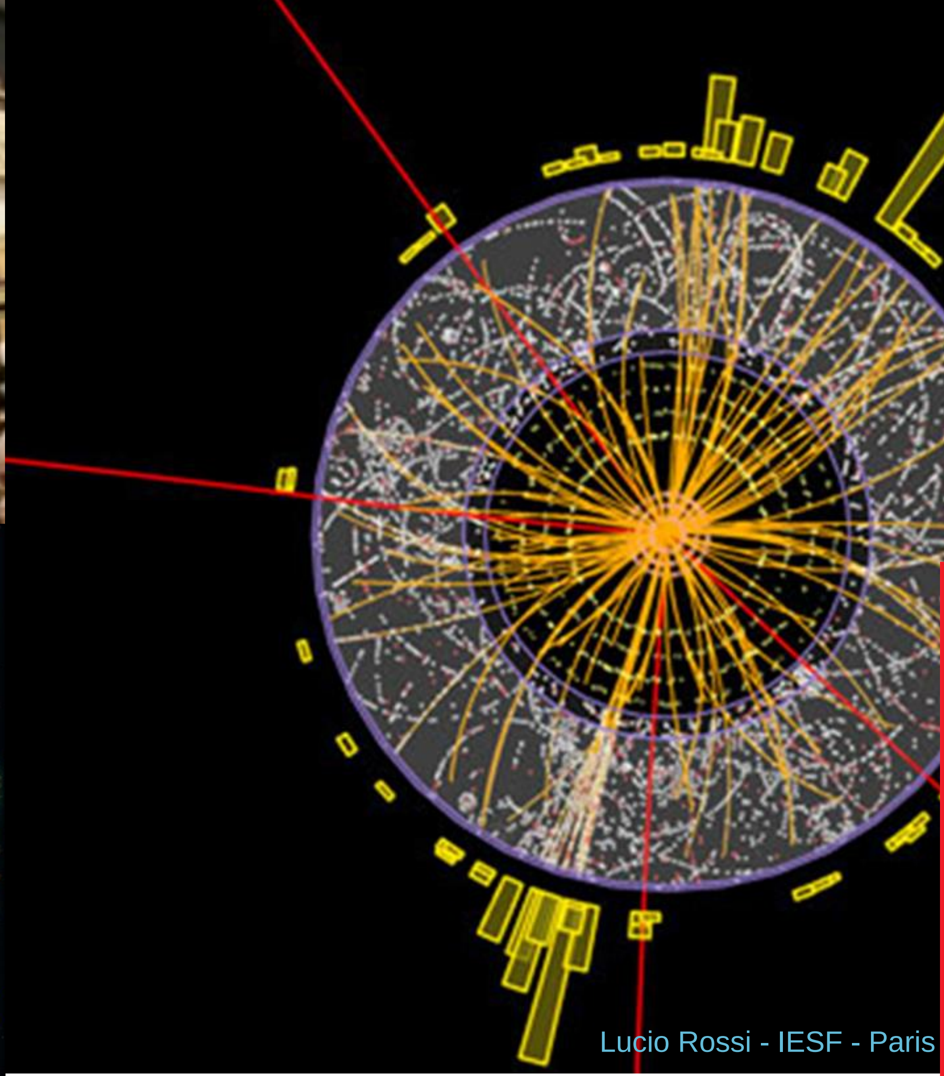
It si really searching for the needle in a haystack!





Z→ μμ event from 2012 data with 25 reconstructed vertices


The Economist
JULY 7TH–13TH 2012
Economist.com
In praise of charter schools
Britain's banking scandal spreads
Volkswagen overtakes the rest
A power struggle at the Vatican
When Lonesome George met Nora
A giant leap for science
Finding the Higgs boson



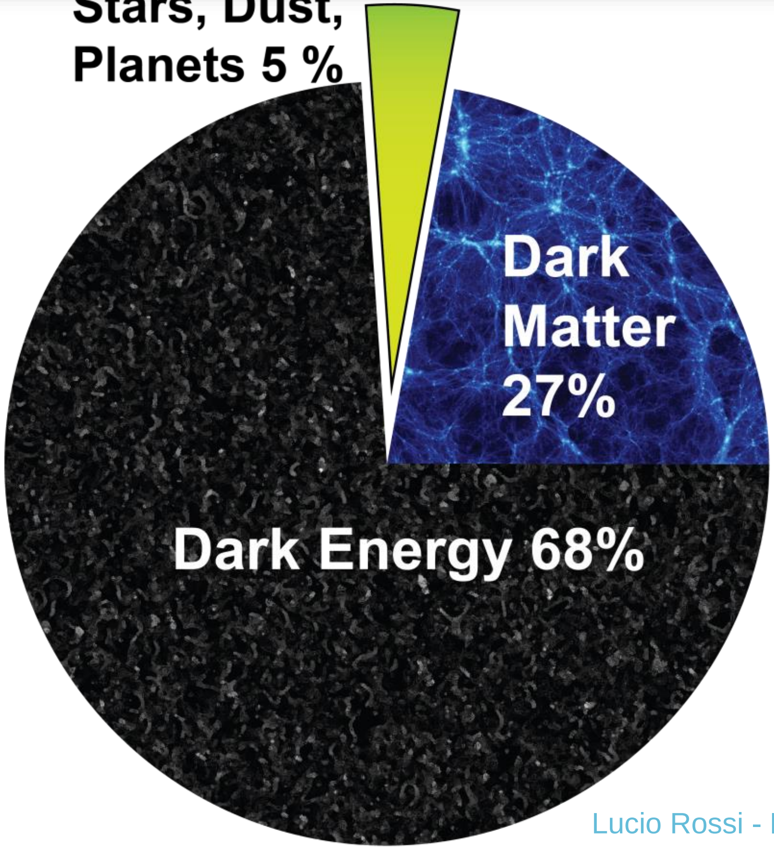

TIME
Nº5
PARTICLE PHYSICIST
FABIOLA GIANOTTI

Prof. Brout

Prof. Englert   Prof. 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**

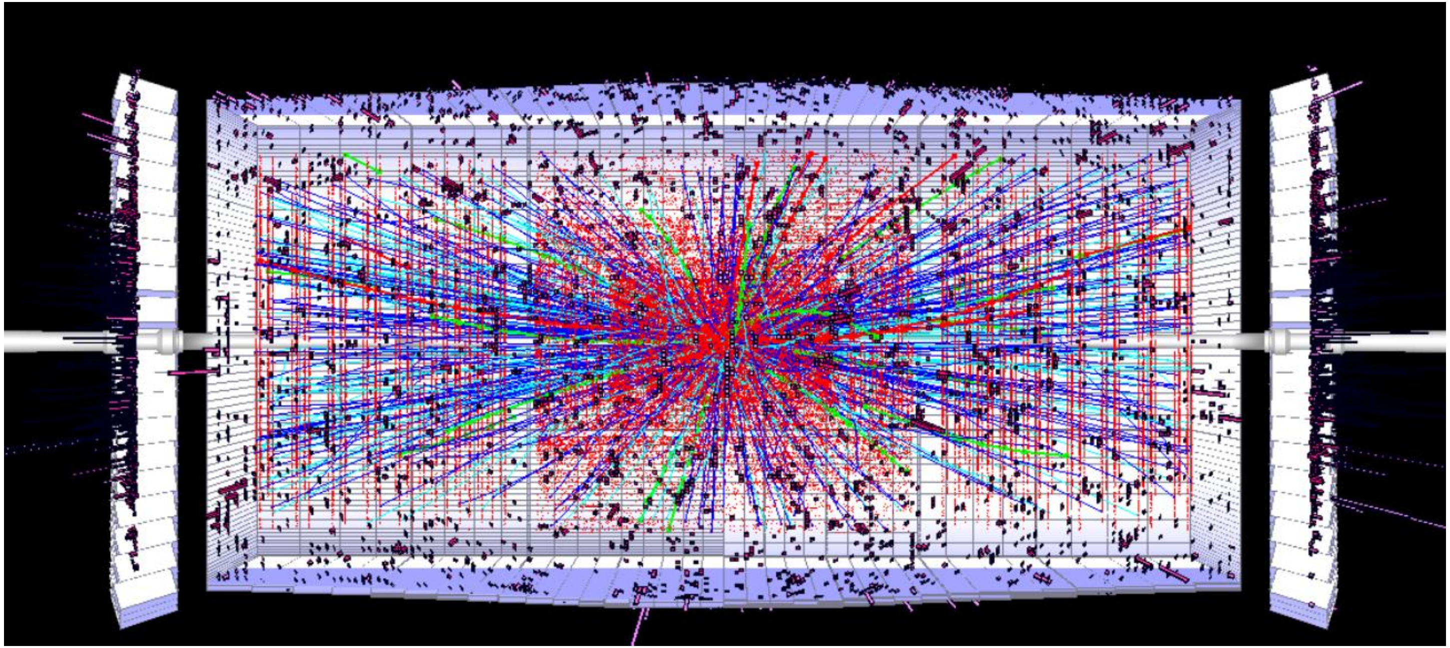
So have we finished our quest? NO! Cosmology tells us that we still miss the most!



SUPERSYMMERTRY:
A Superworld ahead of us?

Sheding light on Dark Matter?
More light to see more…

High Luminosity: a bright future for the LHC
Generate more light → machine upgrade
Better eyes to profit of higher luminosity → detector upgrade



Goal of HL-LHC as fixed in 2010

From FP7 HiLumi LHC Design Study application

The main objective of HiLumi LHC Design Study is to determine a hardware configuration and a set of beam parameters that will allow the LHC to reach the following targets:

A peak luminosity of L_{peak} = **5×10^{34} cm^{-2}s^{-1} with levelling**, allowing:

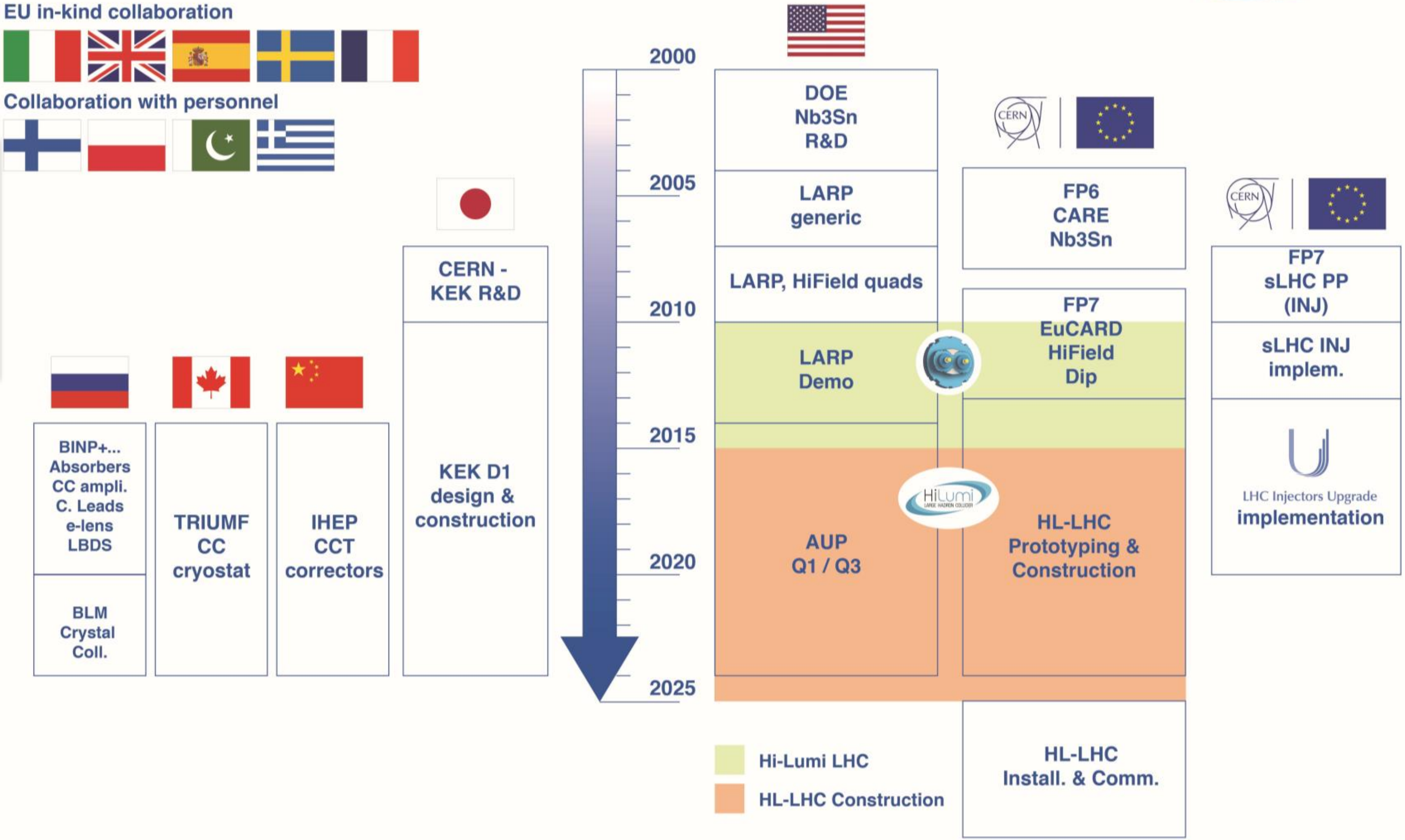
An integrated luminosity of **250 fb^{-1} per year**, enabling the goal of **L_{int} = 3000 fb^{-1}** twelve years after the upgrade.

This luminosity is more than ten times the luminosity reach of the first 10 years of the LHC lifetime.

Launched at end 2010, the HL-LHC project has been approved by CERN Council in June 2016, for start installation in 2024. Total budget of about : 1000 MCHF + 2000 FTE-y CERN (+ collaborators)

IN-KIND CONTRIBUTIONS

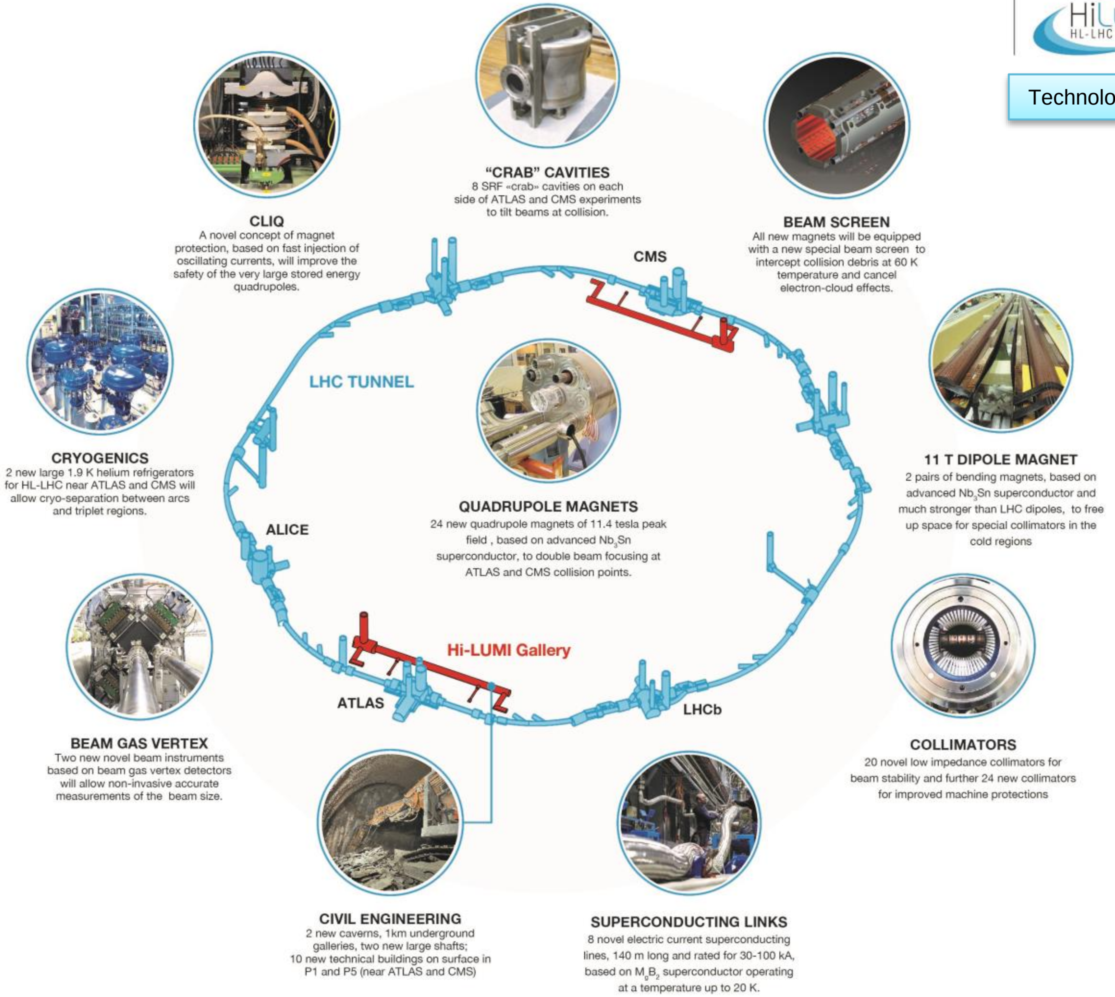
HiLumi:
a global
project
since the
start



HiLumi HL-LHC PROJECT CERN 2019

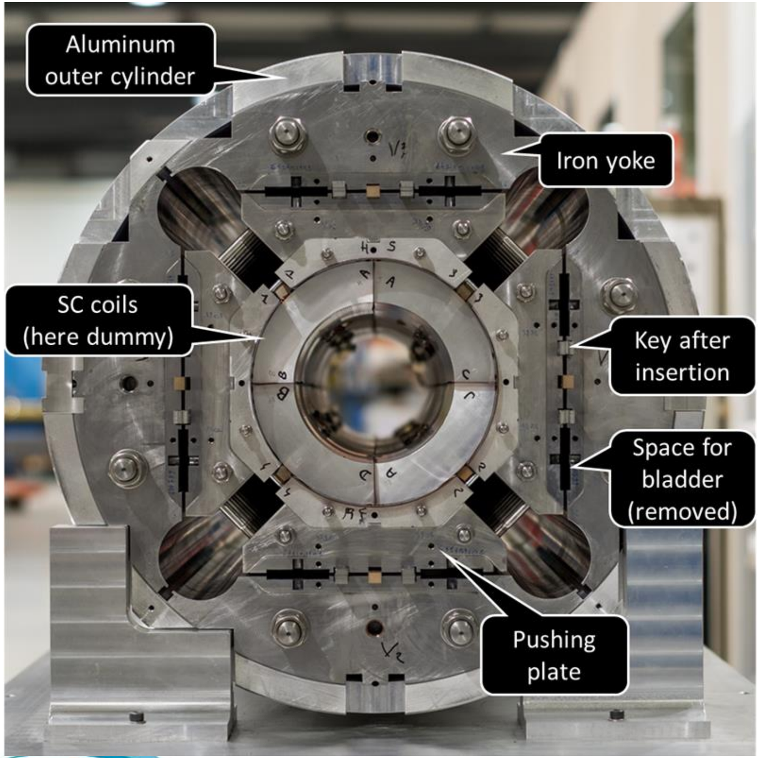
Technology landmarks

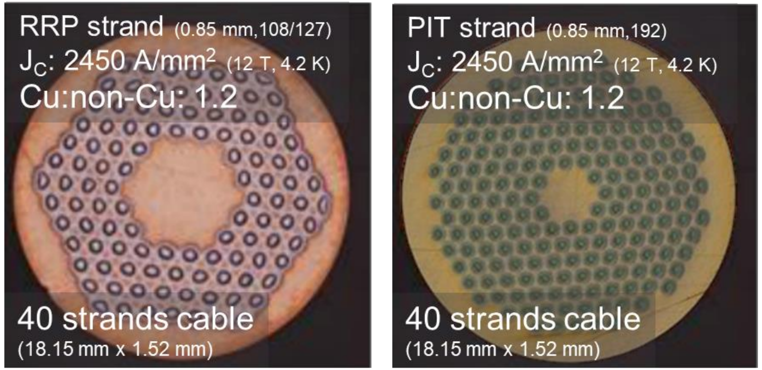
No accelerator project has so many absolute novelties and in such a broad technology spectrum

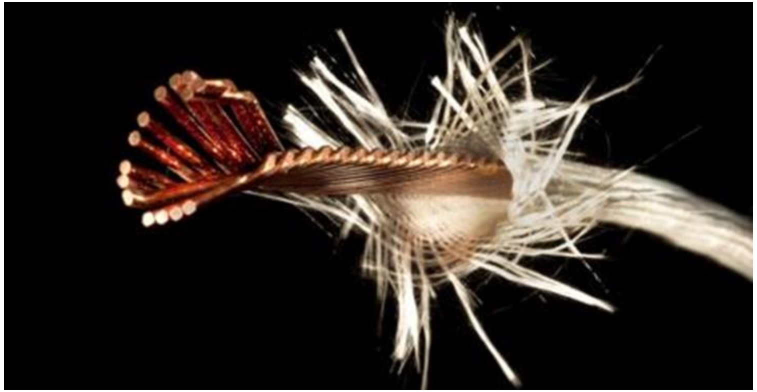


HiLumi HL-LHC PROJECT

New structure to accomodate brittleness of the Nb_3Sn superconductor – 20 kA @ 12 teslas







Real Nb3Sn magnets are coming… first time in an accelerator… and not the smallest one!

11 T dipole

IT QUAD Q2a/Q2b

IT QUAD Q1/Q3

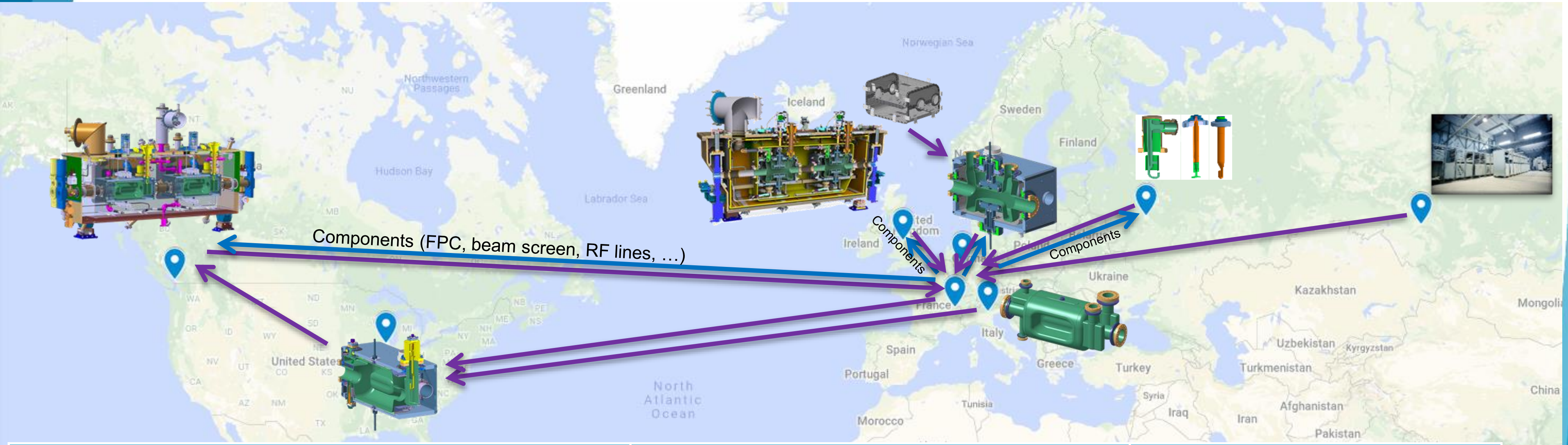
Crab Cavity consruction for SPS test at CERN (DQW type)

FPC on in Conditioning
Test box & installation of DT

FPC installation onto cavity

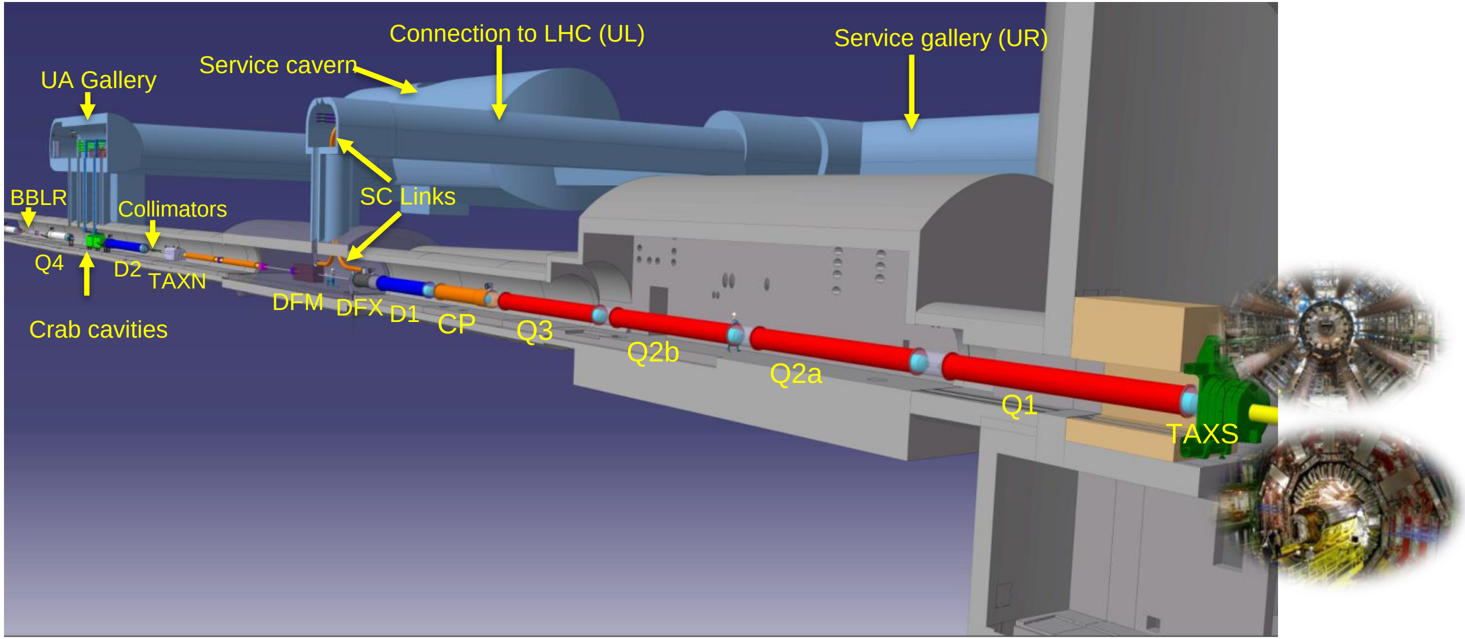
String assembly completed
Aug 18, 2017

Crab Cavity Series (CERN, Canada, Russia, UK, US-AUP)



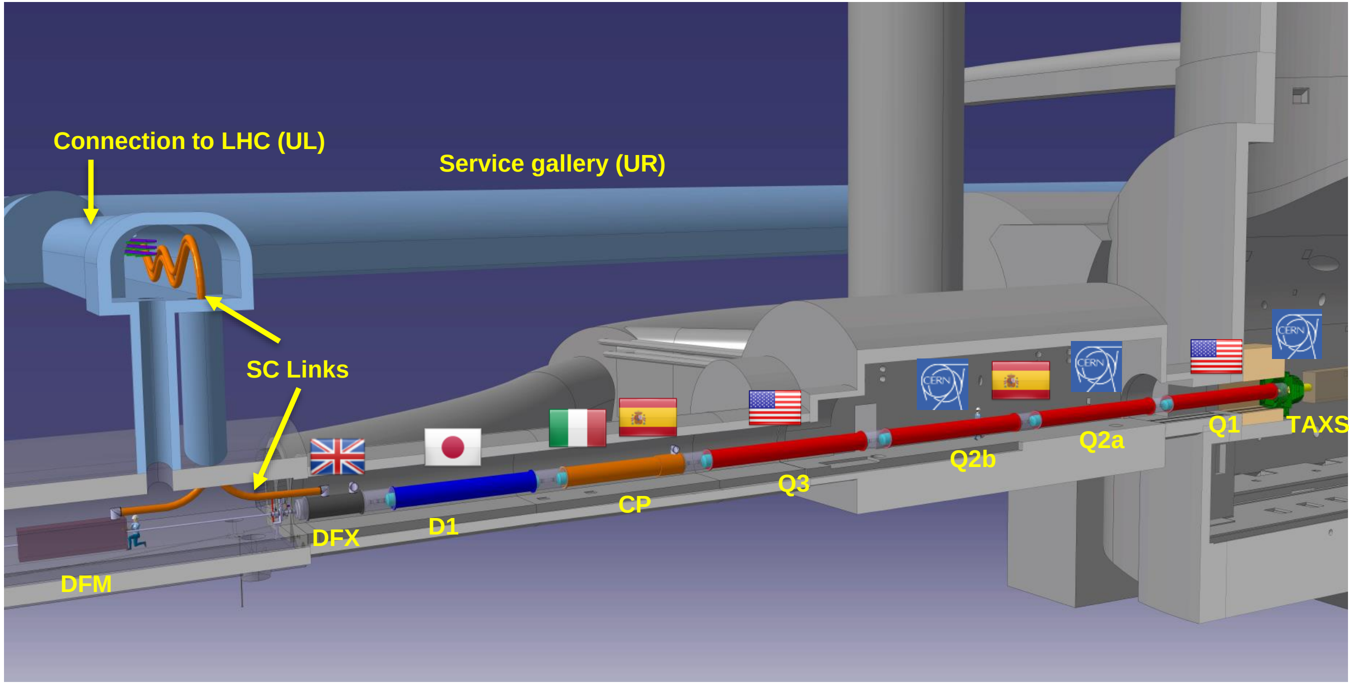
DQW cryomodules (5)	RFD cryomodules (5)	Solid State RF Systems (20)
• Cavities + processing + helium vessels by Research Instruments (**DE**) under **CERN** • Cold magnetic shields by **UK** • HOM couplers + antennas by **MEPHI-Russia & CERN** • 4 CM by **UK** (STFC) & 1 CM at CERN with some components by **CERN** • All cavities & CM cold validation tests at **CERN** (and a few at Uppsala-Sweden)	• Bare cavities by Zanon (**IT**) under **US-AUP** • Processing + cold magnetic shield + helium vessel + HOM couplers + antennas + cold tests by **US-AUP** • 5 CM by **TRIUMF-Canada** with some components by **CERN** • CM cold validation tests at **CERN**	• High power solid state amplifiers by **BINP-Russia** • First step, one amplifier prototype for qualification of SSPA technology

The Insertion Region (till Q4)

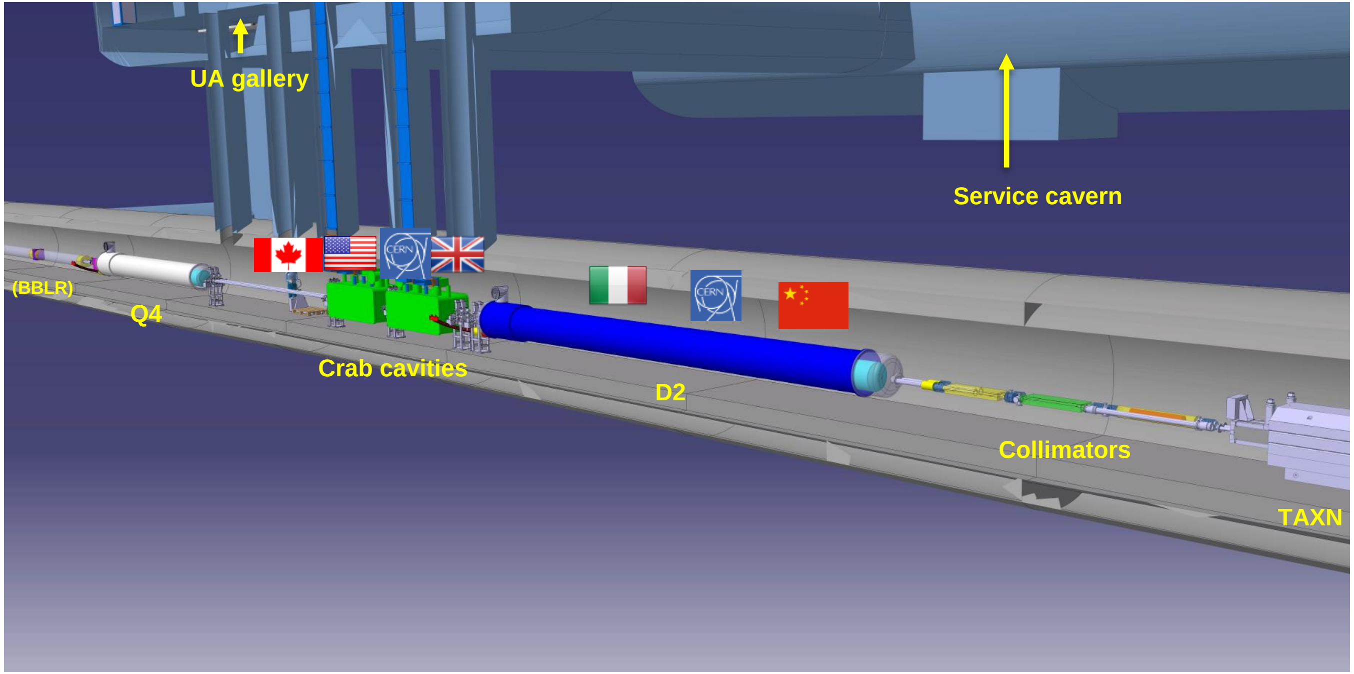


In total about 1.2 km of the LHC will be replaced by new technologies!
Biggest HEP project of this decade, but it has a reasonable size (25-30% of the LHC) to be a test-bed for new technologies…

The Inner Triplet region with in-kinds

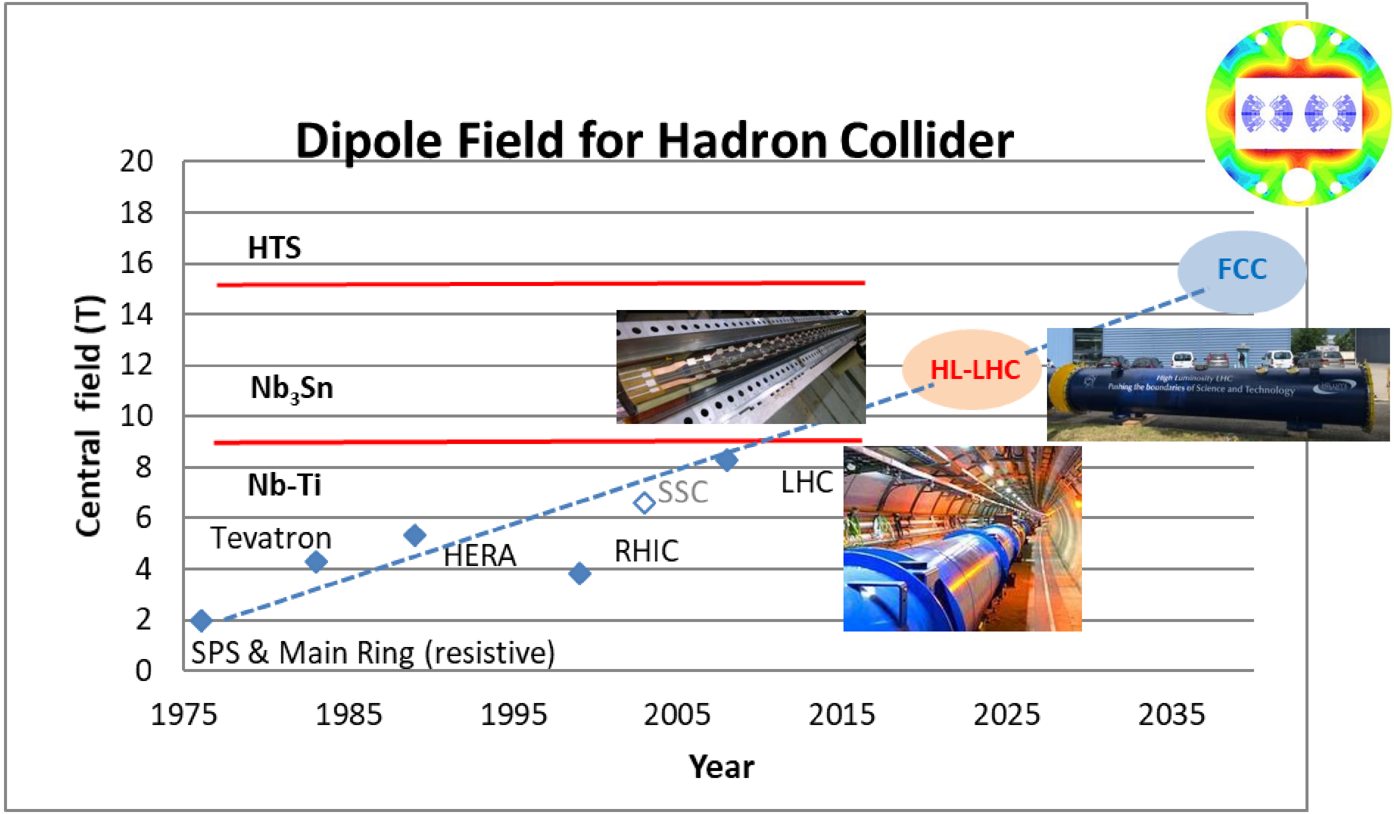


The MS (matching section) region with in-kinds

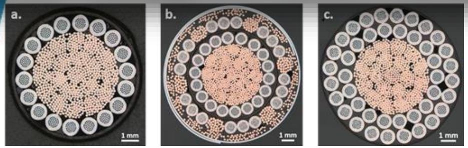


HiLumi HL-LHC PROJECT

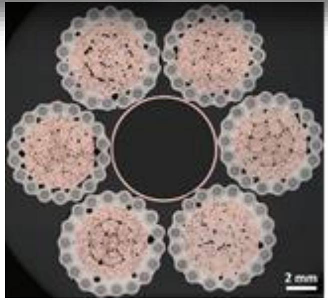
With HiLumi we prepare the technology for a future leap in hadron collider technology…

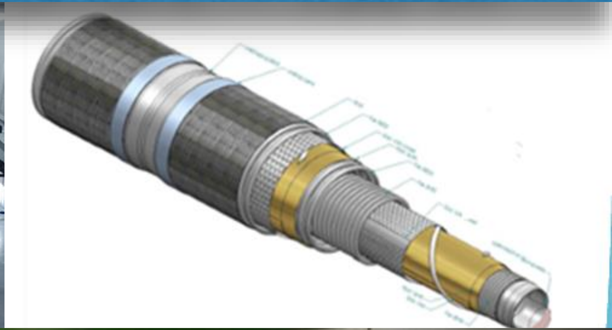


New superconducting links for 100 kA current – 130 m



MgB_2
superconductor

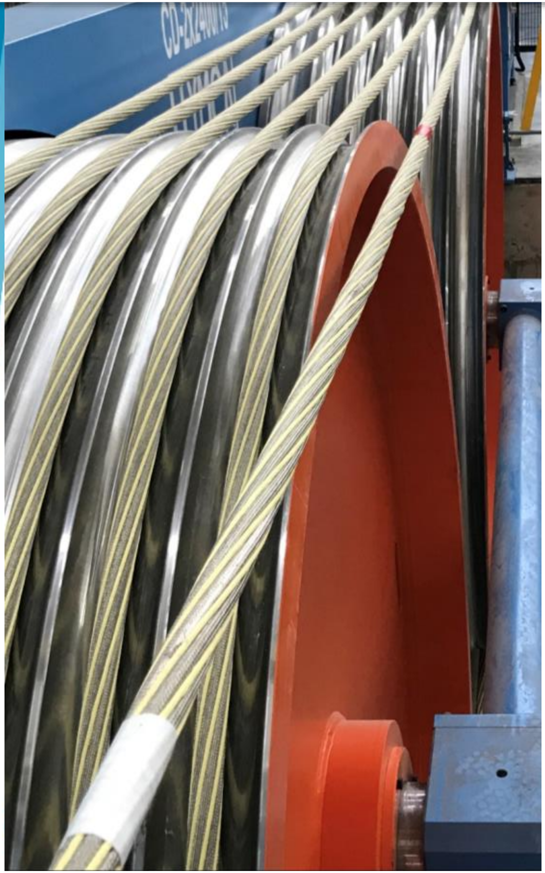


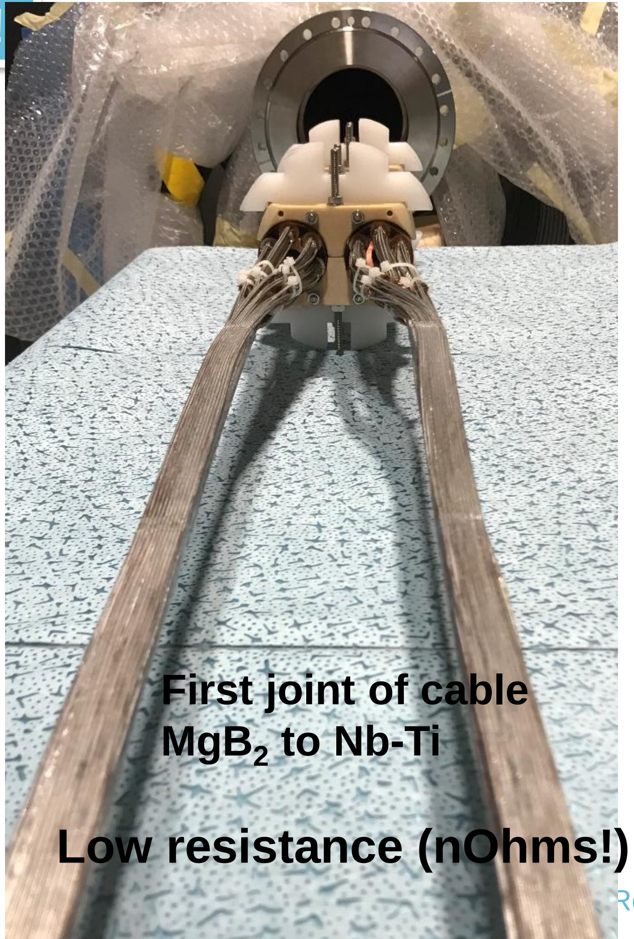


Amalia Ballarino, CERN

SC Links inside flexible cryostat: first 60 m long prototype 100 kA cable tested at CERN

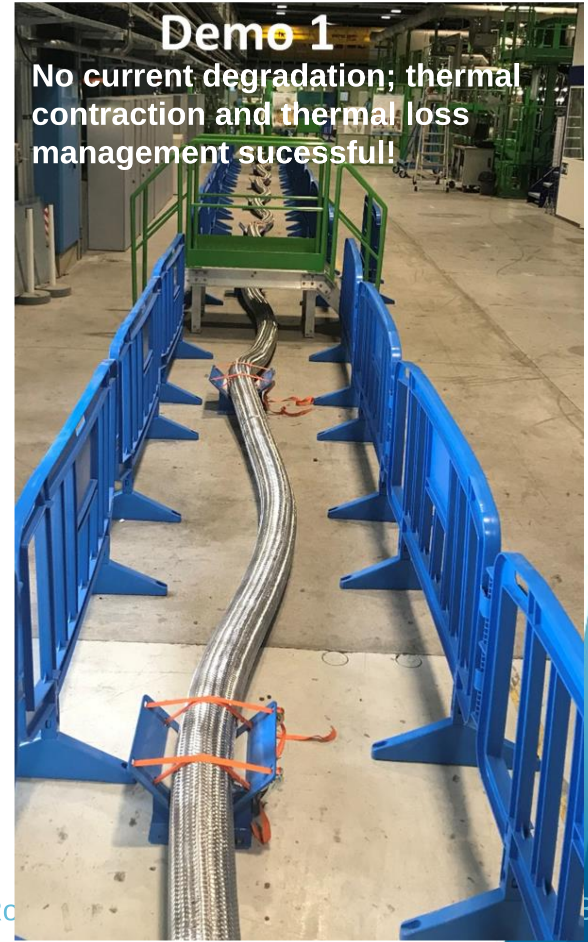
First long length of 100 kA MgB_2 cable tested June 2020!





First joint of cable MgB_2 to Nb-Ti

Low resistance (nOhms!)



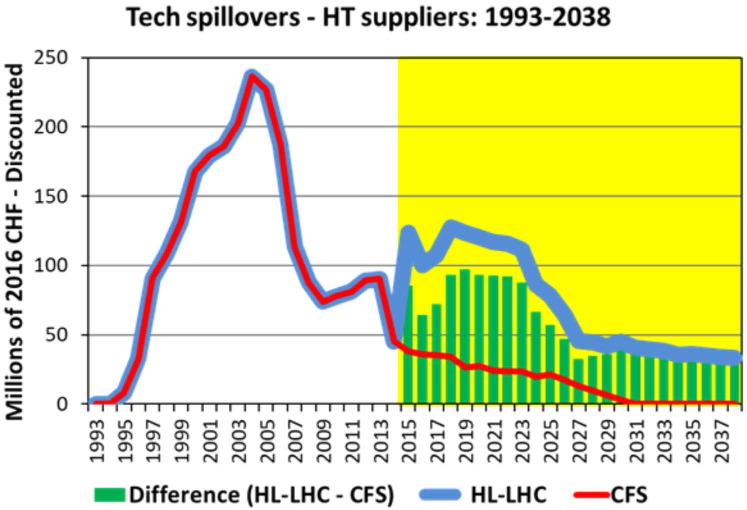
Demo 1

No current degradation; thermal contraction and thermal loss management sucessful!

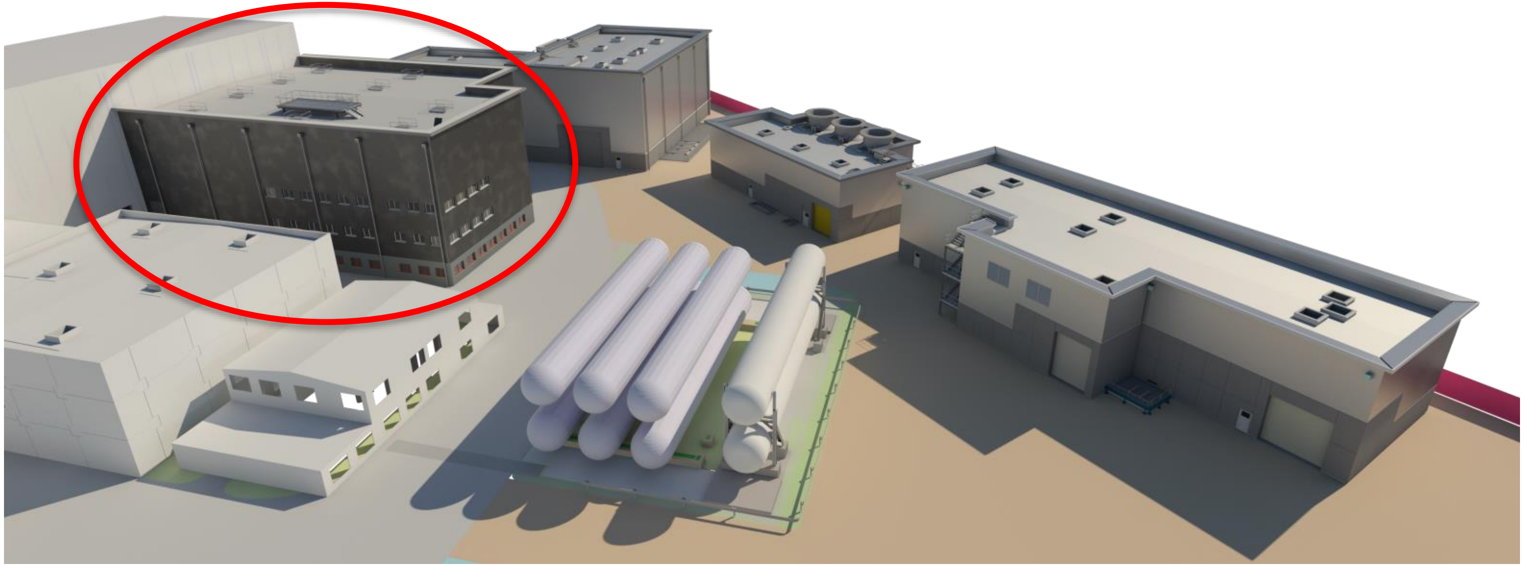
Avec un retour economique prouvé

A recent study of the University of Milan Economy Dept, has estimated that for each CHF invested in the HL-LHC there is a net gain for HiTech companies of about 1.7 CHF

- Technology return to industry
- Training
- Public cultural effect
- Publications of scientific articles

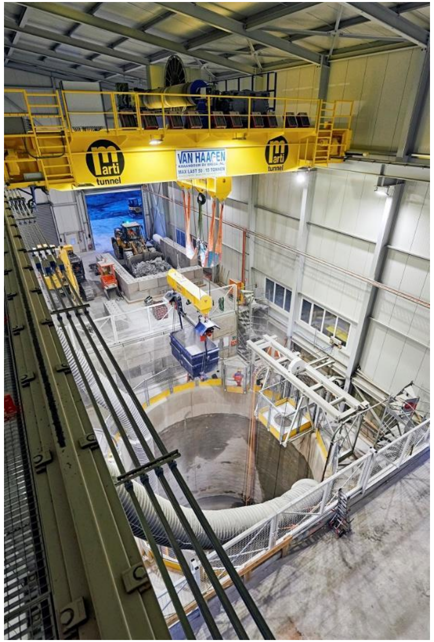


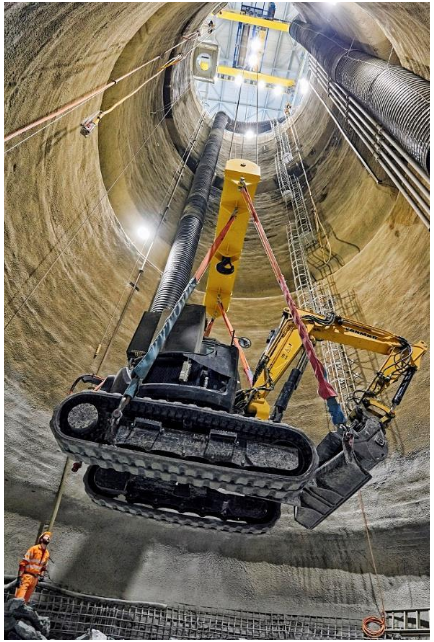
Chantier SXA5



Contract T117 – JVMM – LHC P1 (ATLAS)

Contract T117 – JVMM – LHC P1 (ATLAS)





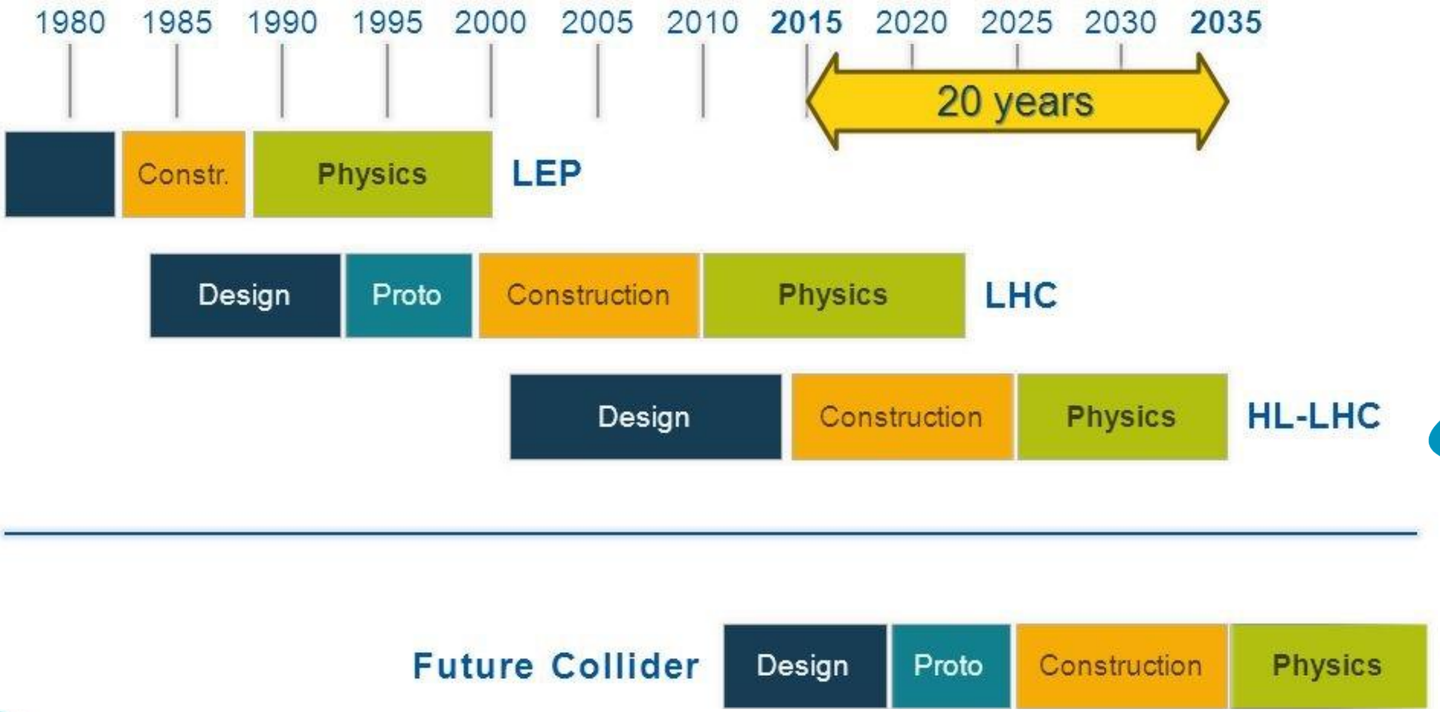
Contract T117 – JVMM – LHC P1 (ATLAS)

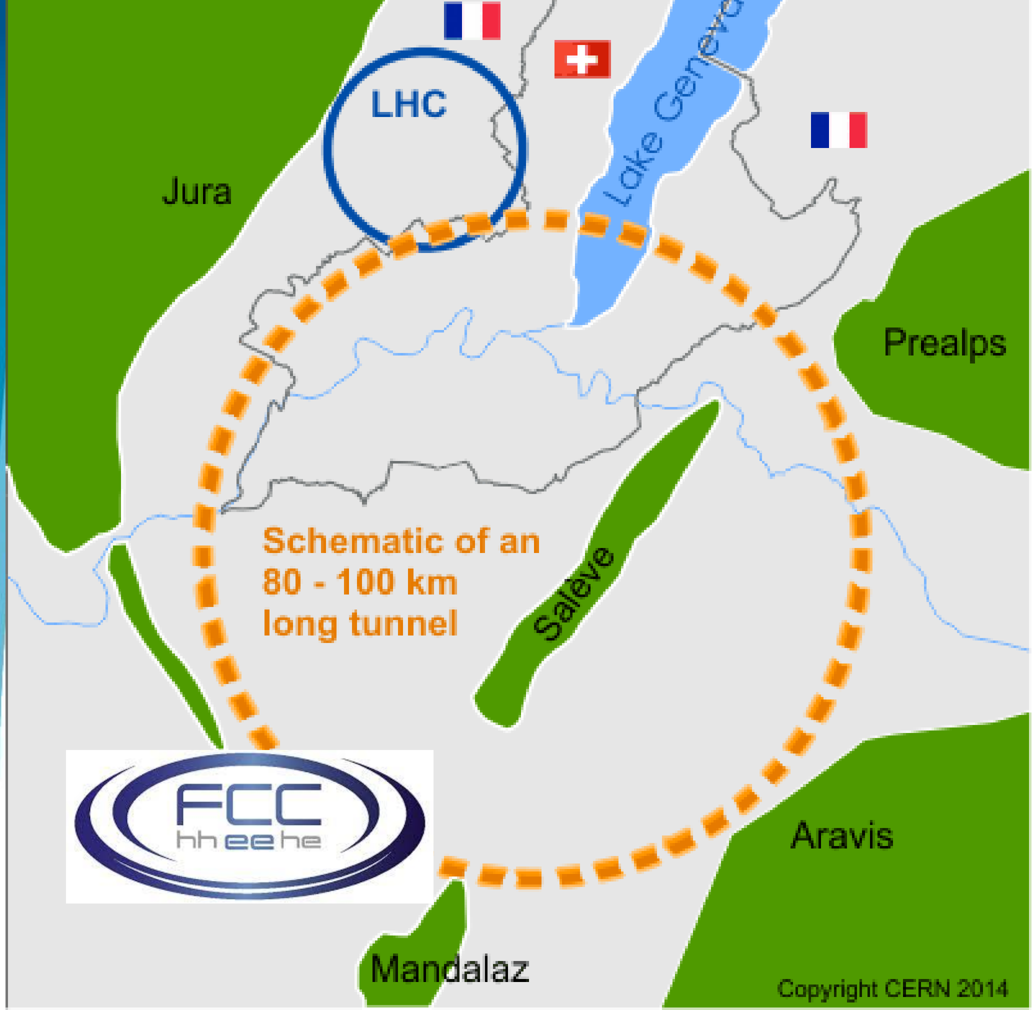
Pictures CE

Santa Barbara, patron saint of miners

Do we have a plan to go behond? YES, we do...

CERN Circular Colliders + FCC





Circular collider in new tunnel

80- 100 km circumference

Circular proton-proton collider
100 TeV collision energy (p+p)

Circular electron-positron collider (VLEP)
(***350 GeV c.m.*** energy, t-tbar threshold)

Lepton-Hadron collider (like HERA)
(***50 TeV p + 100 GeV e***)

Alternatively:

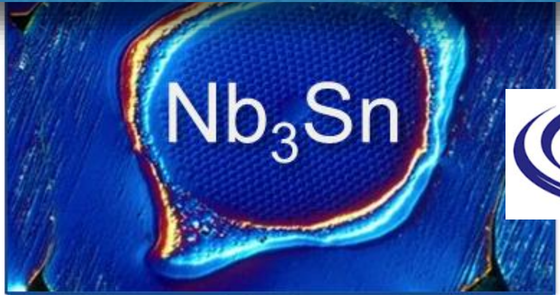
30 TeV p-p collider in LHC tunnel ?
(***16 T magnets***)

Conceptual design report ~ late 2018

Competition? Yes, guess form whom…

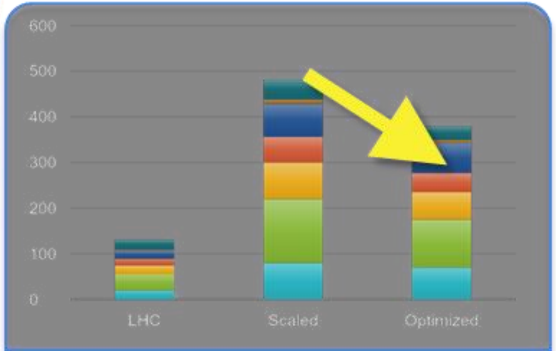
FCC is the natural evolution of HL-LHC with new technology advancement

High-field Magnets



Novel Materials and Processes

Large-scale Cryogenics

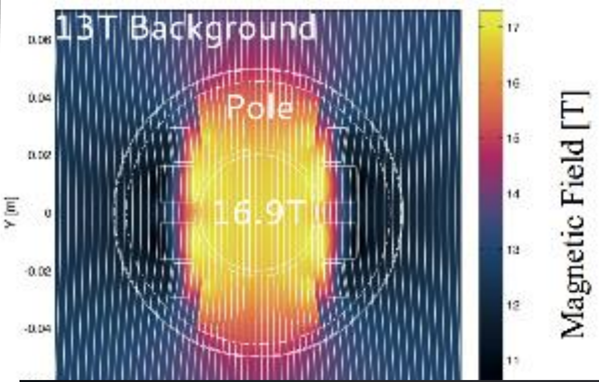


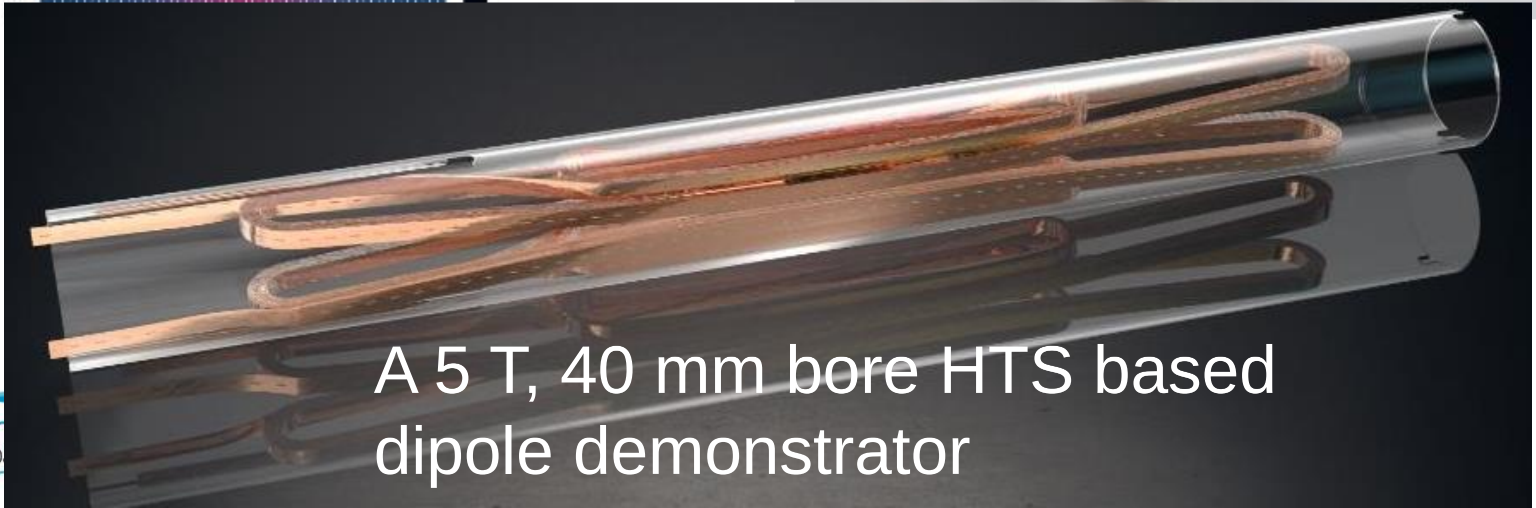
Power Efficiency

Reliability & Availability

Global Scale Computing

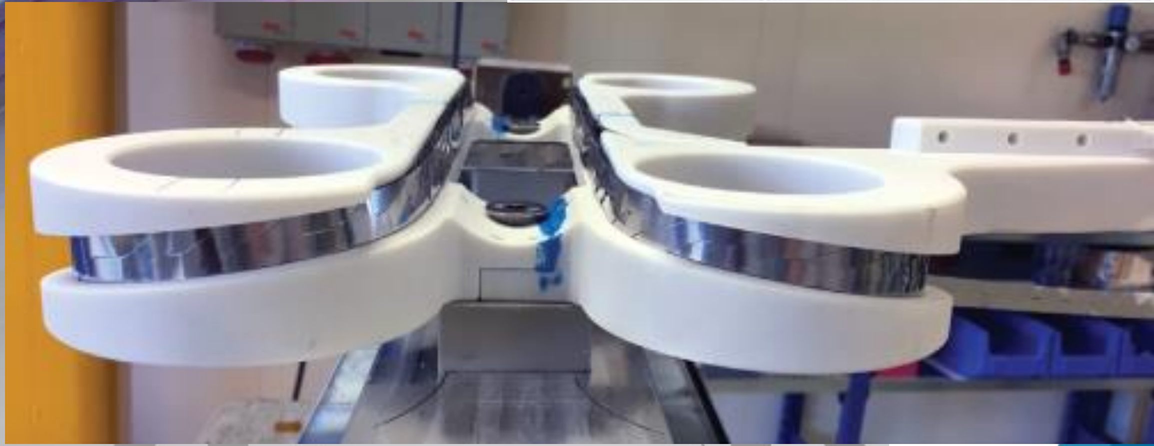
High Temperature Superconductors – HTS
The dream of 20-25 tesla! (2 x HilumiLHC!)





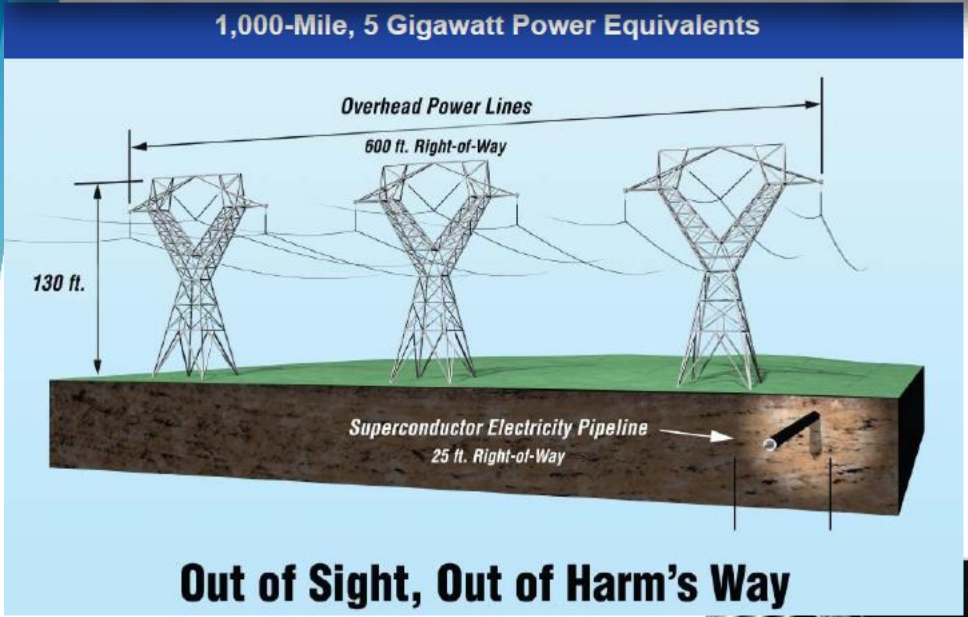
A 5 T, 40 mm bore HTS based dipole demonstrator

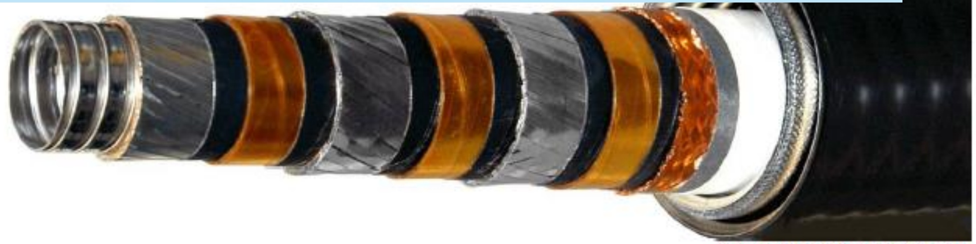
Trying the magnets of the future… 20 tesl or more...



How to go to increase collision energy of constituents

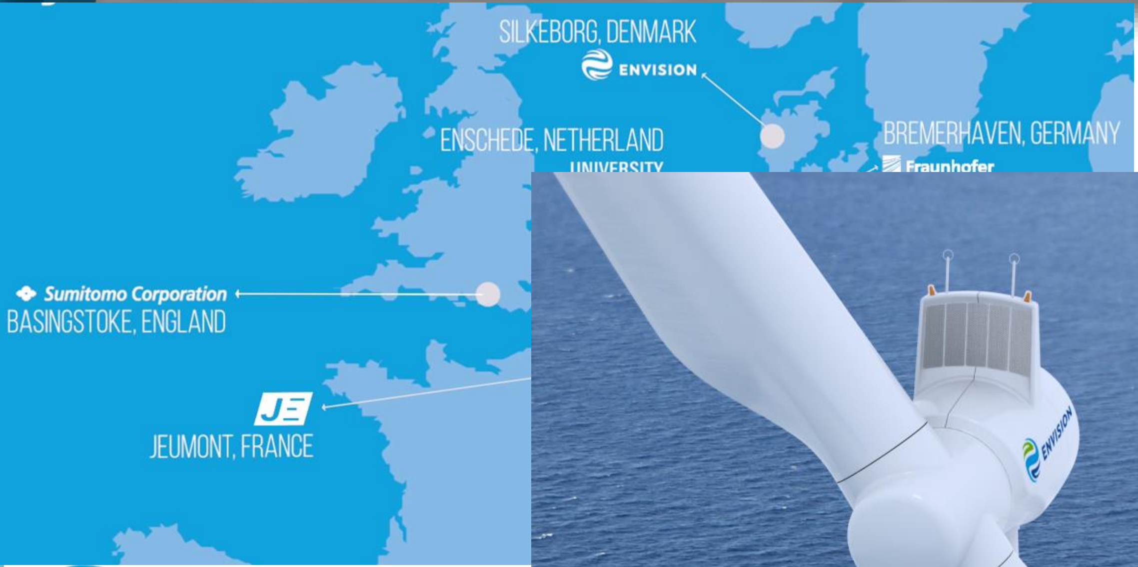
SC and Renewable Energy Technology: Transmission





Courtesy Southwire Company

SC and Renewable Energy Technology: wind generators



ecoswing

AMSC SeaTitan Wind Turbine Generator
Image courtesy of American Superconductor

HiLumi HL-LHC PROJECT

New medical «eyes»: PET

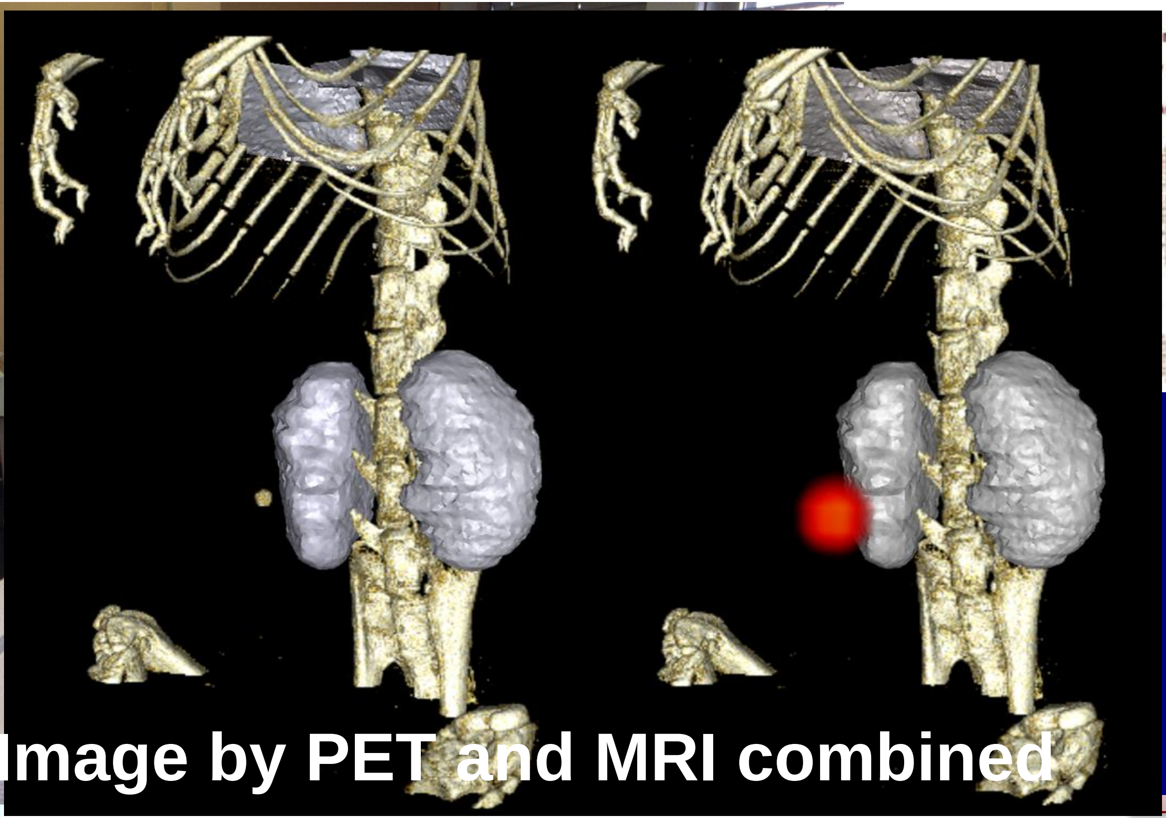
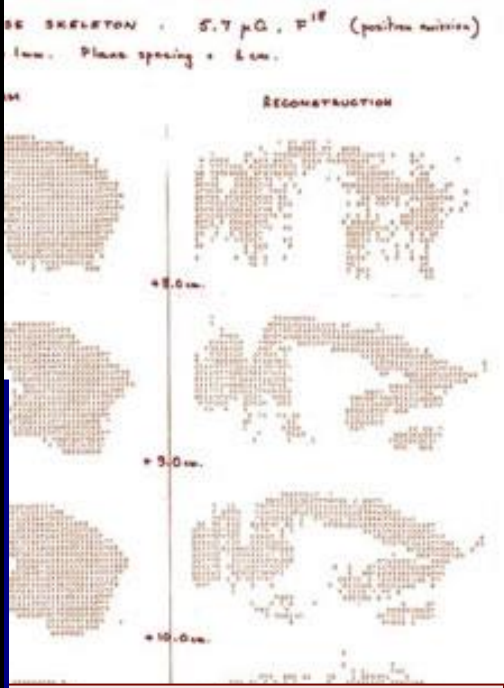
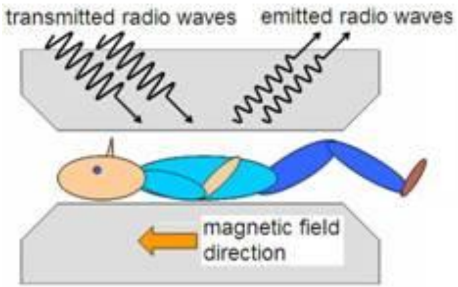


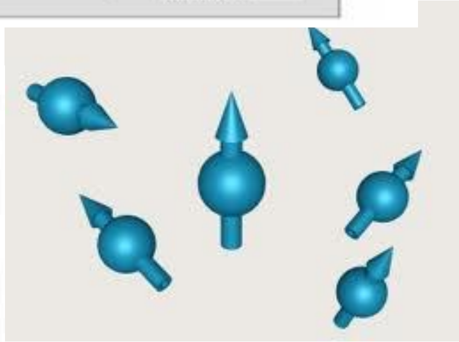
Image by PET and MRI combined



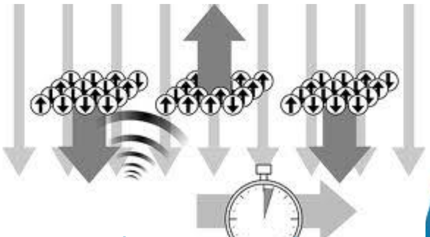
First PET image: CERN, circa 1975

New medical «eyes»: MRI, 2000 large systems/year

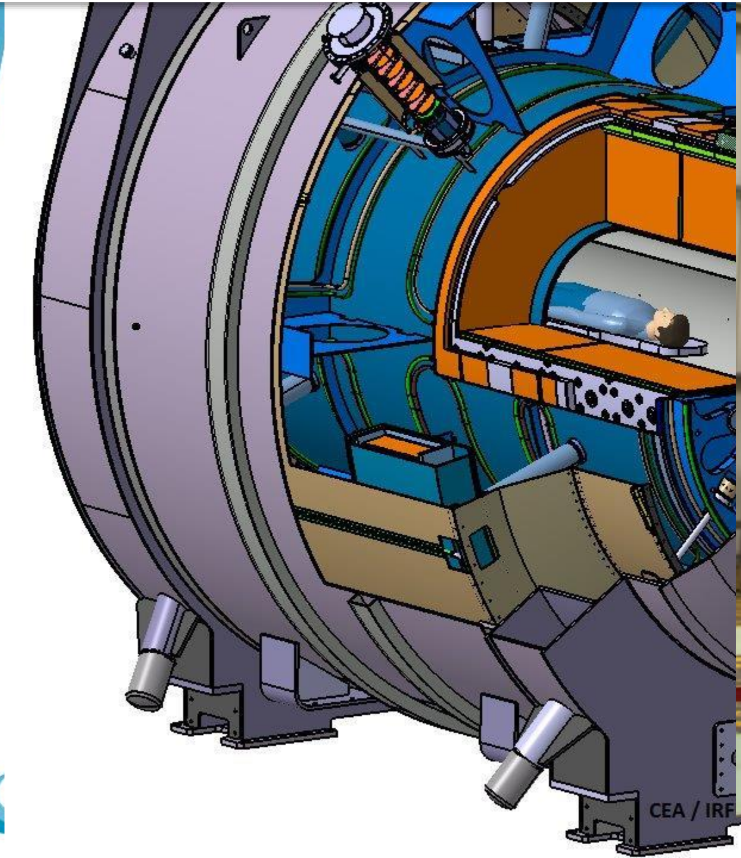




An example of an MRI brain scan
Image courtesy of Scott Camazine, MD



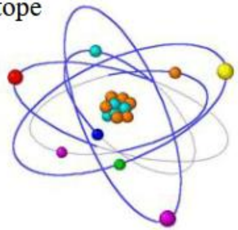
Largest MRI for research: Iseult Magnet for 11.7 T, now under commissioning at Neurospin center in CEA Saclay (Paris)
FUNCTIONAL MRI: breakthrough in cerebral functions



Production of radioisotopes for PET is critical

Radioisotopes in Nuclear medicine

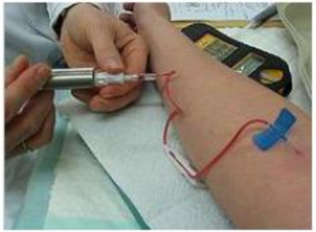
Radioisotope



Radiopharmacy

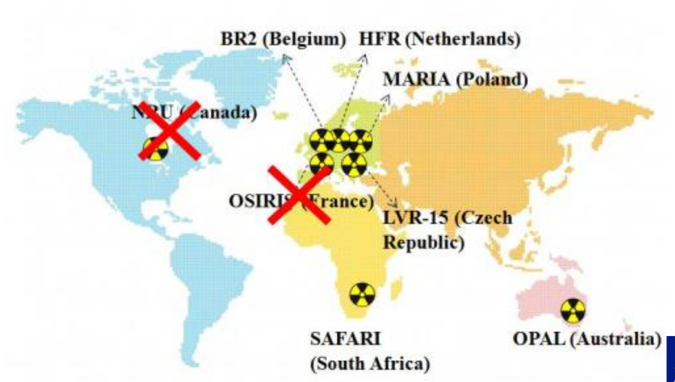
Radiopharmaceutical

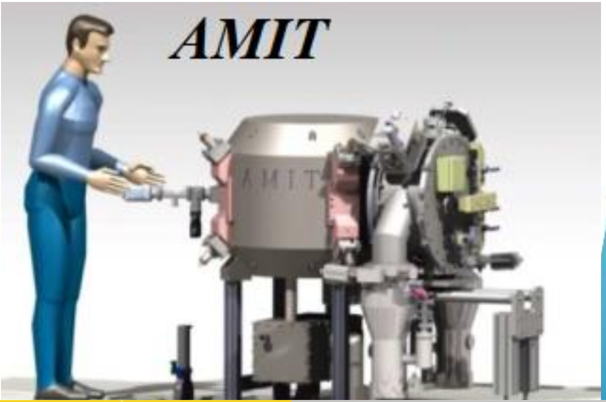
A ^{11}C labeled radiopharmaceutical



Localized in some organs or tumors

Last decade crisis in reactor-production





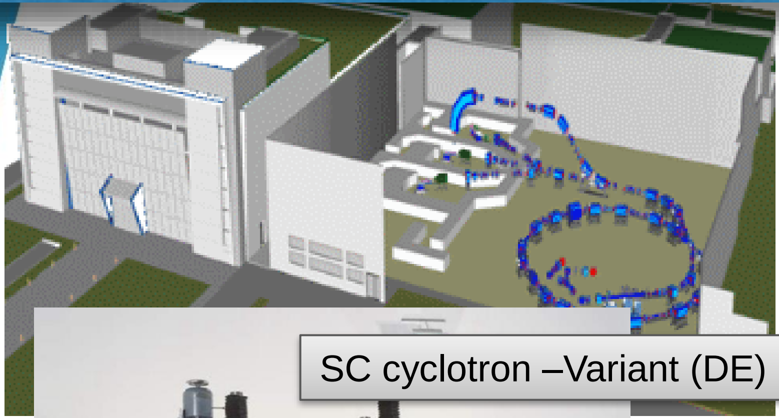
GOBIERNO DE ESPAÑA

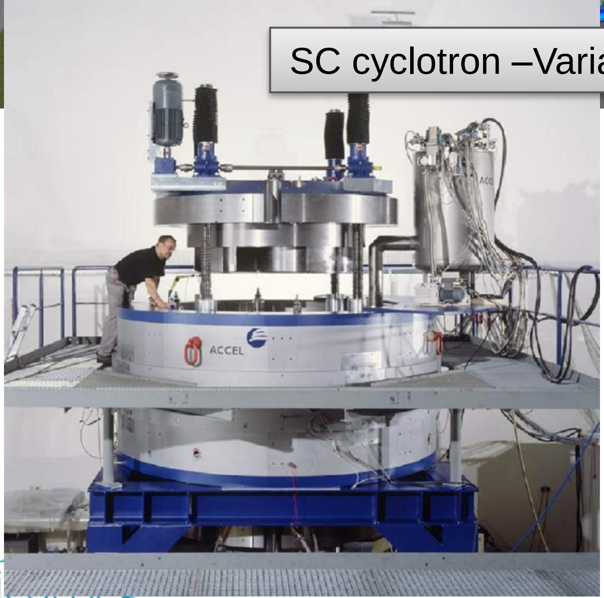
MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

HiLumi HL-LHC PROJECT

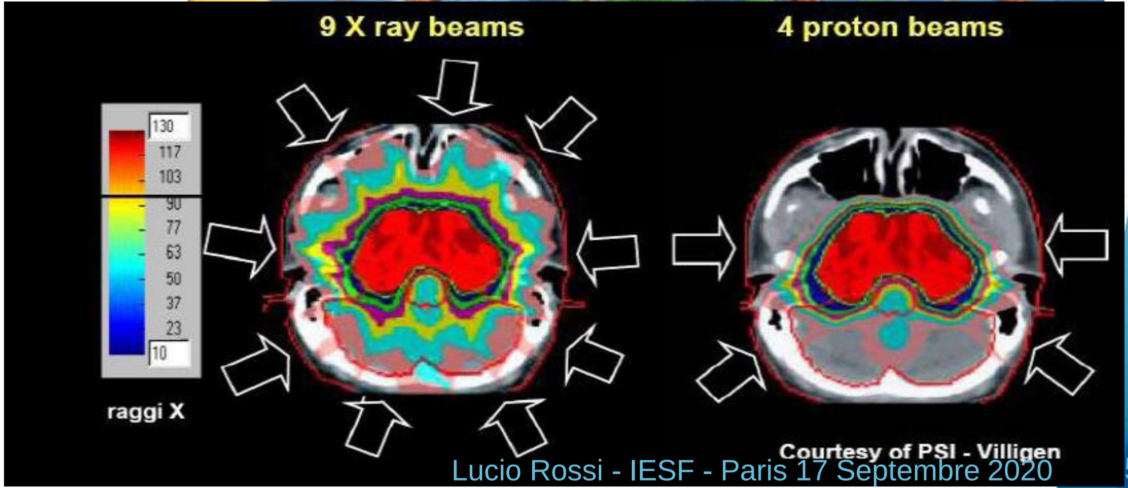
Hadron therapy





SC cyclotron –Variant (DE)

Synchrotron in Pavia (CNAU), IT



Merci pour votre attention!

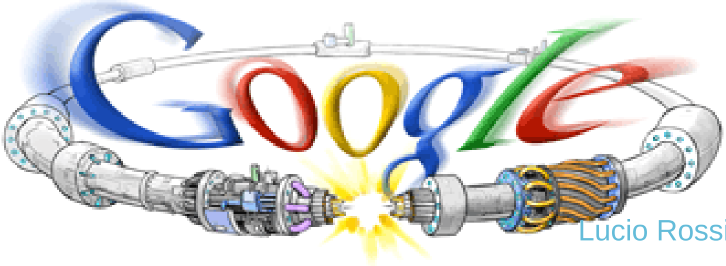
As any activity people tend to look for «stars»

But is like football: it is the team that wins!

The Magnet team (with DG!) at the end of LHC magnet Production

The HiLumi team at the collaboration meeting 2018 - CERN

10 september 2008: the success!

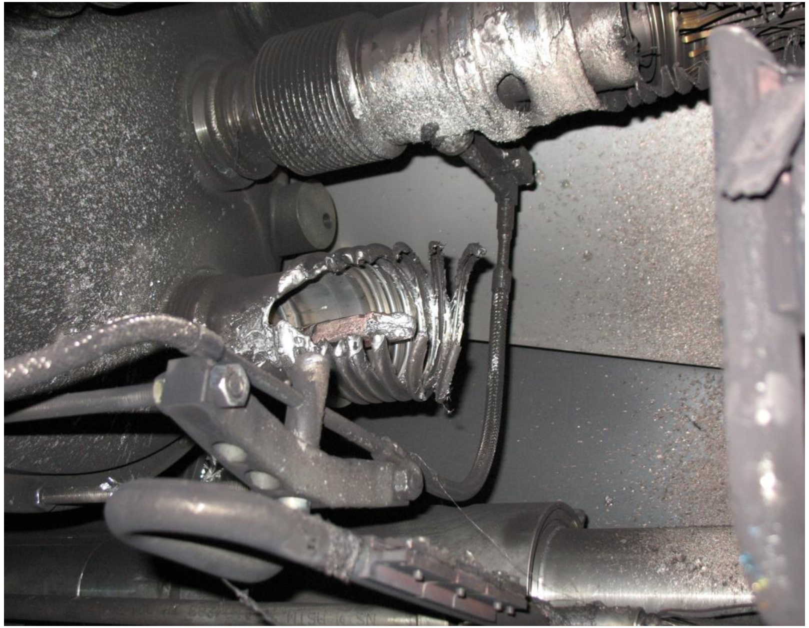


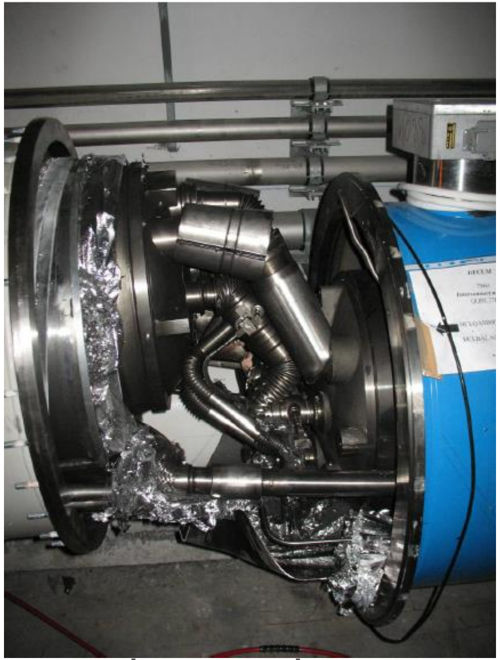
HiLumi
HL-LHC PROJECT

19 september 2008:
The big trouble: magnet interconnection

Vedere articolo su http://www.ilsussidiario.net/articolo.aspx?articolo=48957

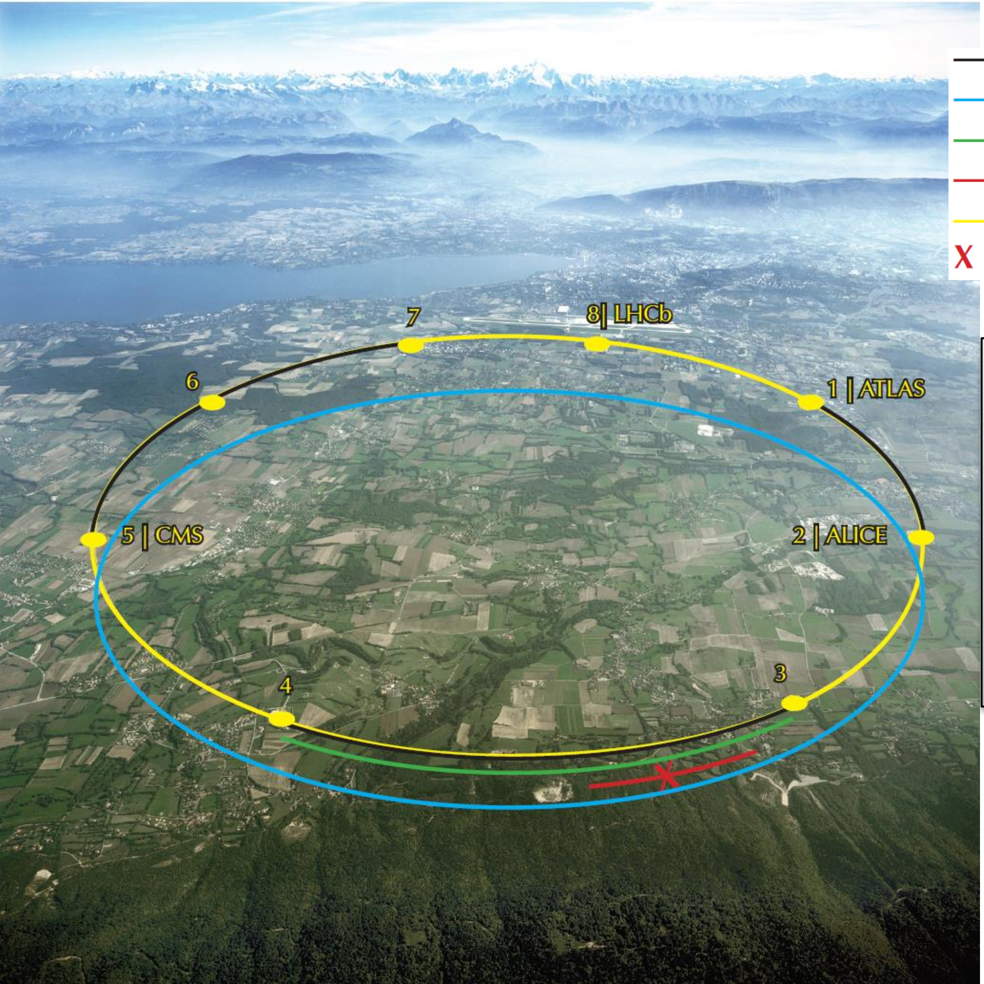
Very large damage





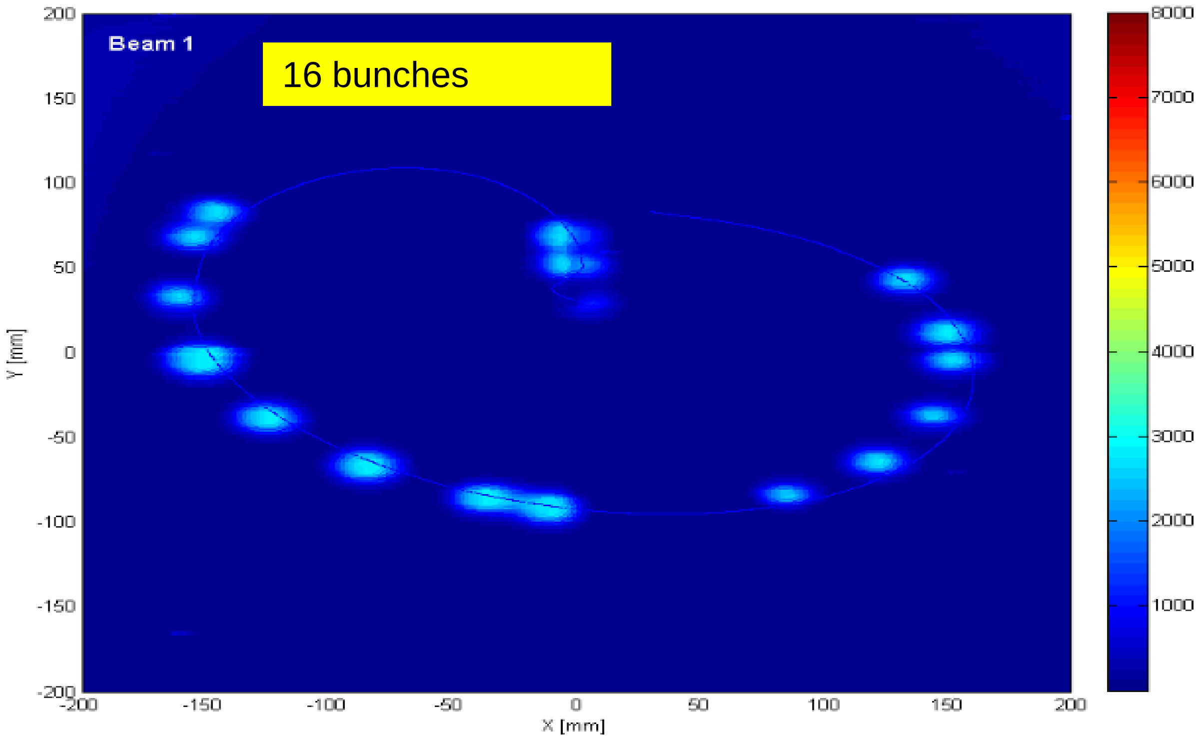
- A design not robust vs bad workmanship or weak procedure
- Procedural defect not identified by QA/QC
- Missing of “eyes” , aka diagnostics, to see defect in time to fight them
- Lack of protection vs collateral damage

Dove ha luogo la riparazione



The re-start:
Awareness that the «common good» is is the only way for a real and sustainable .
In this respect the «mistake», the fault, is not a barrier/obstacle, rather is a push to go beyond our limit and become better…

LHC: the re-start , first beam
13 december 2009 : record 2 × 1.18 TeV



L’importanza del Maestro

- Il tramandarsi una tradizione tiene viva la domanda $\Rightarrow$ grandi scuole di fisica
- **Assicura, aiuta, che l’esperienza sia un cammino verso una certezza piu’ grande con un metodo che è quello di tutte le realtà umane positive:**
- Verifica onesta: esperienza
- Dedizione, affezione
- Capacità di lavorare insieme
- Confronto tra l’esperienza e l’ipotesi
- Condivisione risultati: da questo la domanda si alimenta