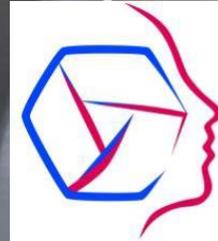


La grand collisionneur LHC du CERN : Les nouvelles technologies pour la découverte de l'infiniment petit



IESF

SOCIÉTÉ DES INGÉNIEURS ET
SCIENTIFIQUES DE FRANCE



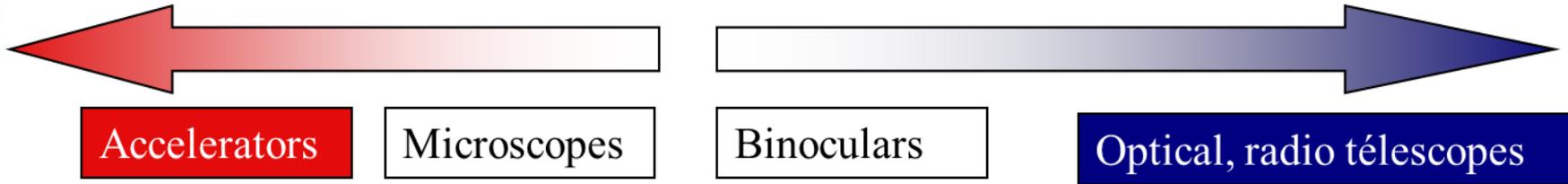
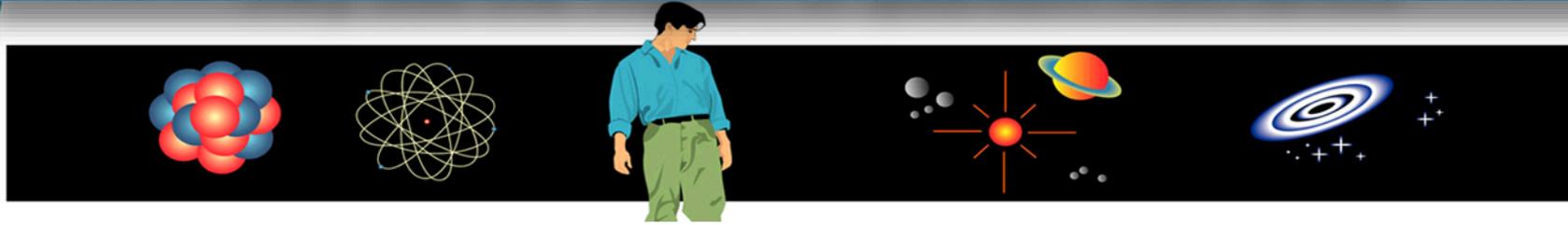
André-Marie Ampère

Lucio Rossi – CERN

HL-LHC Project Leader (2010-1 Juillet 2020)

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!*

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



Accelerators also a wonderful «time machines»

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

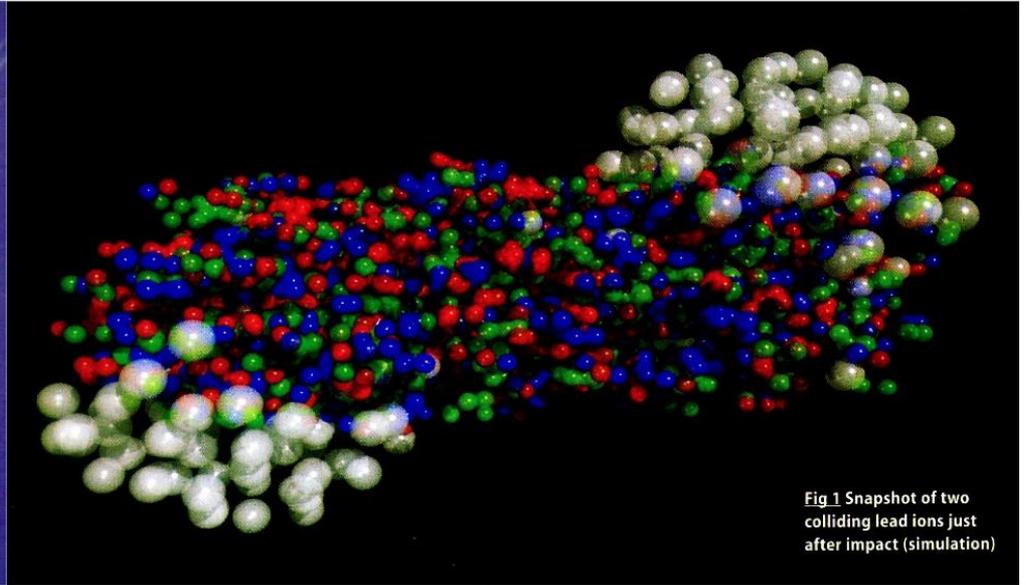
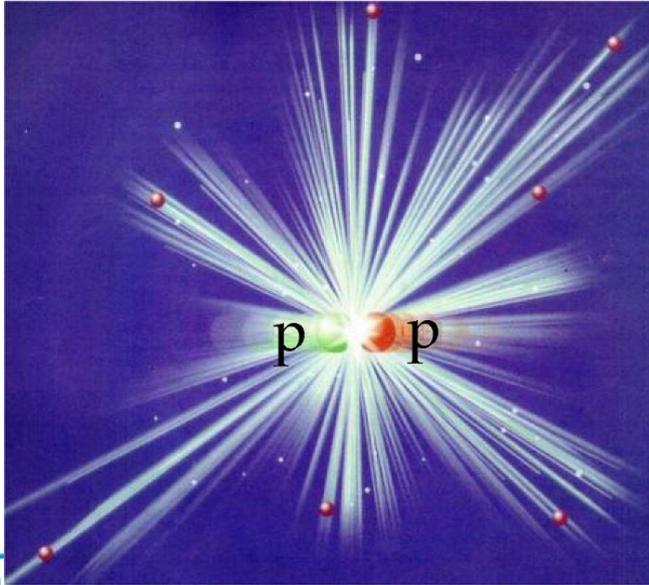
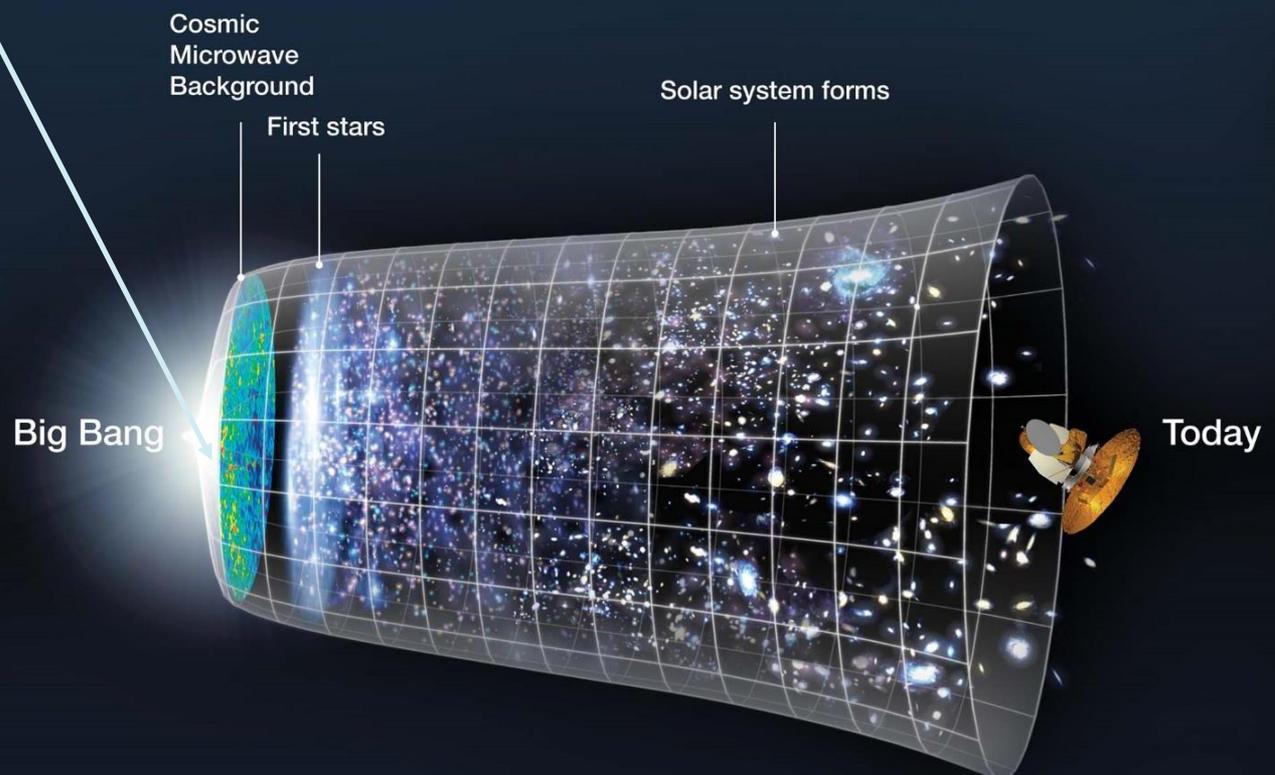


Fig.1 Snapshot of two colliding lead ions just after impact (simulation)

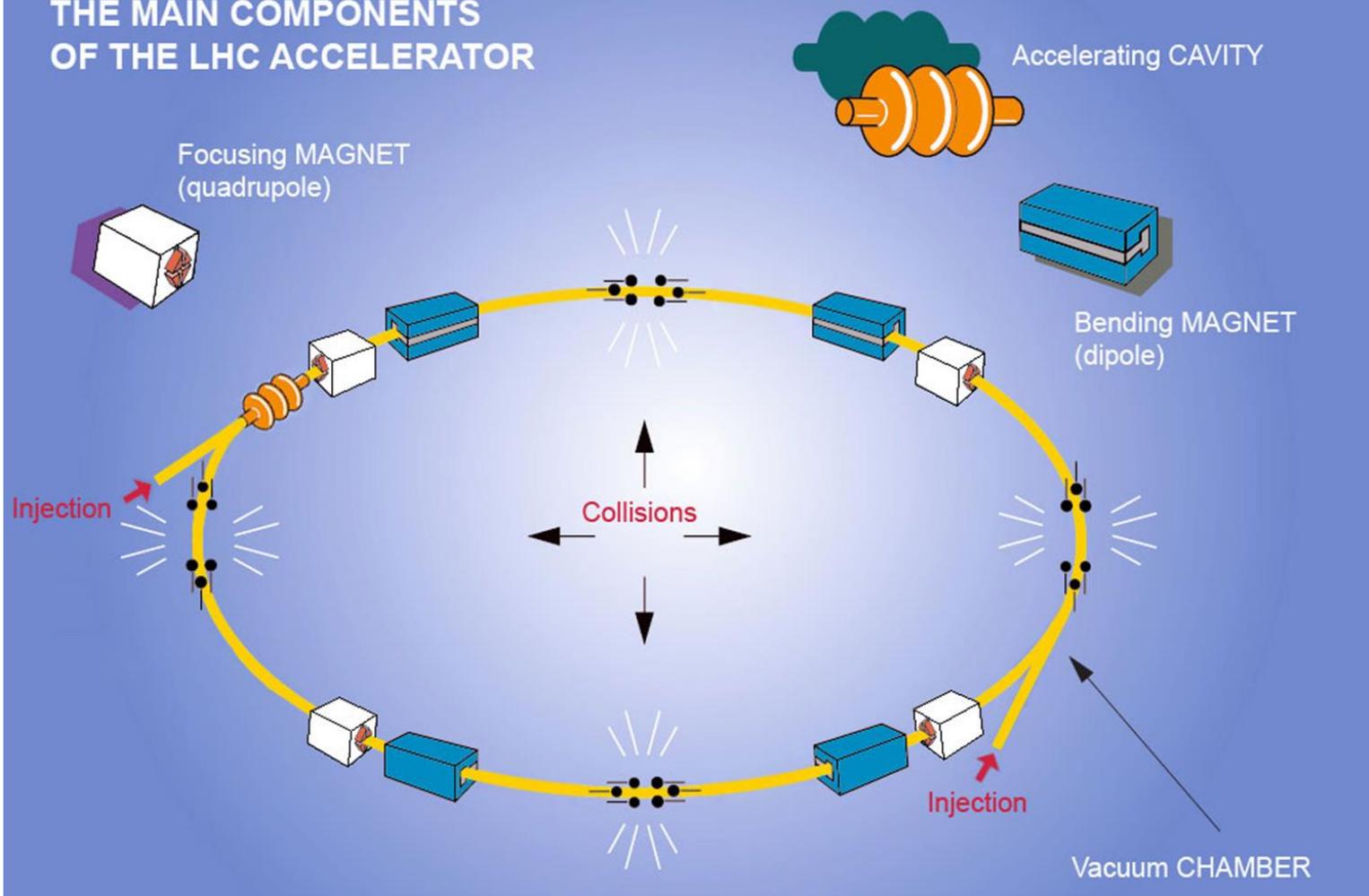
The Universe (and all particles within) is 13.8 billion years old

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



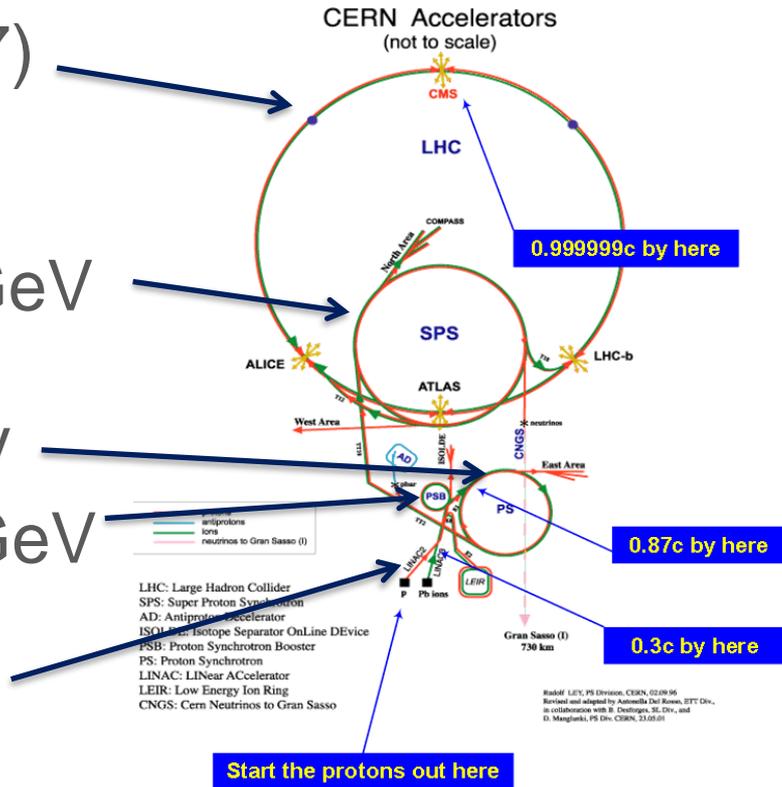
13.8 billion years

THE MAIN COMPONENTS OF THE LHC ACCELERATOR



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

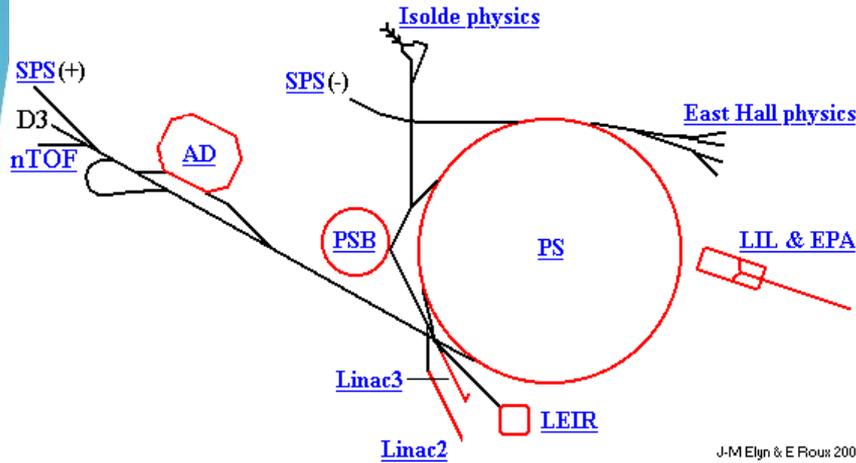
Magnetic structure of PSB
Length : 150 m



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



New neutrino exp. area

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

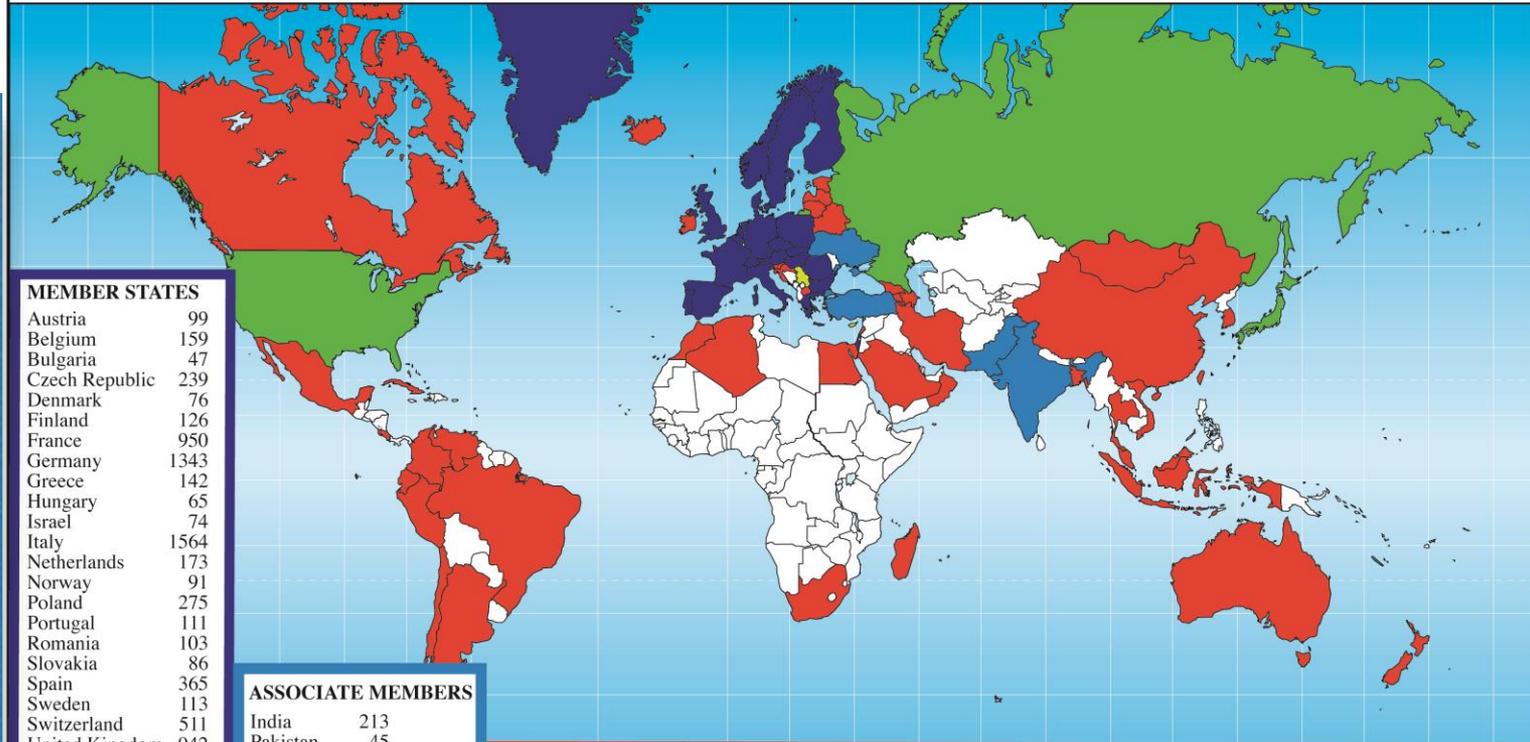
Associate Member States: India, Pakistan, Turkey, Ukraine

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

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

Distribution of All CERN Users by Location of Institute on 12 January 2017

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



MEMBER STATES

Austria	99
Belgium	159
Bulgaria	47
Czech Republic	239
Denmark	76
Finland	126
France	950
Germany	1343
Greece	142
Hungary	65
Israel	74
Italy	1564
Netherlands	173
Norway	91
Poland	275
Portugal	111
Romania	103
Slovakia	86
Spain	365
Sweden	113
Switzerland	511
United Kingdom	942

7654

ASSOCIATE MEMBERS

India	213
Pakistan	45
Turkey	128
Ukraine	30

416

OBSERVERS

Japan	294
Russia	1046
USA	2018

3358

ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP

Cyprus	15
Serbia	35

50

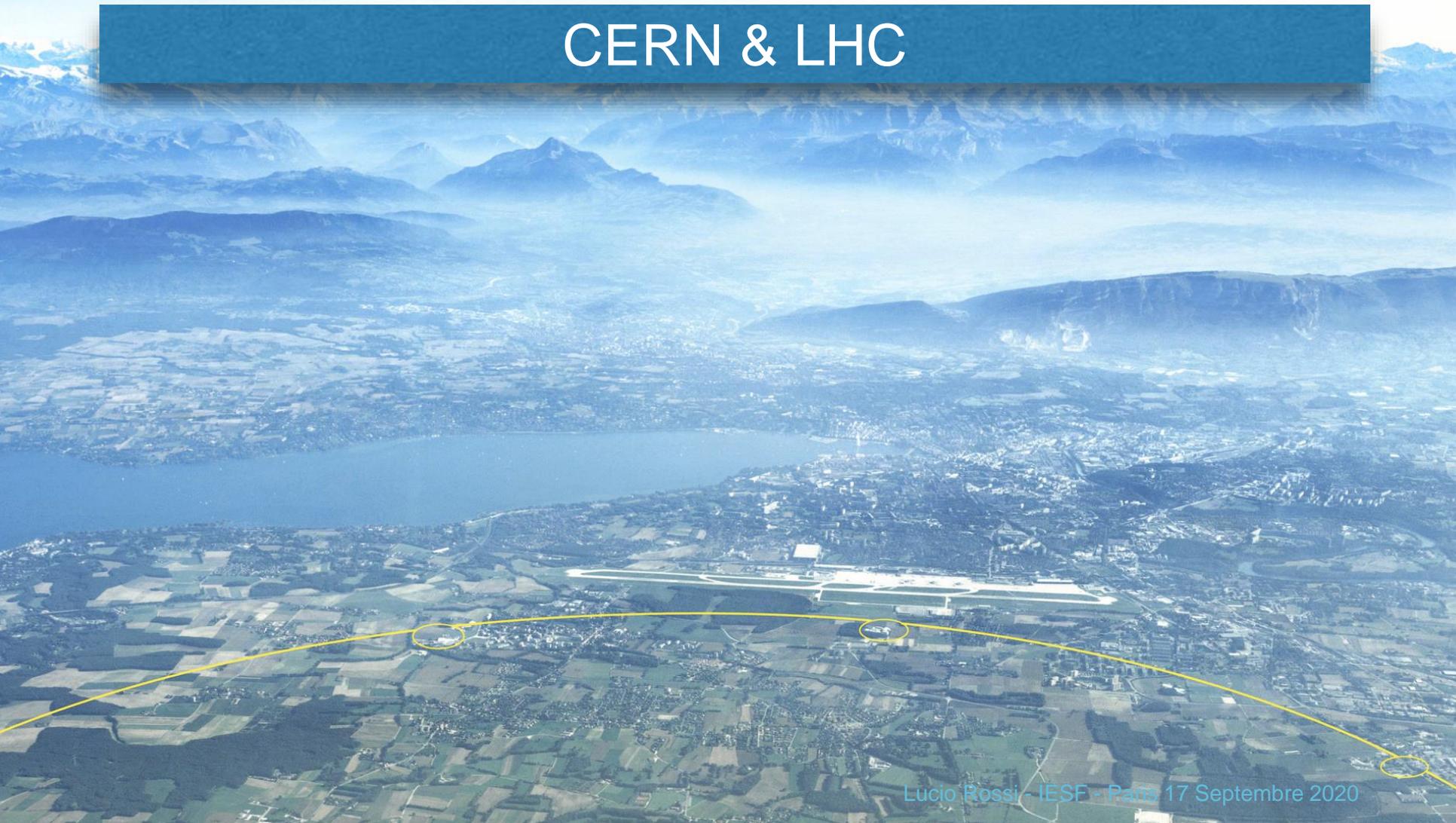
OTHERS

Algeria	1	Chile	19	Hong Kong	21	Malaysia	12	Slovenia	22
Argentina	24	China	216	Iceland	5	Malta	9	South Africa	58
Armenia	19	Colombia	21	Indonesia	9	Mexico	60	Taiwan	74
Australia	39	Costa Rica	1	Iran	34	Mongolia	2	Thailand	17
Azerbaijan	3	Croatia	27	Ireland	9	Morocco	10	TFYROM	2
Bangladesh	4	Cuba	3	Korea	163	New Zealand	8	Venezuela	1
Belarus	23	Ecuador	2	Latvia	1	Oman	3	Viet Nam	1
Brazil	136	Egypt	27	Lebanon	3	Peru	3		
Canada	180	Estonia	16	Lithuania	17	Saudi Arabia	1		
		Georgia	26	Madagascar	2	Singapore	4		

1338



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

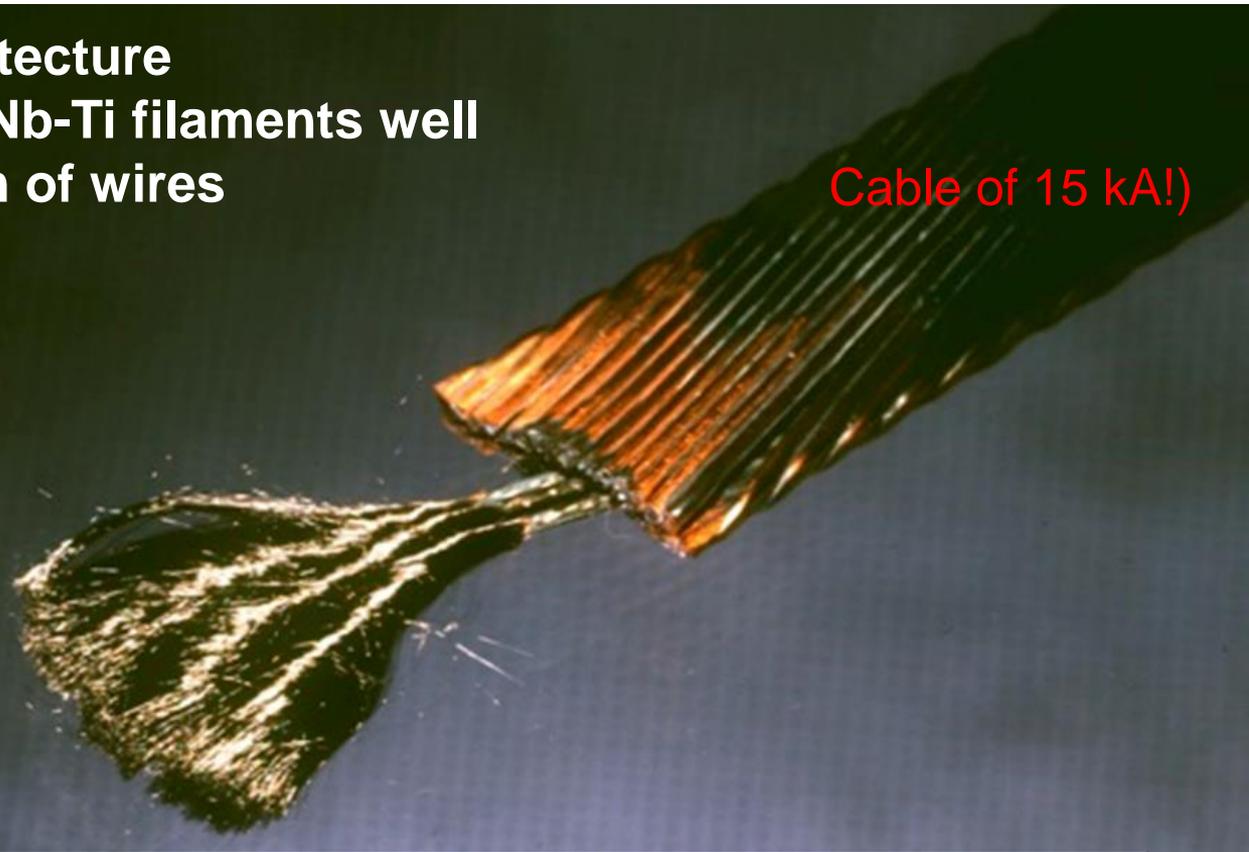
- Tunnel 120 km
- Field : 1.8 T
- Dissipated power at collision: ~ 2,200 MW
- Average power (0.4 coefficient): 900 MW only for accelerator



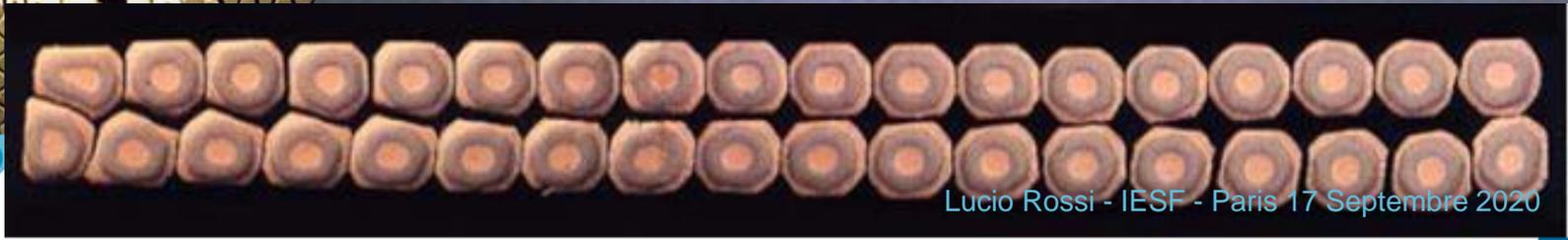
Very complex architecture

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

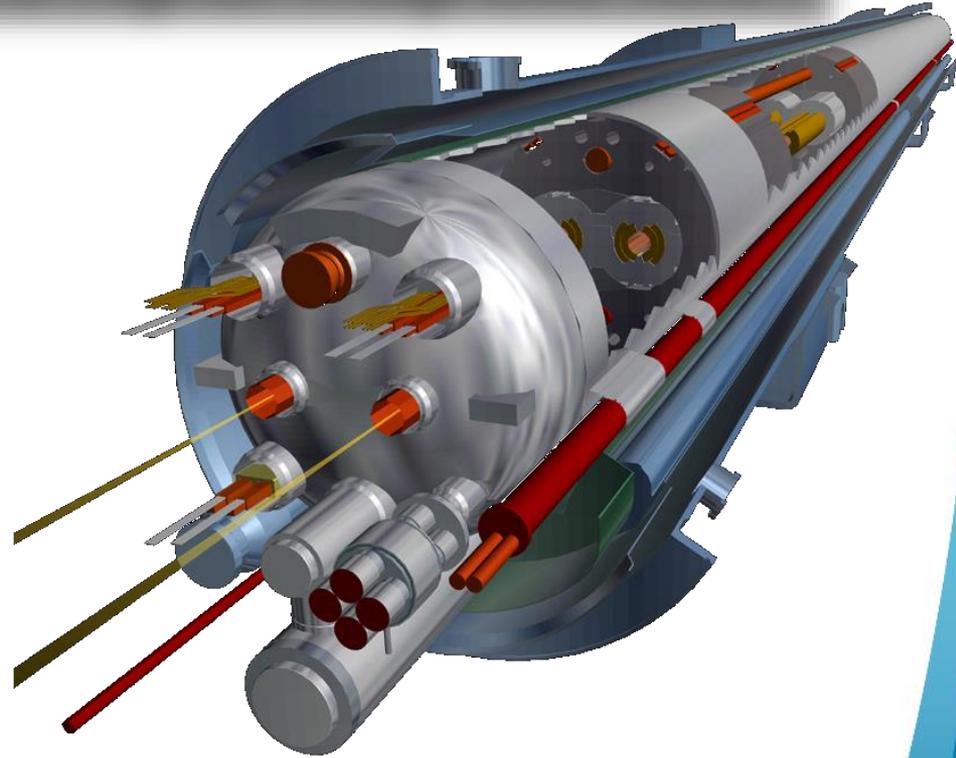
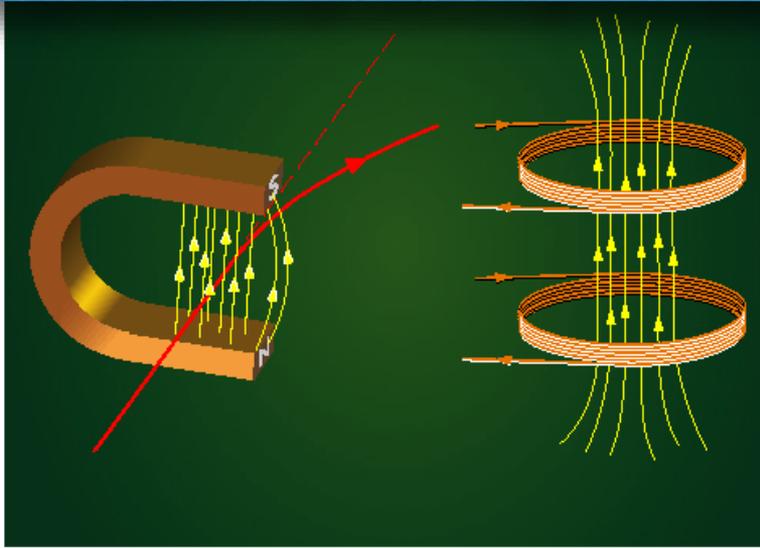
Cable of 15 kA!



Fine filaments of Nb-Ti in a Cu matrix for an LHC dipole wire)



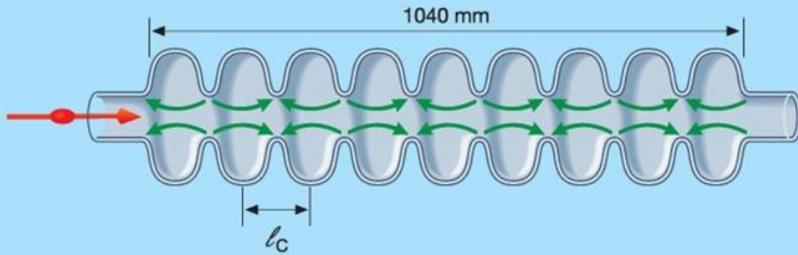
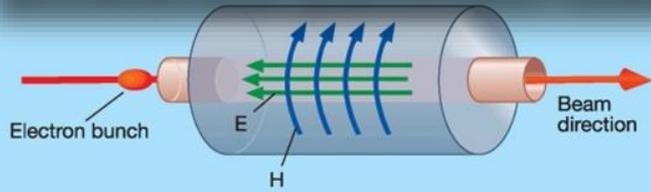
Why looking for higher and higher magnetic field?



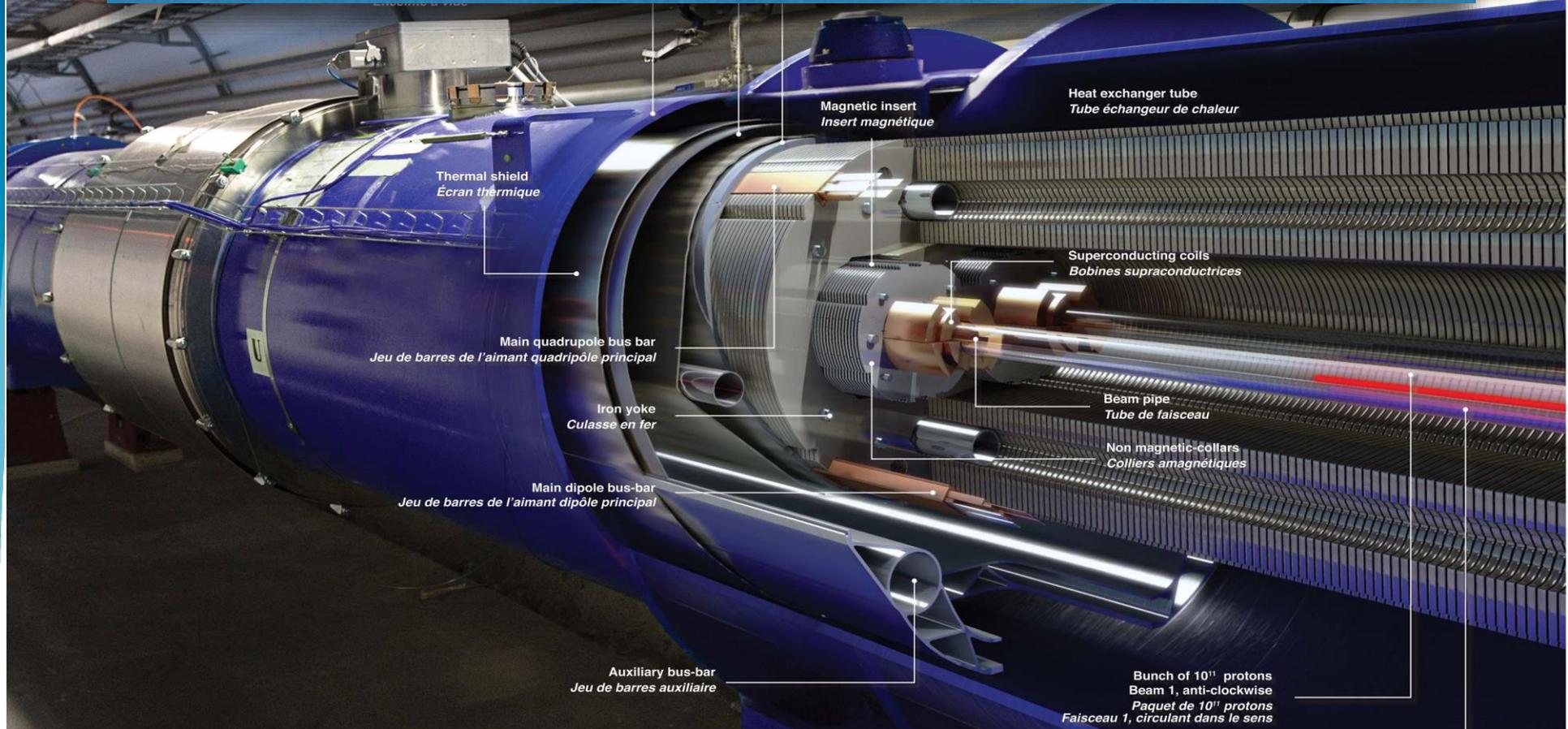
- Circular Accelerators

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

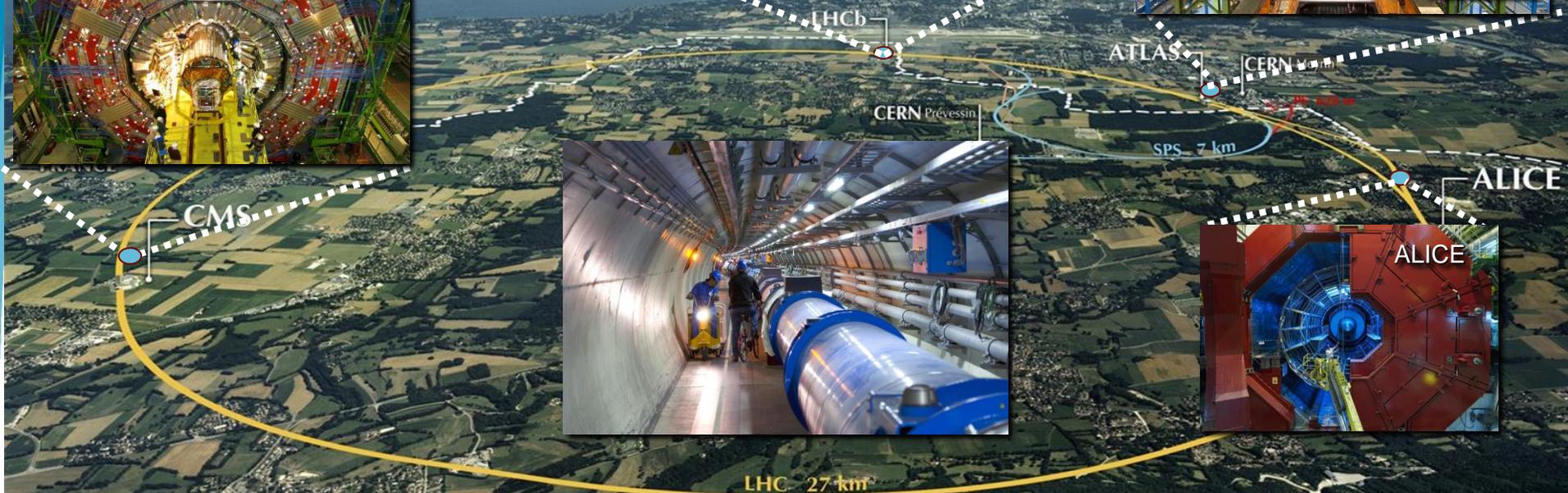
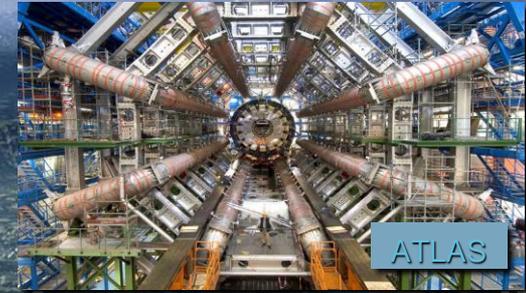
Superconductors (usually pure Niobium) are used to accelerate particles: electric fields in RF cavities (30-50 MV/m)

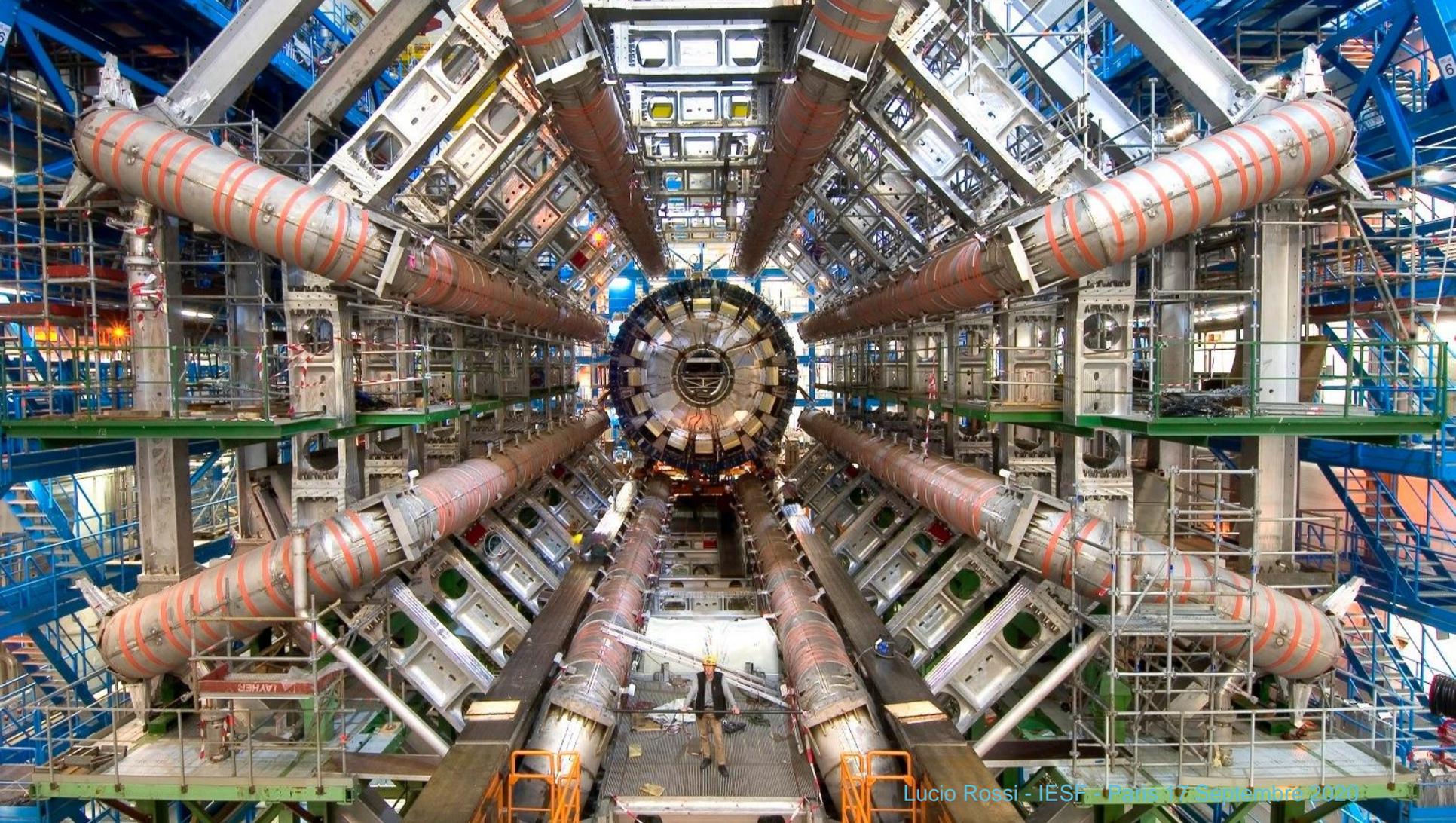


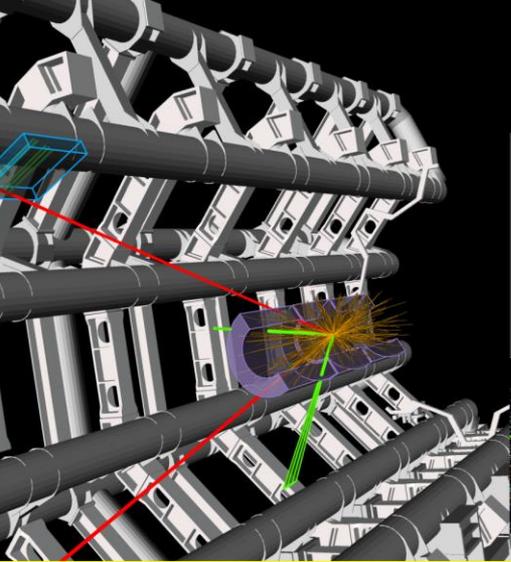
More than 20 years to develop and build the LHC dipole magnets



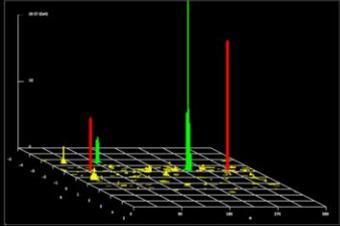
LHC and its big four eyes







ATLAS
EXPERIMENT
<http://atlas.ch>
Run: 205113
Event: 12611816
Date: 2012-06-19
Time: 11:07:47 CEST



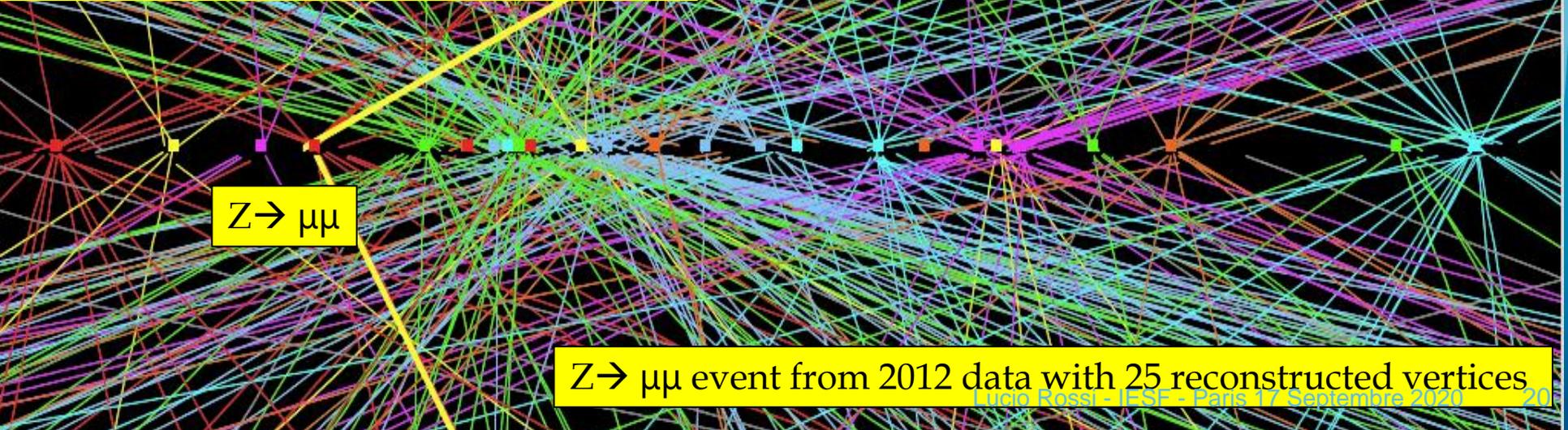
Beams collides 40 MHz

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!



$Z \rightarrow \mu\mu$

$Z \rightarrow \mu\mu$ event from 2012 data with 25 reconstructed vertices



The
Economist

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

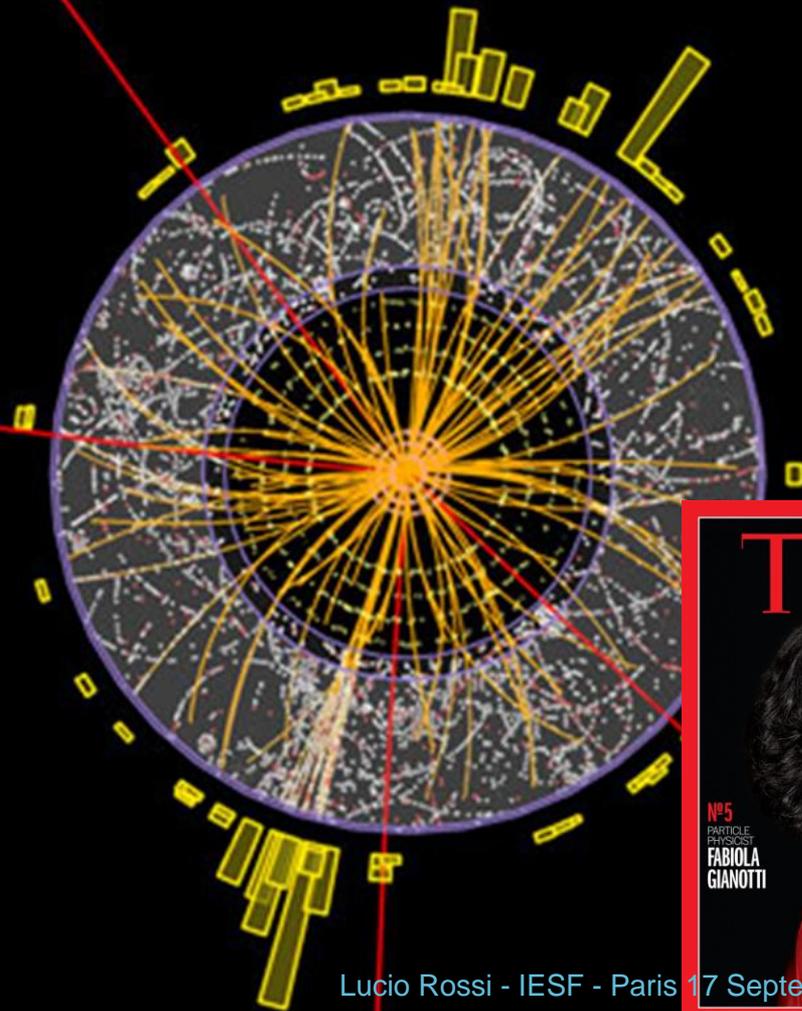
JULY 7TH-13TH 2012

Economist.com

A giant leap for science



Finding the
Higgs boson



TIME

N°5
PARTICLE
PHYSICIST
FABIOLA
GIANOTTI



Lucio Rossi - IESF - Paris 17 Septembre 2020

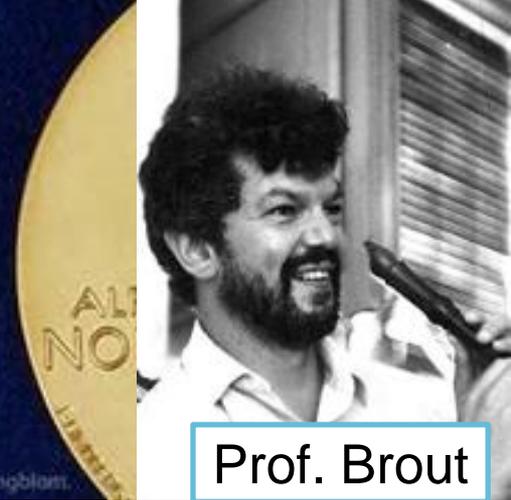


Prof. Englert Prof. Higgs

PRIZE IN PHYSICS

Englert Higgs

© The Nobel Foundation, Photo: Lovisa Engblom.

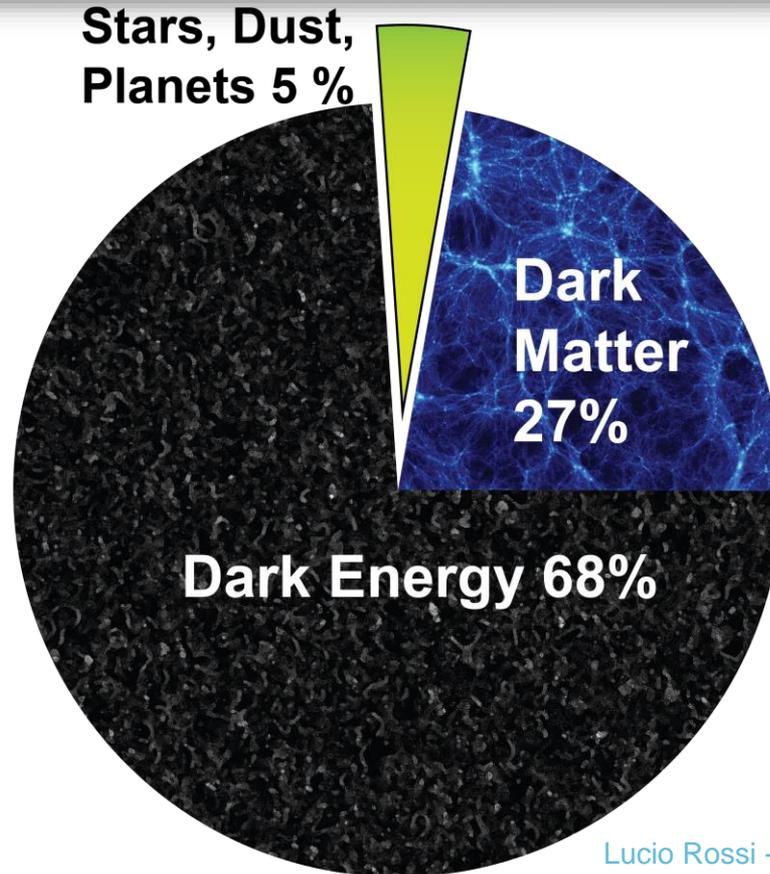


Prof. Brout

...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!



SUPERSYMMETRY: A Superworld ahead of us?

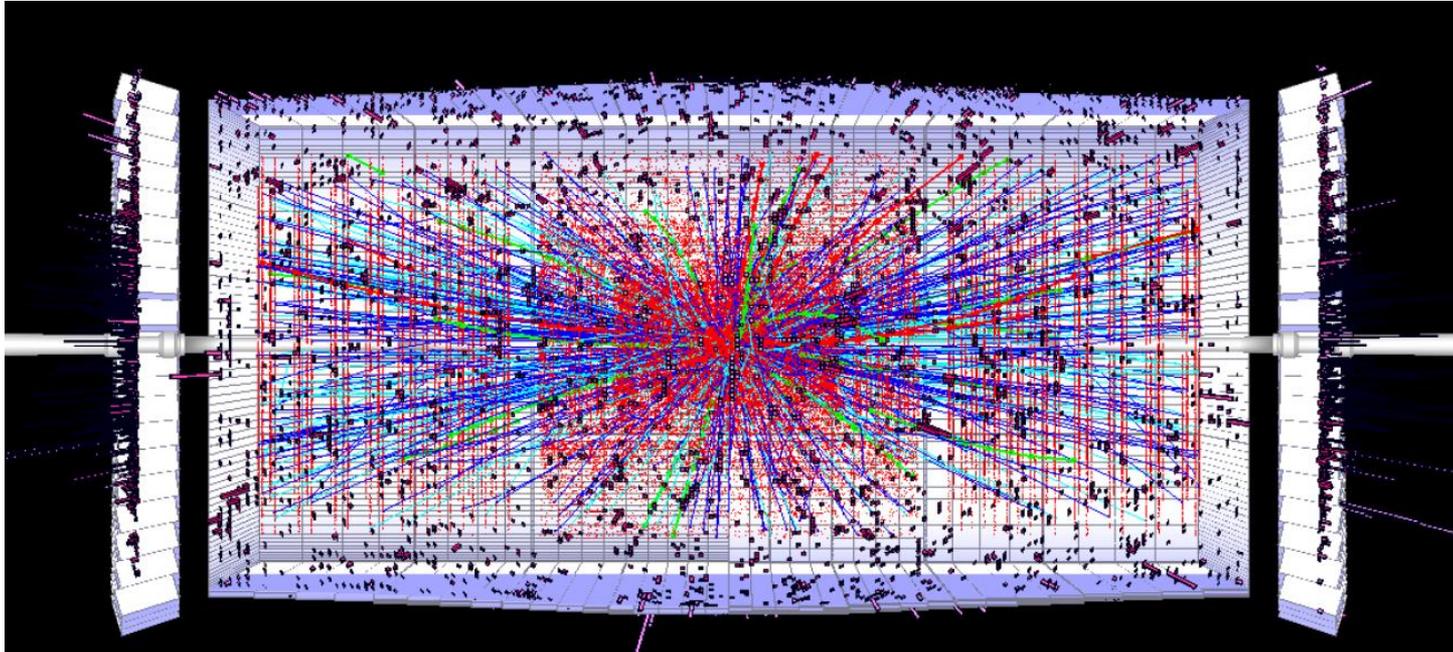


Shedding light on Dark Matter?
More light to see more...

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 $L_{\text{peak}} = 5 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ **with levelling**, allowing:

An integrated luminosity of **250 fb⁻¹ per year**, enabling the goal of

$L_{\text{int}} = 3000 \text{ fb}^{-1}$ 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

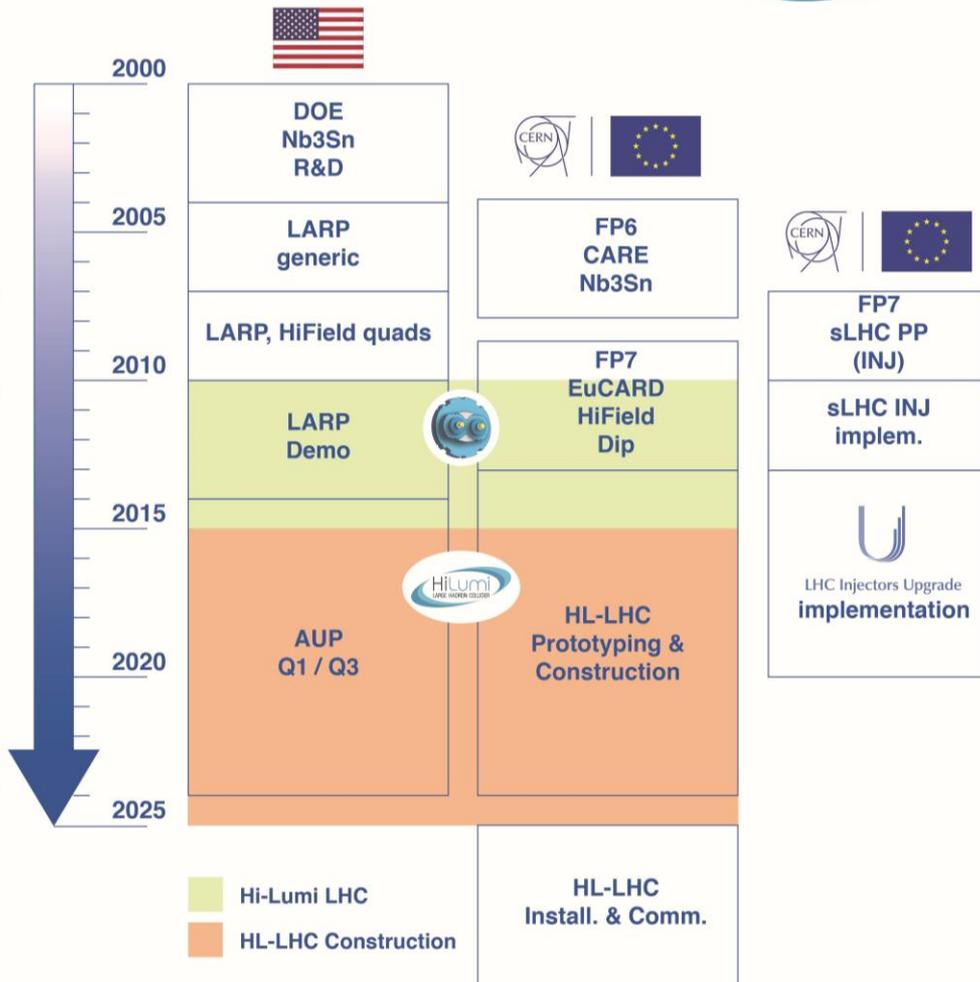
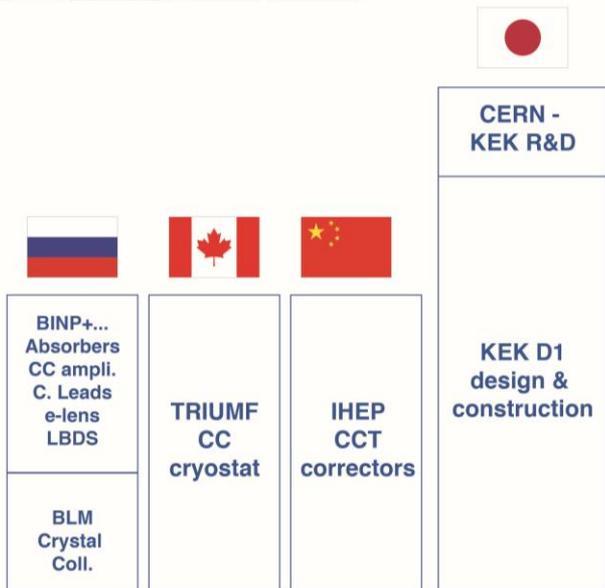
EU in-kind collaboration



Collaboration with personnel



HiLumi:
a global
project
since the
start



Technology landmarks

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



“CRAB” CAVITIES
8 SRF “crab” cavities on each side of ATLAS and CMS experiments to tilt beams at collision.

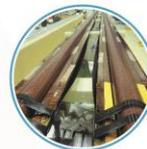


BEAM SCREEN
All new magnets will be equipped with a new special beam screen to intercept collision debris at 60 K temperature and cancel electron-cloud effects.

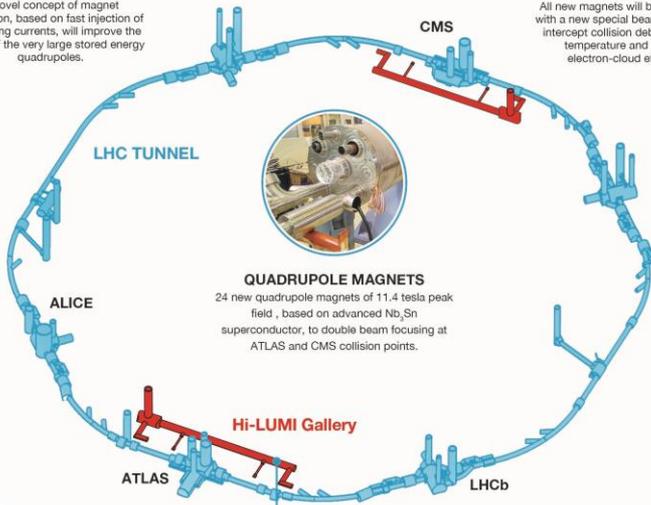
CLIQ
A novel concept of magnet protection, based on fast injection of oscillating currents, will improve the safety of the very large stored energy quadrupoles.



CRYOGENICS
2 new large 1.9 K helium refrigerators for HL-LHC near ATLAS and CMS will allow cryo-separation between arcs and triplet regions.



11 T DIPOLE MAGNET
2 pairs of bending magnets, based on advanced Nb₃Sn superconductor and much stronger than LHC dipoles, to free up space for special collimators in the cold regions



QUADRUPOLE MAGNETS
24 new quadrupole magnets of 11.4 tesla peak field, based on advanced Nb₃Sn superconductor, to double beam focusing at ATLAS and CMS collision points.



BEAM GAS VERTEX
Two new novel beam instruments based on beam gas vertex detectors will allow non-invasive accurate measurements of the beam size.



COLLIMATORS
20 novel low impedance collimators for beam stability and further 24 new collimators for improved machine protections

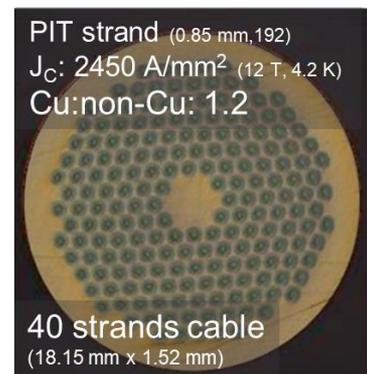
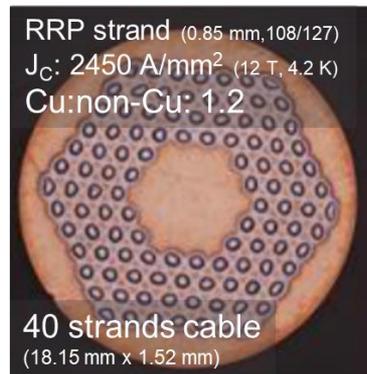
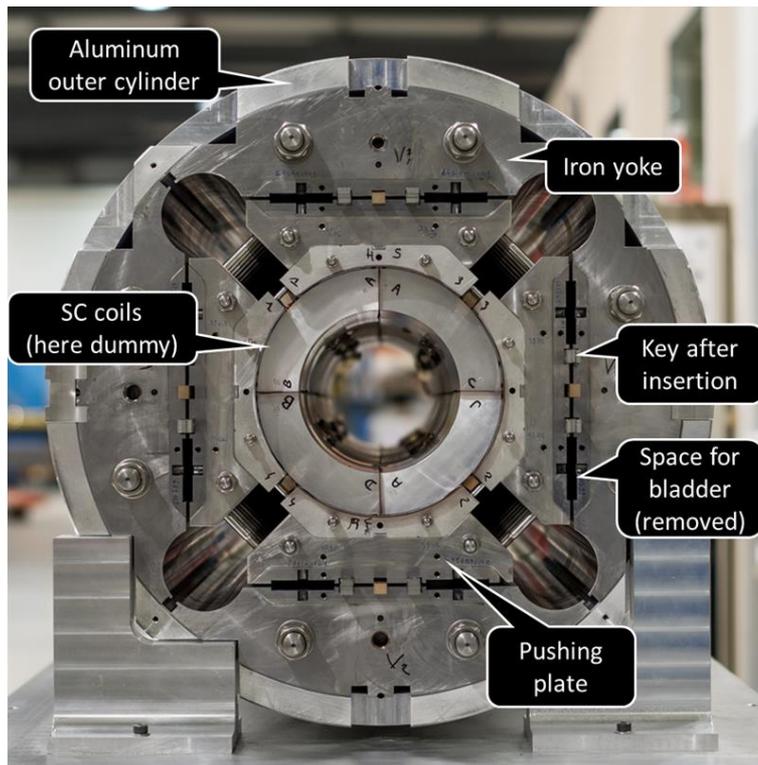


CIVIL ENGINEERING
2 new caverns, 1km underground galleries, two new large shafts; 10 new technical buildings on surface in P1 and P5 (near ATLAS and CMS)



SUPERCONDUCTING LINKS
8 novel electric current superconducting lines, 140 m long and rated for 30-100 kA, based on M₃B₂ superconductor operating at a temperature up to 20 K.

New structure to accommodate 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 construction 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)

- 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)

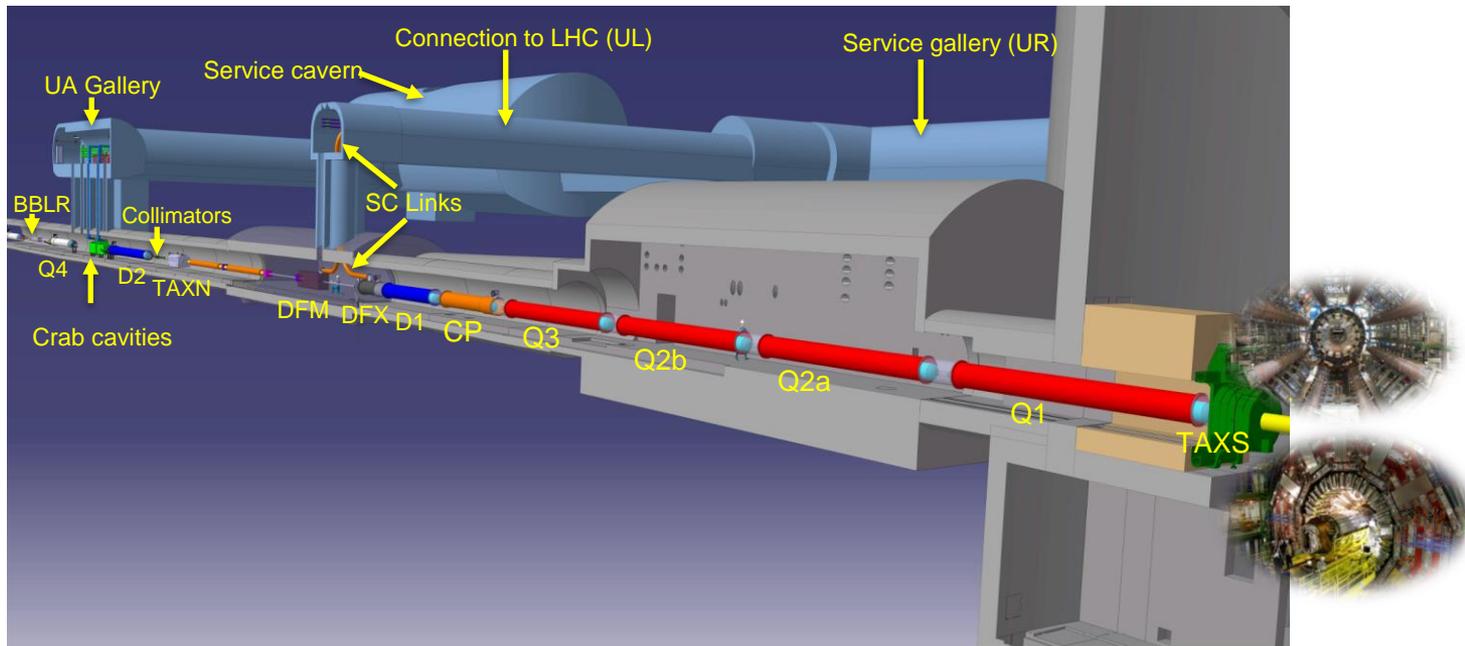
RFD cryomodules (5)

- 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**

Solid State RF Systems (20)

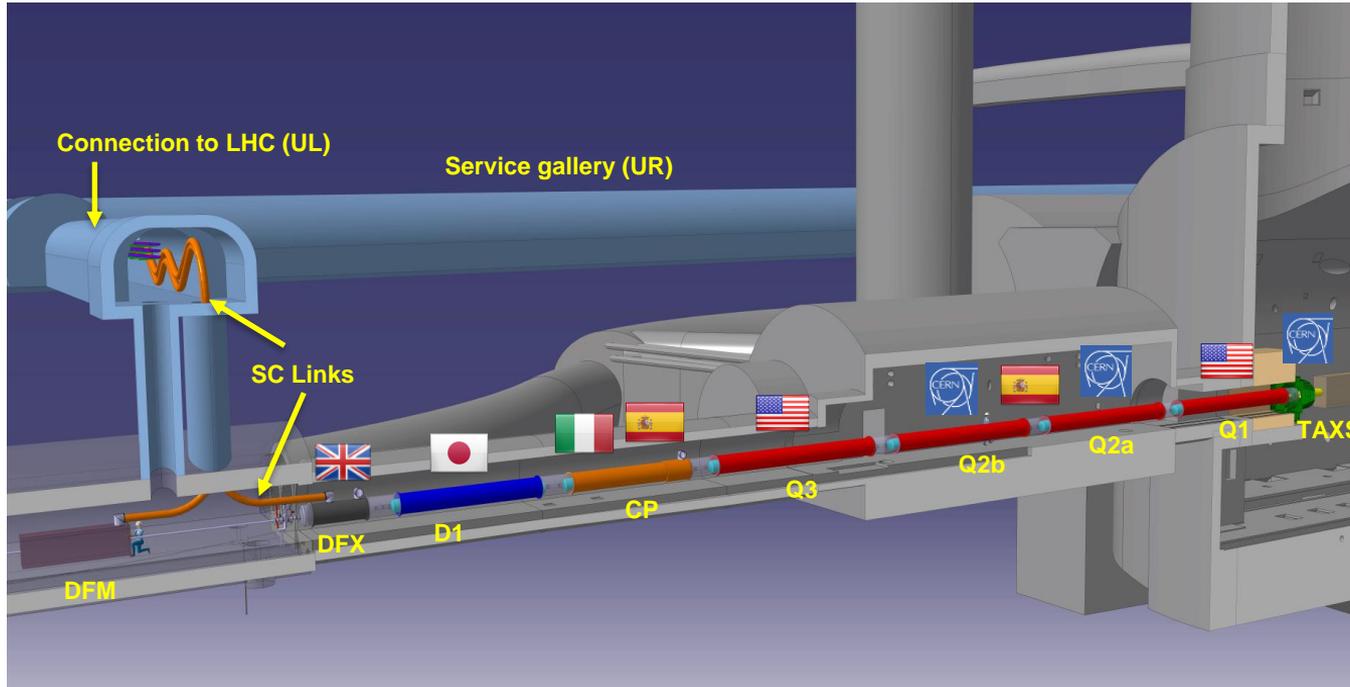
- High power solid state amplifiers by **BINP-Russia**
- First step, one amplifier prototype for qualification of SSPA technology

The Insertion Region (till Q4)

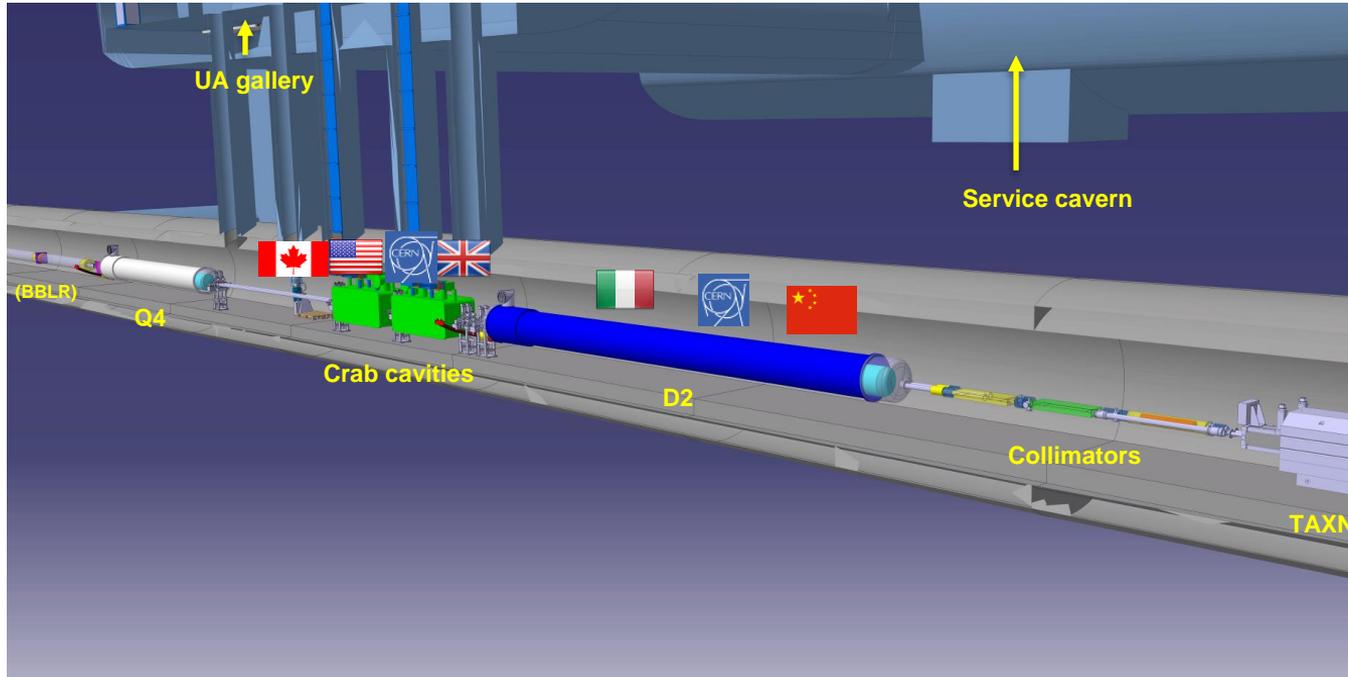


In total about 1.2 km of the LHC will be replaced by new technologies!
Biggest HEP project of this decade, but it has a reasonable size (25-30% of the LHC) to be a test-bed for new technologies...

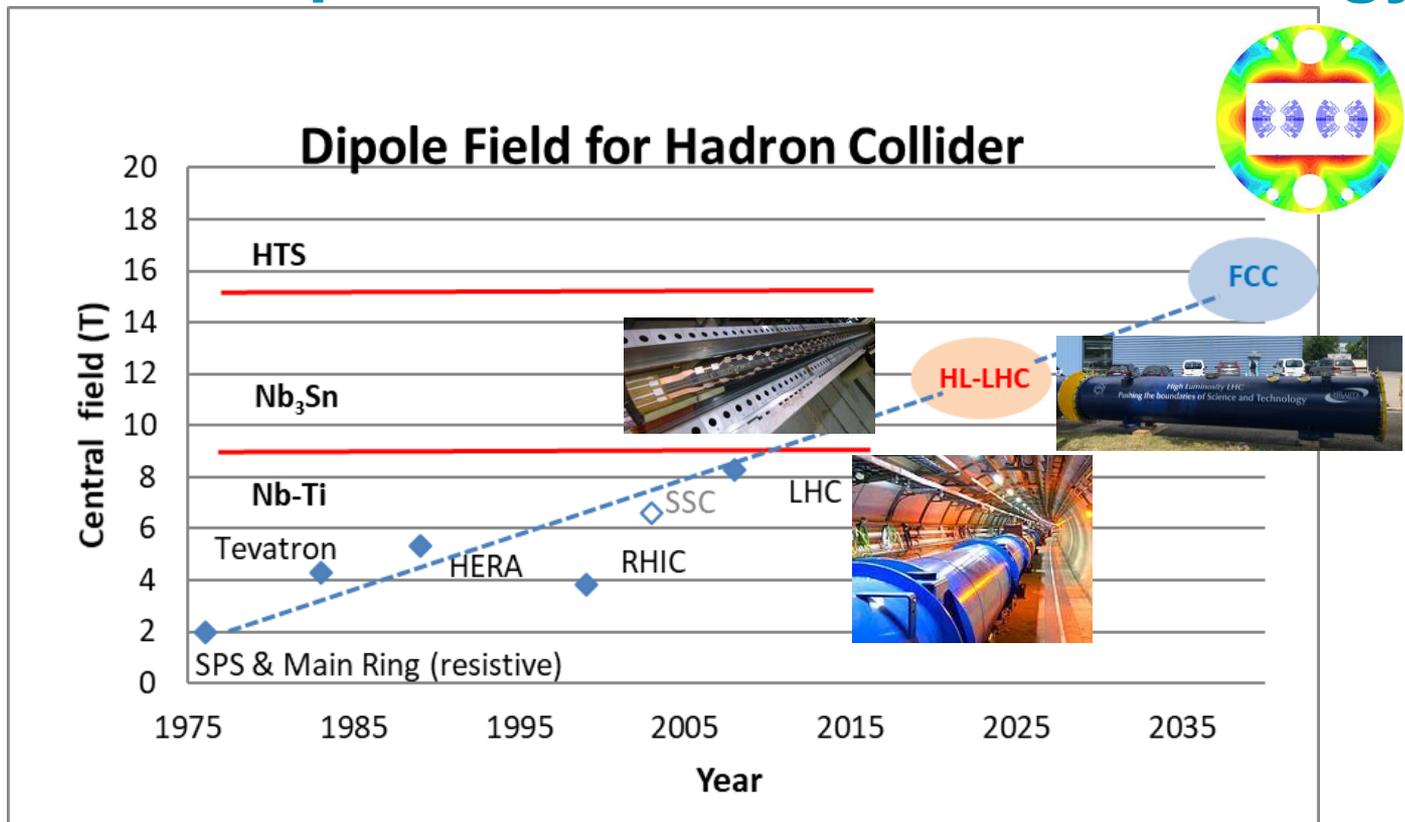
The Inner Triplet region with in-kinds



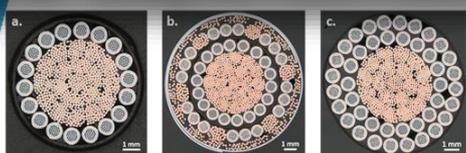
The MS (matching section) region with in-kinds



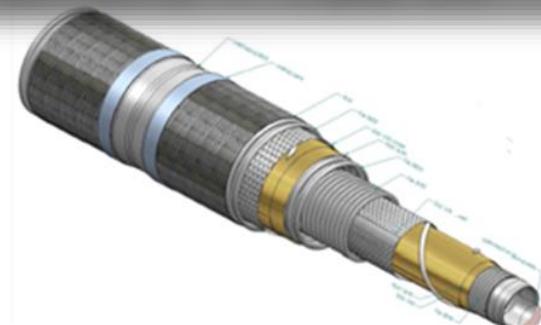
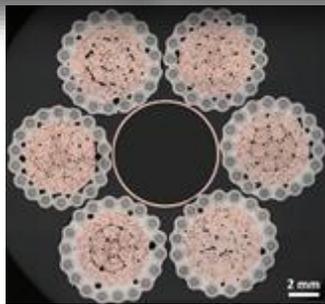
With HiLumi we prepare the technology for a future leap in hadron collider technology...



New superconducting links for 100 kA current – 130 m

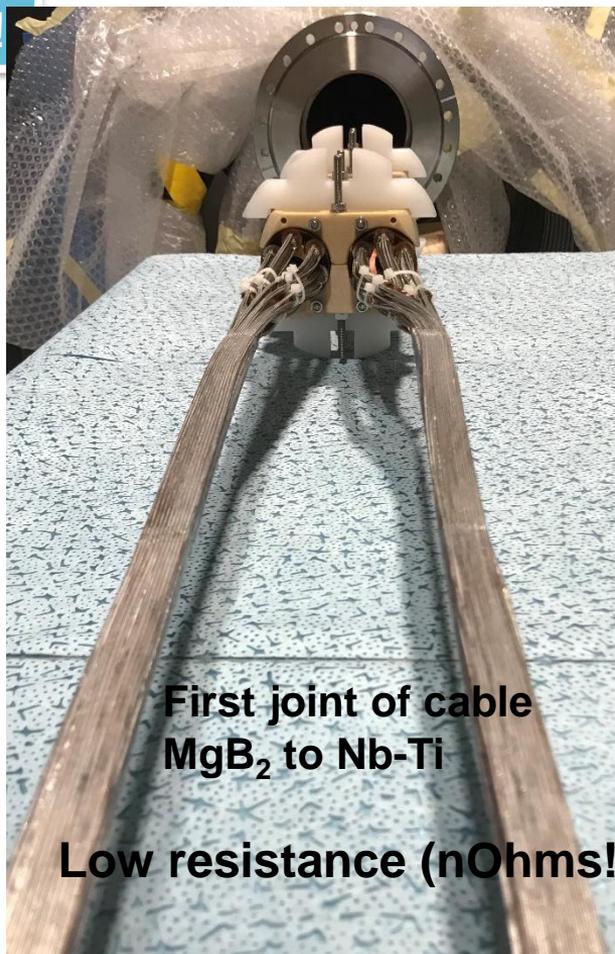


MgB₂
superconductor



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

First long length of 100 kA
MgB₂ cable tested June 2020!



First joint of cable
MgB₂ to Nb-Ti

Low resistance (nOhms!)



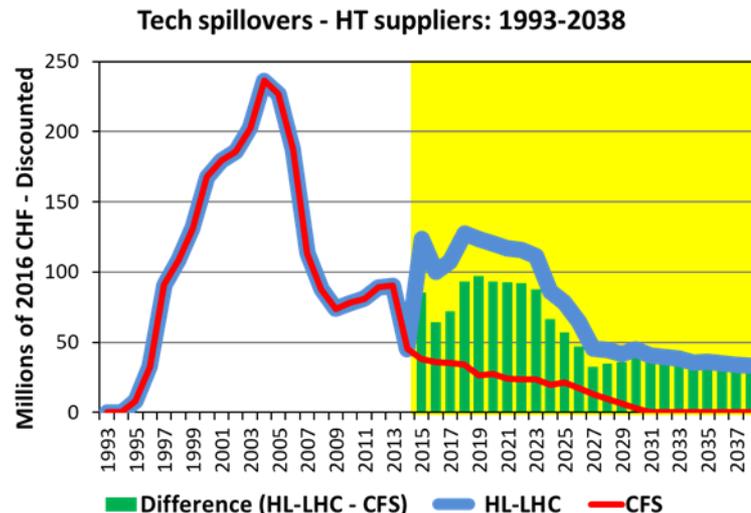
Demo 1

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

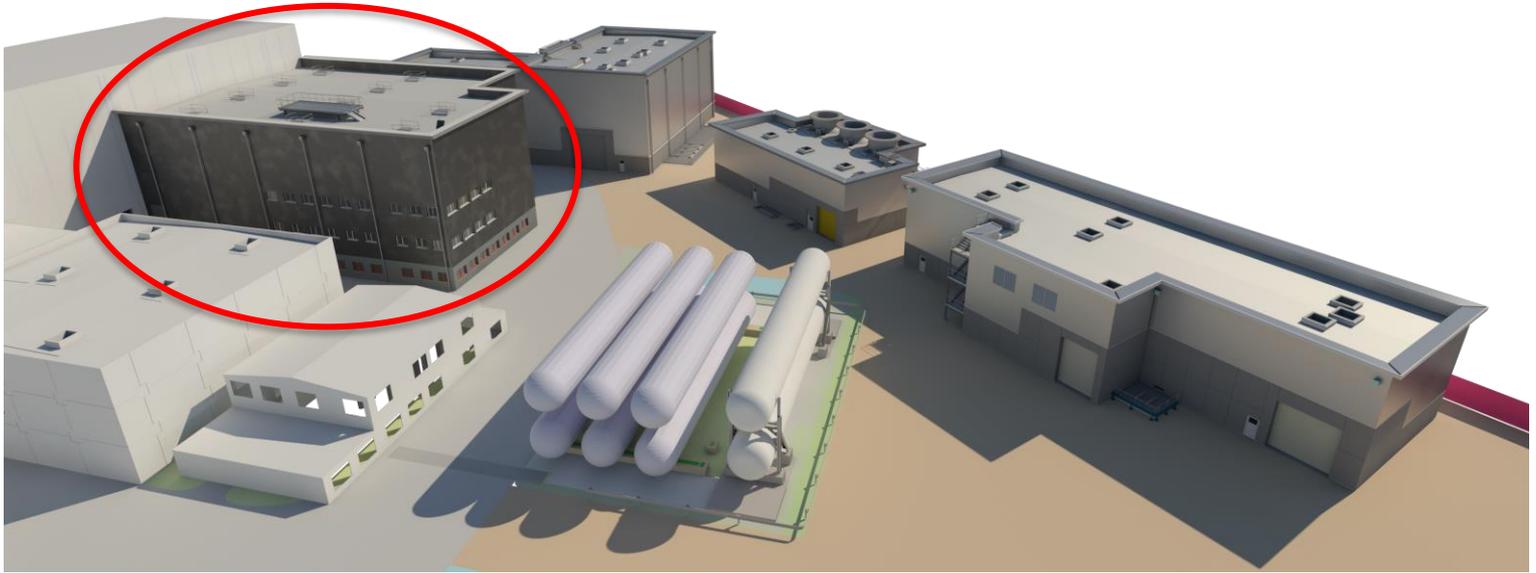
Avec un retour économique prouvé

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)



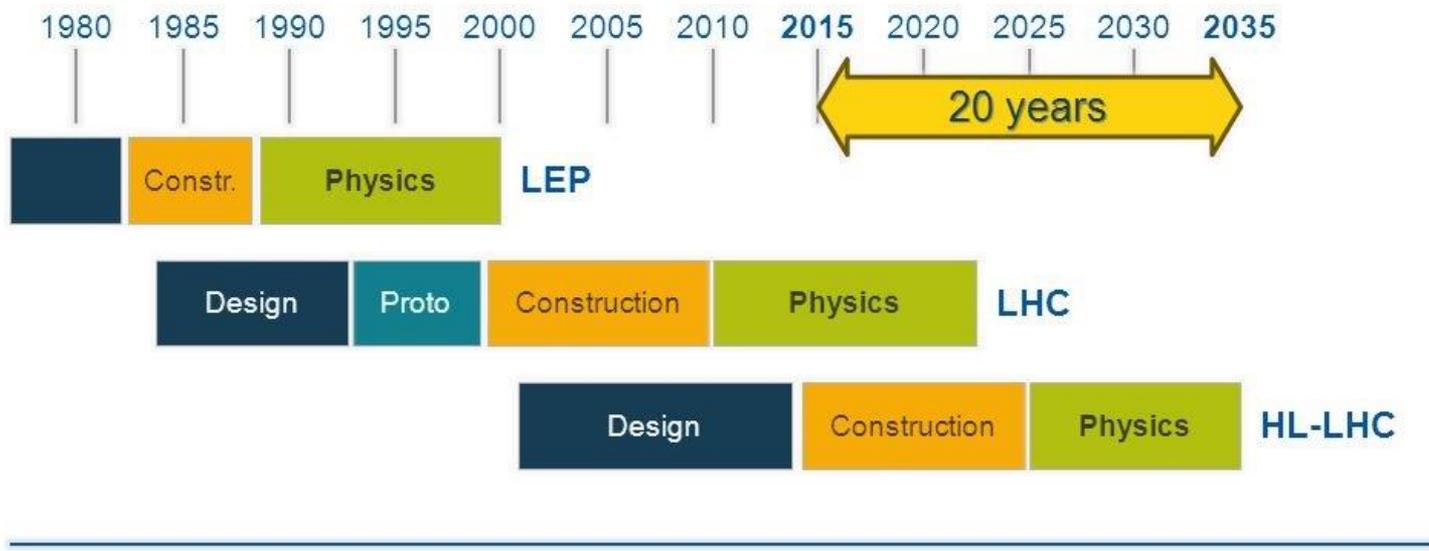
Pictures CE



Santa Barbara, patron saint of miners

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

CERN Circular Colliders + FCC



Future Collider





Conceptual design report ~ late 2018

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



Lucio Rossi - IESF - Paris 17 Septembre 2020

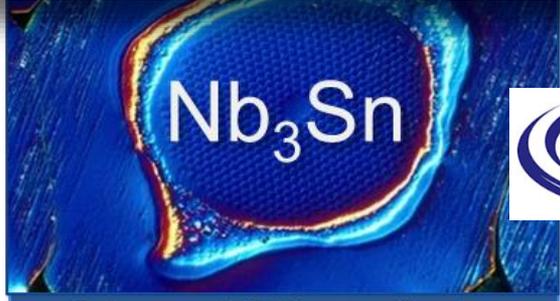
Competition? Yes, guess from whom...



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



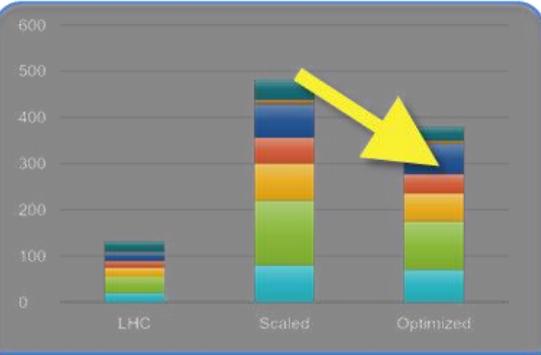
High-field Magnets



Novel Materials and Processes



Large-scale Cryogenics



Power Efficiency



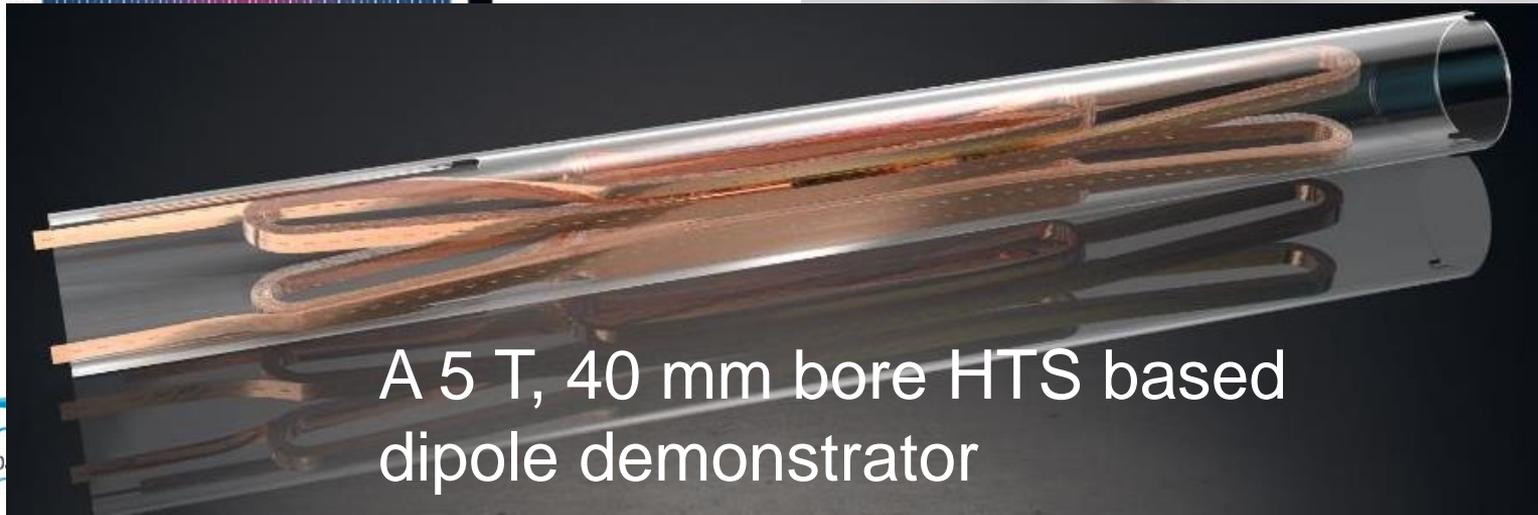
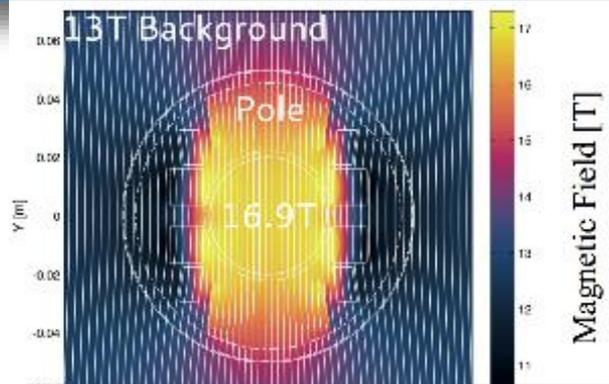
Reliability & Availability



Global Scale Computing

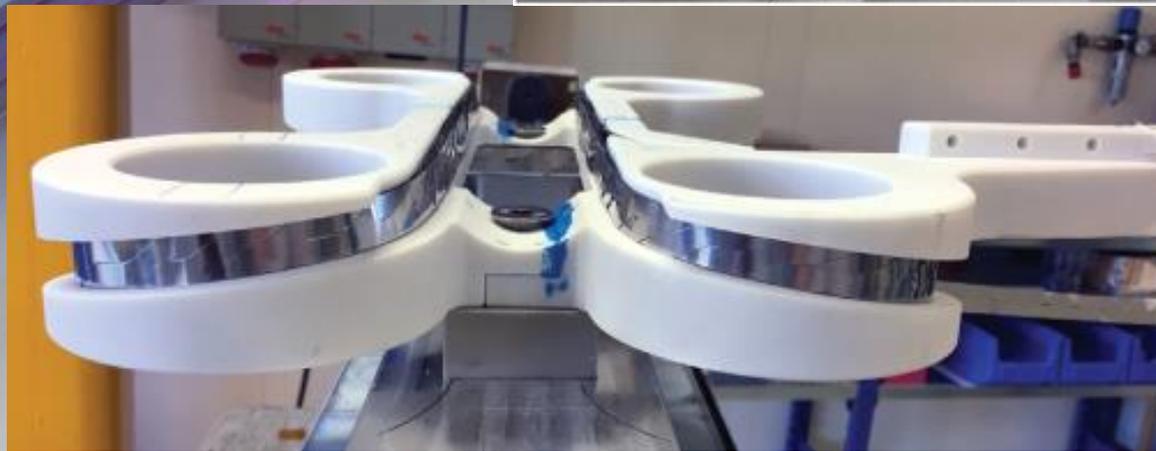
High Temperature Superconductors – HTS

The dream of 20-25 tesla! (2 x HilumiLHC!)

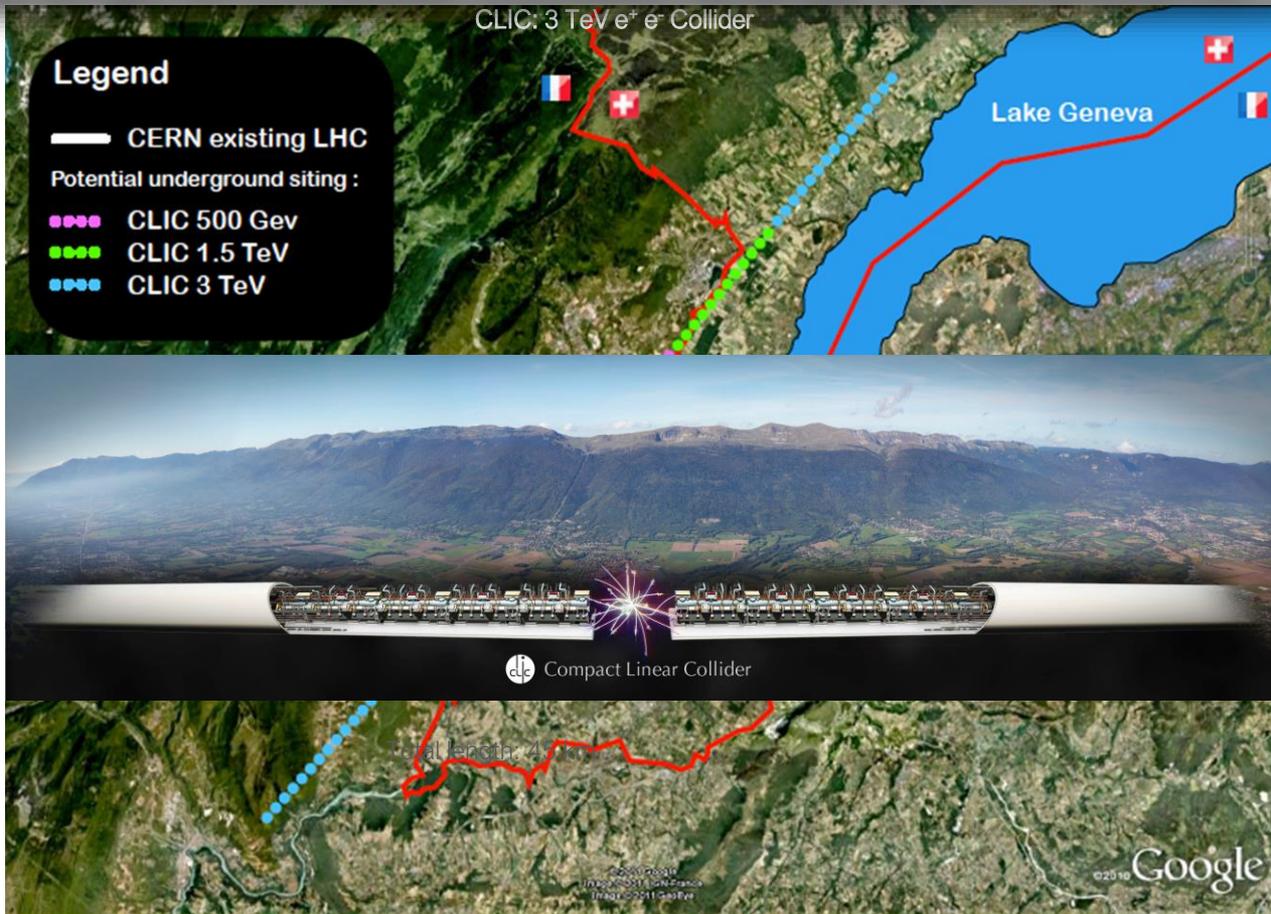


A 5 T, 40 mm bore HTS based dipole demonstrator

Trying the magnets of the future... 20 tesla or more...

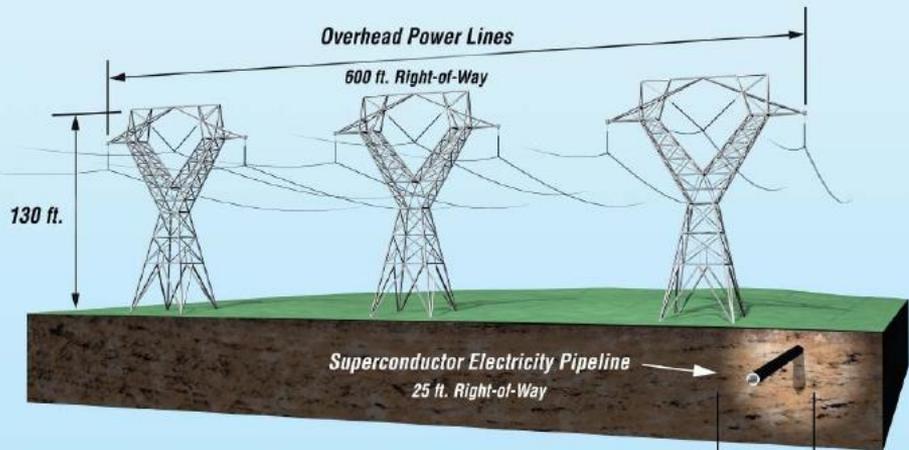


How to go to increase collision energy of constituents

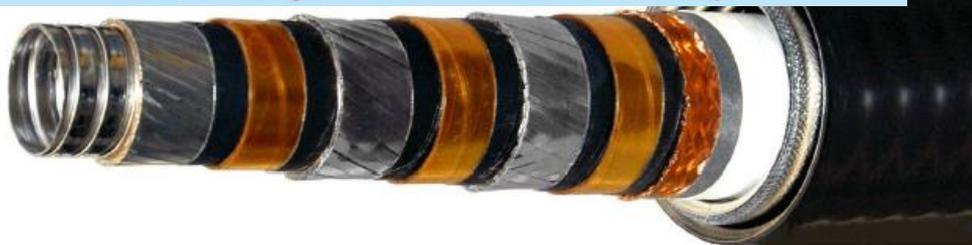


SC and Renewable Energy Technology: Transmission

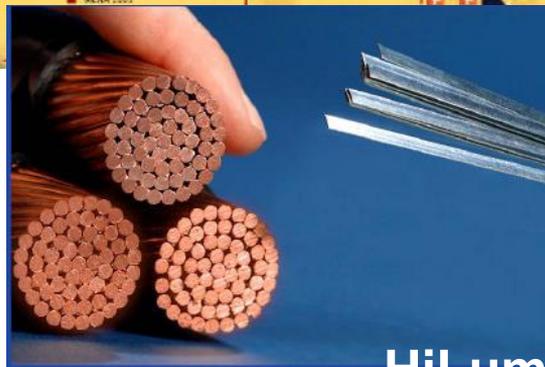
1,000-Mile, 5 Gigawatt Power Equivalents



Out of Sight, Out of Harm's Way



Courtesy Southwire Company



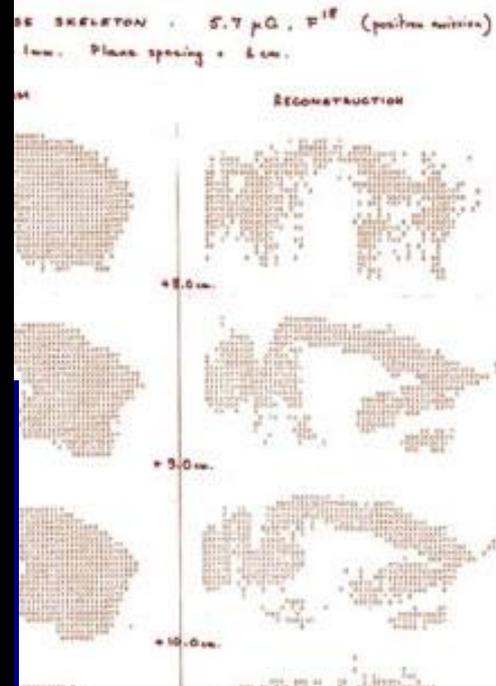
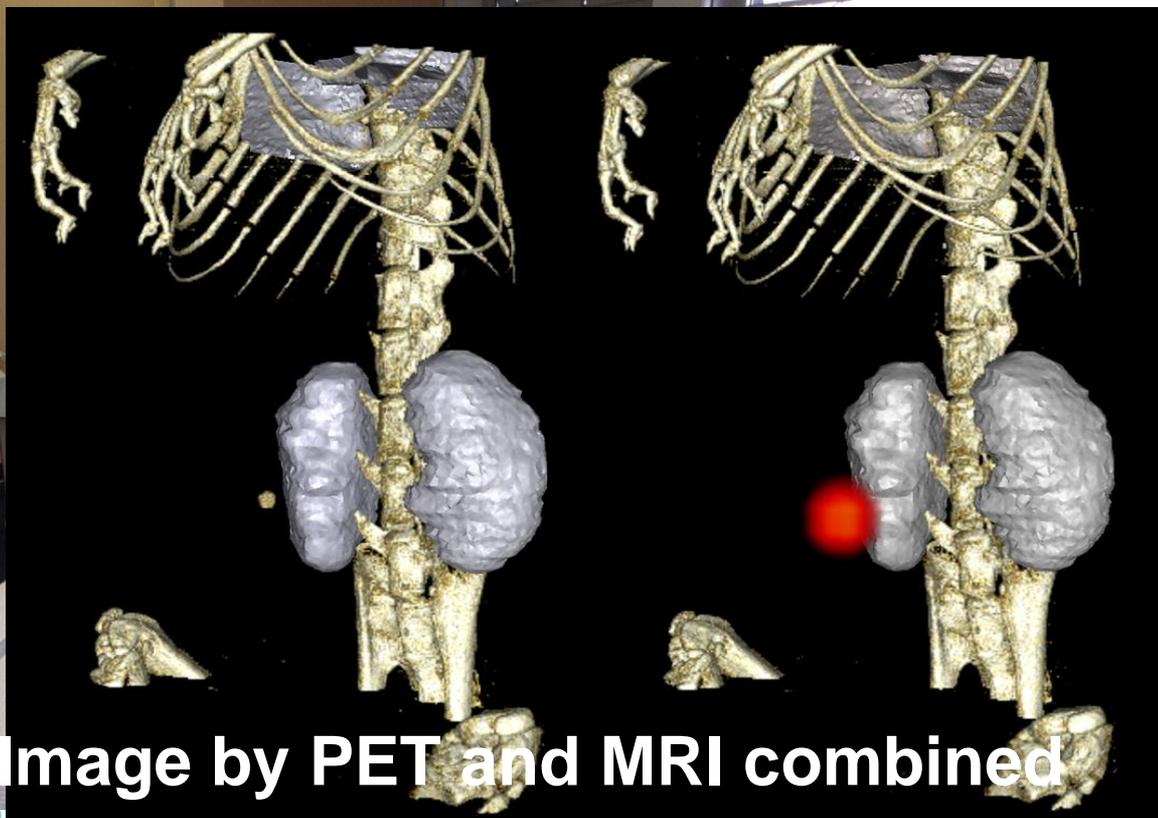
SC and Renewable Energy Technology: wind generators



AMSC SeaTitan Wind Turbine Generator
Image courtesy of American Superconductor

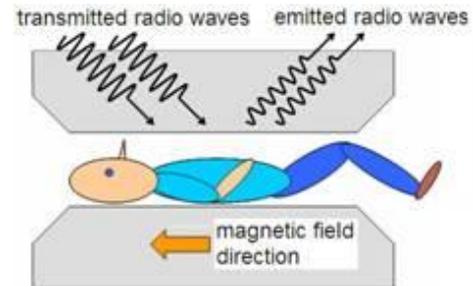
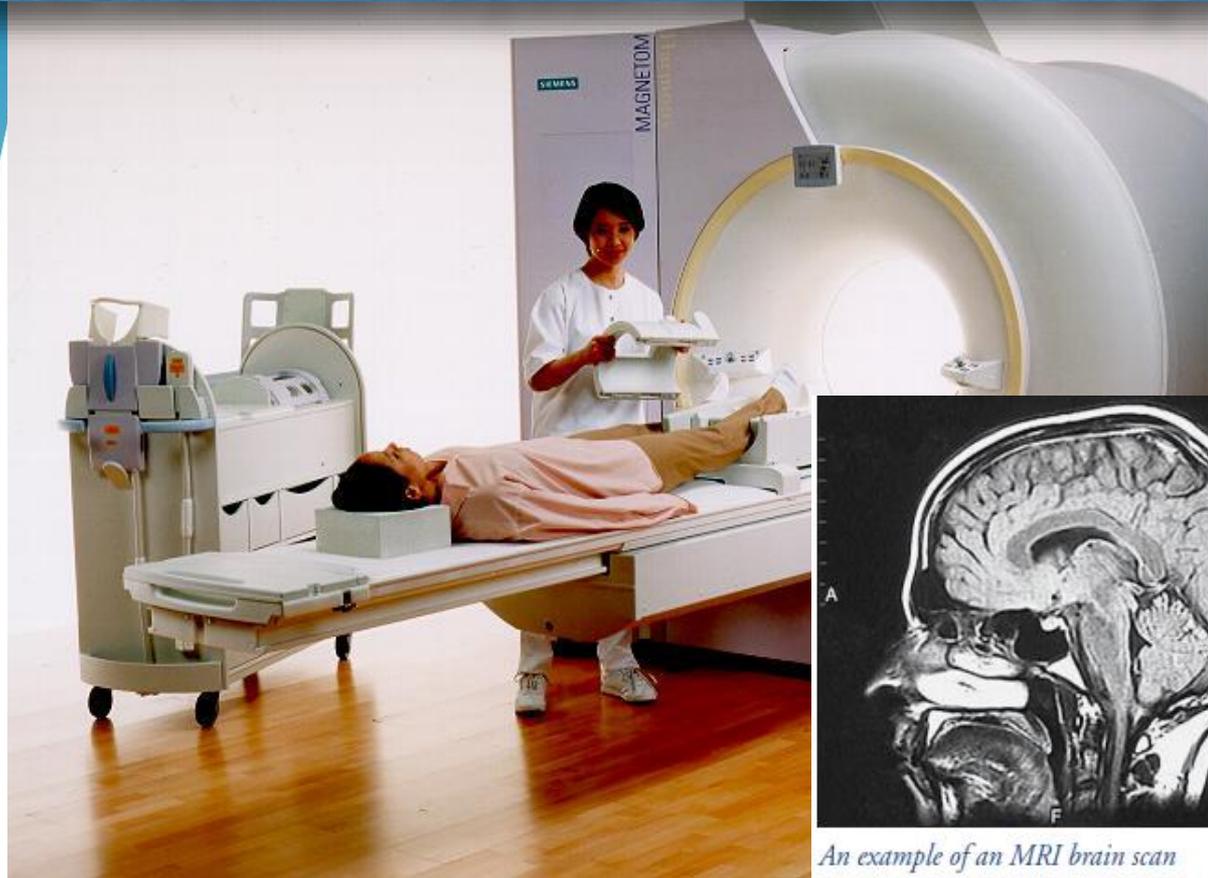


New medical «eyes»: PET

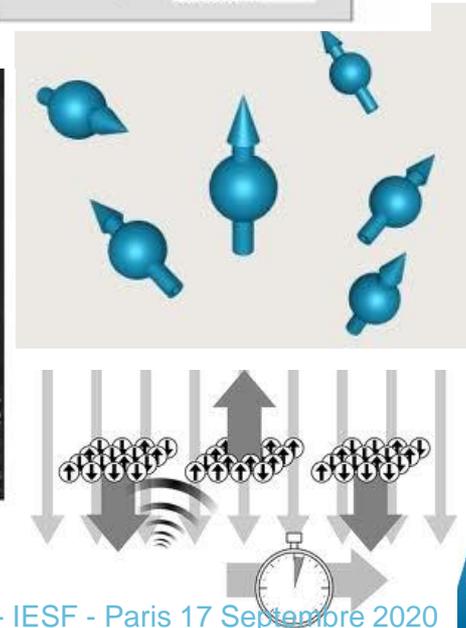


First PET image: CERN,
circa 1975

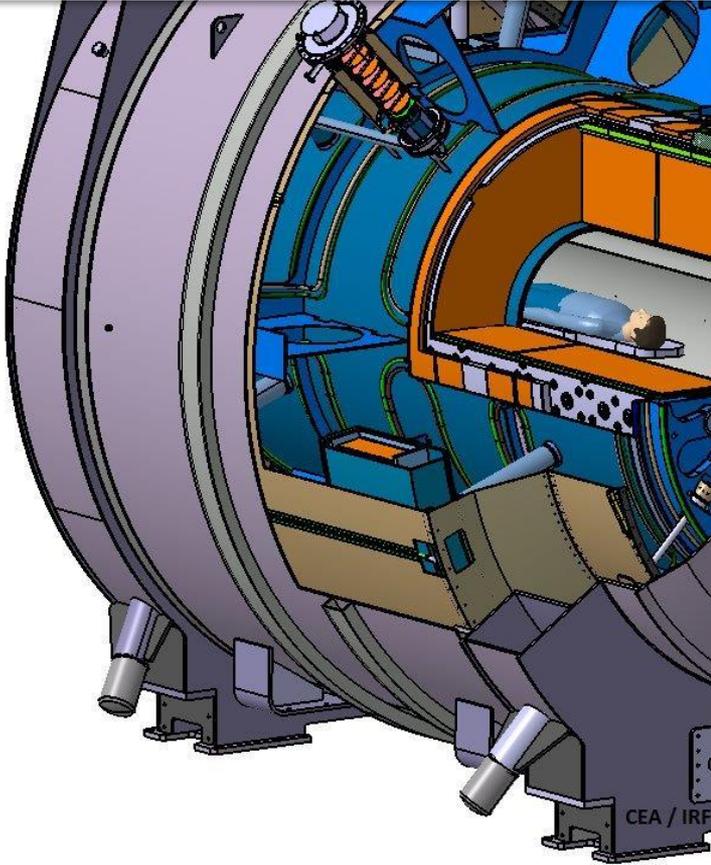
New medical «eyes»: MRI, 2000 large systems/year



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

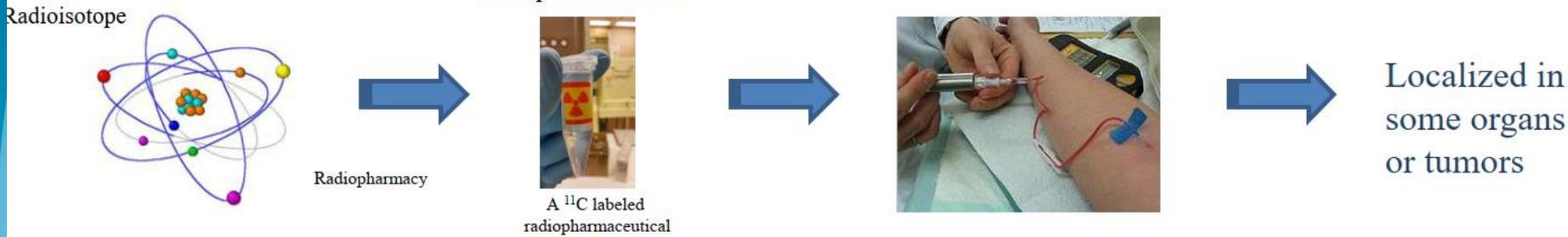


**Largest MRI for research: Iseult Magnet for 11.7 T, now under commissioning at Neurospin center in CEA Saclay (Paris)
FUNCTIONAL MRI: breakthrough in cerebral functions**

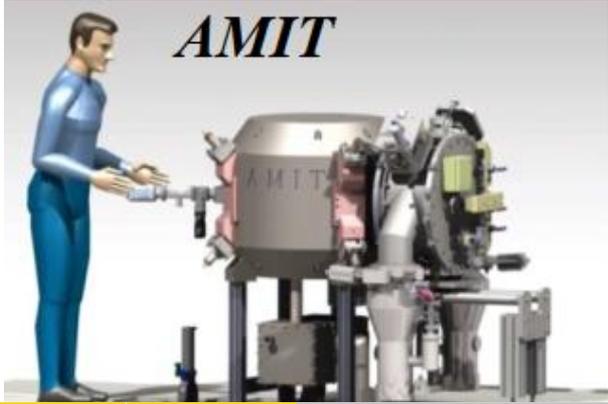


Production of radioisotopes for PET is critical

Radioisotopes in Nuclear medicine



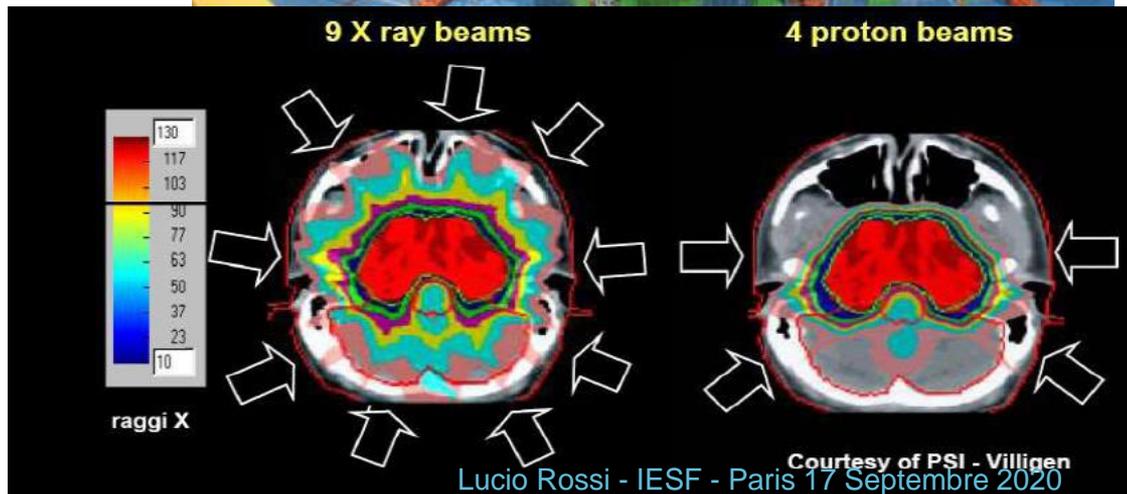
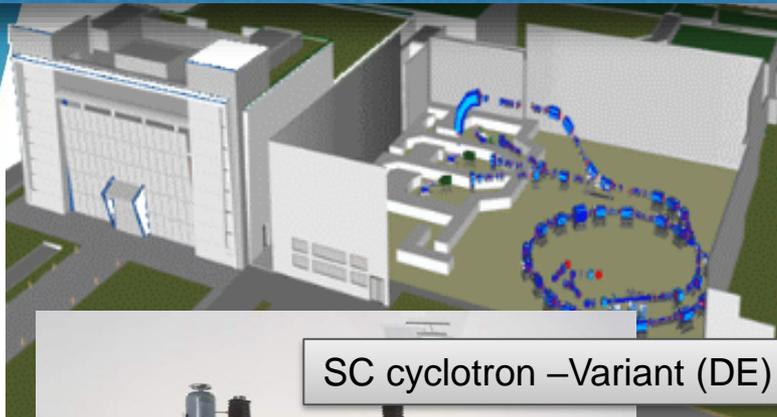
Last decade crisis in reactor-production



GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA, INDUSTRIA Y COMPETITIVIDAD

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Hadron therapy



Merci pour votre attention!



As any activity people tend to look for «stars»



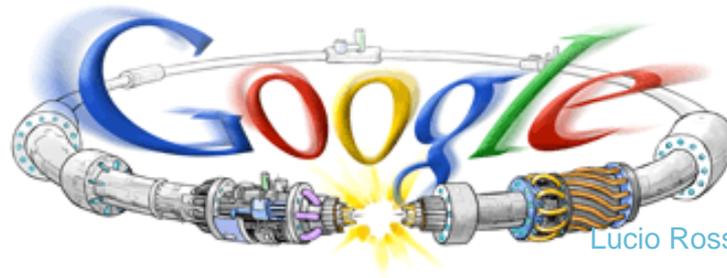
But is like football. It is the team that wins!
The Magnet team (with DG!) at the end of LHC magnet Production



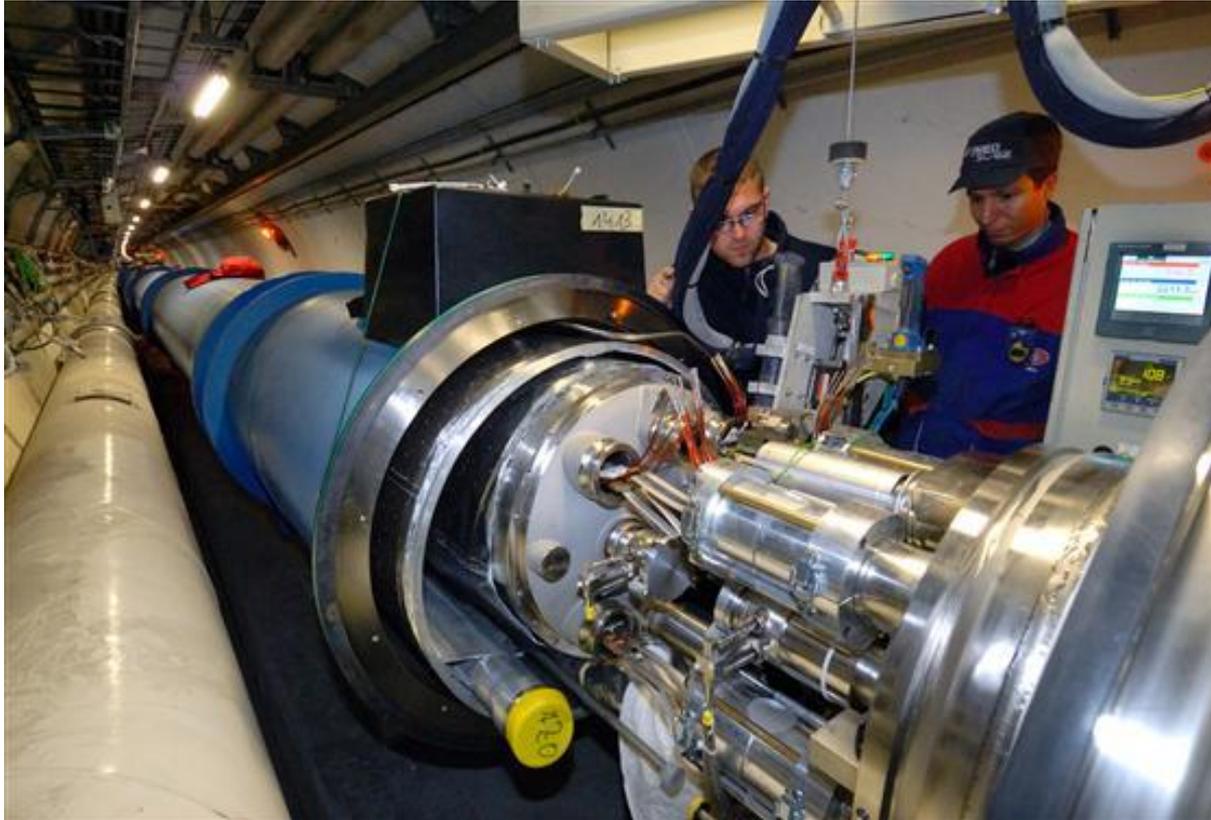
The HiLumi team at the collaboration meeting 2018 - CERN



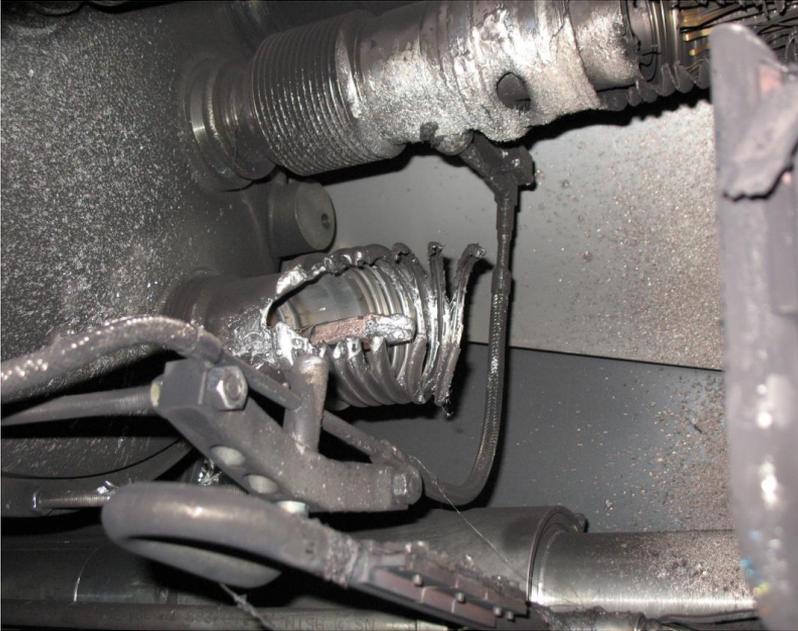
10 september 2008: the success!



19 september 2008: The big trouble: magnet interconnection

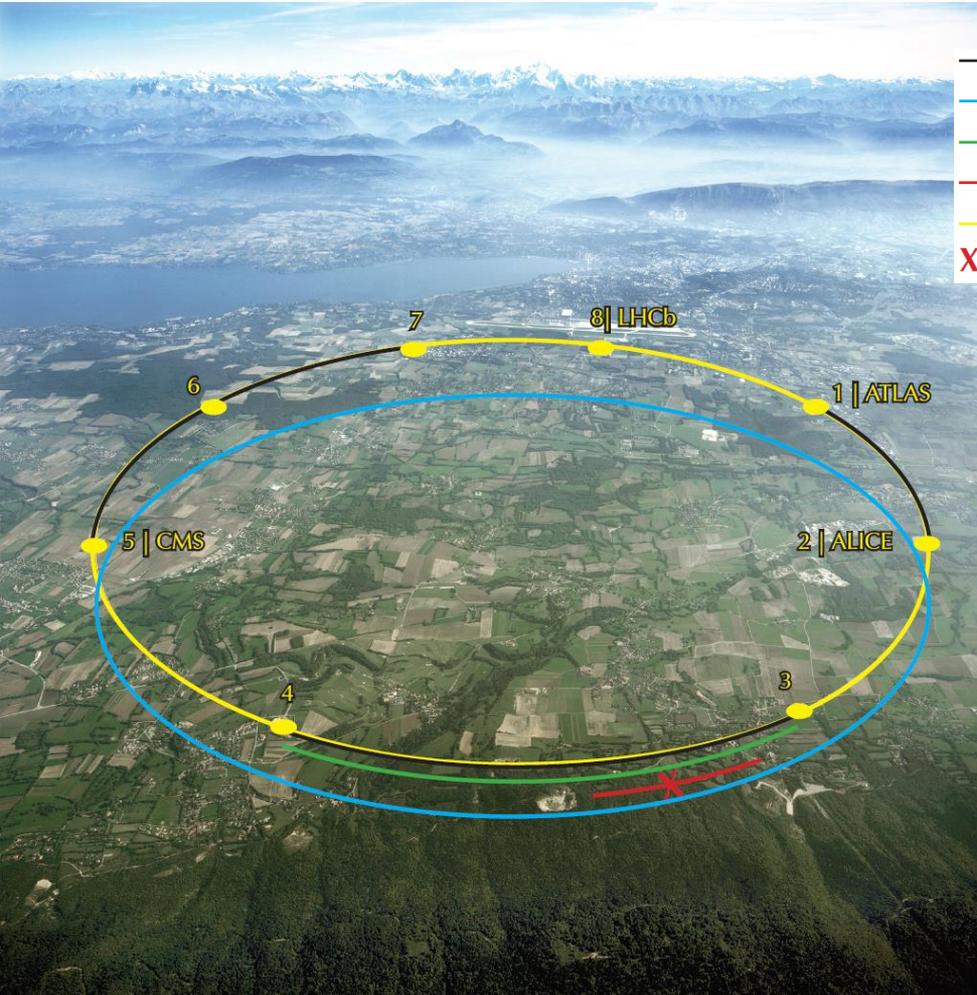


Very large damage



- 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



- Installazione nuove porte per fuoriuscita elio
- Miglioramento del sistema di protezione dei magneti
- Pulizia del tubo a vuoto del fascio
- Sostituzione dei magneti dipoli e quadrupoli e riparazione interconnessioni elettriche
- Anello LHC
- X Incidente

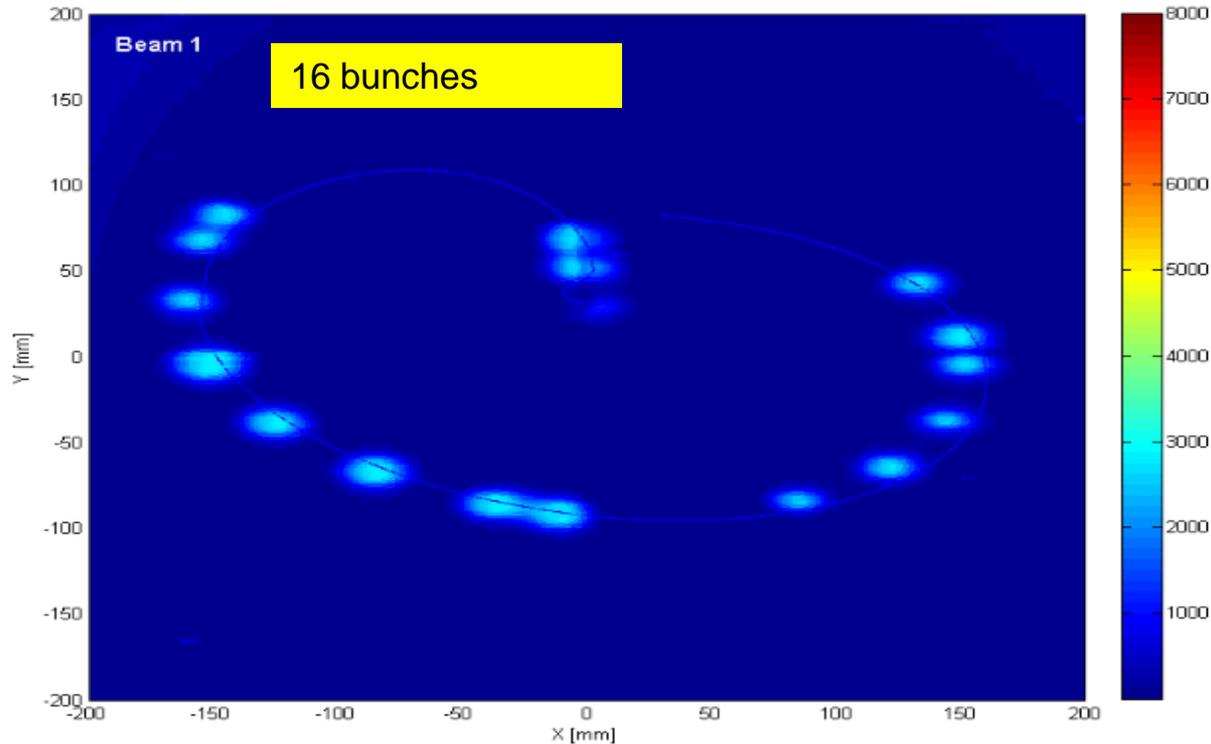
The re-start:

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

