European Organization for Nuclear Research
50 years of research in physics

CERN
The Laboratory

Dr. Sascha Marc Schmeling
CERN PH

Introduction to CERN and HEP

- The Organization
- The Laboratory
- **H**igh **E**nergy **P**hysics
- The Accelerators
- The Experiments
- Spin-Offs

Your Visits @ CERN

Available Tours

The Large Hadron Collider (LHC) – accelerator of the future

See behind the scenes at the sites where huge particle detectors are being assembled for installation at the collision points of the LHC's two proton beams.

- ATLAS experiment worksite
- CMS experiment assembly hall
- Test beam halls (TBH)

The Antiproton Decelerator (AD) – CERN's antimatter factory

Visit the only place in the world where antiatoms are produced in production-line fashion.

- The deceleration machine
- The experimental hall

The Proton Synchrotron (PS) – heart of CERN's accelerator complex

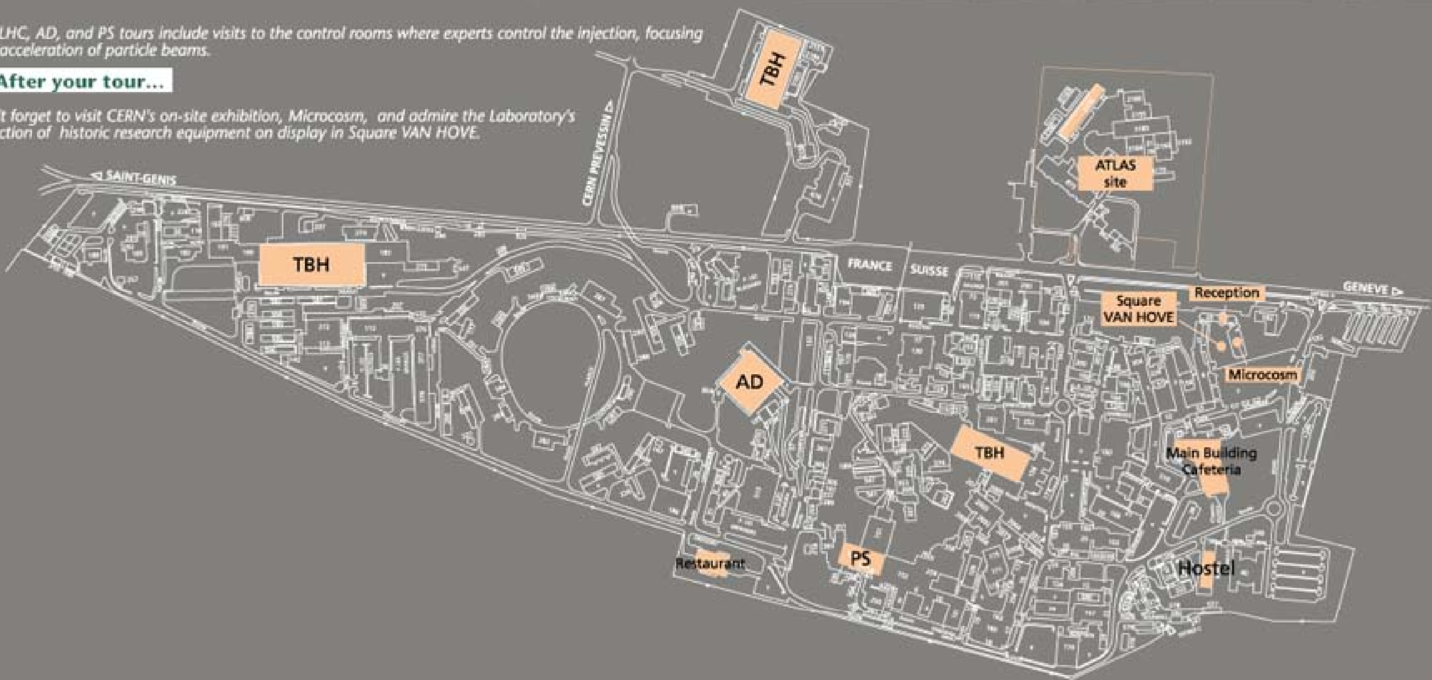
Here particles start their journey to the other accelerators (Super Proton Synchrotron, AD and LHC) Visit:

- LINAC 2, one of CERN's linear accelerators
- LEAR, the machine that produced the very first 9 atoms of antihydrogen in 1995

The LHC, AD, and PS tours include visits to the control rooms where experts control the injection, focusing and acceleration of particle beams.

After your tour...

Don't forget to visit CERN's on-site exhibition, Microcosm, and admire the Laboratory's collection of historic research equipment on display in Square VAN HOVE.



Visiting CERN

© CERN Visits Service, September 2001

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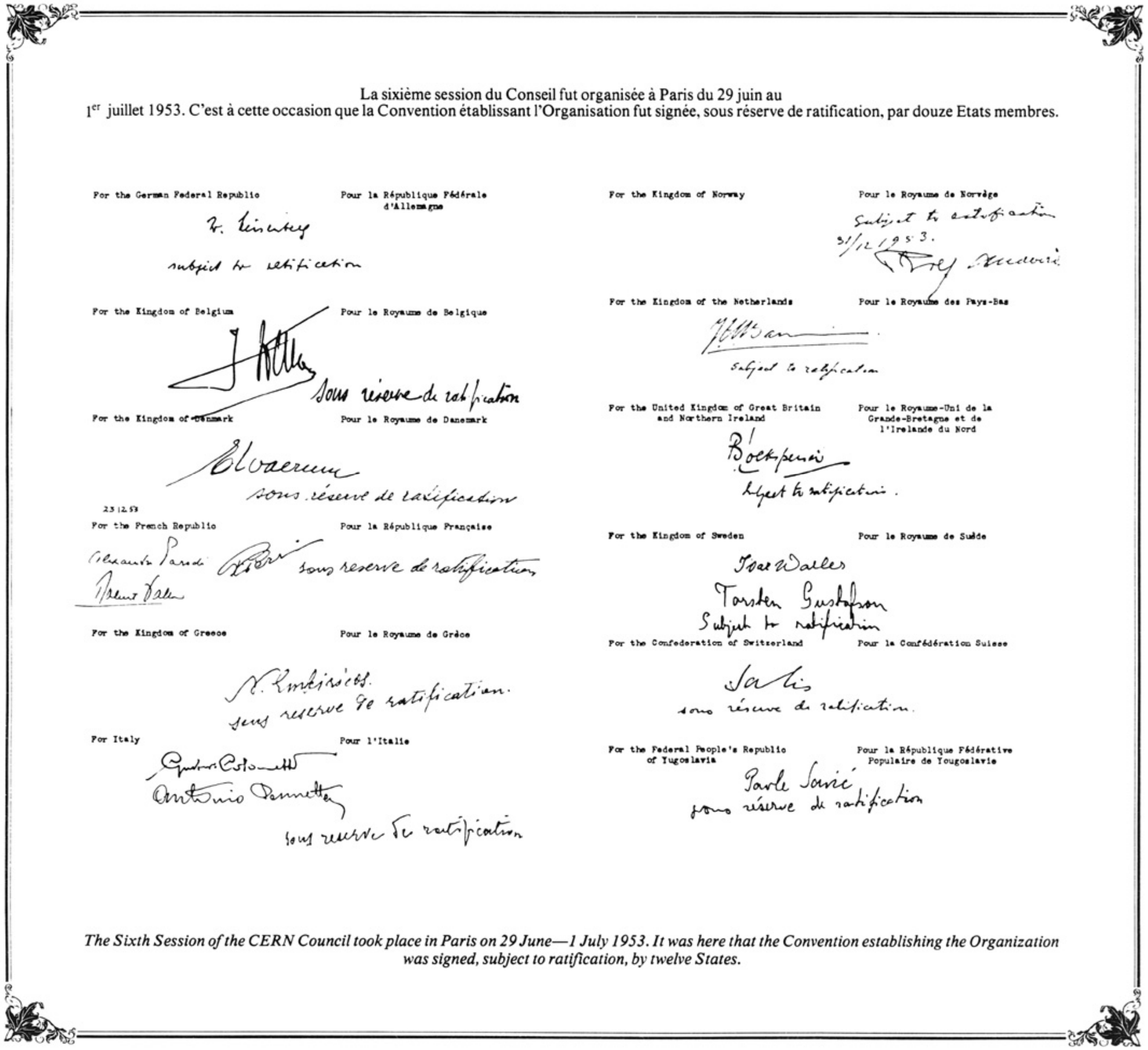

La sixième session du Conseil fut organisée à Paris du 29 juin au 1er juillet 1953. C'est à cette occasion que la Convention établissant l'Organisation fut signée, sous réserve de ratification, par douze Etats membres.

For the German Federal Republic — Pour la République Fédérale d'Allemagne

For the Kingdom of Norway — Pour le Royaume de Norvège

For the Kingdom of Belgium — Pour le Royaume de Belgique

For the Kingdom of the Netherlands — Pour le Royaume des Pays-Bas

For the Kingdom of Denmark — Pour le Royaume de Danemark

For the United Kingdom of Great Britain and Northern Ireland — Pour le Royaume-Uni de la Grande-Bretagne et de l'Irlande du Nord

For the French Republic — Pour la République Française

For the Kingdom of Sweden — Pour le Royaume de Suède

For the Kingdom of Greece — Pour le Royaume de Grèce

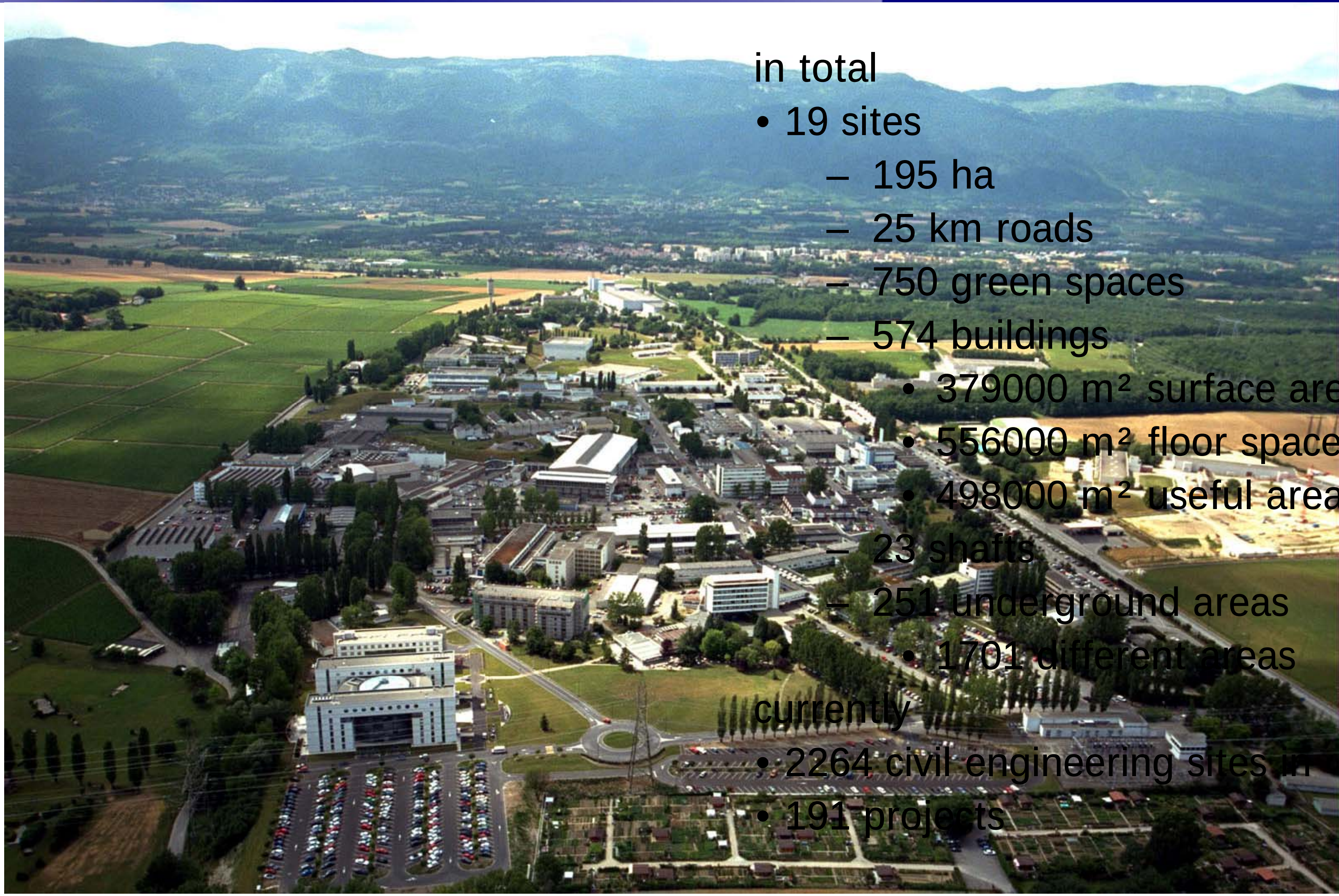
For the Confederation of Switzerland — Pour la Confédération Suisse

For Italy — Pour l'Italie

For the Federal People's Republic of Yugoslavia — Pour la République Fédérative Populaire de Yougoslavie

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.

CERN – The Laboratory



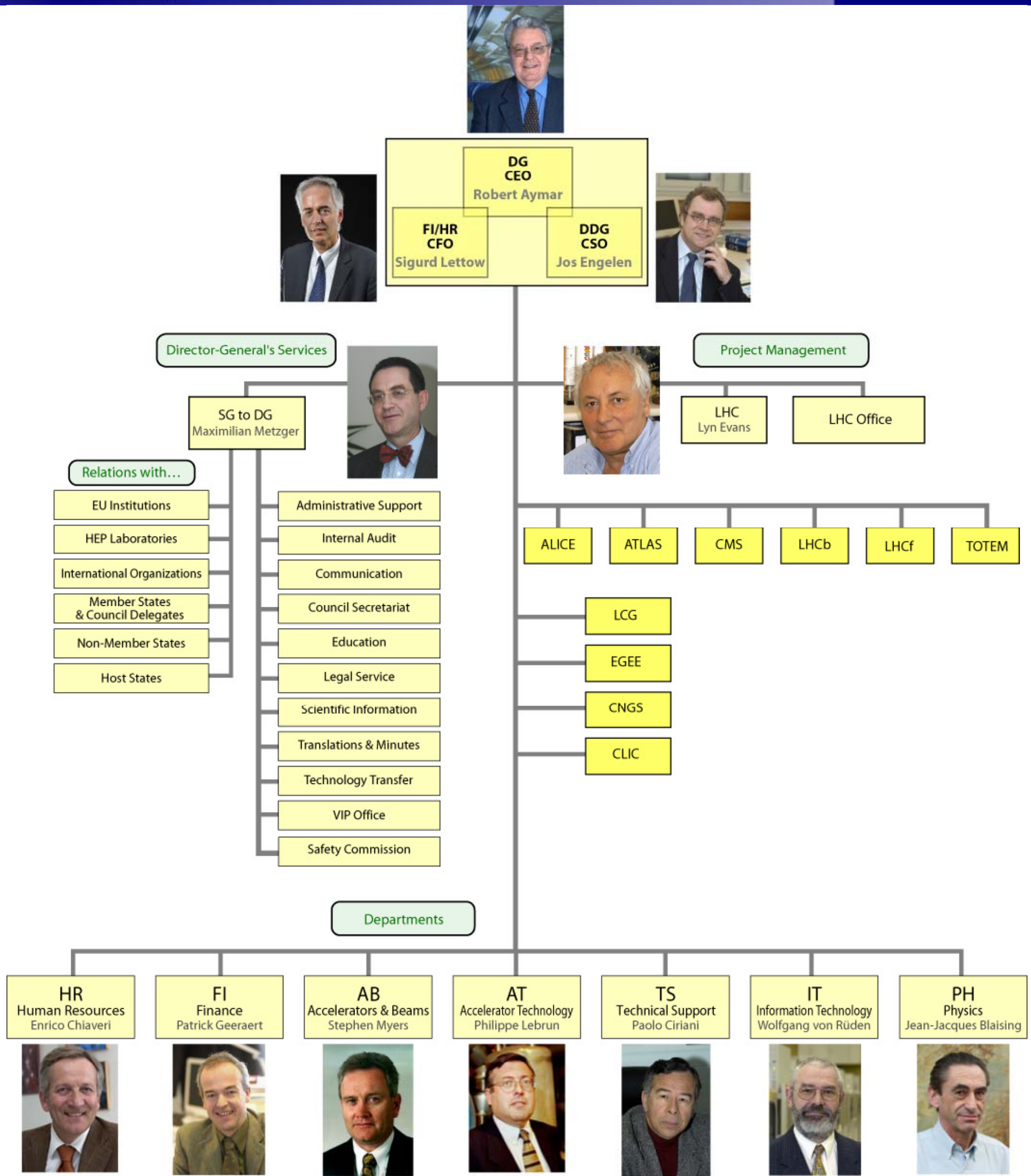
in total

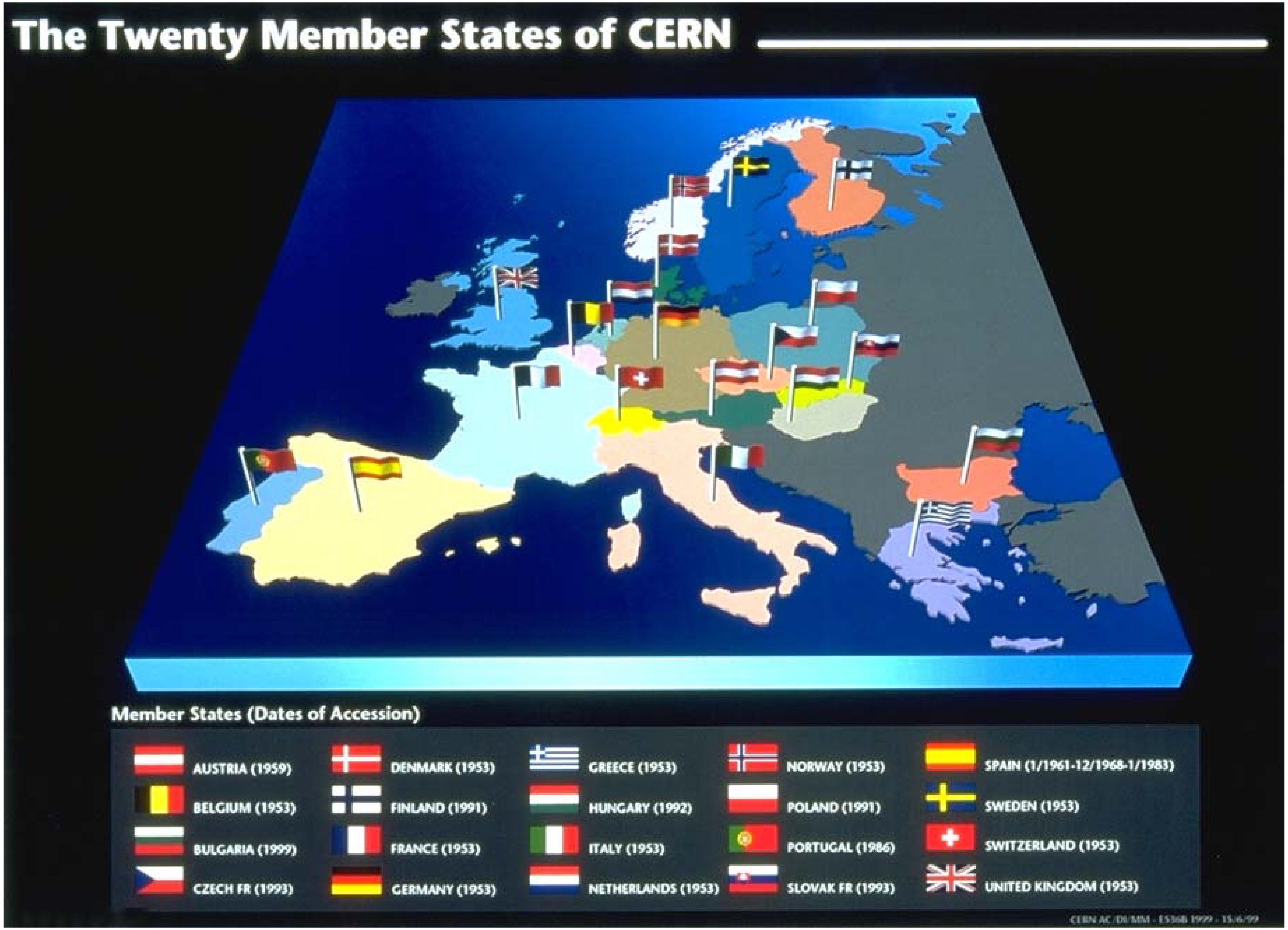
- 19 sites
  - 195 ha
  - 25 km roads
  - 750 green spaces
  - 574 buildings
    - 379000 m² surface area
    - 556000 m² floor space
    - 498000 m² useful area
  - 23 shafts
  - 251 underground areas
    - 1701 different areas

currently

- 2264 civil engineering sites in
- 191 projects

CERN Organisation

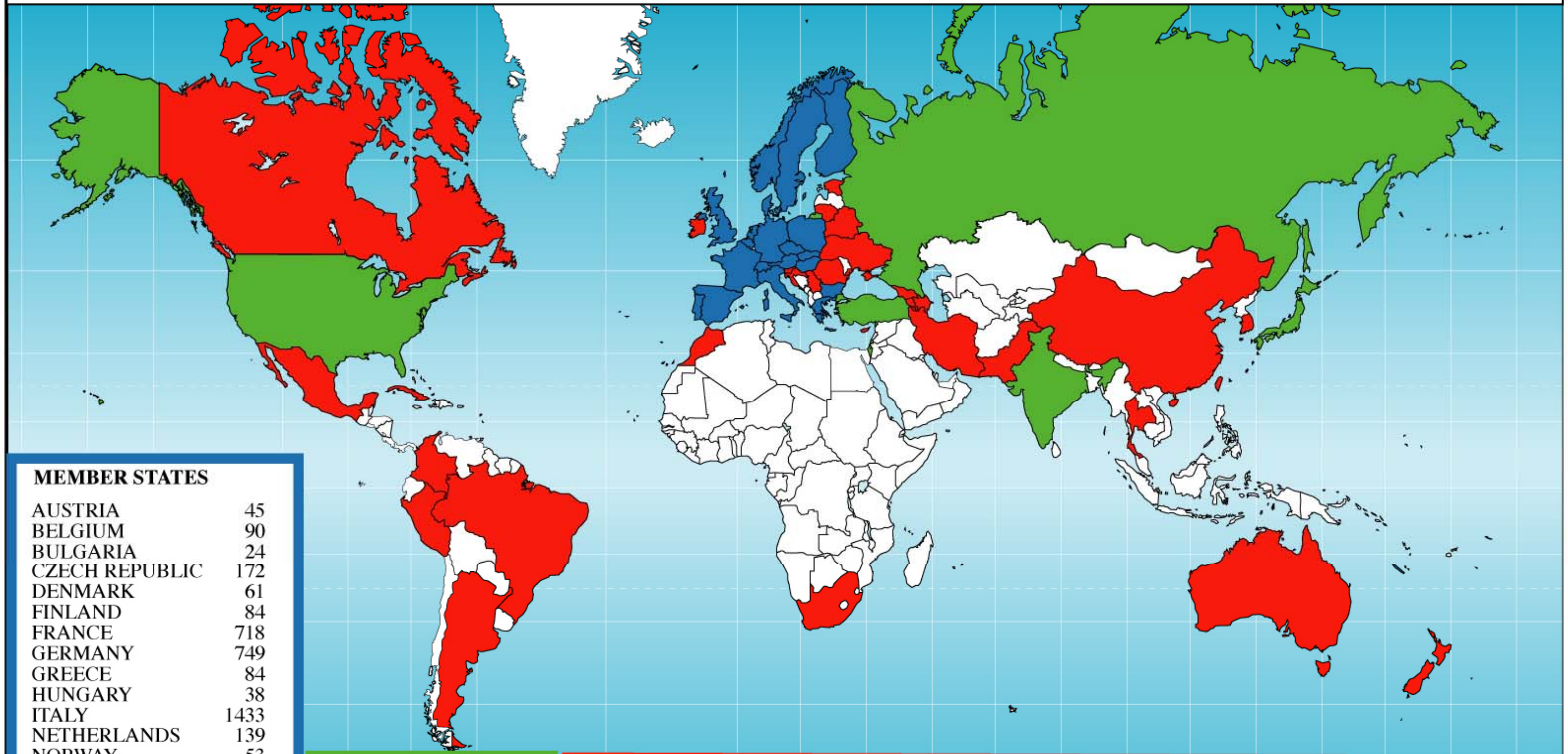




The Twenty Member States of CERN
Member States (Dates of Accession)
AUSTRIA (1959)
BELGIUM (1953)
BULGARIA (1999)
CZECH FR (1993)
DENMARK (1953)
FINLAND (1991)
FRANCE (1953)
GERMANY (1953)
GREECE (1953)
HUNGARY (1992)
ITALY (1953)
NETHERLANDS (1953)
NORWAY (1953)
POLAND (1991)
PORTUGAL (1986)
SLOVAK FR (1993)
SPAIN (1/1961-12/1968-1/1983)
SWEDEN (1953)
SWITZERLAND (1953)
UNITED KINGDOM (1953)

CERN Users

Distribution of All CERN Users by Nation of Institute on 12 October 2006



MEMBER STATES

AUSTRIA	45
BELGIUM	90
BULGARIA	24
CZECH REPUBLIC	172
DENMARK	61
FINLAND	84
FRANCE	718
GERMANY	749
GREECE	84
HUNGARY	38
ITALY	1433
NETHERLANDS	139
NORWAY	53
POLAND	144
PORTUGAL	86
SLOVAKIA	40
SPAIN	228
SWEDEN	49
SWITZERLAND	238
UNITED KINGDOM	512

4987

OBSERVER STATES

INDIA	60
ISRAEL	53
JAPAN	127
RUSSIA	811
TURKEY	29
USA	973

2053

OTHER STATES

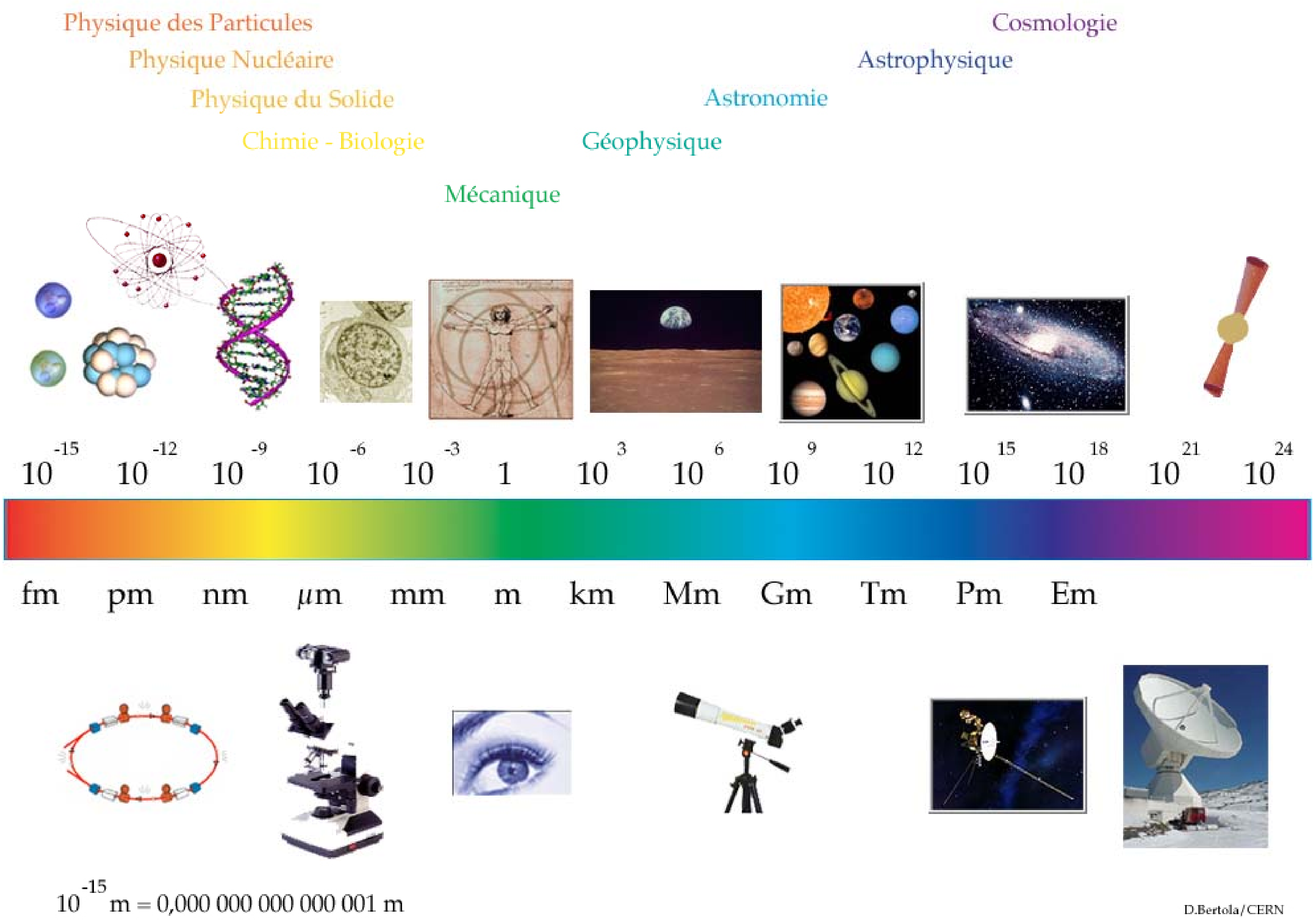
ARGENTINA	4
ARMENIA	11
AUSTRALIA	14
AZERBAIJAN	2
BELARUS	16
BRAZIL	47
CANADA	85
CHINA	55
COLOMBIA	2
CROATIA	14
CUBA	3
CYPRUS	10
ESTONIA	11
GEORGIA	8
IRAN	5
IRELAND	9
KOREA	19
LITHUANIA	1
MEXICO	21
MOROCCO	6
NEW ZEALAND	6
PAKISTAN	23
PERU	1
ROMANIA	28
SERBIA AND MONTENEGRO	12
SLOVENIA	12
SOUTH AFRICA	3
TAIWAN	25
THAILAND	1
UKRAINE	13

467

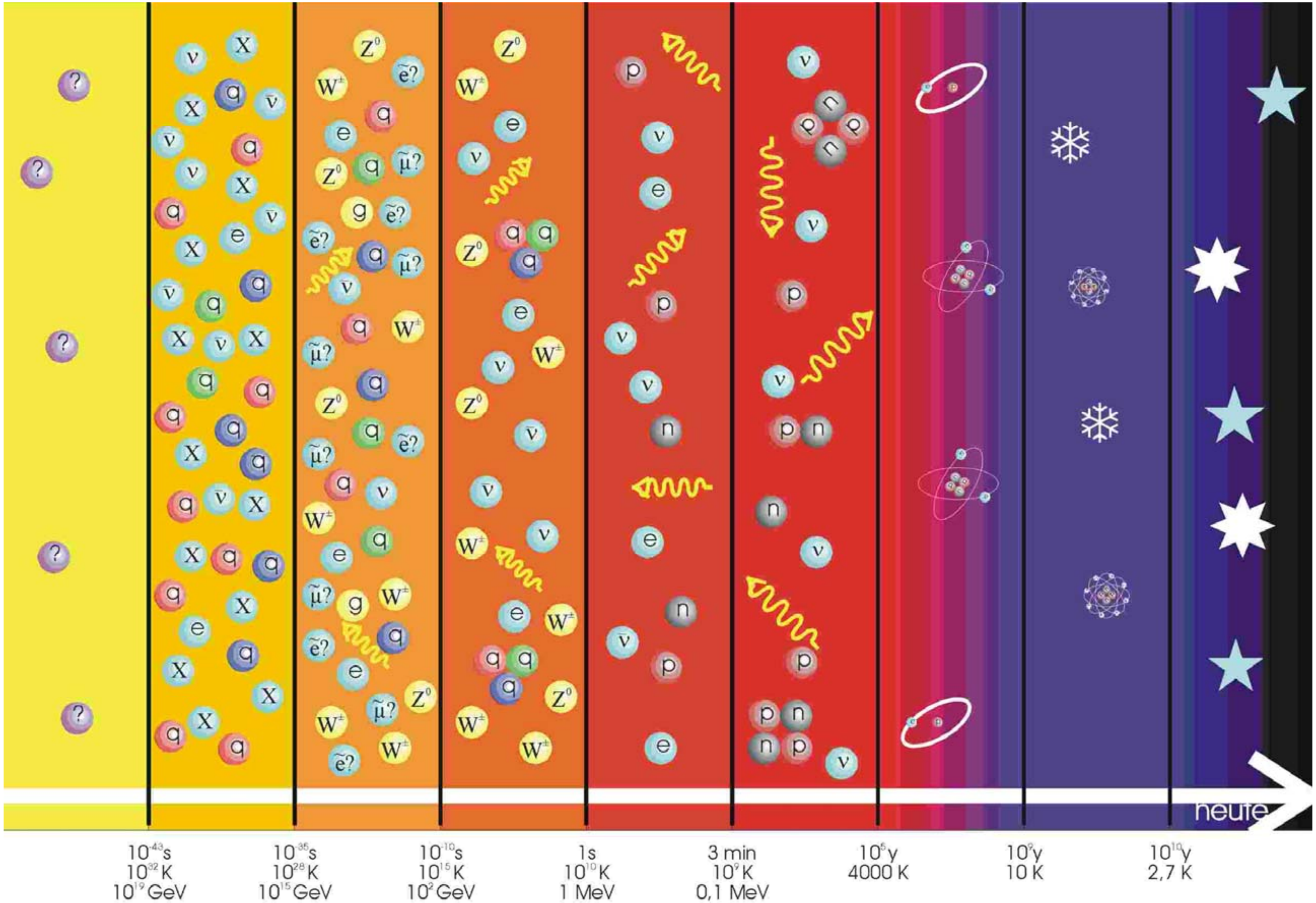
Research to discover the principles that keep the world together.

Search for

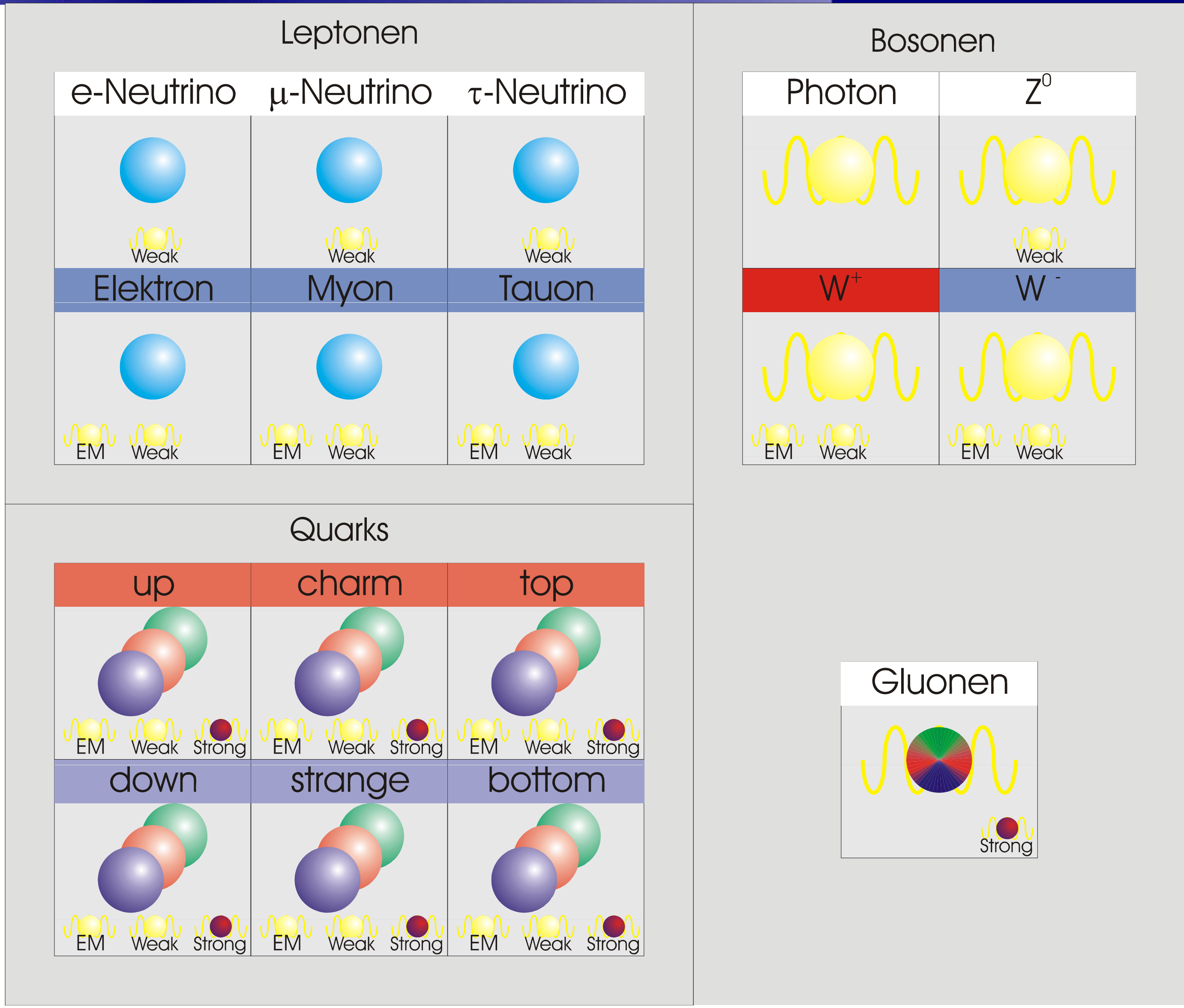
- elementary particles
- forces
- symmetries


Physique des Particules
Physique Nucléaire
Physique du Solide
Chimie - Biologie
Mécanique
Géophysique
Astronomie
Astrophysique
Cosmologie
10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 1 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18} 10^{21} 10^{24}
fm pm nm µm mm m km Mm Gm Tm Pm Em
10^{-15} m = 0,000 000 000 000 001 m
D.Bertola/CERN

History of the Universe



Standard Model

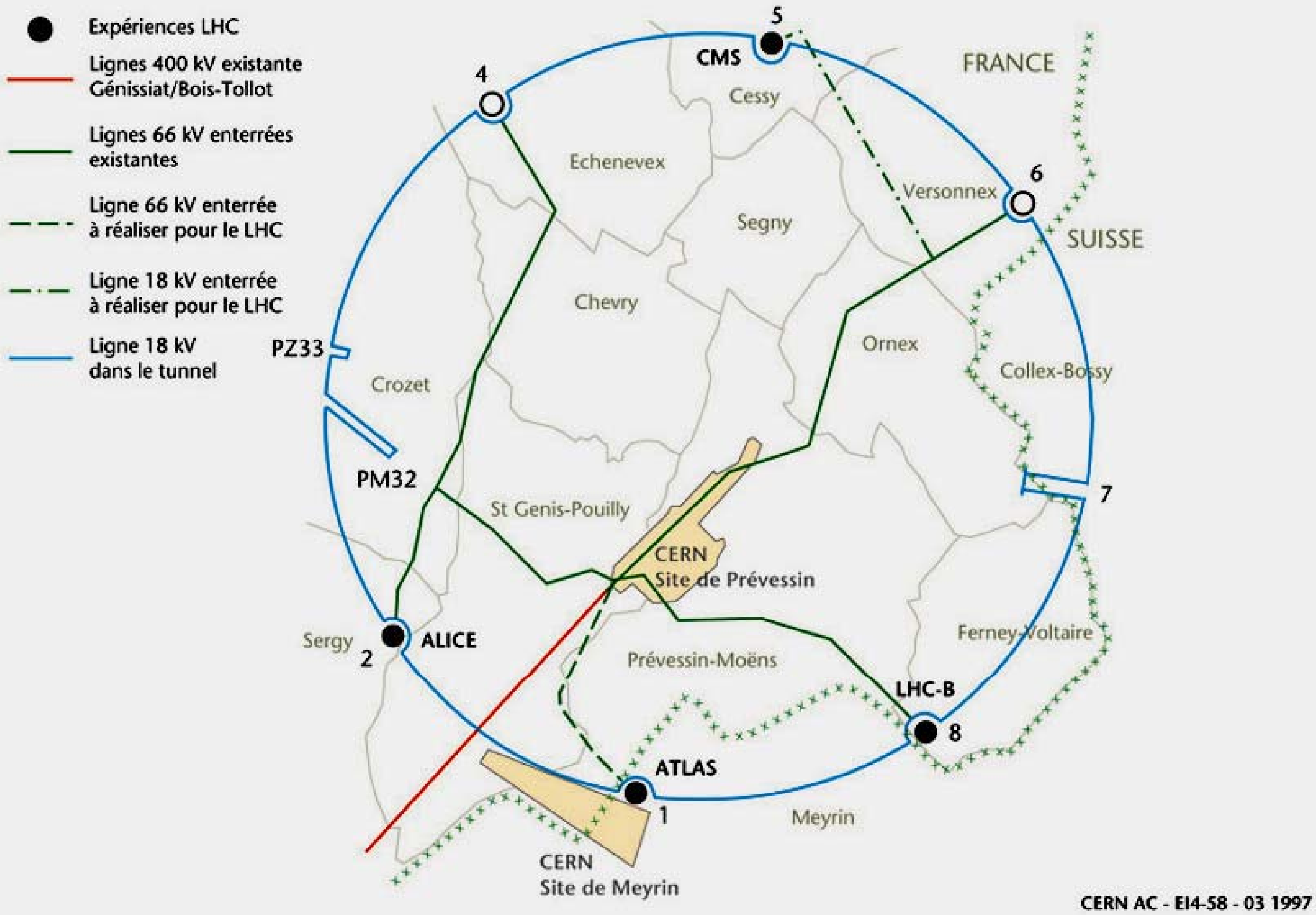


Reach high energies with accelerators

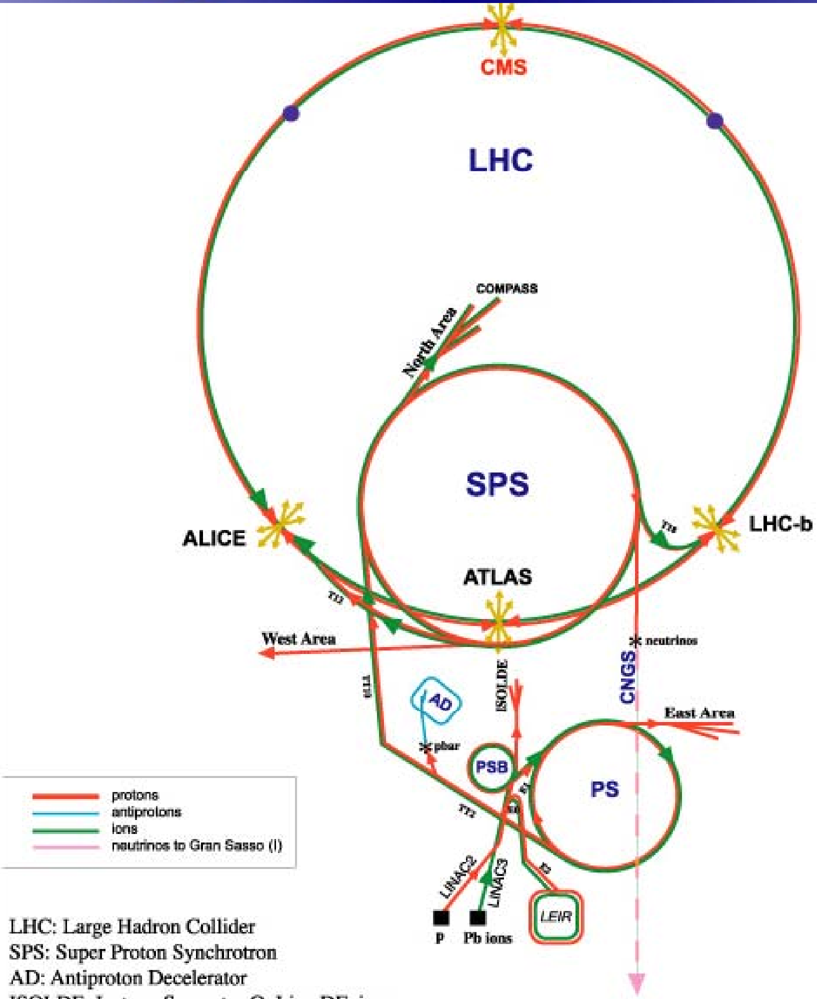
– natural accelerators
  - Astroparticle Physics
– artificial accelerators
  - Particle Physics

Probing of interactions of matter and antimatter with detectors

Plan schématique des liaisons électriques enterrées LEP/LHC



Accelerators at CERN

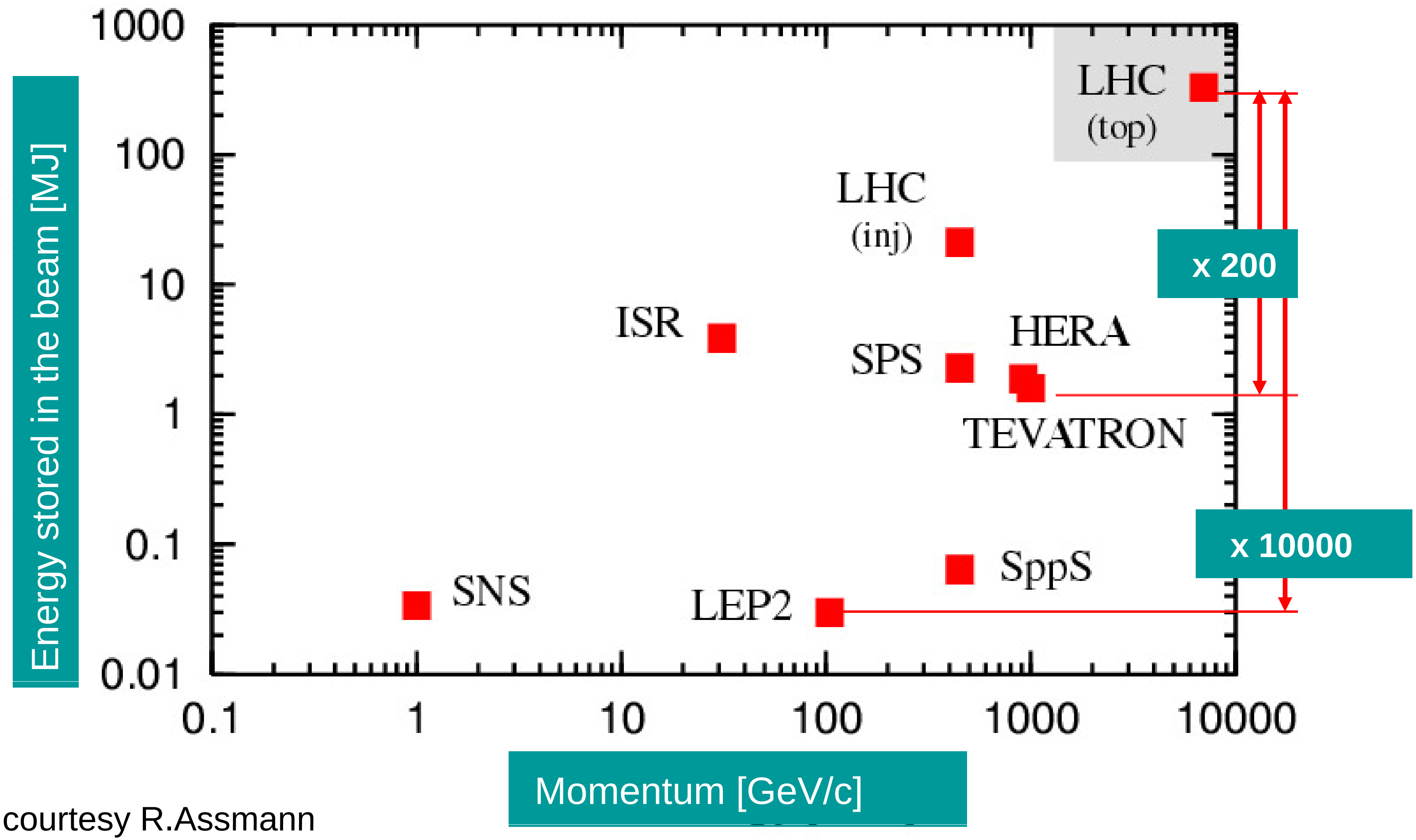


LHC: Large Hadron Collider
SPS: Super Proton Synchrotron
AD: Antiproton Decelerator
ISOLDE: Isotope Separator OnLine DEvice
PSB: Proton Synchrotron Booster
PS: Proton Synchrotron
LINAC: LINear ACcelerator
LEIR: Low Energy Ion Ring
CNGS: Cern Neutrinos to Gran Sasso

Rudolf LEY, PS Division, CERN, 02.09.96
Revised and adapted by Antonella Del Rosso, ETT Di
in collaboration with B. Desforges, SL Div., and
D. Manglunki, PS Div. CERN, 23.05.01

- Decommissioned Accelerators
  - SC
  - ISR
- “Operational” Accelerators
  - PS
    - AD complex
  - SPS
    - fix target experiments
- Future Accelerators
  - LHC
  - CNGS
  - CLIC study

Challenges: Energy stored in the beam



courtesy R.Assmann

LHC: From first ideas to realisation

1982 : First studies for the LHC project

1983 : Z0 detected at SPS proton antiproton collider

1985 : Nobel Price for S. van der Meer and C. Rubbia

1989 : Start of LEP operation (Z-factory)

1994 : Approval of the LHC by the CERN Council

1996 : Final decision to start the LHC construction

1996 : LEP operation at 100 GeV (W-factory)

2000 : End of LEP operation

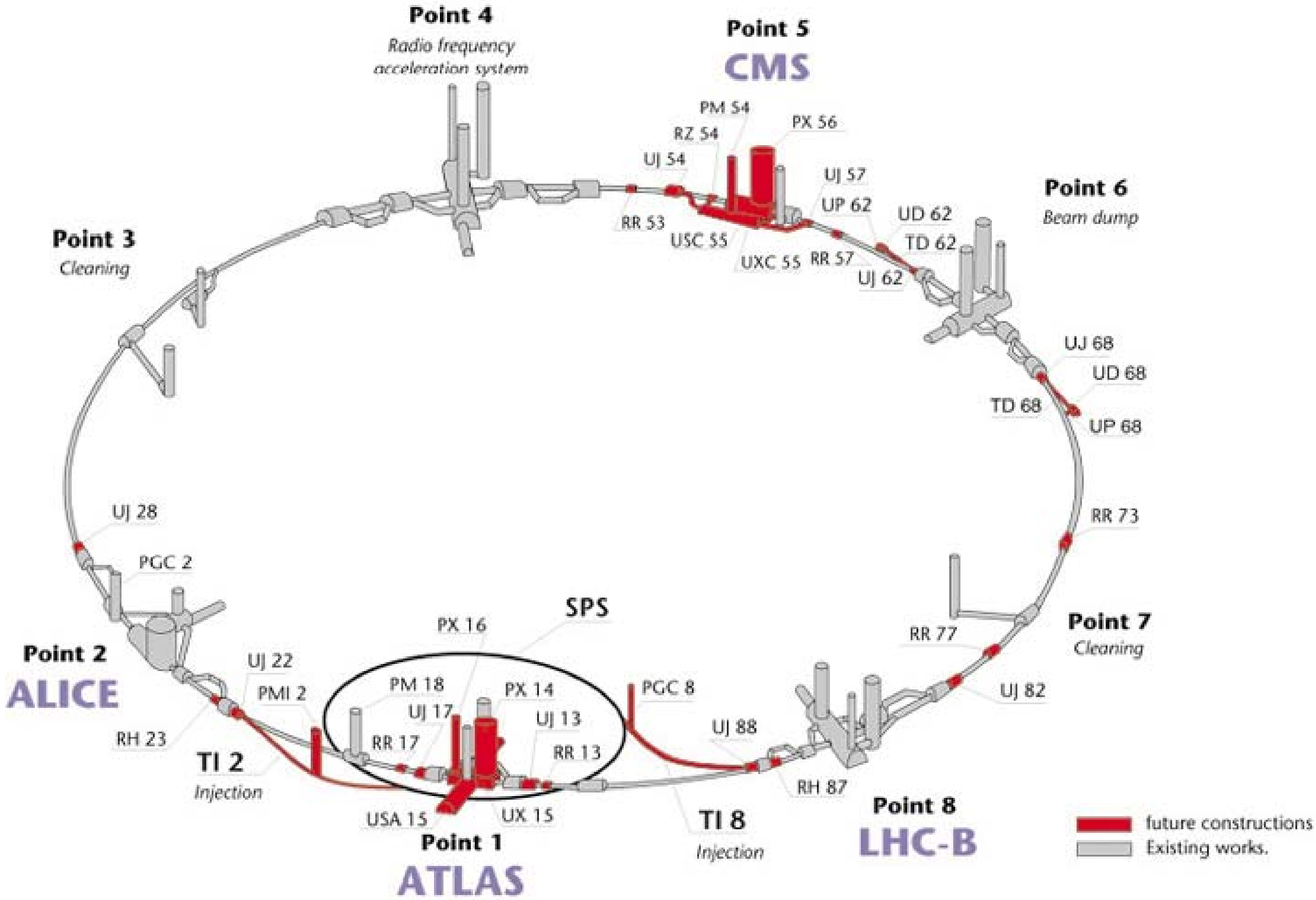
2002 : LEP equipment removed

2003 : Start of the LHC installation

2005 : Start of hardware commissioning

2007 : Commissioning with beam planned

LEP/LHC Tunnel

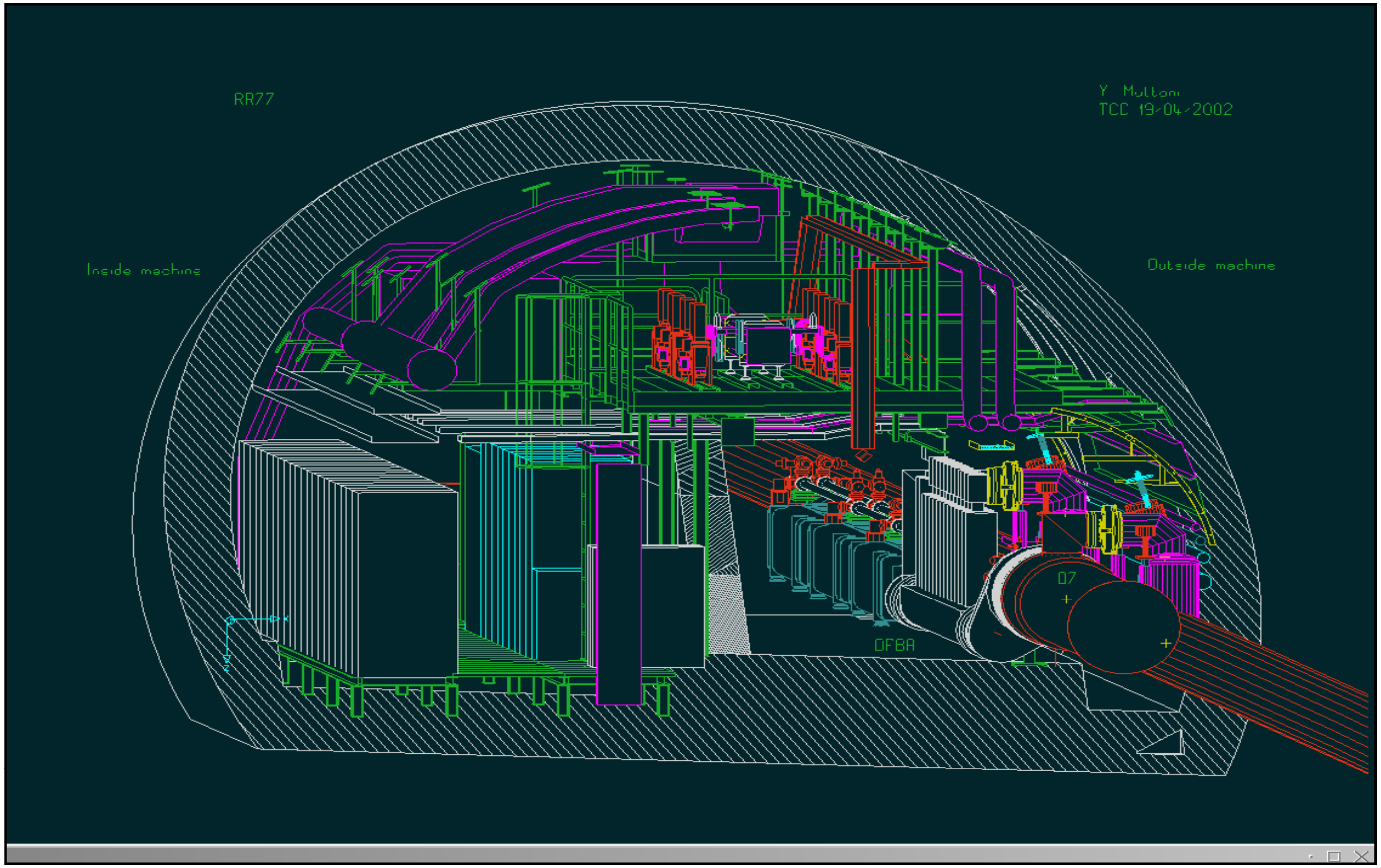


Integration and Installation

Space in tunnel and underground areas is limited

Equipment for many systems need to be installed

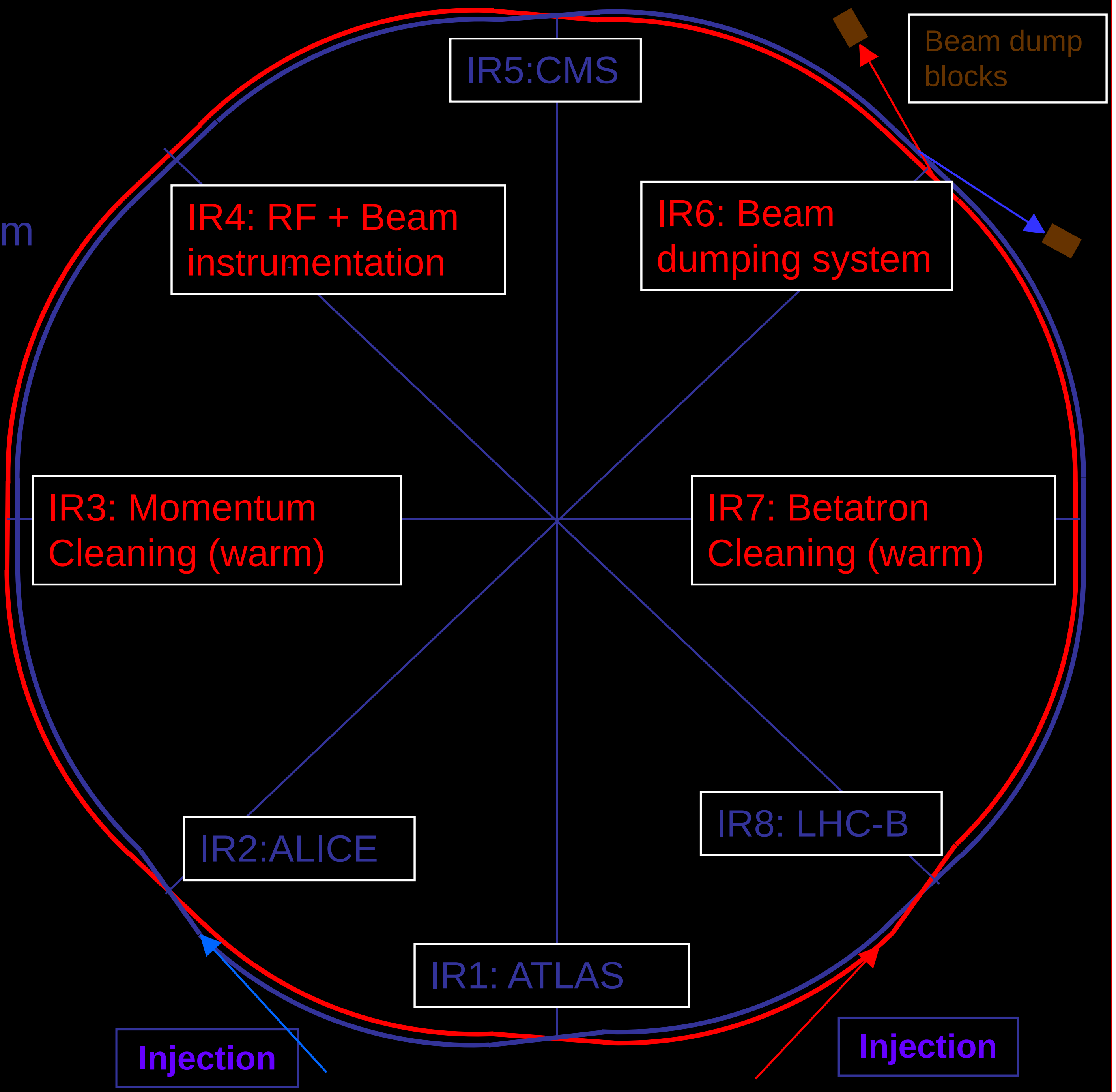
3-D computer model for tunnel and underground areas



LHC Layout

eight arcs (sectors)

eight long straight section (about 700 m long)



Transfer Lines SPS - LHC

Two new transfer line tunnels from SPS to LHC are being built. The beam lines use normal conducting magnets

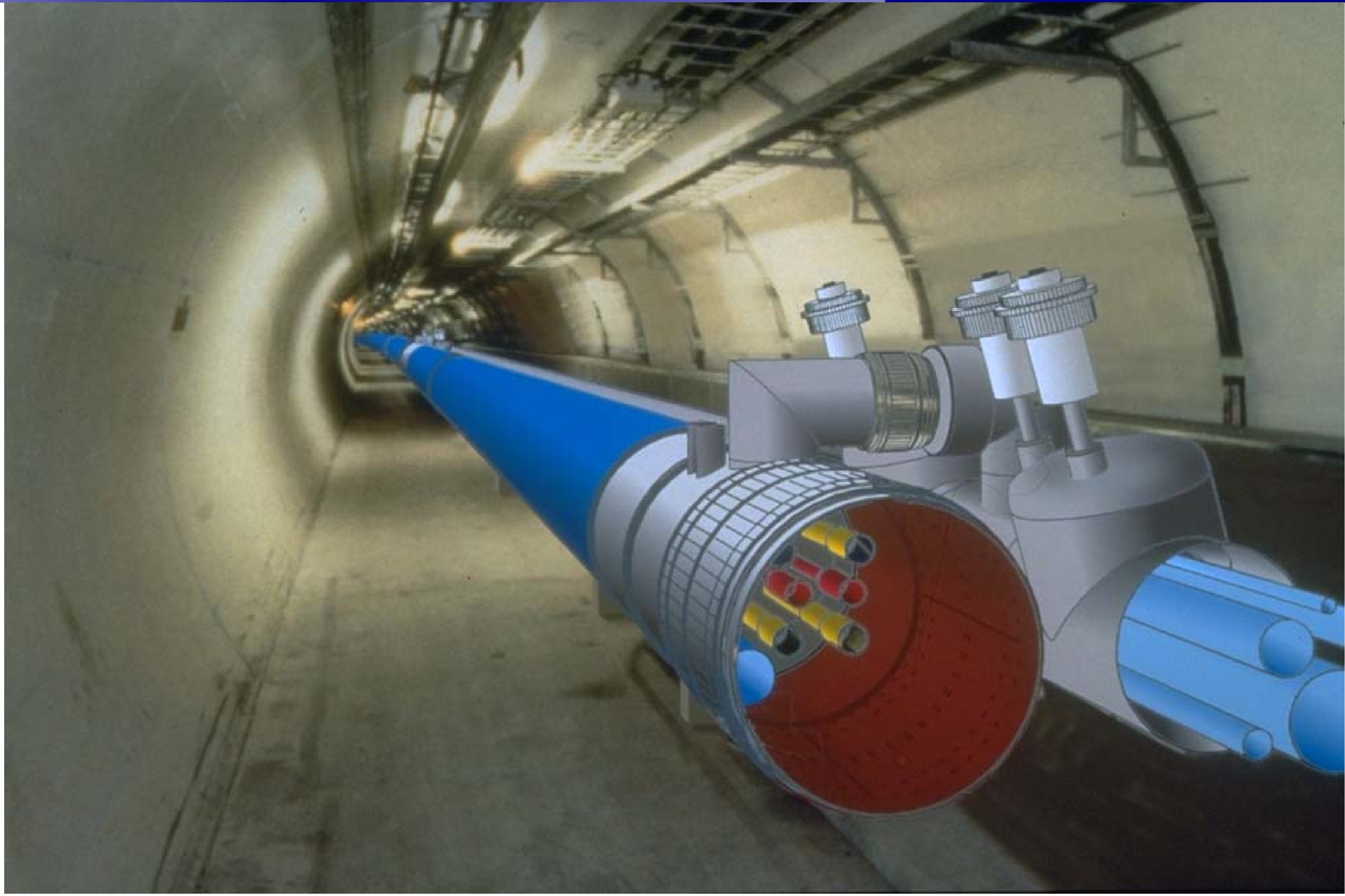
Length of each line: about 2.8 km

Magnets are all available, made by BINP / Novosibirsk

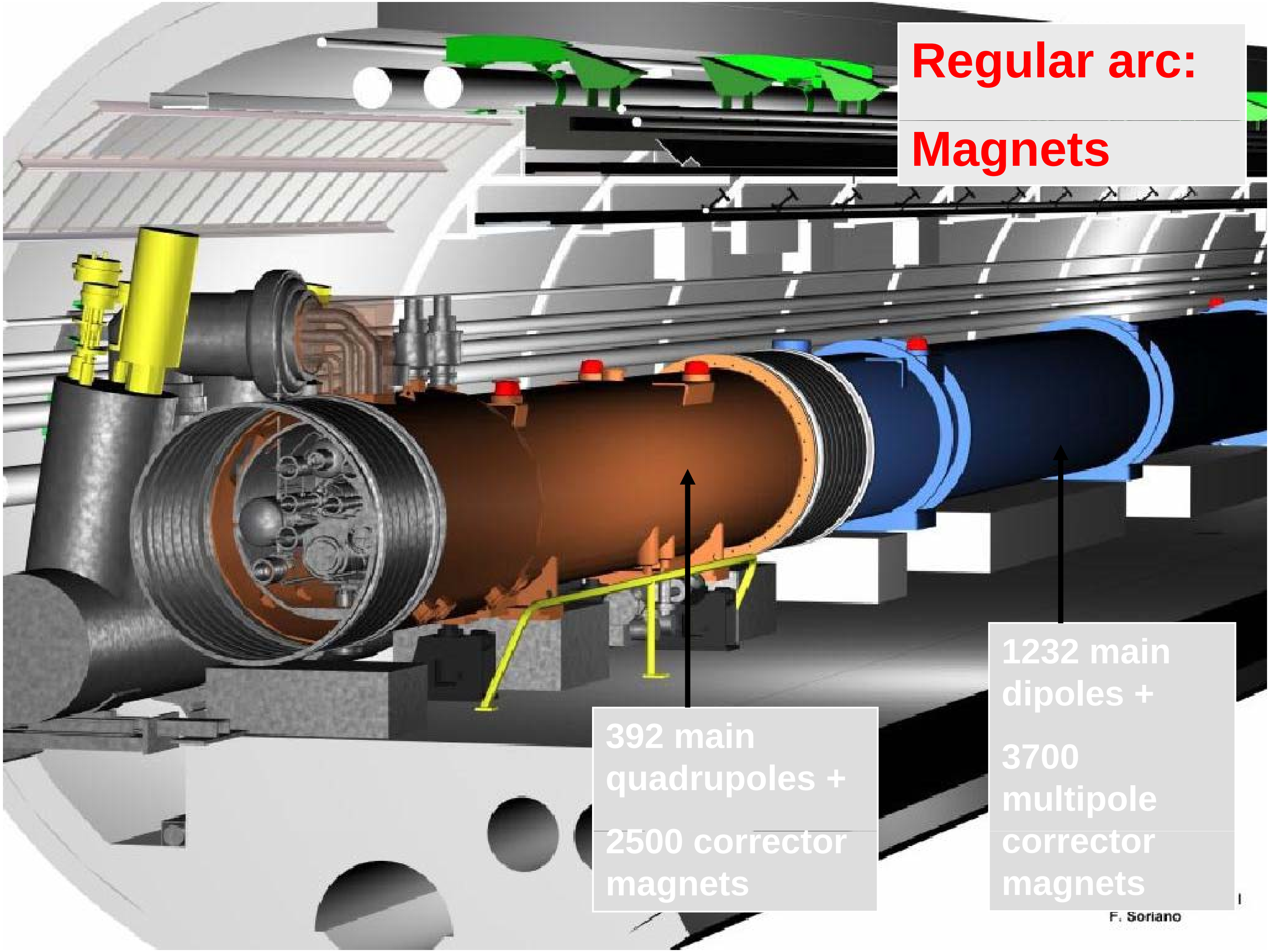
Commissioning of the first line for 2004

Dipole magnets waiting for installation

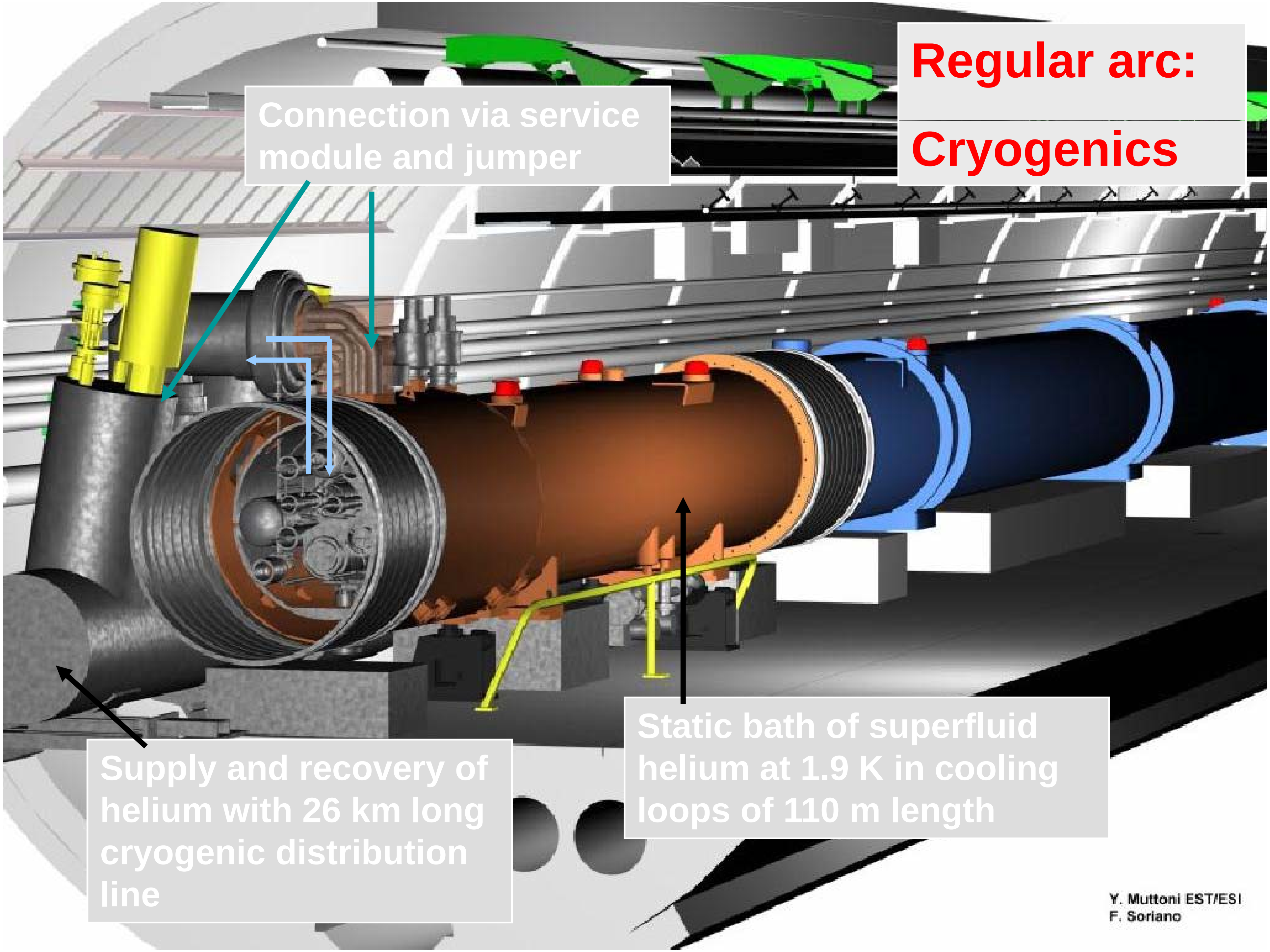
LEP/LHC Tunnel

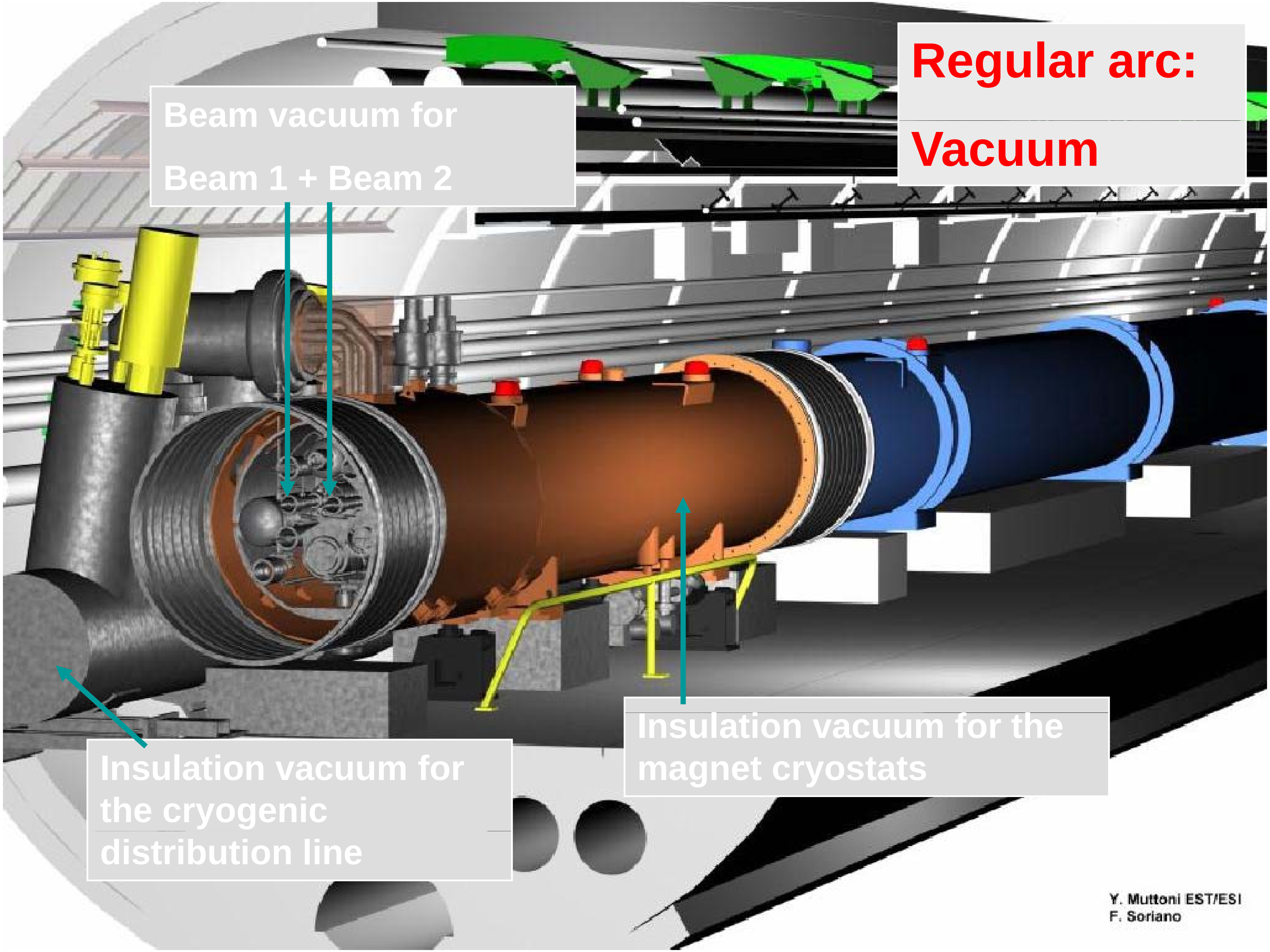


Regular arc: Magnets



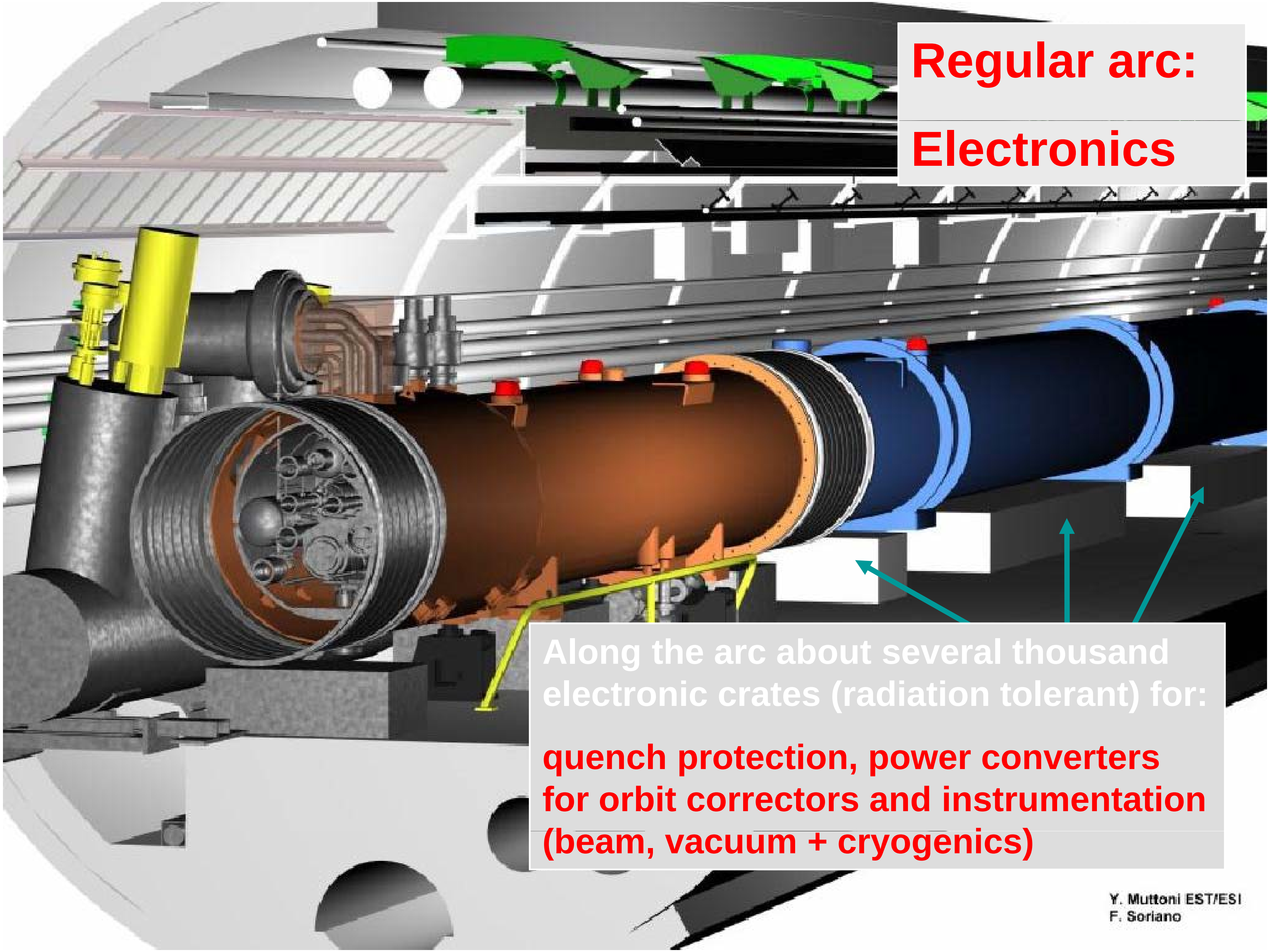
Regular arc: Cryogenics




Regular arc:
Vacuum
Beam vacuum for
Beam 1 + Beam 2
Insulation vacuum for the cryogenic distribution line
Insulation vacuum for the magnet cryostats
Y. Muttoni EST/ESI
F. Soriano

Regular arc:

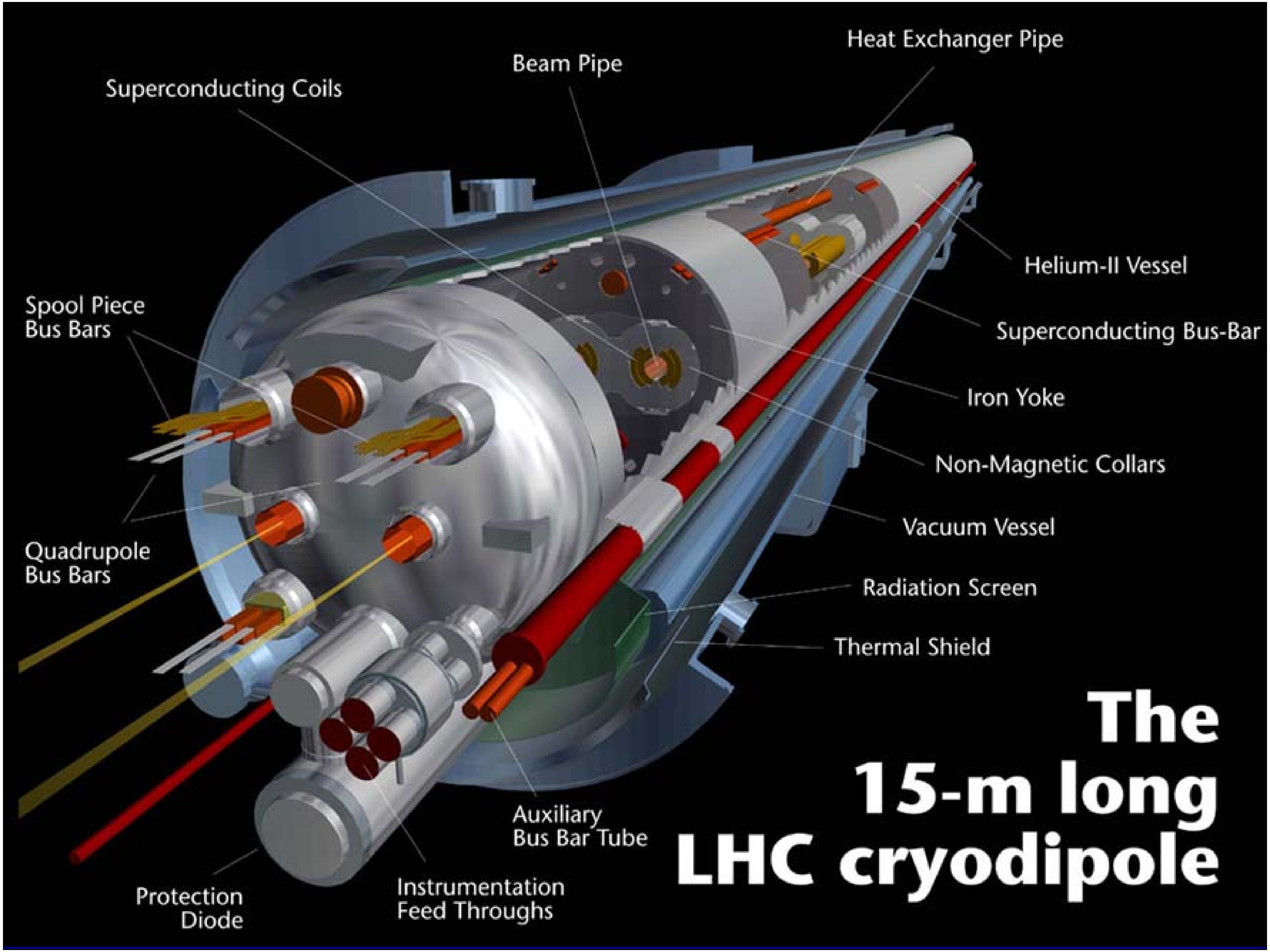
Electronics



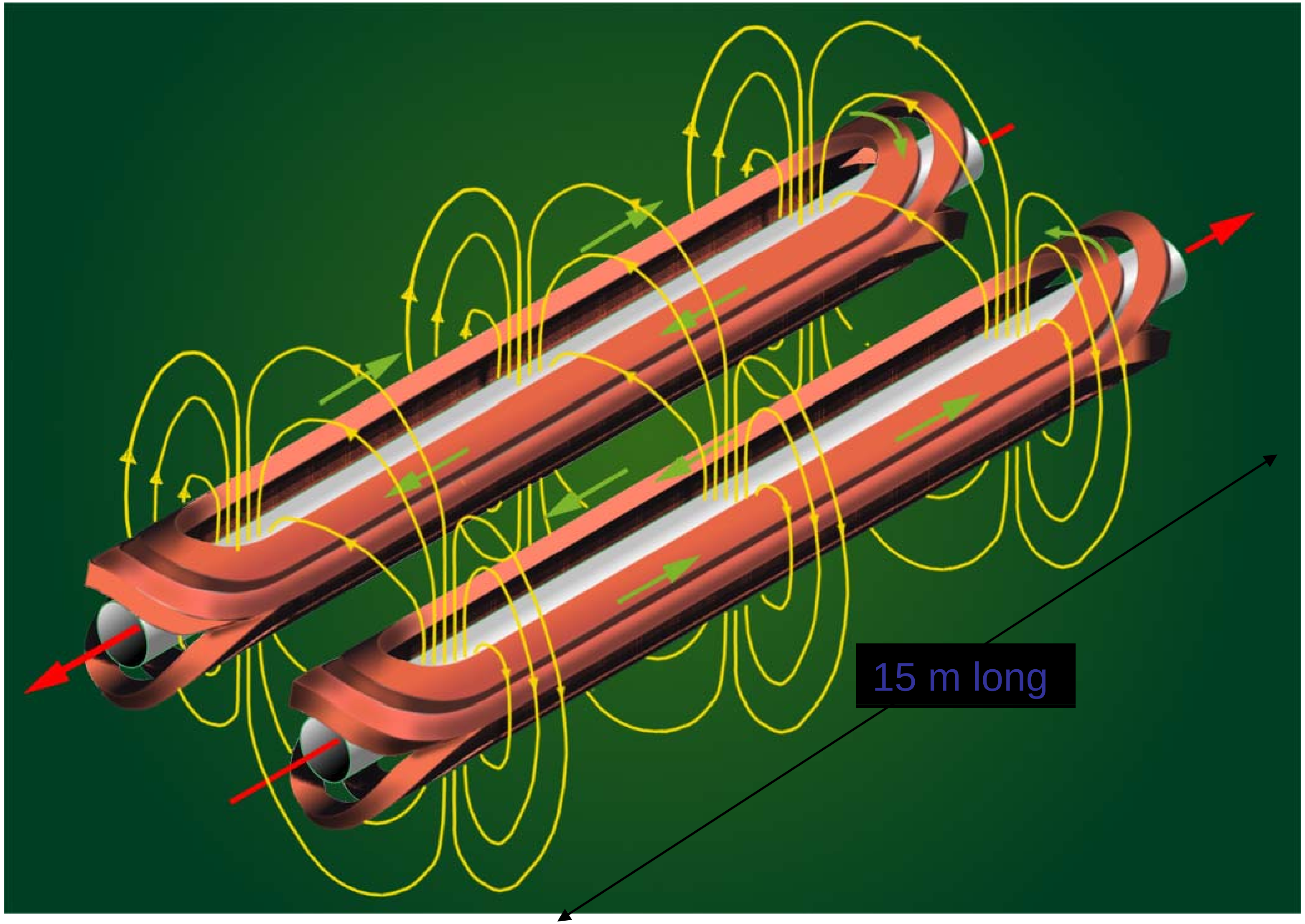
Along the arc about several thousand electronic crates (radiation tolerant) for:

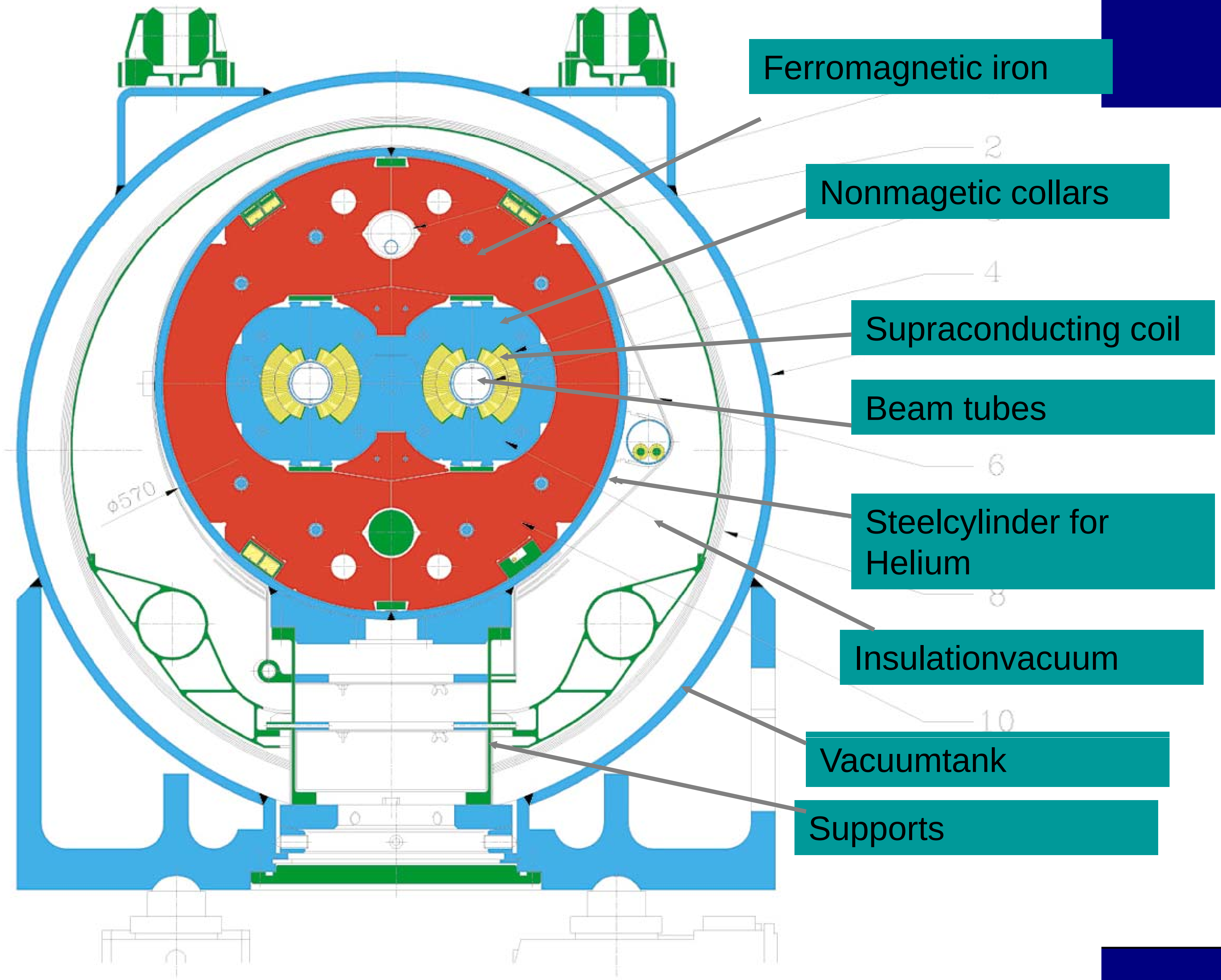
quench protection, power converters for orbit correctors and instrumentation (beam, vacuum + cryogenics)

Y. Muttoni EST/ESI
F. Soriano


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

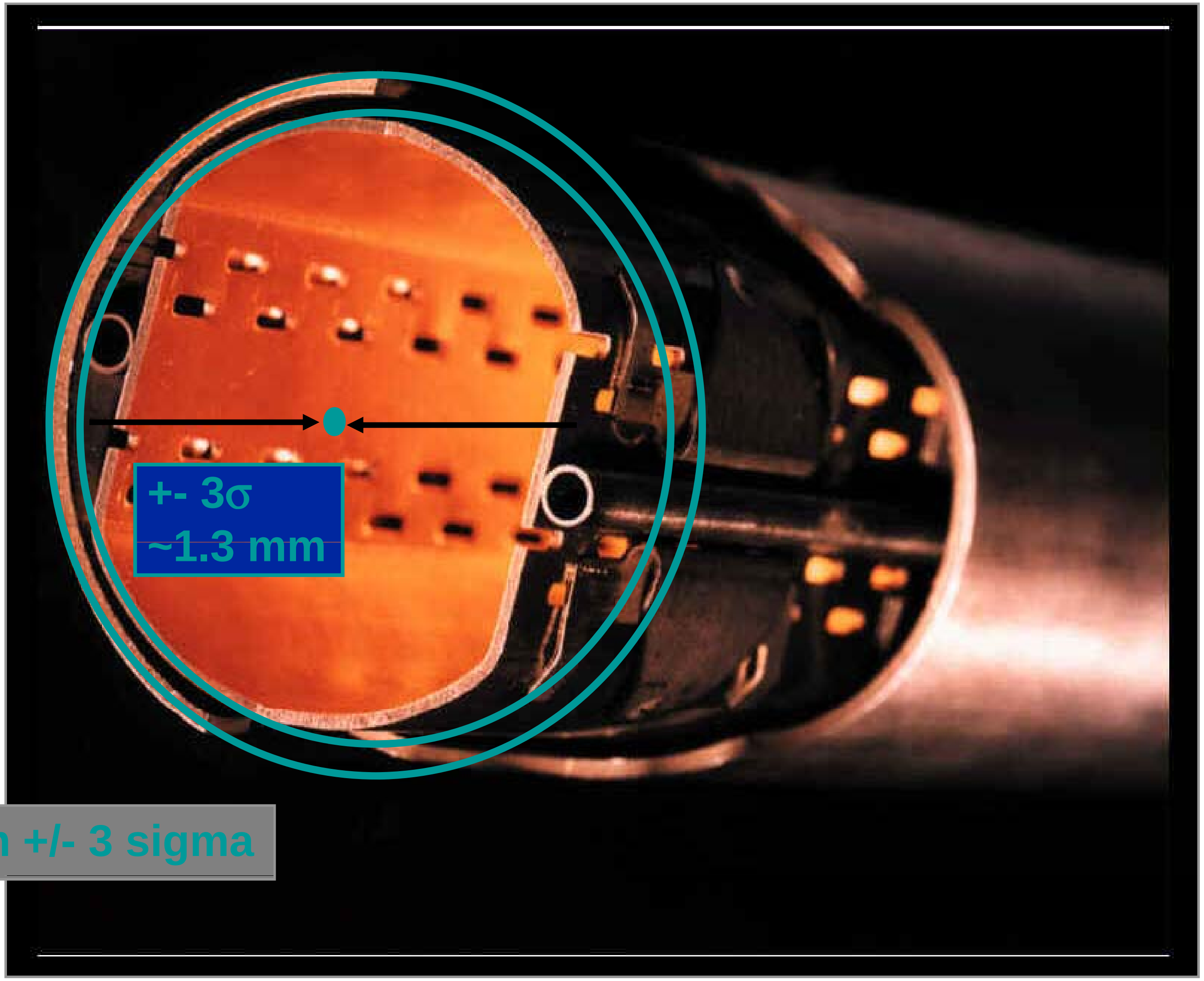
Coils for Dipolemagnets



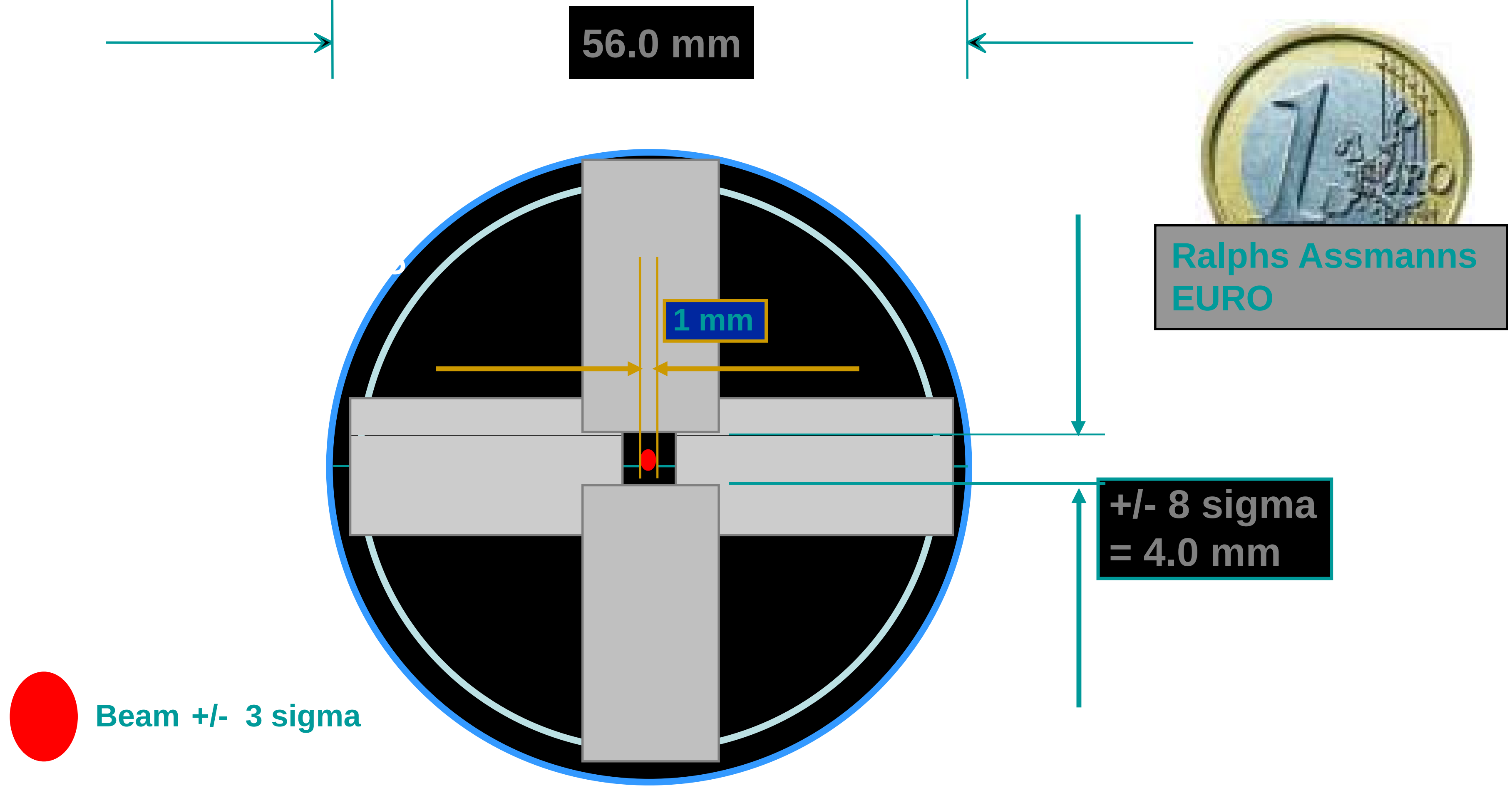


Ferromagnetic iron
Nonmagetic collars
Supraconducting coil
Beam tubes
Steelcylinder for Helium
Insulationvacuum
Vacuumtank
Supports
φ570
2
4
6
8
10

56.0 mm



Beam +/- 3 sigma


56.0 mm
Ralphs Assmanns
EURO
1 mm
+/- 8 sigma
= 4.0 mm
Beam +/- 3 sigma

Installation of cryogenic distribution line in the LHC tunnel – started during summer 2003

Cryostating and measurements (main dipoles and other magnets)

SMA18 cryostating hall at CERN for installing dipole magnets into cryostats

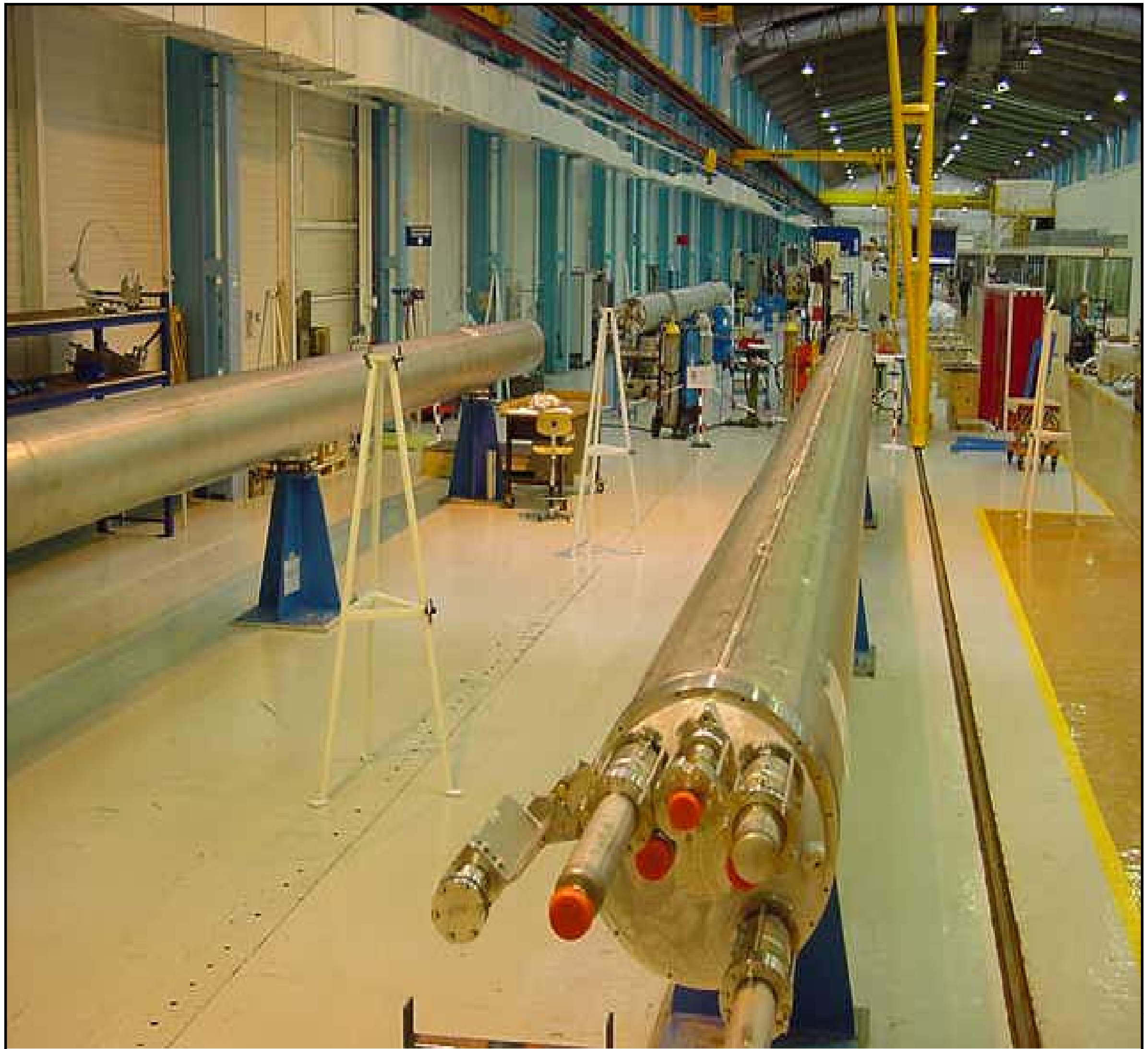
Storage of dipole cold masses waiting for cryostating

LHC: Superconducting Magnets

Arc 15-m dipoles and quadrupoles

Insertion dipoles and quadrupoles

Corrector magnets



Dipole assembly in industry

Cryogenic System

Four new 18 kW plants are added to four existing plants from LEP

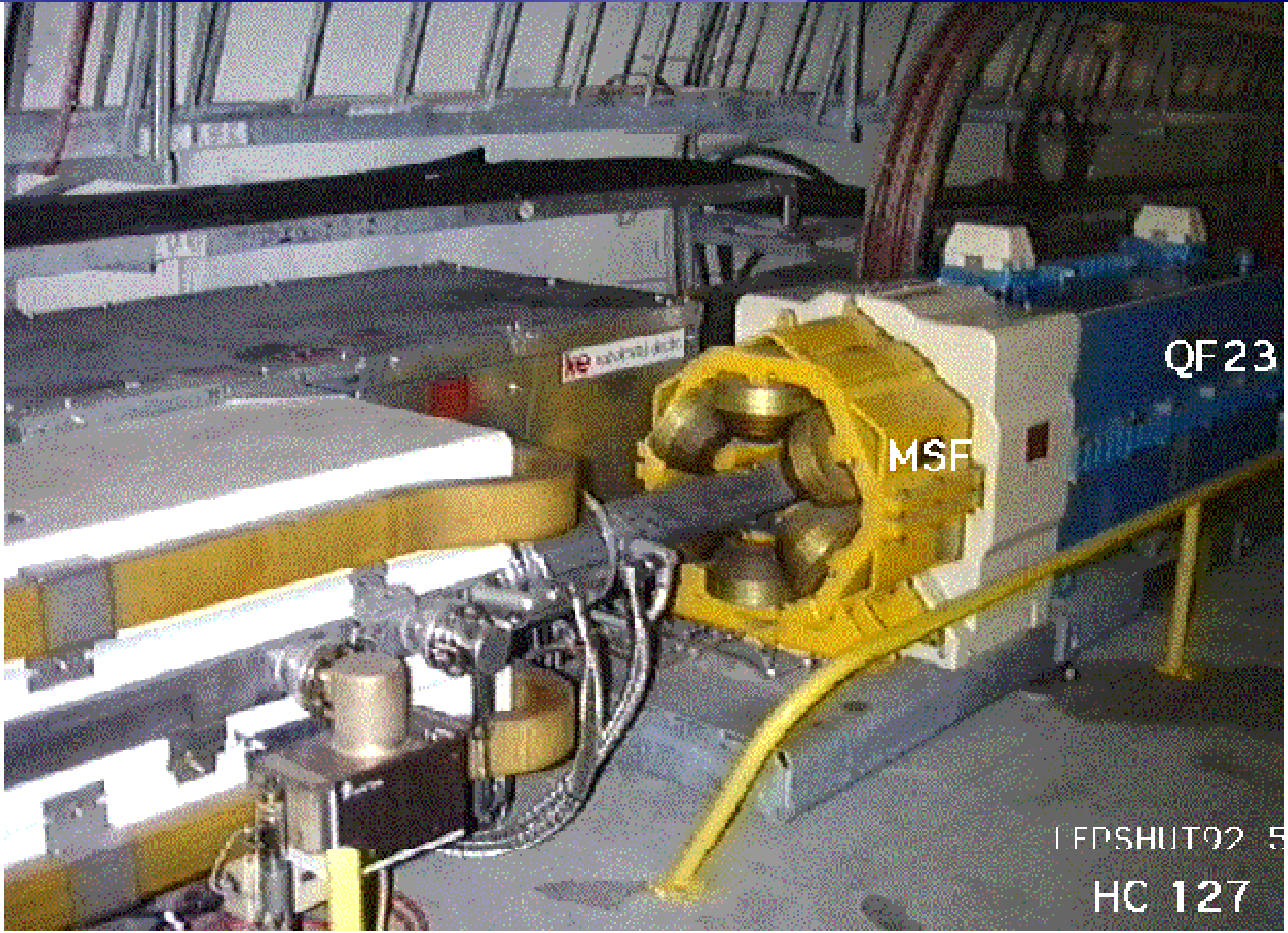
26 km long Cryoline: three 100 m prototypes were built and validated

Contract for construction and installation of the line has been awarded

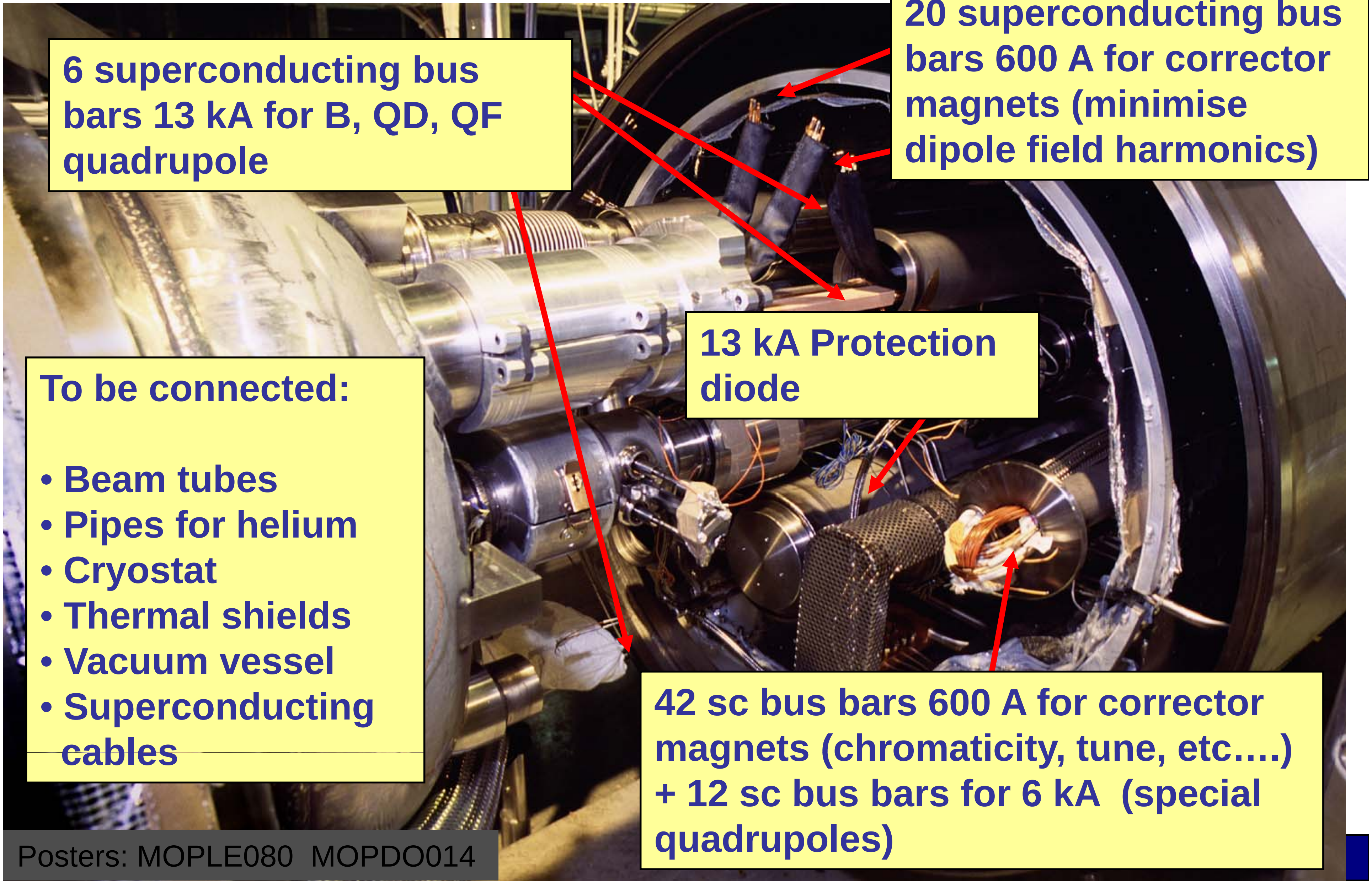
Installation started in 2003

One new plant is being commissioned

Interconnection between magnets: LEP



One of 1800 interconnection between two superconducting magnets: LHC

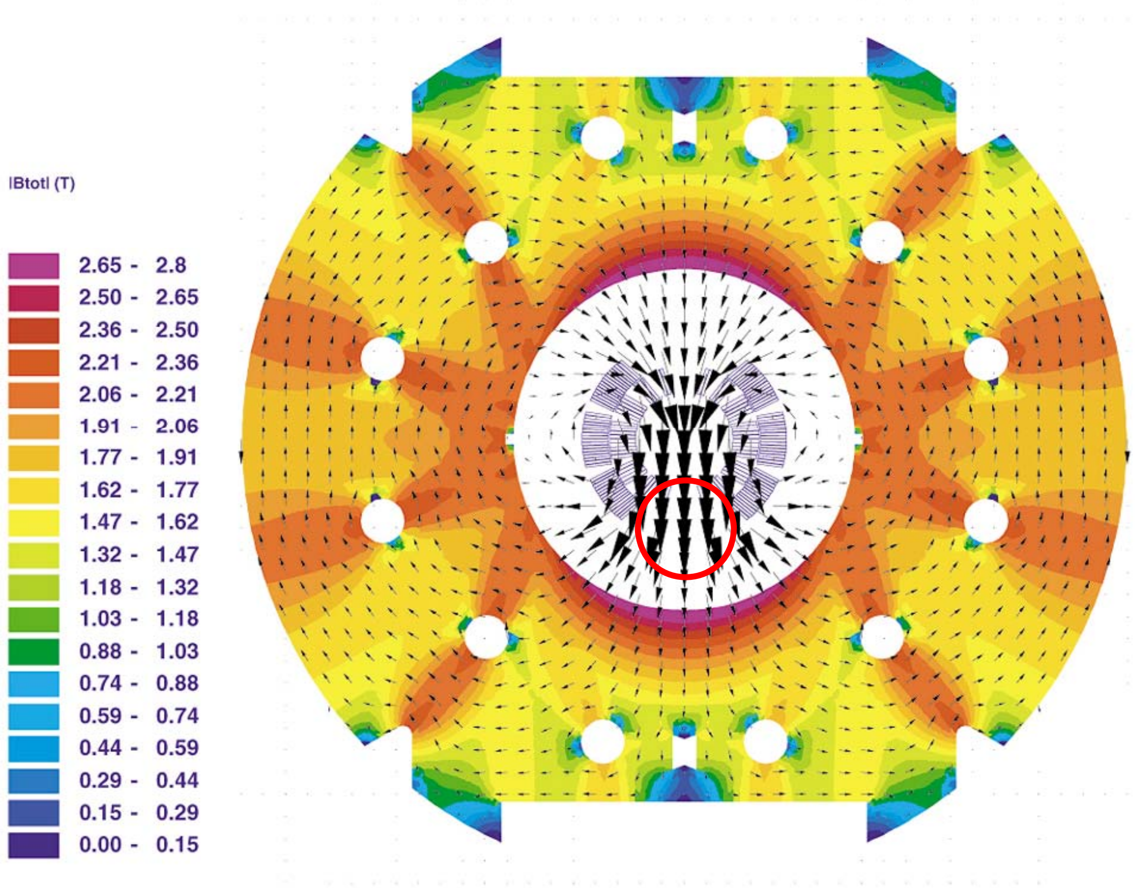


Posters: MOPLE080 MOPDO014

Energy stored in a dipole magnet

Most energy is stored in the magnetic field of the dipoles

Dipole magnet field map for one aperture



B = 8.33 Tesla   I = 11800 A   L = 0.108 H

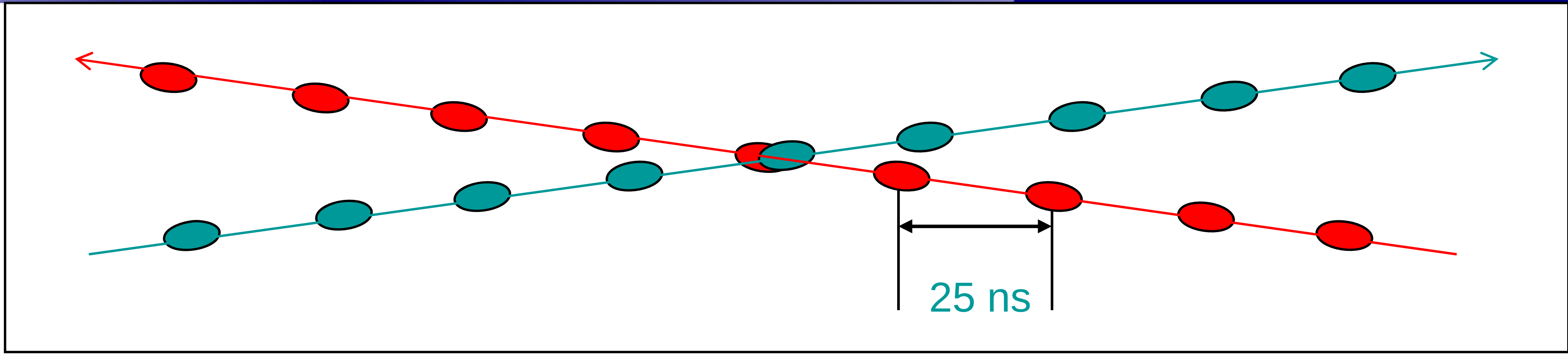
Energy stored in LHC magnets

$$E_{dipole} = 0.5 \bullet L_{dipole} \bullet I^2_{dipole}$$

Energy stored in one dipole is 7.6 MJoule

For all 1232 dipoles in the LHC: 9.4 GJ

Energy stored in the beams



Beam energy: Proton Energy • Number of Bunches • Number of protons per bunch

Proton Energy: 7 TeV

In order to achieve very high luminosity:

Number of bunches per beam: 2808

Number of protons per bunch: $1.05 \cdot 10^{11}$

Energy per beam: 346 MJoule

10 GJoule……

corresponds to the energy of 1900 kg TNT

corresponds to the energy of 400 kg Chocolate

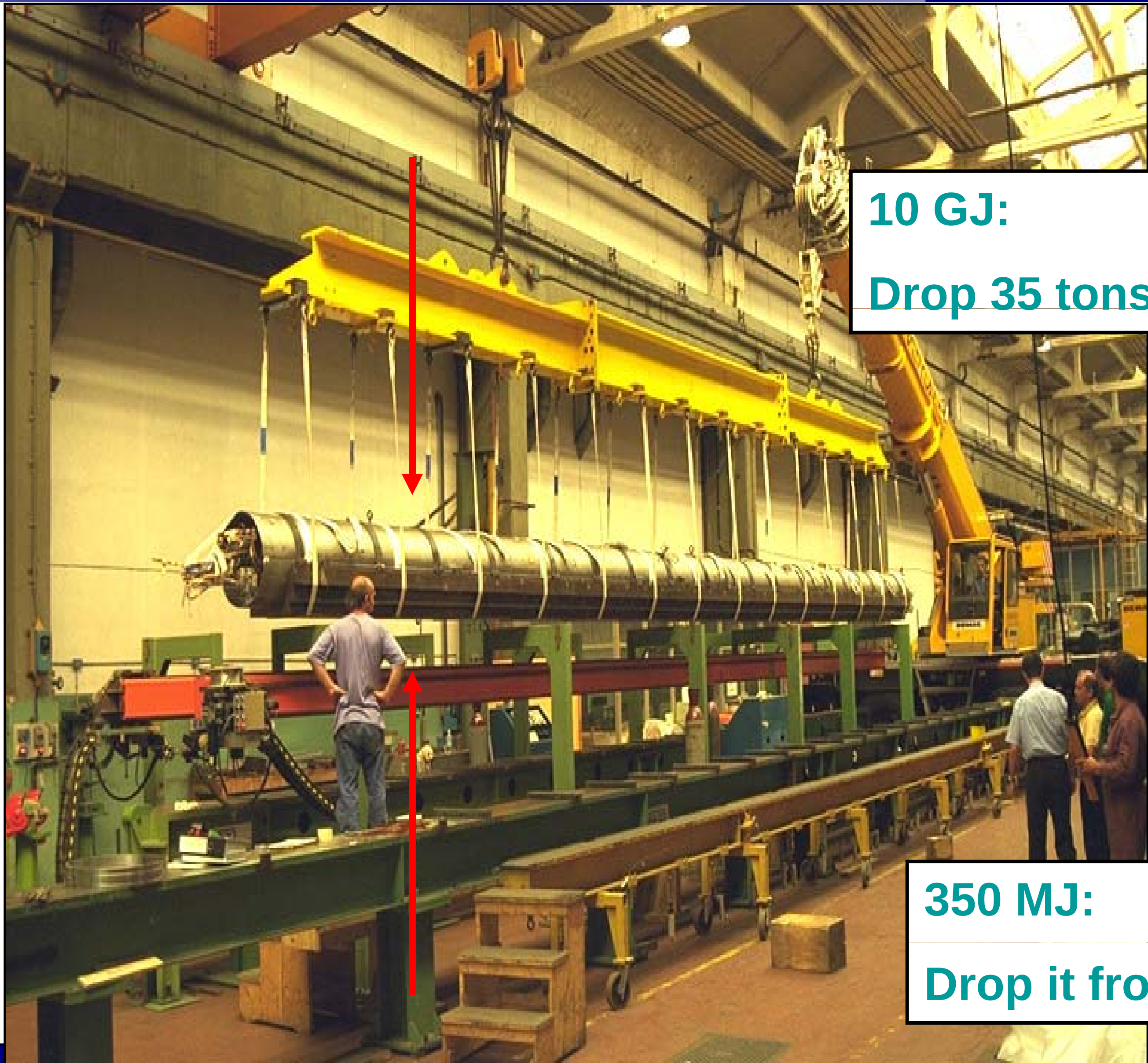
corresponds to the energy for heating and melting 12000 kg of copper

corresponds to the energy produced by of one nuclear power plant during about 10 seconds

Could this damage equipment?

How fast can this energy be released?

Energy in Magnets and Beams



10 GJ:

Drop 35 tons from 28 km

350 MJ:

Drop it from 1 km

Powering and Quench Protection

Almost 1800 circuits from 60 A to 24 kA distributed around the 27 km LHC accelerator => **1800 Power Converter**

The eight sectors of the LHC are largely independent - **accurate tracking** of current is required

Very high performance is needed for the 24 main circuits with main dipole and quadrupole magnets **at I = 12 kA**

- For the main circuits the current needs to be controlled at the ppm level (12 mA at 12 kA)

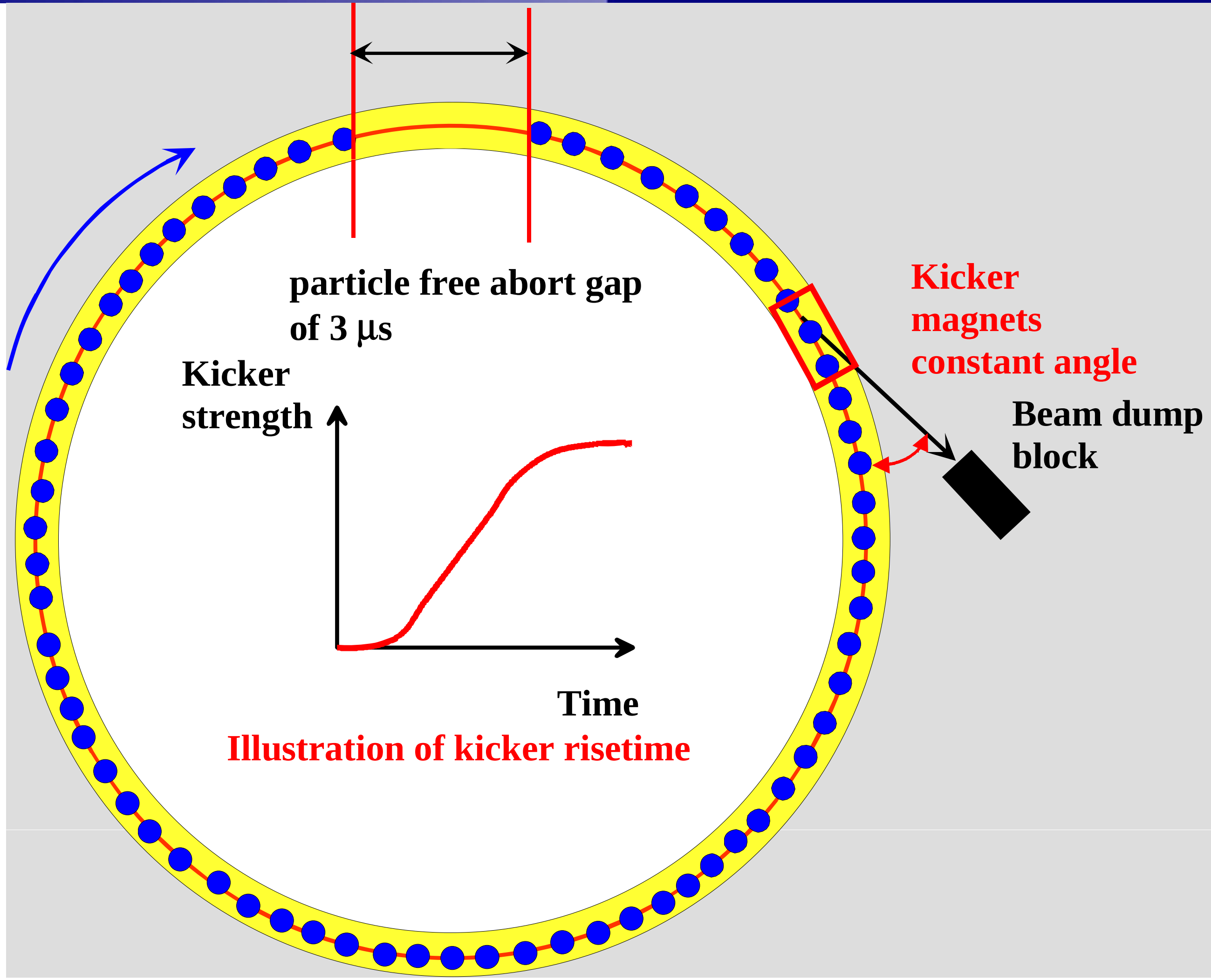
Protection of 8000 magnets, 1800 High Temperature Superconductor current leads, and a large number of superconducting bus bars

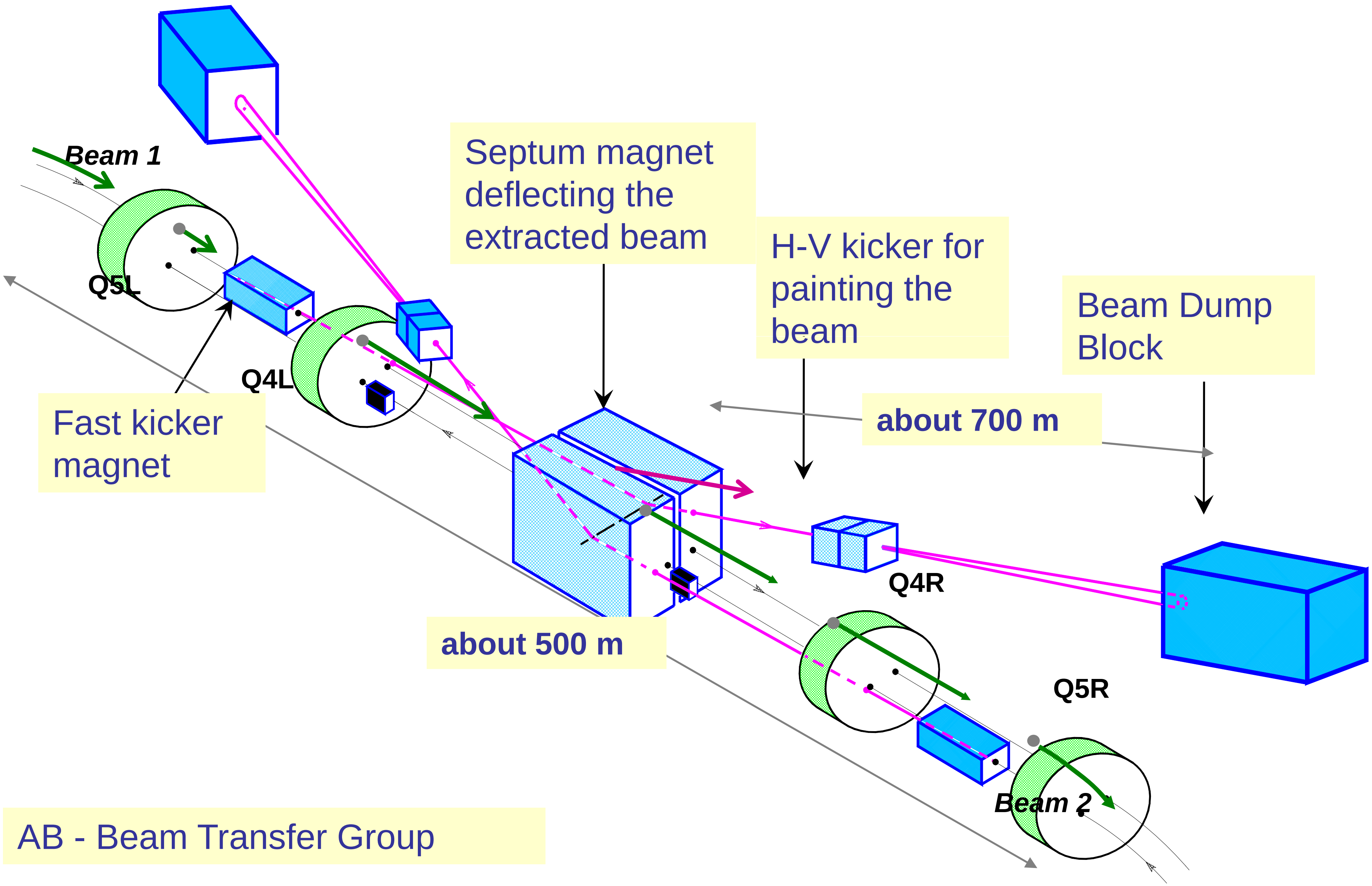
Requirement for clean beam dump

Beam dump must be synchronised with particle free gap

Strength of kicker and septum magnets must match energy of the beam

« Particle free gap » must be free of particles

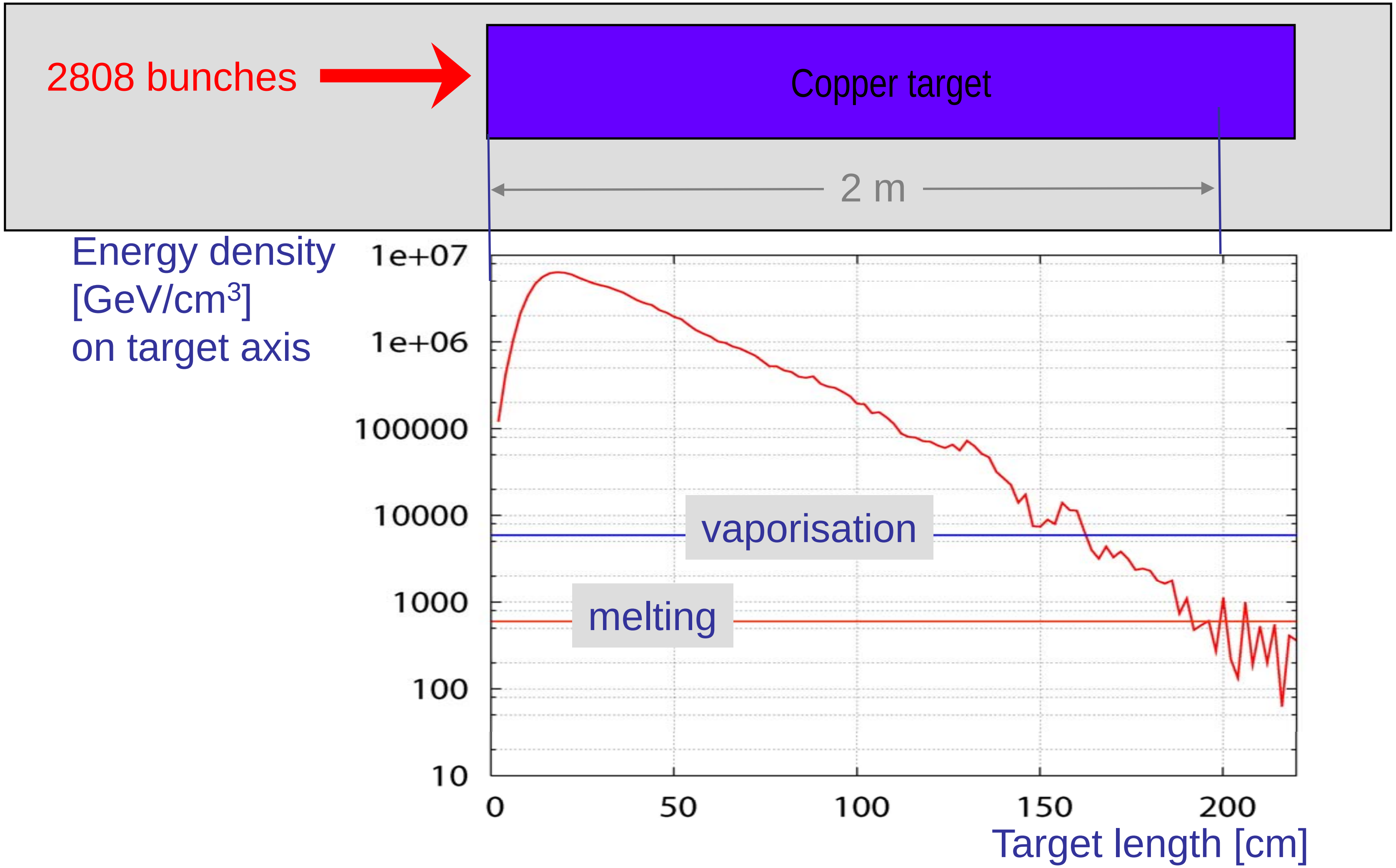




AB - Beam Transfer Group

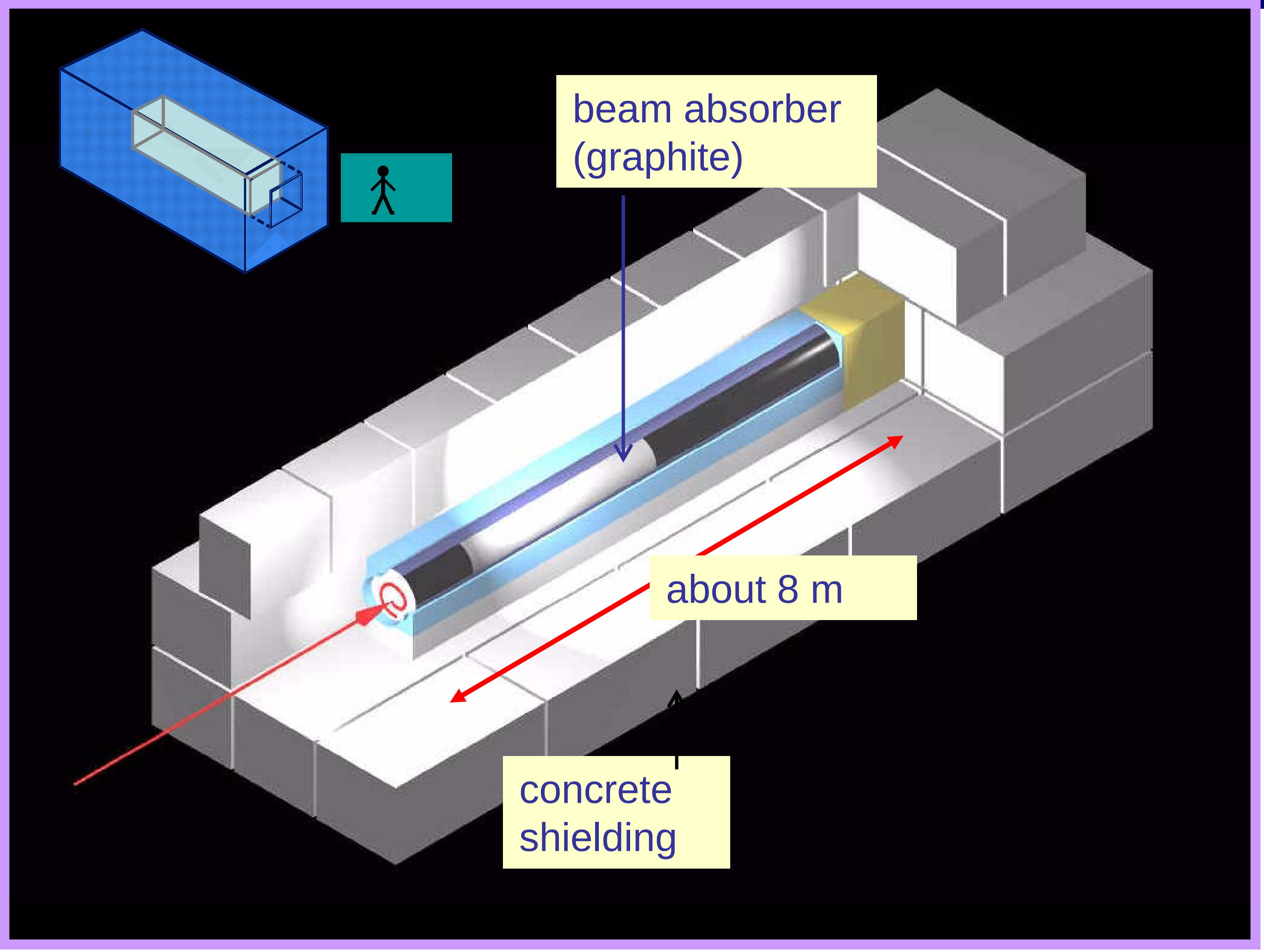

R622
TD62
UJ62
R623

Full LHC beam deflected into copper target



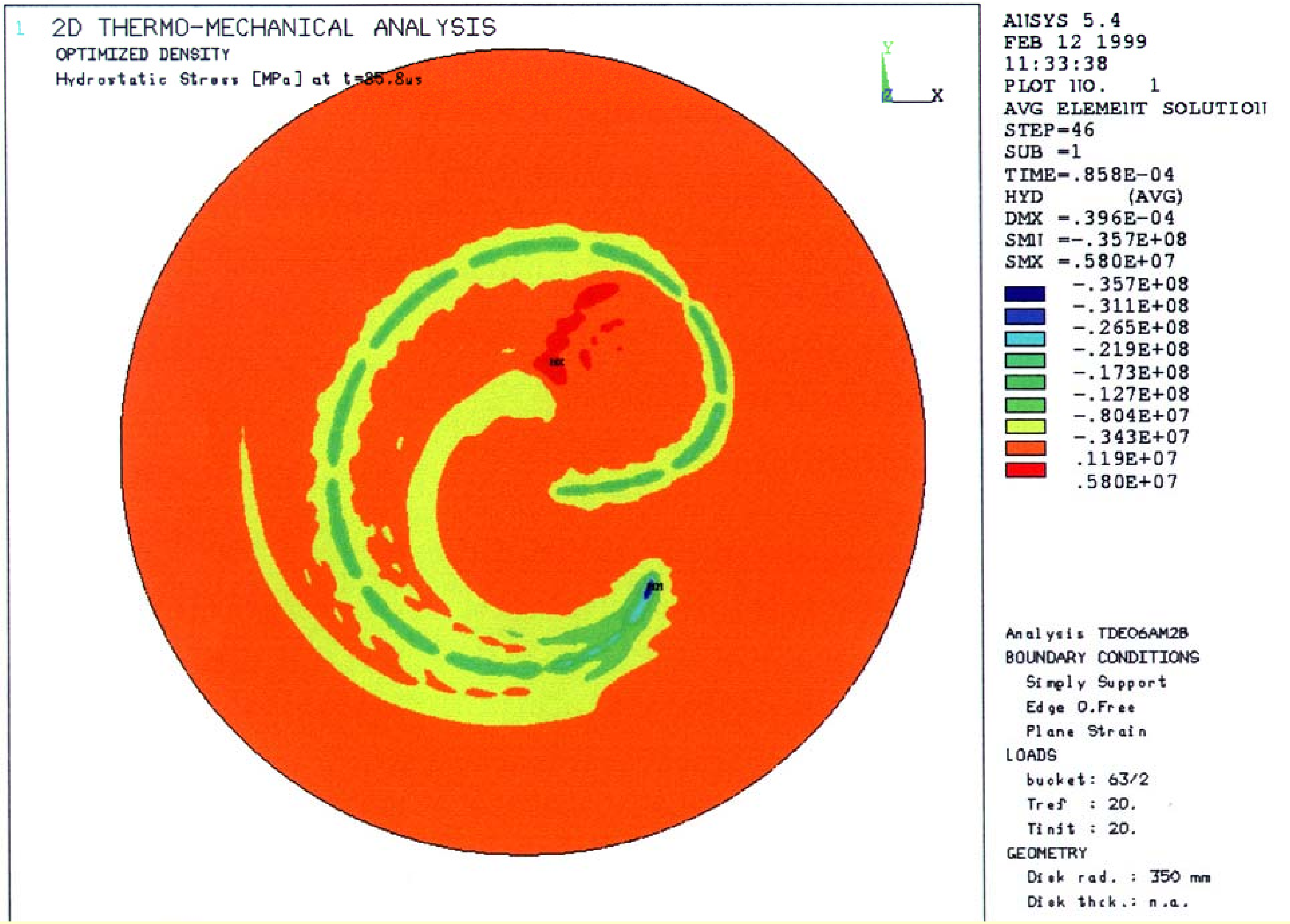
N.Tahir (GSI) et al.

Beam Dump Block - Layout



L.Bruno

Hydrostatic stress after beam deposition



L.Bruno: Thermo-Mechanical Analysis with ANSYS

Machine protection: Magnet energy

Energy in dipole magnets: 10 GJoule

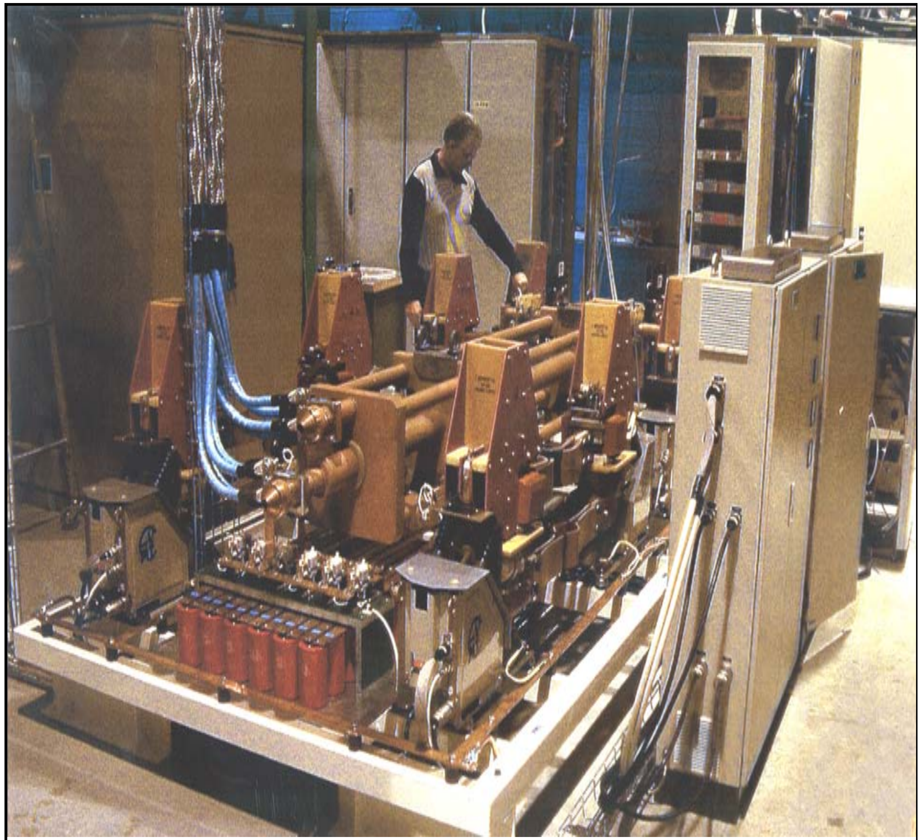
… per sector reduced to 1.3 GJoule

Uncontrolled release of energy is prevented:

Fire quench heaters

Current by-passes magnet via power diode

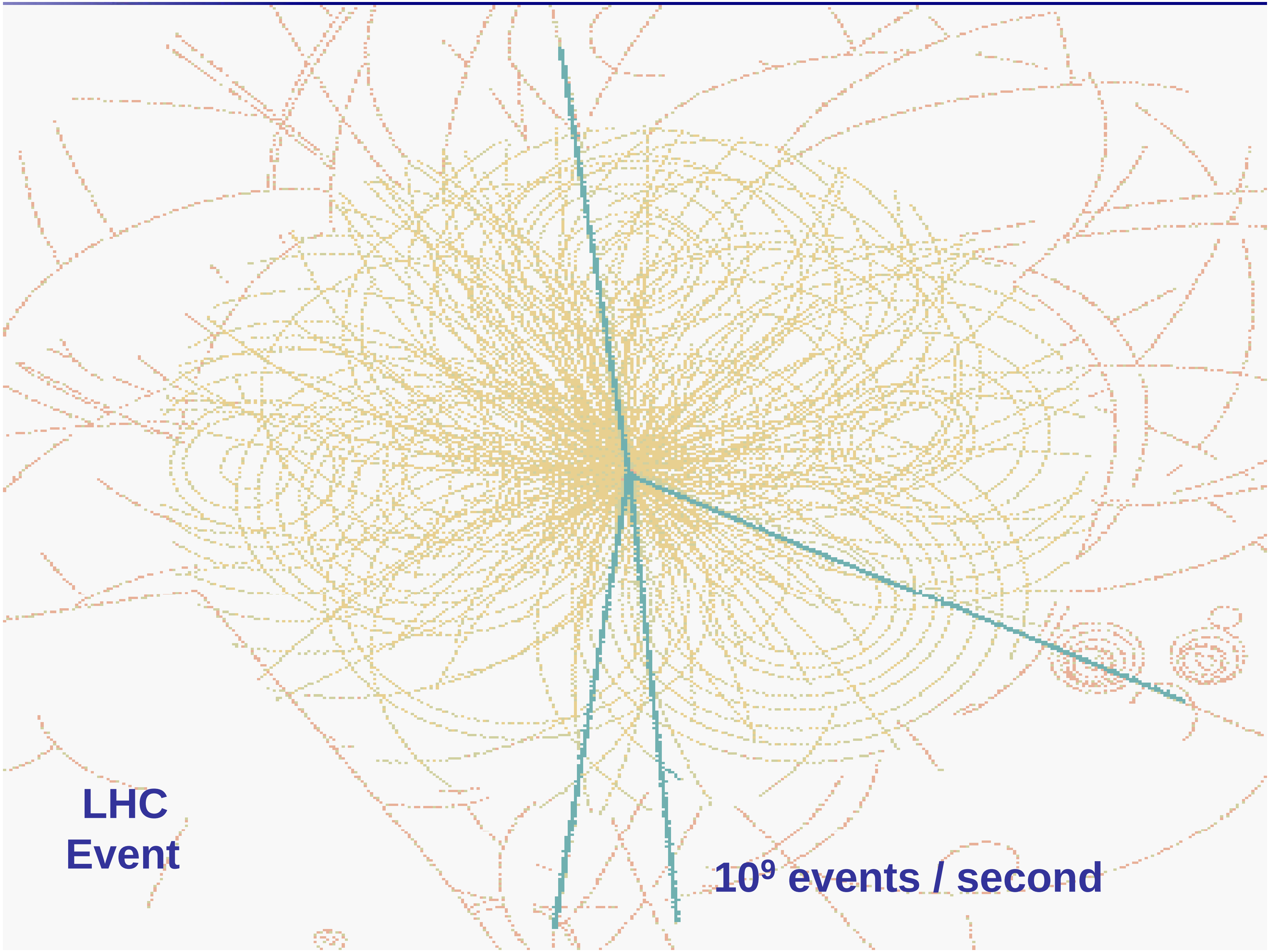
Extract energy by switching a resistor into the circuit - the resistor with a mass of eight tons is heated to 300 °C

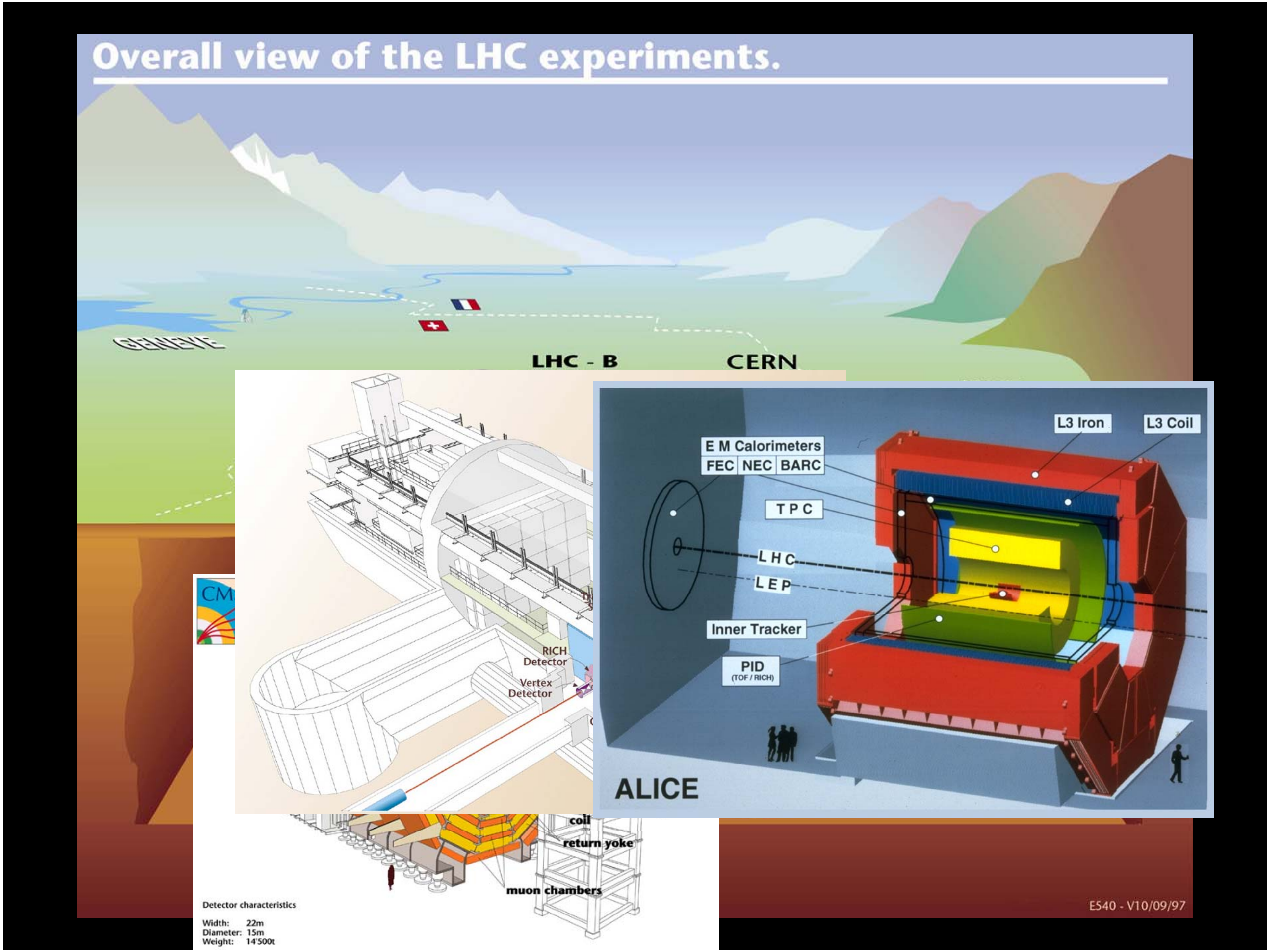


13 kA switches from Protvino Russia

All components of the system have been validated, and production started (part in collaboration with Russia and India)

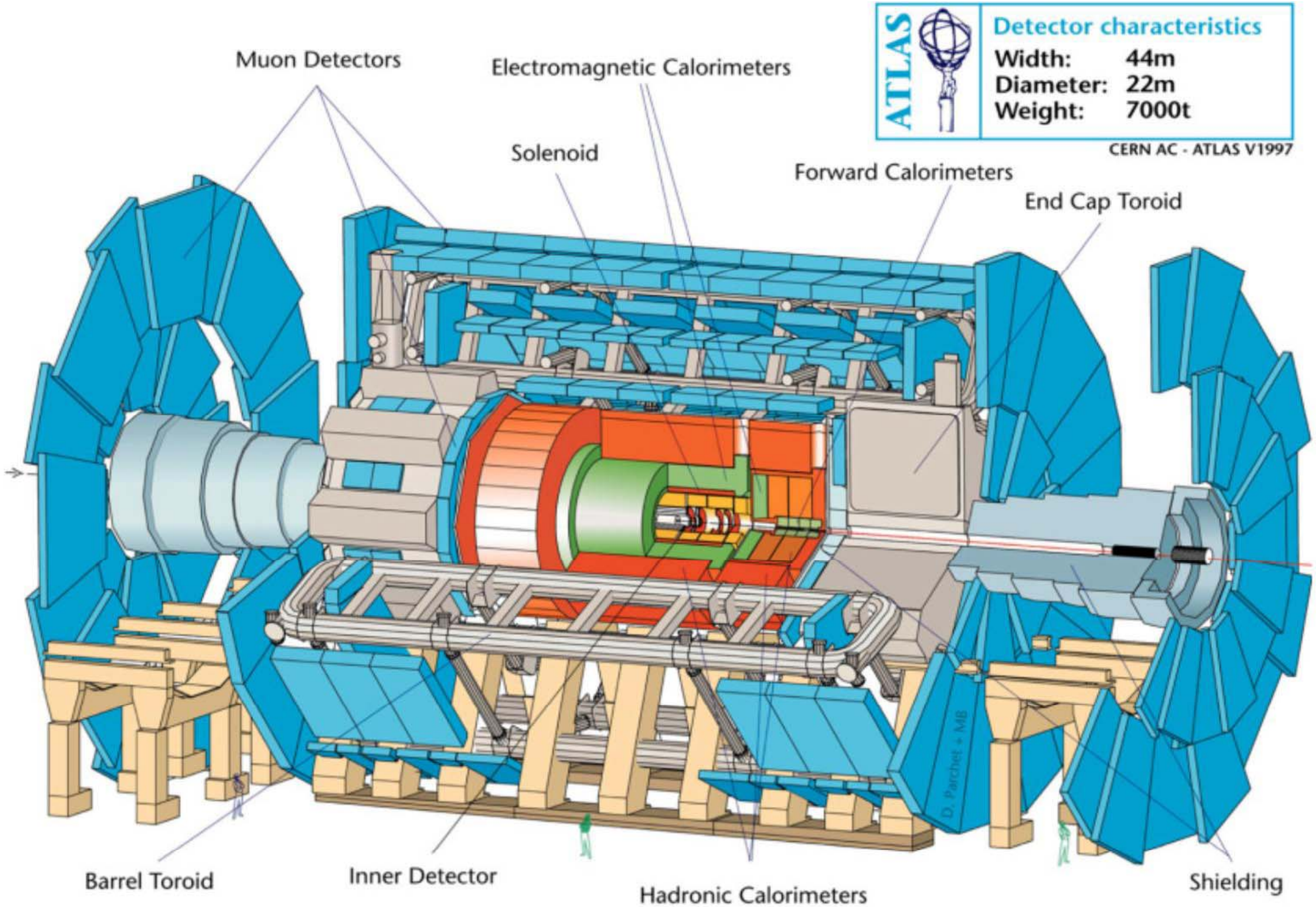
A.Vergara - MOPLE012


LHC
Event
10^9 events / second

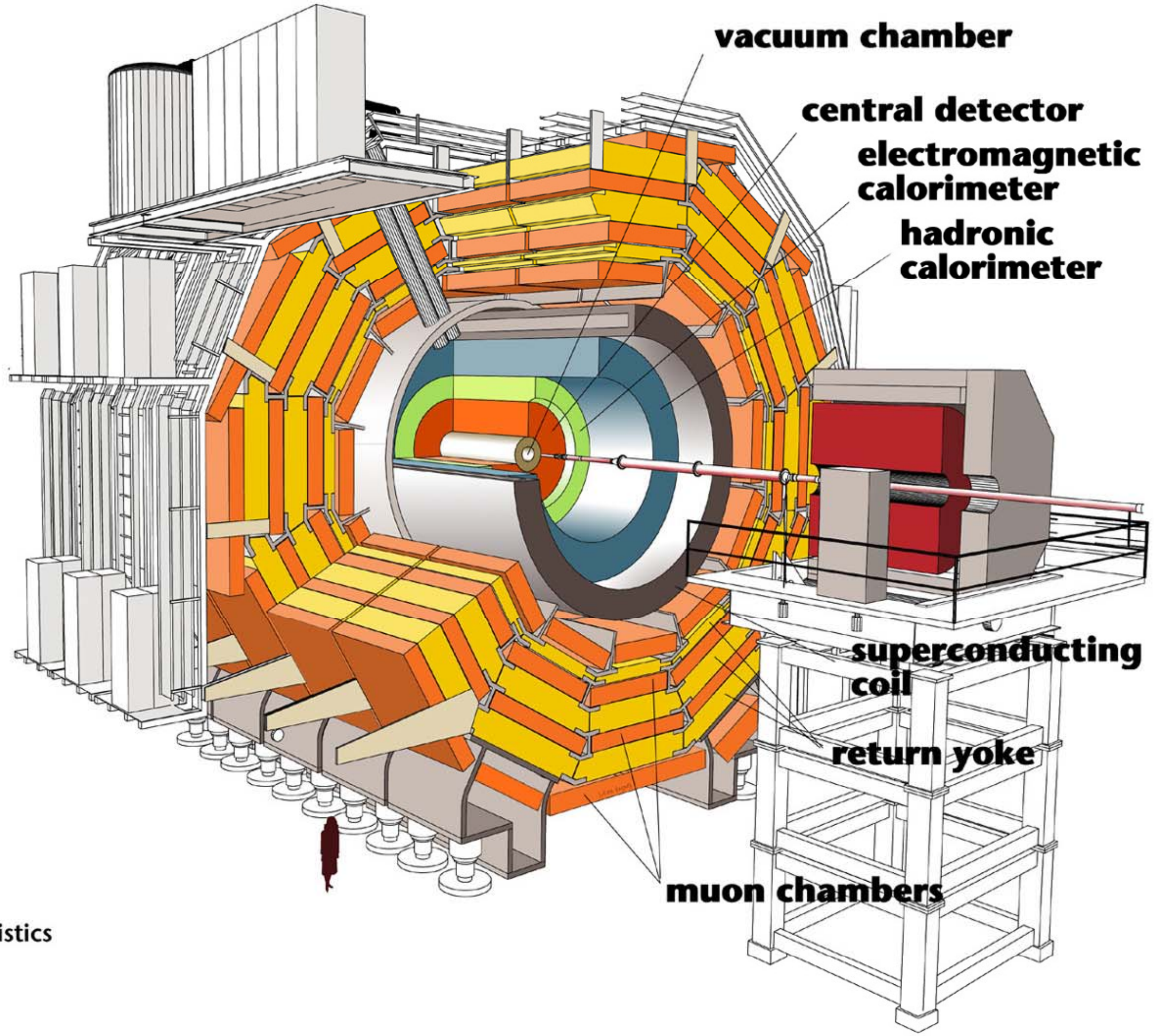


Overall view of the LHC experiments.
GENEVE
LHC - B
CERN
RICH Detector
Vertex Detector
L3 Iron
L3 Coil
E M Calorimeters
FEC NEC BARC
T P C
L H C
L E P
Inner Tracker
PID
(TOF / RICH)
ALICE
coil
return yoke
muon chambers
Detector characteristics
Width: 22m
Diameter: 15m
Weight: 14'500t
E540 - V10/09/97

ATLAS Experiment



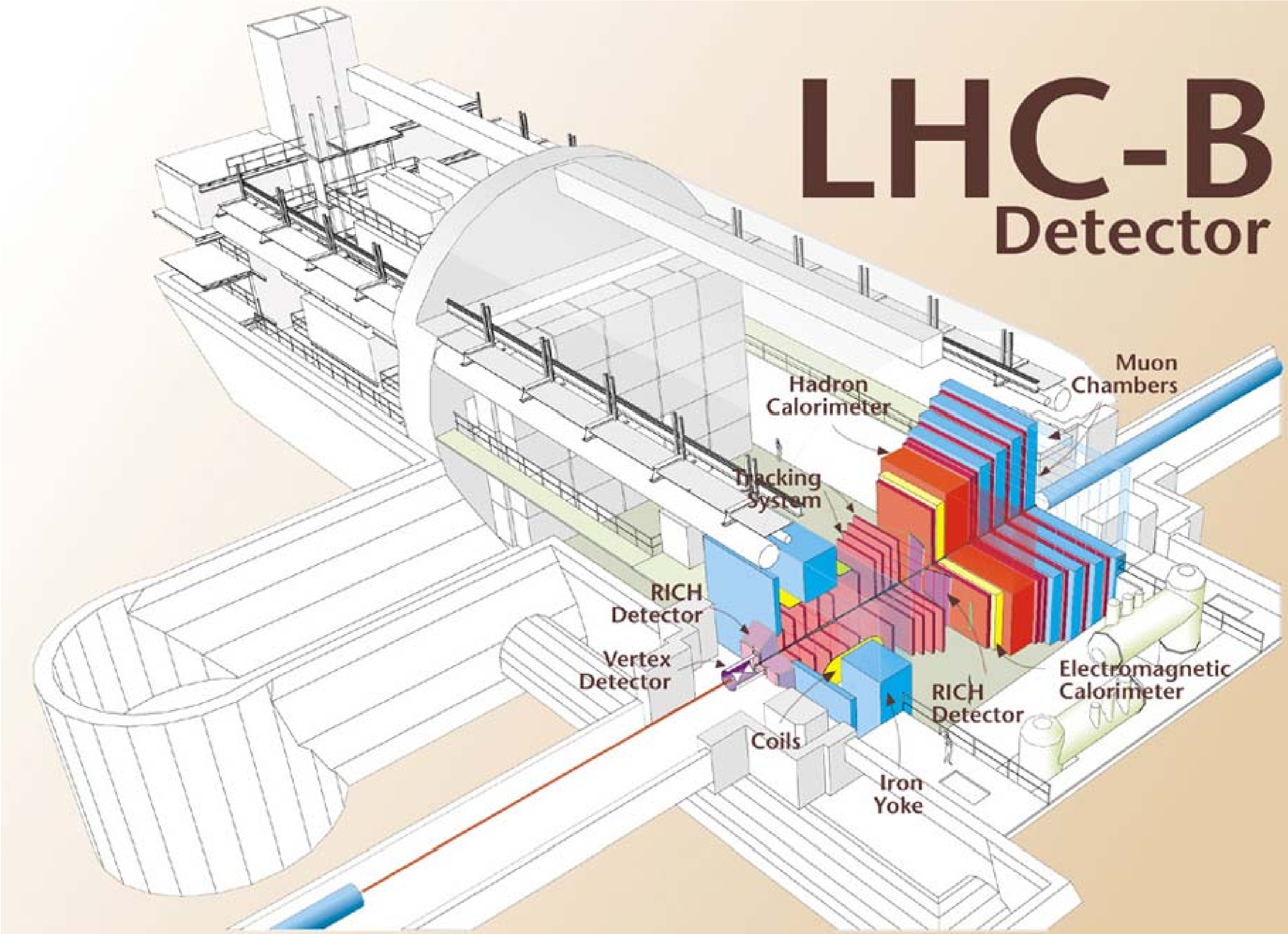
CMS Experiment



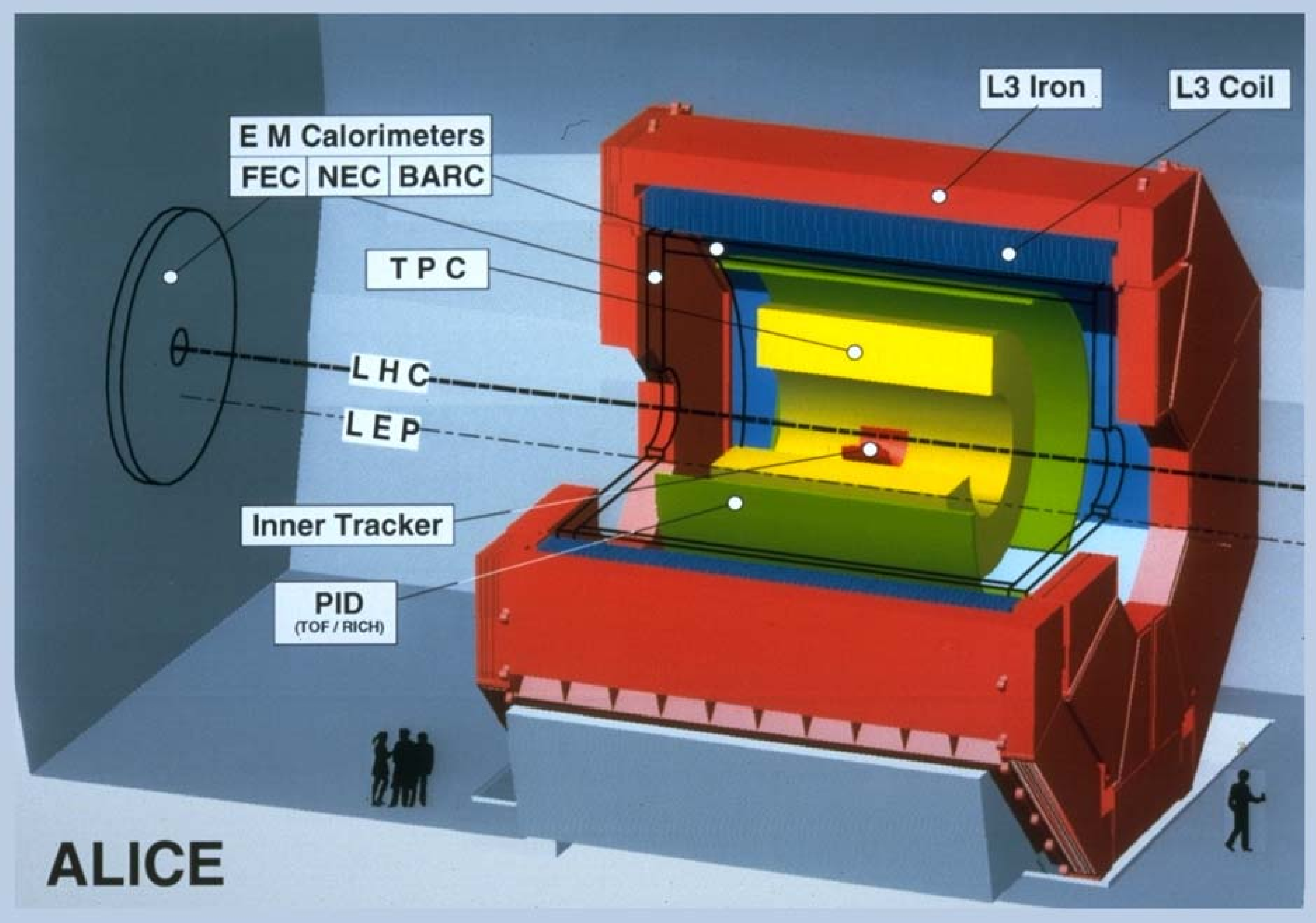
Detector characteristics

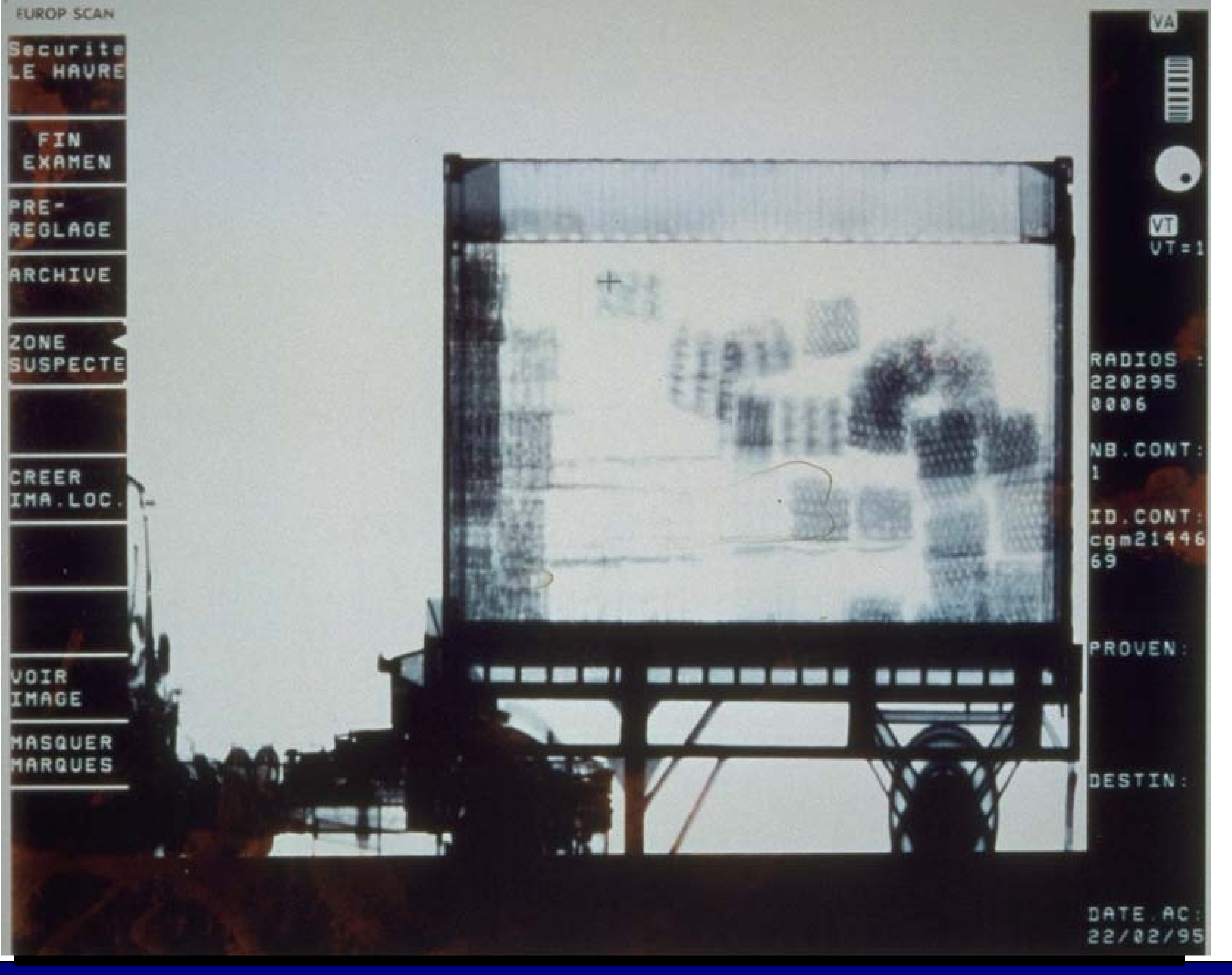
Width: 22m
Diameter: 15m
Weight: 14'500t

LHCb Experiment



ALICE Experiment

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Securite
LE HAVRE
FIN
EXAMEN
PRE-
REGLAGE
ARCHIVE
ZONE
SUSPECTE
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IMA.LOC.
VOIR
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MASQUER
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RADIOS :
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1
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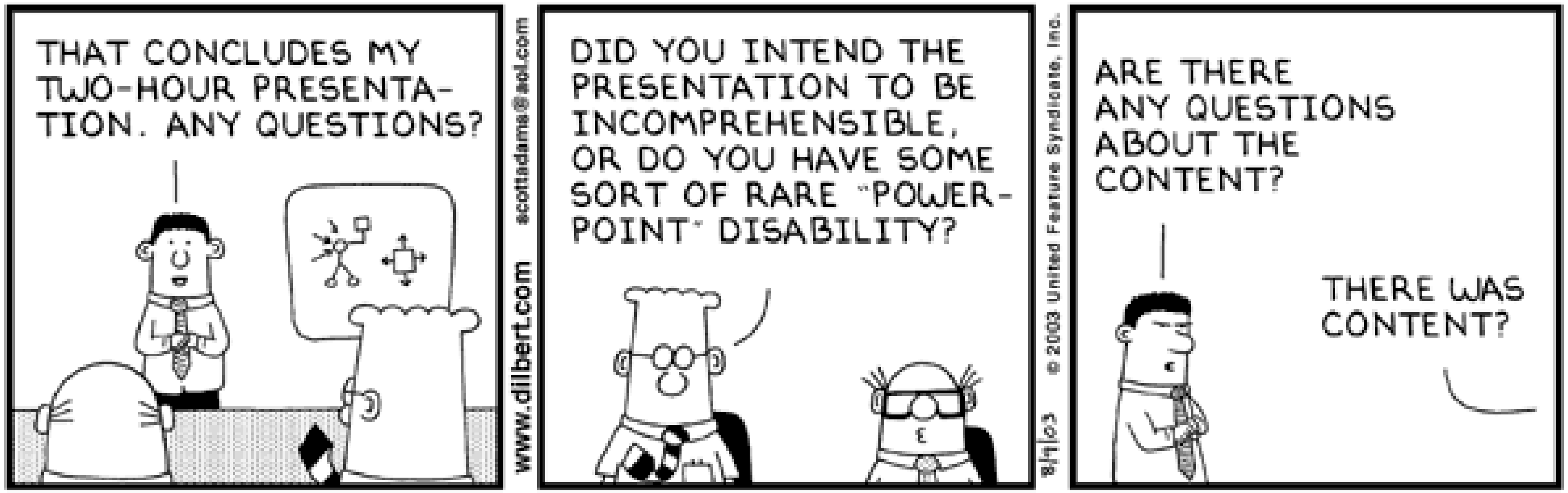
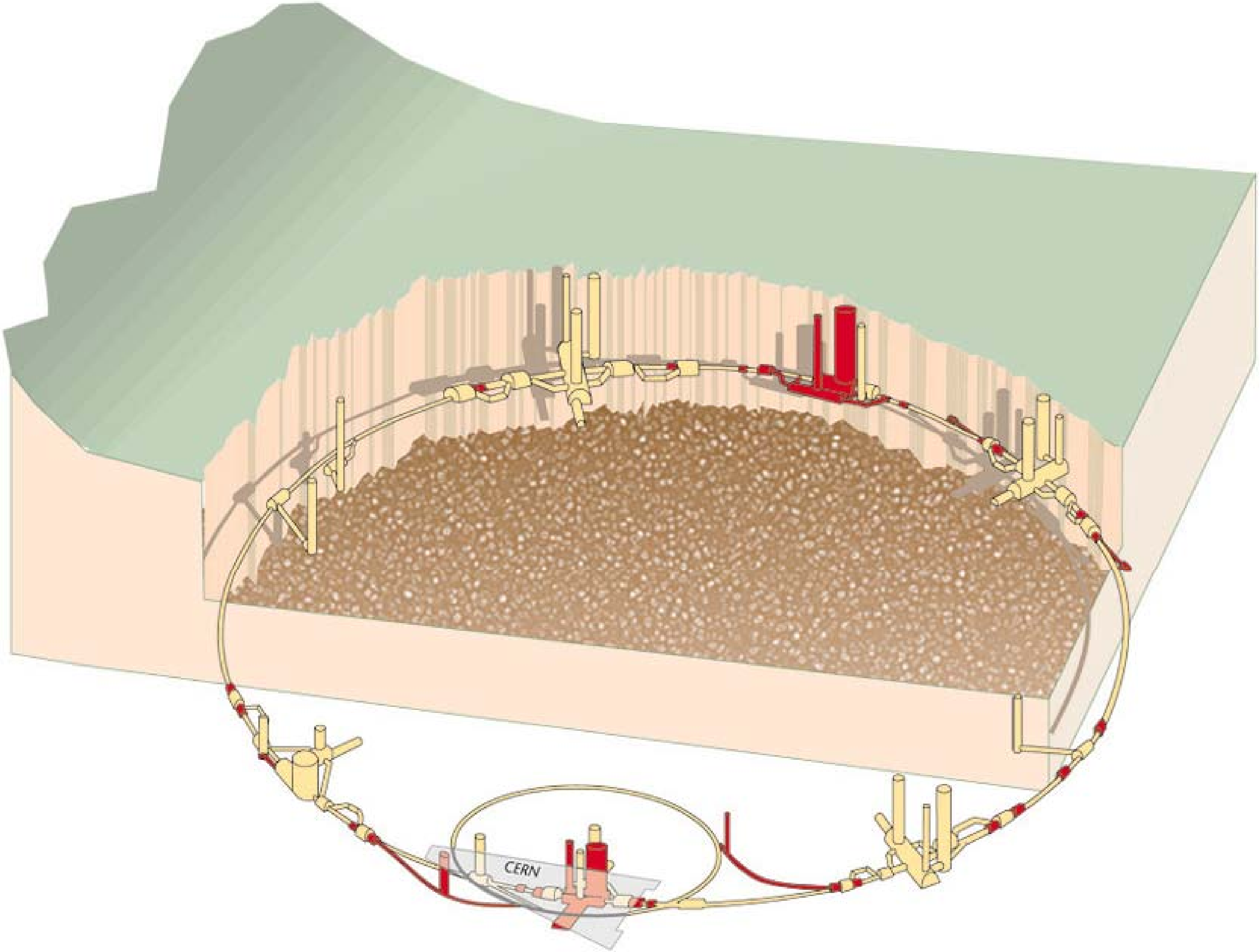
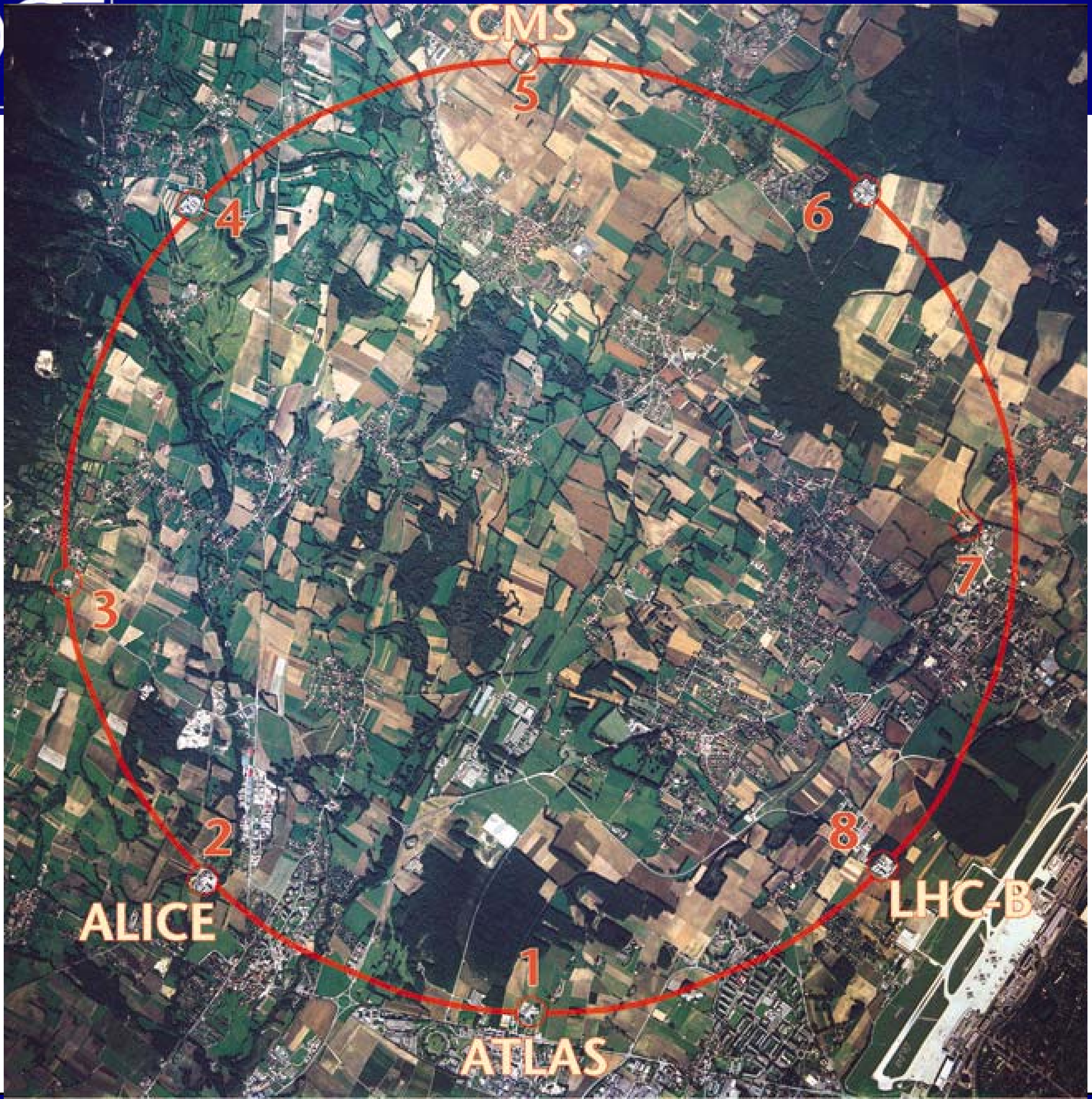
cgm21446
69
PROVEN:
DESTIN:
DATE.AC:
22/02/95

Your Questions ?



LEP/LHC Tunnel




CMS
5
4
6
3
7
2
8
ALICE
LHC-B
1
ATLAS

Beam lifetime with nominal intensity at 7 TeV

Beam lifetime	Beam power into equipment (1 beam)	Comments
100 h	1 kW	Healthy operation
10 h	10 kW	Operation acceptable, **collimation must absorb large fraction of beam energy** (approximately beam losses = cryogenic cooling power at 1.9 K)
0.2 h	500 kW	**Operation only** possibly for **short time**, collimators must be very efficient
1 min	6 MW	Equipment or operation **failure** - operation not possible - **beam must be dumped**
<< 1 min	> 6 MW	**Beam** must be **dumped VERY FAST**

Failures will be a part of the regular operation and MUST be anticipated

Momentum at collision	**7 TeV/c**	
Momentum at injection	450 GeV/c	
Dipole field at 7 TeV	8.33 Tesla	
Circumference	26658	m

High beam energy in LEP tunnel
superconducting NbTi magnets at 1.9 K

Luminosity	**10^{34} $cm^{-2}s^{-1}$**	
Number of bunches	2808	
Particles per bunch	$1.1 \cdot 10^{11}$	
DC beam current	0.56	A
Stored energy per beam	**350**	**MJ**

Normalised emittance	**3.75**	**µm**
Beam size at IP / 7 TeV	15.9	µm
Beam size in arcs (rms)	300	µm

High luminosity at 7 TeV
very high energy stored in the beam

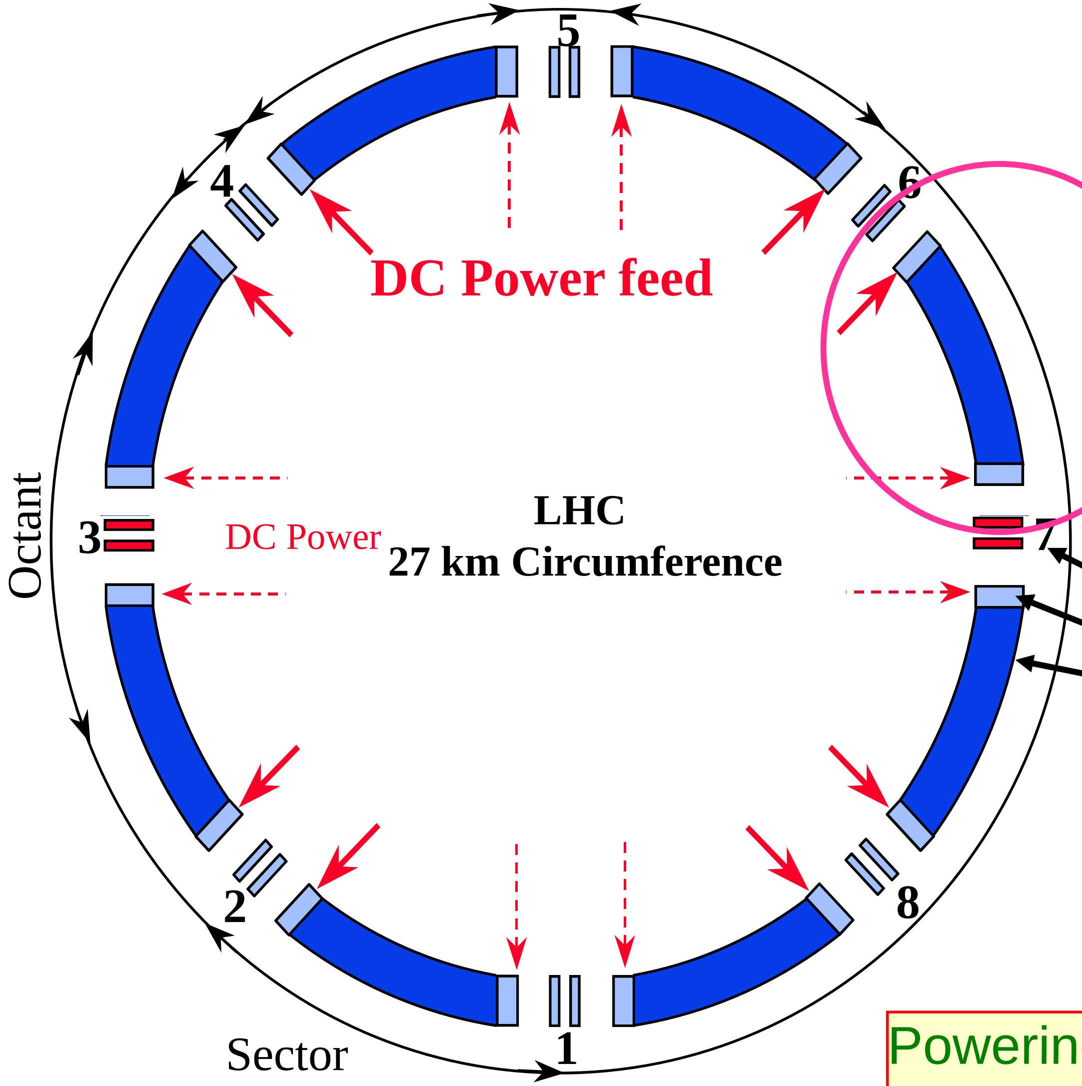
beam power concentrated in small area

Arcs: Counter-rotating proton beams in two-in-one magnets

Magnet coil inner diameter	**56**	**mm**
Distance between beams	194	mm

Limited investment
small aperture for beams

LHC Powering in 8 Sectors



Powering Sector:

154 dipole magnets
about 50 quadrupoles
total length of 2.9 km

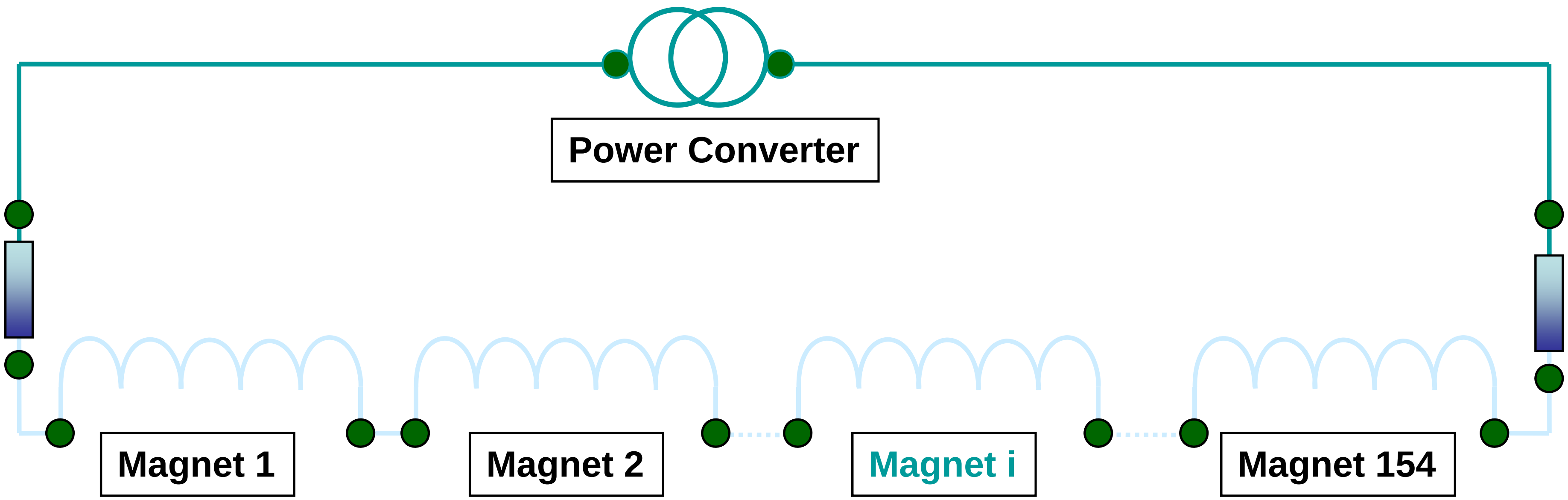
Powering Subsectors:

- long arc cryostats
- triplet cryostats
- cryostats in matching section

Powering Subsectors allow for progressive Hardware Commissioning
- 2 years before beam

P.Proudlock

Ramping the current in a string of dipole magnet



LHC **powered in eight sectors**, each with 154 dipole magnets

Time for the energy **ramp** is about **20-30 min** (Energy from the grid)

Time for discharge is about **the same** (Energy back to the grid)