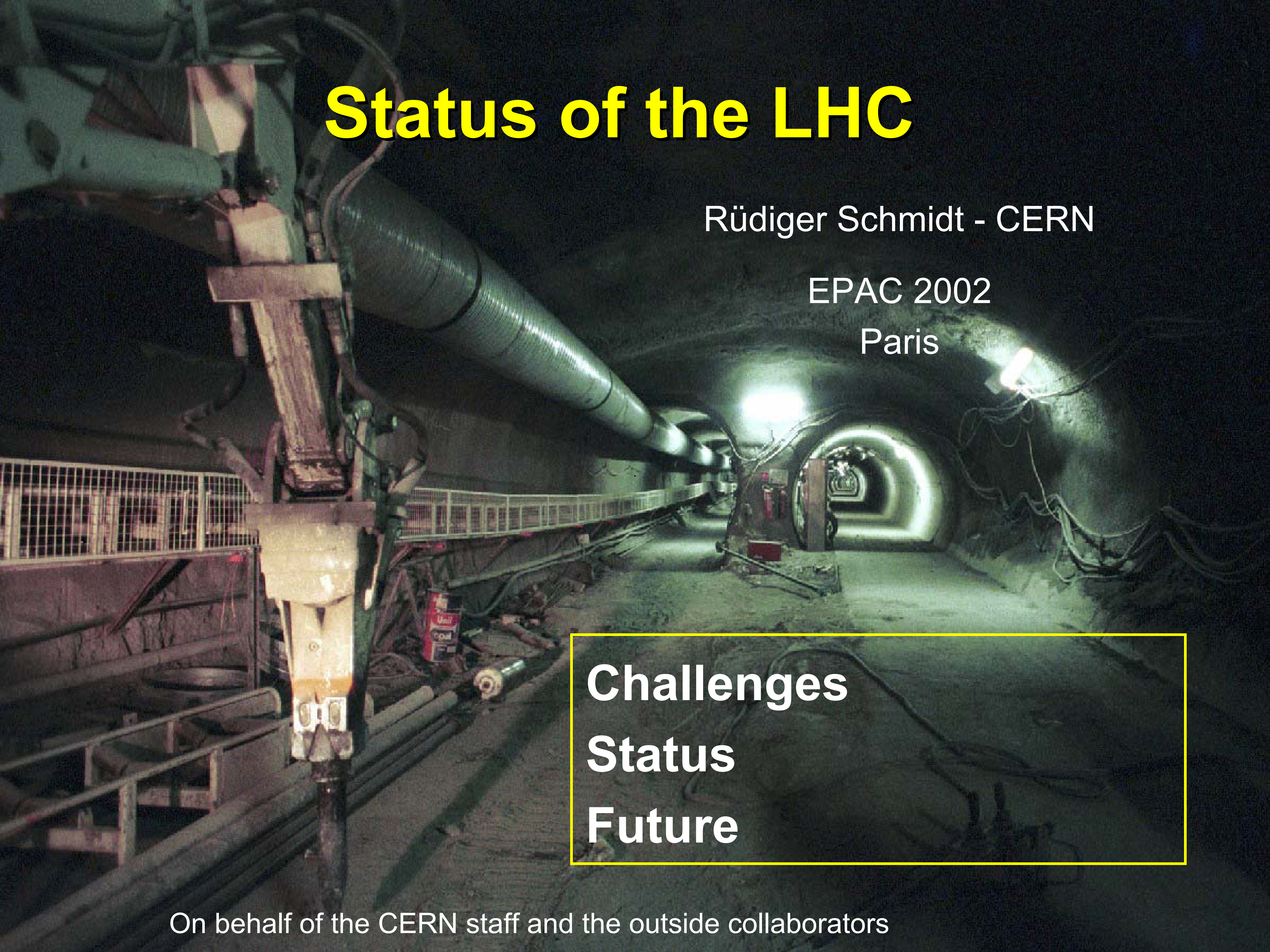


Status of the LHC

Rüdiger Schmidt - CERN

EPAC 2002
Paris

Challenges
Status
Future

On behalf of the CERN staff and the outside collaborators

From the summary of the Large Hadron Collider Machine Advisory Committee in March 2002

- The LHC is a global project with the world-wide high-energy physics community devoted to its progress and results

- As a project, it is much more complex and diversified than the SPS or LEP or any other large accelerator project constructed to date

Machine Advisory Committee, chaired by
Prof. M. Tigner, March 2002

The Status and the complexity of the LHC is documented in more than 80 papers at this conference - this talk is considered as a very brief overview

Outline

- Parameters and layout
- The LHC and some of its challenges

- Injectors and transfer

- Magnets and other systems
- Accelerator physics and LHC operation

- Validation of systems: String 2

- From building components to colliding beams
- Conclusions

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

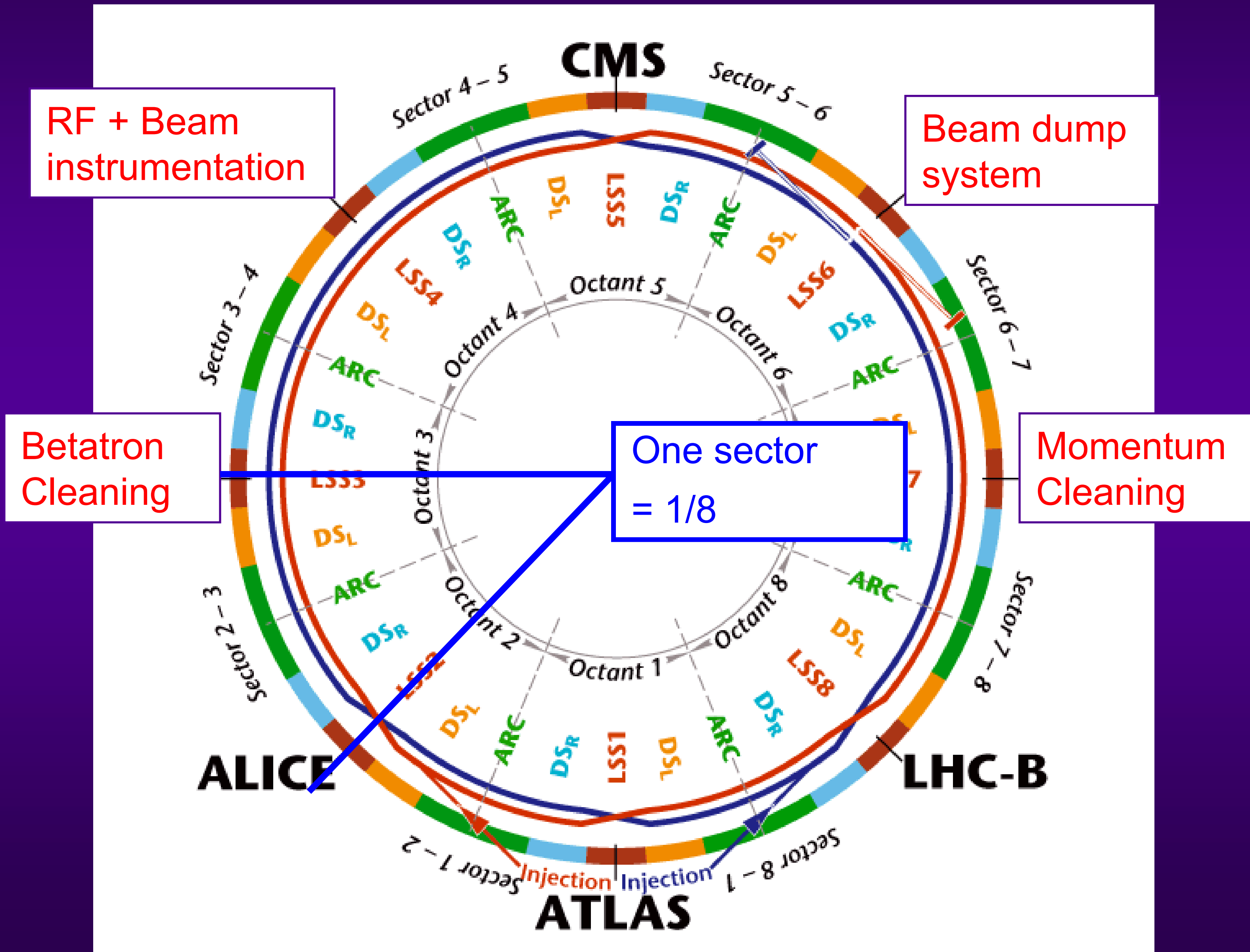
beam power concentrated in small area

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

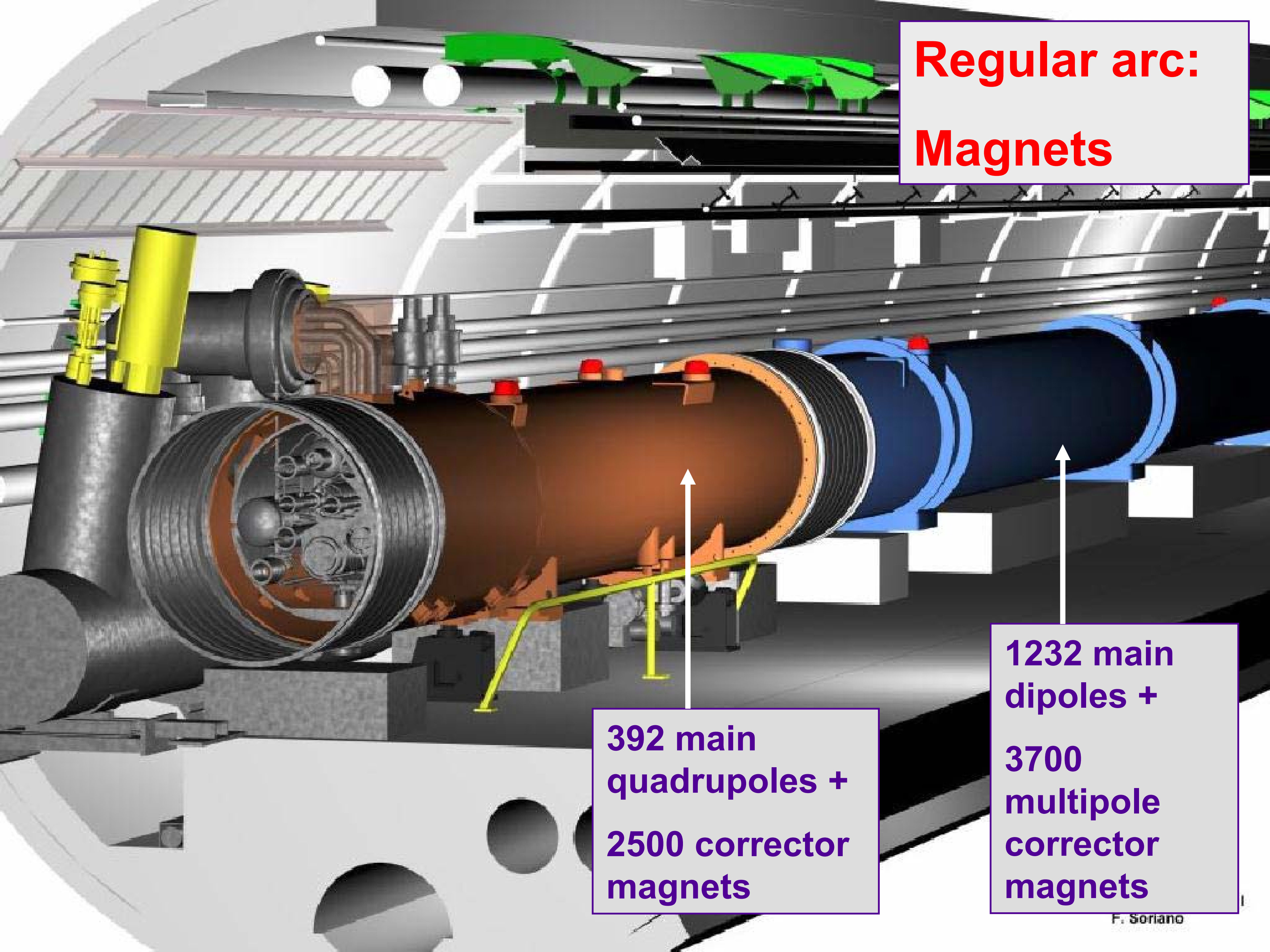
Magnet coil inner diameter	**56**	**mm**
Distance between beams	194	mm

Limited investment
small aperture for beams

Layout of the LHC ring: 8 arcs, and 8 long straight sections



Regular arc: Magnets



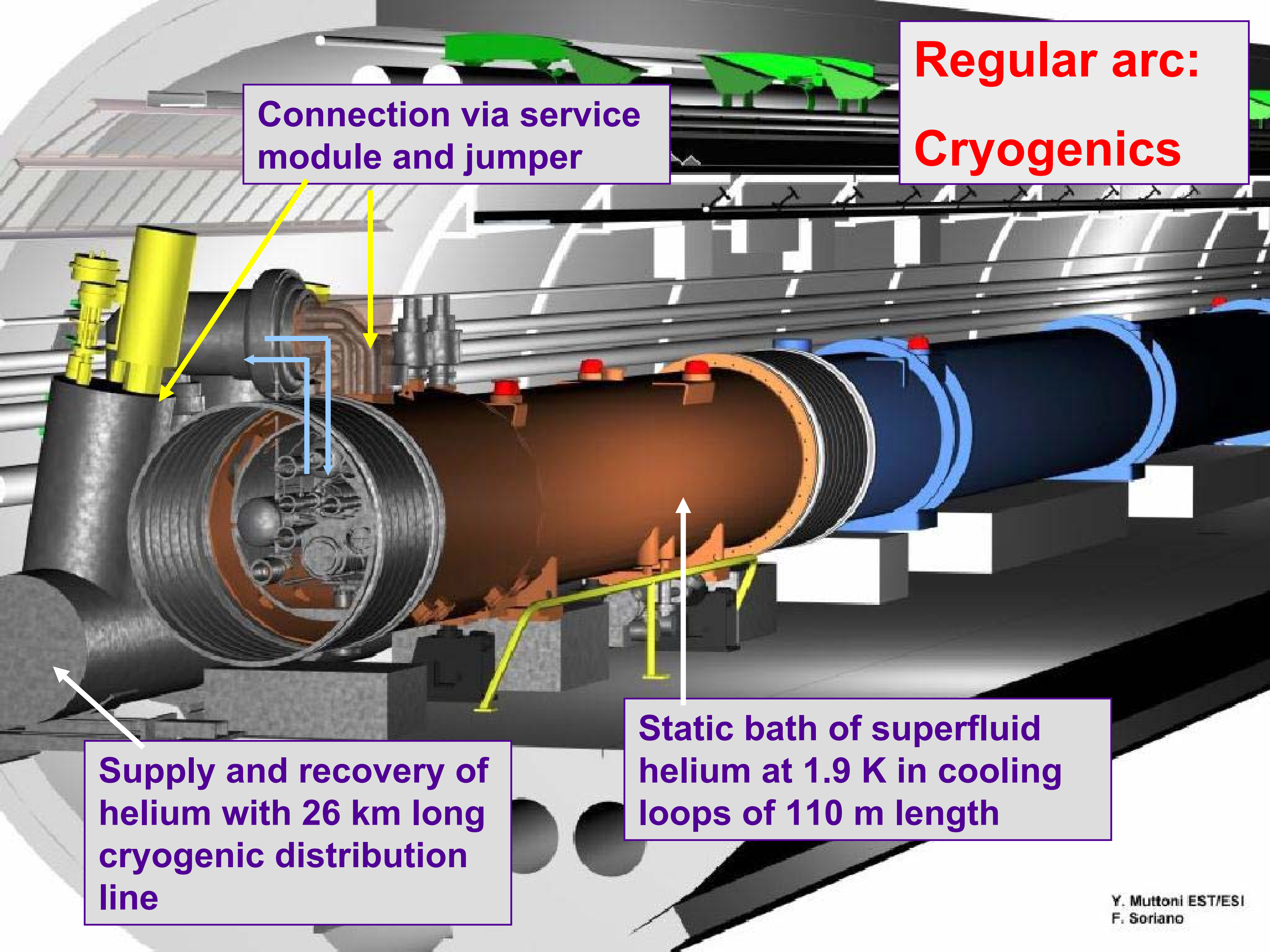
392 main quadrupoles +

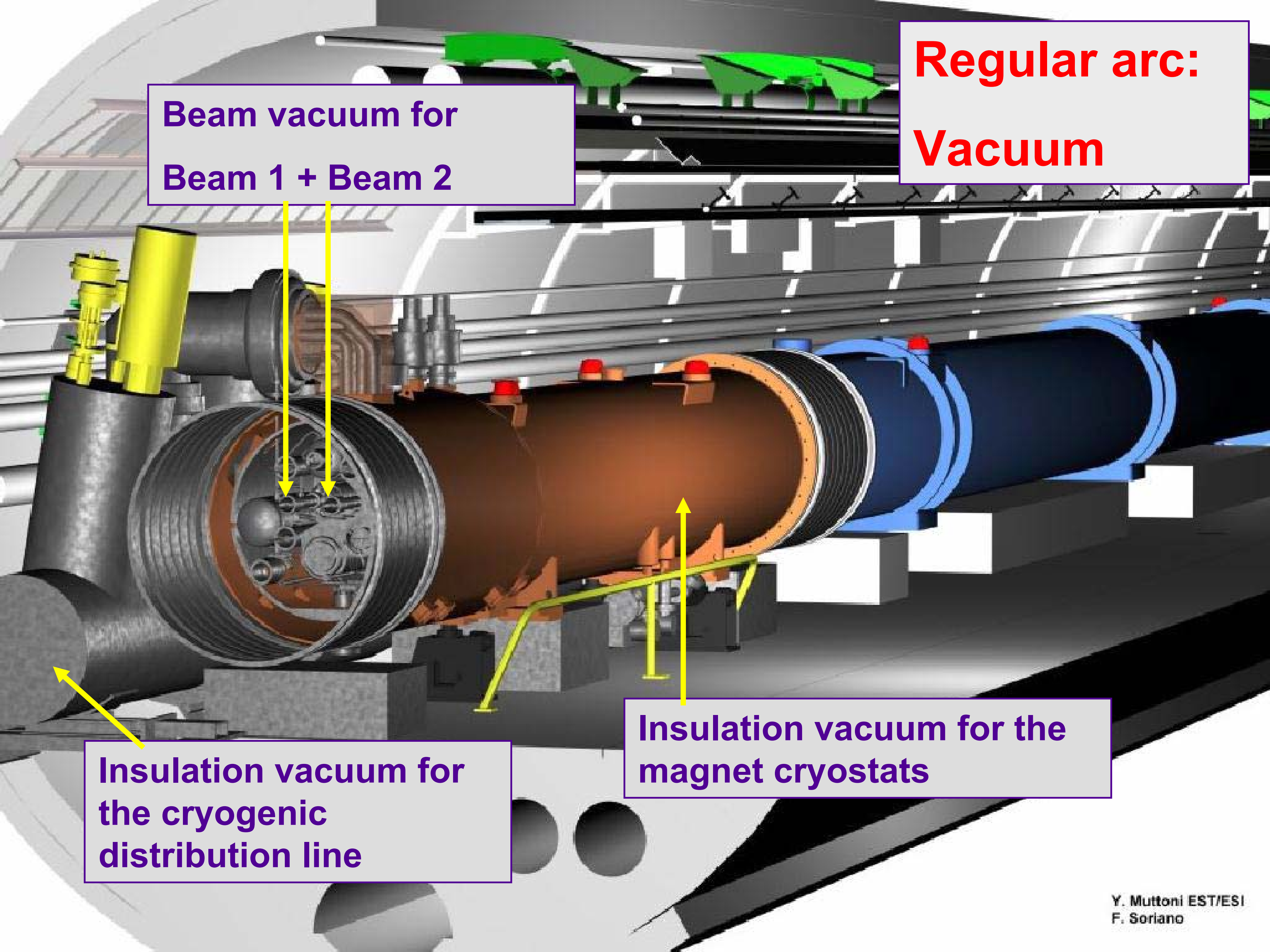
2500 corrector magnets

1232 main dipoles +

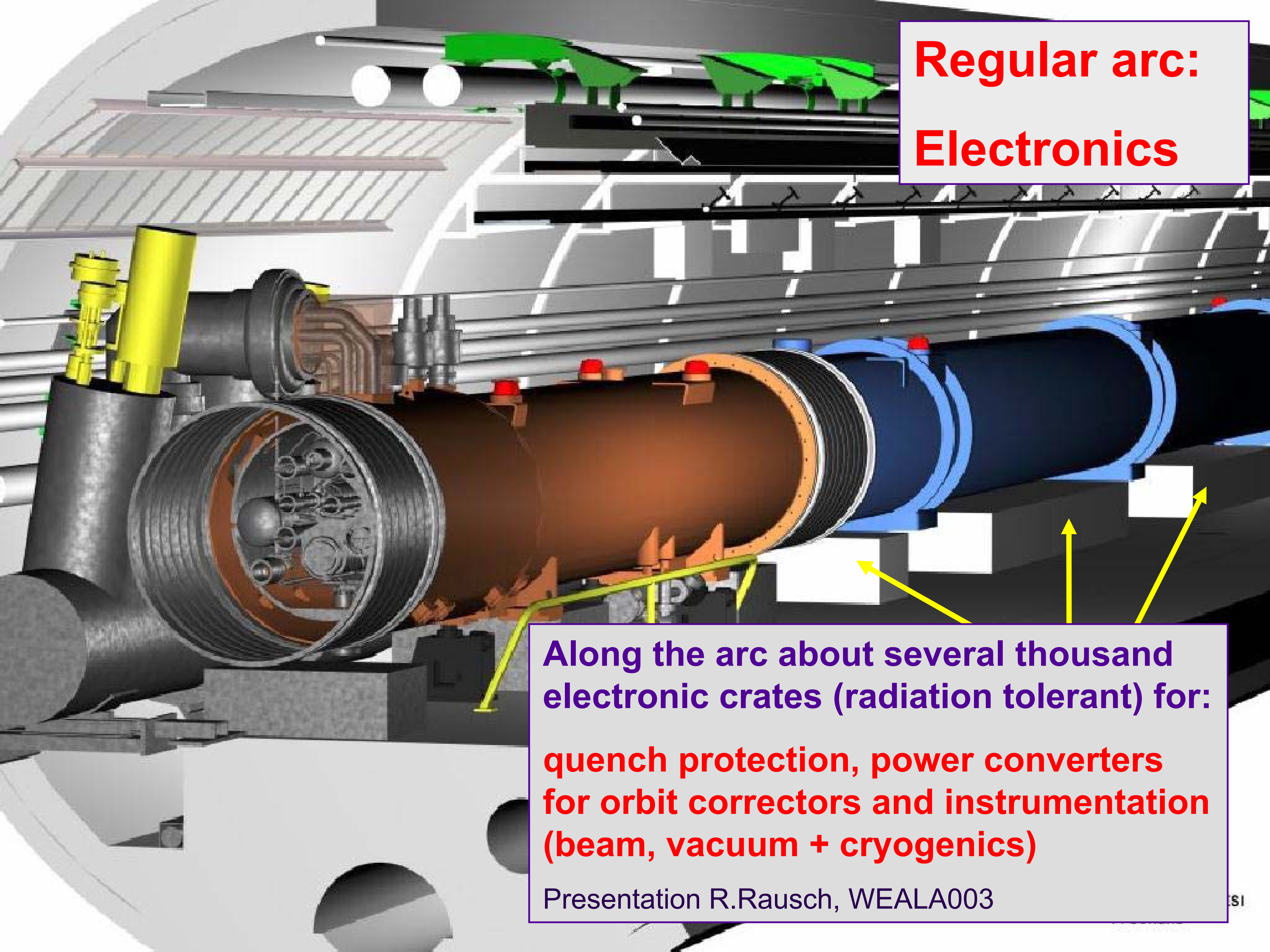
3700 multipole corrector magnets

Regular arc: Cryogenics




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

Regular arc: Electronics

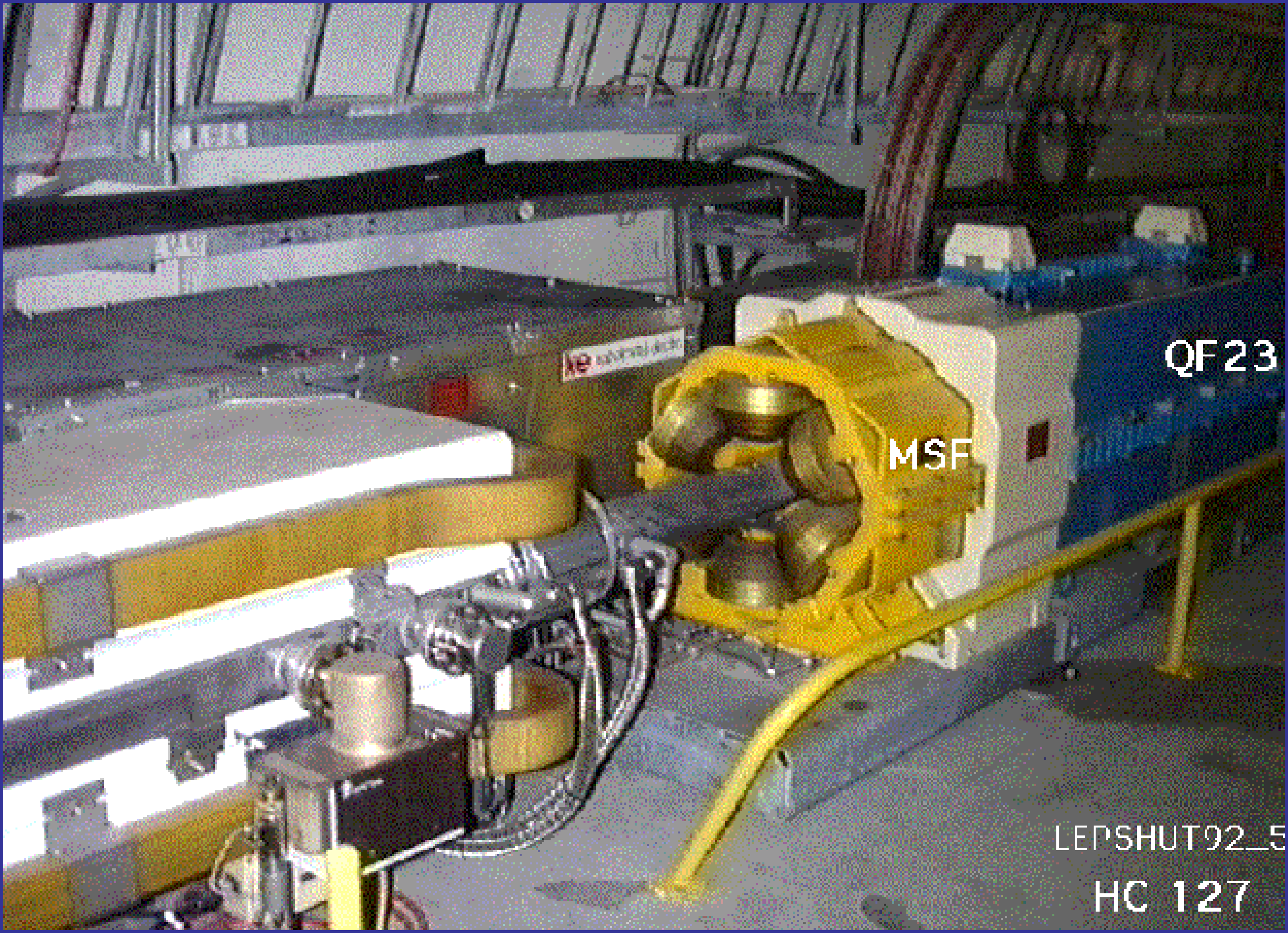


Along the arc about several thousand electronic crates (radiation tolerant) for:

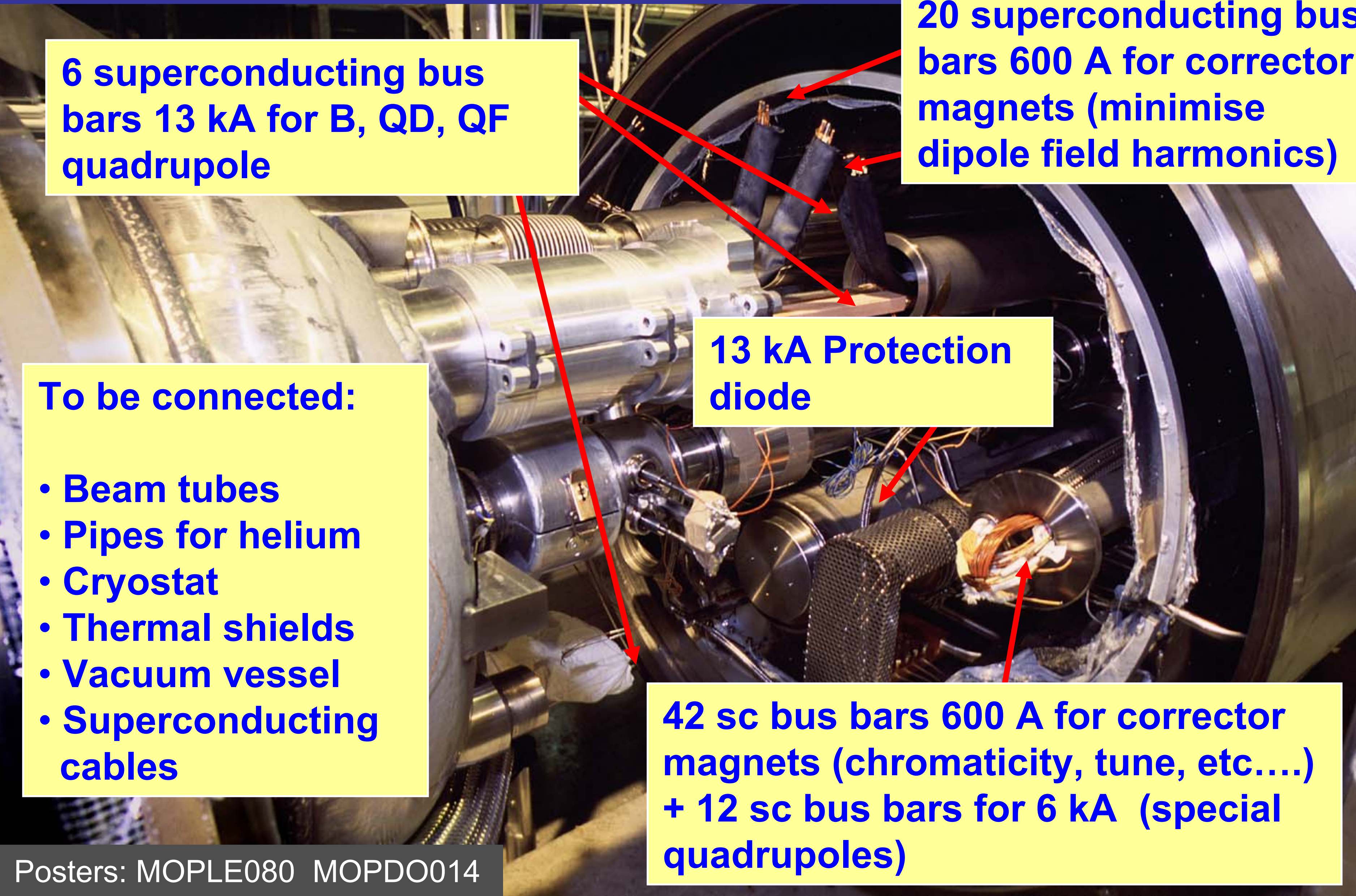
quench protection, power converters for orbit correctors and instrumentation (beam, vacuum + cryogenics)

Presentation R.Rausch, WEALA003

Interconnection between magnets: LEP



One of 1800 interconnection between two superconducting magnets: LHC

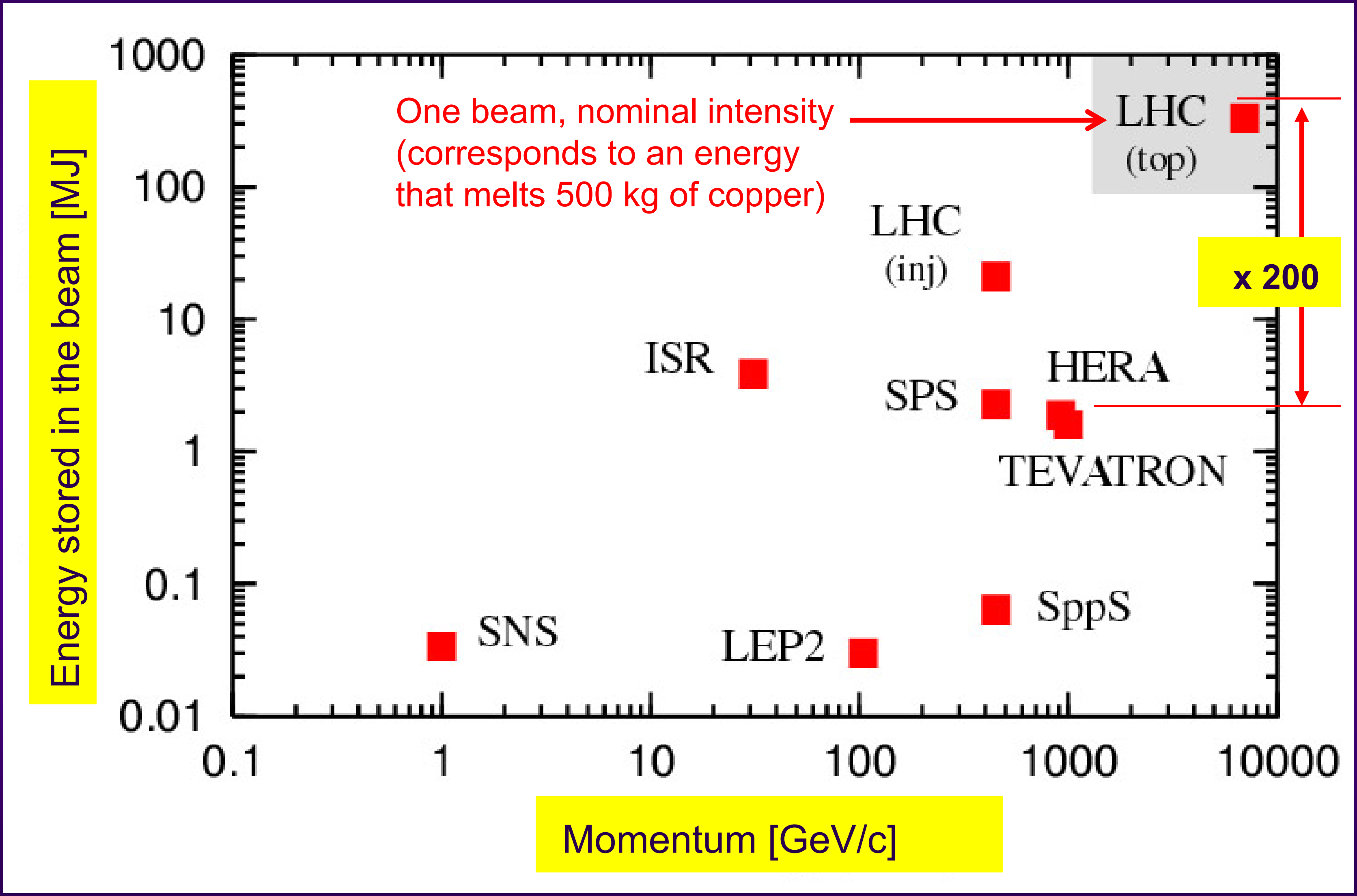


To be connected:

- Beam tubes
- Pipes for helium
- Cryostat
- Thermal shields
- Vacuum vessel
- Superconducting cables

Posters: MOPLE080 MOPDO014

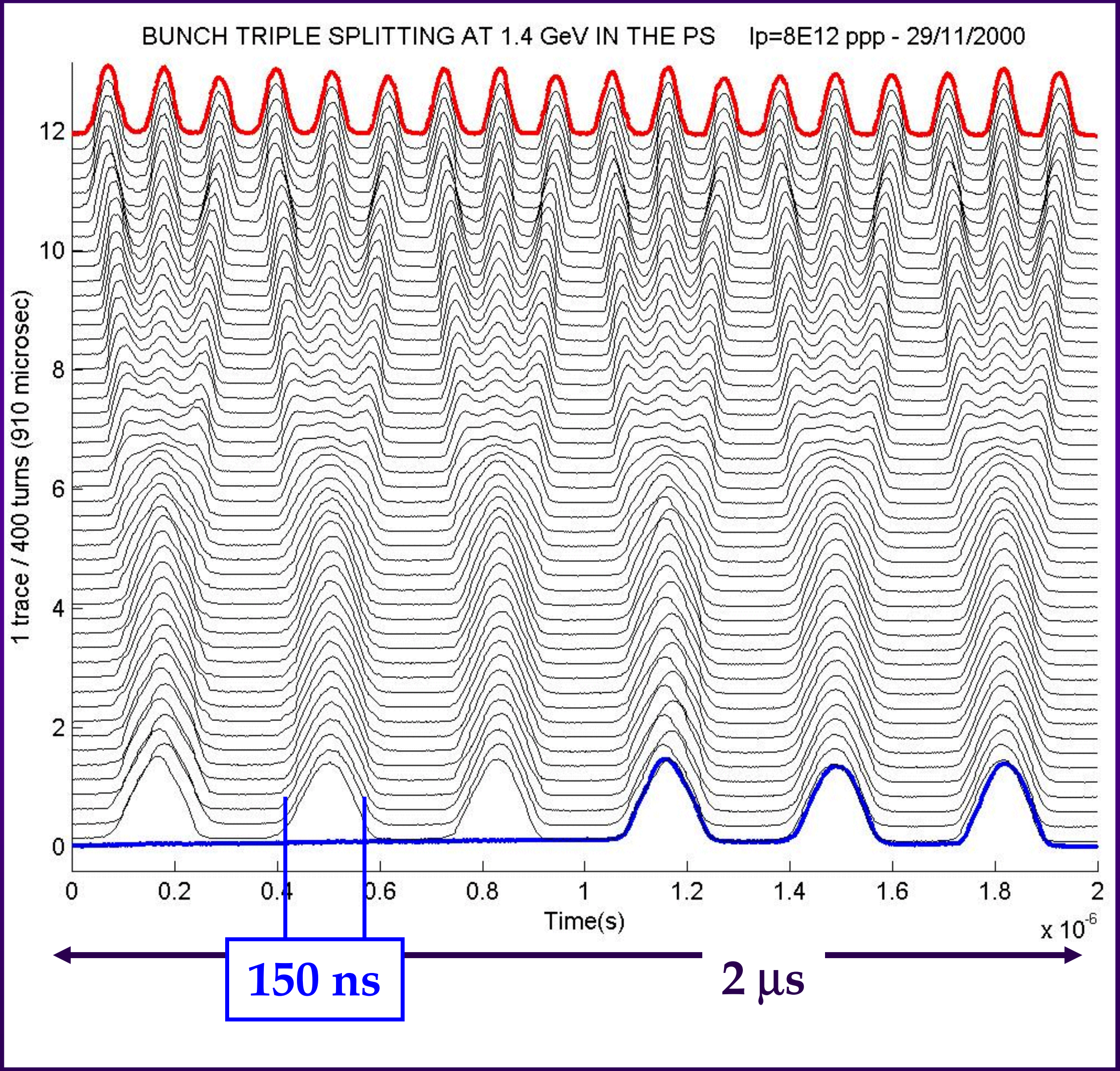
Challenges: Energy stored in the beam

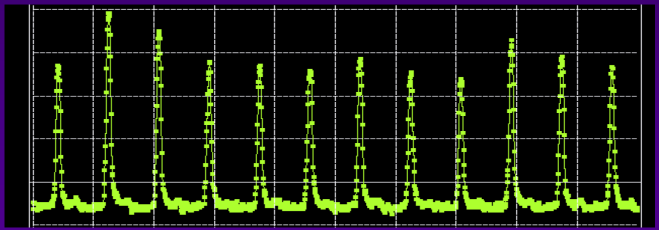


Injector Complex

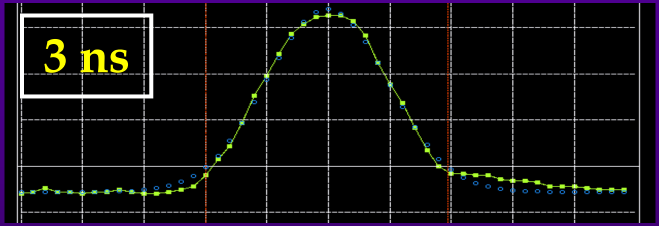
- Pre-injectors: Linac, PS Booster and Proton Synchrotron deliver beam at 26 GeV to the SPS
- The SPS accelerates beam from 26 GeV to 450 GeV
- Both, the pre-injectors and the SPS were upgraded for the operation with nominal LHC beam parameters
- Already today, beams are available close to the nominal beam parameters required for the LHC

Injector Complex: Bunch splitting in the PS





Twelve out of 72 bunches on the last turn of the PS (30 ns/div)



zoom on one bunch (bottom, 1 ns/div).

Mountain range display of bunch splitting at 1.4 GeV

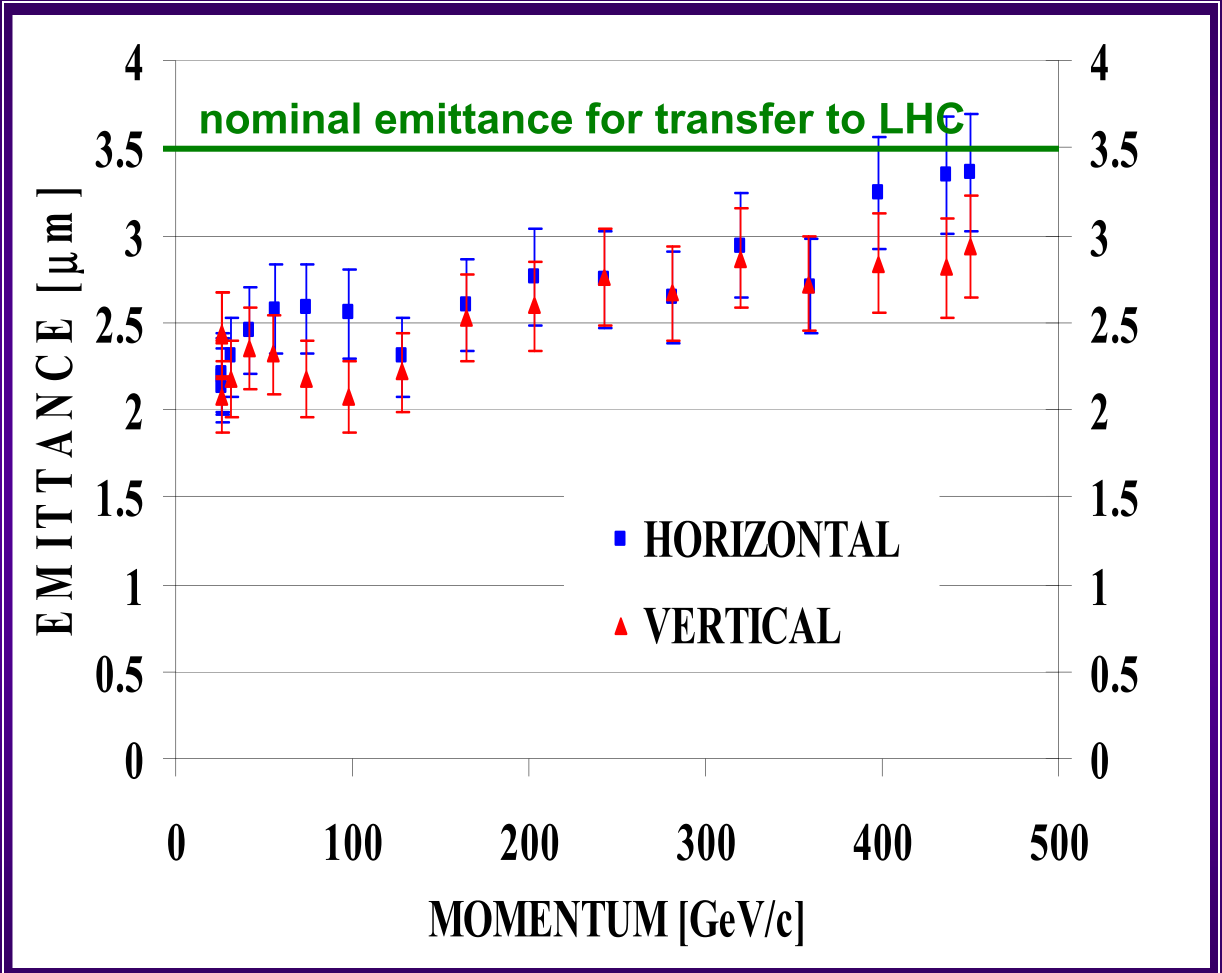
Courtesy R.Garoby

Injector Complex: Acceleration in the SPS

2001: emittance blowup along the ramp, due to the beam induced electron cloud instability (secondary electrons acclerated and multiplied due to high beam intensity)

but still below nominal for LHC - at reduced beam current

2002: beam scrubbing reduced secondary emission => no blow up along injection plateau - studies continue



Emittance as a function of momentum during the 2001 run (reduce beam current)

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

LHC: Superconducting Magnets

Arc 15-m dipoles and quadrupoles

Insertion dipoles and quadrupoles

Corrector magnets

See Poster session MOPLE this afternoon

Presentation by T.Taylor on Super LHC magnets - MOYGB002

Dipole assembly in industry

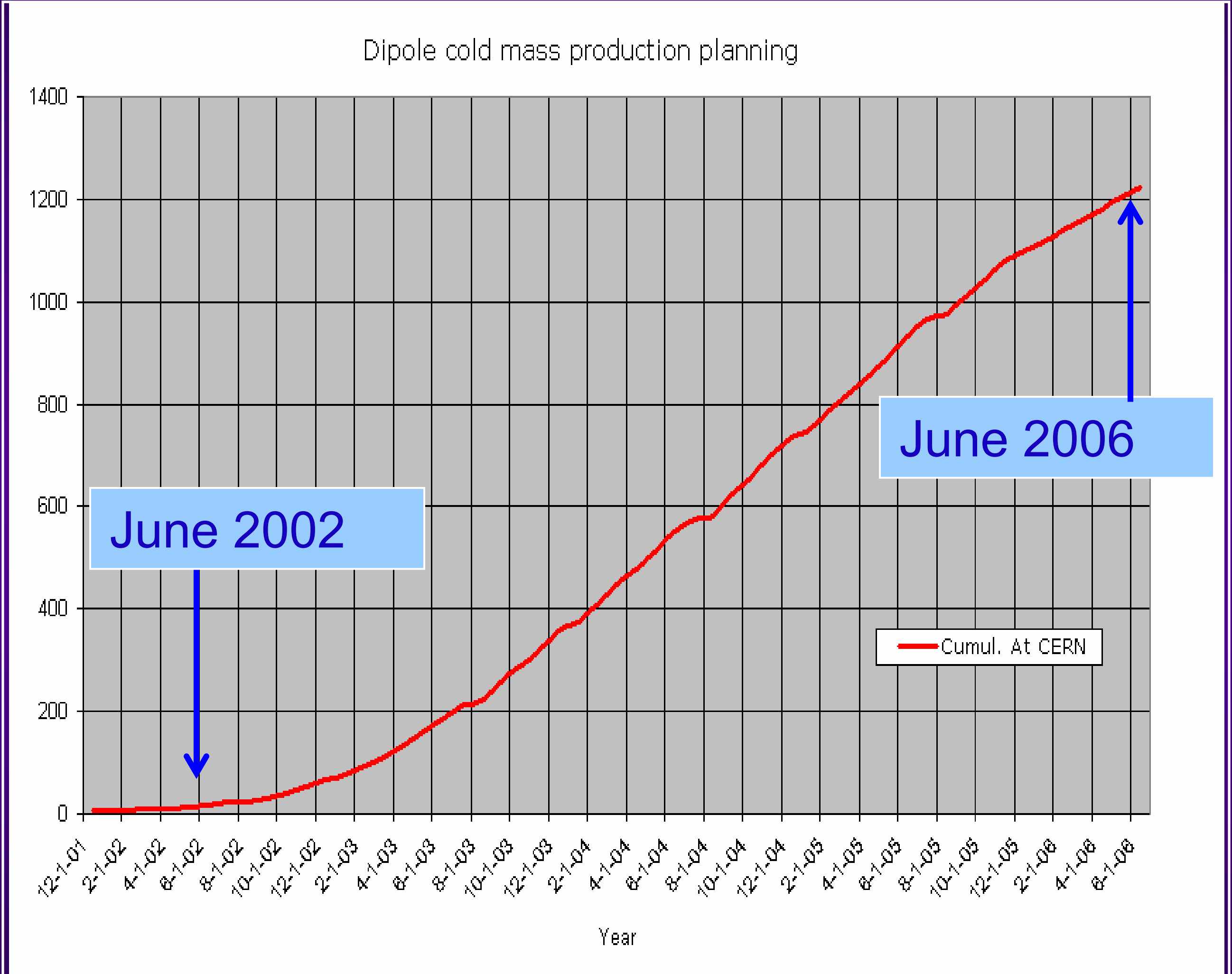
Superconducting main dipoles

After many years of R&D, six prototypes have been built by industry

Later, 90 pre-series magnets were ordered from three firms and are now in production

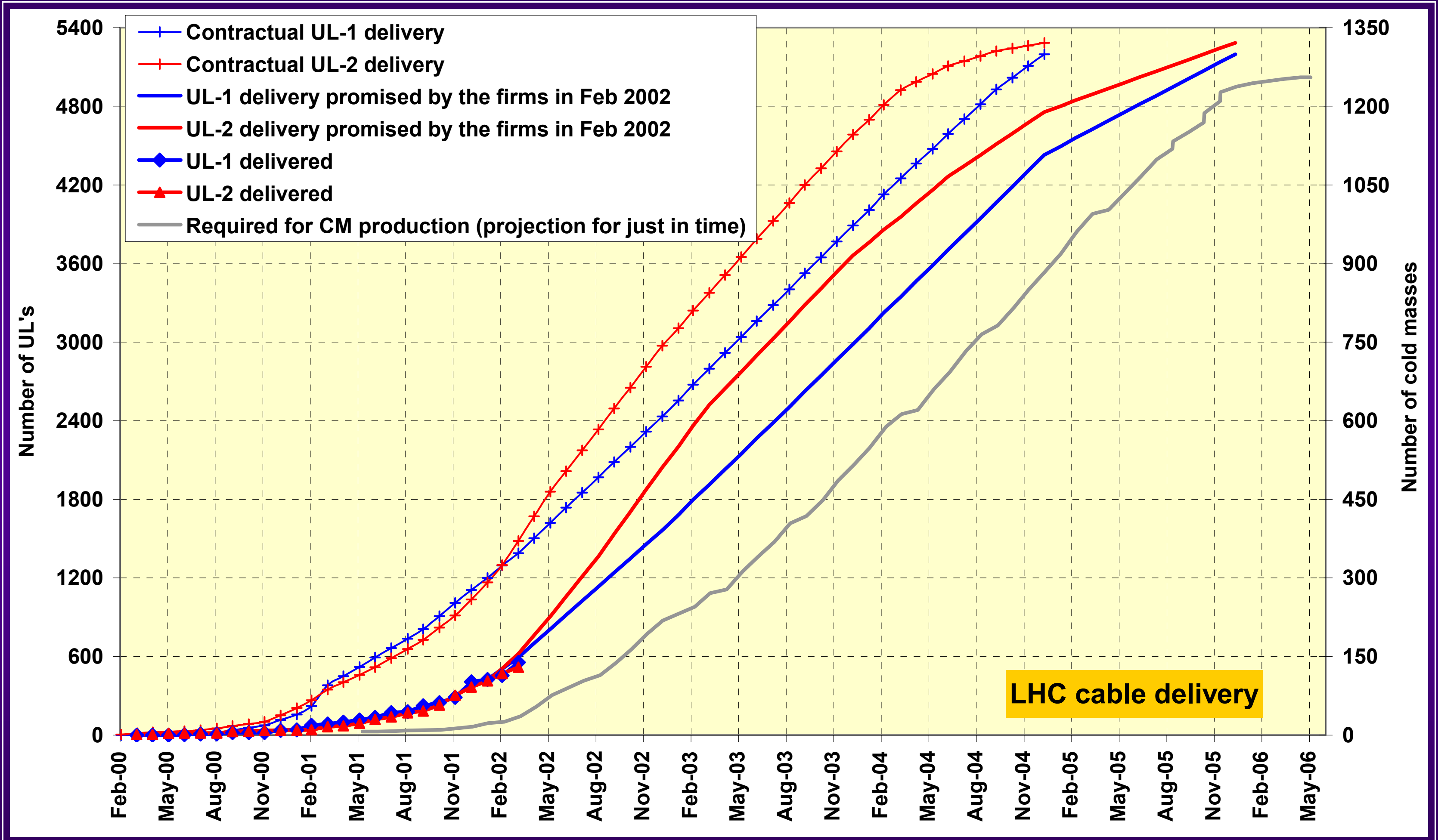
Several ten collared coils were made

Three contracts for the fabrication of all magnets were awarded



Planning of the cold mass production

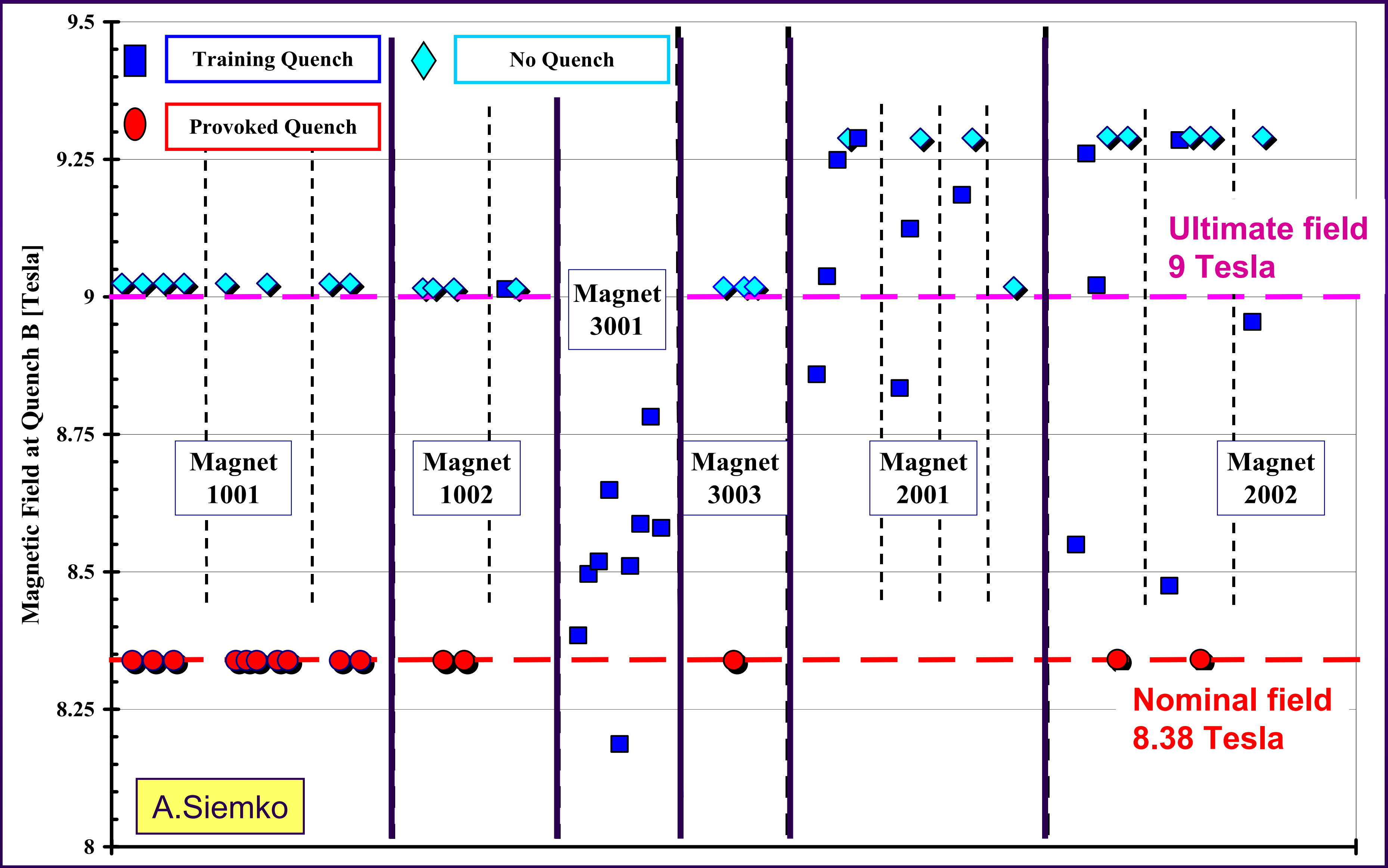
Superconducting main dipoles: cable delivery status and future schedule



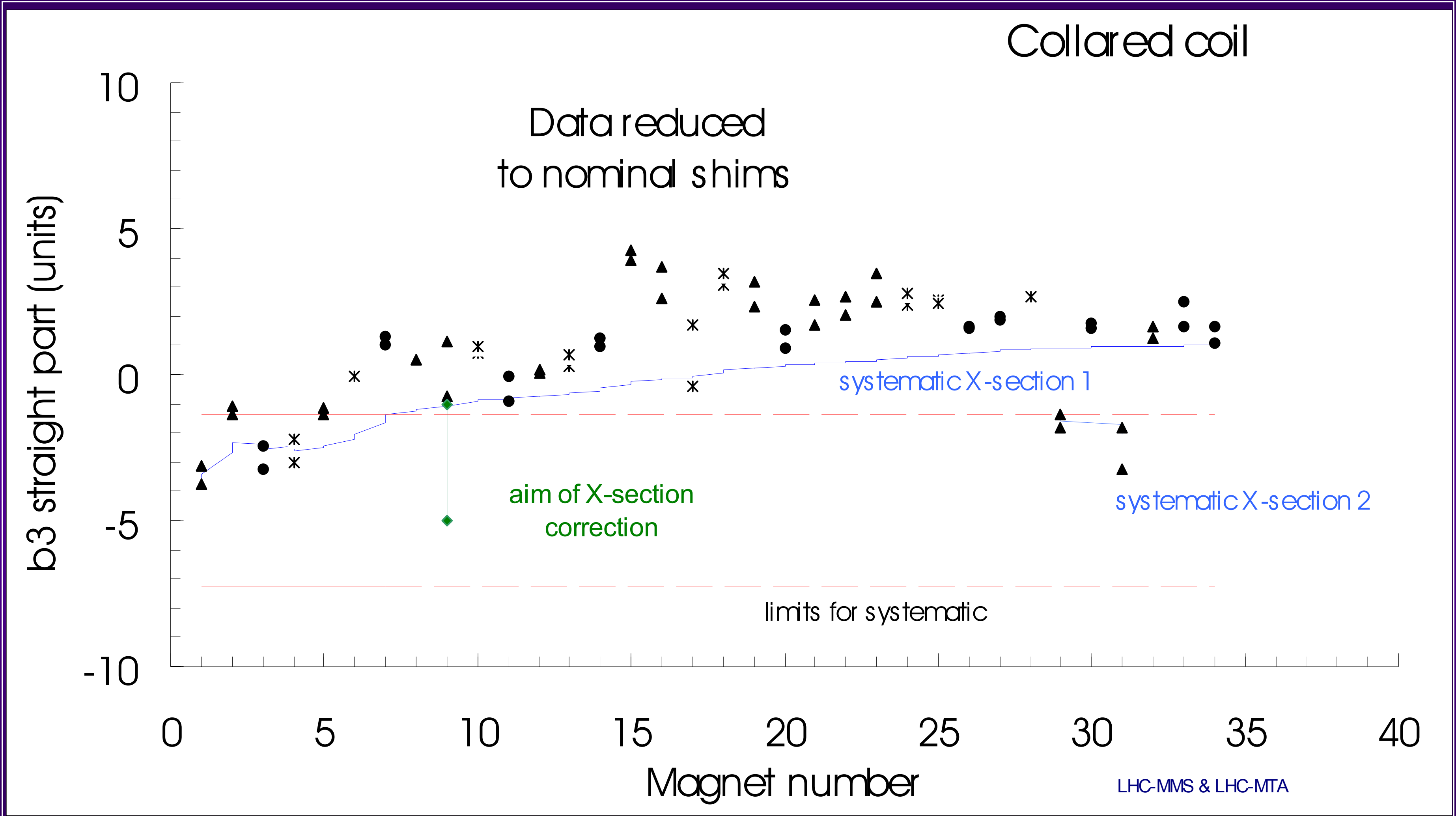
Cable production now following the adjusted planning

A.Verweij

Training of pre-series main dipole magnets



Field harmonics: Correction of the sextupole harmonics in the main dipole magnets



Small changes of the cross section to improve b3 multipole

Cryostating and measurements (main dipoles and other magnets)

SMA18 cryostating hall at CERN for installing dipole magnets into cryostats

SM18: 12 measurement stations are prepared for cold tests of possibly all superconducting magnets

A.Rijllart - MOPDO013

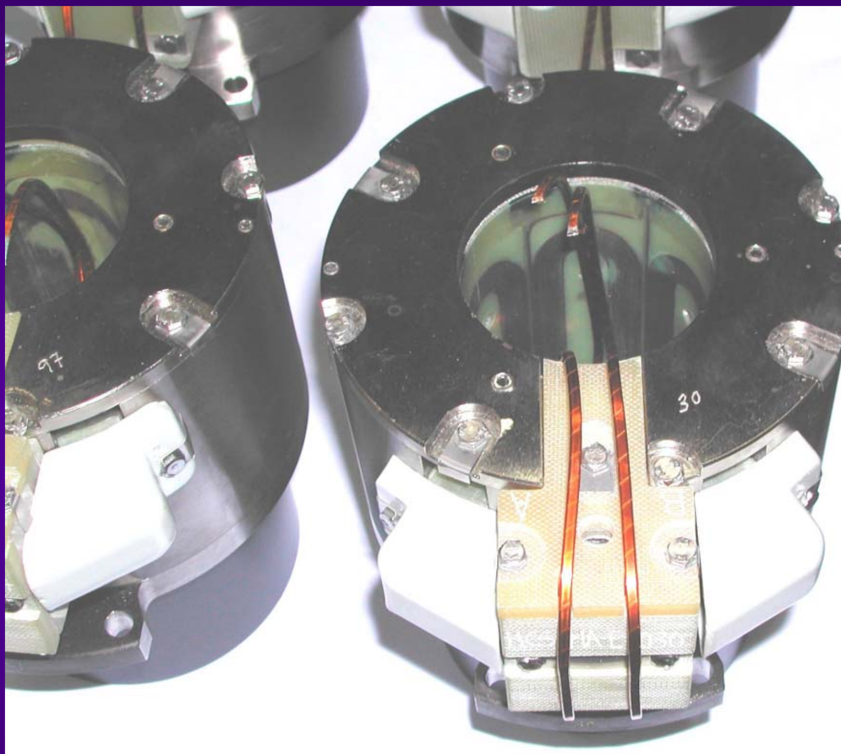
Main arc quadrupole magnets and special quadrupole magnets for the matching sections

Contribution from CEA/Saclay and CNRS (France) to the LHC:

- Prototypes of arc quadrupoles were developed and constructed
- Production was launched in industry
  - Tooling for the fabrication is operational
  - Fabrication of the coils started
  - Delivery of the first magnet in the cryostat expected for the second half of 2002

Insertion quadrupoles will be also fabricated by industry - 1st pre-series for the end of year 2002

Corrector magnet fabrication - construction for 11 types of magnets started

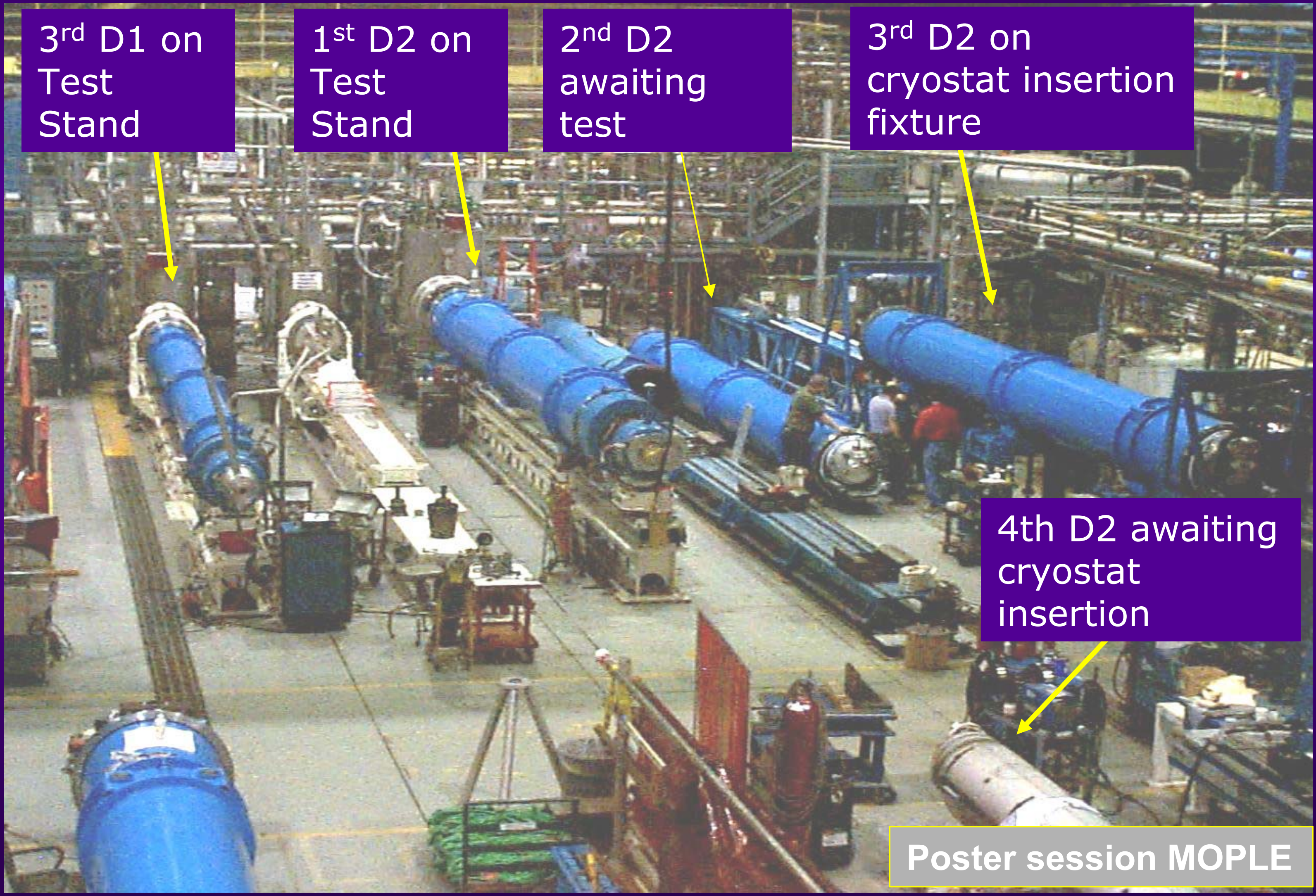


Sextupoles and decapoles to be installed at the extremities of the main dipoles

Delivery must precede dipole magnet fabrication (contribution from India and fabrication in industry)

L. Garcia-Tabares - MOPLE003

Insertion magnets: Dipoles from BNL (USA) for beam separation / recombination



Poster session MOPLE

Insertion magnets: Quadrupoles from KEK (Japan) and FERMILAB (USA)

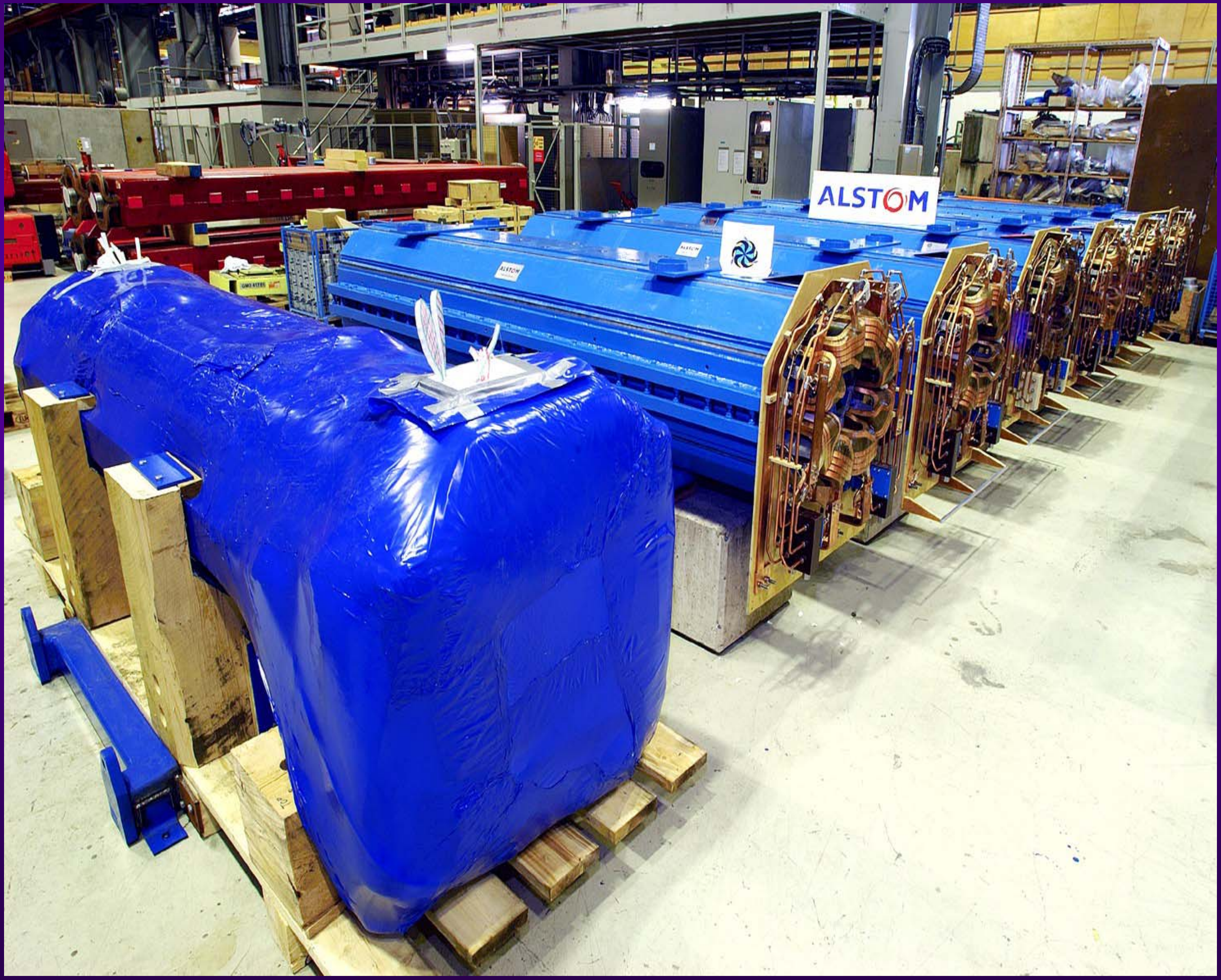
Challenging inner triplet quadrupole magnets with very high gradient from KEK and FERMILAB

Arrival of magnet from KEK at FERMILAB to be installed into the triplet cryostat

Poster session MOPLE

Normal Conducting Magnets: Double aperture quadrupole magnets for the cleaning insertions (warm)

One third of the magnets have been produced (collaboration with TRIUMF / Canada)



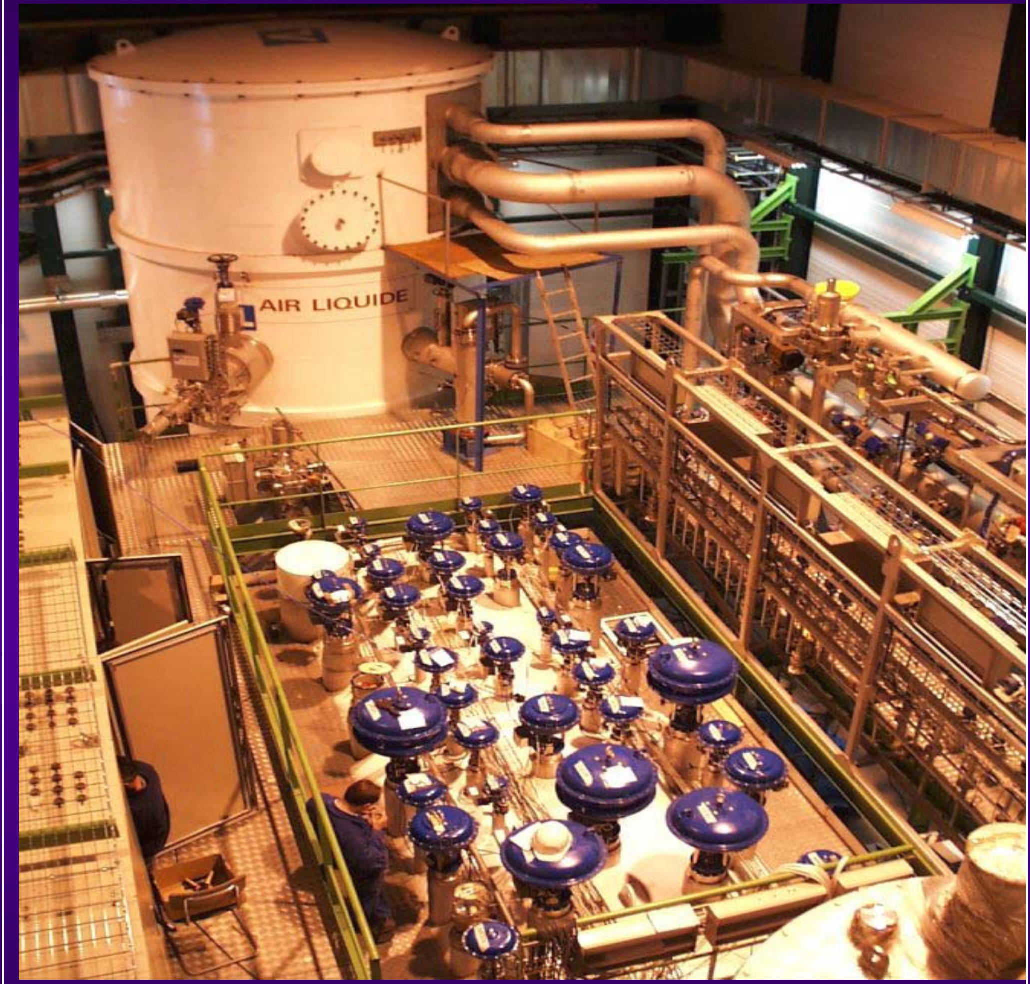
Cryogenic System

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

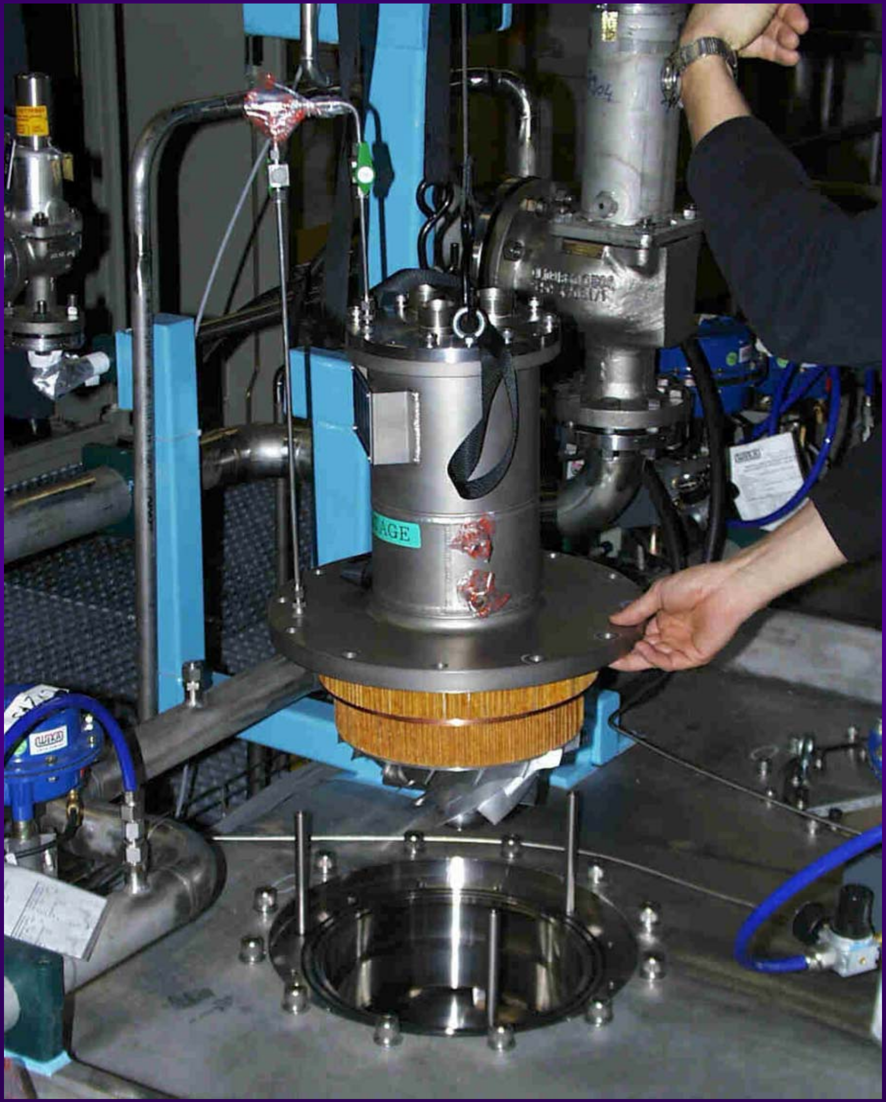
Installation starts in 2003



One new plant is being commissioned

Cryogenic System: Preparation of Cold Compressor Tests

First cold hydrodynamic compressors have been delivered from IHI (Japan) / industry and are being tested at CERN - with promising results



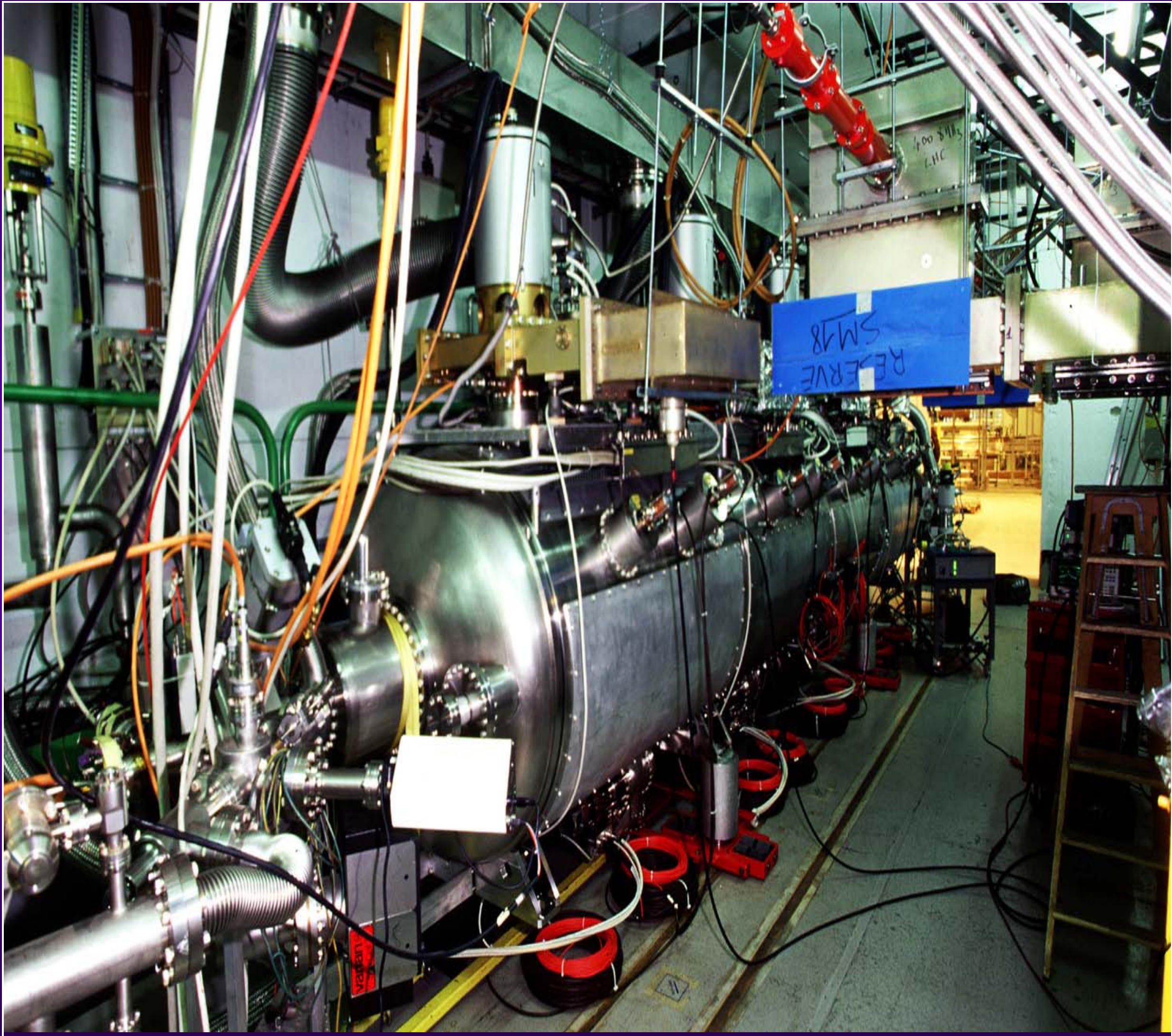
RF systems: 400 MHz and possibly 200 MHz

400 MHz system:

all 16 sc cavities (copper sputtered with niobium) for 16 MV/beam were built and assembled in four modules

200 MHz warm system:

Decision for implementation to be taken in 2004 - to ease the injection process



Power test of the first module

Beam vacuum system

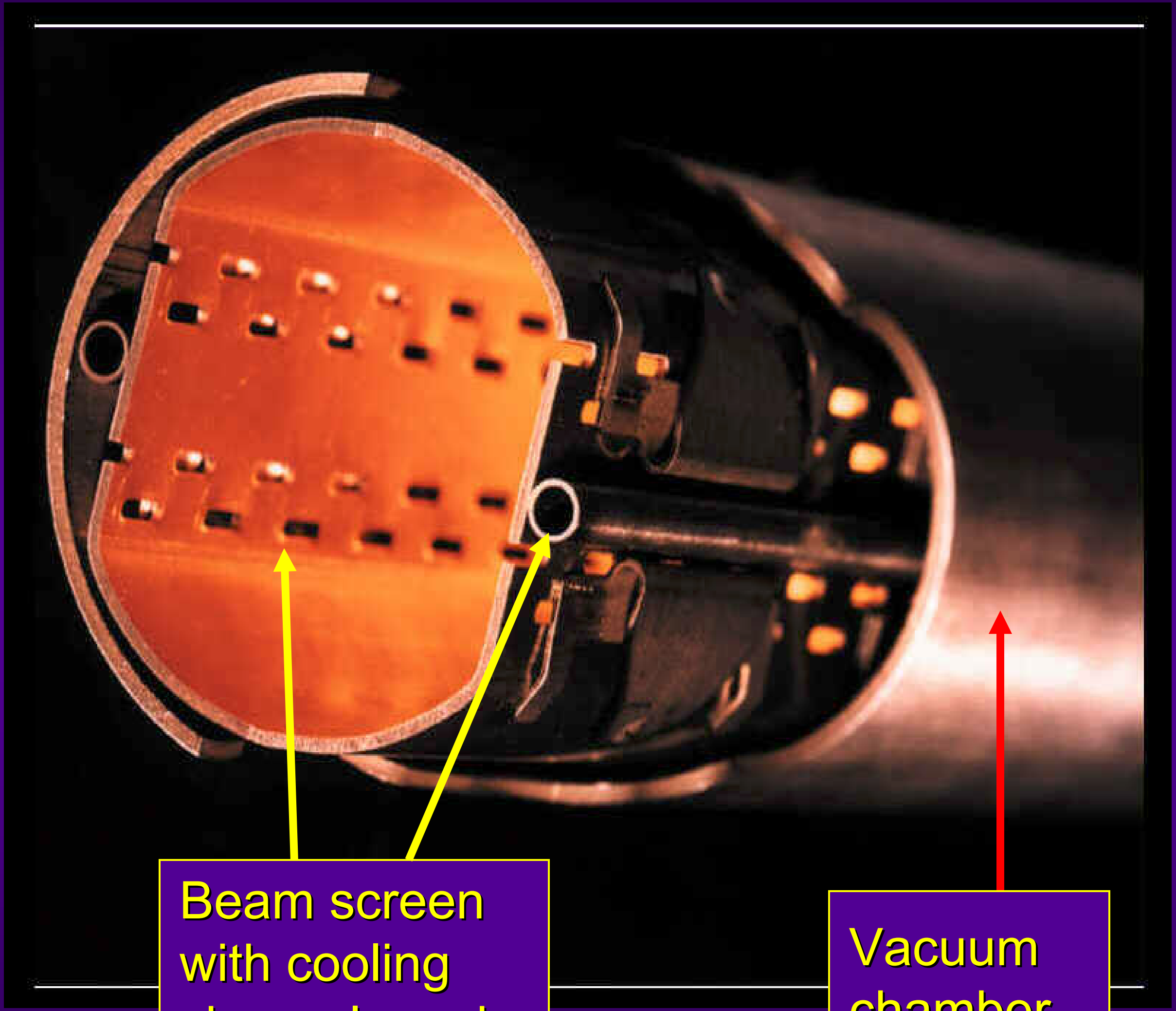
Beam screen is required for most of the machine

Ensures vacuum stability

Captures synchrotron radiation at 5-20 K

Beam stability => Low impedance: thin copper layer
MOPLE047 MOPLE048

Electron cloud effects:
- Minimise reflectivity
- Beam scrubbing
  (as in SPS)



Electron clouds: Several contributions in various sessions

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

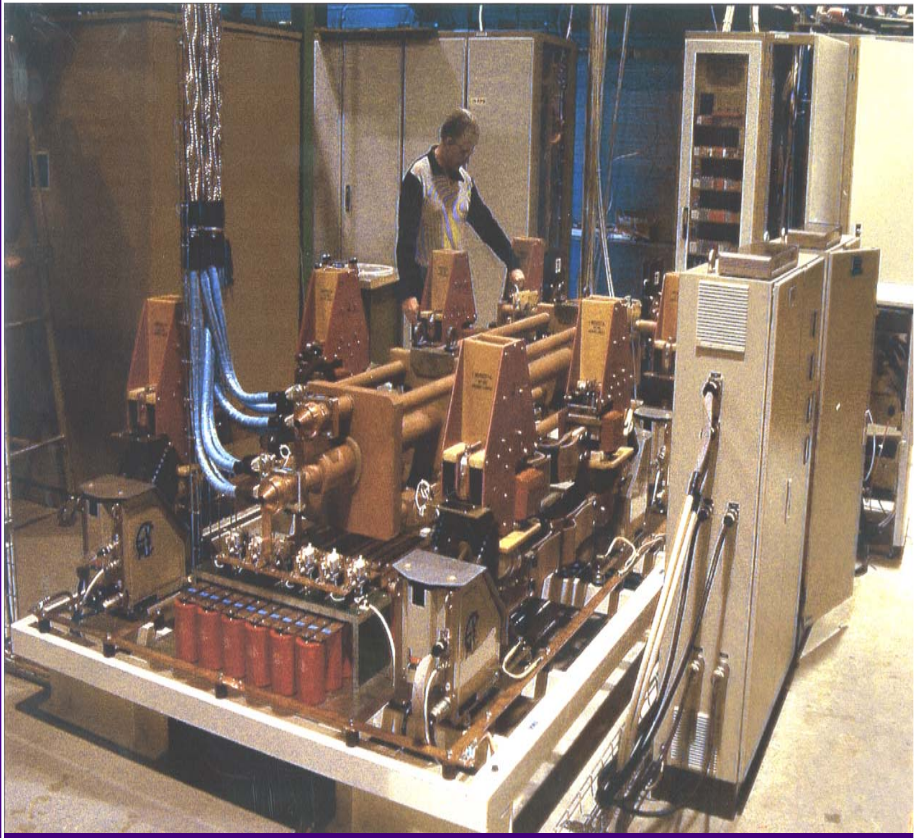
Machine protection: Magnet energy

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

Accelerator physics and operation

- **Dynamic aperture of 11 sigma**: for all magnets the maximum tolerated multipoles were specified
- Preparations based on very well controlled slow ramp with **PELP function** (parabolic, exponential, linear and parabolic)
- Accurate modelling of beam dynamics through the cycle
  - **Magnetic multipoles**
  - **Dynamic effects in superconducting magnets**
  - **Beam beam effects - head on / parasitic crossings**
- Preparation of **slow feedback** for tune and orbit, and possibly chromaticity - prototyping at the SPS
- Online magnetic measurements (**multipole factory**) for feed-forward to corrector circuits

Machine protection: Beam energy

For 7 TeV: fast beam loss between 10^6 and 10^7 protons could quench a dipole magnet

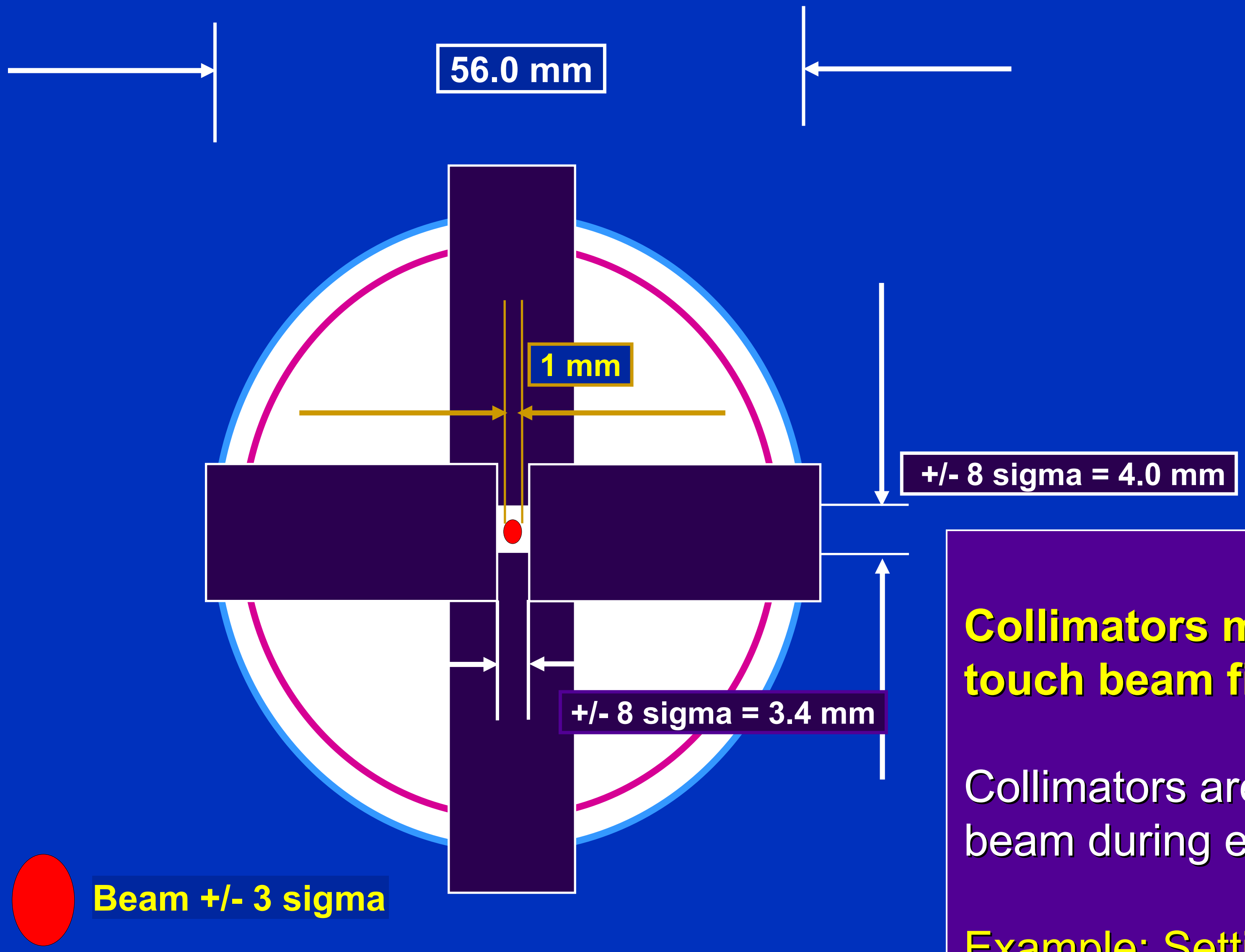
The beam dump block is the only system that can stand the full 7 TeV beam - $3 \cdot 10^{14}$ protons

Beam Cleaning: Capture particles in the warm sections of the LHC with an efficiency of better than 99.9% to avoid losses that could quench superconducting magnets

In case of equipment failure, beam instabilities etc:

- Capture initial beam losses that could damage LHC equipment
- Beam Loss Monitors close to collimators and other aperture restrictions produce a fast and reliable signal to dump the beam if beam losses become unacceptable

E.Gschwendtner THPRI083



Collimators must always touch beam first !

Collimators are close to the beam during energy ramp

Example: Setting of collimators at 7 TeV - with luminosity optics

Optimisation of Cleaning

- Definition of requirements for collimation system - taking into account failure scenarios and imperfect operation
  - **Worst case is the impact of about 20 bunches on the collimator due to pre-firing of one dump kicker module**
- Optimisation of the robustness of the cleaning system
- Material for collimator is being reconsidered - low Z material is favoured
- Proceed with the technical design of the collimators

several papers: MOPLE032 TUAGB001 MOPLE030 WEPLE044
and presentation R.Assmann, TUAGB001

Prototype LHC cell: the 110 m long String 2

Full size model of one LHC cell (six dipoles and two quadrupoles)

2001: 3 dipoles and 2 quadrupoles

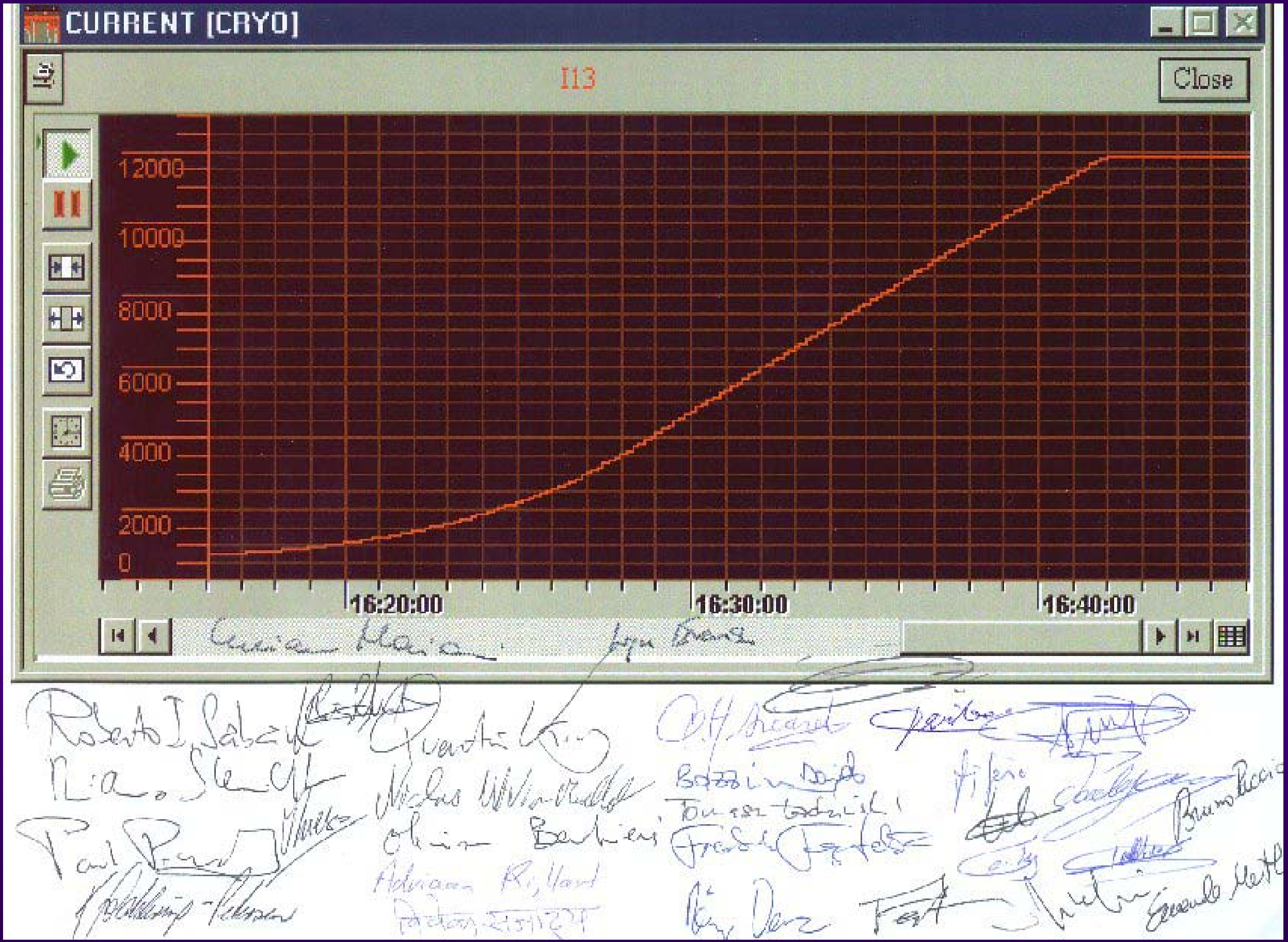
Cooled down to 1.9 K and one dipole and two quadrupole circuits were powered to nominal current

Cell has been completed (now six dipoles) and is today being cooled down

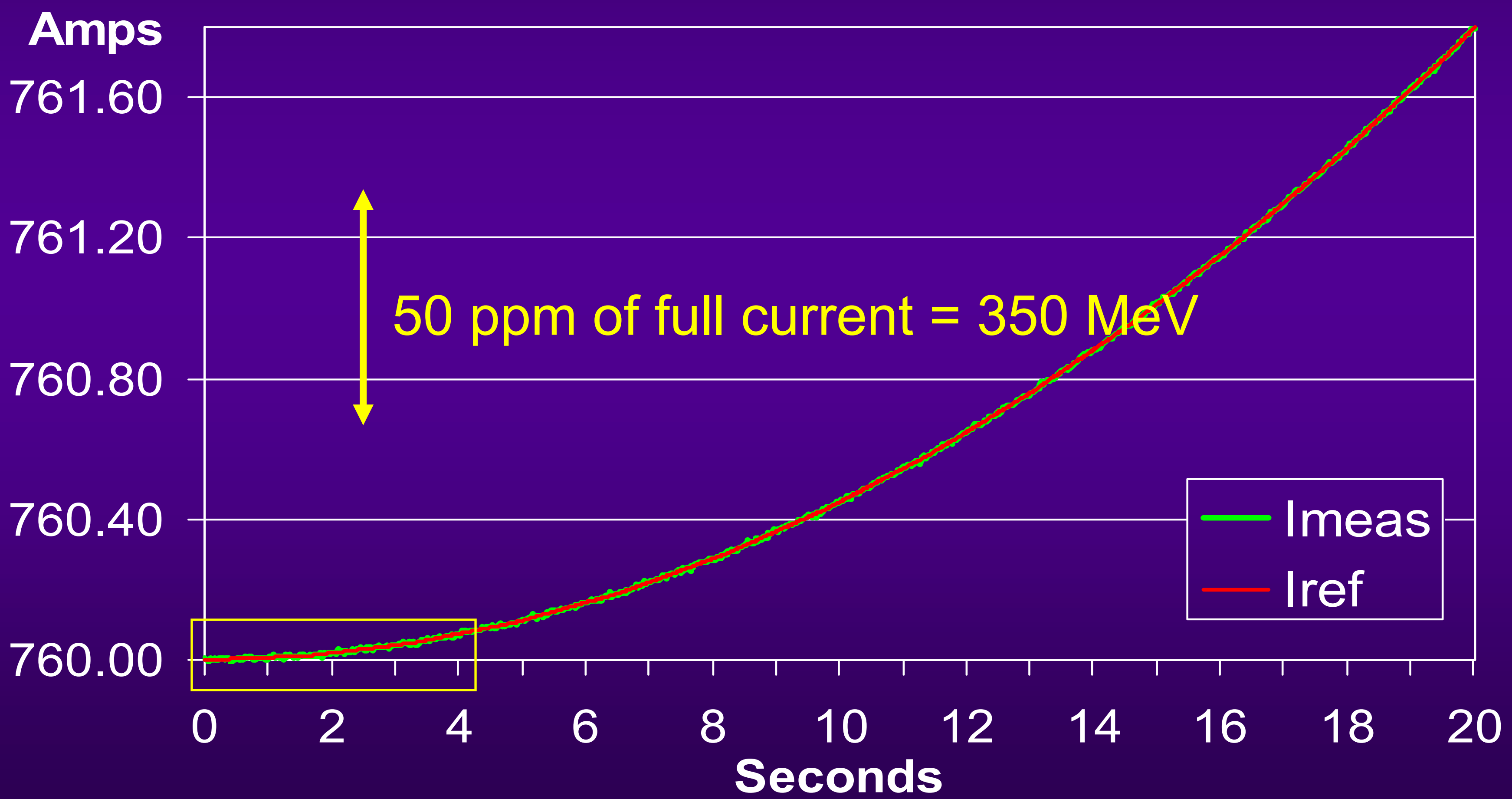
Experiment were performed in 2001 and will continue soon

MOPDO012 MOPLE013 MOPDO010

String 2: First Powering of dipole magnets

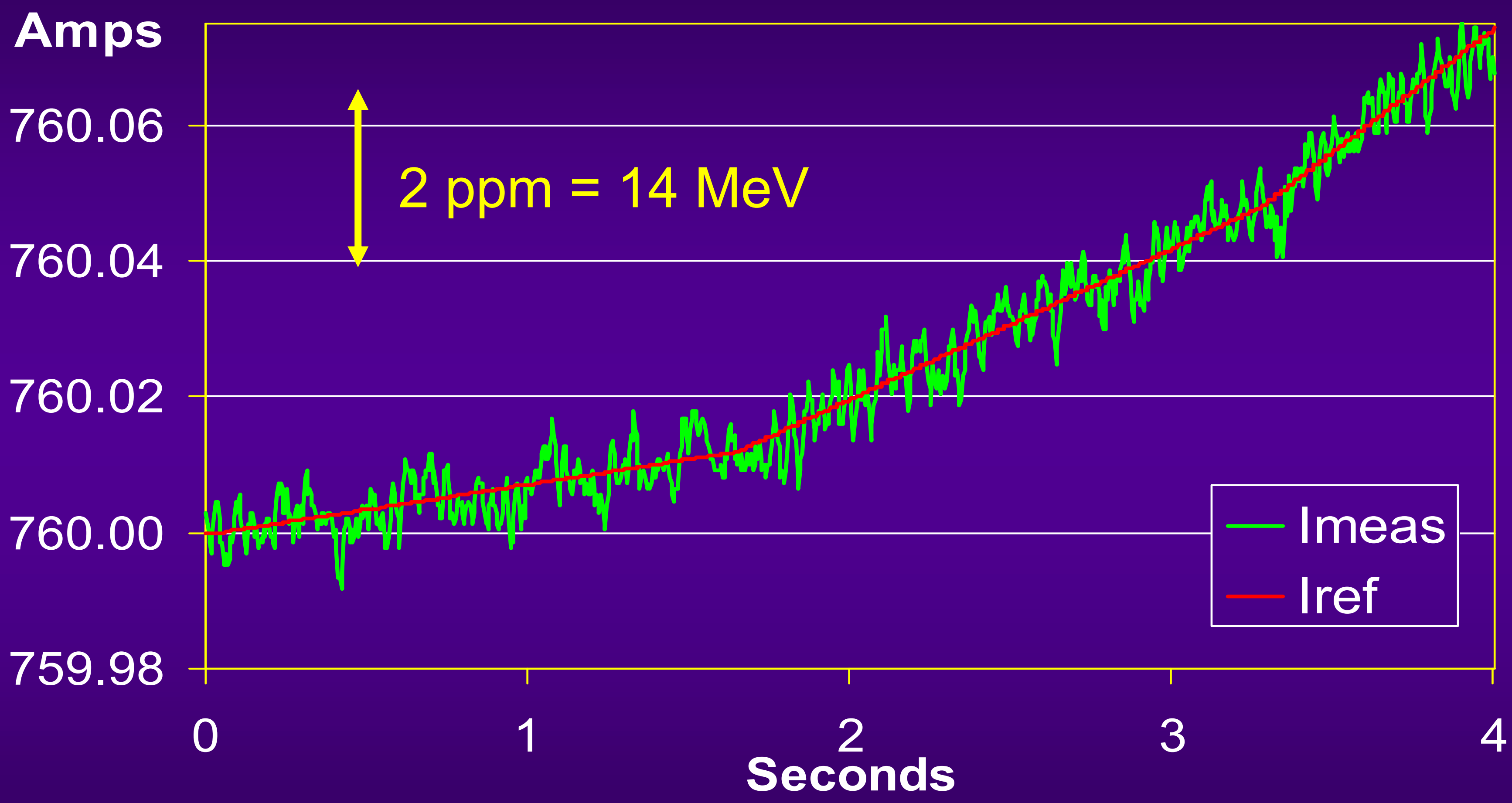


String 2: Start of the LHC dipole circuit ramp (0-20s) simulates ramp after injection of beam at 450 GeV



Q.King et al. ICALEPS 2001

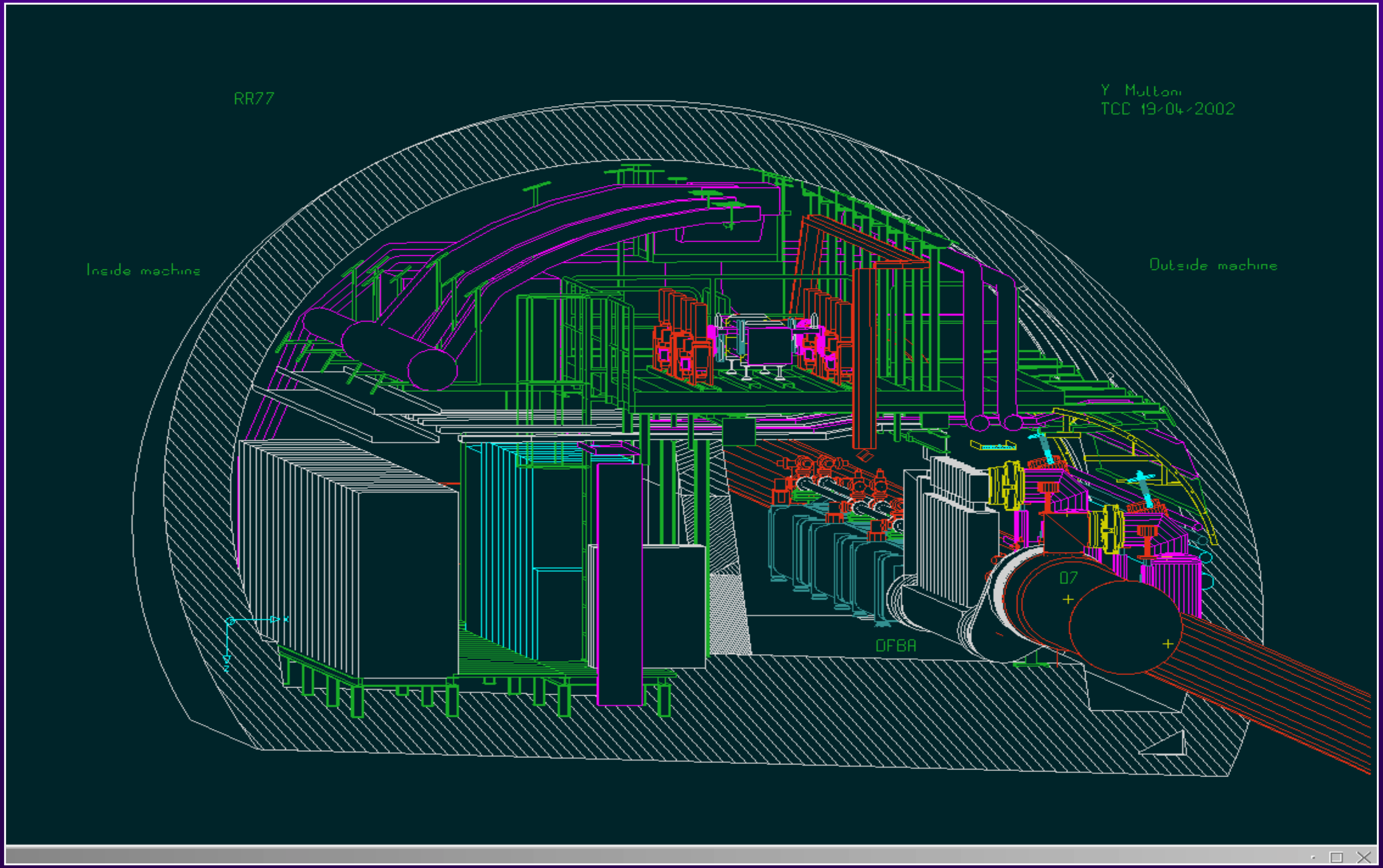
String 2: LHC dipole circuit ramp (0-4s)



Results were achieved with a new method of digital regulation together with an ultra high precision current measurement system

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



Conclusions

- Civil engineering is nearly completed
- Most contracts with industry for equipment supply have been awarded
- Fabrication of equipment under the responsibility of other labs goes well

Planning can now be based on deliveries and contractual documents

The LHC is installed and commissioned in eight (rather) independent sectors - that allows for

activities to be performed in parallel

Installation of LHC started with “general services” March 2002

Conclusions

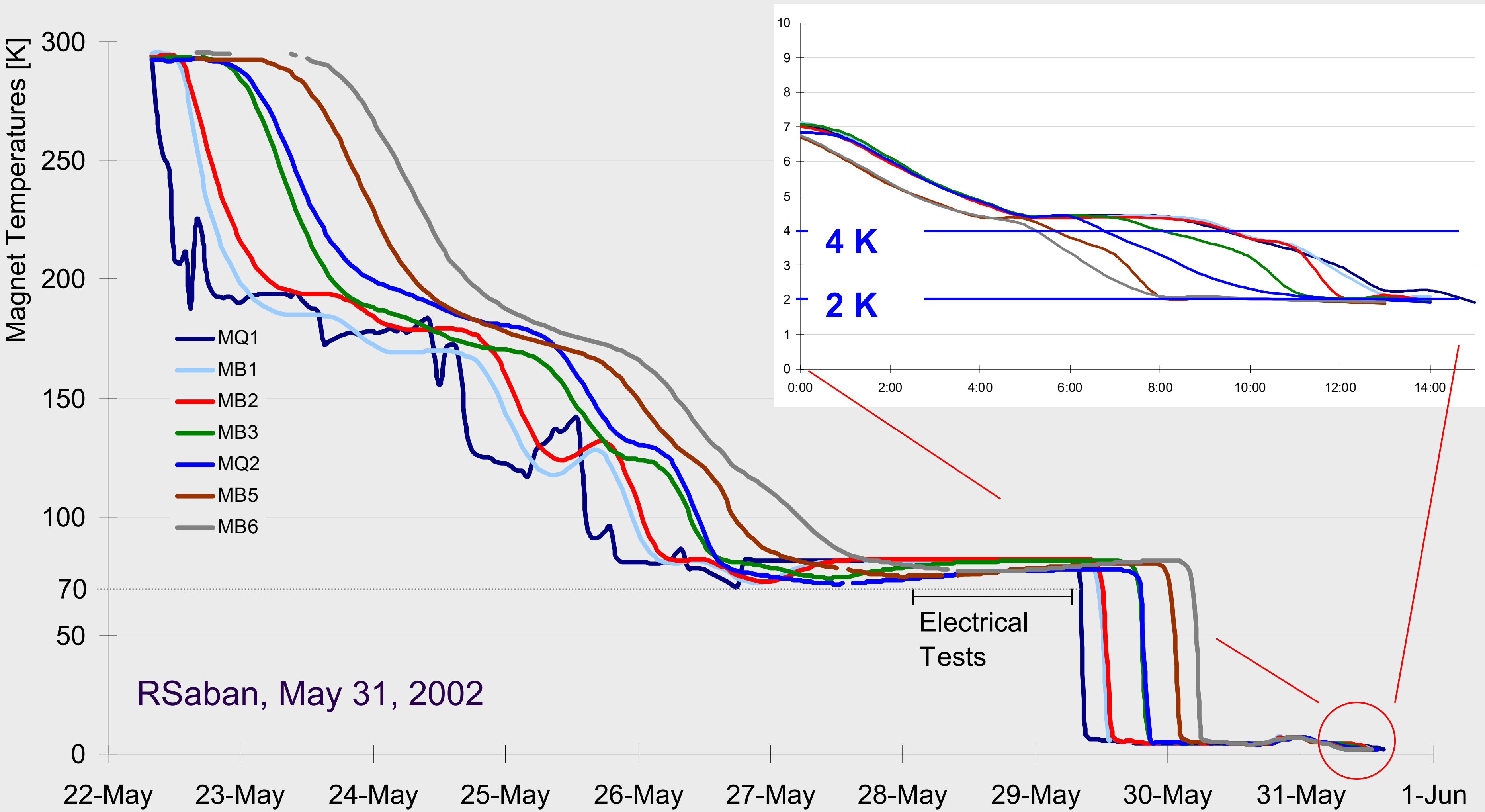
From now to 2006	Fabrication of equipment Installation of completed components Very thorough **commissioning** of the **hardware systems** starting in 2005, **sector by sector**, as key for successful fast start up with beam

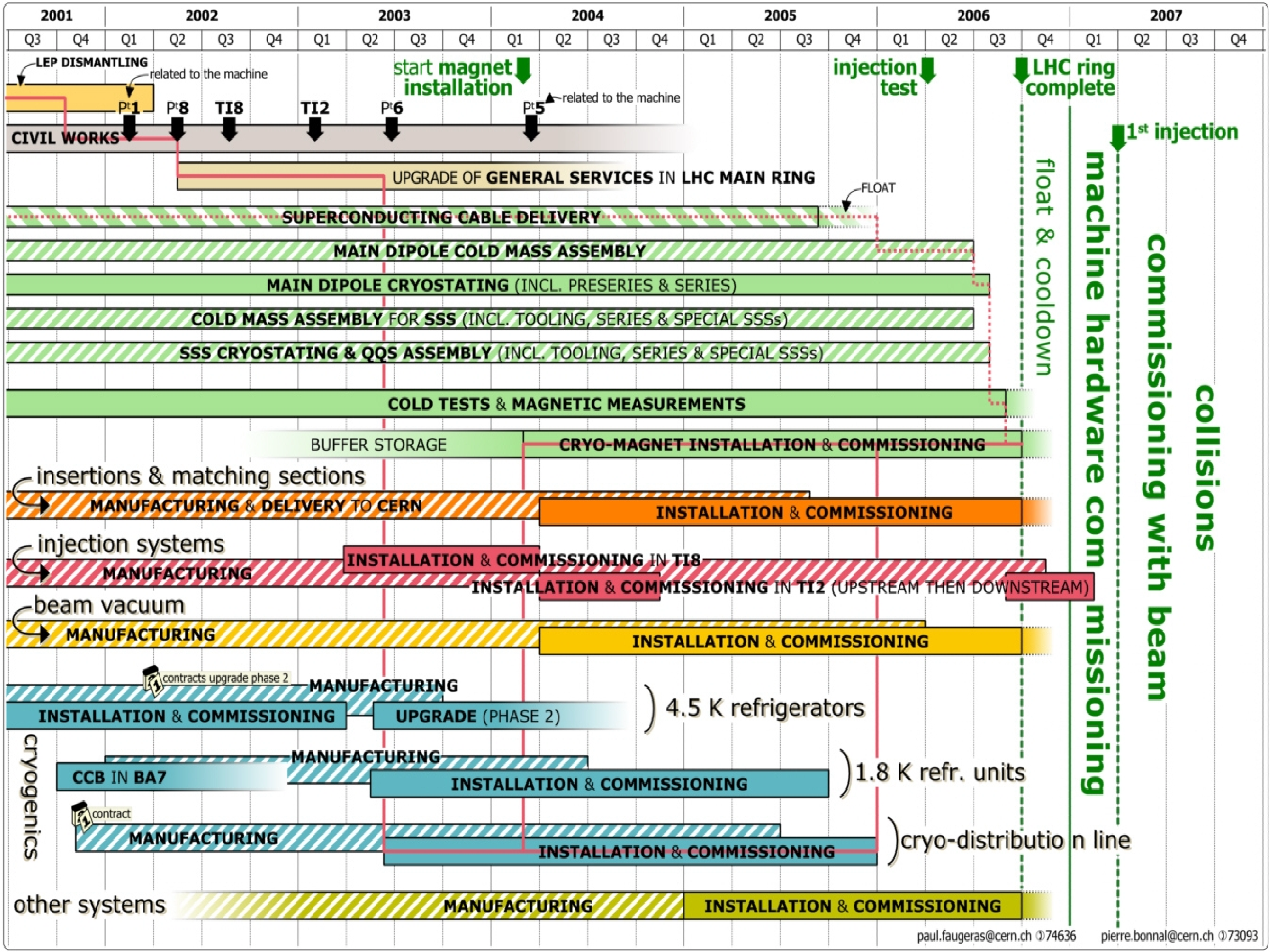
String 2 gave us a lot of confidence as we observed a smooth commissioning of the hardware systems

In **2006 - one beam injected and transported** across two sectors (25% of the ring)

Start-up with two beams in spring 2007

String 2 cooldown Friday, 21 June 2002





2001
2002
2003
2004
2005
2006
2007
Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4
LEP DISMANTLING
related to the machine
start magnet installation
injection test
LHC ring complete
Pt1
Pt8
TI8
TI2
Pt6
Pt5
related to the machine
CIVIL WORKS
1st injection
UPGRADE OF GENERAL SERVICES IN LHC MAIN RING
FLOAT
SUPERCONDUCTING CABLE DELIVERY
MAIN DIPOLE COLD MASS ASSEMBLY
MAIN DIPOLE CRYOSTATING (INCL. PRESERIES & SERIES)
COLD MASS ASSEMBLY FOR SSS (INCL. TOOLING, SERIES & SPECIAL SSSs)
SSS CRYOSTATING & QQS ASSEMBLY (INCL. TOOLING, SERIES & SPECIAL SSSs)
COLD TESTS & MAGNETIC MEASUREMENTS
BUFFER STORAGE
CRYO-MAGNET INSTALLATION & COMMISSIONING
float & cooldown
machine hardware commissioning
commissioning with beam
collisions
insertions & matching sections
MANUFACTURING & DELIVERY TO CERN
INSTALLATION & COMMISSIONING
injection systems
INSTALLATION & COMMISSIONING IN TI8
MANUFACTURING
INSTALLATION & COMMISSIONING IN TI2 (UPSTREAM THEN DOWNSTREAM)
beam vacuum
MANUFACTURING
INSTALLATION & COMMISSIONING
contracts upgrade phase 2
MANUFACTURING
INSTALLATION & COMMISSIONING
UPGRADE (PHASE 2)
4.5 K refrigerators
cryogenics
MANUFACTURING
CCB IN BA7
INSTALLATION & COMMISSIONING
1.8 K refr. units
contract
MANUFACTURING
INSTALLATION & COMMISSIONING
cryo-distribution line
other systems
MANUFACTURING
INSTALLATION & COMMISSIONING
paul.faugeras@cern.ch 74636
pierre.bonnal@cern.ch 73093