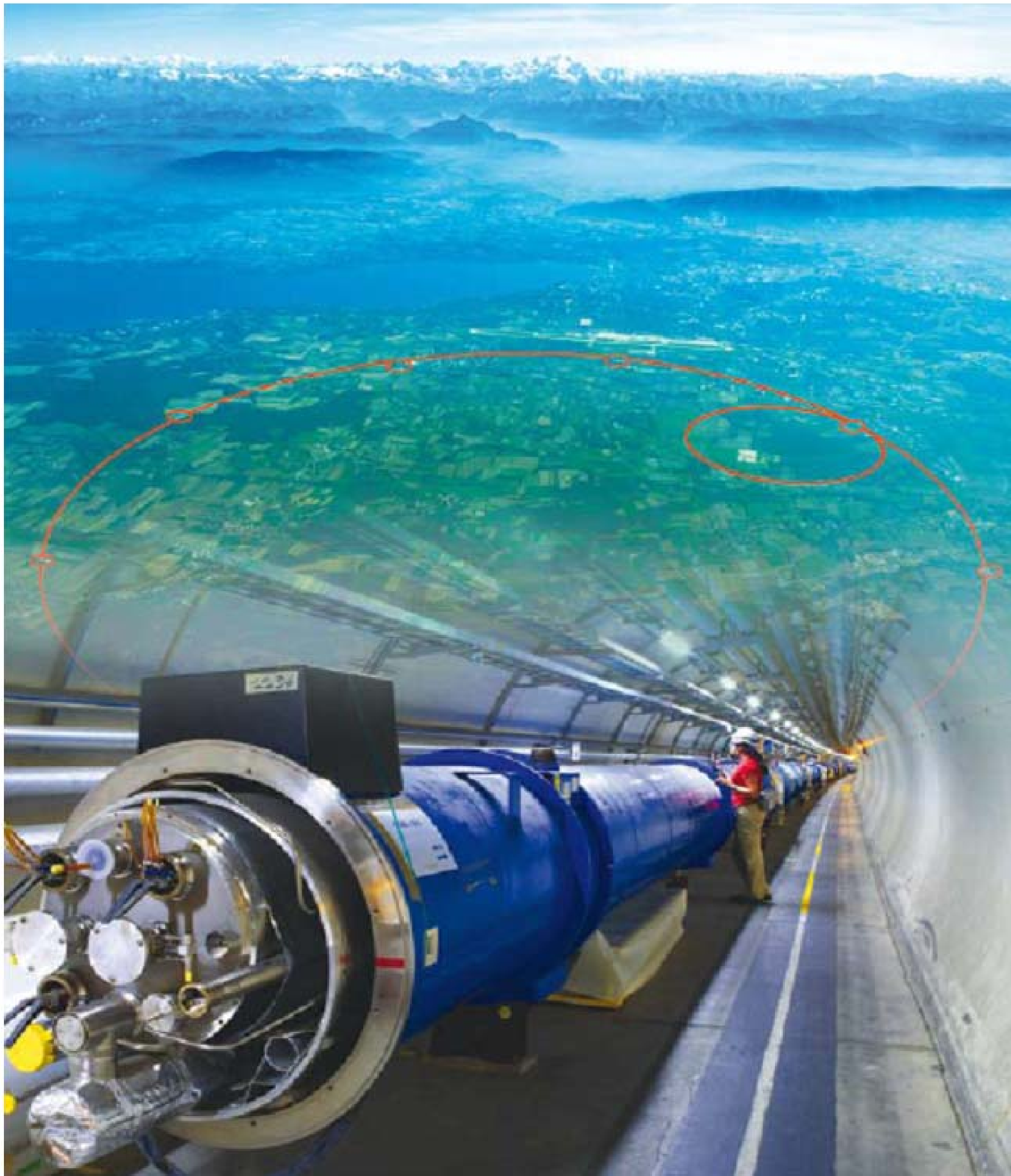
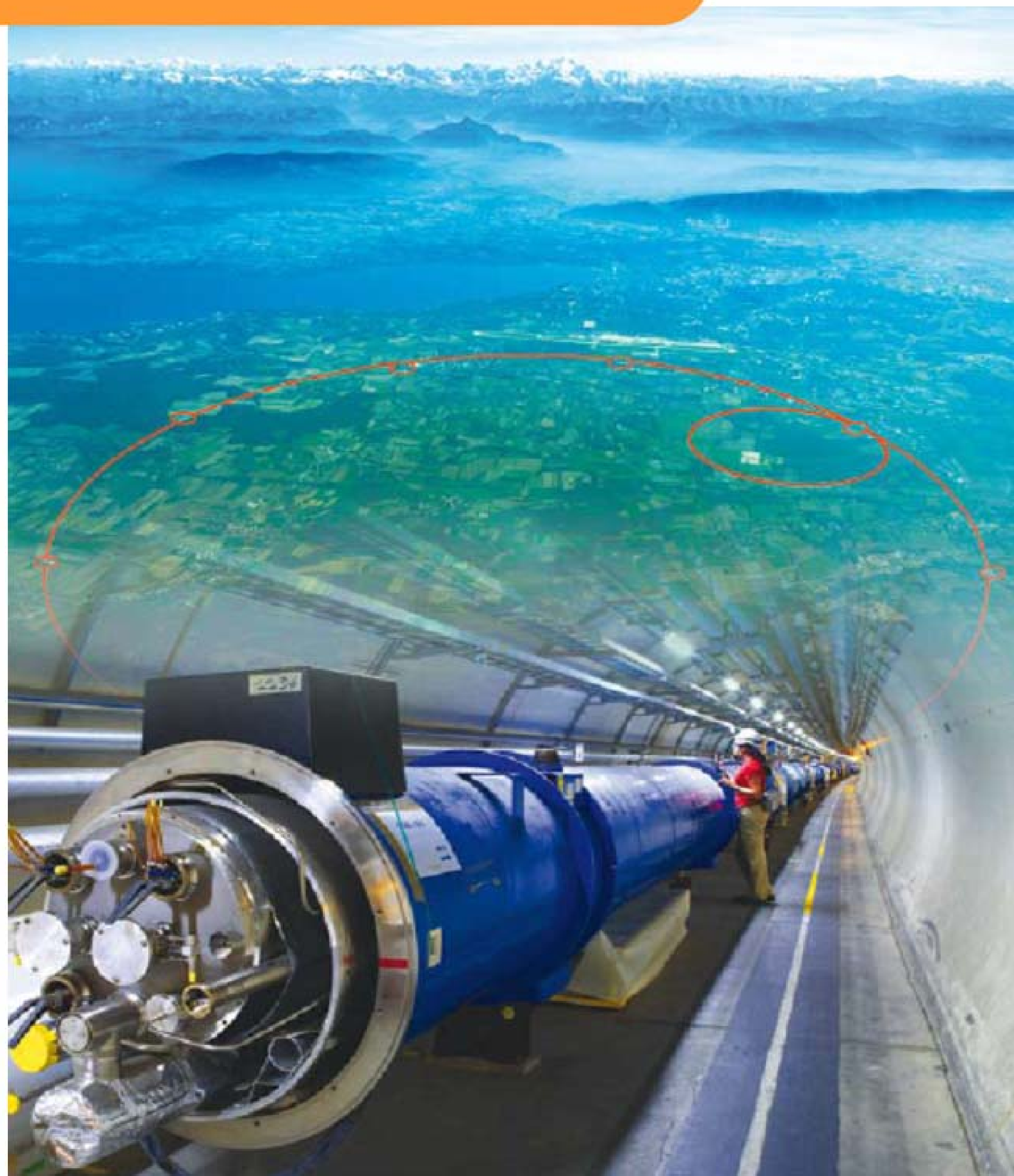
Status of the LHC

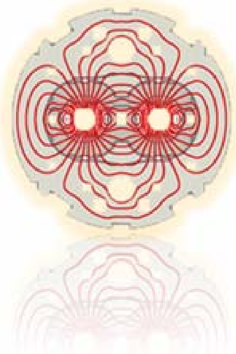


Frédérick BORDRY
On behalf of the CERN staff,
the outside collaborators and industries
CERN

Last Status of the LHC before beam



Frédérick BORDRY
On behalf of the CERN staff,
the outside collaborators and industries
CERN



Is it necessary to introduce ***the lord of the rings*** ?

Advanced Technology Issues in the LHC Project
L.R. Evans **EPAC 1994** , London, UK

ACCELERATOR PHYSICS ISSUES OF THE LHC
Jacques Gareyte, **EPAC 1996** , Sitges , Spain

LHC ACCELERATOR PHYSICS AND TECHNOLOGY CHALLENGES
L.R. Evans , **EPAC 1998** , Stockholm, Sweden

THE CHALLENGE OF FUTURE ACCELERATORS (1st part)
K. Hübner , **EPAC 2000**, Vienna , Austria

STATUS OF THE LHC
R. Schmidt, **EPAC 2002**, Paris, France

Experience with LHC Magnets from Prototyping to Large-scale Industrial Production and Integration 118
L. Rossi, **EPAC 2004**, Lucerne, Switzerland

LHC PROGRESS AND COMMISSIONING PLANS
Oliver Brüning, **EPAC 2006**, Edinburgh, Scotland

LHC: Construction and Commissioning Status
L. R. Evans, **PAC 2007**, Albuquerque, USA

Menu of the day

Amuse bouche

Introduction: LHC and its general parameters

Starter

LHC main milestones from 2002

Main

Last two years events and *"where are we ?"* :

- Completion of the installation and interconnects
- Inner triplet challenges
- Plug-in modules
- Cool-down of the sectors
- Hardware commissioning

Dessert

Beam Plans for 2008 and 2009

Pousse-Café

Conclusions

What is LHC (Large Hadron Collider) ?

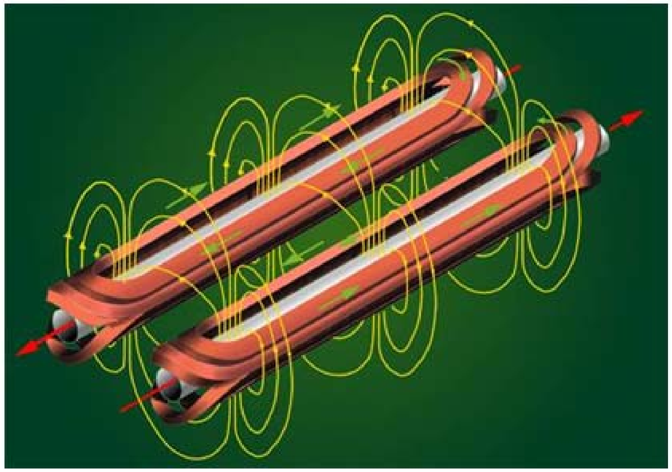
7 TeV proton-proton accelerator-collider built in the LEP tunnel

- **1982 : First studies for the LHC project**
- **1994 : Approval of the LHC by the CERN Council** *("missing" magnet strategy)*
- **1996 : Final decision to start the LHC construction** *(7TeV machine)*
- **2004 : Start of the LHC installation**
- **2006 : Start of hardware commissioning**
- **2007 : End of installation and start of cool-down**
- **2008 : End of hardware commissioning and beam commissioning**

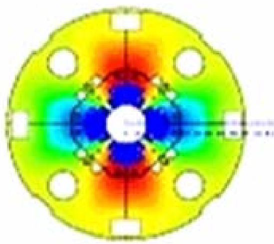
Beams of LEAD nuclei will be also accelerated, smashing together with a collision energy of 1150 TeV

The machine of superlatives

- 7 TeV per beam in LEP tunnel => 8.33 T
- Luminosity goal 10^{34} cm^{-2} s^{-1}
  - Excludes proton – antiproton
  - Hence proton – proton machine
    - Separate magnetic fields and vacuum chambers in the arcs



    - Common sections in the interaction regions



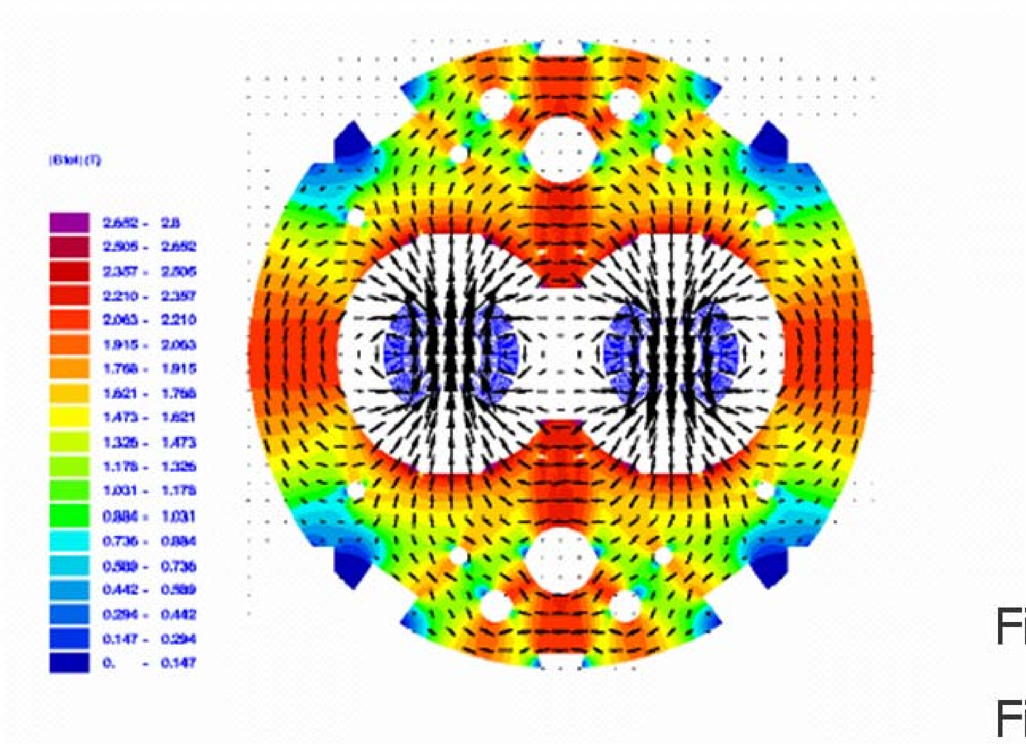
Two-in-one dipole magnet

Tunnel cross section excludes 2 separate rings of magnets:

- Hence twin aperture magnets in the arcs: 8.33 T (ultimate 9 T)
- **Superconducting magnets with high current density**

Trade-off between magnet and cryogenic complexity

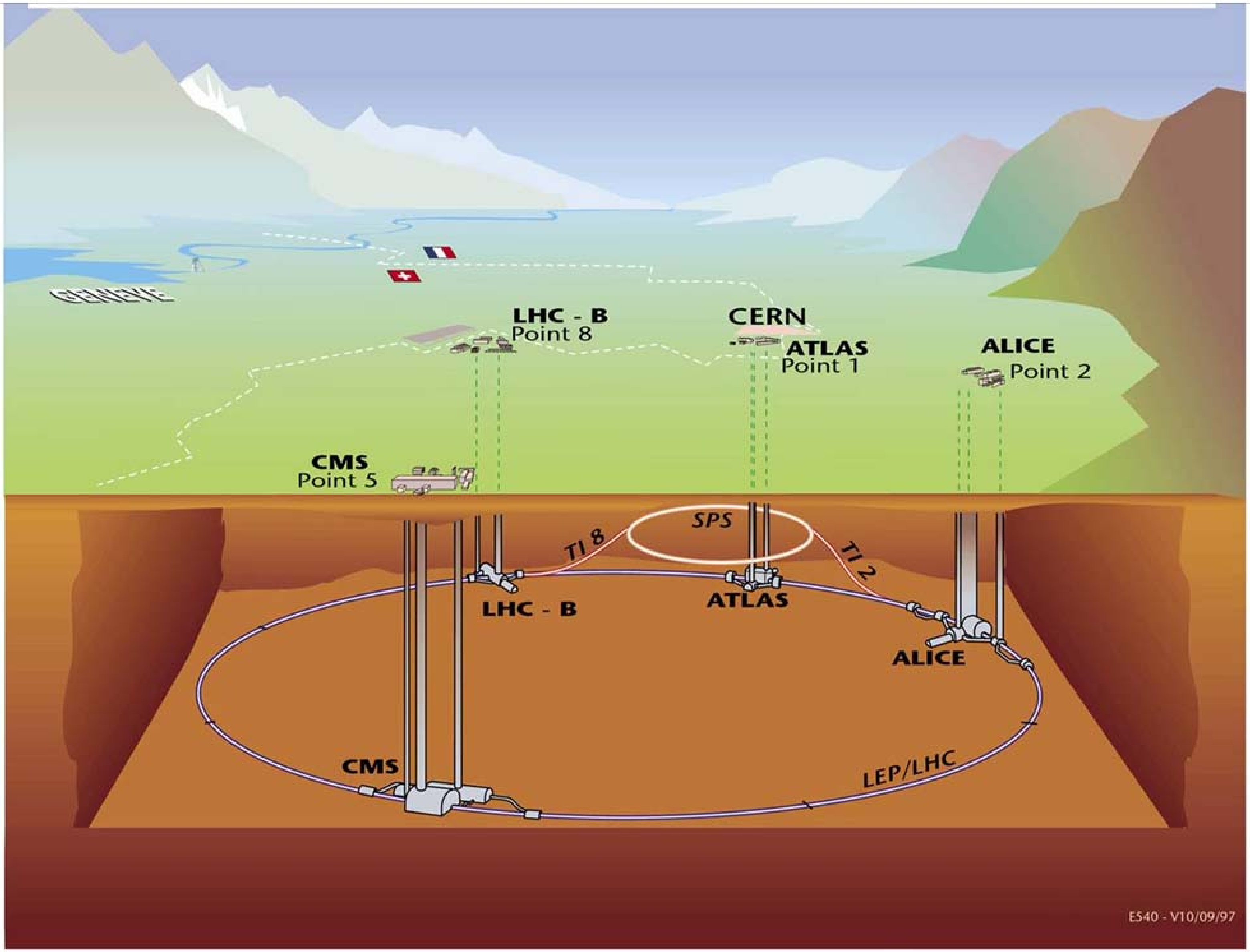
=> NbTi at 1.8K (Superfluid Helium)



Field reproducibility/precision ~ 10^{-3}

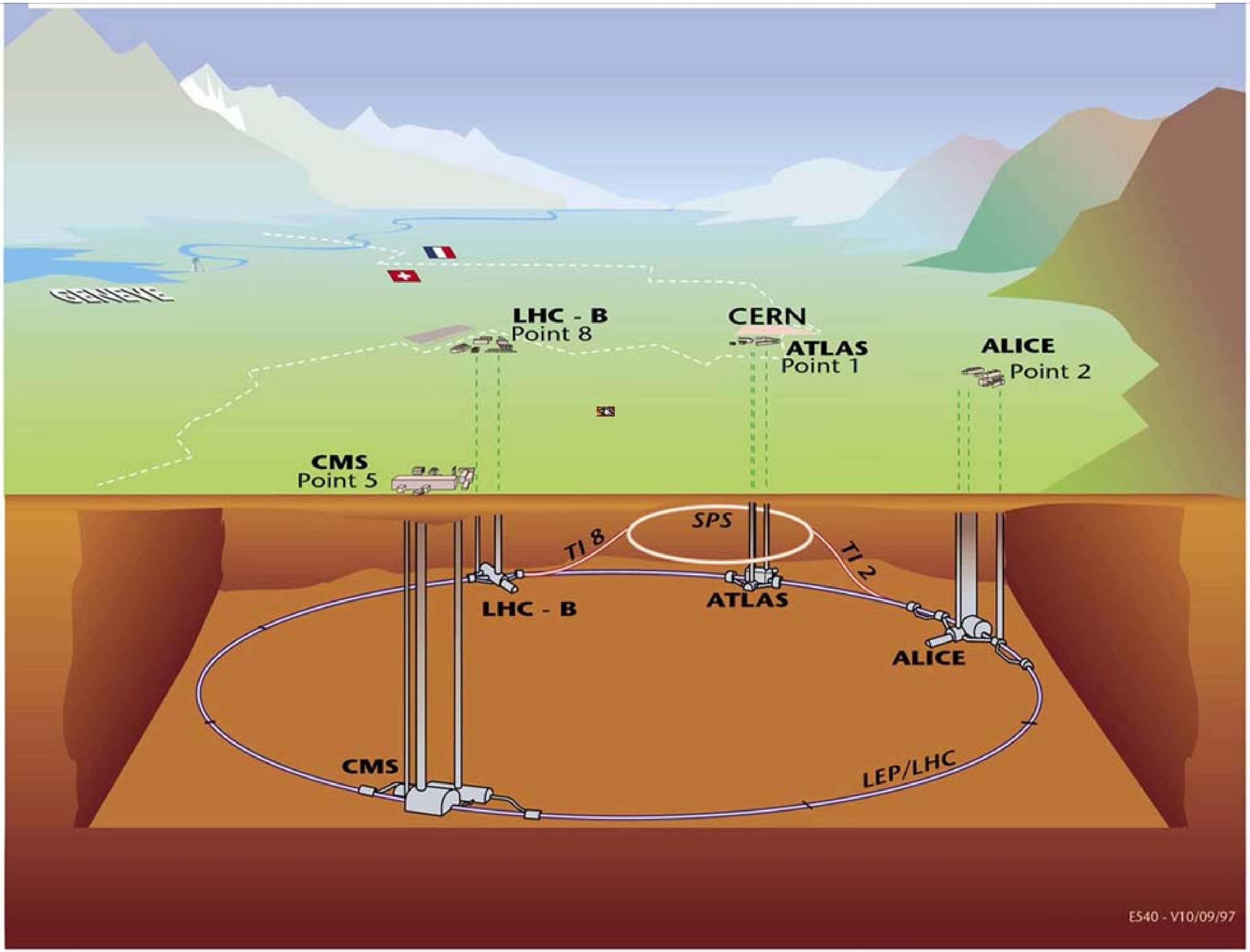
Field homogeneity ~ 10^{-4}

Overall layout of LHC



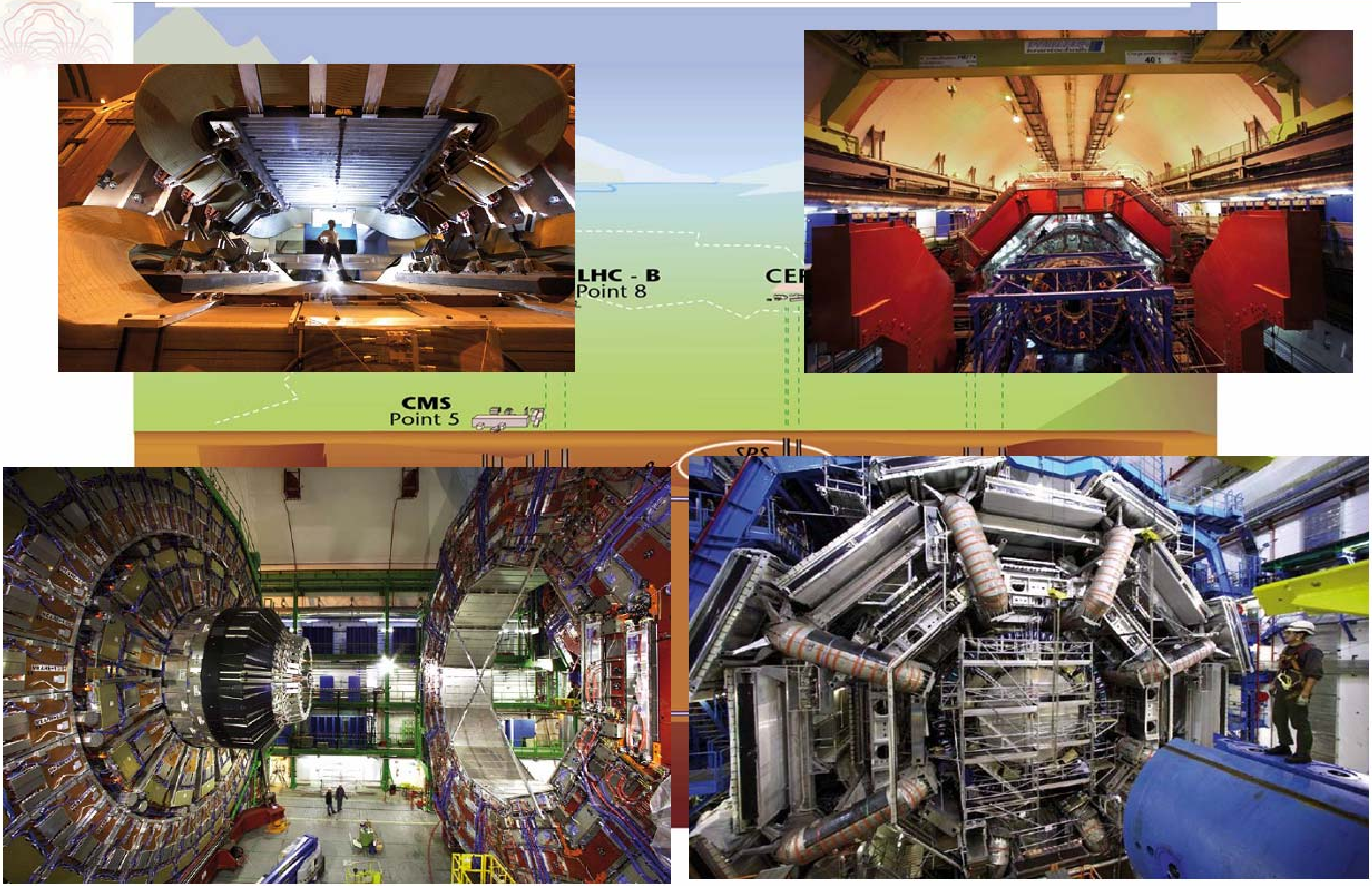
Detectors installed and powered…

will be ready for beam beginning of August 2008



Detectors installed and powered…

will be ready for beam beginning of August 2008



LHC progress 2002-2008

Tunnel activity determined by

LEP

2002	2003	2004	2005	2006	2007	2008

Dismantling

LHC progress 2002-2008

Tunnel activity determined by

LEP

QRL installation and repair
(geometry, weld quality, procedures, leaks, support tables,…)

2002	2003	2004	2005	2006	2007	2008

LHC progress 2002-2008

Tunnel activity determined by

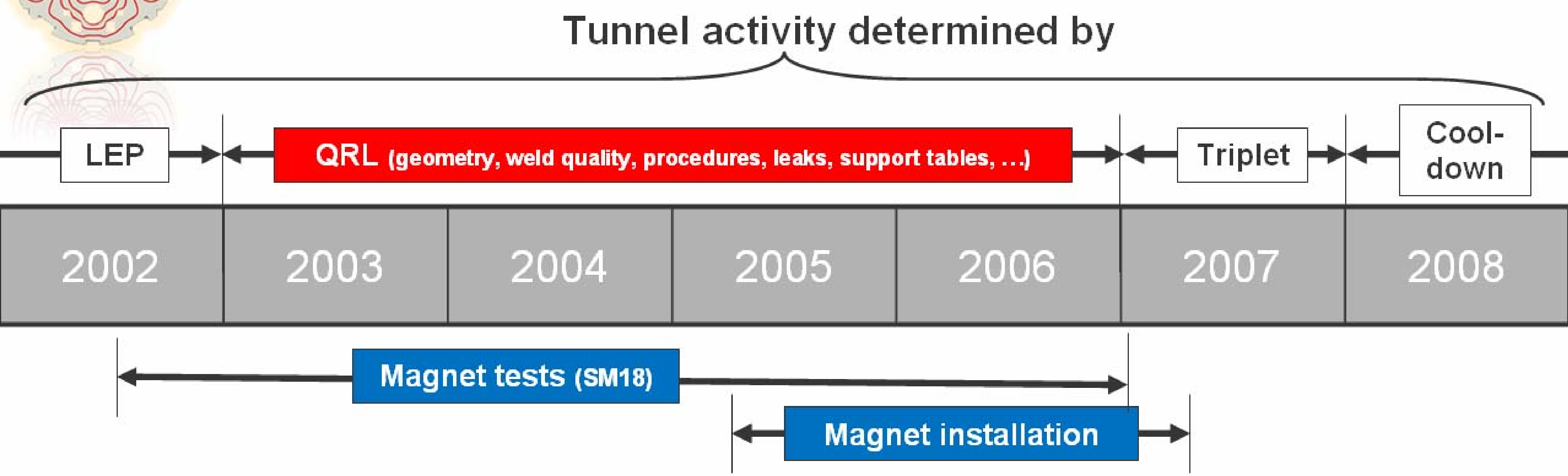
LEP → ← QRL (geometry, weld quality, procedures, leaks, support tables, …) →

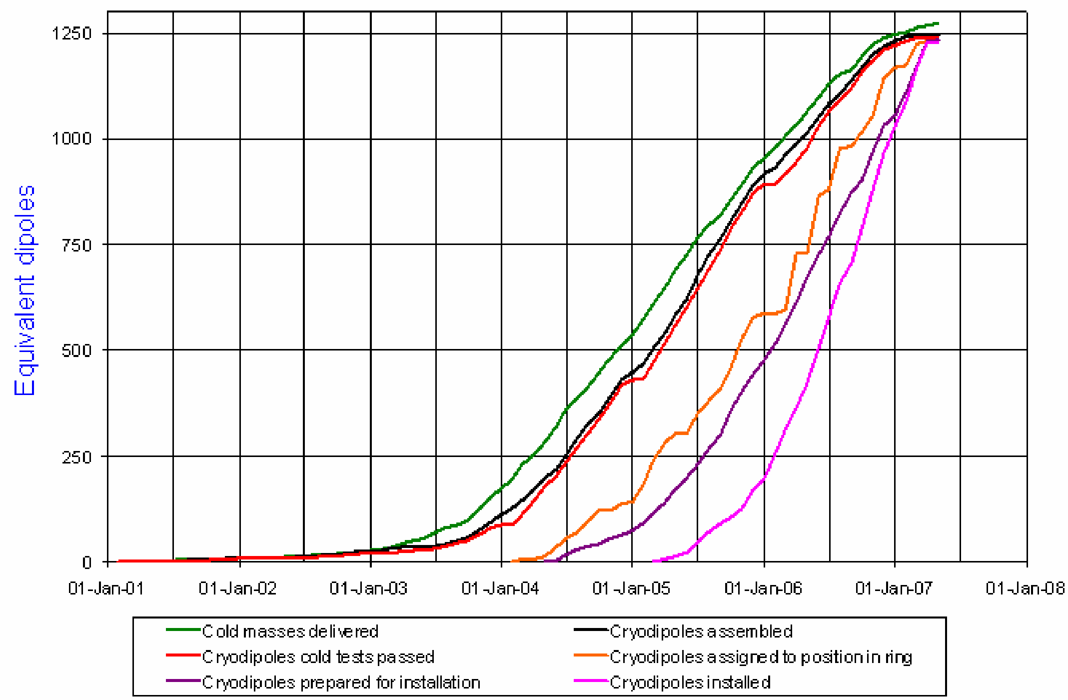
2002	2003	2004	2005	2006	2007	2008

← **Magnet tests (SM18)** →

Completion of magnet cryostating & tests, 1 March 2007

LHC progress 2002-2008





Fk. Bordry , Status of the LHC – 23th June 2008

LHC progress 2002-2008

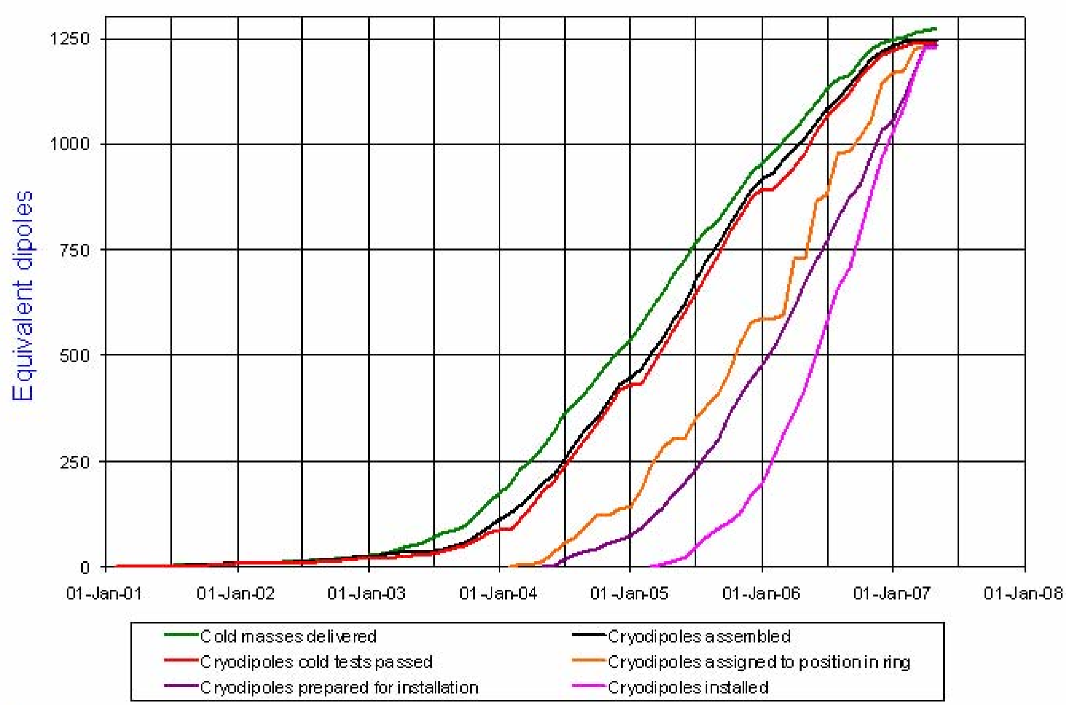
Tunnel activity determined by

LEP	QRL (geometry, weld quality, procedures, leaks, support tables, …)				Triplet	Cool-down
2002	2003	2004	2005	2006	2007	2008

Magnet tests (SM18)

Magnet installation

Required magnet storage ☹



LHC progress 2002-2008

Tunnel activity determined by

LEP | QRL (geometry, weld quality, procedures, leaks, support tables, …) | Triplet | Cool-down

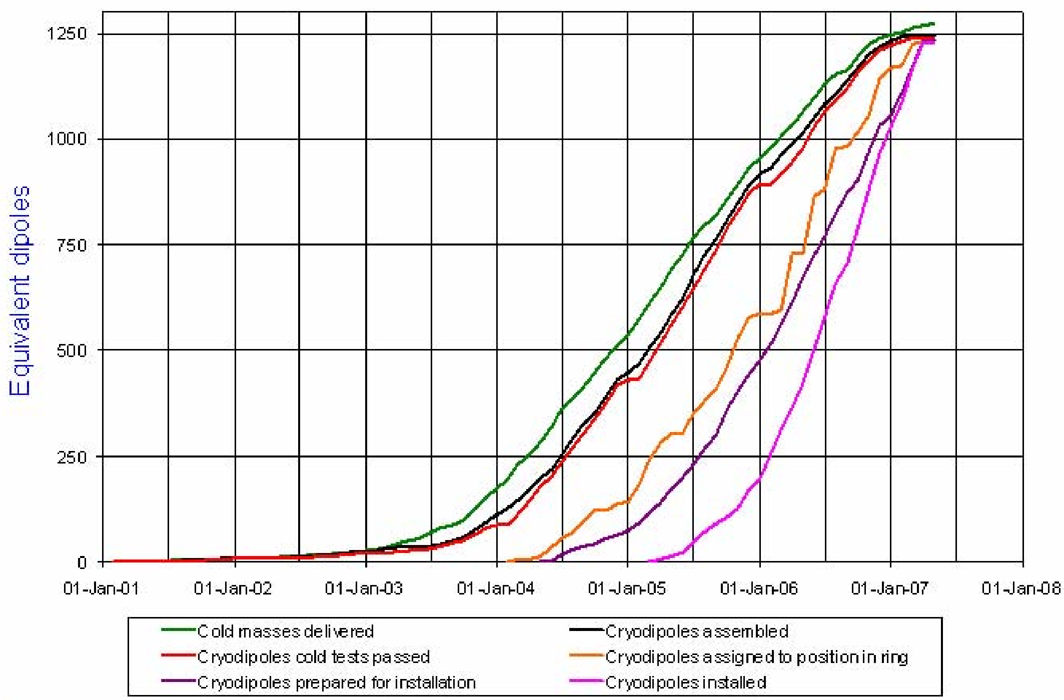
2002	2003	2004	2005	2006	2007	2008

Magnet tests (SM18)

Magnet installation

Required magnet storage ☹

Allowed magnet sorting ☺



LHC progress 2002-2008

Tunnel activity determined by

LEP

QRL (geometry, weld quality, procedures, leaks, support tables, …)

2002	2003	2004	2005	2006	2007	2008

Magnet tests SM18

Magnet installation

Magnet interconnects

Descent of the last magnet 26-04-2007

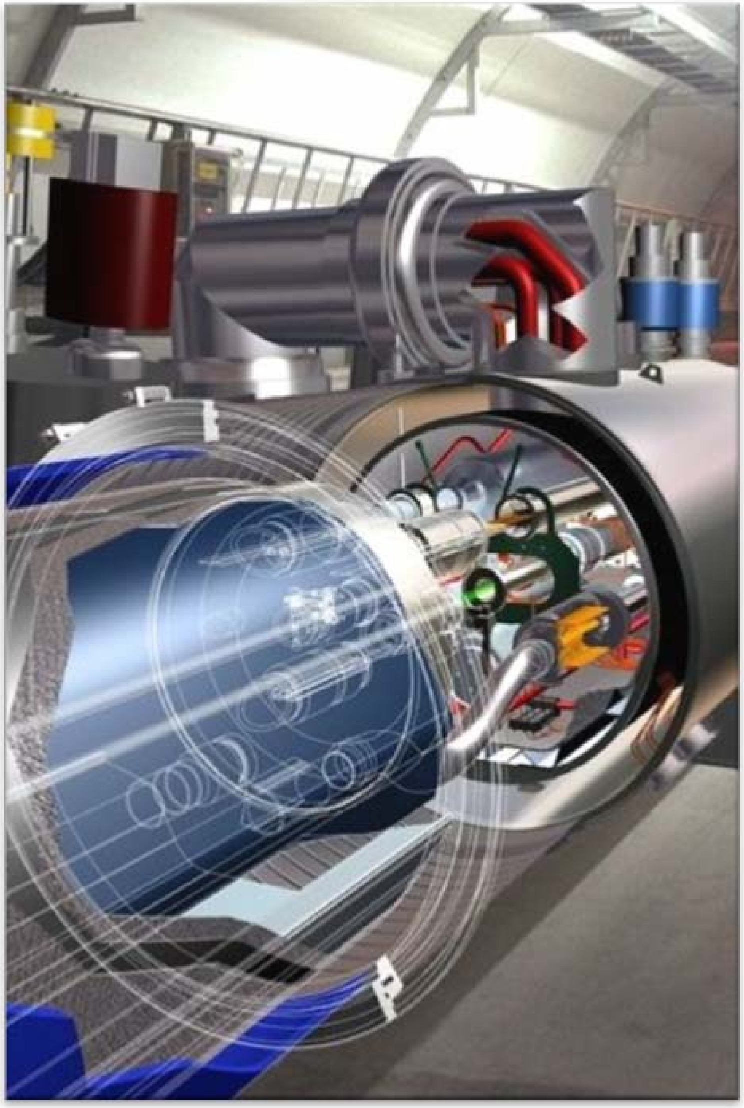
Interconnections : giant work (QA)

Interconnections the superconducting magnets of LHC means:

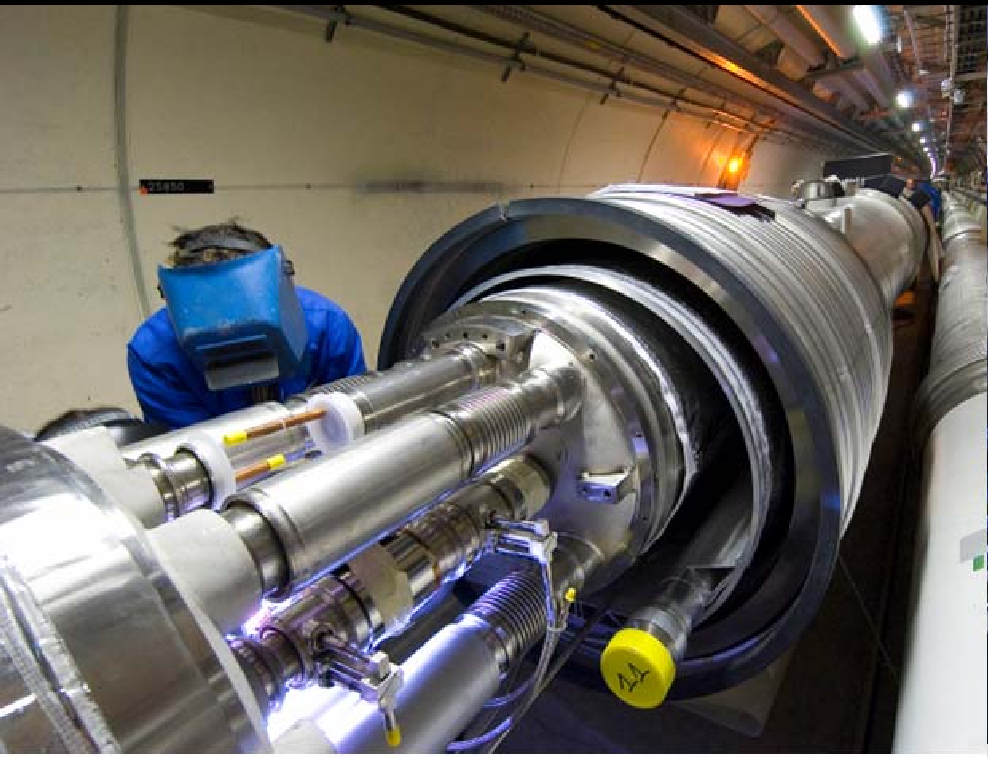
- 1695 magnet-to-magnet interconnects
- 224 magnet to QRL interconnects

Each magnet to magnet interconnect consists of:

- ✓ 18 assembly actions divided in 9 interventions
- ✓ 5 leak tightness check
- ✓ 5 electrical tests
- ✓ 1 RF test



For each sector this is:
1964 assembly interventions
226 electrical tests on sub-assemblies
70 vacuum tests on sub-assemblies
14 RF test on sub-assemblies



7th November 2007
last interconnection

30th of april 2008

All the LHC interconnections are closed at the same time for the first time !

Courtesy J-P Tock

LHC progress 2002-2008

Tunnel activity determined by

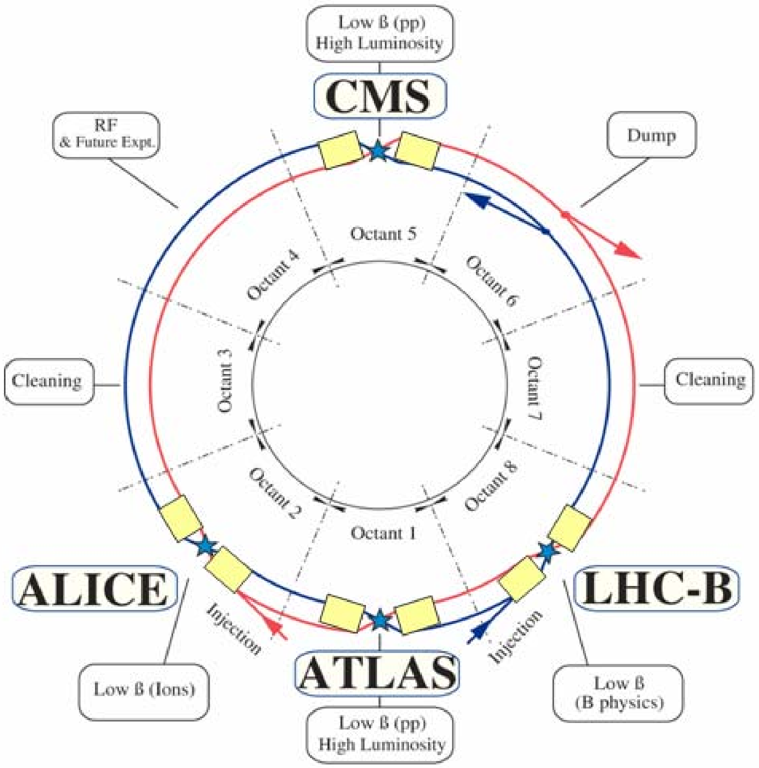
LEP → | ← QRL (geometry, weld quality, procedures, leaks, support tables, …) → | ←→

2002	2003	2004	2005	2006	2007	2008

← **Magnet tests SM18** →

← **Magnet installation** →

← **Magnet interconnects** →



Fk. Bordry , Status of the LHC – 23th June 2008

Problems: Inner Triplet

Pressure test failed in Sector 7-8 (Nov 2006).
The heat exchanger did not withstand the differential pressure of 9 bar.

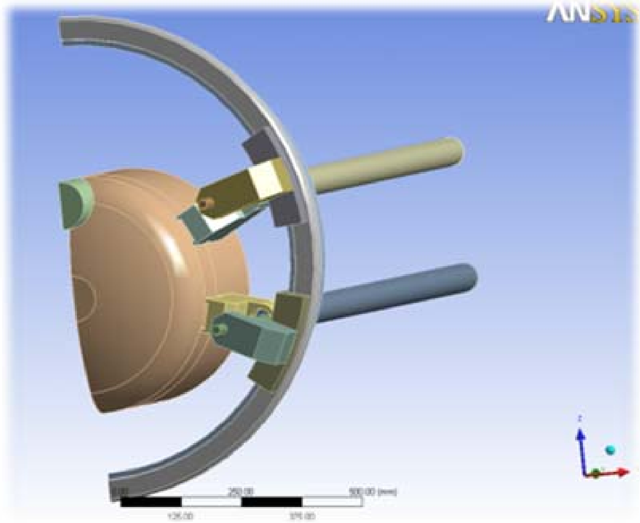
After the repair of the first heat exchanger, pressure test failed in Sector 4-5 (March 2007).
Axial movement of the Q1 cold mass due to the thrust force (12 t at 20 bar), which led to the breaking of the support system and rupture of the bellows between the first two quadrupoles.

Courtesy R.Ostojic

Solutions: Inner Triplet

Redesign of the heat exchanger: new Cu tubes with larger buckling pressure, and new bi-metallic transitions in the ends.

Redesign of the support system based on four invar/StSt cartridges that react the longitudinal forces and retain the fixed point of the cold mass in its original position.
The consolidation of all inner triplets was completed by September 2007.



Courtesy R.Ostojic

Solutions: Inner Triplet

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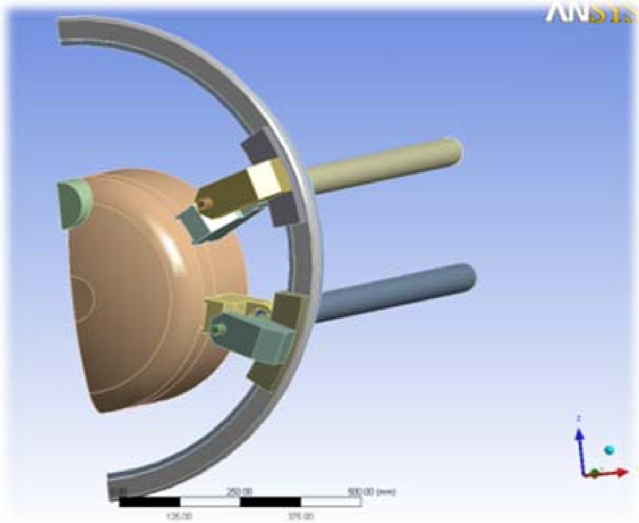
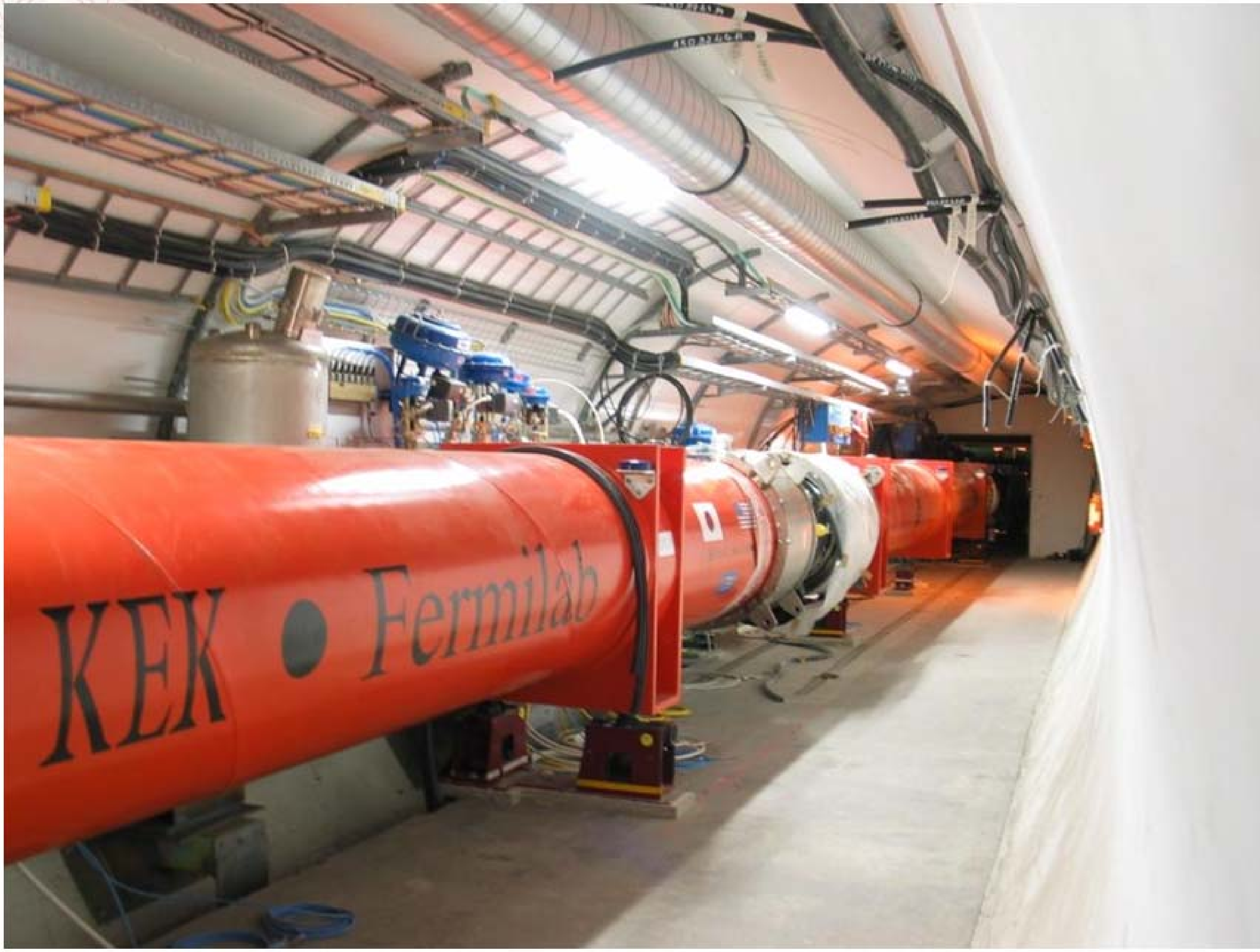


based on four Invar/StSt cartridges that react the longitudinal forces and retain the fixed point of the cold mass in its original position.
The consolidation of all inner triplets was completed by September 2007.

Courtesy R.Ostojic

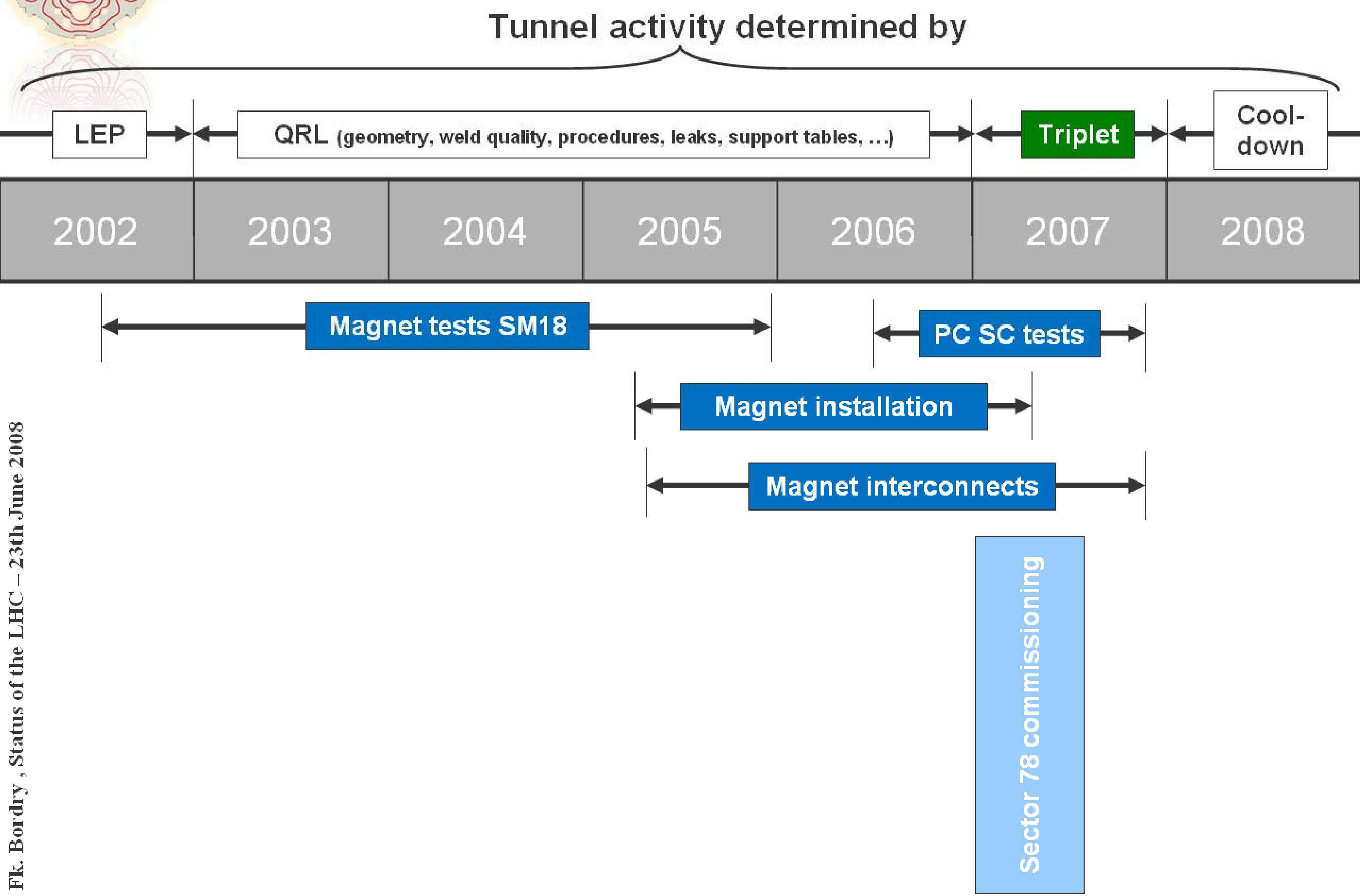
Low-β triplet in CMS ready for powering



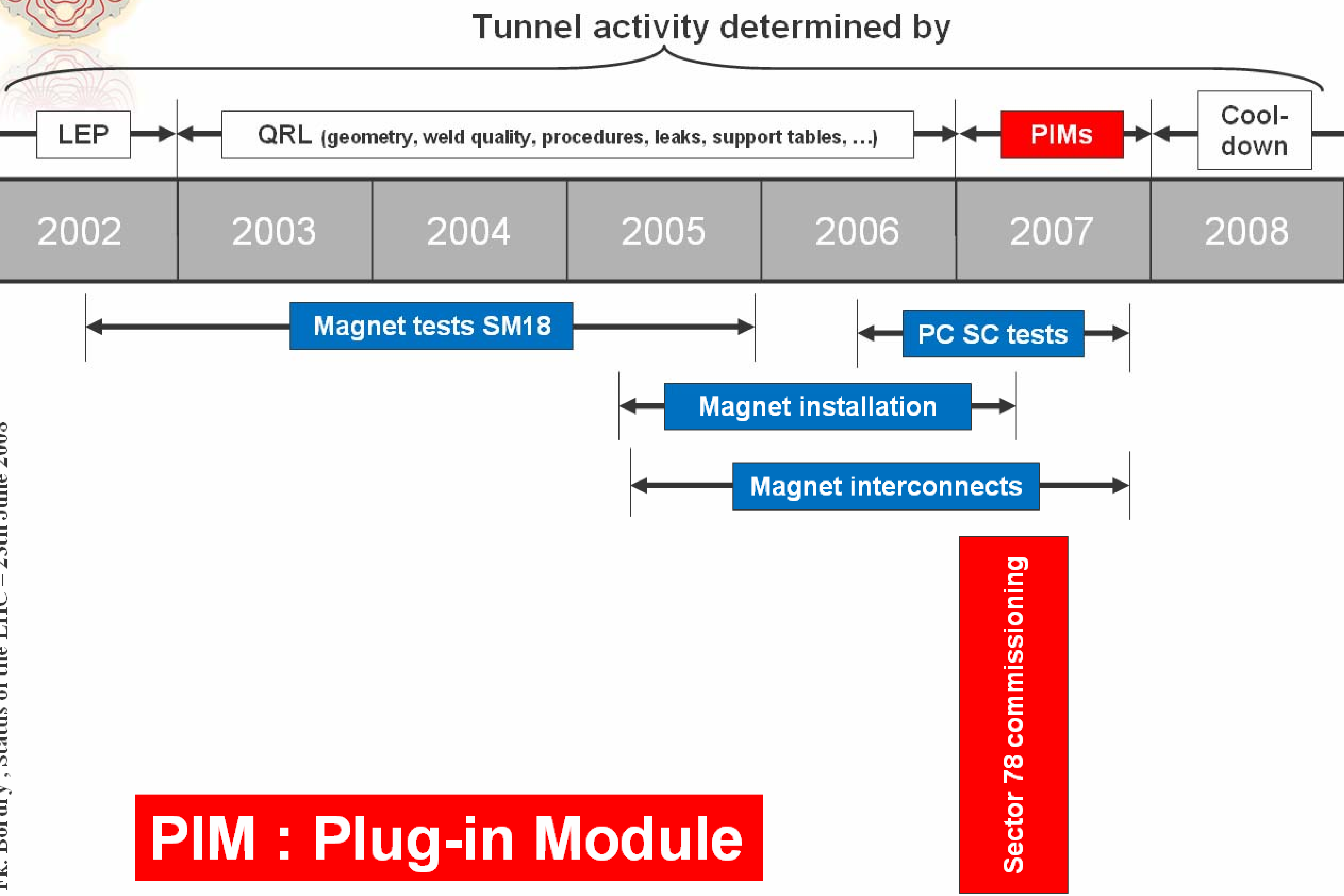
Low-β triplet in CMS ready for powering

Low-β triplet in CMS ready for powering

LHC progress 2002-2008

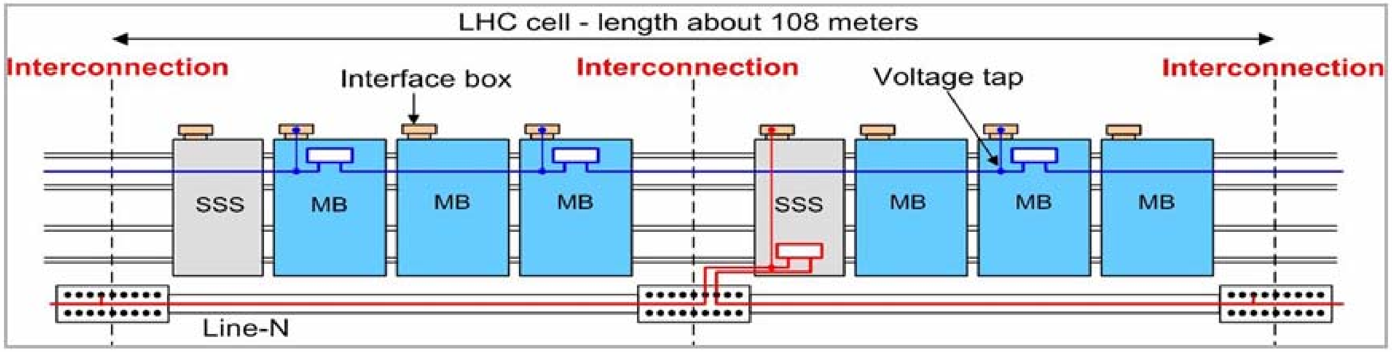


LHC progress 2002-2008



PIM : Plug-in Module

RF bellows in the 1700 interconnections

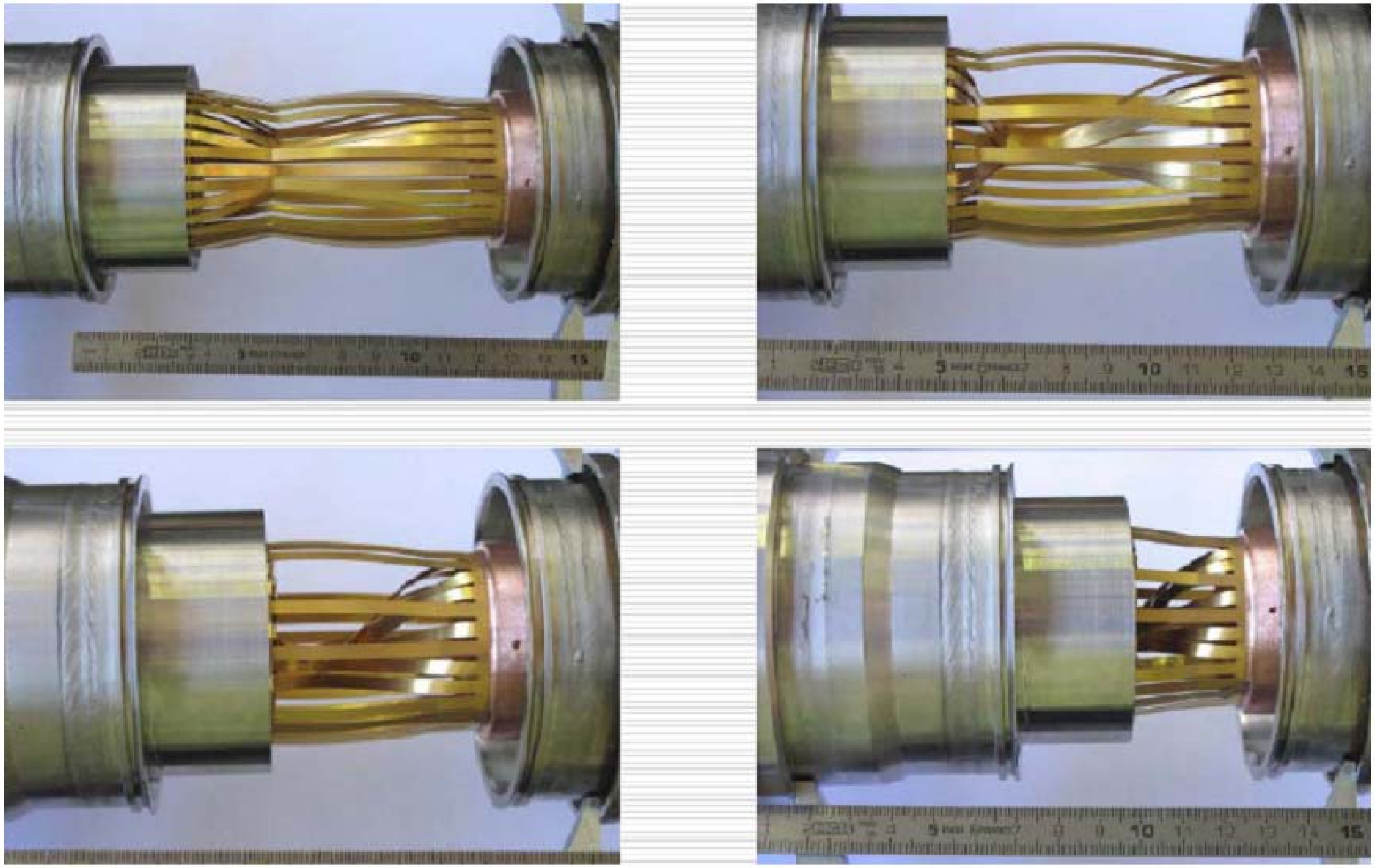


Arc plug-in module at working temperature

Arc plug-in module at warm temperature

Failure Simulation on Test Bench

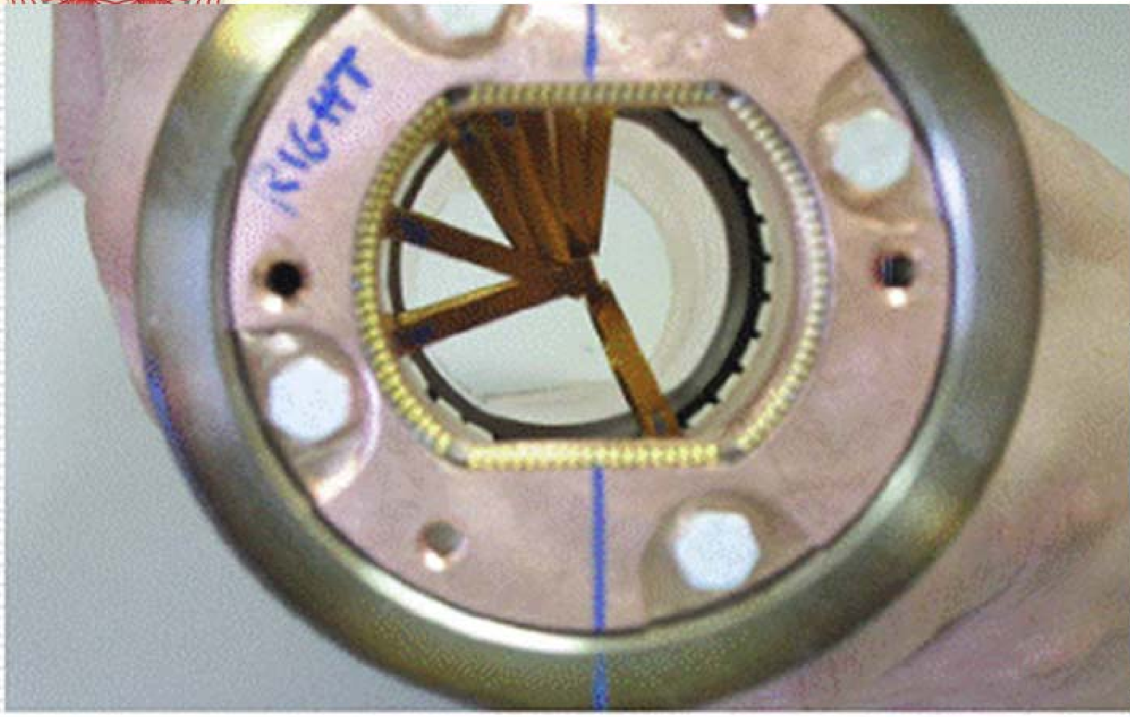
Cold



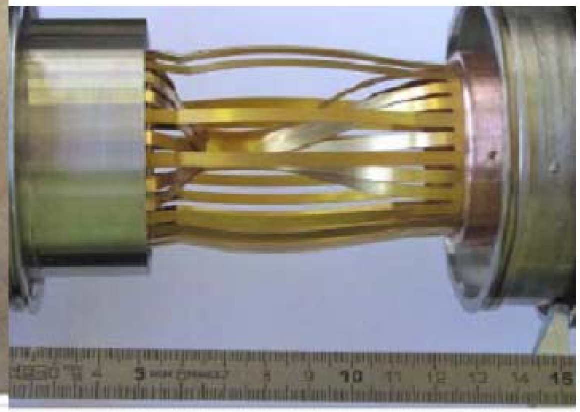
Warm

Non-conforming contacts, simulating warm-up from cold

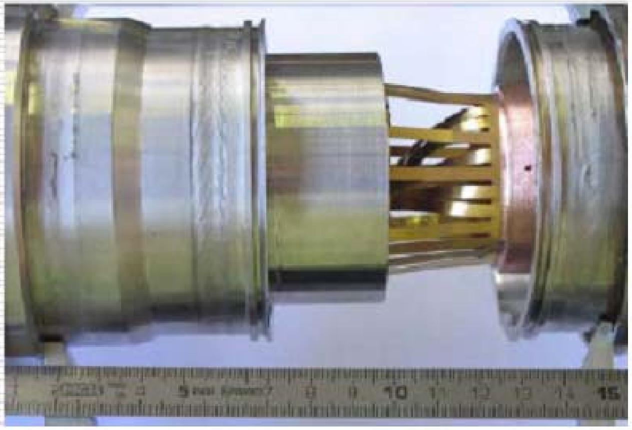
Failure Simulation on Test Bench



Not optimal conditions for the beam !

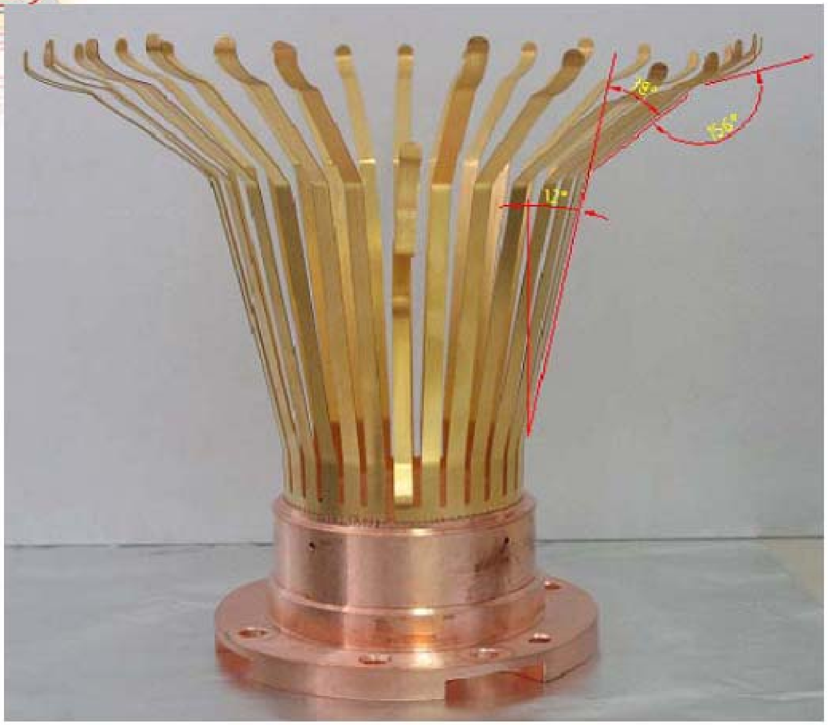


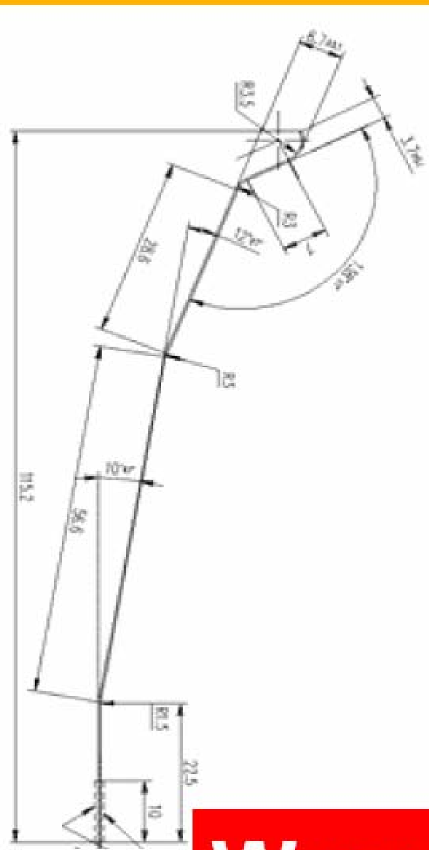
Warm



Non-conforming contacts, simulating warm-up from cold

Out of tolerances bending angles of the RF fingers



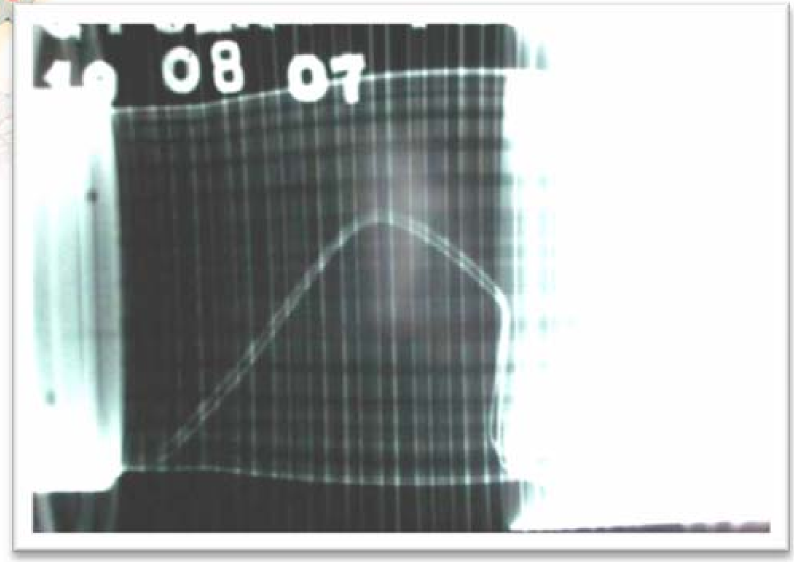


Widespread non-confirmities of this type have been seen in non-installed PIMs

Easy to repair but how to detect ?

Wrong **Right**

Problems: plug-in modules – the solution



16 PIM with buckled fingers of which 9 where unexpected.
In total 28 PIM were replaced.
The interconnects of the whole sector were X-rayed

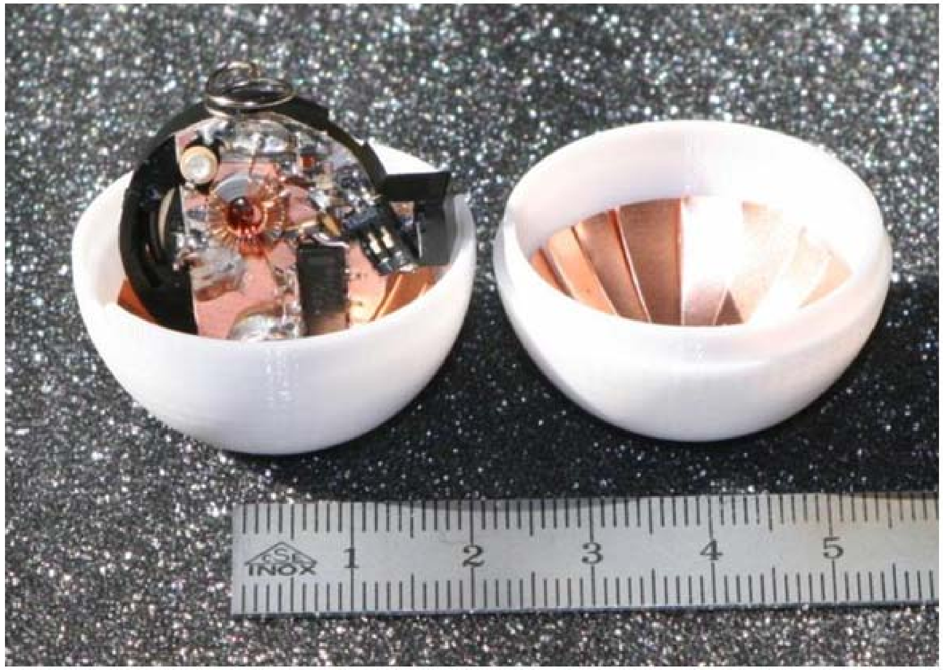
A ball is sucked in at one end of the sector :

- **34mm exterior, 30mm interior**
- **Total weight ~15 g (ball 8g)**

RF characteristics

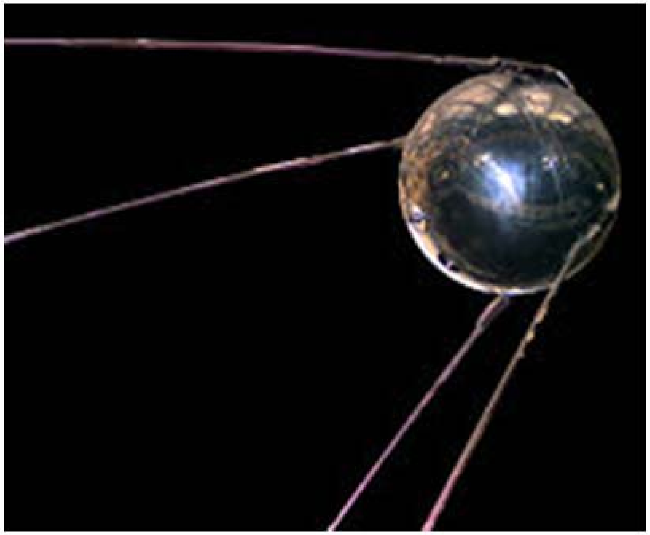
- **40MHz resonant circuit**
- **Generates 20V between copper electrodes**
- **Battery powered Over 2hr lifetime**

-BPM trigger threshold at ~3mV



Good opportunity to test BPM with a large particule !

A nod to history…



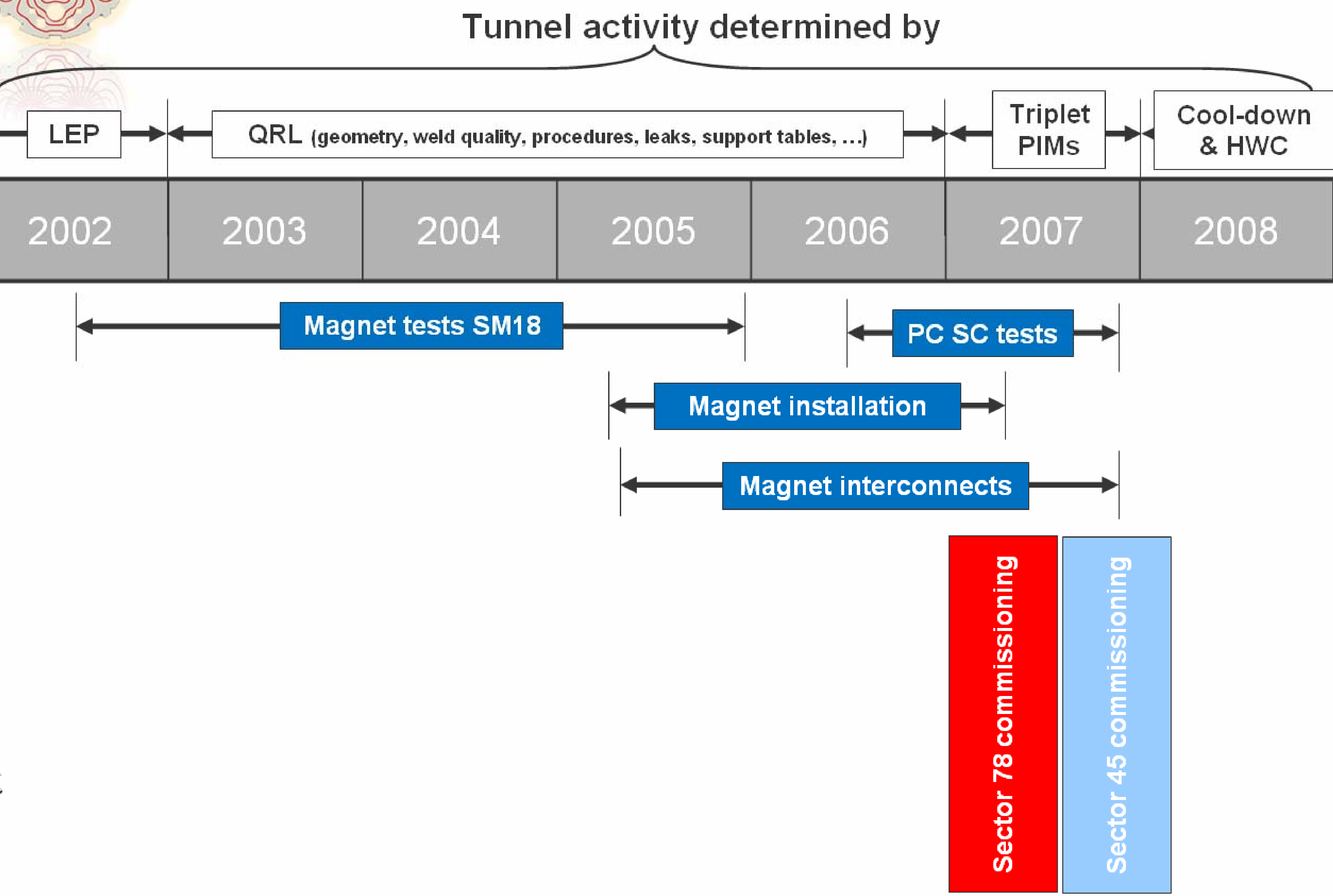
4th October 2007

Sputnik and The Dawn of the Space Age

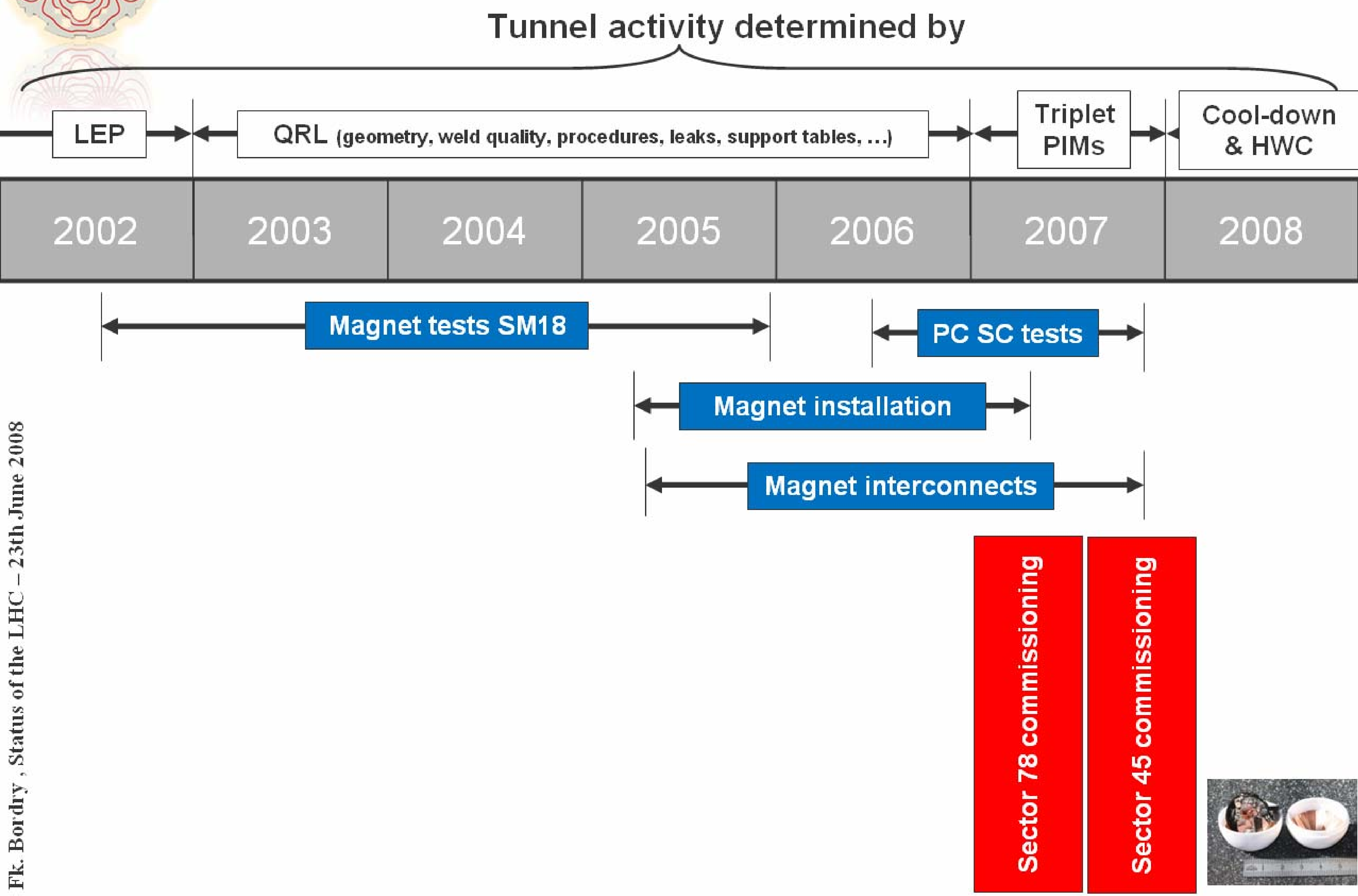
History changed on October 4, 1957, when the Soviet Union successfully launched Sputnik I. The world's first artificial satellite was about the size of a beach ball (58 cm.or in diameter), weighed only 83.6 kg and took about 98 minutes to orbit the Earth on its elliptical path.

The satellite travelled at 29,000 kilometres per hour and emitted radio signals at **40.002 MHz** which were monitored by amateur radio operators throughout the world.

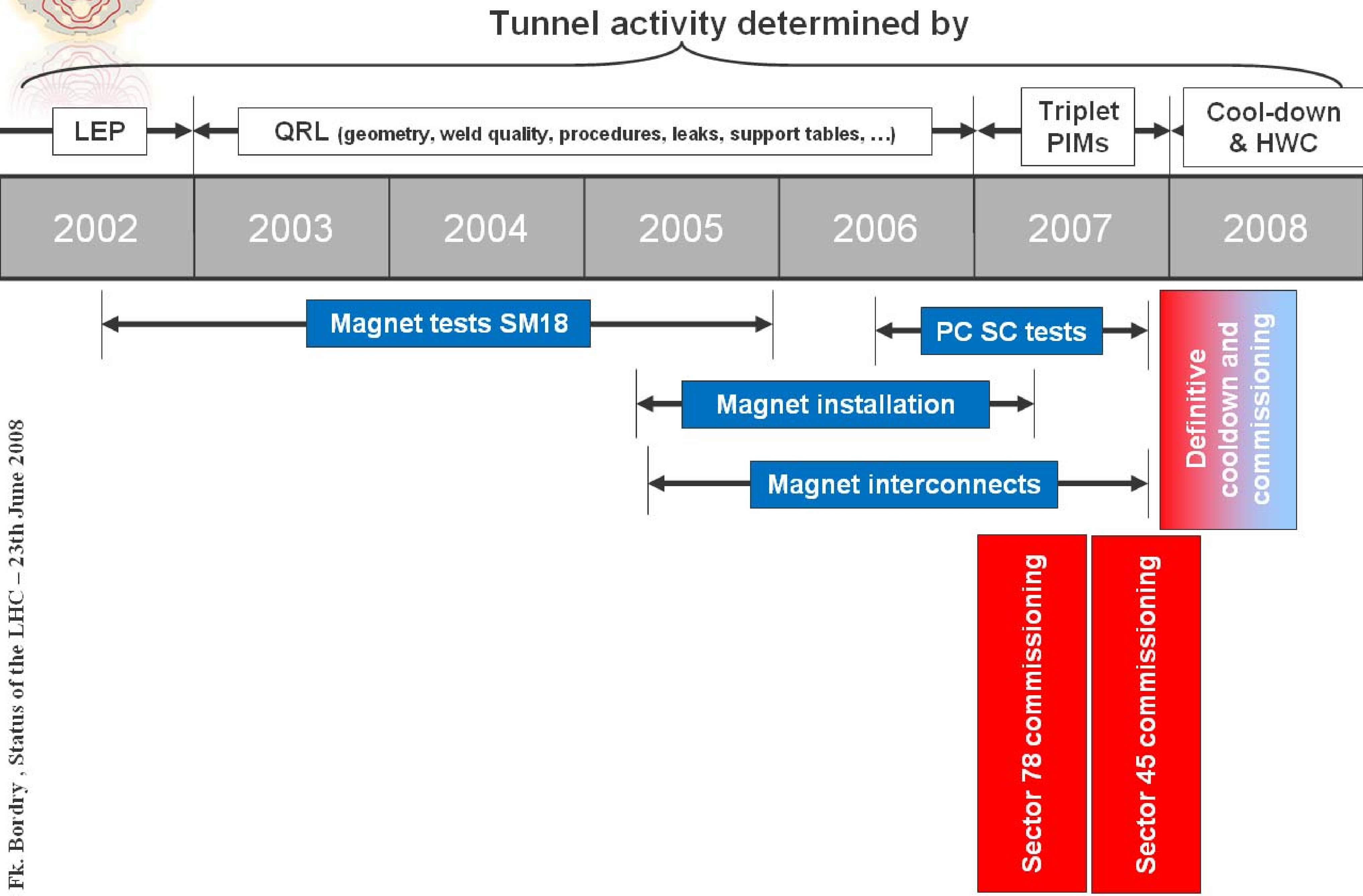
LHC progress 2002-2008



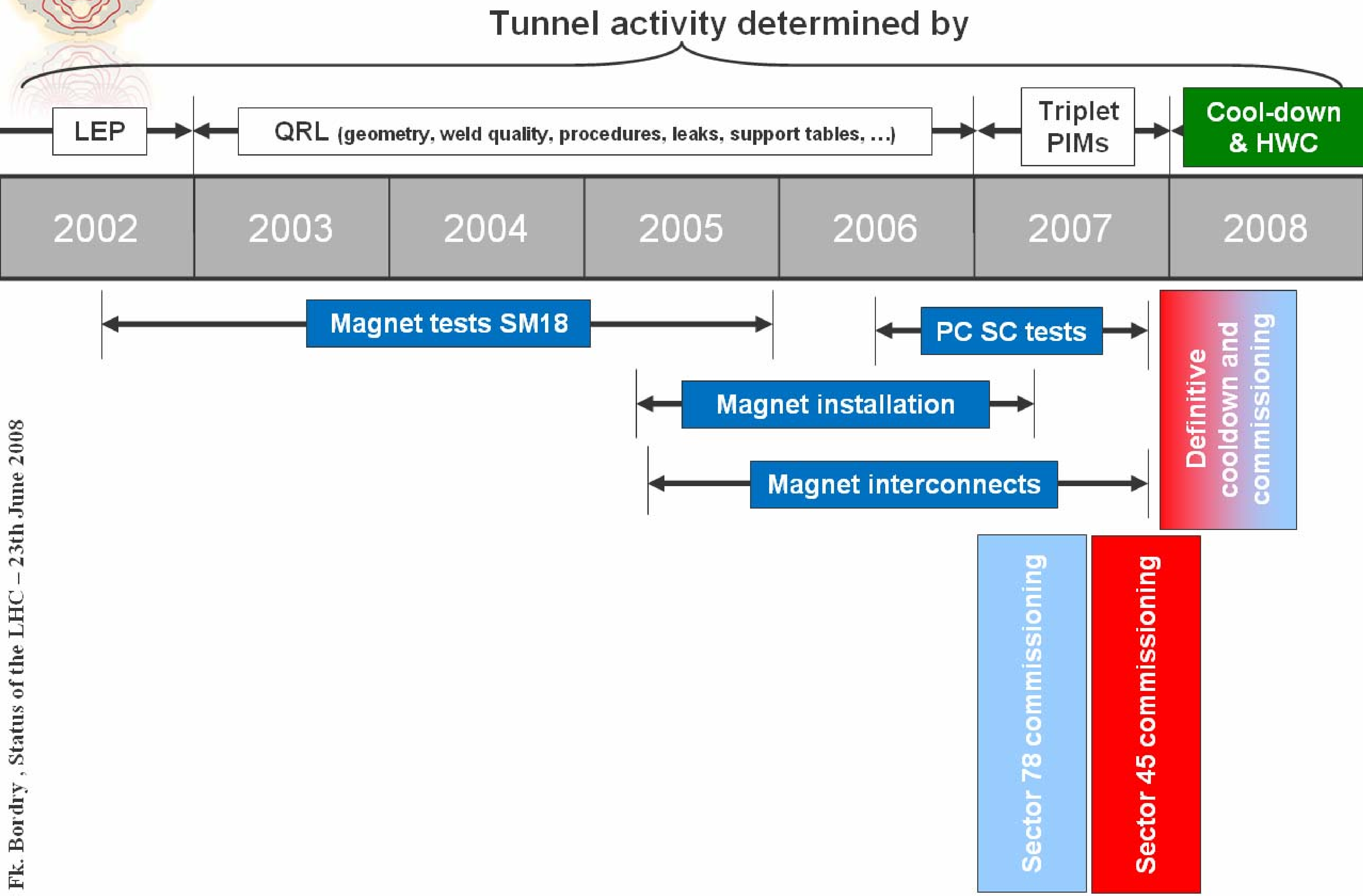
LHC progress 2002-2008



LHC progress 2002-2008



LHC progress 2002-2008



LHC progress 2002-2008

Tunnel acti

LHC is not all plain sailing
Think BEAM !!!

LEP

QRL (geometry, weld quality, proc

& HWC

006 | 2007 | 2008

PC SC tests

allation

interconnects

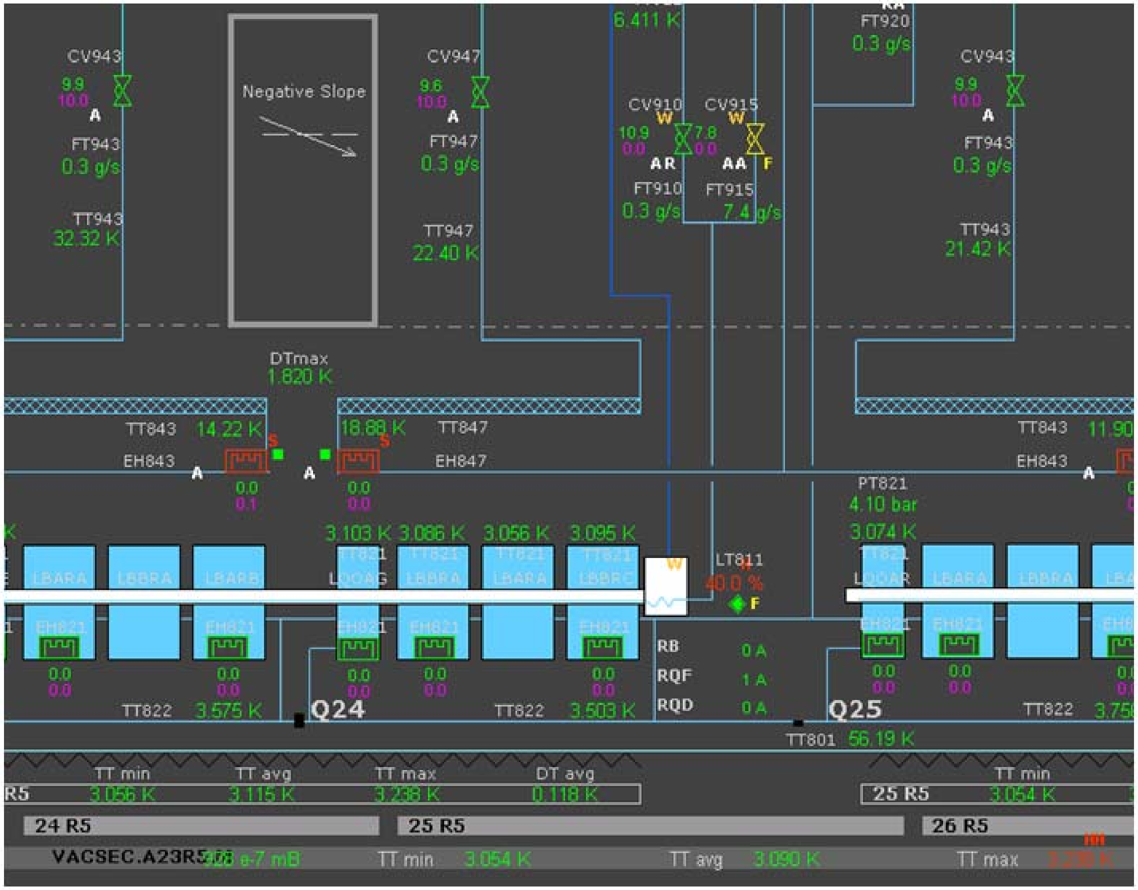
Definitive cooldown and commissioning

Sector 78 commissioning

Sector 45 commissioning

Cryogenics system commissioning

Cryogenic plants of unprecedented capacity (18 kW at 4.5 K) and including main components at the frontier of today's technology (cold compressors for the 1.8 K refrigeration unit)



- Full scale validation of cooling scheme (cool down and warm ups, quench recovery, redundancy)
- Cryogenic circuit integrity
- DFB & CL
- Instrumentation
- Leak tightness
- Insulation vacuum
- Commissioning of the complete cryogenic system

Huge number of PID control loops per sector !

Cryogenics: the learning curve

- Time for getting nominal conditions:
  - Presently 10 to 6 weeks for getting nominal conditions,
  - In routine operation, about 1 month is foreseen,

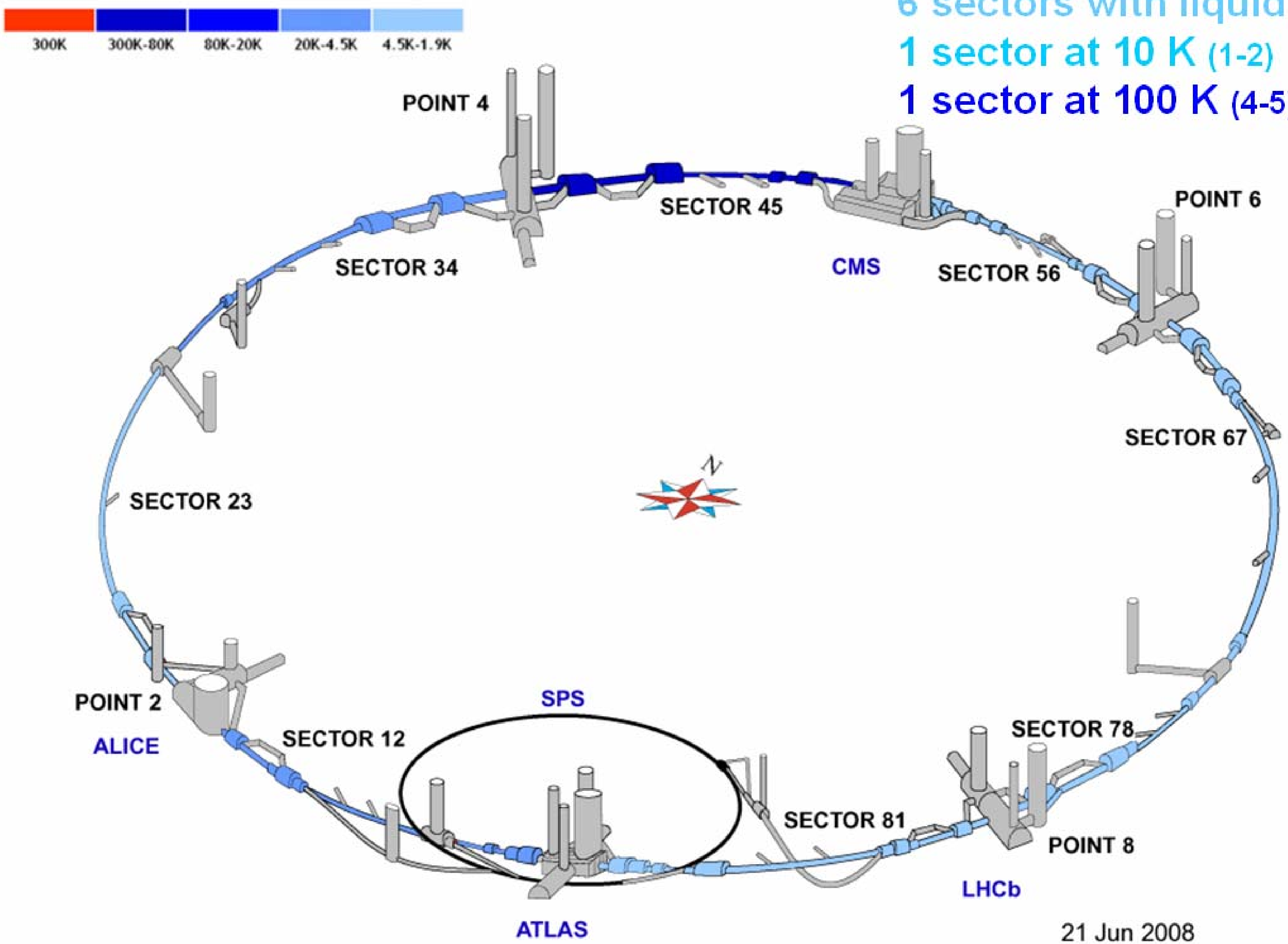
	CW1	CW2	CW3	CW4	CW5	CW6	CW7	CW8	CW9	CW10
Today for HWC	Purge & leak test	Flushing		Cool-down 300-5 K					Filling, CD 1.9 K & cryo-tuning	
Nominal after a routine shutdown	Pur-ge	Cool-down 300-5 K		Filling, CD 1.9 K & cryo-tuning						

- LHC cryogenics is the largest, the longest and the most complex cryogenic system worldwide.
- Operation for the needs of Sector HWC is now demonstrated.
- Based on experience, together with procedures and tools being put in place, availability must be improved for the next phase: ***The Beam Commissioning.***

Courtesy L. Tavian

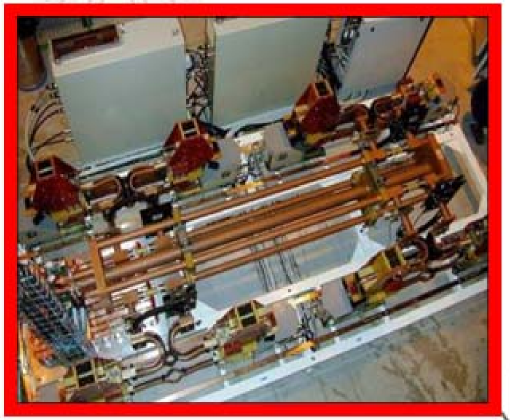
Where are we today ?

6 sectors with liquid He
1 sector at 10 K (1-2)
1 sector at 100 K (4-5)



http://hcc.web.cern.ch/hcc/field.php

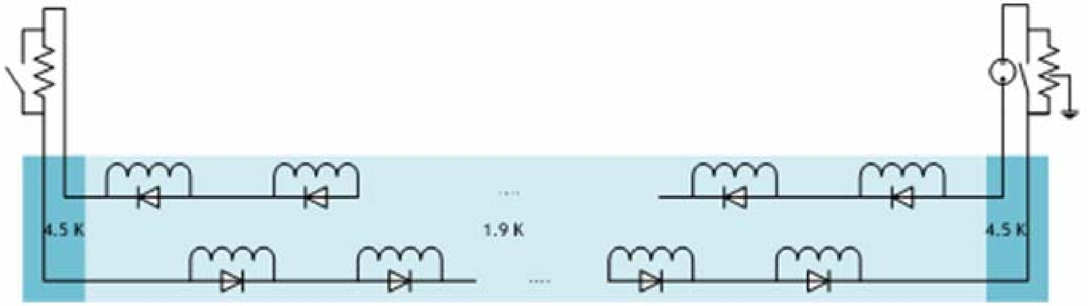
the superconducting circuits



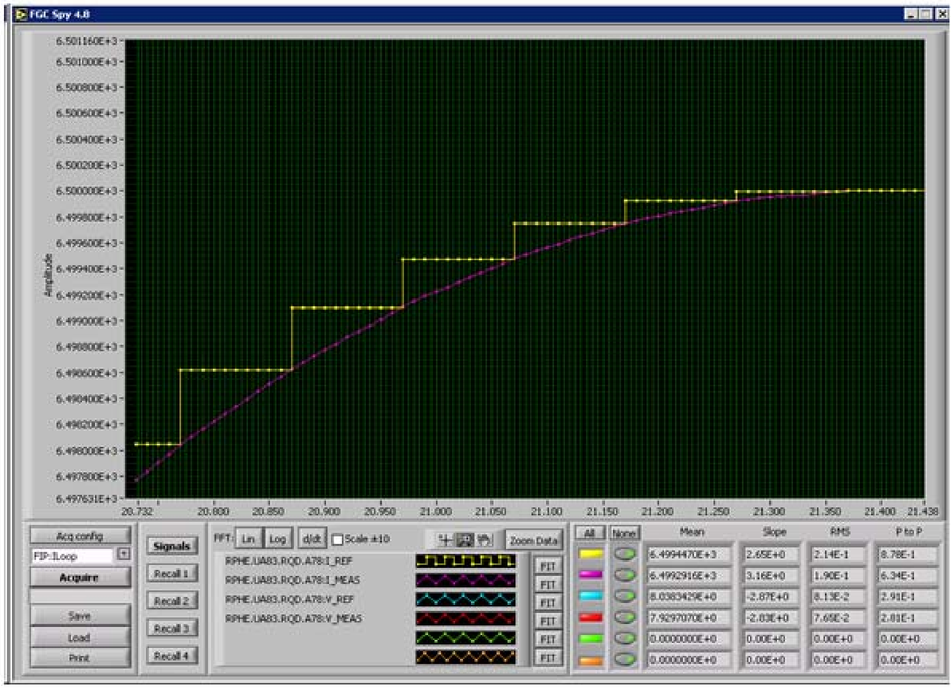
Fk. Bo

What needs to be tested for the power converters ?

~1700 circuits



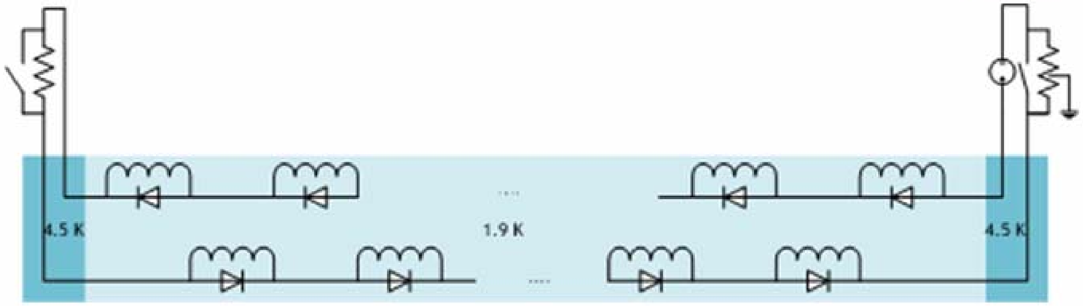
- Regulation loop (with huge time constant: up to 6h)
- Free-wheel system at nominal current with high time constant
- Compatibility with QPS at start up
- Tracking
- No lagging and no overshoot



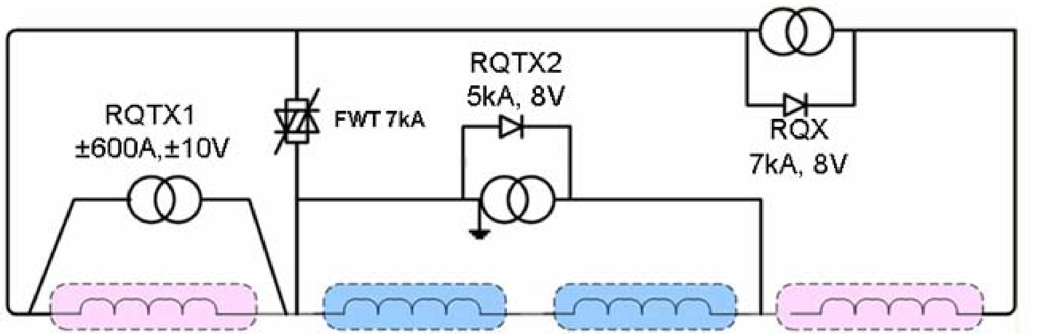
Power converters with unprecedented precision (a few ppm) over a very large dynamic range (10^4)

What needs to be tested for the power converters ?

~1700 circuits



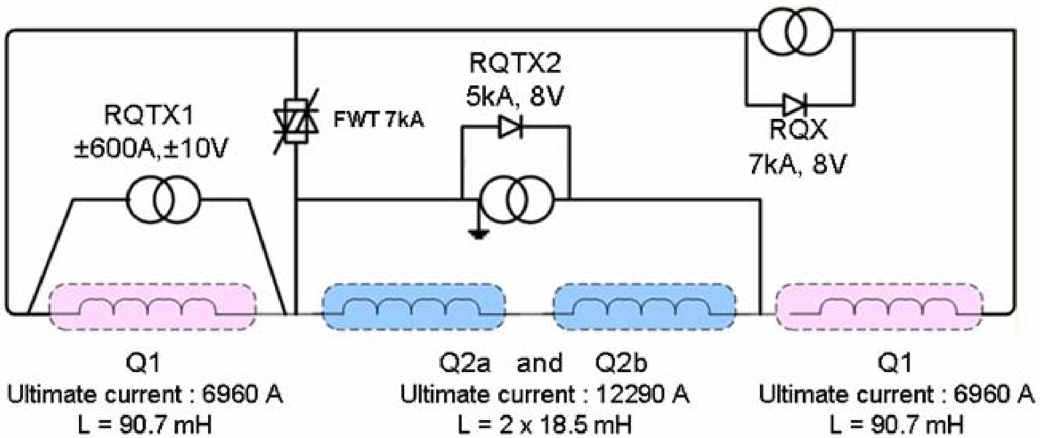
- Regulation loop (with huge time constant: up to 6h)
- Free-wheel system at nominal current with high time constant
- Compatibility with QPS at start up
- Tracking
- No lagging and no overshoot
- Inner triplet



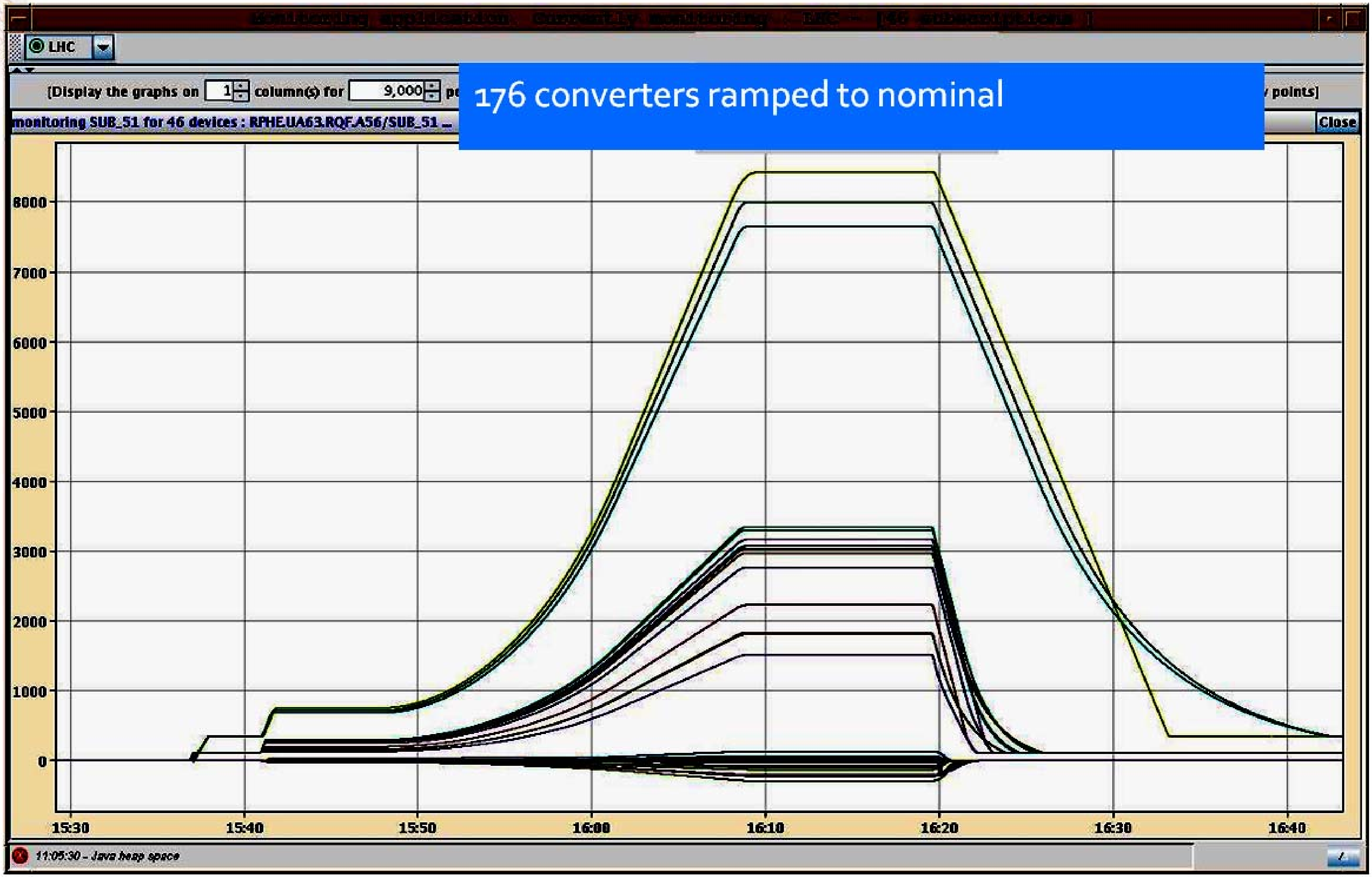
What needs to be tested for the power converters ?

~1700

- Regulation lo
  constant: up to 6
- Free-wheel s
  current with
- Compatibility
- Tracking
- No lagging a
- Inner triplet



Powering Groups of Circuits



Installation and commissioning of …

- ✓ the warm magnets
- ✓ the injection systems
- ✓ the beam dumping system
- ✓ the collimators
- ✓ the RF system
- ✓ the beam instrumentation
- ✓ the vacuum system
- ✓ the control system

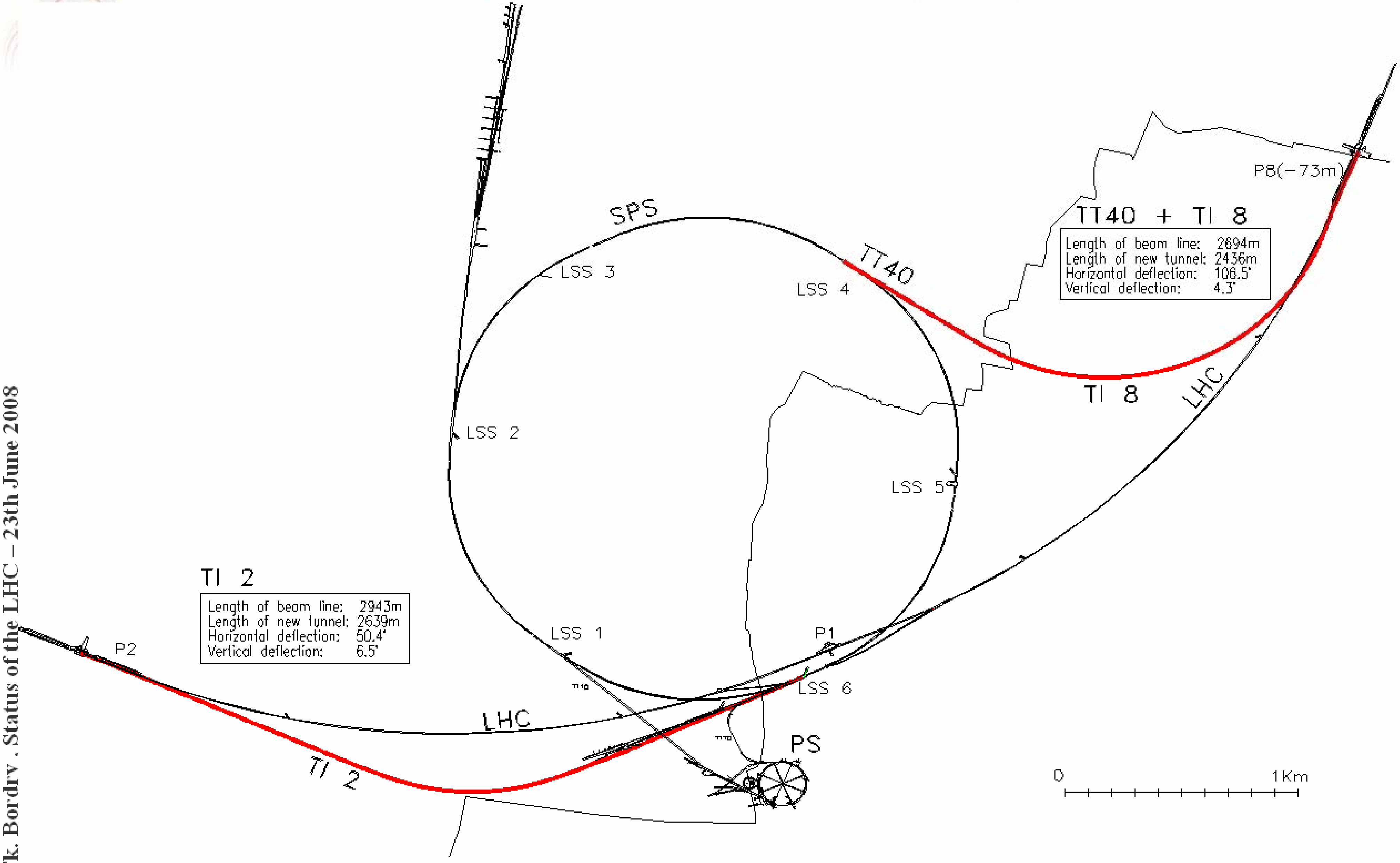
…

are vital from day 1 for beam operation

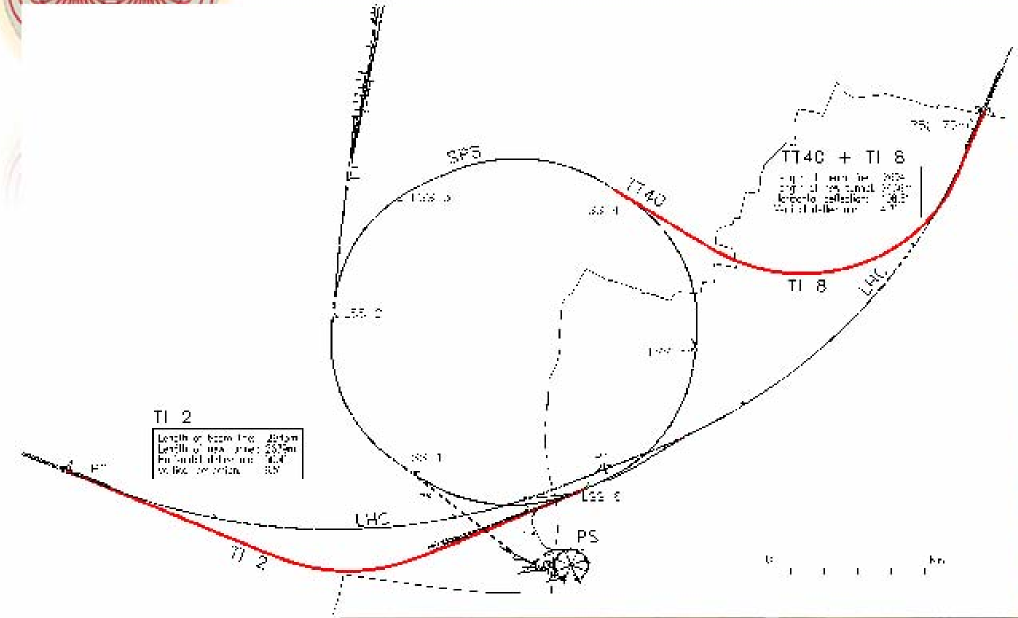
R.Saban LHC Hardware Commissioning Summary
Monday 23th June 15:30 *MOZDM01*

SPS- LHC Transfer Lines: TI8 and TI2

Combined length 5.6 km, over 700 magnets, ~ 2/3 of SPS

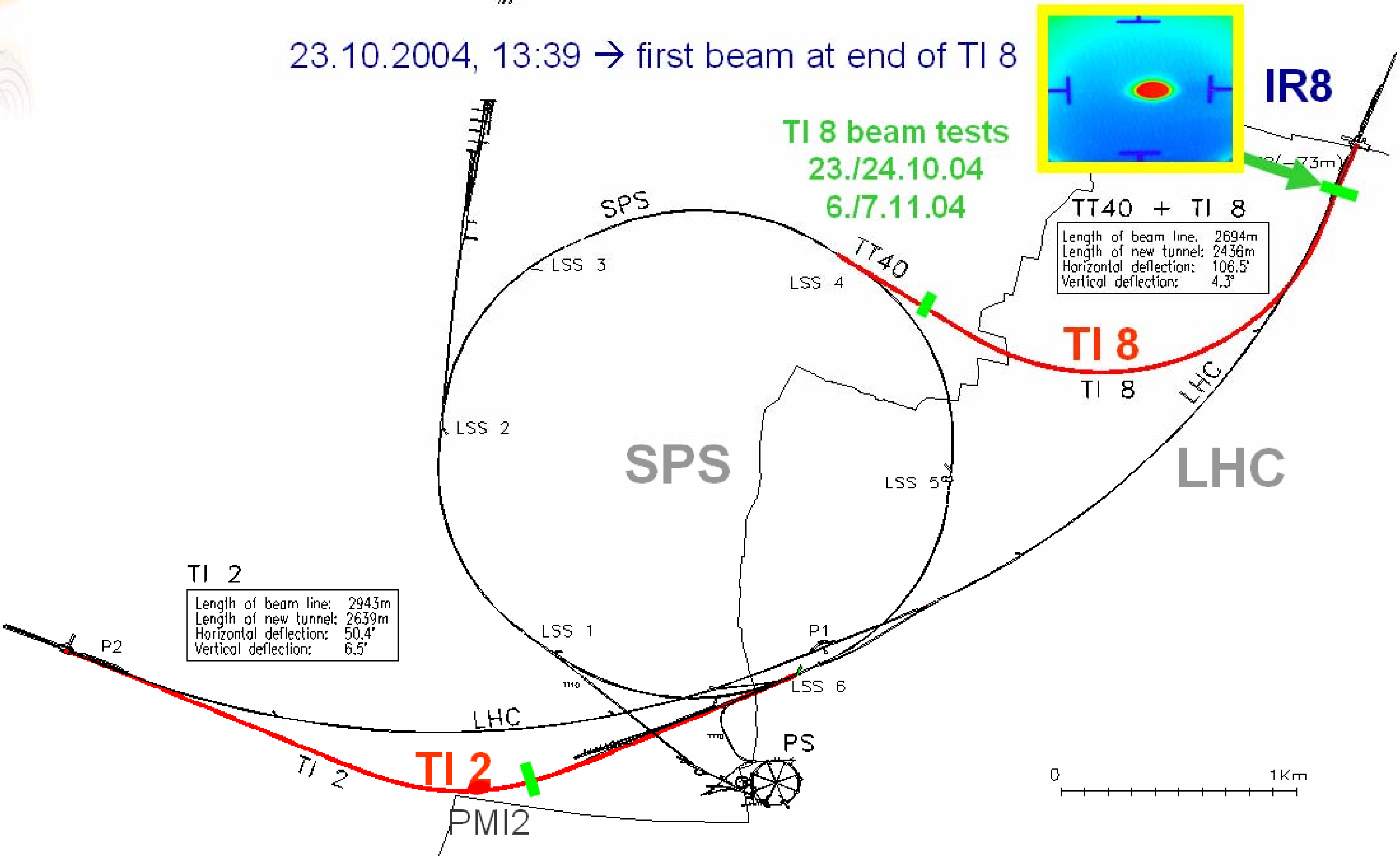


SPS- LHC Transfer Lines: TI8 and TI2

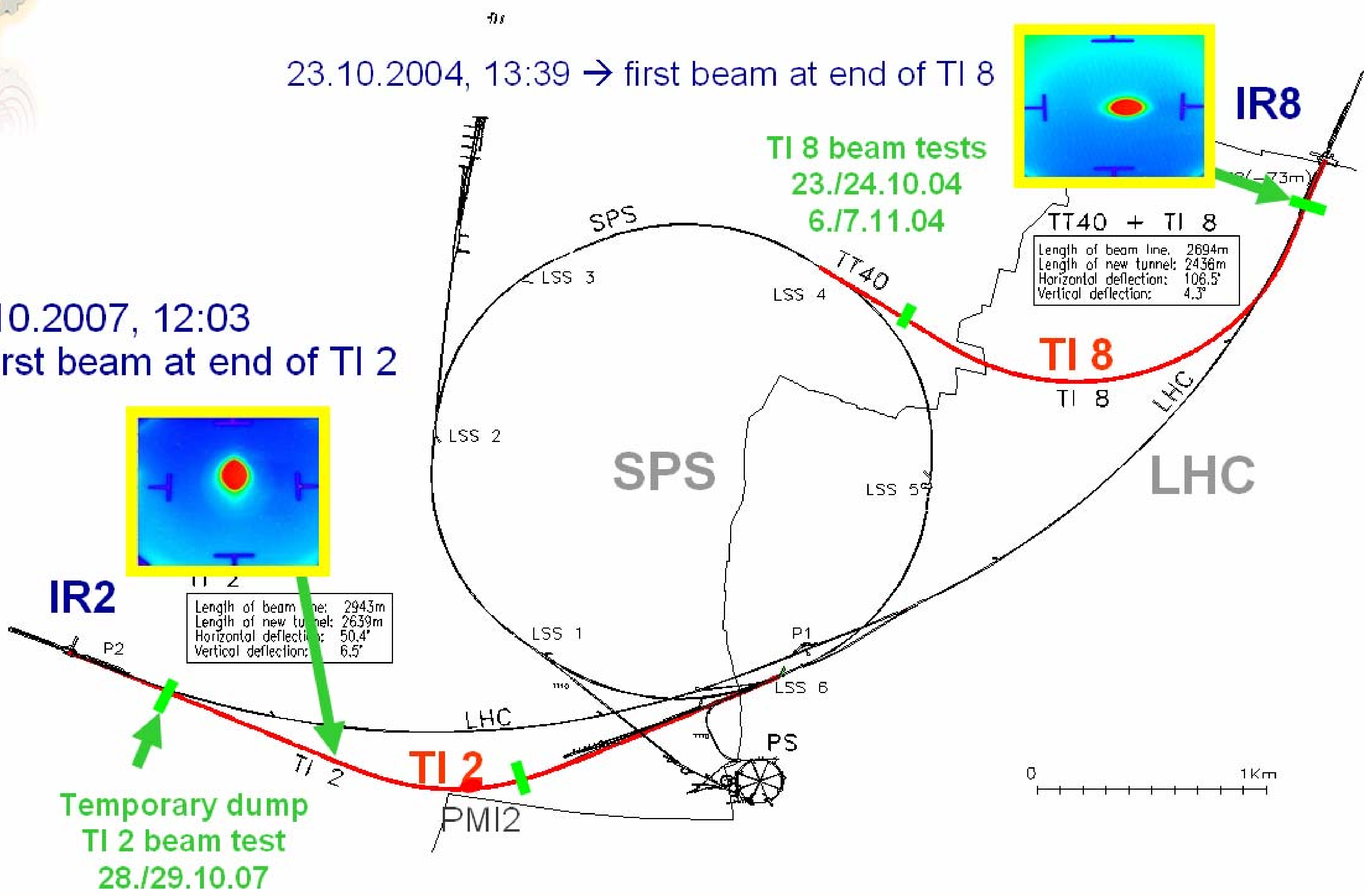


Transfer Lines Tests : TI 8 and TI 2

23.10.2004, 13:39 → first beam at end of TI 8

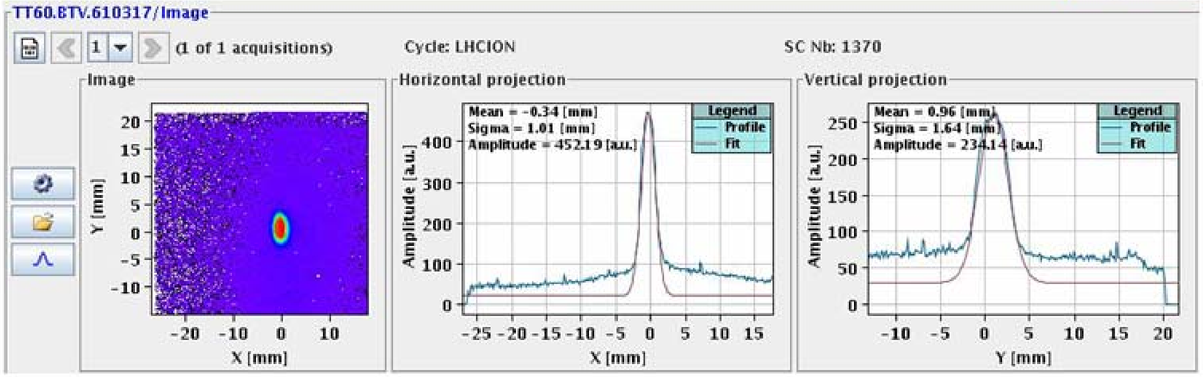


Transfer Lines Tests : TI 8 and TI 2



In view of the first injections into LHC, the beam commissioning of the TI2 and TI 8 lines, was resumed with new successful tests in May and June 2008.

4 bunch "early" ion beam injected and accelerated in the SPS



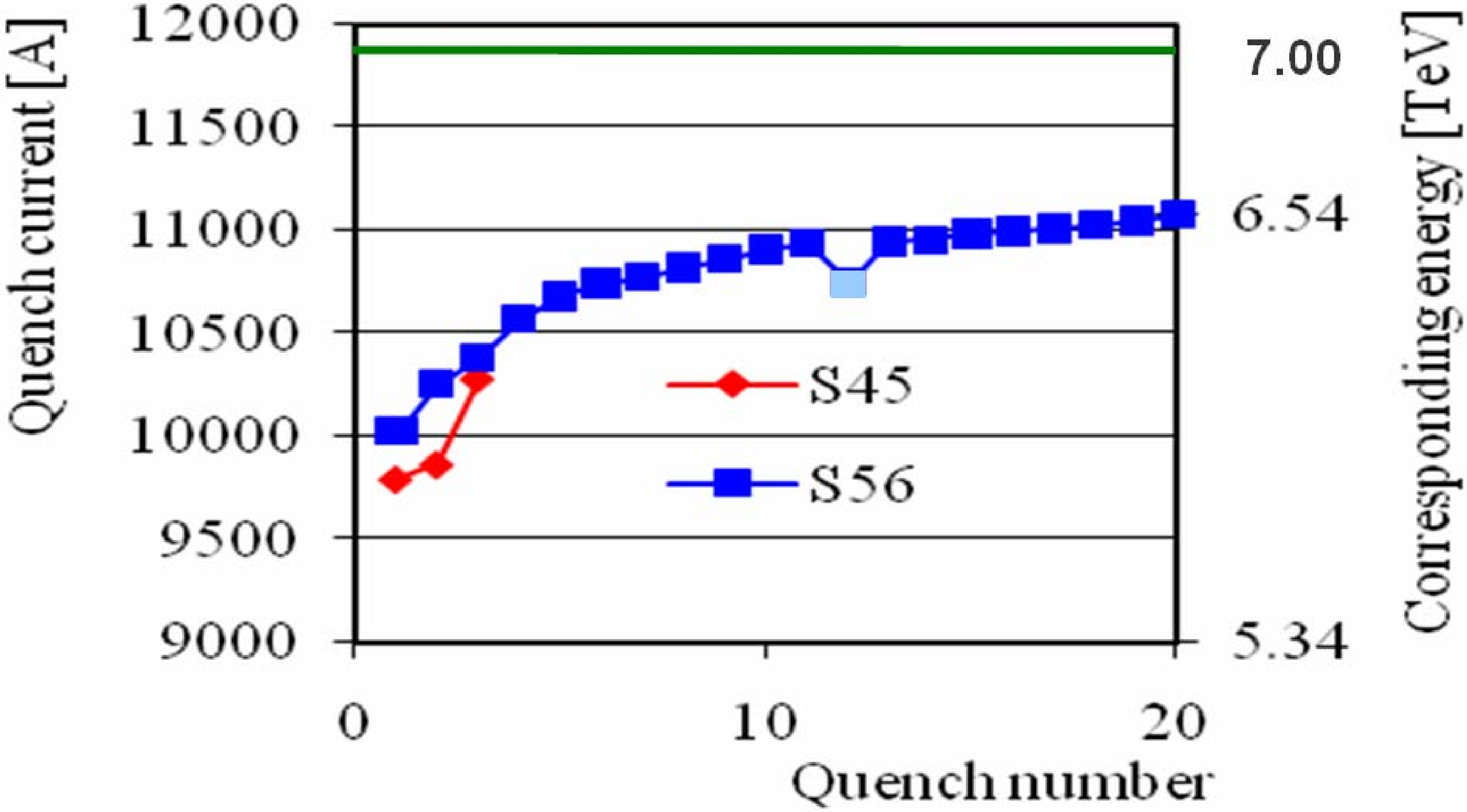
Lead ions: **LEIR and the PS commissioning have been performed in 2005 and 2006 and finally the last machine of the injectors, the SPS, in 2007.**

The 4 bunch "early" ion beam has been injected and accelerated in the SPS, with quasi-nominal intensity (6E7 ions/bunch), transverse emittances (1.2 microns), and bunch length (1.8ns). Some extraction tests into TT60 have also been successfully performed.

D.Manglunki et al,
"Ions for LHC: towards completion of the injection chain" Poster session

The training quenches and 5 TeV strategy

- To meet the summer 2008 deadline for commissioning with beam a reduced beam energy 5 TeV was proposed to the experiments and was accepted.
- **The fact that 5 TeV energy level can be easily reached, has been proven in Sector 4-5, Sector 5-6 and Sector 7-8 (commissioned at 5.5 TeV)**
- **Nevertheless, a quench campaign on the dipoles of Sector 5-6 has been started to find out how much time will be needed to get to 7 TeV.**



Beam first stage: 5TeV collisions

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

- Approx 30 days of beam to establish first collisions
- Approx 2 months elapsed
  - Given optimistic machine availability
  - Un-squeezed
  - Low intensity
- Continue commissioning thereafter
  - Increased intensity
  - Squeeze

Parameters			Rates in 1 and 5	
k_b	N	β* 1,5 (m)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
1 (3)	10^{10}	11	$1.1\ 10^{27}$	<< 1
4	10^{10}	11	$4.5\ 10^{27}$	<< 1
43	10^{10}	11	$5.0\ 10^{28}$	<< 1
43	$4\ 10^{10}$	11	$8.0\ 10^{29}$	<< 1
43	$4\ 10^{10}$	3	$2.9\ 10^{30}$	0.36
156	$4\ 10^{10}$	3	$1.0\ 10^{31}$	0.36
156	$9\ 10^{10}$	3	$5.4\ 10^{31}$	1.8

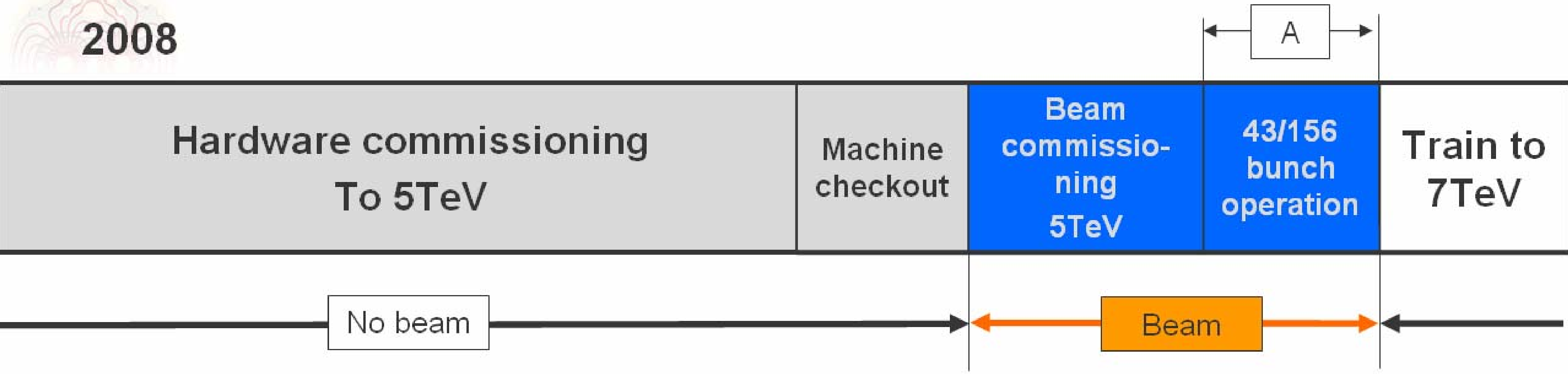
Achievable (in 1 and 5)

30 days of physics
Efficiency for physics 40%

Peak luminosity around 10^{31} cm^{-2} s^{-1}

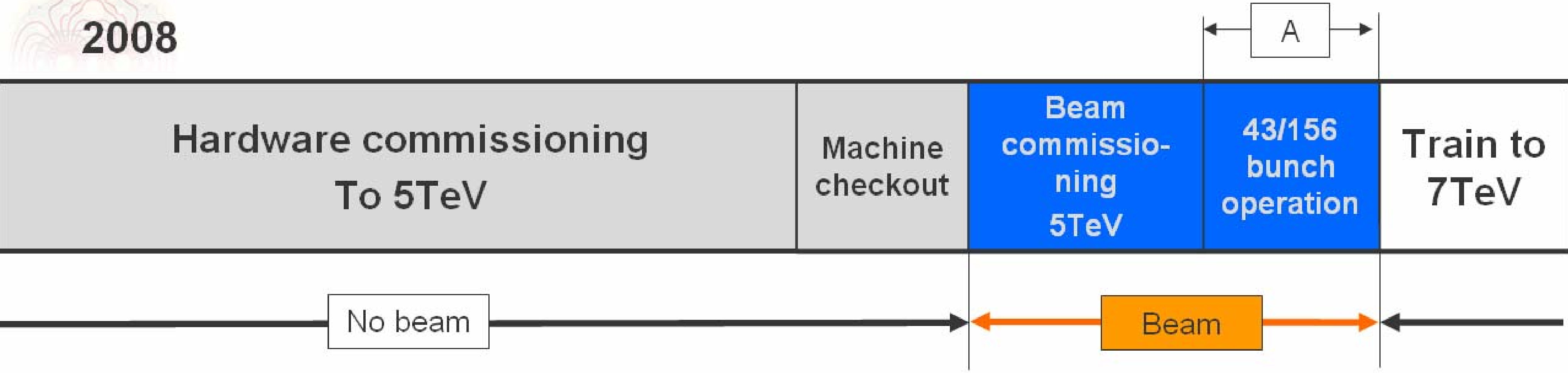
Integrated luminosity ~ 10 pb^{-1}

Strategy for 2008



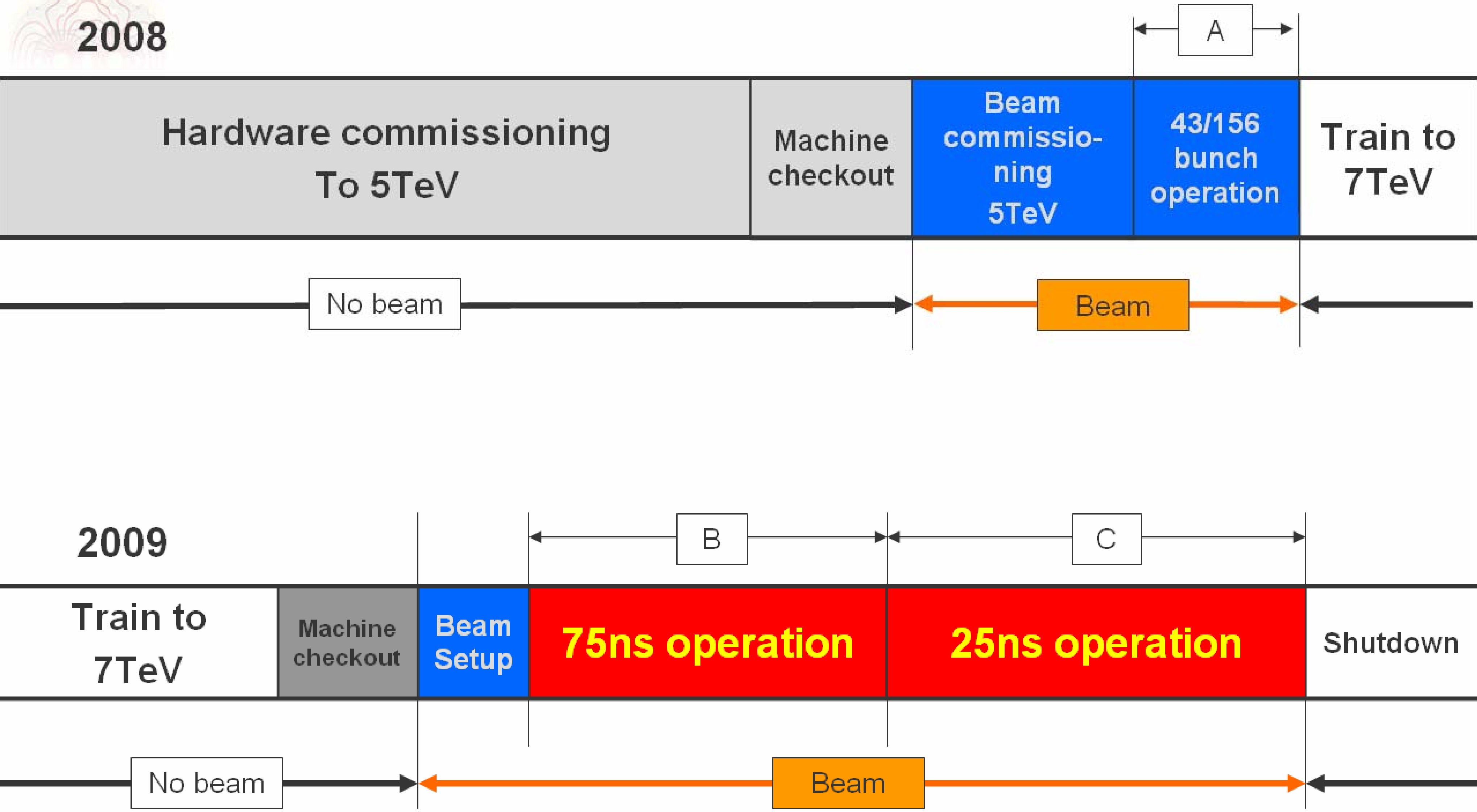
Courtesy R. Bailey

Strategy for 2008 and 2009



Courtesy R. Bailey

Strategy for 2008 and 2009



Courtesy R. Bailey

Aims for 2009

- Commission high energy operation
  - Aim for 7TeV (magnets will decide)
  - 43 /156 bunch running to start (brief)
  - 75ns running
  - 25ns running
  - High 10^{32} cm^{-2} s^{-1} is in reach

- Mixture of
  - Operation for physics
  - Machine studies
  - Scheduled stops
  - Access, injection, ramp, squeeze,…
  - Colliding beams
  - Ion run (to be confirmed)

5 10^6 seconds

Realistically (in 1 and 5)

150 days of physics
Efficiency for physics 40%

Peak luminosity around 10^{33} cm^{-2} s^{-1}

Integrated luminosity ~ few fb^{-1}

(10^6 seconds @ <L> of 10^{33} cm^{-2} s^{-1} $\rightarrow$ 1 fb^{-1})

Courtesy R. Bailey

LHC at EPAC 2008: spot on

R.Saban
LHC Hardware Commissioning Summary
Monday 23th June 15:30 *MOZDM01*

J.M.Jimenez
LHC: The World's Largest Vacuum Systems being Commissioned at CERN
Wednesday 25th June 12:10 *WEOBM04*

P.Lebrun
Collaborating with Industry: Lessons from the LHC Megaproject
Wednesday 25th June 14:30 *WEIM02*

R.Garoby
Upgrade Issues for the CERN Accelerator Complex
Friday 27th June at 11:00 *FRYAGM01*

Conclusion: Schedule for 2008

- ✓ One sector (5-6) give to Operation group for dry runs
  (-> powering of ALL circuits in parallel for injection, ramp and squeeze)
- ✓ The last sector (4-5) will be at 1.9 K by mid July
- ✓ First beam injected early August
- ✓ Colliding beams at 10 TeV in 2008

It's the place where to be this summer !

Conclusion

As any large and complex project, LHC is not all plain sailing but CERN and collaborations have shown an impressive reactive force to overcome the obstacles and continued progressing towards its target of completing the LHC for physics.

The commissioning and the operation of the LHC machine are and will be an absorbing and captivating period

Beam is imminent !