The LHC machine status, commissioning plans and interface with the experiments

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TWEPP 07, Prague 3-7 September 2007

OUTLINE

Status of the LHC machine installation

Hardware commissioning

Plans for beam commissioning

Data/Signals exchange between the accelerator and the experiments:

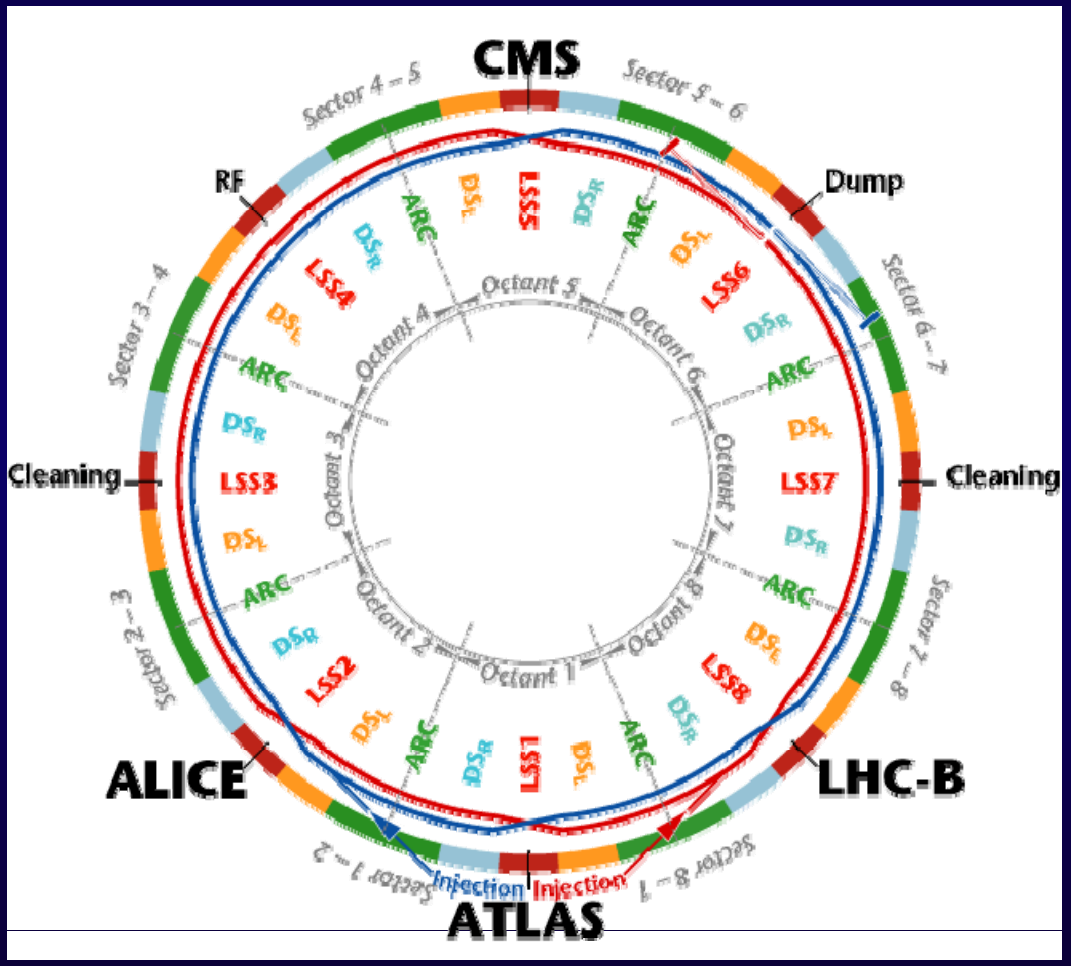
- **Short introduction**
- **Experiment beam interlock for protection from beam failure**

OUTLINE

Status of the LHC machine installation

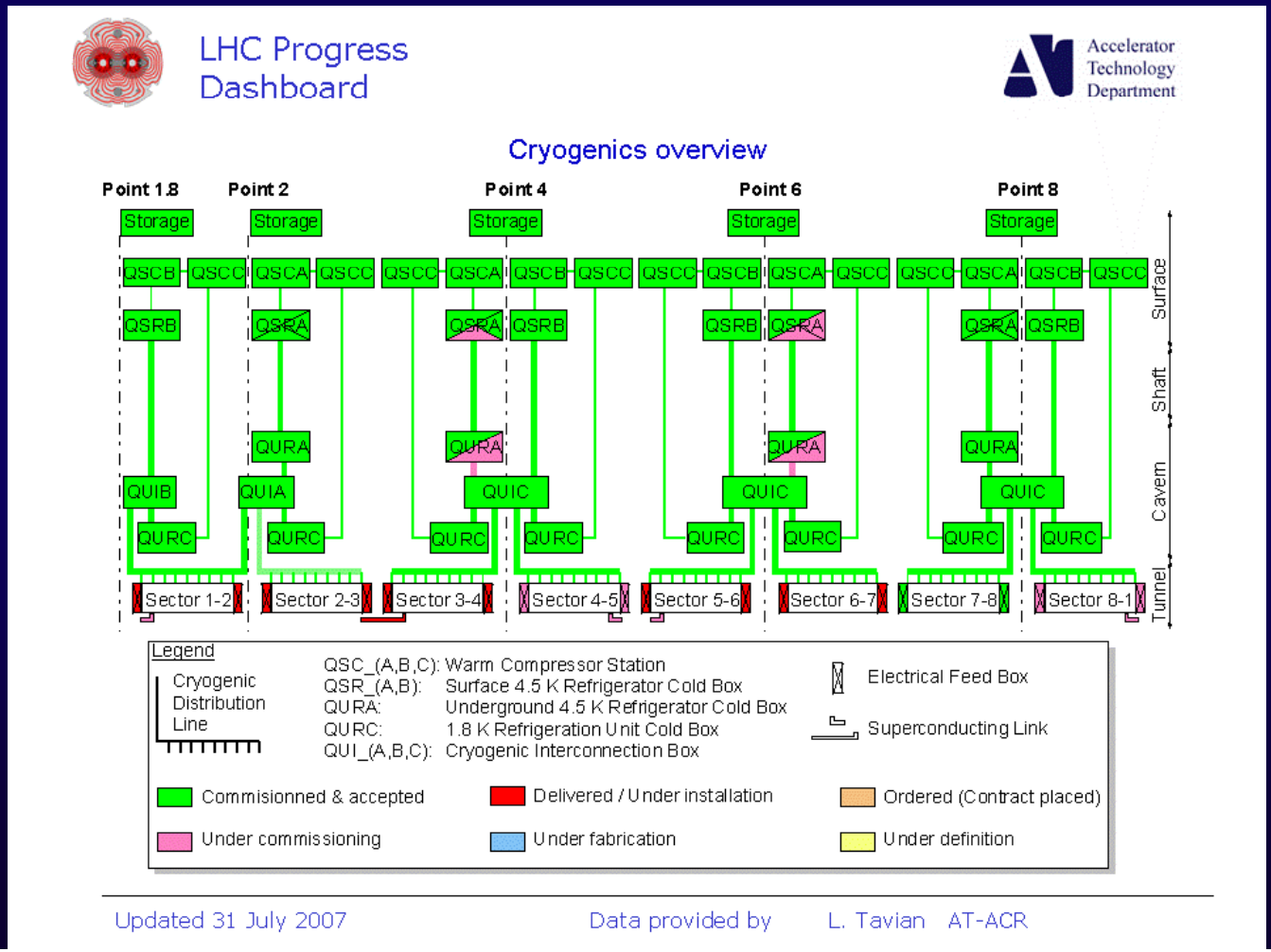
- Short introduction
- Experiment beam interlock for protection from beam failure

LHC LAYOUT


CMS
Dump
Cleaning
Cleaning
ALICE
LHC-B
ATLAS
RF
Injection
Injection
Sector 4 – 5
Sector 5 – 6
Sector 6 – 7
Sector 7 – 8
Sector 8 – 1
Sector 1 – 2
Sector 2 – 3
Sector 3 – 4
Octant 5
Octant 6
Octant 7
Octant 8
Octant 1
Octant 2
Octant 3
Octant 4
LSS1
LSS2
LSS3
LSS4
LSS5
LSS6
LSS7
LSS8
ARC
DSR
DSL

QRL INSTALLATION

- **Installation started in sector 7-8 in July 2003**
  - **Geometry, weld quality, procedures, leaks, support tables …**
- **Installation finished November 2006 (sector 78 by CERN)**



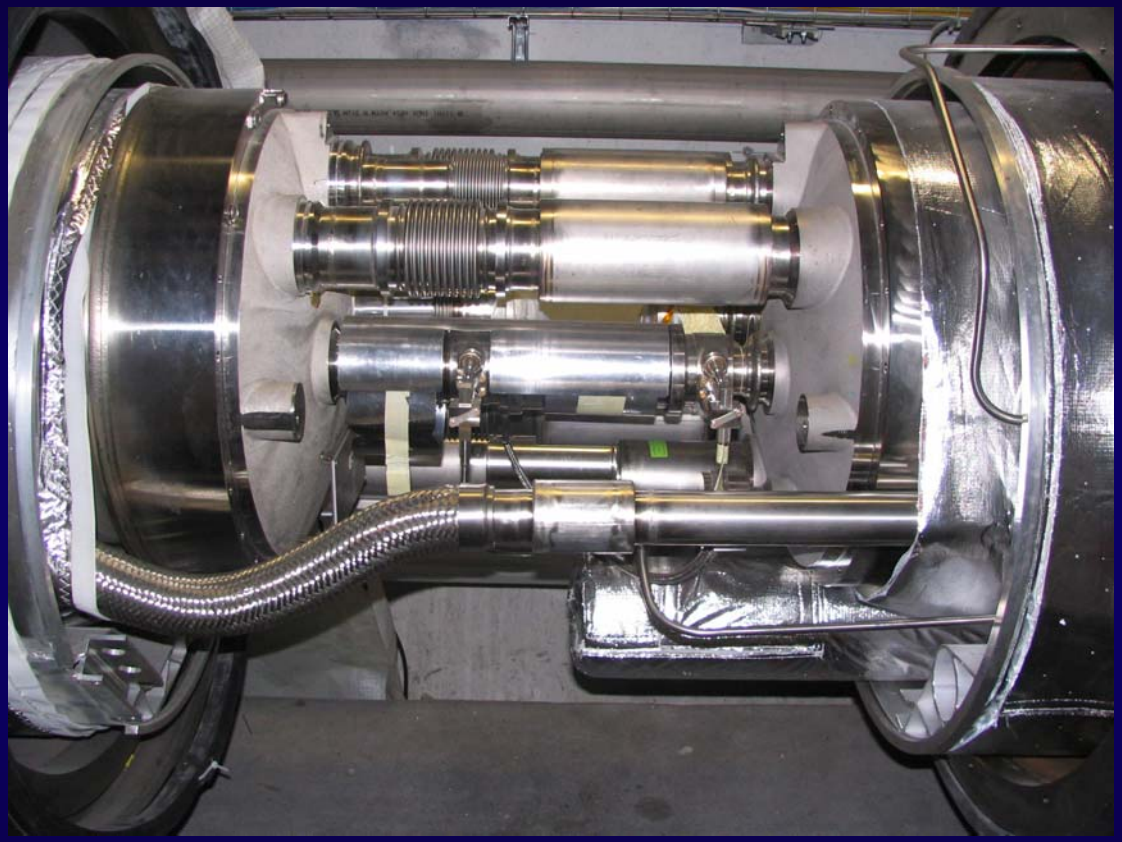
Descent of the last magnet, 26 April 2007

30’000 km underground at 2 km/h!

~ 1700 cryo-magnets assemblies
- 1232 Main Dipoles
- 474 Short Straight Sections
- 16 Separation Dipoles
- 32 Low β Triplets

~ 200 warm magnets

INTERCONNECTIONS



DIPOLE-DIPOLE INTERCONNECT BEFORE FINAL CLOSURE

They consist of several operations:

- TIG welding of cryogenics channels (~50000 welds)
- Induction soldering of main superconducting cables (~ 10000 joints)
- Ultrasonic welding of auxiliary superconducting cables (~ 20000 welds)
- Mechanical assembly of various elements
- Installation multi-layer insulation (~ 200000 m2)

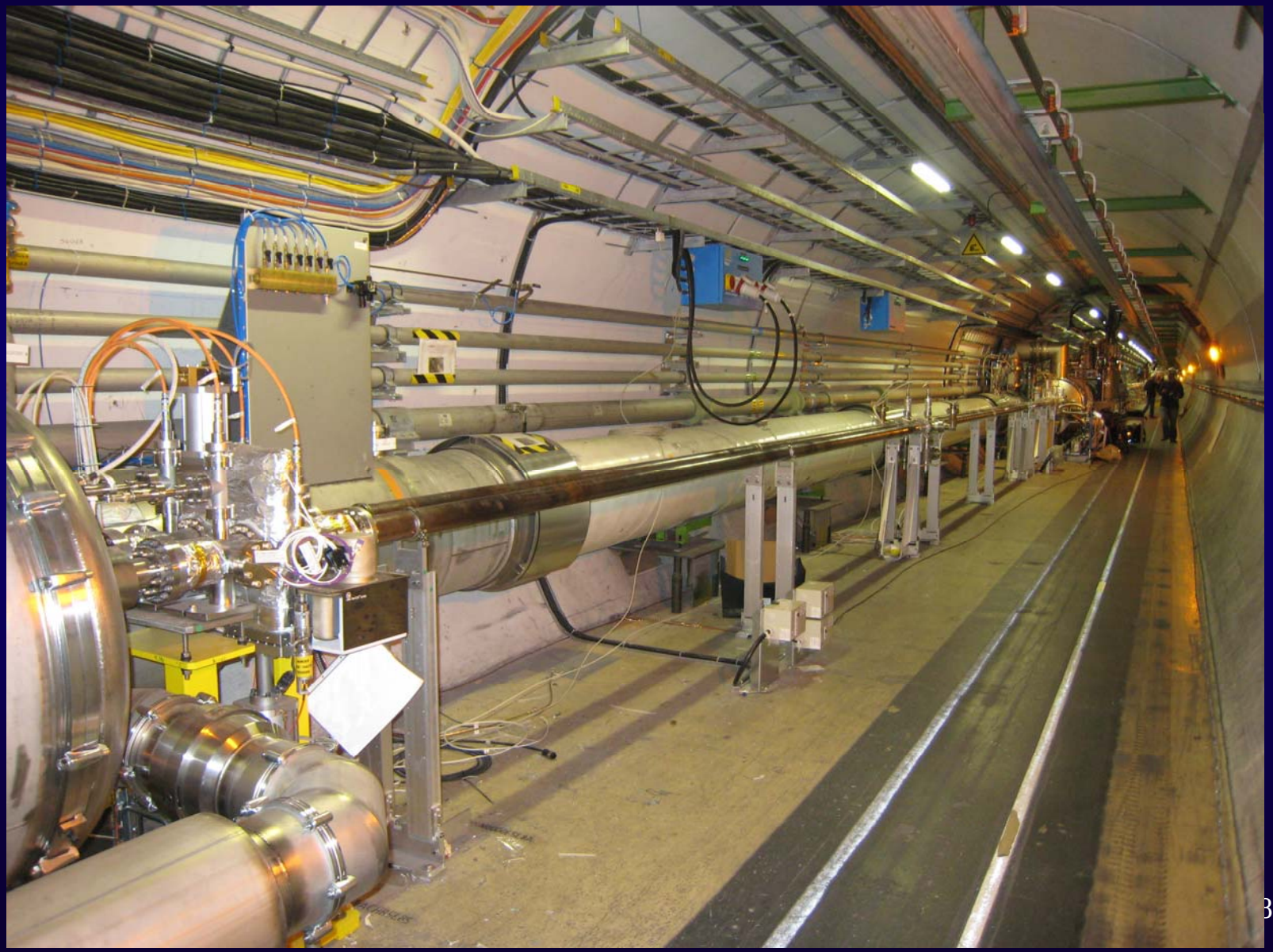
1700 in total !

3 Sectors Completed

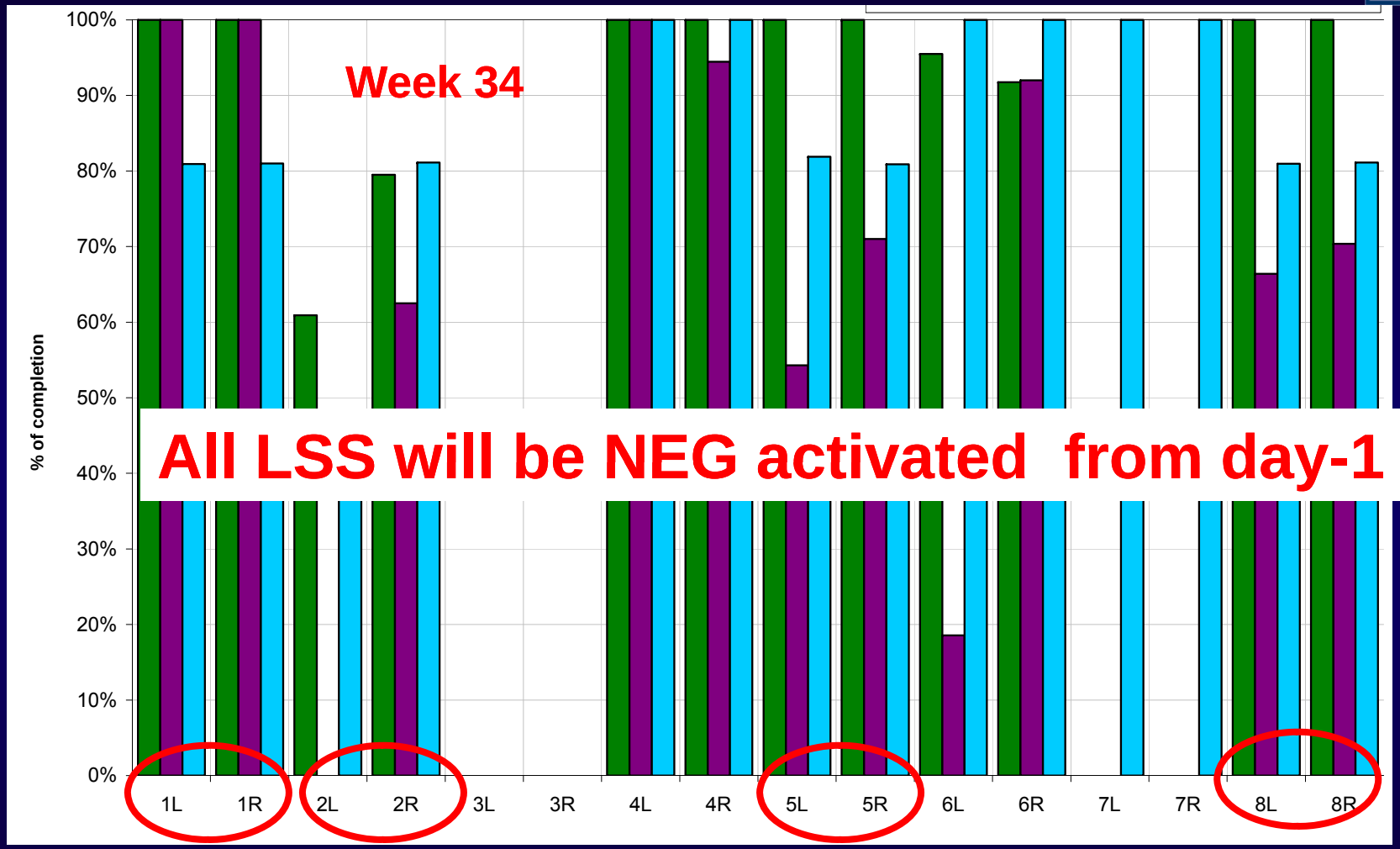
Remaining Sectors nearly finished (80%-99%)

Long Straight Sections (LSS)

sequence of cold and warm element



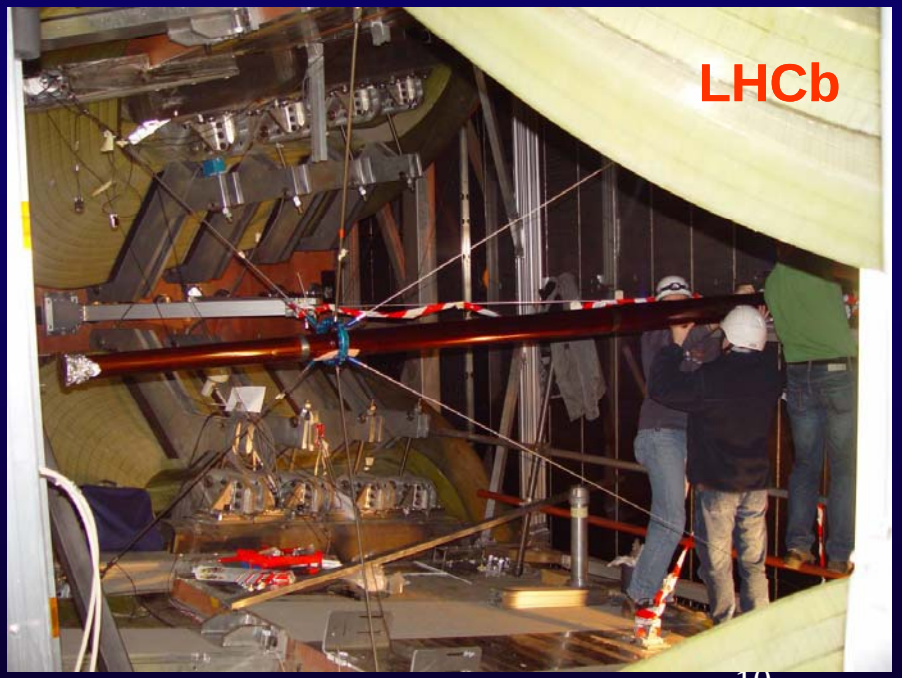
Status of LSS Room Temperature Vacuum System



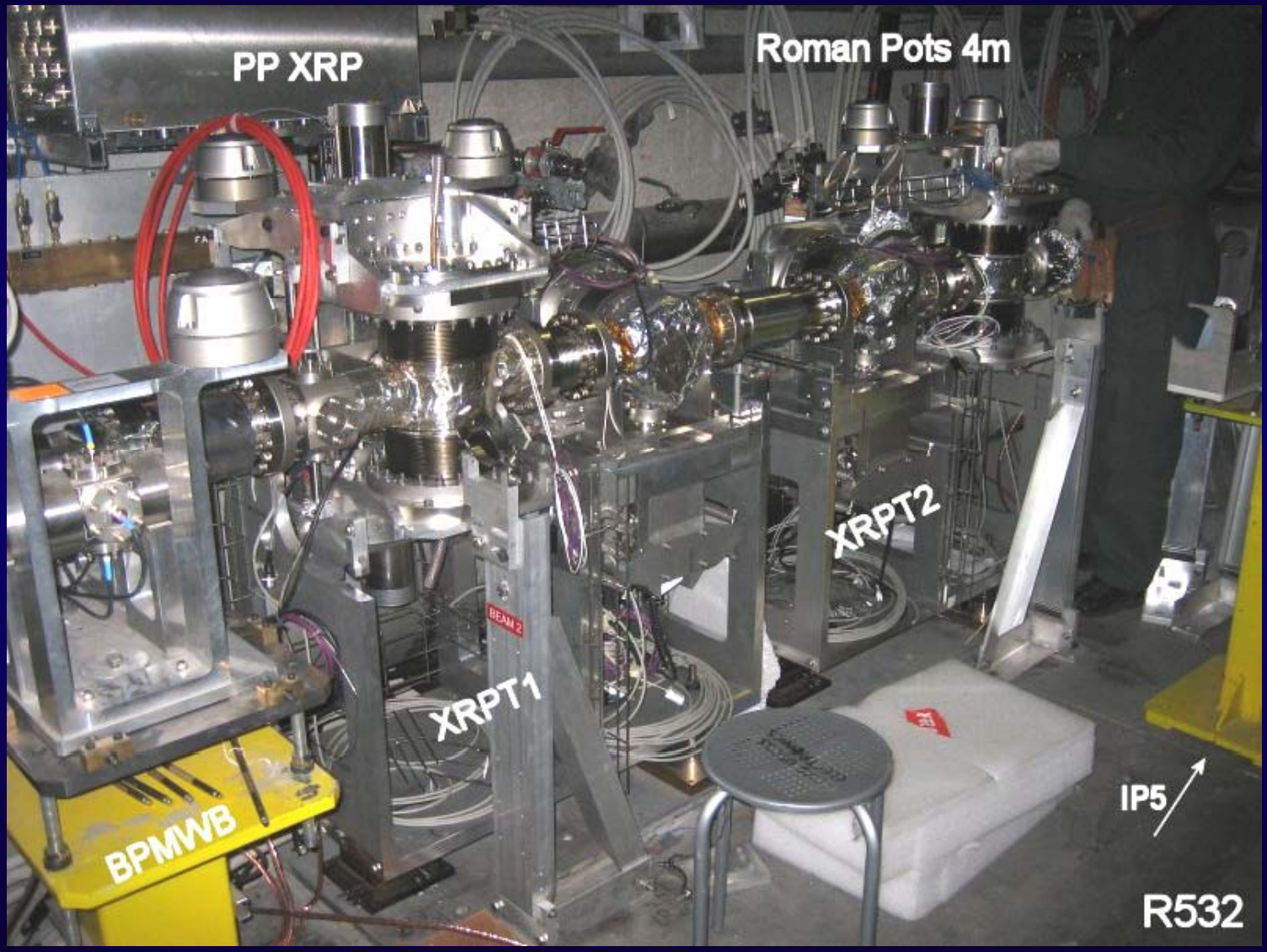
- Standalone magnets beam vacuum under vacuum (IT, D1,D2, Q4…)
- LSS RT Sectors under vacuum
- Bakeout & NEG activation completed

STATUS OF THE EXPERIMENTS BEAM PIPES INSTALLATION

Experiment	Installation	Commissioning
ALICE	~ 80%	~ 50%
ATLAS	~ 90%	-
CMS	~ 20%	-
LHCb	~ 60%	~ 50%



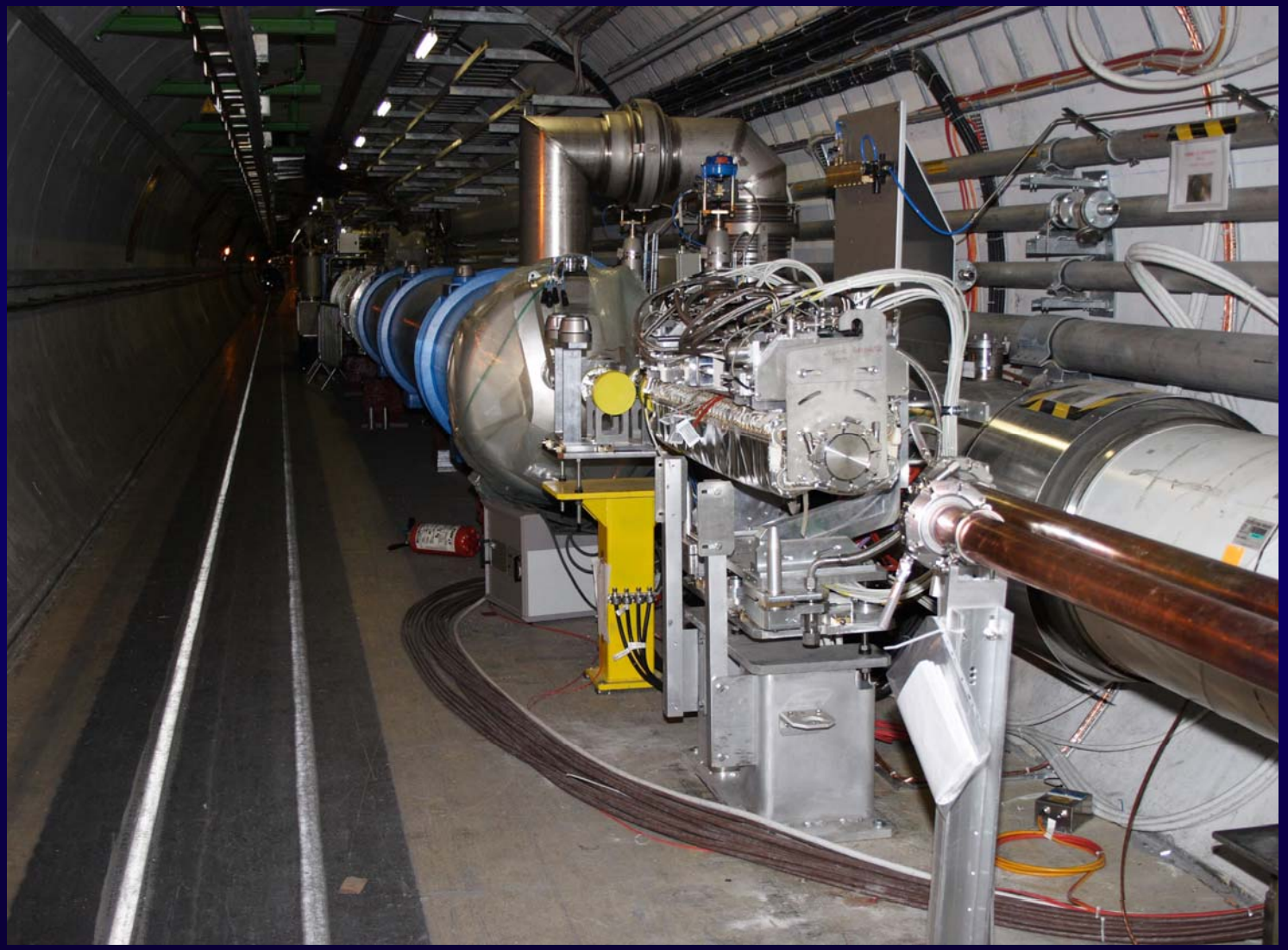
TOTEM ROMAN POTS AT IR5



Vacuum Beam Pipe at Room Temperature

ALICE ZDC AT IR2

Tertiary Collimator (TCT)



OUTLINE

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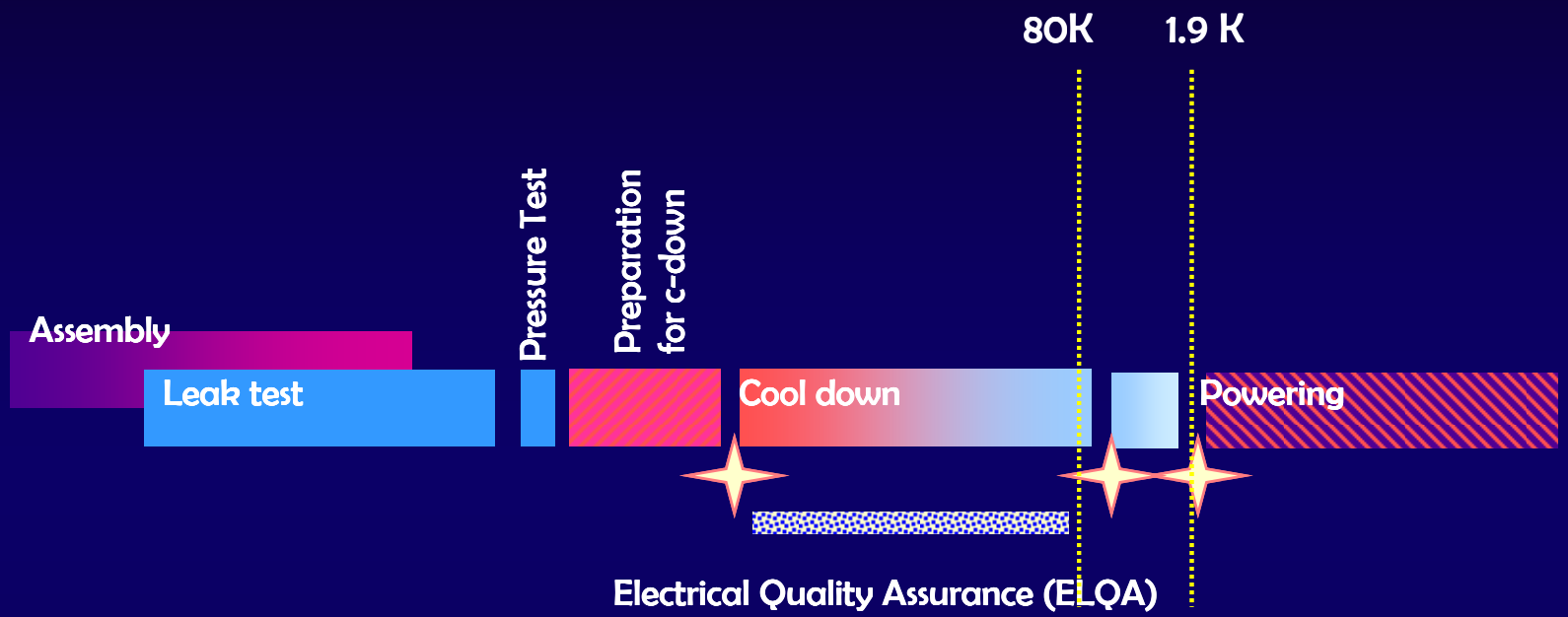
Hardware commissioning

The accelerator and the experiments

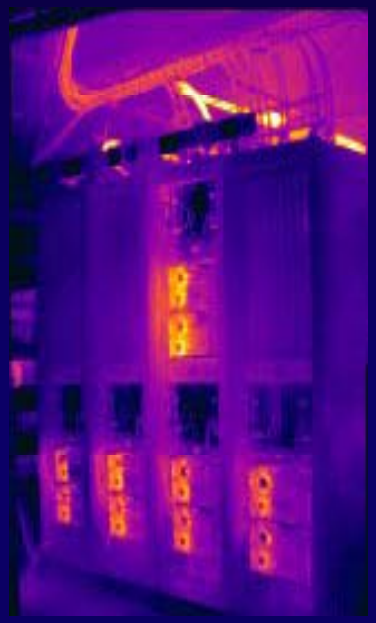
- Short introduction
- Experiment beam interlock for protection from beam failure

Hardware Commissioning of a Sector



- Each system and utility tested and qualified independently prior the Sector Test
- Leak and pressure test
- Preparation for cool-down (flushing, filling, repairs…)
- ELQA at warm
- Power test: power converters connected to the magnets for the first time and tested up to the nominal current

COMMISSIONING THE POWER CONVERTERS



1720/1720 installed

Commissioning campaign on short circuit
From mid 2006 to now
~100% commissioned

Flushing machine

Before

After

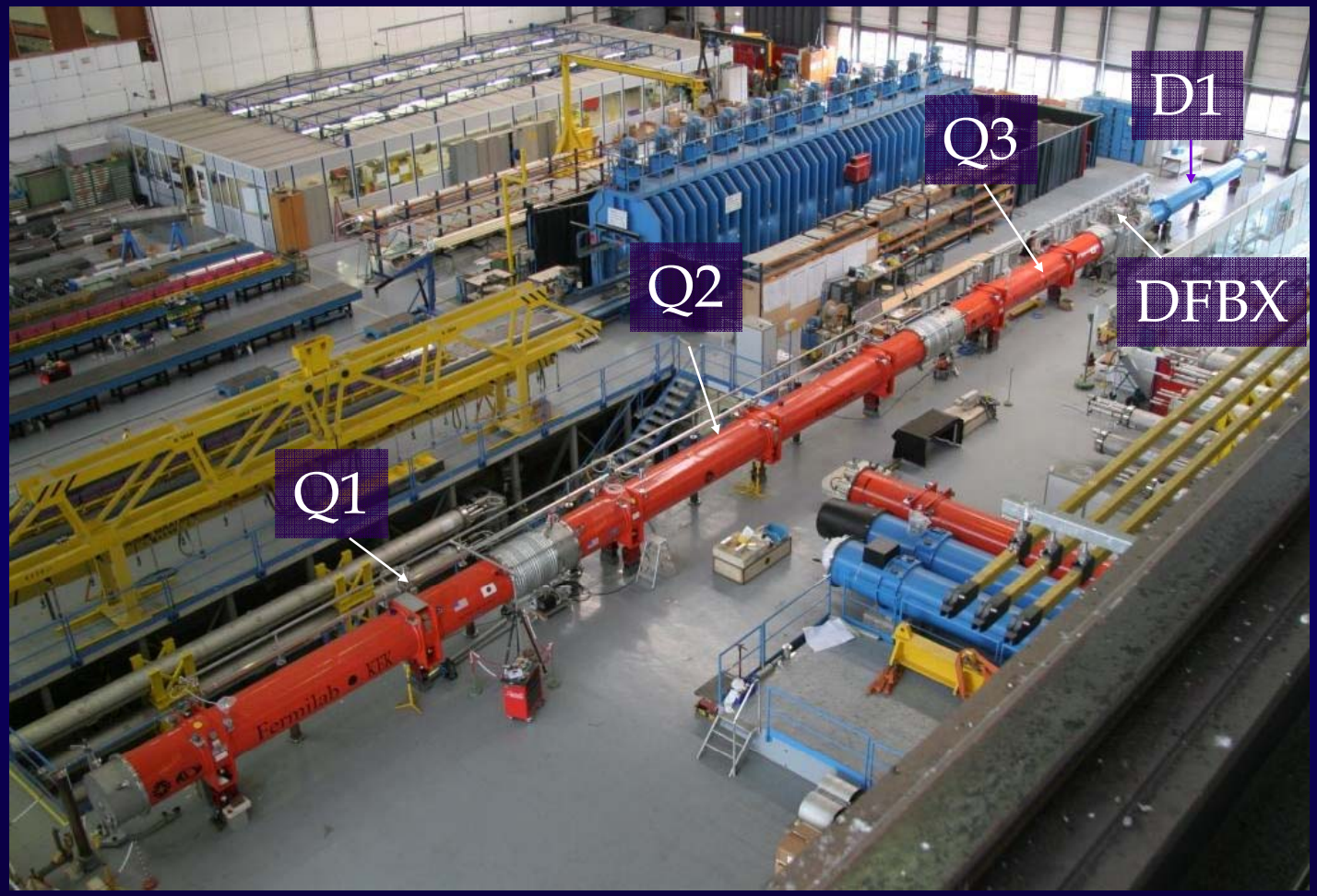
Kapton bits

Metal strips

≈ 50 h
+ 8 L of Water

THE INNER TRIPLET PRESSURE TEST

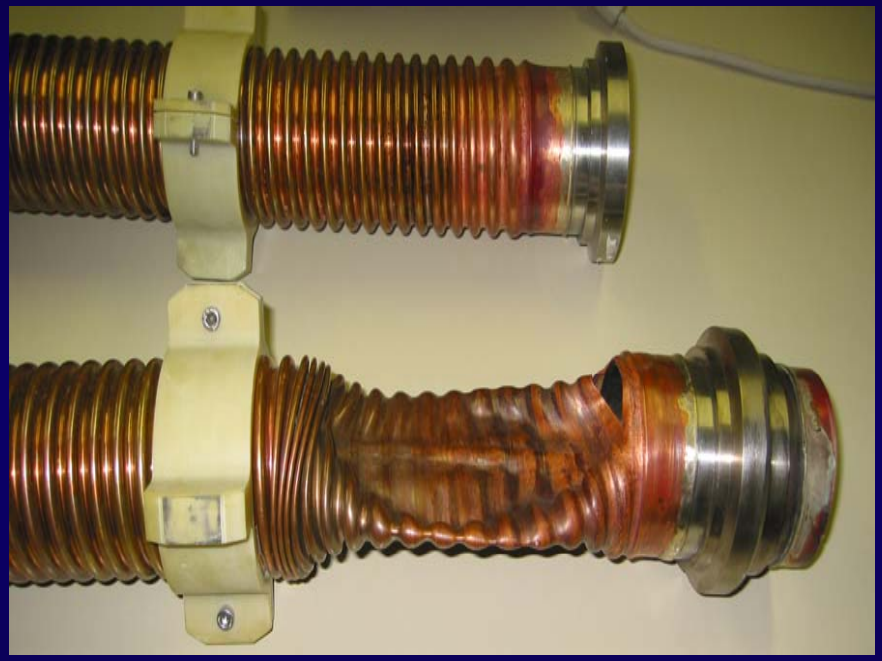
(Inner Triplet focus particle beams prior to particle collisions)



Inner Triplet warm assembly

INNER TRIPLET PRESSURE TEST

INNER TRIPLET PRESSURE TEST: FIRST FAILURE



Failure of HX

- During pressure test in Sector 7-8 (November 2006) the corrugated heat exchanger tube in IT.8L failed by buckling at 9 bar.
- Problem understood and technical solution found: new tubes produced replacement done in situ for all IT

INNER TRIPLET PRESSURE TEST: SECOND FAILURE

During pressure test in Sector 4-5 (March 2007) of the repaired IT.5L, longitudinal fixed points on the "spider" supports of the cold mass broke at 20 bar provoking permanent deformation and rupture of bellows and supports

Rupture of M1 bellows

Break of the support system (spiders)

INNER TRIPLET PRESSURE TEST

- IT Review conducted at CERN (April 2007) and solution found and implemented in situ (four metal cartridges added to reinforce the internal support structures)
- All in
(exce
durin
to th
- As of today, all IT have been repaired and installed in the tunnel.
- 3 IT have been pressure tested in the tunnel: test successful.

Problem solved:
no further delay to the LHC schedule

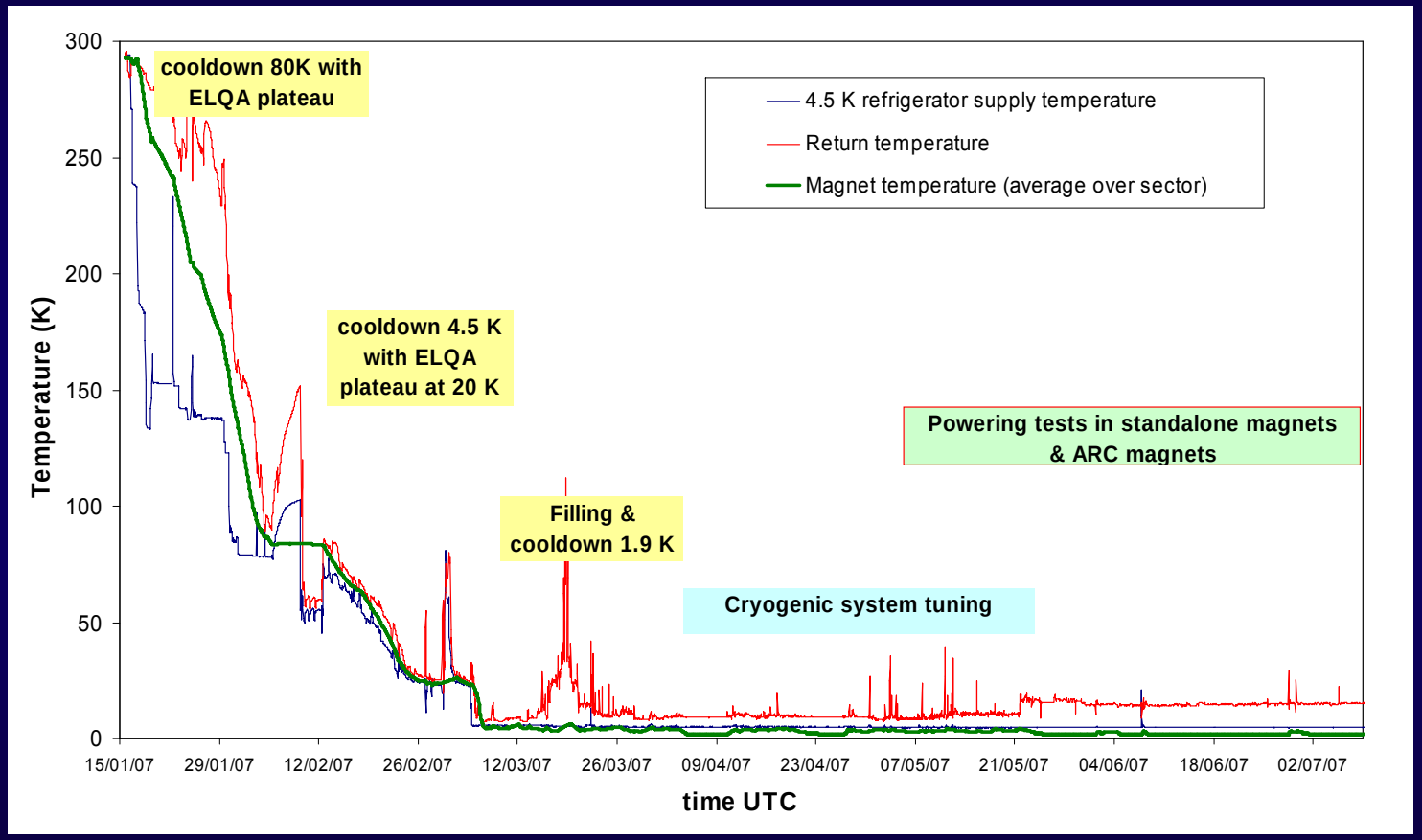
Q1.R8: IT repaired ready for pressure test

Hardware Commissioning Sector 7-8

- **Sector 7-8**
  - **The Sector was successfully cooled-down (faulty IT isolated) and operated with superfluid helium. Teething problems with cold compressor operation have now been fixed**

COOL DOWN SECTOR 7-8

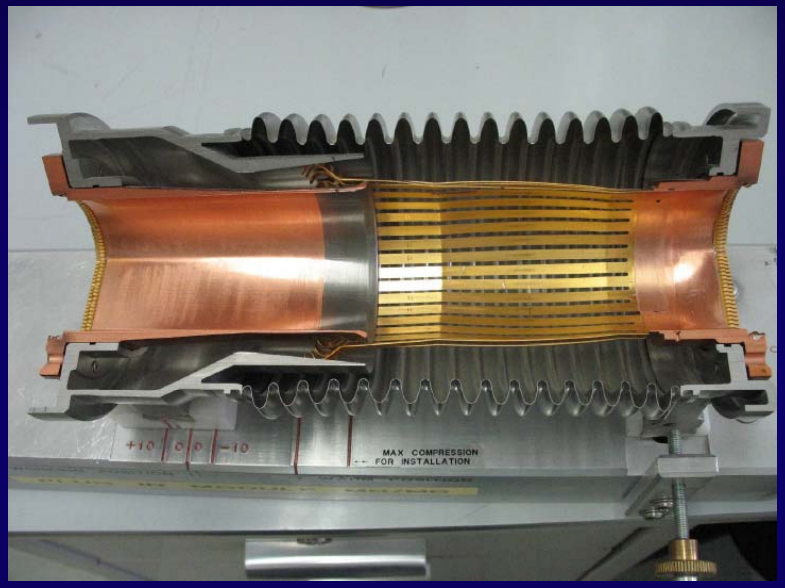
4700 tons of material to be cooled down over 3.3. Km !



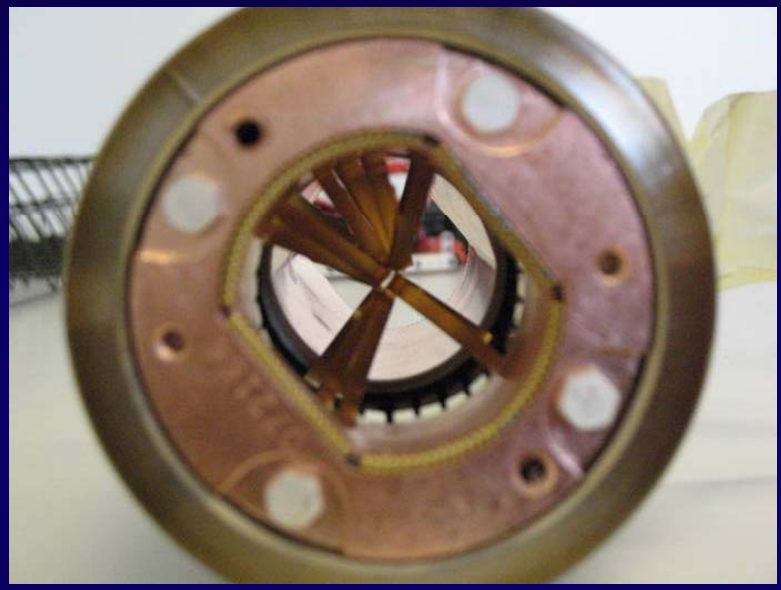
Hardware Commissioning Sector 7-8

- **Sector 7-8**
  - **The Sector was successfully cooled-down (faulty IT isolated) and operated with superfluid helium. Teething problems with cold compressor operation have now been fixed**
  - **Power test successful but:**
    - limited in number of circuits because of lack of time
    - limited in current because of electrical non-conformities in some of the main magnets
  - **The Sector is now warm for consolidation work (IT repair, foreseen non-conformities and a few surprises, notably PIMs).**

Consolidation Sector 7-8: the Plug in Module (PIM) problem



Plug in Module in equivalent cold position



Example of failure
(the problem appears after warm up)

10 PIMs have been found with fingers buckled into the beam aperture :

- 7 foreseen (wrongly installed and working outside specified range)
- 3 non-foreseen

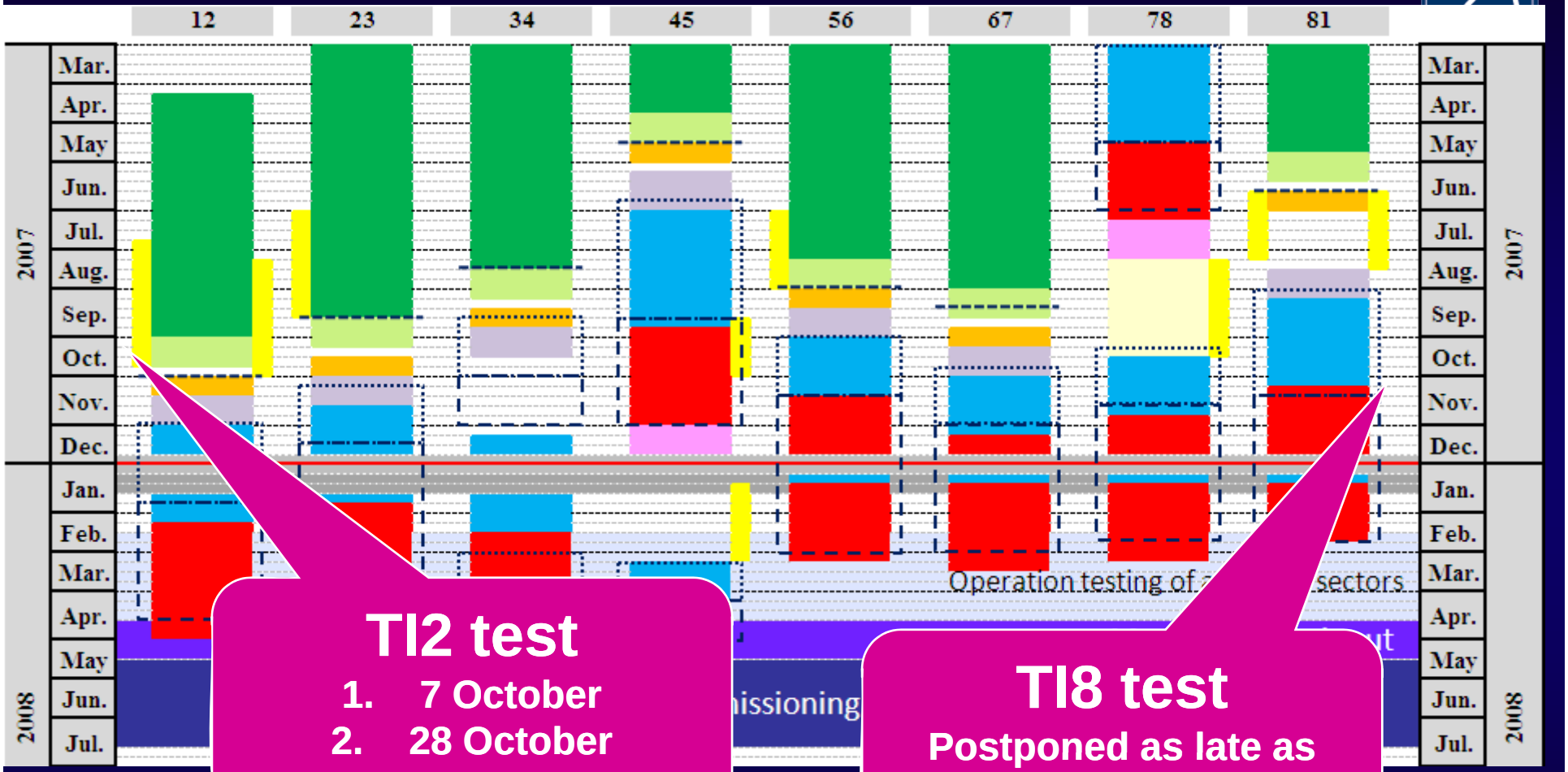
Consolidation Sector 7-8: The Plug in Module (PIM) problem Action underway

- Systematic check of all PIMs in Sector 7-8: as of August 31, 238 examined and no additional faulty PIMs have been found (186 still to be done)
- Inspection damaged PIMs and study of the correlation with external effect (length, cool-down and warm-up scenario etc)
- Validation of design
- Explore means of detection (possibly non invasive)
- Strategy for the remaining sectors is under discussion

Hardware Commissioning 4-5 & 8-1

- **Sector 4-5**
  - **It is under cool-down. A few leaks have been found in the cooling circuit. The sector cool-down continues by isolating the leaking sub-sectors. The sector needs to be warmed up to allow the IT connection and repair of the found non-conformities.**
- **Sector 8-1**
  - **It is now under leak test. Leak detected and needs to be localized or the SSS needs to be replaced.**

General Schedule up to date – 3 August 2007



COMMENTS ON THE GENERAL SCHEDULE

(L. Evans's talk at CERN Council on 22 June 2007)

- Engineering run originally foreseen at end 2007 now precluded by delays in installation and equipment commissioning.
- 450 GeV operation now part of normal setting up procedure for beam commissioning to high-energy

A new schedule update is in preparation. It takes into account:

- **the Helium inventory for 2008**
- **the leak localisation/repair in Sector 8-1**
- **PIMs problem**

The impact on the Master Schedule is expected to be minimal

machine closed April 2008

  - Beam commissioning starts May 2008 & first collisions at 14 TeV c.m. July 2008
- No provision in success-oriented schedule for major mishaps, e.g. additional warm-up/cool-down of sector

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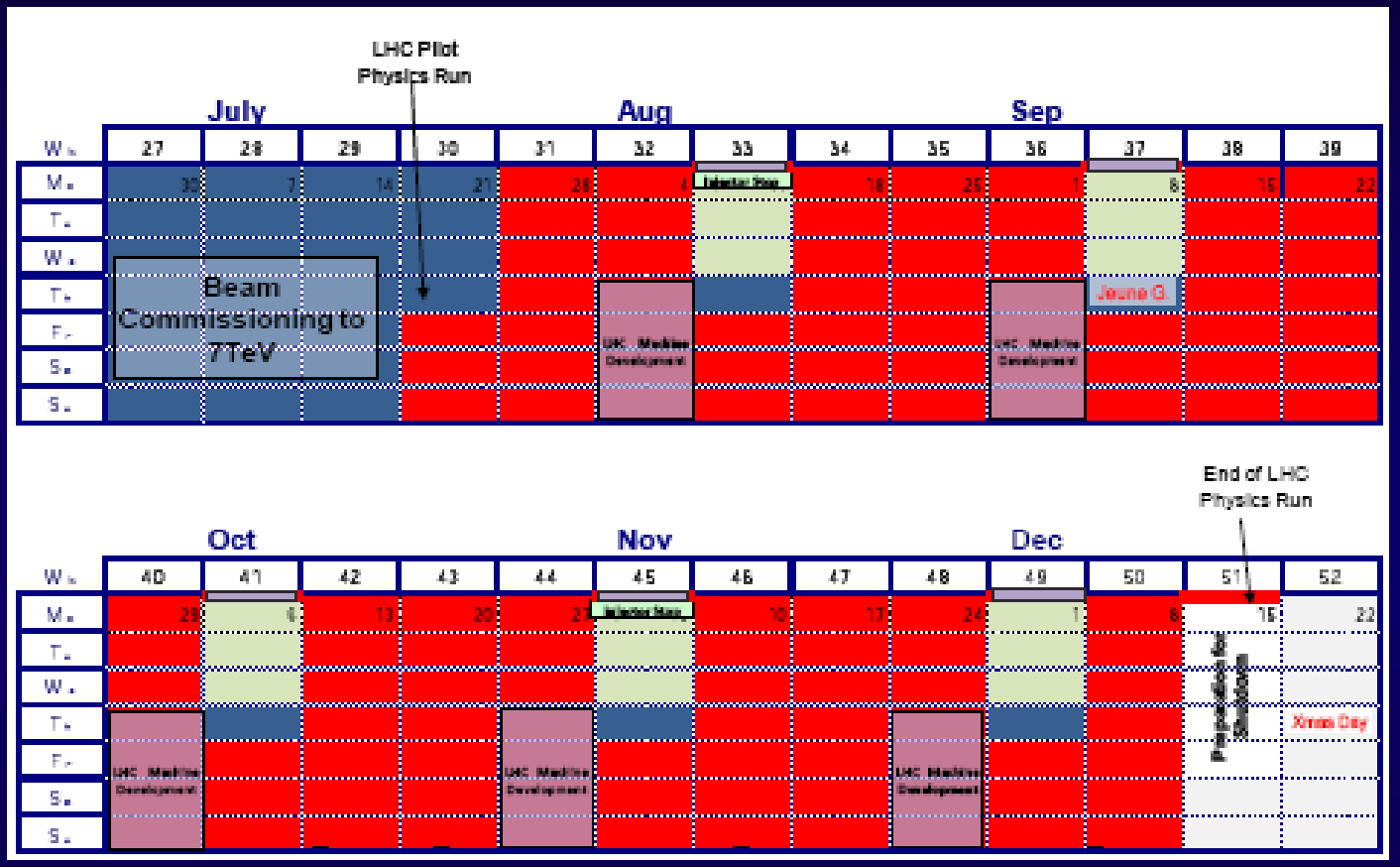
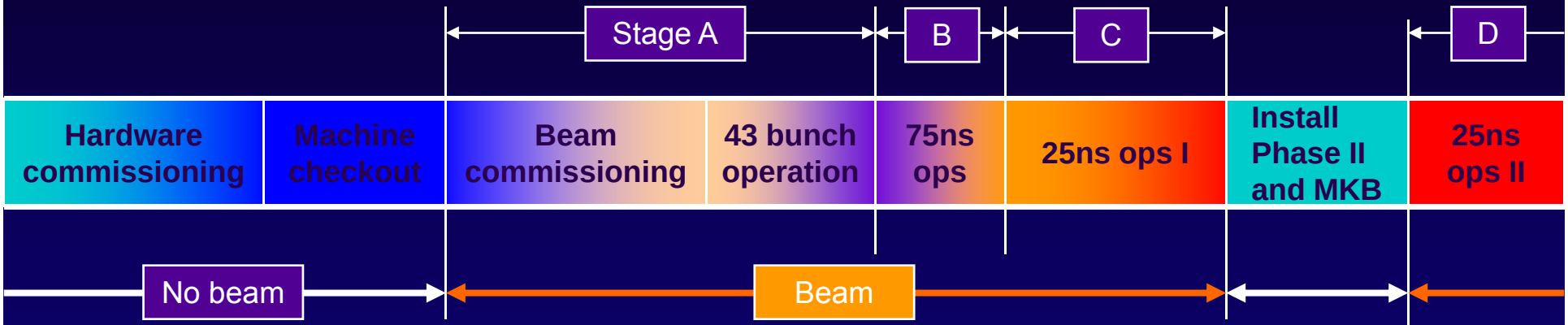
2008 LHC Accelerator schedule (draft)



Overall commissioning strategy for protons



I. Pilot physics run
- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance
- Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

II. 75ns operation
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

III. 25ns operation I
- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit 2 10^{33} cm^{-2} s^{-1}

IV. 25ns operation II
- Push towards nominal performance

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

Minimise
- *Complexity*
- *Beampower*
- *Losses* (β^*)
- *Pileup*

Beam commissioning to 7 TeV Collisions

Name	Commissioning of	Rings	Total [days]
Injection and first turn	Injection, key BI, beam trajectory and threading,…	2	4
Circulating Pilot	Closed orbit, additional BI, circulating beam (few hundred turns), RF capture, …	2	3
450 GeV initial commissioning	BI, dump system, improving lifetime,..		4
450 GeV – Optics	Detailed measurements of aperture, coupling, dispersion,..	2	5
450 GeV – Increased intensity	Beam intensity above 10^{12} p (target 43 bunches $4x10^{10}$)	2	5
450 GeV - two beams		1	1
450 GeV - collisions		1	?
Snapback and ramp, single beam & 2 beams		2	11
7 TeV - setup for physics	Measure and correct optics at 7 TeV, optimization beam lifetime,..	1	2
Physics un-squeezed	Get beams into collision, optimize integrated and relative luminosity, keep background low and stable, provide rough knowledge of the absolute luminosity from beam parameters	1	2
TOTAL TO FIRST COLLISIONS			**37**

Beam time !
~ 2 months elapsed time

Suggested parameter evolution 2008

Parameters			Rates in 1 and 5		Rates in 8 and 2 IF β* = 10 m	
k_b	N	β* 1,5 (m)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
43	$4\ 10^{10}$	11	$1.1\ 10^{30}$	<< 1	$1.2\ 10^{30}$	0.15
43	$4\ 10^{10}$	2	$6.1\ 10^{30}$	0.76	$1.2\ 10^{30}$	0.15
156	$4\ 10^{10}$	2	$2.2\ 10^{31}$	0.76	$4.4\ 10^{30}$	0.15
936	$4\ 10^{10}$	11	$2.4\ 10^{31}$	<< 1	$2.6\ 10^{31}$	0.15
936	$4\ 10^{10}$	2	$1.3\ 10^{32}$	0.73	$2.6\ 10^{31}$	0.15
2808	$4\ 10^{10}$	2	$3.8\ 10^{32}$	0.72	$7.9\ 10^{31}$	0.15
2808	$5\ 10^{10}$	2	$5.9\ 10^{32}$	1.1	$1.2\ 10^{32}$	0.24
2808	$5\ 10^{10}$	1	$1.1\ 10^{33}$	2.1	$1.2\ 10^{32}$	0.24

IP8 will be squeezed down to β* = 2 m to reach nominal luminosity as soon as possible

The 43/156 filling schemes do not provide collisions at IP8 => displace 4/16 bunches by 75 ns (displaced bunches cause event offset by 11.25 m in the other experiments).

Luminosity in ALICE should not exceed ~ $5x10^{30}$ $cm^{-2}s^{-1}$: achieved detuning the insertion from β* = 10 -> 50 m or beam displacement (it depends on the beam intensity)

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Data/Signals exchange between the accelerator and the experiments:

- **Short introduction**
- **Experiment beam interlock for protection from beam failure**

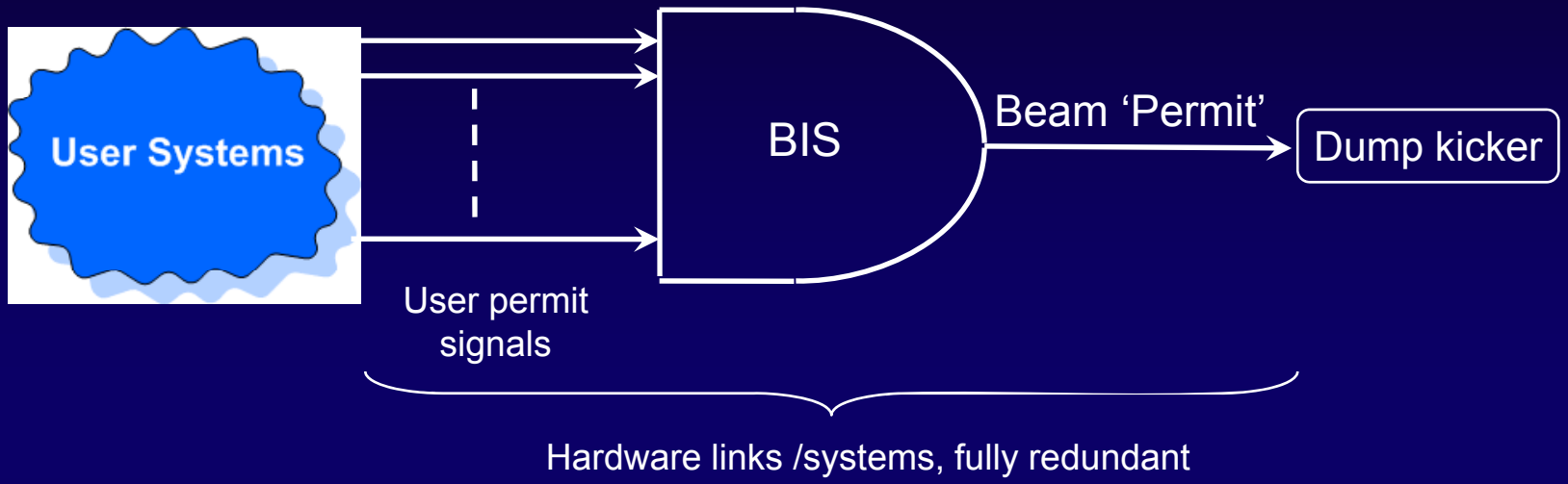
COMMUNICATION EXPERIMENTS ⟷ MACHINE

- **CERN Data Interchange Protocol (DIP)**
  - System which allows relatively small amounts of soft real-time data to be exchanged between very loosely coupled heterogeneous systems
- **Timing, Trigger and Control (TTC)**
- **Machine Beam Synchronous Timing (BST)**

  Developed using TTC technology to provide the LHC beam instrumentation with:
  - 40MHz bunch synchronous triggers
  - 11kHz LHC revolution frequency
  - encoded message (can be updated on every LHC turn) mainly used by the LHC BI to trigger and correlate acquisitions. It also contain the current machine status and values of various beam parameters. The message is sent to the experiments.
- **General Machine Time (GMT)**

  It distributes in a very reliable way the safe beam parameters and flags needed for the interlock system
- **Beam Interlock System (BIS)**

Beam Interlock System



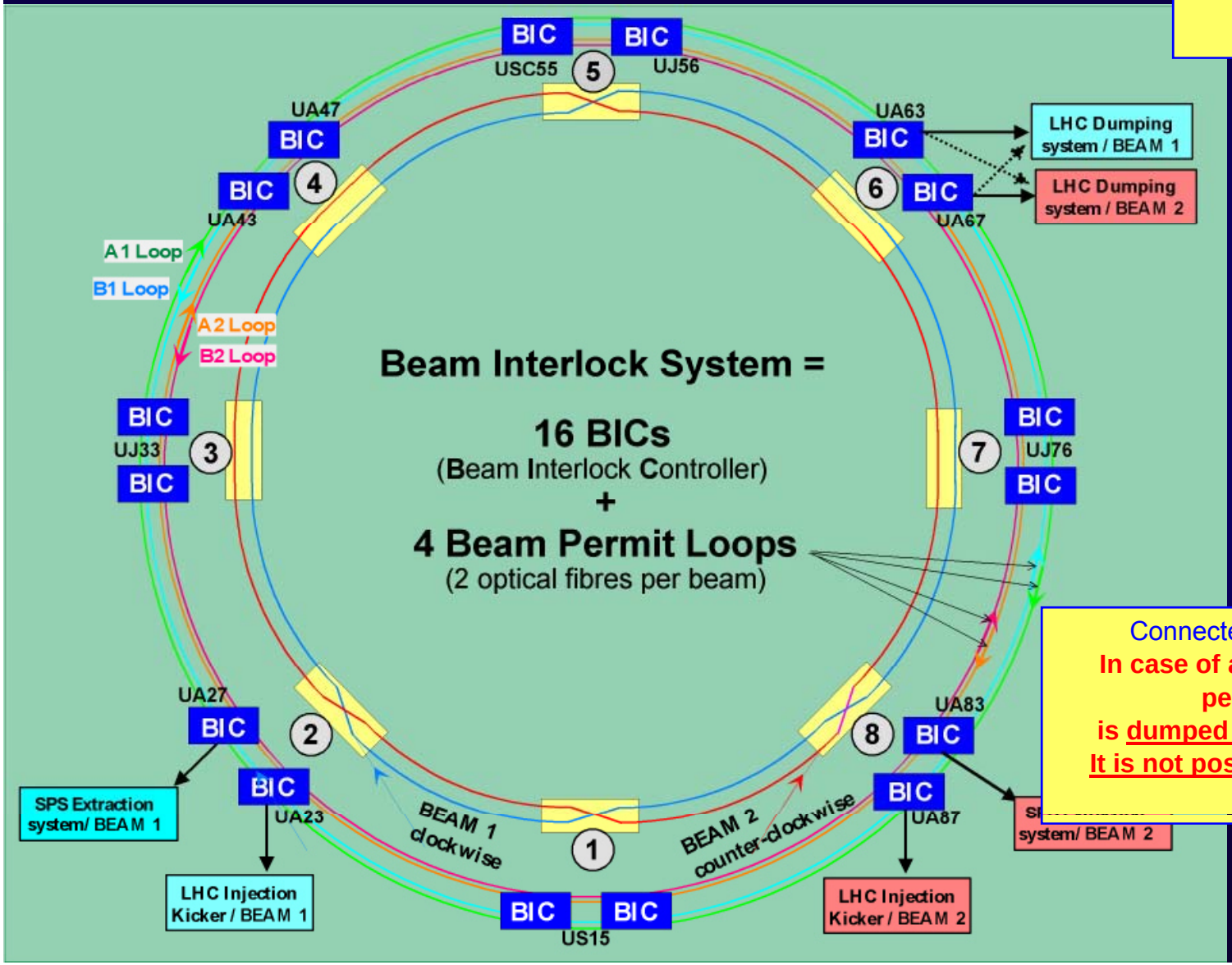
Actors and signal exchange for the beam interlock system:

- 'User systems' : systems that survey equipment or beam parameters and that are able to detect failures a
- Each user syste
- The beam interlock system combines the user permits and produces the beam permit.
- The beam permit is a HW signal that is provided to the dump kicker (also injection or extraction kickers) : absence of beam permit → dump triggered & injection inhibited !

Experiments are included in the Users Systems connected to BIC

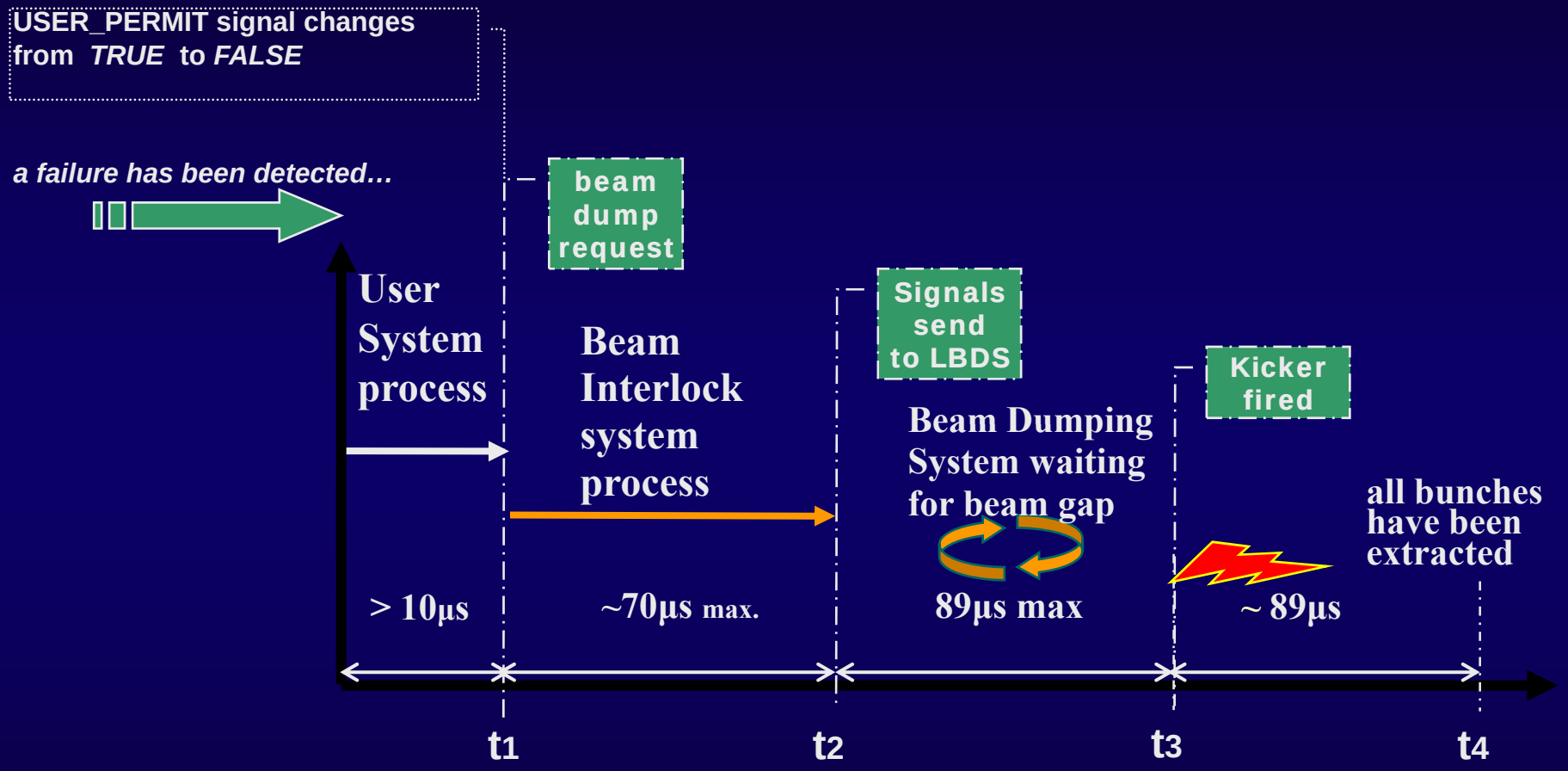
Architecture of the BEAM INTERLOCK SYSTEM

Beam-1 / Beam-2 are Independent!



Connected to injection IR2/IR8:
In case of an interlock (=NO beam permit), the beam is dumped & injection is inhibited.
It is not possible to inhibit injection ALONE.

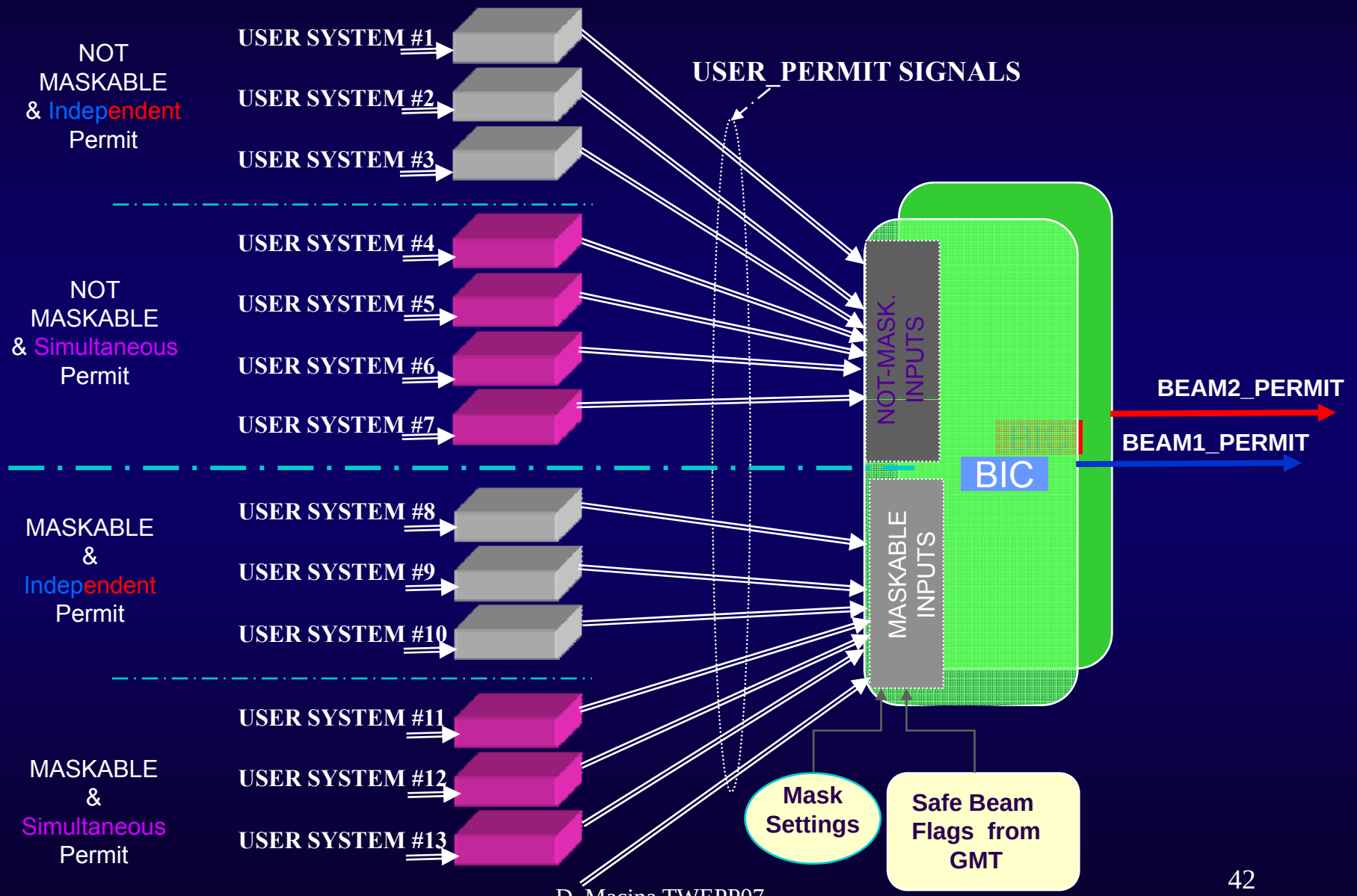
BIS reaction times



Achievable response time ranges between 100 µs and 270 µs

(between the detection of a dump request and the completion of a beam dump)

LHC BIC fixed partition



Safe Beam Flags & Masks

The User Inputs to the interlock systems are split up into 2 groups :

- Un-maskable inputs that are ALWAYS active.
- Maskable inputs that may be de-activated provided the beam is SAFE.

Safe maskin[illegible] SAFE BEAM FLAG (SBF) that is d[illegible]uted to the BIS and that

TRU[illegible]

FALS[illegible]

EXPERIMENTS ARE UN-MASKABLE USERS

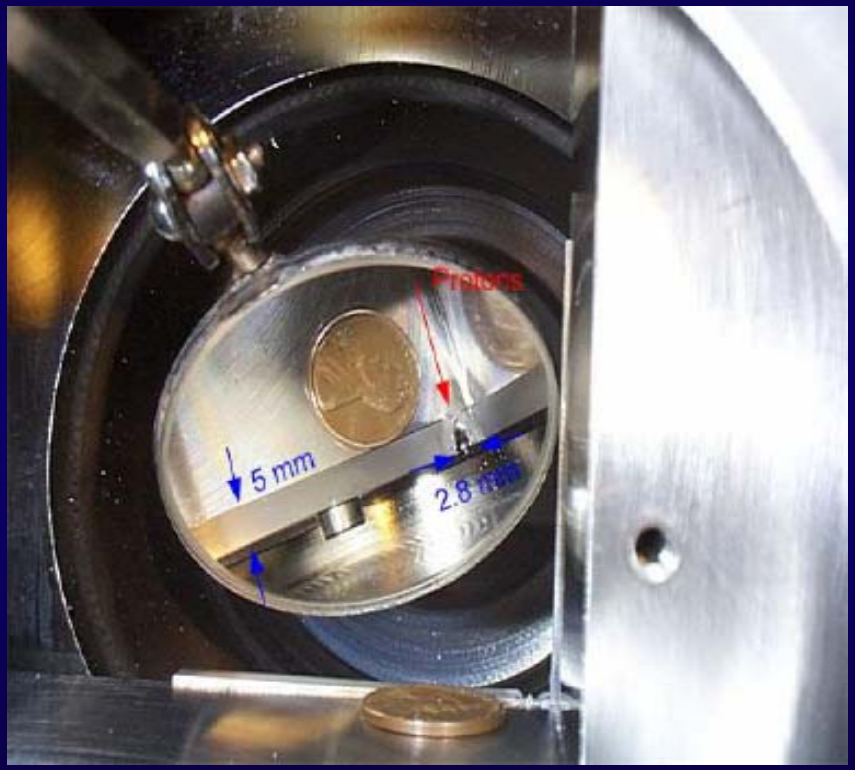
The MP[illegible]has adopted for the LHC a limit for safe beams (nom. emittance) of

10^{12} protons at 450 GeV

10^{10} protons at 7 TeV (scaled from 450 GeV) - under discussion!!

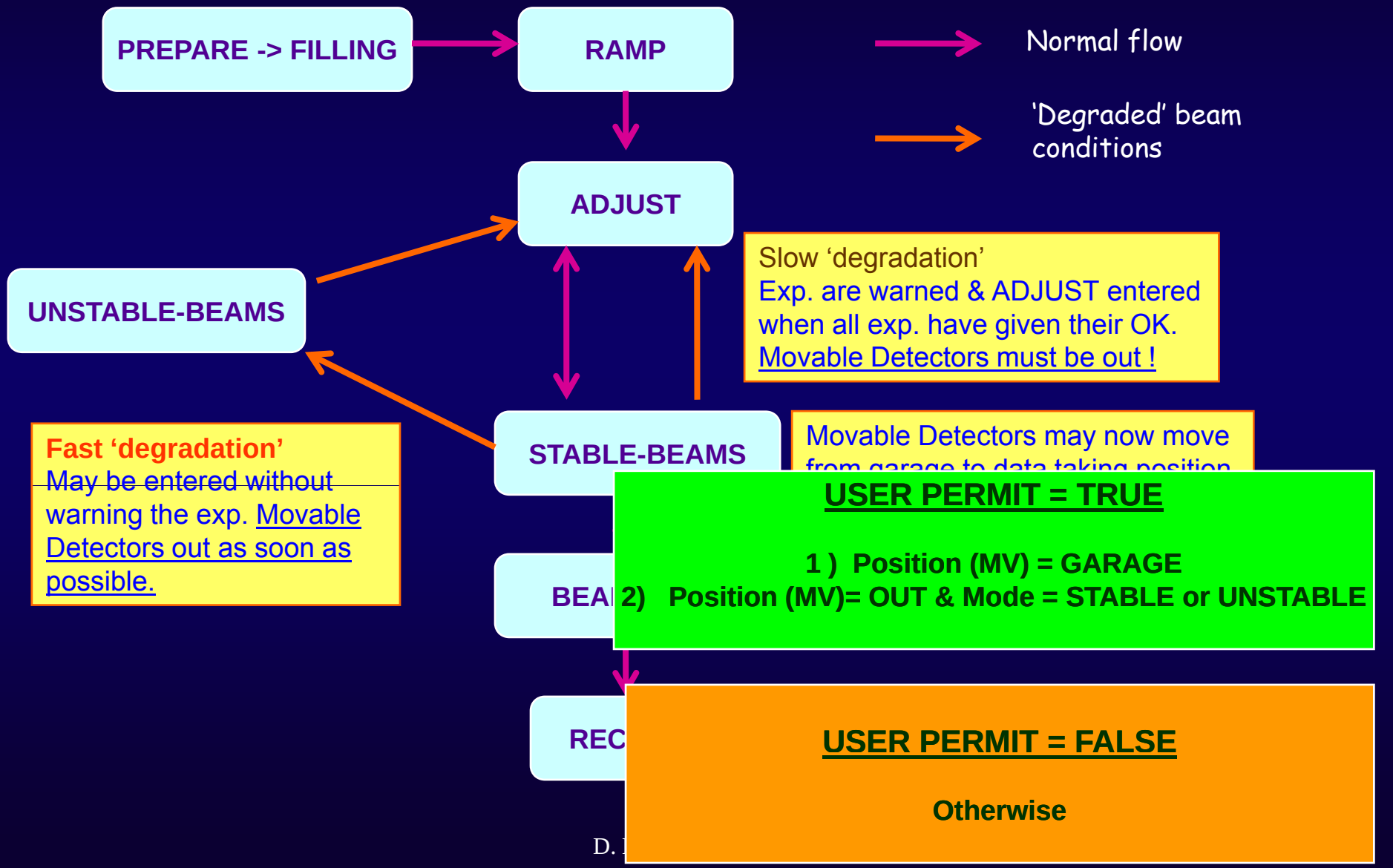
POSITION INTERLOCK FOR EXPERIMENTAL MOVABLE DEVICES

- It concerns detectors moving in the beam vacuum (i.e. VELO and Roman Pots)
- Movable Devices are potentially very dangerous both for machine and experiments
- Dedicated channel for these detectors in the BIC to interlock their movement



Damage to tungsten collimator at TEVATRON due to uncontrolled movement of RP

Position Interlocks for Movable Detectors



HANDSHAKING SIGNALS

PREPARE -> FILLING → RAMP → Normal flow

'Degraded' beam

IN ANY CASE
DO NOT FORGET

UNSTAB

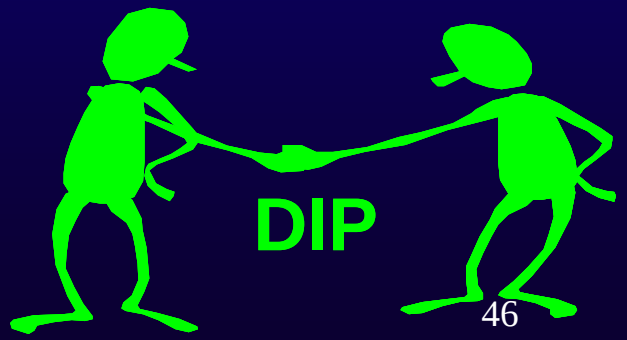
om CCC
from Exp.

NO TIM
(info fro

EST from CCC
DUMP from Exp.

BEAM-DUMP

RECOVER



THE EXPERIMENTS INJECTION INHIBIT

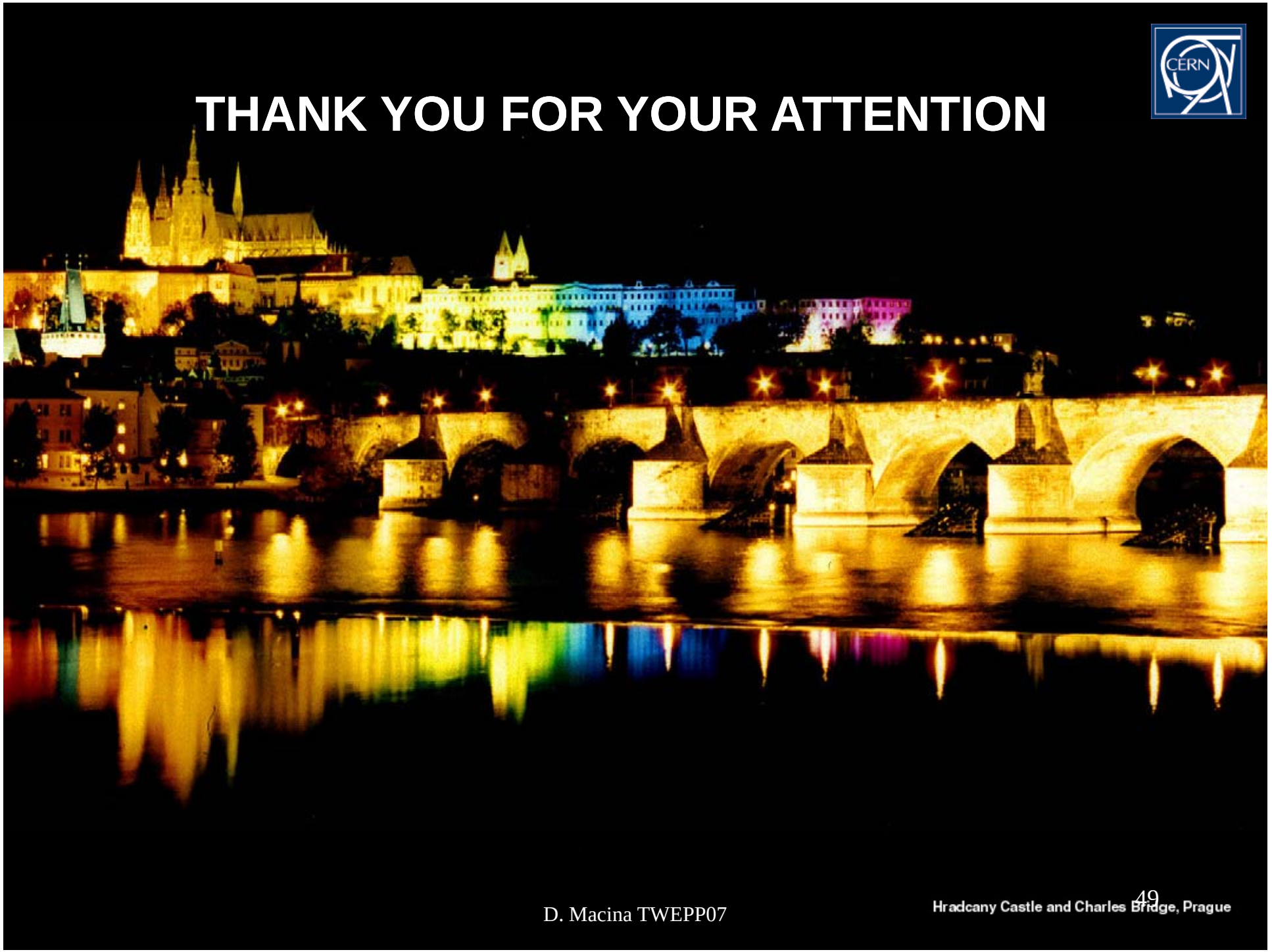
- Experiments have asked the possibility to inhibit injection without dumping the beam. In fact, the injection inhibit is based on the state of the detectors and does not depend on data from radiation monitors (apart from the requirement that the radiation monitors are operational).

- Due to lack of resources, it is impossible to develop an ad-hoc HW system for the LHC start up and it has been agreed to use the already existing Software Interlock Systems (SIS) to send the experiments injection inhibits.
- The SIS provides additional protection – on top of the HW interlock systems
- The reaction time of those systems will be at the level of a few seconds.
- The systems rely entirely on the machine technical network, databases, etc – clearly not as safe as HW systems !

SUMMARY

- The LHC installation is nearly finished.
- The Hardware Commissioning phase is started at full speed. Problems have been encountered during the Hardware Commissioning of the first sectors (leaks localization, IT pressure test, magnets non-conformities, cold compressor operation etc). However, problems have been solved in a very fast and professional way and none of them has resulted in a show-stopper.
- Beam commissioning phase is approaching and it will be very exciting but not easy.
- All communication channels between the machine and the experiments need to be commissioned and functioning during the LHC operation.

THANK YOU FOR YOUR ATTENTION



Hradcany Castle and Charles Bridge, Prague