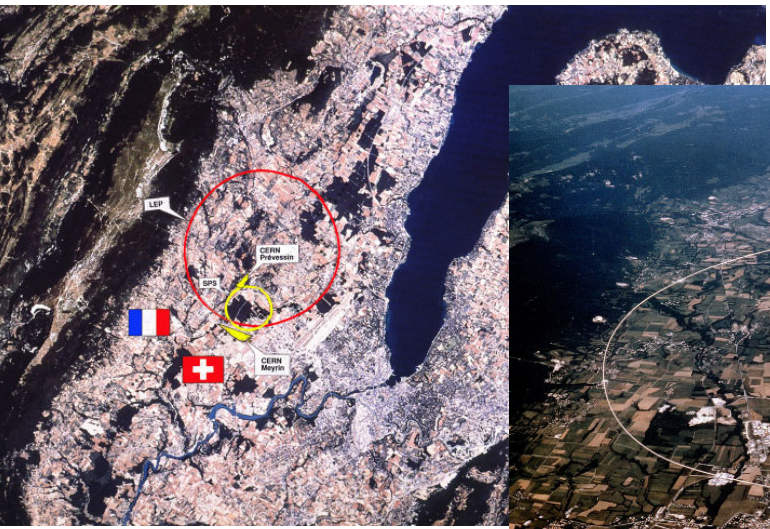
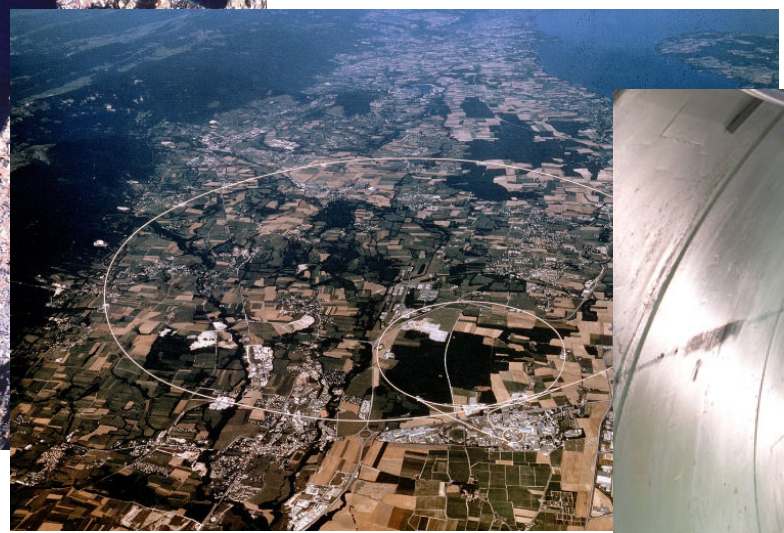
LHC: Status and Commissioning Plans

Mike Lamont, LHC Operations, CERN

26 April 2007

The LHC….work in progress!

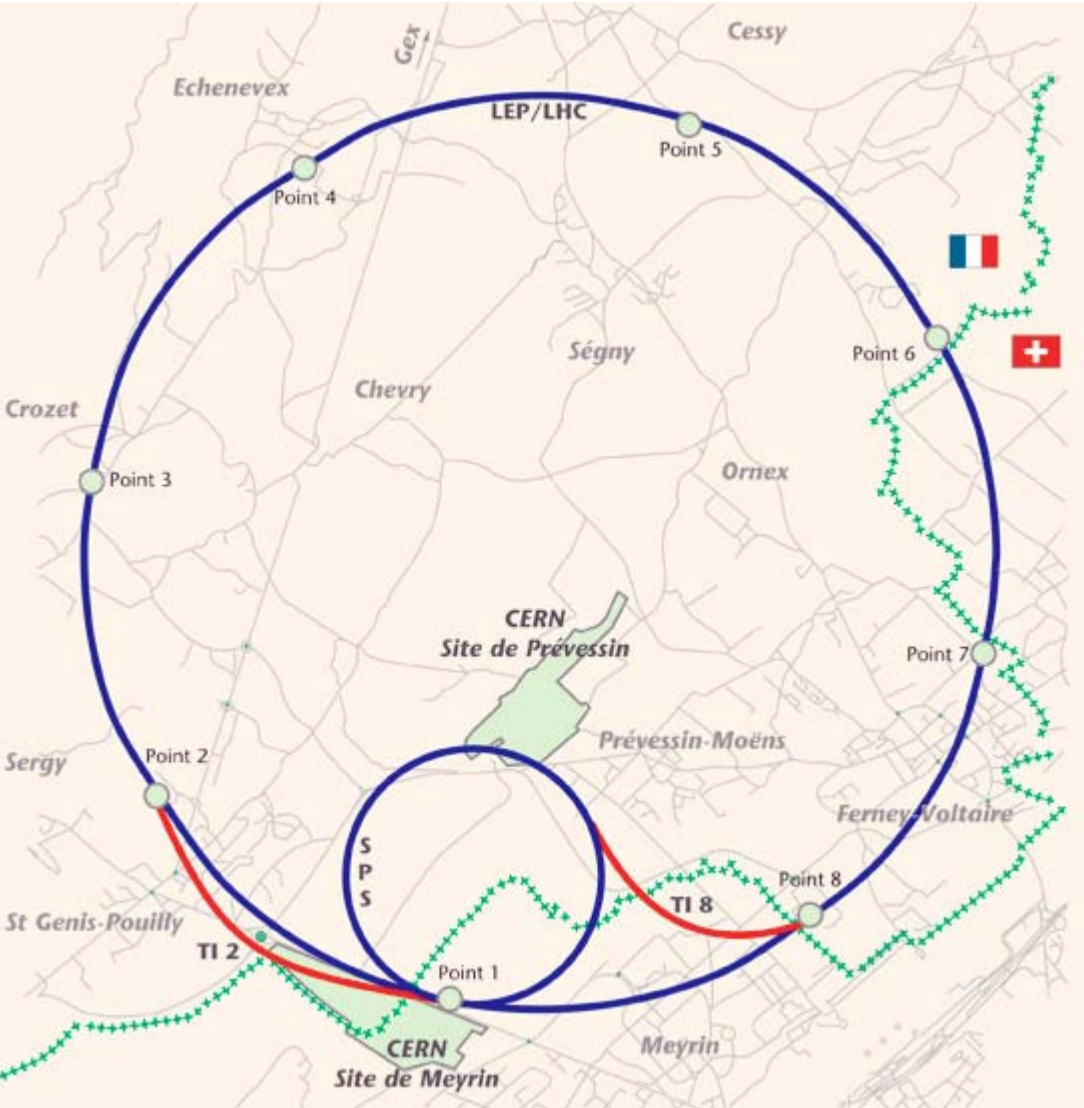


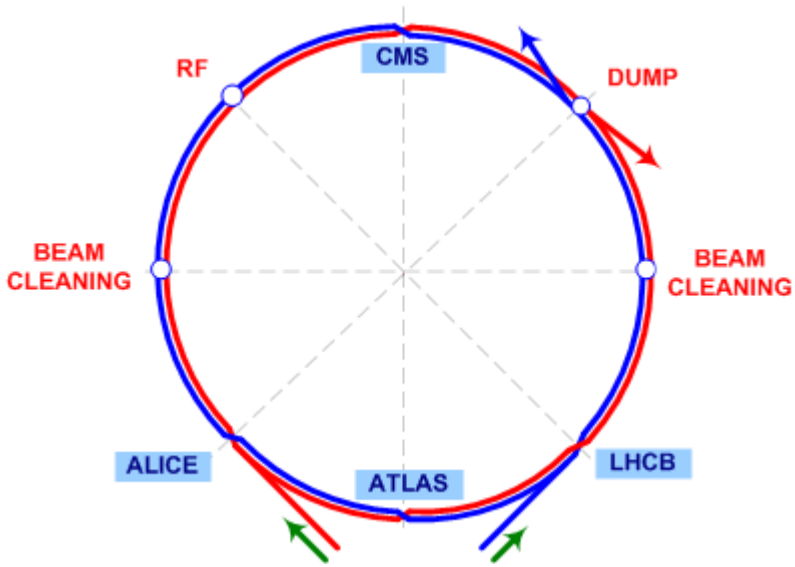


Two beams of trillions of protons will race around the 27km ring in opposite directions travelling at 0.999999991 times the speed of light…

Sometime soon!

LHC





Eight sectors plus:

Point 1: Atlas

Point 2: Alice, injection

Point 3: Momentum cleaning

Point 4: RF

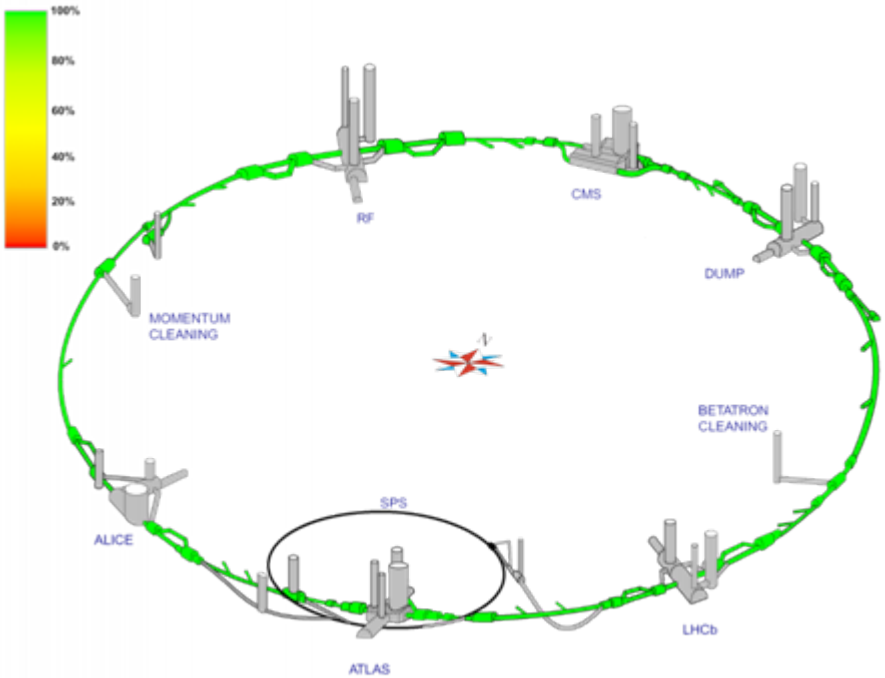
Point 5: CMS

Point 6: Beam Dumps

Point 7: Betatron cleaning

Point 8: LHCb, injection

Components: cryogenics supply line



3.3 km of QRL per sector

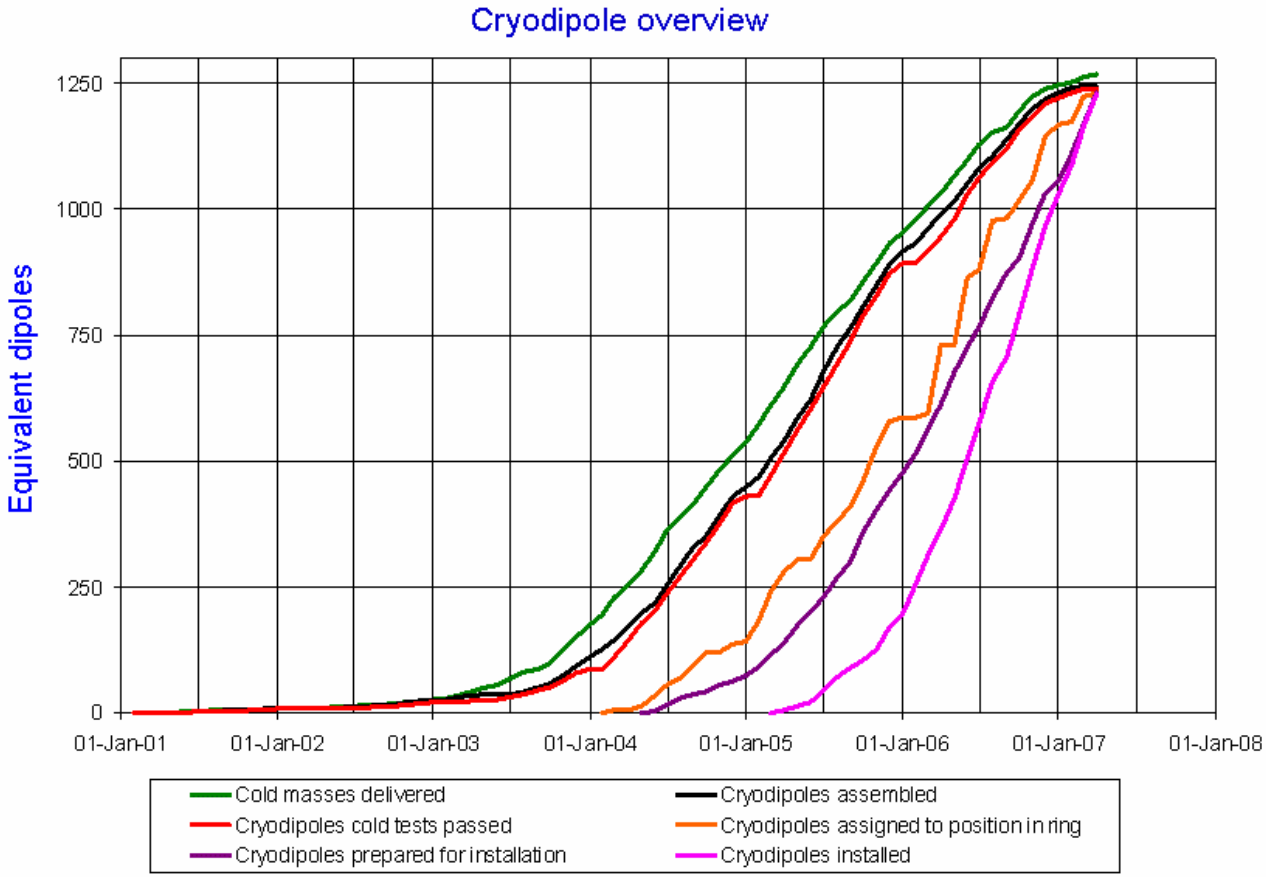
2100 internal welds

700 external manual welds

Components: dipoles

LHC Progress Dashboard

Accelerator Technology Department



Updated 31 March 2007

Data provided by D. Tommasini AT-MCS, L. Bottura AT-MTM

Components: DFBs (feedboxes)

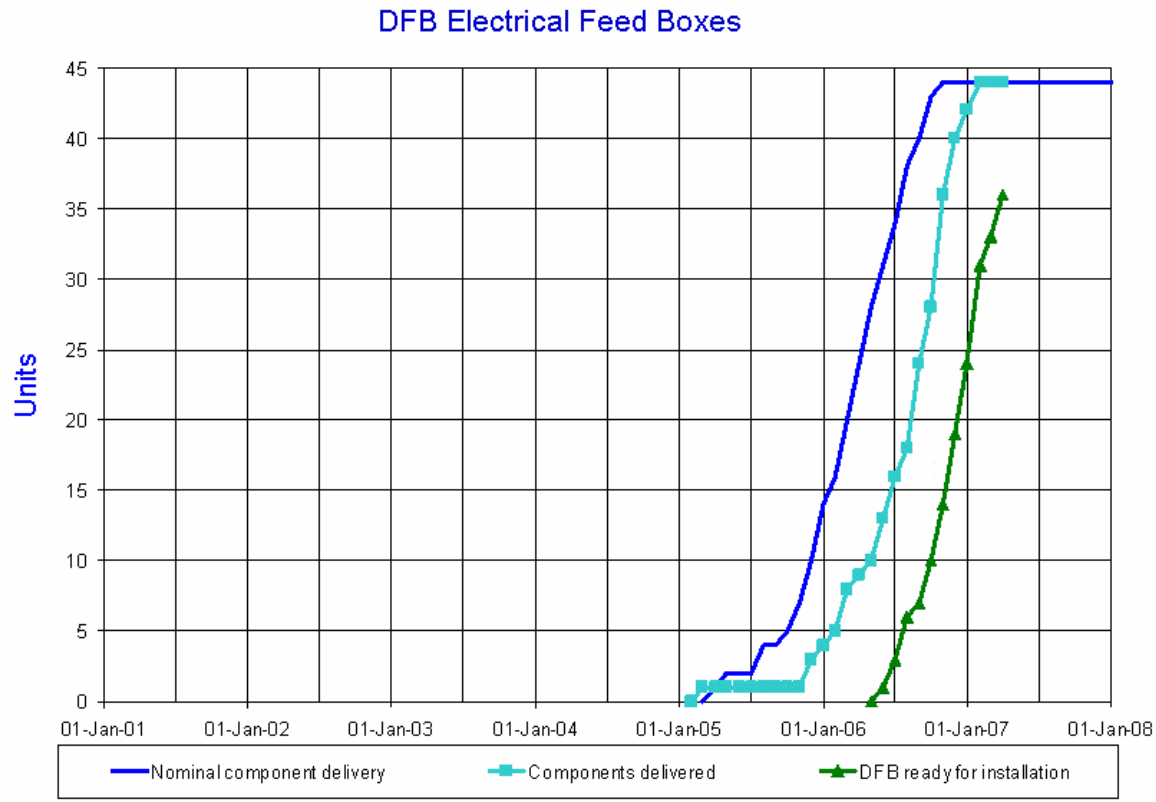
Responsible for feeding the room temperature cables into the cold mass.

DFBA - arcs
DFBM - quads
DFBL - links
DFBX – triplets

DFBs

LHC Progress Dashboard

Accelerator Technology Department



Updated 31 March 2007 Data provided by A. Perin AT-ACR

were close to the critical path…

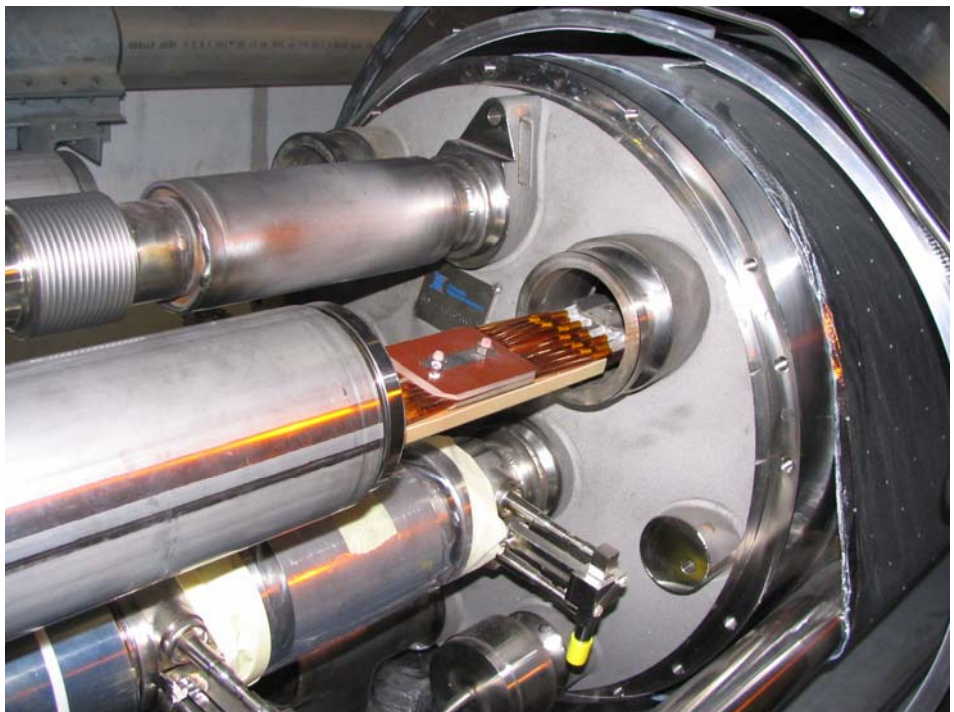
Installation: magnets

The magnets are in.

Interconnects

Vacuum, bellows, RF contacts plus leak checks
Cryogenics, thermal shield, heat exchanger
Bus bars
- superconducting splices x 10,000 (induction welding)

Corrector circuits
- splices x 50,000 (ultrasonic welding)



Joining everything up 1700 times

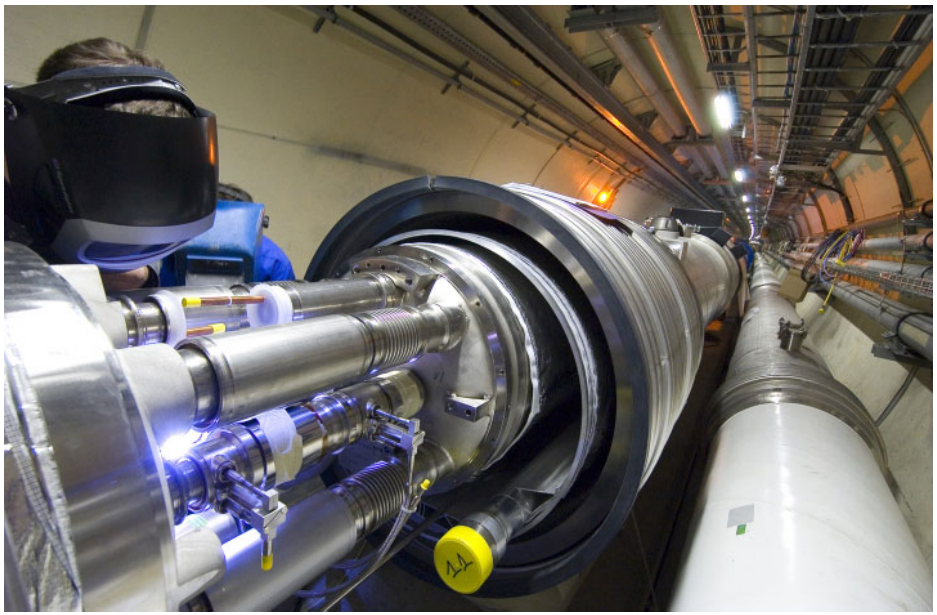
Huge, painstaking & industrialized

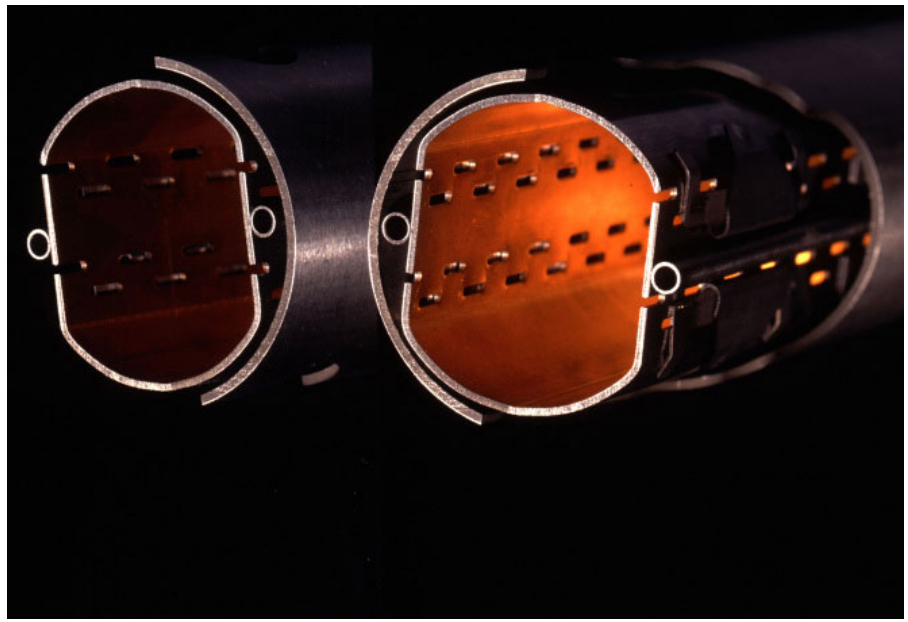
Clearly on the critical path

Check the wiring

Vacuum

27 km (x ~2 +): warm, cold, transitions, valves, gauges, bake-out





The vacuum group are very, very busy…

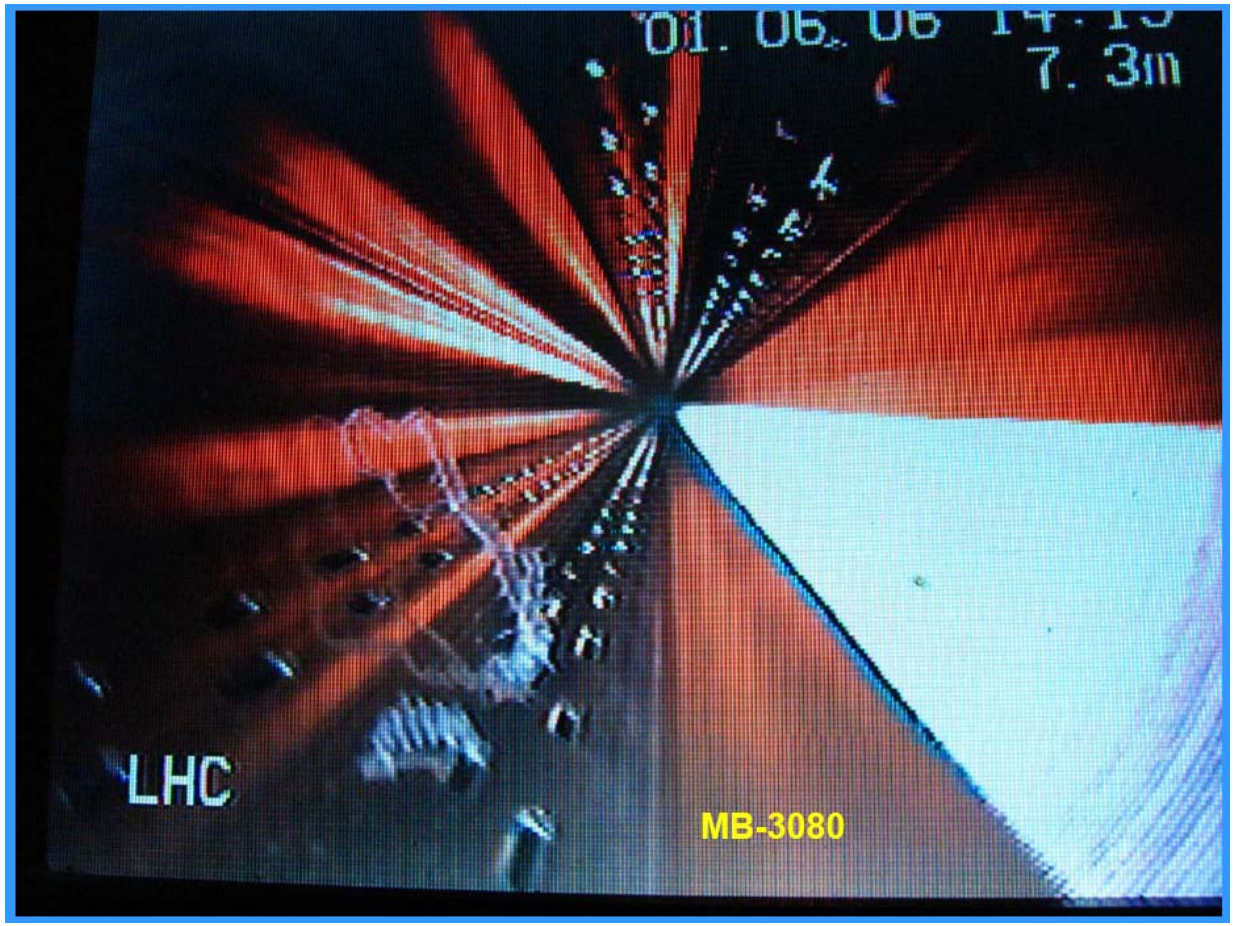
Miscellaneous

MQ.30L8, 31.01.2006

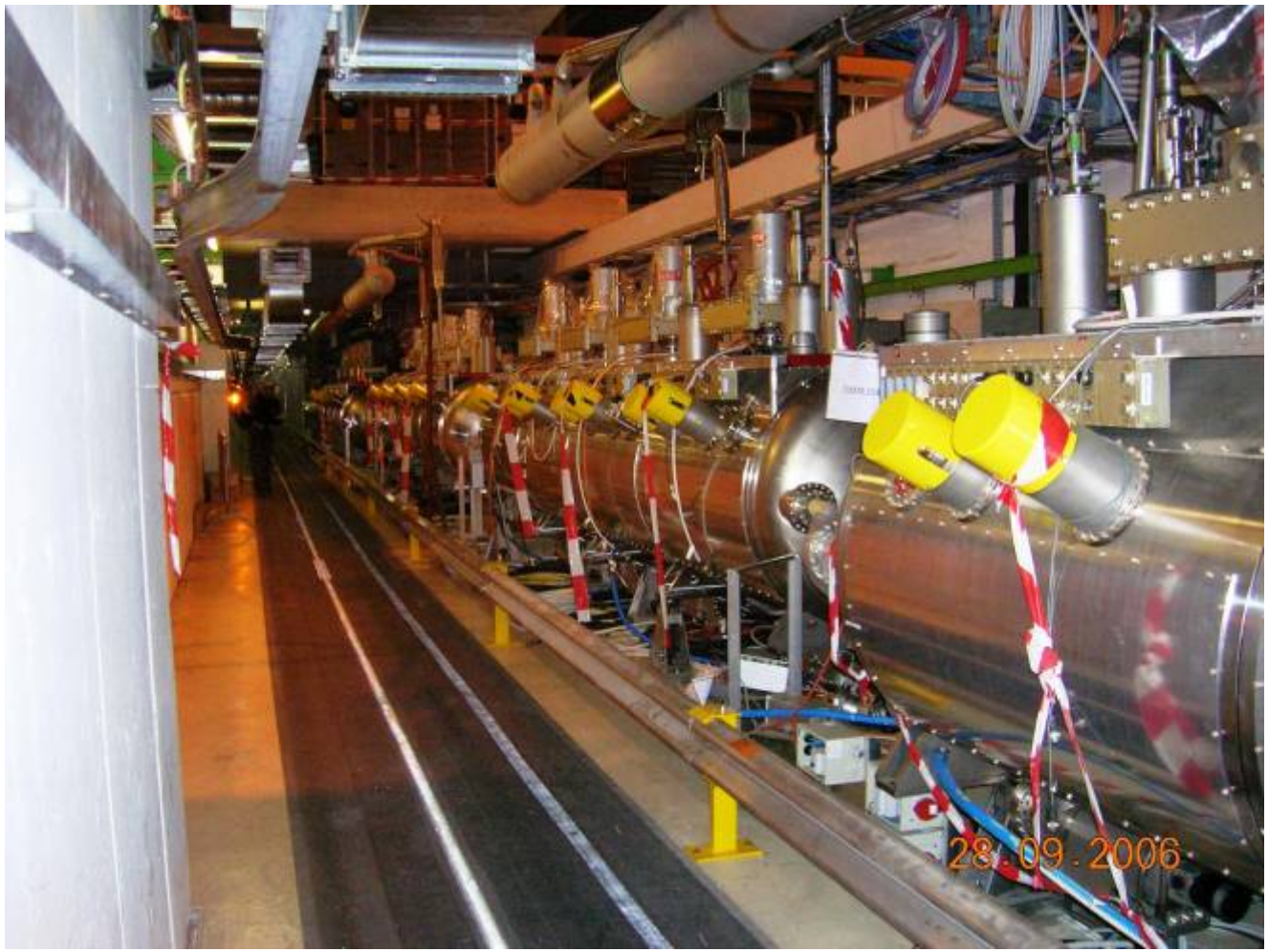
echo -22 dB

Potential aperture restrictions!

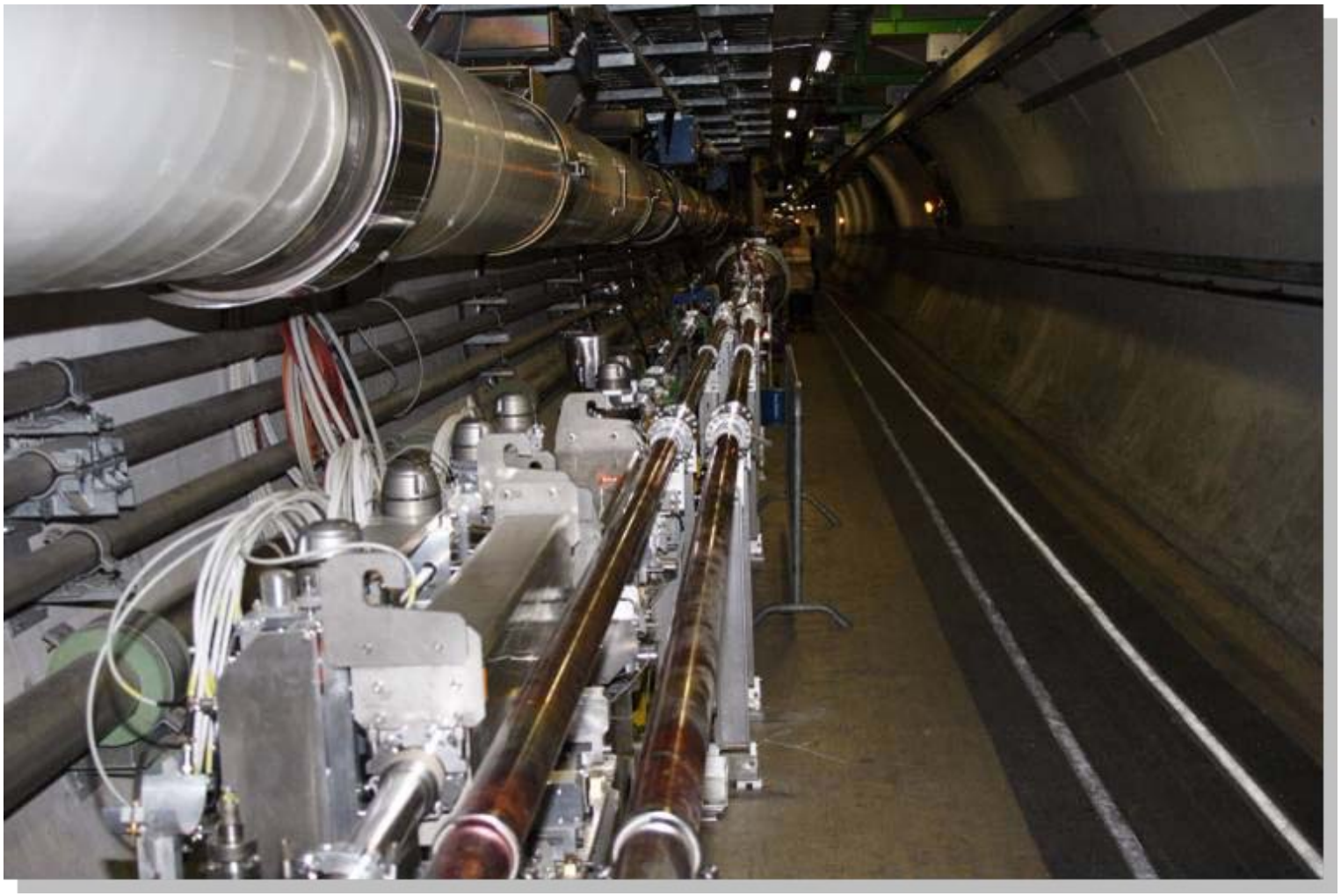
Bits and bobs



Installation: RF - point 4



Installation: junction of TI8 injection line

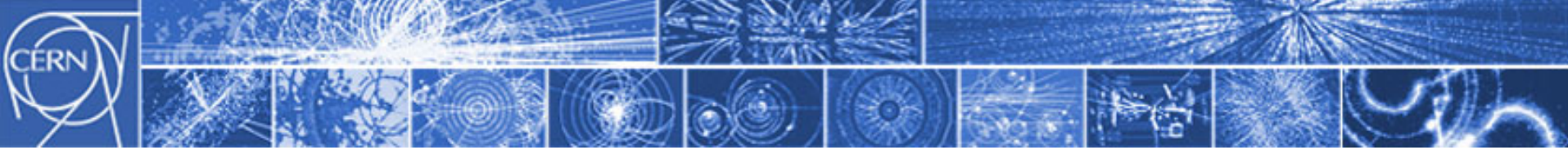


Installation: summary

All dipoles, arc and special SSS have been prepared on schedule

- **Interconnection** on-going in 6 sectors:
  - Closure of sectors 4-5 and 8-1upcoming
  - Pressure test of sector 4-5 (without low-β)
  - Interconnect activity starts in **sector 1-2** soon
- **Feed boxes**
  - 6/8 DFBX, 19/23 DFBM, 9/16 DFBA and 4/5 DFBL are in place
- **Arc 1-2** completed, except 3 MB and 2 SSS (to leave TI2-UJ22-LHC ring passage for low-β)
- **Installation of beam pipe and vacuum elements** is close to nominal rates despite procurement difficulties and co-activities

- **Critical issues**: **low-β triplets**…



Following installation we have in situ hardware tests….

From The Sunday Times

April 8, 2007

Big Bang at the atomic lab after scientists get their maths wrong

Jonathan Leake, Science Editor

A £2 billion project to answer some of the biggest mysteries of the universe has been delayed by months after scientists building it made basic errors in their mathematical calculations.

The mistakes led to an explosion deep in the tunnel at the Cern particle accelerator complex near Geneva in Switzerland. It lifted a 20-ton magnet off its mountings, filling a tunnel with helium gas and forcing an evacuation.

It means that 24 magnets located all around the 17-mile circular accelerator must now be stripped down and repaired or upgraded. The failure is a huge embarrassment for Fermilab, the American national physics laboratory that built the magnets and the anchor system that secured them to the machine.

EXPLORE UK
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TIMES RECOM
› Tarantino reel left on shelf
› The love trian caused feathe
› Darwin nearly evolve in print

EXPLOTA EL MAYOR IMÁN DEL MUNDO

Un error en los cálculos matemáticos destroza el acelerador de partículas del CERN

Actualizado martes 10/04/2007 16:57 (CET)

OLALLA CERNUDA (elmundo.es)

MADRID.- El acelerador de partículas más famoso del mundo, el que se aloja en el subsuelo del Consejo Europeo de Investigación Nuclear (CERN) en Ginebra (Suiza), ha sufrido un serio daño después de producirse **una gran explosión en sus profundidades**. El 'big bang' tiene una explicación absolutamente científica: un error matemático en el diseño de los anclajes de los grandes imanes que se utilizan en la estructura.

▲ Imagen del acelerador de partículas LHC. (Foto: EPA)

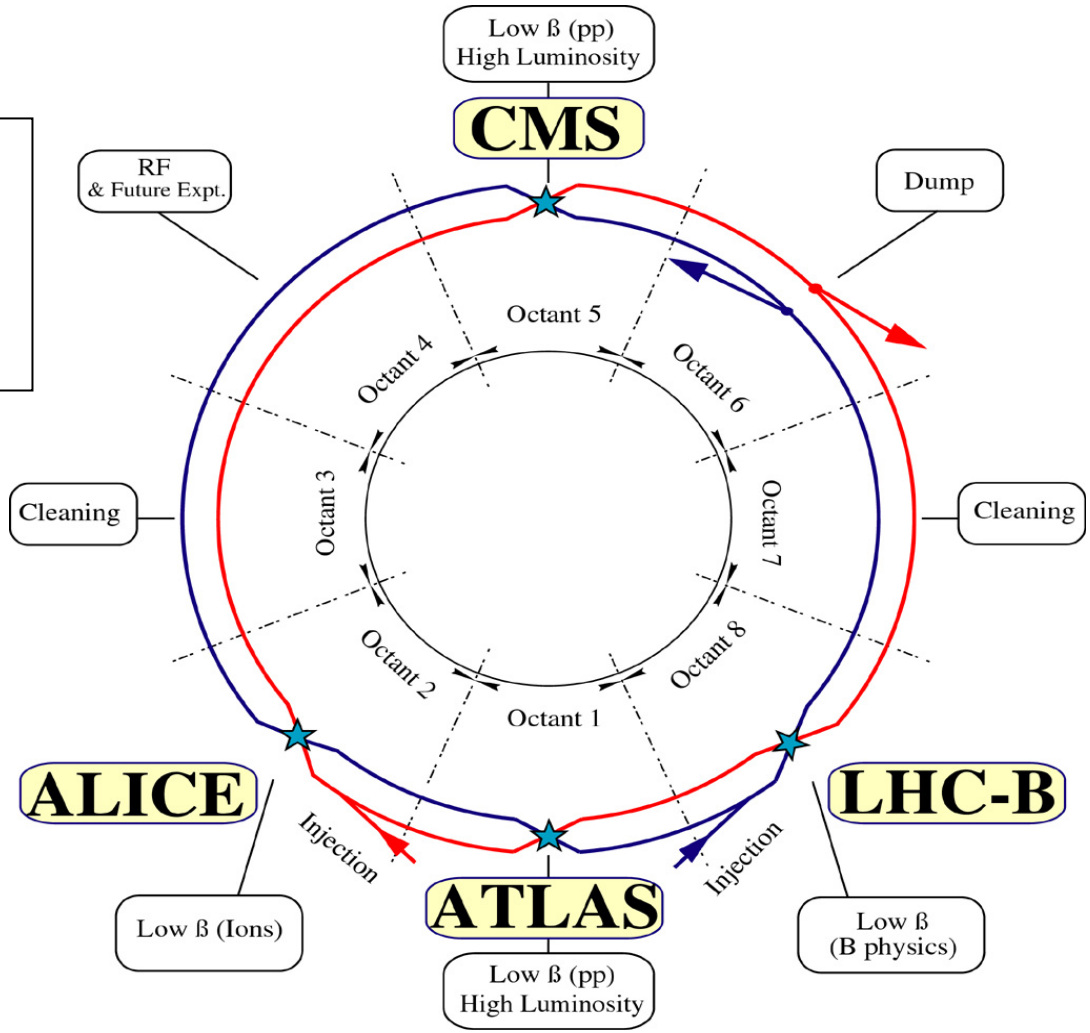
Según publica el diario 'The Times', la explosión se produjo el pasado 27 de marzo, y **levantó de sus sujeciones un imán de 20 toneladas de peso**, llenando de helio una de las galerías y obligando a evacuar el complejo. "Fue una explosión enorme. El túnel que aloja los imanes se llenó de helio y polvo y tuvimos que llamar a los bomberos para evacuar el edificio y tratar de ver los daños causados por la explosión", relató al diario británico un científico presente en el centro en el momento del suceso.

Para que el acelerador de partículas vuelva a funcionar, los técnicos deberán desmontar y reparar al menos tres de los 24 imanes situados a lo largo de los 27 kilómetros del túnel, denominado 'Gran Colisionador de Hadrones'. Según explicó el CERN en una nota de prensa, **"el fallo matemático afecta al sistema de anclaje**, que resultó ser insuficiente una vez el mecanismo entró en funcionamiento".

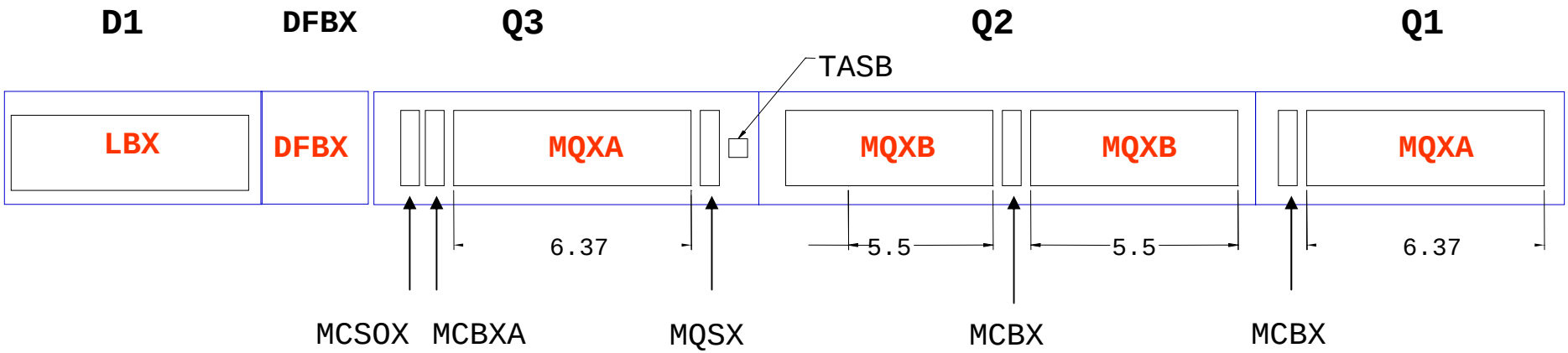
Inner triplets

Experimental insertions in points
1, 2, 5, 8 contain low-beta triplets.

In total, eight triplets are installed.



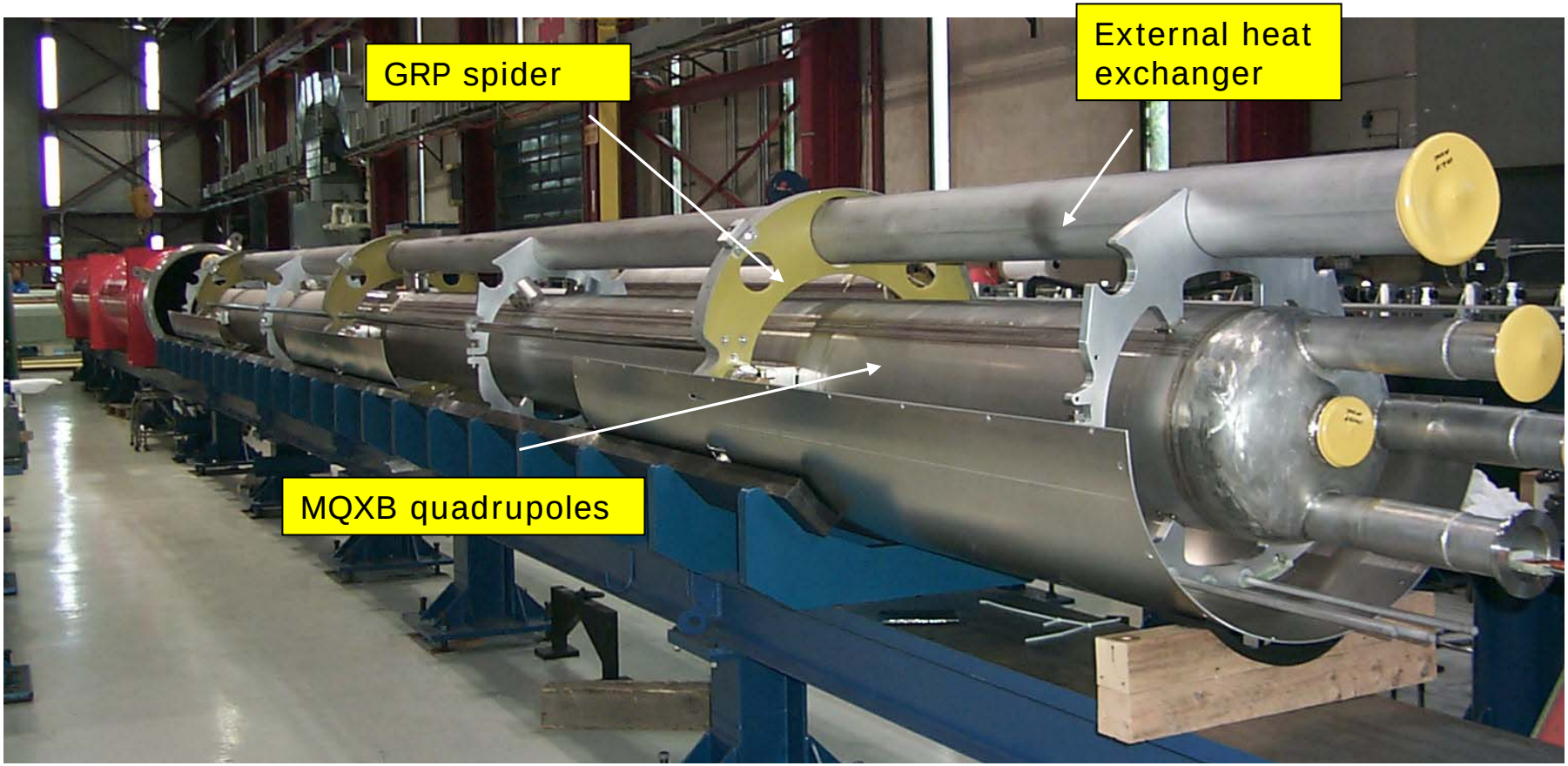
The LHC low-β triplet



IR 1 and 5, D1 is a normal conducting dipole.

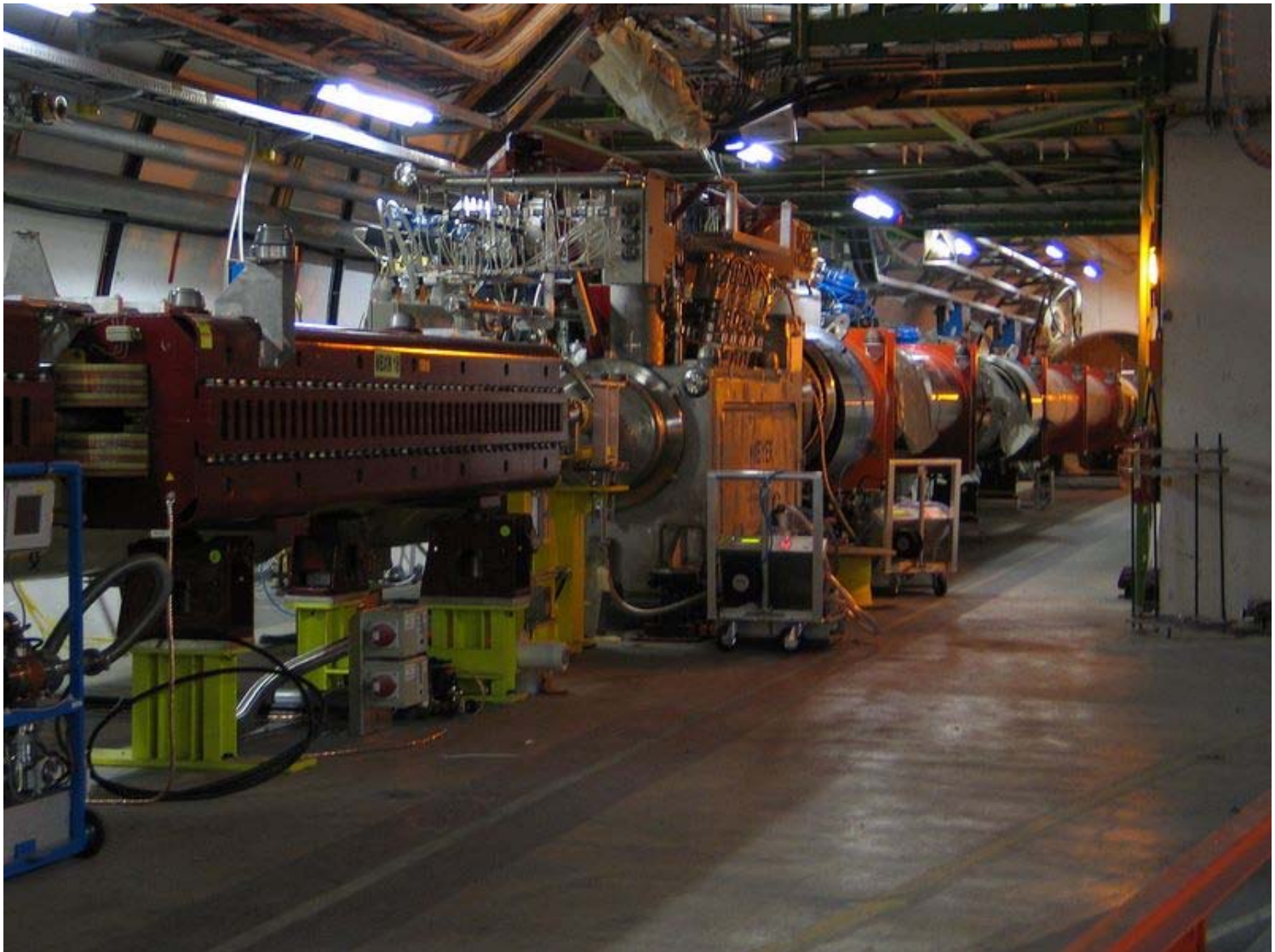
Triplets were designed and built by a collaboration of five laboratories: BNL, CERN, Fermilab, KEK, LBNL.

LHC low-β triplet – Q2



LHC low-β triplet – warm assembly

LHC low-β triplet – DFBX



Q1 - Q2 interconnect

Inner triplet problem 1: heat exchanger

During the pressure test of Sector 8-1 (25th November) the heat exchanger tube in the inner triplet failed at 9 bar differential pressure.

The inner triplet was isolated and the pressure test of the whole octant was successfully carried out to the maximum pressure of 27.5 bar.

Inner triplet problem 2:

Pressure test of triplet in 5L

Pressure test failed at 20 bar. Direct cause:
Axial movement of Q1 cold mass towards the IP due to thrust force, which led to the break of the support system (spiders) and rupture of M1 bellows.

Bang

Analysis at CERN and Fermilab agree with the following loads at warm pressure test (all lines pressurized simultaneously to 1.25 design pressure):

Q1: resultant load of **169 kN** in the direction of the IP,

Q3: resultant load of **143 kN** in the direction of the DFBX.

The loads seen by the triplet in 5L at 20 bar were:

Q1: load of **114 kN** in the direction of the IP,

Q3: load of **93 kN** in the direction of the DFBX.

Transient pressure during cool-down in cold mass circuit: 17 bar.

Nominal design pressure in cold mass circuit at cold: 20 bar.

FAQs (c/o Fermilab)

Did magnets explode during the pressure test?

- No. Nothing exploded. The longitudinal force applied during the test caused a quadrupole magnet to move, stretching the pipe connecting it to the adjoining magnet. The pipe ruptured, making a loud noise and releasing helium gas.

Was anyone hurt?

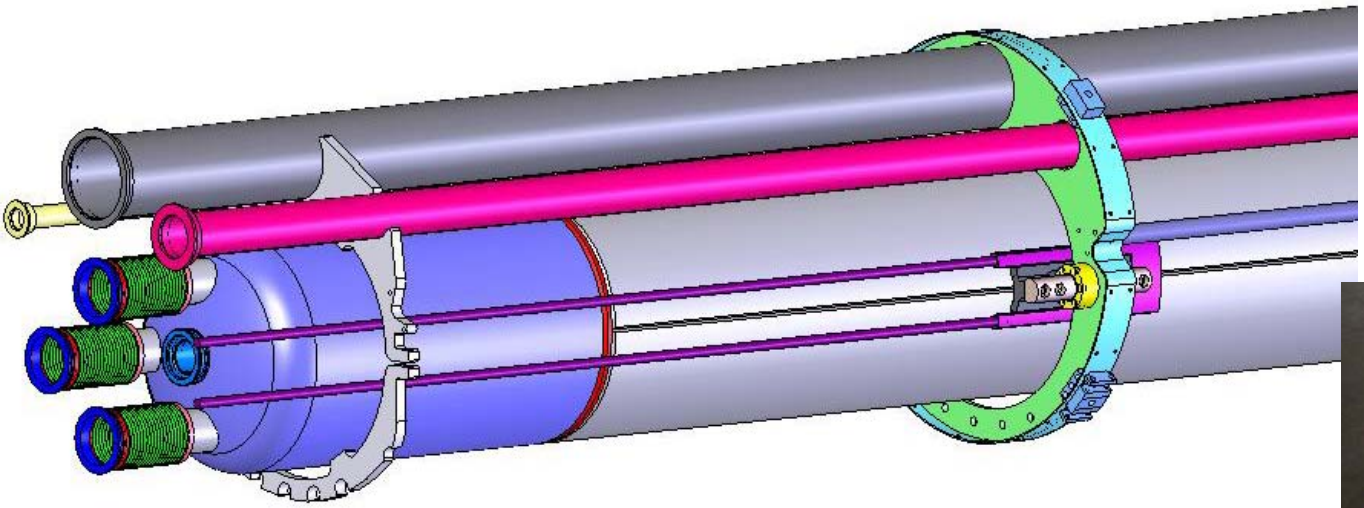
No. Safety precautions were followed and no one was injured.

Did a mistake in mathematics cause the magnet failure?

No. In an engineering oversight, Fermilab magnet designers failed to take into account the strength of longitudinal forces on the magnet in designing the magnet's support structure.

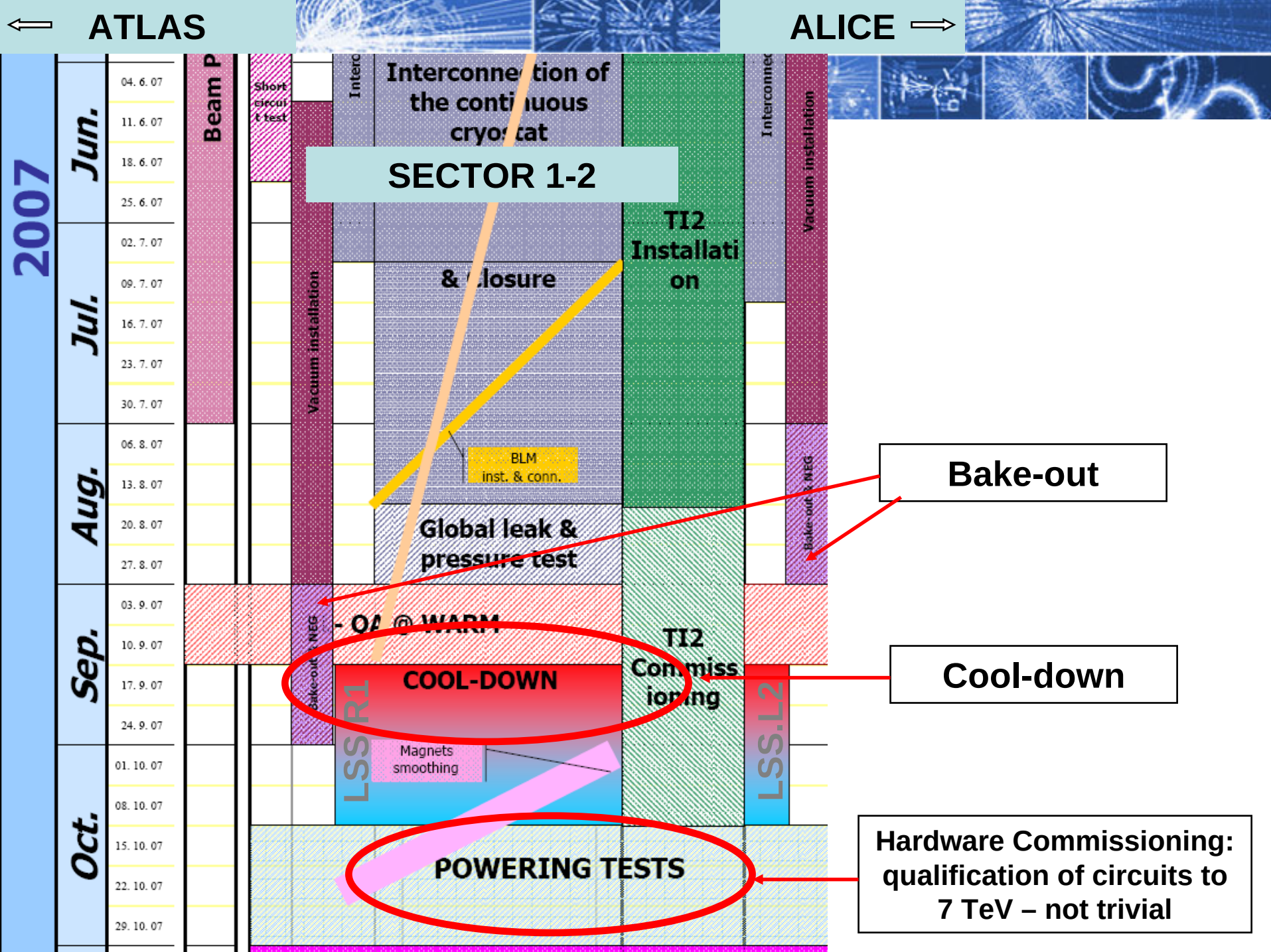
Repairing the fixed points

- Possible solutions:
  - Invar rod/hook assembly to reinforce the existing fixed point
  - Bumpers limiting longitudinal movement in both directions
  - Transfer of loads between magnets
  - A new fixed point at the extremity of the cryostat.

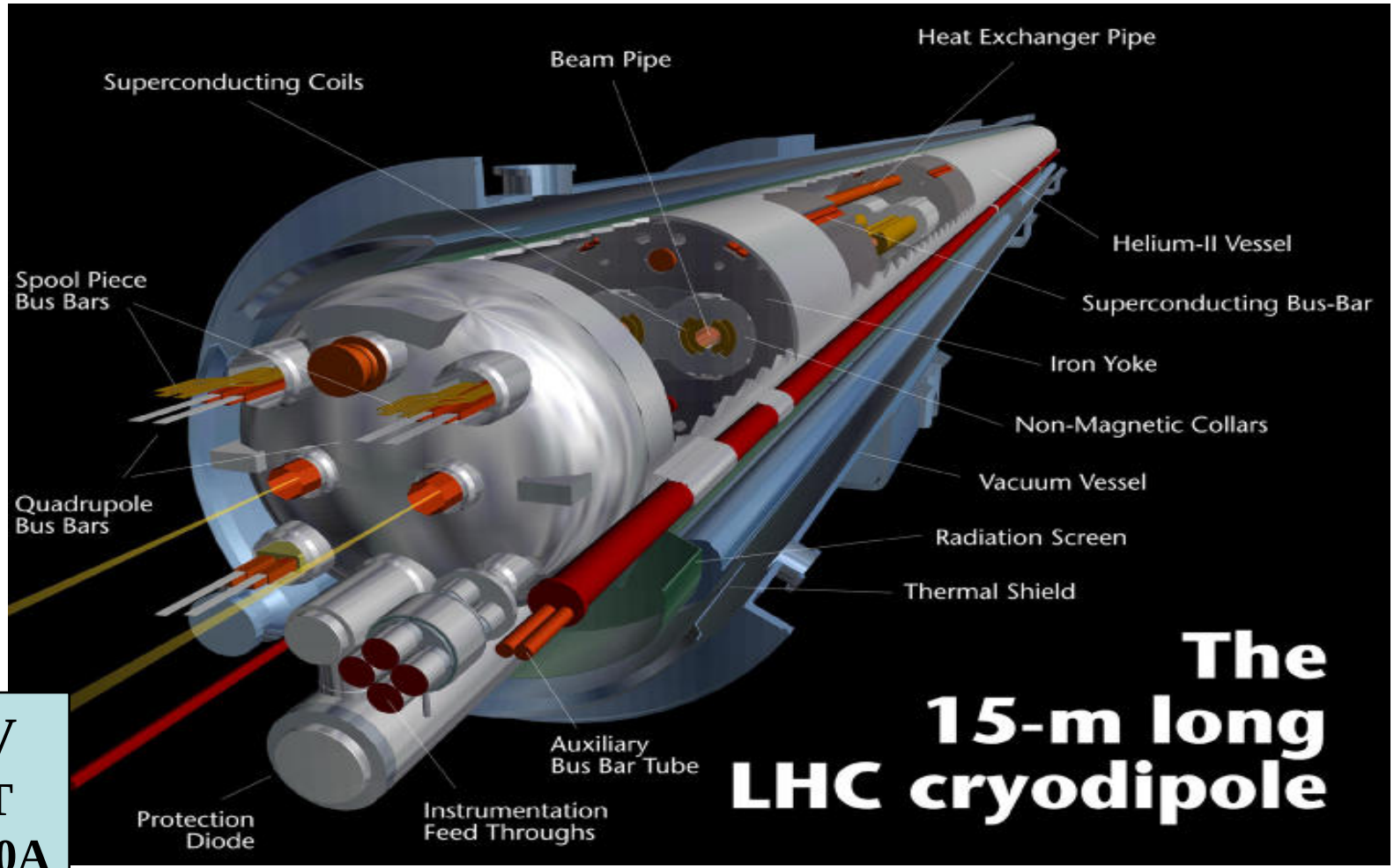


Work very much in progress

Cool down and hardware commissioning


ATLAS
ALICE
2007
Jun.
Jul.
Aug.
Sep.
Oct.
04. 6. 07
11. 6. 07
18. 6. 07
25. 6. 07
02. 7. 07
09. 7. 07
16. 7. 07
23. 7. 07
30. 7. 07
06. 8. 07
13. 8. 07
20. 8. 07
27. 8. 07
03. 9. 07
10. 9. 07
17. 9. 07
24. 9. 07
01. 10. 07
08. 10. 07
15. 10. 07
22. 10. 07
29. 10. 07
Beam P
Short circuit test
Interconnection of the continuous cryostat
SECTOR 1-2
TI2 Installation
& Closure
Vacuum installation
BLM inst. & conn.
Global leak & pressure test
COOL-DOWN
Magnets smoothing
TI2 Commissioning
LSS R1
LSS L2
POWERING TESTS
Bake-out
Cool-down
Hardware Commissioning: qualification of circuits to 7 TeV – not trivial

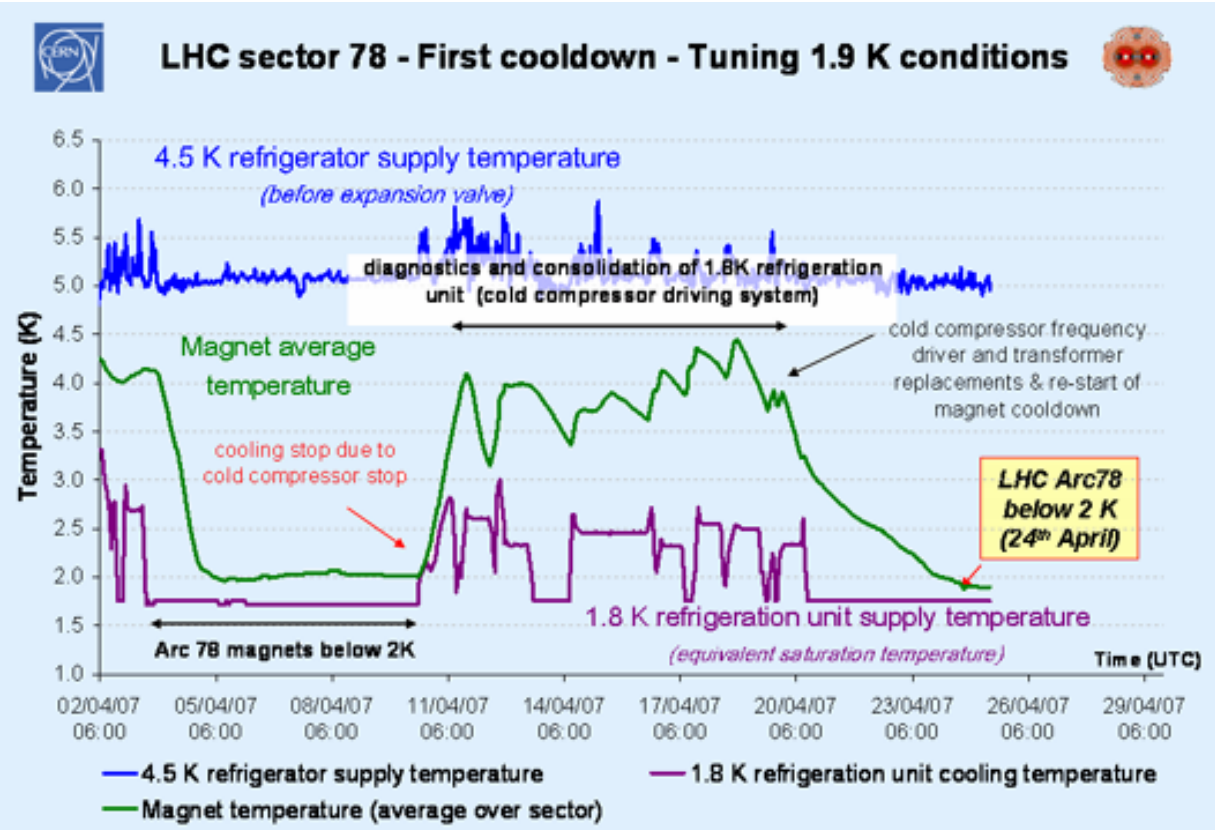
One sector: 3.3 km & 154 dipoles++



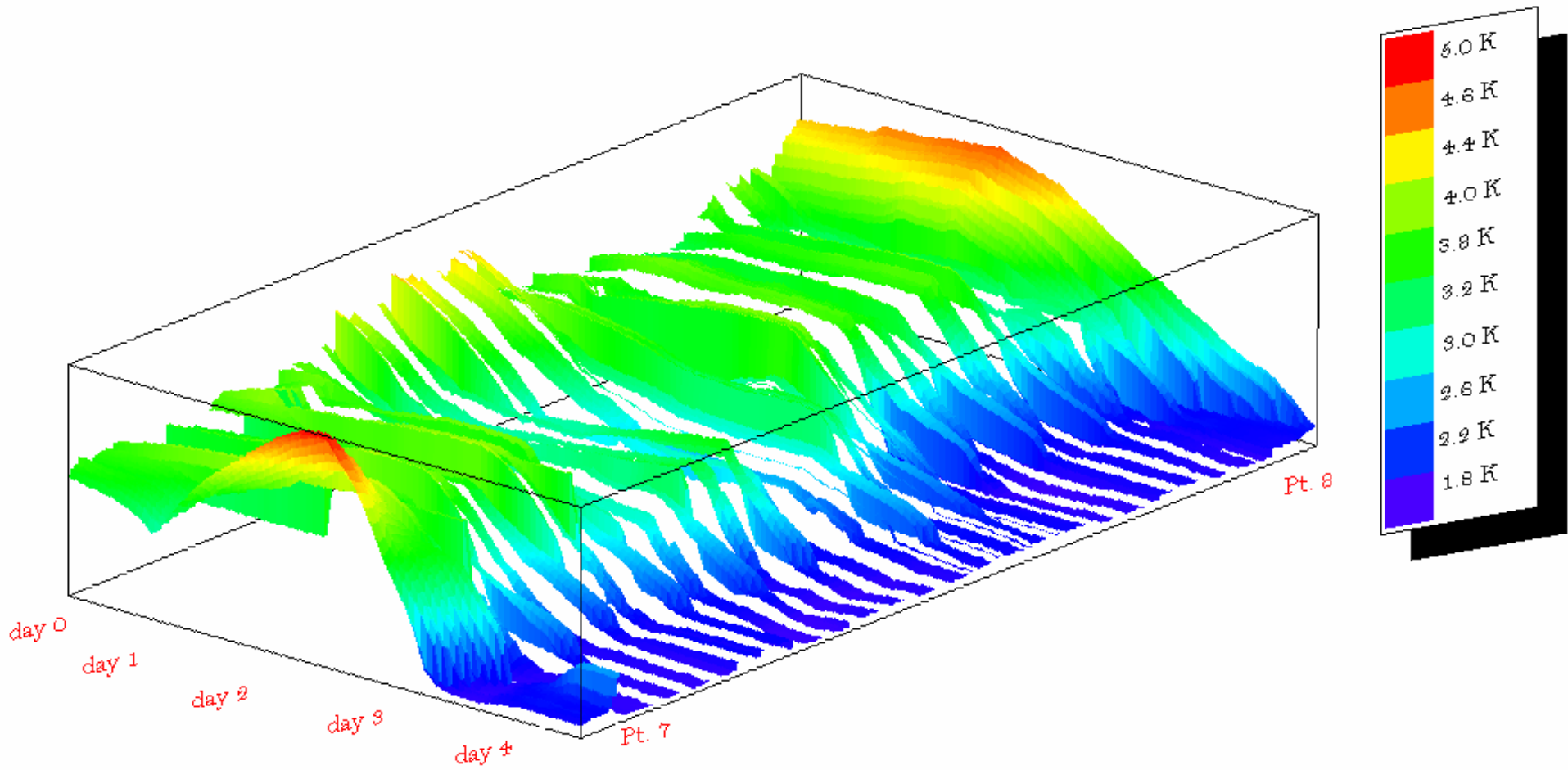
7 TeV

- **8.33T**
- **11850A**
- **7 MJ**

Cool down


LHC sector 78 - First cooldown - Tuning 1.9 K conditions
4.5 K refrigerator supply temperature
(before expansion valve)
diagnostics and consolidation of 1.8K refrigeration unit (cold compressor driving system)
Magnet average temperature
cold compressor frequency driver and transformer replacements & re-start of magnet cooldown
cooling stop due to cold compressor stop
LHC Arc78 below 2 K (24th April)
1.8 K refrigeration unit supply temperature
(equivalent saturation temperature)
Arc 78 magnets below 2K
Temperature (K)
Time (UTC)
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
02/04/07 06:00
05/04/07 06:00
08/04/07 06:00
11/04/07 06:00
14/04/07 06:00
17/04/07 06:00
20/04/07 06:00
23/04/07 06:00
26/04/07 06:00
29/04/07 06:00
4.5 K refrigerator supply temperature
1.8 K refrigeration unit cooling temperature
Magnet temperature (average over sector)

1.9 K cool down along the arc



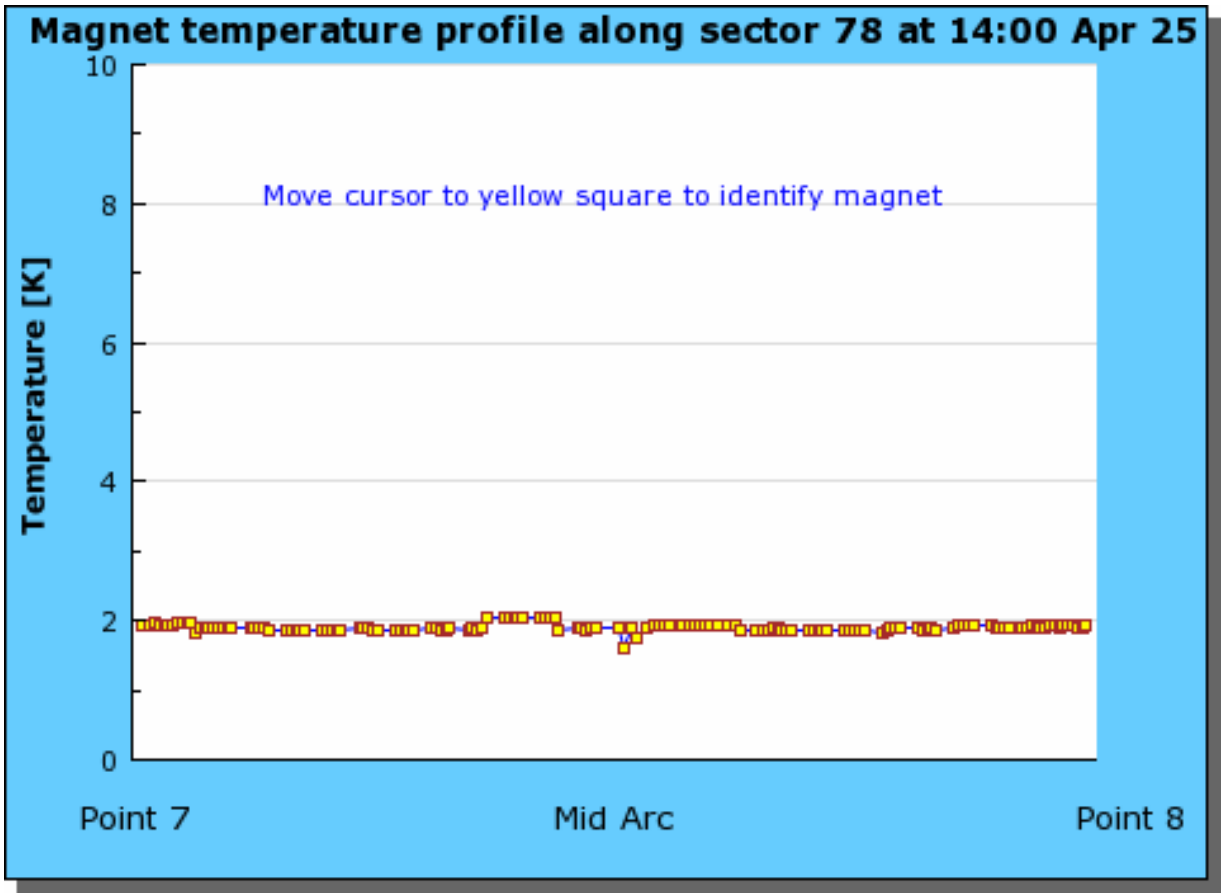
Not without a cryogenic wrestling match

- Power (400V failure on 30Mar'07)
  - cascade effect on cooling water, control networks, mobile vacuum pumping units
- Progressive set-up of procedures to pump-down to 15mbar, while keeping DFB's with 4.5K conditions
- Continued upgrades in instrumentation
  - (Level gauges, Heaters, …) but more efforts required to improve reliability and availability
- Test of magnet temperature control loops for 1.9K operation
- 1.8K Refrigeration unit trips (frequency drive) - difficulties to restore 1.9 K conditions after a stop

- Plus valves, Helium inventory…

but…..

Things are looking better…

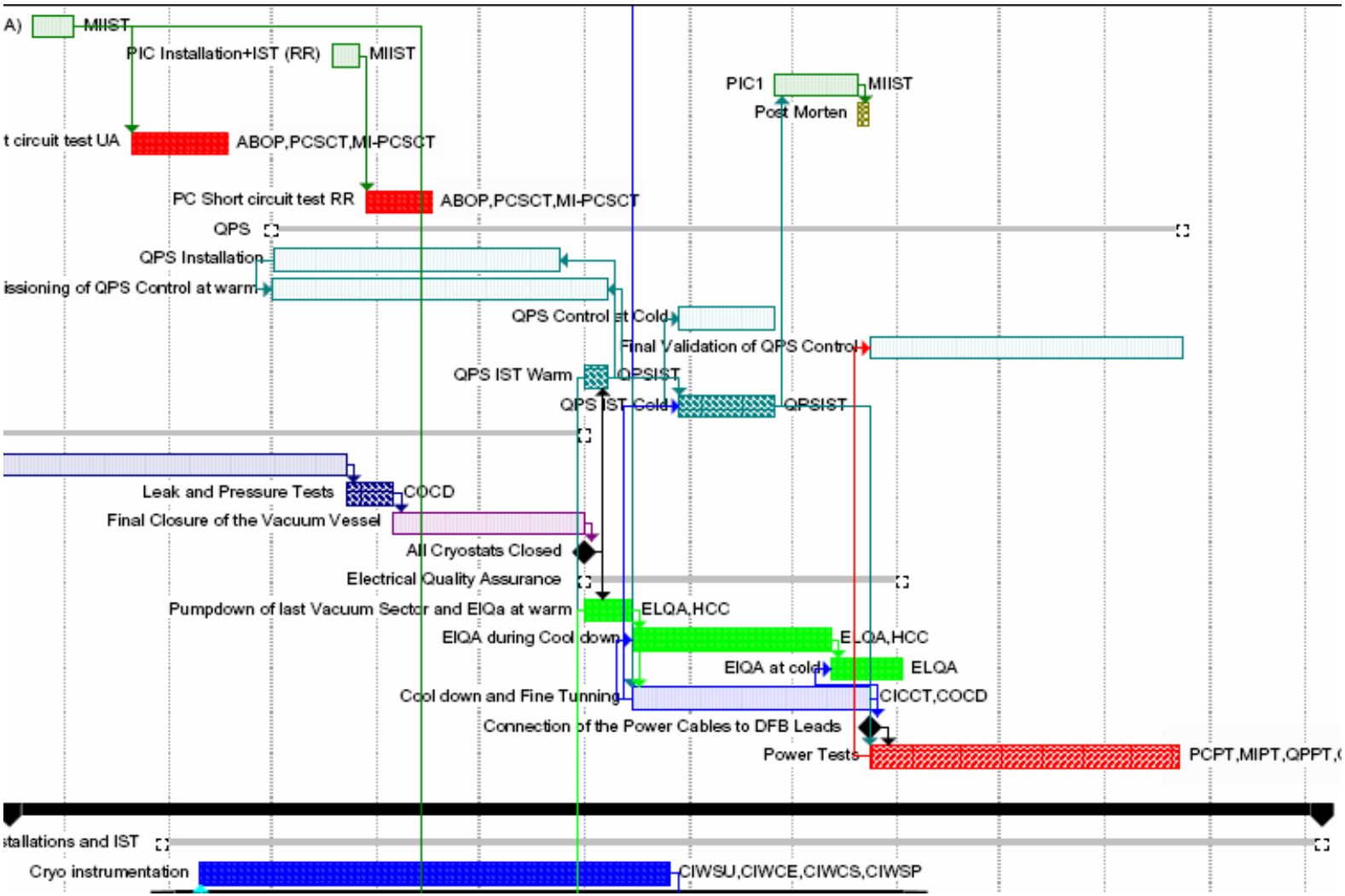


This is major achievement

Hardware commissioning

- Just starting – some 60 A correctors powered
- Detailed program of hardware tests to be performed:
  - Electrical quality assurance
  - Quench protection system
  - Energy extraction
  - Power Interlocks
  - Powering tests:
    - Current in magnets ramped very carefully
    - Recall huge energies involved.
- ~9 weeks per sector

HWC


A)
MIIST
PIC Installation+IST (RR)
MIIST
PIC1
MIIST
Post Morten
t circuit test UA
ABOP,PCSCT,MI-PCSCT
PC Short circuit test RR
ABOP,PCSCT,MI-PCSCT
QPS
QPS Installation
issioning of QPS Control at warm
QPS Control at Cold
Final Validation of QPS Control
QPS IST Warm
QPSIST
QPS IST Cold
QPSIST
Leak and Pressure Tests
COCD
Final Closure of the Vacuum Vessel
All Cryostats Closed
Electrical Quality Assurance
Pumpdown of last Vacuum Sector and ElQa at warm
ELQA,HCC
ElQA during Cool down
ELQA,HCC
ElQA at cold
ELQA
Cool down and Fine Tunning
CICCT,COCD
Connection of the Power Cables to DFB Leads
Power Tests
PCPT,MIPT,QPPT,
tallations and IST
Cryo instrumentation
CIWSU,CIWCE,CIWCS,CIWSP

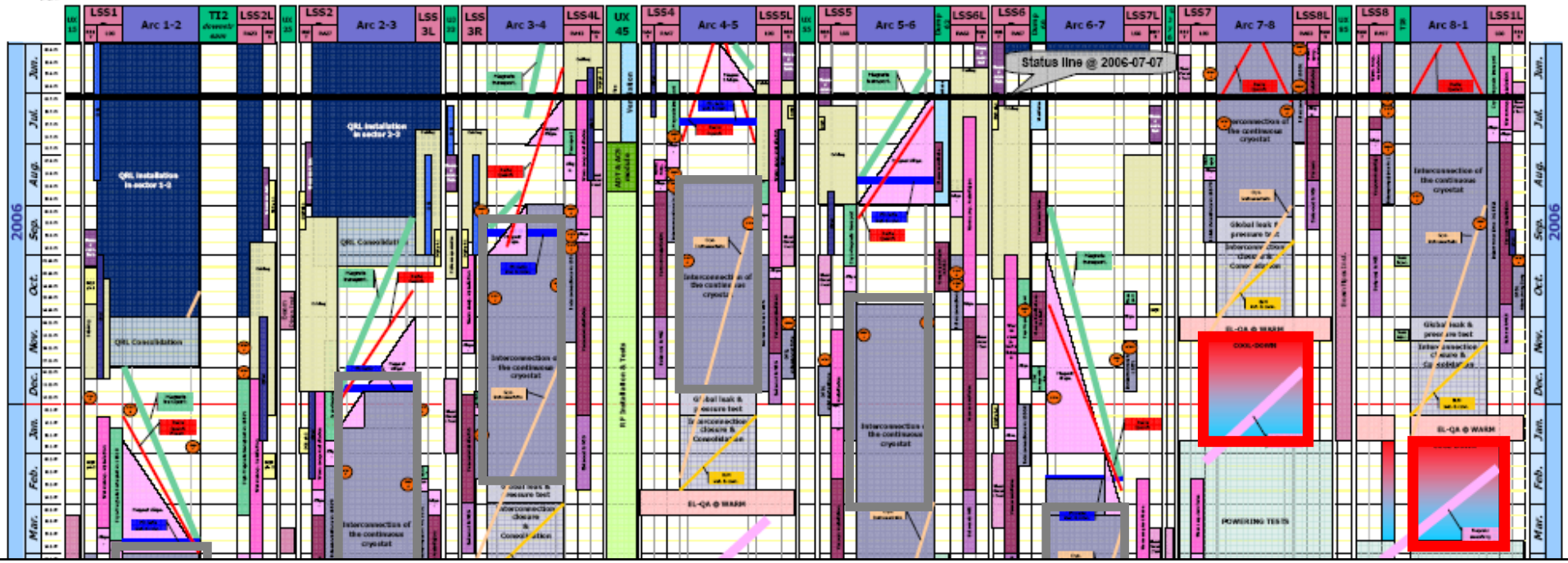
So…

- Feverish activity everywhere
- Sector 7-8 cold
- Hardware commissioning just starting.
- Some problems, for example:
  - Inner triplets
  - Quadrupole circuit earth fault
  - Suspect dipole sector 7-8 to be replaced
  - …

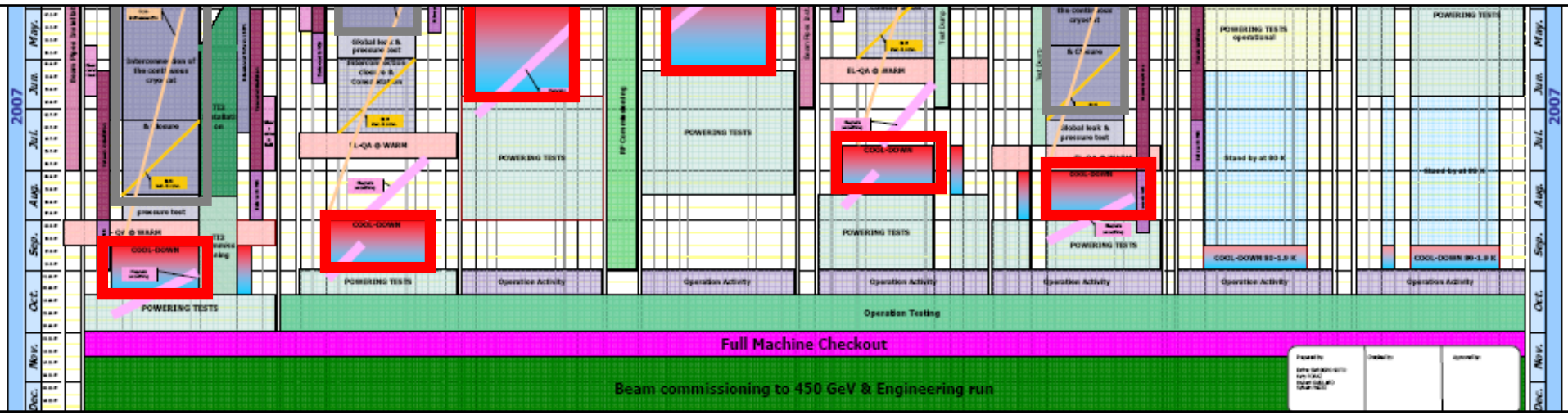
There is a lot left to do.

LHC Construction and Installation

General Co-ordination Schedule

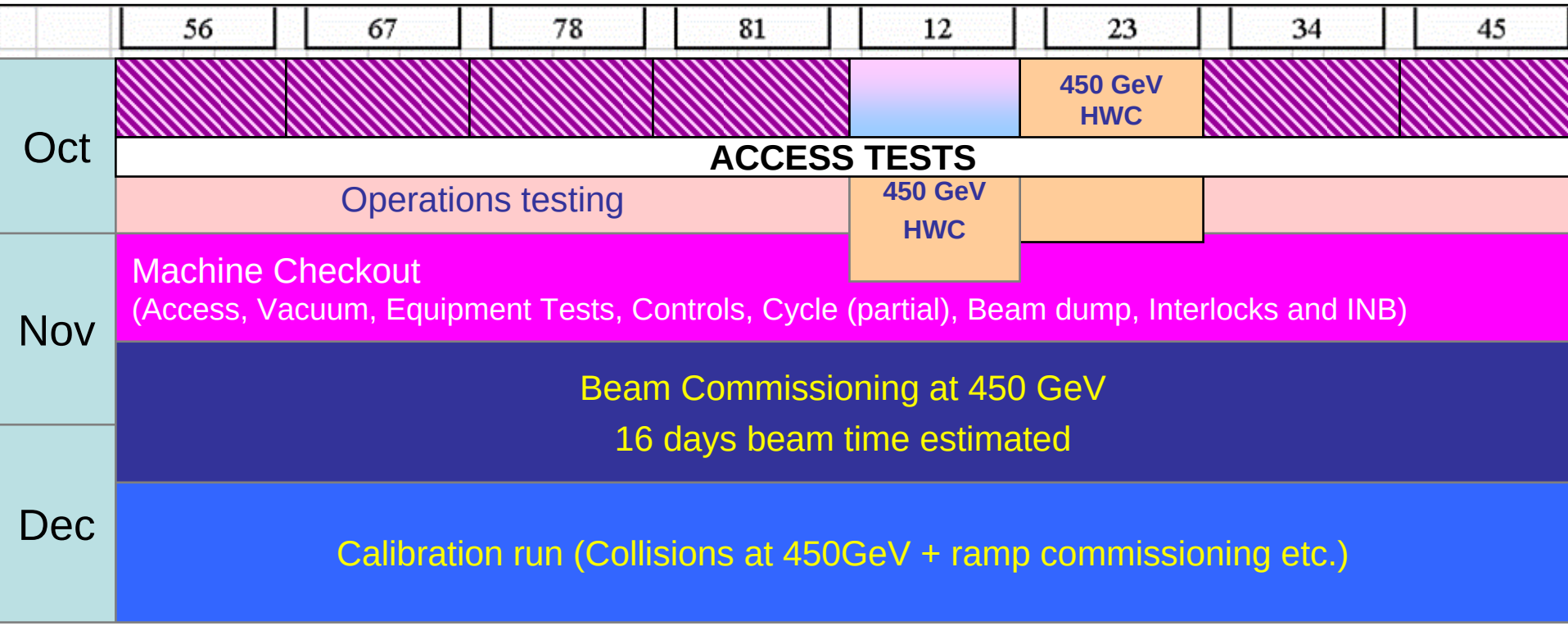


NOW



XMAS 2007

End 2007 – the schedule as it stands



Sectors 5-6, 6-7, 1-2 & 2-3:

- baseline commissioning of main circuits to 1.1 TeV

- minimal circuit set

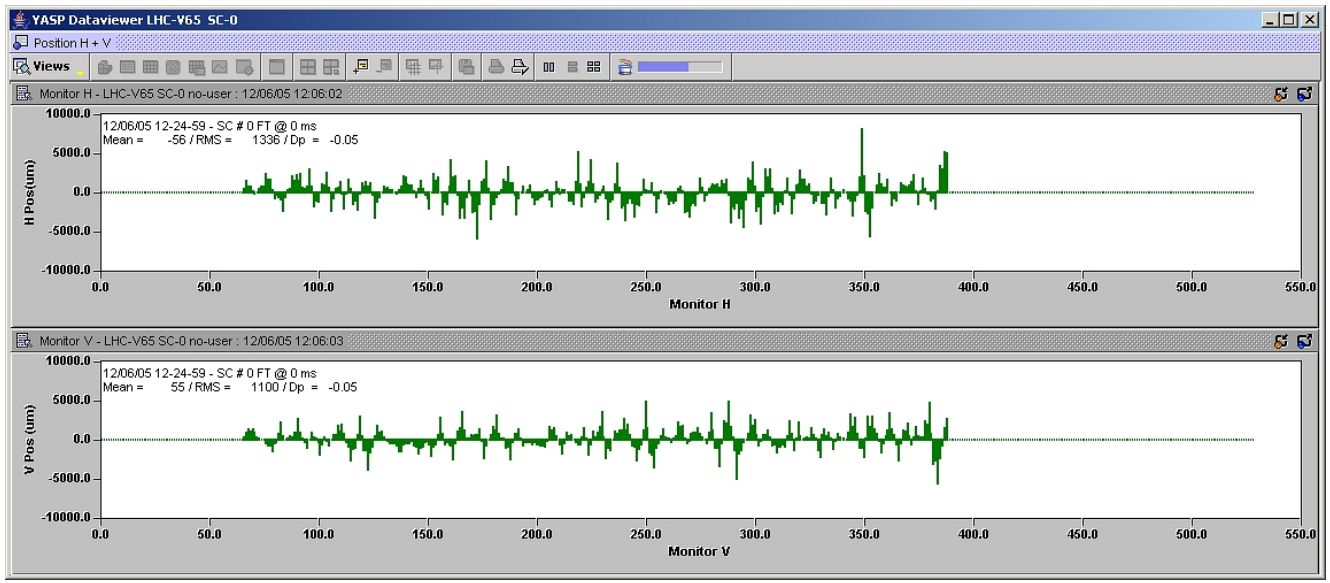
450 GeV – Calibration Run

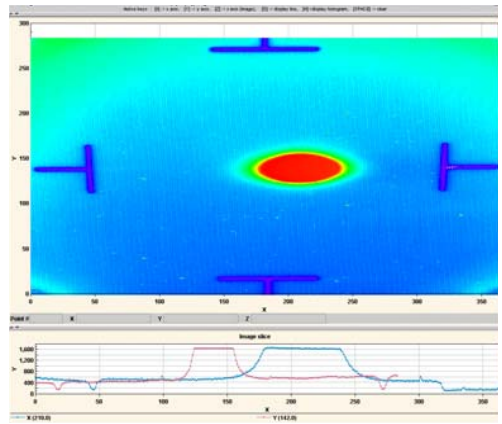
Operations' aims:

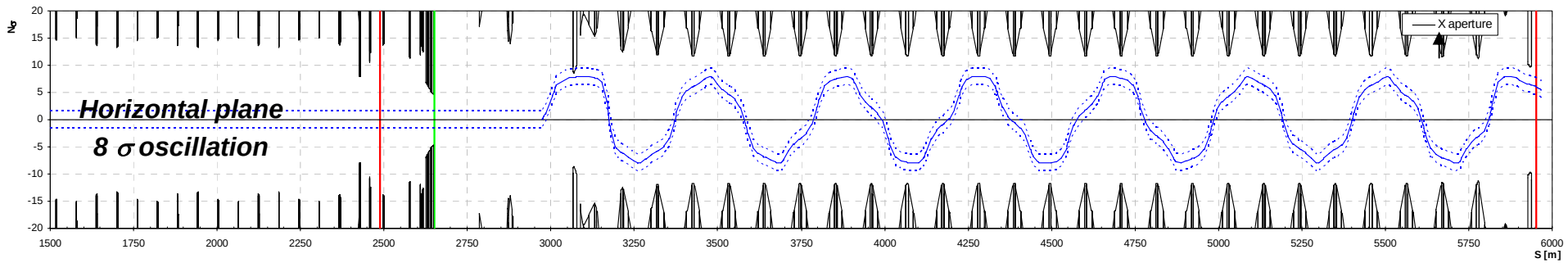
- Commission essential safety systems
- Commission essential beam instrumentation
- Commission essential hardware systems
- Perform beam based measurements to check:
  - Polarities, Aperture, Field characteristics
- Establish collisions
- Provide stable two beam operation at 450 GeV
- Interleave collisions with further machine development, in particular, the ramp.

Should provide a firm platform for eventual commissioning to 7 TeV and provide adequate lead time for problem resolution.

Beam commissioning







Calibration Run 2007

5-6 weeks beam time

2 weeks beam commissioning

- Essentially single beam, low intensity for the most part

3 weeks collisions

- Single bunch initially, with staged increase to 156 x 4 x 10^{10} (+)
- Luminosities: **1.3 10^{28} to 2.6 10^{29} $cm^{-2}s^{-1}$** (+)
- Interleafed with low intensity single beam MD
  - Initial ramping tests to 1.1 TeV etc.

Who knows…

	111	CERN AB	31-11-07	12:20:26
LHC Run	1234	data of	31-11-07	12:20:16

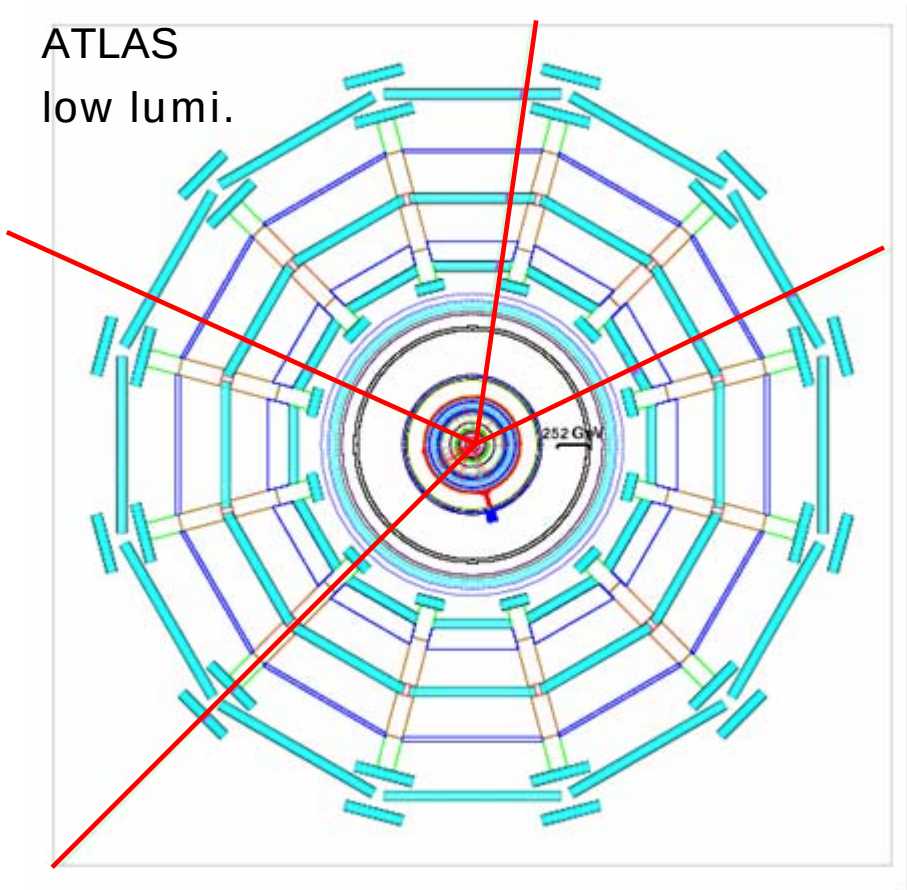
— ** STABLE BEAMS ** —

E = 0.450 TeV/c	Beam	In Coast	0.5 h
Beams	Beam 1	Beam 2	
#bun	43	43	
Nprot(t)	1.71e12	1.73e12	
tau(t) h	121	140	

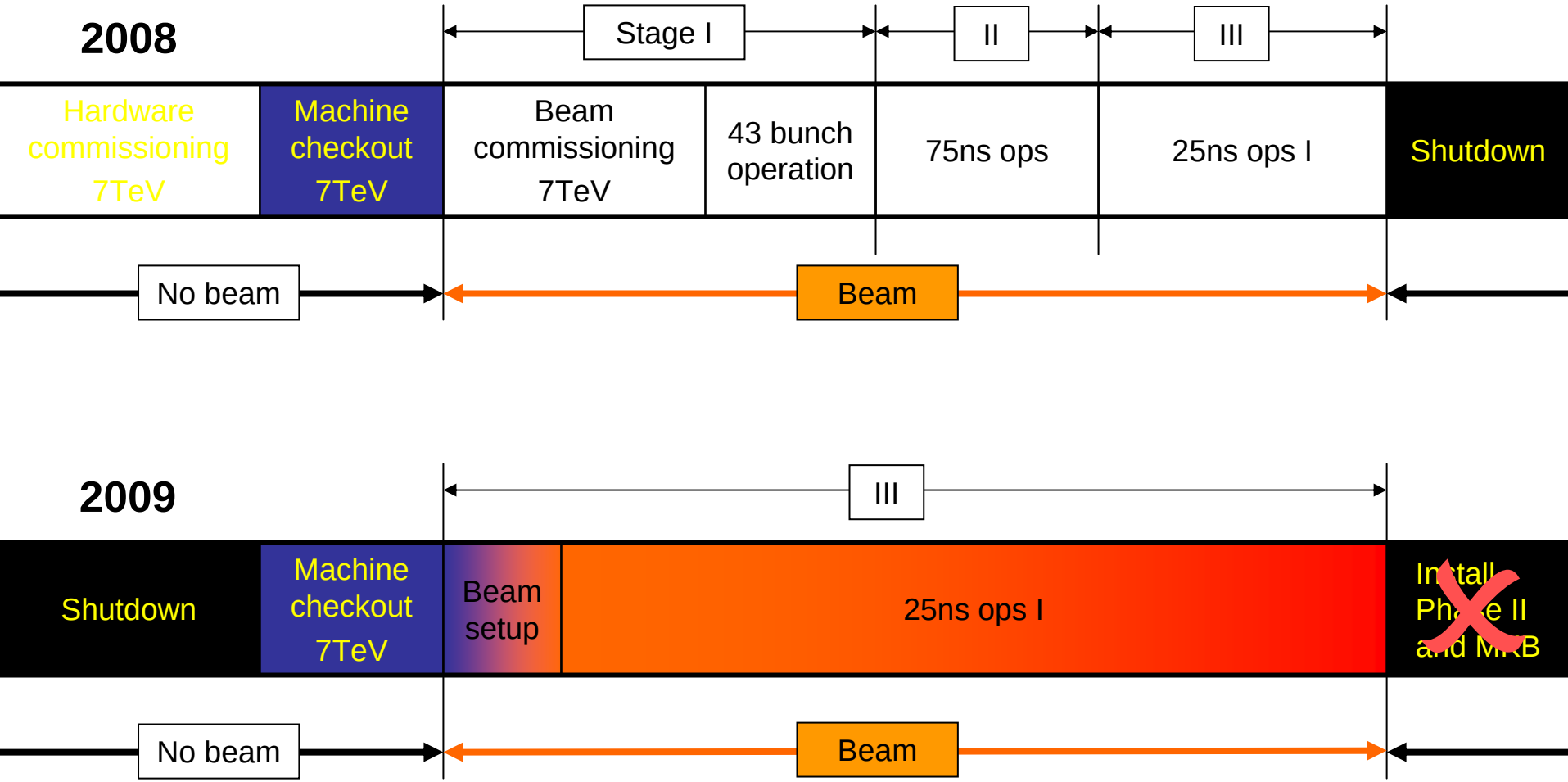
Luminosities	ATLAS	ALICE	CMS	LHC-B
L(t) 1e28 cm-2s-1	5.23	6.23	7.13	5.21
/L(t) nb-1	0.78	0.68	0.78	0.52
BKG 1	1.20	0.52	0.90	0.43
BKG 2	0.85	0.82	0.50	0.80

Comments 31-11-07 11:40:26
COLLIMATORS in coarse settings
Separation Scan in IR1/Atlas

2008 (briefly)



Staged commissioning plan for 7TeV



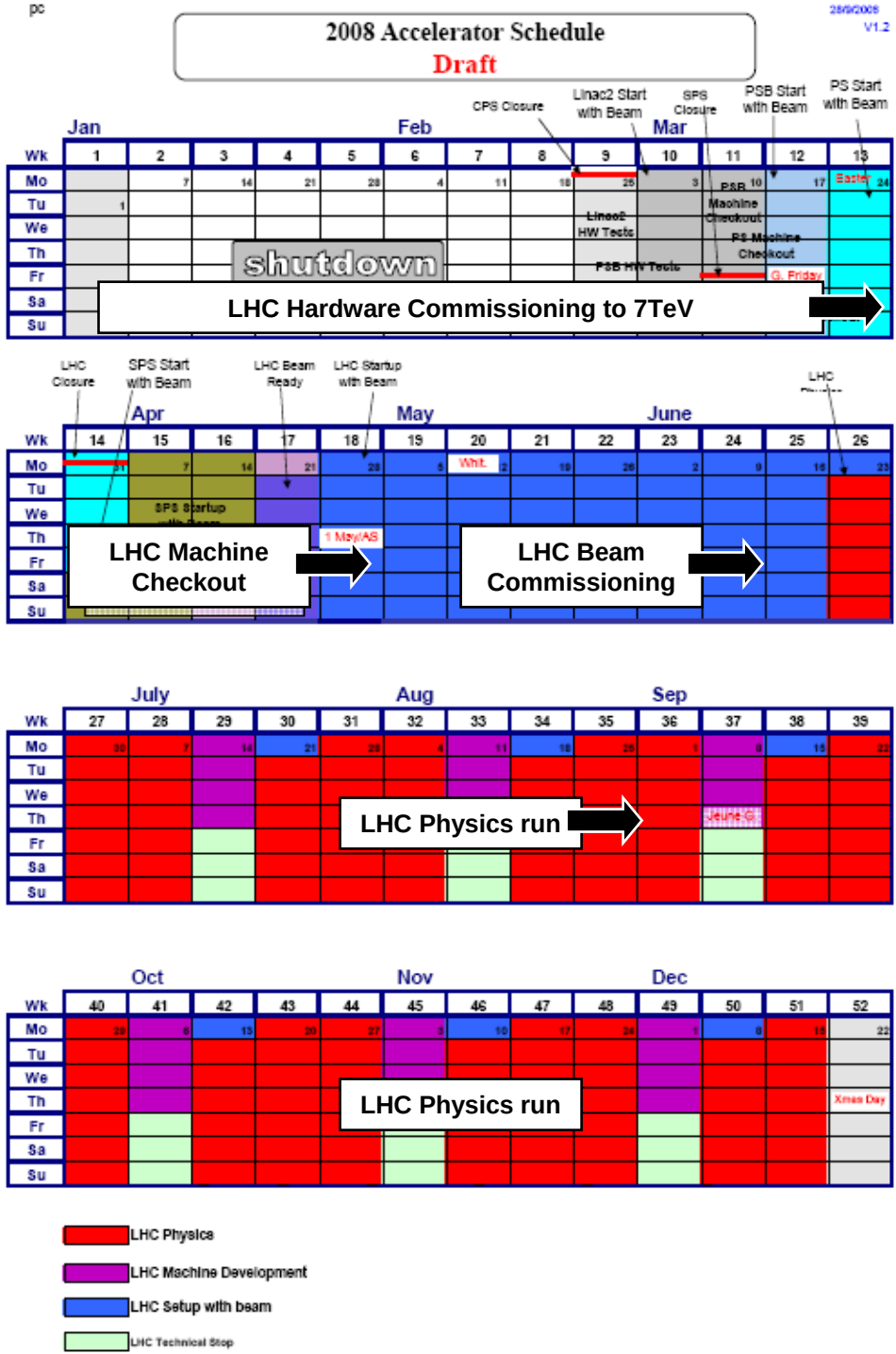
2008 draft schedule

3 month ++ shutdown

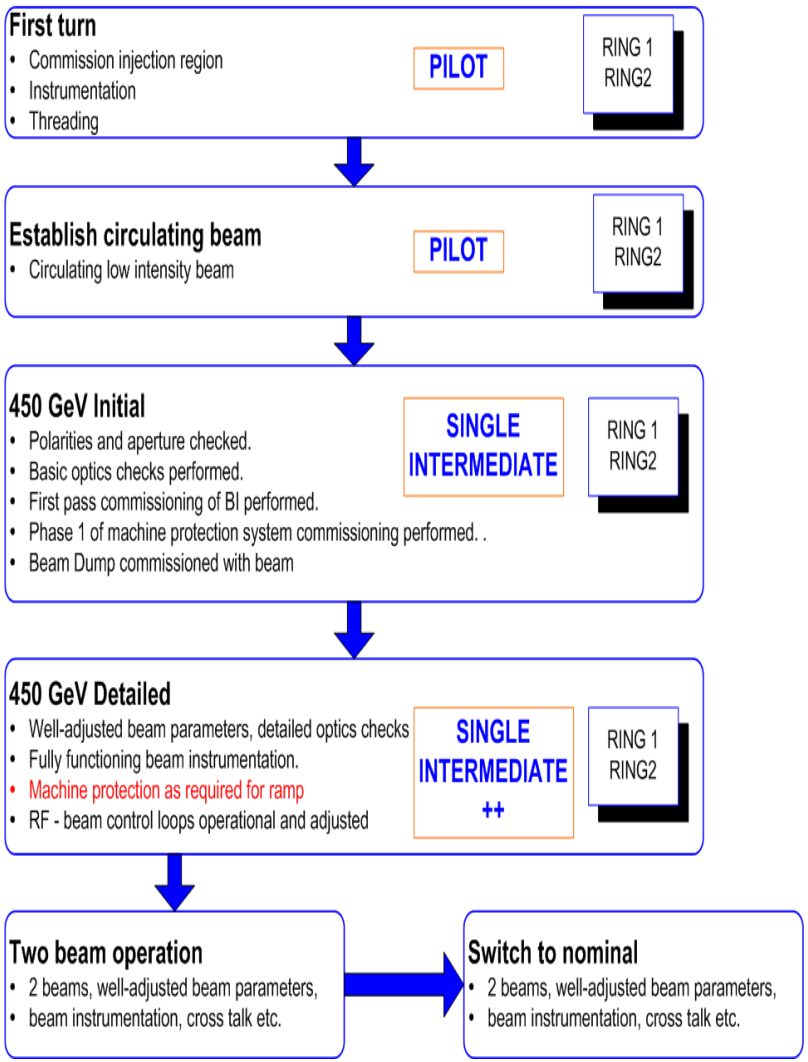
4 weeks checkout (no beam)

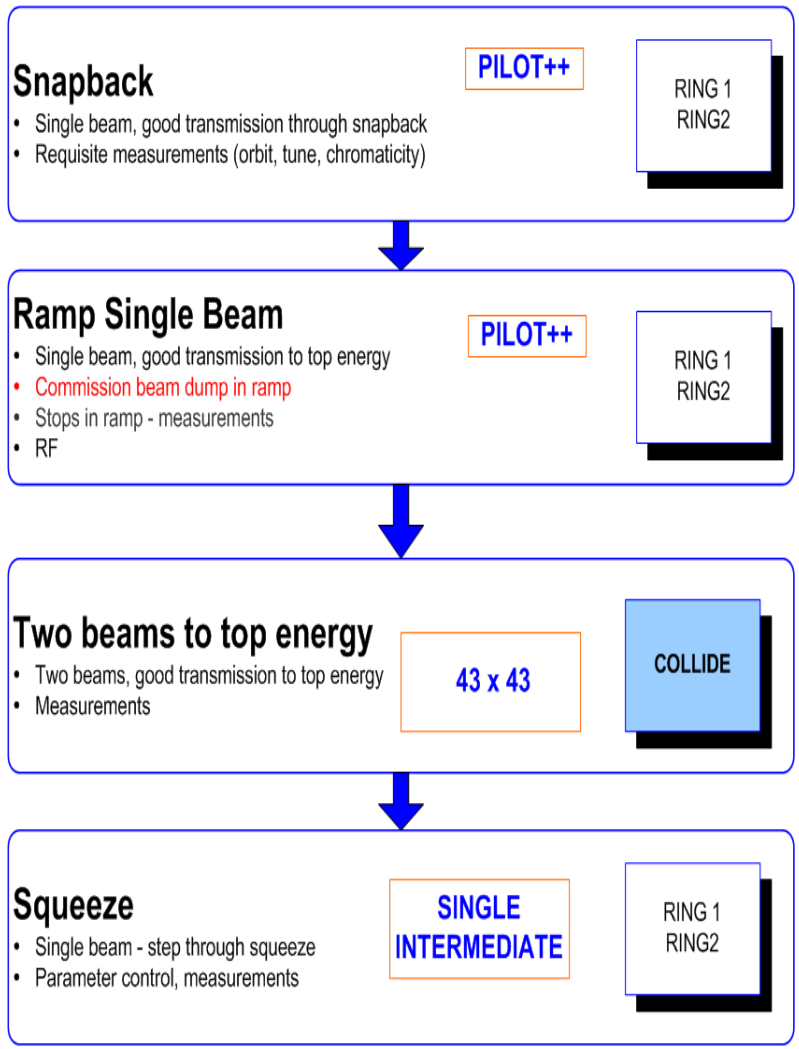
8 weeks beam commissioning

26 weeks physics run (protons)



Beam Commissioning: usual stuff..





Full commissioning to 7 TeV

		Total [days]
1	**Injection and first turn**	**6**
2	**Circulating beam**	**3**
3	**450 GeV - initial**	**5**
4	**450 GeV - detailed**	**12**
5	**450 GeV - two beams**	**2**
6	**Snapback - single beam**	**4**
7	**Ramp - single beam**	**8**
8	**Ramp - both beams**	**3**
9	7 TeV - setup for physics	**2**
10	Physics un-squeezed	**-**
	TOTAL to first collisions	**45**
11	Commission squeeze	**6**
12	Increase Intensity	**6**
13	Set-up physics - partially squeezed.	**2**
14	Pilot physics run	**30**

Given reasonable machine availability might expect first 7 TeV collisions in around 2 months

RHIC 2000:
- **First beam April 3rd**
- **First successful ramp: June 1st**
- **First collisions June 12th**

7 TeV beam commissioning

- Around 2 months elapsed time to establish first collisions
  - Mostly pilot++, low intensity, single beam, simple machine
  - No crossing angle
  - No squeeze: $\beta^* = 17 – 10 – 17 – 10$ m.

Leading into a period of “Pilot physics” plus continuing machine commissioning

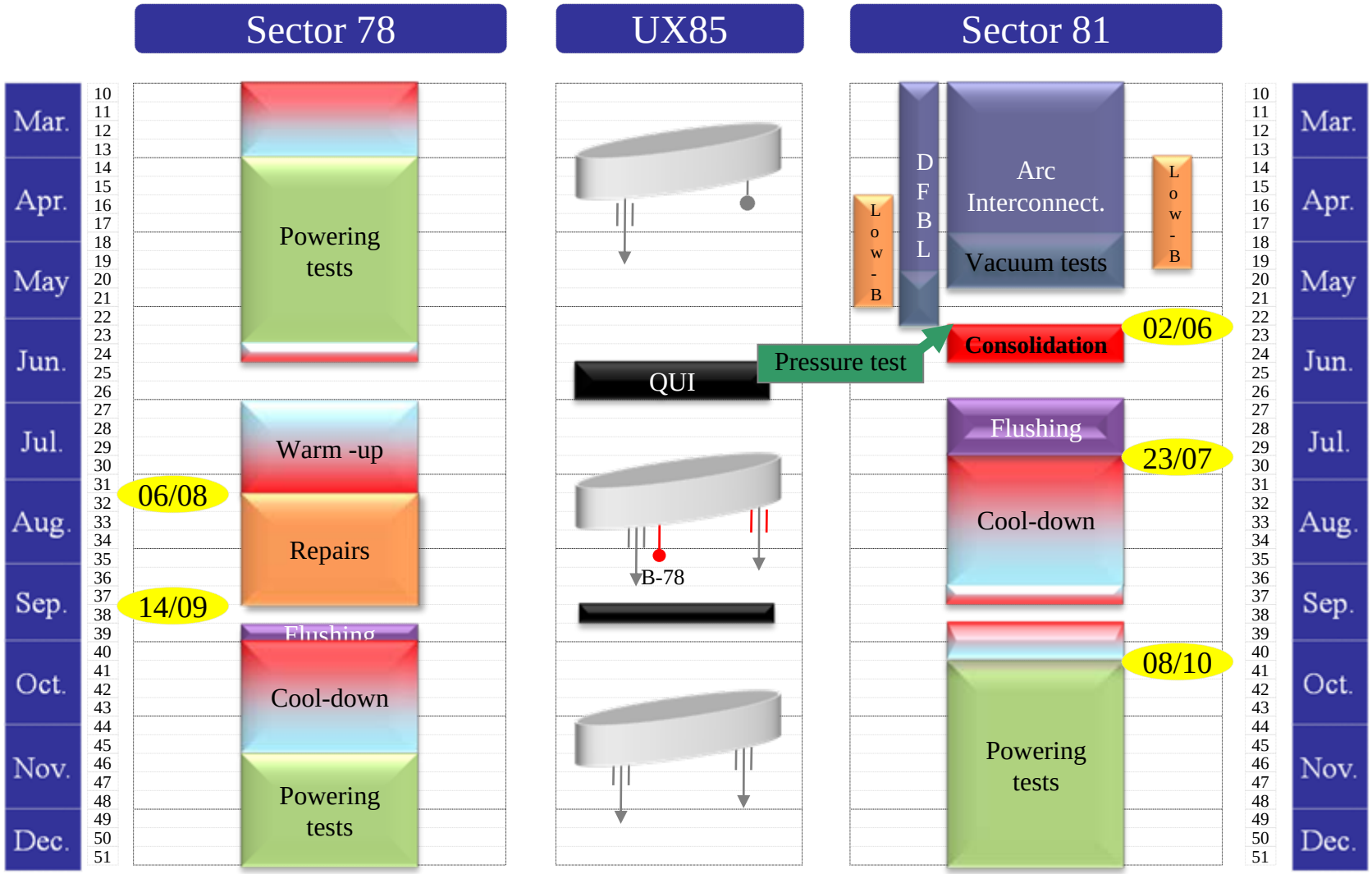
Pilot physics…

Parameters			Beam levels		Rates in 1 and 5		Rates in 2 (and 8)	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
43	$4\ 10^{10}$	11	$1.7\ 10^{12}$	2	$1.1\ 10^{30}$	<< 1	$1.2\ 10^{30}$	0.15
43	$4\ 10^{10}$	2	$1.7\ 10^{12}$	2	$6.1\ 10^{30}$	0.76	$1.2\ 10^{30}$	0.15
156	$4\ 10^{10}$	2	$6.2\ 10^{12}$	7	$2.2\ 10^{31}$	0.76	$4.4\ 10^{30}$	0.15
156	$9\ 10^{10}$	2	$1.4\ 10^{13}$	16	$1.1\ 10^{32}$	3.9	$2.2\ 10^{31}$	0.77
936	$4\ 10^{10}$	11	$3.7\ 10^{13}$	42	$2.4\ 10^{31}$	<< 1	$2.6\ 10^{31}$	0.15
936	$4\ 10^{10}$	2	$3.7\ 10^{13}$	42	$1.3\ 10^{32}$	0.73	$2.6\ 10^{31}$	0.15
936	$6\ 10^{10}$	2	$5.6\ 10^{13}$	63	$2.9\ 10^{32}$	1.6	$6.0\ 10^{31}$	0.34
936	$9\ 10^{10}$	1	$8.4\ 10^{13}$	94	$1.2\ 10^{33}$	7	$1.3\ 10^{32}$	0.76
2808	$4\ 10^{10}$	11	$1.1\ 10^{14}$	126	$7.2\ 10^{31}$	<< 1	$7.9\ 10^{31}$	0.15
2808	$4\ 10^{10}$	2	$1.1\ 10^{14}$	126	$3.8\ 10^{32}$	0.72	$7.9\ 10^{31}$	0.15
2808	$5\ 10^{10}$	1	$1.4\ 10^{14}$	157	$1.1\ 10^{33}$	2.1	$1.2\ 10^{32}$	0.24
2808	$5\ 10^{10}$	0.55	$1.4\ 10^{14}$	157	$1.9\ 10^{33}$	3.6	$1.2\ 10^{32}$	0.24

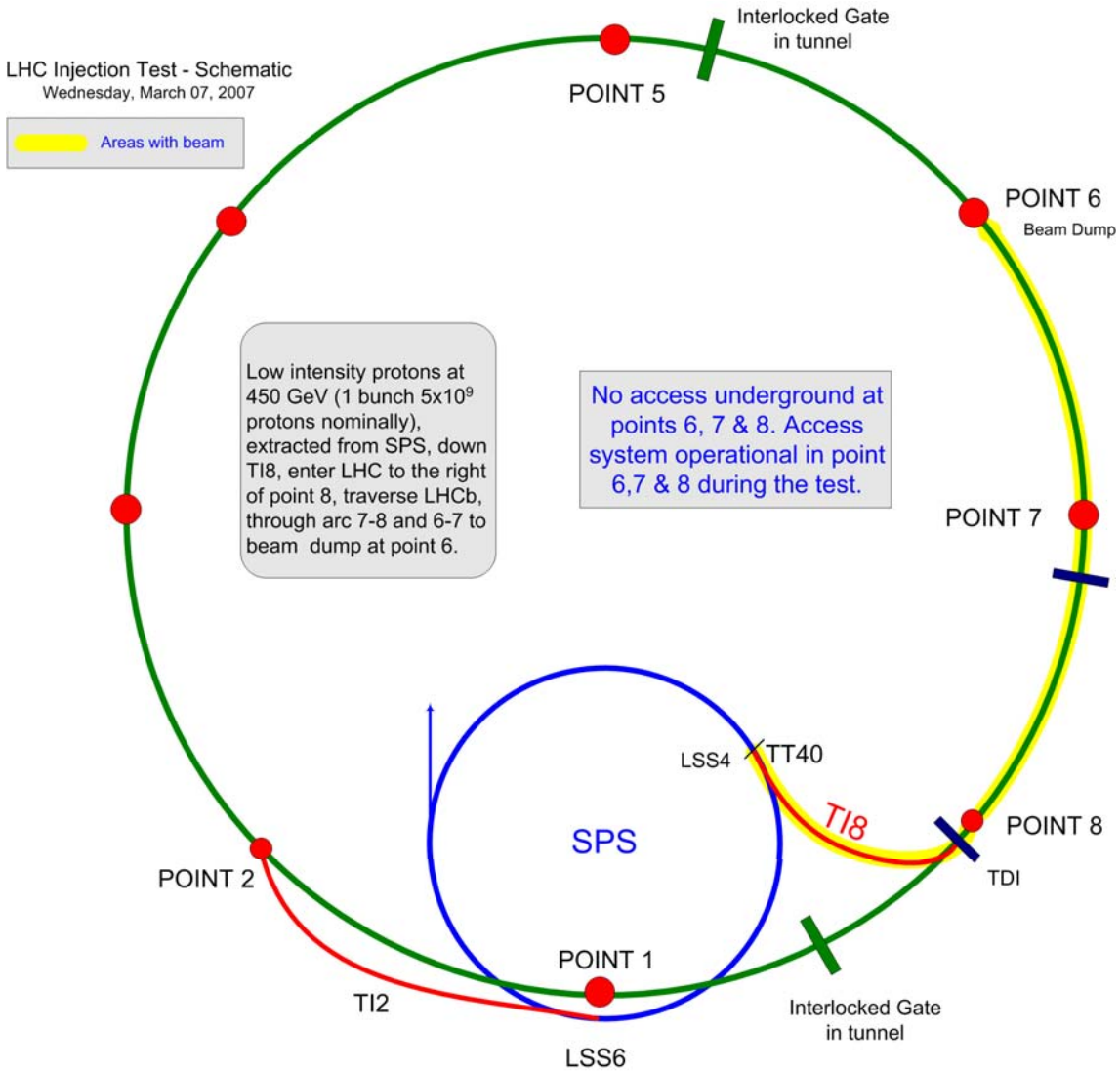
Schedule

- Some delays are accumulating
  - Inner triplets clearly haven't helped
- A new schedule will be presented in May 2007
- Off the record
  - A 450 GeV run this year looks unlikely
  - A sector test this year remains a possibility

Sectors 78 & 81 – very preliminary – not official



Sector test 2007 (backup)



Conclusions

Installation, Cool-down, HWC

- Despite the problems, this is going remarkably well

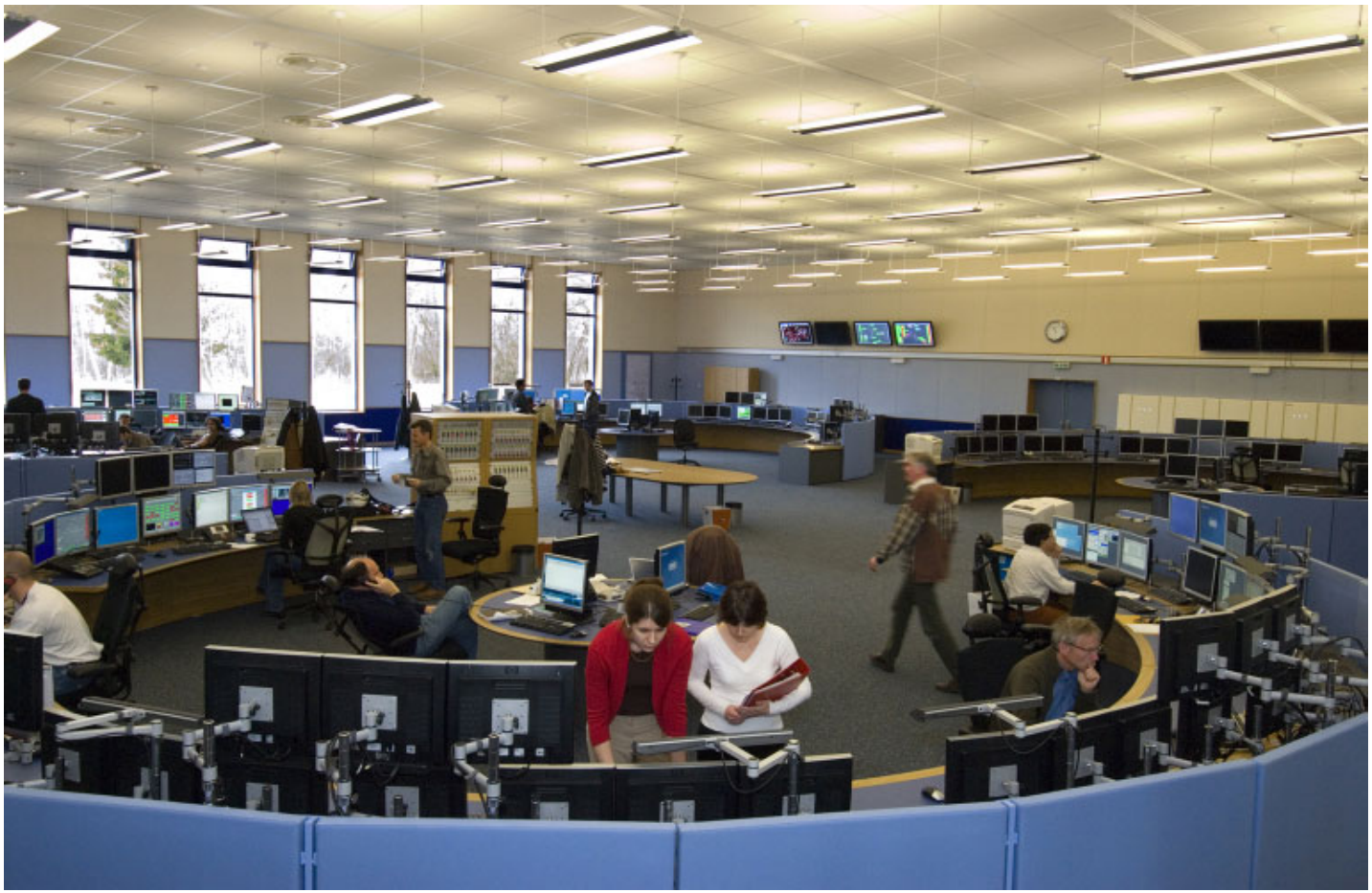
450 GeV Engineering Run

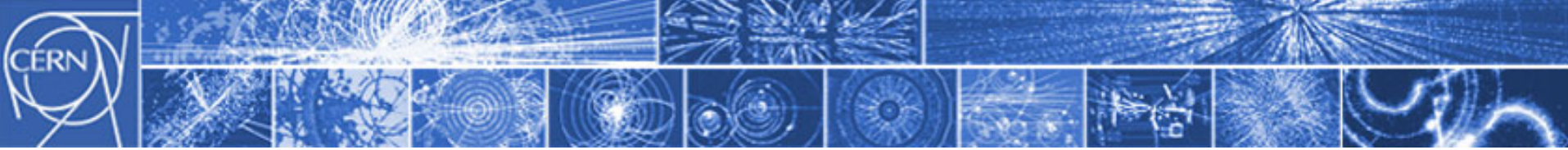
- 2 weeks single beam machine commissioning
- 3 weeks collisions with the hope to push over 10^{29} $cm^{-2}s^{-1}$

7 TeV

- 6-8 weeks single/two beam machine commissioning
- Low beam current
- Un-squeezed initially with minimal collimation
- Still work to do after first collisions – pilot physics

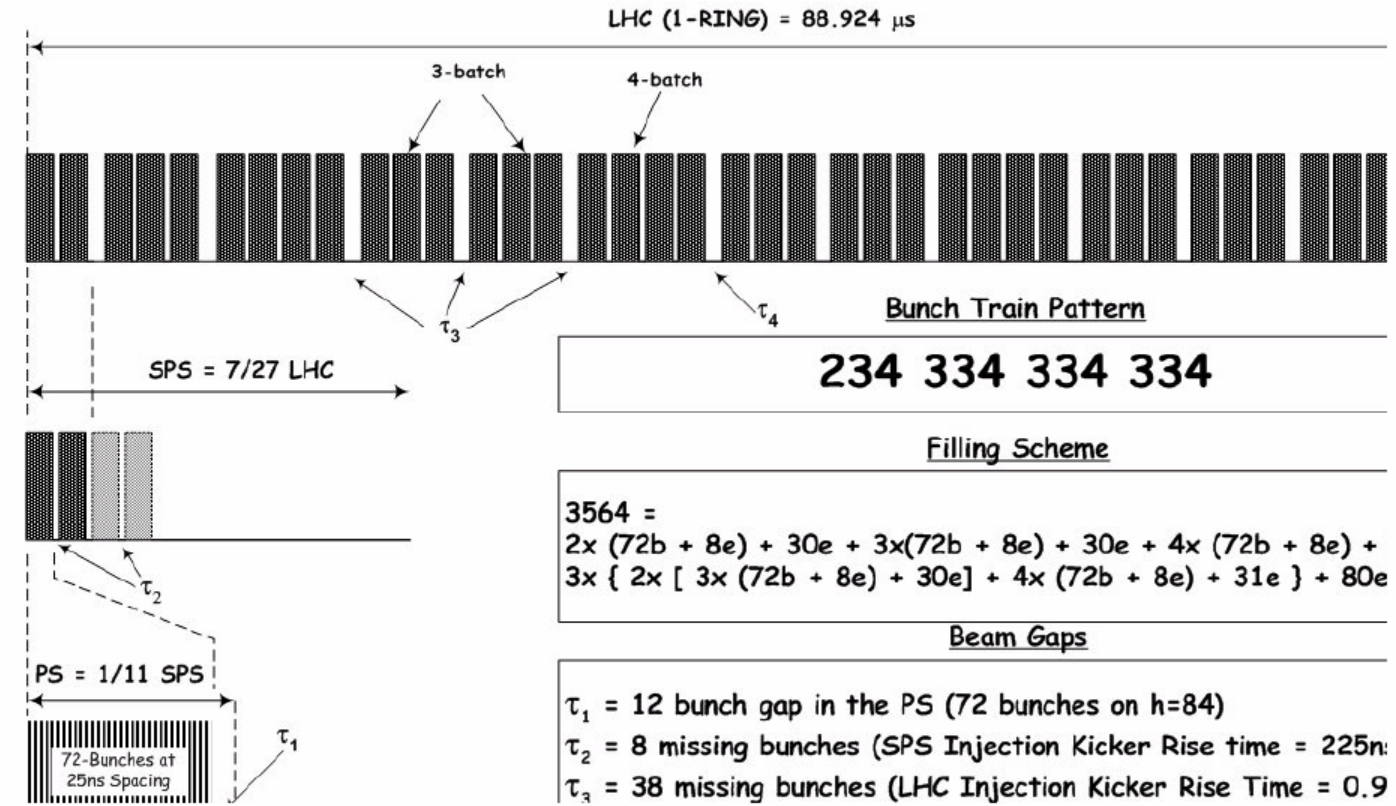
Some delays accumulating – new schedule soon





RESERVE SLIDES

Bunch configuration



Crossing angle