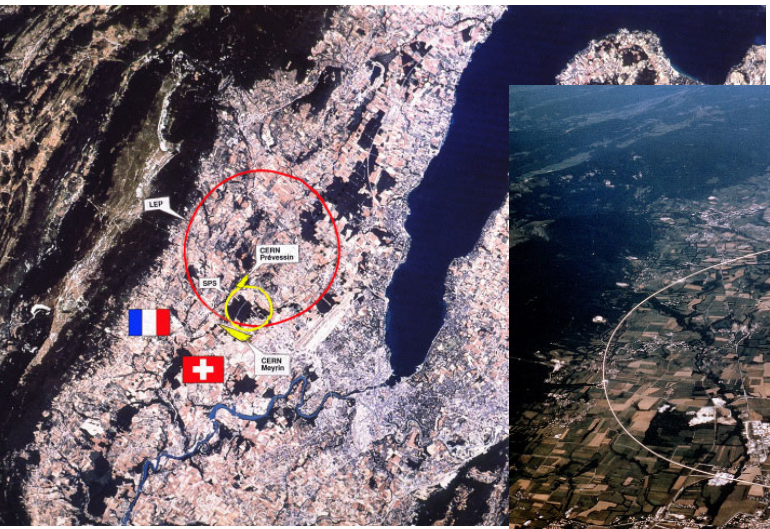
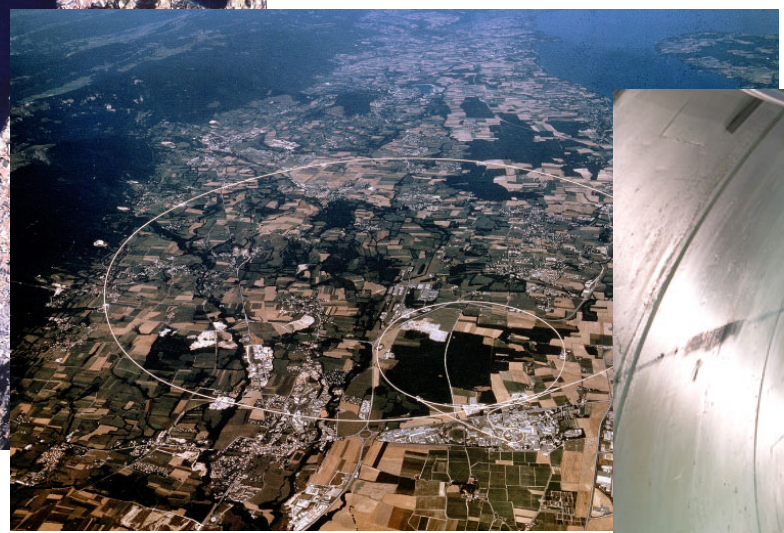
LHC: Overview, Status and Commissioning Plans

Mike Lamont, LHC Operations, CERN

7th May 2007

The LHC….work in progress!





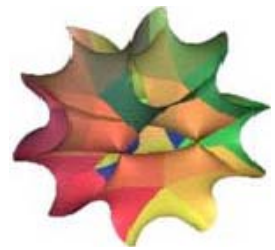
Two beams of trillions of protons will race around the 27km ring in opposite directions travelling at 0.999999991 times the speed of light…

Sometime soon!

Design basics

We want to collide high energy protons
(let's say 7 TeV) (for what ever crazy reasons)

Higgs, Supersymmetry, data matter, extra dimensions

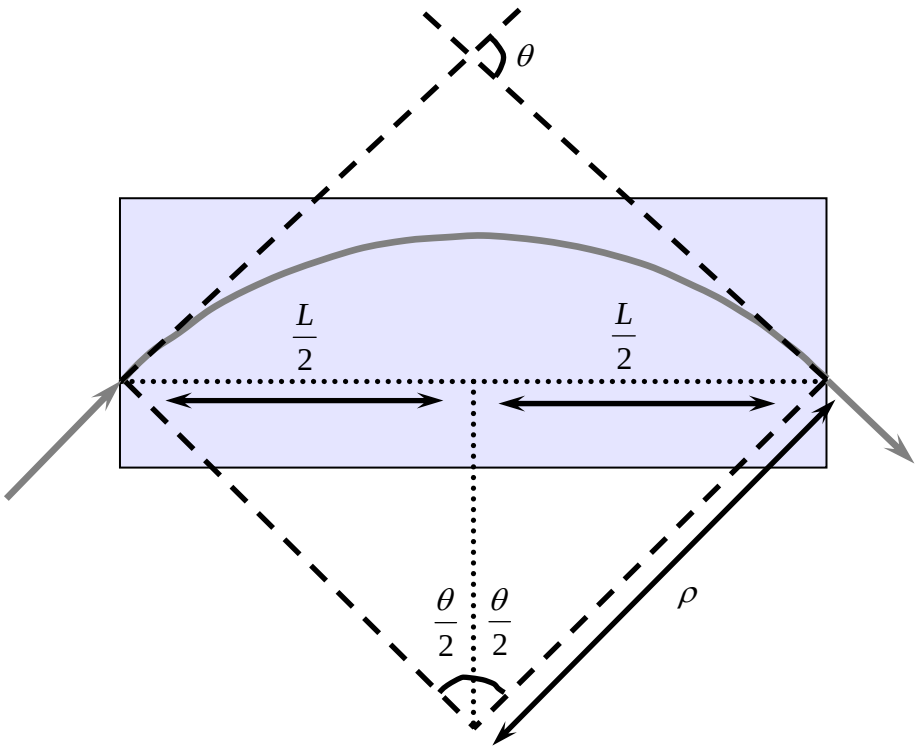


We have the 27 km LEP tunnel which we'd better use

Back of an envelope calculation tells us we need strong magnets to bend the beam around

1232 magnets to get us round in a circle

$$\theta = \frac{l}{\rho} = \frac{2\pi}{1232} = 5.1\times10^{-3}\ \text{rad}$$



7 TeV
- **8.33T**
- **11850A**

Superconductivity

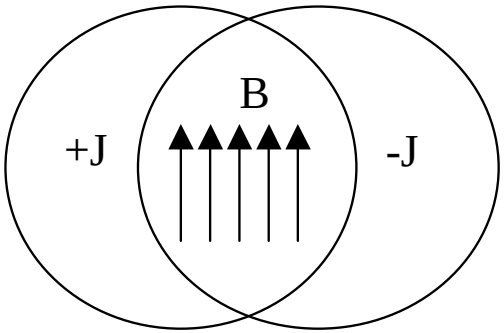
To produce the high magnetic fields we need very high currents…

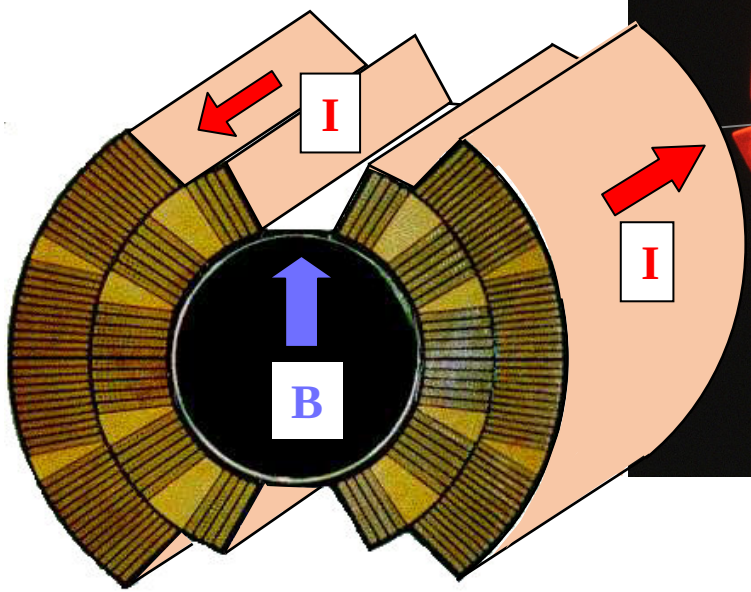
Abolish Ohm's Law!

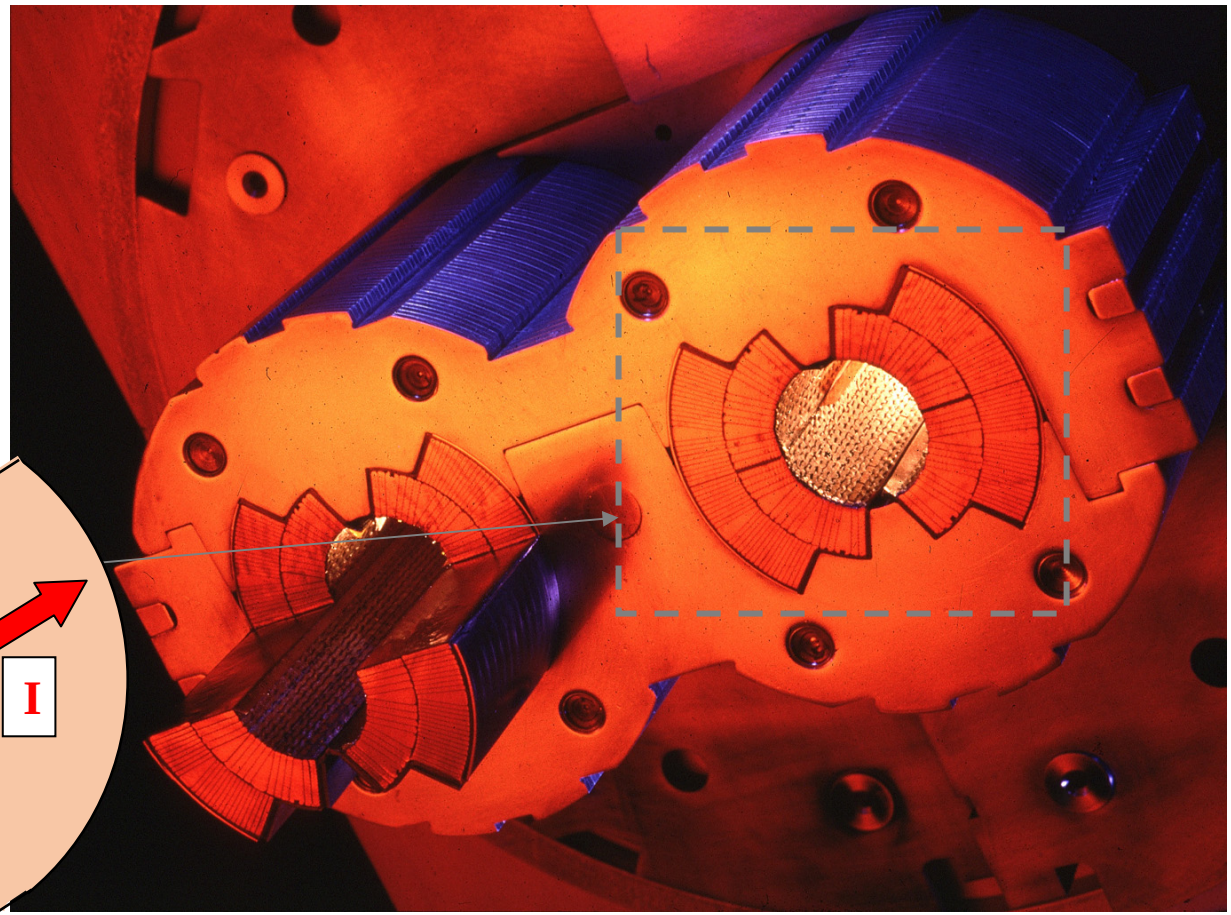
Use of superfluid helium which is a magic coolant and gives us some margin in the high magnetic fields

30 kTons cold mass; 120 Tons of Helium –
a huge cryogenic system

LHC - dipole

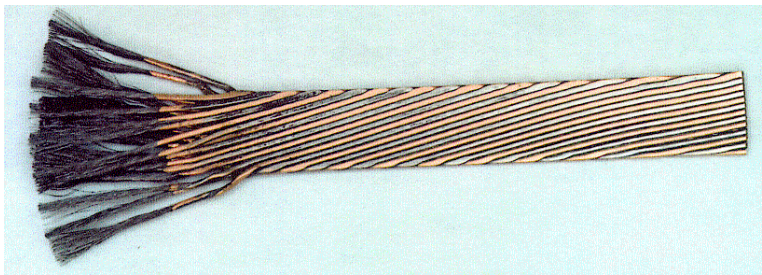




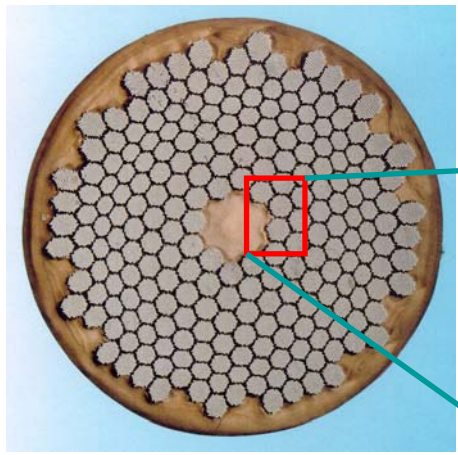


Niobium-Titanium Rutherford cable

Cable



Strand

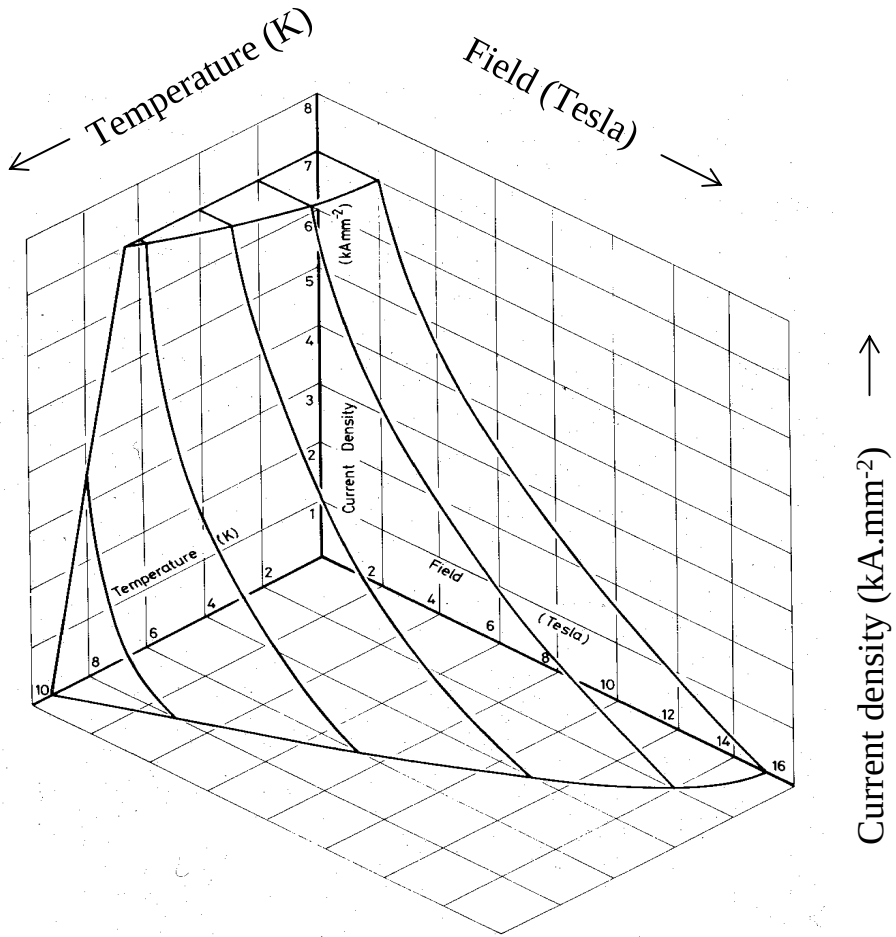


Filament

Total superconducting cable required 1200 tonnes which translates to around 7600 km of cable

The cable is made up of strands which is made of filaments, total length of filaments would go 5 times to the sun and back with enough left over for a few trips to the moon.

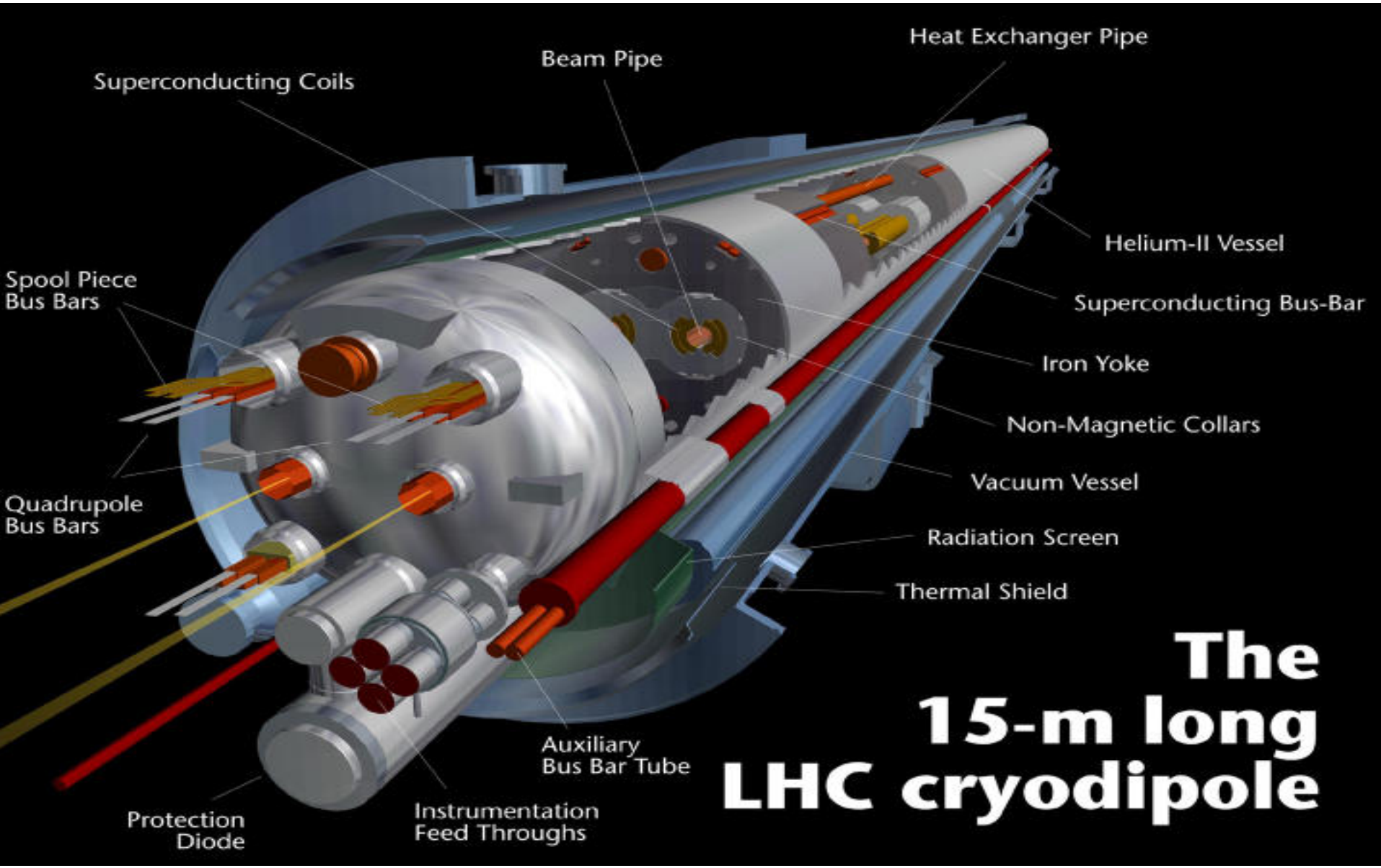
Critical surface of niobium titanium



Niobium titanium **NbTi** is the standard ‘work horse’ of the superconducting magnet business

picture shows the **critical surface**, which is the boundary between superconductivity and normal resistivity in 3 dimensional space

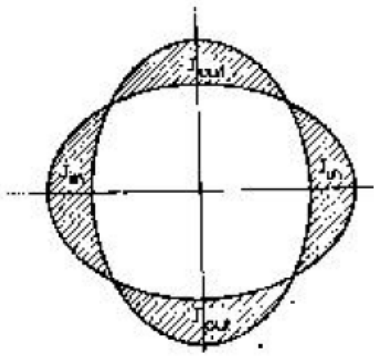
superconductivity prevails everywhere below the surface, resistance everywhere above it


Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Quadrupole
Bus Bars
Vacuum Vessel
Radiation Screen
Thermal Shield
The
15-m long
LHC cryodipole
Auxiliary
Bus Bar Tube
Protection
Diode
Instrumentation
Feed Throughs

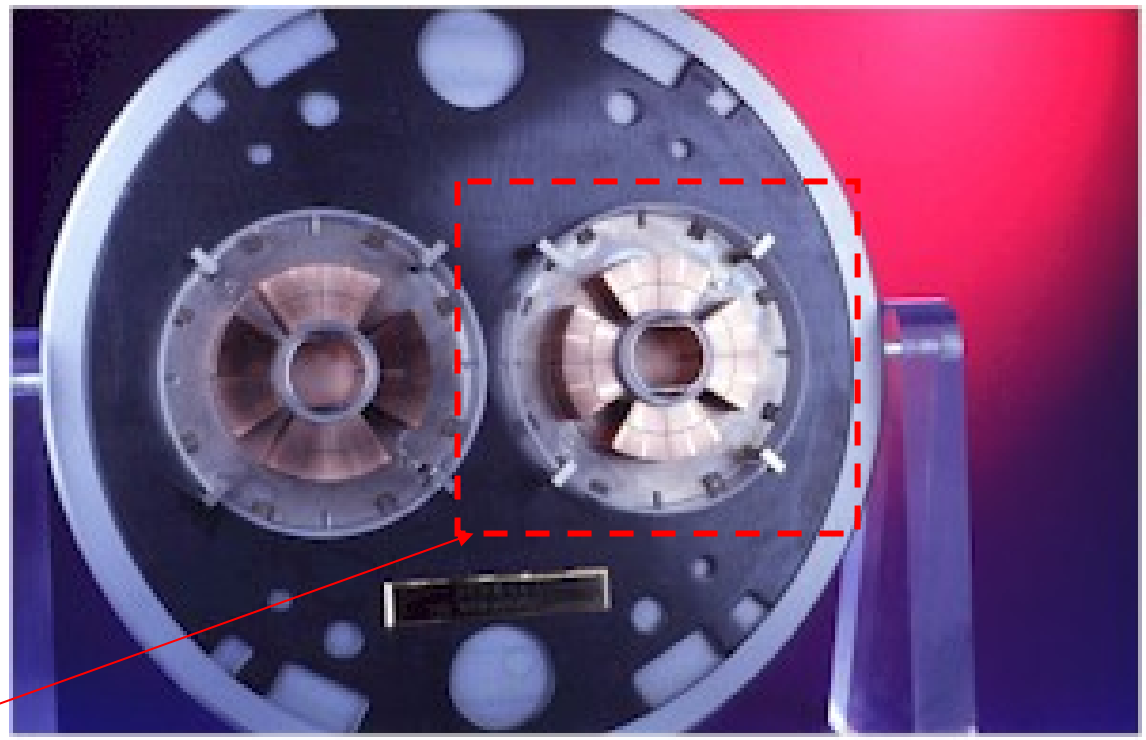
Bend the beam

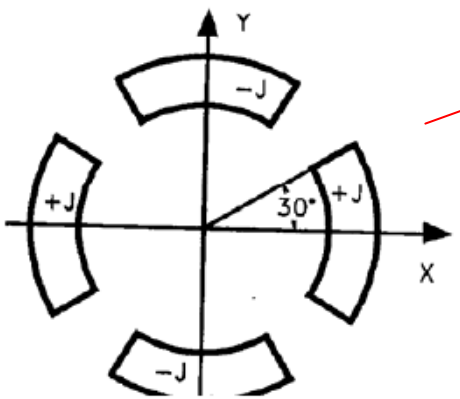
Momentum at collision	7 TeV / c
Momentum at injection	450 GeV / c
Machine Circumference	26658.883 m
Revolution frequency	11.245 kHz
Number of dipoles	1232
Dipole field at 450 GeV	0.535 T
Dipole field at 7 TeV	8.33 T
Bending radius	2803.95 m
Main Dipole Length	14.3 m

LHC - quadrupole

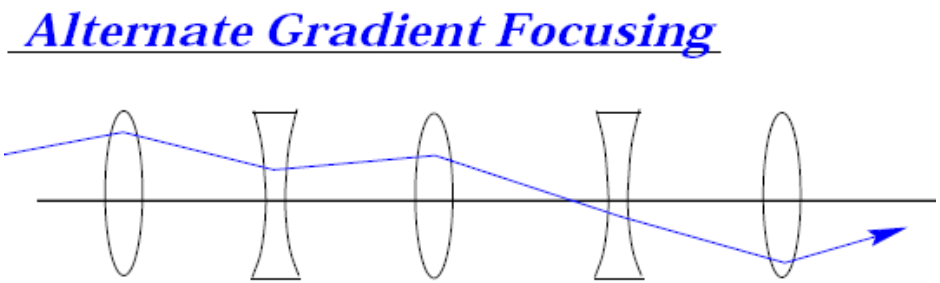


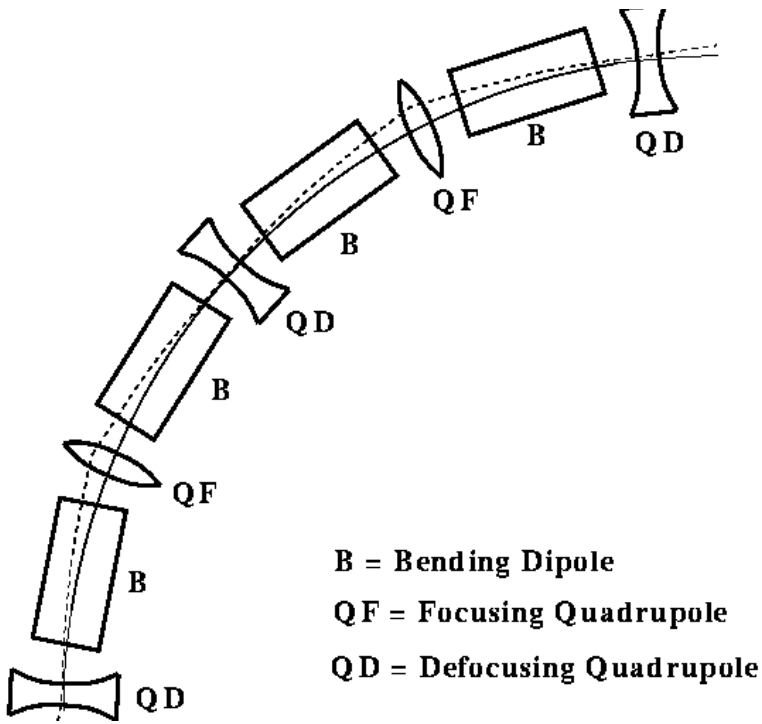
Two intersecting ellipses, rotated by 90°, generate a perfect quadrupole fields

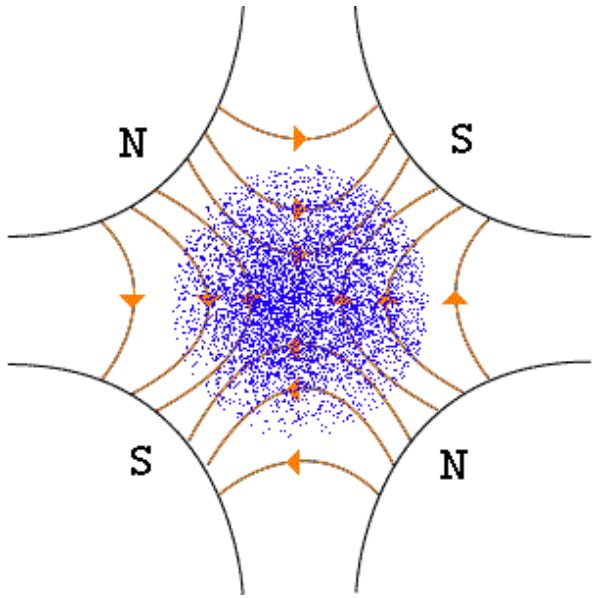




Focus the beam



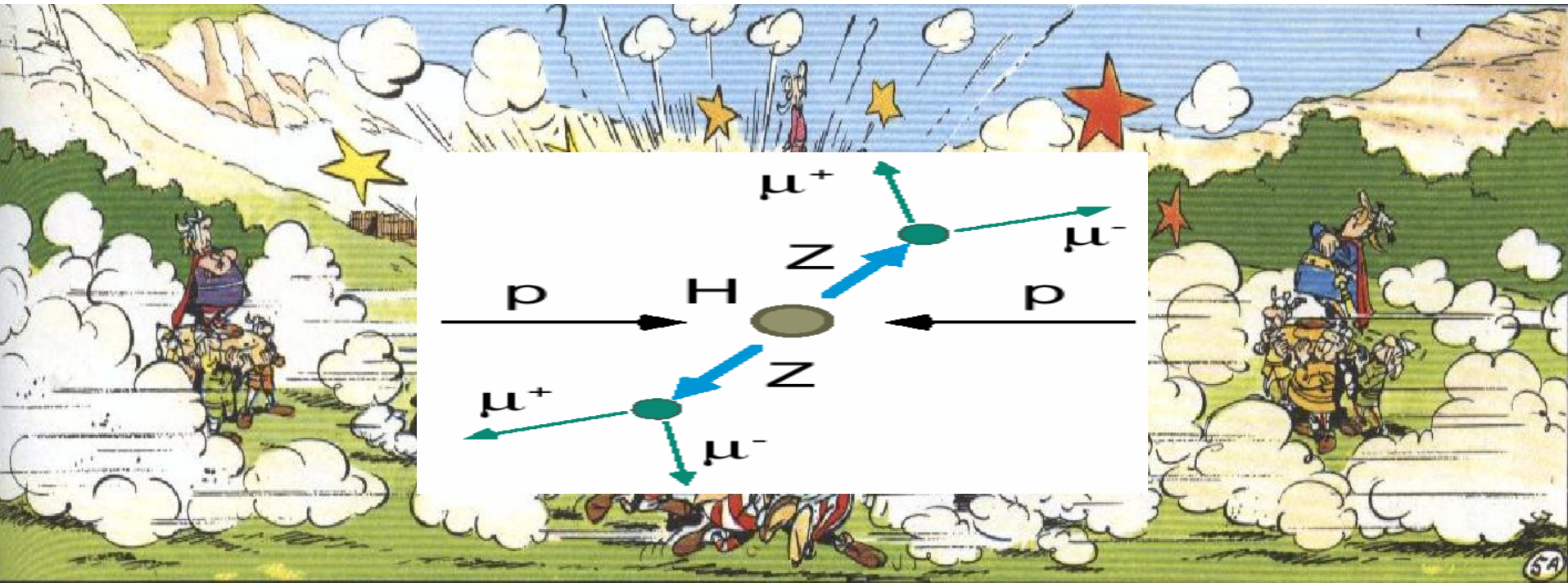




Luminosity

We want to produce high luminosity at high energy so we can discover the Higgs etc.

(for high luminosity read a large number of collisions)



Beam

Many bunches:

2808 bunches per beam

High bunch currents:

1.15×10^{11} protons per bunch

Small beam size at the interaction points

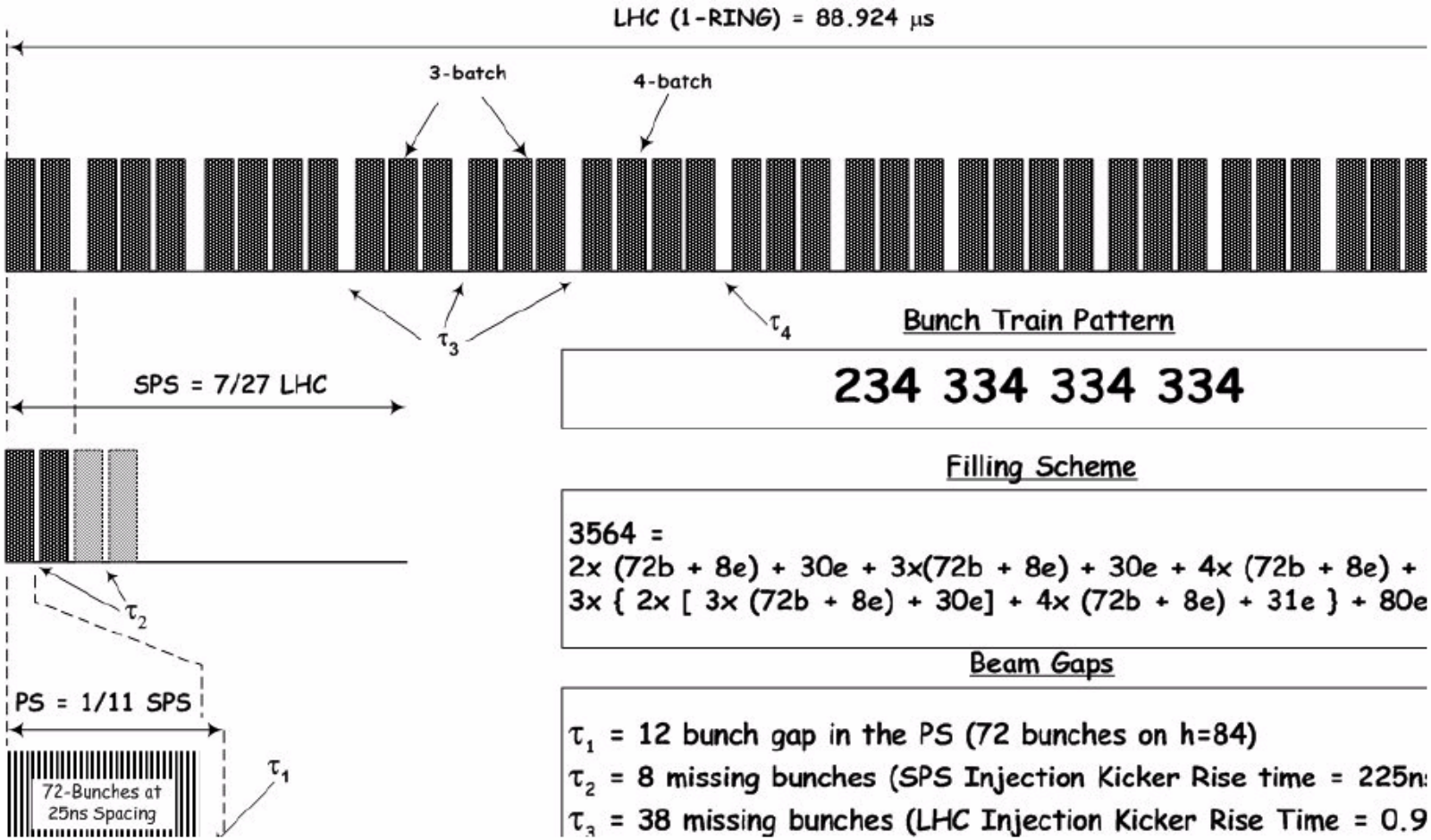
16 µm fully squeezed

Have to keep the beam apart as much as possible

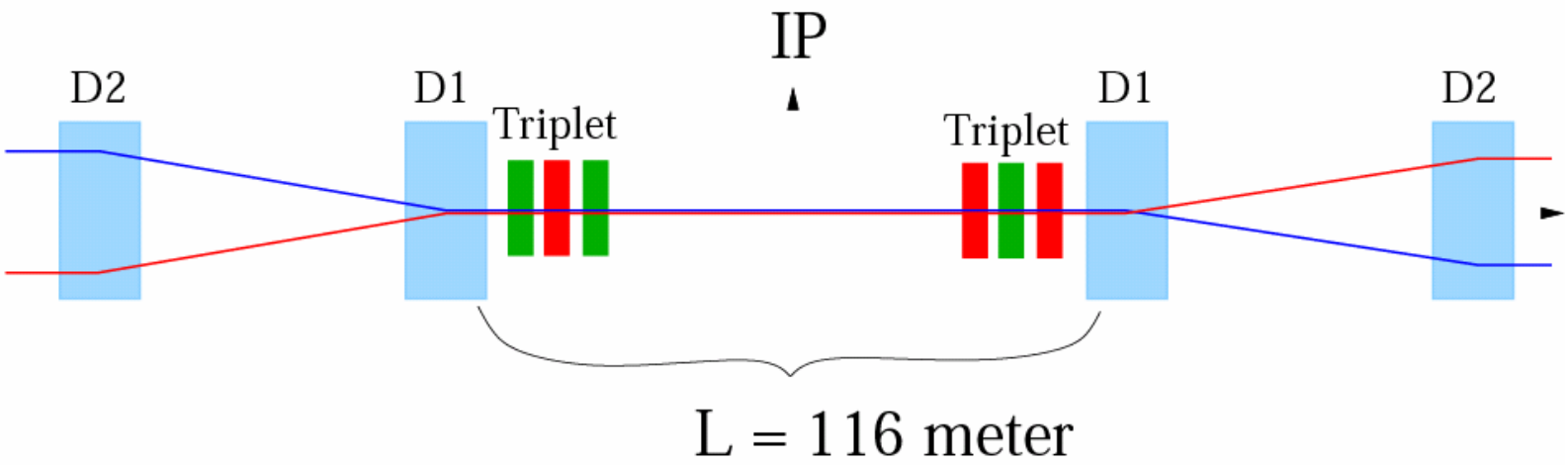
Therefore two beam pipes and for cost reasons a

2 in 1 magnet design

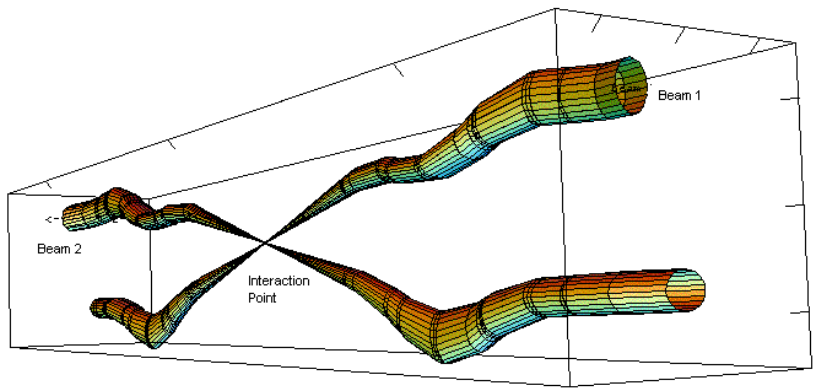
Bunch configuration



Experiment Insertion

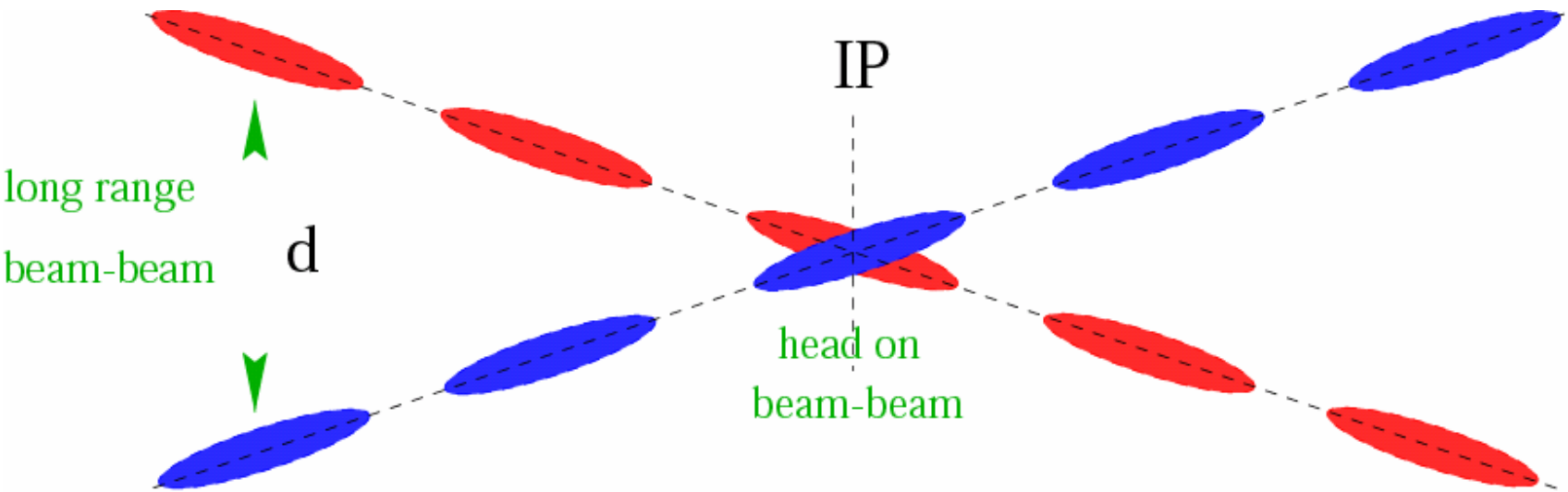


- **Bring the beams together to produced collisions**
- **Squeeze the beam sizes down at the interaction point**



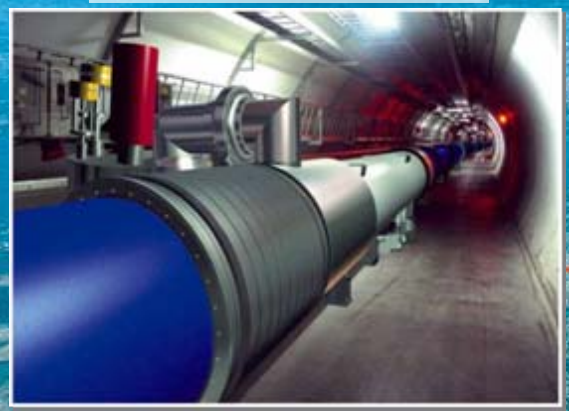
Relative beam sizes around IP1 (Atlas) in collision

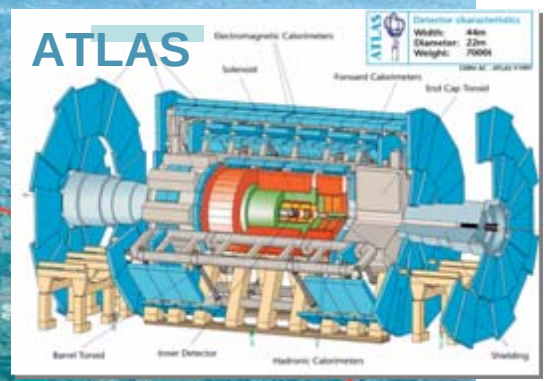
Cross beams at an angle



pp, B-Physics,
CP Violation

LHC : 27 km long
100m underground

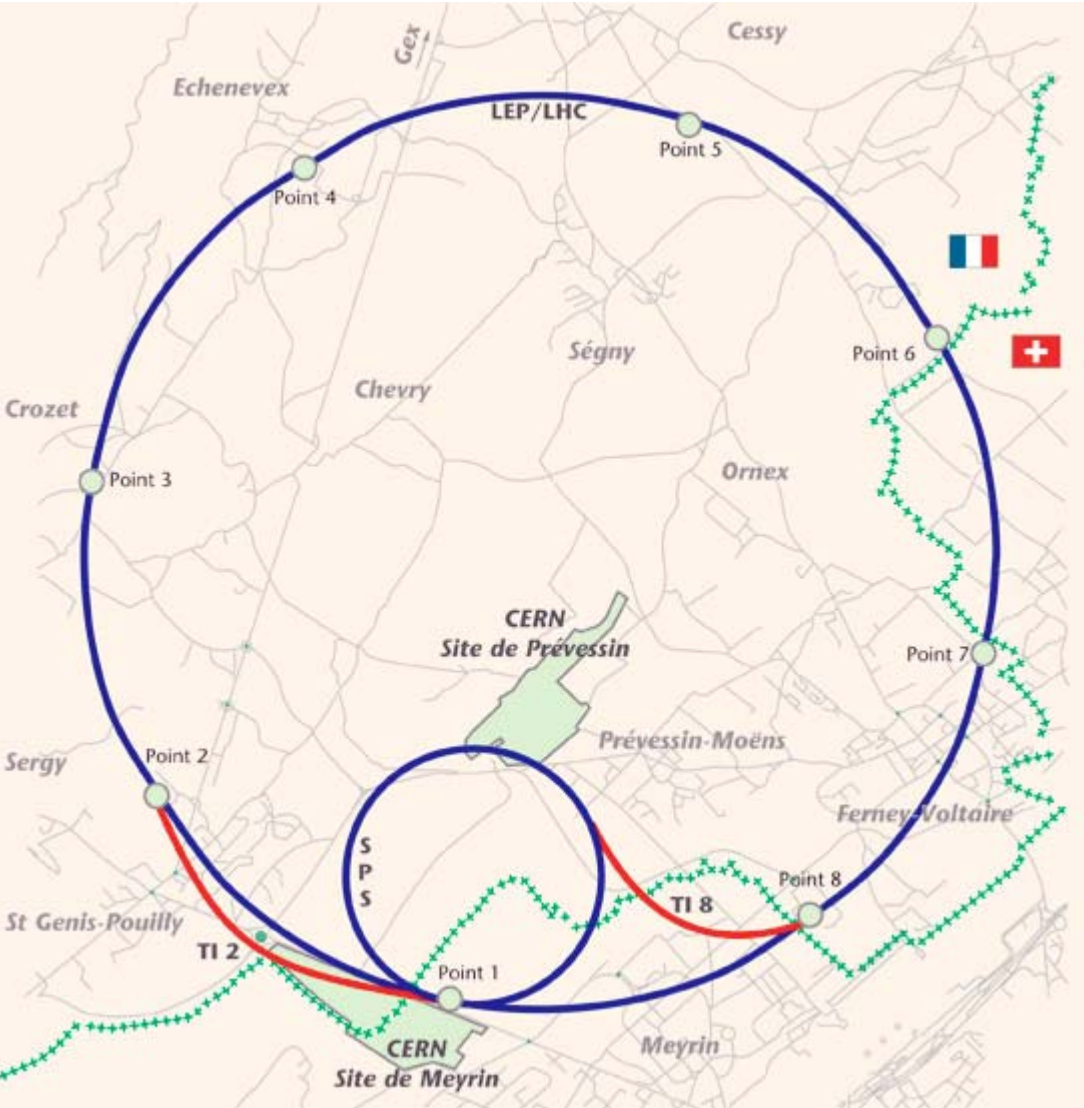


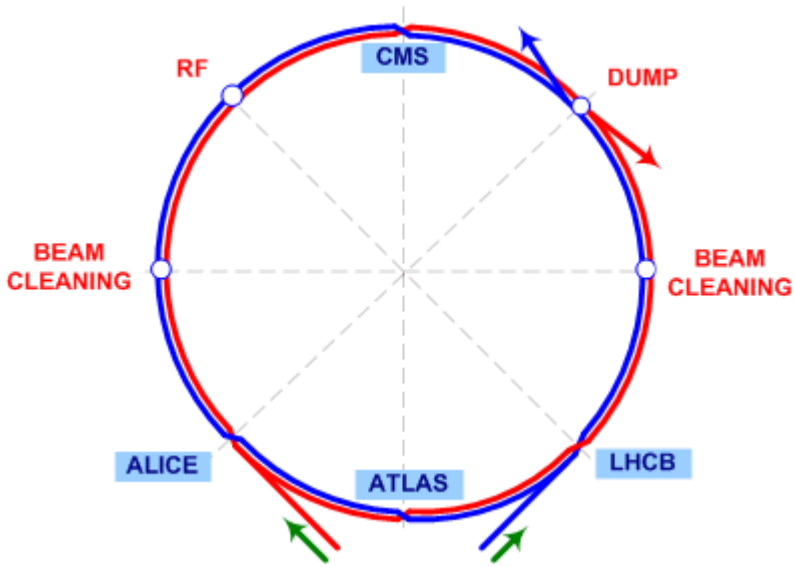


General Purpose,
pp, heavy ions

Heavy ions, pp

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

Beam energy

energy per beam up to 360 MJ

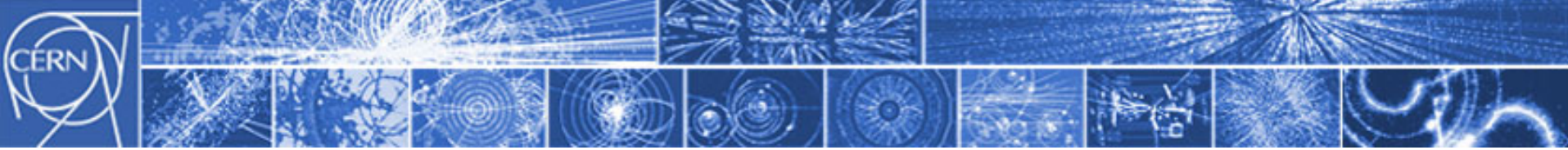
British aircraft carrier at 12 knots

Two very cold, very dark, very small holes...

Beam Dump

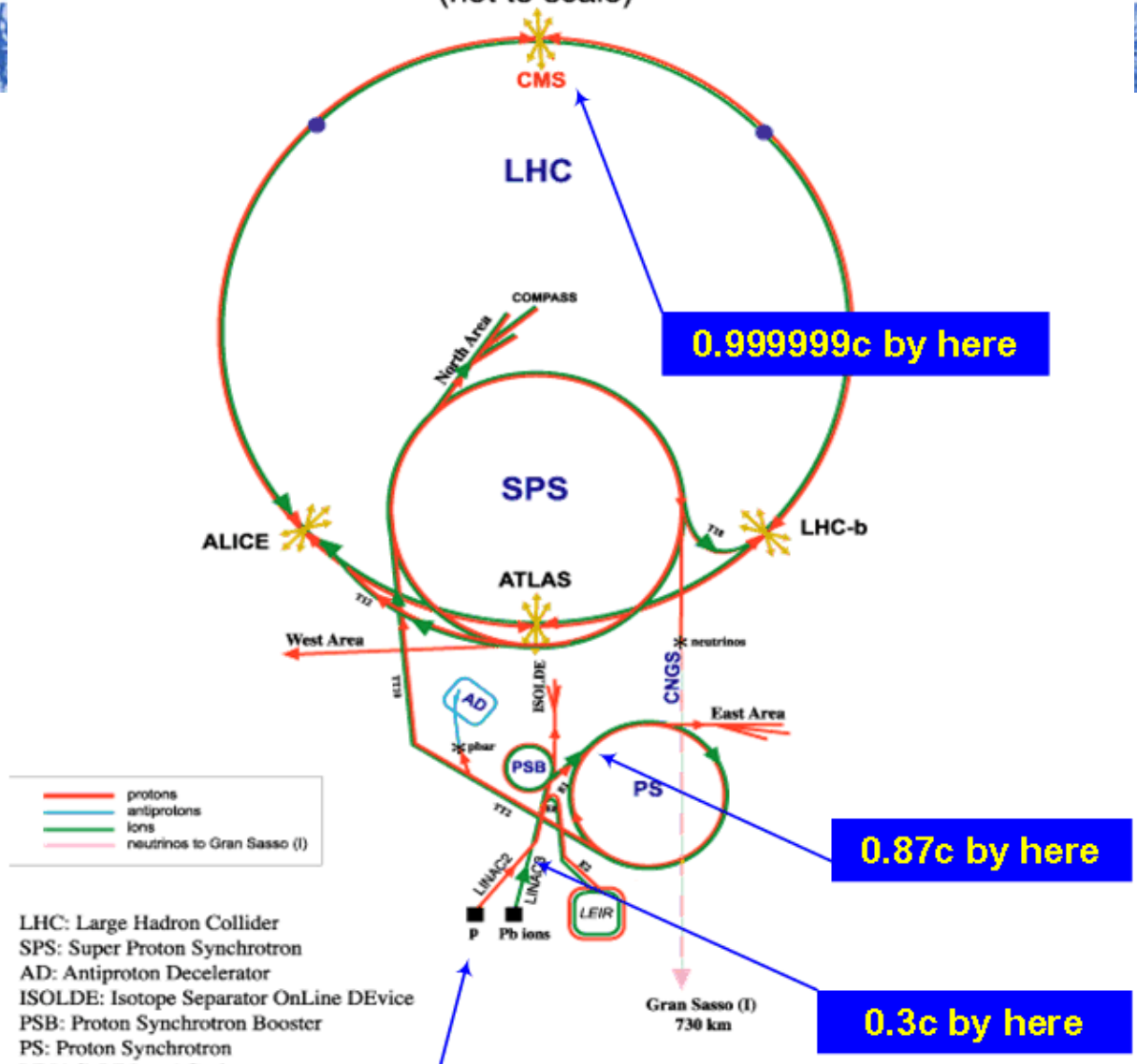
Beam has got out in case of a quench or other problem otherwise we end up with scrap metal

R.Schmidt and J.Uythoven, June 2008, LHC Point 6.
Discussion on how the Beam Dump System reliability could be improved



Operations

CERN Accelerators
(not to scale)



0.999999c by here

0.87c by here

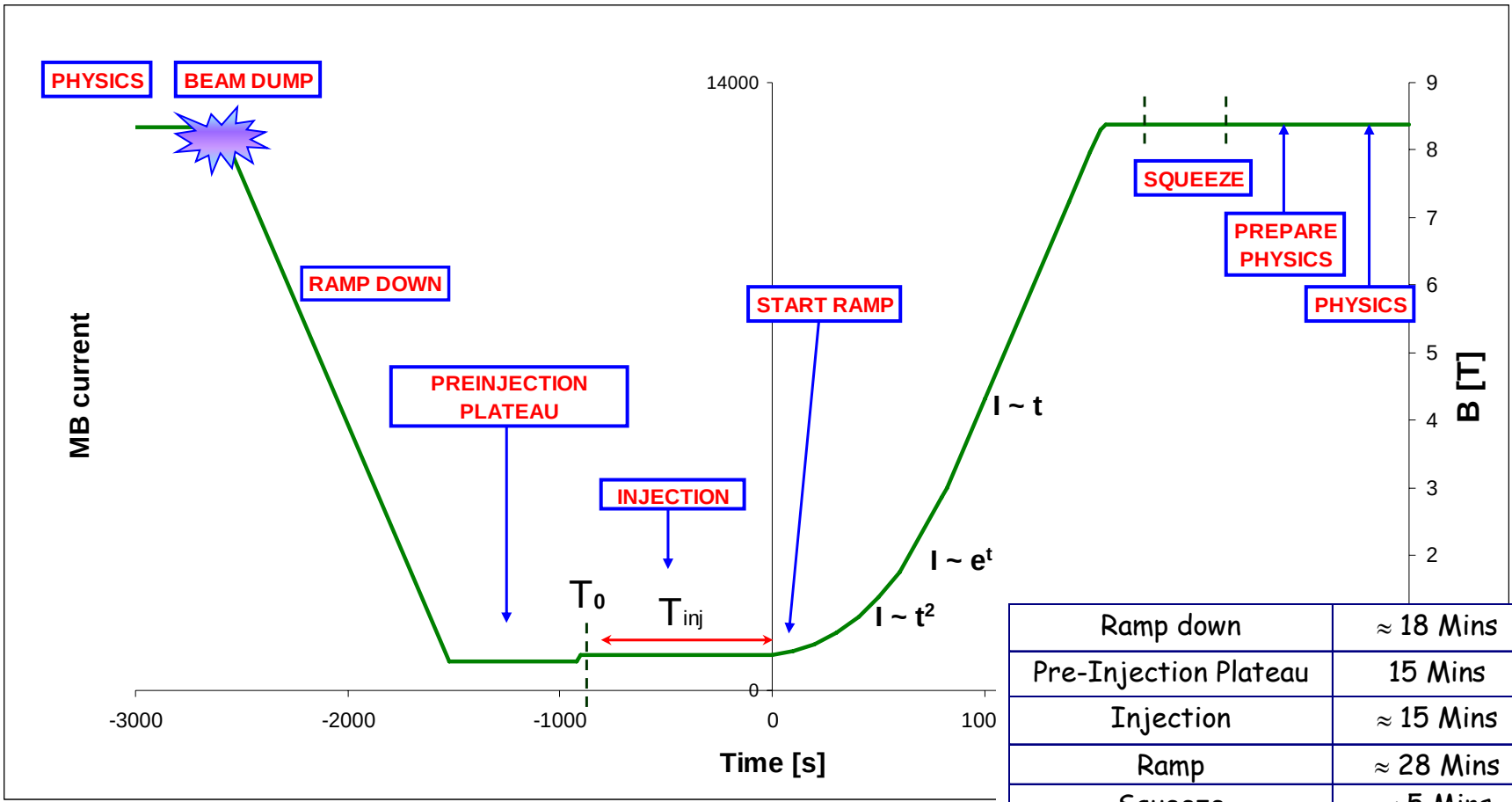
0.3c by here

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

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

Start the protons out here

Nominal cycle



Ramp down	≈ 18 Mins
Pre-Injection Plateau	15 Mins
Injection	≈ 15 Mins
Ramp	≈ 28 Mins
Squeeze	< 5 Mins
Prepare Physics	≈ 10 Mins
Physics	10 - 20 Hrs

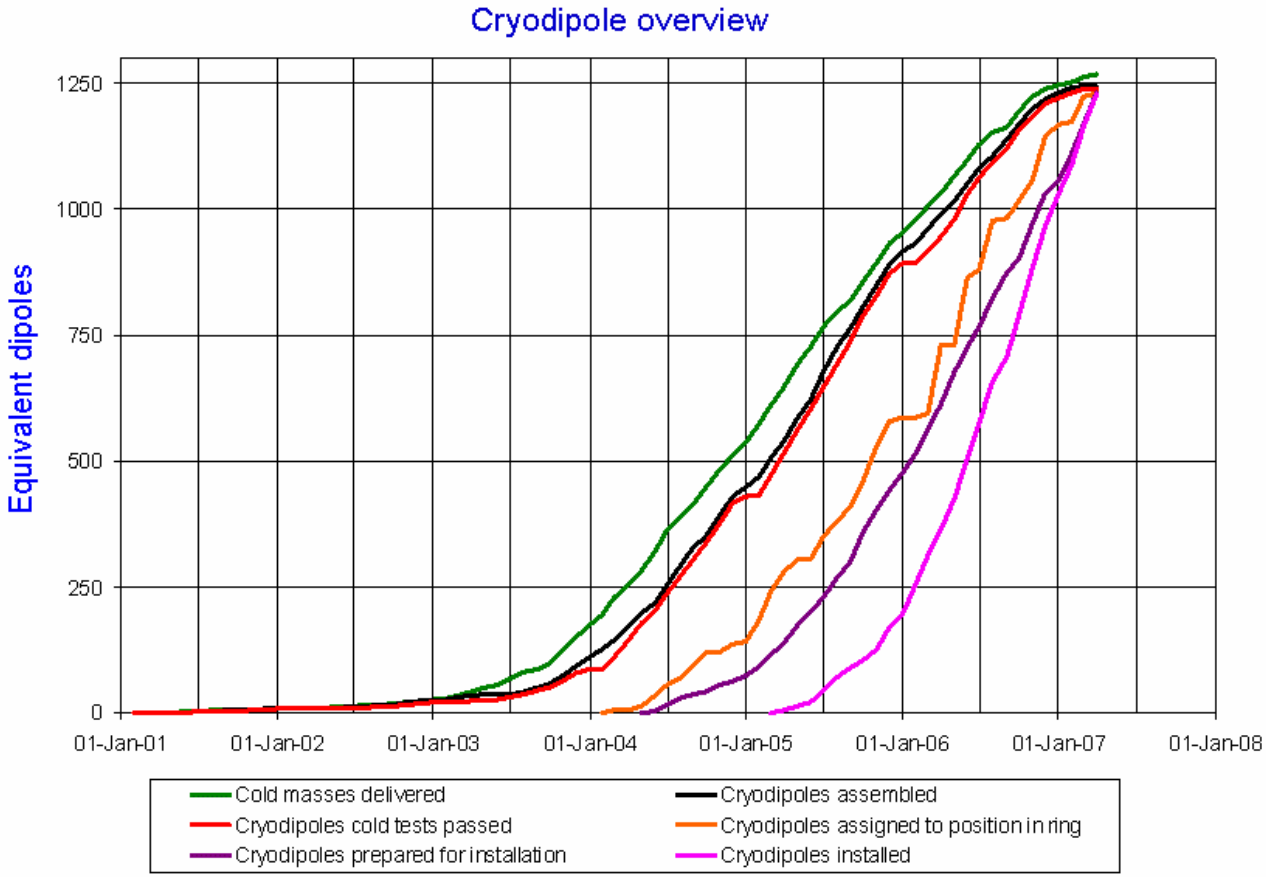
So that’s the idea…

- Bend & Focus
- Produce the components
- Install them
- Get them working and test them
- Put some beam in

Components: dipoles

LHC Progress Dashboard

Accelerator Technology Department



Updated 31 March 2007

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

Last one down

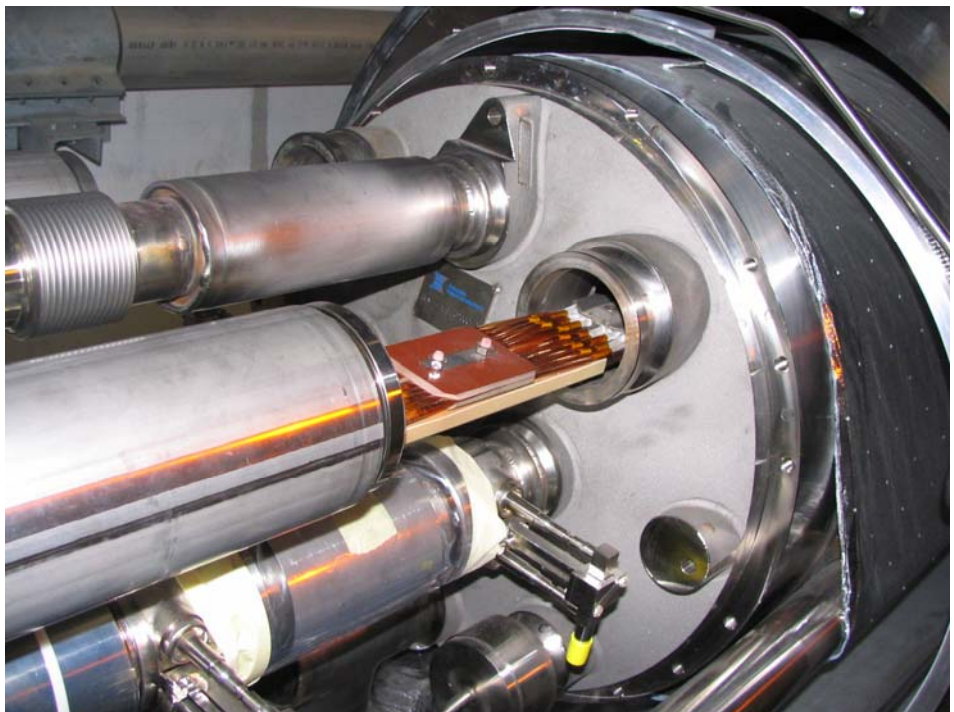
Installation: magnets

The magnets are now 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

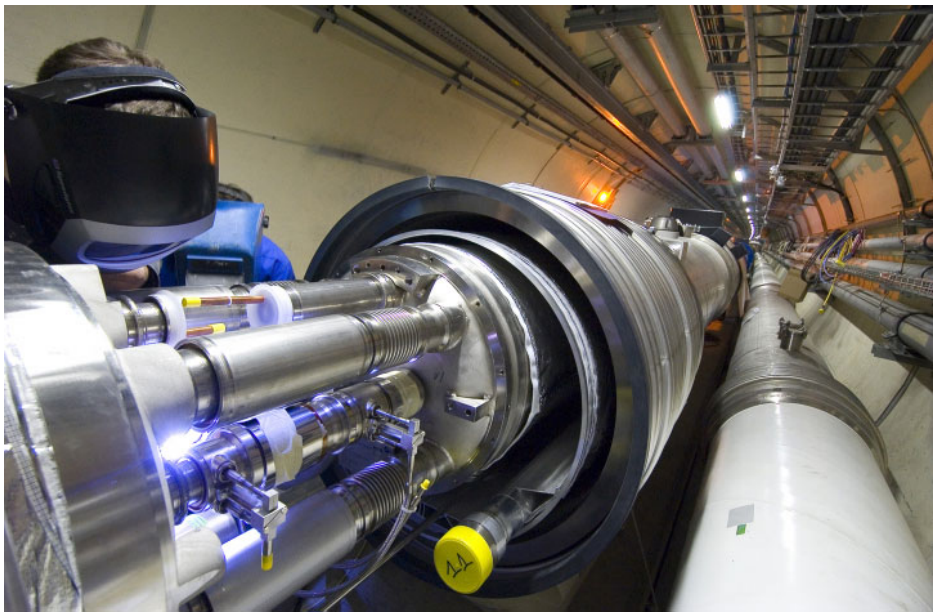
Clearly on the critical path

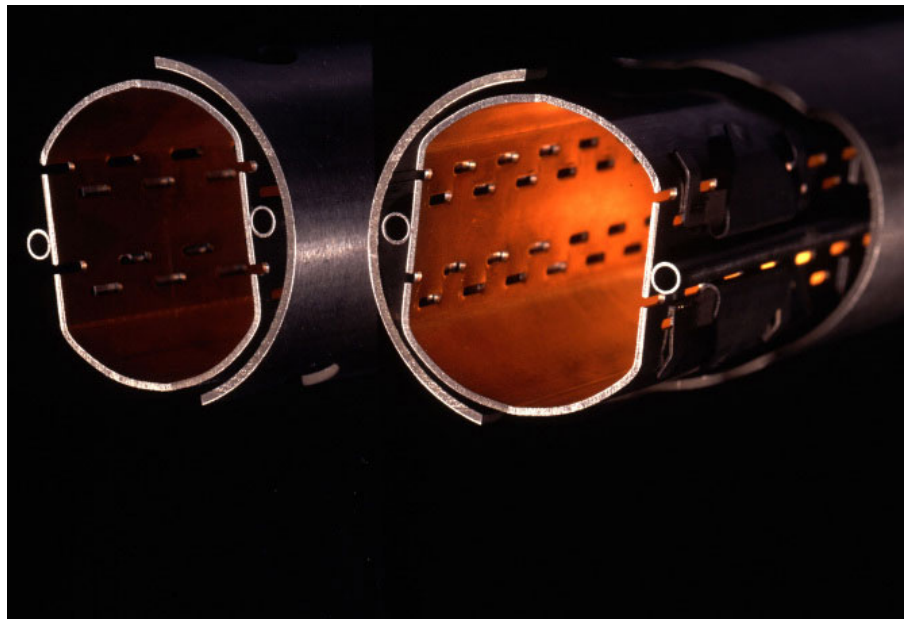
Check the wiring

Vacuum

Beam vacuum 10^{-10} Torr

(~3 million molecules/cm^3), want to avoid collisions with gas molecules





27 km (x ~2 +): warm, cold, transitions, valves, gauges etc.

The vacuum group are very, very busy…

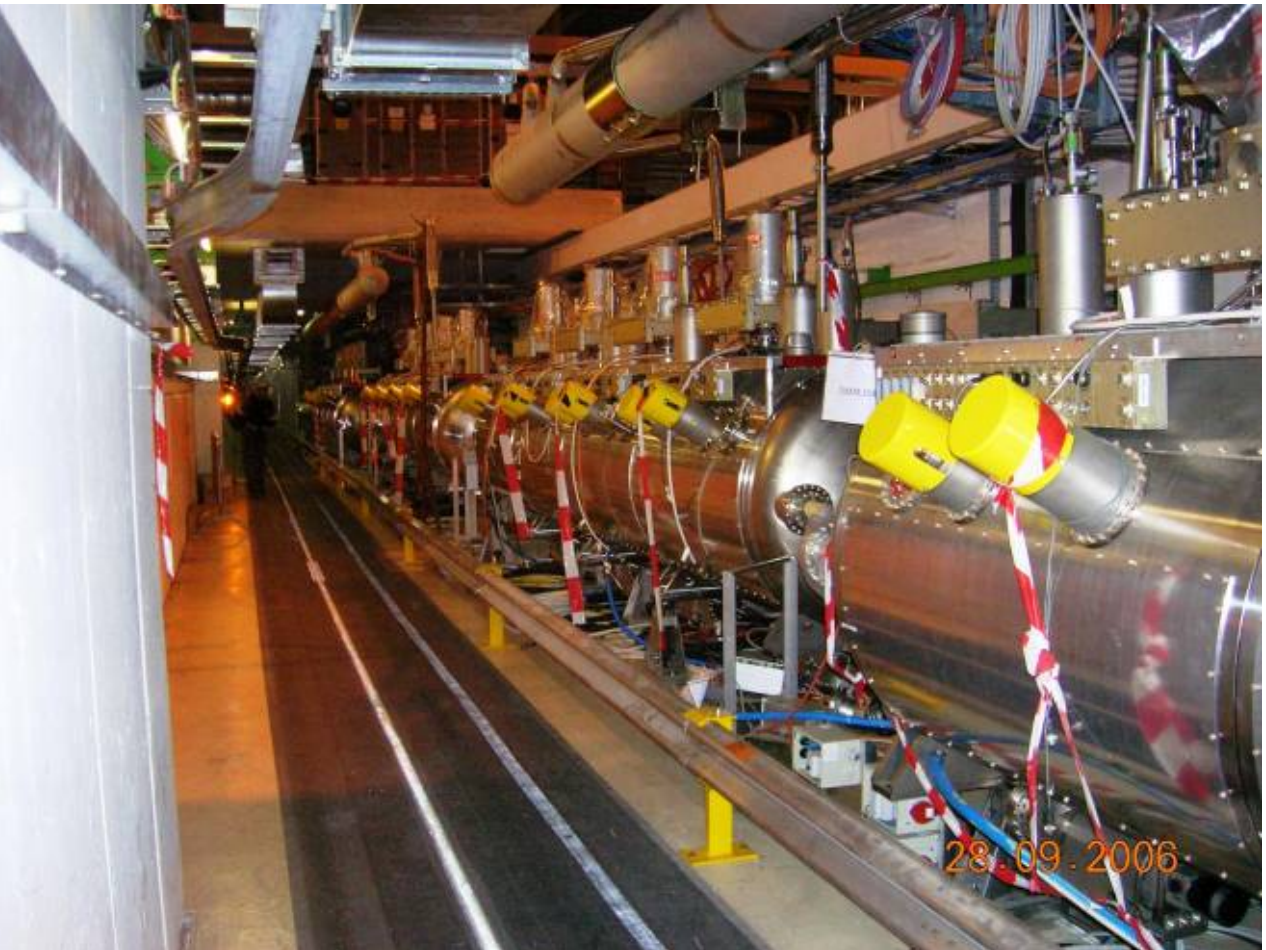
Miscellaneous

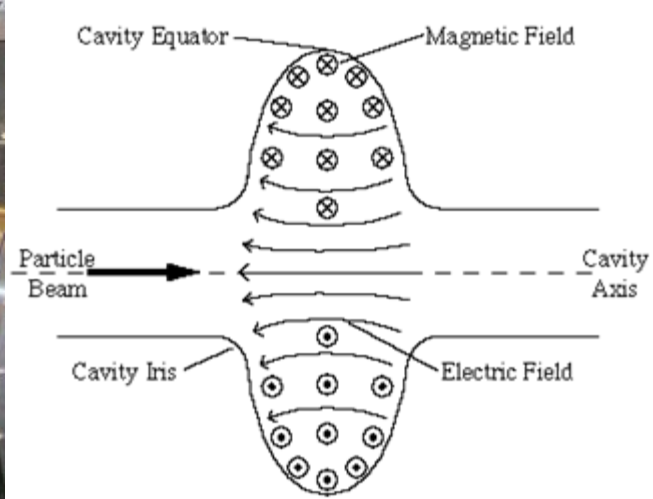
MQ.30L8, 31.01.2006

echo -22 dB

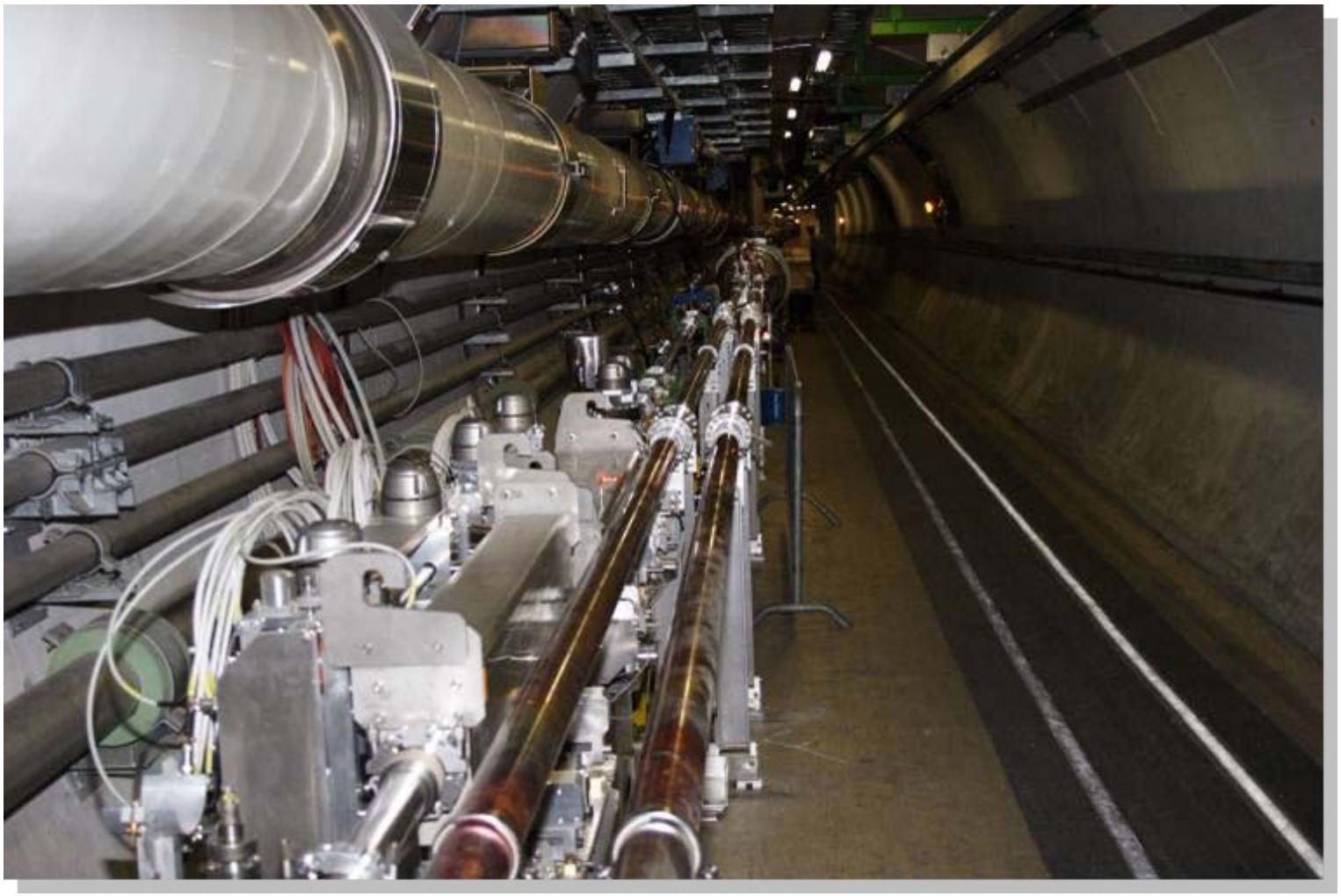
Potential aperture restrictions!

Installation: RF - point 4





Installation: junction of TI8 injection line

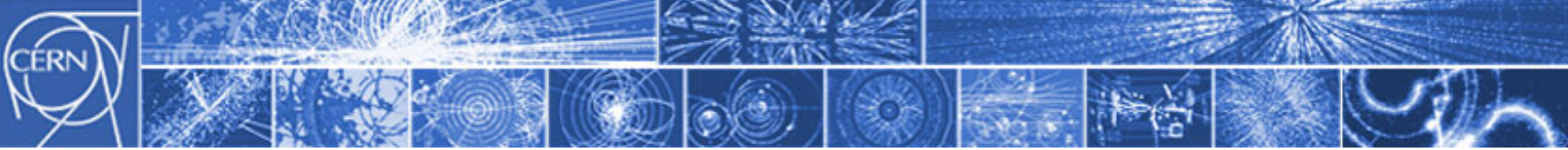


Installation: Summary May 07

All dipoles, arc and special SSS have been delivered

- **Interconnection** on-going in 6 sectors
- Last sector **Arc 1-2** magnets are in place
- **Installation of beam pipe and vacuum elements**
  - Ongoing (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
› CRIME
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› SCIENCE

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)

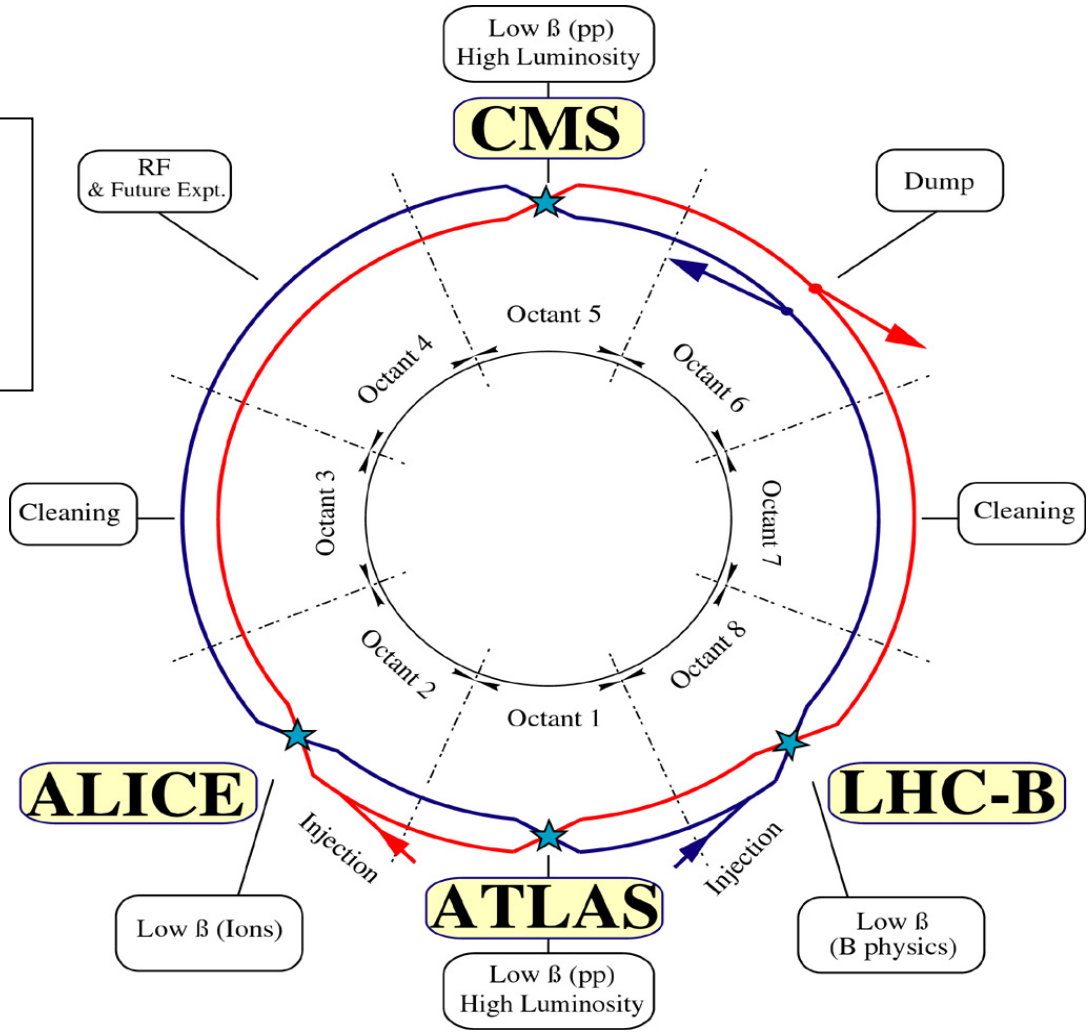
Según publica el diario 'The Times', la explosión se produjo el pasado 27 de marzo, y **levantó de sus sujeciones un imán de 20 toneladas de peso**, llenando de helio una de las galerías y obligando a evacuar el complejo. "Fue una explosión enorme. El túnel que aloja los imanes se llenó de helio y polvo 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".

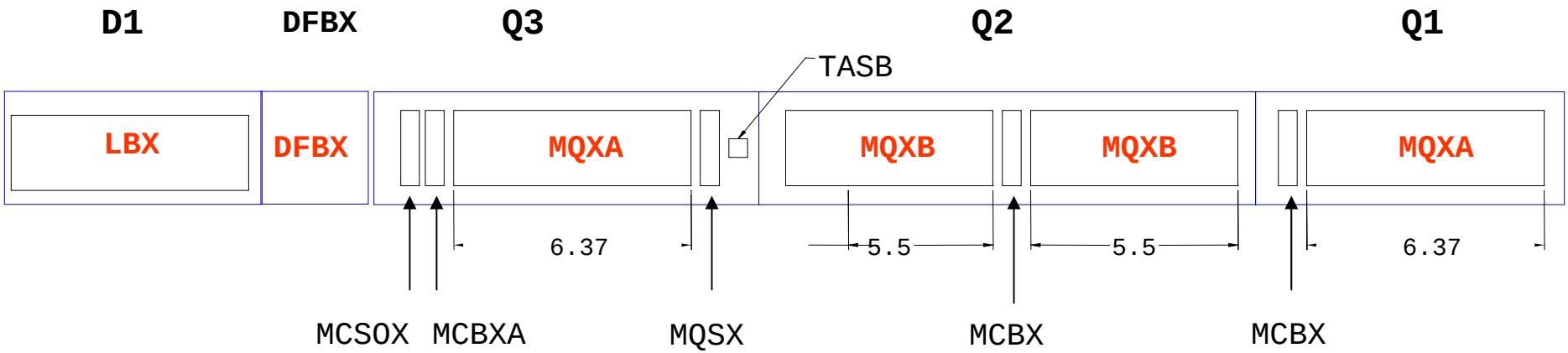
Inner triplets

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

In total, eight triplets are installed.



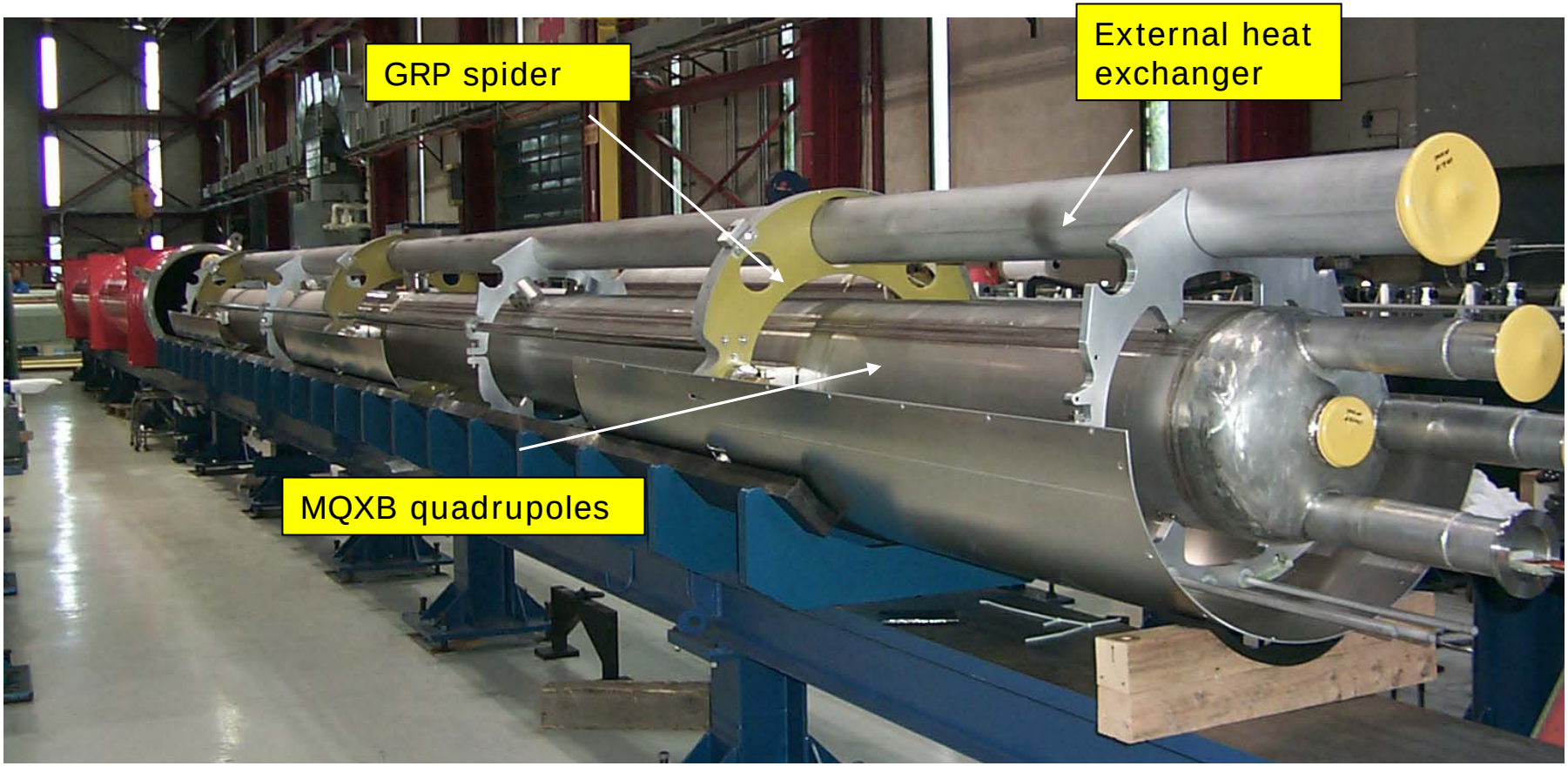
The LHC low-β triplet



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

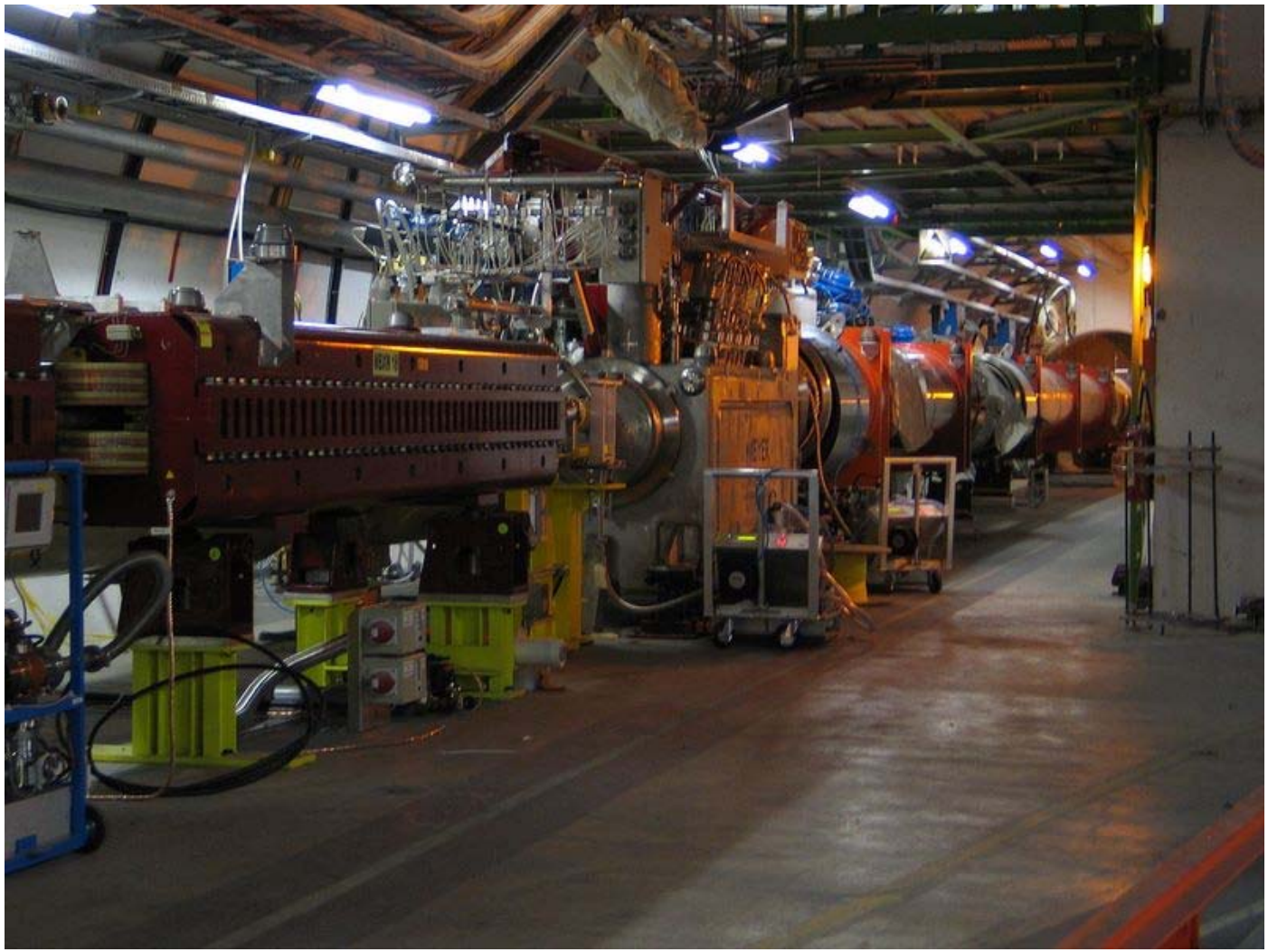
Triplets were designed and built by a collaboration of five laboratories: BNL, CERN, Fermilab, KEK, LBNL.

LHC low-β triplet – Q2



LHC low-β triplet – warm assembly

LHC low-β triplet – DFBX



Inner triplet problem

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.

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.

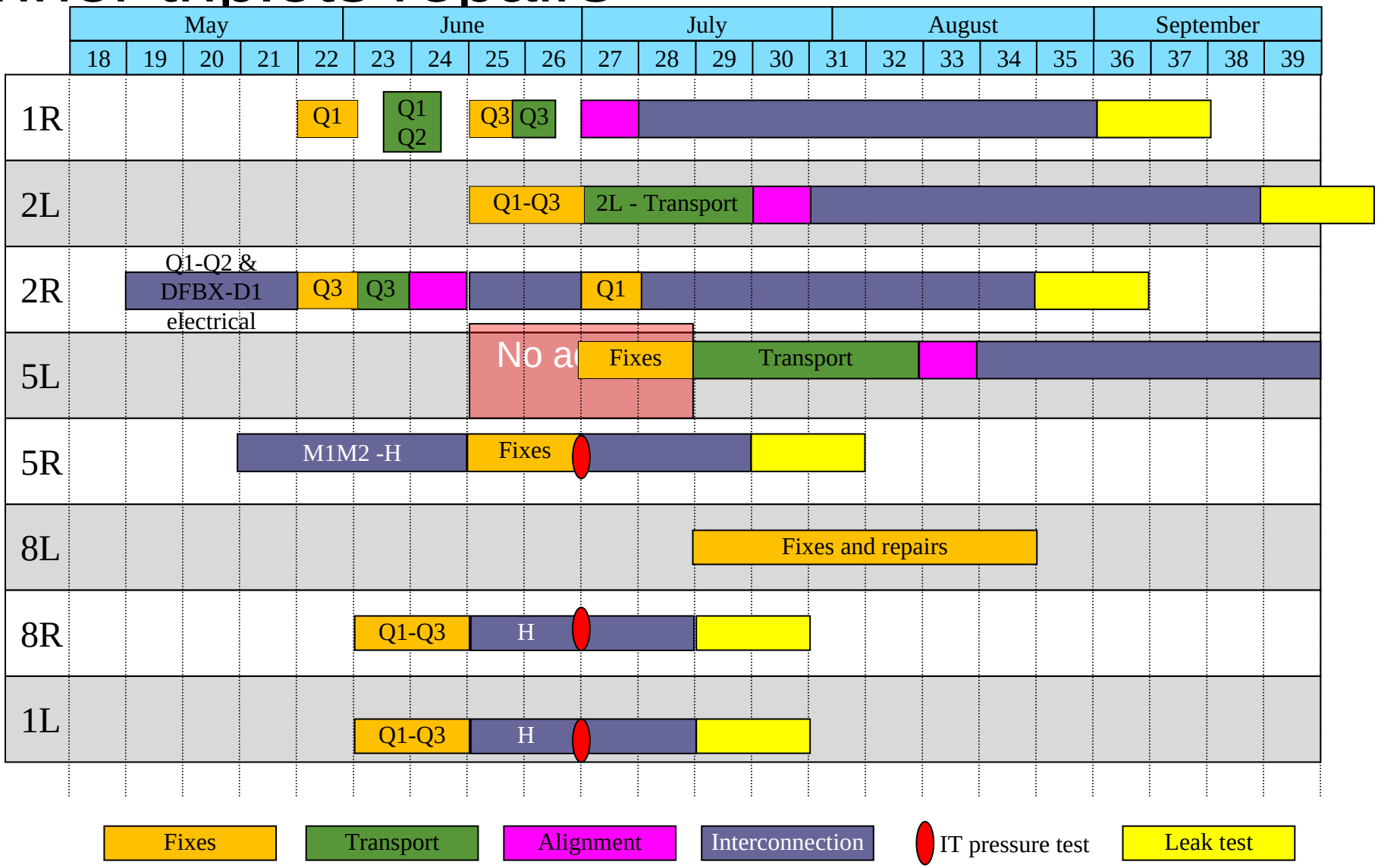
Was anyone hurt?

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

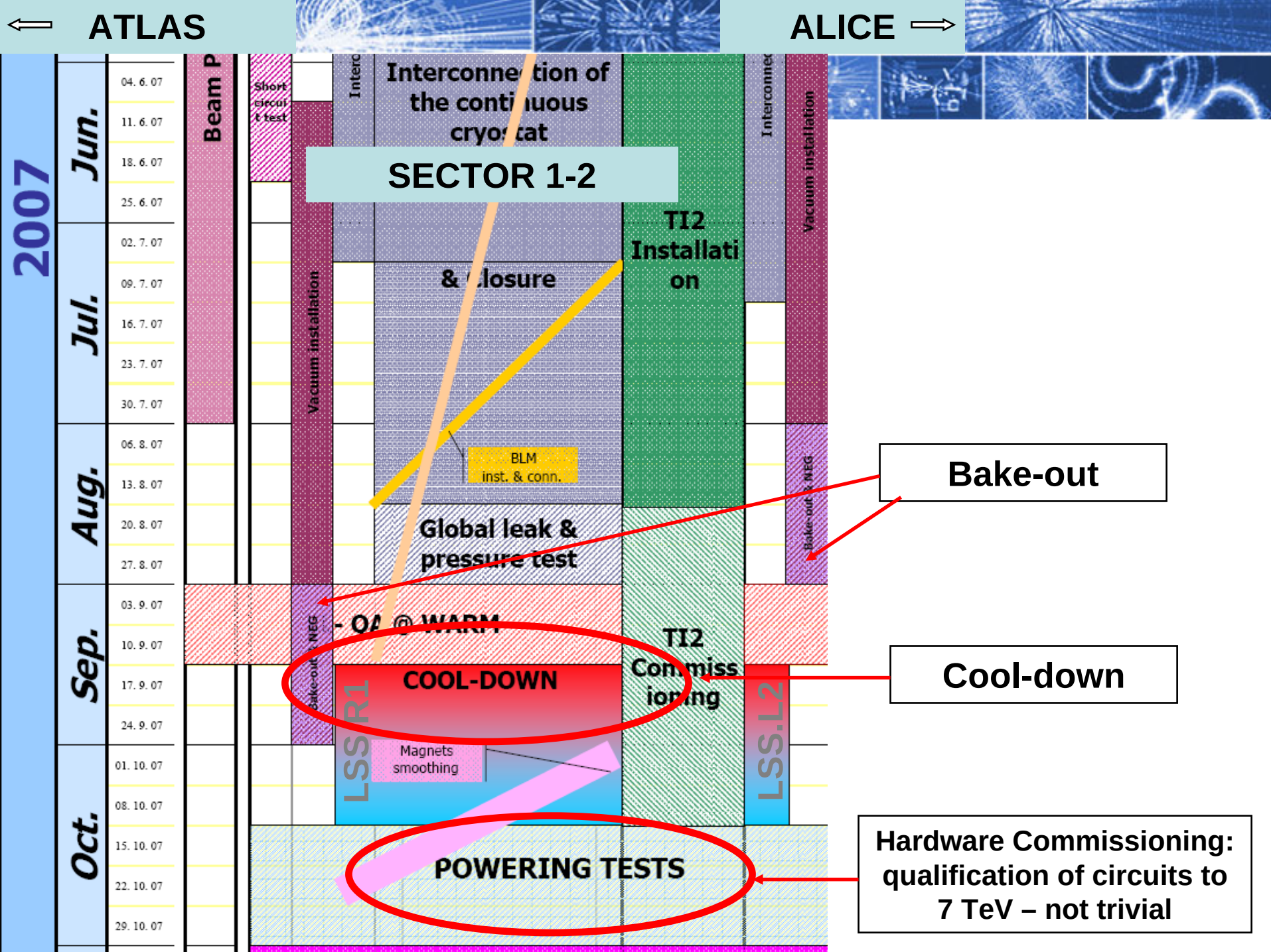
Did a mistake in mathematics cause the magnet failure?

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.

Inner triplets repairs

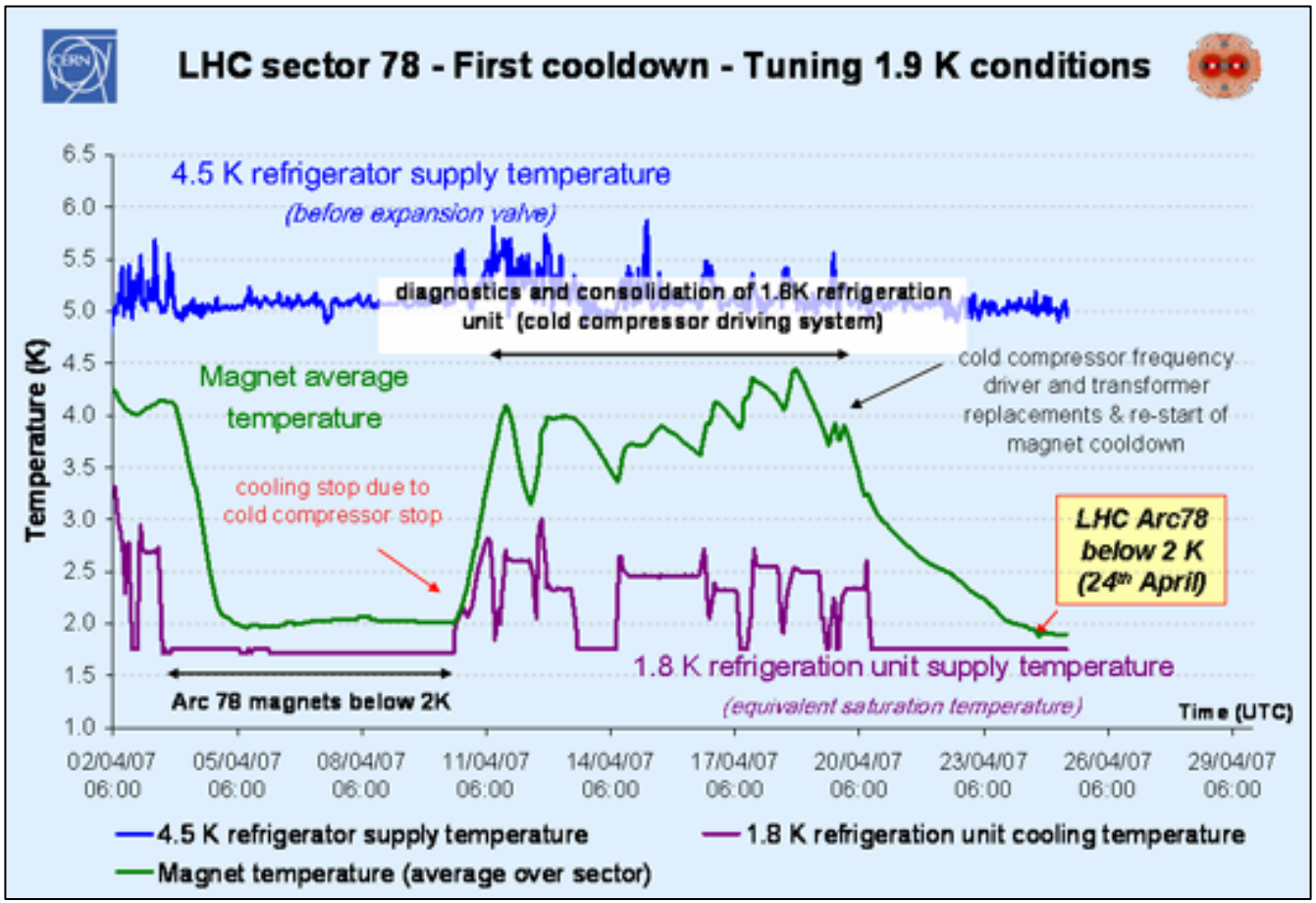


Cool down and hardware commissioning

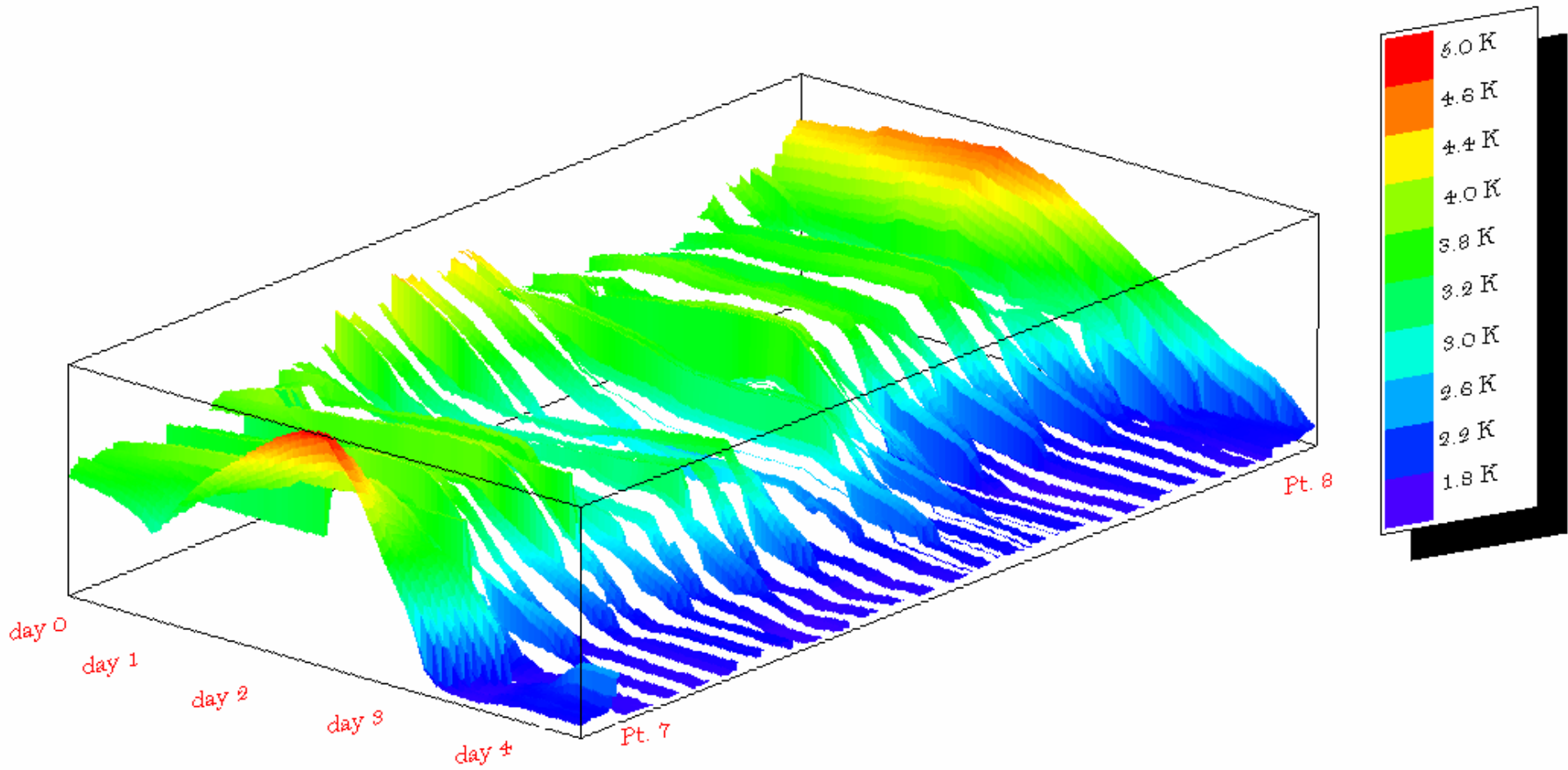

ATLAS
ALICE
2007
Jun.
Jul.
Aug.
Sep.
Oct.
04. 6. 07
11. 6. 07
18. 6. 07
25. 6. 07
02. 7. 07
09. 7. 07
16. 7. 07
23. 7. 07
30. 7. 07
06. 8. 07
13. 8. 07
20. 8. 07
27. 8. 07
03. 9. 07
10. 9. 07
17. 9. 07
24. 9. 07
01. 10. 07
08. 10. 07
15. 10. 07
22. 10. 07
29. 10. 07
Beam P
Short circuit test
Interconnection 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

Cool down

One sector: 3.3 km - 154 dipoles ++



1.9 K cool down along the arc



Not without a cryogenic wrestling match

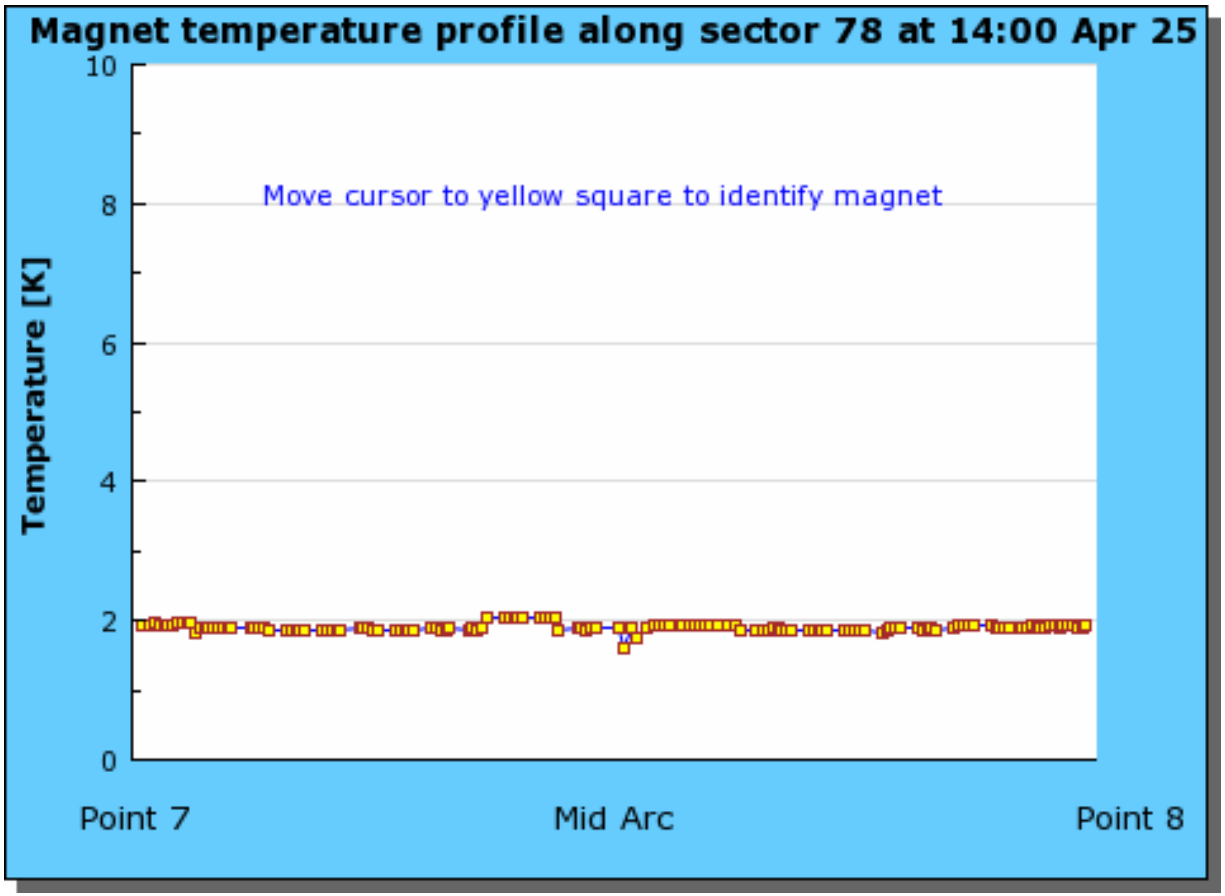
Huge system

- **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…..

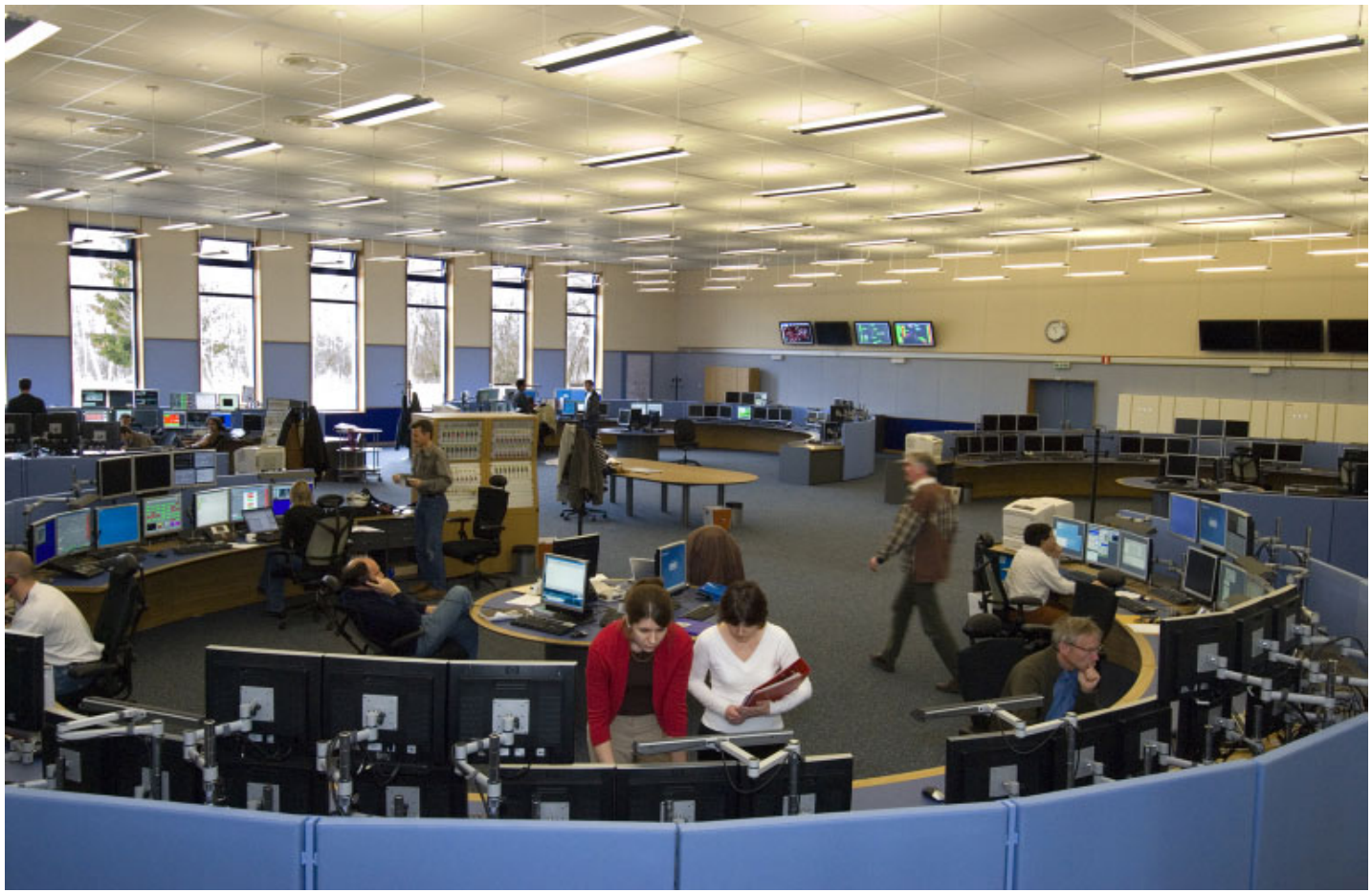
Things are looking better…



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



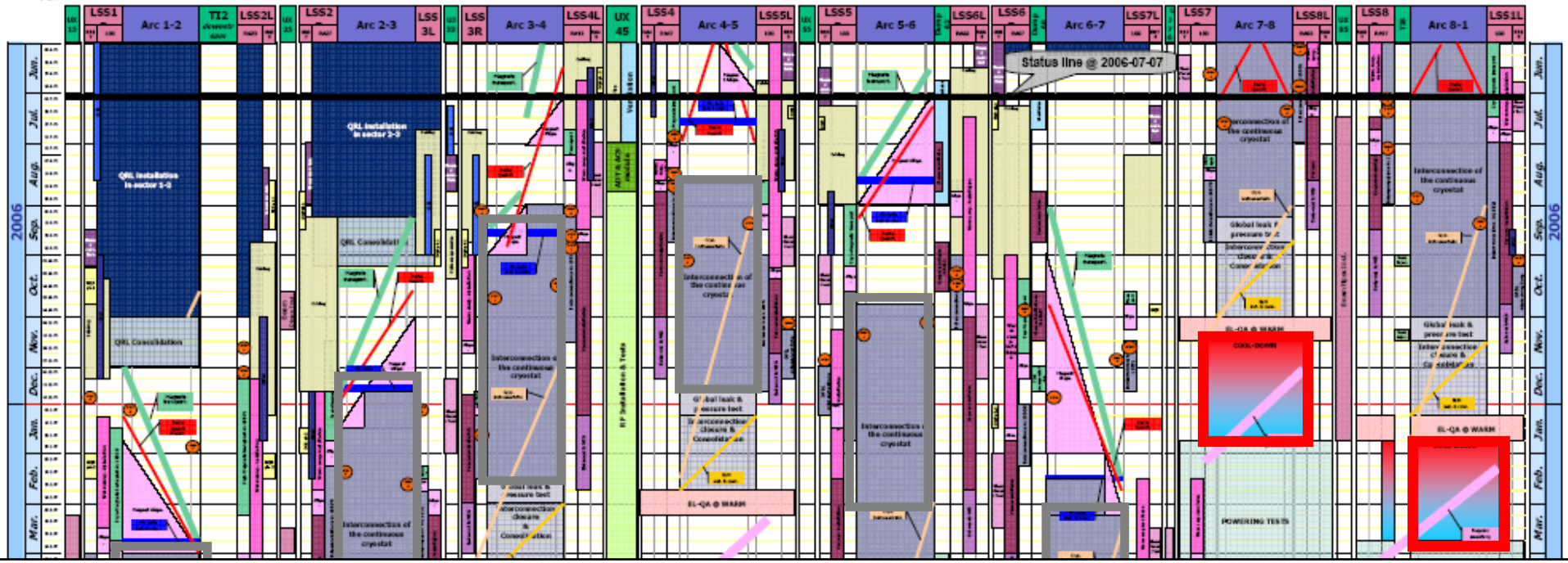
So…

- 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
  - …

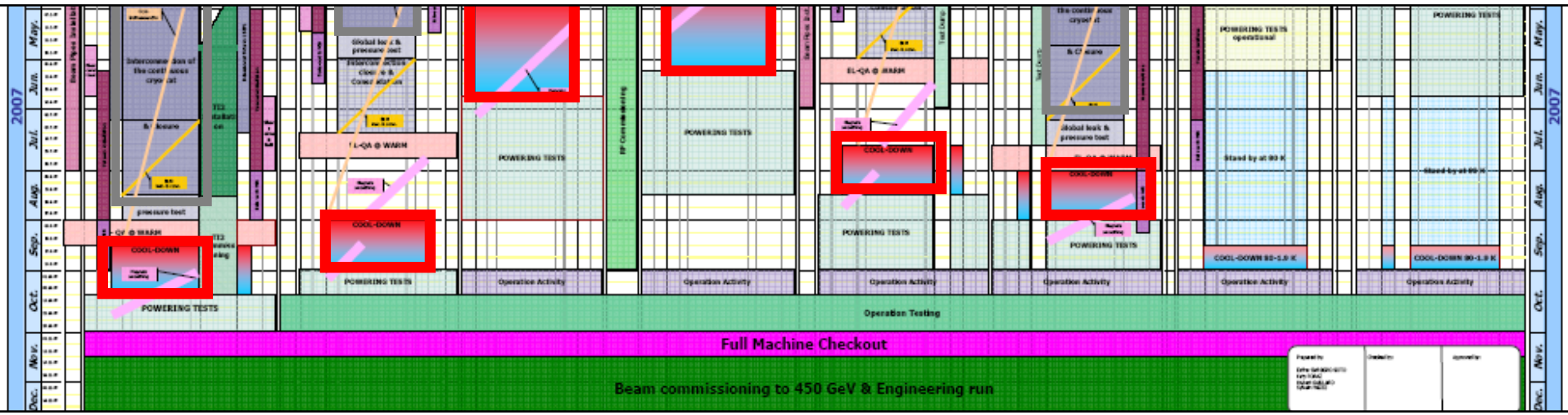
There is a lot left to do.

LHC Construction and Installation

General Co-ordination Schedule

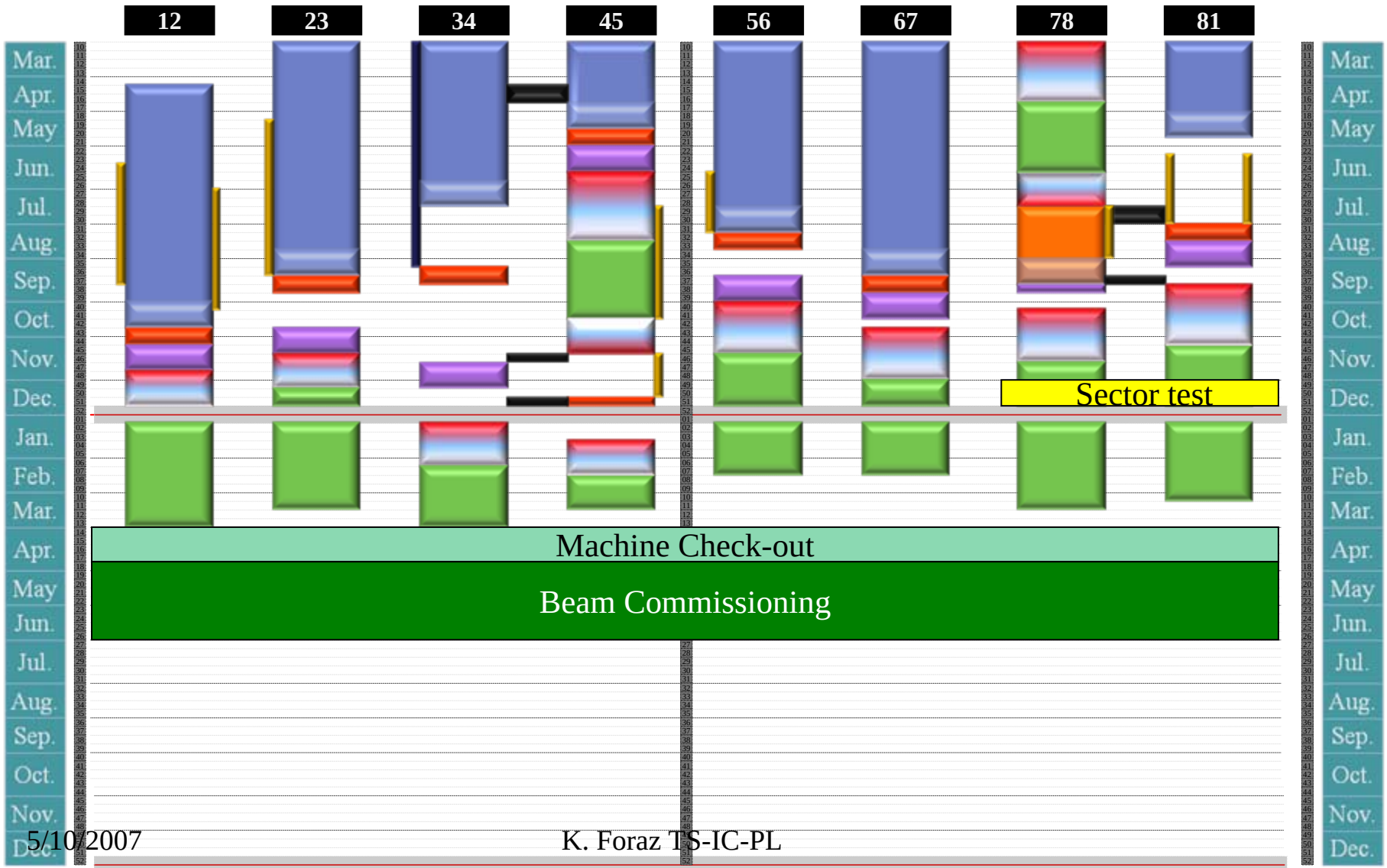


NOW

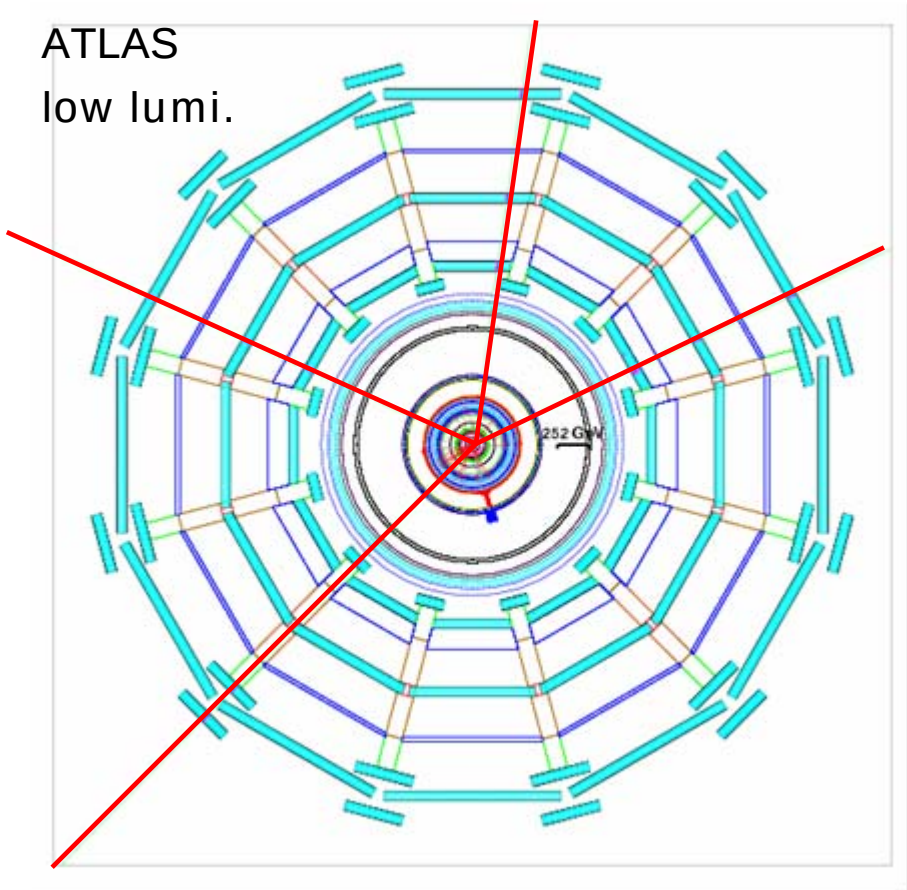


XMAS 2007

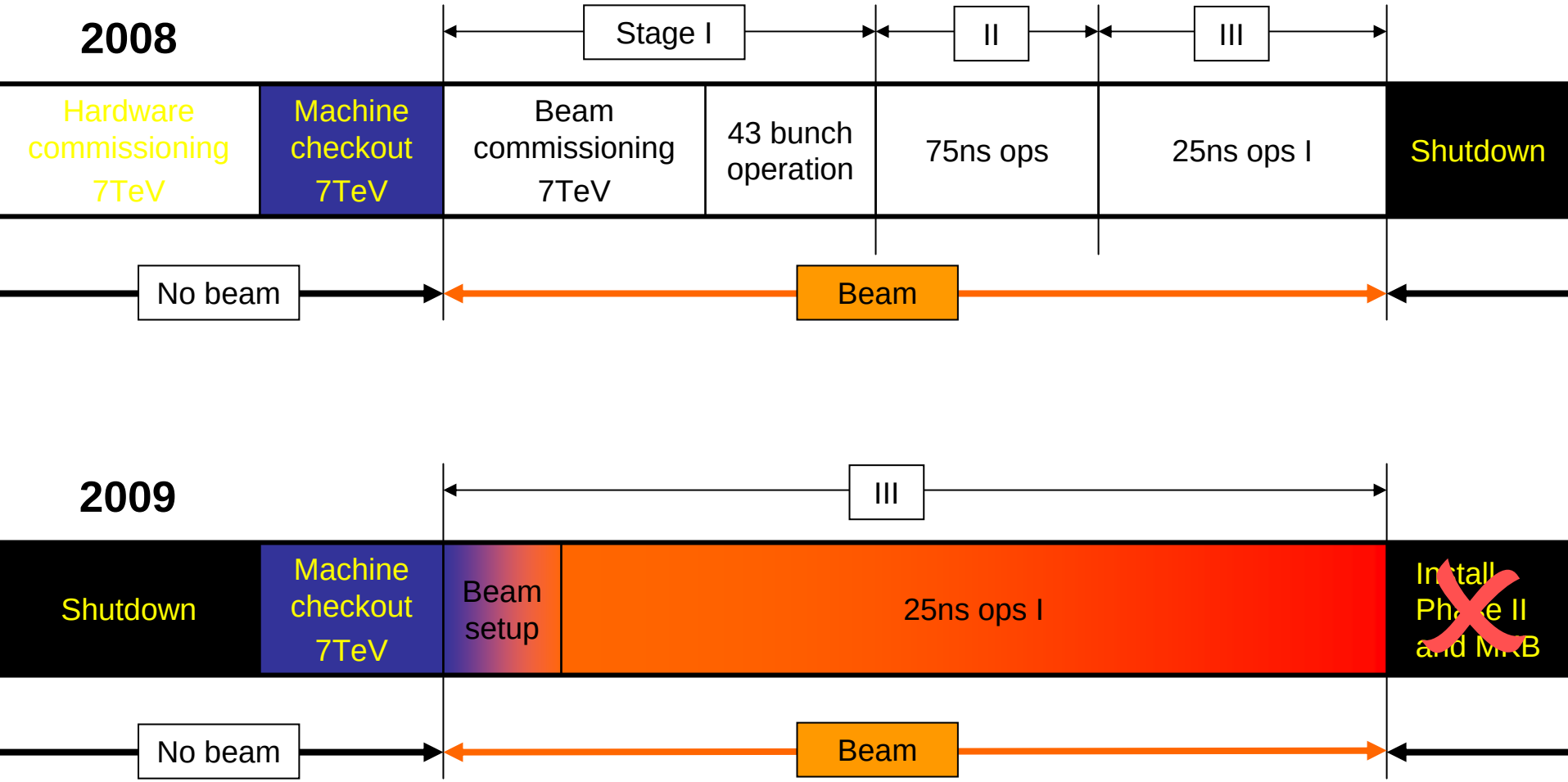
Go straight to 7TeV (with IT repairs & interc.)



2008 (briefly)



Staged commissioning plan for 7TeV



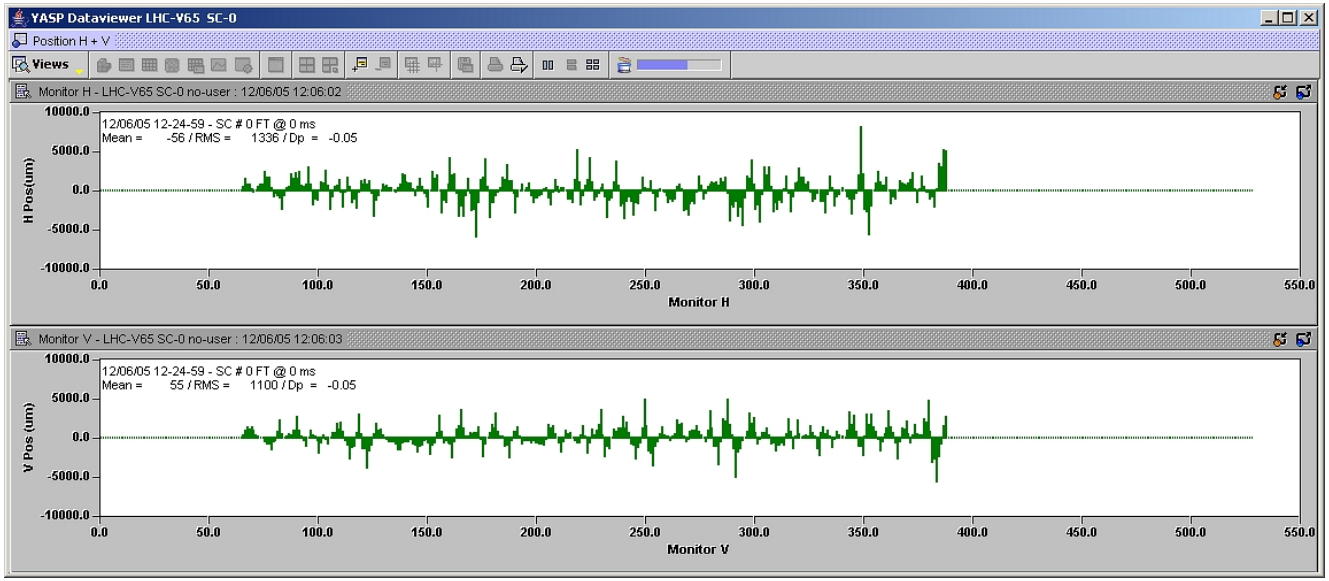
Full commissioning to 7 TeV

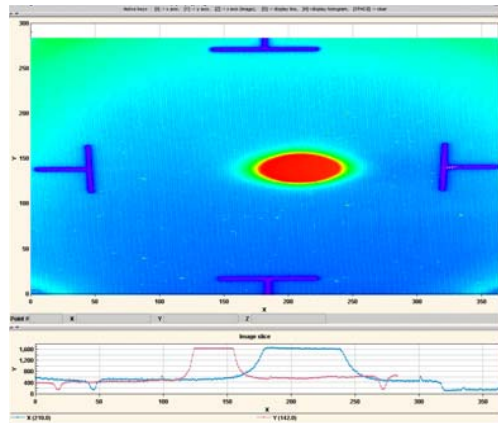
		Total [days]
1	**Injection and first turn**	**6**
2	**Circulating beam**	**3**
3	**450 GeV - initial**	**5**
4	**450 GeV - detailed**	**12**
5	**450 GeV - two beams**	**2**
6	**Snapback - single beam**	**4**
7	**Ramp - single beam**	**8**
8	**Ramp - both beams**	**3**
9	7 TeV - setup for physics	**2**
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**

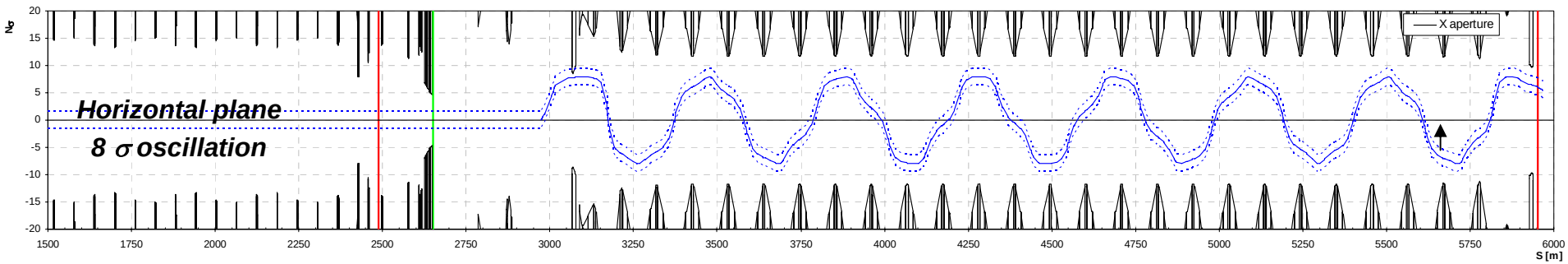
Given reasonable machine availability might expect first 7 TeV collisions in around 2 months

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

Beam commissioning





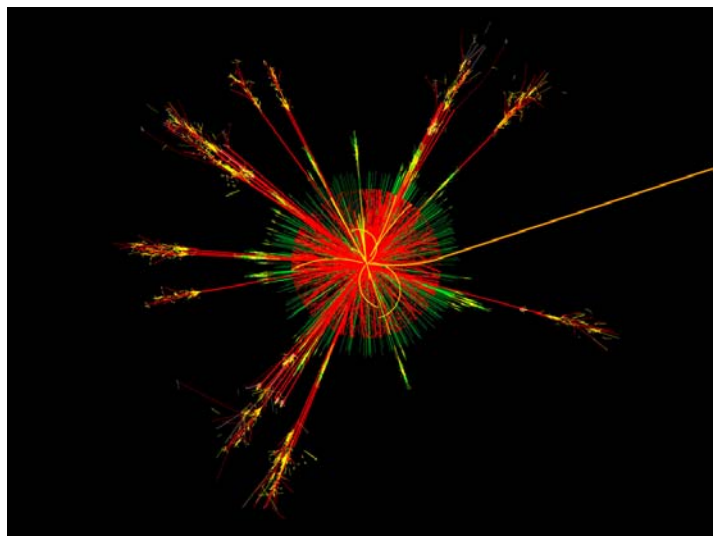


Commission: instrumentation, RF, beam dump, collimators etc,

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

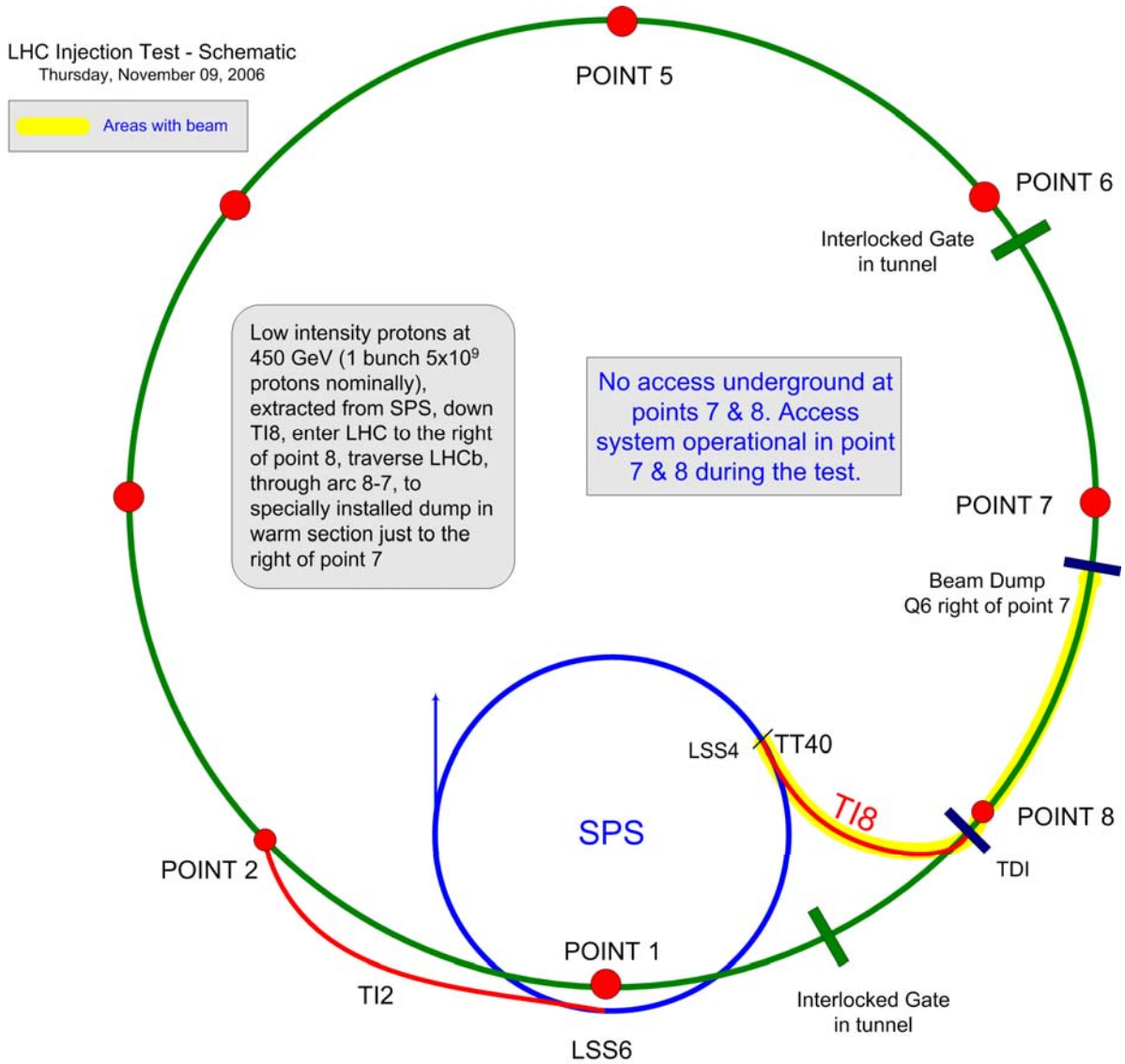
Leading into a period of “Pilot Physics” plus continuing machine commissioning



Schedule

- Some delays are accumulating
  - Inner triplets clearly haven’t helped
- A new schedule will be presented in May 2007
- A 450 GeV run this year is off
- A sector test this year is on

Sector test 2007



Conclusions

Installation, Cool-down, HWC

- Despite the problems, this is going remarkably well
- However, delays have accumulating

2007: Sector test

2008: 7 TeV

- 6-8 weeks single/two beam machine commissioning
- Pilot physics

The next 18 months is going to be a lot of fun.