Obs: you can notice different particle species used in the different colliders: electron-positrons and hadron colliders (either p-p as Tevatron, p-p as LHC).

Higgs and super-symmetry? Or something else maybe?
The coldest ring in the universe!

1.9 K

2.728 K

COBE - DMR Map of CMB Anisotropy
Four Year Results

North Galactic Hemisphere
South Galactic Hemisphere

-100 \( \mu K \) +100 \( \mu K \)
cross-section of LHC cryodipole
\[ B = \frac{\mu_0 J r}{2} \]

\[ B_y = \frac{\mu_0 J}{2} \left\{ -r_1 \cos \theta_1 \right\} + r_2 \cos \theta_2 \]

\[ B_x = \frac{\mu_0 J}{2} \left\{ r_1 \sin \theta_1 \right\} - r_2 \sin \theta_2 \]

\[ = -\frac{\mu_0 J s}{2} \]
distribution of conductors in dipole coil

| |B| (T) |
|---|---|
| 8.256 - 8.705 |
| 7.807 - 8.256 |
| 7.358 - 7.807 |
| 6.909 - 7.358 |
| 6.460 - 6.909 |
| 6.011 - 6.460 |
| 5.562 - 6.011 |
| 5.113 - 5.562 |
| 4.664 - 5.113 |
| 4.215 - 4.664 |
| 3.766 - 4.215 |
| 3.317 - 3.766 |
| 2.868 - 3.317 |
| 2.419 - 2.868 |
| 1.970 - 2.419 |
| 1.521 - 1.970 |
| 1.072 - 1.521 |
| 0.623 - 1.072 |
| 0.174 - 0.623 |
dipole magnetic flux plot
specific heat of LHe and Cu

![Graph showing specific heat of LHe and Cu against temperature in Kelvin. The graph displays a sharp peak at 2 K for LHe and a linear increase for Cu.](image-url)
phase diagram of Helium

- Saturated He II
- Pressurized He II
- Solid
- I line
- Critical point
- Gas

P [kPa] vs T [K]
**linear heat exchanger**

**LHC magnet string cooling scheme**

- saturated He II, flowing
- pressurized He II, static
- heat exchanger tube
- magnet
- sc bus bar connection
- helium vessel
Energy stored in the accelerator beam, as a function of beam momentum. At less than 1% of nominal intensity LHC enters new territory.

Stored energy density as a function of beam momentum. Transverse energy density is a measure of damage potential and is proportional to luminosity.
Energy stored in the accelerator beam, as a function of beam momentum. At less than 1% of nominal intensity LHC enters new territory.

Stored energy density as a function of beam momentum. Transverse energy density is a measure of damage potential and is proportional to luminosity.

30’000 km underground at 2 km/h!
DFBAO in Sector 7-8
dipole-dipole interconnect
From RT to 80K precooling with LN2. 1200 tons of LN2 (64 trucks of 20 tons). Three weeks for the first sector.

From 80K to 4.5K. Cooldown with refrigerator. Three weeks for the first sector. 4700 tons of material to be cooled.

From 4.2K to 1.9K. Cold compressors at 15 mbar. Four days for the first sector.

dipole-dipole interconnect: electrical splices
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600 kW precooling to 80 K with LN2 (up to ~5 tons/h)

33 kW @ 50 K to 75 K
23 kW @ 4.6 K to 20 K
41 g/s liquefaction

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600 kW precooling to 80 K with LN2 (up to ~5 tons/h)

33 kW @ 50 K to 75 K

23 kW @ 4.6 K to 20 K

41 g/s liquefaction

Christmas and water maintenance shut-down

Short in connection cryostats and repairs

Cooling sectors + Cryo tuning + Powering activities

LHC Cryogenics - Status for ICC

SC - 04Jul'08
cooldown status

Sector temperature profile at 18 Aug 08:59

Sector 56

Sector 67

Sector temperature profile at 18 Aug 08:41

Sector 78

Sector 81

Sector temperature profile at 18 Aug 09:04
cooldown status

Sector temperature profile at 18 Aug 08:58

Move cursor to square to identify magnet

Sector 12

Sector 23

Sector temperature profile at 18 Aug 08:58

Move cursor to square to identify magnet

Sector 34

Sector 45

Sector temperature profile at 18 Aug 09:00

Move cursor to square to identify magnet

Point 1
Point 2
Point 3
Point 4
Point 5

Saturated Vapour Temperature: 1.78K

Mid Arc

Inner Triplets
Arc magnets
LSS magnets

Point 1
Point 2
Point 3
Point 4
Point 5

Saturated Vapour Temperature: 1.78K

Mid Arc

Inner Triplets
Arc magnets
LSS magnets

RF cavities
Arc magnets
LSS magnets
the organization

Commissioning Coordinator

Deployed for 4 fronts in parallel

Analysis Team
Magnet Performance Panel

Engineer in Charge
Operator

Quench Protection Team
Powering Team
Interlock Team

Quench Protection Team

Deployed for 4 fronts in parallel

Courtesy Roberto Saban

L. Evans - EDMS document 949682

Courtesy Roberto Saban
the superconducting circuits of an LHC sector

<table>
<thead>
<tr>
<th></th>
<th>XR5</th>
<th>LR5</th>
<th>A56</th>
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<td>IPQ</td>
<td>IP</td>
<td>IPQ</td>
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</tr>
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<td>7</td>
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<td>7</td>
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<td>5</td>
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<td>1.9 K</td>
<td>4.5 K</td>
<td>1.9 K</td>
<td>4.5 K</td>
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<tr>
<td>13 circuits</td>
<td>14 circuits</td>
<td>157 circuits</td>
<td>6 circuits</td>
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</table>

Totalling 190 circuits

L. Evans - EDMS document 949682

Courtesy Roberto Saban
## Circuit Type

### Sector

<table>
<thead>
<tr>
<th>Circuit Type</th>
<th>Sector</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-2</td>
<td>2-3</td>
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<tr>
<td>13 kA</td>
<td>3</td>
<td>3</td>
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<tr>
<td>Independently Powered Dipoles</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Independently Powered Quadrupoles</td>
<td>14</td>
<td>7</td>
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<tr>
<td>600A with Energy Extraction</td>
<td>23</td>
<td>27</td>
</tr>
<tr>
<td>600A Energy Extraction in Converter</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>600A no Energy Extraction</td>
<td>16</td>
<td>9</td>
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<tr>
<td>80-120A Correctors</td>
<td>50</td>
<td>37</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>123</strong></td>
<td><strong>105</strong></td>
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### Circuit Type

<table>
<thead>
<tr>
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<th>Sector</th>
<th>LHC</th>
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<tbody>
<tr>
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<td>60A Closed Orbit Correctors</td>
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SECTOR 5-6

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<th>Sector 3-4</th>
<th>Sector 4-5</th>
<th>Sector 5-6</th>
<th>Sector 6-7</th>
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<td>13 kA</td>
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<td>3</td>
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<td>3</td>
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<tr>
<td>Independently Powered Quadrupoles</td>
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<td>14</td>
<td>7</td>
<td>6</td>
<td>13</td>
<td>12</td>
<td>5</td>
<td>14</td>
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<tr>
<td>600A with Energy Extraction</td>
<td>600A</td>
<td>23</td>
<td>27</td>
<td>28</td>
<td>24</td>
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<td>83</td>
<td>99</td>
<td>95</td>
<td>79</td>
<td>105</td>
<td>123</td>
</tr>
</tbody>
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RF cavities

Fibre-optics signal distribution from RF in SR4 to Experiments, BT & BI equipment and to CCC.

40 MHz bunch clocks, revolution frequencies, 40 MHz 7TeV reference. Injection & dump kicker pulses.
Fibre-optics signal distribution from RF in SR4 to Experiments, BT & BI equipment and to CCC.

40 MHz bunch clocks, revolution frequencies, 40 MHz 7TeV reference. Injection & dump kicker pulses.

RF synchronization in place – clocks and timing now going from SR4 to all users. Recent successful dry run tests with all users and OP group, including basic software.

Cavity Beam Control systems in advanced state but some items on critical path.

Transverse Damper electronics being tested.

Software for beam control also critical, but basic functionality will be available for this run.

Procedures for beam commissioning well defined.

Longitudinal diagnostics in good shape to study and commission first beams....
Fast timing/synch: new prepulse system, stable – some GMT issues (configuration events arriving too late – CBCM issue) which caused random “synch” of kicker pulse. Solved manually for the test – temporary fix being conceived to test on 22nd.

RF frequency control – phasing from LHC back to SPS – limited F range to +/-800 Hz – can double this for measurements. Used rephasing error signal – worked nicely.
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Aims
Champagne
Instrumentation & controls
Measurements
**Friday 15:20**  
Beam on to TI2 TED  
MSI etc pulsing  
Cycle LHC Sector 23  
**OP**  
Beam down TI2 first shot

**Friday 19:00**  
TI2 TED out, beam to TDI,  
kickers off  
Give Alice 20 minute warning before taking TED out  
**INJ**  
Beam on TDI after correction end TI2

**Friday 21:00**  
Kickers on, time in, position checks  
Resolve timing issues  
**INJ**  
Interesting collaboration between timing and RF

**Friday 21:40**  
TDI out - threading - momentum matching - beam to IR3 - beer  
**Jorg & team**  
Beam to IR3 first shot. Tweak SPS.
Friday 15:20
Beam on to TI2 TED
MSI etc pulsing
Cycle LHC Sector 23
OP
Beam down TI2
first shot
Friday 19:00
TI2 TED out, beam to TDI,
kickers off
Give Alice 20 minute warning
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INJ
Beam on TDI
after correction
end TI2
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Kickers on, time in, position
checks
Resolve timing issues
INJ
Interesting
collaboration
between timing
and RF
Friday 21:40
TDI out - threading - momentum
matching - beam to IR3 - beer
Jorg & team
Beam to IR3
first shot.
Tweak SPS.
screens in injection region (septa, kickers, TDI)
screen at point 3 – first shot
Response measurements – used about 50% of correctors and all BPMs – found a few issues (1 dead BPM, 1 inverted BPM, BPMWs systematically with inverted non-linear calibration factors). Found main focusing quadrupole strength about 1% too high. Monitor and corrector gains all look good, correctors within 15%, with one exception. See clear family dependence. Need error bars. Saw problems with fit after ~11L3. Candidate was polarity of MQTL1.11L3 – tried to verify this experimentally – results inconclusive.

Energy matching – trimmed SPS by 0.2% - had a residual of about 0.05%. Some effect seen after recycling.
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Energy matching – trimmed SPS by 0.2% - had a residual of about 0.05%. Some effect seen after recycling.
Dispersion measurement – SPS frequency trim limited to 800 Hz (+/-0.1%). Looks very good in the horizontal plane – starts diverging after ~11L3. In vertical plane might be a bit of residual dispersion, but maybe just due to the noise on the BPMs at these low intensities.
- Free oscillations to check overall clear aperture.
- H +/-18-20 mm in arc, losing in Q6.L3.
- V at least +/-10 mm, again found bottleneck in Q8 and Q7 to about 10 sigma. Did not go to aperture limit in the arc.
strategy for 2008 and 2009

2008

Hardware commissioning
To 5TeV

Machine commissioning
5TeV

Beam commissioning
43/156 bunch operation

Train to 7TeV

No beam

Beam

2009

Train to 7TeV

Machine commissioning

Beam Setup

75ns ops

25ns ops I

Shutdown

No beam

Beam

Phase A.1
First turn

Phase A.2
Circulating pilot

Phase A.3
450 GeV first commissioning

Phase A.4
450 GeV optics

Phase A.5
450 GeV, increasing intensity

Phase A.6
450 GeV, two beam operation

Phase A.7
450 GeV, collisions

Phase A.8
Snap-back and ramp

Phase A.9
Top energy, checks

Phase A.10
Top energy, collisions

Phase A.11
Squeeze

Phase A.12
Experimental magnets

Courtesy Roger Bailey
Commissioning Procedures

Beam Commissioning of the LHC

Phase A.1  First turn
Phase A.2  Circulating pilot
Phase A.3  450 GeV first commissioning
Phase A.4  450 GeV optics
Phase A.5  450 GeV, increasing intensity
Phase A.6  450 GeV, two beam operation
Phase A.7  450 GeV, collisions
Phase A.8  Snap-back and ramp
Phase A.9  Top energy, checks
Phase A.10 Top energy, collisions
Phase A.11 Squeeze
Phase A.12 Experimental magnets

Phase A.4 (450 GeV optics)

Web based with EDMS approval
http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/stageA_index.htm
stage A: 5TeV collisions

- 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

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

\[ \text{Eventrate/Cross} = \frac{L\sigma_{\text{TOT}}}{k_b f} \]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Rates in 1 and 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_b$</td>
<td>$N$</td>
</tr>
<tr>
<td>1 (3)</td>
<td>$10^{10}$</td>
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<tr>
<td>4</td>
<td>$10^{10}$</td>
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<tr>
<td>43</td>
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<td>43</td>
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<tr>
<td>156</td>
<td>$4 \times 10^{10}$</td>
</tr>
<tr>
<td>156</td>
<td>$9 \times 10^{10}$</td>
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</tbody>
</table>

Realistically (1 and 5)
- 30 days of physics
- Efficiency for physics 40%
- Peak luminosity around $10^{-31}$ cm$^{-2}$s$^{-1}$
- Integrated luminosity ~ $10^{36}$ pb$^{-1}$

10$^{6}$ seconds @ <L> of $10^{-30}$ cm$^{-2}$s$^{-1}$!
aims for 2008

- **Commission machine to 5TeV**
  - Multiple bunches circulating in each ring (43)
  - Moderate intensities (few $10^{10}$)
  - Single beam lifetimes ~ 30h
  - Injection optics ($\beta^* = 11$ m in IR 1 & 5, $\beta^* = 10$ m in IR 2 & 8)
  - No squeeze
  - No crossing angle
  - Collisions

- **Secondary aims**
  - Commission squeeze in 1 and 5 to 3m
  - Commission squeeze in 8 to 6m
  - Push intensities (156 bunches, high 1010)

- **Tertiary aims**
  - Commission crossing angle
  - Commission 75ns beams

---

(10^6 seconds @ $\langle L \rangle$ of 10^{30} cm^{-2} s^{-1} → 1 pb^{-1})

- **Realistically (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}
Commission high energy operation
- Aim for 7TeV (magnets will decide)
- 43 /156 bunch running to start (brief)
- 75ns running
- 25ns running
- High 1032 cm\(^{-2}\) s\(^{-1}\) is in reach

Mixture of
- Operation for physics
- Machine studies
- Scheduled stops
- Access, injection, ramp, squeeze etc
- Colliding beams
- Ion run?

Realistically (1 and 5)
- 150 days of physics
- Efficiency for physics 40%
- Peak luminosity around \(10^{33}\) cm\(^{-2}\) s\(^{-1}\)
- Integrated luminosity \(\sim\) few fb\(^{-1}\)

\((10^6\ \text{seconds} \times 10^{33}\ \text{cm}^{-2}\ \text{s}^{-1} \rightarrow 1 \text{ fb}^{-1})\)
The whole machine is now cold and in the final stage of commissioning.

Both the detectors and the machine have converged remarkably well to termination considering the 14-years construction period. No one is sitting around waiting for the others to finish.

Three weeks from now the first beam will be injected into the full machine and beam commissioning will begin.

The first physics run will be at 10 TeV to speed up commissioning and to give adequate operational margin during the learning phase.

The machine will be trained to 14 TeV during the winter shutdown.