Status of the LHC and commissioning plans

Helmut Burkhardt[1]

[1]CERN, 1211 Geneve 23, Switzerland

The LHC is expected to provide first collisions soon. The current machine status and prospects for the near future are reviewed.

1 Introduction

The 27 km long LHC machine is starting operation at CERN in Geneva. The LHC is the worlds largest and most energetic particle collider. It took many years to plan and built this complex machine, which promises exciting, new physics results with an excellent potential for major discoveries.

The status of the LHC as presented in this conference in August 2009, will have significantly changed by the time that these proceedings will be published. Therefore, only a short overview over some of the most challenging aspects of the LHC and a brief summary of the status together with future prospectives are given here. More detailed information on the LHC machine can be found in the design report [1] and a more pedagogical description in the book [2].

2 LHC challenges and critical issues

The LHC is made of two rings which are horizontally separated by 19.4 cm over most of the circumference and brought together in four interaction regions, as schematically shown in Fig.1.

The main LHC parameters are listed in Table 1 and compared to LEP. The parameters for the magnetic field and beam intensity are particularly ambitious. The aim is to get the maximum energy and luminosity reachable with current technology.

A major challenge in the LHC is the large amount of energy stored in the superconducting magnets (10 GJ) and the beams (360 MJ at design parameters). For comparison, the energy required to heat and melt 1 kg of copper is 0.7 MJ.

The LHC is equipped with a machine protection system designed to automatically turn off and safely dump the energy in the magnets and the beams in case of problems.

The LHC relies on high quality, high intensity beams from its injectors, the CERN proton LINAC, the Booster, the PS and the SPS. A schematic view of the LHC with its injectors is shown in Fig. 2. Different from electron beams, which were strongly damped by synchrotron radiation and accumulated in LEP, the *proton beam density* (the normalized emittance) and bunch intensities in the LHC are determined by the corresponding parameters of the injected beams.

The LHC construction already was very challenging and required to diagnose and solve several critical issues. Some of these looked like a real headache when they were discovered, risking to delay the whole project. Among the earlier, solved issues were

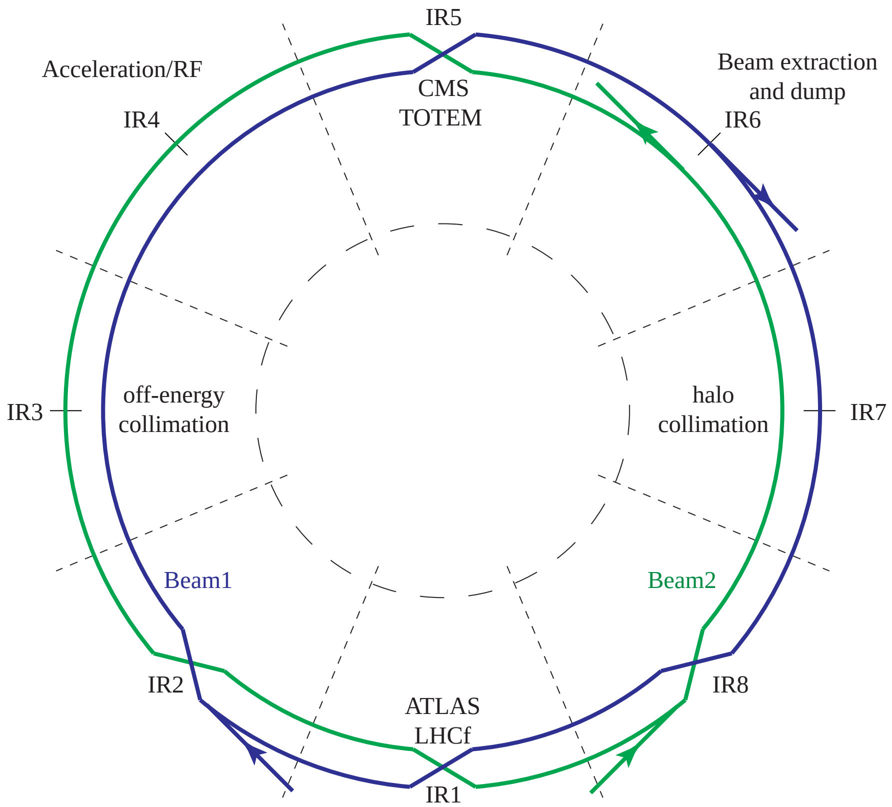

Figure 1: Schematic layout of the LHC collider.

Table 1: Design beam parameters at top energy. LHC compared to LEP.

	LHC	LEP2
Beam energy, E_b, TeV	7	0.1
Nominal design luminosity, $\mathcal{L}$, cm^{-2} s^{-1}	10^{34}	10^{32}
Dipole field at top energy, T	8.33	0.11
Number of bunches, each beam	2808	4
Particles / bunch	1.15×10^{11}	4.2×10^{11}
Typical beam size in the ring, μm	$200 - 300$	1800/140 (H/V)
Beam size at IP, μm	16	200 / 3 (H/V)
Total energy stored in each beam, Mega Joule	360	0.03
Total energy stored in the magnet system, Giga Joule	10	0.016

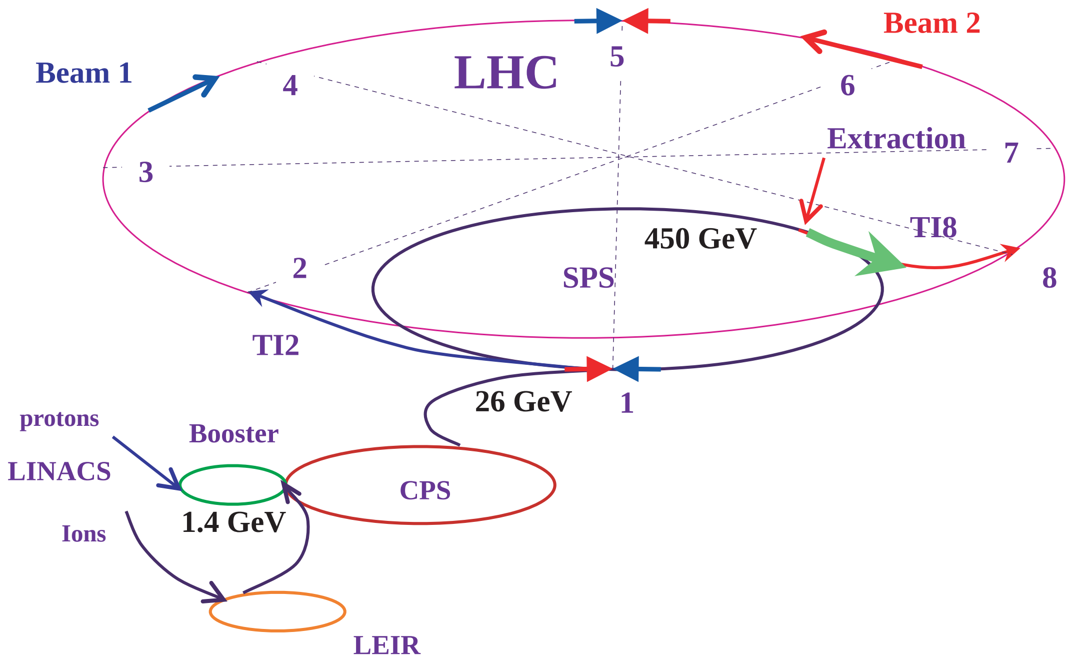

Figure 2: Schematic view of the LHC with its injectors.

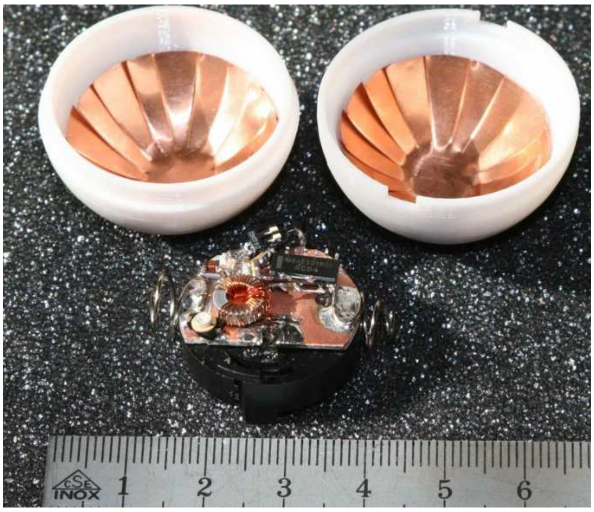

Figure 3: View of a "ping-pong" ball, used to find aperture obstructions in the LHC. Equipped with a small battery, it can emitting a signal at 40 MHz for 2 hours. The passage of a ball within the vacuum chamber is recorded by the LHC beam-position monitors, which are sensitive to 40 MHz, matching the nominal LHC bunch spacing of 25 ns.

- QRL, the cryo-line for the Helium supply
- DFB, the high power electrical connections with warm cold transitions
- Triplet quadrupole cryostat - resistance to differential pressure

and among the more recent and present issues

- PIM, plug in modules with bellows and rf-fingers
- vacuum leaks
- condensation, humidity and corrosion in the tunnel
- magnet powering - cable, connections and polarity checks
- radiation to electronics, single event upset
- magnet re-training, magnets quenching in the tunnel below what was reached in the Lab (SM18)
- magnet interconnects, splices

Some of these issues were solved with rather ingenious methods and delays absorbed or minimized by re-scheduling. An example are the "ping-pong" balls, equipped with radio transmitters, which could be "blown" through the beam pipe. One of them is shown open in Fig. 3. They were quickly developed to check and locate faulty PIM module. In addition to making sure that there are no aperture obstructions for the beams, they were also useful to check the beam position monitors and data acquisition.

3 First operational experience

Over two week-ends in August 2008, beams were injected in parts of the LHC. This allowed to test and adjust injection and check out with beams 3 of the 8 sectors of the LHC.

On the 10th of September 2010, commissioning of the whole LHC with beams started. The injection and beam position monitoring systems performed very well. By measuring and correcting beam positions, it was possible within a couple of hours, to get beams around the full circumference of the LHC, see Fig. 4. The next crucial step was to bring on and synchronize the radio frequency system of the LHC to capture and stabilize the particle bunches (rf-capture). This also worked beautifully. Beam lifetimes of several hours were achieved within three days of commissioning the LHC with beams. This can be considered as a major milestone, demonstrating that there was no major fault in the optics and magnetic lattice.

Just a few days after the start of the commissioning of the LHC with beams in 2008, operation was interrupted by an incident. It occurred in training magnets to higher currents and resulted in a local loss of the energy stored in the magnets, rapid evaporation of Helium and pressure built-up in the insolation tanks, causing significant collateral damage. A poor contact in a splice in a magnet interconnect was identified as initial cause of this incident [3].

The repair and consolidation program which followed is progressing well [4]. Details of the repairs are shown in Fig.5. Fourteen quadrupole and thirty nine dipole magnets had to be removed from the tunnel and replaced or repaired. The last of these magnets was re-installed

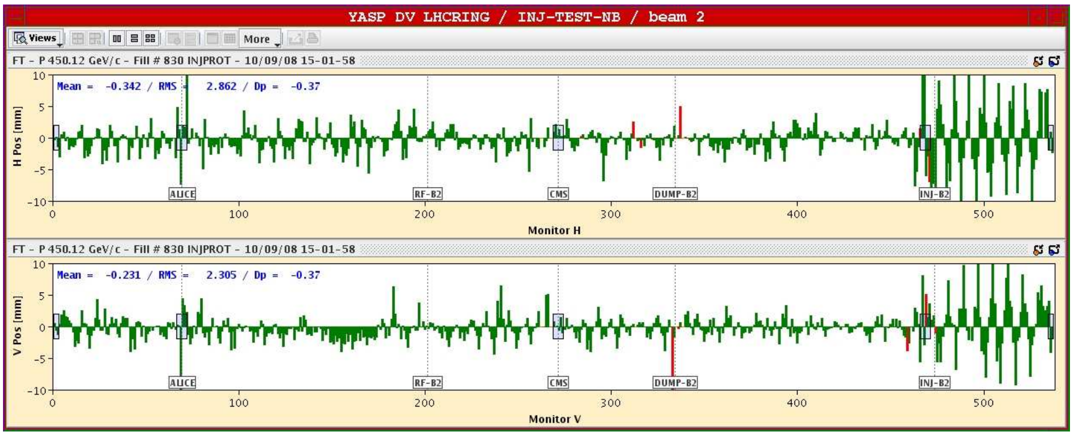

Figure 4: Vertical and horizontal beam positions recorded around the full circumference of the LHC on the 10 Sep. 2008, observed for beam 2 (anti-clockwise beam).

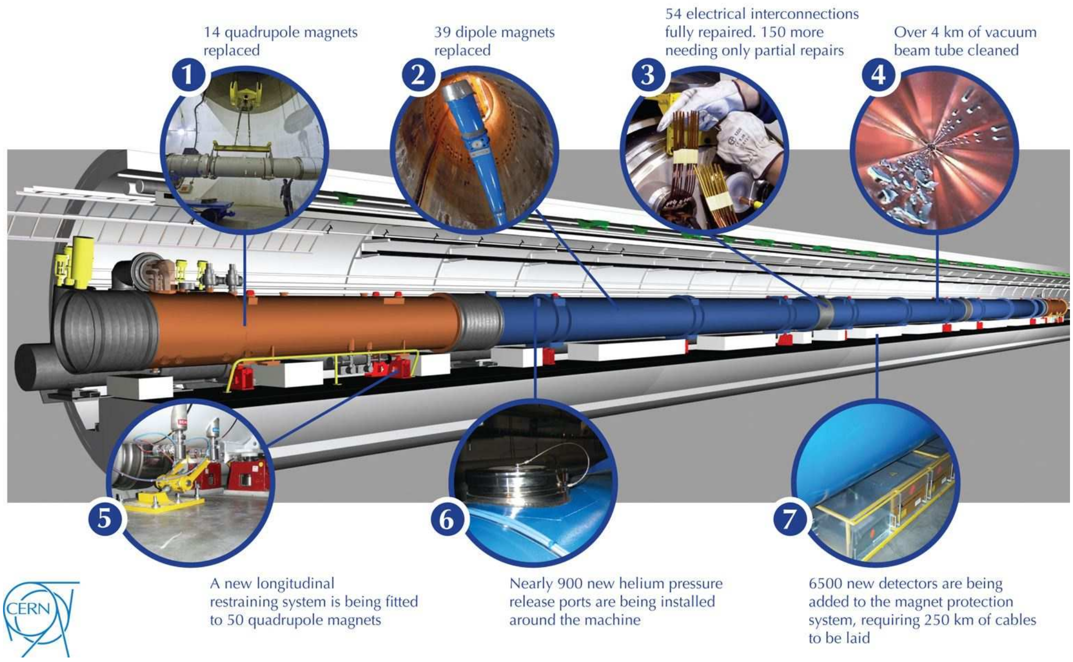

Figure 5: The LHC repairs in detail.

in the LHC on the 30/04/2009 and electrical connections finished on the second June 2009. Methods to diagnose and localize faulty splices were developed and have already been applied to a large fraction of the LHC. In addition to the measures taken to avoid any reoccurrence of such an incident, pre-cautions are also taken to minimize the risk for collateral damage, if this would nevertheless ever happen again. For this, magnet support structures were strengthened and 900 pressure release ports installed to avoid pressure built-up by accidental Helium release.

4 Next steps

The LHC is scheduled to restart for operation with beams in November 2009 and to provide first proton-proton collisions at the injection energy (2×450 GeV) before christmas. Initial transverse beams sizes are expected to be $\sigma^*_{x,y} \approx 300\,\mu$m. It is planned to use the beam position and orbit correction system to measure beam positions around the interaction regions (with an expected precision of 200 μm including electronic offsets) to steer the beams into collisions. Fine tuning of collisions will then be done using transverse luminosity scans and will have to rely on luminosity information from the experiments, since the very forward machine luminosity monitors cannot be expected to work at the injection energy. For collisions at higher energies, it is planned to use more extended luminosity scans to measure the transverse beam sizes to obtain an absolute luminosity calibration [5].

For the initial operation in 2009, currents in the LHC magnets will be limited to 2 kA which corresponds to a maximum centre of mass energy of just over 2 TeV. After a short technical stop in the winter 2009/2010, it is planned to restart the LHC early in 2010, to step up in intensity to roughly 10% of the design values, and to deliver several hundred pb^{-1} integrated luminosity at 7 TeV c.m.s. in proton proton collisions within the year. Before the winter shutdown 2010/2011, a run with lead-ion collisions in the LHC is foreseen.

For the last months with proton collisions in 2010 or early in 2011, it is planned to increase the c.m.s. energy to 10 TeV. Several winter shutdowns may be required to consolidate magnet interconnects and perform magnet training to allow for safe operation of the LHC at the full design energy of 14 TeV. Similarly, ramping up beam intensities and squeezing down beam sizes to increase the luminosity in proton proton collisions towards the very challenging design luminosity of 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ will be done gradually, over several years.

References

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[3] M. Bajko et al., *Report of the task force on the incident of 19th September 2008 at the LHC*, CERN-LHC-PROJECT-REPORT-1168, CERN, March 2009.

[4] M. Lamont, *LHC: status and commissioning plans*, arXiv:0906.0347, CERN, June 2009.

[5] H. Burkhardt and P. Grafstrom, “Absolute luminosity from machine parameters”, CERN-LHC-PROJECT-REPORT-1019, CERN, May 2007

Discussion

Mel Shochet (University of Chicago): Steve Myers said at CERN that in order to safely reach 14 TeV, all of the splices would have to be clamped. I have heard two models for carrying this out. In one, there would be a long shutdown after the first run to install all of the clamps. In the other, the installation would be carried out over a few years during the annual shutdowns planned for other reasons. Has the decision been made on which model to follow?
Answer: Not to my knowledge.