INTRODUCTION AND REVIEW OF THE YEAR, INCLUDING OP ISSUES

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Abstract

In 2011, the LHC entered its phase of real luminosity production, with more than 5 fb-1 delivered to the high luminosity experiments. All this was possible thanks to the continuous increase of machine performance and its good reliability, despite the many problems met during the year. A review of the major events is given, with a list of the issues met and all the steps that lead to a very successful year.

PREMISES

During Chamonix 2011, a proposal had been made by the management (and lately supported by the Council) to run during 2011 at 3.5 TeV and install the snubber capacitors on all main dipole switches [1]. This conclusion was based on the simulations on the maximum safe energy, presented by A. Verweij in the same workshop [2].

With 3.5 TeV, and taking into account the parameters of the beam as extracted from the SPS (1.2e11 p/b, with 2.5 µm emittance), an estimation of the peak and integrated luminosity in 2011 had been done, corresponding to 2e32 $cm^{-2}s^{-1}$ and 1 fb^{-1}, respectively. 2-3 fb^{-1} were considered as well a possibility. 5 fb^{-1} were considered as feasible by the physics coordinator and 1 fb^{-1} for LHCb was as well considered at reach.

Operation in 2011 can be easily distinguished in 5 periods, delimited by the technical stops.

PERIOD 1: RE-COMMISSIONING

The re-commissioning of the machine was carried out in a record time. The powering tests were completed within the estimated time (with some 6000 tests performed in 3 weeks) and the machine check-out was performed in the shadow. The re-commissioning with beam brought to collisions in 3 weeks and the number of colliding bunches was rapidly increased: 32, 64, 136 and then 200 bunches in few days. Though, the downtime was 145 hours, lost in converter trips, electrical glitches, cryogenics and QPS problems and feed-back related trips; also the time spent in the injection steering was 30h and for the collimator alignment 45h.

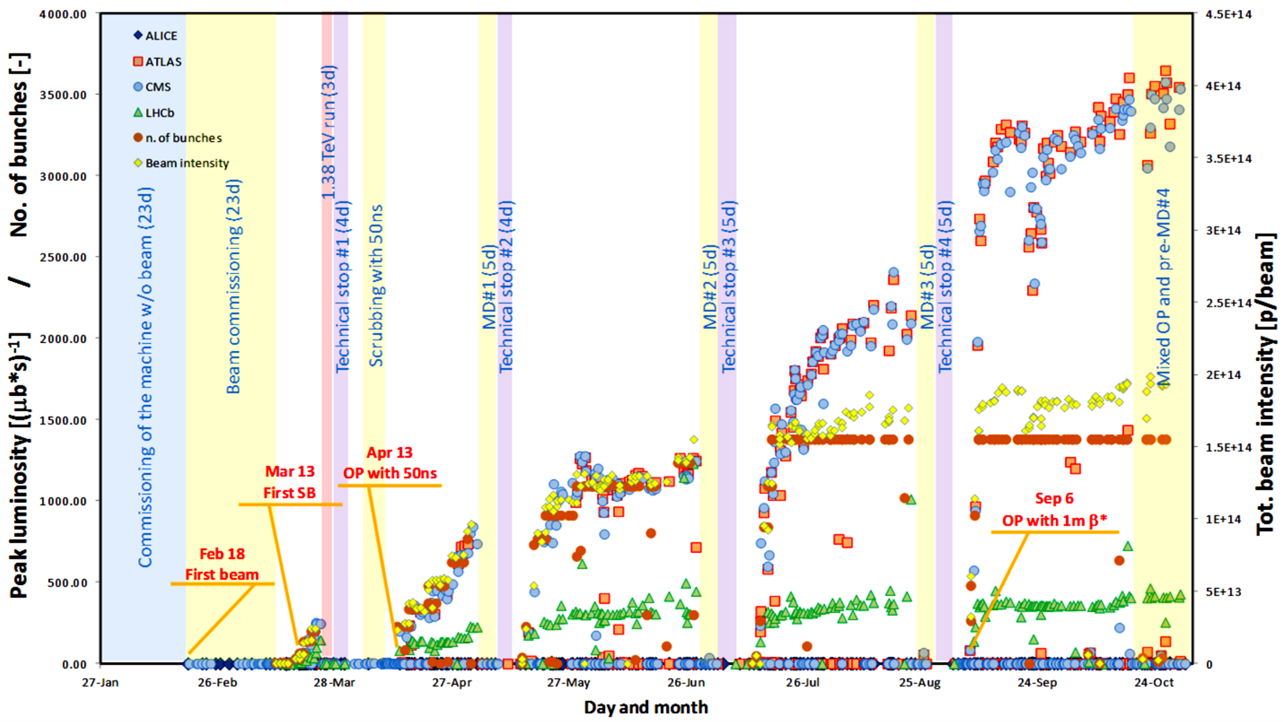

Figure 1: Evolution of peak luminosity and some beam parameters during the year. All technical stops and machine development periods are indicated together with the main events of the year.

PERIOD 2: SCRUBBING

At the end of the first technical stop and after revalidation of the machine protection, the scrubbing run started. The initial setup was done with 75ns-spaced bunches, with injection of 4 trains of 24b. Later, scrubbing with 50ns-spaced bunches started. The chosen strategy was the following:

- progressive increase in the number of injected bunches
- inject up to reach vacuum threshold
- eventually increase the threshold when/where possible
- change intensity and filling scheme (reduce train spacing) to improve the scrubbing efficiency
- set chromaticity and octupoles at full steam.

The beneficial effects of such an approach were soon visible in terms of vacuum improvement [3] and reduction of emittance blow-up. On the other side, surprises came from the heat deposition due to e-cloud, estimated around 70 mW/m/aperture.

Following the successful scrubbing period, the use of 50ns-spaced bunches became operational, after tuning beam life-time, mainly by octupoles and transverse feedback (to cure CBI). The consequent increase in number of bunches lead, on April 21, to the new world record in peak luminosity in a hadron collider (the first one of a long series).

Unfortunately, with the increase of luminosity, people started speaking also about SEE, as well for areas that were considered still safe: between the end of April and the beginning of May, two SEU were recorded on the collimator control located in UJ14, with a cumulative dose of few 10^6 HEH (>20 MeV). This lead to the early planning of Point 1 shielding [4].

During this second period of operation, other problems were observed.

1- Current lead problem in sector 45.

On April 7, a faulty electronics board corrupted the temperature feedback loop, which closed the cooling valves of the current lead of RB.A45, originating a quench in the HTS. It turned out that, due to a tap swap, the HTS protection (U_HTS signal) was missing. The “redundant” protection (U_RES) triggered. All circuits were checked and it turned out that, among all high current circuits, we quenched exactly the one with a cabling problem.

2- Systematic shift of BPMs.

Another problem concerns the systematic shift of BPM signal, which was traced to a filling pattern dependent shift. This was fixed by using a different calibration with distinct references (probe, indiv, train). In this way, the orbits measured with the different filling scheme agree within ~60 microns rms, and the shift of the mean values is at the level of 10-20 microns maximum.

3-Hierarchy violation in B1H @ 450GeV.

The violation of the collimator hierarchy during loss maps is another finding of this period. Suspicion was that moving first the vertical tune through the resonance leads to vertical beam blow-up that could change conditions for the horizontal tune map and leads to issues in skew plane uncorrelated to orbit. Performing the loss maps in the horizontal plane first leads to conform results.

4-Unidentified Falling Objects.

During the initial part of this second period of operation, many Unidentified Falling Objects were observed, some of which eventually lead to the dump of the beam. 90 of such UFOs were for example recorded in 90 minutes on April 14.

5-Flashover on B2 MKI magnet D.

A breakdown on MKI8.D, in between two 36b trains in a 72b batch injection, resulted in 36 bunches over-kicked and grazing the lower jaw of the TDI/TCLI. About half of the intensity (2e12 p) was transmitted into the LHC and the quench heaters fired on 9 dipoles and 2 quads, most likely real quenches.

Implementations.

Several improvements for machine operation were as well introduced at this moment of the year, mainly:

1- the luminosity levelling was tested on mid April and later regularly used by LHCb and ALICE as a solution for luminosity reduction.
2- the dynamic b3 correction was implemented, to get rid of the swing of the chromaticity at injection.

PERIOD 3: CONSOLIDATION FOR LUMINOSITY INCREASE

The restart after the second technical stop was extremely fast: in two weeks the machine was stably running at 1092x1092 bunches, with a luminosity of 1.25e33 $cm^{-2}s^{-1}$. Also the dynamic betastar limits for collimator gaps were tested and the octupoles were set for the injection and for the first part of the ramp.

Though many problems appeared, the main of which were:

- quench on the current lead of RD3.R4, due to a wrong voltage reading of a temperature sensor; TT891 was indicating a temperature of 50K up to the moment of the quench, when it jumped to the real 127K (SEE-driven fault?);
- a SEE on cryogenic PLC in US85 on May 25; this triggered the early relocation of the electronics in UL84 (electronics from UX85 had been already moved to UL84);
- the collimator heating by EM fields, with the collimator temperature increasing with the reduction of bunch length.

The rest of the period was as well signed by many other faults, obviously time-dominated by cryogenics (two major stops due to thunderstorms), but also many from QPS, UFOs, PCs, glitches, RF, collimators, vacuum (3 events which led to increase the thresholds in IR4 from 4e-7 to 2e-6), injectors and many SEE (also a problem on the optical fibers of BIS loop, fixed during the following TS)

But then, just before moving to MD#2, two beautiful fills were obtained:

- 1236b with lumi 1.25e33 $cm^{-2}s^{-1}$, dumped by OP and producing 60 pb^{-1} in 20 h;
- the first fill with 1380b, dumped by OP, with 46 pb^{-1} in ~14h.

Also, before the end of the period, the setup of the 90m optics was done and all the knobs were tested in IP1 and 5 for parallel separation and for lumi scans: 30 mins of data taking were established for ALFA and TOTEM.

PERIOD 4: THE 1380B STANDARD OPERATION

The restart from TS#3 was signed by a major incident: on July 10, a major CERN wide electrical perturbation (short on Verbois OHL, false inter-trip on MP7) was responsible for a serious of faults; several BLM crates went down, the collimators went in auto-retraction, vacuum was affected by communication problems and, above all, cryogenics was heavily affected all over the ring.

Once the conditions were recovered, the revalidation of the machine and the ramp up to the level pre-TS was again very fast, and a new collision scheme for ALICE using satellites bunches was also used.

At that time, the request came (as a result of the so-called mini-Chamonix workshop held in Crozet [5]) to adiabatically increase the bunch intensity, simultaneously reducing the beam emittance. The initial attempts to increase the bunch intensity were not so adiabatic, with the result that the first injection of 1.3e11 protons per bunch resulted in a spectacular kick off by vacuum. After this, the intensity was gently pushed up to ~1.25e11 and the emittances set between 2.2 – 2.5 microns into collisions (later further pushed down to ~2 microns).

The price to pay for the increase of the luminosity performance of the machine, was the increase of losses in IP1 and 5 when going to collision, pushing the losses level above warning on the secondary collimators in IR7, and the lifetime dip when performing the LHCb luminosity optimization. Also the number of SEE increased.

On Jul 28, an erratic on the MKI was recorded, which dumped 144 bunches on the TDI in IR2: the injected beam was not kicked, generating heavy losses in IR2, but no quench. Immediately after, a similar event happened, with the circulating beam hit and kicked onto the TDI: some grazing bunches quenched RD2.R2, RD1.L2 and the triplet in L2 and hit ALICE; important leakage was observed in S23 (but no quench) and some 200b were missing at the dump.

In the same period, the first dumps from PIC were recorded as well: in the two cases, the beams were dumped by a stop of the Powering Interlock PLCs, located in UJ56 and UJ14. PLC stoppage lead to loss of communication with remote I/O units in RR57/UJ14 and consequently initiated Fast Aborts in all protected circuits and the beam dump. The same failure signature was already observed previously, pointing to an internal memory corruption; in both cases, a SEU could not be excluded [for all 9 PLCs in UJ14/UJ16/UJ56 relocation to US152 and USC55 is already prepared (i.e. extension cables pulled), and the start of relocation should take place already during next TS].

Before getting a couple of other important issues (an SPS magnet exchange, with 16 hours lost, or the trip of the cold compressor at point 8), the performance of the LHC could be pushed further, by increasing the intensity up to 1.35e11 p/b, with an average emittance around 2 μm. The peak luminosity went up to 2.2e33 $cm^{-2}s^{-1}$.

The last part of the run was again marked by another major power cut: the damage of a 18 kV power cable during excavation put again the machine on its knees, with many problems on all systems.

Despite all problems met, with as well a lot of faults by QPS, RF, PCs, cryogenics, UFOs and glitches (apart the two power cuts), the production was remarkable, and, by the beginning of the fourth technical stop, the high luminosity experiments were close to 3 fb^{-1} integrated luminosity.

PERIOD 5: SQUEEZING

The last period of operation with protons was certainly marked by the further squeeze to 1 m β*.

As soon as resumed from the technical stop, the tight settings for the collimators were tested and the setup for the 1m β* was started.

	OP 2011	Nominal	Tight	Tight MD1 & 1 m b*	EOF study
TCP-IR7	5.7	6.0	4.3	4.0	4.0
TCSG-IR7	8.5	7.0	5.0	6.0	6.0
TCLA-IR7	17.7	10.0	7.1	8.0	17.7
TCTs IP1/5/8	11.8	8.3	5.9	26.0	11.8
TCSG-IR6	9.3	7.5	5.3	7.0	7.0
TCDQ-IR6	9.8	8.0	5.7	7.5	7.5

Table 1: Target values for the collimators in nominal and tight settings conditions.

The crossing angle in IR1/5 was set from ±120 to ±100 μrad, optics was corrected to better than 10% beating, the TCTs were aligned at the end of squeeze (1m, separated) and in collision, and the machine protection tests (loss maps and asynchronous dump) were also performed.

The squeeze to 1 m was smooth, but then strong instabilities (mostly vertical) were observed, which required the increase of octupoles strength to restore lifetime.

Due to the instabilities observed and the recent measurements of the physical aperture around the triplets (which was found to be larger than initially assumed [6]) a decision was taken at LHC Machine Committee to continue running with same collimator settings as before the TS (TCTs in IR1, 5 and 8 @ 11.8 σ) and to stay with the crossing angle of 120 μrad.

The operation with 1m β* became operational in a very short time and the machine was in four days re-commissioned up to 1380 bunches, with a luminosity of 2.98e33 $cm^{-2}s^{-1}$. Vacuum activity was still continuing, and two dumps were recorded due to losses at the TCTV.4R8.

Just before the end of the run, we had the first SEE quench during the first injection of 144 bunches with satellites: due to injections problems in the SPS, the beam was blown up and, at injection, we got losses in the ring BLMs 6.5 times larger than the dump level. The QPS experts confirmed that the "quench" was due to a spurious self-trigger of a quench heater power supply, an event not observed so far in LHC, not even during the radiation test campaigns.

At the end of the proton run, there was as well the possibility for testing the first stable beams with 25ns-spaced bunches. This was the conclusion of an incredible period of continuous performance increase, which brought, as a final result, a total integrated luminosity of about 5.6 fb^{-1} at the high luminosity experiments.

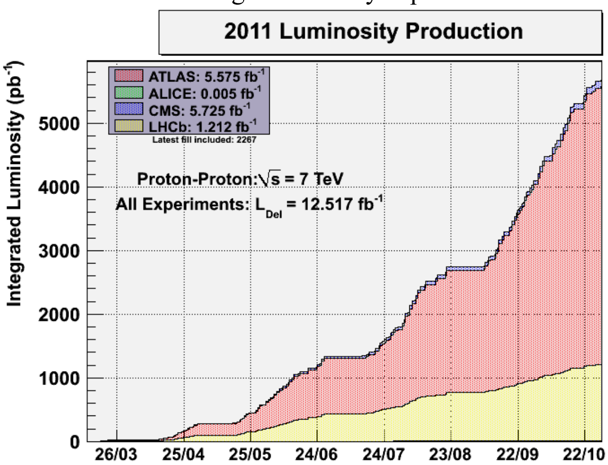

Figure 2: Integrated luminosity for protons recorded by all experiments.

OPERATION WITH LEAD IONS

At the end of October, the operation with heavy ions program was started with the feasibility study of the proton-lead collisions. In particular, on the 31st, beams of protons and lead ions were for the first time injected and accelerated together in the LHC. RF experts were able in a short time to capture and synchronize the two beams; the acceleration was extremely smooth and 2 bunches per beam were brought to high energy.

The heavy ion run, that took place right after the last technical stop, was characterized by equally excellent performance. Thanks to the reduced β* (1 m in 2011 against 3.5 m in 2010) and to the increased number of bunches (358 vs 137), in less than 4 weeks, Operation was able to deliver to the experiments over 450 μb^{-1} integrated luminosity.

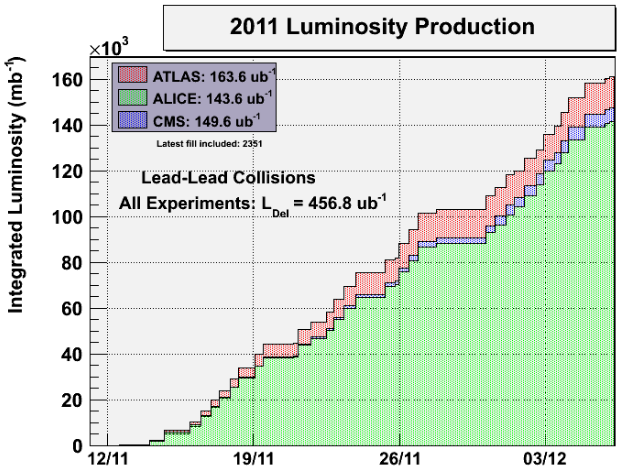

Figure 3: Integrated luminosity for lead ions recorded by three experiments.

POWERING TESTS DURING TECHNICAL STOPS

During all technical stops along the year, more than 860 powering tests were also performed on the LHC superconducting circuits. These tests were needed after the interventions performed in the tunnel (for example, the replacement of a power converter module or an update of the QPS software), but they were as well requested by the equipment owners for specific purposes. Two examples of the special tests executed during the year are the ISRM measurements and the quench propagation tests. The Internal Splice Resistance Measurements were performed on all IPDs and IPQs of the machine to check the resistance of the internal splices. The quench tests were performed on the main circuits of sector 56 to test the propagation of the quench to the busbar splices. Important results came from these last tests concerning the possible weakness of some diode connections.

In all cases, the tests were executed almost in the shadow of the technical stops interventions, thanks to a careful preparation and follow-up.

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