Opening remarks

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Abstract

2011 was a successful year for the LHC. The main contributory factors to are summarized. The challenges of the year ahead are briefly outlined.

2011 - A BRIEF RECAP

The baseline operational scenario for 2011 unfolded as more-or-less as planned. Re-commissioning with beam after the Christmas technical stop took around 3 weeks. The exit condition from this phase was stable beams with low number of bunches. There was a ramp-up to around 200 bunches (75 ns) taking about 2 weeks. Multi-bunch injection commissioning also took place during this phase. A 5 day intermediate energy run (beam energy 1.38 TeV) took place towards the end of March. (Here the proton-proton collision energy is equivalent the nucleon-nucleon collision energy in the lead ion run.)

There was then a scrubbing run of 10 days which included 50 ns injection commissioning After an encouraging performance the decision was taken to go with 50 ns bunch spacing. A staged ramp-up in the number of bunches then took place with 50 ns bunch spacing up to a maximum of 1380 bunches. Luminosity levelling in LHCb via transverse displacement of the beams at the collision point was operational.

Having raised the number of bunches to 1380, performance was further increased by reducing the emittances of the beams delivered by the injectors and by gently increasing the bunch intensity. The result was a peak luminosity of $2.4 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ and some healthy delivery rates which topped 90 pb^{-1} in 24 hours.

The next major step up in peak luminosity followed a reduction in β^* in point 1 and 5 to a value of 1 m. This was made possible by careful measurements of the available aperture in the intereaction regions concerned [**?**]. These measurements revealed excellent aperture consistent with a very good alignment and close to design mechanical tolerances. The reduction in β^* and further gentle increases in bunch intensity produced a peak luminosity of $3.8 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, well beyond expectations at the start of the year.

In conclusion, the LHC has reaped the benefits of exploiting: total beam intensity via bunch spacing and bunch intensity; and reduced beam size by injecting smaller emittance beams and by reducing β^*.

It should not be imagined that the year's operation was easy. In general it was a continual battle as the LHC teams wrestled with the effects of high beam intensity and machine availability. Issues included: single event effects (SEEs); UFOs; vacuum instabilities and beam induced heating. This issues are directly addressed in this workshop.

Operational robustness

Following an intense effort in 2010, the nominal operational cycle (precycle, injection, 450 GeV, ramp, squeeze, collisions, stable beams) proved to be relatively robust. There were some issues but in general the following may be noted.

- The injection process was sometimes challenging but once the beam was injected, baring any hardware problems, it made its way through the ramp and squeeze and into collisions without problems.
- A strict pre-cycling policy ensured excellent reproducibility and stability.
- There is very good transmission through the cycle, and beam lifetimes remain good throughout. Well over nominal bunch intensity with smaller that nominal emittances are taken through the cycle without problems. Beam parameter control (tune, orbit, chromaticity and coupling) is well mastered either with feed-back systems or feed-forward.

As always none of this comes for free and is the result of some serious loving care and attention.

Machine protection

The year's operation was unpinned by superb performance of machine protection and associated systems. Indeed this had to be taken as given to even before starting the intensity ramp-up. The machine protection team has ensure rigorous machine protection follow-up, qualification and monitoring (Post Mortem analysis, MPP, rMPP). The beam dump, injection and collimation teams have pursued rigorous program of set-up and validation tests which have permitted routine collimation of 110 MJ beams without a single quench from stored beams.

System performance

The LHC has enjoyed a excellent and mature system performance across the board.

- Power converters
- RF
- Transverse feedback

- Beam Instrumentation and feedbacks
- LHC beam dump system (LDBS)
- Injection systems
- Collimators
- Vacuum
- Magnets, magnet protection and associated systems
- Cryogenics
- Technical infrastructure

The performance is marked by: attention to detail, painstaking measurements, set-up, continued system development, improvements, optimization, and refinements.

Also of note is the maturity of tools, procedures and software.

- Software (LSA, Sequencer, Software Interlock System, etc) has been key in effective exploitation of the LHC.
- Controls is not generally not mentioned in workshops such as this because of limited problems and high availability of a very extended set of systems. Even the ergonomics in the CCC are getting better.
- A special mention should be made of the LHC databases which underpin operations and post-run analysis. Of particular note are the on-line LSA database and the miracle of the measurement and logging databases and the very widely used interface Timber.

The tools couple with vigorous machine development have allowed an impressive level of understanding of beam dynamics, the interplay between beam and beam related systems and of the various limitations briefly outlined above. They also bring, importantly, confidence.

Beam from the injectors

The bunch spacings on offer from the injectors are shown in table 1. 50 ns proved a good choice in 2011 opening the way to an increased number of bunches and the excellent performance in terms of emittance and bunch intensity. The best that was taken into collisions in 2011 was around 1.45 $\times 10^{11}$ protons per bunch with less than 2 μm at extraction from SPS with around 2.3 μm going into collision. Both intensity and emittance clearly folded directly into luminosity.

Table 1: Beam parameters for various bunch spacings at exit of SPS.

Bunch spacing [ns]	From booster	Protons per bunch	emittance [μm]
150	Single batch	1.1×10^{11}	1.6
75	Single batch	1.2×10^{11}	2.0
50	Single batch	1.45×10^{11}	3.5
50	Double batch	1.6×10^{11}	2.0
25	Double batch	1.2×10^{11}	2.7

AVAILABILITY AND OTHER ISSUES

Despite the inherent complexity of the LHC, availability remains acceptable. However, machine availability is dictated by the exposure to the intersecting failure space of a number of complex systems with huge number of components. Some very extensive equipment systems performed above expectations (considering mean time between failures etc.), but the failure space has been clearly inflated by high intensity effects.

Running with higher total beam intensity has provoked a number of issues including: UFOs; the effects of radiation to electronics in the tunnel; and increased vacuum activity possibly related to residual electron cloud. The RF team has had to carefully monitor the effects of higher beam intensity and adapt its interlock policy accordingly. Beam induced heating of injection kickers, beam screens, and collimators has been observed with a clear dependence on total intensity and bunch length.

One key factor in 2011 was the cost of premature dumps. These dragged the mean length of fill down considerable and had an important impact on the year's performance.

CONCLUSIONS

2011 was a profoundly important year for the experiments and the potential physics reach of the data delivered by the LHC. Beyond this it was important for the organization. The fact that LHC was able to recover so well from the 2008 incident and start to deliver important results under an intense glare of attention has clearly helped CERN's credibility and international standing. As always this is is an impressive testament to everyone involved.

The goals for 2012 will be set high and it will be yet another demanding year.

The workshop aims to look at: the lessons learnt in 2011; improvements for 2012; the provisional parameter list for 2012; and to discuss the priorities and strategy for 2012. And to relax after a blooming tough year.