PROCEEDINGS OF SCIENCE

Optimisation of LHC beam conditions

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We report on the monitoring and optimization of the beam conditions in early LHC operation : luminosity monitoring, optimization and calibration, beam-spot size and position and machine induced backgrounds.

35th International Conference of High Energy Physics
July 22-28, 2010
Paris, France

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PoS(ICHEP 2010)006

1. Introduction

After many years of preparation, the LHC machine just had its first months of physics operation, interleaved with further machine commissioning.

The 27 km long LHC is the worlds largest and most energetic particle collider. A major challenge is the large amount of energy stored in the superconducting magnets and the beams. The commissioning is done very gradually, to minimize the risk of damage to the machine and experiments. It is expected, that several years will be required to reach the very challenging LHC design parameters.

By the time of this conference, the LHC operated at half of the design beam energy and with 12 bunches per beam of which up to 8 were colliding at a given interaction point (IP), which is still far below the nominal value of 2808 bunches.

2. LHC conditions in July 2010

Only a short overview is presented here. More details can be found in the plenary talk given by S. Myers at this conference [1]. General information on the LHC machine can be found in the design report [2] and a more pedagogical description in the book [3].

Table 1: LHC beam parameters, design and actual

	LHC design	July 2010
Momentum at collision, TeV/c	7	3.5
Luminosity, $cm^{-2}\,s^{-1}$	1.0×10^{-34}	1.65×10^{-30}
Dipole field at top energy, T	8.33	4.17
Number of bunches, each beam	2808	12
Particles / bunch	1.15×10^{11}	0.9×10^{11}
β^*, beta-function at the IPs	0.55 m	3.5 m
Typical beam size in ring, μm	200-300	300-500
Beam size at IP, μm	17	59

The main design and actual LHC beam parameters are listed in Table 1. The current LHC peak luminosity of $L = 1.65\times10^{-30}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ is 6000 times below its design value. This may appear low, but is in fact as expected at this early stage of beam commissioning : the reduced number of bunches (8 colliding per IP compared to 2808 nominal) alone represents a factor of 351. The other factors are $3.5/0.55 = 6.4$ in β^*, a factor of 2 from the reduced beam energy and a factor of $(1.15/0.9)^2 = 1.6$ from the reduced bunch intensity. Multiplying the current peak luminosity with these factors gets us to 20% above the design luminosity which is in fact what is needed to compensated for the loss in peak luminosity by the crossing angle that will be required for operation at the nominal LHC beam parameters.

The general experience in LHC machine conditions in terms of stability and reproducibility has been very good. Luminosity and backgrounds signals from the experiments are available in the LHC control room for monitoring and optimisation. Machine induced backgrounds observed by the experiments were low, as can be expected at these intensities [4, 5]. Vertex distributions and positions in x,y,z have also been made available on-line by the LHC experiments [6]. This information is useful for the machine monitoring and optimization and has already been used to improve the calibration of the LHC machine beam size (wire scanner, synchrotron light monitor) and bunch length monitors.

3. Luminosity optimisation and calibration

The horizontal and vertical beam separation at the interaction points can be adjusted using steering magnets. A luminosity scan application was developed, which allows to change the beam separation at the interaction points in pre-programmed steps, and to record and display simultaneously the interaction rates send on-line by the large experiments and by the LHC machine interaction rate monitors [7, 8].

Smaller optimization scans by typically $\pm 0.5\sigma$, where σ is the expected r.m.s beam size at the interaction point, were regularly used to centre the collisions at the beginning of physics fills.

More extended, dedicated luminosity scans were also performed to measure the size and shape of the beam overlap region to provide an absolute luminosity and cross section calibration for proton-proton collisions at LHC energies [9].

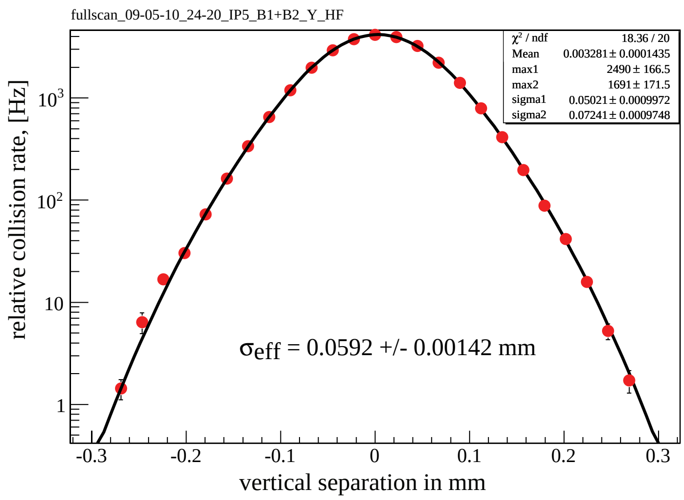

Figure 1: Example for an extended luminosity scan in the LHC. The interaction rate is shown as a function of the vertical beam separation in IP5 (CMS) on the 9 May 2010.

An example of one of the first extended luminosity scans is shown in Fig. 1. These measurements are very clean and allow for an accurate determination of the effective beam-overlap size at the interaction region [10]. As will be further discussed in the following contribution [11], these calibration scans already provided a first absolute luminosity calibration at the 11% level. The accuracy is currently limited by the uncertainty in the knowledge of the beam intensities. The goal is now to decrease this by more measurements and studies of the systematic effects in the beam current monitoring to the 5% level. The current, very clean LHC beam conditions suggest that this could be further improved, mostly depending on the accuracy which can be reached in the absolute determination of the bunch intensities.

A precision on the 1% level was reached in the ISR [12]. This accuracy was obtained after many years and for high intensity, coasting beams. A similar precision in the luminosity calibration from machine parameters for the bunched beams in the LHC appears currently unrealistic, and would if at all possible, require dedicated efforts and new equipment.

4. Concluding remarks

The LHC performed very well in early physics operation. The single bunch beam parameters (bunch intensity, beam-beam tune shifts) quickly reached and in some cases already exceeded the nominal bunch parameters.

The main challenge for the next months and years will be on beam-protection (loss monitoring, fast beam-dump and collimation), to make sure that the LHC remains safe while the performance is ramped up. In addition to increasing the number of bunches, this will imply a reduction of the beam sizes in collisions (reducing β^*), and require an improved knowledge and control of many parameters and tolerances : measuring and optimization of aperture, decreasing the differences between beams and bunches, identification and reduction of sources of beam size blow-up by electronic ripple and noise and mechanical vibrations.

Important tools for the optimization of the beam conditions were luminosity scans, tune adjustments, measuring and correction of optical errors (β-beating) and the commissioning and tuning of the transverse damper and tune-feedback.

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