STRATEGY FOR THE FIRST TWO MONTHS OF THE LHC BEAM COMMISSIONING (COMMISSIONING TO FIRST STABLE BEAMS)

S. Redaelli, G. Arduini, M. Giovannozzi, M. Lamont, R. Tomás, J. Wenninger
CERN, Geneva, Switzerland

Abstract

The 2015 LHC schedule tentatively allocates two months between the start of beam commissioning and the establishment of the first stable beams with a few nominal bunches at top energy. This phase will address the commissioning with beam of all key accelerator systems, taking into account the changes occurred in Long Shutodown 1 (LS1) and new commissioning requirements for the 2015 operational goals. In presence of uncertainties on the key machine and beam parameters, a set of critical measurements to be performed early on in the commissioning are identified in order to establish a validation plan for the machine configuration for the intensity ramp up. In this paper, the strategy for the initial commissioning until the first stable beams is reviewed.

INTRODUCTION

The setup of the first collisions in the experiments at the Large Hadron Collider (LHC) represents an important commissioning milestone. During the data taking phase, usually referred to as *stable beams* (SB), all experiment components are switched on. This is also the phase when the machine sits idle for the longest period of time, being exposed to system failures. It is therefore important to ensure that all the machine protection-related accelerator systems are fully commissioned and operational when the first SB phase is declared. This is done by setting up the SB initially with a few individual nominal bunches, before then proceeding with the beam intensity ramp-up. Tentatively, two months of beam time are allocated in the 2015 LHC schedule to establish the first SB [1].

The validation of a machine configuration entails a lengthy series of beam measurements that culminate with the complete set of loss maps and asynchronous dump tests [2]. If this validation is successful, the following commissioning step consists in beam intensity ramp-up that is performed without any further change of machine configurations, only by increasing the number of bunches. It is crucial that the key parameters such as collimator settings, β^* and bump configurations in the interaction regions (IRs) are finalized before the first SB as later changes would be very costly in terms of commissioning time, mainly driven by the re-commissioning of machine protection systems.

This paper provides an update of the contribution presented at the LHC Beam Operations Workshop, Evian2014 [3], taking into account recent decisions on the choice of machine configuration for the startup in 2015, as well as the updated machine schedule. These items include the decisions (1) to start with a β^* of 80 cm in ATLAS and CMS and (2) to foresee a change of optics later in 2015 [4]. The latter was proposed in [3] as staged deployment of small β^* that leaves time to assess experimentally the LHC performance at higher energies. The commissioning at larger β^* is chosen following the definition of the main priority for the 2015 run as the establishment of a solid operation of the LHC at 25 ns. This is in preparation for the 2016 run that should be a physics production run with the best achievable performance. Detailed parameters for the startup configuration are discussed in [5]. Note that the operational cycle will be as in Run I, with squeeze at flat-top energy. Scenarios like β^* levelling, combined ramp and squeeze, and collide and squeeze will not be deployed at the beginning of the run [6] and hence are not discussed here.

After a recapitulation of the initial commissioning strategy, some relevant inputs from the LHC Run I are recalled. Some of the system changes occurred in LS1 that have impact on the commissioning plans are discussed. New beam measurements required in the initial commissioning phase to optimally prepare the 2015 run are discussed before drawing some conclusions.

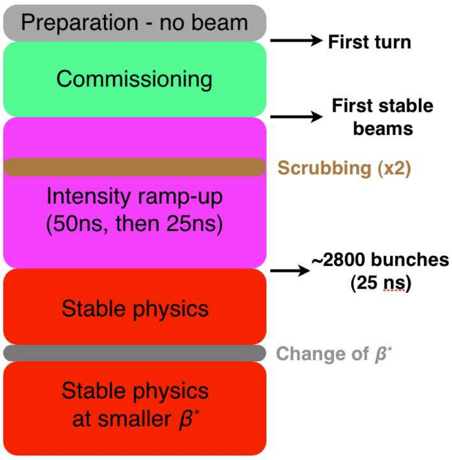

Figure 1: Schematic illustration of the main 2015 commissioning phases.

OVERALL COMMISSIONING STRATEGY

An illustrative scheme with the main phases of the 2015 proton run commissioning is given in Fig. 1 (see [1] for the detailed 2015 schedule). Two months are allocated until the setup of the first SB. This initial phase is then followed by the intensity ramp-up. Two scrubbing periods are planned to prepare the machine for an initial ramp-up at 50 ns, then followed by the 25 ns operation. Once the operation at the maximum number of bunches is established, the machine will enter a period of physics runs. After adequate operational experience is accumulated, it is planned to push further the optics in a dedicated re-commissioning period before the end of 2015.

The main goals for the 2015 commissioning until first SB can be summarized as follows.

1) Establish the key operational phases with beam (threading, beam capture, orbit and optics corrections, IR bump setup, aperture measurements, energy ramp, betatron squeeze, collisions; setup of feedbacks, collimation, RF, injection, LBDS, ...) [7];

2) commission with beam the key accelerator systems;

3) carry out the machine protection commissioning [2];

4) validate by measurements the machine configuration;

5) prepare the β^* optics change planned for later in 2015.

A detailed discussion of the initial commissioning steps is outside the scope of this paper. The operational experience of Run I provides a mature baseline that makes us confident that the standard phases [7] can be addressed successfully. Adequate commissioning time will have to be allocated to cope with the system changes and upgrades that occurred in LS1 and new requirements for the commissioning at a higher beam energy, as discussed below.

RELEVANT INPUT FROM RUN I COMMISSIONING EXPERIENCE

The beam commissioning in 2012 was remarkable as it was carried out in record times [3]. The first stable beams were achieved only 22 days after the beginning of beam commissioning. The intensity ramp-up was then completed in eleven days, achieving the maximum number of bunches – 1380 at 50 ns spacing – after about 1 month from the start of beam operation. This is illustrated by the graph of peak luminosity recorded in ATLAS, see Fig. 2, which reached 80 % of the typical operational values in only about one month.

In the attempt to identify key ingredients for this outstanding operational achievement, one could point out that, amongst others:

– The commissioning effort was focused on high-intensity proton operation. Set up of special runs was left for later phases.

– A minimum number of hardware changes to the key accelerator systems had occurred compared to the 2011 run.

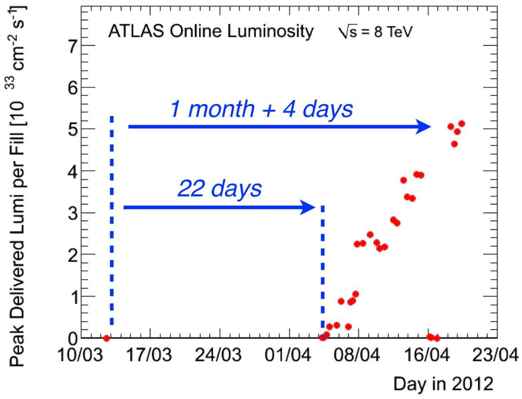

Figure 2: Luminosity versus time as recorded in ATLAS in the first weeks of the 2012 run. Courtesy of the ATLAS collaboration.

– Up to 3 nominal bunches at top energy were within the safe limit for machine protection. This eased and made more efficient several commissioning procedures.

These aspects come in addition to the excellent performance of the accelerator systems, which were very efficiently commissioned thanks to the experience accumulated until 2011. The same efficiency cannot be expected in 2015 due to system changes occurred in LS1 (see below).

The careful choice of 2012 machine parameters was based on a solid knowledge of the LHC and of the accelerator systems. For example, the triplet aperture was predicted [8] within 0.5 beam sigmas and the beta-beating errors were kept below 10 % [9] based on what was achieved in 2011. For 2015, the machine has to be considered as brand new under several aspects due to the long stop of about 2 years. Other uncertainties also apply, like the reproducibility of the machine aperture after having opened the vacuum and the behaviour of magnets at 6.5 TeV and of beam losses and beam instabilities at higher energies [10].

The machine protection aspects pointed out in the list above should not be underestimated [2]. At 4 TeV, 3 nominal bunches were still below the safe limit. This allowed an efficient setup of the collisions in all interaction points and in some cases allowed speeding up the validation (transverse loss maps followed by asynchronous dump tests in the same fill). At higher energy, operational efficiency might in some cases be reduced if validations have to be split over several fills.

Is it interesting to recall, as a comparison, that in 2011 the preparation of the first stable beam took almost the same time as in 2012, i.e. 23 days from first circulating beams (February $19^{\rm th}$) until stable collisions (March) $13^{\rm th}$. Several observations made above apply also to the commissioning experience of 2011. The initial machine configuration at β^* of 1.5 m was decided as an evolution of the previous operational experience from 2010. As opposed to 2012, the intensity ramp-up in 2011 was more tedious as it was done for the first time with 50 ns bunch spacing, respecting a strict validation imposed by machine protection constraints [2].

SYSTEM CHANGES AND REQUIREMENTS

The hardware changes that have taken place during LS1 and the corresponding new system requirements were discussed in detail at the recent LHC Operations workshop in Evian [11]. It was pointed out that important system upgrades will need adequate recommissioning time. Some key points are listed.

- Injection and dump systems [12]: new hardware will be used for the TDI and TCDQ protection blocks; new interlocks on the TDI and TCDQ, based on hardware implementations into the beam energy tracking system [13], will be deployed; dedicated beam measurements are requested for the TDI heating; measurements done at the beginning of Run I, such as wave form scans and kick response, are planned to be repeated.

- Collimation [14]: 18 new devices with in-jaw BPMs have been installed and 8 new IR collimators will need to be commissioned. The new BPM functionality will need dedicated time from the collimation and BI teams.

- Beam instrumentation [15, 16]: there will be new beam size measurements, new BLM layouts, new *little ionization chambers* in the injection regions [12].

- The FiDeL model will have to be assessed for the new pre-cycle. Saturation effects in the magnet yoke will become relevant for the first time and should be take into account.

- RF: several hardware and software changes occurred for the main RF system as well as for the transverse damper, see [17, 18, 19].

This list is not exhaustive, but gives rather a selection of topics that will have an impact on the initial beam commissioning time.

The experiments presented their views and wishes for 2015 in [20]. It is requested to prepare early on various special physics runs such as the ones for Van Der Meer scans and for the LHCf data taking as well as the setup of Roman pots in IR1 and IR5. Contrary to the case of Run I, some of these activities now require different optics than the one used in the standard operational cycle for high-intensity operation. The impact of this requirement on the commissioning time should not be underestimated as it will add new constraints (additional optics measurements, new machine configuration validations, etc.) in a phase when the machine might not yet be fully under control.

2015 BEAM MEASUREMENTS AND DECISION POINTS

In addition to the new commissioning requirements, additional measurements are proposed at the 2015 startup. These are measurements that were not part of the initial beam commissioning but are now considered crucial to validate early on the choice of 2015 machine configuration. It is proposed to define several decision points along the initial commissioning when the choice of parameters is reassessed before moving to the next step.

- ◇ **IR aperture at injection**: the Run I measurements showed that IR aperture measurements at injection can already provide a solid base for extrapolations of β^* reach [21]. IR1/5 aperture at injection was only measured in the 2009 pilot run. This should be done as soon as possible in 2015 after establishing the reference orbit at 450 GeV.

- ◇ **Dedicated local orbit and optics correction in the IRs**: Dedicated time to establish local corrections of IR orbit and optics are essential to provide feedback on the feasibility of various scenarios like β^* levelling. Compared to what was done in the past, one should try to ensure that non-local transients are minimized (e.g., orbit leakage around the ring while changing IR8 β).

- ◇ **Collimator impedance with single bunch**: One important question that could not be solved during Run I is the role of collimation impedance on the instability observed in 2012 [13, 22]. Early measurements with nominal single bunches should be carried out to identify potential impedance issues with the different collimator settings [5].

- ◇ **Stability of orbit and BPM signals**: reproducibility and stability of the machine are crucial inputs for the tolerance margins used to define the achievable β^* and should thus be monitored regularly.

Additional decision points that can only be addressed during the intensity ramp-up phase are: multi-bunch impedance and beam-beam effects (for possible iteration on crossing angle values), two-beam effects and octupoles, monitoring of machine stability and UFOs. The treatment of these measurements beyond the initial commissioning is not in the scope of this paper.

New measurements requirements are:

- ▷ **Chromaticity measurements in different conditions**: Regular chromaticity measurements should be performed to assess the accuracy of the measurement and the reproducibility along the cycle.

- ▷ **Detuning versus amplitude and MCO/MCD settings**: Dedicated tests with octupole and decapole correctors are considered mandatory in order to establish clean conditions for the setup of Landau octupoles. Although in principle the set values should compensate the predicted errors in the main dipoles, the models of de-tuning with amplitude at 450 GeV were not fully understood in Run I. The deployed settings might have played against the Landau octupoles.

▷ **Optics measurements and corrections down to 40 cm**: the optics change in the second half of 2015, can only be deployed efficiently if optics measurements and correction of the target β^* are prepared earlier on. Measurement and corrections for the match points between β^* 80 cm and 40 cm should be part of the initial squeeze setup.

▷ **Aperture verification with squeezed beams** should be performed in detail at the target β^* value of 80 cm in order to validate the feasibility of this configuration and understand the margins for pushing further the performance.

CONCLUSIONS

Plans for the initial beam commissioning of the LHC Run II were presented, addressing the new requirements after the LS1. A first crucial milestone will be to establish first stable beams at 6.5 TeV after having re-commissioned the machine. Important goals of this exercise will be to validate the proposed machine configuration and ensure that the choice of beam and machine parameters is adequate for the intensity ramp-up. While several key validations will only be possible later on with 25 ns beams, we proposed a number of measurements that should be performed early on to provide important feedback already during the initial commissioning phases. Here, changes can still be made with a reasonable overhead, i.e. before the full validation of machine protection that precedes the intensity ramp-up. Other than these additional decision points, the commissioning will follow the very mature experience of Run I. Clearly, changes occurred in LS1 must be taken into proper account.

Taking all these constraints in consideration, and the additional requirements from the experiments that require early on the preparation of various special runs, we consider that achieving the first stable beams in the allocated time of two months is probably still feasible, but certainly very challenging.

ACKNOWLEDGMENTS

The authors would like to sincerely acknowledge all the colleagues from the BE-OP-LHC, BE-ABP-HSS, BE-ABP-HSC sections who provided useful inputs to the preparation of this paper.

REFERENCES

[1] J. Wenninger, “Strategy for Run II,” these proceedings.

[2] B. Salvachua, “MPS Strategy for Commissioning and Operation,” these proceedings.

[3] S. Redaelli *at al.*, “Strategy for the first two months of the LHC beam commissioning and key early measurements,” proceedings of Evian 2014.

[4] Minutes of the 188$^{\rm th}$ LHC Machine Committee held on 3$^{\rm rd}$ Sep. 2014, available at this link.

[5] R. Bruce *et al.*, “Baseline machine parameters and configuration for 2015,” these proceedings.

[6] Minutes of the 194$^{\rm th}$ LHC Machine Committee held on 5$^{\rm rd}$ Nov. 2014, available at this link.

[7] `http://lhccwg.web.cern.ch/lhccwg/Procedures/stageA/stageA_index.htm`

[8] R. Bruce *et al.*, “β^* reach,” in proceedings of Evian 2012.

[9] R. Tomás *et al.*, “Record low β beating in the LHC,” Phys. Rev. ST Accel. Beams **15**, 091001 (2012).

[10] E. Todesco, “Cycles and pre-cycles definitions for 2015,” presentation at the LBOC meeting of July 8, 2014. `https://indico.cern.ch/event/295975`

[11] `http://indico.cern.ch/event/310353/`

[12] W. Bartmann, “Injection: status and plans,” Evian 2014.

[13] N. Magnin, “LBDS: status and plans,” Evian 2014.

[14] G. Valentino, “Collimation: status and plans,” Evian 2014.

[15] T. Lefévre, “Status of tune and orbit measurement and correction, testing strategy,” Evian 2014.

[16] G. Trad, “Transverse beam size measurement,” Evian 2014.

[17] Ph. Baudrenghien, “RF: status and plans,” Evian 2014.

[18] D. Valuch, “ADT: status and plans,” Evian 2014.

[19] J.E. Muller, “Longitudinal parameters and beam induced heating ,” these proceedings.

[20] E. Meschi, “Experiments’ expectations in 2015,” these proceedings.

[21] C. Alabau Pons, M. Giovannozzi, G. Müller, S. Redaelli, F. Schmidt, R. Tomas, J. Wenninger, “LHC aperture measurements,” IPAC2010.

[22] T. Pieloni, “Two beam effects,” these proceedings.