INITIAL COMMISSIONING TO STABLE BEAMS

B. Salvachua, P. Baudrenghien, C. Bracco, E. Bravin,W. Höfle,
G. Iadarola, M. Lamont, T. Lefevre, S. Redaelli, M. Solfaroli, H. Timko,
R. Tomás, J. Wenninger, M. Zerlauth, CERN, Geneve, Switzerland

Abstract

The LHC will resume operations next year with four weeks of dedicated commissioning of the machine with beam. This period will include all the measurements that are needed by the different systems in order to re-establish stable beam conditions after the end-of-year shutdown. In addition, the performance of the machine will be pushed by decreasing the beta-star. A series of measurements (optics, aperture, collimator settings, orbit, etc.) are needed in order to prepare and validate this new configuration. Before ramping up high intensities a dedicated scrubbing at injection will be scheduled. The machine protection intensity ramp up strategy for next year will be defined.

INTRODUCTION

After a successful run in 2015 with more than 4 fb^{-1} of integrated luminosity delivered at 6.5 TeV proton energy, the LHC will resume operation in March 2016.

The run in 2015, after the long shutdown, was dedicated to the understanding of the LHC operation at higher beam energy (6.5 TeV) and at smaller bunch spacing (25 ns) while producing luminosity. In that sense it was a so-called commissioning year while 2016 is meant to be a pure production year. For the same beam parameters the machine will be pushed to smaller $\beta^\star$ and therefore higher peak luminosities. The assumptions for 2016 are summarized in Table 1. The bunch intensity will be kept as last year or if possible even increased to 1.2×10^{11} p/bunch with 25 ns bunch spacing. The maximum number of bunches per train will be increased to 288 bunches. During 2015 injection was limited to 144 bunches per train. It is proposed to start bunch trains operation with similar tunes and chromaticity as during the last of part of 2015 *i.e.* low tunes (0.275 for the horizontal and 0.295 for the vertical) and high chromaticity 15 for horizontal and vertical at injection.

Regarding the machine cycle, the injection will be the same but it has been proposed to implement operationally a combined ramp (to 6.5 TeV) and pre-squeeze to intermediate $\beta^\star$. Details of the final $\beta^\star$ at the Interaction Points (IP) are also listed in Table 1. The final squeeze cycle will be done to achieve the lowest $\beta^\star$, between 0.5 to 0.4 m in IP1 and IP5 with decision on the final $\beta^\star$ to be taken during commissioning. The collision cycle will be adjusted accordingly. The crossing angles proposed are discussed elsewhere [1, 2].

Table 1: Assumptions on 2016 beam parameters and machine cycle.

Parameters	Values
Intensity per bunch	1.2×10^{11} p/bunch
Bunch spacing	25 ns
Max. number of bunches per train	288
Tunes (H/V) at injection	0.275 / 0.295
Chromaticity at injection	15 / 15
Injection cycle	Same as 2015
Ramp and Squeeze $\beta^\star$ IP(1/2/5/8)	3m/10m/3m/5m
Squeeze $\beta^\star$ IP(1/2/5/8)	0.4m/10m/0.4m/3m
Collisions	Adjusted to new $\beta^\star$

COMMISSIONING PHASES

After the hardware commissioning there will be 4 weeks dedicated to commissioning with beam. During this period the setup and validation of all the relevant systems should be done as well as the Machine Protection tests. The goal is to establish:

- all needed measurements to asses the final beam parameters,
- the new cycle and the low intensity *Stable Beam* conditions and
- the preparation of the machine for high intensity beams: setup of trains, scrubbing with the ramp up goal of 2800 bunches.

Figure 1 shows the scheme proposed for the commissioning phases. After the first declaration of Stable Beams at low intensity (3 bunches), a week dedicated to scrubbing is reserved. The proposal, however, is to split this week into a few days with dedicated scrubbing and insert a few shorter scrubbing periods during the intensity ramp up. The motivation for this is to prepare the machine for longer trains that allow the first steps of intensity and then when we are limited again by e-cloud (electron cloud) to program 1 or 2 days of more scrubbing at injection.

SYSTEMS REQUIREMENTS

The main systems concerned are:

- Injection and Dump systems
- Collimation
- Radio Frequency and Transverse Damper
- Beam Instrumentation

The injection system, in particular the SPS extraction, has undergone various modifications during the 2015

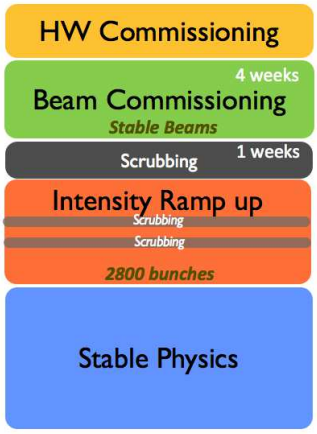

Figure 1: Schematic view of commissioning phases for 2016.

Christmas shutdown [3]. For this reason the MKE4 waveform needs to be re-measured with beam downstream of the TED, as well as the extraction aperture. Regarding the transfer lines, the setup of the collimators (TCDIs) needs to be redone as well as the setup of a good reference for the transfer line steering. The injection protection collimators will need to be aligned and validated.

For the dump system, the setup and validation of the TCDQ and TCSP collimators need to be done. In addition, it is proposed to do calibration measurements for an asynchronous beam dump, see [4]. The aim is to build a reference of the conditions before an asynchronous beam dump happens to be able to compare the state of the machine after this event. This includes: aperture measurements in IP6 and transmission measurements.

The interlock BPMs need to be setup and validated. The final validation that needs to be done for every state of the machine will be the asynchronous dump test.

The collimation system will require the usual alignment time and validation at the four points in the machine cycle (injection, ramp, squeeze and collisions) and the repetition of the machine protection tests in order to validate the interlock triggering and connections. The Roman Pots will be aligned for low beta insertions at collisions. For the collimators with embedded BPMs (with DOROS electronics) it is planned to repeat a validation BLM vs BPM alignment, collimation scans to measure BPMs non-linearities and the test of the BPM interlock implementation. As part of the collimation setup and the preparation for the final $\beta^\star$ a set of global aperture measurements is proposed. Finishing with the final validation with loss maps at all machine stages.

The RF will be setup for nominal parameters, the tests to be done are the RF synchronization and capture. If bunch intensities are pushed above nominal (larger than 1.2×10^{11} p/bunch) it is necessary to commission a phase modulation scheme [5] in addition to the cavity conditioning with a klystron power up to 300 kW planned already to be done during hardware commissioning. The transverse damper will be setup for the proposed bunch intensities and tunes. During commissioning it is planned to test the automatic intensity settings and implementation of the related protection. The new pickups Q8/Q10 will be commissioned later in the run.

Regarding Beam Instrumentation there is a dedicated commissioning plan for each system: beam loss monitors (BLM), beam position monitors (BPM), beam current transformers (BCT), transverse beam size monitors (BSRT and wire-scanners), longitudinal beam size monitors (BSRL), tune measurement (BBQ), beam screeners (BTV), etc... The interlock functionality of the Beam Loss Monitors and the interlocked Beam Position Monitors will have to be verified.

A series of optics measurements will be also scheduled:

- **Ballistic Optics:** A measurement at injection is requested in order to have a more precise calibration of the BPMs around the IP. This will potentially allow for an improvement on the reconstruction of the $\beta^\star$ at the IP [6].
- **Combined ramp and squeeze:** Optics measurements during the ramp will be required [7].
- **Beta-star reach:** Optics measurements, aperture and crossing angle setup will be needed for the final configuration of $\beta^\star$.
- **Non-linearity corrections**: After the measurements, about 2 shifts will be required to implement the non-linearity corrections [8].

2016 SCHEDULE

The proposed LHC schedule is shown in Figure 2 and can be accessed online at [9].

The magnet powering tests are scheduled to start on the 5$^{\text{th}}$ March and will last about 16 days. The machine checkout will be interleaved with the powering tests during the last 4 days. The commissioning with beam is scheduled to start on the 21$^{\text{st}}$ March and will take 4 weeks.

The intensity ramp up is scheduled to start the 18$^{\text{th}}$ April. The first days will be dedicated to machine scrubbing. The first physics production period extends from the first day of the intensity ramp up until the 1$^{\text{st}}$ July when the first Machine Development (MD) block should start followed by a Technical Stop (TS) until the 13$^{\text{th}}$ July.

INTENSITY RAMP UP

During the intensity ramp up the number of injected bunches is increased when we have accumulated about 20 hours of stable beam conditions distributed in at least 3 fills. This requirement ensures that there is enough time to check the machine conditions and the machine protection systems before we increase the stored energy in the machine.

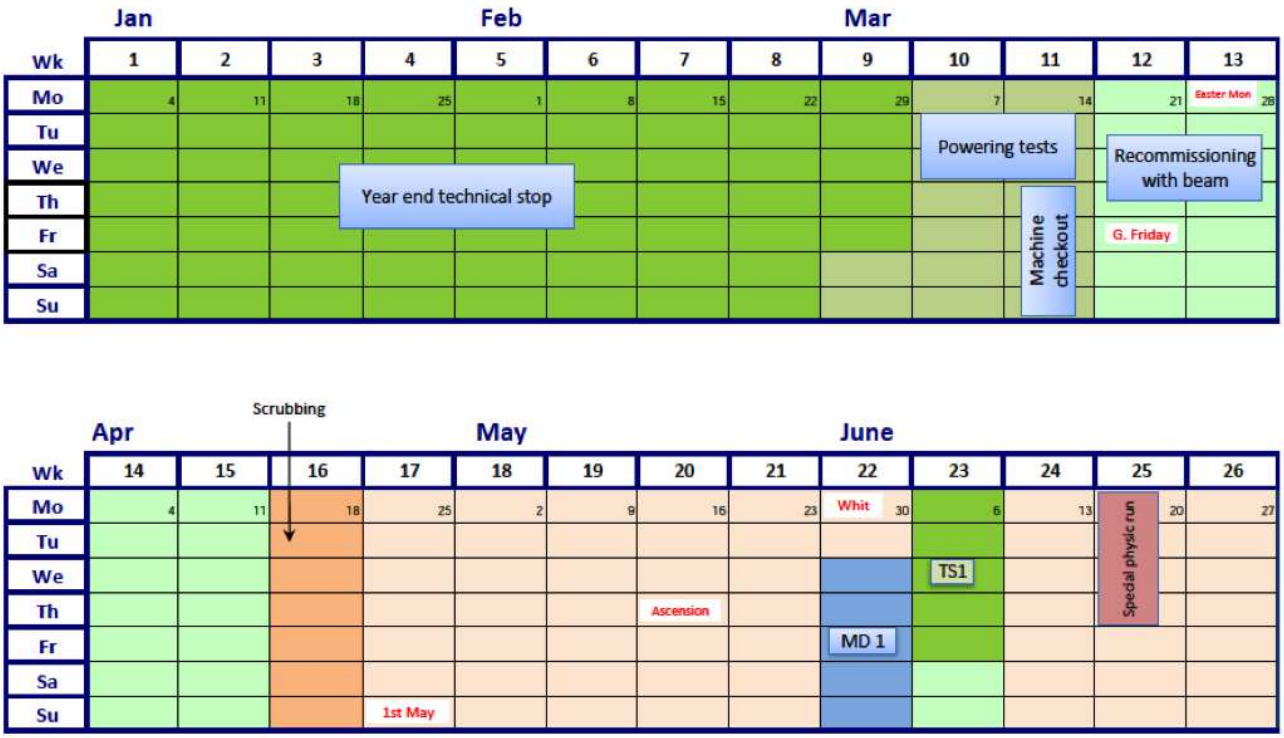

Figure 2: First months of the LHC machine schedule.

During 2015 the machine was in a constant intensity ramp up. Figure 3 shows the number of injected bunches per beam as a function of time expressed in days since the first stable beam conditions were reached. The first period was the ramp up with bunch spacing of 50 ns. It took 11 days to ramp up to 50 bunches. Afterwards the machine was commissioned for 25 ns bunch spacing. The main limitation here was cryogenics and e-cloud. However, the ramp up was speeded up, 450 bunches were injected after 10 days in the middle of the run period, and towards the end the fastest ramp up was done in 3 days up to 1800 bunches.

The intensity ramp up in 2012, when the machine was better conditioned and operation was with 50 ns, less demanding with respect to the e-cloud effect, was generally faster. The initial ramp up to 1400 bunches at the beginning of the run took 11 days, but after the technical stops it could be done in only 3 days, see Figure 4.

The proposal for 2016 is to keep the approach of 3 fills and 20 hours of stable beam conditions at least until 500 bunches have been injected and ramped up. The analysis of this first period is very important in order to validate the new machine configuration and optics. It could be possible that the machine will be limited by cryogenics and heat load when we reach 500 bunches. For this reason a fast scrubbing period around this period is encouraged to be interleaved with the intensity ramp up. Once the machine is validated with more than 500 bunches, "mini" intensity steps of one extra train of 144 or 288 bunches per fill could be considered. Figure 5 shows the proposed strategy.

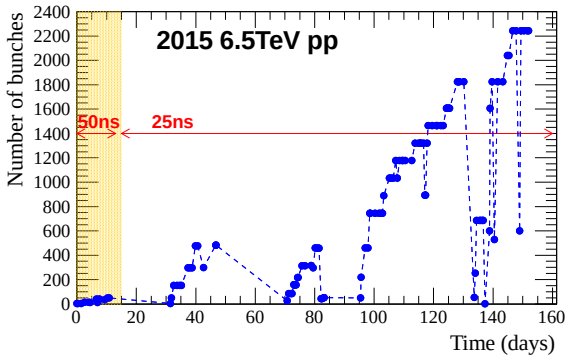

Figure 3: Number of bunches per beam injected in the LHC during 2015 and ramped up to 6.5 TeV as function of time.

CONCLUSION

The LHC will resume operations in 2016 providing proton physics at 6.5 TeV beam energy as in 2015. This time only four weeks are scheduled for the preparation and commissioning with beam. During this period all the systems need to be re-qualified for beam operation. In order to assess the final $\beta^\star$ reach the relevant measurements with beam, such as optics and machine aperture measurements will be done during the same period.

The ultimate goal for the intensity ramp up is to fill the machine with 2800 bunches. The proposed strategy for the first 500 bunches is the same as in 2015. More than 20 hours of stable beams distributed in 3 fills are needed before in-

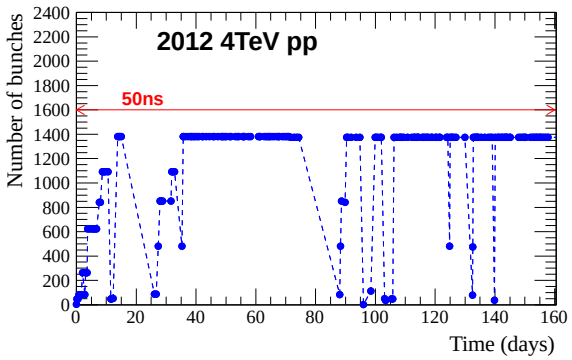

Figure 4: Number of bunches per beam injected in the LHC during 2012 and ramped up to 4 TeV as function of time.

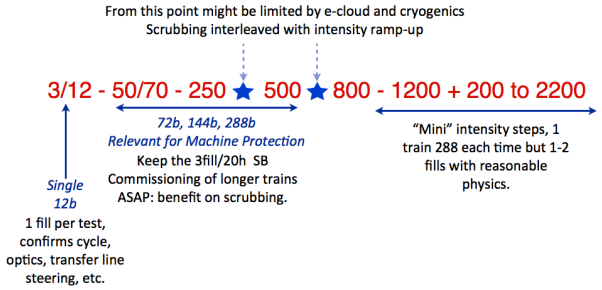

Figure 5: Proposal for intensity ramp up during 2016 (number of bunches).

creasing the allowed stored energy in the machine. Machine protection encourages this approach up to the injection of 500 bunches, which is the critical period for the validation of optics and machine configuration. Thereafter we could envisage to continue with "mini" intensity steps as was done in the last part of the 2015 run.

ACKNOWLEDGMENT

The authors would like to acknowledge all the colleagues involved in the commissioning and operation of the LHC during 2015. In particular the machine coordinators, the engineers in charge and the operators for the continued effort during the run in order to optimize the machine physics production. Special thanks also to the scrubbing, optics, collimation, beam instrumentation, RF and ADT, magnets and cryogenics teams that were available day and night in order to make the 2015 run successful.

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