Wrap-up and prospects for post LS1 operations

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Abstract

A terse summary of the workshop is presented in which an attempt is made to highlight issues with direct bearing on post LS1 operation. A preliminary attempt is made to estimate the potential post LS1 performance, outline the commissioning strategy and the potential limitations for run II.

INTRODUCTION

The 3 day workshop attempted a survey of the following areas with the emphasis very much on identifying issues pertinent to operations in the post LS1 era.

The sessions covered:

- Availability during 2012 : review of the year; availability; R2E; and machine protection.
- Performance of the nominal cycle and potential performance improvements for post-LS1. This section considers the implications of 7 TeV, possibly squeezing colliding beams, and the operation of LHCb and ALICE's spectrometers after LS1. Also included under this heading below are consideration of the presentations on: optics measurement and corrections; emittance growth through the cycle, and beam loss through the cycle.
- System performance was considered in a number of sessions and included critical reviews of:
    - beam instrumentation;
    - RF;
    - transverse damper system;
    - injection and beam dump systems;
    - vacuum;
    - cryogenics;
    - collimation;
    - beam loss monitors.
- Limitations: beam induced heating, electron cloud, instabilities, UFOs, and cryogenics.
- A look forward to 2015 and the experiments requirements; beams from injectors; the plans for restart; and the potential performance.

AVAILABILITY

Review of 2012 [1]

2012 was a production year at an increased beam energy of 4 TeV. The choice was made to continue to exploit 50 ns and run with a total number of bunches of around 1380. Based on the experience of 2011, the decision was taken to operate with tight collimator settings. The tighter collimator hierarchy shadows the inner triplet magnets more effectively allowing a more aggressive squeeze to a β^* of 0.6 m. The price to pay was increased sensitivity to orbit movements, particularly in the squeeze, and increased impedance. The latter having a clear effect on beam stability as expected.

2012 was a very long operational year and included the extension of the proton-proton run until December resulting in the shift of the proton-lead run to 2013. Integrated rates were healthy at around the 1 fb^{-1} per week level and this allowed a total for the year of about 23 fb^{-1} to be delivered to both ATLAS and CMS.

The 257 day run included around 200.5 days dedicated to proton-proton physics. 36.5% of the time was spent in Stable Beams with an overall Hübner factor of around 0.18. Cryogenics availability improved to 94.4 % during proton-proton operation. In terms of beam dumps above 450 GeV, QPS leads in occurrence and recovery time and in the number of SEUs suffered.

Table 1: LHC availability 2012

Mode	% of scheduled time
Access	14%
Setup	28%
Beam in	15%
Ramp and squeeze	8%
Stable beams	36%

Of note:

- Technical stops still disturb the flow, and we lose highly optimized conditions across the complex. This is less due to technical problems (although they do figure), and rather more due configuration changes (PS extraction modifications, ALICE etc.)
- Peak luminosity got up close to its peak pretty quickly. This was followed by a determined and long running attempts to improve peak performance. This was successful to a certain extent, but with little effect on integrated rates. Instabilities, discussed below, although never debilitating, were a reoccurring problem and

there were phases when they cut into operational efficiency. Essentially the 1.5e11 ppb per bunch limit was passed by a switch in octupole polarity and, perhaps, more importantly a large increase in chromaticity which at least partially negated the instability problems that had dogged the end of the squeeze and going into collisions.

Availability [2]

LHC is a critical asset with a CHF 5-6 billion capital cost and around 300 MCHF/year operating costs. Effective fault tracking and analysis for targeting weak points and system improvements could be considered mandatory. There are some short coming in this area and **a team needs to be give a mandate and resources to put in place an effective, robust solution for the re-start**. Note other initiatives with operational issue management being considered as part of the Maintenance Management project.

Although fault tracking maybe less than ideal it should be noted that the major issue up to now (R2E) has seen a coordinated approach and the individual system teams have targeted improvements based on their own experience (e.g. power converters, RF, QPS) with some success.

Radiation to Electronics (R2E) [3]

The success of this campaign is impressive. There were several shielding campaigns prior to the 2011 run including relocations on the fly and equipment upgrades. The 2011/12 Christmas stop saw some Early relocation and additional shielding and further equipment upgrades. This has resulted in the reduction of premature dumps from 12/fb^{-1} to 3/fb^{-1} in 2012, going a long way to helping the efficiency of integrated luminosity delivery.

The R2E-Project is aiming post LS1 for 0.3 premature dumps per fb^{-1} via a combination of: equipment relocations at 4 LHC Points; additional shielding; and critical system upgrades (QPS, FGC).

Machine Protection [4]

The machine protection system as a ensemble has worked well. There were around 1000 clean beam dumps performed in 2012 with 585 beam dumps above 450 GeV. There were some interesting probes of problem space in 2012 even with the system in its present state of maturity. Issues included: problem with the orbit feedback survey unit (OFSU); 12 V supply issues to the TSU of the LBDS; BSRT mirror deformation following beam induced heating; trasfer line collimator settings not tracking an optics change; and timing issues injecting the H9 low emittance beam; MD safety could do with some re-enforcement.

Full analysis and follow-up to be present at the MPP workshop in Annecy [5].

OPERATIONAL CYCLE

The present operational cycle, after a lot of effort, is well optimized and transfers reasonably well to 7 TeV [6]. The magnetic machine is well established and there is excellent understanding of linear and non-linear optics. Methods for the necessary optics measurement and correction have demonstrated excellent results.

Further optimization of the cycle are possible and those highlighted at the workshop include the following.

- A **combined ramp and squeeze** which would allow certainly allow time saving, but the proposal is not without operational risks and implications for systems such as orbit feedback and collimation.
- A partial **squeeze with colliding beams** which would provide Laudau damping and certainly help the instability issue that dogged the end of the squeeze in 2012.
- β^* **levelling** could also be important, particularly if 50 ns is needed as a long term operational solution. **Possible implementations have been/need to be explored further and an effective solution should be in place for post LS1.**
- The use of a lower β^* at injection.
- The possible used of Achromatic Telescope Scheme (ATS) optics.
- Squeezing more in one plane than the other (flat beams).
- Start with a lower ramp rate to ease the impact of heat load transients on the cryogenics system.
- Keep the collimators out for as long as possible in the ramp and squeeze avoiding the increased impedance until absolutely necessary.
- Non-synchronized collisions to avoid potential dangerous cancellation of beam-beam tune spread and effect of Landau octupoles.

2012 issues

Despite the impressive final integrated luminosity total there were a number of issues that hampered smooth operation in 2012, and lessons certainly deserved to be drawn from the experience.

- Enhanced satellites got blamed for a lot, perhaps unfairly. Improved diagnostics should be provided.
- Frequent re-steering of transfer lines was required. See the section on Injection below.
- The use of a tilted crossing angle in LHCb caused problems initially. Bringing all experiments into collisions at the same time did not help matters, and things fully stabilized when going into collisions in 1 & 5 was separated from that in 8.

- The **handling of all orbit corrector settings at the round in and round out at the matched points in the squeeze** requires a consistent approach.

- We were clearly sensitive to beam conditions from injectors with tight collimator settings, particularly during the squeeze. **Improved tail and scraping diagnostics are needed in the injectors.** There are systematic losses at end of the ramp as we transition to tight collimator settings. The extrapolation of this to 7 TeV needs further study and the exploration of possible strategies to alleviate potential limitations at higher energies.

Spectrometers

The switch of the IR8 crossing angle to the vertical plane at injection, while being elegant solution (for 25 ns operation), implies global change of aperture limit to point 8 [7]. The implications are to be fully explored. The lack of a possibility to rotate the beam screen during LS1 has been confirmed.

Emittance blow-up [8]

- It is still very difficult to measure emittances and emittance blow-up. **Details of required improvements to beam diagnostics were detailed - need reliable and accurate transverse profile measurement systems after LS1.** We still not sure about the wire scanner results - issues with calibration; emittances from luminosity results are the most reliable.

- Overall the emittance blow-up situation in 2012 was similar to 2011 with significant blow-up from injection and through the ramp. It is also observed, sometimes, at the end of squeeze.

- Among the clear sources are IBS and 50 Hz noise - one should be able to quantify these effects. We are sitting on the 50 hZ line with the horizontal tune at injection and in the ramp.

- Absolute emittance growth through cycle is between 0.7 and 1 microns based on the convoluted, averaged emittance from luminosity.

- Any potential mitigation like RF batch-by-batch blow-up and higher transverse damper gain have not yet lead to significant improvement of emittance blow-up on the normal injection timescale.

- It is curious that the low emittances delivered by the Q20 optics end up at the same values as the Q26 optics going into collisions.

Optics and dynamic aperture[9]

LHC achieved record low β-beating for hadron colliders and many other first achievements in 2012:

- dynamic aperture measurement at injection;

- chromatic coupling correction;

- triplet non-linear correction;

- measurement of amplitude detuning with AC dipoles.

The linear and non-linear dynamics is now very well understood.

Suggested modifications to the cycle included: injecting into a β^* of 7 m with collisions tunes. The combined ramp and squeeze and squeezing with colliding beams will come with a price and dynamic measurements in these configurations will need improved tools. The final β^* has yet to be decided but triplet non-linear correctors are needed for dynamic aperture and/or Landau damping (but watch the dynamic aperture in the latter case).

SYSTEM PERFORMANCE

Analysis of systems issues from an OP perspective [10]

In general we have seen good to very good performance across the board. System are now mature. Outstanding issues have been identified, and improvements and upgrades are planned. One can imagine these coming back post LS1 in good shape with appropriate time dedicated to recommissioning and tests.

Outstanding issues of note include:

- **The need for fully reliable tune measurement and feedback**

- **Orbit feedback system issues to be resolved.** Clearly a critical system and instrumental in the successful commissioning, however 21 dumps were assigned to OFC/OFSU problem in 2012. Besides the obvious requirements of stability, staying on through the cycle etc. better release management and testing and better information flow is requested.

- **Interlocked BPMs** All sorts of problem here related to their sensitivity to different bunch currents. Situation has to be resolved post LS1.

- Beam size measurement systems (BSRT, BGI) deserved fully operational applications in the CCC.

- Improved instability observation tools are required.

- Reduce the time spent steering the lines and address the cause of the problem: orbit variations in the SPS, ripple in the SPS extraction septa.

- Injection kickers and associated systems often need expert counselling and input. This related to vacuum activity, electron cloud, breakdown etc. Clear need to be attentive but difficult to track changes in limits etc.

- RF: interlock diagnostics; phase acquisition per batch; faster BQM; phase/amplitude noise for each klystron
- ADT settings management: less dependency on experts is to be encouraged. But again, this is a sensitive system with potential damage potential, any shift of functionality to operations has to be accompanied by appropriate safe guards.

Regarding Control System and data management, 4 pages of issues, requirements and proposed improvements were presented. Full follow-up is required.

ADT [11]

The transverse damper system has reached maturity with impressive performance through the cycle and a host of novel functionality. This has included resolution of outstanding issues related to the interplay with the BBQ by the use of gating out a few bunch.

For settings management the ADT team worries about operational rigour and the safety of their equipment!

There are lot more plans for improved and additional functionality and ADT2 post LS2 will require some concerted re-commissioning.

Will we keep the gated bunches? The consensus at the workshop was yes we will. The requirements of tune control etc. will only become more rigorous as the total beam intensity increases and this approach certainly has proved its utility.

Beam instrumentation [12]

- DOROS looking very encouraging and would certainly address the IR requirements. The triplet BPMs thus equipped could certainly help luminosity stability with β^* levelling.
- The interlocked BPMS system should really improve its intensity dependence behaviour.
- There were a number of issues with the orbit feedback system and a full orbit feedback review is incoming.
- Abort gap monitoring needs to be revisited from a machine protection perspective.
- Analysis of the source of 50 Hz lines and potential mitigation needs to be pursued.
- Beam size measurements: follow-up is required across the board.

RF [13]

The key issues here is the preparation for higher beam currents post LS1. At least 200 kW forward power will be required at nominal intensity, and to deal with this the importance of cavity voltage set-point modulation for 25 ns operation was stressed.

Module 1B2 to be replaced because of an underperforming cavity.

The importance of longitudinal bunch distribution when considering beam induced heating was stressed.

Injection [14]

- Reproducibility of transfer lines compromised by: MSE current ripple and flat-top orbit variation in SPS. To be addressed.
- A certain amount of intellectual rigour is required by operations. Conclusions from surmise are to be avoided. It wasnt always the satellites; correct for the right problem; could be helped by improved diagnostics.
- The sunglasses scheme and the use of LICs is to be followed-up.
- There were many well documented issues with the injection kickers heating and flash-overs - new chambers across the board post LS1.
- The TDI has also experienced a number of well documented problems. Even after refurbishment during LS1, will they remain a risk in the medium term?

Beam dump system [14]

- New TCDQs to be installed.
- Common mode failure on 12V line has been addressed, but one might worry about increasing probability of asynchronous dump with the additional interlocks.
- There will be higher voltages on the switches at 6.5 TeV and thus an increased risk of erratics.

Controls [15]

Major infrastructure upgrades are planned and commissioning time will be required. Upgrade team should remember the requirements of ongoing TI monitoring etc.

- Timing/cycle management improvements required and incoming with coherent approach across the complex required.
- Improved data analysis tools are required.
- We have learnt a lot, we know how to operate the machine, and the question beggedis : can we do it better? Operations should consider the coherency of the high level approach after 5 years of sometimes ad hoc development. A review should be organized.

LIMITATIONS

Instabilities [16]

Instabilities were an interesting problem that dogged operations through 2012. Although never debilitating there were phases when they cut into operational efficiency. Although it should be noted that these problems paralleled a gentle push in bunch intensity with the peak going into stable beams reaching around 1.7e11 ppb i.e. ultimate bunch intensity. Cofactors included increased impedance from tight collimator settings; smaller than nominal emittance; and operation with low chromaticity during the first half of the run.

Of note:

- The first period was dogged by occassional beam loss provoked by instabilities that occured at the end of the squeeze and while going into collision.
- Switch of octupole polarity at start of August. To stabilize the beam during the squeeze, it proved necessary to push the chromaticity to the order 15, and increase the Landau damping octupoles to near their maximum value. Even this didn't fully solve the problem and instabilities were still observed (B1V) on certain bunches at the end of the squeeze with associated emittance blow-up.

Three main classes of instabilities were observed:

- The so-called snowflakes phenomenon, individual bunch drop-out - extremely bad lifetime for some seconds, stabilizing at much reduced bunch intensity. This was seen on the so-called IP8 private bunches which experienced luminosity levelling motivated offset collisions.
- During the collapse of separation bumps. One cause was ending with too large residual separation which provoked coherent beam-beam instabilites. Another possibility was interference between long range beam-beam tune spread and octupole detuning resulting in the loss of Landau damping.
- Instabilites at the end of squeeze were generally on a few bunches of one beam. The bunches affected tended to be a the end of batches. Folling the flip of the octupole sign, the instability moved to beam 1 vertical. This appeared to be a two beam effects and long-range beam-beam and electron cloud have been proposed as co-factors.

Impedance [17]

This is still a bit of a mystery, we observe ≈3 times more impedance than expected at 450 GeV and ≈2 times more than expected at 4 TeV. For post LS1 operation, performance can be sacrificed if required by drawing on impedance dependence on collimators settings: nominal gives a +50% increase in impedance tight settings +10%; with relaxed settings buying a 25% reduction.

Beam induced heating [18]

Beam induced heating will remain an issue, and the possible guilty parties were clearly enumerated. In particular the upgrade of TDI should be pursued - this foreseen for post-LS2. The maximum bunch length should be pursued compatible with maximum extension of the luminous region - 1.35/1.4 ns seems to be within reach.

Scrubbing [19]

There were 3.5 days of scrubbing with 25 ns beams at 450 GeV between 6 - 9 Dec. 2012. The tests saw regular filling of the ring with up to 2748 bunches with a total intensity per beam of up to 2.7×10^{14}. Overall there was very good efficiency with the injection rate determined by MKI vacuum interlocks (in the beginning) and by time required by the cryogenic system to adapt to the increasing heat load (mainly in stand-alone magnets).

Scrubbing effects in the arcs saw quite rapid conditioning observed in the first stages. The SEY evolution significantly slows down during the last scrubbing fills (more than expected by estimates from lab. measurements and simulations).

There is a potential change of mode of operation with 25 ns. An electron cloud free environment after scrubbing at 450 GeV seem not be reachable in acceptable time. Operation with high heat load and electron cloud density (with blow-up) seems to be unavoidable with a corresponding slow intensity ramp-up. In 2015 following the warm-up and opening of the entire ring to atmosphere, the SEY and vacuum conditions will be reset and initial re-conditioning will be required. **It is anticipated that we will need to start with 50 ns and only later to move to 25 ns to recover vacuum, cryogenics, UFOs conditions were used in 2012.**

Cryogenics [20]

Scaling with the 2015 beam parameters shows sufficient margin with respect to local and global cooling limitations by implementing the following consolidations:

- consolidation of the copper braid configuration on 6/8 IT (planned for LS1);
- increase of the maximum flow coefficient of the BS control valve of the standalone magnets (seat and poppet exchange) - compatible with e-cloud deposition of 1.6 W/m per aperture - to be planned for LS1;
- however, a triplet cryogenic limit on luminosity of around 1.7e34 $\text{cm}^{-1}\text{s}^{-2}$ (±20%) is noted. This due to the reduced diameter heat exchanger pipes installed following the first triplet incident during installation.

The 25 ns beam scrubbing run in December 2012 has identified or confirmed: a tricky transient at the start of the energy ramp; and a discrepancy (factor 2) between the cryogenic heat load measurement (typically 20 kW) and the RF power (typically 40 kW).

Vacuum[21]

Subjects covered include the integrity of the protection functionality; beam dumps in 2012; interventions in 2012; and the outlook for 2015.

Of note:

- all RF non-conformities to be repaired during LS1;
- vacuum interlocks required for integrity of the vacuum system (e.g. NEG coating) have been relaxed (classed as a non-conformity);
- vacuum interventions need a lot of care to minimize unacceptable conditions after the interventions;
- no particular issues for scrubbing, again it is noted than the SEY and vacuum conditions in general will be reset during LS1.

Initial conditioning will be required post LS1. It was argued that it would be better to start with 50 ns.

BLM thresholds [22]

- Modified BLM layout is essential, otherwise thresholds to prevent quenches from UFOs in the dipole magnets are too low
- Risk of magnet quenching must be accepted at the start. We need to plan for beam induced quenches! BLM thresholds in arc to be set above expected quench threshold (as proposed in Chamonix 2012 for 2012, but not done)
- Can we use different algorithms to detect UFOs from BLMs? E.g. validation time as for QPS? Quench tests gave more insight and will be important for establishing thresholds.
- Noise: optimistic that BI will solve this issue.
- Triplets: IR8 will be in the shadow of 1 and 5.

Cleaning and collimation operation [23]

We now have excellent performance and fast setting up and validation. The TCL collimators have proved to reduce the effects of luminosity debris. Further improvement is expected with button equipped TCTs.

Different scenarios for collimation settings were proposed - see Belen's talk for details [23].

- Pessimistic scenario (larger emittance): β^* = 70 cm at 25 ns or β^* = 57 cm at 50 ns
- Optimistic scenario (H9 emittance) β^* = 37 cm at 25 ns or β^* = 30 cm at 50 ns

Quench tests will provide more input. We are encouraged to start with a relaxed approach in 2015.

UFOs [24]

UFOs were presented as a potential show-stopper for 25 ns at 6.5 TeV. There will be a tenfold increase in rate and the UFOs will be harder. However it is noted that there was no increase in low total intensity 25 ns fills following the scrubbing run.

- UFO "scrubbing": how does it work? What are the relevant parameters?
- 91 arc UFOs in 2012 would have lead to a dump at 7 TeV.
- De-conditioning to be expected after LS1 and an operational scenario is to be developed. For example do we: start with lower energy and/or 50 ns beam for UFO conditioning?
- Other options include increasing BLM thresholds and optimizing the BLM spatial distribution. There were interesting results from the quench tests in this regard.

POST LS1

Physics requirements

- **25 ns proton-proton operation is a strong request of all the experiments.** In fact, they would prefer not to have any significant luminosity with 50 ns (different triggers, out of time pile-up, Monte Carlos etc.). Significant here is of the order 1 fb^{-1}. 25 ns provides a cleaner environment for precision physics (trigger and reconstruction efficiencies, resolution) and is less demanding in terms of resources (online and offline computing).
- The experiments accept that the commissioning period for 25 ns operation may be longer than usual if 50 ns not used as a stepping stone but are prepared to accept the overhead.
- **Extended 50 ns running is only an option in case of major show-stoppers.**
- Optimization of other parameters (bunch length, crossing angles) is accepted as needed, but with a clear demand for stable conditions.
- ALICE proton-proton operation with 25 ns needs further studies.
- Special runs program (TOTEM, ALFA, high β^*, LHCf) will be similar to 2012.
- A heavy ion run at 13Z TeV is foreseen in 2015.

Table 2: Beam parameters for various bunch spacings at exit of SPS.

Scheme	Nb	ppb 10^{11}	emittance exit SPS [μm]	emittance into collisions [μm]
25 ns nominal	2760	1.15	2.8	3.75
25 ns BCMS	2760	1.15	1.4	1.9
50 ns	1380	1.65	1.7	2.3
50 ns BCMS	2760	1.6	1.2	1.6

Beam from the injectors LS1 to LS2 [25]

The bunch spacings and associated performance on offer from the injectors between LS1 and LS2 are shown in table 2. 50 ns proved a good choice in 2011 and 2012 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 2012 was around 1.7 $\times 10^{11}$ protons per bunch with an emittance of around 2.5 μm.

Further imaginative developments on the PS side have lead to the creation of the so-called BCMS (Batch Compression and (bunch) Merging and (bunch) Splittings) scheme. This scheme opens the way to above nominal performance in the post LS1 era.

Post LS1 operations

β^* reach at 6.5 TeV As discussed above different scenarios for collimation settings were proposed: pessimistic scenario (larger emittance): β^* = 70 cm at 25 ns or β^* = 57 cm at 50 ns; optimistic scenario (BCMS) β^* = 37 cm at 25 ns β^* = 30 cm at 50 ns. Further optimization via the use of flat beams were also considered. An average of around 40 cm is assumed in the performance estimates presented below.

Schedule 2015 2015 will be a re-commissioning, reconditioning year. Following initial commissioning with beam, the intensity and performance ramp-up will take longer than it did in 2011 and 2012. It will also take some time to flush out inevitable issues and we should foresee availability also taking a hit.

In the estimates presented below, 160 days for proton physics are assumed including the ramp-up in beam intensity.

The potential performance for four scenarios are shown in table 4. Assumptions therein are: Assumptions:

- 6.5 TeV
- 1.1 ns bunch length
- 150 days proton physics, HF = 0.2
- 85 mb visible cross-section

Table 3: Approximate breakdown of LHC's 2015 schedule.

Activity	Time assigned
Recovery, machine check-out etc.	32
Commissioning with beam	56
Machine development	22
Technical stops	15
Scrubbing run	14
Technical stop recovery	6
Proton physics running inc. ramp-up	160
Special physics runs	7
Ion run setup	4
Ion physics run	24
Christmas 2015 technical stop	14
Contingency	7

It should be noted that the 50 ns options necessitate the use of a levelling scheme of some sort, as yet unproven operationally.

Summarizing the contents of table 4:

- Nominal 25 ns gives more-or-less nominal luminosity as one might expect.
- BCMS 25 ns gives a healthy 1.6e34 cm^{-2}s^{-1}, peak mean mu of around 50 with about 83% nominal intensity
- What has become nominal 50 ns gives a virtual luminosity of 1.6e34 cm^{-2}s^{-1} with a pile-up of over 70 levelling mandatory
- BCM 50 ns gives a virtual luminosity of 2.3e34 cm^{-2}s^{-1} with a pile-up of over 100 levelling even more mandatory

Cryogenics: cool-down and availability [26] We know now how to operate the LHC cryogenic system with a correct availability for beams of 95%. All identified repairs-maintenance-consolidations are being prepared to be done in 2013. It should help! Complete cryogenics recommissioning is foreseen before scheduled date for cooldown of corresponding sector This will help the (two thirds of the team new) cryogenics operation team to get up its new learning curve while preparing for energies greater

Table 4: Post LS1 performance estimates - usual warnings apply

Scheme	Nb	ppb 10^{11}	beta *	emittance [μm]	peak	pile-up	Int.
25 ns nominal	2760	1.15	55/43/189	3.75	9.3e33	25	≈24
25 ns BCMS	2760	1.15	45/43/149	1.9	1.7e34	52	≈45
50 ns	1380	1.65	42/43/136	2.3	1.6e34	87	≈40
50 ns BCMS	2760	1.6	38/43/115	1.6	2.3e34	138	≈40

than 6 TeV. Target availability for next physics run is in the nineties.

2015 strategy The following outline schedule was presented for discussion.

- 2015 starts with system tests in parallel with hardware commissioning. Dry runs in parallel.
- Machine checkout
- Low intensity commissioning of full cycle for about 2 months, including first pass machine protection commissioning and validation in parallel with system commissioning.
- First stable beams, low number of bunches, low luminosity.
- Scrubbing for 6 to 8 days will be required early on (partially with 25 ns).
- Intensity ramp-up for 1 to 2 months. Commissioning with higher intensity continued: system commissioning (instrumentation, RF, TFB etc.), injection, machine protection, instrumentation Variables at this stage: bunch intensity, number of bunches, emittance. Would imagine passing straight to 50 ns and then stepping up in number of batches as previously.
- 50 ns operation (at pile-up limit): characterize vacuum, heat load, electron cloud, losses, instabilities, UFOs, impedance Nominal bunch intensity, 40 cm, 2.3 microns gives 9e33 $cm^{-2}s^{-1}$ and a pile-up of around 40.
- Thereafter: 1 week scrubbing for 25 ns, say 1 week to get 25 ns operational (if beta* and crossing angles are changed), intensity ramp up with 25 ns with further scrubbing as required. 50 ns held in reserve in case of serious problems with 25 ns.

CONCLUSIONS

Good year. Availability pretty good considering. We're enjoying the fruits of targeted improvements. Fault tracking could be better. Machine now magnetically, optically, operationally well understood. 6.5 TeV sequence shouldnt pose too many problems. Some new functionality to be developed, options to be explored. System performance has been generally good to excellent with issues identified and being addressed. Limitations well studied, well understood and quantified with still some potential implications for post LS1 operation. Imagine restarting post LS1 with 50 ns before moving to 25 ns. A non e-cloud free environment to be accepted at least initially, the strategy to be fully defined.

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