OVERALL STRATEGY FOR RUN 2

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Abstract

This documents is focused on the strategy for the first year of Run 2. Global strategies and various scenarios for Run 2 were already discussed in details at the RLIUP workshop in October 2013. The top goal of LHC operation for 2015 is to establish reliable operation at 6.5 TeV with 25 ns bunch spacing, and with a competitive luminosity. The overall strategy for the year 2015 will be discussed; this includes scrubbing runs, intensity ramp ups, reaching out for lower β^* and higher luminosity. Besides high intensity proton operation, high β^* and ion runs will also be discussed.

RUN 2 TARGETS

The performance of future LHC runs was discussed at the RLIUP review [1] in October 2013. The performance targets have not varied over one year and they are used as reference target in this document. For Run 2 the target integrated luminosity is 100 fb^{-1}, while at the end of Run 3 (around 2022) the total collected integrated luminosity should reach 300 fb^{-1}. A summary of the assumed beam parameters in collision (with and without Linac4, including emittance blow-up) are given in Table 1. The yearly performance is evaluated for runs with 160 days of scheduled physics time in Table 2 and Figure 1 [2]. For 35% efficiency of stable beams the yearly integrated luminosity reaches up to 50-60 fb^{-1}. Some luminosity leveling is required in all scenarios except for the standard 25 ns beam. The performance loss with 50 ns beams is roughly 50% due to the pile-up limitation of the experiments. The cooling of the triplet magnets sets a limit to the maximum achievable luminosity of $1.75 \times 10^{34} \mathrm{cm}^{-2}\mathrm{s}^{-1}$, with an uncertainty of 10 to 20% [3]. This limit will have to be explored during Run 2.

To achieve the targets set out at the RLIUP workshop, the following ingredients will be required:

- Small β^* (around 40 cm),
- Very bright and stable beams,
- Luminosity leveling.

GUIDELINES FOR RUN 2

Possible parameters for the startup configuration were discussed at the last Evian workshop on LHC operation in June 2014 [4]. Some parameters that were still open for discussion at the Evian Workshop were defined at recent LMC meetings: the main strategy is to concentrate on 6.5 TeV and 25 ns beam to reduce the complexity [5]. A relaxed β^* of 80 cm will be used for the startup. This provides for example an extra margin of 2σ at the TCT as compared to the β^* of 65 cm proposed at Evian. From the side of the experiments, there is a strong interest to use 2015 as a test year and ensure that in 2016 the LHC can be operated at its peak performance.

Possible 25 ns beams in 2015 (emittances correspond to injection):

- The BCMS beam with very low emittance (1.3×10^{11} p/b, $\varepsilon = 1.3\ \mu$m) is limited to a maximum of

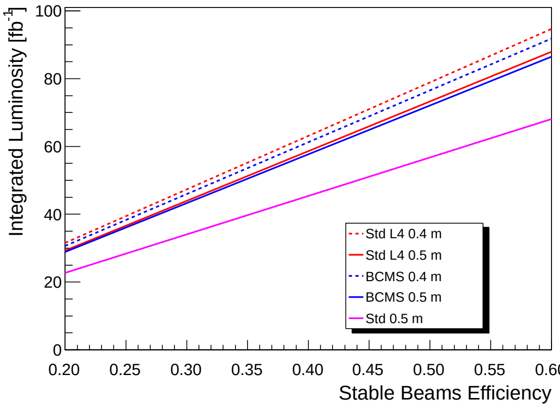

Figure 1: Integrated performance per year for the different beams as a function of the stable beams efficiency in case the luminosity is leveled according to Table 2 [2].

Table 1: Expected beam parameters of 25 ns beams at start of collisions after LS1 for the BCMS beam, the standard 25 ns beam and the standard beam with Linac4 (only for Run 3) [2]. For the BCMS beam there is no difference with or without Linac4. k is represents the number of colliding bunch pairs in ATLAS/CMS, θ is the half-crossing angle.

Beam type	N (10^{11})	ε^* (μm)	k	β^* (m)	θ (μrad)
BCMS	1.25	1.65	2590	40/50	150/140
Standard	1.25	2.9	2740	50	190
Standard+L4	1.25	2.0	2740	40/50	150/140

Table 2: Peak ($\mathcal{L}_p$) and leveled luminosity ($\mathcal{L}_l$) after LS1 for the various 25 ns beams in collision at the LHC.

Beam type	β^* (m)	$\mathcal{L}_l/10^{34}$ ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	$\mathcal{L}_p/10^{34}$ ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	Leveling time (h)
BCMS	0.4	1.54	2.2	2.5
Standard	0.5	1.65	1.2	–
Standard+L4	0.4	1.65	2.1	1.6

144 bunches per injection to ensure that in case of a failure the TCDIs are not damaged [6].

- The standard 25 ns beam (1.3×10^{11} p/b, $\varepsilon = 2.6\ \mu$m) with up to 288 bunches per injection.

Despite stronger IBS and expected issues with beam stability, the smaller BCMS beams may provide margins for emittance blow-up that eventually yields higher performance. So far small emittance beams were used rather effectively during Run 1 despite the worries on the beam stability.

2015 Startup

The current schedule of the LHC run in 2015 is split into the following phases as shown on Fig. 2:

1. Low intensity commissioning (2 months),
2. First physics with a few isolated bunches, LHCf run,
3. First scrubbing run (50 ns),
4. 50 ns operation up to 1380 bunches/beam (3 weeks),
5. 25 ns scrubbing run,
6. 25 ns operation, special runs (90 days), potentially with two β^* values,
7. Ion run

For the performance estimates presented in this document, the values for the standard 25 ns beam are aligned to the presentation by R. Bruce [5]. For the BCMS beam an emittance in collision of 2.5 μm is assumed. This is at the limit of the beam stability and provides margin for blow-up from various sources as compared to an injected emittance of 1.3 μm. The margin gained from the relaxed β^* is assigned to MP, and the LRBB separation is maintained at 11σ.

50 ns Operation

The objective for the 50 ns operation phase is to reproduce a performance similar to 2012 at 6.5 TeV without having to worry too much about e-clouds. This phase begins with a scrubbing run - initially with 50 ns and later with 25 ns beams, see Fig. 3 - a well established scenario from Run 1 [7].

Figure 2: Schedule of the LHC for 2015. The different periods are marked with the numbers.

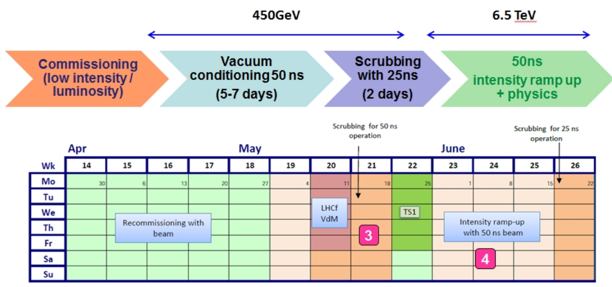

Figure 3: Scrubbing run strategy for 50 ns beams.

The scrubbing run is followed by a 21 day long intensity ramp up. The scheduled 3 weeks seem too short to reach 1380 bunches (full 50 ns beam). During Run 1 the ramp up durations were (see Fig. 4):

- The 2011 intensity ramp up took 9 effective weeks - spread over 11 intensity steps - where the progress was dictated by non-MPS issues as soon as 600 bunches were reached. Losses and BLM threshold adjustments, heating and beam stability slowed down the progress.
- With the experience gained in 2012, the intensity ramp up took only 2 weeks - spread over 7 intensity steps.

The following preliminary ramp up scenario (pending decision by rMPP) of 9 steps is envisioned for 2015: 50, 100, 250, 500, 760, 900, 1100, 1240 and finally 1380 bunches. One step in intensity will last around 3 days if there are no issues. If no show stoppers are encountered, it should be possible to reach the 1000 bunch regime which is a reasonable target for the 50 ns period. During this phase there should not be significant e-cloud problems, but the UFOs will already strike. The first heating effects may be observable. The current plan is to use similar bunch intensities than for 25 ns beams (1.2×10^{11} p/b). Pushing the bunch population toward 1.5×10^{11} may be used to probe the beam stability (also later as test during the 25 ns phase).

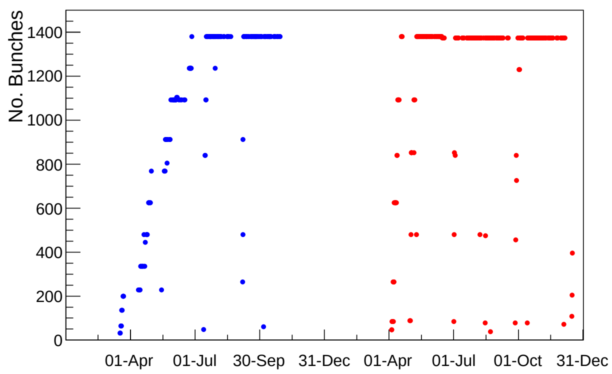

Figure 4: Evolution of the number of bunches per beam in the LHC for 2011 and 2012. The intensity ramp up periods of 2011 (blue) and 2012 (red) are clearly visible

25 ns Operation

The central issue for the 25 ns beam is evidently scrubbing and e-cloud control. The December 2012 experience indicates that we may have to change the strategy and introduce a more powerful scrubbing beam, the 5-20 ns doublets [7], as indicated in Fig. 5. Duration and outcome of the scrubbing run are not as clear as for 50 ns case.

The double beam may be absolutely essential for scrubbing, and it requires adequate time for preparation in the SPS and the LHC:

- SPS: capture, slow ramp (intensity per doublet 1.6×10^{11} p/b), extraction.
- LHC: injection, capture, instrumentation.

Most LHC instruments or systems will be able to cope with the doublets, in general by averaging the over the doublets. Critical items on the LHC side are the interlock BPMs in IR6 (protection of dump channel). The systematic orbit shifts associated to the doublet structure will require tighter interlocks, but the configuration must remain manageable in terms of tolerances. Very important tests will be performed at the SPS this year, and it is essential to test the doublet beam (typically 12 doublets) as soon as possible during the early LHC commissioning.

During Run 1 400 bunches per beam were collided with 25 ns spacing, and collisions with 800 bunches were almost achieved (beam dump unrelated to e-cloud effects): this corresponds to almost 30% of the target, but it is also the easier part of the ramp up. With the conditions (SEY) of December 2014 the machine filling will be limited to approximately 30-50% of the total intensity due to the heat load into the cryogenics system [7].

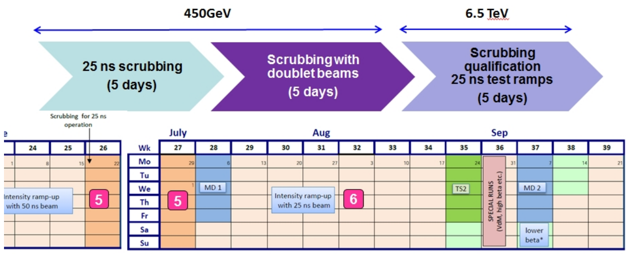

Figure 5: Scrubbing run strategy for 25 ns beams.

The intensity ramp up for 25 ns beam is tentatively split in 11 steps (to be discussed and approved by rMPP): 140, 300, 600, 900, 1200, 1500, 1750, 2000, 2300, 2600 and finally 2800 bunches. On the way UFOs will appear, stability issues are likely to be encountered (depending on the emittance of the beam), heating may be observed etc. Operation and machine coordination will have to be reactive and be ready to invest into tests and MDs. Slow scrubbing during physics operation is probably the most annoying scenario, leading to an endless intensity ramping. Special beams with low e-cloud activity are a safety net (for example 8b+4e which is a 25 ns variant with many holes [8]), but not a real solution (around 1800 bunches instead of more than 2500 bunches for a more standard 25 ns beam).

In parallel to the 50 ns and 25 ns intensity ramp up and operation periods, it will be necessary to prepare the future, i.e. to push to peak performance with ALARA-type β^* and the highest possible beam brightness and stability. The 2015 running period has only 3 MDs, and one is already before the 25 ns ramp up. It is unlikely that all tests fit into so little time, see the presentation by J. Uythoven [9]. Tests interleaved with physics operation will be required to fill the gaps. Many studies must be performed in parallel to early 25 ns operation. Since this will set limits on achievable beam parameters, one may have to use 50 ns beams and alternate standard/BCMS beams for some of the tests.

PRIORITIES AND PERFORMANCE

There is a large phase space for tuning the beams in 2015, there are many players and significant time requirements. It will be essentially to remain focused on the first priority of **operating with 2800 bunches and 25 ns spacing at 6.5 TeV**. The second priority is to prepare for operation at lower β^*. Reaching β^* below 50 cm is essential

Table 3: Expected 2015 performance at 6.5 TeV assuming 35% efficiency for stable beams. The run has been split into 3 phases, 50 ns operation, early 25 ns operation (both with β^* of 80 cm), 25 ns pushed to low β^*. μ is the peak average pile-up.

Beam	N (10^{11})	ε^* (μm)	k	β^* (m)	$\mathcal{L}_p$ (cm$^{-2}s^{-1}$)	μ	Days	$\mathcal{L}_{int}$ (pb^{-1}/day)
50 ns	1.2	2.5	1370	80	5.3×10^{33}	30	21	≈ 1
25 ns	1.2	2.5	2500	80	8.1×10^{33}	26	44	≈ 4
25 ns	1.2	2.5	2500	40	14.7×10^{33}	45	46	≈ 13

to achieve the performance goal of 100 fb^{-1} for Run 2. It will be essential to prioritize MDs and tests along a coherent line. Starting from a higher β^* (80 cm instead of the achievable 65 cm) has the drawback of a significantly longer distance to the target.

A step towards lower β^* should be made in 2015 independently of a potential gain in integrated luminosity. It is also important to foresee an operation period of 3-4 weeks after the change of β^* to have a chance of operating with high intensity (ramp up!). A step to β^* around 60 cm should be realizable from the MP and collimation perspective as soon as we confirm the aperture (early commissioning) as well as the orbit and optics reproducibility. With improved temperature stabilization of the BPM crates the reproducibility of the orbit should improve. A combined ramp and squeeze to β^* of 3 m could be injected at this stage (if not done earlier) as a step towards higher efficiency.

Performance estimates for 2015 are given in Table 3 for a stable beams efficiency of 35%. To evaluate the integrated luminosity it was assumed that the first intensity ramp up with 25 ns beam takes the entire 7 weeks of operation at β^* of 80 cm. The integrated luminosity will be around 10-15 fb^{-1}.

SPECIAL RUNS AND IONS

LHCf and VdM Scans

The LHC luminosity (cross-section) calibration is performed in special fills with van de Meer scans (VdM). For a good measurement accuracy, larger β^* (injection value for 4 TeV operation) and emittances are used to lower pile-up and increase the spot sizes for diagnostics. To maintain the same performance than at 4 TeV the scans should be performed with β^* of 20-40 m at 6.5 TeV VdM. A de-squeeze is therefore required with respect to the injection β^* of 10-11 m.

LHCf requested a special low intensity run with β^* in the range of 7-20 m during the first days of operation (radiation damage). Since both LHCf (radiation) and VdM scans (initial calibration) must be scheduled in the first week(s) of operation, it was proposed to combine the LHCf and VdM setups with the same β^*. VdM scans may be performed in all IRs except IR1 in parallel to the LHCf run which saves some operation time. This means however that two setups (low and medium β^*) must be prepared during initial commissioning.

High β^*

The high intensity 90 m run foreseen for 2015 requires a significant setup time, followed by an intensity ramp up. The beam should have up to 1000 bunches of near-nominal intensity with a spacing larger or equal to 75 ns. Assuming that standard injection and ramp are re-used, the preparation of this run requires:

- Low intensity commissioning of the de-squeeze (flat machine) including optics measurements and corrections, preferably done in advance.
- Collision setup and collimator (TCT) alignment,
- MP validation and short intensity ramp up.

The estimated total commissioning time is around 3 days, of similar scale than the VdM setup and ion runs.

Ion Run

The 2015 running period ends with the traditional ion run (Pb-Pb). The preferred energy is 6.37 Z TeV and not 6.5 Z TeV to match the centre-of-mass energy per nucleon of the 2012 p-Pb run at 4 Z TeV. No energy change with respect of the proton run is evidently always simpler, but the overhead of an energy change may be marginal. Since all MPS validations must be repeated with ions and a new combined squeeze of IR1+IR5+IR2 must be setup, changing the energy does create any overhead for the flat top, squeeze and collision. Only the ramp must be shortened a bit and re-tested (with truncated settings). The overhead of lowering the energy should not exceed around 1 shift.

Intermediate Energy Run

An intermediate energy run at 2.56 TeV per beam will be requested for comparison with the Pb-Pb data at 6.5 Z TeV. This run will be setup in a similar way than in 2013:

- The ramp is shortened,
- β^* will remain at its injection value of 10 or 11 m (no squeeze),
- Trains of 25 or 50 ns may be used.

Table 4: Expected performance at 2.56 TeV assuming 35% efficiency for stable beams, β^* of 11 m and a half crossing angle of 170 μrad.

Beam	N (10^{11})	ε^* (μm)	k	$\mathcal{L}_p$ ($cm^{-2}s^{-1}$)	$\mathcal{L}_{int}$ (pb^{-1}/day)
50 ns	1.2	2.5	1370	1.7×10^{32}	≈ 4
25 ns	1.1	2.5	2500	3.1×10^{32}	≈ 7

In 2013 the setup time was approximately 2 days (1.38 TeV), it is expected to be similar for 2.56 TeV. The expected performance assuming 35% efficiency for stable beams and a half crossing angle of 170 μrad in given in Table 4. With 25 ns beams the requested 30-40 pb^{-1} can be collected in 4-6 days.

SUMMARY

The 2015 run presents the LHC operation teams with a fantastic mix of challenges. In parallel to learning how to operate at 6.5 TeV and with 25 ns beams, it will be essential to prepare the high luminosity operation in 2016 and beyond. It will be essential to remain focused on 25 ns beams. MD periods are likely to be too short for a full program, some time for tests will have to come from the physics operation time. It will be important to define an organized path to lower β^*. Assuming that things progress reasonably, a reduction of β^* should be foreseen in the second 25 ns operation period based on the available information.

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