SUMMARY OF SESSION 5: 2016 AND RUN 2

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Abstract

The fifth session of the LHC Performance Workshop, Chamonix 2016, contained the following talks:

1) **LHC YETS Recovery**, by M. Pojer;
2) **Experiments: Expectations and Requirements**, by J. Boyd;
3) **LHC Machine Configuration in the 2016 Proton Run**, by R. Bruce;
4) **Beams from Injectors in 2016**, by R. Steerenberg;
5) **Plans for the Ion Run in 2016**, by R. Alemany Fernandez;
6) **Key Machine Developments for 2016 and Run 2**, by R. Tomas Garcia;
7) **Plans for 2016 and Run 2**, by M. Lamont.

For each presentation of the session, summaries of the presentation and of the discussion that followed are given.

LHC YETS RECOVERY

The key dates that lead up to first beam were recalled: the DSO test at the end of February, the UPS tests on 1 March, the machine closed as of 4 March, the powering tests from 4 to 16 March (7000 tests in 12 days), the start of the machine checkout on 16 March, the start of beam commissioning on 21 March. Various activities with a possible impact on the powering tests were recalled: e.g. for the QPS, ideally tests of the hardware and software for the 600 A radiation tolerant detection would be performed early to allow roll-back in case of issues. Concerning the ElQA, additional verifications on the RCS.A78B2 earth fault are planned.

For the machine checkout, all systems have to be declared operational and the BIS loop has to be closed (no interlocks from non-maskable clients should be present). For the LBDS system, a short reliability run is included in the planning. Concerning the RF, four weeks are needed for conditioning and commissioning, and additional time is requested to condition the klystrons at higher cathode current.

P. Collier stressed that the high number of tests requires a lot of expert signatures. *M. Pojer* agreed that MP3 is heavily involved, but also added that a good fraction of the test are automatically executed and analyzed, mostly for the low current circuit.

EXPERIMENTS: EXPECTATIONS AND REQUIREMENTS

The varied physics program carried out in 2015 was acknowledged as successful. The experiments' requests for 2016 include:

- $\approx$ 30 fb^{-1} of 13 TeV p-p data at ATLAS and CMS (25 ns beam, lowest achievable β^*, hoping to exceed 1×10^{34} Hz/cm^2), and leveling at LHCb and ALICE with a configuration similar to 2015.
- one early vdM scan (the need for a second one will depend on the results).
- a high β^* run for TOTEM and ALFA ($\approx$2.5 km; while 90 m is not foreseen).
- a 4 week heavy ion run is foreseen but the details are under discussion.

There is no request to change the collision energy as a consistent data set is preferred to a small increase (the minimum step is 0.5 TeV). It is becoming more interesting to reduce the beam energy uncertainty, but at present this is not a strong request. It is confirmed that 25 ns beams are the preferred option. A maximum pile-up of 50 is tolerable by ATLAS and CMS at the start of the fill (levelling would be needed above it). The shrinking bunch length and the pileup density for a luminous region length of >5 cm are not considered a problem. The longitudinal spot size shrinkage affects LHCb and ALICE though, resulting in a request for reducing this effect. For CMS, the luminous centroid was shifted by $\approx$1 mm in 2015 and this is at the limit of affecting physics.

All experiments request early stable beams with single bunches for the purpose of commissioning the detectors. Among others, CMS requests a high pile-up fill for trigger commissioning. The use of non-colliding bunches is supported as long as they do not compromise luminosity production. Note that the extra 12 bunch injection for transfer line steering is to be balanced against the loss of integrated luminosity (for a full machine). The vdM scans use the same configuration used in 2015 and should take place in week 20. The very high β^* run, with Roman Pots at 3 sigma, should be commissioned early (possibly adding one day of preparation close to the MD blocks). The details of the heavy ion run are still under discussion, and will converge for the LCC in March.

O. Bruening asked about the importance of an improved energy calibration, and *J. Boyd* replied that it is the second largest component to the uncertainty of certain measurements (e.g. for top measurements at ATLAS). *J. Wenninger* added that the precision from the magnet model is at the 10^{-3} level. The energy calibration was done in the p-Pb run at 4 TeV, and another iteration would need 2 shifts and the two particles types.

F. Gianotti stressed the importance of having a long term plan for the ion run, and to foresee time to train the magnets to the higher energy (maybe in the next YETS). *E. Elsen* agreed on the importance of a long term plan, e.g. for the forward detectors, AFP could join a later TOTEM run, instead of taking data in 2016. *M. Deile* added that the 2015 request for CTPPS has basically no cost (2 hours in 2015), and also the request to insert pots in all fills in the second part of the year should be transparent. A 90 m run is a different subject.

P. Collier wondered whether the standard optics could be used for vdM scans, as the extra cost to develop a special optics is important. *J. Boyd* replied negatively, due to the need for a big beam size, which is required for the resolution.

N. Holtkamp suggested trying to minimize the stops, *J. Boyd* agreed but recalled the need for regular maintenance.

R. Schmidt asked about the possibility to train some of the main dipoles to 7 TeV at the start of the YETSs. *F. Bordry* recalled the need to empty the magnets from helium before the Xmas break (with impact on the helium inventory), which requires 2 weeks. He also stressed that scheduling the training at the end of the YETS also poses risks, so there is no obvious solution. *M. Pojer* commented that the delay would be on 1 or 2 sectors only, not on the whole machine.

E. Shaposhnikova highlighted that one could start physics with shorter bunches, and that this would result in higher IBS growth rates. *J. Boyd* confirmed that the 2015 values were ok, but if much shorter it might not be. *T. Camporesi* recalled that the quoted 5 cm length corresponds to 1 sigma, while machine measures in units of 4 sigma.

LHC MACHINE CONFIGURATION IN THE 2016 PROTON RUN

While 2015 was a commissioning year, 2016 is a production year. Performance is quantified by the integrated luminosity, and an increase in peak performance is advantageous only as long as it does not compromise availability. Concerning the beam parameters from injectors, BCMS beams are limited to 144 bunches per injection because of the injection protection elements (until the end of Run 2). Thus, a maximum of 2256 bunches can be injected as opposed to 2748. It is proposed to finish the intensity ramp-up with standard beams and consider BCMS for later. The geometric factor is affected by the crossing angle, which in turns is limited by the beam-beam separation and the minimum aperture: the crossing angle for 2016 could be reduced from 11 to 10 sigma. The shortest possible bunch length is limited by e-cloud and longitudinal instabilities: fills could start at 1.3 ns, aiming at shortening towards 1 ns after the intensity ramp up.

The possibility to reduce β^* was studied in several MDs in 2015. The following measures are needed for a very small β^*: remove the extra 2 sigma margin used in 2015 between TCTs and TCDQ, reduce to 2 sigma the retraction between TCPs and TCSs in point 7, profit of the slightly improve orbit stability, and use a favourable phase advance from the dump kickers to the TCTs (choice already taken, independent of β^*). The aperture that was measured with protons was not confirmed by the measurements with Pb ions (with a loss of 5-10 cm), so measurements at the start of beam commissioning are required before the final decision on β^*.

K. Oide suggested using regularly the BCMS beams for the benefit of scrubbing. R. Bruce recalled that there might be issues with stability.

O. Bruening asked to quantify the overhead in backing off from 40 cm to 50 cm. *R. Bruce* replied that the impact depends majorly on when the choice is made: e.g if taken early enough, then the crossing angle could be reduced and the TCTs re-setup, followed by the usual set of loss maps (i.e. ≈2 shifts).

Y. Papaphilippou stressed the ≈10% emittance growth in collisions which is to be understood. *P. Collier* stressed that the emittance growth, if not fully controlled, might be an issue at 40 cm β^*. *M. Lamont* recalled that the transverse size was often 3.8 μm at the start of collisions. After a question by *S. Redaelli*, it was recalled that the BCMS beams have smaller emittance and come in shorter trains. For allowing trains of 144 bunches instead of 96 bunches though, one would need an interlock on brightness, which is not available at present.

L. Rossi asked about the peak luminosity projections, and *R. Bruce* replied that at present the bunch length is longer than the one in the LHC Design Report, which decreases the geometric factor. *P. Collier* added that also the number of bunches is lower than 2808.

P. Collier stressed that the difference between 40 and 50 cm β^* is 7-8%, but 40 cm might require additional interlocks that might reduce the availability.

After a question by *E. Elsen*, *R. Bruce* expanded that the beta-beating corrections are very good and very stable, and they are not a concern any more and are included in the tolerances.

V. Kain commented that there are issues with transmission at the SPS, and the maximum deliverable is 1.4×10^{11} ppb in 3 μm.

BEAMS FROM INJECTORS IN 2016

The advantage of BCMS beams is the 50% lower transverse emittance that can be obtained for the same intensity. The 8b4e variant is produced by substituting the triple splitting with a double splitting, resulting in empty buckets (56 bunches from the PS, instead of 72). It has advantages from the point of view of e-cloud build up, and can reach up to 1.7×10^{11} ppb in 3 μm transverse emittance. Doublet beams are based on the standard 25 ns beams (without the last double splitting), and injecting on the unstable phase at the SPS. They can reach high intensity, but the emittance is not as carefully setup (as it is less important for scrubbing).

The spread in bunch intensities within the trains was improved by the 1-turn delay feedback on the 10 MHz PS cavities, which was commissioned in 2015. A Finemet cavity used as longitudinal damper helped with coupled bunch instabilities at the PS. The SPS suffers from non-negligible uncaptured beam due to the imperfect longitudinal matching between the PS and SPS: higher intensity results in lower transmission. The 80b4e scheme (4 empty spaces are for the PS extraction kicker) holds potential as it gives an increase of 10% in number of bunches. It was not yet injected in the SPS.

The injectors in 2016 can deliver, at SPS extraction, the standard 25 ns beams with 1.2×10^{11} ppb in 2.6 μm. Beams at the injectors (both standard and BCMS) were very close to the injector limits in 2015, so there is little room for improvements before LS2.

After a question by *L. Rossi*, *R. Steerenberg* clarified the bunch parameters for the 80b scheme: it has the same emittances and intensities, but it needs a gated transverse feedback (it is planned to check what happens to the bunches adjacent to the gate).

PLANS FOR THE ION RUN IN 2016

The details of the 2016 ion run are still under discussion. Some particularities of p-Pb operation are recalled: due to the 2-in-1 magnet design, the two beams have to have the same rigidity, which fixes the ratio of the two momenta. The two separate RF systems are used with different RF frequencies, which are equalized only at high energy (the beams are then on slightly different orbits). Then cogging is required to align the collision point with the centre of the detector. Ion runs try and profit as much as possible from proton optics setup to reduce dedicated setup time, given the short total run time. Note that in case of p-Pb physics, additional chromatic effects due to the off-momentum orbits result in increased beta-beating. The ALICE detector is vertically displaced by ≈ 5 mm, which was partly compensated by a displacement of the IP by $y = -2$ mm: this will be needed also in 2016-2018, but will be fixed in LS2. Note that there is an issue with luminosity sharing: while IP1/5 can be squeezed further than IP2, the resulting increased burn-off penalizes the luminosity lifetime. ALICE will be operated at a levelled luminosity.

P. Collier asked whether 40 cm β^* in IP1/5 is reasonable with off-momentum orbits. *J. Jowett* replied that the issue is still under study, but that it could be possible at 8 TeV, if ALICE is not squeezed too far.

After a question by *N. Holtkamp*, *R. Alemany* clarified that the decision to be taken before the LCC in March concerns the energy and the particle type (p-Pb or Pb-Pb). The experiments need to reach an agreement, but all scenarios are feasible from the accelerator point of view.

R. Steerenberg recalled that the 100 ns beam were used in the 90 m run, but there were issues with sparking on the septa for the North Area. This should be improved.

A. Siemko asked about possible improvements on the interlocked BPMs, as they terminated a number of fills in the past. *R. Jones* explained that, when the detection limit of the electronics is reached, the valid readings cease and the interlock is pulled. This happens at $\approx 2 \times 10^9$ ppb, as per design.

KEY MACHINE DEVELOPMENTS FOR 2016 AND RUN 2

2015 was a successful year for the machine developments; 92 requests (>30 days) were presented for 15 days allocated on the schedule. Highlights of the results were already presented earlier in this workshop. Most MD notes are published. The studies enjoyed good machine availability (>71%). Concerning the optics developments for physics (i.e. very high β^*) attached to the MD blocks, the expert coverage has to be carefully evaluated. A total of 59 MD days are allocated until the end of Run 2. For 2016, the equivalent of 30 days are requested, while 22 days are allocated on the schedule.

A list of highlights for 2016 MDs was presented: optics (ATS to be tentatively validated in the first 2 MD blocks, while the high β^* is commissioned in physics time), for linear and non-linear optics, collective effects (single bunches are well understood while coupled bunch instabilities are less understood), luminosity and beam-beam, collimation MDs, MDs with ion beams, from operations (e.g. use of the MCBXs in the orbit feedback), RF studies (the full detuning mode has to be validated with beam), on beam instrumentation (especially DOROS and BSRT), ABT (including injection of the 80b beam), Machine Protection MDs, and some studies for the very long term plan (FCC-hh and FCC-ee). Additionally, a list of MDs that can be performed in parallel to physics and as end-of-fill was shown.

N. Holtkamp asked about the number of days allocated to MDs. *M. Lamont* and *P. Collier* replied that, historically, ≈10% of the total time is devoted to machine studies.

N. Holtkamp asked to clarify the definition of priorities. *R. Tomas* replied that they are discussed in regular meetings, and higher priority MDs are called to present the details of their plans. Consensus was so far easy to reach. *J. Uythoven* added that the presented priorities come from MD groups.

PLANS FOR 2016 AND RUN 2

The challenges for 2016 are the high e-cloud and beam-induced heating, UFOs and ULO, beam instabilities, and R2E. The priority for 2016 is the stable and safe operation with small e-cloud. The choice of a “not too challenging” operating regime allows more stable and reproducible physics production. Avoidable interruptions to physics production should be kept to a minimum, and safety should not be compromised. The excellent machine reproducibility is one of the strengths of the LHC.

The 2016 schedule includes 4 weeks for beam commissioning, and 4 weeks for scrubbing and intensity ramp-up (including 4 days of dedicated scrubbing at 450 GeV, while most scrubbing will be done while in physics). A total of 152 days are allocated for p-p physics. A possible target for the integrated luminosity is ≈30 fb^{-1}. A β^* of 50 cm allows for a smaller crossing angle than 40 cm, resulting in a similar peak luminosity. The BCMS beams have potential and should be explored during 2016: the smallest bunches got into physics with 1.9 μm transverse emittance.

The 2016-2017 YETS will be "extended" and the machine will be cold throughout its duration. No ions will be taken at the LHC in 2017, while 2018 will be a standard production year. For the general purpose experiments, $> 100\ \text{fb}^{-1}$ seem to be within reach in Run 2.

P. Collier commented that a possible strategy is to make scrubbing a priority during the intensity ramp up, and then allow scrubbing with physics beams when the machine is full (2748 bunches). *M. Lamont* added that eventually Q' and MO could be decreased to improve the dynamic aperture and the lifetime in stable beams.

L. Rossi recalled that BCMS results in 10% less bunches and some extra pile-up. *O. Bruening* pointed out that after LS2 one could benefit from LIU upgrades. *P. Collier* recalled that it is likely that extensive scrubbing will be required after LS2. *G. Arduini* recalled that it is possible that e-cloud will never disappear in quadrupoles and triplets.

R. Schmidt asked to confirm that the assumption is to continue running at 6.5 TeV for 2017-2018, *P. Collier* and *F. Bordry* agreed.

N. Holtkamp suggested minimizing all other activities to increase the days for p-p physics. *M. Lamont* recalled that ≈200 days were spent in p-p physics in 2012, but that has a price on the variety of the physics program. He also recalled that there are limited resources in manpower, and some breaks are necessary.

G. Arduini stressed that machine reproducibility is a key ingredient, to be kept in mind when deciding alternative strategies to precycling, and *E. Todesco* agreed. *M. Lamont* agreed that alternative strategies would need to be characterized.