SUMMARY OF SESSION 1: "OVERVIEW OF RUN 2"

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Abstract

The first session of the 9^{th} LHC Operations Evian Workshop showed an overview of the LHC operation in Run II. Both the Protons and Ions Runs were summarized, highlighting the machine commissioning steps from the powering tests to the magnets training, the beam commissioning steps from the optics measurements to the optics corrections and their implementation, the intensity ramp up and its impact on the machine settings and beam parameters. The physics production and the milestones achieved were treated in addition from the point of view of the LHC experiments. The injectors complex availability and the variety of beams provided to the LHC in Run 2 were also discussed. Finally a review of the availability and faults figures in the whole complex was presented.

B. SALVACHUA: OVERVIEW OF PROTON RUNS DURING RUN 2

B. Salvachua gave an overview of the main LHC proton-proton program at 6.5 TeV beam energy in Run II. Summarizing the yearly highlights and limitations, the strategy followed to achieve the luminosity goals, accumulating up to $160\,\text{fb}^{-1}$, was presented. The main blocking faults encountered in the Run, like the 16L2 beam losses and issues with the LHC and SPS beam dumps were discussed. **B. Salvachua** showed also how some of the features expected for High Luminosity LHC scenarios were tested and in many cases became the operational scenario such as luminosity levelling, combined ramp and squeeze, Achromatic Telescopic Squeeze (ATS) optics. Furthermore, the performance of the machine in terms of beam losses, orbit stability and beam lifetime was also discussed.

Discussion:

A. Siemko commented that, for sake of documentation, it may be useful to compile a full list of the "mysteries" encountered in Run II, i.e. issues like 16Le were workarounds to mitigate their impact on operation were found without having the mechanisms fully explained.

J. Uythoven asked about the orbit stability in 2018 that was presented whether it is compared to the reference orbit, **J. Wenninger** replied explaining that it presents the rms orbit evolution including only the 25 ns beam with respect to an orbit chosen at the start of the year (May 2018). He added saying that it may also contain uncorrected orbit drifts.

W. Hofle wanted to know if the lifetime asymmetry between B1 and B2 is fully understood. **B. Salvachua** replied that it is not fully understood yet, but it is worth noting that B1 lifetime being worse than B2 is linked to the fact the B2 was behaving extremely good. **Y. Papaphilippou** added that in the next talk of **S. Kostoglou** where a bunch by bunch analysis of the lifetime gives a hint on the origin of the asymmetry.

R. Steerenberg asked whether there is a need to use the doublets beam in Run III. **G. Iadarola** commented that Run II experience shows that a scrubbing Run is not enough to remove the heatload but just to get control over the beams to continue scrubbing the machine while in Physics production. Based on this, unless the LHC changes dramatically in LS2 in terms of e-cloud, the interest in the doublets is not big.

P. Collier asks whether relaxing β^* to 80 cm at the start of Run II as proposed in Evian 2015 to gain margin was really needed or whether it resulted in a loss of performance. **B. Salvachua** replied that it is true that a pushed β^* with a tighter collimation setting would have increased the sensitivity to localized beam losses, representing a risky option. However, looking to data from Run II, the risk taking would have paid in a higher performance. **E. Metral** added that from the instability point of view, a staged decrease of β^* was appreciated and presented a learning opportunity.

J. JOWETT: OVERVIEW OF ION RUNS DURING RUN 2

J. Jowett summarized the four heavy-ion runs in Run II. The diversity of the collided nuclei, beam energies, machine configurations and collision conditions were presented.

He showed how the major improvements in the bunch intensity and spacing of the beams produced in the injectors complex, combined with decreased β^* were key in the success of the Runs and led to a significant gains in peak and integrated luminosity.

The resulting challenges of controlling of heavy-ion beam losses, like collimation and BFPP, with carefully adjusted BLM settings were highlighted and the adopted solutions were explained.

J. Jowett pointed out also that close to the full "HL-LHC" performance in Pb–Pb and p–Pb collisions has been achieved. Finally, the potential of short Runs of light species (i.e. Xe-Xe) was underlined.

Discussion:

J. Wenninger commented that for a fair comparison between the LHC and the HL-LHC goals the LHC numbers, intended for 2 weeks of Run, need to be doubled when comparing to the HL goals with a one month Run duration.

D. Nisbet commented on the value of the last minute validation of the various configuration in the ion Run. **J. Jowett** replied highlighting the experience in 2018^{th} Run, where the optics problem in IR2 identified and solved throughout the Run made an eventual pre-validation as the start of the Run useless as it needed to be redone.

H. Timko, commented that slotting the partially stripped ion MD in the proton block incurred a big overhead for the

RF team, and efforts should be made to try to avoid it in the future.

C. SCHWICK: LPC VIEW ON RUN II

C. Schwick summarized from the viewpoint of the experiments Run II, especially the different machine configurations. The latter were split in running configurations:

- due to experiments constraints such as the bunch lengthening in Physics, the lumi-leveling by separation and some optics constraints for the forward Physics experiments,
- work around problems such as the 16L2 losses adopting unusual filling schemes (i.e. 8b4e),
- gaining experience for HL-LHC with the RF full detuning and the achromatic telescopic optics,
- enhancing the machine performance with the high brightness BCMS beam and the luminosity leveling techniques (β^* and crossing angles).

The motivations and consequences of the various scenarios on the experiments was discussed. Finally, major Physics results of the Run 2 pp run were highlighted together with the physics motivation of the special runs was briefly introduced, mainly for the Van der Meer scans, the forward physics, elastic scattering and the high β^*.

Discussion:

R. Steerenberg, on the behalf of the machine, thanked the LPC team contribution to the operation and highlighted their challenging plan in coordinating the diverging requests of the experiments.

S. Fartoukh asked when would the LHCb analysis will be completed and whether it is expected to have impact on the coming running scenarios. **F. Alessio** replied that the full data of Run II is being reprocessed and is estimated to take several months, in parallel to other analysis and channels under studies that require more statistics and are still awaiting Run III data.

A. Siemko asked about the evolution of the Higg's confidence level in Run II. **B. Petersson** replied that after exceeding the 5σ level in combined studies in Run I, work is still ongoing in analysing the full data sets in both experiments.

B. TODD: LHC AND INJECTORS AVAILABILITY IN RUN 2

B. Todd presented on the behalf of the the Availability Working Group the LHC and the injector complex availability. The performance of 2018 was evaluated at first then covering the full Run II. An evaluation of the LHC exploitation and performance was shown identifying operational aspects, beam mode ratios, beam dump causes, fill length and turn-around. A detailed breakdown of all faults and impacts followed, with notable faults and new root causes identified, before concluding with listing the LHC high impact and recurring faults across Run II. **B. Todd** continued covering the injector complex as well with the analysis, identifying top faulty systems across the complex.

Finally, new concepts and approaches which are currently being considered for practical application in availability studies were introduced such as the "Lost Physics" penalty adoption for losses happening at Flat Top energy because of the operational overhead incurred to restore same machine conditions. Also the concept of "Complexity Scaling" was introduced to compare the allocated availability based on the system complexity under study.

Discussion:

J. Wenninger commented that care should be taken when comparing the yearly turn-around as it needs to be corrected by the nominal cycle length and the filling schemes and the number of injections. Additionally, he asked if reaching availability exceeding 60% coudl be done by attacking the unavailability of the QPS and power converters. **B. Todd** agreed and showed that presently suck availability has been reached but cannot be sustained.

W. Hofle appreciated the developed metric quantifying a return in availability based on investment, however he commented that also human resources investment and training needs also to be accounted for.

A. Siemko also highlighted that this metric is interesting to be adopted by the consolidation project leaders. **M. Lamont** replied stressing that the impressive availability and performance reached is fruit of ongoing investment in consolidation by the groups to identify shortcomings. The next step will be identifying where the possible improvements can come from seen the limited resources.

G. Iadarola commented on the turn around distribution in 2018, pointing out that part of the long tail is due to dedicated studies at injection where the machine was not brought to physics on purpose.

A. Siemko added that comparisons from year to year on systems such QPS and PC need to account for the yearly accumulated total luminosity. **E. Metral** also added that it needs to be correlated with the imposed limitations in the beam parameters such as number of bunches and intensity per bunch and not only luminosity.

T. Lefevre asked whether this availability studies could help identifying requirements on the support for the systems, whether piquet services or best efforts. **B. Todd** replied that for the power converters, the piquet service is key for short interventions and thus in the performance of the system. **J. Wenninger** also stressed how essential is the piquet service of QPS and EPC and added that best efforts outcome are really dependent on individuals.

D. Nisbet commented that the metric used to quantify the fault impact on Physics did not change radically the analysis nor the systems involved in the down time.

M. Lamont concluded that this level of availability has a high cost and with the present financial situation we may have to sacrifice some of these figures.

H. BARTOSIK: INJECTORS BEAM PERFORMANCE EVOLUTION DURING RUN 2

Several proton beam types from the injectors were presented (standard 50 ns, standard 25 ns, BCMS, 8b4e, BCS), which were regularly used for LHC physics operation in Run 2. For each beam type, the achieved parameters at extraction from the SPS were shown, as well as the dominant limitations throughout the injector chain. An overview was also given of various improvements implemented in the different machines, which have helped significantly in pushing the brightness and intensity and hence the LHC performance.

Furthermore, the operational ion beams were presented, and also here significant improvements over the years were demonstrated, following studies to better understand the limitations. This gave a major contribution to the very good LHC performance.

Discussion:

C. Schwick asked whether for future ion runs, in the assumption that slipstacking in the SPS is operational, it could be possible to use a mixture of 50 ns and 75 ns trains, in order to provide more luminosity to LHCb. **H. Bartosik** answered that it is possible to have a mixture of slipstacking in some SPS cycles and a standard 75 ns scheme without slipstacking in other cycles.

J. Jowett asked whether a slipstacking could be applied to a 75 ns beam to achieve a 25 ns spacing. **H. Bartosik** said that such an interleaved scheme with 25 ns and 75 ns could be produced. However, it is already challenging to get the baseline slipstacking working due to, e.g., longitudinal instabilities, and new schemes should be explored only when standard operation is established.

W. Hofle asked about whether also transverse instabilities could be a problem during slipstacking in the SPS. **H. Bartosik** replied that no analysis exists yet, however, this should be studied during LS2.

T. PERSSON: RUN 2 OPTICS AND CORRECTIONS

The strategy for optics corrections applied during Run 2 was presented. Details were shown on how the commissioning strategy for new optics evolved over the years, in order to improve the final operational optics in spite of the challenge of decreasing β^* and large crossing angles. New strategies made operational include K-modulation to correct the waist shift, corrections with the crossing angle on, and sextupolar and octupolar corrections. The needed corrections were found to be different in 2015 compared to Run 1, however, within Run 2, corrections could be reused to a larger extent. The β-beating was found to drift only by a few percent within one year.

In the 2018 Pb ion run, an initial setting error could be fixed using the colinearity knob and triggered also the development of new methods to measure the local coupling. An automatic tool to correct the coupling was also presented, which had been made operational and was used regularly during standard operation and MDs.

Discussion:

J. Wenninger asked whether a complete optics optics recommissioning will be needed after LS2. **T. Persson** said that although some corrections might be reused depending on the initial measurements, it is likely that a full commissioning campaign is needed. **J. Wenninger** inquired also about the needs to recheck the sextupolar corrections, which are likely to be due to misalignments. **T. Persson** confirmed that this is needed, but the commissioning overhead to perform measurements with the different sextupole families is only about 1 h.

S. Fartoukh pointed out that in the future, the ATS telescope will be used more extensively and that β^*-leveling will be used with a much larger dynamic range than in 2018. Therefore, following the ATS philosophy, it could be interesting to incorporate local corrections in IR1 and IR5 only, and global corrections in the other IRs that do the telescopic squeeze. **T. Persson** mentioned that the optics correction is presently not as performing under large variations of the telescopic index, which is planned to be studied in LS2. He further welcomed any improvements to the present correction strategy although this is not an easy task.

R. Bruce asked whether anything will be changed in future optics commissioning to avoid issues similar to the ones in the 2018 ion run. **T. Persson** replied that an automatic way of generating the settings will be implemented and said that, in addition, it would be useful to have a validation of the settings. The procedure tested in MD in 2018 (rigidity knob) could be one option.

G. Arduini inquired about the understanding of the previous discrepancy between magnetic measurements of the triplet and what is found with beam measurements. **E. Maclean** commented that the discrepancy in lower orders is likely due to alignment and feeddown effects. For the higher orders, many multipoles at both IR1 and IR5 are likely to contribute and hence hard to disentangle.

In the context of the new coupling application, **G. Trad** asked what work needs to be done to have a similar application to measure the tune wit the ADT, and whether the technique has been fully validated. **D. Valuch** replied that measurements with active excitation work well and only the software is missing. For passive measurements, promising data exist and there is good hope that this will be available in Run 3.

P. Collier commented that there is a risk that the nonlinear correctors in the triplet might show limitations due to radiation damage during Run 3. Therefore, a sensitivity study should be performed to understand the impact of failures or current limitations on the corrections. **T. Persson** agreed that this is a useful study that should be performed in LS2.

M. MENTINK: POWERING TESTS AND MAGNET TRAINING

M. Mentink gave an overview of the powering tests and magnet training in Run 2. It was shown that powering tests have become more efficient and that circuits are re-qualified after interventions using an MP3 intervention matrix. **M. Mentink** showed that magnet training is needed after every thermal cycle and that the training has been made more efficient by minimizing spurious secondary quenches. The risk of inducing a short-to-ground during the training will be mitigated through diode consolidation in LS2.

M. Mentink showed the results of the training campaign in December 2018 with the goal to check the feasibility of 7 TeV operation. The training of the main dipole circuits was slower than expected but did not reveal any intrinsic limitation for reaching 7 TeV. The main quadrupole circuits are not expected to be a bottleneck, and most individually powered magnets have reached 7 TeV with margin. Running at 7 TeV is expected to increase the sensitivity to beam-induced quenches due to, e.g., UFOs.

Discussion:

R. Steerenberg asked what margin on the current achieved in the training is judged to be sufficient. **M. Mentink** replied that the present assumption is a margin of 100 A, although this number is not cast in stone.

B. Petersen asked about whether the beam-induced quenches shown were only due to UFOs. **A. Lechner** clarified that these included 8 UFOs, 3 ULOs and one 16L2 event.

F. Bordry commented that even if it was presented that there is no showstopper for 7 TeV, it will be significantly more difficult to reach 7 TeV than previously thought, based on time constraints. The time presently allocated for the recovery after LS2 was based on a more optimistic estimate of the number of needed quenches, and it has to be discussed with the experiments whether it is still worth to go directly to 7 TeV if the number of needed quenches is larger. The decision should be taken before September 2019.

D. Nisbet commented that it would be useful to review the procedure for recovery after interventions, in particular for the most common interventions, and to examine if the presently available tools can be improved.

R. Steerenberg inquired about the feasibility of the idea for a faster training cycle that was presented. **F. Bordry** commented that such a procedure would require extreme care, and that this had been proposed already at the LHC startup but rejected. **A. Siemko** mentioned that this procedure is under study but it is not the baseline.

E. Todesco commented that so far, the time needed for magnet training has been in the shadow of other activities, however, this will no longer be the case for the training to 7 TeV, which will likely require several months. **F. Bordry** stated that the gain in integrated luminosity from the 7 TeV beam energy is relatively small, while there is a significant impact from the time lost for training. Therefore, a good strategy could be to restart at 6.5 TeV after LS2. With one month of magnet training, more elements will be known to allow taking the decision on when to go to 7 TeV.

C. Schwick commented that there is an interest from the experiments to operate at 7 TeV, since discovery limits for many channels improve significantly. It should be studied in detail to see if it pays off. Smaller steps in energy are, however, not desirable. **F. Bordry** asked if 6.75 TeV is considered a small step. **B. Petersen** replied that based on very preliminary feedback, even this step could be interesting.