

SESSION2: POST-LS1 SCENARIOS WITHOUT AND WITH LINAC4

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Abstract

This document summarizes the talks and discussion that took place in the second session of the RLIUP Review. The main aims were to examine the performance of the injectors and LHC and what could be the integrated luminosity by 2035 if no major upgrade except the connection of LINAC4 and H^- injection is implemented and to take into account the lifetime of major accelerator components whose repair or replacement would require long shutdowns. The session comprised four presentations: “Expected performance in the injectors at 25 ns without and with LINAC4” by G. Rumolo; “Integrated performance of the LHC at 25 ns without and with LINAC4” by J. Wenninger; “Required maintenance and consolidation to run like that (injectors and LHC) until 2035?” by K. Foraz; and “What could stop us, when and how long?” by L. Bottura.

EXPECTED PERFORMANCE IN THE INJECTORS

Taking accepted beam loss and emittance blow-up budgets into account, it was shown that 25 ns beams delivered by the injectors (i.e., at the exit of the SPS) in 2012 were at or close to the brightness limit determined by space charge at injection in the PS, both for the standard production scheme and for the so-called batch compression, merging and splitting (BCMS) one. At the current PS injection energy of 1.4 GeV, this limit is closely aligned with the maximum brightness available from the PSB for these beams. A modest improvement could nevertheless be expected by increasing the longitudinal emittance in the PSB and using the second-harmonic rf in that machine to maintain the bunch length at extraction within the upper limit imposed by its recombination kickers.

A more substantial increase in brightness could be achieved using a new scheme with no splitting at low-energy in the PS – so-called pure batch compression. This would incur a filling penalty of around 13% in the total number of bunches in the LHC, but the shorter PS batches (trains of 32 bunches) would be beneficial from the standpoint of electron cloud.

All post-LS1 25ns schemes are limited to a maximum intensity per bunch of some 1.3×10^{11} by the rf power available in the SPS.

Linac4 offers the prospect of a factor of two increase in the brightness from the PSB. Consequently, space charge at injection in the PS becomes a clear limiting factor at 1.4 GeV. Even with the relaxed longitudinal emittance from the PSB, a 50% improvement is all that can be passed on directly and this only for the standard scheme. The BCMS scheme already operates at the space charge limit in the PS and has less margin to increase the longitudinal emittance injected into that machine.

It may be possible to recover more of the brightness gain by creating hollow bunches in the PSB or by employing high-dispersion or coupled optics at injection in the PS, but these approaches will require extensive MD time to develop. Also, a hollow distribution in longitudinal phase space will present a different tune footprint and will be difficult to triple split into bunches of equal intensity and longitudinal emittance.

The double brightness of Linac4 offers the additional possibility of delivering the present performance of LHC-type beams using single-batch transfer from the PSB. This could reduce the minimum waiting time of the LHC at 450 GeV by 17%, while the absence of a long injection plateau in the PS could permit the space charge ΔQ limit to be pushed beyond -0.31.

Discussion

R. Jacobsson asked what the 13% filling penalty of the pure batch compression scheme is with respect to. G. Rumolo replied that this is compared with the standard scheme.

S. Myers asked what increase in brightness could be expected from the pure batch compression scheme. G. Rumolo replied that a ~40% improvement is expected over what the BCMS beam will be able to deliver.

INTEGRATED PERFORMANCE OF THE LHC

This talk summarized the performance reach expected at the LHC by integrating the predictions of the previous one. It was re-iterated that only the standard scheme gains appreciably from Linac4, which left three cases to be analysed: the standard beam without Linac4 and the standard and BCMS beams with Linac4.

Electron cloud was considered to be the most serious potential limitation despite promising MDs in 2012 at 450 GeV in the SPS with doublet beams to enhance scrubbing. Although scrubbing is effective in the dipoles, where it is hoped to remove the effects of electron cloud completely, there is little evidence of improvement in the quadrupoles. This could be important for the inner triplets where the maximum heat load already translates into a luminosity limit of around $1.8 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$. Extrapolation of the UFO rate from 2012 data to 7 TeV suggests that roughly 100 beam dumps per year could be expected, although there is also evidence of fast conditioning with 25 ns beams. Serious deconditioning must be expected after LS1.

Assuming a stable beams efficiency of 35% (based on 37% achieved in 2012 and a 20 minute longer cycle to reach 6.5 TeV), an exponential fill length distribution with a mean of 6.5 hours (as observed in both 2011 and 2012) and a luminosity lifetime of 12 hours, then the standard and BCMS beams with Linac4 both have a very similar

levelled (at a pile-up of 45) performance reach of close to 50 fb^{-1} per year for β^* in the range 40-50 cm. Without levelling, this increases to $\sim 55 \text{ fb}^{-1}$ per year for both schemes at $\beta^* = 40 \text{ cm}$, but with the penalty of increased pile-up. Pile-up is worse in the BCMS case because of the lower number of bunches stored. The (unlevelled) standard scheme without Linac4 would give only 38 fb^{-1} per year at $\beta^* = 50 \text{ cm}$, which gives the BCMS beam a clear advantage until Linac4 comes online.

Discussion

L. Rossi claimed that the bunch population should always win as the most important factor. R. Garoby explained that this is a fallacy because the intensity per bunch throughout Run 2 will be limited by the injectors to a maximum of $\sim 1.3 \times 10^{11}$ for 25 ns beams.

L. Rossi then asked if any benefit of smaller transverse emittances would simply be negated by increased blow-up. M. Lamont said not necessarily and cited the example of the 50 ns BCMS beam in 2012 which suffered similar overall blow-up in the LHC to the standard 50 ns beam.

S. Myers asked whether the 50 ns beam was the only option given that there is no guaranteed solution to the problem of electron cloud. J. Wenninger replied that this would be covered in V. Kain's talk.

REQUIRED MAINTENANCE AND CONSOLIDATION

The aim of this talk was to establish a baseline scenario for shutdowns until 2035 within the somewhat artificial remit of no LIU upgrades (except for Linac4) and no HL-LHC. It constitutes a summary of extensive interviews with the relevant equipment groups.

CV and CRG maintenance determines the duration and frequency of all routine technical stops. These would have a duration of 5 days seen at the LHC and are required roughly every 10 weeks, with a further year-end technical stop of 10 weeks (including the Christmas holidays). The latter assumes operating with ions in the LHC at the end of each year in order to increase the cool-down time before access without high-intensity protons in the injectors.

Additionally, in a first scenario, there would be two long shutdowns each of 16 months duration for the LHC (LS2 from 2018 and LS4 from 2027), once again driven by the combined maintenance requirements of cooling, ventilation and cryogenics equipment, together with two long shutdowns each of 20 months duration for the LHC (LS3 from 2022 and LS5 from 2031) for the replacement of the inner triplets. Thus significantly long stops are required even with no upgrades. The 9 months to connect Linac4 would be in the shadow of LS2 in this scenario, which gives 57% for the scheduled availability of the LHC.

In an alternative scenario, the four long shutdowns are delayed by one year to permit Linac4 to be connected in 2017. This would mitigate the risk of the failure of

Linac2 and spread the workload of LS2, but the scheduled availability of the LHC would be reduced to 54%.

Discussion

F. Bordry noted that a scenario with the connection of LINAC4 in 2017 during an extended year-end technical stop (dubbed "LS1.5") would imply a short run before LS2, which might not be desirable by the experiments.

R. Losito pointed out that, contrary to what was mentioned during the presentation, EN/STI does require technical stops during the run.

WHAT COULD STOP US?

The magnets of the LHC are subject to several failure modes: mechanical fatigue due to powering and thermal cycles; thermal and electrical stress due to singular events such as quenches; and radiation damage, particularly for those magnets in the triplet and collimator regions.

For the electromechanical issues, the mean time between failures of the superconducting magnets has been estimated at 400-500 years. This translates into 3 or 4 electrical non-conformities per year of operation and to at least 10-15 magnet exchanges per long shutdown, while one of the triplet magnets could be expected to fail within the next 10 years. The experimental magnets remain an open question.

Although there is a 50% uncertainty on the radiation dose that the triplets will accumulate by LS3, it may be sufficient to provoke a mechanically induced insulation failure. By that time the exchange of a triplet magnet could take ~ 1 year, including up to 6 months for cool-down. This limit to the radiation hardness of the triplets corresponds to an integrated luminosity of $\sim 300 \text{ fb}^{-1}$ and is consistent with previous analyses.

For the warm magnets of the collimation regions, actions have already been proposed and accepted to prevent insulation failure during Run 3.

Personal dose will be an important issue and all interventions must be carefully prepared. Access and work in the triplet and collimator areas will be subject to ALARA level III rules.

Discussion

S. Myers asked what is envisaged to avoid radiation damage to the new HL-LHC triplets. L. Rossi replied that sufficient shielding of the beam screen is foreseen to reduce radiation to the coils. The integrated radiation dose for a total integrated luminosity of 3000 fb^{-1} is expected to be smaller than that estimated for the coils of the present triplets after 300 fb^{-1} . L. Rossi added that this subject would be developed in the presentation of P. Fessia in Session 3.

O. Brüning asked whether the mean time between failures depends on the number of cycles (magnetic and thermal) to which the magnets are subjected. L. Bottura replied that this needs to be studied.

B. Di Girolamo asked if the experimental magnets might suffer from radiation damage. L. Rossi replied that this should be studied but he believes that the radiation

dose accumulated by the experimental magnets should be smaller than that accumulated by the triplets by three orders of magnitude (in the range of 10 kGy).