STATUS AND PLANS FOR THE UPGRADE OF THE LHC INJECTORS

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Abstract

The plans for preparing the LHC injectors to fulfil the needs of the LHC during the next decade have significantly progressed in 2012. Linac4 construction has passed major steps of pre-series fabrication. Hardware developments and beam studies have allowed refining the baseline actions to implement and the beam characteristics achievable at injection into the collider for protons as well as for Lead ions. These achievements are described in this paper, together with the updated project planning matched to the new schedule of the LHC.

INTRODUCTION

During the first physics run of the LHC which finished in February 2013, the integrated luminosity in all experiments and for all types of beams (protons as well as Lead ions) have exceeded expectations [1] and led to the discovery of a Higgs-like boson, announced on July 4, 2012. This has been made possible by the unprecedented characteristics of the injected beam (see Table 1 for protons), largely driven by the effort of the LHC Injectors Upgrade (LIU) team to understand and fight limitations in the cascade of injectors. Even more significant is the demonstration of the Batch Compression, Merging and Splittings (BCMS) scheme which circumvents the PS space charge limit (Table 1). This scheme is now the baseline solution after the present first Long Shutdown (LS1) and should allow reaching and possibly exceeding the nominal luminosity in the LHC with 25 ns bunch spacing. The goal of the LIU project is to improve further the beam characteristics of the injectors up to level required for High Luminosity in the LHC (HL-LHC) [2, 3], as shown in Table 1.

While the collider is stopped until the end of 2014, the injector complex will progressively restart between March and July 2014. Beyond extensive maintenance, consolidation and some upgrades are taking place. The hardware required for the main upgrades of the injectors will need a few more years to be built [3]. Installation will proceed during the second Long LHC Shutdown (LS2) which is presently scheduled to start at the end of 2017.

Design and construction of the already defined equipment is progressing as planned (e.g. Linac4 and injection system in the PSB). The nature and the specifications of the other upgrades are being finalized, based on the beam studies conducted during run 1.

LINAC4 CONSTRUCTION

The parameters of Linac4 [4] are aimed at doubling the brightness of the beam in the PSB using charge-exchange injection of H^- ions at 160 MeV.

Following the completion of Civil Engineering at the end of 2010, infrastructure has been installed in 2011 and 2012 (ventilation, cables, pipes, etc.) [5]. The low-energy section up to 3 MeV energy is under commissioning in a dedicated Test Stand (Fig. 1). The present H^- beam is provided by an RF volume-type ion source limited to 17 mA. A Cesiated version will be used from 2014 to provide the intensities required for Linac4 operation.

Figure 1: View of the 3 MeV Test Stand of Linac4.

The 4-vane type 3 m long RFQ has successfully accelerated beam in the test stand after an extremely short RF conditioning time. Beam commissioning of the 3.6 m chopping and matching line is now in progress.

The construction of the other types of accelerating structures is progressing according to schedule. The first part of the Drift Tube Linac (DTL) has been successfully assembled. Construction of the other segments and their drift tubes is well advanced. Four of the 7 Cell-Coupled DTL (CCDTL) modules are already built and undergoing high power tests. Following a successful prototyping, the construction of the third type of accelerating structures (Pi-Mode Structure (PIMS)), is now in full swing.

Other equipment is gradually being prepared: the klystron-based RF system with its modulators is progressively installed, Low Level RF is being completed and some beam instrumentation devices are being commissioned in the Test Stand.

Following the move of the 3 MeV section in the tunnel during the summer 2013, the other linac elements will be added in stages and progressively commissioned until the end of 2015. A year-long reliability run will take place in 2016, to assess and debug potential weaknesses prior to connection to the PSB that will be possible immediately after.

Table 1: Characteristics of the 25 and 50 ns proton beams for LHC (1 σ normalized emittances): nominal design values compared to 2012 achievements (regular and BCMS schemes in red) [1] and HL-LHC requirements (in blue) [2].

Beam		PSB extraction			PS extraction			SPS extraction			
Spacing	Type	p/ring [×10^11]	$\varepsilon_{h/v}$ [μm]	nb bunch	p/bunch [×10^11]	$\varepsilon_{h/v}$ [μm]	nb bunch	p/bunch [×10^11]	$\varepsilon_{h/v}$ [μm]	$\varepsilon_{long.}$ [eVs]	nb bunch
25 ns	Nominal	≤ 13.8	≤ 2.5	4 + 2	≤ 1.15	≤ 3	72	≤ 1.15	≤ 3.5	≤ 0.8	1 - 4×72
	2012	16	2	4 + 2	1.3	2.4	72	**1.15**	**2.6**	0.7	1 - 4×72
	BCMS	7.5	1	4 + 4	1.2	1.2	48	**1.15**	**1.4**	0.7	1 - 4×48
	HL-LHC	32	1.8	4 + 2	2.6	1.9	72	**2.3**	**2.1**	0.7	1 - 4×72
50 ns	Nominal	≤ 6.9	≤ 2.5	4 + 2	≤ 1.15	≤ 3	36	≤ 1.15	≤ 3.5	≤ 0.8	1 – 4×36
	2012	12	1.35	4 + 2	1.9	1.5	36	**1.65**	**1.65**	≤ 0.8	1 – 4×36
	BCMS	6	0.9	4 + 4	1.9	1.1	24	**1.6**	**1.2**	≤ 0.8	1 – 4×24
	HL-LHC	26	2.2	4 + 2	4.1	2.3	36	**3.7**	**2.5**	≤ 0.8	1 – 4×36

PS BOOSTER UPGRADE

Machine studies and constant optimisation have resulted in improved beam characteristics for LHC [6], significantly exceeding the original goal and consolidating expectations with 160 MeV injection.
An outstanding achievement in hardware development in 2012 was the successful test with beam of a 5 cell prototype of a wide band Finemet® RF cavity [7].

Installations during LS1

Besides standard maintenance, many modifications and upgrades will be done during LS1 [6]: replacement of the beam dump, start of the cable clean-up campaign, extensive renovation of beam instrumentation systems and controls, consolidation of machine interlocks and main magnet connections, modernization/replacement of multipole power supplies, low-level RF and transverse feedback systems, installation of 5 more cells to the Finemet® RF cavity…

Preparations for the Main Upgrades

The engineering design of a completely new system for charge exchange injection of H^- at 160 MeV from Linac4 has satisfyingly progressed [6]. Assembly will take place in 2015, and tests with the Linac4 beam will be done in 2016 in view of being ready for installation at the end of the year. The hardware designs and modifications required for bringing to 2 GeV the energy of the beam sent to the PS are advancing on-time for implementation during the second long LHC shutdown (LS2).

PS UPGRADE

Progress in the Transverse Phase Planes

Space charge has motivated extensive beam dynamic studies and experiments [8]. Resonances compensation is being investigated. Encouraging results have been obtained on two third order resonances. The fact that most of the space-charge induced blow-up takes less than 200 ms after injection could lead to favour schemes where beam spends the least possible time at injection energy.

The transverse damper has been successfully tested, damping oscillations and headtail instability at injection energy and delaying the transverse coupled bunch instability, probably electron cloud driven, observed after formation of the 40 MHz bunch train at high energy. Combined with an intensive experimental and theoretical effort to measure and simulate the observed phenomena, the upgrade taking place during LS1 (2 GeV injection, increased average power and bandwidth) is expected to be sufficient for getting rid of this high energy transverse instability, removing the need for coating the vacuum chamber to avoid electron cloud formation.

Progress in the Longitudinal Phase Plane

The BCMS scheme based on batch compression, bunch merging and triple splitting at an intermediate energy (Fig. 2), followed by the "usual" double splittings at high energy was successfully implemented and sent to the LHC, giving a net increase in luminosity with 50 ns bunch spacing and promising nominal luminosity in the LHC with 25 ns after LS1 [8].

To fight coupled bunch instabilities, a dedicated longitudinal damper, based on a Finemet® cavity, will be installed during LS1. The fast feedbacks and one-turn delay feedbacks of the main RF systems are being upgraded. Tests will be done with the 40 MHz system to eventually increase the available voltage if it measurably improves capture efficiency in the SPS.

Other Upgrades

Important civil engineering work is taking place during LS1 to improve shielding in the injection and extraction regions. The engineering design for 2 GeVinjection is progressing for implementation during LS2.

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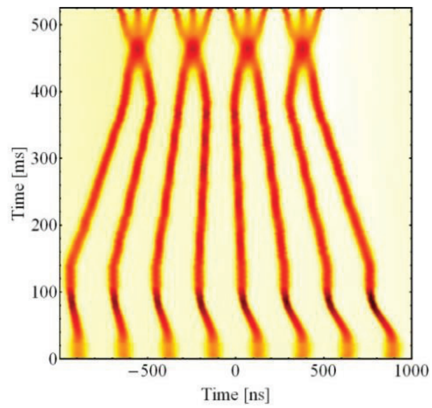

Figure 2: Mountain range of PU signal during BCMS.

SPS UPGRADE

Significant progress was made in the SPS in 2012 on many fronts [9]. Intensive tests of scrubbing were used to benchmark simulations and test new methods [10], with the various effects and dependencies now well understood. The electron cloud was not a limitation for the operational LHC beams, but effects were seen with very high bunch intensity for 25 ns spacing, with some transverse emittance blow-up on the trailing bunches in the batches. The amorphous carbon coating was fully validated as a mitigation measure and a sputtering technique was demonstrated which does not require the removal of the vacuum chamber from the magnet.

The low-gamma transition optics (Q20) was deployed operationally, after intensive testing and development, necessitating re-matching of the extraction systems and transfer lines to LHC and a re-setup of the transfer line protection collimators. As expected, the longitudinal quality of the beam extracted from the SPS improved, although longitudinal stability remains a limitation. In addition, the transverse brightness increased from an average of 0.92×10^{11} p+/μm to 1.05×10^{11} p+/μm [11].

A series of reviews has examined remaining open questions and limited the upgrade possibilities to a much more focused baseline. The existing scraper system will be retained, with the magnetic bump solution documented as a Technical Design. The existing extraction system will also be kept, with some improvements to cooling and a reduction in the total number of kickers. The internal beam dump absorber block will be upgraded to withstand full LIU beam parameters, and an external block in an existing transfer line investigated for high energy. The pumping of the ZS electrostatic septa will be improved and remote voltage modulation implemented. Local correction of the extraction orbit will be investigated using the extraction bumpers, but no general closed orbit correction system for high energy is required.

During LS1, the 800 MHz RF system is being extensively renovated and its voltage will be doubled. The existing transverse damper system is also being upgraded with new low level controls and dedicated pick-ups. The preparation for the upgrade of the 200 MHz RF continues with the prototyping of the power amplifiers under way, the design of the new power couplers in progress and the layout change to the RF cavities and associated SPS straight section defined.

Following the successful test of the wideband (intra-bunch) transverse damper demonstrator in closed-loop mode with a single bunch, the design of a multi-bunch prototype is now under way.

Concerning beam instrumentation, performance upgrades of almost every system have been defined and specified, and work is progressing with the pulling of fibres and cables, and the prototyping of specific systems, for example a new high-resolution wire scanner.

UPGRADE OF THE ION INJECTORS

To reach the luminosity of 6×10^{27} Hz/cm^2 for Pb-Pb collisions expected by the ALICE experiment after its upgrade during LS2, specific upgrades will also have to be performed in the heavy ion injector complex [12]. The proposed scheme is based on increasing the number of bunches per LHC ring, with the intensity per bunch achieved during the latest p-Pb run [13]. The proposed baseline filling scheme consists of an alternating 100 ns and 50 ns bunch spacing, yielding up to 912 bunches of over 1.5×10^{8} Pb^{82+} ions per LHC ring. The main ingredients will be batch compression in the PS, and a new 50 ns rise-time injection system in the SPS [12]. Alternate schemes are under study, which would need doubling the bunch intensity in LEIR, and an additional bunch splitting in the PS.

REFERENCES

[1] R. Steerenberg et al., “Post LS1 25 and 50 ns Options from the Injectors”, Proc. of LHC Beam Operation workshop, Dec. 2012, Evian.
[2] O.S. Bruning, F. Zimmermann, “Parameter Space for the LHC Luminosity Upgrade”, IPAC’12, New Orleans, May 2012, MOPPC005, http://www.JACoW.org
[3] R. Garoby et al., “Upgrade Plans for the LHC Injector Complex,” IPAC’12, New Orleans, May 2012, TUXA02.
[4] F. Gerigk, M. Vretenar (eds.), “Linac4 Technical Design Report”, CERN-AB-2006-084.
[5] L. Arnaudon et al., “Progress in the Construction of Linac4 at CERN”, LINAC’12, Tel-Aviv, Sept. 2012, THPB010.
[6] K. Hanke, “Status of the Upgrade of the CERN PS Booster”, THPWO078, these proceedings.
[7] M. Paoluzzi et al., “Beam Tests and Plans for the CERN PS Booster Wideband RF System Prototype”, WEPEA065, these proceedings.
[8] H. Damerau et al., “The PS Upgrade Programme: Recent Advances”, WEPEA042, these proceedings.
[9] B. Goddard et al., “ Progress with the Upgrade of the SPS for the HL-LHC Era”, WEPEA053, these proceedings.
[10] H. Bartosik et al., “Recent Electron Cloud Studies in the SPS”, WEPEA014, these proceedings.
[11] Y. Papaphilippou et al., “Operational Performance of the LHC Proton Beams with the SPS Low Transition Energy Optics”, THPWO080, these proceedings.
[12] D. Manglunki et al., “Plans for the upgrade of CERN’s heavy ion complex”, WEPEA060, these proceedings.
[13] D. Manglunki et al., “The first LHC p-Pb run: performance of the heavy ion production complex”, WEPEA061, these proceedings.

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