PERFORMANCE OF THE CERN HEAVY ION PRODUCTION COMPLEX

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Abstract

The second LHC ion run took place at 1.38 A TeV/c per beam in autumn 2011; more than 100 inverse microbarns were accumulated by each of the experiments. In addition, the LHC injector chain delivered primary Pb and secondary Be ion beams to fixed target experiments in the SPS North Area. This paper presents the current performance of the heavy ion production complex, and prospects to further improve it in the near future.

INTRODUCTION

After the first Pb ion run, which took place in autumn 2010, had delivered just under 10 μb^{-1} of integrated luminosity to each one of the interested LHC experiments (ALICE, ATLAS, CMS), with a peak luminosity of 3×10^{25} Hz/cm^2, expectations were quite high for the following run, in autumn 2011. To this effect, a new beam was designed, allowing more than 10^8 Pb^{82+} ions per bunch to be transferred to the LHC. The goals for 2011 were to integrate between 30 and 50 μb^{-1} per experiment, and to reach a peak luminosity of 1.4×10^{26} Hz/cm^2 [1, 2].

The renewed availability of ions in the CERN accelerator complex had already triggered the interest of a large community for fixed target beams in the North Area. After the successful demonstration, in 2010, of the fragment separator technique to produce secondary light ion beams [3], the first fixed target physics run also took place in autumn 2011, in parallel with the LHC Pb-Pb collisions.

Here we review the performance of the heavy ion accelerator complex during 2011, and we present its planned upgrades for the immediate future, both for the LHC and for the SPS fixed target beams.

THE LHC BEAMS

Two different types of beams were used for the LHC during the run:

- The single bunch "Early" beam [4], similar to that used during the 2010 run, but intentionally limited in intensity to less than 6×10^7 Pb^{82+} ions, was used as a pilot beam to boostrap the injection process, as it can be considered a "safe beam" [5].
- The "Intermediate" beam [2, 6] was used for collisions. It consisted of a train of 24 or 22 bunches, of average intensity 1.4×10^8 Pb^{82+} ions/bunch, with a regular 200 ns spacing.

A third beam, similar to the nominal beam [7], was ready to be delivered. Unfortunately no time could be allocated to test its behaviour in the collider itself.

To produce the intermediate beam (Fig. 1), the 20 μA, 200 μs long pulse of 4.2 MeV/u Pb^{54+} is accumulated over 70 turns in the Low Energy Ion Ring (LEIR). The injection process is repeated 7 times, under continuous electron cooling (Fig. 2).

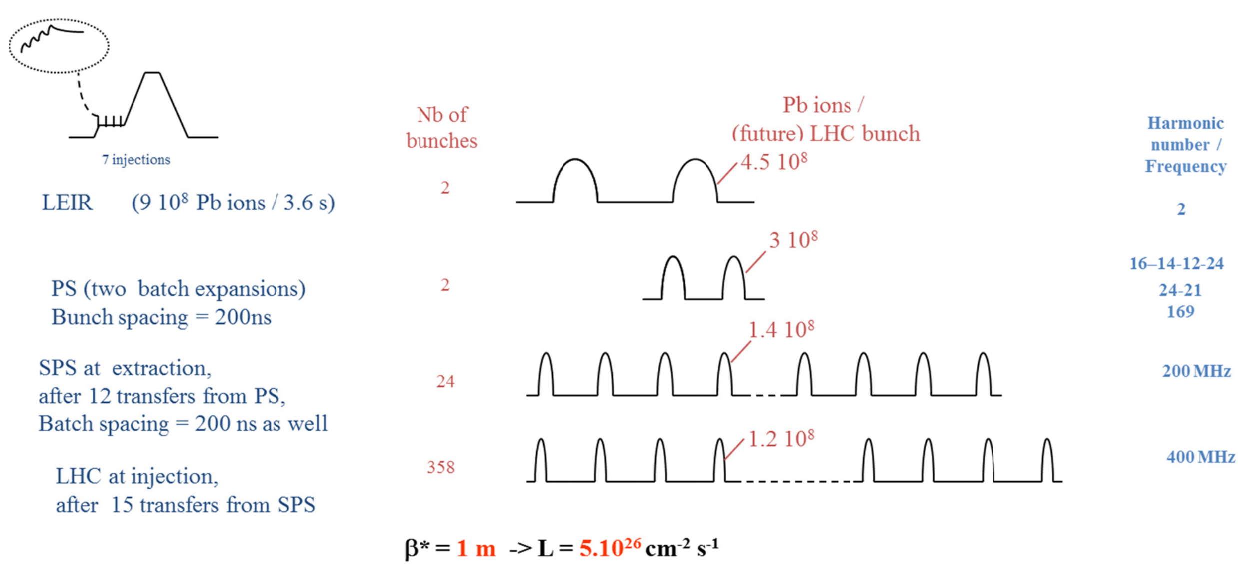

Figure 1: Production of the "Intermediate" beam.

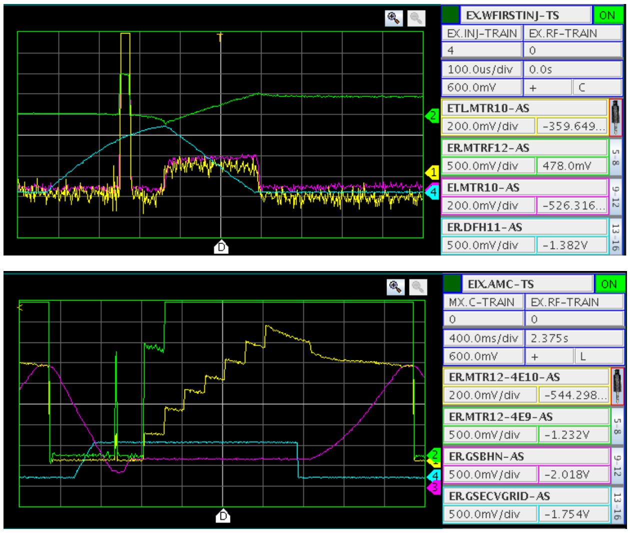

Figure 2: Injection into LEIR. Top (100 µs/div): the 200 µs linac pulse (yellow/magenta: current in transfer line) is accumulated (green: current in LEIR) over 70 turns (cyan: injection bumper). Bottom (400 ms/div): the process is repeated 7 times (yellow/green: current in LEIR), then the electron cooling is turned off (cyan: grid electrode) and acceleration starts (magenta: magnetic field).

The beam is then bunched on $h = 2$, accelerated to 72 MeV/u and transferred to the Proton Synchrotron (PS). In the PS, the bunches are accelerated to 4.2 GeV/u. They are then successively subjected to a batch expansion ($h = 16, 14, 12$), a rebucketing ($h = 12, 24$), another batch expansion ($h = 24, 21$) and a final rebucketing ($h = 21, 169$). The two resulting bunches, spaced by 200 ns, are then transferred to the Super Proton Synchrotron (SPS). The ions are fully stripped to Pb^{82+} by a 0.8 mm thick Al foil in the transfer line. This operation is repeated 12 times, every 3.6 second – the duration of the LEIR cycle – in order to fill the SPS with 24 bunches, equally spaced by 200 ns, thanks to a shortened injection kicker rise time. To fill the LHC with 2×358 bunches, 15 such trains are injected in each ring.

The long duration of the SPS front porch implies that the first injected bunches experience the detrimental effects of IBS, space-charge, and RF noise, for 40 seconds more than the last ones. The result is a trapezoidal intensity distribution along the bunch train sent to the LHC (Fig. 3).

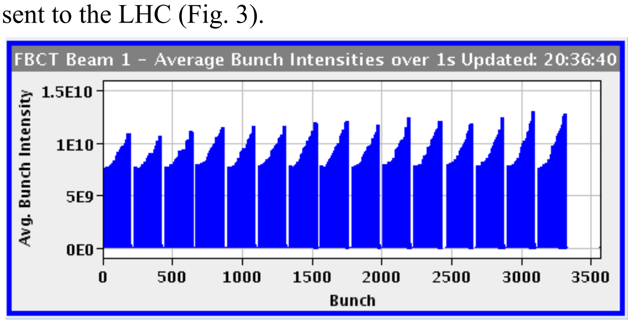

Figure 3: Bunch intensity distribution in the LHC.

Table 1 presents the comparison between the design parameters [4, 7], as expected with the LHC running at twice the current energy, and the results of the 2011 run. Scaled to the energy and the corresponding β^*, the intermediate scheme allowed to reach twice the design luminosity. Over the four weeks of run, more than 100 μb^{-1} were integrated per experiment, a factor 3 above the goal for the year.

Table 1: Comparison with Design Parameters

	Design	**2011 run**
	SPS extraction	
Bunches/batch	32, 48 or 52	22 or 24
$\varepsilon^*_{H,V}$ [µm]	1.2	0.9
N_b [ions/bunch]	9×10^7	1.4×10^8
	LHC collisions	
p [TeV/c/u]	2.76	1.38
k_n [bunches]	592	358
β^* [m] at IP2	0.5	1.0
L [Hz/cm^2]	10^{27}	5×10^{26}

Just before the Pb-Pb run, a very successful feasibility test of p-Pb operation of the LHC was carried out [6]. Unfortunately, some further tests and a first pilot physics run had to be cancelled because of a breakdown of the proton injection septum of the PS. However the LHC will be operated for physics in this mode in 2012.

For the next Pb-Pb run, scheduled for 2015, several issues are being addressed:

- The beam loss in LEIR at the start of the acceleration ramp (see Fig. 2) needs to be understood, and, if possible, cured.
- A new scheme, involving different gymnastics such as a batch compression in the PS, has been designed in order to shrink the bunch spacing down to 100 ns in the PS. Taking into account the SPS and LHC injection kickers rise times, the expected peak luminosity gain is 25%. [8]
- To mitigate the space charge and IBS effects on the SPS injection porch, new optics, based on a lower integer tune ("Q20") [9] will be implemented on the ion cycles.
- To decrease the effects of the RF noise during injection, the low level RF will be switched to a fixed harmonic programme instead of a fixed frequency.

SPS FIXED TARGET BEAMS

In 2010, the feasibility of producing secondary light-ion beams by the fragmentation method was demonstrated during a two week test period. Primary Pb ion beams of

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13.9 and 80 *A*GeV/*c* were used to produce ^{7}Be and ^{11}C beams for the NA61 experiment.

In 2011, a first physics run took place, with the production of ^{7}Be ions at 40, 75 and 150 *A*GeV/*c*, respectively from primary Pb beams at 42, 80, and 162.4 *A*GeV/*c*. This latter value corresponds to the same magnetic rigidity as 411.9 GeV/*c* protons, so the machine had to be exceptionally stretched by a few % above the "normal" momentum of 400GeV/c for slow extraction. A short period of primary Pb ions at 80 *A*GeV/*c* was also delivered in the North Area.

In order to optimise the resources, the same type of beam was produced from the injector chain (Linac, LEIR, PS) as for filling the LHC, but with only 2 injections in the SPS. The intensity on the T2 target was about 2×10^8 Pb^{82+} ions per spill. In total 1.2×10^8 ion interactions were recorded by the experiment [10].

In 2012, the fixed target ion run will take place during the summer, outside the LHC ion run. During 6 weeks, the experiment will take ^{7}Be ions at 13, 20 and 30 *A*GeV/*c*; the primary Pb beam will have to be more intense, to compensate for the lower production yield at these lower energies. Some time will be devoted during this run to start studying a debunching method in order to improve the time structure of the spill.

In 2013, during the long technical stop, Ar and Xe beams will be studied in the ECR source, and accelerated in the RFQ and Linac3, to prepare the fixed target runs of 2014 and 2015, respectively [11]. Finally, an interlock system is being installed to safely allow the concurrent presence of primary ion beams and high intensity proton beams in the same supercycle in the SPS [12, 13].

CONCLUSIONS

- The heavy ion injector chain delivered more than the expected beam quantity and quality for the second LHC run in autumn 2011: the collider integrated more than 100 μb^{-1} per experiment, with a peak luminosity of 5×10^{26} $cm^{-2}.s^{-1}$, over three times the goal for the year. A scheme has been designed to deliver Pb-Pb collisions with an additional gain of 25% in peak luminosity in 2015.
- Because of the unavailability of protons, the p-Pb demonstration tests could not be completed. Nevertheless, the first p-Pb collision physics run is foreseen to take place in autumn 2012, just before the long technical stop.
- For the SPS fixed target programme, in 2011, ^{7}Be fragments have been delivered to NA61 at 40, 75, and 150 AGeV/*c*, as well as primary Pb ions at 80 AGeV/*c*. In 2012, ^{7}Be fragments will be delivered at 13, 20 and 30 AGeV/*c*. Ar and Xe beams will be studied in the ECR source, RFQ and Linac in 2013, in order to be ready for fixed target runs in 2014 and 2015.

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