Large Hadron Collider Project

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GTS-LHC: A NEW SOURCE FOR THE LHC ION INJECTOR CHAIN

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INTRODUCTION

Following the success of the light ion fixed target programme at the SPS, an international collaboration was formed to build a heavy ion injector [1] for the CERN complex and most especially for the SPS. This installation became operational in 1994 [2] providing Lead ions to physics. This programme came to an end in 2003 with a final operational period using Indium ions instead of the habitual Lead. The experience gained with this beam will be described later in another paper at this workshop [3].

Within the CERN accelerator complex (Fig. 1) the current major accelerator project is the Large Hadron Collider (LHC) which is being constructed in the border zones between France and Switzerland to collide 2×7 TeV proton beams deep underground [4]. Although the emphasis for the project has been on protons Lead ion beams at 2.76 TeV/u have been requested by the physics community. Although initially only one experiment wanted ion/ion collisions a number of the other experimental groups have expressed a desire to benefit from the presence of these ions in the rings. The changes needed to the Linac injector needed to meet the stringent requirements of the heavy ion beam will be presented together with some ideas schedule for construction and commissioning of the new source.

FIGURE 1. The CERN Accelerator Complex

INJECTION OF LEAD BEAMS

As mentioned above, an option for heavy (and eventually medium and light) ions has been retained for the LHC machine. The present injection scheme used for fixed target physics is via the PS Booster (PSB) but using this route results in missing a factor of 30 in beam brightness. Naturally this could be overcome by increasing the source current by the same factor. Unfortunately, the LHC has a very tight emittance and beam quality budget to avoid unnecessary quenches of the superconducting magnets.

This emittance budget reflects back down the injector chain and it would be highly unlikely that the multiturn injection process used at the PSB with this higher source current meets this criterion. Even the emittances resulting from multiturn injection with the present beam could give rise to problems. A high instantaneous current short pulse laser ion source project was instituted to allow single turn injection but this was abandoned due to lack of satisfactory performance and stability of this type of source [5].

CERN has considerable experience in phase space cooling of antiprotons and had a mothballed antiproton decelerator and stretcher ring available (LEAR). Experiments to prove the feasibility of stacking and electron cooling of highly charged ions in this ring proved successful. However, it did demonstrate that although the lifetime of lead ions was interesting, the lifetime of Pb^{53+} was considerably shorter than that of Pb^{54+} under electron cooling. Fortunately stripping lead ions at 4.2 MeV/u gives virtually the same yield of both charge states.

Further experiments using phase space stacking in three planes in the storage ring together with electron cooling were carried out to determine the possibilities of these techniques. With the linac injecting at 2.5 Hz (instead of 0.8 Hz) it was shown that at least 25% of the required number of ions per PS pulse could be accumulated in this ring [6]. The limitation in the accumulation was the vacuum. Ion induced desorption caused pressure bumps which increased recombination losses until an equilibrium was reached with the injected beam.

Phase space cooling applied to the stacked beam increases its brightness and with the ions accelerated to a 77.2 MeV/u in this ring space charge blow up during injection, this time into the Proton Synchrotron, would be alleviated. Hence by doubling the repetition rate of the linac again, to 5 Hz, doubling the source current and improving the LEIR dynamic vacuum, the desired number of ions per injection should be achieved. This is the scenario that has been retained for the Ions for LHC project (I-LHC) [7]. Fortunately most of the ion linac was designed for 10 Hz operation and thus a maximum amount of the existing infrastructure and equipment can be retained. The storage ring is being rebuilt and renamed LEIR (Low Energy Ion Ring)

Lead ions at 4.2 MeV/u have been used in an extensive programme to understand ion induced desorption by heavy ion beams and the lessons learnt from these tests will be used to reduce pressure bumps due to beam loss in the already very good vacuum of the ring (10^{-12} mbar).

ION CURRENT INCREASE

Once the basic scenario had been defined, it was necessary to plan an upgrade of the present ECRIS. A European collaboration had been set up under the European Union Framework 5 research programme [8] to study scaling in ECRIS with the objective of trying to understand the parameters affecting source performance. A study for a high intensity source that could possibly be used for LHC or other laboratories was included. A large portion of this work was directed to understanding the scaling laws not only for an increase in frequency, but also the relationship between the longitudinal and radial magnetic fields so as to maximise a desired ion species. 28 GHz was chosen as the next frequency step because it is a standardised frequency and a power source was available.

It was quickly realised that an upgrade to this frequency at CERN would be extremely expensive. To combat space charge blow up the extraction energy from the source would have to be upgraded from 2.5 keV/u. This would require a new, longer, RFQ, a new Low Energy Beam Transport (LEBT) and spectrometer line and civil engineering works. Following the budget crisis of LHC in 2001 this type of money was not available. It was felt that by increasing the frequency to 18 GHz, by accelerating Pb^{25+} , by studying and eliminating possible bottlenecks in the linac and by tuning to peak performance on demand rather than stability (LHC filling will be programmed) the desired number of ions could be produced.

SOURCE UPGRADING

This initial source upgrade was pursued in spite of some doubts being expressed as to the adequacy of the radial confinement provided by the hexapole. In view of the fact that the longitudinal fields used in the 14 GHz ECR4 in optimised afterglow mode were weaker than those expected from CW operation, it was felt that a weaker radial confinement could be an advantage.

During 2003 information became available on an ECRIS that had demonstrated 200 μA of Bi^{24+} in afterglow mode at 14.5 GHz with moderate RF power [9]. This source, the Grenoble Test Source (GTS) [10] [11], uses a traditional minimum-B configuration optimised to obtain a better compromise between plasma confinement and ion losses. The principles of

this optimisation was one of the spin-offs of the Innovative ECRIS collaboration [12]. Apart from the improved magnetic field configuration and a larger plasma chamber this source could be adapted into the existing infrastructure in the ion linac building with a minimum of expenditure and modification.

The final design of the source, which is currently under construction after approval from the CERN project management, will include the possibility of an upgrade to 18 GHz or to 14 + 18 GHz with only very minor modifications. Two medium temperature ovens designed and constructed in collaboration with GSI will be installed in the source (another spin-off of "Innovative ECRIS").

CERN will provide the infrastructure and commission the source in collaboration with CEA, Grenoble and GANIL. Overall, the cost of this upgrade will fall within the budget envelope defined for the earlier upgrade ideas. Additionally the source could be commissioned within the current timetable of the LHC project, Fig. 2 is an drawing of the source.

FIGURE 2. An impression of the GTS-LHC source with its lead shielding.

TIMETABLE

The planning of the source construction and commissioning is constrained by the need to have an ion beam ready for the start of testing of the injection line for LEIR and by the desire to utilise the lead beam to its maximum for equipment tests. One important test that need to be carried out is to observe the behavior of the stripper foil with a 5 Hz. beam It is known to have resisted destruction at 2.5 Hz.

The procurement procedure within CERN proved more onerous than anticipated but the source should arrive at CERN in November 2004, well in advance of the required test beam for the injection line is scheduled for the beginning of May 2005. Installation and the start of testing of the source will be controlled by the needs of the annual maintenance of the water and electrical services but is scheduled to start in mid January 2005.

Until the beam is required by the LEIR machine physicists, opportunity will be taken to acquire running and operational experience with the new source. In parallel with all this work will be the design and construction of the ovens so that they can be ready for this running-in phase.

FINAL COMMENTS

Because the LHC is a big machine it must not be considered that it needs a big ion current from the injectors. The minimum circulating intensity in LHC is defined by the beam observation system sensitivity and the maximum was defined by Electromagnetic Dissociation and probably by Electron Capture by Pair Production.. Collimation of the ion beam may also be a problem. The range of Luminosities available will be $5 * 10^{25}$ to $1 * 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$ with $7 * 10^7$ ions per bunch which means that regardless of the final luminosity, the Linac will have always to supply the same ion current.

The presence of a circulating heavy ion beam at LHC energies could give rise to unexpected surprises that can not be anticipated from the proton commissioning period. Ion physics in LHC is scheduled to start in April 2008 .

REFERENCES

1. D. Warner, Editor. "CERN Heavy-Ion Facility Design Report", CERN 93-01, 1993 .
2. H. Charmot et al. "Operational Experience with the CERN Hadron Linacs", Proc. 18th Int. Linac Conf., Geneva, 1996, CERN 96-07, 360, 1996
3. C. Andresen et al., "Characterisation and Performance of the CERN ECR4 Ion Source", This Workshop.
4. O. Brüning et al. (Eds) "LHC Design Report, Vol 1, The Main Ring", CERN 2004-003, 2004.
5. A. Balabaev et al., "Laser Ion Source Based on a 100 J 1 Hz CO₂ Laser System", Proc. 10th Int., Conf. Ion Sources, Dubna, 2003, Rev. Sci. Inst., 75, 1572., 2004

6. J. Bosser et al. "Experimental Investigations of Electron Cooling and Stacking of Lead Ions in a Low Energy Accumulation Ring" *Particle Accelerators*, 63, 171, 1999
7. O. Brüning et al. (Eds), "LHC Design report, Vol 3, The LHC Injector Chain", CERN 2004-003, In publication, 2004.
8. European Commission Framework 5 Contract HPRI-1999-50014 "New Technologies for the Next Generation ECRIS".
9. D. Hitz, Private Communication.
10. D. Hitz et al., "Grenoble Test Source (GTS): A multipurpose Room Temperature ECRIS", *Proc. 15th Int. Workshop on ECR Sources*, Jyväskylä, 2002, JYFL Research Report 4/2002, 2002.
11. D. Hitz et al., "Production of Highly Charged Ions with the Grenoble Test ECT Ion Source", *Proc. 10th Int. Conf. Ion Sources*, Dubna, 2003, *Rev. Sci. Inst.*, 75, 1403, 2004
12. D. Hitz et al., "Results and interpretation of High Frequency Experiments at 28 GHz in ECR Sources: Future Prospects", *Proc. 9th Int. Conf. Ion Sources*, Oakland, 2001, *Rev. Sci. Inst.*, 73, 509, 2002.