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1 INTRODUCTION

CERN's heavy ion physics programme started operation in 1994. In order to accelerate lead ions, a new pre-injector, Linac 3, was constructed [1]. The layout of the linear accelerator is shown in Figure 1.

The Linac consists of a 14.5 GHz ECR source, which can produce a beam of 120 µA of Pb^{27+} [2] in the afterglow mode of operation. The beam is accelerated by an RFQ followed by an Interdigital-H structure to 4.2 MeV/u. The ions then pass through a carbon stripper foil before the Pb^{53+} beam, with a maximum current of 24 µA, is injected into the Proton Synchrotron Booster (PSB) by a multi-turn injection. At the output of the PSB, $4x10^8$ ions are extracted in emittances ($\varepsilon=4\sigma^2/\beta_x$) of 22 and 5 mm.mrad in the horizontal and vertical planes respectively.

This scheme misses the required beam brightness for ion collisions in the LHC by a factor 30.

2 THE PB PRE-INJECTOR

The present Linac 3 heavy ion pre-injector was designed for low current beams. A full survey of the limitations and bottlenecks has yet to be performed. Presented in Table 1 is a summary of the limitations in acceptance and space charge that were inherent in the design or have been simulated.

This list shows that sources using the present RFQ would be restricted to 2 mA in a total normalised emittance of 0.8 mm.mrad (with 80% transmission). If the RFQ is replaced, the limits for the Linac increase to 1 mm.mrad and 6 mA.

Table 1. Limitations in acceptance and space-charge limit for different components of the CERN lead ion injector.

	Acceptance[1]	SCL[2]
Source	0.28 [3]	>0.27 mA[3]
Low Energy Line	0.46	
RFQ	0.81	2 mA
Medium Energy Line	1.04	
IH accelerator	1.02	6 mA

[1] Acceptance is given in π.mm.mrad normalized [3].
[2] SCL: Space Charge Limit (for Pb^{27+}) in mA.
[3] Source emittance (mm.mrad) and maximum measured current from the source for 20kV extraction are given.

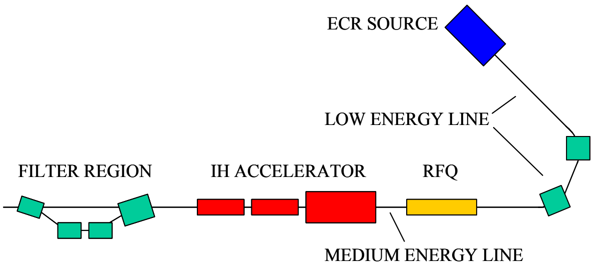

Figure 1. Layout of the present CERN Linac 3 heavy ion pre-injector.

3 OPTIONS FOR THE SOURCE

Four main options for the source exist for the LHC era. If a Low Energy Ion Ring (LEIR) is used for stacking and cooling ions, the options are a) the present ECRIS, b) an upgraded 18 GHz ECRIS and c) a 28 GHz ECRIS. A fourth option (d) is a Laser Ion Source which could be used with the present ion injection chain.

3.1 Option A – Present ECR + LEIR

The present ECR source coupled to Linac 3 is a very reliable source of ions for the PSB. In order to use this option with the LHC, 4 – 5 pulses of 200µs length of Pb^{54+} with an intensity of 24 µA will be injected into the Low Energy Ion Ring (LEIR). The ions are stacked, cooled and accelerated to produce 10^9 ions in a normalized transverse emittance of 0.7 µm (1σ) [4]. The stacking and cooling phase requires that the Linac produce beam at 5 Hz, which requires upgrading some of the pulsed power supplies in the Linac, and the addition of air-cooling on some quadrupoles. Furthermore, a new energy ramping cavity should be installed to allow multi-turn injection into LEIR in the longitudinal phase space.

The production of the required number of ions at the output of LEIR from four Linac pulses requires that the losses remain below 30% (after the multi-turn injection losses of 50% are taken into account). Producing more ion current from the source and Linac would relax the high transmission requirement.

Experience with the present source suggests that more current can be produced by more operator intensive fine-tuning. Furthermore, optimisation of charge-state with the highest particle yield (either Pb^{25+} or Pb^{26+}) may gain a few more percent in particle current.

3.2 Option B – ECR Upgraded to 18 GHz + LEIR

ECR sources have shown that the ion intensity that can be extracted is proportional to the square of the cyclotron-frequency [5]. Upgrading from 14.5 to 18 GHz could provide a ~54% increase in ion intensity. In addition to the increase in ion yield possible from the present 14.5 GHz source, a total increase in ion intensity of a optimistic factor 2 could be envisaged which would greatly ease the high transmission requirements of the LEIR machine.

Increasing the cyclotron-frequency of the source requires the following upgrades

- A new, pulsed 18 GHz generator.
- One of the source solenoid power supplies upgraded to at least 1500 A in order to maintain the present axial magnetic mirror ratio.
- Upgrade to a three-electrode extraction system.
- Possible modification of the coaxial antenna arrangement [6].

Preliminary simulations of the low energy beam transport have been performed using PATH. Modelling a single charge-state beam with an energy of 20keV/charge through the first solenoid and quadrupole of the low energy line, up to the entrance of the spectrometer, gives an indication of the magnitude of emittance growth.

The results have shown that the emittance growth in this line for the 14.5 GHz source with 4 mA total beam is approximately 10%, which would increase to 35% with a 18 GHz source and 8 mA. A further increase in the emittance from the source may arise due to the reduced radial confinement at higher microwave frequencies, if the hexapole magnets are not changed.

Two sources operating at 18 GHz and demonstrating high ion currents are the Plateau-ECRIS at Münster [7], and the Grenoble Test Source (GTS) [8].

The Münster source uses a long region of minimum B-field and a multi-mode travelling wave tube as a power source. The source has produced more than 1 mA of Ar^{8+} in CW mode. The afterglow mode did not greatly enhance performance, and they plan to install a pulsed magnetic extraction system to increase the ion current in a short pulse.

The Grenoble source is a highly flexible test source, which can be used for studies at 10, 14.5, 18 and 28 GHz. The 1 mA level of Ar^{8+} has been reached when operating at 18 GHz.

These currents are highly favourable when compared to the CERN ECR4 that has produced 0.16 mA of Ar^{8+}, measured at the exit of the RFQ [9]. However, caution is advised when scaling these comparisons to the production of lead ions in the afterglow mode.

3.3 Option C – High Intensity 28 GHz ECR source + LEIR

A European collaboration [10] is investigating the technology required to produce a 28 GHz ECRIS. A Varian VGA 8028 gyrotron has been coupled to the SERSE source in Catania, where a 500 µA beam of Xe^{25+} has been produced in an afterglow pulse [11]. Scaling laws suggest that 2 mA of Pb^{27+} could be produced from a >28 GHz ECR source [5]. Already a room temperature source at 28 GHz has produced 600 µA of Pb^{24+}, using an extraction voltage of 55 kV [12].

Optimistically assuming a similar ratio of 40 of total extracted current of all ion species to the wanted ion species, as well as restricting the desired current to 1 mA, requires a total current of 40 mA to be transported up to the low energy spectrometer. The ion measurements at Catania have demonstrated the need to match the ion extraction and transport systems to this high current.

Preliminary simulations of the same beam line as given in the previous section, with a total beam current of 40 mA, give an emittance growth factor of ten for the short section of line up to the ion spectrometer.

Hence upgrading of the present low energy line from 20 kV to 60 kV extraction is proposed. Simulation of the same portion of the line with the higher energy reduces the emittance growth to 50%. If the same line configuration is required, the two solenoids and the bending magnets would have to be changed, but the present quadrupole magnets would be sufficient.

3.4 Option D – A Laser Ion Source + PSB

The Laser Ion Source (LIS) is well suited for the production of a beam for injection into a synchrotron, as a high beam current can be produced in a short pulse that is similar to the revolution time of the circular machine.

At CERN, a test source is being constructed to produce a 5 to 10 mA beam of Pb^{25+} with a target pulse length of 5.5 µs. This beam could be single turn injected into one ring of the Proton Synchrotron Booster (PSB). The PSB may require upgrading of the vacuum system to accelerate this beam with low beam losses. However, the construction of a dedicated Low Energy Ion Ring would be avoided.

The following items remain serious challenges:

- The ion current is not constant during the pulse and the shot-to-shot variation in beam current is large.
- The reliability of high energy pulsed gas lasers has yet to be demonstrated.
- Elements that are not available in solid metallic form have mostly yet to be demonstrated.

- A high transmission and high reliability system for low energy beam transport does not yet exist.

To date, the CERN LIS test source has used a low repetition rate 30 J CO_2 laser. With this system it was possible to accelerate 2.7 mA of high charge state tantalum ions (containing at least three charge-states) to 100 keV/u with a RFQ [13], with a shot-to-shot fluctuation of σ=8.5%.

Presently, the collaboration between CERN, ITEP (Moscow) and TRINITI (Moscow) are installing a high-energy, 1 Hz repetition rate, CO_2 laser amplifier. Once the construction and commissioning of the full laser chain has been completed, ion production can begin. During the pre-commissioning in Moscow, 35,000 shots of the laser as an oscillator were made in an uninterrupted run, where the standard deviation of the laser pulse energy and width was 5% [14].

The target, illumination and extraction systems of the source are installed and a preliminary design of the beam dynamics of the Radio Frequency Quadrupole (RFQ) exists [15]. Preliminary designs for the installation of the source, and the beam injection into Linac 3 have been done [16].

4 ALTERNATIVE IONS

LHC High Energy Physics experiments have requested beams of ^{4}He, ^{16}O, ^{40}Ar, ^{84}Kr, ^{115}In and ^{208}Pb. This list is tailored to the production mode of the ECR source, which favours gases and low melting point metals.

Laser Ion Sources are not well suited to the production of ions from a gaseous jet target, and the choice of noble gases leaves no solid compounds.

Choosing the closest metallic elements in which one isotope is dominant, the list can be modified to read ^{7}Li, ^{12}C, ^{40}Ca, ^{93}Nb, ^{115}In and ^{208}Pb, where highly reactive metals (e.g. yttrium) have been avoided for safety considerations. The low melting point of Li and In means that the target consumption must be assessed for these elements. Furthermore, the production of a large, high isotope purity lead target has yet to be realised.

Many sources exist that can produce medium currents of helium ions, and one of these could be used on the injector instead of a LIS when such ions are demanded.

5 ELECTRON BEAM ION SOURCE (EBIS)

An EBIS test source at BNL[17] is used to study the production of gold ions for a possible injection scheme into RHIC. Approximately 10^9 Au^{32+} ions have been produced from the source, which is a half-length full power prototype. The final BNL source requirements of 3.4×10^9 Au^{32+} ions is approximately half the number of Pb^{25+} ions required for the LHC.

6 CONCLUSION

The choice of the source for the production of ions for LHC is still open. More detailed assessment of the R&D requirements and cost estimates are required for each source type. This must include the upgrading required for the rest of the Linac (in particular the low energy transport and RFQ).

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